Selected results from nucleus collisions at the LHC

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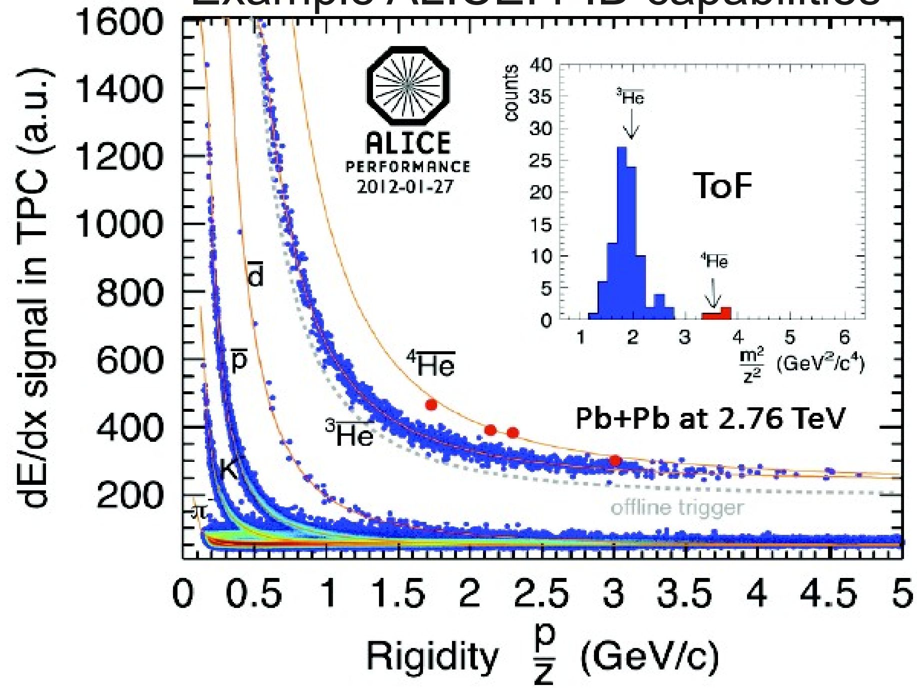
(LBNL/EMMI)

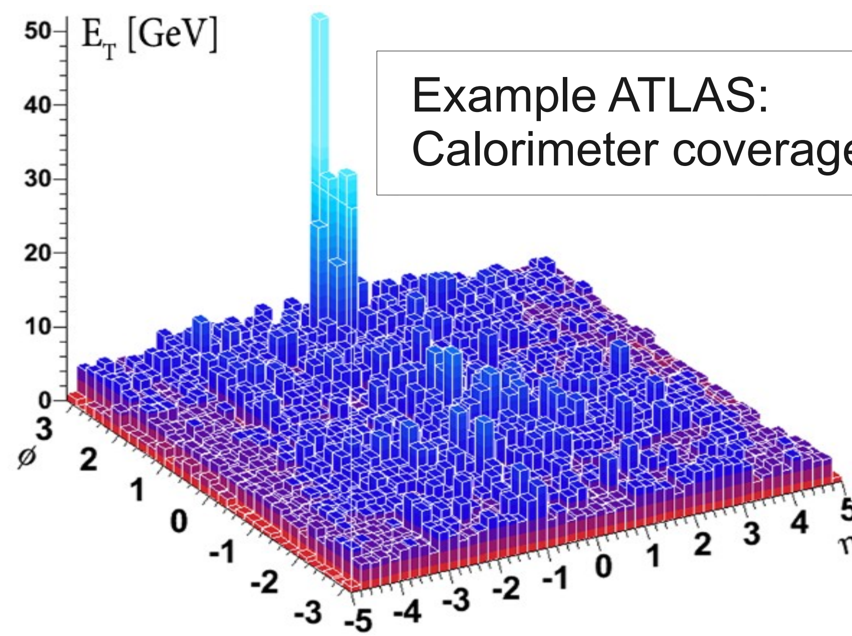
EMMI Physics Days 2012
GSI, Darmstadt, Germany
November 13-14, 2012

Heavy-ion data-taking experiments at LHC 2

Example ALICE: PID capabilities

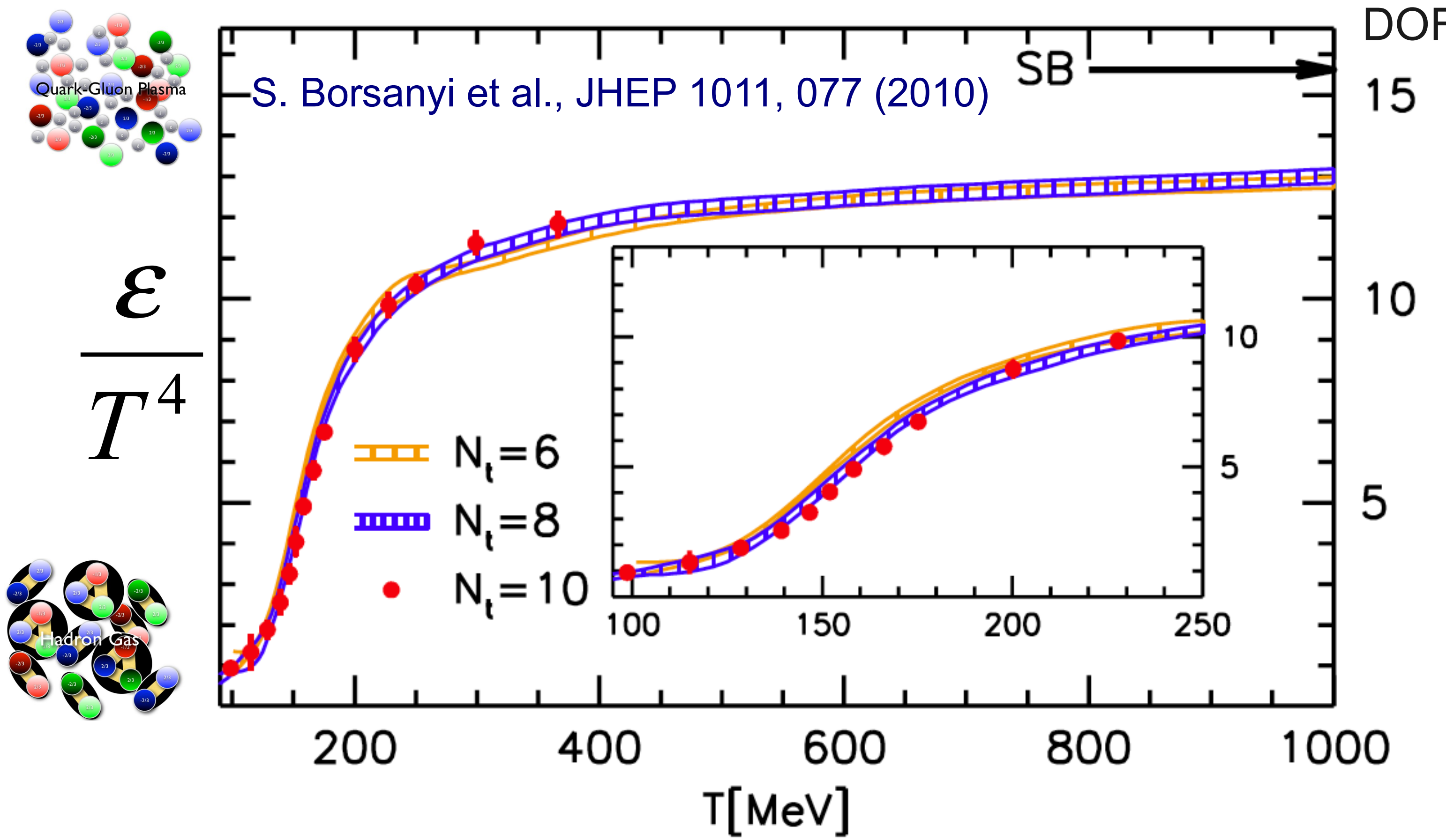


- LHC: First beams in Nov 2009
  - p+p (900, 2.36, 2.76, 7, 8 TeV)
  - Pb+Pb at 2.76 ATeV in Nov 2010/11 (~10/μb and ~150/μb)
  - p+Pb at 5.02 ATeV in Nov 2012
- ALICE dedicated HI experiment
  - Low-p_T tracking, PID, mid-rapidity
- ATLAS/CMS large HEP experiments
  - Large acceptance, full calorimetry



Example ATLAS: Calorimeter coverage

QCD cross-over transition from lattice



SB gas limit
not reached

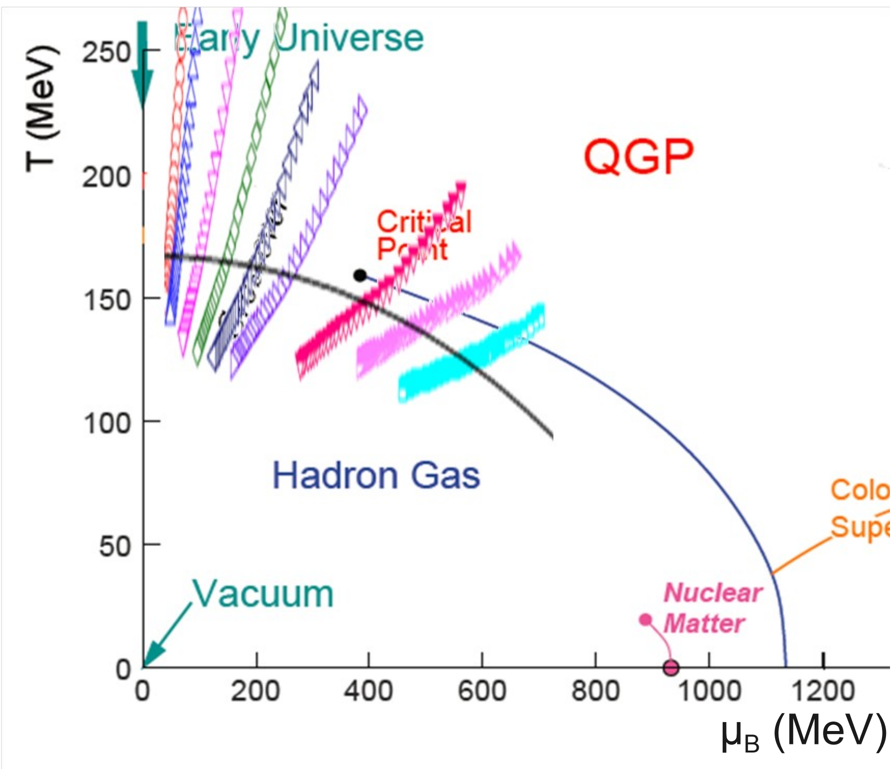
Lattice calculations predict a cross-over transition from hadronic to partonic degrees of freedom at

$T_c \approx$ 150-160 MeV
$\varepsilon_c \approx 0.5$ GeV/fm^3

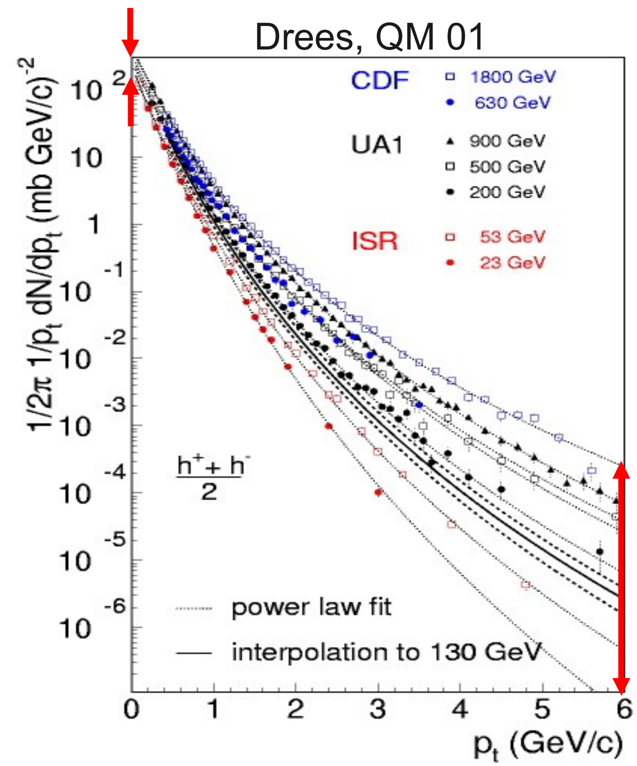
External parameters: Collision energy

Collision energy

Initial conditions
and freeze-out paths

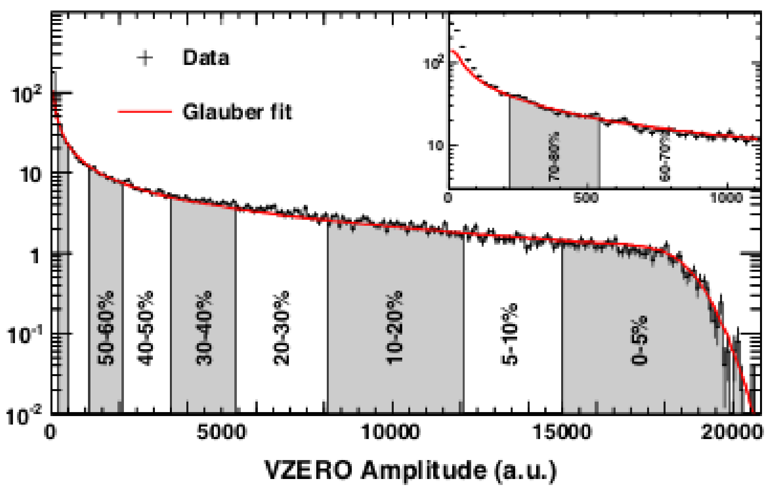


Ratio of “soft” to “hard” processes

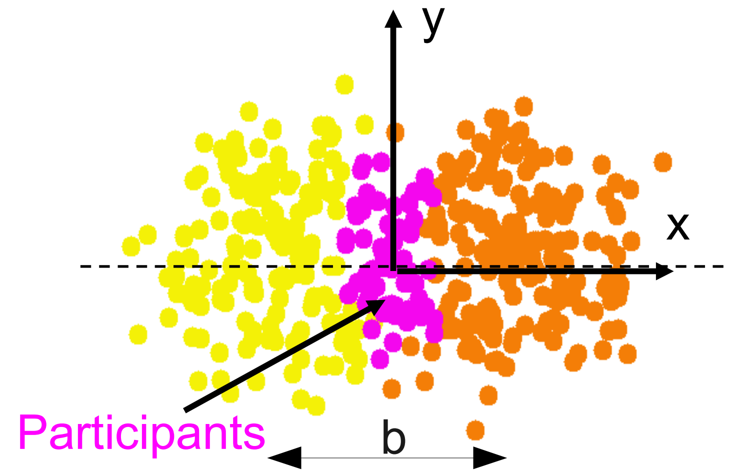


External parameters: Collision centrality

Nuclear cross-section classes
(by slicing in bins of multiplicity)



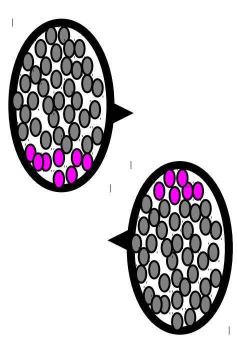
Glauber model

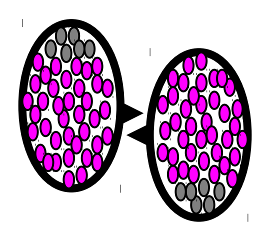


Impact parameter

Cross-section percentile (in %) ⟷ Number of participants (collisions)

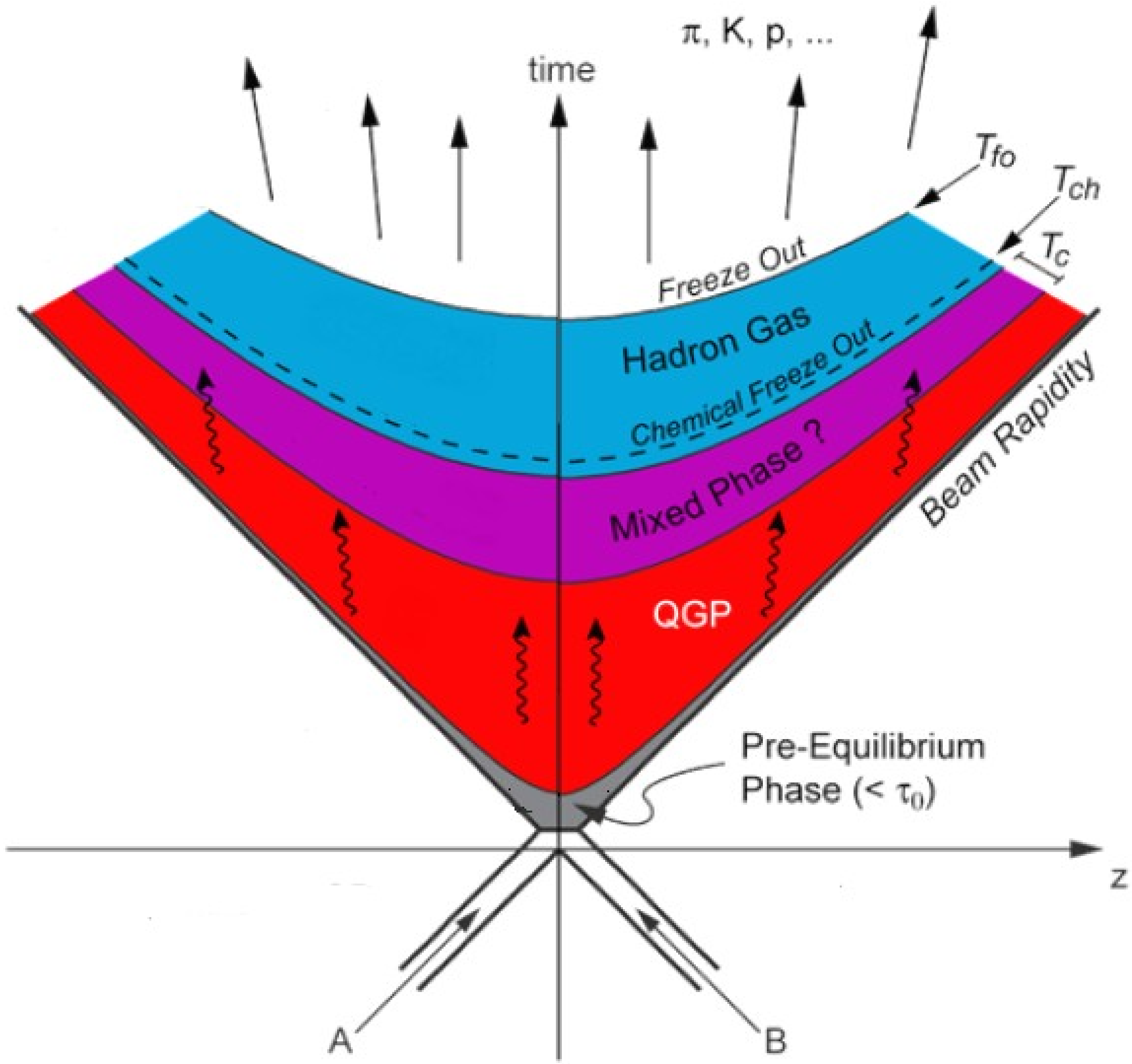
Collision energy





Collision centrality

Heavy-ion standard reaction model



Global properties

Kinetic freeze-out

Chemical freeze-out

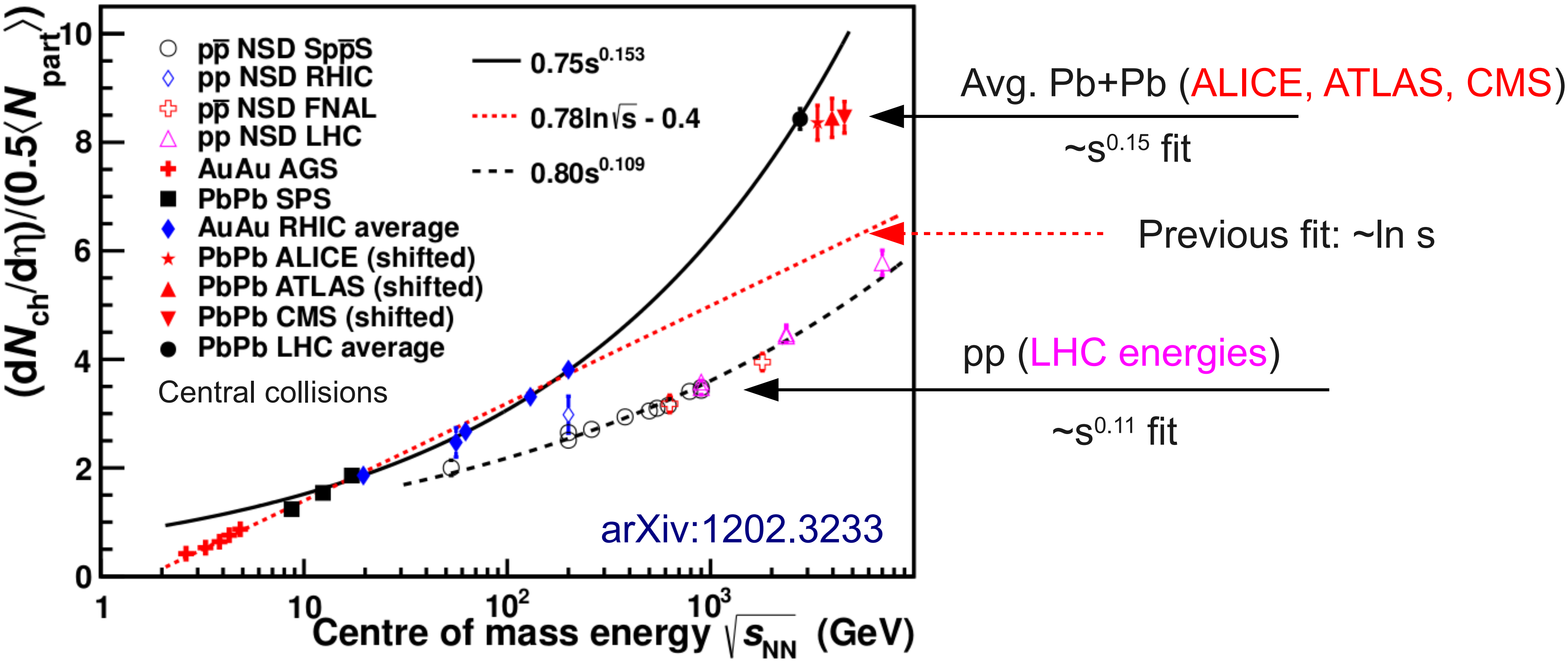
Collective flow

Hard probes
(jets, heavy flavor)

Order discussed in talk

"Rewind dynamical evolution" to access QGP by studying many observables with different sensitivity to the stages of the collision

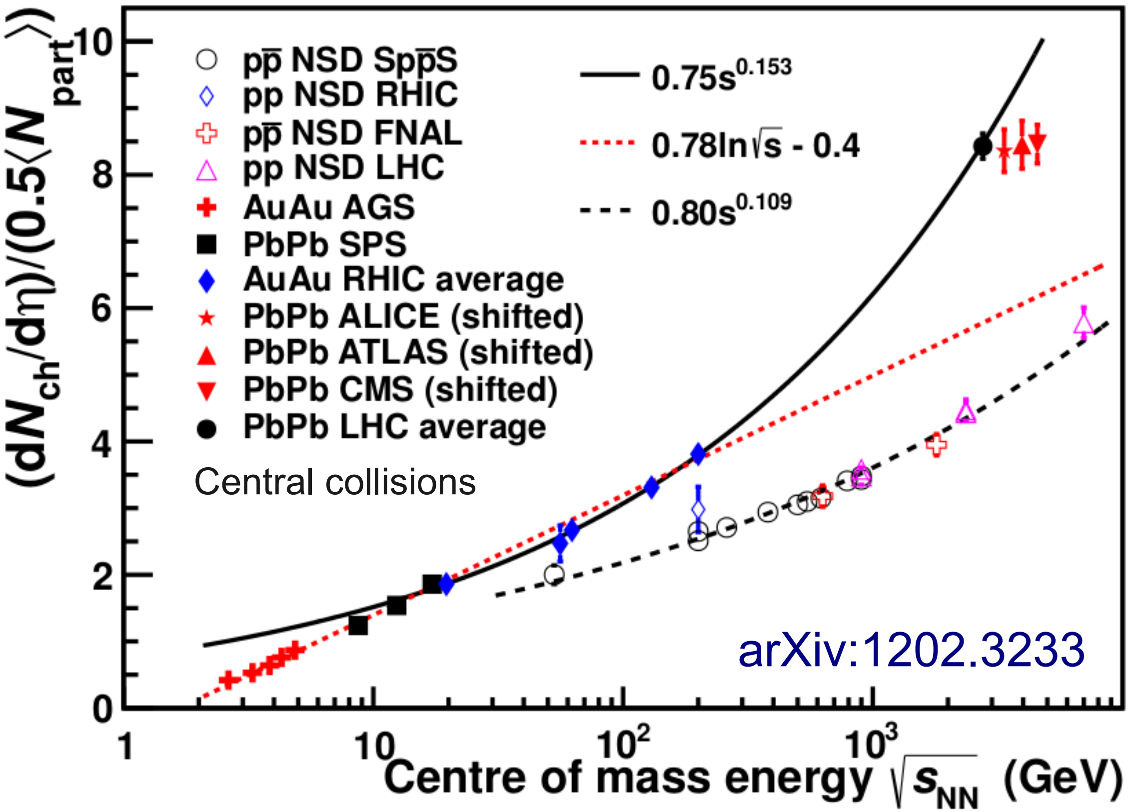
Energy dependence of dN/dη

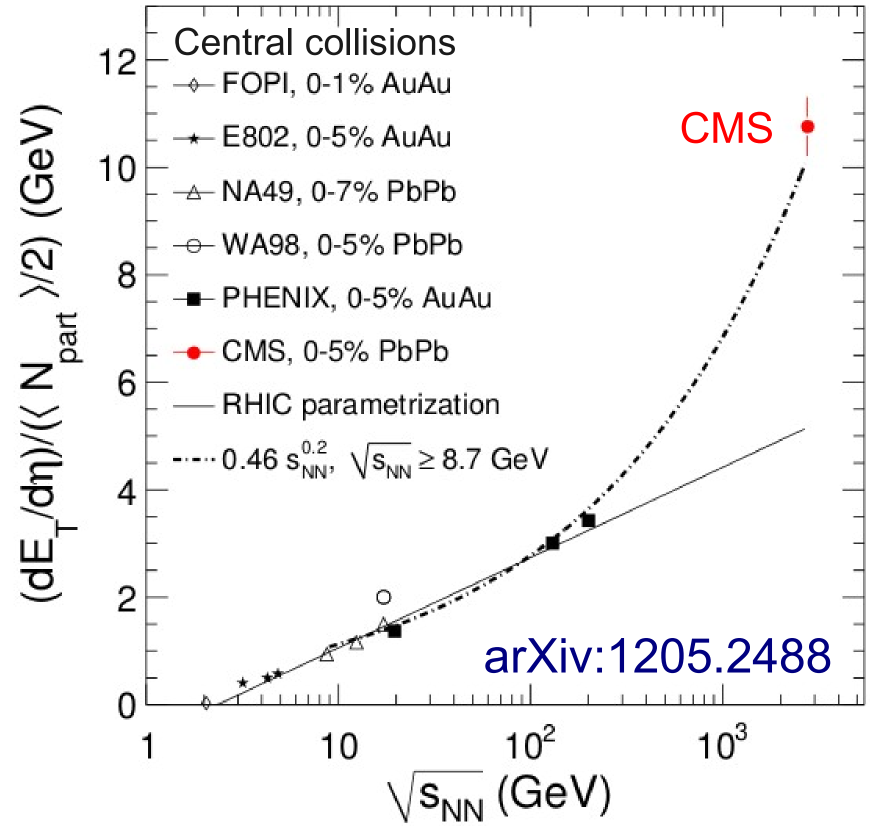


Stronger rise with center-of-mass energy in AA wrt to pp, and wrt to extrapolations from lower energies ($dNch/d\eta_{LHC} \approx 1600 \sim 2 \times dNch/d\eta_{RHIC}$)

ALICE, PRL 106 (2011) 032301
CMS, JHEP 1108 (2011) 141
ATLAS, PLB 710 (2012) 363

Energy dependence of dN/dη and $dE_T/d\eta$





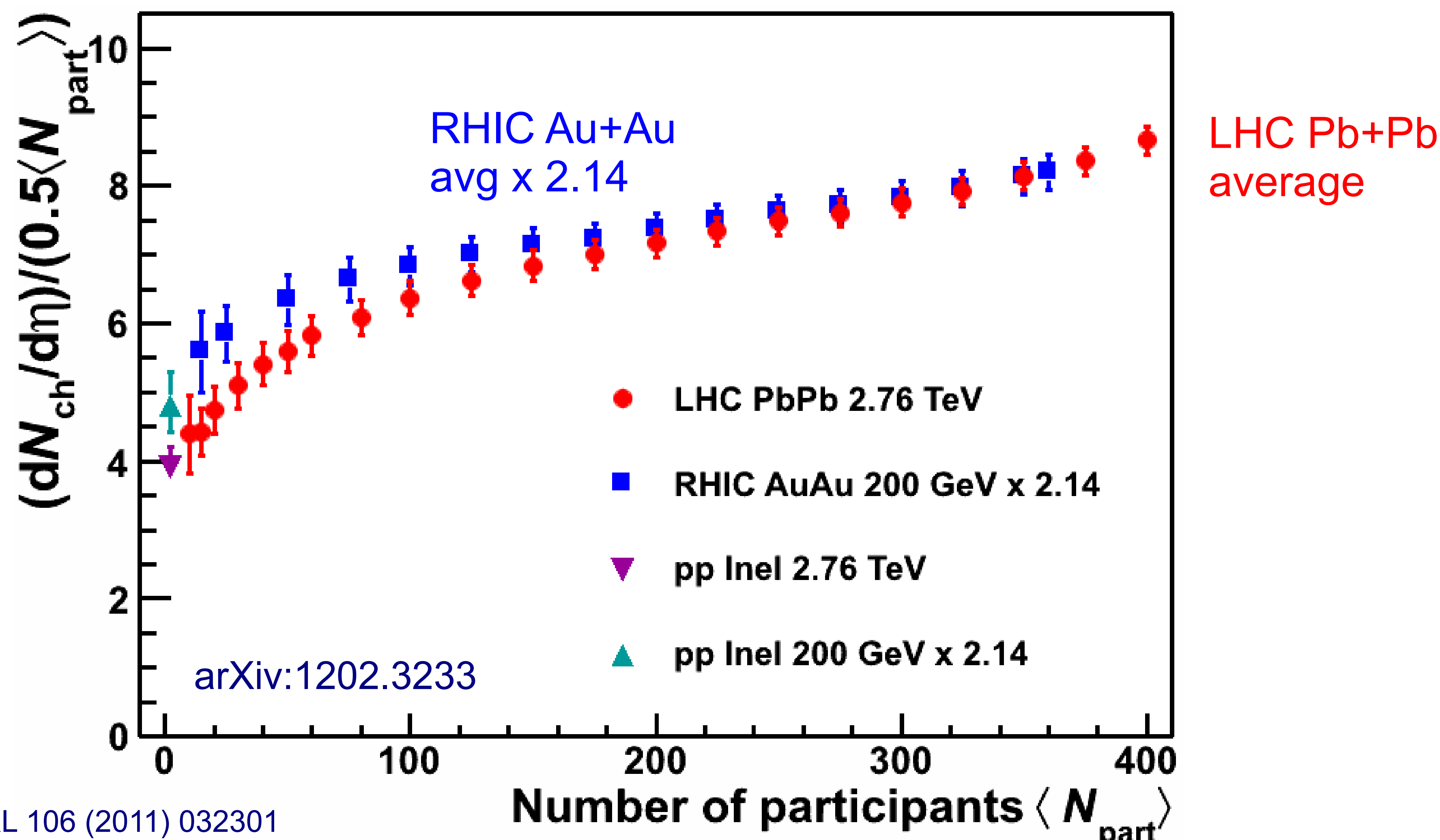
Stronger rise with center-of-mass energy in AA wrt to pp, and wrt to extrapolations from lower energies ($dNch/d\eta_{LHC}$ ≈1600 ~ 2 x $dNch/d\eta_{RHIC}$)

$$\epsilon(\tau) = \frac{dE_T/d\eta}{\pi R^2 \tau} \approx 3/2 \langle m_T \rangle \frac{dN_{ch}/d\eta}{\pi R^2 \tau}$$

$$\tau\,\epsilon_{LHC} \simeq 2.5 \times \tau\,\epsilon_{RHIC}$$

Initial energy density at LHC (as at RHIC) is well above $\varepsilon_c \approx 0.5$ GeV/fm^3

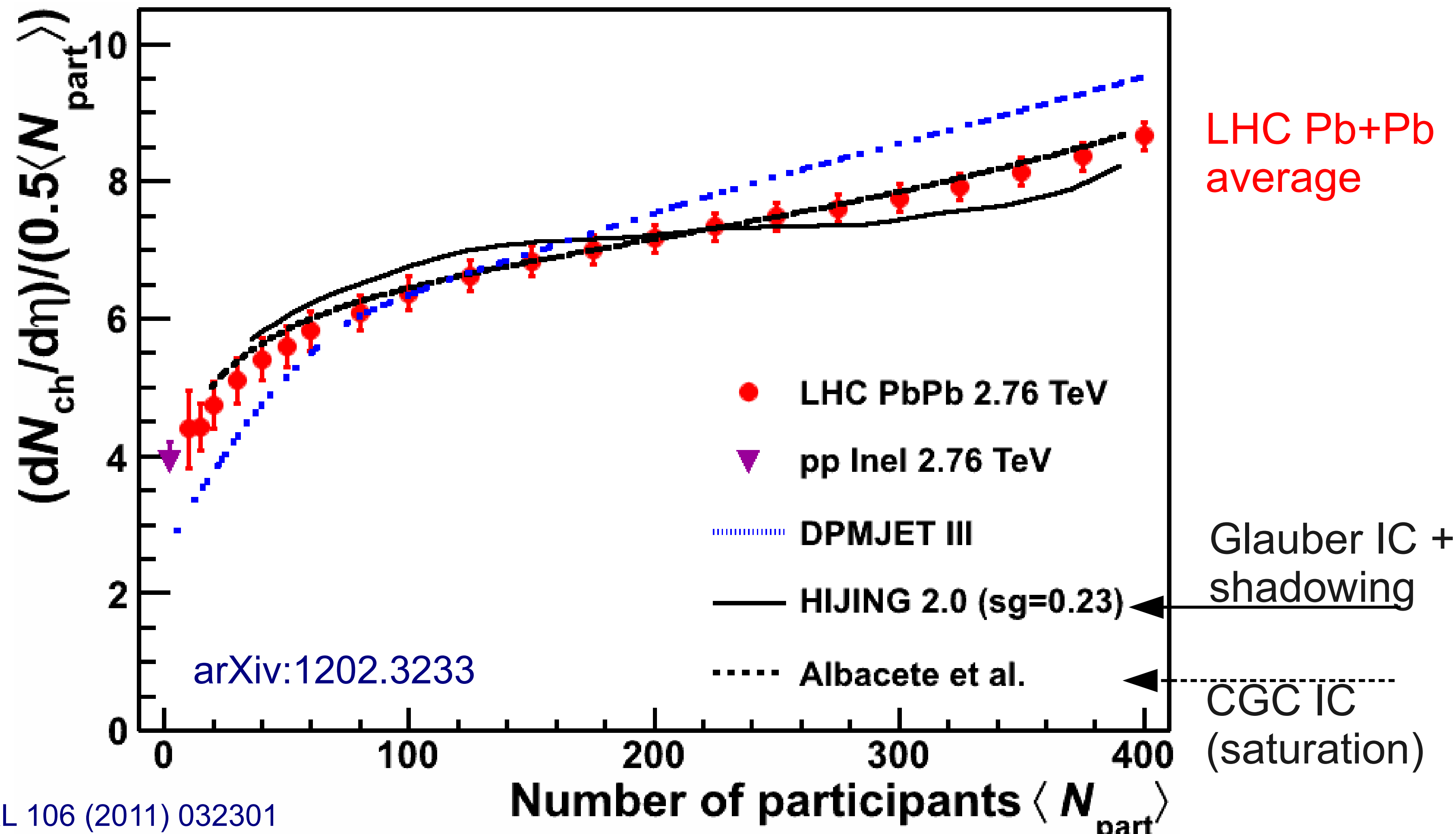
Centrality dependence of dN/dη



ALICE, PRL 106 (2011) 032301
CMS, JHEP 1108 (2011) 141
ATLAS, PLB 710 (2012) 363

Centrality dependence is strikingly similar to RHIC.
This actually holds all the way down to 19.6 GeV (not shown)

Centrality dependence of dN/dη



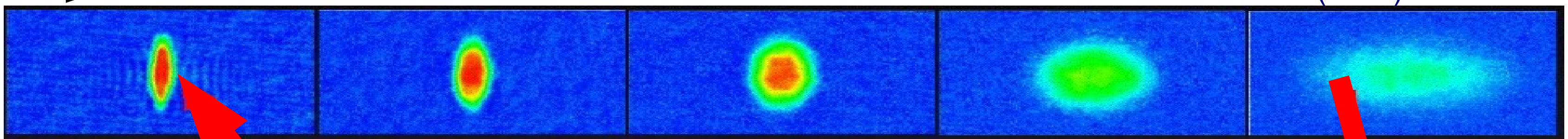
ALICE, PRL 106 (2011) 032301
CMS, JHEP 1108 (2011) 141
ATLAS, PLB 710 (2012) 363

Two-component models need to incorporate strong nuclear modification. Models based on Glauber and CGC initial conditions can describe the data.

