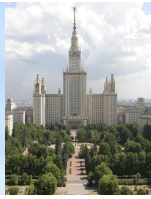
Heavy Ion Physics at the LHC with CMS experiment



Igor Lokhtin

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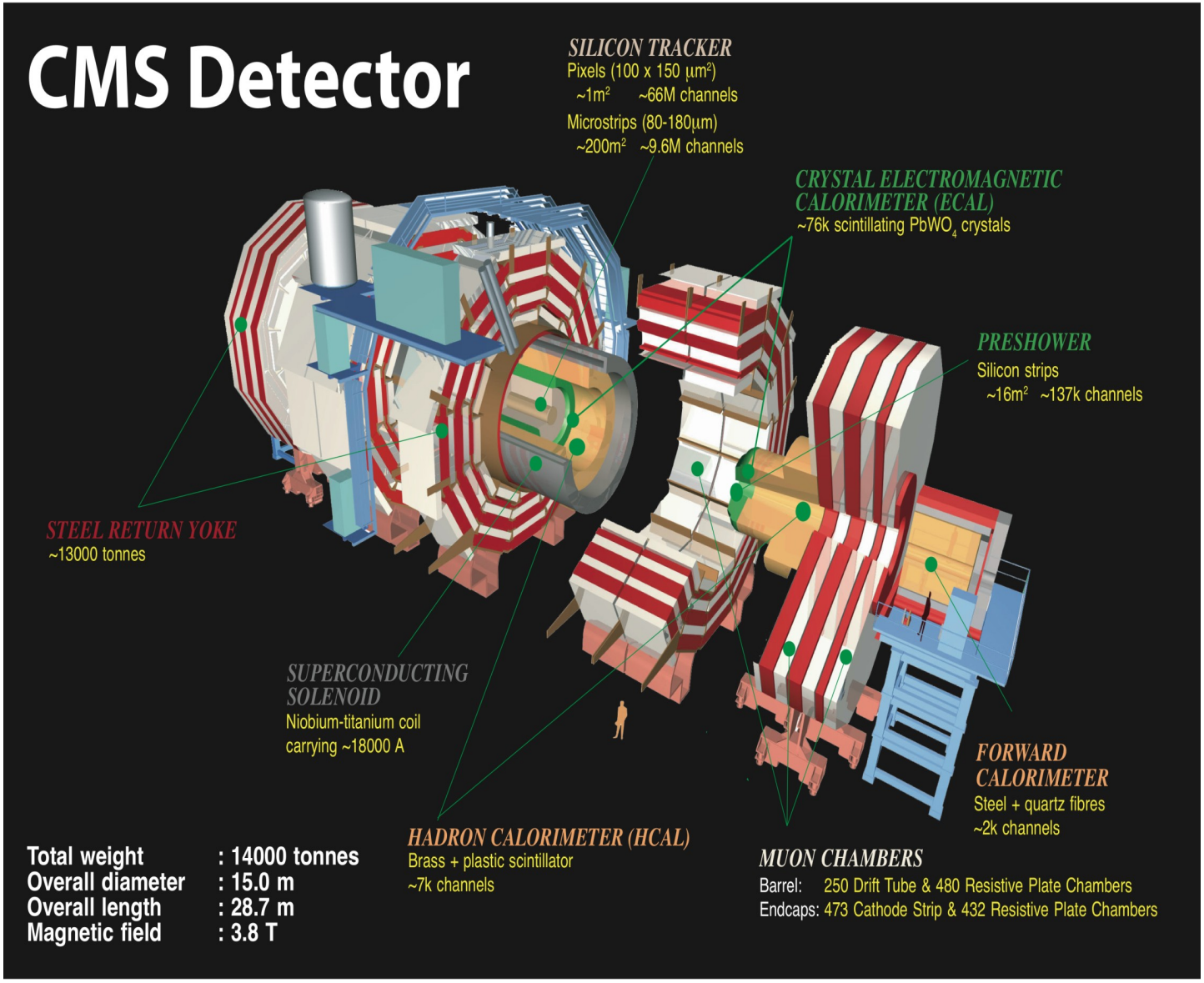
- CMS detector and heavy ion data taking
- CMS results on PbPb and pPb collisions
  - *Charge hadron multiplicity*
  - *Transverse energy density*
  - *Anisotropic flow*
  - *Dihadron angular correlations*
  - *Electroweak probes (Z and W bosons, prompt photons)*
  - *High transverse momentum hadrons*
  - *Jets*
  - *Quarkonia*
- Summary

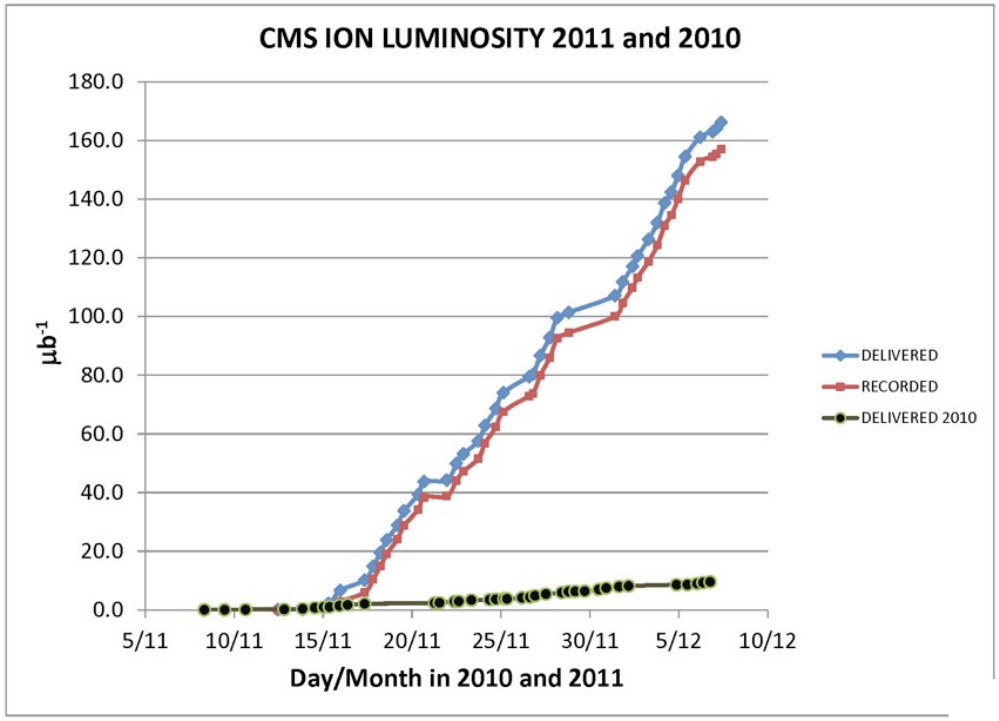
CMS Detector

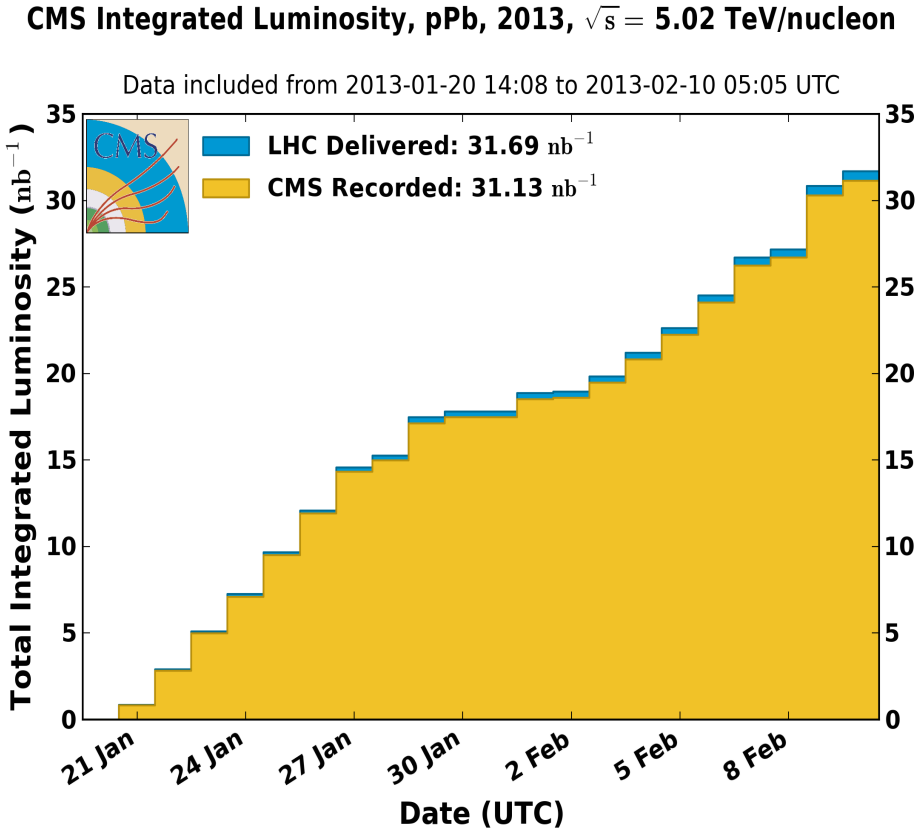


- Silicon Tracker
  $|\eta| < 2.4$
- Electromagnetic calorimeter
  $|\eta| < 3.0$
- Hadron Calorimeter
  barrel and endcap
  $|\eta| < 3.0$
  with HF-calorimeter up to
  $|\eta| < 5.2$
- Muon Chambers
  $|\eta| < 2.4$

+ CASTOR detector
$5.2 < |\eta| < 6.6$
+ Zero-degree calorimeter
+ TOTEM

LHC PbPb and pPb runs (2010-2013)





Pb+Pb ($\sqrt{s_{NN}}$=2.76 TeV)

CMS recorded in 2010 ~7.3 μb^{-1}

CMS recorded in 2011 ~150 μb^{-1}

p+Pb ($\sqrt{s_{NN}}$=5.02 TeV)

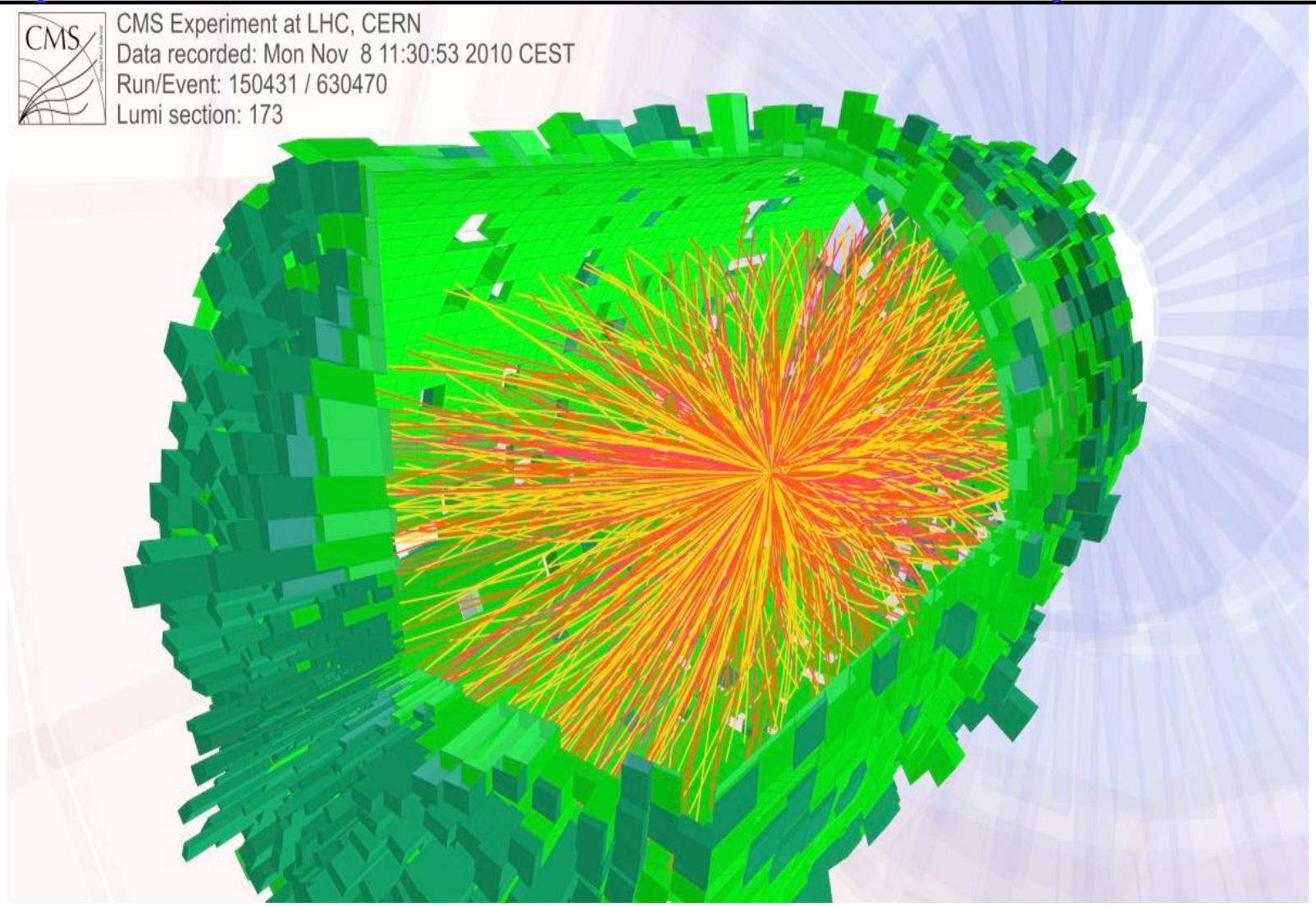
CMS recorded in 2013 ~31 nb^{-1}

(first pilot pPb run was in 2012)

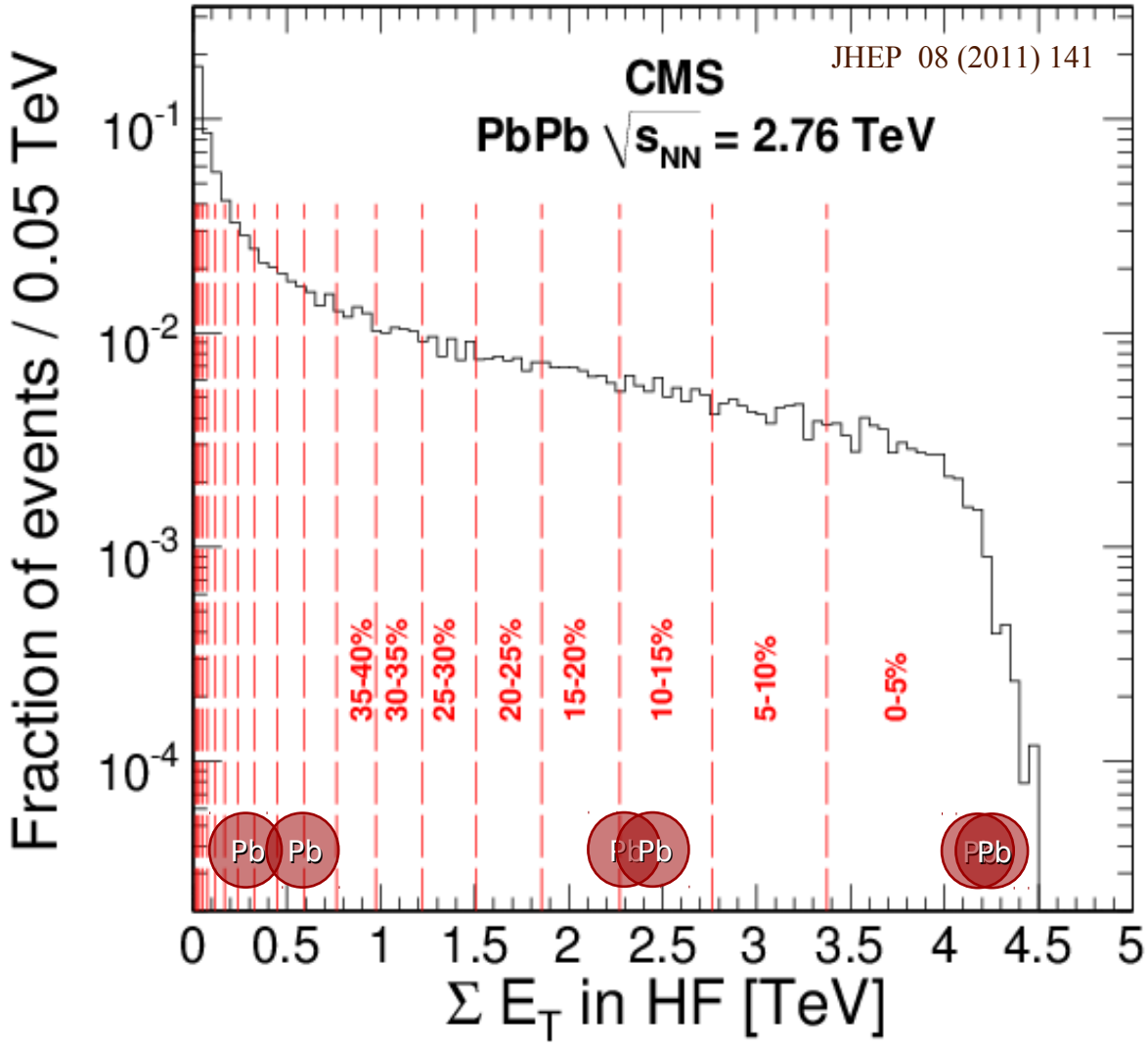
CMS also recorded pp data at $\sqrt{s}$=2.76 TeV (~5.4 pb^{-1} in 2013 & ~240 nb^{-1} in 2011)

CMS Heavy Ion Public Results

23 published/submitted papers, 15 Physics Analysis Summaries (CMS PAS):
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

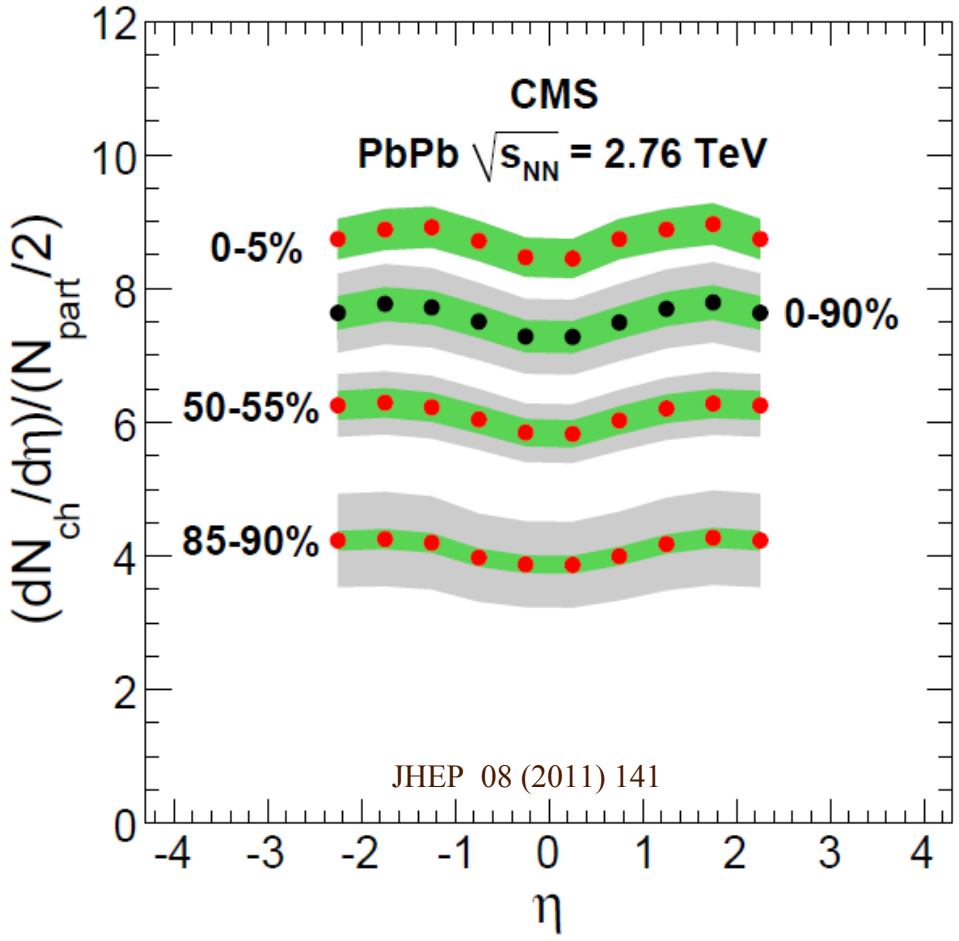


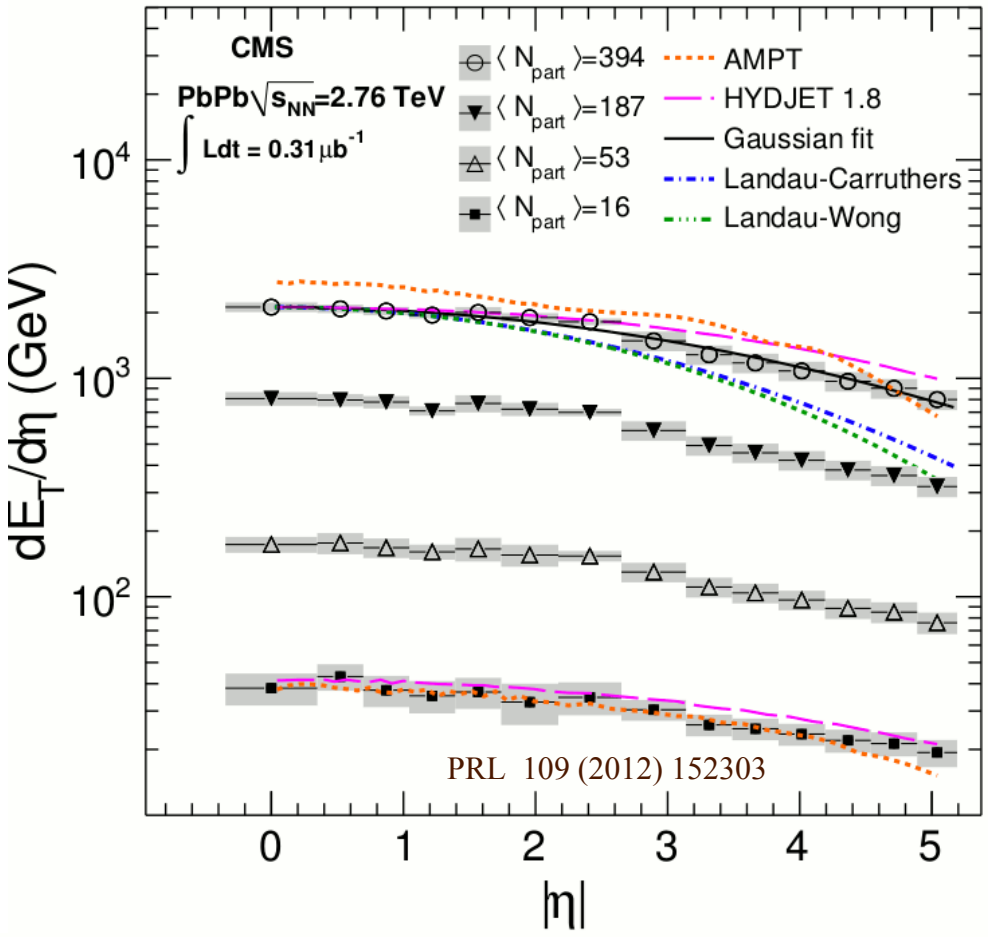
Heavy ion event centrality determination



Events are classified according to the percentile of the PbPb inelastic cross section based on *total deposited energy in the forward calorimeters*

Hadron multiplicity & energy density in PbPb





central PbPb (0-5%): $dN_{ch}/d\eta(\eta=0) \approx 1600$

(by a factor of 2.2 higher than at RHIC)

central PbPb (0-2.5%): $dE_T/d\eta\ (\eta=0) \approx 2.1$ TeV

(by a factor of 3.3 higher than at RHIC);

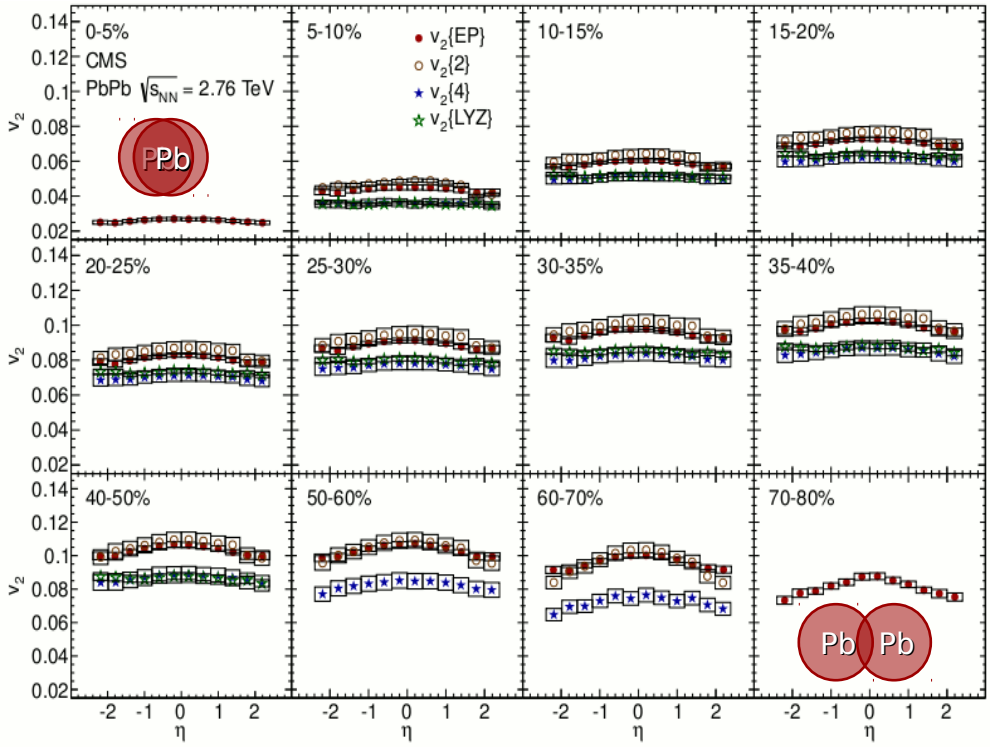
$\varepsilon\ (\tau_0=1\ \text{fm/c}, \eta=0) \sim dE_T/dy\ (y=0) \approx 14\ \text{GeV/fm}^3$

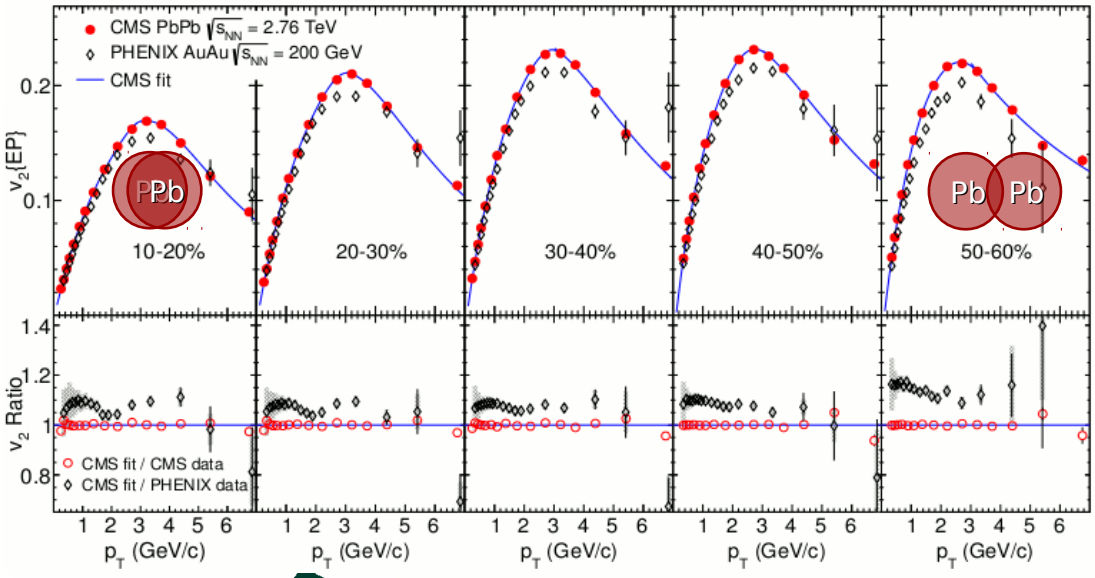
(by a factor of 2.8 larger than at RHIC)

