Rencontres de Moriond: QCD and high energy interactions Summary.

LHC physics discussions

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Deutsches Elektronen-Synchrotron (DESY)

April 10th, 2017

HELMHOLTZ GEMEINSCHAFT

DESY

Disclaimer

- $\sim$ 90 talks of 15' each over 7 days (total 22.5 hrs).
- Summary in 20' (factor 60 reduction). Not all topics treated.
- I am not an expert in most of the topics mentioned in the talk.
- I tried to be as complementary as possible with the previous talk.
- All the Moriond QCD talks are available online if you are interested: the link
  (especially the experimental and theoretical summary talks)

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- **Ready?**

Outline

- Light hadrons
- Heavy flavour anomalies
- Exotic states at LHCb
- QCD at high energy with jets, photons and multibosons
- Heavy ions (if time (if time))

Light hadrons at BESIII and NA48

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- **BESIII (China):** e^+e^- collisions from 1 to 2.3 GeV since 2009.
  - Hadron spectroscopy. Large sample at J/ψ, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, ...
  - Light unflavored scalar f_0 states $\rightarrow$ question of glueball content, more data needed.
  - pseudoscalar η and X states $\rightarrow$ how many separate state around $X(18xx)$?

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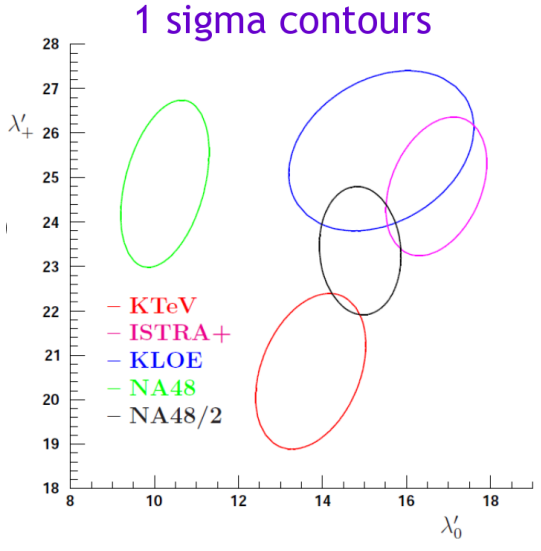
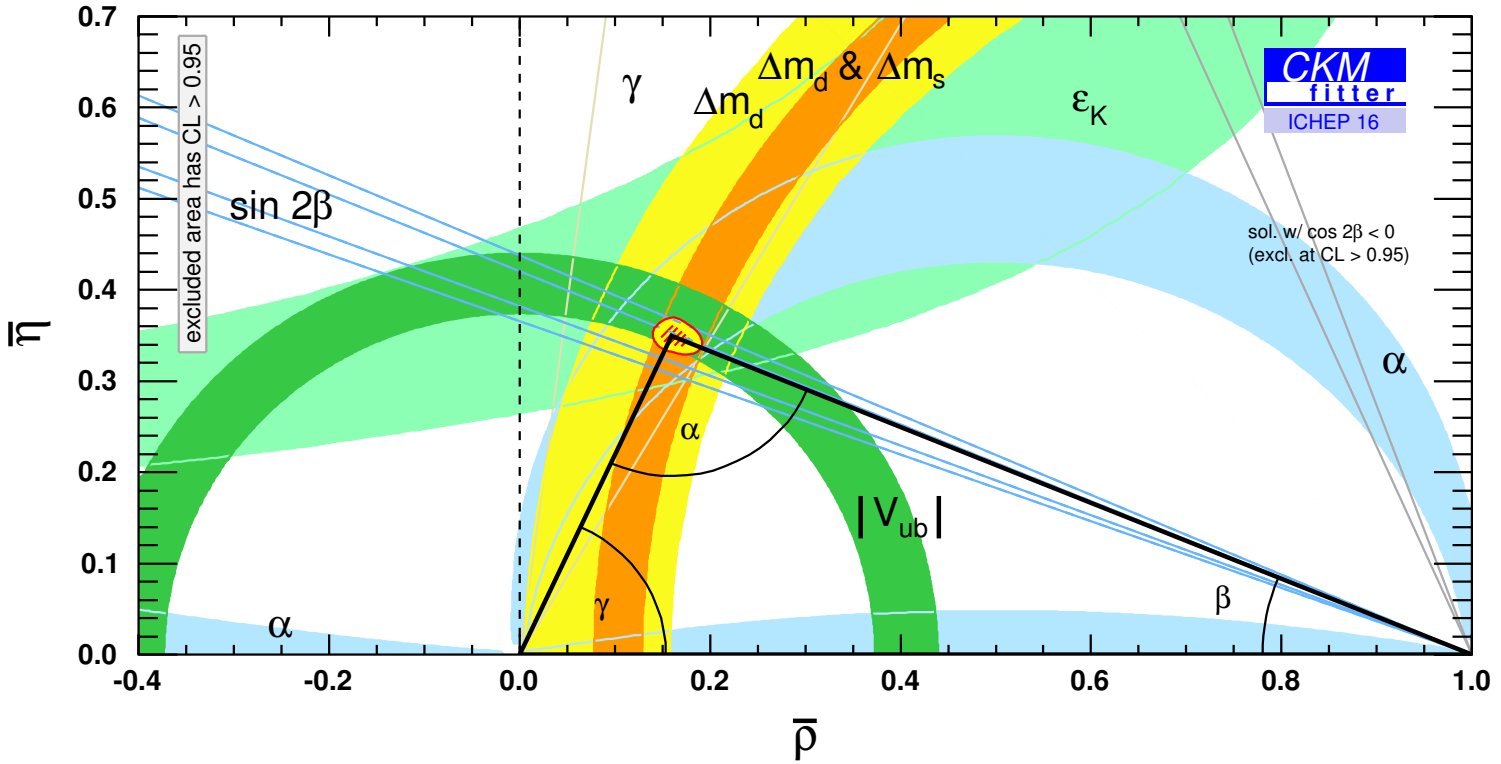
- **NA48 (CERN):** K^+ and K^- beams. $\sim 2 \cdot 10^{11}$ decays collected.

- New measurement of $K^+ \rightarrow \pi^0 l^+ \nu$ form factors.
- input for V_{us} extraction.
- More precise and displaced w.r.t. previous NA48 measurement.
  (improved knowledge of the beam shape)

$\rightarrow$ Now in good agreement with the other experiments.



Heavy flavour: overview



- Study of the decays of HF mesons to test the CKM model.
  $\rightarrow$ Overall the CKM picture is in excellent agreement with data.
- General precision test of SM and study of rare decays to get hints on New Physics.
- Find new exotic states predicted (or not) by (non-perturbative) QCD.

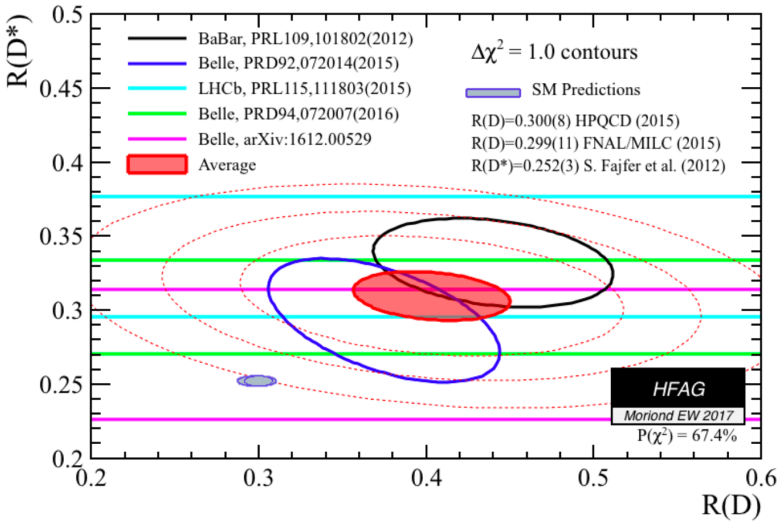
Heavy flavour: list of 2-3σ anomalies

$\sim 3.5\sigma$	$(g-2)_\mu$ anomaly	
$\sim 3.5\sigma$	non-standard like-sign dimuon charge asymmetry	
$\sim 3.5\sigma$	enhanced $B \to D^{(*)}\tau\nu$ rates	$R_{D^{(*)}}$
$\sim 3.5\sigma$	suppressed branching ratio of $B_s \to \phi\mu^+\mu^-$	
$\sim 3\sigma$	tension between inclusive and exclusive determination of $\lvert V_{ub}\rvert$	
$\sim 3\sigma$	tension between inclusive and exclusive determination of $\lvert V_{cb}\rvert$	
$2-3\sigma$	anomaly in $B \to K^*\mu^+\mu^-$ angular distributions	P_5'
$2-3\sigma$	SM prediction for ϵ'/ϵ below experimental result	
$\sim 2.5\sigma$	lepton flavor non-universality in $B \to K\mu^+\mu^-$ vs. $B \to Ke^+e^-$	R_K
$\sim 2.5\sigma$	non-zero $h \to \tau\mu$	

(Wolfgang Altmannshofer, Aspen Winter Conference on Particle Physics 2016)

Heavy flavour: lepton universality

– Observation of enhanced semileptonic decay rates for 3rd generation leptons.



$$R_{D^{(*)}} = \frac{\Gamma(\bar{B} \to D^{(*)}\tau\bar{\nu})}{\Gamma(\bar{B} \to D^{(*)}\ell\bar{\nu})}; \quad \ell = e, \mu$$

- CKM-favoured decay modes occuring at tree level.
- **Measurement $\sim 3.9\sigma$ from SM.**
- Form factor contributions suppressed by $(m_\tau/m_B)^2$
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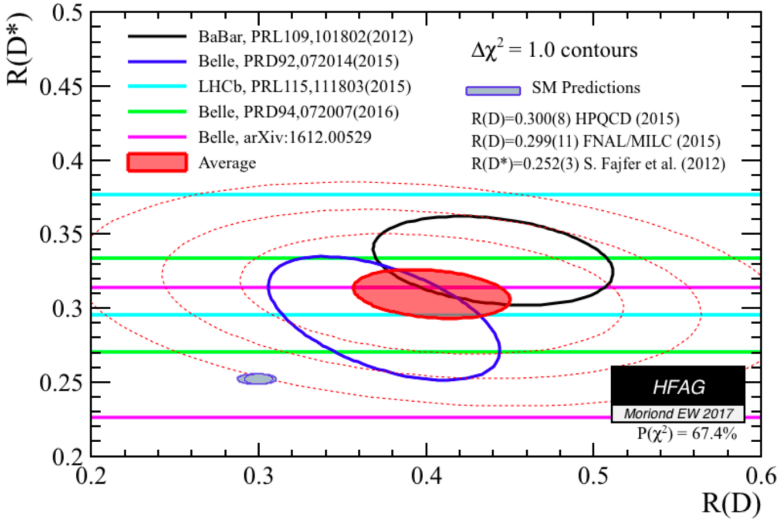

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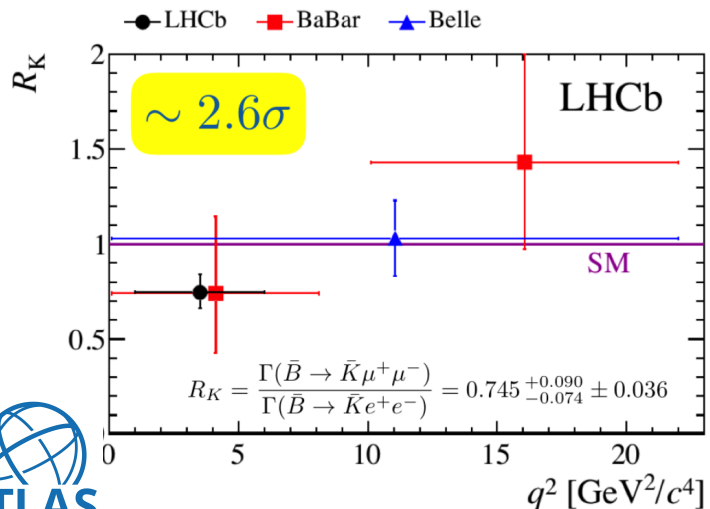
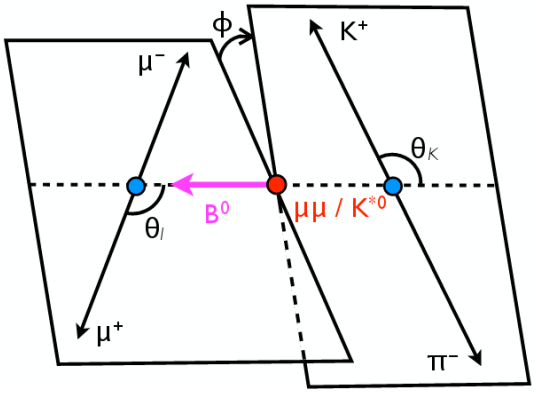
– Observation of enhanced muons vs electrons in the rare $B \to K\, l^+l^-$ decays.