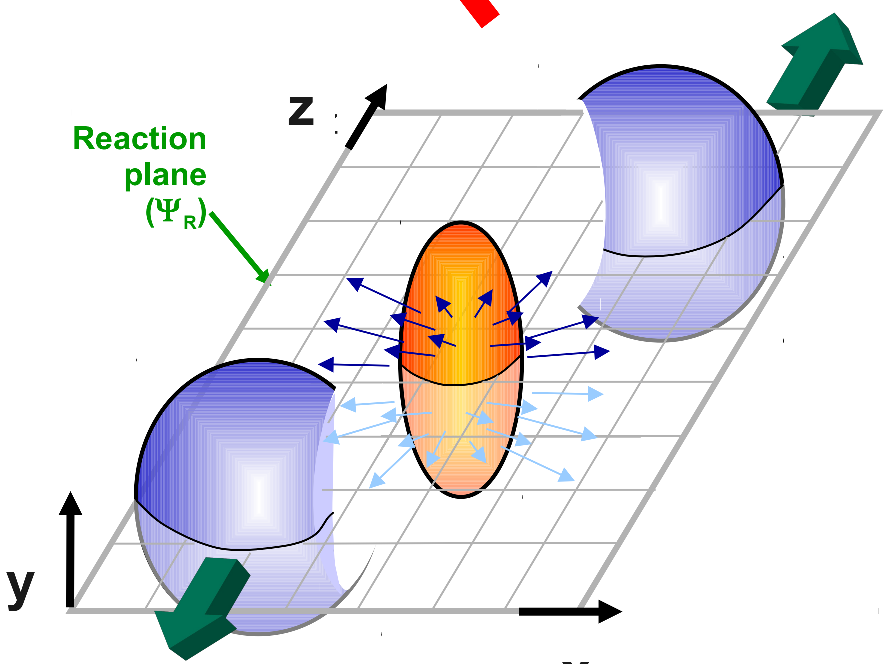
Initial and final state anisotropy

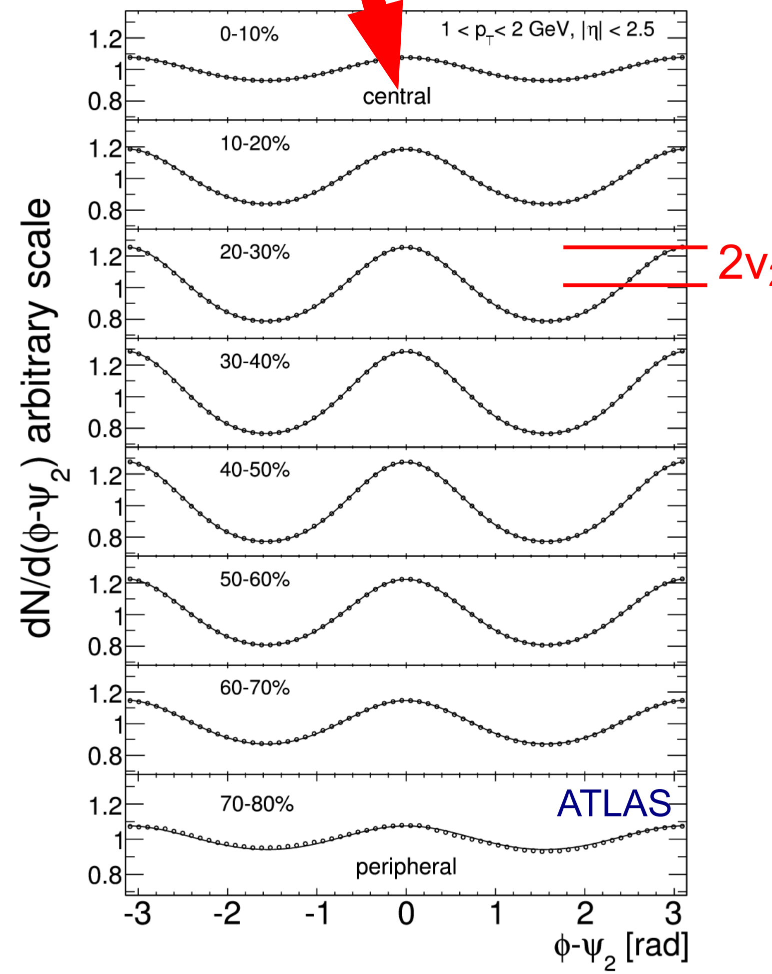
Time

Science 298 5601 (2002) 2179-2182



(self quenching)



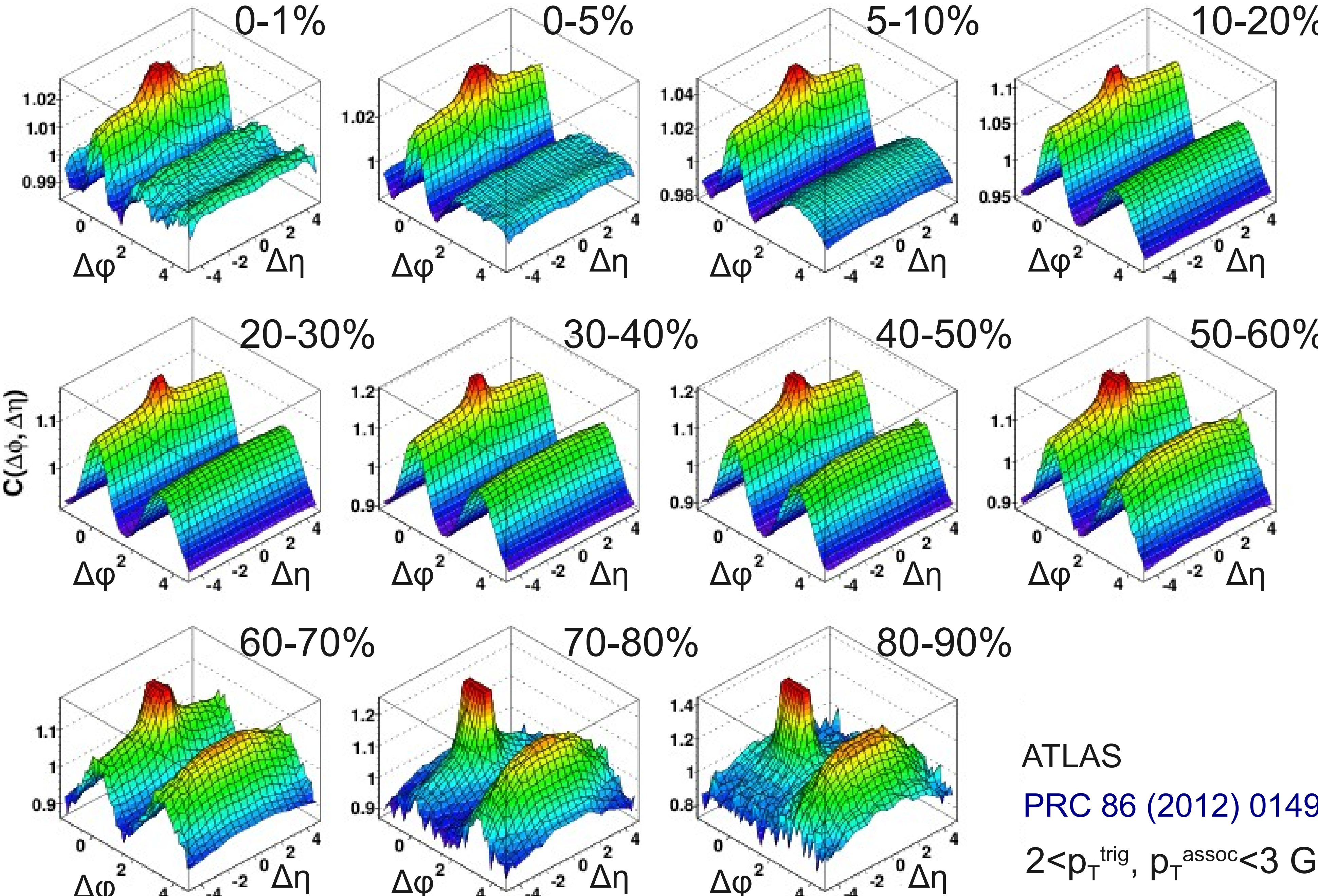


Initial spatial anisotropy: eccentricity ε

Interactions present early

Momentum space anisotropy: elliptic flow $v_2 = \langle \cos(2\phi - 2\Psi_R) \rangle$

Two-particle correlations

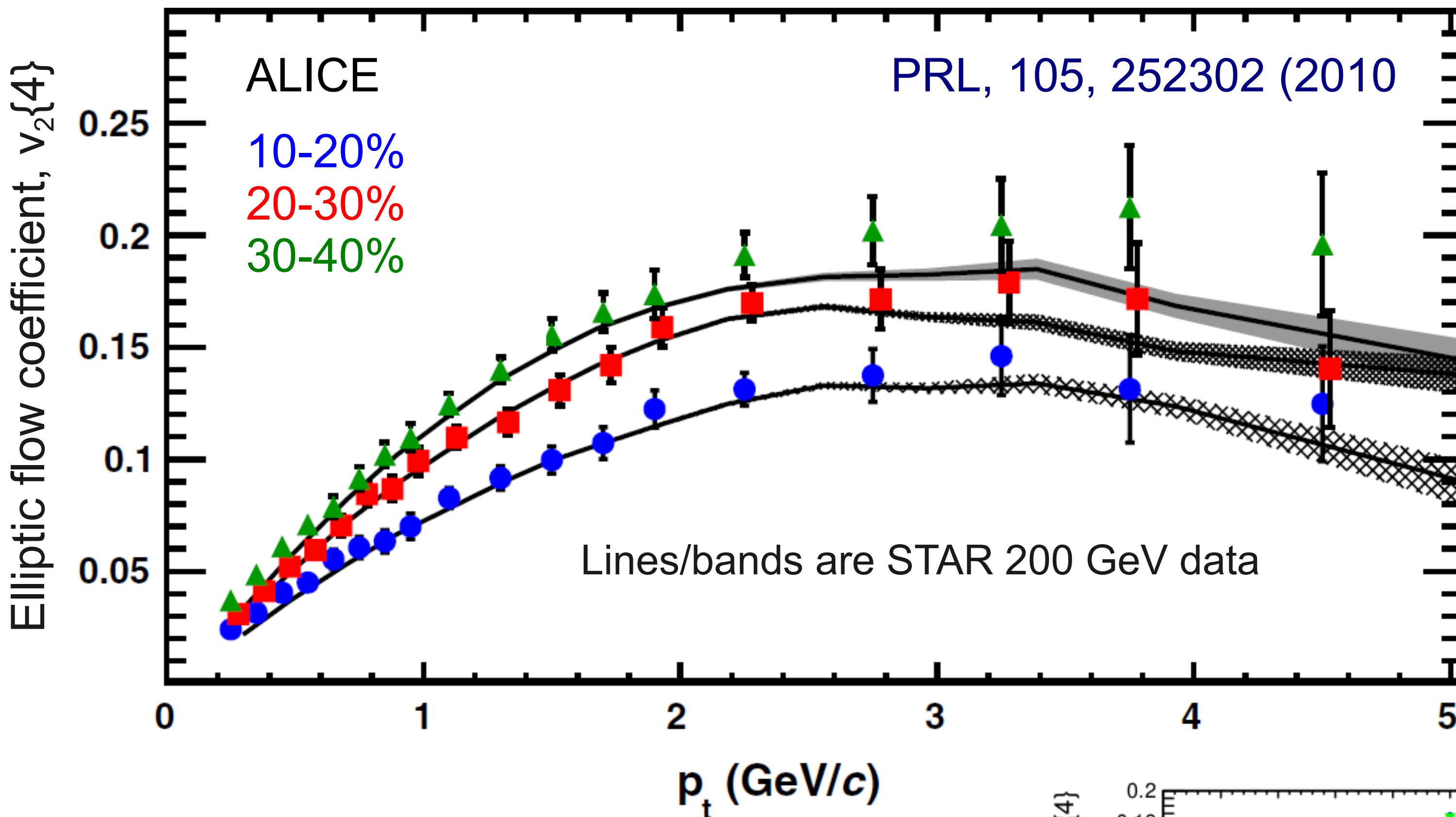


ATLAS

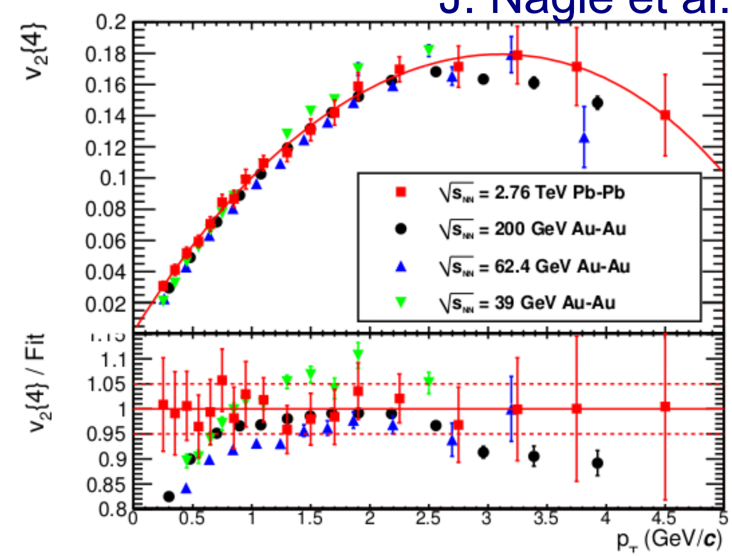
PRC 86 (2012) 014907

$2 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

Charged particle elliptic flow

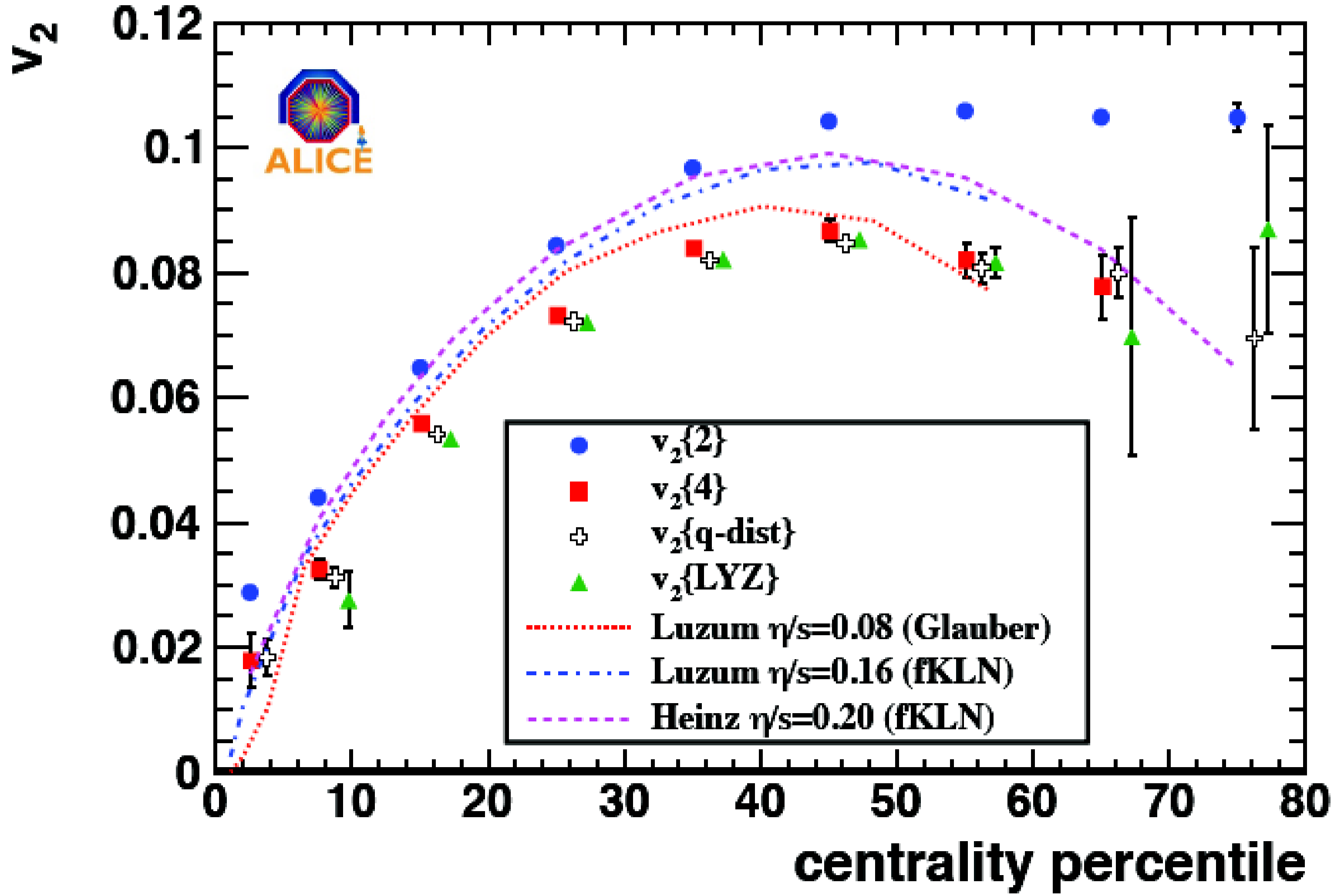


J. Nagle et al.



Observe $v_2(p_T)_{LHC} \approx v_2(p_T)_{RHIC}$,
despite factor 14 increase in cms energy!
(Integrated v_2 30% larger due to radial flow)

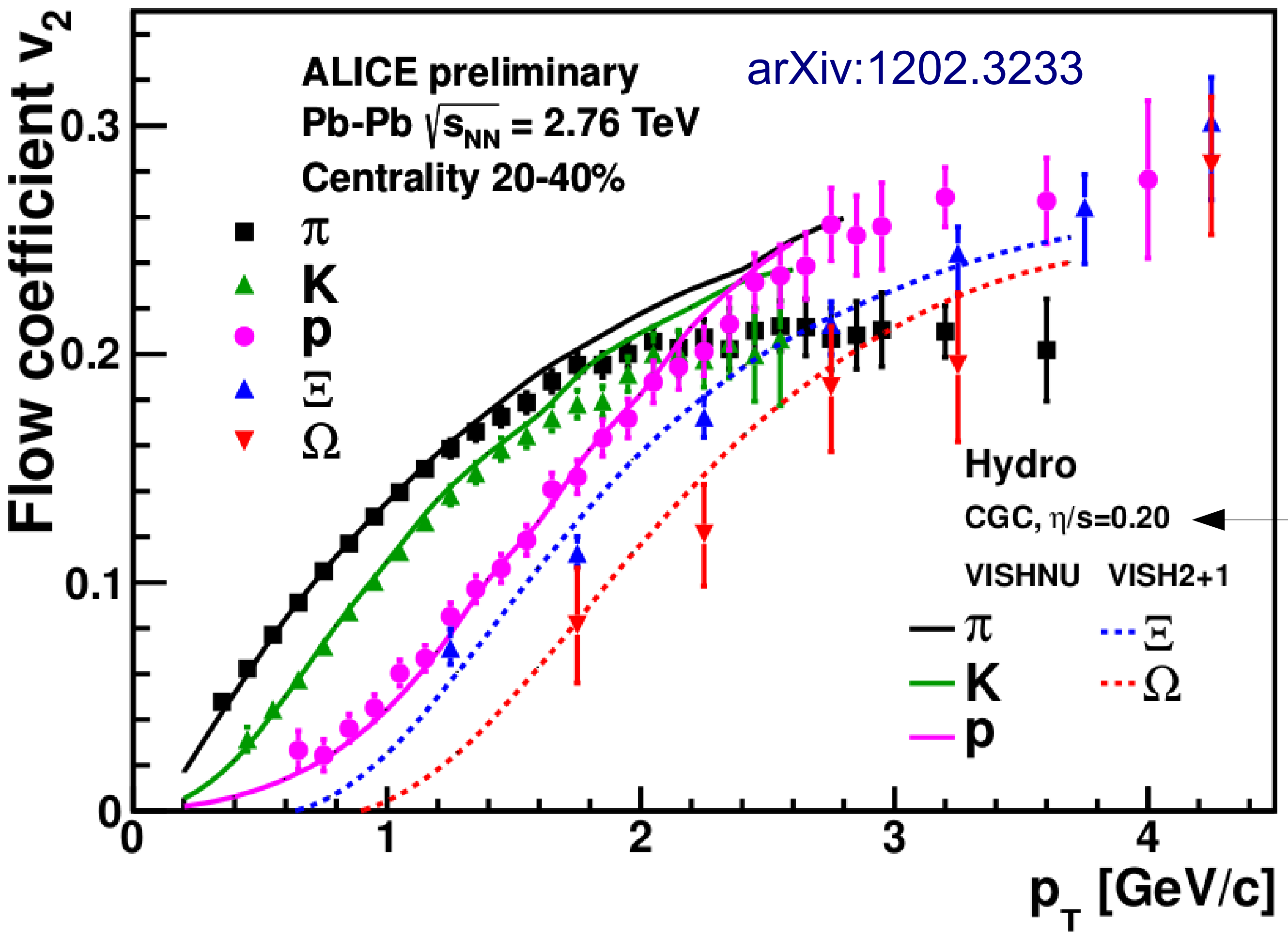
Low viscosity fluid also at the LHC



Calculation:
M.Luzum,
arXiv:1011.5173

Increase well within the range of viscous hydro predictions

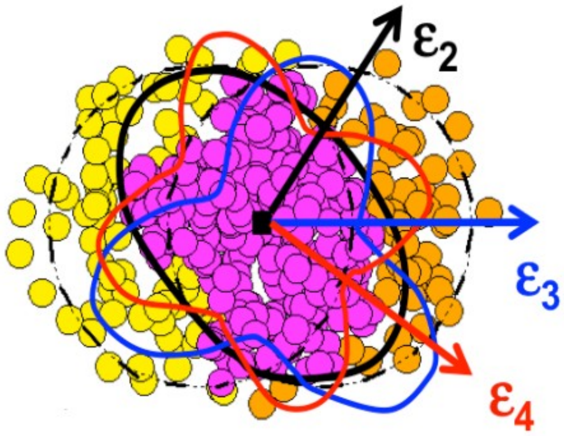
Identified particle elliptic flow



η/s=0.2

Observed mass ordering due to radial flow
as predicted by hydrodynamical calculations

Higher harmonics and viscosity

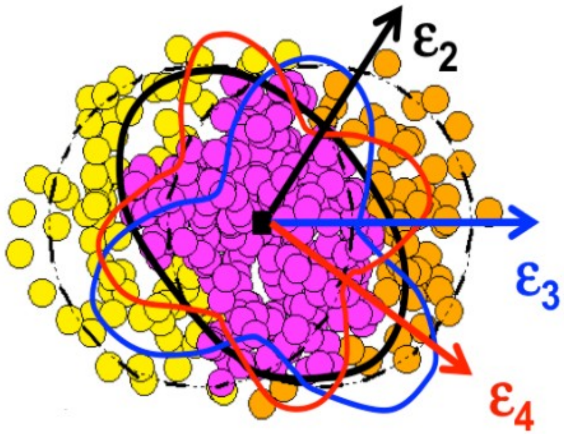


Alver, Roland

Initial spatial anisotropy not smooth, leads to higher harmonics / symmetry planes.

$$\frac{dN}{d\phi} \sim 1 + 2v_2 \cos[2(\phi - \psi_2)] + 2v_3 \cos[3(\phi - \psi_3)]$$
$$+ 2v_4 \cos[4(\phi - \psi_4)] + 2v_5 \cos[5(\phi - \psi_5)] + \ldots$$

Higher harmonics and viscosity



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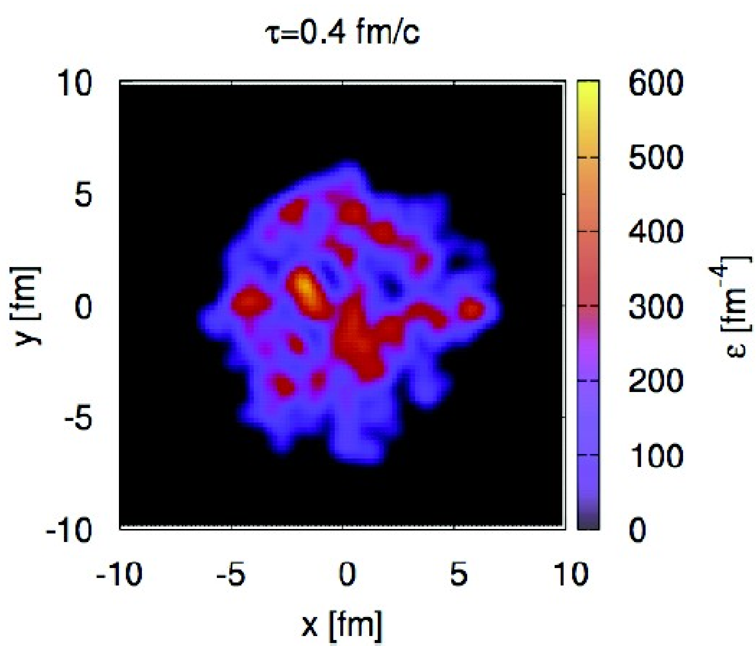
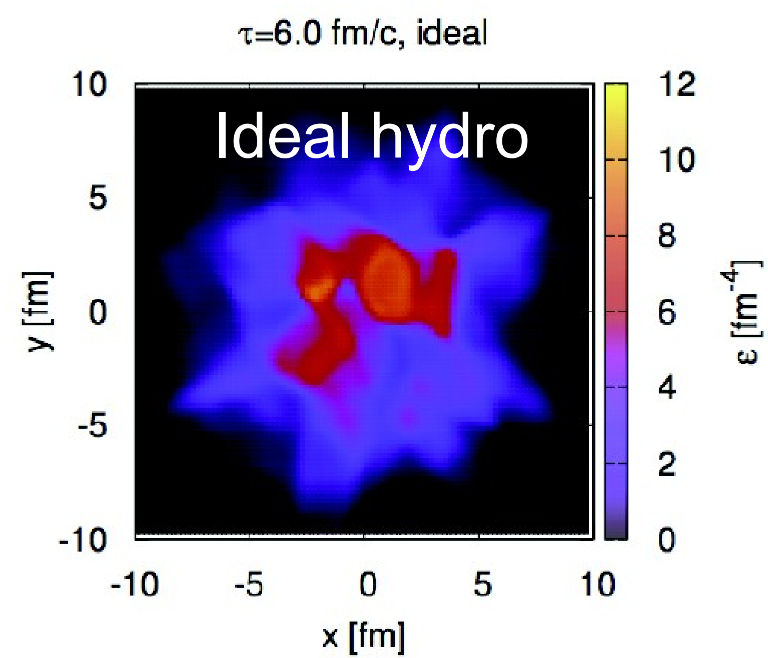


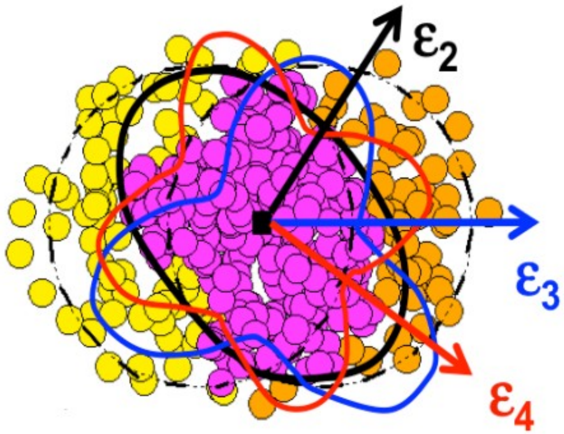
e-by-e hydro

B. Schenke et al.



Ideal hydrodynamical models preserves these “clumpy” initial conditions

Higher harmonics and viscosity



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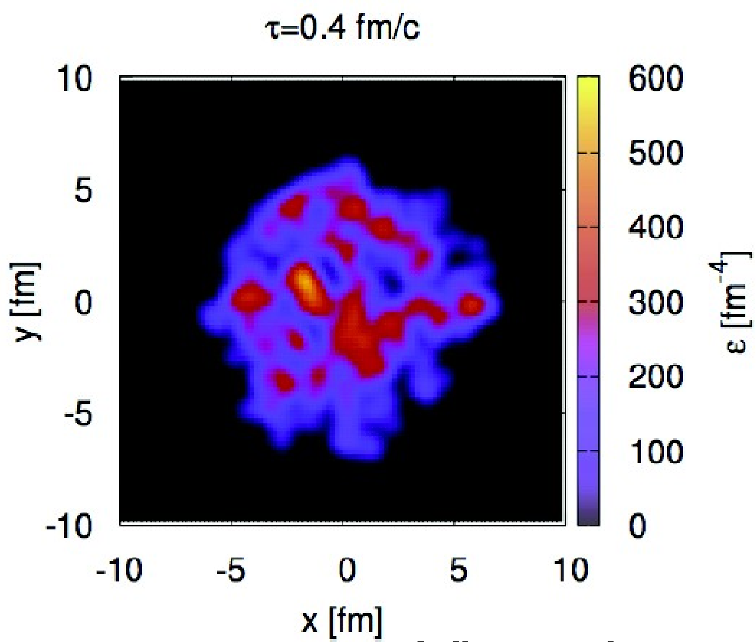
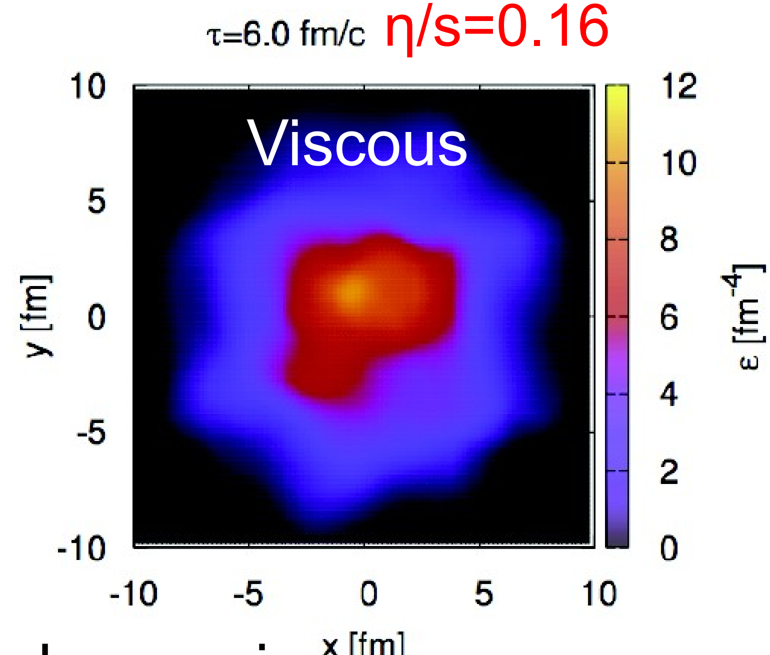


e-by-e hydro →

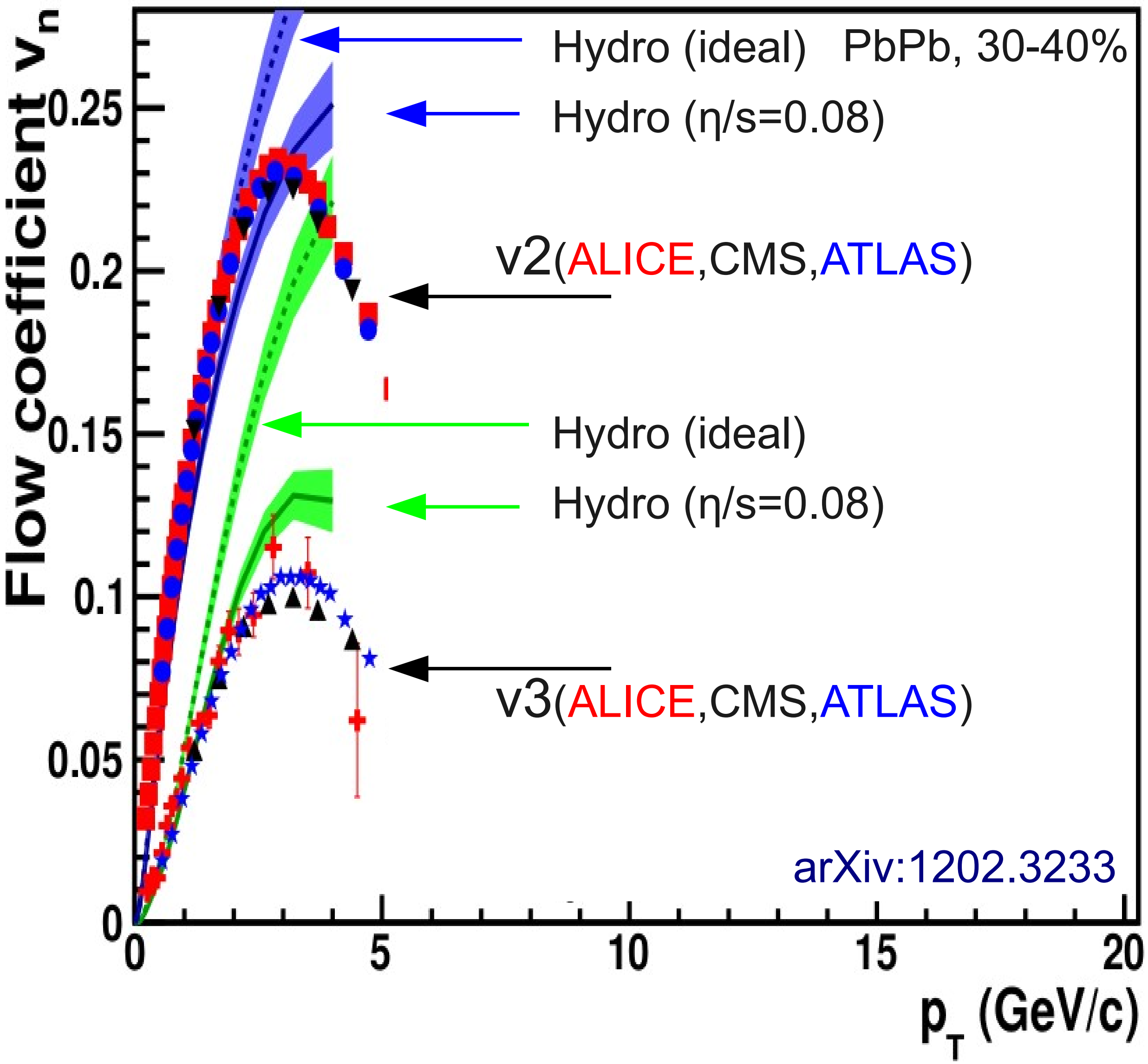
B. Schenke et al.