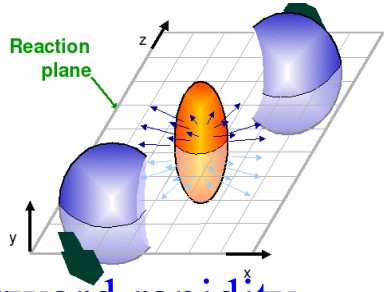
Elliptic flow v_2 in PbPb

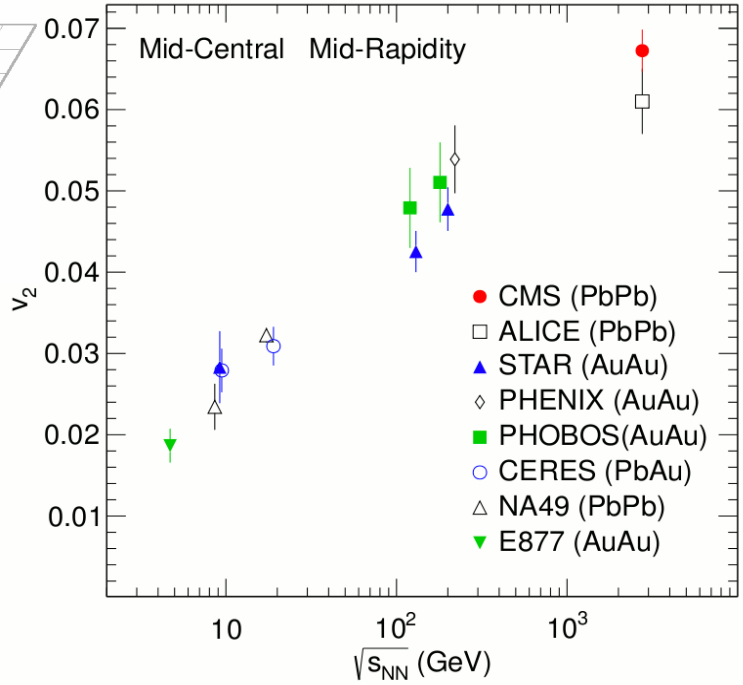
$$\frac{dN}{d^2p_t dy} = \frac{dN}{2\pi p_t dp_t dy}(1 + v_2\cos 2\varphi + 2v_4\cos 4\varphi + \ldots)$$

PRC 87 (2013) 014902



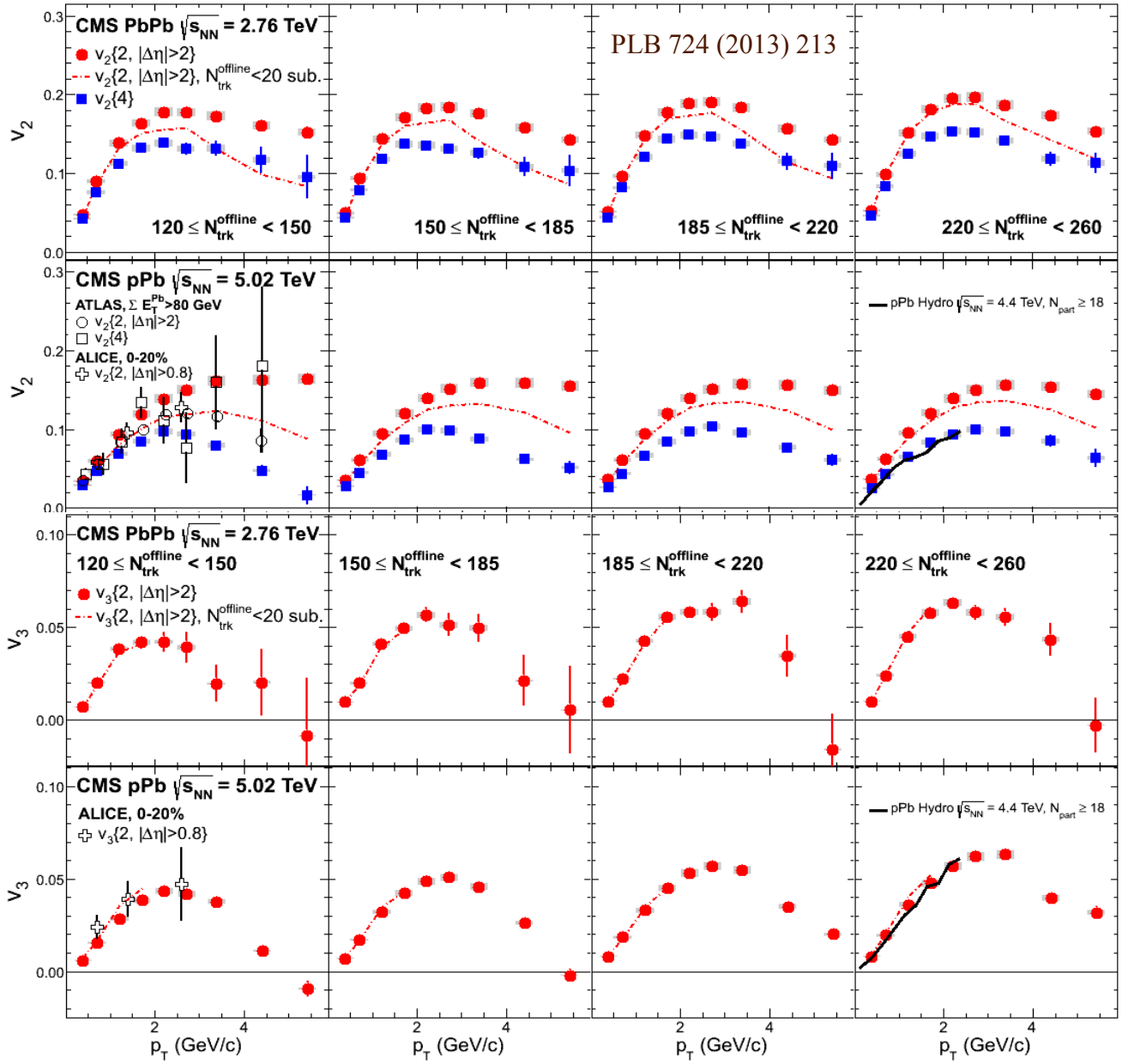






- v_2 slowly decreases from mid-rapidity to forward rapidity
  stronger rapidity dependence is for the most peripheral collisions
- $v_2(p_T)$ peaks at ~ 3 GeV/c
  p_T-dependence of v_2 at LHC is similar to RHIC
- v_2 is strongest for 30-50% centrality
- Integral v_2 at the LHC is higher than at RHIC by ~15-30%
  due to the rise of $\langle p_T \rangle$

Elliptic and triangular flow in pPb vs. PbPb



$dN/d\varphi = N\{1+\Sigma_n 2v_n \cos(n\varphi)\}/2\pi$,
$v_n = \langle\cos(n\varphi)\rangle$

Significant v_2 and striking similarity of v_3 for pPb and PbPb systems with drastically different *collision geometry and its fluctuations*

Dihadron angular correlations

p+p 7 TeV

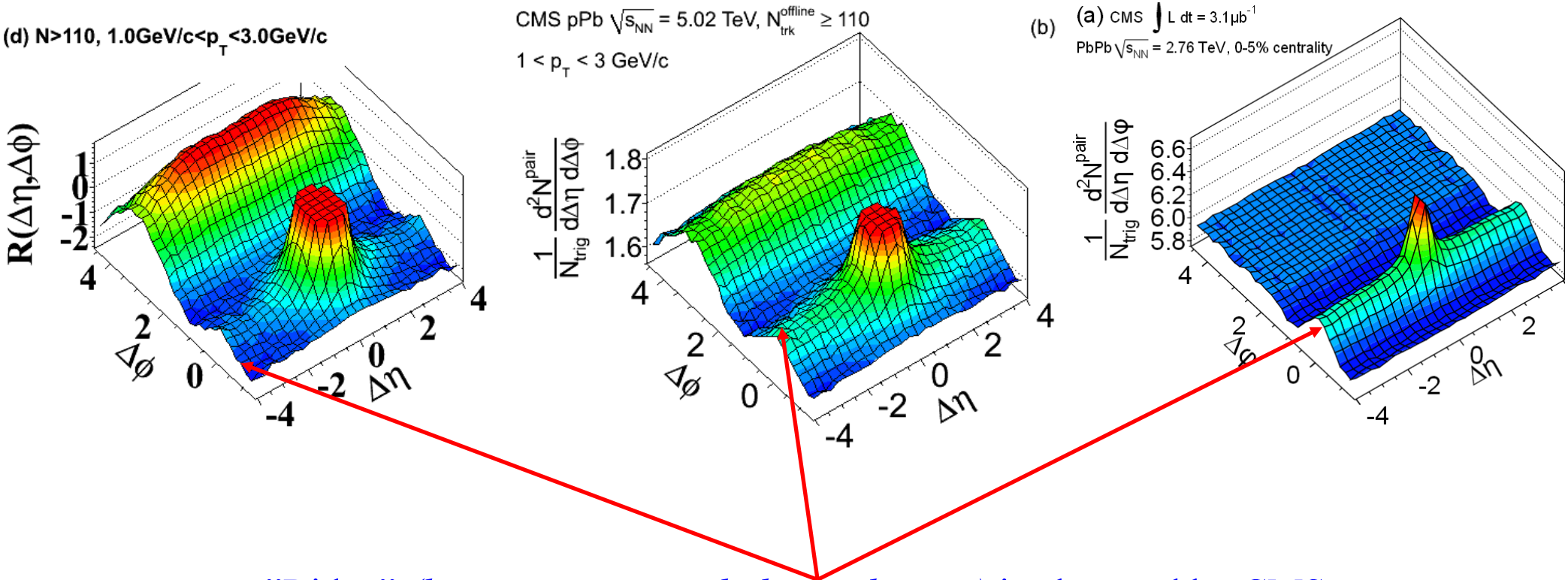
JHEP 09 (2010) 091

p+Pb 5.02 TeV

PLB 718 (2013) 795

Pb+Pb 2.76 A TeV, 0-5%

JHEP 07 (2011) 076

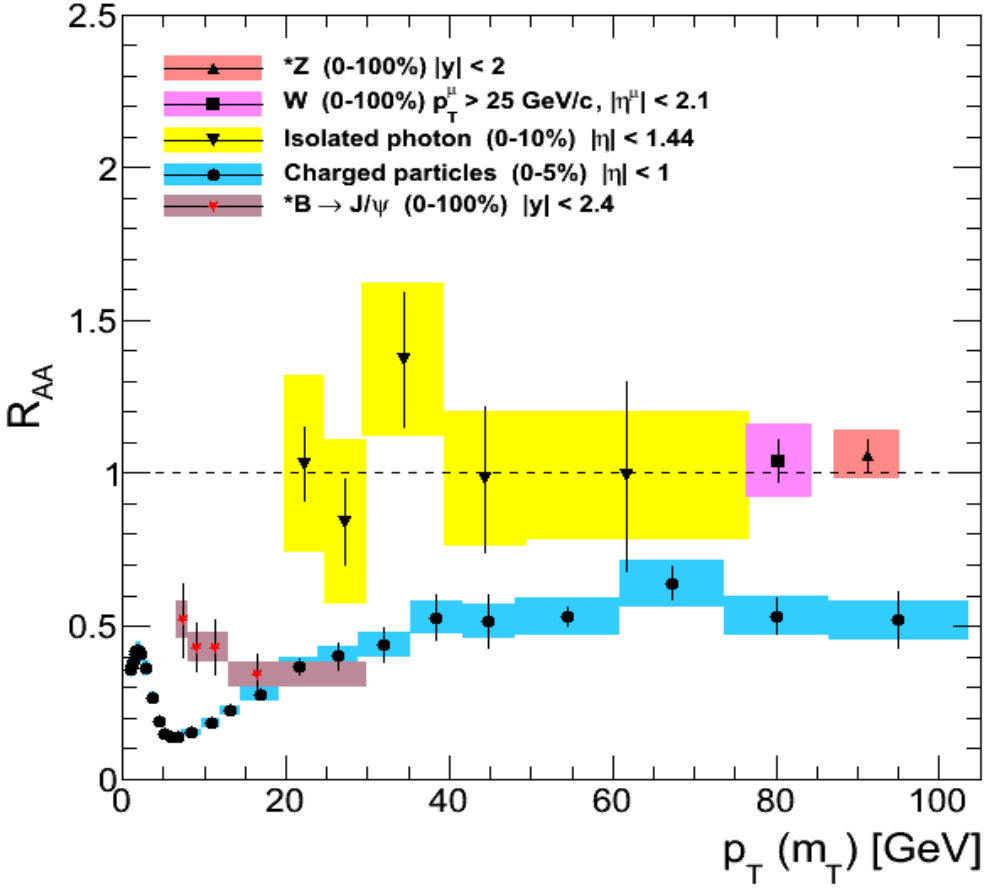


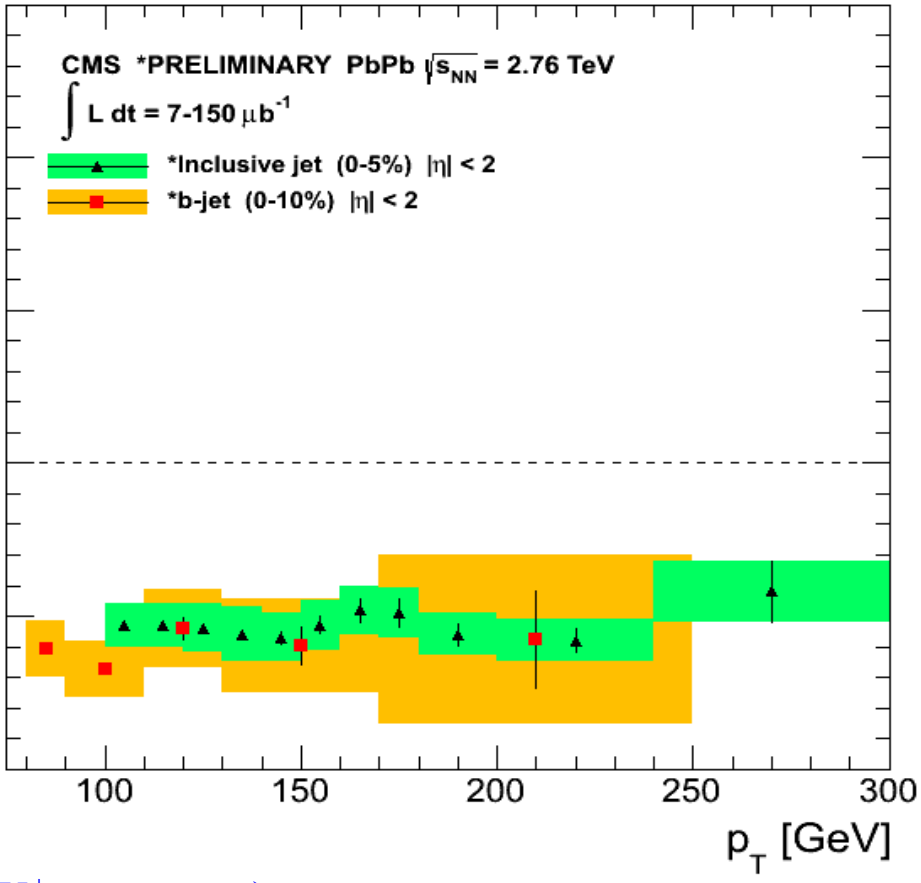
”Ridge” *(long-range azimuthal correlations)* is observed by CMS in high multiplicity pp and pPb as well as in central PbPb collisions

Nuclear modifications factors
(hadrons, jets, b-jets, secondary J/ψ, electroweak probes)

$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta} \sim \frac{\text{“QCD Medium”}}{\text{“QCD Vacuum“}}$$

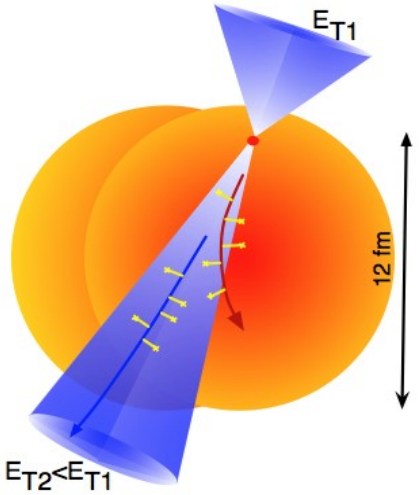
R_{AA}>1: enhancement
R_{AA}=1: no medium effect
R_{AA}<1: suppression





- No medium effects for electroweak hard probes (Z^0, $W^{\pm}$, prompt γ)
- Charged particles and jets are suppressed, suppression factors saturate at high transverse momentum
- Observation of b-quark (via secondary J/ψ's) suppression
- B-jets (*extracted using vertex info*) seem suppressed on the similar level as inclusive jets

Asymmetry of dijet energy in PbPb



$$A_J = \frac{E_T^{j1} - E_T^{j2}}{E_T^{j1} + E_T^{j2}}$$

A strong *increase in the fraction of highly unbalanced dijets* in central PbPb as compared with pp and peripheral PbPb, and the dijet embedded MC simulations

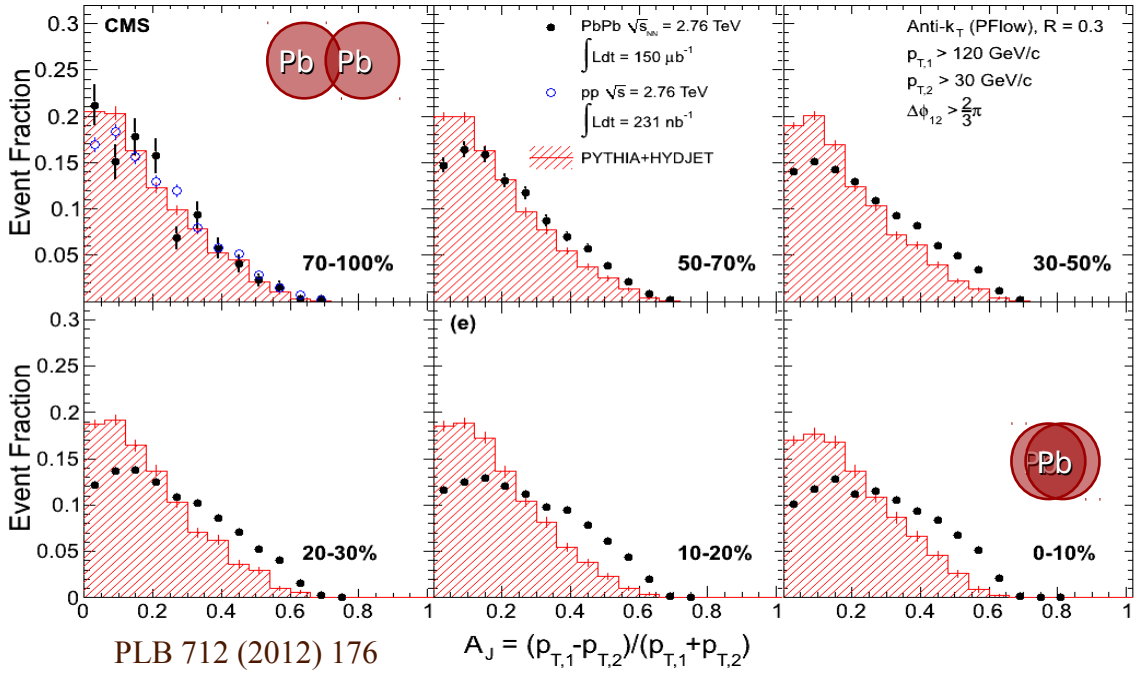
⇩

direct observation of jet quenching

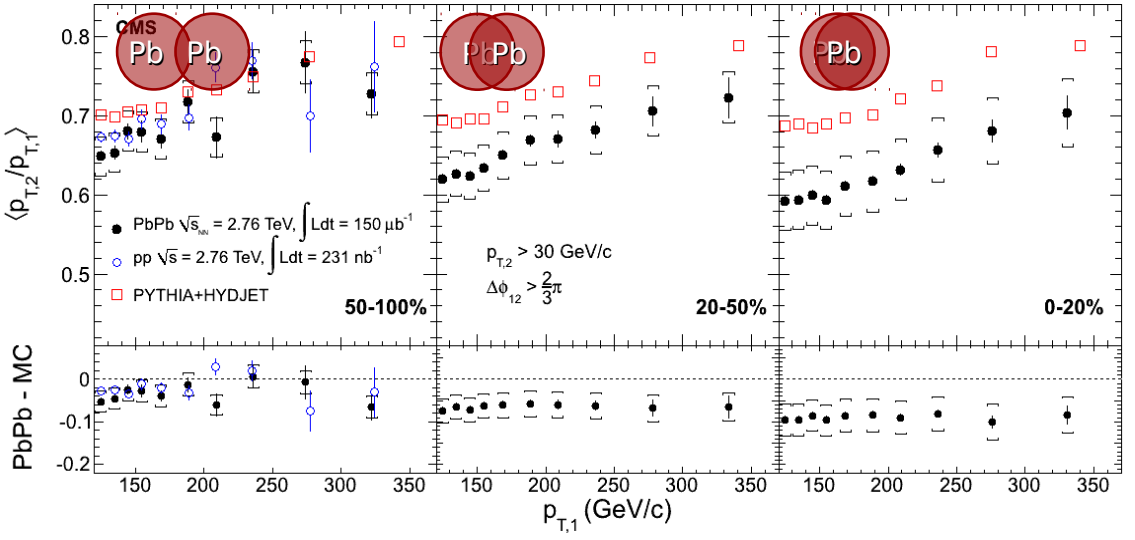
The fraction of the energy that a jet loses increases monotonically with increasing collision centrality, and does not dramatically change with jet p_T

⇩

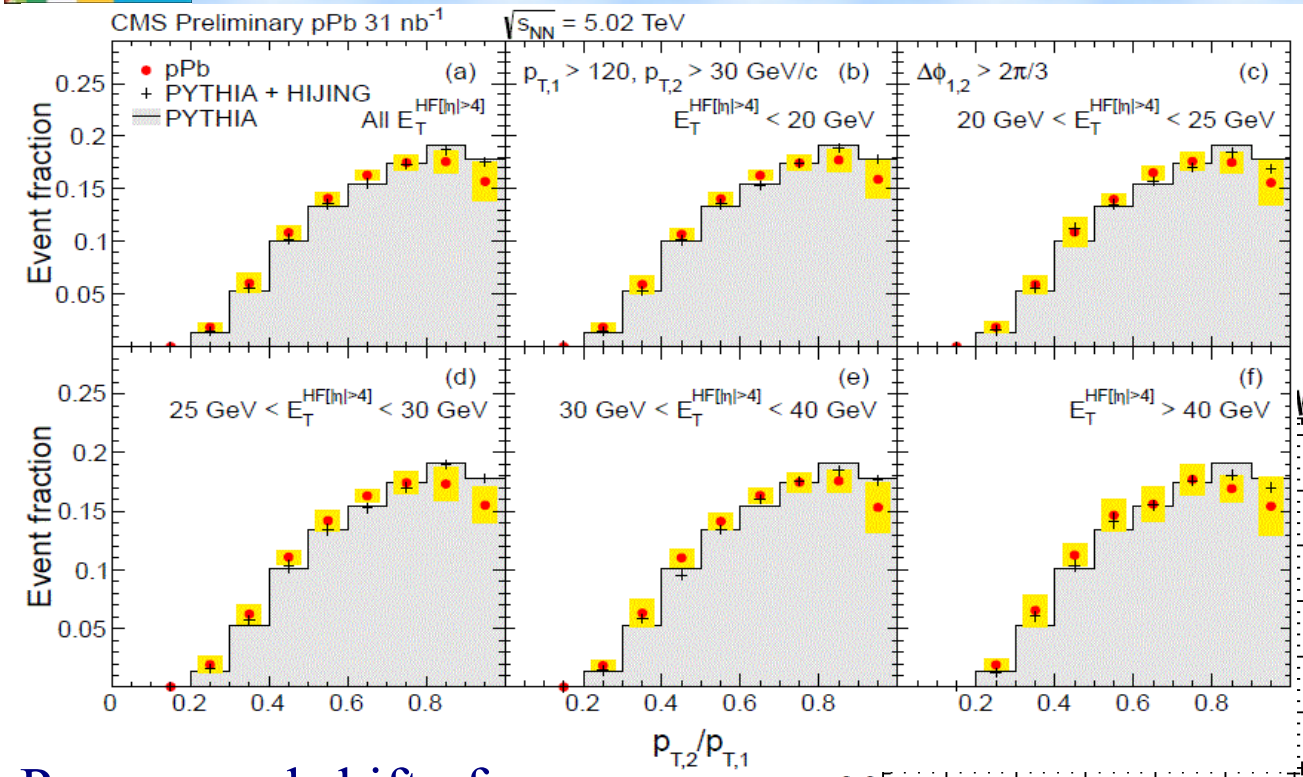
constant relative energy loss?



PLB 712 (2012) 176



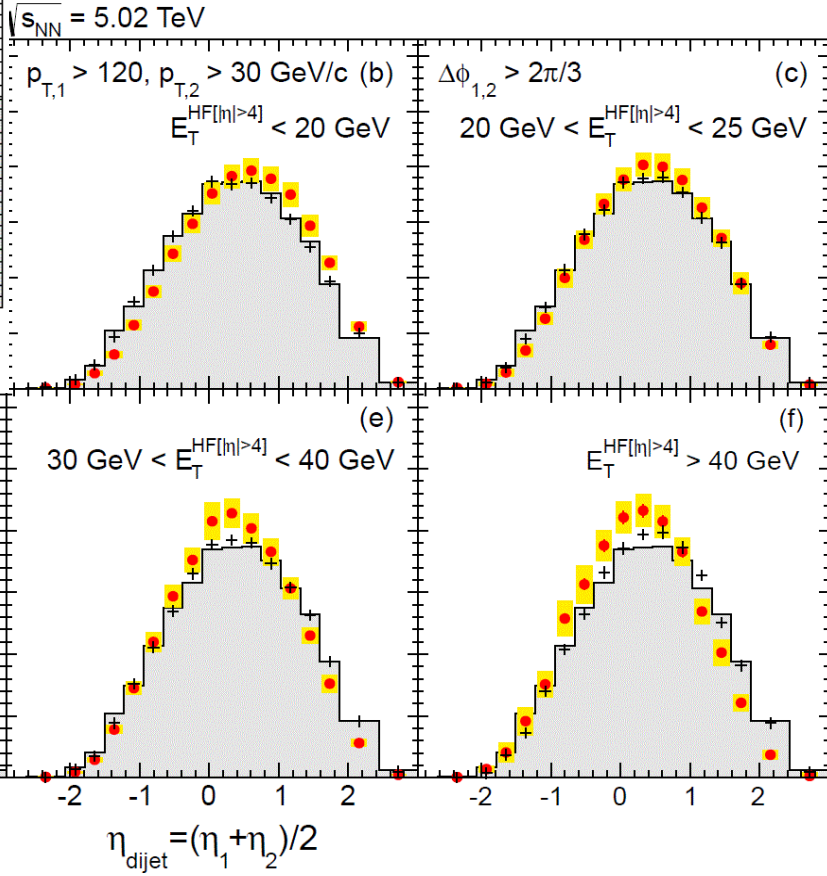
Dijets in pPb



CMS-PAS-HIN-13-001

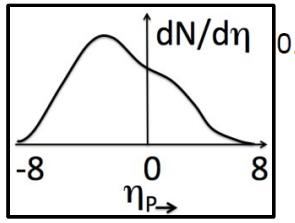
No centrality dependence of dijet momentum balance

No jet quenching?

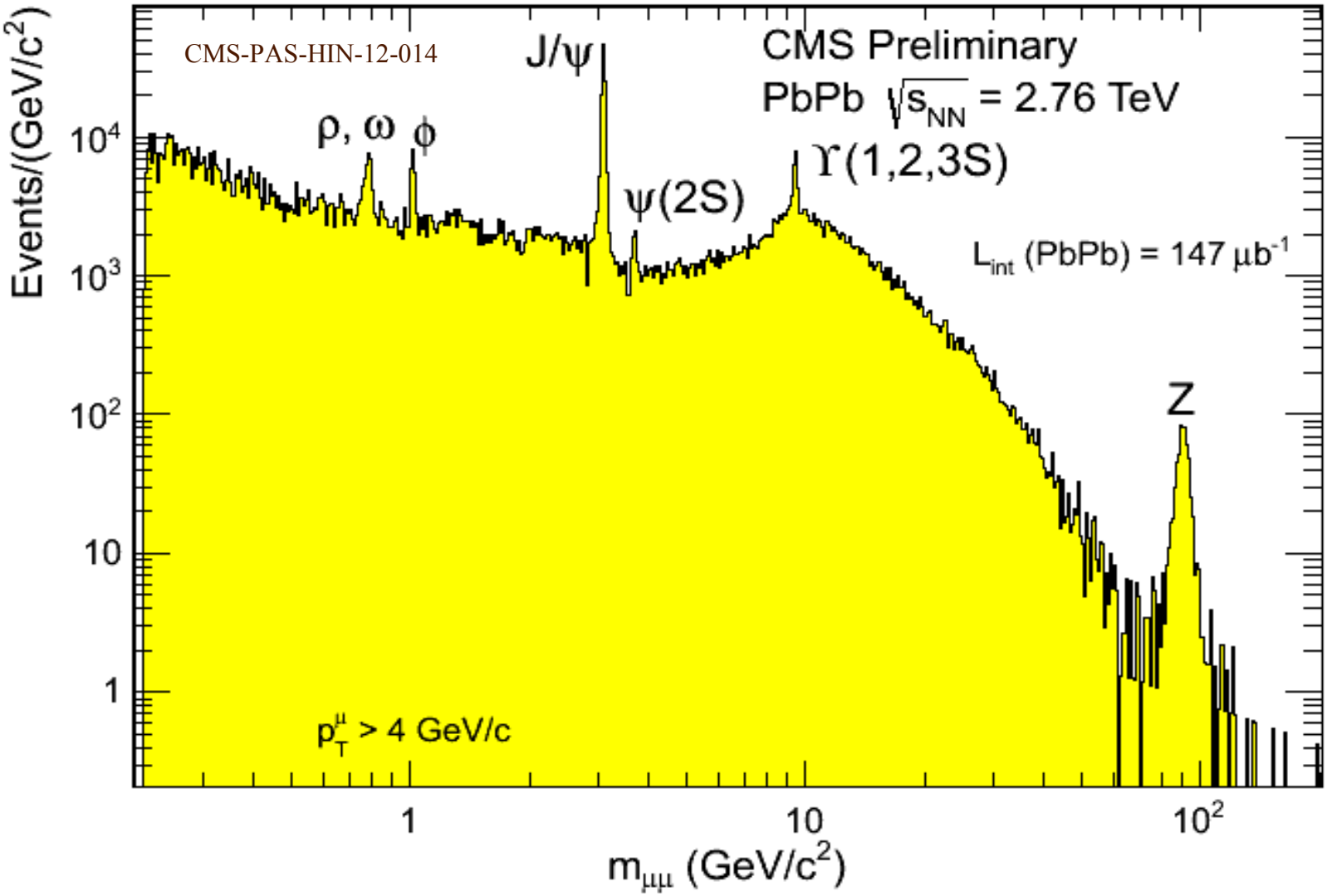


Pronounced shift of mean dijet rapidity in Pb-going η direction vs centrality

Initial state effect (nuclear shadowing)?



