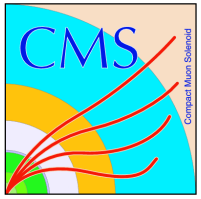
Overview of results on **jets** from the CMS Collaboration

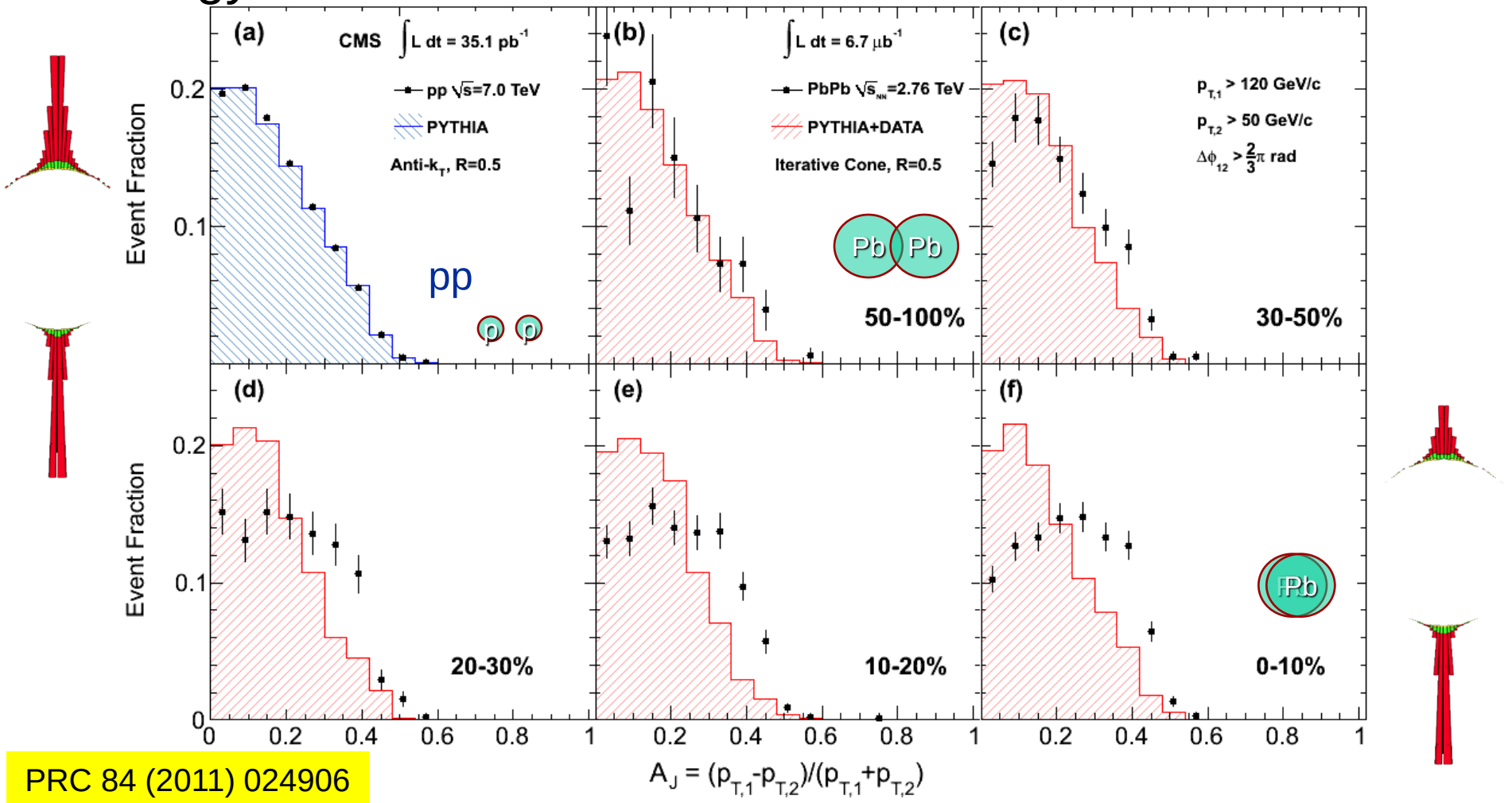


Gábor Veres
(CERN)
for the CMS Collaboration

Quark Matter conference, Washington DC
14th Aug, 2012

QM'11 – jet energy imbalance

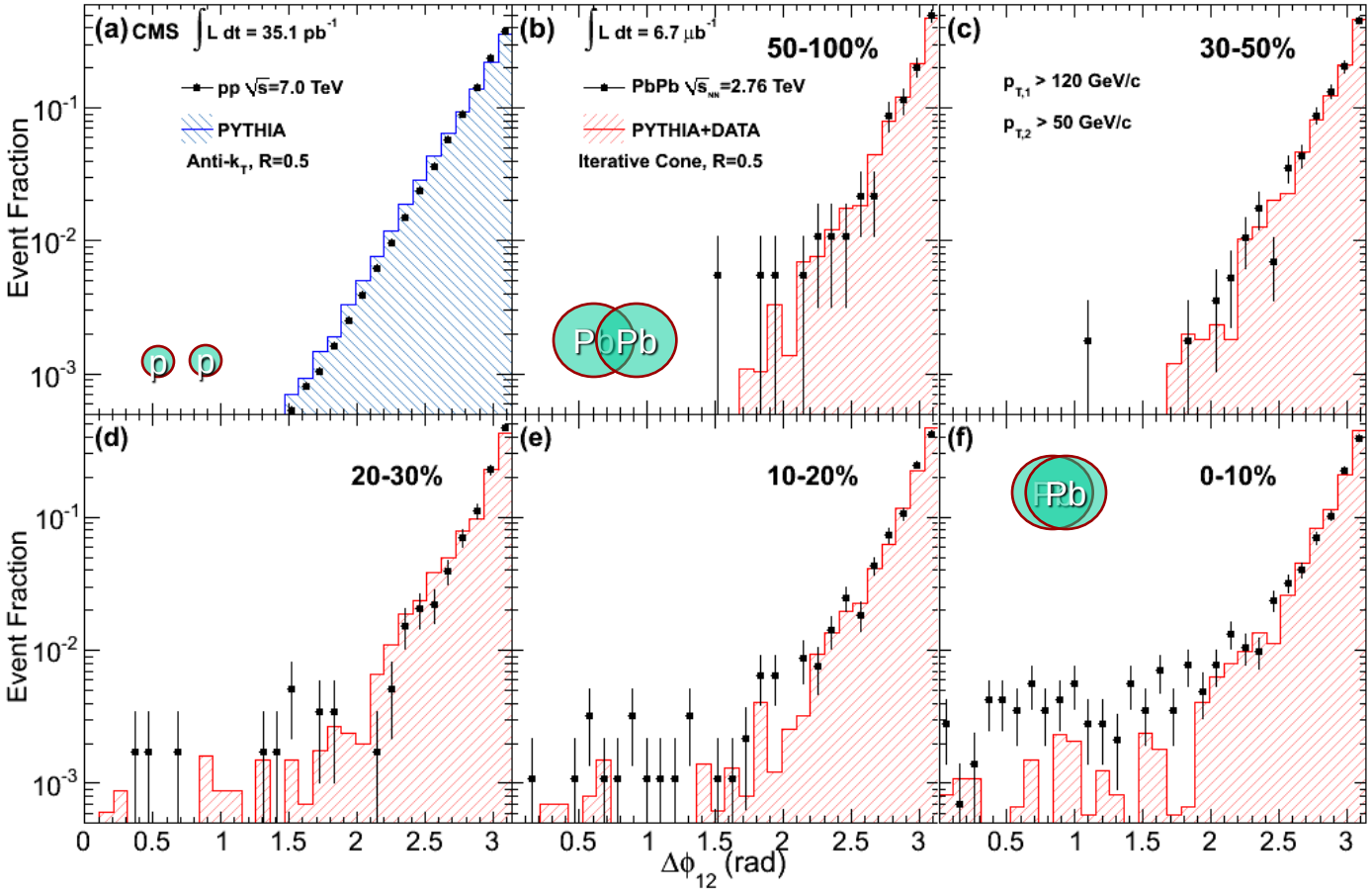
- Parton energy loss is observed as a pronounced dijet energy imbalance in central PbPb collisions



PRC 84 (2011) 024906

QM'11 – no φ-decorrelation

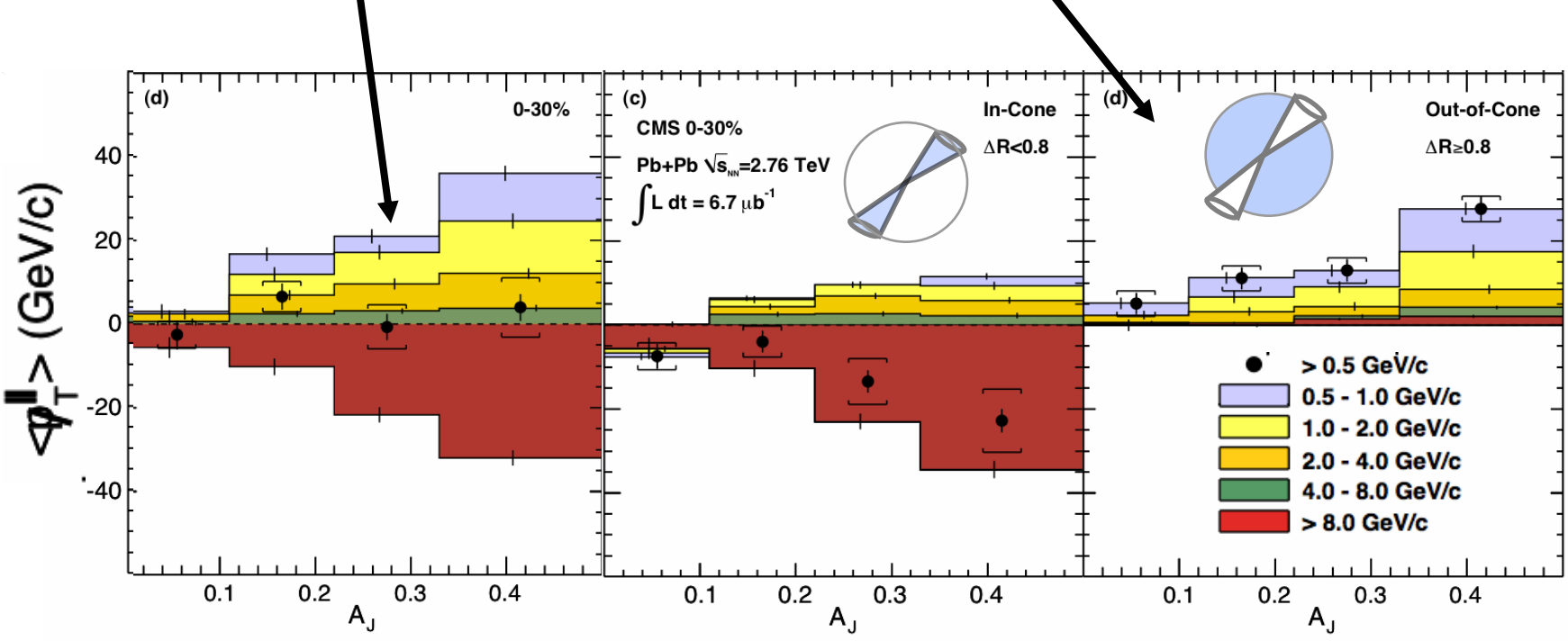
- The propagation of high-p_T partons in a dense nuclear medium does **not** lead to a visible angular decorrelation



PRC 84 (2011) 024906

QM'11 – energy redistribution

- The momentum difference in the dijet is balanced by low p_T particles mainly at large angles relative to the away side jet axis

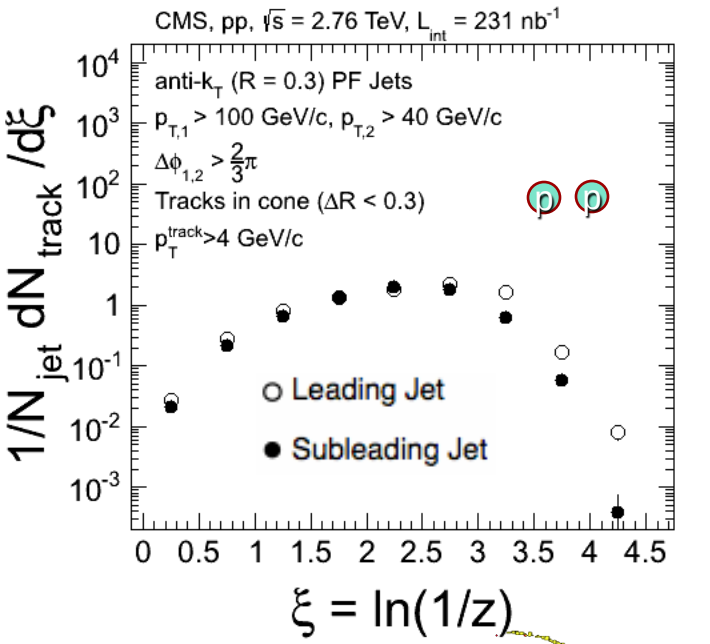


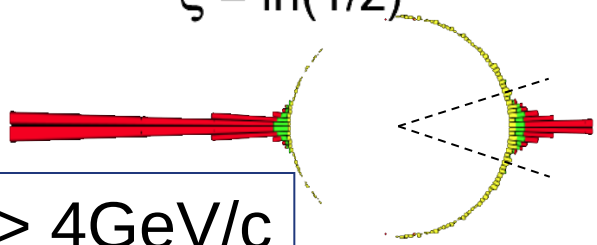
$$A_J = (p_{T,1}-p_{T,2})/(p_{T,1}+p_{T,2})$$

