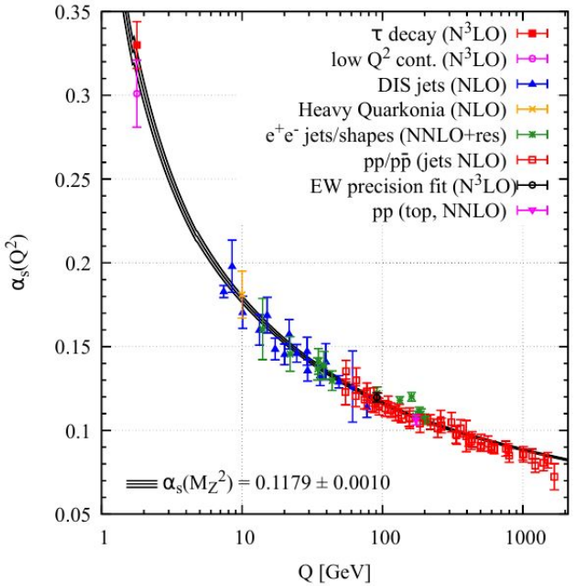
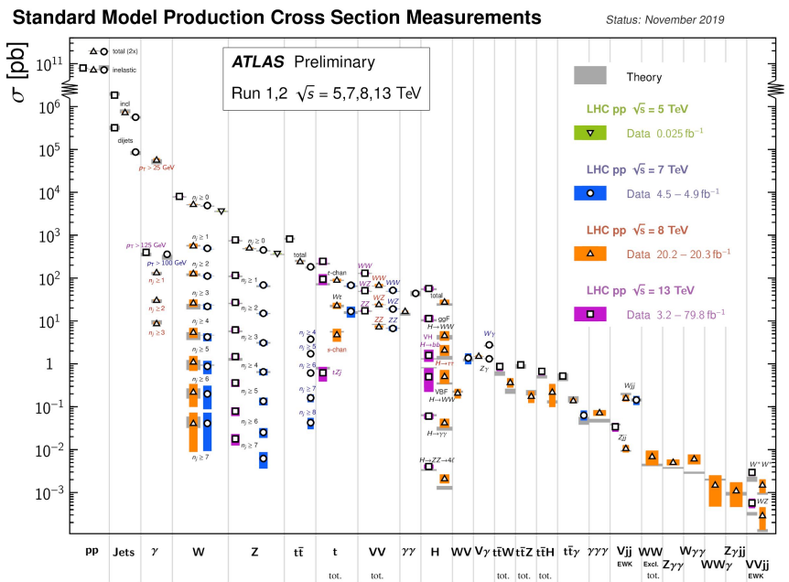
Highlights of Activities: EF05

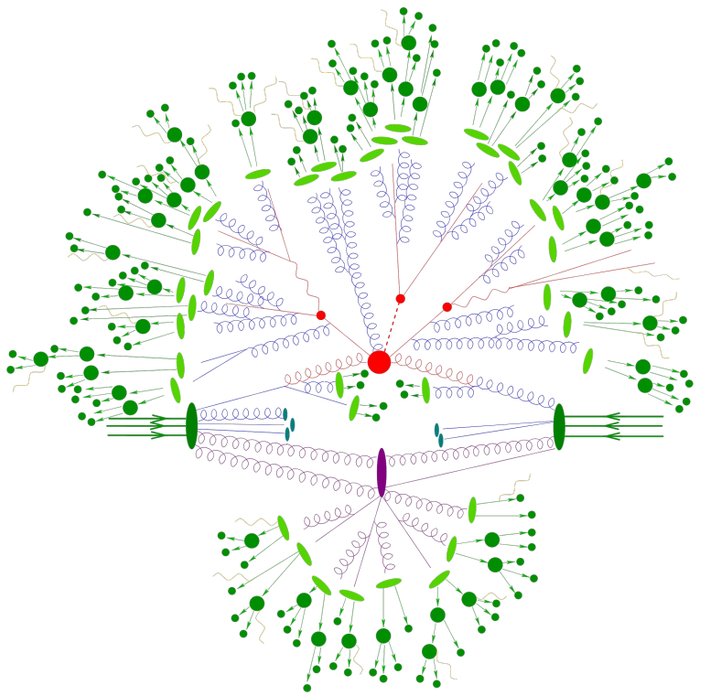
Michael Begel
Stefan Hoeche
Michael Schmitt