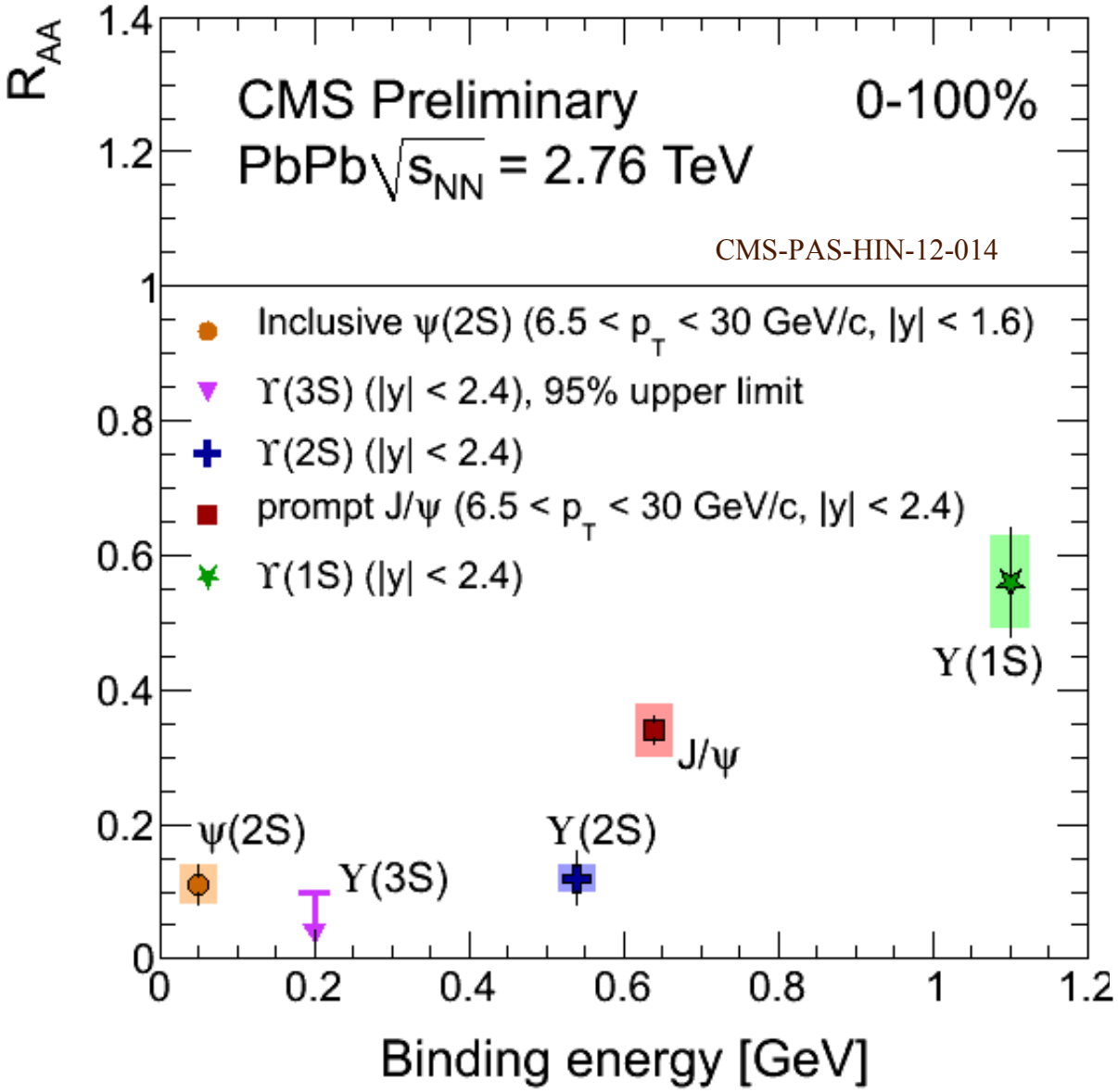
Dimuon mass spectrum in PbPb



ρ, ω, ϕ, J/ψ, ψ', Y(1S, 2S, 3S) and Z^0 peaks are clearly visible

CMS has the best dimuon mass resolution of all LHC experiments in heavy ion collisions

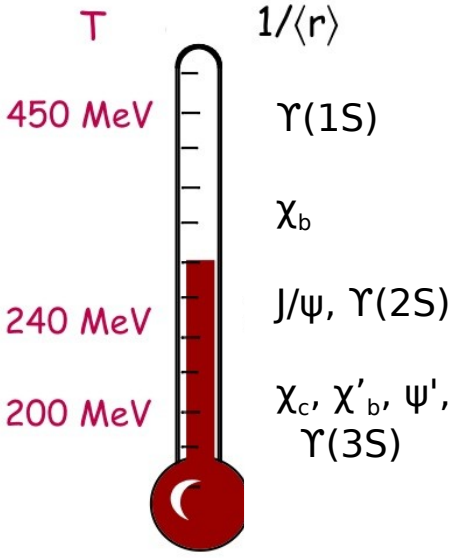
Quarkonium suppression in PbPb



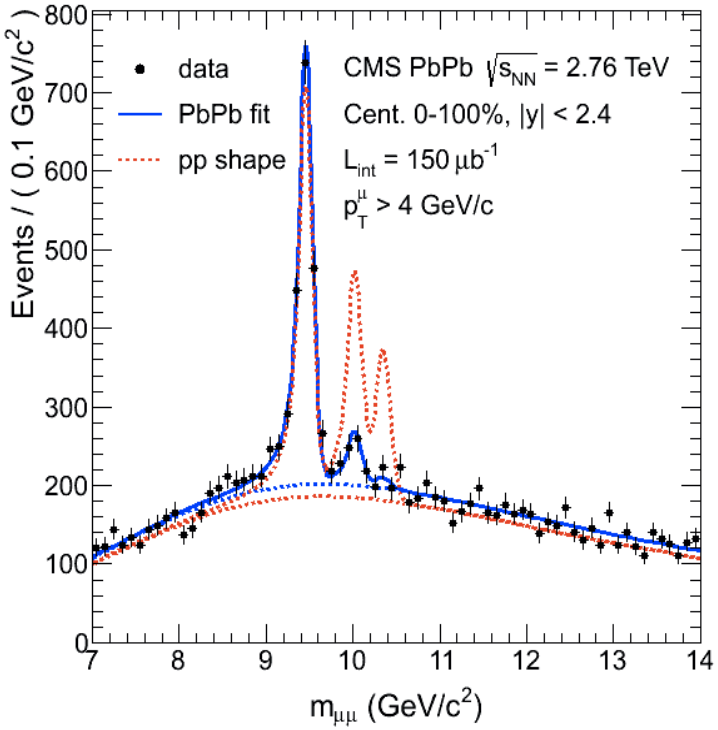
sequential suppression of different quarkonium states

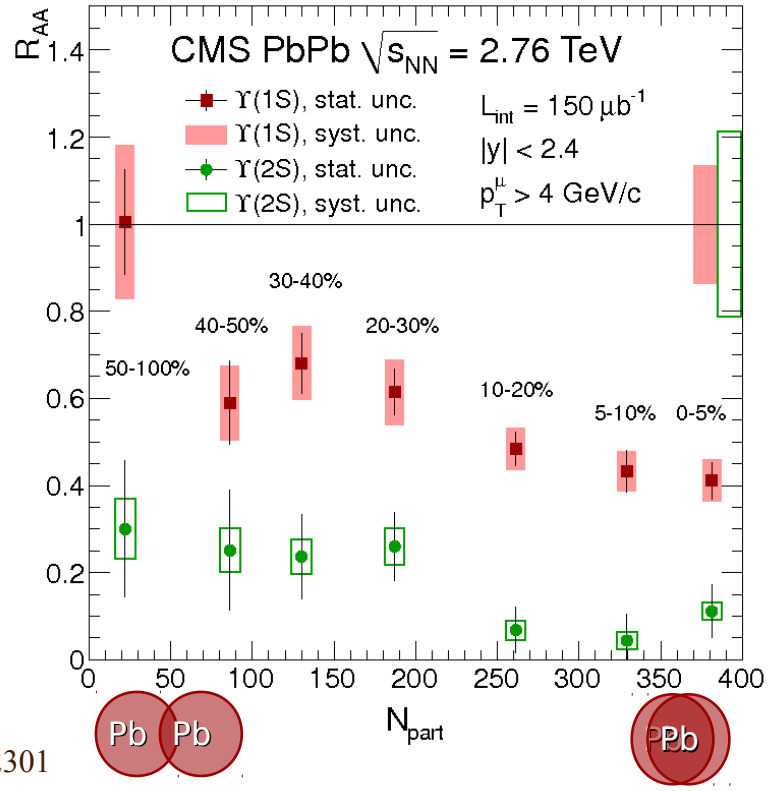
⇩

hint of Debye screening in quark-gluon plasma?



Υ(2S+3S)/Υ(1S) suppression in PbPb





PLB 109 (2012) 222301

$$[\Upsilon(2S)/\Upsilon(1S)]_{PbPb} / [\Upsilon(2S)/\Upsilon(1S)]_{pp} = 0.21 \pm 0.07 \pm 0.02$$

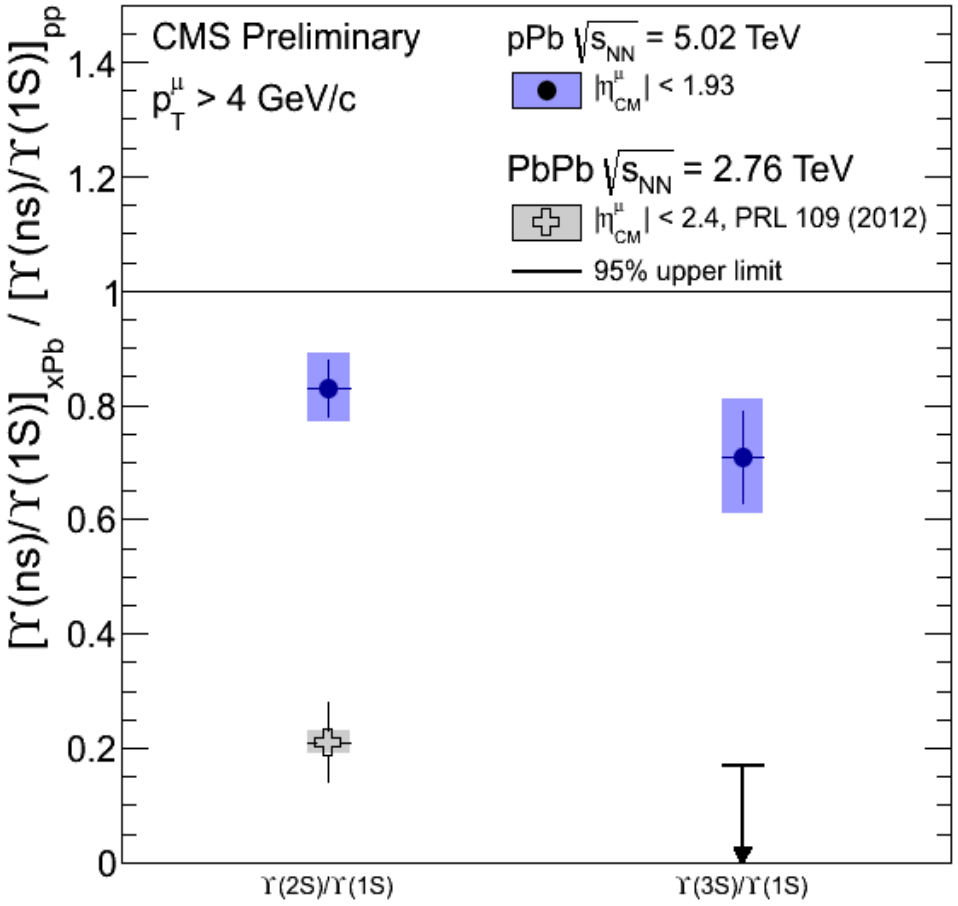
$$[\Upsilon(3S)/\Upsilon(1S)]_{PbPb} / [\Upsilon(3S)/\Upsilon(1S)]_{pp} = 0.06 \pm 0.06 \pm 0.06 \ (< 0.17, 95\%\text{C.L.})$$

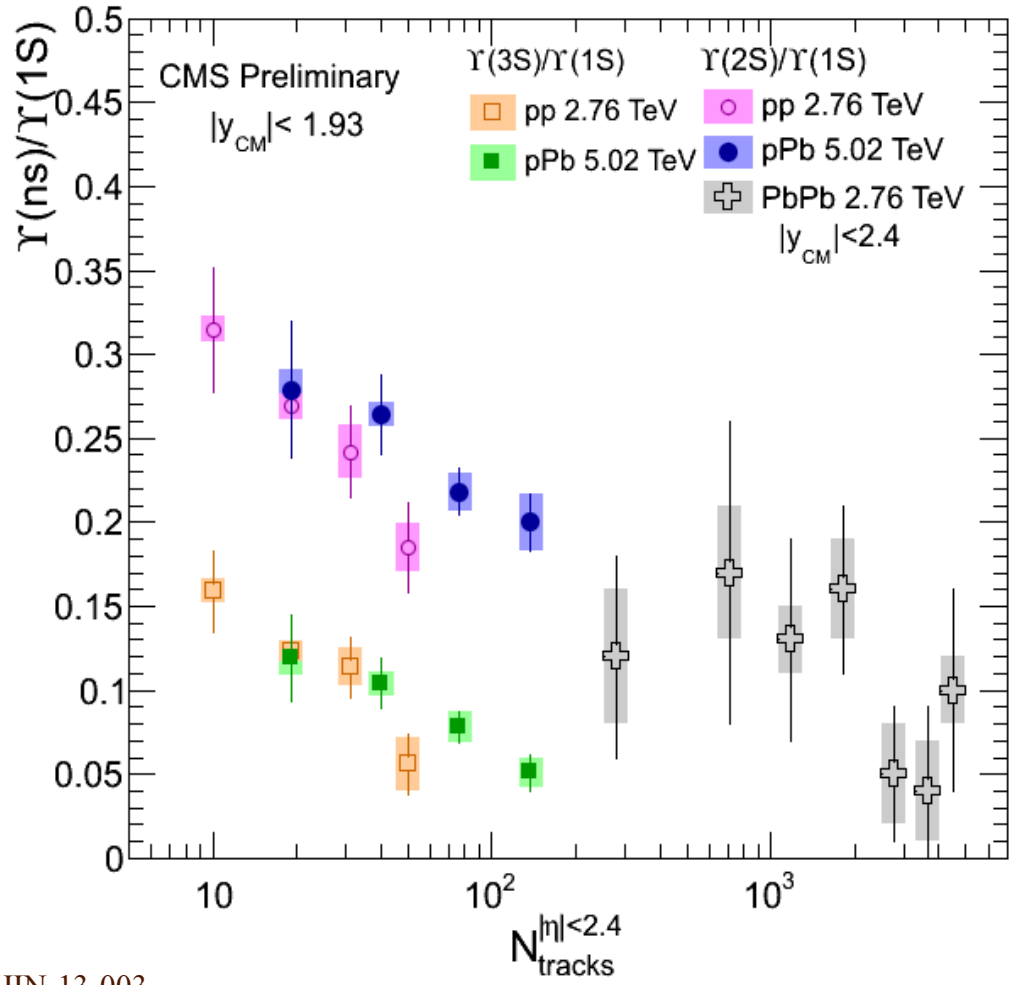
$$[\Upsilon(2S+3S)/\Upsilon(1S)]_{PbPb} / [\Upsilon(2S+3S)/\Upsilon(1S)]_{pp} = 0.15 \pm 0.05 \pm 0.02$$

Υ(nS) suppression is ordered as Υ(3S) > Υ(2S) > Υ(1S), and increases with the centrality of the PbPb collision

sequential melting of the excited Υ-states in quark-gluon plasma?

Υ(2S+3S)/Υ(1S) suppression in pPb

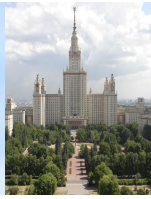




CMS-PAS-HIN-13-003

- Moderate Y(nS)/Y(1S) *suppression (much lesser than in PbPb)* - initial or final state effect?
- Y(nS)/Y(1S) decreases with event multiplicity *for all systems:* pp, pPb, PbPb

Summary on CMS Heavy Ion results



PbPb collisions

- *Global observables:* high multilipcity and energy density, anisotropic flow, ridge

⇨ Strongly interacting matter with hydrodynamical properties

- *High transverse momentum hadrons and jets:* overall rate suppression, dijet and γ-jet energy asymmetry, modification of jet shapes and fragmentation function

⇨ Jet quenching due to partonic energy loss in hot QCD-matter

- *Quarkonia:* suppression of prompt and secondary J/ψ's, sequential suppression of Υ(nS)

⇨ Debye screening of color charge in QCD-matter, in-medium b-quark energy loss

- *Electroweak probes:* first measurements of Z^0,$W^{\pm}$ bosons and prompt photons in HI

⇨ No medium effects for electroweak bosons, confirmation of NN binary scaling

pPb collisions (first look)

- *Global observables:* multi-particle correlations and ridge in high multiplicity events

⇨ some collectivity?

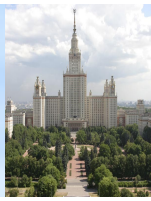
- *Jets:* no dijet asymmetry, dijet η distributions shift with event activity

⇨ no jet quenching? initial state effect (nuclear shadowing)?

- *Quarkonia:* moderate suppression of Υ(2S,3S)/Υ(1S) (stronger for higher multiplicities)

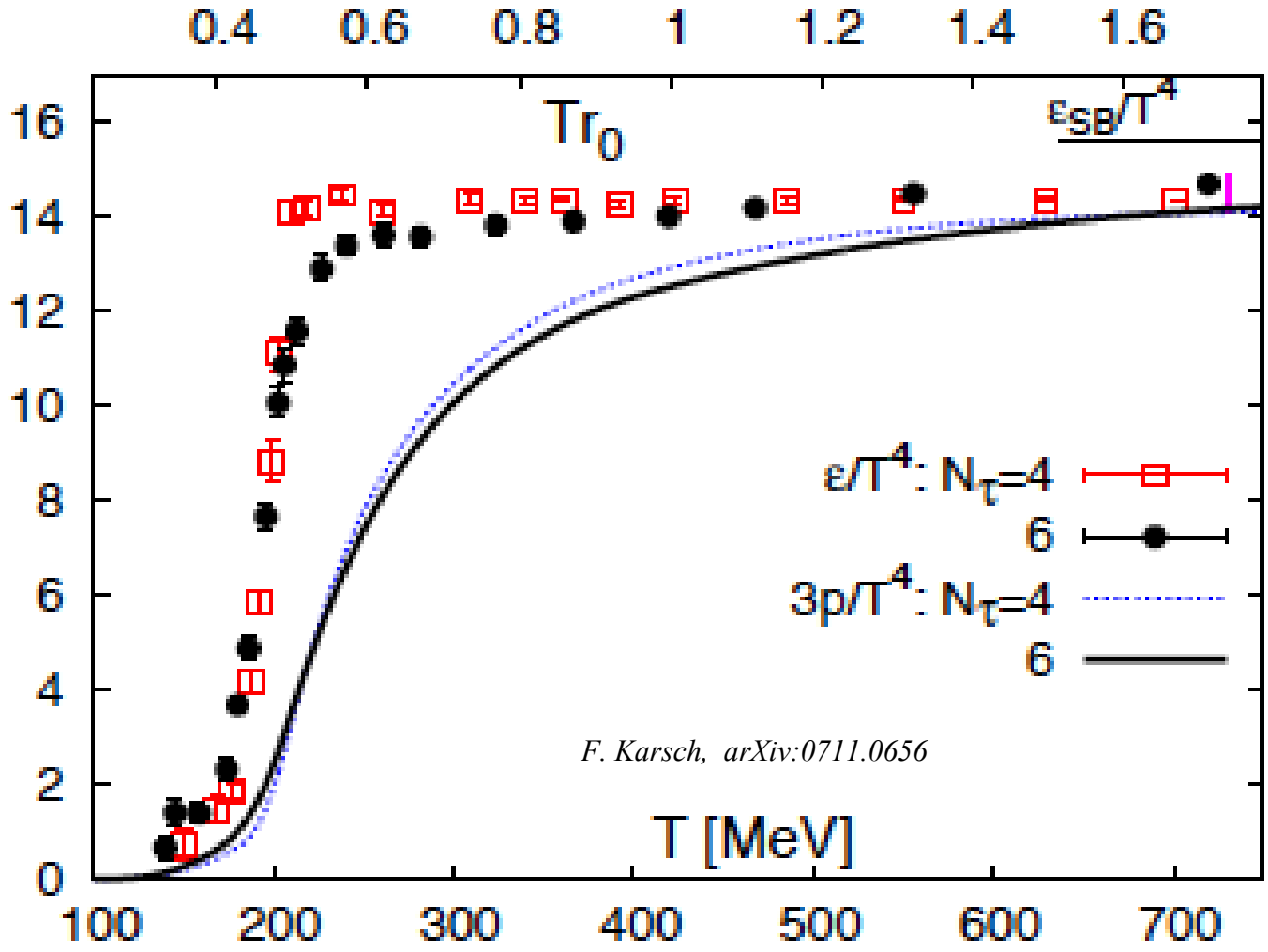
⇨ initial or final state effect?

More results are coming...



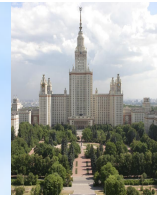
BACKUP SLIDES

Deconfinement of nuclear matter

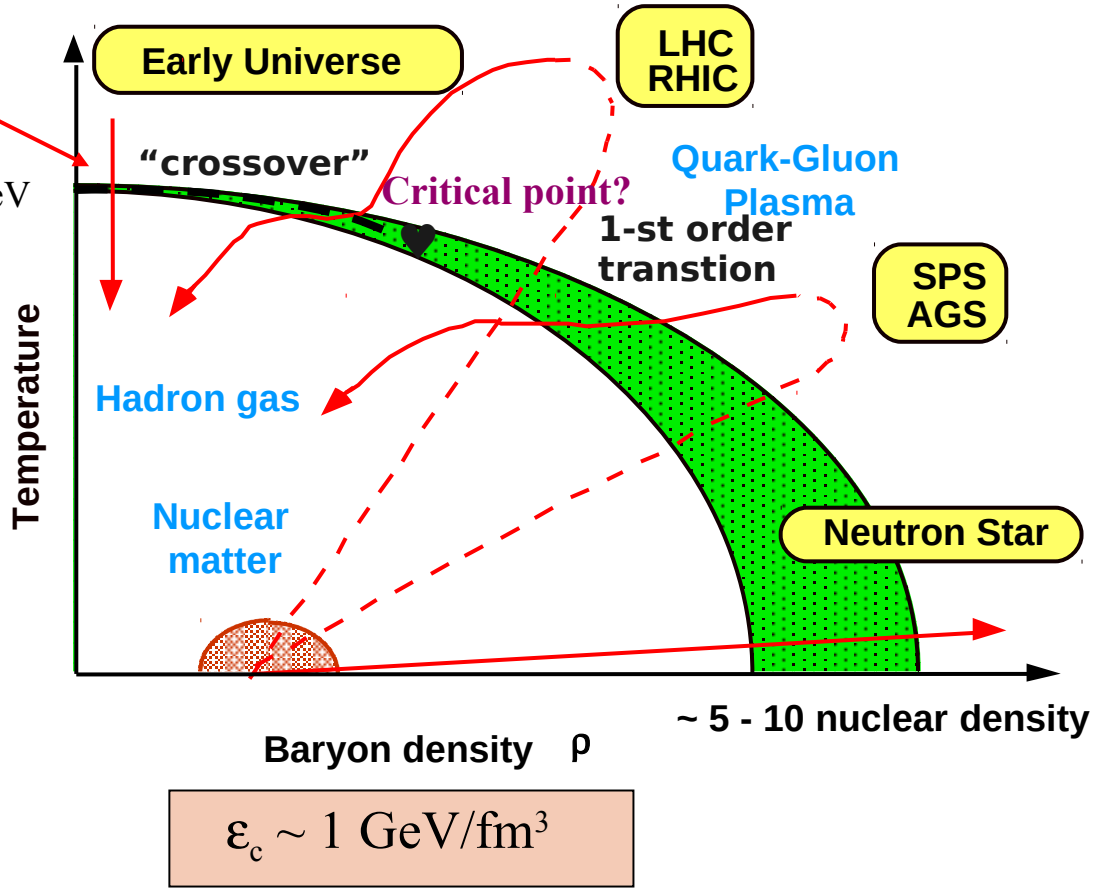


Deconfinement of nuclear matter and quark-gluon matter (QGM) formation – the prediction of Lattice Quantum Chromodynamics (QCD) for systems with high enough temperature and/or baryon density

QCD phase diagram



~ 10 μs after Big Bang



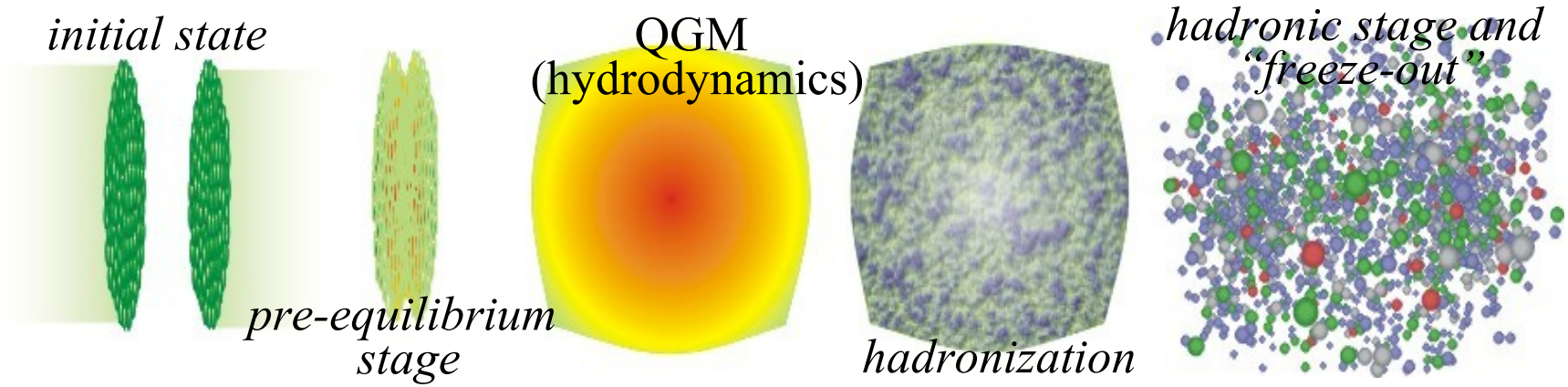
$\varepsilon_c \sim 1$ GeV/fm^3

Order of phase transition (Lattice QCD)
high T, low ρ – smooth "crossover"
low T, high ρ – 1-st order transition
Between two extremal states
(T(cp)~140-160 МэВ, $\mu_в$(cp)~350-650 МэВ)
critical point?
Non-statistical fluctuations!

→ energy scan at RHIC ($\sqrt{s}$ = 5-50 GeV) & NA61@SPS (E_{lab} = 10-158 GeV);
→ new projects CBM@FAIR (GSI) and NICA (JINR)

Study of quark-gluon matter in HI collisions

The formation of super-dense and hot state of QCD-matter in relativistic heavy ion collisions is possible on large space-time scales (quasi-macroscopic as compared with characteristic hadronic scales).