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

QM'11 – jet fragmentation

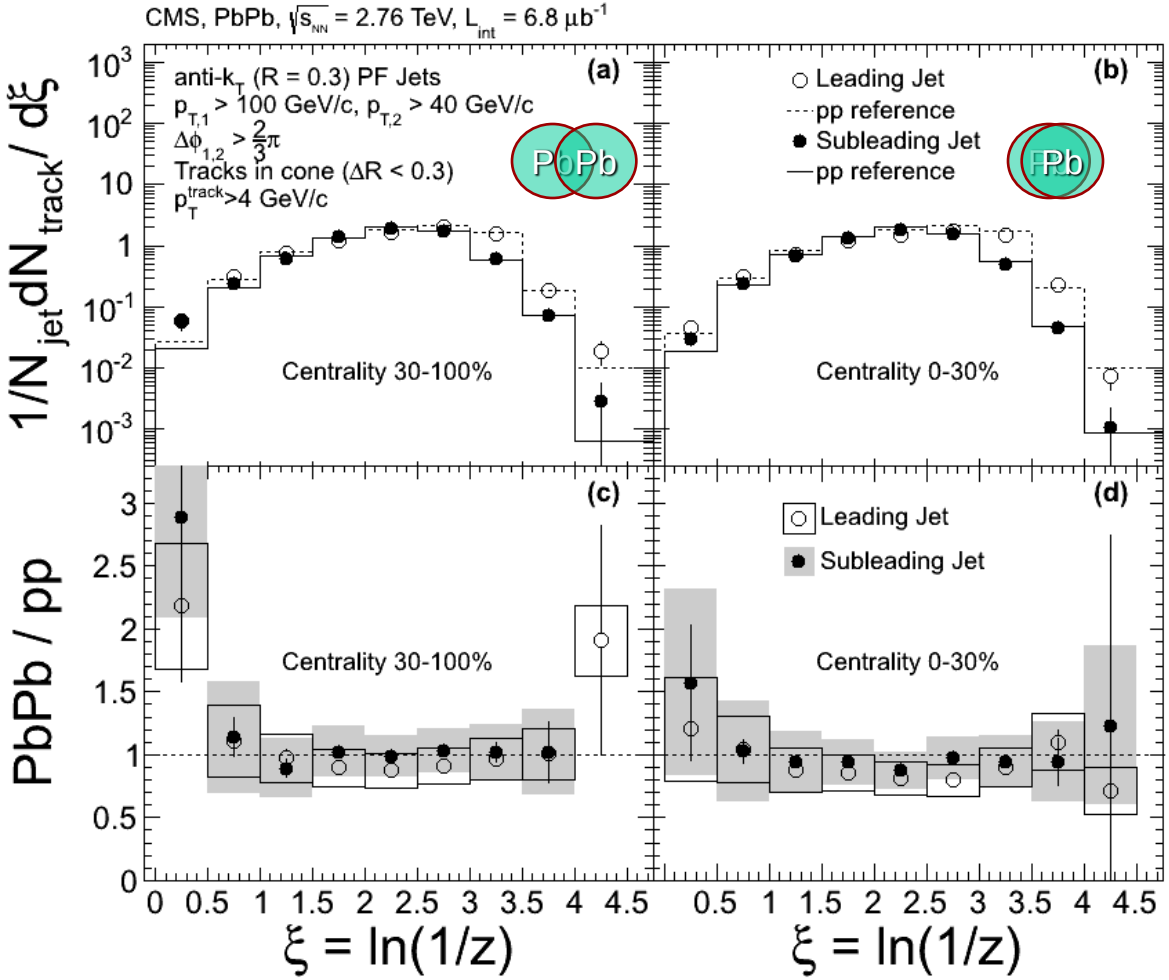
- Hard part of the fragmentation is independent of energy lost in medium, ~consistent with pp





p_T > 4GeV/c

ΔR=0.3



arXiv:1205.5872

New research directions for QM'12

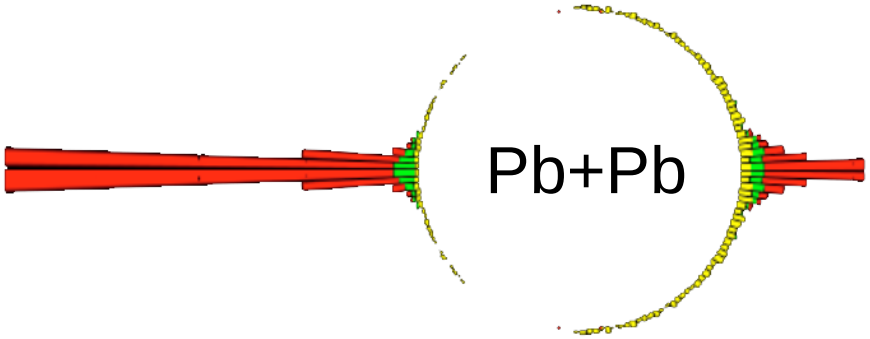
- Energy loss studies using **jets**:
  - Dijet energy imbalance vs jet p_T for higher p_T jets (120-350 GeV/c) — Tue 16:45 M. Nguyen
  - Jet R_{AA} (100 – 300 GeV/c) — Tue 17:25 M. Tonjes
  - Gamma-jet energy balance — Tue 14:15, Y. Lai
  - Tagged b-quark jets — Tue 16:45 M. Nguyen

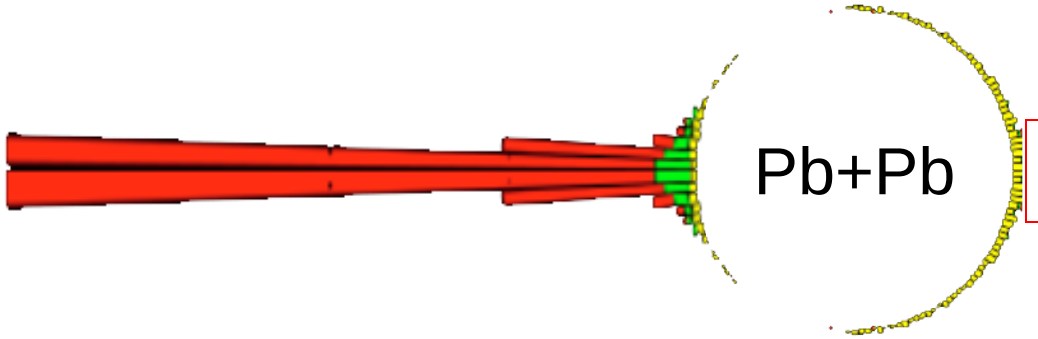
- Jet modification studies using **jets and tracks**:
  - Jet shapes: radial distribution of energy flow — Wed 9:10, P. Kurt
  - Jet fragmentation functions: longitudinal energy flow — Wed 9:50, F. Ma
- Energy loss and jet structure studies using **tracks**:
  - Charged-hadron R_{AA} up to 100 GeV/c
  - v_2 of high-p_T hadrons up to 60 GeV/c — Tue 15:55, V. Zhukova
  - Two-particle correlations triggered by a high-p_T hadron — Tue 15:15 R. Conway

All of them make use of the new, high statistics data taken in 2011!

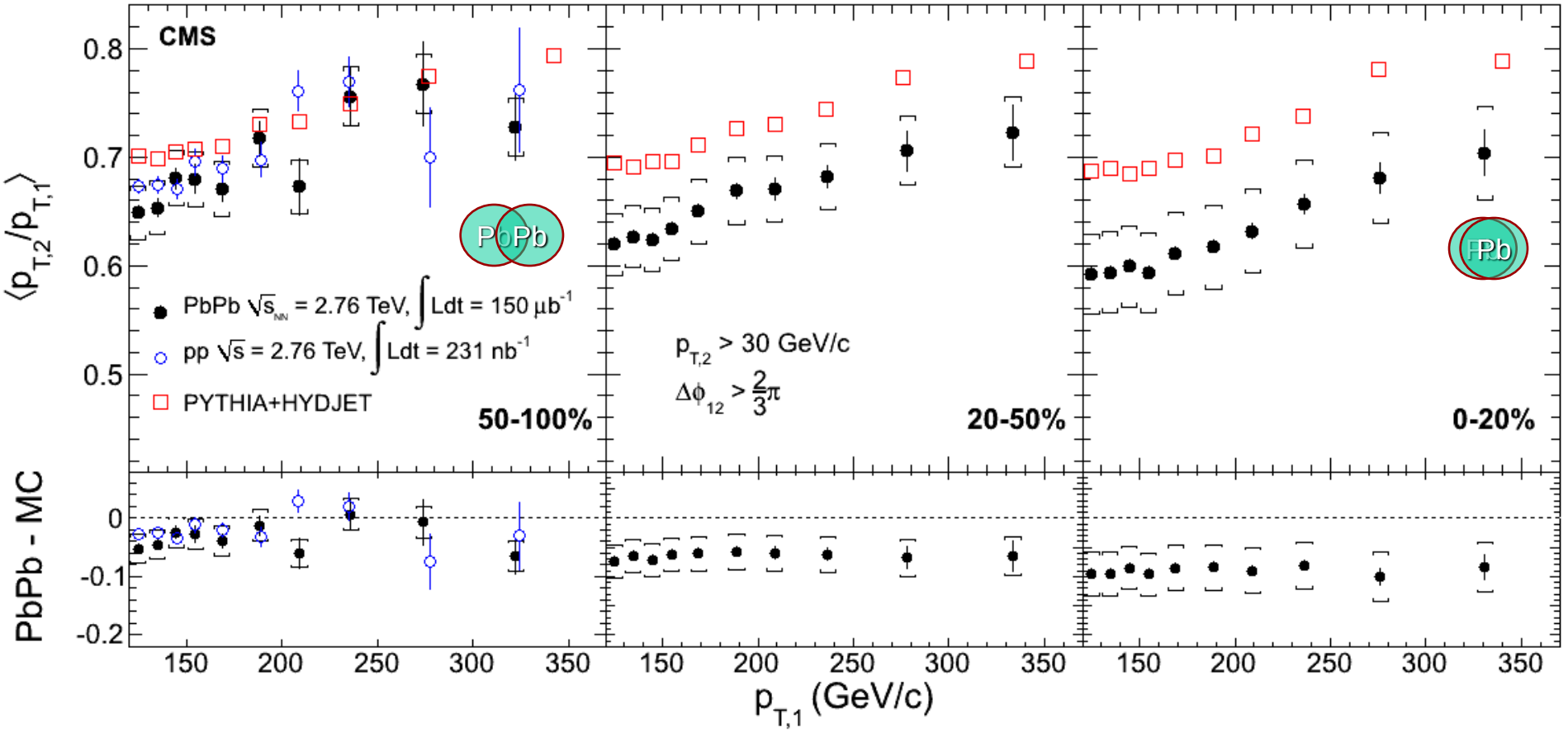
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

How does the dijet imbalance depend on the leading jet energy?





