

Energy Loss Measurements with Jets in CMS

(and some news on pPb)



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for the CMS Collaboration

8th International Workshop on High p_T physics

Wuhan Oct 21, 2012



CMS heavy-ion papers

PHYSICAL REVIEW LETTERS 106, 032301 (2011)

Observation and studies of quenching in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

S. Chatrchyan et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

In production of heavy-flavor mesons in Pb-Pb collisions, the quenching of the fragmentation function is observed in the form of a suppression of the yield of heavy-flavor mesons in the central region compared to the peripheral region. This quenching is observed to be independent of the meson flavor and is consistent with the predictions of energy loss models. The quenching is observed to be independent of the meson flavor and is consistent with the predictions of energy loss models.

1. INTRODUCTION

Heavy-ion collisions have opened a new window into the nuclear matter under extreme conditions. The quenching of the fragmentation function is observed in the form of a suppression of the yield of heavy-flavor mesons in the central region compared to the peripheral region. This quenching is observed to be independent of the meson flavor and is consistent with the predictions of energy loss models.

PHYSICAL REVIEW LETTERS 106, 032302 (2011)

Study of Z boson production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

A study of Z boson production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is presented. The Z boson is produced in the central region and decays into a pair of leptons. The yield of Z bosons is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

1. INTRODUCTION

The production of Z bosons in Pb-Pb collisions is studied as a function of the centrality of the collision. The yield of Z bosons is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

PHYSICAL REVIEW LETTERS 106, 032303 (2011)

Long-range and short-range dihadron angular correlations in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

Long-range and short-range dihadron angular correlations are studied in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The correlations are measured as a function of the centrality of the collision and compared to the predictions of the standard model.

1. INTRODUCTION

The production of dihadrons in Pb-Pb collisions is studied as a function of the centrality of the collision. The correlations are measured as a function of the centrality of the collision and compared to the predictions of the standard model.

PHYSICAL REVIEW LETTERS 106, 032304 (2011)

Indication of Suppression of Excited Y States in Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The production of excited Y states in Pb-Pb collisions is studied as a function of the centrality of the collision. The yield of excited Y states is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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PHYSICAL REVIEW LETTERS 106, 032305 (2011)

Dependence on pseudorapidity and on centrality of charged hadron production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The production of charged hadrons in Pb-Pb collisions is studied as a function of the centrality of the collision. The yield of charged hadrons is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CMS
CMS H1-10-04

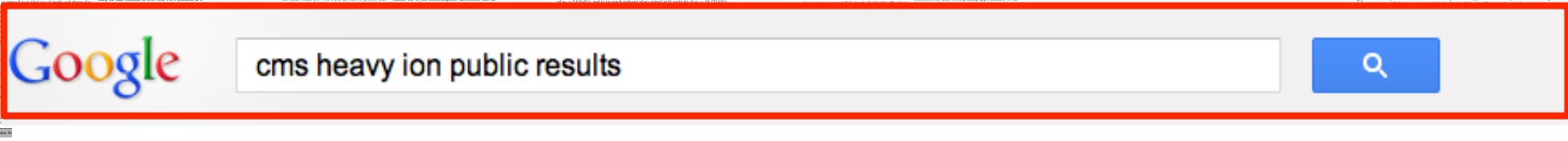
Measurement of the elliptic anisotropy of charged particles produced in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The elliptic anisotropy of charged particles produced in Pb-Pb collisions is measured as a function of the centrality of the collision. The elliptic anisotropy is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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PHYSICAL REVIEW LETTERS 106, 032306 (2011)

Measurement of isolated photon production in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The production of isolated photons in pp and Pb-Pb collisions is studied as a function of the centrality of the collision. The yield of isolated photons is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

1. INTRODUCTION

The production of isolated photons in pp and Pb-Pb collisions is studied as a function of the centrality of the collision. The yield of isolated photons is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

PHYSICAL REVIEW LETTERS 106, 032307 (2011)

Suppression of non-prompt J/psi, prompt J/psi, and Y(1S) in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The production of J/psi, prompt J/psi, and Y(1S) in Pb-Pb collisions is studied as a function of the centrality of the collision. The yield of J/psi, prompt J/psi, and Y(1S) is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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The production of J/psi, prompt J/psi, and Y(1S) in Pb-Pb collisions is studied as a function of the centrality of the collision. The yield of J/psi, prompt J/psi, and Y(1S) is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

PHYSICAL REVIEW LETTERS 106, 032308 (2011)

The CMS Collaboration

The CMS Collaboration is a joint effort of scientists from various countries, working together to study the properties of the strong interaction and the structure of matter under extreme conditions.

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PHYSICAL REVIEW LETTERS 106, 032310 (2011)

Measurement of the pseudorapidity and centrality dependence of the transverse energy density in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The pseudorapidity and centrality dependence of the transverse energy density in Pb-Pb collisions is studied as a function of the centrality of the collision. The transverse energy density is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

1. INTRODUCTION

The pseudorapidity and centrality dependence of the transverse energy density in Pb-Pb collisions is studied as a function of the centrality of the collision. The transverse energy density is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

PHYSICAL REVIEW LETTERS 106, 032311 (2011)

Jet momentum dependence of jet quenching in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The jet momentum dependence of jet quenching in Pb-Pb collisions is studied as a function of the centrality of the collision. The jet quenching is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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The jet momentum dependence of jet quenching in Pb-Pb collisions is studied as a function of the centrality of the collision. The jet quenching is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

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CMS H1-10-04

Study of W boson production in Pb-Pb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The production of W bosons in Pb-Pb and pp collisions is studied as a function of the centrality of the collision. The yield of W bosons is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CMS
CMS H1-10-04

Measurement of jet fragmentation into charged particles in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The fragmentation of jets into charged particles in pp and Pb-Pb collisions is studied as a function of the centrality of the collision. The fragmentation is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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The fragmentation of jets into charged particles in pp and Pb-Pb collisions is studied as a function of the centrality of the collision. The fragmentation is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

PHYSICAL REVIEW LETTERS 106, 032312 (2011)

Measurement of the azimuthal anisotropy of neutral pions in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The azimuthal anisotropy of neutral pions in Pb-Pb collisions is studied as a function of the centrality of the collision. The azimuthal anisotropy is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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The azimuthal anisotropy of neutral pions in Pb-Pb collisions is studied as a function of the centrality of the collision. The azimuthal anisotropy is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

PHYSICAL REVIEW LETTERS 106, 032313 (2011)

Study of W boson production in Pb-Pb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The production of W bosons in Pb-Pb and pp collisions is studied as a function of the centrality of the collision. The yield of W bosons is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

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CMS H1-10-04

Studies of jet quenching using isolated-photon-jet correlations in Pb-Pb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The studies of jet quenching using isolated-photon-jet correlations in Pb-Pb and pp collisions are studied as a function of the centrality of the collision. The jet quenching is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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The studies of jet quenching using isolated-photon-jet correlations in Pb-Pb and pp collisions are studied as a function of the centrality of the collision. The jet quenching is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

PHYSICAL REVIEW LETTERS 106, 032314 (2011)

Observation of sequential hadron suppression in Pb-Pb collisions

A. Chatterjee et al.
CMS Collaboration
Received 17 February 2011; published 14 August 2011

The observation of sequential hadron suppression in Pb-Pb collisions is studied as a function of the centrality of the collision. The sequential hadron suppression is measured as a function of the centrality of the collision and compared to the predictions of the standard model.

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19 published/submitted papers, 0 Physics Analysis Summaries (CMS PAS):
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN>

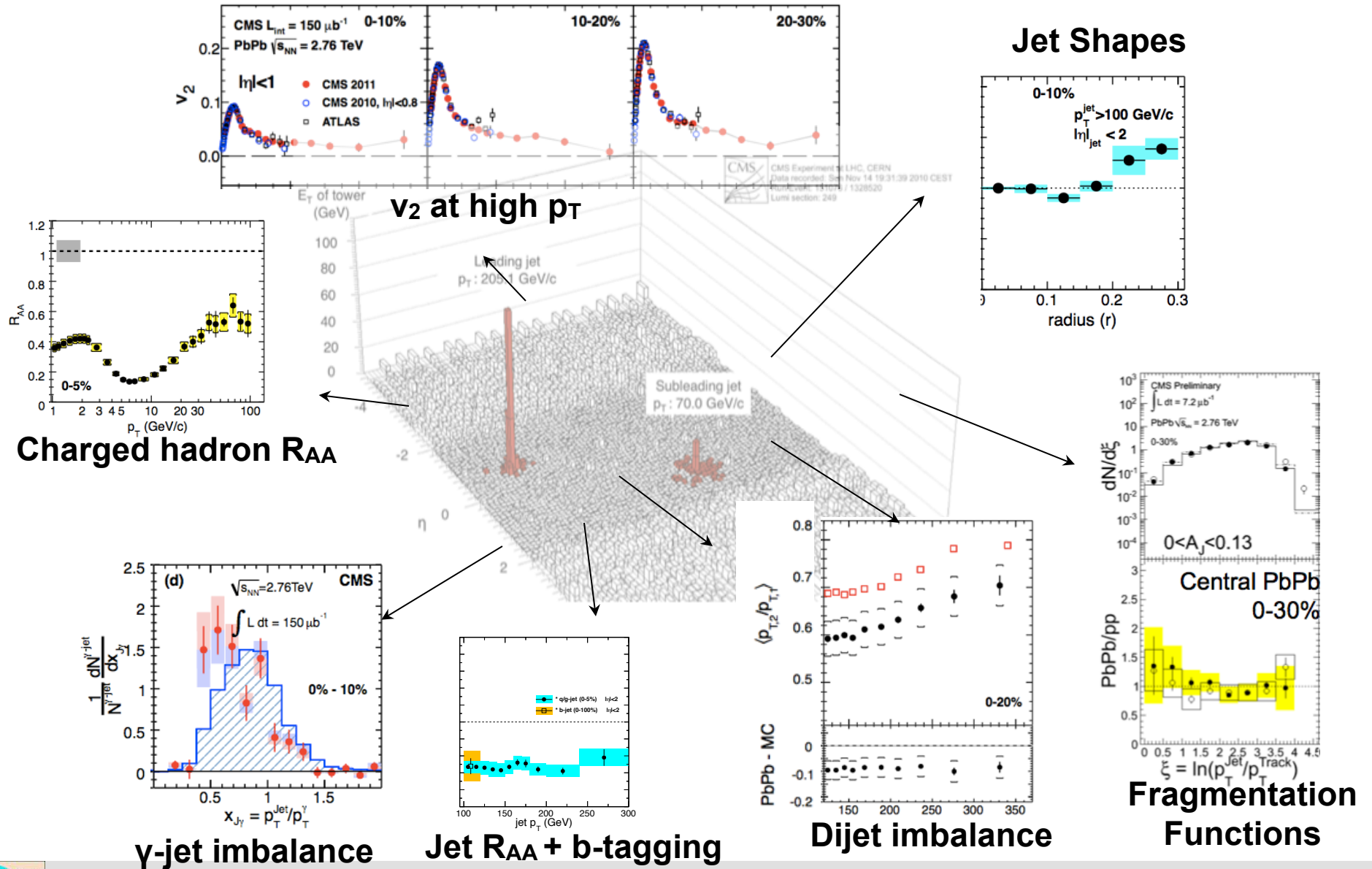


Gunther Roland

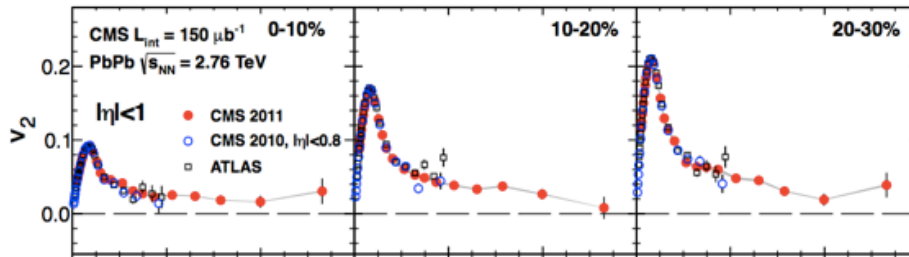
High p_T workshop, Wuhan, Oct 2012



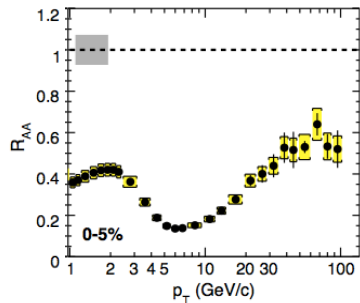
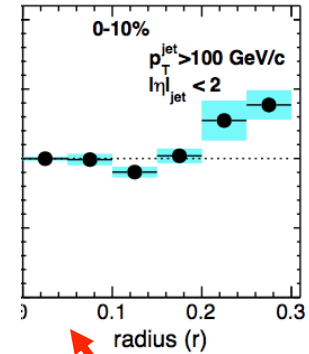
CMS Perspectives on Jet Quenching



