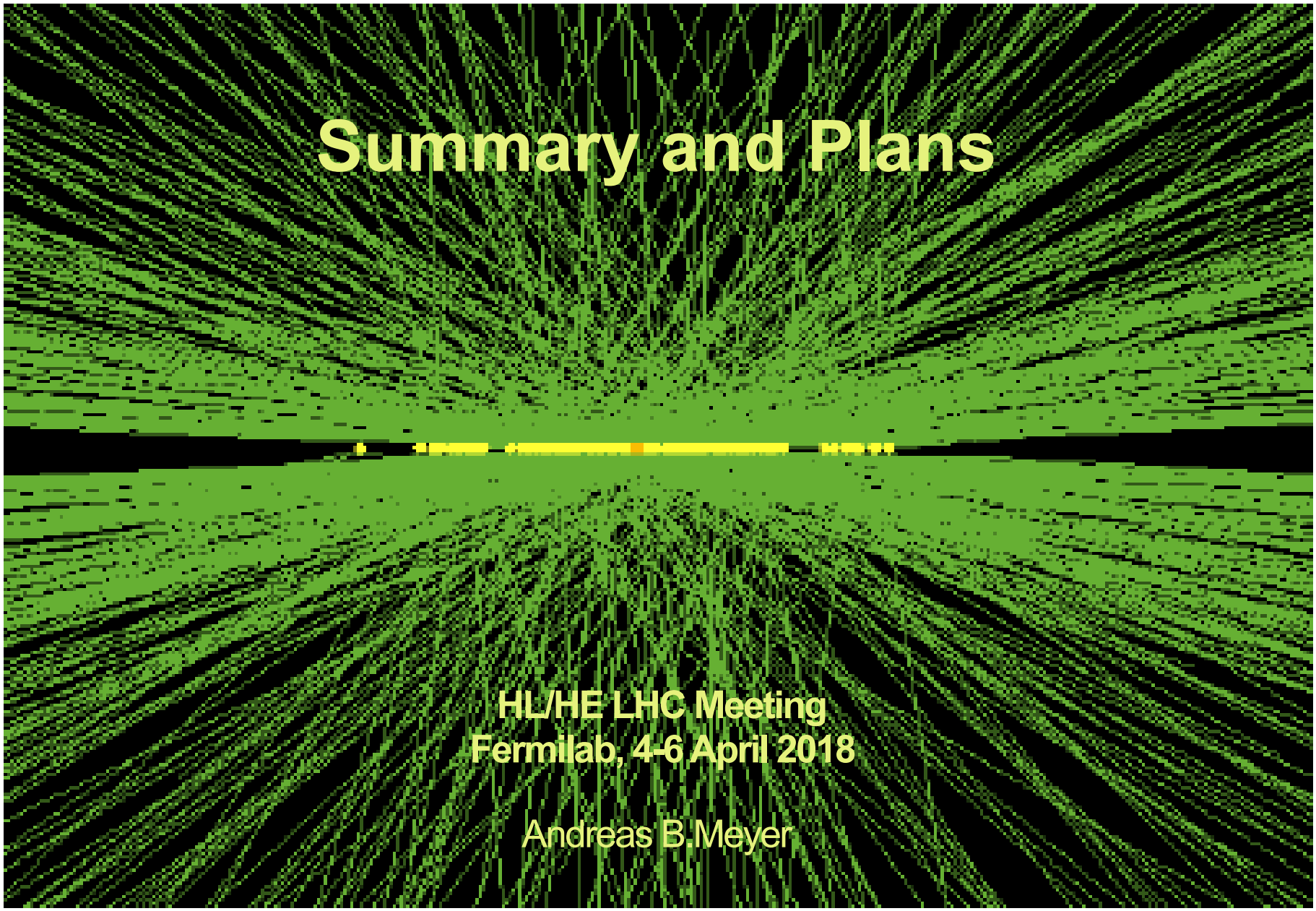


Summary and Plans

HL/HE LHC Meeting
Fermilab, 4-6 April 2018

Andreas B.Meyer

Meeting agenda, workshop webpage and mailing list

Goal of the HL/HE-Workshop

- **Review, extend and further refine our understanding of the physics potential of HL-LHC**
  - stimulate new ideas for measurements and observables,
  - extend the LHC discovery reach,
  - improve the modelling of LHC phenomena towards measurements at ultimate precision,
  - prepare to exploit the HL-LHC data to the fullest possible extent.
  - begin a more systematic study of physics at the HE-LHC (a possible pp collider in the LHC ring with energy of about 27 TeV).

- **Concretely**
  - Update existing projections, perform new analyses, complete partial analyses and combine to provide the most complete picture.
  - Identify critical areas, harmonize (and combine where useful) results experiments and theory
  - Discuss new ideas and reassess prospects, in light of increased precision and new methods and insights

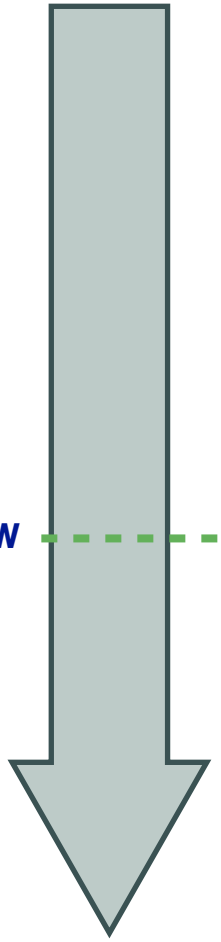
- **Produce a CERN Yellow Report as input to the European Strategy group by the end of 2018.**

- **Five Working Groups (one YR chapter each): Standard Model, Higgs, BSM, Flavour, Heavy Ions**
  - 10-page executive summary for submission by Dec 2018

Workshop Timeline

http://lpcc.web.cern.ch/hlhe-lhc-physics-workshop

https://twiki.cern.ch/twiki/bin/viewauth/CMS/HLandHELHCYR



- June/July 2017: creation of the structure
- Oct/Nov 2017: Kick-off meeting
- 21 Dec 2017: WG convenors meeting: skeleton table of contents
- March/April 2018: Draft table of contents, start writing

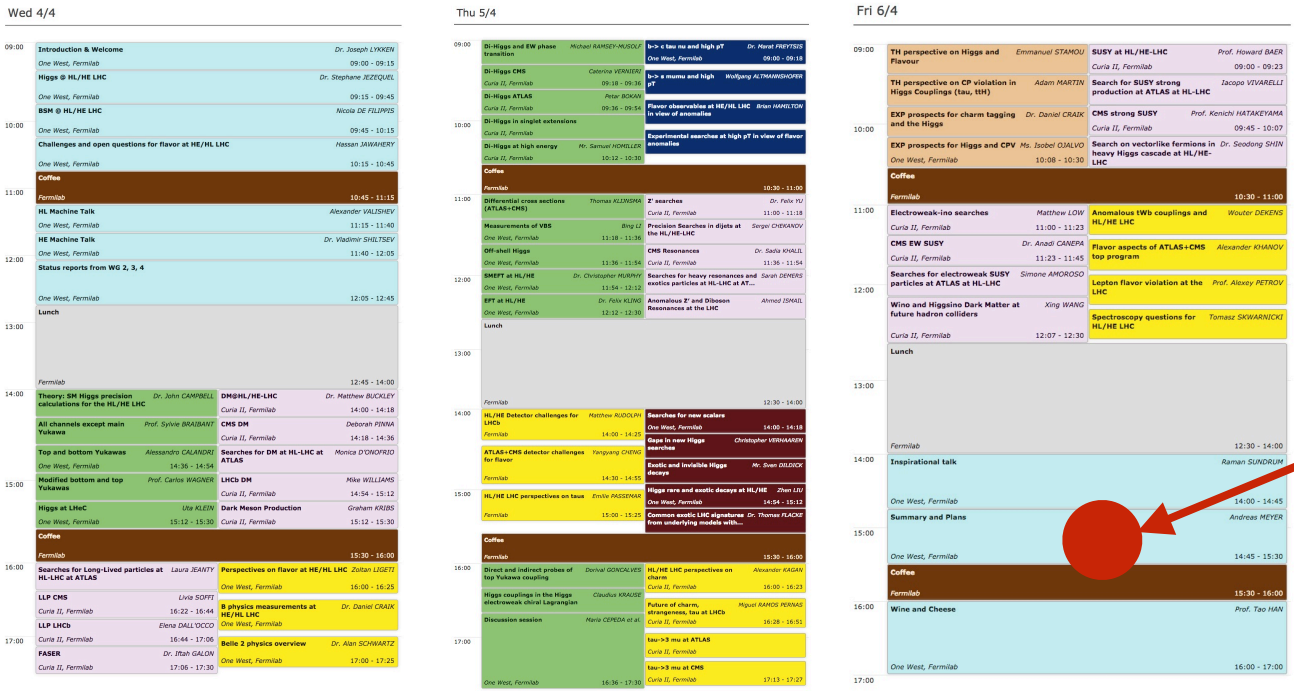
now

- 18-20 June 2018 (Plenary Meeting): Close-to-final table of contents
  https://indico.cern.ch/event/686494
- September 2018: Full drafts
- December 2018: Submission

European Strategy for Particle Physics: Open Symposium in May 2019

Workshop Program

- **16 Sessions, 4-5 talks each, about half theory, half experiments**
- **Participants: 105 registered/local Vidyo: a few tens**



- **Material presented:**
  - Experimental results: those already shown at kick-off + updates from recently published TDR + a number of planned analyses for the YR
  - Theory: many new results (many also including HE-LHC)

Agenda largely following foreseen chapter structure

WG2: Higgs

Draft chapter structure https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHEWG2

1. **Introduction: Main goals and timeline**

2. **Pr** — **Precision Higgs Production and Couplings**
   - …rements.
   2. Channels reach in main Yukawa couplings, including fiducial and differential measurements.
   3. Special focus on direct and indirect probe of top Yukawa coupling
   4. Progress on TH uncertainties: what to expect?
   5. Impact from PDFs and alphaS on Higgs measurements.
   6. Progress on Higgs specific MC.
   7. Higgs couplings precision overview.
   8. Probes using differential distributions of CP sensitive observables (and other dimension -6).
   9. Interpretation in terms of Composite Higgs and the MSSM

   with WG1

3. **Di** — **HH Production and Self-Coupling**
   2. Double Higgs measurements and trilinear coupling.
   3. Indirect probes of the trilinear coupling through differential distributions measurements.
   4. Indirect probes through single Higgs boson production.
   5. Theory Implications (including a critical view of the validity of direct and indirect trilinear couplings measurements.

   Precision

4. **O** — **Other High-Energy Probes (off-shell, VBS)**
   2. tth differential measurements
   3. WH/ZH at high energy/luminosity
   4. WW WZ at high energy/luminosity
   5. VBF
   6. longitudinal VBS and di-higgs

5. **T** — **Higgs Mass and Width**
   2. Measurement of the Higgs boson mass.
   3. Mass shift from the diphoton interference: constraints on the width.
   4. Direct constraints from the Higgs boson lineshape.
   5. Direct constraints from the Higgs boson lifetime measurements.
   6. Width from Off-Shell higgs boson coupling.
   7. Width from the diphoton interference rate.

6. **In** — **Higgs to Invisible** — **…oson (DM WG?)**
   1. Main channels for direct searches.
   2. Interpretation and combination with precision Higgs boson measurements.
   3. Higgs portal interpretations.

7. **H** — **Higgs-Flavour and Rare Decays**
   1. Flavor aspects Yukawa modifications in flavor models
   2. Exclusive Higgs decays
   3. Flavor tagging (charm and strange) exp mostly
   4. LFV decays of the Higgs exp mostly (CMS can try to cover this)
   5. Yukawa constraints from Higgs distributions
   6. CP violation in Higgs couplings (tau, ttH) exp mostly.

   with WG4

8. **BS** — **BSM Higgs**
   1. …ional Higgs bosons in fermionic final states (taus, b's, muons and tops)
   2. Searches for additional Higgs bosons in diboson final states.
   3. Searches for intermediate mass Higgs bosons (60 GeV - 120 GeV)
   4. Searches for low mass Higgs bosons (up to 60 GeV).
   5. Covering the MSSM, 2HDMs and the NMSSM, composite Higgs.
   6. Searches for unconventional signatures of additional Higgs bosons
   7. Searches for exotic decays of the Higgs boson

   Rare

   with WG3

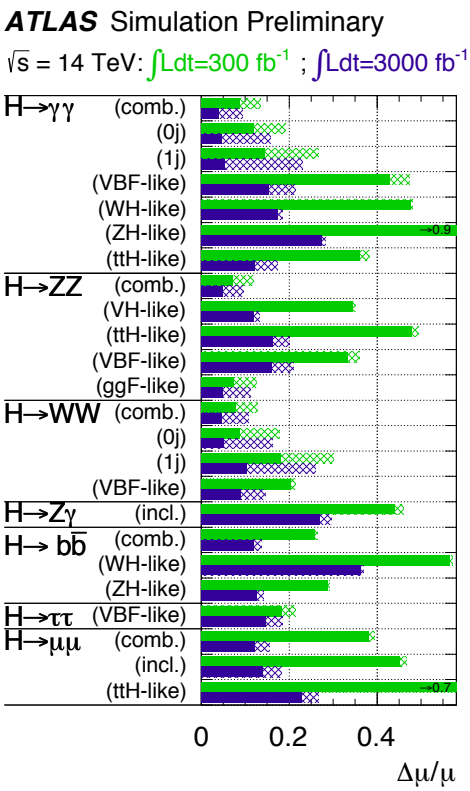
9. **Conclusions and outlook**

Is the Higgs the Higgs of the Standard Model ?

Higgs Couplings

Wed afternoon: **J. Campbell,** Higgs precision calculations; **S. Braibant,** all channels except main Yukawa; **A. Calandri,** Top and bottom Yukawas; **C. Wagner,** Modified bottom and top Yukawas; **U. Klein,** Higgs at LHeC

Talk A.Calandri

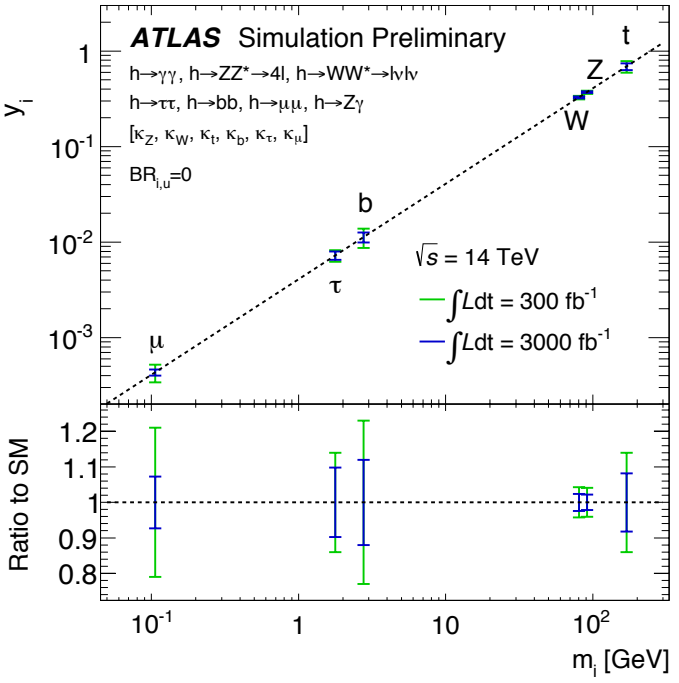


HL-LHC is a Higgs Factory: 140 M Higgs / Experiment

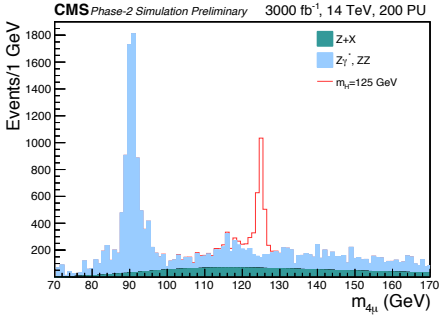
Couplings will typically be systematics limited

can be further improved e.g. by taking ratios and/or with more experimental work

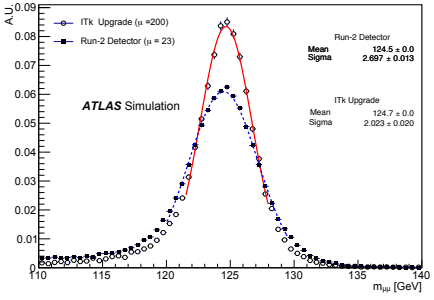
Talk A.Calandri



Talk S.Braibant



ATLAS-TDR-25 Talk S.Braibant



-25

- Updates underway incorporating latest improvements from Run-2
- Revisit exp./theo. uncertainties

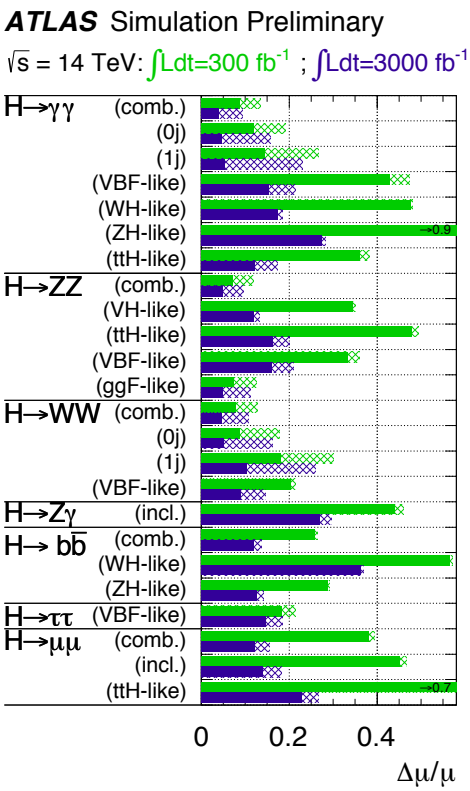
$\mu_{ZZ}(exp) = 1 \pm 0.02\,(stat.) \pm 0.03\,(exp.) \pm 0.03\,(theo.)$

μ: ~8% and k_μ: ~5%

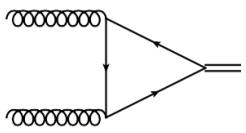
Higgs Couplings

Wed afternoon: **J. Campbell,** Higgs precision calculations; **S. Braibant,** all channels except main Yukawa; **A. Calandri,** Top and bottom Yukawas; **C. Wagner,** Modified bottom and top Yukawas; **U. Klein,** Higgs at LHeC

