Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the ATLAS Detector at the LHC

[arXiv:1011.6182 (hep-ex)]

a.k.a. "that jet quenching paper from ATLAS"

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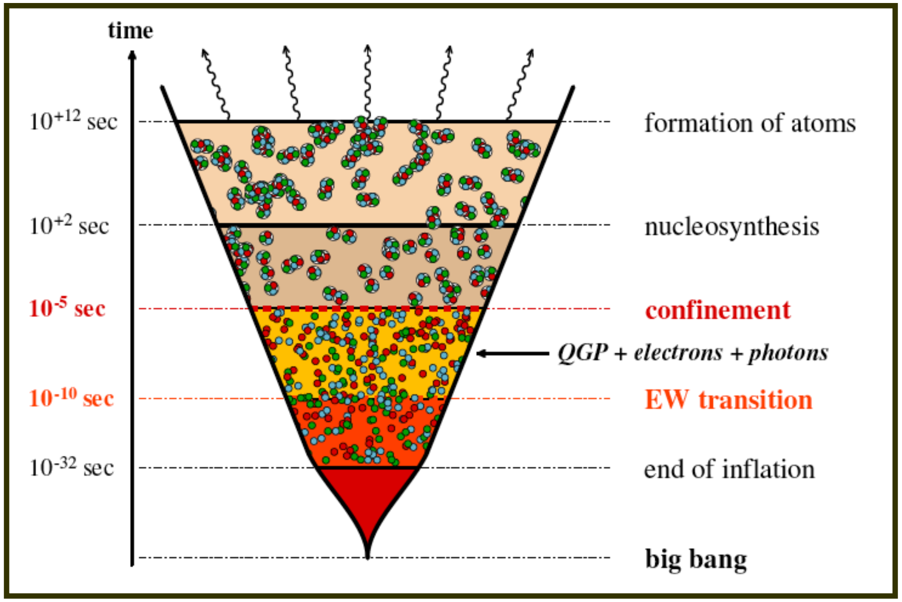
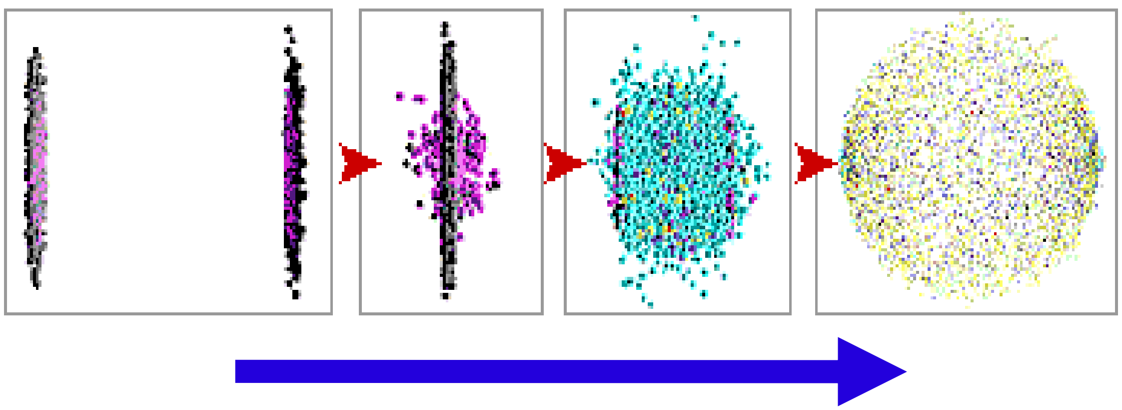
(on behalf of group D)

CLASHEP 2011 - Natal-Brazil

Heavy ion collisions and the Quark Gluon Plasma (QGP)

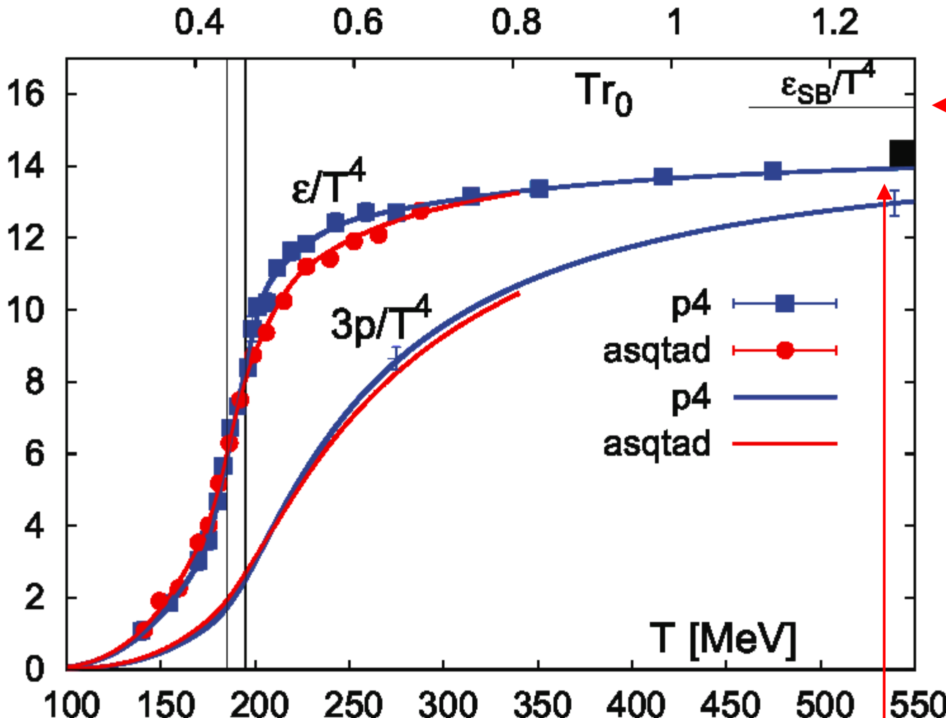
In the early universe, matter was found in a state where quarks and gluons were deconfined degrees of freedom (i.e. the QGP).





The matter generated in heavy-ion collisions can reach temperatures of the order of 4 trillion degrees Celsius, enough to induce the QGP phase transition.

se medium



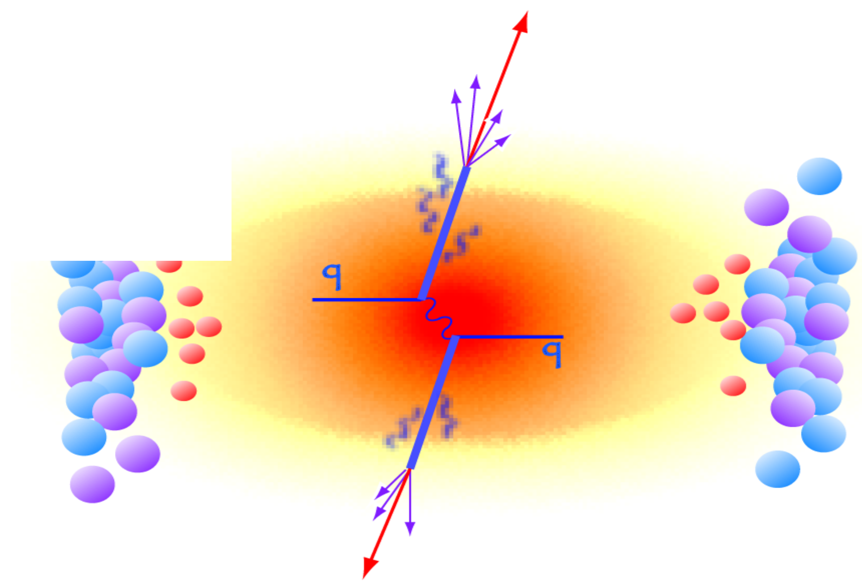
P. Petreczky, ArXiv: 1012.4425v1/nucl-th

Ideal gas

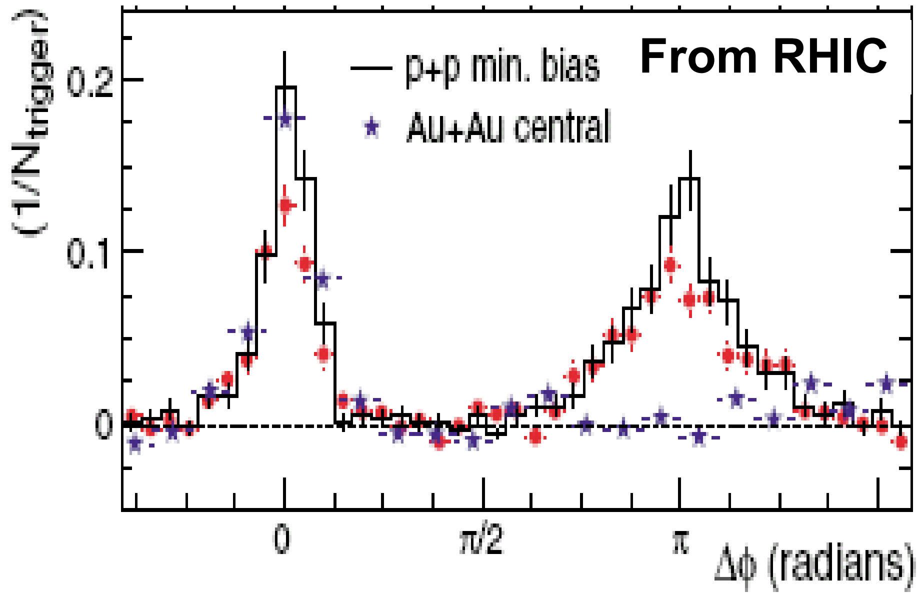
LHC

s not an ideal gas: it is a
coupled liquid (effects of color
n and quark masses).
cle inside the QGP suffers
atterings.
loss by "jet quenching"
l by Bjorken (1982)

Transverse momentum conservation in hard scattering after Heavy-Ion Collision. In the vacuum: angular correlations in final state p_T.

