Theory highlights from Moriond QCD

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DESY
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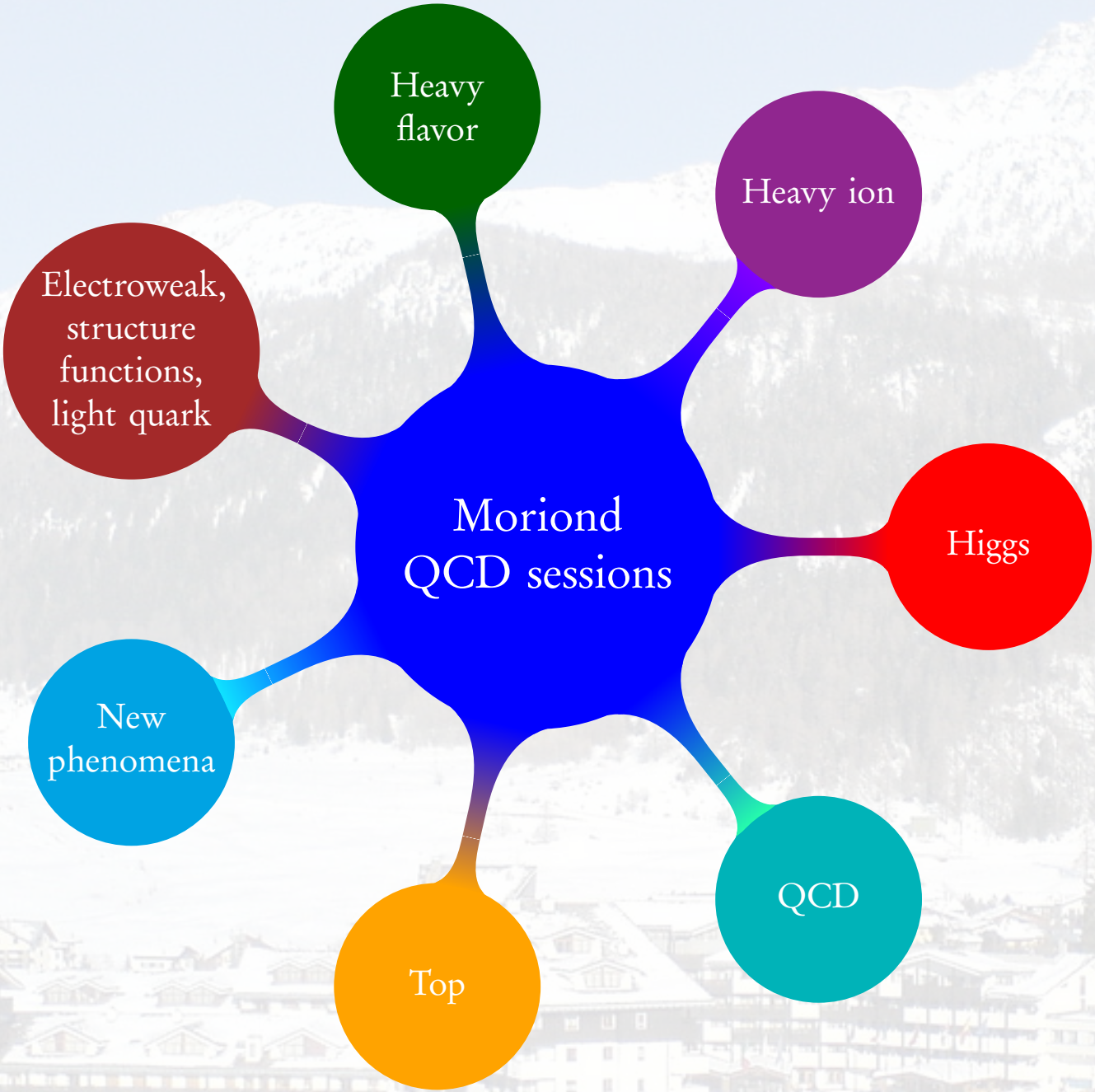
Hamburg, Germany

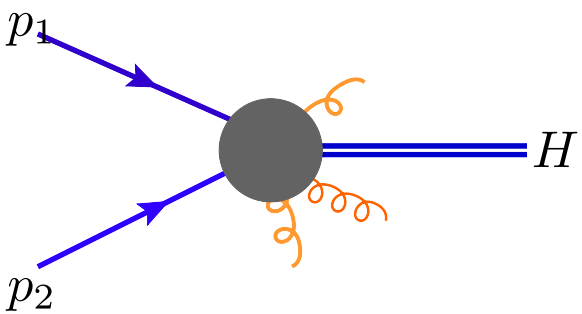

Heavy flavor
Heavy ion
Electroweak, structure functions, light quark
Moriond QCD sessions
Higgs
New phenomena
QCD
Top

Higgs session

Inclusive Higgs production at N3LO

- The gluon fusion subprocess dominates at the LHC.
- Slow converge of perturbative series requires computation at higher order in perturbation theory.
- New results at N3LO obtained by using a threshold expansion.

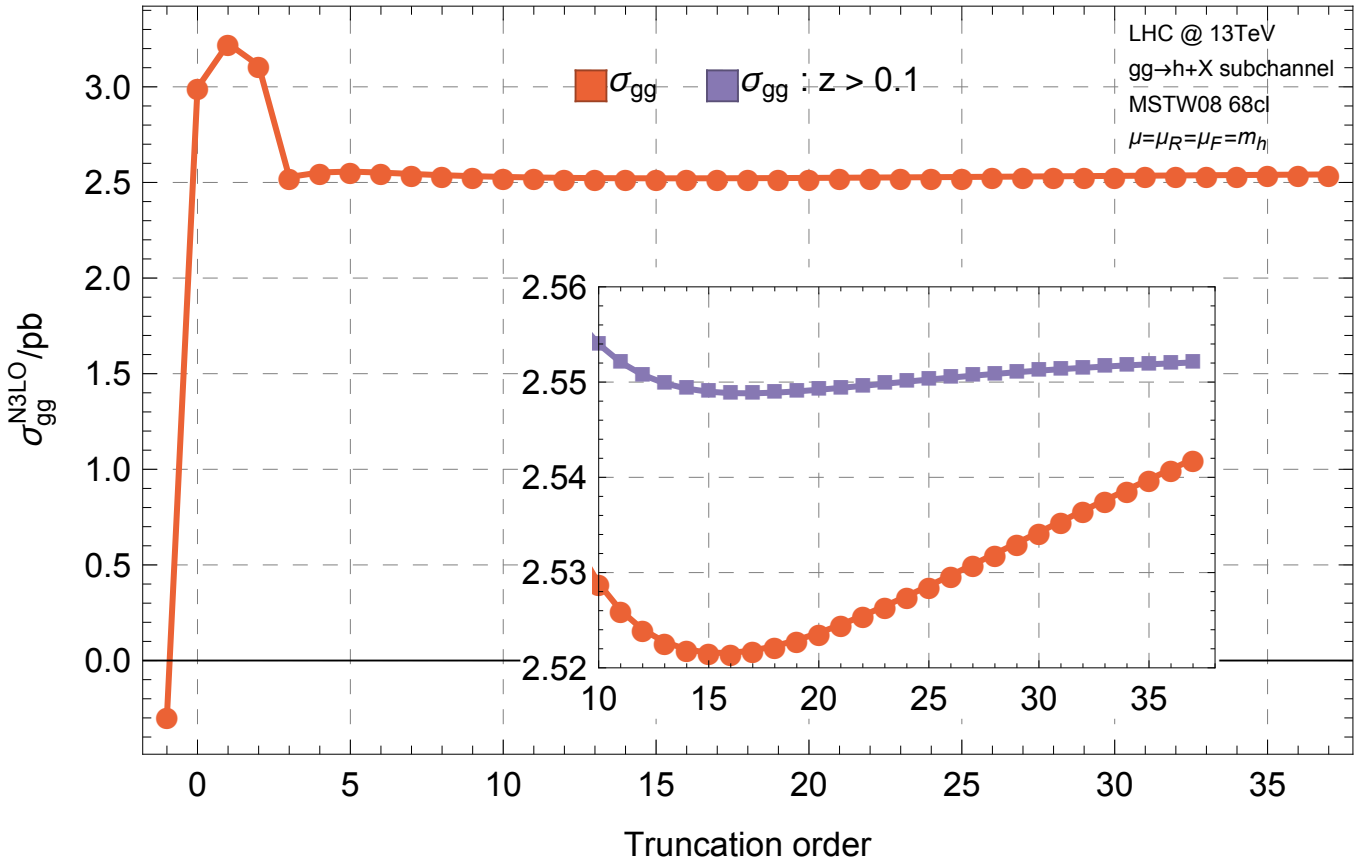
$$\bar{z} = 1 - z \quad \Rightarrow \quad \hat{\sigma}(\bar{z}) = \sigma^{SV} + \sigma^{(0)} + \bar{z}\sigma^{(1)}$$



