Jets and charged hadrons in pPb collisions with CMS

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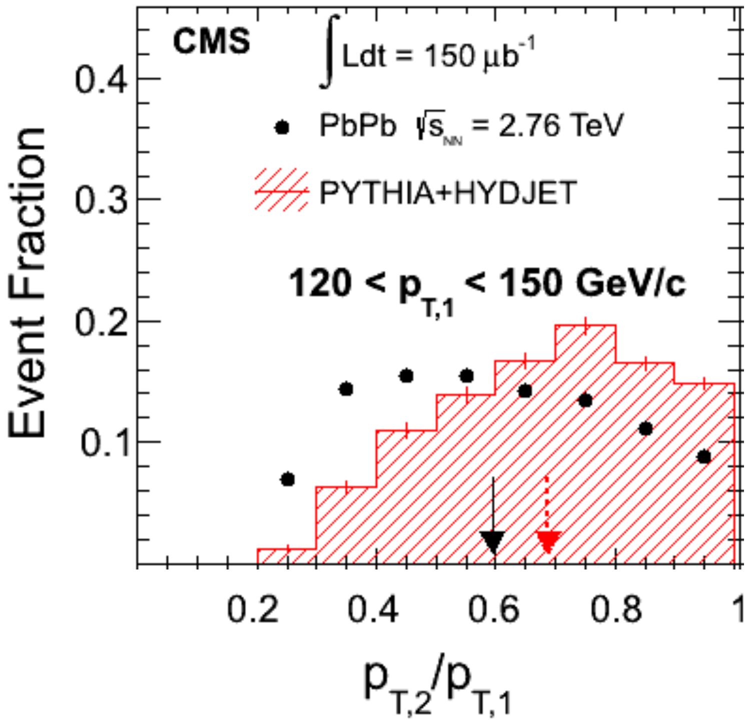
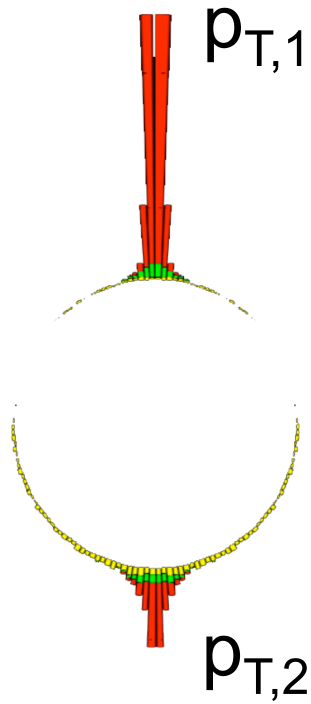
for the CMS Collaboration

High-p_T 10, Nantes
11th September, 2014

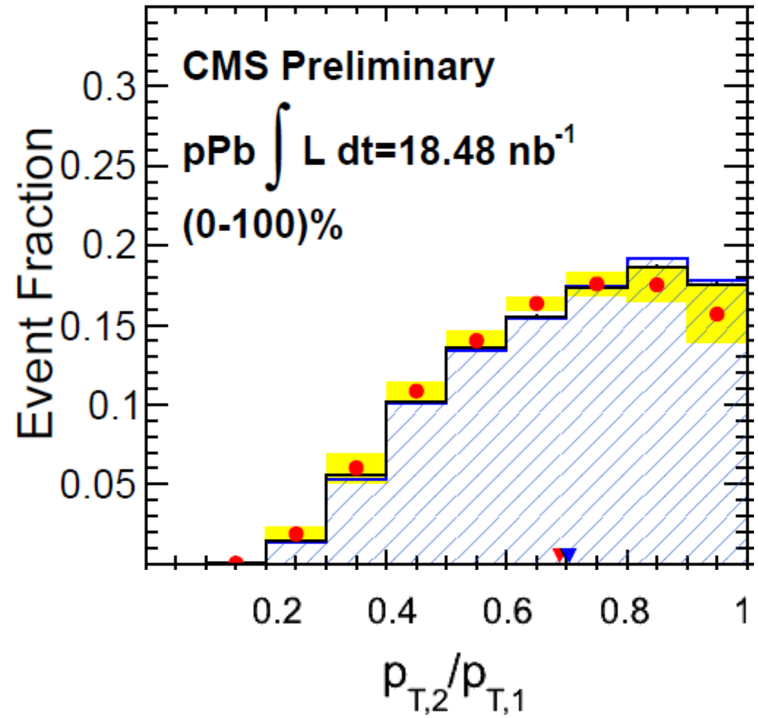
Previously in CMS...

PbPb



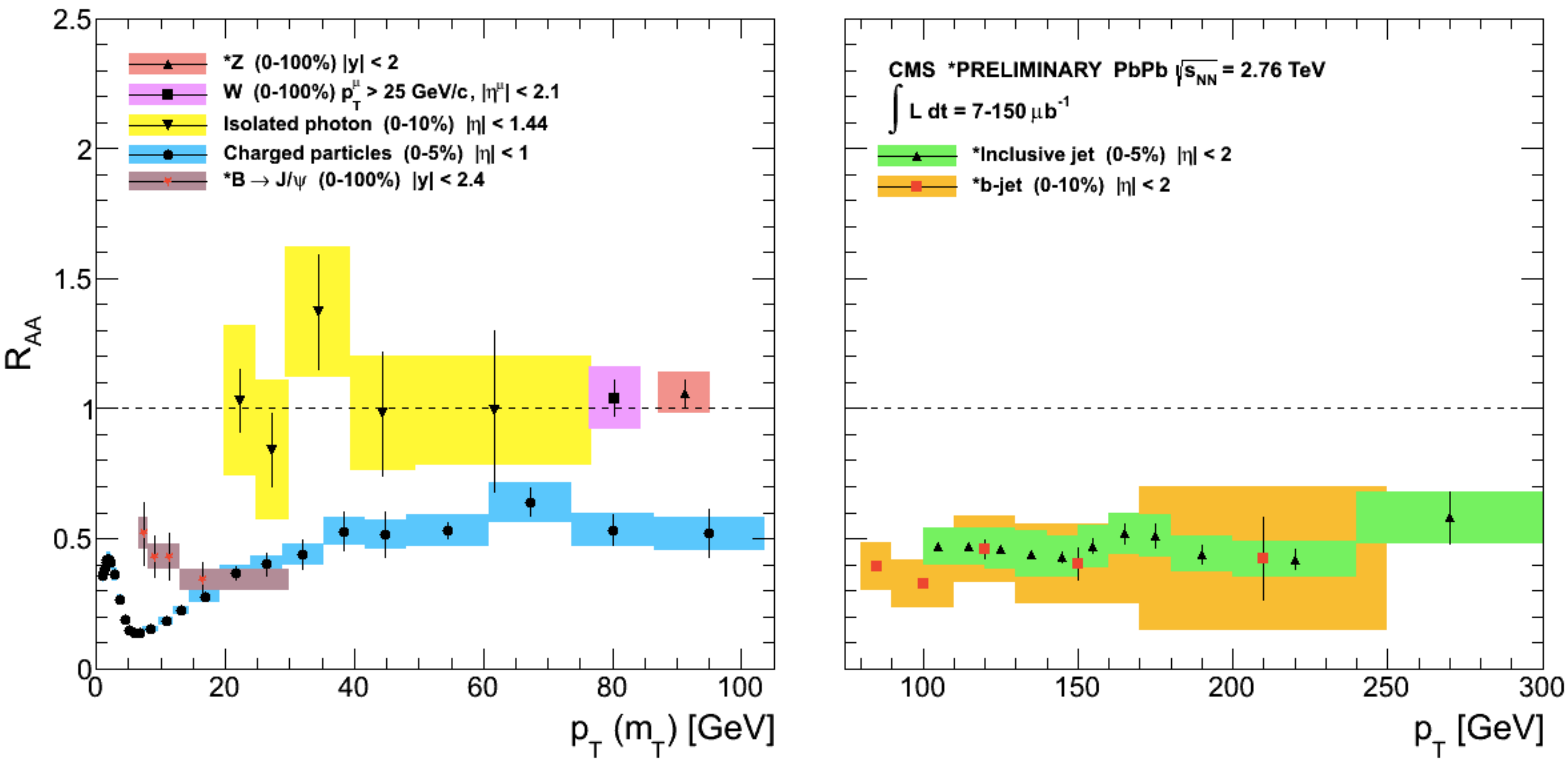


pPb



Dijet imbalance gives a clue about the quenching as a final state effect, however cannot let conclude on the amount of the lost energy

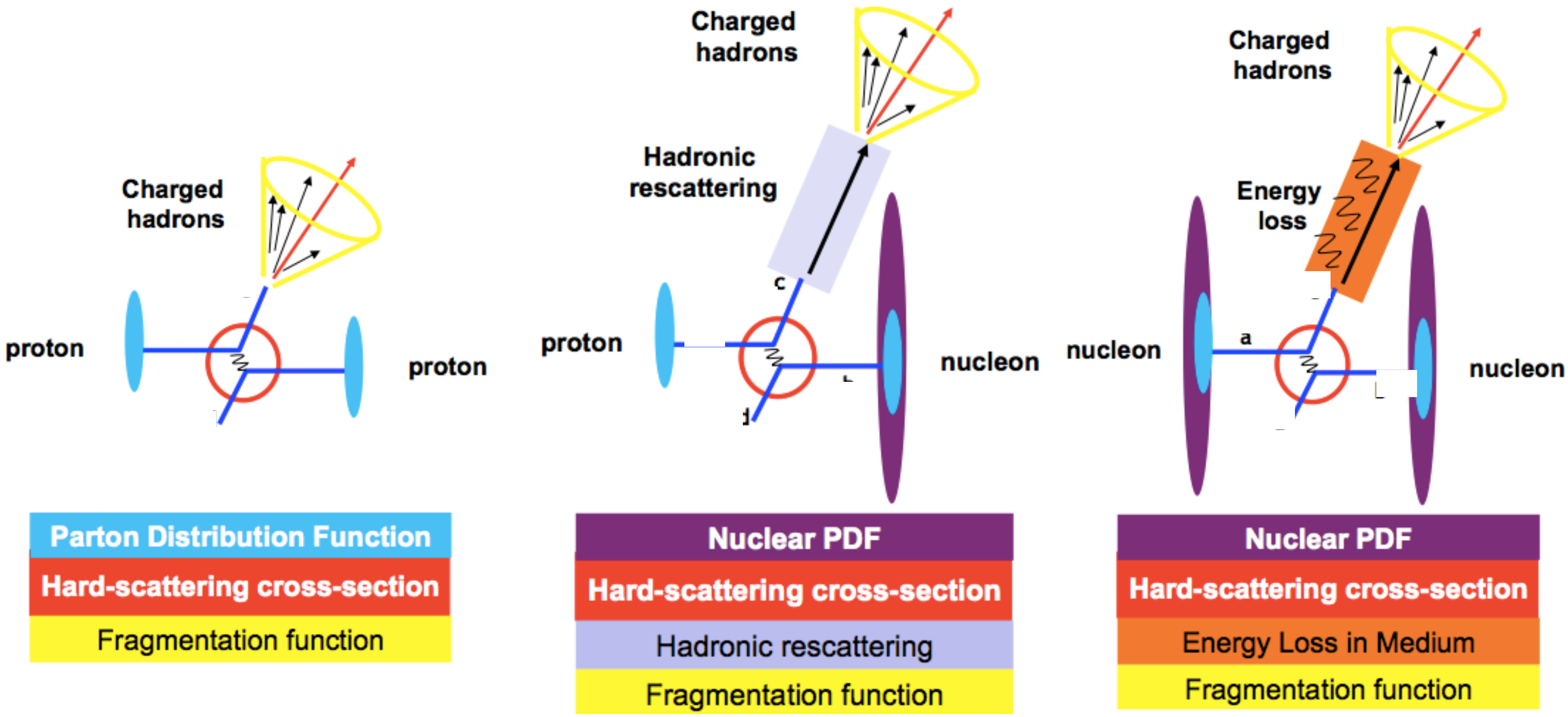
R_{AA} Results from PbPb Collisions



- Initial-state and final-state effects combined
- Need R_{pPb} for the interpretation of the suppression

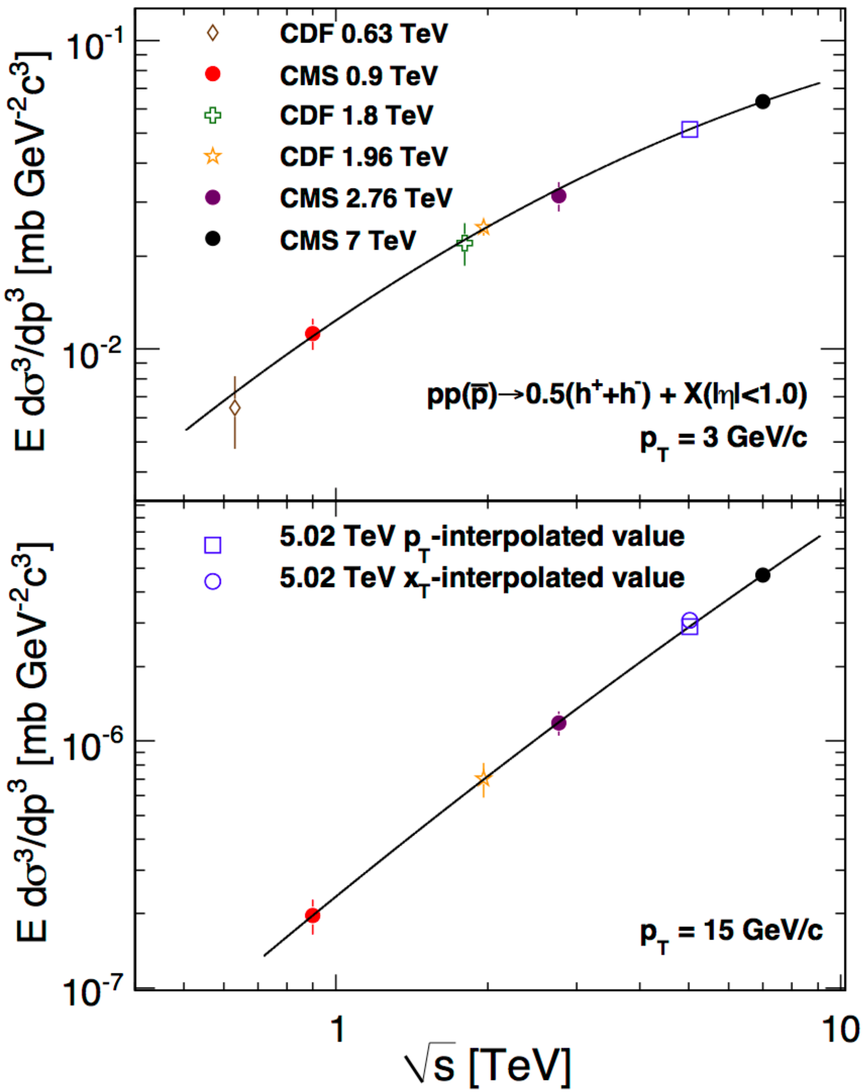
CMS: EPJC 72 (2012) 1945 , PLB 715 (2012) 66, PLB 710 (2012) 256,
HIN-12-014, HIN-13-004, HIN-12-004, HIN-12-003

Nuclear Effects in pPb and PbPb Spectra



Challenge: pPb at a different energy than pp and pPb

Charged Particle pp Reference Spectrum

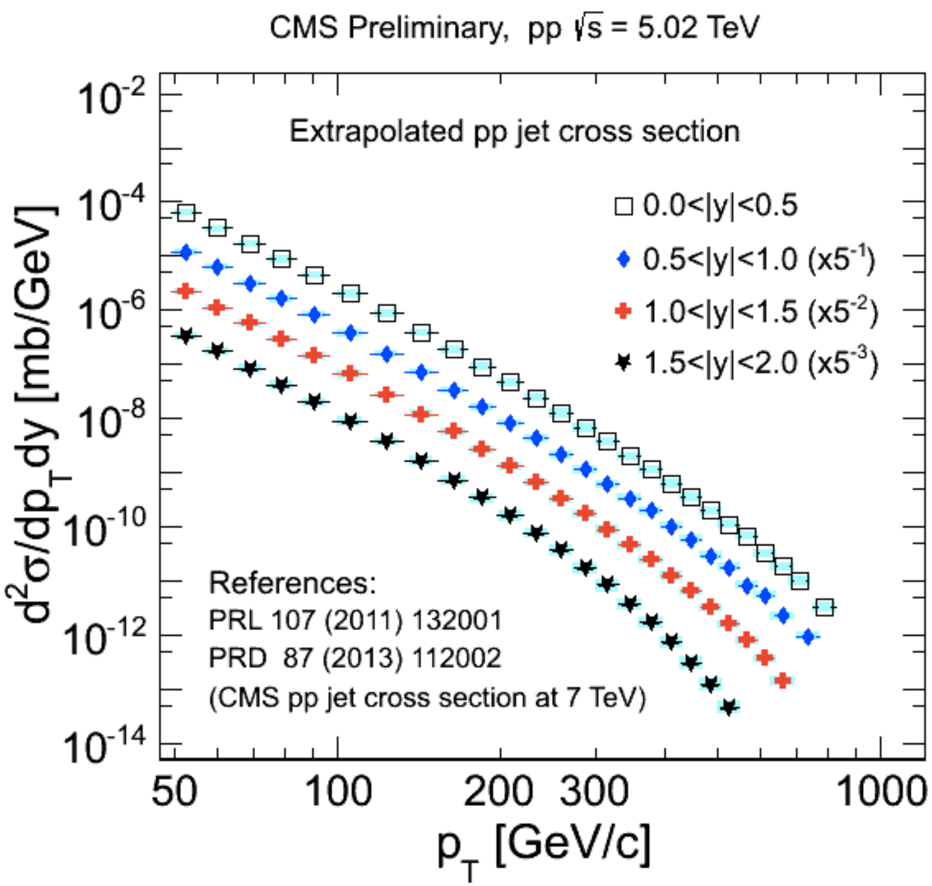


Direct Interpolation Method

- Six datasets used from 0.63 to 7 TeV
- Only the 2.76 and 7 TeV data extend beyond 30-40 GeV/c
- Technique for high-p_T interpolation:
  Use $x_T = 2\, p_T / \sqrt{s}$
- Total uncertainty: 10%

