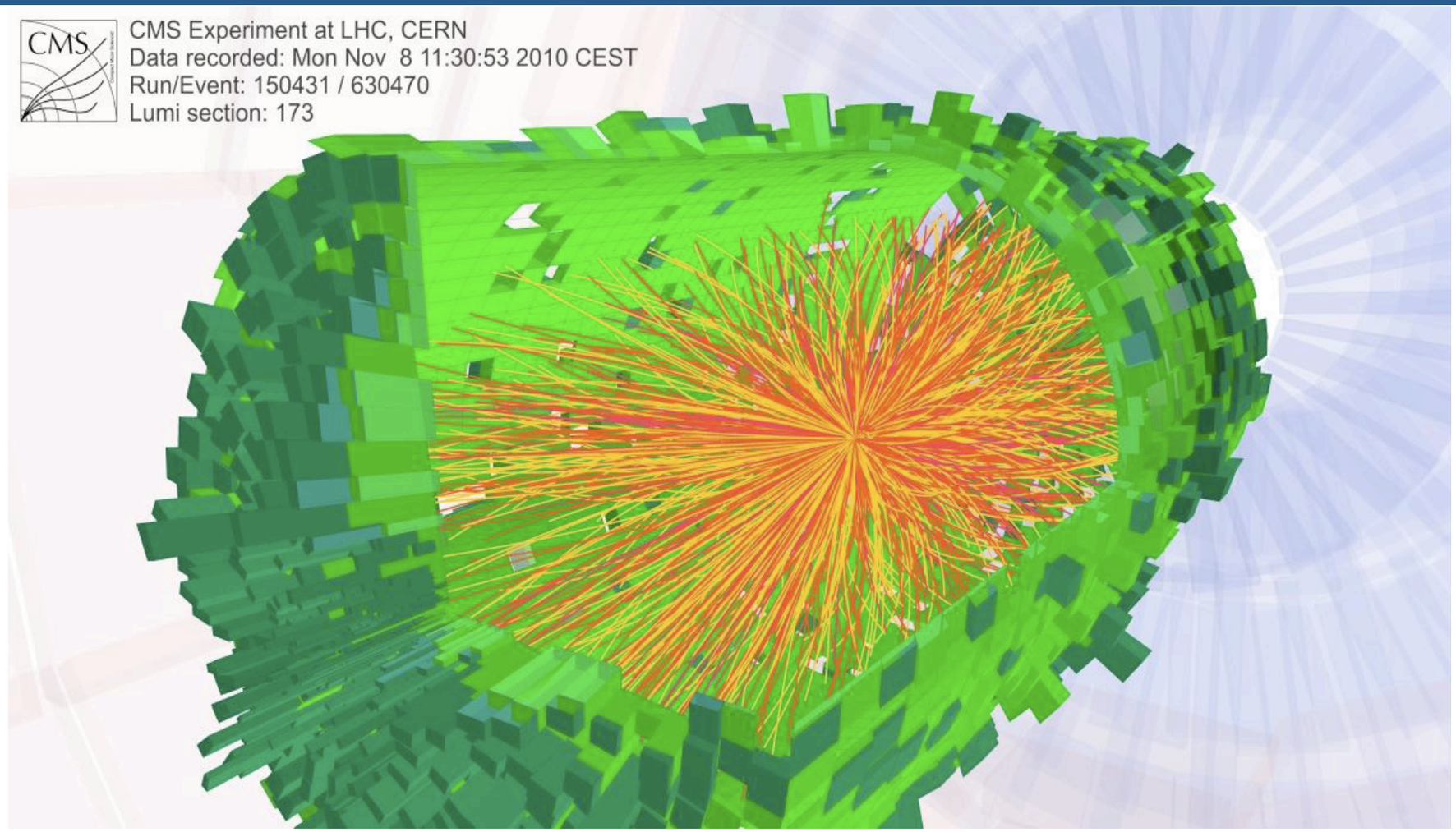
Charged Particle R_{AA} and v_2 at High p_T in PbPb Collisions



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for the CMS Collaboration

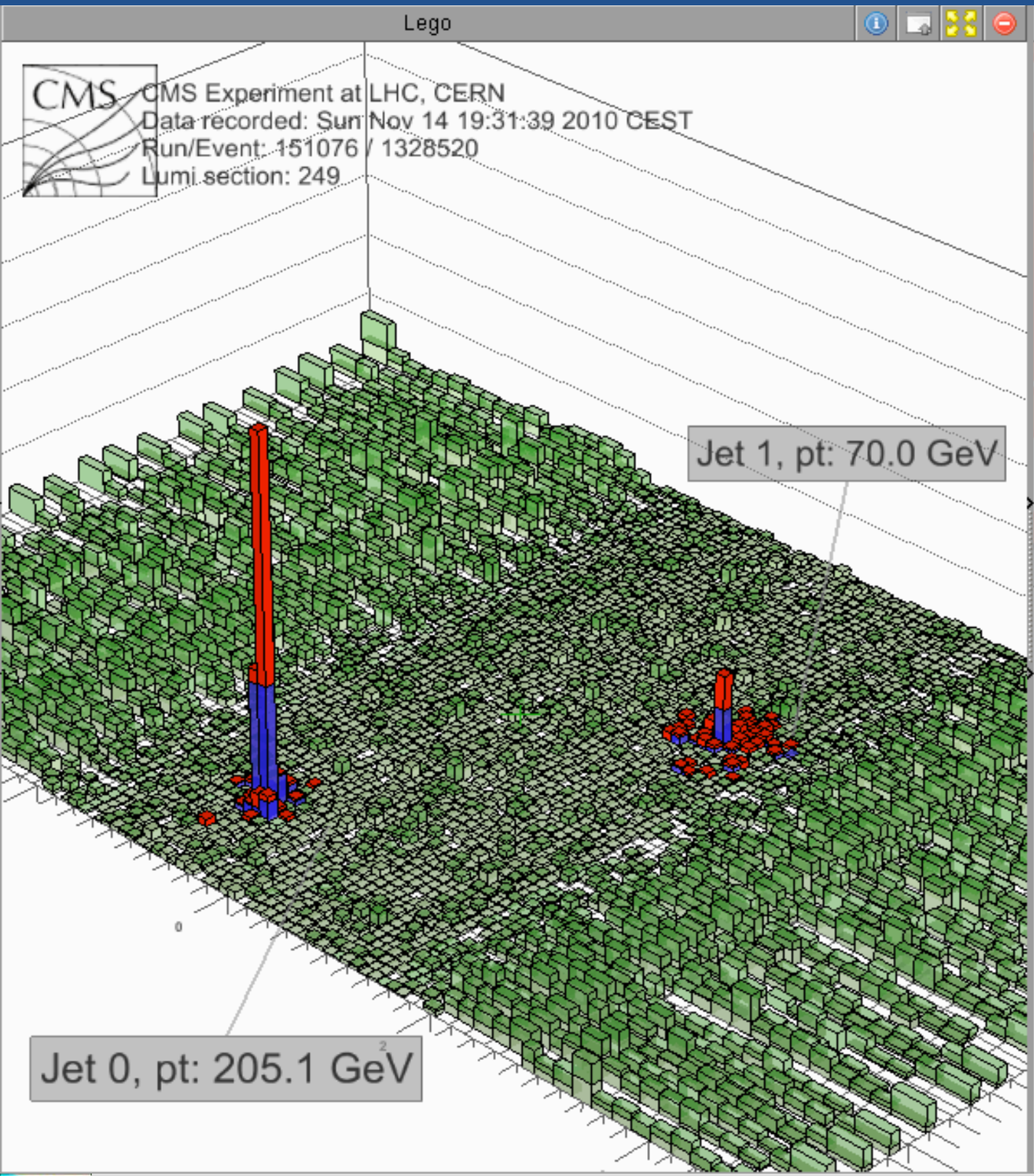
7th Workshop on High p_T @ LHC

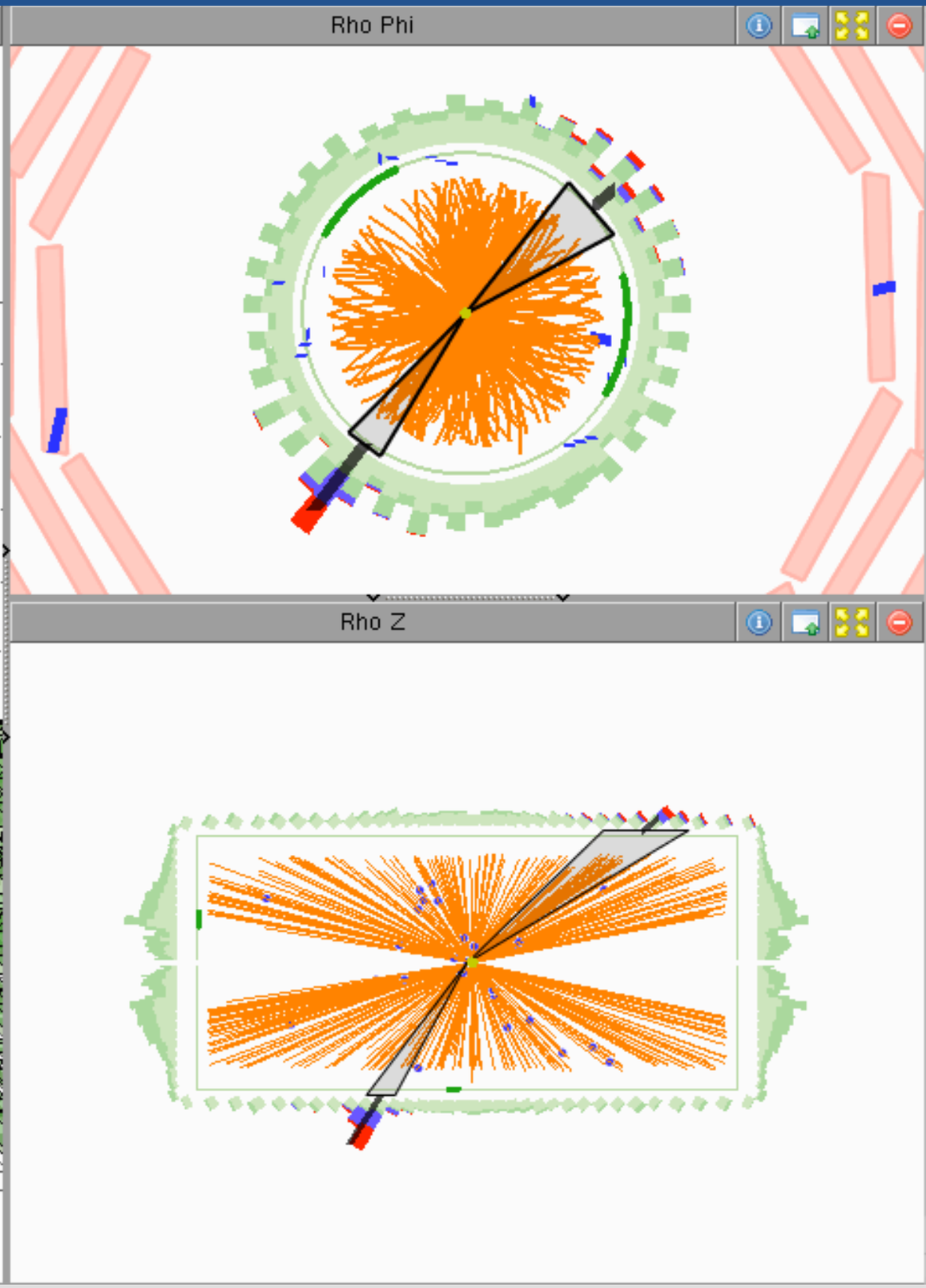
CMS PbPb Results

see our webpage at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

Analysis	Reports	Publication
Jet momentum dependence of jet quenching (submitted to PLB)	CMS-HIN-11-013 arXiv:1202.5022 CERN-PH-EP-2012-042	-
Charged particle RAA (Accepted by EPJC)	CMS-HIN-10-005 arXiv:1202.2554 CERN-PH-EP-2012-043	-
Quarkonium production (submitted to JHEP)	CMS-HIN-10-006 arXiv:1201.5069 CERN-PH-EP-2011-170	-
Isolated photons (Accepted by PLB)	CMS-HIN-11-002 arXiv:1201.3093 CERN-PH-EP-2011-221	-
Dihadron correlations centrality dependence (submitted to PLB)	CMS-HIN-11-006 arXiv:1201.3158 CERN-PH-EP-2011-222	-
Charged particle multiplicity	CMS-HIN-10-001 arXiv:1107.4800 CERN-PH-EP-2011-092	JHEP 08 (2011) 141
Suppression of Y excited states	CMS-HIN-11-007 arXiv:1105.4894 CERN-PH-EP-2011-074	PRL 107 (2011) 052302
Dihadron correlations	CMS-HIN-11-001 arXiv:1105.2438 CERN-PH-EP-2011-056	JHEP 07 (2011) 076
Z boson production	CMS-HIN-10-003 arXiv:1102.5435 CERN-PH-EP-2011-003	PRL106, 212301 (2011)
Dijet imbalance	CMS-HIN-10-004 arXiv:1102.1957 CERN-PH-EP-2011-001	Phys Rev C84 (2011) 024906