- Form factors cancel out in the ratio
- several triggers used for electrons, different efficiency μ/e
- LHCb: 1200 $K\mu\mu$ reco. events, 250 Kee reco. events.
- use of double ratios from $J/\psi \to l^+l^-$
- coming soon: $R(K^*)$, $R(\phi)$.

Heavy flavour: P_5' in rare $B \to K^* \mu\mu$



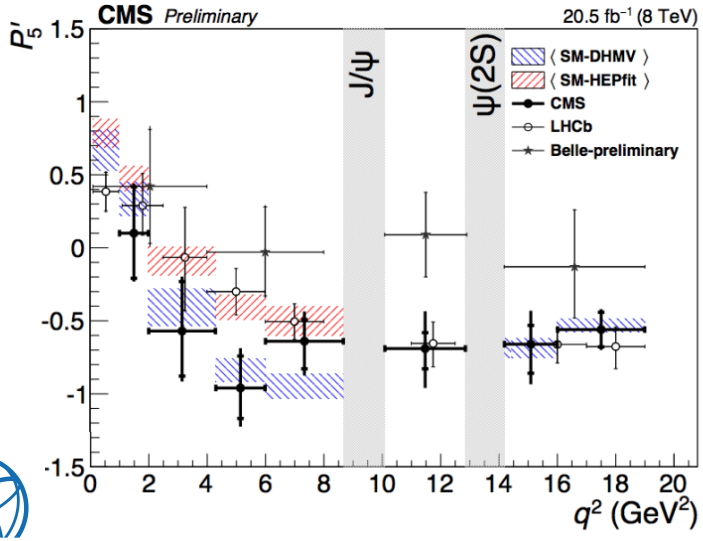
$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{dq^2 d\cos\theta_l d\cos\theta_K d\phi}$$

S-wave and S&P-wave interference

$$= \frac{9}{8\pi}\left\{\frac{2}{3}\left[(F_S + A_S\cos\theta_K)(1-\cos^2\theta_l) + A_S^5\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right] + (1-F_S)\left[2F_L\cos^2\theta_K(1-\cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{1}{2}P_1(1-F_L)(1-\cos^2\theta_K)(1-\cos^2\theta_l)\cos 2\phi + 2P_5'\cos\theta_K\sqrt{F_L(1-F_L)}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right]\right\}$$

P-wave

(artwork from talk by Mauro Dinardo @ Moriond-EW)



- P'_5 should be one of the less sensitive to hadronic corrections.
- $\sim 2.5 - 3\sigma$ for $4 < q^2 < 8$ GeV
- No significant deviation from ATLAS / CMS.
- **Warning: uncontrolled off-peak effects of the charmonia.**
- DHMVJC: hadronic from calculations, HEPFit: fitted from LHCb data
- **CMS takes F_L and S-wave from separate analysis.**

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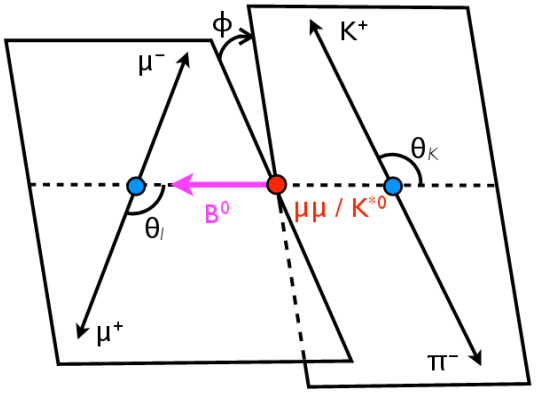

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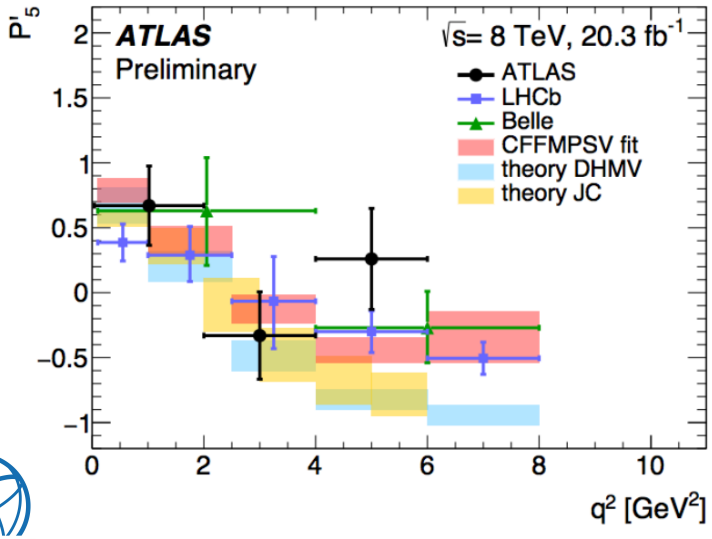

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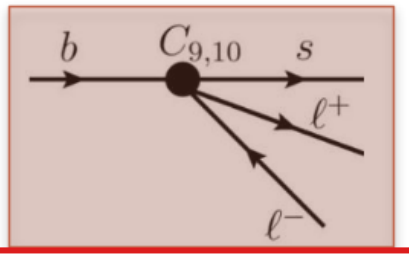
Heavy flavour: Global fit of b $\longrightarrow$ s data with EFT operators

- Global fit of LHCb data using EFT for short-distance effects (Wilson's coefficients)

$$\mathcal{L}_W = \mathcal{L}_{\rm QCD} + \mathcal{L}_{\rm QED} + \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{\star} \sum_i \mathcal{C}_i(\mu)\, \mathcal{O}_i(\mu)$$



$$O_9 = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \ell)$$

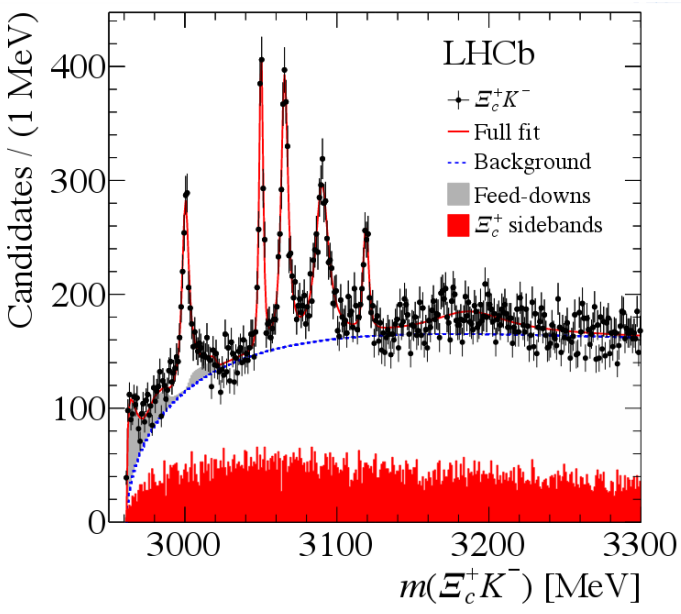
$$O_{10} = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu \gamma_5 \ell)$$

- Many combinations of $b \to s$ data tested as input of the fit.
- Agreement of many studies that $C_{9\mu}^{NP} \sim -1$ improves the fit, whatever the set of measurements used as input.
  - Additional studies show that very large hadronic power corrections would be required to remove the tension ($> 150\%$).
  - Unresolved puzzle for theorists, which are waiting for more experimental inputs.

New exotic states at LHCb

- 5 new Ω_c^0 excited states observed in $\Xi_c^+ K^-$ spectrum (with $\Xi_c^+ \to pK^-\pi^+$)
  - Beautiful result, very narrow peaks - hard to match to predictions

[arXiv:1703.04639]



Also:

- The investigation of pentaquarks keeps going at LHCb, looking for new decay modes of $P_c(4450)$
- Involves preliminary steps, e.g. observation of $\Omega_b^0 \to \chi_{c1(2)} pK^-$, $\Xi_b^- \to J/\psi \Lambda K^-$, presented at Moriond QCD *(discovery in $\Lambda_b^0 \to J/\psi pK^-$).*

$\to$ Next steps: search in $\chi_{c1(2)} p$ and $J/\psi\Lambda$ mass spectra.

Total $b\bar{b}$ and $c\bar{c}$ production at NNLO

- NNLL resummation not yet included $\rightarrow$ total cross sections only.
- Modified Top++ (NNLO) adapted to $b\bar{b}$ and $c\bar{c}$ production in hadron collisions.
  Large K-factors observed: ~ 2 (fixed-target) ~ 1.2 (LHC) / At $\sqrt{s} = 300$ TeV (cosmic rays), $\sigma_{cc} \sim \sigma_{inel}$.