Dijet energy ratio (imbalance)

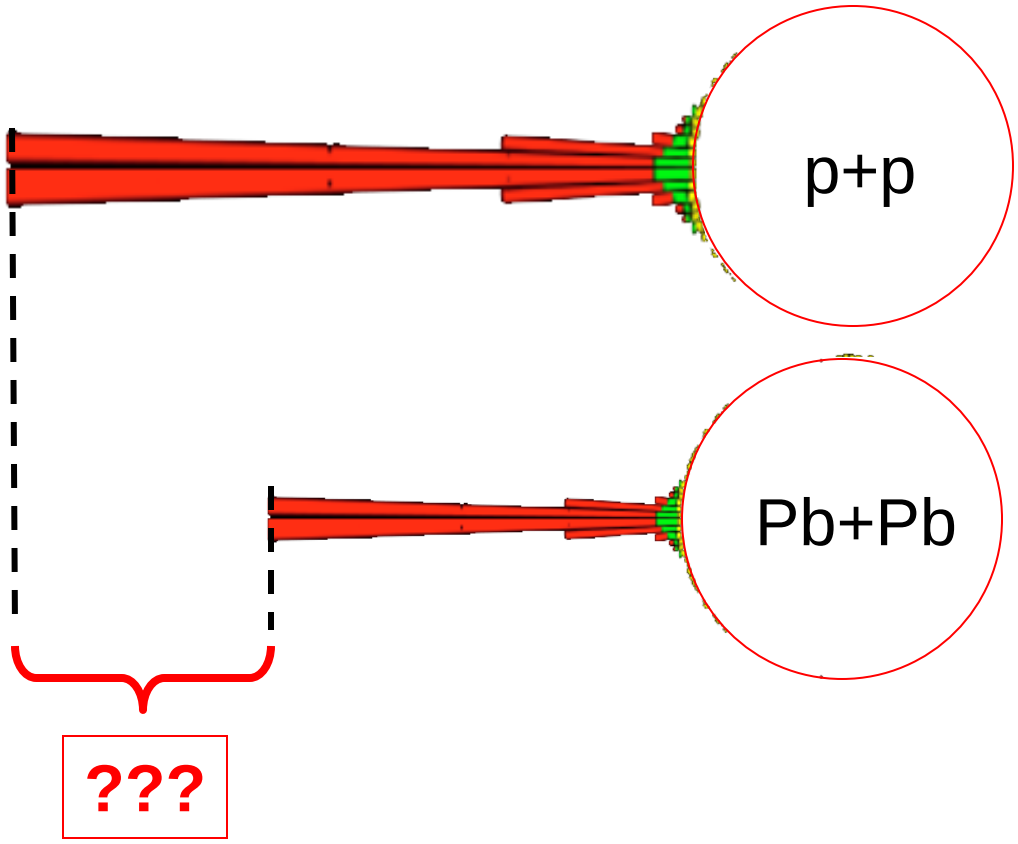


- Energy imbalance increases with centrality
- p_T-ratio deviates from the unquenched reference in a p_T-independent way

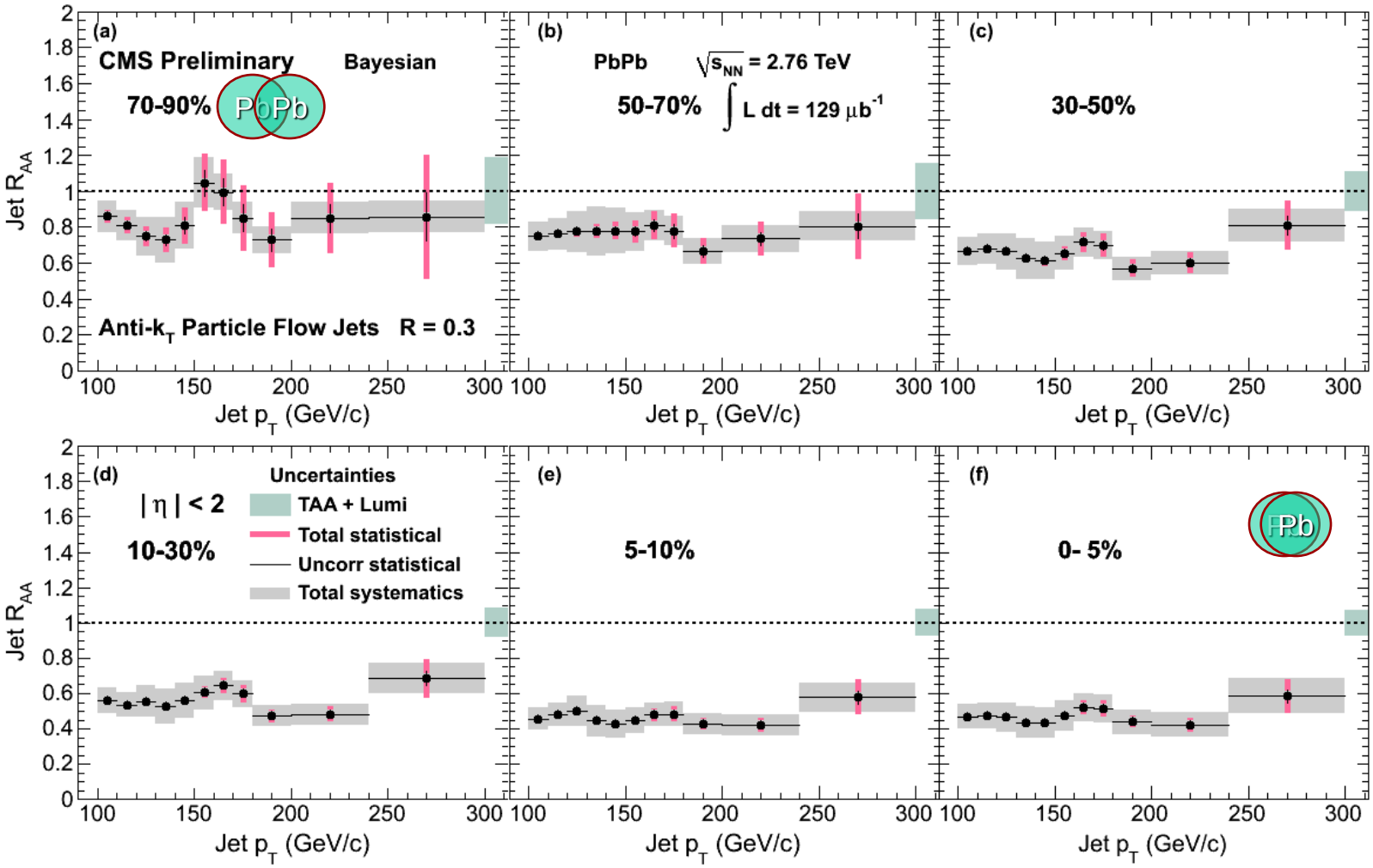
PLB 712 (2012) 176

Tue 16:45, Matt Nguyen

How much energy do single jets lose?