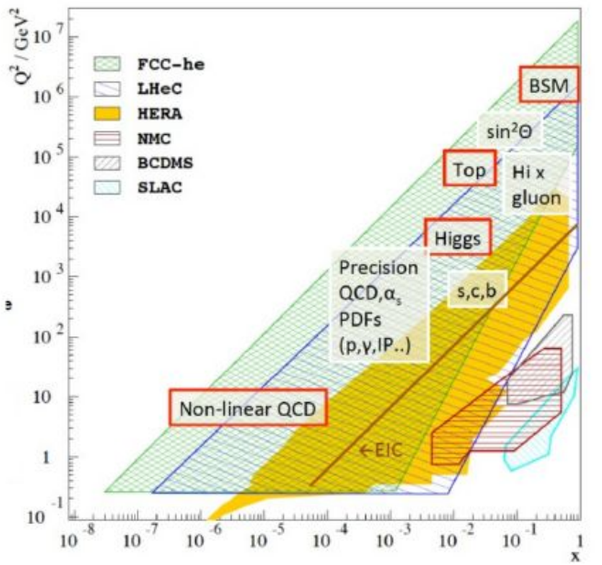
Topics covered by the group

- ***Strong Coupling***
- ***Precision tests of the Standard Model***
- ***Parton Distributions** [With EF06]*
- ***Overlap between HL-LHC and EIC** [With EF06/EF07]*
- ***Perturbative calculations - Fixed order & Resummation***
- ***Simulation and MC event generators***
- ***Non-perturbative aspects***
- ***Jet substructure***



