High p_T Probes in Pb-Pb and p-Pb Collisions with ATLAS Detector

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on behalf of Atlas Collaboration

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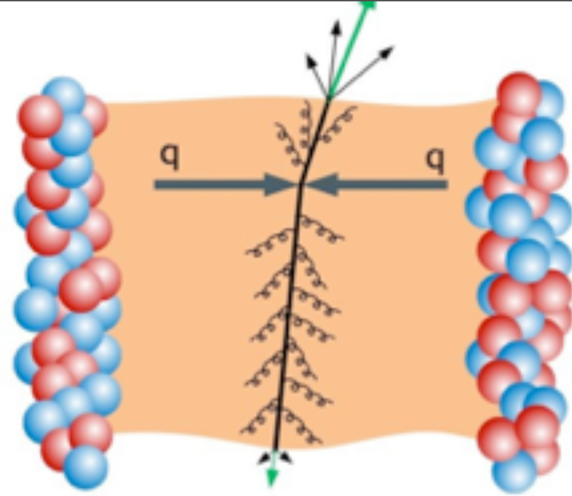
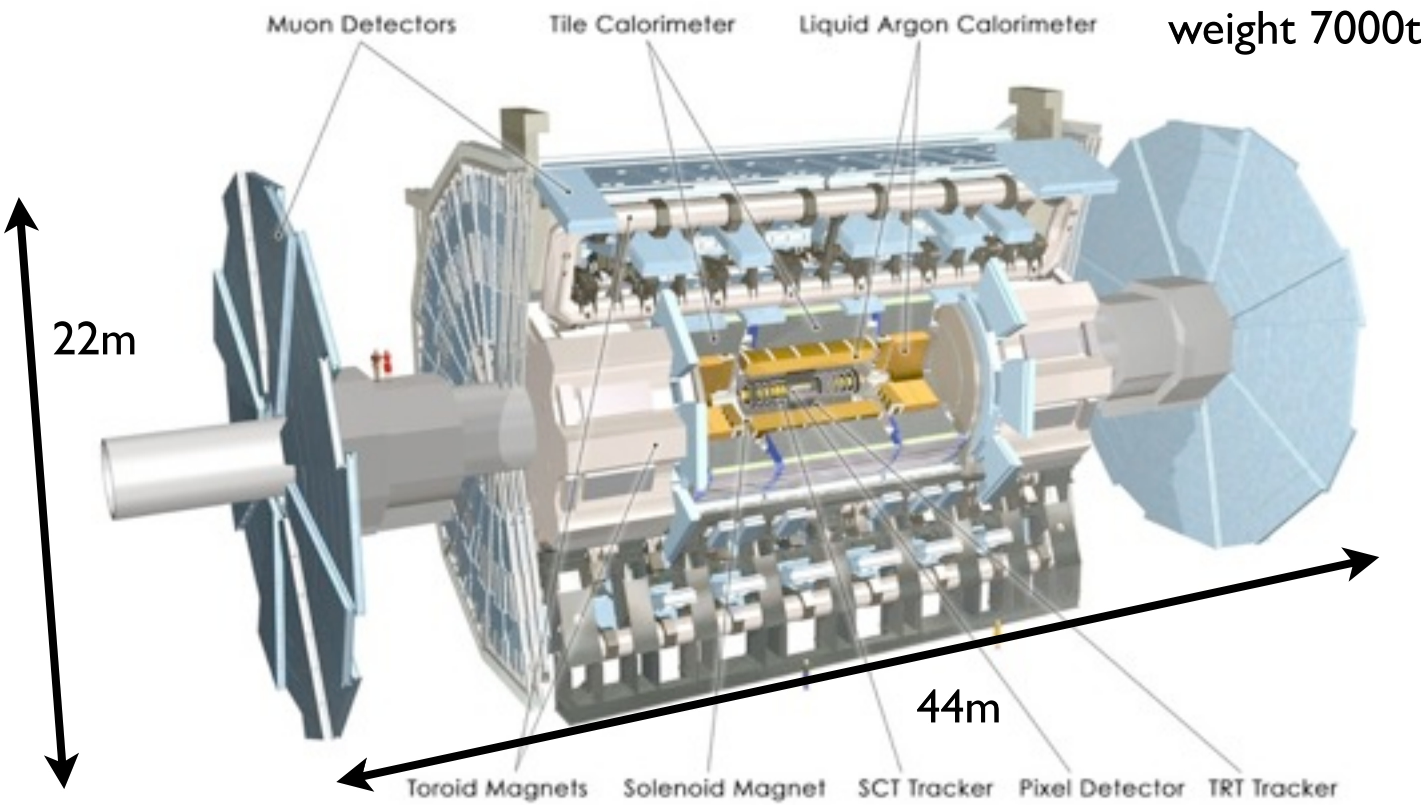
HI collisions



- main purpose: investigate the properties of quark-gluon plasma (QGP) - hot, dense, strongly interacting matter - where quarks and gluons become locally deconfined
- constituents of parton shower may scatter and lose energy in radiation in the medium, so modifying properties of the final jet → jet quenching
- QGP should be transparent for particles not carrying color-charge (e.g. γ, Z,W), so these particles can be used to determine initial jet energy

ATLAS Detector



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

Calorimeter $|\eta| < 3.2$ jet, electron, photon reconstruction

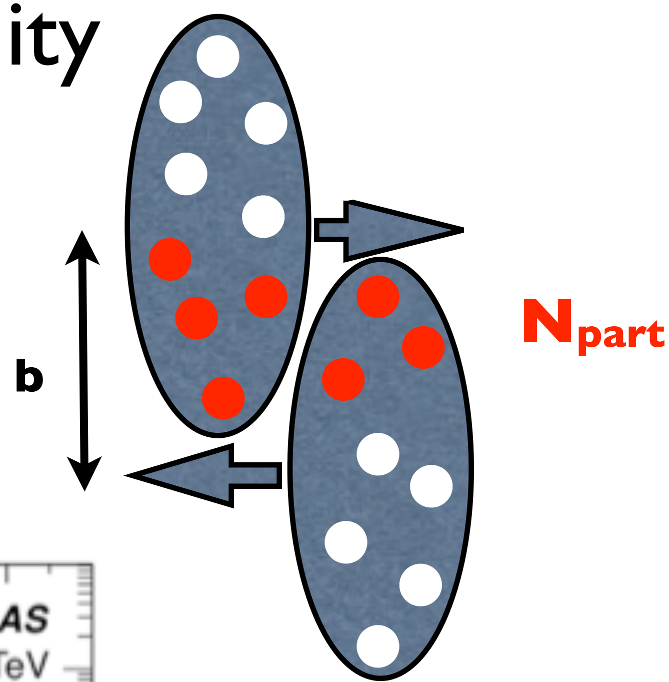
Forward Calorimeter $3.1 < |\eta| < 4.9$ centrality determination

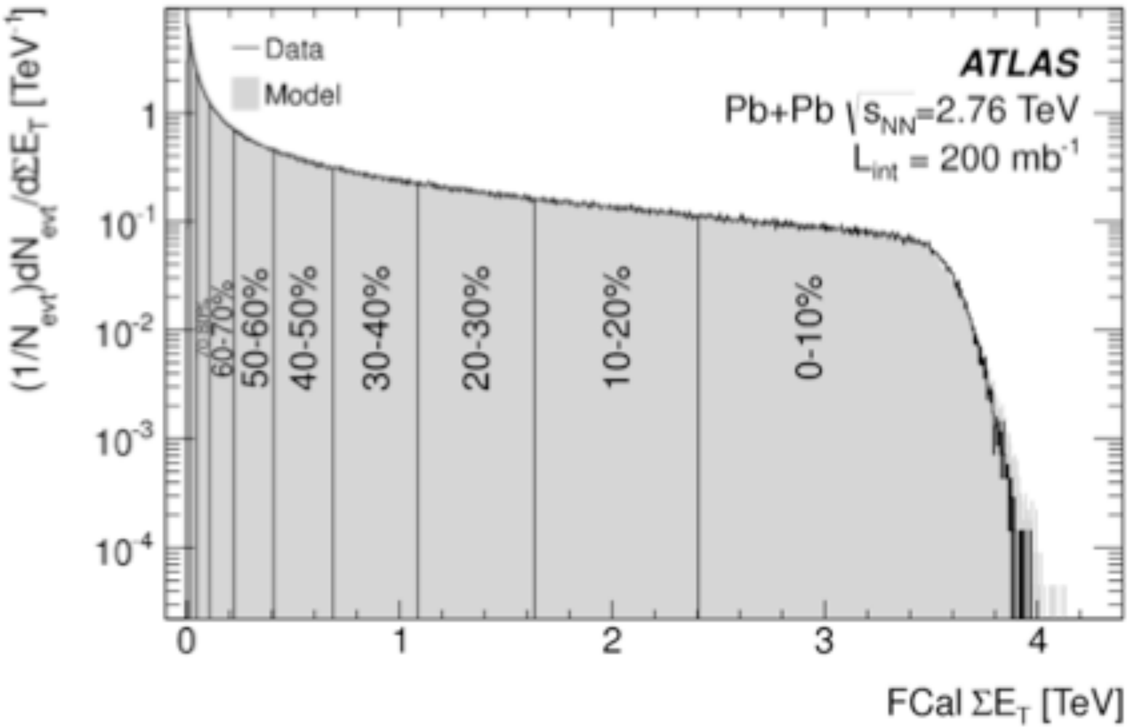
Muon Spectrometer $|\eta| < 2.7$

Centrality

Centrality related to:

- overlap volume of two colliding nuclei
- impact parameter
- ⟨N_{part}⟩ mean number of participant nucleons
- ⟨N_{coll}⟩ average number of binary collisions





Centrality measured with FCAL.