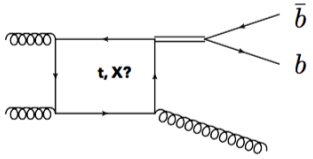
Talk A.Calandri



Talk J. Campbell

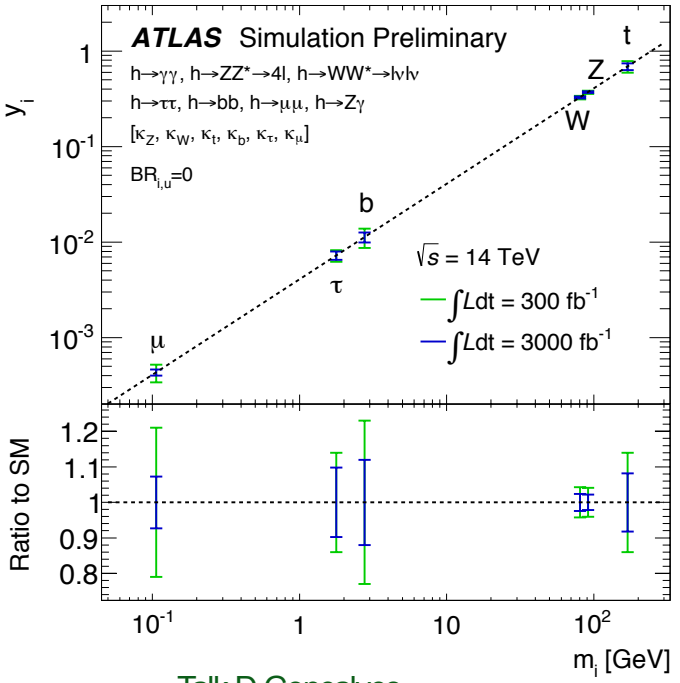


now known to N³LO

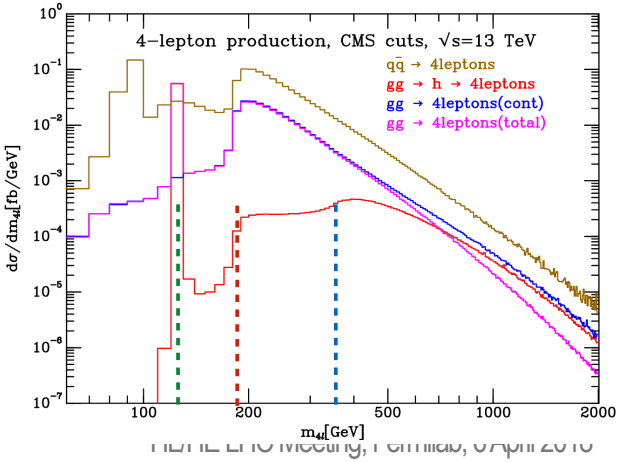


now known to N³LL+NNLO

Talk A.Calandri



Talk D.Goncalves



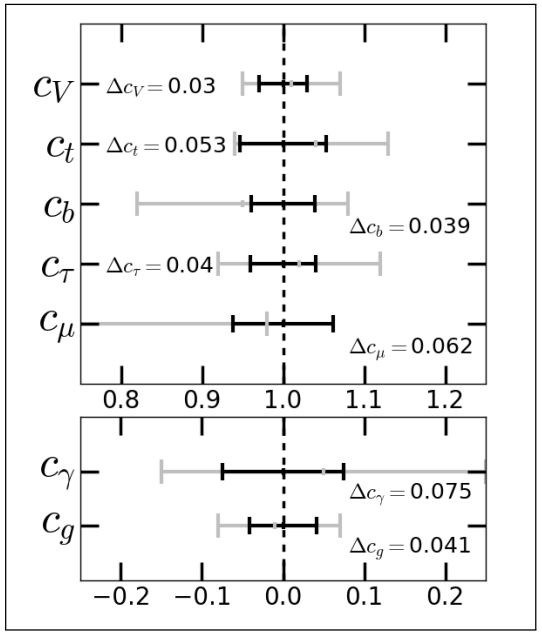
- Updates underway incorporating latest improvements from Run-2
- Revisit exp./theo. uncertainties

Off-shell 4ℓ mass spectrum: thresholds and interference effects carry information on Higgs couplings at different energy scales

Higgs Couplings

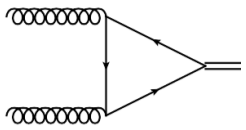
Wed afternoon: **J. Campbell,** Higgs precision calculations; **S. Braibant,** all channels except main Yukawa; **A. Calandri,** Top and bottom Yukawas; **C. Wagner,** Modified bottom and top Yukawas; **U. Klein,** Higgs at LHeC

Alternative to kappa: fit in EW chiral Lagrangian formalism C.Krause

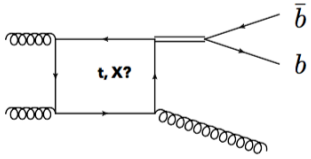


de Blas/Eberhardt/CK [1803.00939]

Talk J. Campbell

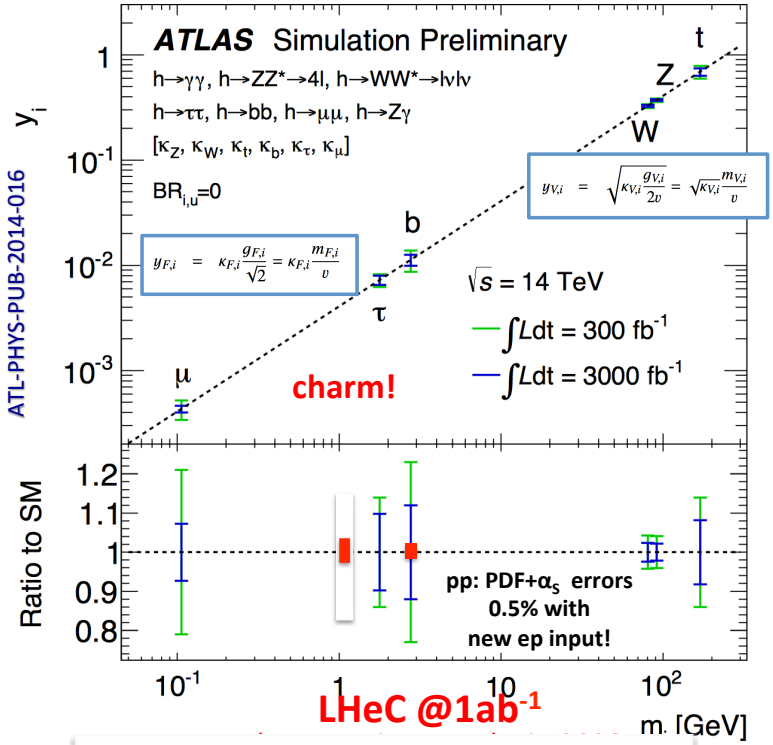


now known to N³LO



now known to N³LL+NNLO

Talk U.Klein (this figure taken from kick-off mtg Oct 2017)



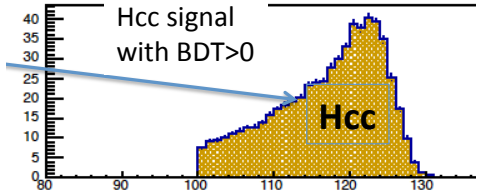
LHeC @1ab^{-1}

After 10 years of LHeC + HL-LHC

- Updates underway incorporating latest improvements from Run-2
- Revisit exp./theo. uncertainties

Talk C.Wagner

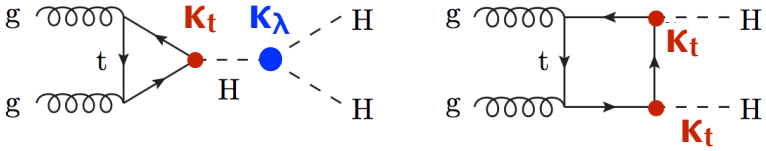
Modification of k_b would lead to large modification of all other BR



Talk U.Klein

$\delta\mu/\mu$(Hcc) = 7.4 %

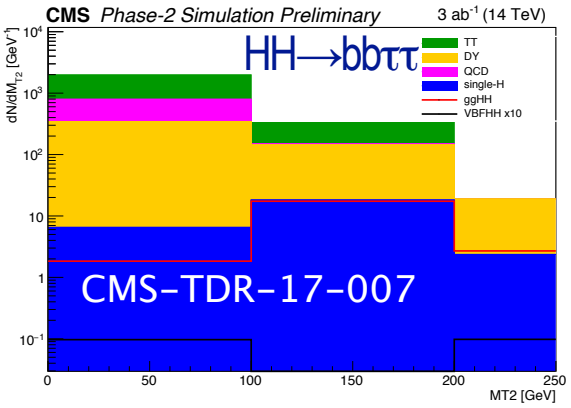
HH



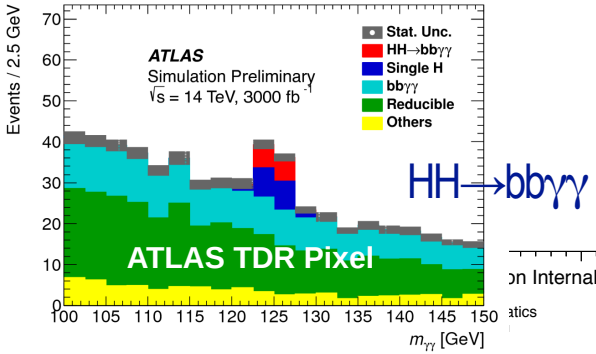
Thu morning: **C. Vernieri:** Di-Higgs CMS; **P. Bokan:** Di-Higgs ATLAS

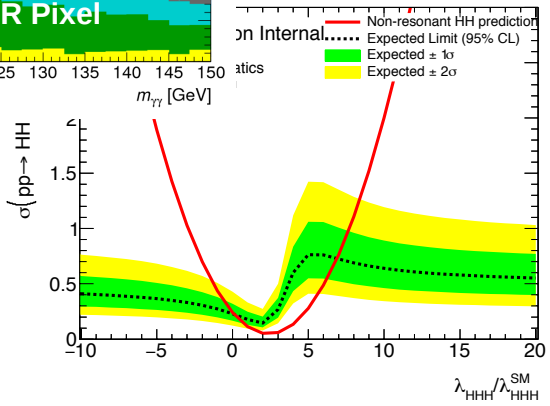
- Di-Higgs cross section (SM: 39 fb (±6%) at 14 TeV
- HL-LHC: aim to measure λ_{HHH}
- Need control of backgrounds and single Higgs production
- (Negative) Interference: need calculations to high accuracy
- Additional constraints on λ_{HHH} from single Higgs precision measurements

Plenary: Jezequel



Talk: P. Bokan

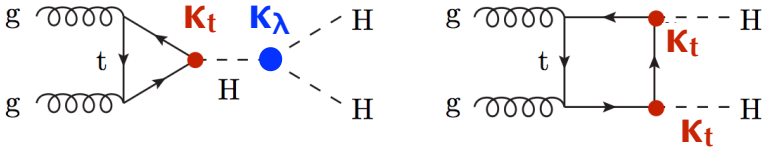




Channel	CMS	ATLAS
HH → bbbb	$Z(\sigma_{HH}(SM))=0.39\ \sigma$	$-4.1 < \lambda_{HHH}/\lambda_{SM} < 8.7$ @95 % C.L.
HH → bbττ	1.6 SM	0.6 σ $-4.0 < \lambda_{HHH}/\lambda_{SM} < 12.0$ @95 % C.L.
HH → bbγγ	1.43 σ	1.5 σ $0.2 < \lambda_{HHH}/\lambda_{SM} < 6.9$ @95 % C.L. (stat only)
HH → WWbb	0.45 σ	
tt(HH → bbbb)		0.35 σ

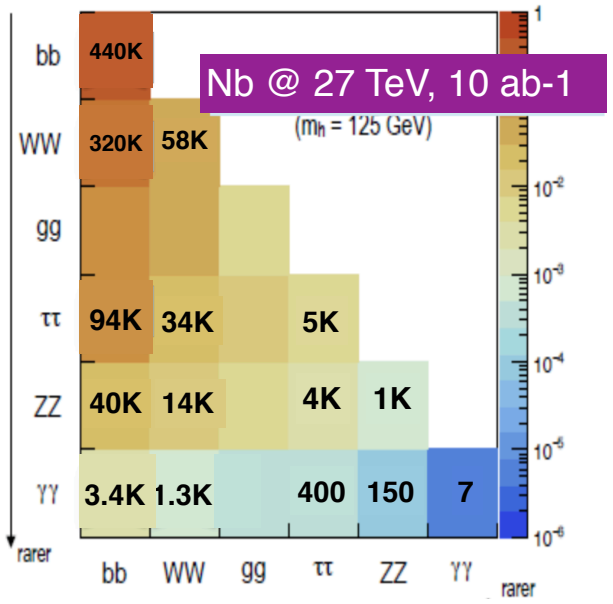
Being updated with most recent results from Run-2 and combination

HH



Thu morning: **M. Ramsey-Musolf:** Di-Higgs and EW phase transition; **M.Sullivan.:** Di-Higgs in singlet extensions; **S. Homiller:** HH at high energy

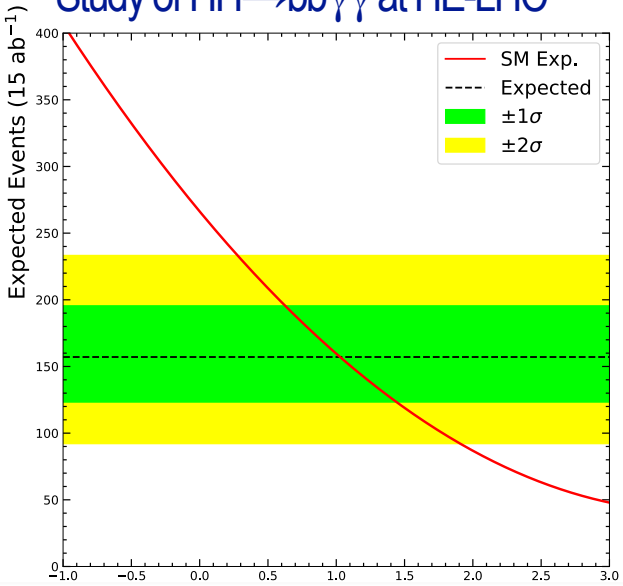
From kick-off mtg



Factor 10 more HH events at HE-LHC: measure λ_{HHH} down to ~20%

Study of HH→bbγγ at HE-LHC

Talk: Homiller



HE-LHC: expect ~4σ significance from single channel bbγγ => 40% precision on λ_{HHH}

Talk: Ramsey-Musolf

- HL/HE-LHC have potential to probe the nature of the electro-weak phase transition

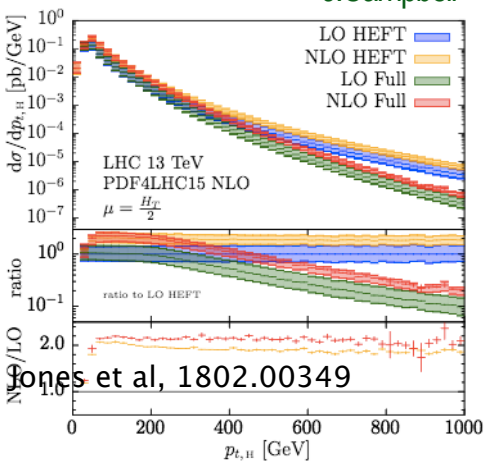
Talk: Sullivan

- New scalars could be measured in resonant HH production observable at the HL/E-LHC

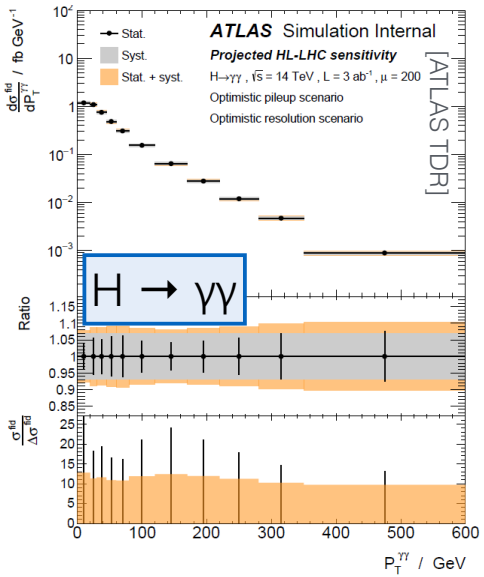
Higgs Distributions

Thu: T. Klijnsma: Differential cross sections;
D.Goncalves: Higgs Couplings at high energies

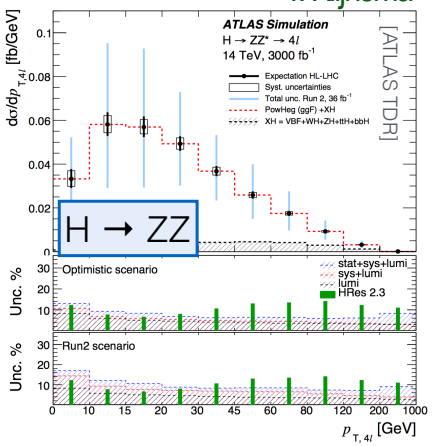
J.Campbell



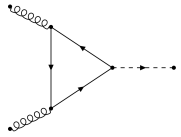
Jones et al, 1802.00349



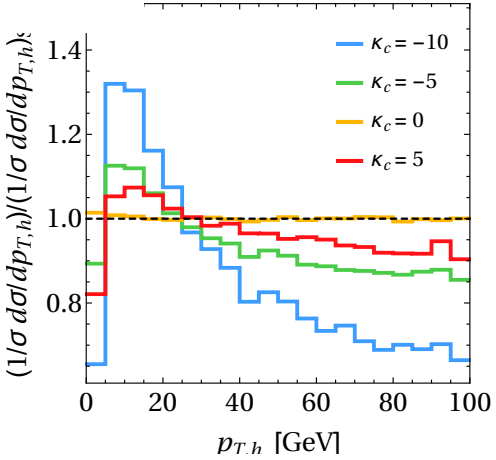
T. Klijnsma



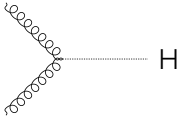
- At low/moderate pt: sensitivity to k_c, k_b — at high pt: k_t and BSM — angular distributions: CP structure