Soft probes ($p_T \sim \Lambda_{QCD}$=200 MeV)

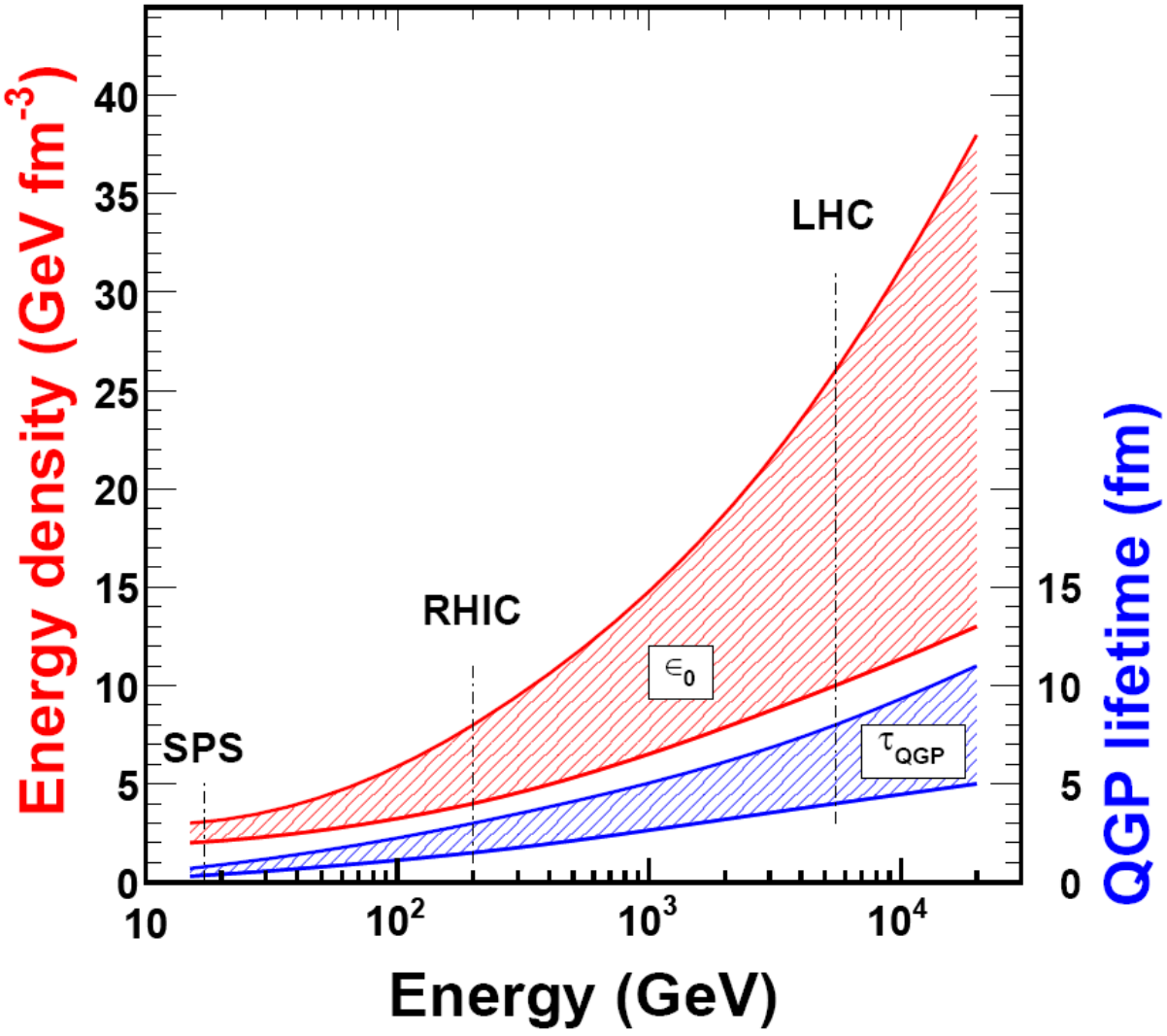
- ✓ spectra of particles with low transverse momenta, femtoscopic momentum correlations;
- ✓ flow effects;
- ✓ thermal photons and dileptons;
- ✓ strange particle yield.

Hard probes ($p_T, M >> \Lambda_{QCD}$=200 MeV)

- ✓ spectra of particles with high transverse momenta, their angular correlations;
- ✓ hadronic jets;
- ✓ quarkonia (dileptons);
- ✓ heavy quarks (leptons, tagged b-jets).

Study of quark-gluon matter in HI collisions

SPS (CERN) → RHIC (BNL) → LHC (CERN)

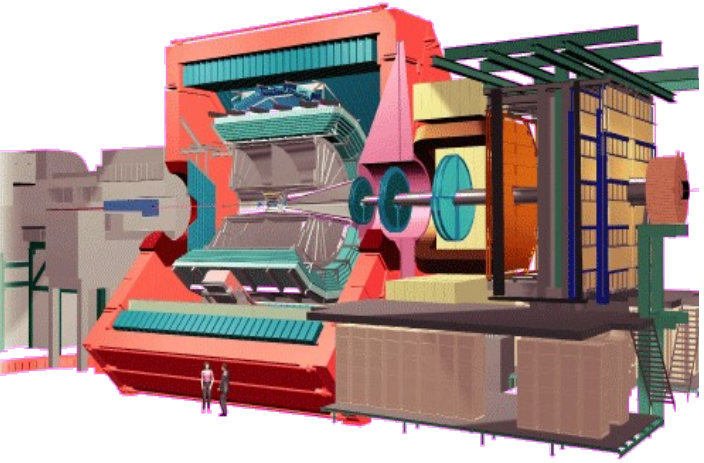


Heavy ion physics at the LHC

2010, 2011: PbPb ($\sqrt{s_{NN}}$ = 2.76 TeV);
2012/2013: pPb ($\sqrt{s_{NN}}$ = 5.02 TeV); *≥2015:* PbPb ($\sqrt{s_{NN}}$ = 5.1-5.5 TeV?);...

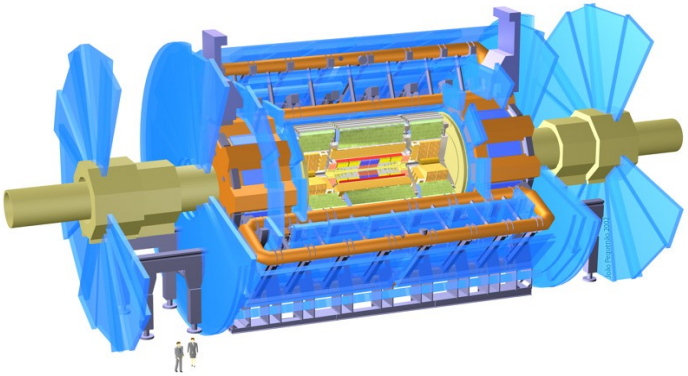
New regime of heavy ion physics with the important role of hard QCD-processes in hot and long-lived quark-gluon medium
complementary measurements from ALICE & CMS/ATLAS

ALICE

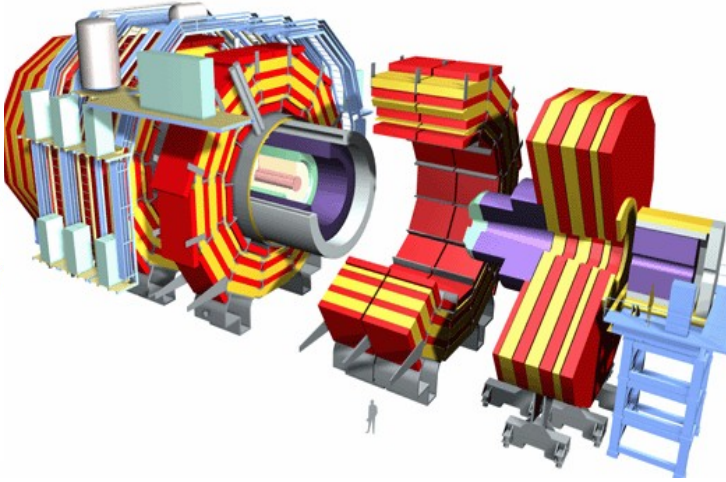


ALICE (low-p_T charged particle tracking, hadron ID, central *e*, forward μ (J/ψ, Υ), γ multiplicity,...)
soft probes + selected hard probes

ATLAS

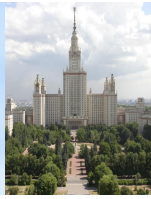


CMS



CMS/ATLAS (high-p_T charged particle tracking, central μ (J/ψ, Υ, Z, W), hard γ, calorimetric jets...)
hard probes + selected soft probes

CMS papers on PbPb & pPb collisions



[1] "Observation and studies of jet quenching in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Rev. C 84 (2011) 024906.*
[2] "Study of Z boson production in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Rev. Lett. 106 (2011) 212301.*
[3] "Long-range and short-range dihadron angular correlations in central PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *JHEP 07 (2011) 76.*
[4] "Indications on suppression of exited Y states in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Rev. Lett. 107 (2011) 052302.*
[5] "Dependence on pseudorapidity and on centrality of charged hadron production in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *JHEP 08 (2011) 141.*
[6] "Measurement of isolated photon production in pp and PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Lett. B 710 (2012) 256.*
[7] "Study of high-p_T charged particle suppression in PbPb compared to pp collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Eur. Phys. J. C 72 (2012) 1945.*
[8] "Suppression of non-prompt J/ψ, prompt J/ ψ, and Y(1S) in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *JHEP 05 (2012) 063.*
[9] "Jet momentum dependence of jet quenching in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Lett. B 712 (2012) 176.*
[10] "Centrality dependence of dihadron correlations and azimuthal anisotropy harmonics in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Eur. Phys. J. C 72 (2012) 2012.*
[11] "Azimuthal anisotropy of charged particles at high transverse momenta in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Rev. Lett. 109 (2012) 022301.*

CMS papers on PbPb & pPb collisions (cont.)

[12] "Study of W boson production in pp and PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Lett. B 710 (2012) 256.*

[13] "Measurement of the pseudorapidity and centrality dependence of the transverse energy density in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Rev. Lett. 109 (2012) 152303.*

[14] "Measurement of jet fragmentation into charged particles in pp and PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *JHEP 10 (2012) 087.*

[15] "Observation of sequential Y suppression in PbPb collisions", *Phys. Rev. Lett. 109 (2012) 222301.*

[16] "Measurement of the elliptic anisotropy of charged particles produced in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Rev. C 87 (2013) 014902.*

[17] "Studies of jet quenching using isolated photon+jet correlations in PbPb and pp collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Lett. B 718 (2013) 773.*

[18] "Measurement of the azimuthal anisotropy of neutral pions produced in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *Phys. Rev. Lett. 110 (2013) 042301.*

[19] "Observation of long-range near-side angular correlations in proton-lead collisions at the LHC", *Phys. Lett. B 718 (2013) 795.*

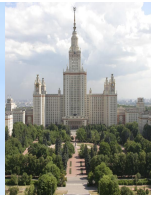
[20] "Multiplicity and transverse-momentum dependence of two- and four-particle correlations in pPb and PbPb collisions", *Phys. Lett. B 724 (2013) 213.*

[21] "Study of the production of charged pions, kaons, and protons in pPb collisions at $\sqrt{s_{NN}}$=5.02 TeV", *arXiv:1307.3442, submitted to Eur. Phys. J. C.*

[22] "Modification of jet shapes in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *arXiv:1310.0878, submitted to Phys. Lett. B.*

[23] "Measurement of higher-order harmonic azimuthal anisotropy in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV", *arXiv:1310.8651, submitted to Phys. Rev. C.*

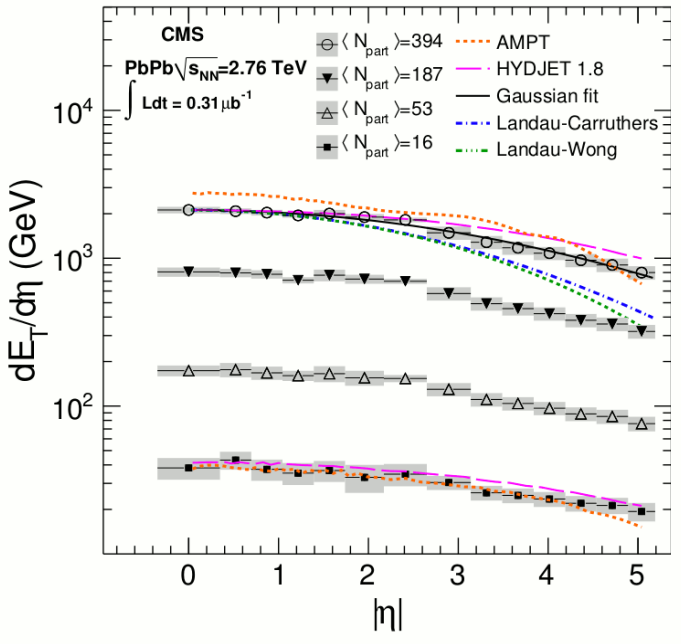
Heavy ion event centrality determination

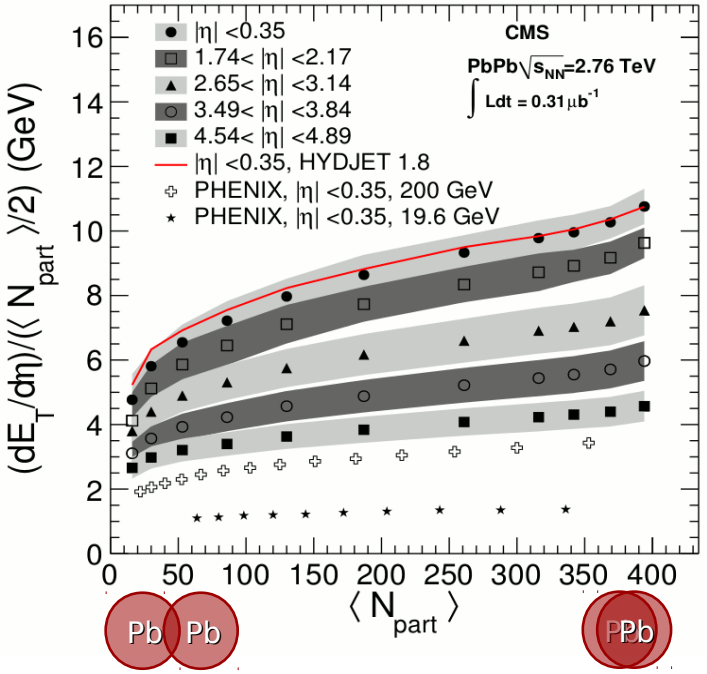


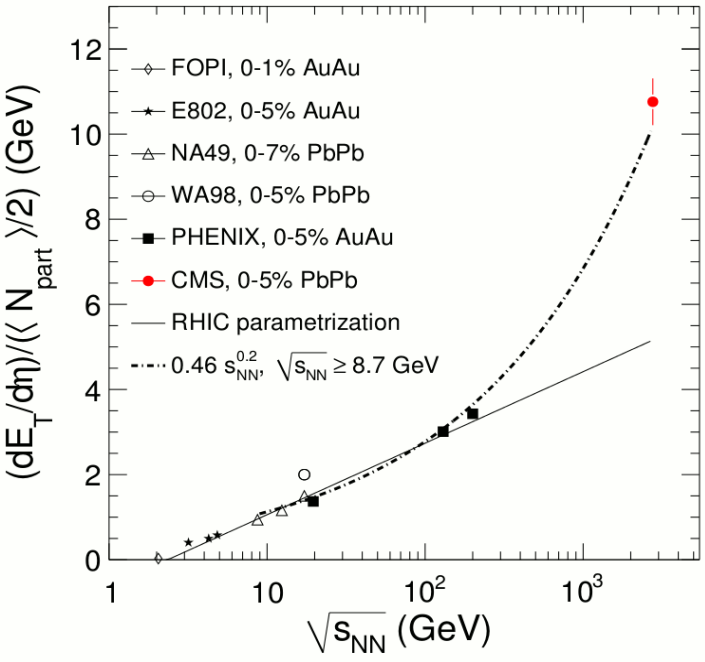
Centrality	b mean (fm)	b RMS (fm)	N_{part} mean	N_{part} RMS	N_{coll} mean	N_{coll} RMS
0–10%	3.4 ± 0.1	1.2	355 ± 3	33	1484 ± 120	241
10–20%	6.0 ± 0.2	0.8	261 ± 4	30	927 ± 82	183
20–30%	7.8 ± 0.2	0.6	187 ± 5	23	562 ± 53	124
30–50%	9.9 ± 0.3	0.8	108 ± 5	27	251 ± 28	101
50–100%	13.6 ± 0.4	1.6	22 ± 2	19	30 ± 5	35

Energy density in PbPb

PRL 109 (2012) 152303

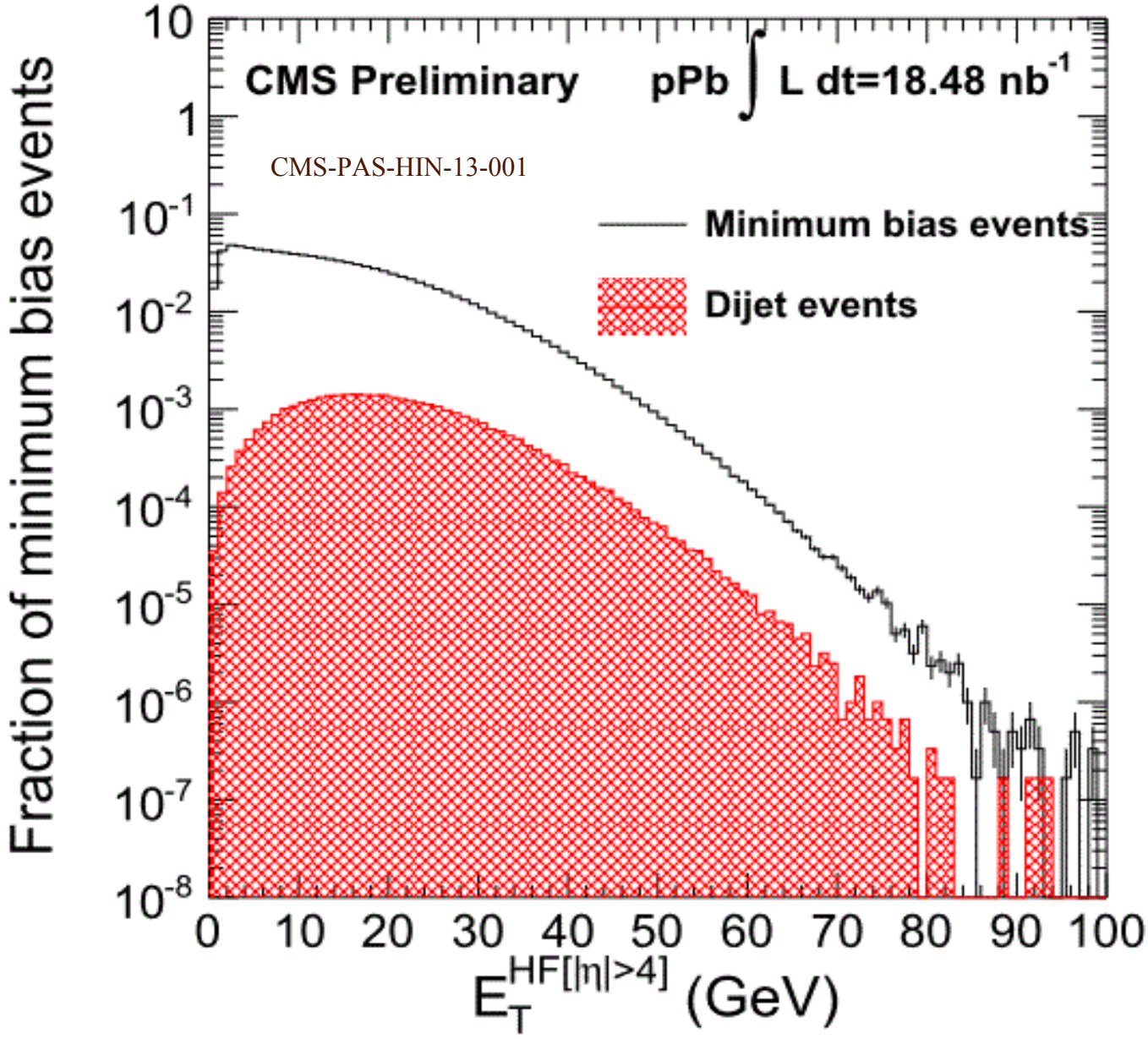




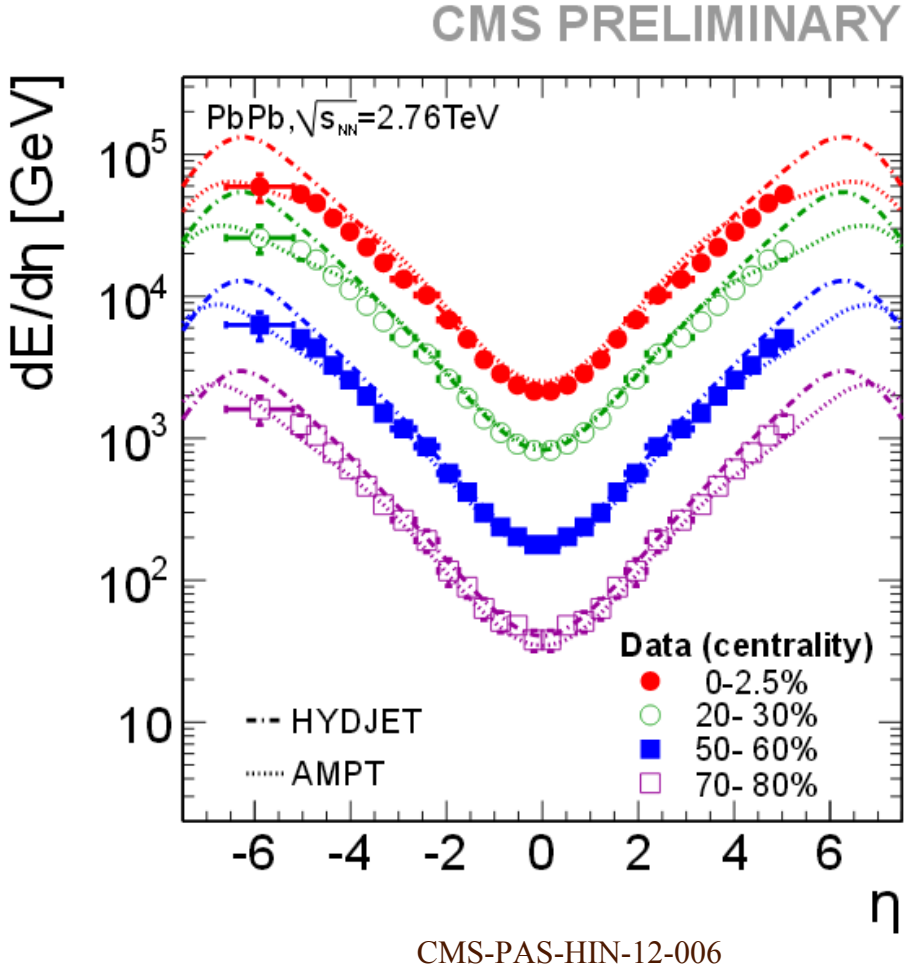


- $dE_T/d\eta$ is maximal at $\eta = 0$, shape is consistent with a Gaussian with $\sigma_\eta = 3.4 \pm 0.1$ for central collisions (and wider for peripheral collisions)
  central PbPb (0-2.5%): $dE_T/d\eta$ (η=0) ≈ 2.1 TeV - by a factor of 3.3 higher than at RHIC;
  ε (τ_0=1 fm/c, η=0) ~ dE_T/dy (y=0) ≈ 14 GeV/fm³ - by a factor of 2.8 larger than at RHIC
- $dE_T/d\eta$ /(0.5<N_{part}>) increases monotonically with centrality, <N_{part}>
- $dE_T/d\eta$ ($\sqrt{s_{NN}}$) rises faster than dN/dη (power law, logarithmic parameterization breaks down)
  more transverse energy per particle than at lower energies

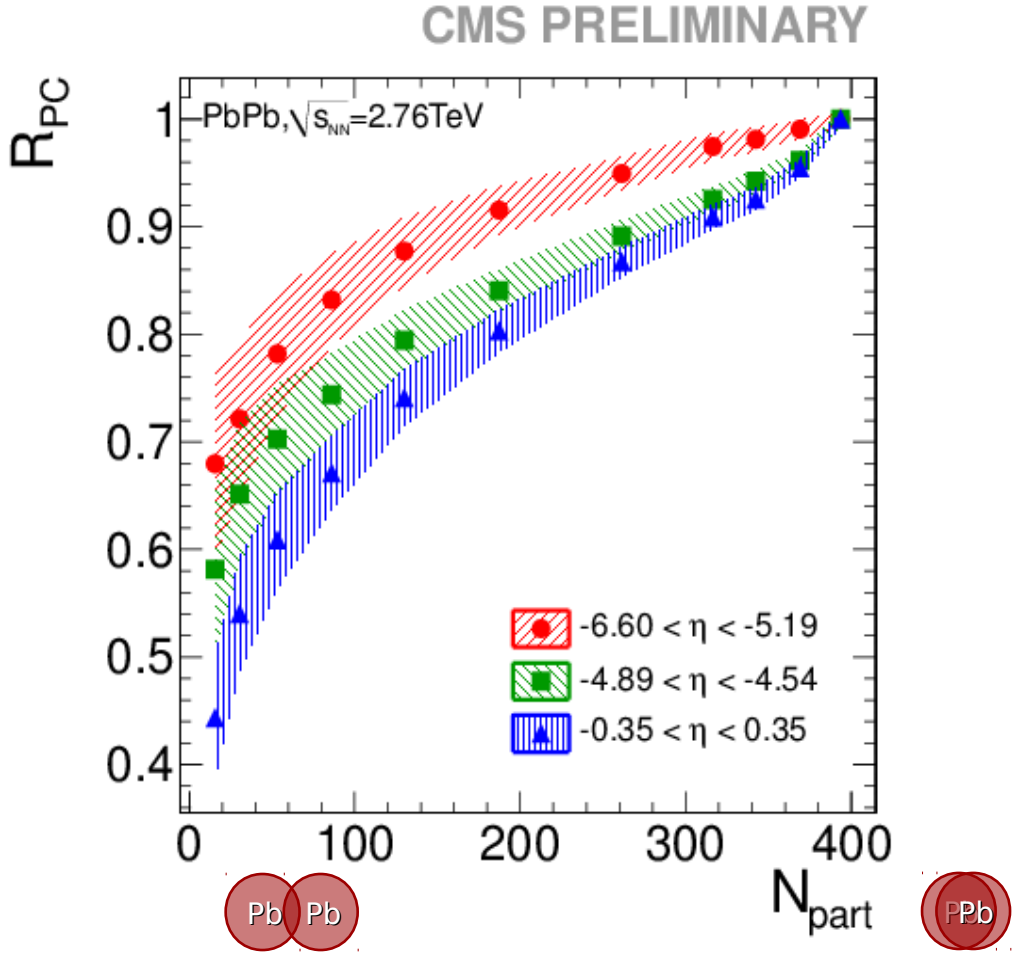
Proton-lead event centrality determination



Energy deposition up to very forward rapidity



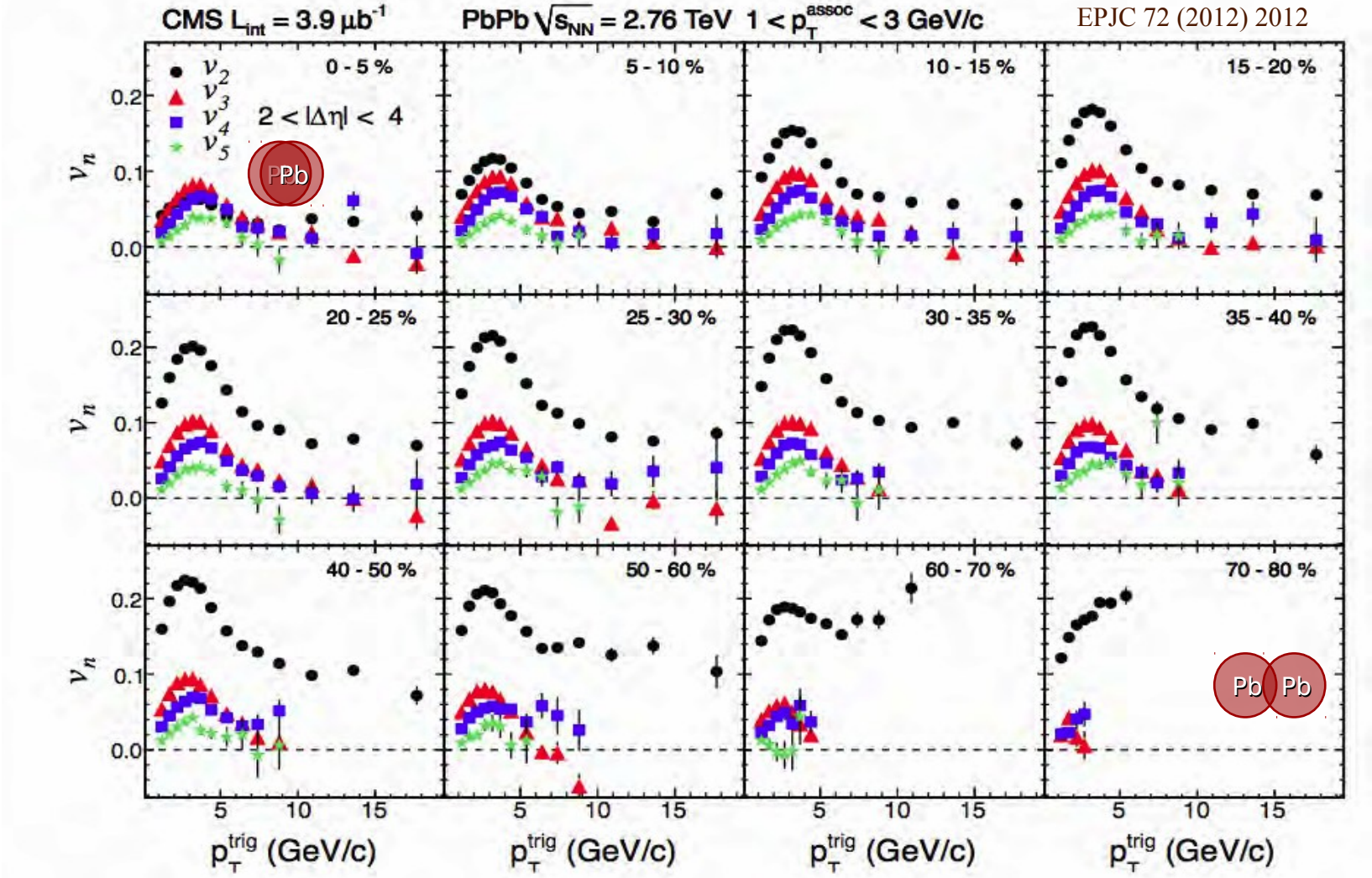
CMS-PAS-HIN-12-006



- First results using the CMS *CASTOR* calorimeter
- At high |η|, the ratio between the energy production in *central* and *peripheral* collisions is closer to 1 than at midrapidity