CDF: PRL 61 (1988) 1819, PRD 82 (2010) 119903
CMS: JHEP 08 (2011) 086, EPJC 72 (2012) 1945

Anti-k_T R=0.3 Jet pp Reference Spectrum



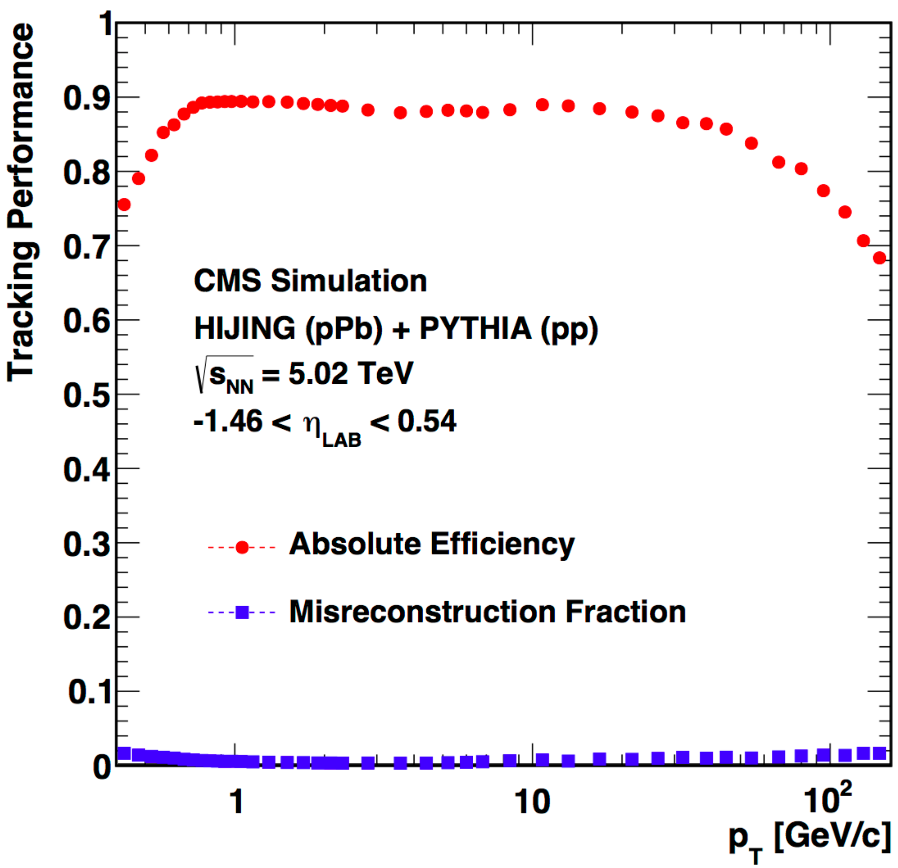
CMS: PRL 107 (2011) 132001, PRD 87 (2013) 112002

Scaling to R=0.3 and 5.02 TeV

- CMS jet Spectra available for 7 TeV with R=0.5 and R=0.7
- PYTHIA Z2 correctly describes ratio of R=0.7/R=0.5, used to scale CMS results to R=0.3
- PYTHIA Z2 ratio of 5.02/7 TeV used to scale CMS results to lower energy
- Systematic uncertainties taken from use of different PYTHIA tunes, shifting underlying measured spectra, changing the underlying data set used.
- Total uncertainty range: 12-20%

Charged Particle Reconstruction

Reconstruction Performance

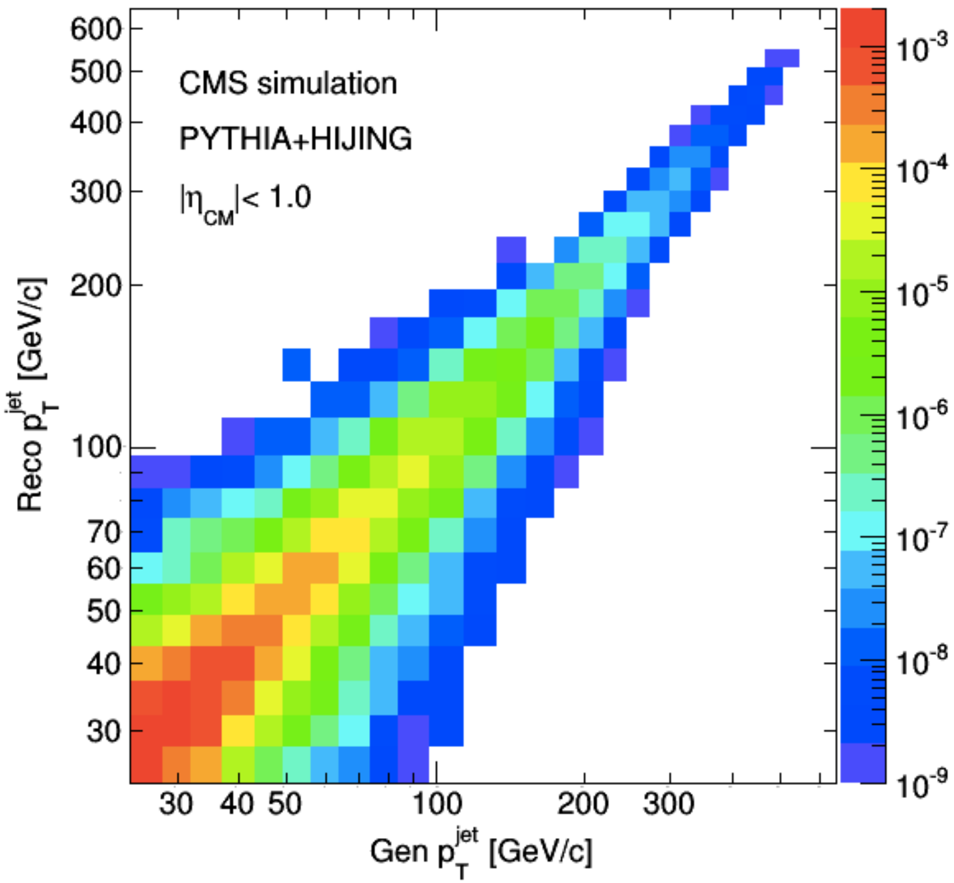


- High efficiency of ~ 70-90%
- Low misreconstruction fraction
- Momentum resolution of 1-2% at p_T = 100 GeV/c.
- Spectra are not significantly distorted by momentum smearing.

CMS: HIN-12-017

Jet Reconstruction

Detector Response Matrix

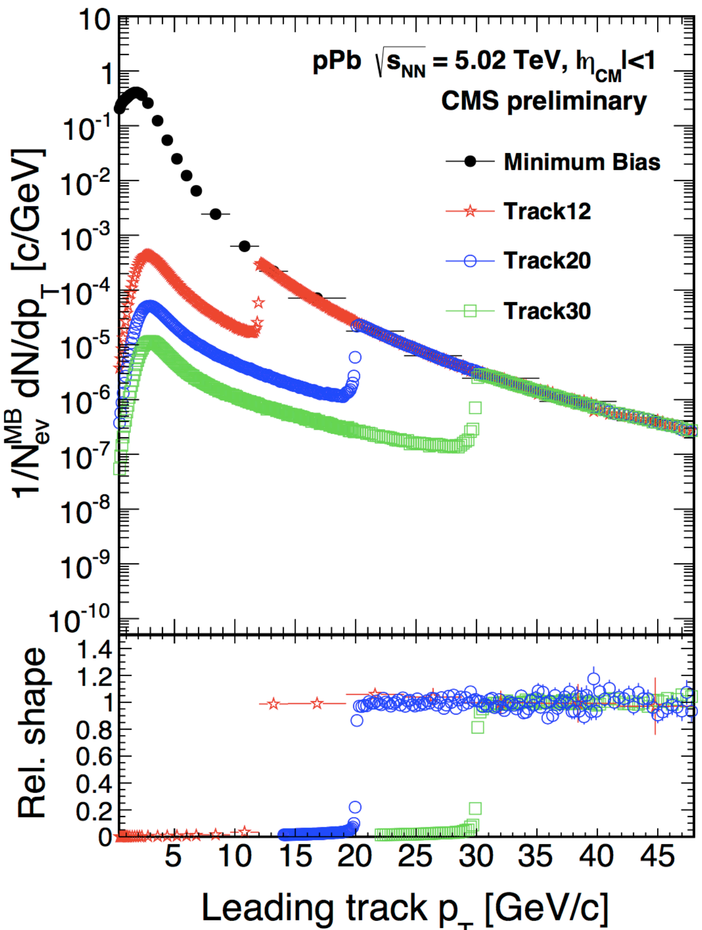


- Anti-k_T algorithm with R=0.3 cone size applied to projections from particle-flow candidate objects
- Iterative Pileup subtraction method applied to remove background.
- Jet energies corrected to final state particle jets
- Smearing effects of the finite-p_T resolution on the spectrum are corrected using an "unfolding" procedure with MC-derived response matrix.

