Latest QCD results in p+p and Pb+Pb collisions from ATLAS

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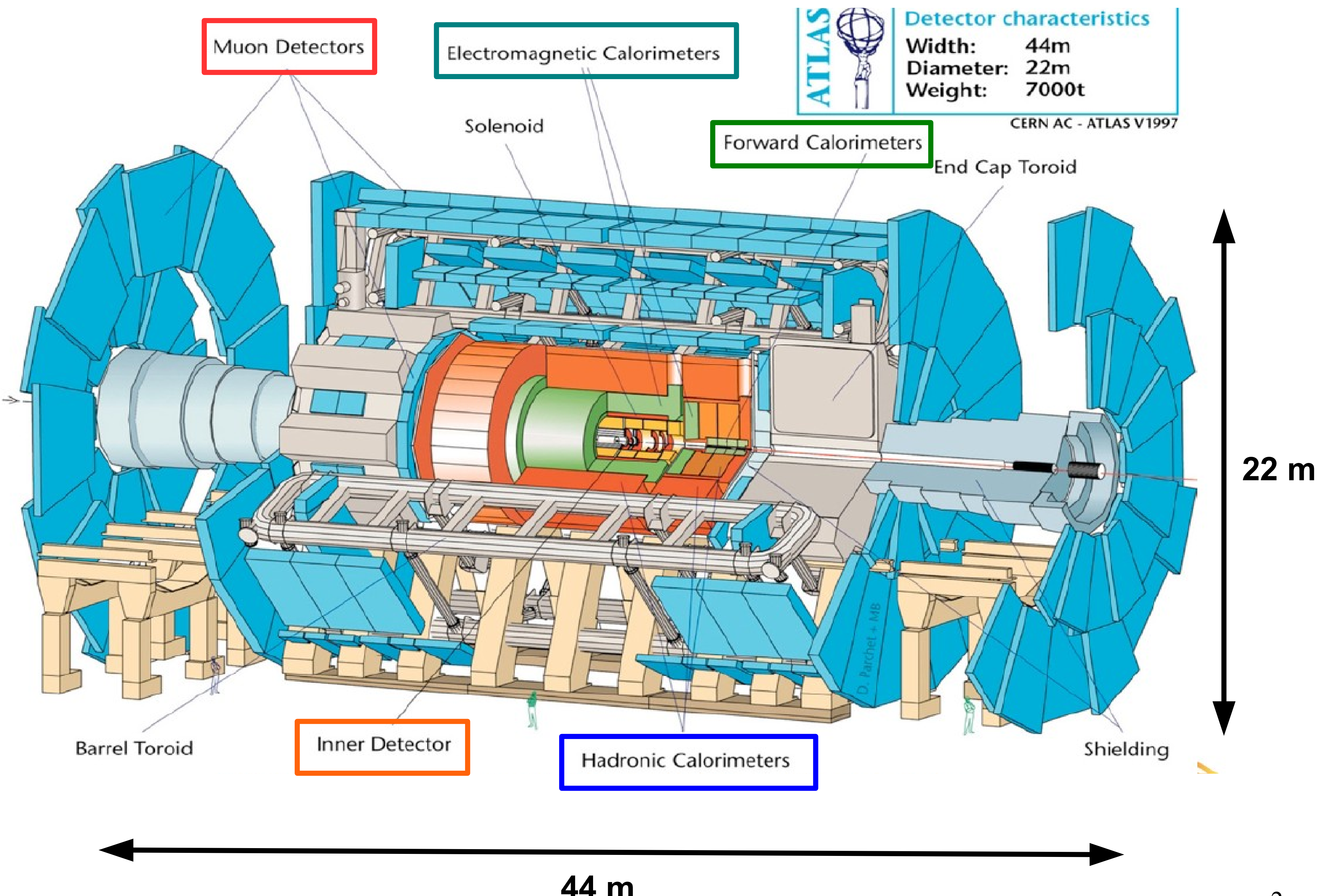
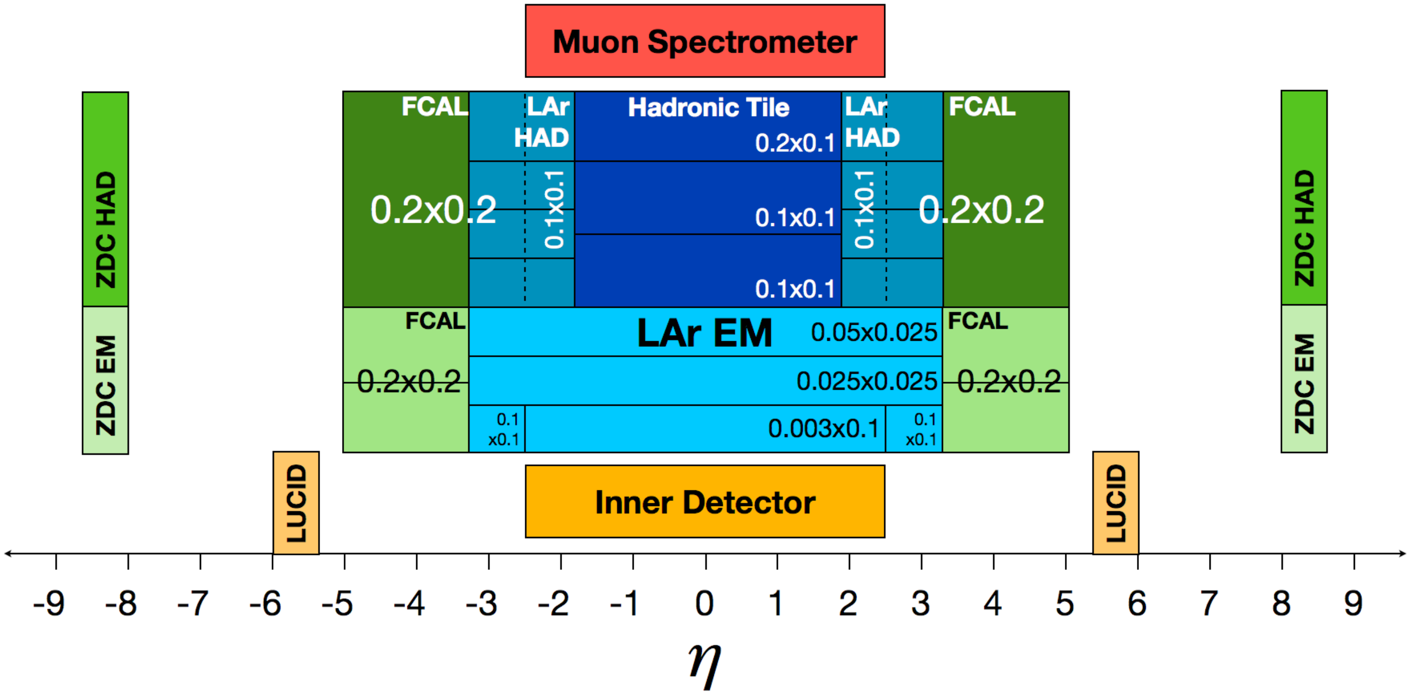
for the ATLAS Collaboration

The ATLAS detector



The ATLAS detector



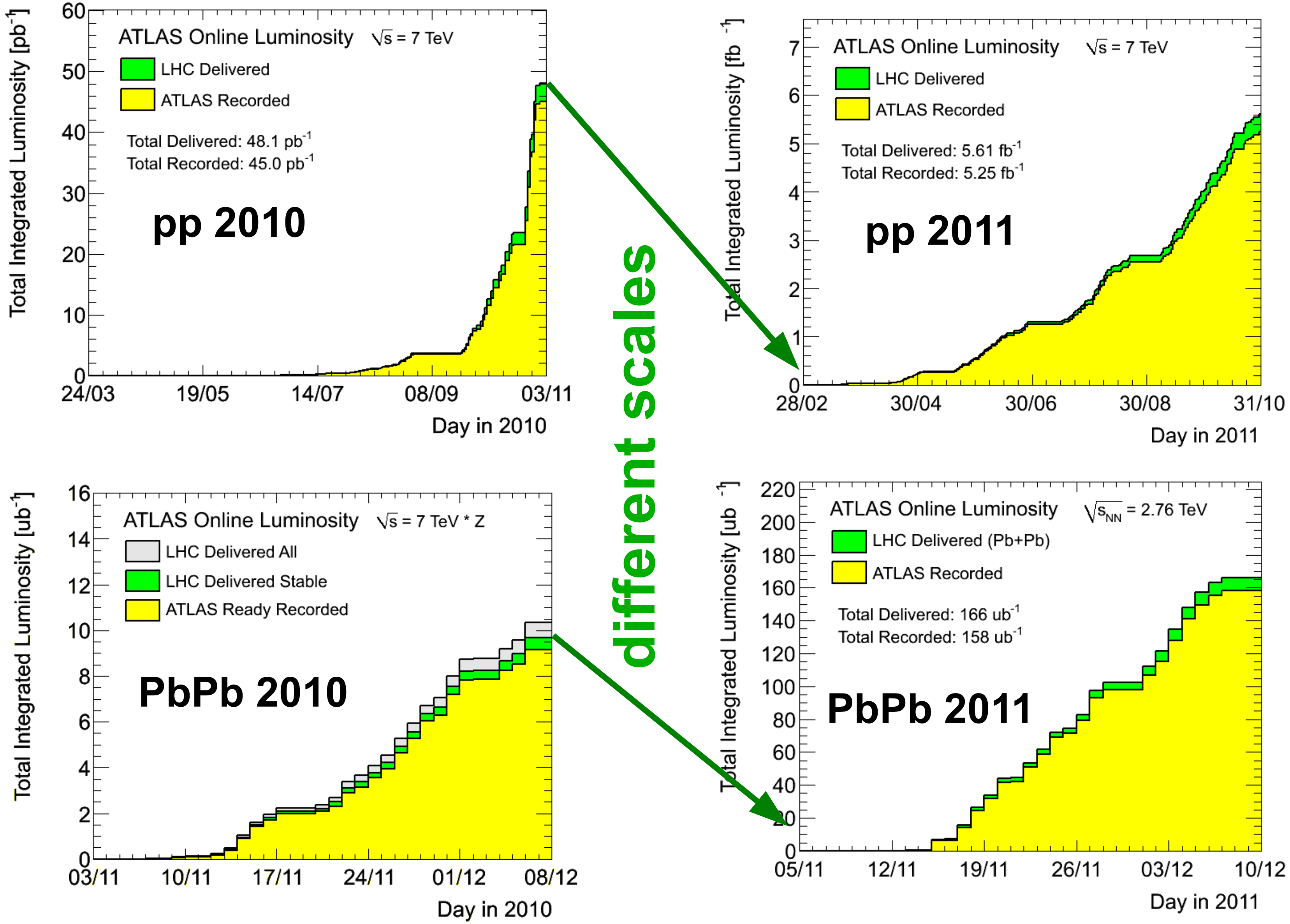
Inner detector ↔ $|\eta|<2.5$ → track reconstruction

Calorimeter ↔ $|\eta|<3.2$ → jet reconstruction

Forward Calorimeter ↔ $3.2<|\eta|<4.9$ ↔ centrality determination

Muon spectrometer ↔ $|\eta|<2.7$ → muon reconstruction

Data collected in 2010-2011

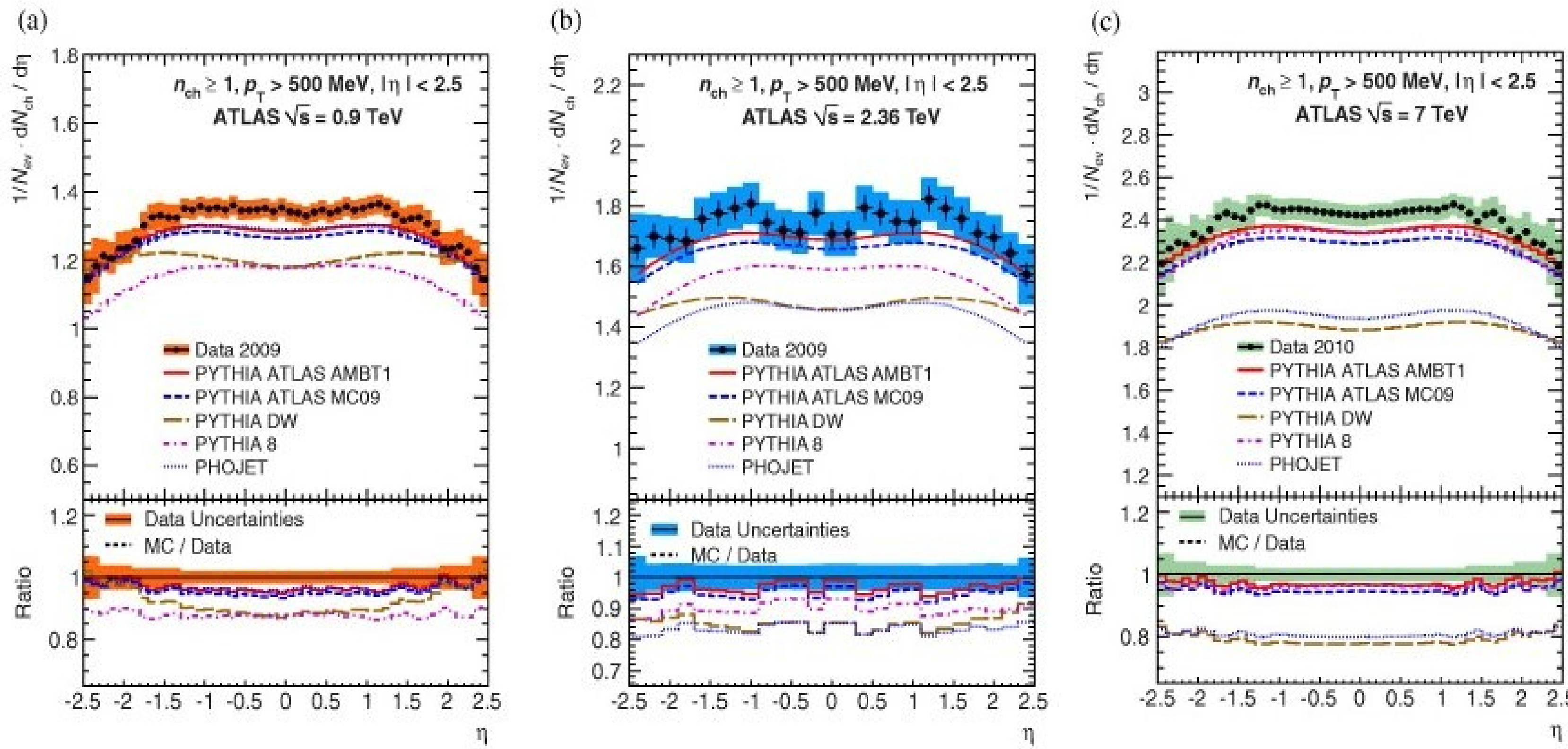


$5.25\ fb^{-1}$

$\sim 160\ \mu b^{-1}$

Particle production

$dN_{ch}/d\eta$ distribution in a wide pseudorapidity range $|\eta|<2.5$

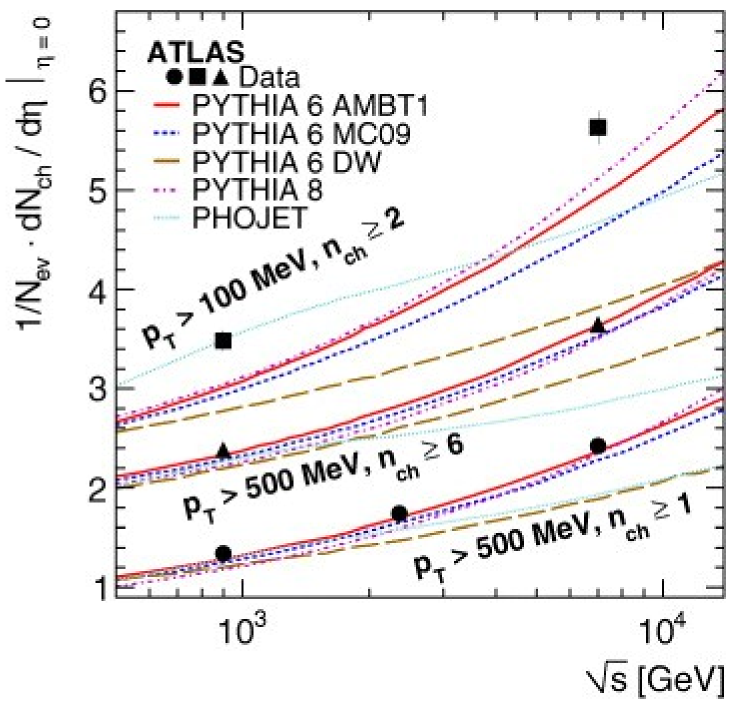


- three energies available: 900 GeV, 2.36 TeV and 7 TeV
- an increase in the number of particles by a factor ~2 from 900 GeV to 7 TeV
- data above predictions from all models

New. J. Phys. 13 (2011) 053033.