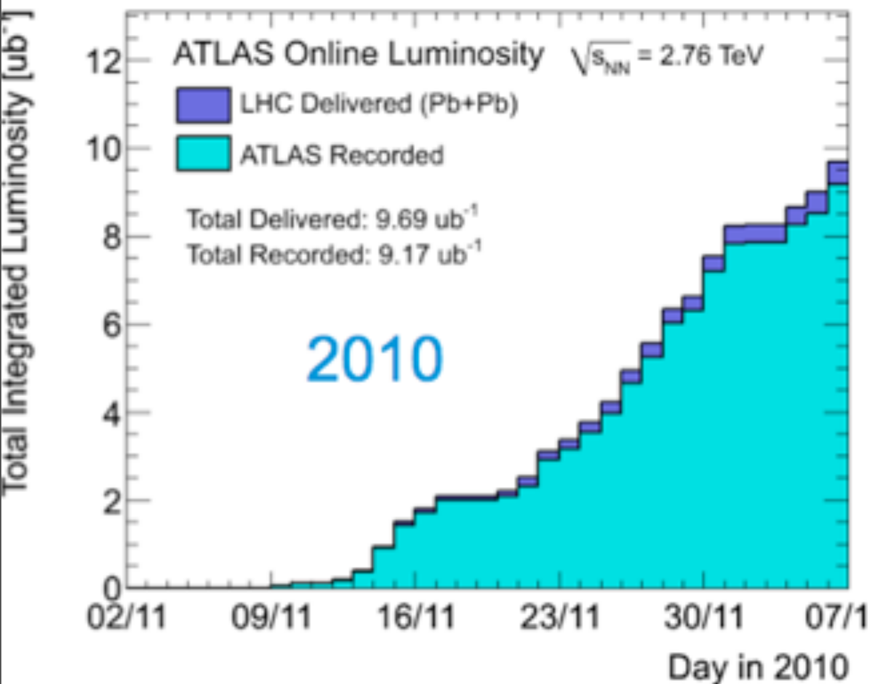
Most central C=0-10%, ΣE_T>2.4TeV.

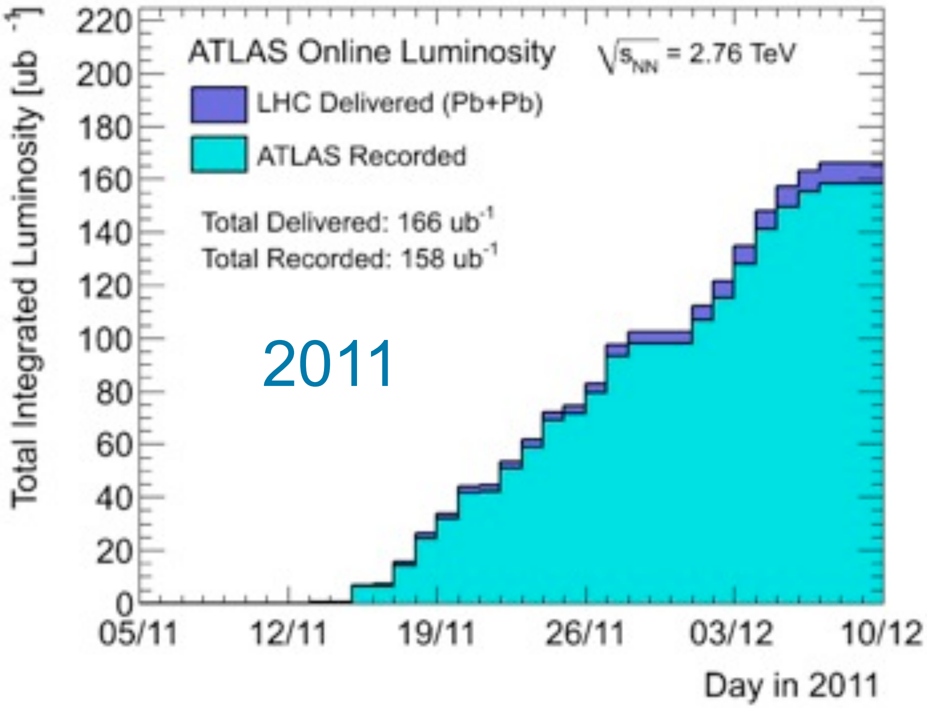
Pb-Pb runs

nucleon-nucleon center-of-mass E = 2.76 TeV

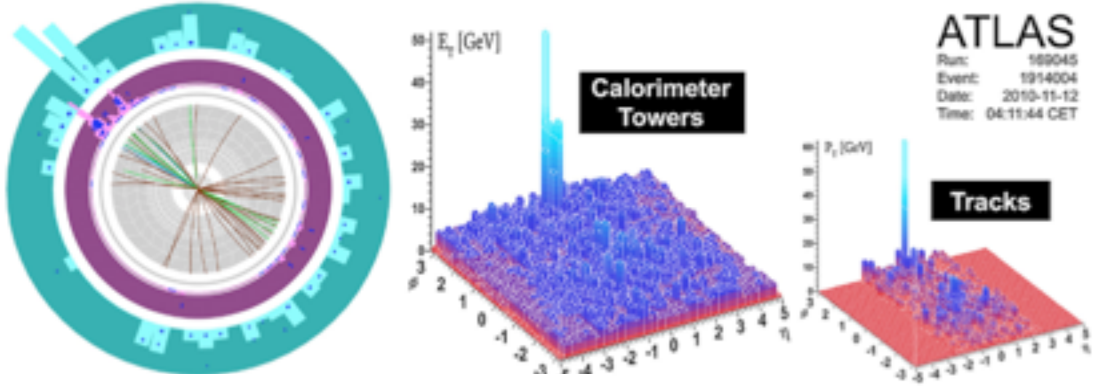
L = 7 μb^{-1} (with magnetic field on) in 2010 runs, Min Bias trigger