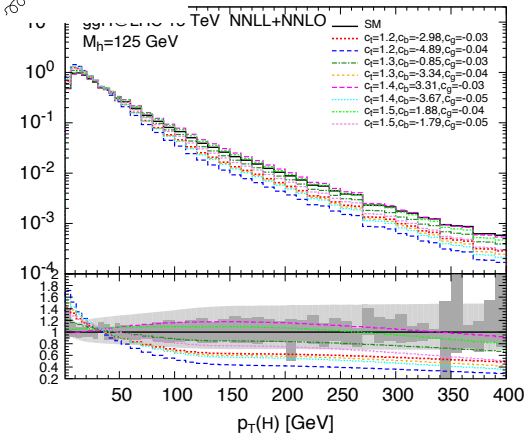
Bishara, Haisch, Monni, Re (2016) [1606.09253]



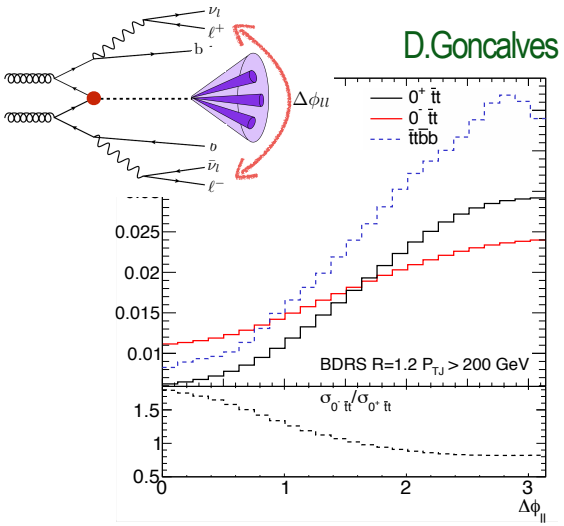
$y_c/y_{cSM} \in [-0.6, 3.0]$



Grazzini, Ilnicka, Spira, Wiesemann (2017) [1705.05143]



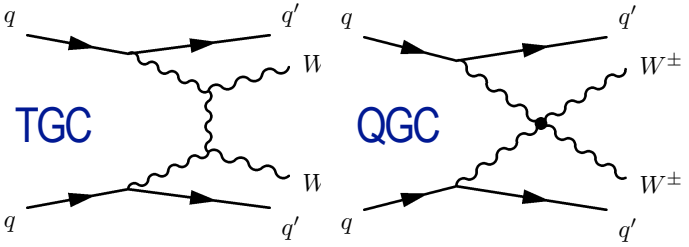
D.Goncalves



VBS and EFT

Thu morning: **B. Li:** VBS Measurements; **C.Murphy:** SMEFT; **F. Kling:** EFT

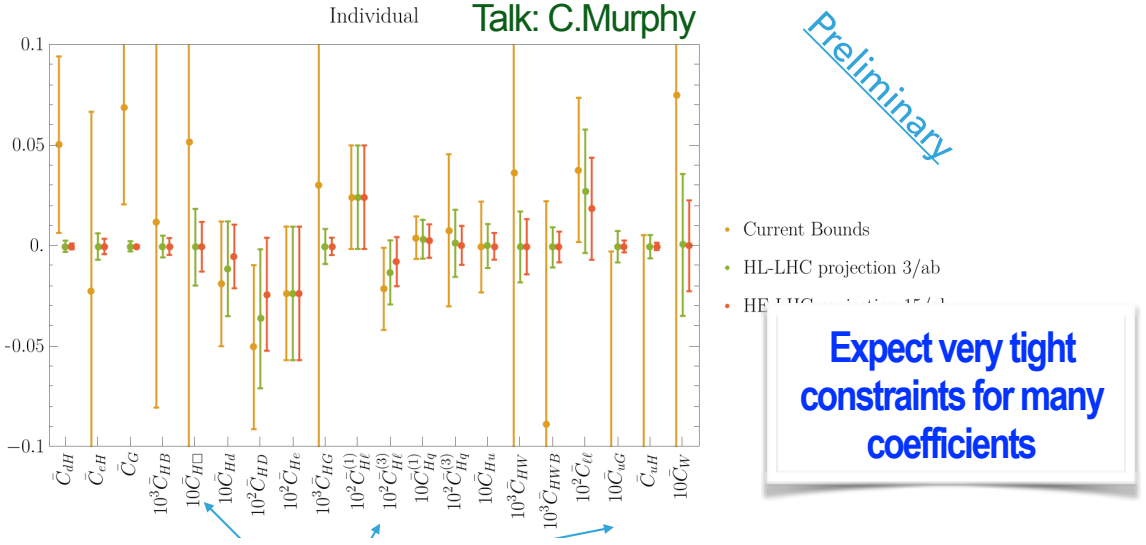
- Probe Higgs-mechanism (TGC and QGC)
- Recently observed (CMS Run-2 5.5σ)
- EFT: new physics is heavy ($\Lambda >> E_{Exp}$) quantify deviations from SM



$$\mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}} + \sum_{d>4} \sum_{i} \frac{f_i^{(d)}}{\Lambda^{d-4}} \mathcal{O}_i^{(d)}$$

- Practical issue: many operators → EFT phenomenology
- Projection of global fit to Higgs, diboson and electroweak data

Talk: C.Murphy

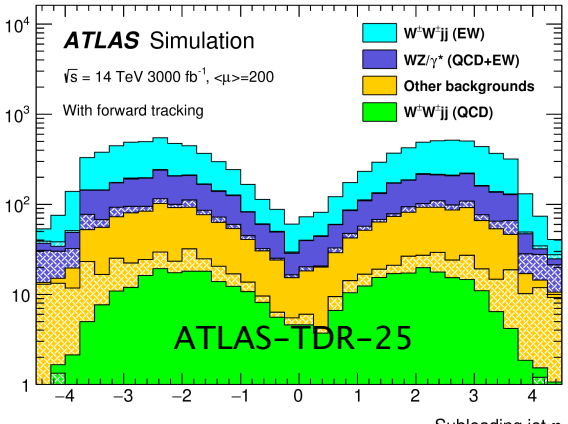


Expect very tight constraints for many coefficients

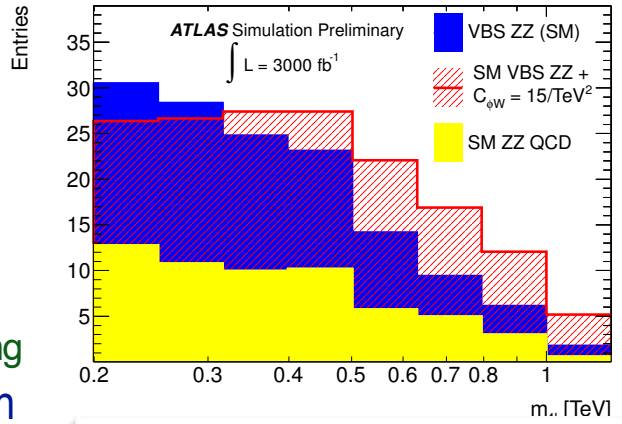
Talk: F.Kling

- Identify the most powerful EFT observables using Fisher information

$W^{\pm}W^{\pm} \rightarrow \ell\nu\ell\nu$



$ZZ \rightarrow \ell\ell\ell\ell$



Talk: B.Li

5σ discovery limit: $c_{\varphi W}/\Lambda^2$: 15/TeV²

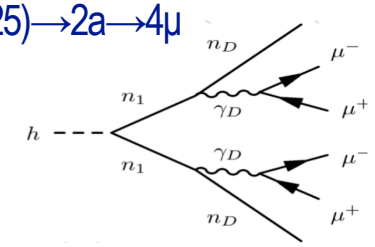
Exotic, invisible or rare Higgs

Thu afternoon; **C. Verhaaren:** Gaps in new Higgs searches; **S. Dildick:** Exotic and invisible Higgs decays; **Z. Liu:** Higgs rare and exotic decays; **T. Flacke:** Common exotic signatures

- **Exotic decays:** H→BSM or forbidden SM decays, currently B_{BSM} < 34%
- **Invisible decays:** unseen SM (e.g. neutrino) or BSM (e.g. DM), B_{inv} < 24%
- **Rare SM decays:** H →Zγ, H →φγ, H →ργ (Run-2 O(50) x SM)

planned for YR

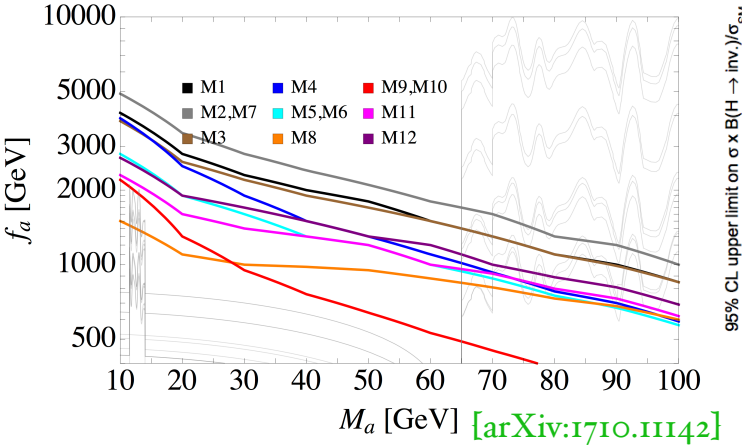
h(125)⟶2a⟶4μ



Z.Liu

- Still a lot of exotic decay channels not investigated
- Composite Higgs Models
  - additional particles, vector-like fermions, scalars
  - Study of H⟶ ττ recoiling against jet could help fill the gap

Th. Flacke

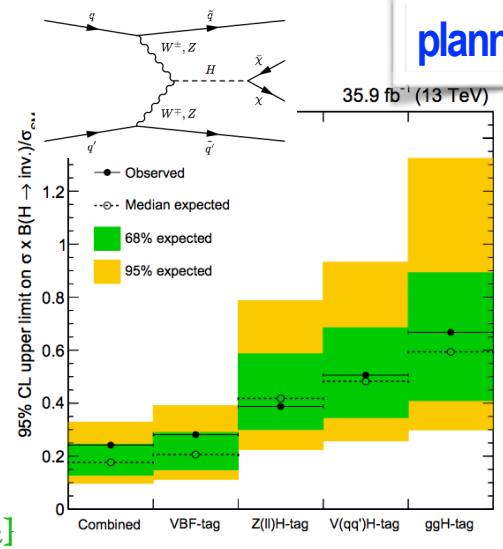


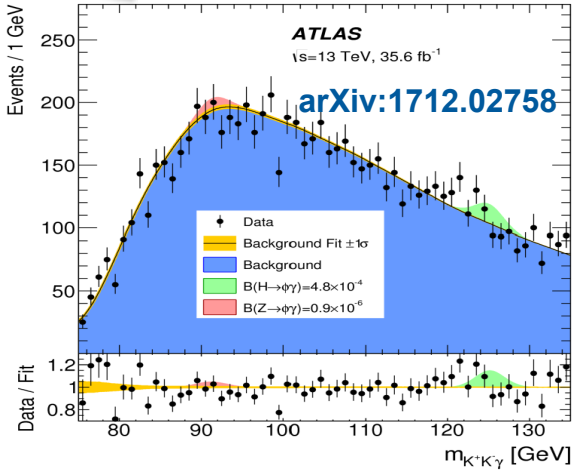
[arXiv:1710.11142]

planned for YR

Talk: S.Dildick

H→ 2 light quarks





Working on updates for YR, taking into account latest analysis improvements

CP Violation in the Higgs Sector

Fri morning: **A. Martin:** TH perspective CPV; **I. Ojalvo:** EXP prospects for Higgs and CPV

- **HVV:**
  - CP even established
    CP odd admixture not excluded

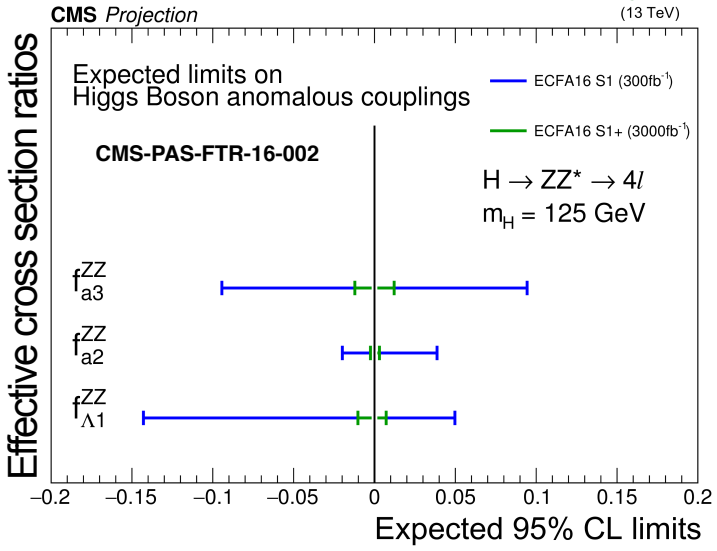
$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_1^2 + \kappa_2^{\mathrm{VV}} q_2^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} + \frac{\kappa_3^{\mathrm{VV}} (q_1+q_2)^2}{\left(\Lambda_Q^{\mathrm{VV}}\right)^2} \right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu},$$

SM — CP odd

  - New Run-2 method: expect much improved precision w.r.t ECFA'16 projection, taking both production and decay information into account
  - For planned update for YR also include upgrade detector, expecting to reach permille-level precision

$$f_{ai} = |a_i|^2 \sigma_i \Big/ \sum |a_j|^2 \sigma_j \qquad \phi_{ai} = \arg\left(a_i / a_1\right)$$

Talk: I.Ojalvo



ECFA'16 result based on Run-1 $f_{ai} \times \cos(\varphi_{ai})$

- **Hff:**

Talk: A.Martin

  - Need fermion with observable polarisation information:
    $H \to \tau\tau$ or $H \to tt$

$$\mathcal{A}(\mathrm{H}ff) = -\frac{m_f}{v} \bar{\psi}_f \left(\kappa_f + \mathrm{i}\,\tilde{\kappa}_f \gamma_5\right) \psi_f$$

CP Even — CP Odd

Talk: I.Ojalvo

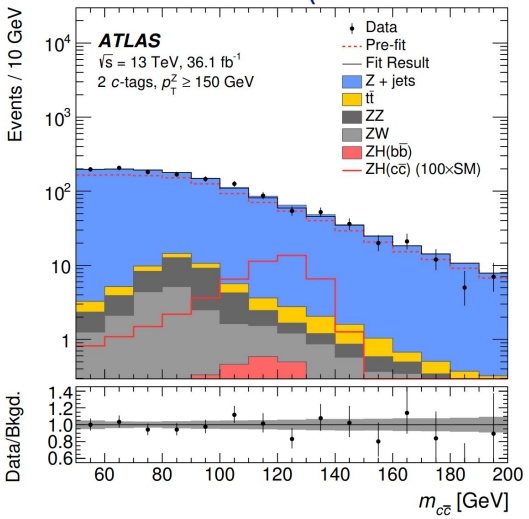
  - Experiments: severe backgrounds dilute extraction, difficult to project, but aiming for YR

Higgs and Charm

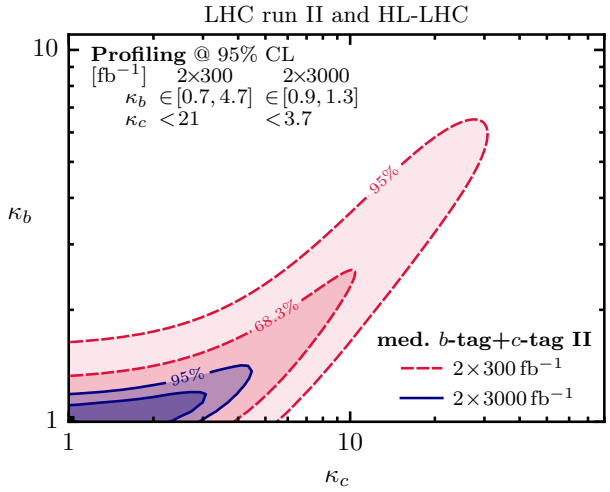
Fri morning: **E.Stamou:** TH perspective Higgs and Flavour; **D. Craik:** EXP prospects for charm tagging

- Higgs-fermion coupling so far only with 3rd generation
- Higgs-charm couplings from diff dists. k_c [-0.6 … 3.0] (see above)
- LHCb: H ⟶ cc (Run-1): μ < 7900 x SM
  For 300 fb^{-1} expect better than 7 x SM
- ATLAS: ZH ⟶ cc (Run-2): μ < 110 x SM
- Recast of ATLAS and CMS H ⟶ bb measurements: Assuming ε_c = 30% and ε_b = 20%: **expect $|k_c| < 3.7$ @ 3 ab^{-1}**

ATLAS ZH⟶cc Run-2 (arXiv:1802.04329)

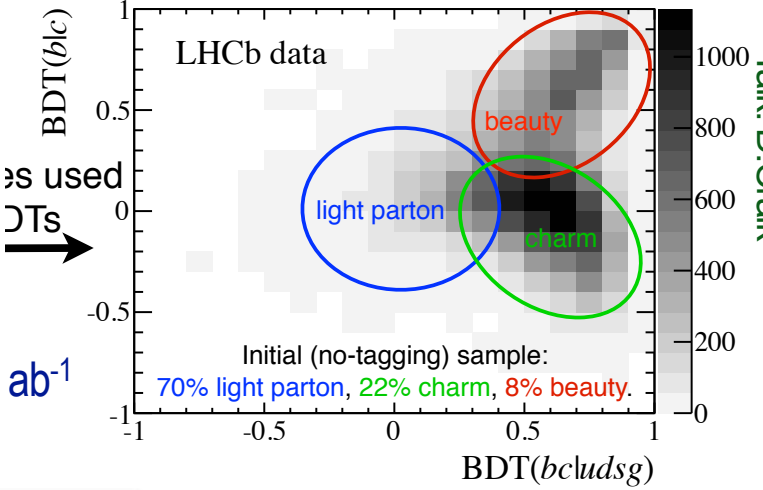


Talk: D.Craik



Talk: E.Stamou

Combination of BDT for flavour separation



Talk: D.Craik

- Exclusive: e.g. ATLAS H->J/ψ(μμ)γ (BR(2x10^{-7}): 15 x SM @ 3 ab^{-1}
- Exclusive and differential approach also work for light quarks