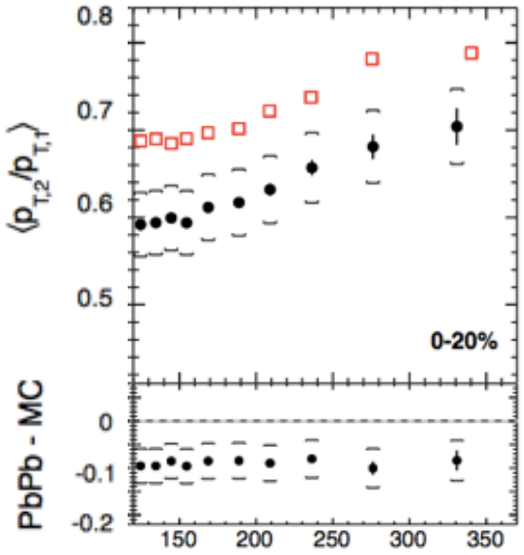
Jet Quenching at LHC



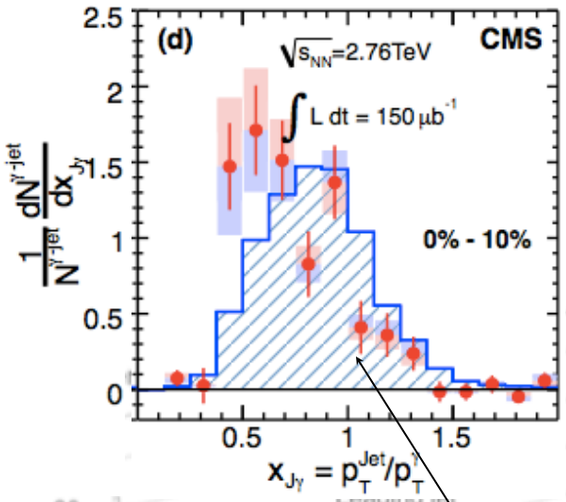


CMS Perspectives on Jet Quenching

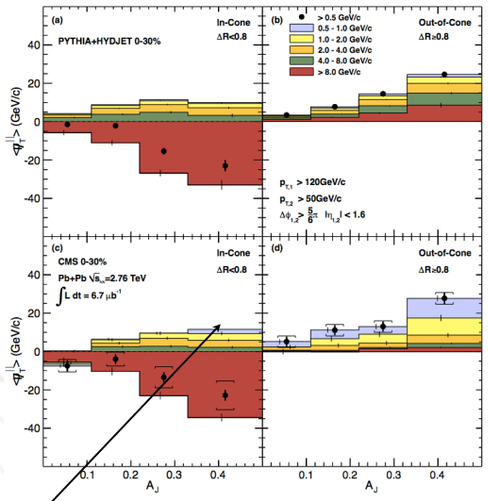
Dijet imbalance



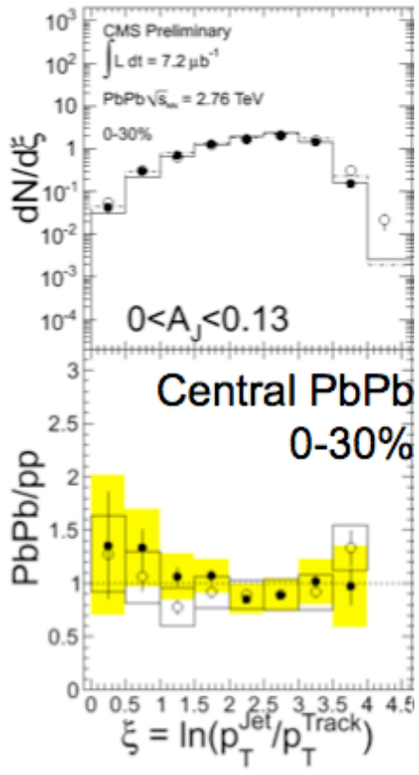
γ-jet imbalance

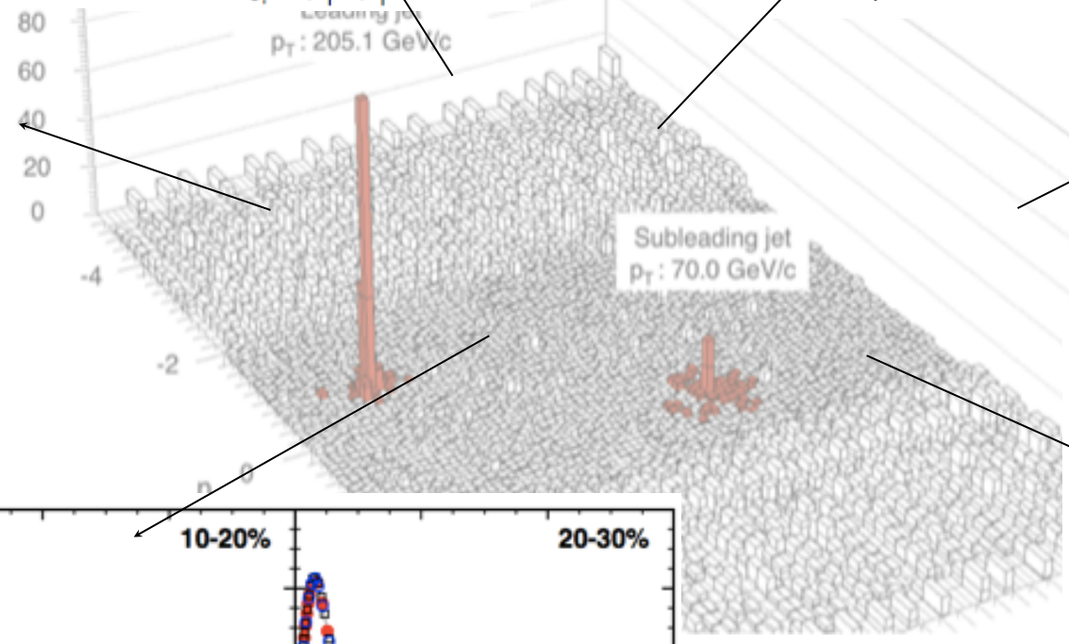


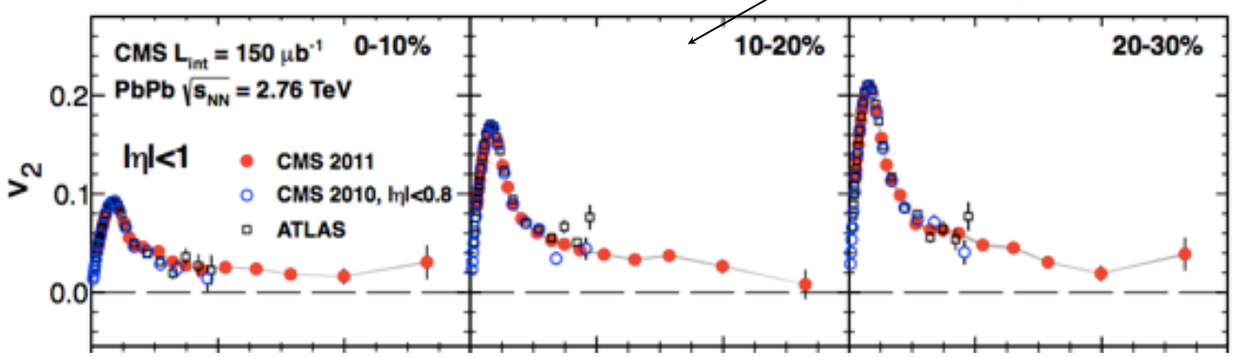
Missing p_T



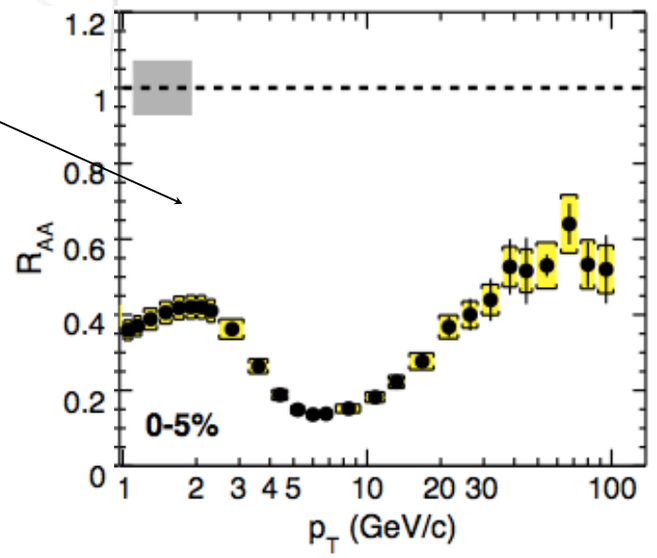
Fragmentation Functions





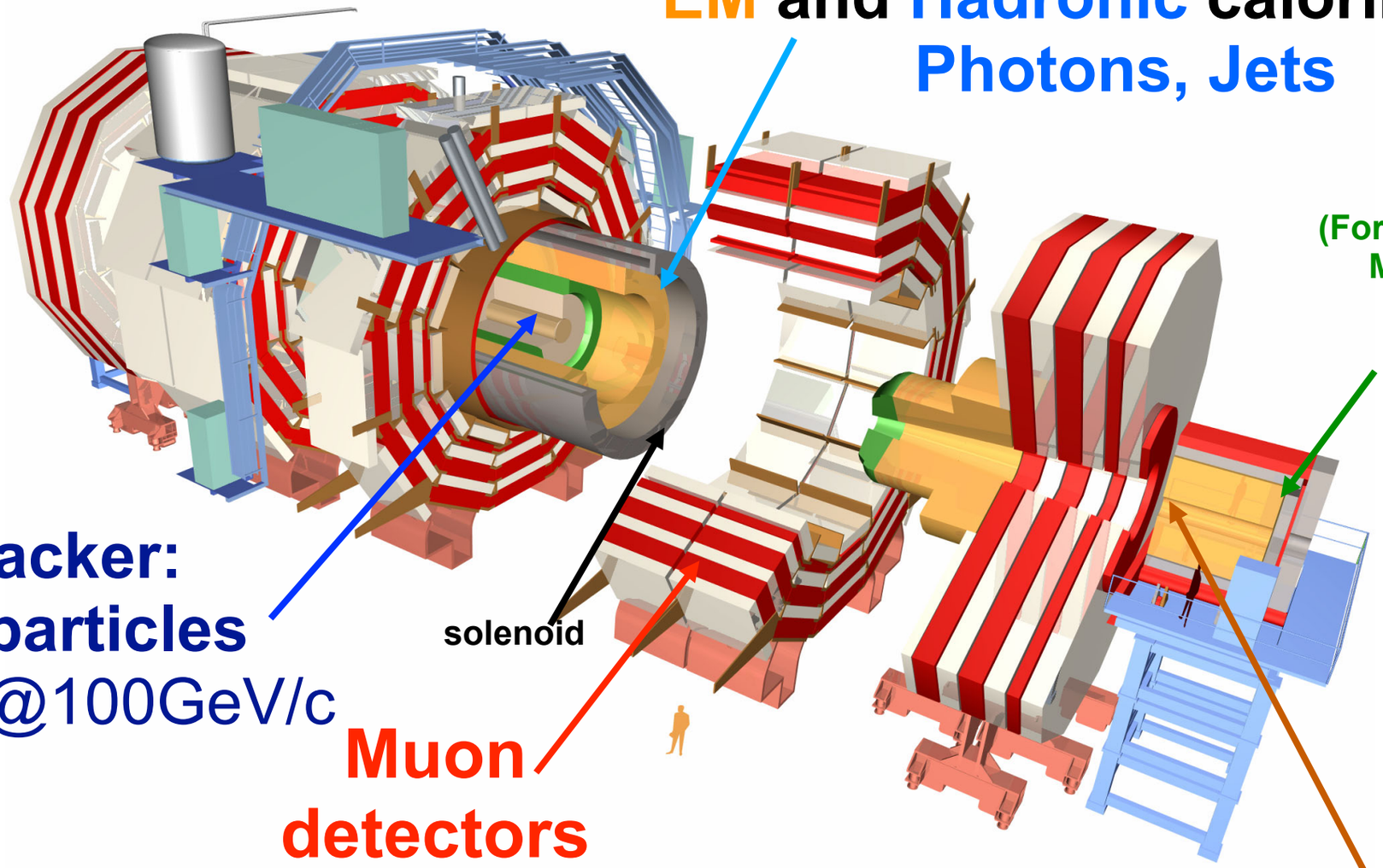


v_2 at high p_T



Charged hadron R_{AA}

CMS Detector



EM and Hadronic calorimeters
Photons, Jets

HF
(Forward Calorimeter)
MinBias Trigger
Centrality

Inner tracker:
Charged particles
$\sigma(p_T)/p_T$ <3%@100GeV/c

solenoid

Muon detectors

BSC
(Beam Scintillation Counter)
MinBias Trigger

Muon	|η|< 2.4
HCAL	|η|< 5.2
ECAL	|η|< 3.0
Tracker	|η|< 2.5

Trigger and Event Selection

- MinBias Trigger:
  - Coincidence of BSC or HF signal
  - Trigger efficiency: 97% ± 3%