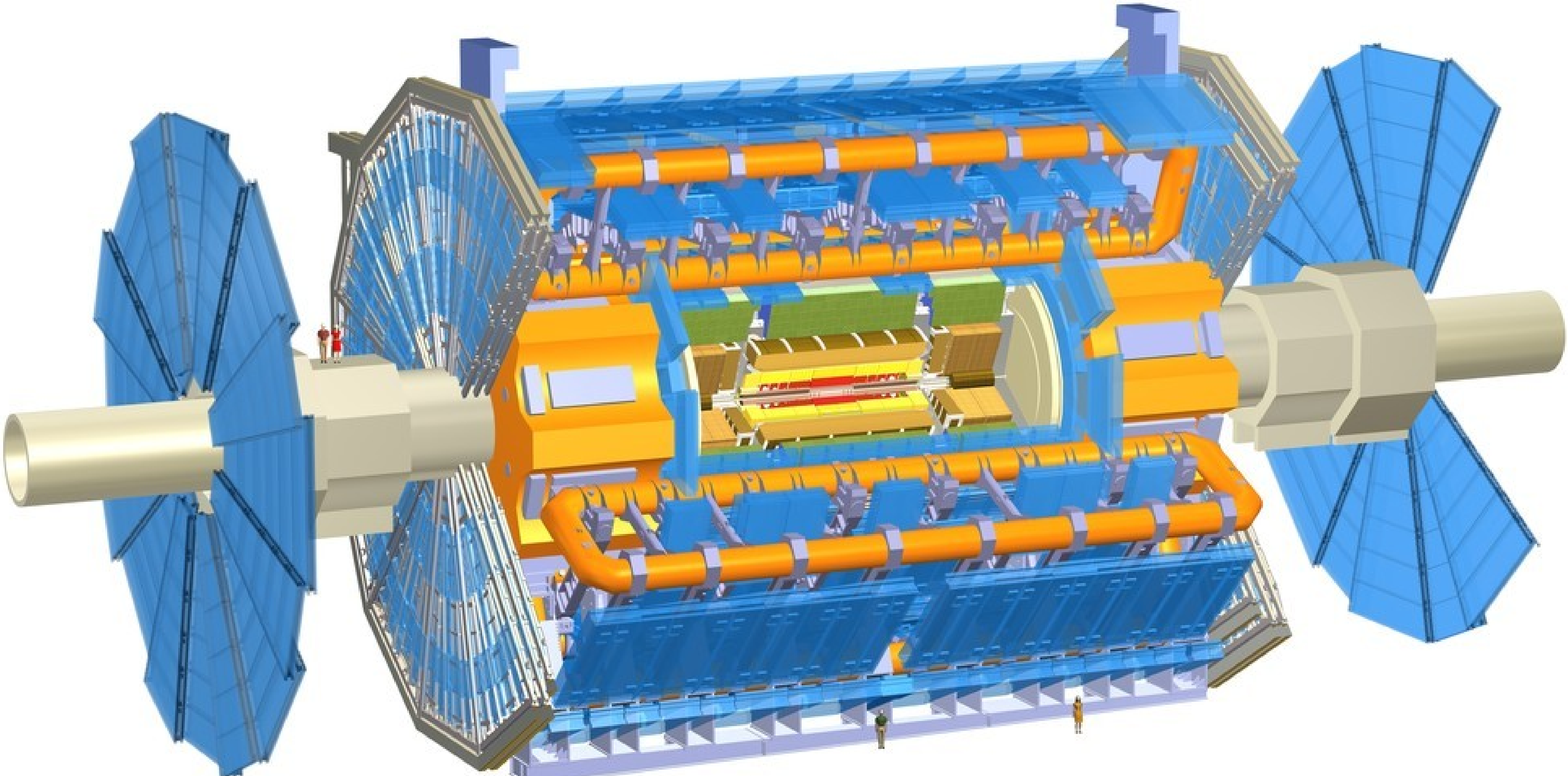


One lesson from RHIC and one motivation for LHC



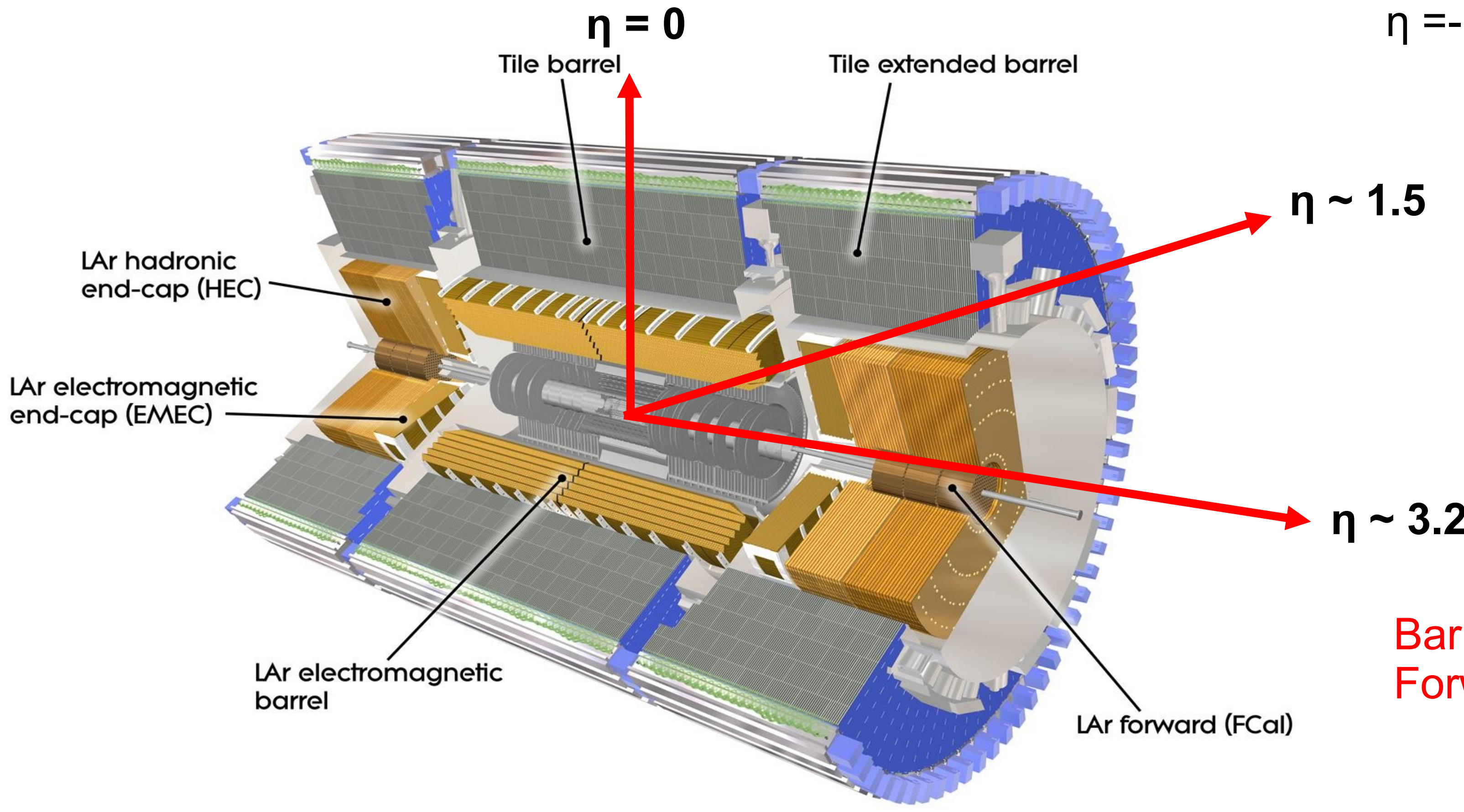
At LHC: expected to be closer to theoretical assumptions (equilibrium smaller α_S).
→ "Bigger is better!"