CMS: HIN-14-001

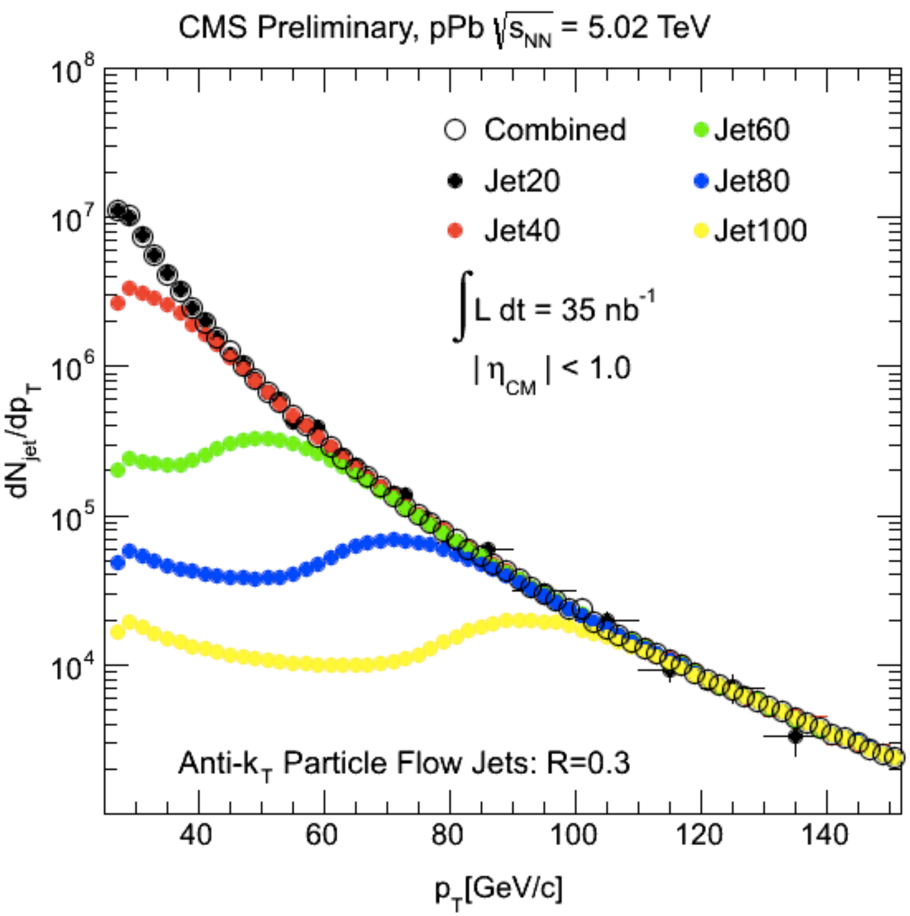
Trigger Combinations

Charged Particles



CMS: HIN-12-017

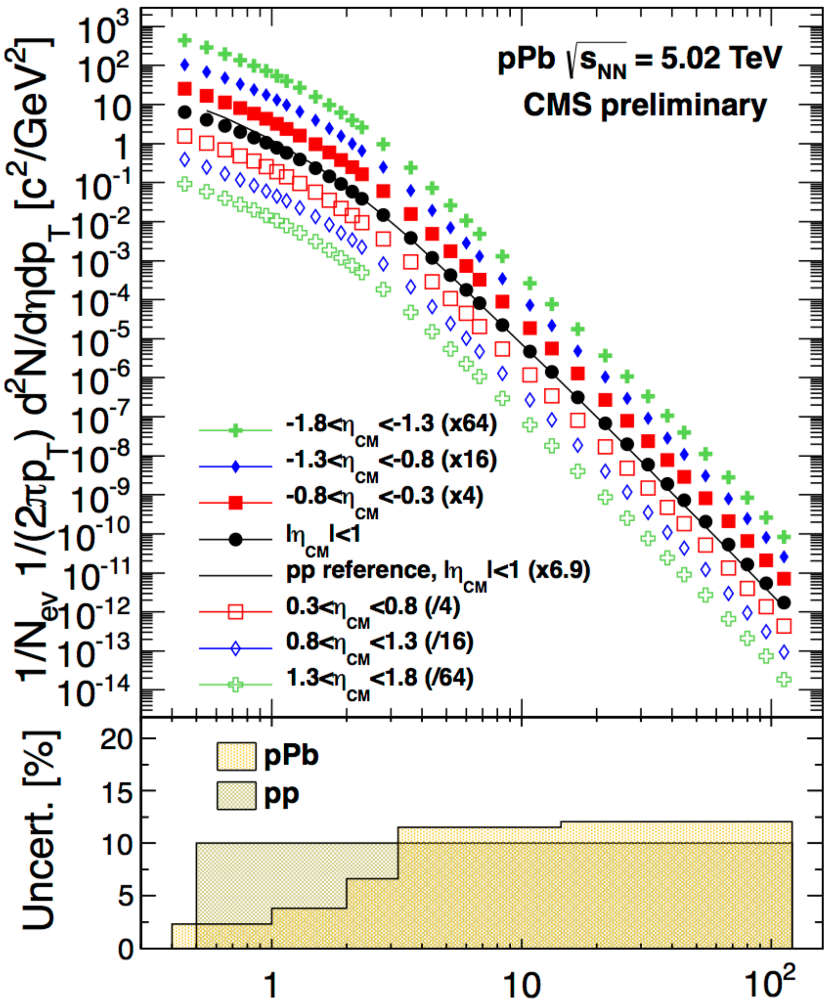
Anti-k_T R=0.3 Jets



CMS: HIN-14-001

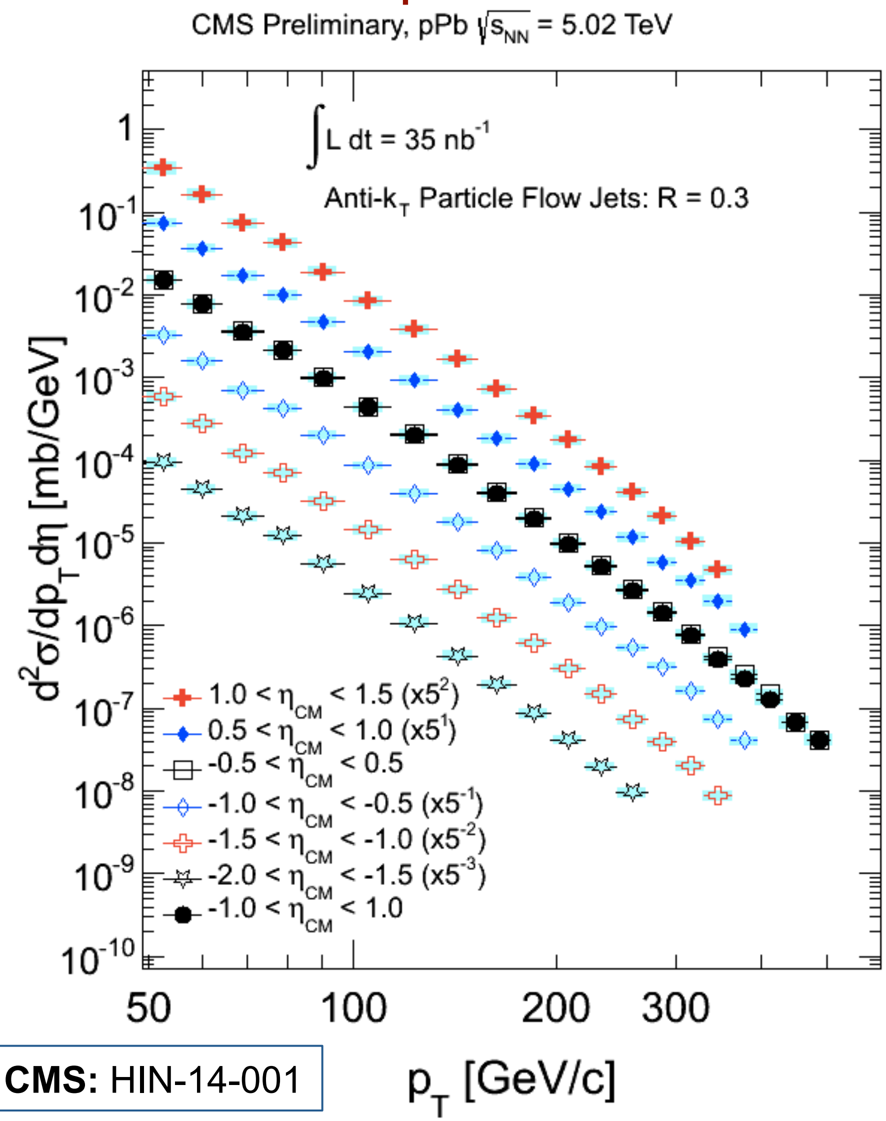
Measured pPb Spectra

Charged Particles



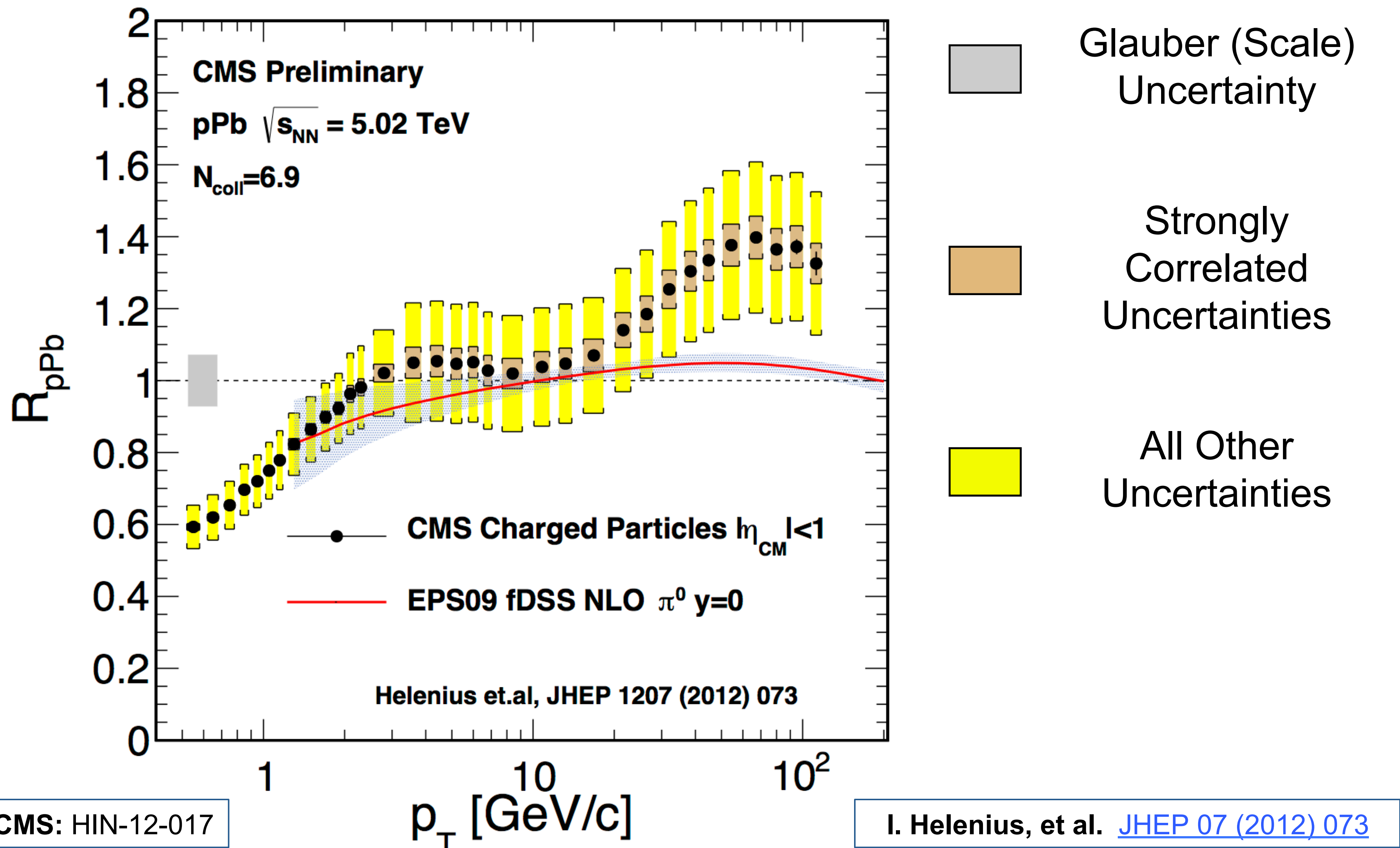
CMS: HIN-12-017

Anti-k_T R=0.3 Jets



CMS: HIN-14-001

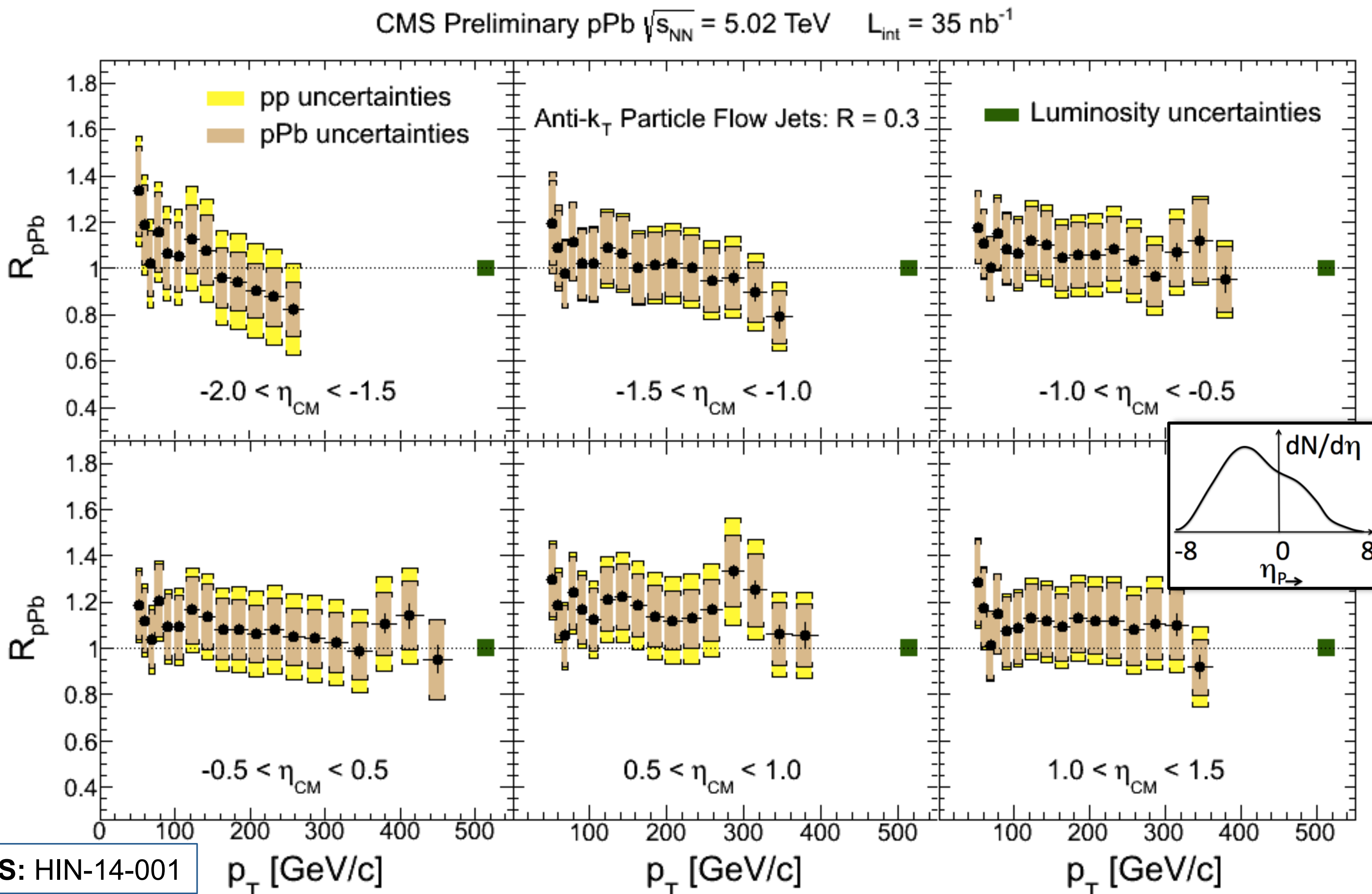
Nuclear Modification Factor (Charged Particles)



CMS: HIN-12-017

I. Helenius, et al. JHEP 07 (2012) 073

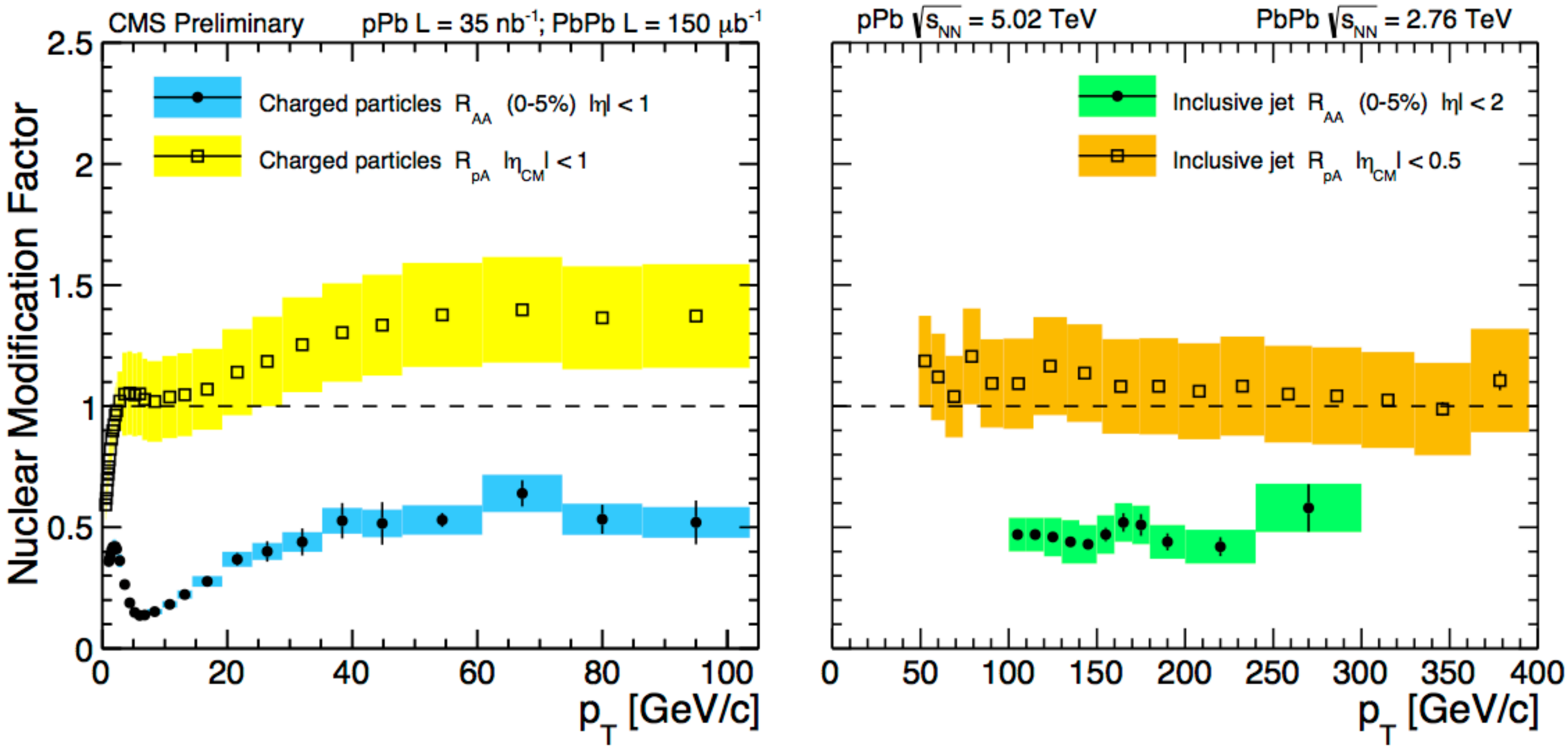
Nuclear Modification Factor (Jets)



CMS: HIN-14-001

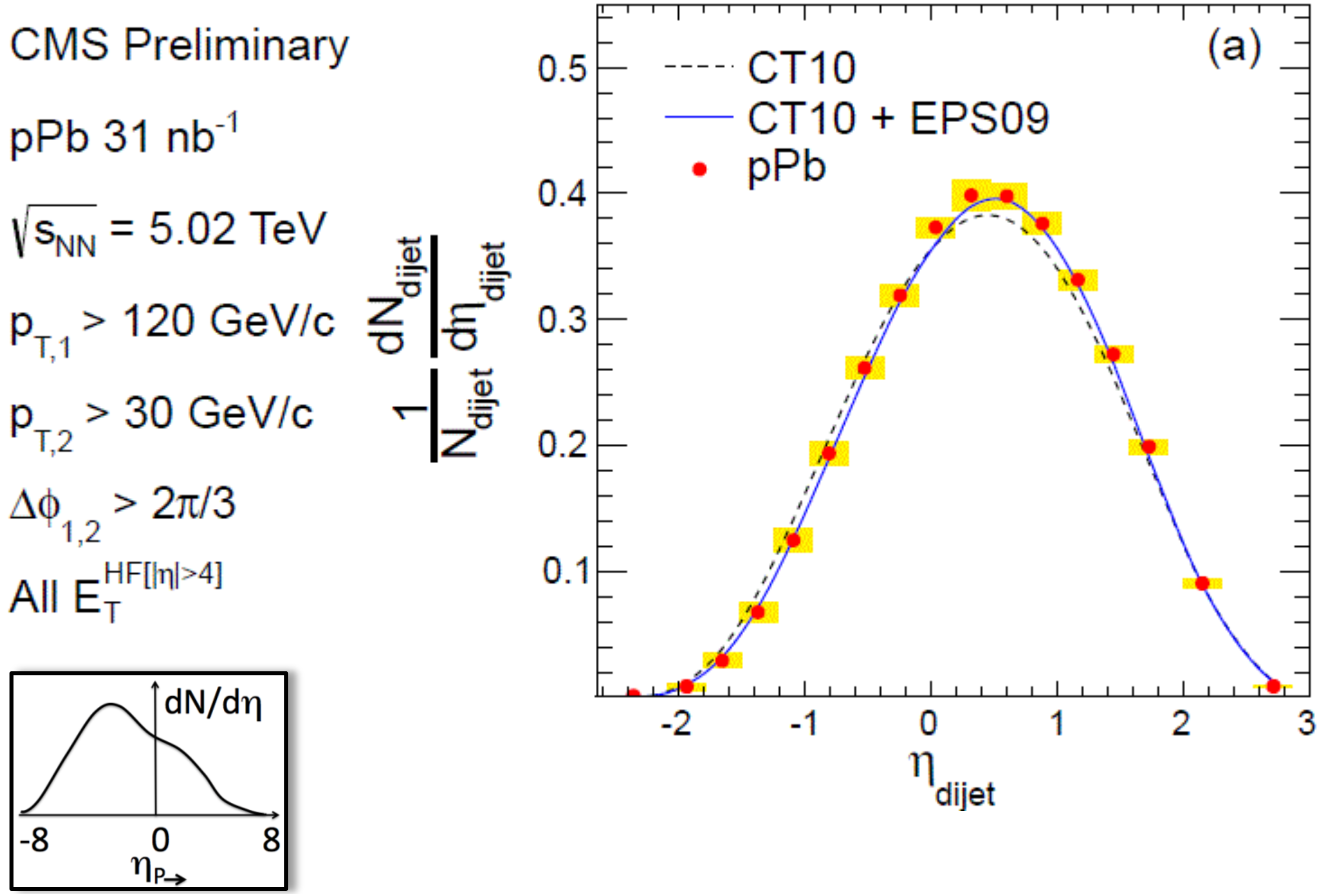
Comparison of R_{pPb} and R_{PbPb} Results

Charged Particles | **Anti-k_T R=0.3 Jets**



CMS: EPJC 72 (2012) 1945 , HIN-12-004, HIN-12-017, HIN-14-001

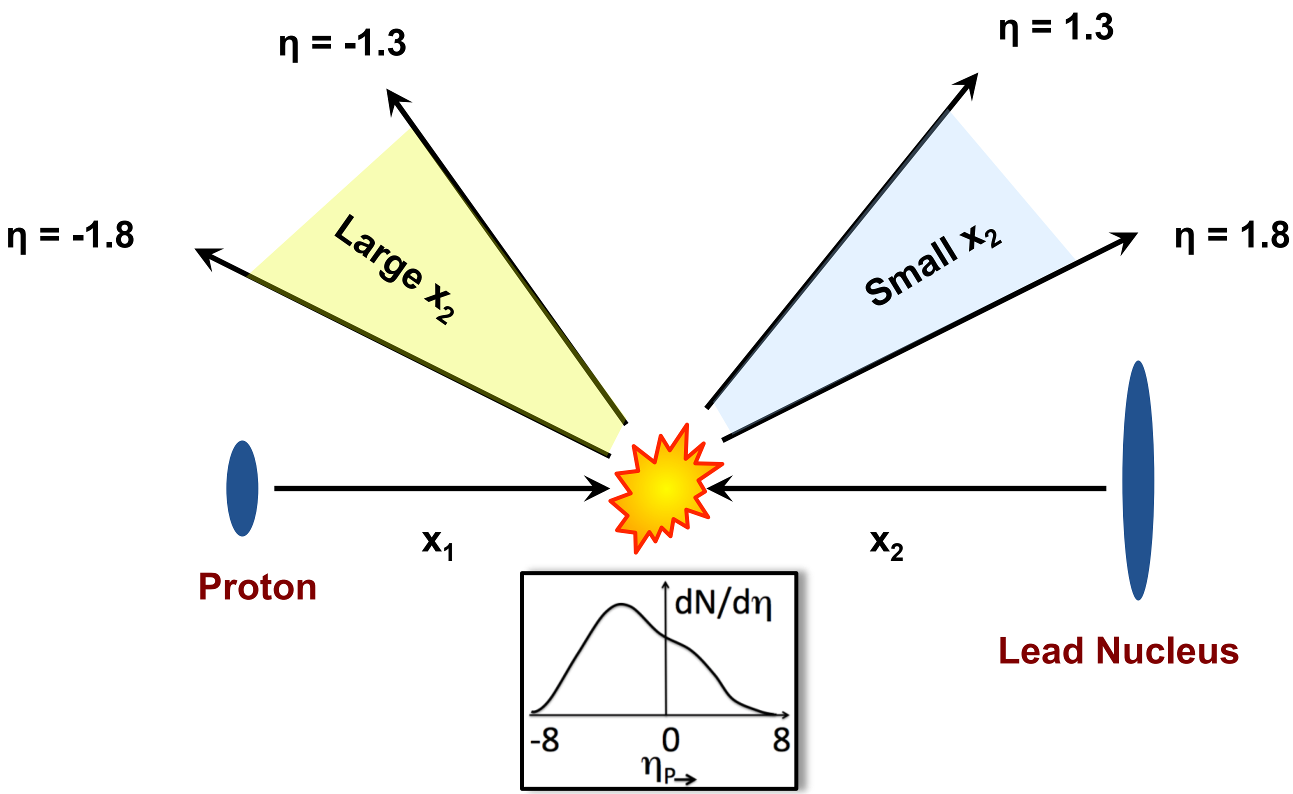
Relation to x



Modification to rapidity of jets previously observed, except,

- absolute normalization not known
- limited p_T range → Crucial for understanding the various effects

Forward-Backward Asymmetry



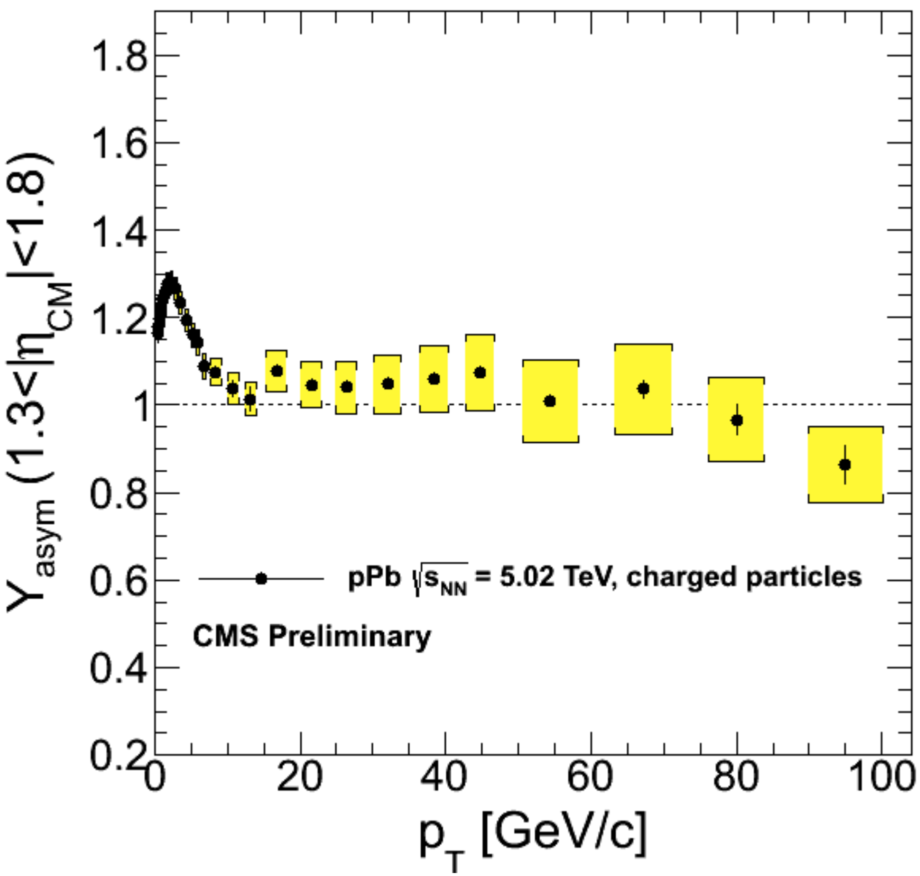
$$Y_{\mathrm{asym}}(p_{\mathrm{T}}) = \frac{d^2N_{ch}(p_{\mathrm{T}})/d\eta dp_{\mathrm{T}}|_{\eta_{\mathrm{CM}}\in[-b,-a]}}{d^2N_{ch}(p_{\mathrm{T}})/d\eta dp_{\mathrm{T}}|_{\eta_{\mathrm{CM}}\in[a,b]}}$$