η/s=0.16



Viscosity suppresses higher harmonics,
→ v_n provide additional sensitivity to η/s

Limits on η/s from v_2 and v_3



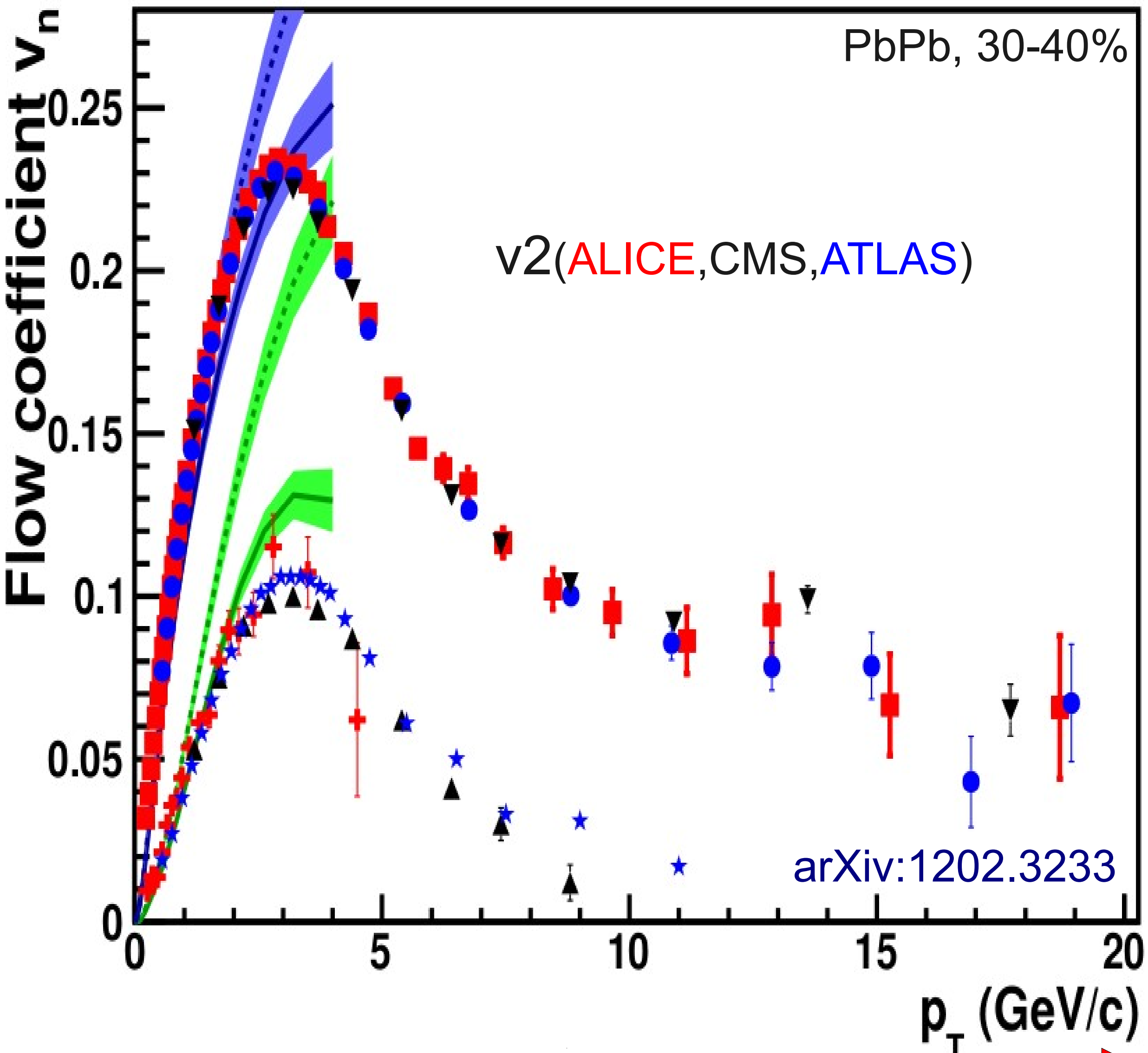
- Significant v_3 component
- Viscosity dissipates initial pressure gradients and reduces the collective flow
- v_3 provides additional constraints on η/s
- Current bound at LHC
  - $\eta/s < 2/(4\pi) = 2(\eta/s)_{min}^{ADS/CFT}$

Qui, Shen, Heinz, PLB 707 (2012) 151

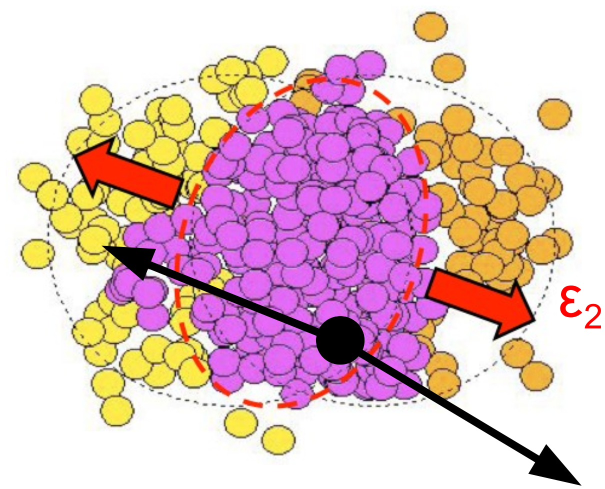
ALICE, PRL 107 (2011) 032301
ATLAS, PLB 707 (2012) 330
ATLAS, PRC 86 (2012) 014907
CMS, arXiv:1204.1409

The quark-gluon plasma at the LHC is still a nearly perfect liquid

Soft, intermediate and hard p_T region



Path-length dependent energy loss



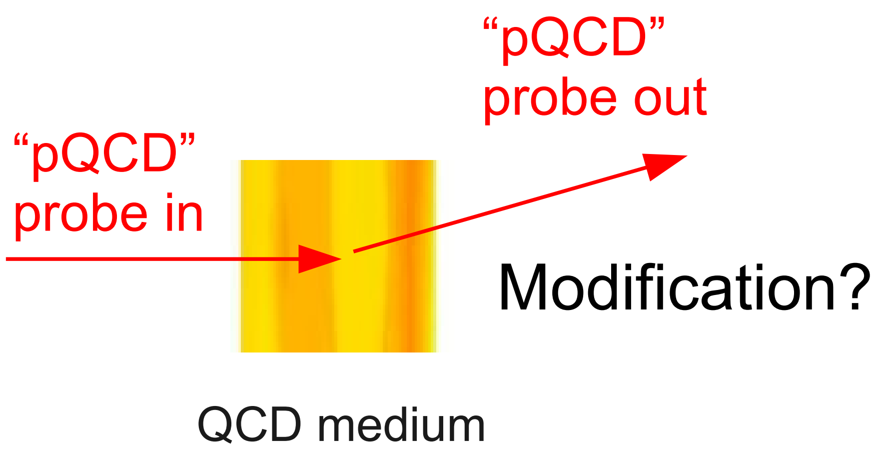
Soft p_T

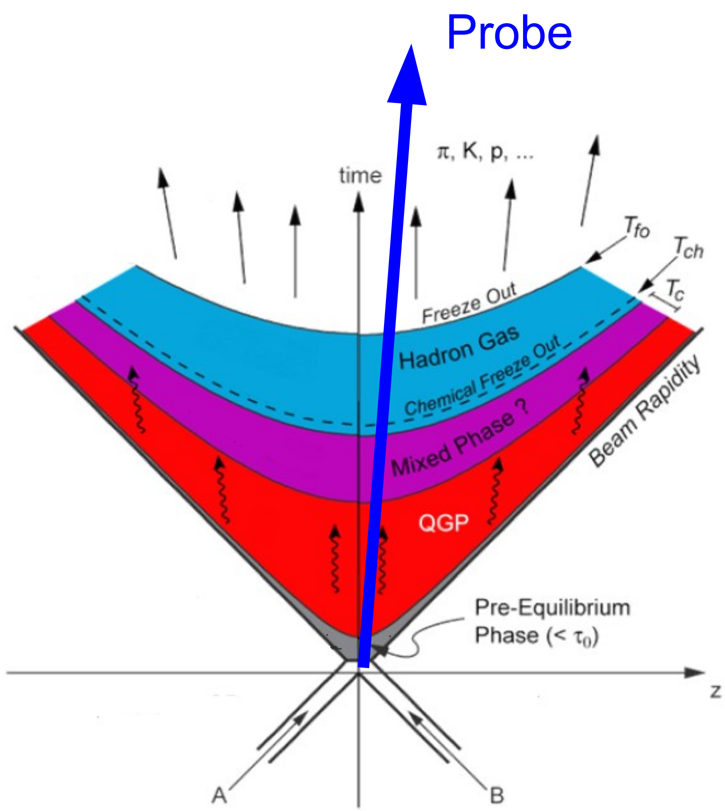
High p_T

Parton energy loss

Tomography of QCD matter

- Hard (large Q^2) probes of QCD matter: jets, heavy-quark, $Q\overline{Q}$, γ, W, Z
  - "Self-generated" in the collision at $\tau<1/Q$ (or $\tau<1/m$) < 0.1 fm/c
  - "Tomographic" probes of hottest and densest phase of medium





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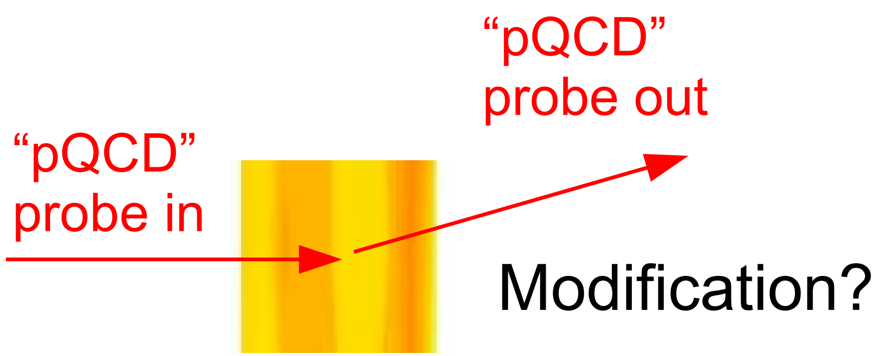
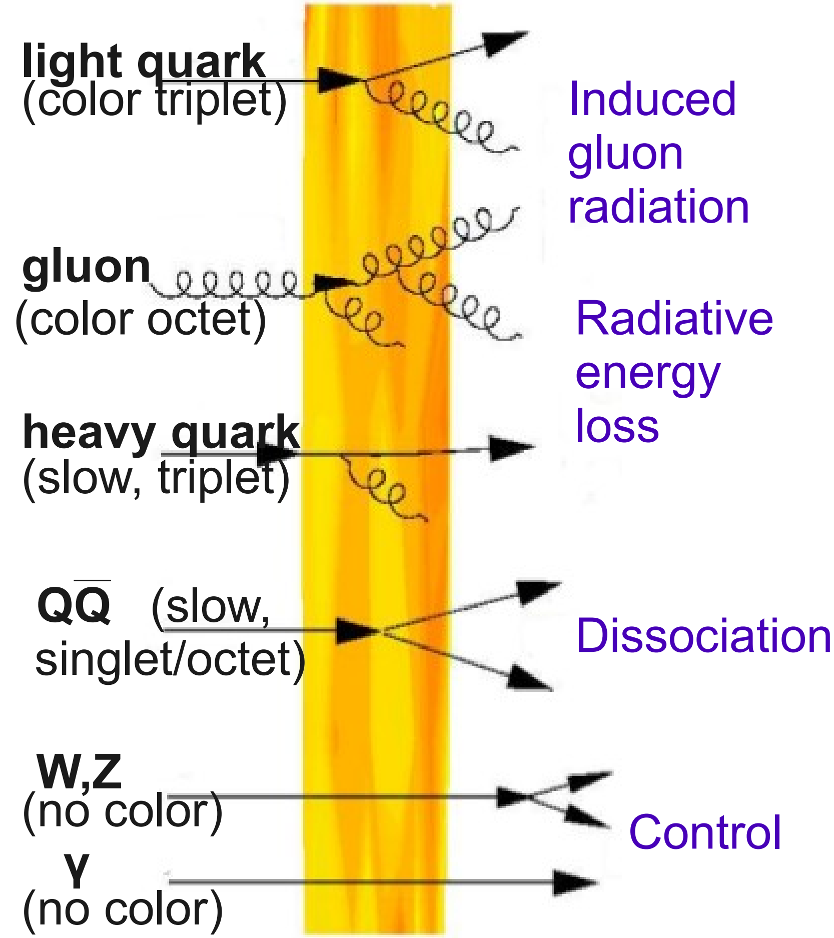


QCD medium



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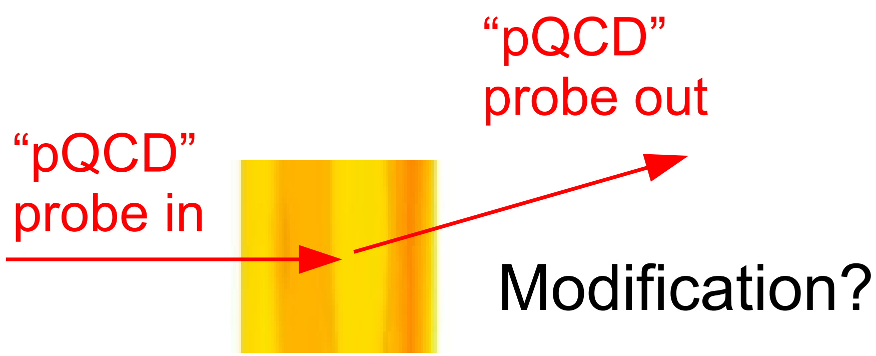

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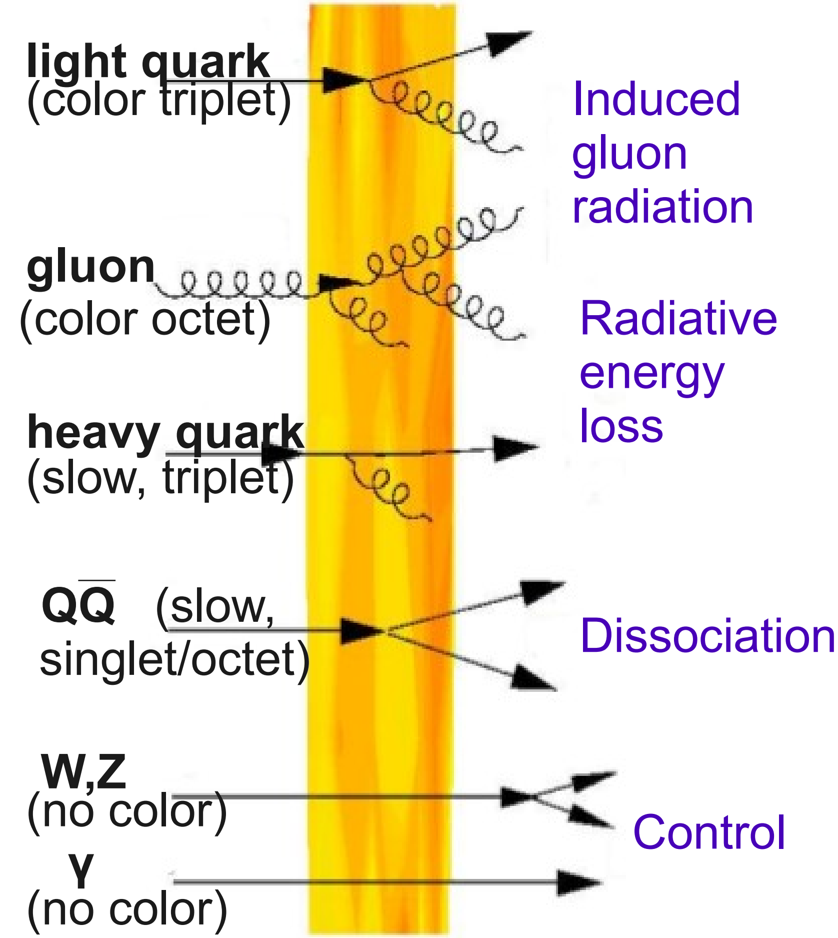


QCD medium

- Nuclear modification factor

  - $R_{AA}(,p_T) = \frac{1}{N_{coll}} \times \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T} = \frac{dN_{AA}/dp_T}{T_{AA}\, d\sigma_{pp}}$

  $R_{AA} = 1 \rightarrow$ no deviation from scaling
  $R_{AA} < 1 \rightarrow$ suppression

  - Quantify change of production rates from expected binary scaling

Jet quenching

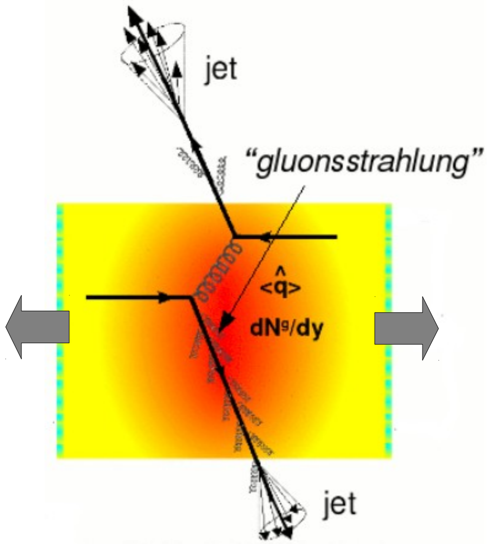
Elastic energy loss:

$$\frac{dE}{dx} = -C_2\,\hat{e}$$

Radiative energy loss:

$$\frac{dE}{dx} = -C_2\,\hat{q}\,L$$

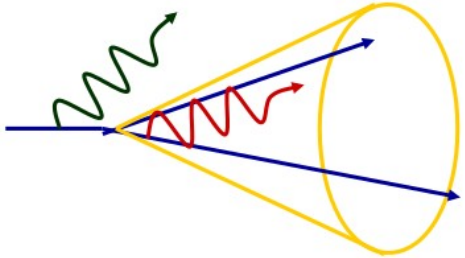
Energy/momentum diffusion tensor: encodes properties of the medium.



- Induced radiation
  - Increased splitting probability (broadens radiation)
  - Finite quark mass vetos small angle radiation (dead-cone effect)
  - Modified angular pattern due to enhanced incoherence between successive splittings
- Color exchange with medium
  - Modifies color flow in the jet (affects hadronization)
- Modelling dependence
  - Piecewise description
  - Approximations

Search for effects in data:

Out-of-cone radiation (Jet $R_{AA}<1$)



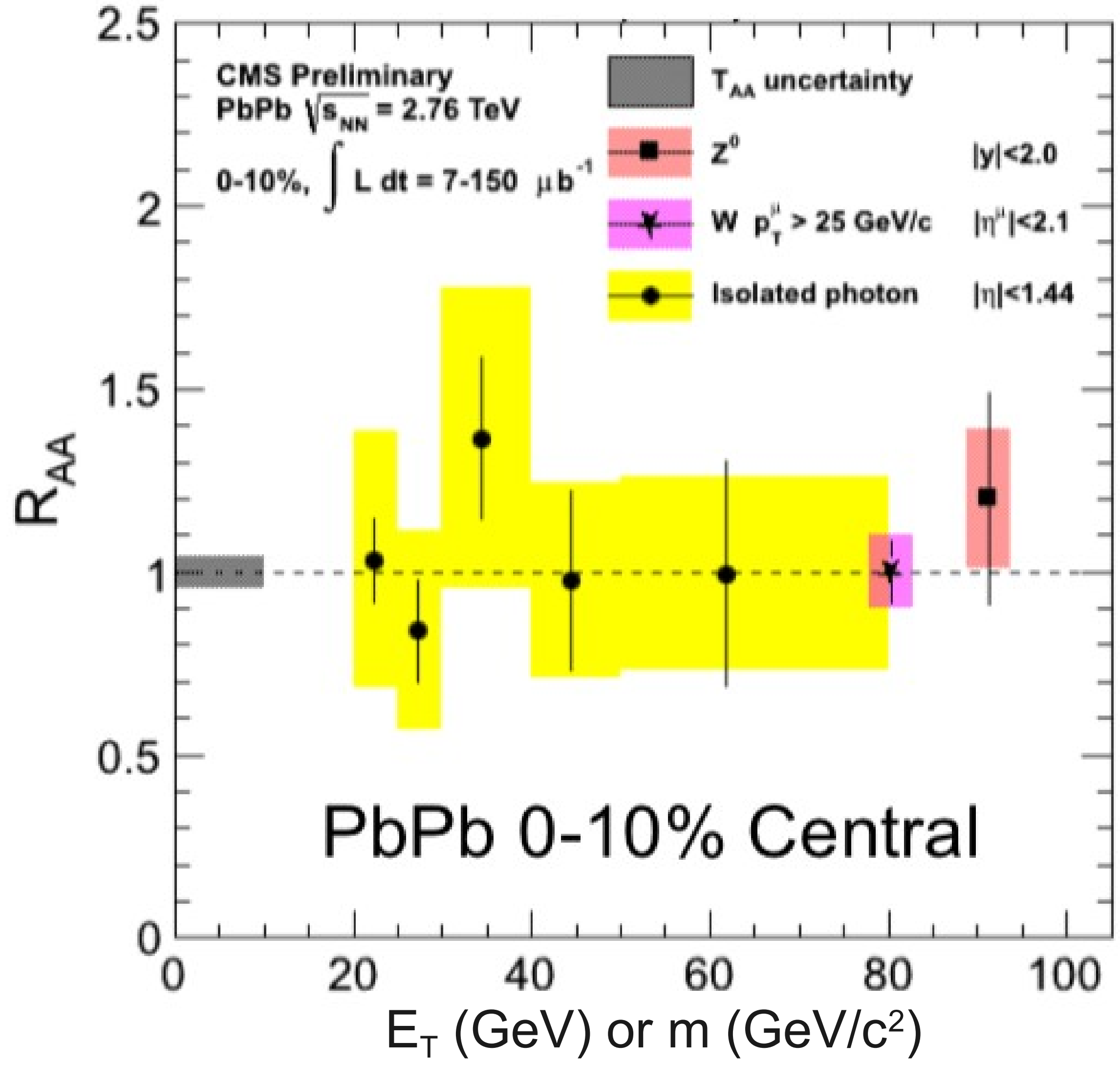
In-cone radiation (FF modification)

$\Delta E_{loss}(g) > \Delta E_{loss}(q) > \Delta E_{loss}(Q)$

(color factor) (dead-cone effect)

Check $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$

Control probes (high E_T)



Isolated γ:
ATLAS, ATLAS-CONF-2012-051
CMS, PLB 710 (2012) 256

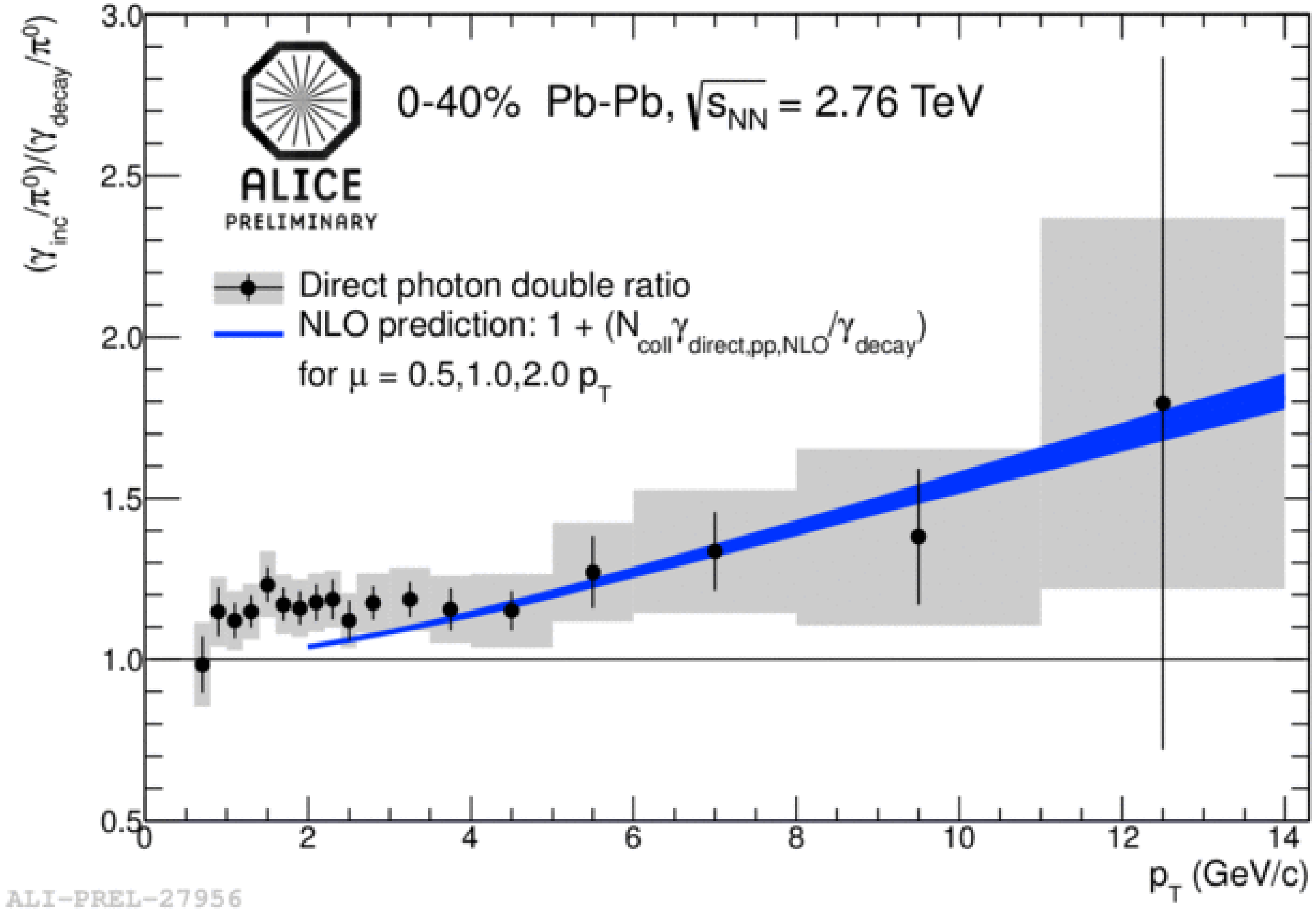
Z boson:
ATLAS, arXiv:1210.6486
ATLAS, PLB 697 (2011) 294]]
CMS, PRL 106 (2011) 212301

W boson:
ATLAS, ATLAS-CONF-2011-78
CMS, PLB 715 (2012) 66

Control probes (isolated γ, Z, W) follow expected scaling ie. R_{AA} ~ 1

Control probes (low p_T)

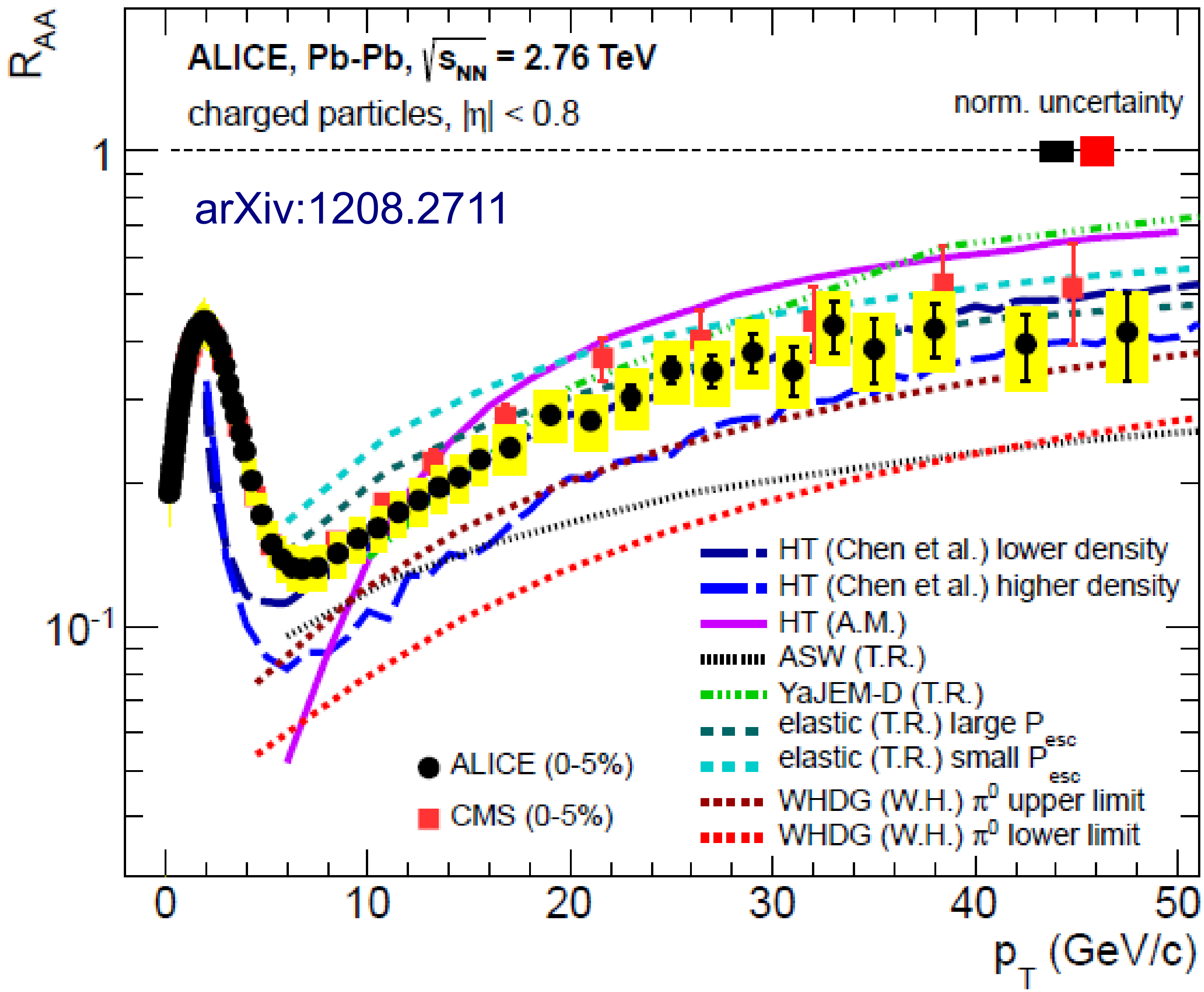
Double Ratio (Inclusive γ/π^0 divided by decay γ/π^0)



- Reconstruction of converted photons in ITS+TPC
- Double ratio strategy ala PHENIX
  - Measure inclusive photons and π^0
  - Model decay contribution with cocktail of all decay photon sources
- Ratio > 1 for direct γ

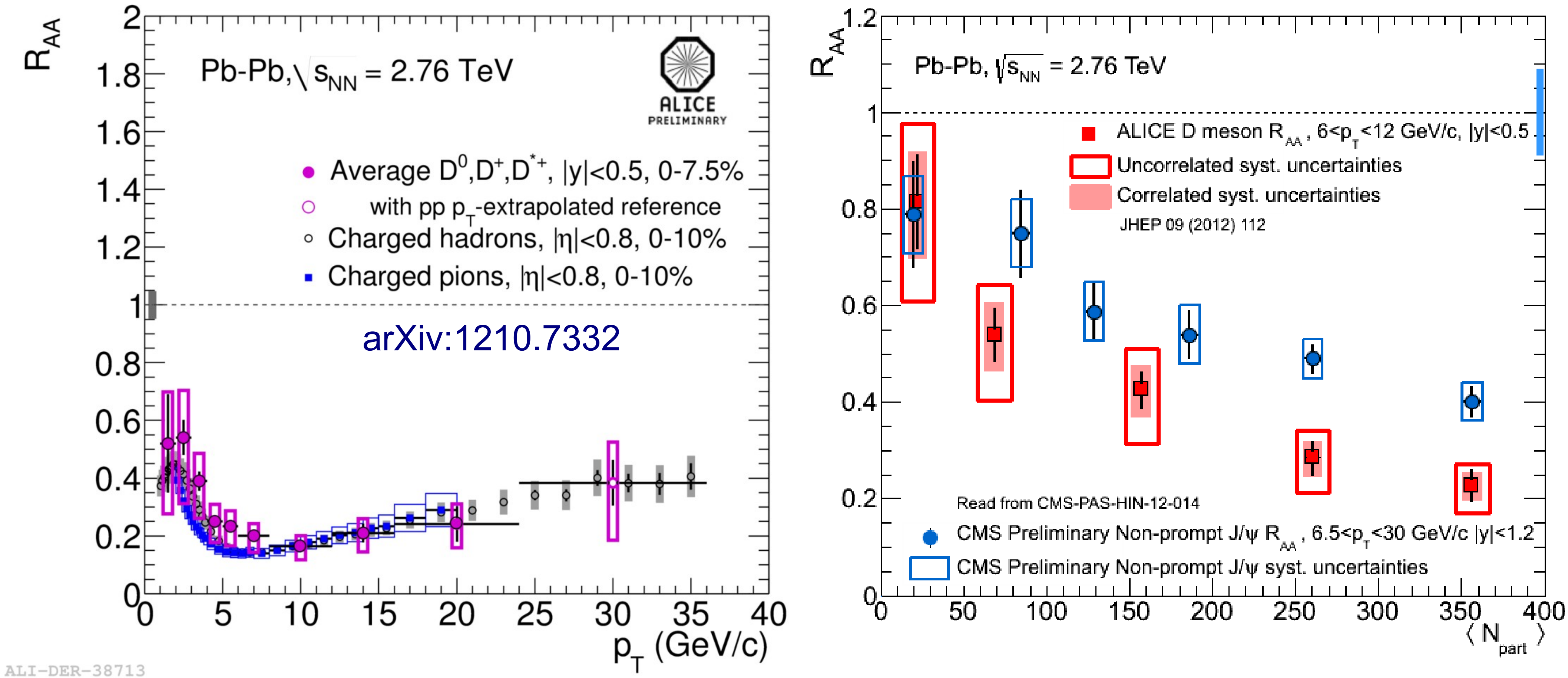
Double ratio consistent with Ncoll scaling of NLO direct γ prediction
Excess at low p_T indicates source of non-decay photons at low p_T

Charged particle suppression factor



Strong suppression observed; max at 6-7 GeV/c, followed by slow rise.
Sensitivity to energy dependence of quenching, or effect of initial state?

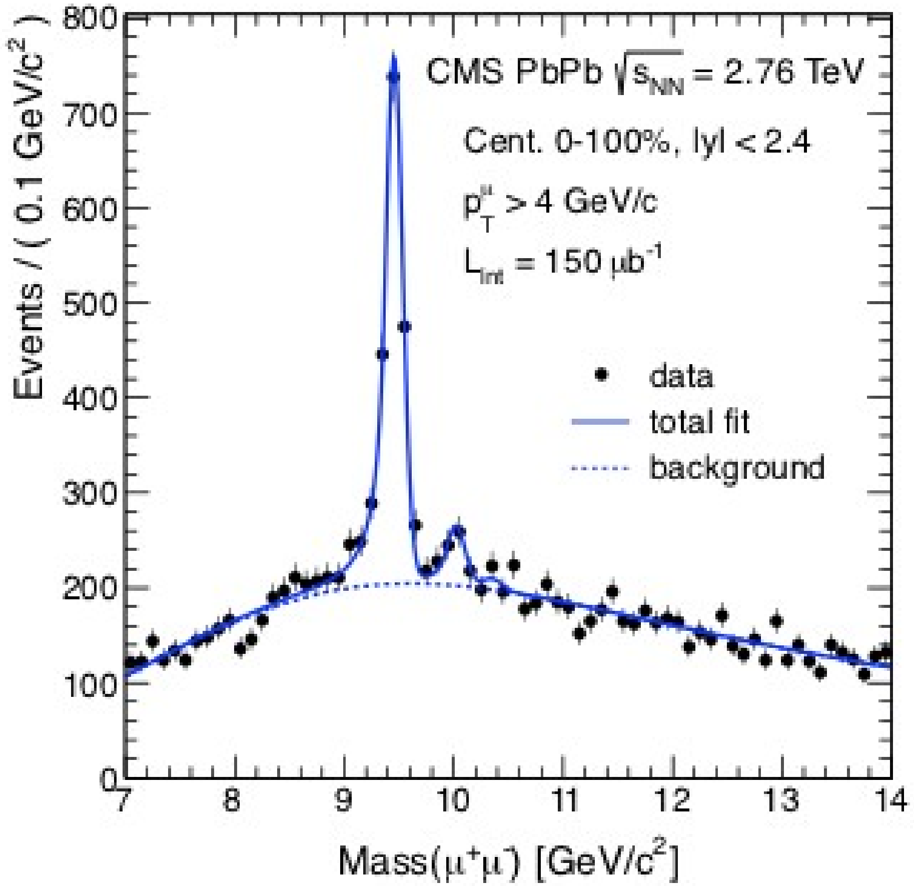
Heavy-quark suppression

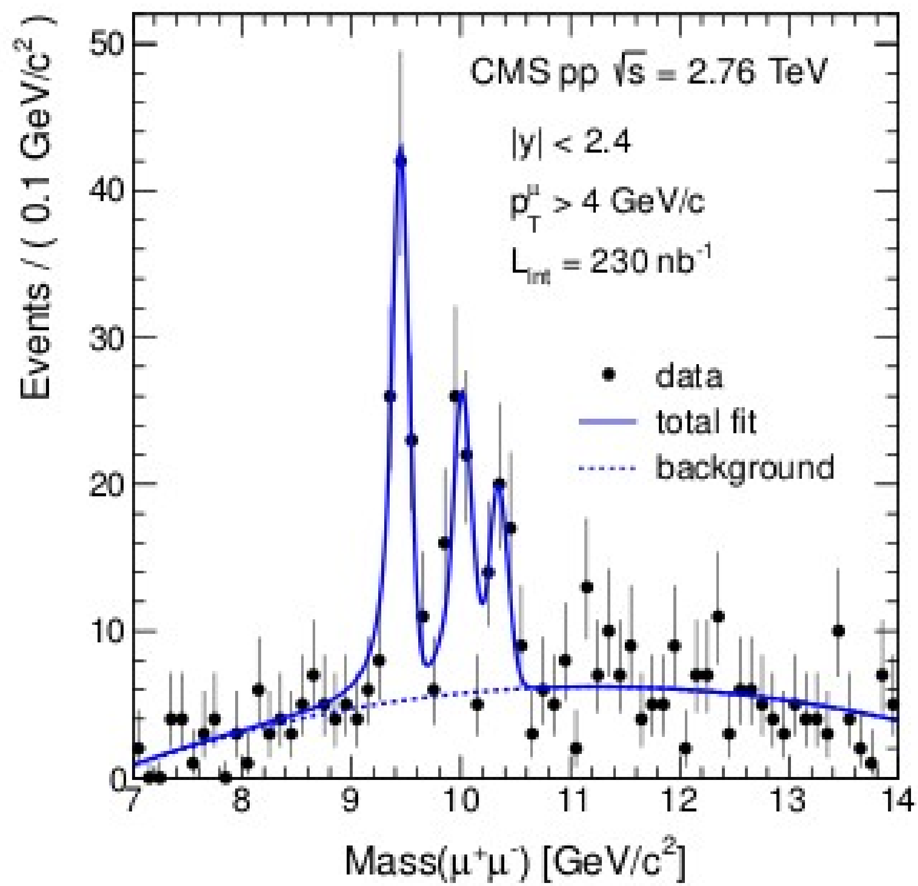


$R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$?

