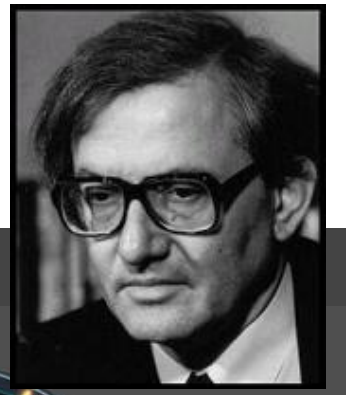
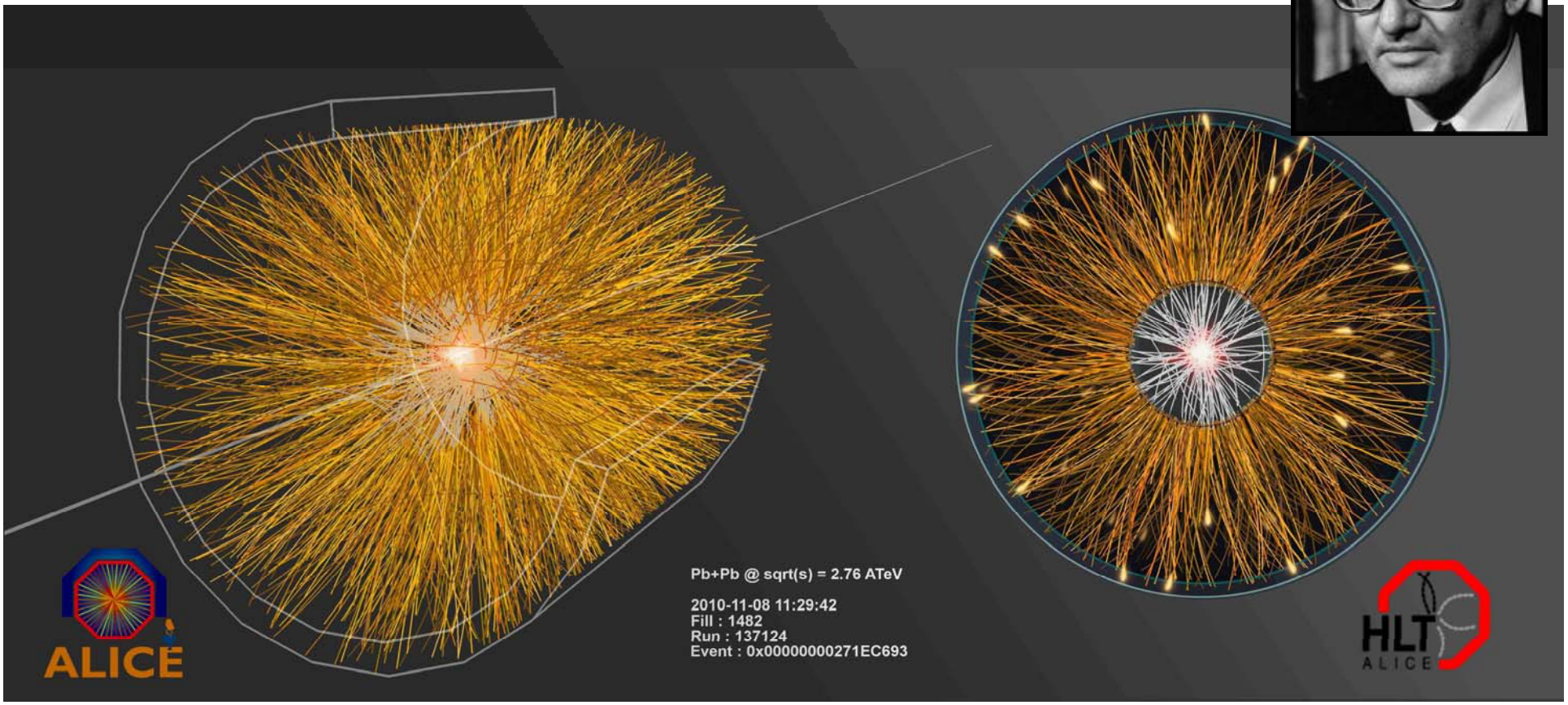
Latest results from the Heavy Ion Run at LHC
ALICE Collaboration





Péter Lévai, MTA KFKI RMKI

Zimányi Winter School

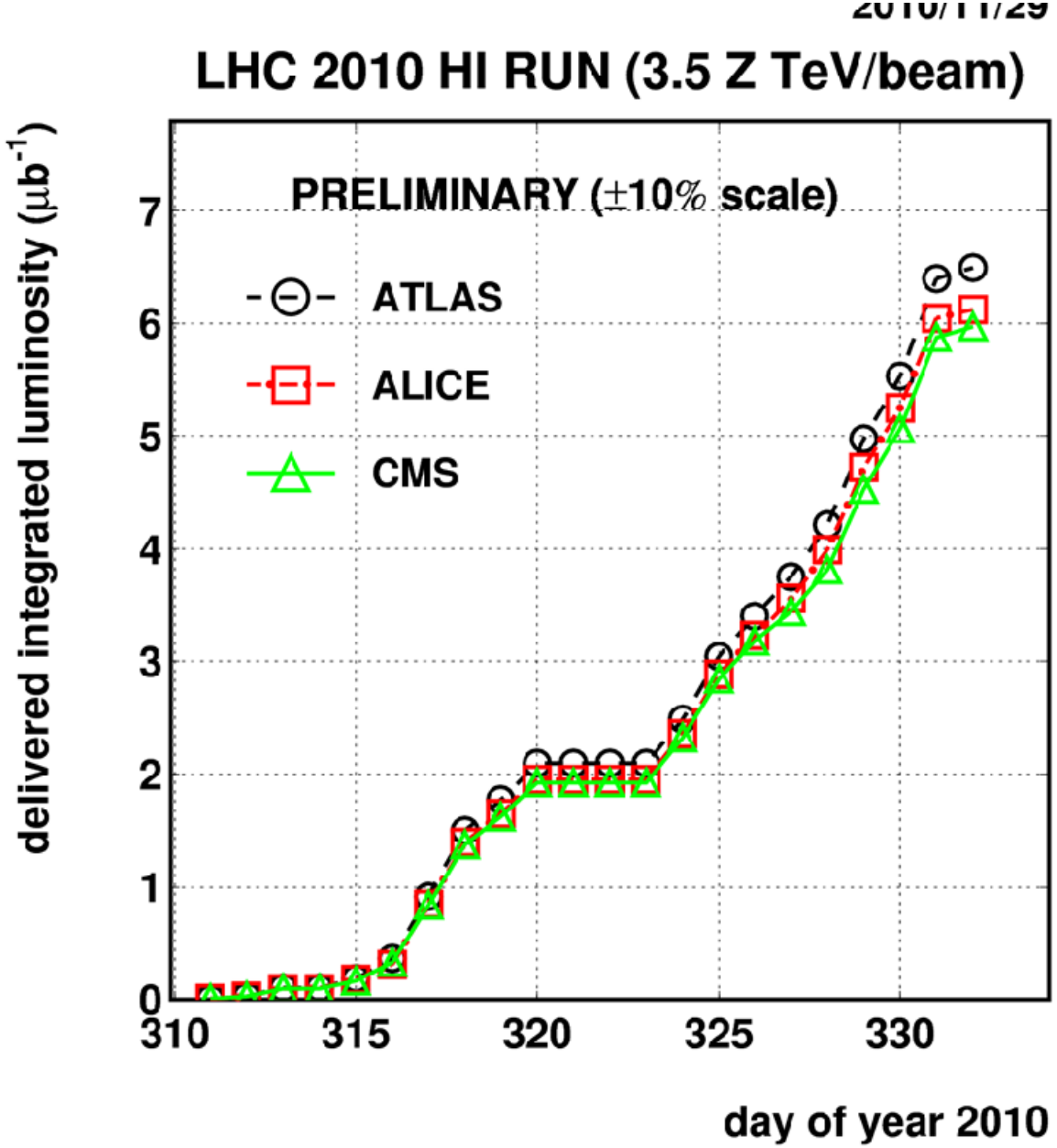
3 December 2010

Heavy Ion Programm in November 2010

4 November: Pb ions runs in the LHC (82*450 GeV)
6 November: First Pb acceleration (82*3500 GeV)

7 November: 0h 35' – first HI collisions (5000 in 1h)
8 November: First stable beam, all ALICE detector is up
2 * 2 bunch
9 November: 5 * 5 bunch, 17 * 17 bunch
12 November: 69*69 bunch
13 November: 121 * 121 bunch, 4.6 M# during 6h
14 November: After 1 week of run 1 microbarn-1 events

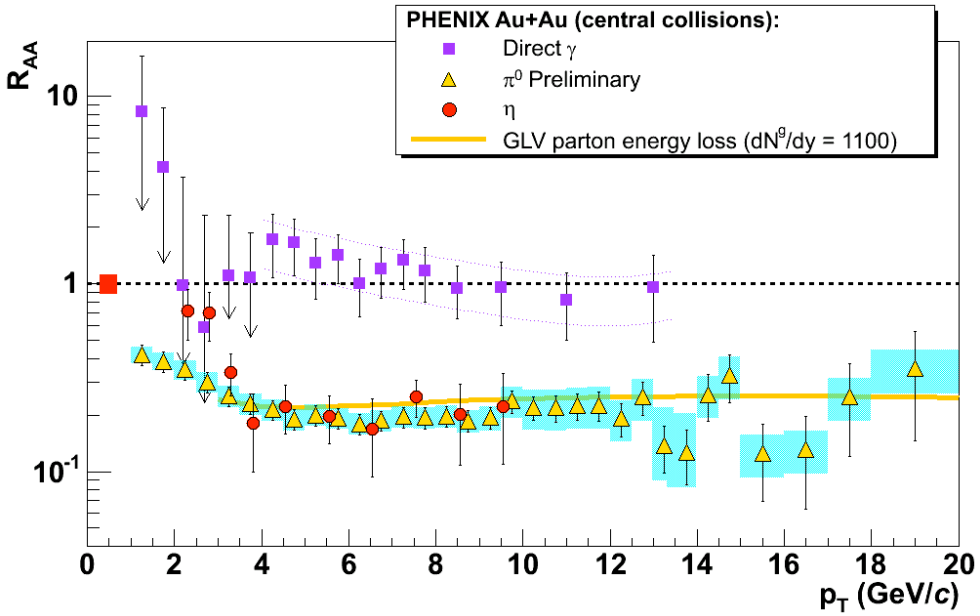
29 November: After 3 weeks of run 6.4 microbarn-1 events

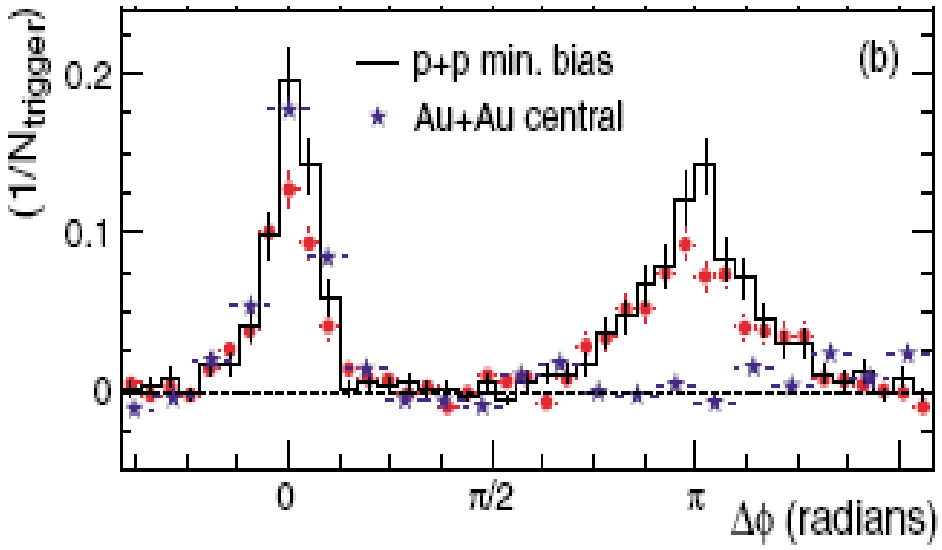


Until 2 Dec:
8 ub-1

One week
left until end of
data collection

Excellent job from the beam engineers. Congratulations !





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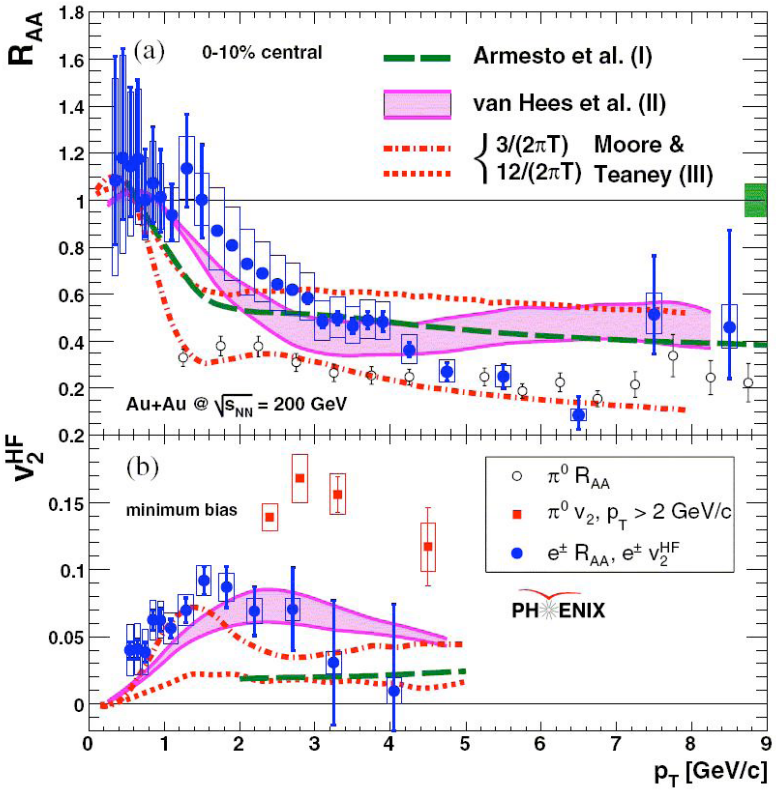
Three iconic physics results from RHIC experiments:



What could we obtain in the LHC experiments?

First Results from Heavy Ion Collisions at the LHC (ALICE, ATLAS, CMS) 2 December, 2010, CERN

Summary of the analysed results after 3 weeks

ALICE:	**Jürgen SCHUKRAFT**
ATLAS:	**Brian A. COLE**
CMS:	**Bolek WYSLOUCH**

CERN Indico:
http://indico.cern.ch/conferenceDisplay.py?confId=114939

Most of the next slides from the above talks – many thanks for them !!