L = 0.15 nb^{-1} in 2011 runs, Min Bias, γ, μ, jets triggers





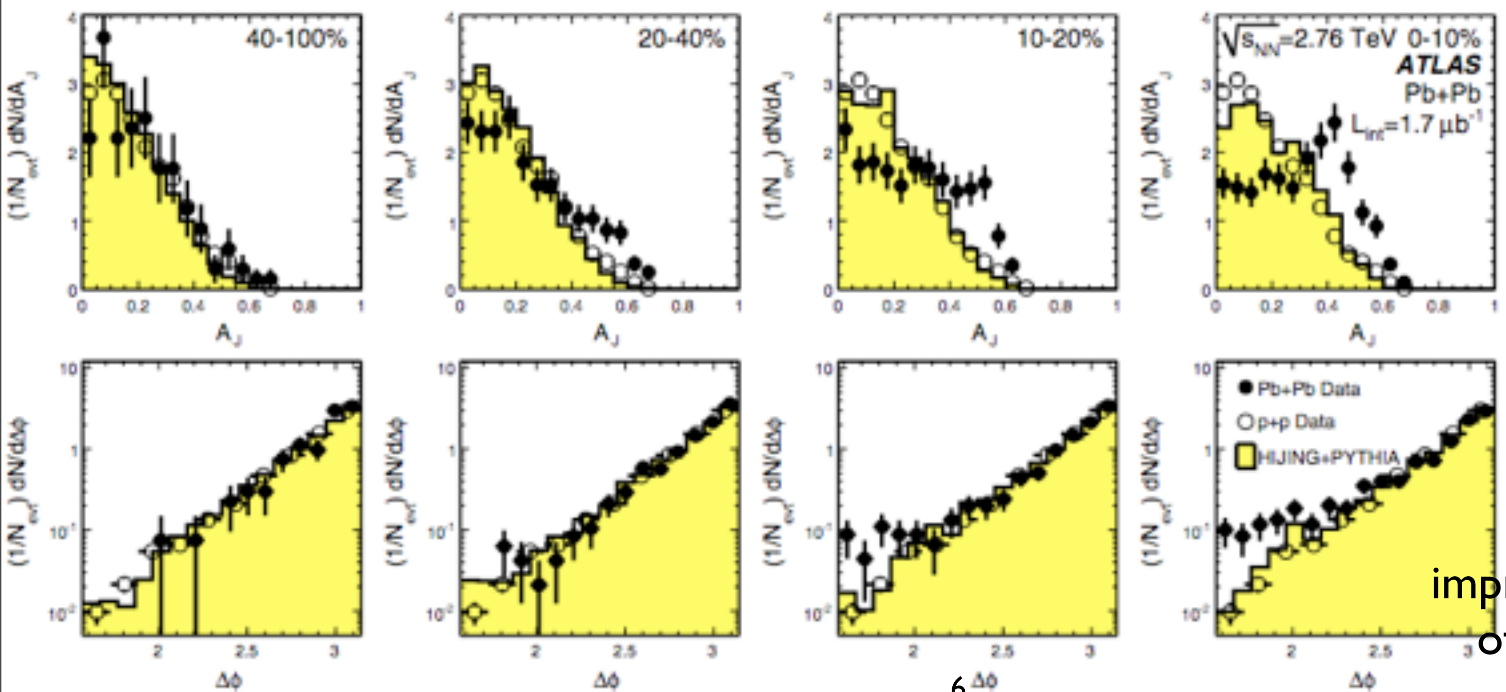
Jet quenching - first observation in ATLAS



Highly asymmetric dijet event : one jet E_T>100GeV and no evident high E_T recoiling jet.
With tracks cut p_T> 2.6 GeV and calo cell thresholds - recoil seen dispersed widely over the azimuth.

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}, \qquad \Delta\phi > \frac{\pi}{2},$$

E_{T1} > 100 GeV, E_{T2} > 25 GeV



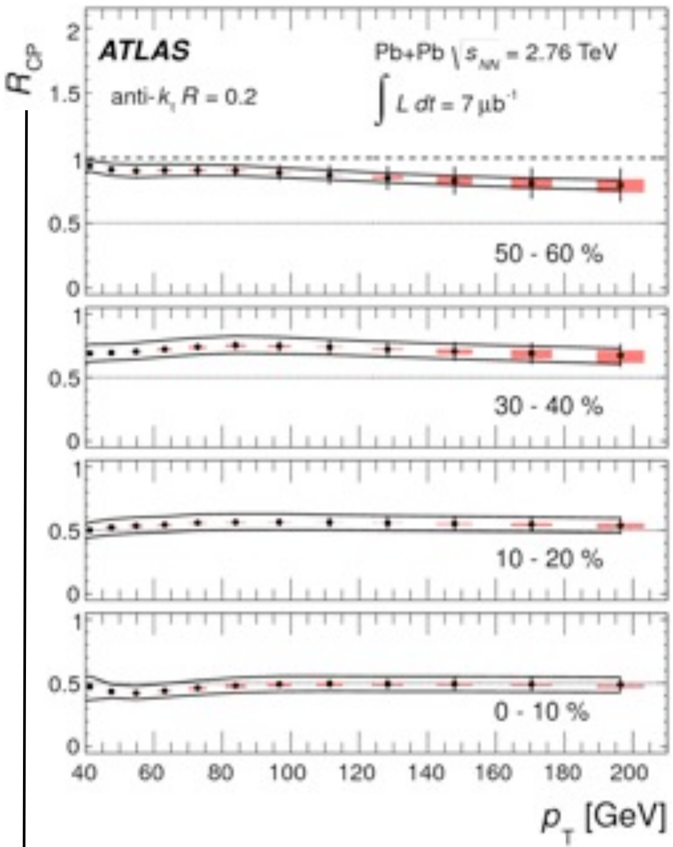
Asymmetry in E_T between first and second jet observed for increasing centrality.

Assumed that leading jet unquenched. Only “differential” jet quenching in limited kinematical region.

Complementary measurements improving understanding of quenching effects available.

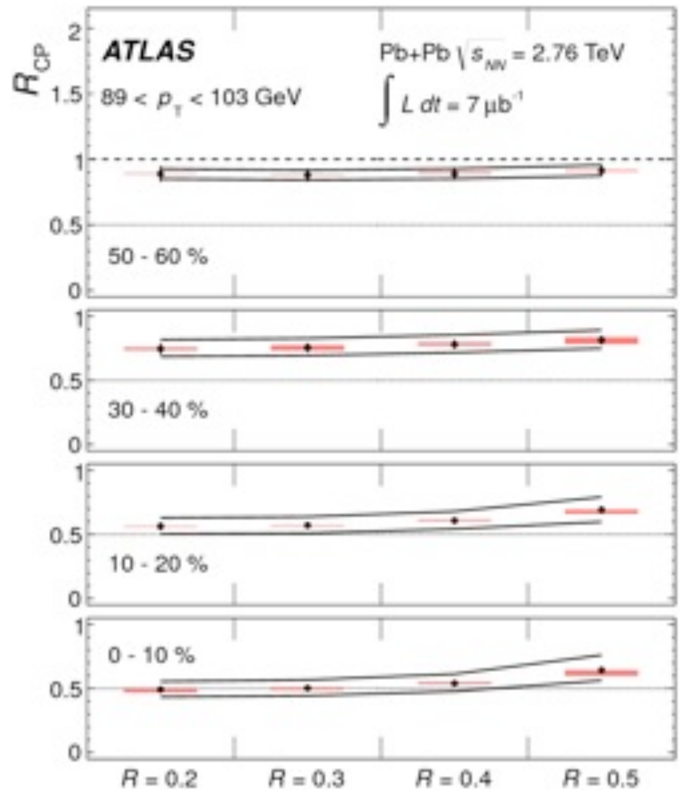
Inclusive jet suppression

When both dijets lose comparable amount of energy - event not detected by previous analysis. Inclusive measurement needed.



At most weak dependence on p_T.

In central collisions jet production yields suppressed by a factor of 2.



Weak but significant variation of R_{CP} with jet radius.
Jets broadening ...

$$R_{CP}^{meas}(p_T)|_{cent} = \frac{1}{R_{coll}^{cent}} \left(\frac{\frac{N_{jet}^{cent}(p_T)}{N_{evt}^{cent}}}{\frac{N_{jet}^{60-80}(p_T)}{N_{evt}^{60-80}}} \right)$$