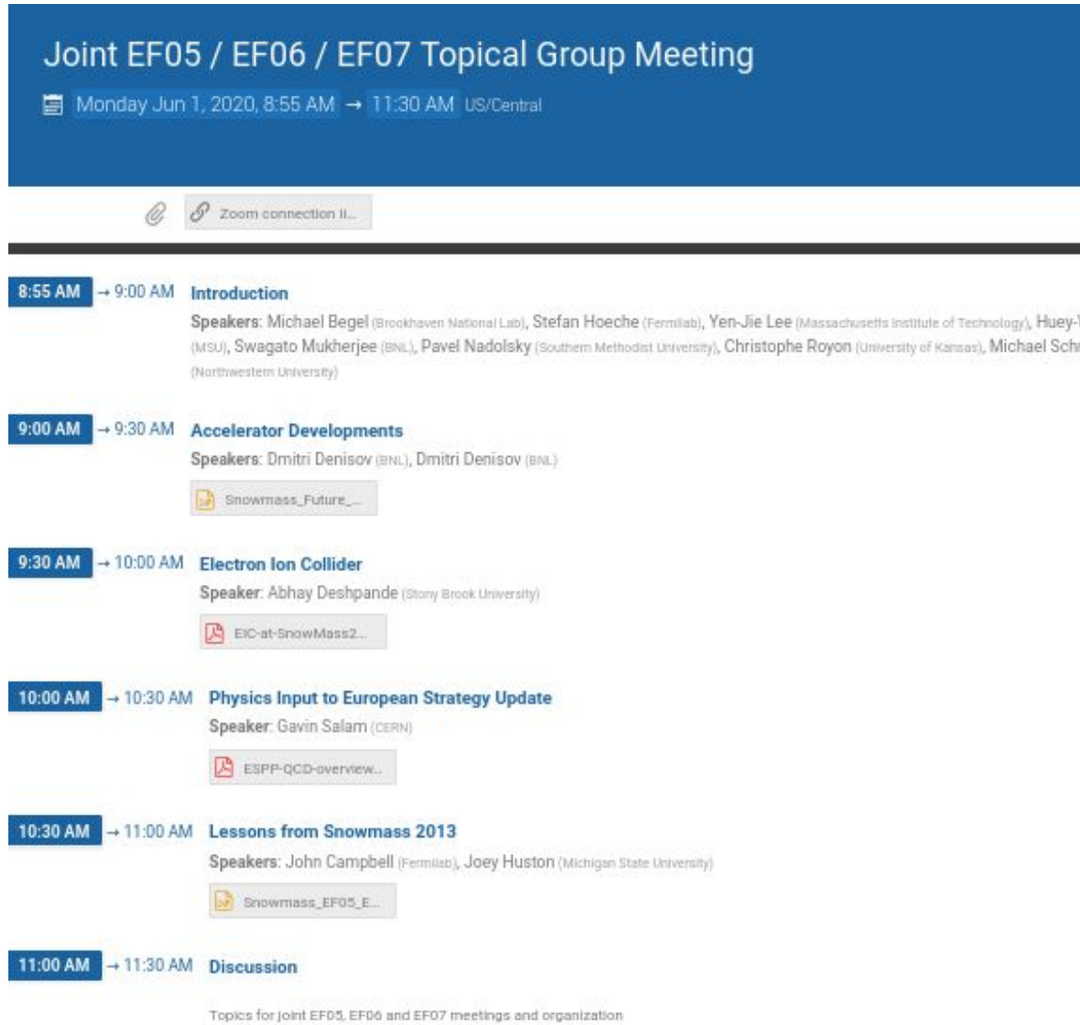






Joint Kickoff Meeting on QCD at the Energy Frontier

- ***EF05 (pQCD) / EF06 (PDF) / EF07 (HI) meeting on June 1***
  - https://indico.fnal.gov/event/43488/
  - well attended by all three communities
- ***Four excellent summary talks***
  - Dimitri Denisov on Accelerator Developments
  - Abhay Deshpande on Electron-Ion Collider
  - Gavin Salam on European Strategy Update
  - Joey Huston on Snowmass 2013
- ***This was an excellent combined forum with the three QCD task groups***
  - Inspiring discussions on physics connections between LHC and EIC
  - Discussions on forward and diffractive physics



QCD theory anticipated / needed for full exploitation of HL-LHC

(2) General purpose Monte Carlo event-generator tools

- Perturbative improvements for Matching and Merging (e.g. generalisation of approaches for parton shower + NNLO merging,)
- Understanding & exploiting relation between parton-shower algorithms and resummation
- Phenomenological Models (hadronisation, underlying event, **also connects with HI physics, neutrino programmes, low energy QCD, various "beyond colliders" experiments, cosmic-ray physics**)

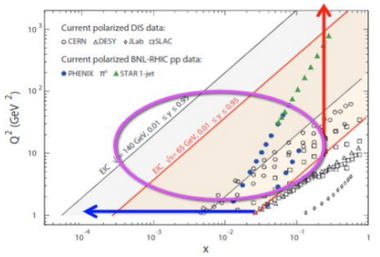
Salam

Question 1c

- Survey of the importance of EWK corrections. Do we need an EWK wishlist similar to the now-defunct NLO QCD one
- Where are combined QCD-EWK corrections important?
- EWK corrections important for many of the kinematic regions at the LHC, both current and to be expected with 4000 fb^{-1}
  - it's what Kalanand Mishra in 2013 called "the Sudakov Zone"
- Even more so for 33 or 100 TeV
- QCD and EWK corrections can be of equal importance
- See later discussion of Les Houches wishlist

Huston

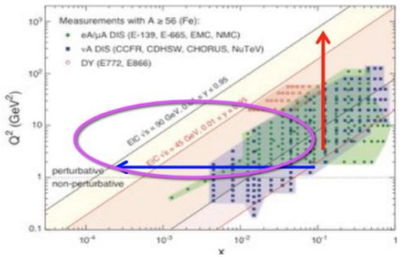
EIC: Kinematic reach & properties



For e-N collisions at the EIC:
- ✓ **Polarized** beams: e, p, d/^{3}He
- ✓ Variable center of mass energy
- ✓ Wide Q^2 range → evolution
- ✓ Wide x range → spanning valence to low-x physics

Deshpande

For e-A collisions at the EIC:
- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy
- ✓ Wide x range (evolution)
- ✓ Wide x region (reach high gluon densities)

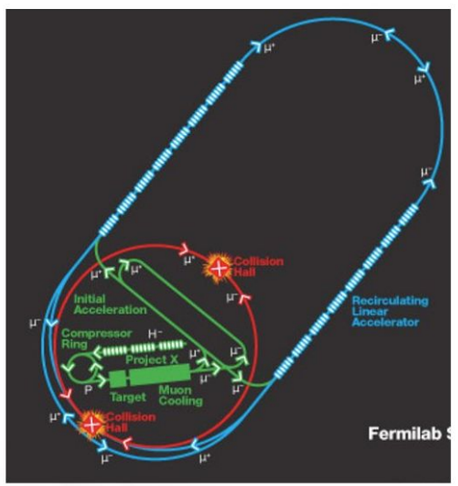


$\mu^+\mu^-$ Colliders

Denisov

- Muons are "heavy electrons", they have low synchrotron radiation making circular accelerators viable for multi TeV energies
  - γ factor at the same energy is ~200 times less than for electrons
- Muons are unstable with life-time of 2.2 micro seconds
  - Decay to an electron and a pair of neutrinos
- Main accelerator challenge
  - To make large number of muons quickly and then "cool" them to focus into small diameter beam to collide
- Another issue are decays and irradiation by electrons from muon decays
  - And neutrinos irradiation!