Full harmonic spectrum in PbPb

$dN/d\varphi = N\{1+ \Sigma_n 2v_n \cos(n\varphi)\}/2\pi, \quad v_n=\langle\cos(n\varphi)\rangle$



Non-zero high Fourier coefficients (the shapes of p_T-dependence are similar to v_2)

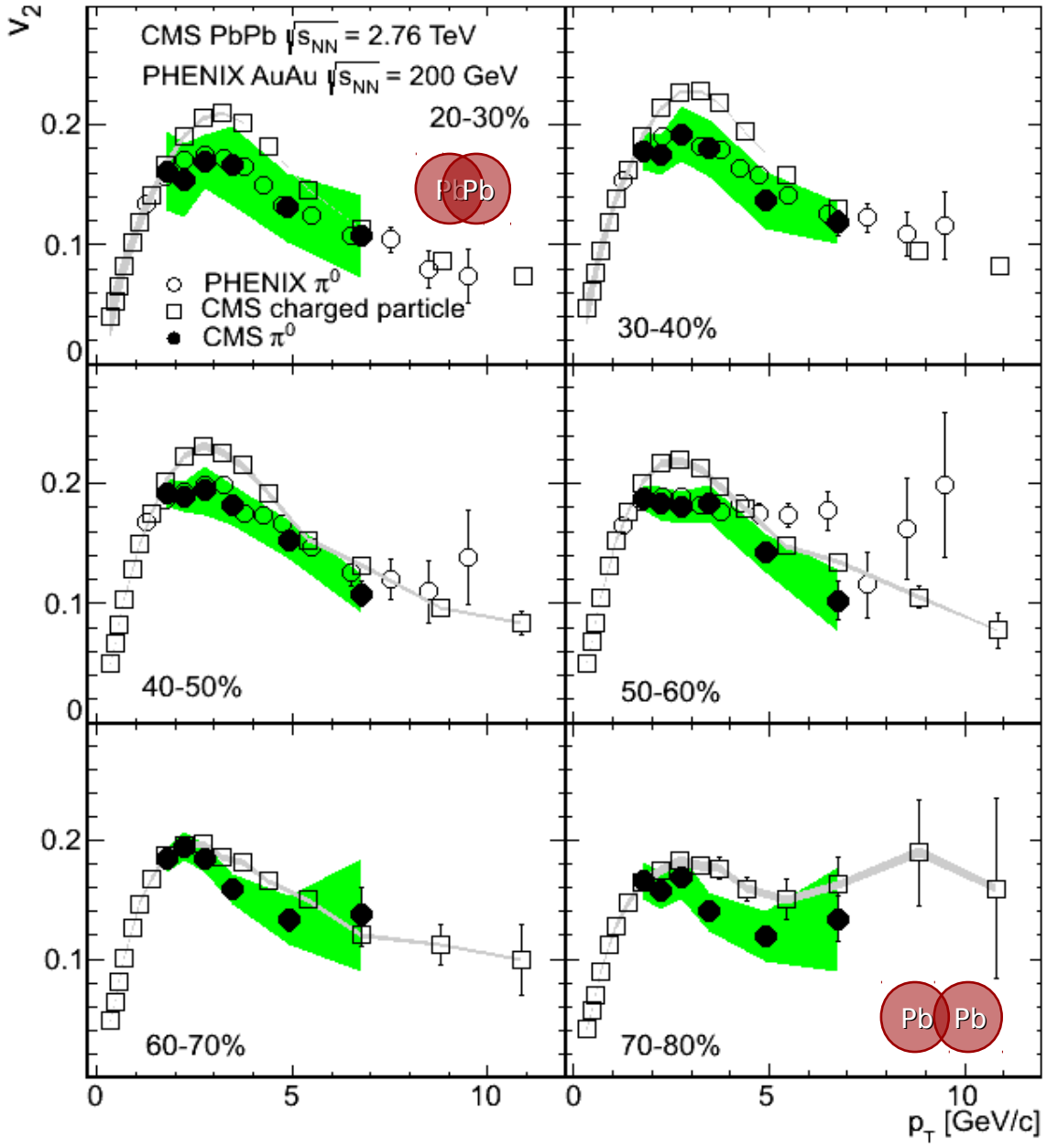
carry information about the details of the medium space-time evolution and initial state fluctuations

Elliptic flow v_2 of neutral pions in PbPb

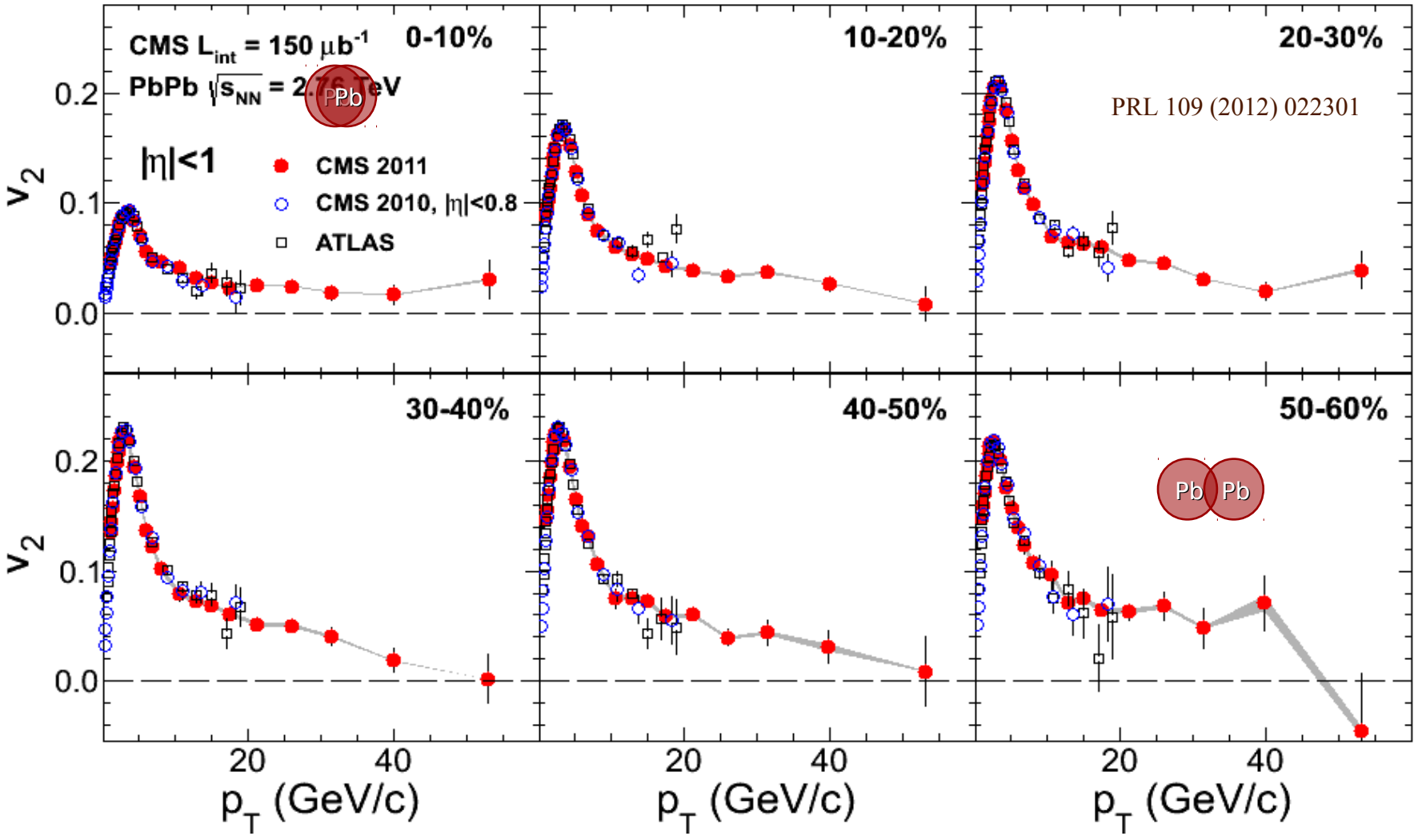
PRL 110 (2013) 042301

v_2 (p_T) / LHC ~
v_2 (p_T) / RHIC

v_2 (hadrons) >
v_2 (pions)
at p_T>2GeV/c



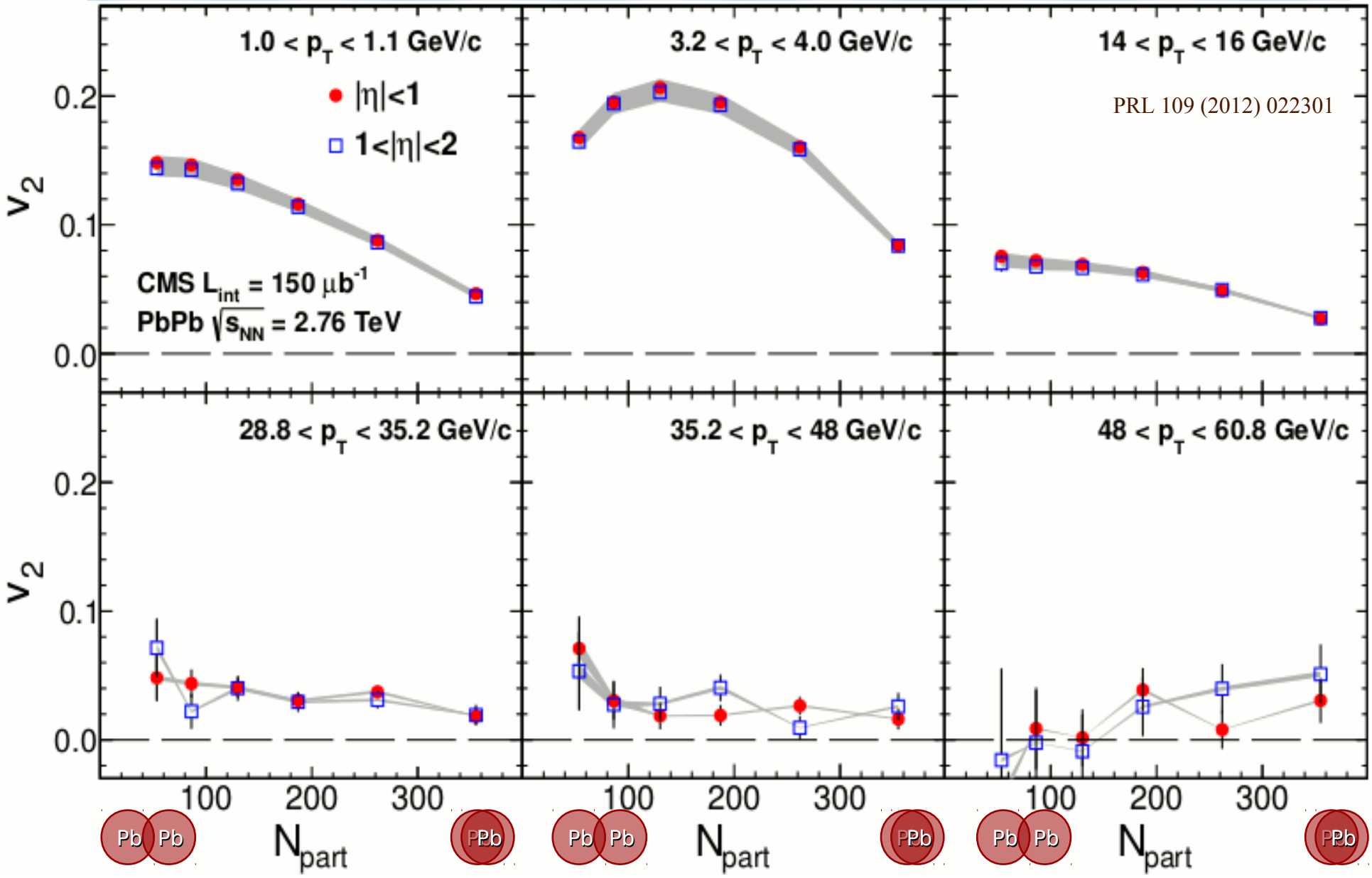
Elliptic flow v_2 at high p_T in PbPb



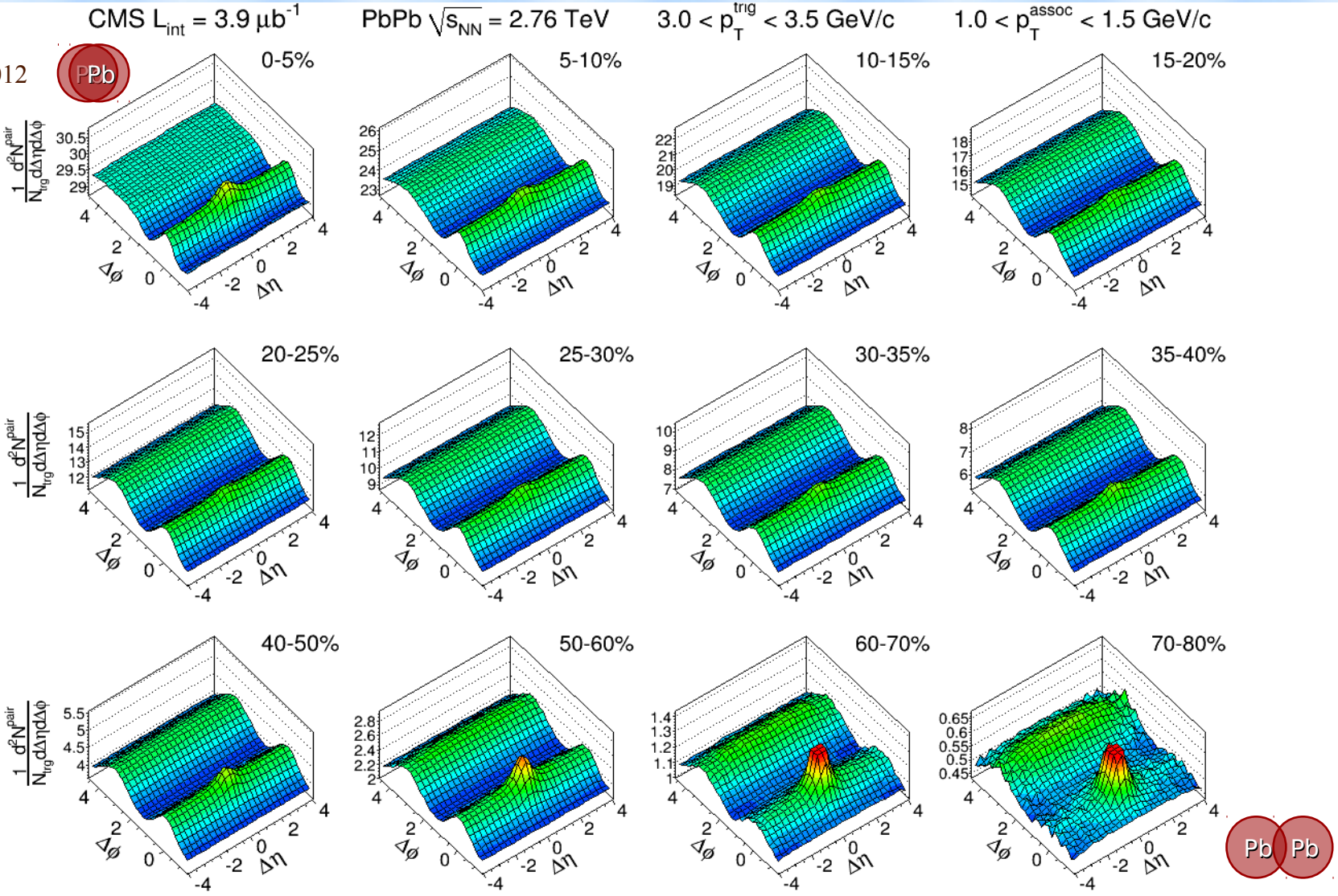
Beyond p_T~10 GeV/c, the observed v_2 values show a moderate decrease with p_T, being consistent with zero only above p_T~40 GeV/c and for mid-central (30–60%) collisions

connection to the initial geometry & constraints on partonic energy loss models

Elliptic flow v_2 at high p_T in PbPb



Dihadron angular correlations in PbPb



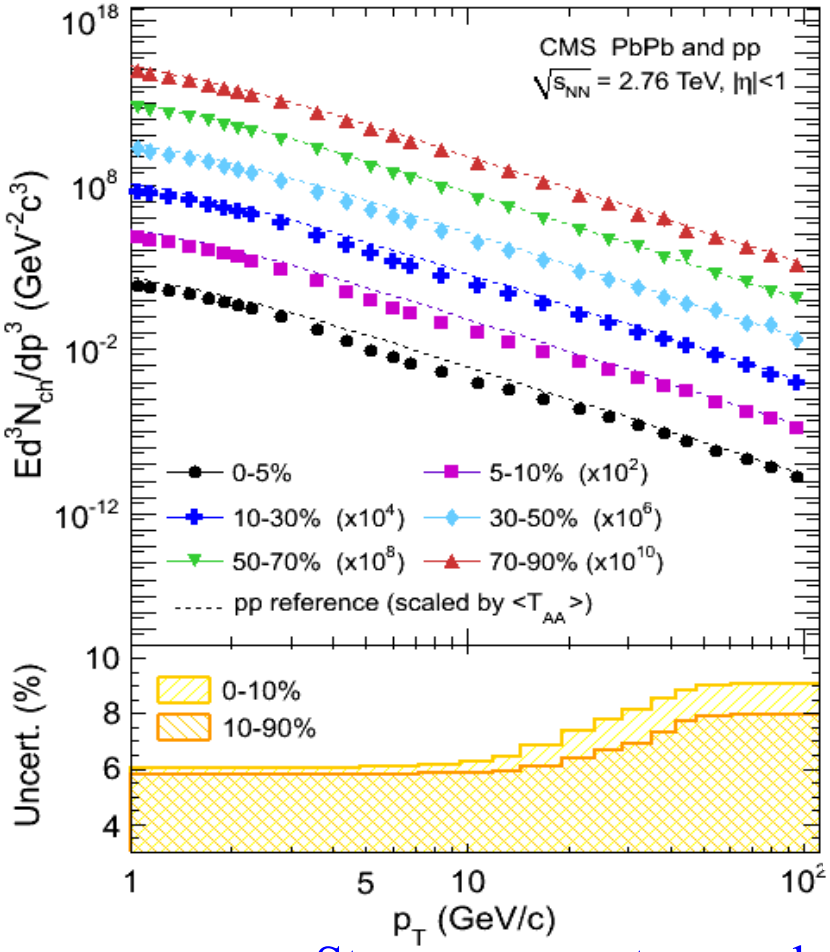
EPJC 72 (2012) 2012

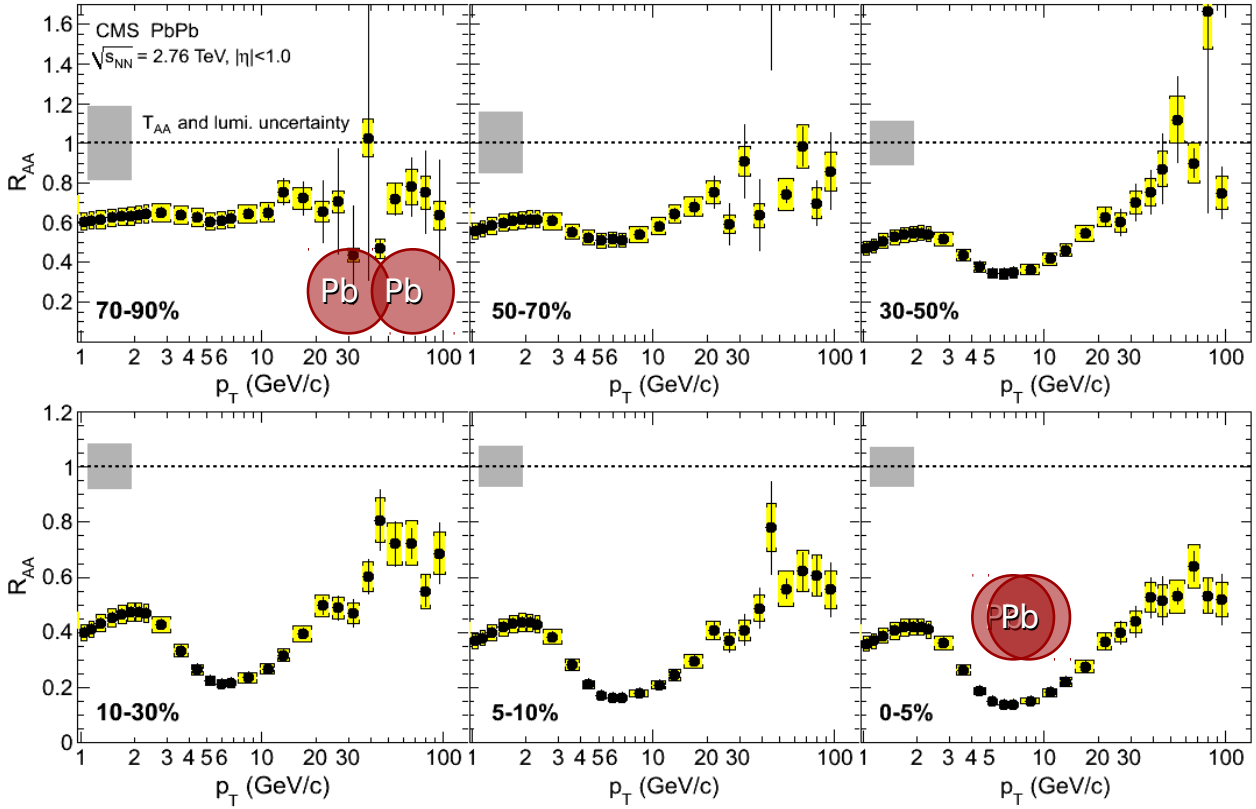
”Ridge” is strongest for most central PbPb collisions and disappears in peripheral events

Charged hadron p_T-spectra in PbPb and R_{AA}

$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta} \sim \frac{\text{“QCD Medium”}}{\text{“QCD Vacuum“}}$$

R_{AA}>1: enhancement
R_{AA}=1: no medium effect
R_{AA}<1: suppression





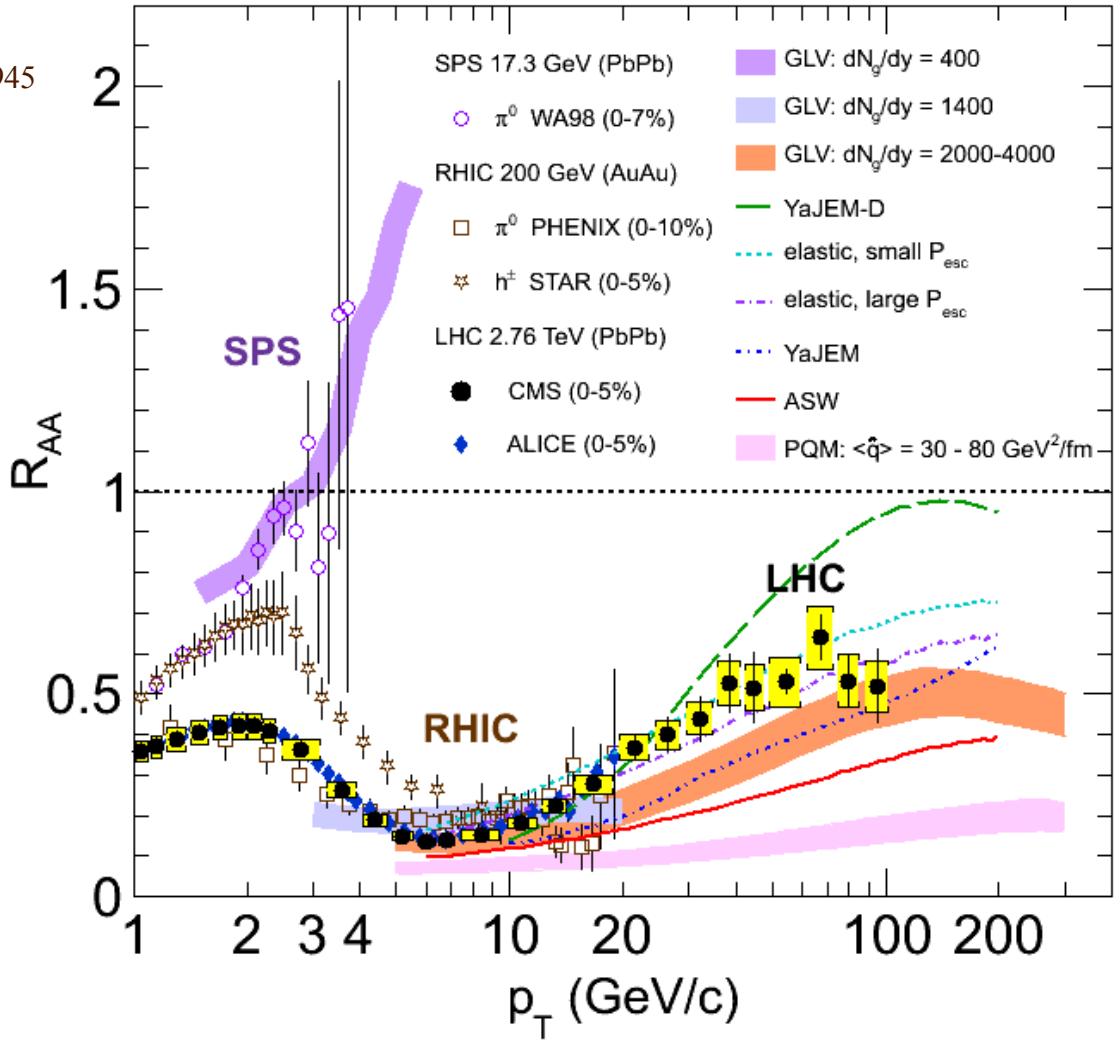
EPJC 72 (2012) 1945

Strong momentum and centrality dependences of suppression factor

also the tendency to saturation at p_T>50 GeV/c ⇨ constraints on partonic energy loss models