CMS Perspectives on Jet Quenching



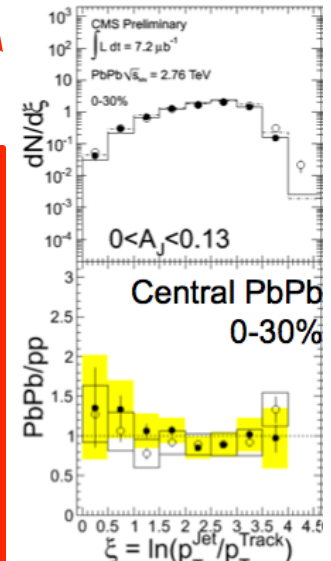
Jet Shapes



Eric Appelt

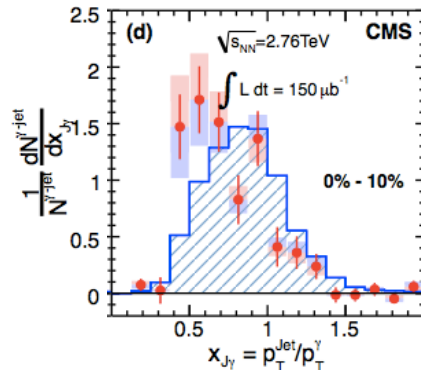
Charged hadron R_{AA}

Yaxian Mao

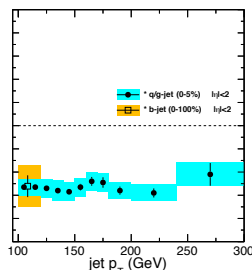


Fragmentation Functions

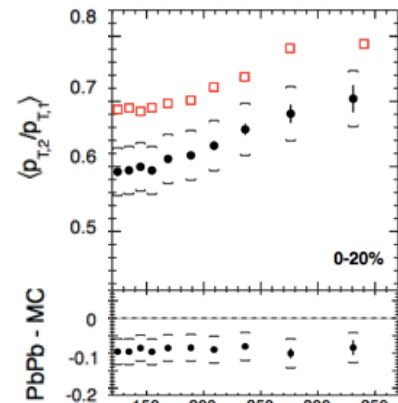
This talk



γ -jet imbalance



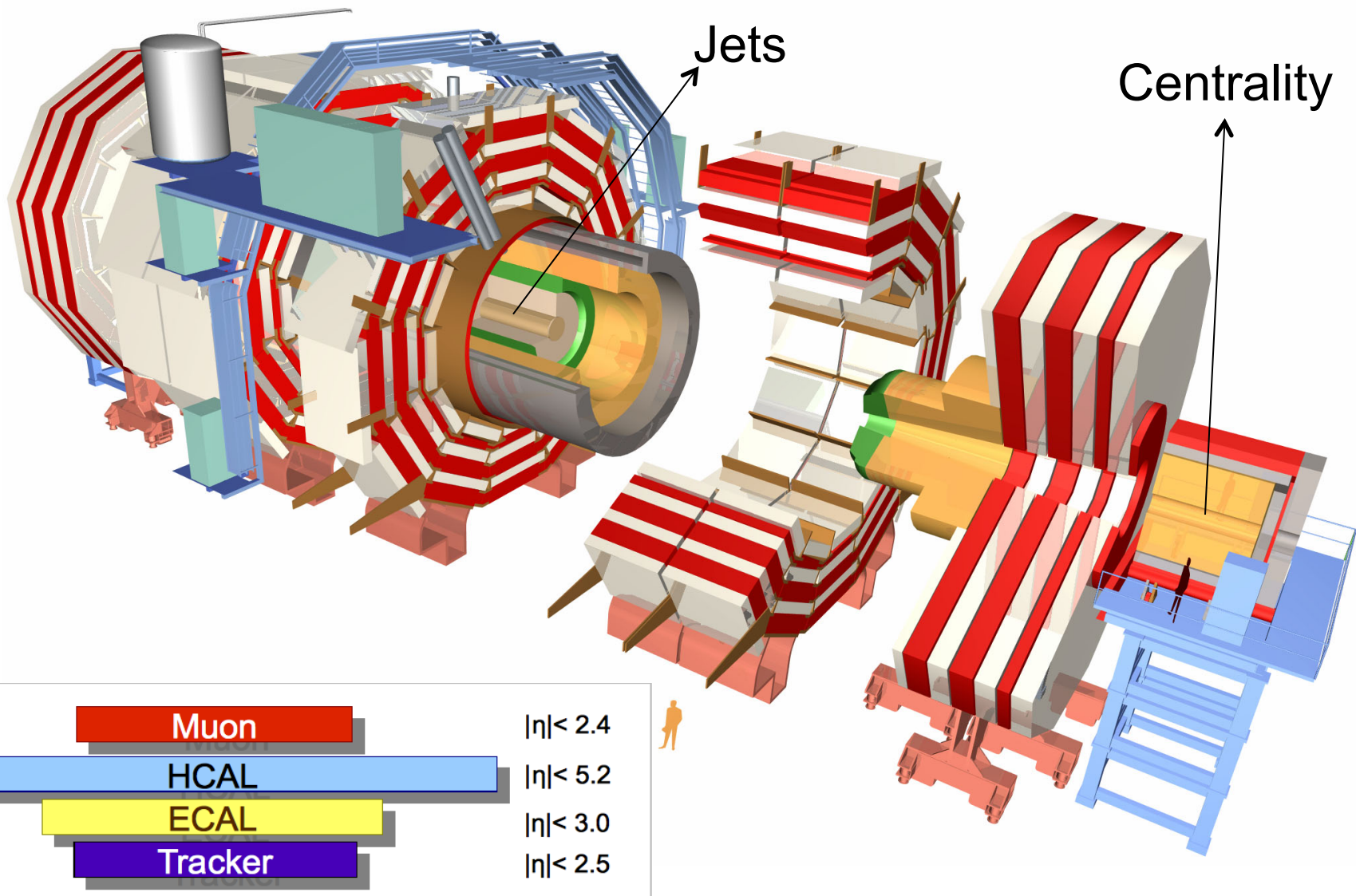
Jet R_{AA} + b-tagging



Dijet imbalance

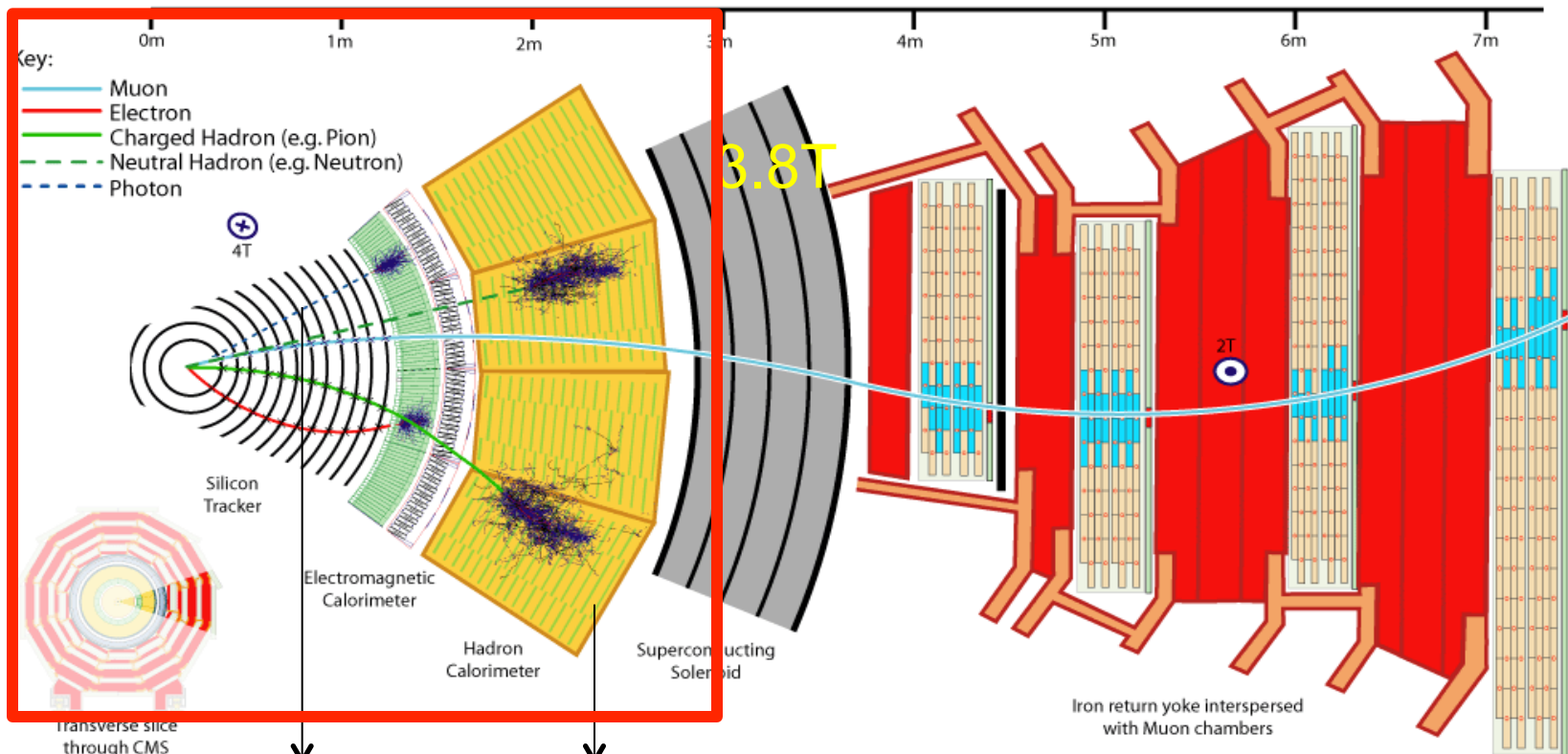


CMS Detector



CMS Detector

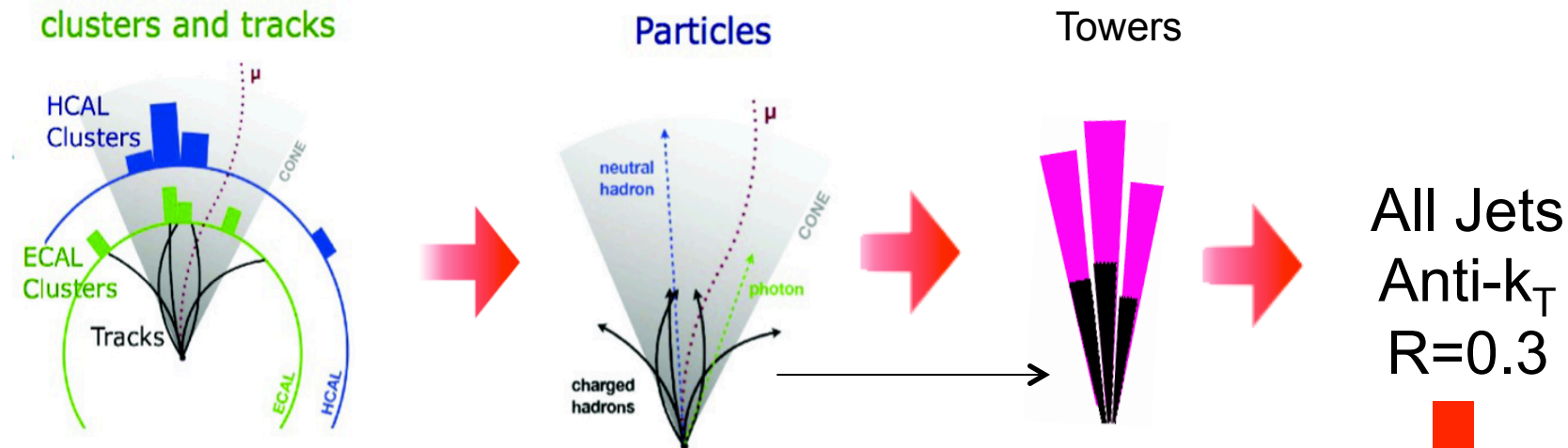
Combine tracking and calorimeter information: “Particle Flow”