$$z = \frac{m_H^2}{\hat{s}} \sim 1$$

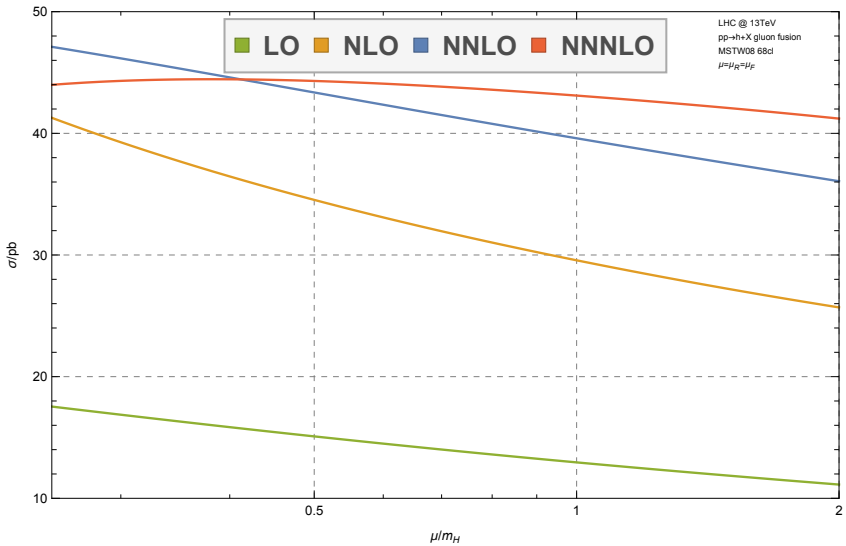
From Talk by B. Mistlberger (U. Zurich). [Anastasiou et al, 1503.06056]

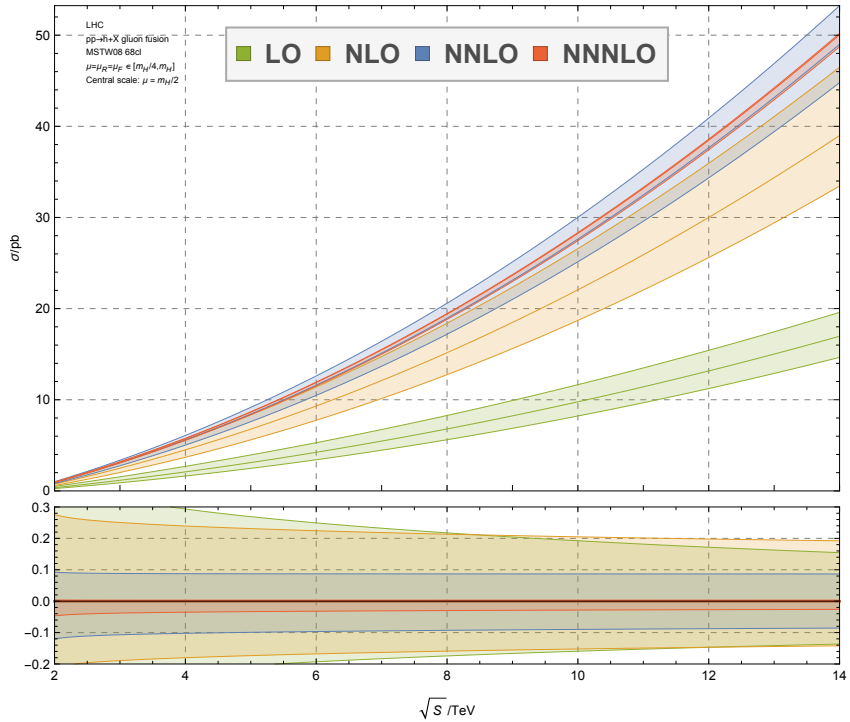
Inclusive Higgs production at N3LO



- 37 terms in the expansion.
- Analogous procedure at NNLO shows that the result is trustable.

Inclusive Higgs production at N3LO



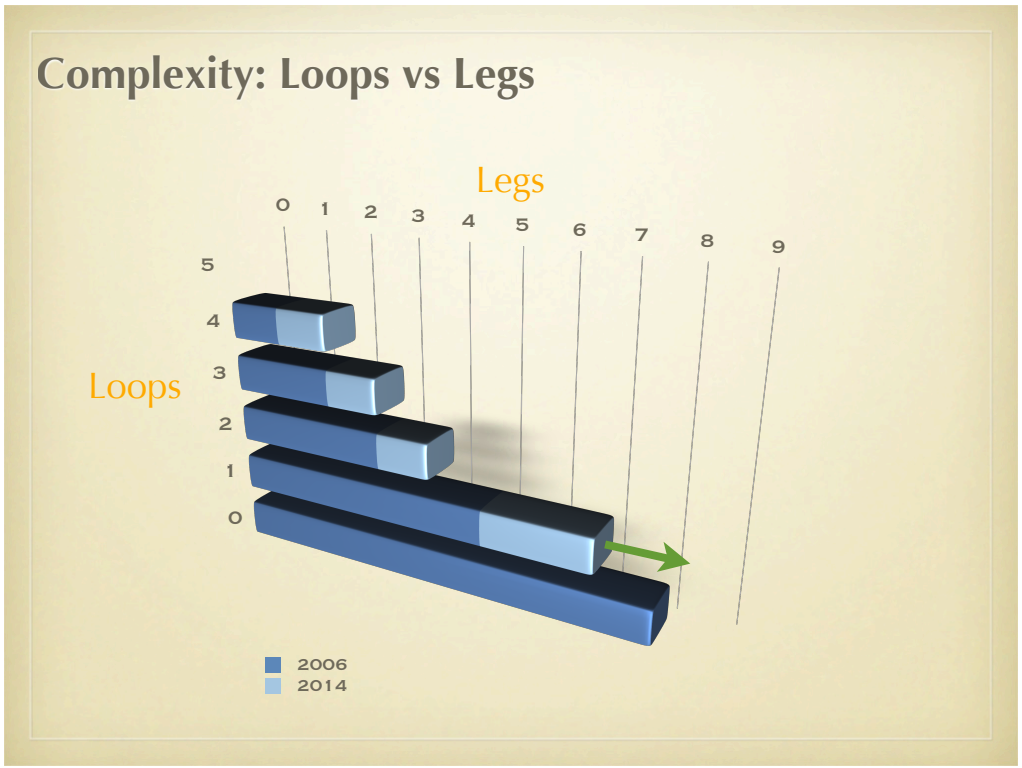


- 2% correction at $m_H/2$ with a 2% scale variation.
- Other uncertainties now become important: PDFs, EW corrections, validity of the HQEFT etc.

QCD session

Calculation of multiloop QCD amplitudes

- Goal: identify a unique mathematical framework for any multi-loop amplitude.
- Unitarity based methods successful at loop. Ongoing development to go beyond.