2x2 TeV

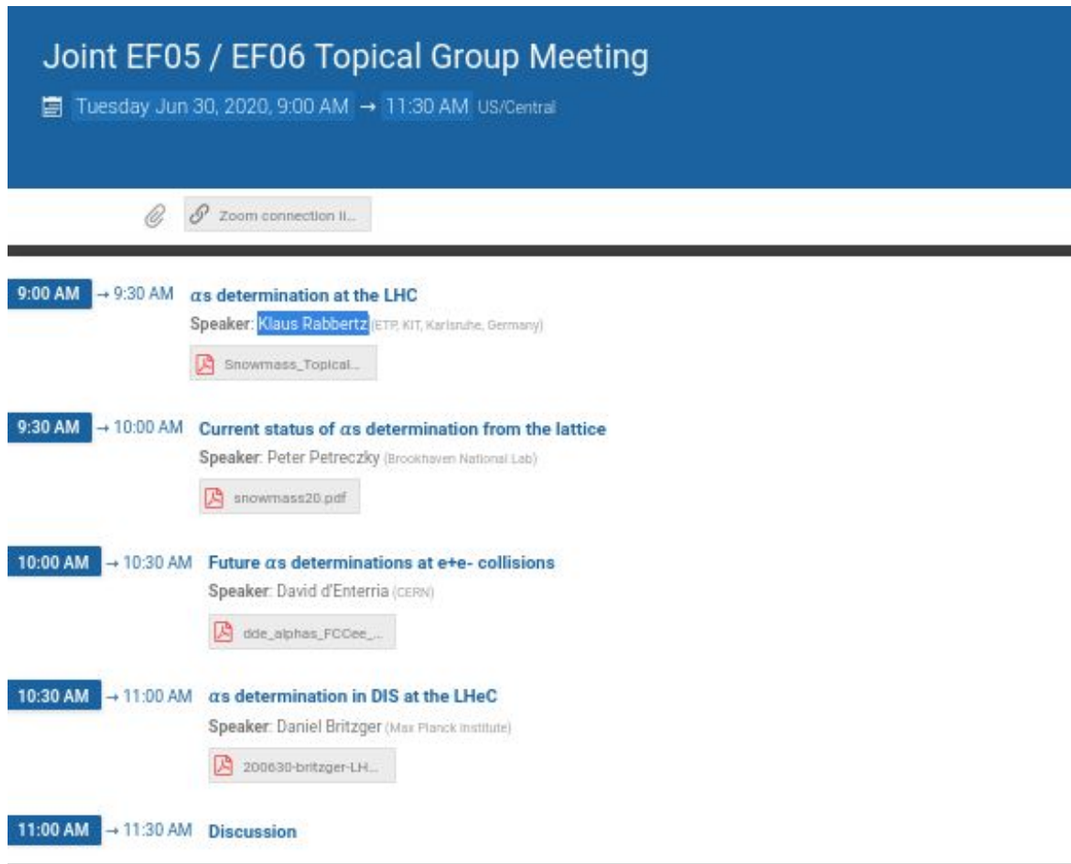


Focus questions

1. **What is the ultimate precision for α_s and how do we achieve it?**
   LHC, future pp/e+e-/DIS (ep and eA), particle decays (τ, hadrons), lattice
2. **What theoretical developments are needed to support precision measurements of Higgs and top quark production and properties?**
   including electroweak corrections, threshold effects, non-perturbative, ...
3. **Evaluation and interplay of uncertainties from theory and experiment**
   fixed-order/resummation scales, non-perturbative effects, etc.
4. **Can we better quantify non-perturbative uncertainties?**
   in cross-cutting effort between experiments, MC community & lattice QCD
5. **How to include more higher-order QCD in MC event generators?**
   Fixed-order and parton shower development (incl EW emissions, color flow, multi-parton interactions, rescattering, scale choices, ...)
6. **[Together with EF06] What is the future of PDF determination?**
   From the LHC, DIS, theoretical developments (NNLO, photon, pion, ...)