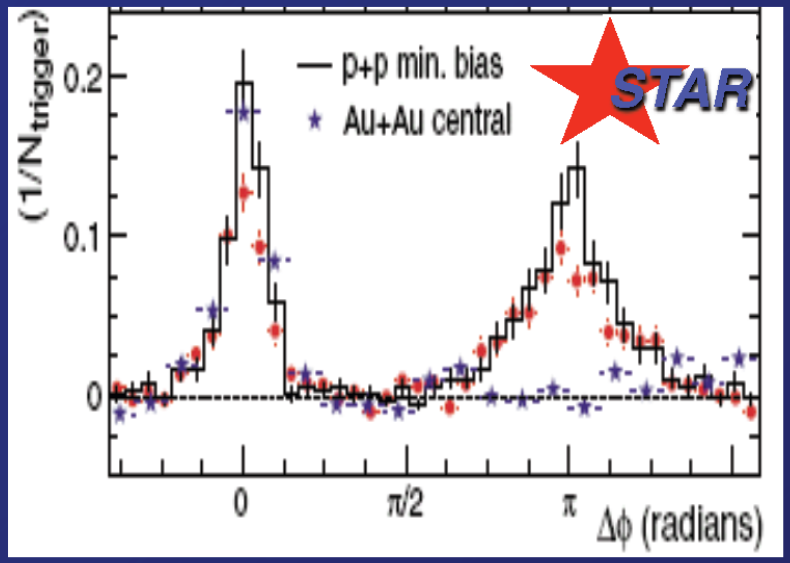
The paper: arXiv:1011.6182

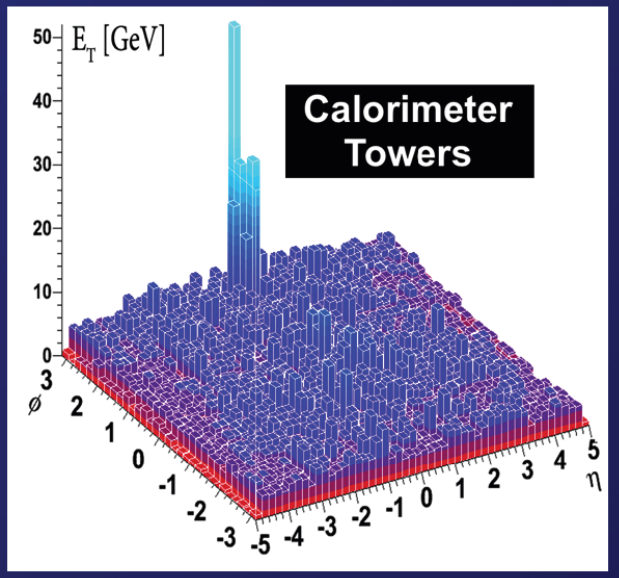
Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS Detector at the LHC

G. Aad *et al.* (The ATLAS Collaboration)*

Using the ATLAS detector, observations have been made of a centrality-dependent dijet asymmetry in the collisions of lead ions at the Large Hadron Collider. In a sample of lead-lead events with a per-nucleon center of mass energy of 2.76 TeV, selected with a minimum bias trigger, jets are reconstructed in fine-grained, longitudinally-segmented electromagnetic and hadronic calorimeters. The underlying event is measured and subtracted event-by-event, giving estimates of jet transverse energy above the ambient background. The transverse energies of dijets in opposite hemispheres is observed to become systematically more unbalanced with increasing event centrality leading to a large number of events which contain highly asymmetric dijets. This is the first observation of an enhancement of events with such large dijet asymmetries, not observed in proton-proton collisions, which may point to an interpretation in terms of strong jet energy loss in a hot, dense medium.

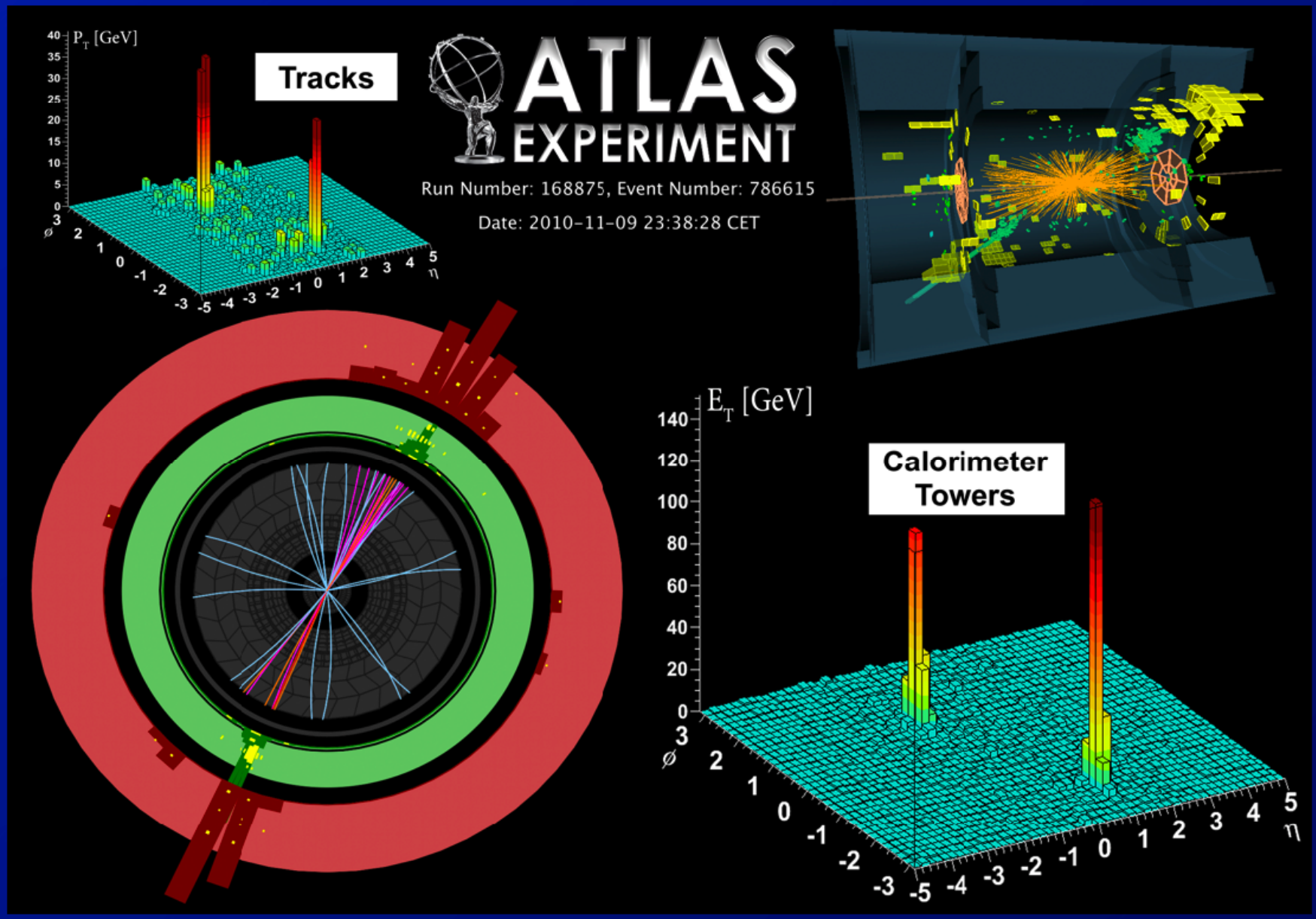
- **Paper submitted on Nov 25, accepted by PRL**





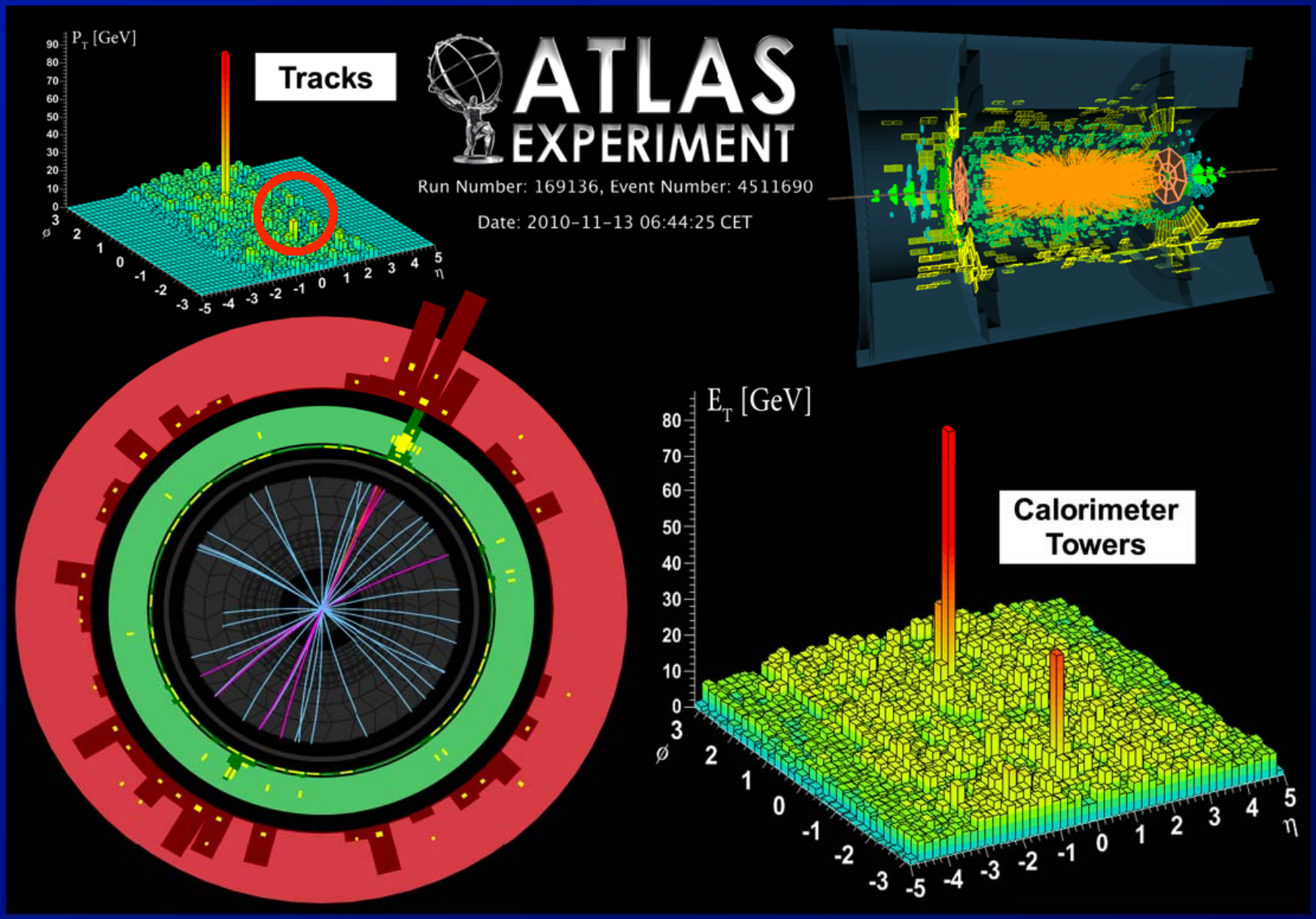
Indirect jet quenching @ RHIC Direct quenching @ LHC? 2