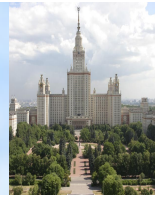
R_{AA}: CMS vs. ALICE, RHIC and models

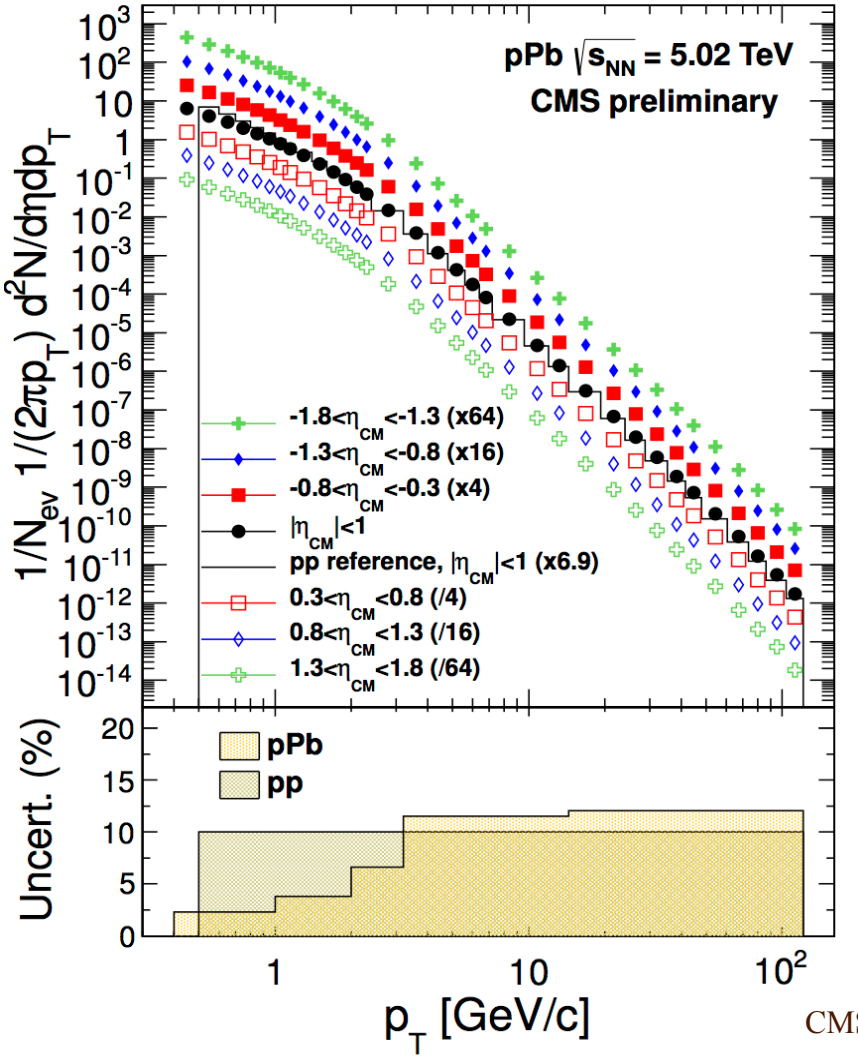
EPJC 72 (2012) 1945

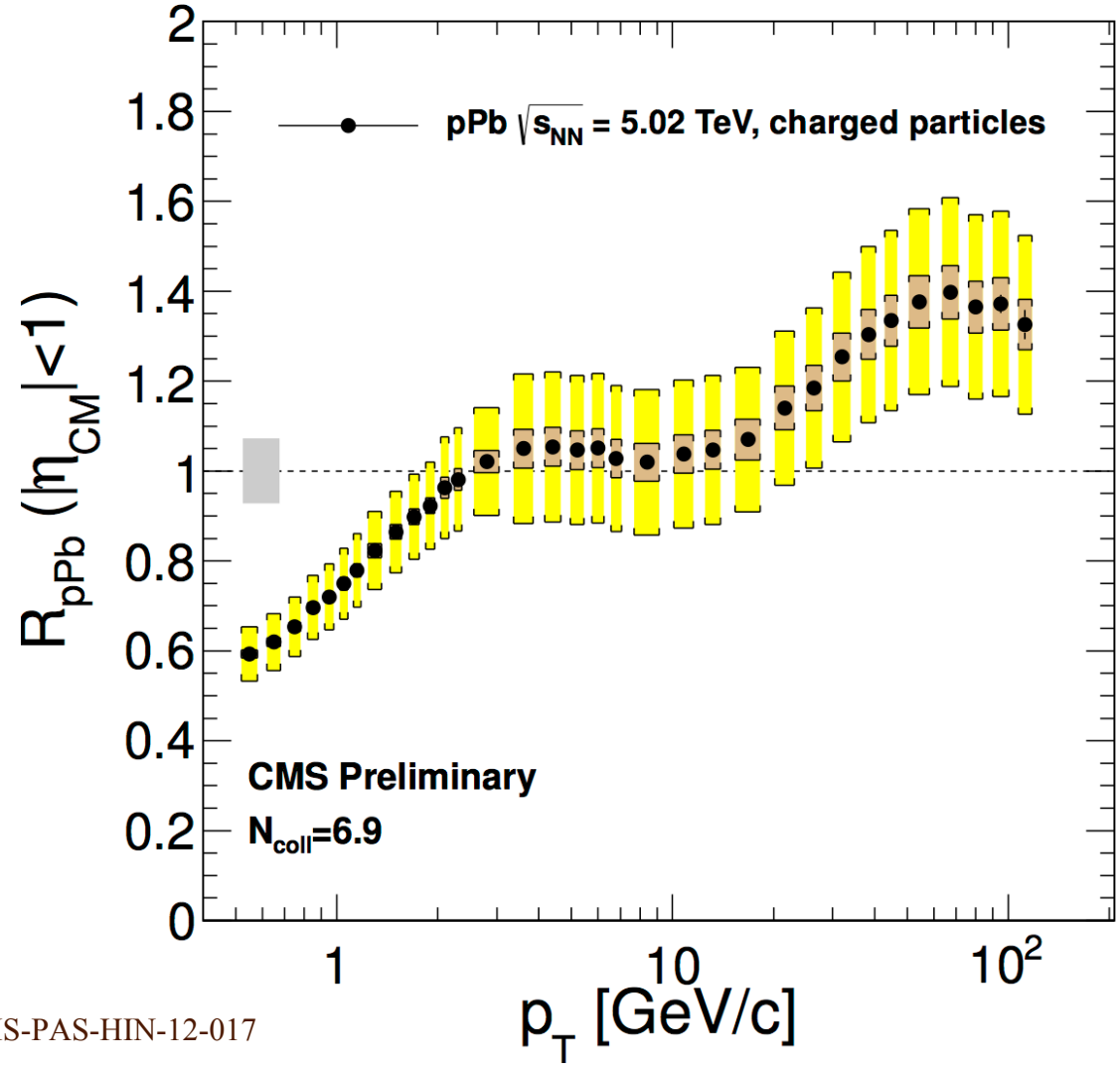


- Much higher p_T than at RHIC, up to ~ 100 GeV/c, are available
- CMS and ALICE are in agreement, but CMS reaches higher p_T (due to using the jet trigger)
- $R_{AA}(p_T)$ – strong constraints on partonic energy loss model (access to medium properties)

Charged hadron p_T-spectra in pPb and R_{pA}



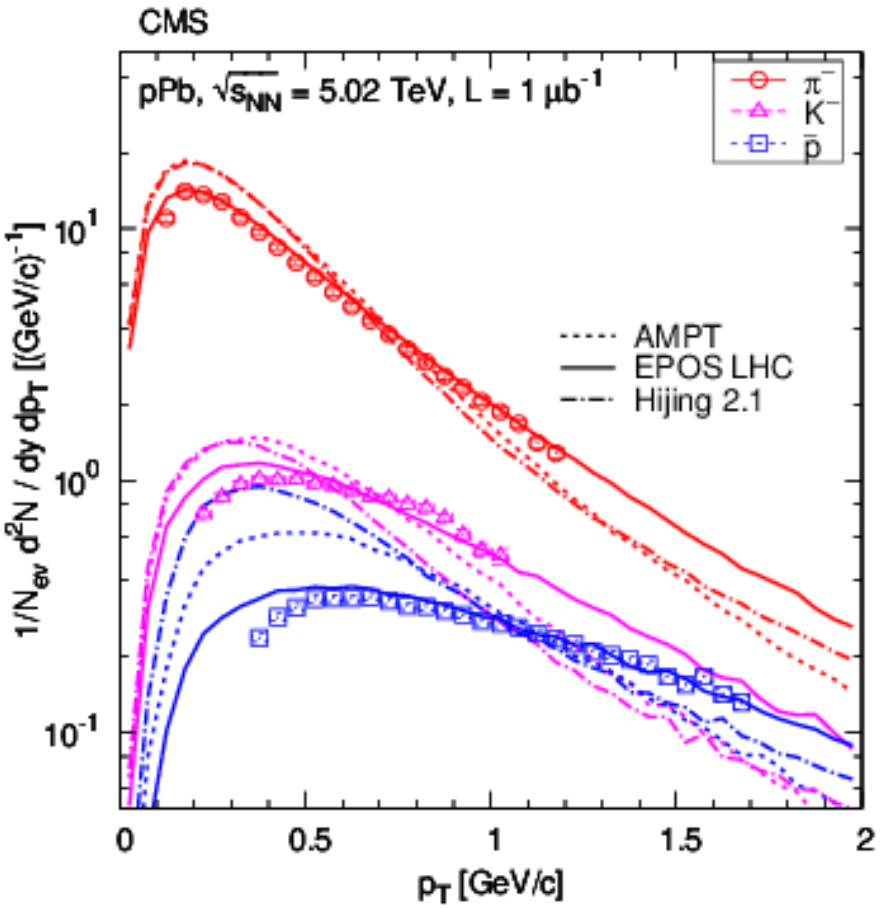


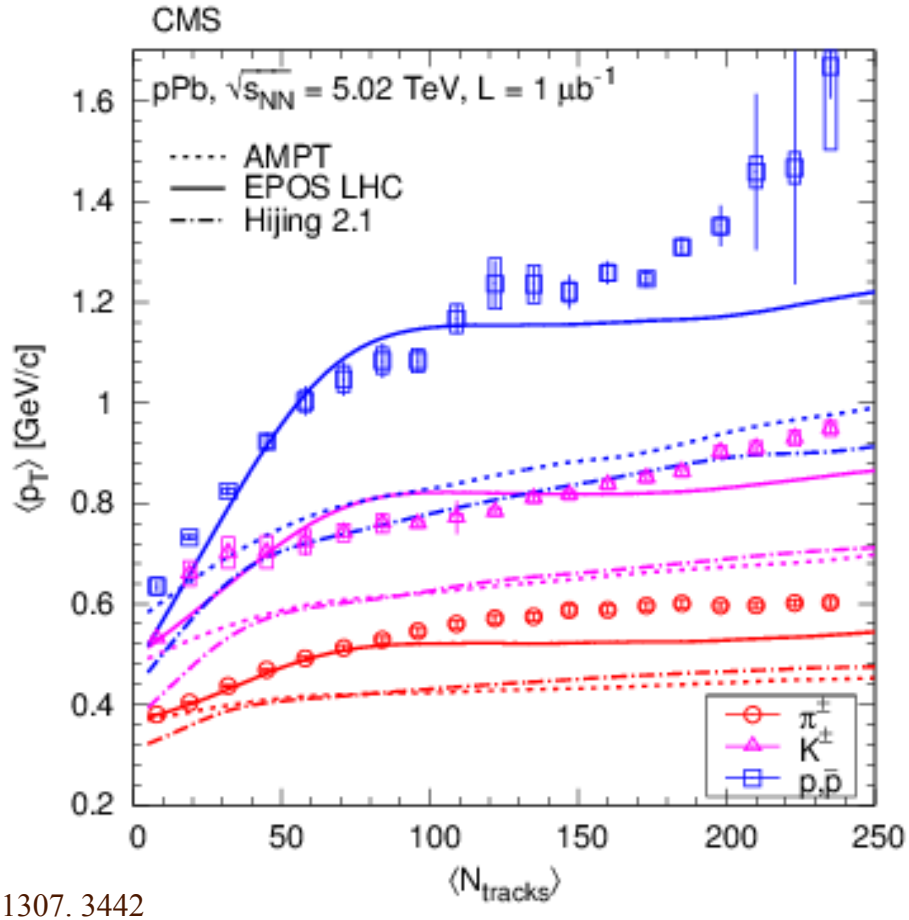


CMS-PAS-HIN-12-017

- Modification factor compatible with 1 at p_T~2-20 GeV/c ⇨ no jet quenching?
- Enhancement at p_T>20 GeV/c ⇨ initial state effect (”antishadowing”)?

Pion, kaon and proton spectra in pPb

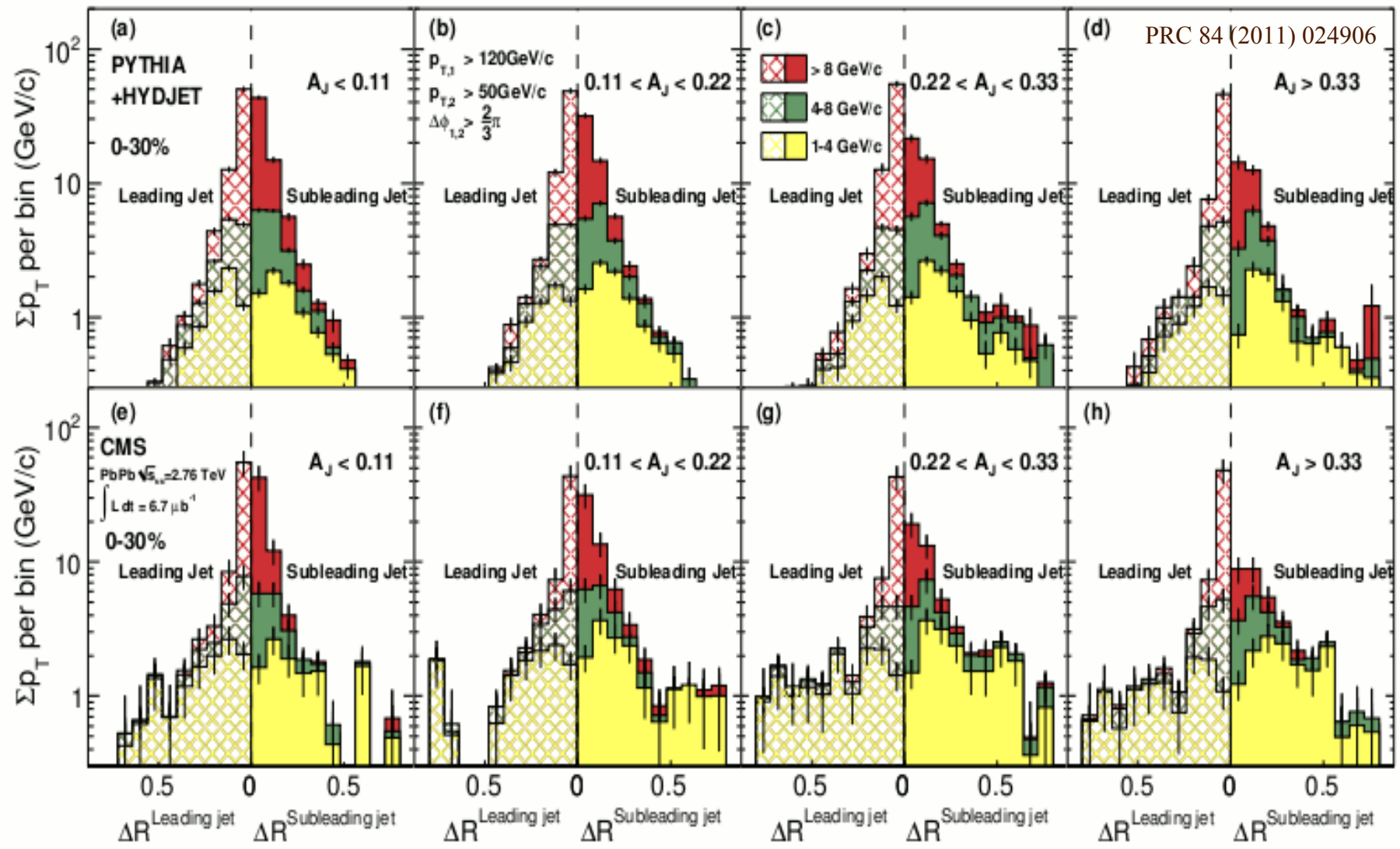




arXiv 1307. 3442

- Spectra are generally *flatter than predicted by models*
- Mean transverse momentum *rises with multiplicity at low multiplicities* (harder single NN scatterings like pp) & *saturates at high multiplicities* (multiple NN scatterings like PbPb)

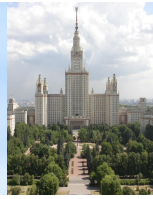
Jet-track correlation in PbPb



Relative contribution of low-p_T tracks grows with A_J & spreads at large distances to the jet axis

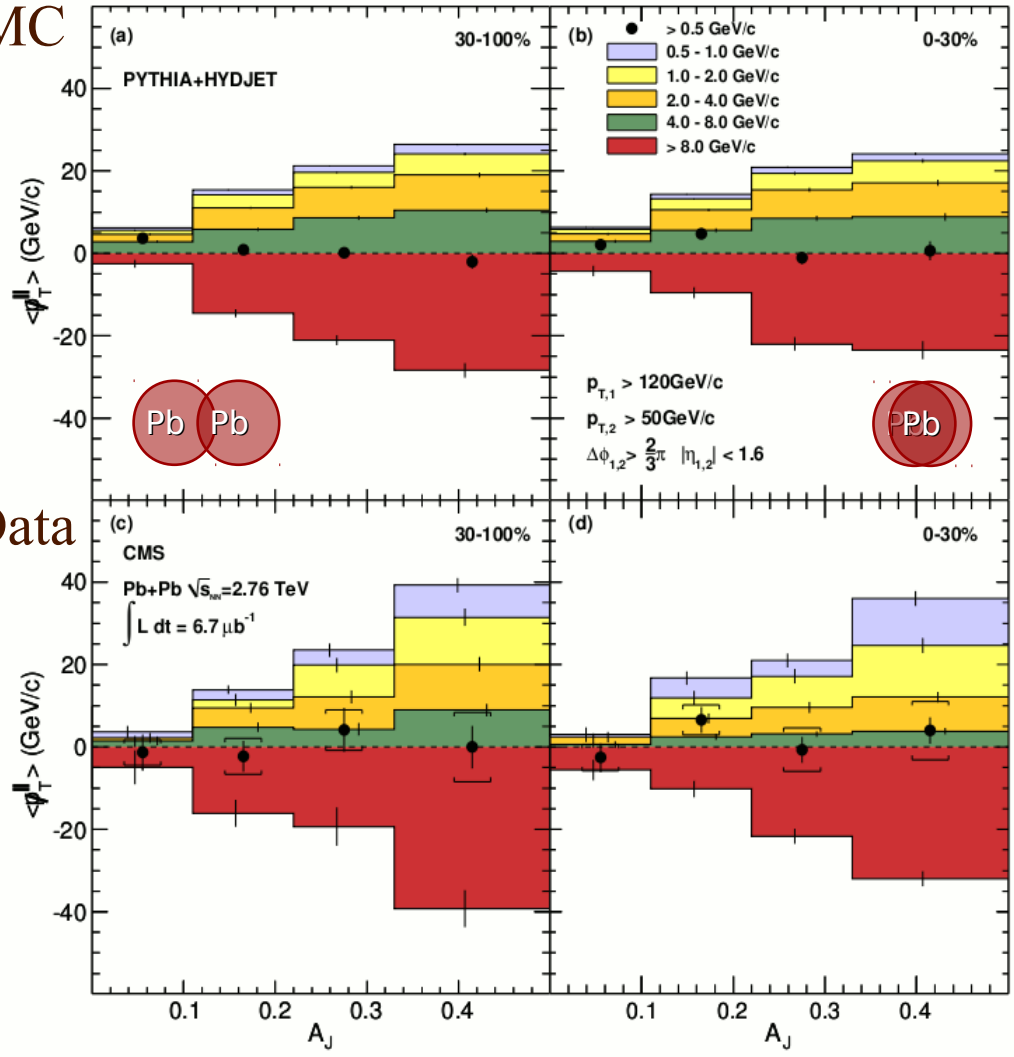
lost energy is transferred to soft hadrons scattered far away from the jet axis?

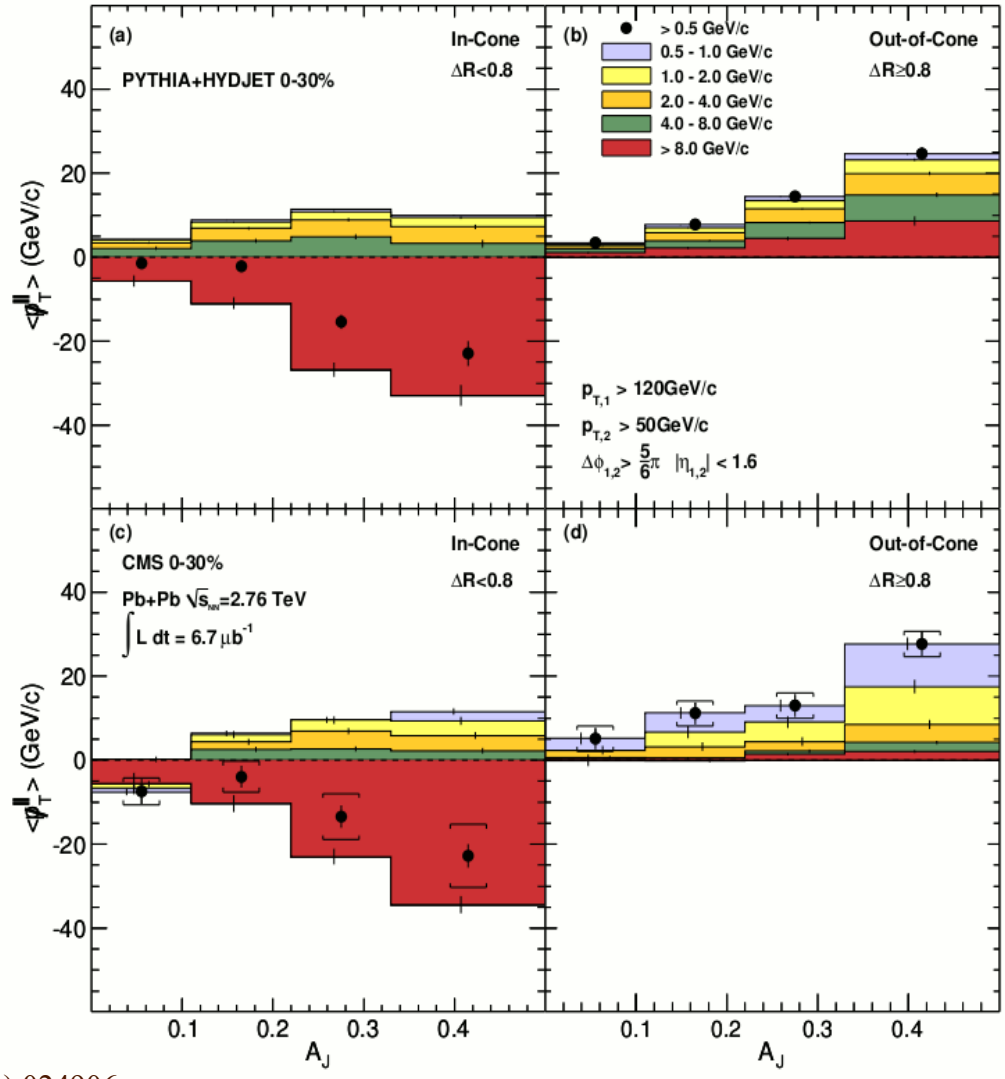
Jet-track correlation (missing p_T) in PbPb



MC

Data

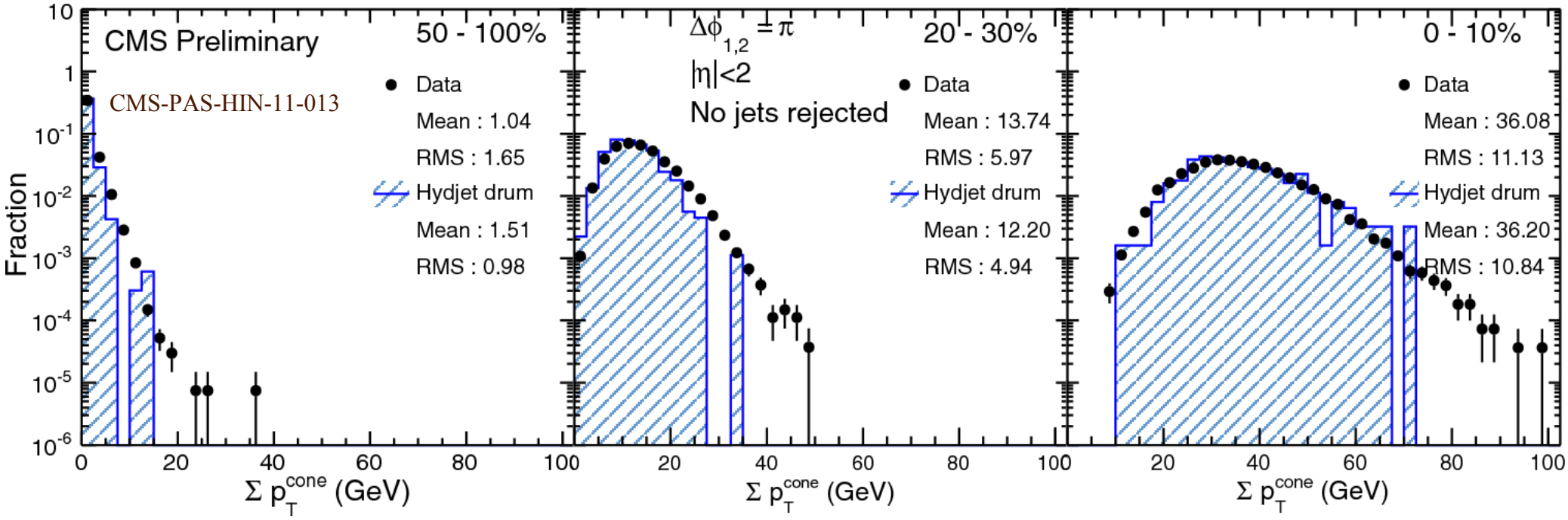




PRC 84 (2011) 024906

Dijet momentum balance for PbPb data is covered by out-of-cone low p_T tracks

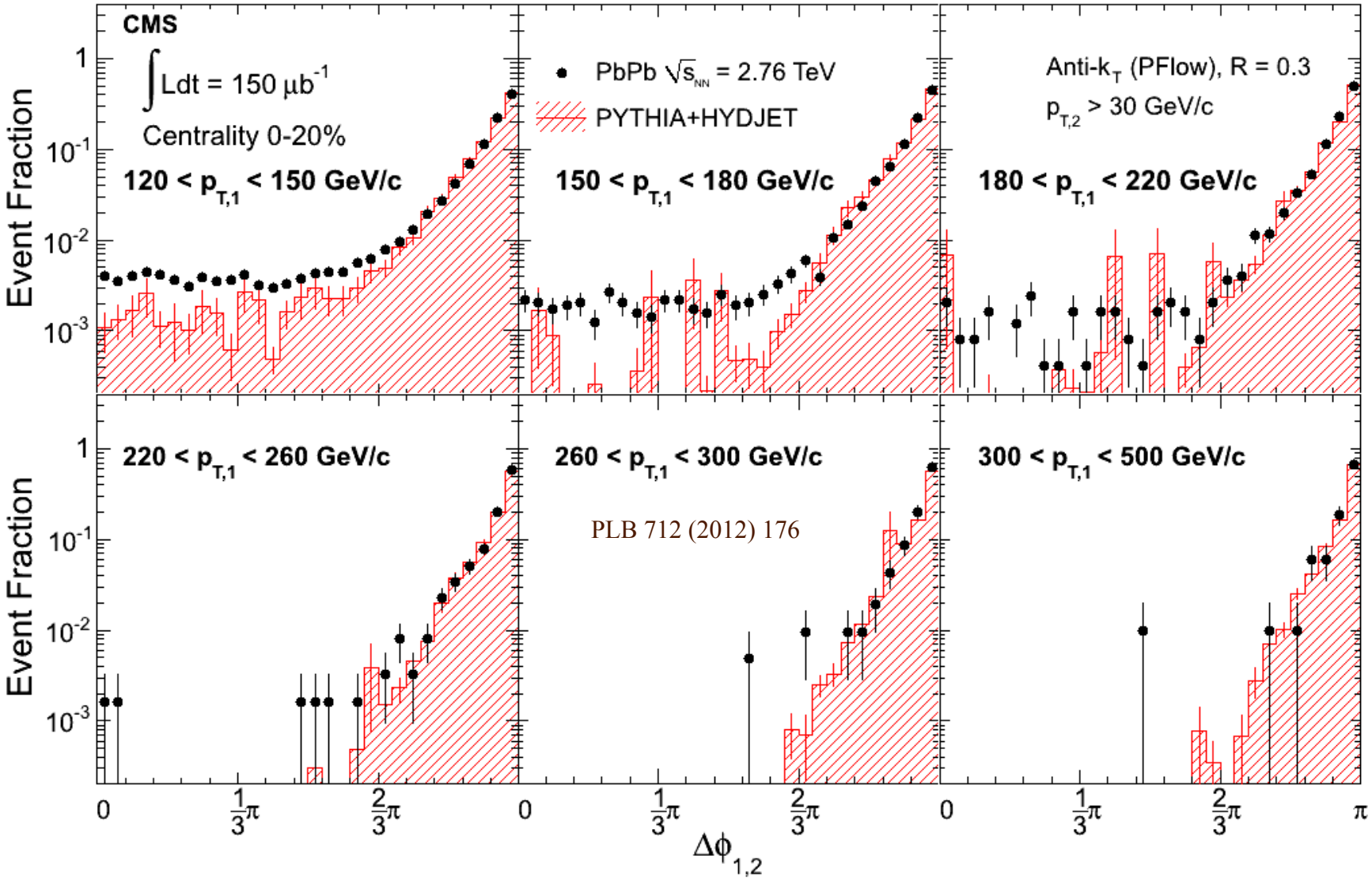
Jet background fluctuations in PbPb



Tuned HYDJET event generator reproduces jet background fluctuations, that allows us to use it as the reference for jet quenching analysis in PbPb collisions

- Use PYTHIA and N_{coll} scaling for unquenched reference
- Embed in HYDJET (underlying event)