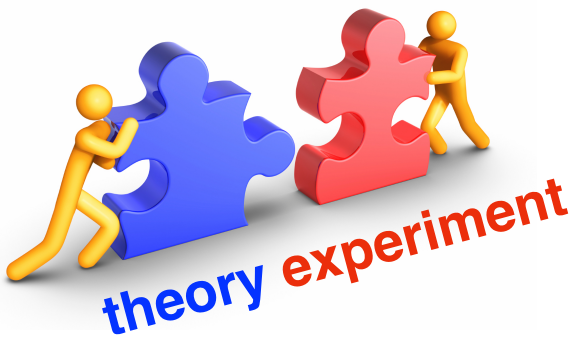
Prospects for H⟶qq looking up

Experimental Wishlist / Plan for YR 2018

Plenary S.Gori

	CMS	ATLAS	LHCb
Coupling studies	✔✔★	✔✔★	
Differential cross sections	✔★	✔★	
Width		✔	
Anomalous couplings	✔★	✔	
Rare decays	μμ,cc	Zγ,J/ψγ,FCNC μμ,ργ,cc	Hcc/Hbb
Exotic decays	LFV; Invisible, DarkSusy; 4jets		
Di-Higgs	✔✔★	✔✔★	
Additional scalars	A->Zh, high mass ττ, low mass γγ	μμ, ZZ, A->Zh, ττ, WW	

Legend: Past Studies, **2017 TDRs**, Wishlist for 2018



S.Gori

from M.Cepeda talk at the assembly meeting of the LHCHXSWG, March 26

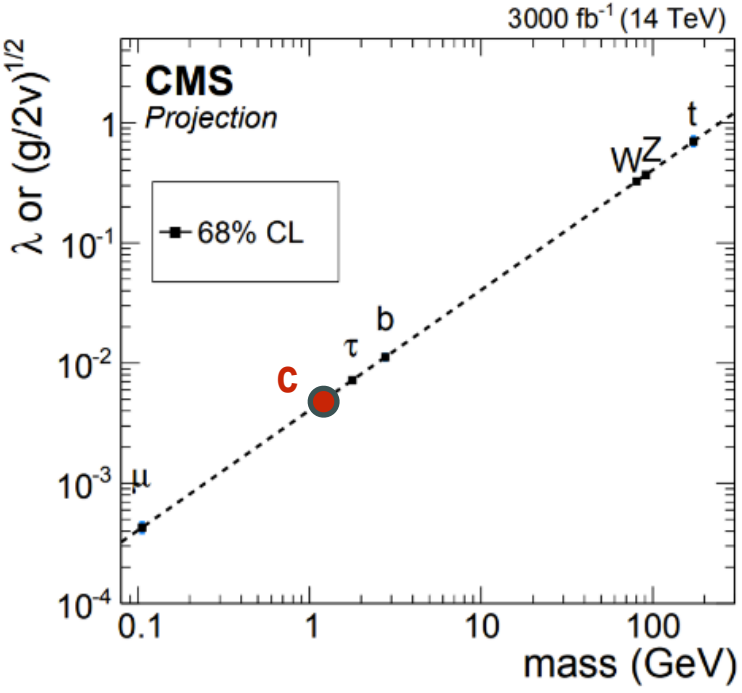
6/11

WG2: Higgs - Wrap up

- **Lots of recent experimental and theoretical progress leading to substantial improvements**
  - Prospects for λ_{HHH}
  - Charm coupling
  - Anomalous couplings

- **For YR:**
  - Update existing results in a coherent way
  - Combinations: single Higgs and HH
  - Several new topics
  - Theory: update of cross sections for 14 and 27 TeV (done)

- **Discussion / Homework:**
  - Investigate Charm-Higgs associated production
  - Coordinated effort on combination and systematics
  - Editorial Overlap: Exotic Higgs + BSM



- **Other relevant Higgs events:**
  - CMS HH workshop (this week)
  - latest Higgs XS WG meeting https://indico.cern.ch/event/665524/timetable/?view=standard

WG3: BSM

Draft chapter structure: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHEWG3

1. I **Introduction and overview**
2. Analysis methods and approaches
   - …inties
2. S **Supersymmetry**
   - …SY models at the HL-/HE-LHC *(S. Heinemeyer et al.)*
   - b. Probing SUSY at HL- and HE-LHC *(T. Han et al.)*
   2. SUSY strong production
      - a. SUSY strong - improved searches for squark/gluinos *(ATLAS)*
      - b. Prospects for third generation squark production at the HL-LHC and HE-LHC *(I. Vivarelli et al. ATLAS)*
      - c. same-sign dilepton SUSY *(CMS)*
      - d. Implications of a Stop Sector Signal at the LHC *(A. Pierce et al.)*
   3. SUSY EWK production
      - a. Prospects for C1N2 via WZ and Wh in multilepton at the HL-LHC and HE-LHC *(A. de Santo et al. ATLAS)*
      - b. Prospects for chargino pair production at HL- and HE-LHC *(S. Carra' et al. ATLAS)*
      - c. Search for charg-neut in Wh channel using 1Lbb final states *(M. D'Onofrio et al. ATLAS)*
      - d. Prospects for direct stau production at the HL-LHC *(C. Zhung et al ATLAS)*
      - e. Prospects for direct stau production at the HL-LHC *(CMS)*
      - f. Compressed electroweakinos at HL- and HE-LHC *(S. Amoroso et al. ATLAS)*
      - g. Prospects for radiative natural SUSy at HL- and HE-LHC *(H. Baer et al.)*
      - h. Constraining slepton and chargino through compressed top squark search *(P.*
3. D **Dark Matter**
   - …SR + 2leptons and VBS + 2leptons *(CMS)*
   - a. Prospects for DM interpretations in jet+MET analysis at HL/HE-HLC *(C. Gustavino et al. ATLAS)*
   - b. Monojet searches for DM *(CMS)*
   2. DM + ttbar / bbbar
      - a. Prospects for associated production of dark matter and top quark pairs at the HL-LHC *(F. Meloni et al. ATLAS)*
      - b. Prospects for associated production of dark matter and bottom quark pairs at the HL-LHC (M. McDonald et al. ATLAS)_
      - c. HL/HE-HLC prospect for determining the CP nature of spin-0 mediators in associated production of dark matter and top pairs *(U. Haisch et al.)*
   3. DM + single top
      - a. HL/HE-HLC prospect for DM and a single top-quark production in a 2HDM model with a pseudoscalar mediator *(P. Pani et al.)*
      - b. Sudies of DM production in single-top events *(CMS)*
      - c. Sudies of DM production in single-top events *(ATLAS)*
   4. More models expected to be targeted
      - a. Prospects for pure WIMP (pure triplet) Dark Matter at HL-LHC *(L. Carminati et al. ATLAS)*
4. L **Long-Lived Particles**
   - …els at HL/HE-LHC *(Y.G.Kim et al.)*
   - …L/HE-LHC *(P. Pani, F. Meloni)*
   - …L-LHC *(J. Anders et al. ATLAS)*
   2. Prospects for disappearing track analysis at HE-LHC *(M. Saito et al.)*
   3. displaced vertex
      - a. Displaced R-Parity Violation at the LHC *(H. Dreiner et al.)*
      - b. Prospects for LLP->DV+MET *(L. Jeanty et al. ATLAS)*
      - c. displaced muons *(CMS)*
      - d. Prospects for LLP->mu+jets at the HL-LHC *(X. Cid Vidal et al. LHCb)*
      - e. Prospects for LLP->dijets at the HL-LHC *(X. Cid Vidal et al. LHCb)*
   4. heavy stable charged particles (dE/dx and TOF) *(CMS)*
   5. fast timing signatures for long-lived particles *(CMS)*
   6. various interpretations
      - …and ATLAS/CMS *(A. Pierce et*
5. I **Dark sector: dark Photons**
   - …the HL-LHC and HE-LHC *(S. Biswas et al.)*
   - b. Axion-like particles at the LHC *(A. Mariotti et al.)*
6. **Heavy Resonances**
   - …(lepton-jets) at HL-LHC and HE-LHC *(C.*
   - …nd HE-LHC *(S. Chekanov et al.)*
   - b. Prospects for diboson resonance at HL-LHC and HE-LHC *(R. Les et al. ATLAS)*
   - c. Improving sensitivity to heavy resonance decaying 4 leptons at the HL-/HE-LHC *(D. Dobnath et al.)*
7. V **Vector-Like Quarks**
   - …-LHC and HE-LHC *(P. Azzi et al. CMS)*
   - …C *(H. Alhazmi et al.)*
   - b. Vectorlike quarks and leptons in extended Higgs sector *(R. Dermisek et al.)*
   - c. VLQs at HL- and HE-LHC: discovery and characterization *(D. Barducci, L. Panizzi)*
8. F **Flavour-related studies**

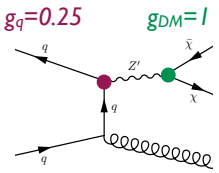
Dark Matter …

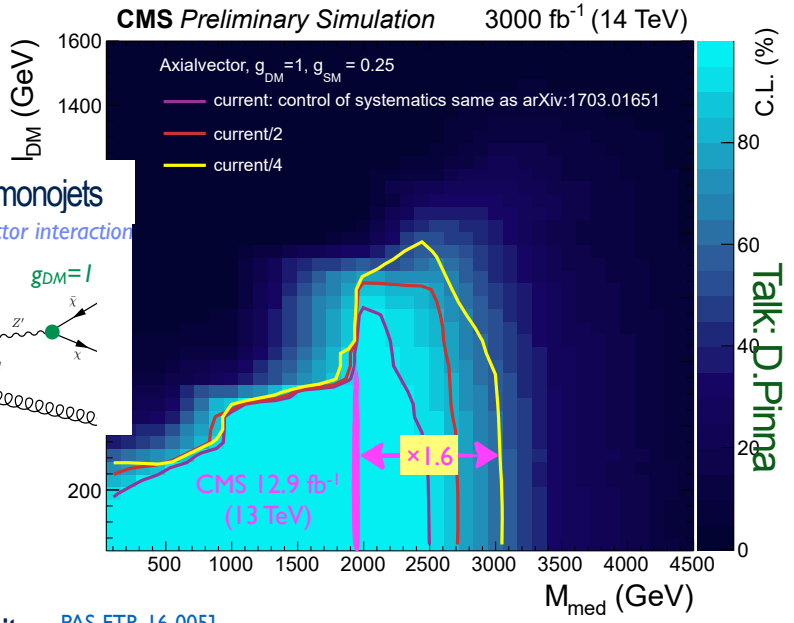
Wed afternoon: **M. Buckley:** DM@HL/HE-LHC; **D. Pinna:** CMS DM; **M. D'Onofrio:** ATLAS DM; **M. Williams:** LHCb DM; **G. Kribs:** Dark Mesons

- **… must be there somewhere, possibly at the LHC**
- **Simplified models for specific interactions**
  - EFT only valid if Λ_{DM} large enough
  - Theory evolving rapidly: e.g. account for interference of amplitudes (H→invisible)
- **MET: Need good control of SM Bg**
  - Experimental and theory syst. (Pile-up, JES and PDF): expected sensitivities strongly depend on assumed uncertainties

Example: monojets

vector/axial-vector interaction

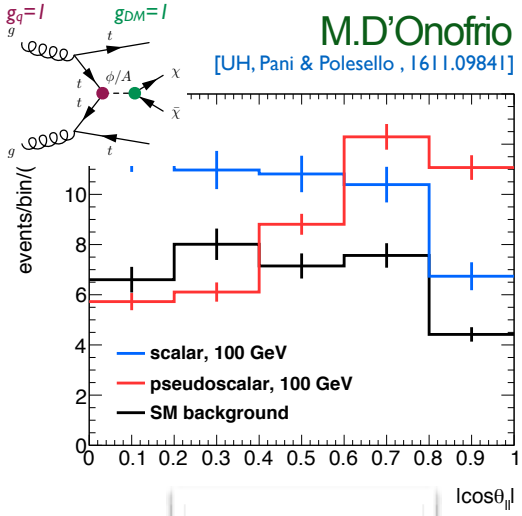




tt+DM, via spin correlations

M.D'Onofrio

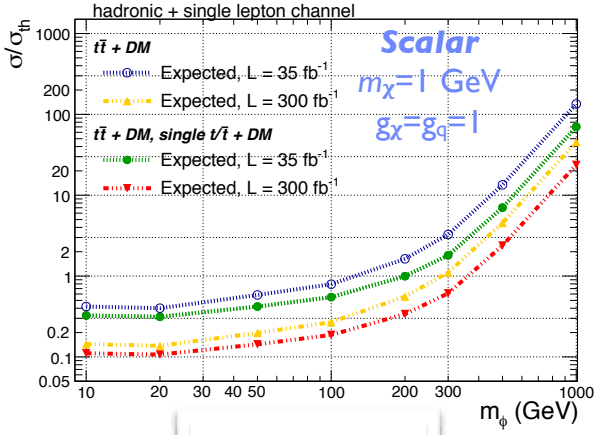
[UH, Pani & Polesello , 1611.09841]



planned for YR

single top+DM adds to sensitivity [ATL-PHYS-PUB-2016-019, ATL-PHYS-PUB-2017-003, ATL-PHYS-PUB-2017-005, CMS-PAS-FTR-16-005]

D.Pinna



planned for YR

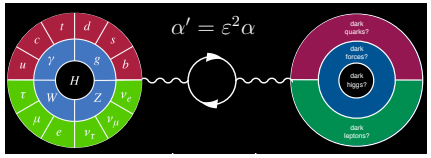
X.Wang

- Mass limits for monojet/MET analysis, assuming DM is Wino (Higgsino):
  - HL-LHC: ~250(150) GeV
  - HE-LHC: ~600(400) GeV
  - FCC-hh: ~1000(500) GeV

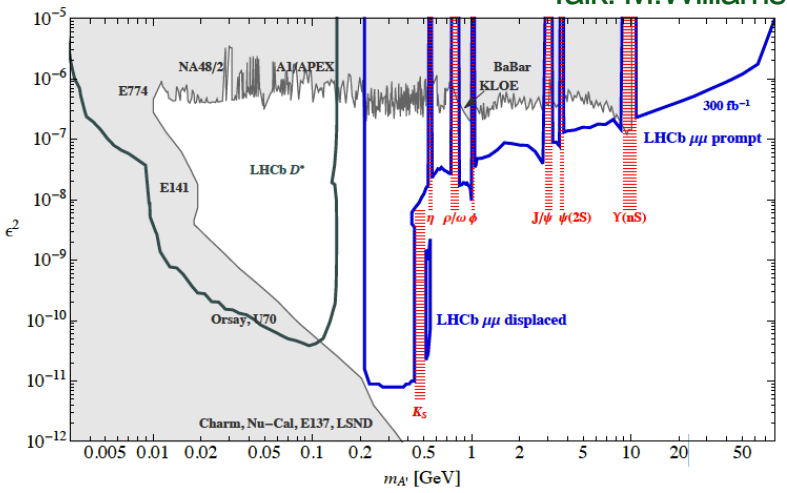
Dark Sector

Wed afternoon: **M. Buckley:** DM@HL/HE-LHC; **D. Pinna:** CMS DM; **M. D'Onofrio:** ATLAS DM; **M. Williams:** LHCb DM; **G. Kribs:** Dark Mesons

Dark Photons



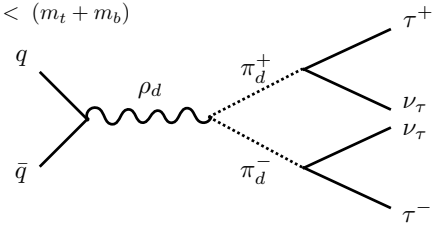
Talk: M.Williams



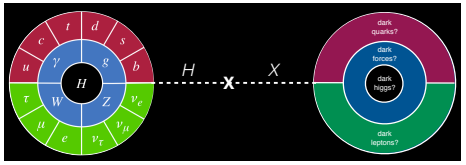
G.Kribs

DM could also be a new strongly coupled, confining theory, which exists near the weak scale, could look like stau

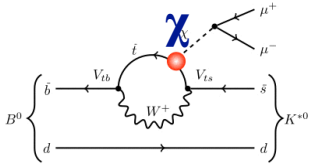
When $m_{\pi_d} < (m_t + m_b)$

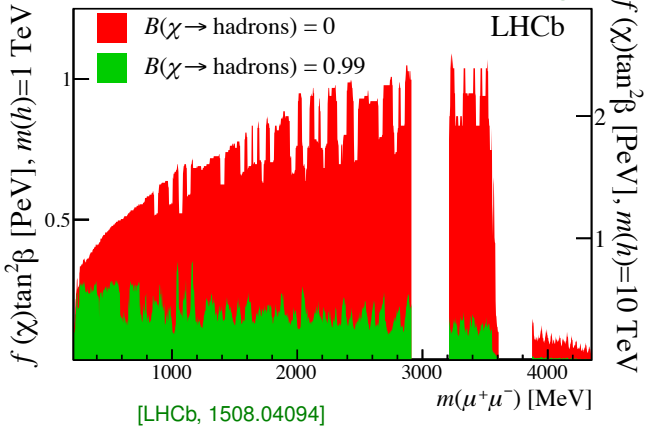


Higgs Portal



Talk: Z.Ligeti

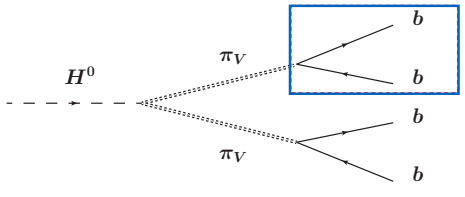


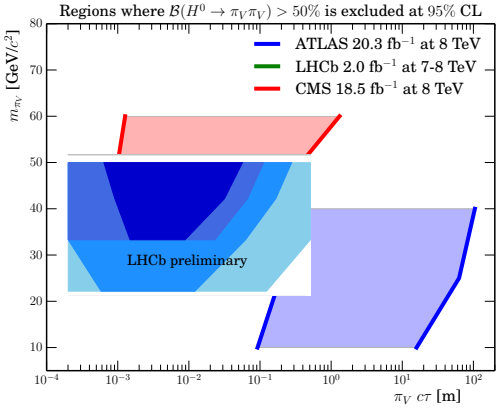


[LHCb, 1508.04094]