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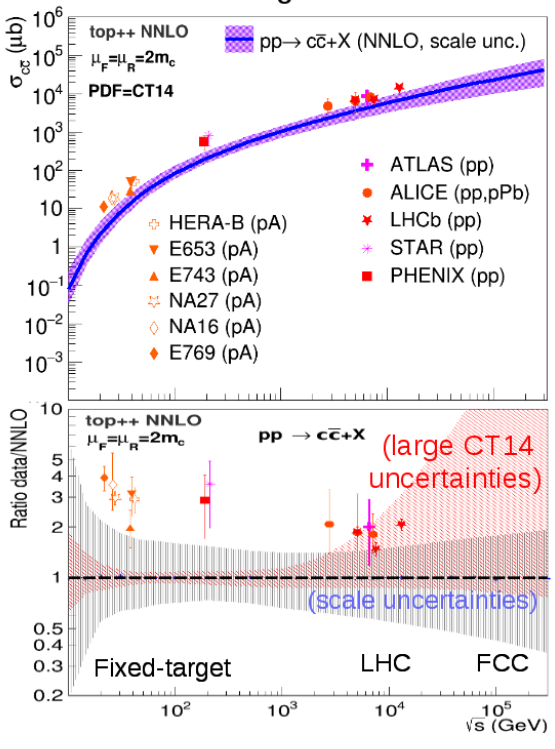
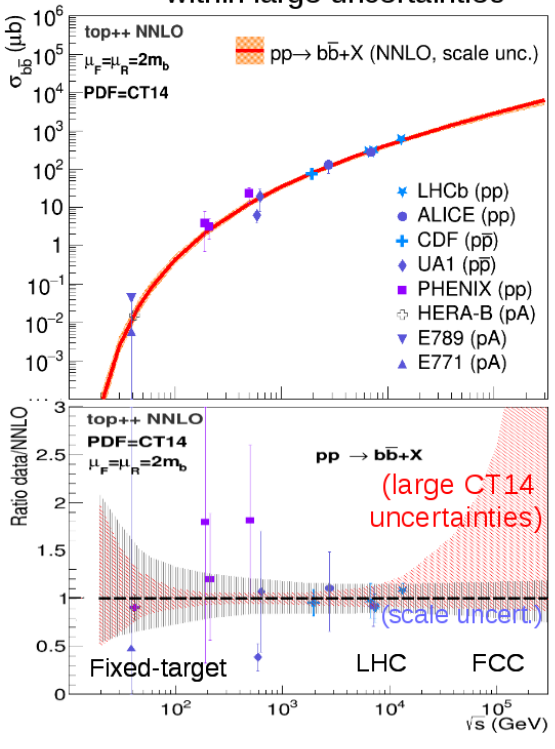
■ Charm: Data ×2 theory, but agreement within large uncertainties



■ Bottom: Very good agreement at all √s within large uncertainties



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Test of QCD at high energy: overview

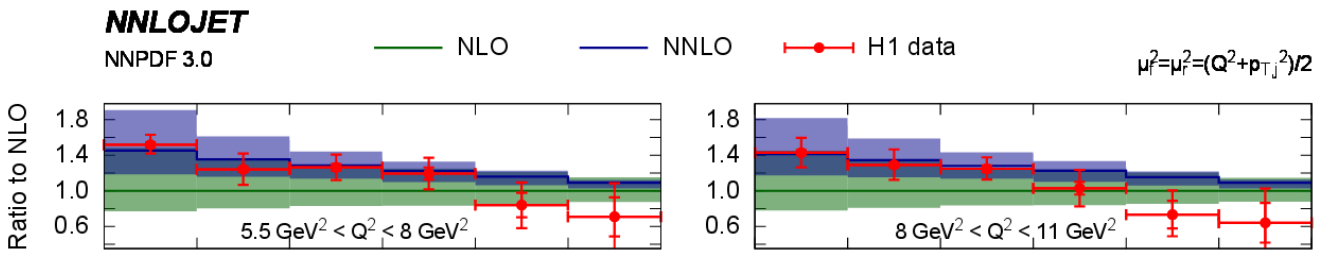
- **Before, QCD used to be studied for its own sake:**
  - Confirm data/theory agreement improvement when adding more α_s corrections
  - Test of the running of α_s predicted by pQCD.
  - Test of the QCD infrared structure: resummation techniques.

- **Now, QCD corrections are more seen as mandatory inputs for accurate background predictions:**
  - Constrain the proton PDFs at high x with inclusive jet (and photons?) data for new physics searches at the energy frontier.
  - Higgs background modeling: SM accurate predictions of ZZ, WW, $\gamma\gamma$, ...
  - Check of soft QCD effects (underlying event, double parton scattering) to make sure it is reasonably well modeled in current MC generators.
    (not reported in this talk)

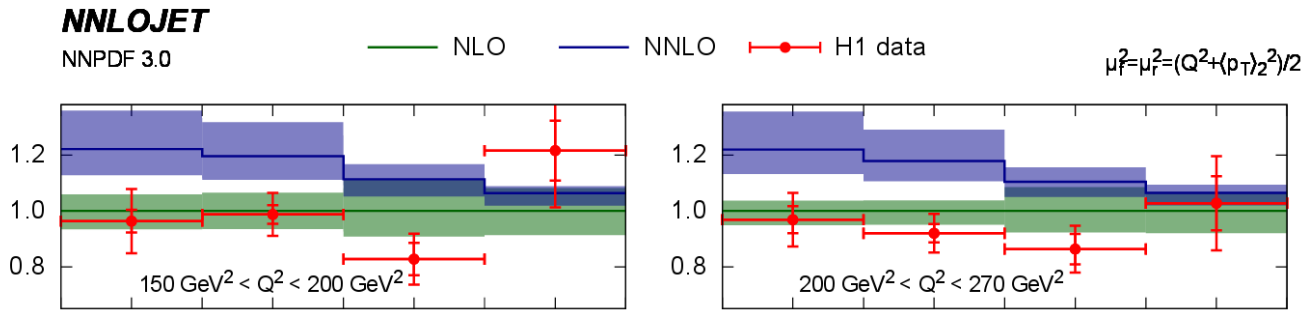
Jet production at NNLO in DIS collisions

- Full NNLO computation for single jet and dijet production in DIS collisions available (NNLOJET).
- Shape in general better described, but data / NNLO normalisation issue $\rightarrow$ refit of the PDF required?

Inclusive 1 jet



Inclusive dijet



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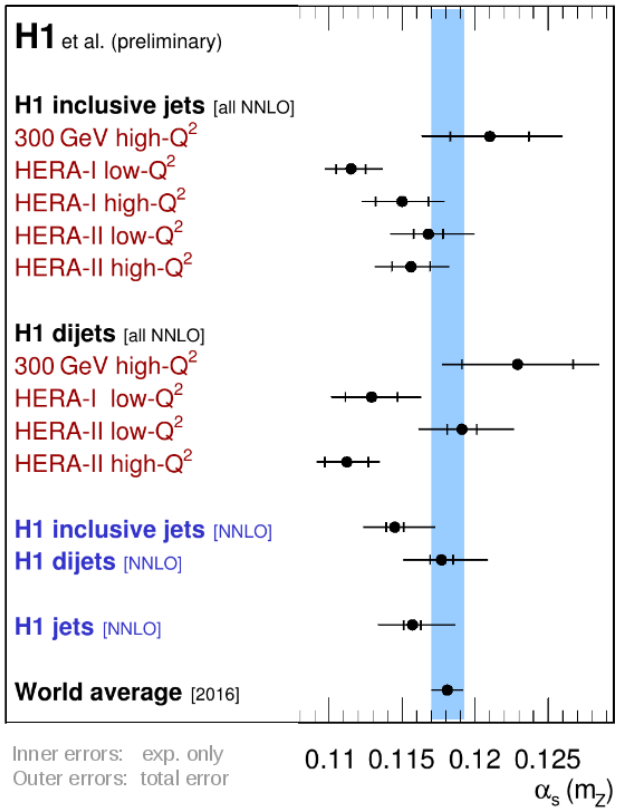
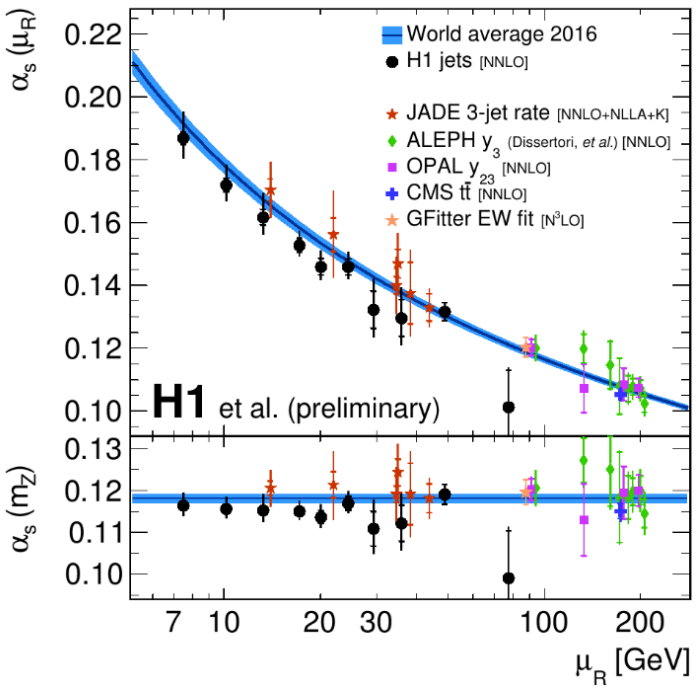
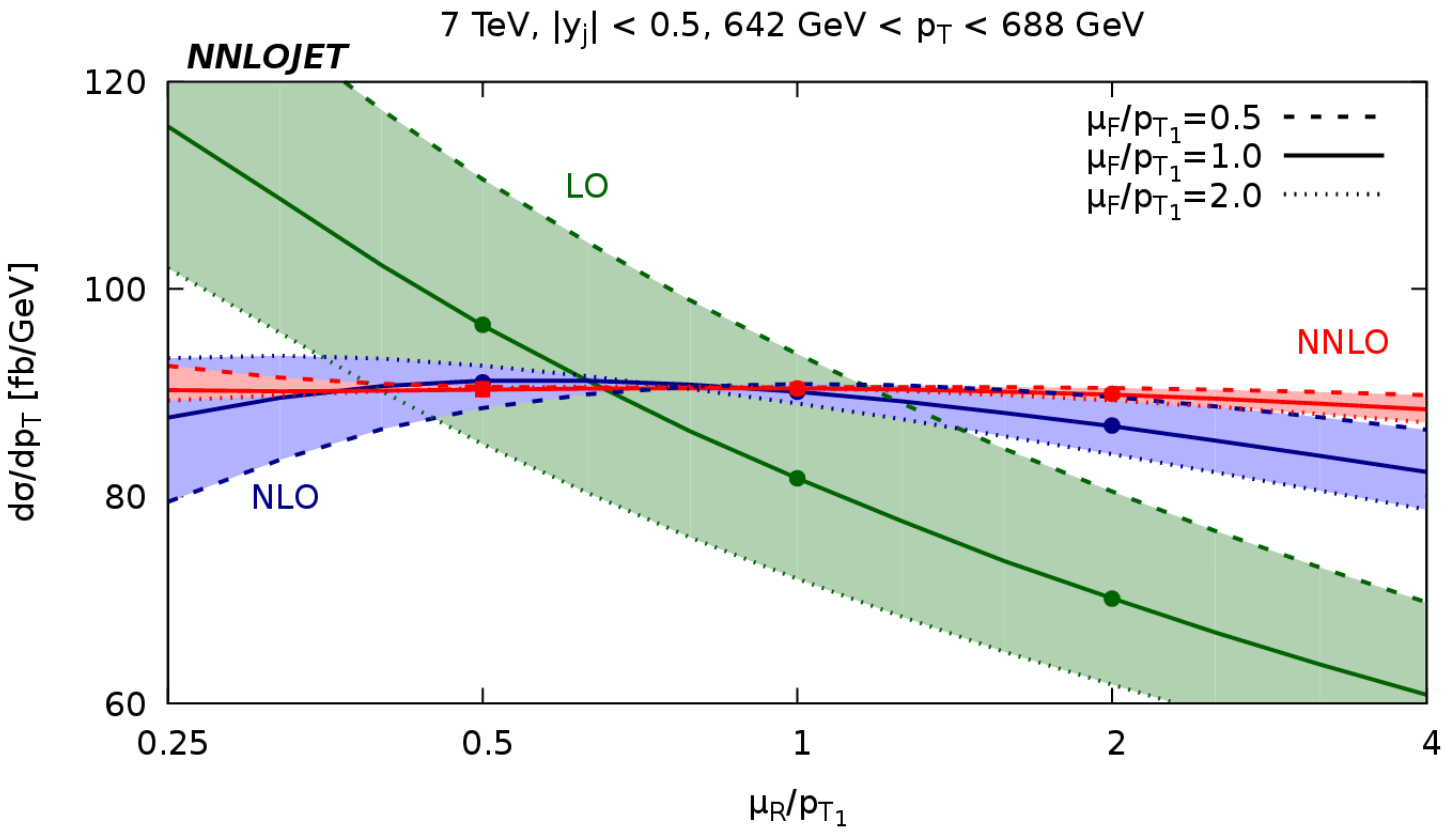
- **Extraction of α_s at NNLO by H1.**





NNLO single jet production at the LHC

– Full NNLO computation for single jet production at the LHC now available (NNLOJET) → percent level scale uncertainty!