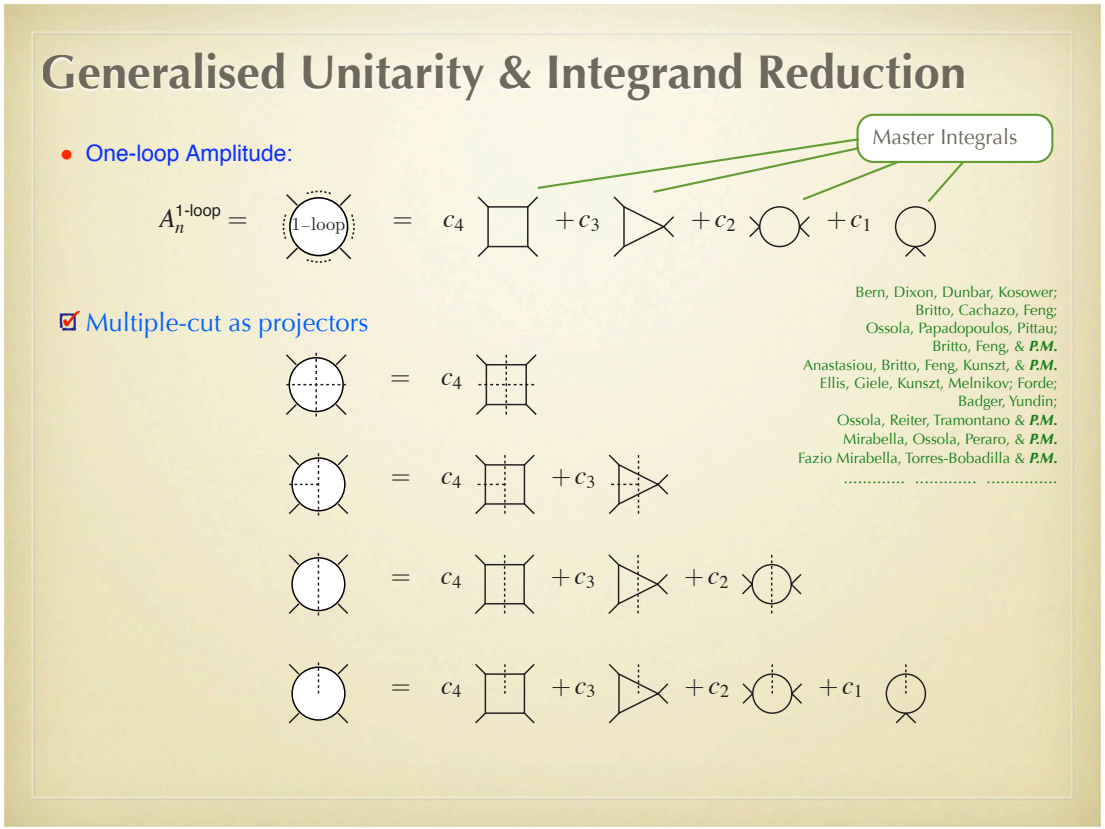


Talk by P. Mastrolia (U. Padova, MPI Munich)

Calculation of multiloop QCD amplitudes

Properties of the S-matrix

1. Analicity – Scattering amplitudes are determined by their poles and branch-cuts.
2. Unitarity – The residues at poles and branch points are products of simpler amplitudes with lower number of particles and/or less loops.



pp --> Hjjj with GoSam

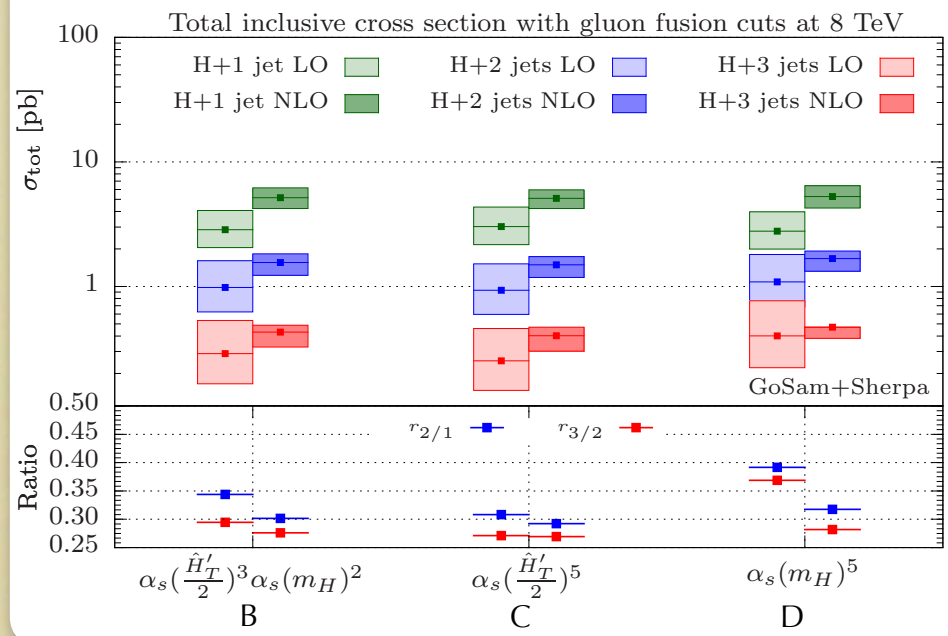
- **Hjj with GoSam + Sherpa (Amegic)** vanDeurzen Greiner Luisoni Mirabella Ossola Peraro vonSodenFraunhofen Tramontano & **P.M.**
- **Hjjj with GoSam + Sherpa + MadGraph4** Cullen VanDeurzen Greiner Luisoni Mirabella Ossola Peraro Tramontano & **P.M.**
- **Hjjj (virtual) with GoSam2.0:** improved reduction **(Ninja)** vanDeurzen Luisoni Mirabella Ossola Peraro & **P.M.**

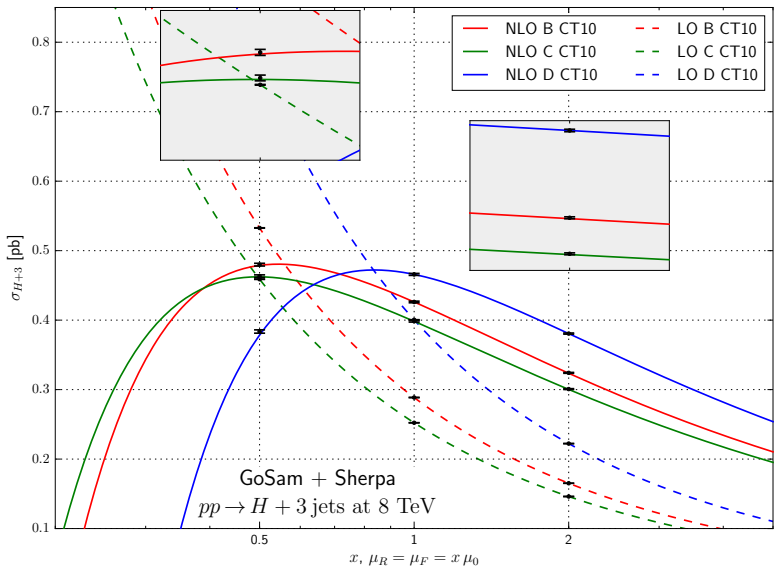
Hj, Hjj, Hjjj with GoSam2.0 + Sherpa (Comix): *a new analysis*

Greiner Hoecke Luisoni Schoenherr Winter Yundin (*to appear*)

- Cuts: 8 TeV, anti-kt $R = 0.4$ jets with $p_T > 30$ GeV, $|\eta| < 4.4$
- PDF: CT10nlo for LO, CT10nlo for NLO