A (more) symmetric dijet event



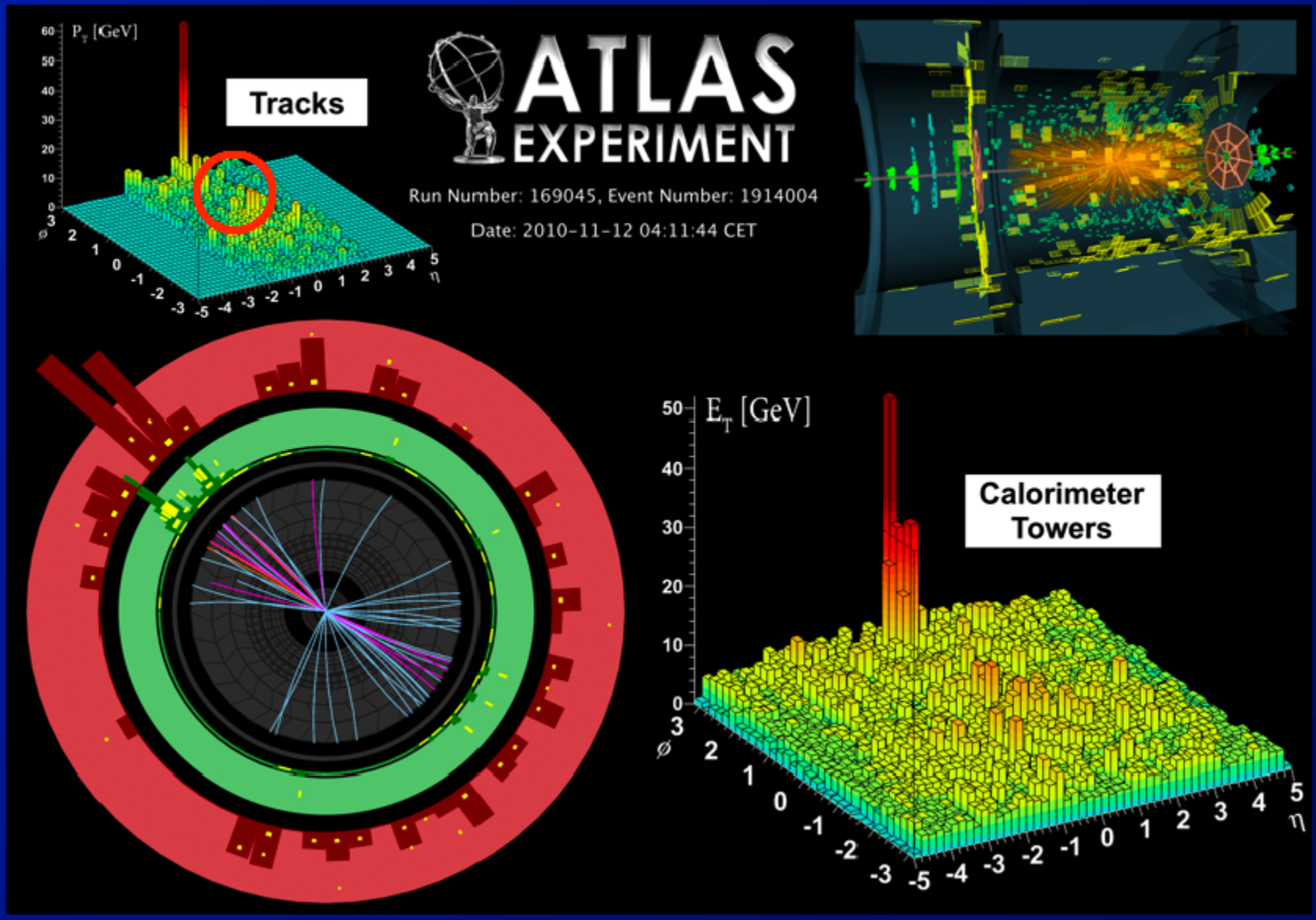
Peripheral, symmetric dijet event

An asymmetric event



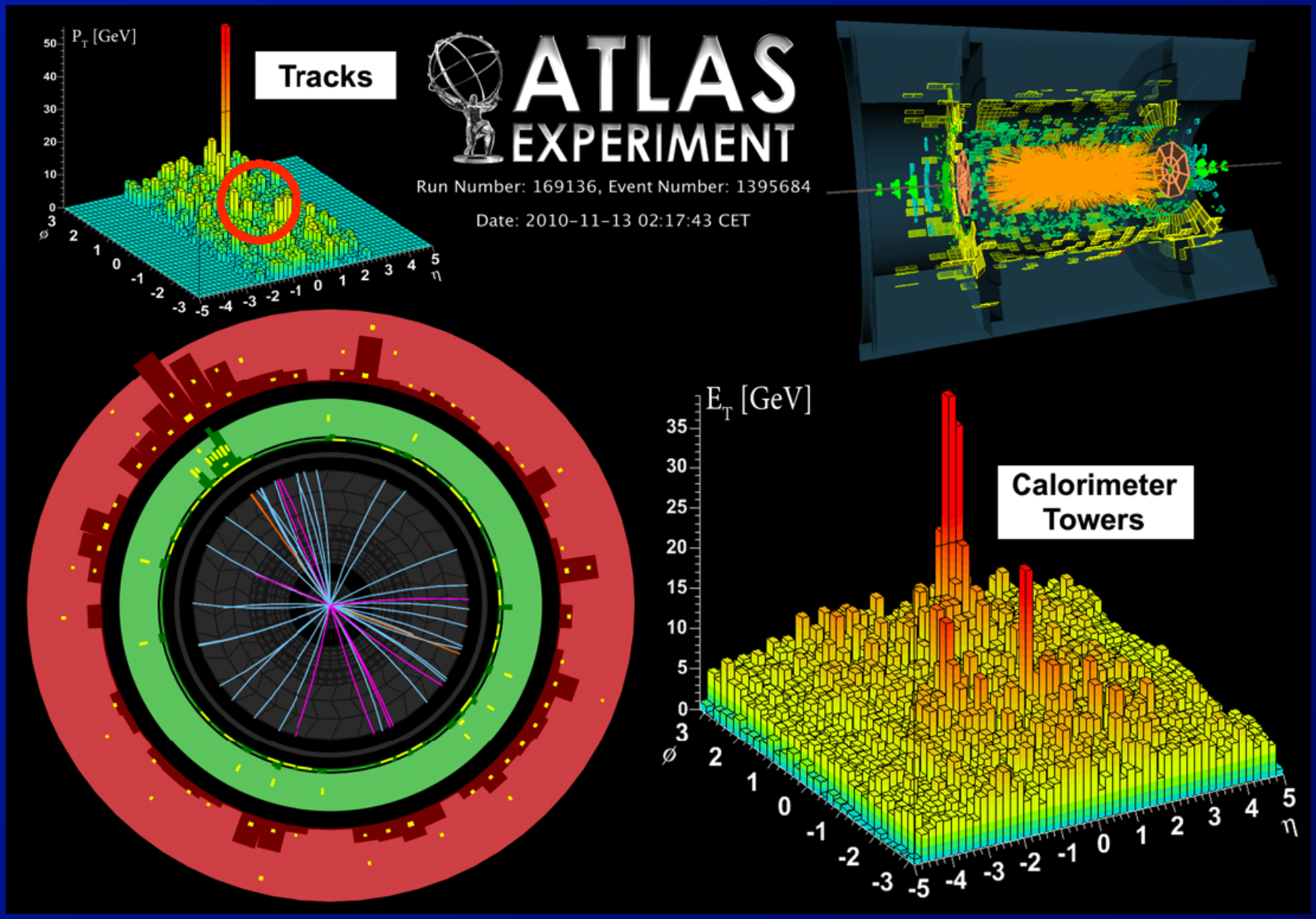
More central, asymmetric dijet event

Another asymmetric event



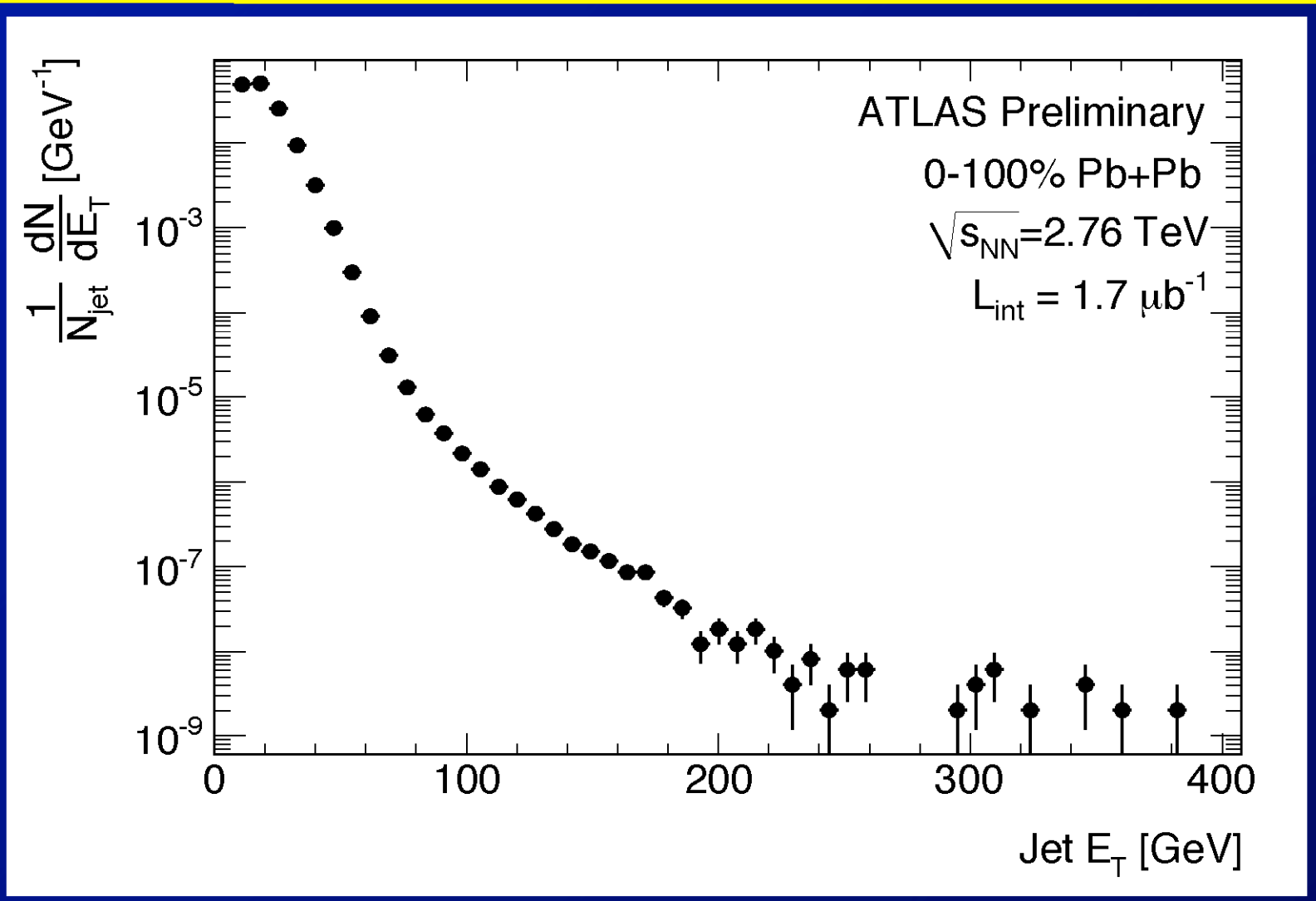
Even more central collision, more asymmetric dijet

Yet another asymmetric event



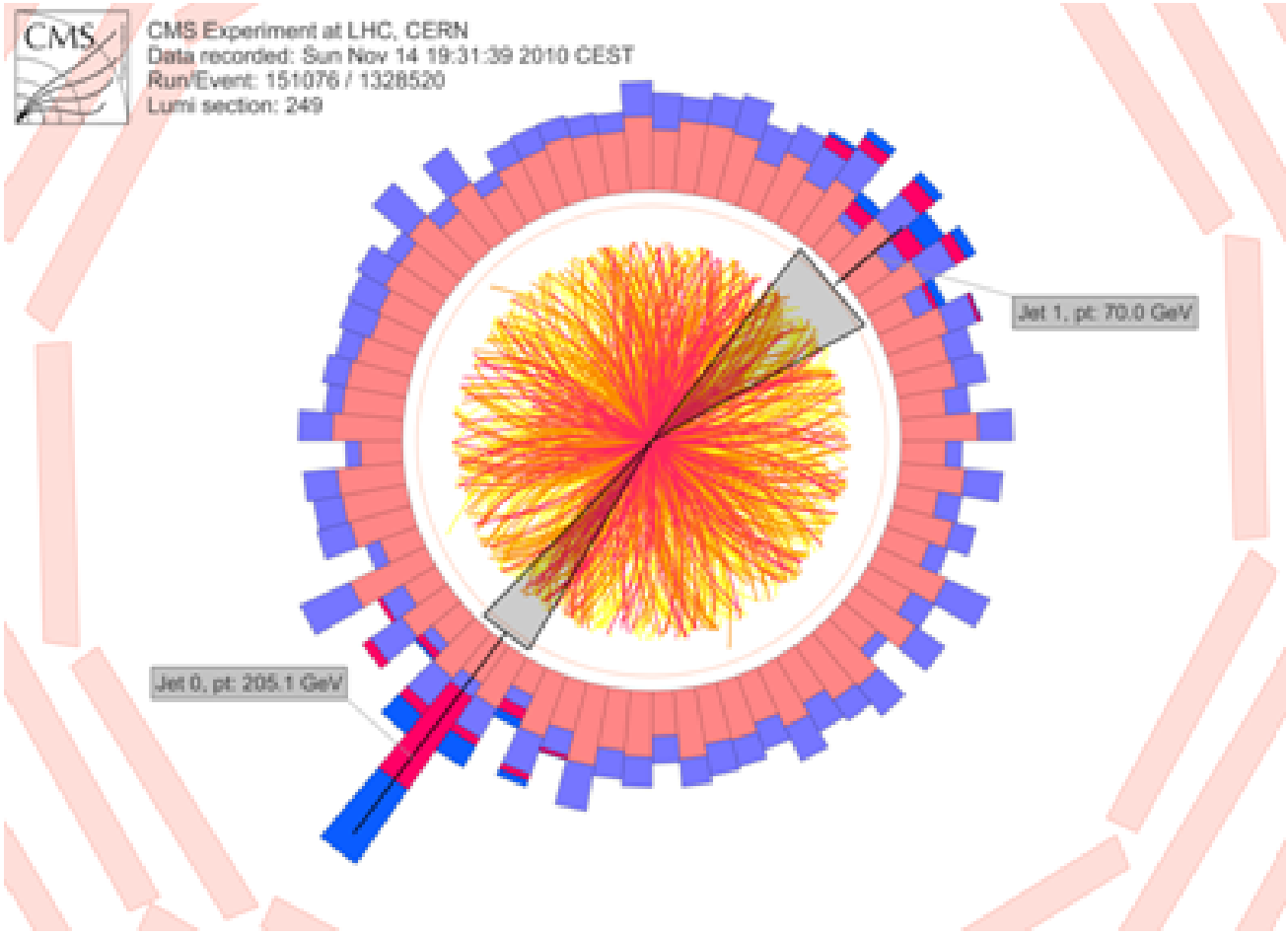
Central event, with split dijet + additional activity

Inclusive jet spectrum



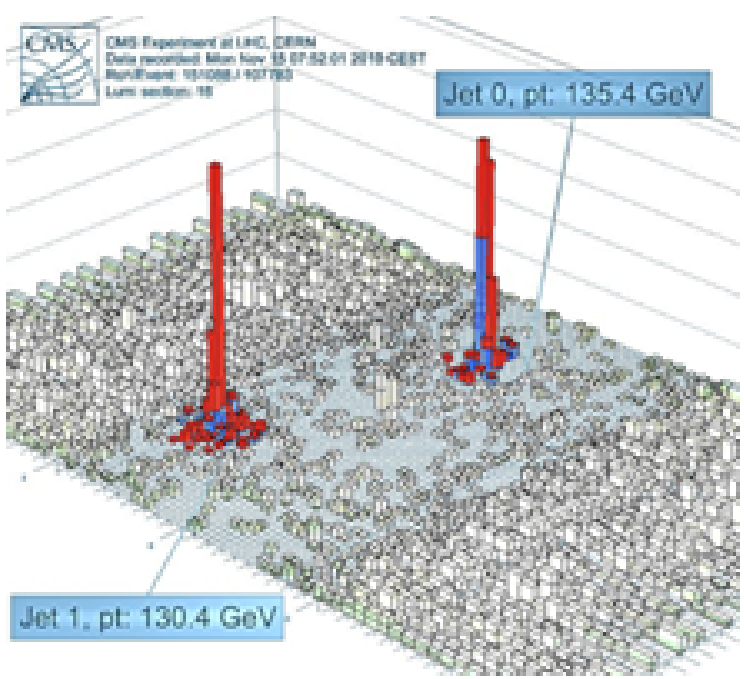
- Uncorrected jet E_T spectrum in minimum-bias Pb+Pb, R = 0.4, anti-k_t.

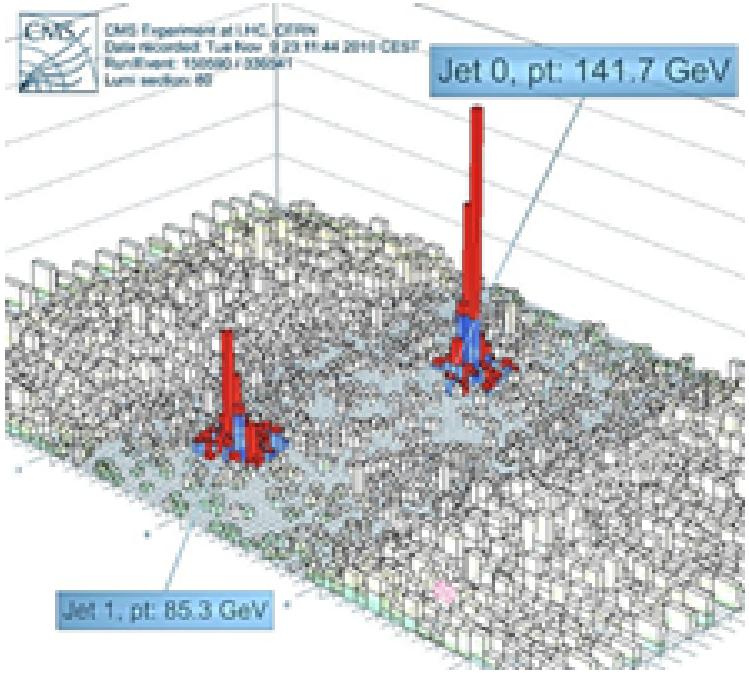
Typical dijet in PbPb Collisions at CMS



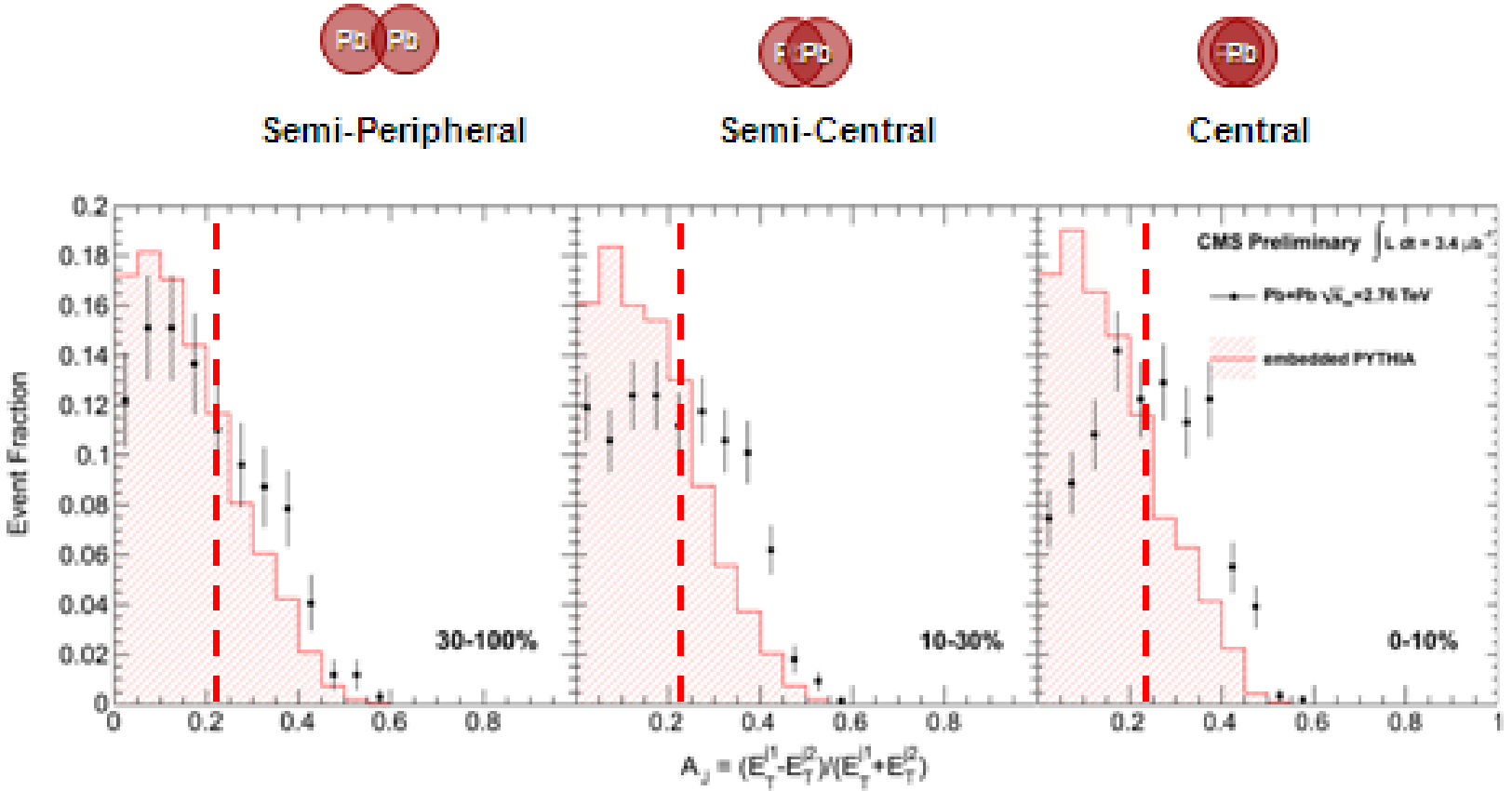
Dijet event candidates in CMS

- First hours of LHC running
  - We see dijet events
  - We see dijets with unbalanced energy: is this real?