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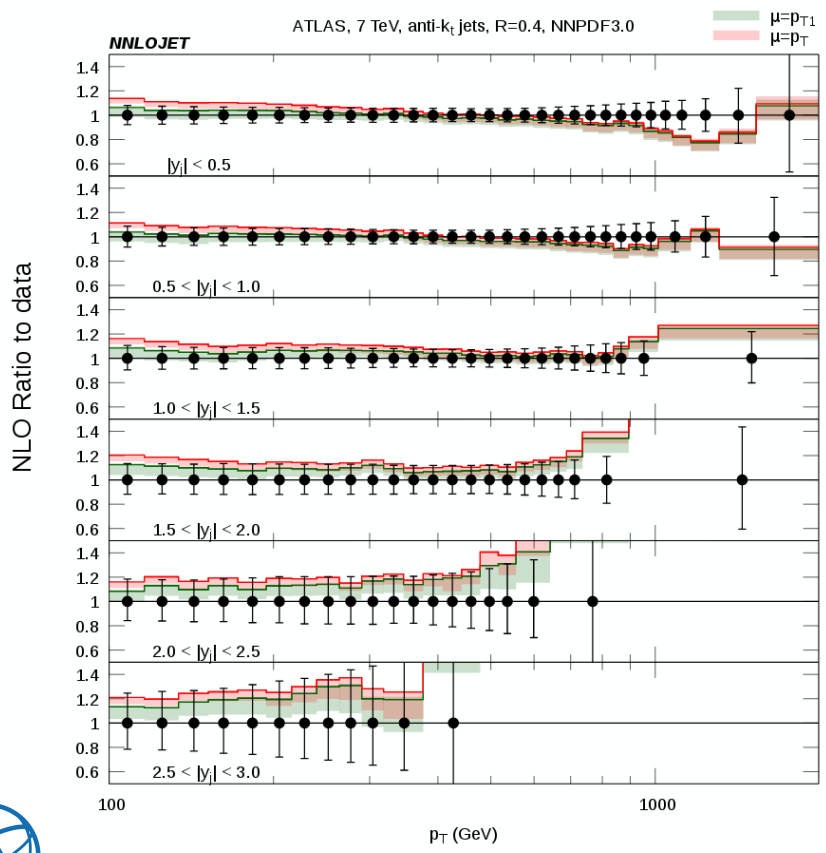
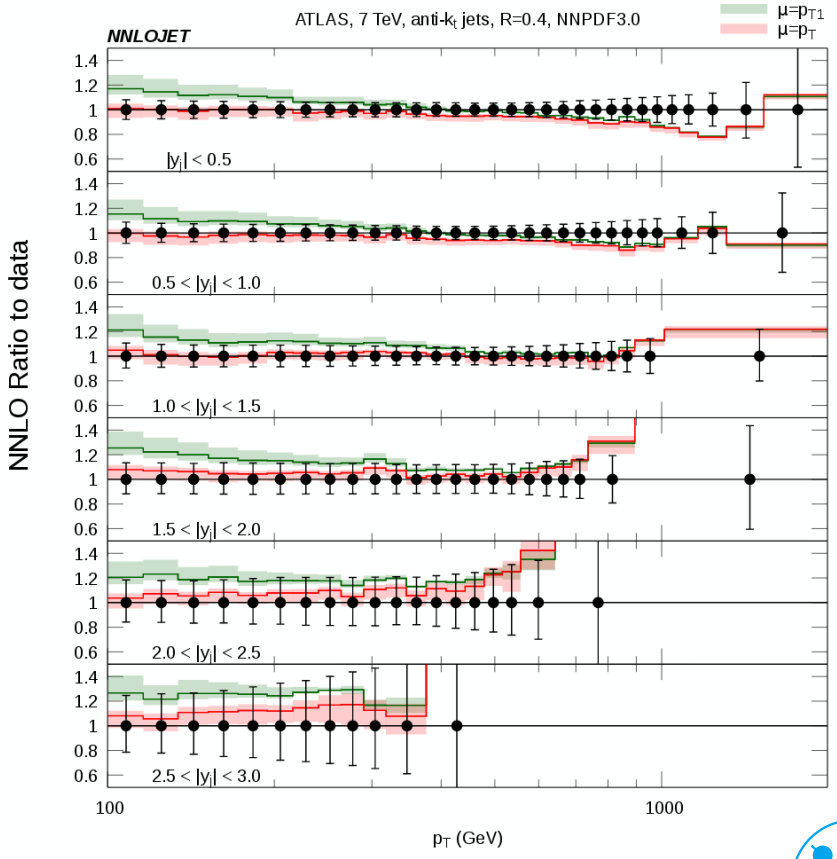
- Contributions to inclusive distributions come from individual jets, not events. Makes choice of scale ambiguous. Best choice different at NLO and NNLO.





ATLAS and CMS QCD results with jets and photons

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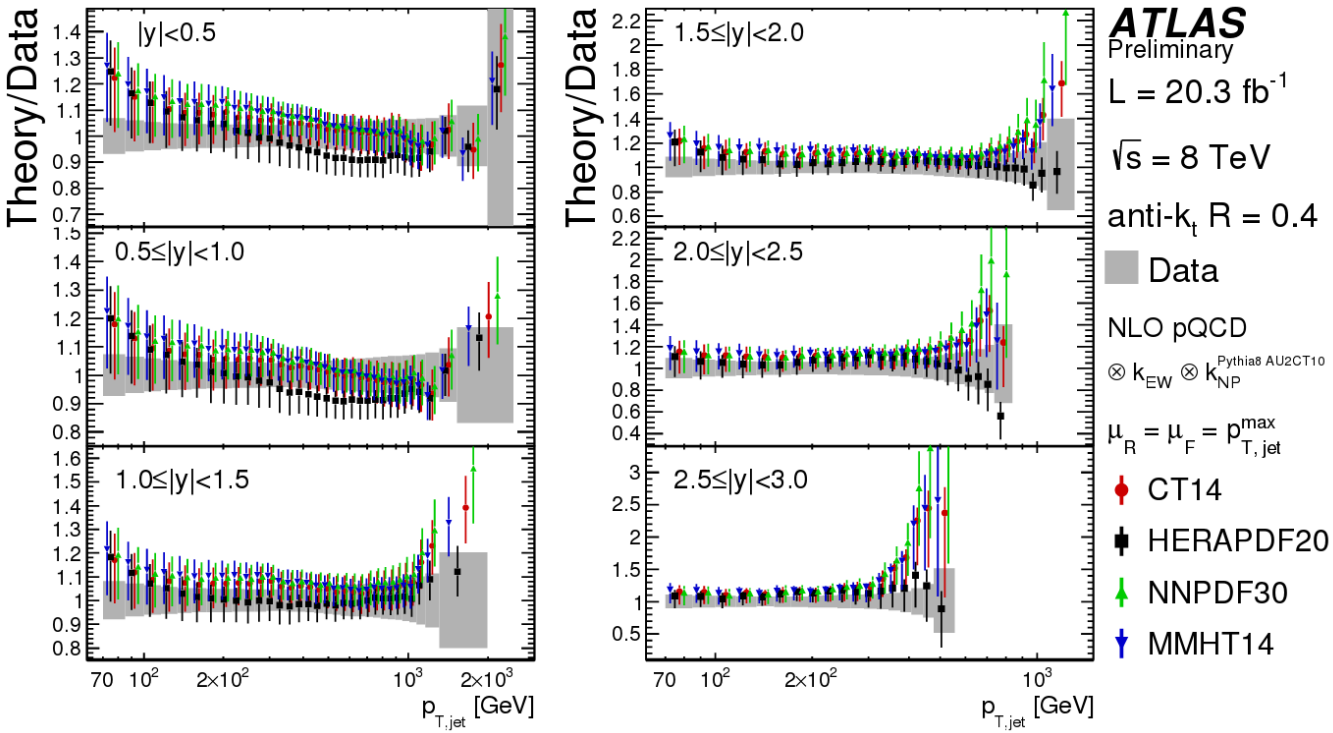
- Best qualitative agreement with CT14. All required inputs to PDF fits are being finalised.



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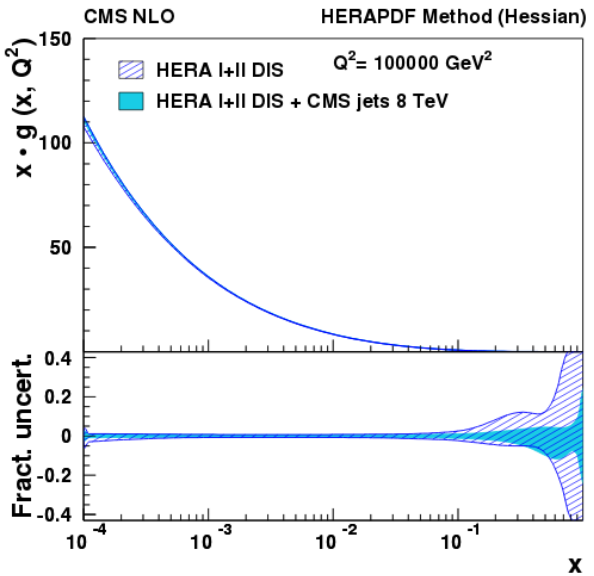