$$\hat{H}_T = \sqrt{m_H^2 + p_{T,H}^2} + \sum_i^{partons} p_{T,i}$$

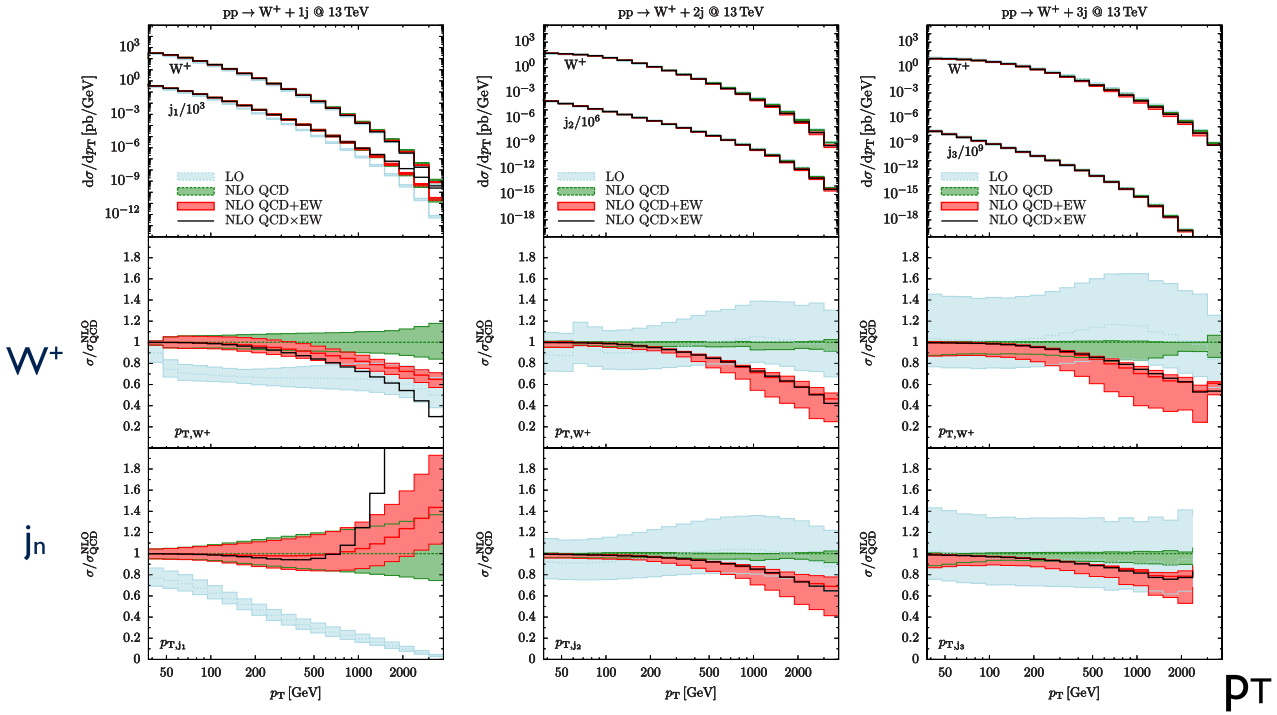




Automatic computation of QCD and EW corrections

- Automatic computation of QCD & EW corrections to (onshell) W+1,2,3 jet (`OPENLOOPS+MUNICH+SHERPA`).
- At high p_T, of $\mathcal{O}(1)$ TeV, EW corrections are important and must be included.

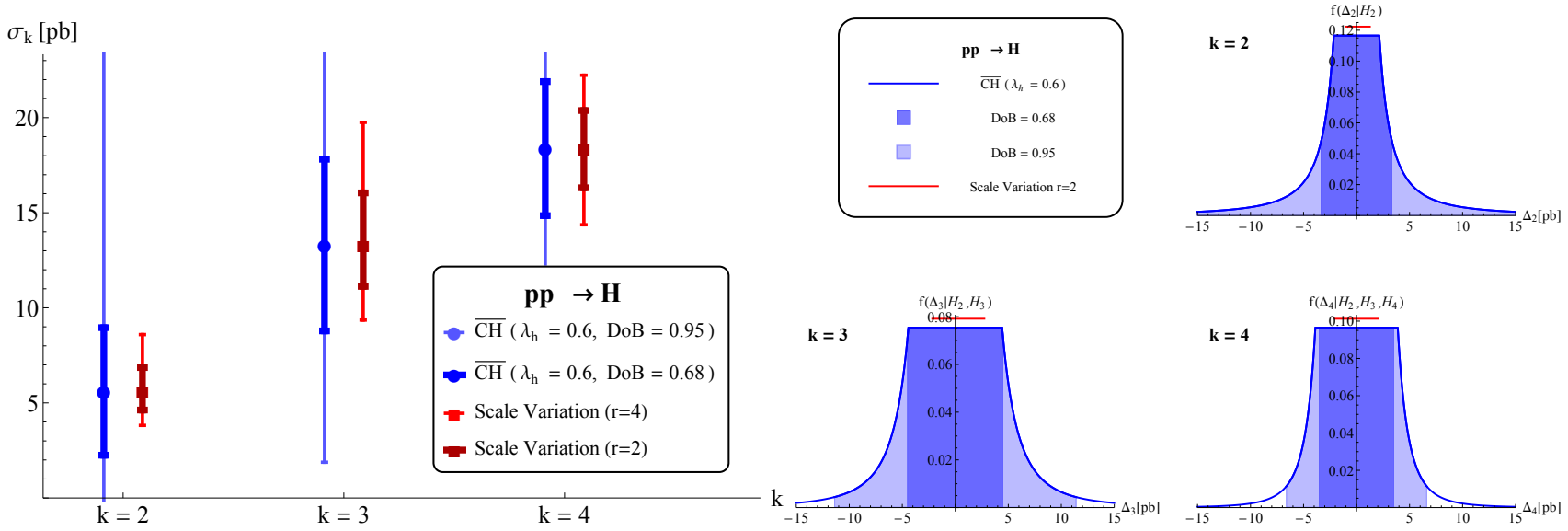
W⁺ + 1,2,3 jets: large EW corrections



Talk by J. Lindert (U. Zurich)

Bayesian estimate of theoretical uncertainties

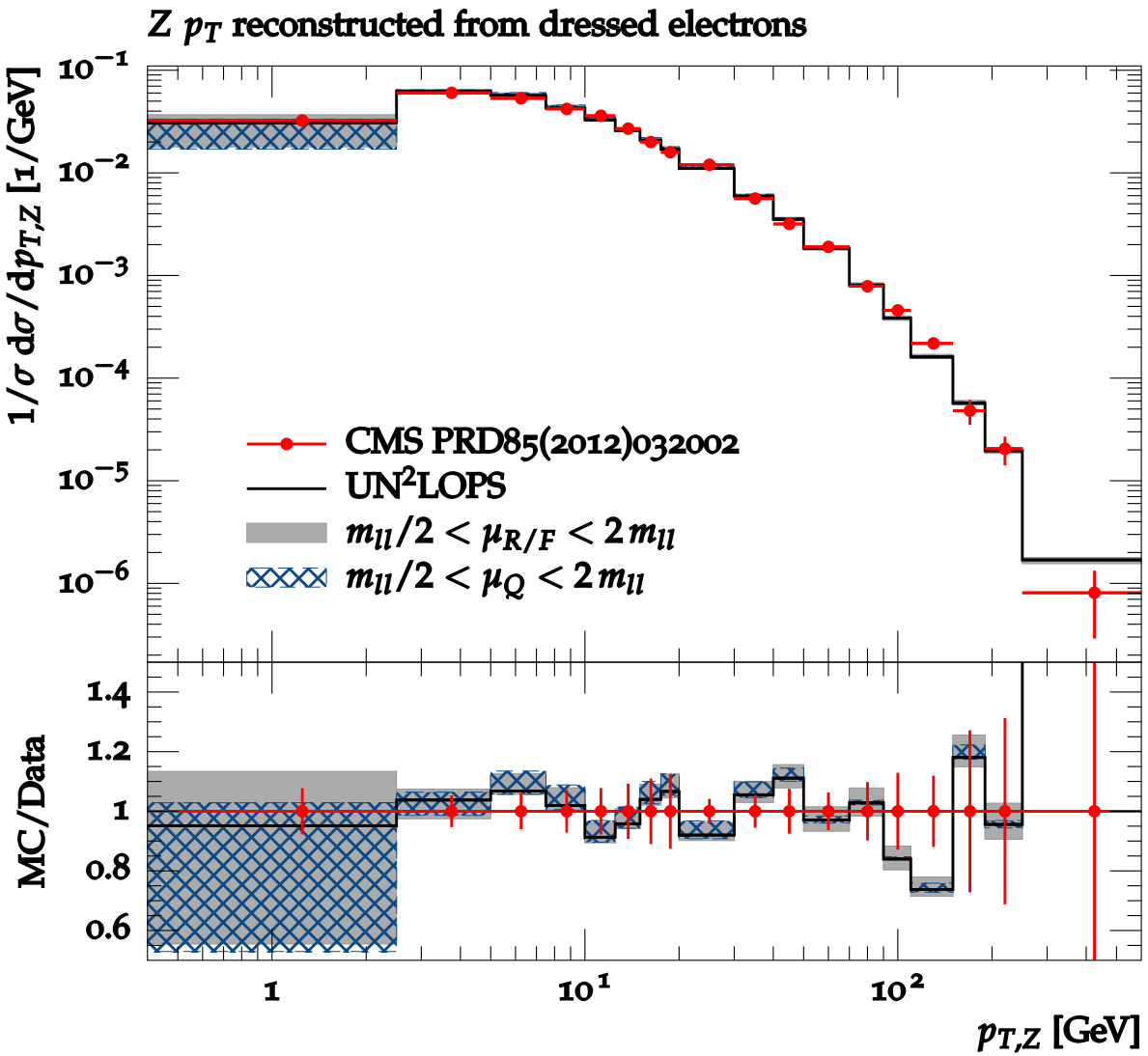
- Different approach to the estimation of theoretical uncertainties due to missing higher order corrections.
- Based on the Bayesian approach by Cacciari and Houdeau ($\overline{\text{CH}}$)
- Survey of the performances of $\overline{\text{CH}}$ and scale variation.