Recast of LL searches into hidden-valley dark pions from Higgs

Talk E.Dall'Occo



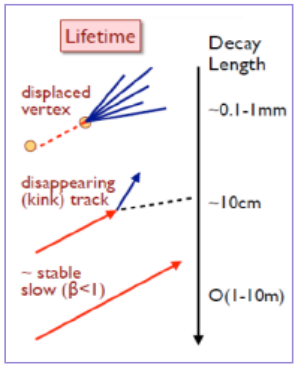


LHCb: 95% exclusion limits for BR > 1% … > 50%

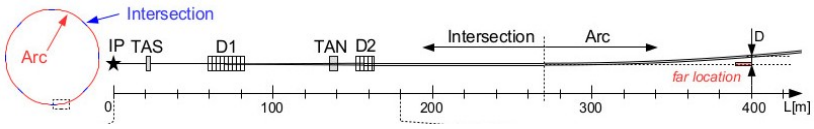
Long-Lived Particles

Wed afternoon: **L. Jeanty:** LLP at ATLAS; **L. Soffi:** LLP at CMS; **E. Dall'Occo:** LLP at LHCb; **I. Galon:** FASER

- **Various Long-Lifetime Scenarios**
  - Approximate symmetries
  - Small couplings
  - Very heavy off-shell mediators
  - Phase space suppression
- **Different experimental strategies**
  - direct detection or "collateral event features"
  - Creative use of experiments
- **Better trigger rate estimates to be done**



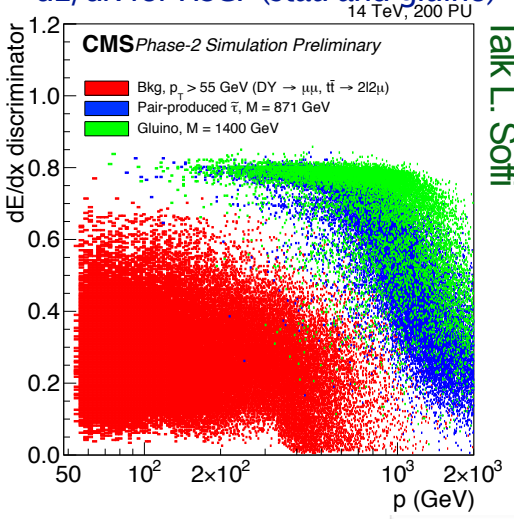
Talk I.Galon



FASER: ForwArd Search ExpeRiment at the LHC:
Signal: two high-energy opposite-charge tracks
(e.g. from dark photons) **starting inside the detector**
10^{17} π^0 expected, decay-in-volume eff.: 10^{-4}

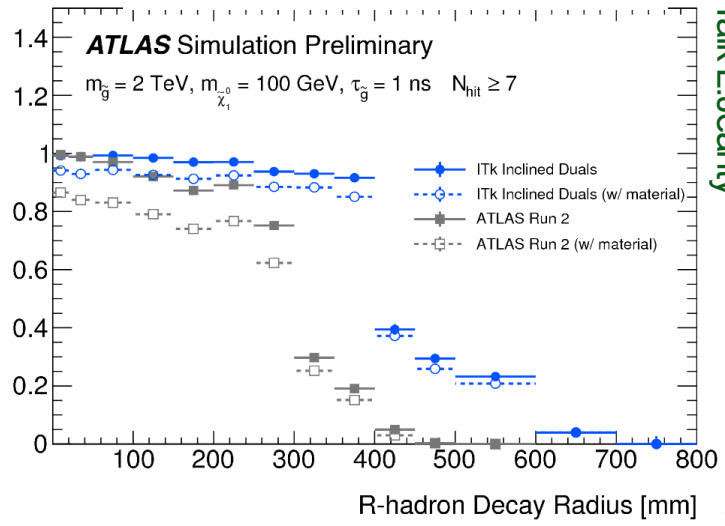
Other exps: Codex-b, Mathusla, MilliQan

dE/dx for HSCP (stau and gluino)

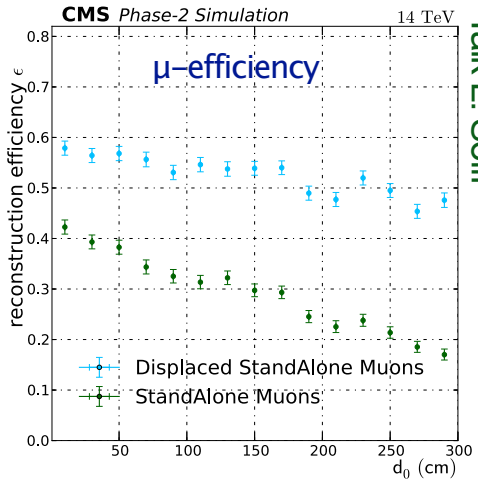


Talk L. Soffi

track efficiency as fct of vertex radius



Talk L.Jeanty



Talk L. Soffi

Dramatic improvements of experimental capabilities for LLP

Heavy Resonances

Thu morning; **F. Yu:** Z' searches; **R.Wang:** Searches in Dijets; **S. Khalil:** CMS resonances; **S. Demers:** ATLAS resonances; **A. Ismail:** Anom. Z' and diboson res.

- Resonances predicted in many BSM scenarios, Z', VLQ

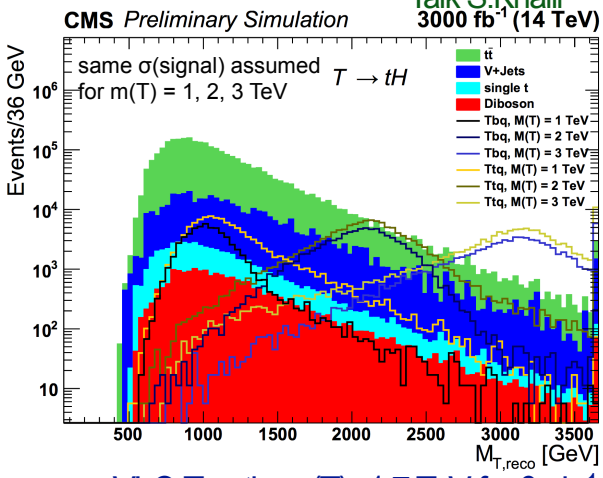
Talk S.Shin

- VLQ could also arise in heavy Higgs cascade decay

Talk A.Ismail

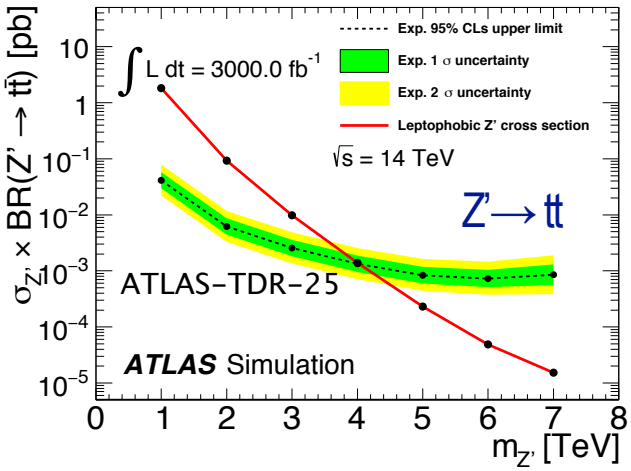
- Z' could also be light
- If a new resonance was found by Run-3, upgraded detectors could help measure its properties

Talk S.Khalil

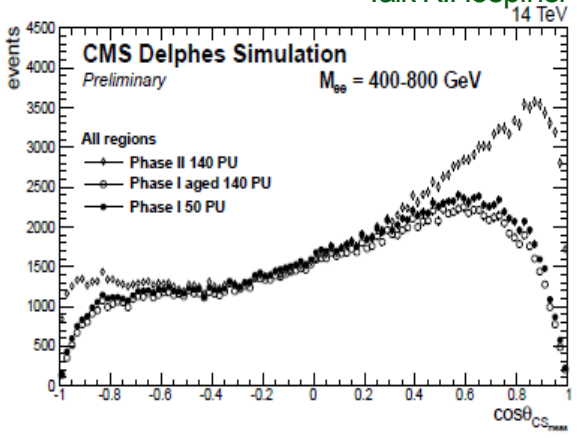


VLQ T→th: m(T)>1.7 TeV for 3 ab^{-1}

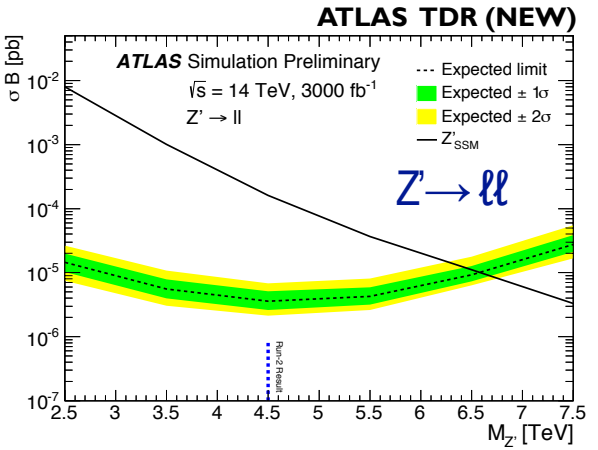
Talk S.Demers



Talk K.Hoepfner



Talk S.Demers

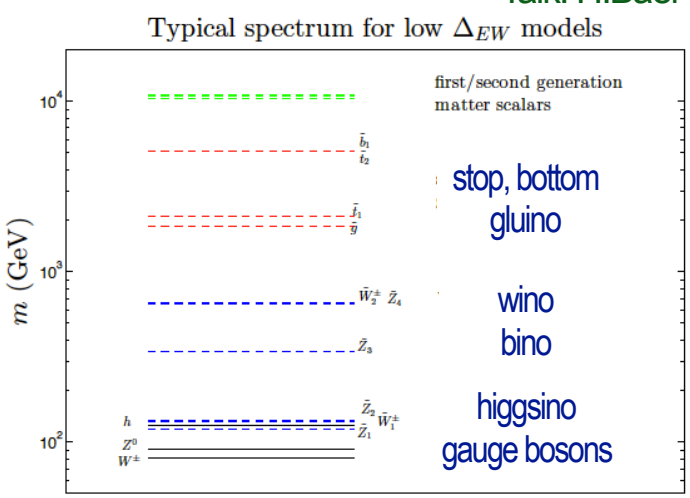


Sequential SM as benchmark: exclude up to 6.5 TeV more than 2 TeV better than current

Strong SUSY

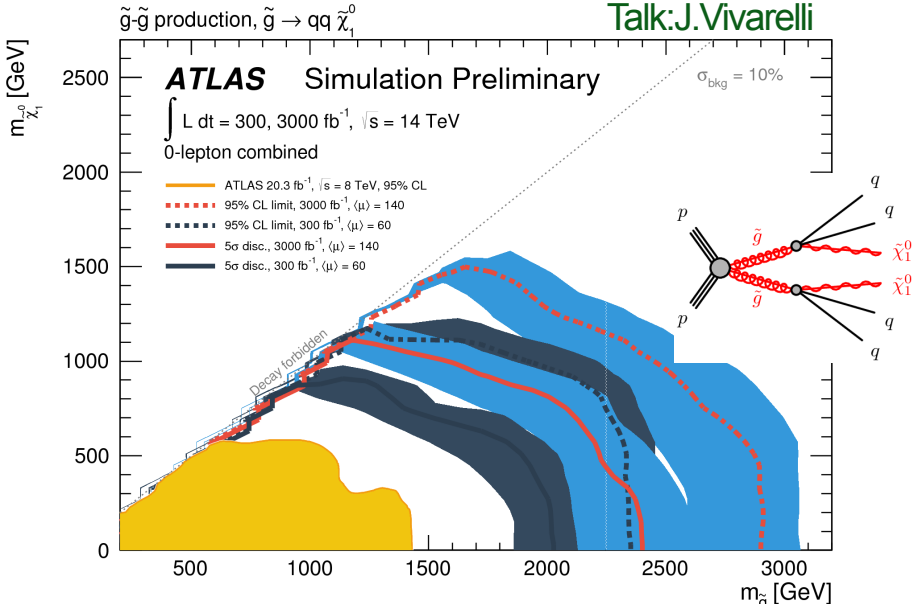
Fri morning: **H. Baer:** SUSY; **I. Vivarelli:** Strong SUSY ATLAS; **K. Hatakeyama** Strong SUSY CMS; **S. Shin:** Vector-like fermions in heavy Higgs cascades

Talk: H.Baer

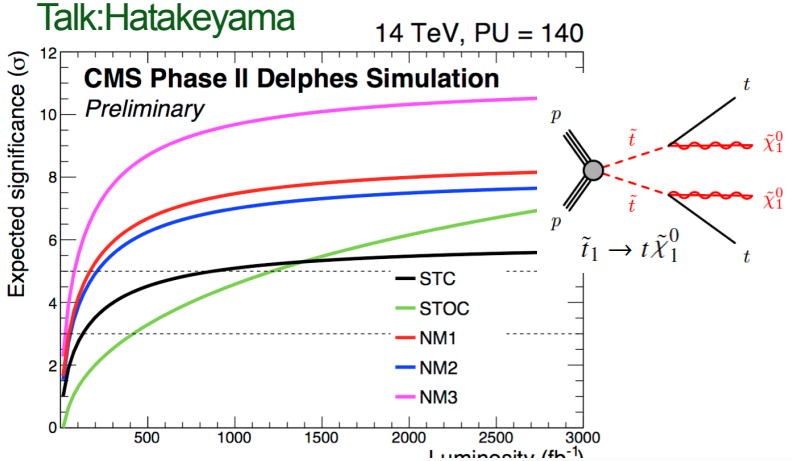


SUSY could still be reasonably natural

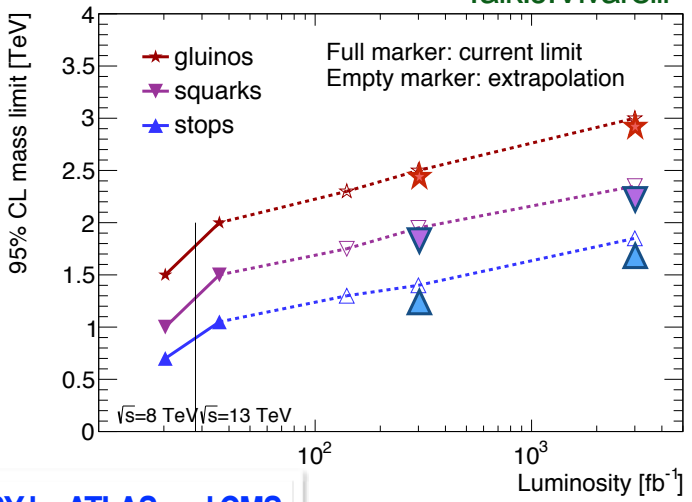
Talk:J.Vivarelli



Talk:Hatakeyama



Talk:J.Vivarelli



Many RPC benchmark projections for SUSY by ATLAS and CMS
hadronic, single-l, compressed, di-lepton edge, mono-jet, MET…

Electroweak SUSY

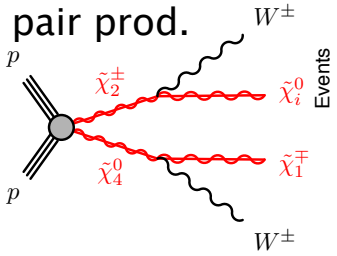
Fri morning: **M. Low:** Electroweakino Searches; **A. Canepa:** EW SUSY CMS; **S. Amoroso:** EW SUSY ATLAS; **X. Wang:** Wino and Higgsino DM

- Natural electroweakinos and sleptons: multilepton final states with (low-pt) leptons

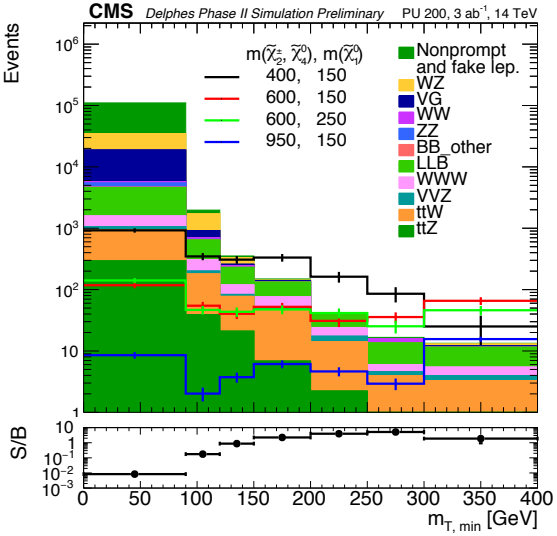
Talk M.Low

- Charginos could be as light as 74 GeV
- Significant benefits from improved detectors (calo, muon, trigger, timing)
- For YR planning new analyses

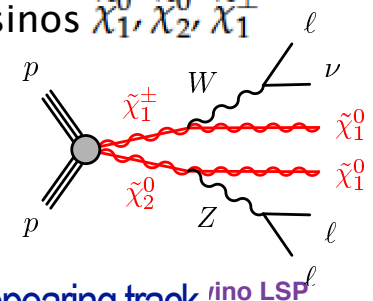
wino-like pair prod.



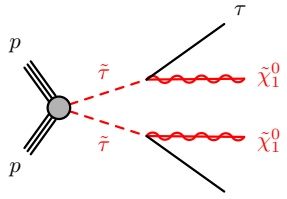
CMS-TDR-17-006 Talks: A.Canepa

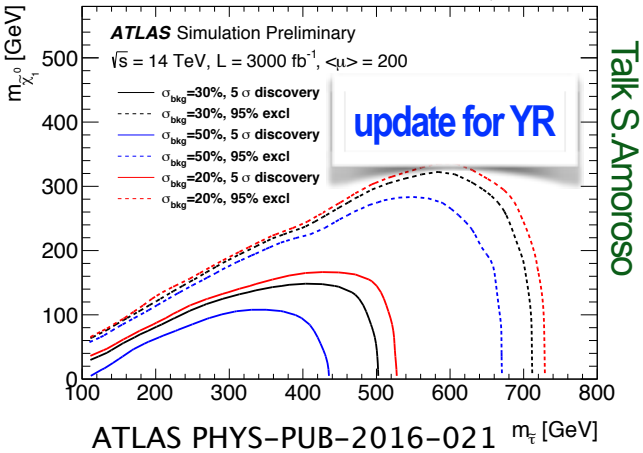


mass-degenerate higgsinos $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^\pm$



Stau pair prod.