Particle production

Particle pseudorapidity density at $\eta=0$



An attempt to identify regions with a better data-MC agreement:

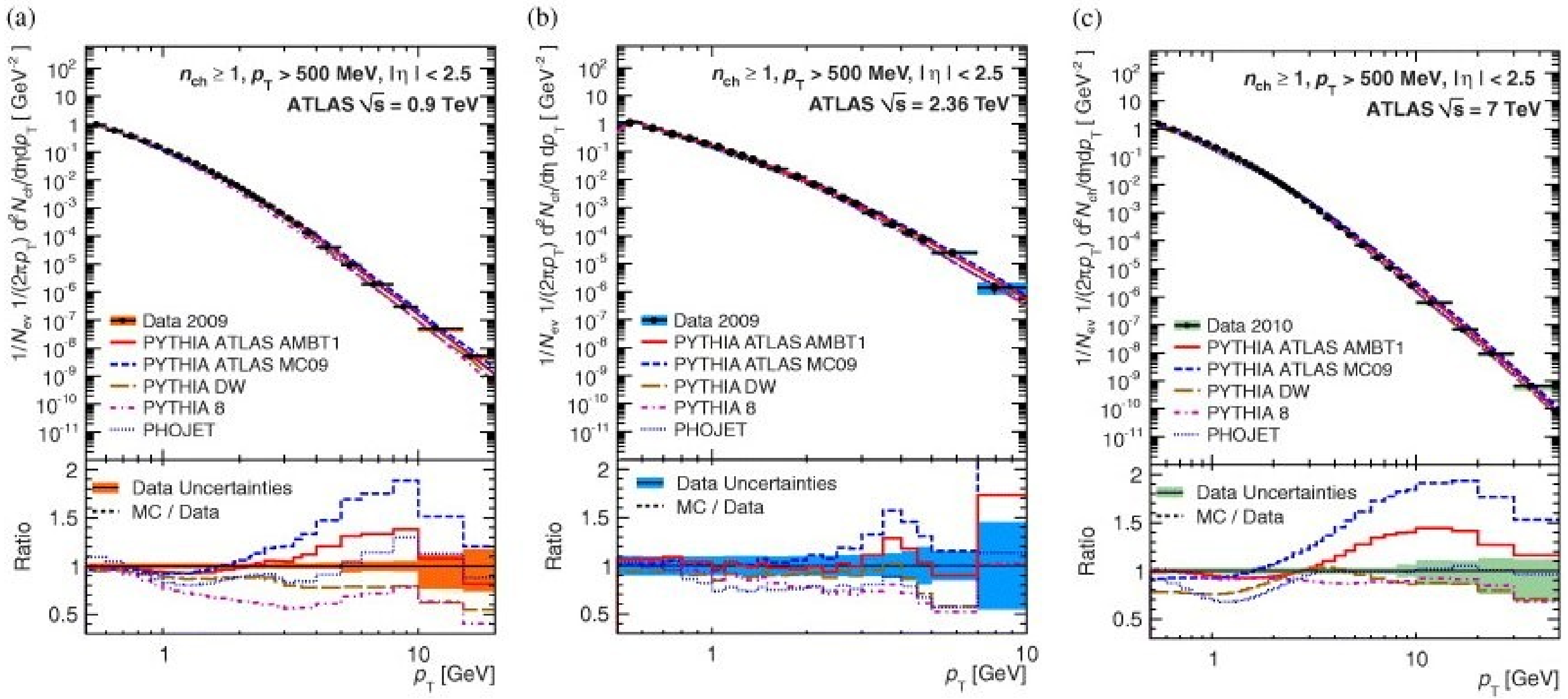
- **energy dependence studied**
- **minimal transverse momentum p_T>100 MeV or p_T>500 MeV**
- **events with different minimal number of tracks ($n_{ch}\geq1$, $n_{ch}\geq2$ or $n_{ch}\geq6$)**

Data points always above predictions from Monte Carlo models

New. J. Phys. 13 (2011) 053033.

Particle production

dN_{ch}/dp_T distribution

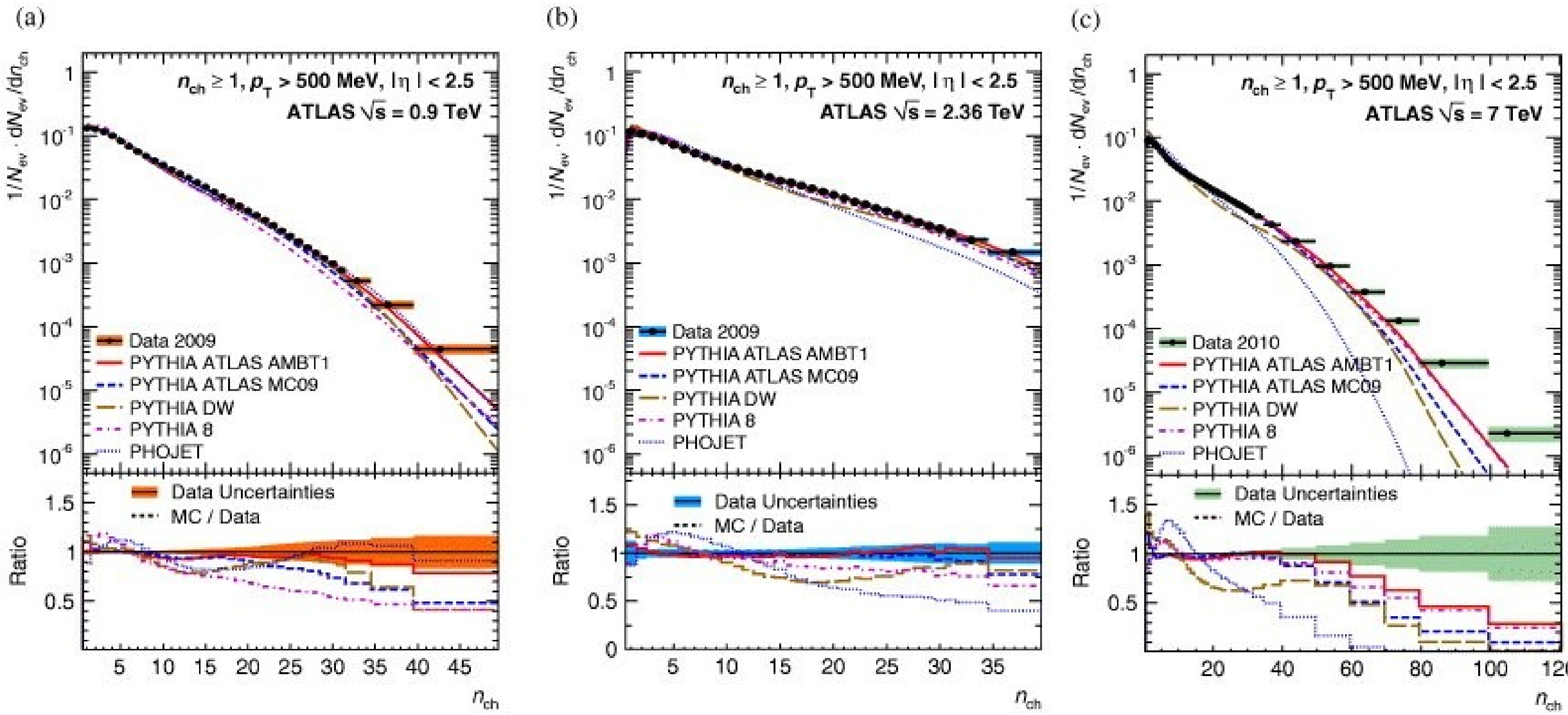


- **measured yields range up to 10 orders of magnitude**
- **differences in some p_T ranges**
- **PHOJET closest to the data**

New. J. Phys. 13 (2011) 053033.

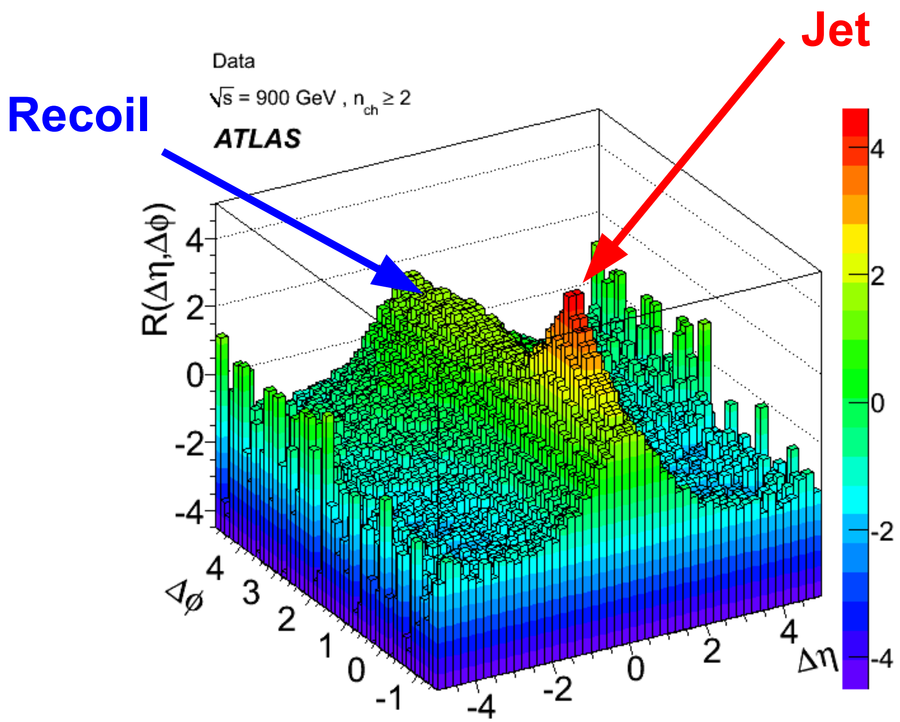
Particle production

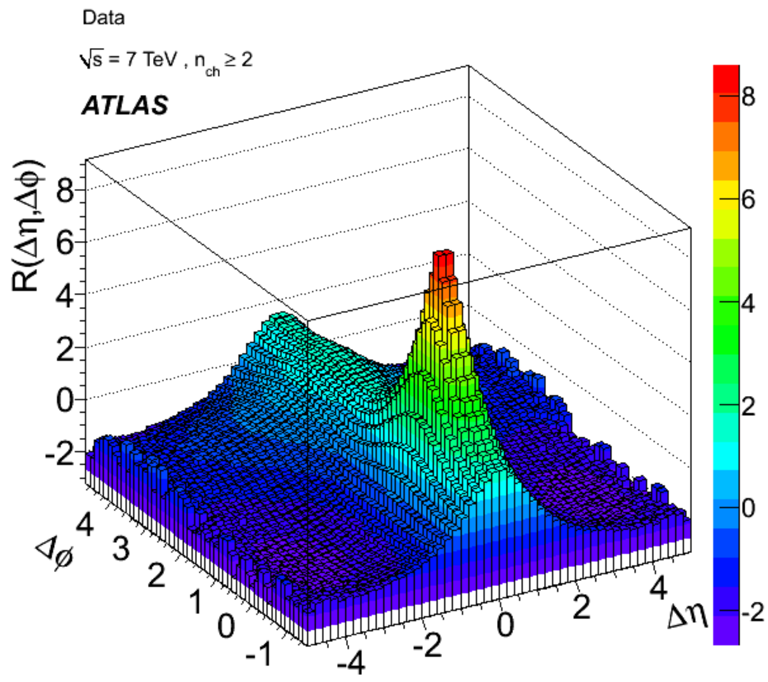
dN_{ev}/dn_{ch} distribution



- **differences in low n_{ch} region possibly due to large diffractive component**
- **poor agreement at large n_{ch}**

New. J. Phys. 13 (2011) 053033.





Two-particle correlations

$$R(\Delta\eta,\Delta\phi) = \frac{\langle (n_{ch}-1)F(n_{ch},\Delta\eta,\Delta\phi)\rangle_{ch}}{\langle B(n_{ch},\Delta\eta,\Delta\phi)\rangle_{ch}} - \frac{\langle (n_{ch}-1)B(n_{ch},\Delta\eta,\Delta\phi)\rangle_{ch}}{\langle B(n_{ch},\Delta\eta,\Delta\phi)\rangle_{ch}}$$

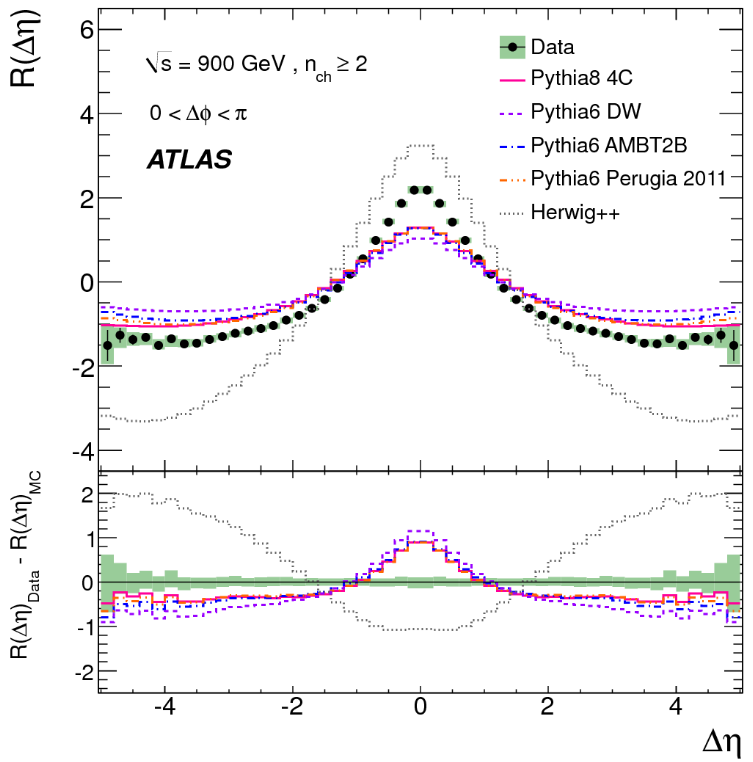
$$F(n_{ch},\Delta\eta,\Delta\phi) = \left\langle \frac{2}{n_{ch}(n_{ch}-1)} \sum_i \sum_{j\neq i} \delta(\eta_i-\eta_j-\Delta\eta)\,\delta(\phi_i-\phi_j-\Delta\phi) \right\rangle$$

$B(n_{ch},\Delta\eta,\Delta\phi)$ – background obtained from single particle distribution

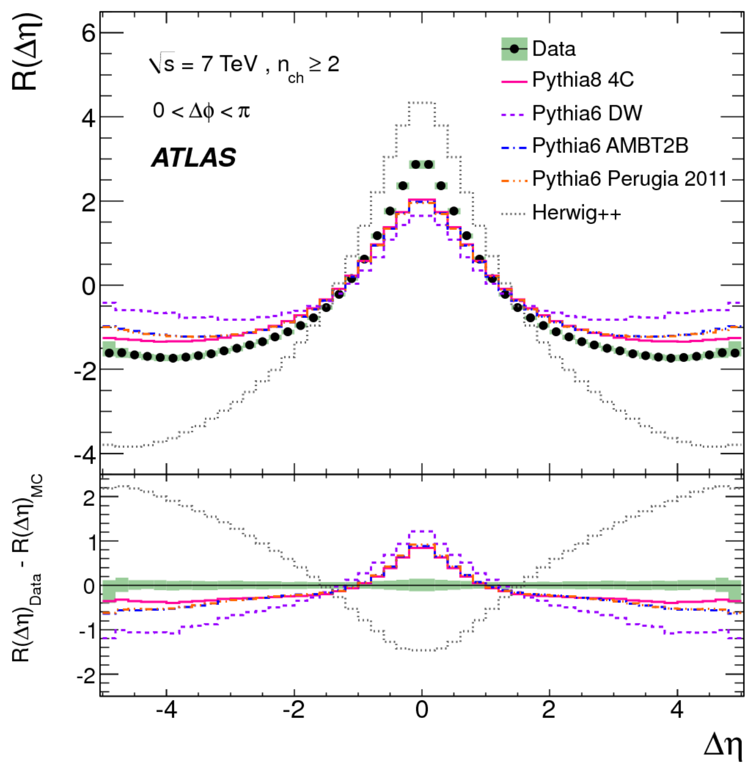
arXiv:1203.3549v1 [hep-ex]

Correlations

900 GeV 7 μb^{-1}



7 TeV 190 μb^{-1}



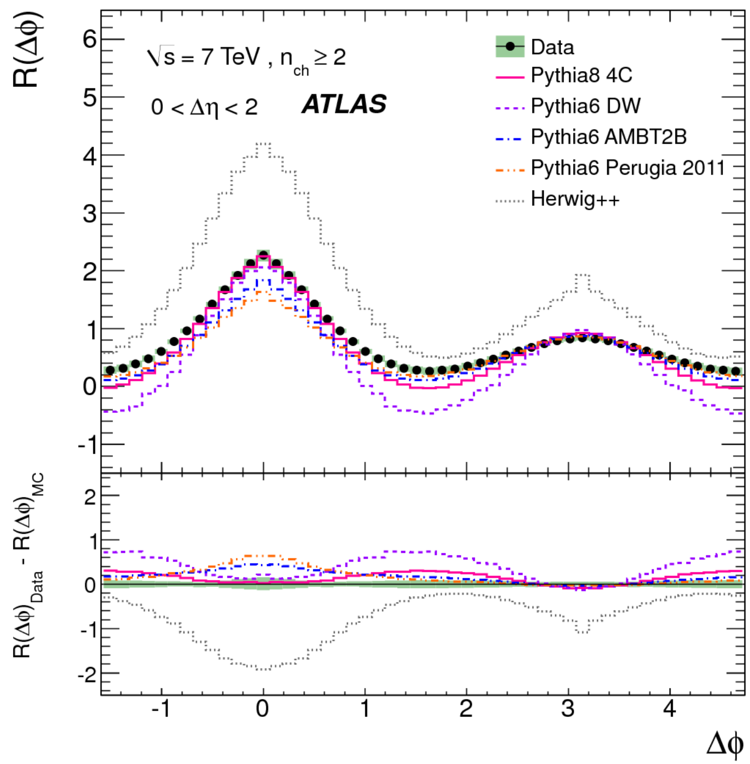
Two-particle correlations in pseudorapidity, integrated over Δϕ:

- **narrower at larger energy**
- **narrower in the events with higher multiplicity (not shown here)**
- **MC does not describe R(Δη) satisfactorily**

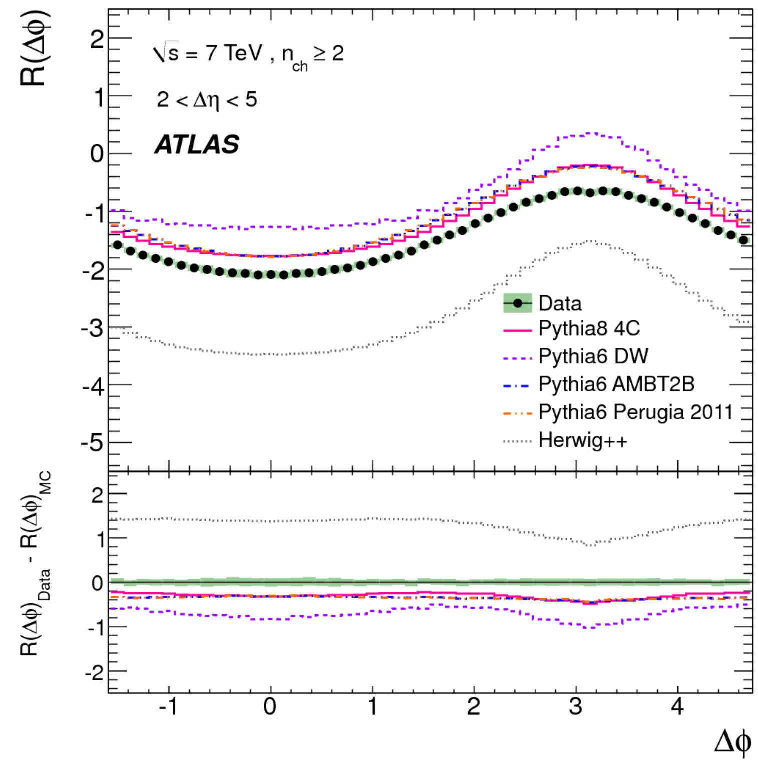
arXiv:1203.3549v1 [hep-ex]

Correlations

7 TeV 190 μb^{-1} short range



7 TeV 190 μb^{-1} long range

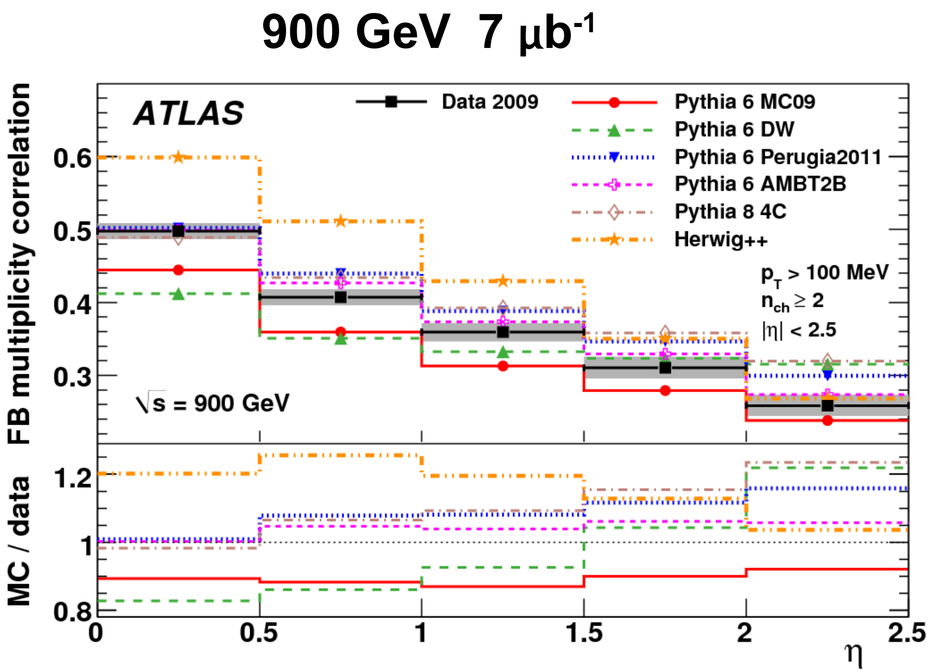


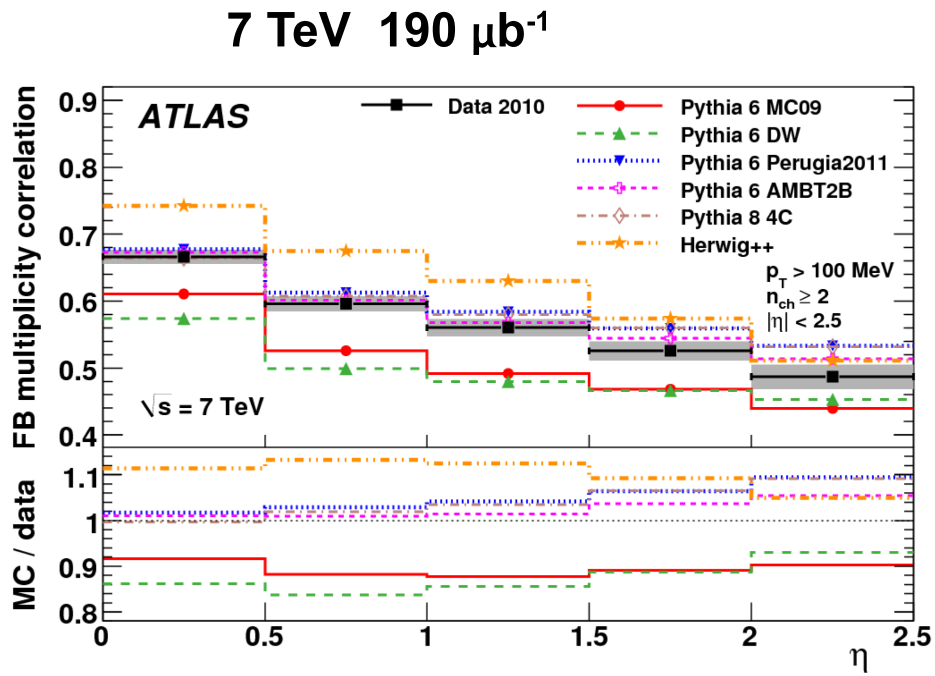
Two-particle correlations in azimuth, integrated over $\Delta\eta$ in short-range ($0<\Delta\eta<2$) or long-range ($2<\Delta\eta<5$):

- **short-range correlation: the main maximum at $\Delta\phi=0$ increases with energy, the second maximum at $\Delta\phi=\pi$ is approximately constant**
- **long-range correlations: a maximum at $\Delta\phi=\pi$ only**
- **MC describes the shape of R($\Delta\phi$), but not the correlation strength**

arXiv:1203.3549v1 [hep-ex]

Correlations

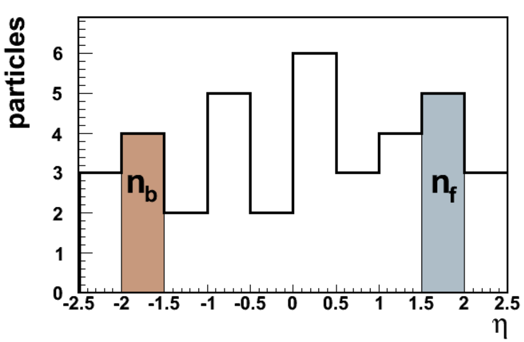




Forward-backward multiplicity correlation in symmetric bins in pseudorapidity:

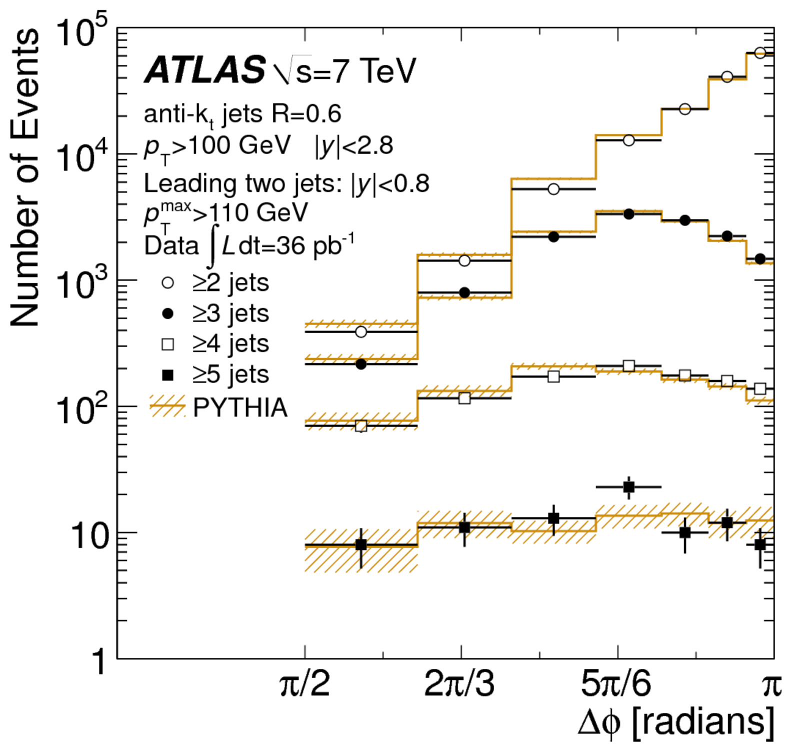
$$\rho_{fb} = \frac{\langle (n_f - \langle n_f \rangle)(n_b - \langle n_b \rangle) \rangle}{\sqrt{\langle (n_f - \langle n_f \rangle)^2 \rangle \langle (n_b - \langle n_b \rangle)^2 \rangle}}$$

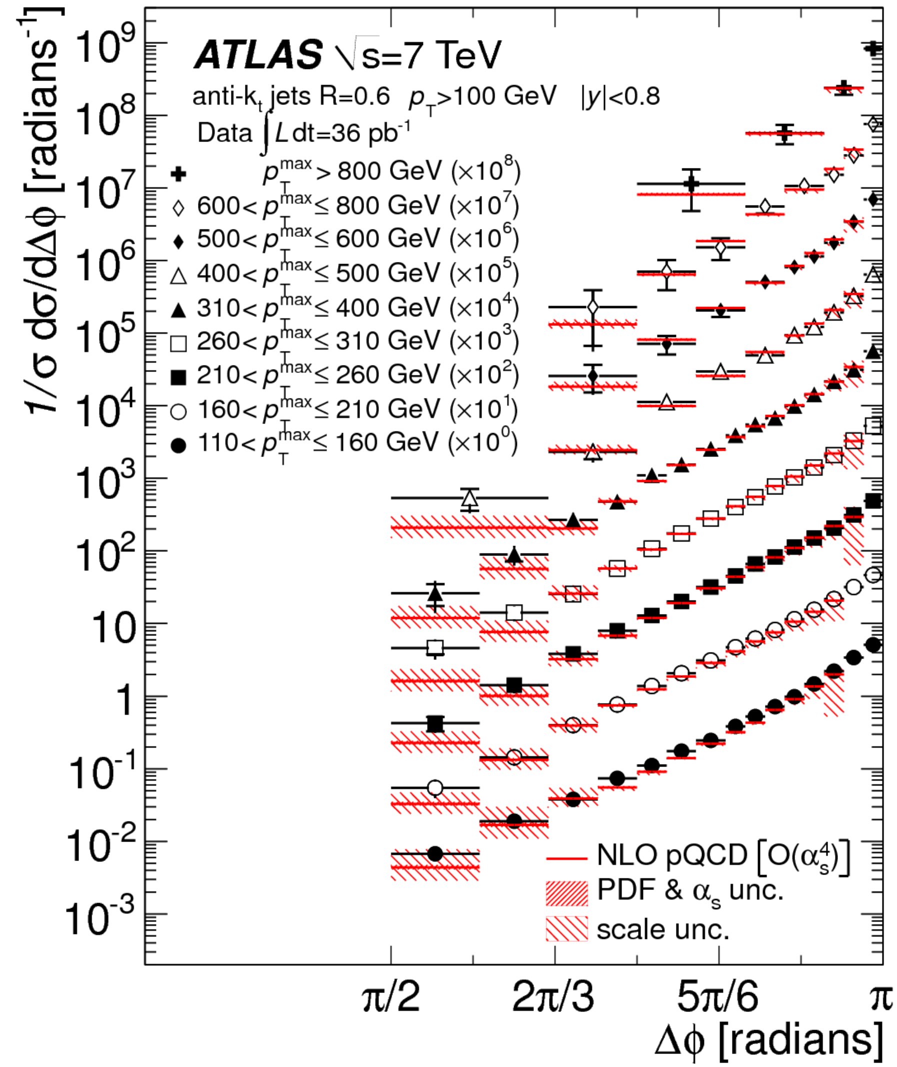
- **stronger in 7 TeV than at 900 GeV**
- **correlation decreasing with the distance in η**
- **correlation falling down with transverse momentum (not shown)**
- **MC models give similar correlations, but predict different values and/or different trends**



arXiv:1203.3100v1 [hep-ex].

Dijet azimuthal decorrelation

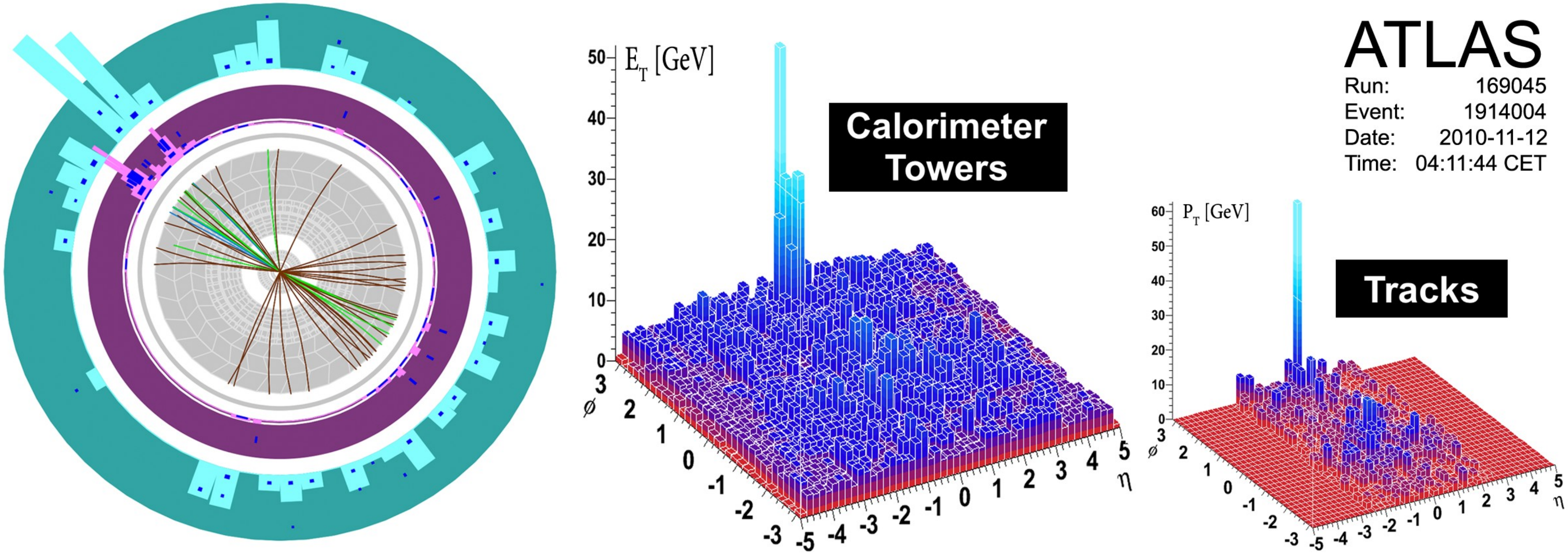




- **Partons producing jets are emitted back-to-back (Δϕ ≈π)**
- **QCD predicts azimuthal decorrelation especially in the multijet events**
- **MC models successfully describe the measured distributions**

Phys.Rev.Lett. 106 (2011) 172002.

13



Disappearance of one of the jets - attributed to interactions of partons in the hot and dense medium created in heavy ion collisions.