Talk by E. Bagnaschi (DESY)

Monte Carlo at NNLO

- NNLO+PS in the UNNLOPS approach for Drell-Yan and Higgs production
- Problem: does not shower $\alpha_s^2 \delta(p_T)$ terms.



Talk by S. Prestel (SLAC)

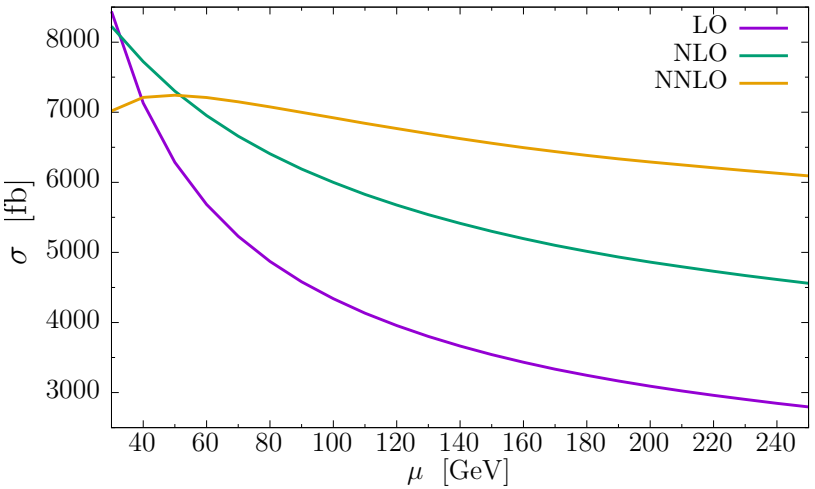
NNLO corrections for LHC processes

- Review of NNLO computations.
- Full H+1 jet cross section at NNLO presented for the first time at Moriond.

H+jet@NNLO: LHC8 results

[Boughezal, FC, Melnikov, Petriello, Schulze, to appear]

HEFT; anti-k_T, R=0.5, $p_{T,CUT}$ = 30 GeV
NNPDF2.3 parton sets, $\mu=m_H$=125 GeV



$$\sigma_{\rm LO} = 3.9^{+1.7}_{-1.1}\ {\rm pb}$$

$$\sigma_{\rm NLO} = 5.6^{+1.3}_{-1.1}\ {\rm pb}$$

$$\sigma_{\rm NNLO} = 6.7^{+0.5}_{-0.6}\ {\rm pb}$$

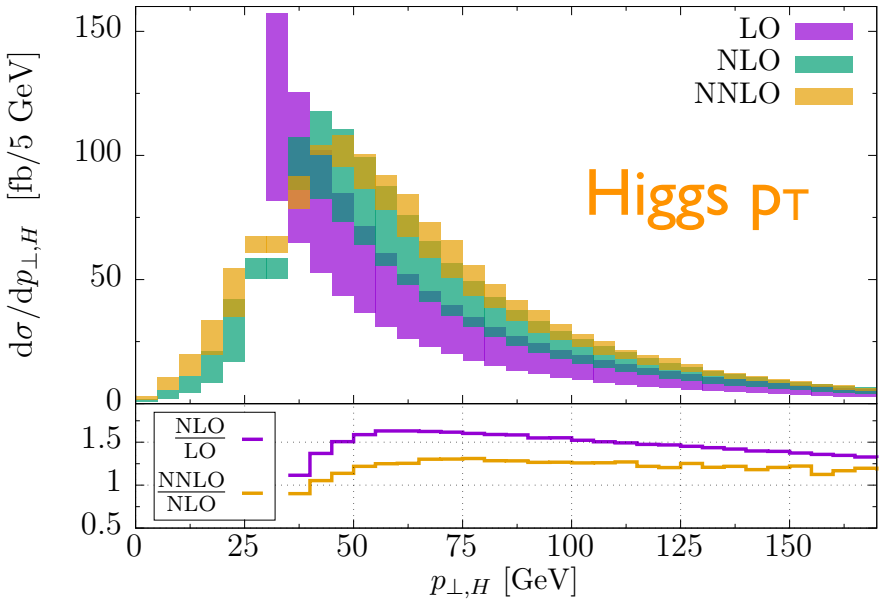
$$K_{\rm NNLO} \sim 20\%$$

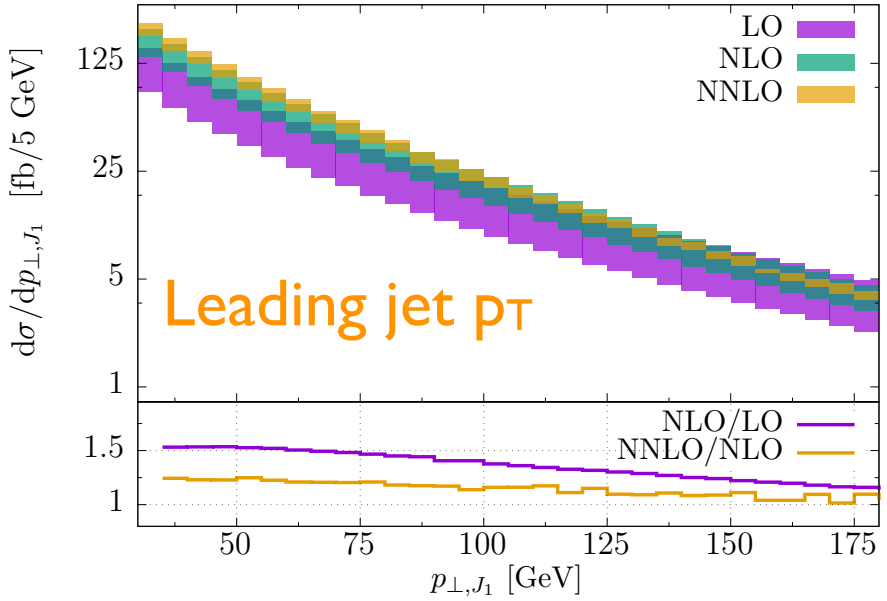
$$\delta_{\rm PDF} \sim 5\%$$

Talk by F. Caola (CERN)

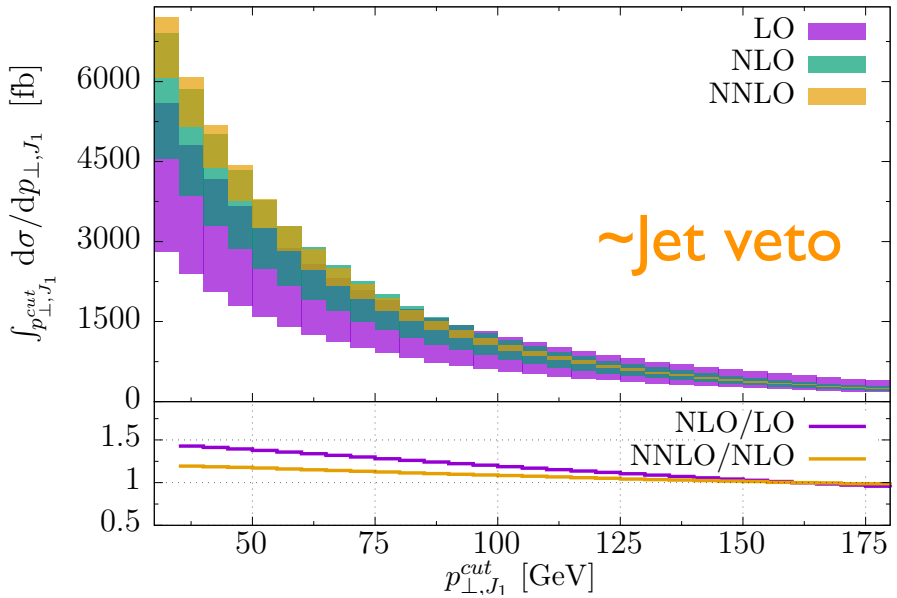
Sizable corrections, significantly improved scale uncertainty

H+jet@NNLO: LHC8 results





- Differential distributions under control
- Non trivial K-factor shape
- Corrections larger at low pT
- At high pT, K->1



Other talks from the QCD session

- Small-radius jets to all orders [F. Dreyer (LPTHE)].
- Multiple gluon exchange webs [M. Harley (Durham)].
- Forward dijets production and effective TMD factorization [S. Sapeta (CERN)].
- Quantization of the QCD string with a helical structure [S. Todorova-Nova (Prague)].
- From OPE to Chiral perturbation theory through Regge trajectories: Vector and axial correlators [G. D'Ambrosio].
- Colour connection and doubly heavy hadron production in e+e– [S. Li (Shandong)].
- Multiparticle Dynamics and Pion Production in a Flux Tube [A. Koshelkin (Moscow)].
- Discretization effects in Nc=2 QCD and Random Matrix Theory [S. Zafeiropoulos (Frankfurt)].