→ high x - gluon PDF improved, important for searches

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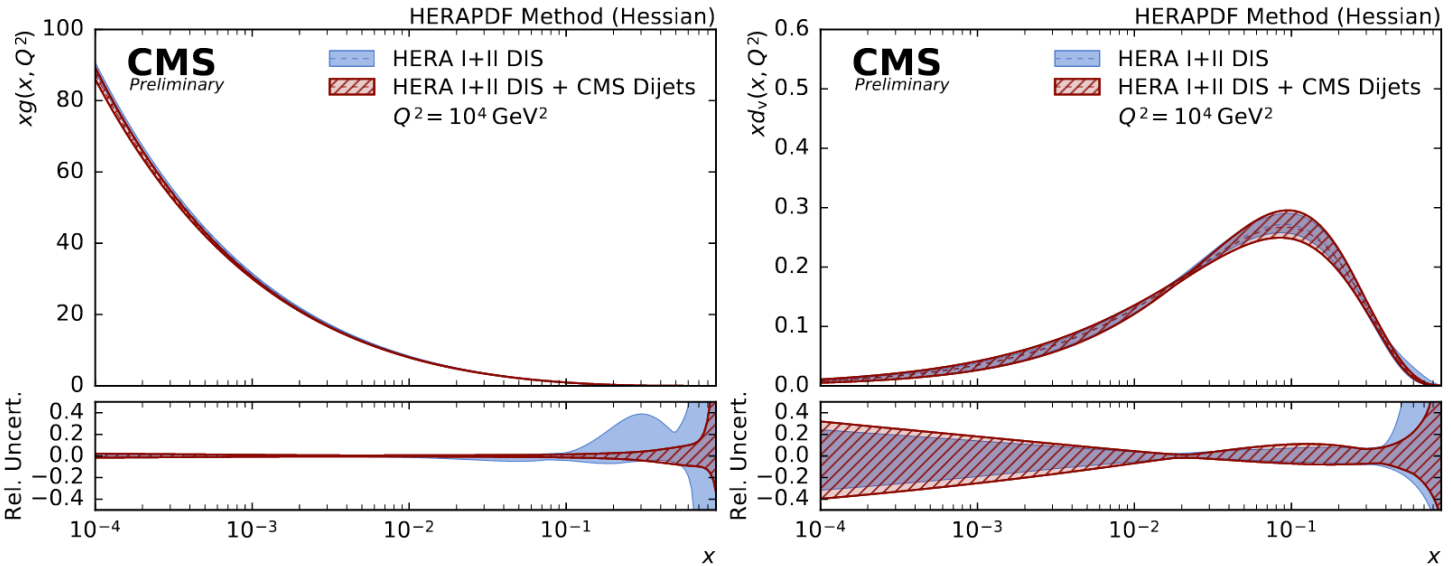
Providing effective constraints on PDFs for high x with HERA DIS results in XFITTER



ATLAS diphoton cross sections at 8 TeV

- My PhD analysis so I had to highlight it :) No CMS measurement available yet.
- Fiducial and differential cross section measurements of $m_{\gamma\gamma}$, $p_{\mathrm{T},\gamma\gamma}$, a_{T}, ϕ^*_η, $|\cos\theta^*_\eta|$, $\Delta\phi_{\gamma\gamma}$.
- Strong efforts put to probe the low q_T region, complementary to Drell-Yan measurements (which are $q\bar{q}$-dominated). Probe the infrared structure of QCD.

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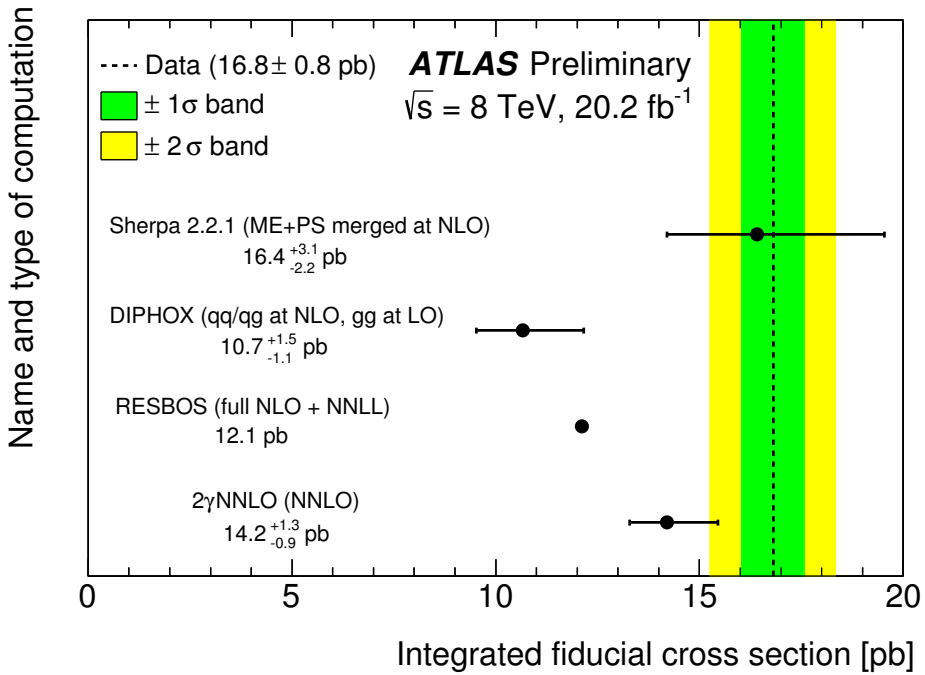
- RESBOS (NLO+NNLL) provides a good description of the low q_T region
- The new SHERPA 2.2.1 predictions (ME+PS@NLO) in good agreement with data



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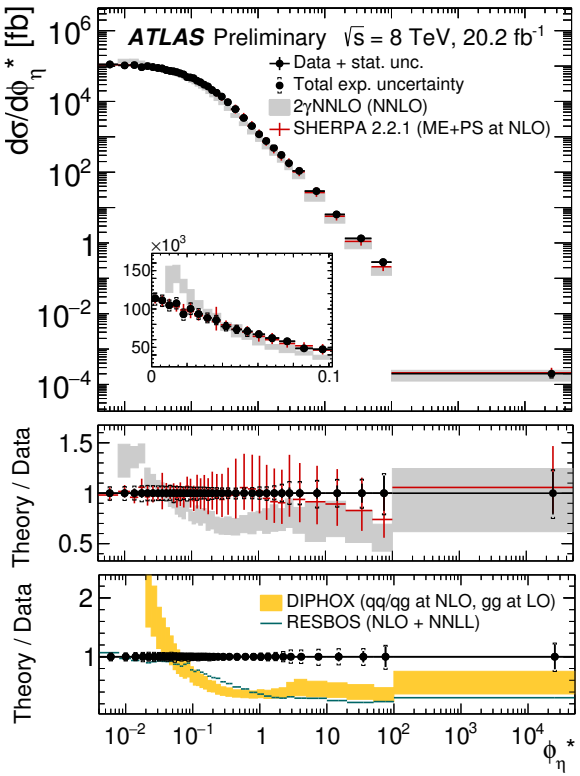

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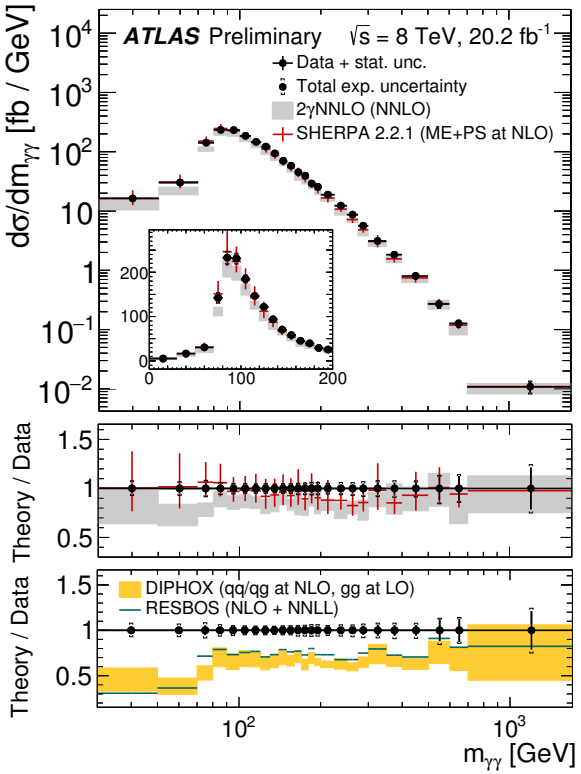
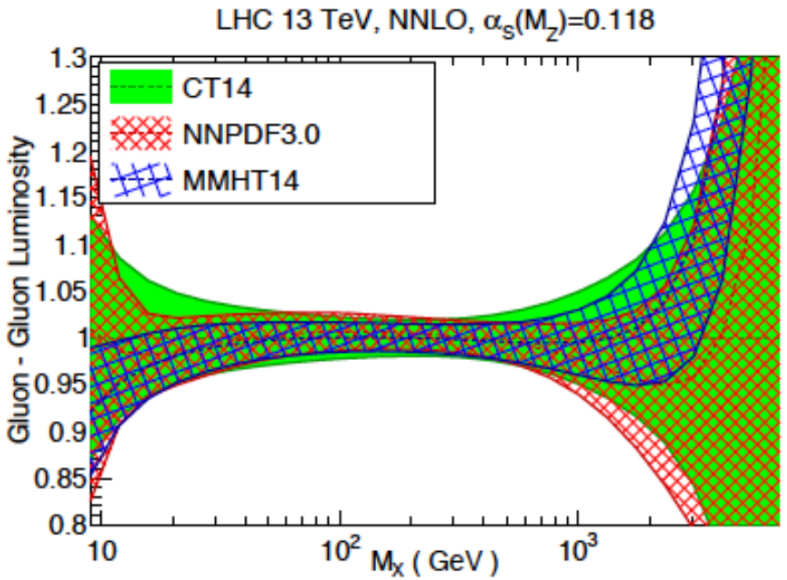


Progress in proton PDFs

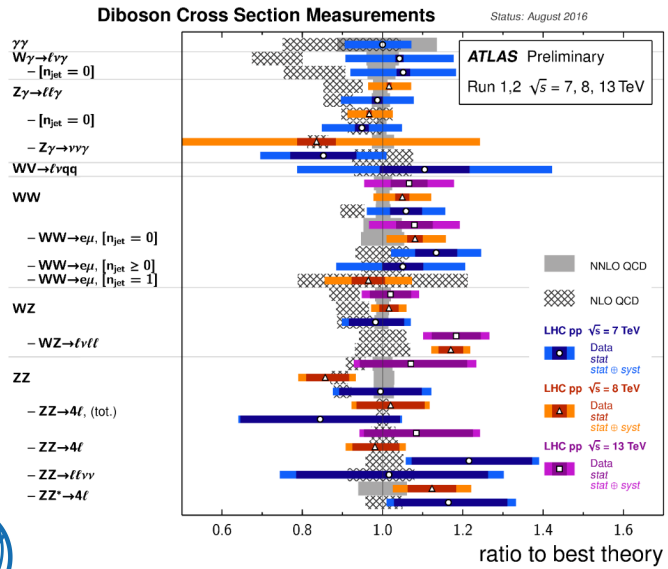
- The NNPDF3.1 set will likely be released first, including a compatible subset of the new LHC data.
- CT17 and MMHT16 to be released within a few months.
- ABMP16 (arXiv:1701.05838) includes a large LHC W/Z data set, got closer to the other PDF sets.
- **In progress in all groups:** understanding of apparent disagreements between the available data sets.
- **Reminder:** already good agreement between the 3 main PDF sets for gluon-gluon luminosity achieved for Run 2.