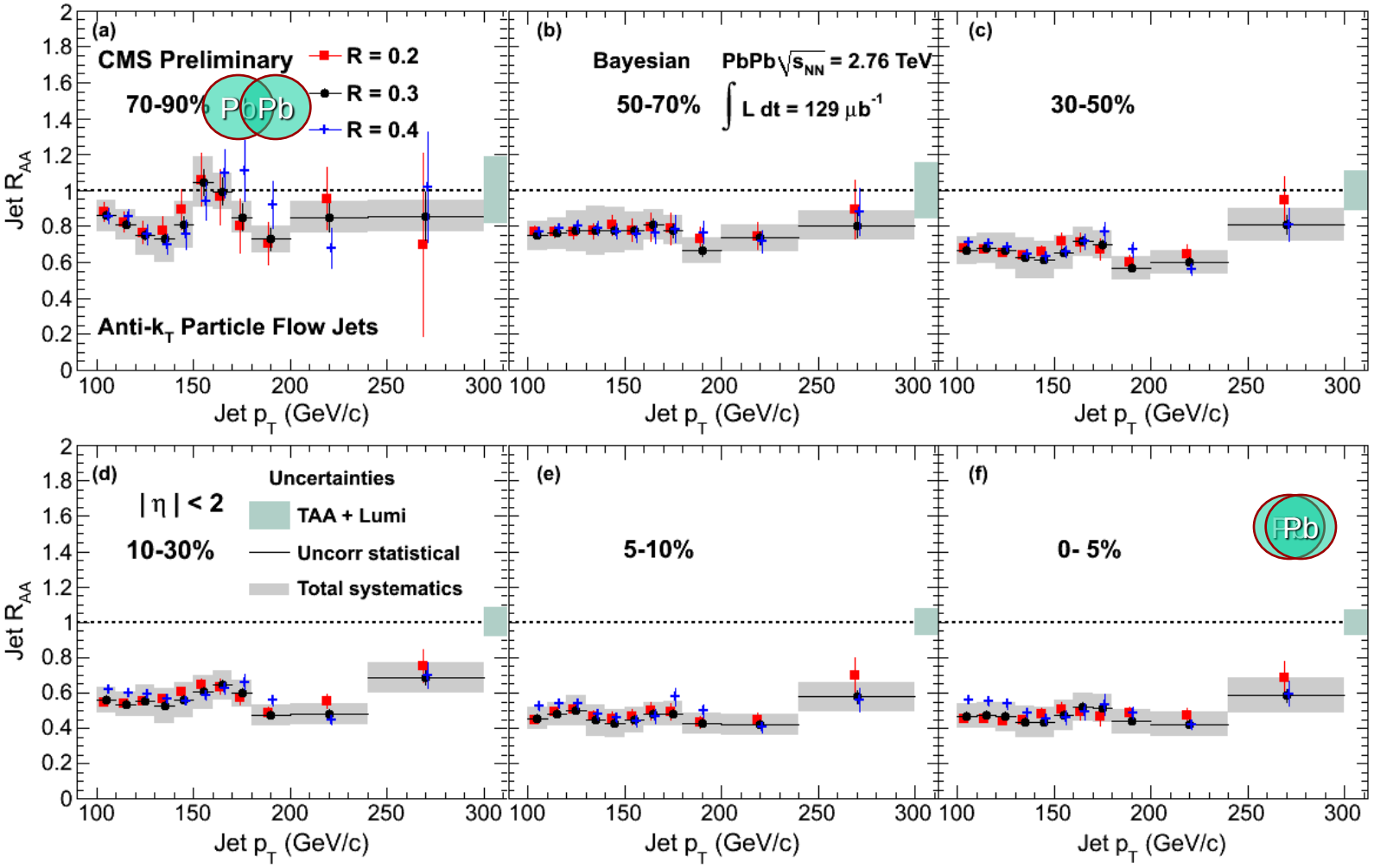
Nuclear modification factors of jets



Suppression: no significant p_T–dependence

Tue 17:25
Marguerite Tonjes

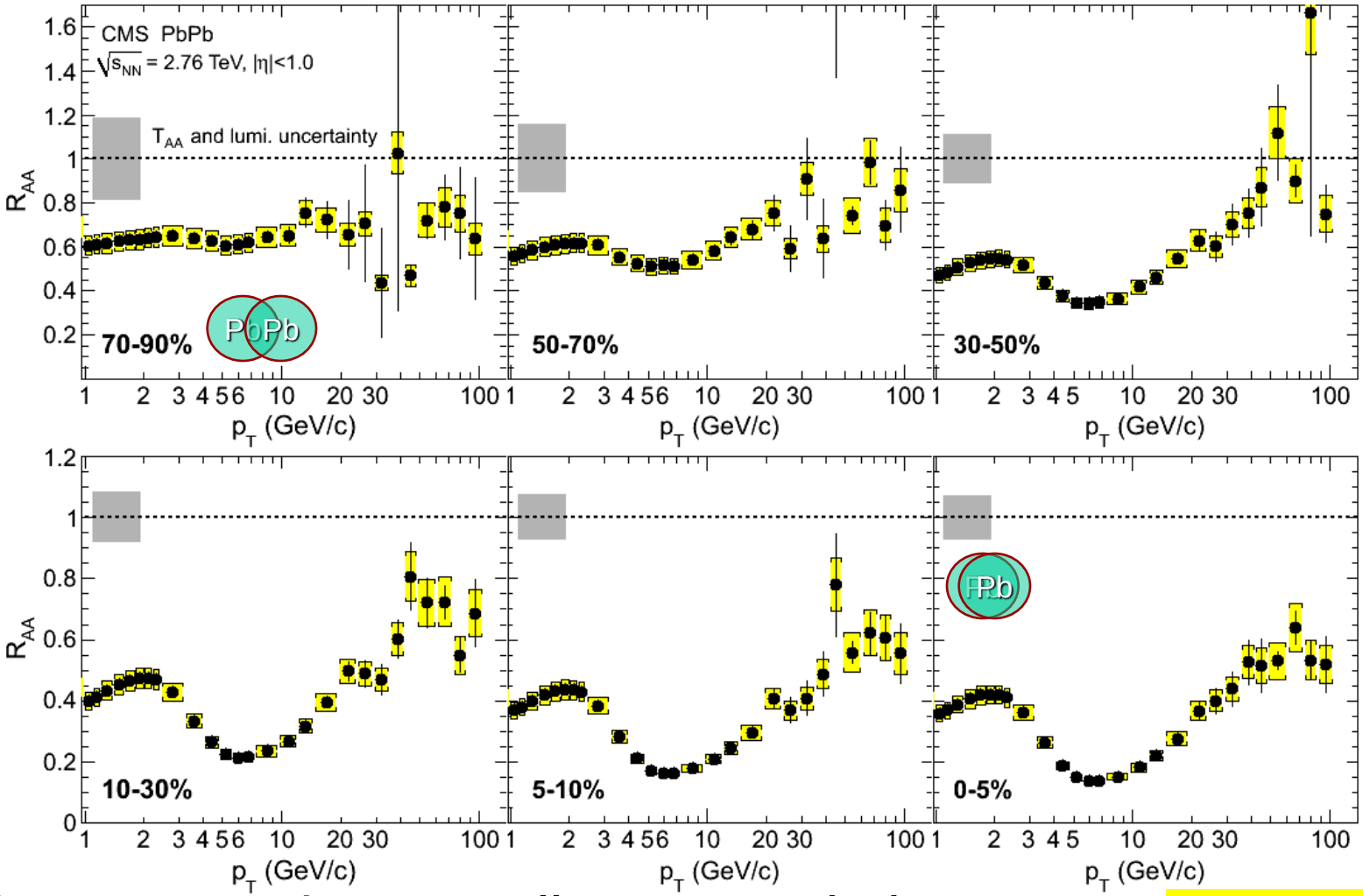
Nuclear modification factors of jets



Suppression: no significant cone size dependence

Tue 17:25
Marguerite Tonjes

Charged hadron R_{AA}: update with 2011 data



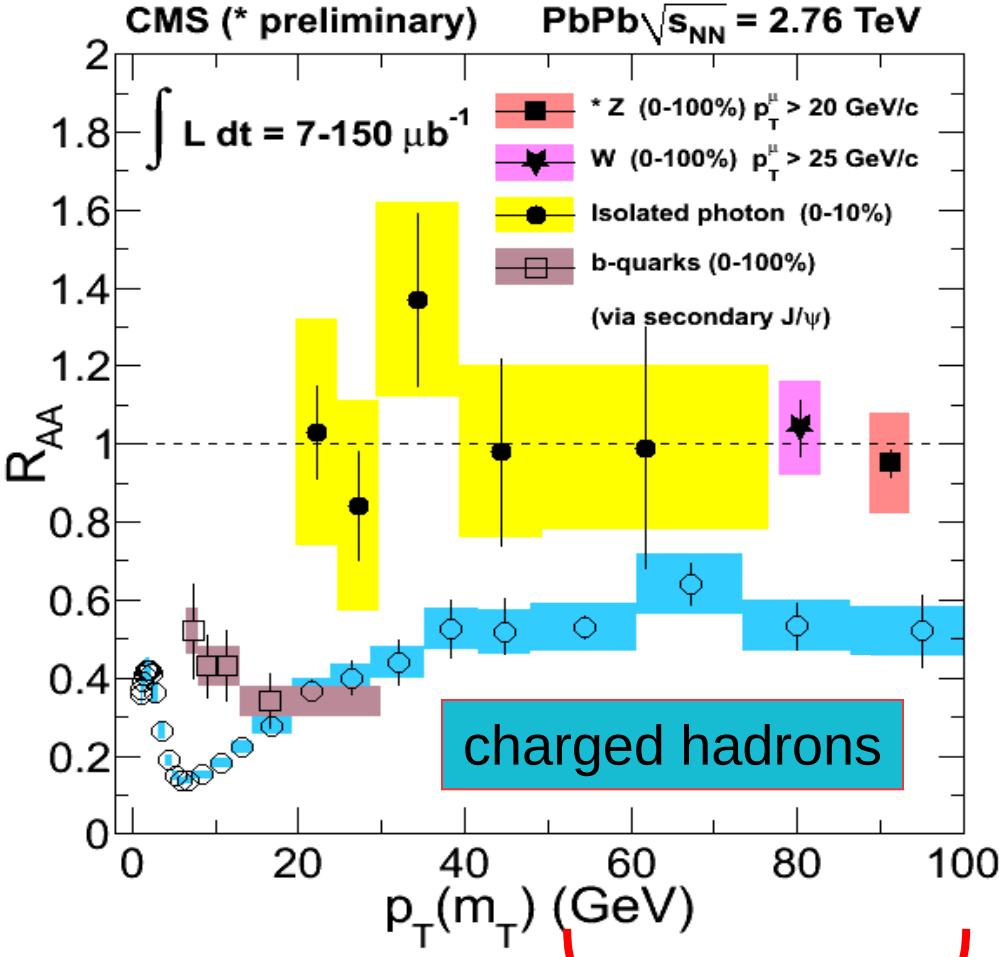
20 times more data, smaller uncertainties

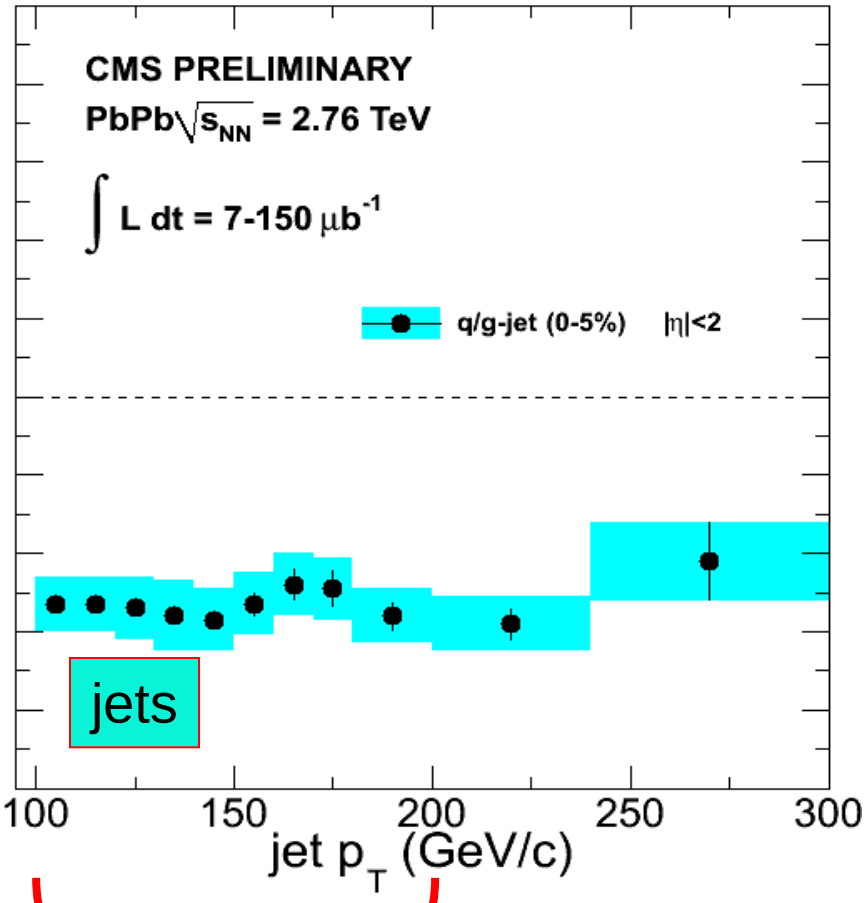
→ what is the connection to jet R_{AA}?

EPJC 72 (2012) 1945

Tue 17:25, Marguerite Tonjes

Nuclear modification factors

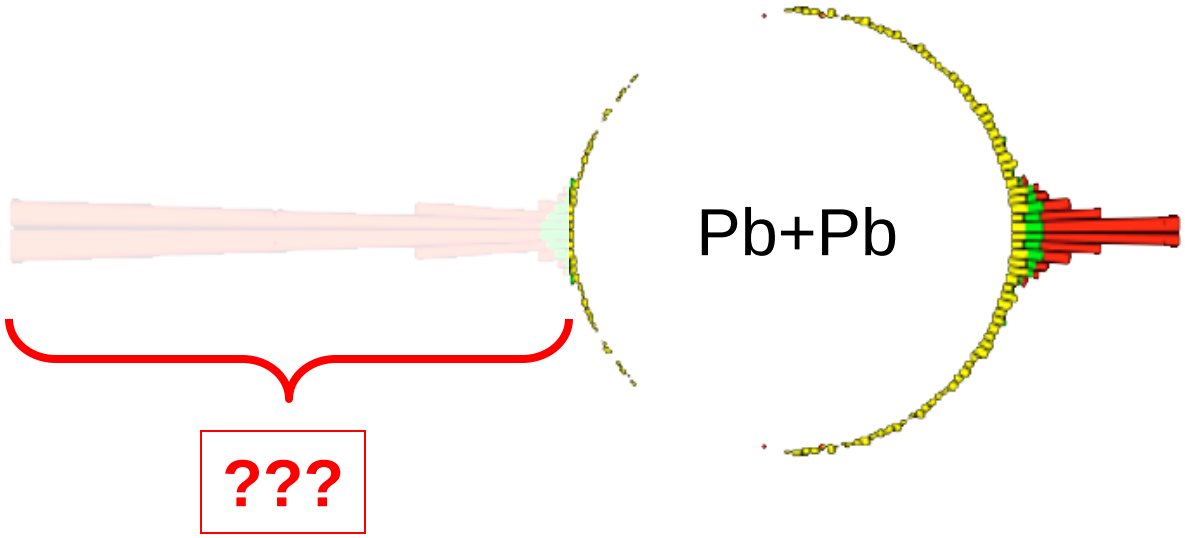




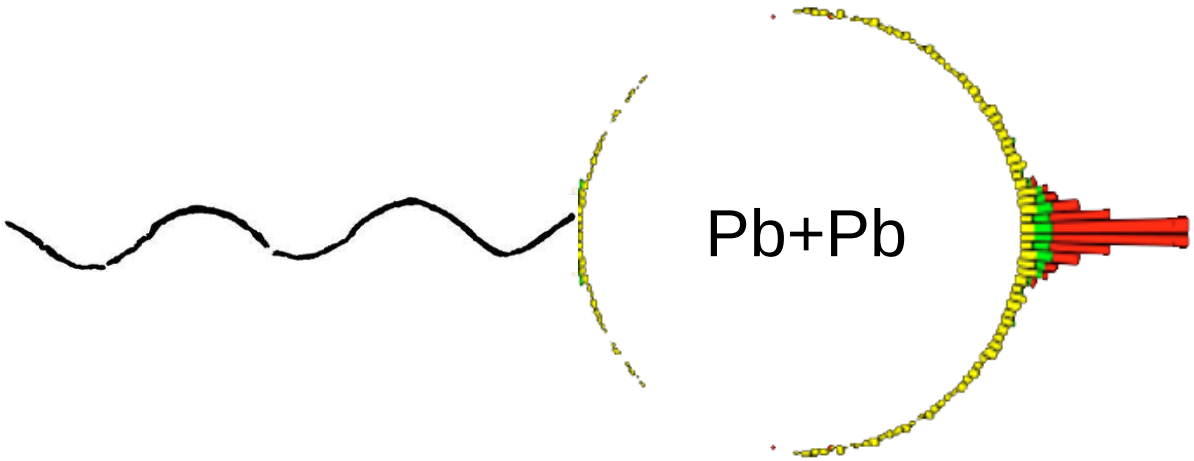
Sampling the ~same parton p_T range

Note: jets fragment into high-p_T particles in pp and PbPb the same way – *see later…*

How can we quantify the jet energy loss with a ‘calibrated’ measurement?

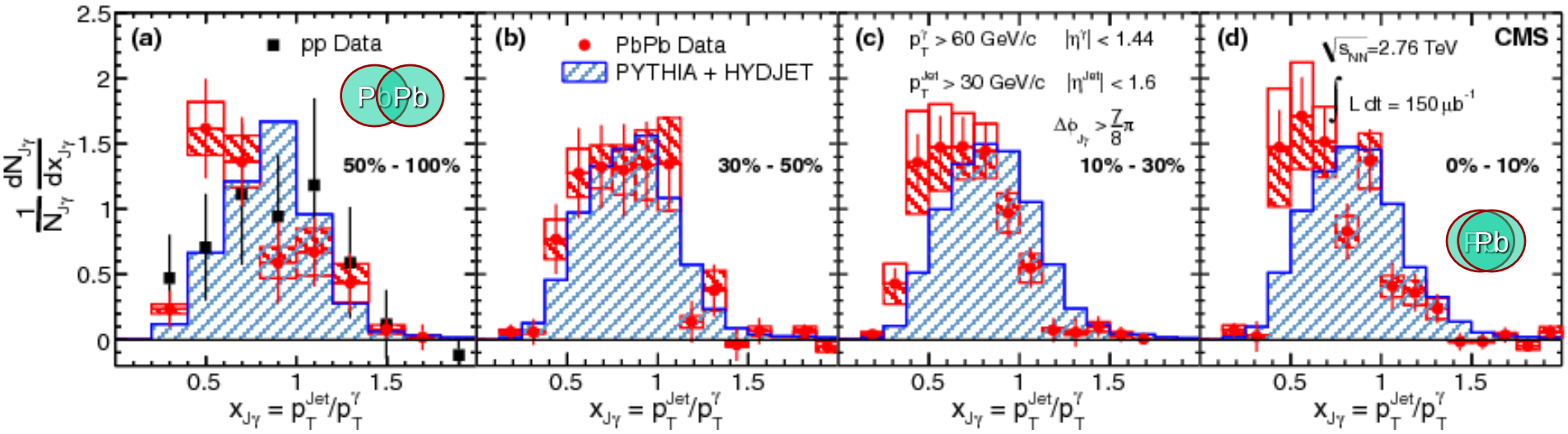


How can we quantify the jet energy loss with a ‘calibrated’ measurement?