PARTICLE YIELD LEAD GOING SIDE

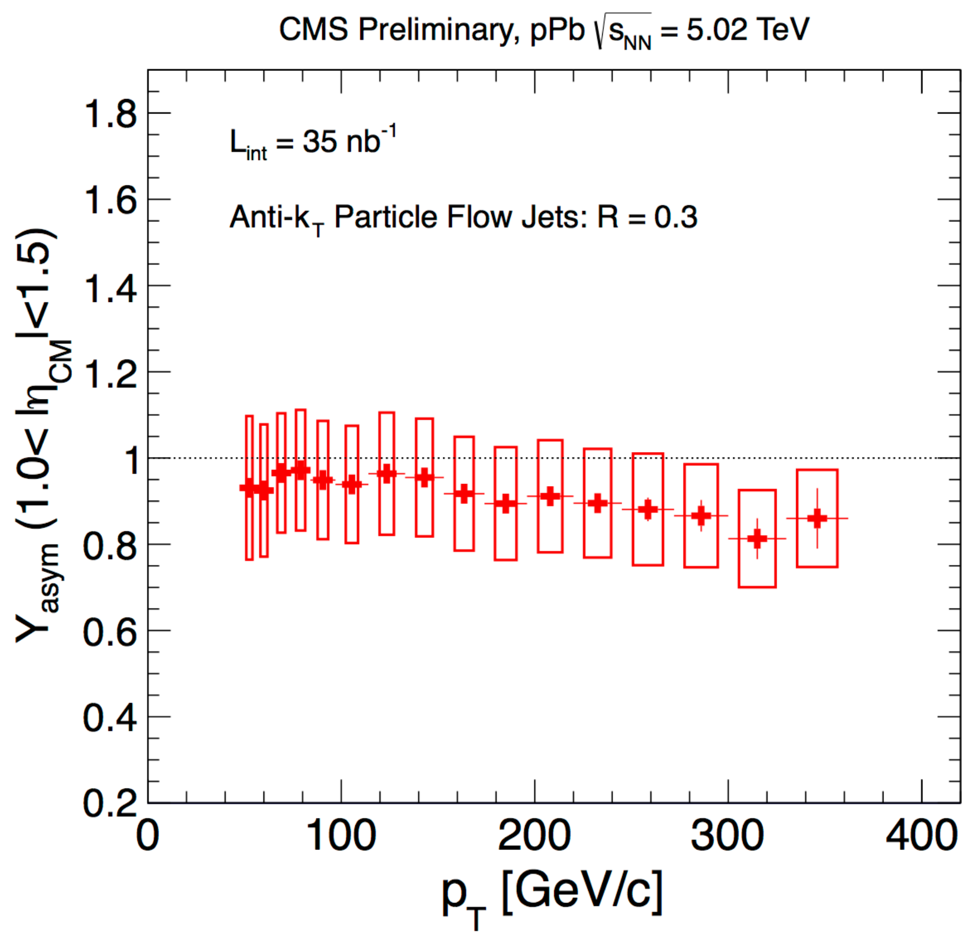
PARTICLE YIELD PROTON GOING SIDE

Forward-Backward Asymmetry

Charged Particles



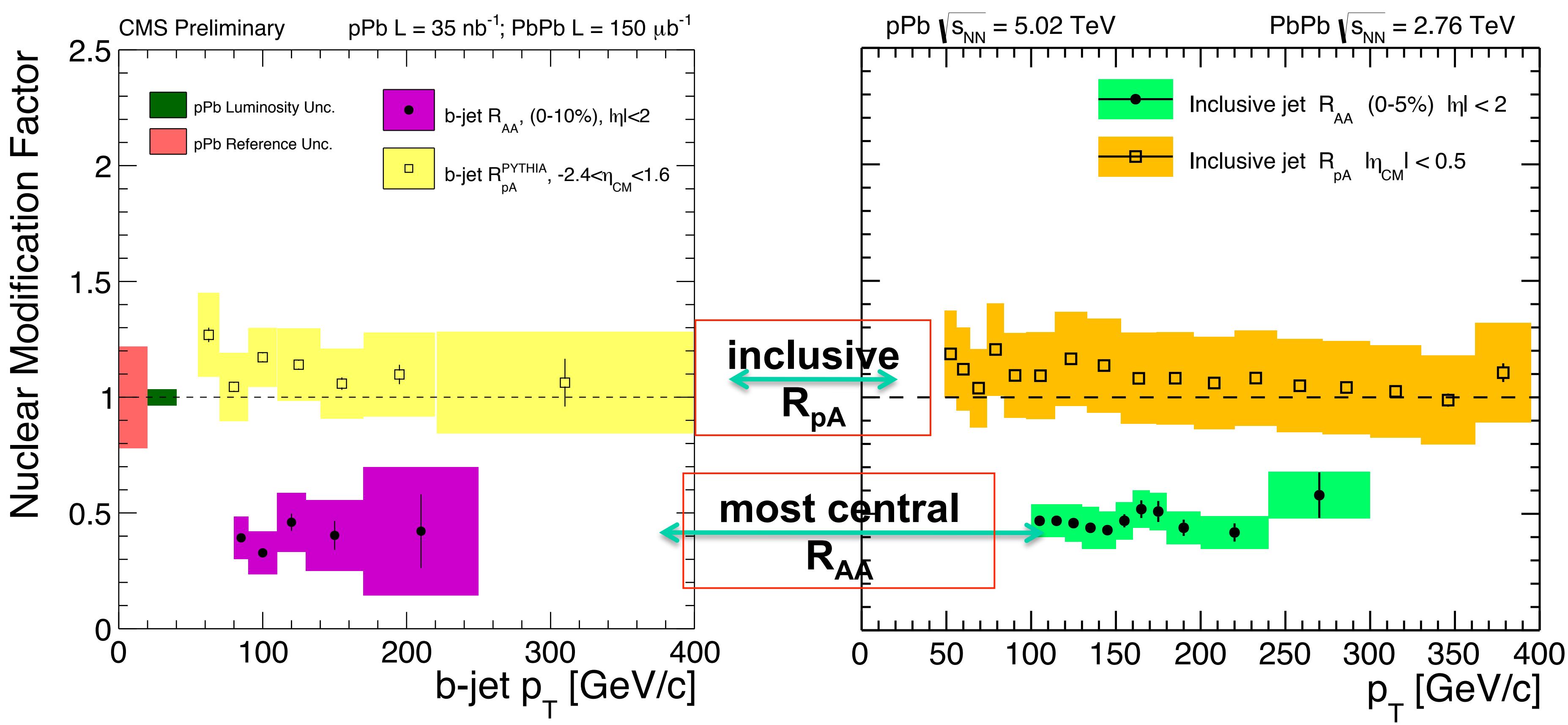
Anti-k_T R=0.3 Jets



CMS: HIN-12-017

CMS: HIN-14-001

More: b-jets



- Dramatic energy loss for jets in PbPb collisions
- Virtually no modification seen in pPb collisions
- ***We observe virtually no modification as a function of jet flavor***

CMS PAS HIN-12-003 | **CMS PAS HIN-14-007** | **CMS PAS HIN-12-004** | **CMS PAS HIN-14-001**

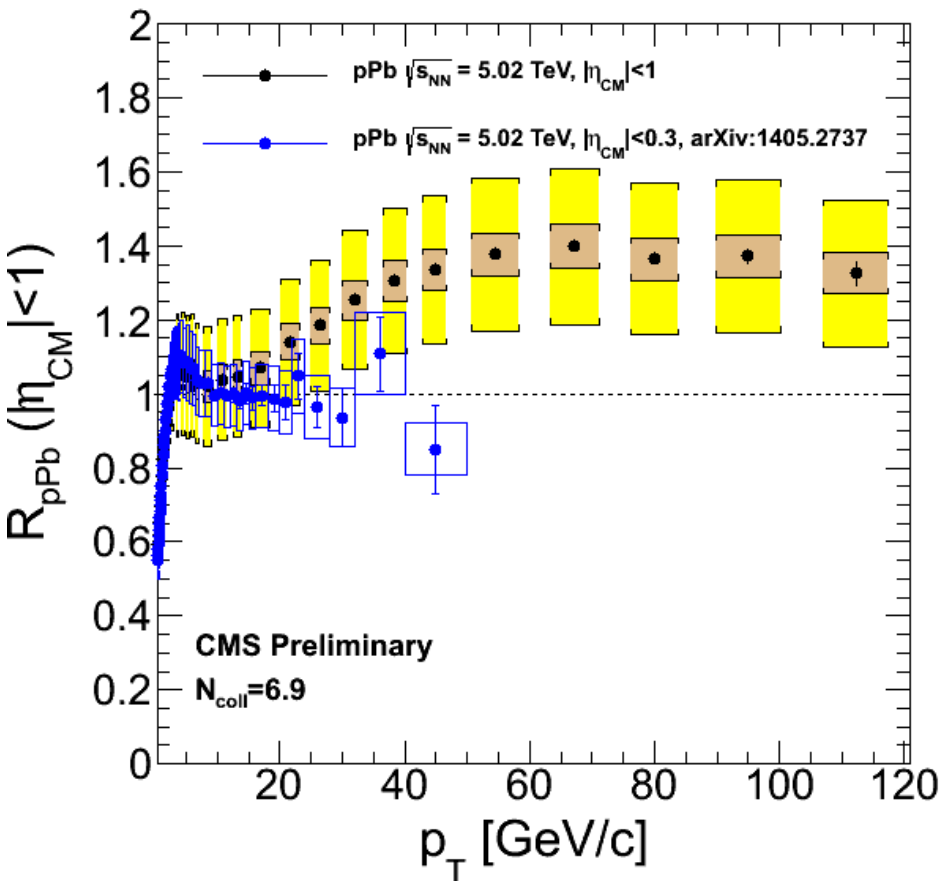
Conclusions

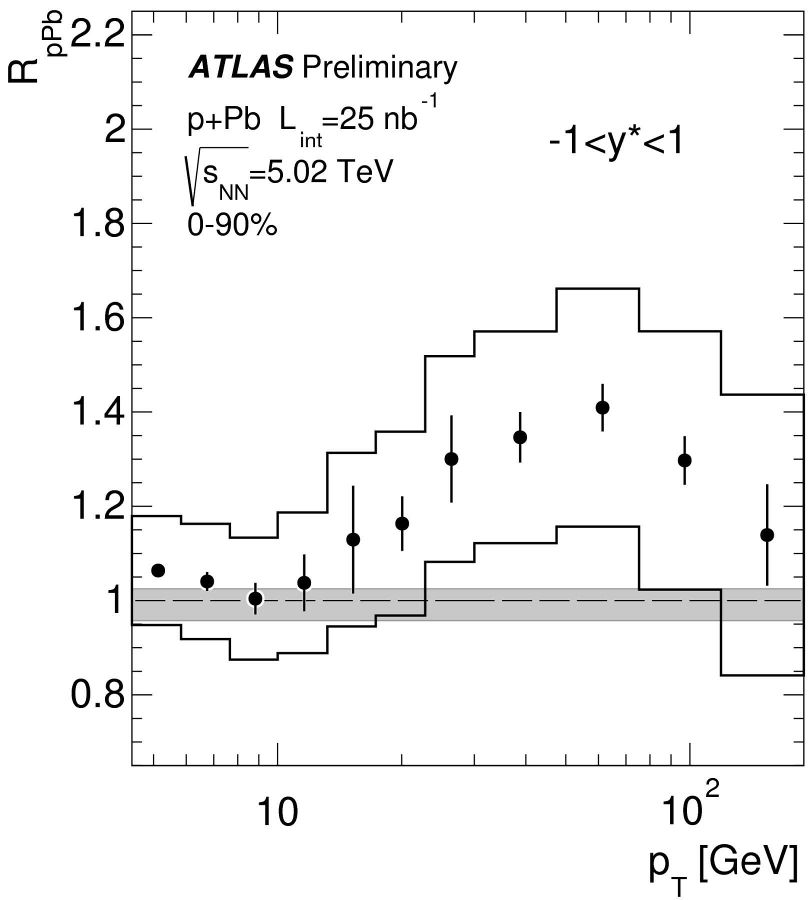
- Charged particle pPb spectrum measured to p_T = 100 GeV/c
- Inclusive Jet pPb spectrum measured to p_T > 400 GeV/c
- R_{pPb} of charged particles for $50 < p_T < 100$ is approximately 1.38 ± 0.22
- R_{pPb} of jets for $100 < p_T < 200$ is approximately 1.11 ± 0.23
- 5.02 TeV pp reference data needed to increase R_{pPb} precision!
- At high-p_T, Y_{asym} for both jets and charged hadrons is consistent with unity, at low-p_T, charged hadrons have larger yield in Pb fragmenting direction
- Need to evaluate how the new knowledge of initial-state influences the quenching interpretations in PbPb

- Charged Particle Analysis Summary: CMS-PAS-HIN-12-017
- Inclusive Jet Analysis Summary: CMS-PAS-HIN-14-001

BACKUP

Comparison to other experiments



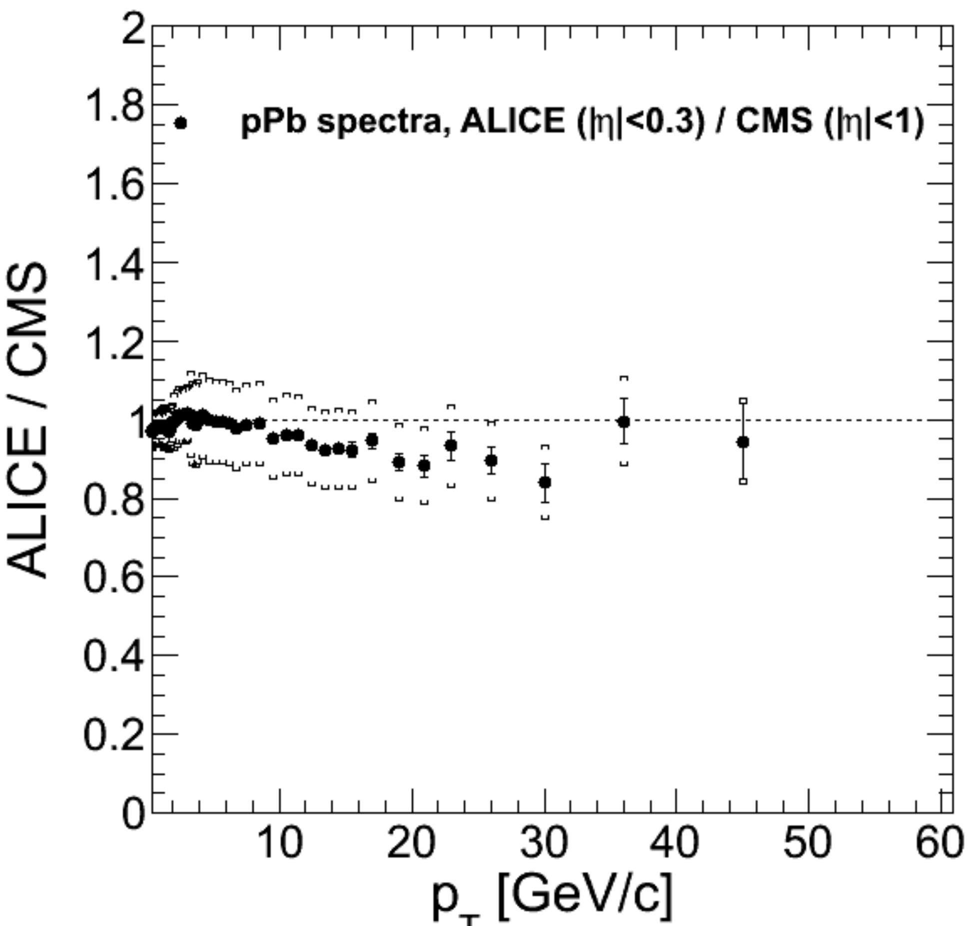


ALICE: arXiv:1405.2737
CMS: HIN-12-017
ATLAS: ATLAS-CONF-2014-029

Comparison to ALICE Charged Particles

pPb Measured Spectra

- **ALICE and CMS results generally consistent within combined systematic uncertainty.**
- **CMS results ~5-10% higher**
- **Measured pPb spectra account for ~ 1/3 of the tension**

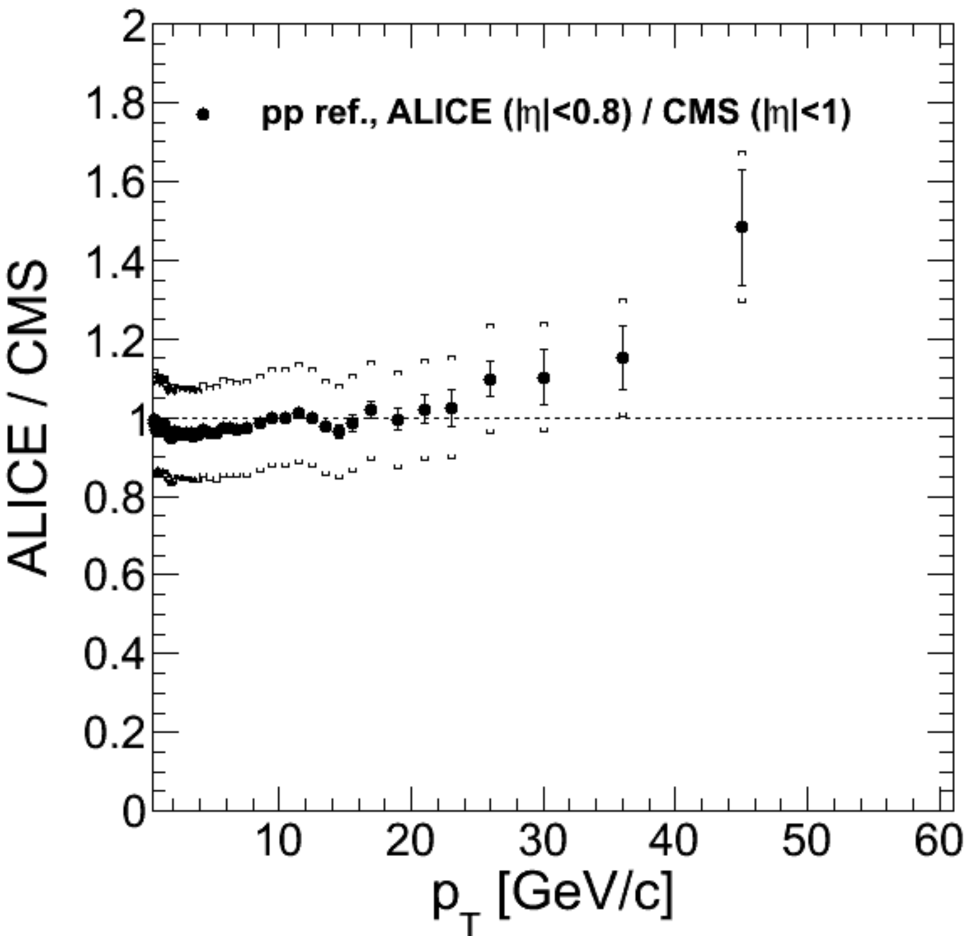


ALICE: arXiv:1405.2737
CMS: HIN-12-017

Comparison to ALICE Charged Particles

Artificial pp Reference Spectra

- **ALICE and CMS references diverge at high-p_T**
- **Accounts for ~ 2/3 of the tension**
- **Different methods used**
  - **NLO-scaling (ALICE)**
  - **Direct Interpolation (CMS)**
- **Different underlying data used for ALICE and CMS**