Above 8 GeV/c, suppression same for D and π, below smaller.
At >6-7 GeV/c indication that beauty is less suppressed!

arXiv:1208.2826

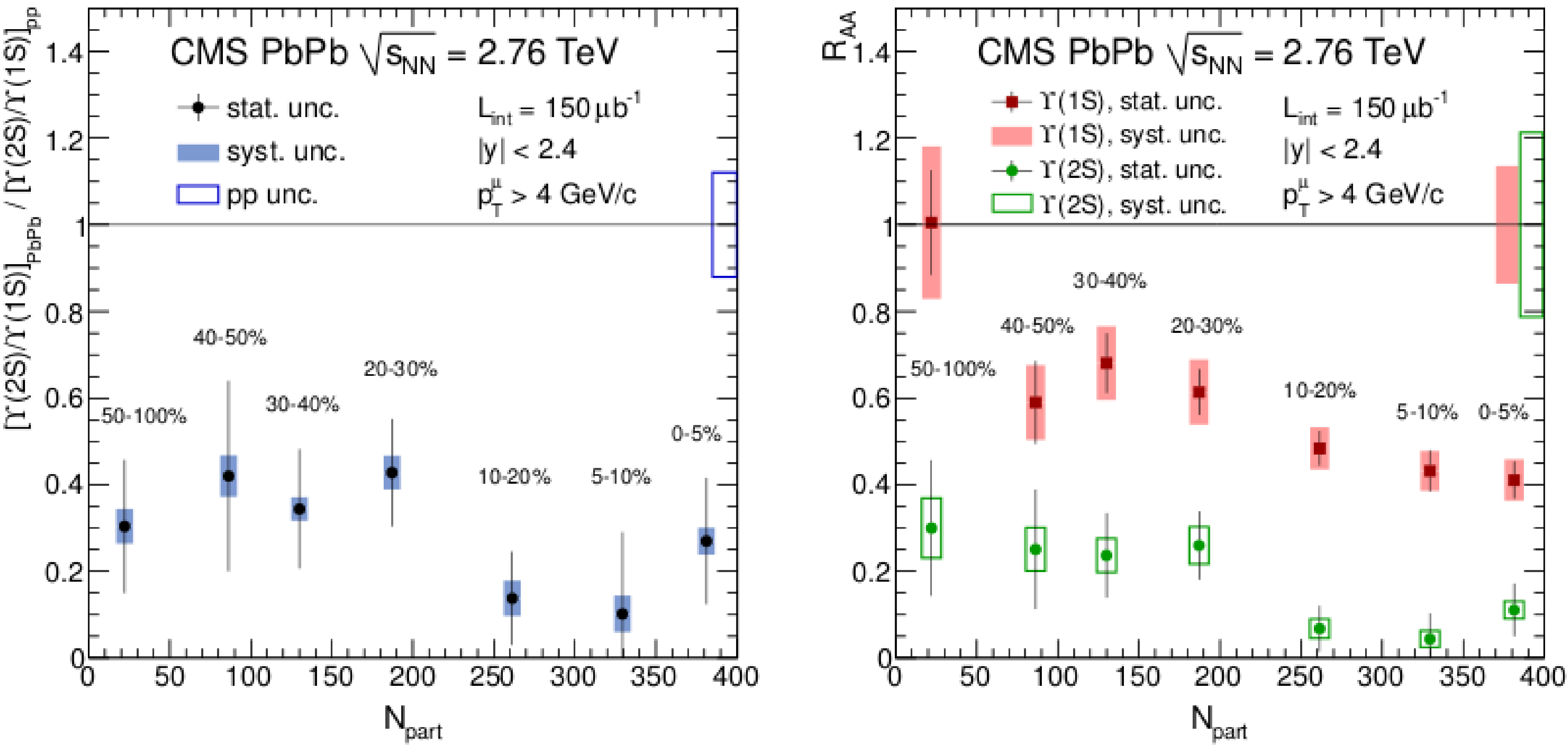




Combined line-shape fit for Υ(1S), Υ(2S) and Υ(3S) state to extract yields. Note already by eye the 3S state is not visible.

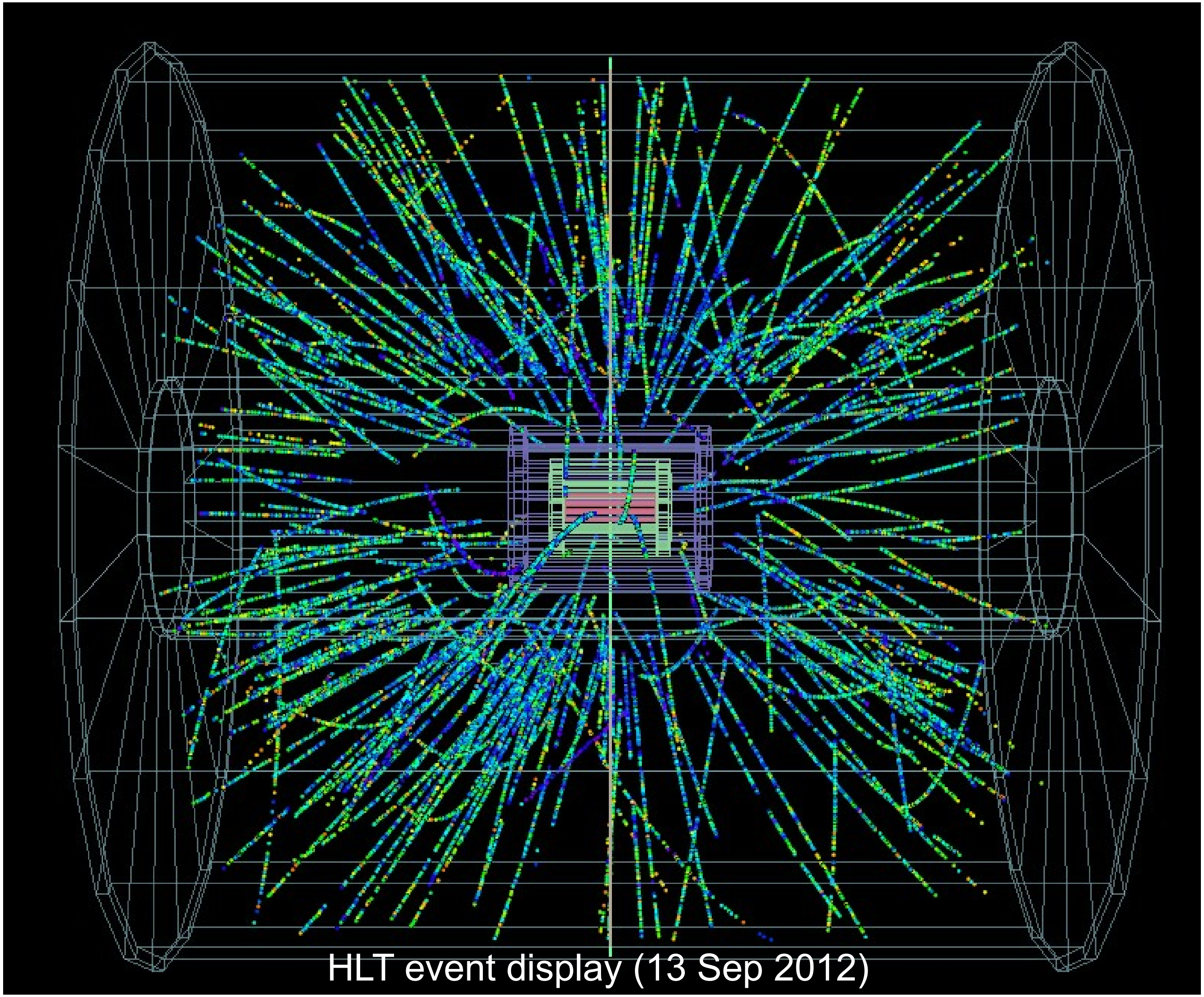
Ypsilon suppression

arXiv:1208.2826



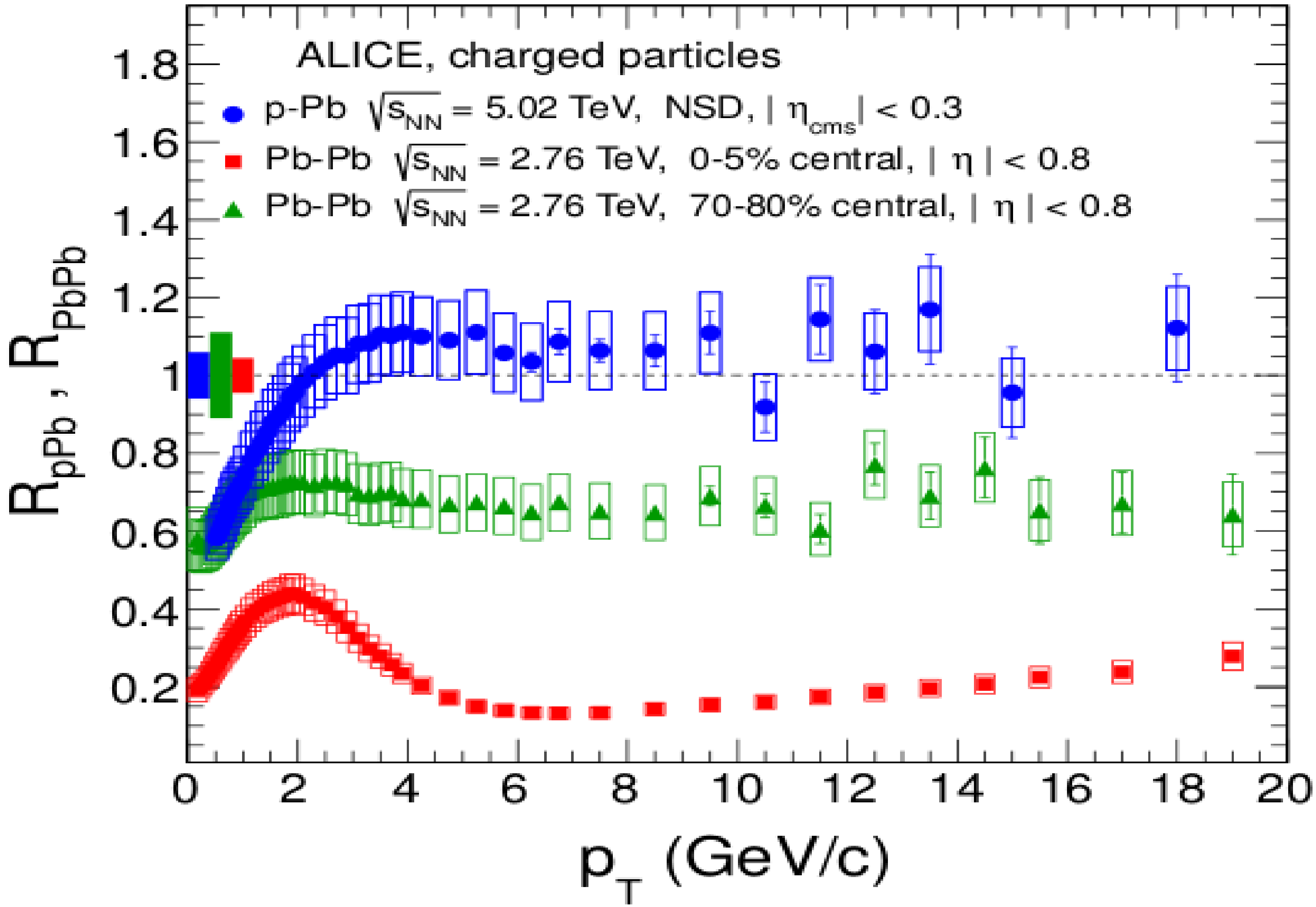
Even Ypsilons are dissociated by the medium.
As expected, suppression much larger for 2S than 1S.

p+Pb: collisions at $\sqrt{s_{NN}}$=5.02 TeV



p+Pb: Nuclear modification factor

arXiv:1210.4520

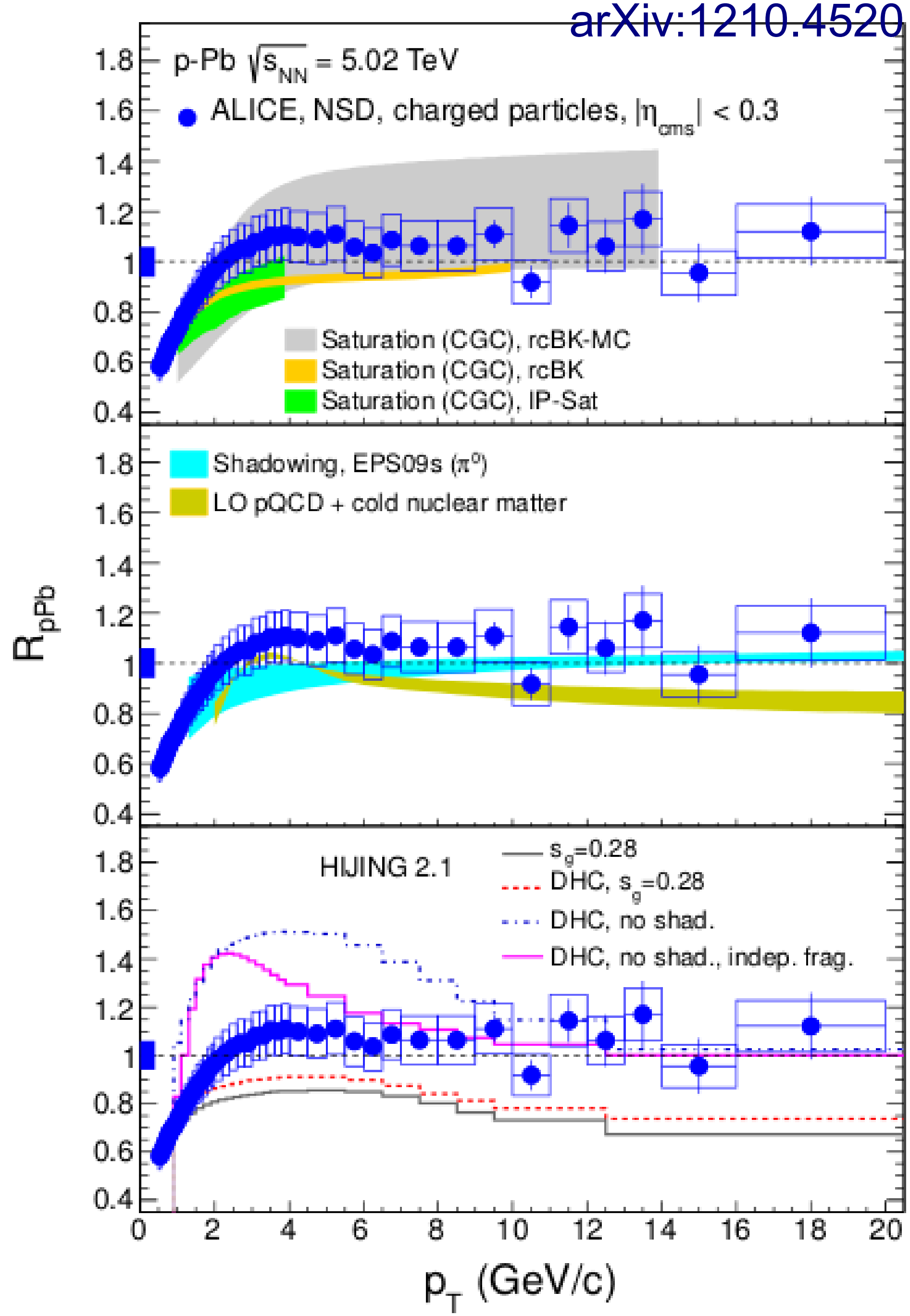


High-p_T charged particles exhibit binary scaling. Initial state effects are small.
(Note: pp reference interpolated between 2.76 and 7 TeV)

p+Pb: Comparison to model predictions

arXiv:1210.4520

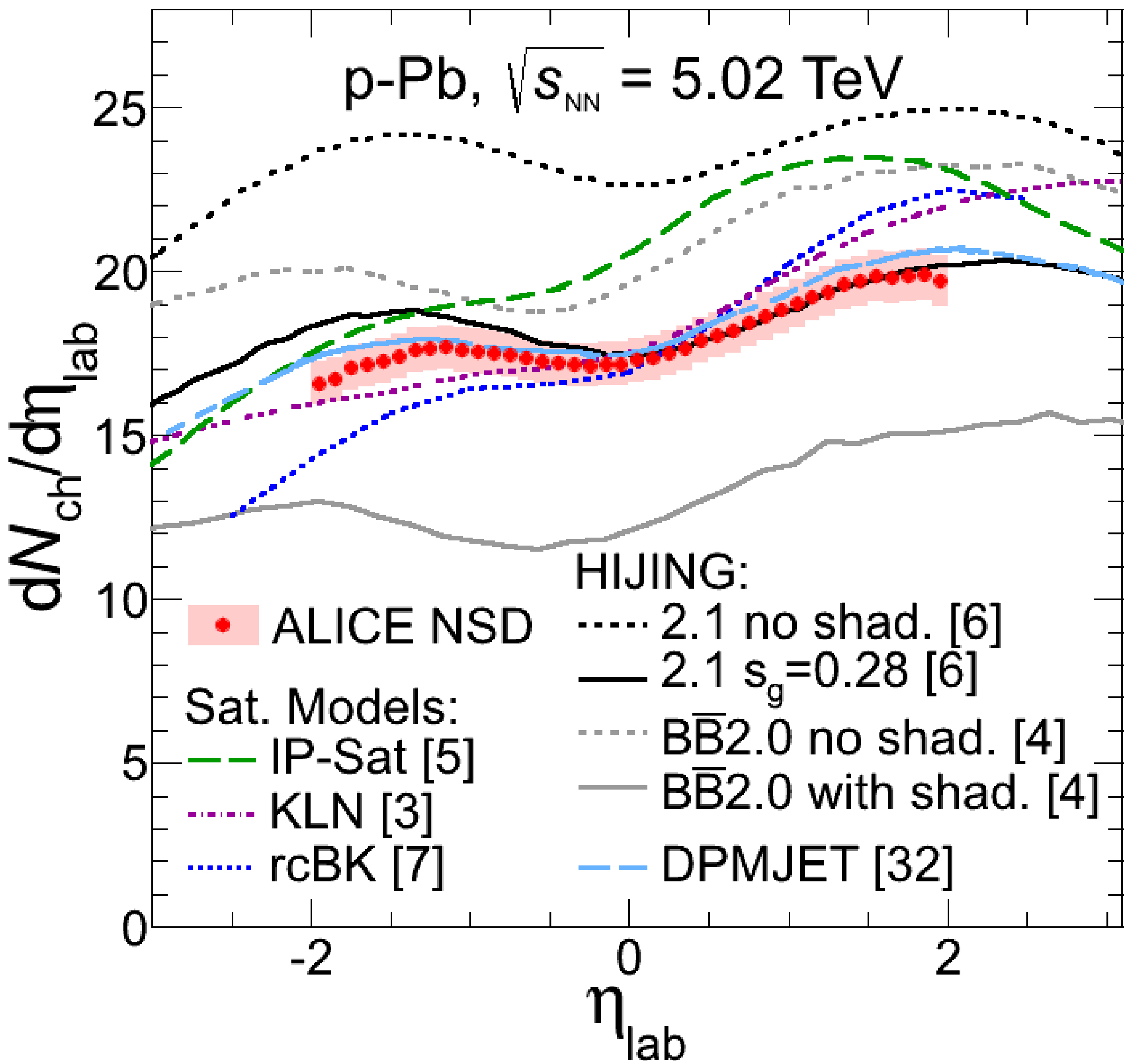
- Most models describe R_{pPb} quite well at high p_T
- Differences mainly at low p_T
- HIJING 2.1 with sg=0.28 parameter overshadows
- Neither HIJING 2.1 nor DPMJET describe the p_T spectra itself



NB:
HJING calculations for NSD expected to increase by ~4%

p+Pb: Pseudorapidity (data + models)

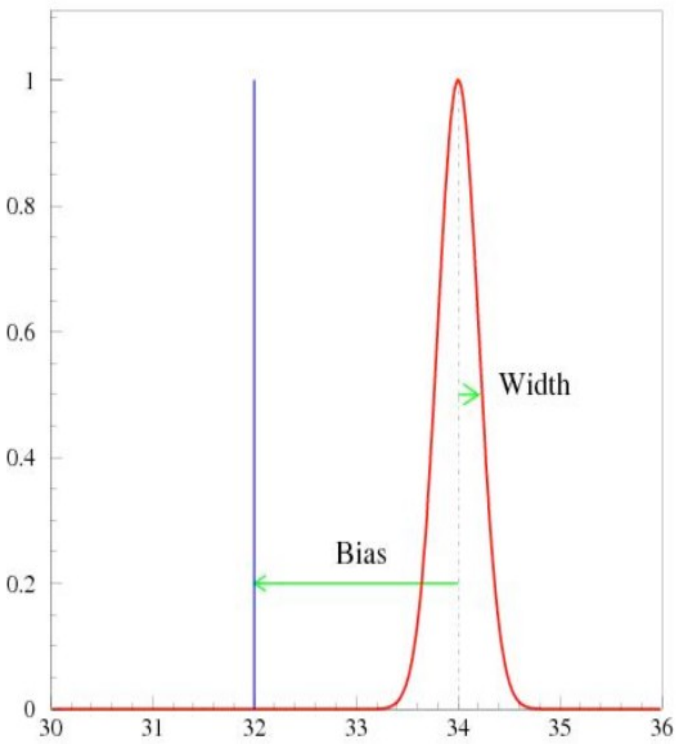
arXiv:1210.3615

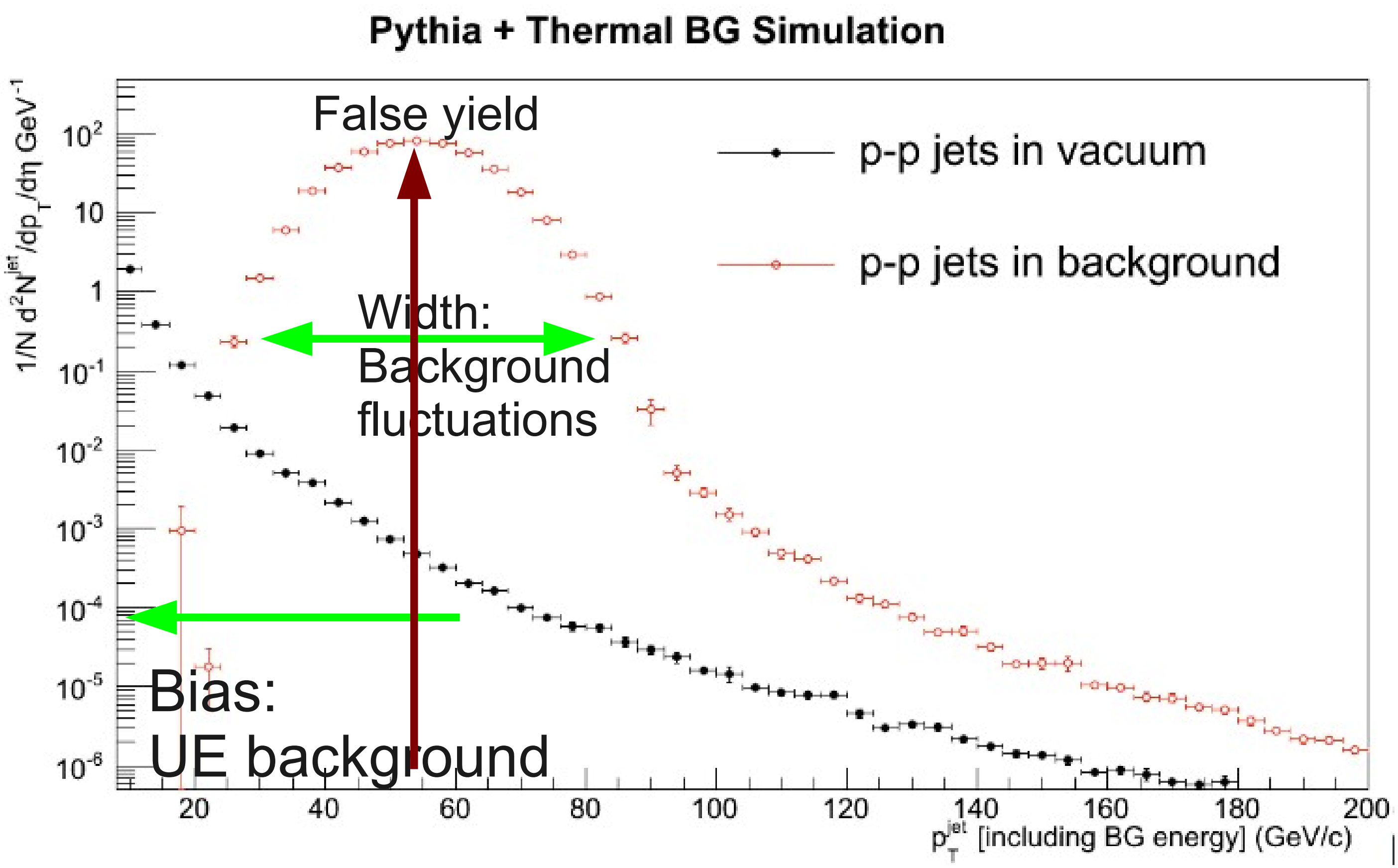


NB:
HJING calculations for NSD expected to increase by ~4%

Most models predicted values within 20%. Saturation models have too steep rise between p and Pb region.

Jet reconstruction in Pb+Pb

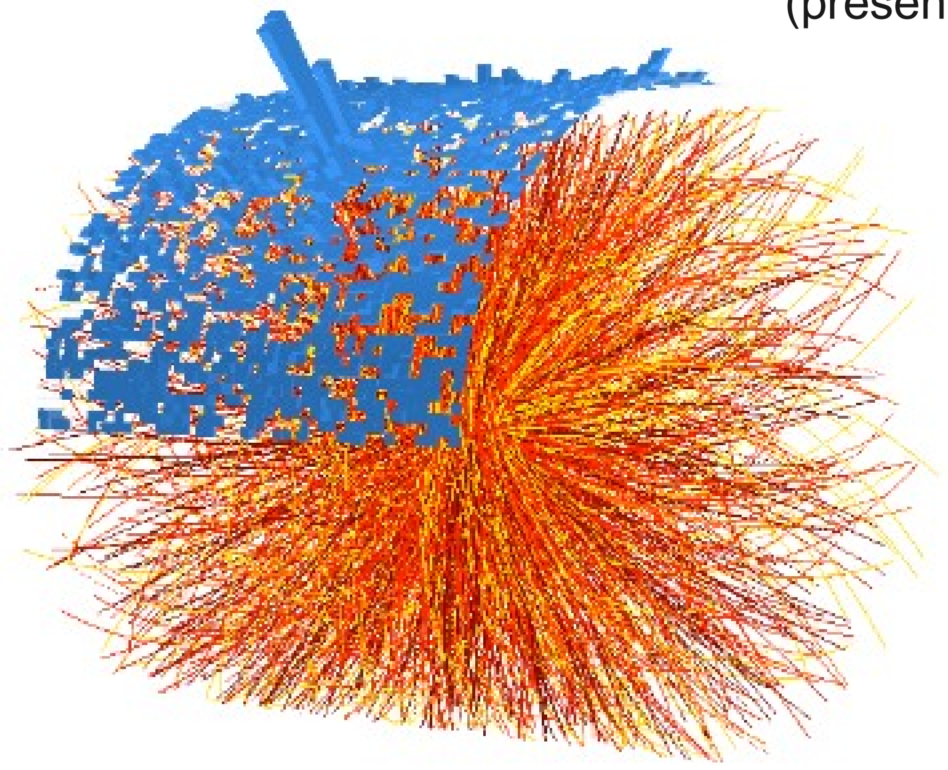




- Procedure
  - Subtract background
  - Correct for background fluctuations

Jet reconstruction in Pb+Pb

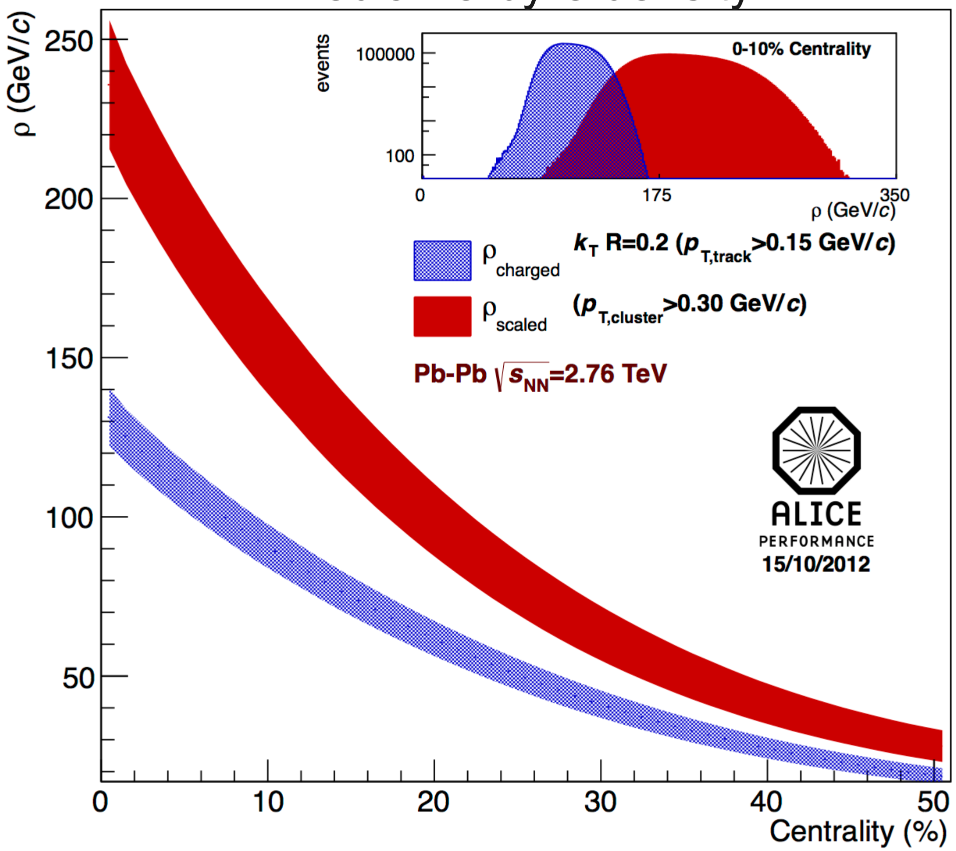
First ALICE full jet result for Pb+Pb
(presented at HQ'12)



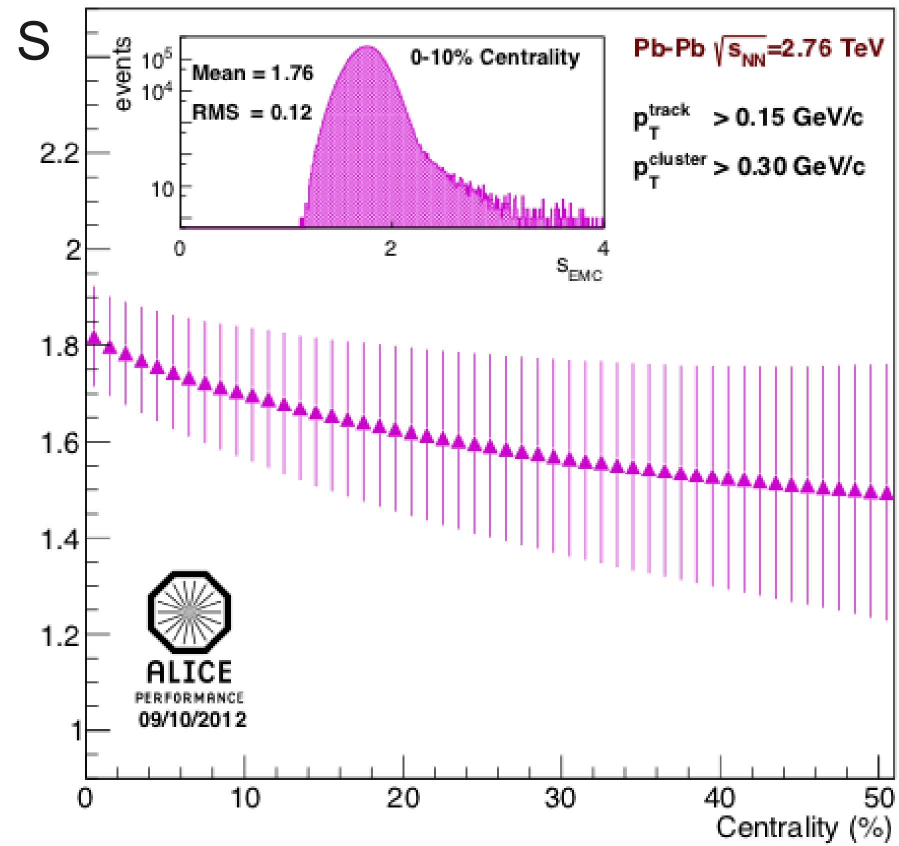
- Challenge: Underlying event (UE)
  - Average background
  - Background fluctuations
  - Combinatorial (fake) jets

Average background

Median e-by-e density



Scale factor



- Calculate density on event-by-event basis
  - The median of the density of k_T charged jets: ρ_{ch}= median $\{p_{Ti}/A_i\}$
  - Use scale factor to obtain $\rho = s \times \rho_{ch}$
  - Similar to arXiv:1201.2423

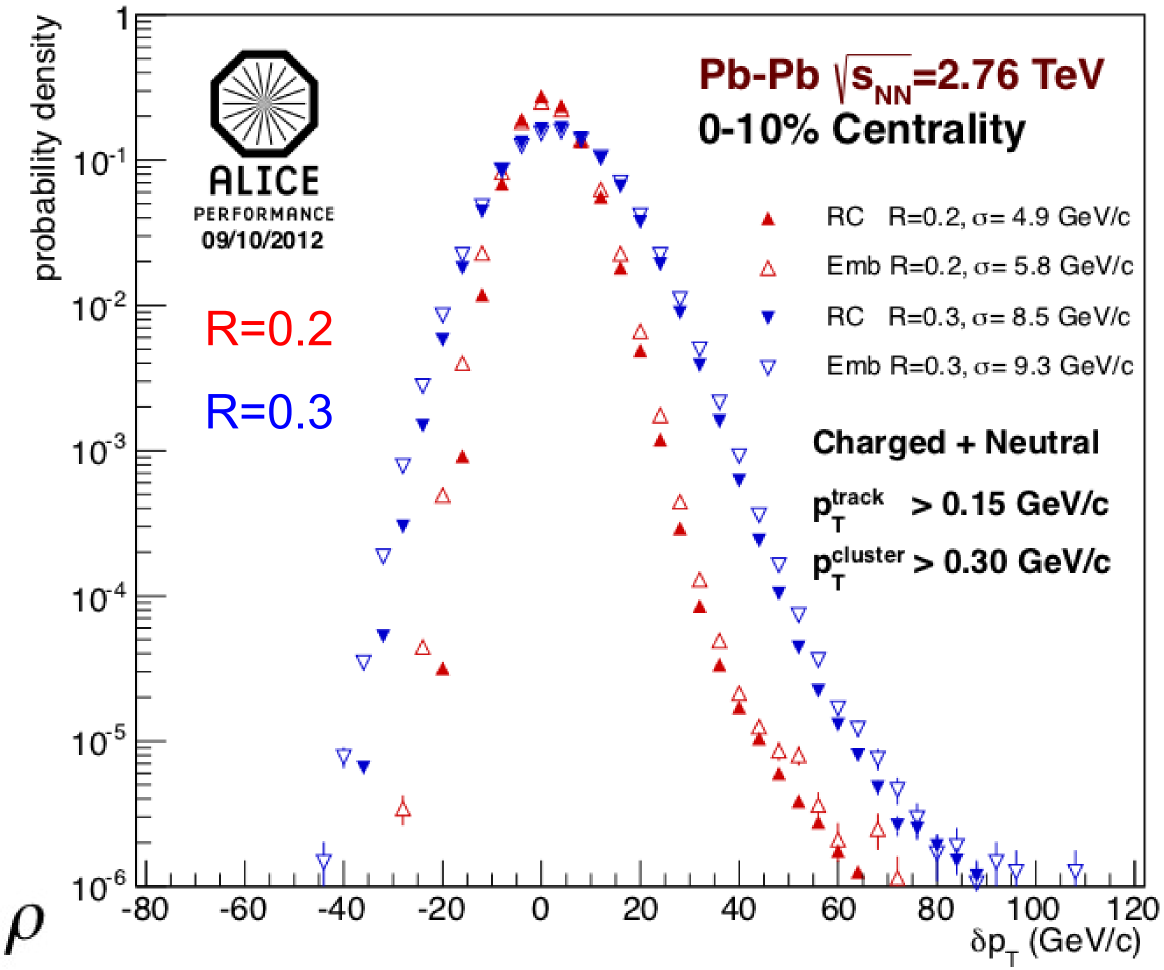
Background fluctuations

- Region-to-region background fluctuations limit the jet energy resolution
- Size of fluctuations are estimated using
  - Random cones

$$\delta p_{\mathrm{T}}^{RC} = p_{\mathrm{T}}^{RC} - \pi R^2 \rho$$

  - Single particle embedding

$$\delta p_{\mathrm{T}}^{emb} = p_{\mathrm{T}}^{jet} - p_{\mathrm{T}}^{probe} - A^{jet} \rho$$