Quantitative description of the jet suppression:

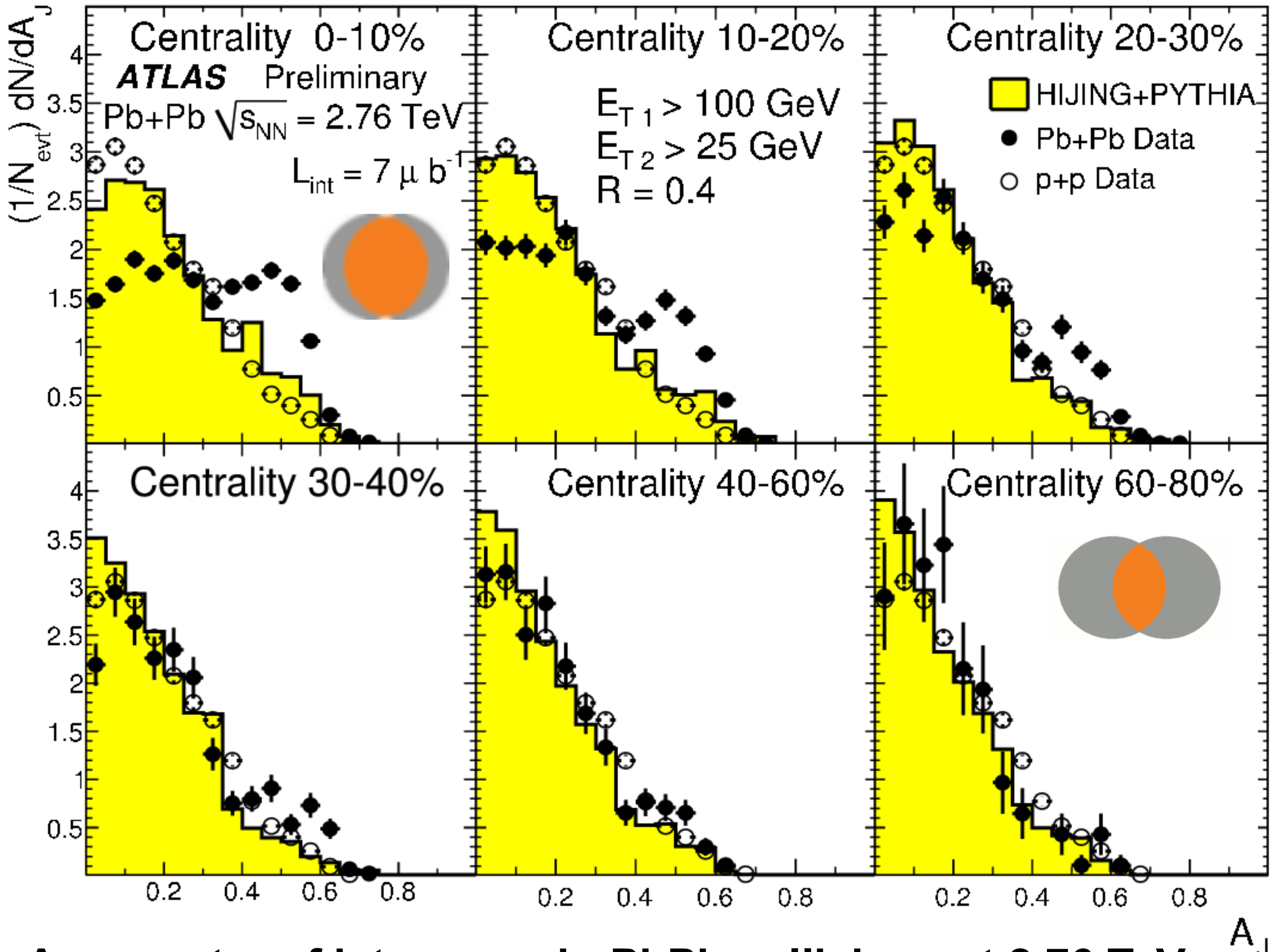
- **dijet energy asymmetry**
- **dijet azimuthal angle difference**

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

$$\Delta\phi = |\phi_1 - \phi_2|$$

Phys.Rev.Lett. 105 (2010) 252303.
ATLAS-CONF-2011-075.

Jets in PbPb collisions



$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

jet size parameter
R=0.4

Asymmetry of jet energy in PbPb collisions at 2.76 TeV:

- **in peripheral collisions is similar to that in pp collisions**
- **becomes much larger for more central events**
- **in HIJING+PYTHIA the dependence on centrality is much smaller.**

ATLAS-CONF-2011-075.

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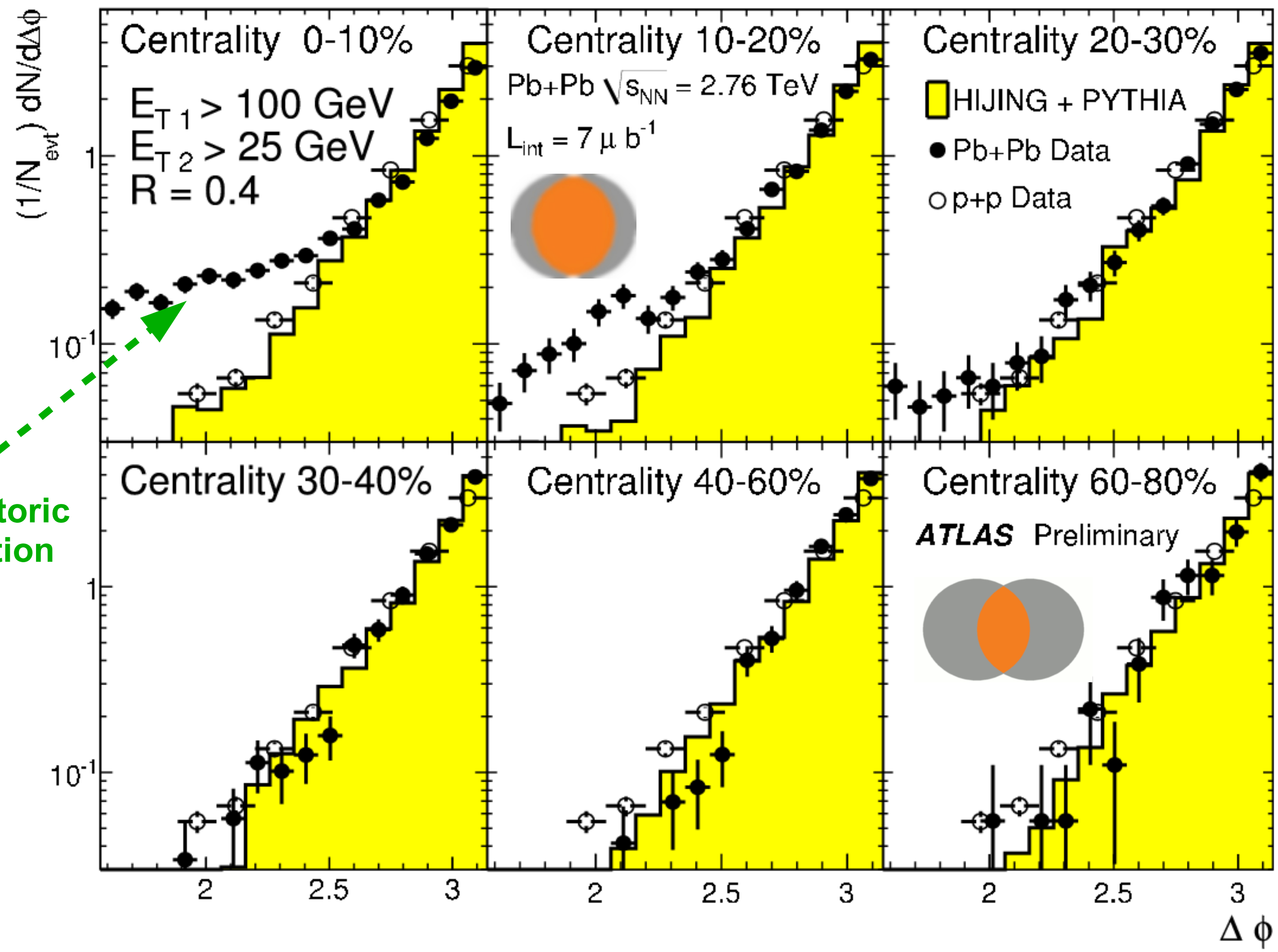
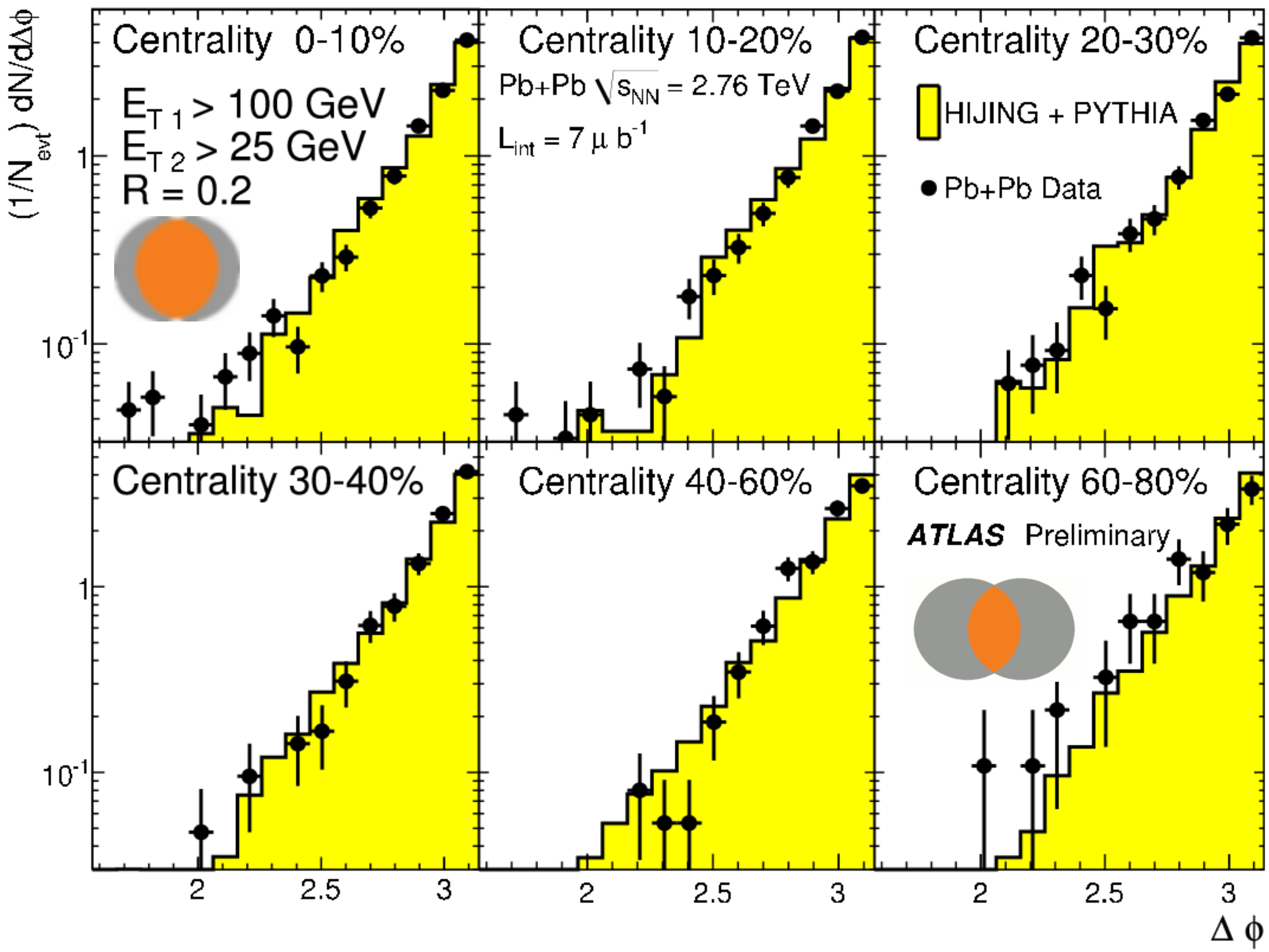


$$\Delta\phi = |\phi_1 - \phi_2|$$

jet size parameter R=0.4

Azimuthal dijet decorrelation almost independent of centrality
(with some combinatoric contribution for 0-20% centrality)

ATLAS-CONF-2011-075.



$$\Delta\phi = |\phi_1 - \phi_2|$$

jet size parameter

R=0.2

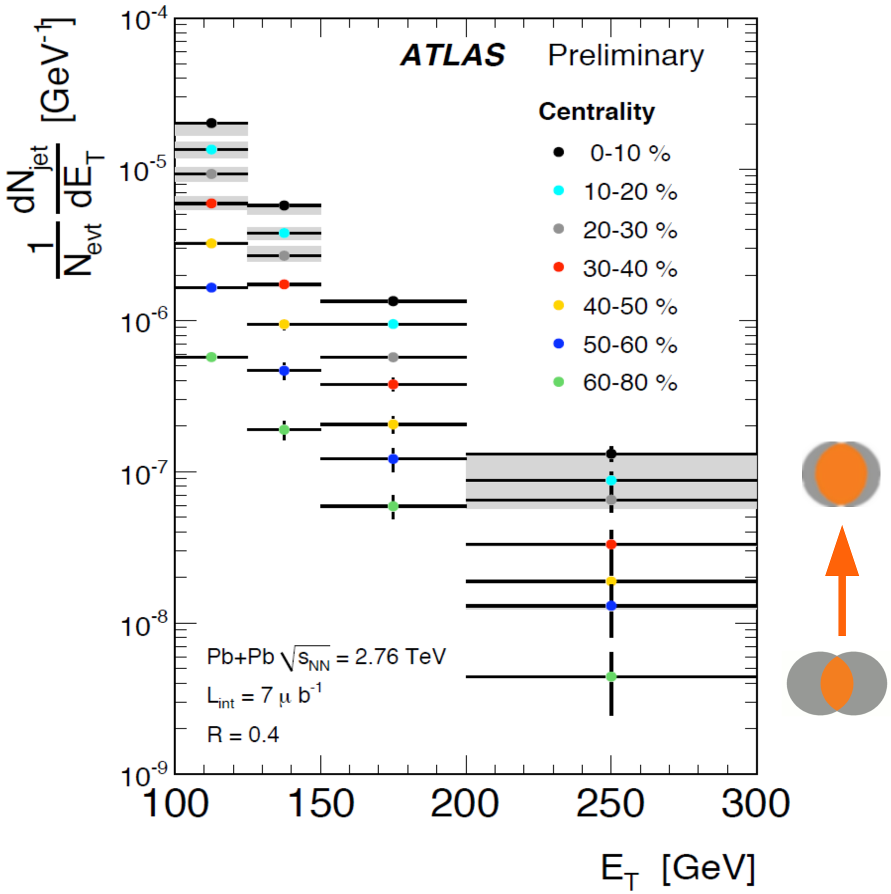
Azimuthal dijet decorrelation almost independent of centrality

(no combinatoric contribution for R=0.2)

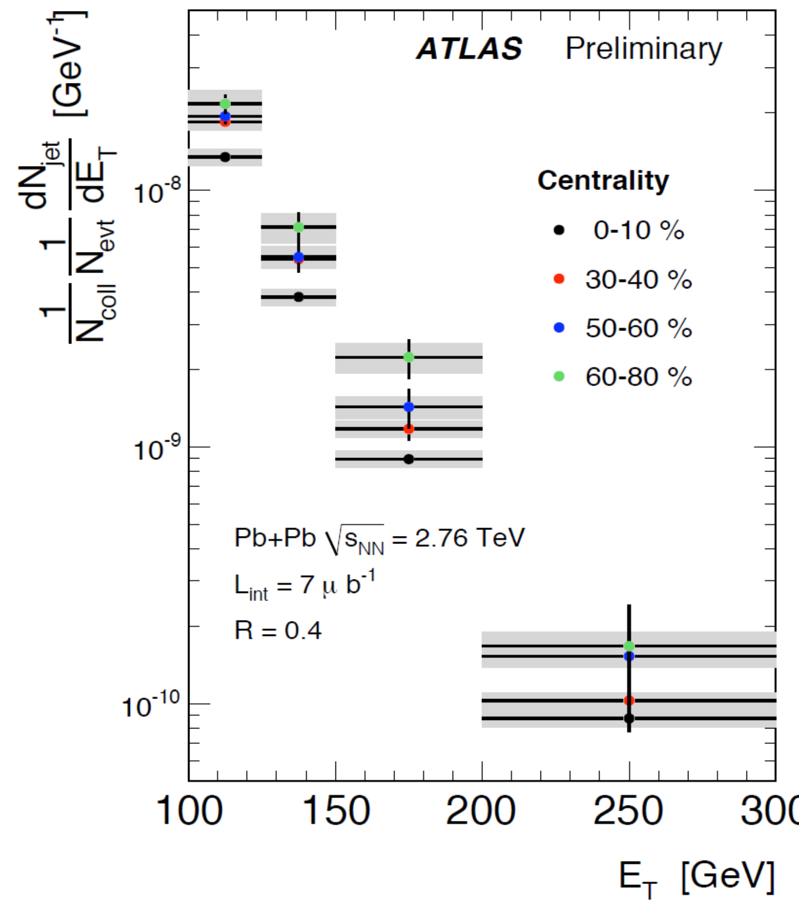
ATLAS-CONF-2011-075.