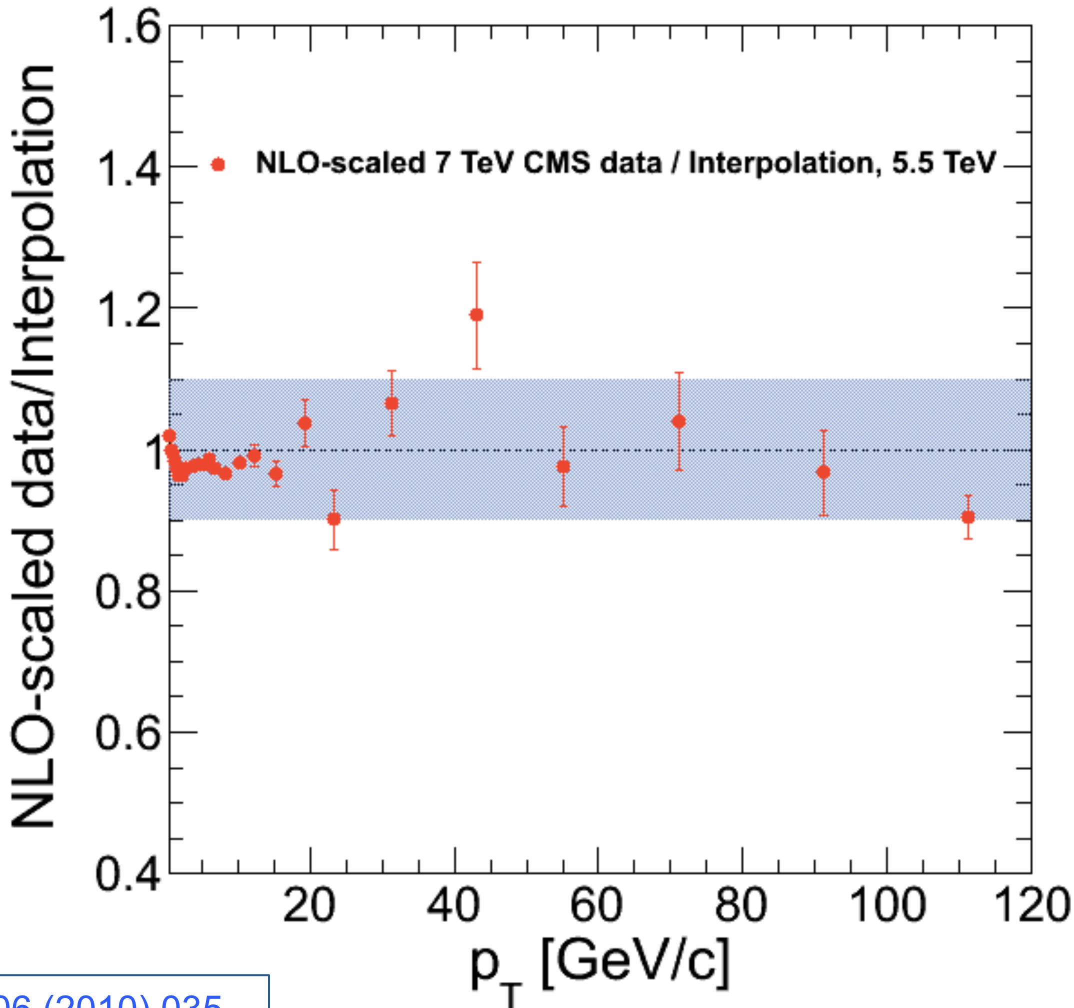


ALICE: arXiv:1405.2737
CMS: HIN-12-017

Comparison to ALICE Charged Particles

Comparison of Methods

- Perform NLO Scaling on CMS data to 5.5 TeV and
- Compare with interpolation to 5.5 TeV
- Two methods generally agree within 10%
- No clear systematic trend above or below unity

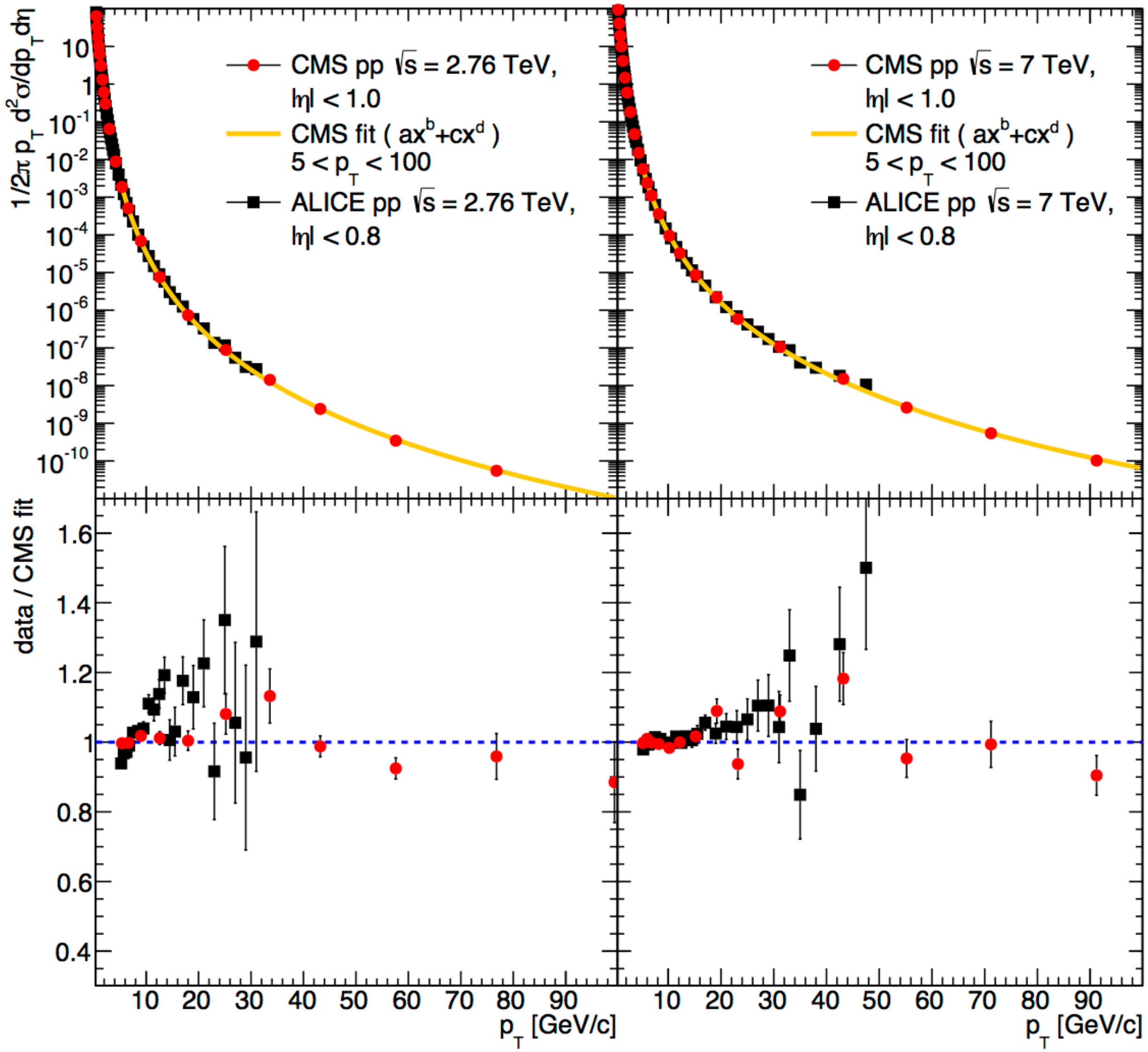


NLO – F. Arleo, D. d'Enterria, A. Yoon: JHEP 06 (2010) 035
CMS: HIN-12-017

Comparison to ALICE Charged Particles

Comparison pp Data from CMS and ALICE

- **7 TeV and 2.76 TeV datasets compared**
- **Larger statistical uncertainty on high-p_T ALICE data**

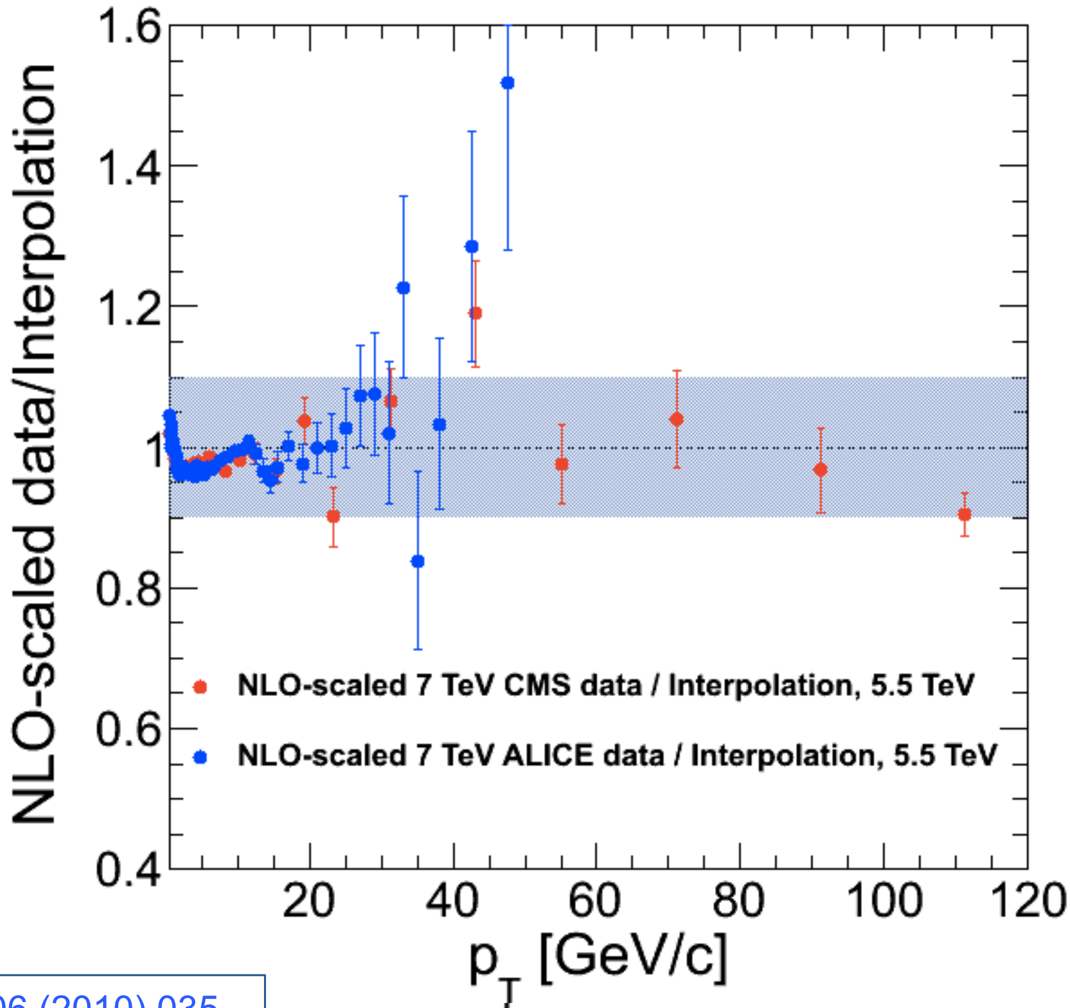


ALICE: EPJC 73 (2013) 2662
CMS: HIN-12-017

Comparison to ALICE Charged Particles

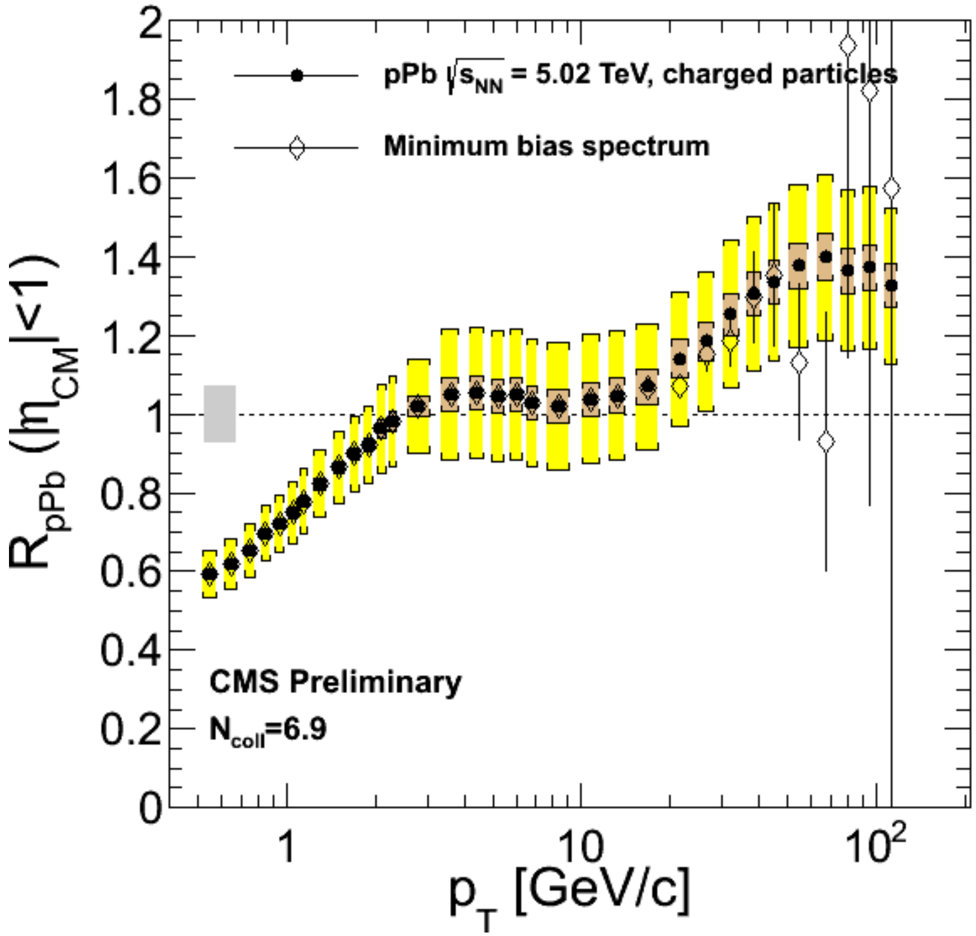
Comparison of NLO-Scaling with ALICE and CMS

- **Perform NLO-Scaling on both ALICE and CMS data to 5.5 TeV and**
- **Compare with CMS interpolation to 5.5 TeV**

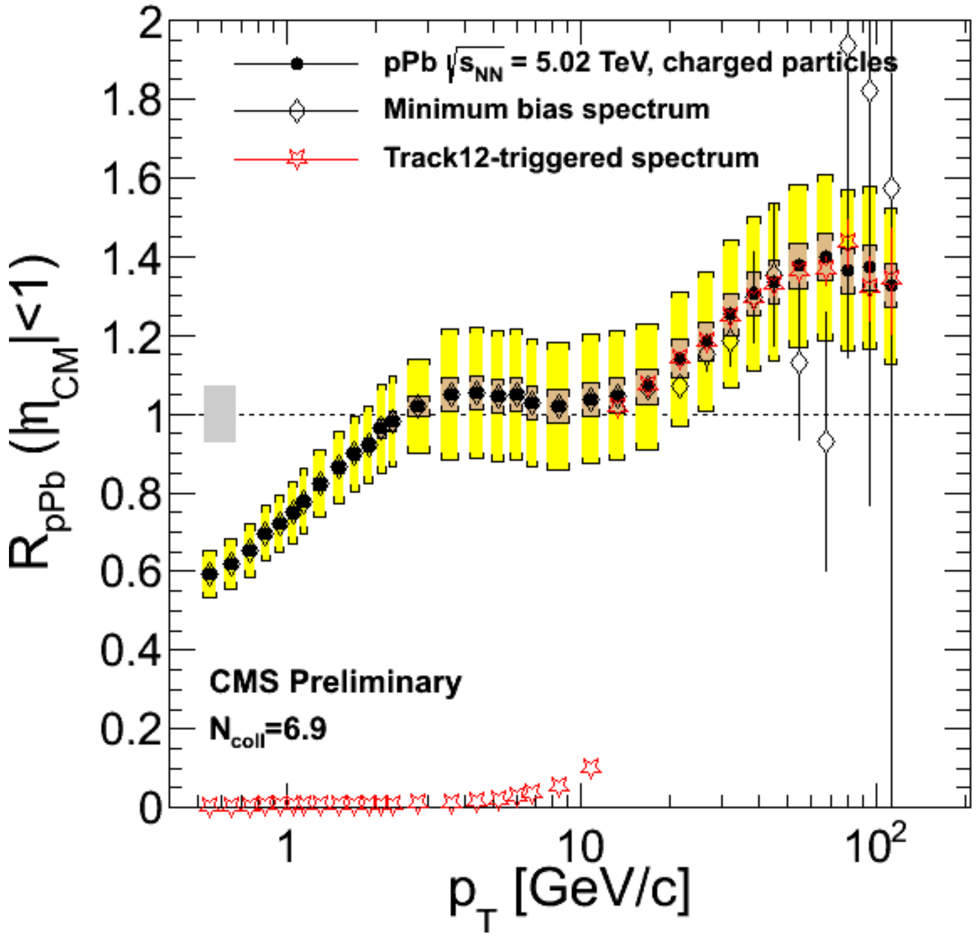


NLO – F. Arleo, D. d'Enterria, A. Yoon: JHEP 06 (2010) 035
ALICE: arXiv:1405.2737 **CMS:** HIN-12-017