Better
resolution of p_T

Neutral energy and
safety factor for
tracking efficiency

Jet measurements



(Tracking for only the primary vertex)

Calorimeter clusters and tracks are matched and combined to obtain most detailed information of particles in the event

(Details: CMS-PAS-HIN-11-004)

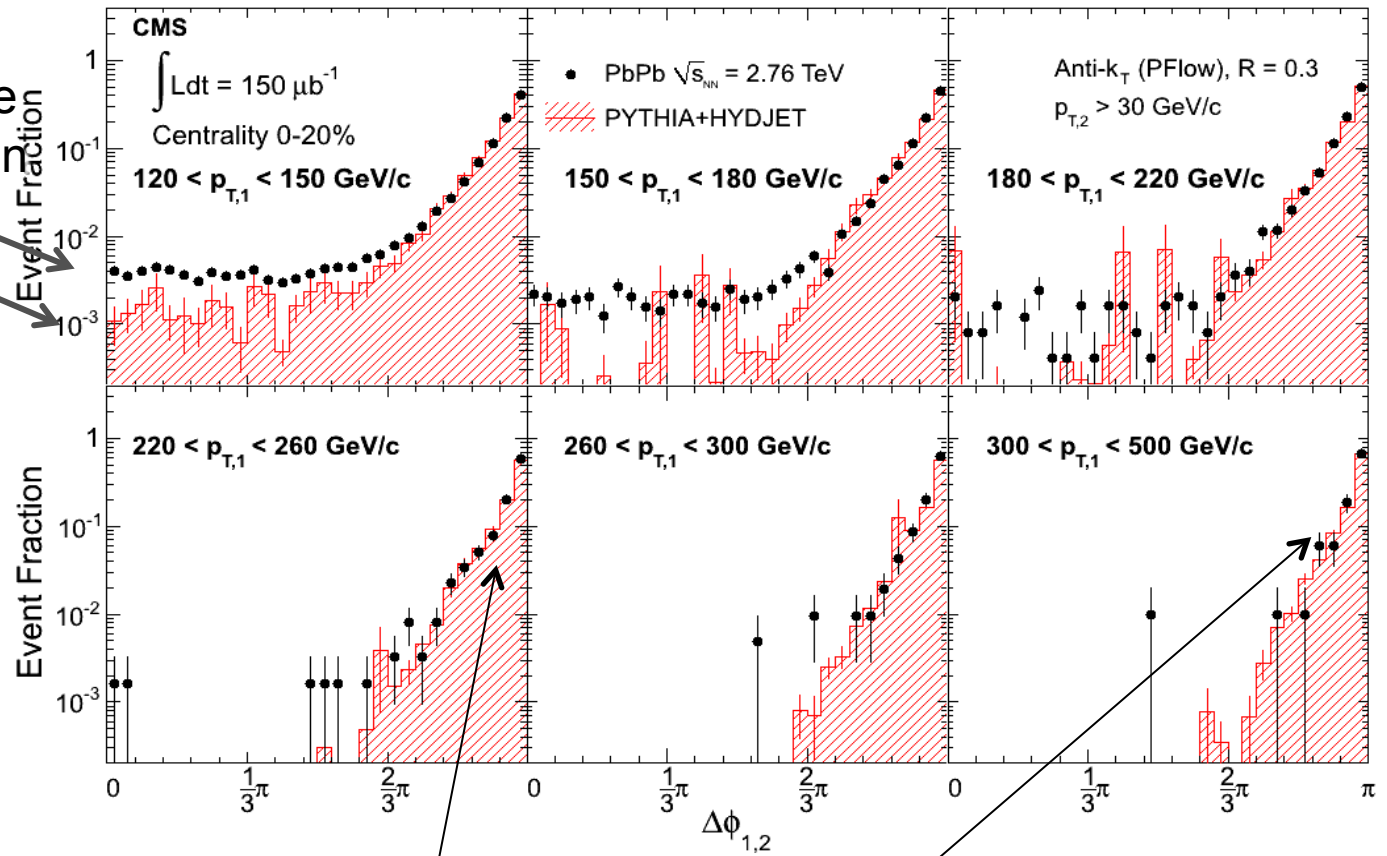
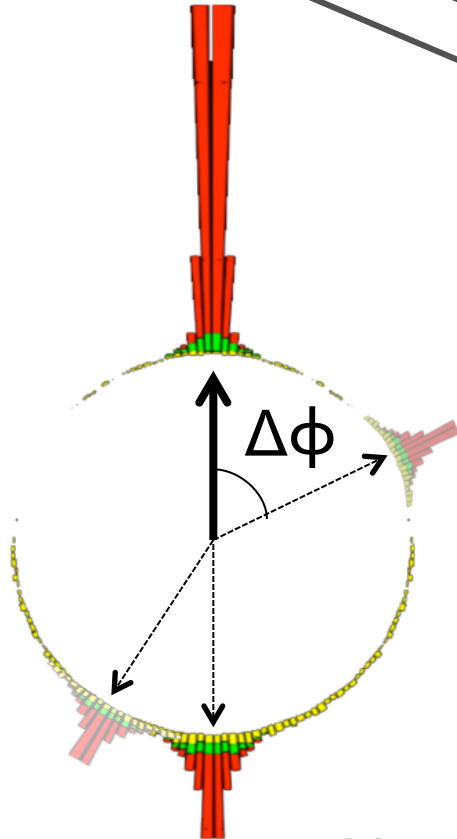
Estimated background is subtracted from merged energy in each calorimeter segmentation

$\Delta\eta \times \Delta\phi$
 0.076×0.076
in barrel

Analysis selection

Dijet angular correlations

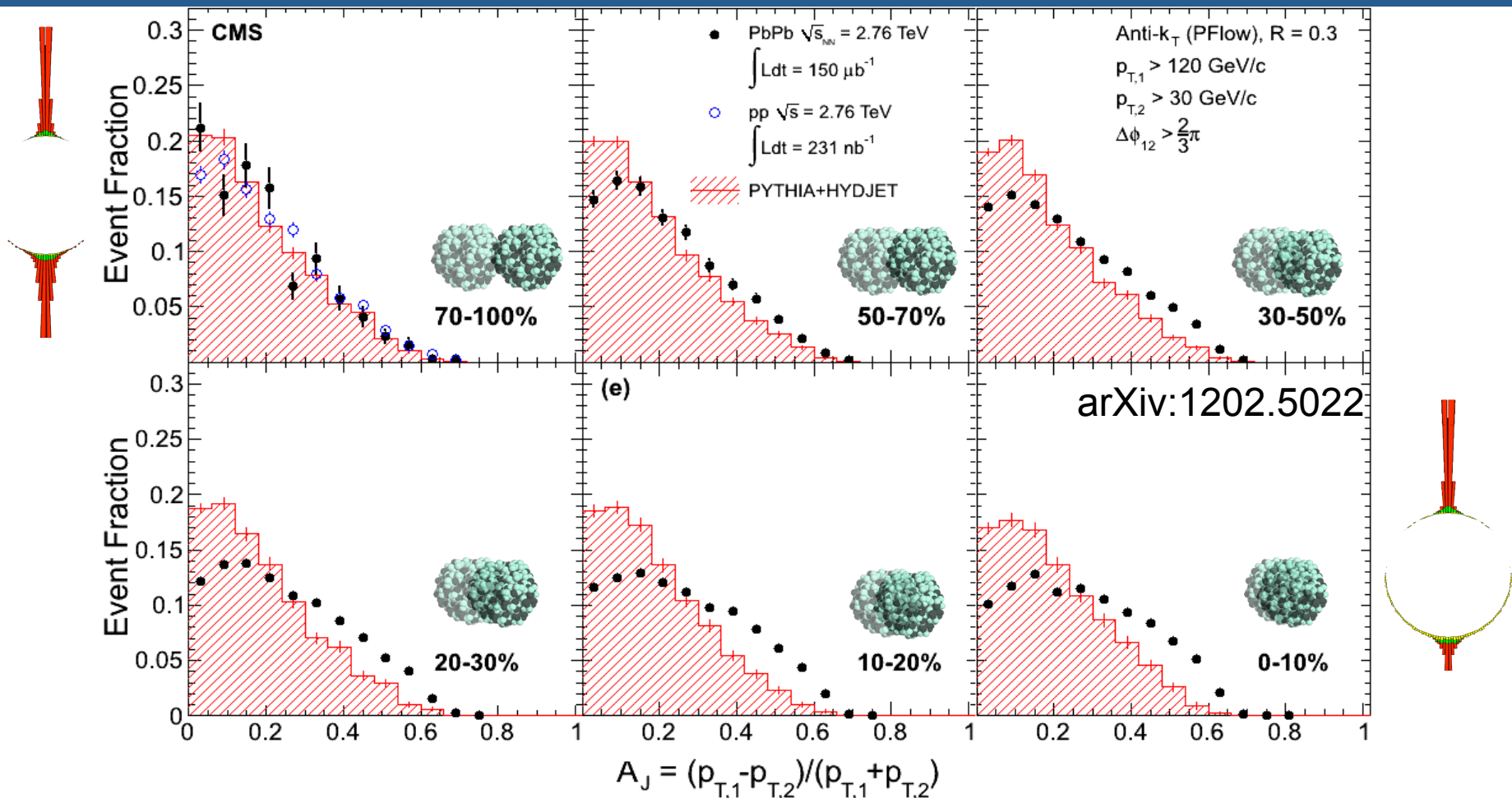
Background fluctuations supersede the recoil jet more often in data



Correlation peak is the same in data and Pythia across all values of p_T

No significant angular decorrelation of dijets.

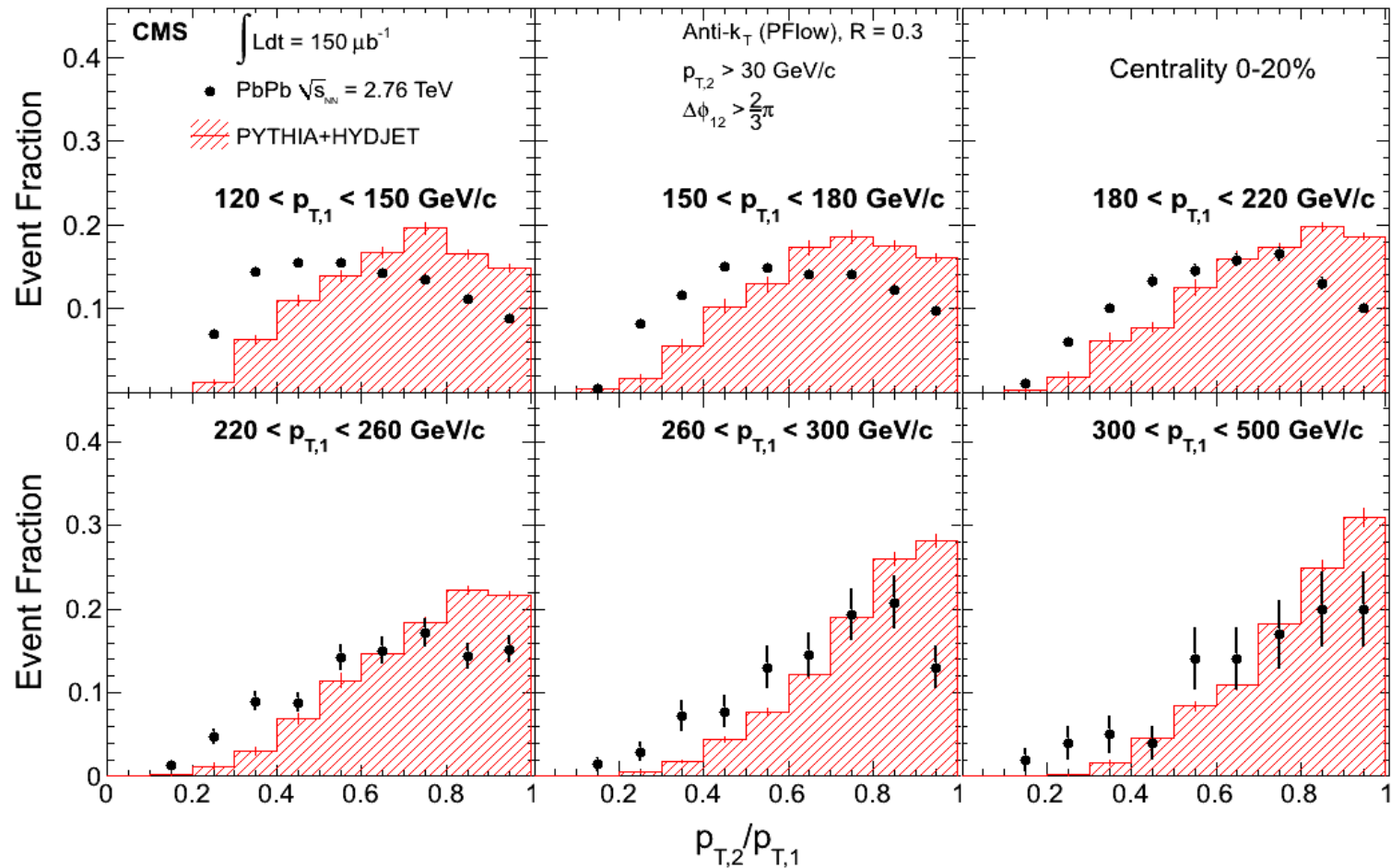
Dijet imbalance in centrality bins



150 μb^{-1} ~ 20 times more data than in 2010!!!