Top session

Forward-backward asymmetry puzzle from Tevatron

- Recently theory prediction upgraded to full NNLO corrections (though with stable tops).
- Two possible expansions:

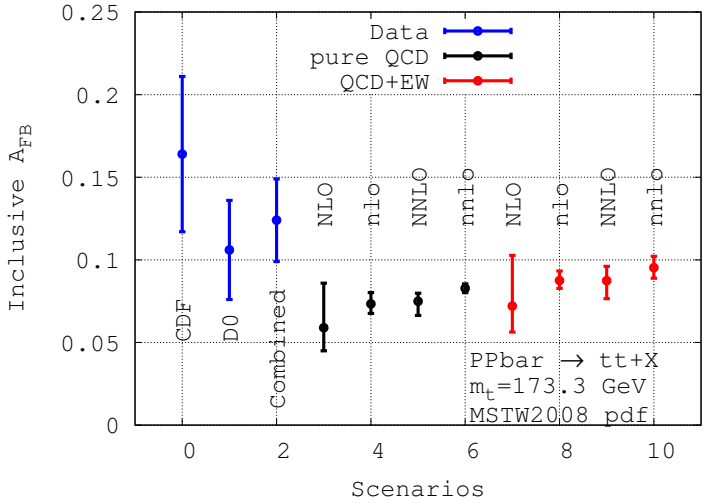
$$A_{\mathrm{FB}} = \frac{N_{EW} + \alpha_S^3 N_3 + \alpha_S^4 N_4 + \mathcal{O}(\alpha_s^5)}{\alpha_S^2 D_2 + \alpha_S^3 D_3 + \alpha_s^4 D_4 + \mathcal{O}(\alpha_S^5)} =$$

$$= \alpha_s \frac{N_3}{D_2} + \frac{N_{\mathrm{EW}}}{\alpha_S^2 D_2} + \alpha_S^2 \left(\frac{N_4}{D_2} - \frac{N_3 D_3}{D_2^2} \right) - \frac{N_{\mathrm{EW}} D_3}{\alpha_S D_2^2} + \mathcal{O}(\alpha_S^3)$$

Talk by M. Czakon (Aachen)

Results for inclusive AFB

- *NLO*, *NNLO* :
  exact numerator and denominator
- *nlo*, *nnlo* : expanded in powers of a_S



✓ We find large QCD corrections:
NNLO ~ 27% of NLO (recall EW is 25% of LO).

➔ This was not expected, given soft-gluon resummation suggests negligible correction.

✓ Adding all corrections A_{FB} ~ 10%.

- ✓ Agrees with D0 and CDF/D0 naive combination
- ✓ Less than 1.5σ below CDF

✓ We consider this as *agreement* between SM and experiment.

✓ We observe good perturbative convergence (based on errors from scale variation)

✓ Expanded results (both *nlo* and *nnlo*) seem to have accidentally small scale variation

Rapidity dependence of AFB

Errors due to scale variation only
- Pdf error small
- MC error negligible

- Perfect agreement with D0
- No agreement for A_{FB} with CDF
- But differential x-section reasonably close to CDF …

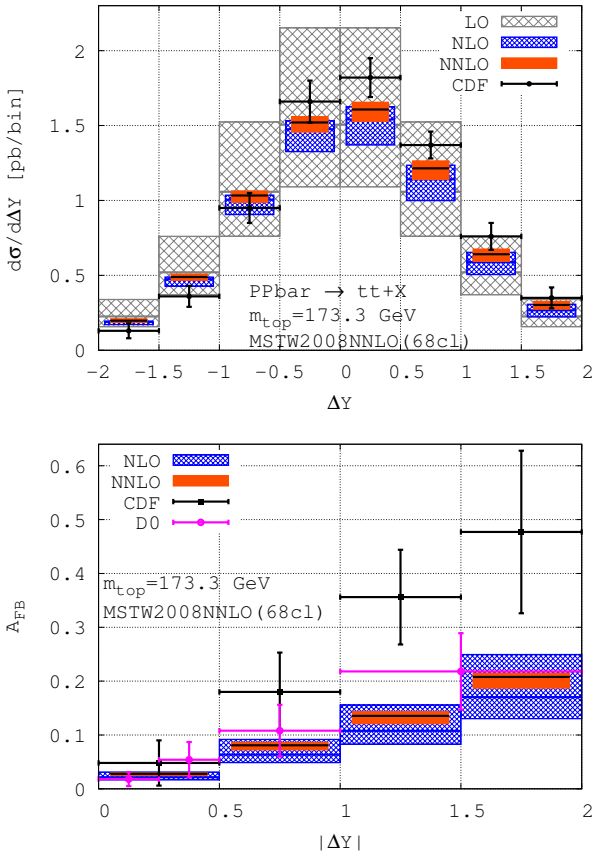


FIG. 2: The $|\Delta y|$ differential distribution (top) and asymmetry (bottom) in pure QCD at LO (grey), NLO (blue) and NNLO (orange) versus CDF [2] and D0 [1] data. Error bands are from scale variation only. For improved readability some bins are plotted slightly narrower. The highest bins contain overflow events.

New phenomena session

Collider Searches for Dark Matter: Moving Beyond the EFT

- Complementarity between DM searches to cover the parameter/model space.
- EFT approach limited by the scale at which the new dynamics appear.
- Use instead simplified models for DM searches.
- However information from simplified models should **not** be used to exclude more detailed models (i.e. SUSY).
- Example, Minimal Simplified Dark Matter (MDSM) [Buchmueller et al, 1407.8257]:

$$\mathscr{L}_{\text{vector}} \supset \frac{1}{2} M_{\text{med}}^2 Z'_\mu Z'^\mu - g_{\text{DM}} Z'_\mu \bar{\chi} \gamma^\mu \chi - \sum_q g_q Z'_\mu \bar{q} \gamma^\mu q$$

$$\mathscr{L}_{\text{axial}} \supset \frac{1}{2} M_{\text{med}}^2 Z''_\mu Z''^\mu - g_{\text{DM}} Z''_\mu \bar{\chi} \gamma^\mu \gamma^5 \chi - \sum_q g_q Z''_\mu \bar{q} \gamma^\mu q$$

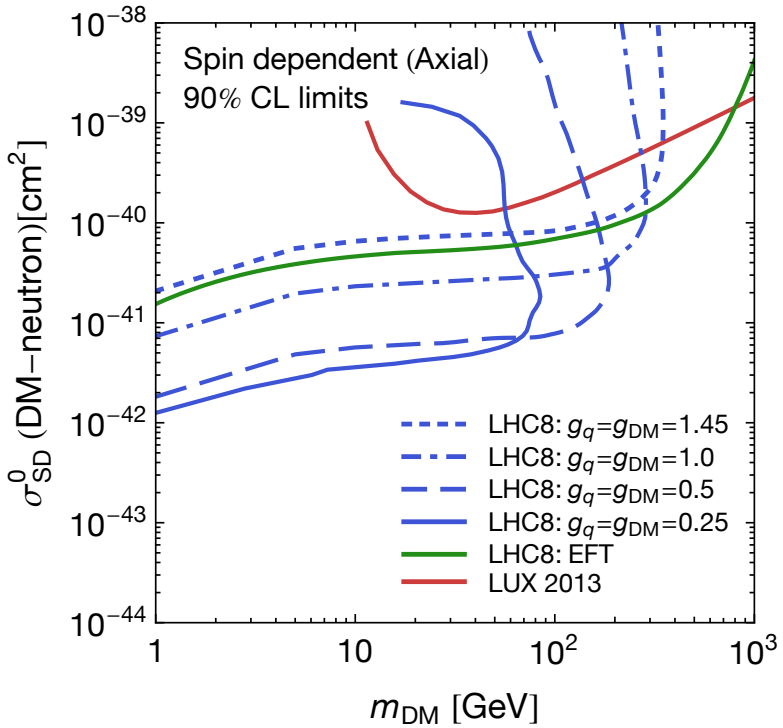
Talk by G. Landsberg (Brown University)