	SPS	RHIC	LHC
$\sqrt{S_{NN}}$ (GeV)	17	200	2760
T/T_C	1.1	1.9	2.7
ε (GeV/fm^3)	3	5	14
τ_{QGP} (fm/c)	< 2	2-4	6



ATLAS

Calorimeter and Trigger



η =- ln(tan θ/2)

Barrel: $|\eta| < 3.2$
Forward: $3.2 < |\eta| < 4.9$

low event rate → **Minimum Bias** Trigger Scintillator coincidences
+ Primary vertex requirement

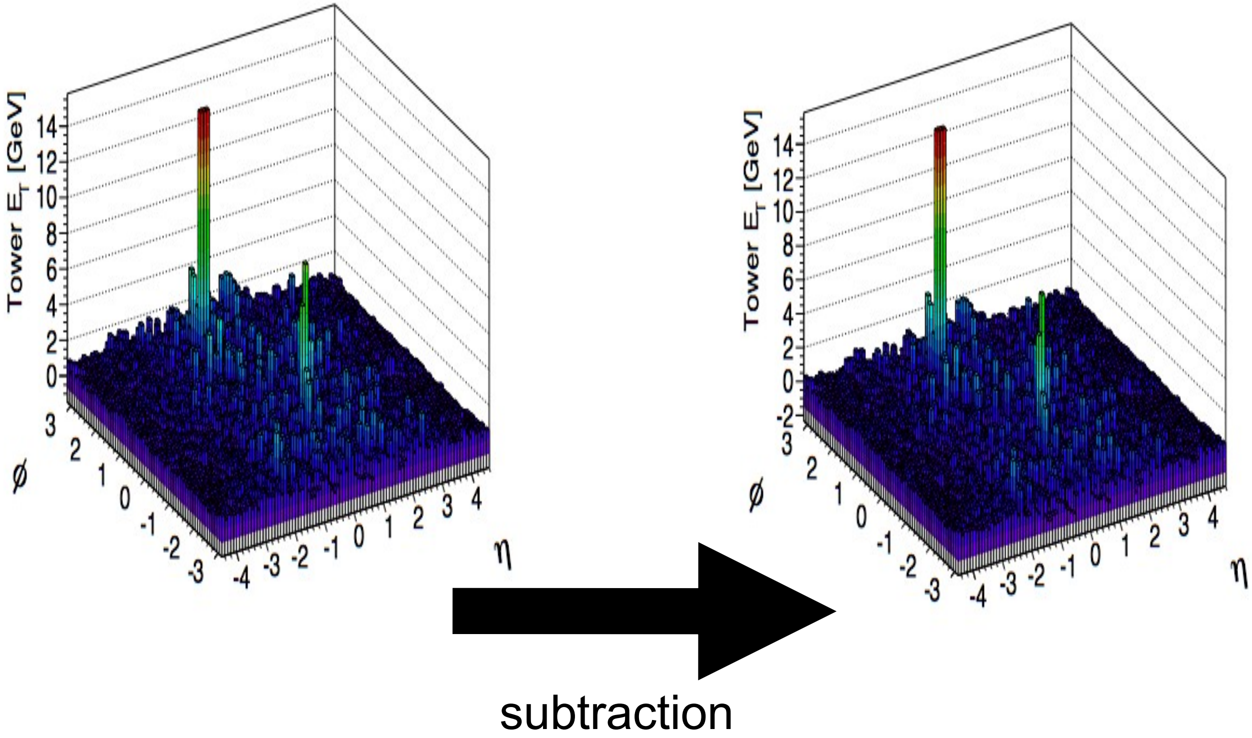
To further reduce bias, additional signals from ZDC and LUCID are also included

Jet reconstruction and underlying event subtraction

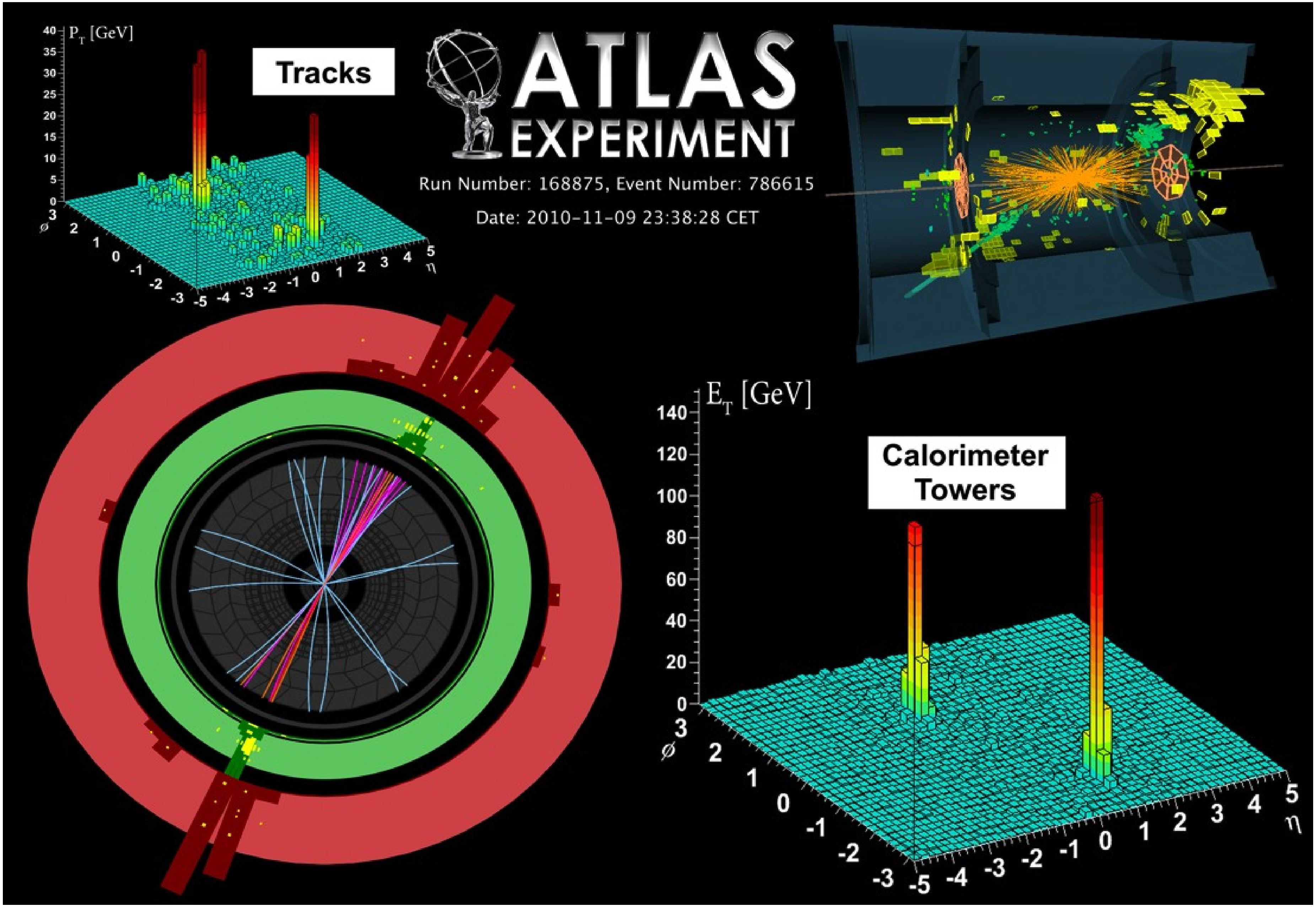
- **Take advantage of high granularity of calorimeters with towers of $\Delta\eta \times \Delta\Phi = 0.1 \times 0.1$**
- **Towers are weighted using energy density dependent factors**
  - **Correct for calorimeter non compensation.**
  - **Other energy losses**

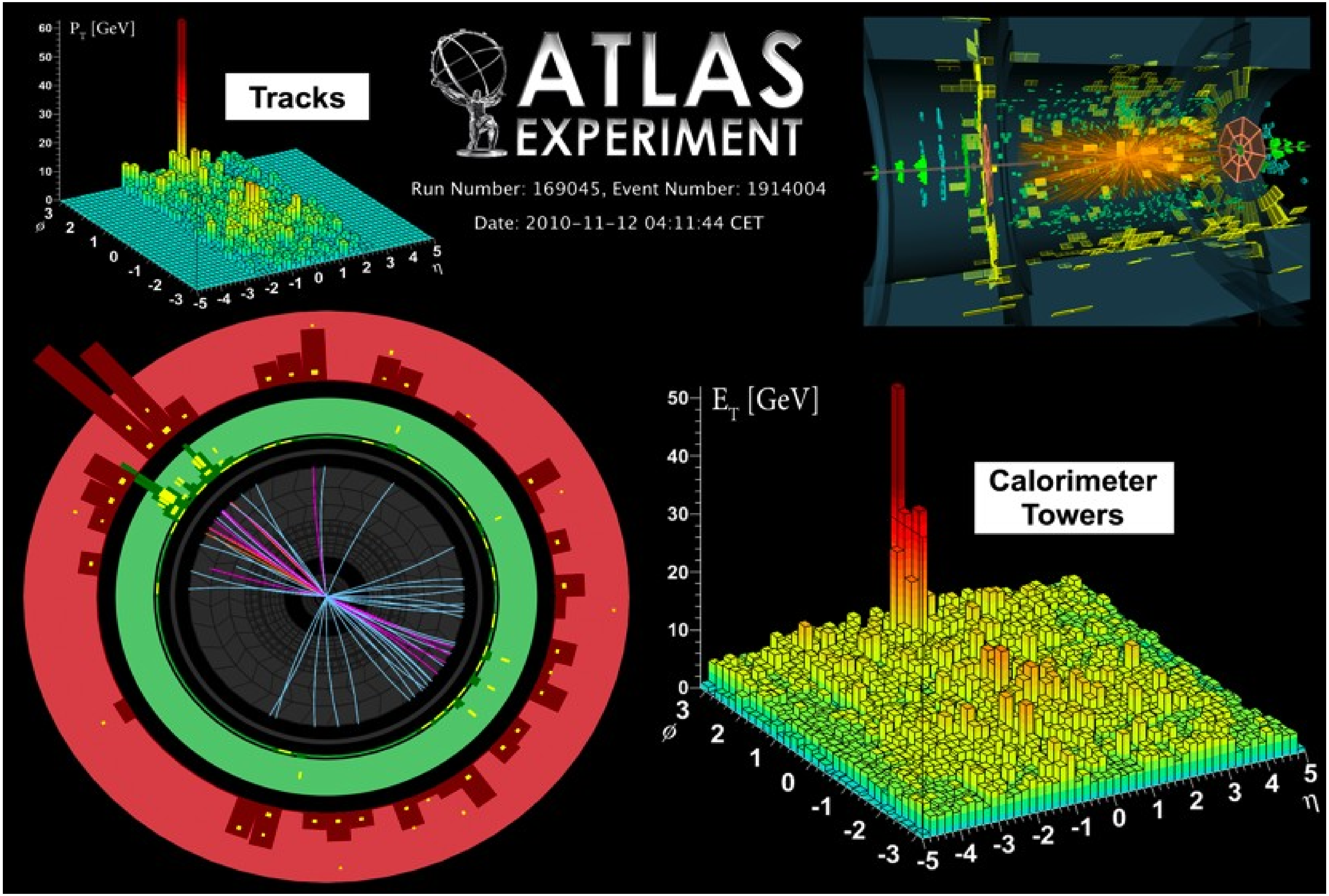
- **Towers used as input for infrared safe anti-kt jet algorithm with R=0.4**
- **Subtract underlying event by averaging transverse energy depositions over Φ in regions of $\Delta\eta = 0.1$.**

$$E_{corr} = E_{meas} - \rho A$$



- **Event structure, topology unchanged by subtraction.**
- **Four-momentum of the jets is recalculated after corrections**