Discussions on α_s

- ***Joint EF05 (pQCD) / EF06 (PDF) meeting on June 30***
  - https://indico.fnal.gov/event/43490/
  - well attended by both communities
- ***Four excellent summary talks***
  - Klaus Rabbertz on α_s determination at the LHC
  - Peter Petreczky on α_s from the lattice
  - David d'Enterria on α_s in e^+e^- collisions
  - Daniel Britzger on α_s in DIS at the LHeC
- ***Much discussion on improvements at existing and future machines***
  - Requirements on theory progress
  - Hadronization uncertainties
  - New projections for LHeC

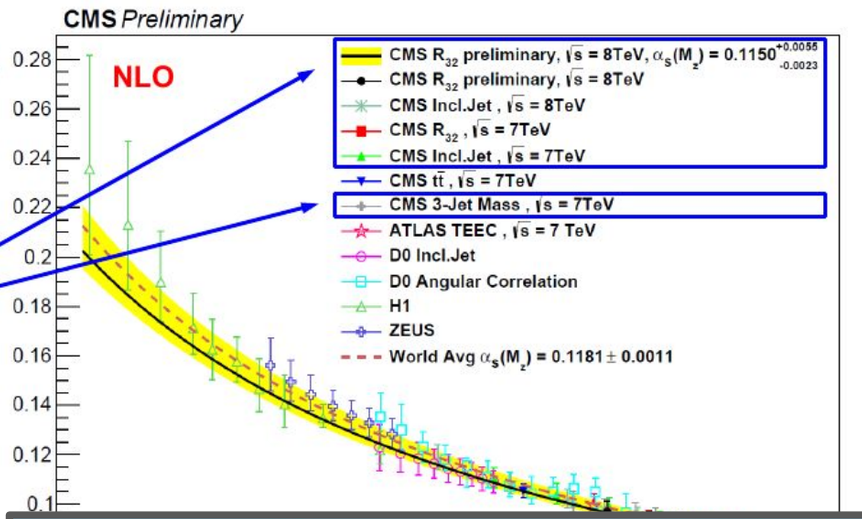


Running of $\alpha_s(Q)$

Perform fits in fixed intervals of the chosen scale Q

$\alpha_s(Q)$

Jet cross sections and ratios



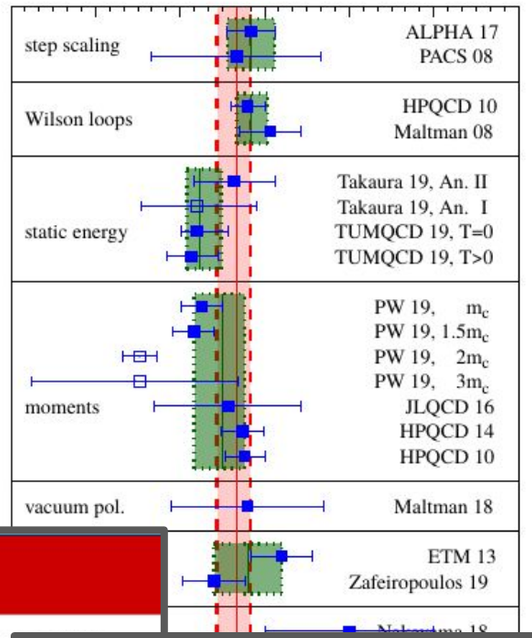
Rabbertz

Needs an update for latest ATLAS, CMS, & H1

Klaus Rabber

Summary of α_s from the lattice

Petreczky



Form pre-averages for each of the quantities and estimate the errors to account the spread in the determinations from different lattice groups. Averaging over pre-averages gives:

$$\alpha_s(M_Z) = 0.11803^{+0.00047}_{-0.00068}, \quad \frac{\chi^2}{df} = \frac{6.5}{6}$$

w/o static pot. :

$$\alpha_s(M_Z) = 0.11838^{+0.00044}_{-0.00048}, \quad \frac{\chi^2}{df} = \frac{2.8}{5},$$

w/o Dirac eig. :

$$\alpha_s(M_Z) = 0.11802^{+0.00046}_{-0.00069}, \quad \frac{\chi^2}{df} = \frac{4.8}{5},$$