Jets in PbPb collisions

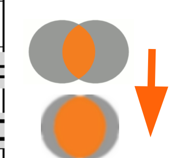
Absolute yields



Yields per collision



jet size parameter
R=0.4

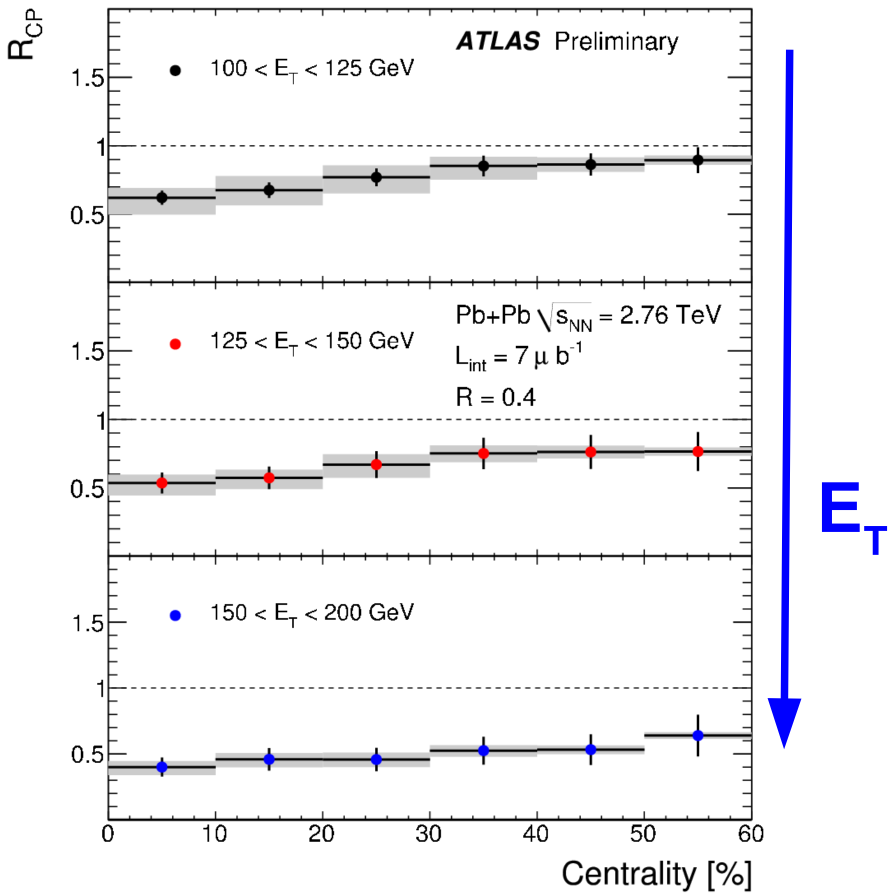


Jet yields in PbPb collisions at 2.76 TeV:

- **increase with centrality of PbPb collisions (~30 times)**
- **after scaling by the number of nucleon-nucleon collisions the trend becomes opposite - in peripheral collisions scaled yields are ~ 2 times larger**

ATLAS-CONF-2011-075.

Jets in PbPb collisions



R=0.4

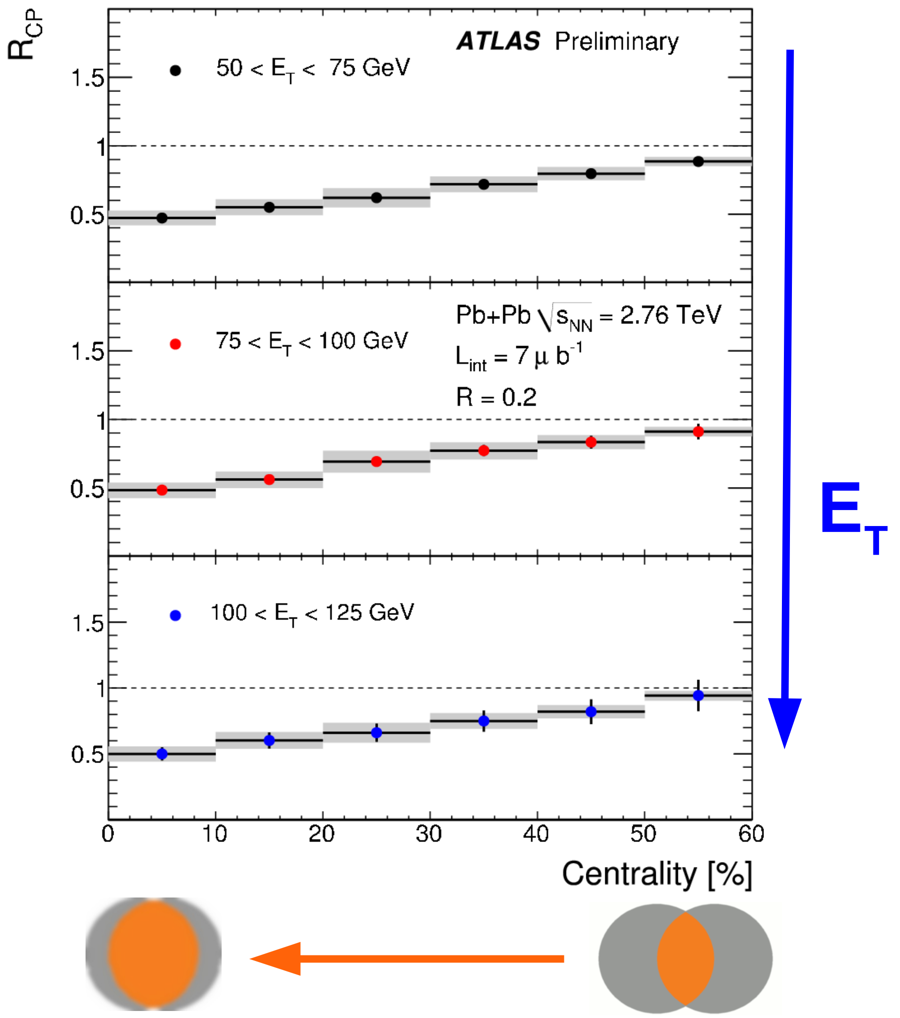
Relative jet yields - yields for centrality 0-10%, ... , 50-60% - divided by the yield for peripheral collisions (60-80%):

$$R_{CP} = \frac{\frac{1}{N_{coll}^{centr}} \frac{1}{N_{ev}^{centr}} \frac{dN_{jet}^{centr}}{dE_T}}{\frac{1}{N_{coll}^{60-80\%}} \frac{1}{N_{ev}^{60-80\%}} \frac{dN_{jet}^{60-80\%}}{dE_T}}$$

- **similar dependence on centrality in different jet energy ranges**
- **R_{CP} is smaller for more energetic jets**

ATLAS-CONF-2011-075.

Jets in PbPb collisions



R=0.2

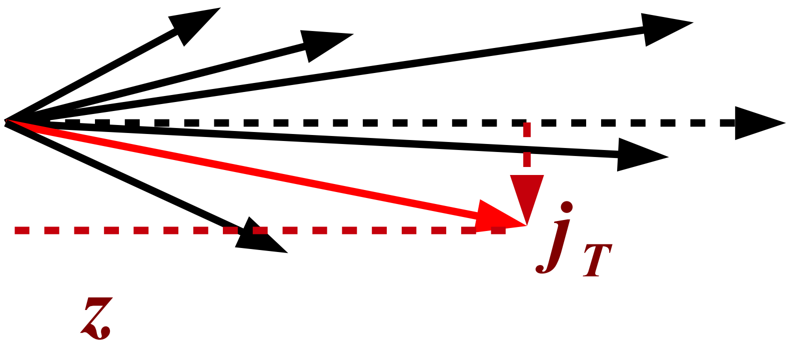
Relative jet yields - yields for centrality 0-10%, ... , 50-60% - divided by the yield for peripheral collisions (60-80%):

$$R_{CP} = \frac{\frac{1}{N_{coll}^{centr}} \frac{1}{N_{ev}^{centr}} \frac{dN_{jet}^{centr}}{dE_T}}{\frac{1}{N_{coll}^{60-80\%}} \frac{1}{N_{ev}^{60-80\%}} \frac{dN_{jet}^{60-80\%}}{dE_T}}$$

- **the same R_{CP} in all three jet energy ranges**

ATLAS-CONF-2011-075.

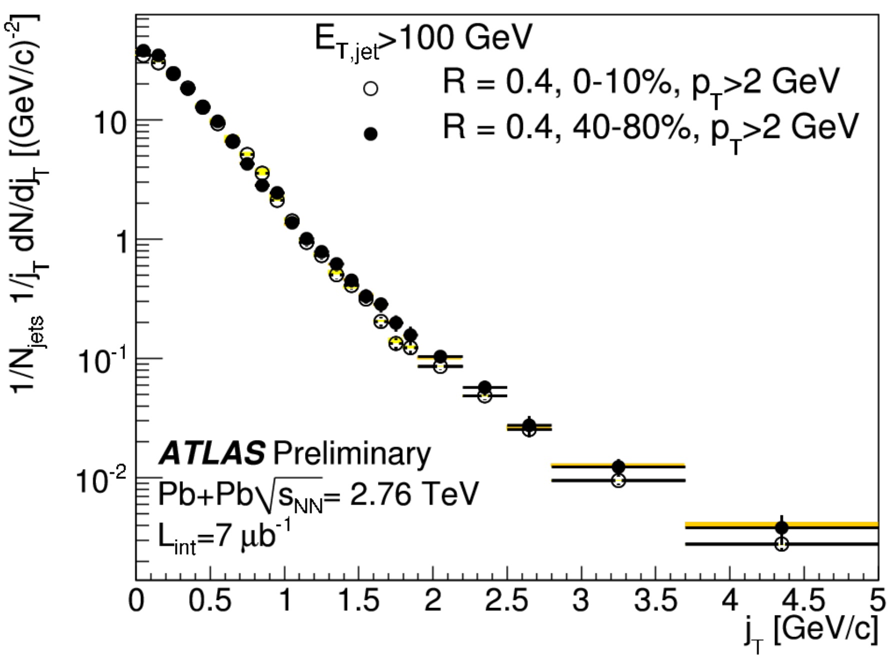
Transverse and logitudinal structure of jets

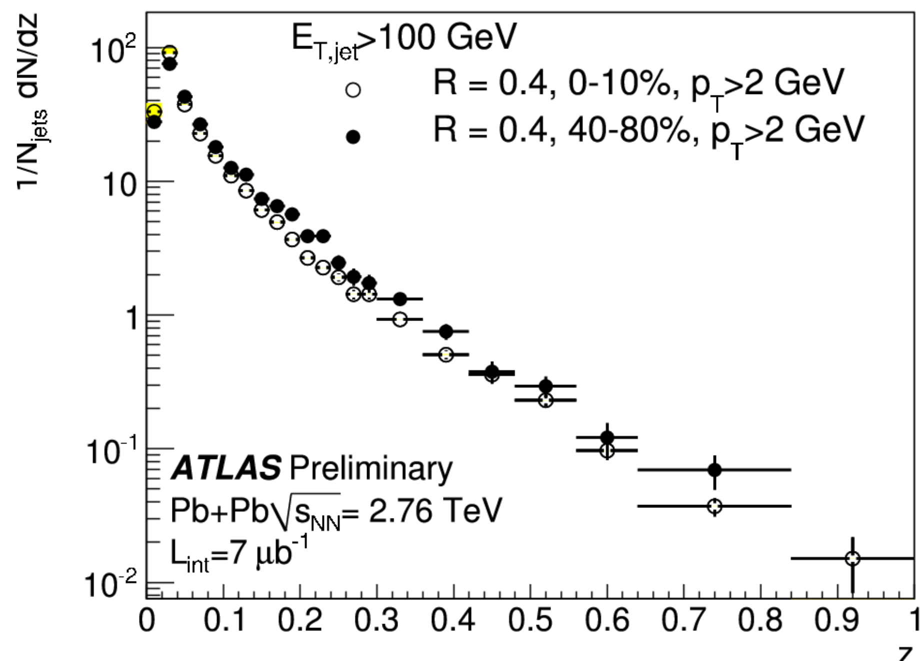


$$j_T = p_T^{had} \sin(\Delta R)$$

$$z = \frac{p_T^{had}}{E_T} \cos(\Delta R)$$

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$





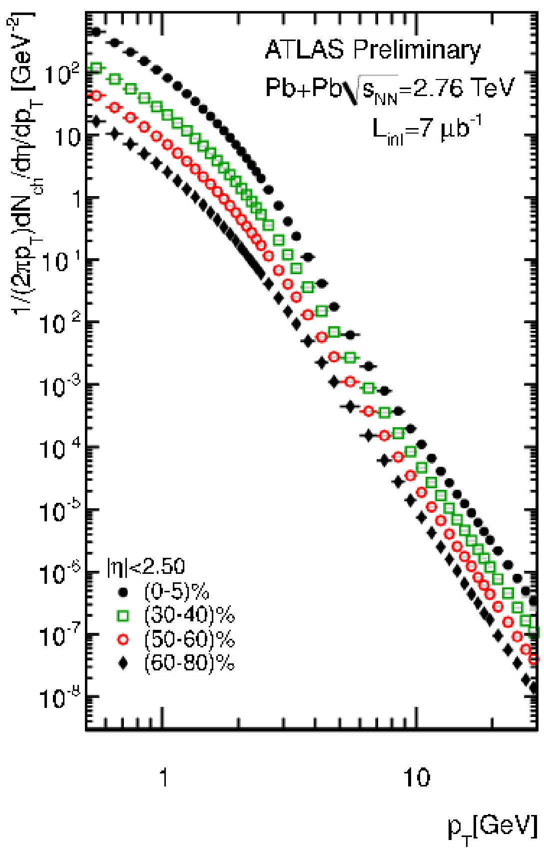
Comparison of longitudinal structure in 0-10% and 40-80% centralities

- **No evidence of significant softening of jets.**

ATLAS-CONF-2011-075.

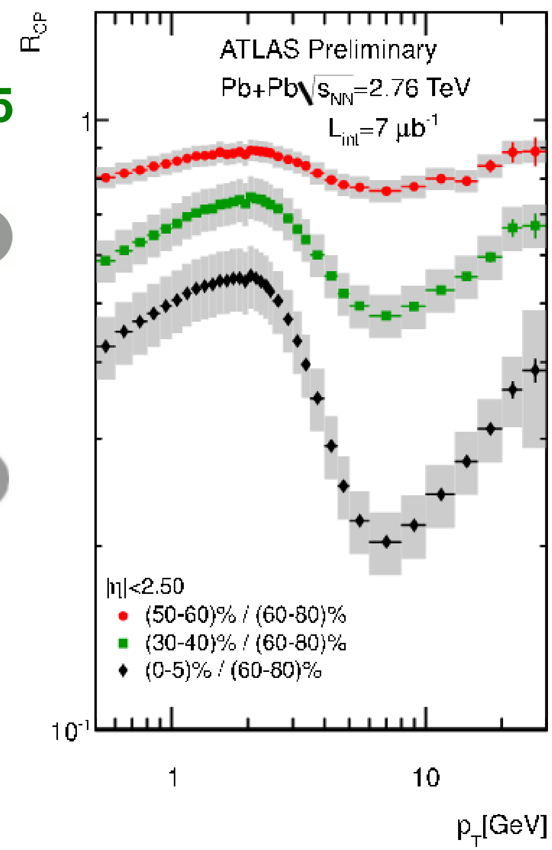
Particle production in PbPb collisions

Charged particle spectra



Charged particle R_{CP}

|η|<2.5



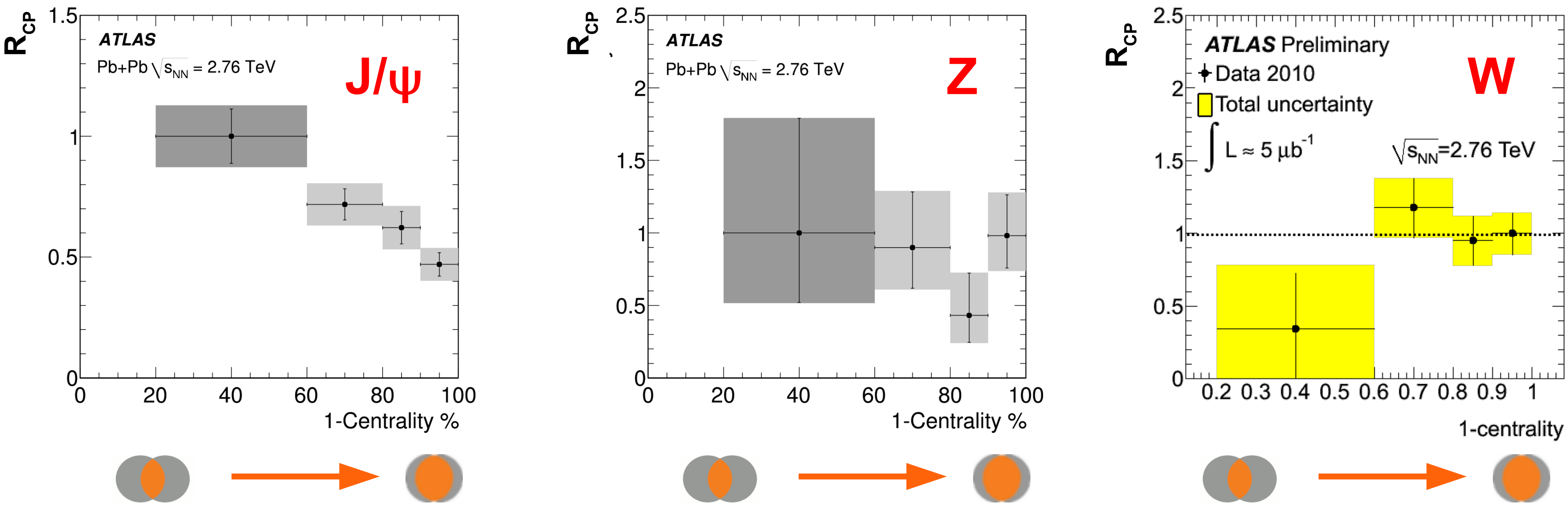
$$R_{CP} = \frac{\frac{1}{N_{coll}^{centr}} \frac{1}{N_{ev}^{centr}} \frac{d^2 N^{centr}}{d\eta\, dp_T}}{\frac{1}{N_{coll}^{60-80\%}} \frac{1}{N_{ev}^{60-80\%}} \frac{d^2 N^{60-80\%}}{d\eta\, dp_T}}$$

Charged particle spectra in PbPb collisions at 2.76 TeV:

- **measured up to ~30 GeV as a function of centrality and η (not shown)**
- **R_{CP} drops between 2-7 GeV to the values observed at RHIC**
- **above 7 GeV R_{CP} increases reaching 0.5 for the most central collisions**

ATLAS-CONF-2011-079.