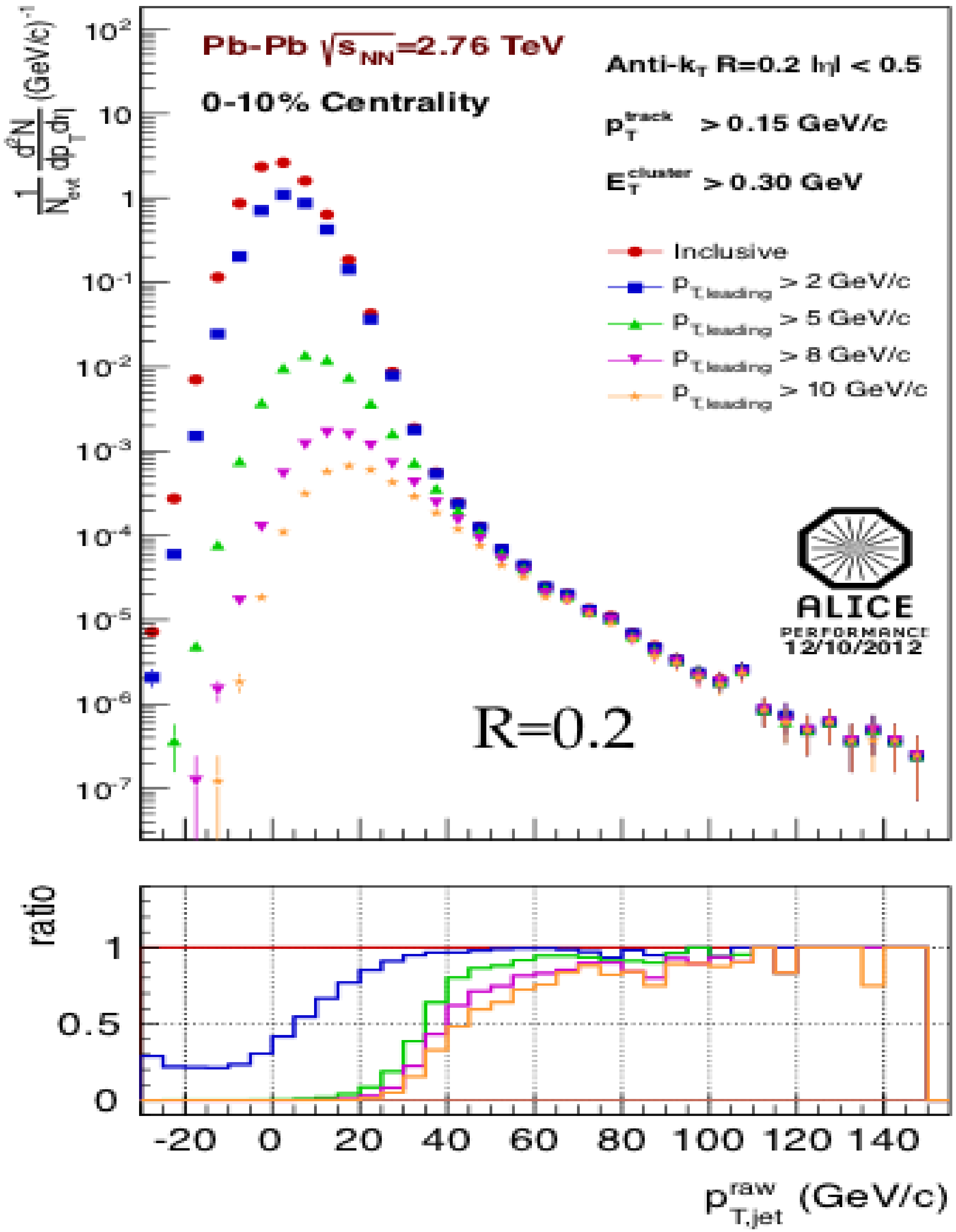


σ ≈ 5.5 GeV/c for R=0.2

σ ≈ 9.0 GeV/c for R=0.3

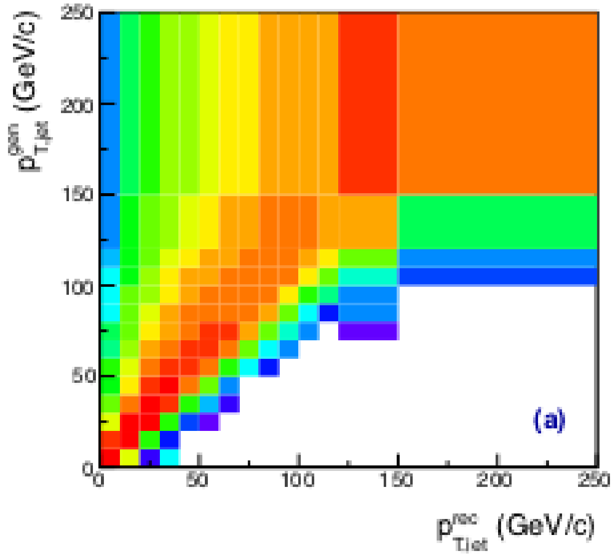
Combinatorial jets

- Combinatorial jets are obtained from jet finder by clustering soft, mostly uncorrelated particles from UE
- Leading hadron bias
  - Combinatorial jets can be effectively suppressed by requiring a high p_T track
  - Bigger effect when changing from 0 to 5 GeV, than from 5 to 10 GeV
  - Bias present up to 60-100 GeV
  - Use 5 GeV/c for R=0.2

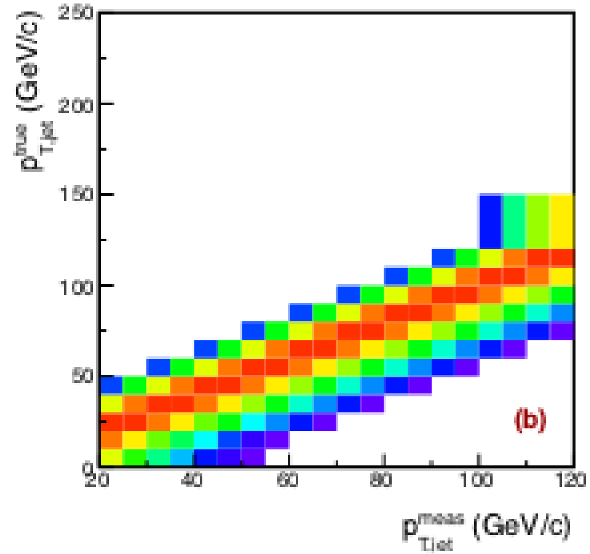


Response matrix

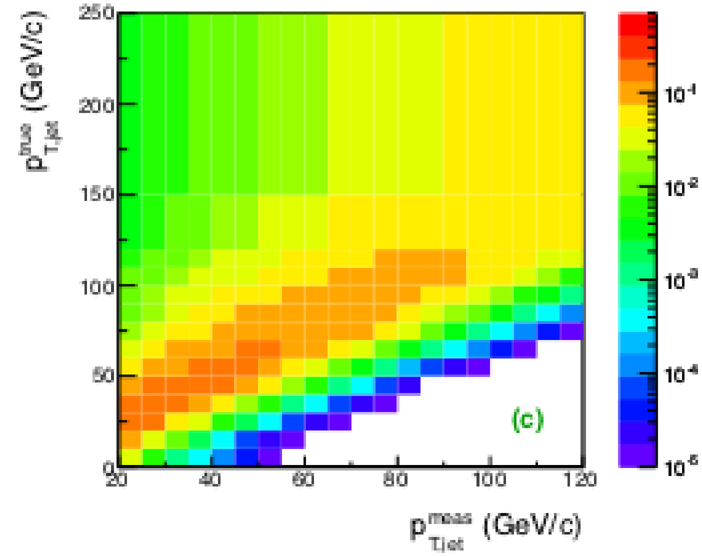
Detector response

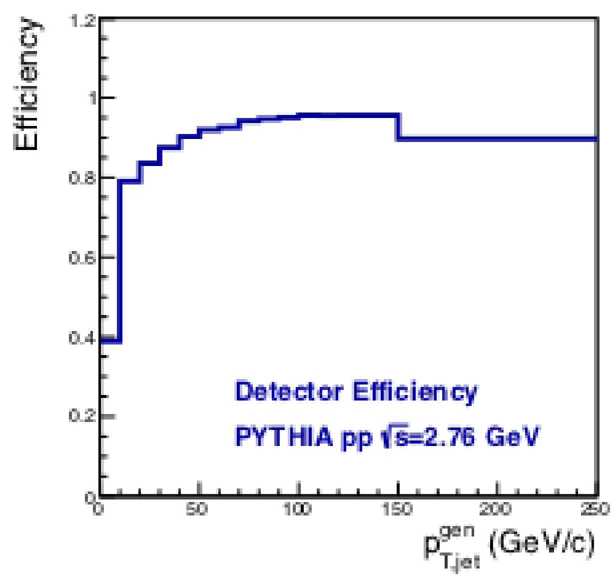


Background fluctuations



Final response





Anti-K_T jet finder:

R = 0.2

p_T^{track} > 0.150 GeV/c

E_T^{clus} > 0.3 GeV/c

$p_T^{leading\ track}$ > 5 GeV/c

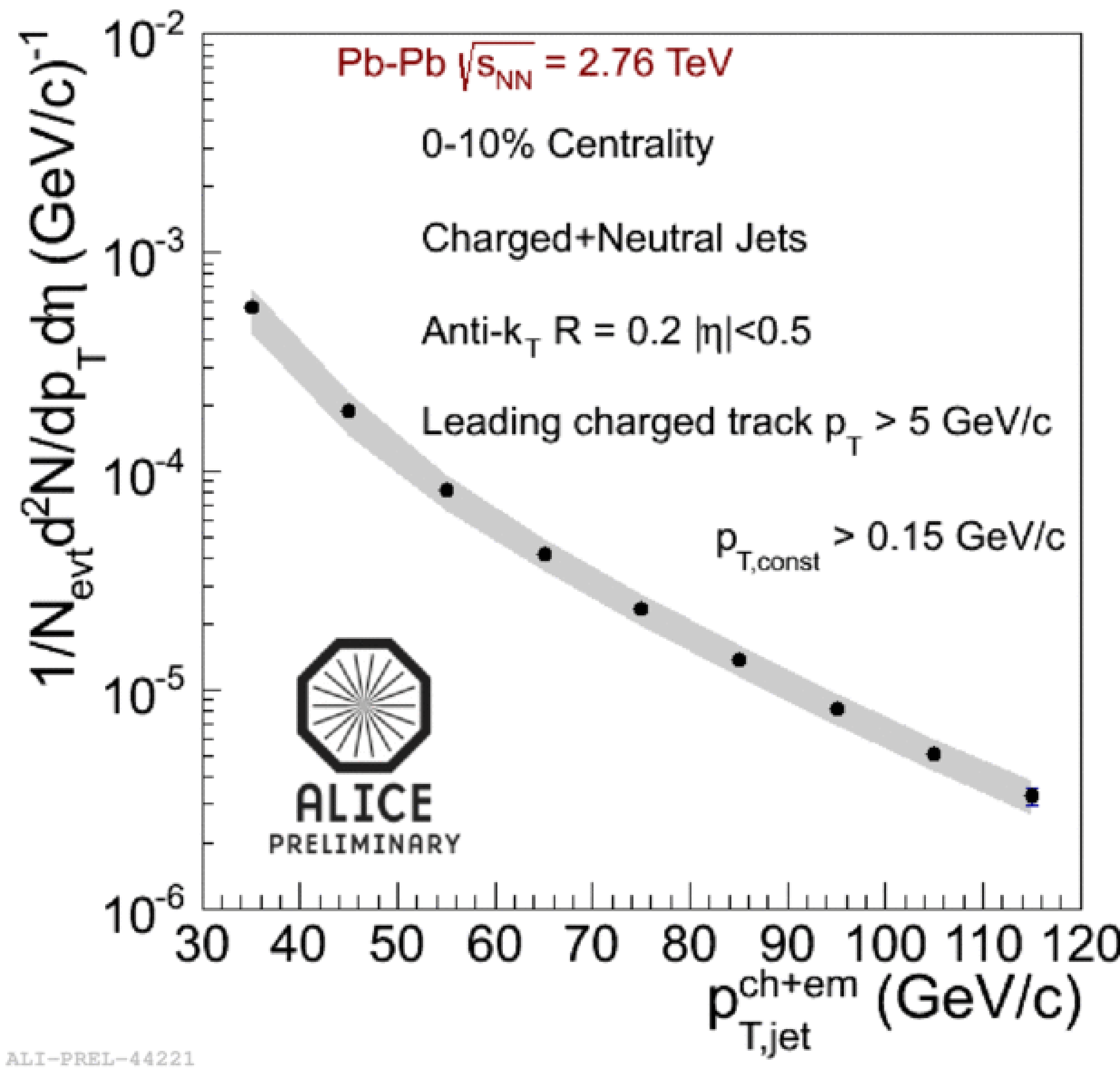
Pb-Pb $\sqrt{s_{NN}}$=2.76 TeV

0-10% Centrality

ALICE PERFORMANCE

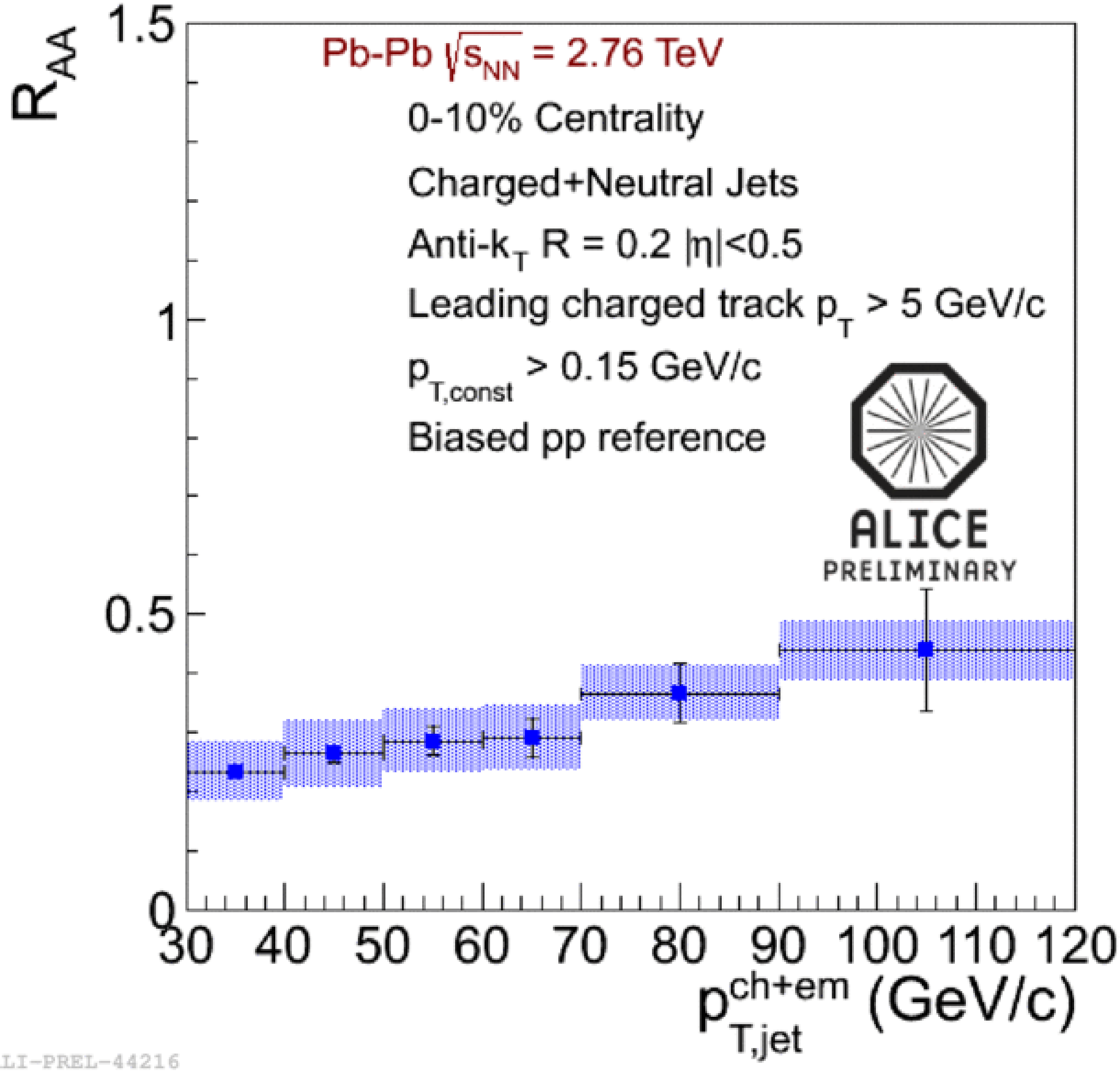
10/10/2012

Jet spectrum in central Pb-Pb



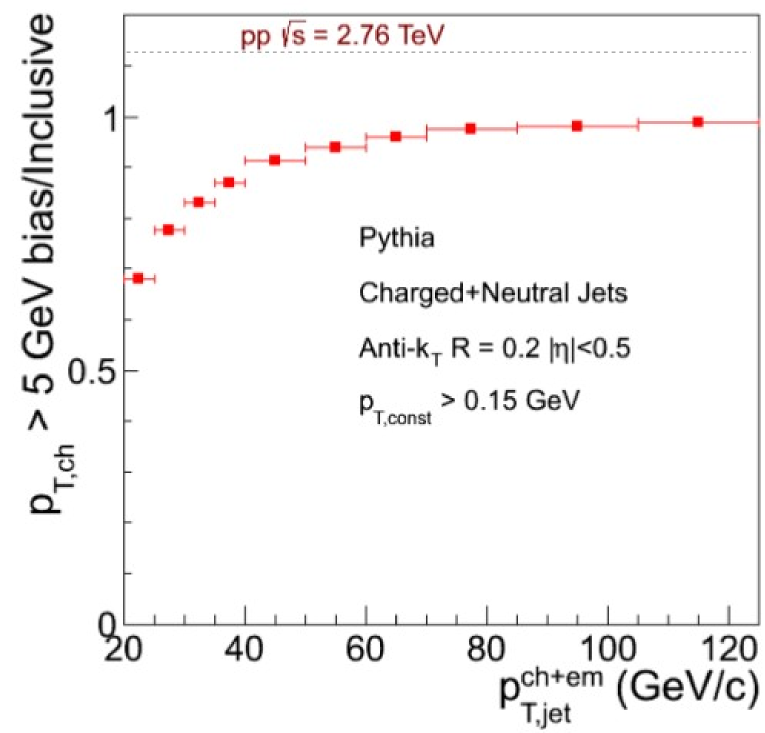
- Jet spectrum after background correction and unfolding
- Statistical uncertainty from cov. matrix
- Systematic uncertainties
  - ~20% (p_T dependent)
  - Unfolding
  - Hadronic correction
  - Tracking efficiency
  - EMCal related effects (energy resolution + scale, clusterizer, non-linearity)
  - Background fluctuations

Jet R_{AA} in central collisions



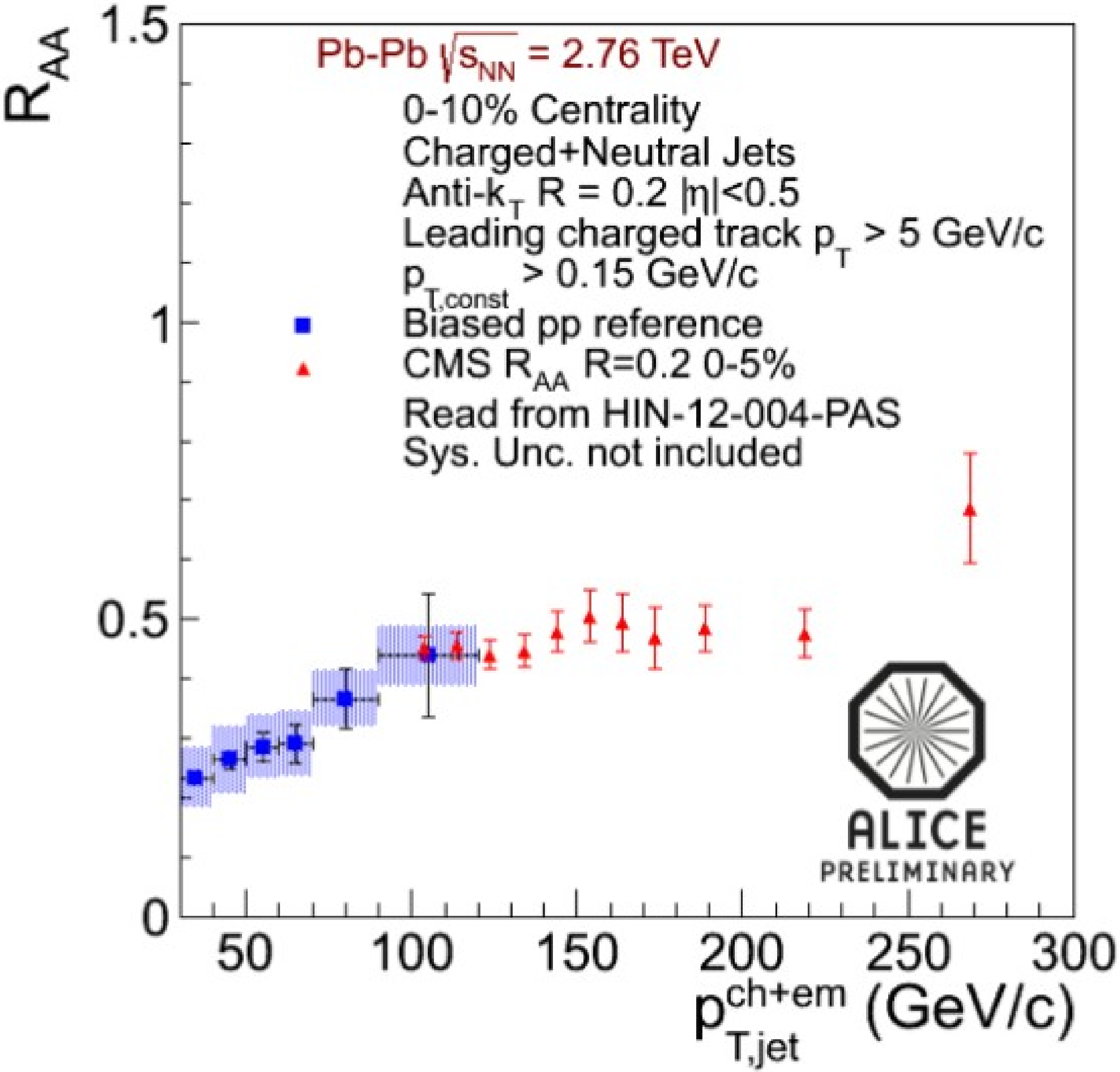
Bias/Inclusive PYTHIA

(~0.85 at 30-40 GeV/c)

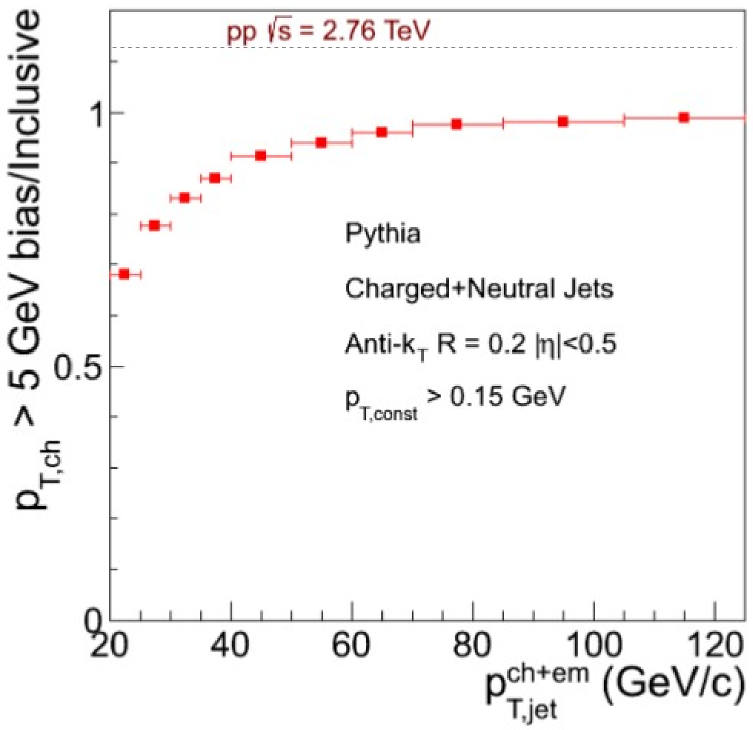


Jet suppression is jet p_T dependent

Jet R_{AA} in central collisions

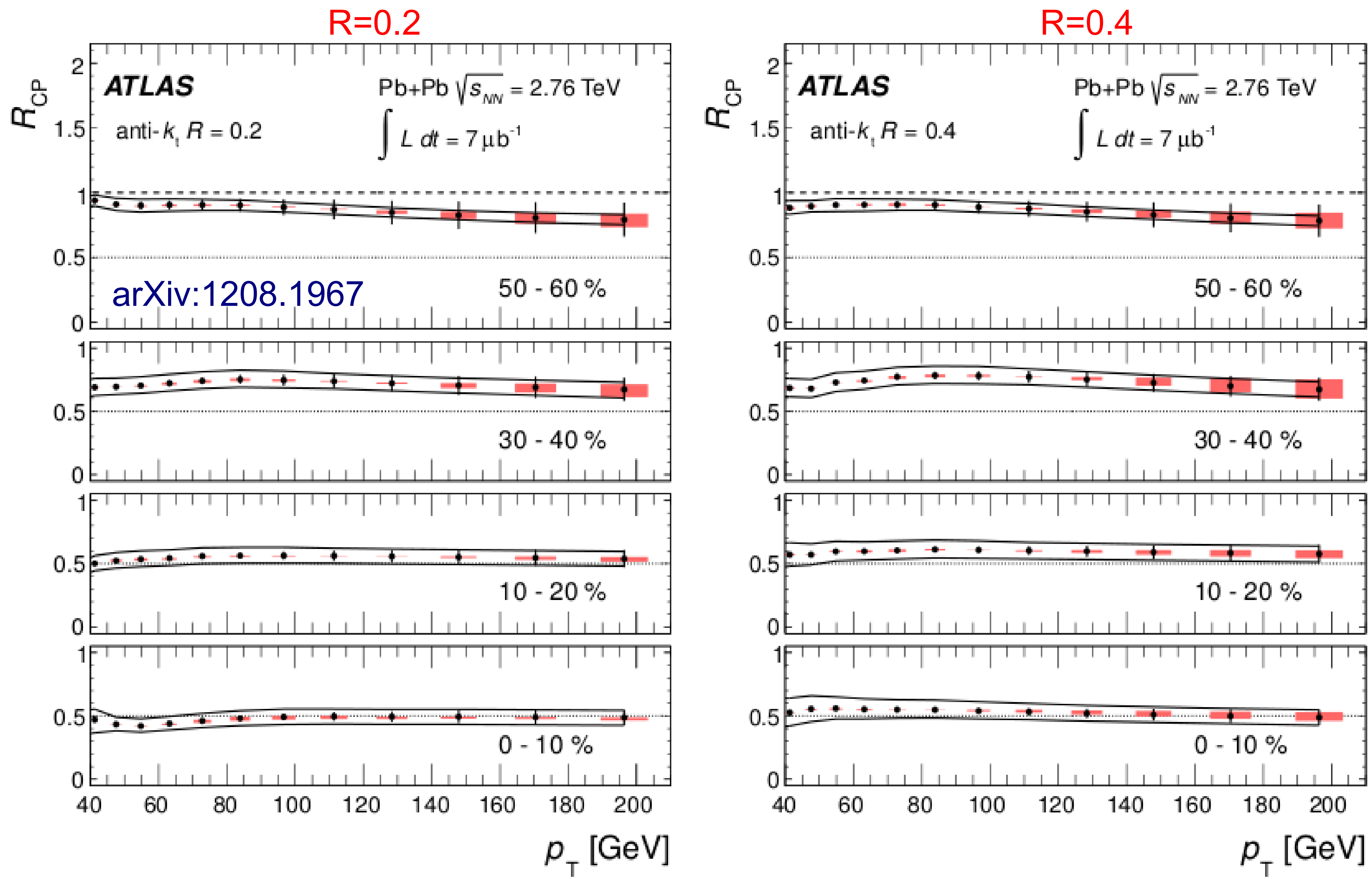


Bias/Inclusive PYTHIA
(~0.85 at 30-40 GeV/c)

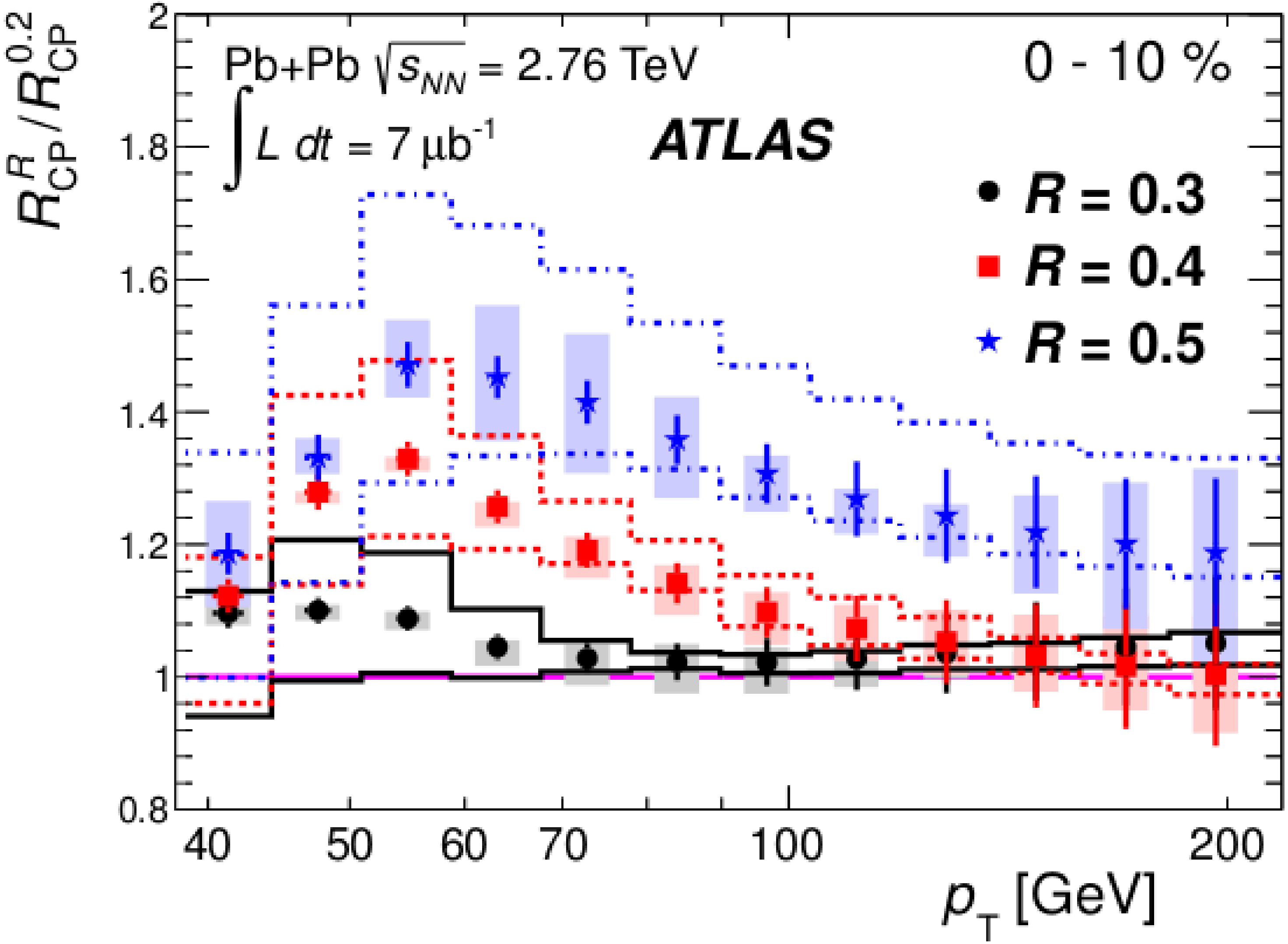


Consistent with CMS prel. results at 100 GeV/c

Jet suppression (R_{CP})



Substantial suppression, out to very high jet energy

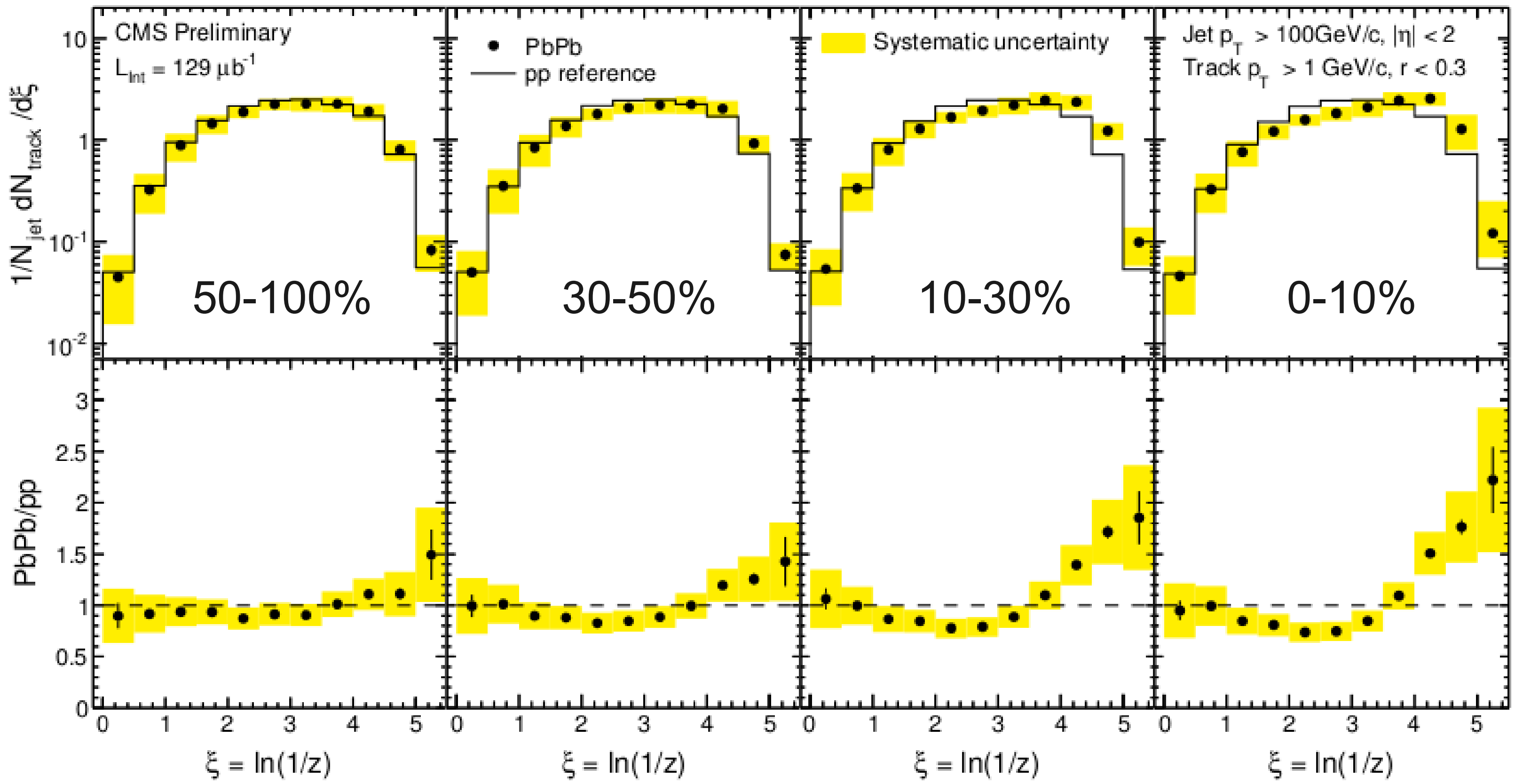


Interesting modulation at 60 GeV/c

Jet fragmentation function

Fragmentation functions constructed using tracks with p_T>1 GeV/c in R<0.3 and the reconstructed (quenched) jet energy