Tracks
ATLAS EXPERIMENT
Run Number: 168875, Event Number: 786615
Date: 2010-11-09 23:38:28 CET
Calorimeter Towers
E_T [GeV]
P_T [GeV]
η
ø



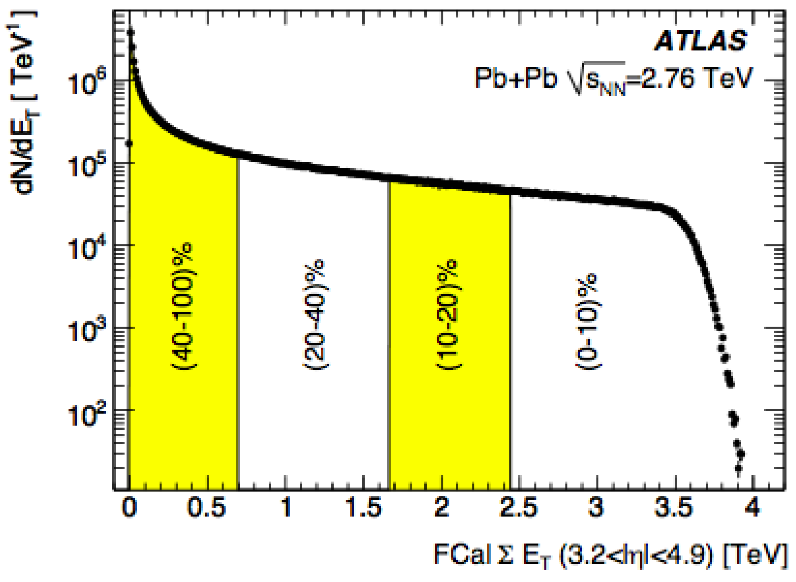
Clear asymmetry

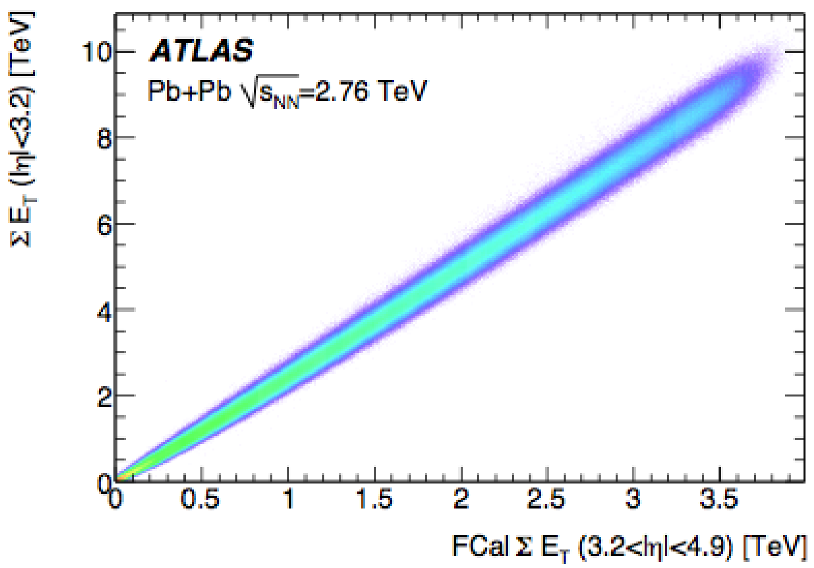
Event Selection

- Jet $|\eta| < 2.8$
- Leading jet $E_T > 100$ GeV
- Second jet $E_T > 25$ GeV
- $\Delta\varphi > \pi/2$ between jets

1.7 μb^{-1} yields 1693 events

Centrality



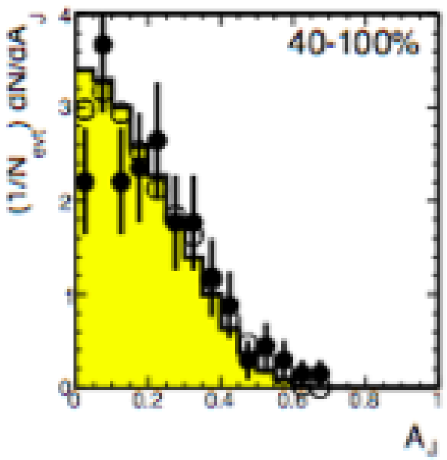


- Centrality is related to particle multiplicity.
- Measure centrality using ΣE_T in forward calorimeter (3.2 < |η| < 4.9) to avoid biasing the measurement (|η| < 2.8).
- Asymmetry measured in bins of centrality.

Asymmetry versus centrality

$$A_J = (E_{T1} - E_{T2})/(E_{T1} + E_{T2})$$

more central events



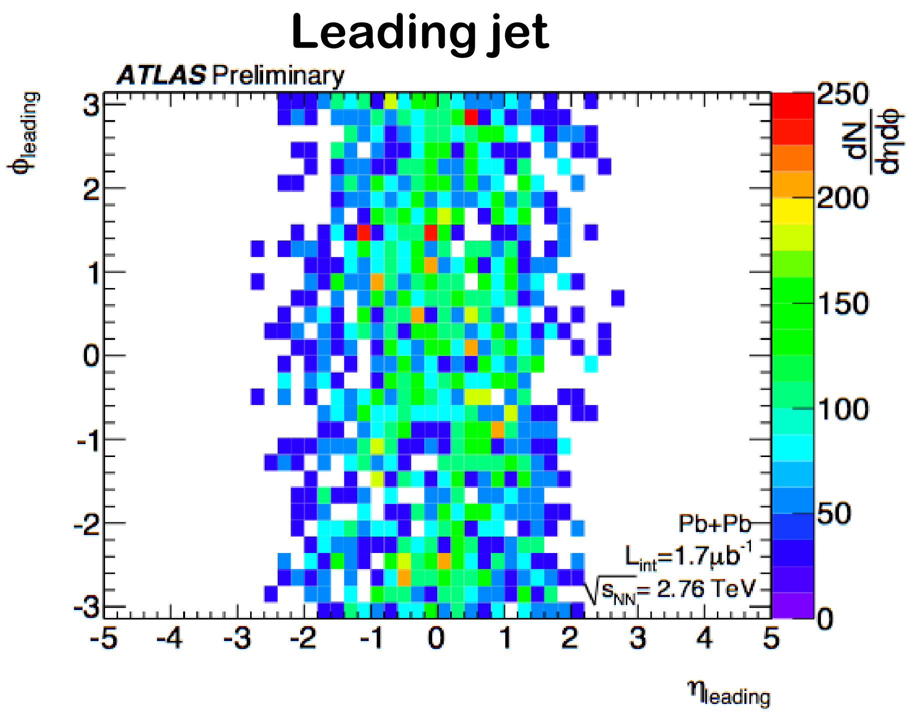
HIJING + PYTHIA (MC) agree with p+p data.
Clear discrepancy with Pb+Pb data.
Asymmetry not from underlying event jet.
Quenching not included in HIJING.

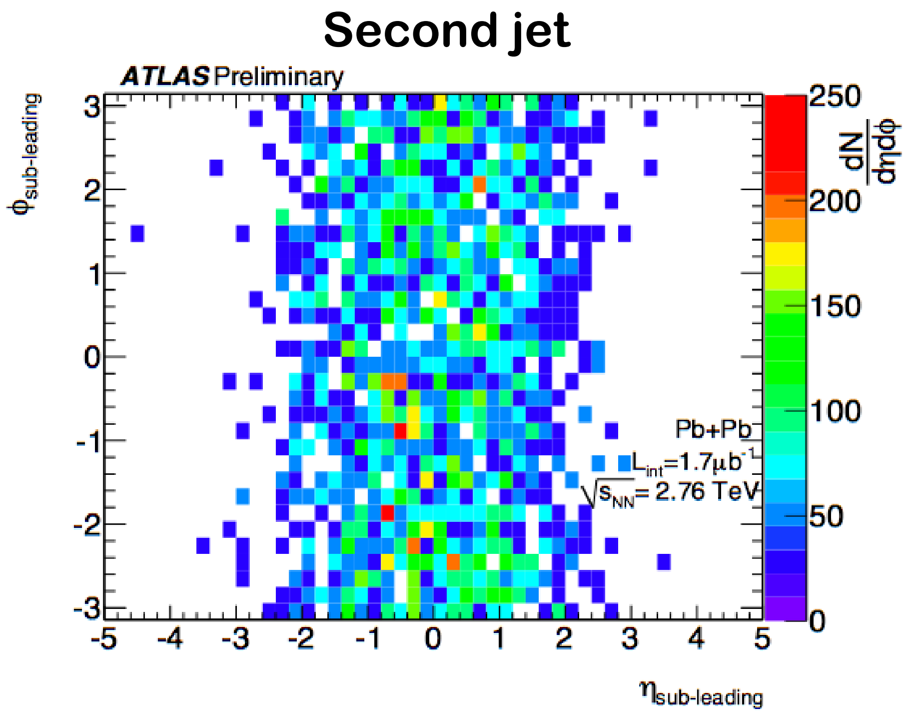
Clear asymmetry observed, now what?