Able to perform same measurements differentially in p_T
 pp data at the same \sqrt{s} available, more statistics welcome!

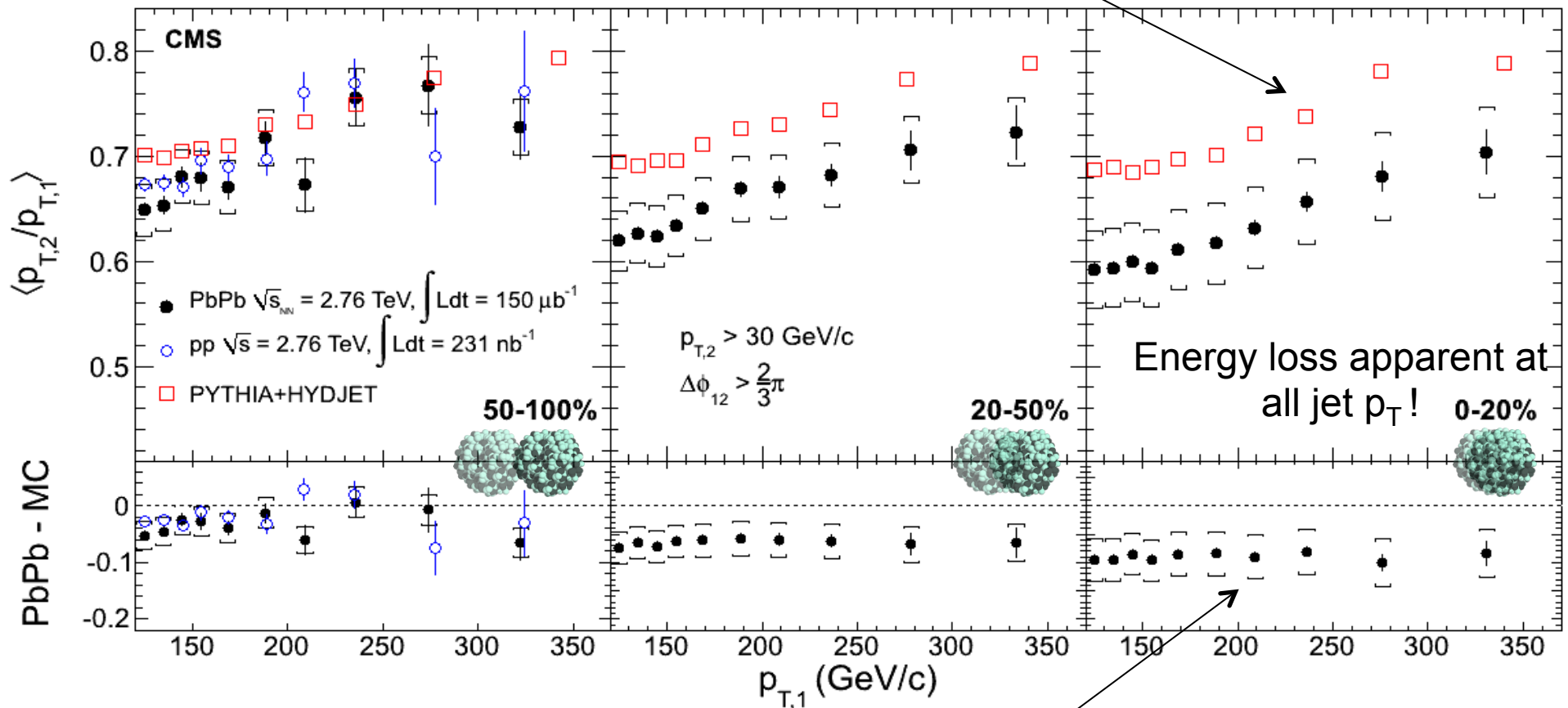
p_T -dependence of the dijet imbalance



Dijets in PbPb are more imbalanced than Pythia at
all bins of leading jet p_T

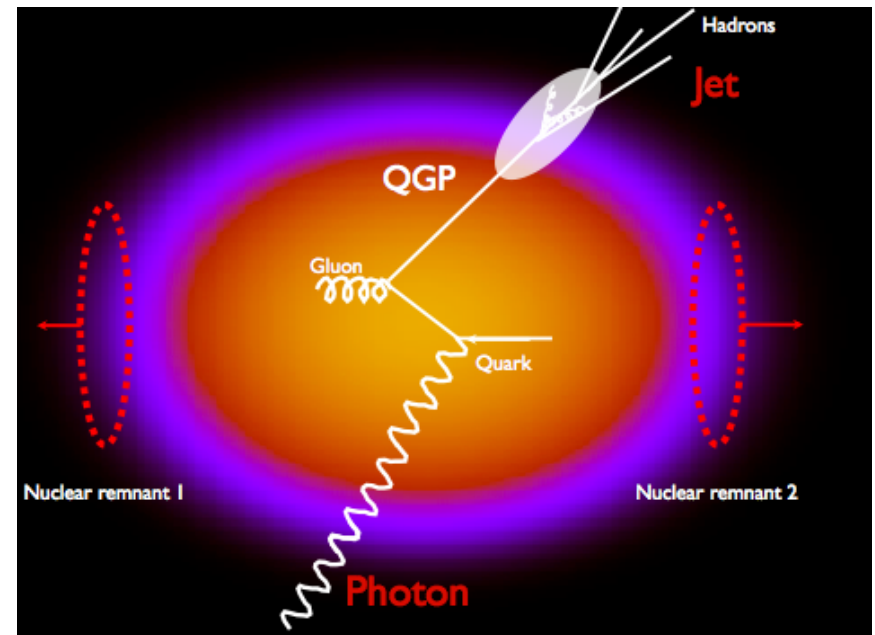
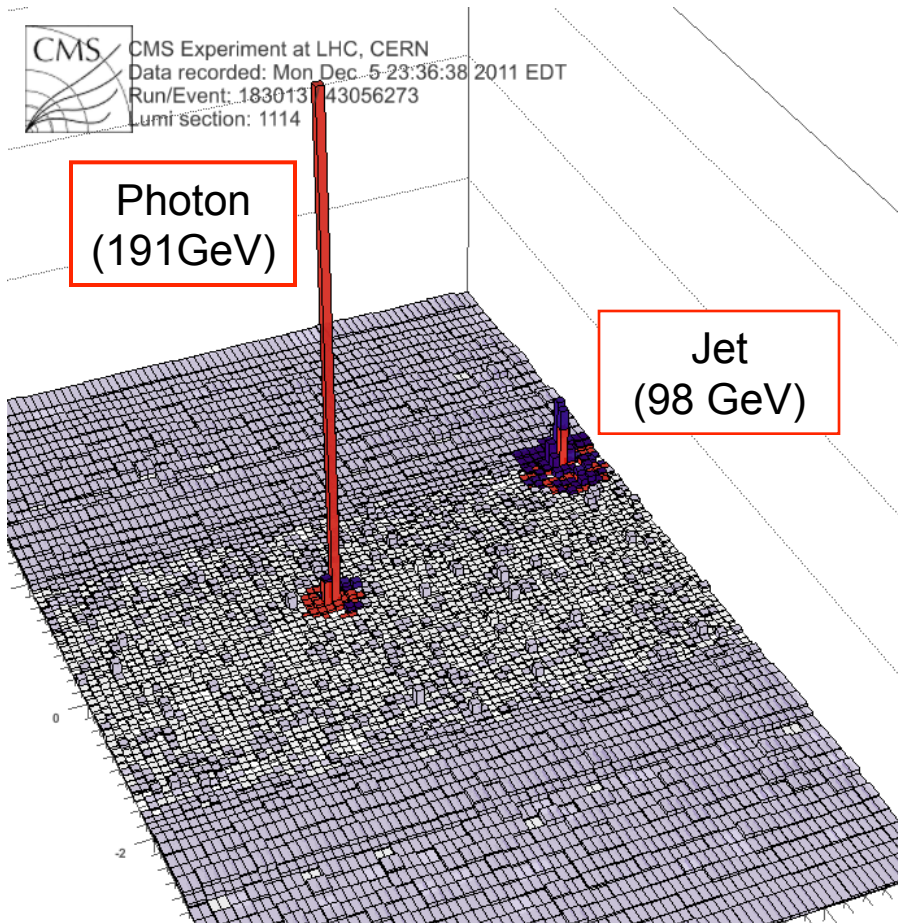
p_T -dependence of the dijet imbalance

Reference itself has an increasing trend



No significant dependence on jet p_T

γ +jet: u,d quark energy loss

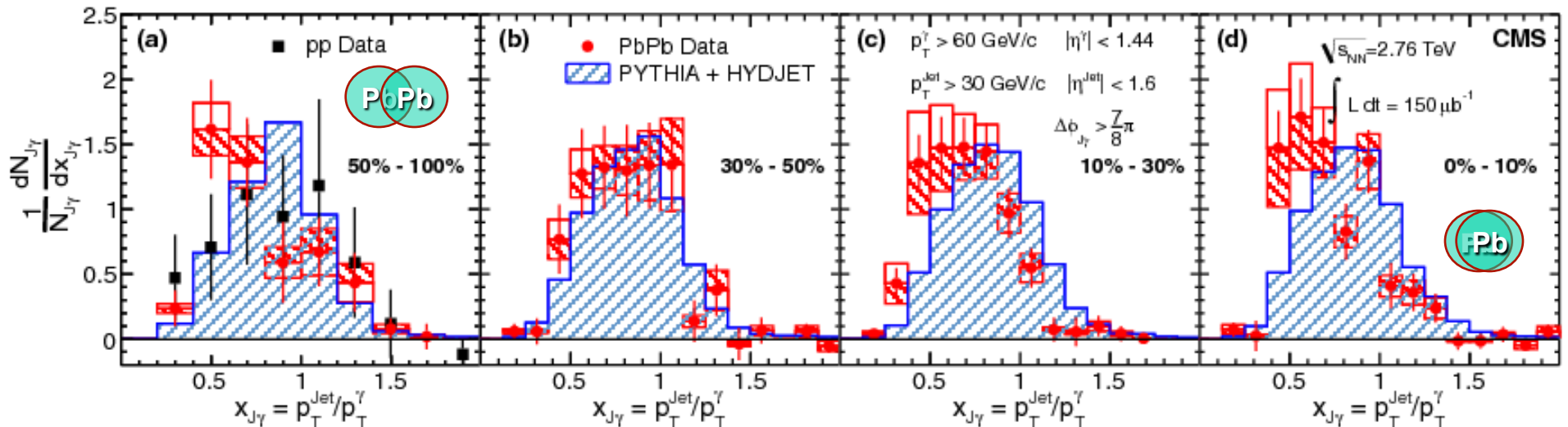


Photon tag:

- Identifies jet as u,d quark jet
- Provides initial quark direction
- Provides initial quark p_T

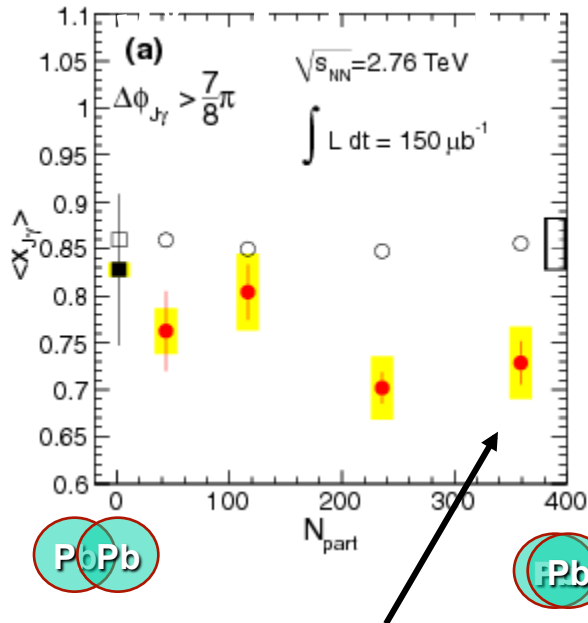
γ -jet correlations

- Ratio of the p_T of jets to photons ($x_{J\gamma} = p_T^{\text{jet}}/p_T^\gamma$) is a direct measure of the jet energy loss
- Gradual centrality-dependence of the $x_{J\gamma}$ distribution



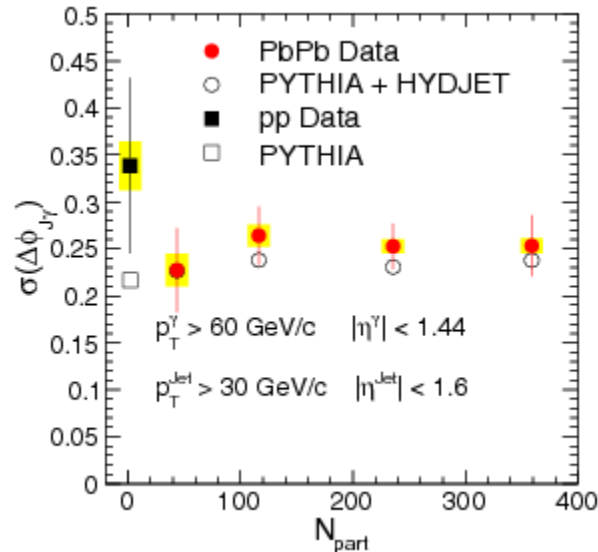
arXiv:1206.0206

γ -jet correlations

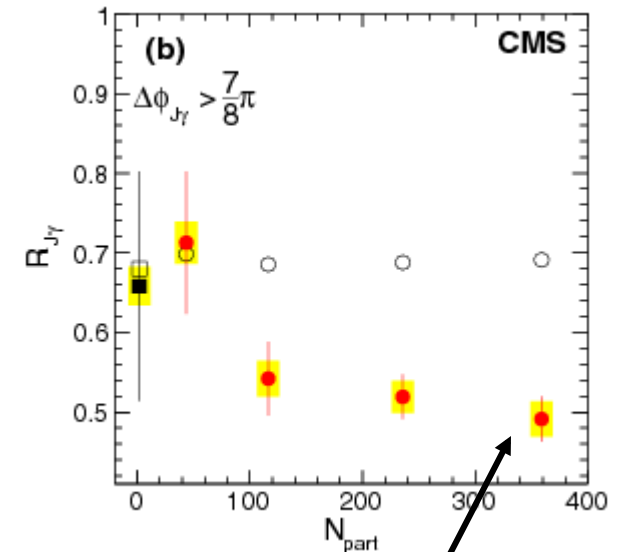


Increasing p_T -imbalance

Jets lose ~14% of their initial energy



No ϕ -decorrelation



Less jet partners above threshold

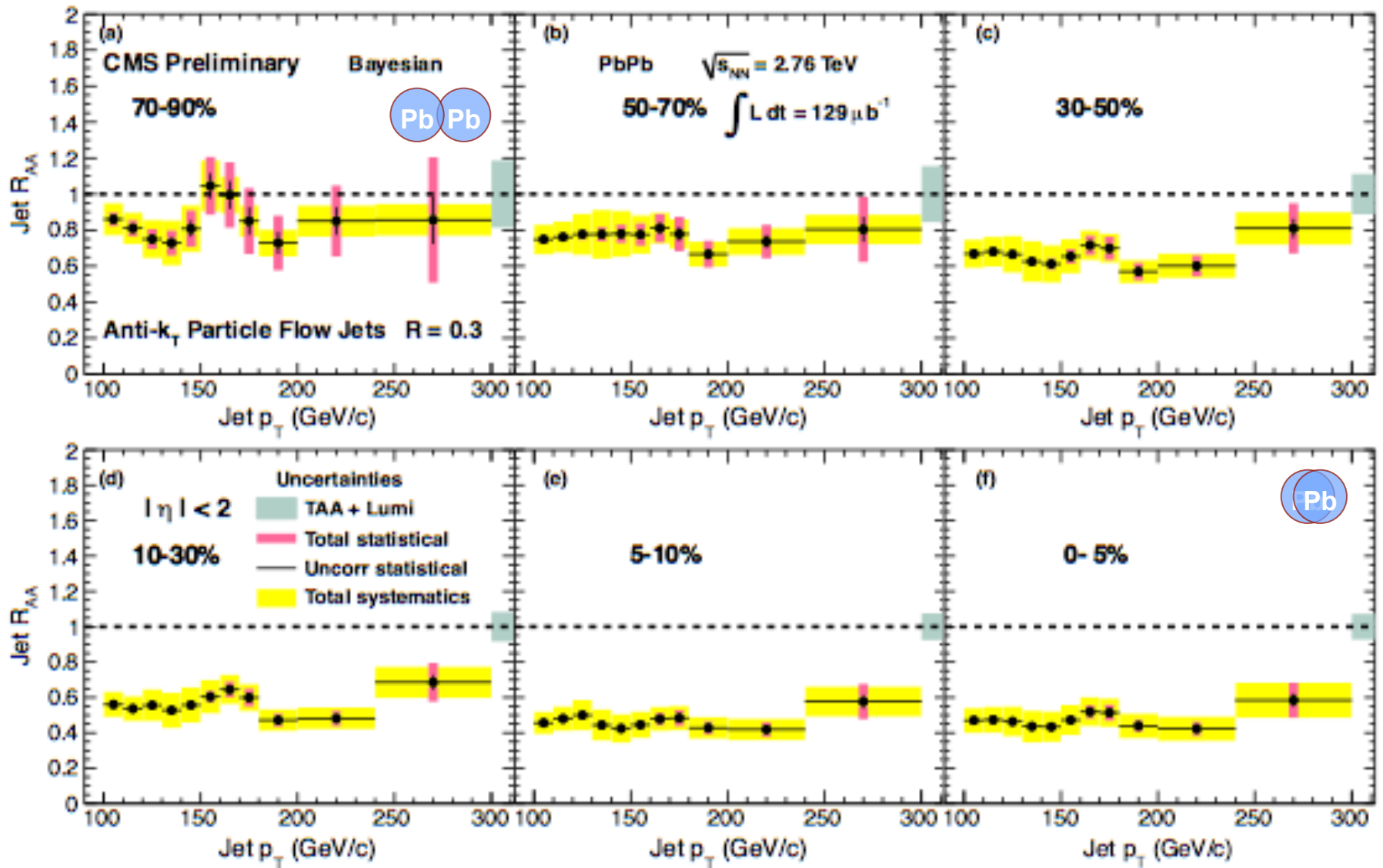
~20% of photons lose their jet partner

arXiv:1206.0206

Jet R_{AA}

- Measured jet spectra
 - Jet triggered events $E > 80$ GeV
 - Inclusive jets $p_T > 100$ GeV/c, $|\eta| < 2$
 - Anti- k_T particle flow jets, iterative background subtraction (PbPb)
- Unfold detector effects in PbPb + pp:
 - jet p_T resolution and jet p_T scale
 - Bayesian unfolding based on PbPb MC
 - Cross-checks:
 - Generalized Singular Value Decomposition (GSVD) unfolding
 - Bin-by-bin unfolding
 - Smear pp data based on jet resolution & scale from PbPb MC (different jet p_T , centrality bins)
- Ratio of jet spectra: unfolded PbPb to unfolded pp

R_{AA} from unfolded jet spectra



b-jet Identification

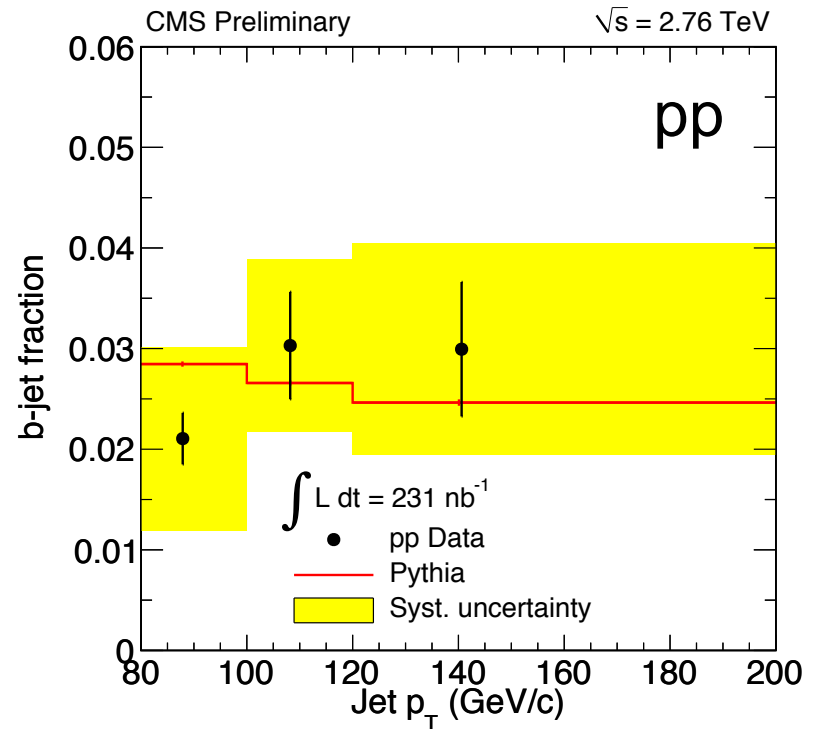
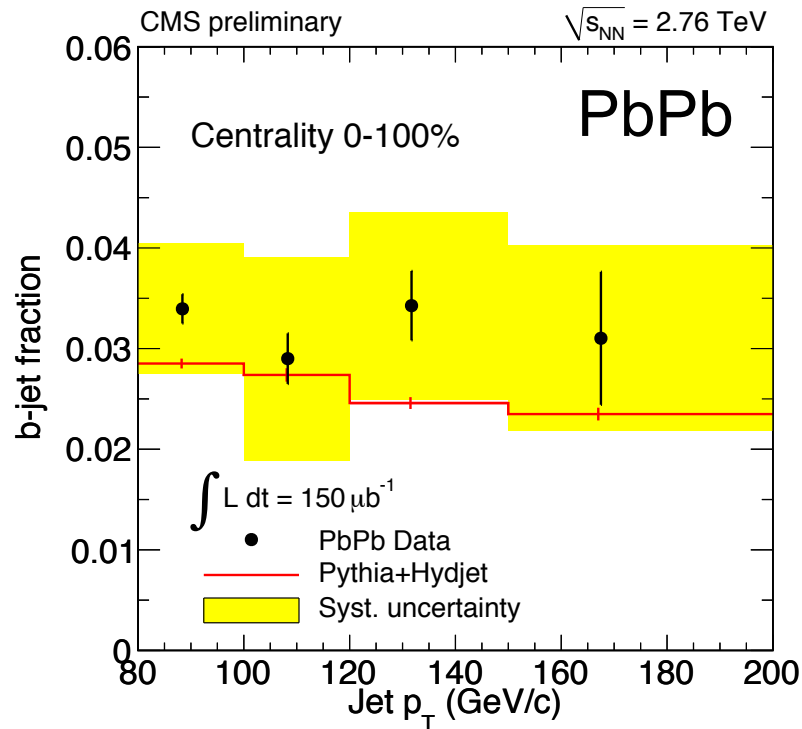
- Long lifetime of b (~ 1.5 ps) leads to measurable (mm or cm) displaced secondary vertices (SV)