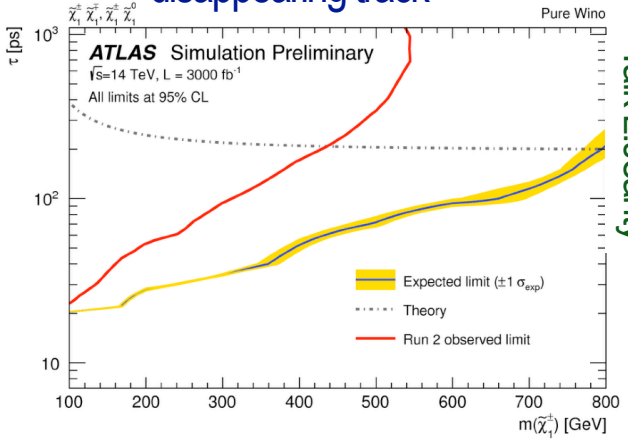




Talk S.Amoroso

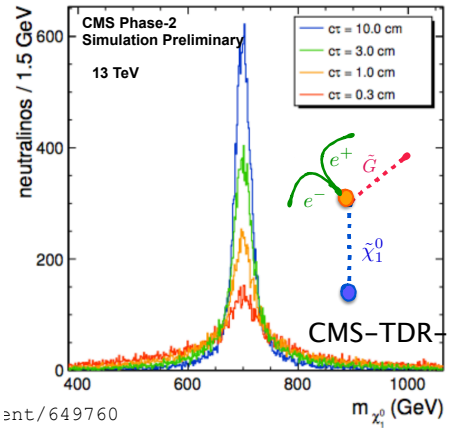
ATLAS PHYS-PUB-2016-021

HL-LHC disappearing track wino LSP



Talk L.Jeanty

appearing tracks



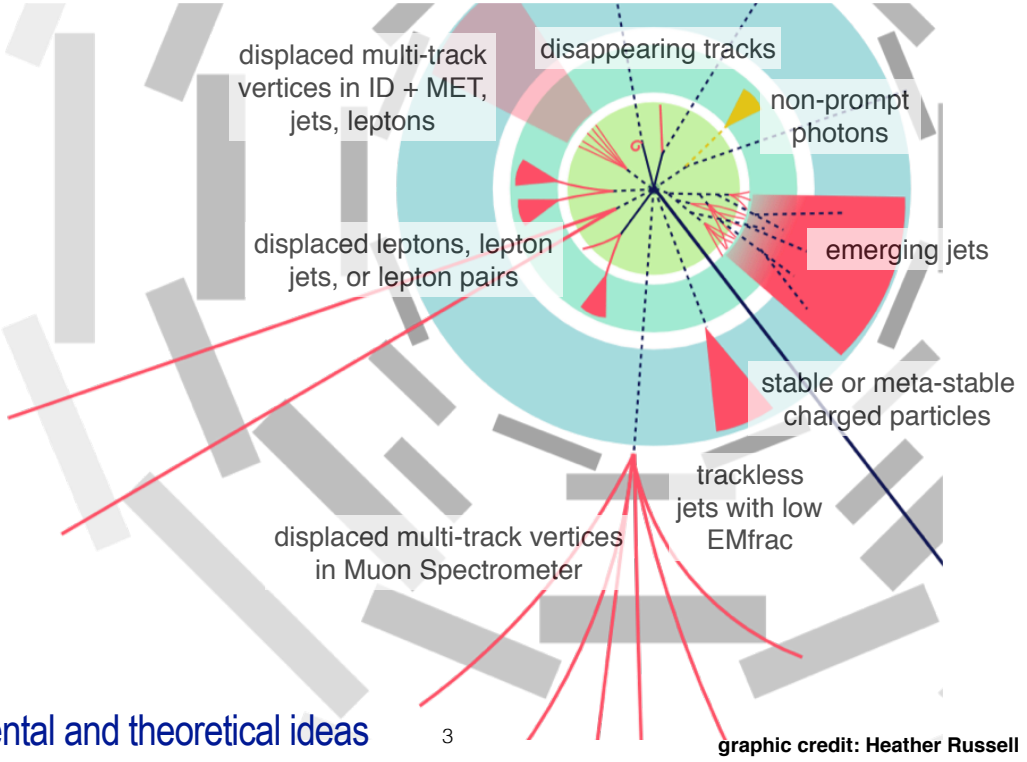
Talk L.Soffi

CMS-TDR-17-006

MIP timing detector (30ps resolution): improved sensitivity to LLP

WG3: BSM - Wrap up

- **Significant benefits from detector upgrades and analysis techniques, e.g. EWK SUSY and LLP.**
  - Still room for light, weakly coupled new physics, HL/E-LHC could find it at high pt
  - … and also moderate pt, depending on understanding of SM background



graphic credit: Heather Russell

- **For YR:**
  - Coherent documentation of all the new experimental and theoretical ideas

3

- **Discussion / Homework:**
  - How do we implement in the report complementarity with other experiments (i.e. long-lived-particles additional detectors (FASER, COdeX etc) and facilities (LHeC).
  - Fully workout editorial overlap with Higgs and Flavour

- **Upcoming WG3 dates:**
  - Vidyo Meeting 23 April
  - Vidyo Meeting ~21 May (tba)
  - Target drafts write-ups of contributions by 30 May

WG4: Flavour

Draft chapter structure: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHEWG4

1. V
2. C

CKM Metrology and HL/HE questions for B Physics

   b. F=2 processes and unitarity triangle
   c. Future of inputs from charm and K-Kbar mixing
   d. Experimental prospects (including interplay with **Belle II**)
   th/exp perspective on future of global CKM fits

3. I

Charm

   s for charm (15 pages)
   ixing
   b. Direct CP violating probes
   c. Null tests from isospin sum rules
   d. Radiative and leptonic charm decays
   e. Inputs for B physics
   f. Experimental prospects (including interplay with **Belle II** and **BES III**)
   g. Combined th/exp perspective on charm mixing/CPV global fits and charm as input to B

4.

Strangeness

   ngeness (5 pages)
   e
   b. KS->πμμ
   c. KS->ππee
   d. KS->μμμμ
   e. Questions for hyperons
   spects (including interplay with **NA62** ??)

5. H

τ-Leptons

   us (5 pages)
   niversality
   b. LFV in tau decays (tau-> μμμ) !!
   c. Tests of QCD
   d. Vus determination

6.

Spectroscopy

   troscopy
   b. Experimental probes in B decay
   c. Probes from prompt production in pp
   d. Experimental prospects (including interplay with **Belle II**)
   e. Combined th/exp perspective, including how far **ATLAS** / **CMS** can contribute to finding new states, confirming the pentaquark etc. observations, and studying their properties

7. Im

Implications of flavour anomalies

   b. Theoretical prospects tree-level b-> c tau nu and b-> u tau nu
   c. Experimental perspective (including interplay with **Belle II**)
   d. Combined th/exp perspective on global interpretations (EFT/non-EFT), with particular emphasis on impact of **LHC** -only combined analysis and complementarity of this with

8. Fl

Flavour aspects of top physics

   ffects from T-odd kinematic distributions
   c. Interpretation of limits in top FCNCs
   d. SMEFT analysis and complementarity with B-decays

9. Fl

Flavour aspects of Higgs

   es)
   b. Exclusive Higgs decays
   c. Flavor tagging (charm and strange), *exp mostly*
   d. LFV decays of the Higgs, *exp mostly*
   e. Yukawa constraints from Higgs distributions
   f. CP violation in Higgs couplings (tau, ttH), *exp mostly*

10. h
    p

High pT searches in the context of flavour anomalies

   with **WG3** (10
   d. Constraints on combined models

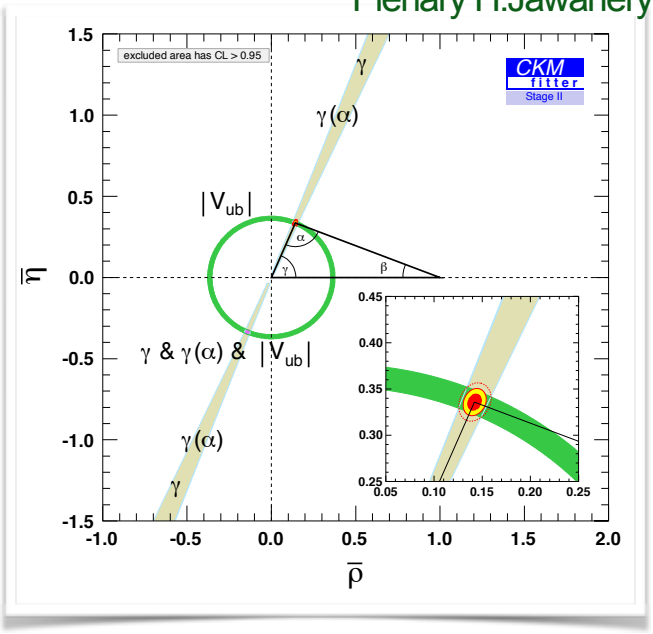
11. *Summary of theory + experimental outlook*

Flavour Physics

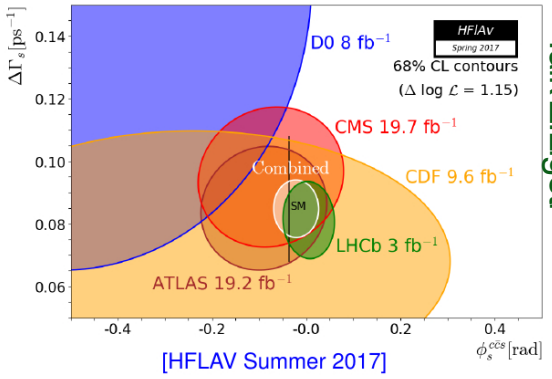
Z.Ligeti: Flavour at LHC; **D. Craik:** B Physics at HL/HE-LHC;
A.Schwartz: Belle 2; **T. Skwarnicki:** Spectroscopy questions for LHC

- **Classical B-physics metrology: Overconstrain CKM**

Plenary H.Jawahery



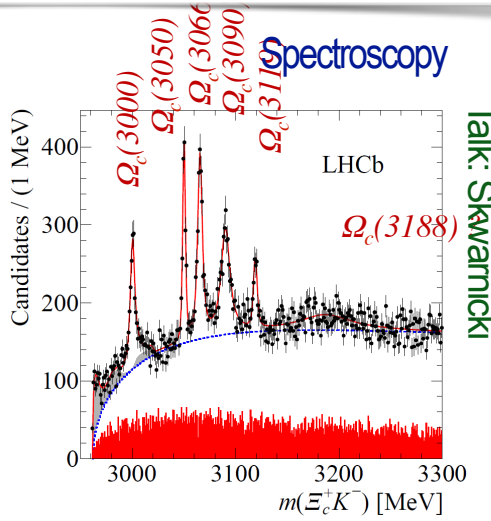
Time-dep. CP analysis of B→J/ψφ



[HFLAV Summer 2017]

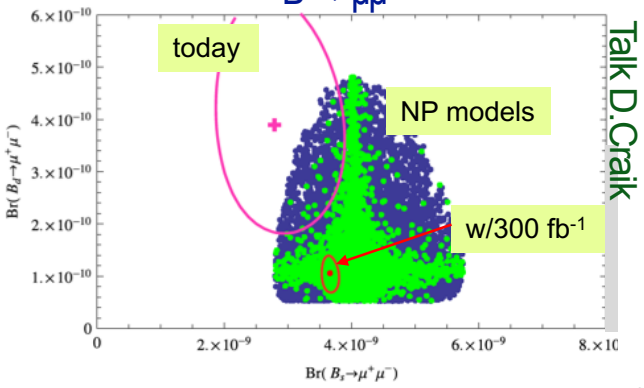
Talk Z.Ligeti

Spectroscopy



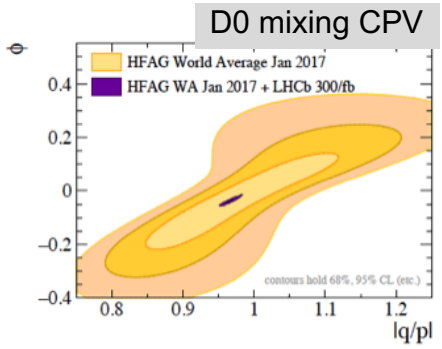
Talk: Skwarnicki

B→ μμ



Talk D.Craik

D0 mixing CPV



Talk: Pernas

expectation using 50ab^{-1} Belle II and 50fb^{-1} LHCb data

ATLAS and CMS can help in a few channels

In several areas LHCb (also Belle) are w/o cross check

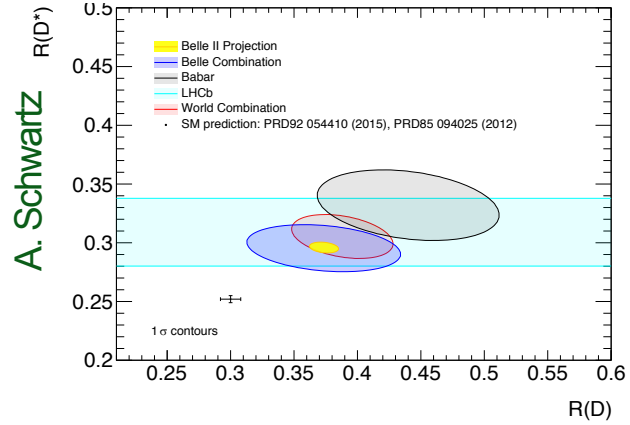
- **Flavour could have a crucial role in falsifying the standard model.**
- **If/when falsified, is there a chance to understand the new physics?**

Flavour Anomalies

Fri morning: **M. Freytsis:** b→c τν and high pt; **W. Altmannshofer:** b→s mumu and high pt; **B. Hamilton:** Flavour observables; **K. Hoepfner:** High pt searches

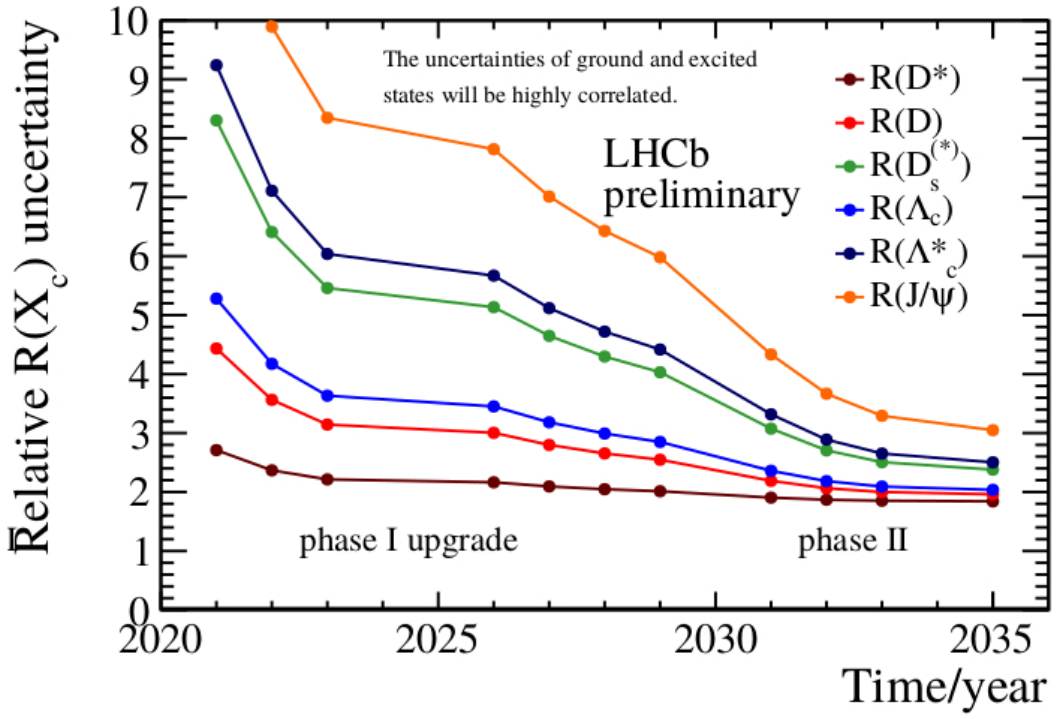
$$R^{\tau/\ell}_{D^{(*)}} = \frac{\Gamma(\bar{B} \to D^{(*)}\tau\bar{\nu})}{\Gamma(\bar{B} \to D^{(*)}\ell\bar{\nu})}$$

A. Schwartz



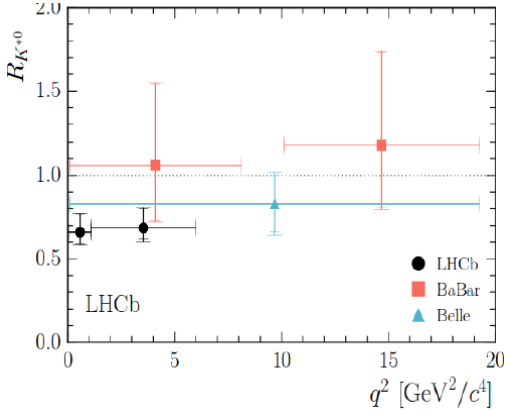
- **If confirmed** by LHCb with Run-2, need confirmation → Belle II
- LHCb can measure several more channels, also with B_s, Λ_b and B_c
- ATLAS/CMS: low-pt in a few channels, and high pt

B.Hamilton



$$R_{K^{(*)}} = \frac{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}^{(*)}e^+e^-)}$$

W.Altmannshofer

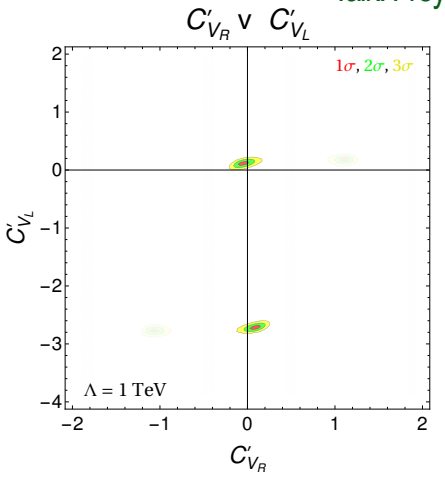


Flavour Anomalies

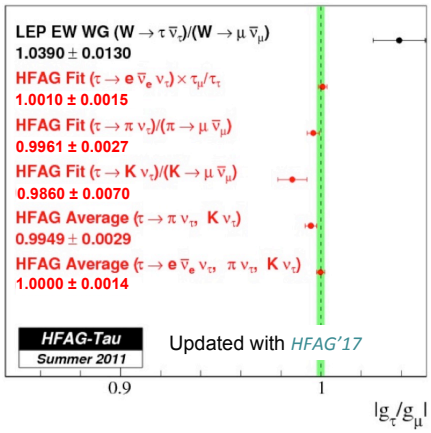
Fri morning: **M. Freytsis:** b⟶c τν and high pt; **W. Altmannshofer:** b⟶s mumu and high pt; **B. Hamilton:** Flavour observables; **K. Hoepfner:** High pt searches