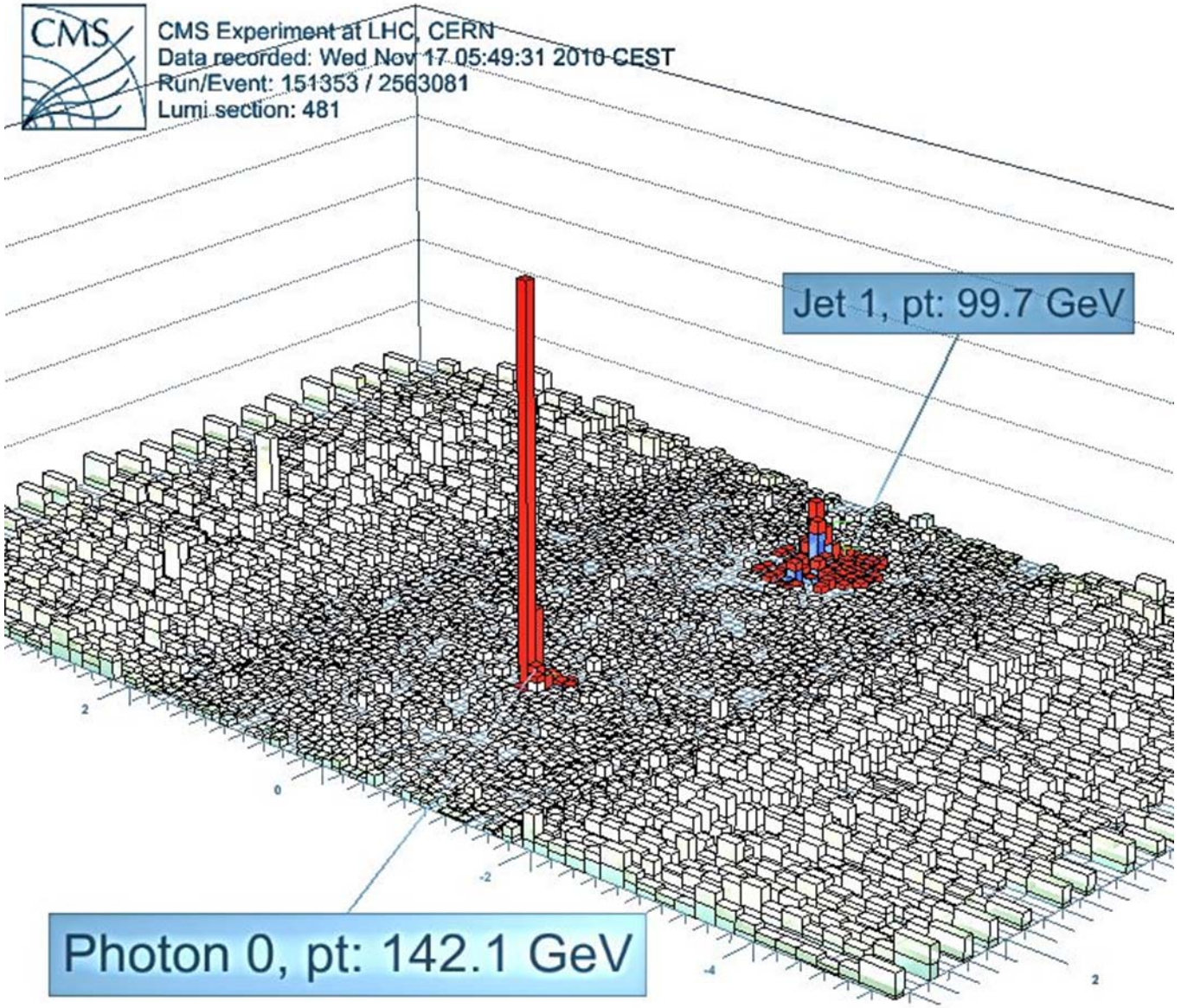


Dijet energy imbalance

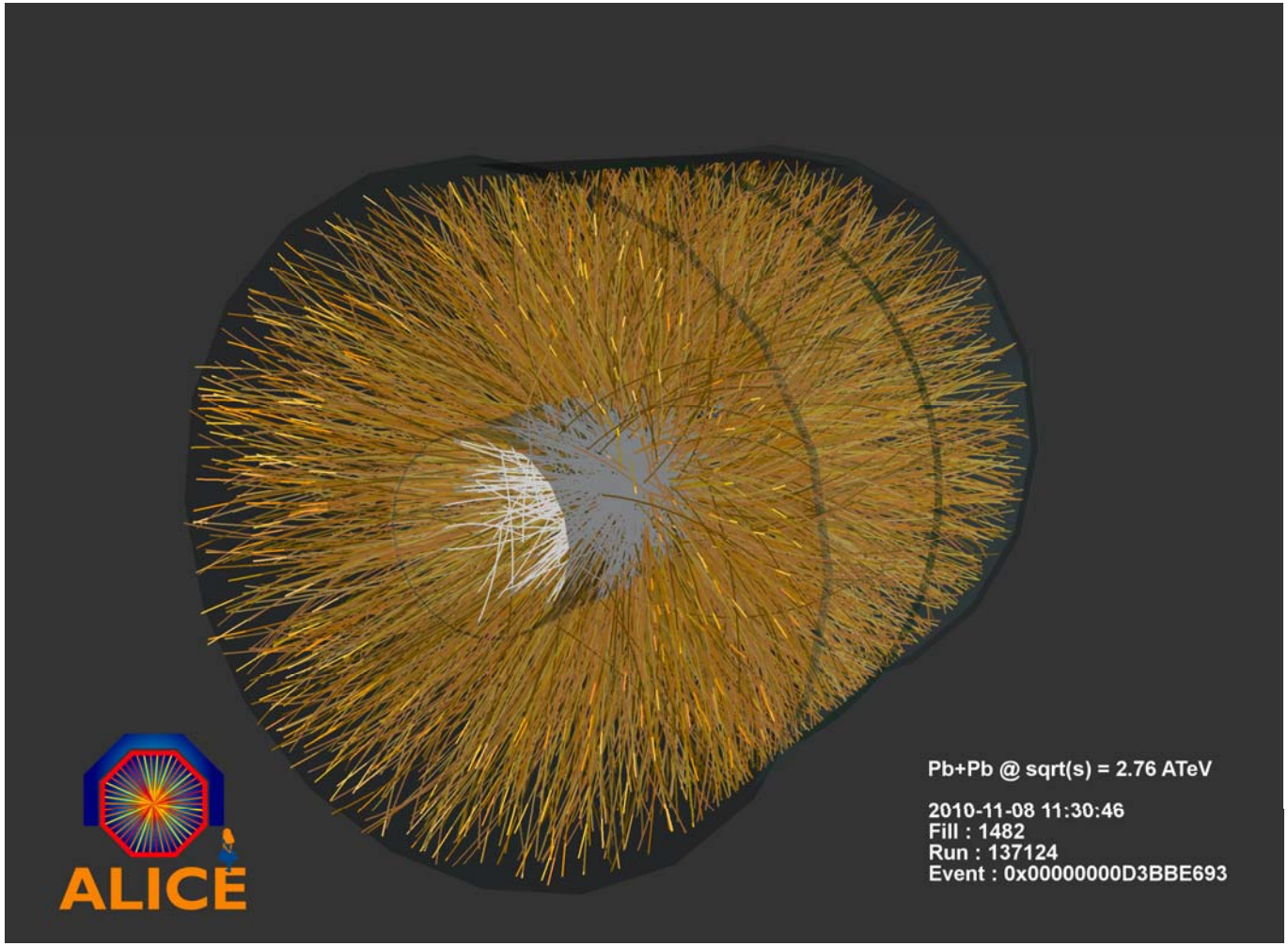


A significant dijet imbalance, well beyond that expected from unquenched MC, appears with increasing collision centrality

CMS


CMS
CMS Experiment at LHC, CERN
Data recorded: Wed Nov 17 05:49:31 2010 CEST
Run/Event: 151353 / 2563081
Lumi section: 481
Jet 1, pt: 99.7 GeV
Photon 0, pt: 142.1 GeV

One of the first Pb+Pb collisions in the ALICE TPC, ITS, …



— **Search** for the 'QGP' is essentially over

– **Discovery** of QGP is well under way (with fantastic results & surprises at RHIC)

– **Measuring** QGP parameters has just begun

• **1) Quantitative differences**

– significantly different state of QGP in terms of energy density, lifetime, volume

– large rate for 'hard probes' : jets, heavy quark states (b,c,U,J/Y),…

•**2) Test & validate the HI 'Standard Model'** **(< 10 years old !)**

QGP = very strongly interacting (almost) perfect liquid

– Test predictions/extrapolations from RHIC to LHC

- examples: **flow** ('soft') **Quarkonia suppression** ('hard')

• **3) 'Precision' measurements of QGP parameters**

– Quantitative and systematic study of the new state of matter

- **Equation-of-State** f(e,p,T), **viscosity** h (flow), **transport coefficient q** (jet quenching), Debye **screening mass** (Quarkonia suppression), …

– Confront data with Theory and Models:

- **standard tools:** Lattice QCD, pQCD, Thermo- and Hydrodynamics, …
- **new tools:** AdS/CFT ('duality'), Classical QFT ('Colour Glass Condensate')

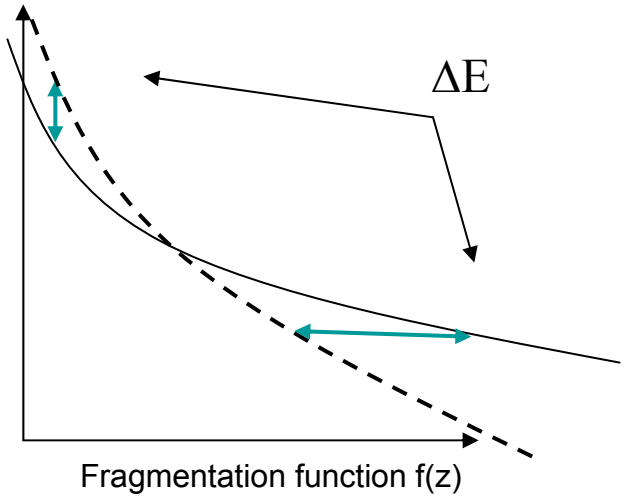
• 4) **Surprises ?**

– **we are dealing with QCD in the strong coupling limit !**

Jet quenching: **jet E -> jet E' (=E-DE) + soft gluons (DE)**

modified jet fragmentation function via matter induced gluon radiation/scattering

=> QGP properties



how much energy is lost ? (measures e.g. **q^**)

most difficult question, may depend on jet cone R, pt-cutoff, ..

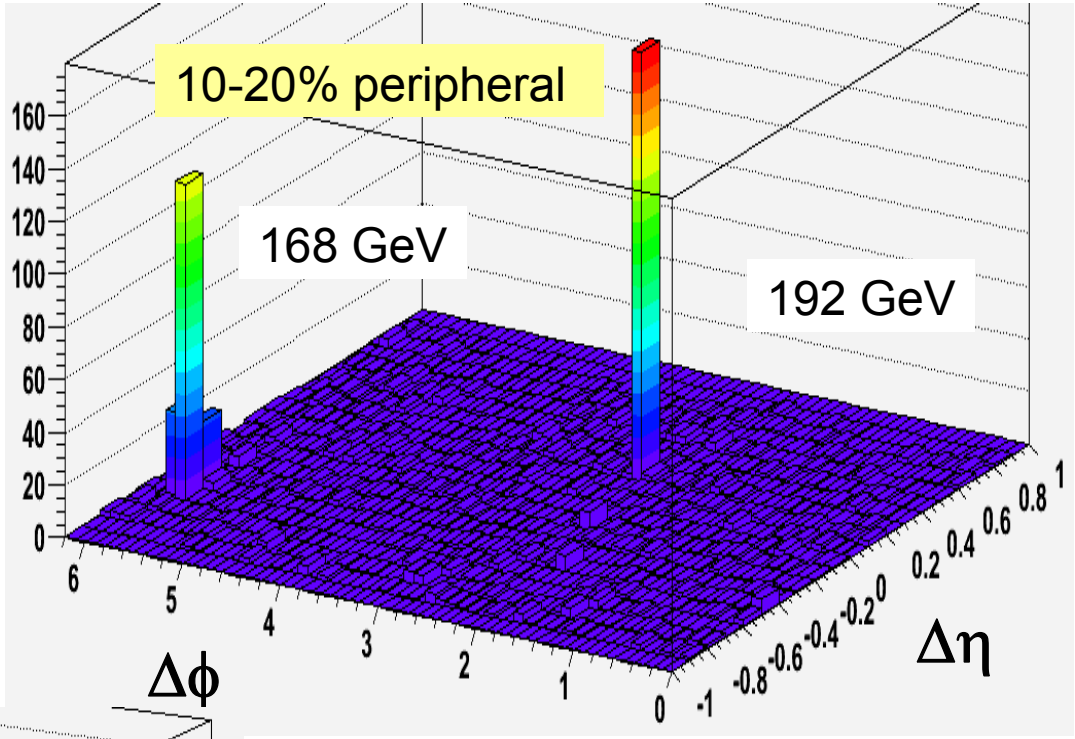
how is it lost ? (e.g. multiple soft or few hard gluons ?)

