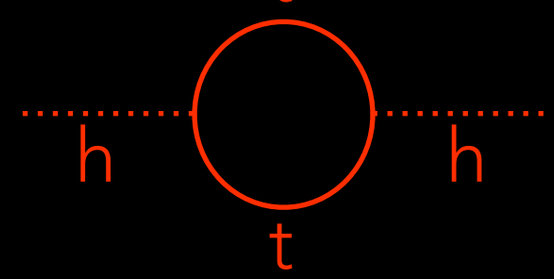
BSM SEARCHES AT CMS

SADIA KHALIL
MC4BSM WORKSHOP
MAY 20, 2015
FERMILAB, IL, USA

OUTLINE

- Motivation
- Run1 BSM searches status
- Run 1 high lights
- Run 2 Perspectives
- Conclusion

MASS HIERARCHY

- The Higgs mass sets the EW scale
- Receives radiative corrections to its mass from top loops
  - $m_h^2 = m_{bare}^2 + \delta m_h^2$
  - $\delta m_h^2 =$ 

$$\frac{\delta m_h^2}{m_h^2} = \frac{3G_F}{4\sqrt{2}\pi^2}\left(\frac{4m_t^2}{m_h^2} - \frac{2m_W^2}{m_h^2} - \frac{m_Z^2}{m_h^2} - 1\right)\Lambda^2 = \left(\frac{\Lambda}{500\ \mathrm{GeV}}\right)^2$$

- Uncomfortable size of correction when momentum cutoff (Λ) becomes larger than about 500 GeV.

NATURALNESS

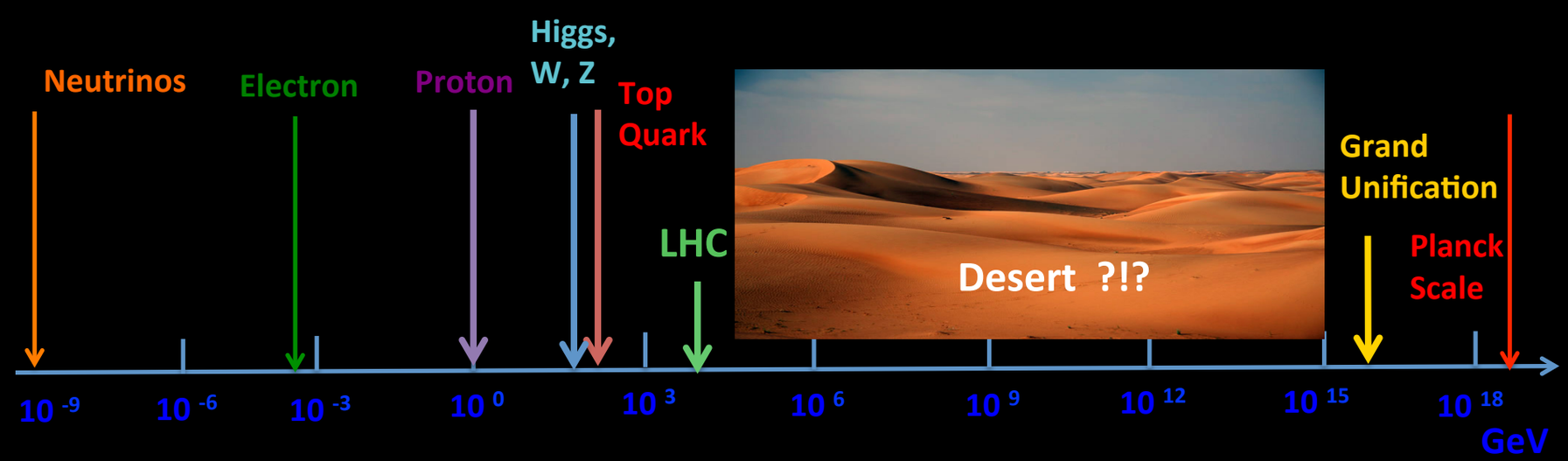
- Assuming Λ at Plank scale, and to get an agreement with the measured Higgs mass, a cancellation of 1 part per 10^{34} is required

$$36127890984789307394520932878928933023 - 36127890984789307394520932878928917398 = m^2_H = 125^2$$

m_{bare}

δm_h

- This is called fine tuning



NATURALNESS

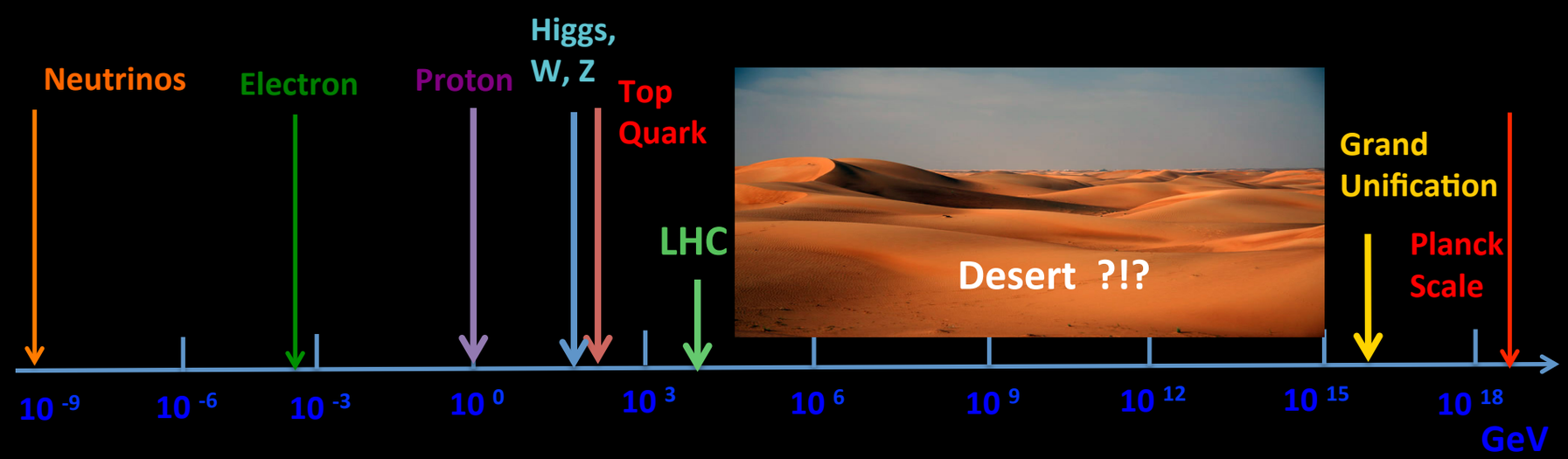
- Assuming Λ at Plank scale, and to get an agreement with the measured Higgs mass, a cancellation of 1 part per 10^{34} is required

$$\begin{array}{l} 36127890984789307394520932878928933023 - \\ 36127890984789307394520932878928917398 = \\ = m^2_H = 125^2 \end{array}$$

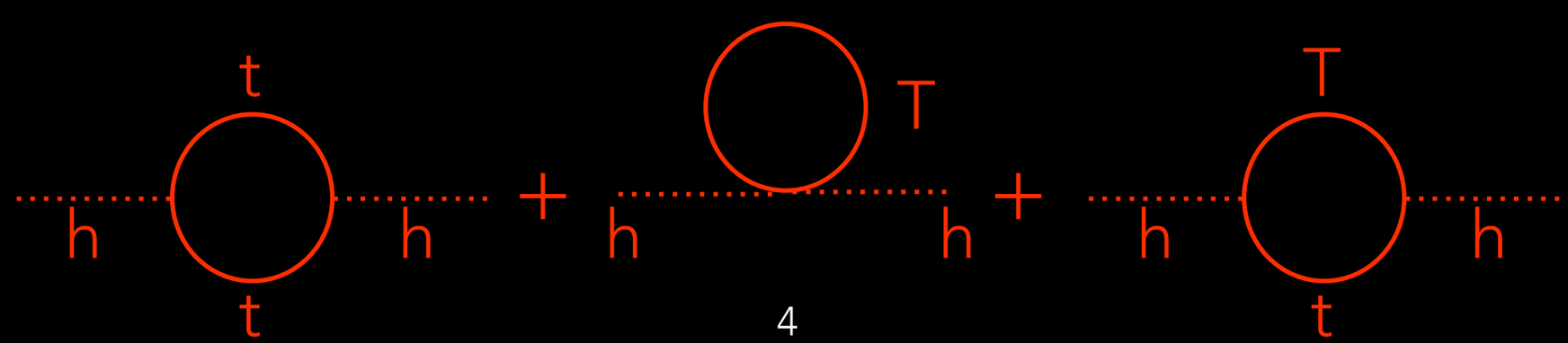
m_{bare}

δm_h

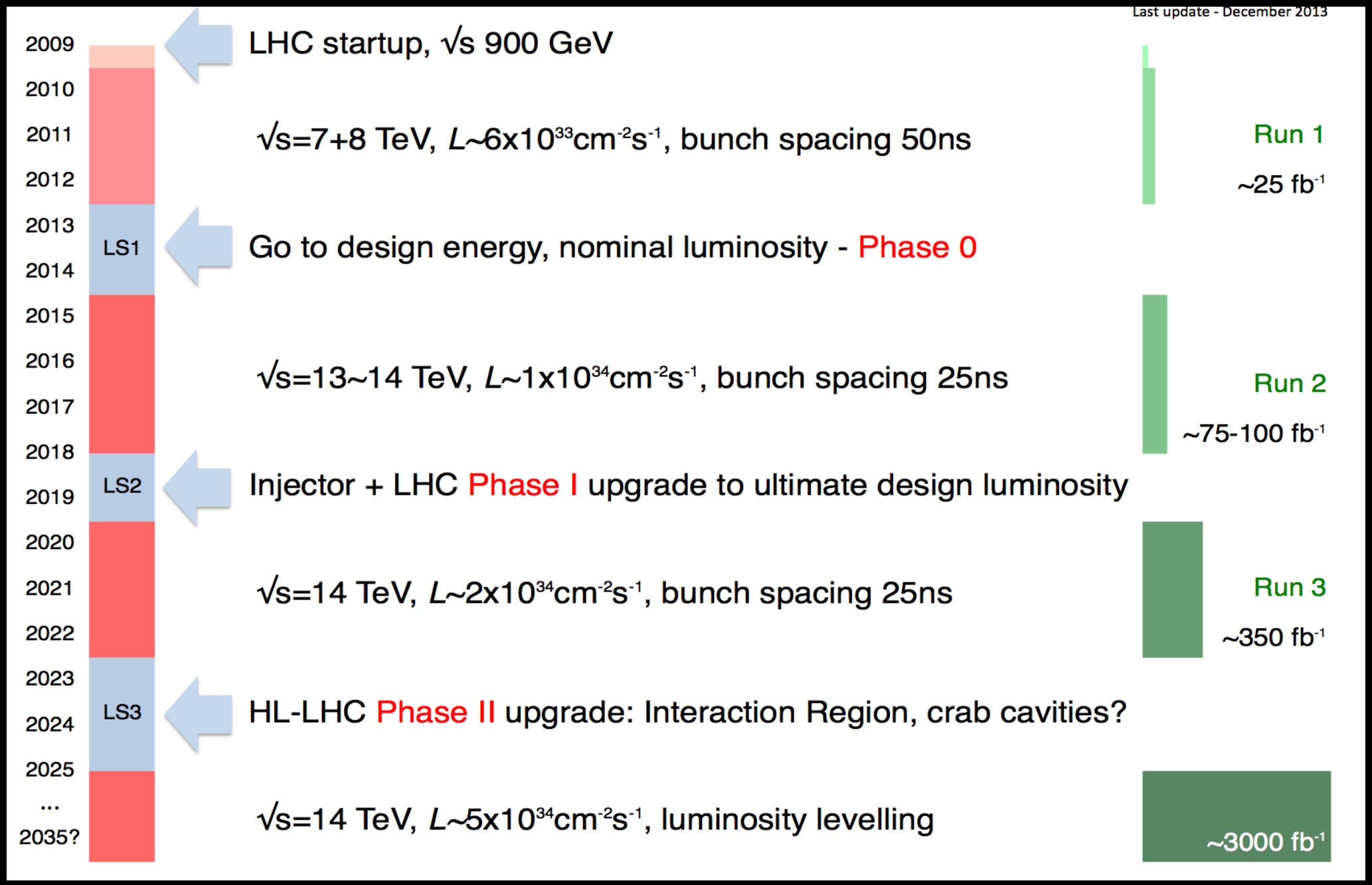
- This is called fine tuning



- With a symmetry ~ TeV scale, this divergence can be cancelled minimally!



LHC SCHEDULE



- We are here !

RUN 1 TARGETS

- **Higgs discovery:** All "big 5" channels published.Full combo submitted for publication: http://arxiv.org/abs/arXiv:1412.8662

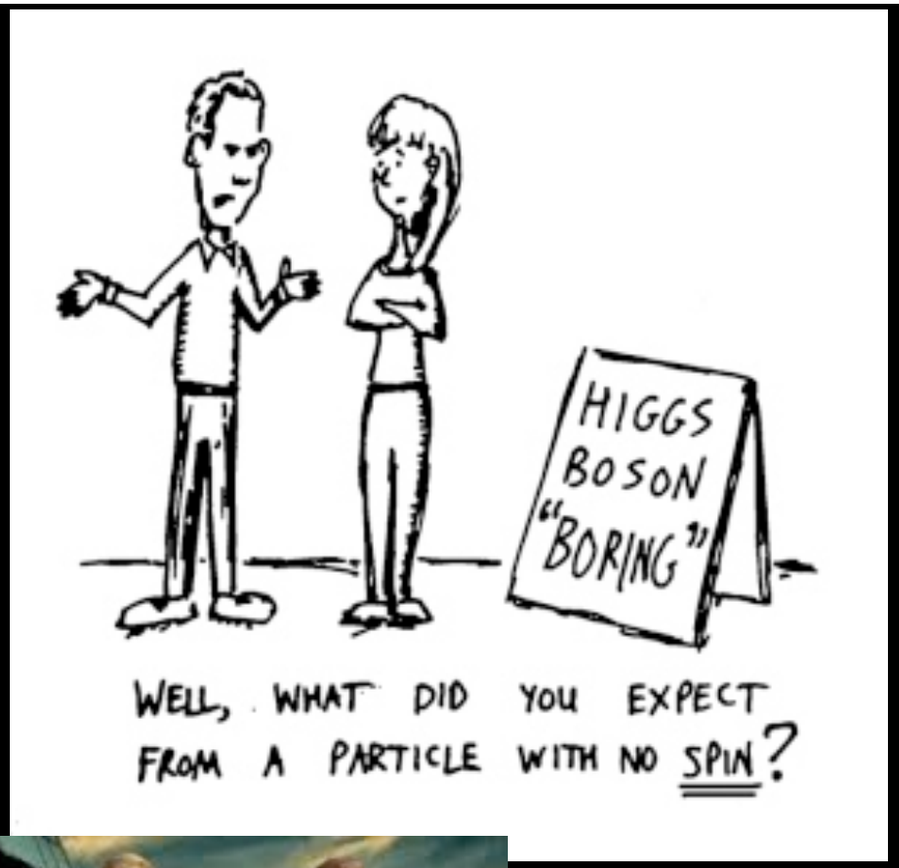
$$m_{\mathrm{H}} = 125.03\,^{+0.26}_{-0.27}\,(\mathrm{stat.})\,^{+0.13}_{-0.15}\,(\mathrm{syst.})\,\mathrm{GeV}$$

$$\mu = 1.00^{+0.14}_{-0.13}\left[\pm 0.09(\mathrm{stat.})^{+0.08}_{-0.07}(\mathrm{theo.}) \pm 0.07(\mathrm{syst.})\right]$$