- Subsequent charm decay may lead to a tertiary vertex
- B-jets are tagged using reconstructed SV's, using the flight distance of the SV as a discriminating variable
- We then extract the b-jet fraction by a fit to the SV mass
- An alternative tagger based only the impact parameter of the tracks in the jet is used to corroborate the SV performance

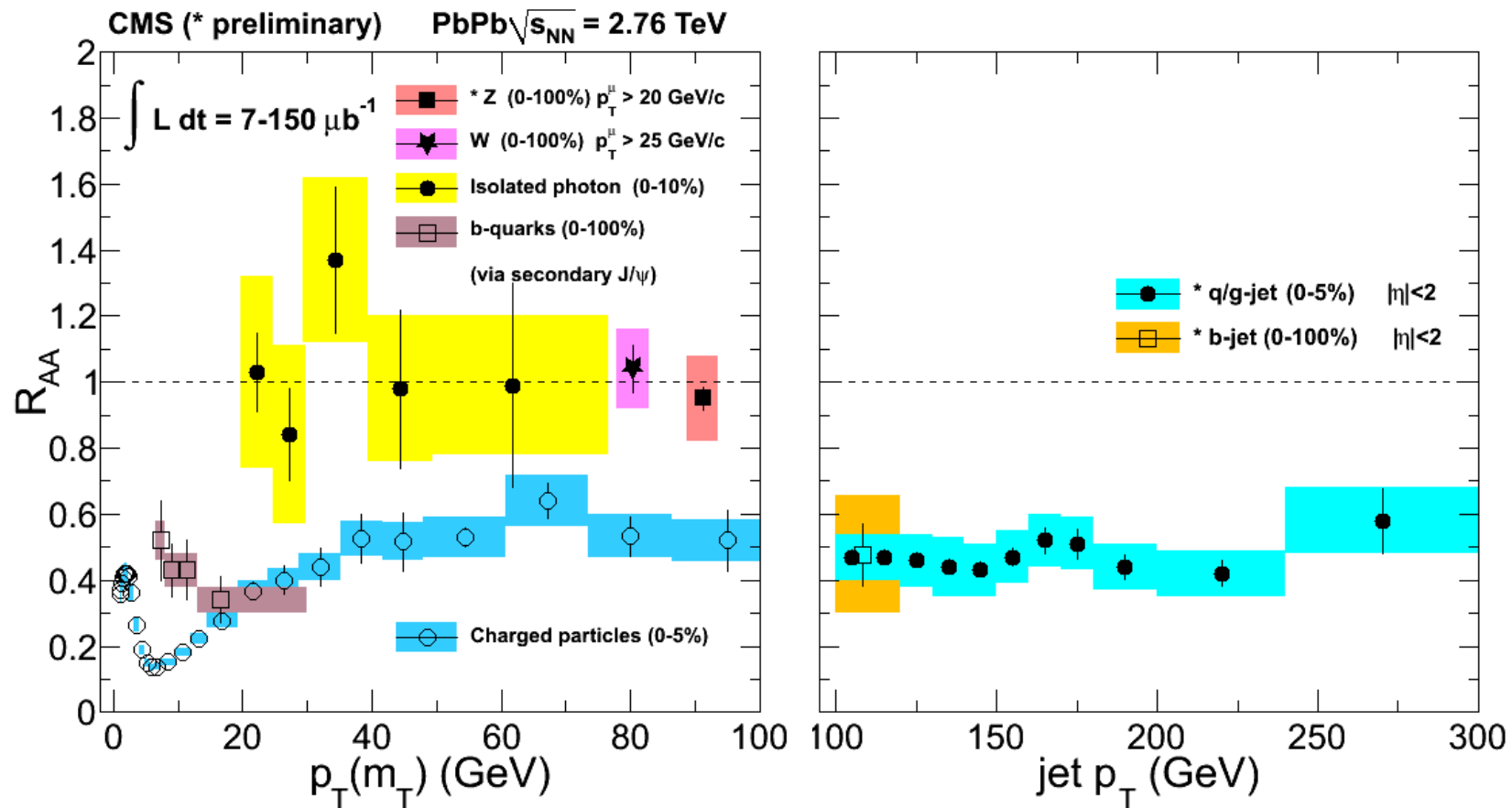
b-jet to Inclusive Jet Ratio

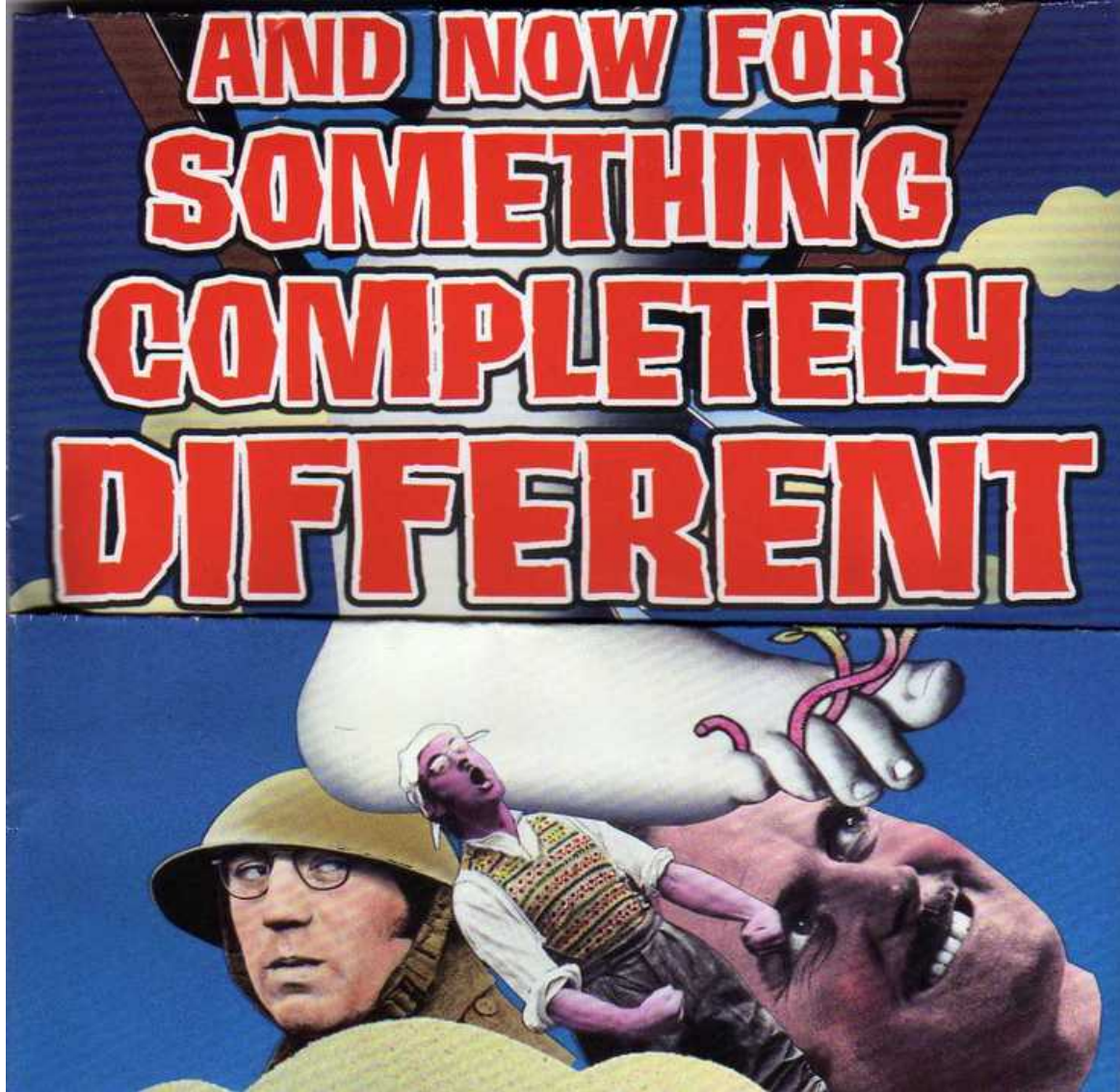
b-jet fraction = # of tagged jets * purity / efficiency



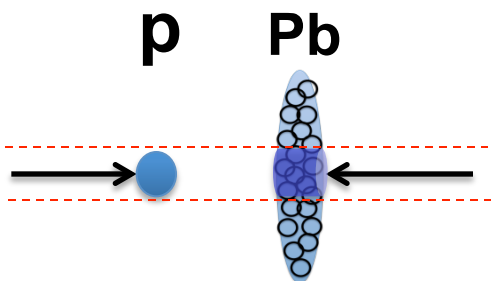
- b-jet fraction in PbPb larger than MC, but consistent within uncertainties
- pp data are also consistent with MC prediction

Summary of jet R_{AA}



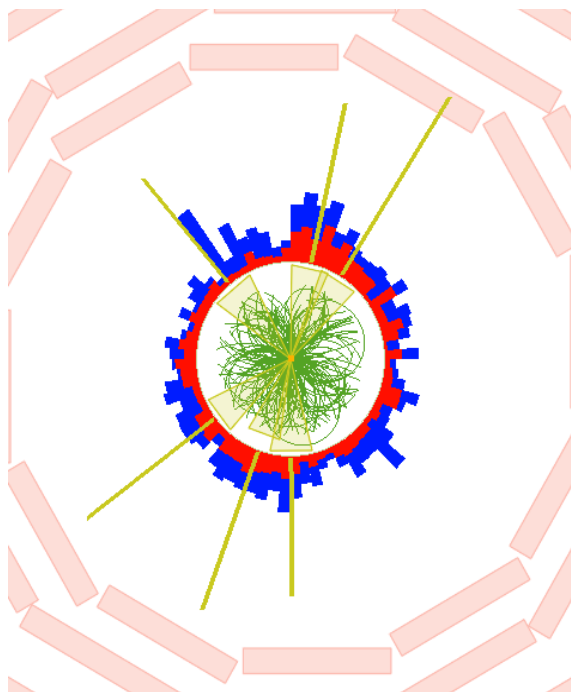


First Look at pPb data in CMS

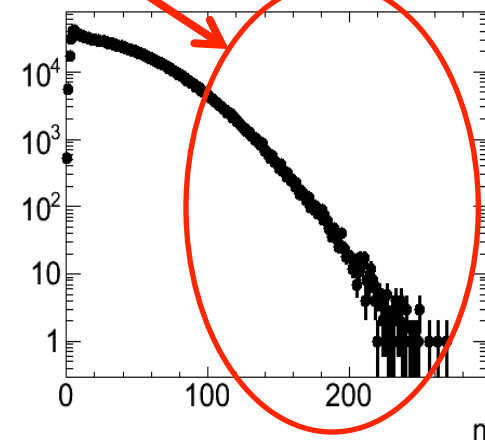
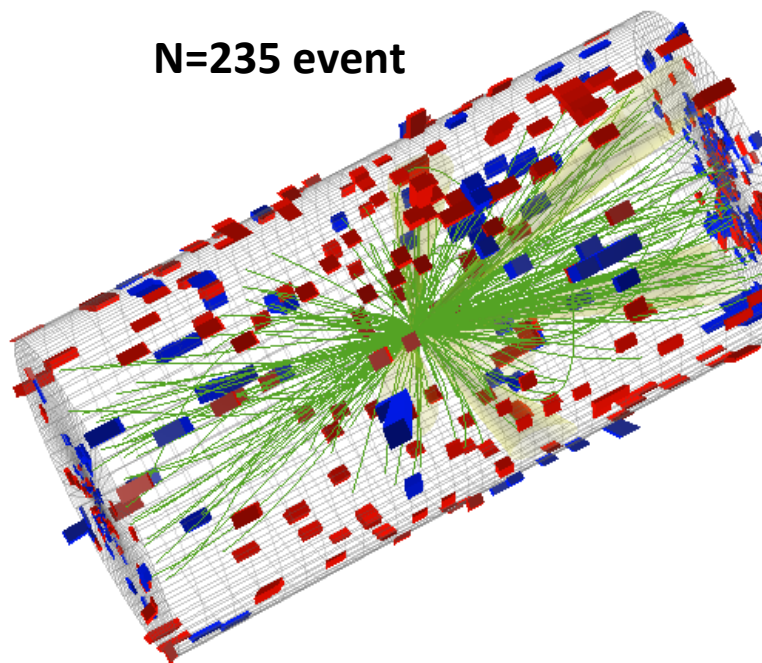


CMS collected 2M min bias pPb events in Sep 2012 pilot run

Anything interesting in high multiplicity pPb?