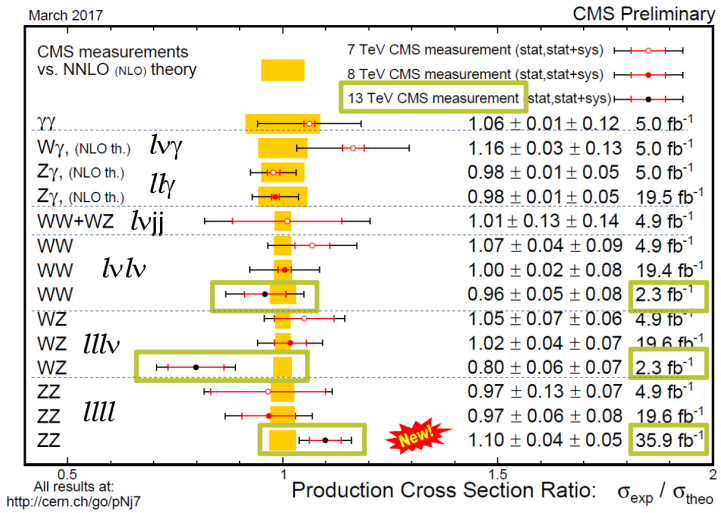


Diboson production at ATLAS and CMS

- **News from the theory side:**
  - MATRIX: framework for automated NNLO+NNLL calculations
    (public release in preparation)
  - **New at Moriond:** VV production via gluon fusion at NLO (interf. with Higgs), differential WW and WZ cross sections at NNLO
  - NNLO / NLO $\sim$ 10 – 15%. NNLO scale uncertainties $\sim$ 5%

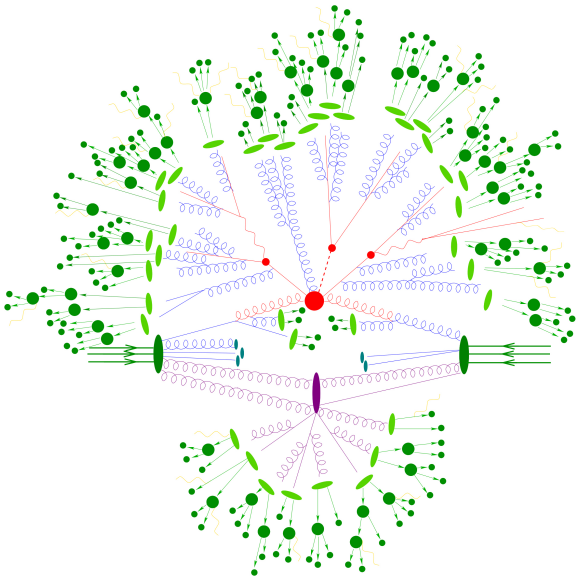
- **ATLAS and CMS results:** good agreement with NNLO calculations, limits on aTGC/aQGC.





Heavy ions: overview

– Do you believe than proton proton collisions are complicated?



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- Do you believe than proton proton collisions are complicated?
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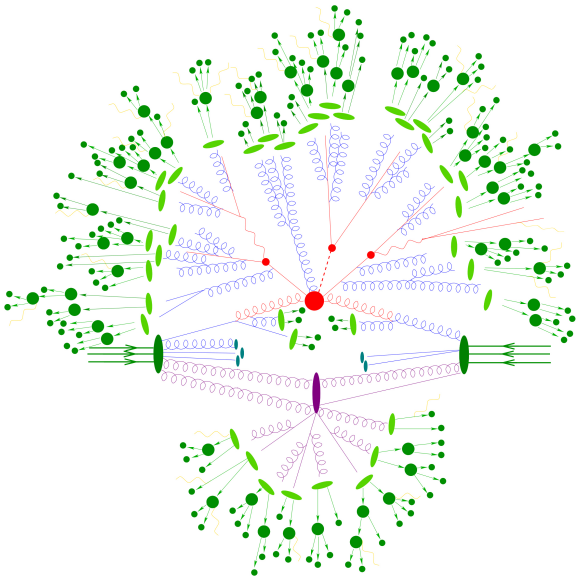

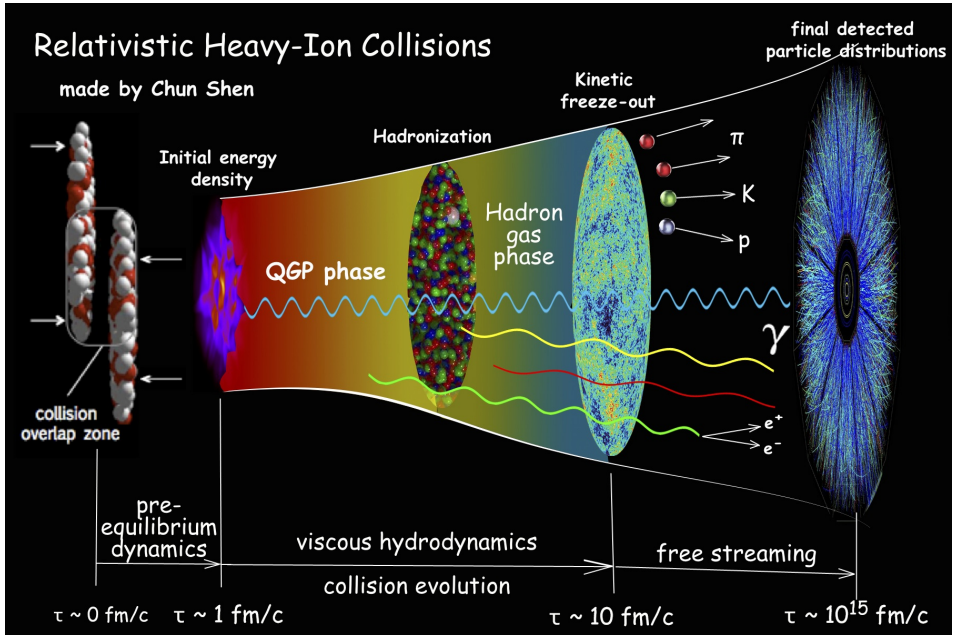

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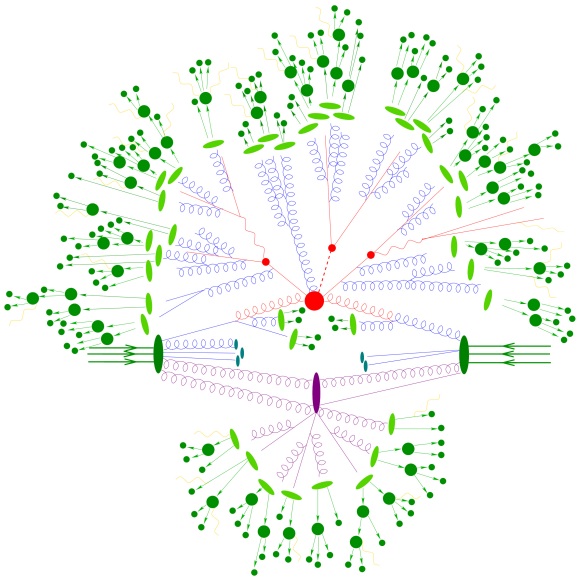

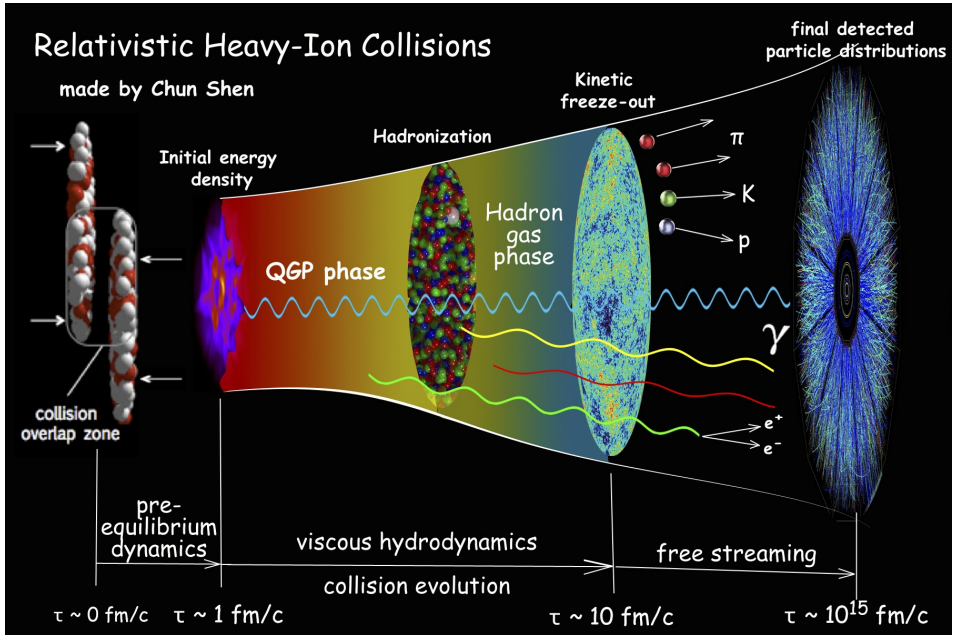

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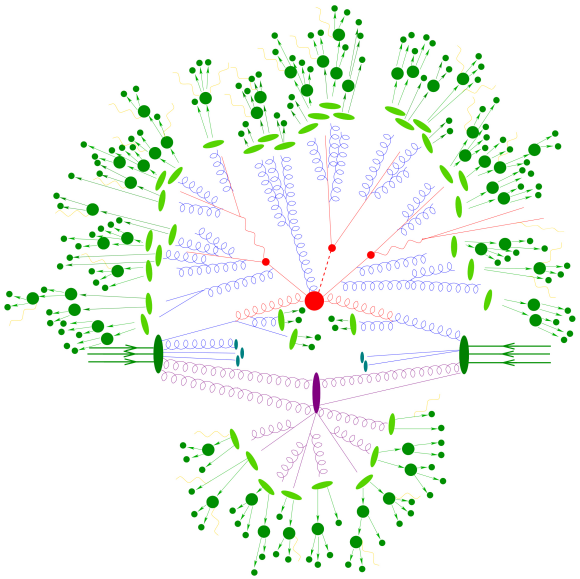