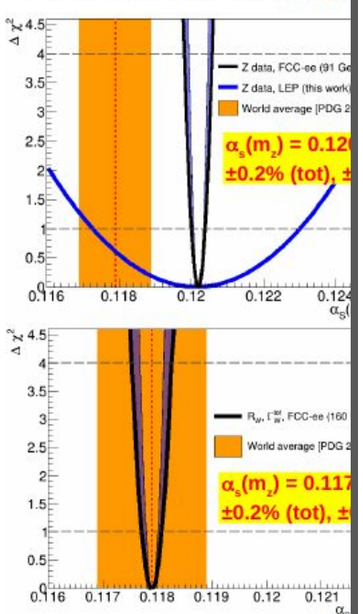
w/o step sclaing :

$$\alpha_s(M_Z) = 0.11791^{+0.00054} \quad \frac{\chi^2}{} = \frac{6.4}{}$$

Summary: α_s at FCC-ee

- World-average QCD coupling at N^{2,3}LO today:
  - *Determined from 7 observables with combined 0.85% uncertainty (least well-known gauge coupling).*
  - *Impacts all LHC QCD x-sections & decays.*
  - *Role beyond SM: GUT, EWK vacuum stability, New colored sectors?*
- e^+e^- extractions:
  - Hadronic tau decays: ±1% TH
  - Event shapes, jet rates: ±1% TH
  - Z&W pseudo-observ.: ±0.1% TH
- State-of-the-art extractions:
  - Z boson: New fit with high-order EW corrections + updated LEP data: ~2.3% (exp.) uncertainty today.
  - ew N^{3}LO fit to Γ_W, R_W uncertainty today.

- Permil uncertainty only p with a machine like FCC



d'Enterria

QCD Snowmass Meetg, June 2020 20/20

Summary of α_s at LHeC

Britzger

LHeC is an ideal QCD laboratory

- LHeC connects low-scale to Z-pole and beyond with high experimental precision

Inclusive NC/DIS

→ 'indirect' determination from QCD dynamics

$$\Delta\alpha_s(M_Z)(\text{incl. DIS}) = \pm 0.00022_{(\text{exp+PDF})}$$

Inclusive jet cross sections

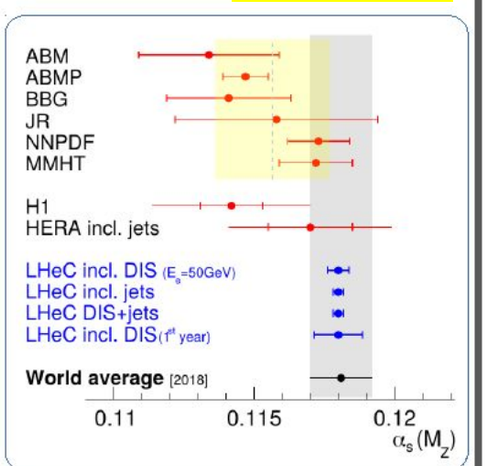
→ α_s from direct measurement of a QCD-jet

$$\Delta\alpha_s(M_Z)(\text{jets}) = \pm 0.00013_{(\text{exp})} \pm 0.00010_{(\text{PDF})}$$