N=235 event



Correlations in 7TeV pp collisions

Results based on 1fb^{-1} ,
i.e. sampling 50 billion pp events
with high multiplicity trigger

Intermediate p_T : 1-3 GeV/c

(b) MinBias, $1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$

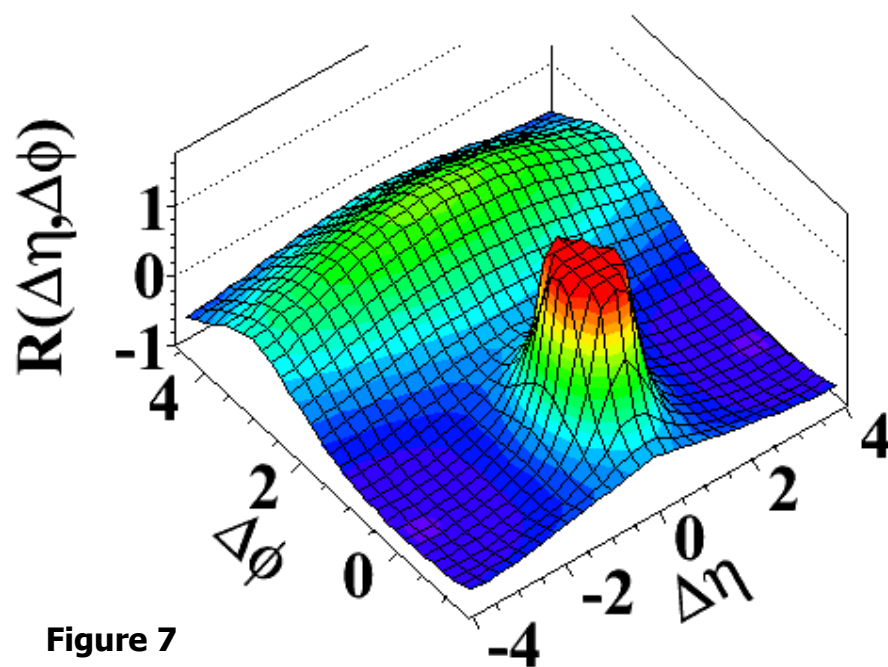
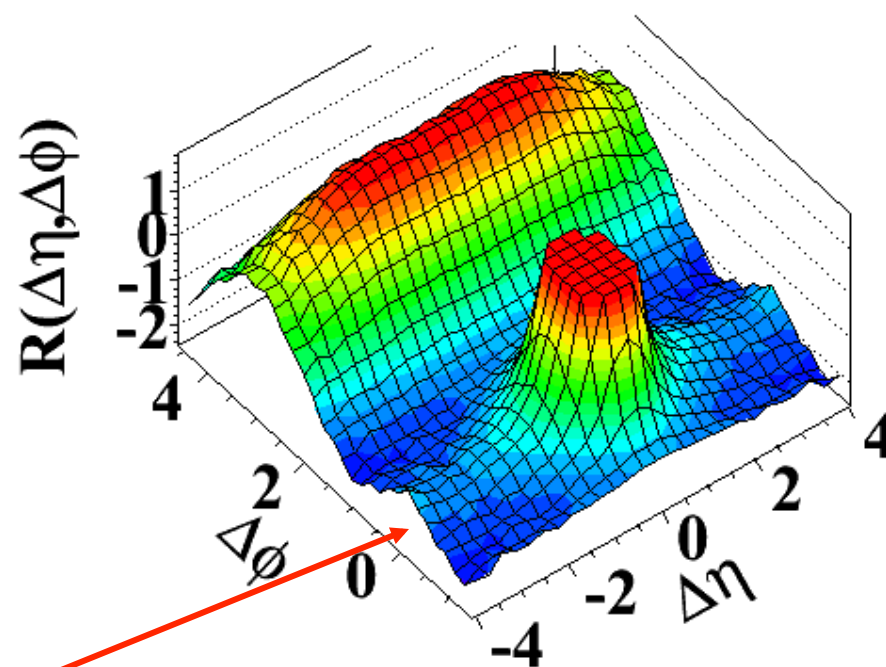


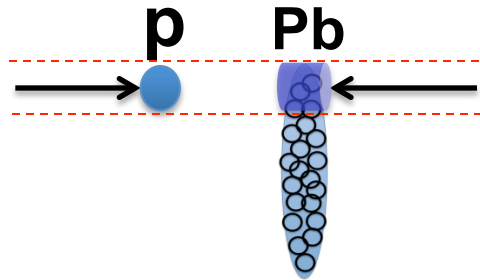
Figure 7

(d) $N > 110$, $1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$



Pronounced structure at large $\delta\eta$ around $\delta\phi \sim 0$!

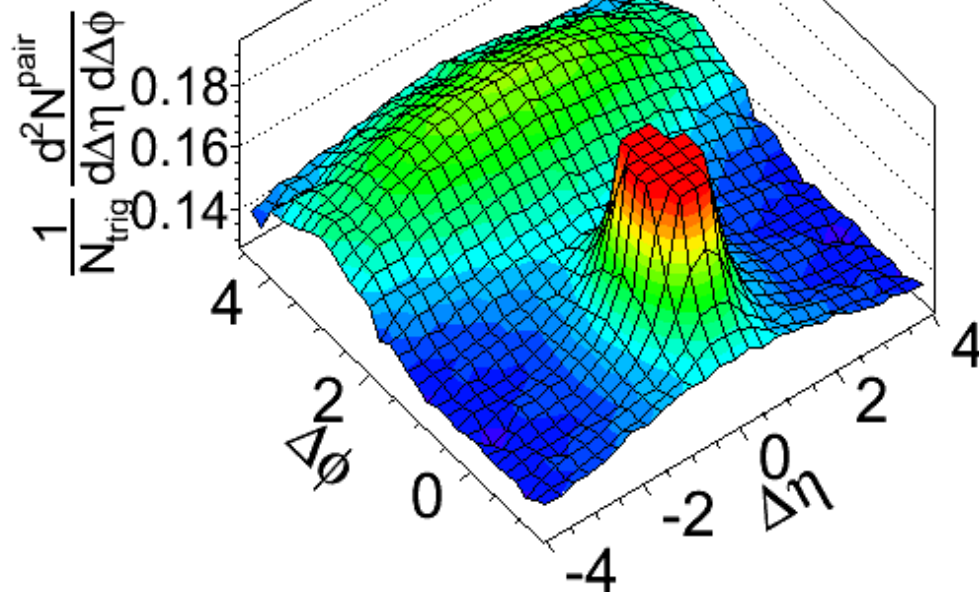
Multiplicity Evolution in pPb



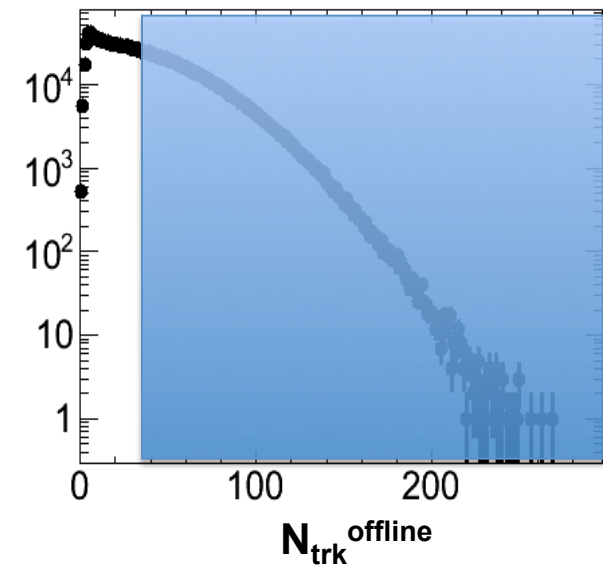
Low multiplicity

CMS pPb $\sqrt{s} = 5.02$ TeV $N < 35$

$1 < p_T^{\text{trig}} < 2$ GeV/c
 $1 < p_T^{\text{assoc}} < 2$ GeV/c

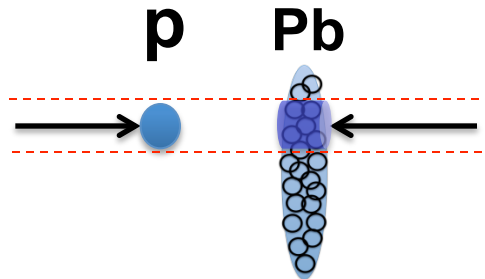


Divide into 4 multiplicity bins:



Multiplicity Evolution in pPb

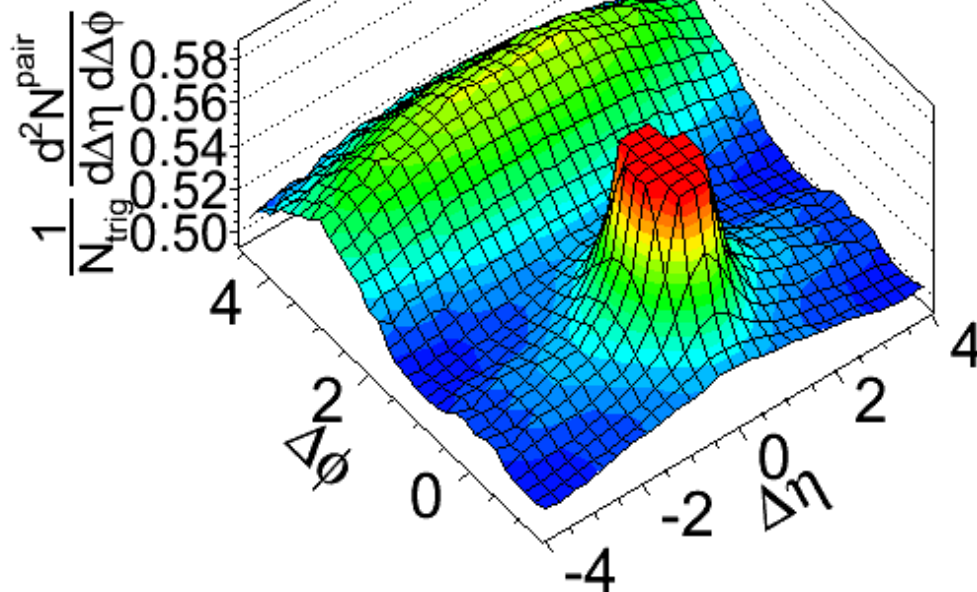
Increasing multiplicity



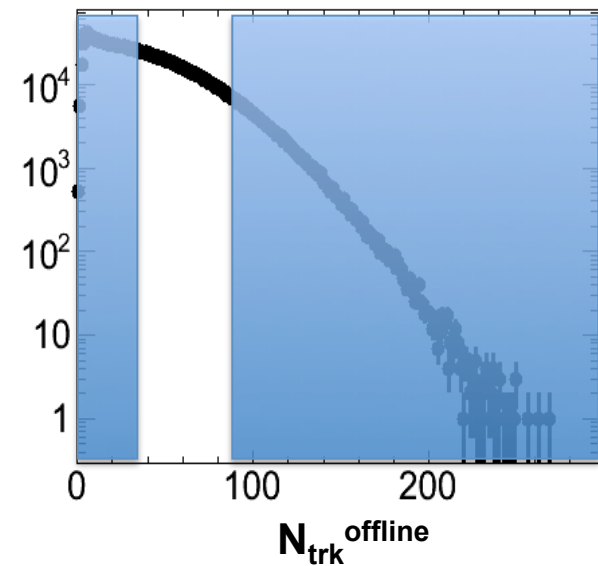
CMS pPb $\sqrt{s} = 5.02$ TeV $35 \leq N < 90$