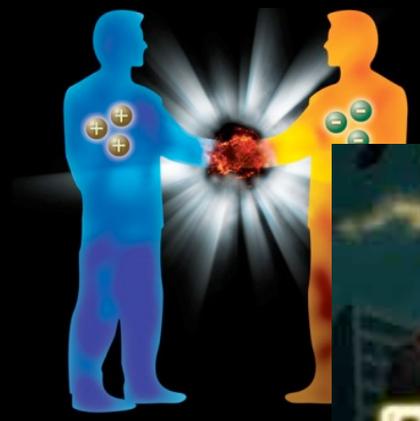
- Standard Model: W/Z, Top, Diboson, and Higgs x-sections
- Top quark Physics: Top mass combination (ATLAS+CMS)
- Heavy Ion Physics: Z/W production in PbPb/pPb collisions
- B physics and quarkonia: $B_{(s)} \rightarrow \mu\mu$
- BSM Searches: SUSY, dark matter, new resonances, …

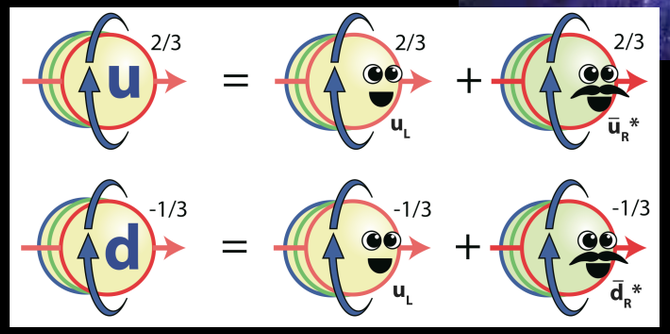
RUN 2 TARGETS

- BSM Searches
- BSM Searches
- BSM Searches
- BSM Searches
- BSM Searches
- BSM Searches



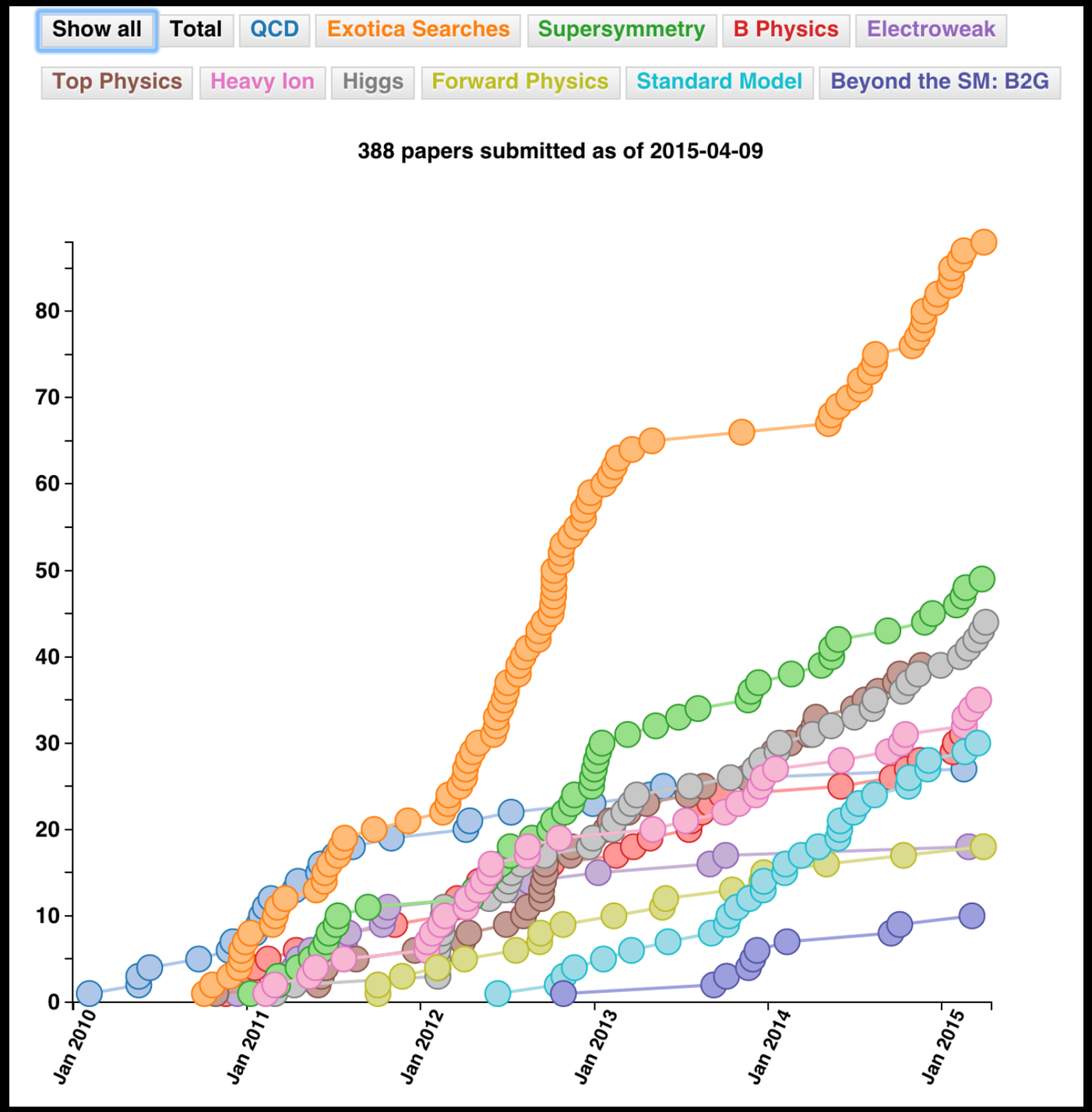
Baryogenesis





VLQ

RUN 1 PUBLICATION STATUS



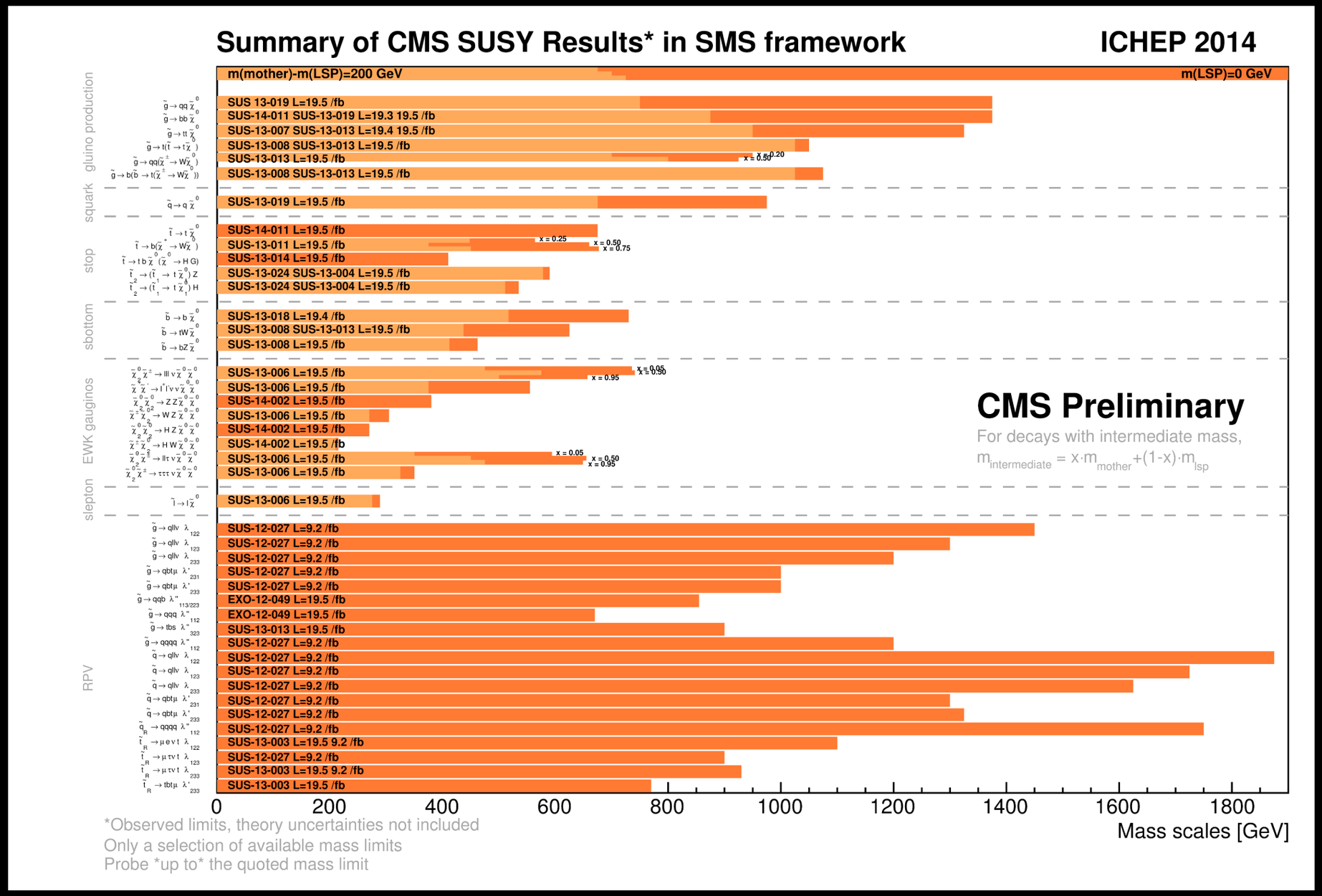
- Pub rate steady in LS1, few submissions / week
- 387 papers published:
- Huge contribution from Exotica searches

Citation summary results	Citeable papers	Published only
Total number of papers analyzed:	431	387
Total number of citations:	32,286	31,522
Average citations per paper:	74.9	81.5
Breakdown of papers by citations:		
Renowned papers (500+)	5	5
Famous papers (250-499)	9	8
Very well-known papers (100-249)	54	54
Well-known papers (50-99)	99	98
Known papers (10-49)	178	172
Less known papers (1-9)	74	50
Unknown papers (0)	12	0
h_{HEP} index [?]	85	84

NP SEARCHES STATUS

- No NP found at Run 1 **(SUSY in SMS framework)**

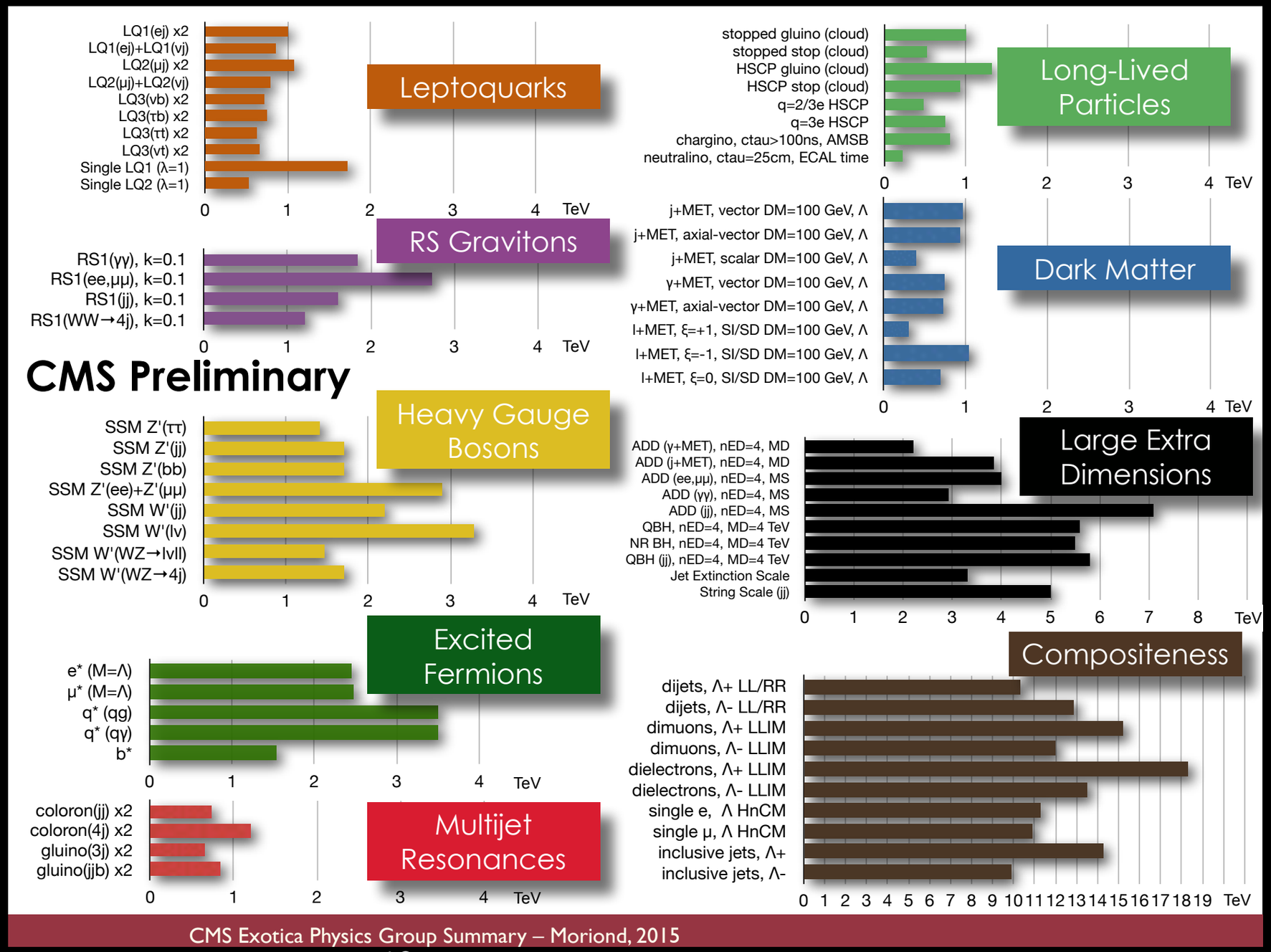
- gluino exclusion~1.3 TeV
- stop/bottom ~700 GeV
- EWKino ~ 300 GeV