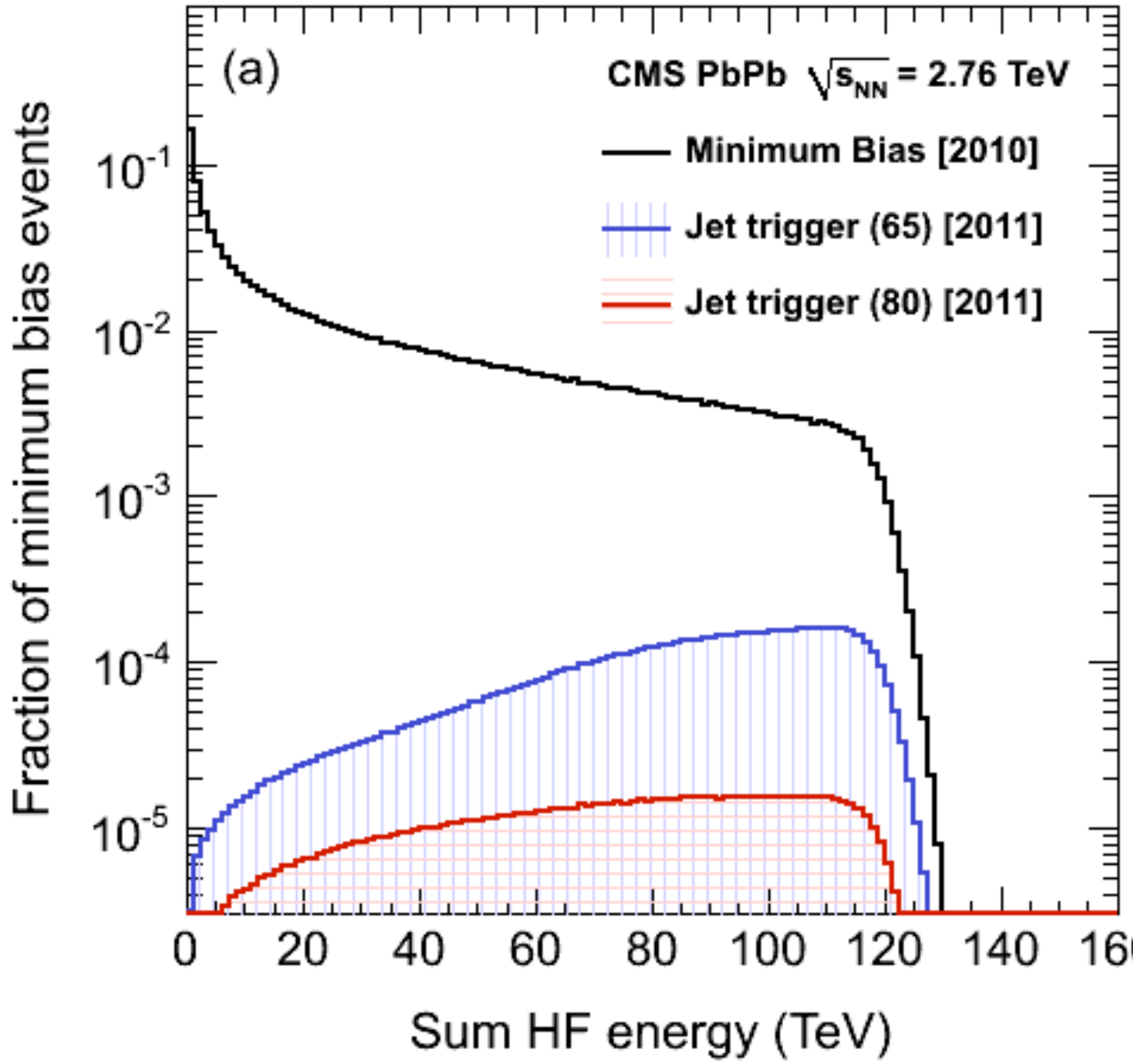
- Di-Muon Trigger:
  - Two tracks in the muon detector

- Photon Trigger:
  - Uncorrected photon E_T> 15 GeV

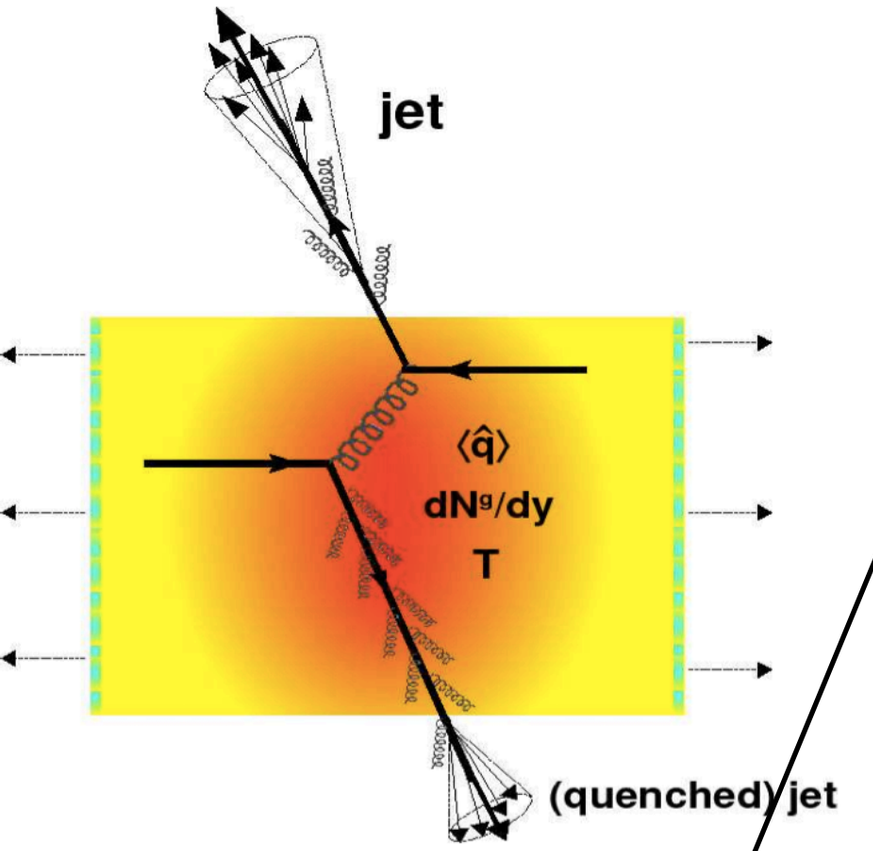
- **Jet Trigger:**
  - Uncorrected jet E_T> 35, 50 GeV

- **High p_T track trigger:**
  - Charged particles p_T> 12 GeV

- Centrality determination:
  - Forward calorimeter (HF) energy



Jet Quenching and R_{AA}



$$R_{\mathrm{AA}} = \frac{1/N_{\mathrm{evt}}\, d^2N/dy dp_T}{\langle T_{\mathrm{AB}}\rangle d^2\sigma_{pp}/dy dp_T}$$

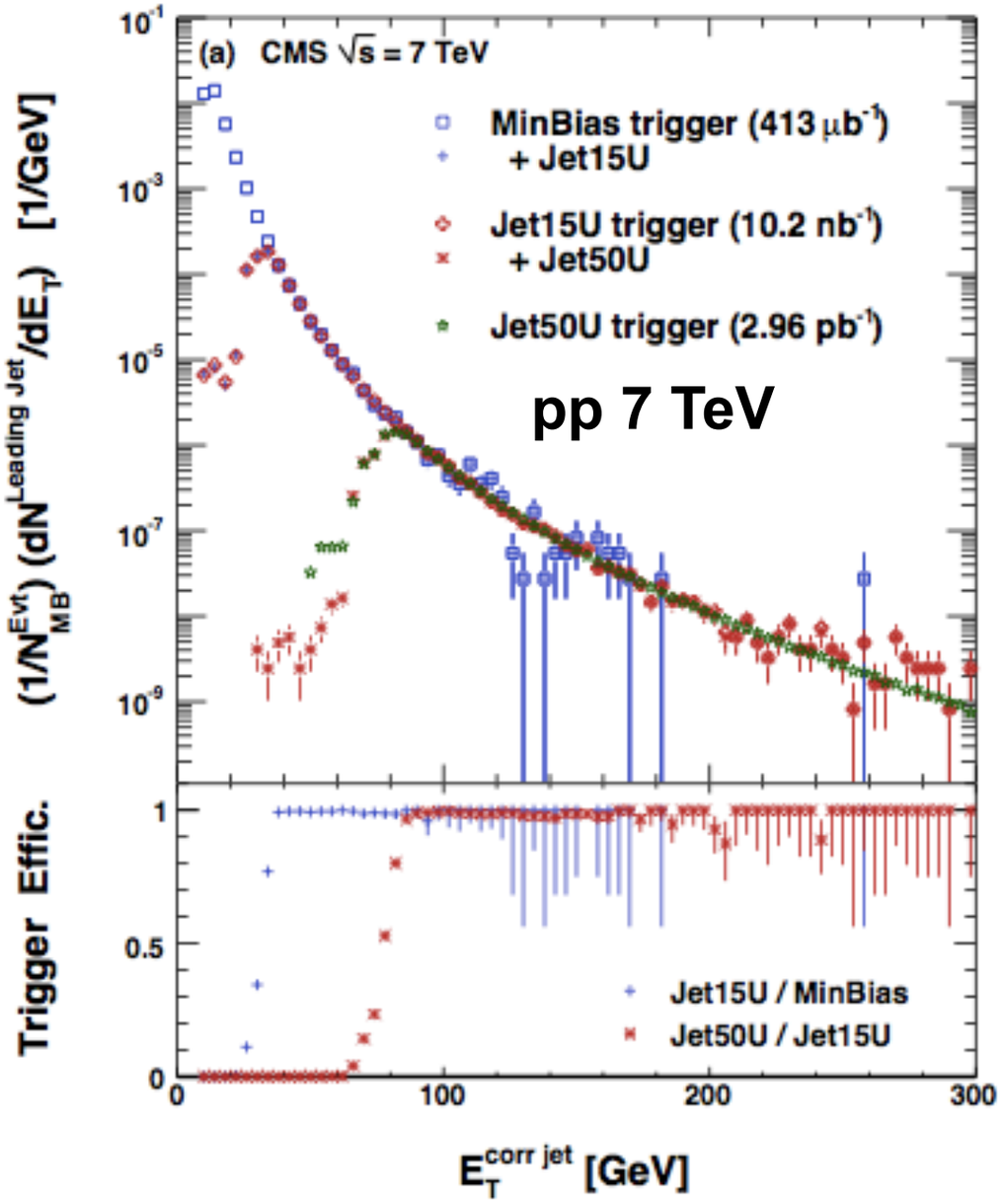
For color-less probes, RAA ~ 1:
- Photons
- Z0s

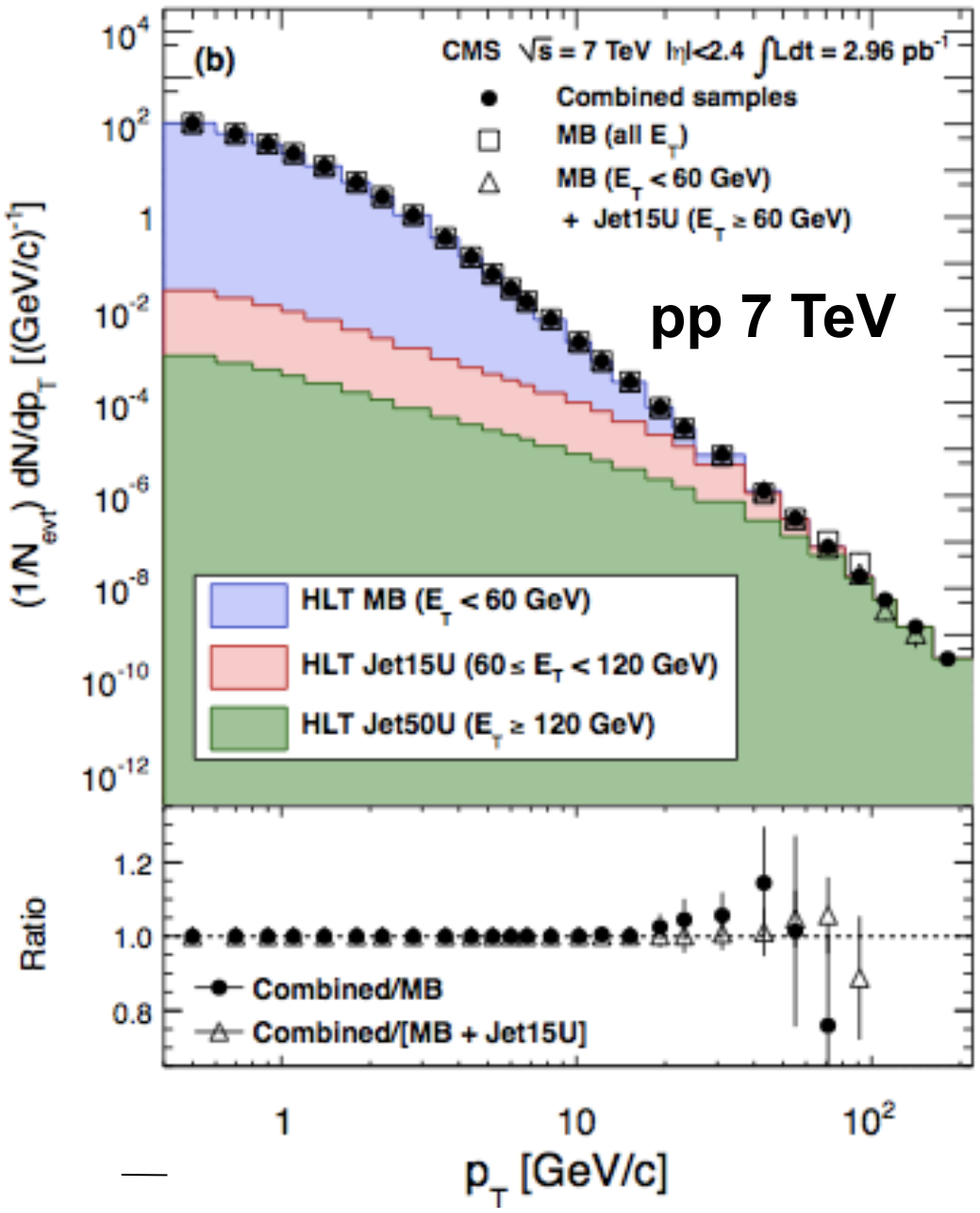
For jets fragmentation products, RAA < 1 ("jet quenching")
- Charged hadrons
- B → J/ψ