Taking jet data and inclusive DIS data

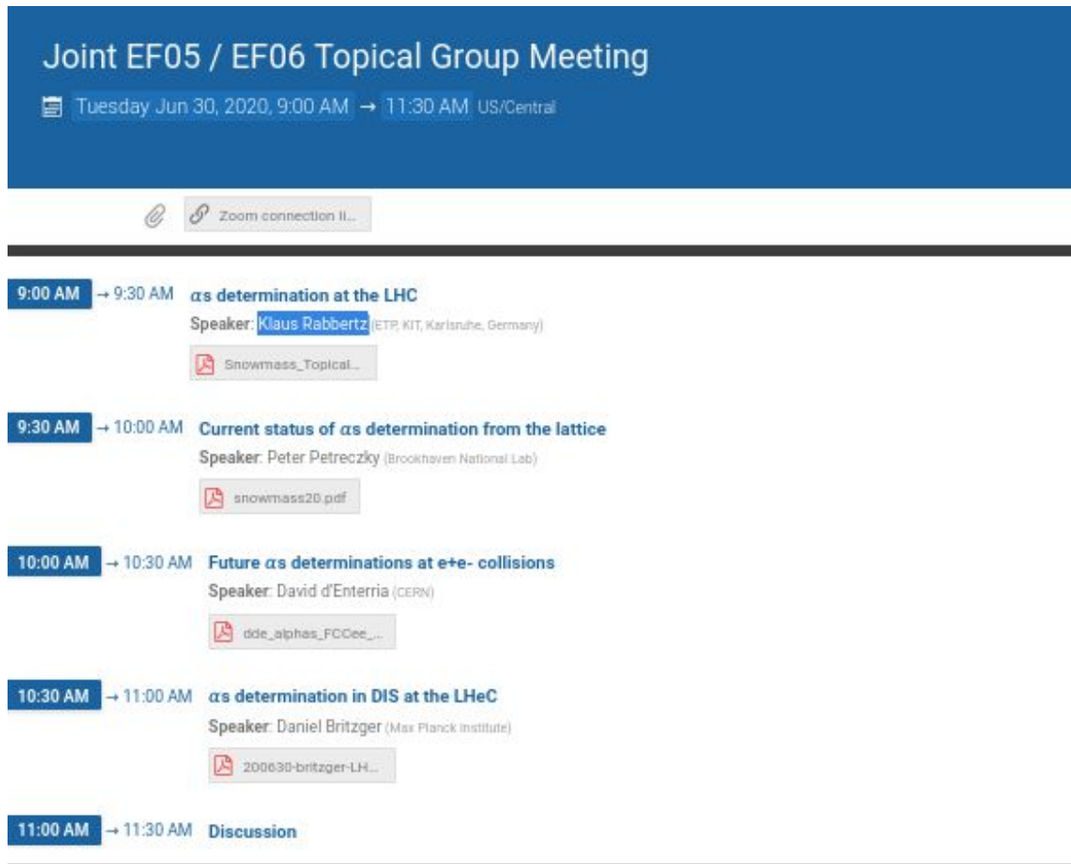
$$\Delta\alpha_s(M_Z)(\text{incl. DIS \& jets}) = \pm 0.00018_{(\text{exp+PDF})}$$

→ ***pQCD theory may be the limiting factor for ultimate precision for α_s***



Discussions on perturbative uncertainties in MC simulations

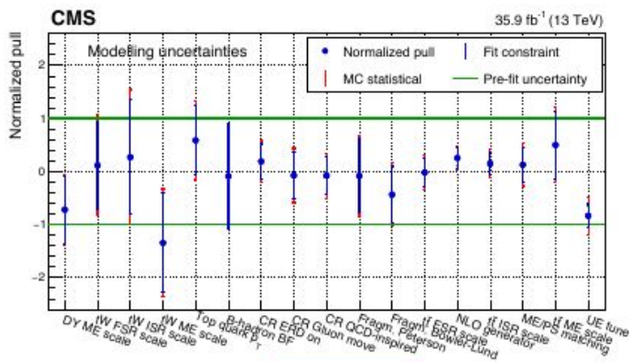
- ***EF05 (pQCD) meeting on July 17***
  - https://indico.fnal.gov/event/44315/
  - attended by many experts
- ***Three excellent summary talks***
  - Simone Amoroso on ATLAS perspective
  - Saptaparna Bhattacharya on CMS perspective
  - Marek Schönherr on theory perspective
- ***Stimulating discussion on proper uncertainty estimates***
  - Interpretation of scale uncertainties
  - Scale uncertainties in parton showers
  - Uncertainties in matching/merging procedures
  - Question on identified particle production



Relative contribution of the uncertainties

Bhattacharya

Simultaneous measurement of the top quark mass (m_t) and cross section (σ_{tt}) in dilepton top events



TOP-17-001

Does not show the effect of variation of the top p_T directly; shows the uncertainty in the unfolding

Measurement of the top mass in all-jets final state and combination with lepton+jets channel