NP SEARCHES STATUS

- No NP found at Run 1 **(Exotica)**

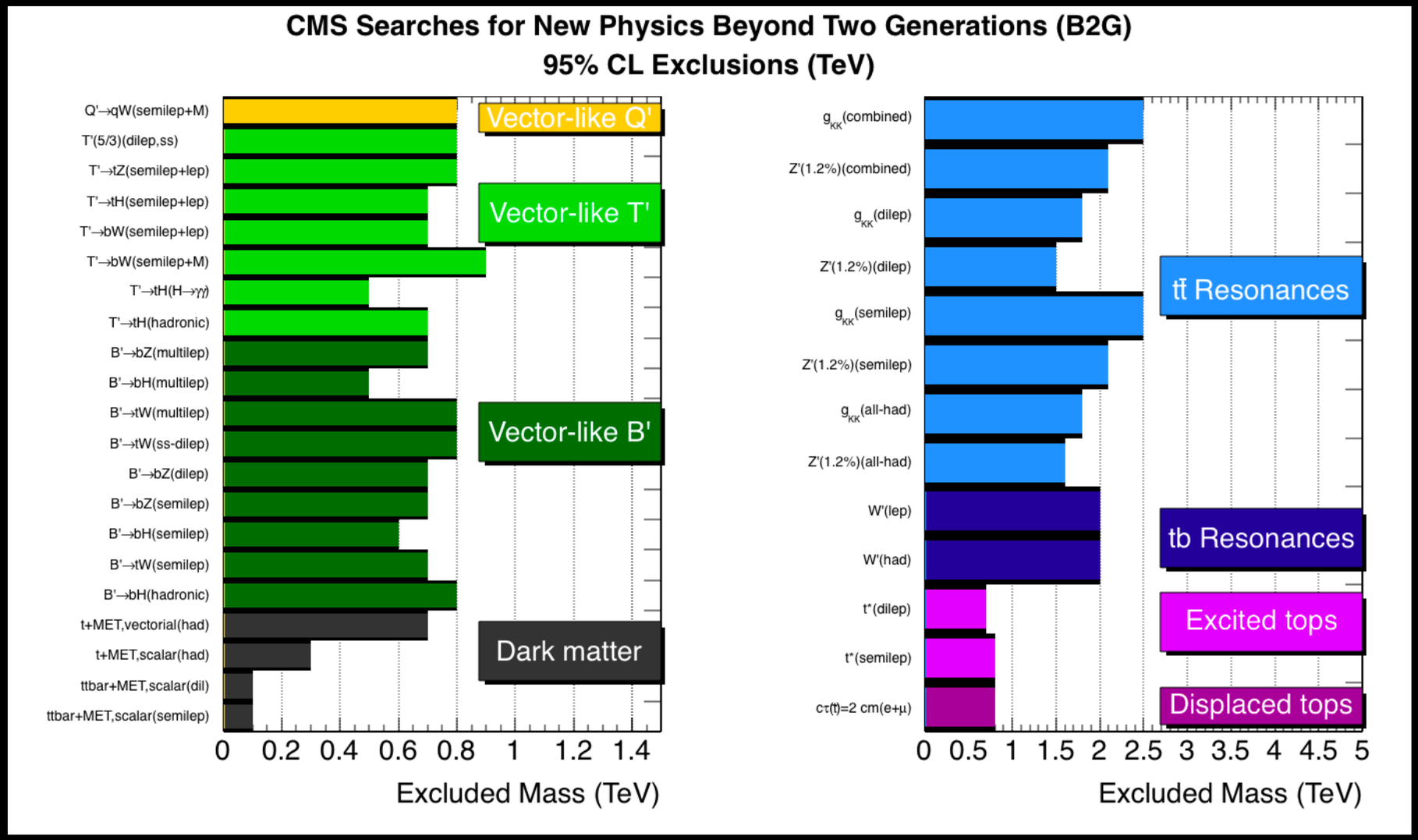
- Excited quarks~3.5 TeV
- W′/Z′ ~2 TeV
- RS graviton ~ 1.6 TeV
- quantum blackholes~5-6 TeV
- excesses: LQ1, W′, OS dilepton



NP SEARCHES STATUS

- No NP found at Run 1 **(Beyond 2 Generation)**

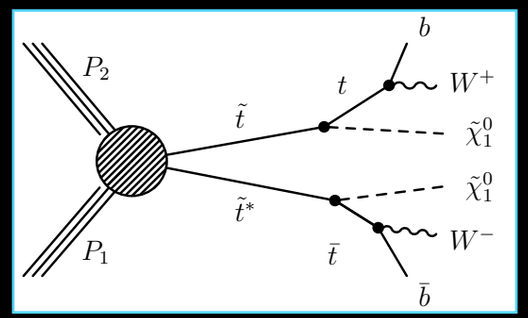
- Z′/KK gluons~3 TeV
- VLQ ~ 0.8-0.9 TeV
- t+DM: scalar (vector)~0.3(0.6) TeV
- tt+DM: For 0.1 TeV DM, M*~ 118 GeV

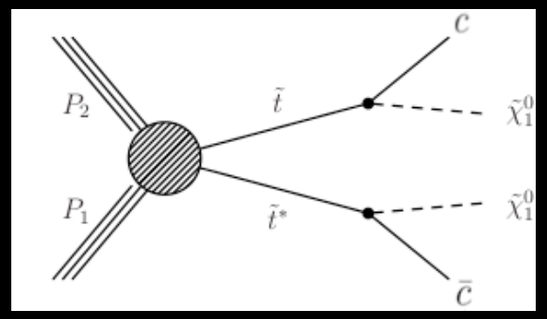


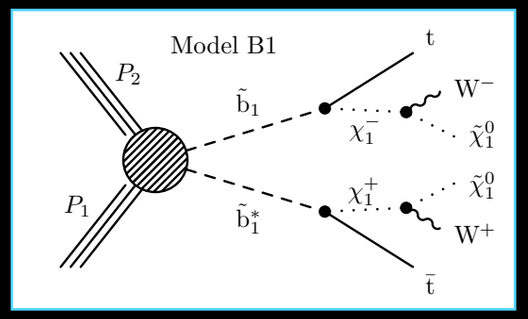
SUSY SEARCHES

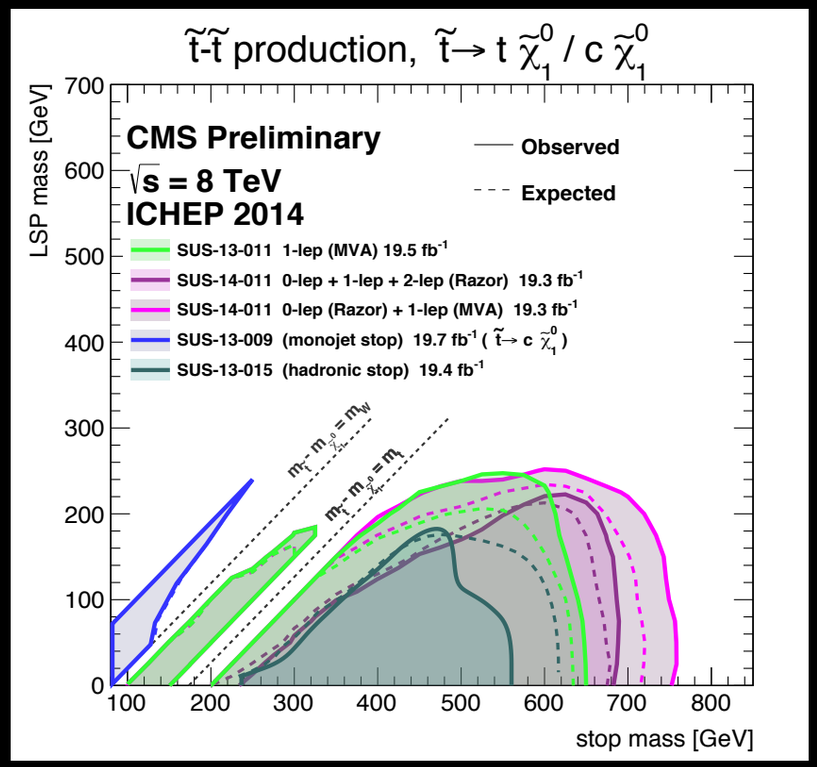
stop/sbottom

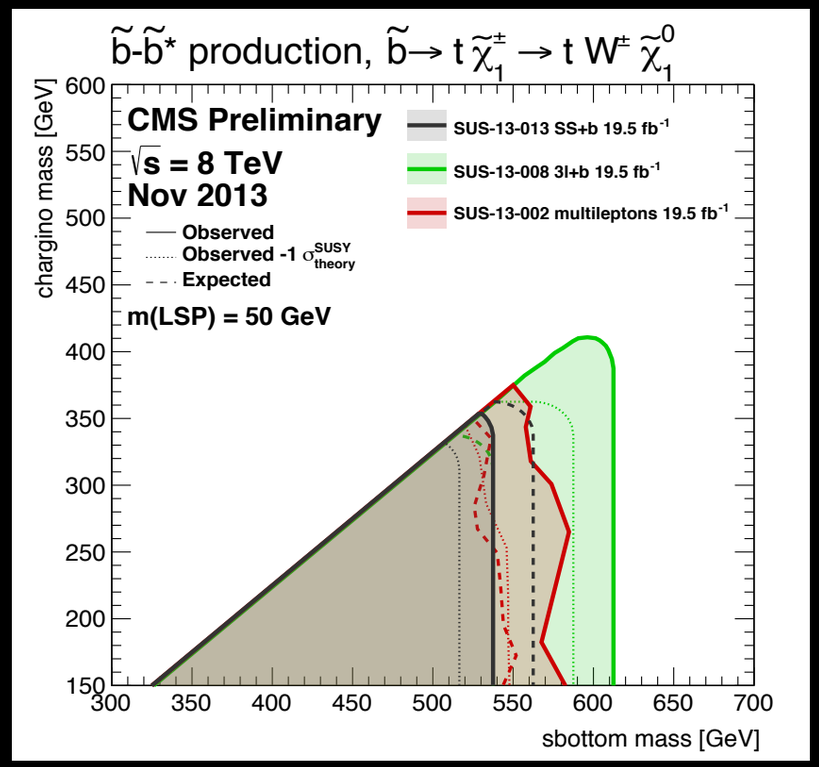
- Analyses targeting the stop/sbottom productions, covering these signatures with different exclusive final states