γ-jet correlations

- Photons serve as an unmodified energy tag for the jet partner
- Ratio of the p_T of jets to photons ($x_{J\gamma}=p_T^{jet}/p_T^{\gamma}$) is a direct measure of the jet energy loss
- Gradual centrality-dependence of the $x_{J\gamma}$ distribution

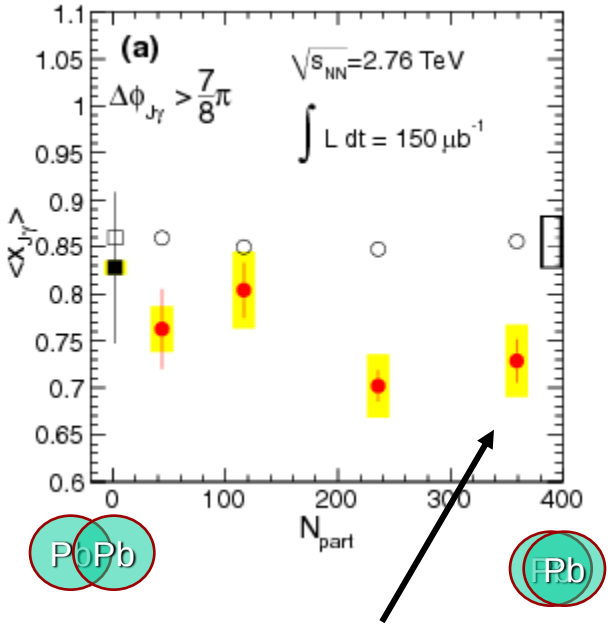


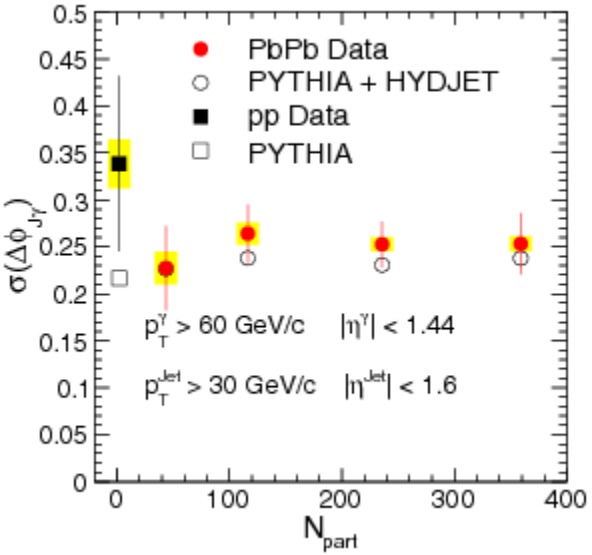
arXiv:1206.0206

Tue 14:15, Yue Shi Lai

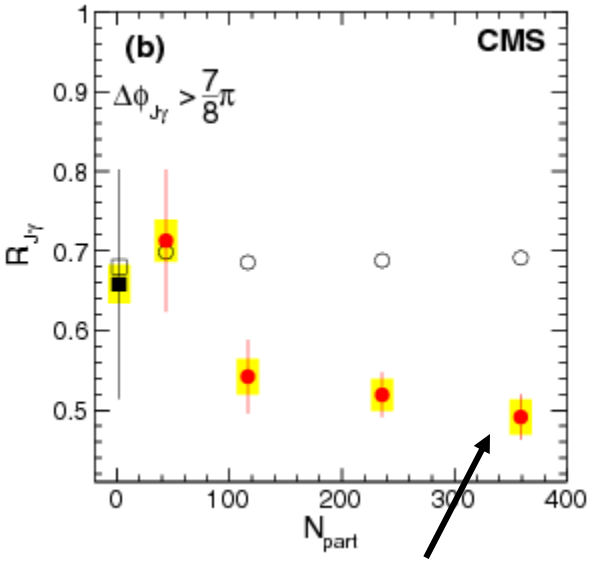
γ-jet correlations

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





$R_{J\gamma}$ = fraction of photons with jet partner >30 GeV/c



Increasing p_T-imbalance

Jets lose ~14% of their initial energy

No φ-decorrelation

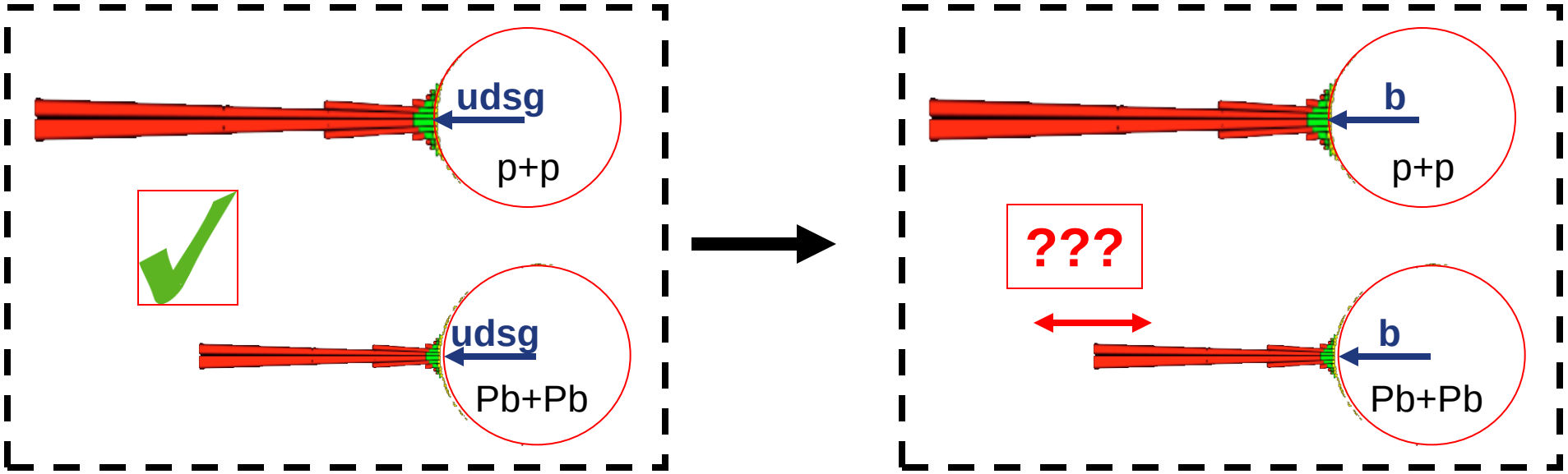
Less jet partners above threshold

~20% of photons lose their jet partner

arXiv:1206.0206

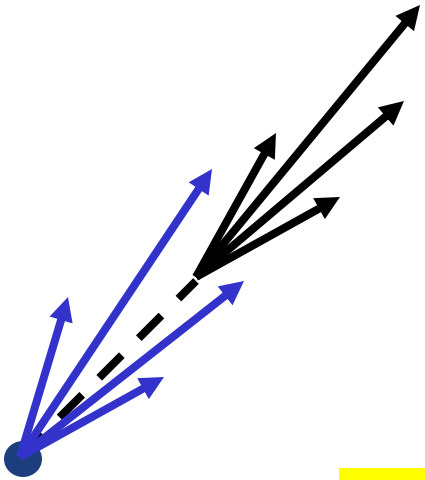
Tue 14:15, Yue Shi Lai

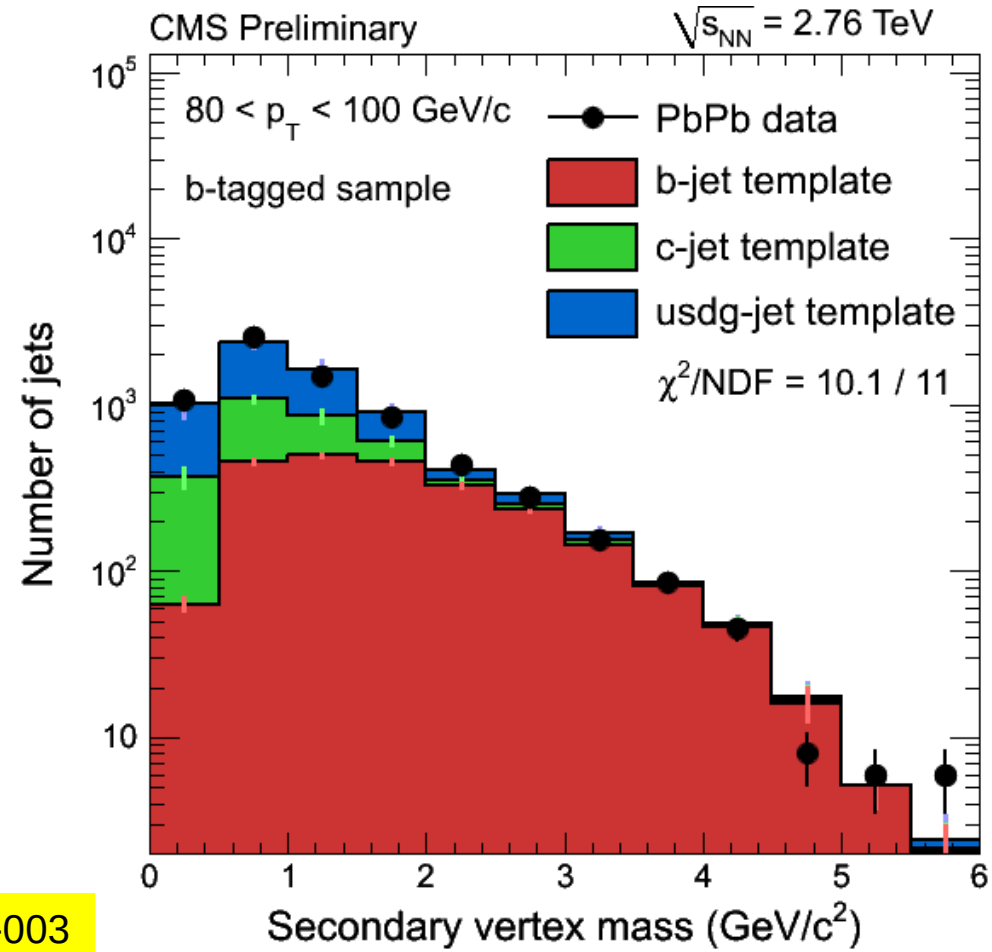
Are heavy-quark jets quenched, too?



Tagging and counting b-quark jets

- Secondary vertex tagged using flight distance significance
- Tagging efficiency estimated in a data-driven way
- Purity from template fits to (tagged) secondary vtx mass distributions

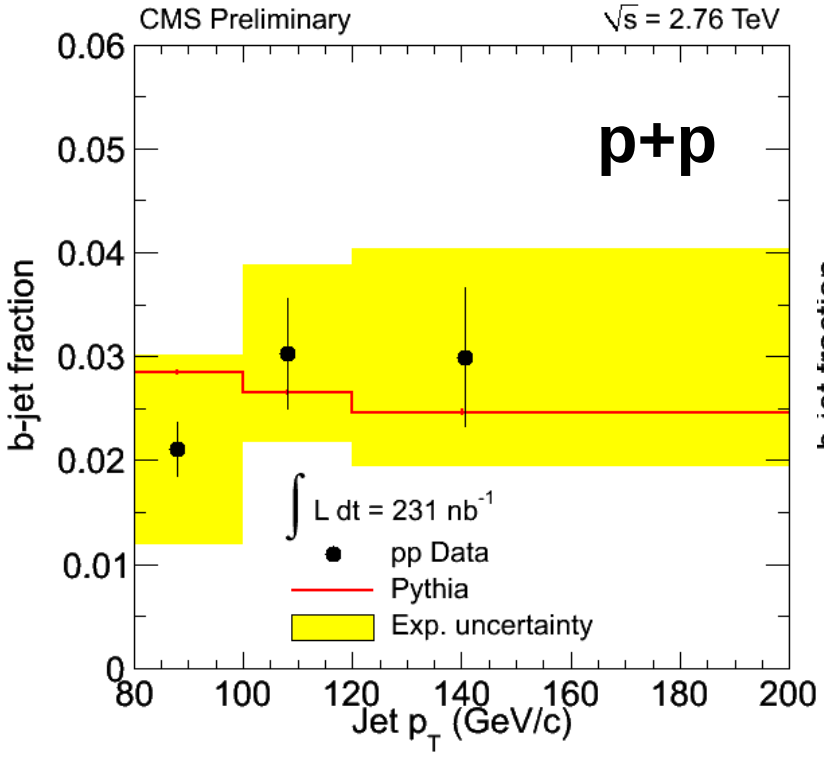


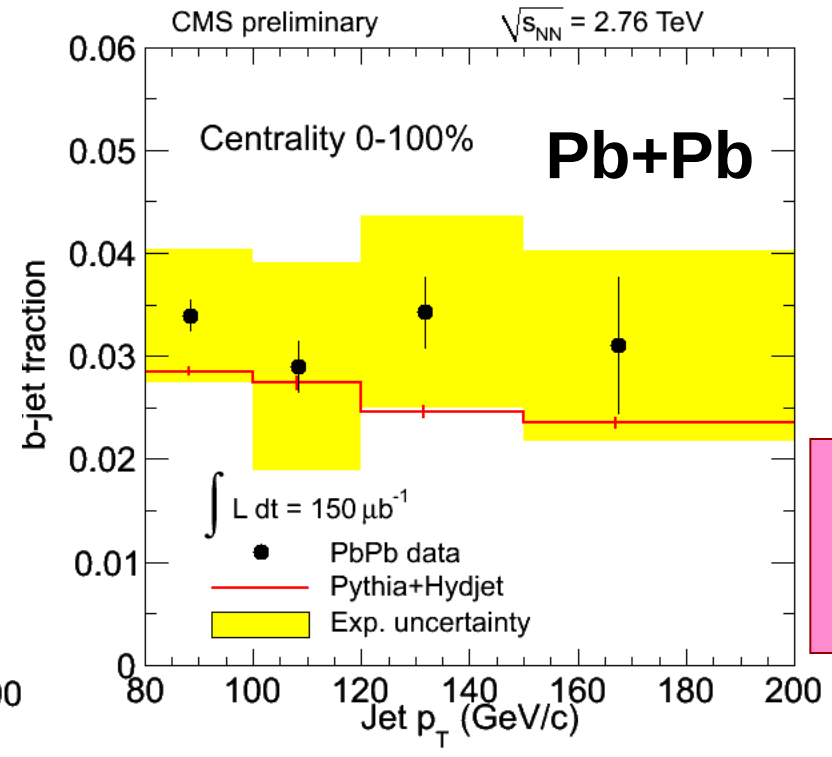


CMS PAS HIN-12-003

Fraction of b-jets among all jets

b-jet fraction: similar in pp and PbPb
→ b-jet quenching is comparable to light-jet quenching (R_{AA}≈0.5), within present systematics