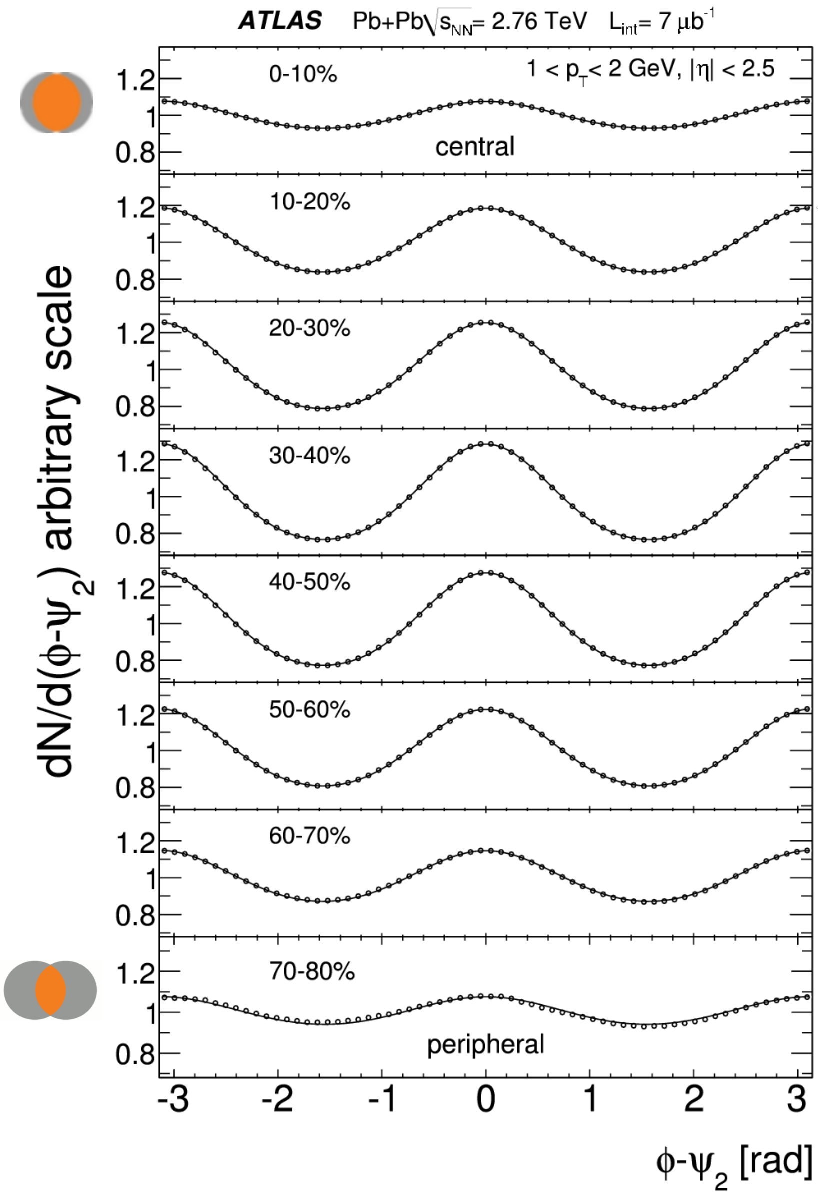
Particle production in PbPb collisions



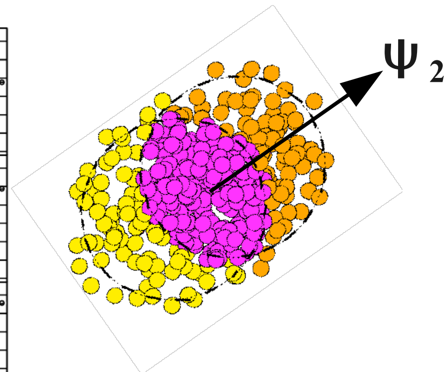
- for J/ψ R_{CP}=0.5 for the most central collisions
- Z boson and W boson measurements are consistent with no suppression, R_{CP}=1

Phys.Lett. B697 (2011) 294-312, ATLAS-CONF-2011-078.

Flow in PbPb collisions - event plane method

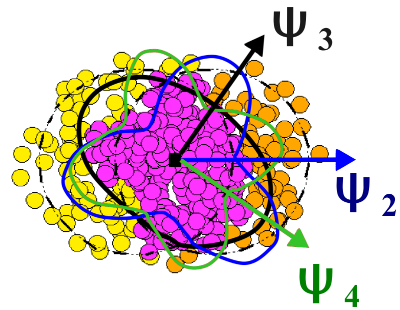


Overlap of the nuclei has approximately elliptic shape:



$$\frac{dN}{d(\phi-\psi_2)} \sim 1 + 2v_2\cos(2(\phi-\psi_2))$$

Due to fluctuations of nucleon positions the shape of the overlap is frequently deformed and higher order components of a Fourier series are necessary:



$$\frac{dN}{d(\phi-\psi_2)} \sim 1 + 2\sum_{n=1}^{\infty} v_n\cos(n(\phi-\psi_n))$$

Components up to n=6 are large enough to be determined with sufficient accuracy.

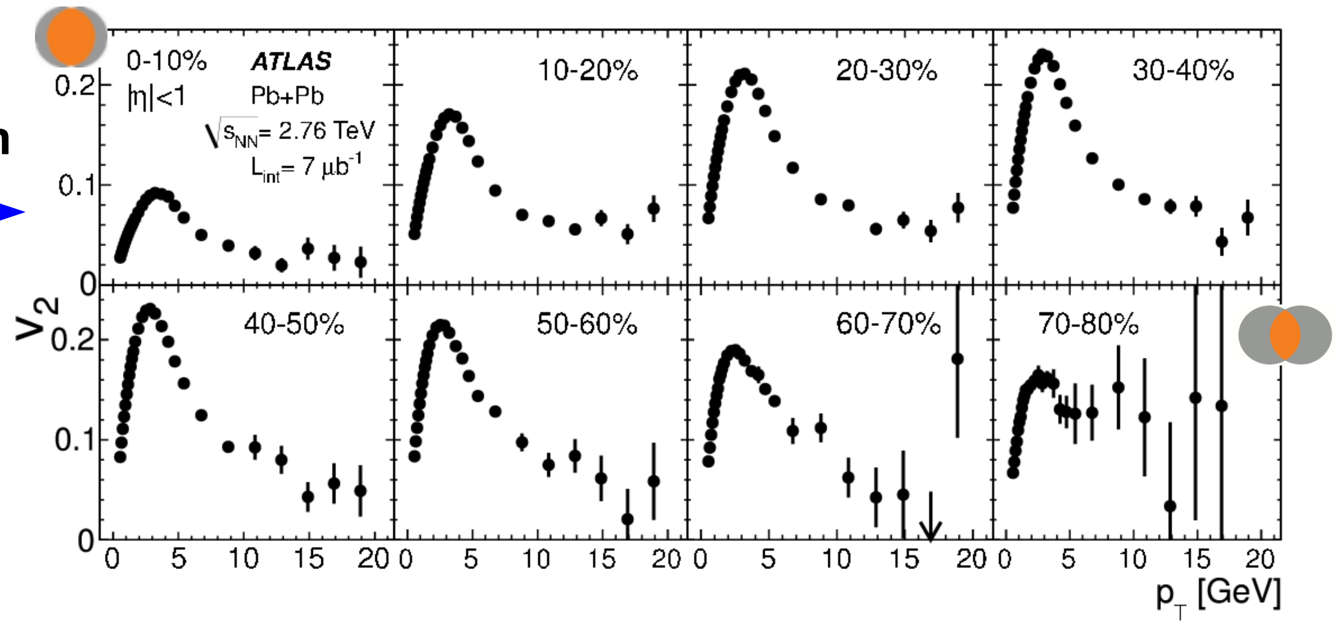
Presence of flow is explained by hydrodynamics and requires a fluid with very low viscosity.

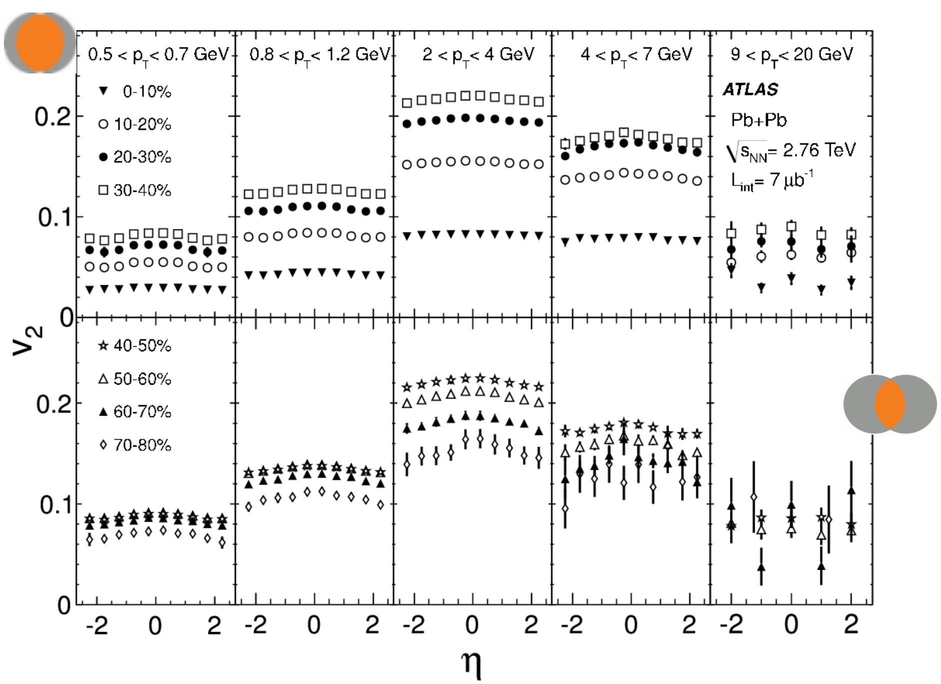
Phys.Lett. B707 (2012) 330-348.

Flow in PbPb collisions - event plane method

Elliptic flow v_2 dependence on

- **transverse momentum**
- **pseudorapidity**





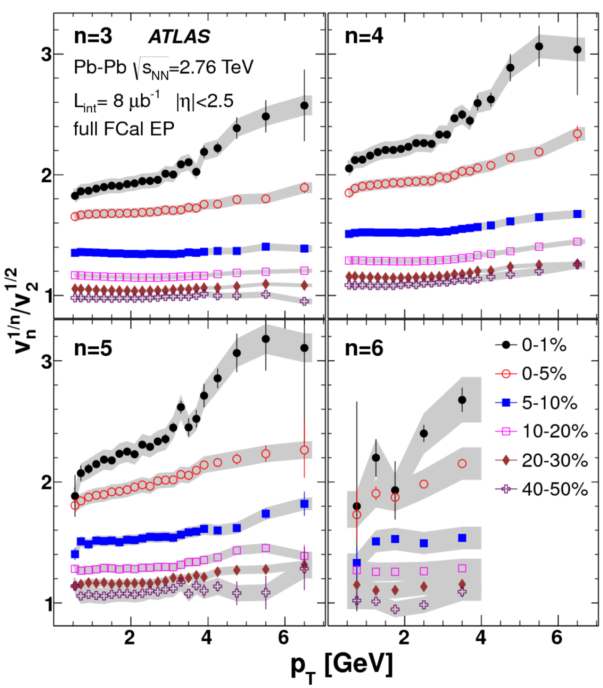
- **in the most central events flow is small**
- **the largest v_2 values are obtained for centrality 30-50%**
- **the maximal v_2 value is reached for transverse momentum 3-4 GeV**
- **v_2 is approximately flat in the pseudorapidity range |η| < 2**

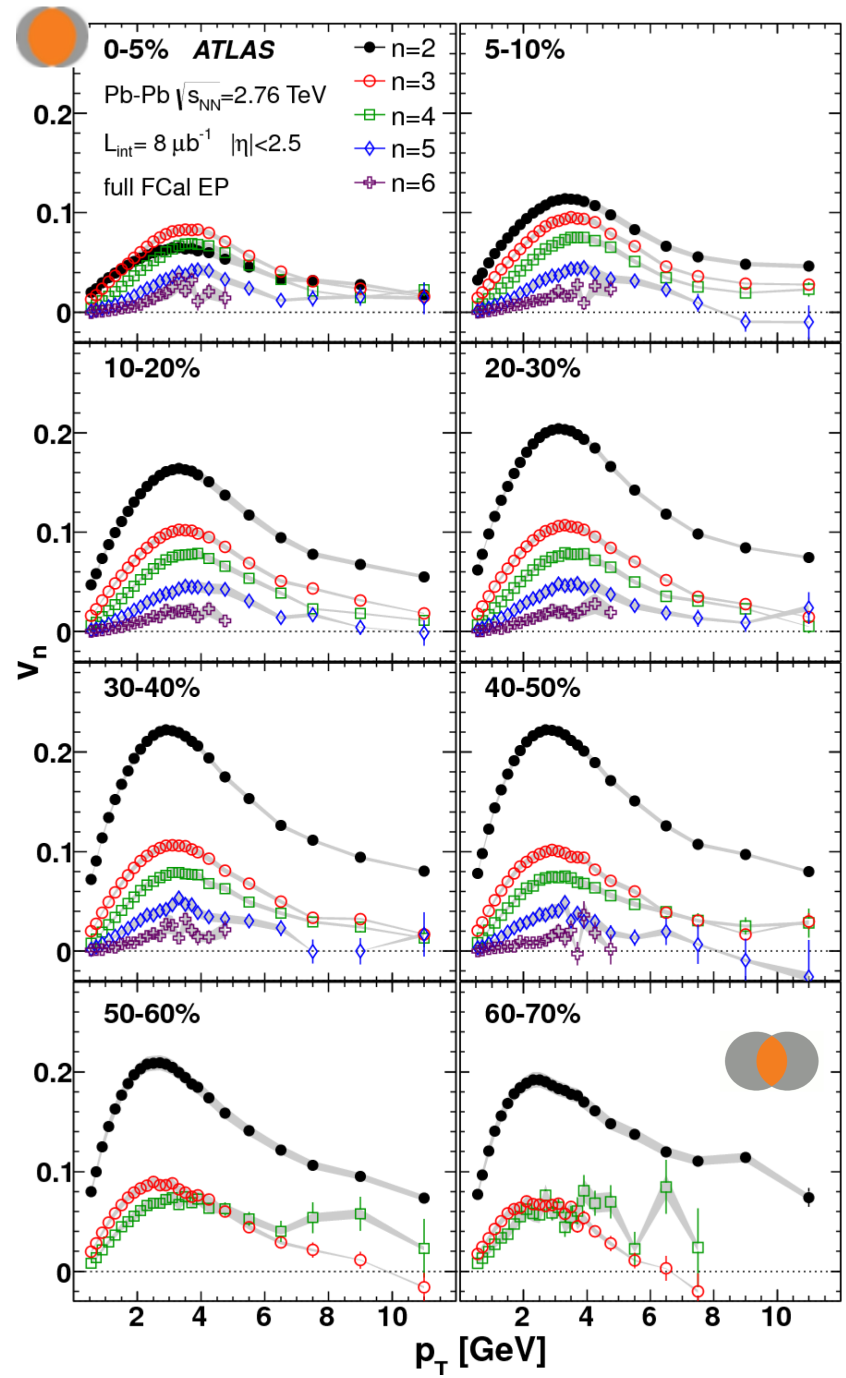
Phys.Lett. B707 (2012) 330-348.