Are we sure this observation is not due to detector effects and/or biases from analysis (objects)?

Cross checks

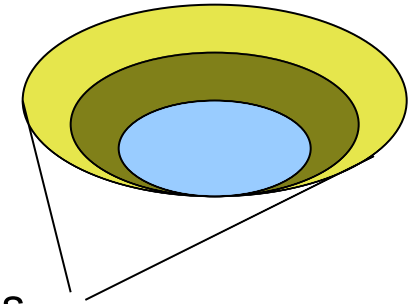
Detector effects



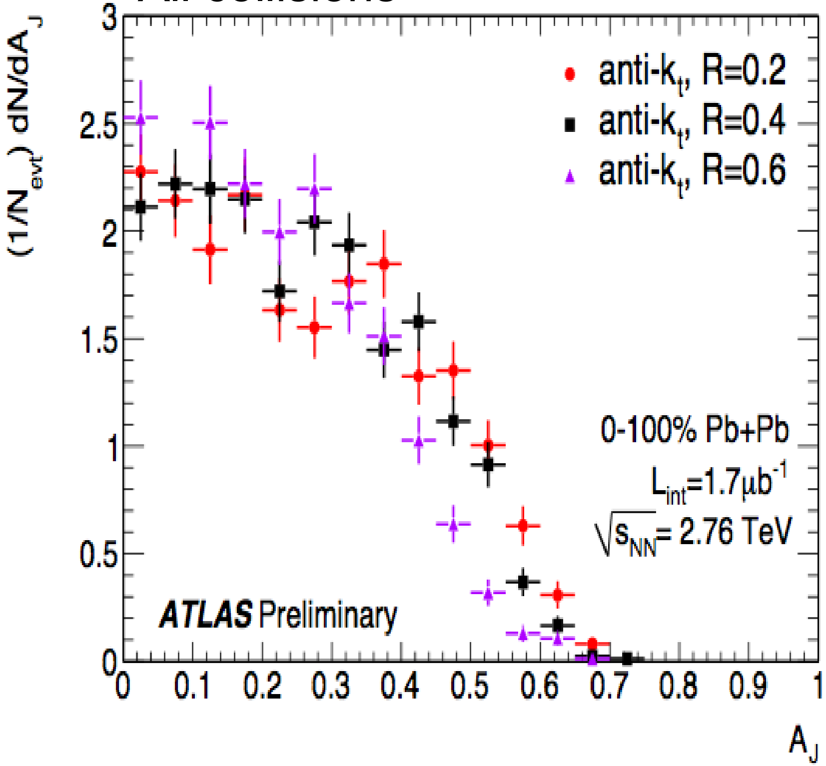


Jets uniformly distributed

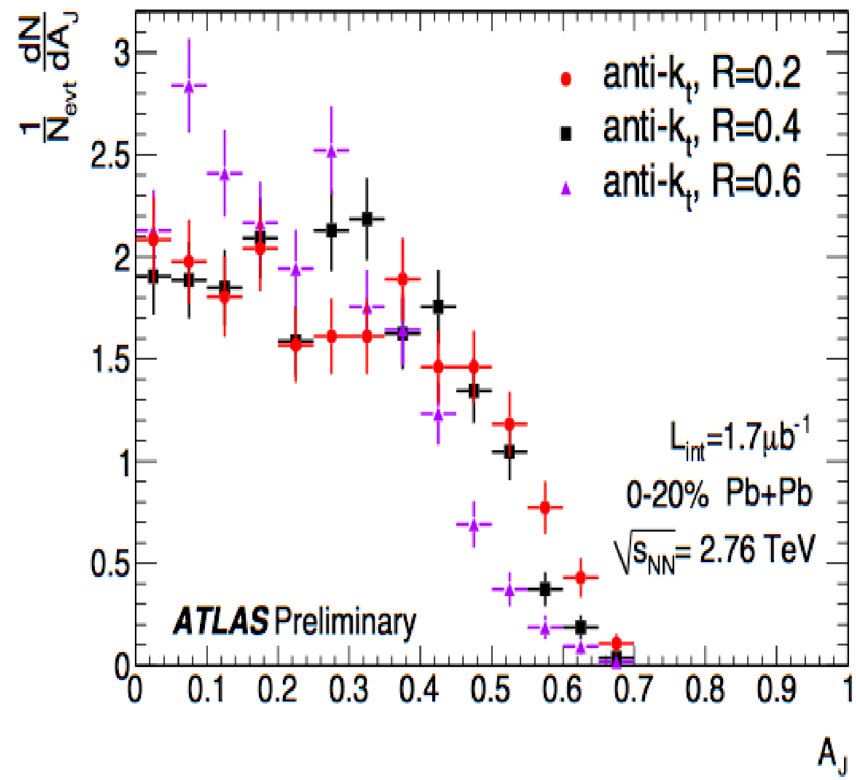
Cone size



All collisions



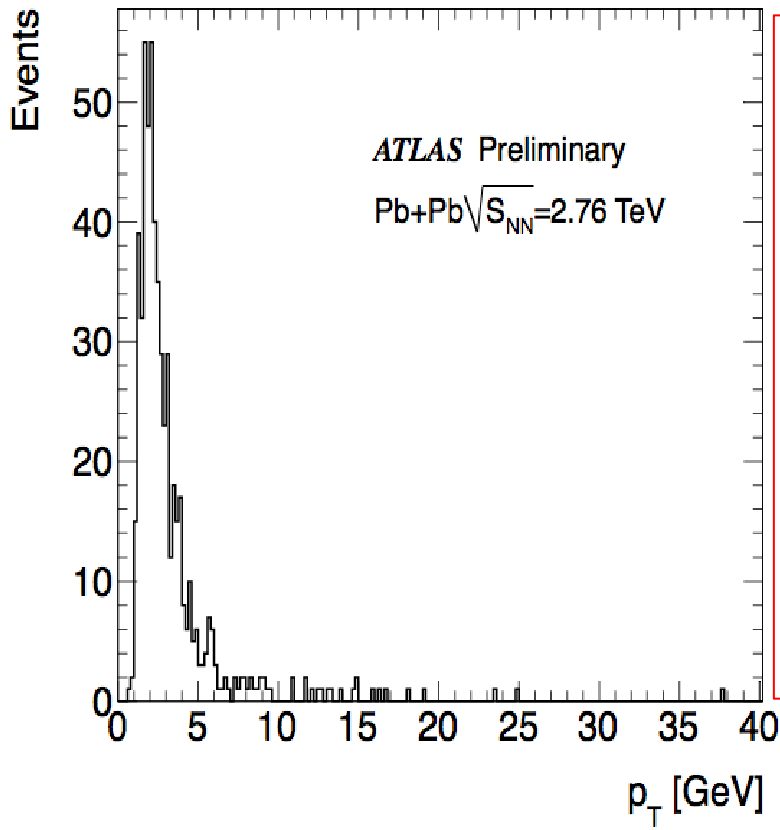
Most central collisions



No dependence on cone size

→ Asymmetry not from underlying event

Recoil muons and more



<2% muons with pt>10 GeV

More cross checks done, including:
- track jets
- jet shape
- missing energy resolution

"None of these investigations indicate that the highly asymmetric dijet events arise from backgrounds or detector related effects" → it's physics!

Conclusions

Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the ATLAS Detector at the LHC

Paper says that asymmetries ***"may point to an interpretation in terms of strong jet energy loss in a hot, dense medium"*** **(i.e. QGP).**

Possible further studies

In the opposite hemisphere, study

- particle multiplicities
- momentum distribution

→ other mechanisms explaining the asymmetry?