$$R_{coll} \equiv \langle N_{coll} \rangle / \langle N_{coll}^{60-80} \rangle$$

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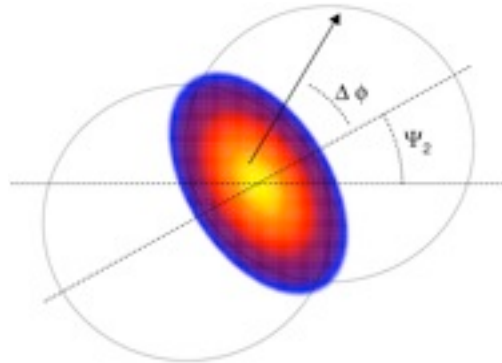
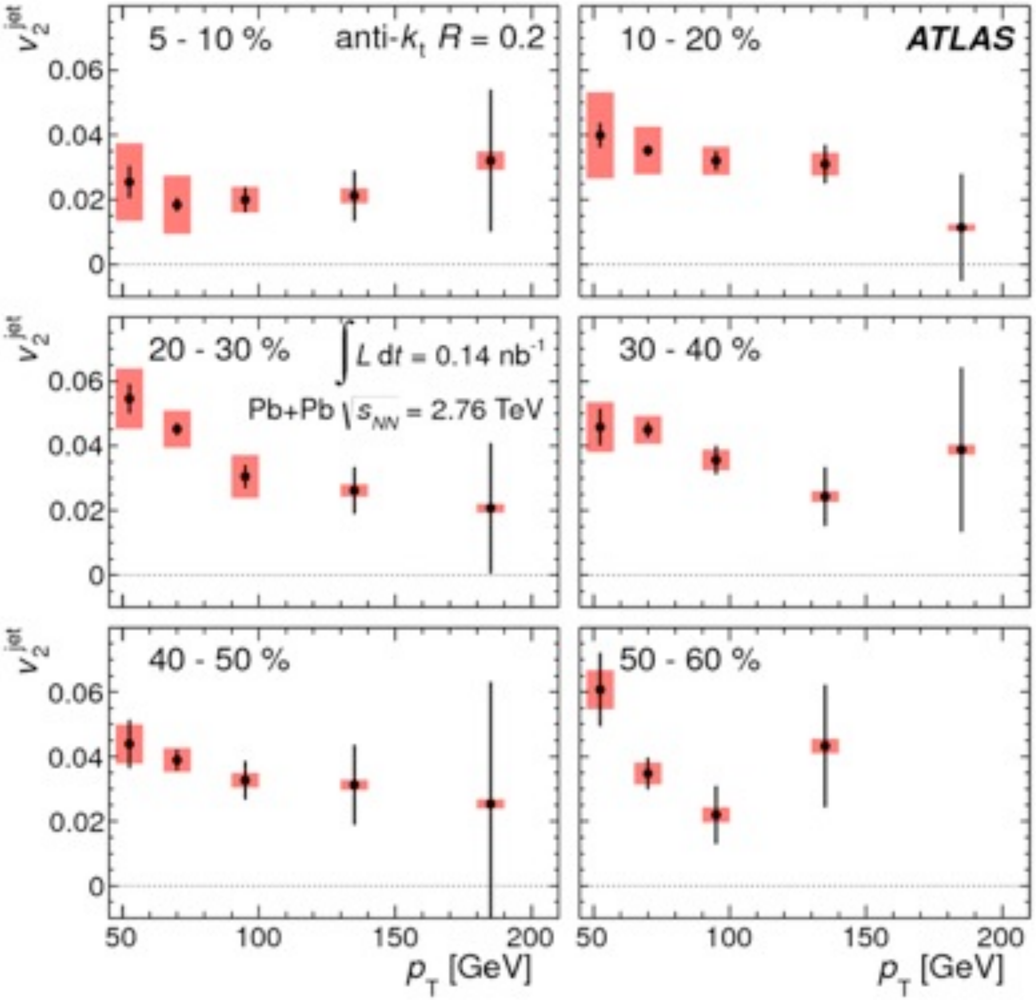
Azimuthal dependence of inclusive jet suppression

Variation of inclusive jet suppression in azimuthal angle gives insight on the path length dependence of jet quenching.





v_2^{jet} characterizes fractional variation of the jet yield with $\Delta\phi$ at given p_T.

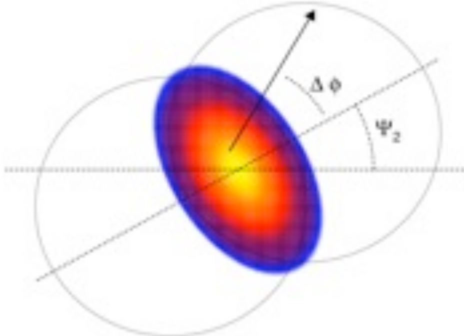
v_2^{jet} significantly different from zero for $45 < p_T < 160$ GeV.

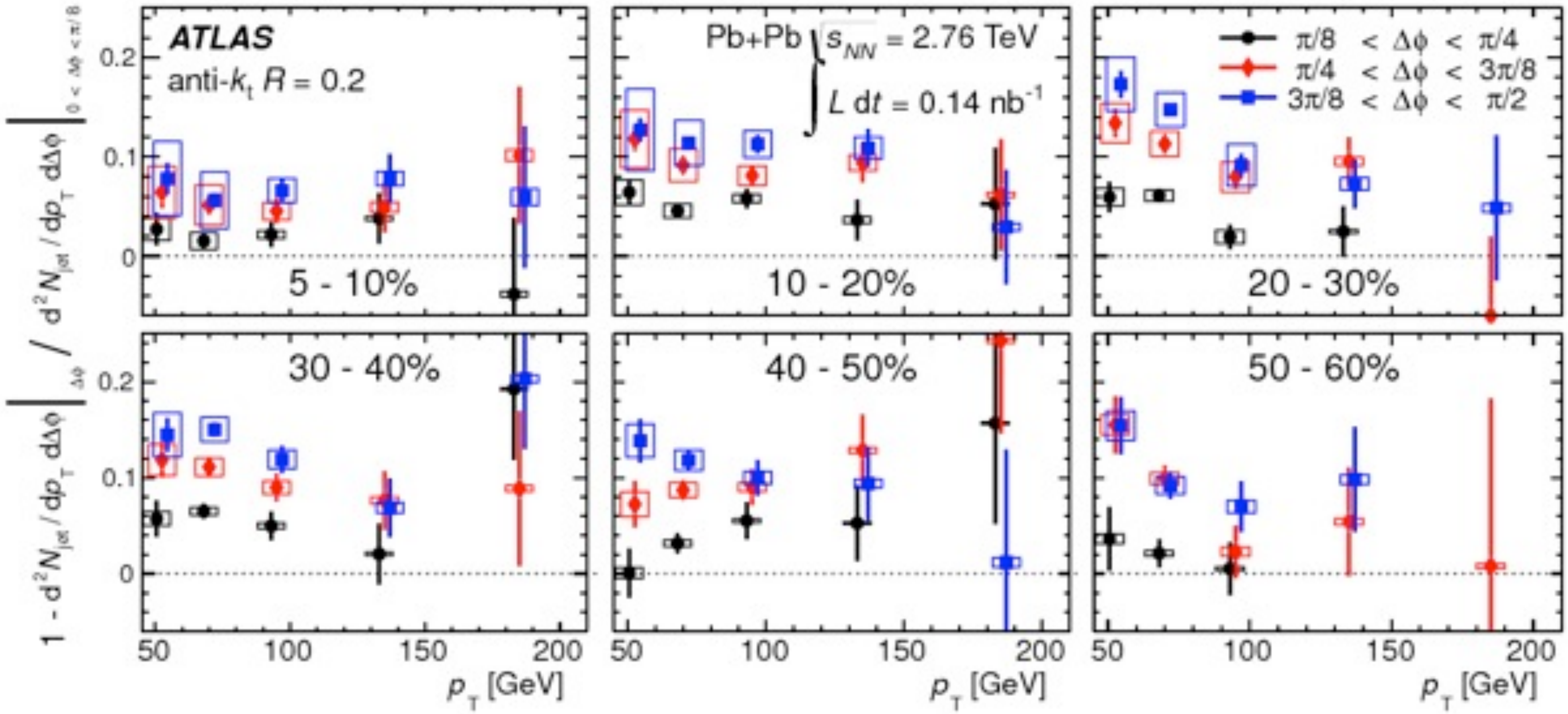
arXiv:1306.6469

Azimuthal dependence of inclusive jet suppression

$$R_{\Delta\phi} = \frac{\left.\frac{d^2N_{\rm jet}^{\rm corr}}{dp_{\rm T}d\Delta\phi}\right|_{\Delta\phi=\Delta\phi_i}}{\left.\frac{d^2N_{\rm jet}^{\rm corr}}{dp_{\rm T}d\Delta\phi}\right|_{\Delta\phi=\Delta\phi_j}}.$$

$\Delta\phi_j$ - interval closest to the minor axis
i.e. $0<\Delta\phi<\pi/8$





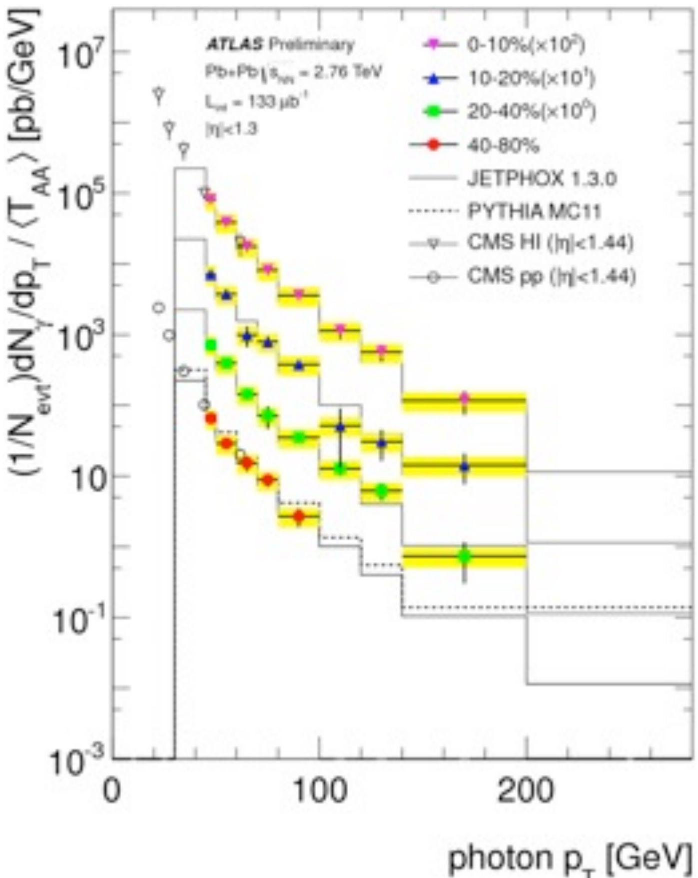
Clear reduction of jet yield with increasing $\Delta\phi$ (mainly for p_T<100 GeV).