Flow in PbPb collisions - event plane method

Comparison of v_n values:

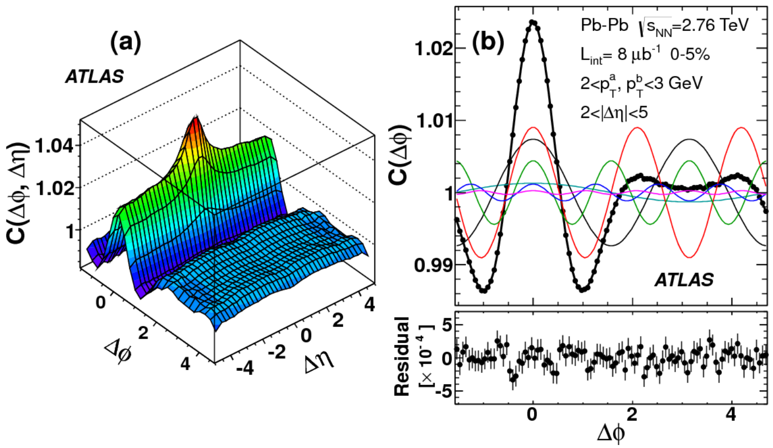
- v_2 is the largest - with exception of the most central events
- dependence on p_T for all v_n components is similar, they increase with p_T up to 3–4 GeV and then decrease
- approximate scaling of $\frac{v_n^{1/n}}{v_2^{1/2}}$





arXiv:1203.3087v2 [hep-ex]

Flow in PbPb collisions - two particle correlations method

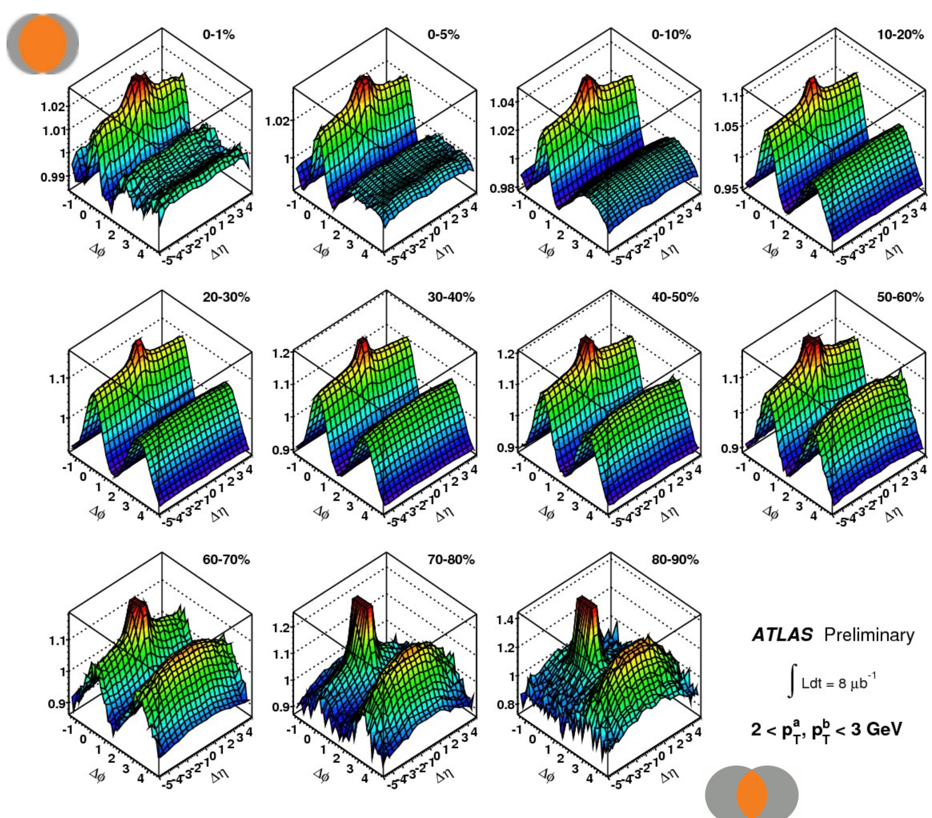


Decomposition of two-particle correlations:

$$\frac{dN}{d\Delta\phi} \sim 1 + 2\sum_{n=1}^{\infty} v_{n,n}\cos(n\Delta\phi)$$

Factorization in the case of collective expansion:

$$v_{n,n}(p_T^a, p_T^b) = v_n(p_T^a)\, v_n(p_T^b)$$

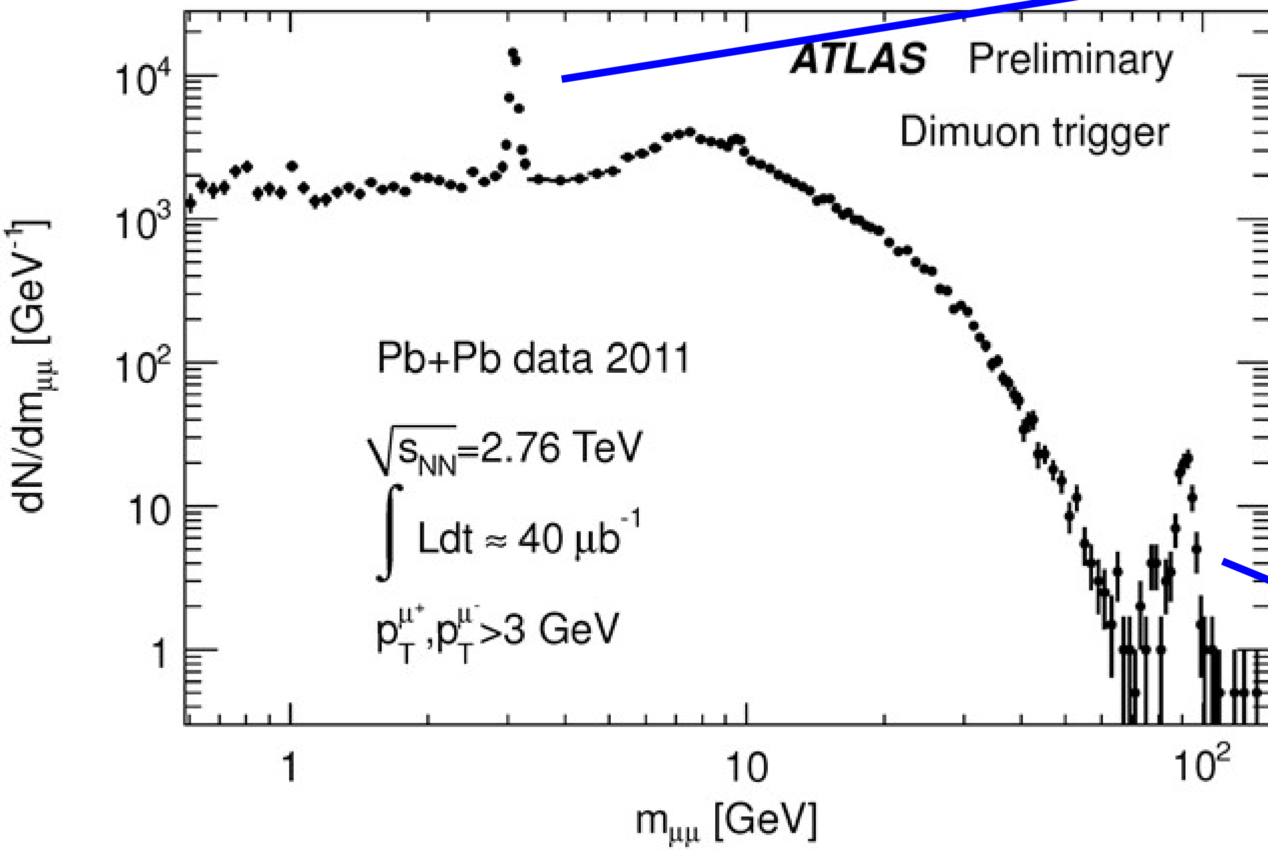


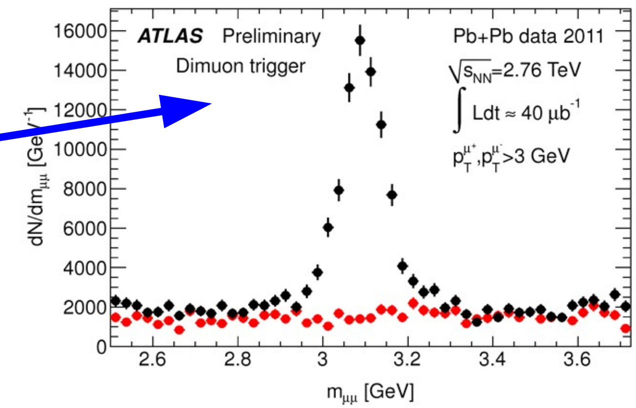
- Calculations of $v_{n,n}$ coefficients in slices of $|\Delta\eta|$ and p_T
- in central and semicentral collisions for $|\Delta\eta|>2$ and p_T < 3 GeV factorization of coefficients expected in collective expansion and reflecting initial nucleon fluctuations is valid
- no factorization for larger momenta (effects from jets) and $v_{1,1}$ (momentum conservation)

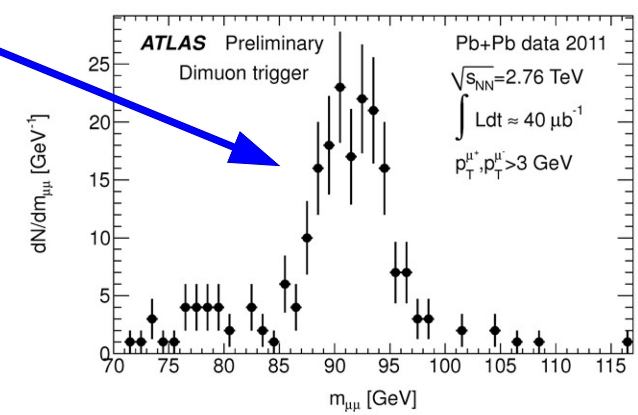
arXiv:1203.3087v2 [hep-ex]

Analysis of PbPb data from 2011

Preliminary performance results

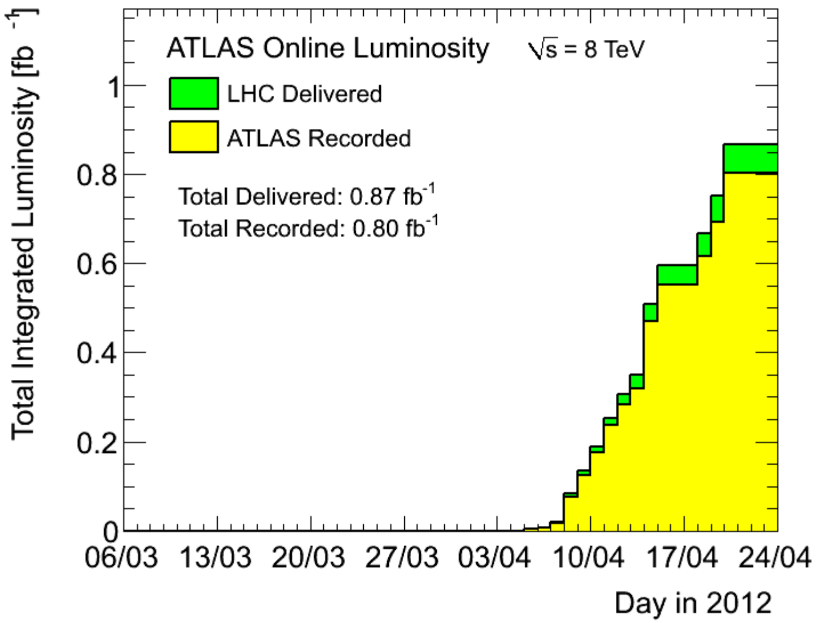




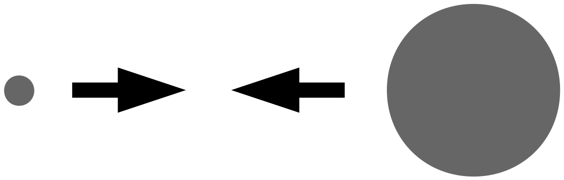


New data to be collected

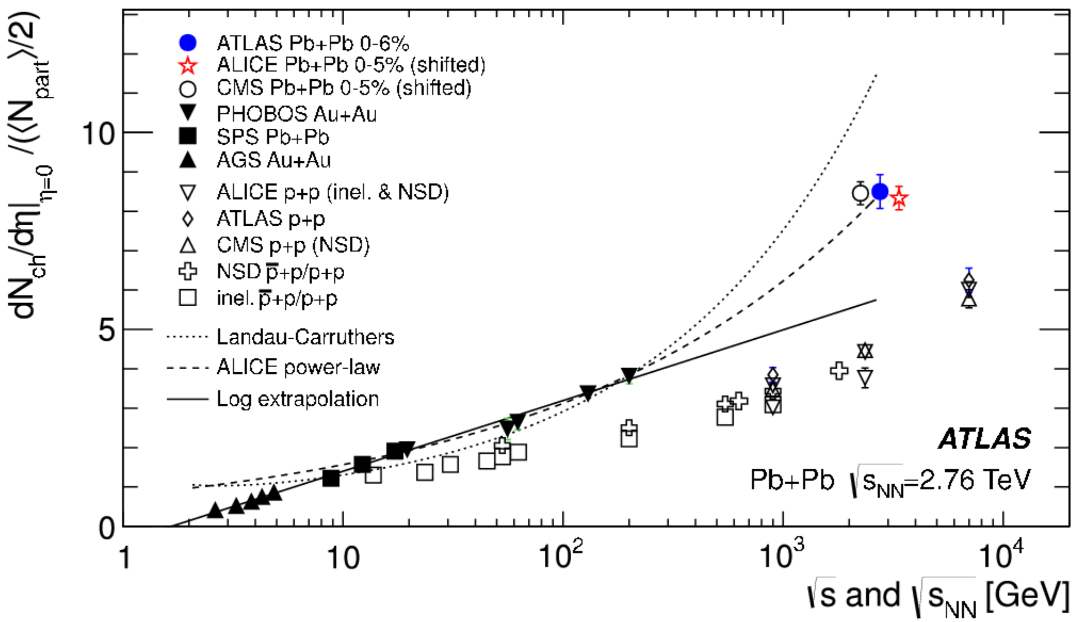
- **pp collisions at 8 TeV**

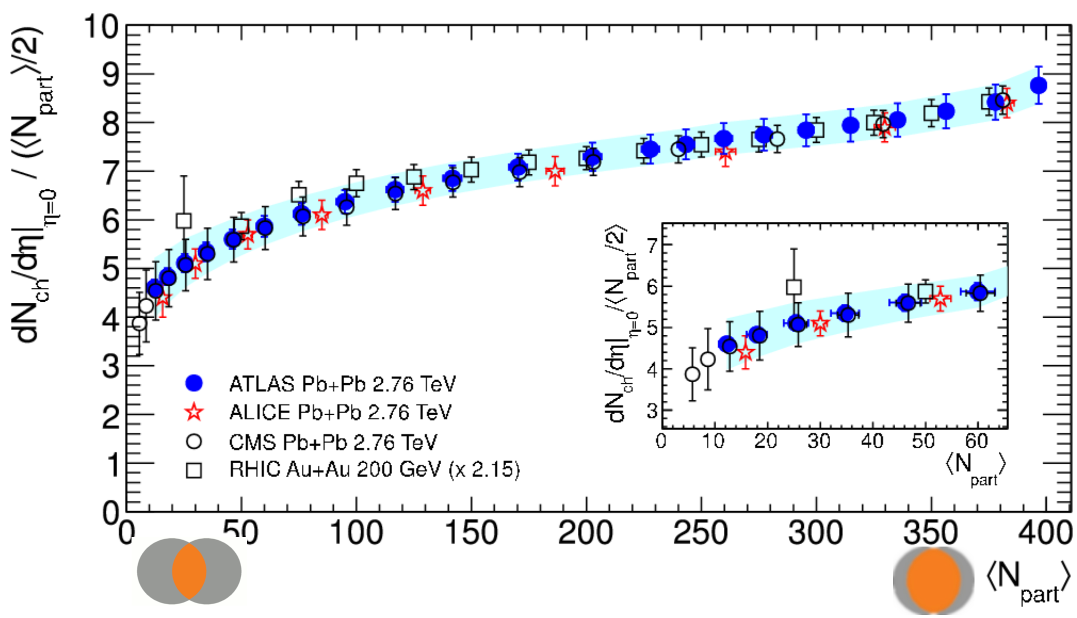


- **pPb collisions in November 2012**



Particle production in PbPb collisions

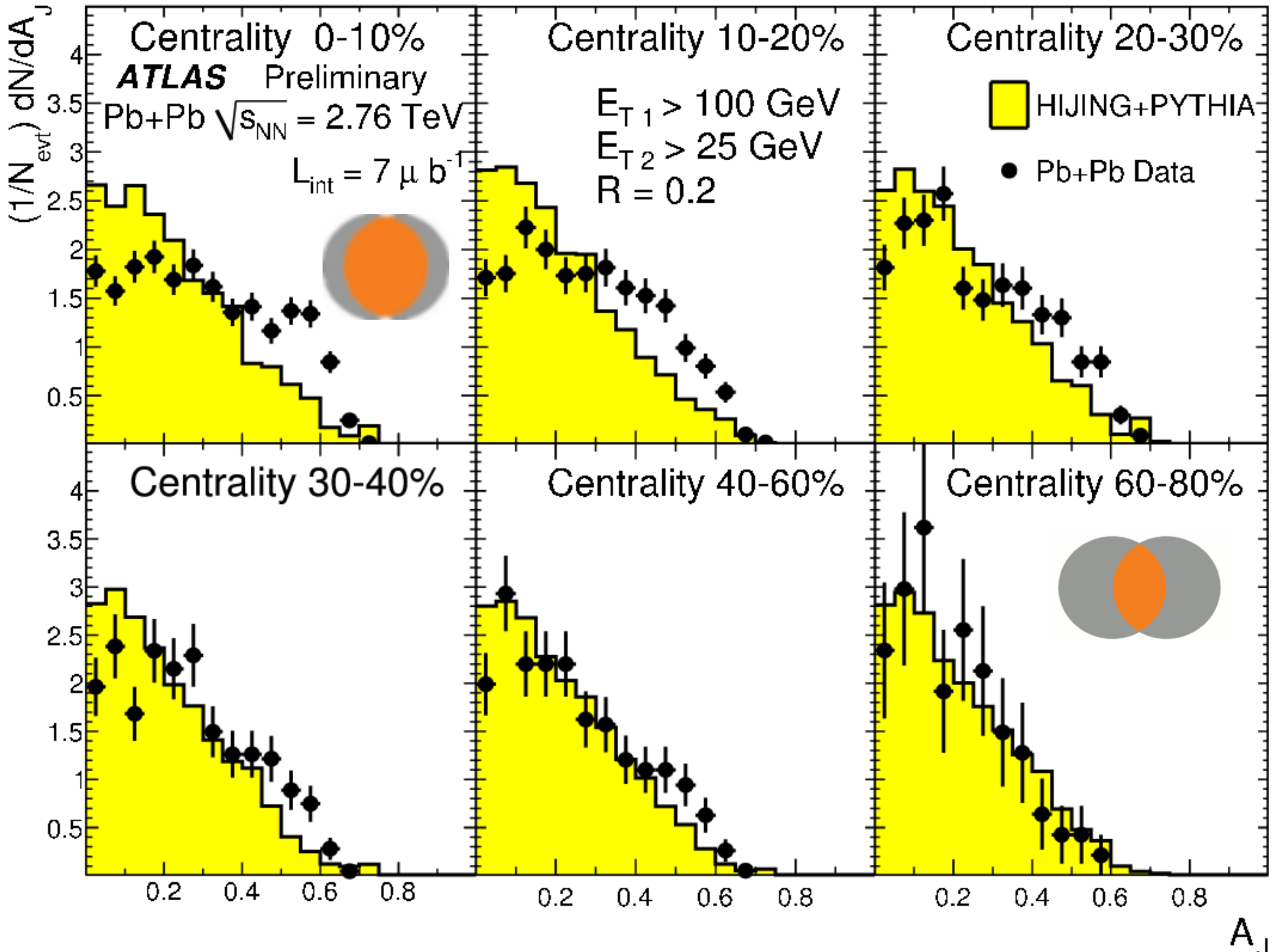




Charged particle multiplicity:

- three reconstruction methods applied
- measurements without magnetic field used to register particles with p_T downto 30 MeV
- multiplicity increasing with energy faster than logarithmically, but slower than predicted by Landau hydrodynamics
- the centrality dependence of particle density scaled by the number of participants (at η=0) has the same shape as at RHIC - when the **factor of 2 increase** is taken into account

Phys.Lett.B710 (2012) 363-382.