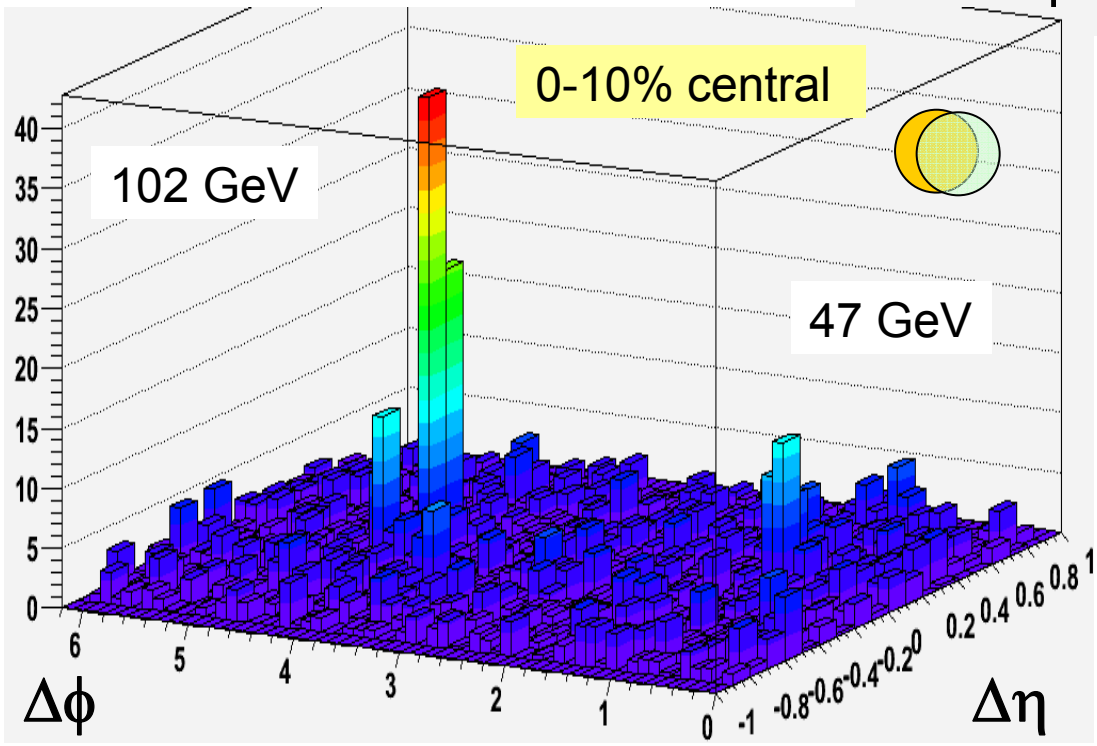
look at soft part of f(z), pt < 2-5 GeV

'response of QGP' (shock waves, Mach cones ??)

properties of bulk matter around jet, pt ~ 1 GeV

Jets in the ALICE TPC

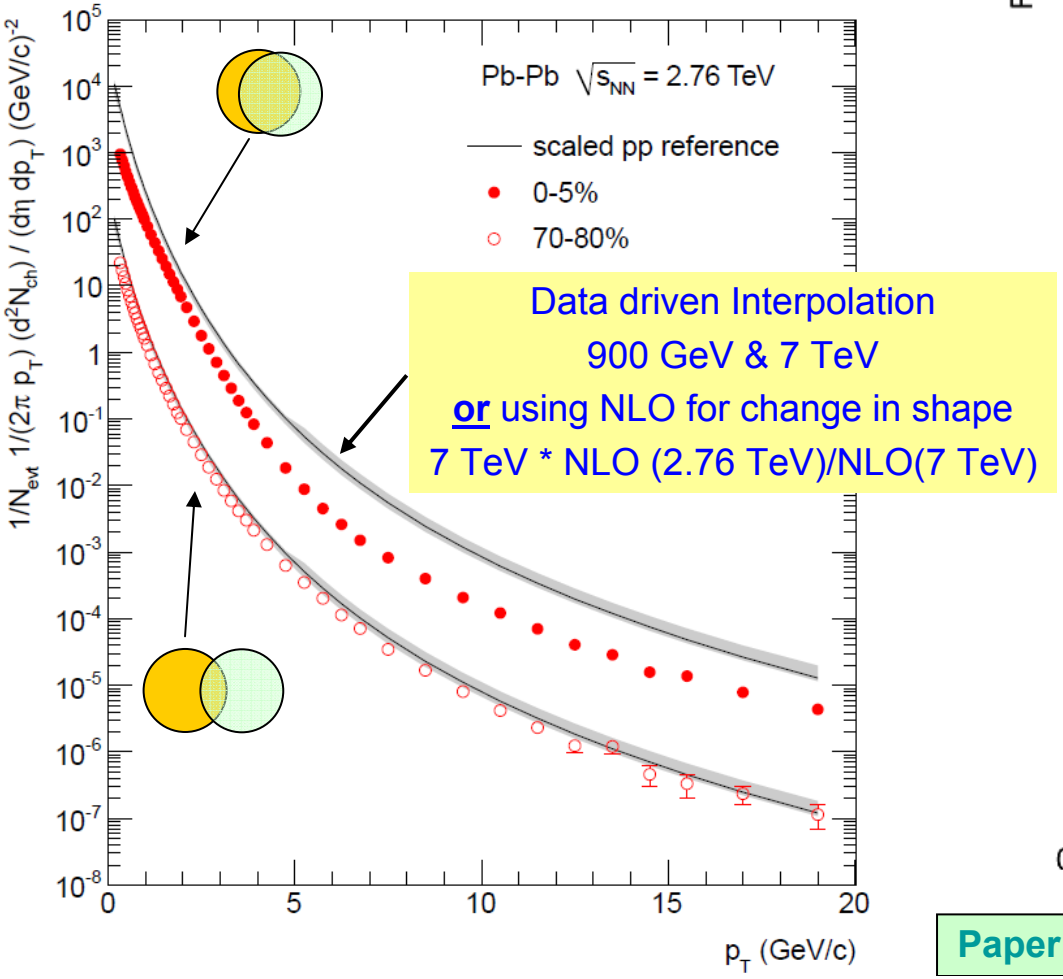




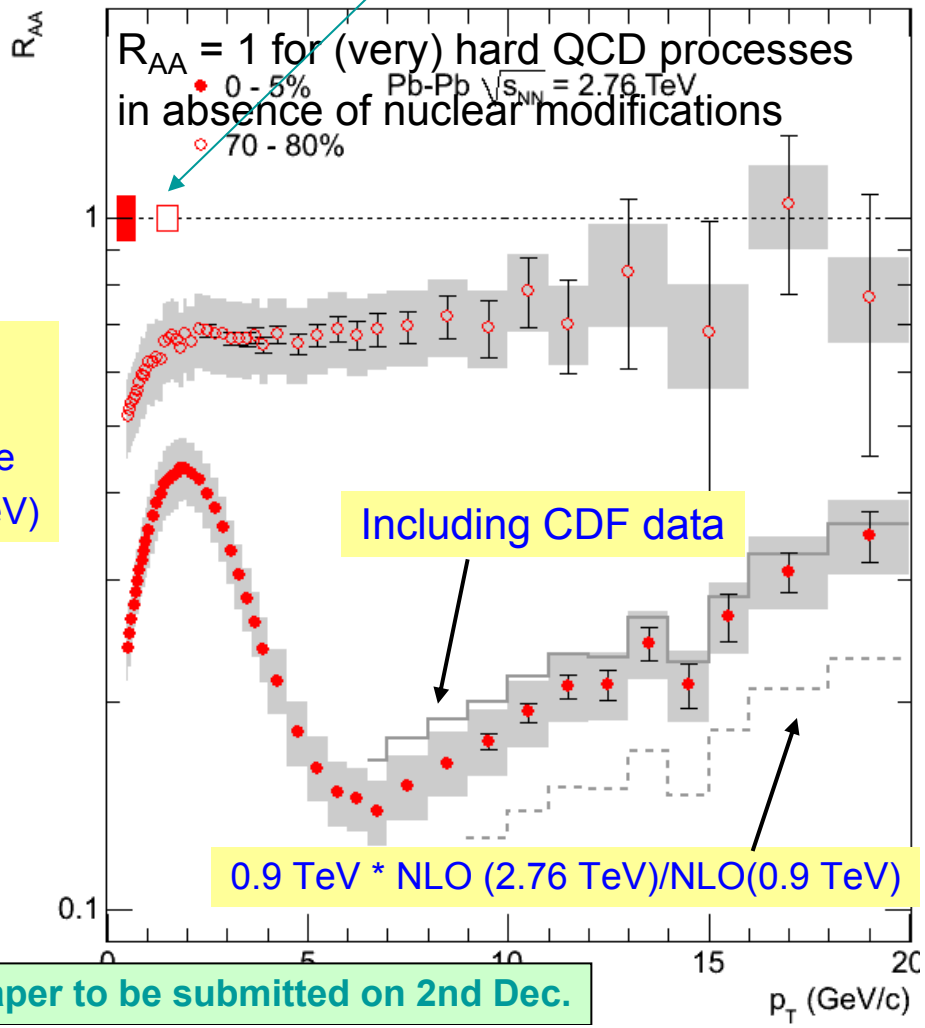
‘Jet Quenching’ as seen by p_t spectra

- Suppression of high p_t particles (~ leading jet fragments)
  - Minimum R_{AA} ~ 1.5 – 2 x smaller than at RHIC
  - Rising with p_t ! (ambiguous at RHIC !)
  - accuracy limited by pp reference
    => need pp at 2.76 TeV !

$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta dp_T}{\langle N_{coll}\rangle (1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta dp_T}$$

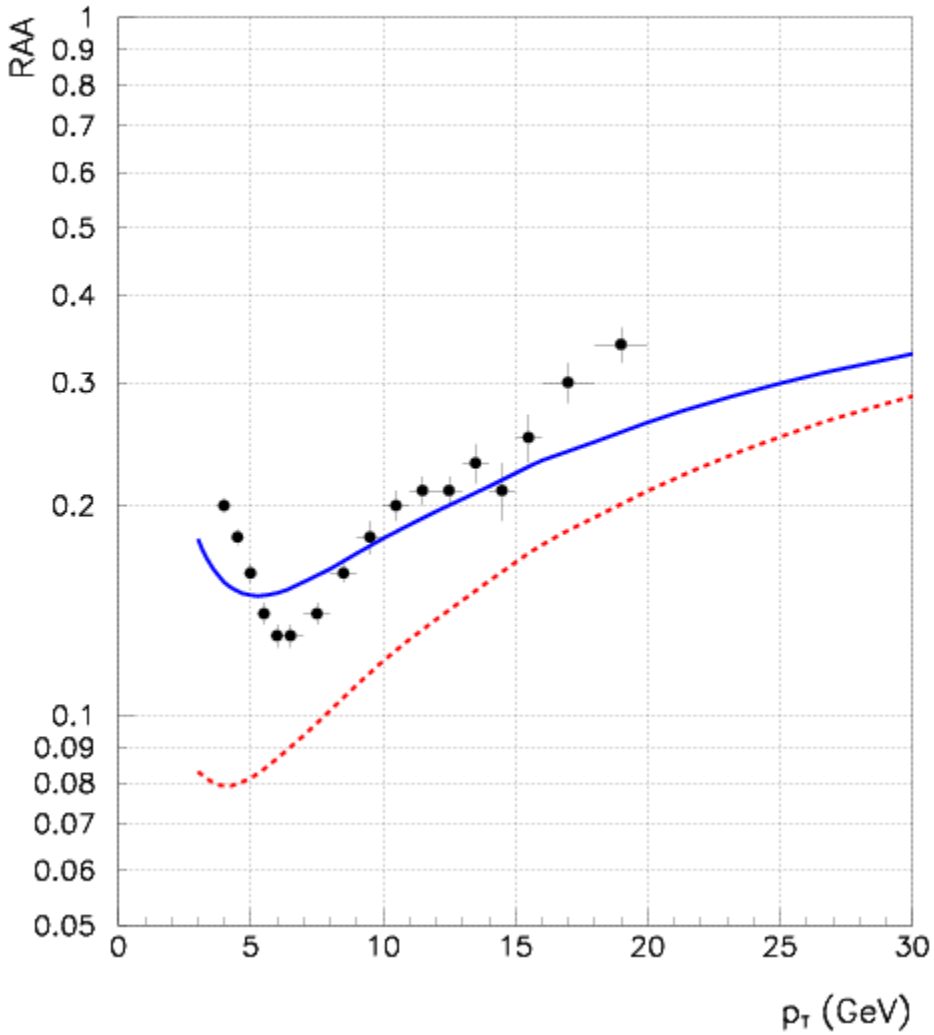


Data driven Interpolation
900 GeV & 7 TeV
or using NLO for change in shape
7 TeV * NLO (2.76 TeV)/NLO(7 TeV)



Paper to be submitted on 2nd Dec.

GLV results at 2.76 ATeV PbPb
Jet-quenching (+shadowing) – P.Lévai



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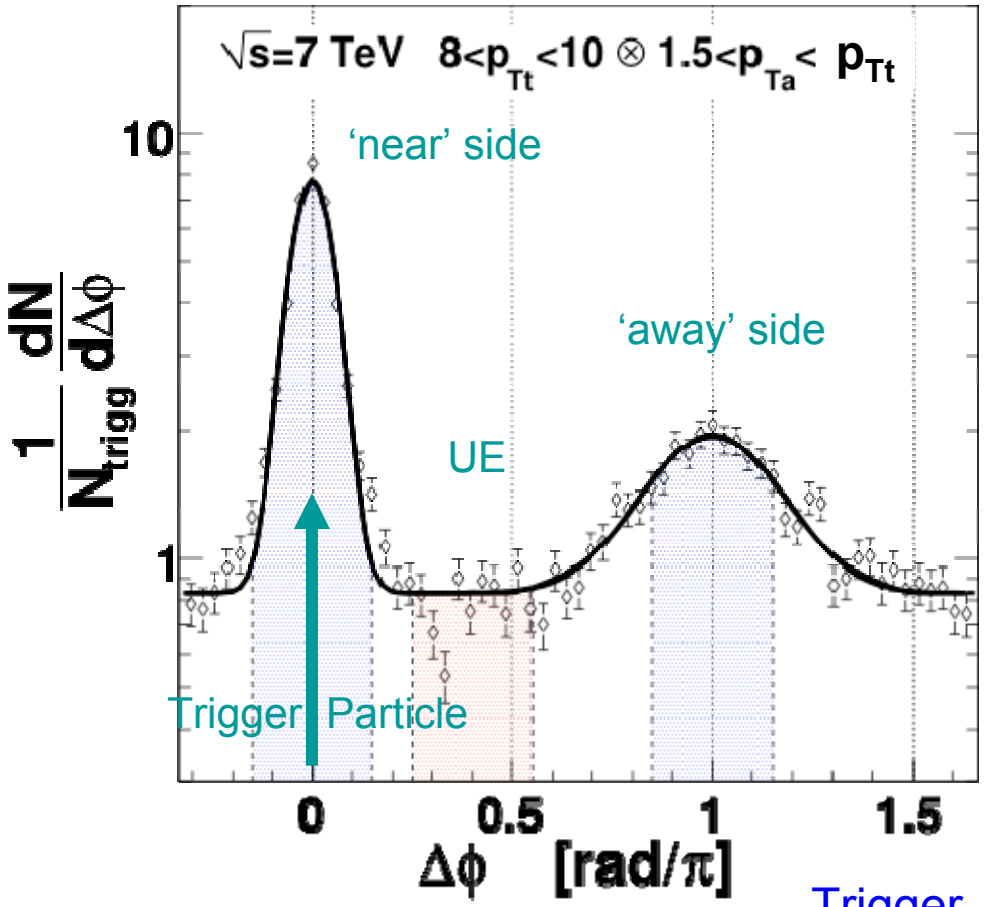
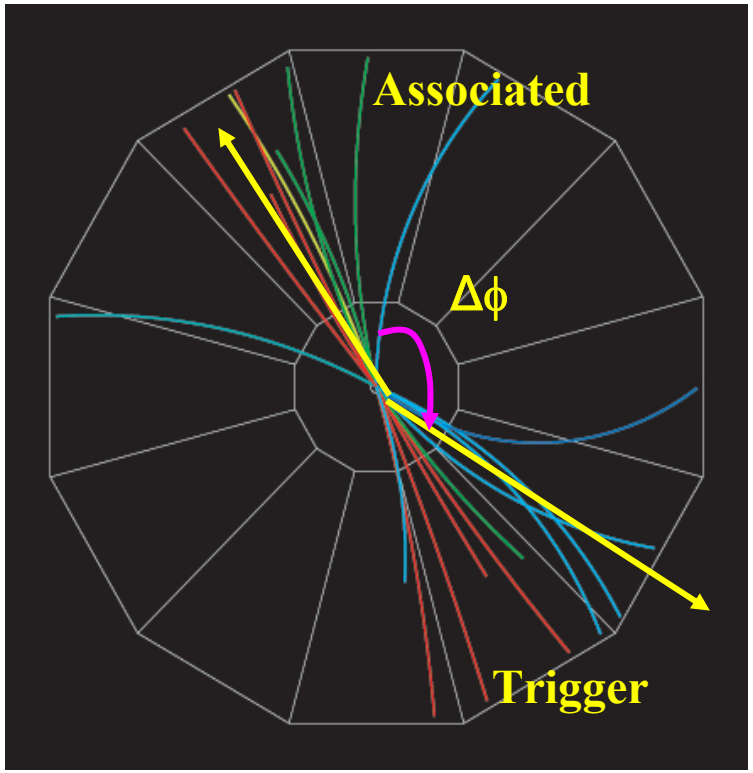
High p_T Particle Correlations