arXiv:1306.6469

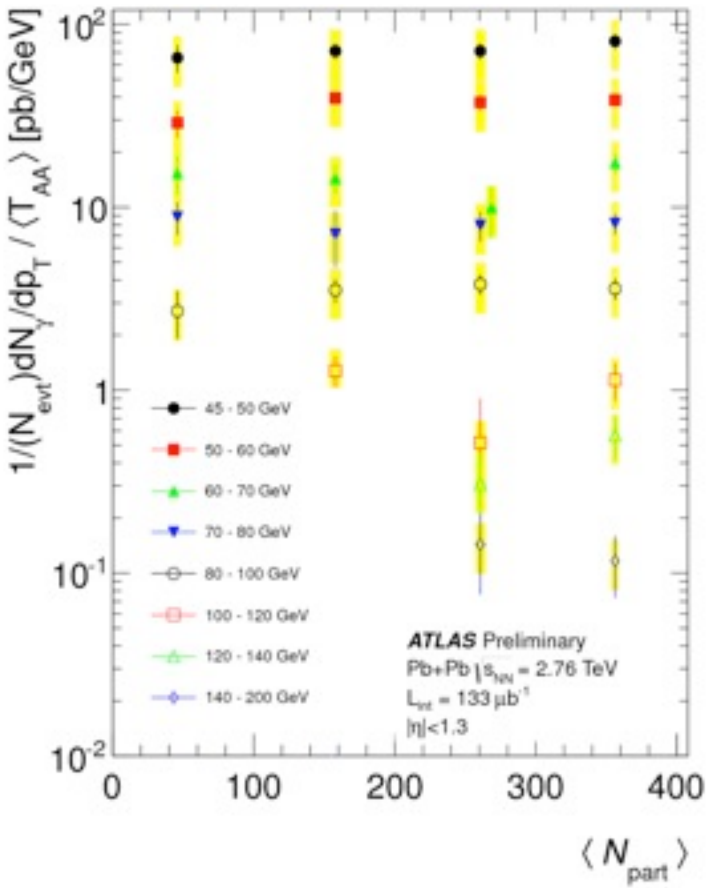
Isolated prompt photons

Prompt photons give access to the initial state PDFs and provide means to calibrate initial energy of jets.

Photon yield per event scaled by average nuclear thickness $<T_{AA}>=N_{coll}/\sigma_{pp}$



Good agreement with JETPHOX (pp scalled with $<N_{coll}>$, no nuclear corrections, NLO CTEQ6.6)

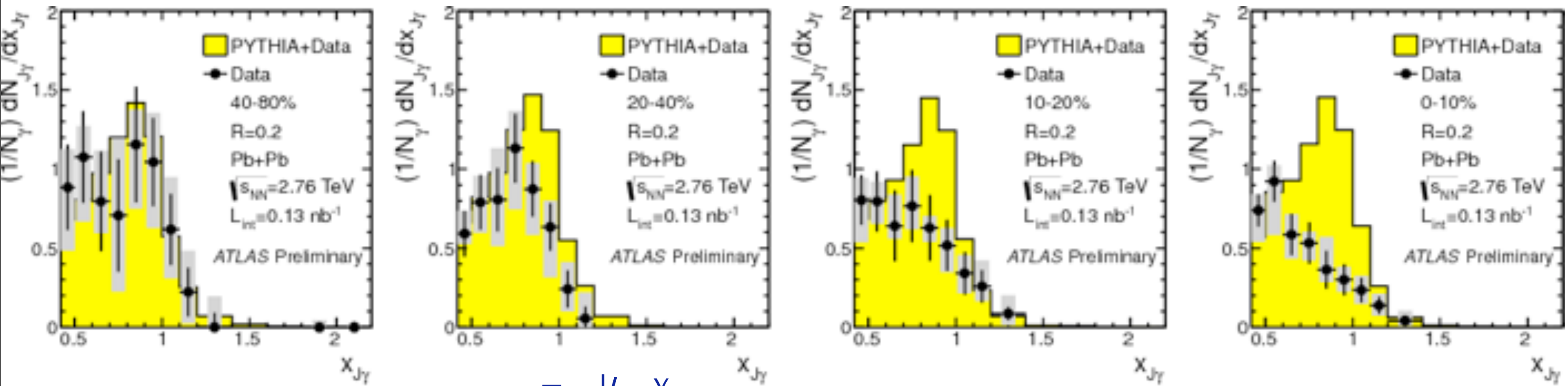


$|\eta| < 1.3$
$R_{iso}=0.3$
$E_T(R_{iso})<6$ GeV
double sideband to remove jet fragmentation contribution

No centrality dependence.
Linear scaling with the number of binary collisions.

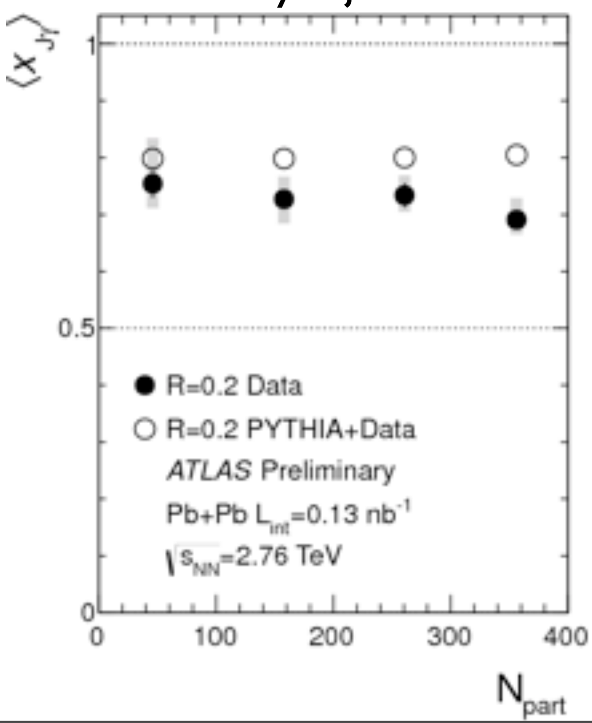
Atlas-Conf-2012-051

Jets and high p_T prompt photons correlation

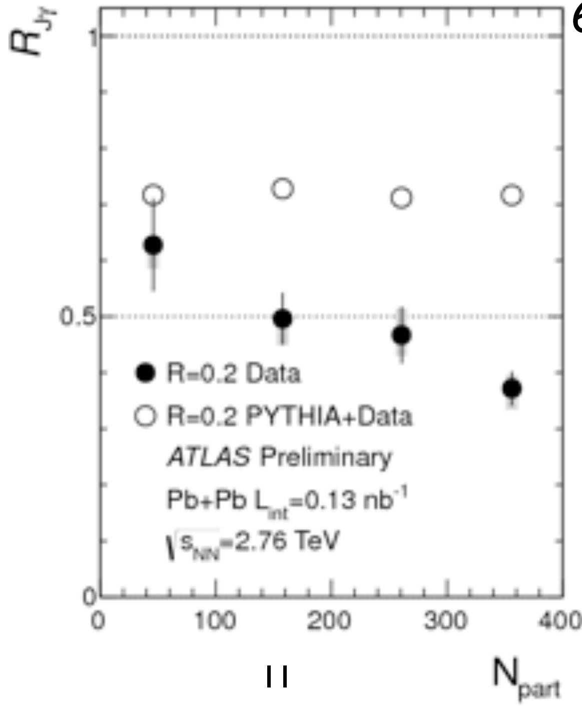


$x_{J\gamma}=p_T^J/p_T^\gamma$

mean energy fraction carried by a jet



per-photon jet yield



photons:
$60 < p_T < 90$ GeV
$|\eta|<1.3$
$R_{iso}=0.3$
$E_T(R_{iso})<6$GeV

jets:
$p_T>25$ GeV
$|\eta|<2.1$
$x_{j\gamma}>25/60$
$|\Delta\phi_{j\gamma}|>7\pi/8$