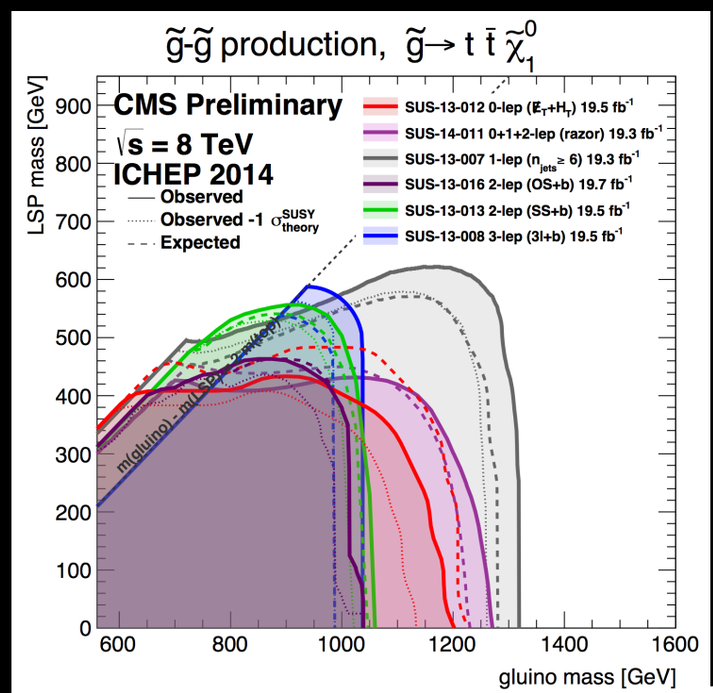


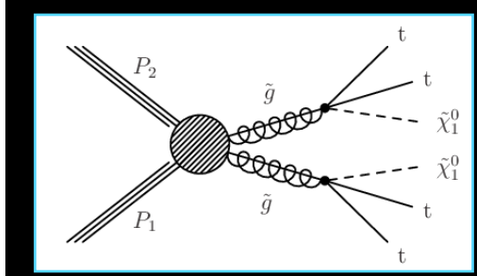


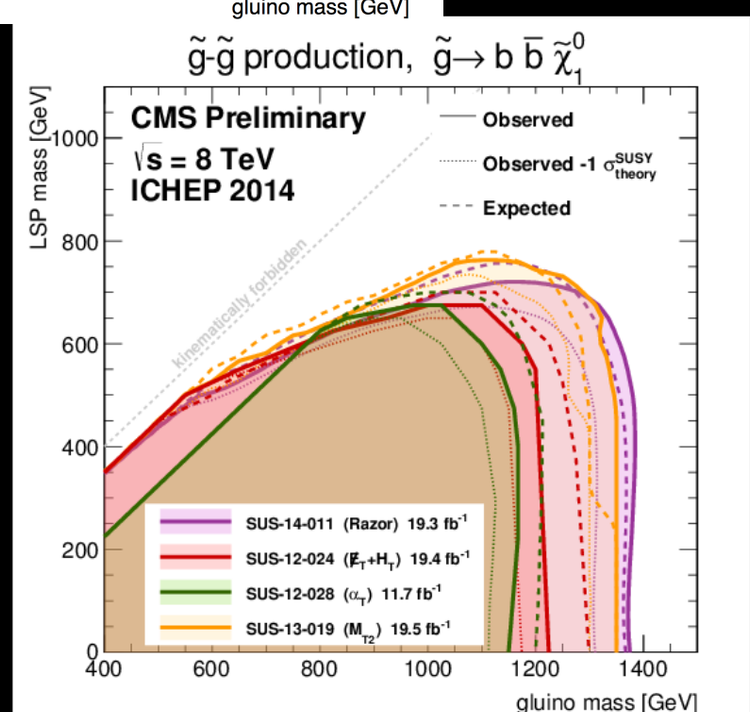


SUSY SEARCHES

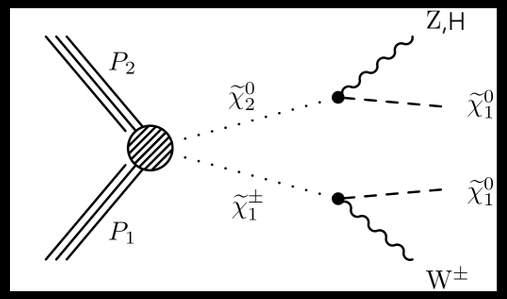
gluino

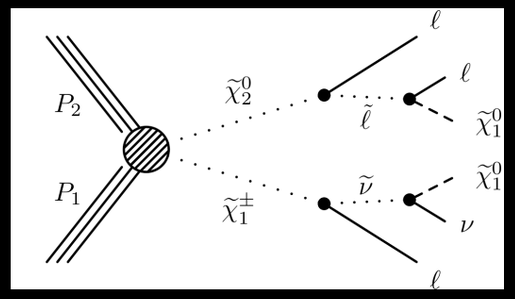


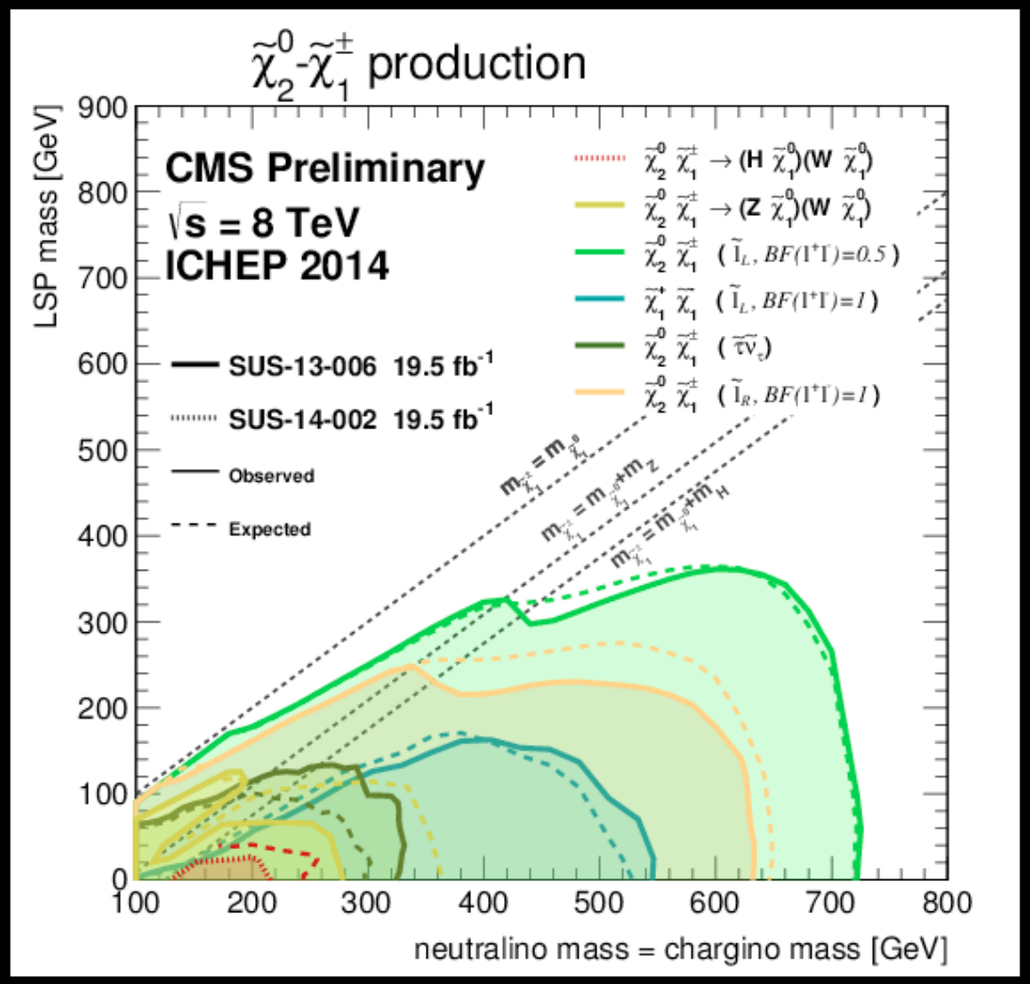




EWKino





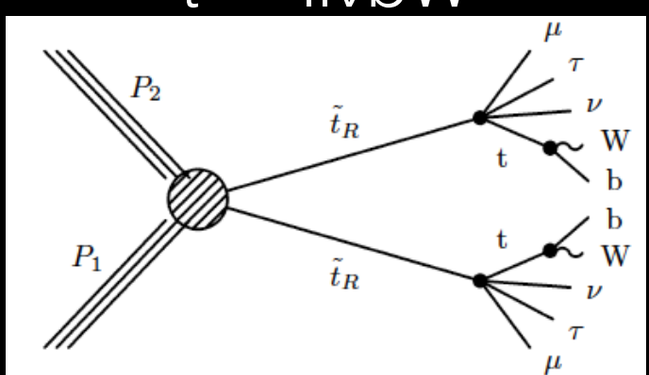


RPV SUSY SEARCHES

Lepton number violating terms — Baryon number violating term

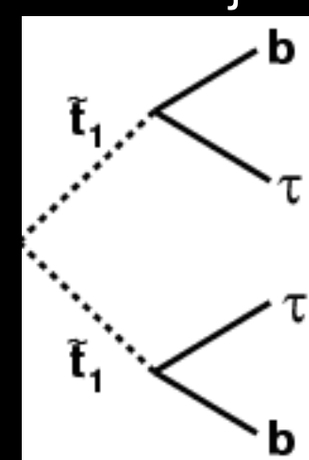
$$W_{\not{R}_p} = \mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

t~→llvbW



SUS-12-027

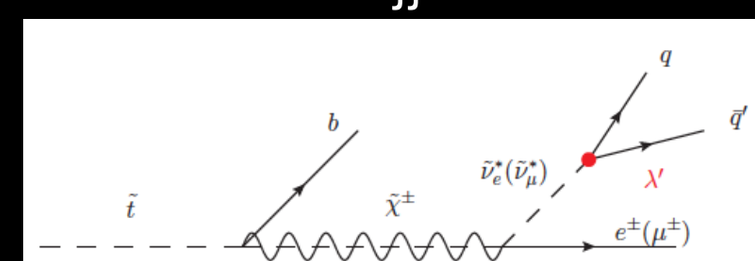
t~→lj



EXO-12-032/041/042

m(t~) > 700 GeV

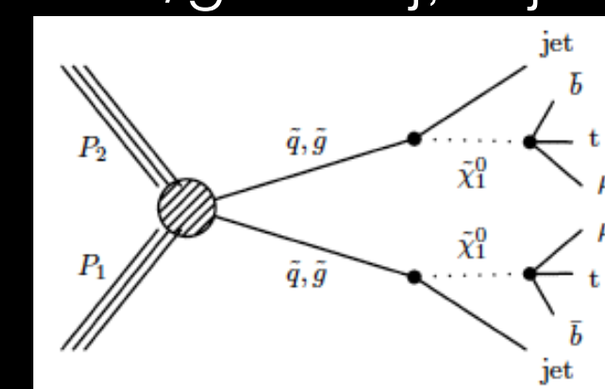
t~→ljjb



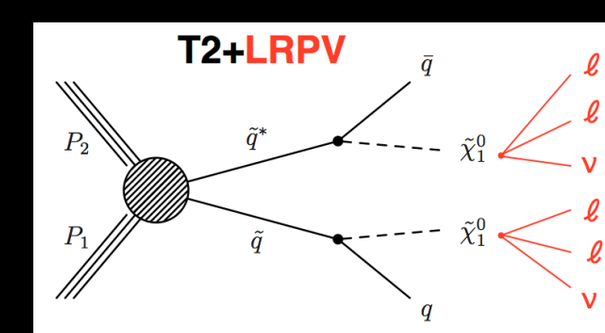
EXO-14-013/032

m(t~) > 0.9-1.0 TeV

t~/g~→ltbj, llvj



SUS-12-027

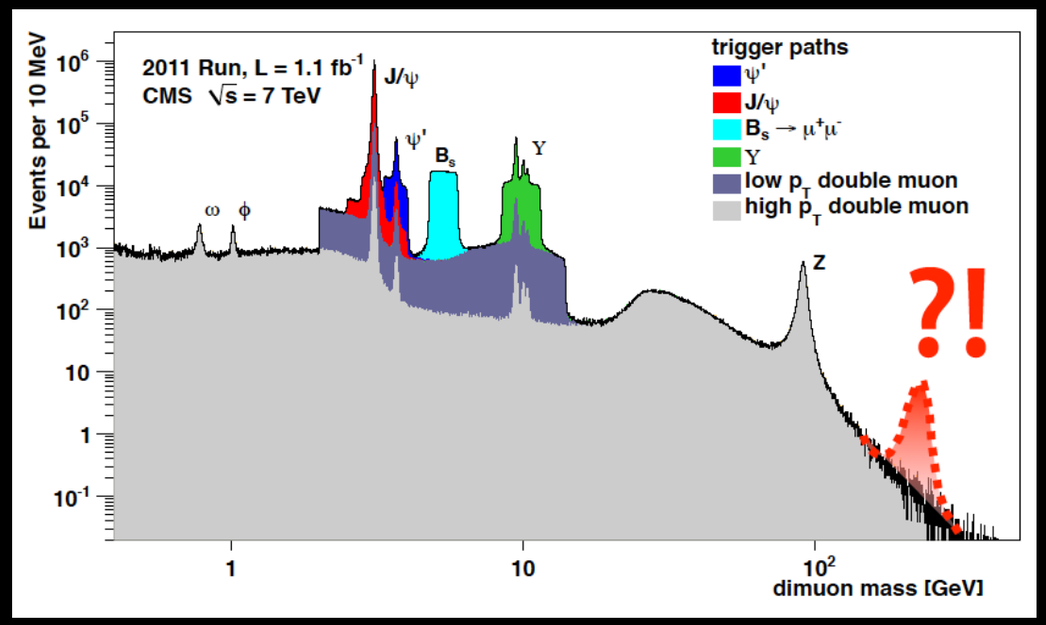


SUS-13-010

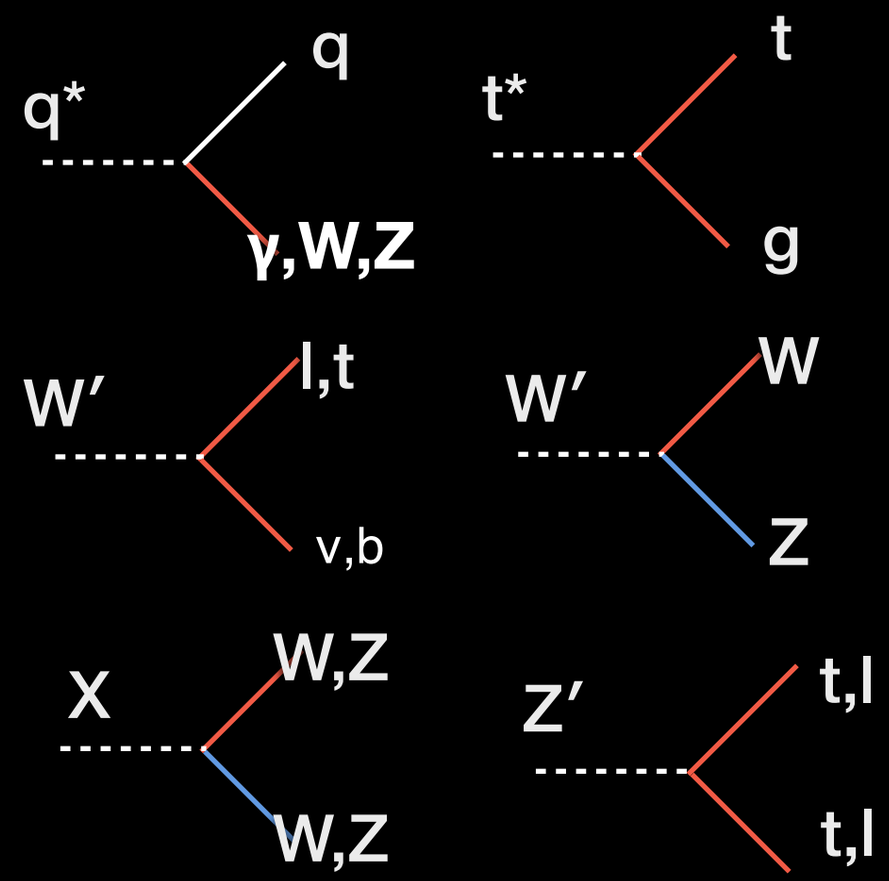
- LQD models have been searched in
  - multileptons+jets+MET
  - OS dilepton pairs (ee, μμ, ττ +jets)

RESONANCES

- Powerful, model-independent probe to new physics
  - Simple Strategy: Reconstruct invariant mass and look for "bump"
  - Bump at $m_{ff} > m_Z$ or m_H ➡ New Physics!

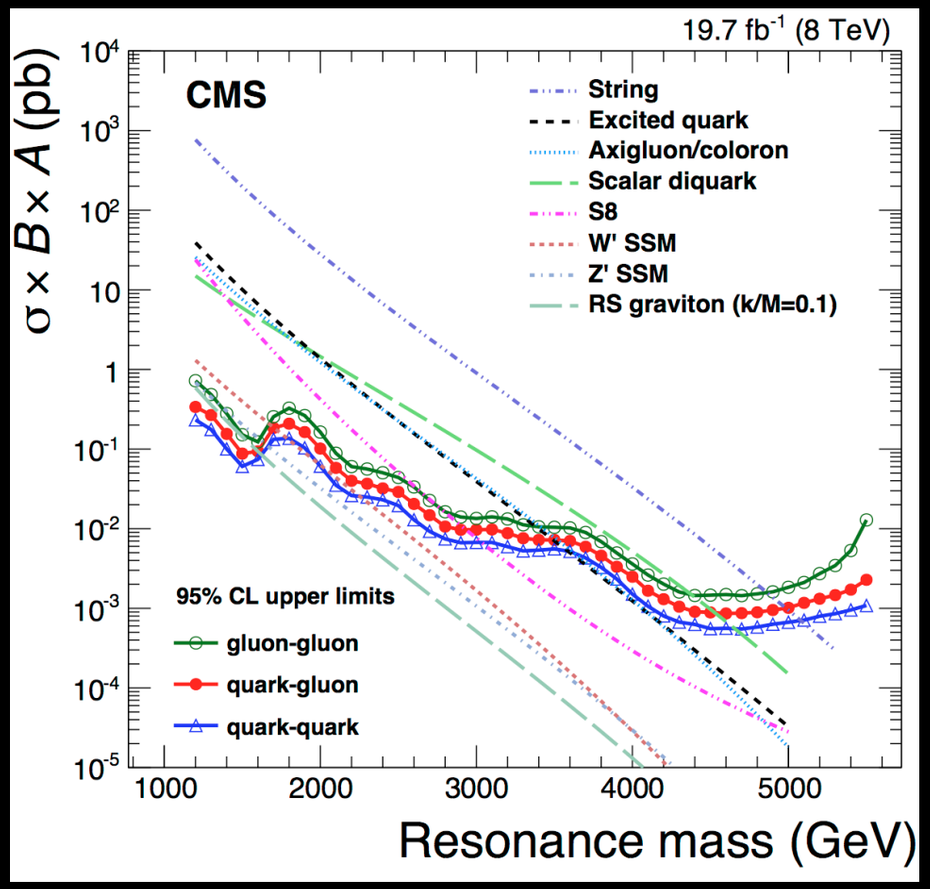


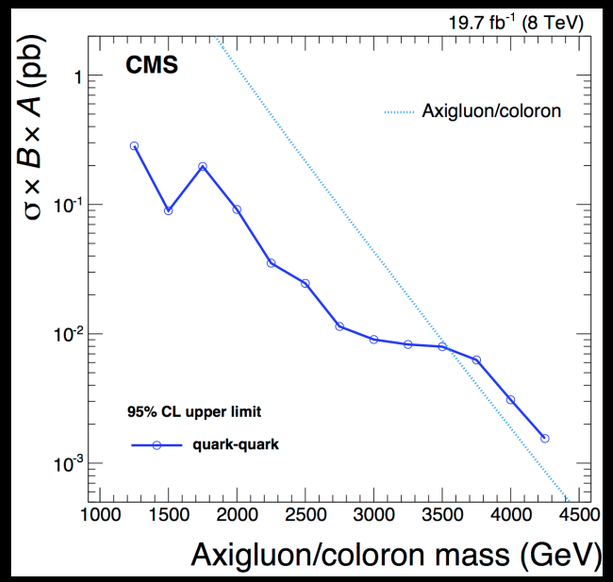
- Top quark resonances in BSM Models
  - Extended gauge sectors: Z′, W′ and G′ bosons
  - Complex Strategy: Use boosted techniques to identify t, W, Z, H along with b and reconstruct the resonance mass