Trigger Particle: highest p_T particle in event (p_{Tt})

Associate Particle: all the others (p_{Ta})

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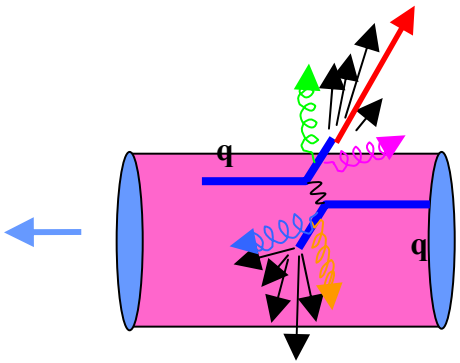
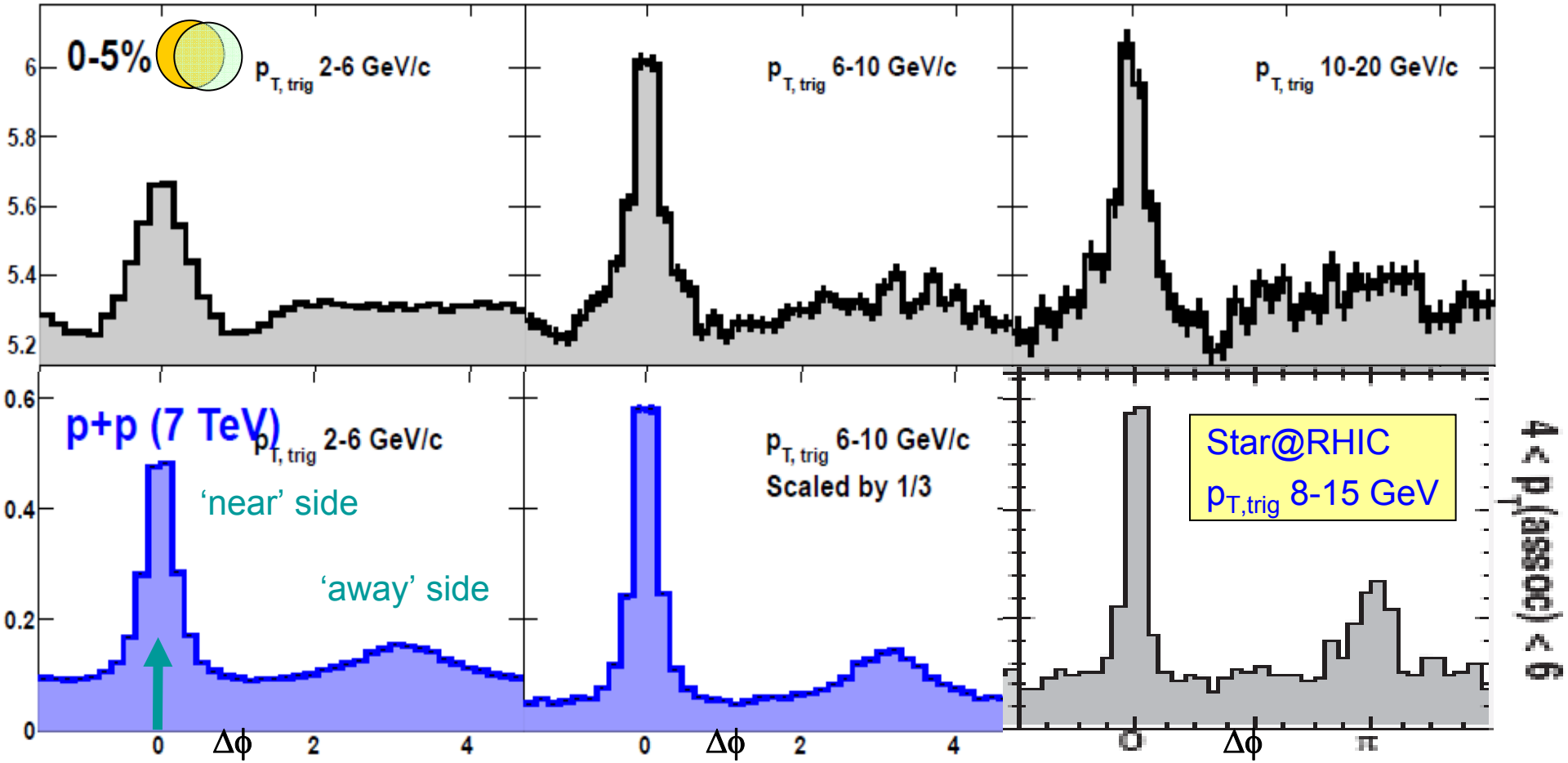
Jet Quenching seen by High p_T Correlations

- classic 'jet quenching signal'
  - away side correlation in central Pb-Pb washed out up to $p_{T,trig} > 10$ GeV



P_T associated 2 – 6 GeV

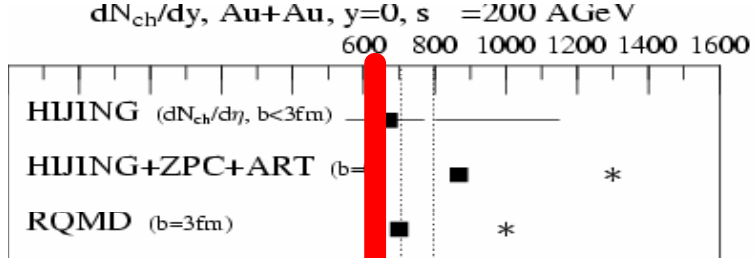


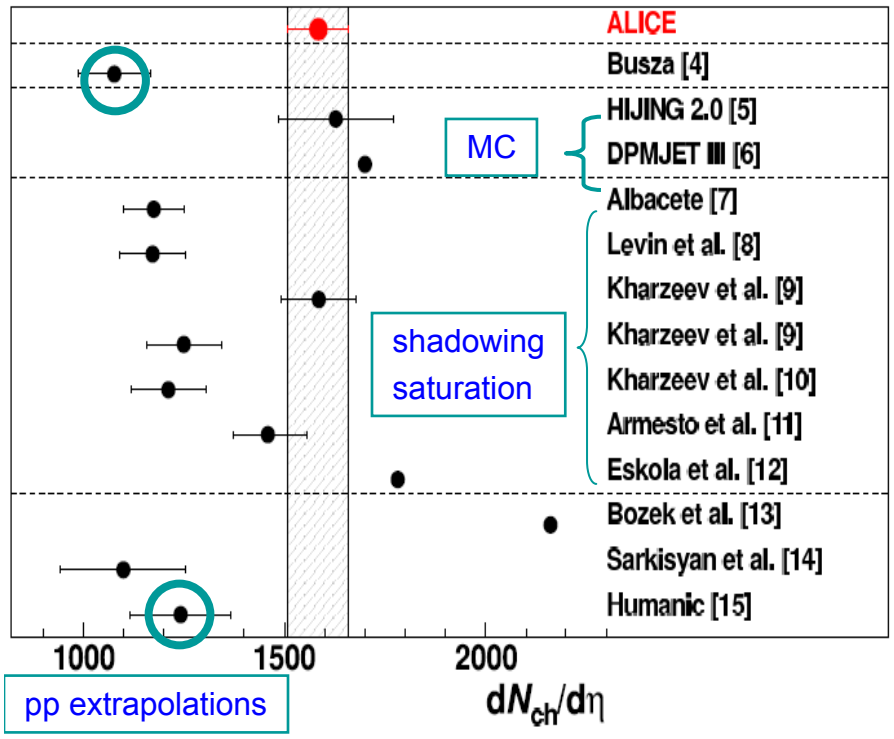
1) What's the Difference ?

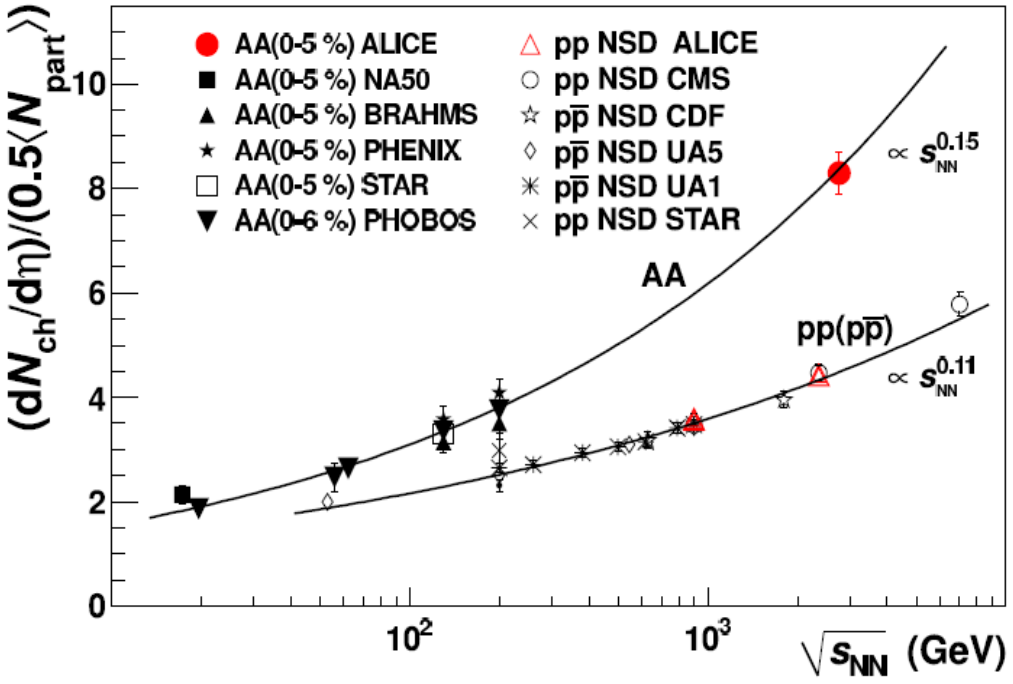
- Multiplicity and Energy density e:
  - **$dN_{ch}/dh \sim 1600 \pm 76$ (syst)**
    - somewhat on high side of expectations
    - growth with √s faster in AA than pp (√s dependent 'nuclear amplification')
  - **Energy density ≈ 3 x RHIC** (fixed t)

$$\varepsilon(\tau) = \frac{E}{V} = \frac{1}{\tau_0 A}\frac{dN}{dy} < m_t >$$

17 Nov: arXiv:1011.3916, acc. PRL







Who gets it right and why ?

- **dN_{ch}/dh as function of centrality** (normalised to 'overlap volume' ~ N_{partic})
  - **soft process dN_{ch}/d_h ~ number of scattered nucleons (strings, participants, …)**
    - 'nuclear amplification' should be energy independent
  - **(very) hard processes dN_{ch}/d_h ~ number of nucl-nucl collisions**
    - getting more important with √s **&** with

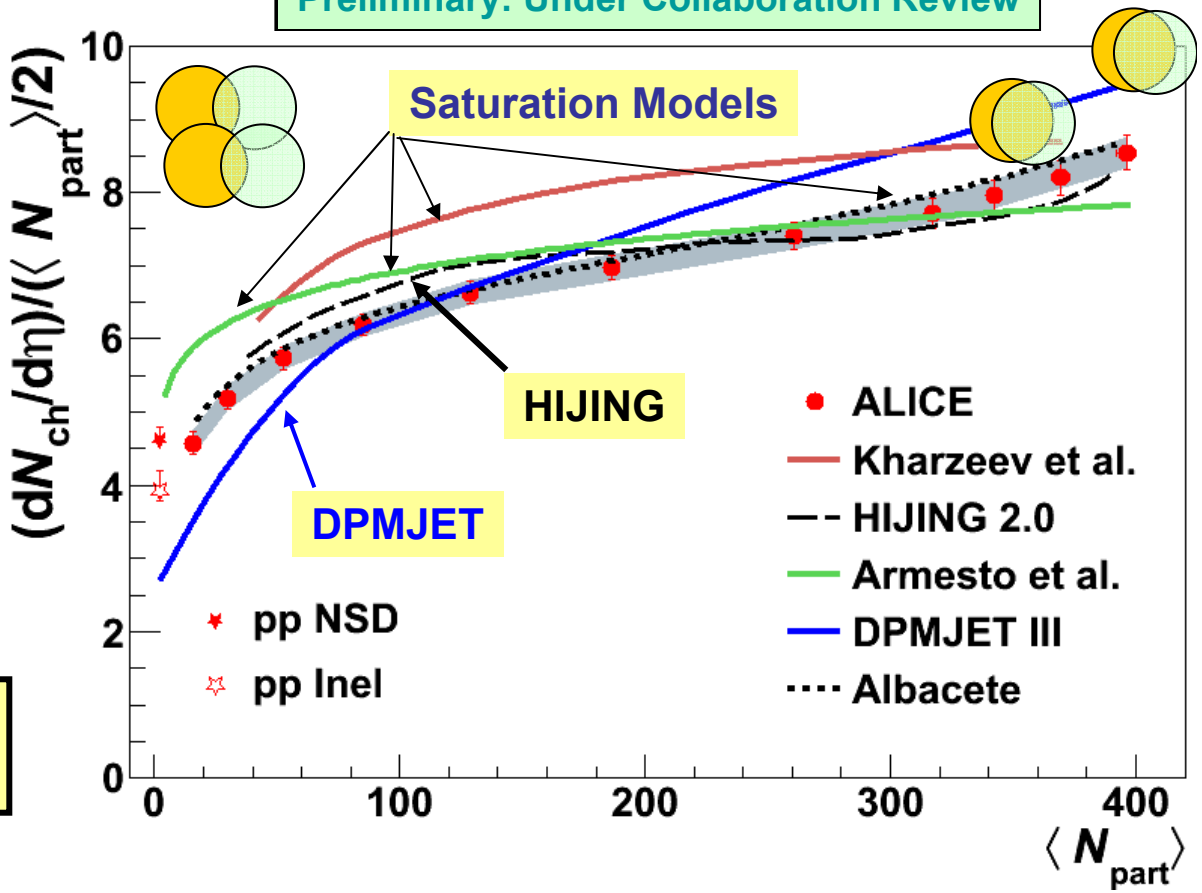
– **DPMJET MC**
- gets it right for the wrong reason

– **HIJING MC**
- strong centr. dependent **gluon shadowing**

– **Others**
- **saturation models:**

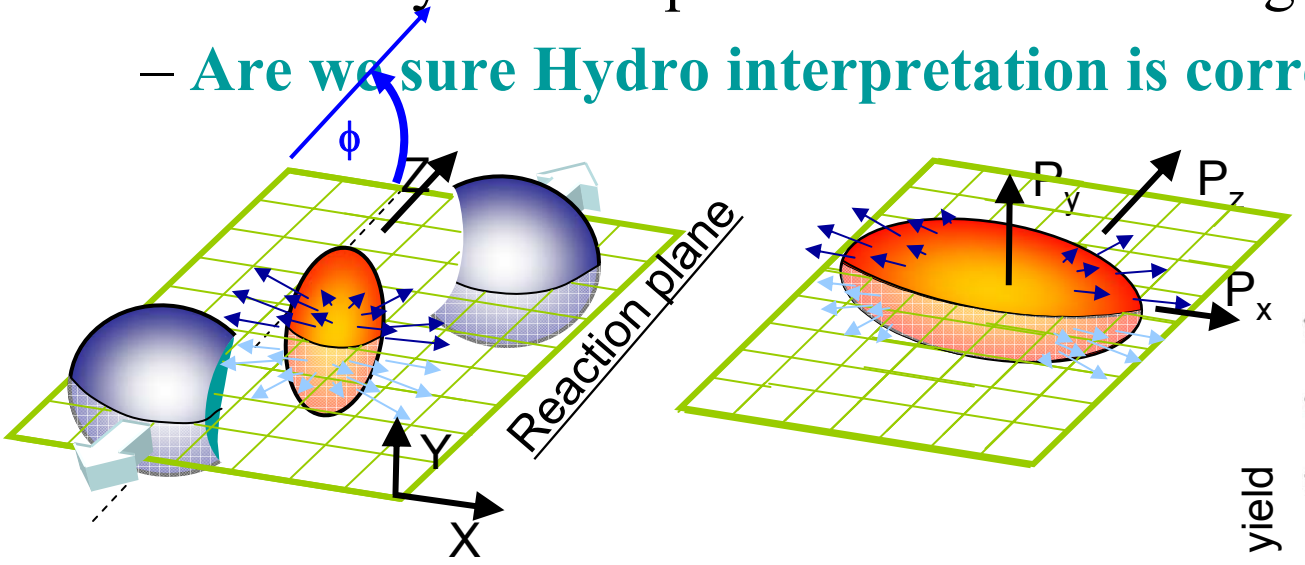
Important constraint for models sensitive to details of saturation

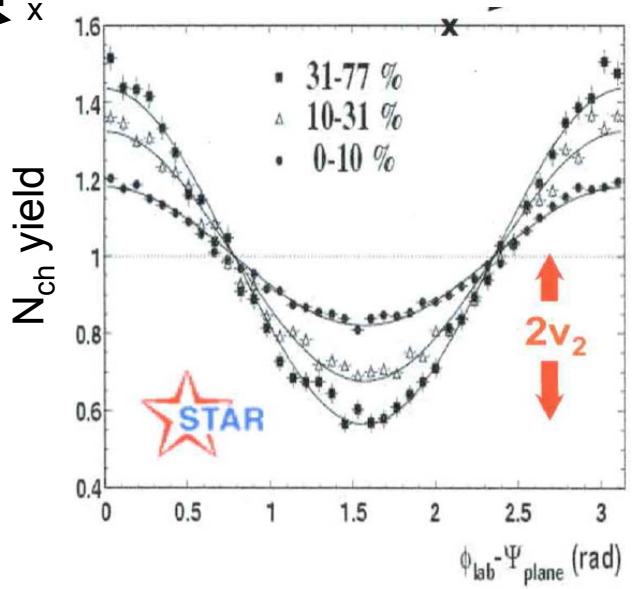
HERA/ photonuclear react.