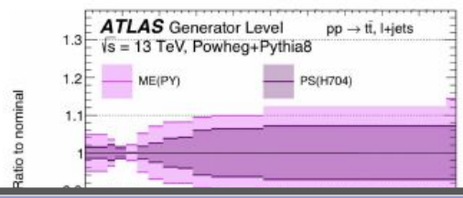
TOP-17-(

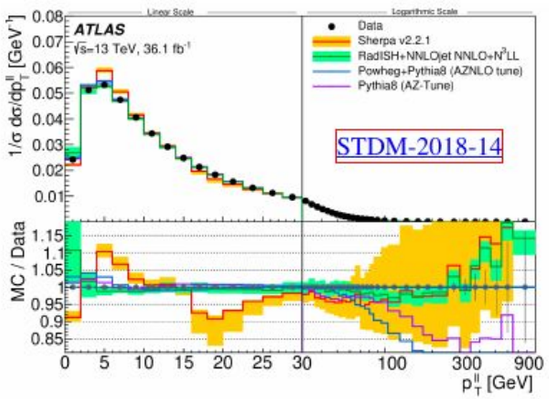
	δm_t^{hyb} [GeV] all-jets	ℓ+jets	combination
Experimental uncertainties			
Method calibration	0.06	0.05	0.03
JEC (quad. sum)	0.15	0.18	0.17
– Intercalibration	−0.04	+0.04	+0.04
– MPFInSitu	+0.08	+0.07	+0.07
– Uncorrelated	+0.12	+0.16	+0.15
Jet energy resolution	−0.04	−0.12	−0.10
b tagging	0.02	0.03	0.02
Pileup	−0.04	−0.05	−0.05
All-jets background	0.07	–	0.01
All-jets trigger	+0.02	–	+0.01
ℓ+jets background	–	+0.02	−0.01
Modeling uncertainties			
JEC flavor (linear sum)	−0.34	−0.39	−0.37
– light quarks (uds)	+0.07	+0.06	+0.07
– charm	+0.02	+0.01	+0.02
– bottom	−0.29	−0.32	−0.31
– gluon	−0.13	−0.15	−0.15
b jet modeling (quad. sum)	0.09	0.12	0.06
– b frag. Bowler–Lund	−0.07	−0.05	−0.05
– b frag. Peterson	−0.05	+0.04	−0.02
– semileptonic b hadron decays	−0.03	+0.10	−0.04
PDF	0.01	0.02	0.01
Ren. and fact. scales	0.04	0.01	0.01
ME/PS matching	+0.24	−0.07	+0.07
ME generator	–	+0.20	+0.21
ISR/FS scale	+0.14	+0.07	+0.07

RESUMMATION (SHOWER)

Amoroso

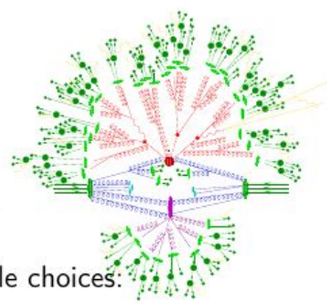
- Parton shower perturbative uncertainties are often a dominant source of uncertainty
  - For top and DY precision measurements we still rely on NLO+PS samples for an accurate description of inclusive quantities and uncertainties in the resummation region are (large and) important
  - NLO-merged samples often do not provide a good description of inclusive quantities (can this be fixed?) hence cannot/are not used





STDM-2018-14

… and how to estimate them



Parametric uncertainties

- assess through variation of input parameters within limits given by existing data

Perturbative uncertainties

- use that full result must be independent of scale choices:
  renormalisation & factorisation scales
  resummation scales / profile scales / …
  → can always only capture scale-dependent terms, never scale-independent ones

Algorithmic uncertainties

- implement different algorithms
  → always a discrete variation
  → tricky as algorithm development takes up the majority of the time

Modelling uncertainties

- if we knew how physics works in this regime …

Schönherr

Upcoming: Mini-workshop on non-perturbative uncertainties

- ***EF05 (pQCD) will hold two meetings, Aug 3 & 4, 9am-12pm CDT***
  - https://indico.fnal.gov/event/44316/
- ***We will have talks by experts on experiment, theory and MC simulation***
  - Torbjörn Sjöstrand - String Fragmentation
  - Frank Krauss - Cluster Fragmentation
  - Luigi del Debbio - Lattice perspective
  - Peter Loch - ATLAS/CMS perspective
  - Florian Bernlochner - Belle II perspective
  - ...
- ***We're looking forward to seeing you at the meeting, and to interesting and stimulating discussions***

Thank you for participating in the EF05 activities!

Please send us suggestions for study or meeting topics, comments, expressions of interest, LOIs, ...

michael.begel@cern.ch
shoeche@fnal.gov
m-schmitt@northwestern.edu