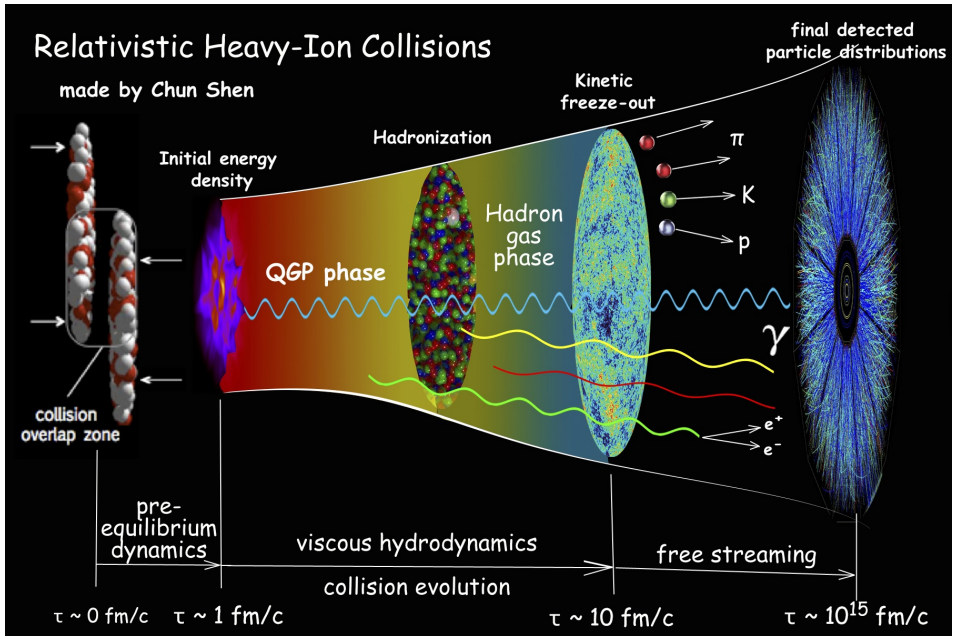

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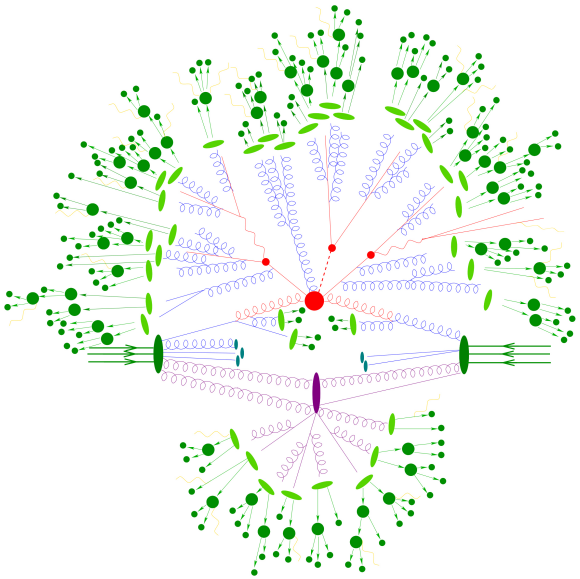
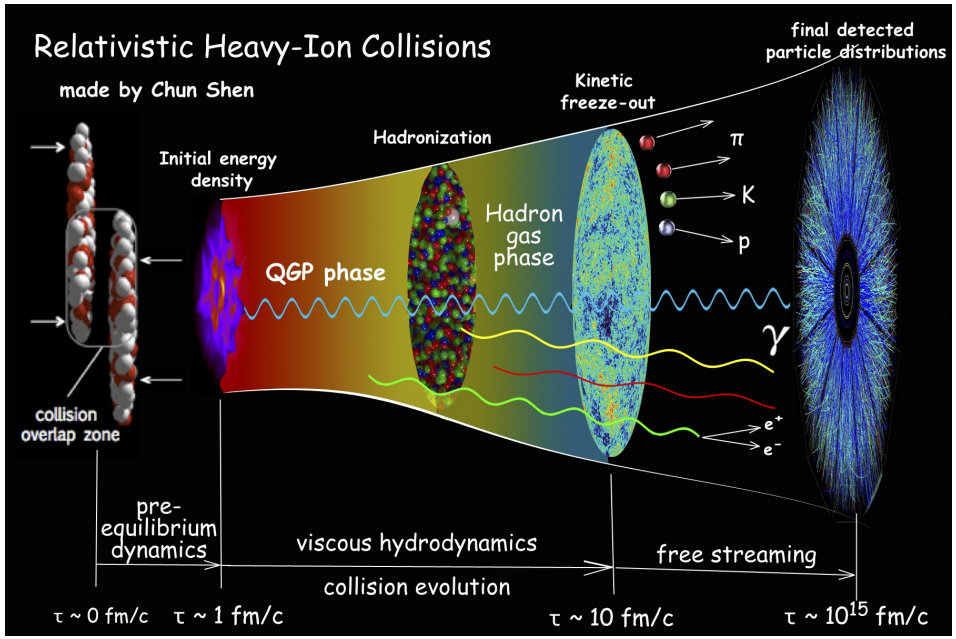
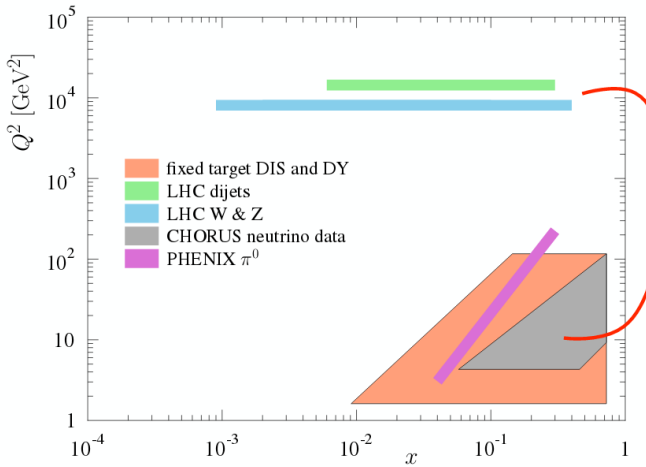




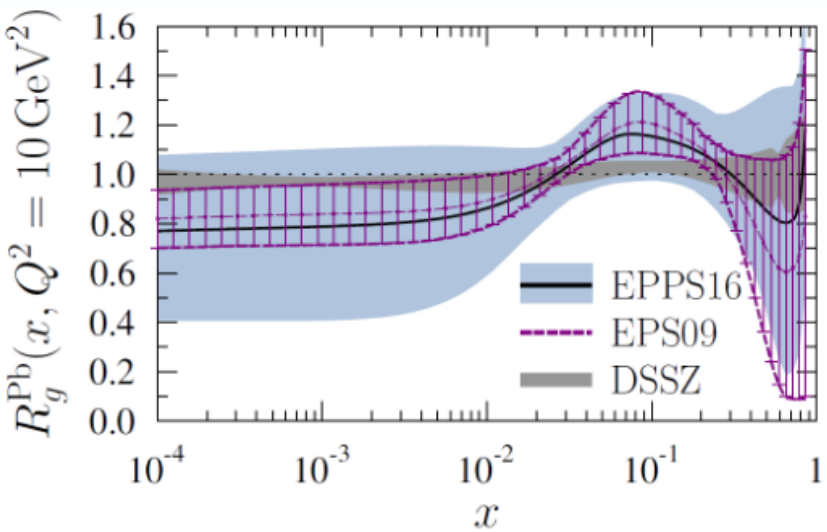
- γ, W, Z do not interact strongly $\rightarrow$ provide information about initial state (nuclear PDFs).
- Hydrodynamic expansion $\rightarrow$ "anisotropic flow" (fluctuations, impact parameter)
- Jets (quenching, near-side peak), quarkonia (thermo-chronometers), used to probe the medium properties

Nuclear PDFs

- EPPS16: 1st nuclear parton distributions with LHC pPb data (previous: EPS09)
- Larger uncertainties reflect more realistic analysis
- No tension between data sets exist → universality
- Proton-Lead run in 2016 expected to have strong impact in nPDFs

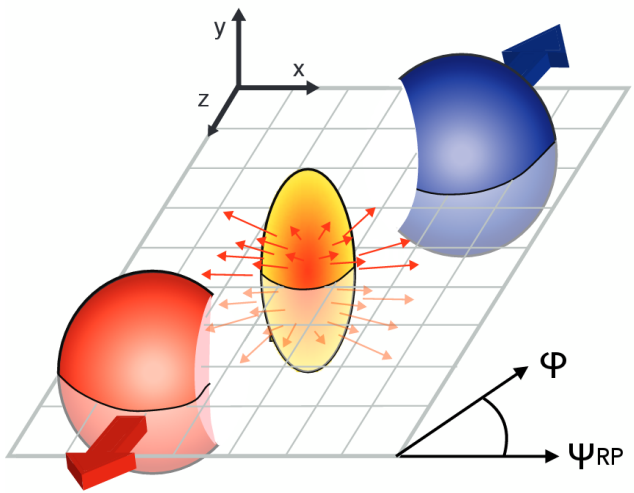


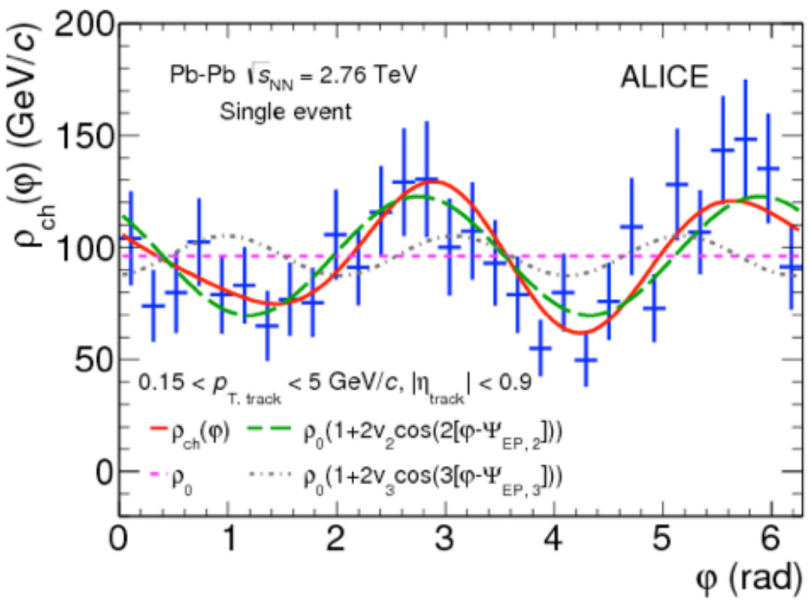
New in EPPS16



Flow anisotropies in ALICE

- Heavy ion collision: strongly-interacting non-spherical system
  (mainly driven by the impact parameter and event fluctuations)
- Spatial anisotropies (pressure) lead to momenta anisotropies (Navier-Stokes)
- Analyse Fourier components of azimuthal distribution. Expect a big dipole component "v_2" at mid-centrality (very elliptic)