Implementation of jet-medium interactions in MC simulations → comparison to Pb-Pb data


THANK YOU
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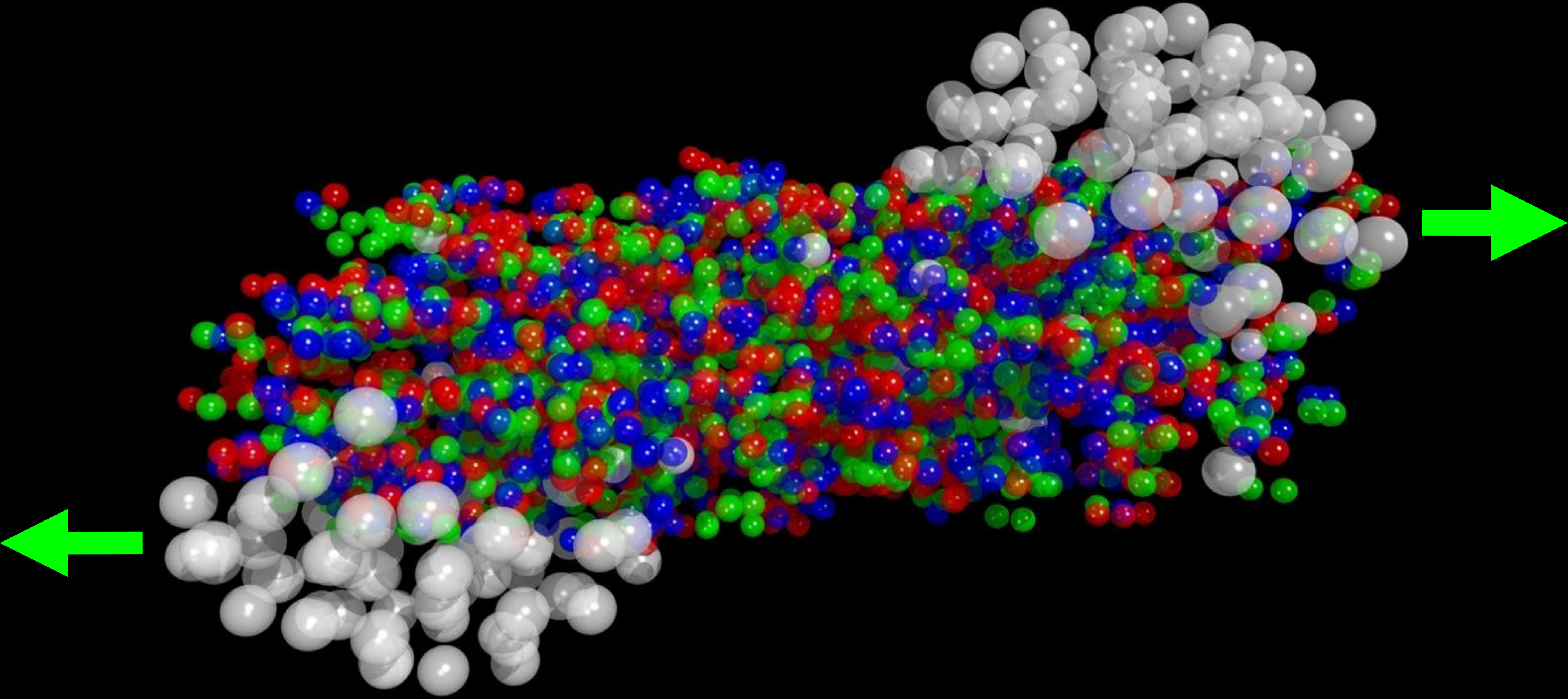
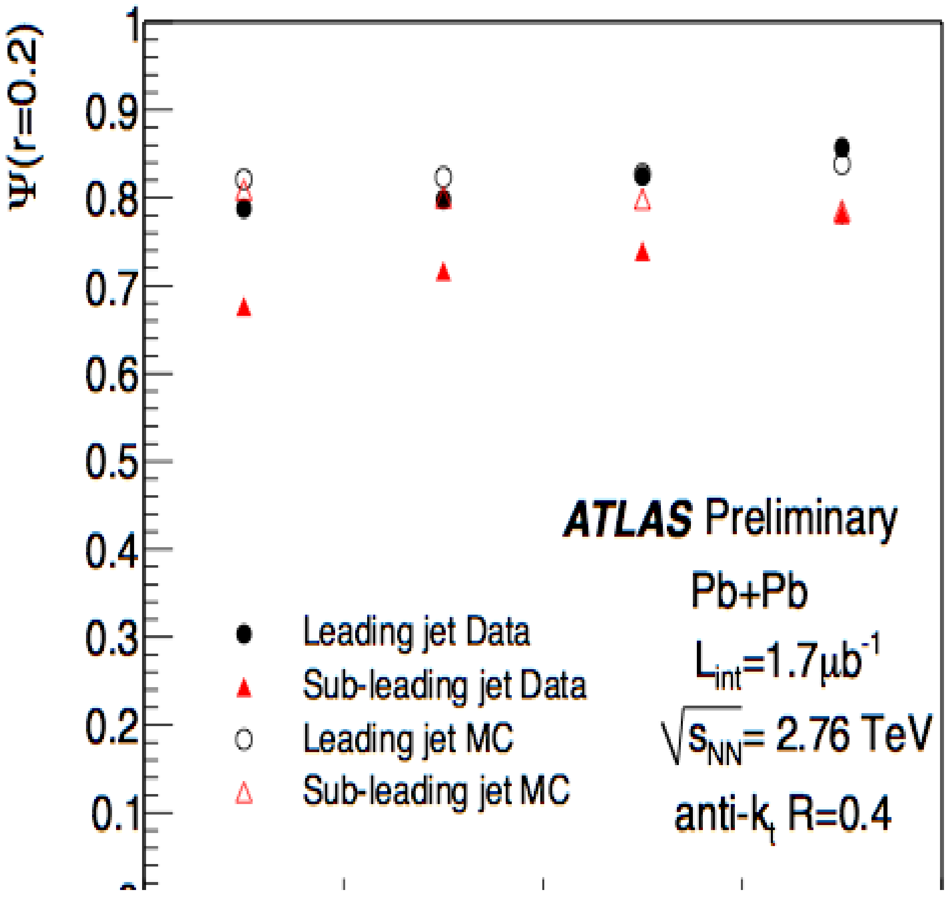


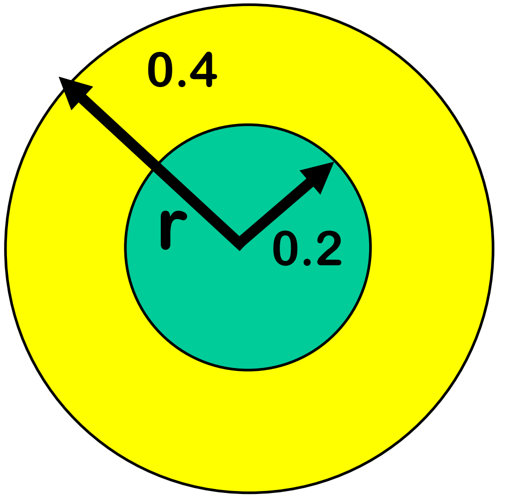
backup

Monte Carlo

- PYTHIA (event generator) + HIJING (subsequent energy flow without jet quenching).
- Data are compared with MC and with pp collisions.

Jet shape



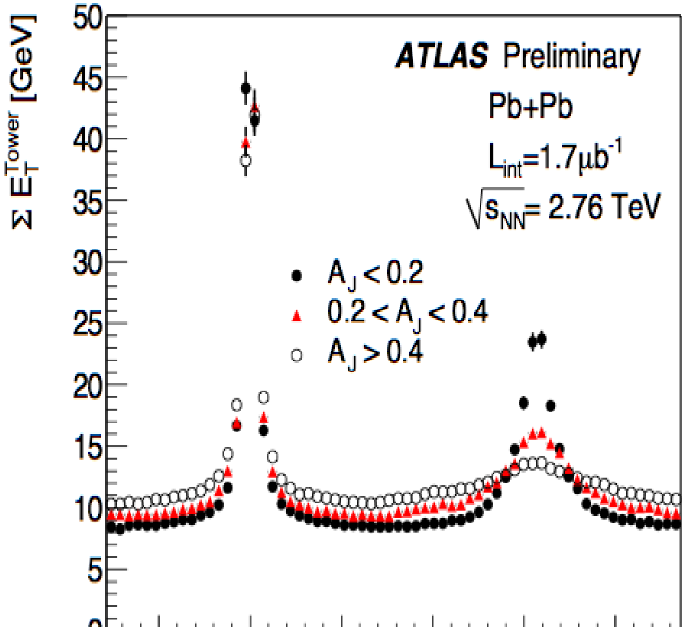


$$\Psi(r = 0.2) = \frac{E_T^{jet}(r \leq 0.2)}{E_T^{jet}(R \leq 0.4)}$$

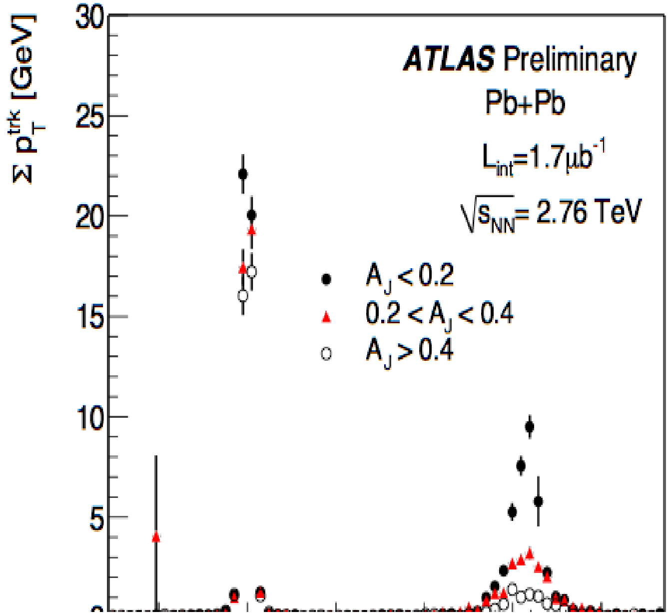
Leading jet: no dependence
Sub-leading jet: slight dependence
these jets are softer! (understood)