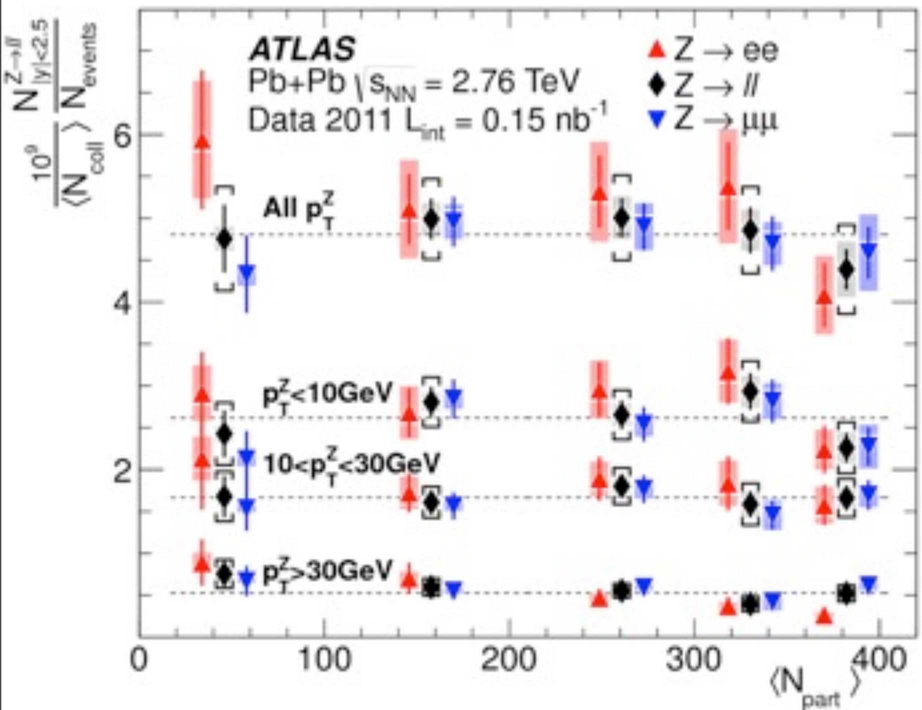
Only the most peripheral events agree with MC (PYTHIA +Data).

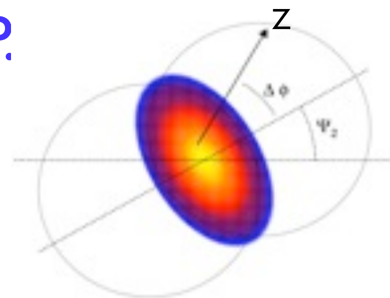
Atlas-Conf-2012-121

Z boson production

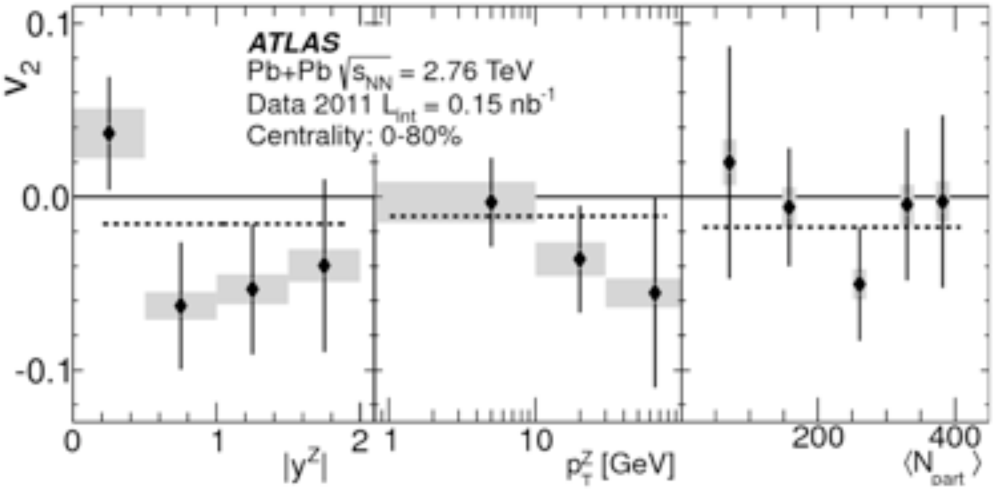
Similarly like photons Z bosons should not interact with QGP, so provide means for understanding interactions of color sensitive objects with QGP.

Z boson yields divided by mean number of collisions





Elliptic anisotropy: $v_2 = \langle \cos 2(\Delta\phi) \rangle / \sigma_2$



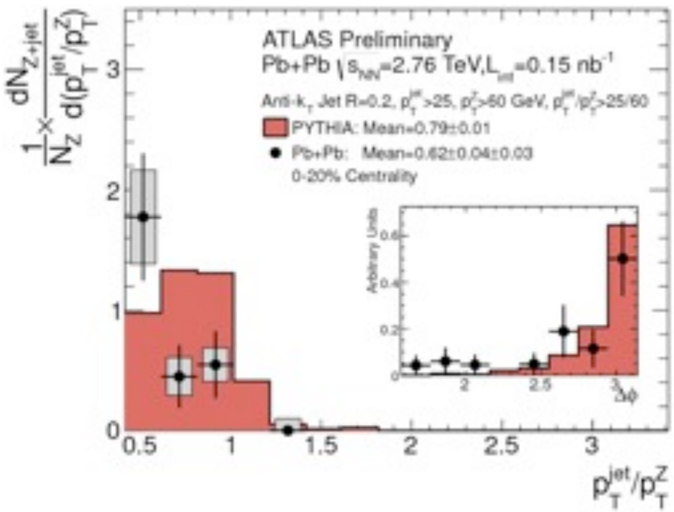
Results for $Z \rightarrow ee$ consistent with $Z \rightarrow \mu\mu$.
Binary scaling holds.

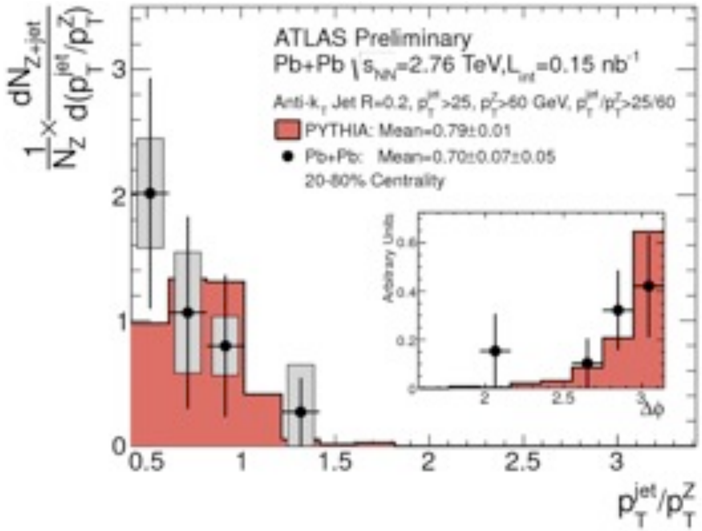
v_2 consistent with zero.
No interactions with QGP.

PRL 110 (2013) 022301

Jet and Z boson momentum imbalance

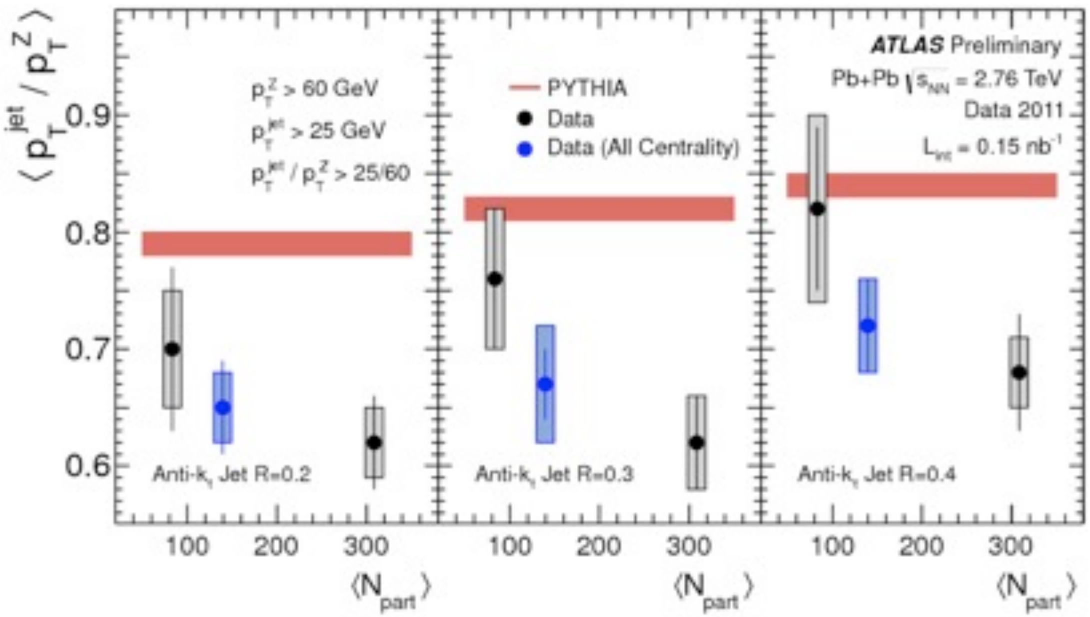
Ratio p_T^{jet}/p_T^Z normalized per Z boson