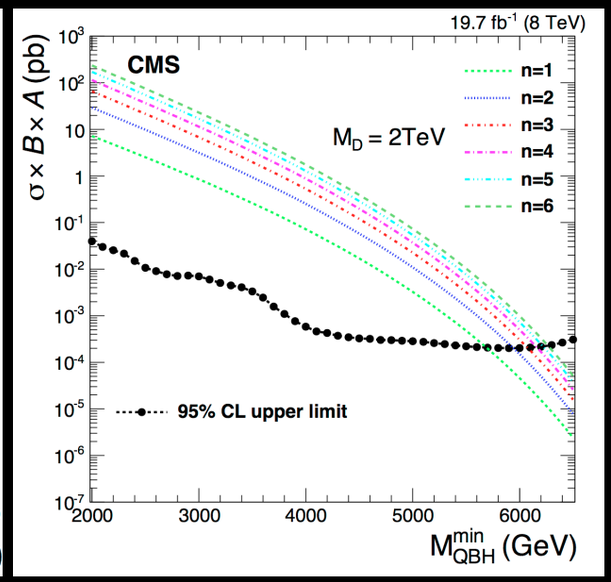


DI-JET

- Narrow resonances that couple to pairs of qq, qg, gg
  - string resonances (< 5.0 TeV)
  - excited quarks (< 3.5 TeV)
  - scalar diquarks (< 4.7 TeV)
  - W′ (<1.9 or 2.0 < $m_{W'}$ < 2.2 TeV)
  - Z′ (<1.7 TeV)
  - RS graviton (<1.6 TeV)
- Narrow resonance: b* (1.2 < m_{b*} < 1.6 TeV)
- Wider resonance (width to mass ratio up to ~30%):
  - axigluons and color-octet colorons (< 3.6 TeV)
  - color-octet scalars (<2.5 TeV)
- Quantum black hole (5.0 <m_{BH} < 6.3 TeV)





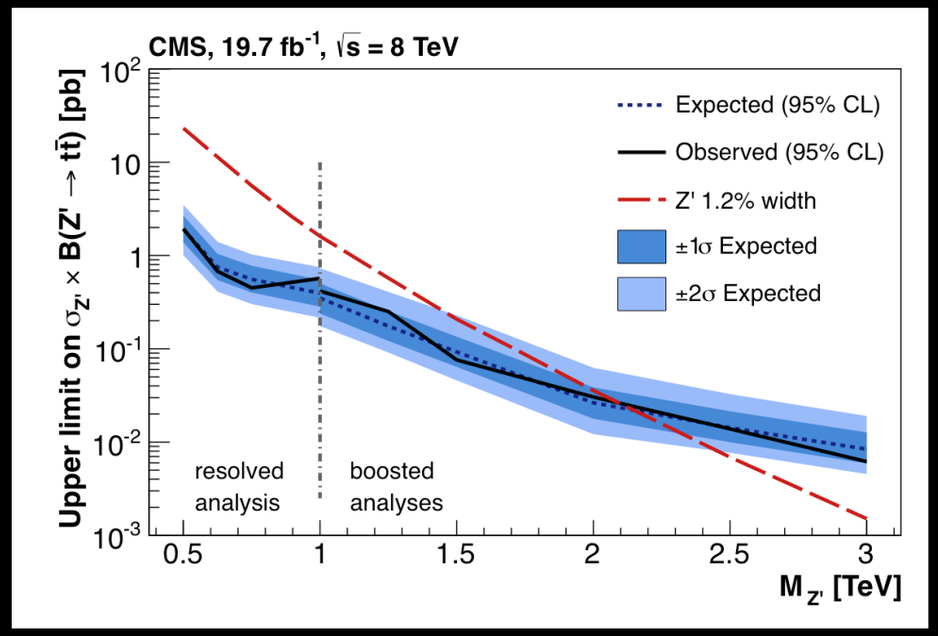


Z′

Z′→tt

- Resolved and boosted lepton+jet analysis
- Boosted all-hadronic analysis
- Combined limits
  - Z′→tt (1.2% width): $M_{Z'} < 2.1$ TeV ; (10% width): $M_{Z'} < 2.7$ TeV
  - RS KK gluons: $M_{g^*} < 2.5$ TeV

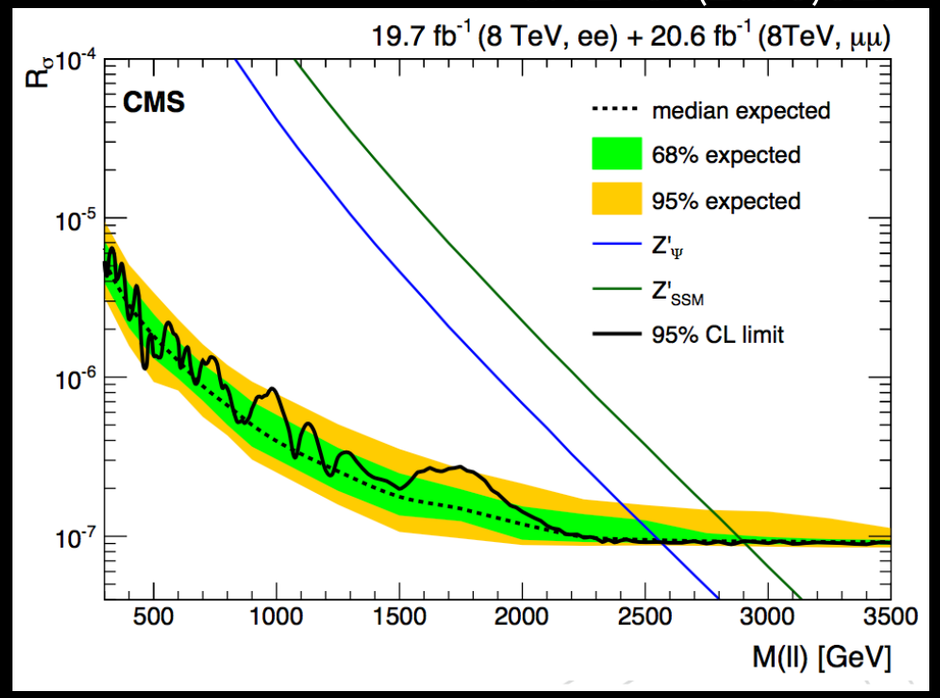
PRL 111, 211804 (2013)



Z′→ll

- Resonant (model predicting a spin-1/2 narrow resonance)
  - Sequential SM: Z'_{SSM} (< 2.90 TeV)
  - GUT, group E6: Z'_{ψ} (< 2.57 TeV)
  - KK graviton: G_{KK} (< 2.73, 2.35, 1.27 TeV for couplings of 0.10, 0.05, and 0.01)
- Non-resonant
  - ADD: x-sec enhancement due to virtual graviton-mediation (lower limits on M_s range from 4.9 to 3.3 TeV for 3 to 7 additional spatial dimension)
  - Contact interactions: left-left isoscalar model: $\Lambda < 12.0$ (15.2) TeV for muons and 13.5 (18.3) for electrons in const. (dist.) interference

JHEP04(2015)025

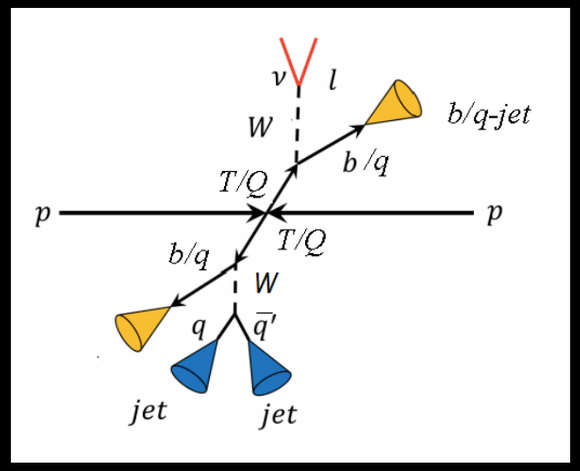


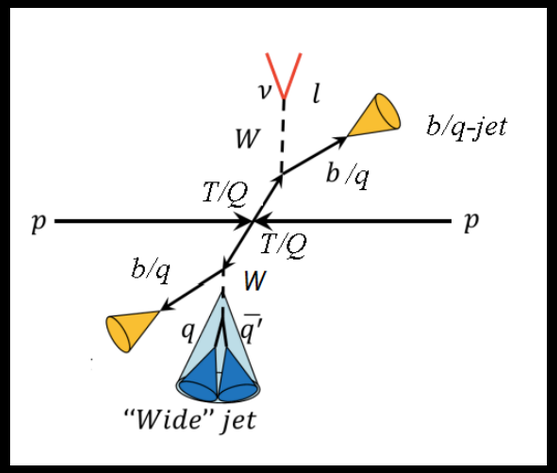
T′T′ (L+JETS)

PAS B2G-12-017

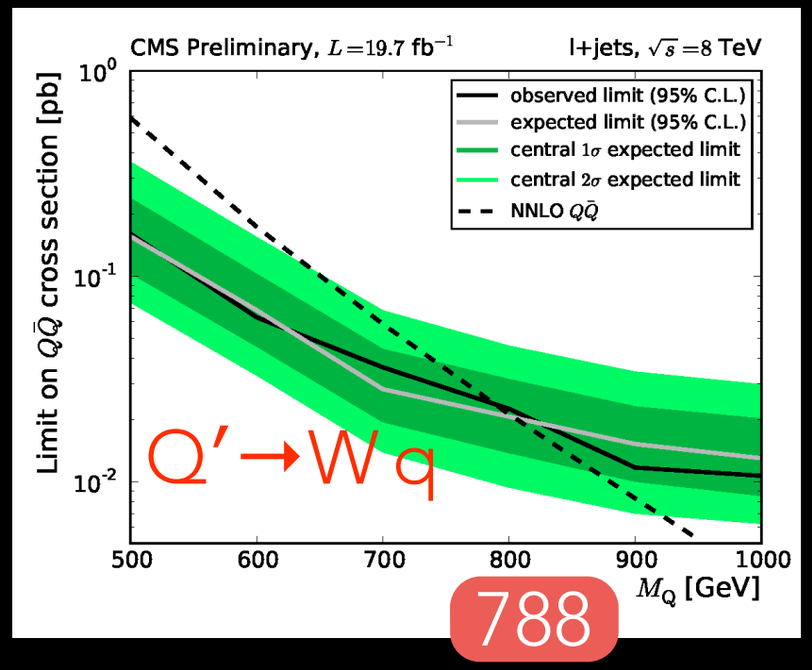
T′→Wb,Q→Wq

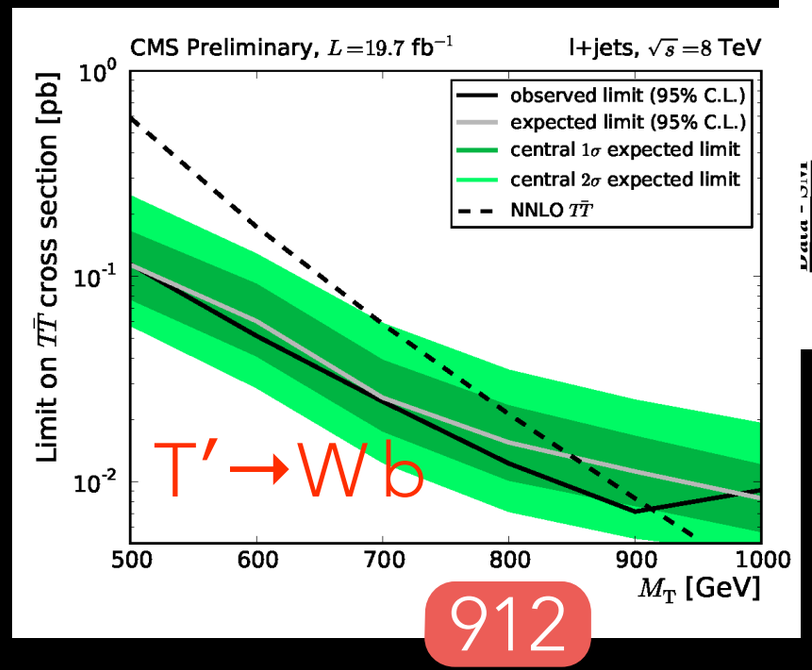
- 1 tight lepton, at least 4 high p_T jets, MET
  - T′T′→bWbW: ≥ 1-bjet
  - Q′Q′→Wq(W/Z/H)q : 0-bjet

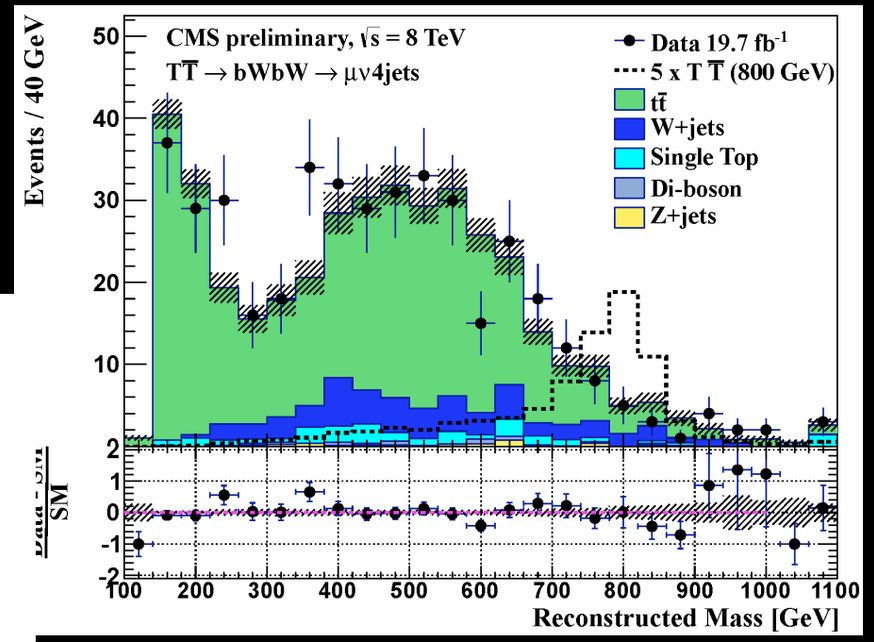




- Using kinematic fit perform mass reconstruction, using jet substructure techniques and S_T