Track jets

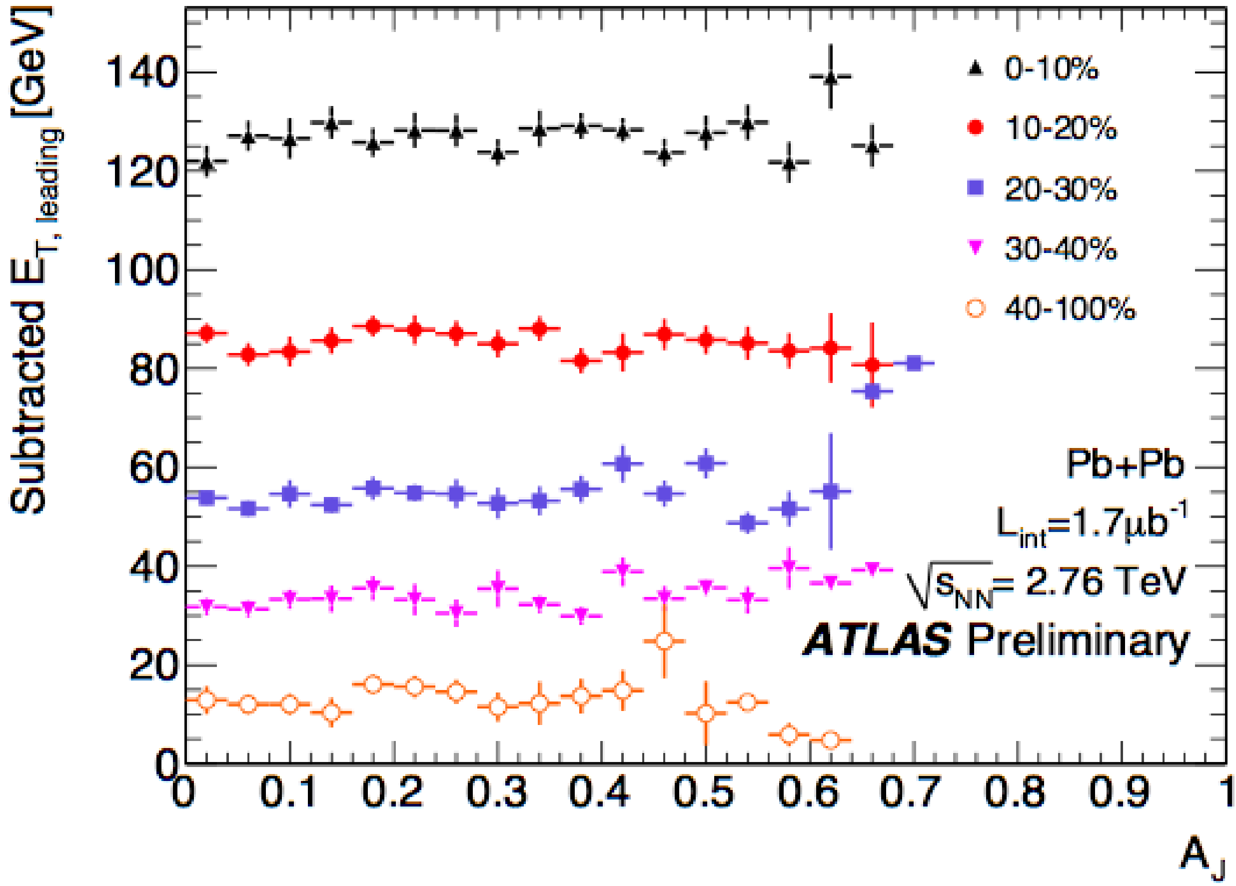
calorimeter



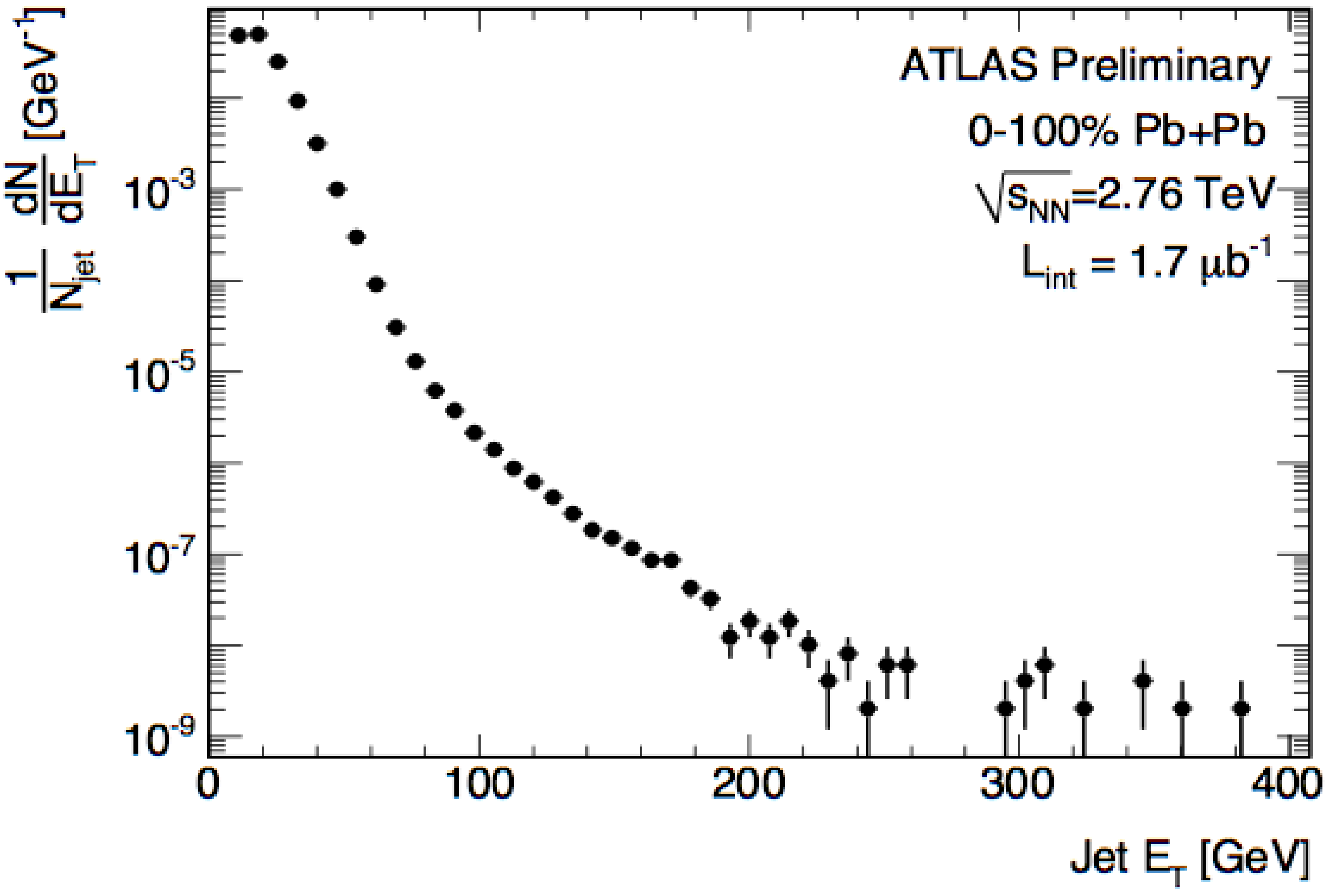
track jets



Subtraction bias



Inclusive jet pt spectrum

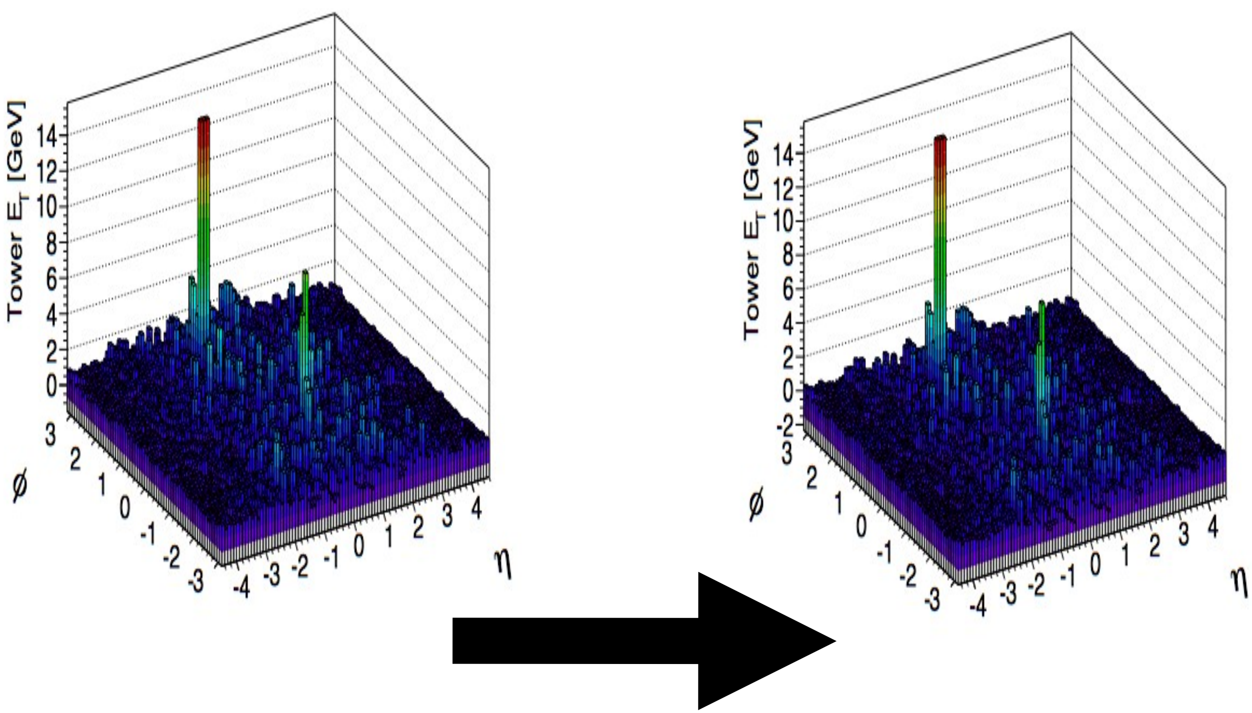


How to build a jet in ATLAS

- **Take advantage of high granularity of calorimeters with towers of Δη x ΔΦ = 0.1 x 0.1**
- **Towers are weighted using energy density dependent factors**
  - **Correct for calorimeter non compensation.**
  - **Other energy loses**