p_T^Z>60GeV
p_T^{jet}>25GeV
p_T^{jet}/p_T^Z>25/60
$|\Delta\phi|>\pi/2$

very few events available



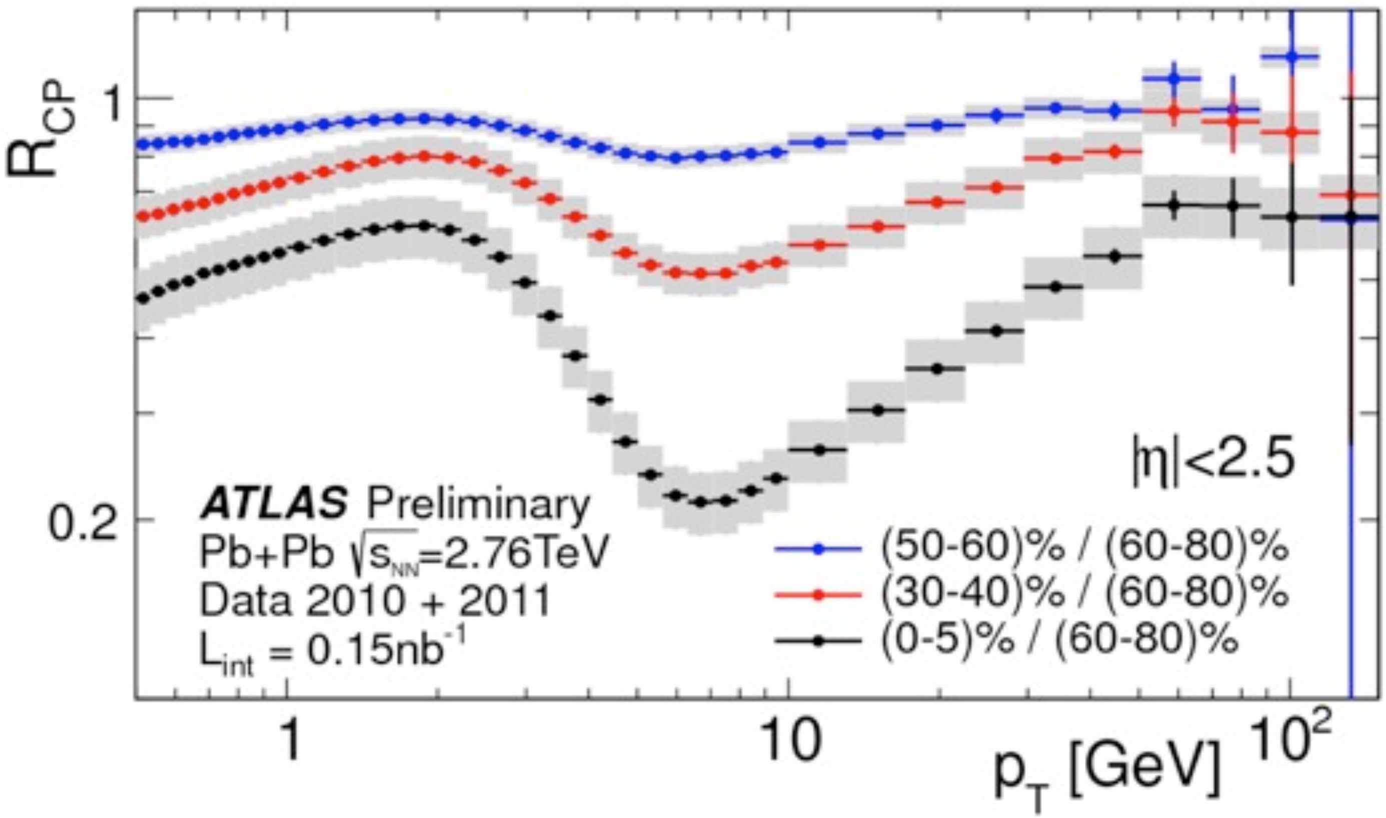
$\Delta\phi$ distribution in agreement with Pythia.
p_T^{jet}/p_T^Z agrees with Pythia only for more peripheral events.
For high centrality data suggests jet energy loss.

Atlas-Conf-2012-119

Charged particle spectra

Inclusive charged hadron production at high p_T is another way to understand properties of QGP.

$$R_{CP} = \frac{\langle N_{coll} \rangle (P)}{\langle N_{coll} \rangle (C)} \frac{(1/N_{evt,C}) d^2 N_C / d\eta d p_T}{(1/N_{evt,P}) d^2 N_P / d\eta d p_T}$$



Some models predict saturation below R_{CP}=1 others expect R_{CP} increase to 1 at high p_T.

Measurement limited by the statistics of the peripheral bin.

Strong suppression of hadron production increasing with centrality. R_{CP} for 0-5% to 60-80% centrality reaches minimum at 7GeV.

Atlas-Conf-2012-120

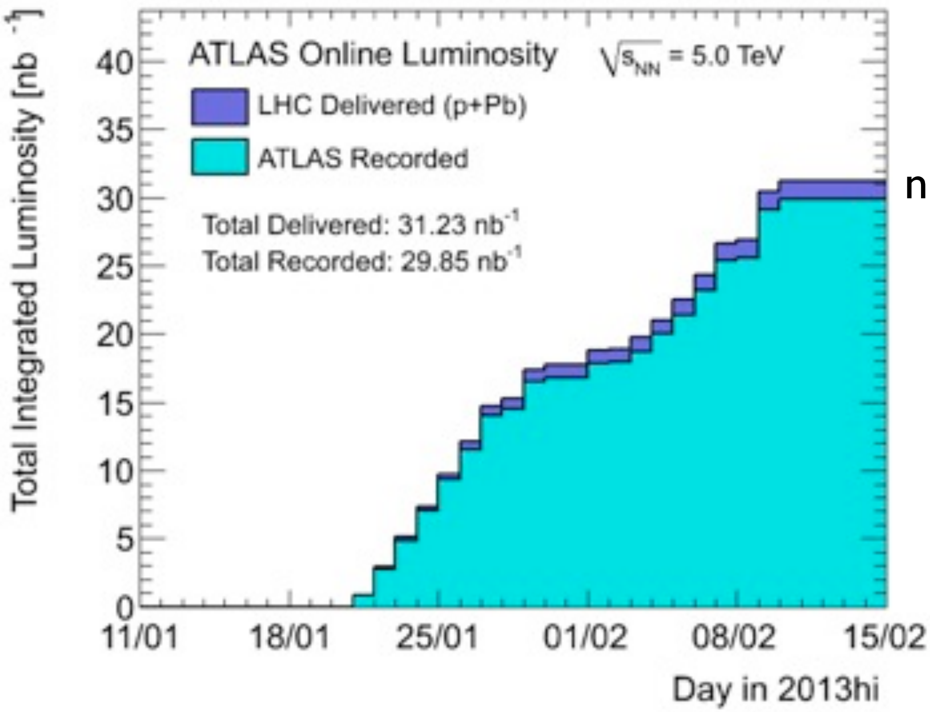
p-Pb collisions in ATLAS

• p-Pb - intermediate step between p-p and Pb-Pb collisions, so contains elements of both collision types