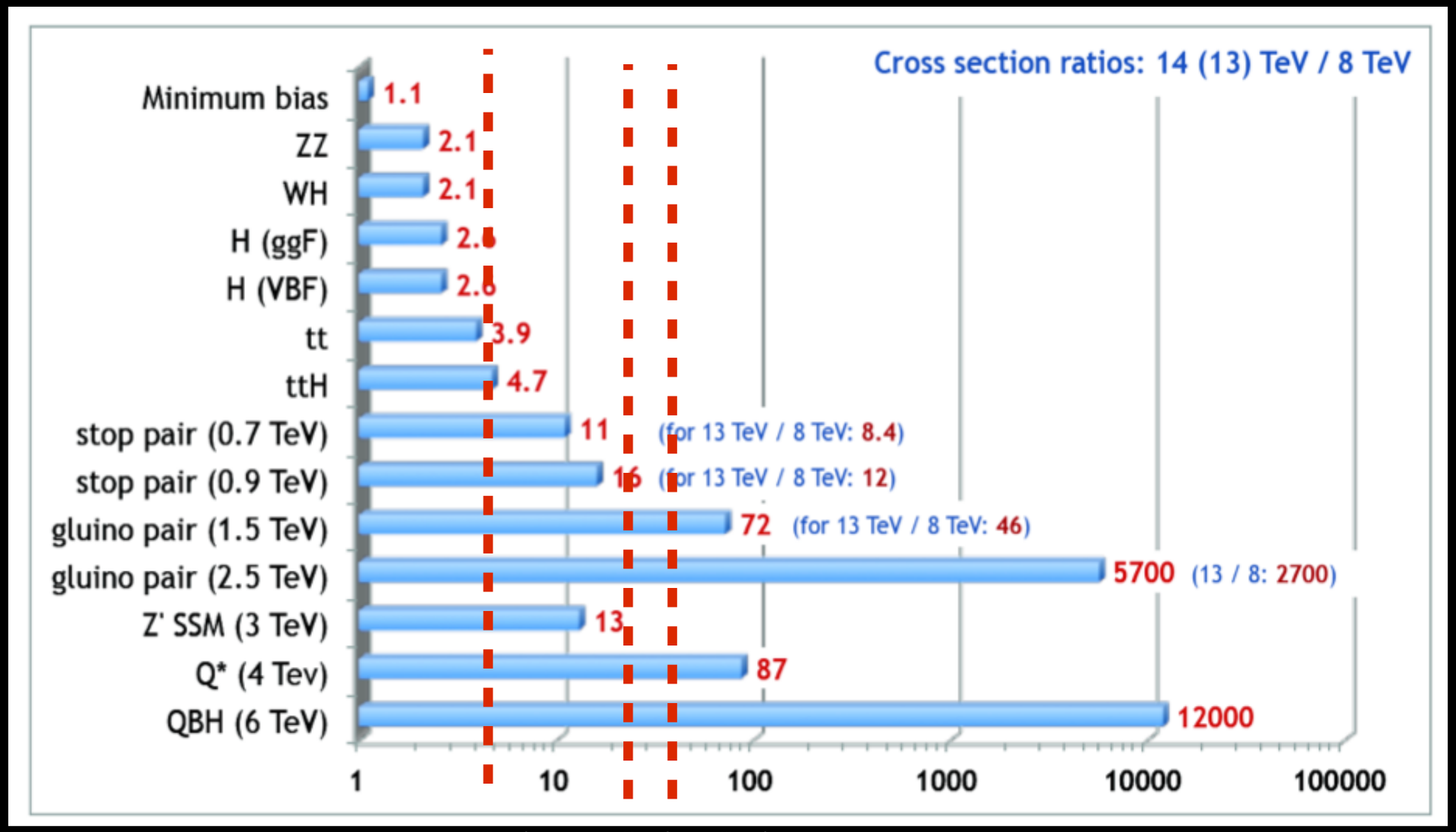
- The result also quotes upper limits on the mass and x-sections for several branching ratio combinations

NP@RUN2

L. Malgeri, J. Olsen: W&C seminar

- A different way to look at the Stirling plot:
- How much luminosity @13TeV is needed to equal the 8 TeV discovery potential (a really approximate view!)

Equivalent lumi to Run 1



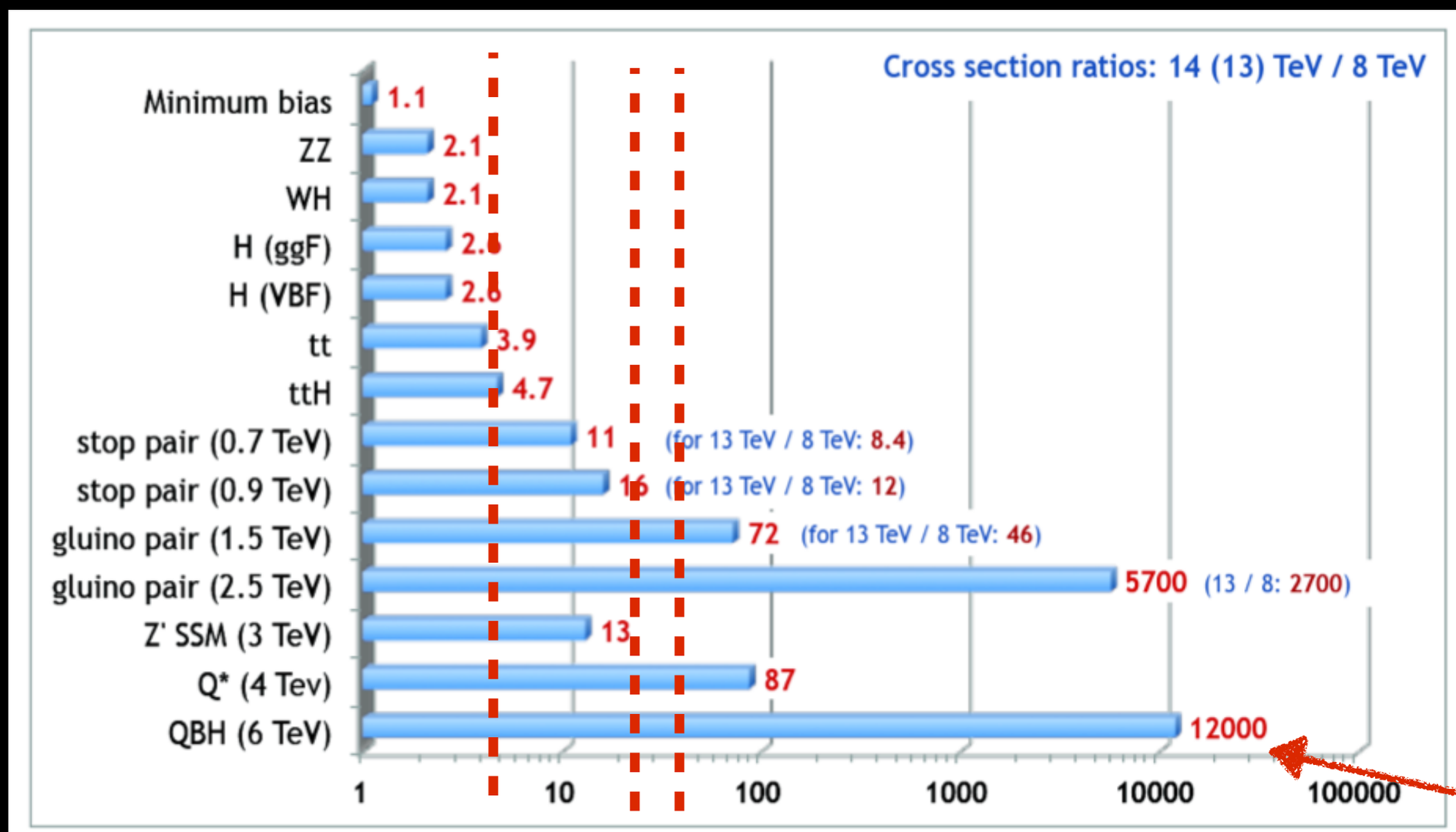
10 fb^{-1} 2 fb^{-1} 1 fb^{-1}

NP@RUN2

L. Malgeri, J. Olsen: W&C seminar

- A different way to look at the Stirling plot:
- How much luminosity @13TeV is needed to equal the 8 TeV discovery potential (a really approximate view!)

Equivalent lumi to Run 1



literally day 1 (**<100 pb^{-1}**)

10 fb^{-1} 2 fb^{-1} 1 fb^{-1}

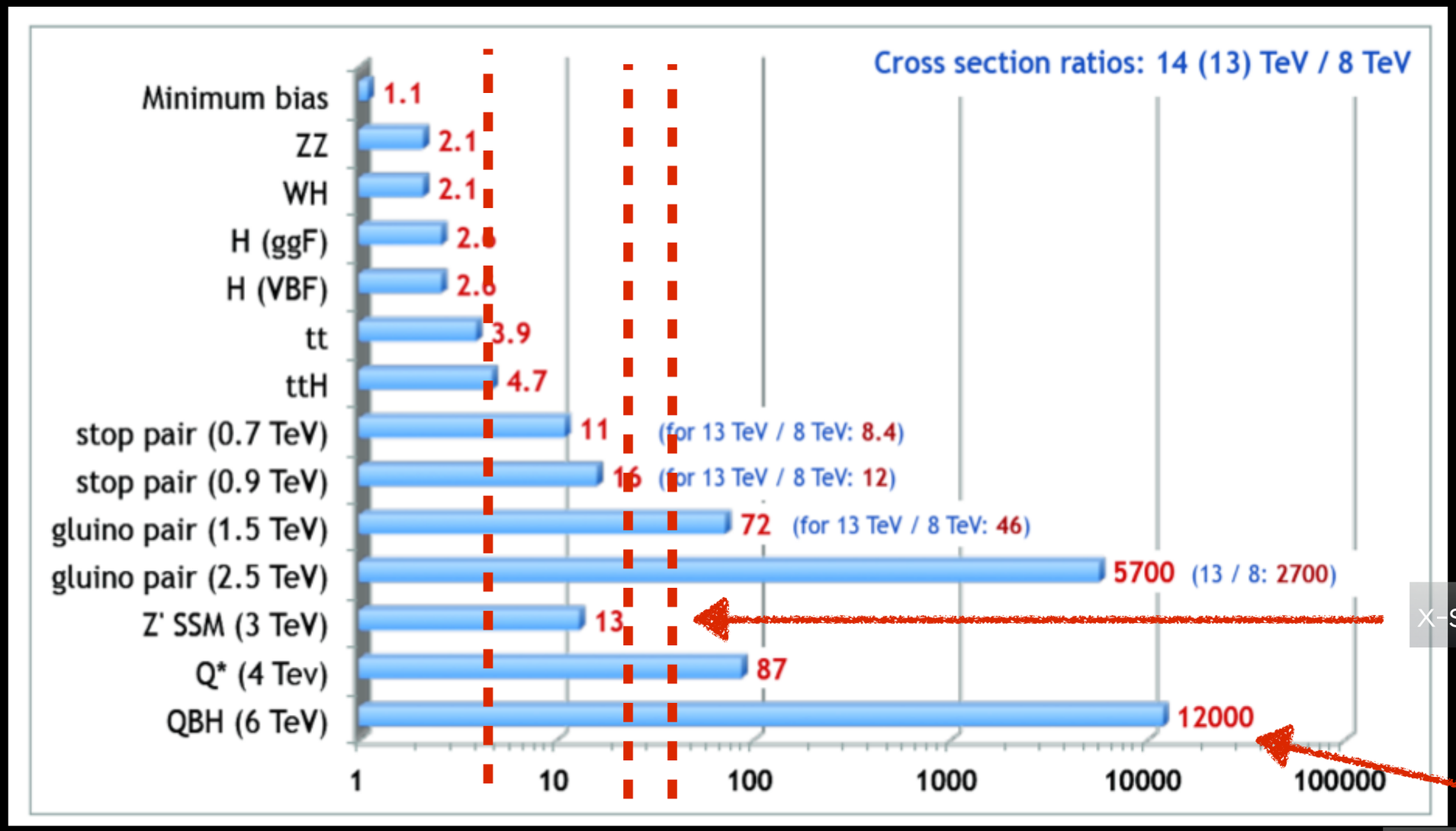
x-sec factor = 100; M=4-5 TeV

NP@RUN2

L. Malgeri, J. Olsen: W&C seminar

- A different way to look at the Stirling plot:
- How much luminosity @13TeV is needed to equal the 8 TeV discovery potential (a really approximate view!)

Equivalent lumi to Run 1



1-2 fb^{-1}

x-sec factor =13 ; M=3 TeV

literally day 1 (**<100 pb^{-1}**)

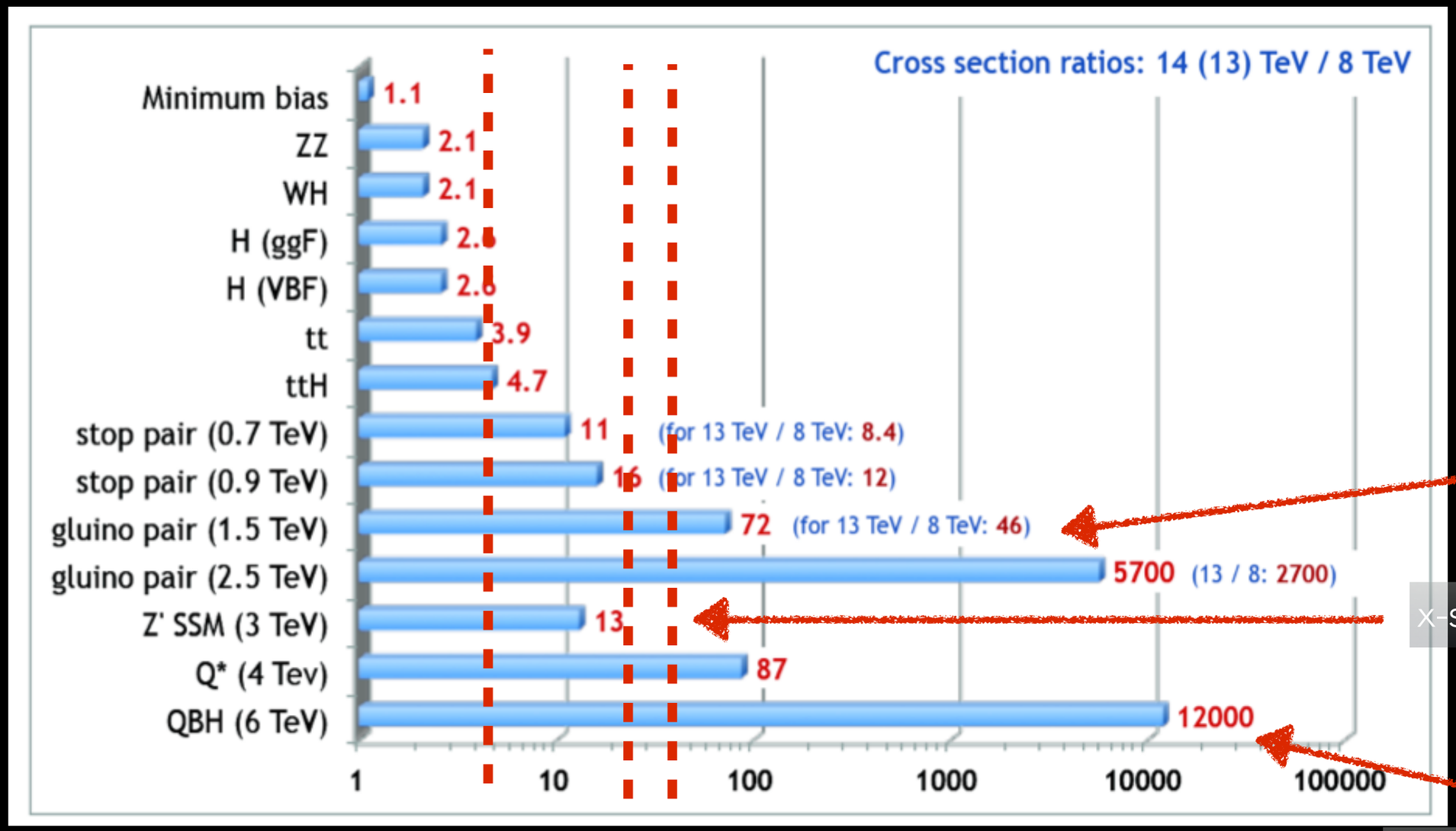
x-sec factor = 100; M=4-5 TeV

NP@RUN2

L. Malgeri, J. Olsen: W&C seminar

- A different way to look at the Stirling plot:
- How much luminosity @13TeV is needed to equal the 8 TeV discovery potential (a really approximate view!)