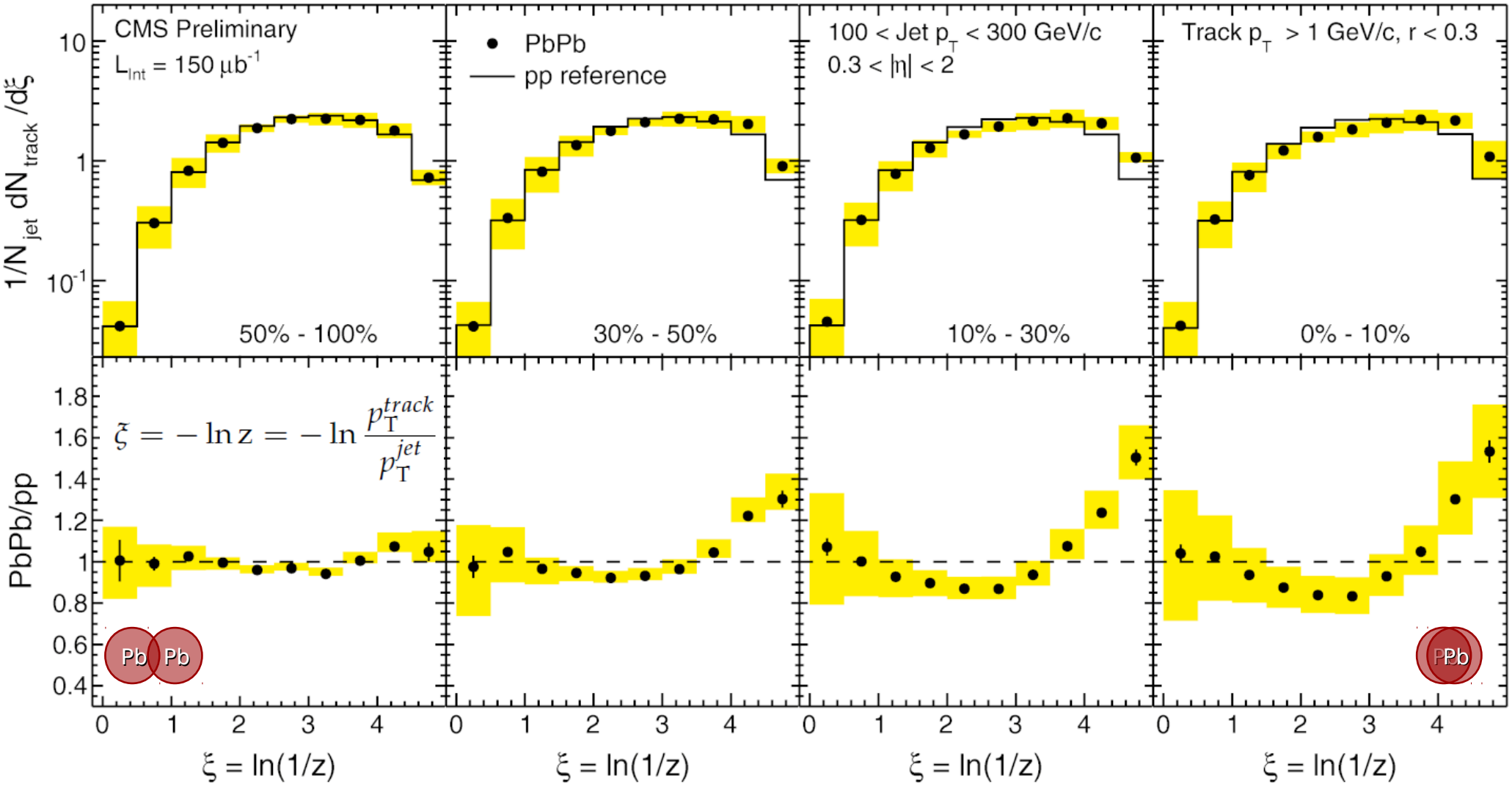
Angular dijet correlation in PbPb



No angular dijet decorrelation observed

Jet fragmentation in PbPb

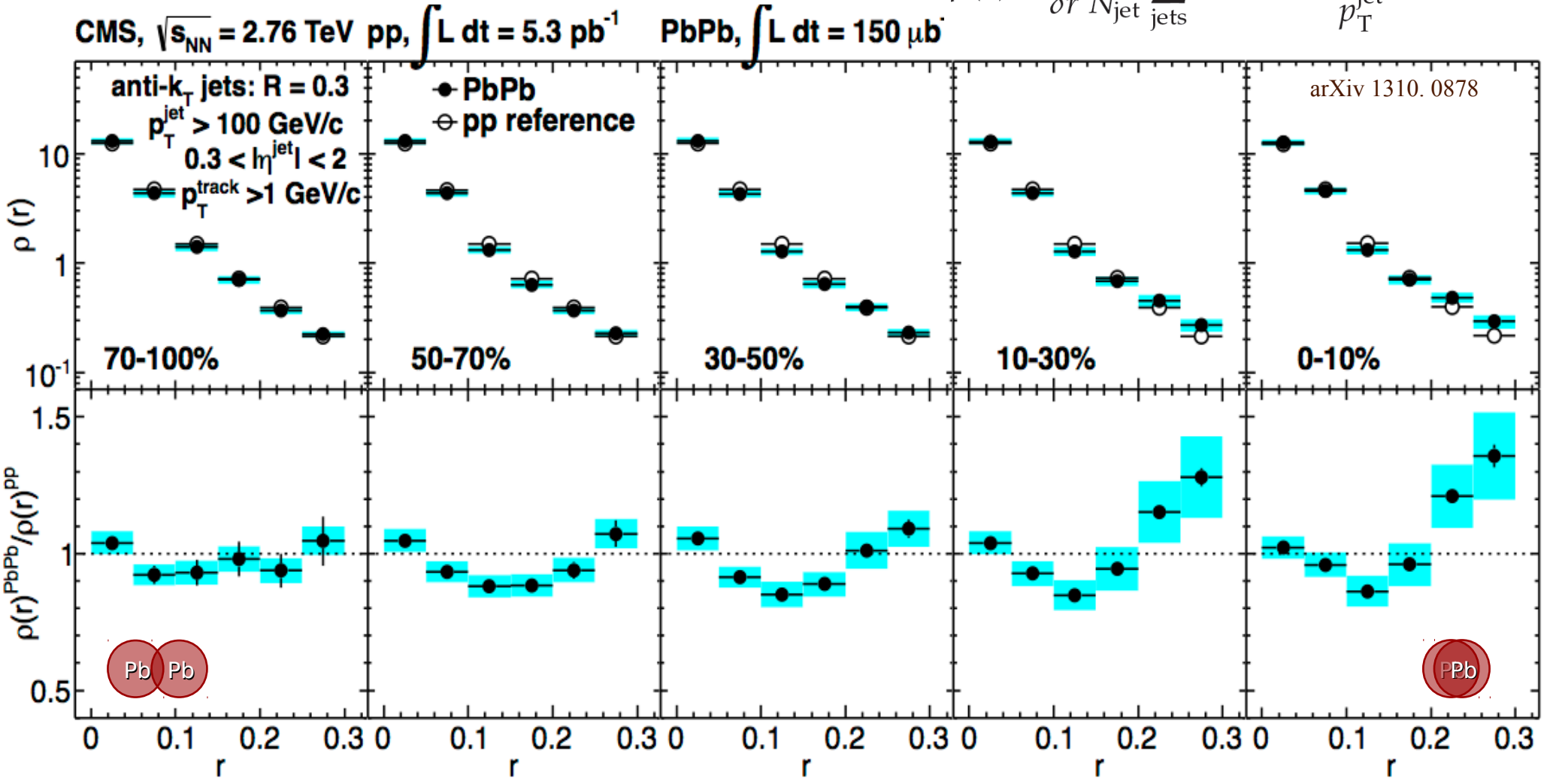
CMS-PAS-HIN-12-013



The modifications of *longitudinal jet profile*: excess at low p_T but high p_T is unchanged

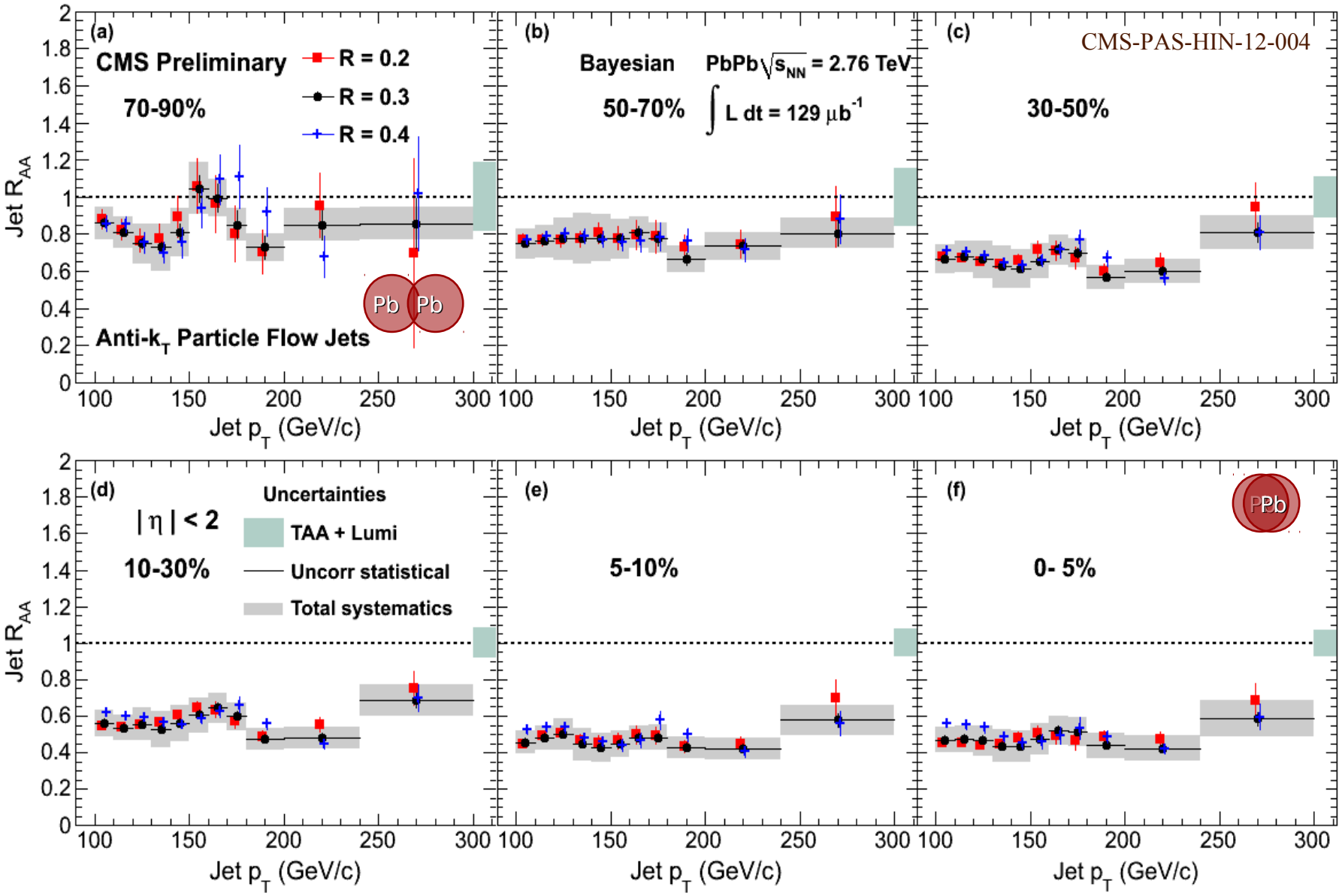
Jet shapes in PbPb

$$\rho(r) \sim \frac{1}{\delta r}\frac{1}{N_{\text{jet}}}\sum_{\text{jets}}\frac{p_{\text{T}}(r-\delta r/2, r+\delta r/2)}{p_{\text{T}}^{\text{jet}}}$$



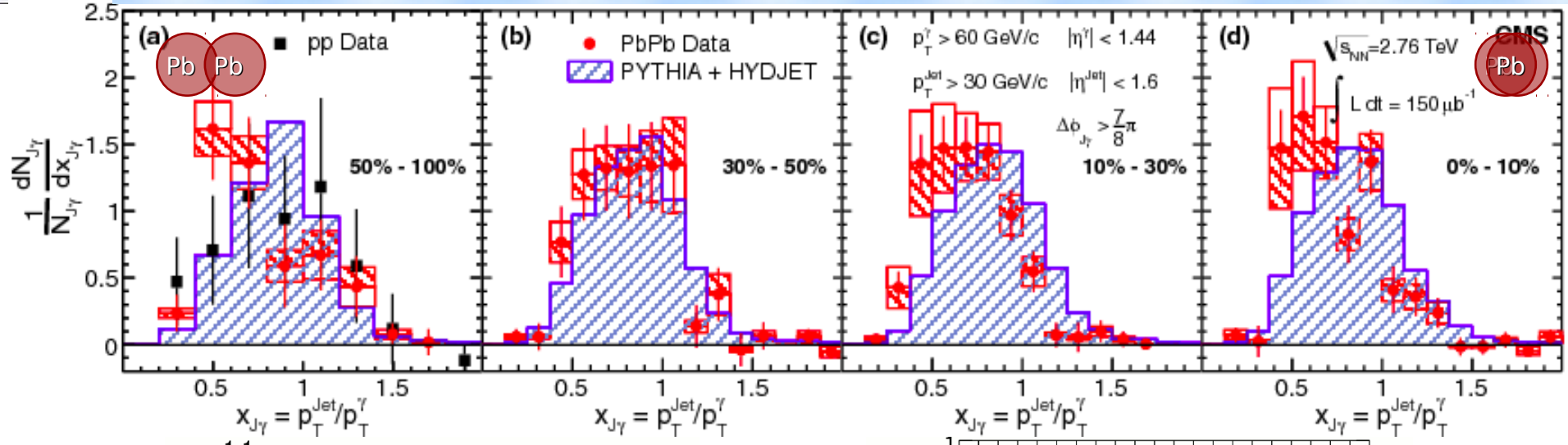
The modifications of *radial jet profile*: excess at large radii but core is unchanged

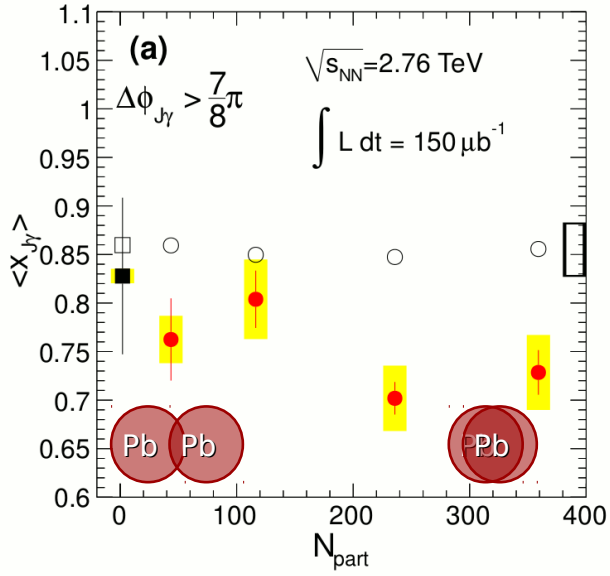
Suppression of inclusive jet rates in PbPb



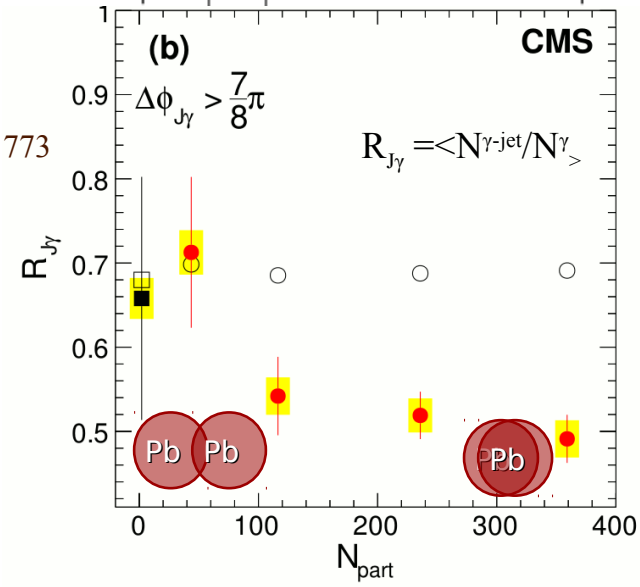
R_{AA}(jets) ≥ R_{AA} (hadrons), and almost independent of jet p_T and cone size

Photon+jet correlation in PbPb



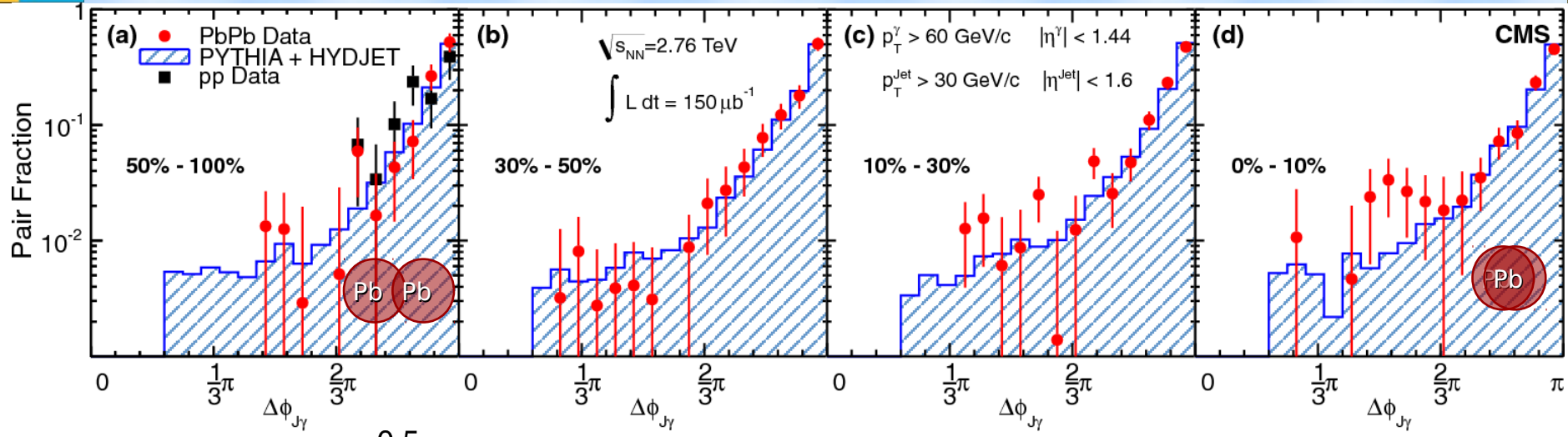


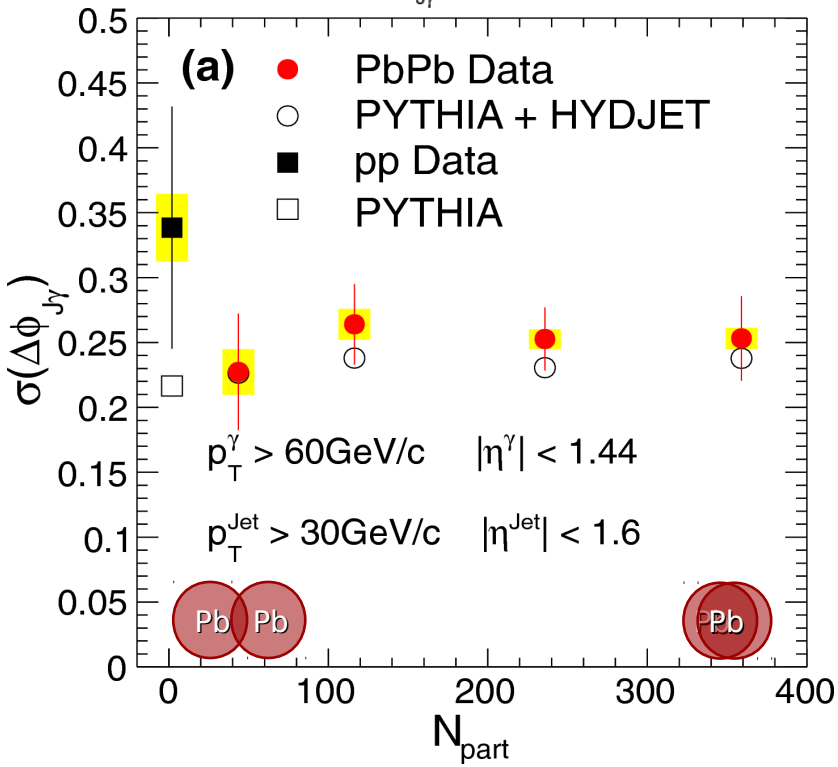
PLB 718 (2013) 773



A significant *shift of jet–photon p_T-ratio (~15%)* and *reducing the fraction of isolated photons with associated partner jet (~20%)* in central PbPb collisions as compared with pp and peripheral PbPb events, and MC simulations ⇨ jet quenching in hot QCD-matter

Photon+jet correlation in PbPb

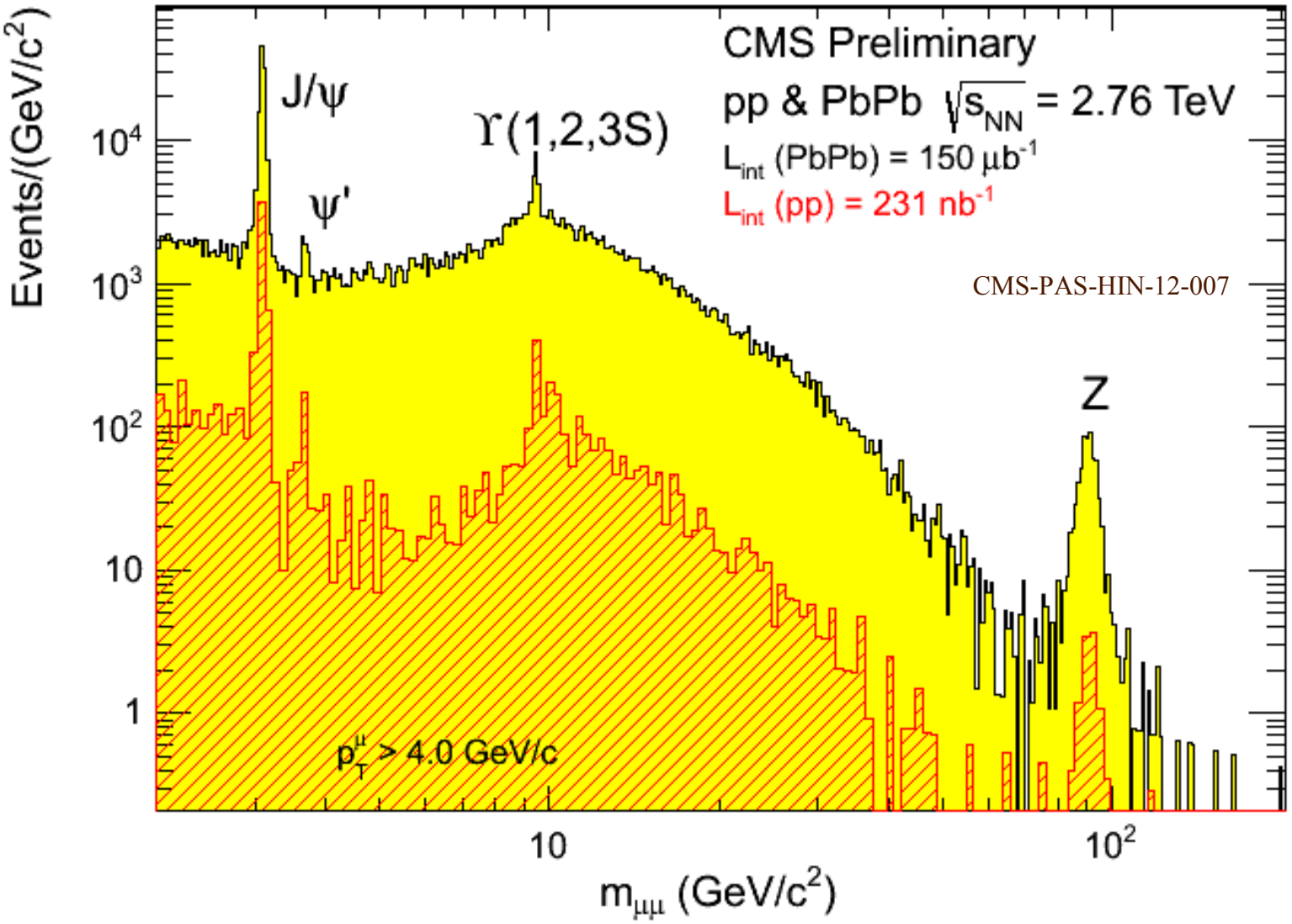




PLB 718 (2013) 773

No angular photon-jet decorrelation observed

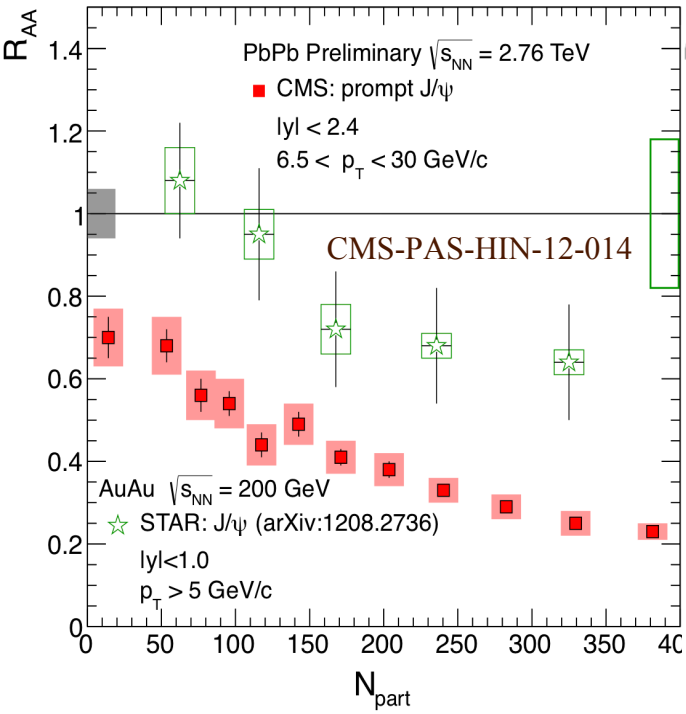
Dimuon mass spectrum in PbPb

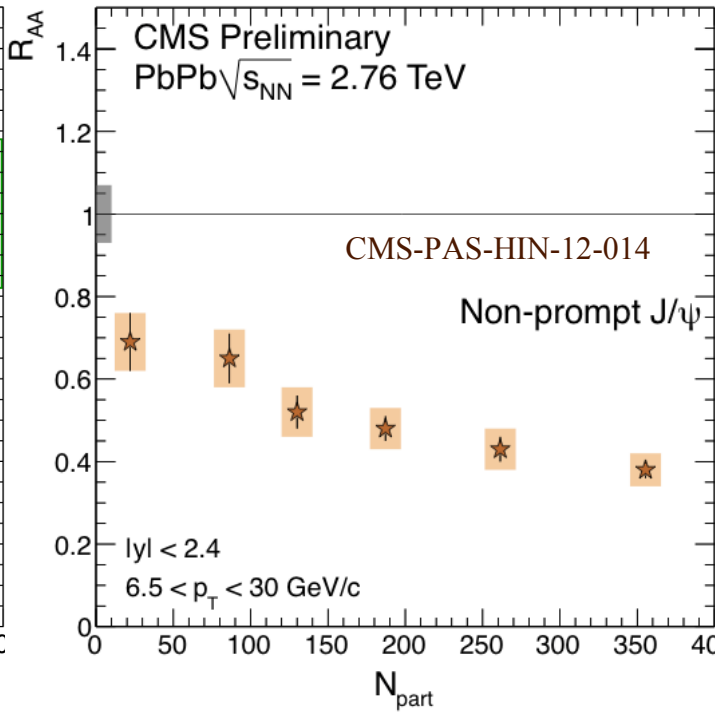


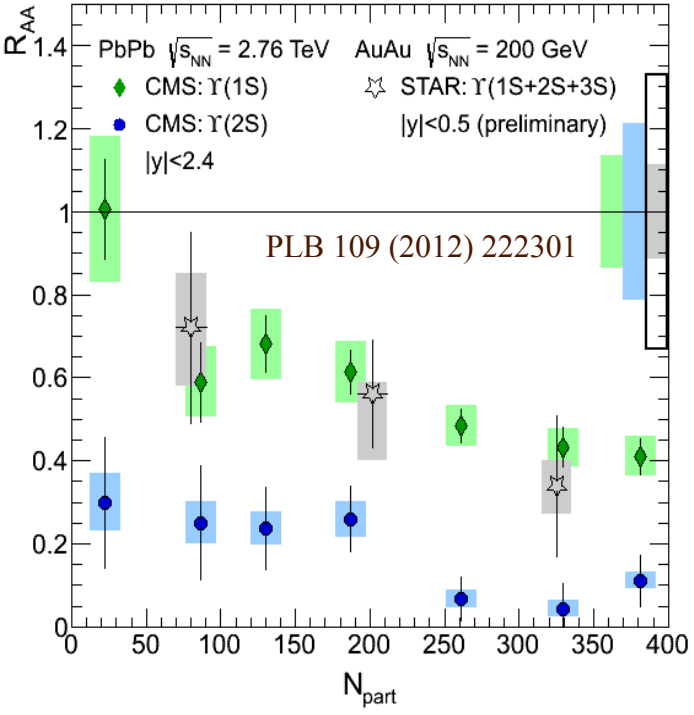
J/ψ, ψ', Y(1S, 2S, 3S) and Z^0 peaks are clearly visible