CMS-HIN-12-013



R=0.3

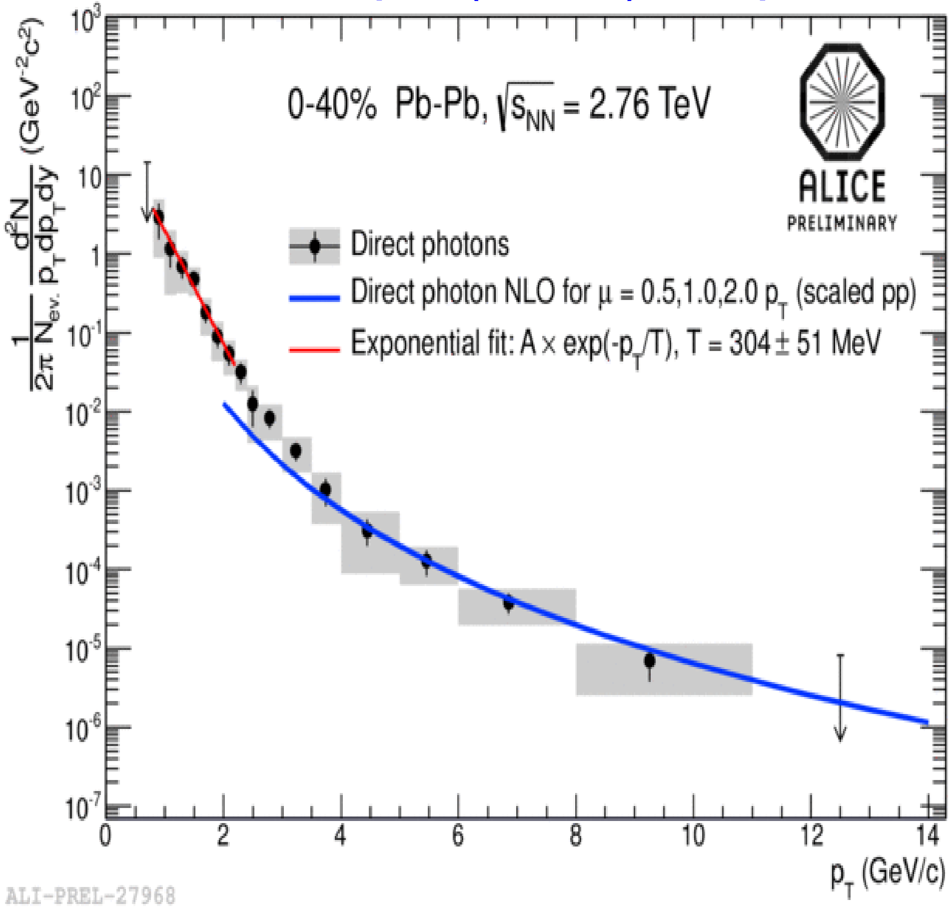
P_T > 100 GeV/c

Track p_T>1 GeV/c

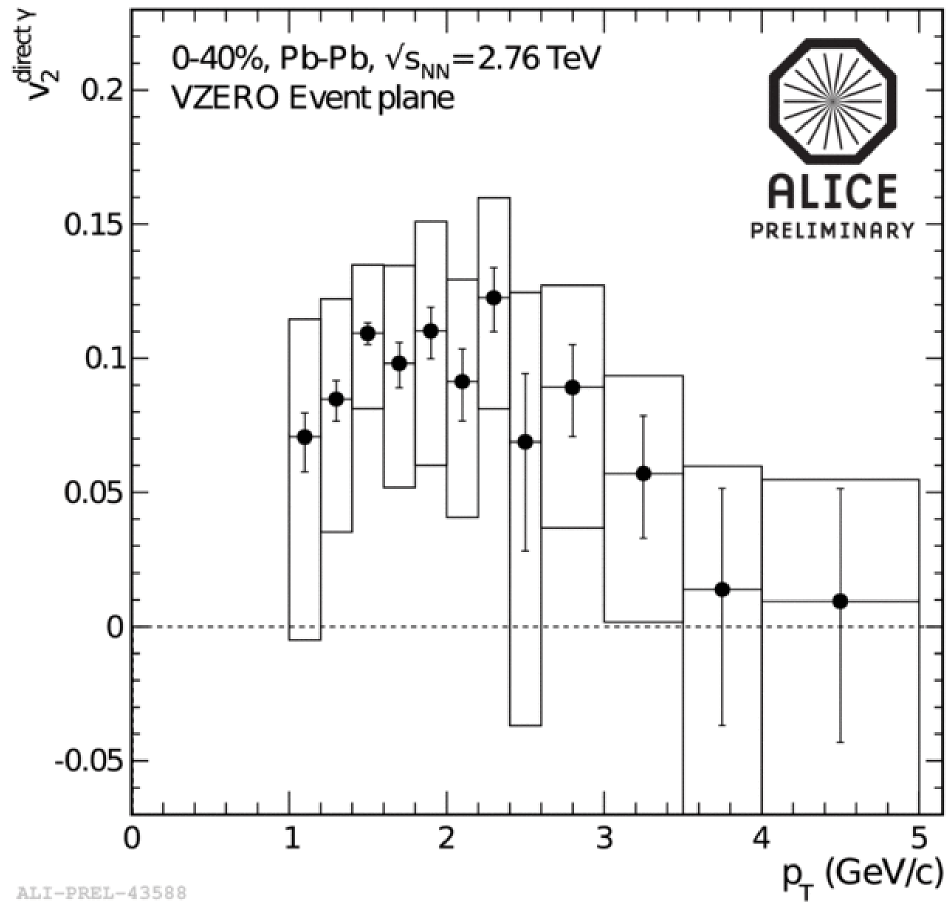
Fragmentation function is modified: More particles at low p_T (<3 GeV/c) in more central collisions rel. pp

Direct photon spectrum and their v_2

Dirγ = (1-1/R)·inclγ



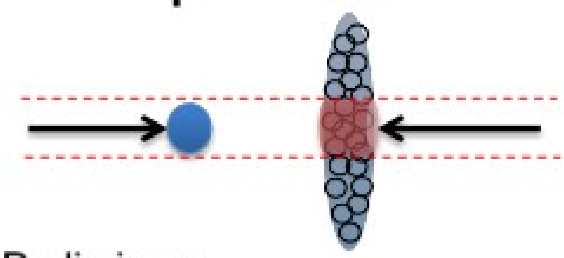
$v_2^{dir\gamma} = (R \cdot v_2^{incl\gamma} - v_2^{dec\gamma})/(R-1)$

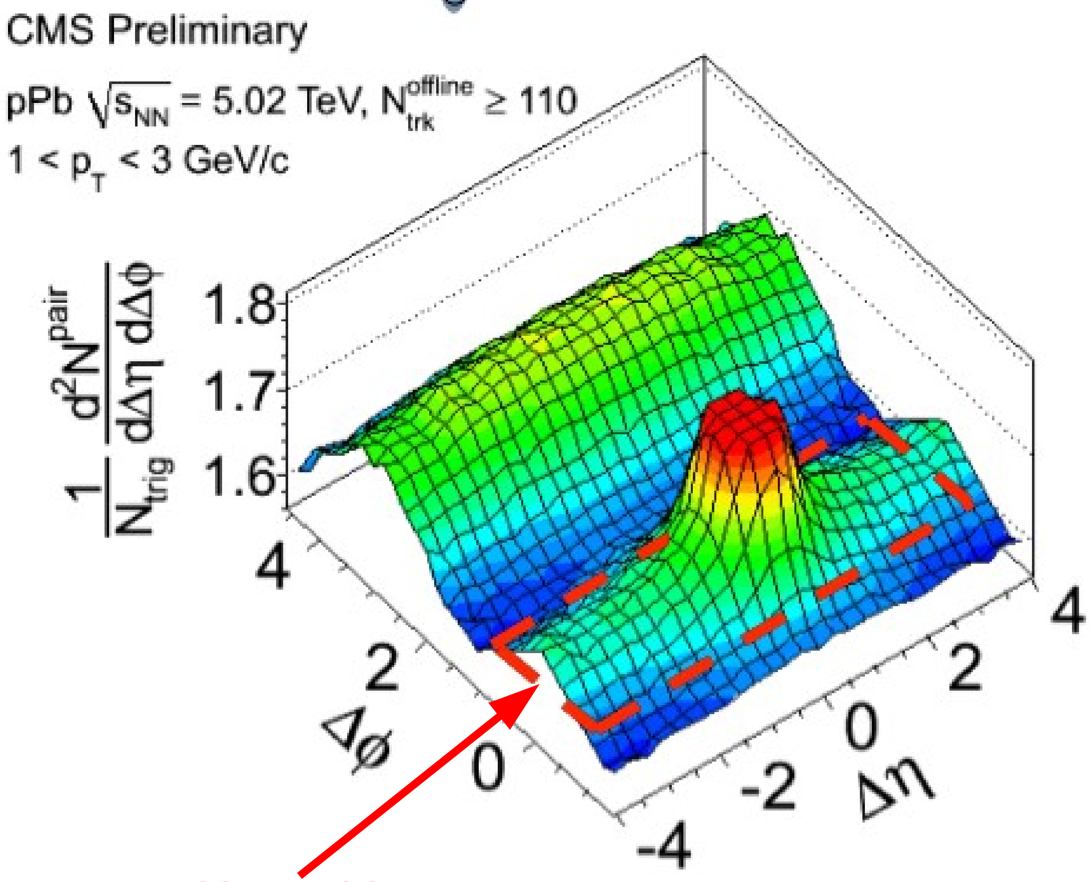


- Inverse slope: T=304±51 MeV
  - If interpreted naively close to initial temperature
  - Consistent with Y(2) and Y(3S) melting

- Significant $v_2^{dir\gamma}$ below 3 GeV/c
  - Compatible to charged hadrons or no direct γ
  - Difficult to reconcile with T

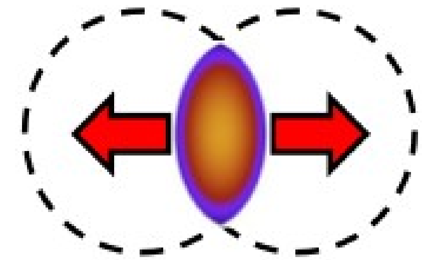
Near-side ridge structure in p+Pb

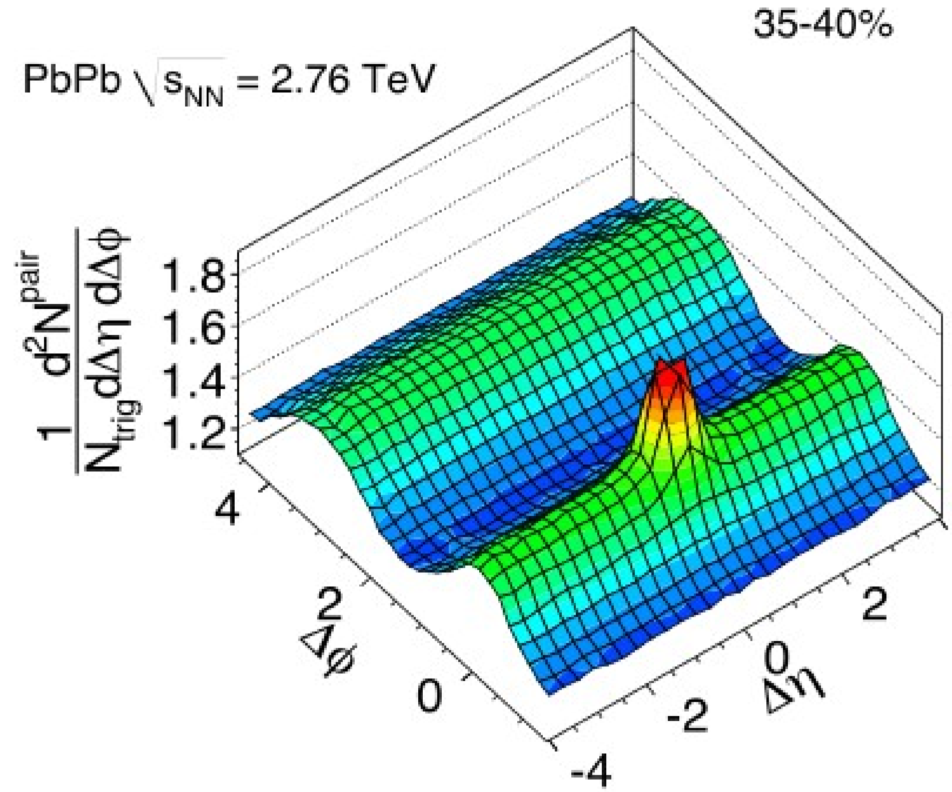




Near-side ridge

Initial-state geometry
+
collective expansion





Courtesy of D. Velicanu (CMS)

Summary

- The LHC is ideal for studying the QGP
  - $\varepsilon_{init} > \varepsilon_c$, large volume, long life-time, plenty of hard probes
  - QGP has similar "perfect liquid" properties as at RHIC
- Hard probe results constrain the physics of parton energy loss
  - There has been a burst of new data. And more to come!
    - We are in exploratory phase with some of the observables
  - Should attempt to describe all aspects in common model.
  - Upcoming p+Pb run in Jan 2013 will further clarify role of initial state effects
- Watch out for (further) surprises at the LHC

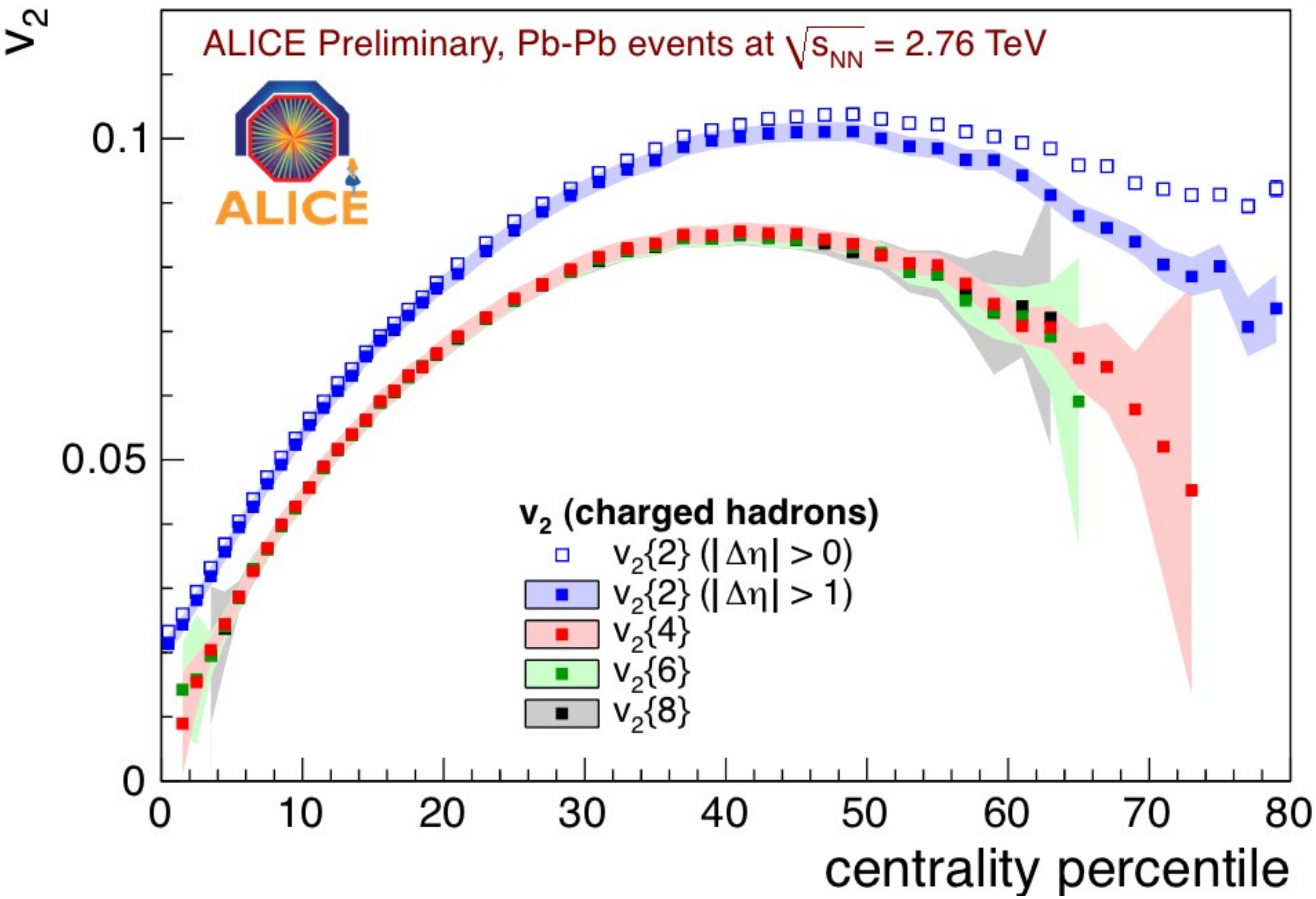
CMS HI results
ALICE HI papers
ATLAS HI results

Special thank you to my ALICE, ATLAS and CMS colleagues for their great material, and to the LHC for fantastic operations in the past years!

Extra slides

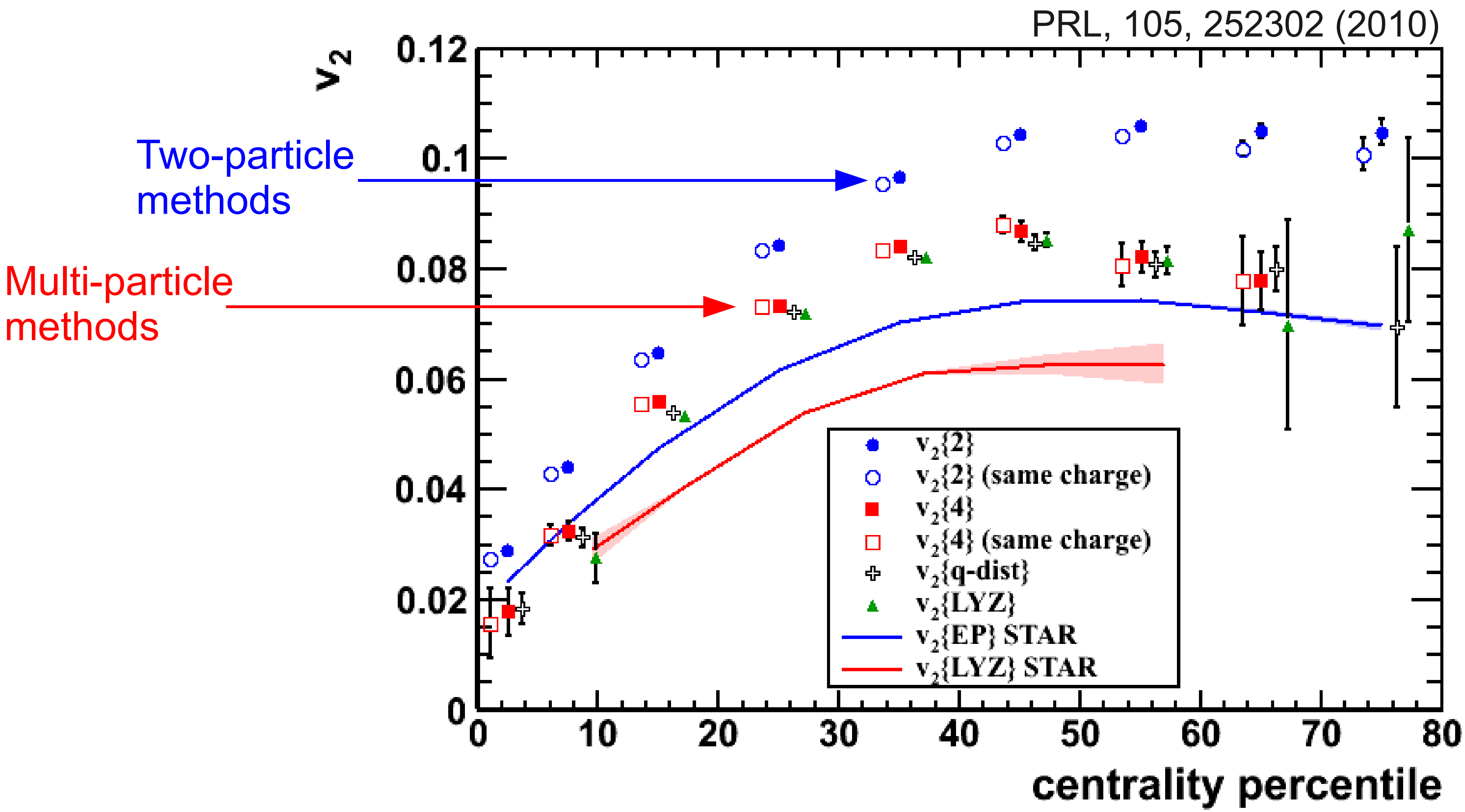
Multiparticle correlation studies

A.Bilandzic for ALICE, QM'11



Multi-particle correlations (cumulant) studies extract the genuine multi-particle correlation

Integrated elliptic flow

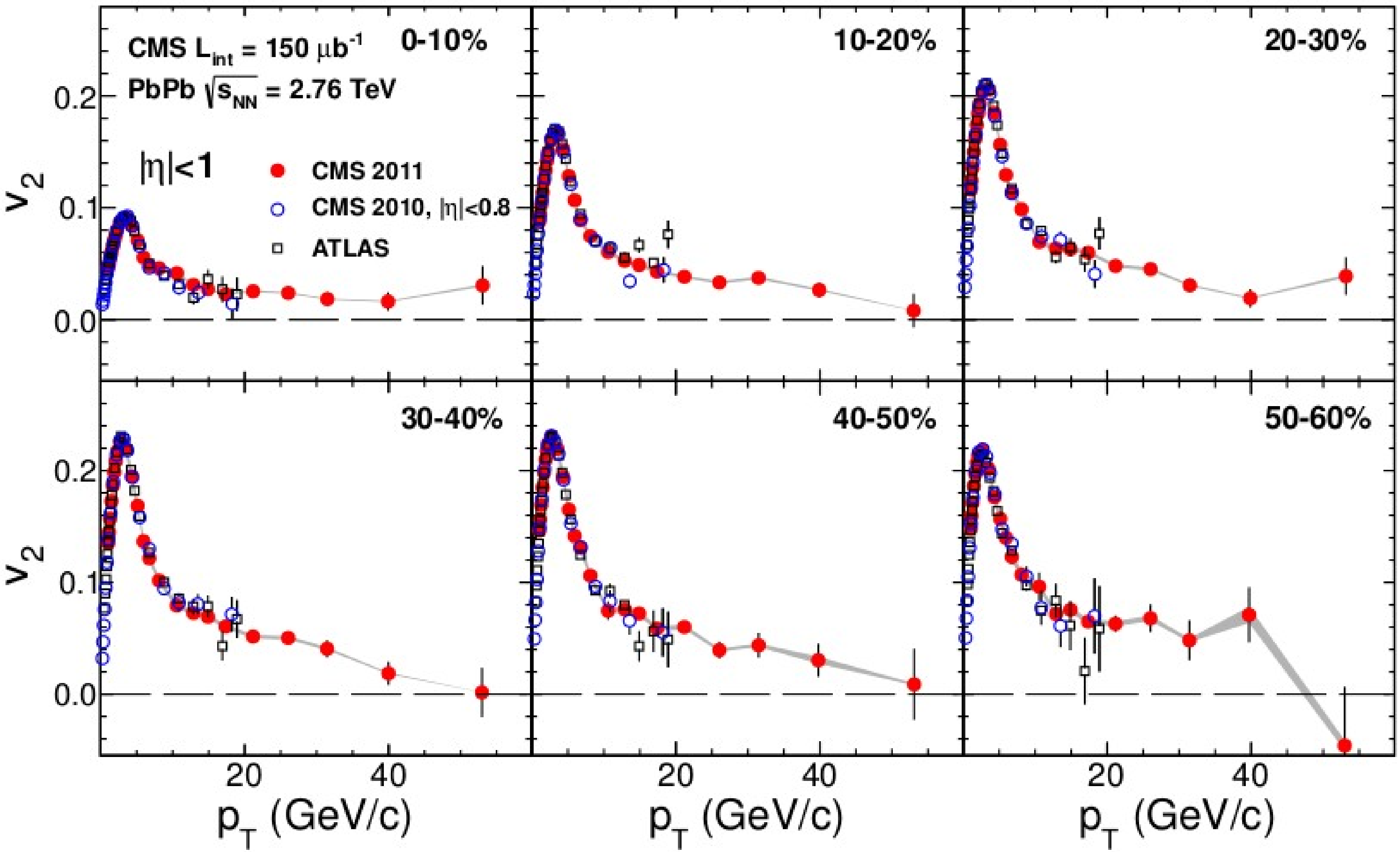


Integrated v_2: ~30% larger than at RHIC
(due to the increase of <p_T>)

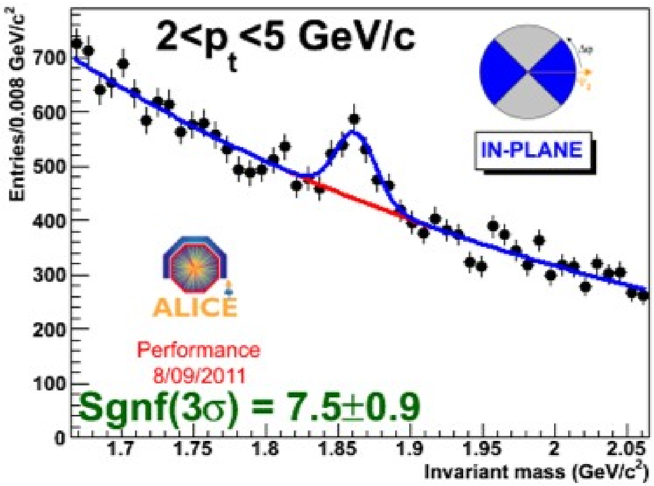
$$v_2 = \langle \cos[2(\phi - \Psi_{RP})] \rangle$$

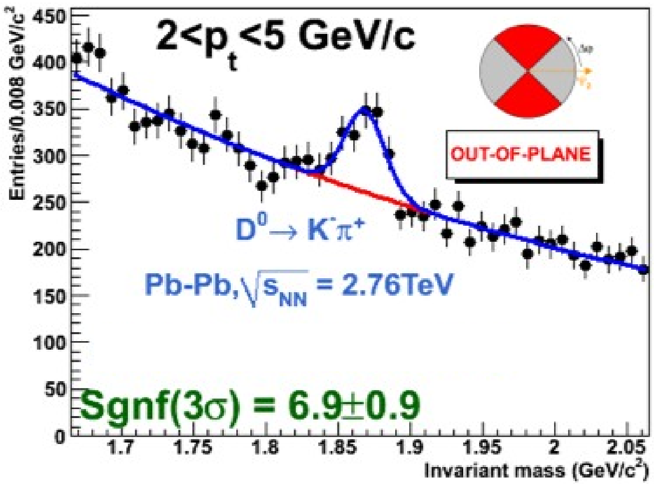
Elliptic flow at high p_T

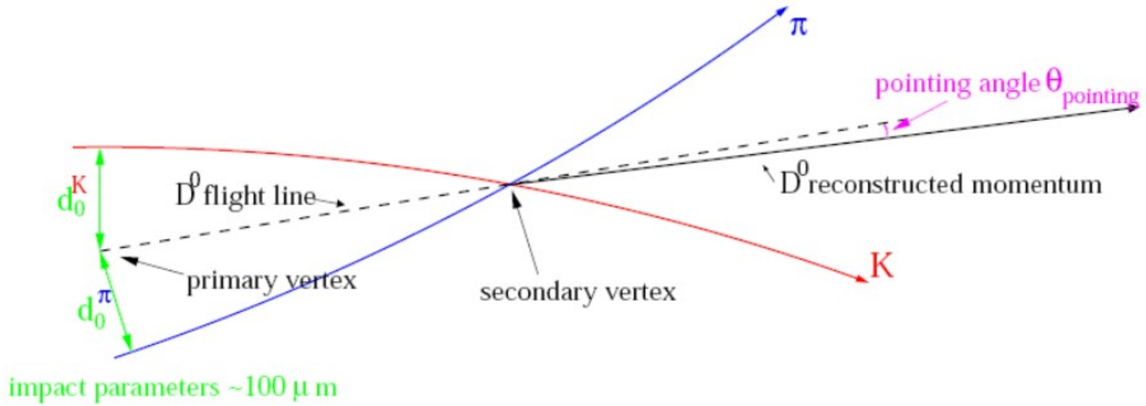
arXiv:1204.1850



D meson elliptic flow

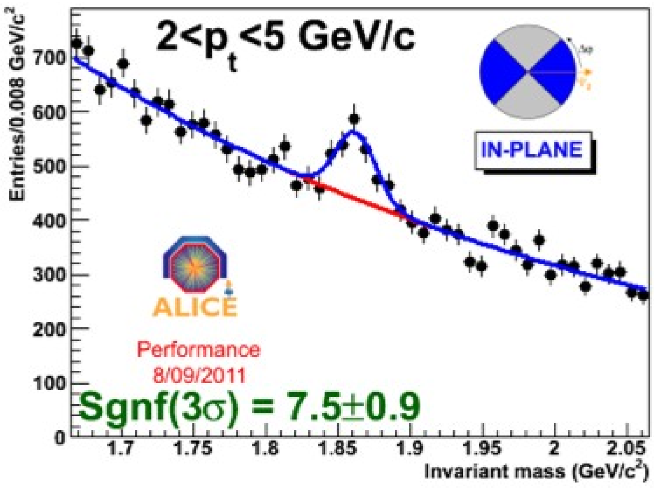


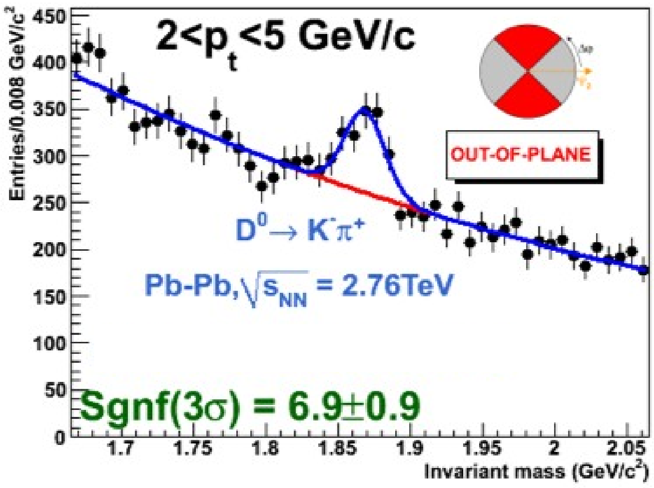




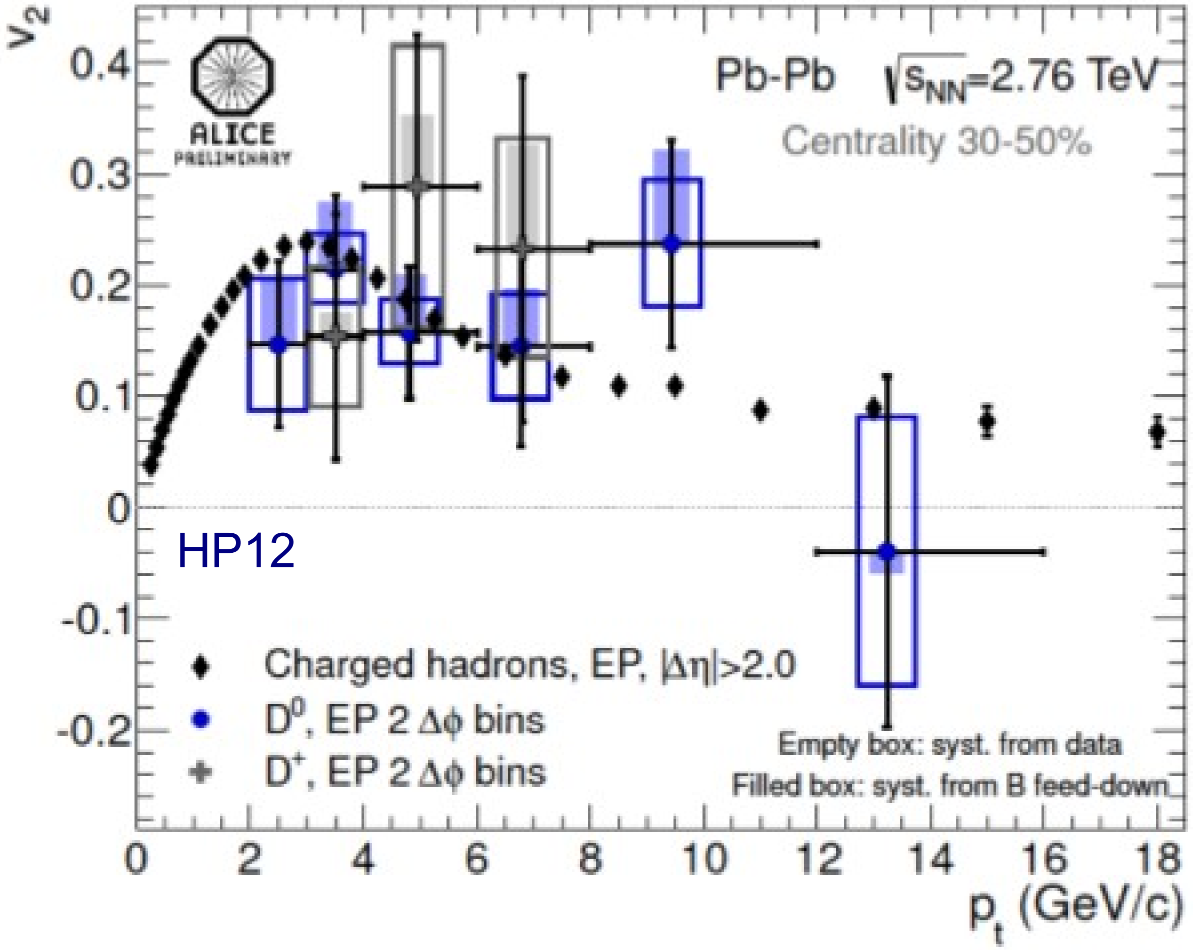
- Invariant mass analysis of fully reconstructed decay topologies (inc. PID)
- Displacement from primary vertex
- Feed-down from B (10-15%) after cuts subtracted using FONLL
  - Conservative hypothesis on Raa of D from B

D meson elliptic flow



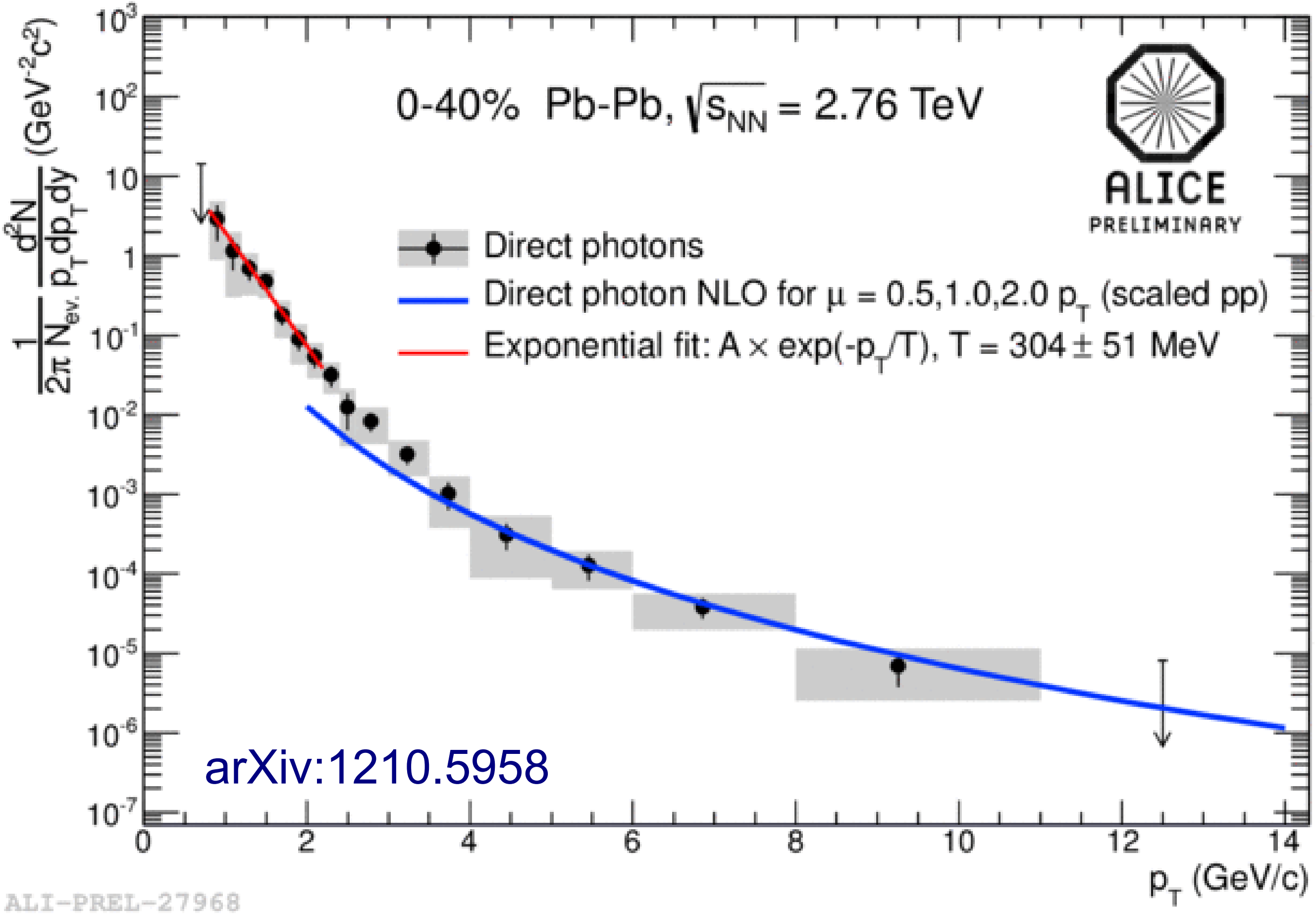


$$v_2 = \frac{\pi}{4}\frac{N_{IN}-N_{OUT}}{N_{IN}+N_{OUT}}$$



Even charm mesons exhibit elliptic flow

Direct photon spectrum



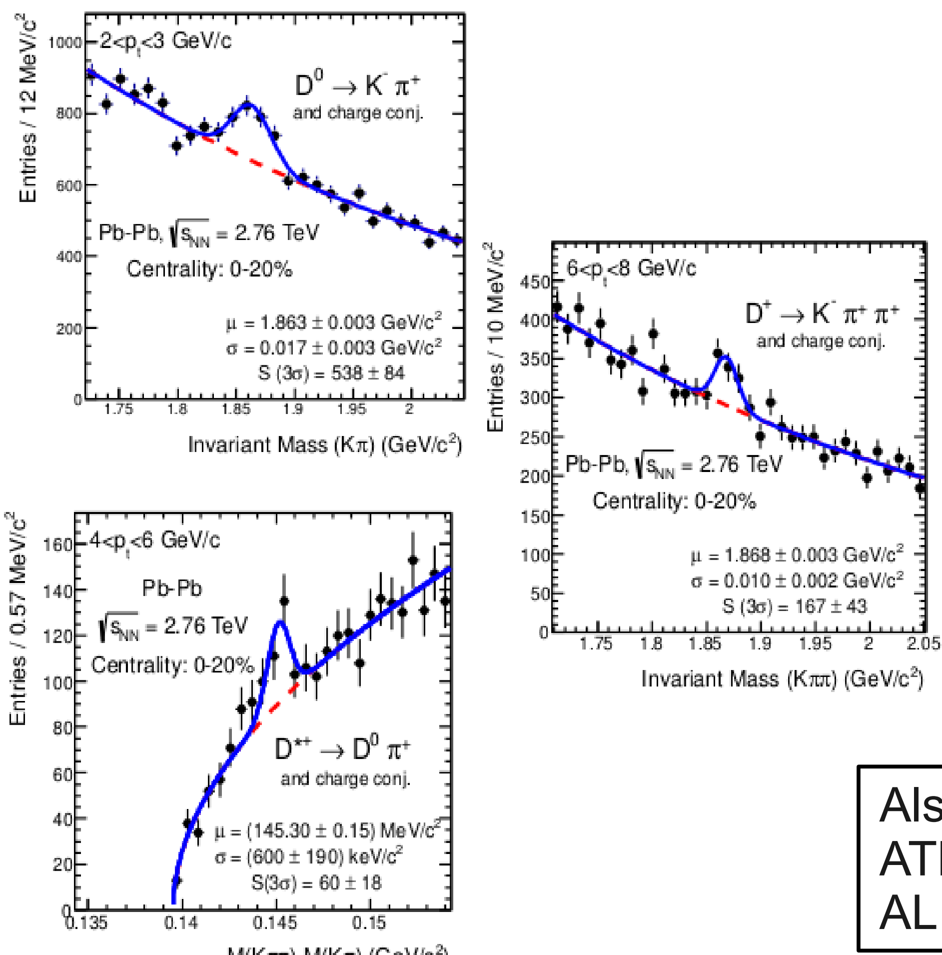
- Reconstruction of converted photons in ITS+TPC
- Double ratio strategy ala PHENIX
  - Measure inclusive photons and π^0
  - Model decay contribution with cocktail of all decay photon sources
- Spectrum derived as direct $\gamma = (1\text{-}R)\ \gamma^{inc}$

Spectrum above 3-4 GeV/c consistent with NLO prediction scaled by Ncoll. Below it can be fit with exponential with inverse slope: T=304±51 MeV (combined Hagedorn+Exponential fit gives similar value)

Heavy-quark probes: D and B mesons

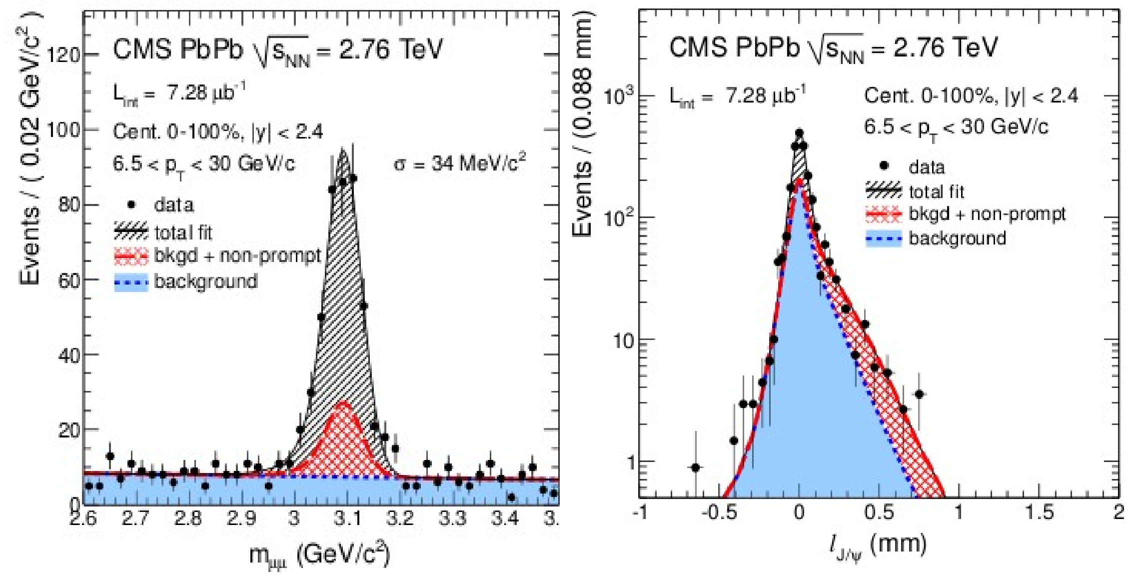
D mesons reconstructed from displaced vertices in 3 invariant mass channels. Contribution from B subtracted with FONLL.