Equivalent lumi to Run 1



0.5 fb^{-1}

x-sec factor =40

1-2 fb^{-1}

x-sec factor =13 ; M=3 TeV

literally day 1 (**<100 pb^{-1}**)

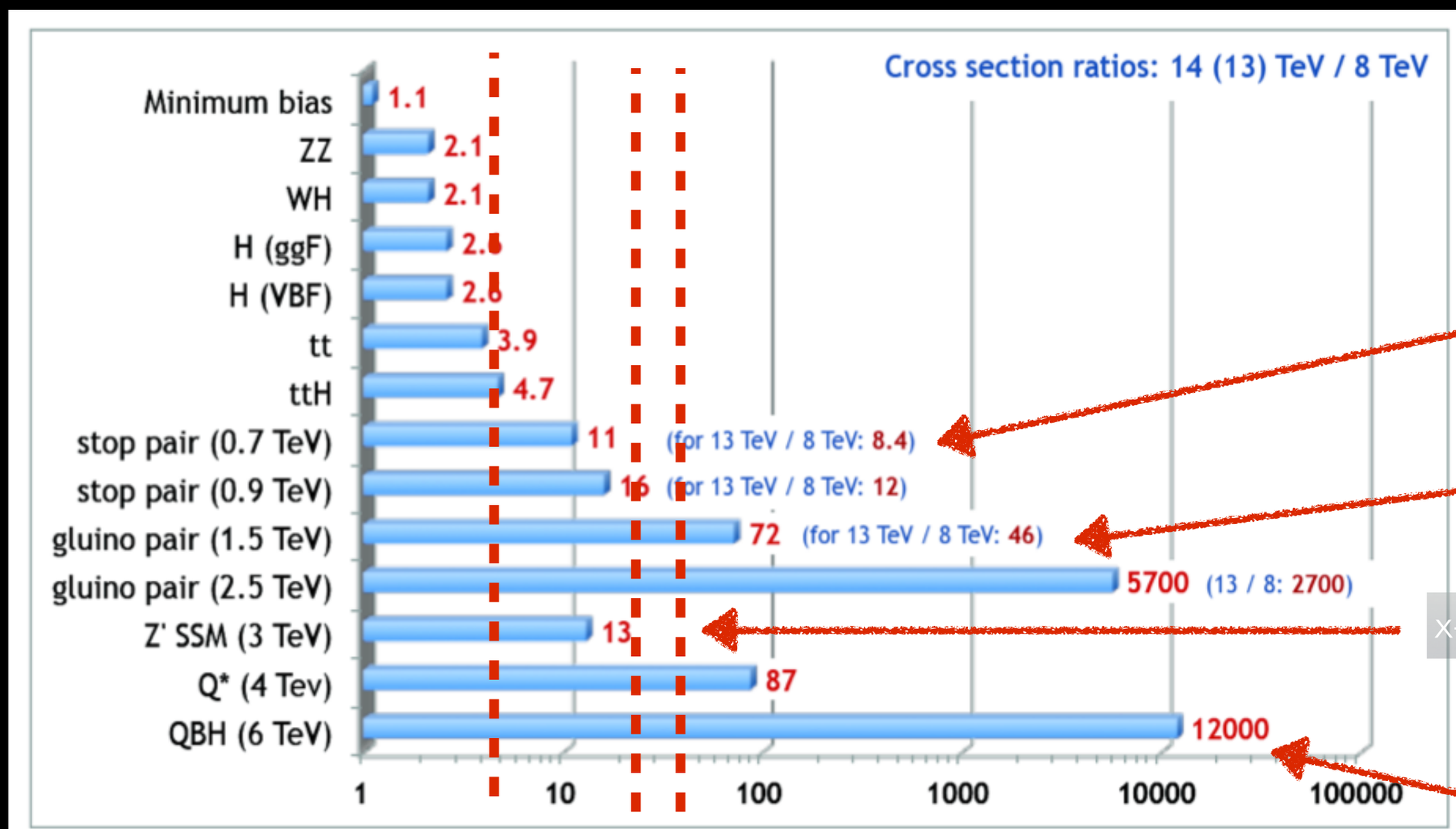
x-sec factor = 100; M=4-5 TeV

NP@RUN2

L. Malgeri, J. Olsen: W&C seminar

- A different way to look at the Stirling plot:
- How much luminosity @13TeV is needed to equal the 8 TeV discovery potential (a really approximate view!)

Equivalent lumi to Run 1



0.7 fb^{-1}

x-sec factor 6

0.5 fb^{-1}

x-sec factor =40

1-2 fb^{-1}

x-sec factor =13 ; M=3 TeV

literally day 1 (**<100 pb^{-1}**)

x-sec factor = 100; M=4-5 TeV

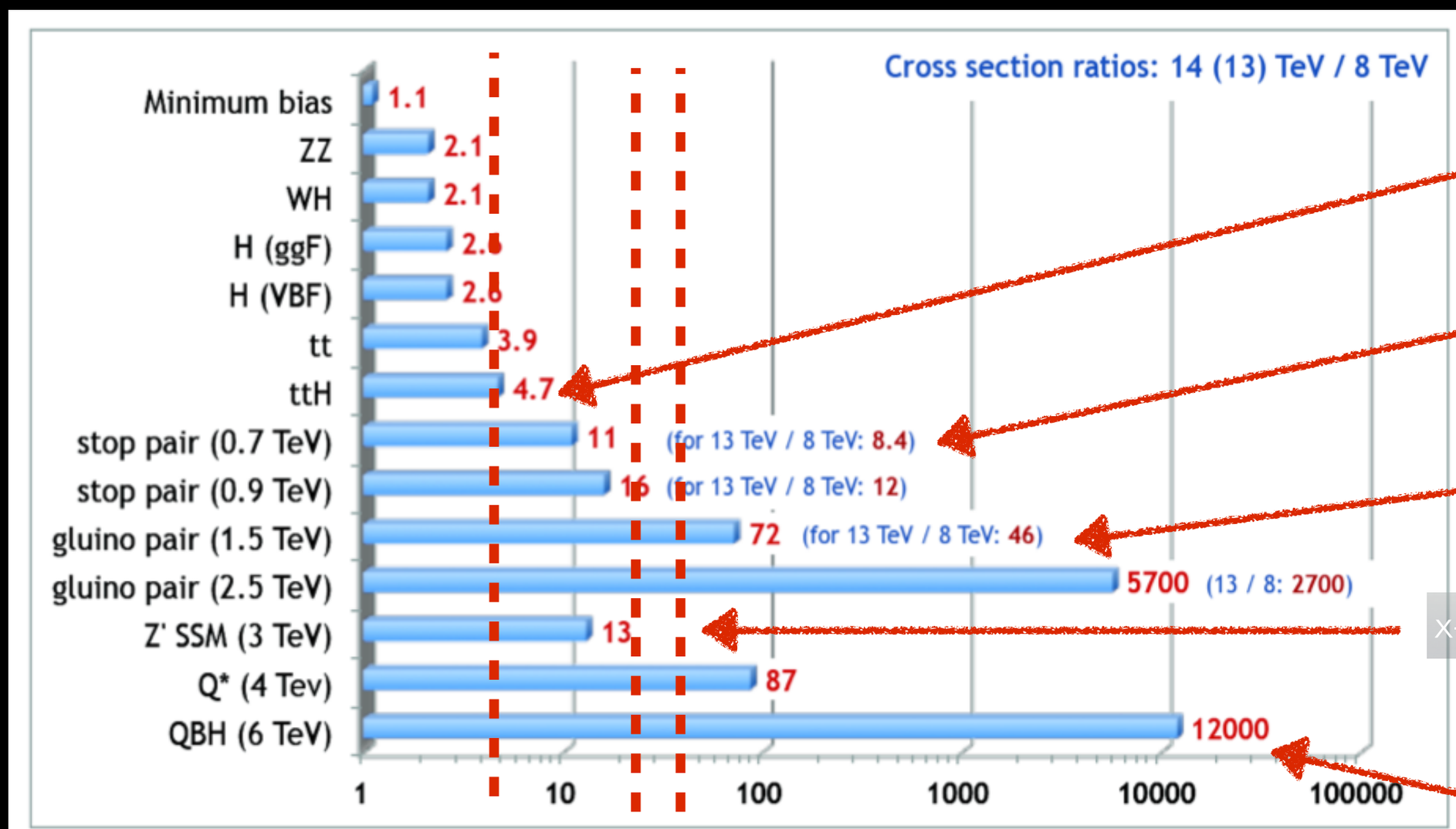
10 fb^{-1} 2 fb^{-1} 1 fb^{-1}

NP@RUN2

L. Malgeri, J. Olsen: W&C seminar

- A different way to look at the Stirling plot:
- How much luminosity @13TeV is needed to equal the 8 TeV discovery potential (a really approximate view!)

Equivalent lumi to Run 1



10 fb^{-1}

x-sec factor 4

0.7 fb^{-1}

x-sec factor 6

0.5 fb^{-1}

x-sec factor =40

1-2 fb^{-1}

x-sec factor =13 ; M=3 TeV

literally day 1 (**<100 pb^{-1}**)

x-sec factor = 100; M=4-5 TeV

10 fb^{-1} 2 fb^{-1} 1 fb^{-1}

CLOSING REMARK

L. Malgeri, J. Olsen: W&C seminar

We don't have to exclude what we have already seen the **tip of the iceberg** and watch carefully for all our >2σ deviations.

- Caveat:Many of them have been subject to the scrutiny of the community, but has generated some heat
- No suitable explanations has been found that would accommodate at least two of them with a single NP source

See talk by Adam Martin

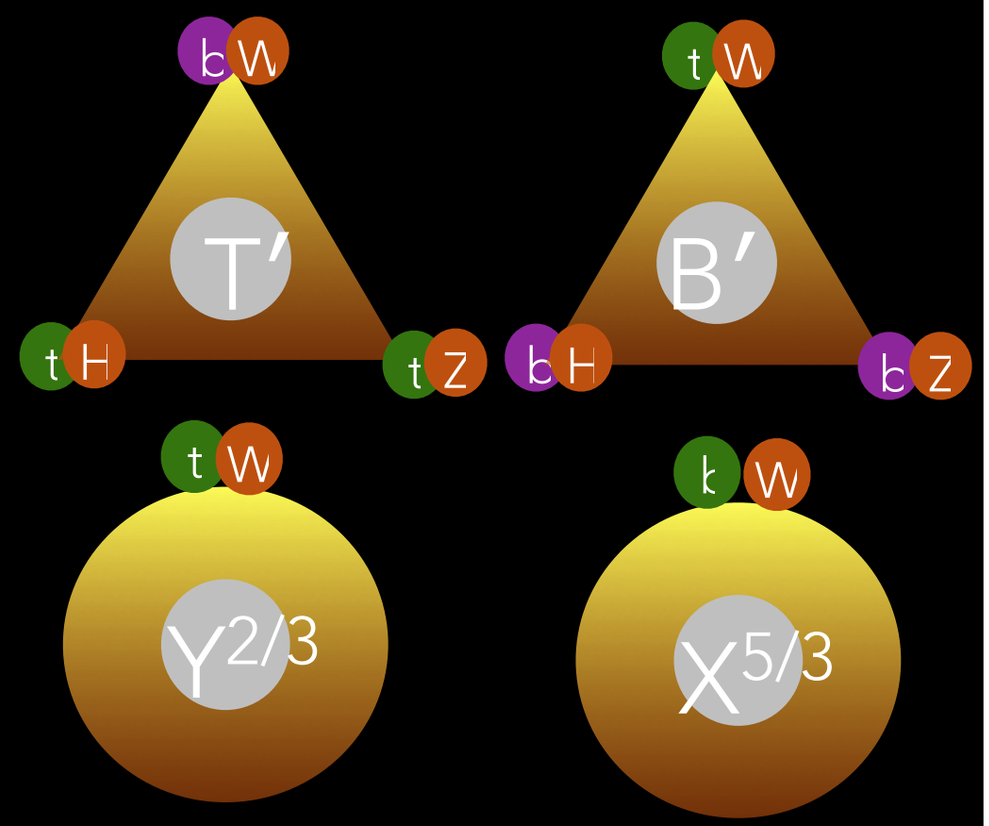
- No detailed statistics evaluation has been made so far but out of >300 results the probability of having few 3σ-ish deviation is NOT negligible

SUPPLEMENTARY MATERIAL

B2G RUN2 MENU

Patrizia Azzi, CMS Week, May 2015

Vector-like quarks



- Direct production (**single** and pair)
- Indirect production from Z′/W′ decays