CMS has the best dimuon mass resolution of all LHC experiments in heavy ion collisions

J/ψ and ϒ suppression in PbPb

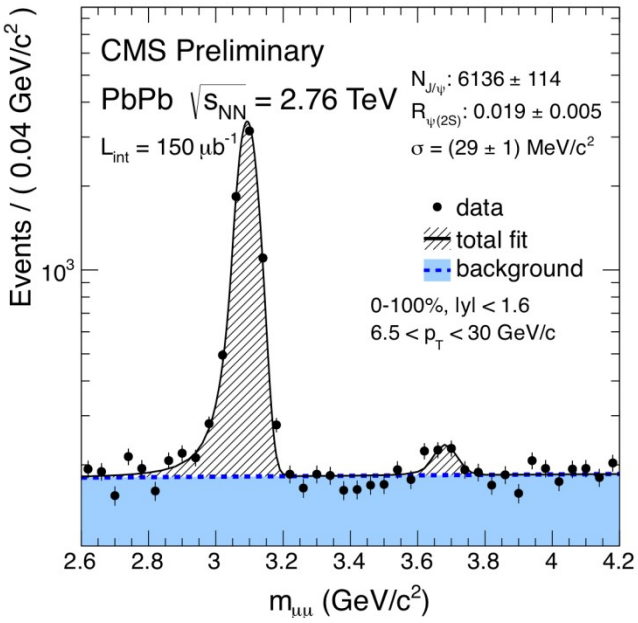


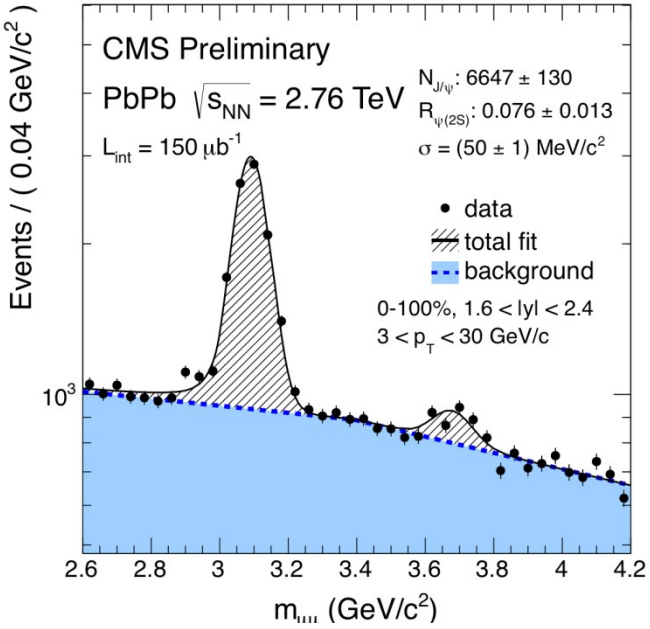


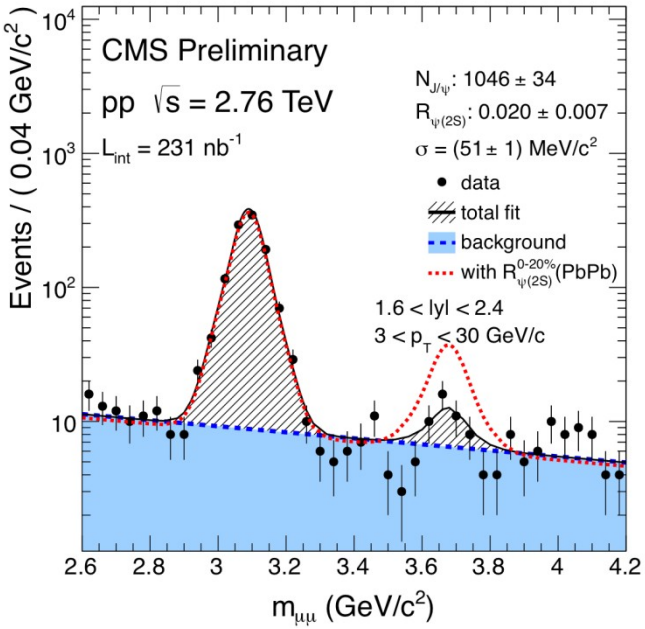


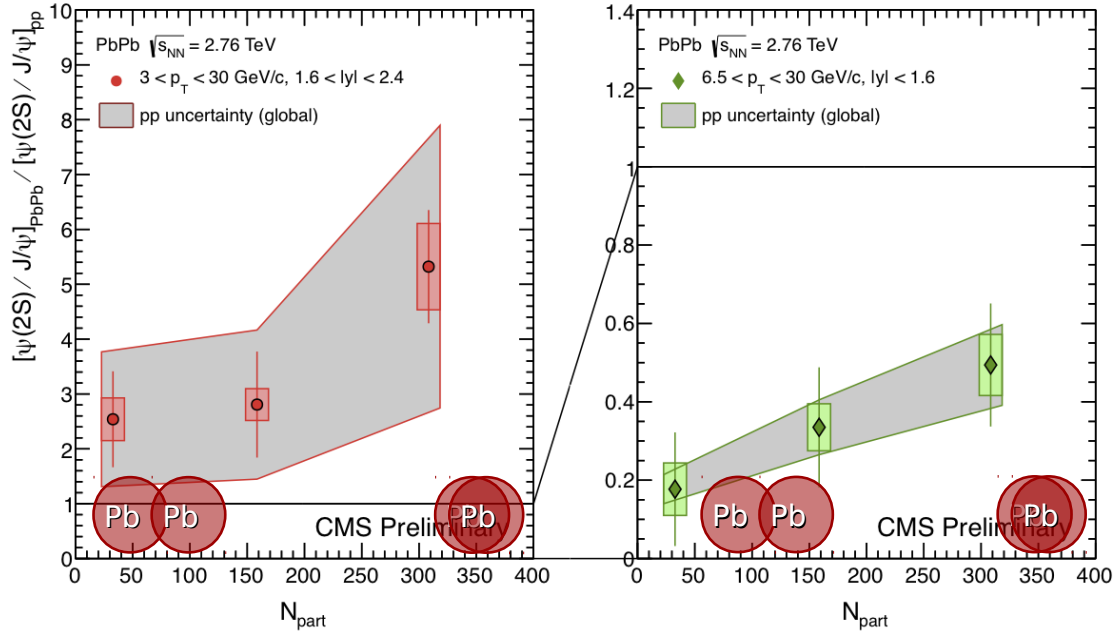
- Prompt J/ψ's are suppressed in central (peripheral) PbPb by a factor 5 (1.6) vs. pp
  more high-p_T suppression at LHC than at RHIC ⇨ melting in hotter quark-gluon matter?
- Secondary J/ψ's are suppressed in central (peripheral) PbPb by a factor of 2.5 (1.6) vs. pp
  not available at RHIC ⇨ first indication on medium-induced energy loss of b-quarks?
- Y's (1S) are suppressed in central PbPb by a factor 2.2 with respect to pp
  suppression is comparable at RHIC and LHC ⇨ sequential melting of only the excited states?

Ψ(2S) suppression vs. centrality in PbPb









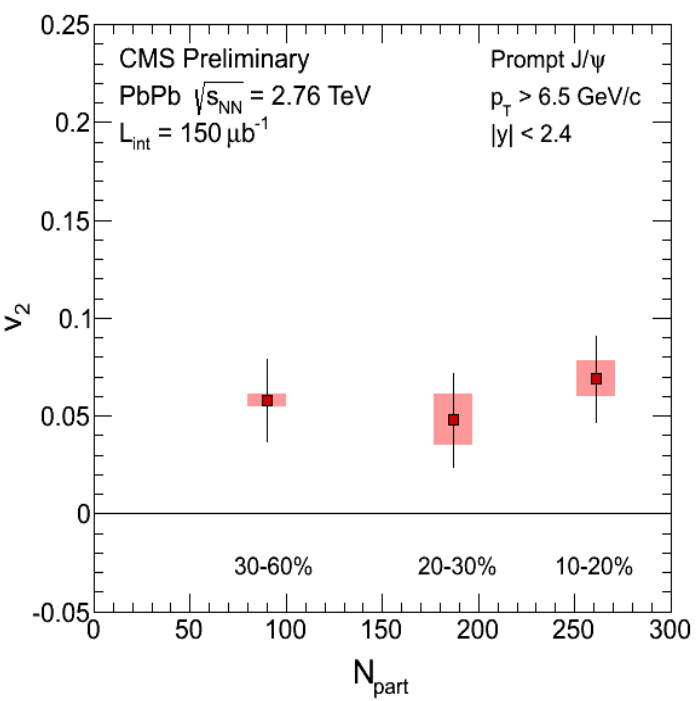
CMS-PAS-HIN-12-007

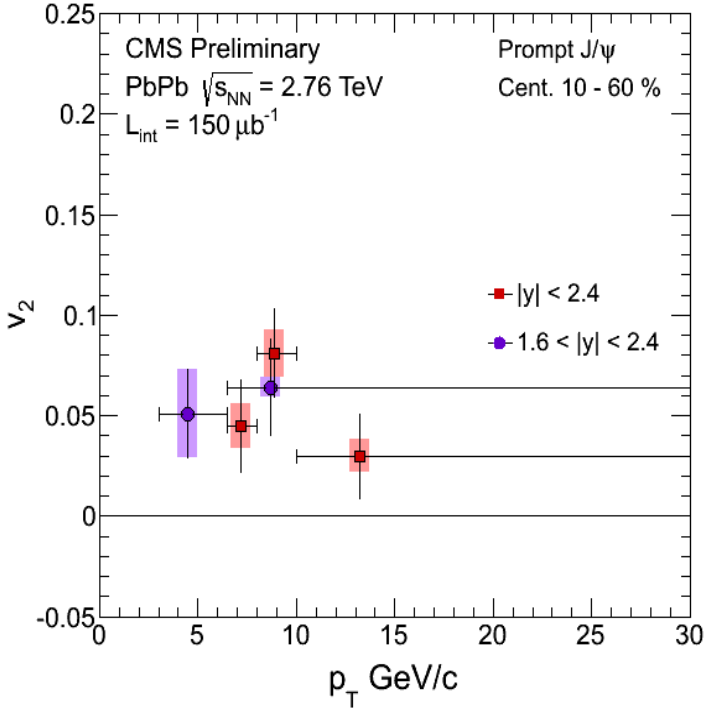
CMS gets indications on a suppression (enhancement) of excited ψ-states (2S) relatively to J/ψ (1S) in PbPb vs. pp collisions at central (forward) rapidity and higher (lower) p_T

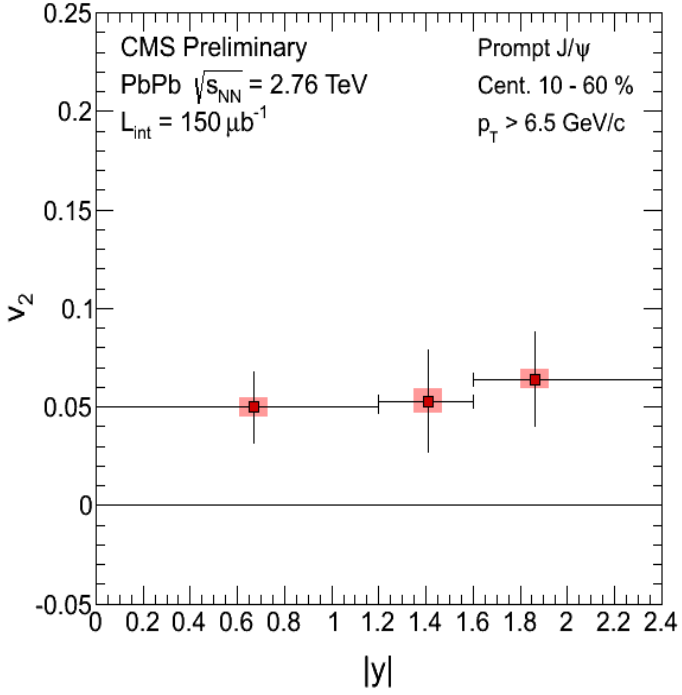
hint of ψ(2S) regeneration?

Elliptic flow of J/ψ in PbPb

CMS-PAS-HIN-12-001



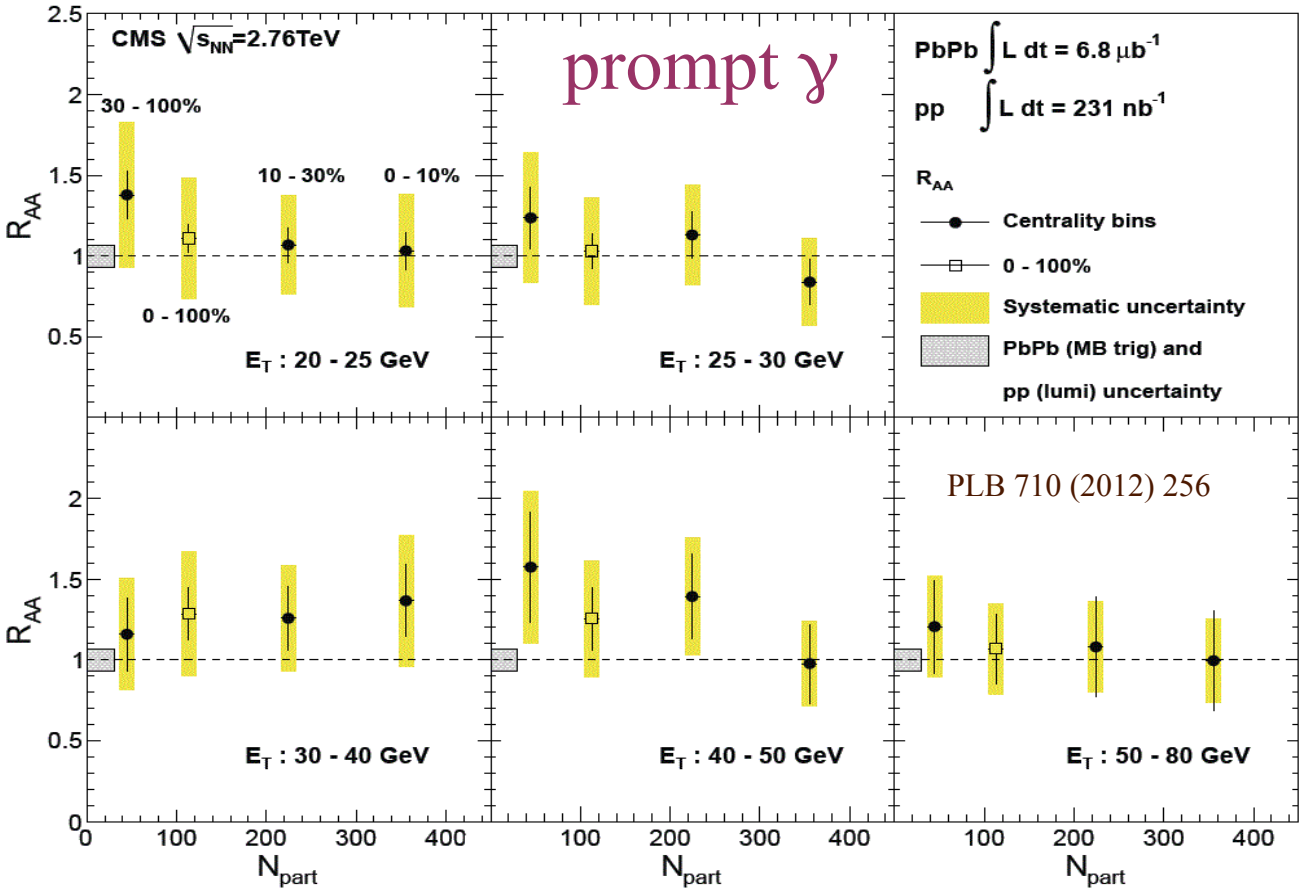


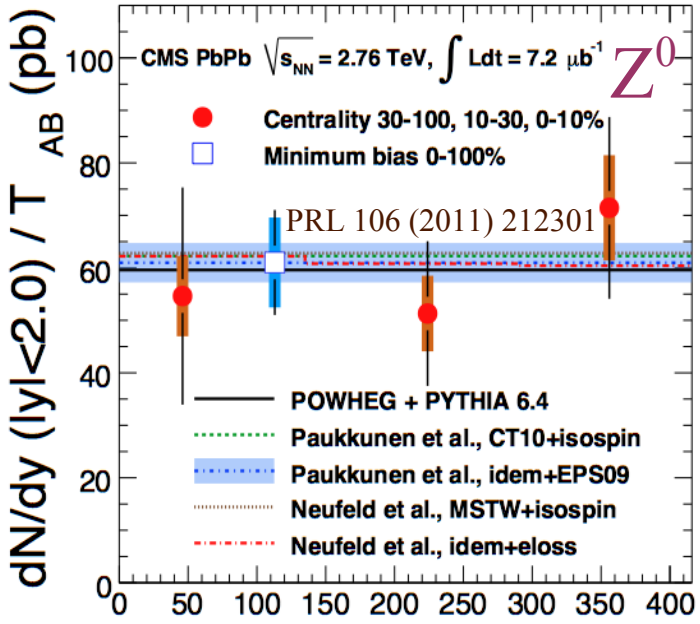


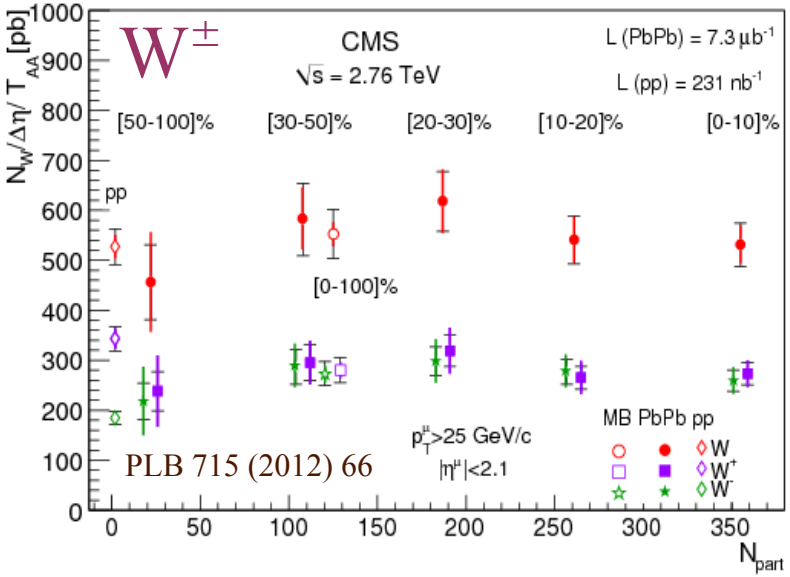
Significant elliptic flow of J/ψ

No centrality, transverse momentum and rapidity dependence?

Electroweak probes (Z^0, $W^{\pm}$, γ) in PbPb







No medium effects for electromagnetic hard probes

⇩

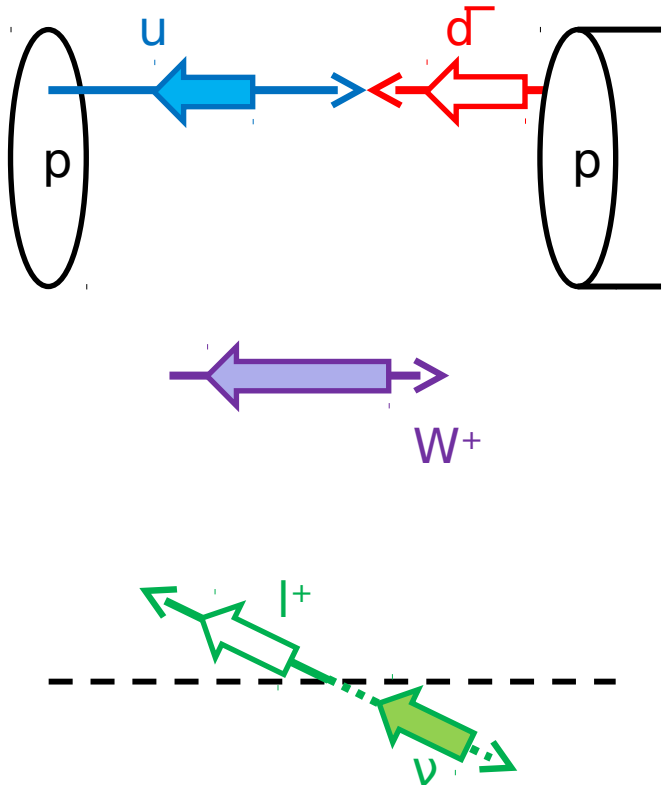
confirmation of NN binary scaling

Charge asymmetry for W production

@LO: $u\bar{d} \rightarrow W^+$ & $\bar{u}d \rightarrow W^-$

- Less W^+ and more W^- in PbPb than in pp (*isospin* effect)
  - Cancels for $W^+ + W^-$
- W boosted towards the valence quark (higher rapidity)
- Spin conservation → μ^+ (μ^-) boosted back to (away from) midrapidity

→ A strong acceptance difference (not heavy-ion specific)



$W^{\pm} \rightarrow \mu^{\pm} \nu$ in PbPb

$$M_T = \sqrt{2 p_{T\mu} p_{T\nu} (1 - cos(\phi_{\mu\nu}))}$$

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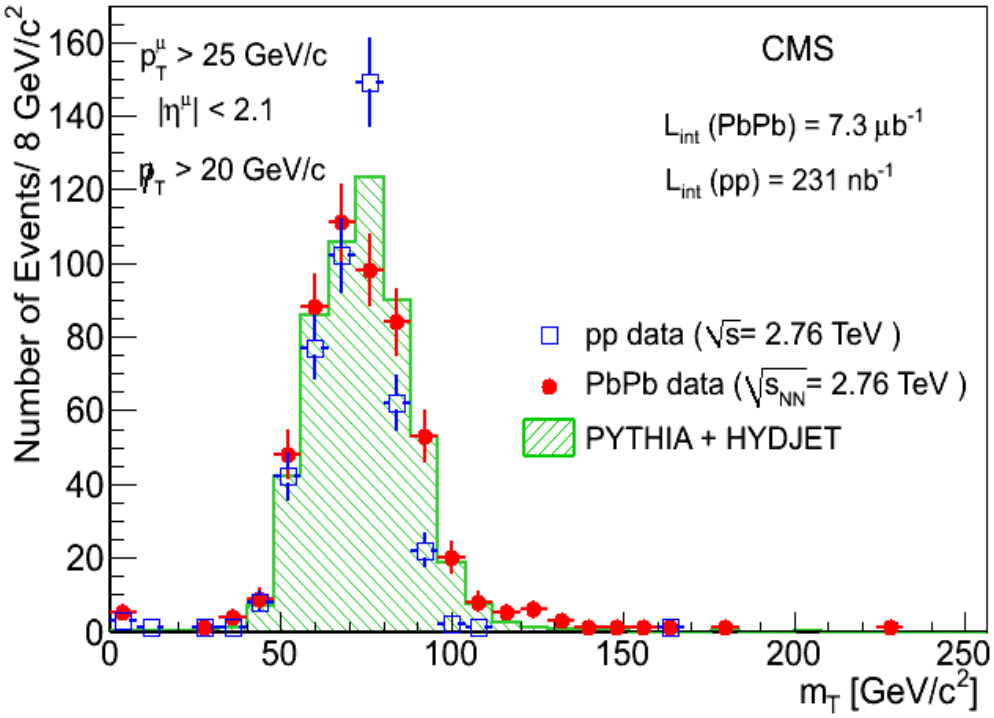
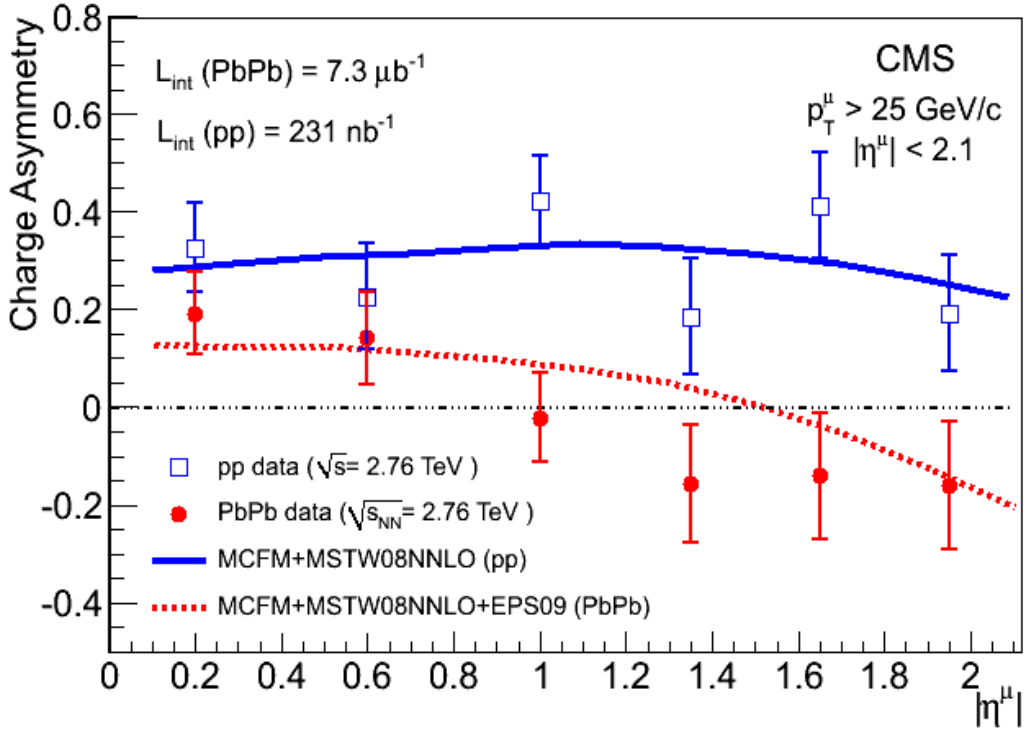
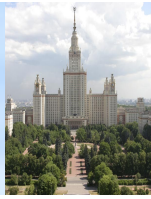




The different charge asymmetry $(dN(W^+) - dN(W^-)) / (dN(W^+) + dN(W^-))$ dependence with muon pseudorapidity is observed in the PbPb and the pp systems (isospin effect):

$R_{AA}(W^+) \approx 0.82$, $R_{AA}(W^-) \approx 1.46$, $R_{AA}(W) = 1.04 \pm 0.07 \pm 0.12$

Summary on PbPb results



Global observables

- Charge hadron multiplicity and transverse energy density are much higher than at RHIC
- Strong elliptic flow (momentum dependence is similar to RHIC, integral value is larger)
- Long range dihadron azimuthal correlations ("ridge")

⇨ Strongly interacting matter with hydrodynamical properties

Jets and high transverse momentum hadrons

- Large suppression of inclusive high transverse momentum hadron and jet yields
- Significant increase in the fraction of highly unbalanced dijet events
- Reducing the fraction of isolated photons with associated partner jet, γ-jet energy imbalance
- Observation of jet energy loss at low transverse momenta and large angles
- Modifications of radial and longitudinal jet profile
- Finite elliptic flow of hadrons at very high transverse momenta

⇨ Jet quenching due to partonic energy loss in hot QCD-matter

Quarkonia

- Strong suppression of high momentum prompt and secondary J/ψ yields
- Sequential suppression of Y(nS) states

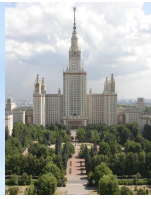
⇨ Debye screening of color charge in QCD-matter, in-medium b-quark energy loss

Electroweak probes

- First measurements of Z^0 and $W^{\pm}$ bosons and prompt photons in heavy ion collisions

⇨ No medium effects for electroweak bosons, confirmation of NN binary scaling

Summary on first pPb results



Analysis of proton-lead collisions helps us to clarify the influence of initial state ("cold nuclear matter") effects on various PbPb observables

Global observables

- Ridge and multi-particle correlations are observed in high multiplicity events
  ⇨ some collectivity?

Jets

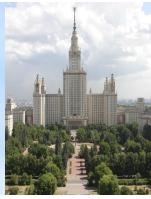
- No dijet asymmetry observed, but dijet η distributions shift with event activity
  ⇨ no jet quenching? initial state effect (nuclear shadowing)?

Quarkonia

- Moderate suppression of Y(2S,3S) relatively to Y(1S), stronger for higher multiplicities
  ⇨ initial or final state effect?

More results are coming...

CMS Heavy Ion Physics: Outlook



Near future

⇨ Continutation of analysis on pPb and PbPb data

⇨ Preparations for future CMS HI physics

Some later future

⇨ Heavy ion studies with higher energy and luminosity *(after LS1, ≥ 2015)*

• Jets

Precision measurements: γ+jet, Z+jet, b-jets, multi-jets

Detailed studies of jet fragmentation functions and jet shapes

TeV-scale jet quenching

• Quarkonium spectroscopy

Detailed studies of Y(1S, 2S, 3S) and ψ (1S, 2S), onset-behaviour

• Exotica, forward physics, ultraperipheral collisions,...