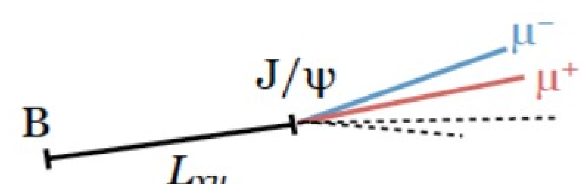
ALICE, arXiv:1203.2160



B mesons via secondary J/ψ:

CMS, JHEP 1205 (2012) 063





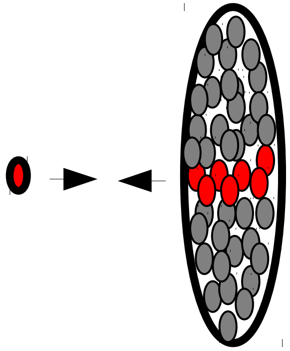
Clean separation of 2nd vertex for J/ψ with p_T>6.5 GeV/c

Also recently presented (not discussed here):
ATLAS HF muon, mid-rapidity (ATLAS-CONF-2012-050)
ALICE HF muon, forward (arxiv:1205.6443)

p+Pb: NSD event sample

arXiv:1210.3615

- Event selection
  - VZERO-A and VZERO-C
  - Cross check with ZDC on nucleus side
- Resulting event sample
  - Non single-diffractive with negligible contamination from SD and EM processes
- Validated from cocktail
  - DPMJET for NSD (2b)
  - PHOJET + Glauber for incoherent SD part (0.1b)
    - SD/INEL = 0.2 (arXiv:1208.4968)
  - EM with STARLIGHT (0.1-0.2b)
- Normalization uncertainty: 3.1%



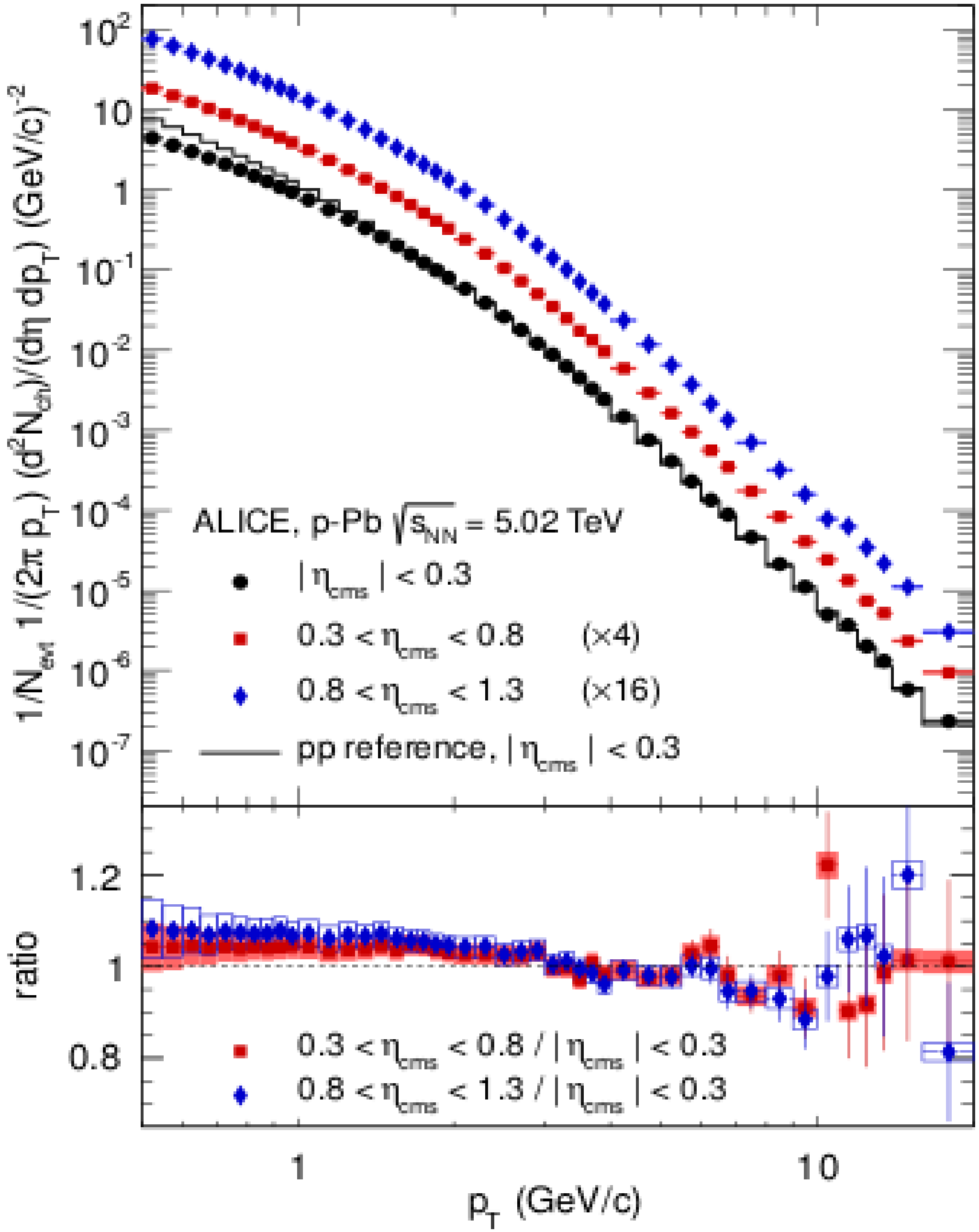
A p-Pb collision is defined to be NSD if at least one binary collsion is NSD.

(Fraction of SD p-Pb collisions is dominated by Npart = 2 events.)

p+Pb: Charged particle spectrum

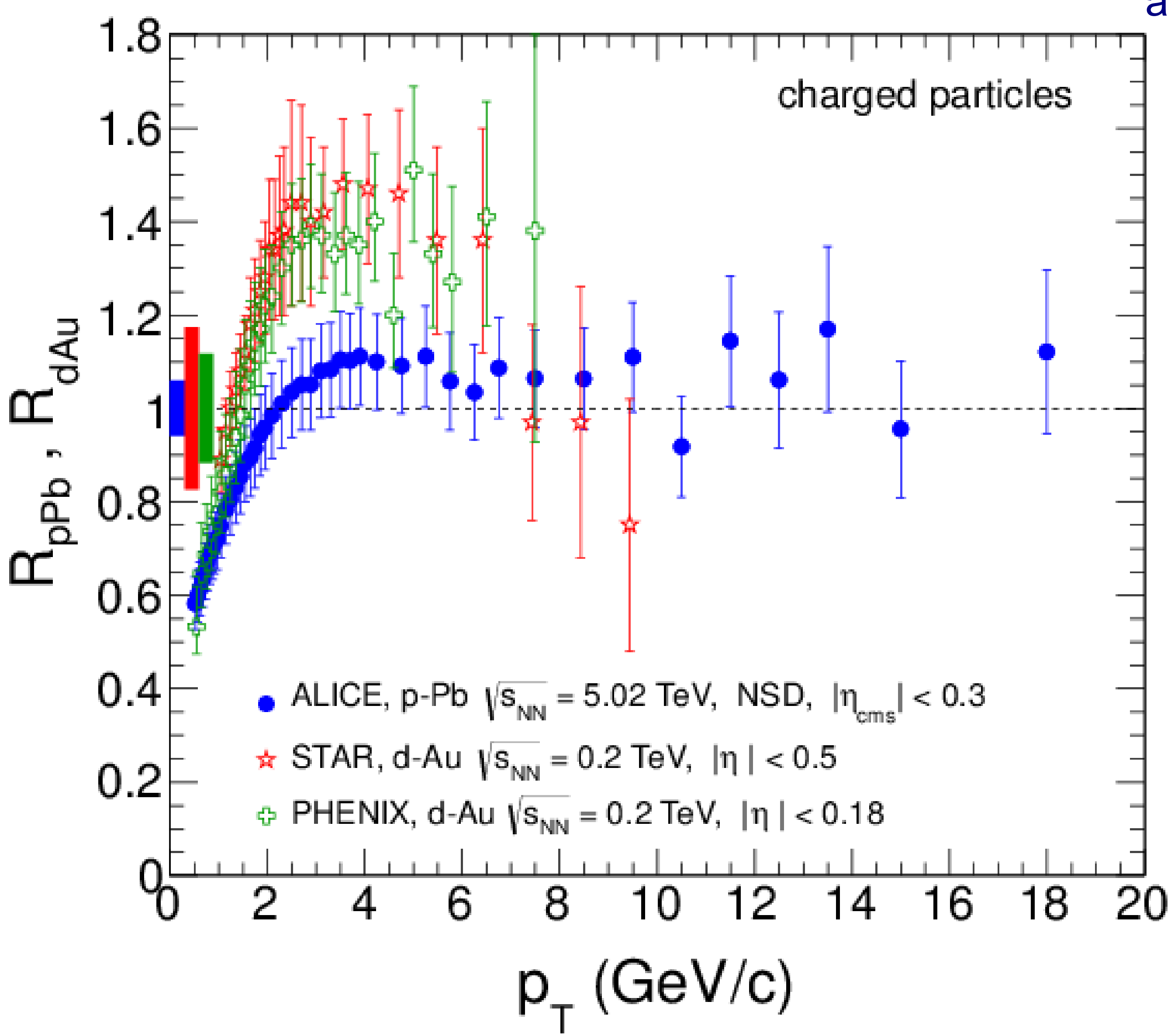
arXiv:1210.4520

- Measurement (track based) in p-Pb in 3 η-intervals
  - Corrections based on DPMJET and HIJING
  - Systematic uncertainty: ~5.3%
  - NSD normalization: 3.1 %
- No strong η dependence within our acceptance
- Reference constructed from pp (INEL) data at 2.76 and 7 TeV
  - Scaled by factor obtained from NLO calculation
  - Interpolation below 5 GeV/c
  - $\langle T_{pPb} \rangle = 0.0983 \pm 0.0035\ mb^{-1}$ from Glauber model



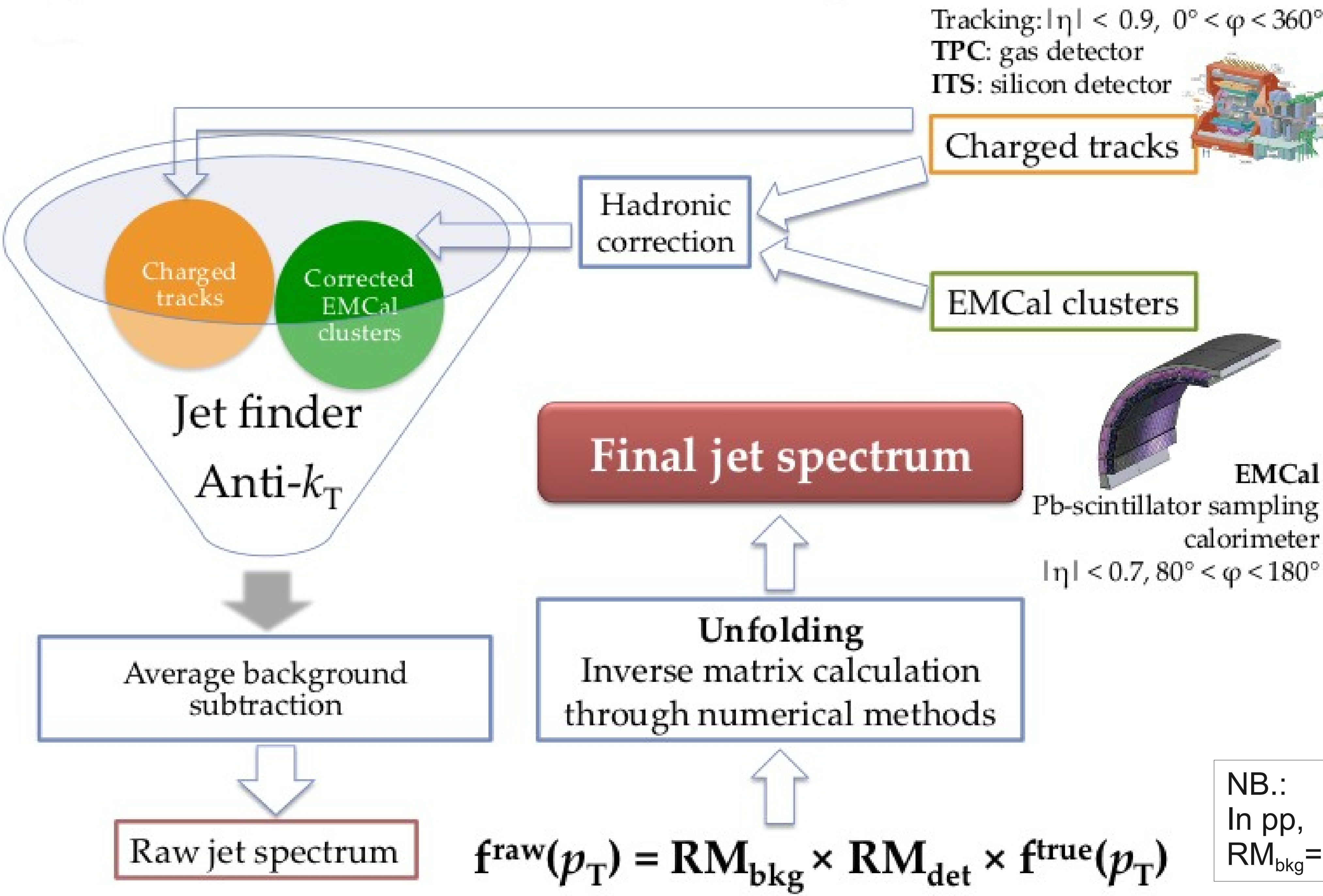
p+Pb: Comparison to d+Au at 0.2 TeV

arXiv:1210.4520



Cronin effect much smaller (if at all present) at the LHC energies.

Jet reconstruction overview



NB.:
In pp,
$RM_{bkg}=1$

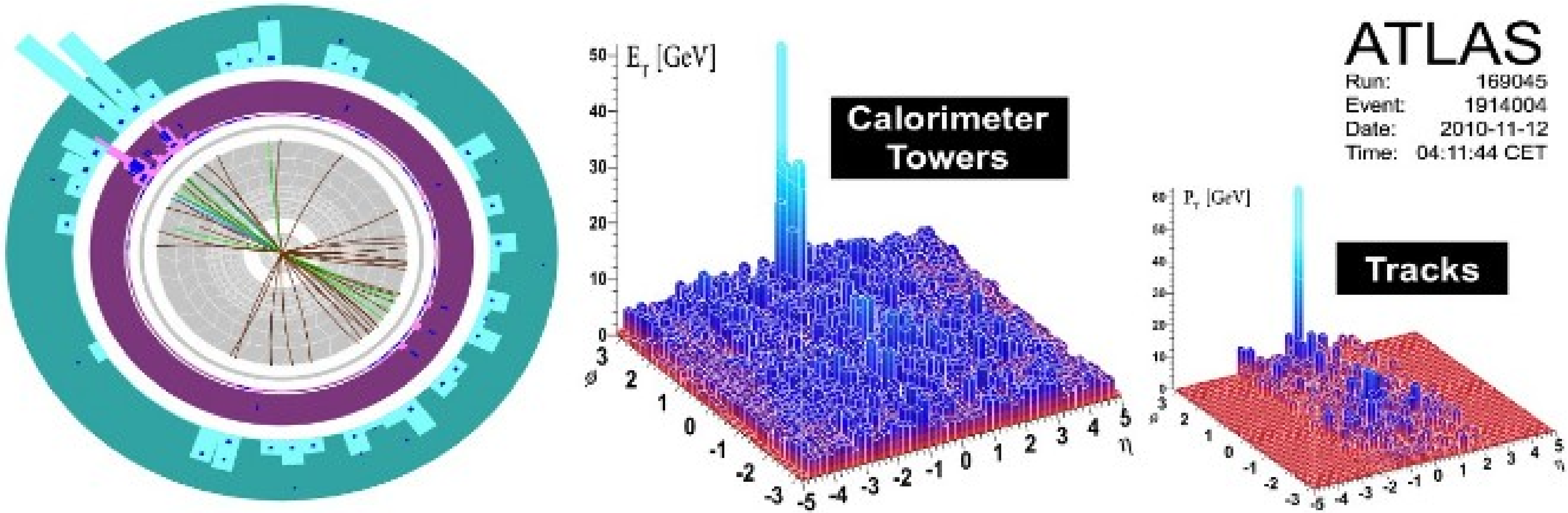
Jet reco in pp and Pb+Pb at 2.76 TeV

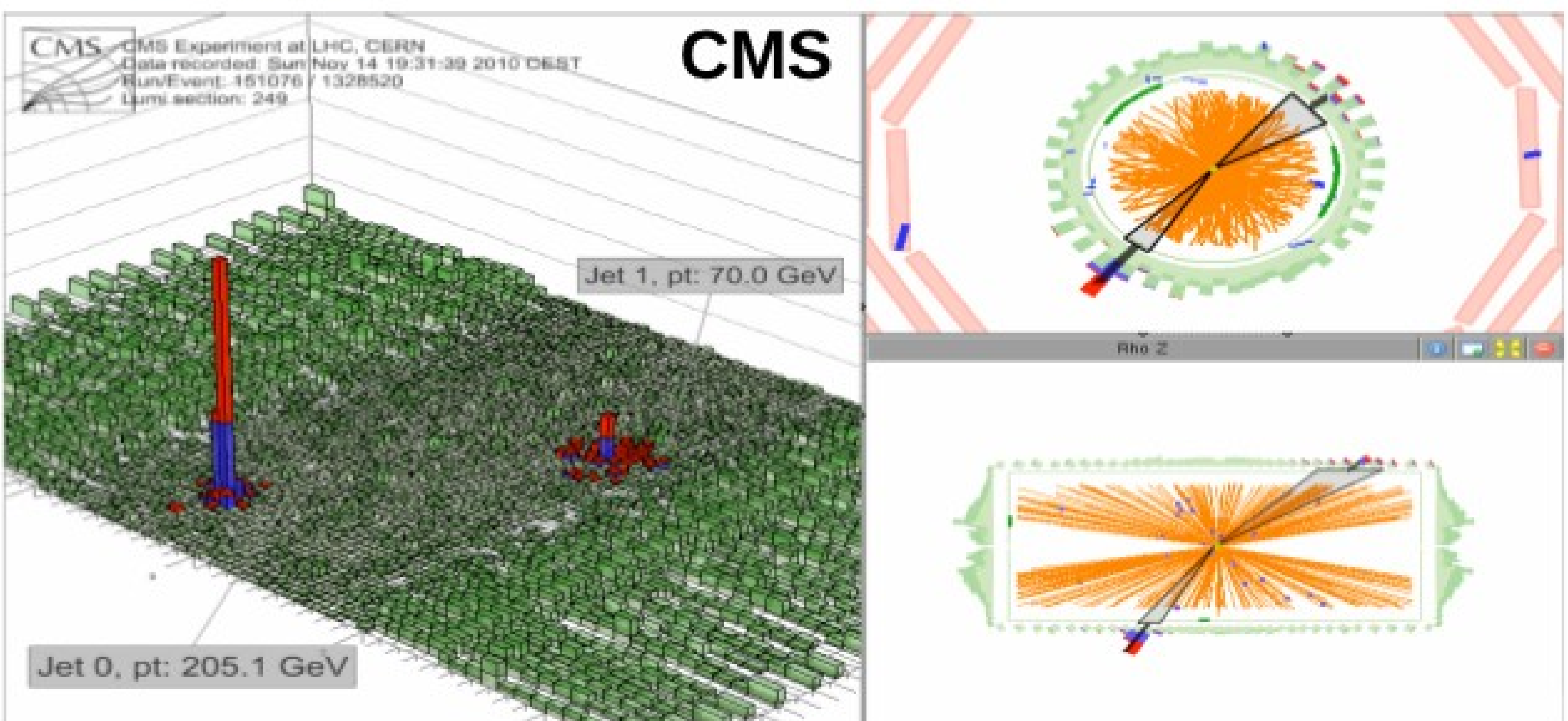
- Constituents (input to jet finder)
  - Assumed to be massless
  - Charged tracks with p_T>150 MeV/c
  - EMCAL clusters with E_T > 300 MeV/c after hadronic correction
    - Correction for track-matched clusters to prevent double counting

$$E_{clus}^{cor} = E_{clus}^{orig} - f \sum p_{track}^{matched}, \; E_{clus}^{cor} \geqslant 0$$

    - As default, f=100% used
- Jet reconstruction using FASTJET
  - R=0.2 (also R=0.4 for pp)
  - Anti-k_T for signal jets
    - Area cut > 0.6 πR^2
    - Fiducial cuts to select jets fully contained within the EMCAL
  - K_T for background estimate (Pb-Pb)

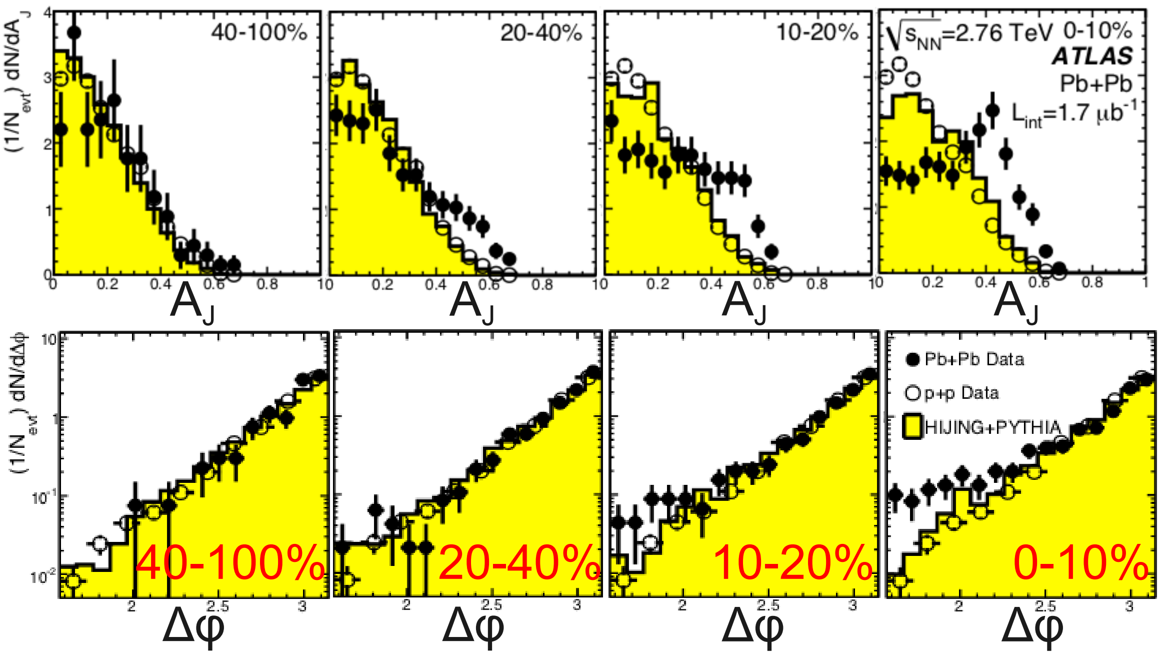
Jet quenching in dijet events





Dijet momentum imbalance

Dijet momentum asymmetry: $A_J = (p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2})$



Larger momentum imbalance wrt to MC reference.

Difference increases with increasing centrality.

But no (very little) increasing azimuthal decorrelation.

ATLAS, PRL 105 (2010) 252303
CMS, PRC84 (2011) 024906

Dijet momentum imbalance

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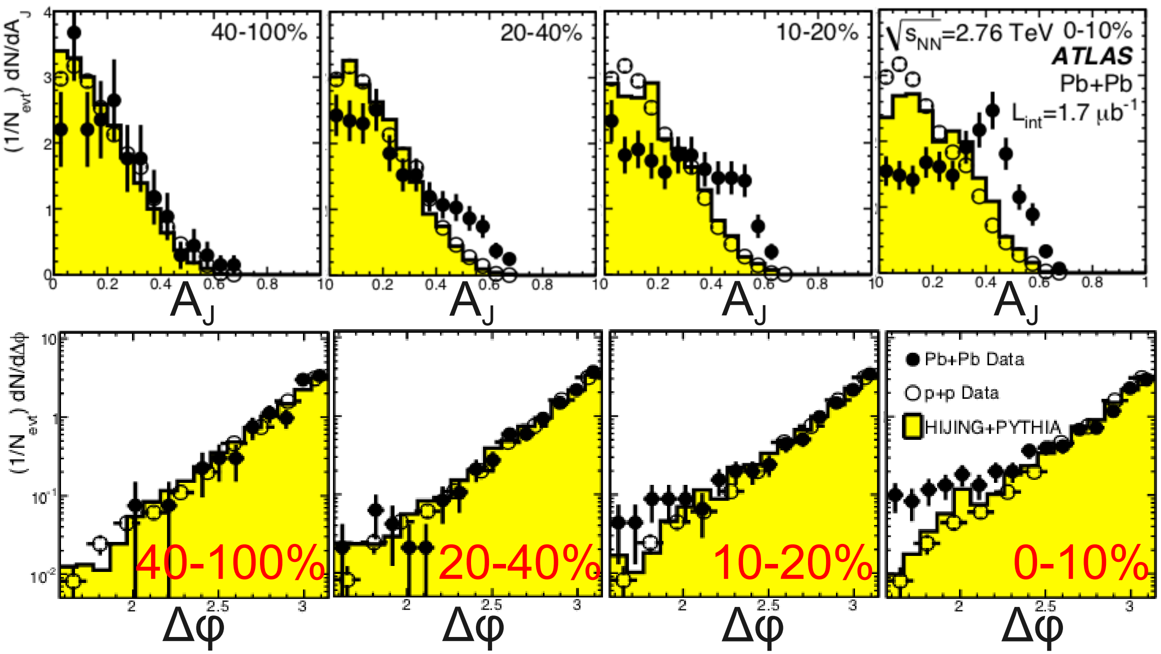
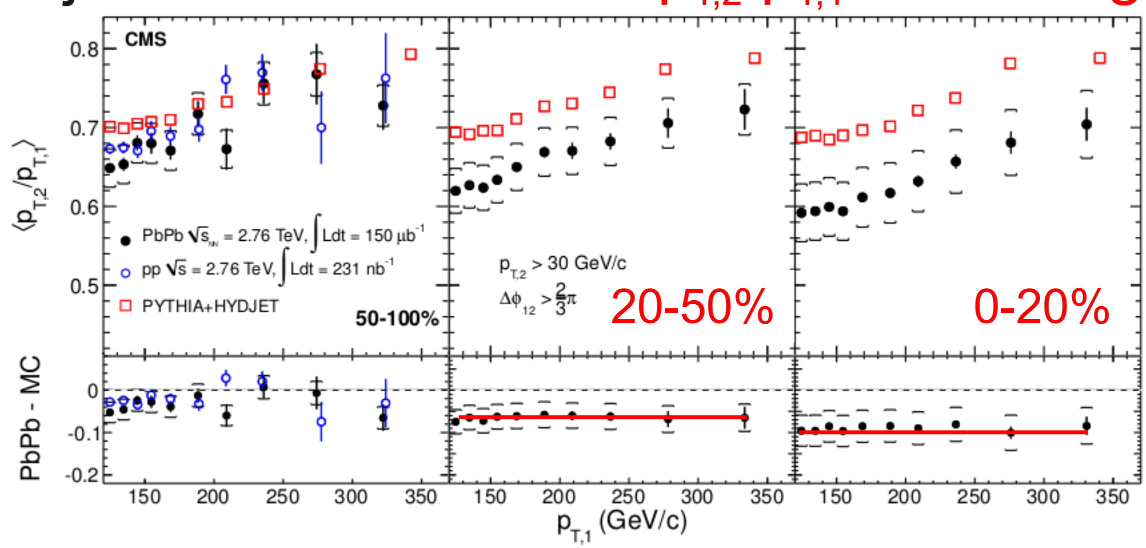


Larger momentum imbalance wrt to MC reference.
Difference increases with increasing centrality.
But no (very little) increasing azimuthal decorrelation.

ATLAS, PRL 105 (2010) 252303
CMS, PRC84 (2011) 024906

Dijet momentum ratio: $p_{T,2}/p_{T,1}$ vs leading jet $p_{T,1}$

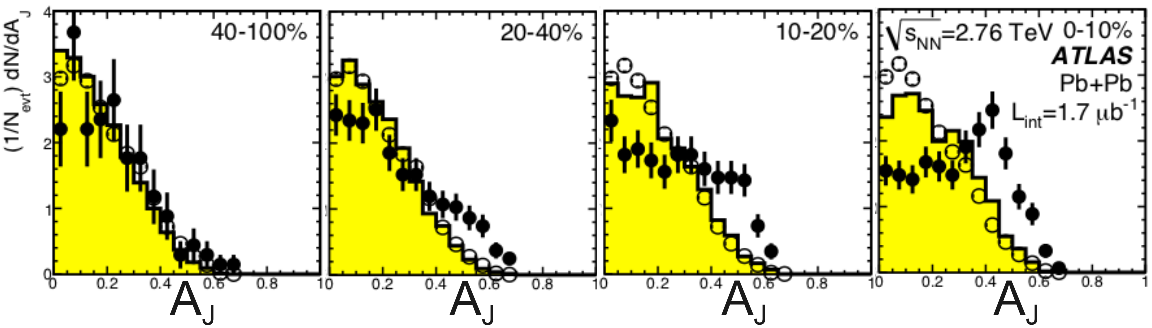


Even ~350 GeV/c jets are quenched!
Fraction of energy lost constant up to ~350 GeV/c.