Full jet reconstruction

- Dijet asymmetry and angular correlation
- Missing p_T
- Fragmentation functions
- Jet-track correlations

From Jet Triggers to Particle Spectra



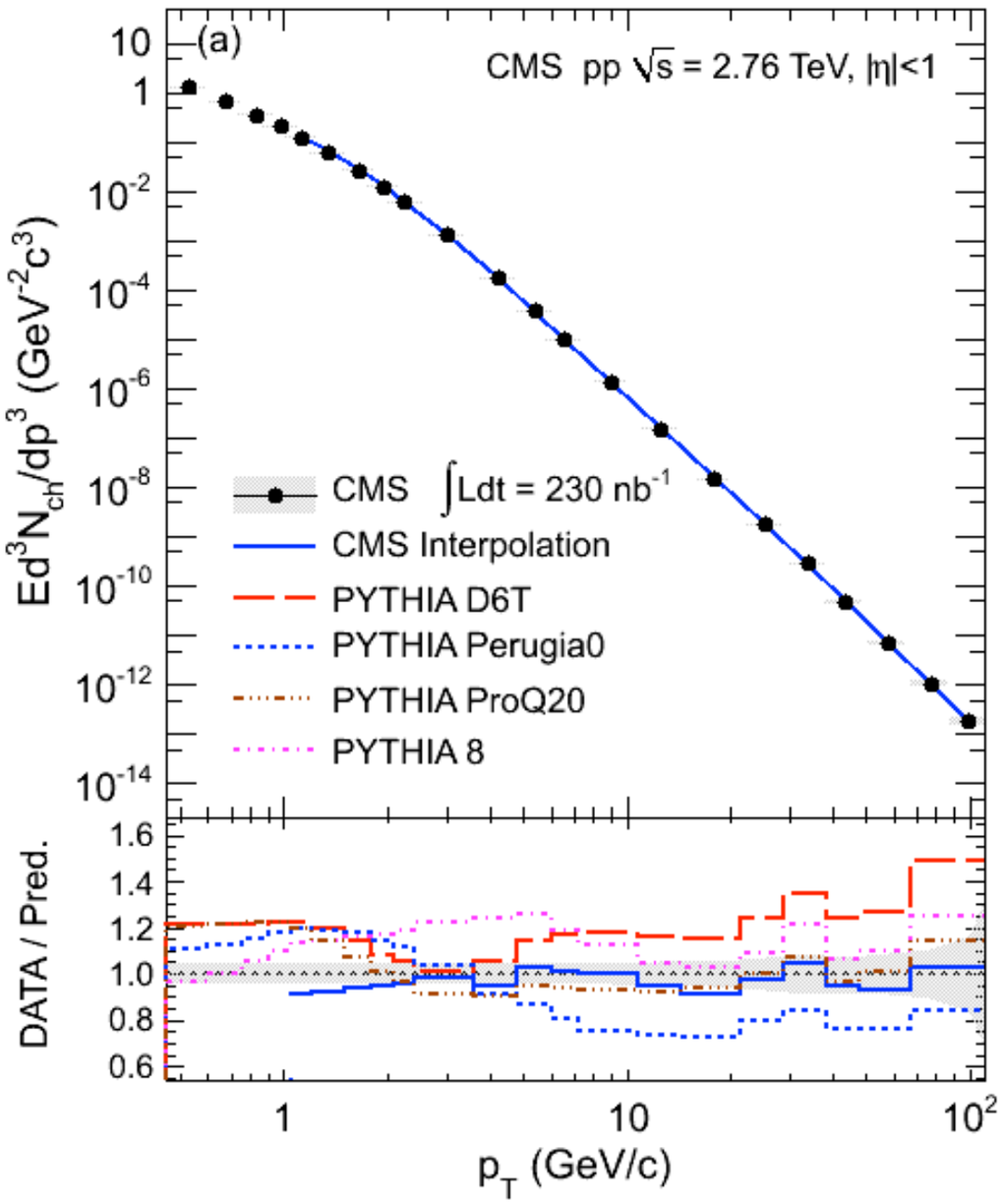


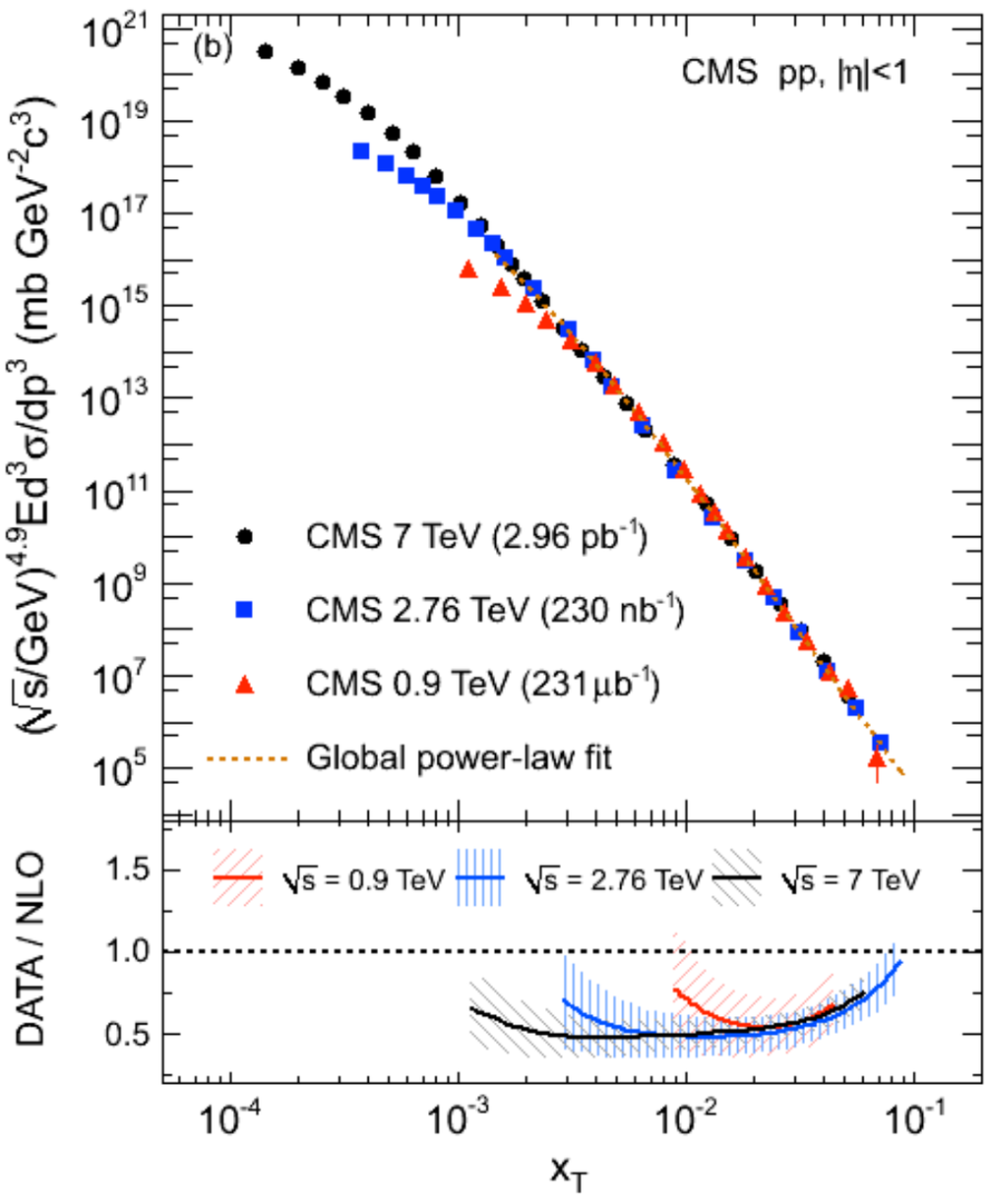
- Calorimeter-based jet triggers to select events with high p_T tracks:
  - Maxmimize p_T reach (up to 200GeV/c in pp)
  - Suppression of fake tracks