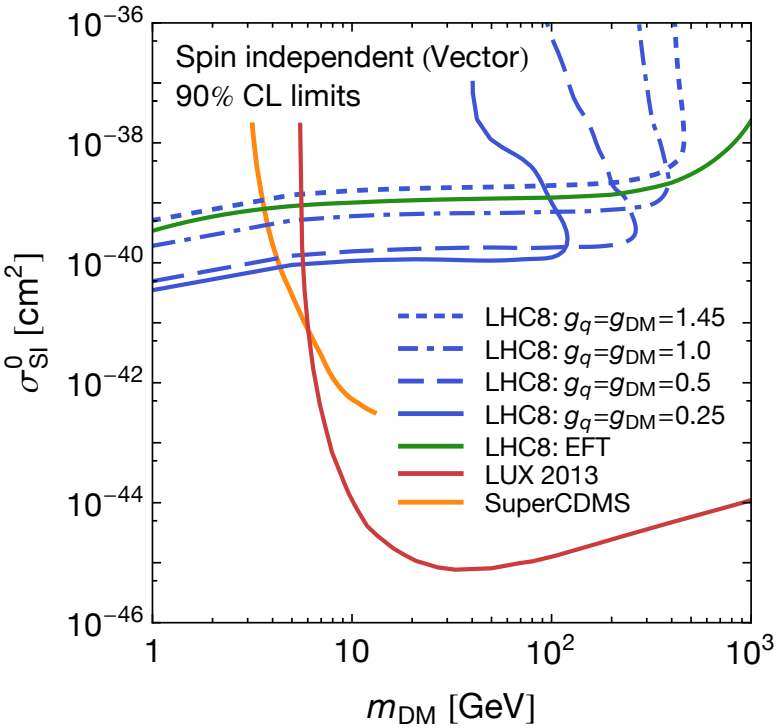
BROWN

MSDM vs. EFT

S. Malik et al., arXiv:1409.4075

- Comparison of the limits derived from the CMS monojet search between the EFT and full calculation
  - Note that the case of low coupling where EFT breaks dramatically (this is the case when one can't exclude M = 0, resulting in finite cross section range)





Other talks from the new phenomena session

- Looking for supersymmetry: the power of complementarity in LHC and dark matter searches [Leszek Roszkowski (Warsaw)].
- Electroweak baryogenesis [Eibun Senaha (Nagoya)].
- Quest for new physics driven by experiment and simplicity [Oleg Ruchayskiy (EPFL Lausanne)].

Electroweak, structure functions, light quark session

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- On the pomeron in AdS/QCD [M. Costa (Porto)].

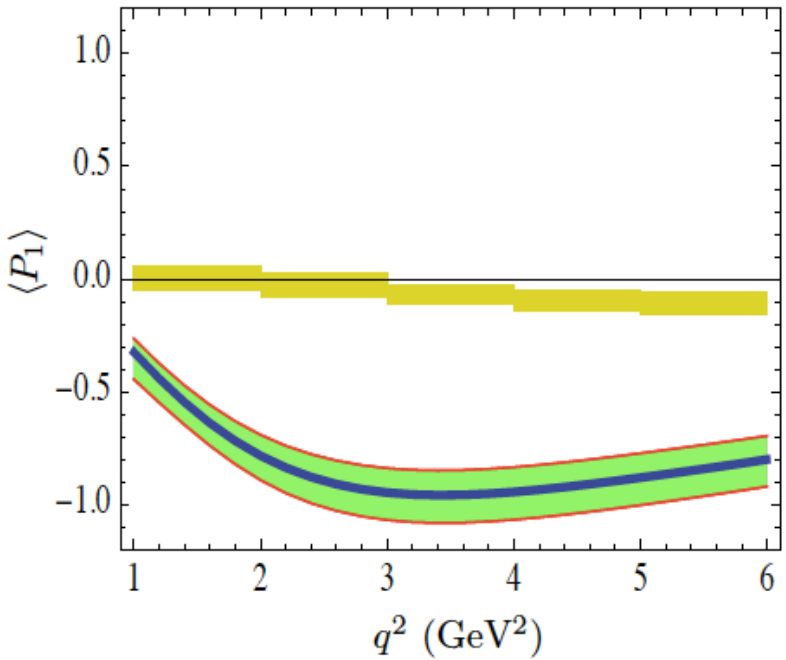
Heavy flavor session

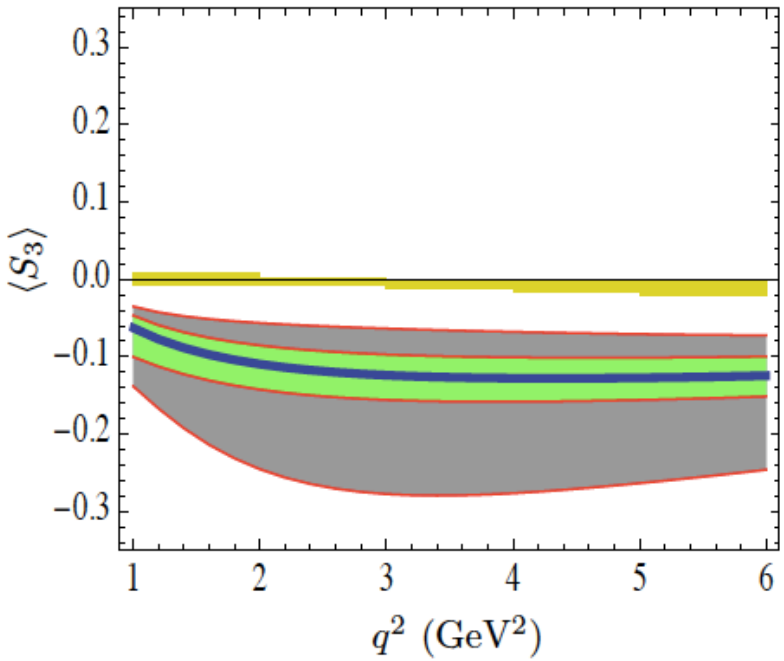
Flavor anomalies at the LHC

- Flavor physics can probe scales much higher than collider direct searches.
- Various tensions appearing in the LHC data:
  1. $h \to \mu\tau$ – Obs: $0.84 \pm 0.40\%$, Exp: 0.
  2. $B \to K^* \mu^+ \mu^-$ – From P_5'
  3. $R(K) = (B \to K\mu^+\mu^)/(B \to Ke^+e^-)$ – Obs: 0.75 ± 0.10, Exp: 1.
  4. $B_s \to \phi\mu^+\mu^-$ – Branching ratios at high q^2 larger than expected.

$B^0 \to K^* \mu\mu$: theory interpretation

- Large uncertainties from QCD predictions.
- NLO QCD factorization / OPE+HQET
- Power corrections.