Resonances

Z′→tt,Tt, TT
W′→tb
LQ3→tτ
t*→tg,tγ

- Heavy particles decaying (directly) to top

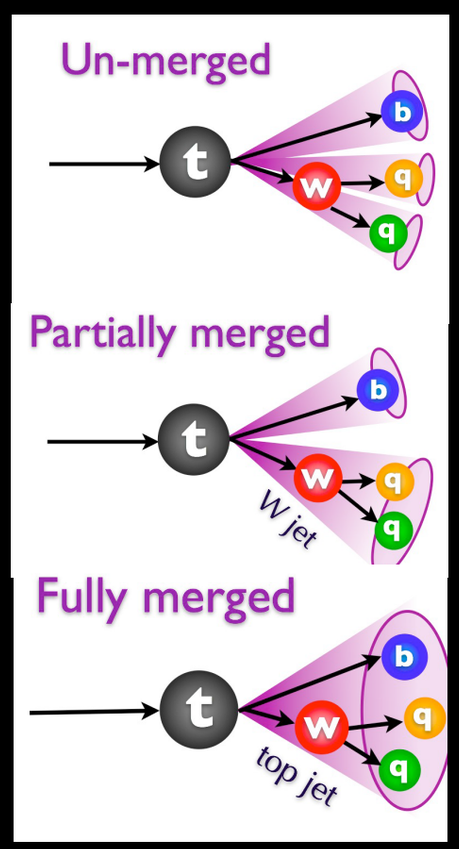
DM+HF

t(b)+DM
tt(bb)+DM
b-FDM

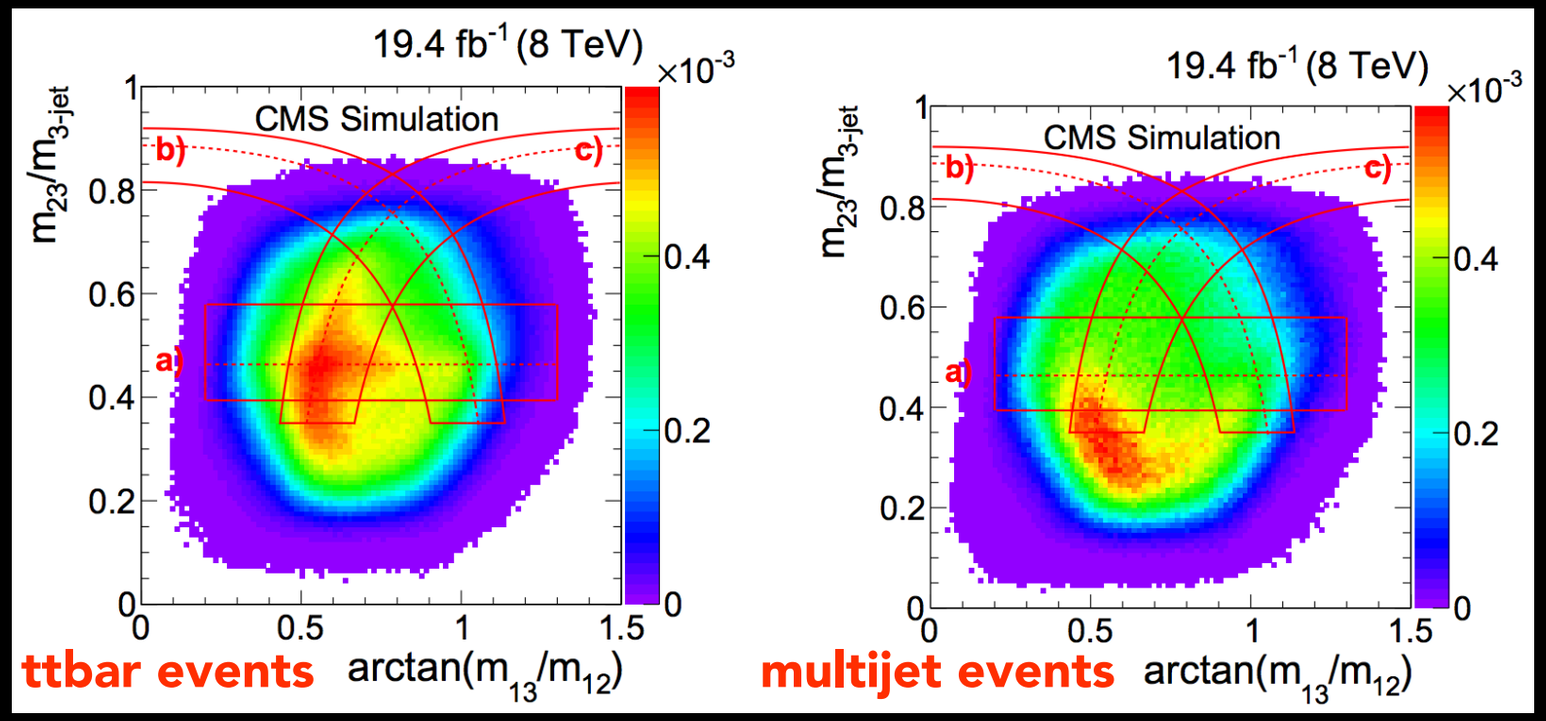
- EFT and simplified models

EXPERIMENTAL TECHNIQUES

- Discriminants:
  - Look for excesses over a known background in high S_T (sum p_T of final decay products) and/or reconstructed mass tails, BDT, …
- Substructure tools:
  - Boosted topologies are a distinct signature of the VLQ searches and are critical to retain high efficiency for the signal acceptance
    - top, Higgs, W/Z tagger …



The top tagging performance at CMS



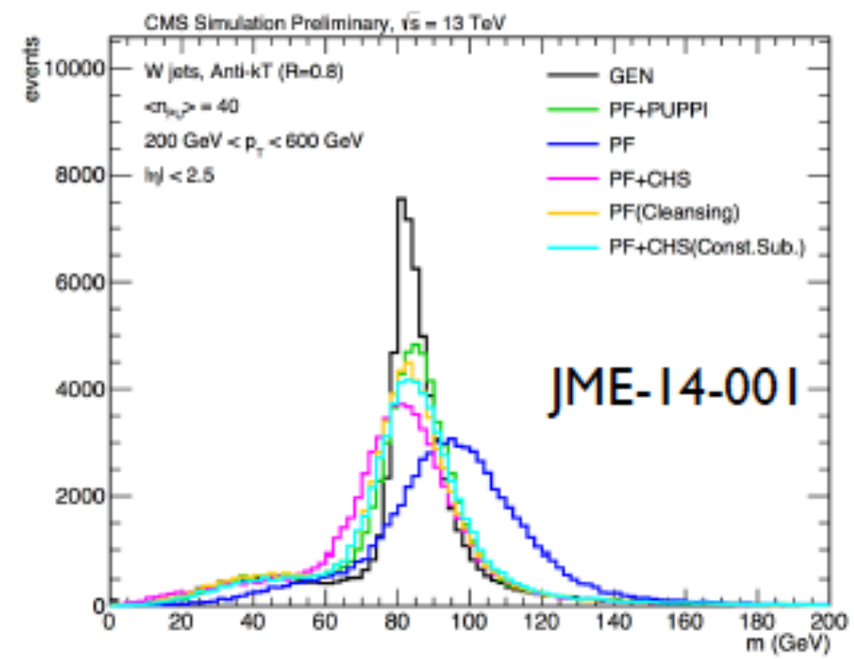
Challenges and new tools for 2015

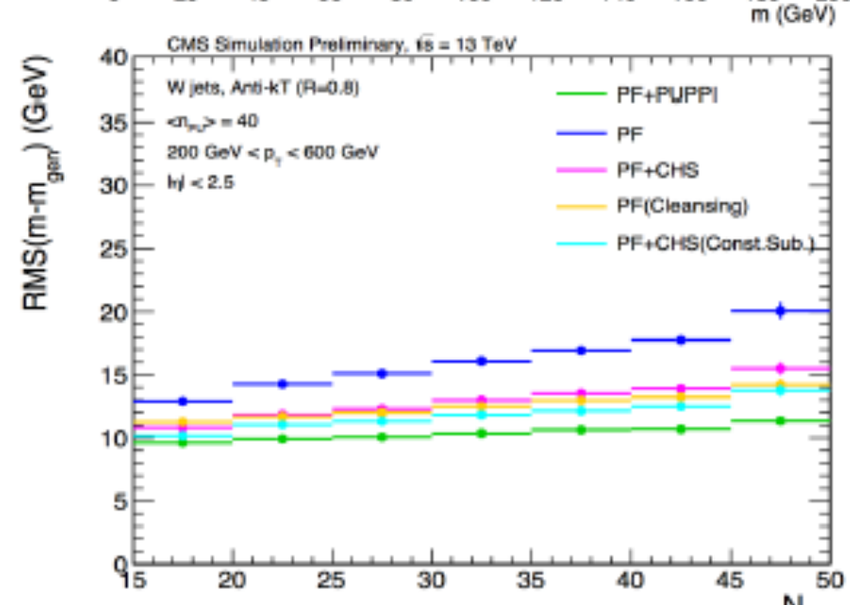
Pile up in 2015 will reach another frontier:

- In time pile up (PU) can get as high as 40 in average
  - in 2012 we have collected less than 1% of our luminosity with PU>35
- new techniques are being developed at high level reco using mostly information from Particle Flow objects
  - most of them associate a weight to all particle candidates corresponding to the probability to come from a PU collision:

$$w_i = \frac{\Sigma log \frac{p_{Tj}}{\Delta R_{ij}}(LV)}{\Sigma log \frac{p_{Tj}}{\Delta R_{ij}}(LV) + \Sigma log \frac{p_{Tj}}{\Delta R_{ij}}(PU)}$$

  - in a simple approach the weight comes from the distance of the neutral particle w.r.t. to candidates associated to the primary vertex
  - more sophisticated approach (PUPPI) add to the weight many other observables

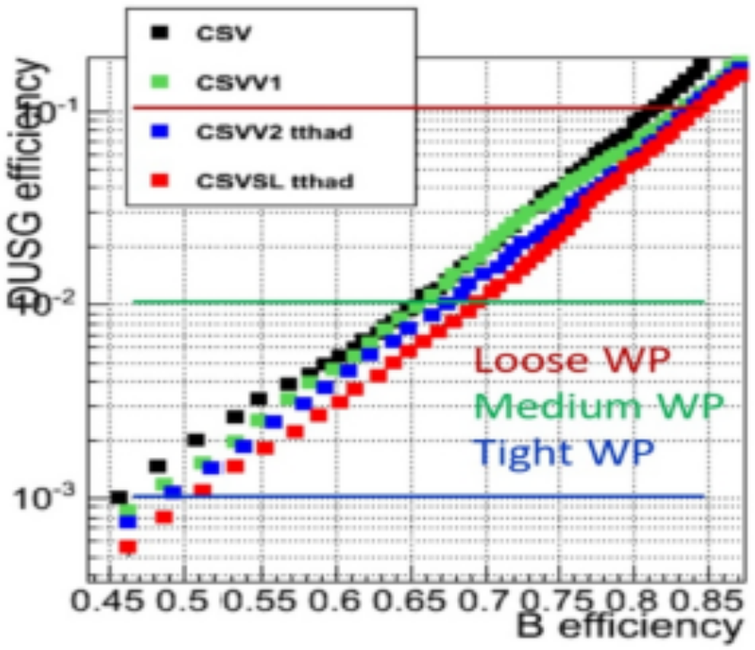




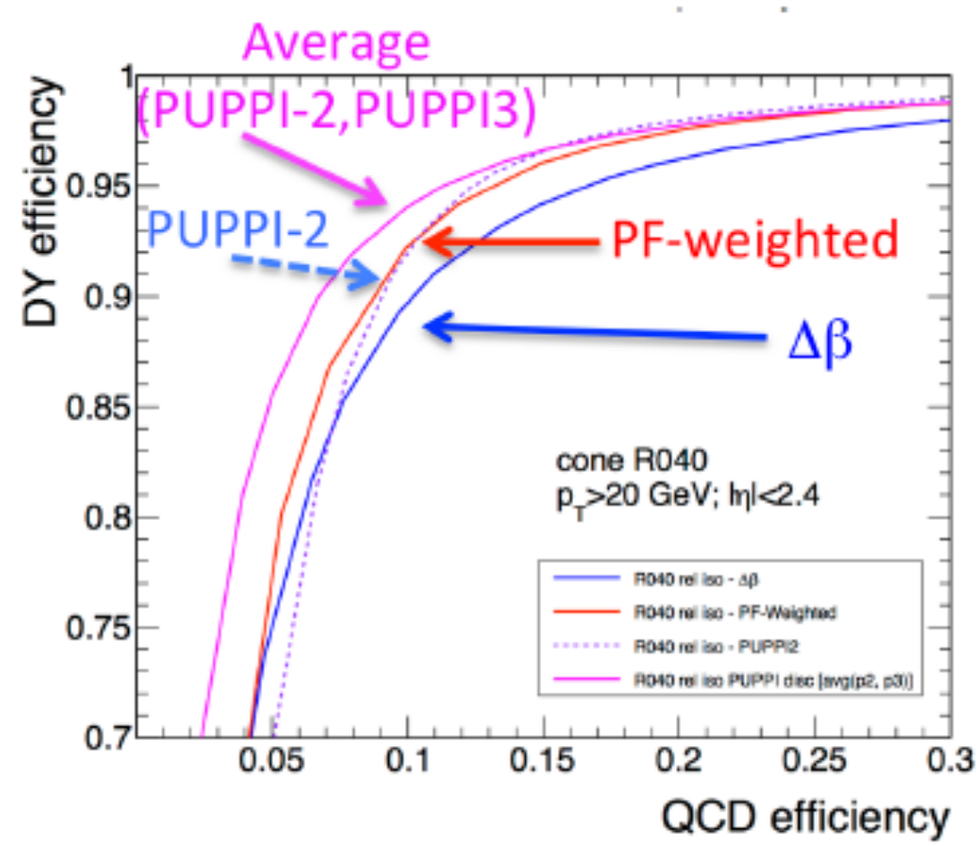
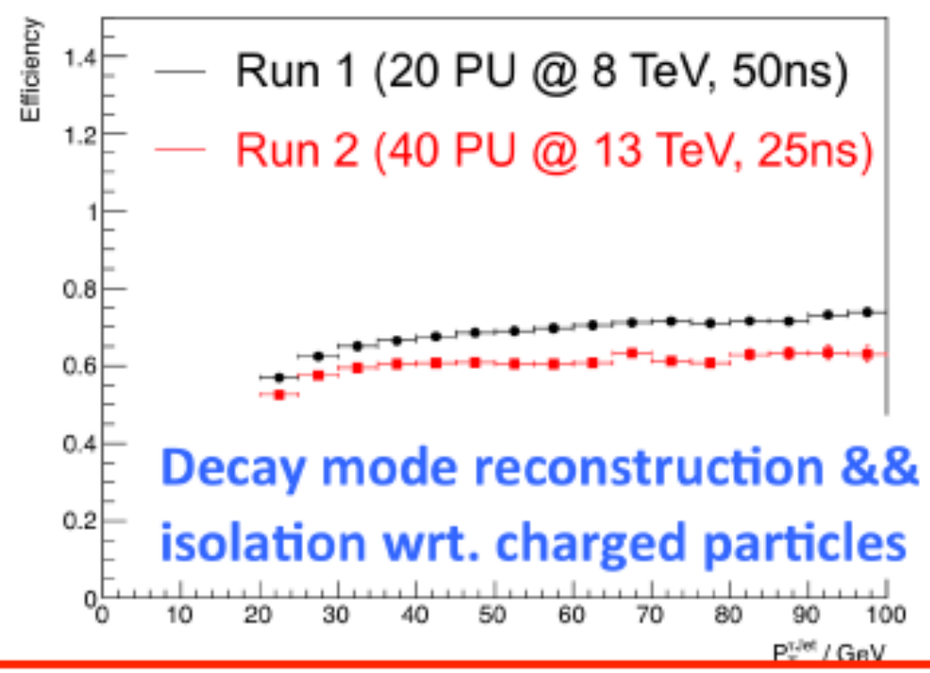
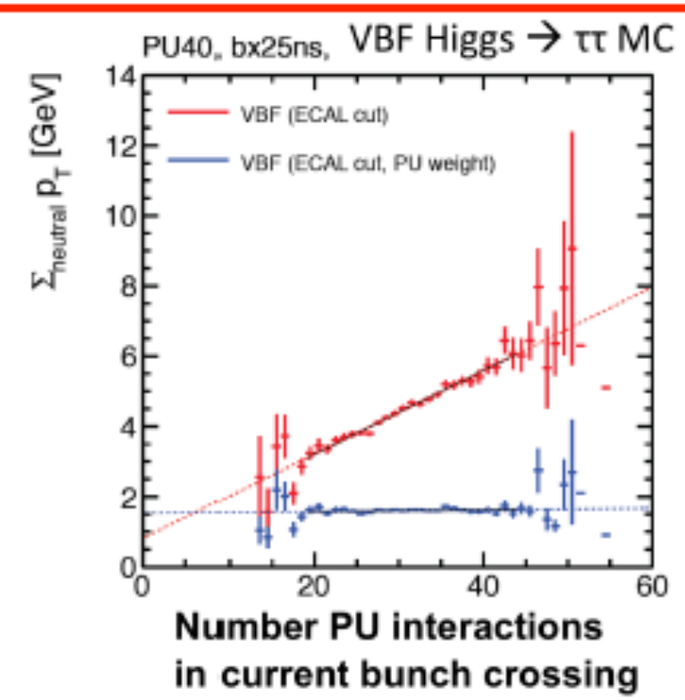
Challenges and new tools for 2015

Btag continuously improving:

- CSV = Run1
- CSVV2/CVSSL = Run2



Muon isolation also improved with new PU subtraction techniques



Tau efficiency marginally worse but isolation improved!