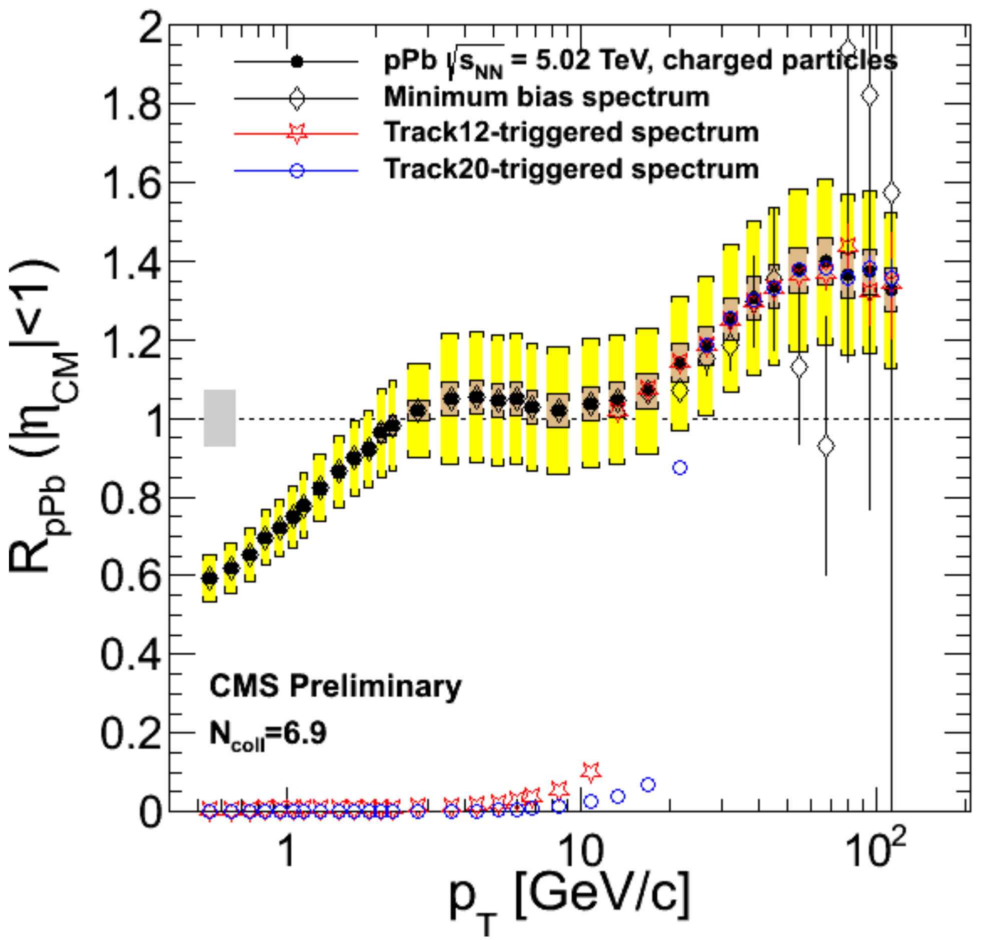
R_{pPb} from Individual Triggers



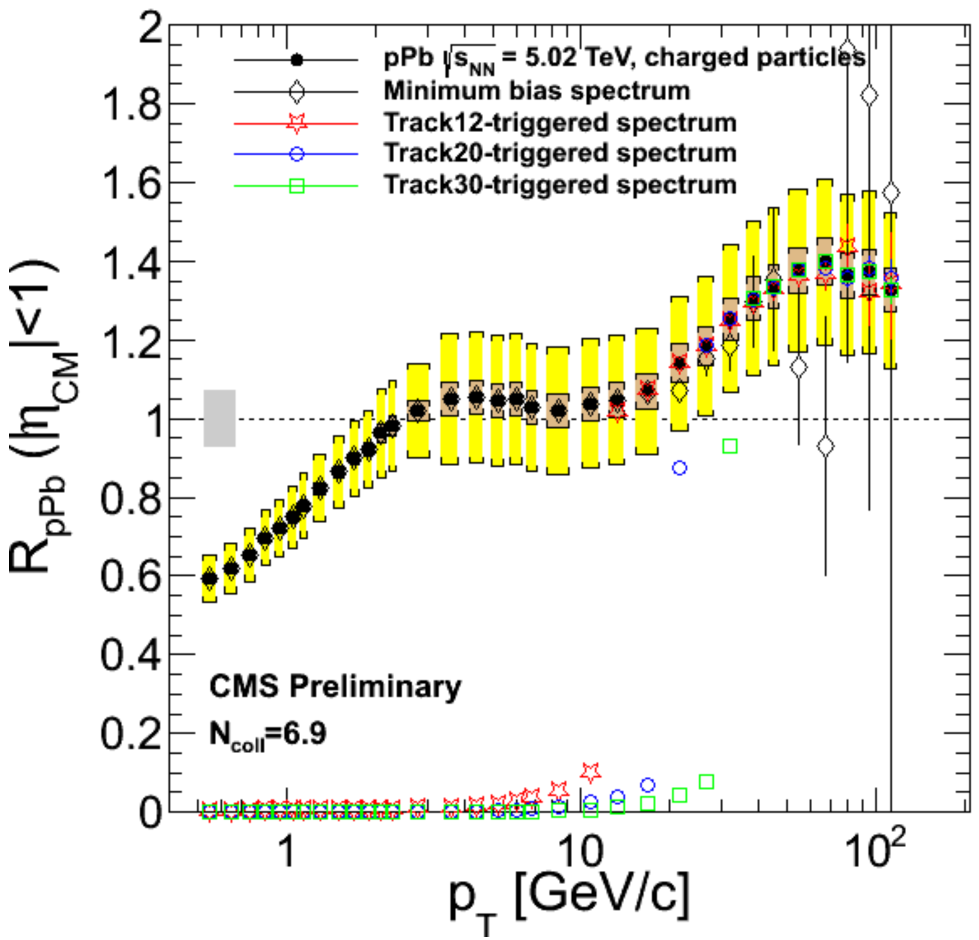
R_{pPb} from Individual Triggers



R_{pPb} from Individual Triggers

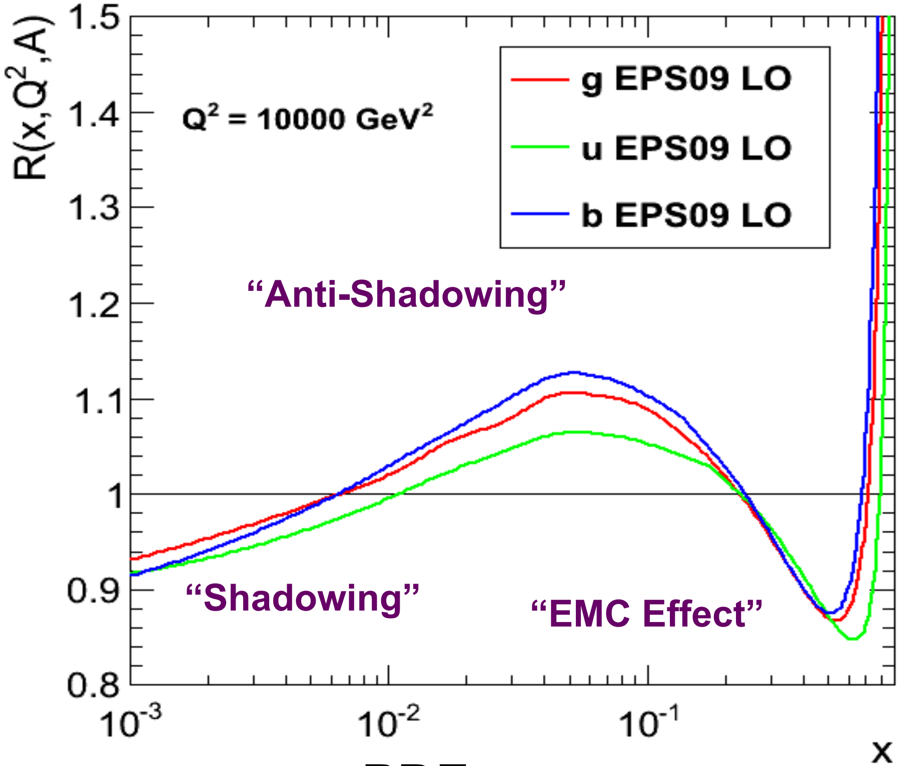


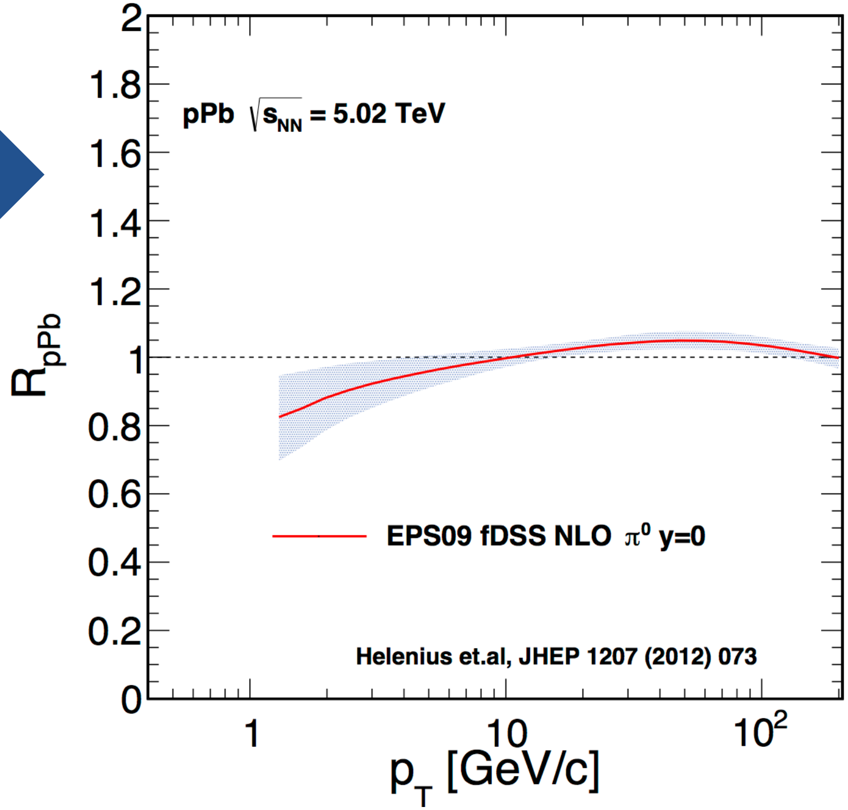
R_{pPb} from Individual Triggers



Nuclear PDFs

François Arleo and Jean-Philippe Guillet
http://lapth.cnrs.fr/npdfgenerator/



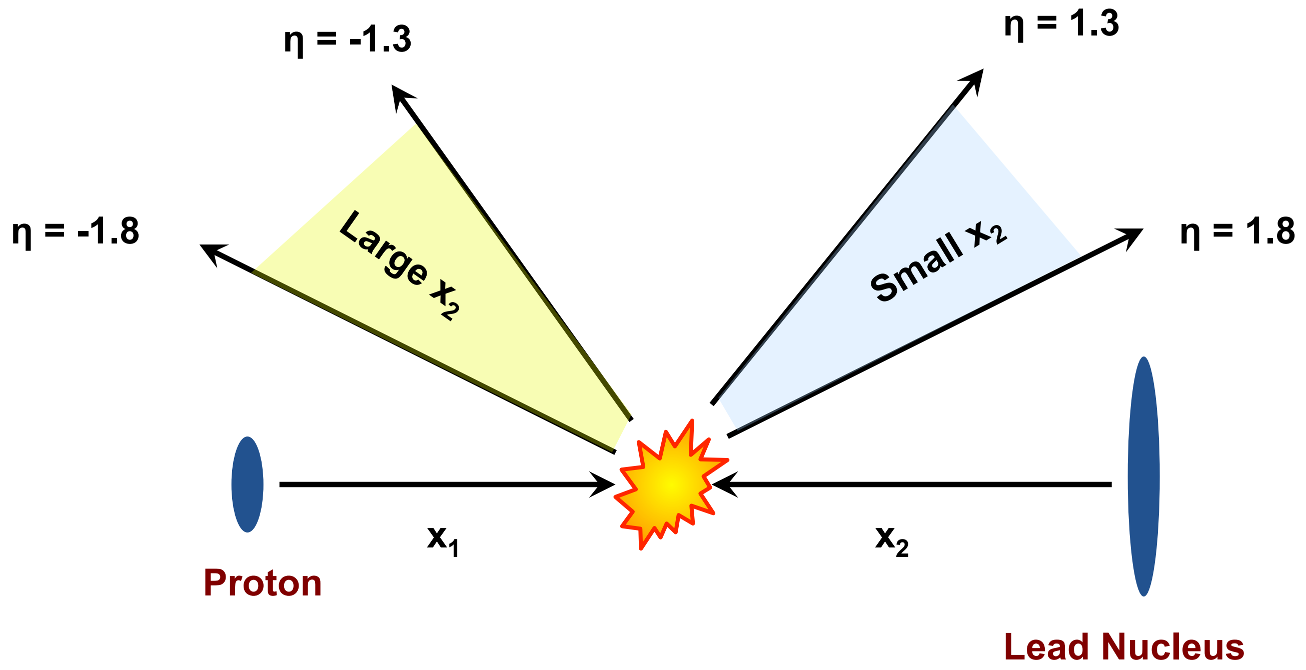


$$R = \frac{\text{nPDF}}{\text{PDF}}$$

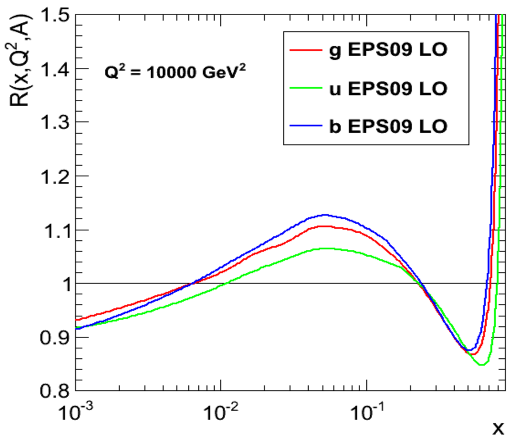
EPS09 - K. Eskola, H. Paukkunen, C. Salgado: JHEP 04 (2009) 065

I. Helenius, et al. JHEP 07 (2012) 073

Forward-Backward Asymmetry



Nuclear PDF prediction



Expectations:

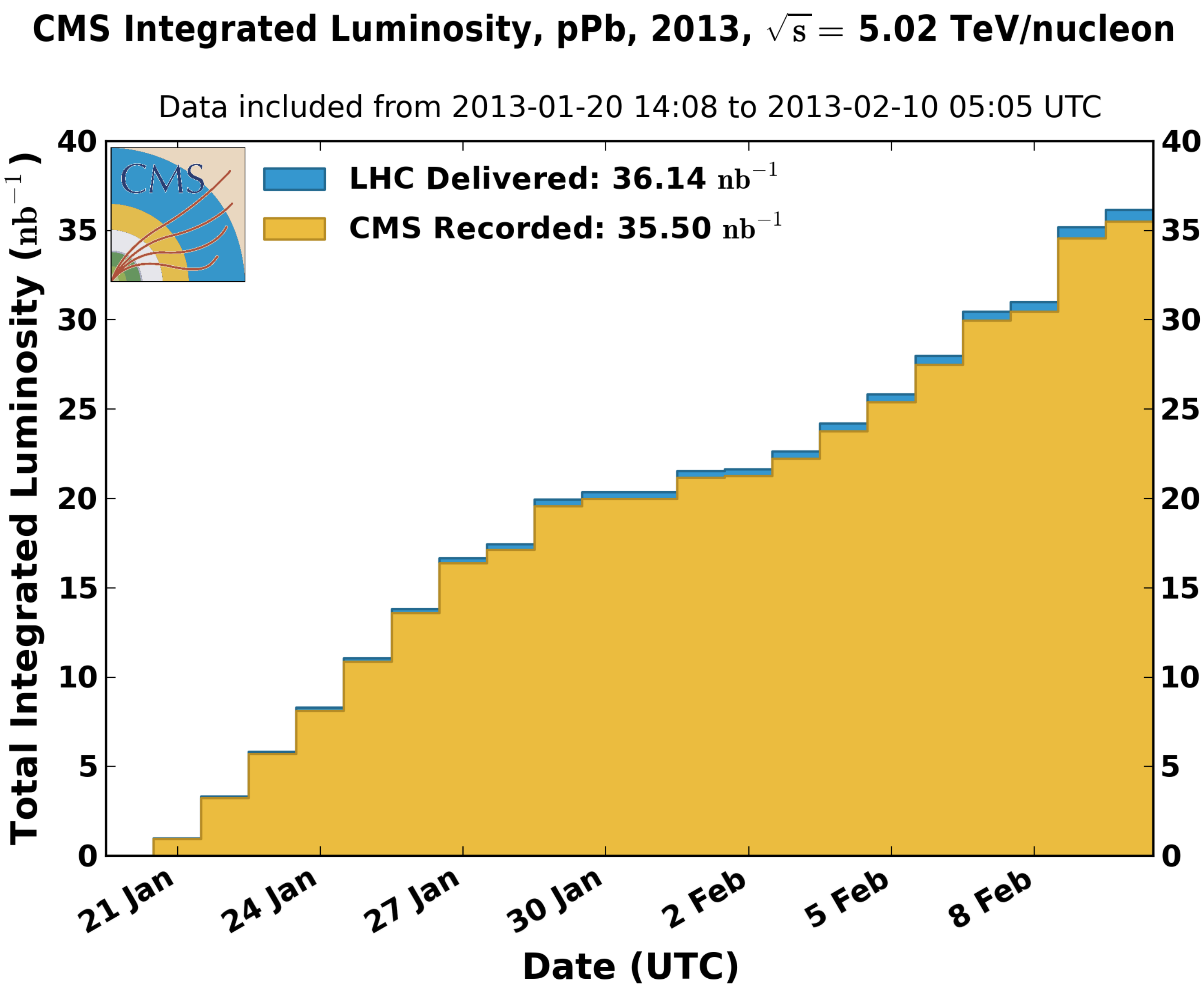
Y_{asym} > 1 at low p_T
Y_{asym} < 1 at very high p_T

$$Y_{\mathrm{asym}}(p_{\mathrm{T}}) = \frac{d^2N_{ch}(p_{\mathrm{T}})/d\eta dp_{\mathrm{T}}|_{\eta_{\mathrm{CM}}\in[-b,-a]}}{d^2N_{ch}(p_{\mathrm{T}})/d\eta dp_{\mathrm{T}}|_{\eta_{\mathrm{CM}}\in[a,b]}}$$

PARTICLE YIELD LEAD GOING SIDE

PARTICLE YIELD PROTON GOING SIDE

2013 pPb Luminosity



Charged Particle Dataset and Definitions

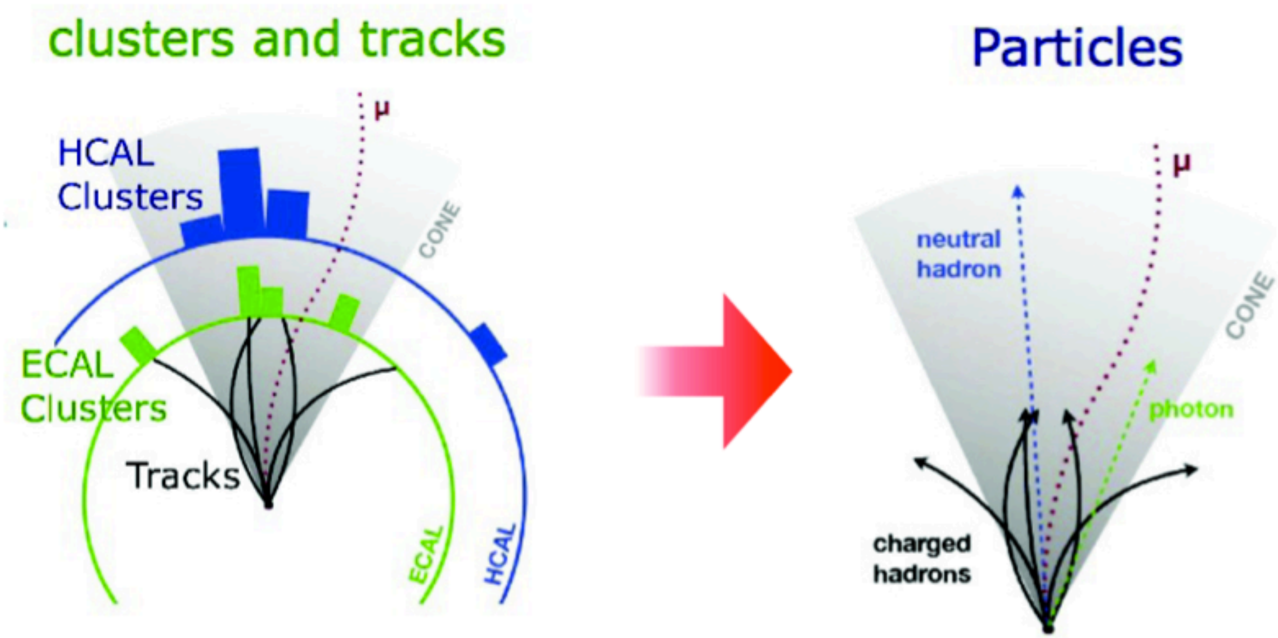
- **Dataset: 29 nb^{-1} of pPb collision data at $\sqrt{s_{NN}}$ = 5.02 recorded in early 2013**