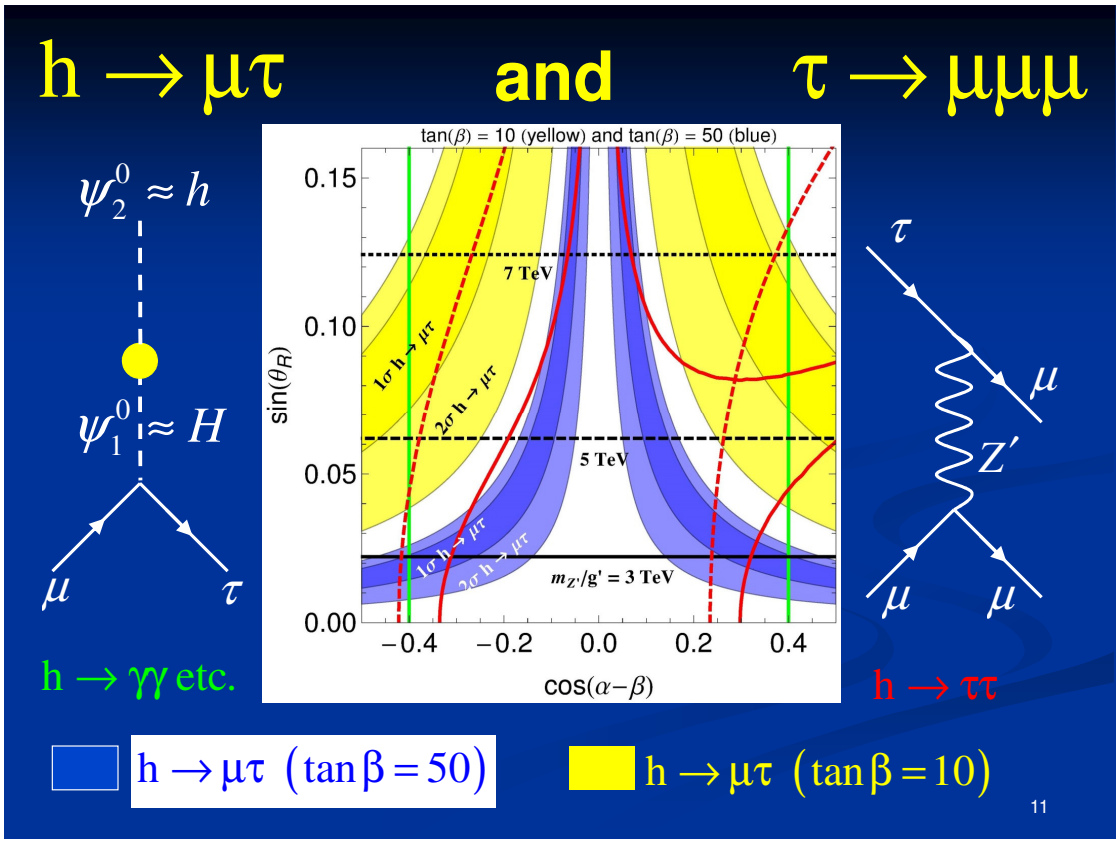


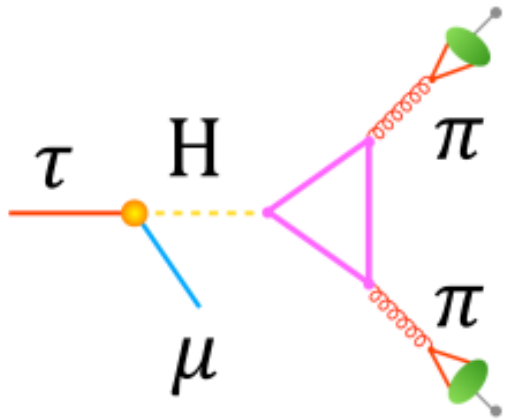


Talk by S. Descotes-Genon (Orsay)

Lepton flavour universality violation in B decays: implications for new physics

- 2HDM with vector-like quarks.
- 3HDM with gauged flavor dependent B-L charges.
- The model predicts $\tau \to 3\mu$.





Talk by A. Crivellin (CERN)

Flavour violation in a class of Two Higgs Doublet Model

- 2HDM as a framework to study new physics in the scalar sector.
- Tree level FCNC should be suppressed to pass experimental measurements.
- BGL models with naturally suppressed FCNC (Lagrangian symmetries impose CKM structure to flavor violation).
- Introduce symmetry in the Lagrangian under the following transformations:

$$Q^0_{Lj} \to e^{i\tau} Q^0_{Lj} \quad , \quad u^0_{Rj} \to e^{2i\tau} u^0_{Rj} \quad , \quad \phi_2 \to e^{i\tau} \phi_2 \quad \text{with} \quad \tau \neq 0, \pi$$

Talk by G. Castelo-Branco (Lisbon)

Other talks from the heavy flavor session

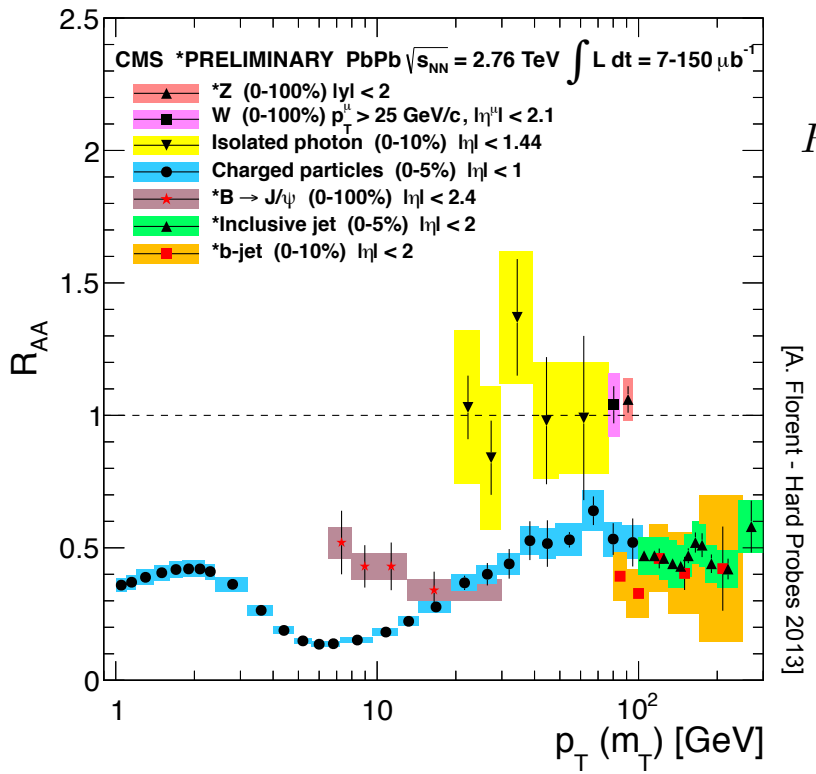
- Polarization study in the B_s meson decays to two vector meson final states [C. Lu (Beijing)].
- Lepton nonuniversality? [B. Grinstein (San Diego)].
- A long-distance contribution to the R_k anomaly [A. Guevara (Mexico)].

Heavy ion session

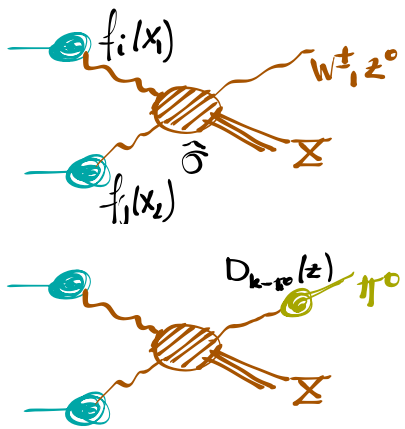
Heavy ions collisions and jet quenching

- Unexpected role of proton-nucleon collision.
- Hydrodynamic system (Eliptic flow).
- Jet quenching probe the medium.

Suppression in one plot



$$R_{AA} = \frac{dN^{AA}/dp_t}{\langle N_{coll}\rangle dN^{pp}/dp_t}$$



Talk by C. Salgado (U. Santiago de Compostela)

Other talks from the heavy ion session

- Flow in heavy ion collisions [M. Luzum (Santiago de Compostela)].
- Chiral magnetic moment [A. Boyarsky (Leiden)].
- The origin of thermal component in the transverse momentum spectra in high energy hadronic processes [A. Bylinkin (Moscow IPT)].
- Magnetic Wilson loop in the classical field of high-energy heavy-ion collisions [E. Petreska (Palaiseau)].

Conclusions

- Broad range of topics discussed all across the various sessions.
- New predictions/techniques are being developed to improve our predictions at the LHC.
- Precise predictions are necessary to distinguish between background and (possible) new physics signals.

Thanks to G. Zanderighi (Oxord/CERN) for her theory summary talk.

Backup slides