- **R(D) and R(D*) b⟶ c τν**
  - Good fits for **W' vector, scalar or vector LQ**
  - Full range of LQ c/should be done by exps.
  - Discussion: also directly check ratio between τ and μ processes at high p_t, e.g. in ttbar evts

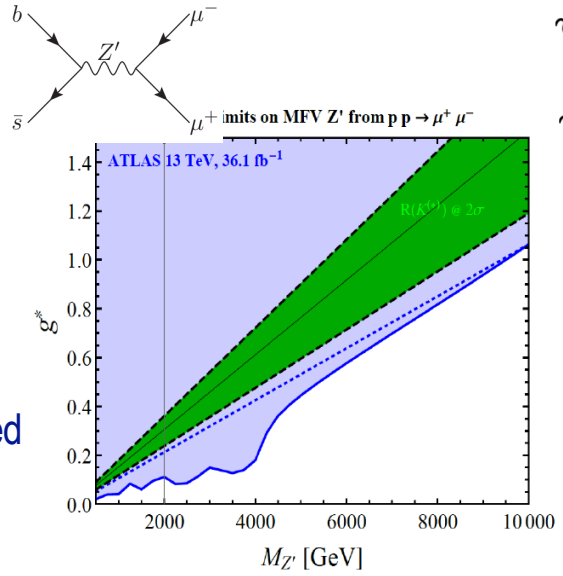
Talk: Freytsis

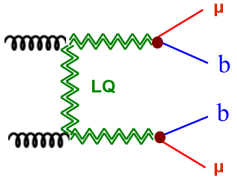


Talk: Passemar

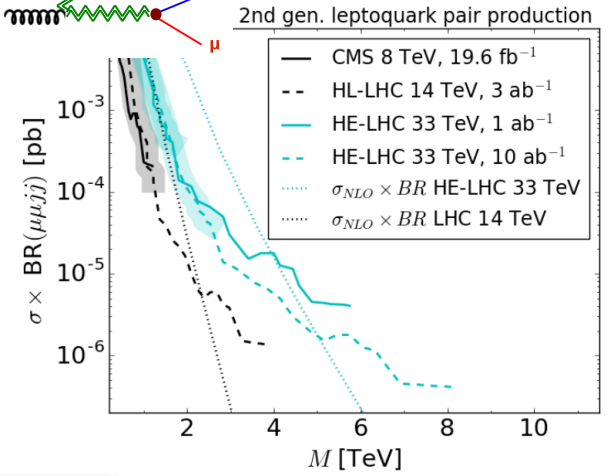


- **R(K*) b ⟶ sℓℓ**
  - theoretically **very clean**
  - Best description for new physics in final states with muons (very high energy)
  - Minimally flavour violating Z' ruled out by dimuon resonance searches
  - Minimalistic Z' can not be fully accessed even at HE-LHC
  - Minimalistic LQ could be very heavy





Talk: Altmannshofer

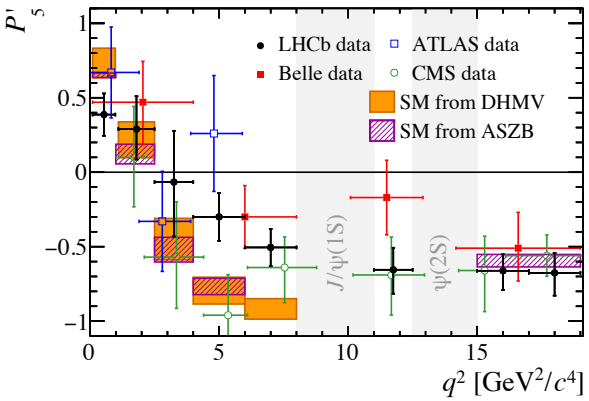


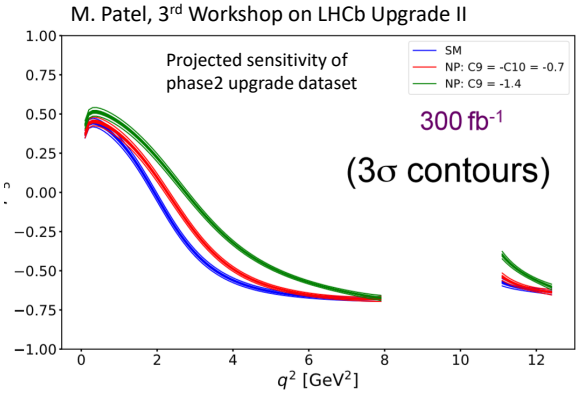
Light LQ could explain both R(D) and R(K*)

Flavour Anomalies

Fri morning: **M. Freytsis:** b→c τν and high pt; **W. Altmannshofer:** b→s mumu and high pt; **B. Hamilton:** Flavour observables; **K. Hoepfner:** High pt searches

- **Low pt searches (LHCb)**
  - Differential dists, e.g. P_5' and other angular observables, separately for different leptons
  - Also other channels, e.g. b->dll (e.g. B_S->K^{*0}μμ)

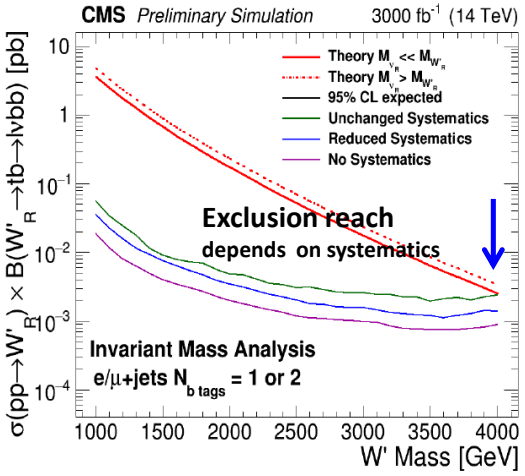




Talk B.Hamilton

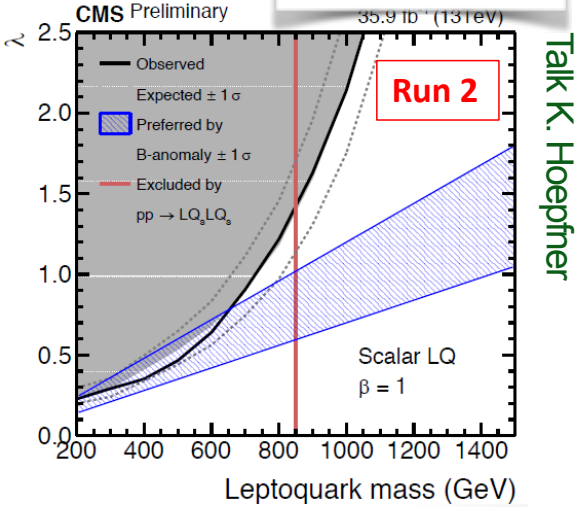
- **High pt searches: Z',W' or LQ_3**
  - Several HL-LHC studies of W', Z' exist and/or are being updated or planned Z'→ tt, W'→ tb, LQ_3→τb
  - Discussion:
    - how important is W'→τν, Z'→ ττ?
    - Can we also measure ratios of τ and μ rates

W'→ tb



LQ_3→ τb

planned for YR



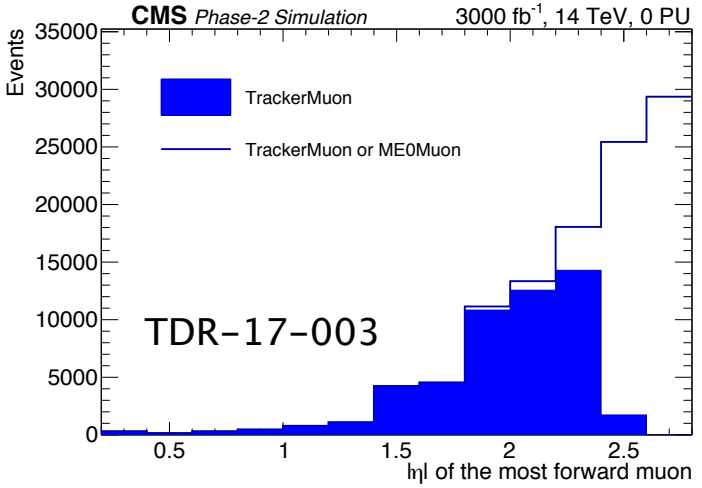
Talk K. Hoepfner

Lepton Flavour Violation

Thu afternoon: **E. Passemar:** Perspectives on τ; **A. Petrov:** Lepton Flavour Violation; **A. Kagan:** Perspectives on charm; **M. Pernas:** c, s and τ at LHCb; **M. Morgenstern:** τ→3μ ATLAS; **K. Mazumdar:** τ→3μ CMS

- **τ→3μ:** current best limit (Belle) B < 2.1 × 10^{-8} at 90% CL
- HL-LHC: 10^{15} τ, mostly in fwd region (from $D_s \to \tau\nu$)
- Extended coverage up to |η| < 2.8, 3μ acceptance ~2.5%
- Bg from B->D cascade decays (K or π decays in-flight)
- **CMS expected limit B(τ→3μ) < 4 × 10^{-9} at 90% CL**

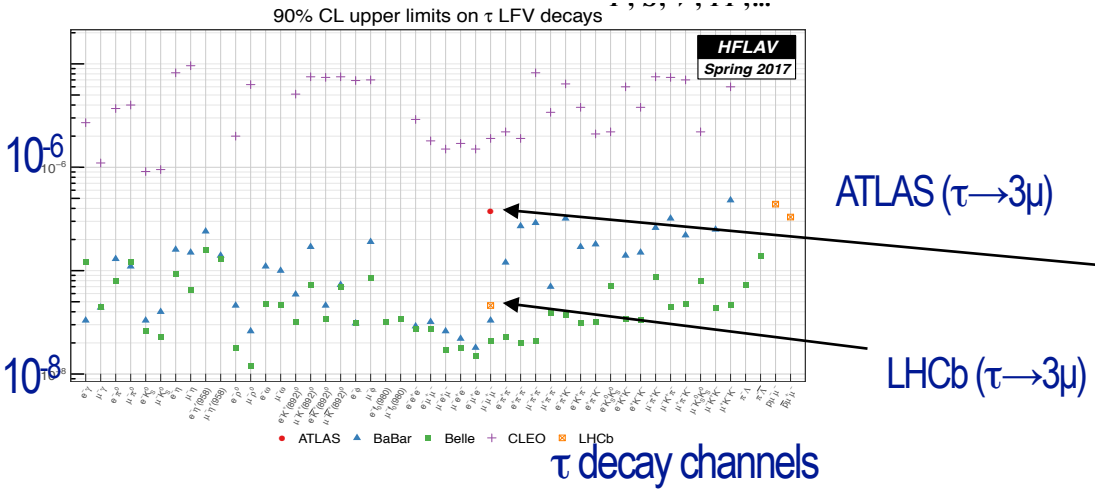
Number of reconstructed τ→3μ events



Talk: K.Mazumdar

- Perspectives on τ and Lepton Flavour Violation:

Talks: E. Passemar and A.Petrov

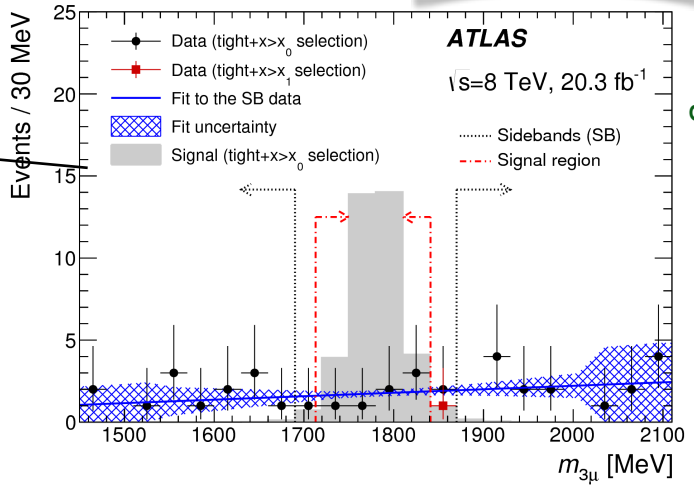


ATLAS (τ→3μ)

LHCb (τ→3μ)

B(τ→3μ) < 3.7 × 10^{-7}

planned for YR



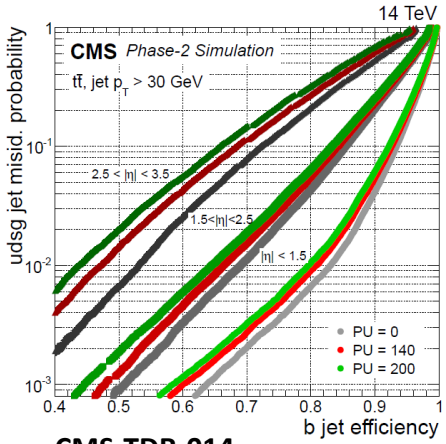
M.Morgenstern

Top Couplings

Fri morning: **W. Dekens:** Anomalous Wtb couplings;
A. Khanov: Flavour aspects of top (CMS+ATLAS);

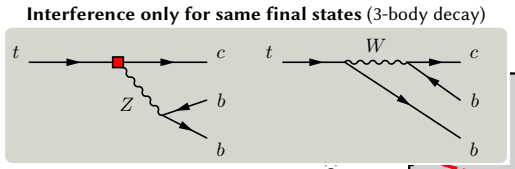
A.Khanov

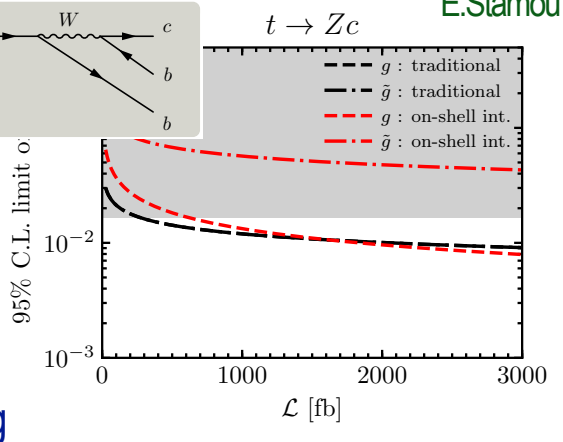
Challenges for top reconstruction at HL-LHC e.g. b-tagging



CMS-TDR-014

E.Stamou

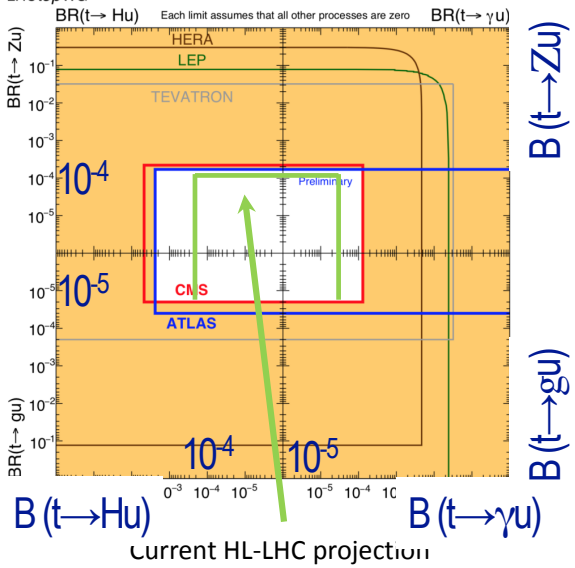




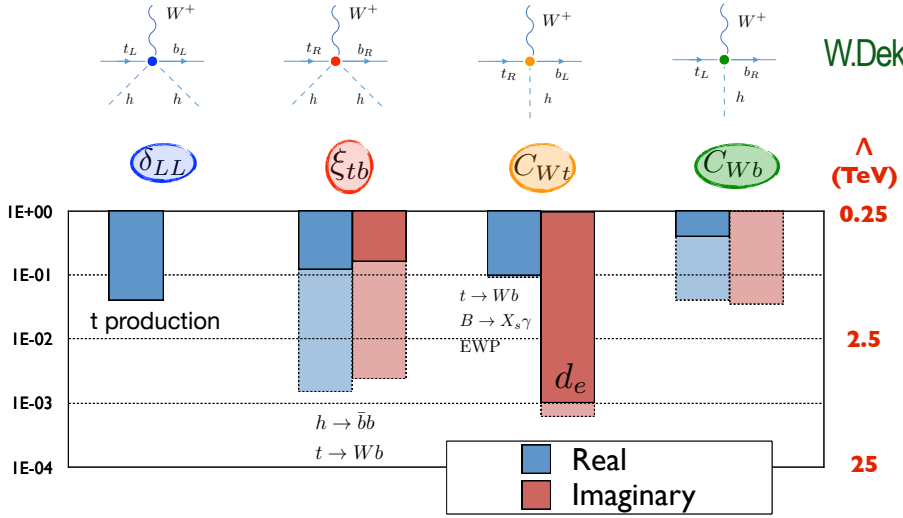
Increase FCNC sensitivity exploiting on-shell interference between signal and bg

Current and expected limits on FCNC

A.Khanov November 2017



W.Dekens



EFT global fit of Wtb couplings using low and high energy data (assuming no FCNC)

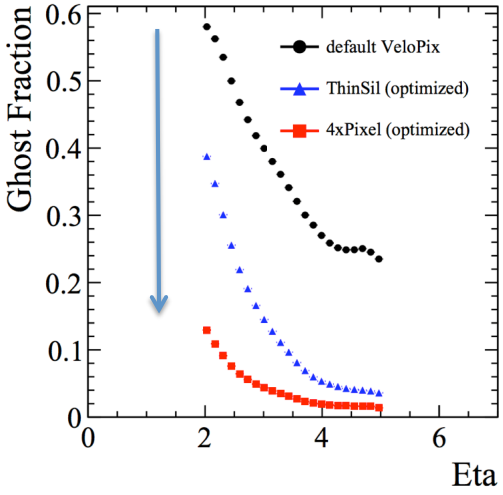
updates planned for YR

Detector Challenges

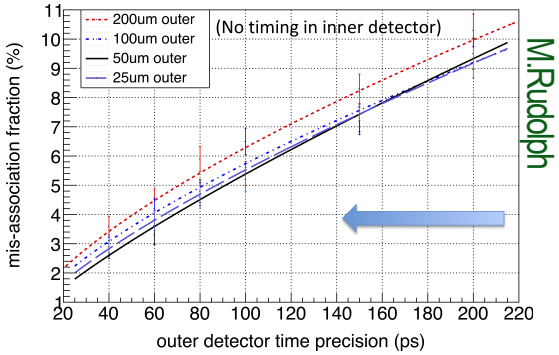
Thu afternoon: **M.Klimek,** Boosted tagging with precision timing; **M. Rudolph:** Detector challenges for LHCb; **Y. Cheng:** Detector challenges for ATLAS + CMS

- **LHCb**
  - complete new experiment
  - 4D detector by including timing

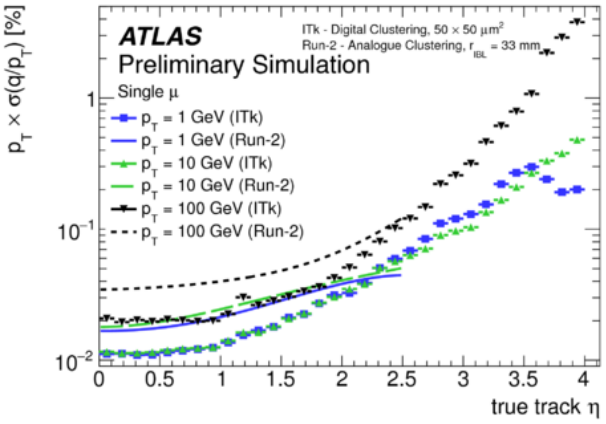
LHCb Vertex Locator M.Rudolph



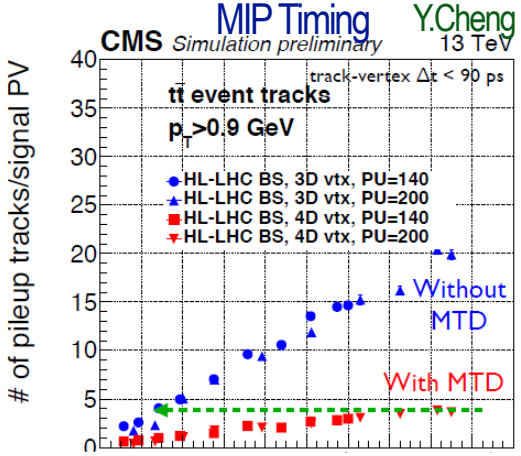
Mis-Association fraction as fct of time res.