CMS, PLB 712 (2012) 176

Dijet momentum imbalance

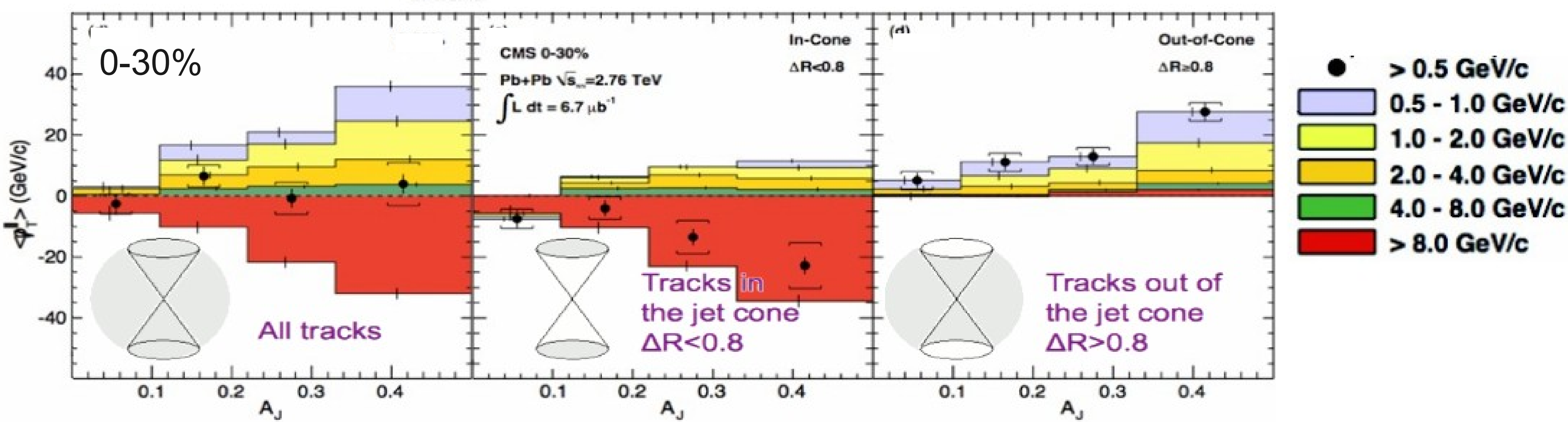
Dijet momentum asymmetry: $A_J = (p_{T,1}-p_{T,2})/(p_{T,1}+p_{T,2})$



ATLAS, PRL 105 (2010) 252303
CMS, PRC84 (2011) 024906

Lost energy emitted at low p_T (<4 GeV/c) outside jet cone (R>0.8)

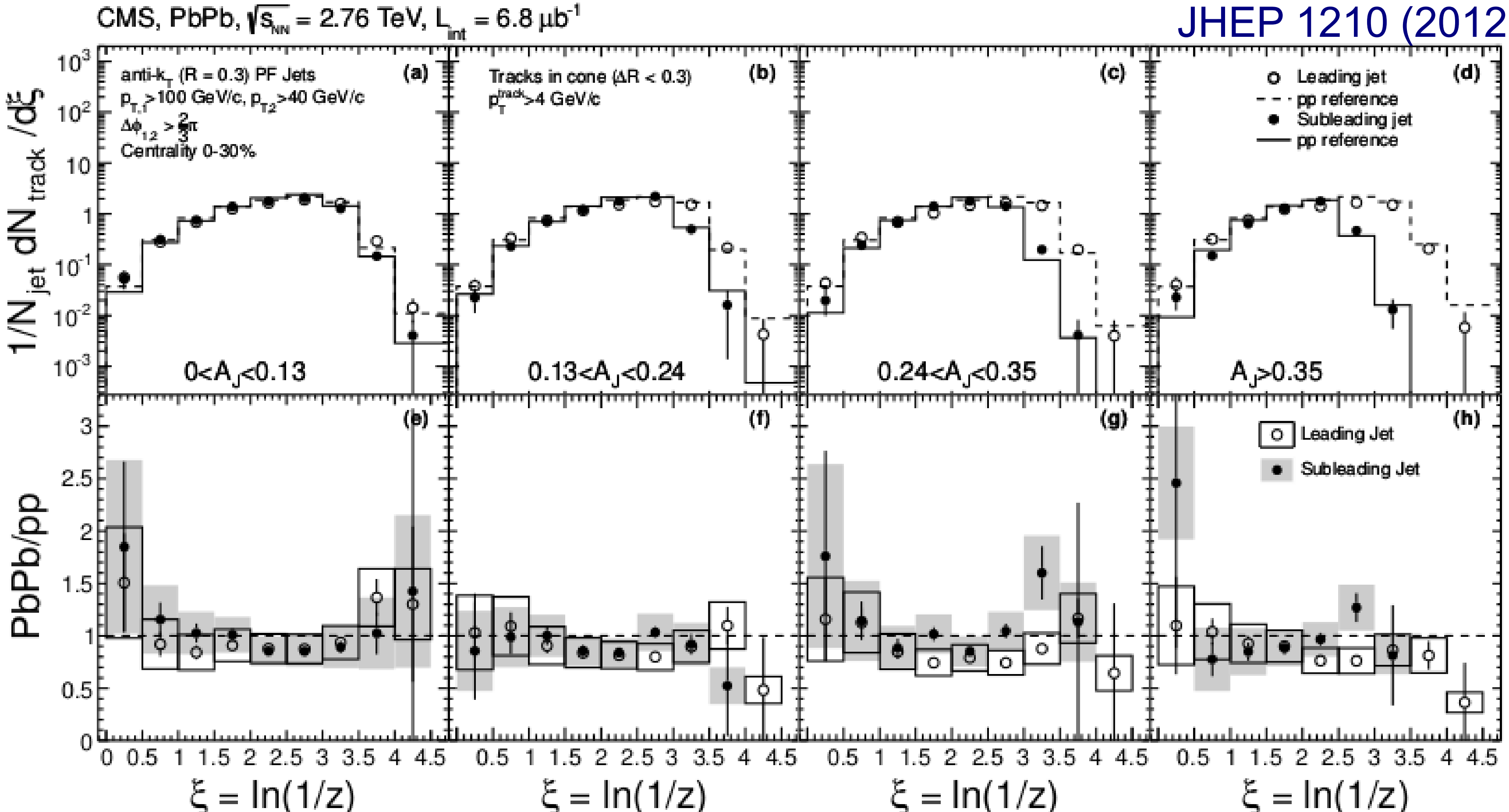
$$\not{p}_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos\left(\phi_{\text{Track}} - \phi_{\text{Leading Jet}}\right)$$



Jet fragmentation function

Fragmentation functions constructed using tracks with p_T>4 GeV/c in R<0.3 and the reconstructed (quenched) jet energy

JHEP 1210 (2012) 087



R=0.3

P_{T1} > 100 GeV/c

P_{T2} > 40 GeV/c

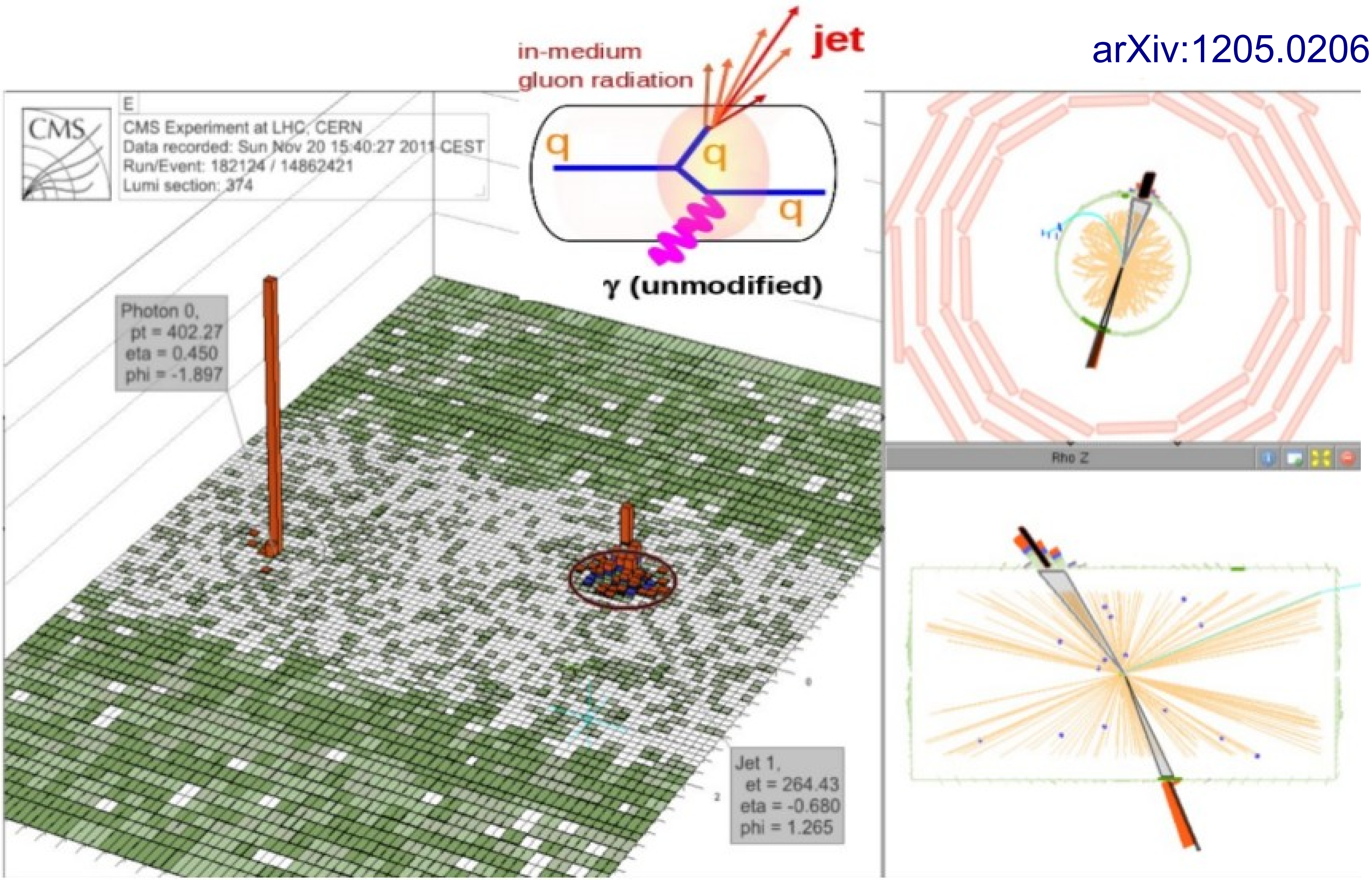
$\Delta\Phi_{12}$>2/3π

Track p_T>4 GeV/c

Leading and sub-leading jet in Pb+Pb fragment like jets of corresponding energy in pp

Jet quenching in γ-jet events

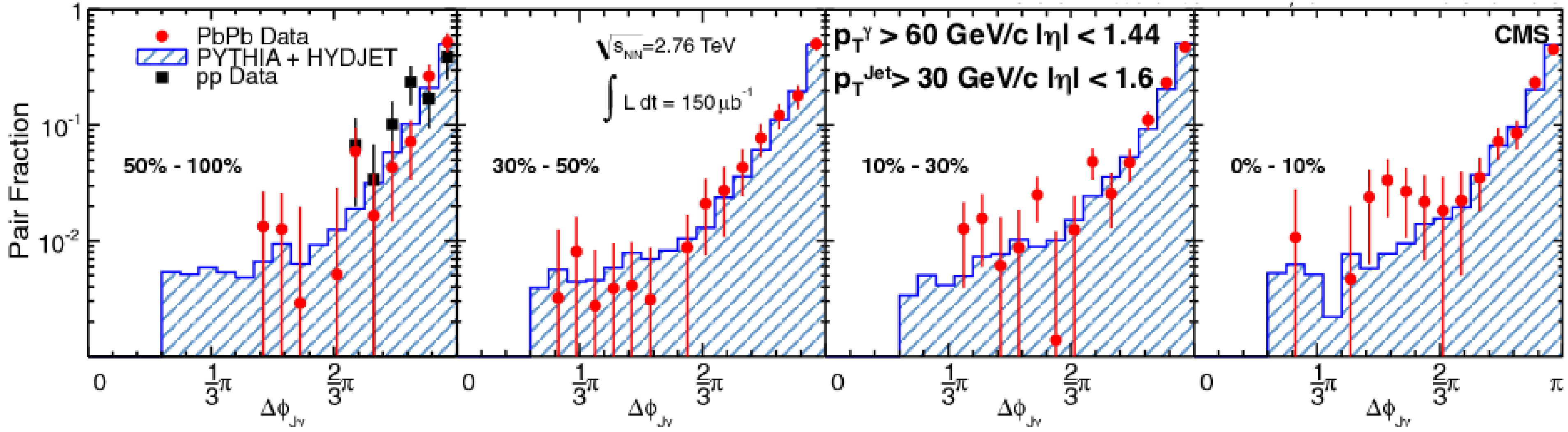
arXiv:1205.0206



Photon p_T>60 GeV/c   Jet p_T>30 GeV/c

γ-jet azimuthal correlation

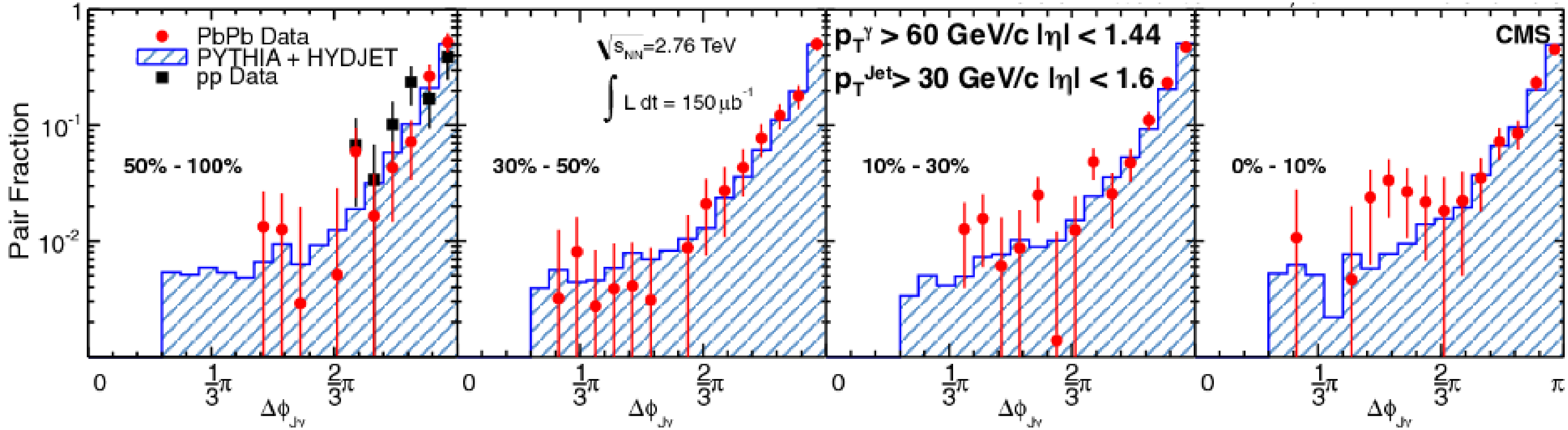
arXiv:1205.0206



- Azimuthal decorrelation consistent with pp and MC (PYTHIA+HYDJET)

γ-jet azimuthal correlation

arXiv:1205.0206

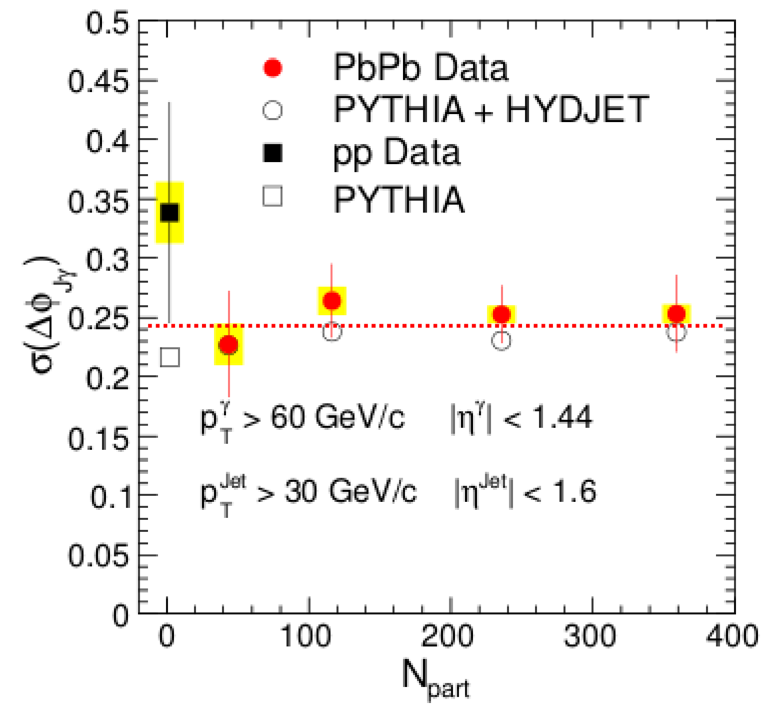


- Azimuthal decorrelation consistent with pp and MC (PYTHIA+HYDJET)
- Angular width parametrized with

$$\frac{1}{N_{J\gamma}}\frac{dN_{J\gamma}}{d\Delta\phi_{J\gamma}} = \frac{e^{(\Delta\phi-\pi)/\sigma}}{(1-e^{-\pi/\sigma})\,\sigma}$$

found to be constant vs centrality

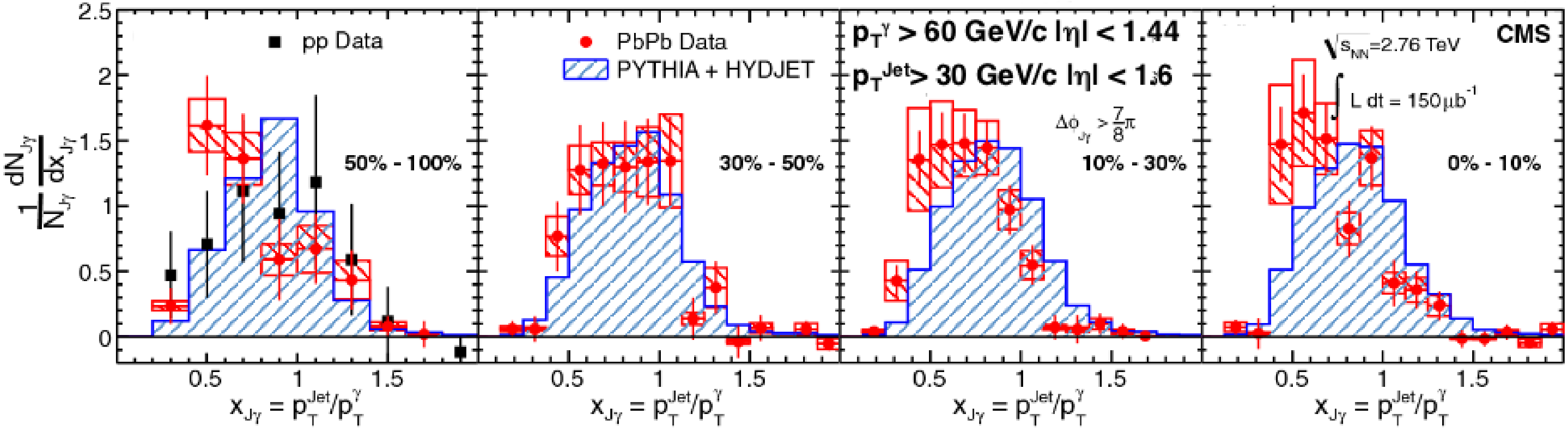
- Quenched jet is back-to-back to γ: Energy transfer not via one single hard gluon radiation



γ-jet momentum imbalance

Momentum ratio distribution

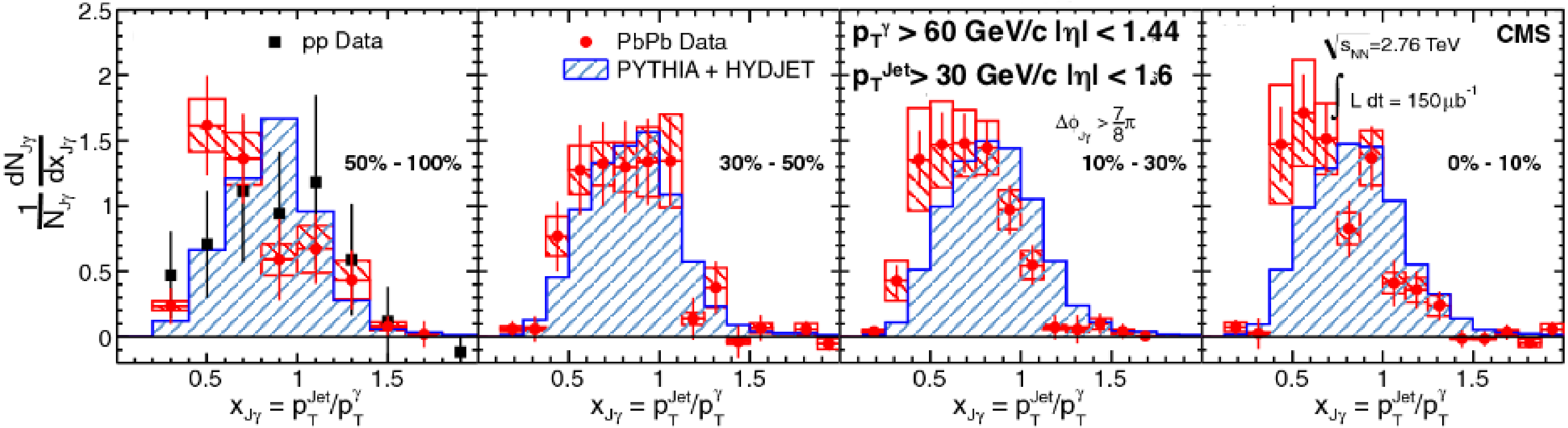
arXiv:1205.0206



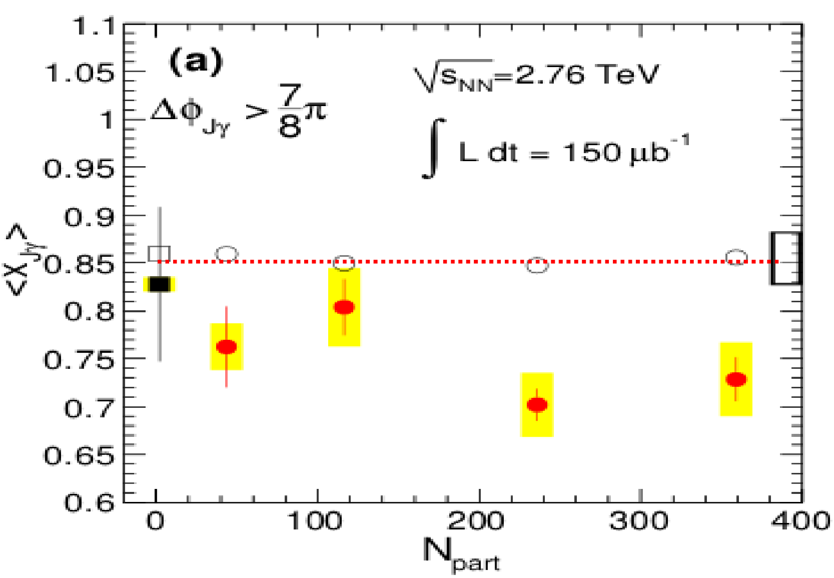
γ-jet momentum imbalance

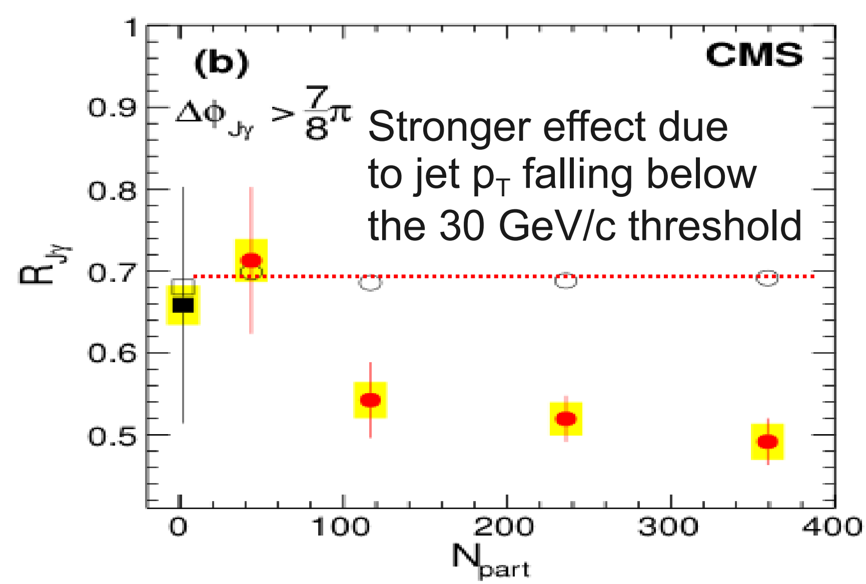
Momentum ratio distribution

arXiv:1205.0206



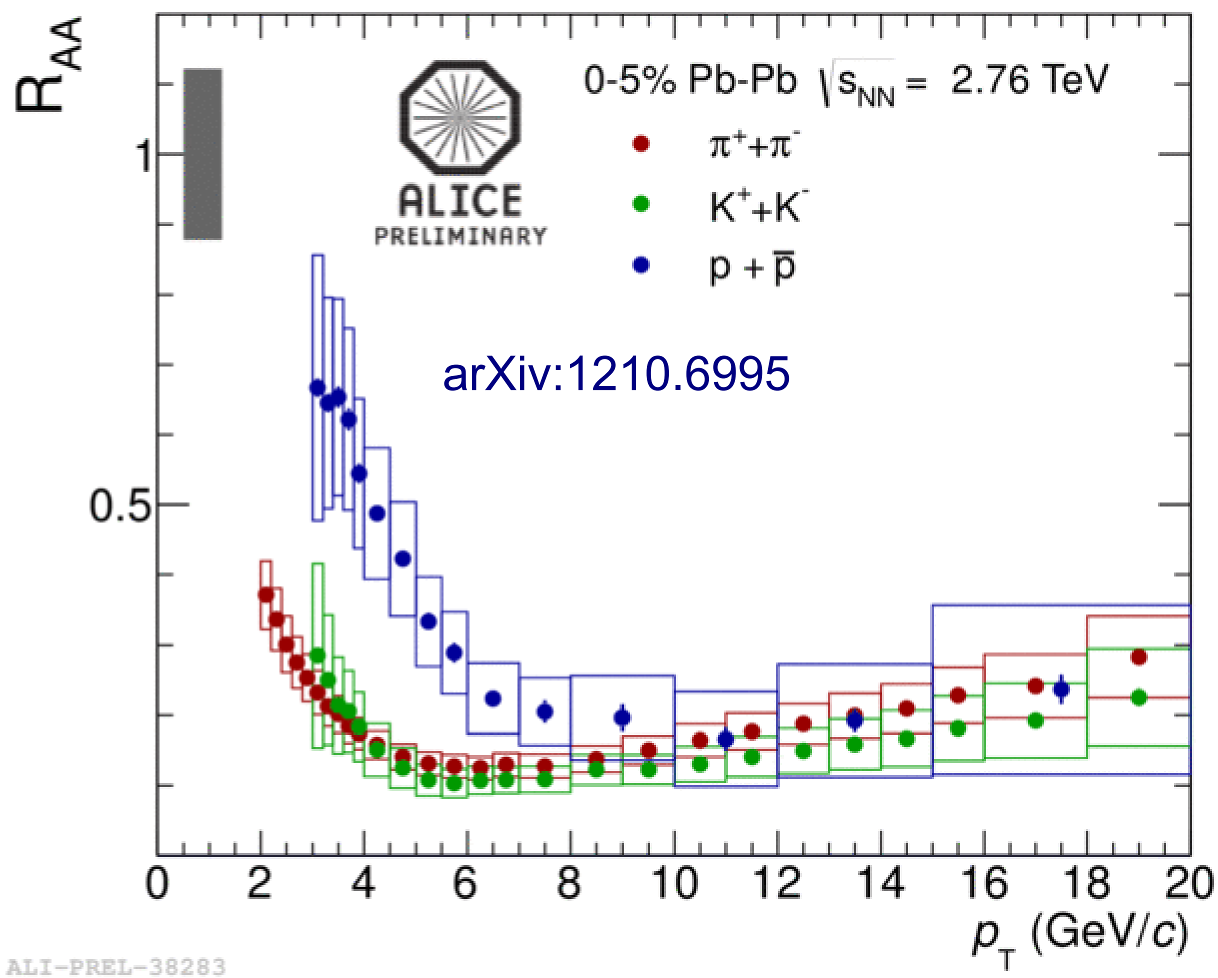
Momentum ratio ($x_{J\gamma}$) and fraction of γ-jet associations ($R_{J\gamma}$) decrease significantly with centrality compared to pp or MC





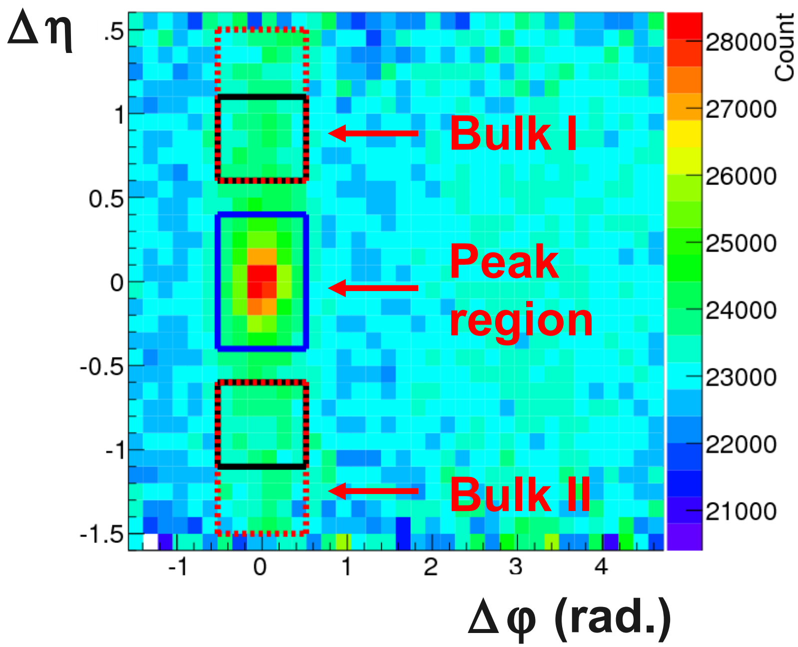
Stronger effect due to jet p_T falling below the 30 GeV/c threshold

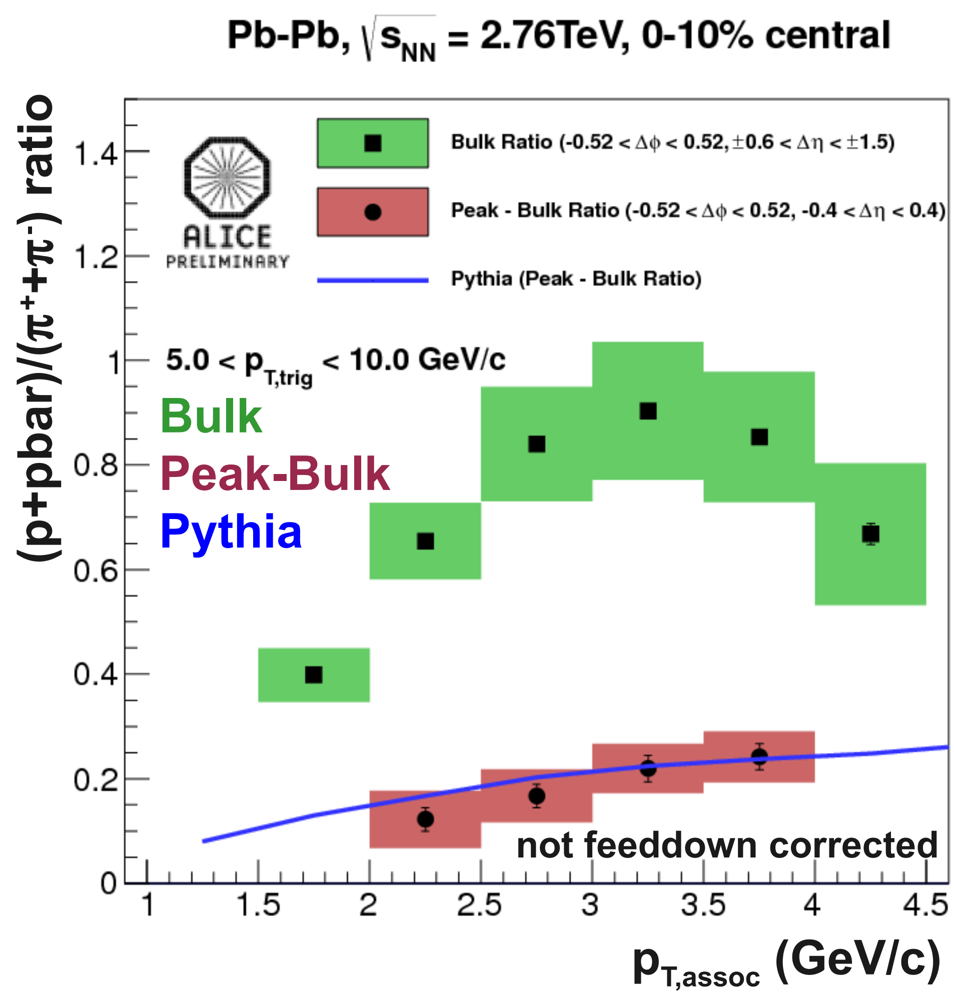
Identified particle R_{AA} at high p_T



- Differences only at low p_T
  - Sensitivity to in-medium hadronization
- In particular, no visible difference for p_T above 10 GeV/c
- Little room for in-medium modification at high p_T
- However, will have to measure inside reconstructed jets

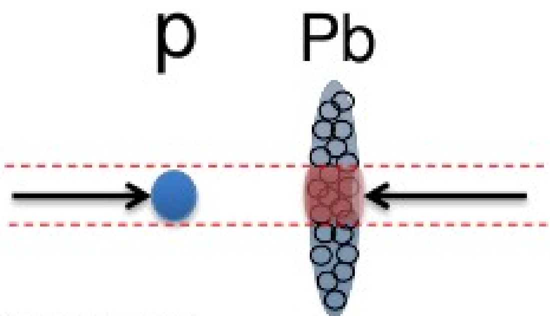
Near-side dihadron correlations: p/π ratio



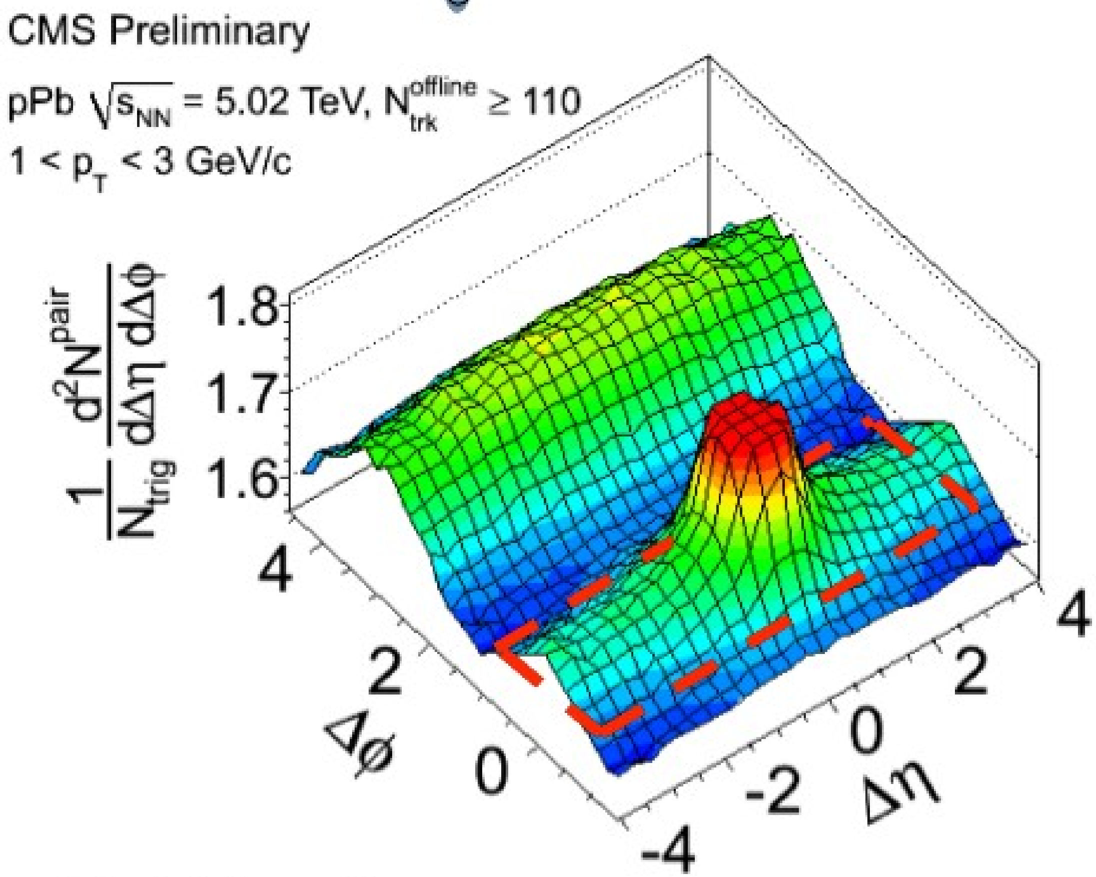


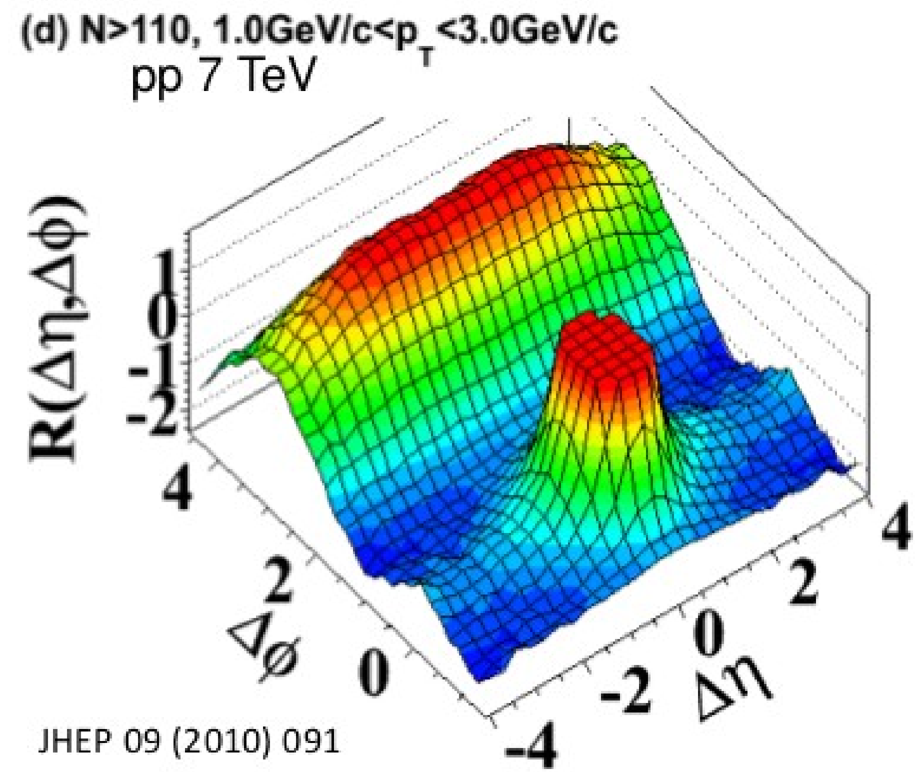
- p/π ratio in the bulk is consistent with inclusive p/π ratio
  - NB. Inclusive ratio in 0-5% and feed-down corrected
- p/π ratio in peak - bulk is consistent with ratio from Pythia (6.4 default tune)
- No evidence for medium-induced modification of jet fragmentation (R ~ 0.4-0.5) in this p_T regime

Ridges in p+Pb and pp



Phisical origin still unclear





Much bigger than pp

Courtesy of D. Velicanu (CMS)