$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

R=0.2

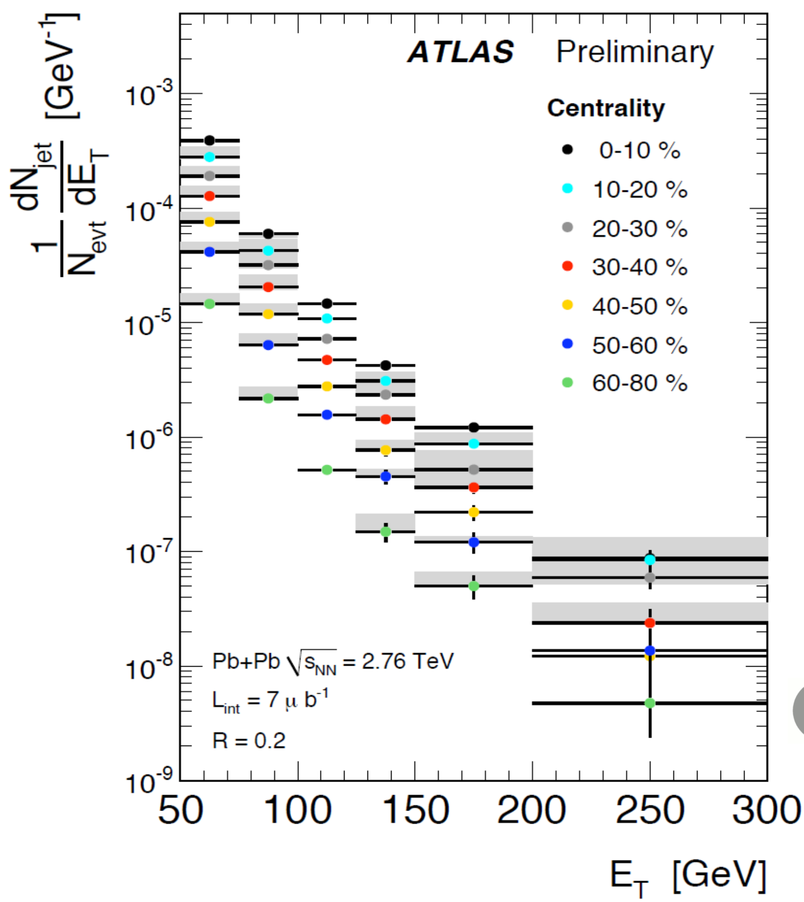
Asymmetry increasing for more central events

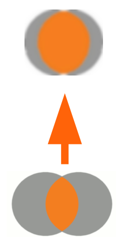
Values of A_J obtained for R=0.2 are very close to that for R=0.4

ATLAS-CONF-2011-075.

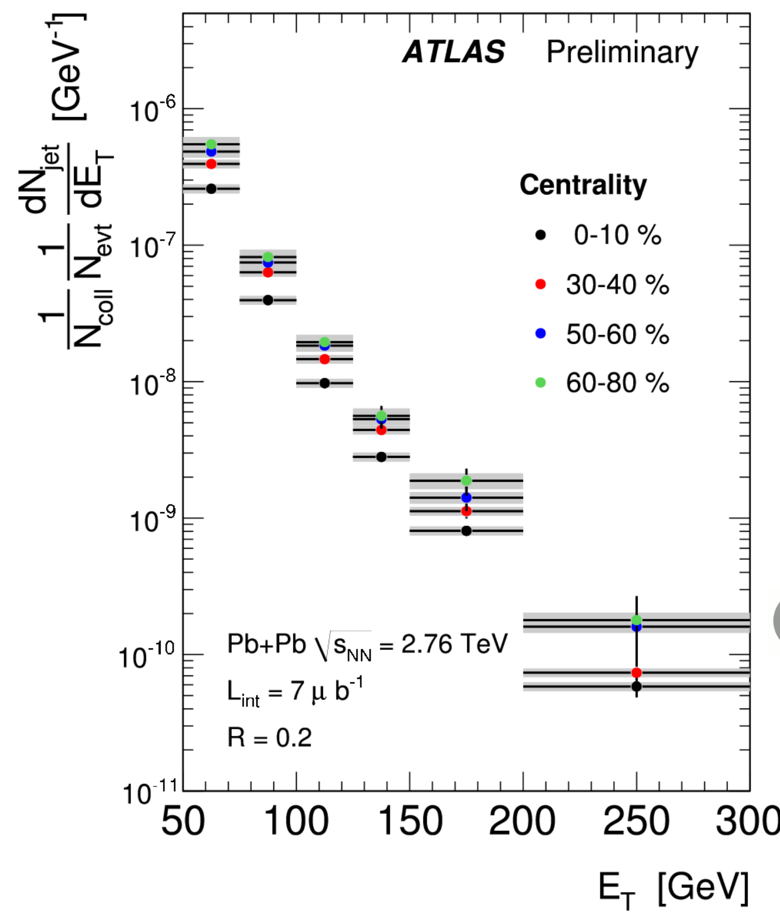
Jets in PbPb collisions

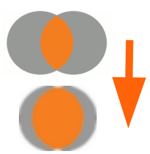
Absolute yields





Yields per collision





R=0.2

THE SAME TREND

Jet yields in PbPb collisions at 2.76 TeV:

- **increase with centrality of PbPb collisions (~30 times)**
- **after scaling by the number of nucleon-nucleon collisions the trend becomes opposite - in peripheral collisions scaled yields are ~ 2 times larger**

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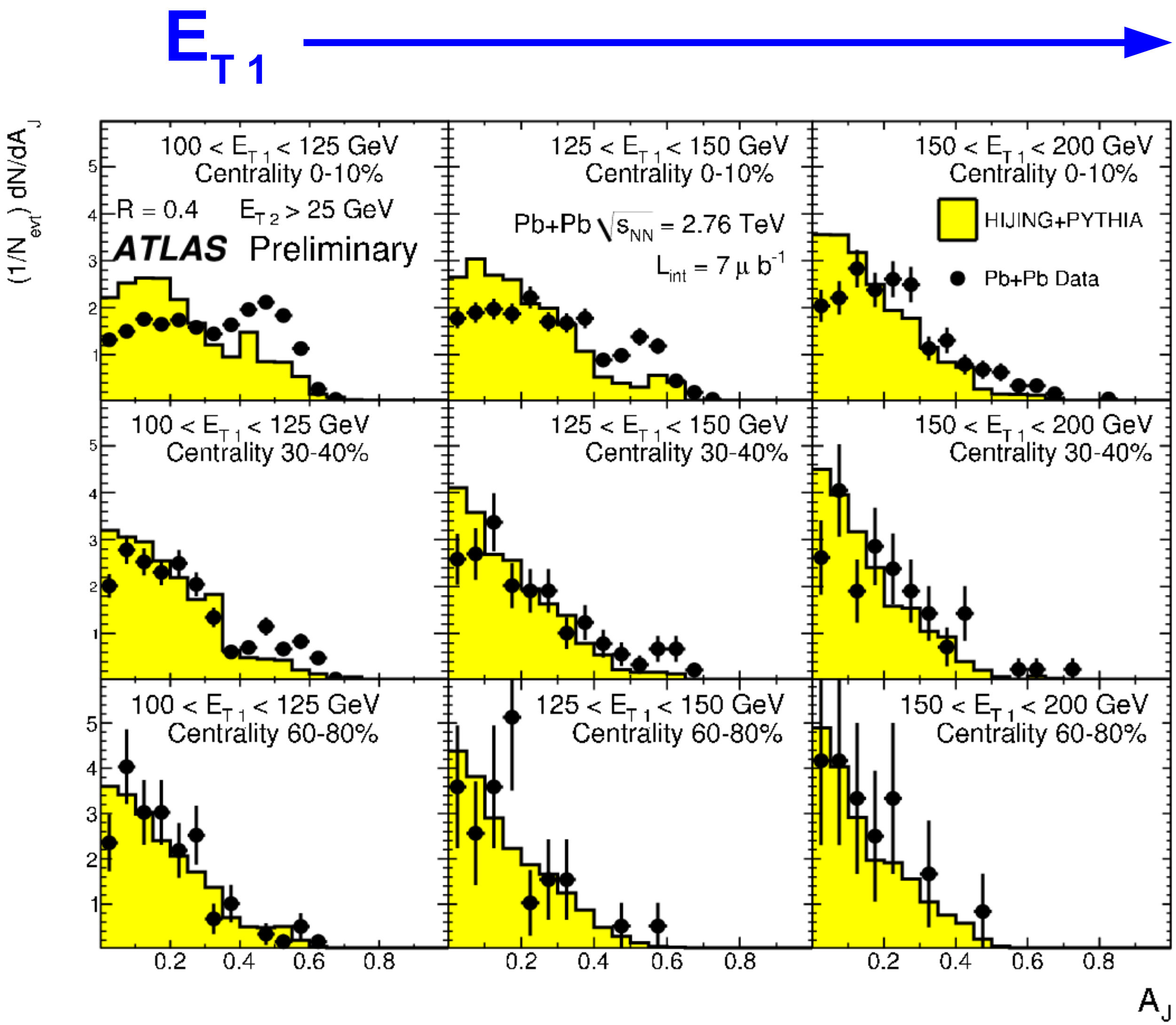
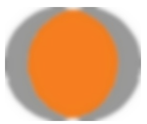
Jets in PbPb collisions

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$





R=0.4

Three ranges of leading jet energy: 100-125 GeV, 125-150 GeV, 150-200 GeV

- **asymmetry more pronounced for lower energy of the leading jet**

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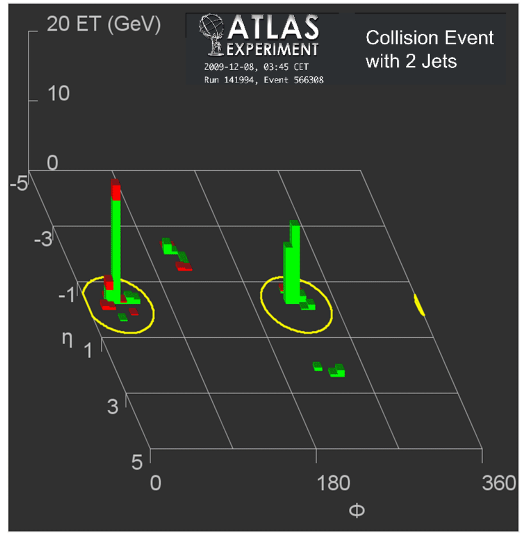
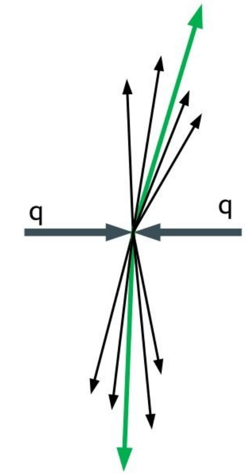
Disapperance of jets at LHC

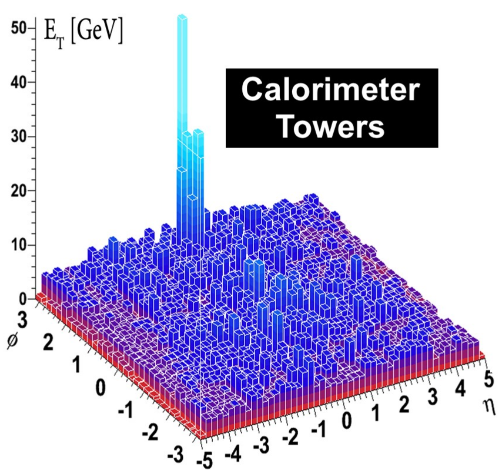
p+p





p+p

Pb+Pb



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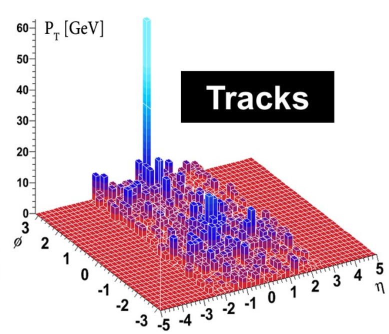
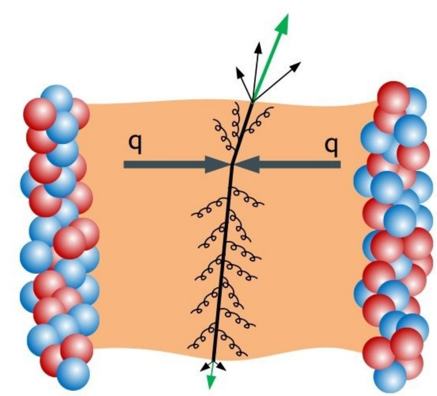
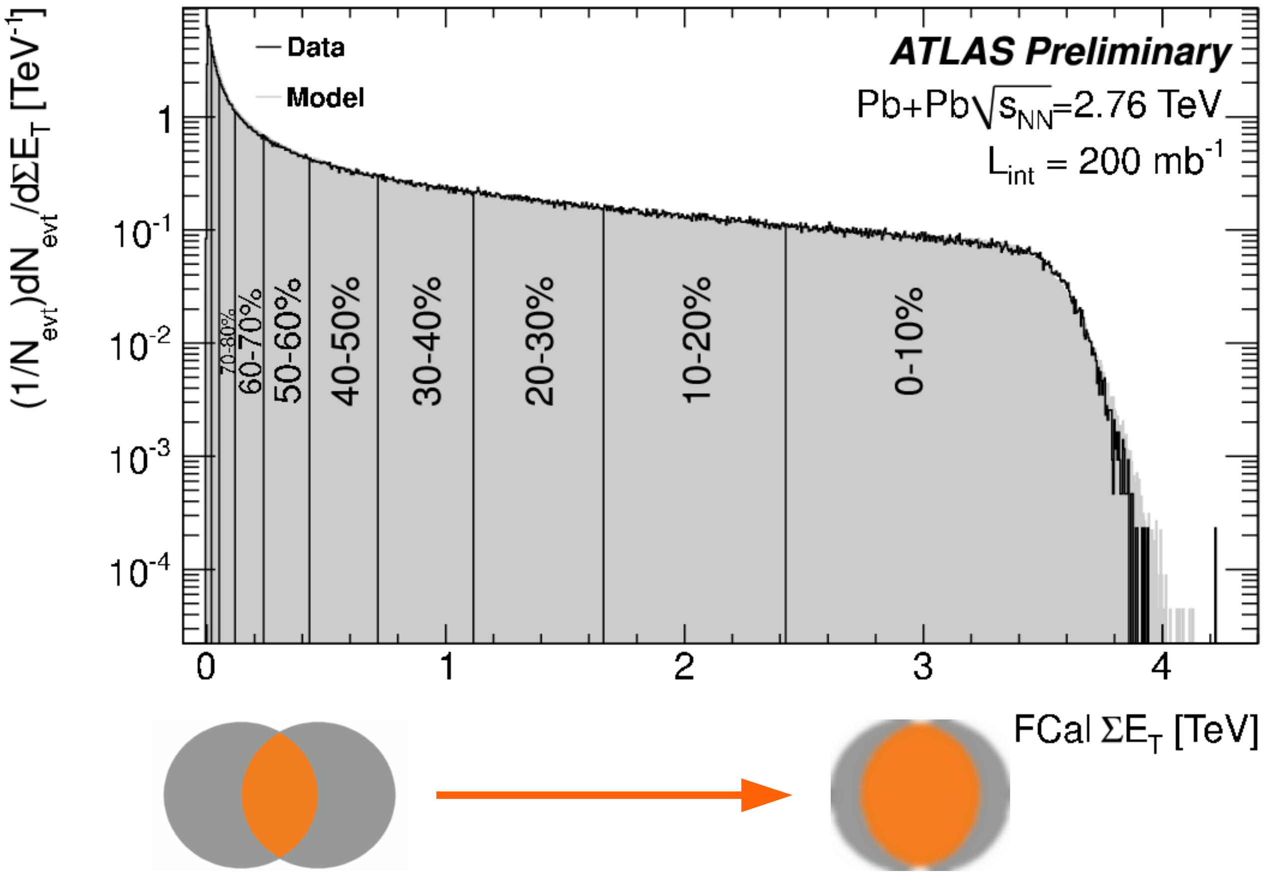




A+A

Centrality of PbPb collisions



Distribution of the signals registered in the Forward Calorimeter (FCal) is divided into bins with the same number of events (10% of the total).

Fraction of the sampled non-Coulomb inelastic cross section after all trigger selection cuts is estimated to be 100% ±2%