• allows to disentangle initial and final state effects

• helps to investigate QCD at high gluon density: shadowing and saturation

• probes nuclear wave function at small x



Pb beam - 1.75 TeV

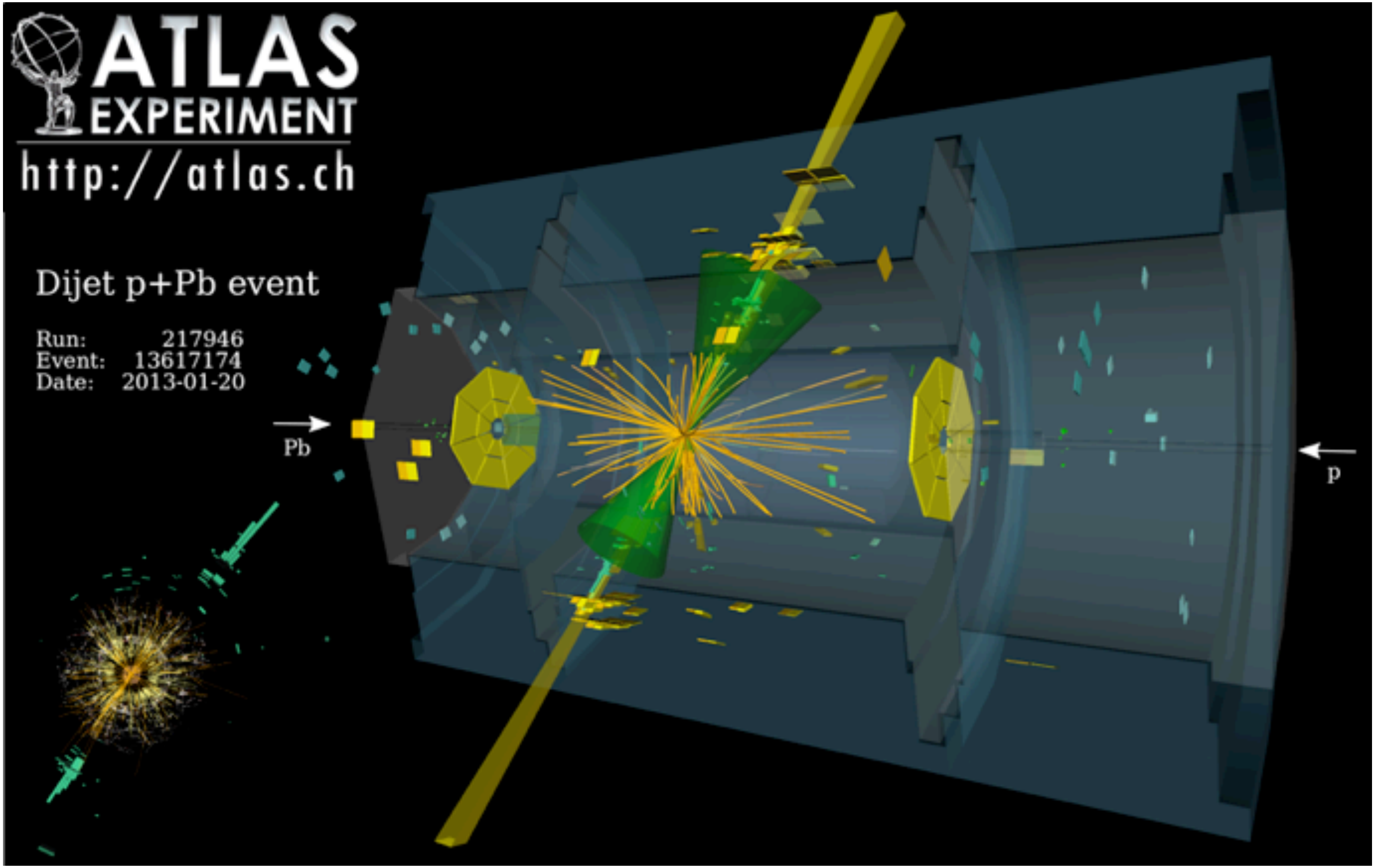
p beam - 4 TeV

nucleon-nucleon center-of-mass E = 5.02 TeV

pilot run 12/13 09 2012 L = 1 μb^{-1}

p-Pb runs 21.01-15.02 2013 L = 30 nb^{-1}

High pT dijet event in p+Pb



Summary

- Jet quenching observed in 2010 in dijet analysis investigated by means of other high p_T probes
- Factor two suppression in jet yields in central to peripheral collisions for inclusive jet production
- Similar suppression in yields of high p_T charged particles for increasing centrality
- Jet yield reduction with increasing path length in QGP - jet elliptic flow significantly different from zero and jet yield suppression with $\Delta\phi$
- Binary scaling, the absence of suppression effects and zero elliptic flow (measured for Z) consistent with electroweak bosons to not be affected by the hot, dense matter.
- Energy imbalance in γ-jet and Z-jet strongly increasing with increasing centrality
- Promising analyses of high pT probes in p-Pb collisions - ongoing

Backup slides

Inclusive jet charged particle fragmentation function

Jet quenching can potentially soften the spectrum of fragment hadrons and reduce the total energy of reconstructed jets → measurement of single jet suppression and of jet fragment distributions.

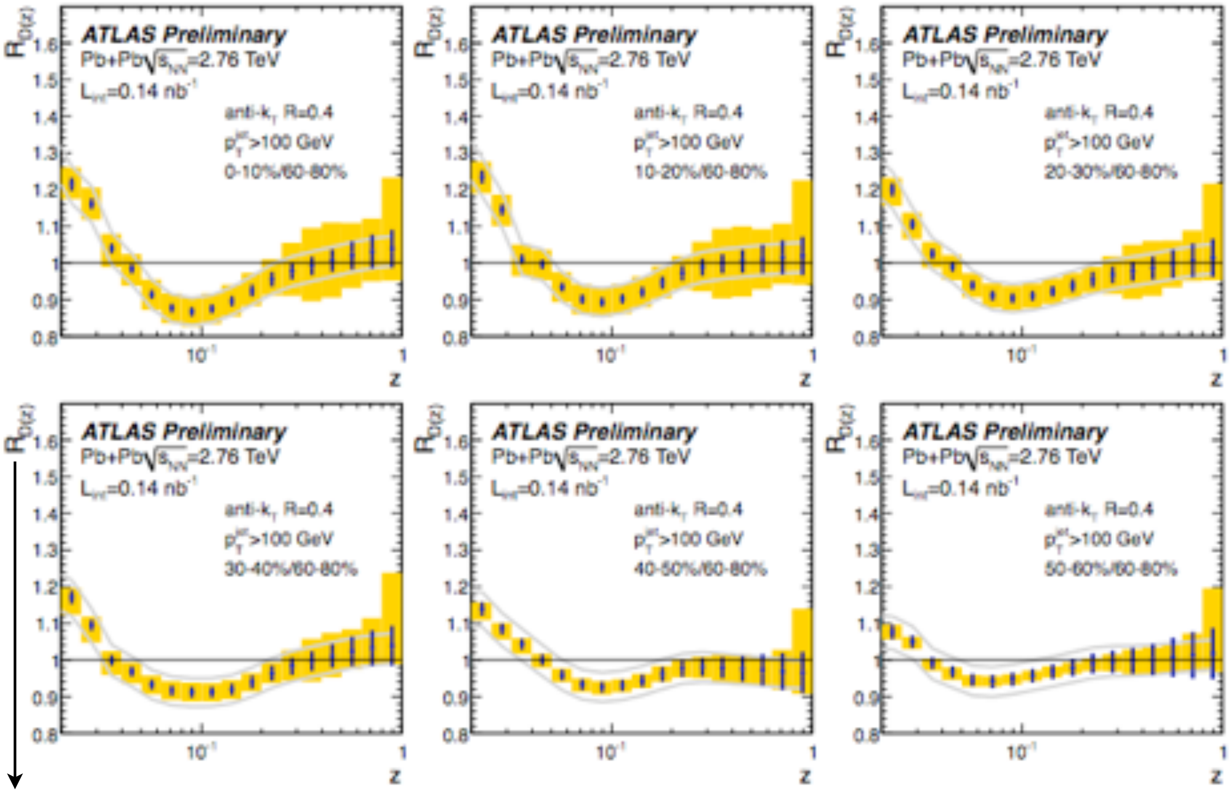
longitudinal mom. fraction:

$z = p_T^{ch} / p_T^{jet} \cos \Delta R,$ ΔR - radius between charged part. and jet

Charged particles fragment distribution:

$$D^{meas}(z) \equiv \frac{1}{N_{jet}} \frac{1}{\varepsilon} \frac{\Delta N_{ch}(z)}{\Delta z}$$

Ratio of fragmentation spectra to the spectra in 60-80% centrality.



Reduction of fragment yield in all centrality bins relative to 60-80% at intermediate z values, enhancement for low z, no significant modification at large z.

The reduction in the yield at intermediate z decreases gradually from central to peripheral collisions.

Ratio of D(z) for different centrality bins to those in peripheral collisions

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