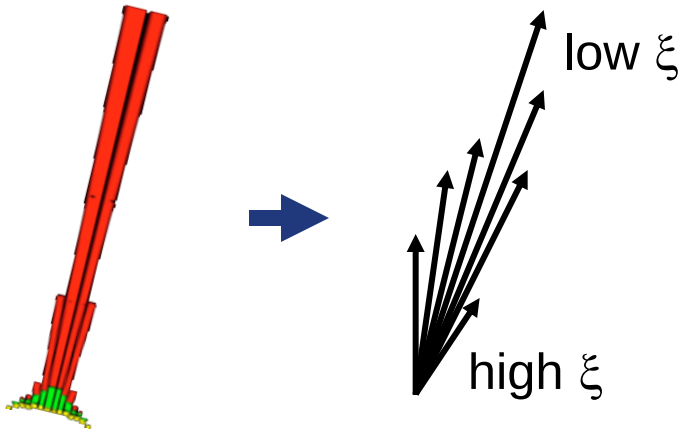


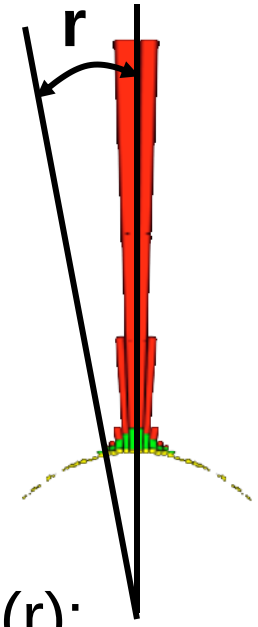
Tue 16:45
Matt Nguyen,
and **poster** by
Jorge Robles

CMS PAS HIN-12-003

How do jets get modified? Do their shape, or fragmentation change?

Jet fragmentation function:
Distribution of track momenta projected onto the jet axis, presented as a function of $\xi=\ln(p^{jet}/p_{||}^{track})$:

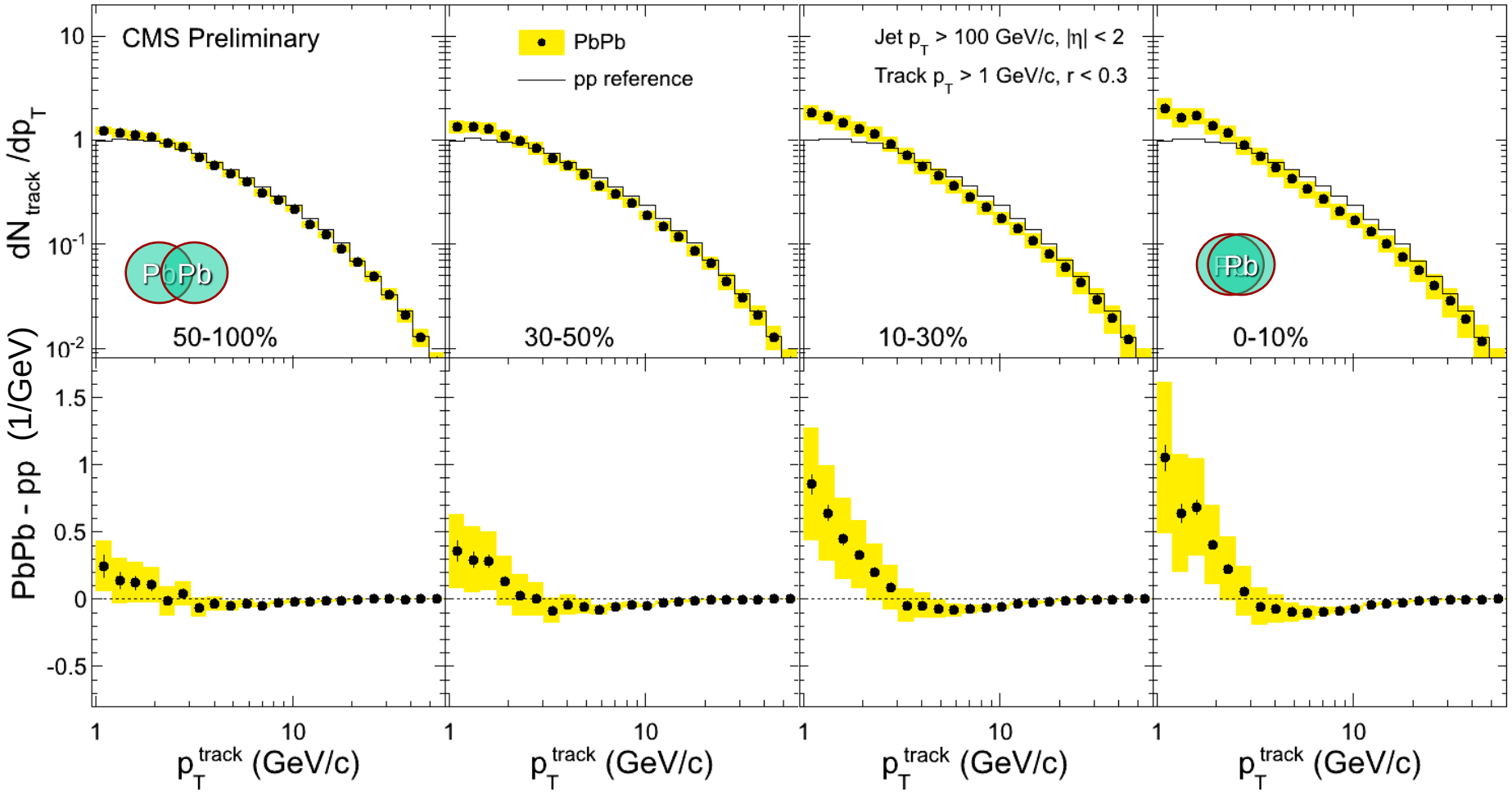




Jet shape:
p_T-flow vs. η-φ distance from the jet axis (r):

$$\rho(r) \sim \frac{1}{\delta r}\frac{1}{N_{\text{jet}}}\sum_{\text{jets}}\frac{p_{\text{T}}(r-\delta r/2, r+\delta r/2)}{p_{\text{T}}^{\text{jet}}}$$

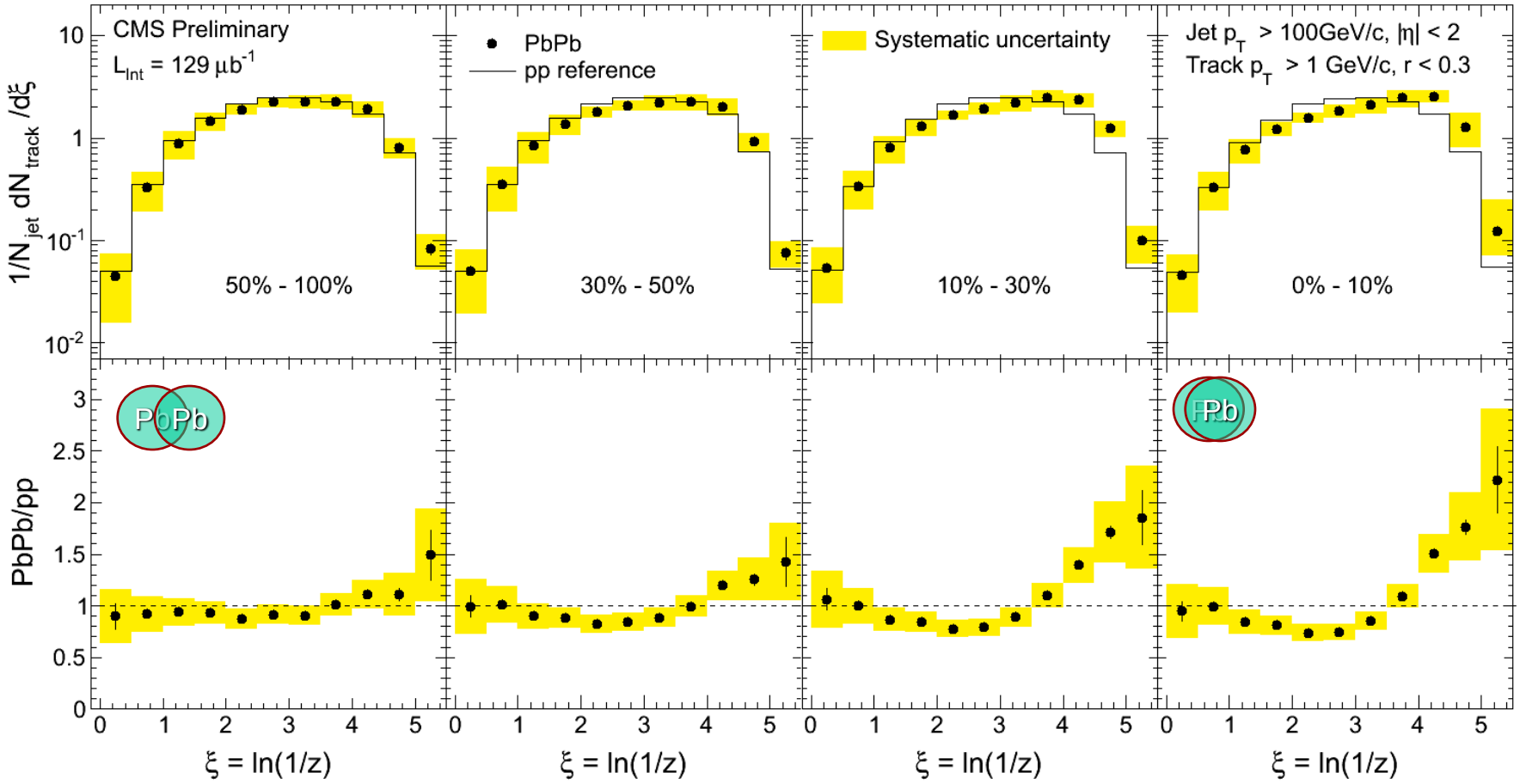
Track p_T distributions in jet cones (R=0.3)



High p_T (low ξ): **no change** compared to jets in pp collisions

In (central) PbPb: **excess** of tracks compared to pp at low p_T (high ξ)

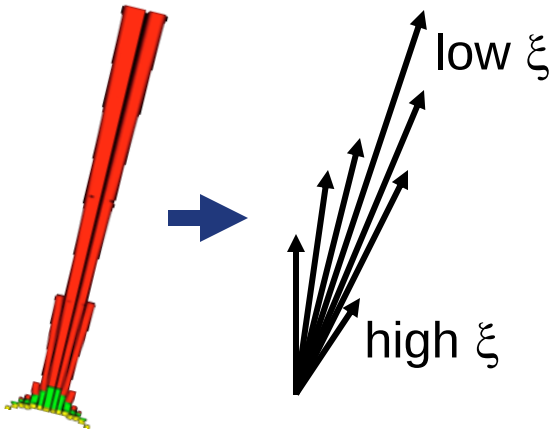
Jet fragmentation functions



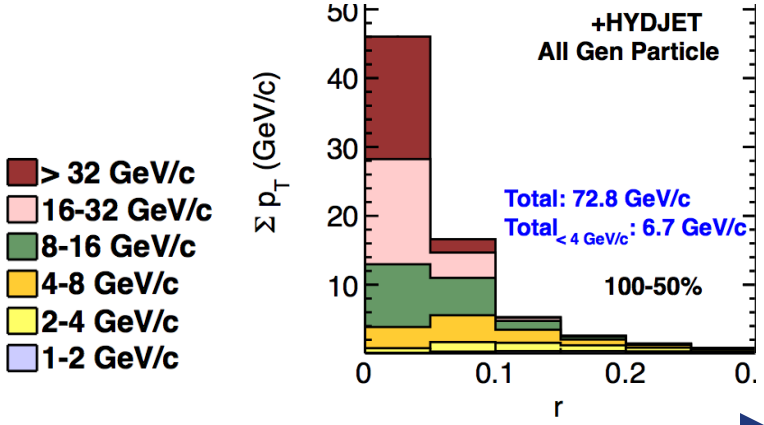
20 times more data in 2011: decreased uncertainties down to much lower track p_T (starting from 1 GeV/c) reveals an excess at high ξ compared to pp

Wed 9:50, Frank Ma

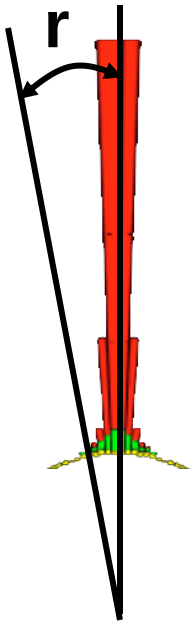
What do we expect for the jet shapes?