J. High Energy Phys. 08 (2011) 086

Charged Particle Spectra in pp

arXiv:1202.2554

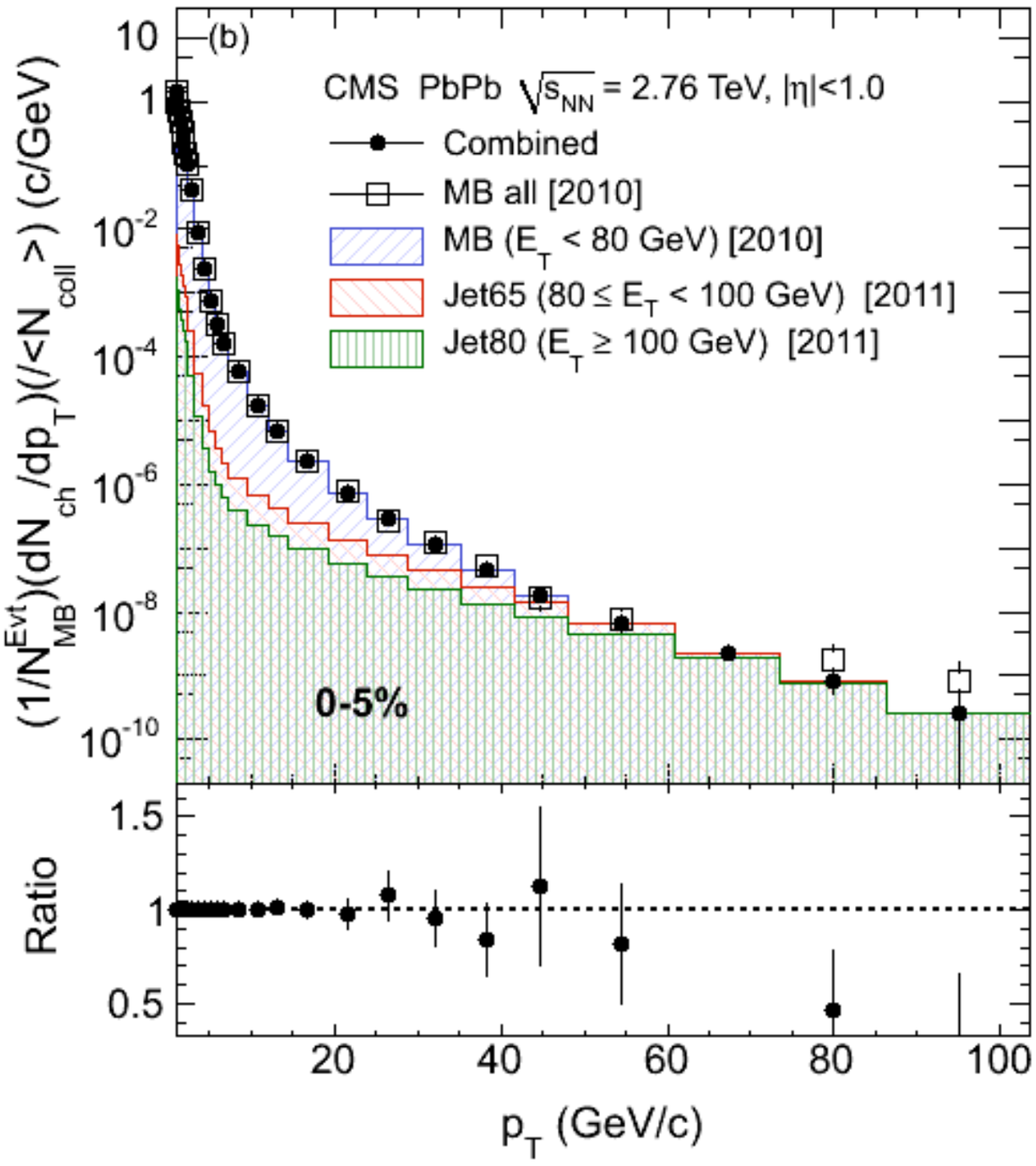


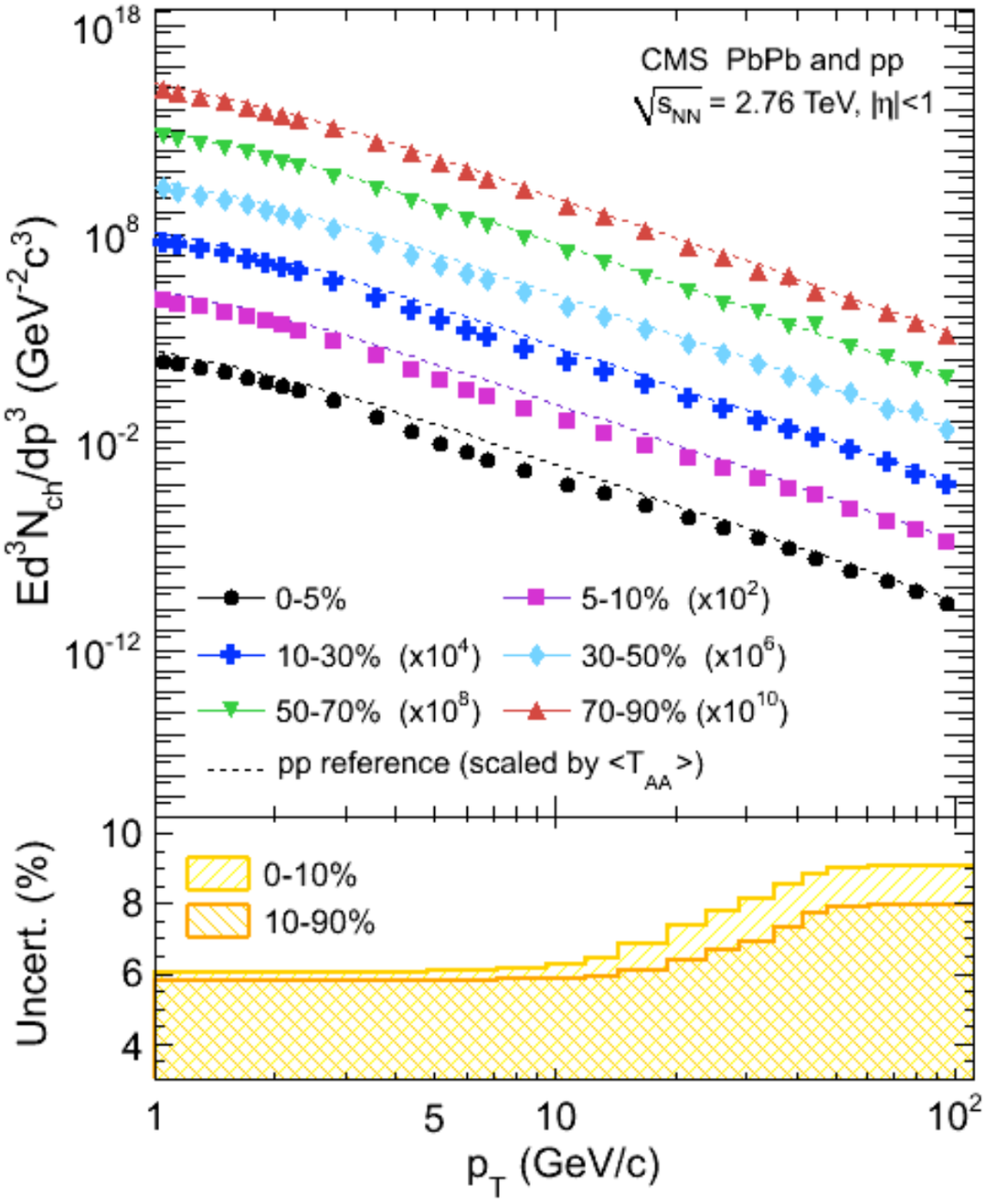


- Obtained results for 0.9, 2.76 and 7 TeV pp
- PYTHIA does ‘ok’, but not good enough as reference
- x_T scaling seen at high p_T

Charged Particle Spectra in PbPb

arXiv:1202.2554



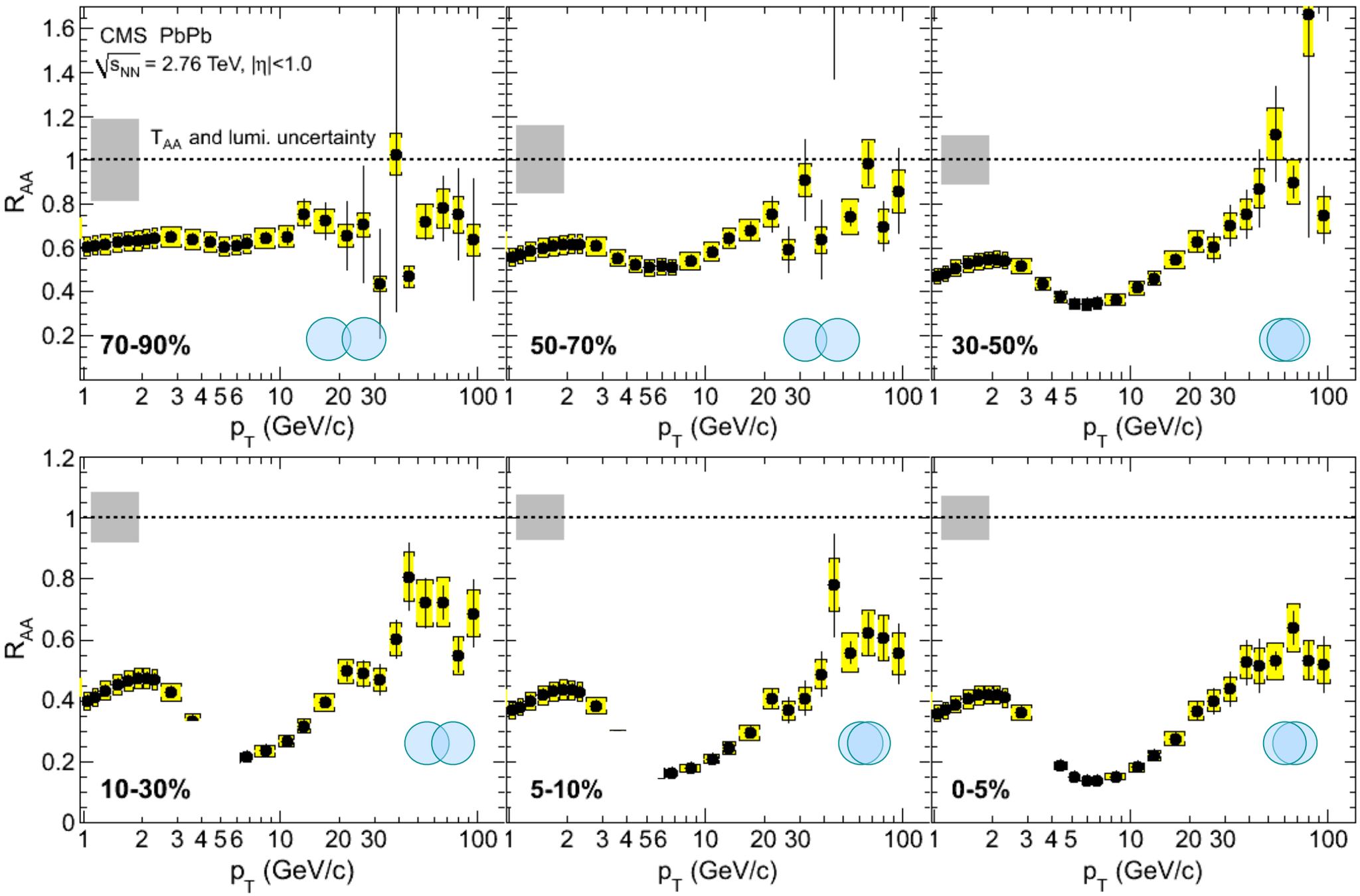


Spectra measured to 100 GeV/c in PbPb

Uses full statistics of 2011 run at high p_T (150mub^{-1})

Charged Particle R_{AA} vs Centrality

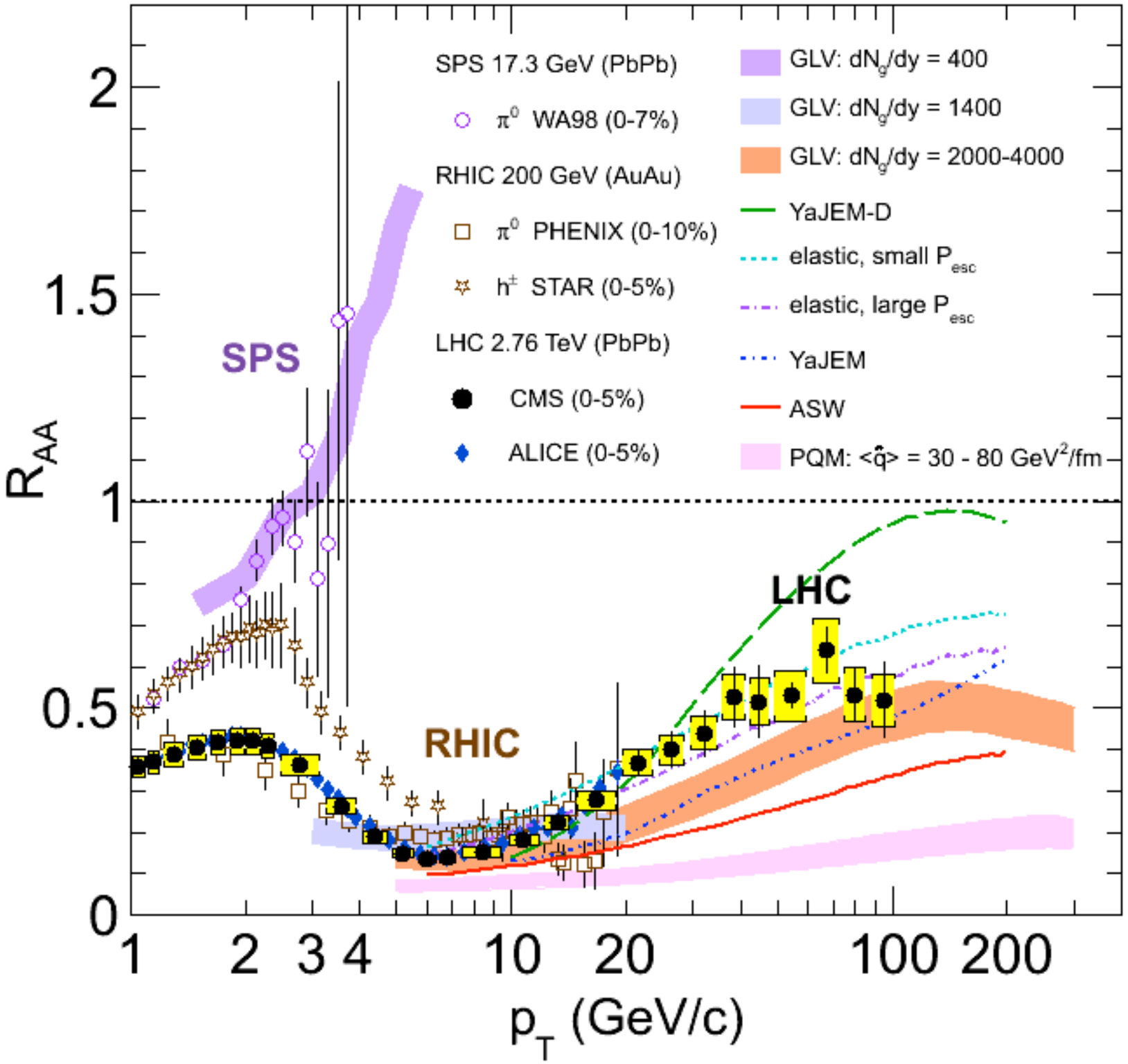
arXiv:1202.2554



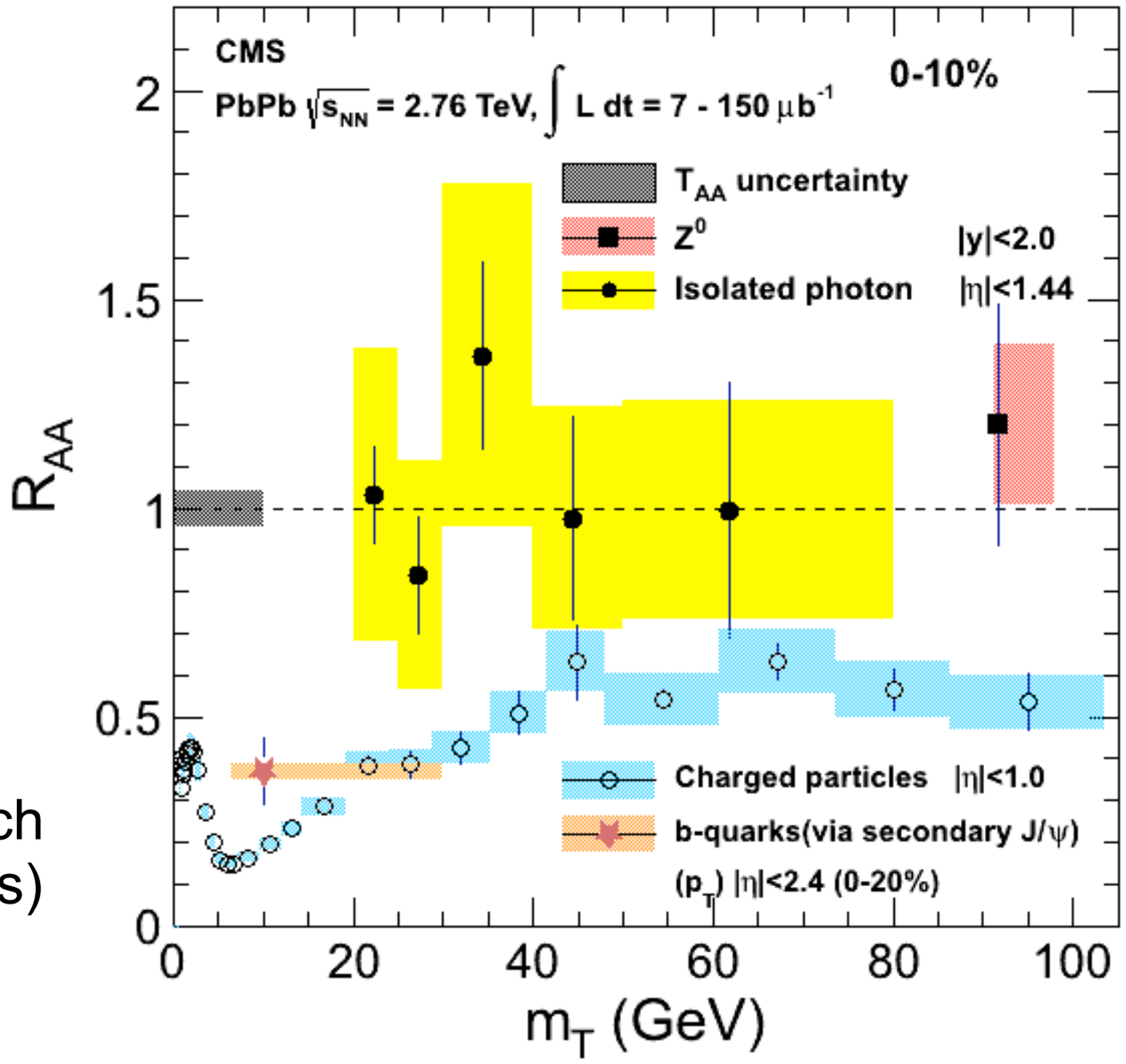
- Dip structure develops as a function of centrality
- R_{AA} increases as a function of p_T in the p_T>10 GeV/c region