- **Towers used as input for infrared safe anti-kt algorithm. R=0.4**

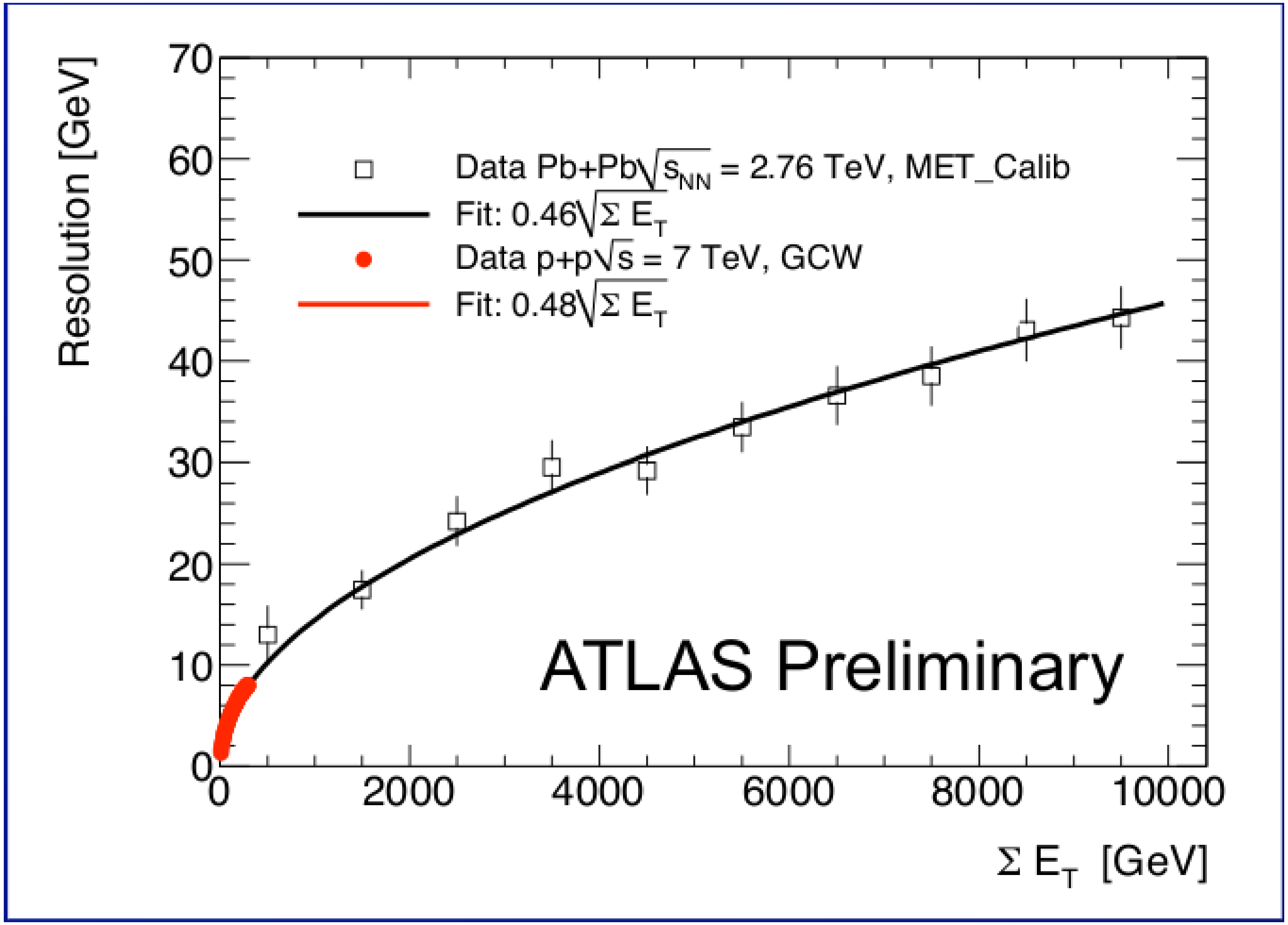
- **Subtract underlying event by averaging transverse energy depositions over Φ in regions of   Δη = 0.1.**
  - **Avoid bias in the energy density by excluding jets with D > 5 from average.**



$$D = E^{tower}_{\max} / \left\langle E^{tower}_{T} \right\rangle > 5$$

- **Event structure, topology unchanged by subtraction.**
- **Four-momentum of the jets is recalculated after corrections**

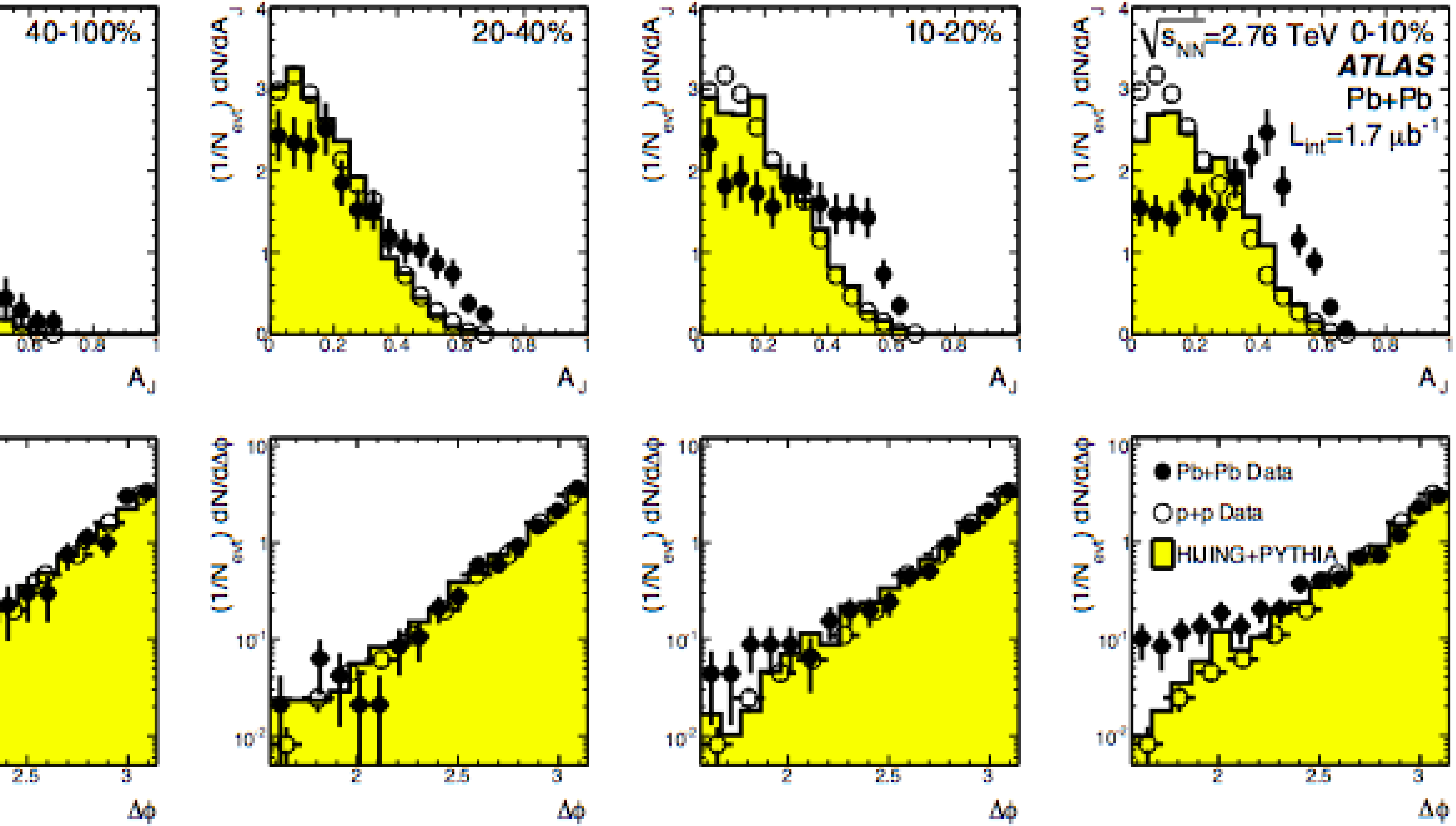
Missing Energy Resolution



The MET resolution shows the same behavior as in proton-proton collisions.

Plus: none of the events in the Jet selected sample was found to have an anomalously large MET.

Asymmetry



40-100%
20-40%
10-20%
$\sqrt{s_{NN}}$=2.76 TeV 0-10%
ATLAS
Pb+Pb
L_{int}=1.7 μb^{-1}
$(1/N_{evt})$ dN/dA_J
A_J
$(1/N_{evt})$ dN/dΔφ
Δφ
Pb+Pb Data
p+p Data
HIJING+PYTHIA