2) Testing the HI 'Standard Model'

- **Elliptic Flow: one of the most anticipated answers from LHC**
  - **experimental observation:** particles are distributed with azimuthally anisotropic around the scattering plane
  - **Are we sure Hydro interpretation is correct ?**





Elliptic Flow v_2 as interpreted by **Hydrodynamics**

Pressure gradient converts

spatial anisotropy → momentum anisotropy

→ particle yield anisotropy

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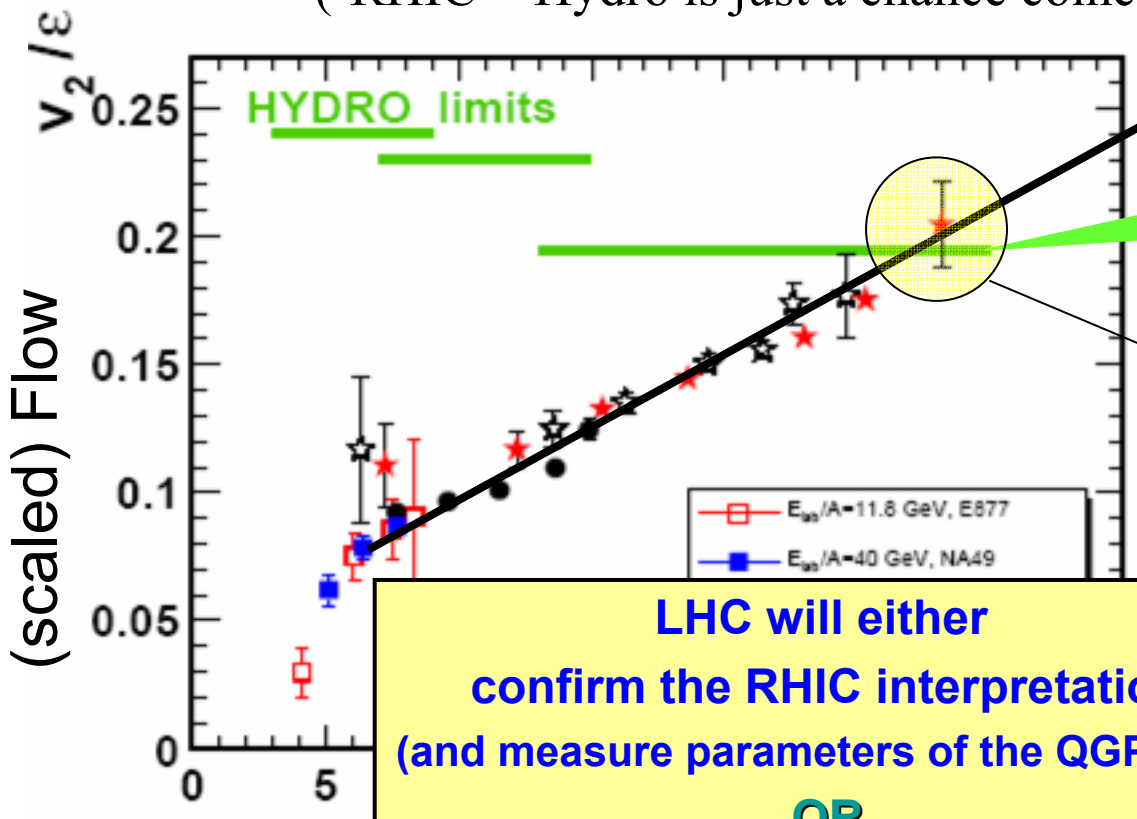
Testing the HI 'Standard Model'

- **Hydro seems to work very well for first time at RHIC**
  - LHC prediction: modest rise (Depending on EoS, viscosity, speed of sound, dN_{ch}/dh, ..) ('better than ideal is impossible')
  - experimental trend & scaling predicts large increase of flow
    - ('RHIC = Hydro is just a chance coincidence')

LHC ?



BNL Press release, April 18, 2005:

Data = ideal Hydro

"Perfect" Liquid

New state of matter more remarkable than predicted – raising many new questions

LHC will either

confirm the RHIC interpretation

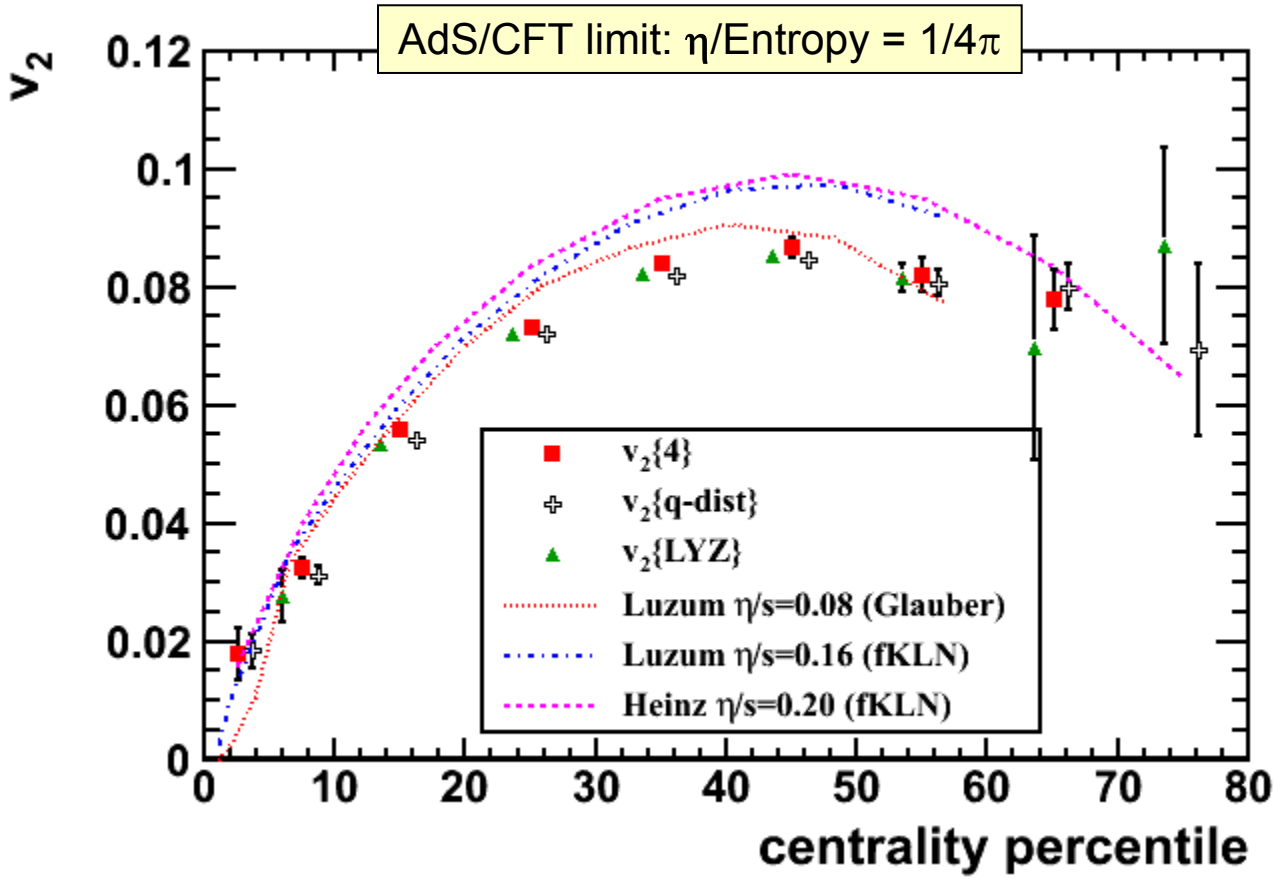
(and measure parameters of the QGP EoS)

OR

Multiplicity ????????

3) Towards Precision Measurements

- **Sensitivity to fluid viscosity h**
  - **Quantitative results will need much more time and more experimental input …**
    - **elliptic flow with identified particles, radial flow ('radial expansion'),**
      better determination of initial geometry, ……



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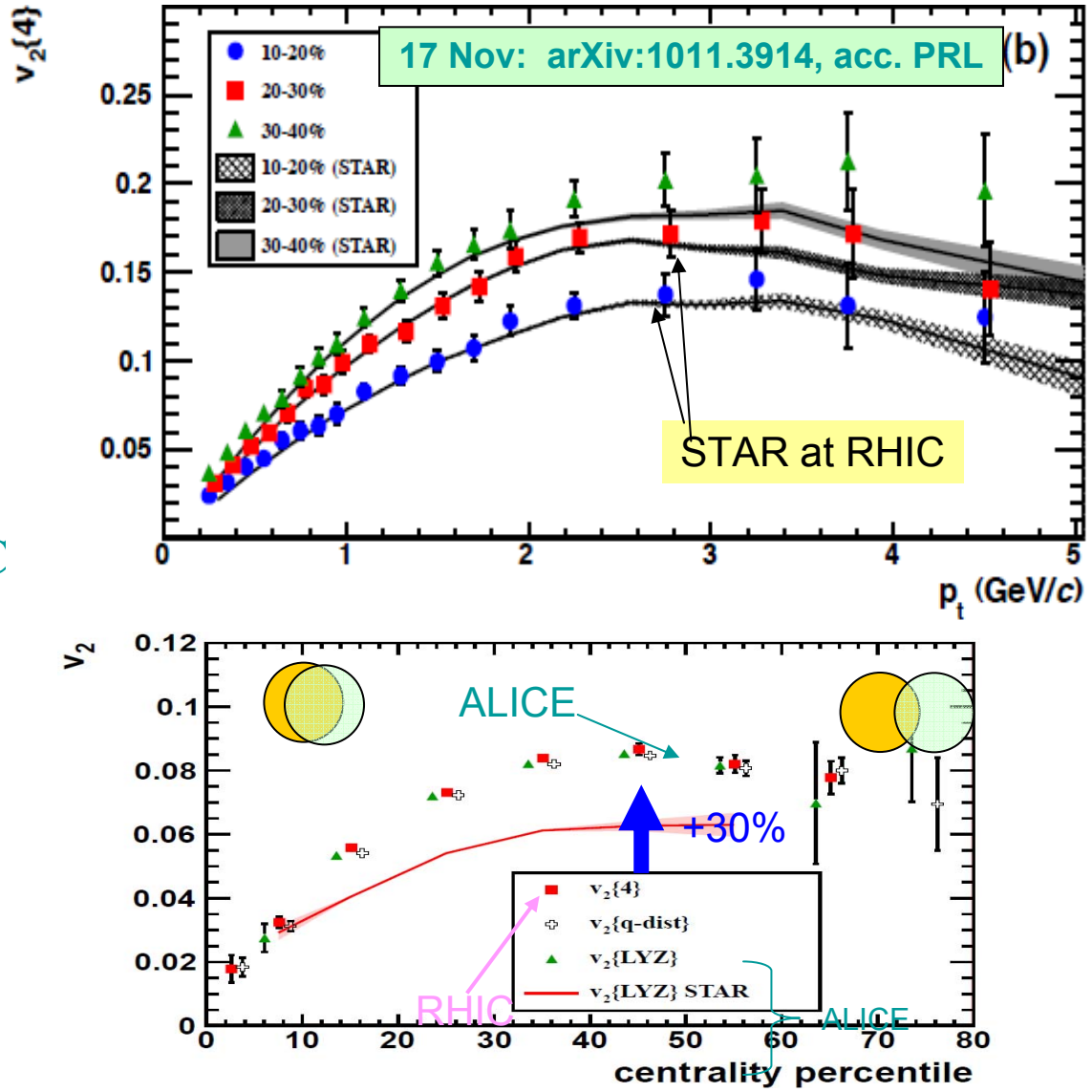
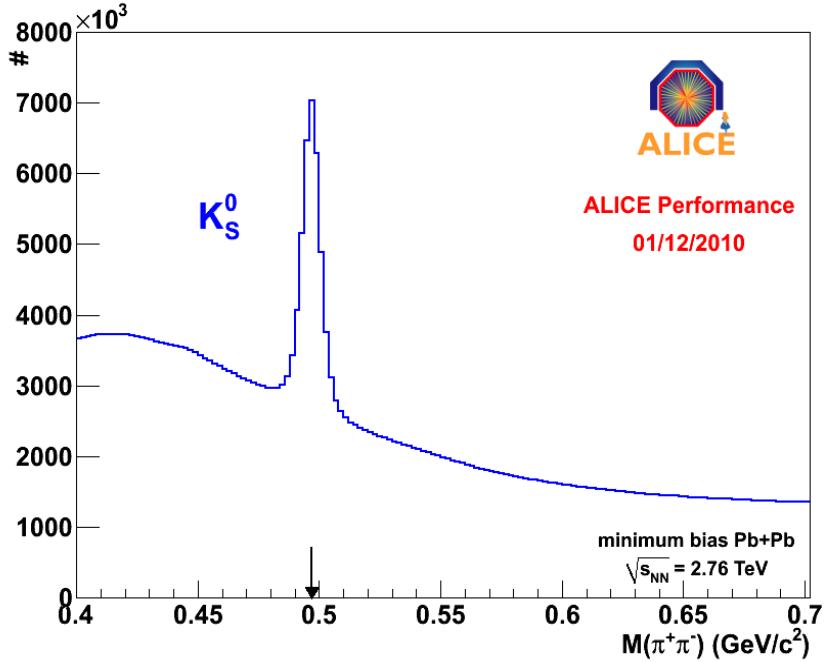
First Elliptic Flow Measurement at LHC

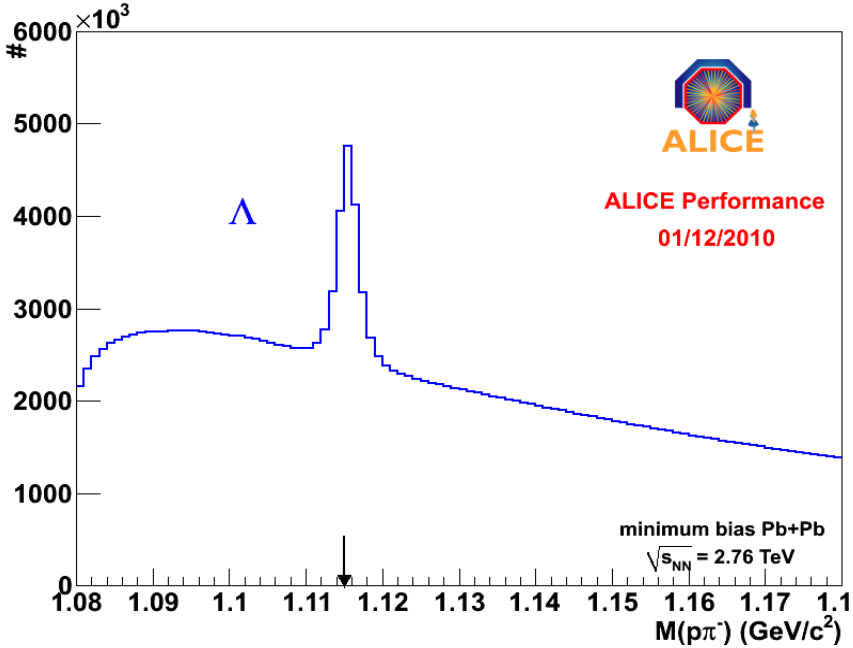
- v_2 as function of p_t
  - **practically no change with energy !**
    - extends towards larger centrality/higher p_t ?