Pt resolution Y.Cheng

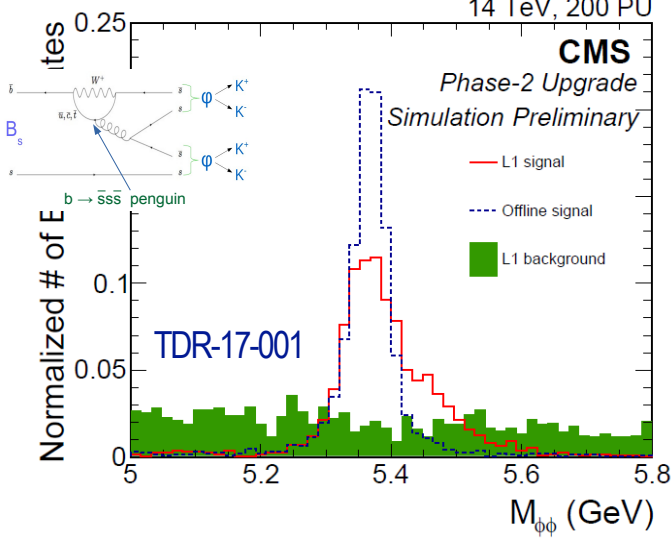


MIP Timing Y.Cheng



Y.Cheng

$B_s \to \varphi\varphi \to 4K$: trigger threshold 2 GeV

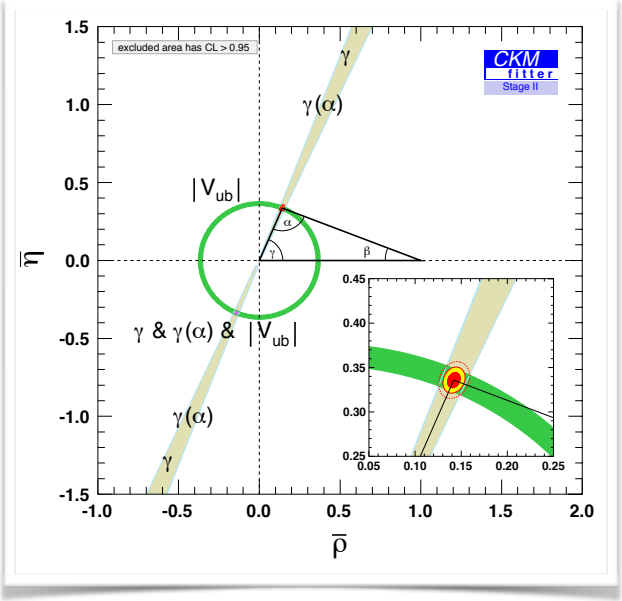


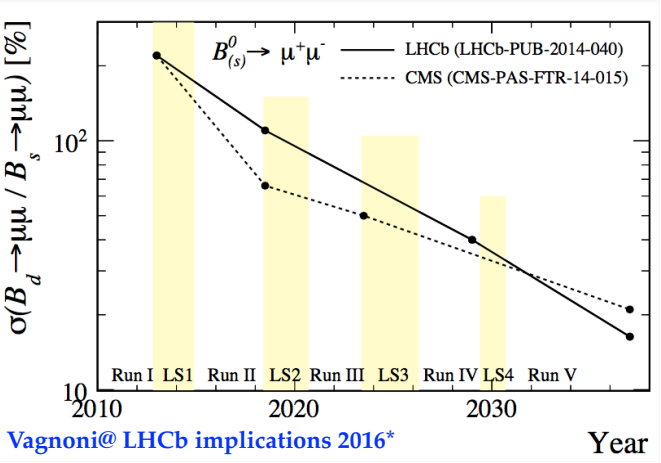
- **ATLAS + CMS**
  - New (all-silicon) inner track detectors up to η<4
  - MIP timing detectors (against PU and for PID

- Improve boosted tagging: M.Klimek
  resolve substructure by arrival time distribution

WG4: Flavour - Wrap up

- **Planned:**
  - Expecting LHCb proposal for Upgrade-II soon (May)
  - No change of YR contents expected in case of possible confirmation of anomalies
- **Discussion / Homework:**
  - Flavour anomalies: can we formulate a no-loose theorem ?
  - Discussing simple combination of results from ATLAS and CMS with LHCb
- **Editorial Overlaps:**
  - BSM and Flavour: separation of direct and indirect searches in context of flavour anomalies

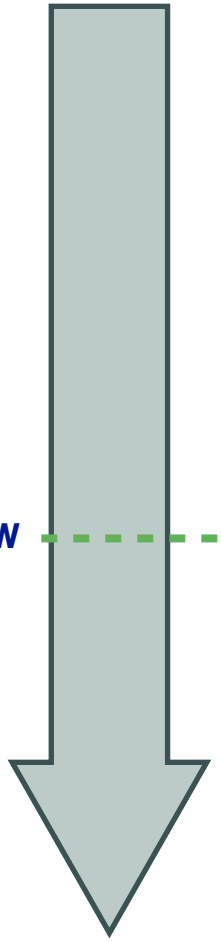




Workshop Timeline

http://lpcc.web.cern.ch/hlhe-lhc-physics-workshop

https://twiki.cern.ch/twiki/bin/viewauth/CMS/HLandHELHCYR



- June/July 2017: creation of the structure
- Oct/Nov 2017: Kick-off meeting
- 21 Dec 2017: WG convenors meeting: skeleton table of contents
- March/April 2018: Draft table of contents, start writing

now

- 18-20 June 2018 (Plenary Meeting): Close-to-final table of contents
  https://indico.cern.ch/event/686494
- September 2018: Full drafts
- December 2018: Submission

European Strategy for Particle Physics: Open Symposium in May 2019

Working Group Meetings

- **WG1 (Standard Model)**
  - Top Wed, 28 Feb https://indico.cern.ch/event/702718/
  - EWK1, Thu 1 Mar https://indico.cern.ch/event/702716/
  - EWK2, Tue 6 Mar https://indico.cern.ch/event/702717/
  - QCD, Fri 2 Mar https://indico.cern.ch/event/702715/
- **WG5 (Heavy Ions, 6 Mar)** https://indico.cern.ch/event/698005/
- **WG2 (CMS/ATLAS/LHCb) 20 Mar** https://indico.cern.ch/event/714119/

- **WG1 progress meetings foreseen for April/May**
- **WG2 vidyo meeting first half of May (tba)**
- **WG3 meeting: 23 April, and around 21 May (tba)**
- **WG4 vidyo meetings until June (tba)**
- **WG5 open meeting: 1 June (after QM)**

- **HL/HE-LHC Plenary 18-20 June 2018** https://indico.cern.ch/event/686494/

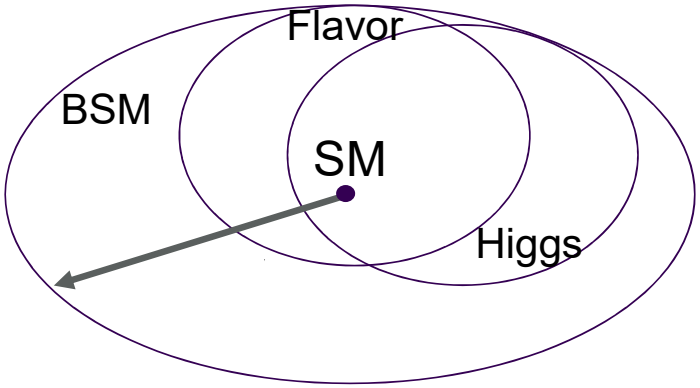
- **More meetings (various formats, formal and informal) towards submission**

indico category: https://indico.cern.ch/category/9411

Editorial Work

- **Goal**
  - Report length: max. 150 pages per chapter
  - Start filling with material now (!), full draft by September
  - Expect technical instructions (overleaf template) from WG convenors soon

- **Being discussed**
  - **Overlap** between chapters: In general overlap is ok, but should try to coordinate
    - Higgs and BSM
    - BSM and Flavour: separation of direct and indirect searches in context of flavour anomalies ?
    - Higgs and Flavour
    - Flavour and SM (esp. top anomalous couplings: theory description in chapter 4, experimental results in both chapter 1 and 4)



  - **"Chapter 0":** concise description of "technical infrastructure" common to all chapters.
    - Detector Performance
    - DELPHES and other tools

Systematic Uncertainties

- **Encourage realistic evolution of uncertainties**
  - We can be optimistic! Larger data samples, refined and/or novel analysis methods, greater computing resources.

- **Formulate ambitious physics goals**
  - HL-LHC is much more than just a factor 10 (100) more data than phase-I (2016) in a more adverse environment.
  - Time and resources for substantial improvements of tools and methods (theory and exp.). This is exciting!
  - Use the statistics to constrain systematics !!!

- **Currently discussing guideline scenarios for systematics within and among experiments**
  - Targeting numbers at the timescale end of April (necessary for update results for June),
  - Collect information from theory about what is achievable for SM backgrounds (and Higgs signal)
  - Foreseeing presentations for inspiration at June meeting

- **Each analysis is different → guidelines, not regulations**
  - SM / HIG: running into systematics limitations, strongly depending on ancillary measurements
  - BSM: many analyses will be optimised for more statistics
  - Flavour: big impact from new detectors

Misc. Issues

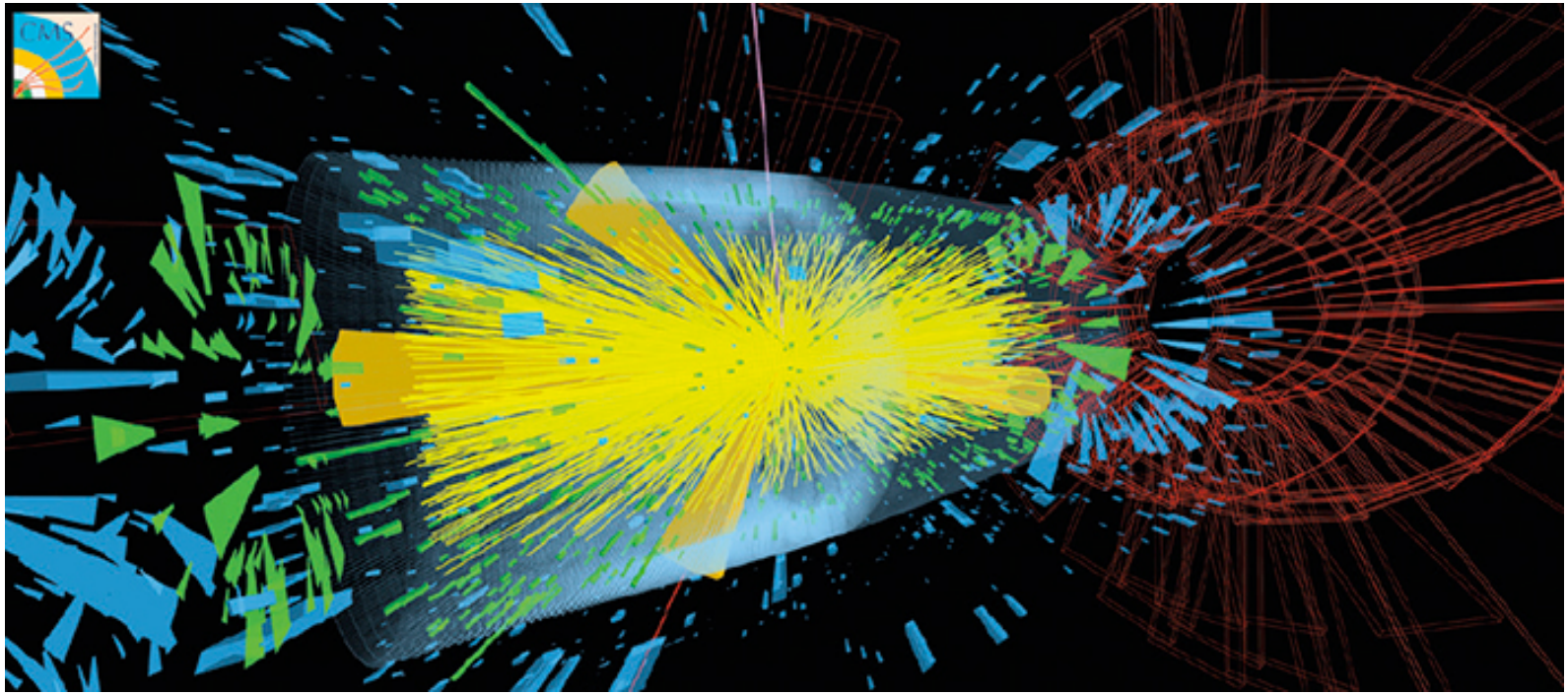
- **Reference parameters:**
  - **HL-LHC:** $\sqrt{s}$ = 14 TeV; L = 3 ab^{-1}; for LHCb: 50 → 300 fb^{-1}
  - **HE-LHC:** $\sqrt{s}$ = 27 TeV; L = 15 ab^{-1} (would like to unify this to 27 TeV
- **What if HL-LHC will operate at 15 TeV?**
  - Keep 14 TeV as unique reference value, and optionally present in the report estimates for rate increase for a subset of processes (e.g. Higgs and HH production and very-high mass states). Expect improvement to be marginal and potentially compensated by a possible reduction in integrated luminosity. For mass searches 1 extra ~TeV can be added to the reach (~0.5 TeV for pair production).

Conclusions

lpcc.web.cern.ch/hlhe-lhc-physics-workshop

HL-LHC workshop mailing list

- **HL-LHC is much much more than a factor 10 more data**
- **Many new results and (even more) plans for YR shown**
- **Many new studies started since the kick-off in October**
- **A great thank you to organisers, speakers, contributors and audience!**



Backup

Hadron Collider Parameters - 1

Talk V. Shiltsev

parameter	FCC-hh		HE-LHC	(HL) LHC
collision energy cms [TeV]	100		27	14
dipole field [T]	16		16	8.33
circumference [km]	100		27	27
straight section length [m]	1400		528	528
# IP	2 main & 2		2 & 2	2 & 2
beam current [A]	0.5		1.12	(1.12) 0.58
bunch intensity [10^{11}]	1	1 (0.2)	2.2 (0.44)	(2.2) 1.15
bunch spacing [ns]	25	25 (5)	25 (5)	25
rms bunch length [cm]	7.55		7.55	(8.1) 7.55
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	25	(5) 1
events/bunch crossing	170	1k (200)	~800 (160)	(135) 27
stored energy/beam [GJ]	8.4		1.3	(0.7) 0.36
beta* [m]	1.1-0.3		0.25	(0.20) 0.55
norm. emittance [μm]	2.2 (0.4)		2.5 (0.5)	(2.5) 3.75

Challenges FCC:

- Cost of 100 km magnets and civil
- 16 T magnets
- ~1000 pileup
- Collimation/protection

Challenges HE-LHC:

- Cost of 27 km magnets
- 16 T magnets
- ~800 pileup
- High current

Hadron Collider Parameters - 2

Talk V. Shiltsev

parameter	FCC-hh	HE-LHC	(HL) LHC
rms IP beam size [μm]	6.7 (3) – 3.5 (1.5)	6.6 (3.0)	(8.2) 16.7
half crossing angle [μrad]	37 - 70	131 (60)	(255) 143
Piwinski angle	0.42 – 1.51	1.50 (1.50)	(2.52) 0.65
crab cavities needed	NO - YES	YES (YES)	(YES) NO
synchr. rad. power / ring [kW]	2400	101	(7.3) 3.6
beam-screen half aperture [mm]	13.2	13.2 or 14	17
beam-screen temperature [K]	50	20 or 50	20
SR power / length [W/m/ap.]	28.4	4.6	(0.33) 0.17
ΔE / turn [keV]	4600	93	6.7
long. emit. damping time [h]	0.54	1.8	12.9
initial beam lifetime [h]	18 | 3	3	(15) 40
total / inelastic cross section [mbarn]	156 / 109	125 / 91	112 / 82
injection energy [TeV]	3.3	1.3	0.45
hor.,vert. arc half aperture [mm]	15,13.2	15, 13.2 (19, 14)	22, 17

Challenges FCC:

- Need new 3.3 TeV injector
- x100 LHC radiation power /meter

Challenges HE-LHC:

- Need new 1.3 TeV injector/beamlines
- x15 LHC radiation power /meter