- **Particle yields measured for "Double Sided Events"**
  - Collision producing a particle with E > 3 GeV in 3 < η < 5 and similarly in -5 < η < -3.
  - 94-97% of total inelastic cross section, similar to NSD
  - Close to offline event selection and min-bias trigger

- **Primary Charged Particles**
  - Charged particles produced in the collision with cτ > 1 cm
  - Charged decay products of any particle produced in the collision with cτ < 1 cm
  - Compatible with results of the PYTHIA generator
  - Includes strange baryons: Σ, Ξ, Ω

Particle Flow

Particle flow reconstructs all stable particle in the event: $h^{+/-}$, γ, h^0, e, μ

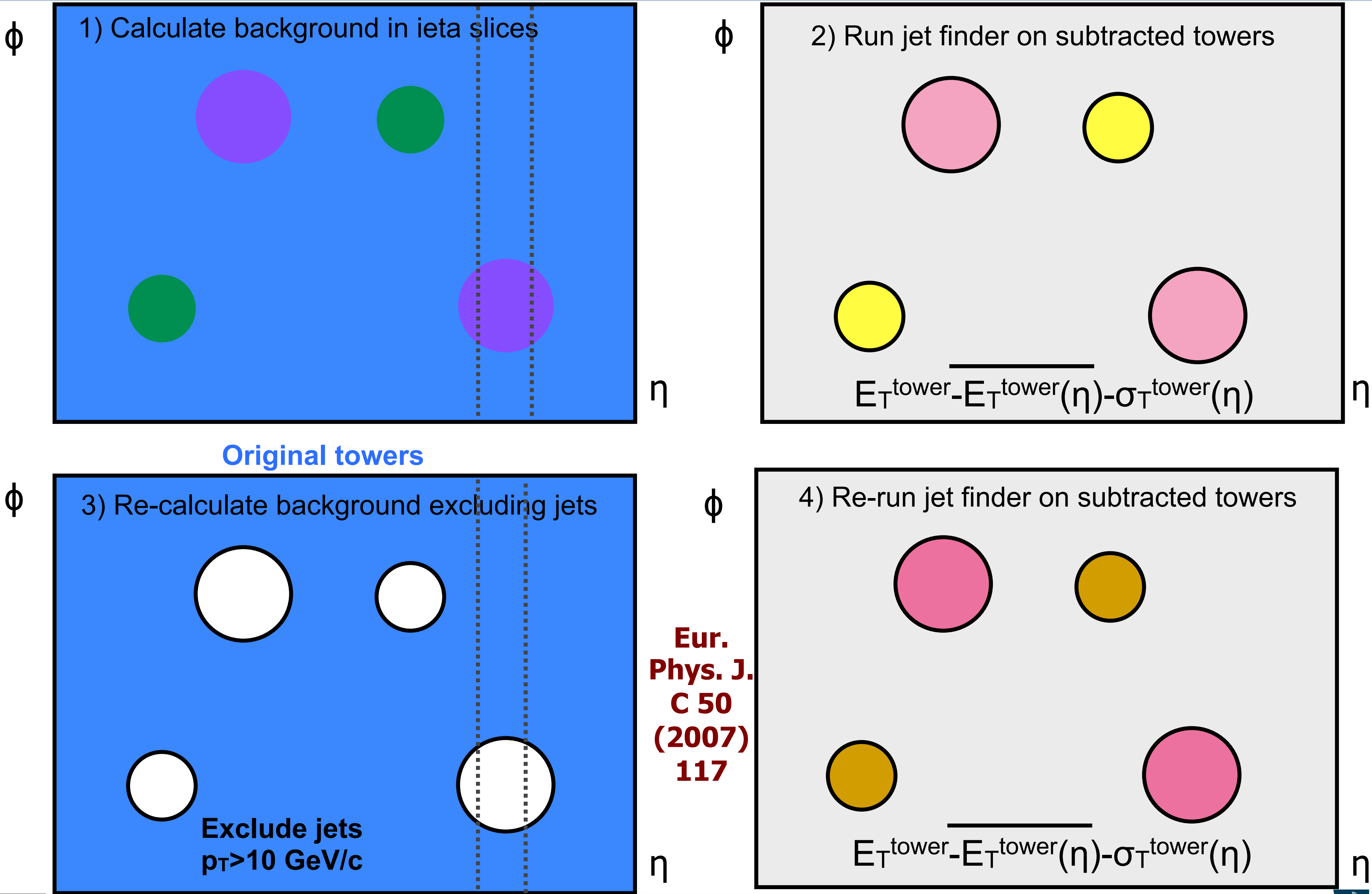


- **On average jets are:**

  ~ 65% charged hadrons, ~ 25% photons, ~ 10 % neutral hadrons
- **Using the silicon tracker (vs. HCAL) to measure charged hadrons**
  - **Improves resolution, avoids non-linearity**
  - **Decreases sensitivity to the fragmentation pattern of jets**
- **Used extensively in ALEPH, CMS and proposed for the ILC**