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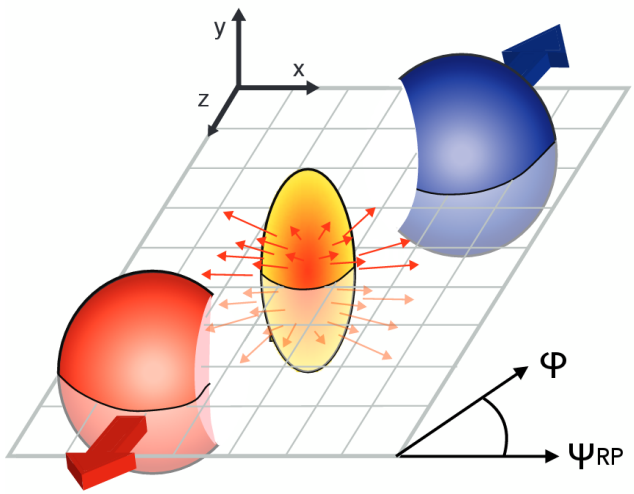
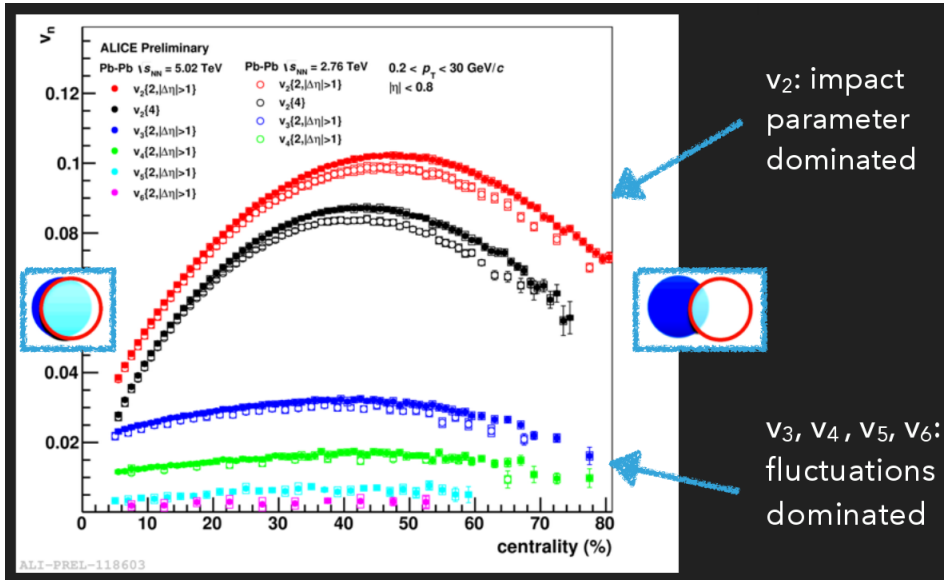
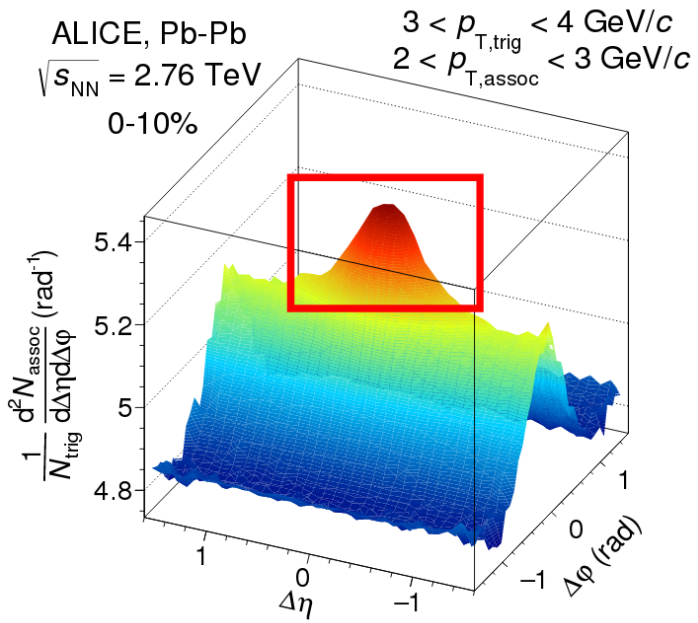
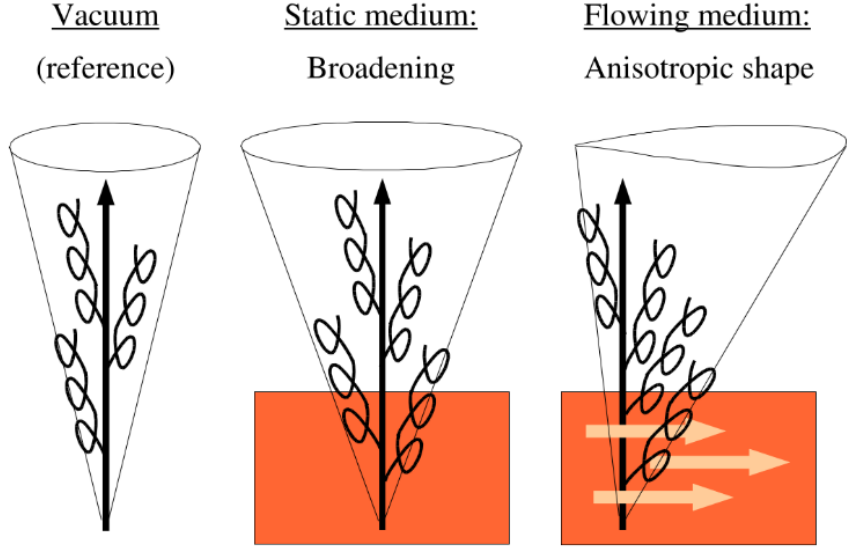




Anomalous evolution of the near-side jet peak shape in ALICE

- **Goal:** study interaction of low p_T jets with medium
- Consider angular correlation between a trigger and an associated particle.
- Interactions would appear as modification of **the near-side peak**





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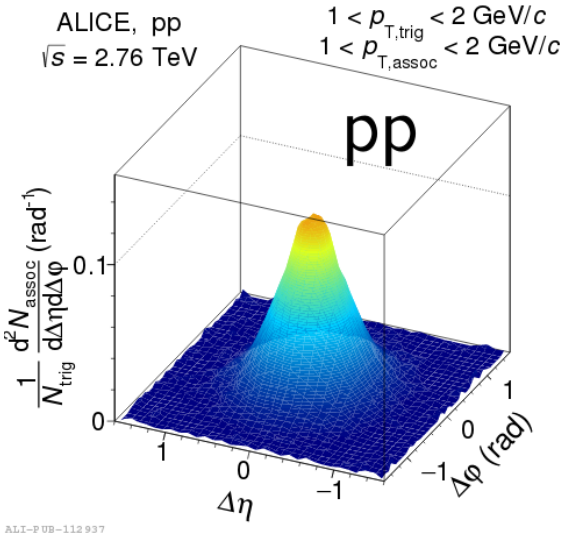

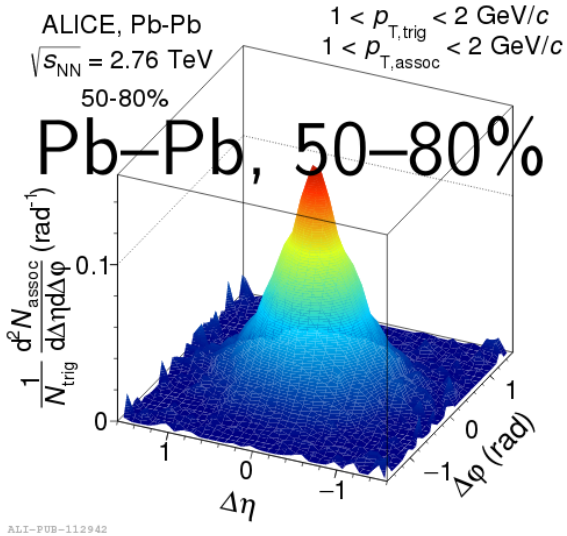

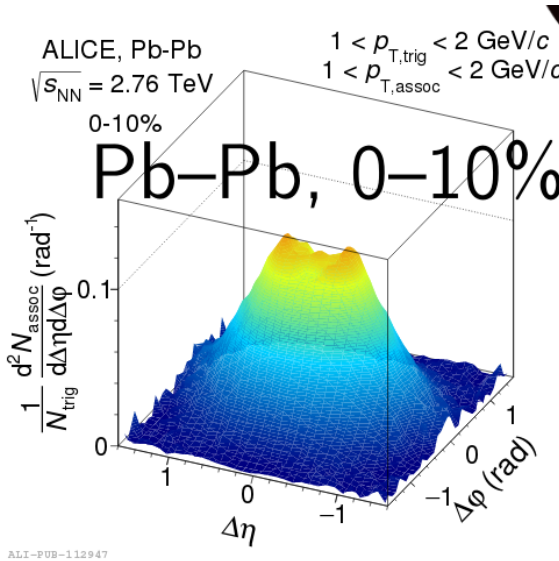

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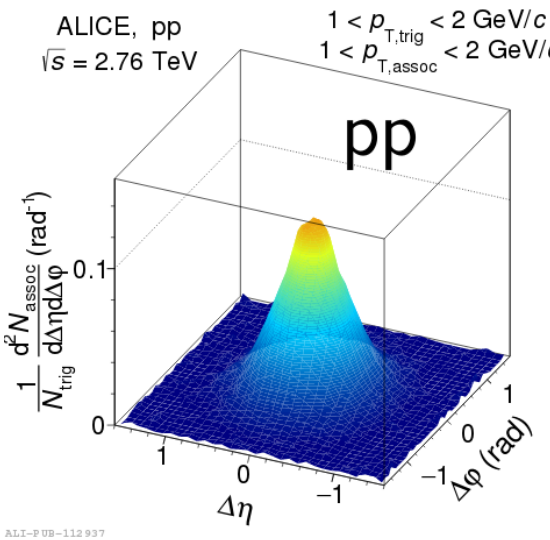

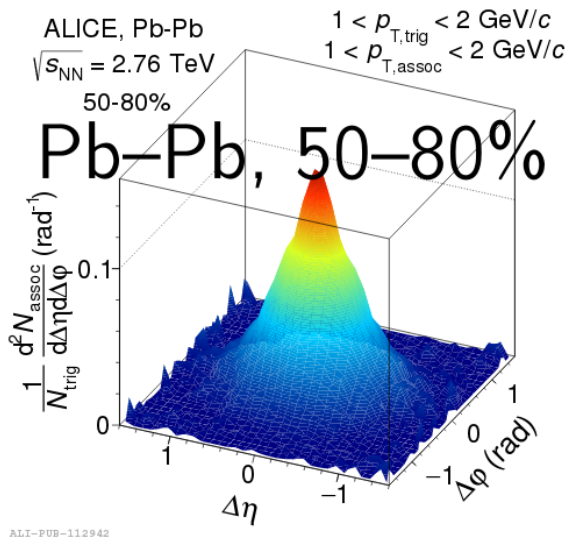

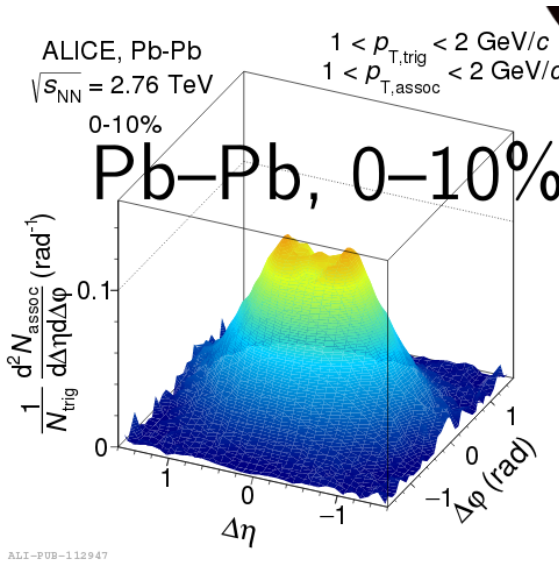

- Small (Large) broadening in $\Delta\phi$ ($\Delta\eta$), Depletion around ($\Delta\phi$,$\Delta\eta$) = (0,0).
  Comparison with multi-phase transport models.

My personal conclusion

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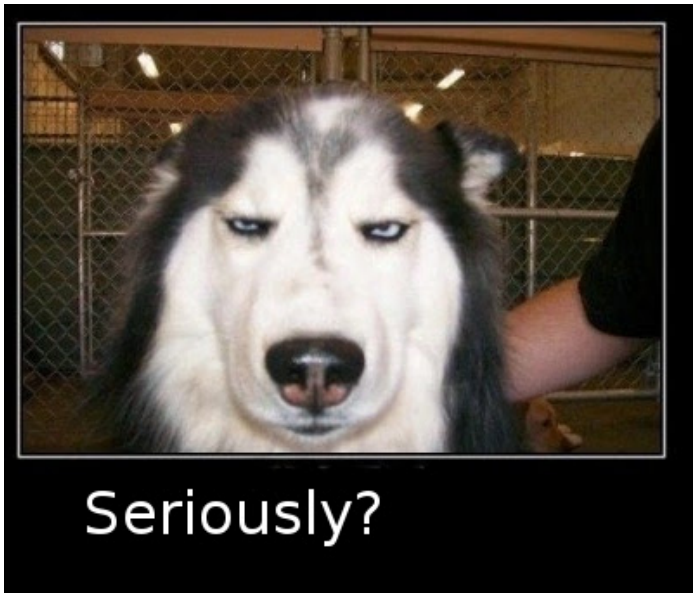

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- If confirmed, it seems very hard to explain why lepton universality breaks down only in such very peculiar processes.

Rencontres de Moriond: QCD and high energy interactions Summary.

Thank you for your attention!

Matthias Saimpert (DESY)

LHC physics discussions

10/04/2017