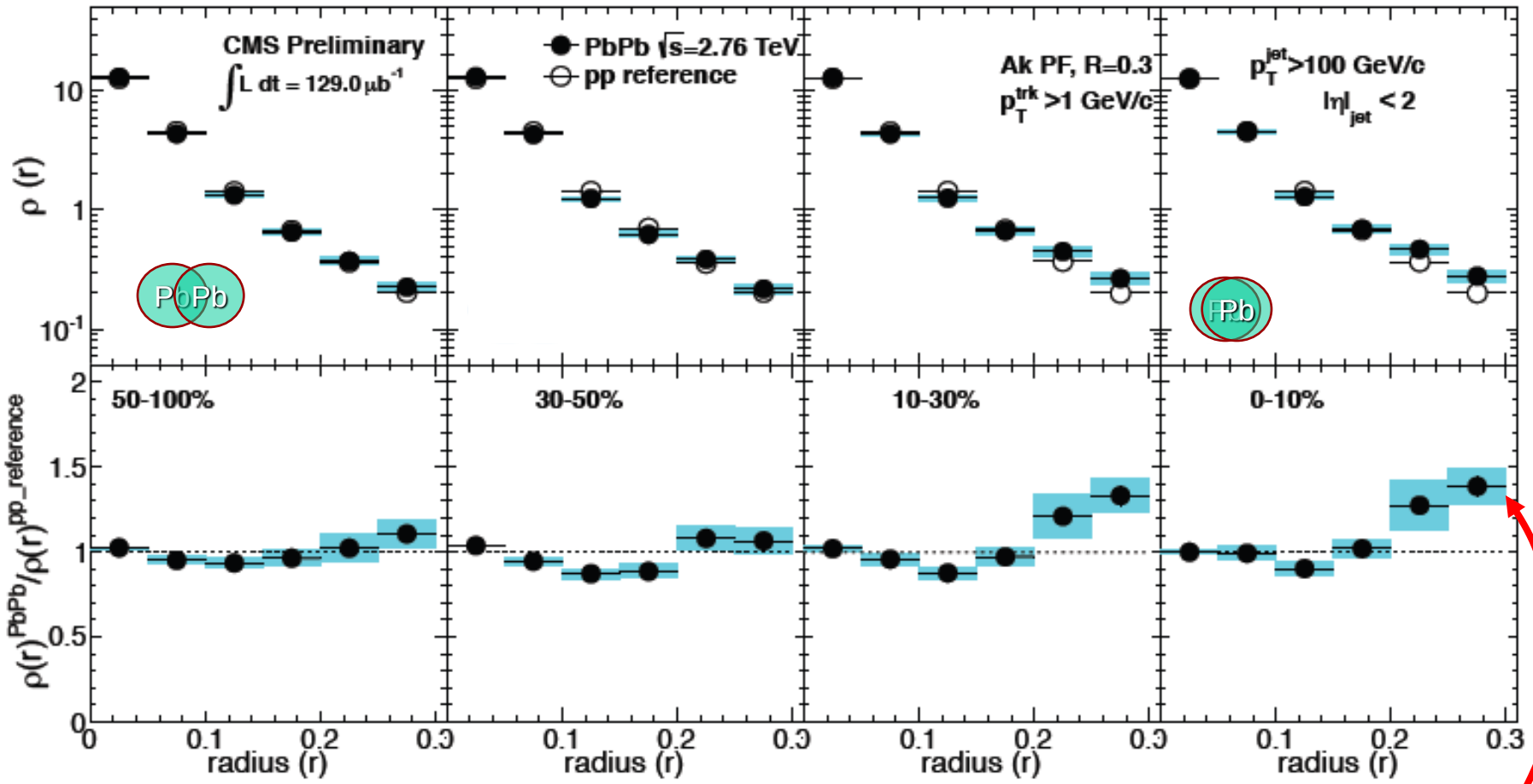
Low-ξ particles tend to be closer to the jet axis; high-ξ particles extend to large distances (radii).



Excess p_T-flow is expected at large radii, and no change at r≈0 (compared to pp collisions).



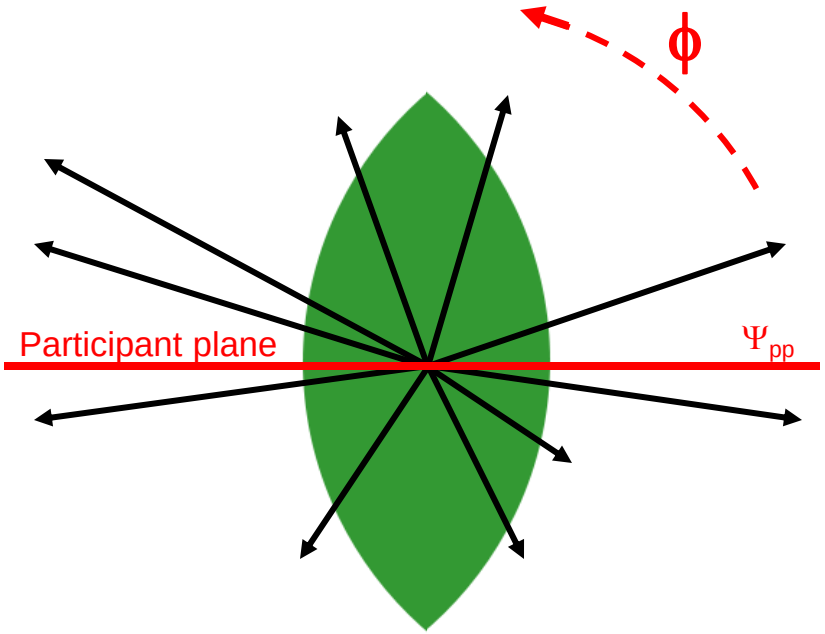
Changing jet shapes vs. centrality



Compared to pp: same p_T-flow close to the jet axis;
more p_T-flow at large radii;
and a bit less in between.

Wed 9:10, Pelin Kurt

Testing energy loss with high-p_T tracks, as a function of azimuthal angle (v_2)



Overlap zone is almond-shaped

→ Parton energy loss is smaller along the short axis

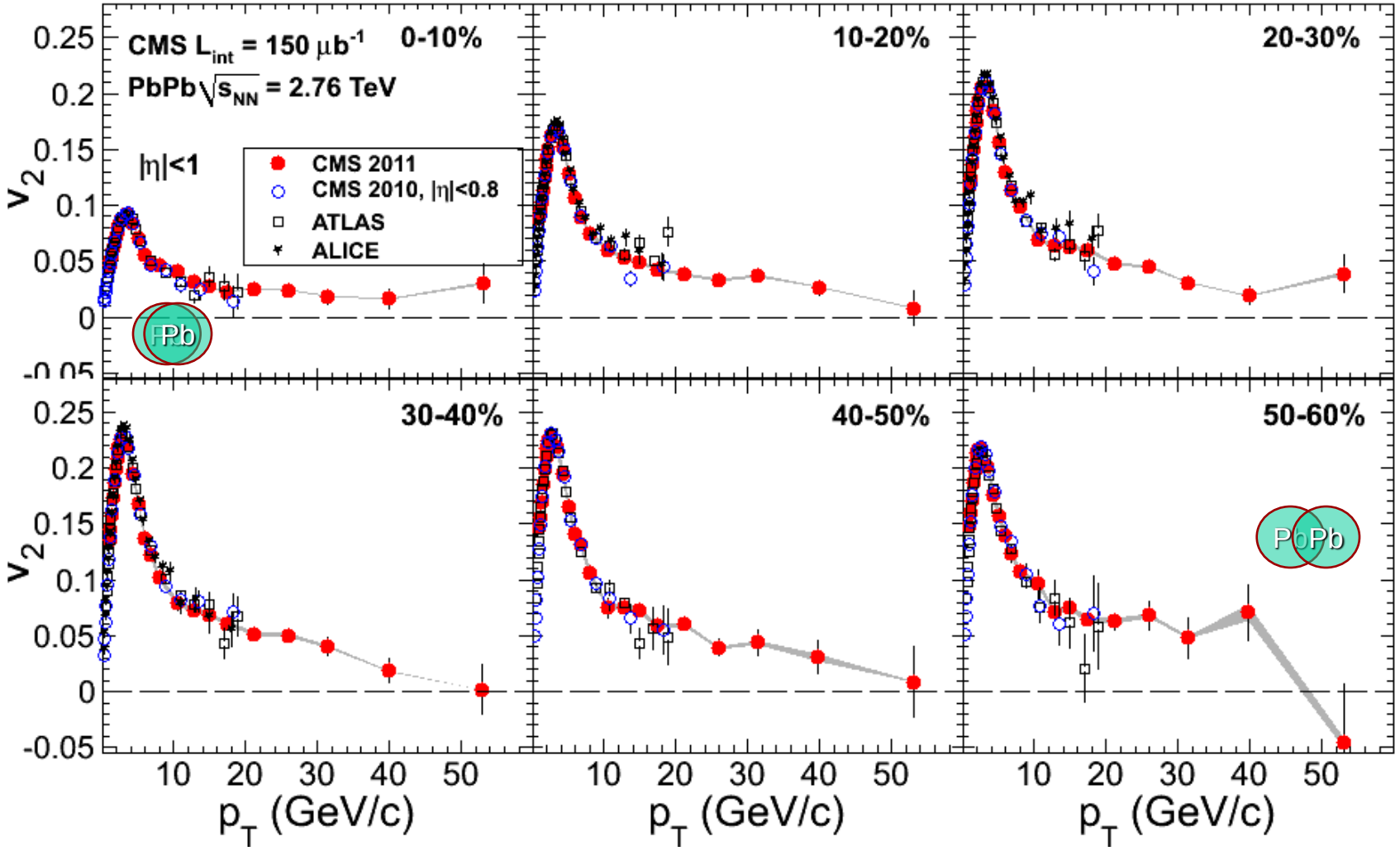
→ More high-p_T tracks expected closer to the event plane

→ Azimuthal asymmetry (v_2):

$$dN/d\phi \propto 1 + 2v_2 \cos(2(\phi - \Psi_{EP}))$$

→ v_2 is sensitive to the path-length dependence of the energy loss

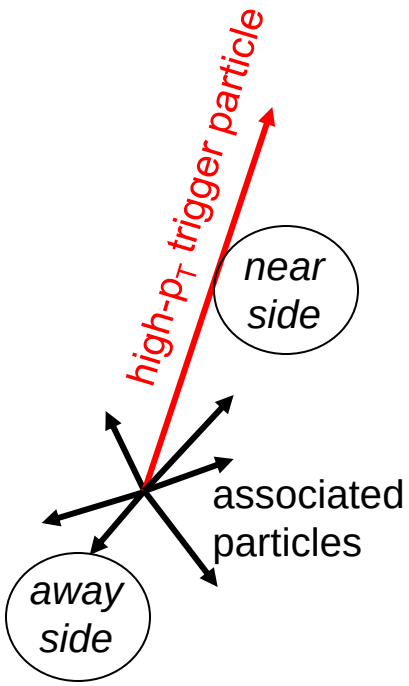
Charged hadron v_2 at very high p_T



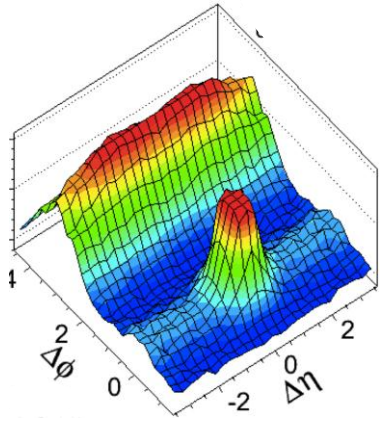
- v_2 is non-zero up to very high p_T
- Sensitive to the path length dependence of energy loss

Tue 15:55, Victoria Zhukova

Studying jet modification: particles associated to a high-p_T trigger particle



High-p_T trigger particle
from jet fragmentation.
Let us subtract all v_n harmonics! (n≥2)



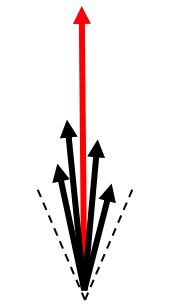
Expectation on the "near side":
- some excess at low p_T (as seen in the jet FF)

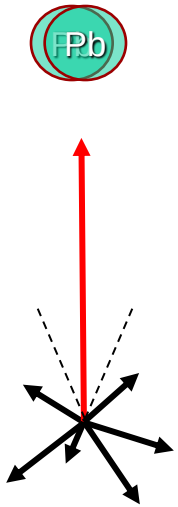
Expectation on the "away side":
- high p_T: deficit compared to pp (quenching)
- low p_T: excess, due to redistribution of momentum