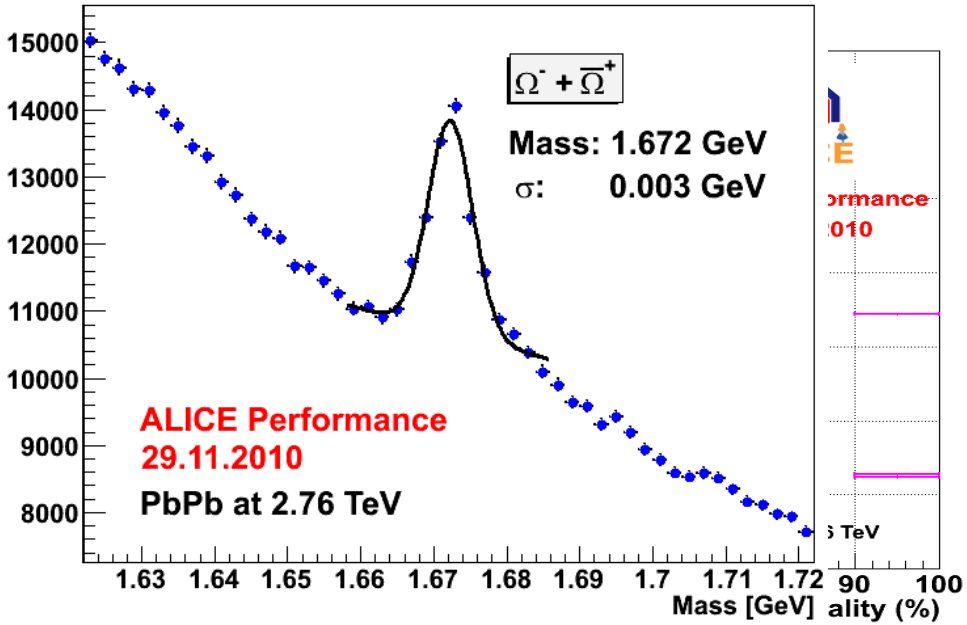
- v_2 integrated over pt
  - **30% increase from RHIC**
  - $\langle p_t \rangle$ increases with $\sqrt{s}$
    - pQCD powerlaw tail ?
  - Hydro predicts increased 'radial flow'
    - very characteristic p_t and mass dependence; **to be confirmed !**

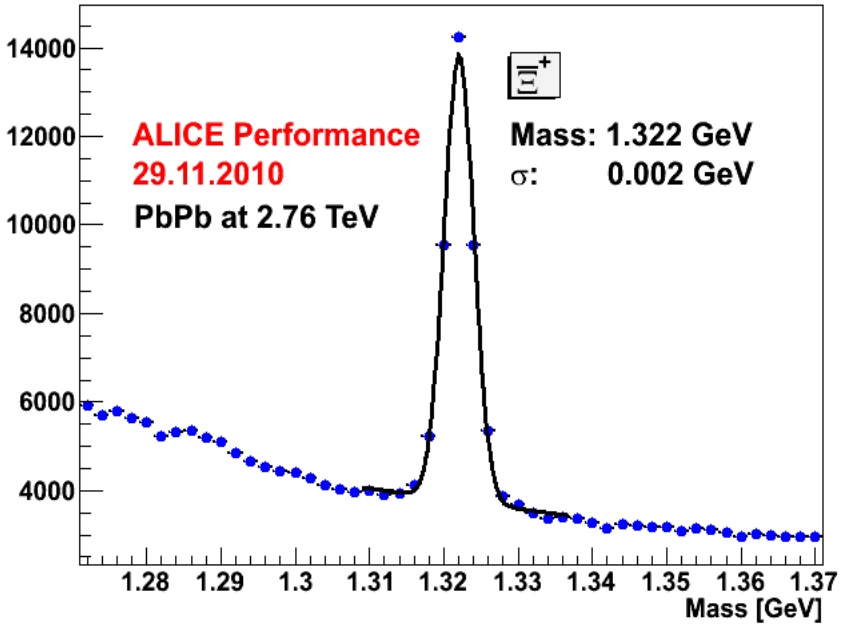


Strangeness in Pb-Pb

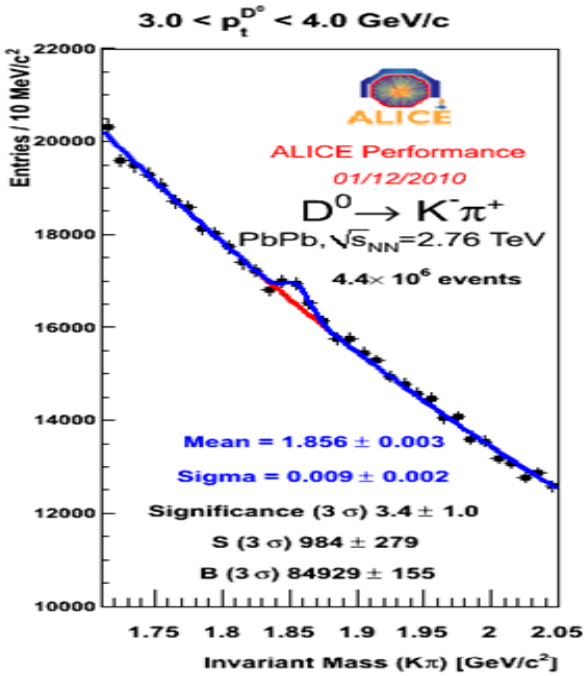


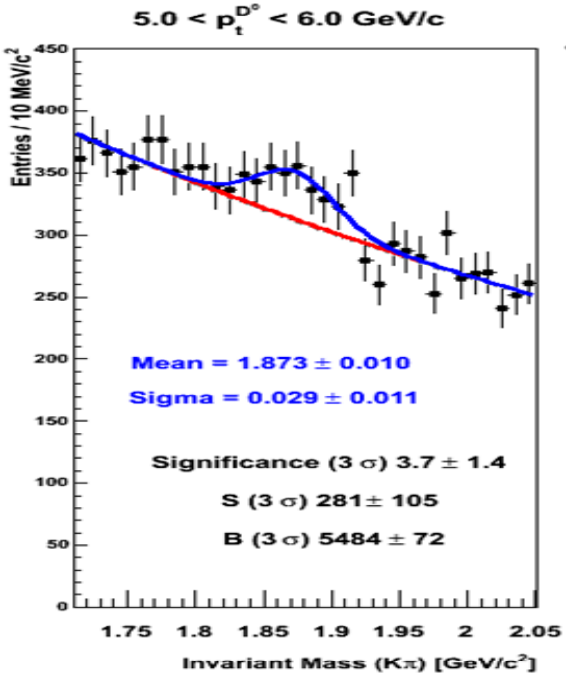


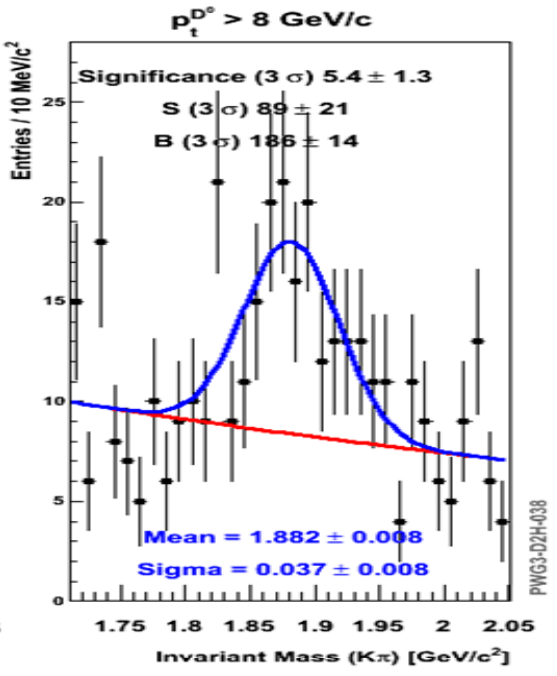




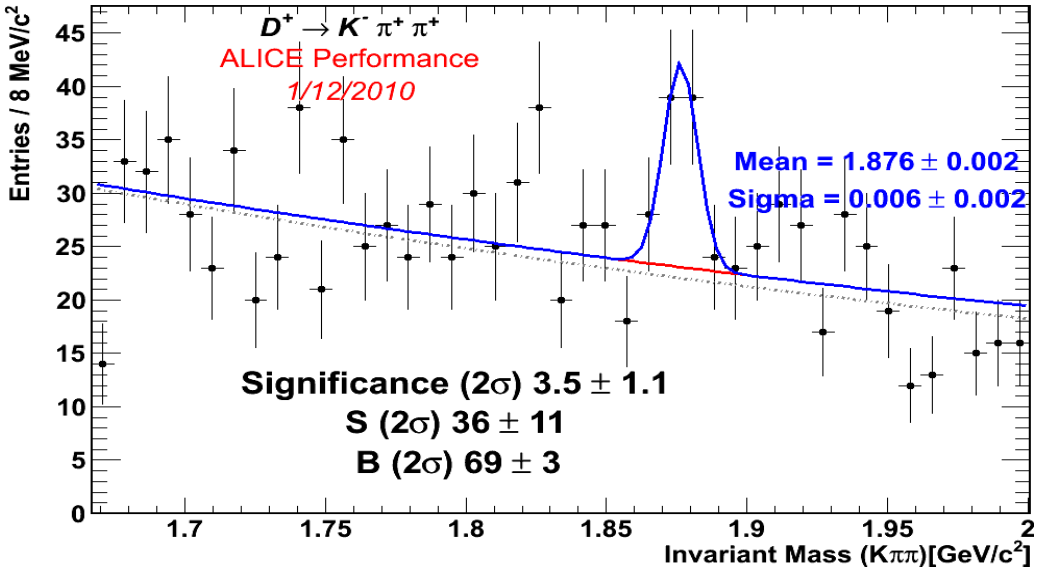
Charm in Pb-Pb







Pb-Pb $\sqrt{s}$=2.76 TeV, 1.7 × 10^6 events, $p_t^{D^+}$ > 6 GeV/c



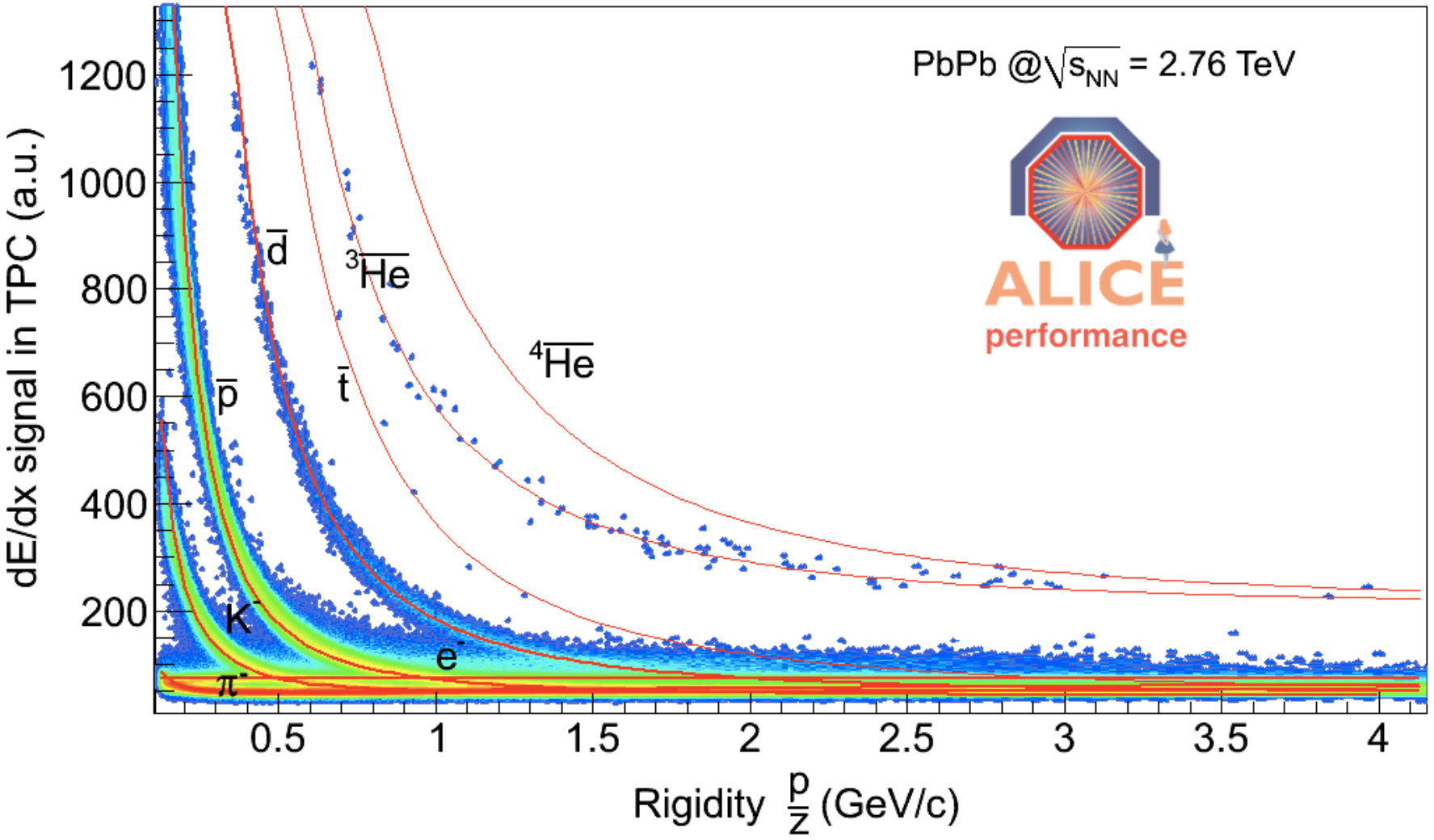
‘Jet quenching’ with heavy quarks:

Energy loss depends on

- color charge (quark/gluon)
- mass (light/heavy quarks)

Levai P, Zimanyi'2010

Anti-Nuclei



Levai P, Zimanyi'2010

~ 2 M Pb-Pb Min Bias events

Summary:

Experimental work is going on

Theoretical analysis can be started now !!!

Members of the Hungarian ALICE team: P. Lévai





Molnár L. **Barnaföldi GG** **Dénes E.** **Boldizsár L.*** **Futó E.**





Agócs A.G.* **Hamar G.*** **Pochybova S.*** **Bencze Gy.** **Varga D.**

Pálla G., **Fodor Z.,** **Tölyhi T.*,**

Lipusz Cs., **Berényi D.*,** **Nagy M.F.*** **Pásztor A.** **+ many more stud.**