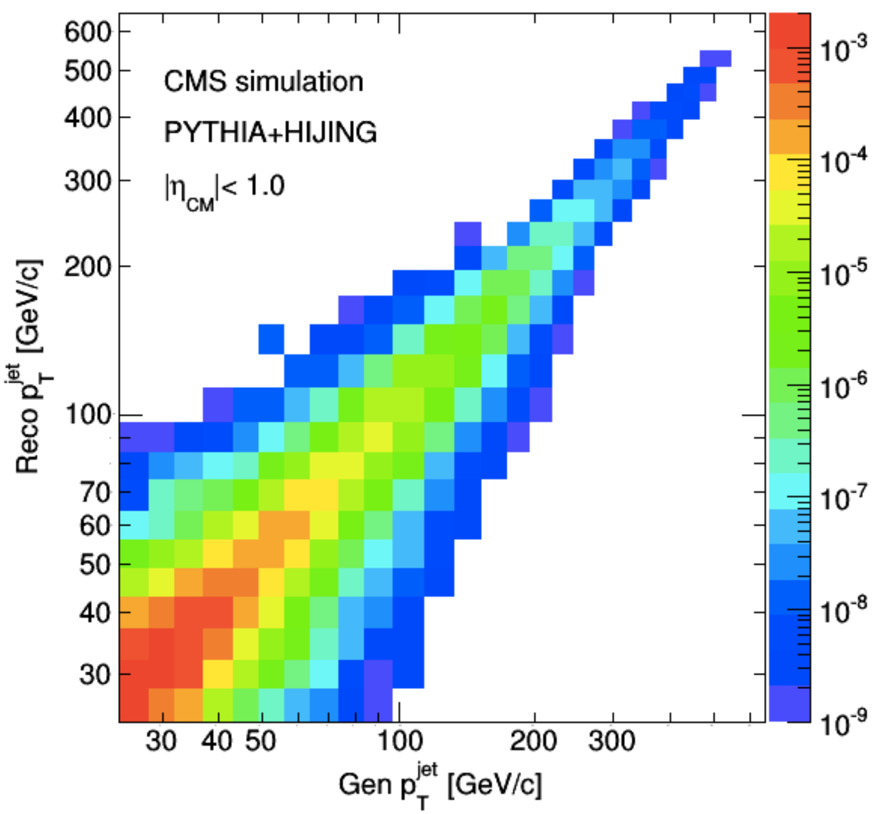
M. Nguyen for CMS, QM2011 talk

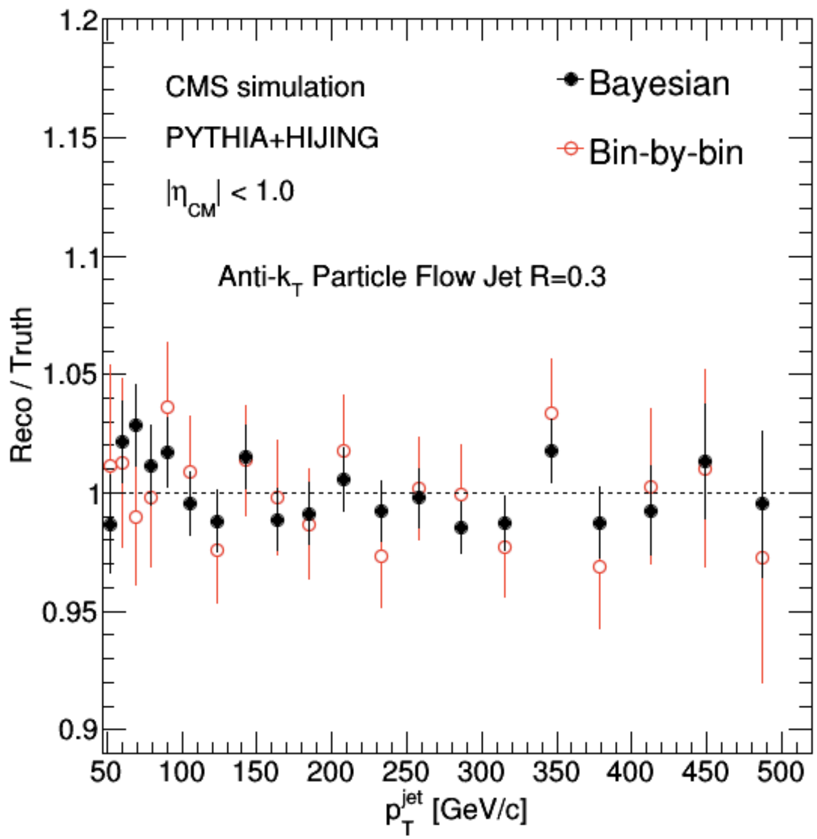
Iterative Pileup Subtraction



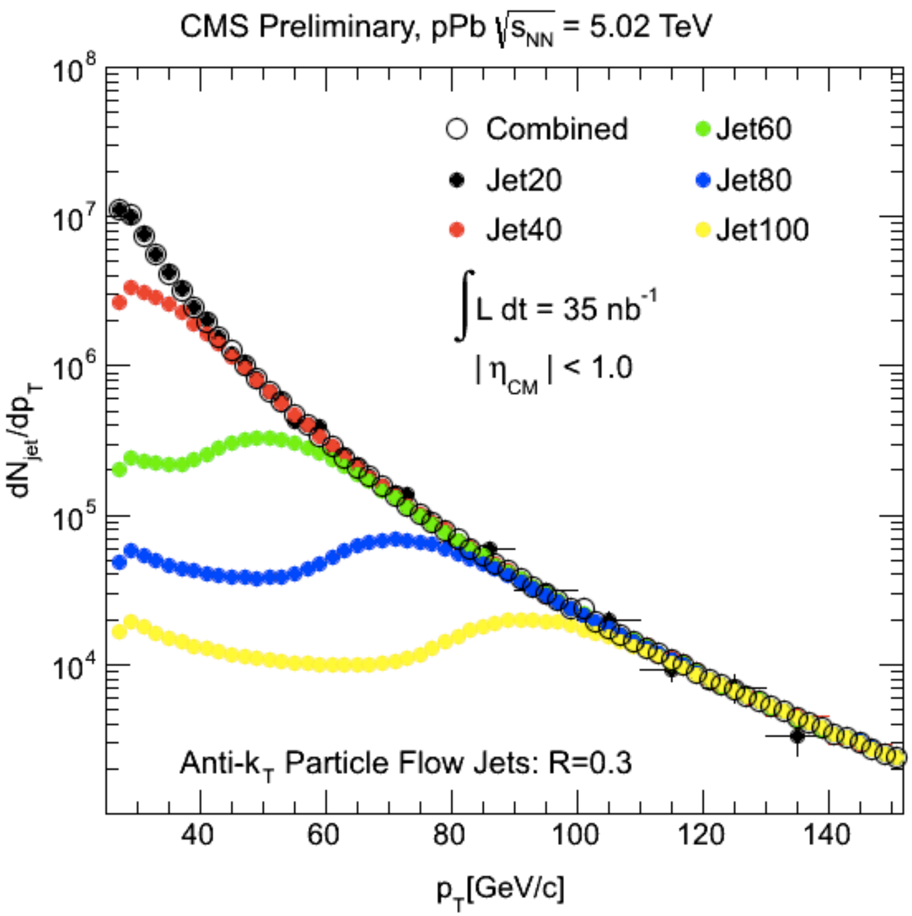
Eur. Phys. J. C 50 (2007) 117

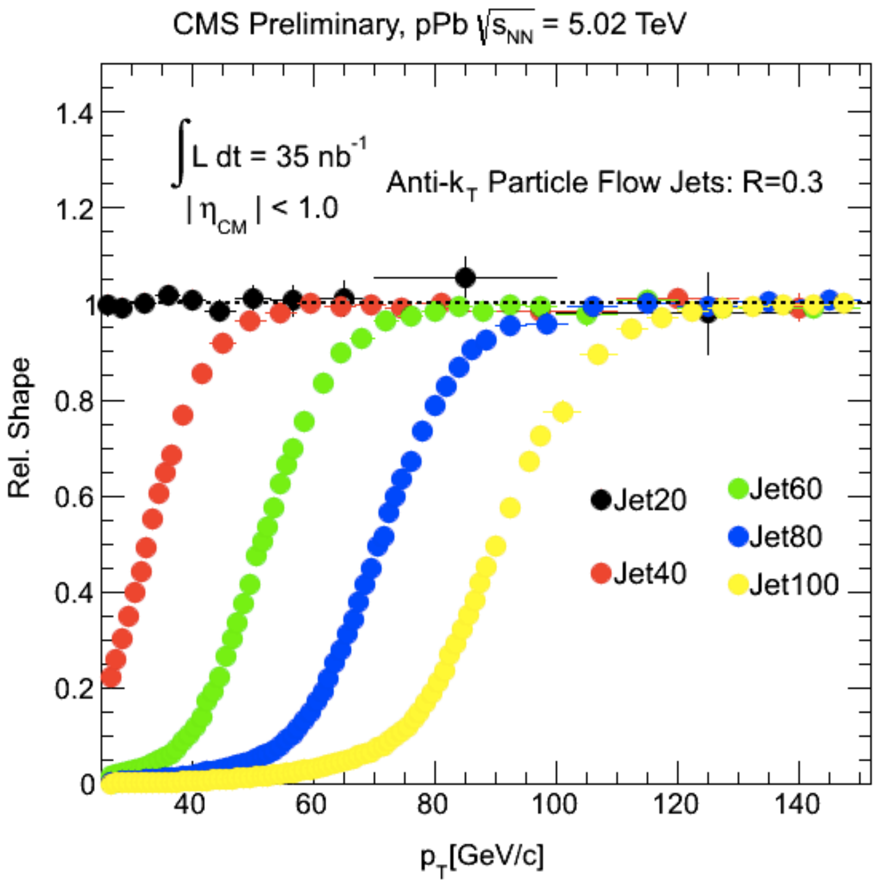
Jet Unfolding





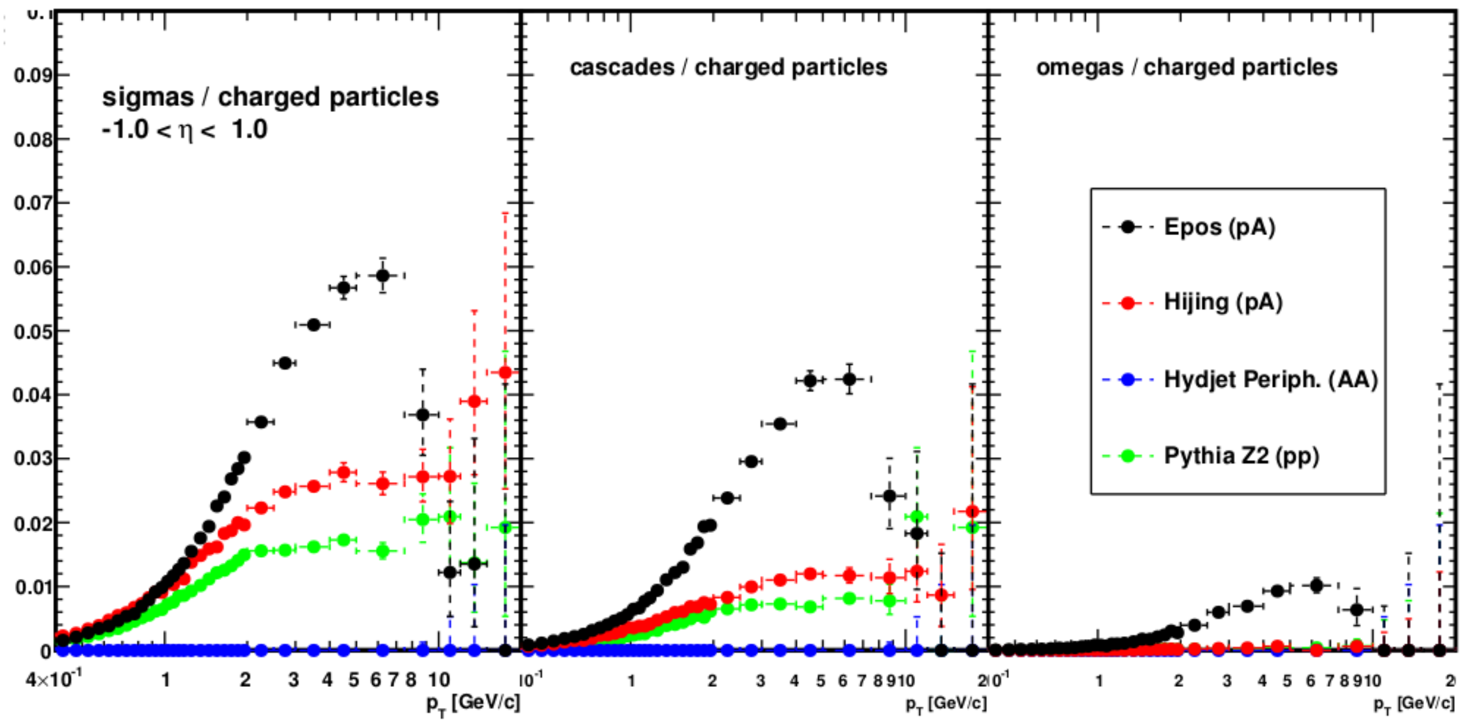
Jet Triggers – Relative Shape



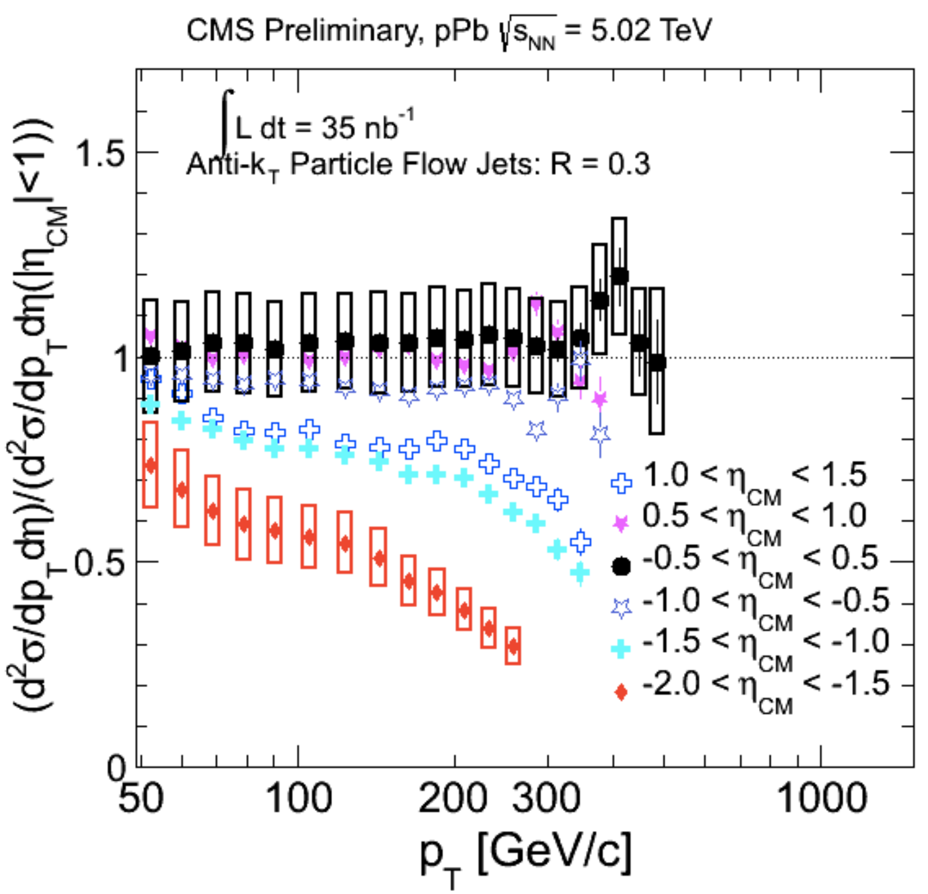


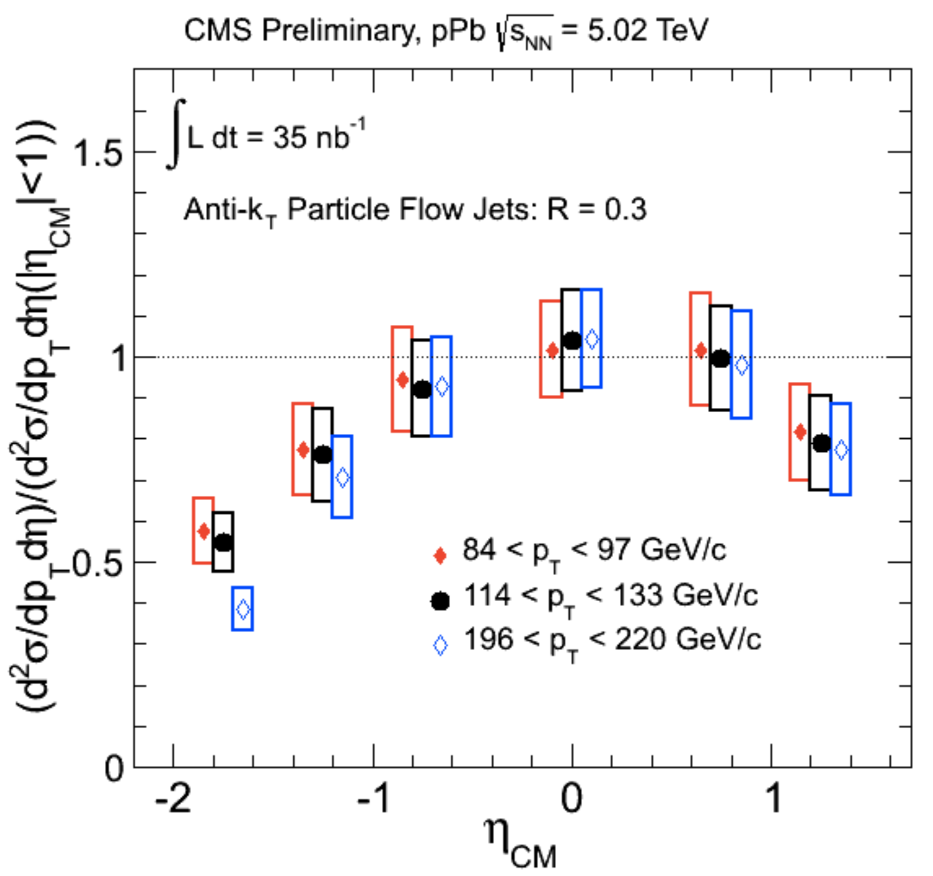
Particle Composition Uncertainty

- Definition of primary charged particles includes strange baryons: Σ, Ξ, Ω
- Low efficiency due to short lifetime, better efficiency at high-p_T
- EPOS model predicts large fraction of strange baryons
- Dominant uncertainty for p_T ~ 5-10 GeV/c

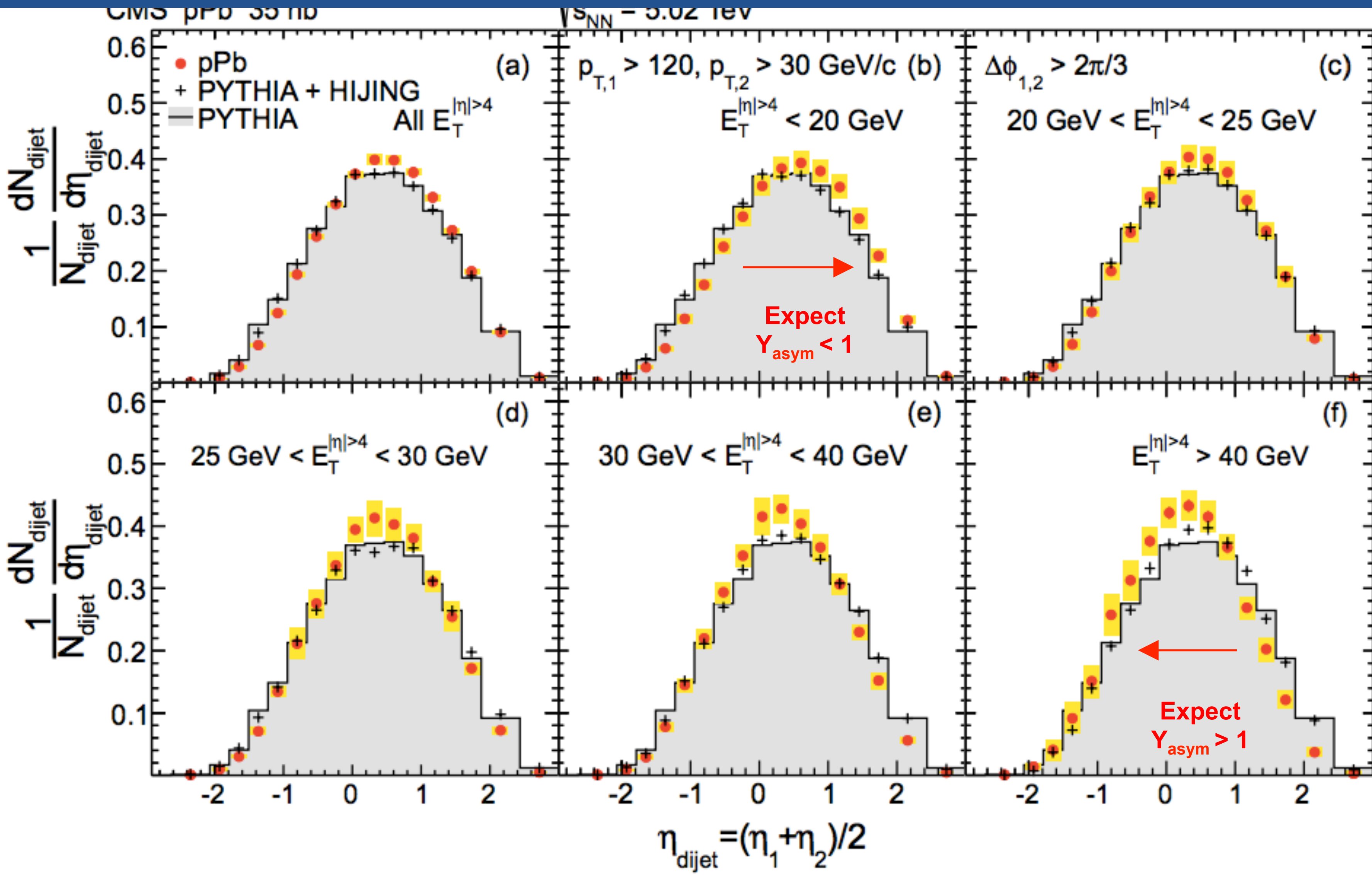


Jet Spectrum Eta Dependence



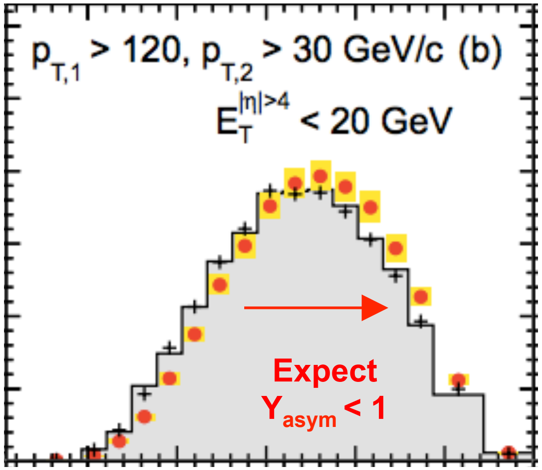


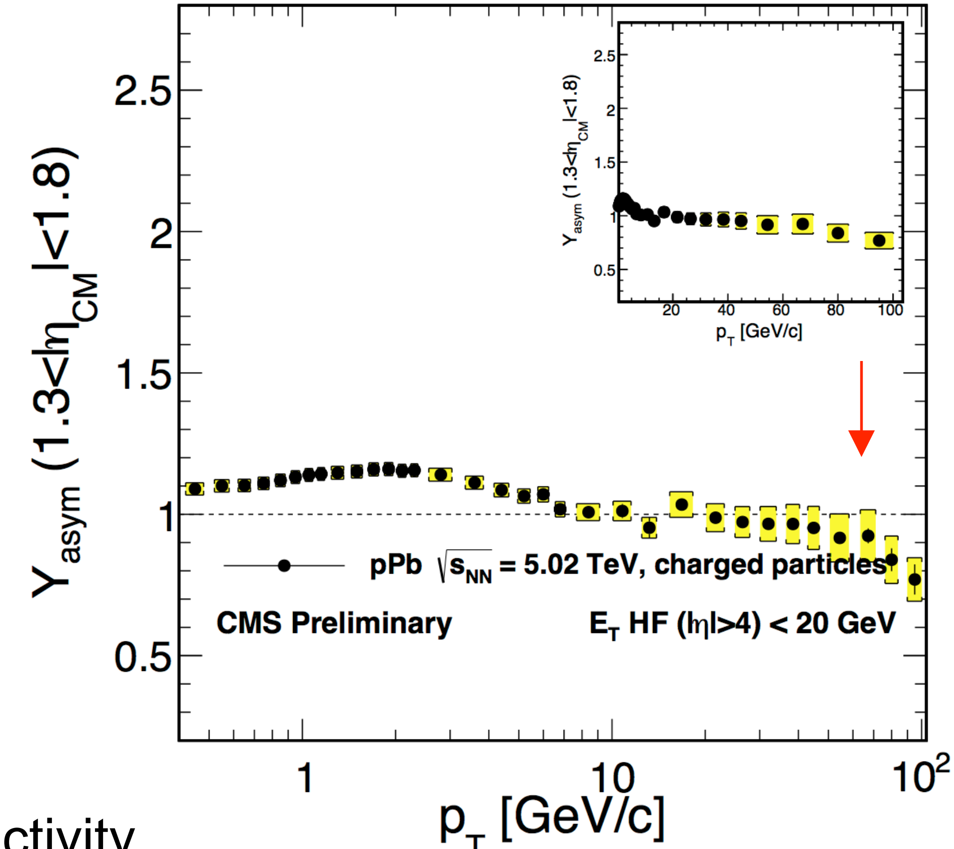
Dijet Asymmetry Comparison



CMS-HIN-13-001, Submitted to EPJC, **arXiv:1401.4433**

Dijet Asymmetry Comparison

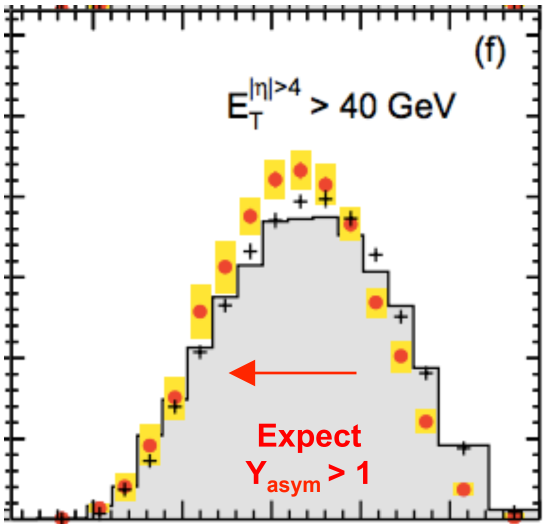


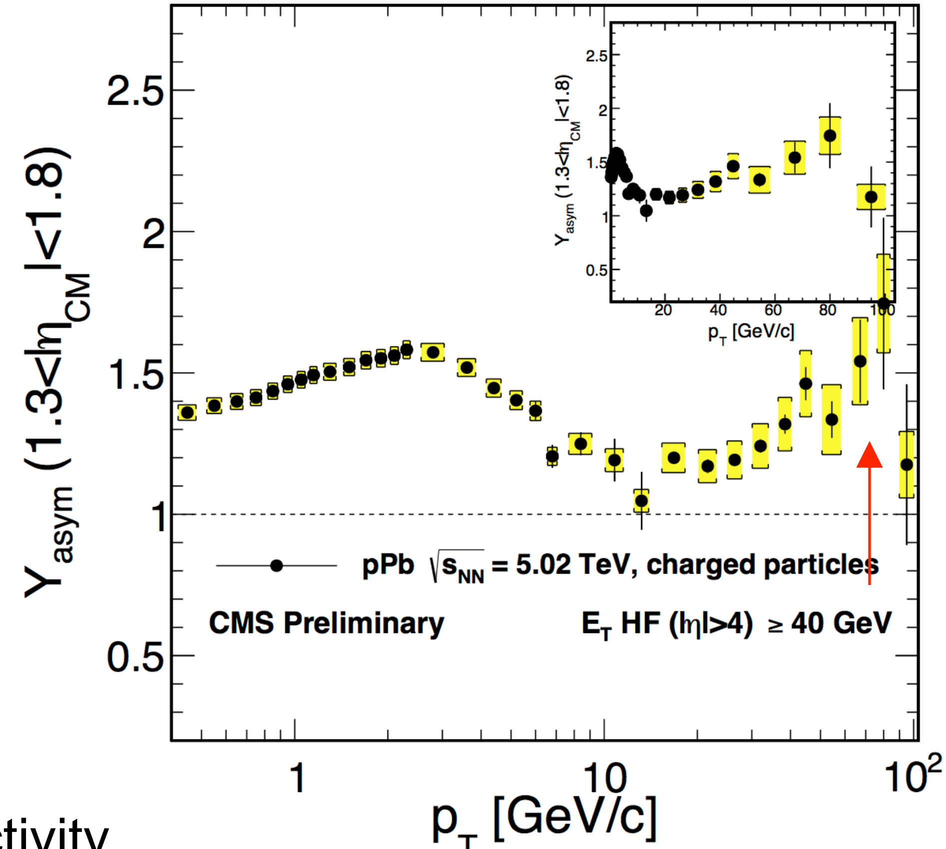


"Peripheral" events with low HF activity

Dijets shifted to p-going side, expect Y_{asym} < 1

Dijet Asymmetry Comparison



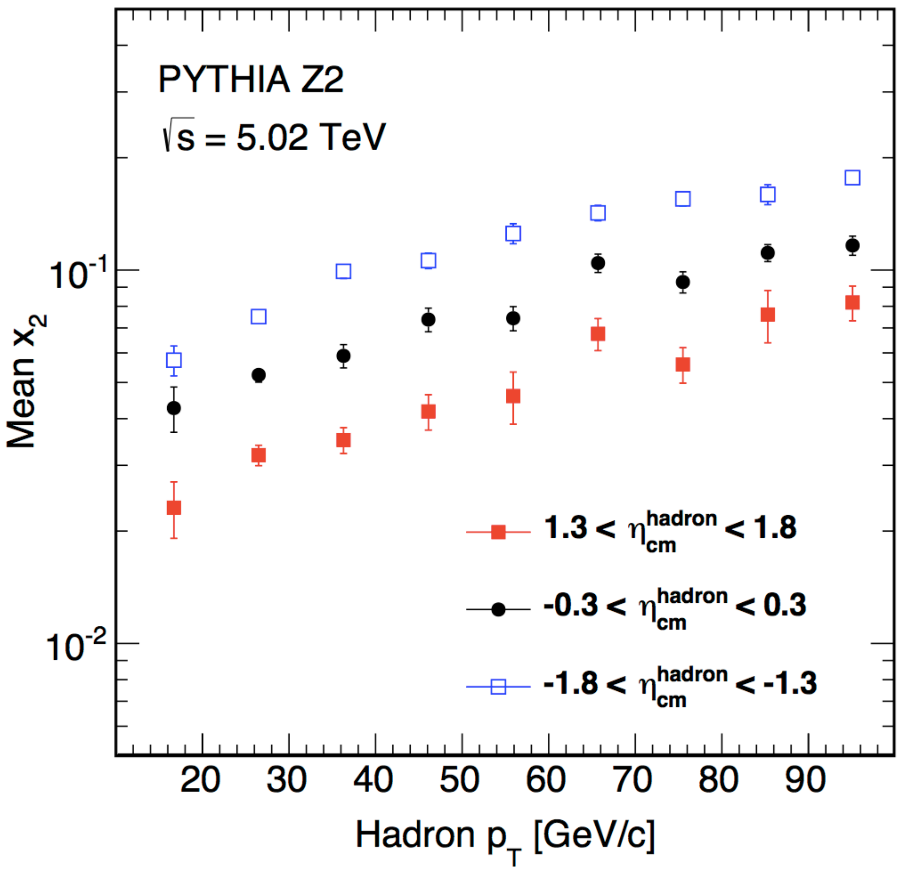


"Central" events with high HF activity

Dijets shifted to Pb-going side, expect $Y_{asym} > 1$

Bjorken x and p_T from PYTHIA

Charged Particles



Anti-k_T R=0.3 Jets