Charged particle R_{AA} compared to models

arXiv:1202.2554



Summary of CMS R_{AA} results



b-quarks are quenched (but not as much as light hadrons)

arXiv:1201.5069

arXiv:1201.3093

arXiv:1102.5435

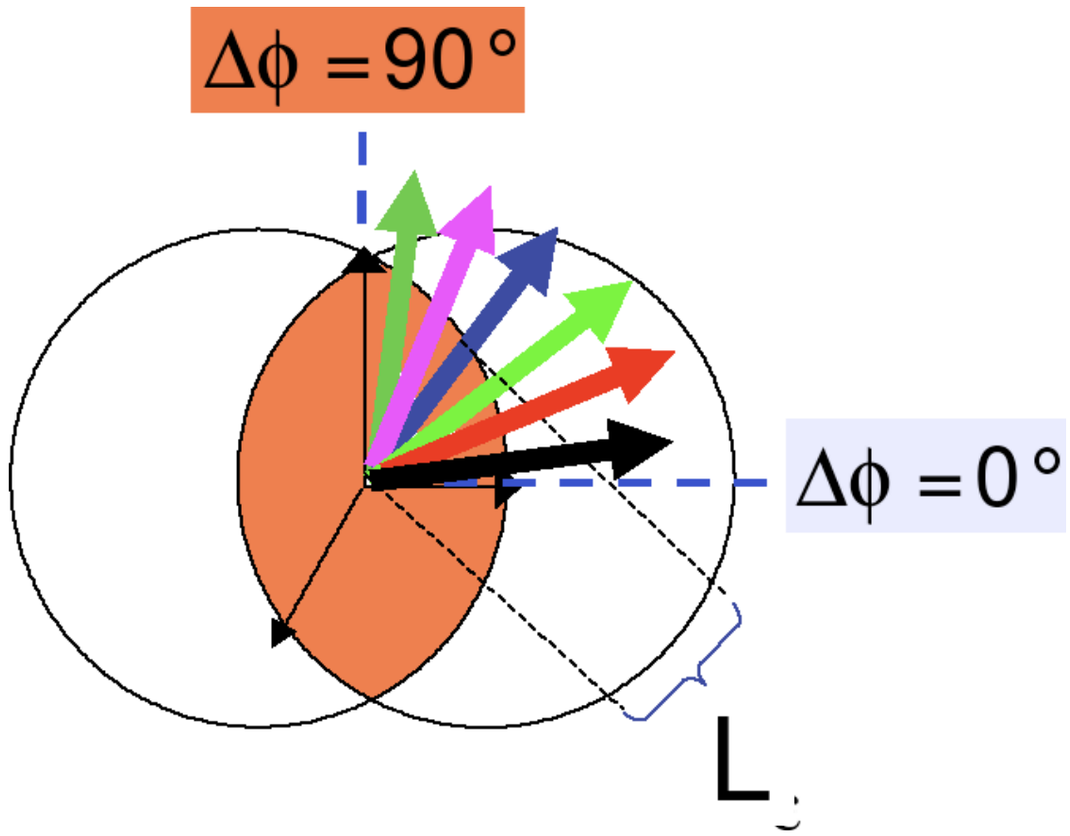
Color-less probes are unsuppressed

Strong quenching for light hadrons

arXiv:1202.2554

Jet Quenching and Azimuthal Anisotropy

Path length (L) dependence of jet energy loss (ΔE)



$\Delta E \sim L^{\alpha}$:

"α = 1" for QCD, collisional

"α = 2" for QCD, radiative

"α = 3" for AdS/CFT

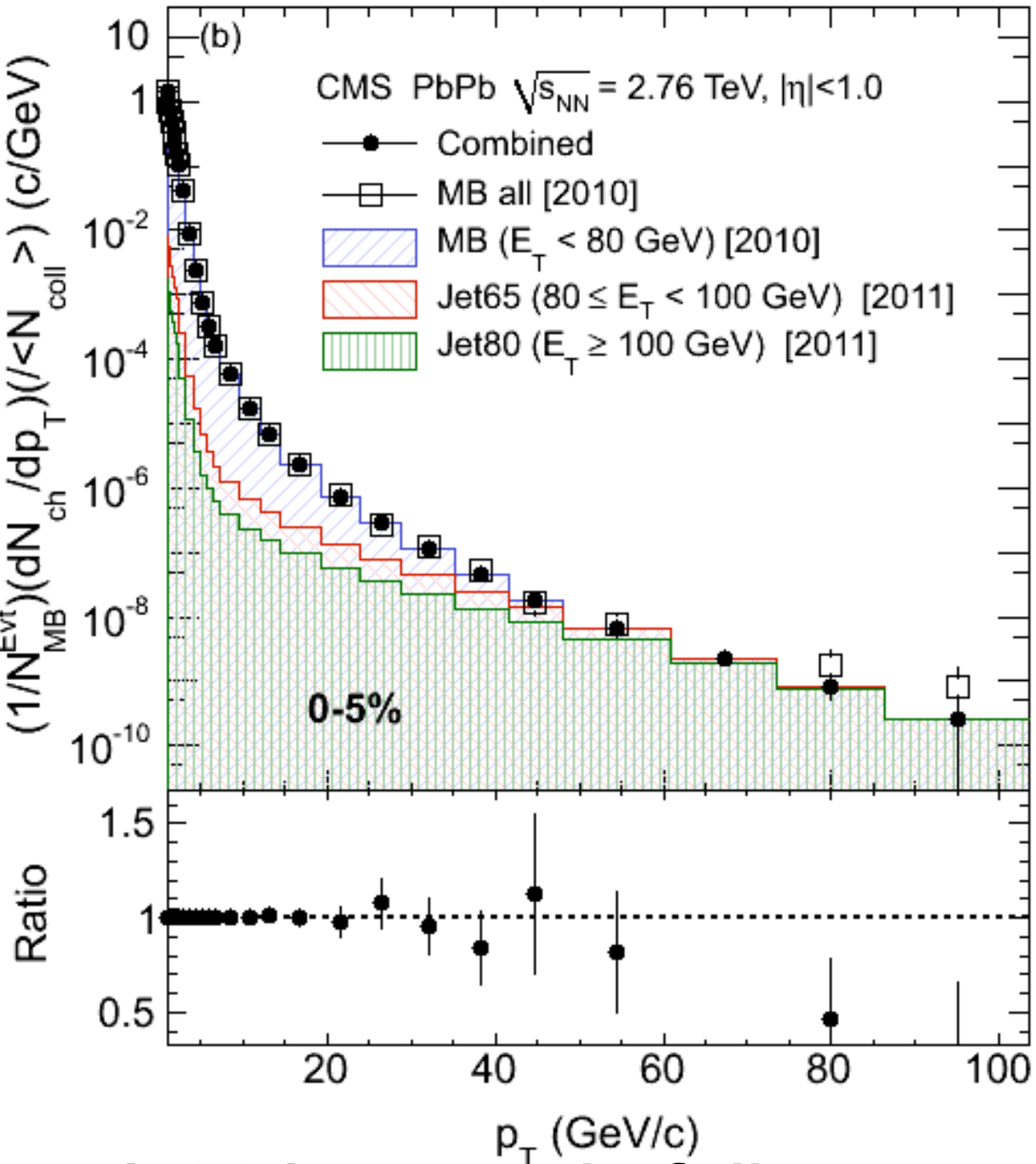
Different initial conditions:

Glauber

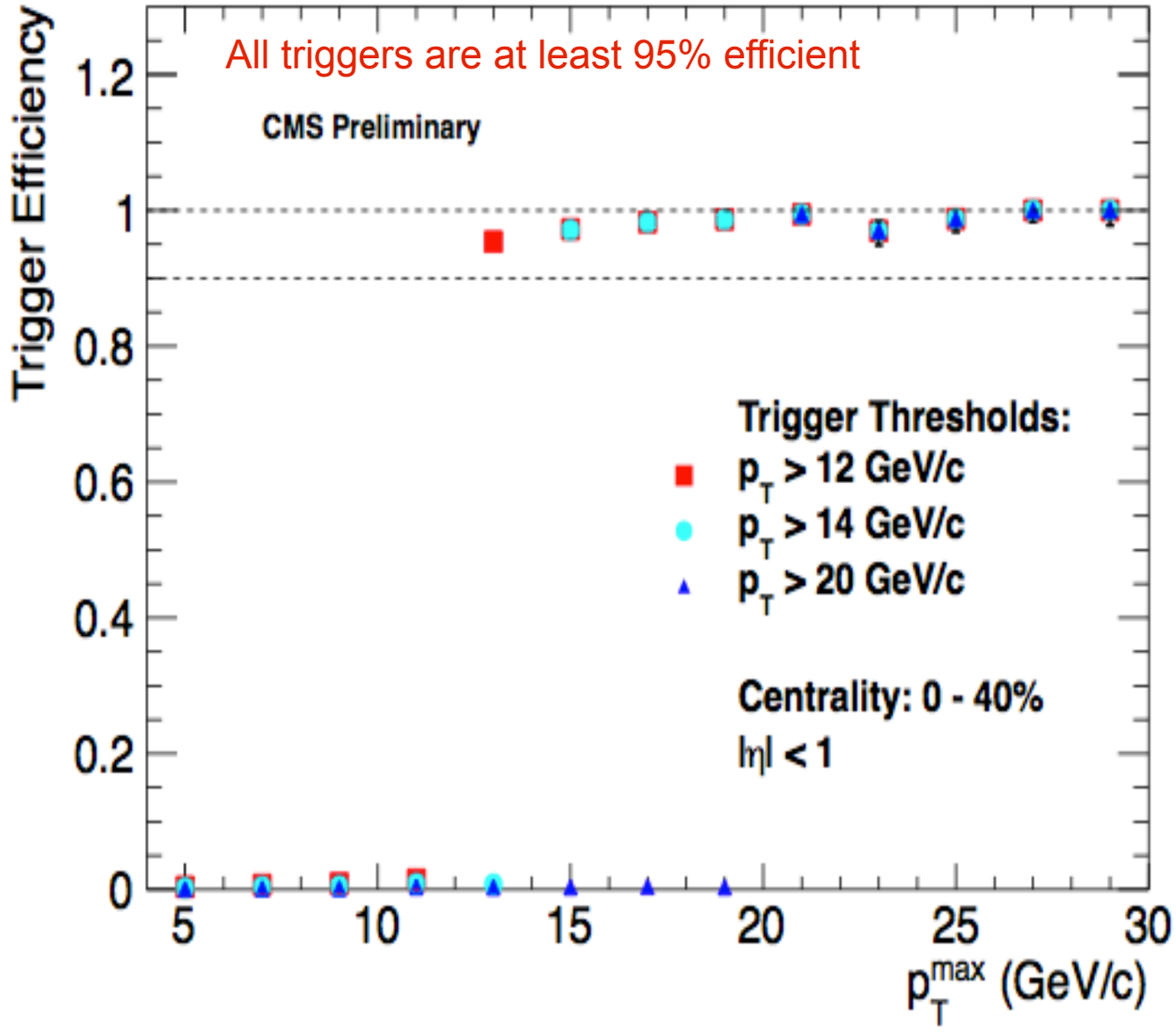
Color glass condensate

Azimuthal anisotropy (v2) of high pT jets

High p_T Single Track Trigger



Jet trigger only fully efficient for 40+GeV tracks

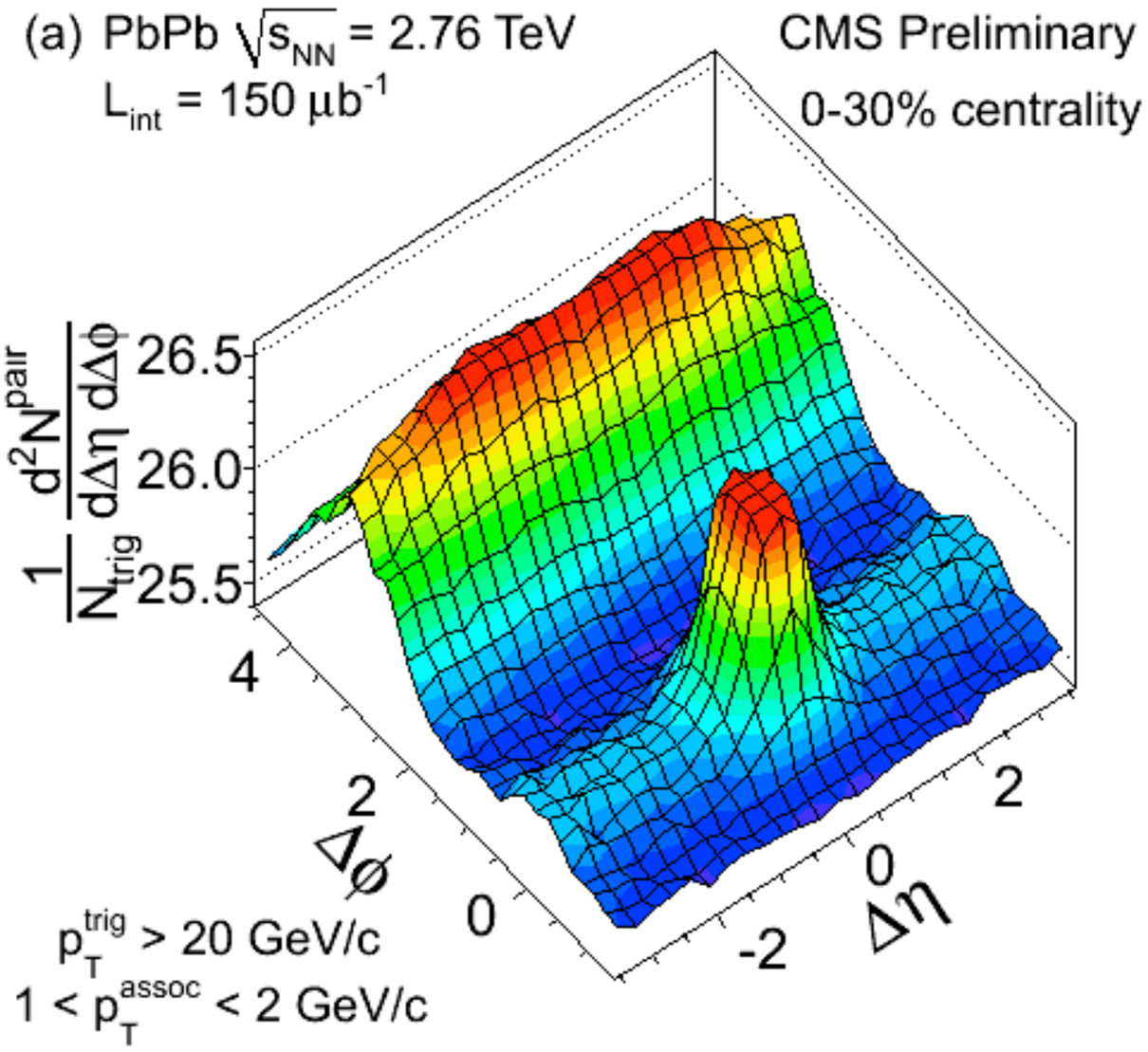


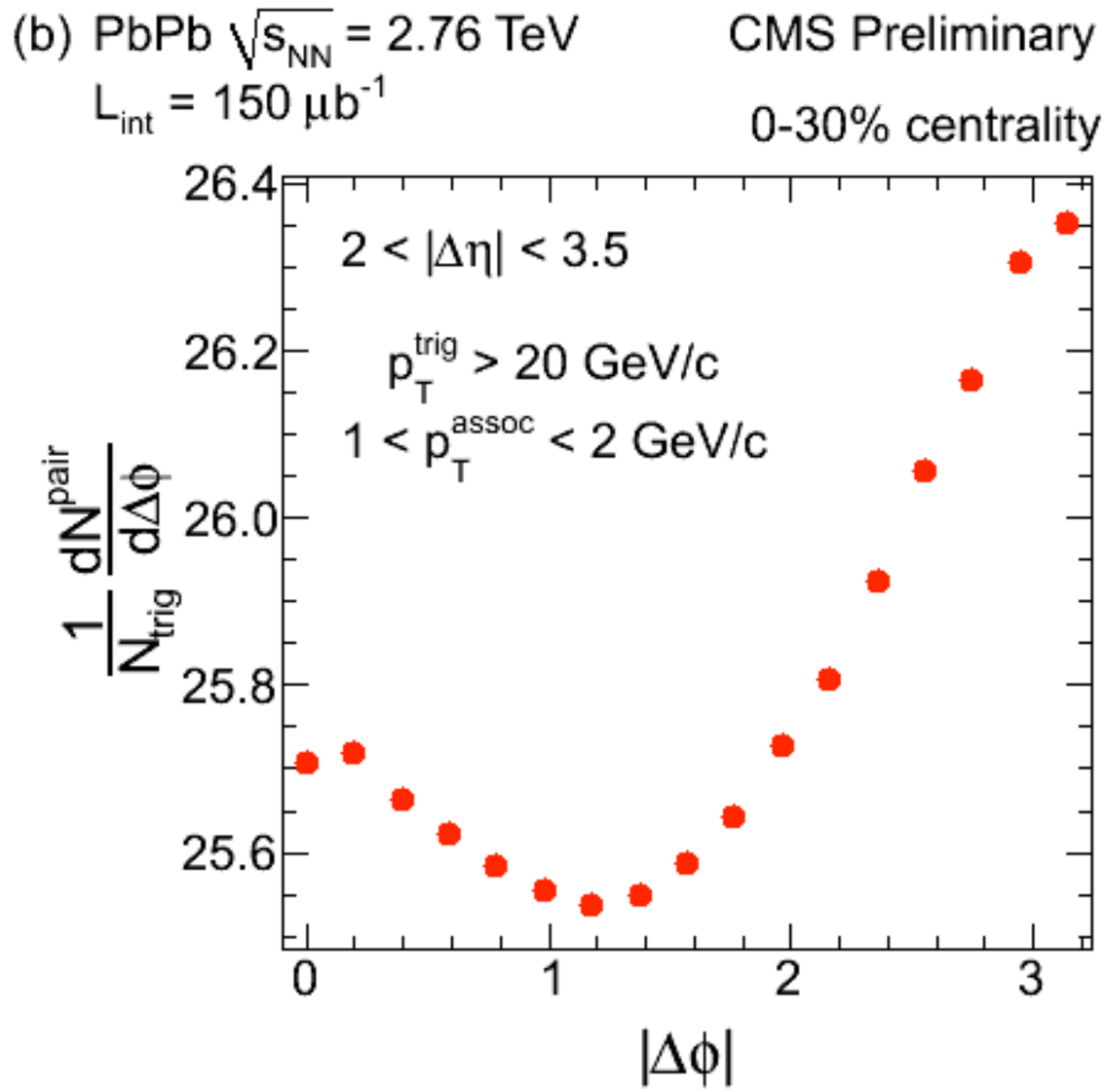
Single-Track Trigger

Track reconstruction in HLT

1.5M 20+GeV tracks for 2011!

Azimuthal Correlations at High p_T



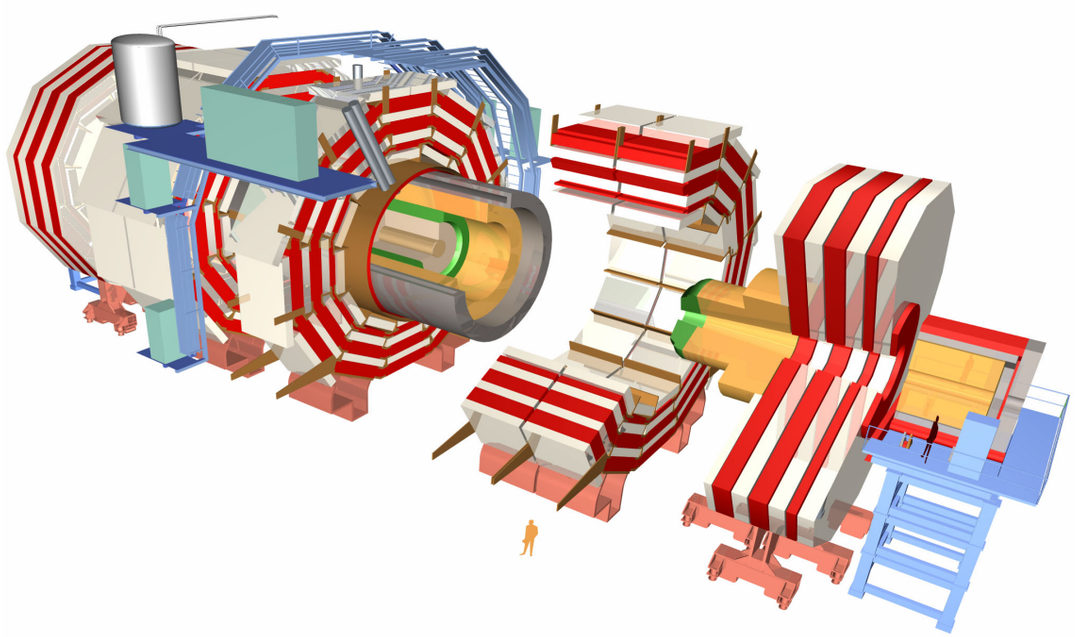


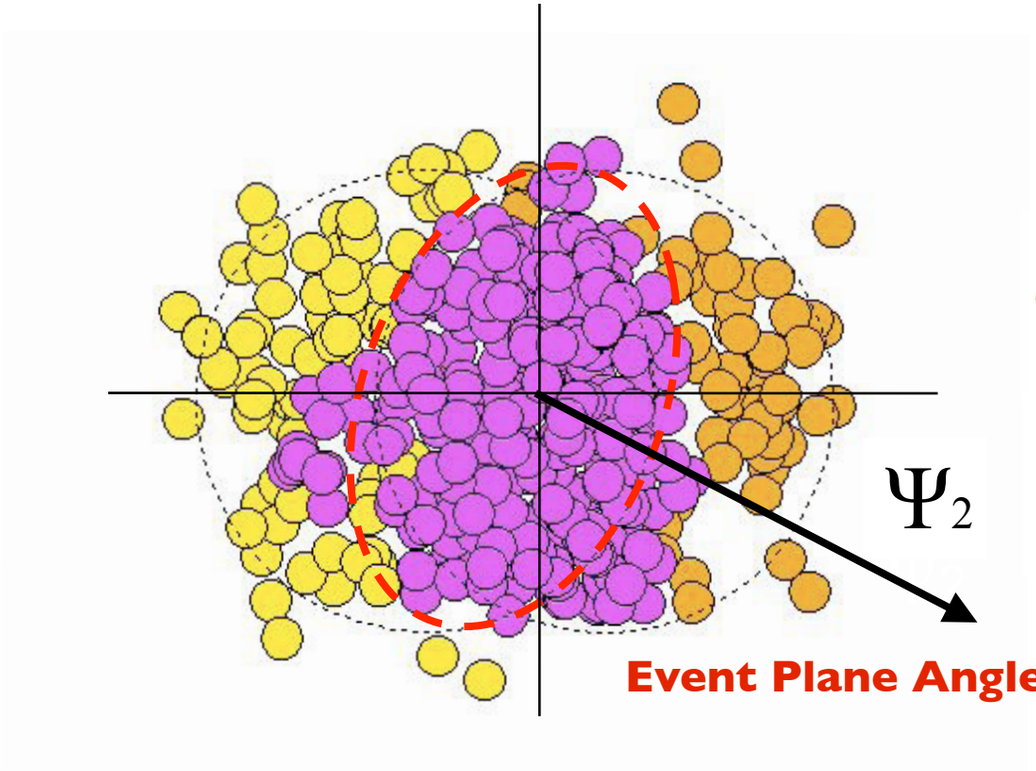
First two-particle correlation function for p_T^{trig} > 20GeV/c

Event-Plane Method

Event Plane

$$\Psi_n' = \frac{1}{n}\tan^{-1}\frac{\sum_i w_i \sin(n\varphi_i)}{\sum_i w_i \cos(n\varphi_i)}$$





Note that event plane != reaction plane

Elliptic Flow Coefficient

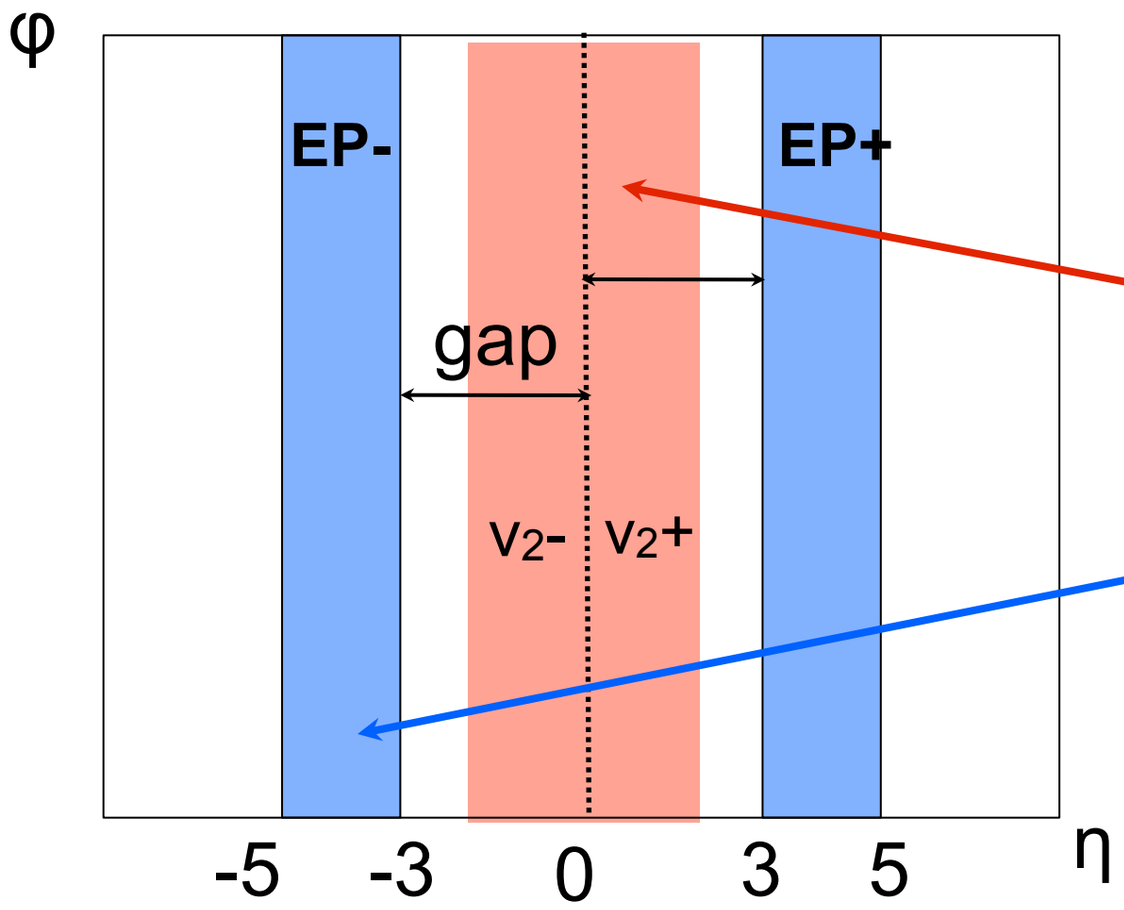
$$v_2^{obs}\{EP\} = \langle \cos 2(\varphi - \Psi_2') \rangle = \frac{1}{N_{ev}} \sum_j \left[\frac{1}{M_j} \sum_i \cos 2\left(\varphi_i^j - \Psi_2^j\right) \right]$$

$$v_n\{EP\} = \frac{v_n^{obs}\{EP\}}{R} = \frac{\langle \cos n(\varphi - \Psi_n) \rangle}{\langle \cos n(\Psi_n - \Psi_R) \rangle}$$

Resolution Correction:

Accounts for the experimental uncertainty in estimating the true event plane.