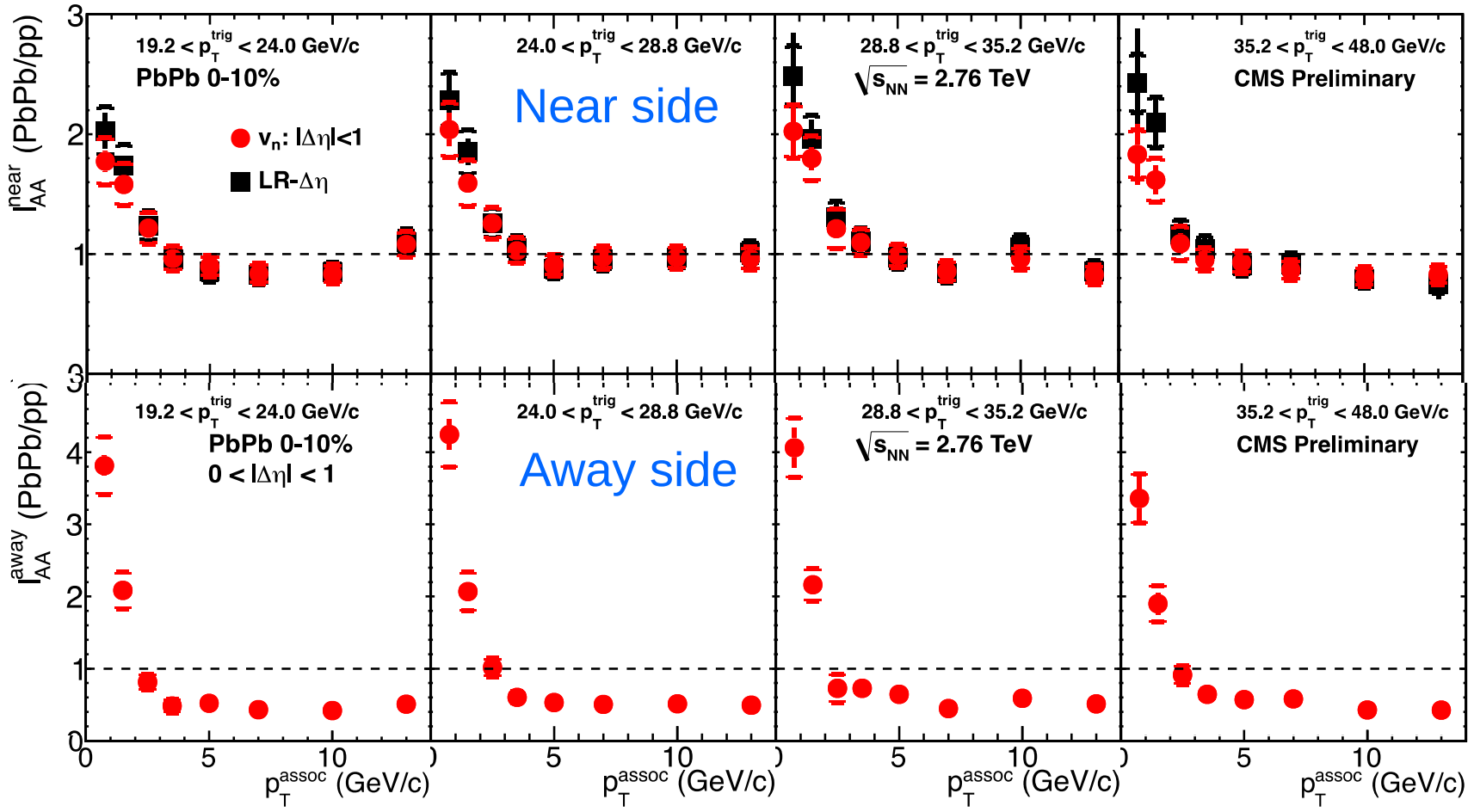
$$I_{AA}^{near} = \frac{Y_{PbPb}^{near}}{Y_{pp}^{near}}$$

$$I_{AA}^{away} = \frac{Y_{PbPb}^{away}}{Y_{pp}^{away}}$$

High-p_T triggered two-particle correlations







Away-side: large enhancement below ~3 GeV/c and deficit at higher p_T.

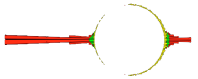
Near-side: consistent with jet FF's.

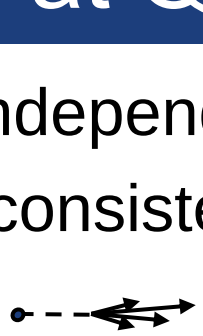
All v_n harmonics subtracted! (n≥2)

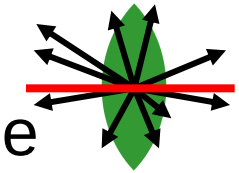
Tue 15:15, Rylan Conway

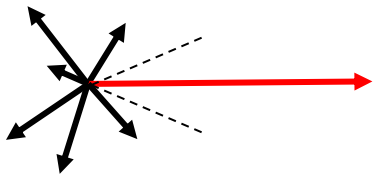
Summary: jets at QM'12

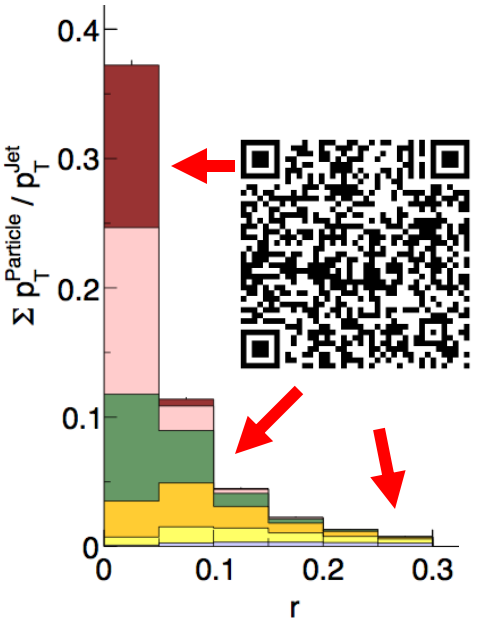
- Energy imbalance and jet R_{AA} independent of jet p_T
- First γ-jet measurement shows consistent energy loss
- b-quark jets are also quenched
- Jet shapes and fragmentation functions show excess at low p_T (large radii) but high p_T (core) is unchanged
- v_2 persists to very high p_T, reflects path length dependence
- Two-particle correlations: low-p_T enhancement and high-p_T suppression on the away side (compared to pp)











Jet-quenching picture is made more precise and quantitative!

QM'12 talks from CMS on jets

Tue 9:30am, **Gabor Veres**, Overview of results on jets

Tue 2:15pm, **Yue Shi Lai**,
Study of jet quenching using photon-jet events in PbPb collisions

Tue 3:15pm, **Rylan Conway**,
Short- and long-range very-high-p_T triggered dihadron correlations in PbPb collisions

Tue 3:55pm, **Victoria Zhukova**,
Azimuthal anisotropy of charged hadrons at very high p_T in PbPb collisions

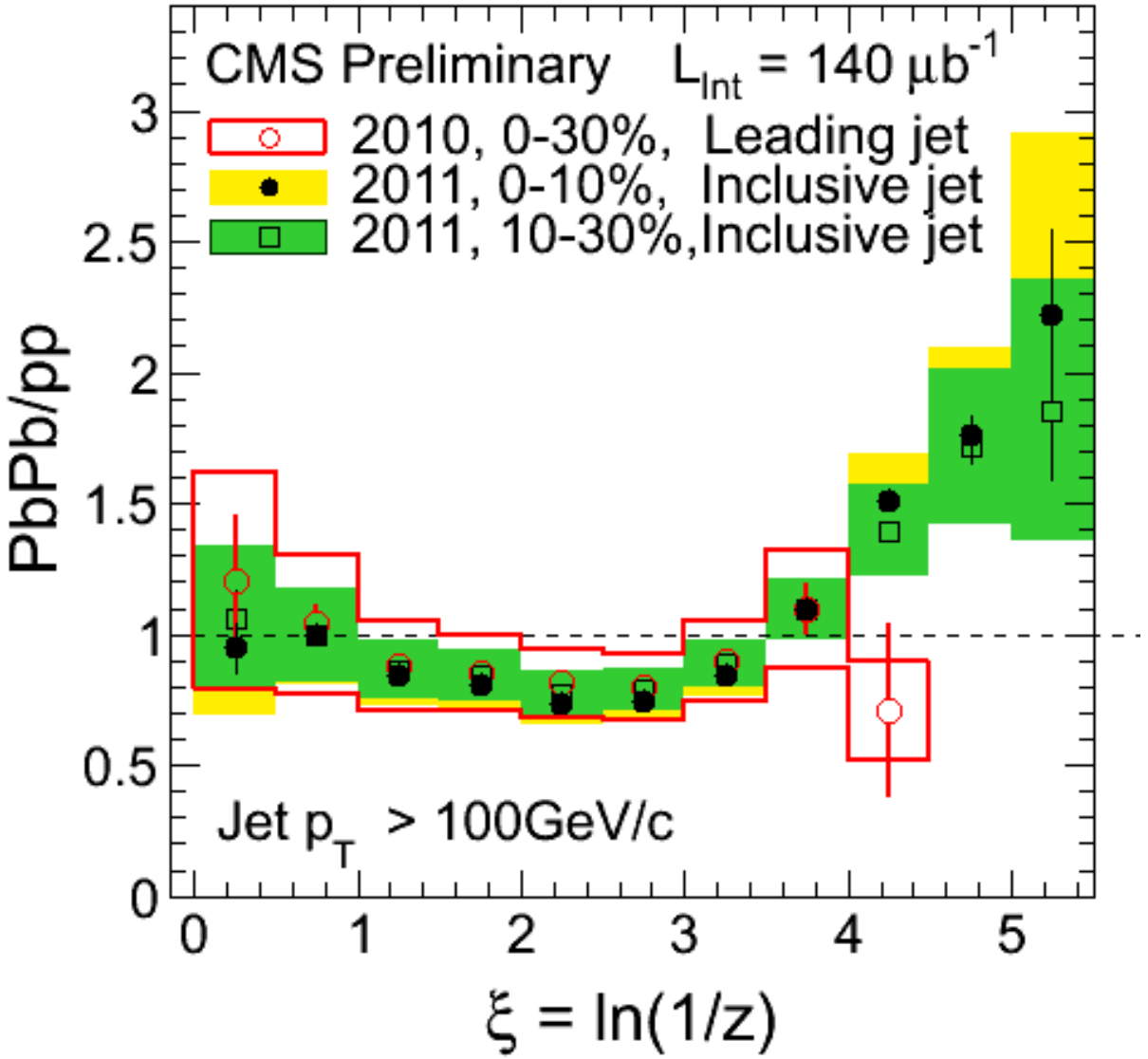
Tue 4:45pm, **Matthew Nguyen**,
Studies of jet quenching and b-jet tagging in PbPb collisions

Tue 5:25pm, **Marguerite Tonjes**,
Inclusive jet and charged hadron nuclear modification factors in PbPb collisions

Wed 9:10am, **Pelin Kurt**,
Jet shapes in pp and PbPb collisions

Wed 9:50am, **Frank Ma**,
Jet fragmentation functions in PbPb and pp collisions

BACKUP


CMS Preliminary L_{Int} = 140 μb^{-1}
2010, 0-30%, Leading jet
2011, 0-10%, Inclusive jet
2011, 10-30%, Inclusive jet
Jet p_T > 100GeV/c
PbPb/pp
$\xi = \ln(1/z)$
0
0.5
1
1.5
2
2.5
3
0
1
2
3
4
5

QM'12 talks from CMS

Mon 12:25pm, Gunther Roland, **Experimental highlights**

Mon 5:15pm, Stephen Sanders, **Overview of results on flow and correlations**

Tue 9:30am, Gabor Veres, **Overview of results on jets**

Tue 2:15pm, Yue Shi Lai, Study of jet quenching using photon-jet events in PbPb collisions

Tue 2:15pm, Dongho Moon, Detailed measurements of charmonium suppression in PbPb collisions

Tue 3:15pm, Rylan Conway, Short- and long-range very-high-p_T triggered dihadron correlations in PbPb collisions

Tue 3:55pm, Victoria Zhukova, Azimuthal anisotropy of charged hadrons at very high p_T in PbPb collisions

Tue 4:45pm, Matthew Nguyen, Studies of jet quenching and b-jet tagging in PbPb collisions

Tue 4:45pm, Guillermo Rangel, Detailed measurements of bottomonium suppression in PbPb collisions

Tue 5:25pm, Marguerite Tonjes, Inclusive jet and charged hadron nuclear modification factors in PbPb collisions

Tue 5:45pm, Magdalena Malek, Pseudorapidity and centrality dependence of transverse energy flow in PbPb collisions

Wed 8:30am, Hauke Wohrmann, Studies of the nuclear stopping power in PbPb collisions

Wed 9:10am, Pelin Kurt, Jet shapes in pp and PbPb collisions

Wed 9:50am, Frank Ma, Jet fragmentation functions in PbPb and pp collisions

Wed 11:20am, George Stephans, Inclusive isolated photons in pp and PbPb collisions

Wed 12:00pm, Lamia Benhabib, W and Z boson production in PbPb collisions

Thu 9:45am, Raphael Granier de C., **Overview of results on photon and electroweak boson production**

Thu 11:05am, Camelia Mironov, **Overview of results on heavy flavor and quarkonia**

Fri 2:20pm, Eric Appelt, Elliptic azimuthal anisotropy of charged hadrons and neutral pions in PbPb collisions

Fri 3:40pm, Mihee Jo, Suppression of open bottom at high p_T via non-prompt J/psi decays in PbPb collisions

Fri 5:30pm, Shengquan Tuo, Studies of higher-order flow harmonics and factorization of dihadron correlations in PbPb collisions