Event-Plane Method

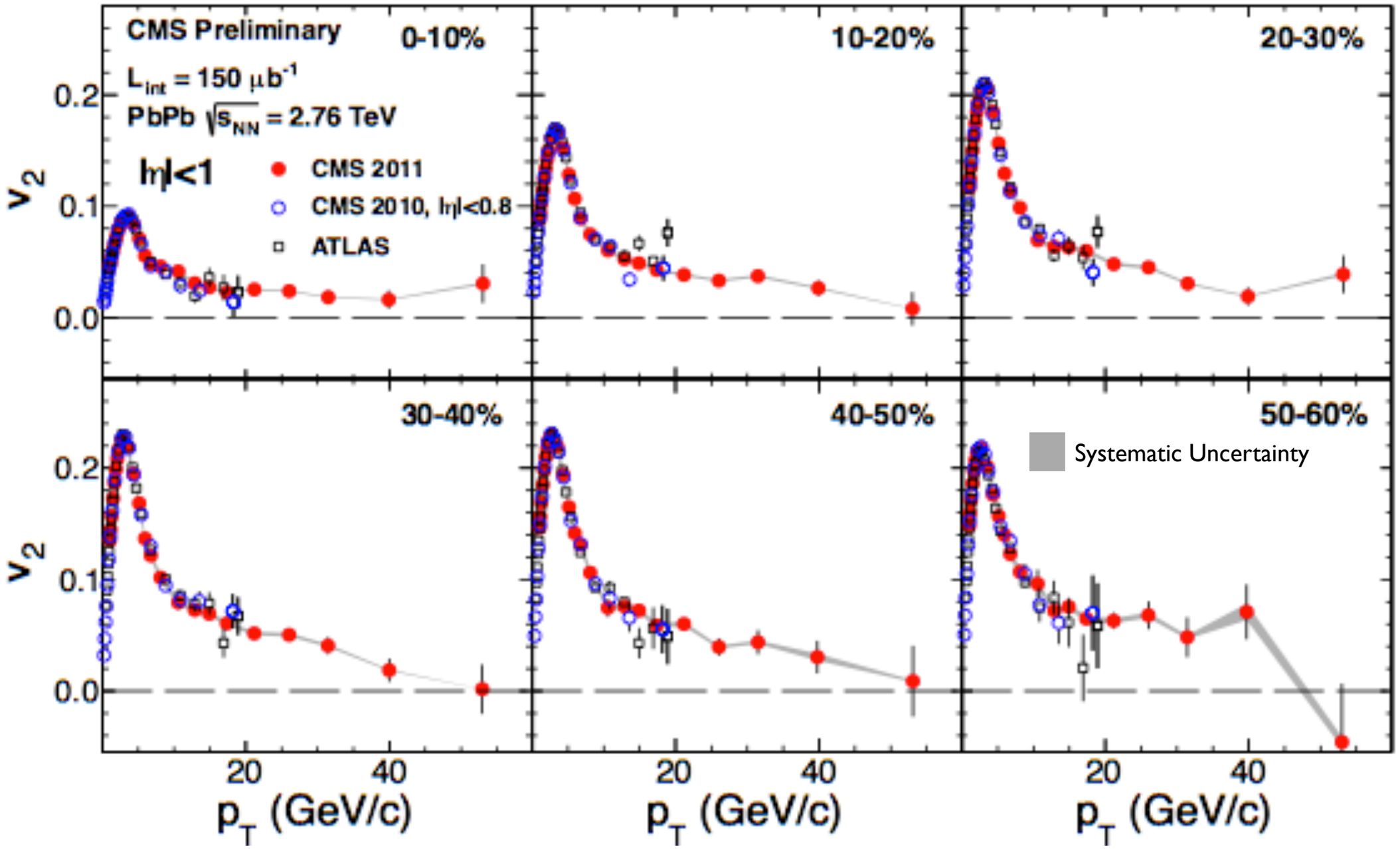


v_2+ with EP- and v_2- with EP+

Particles from the positive η region are correlated with the event plane calculated in the negative η region.

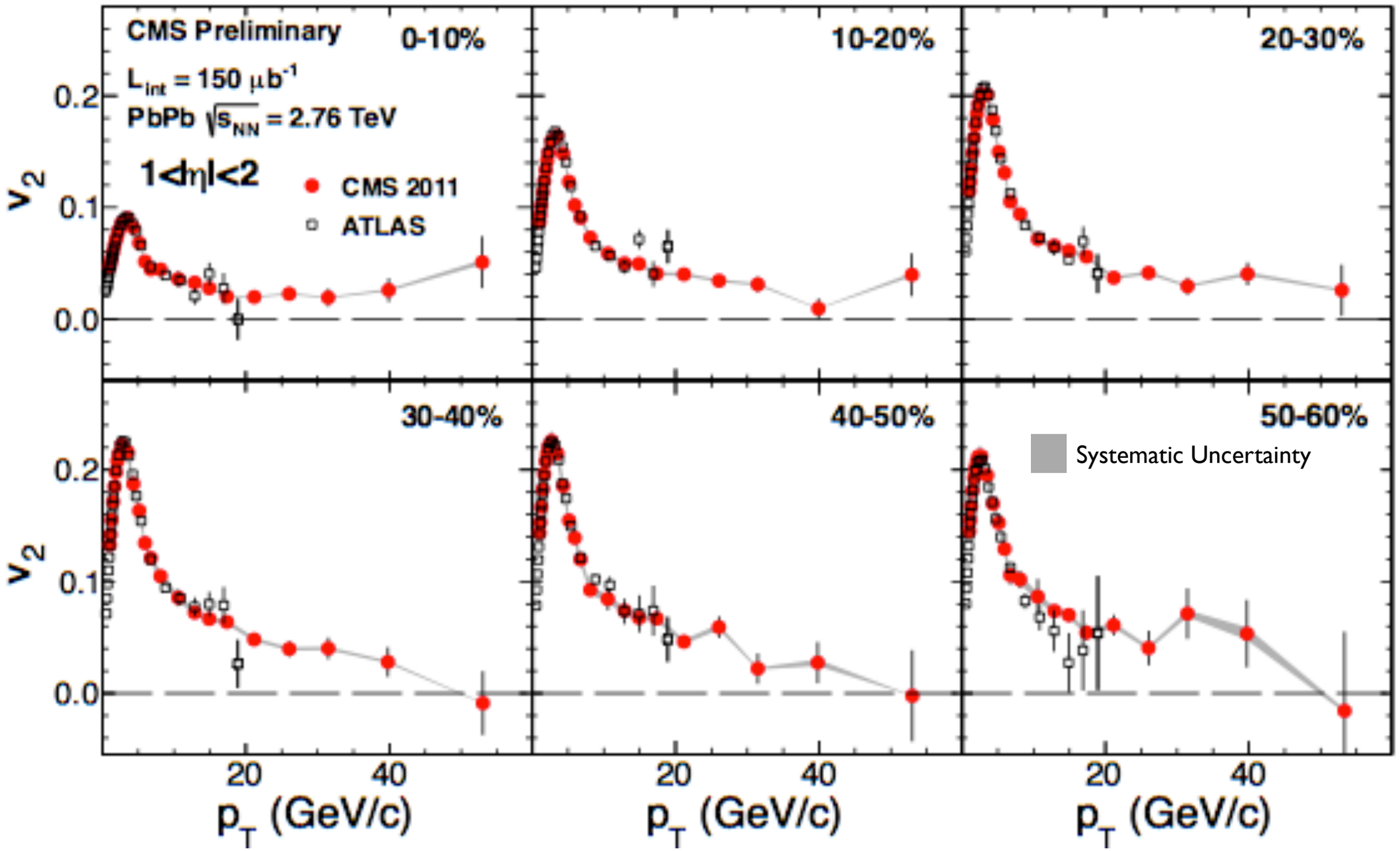
EP+ (3<η<5)
EP- (-5<η<-3)
*Hadronic Forward Calorimeters used for determining the Event Plane.

v_2 vs p_T ($0<|\eta|<1$)



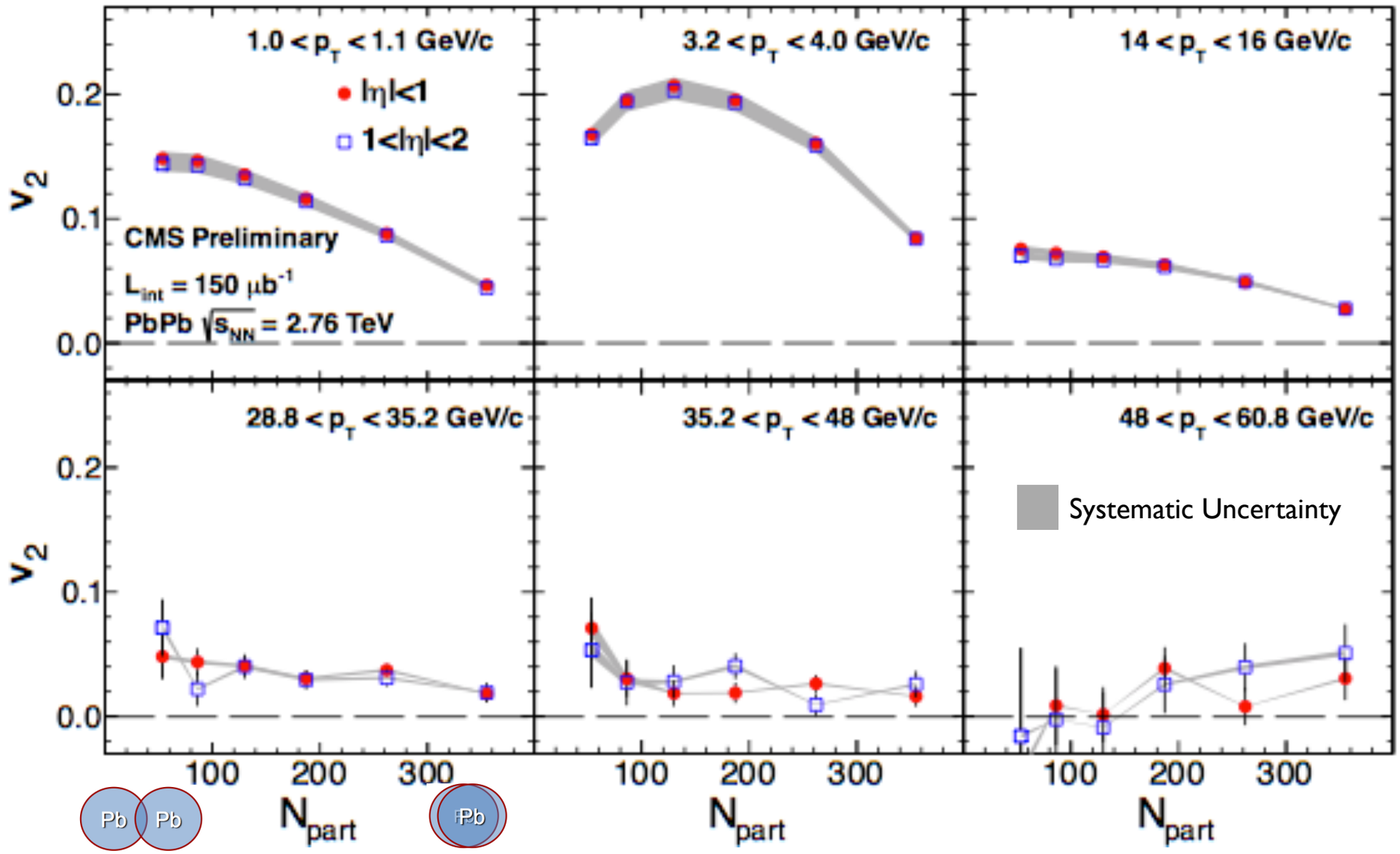
- **First v2 measurements at high p_T**
- Gradual decrease of v_2 above p_T ~ 10 GeV/c

v_2 vs p_T (1<|η|<2)



No significant η dependence of v_2

v_2 vs Centrality



Significant non-zero v2 up to p_T < 48 GeV/c for all centralities

For p_T > 48 GeV/c, v2 consistent with 0 in peripheral collisions

Summary

- New results on high p_T charged hadron R_{AA} and v_2
  - R_{AA} measured up to pT = 100 GeV/c
  - v_2 measured up to pT = 60 GeV/c
- R_{AA} approximately flat at 0.5 for p_T > 35GeV/c
- v_2 shows gradual decrease for p_T > 10GeV/c, but remains finite at least up to p_T ~ 40GeV/c
- Combination of R_{AA} and v_2 results constrains path-length dependence in energy loss models
- Need to aim for a consistent description of *ALL* jet quenching observables - see talks by Yetkin, Christof, Mihee and Yue-Shi