$1 < p_T^{\text{trig}} < 2$ GeV/c

$1 < p_T^{\text{assoc}} < 2$ GeV/c

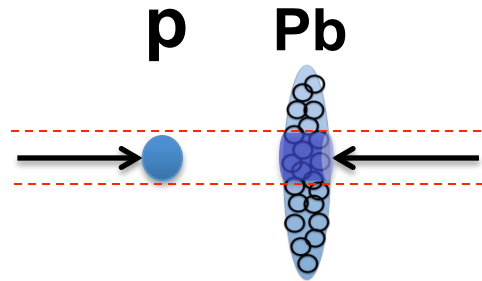


Divide into 4 multiplicity bins:



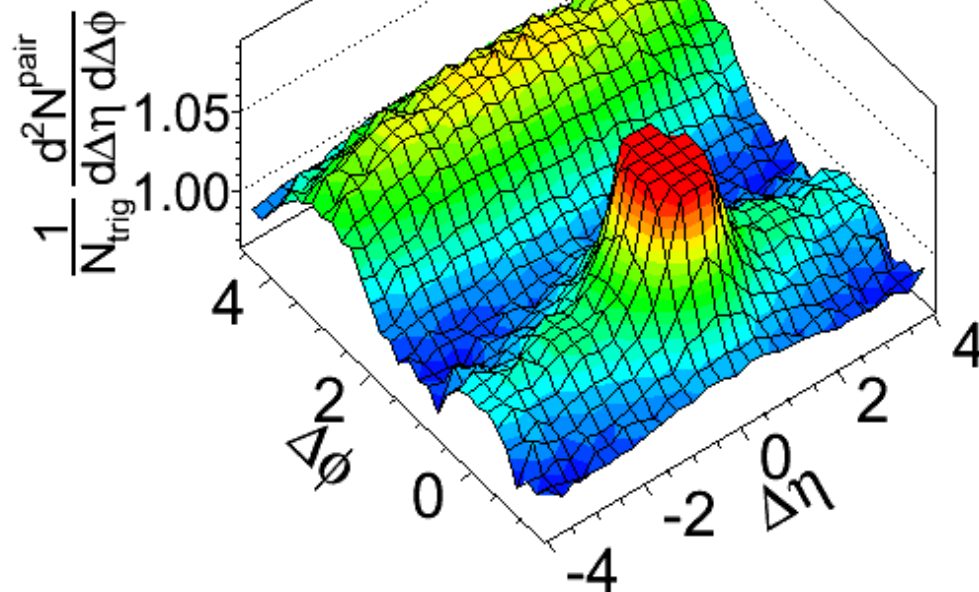
Multiplicity Evolution in pPb

Increasing multiplicity

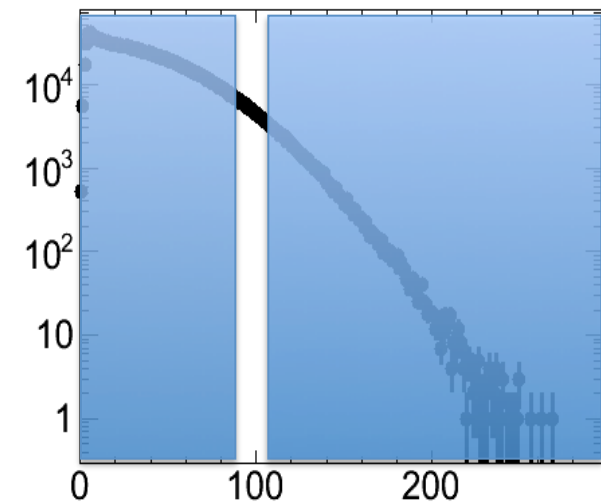


CMS pPb $\sqrt{s} = 5.02$ TeV $90 \leq N < 110$

$1 < p_T^{\text{trig}} < 2$ GeV/c
 $1 < p_T^{\text{assoc}} < 2$ GeV/c

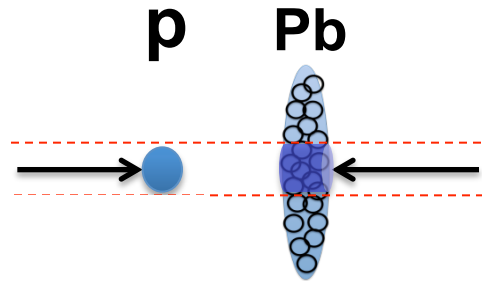


Divide into 4 multiplicity bins:



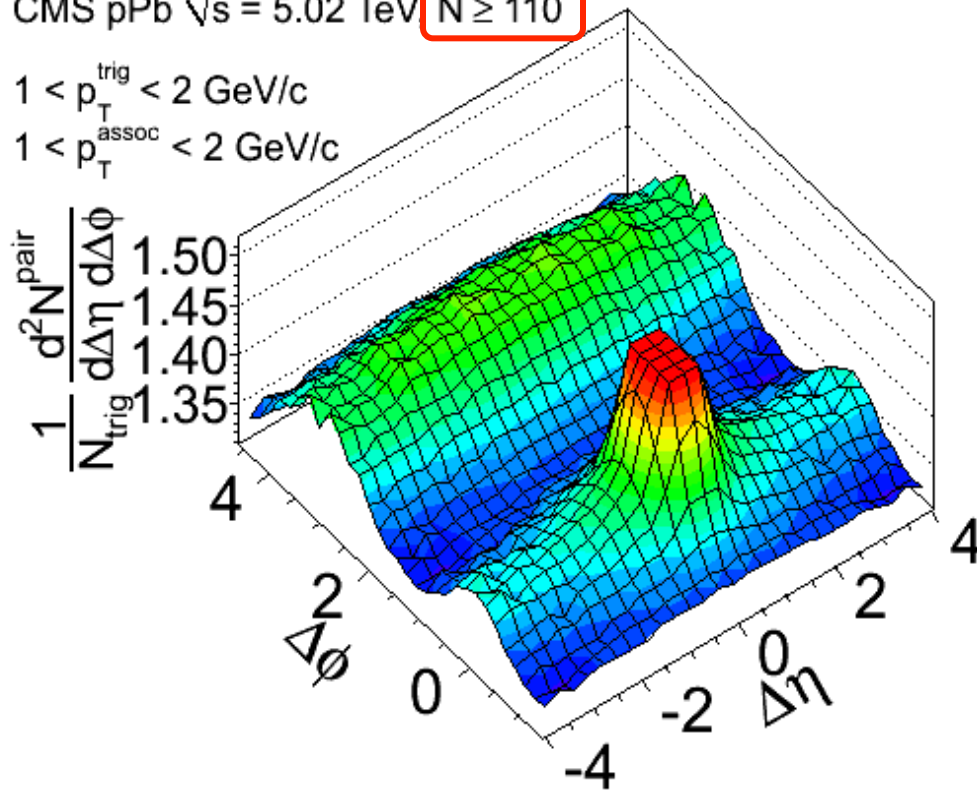
Multiplicity Evolution in pPb

Increasing multiplicity

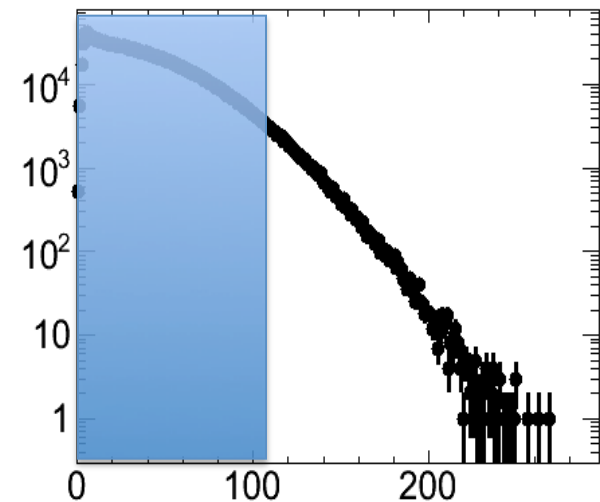


CMS pPb $\sqrt{s} = 5.02$ TeV $N \geq 110$

$1 < p_T^{\text{trig}} < 2$ GeV/c
 $1 < p_T^{\text{assoc}} < 2$ GeV/c



Divide into 4 multiplicity bins:

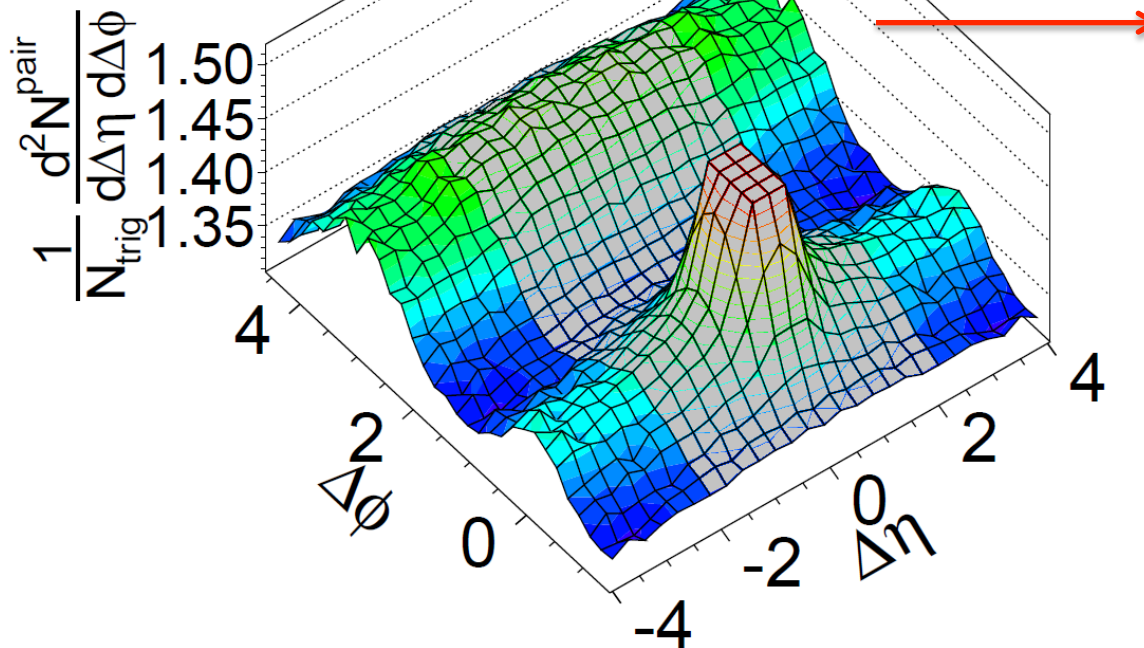


Quantitative evolution of ridge effect

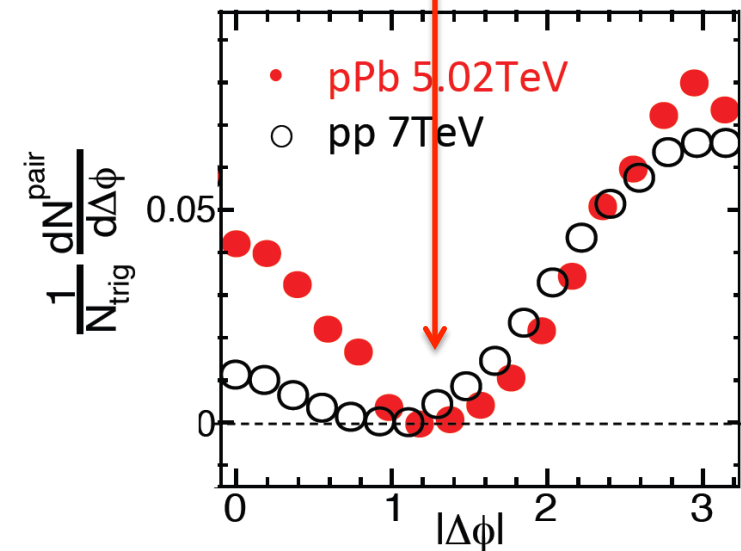
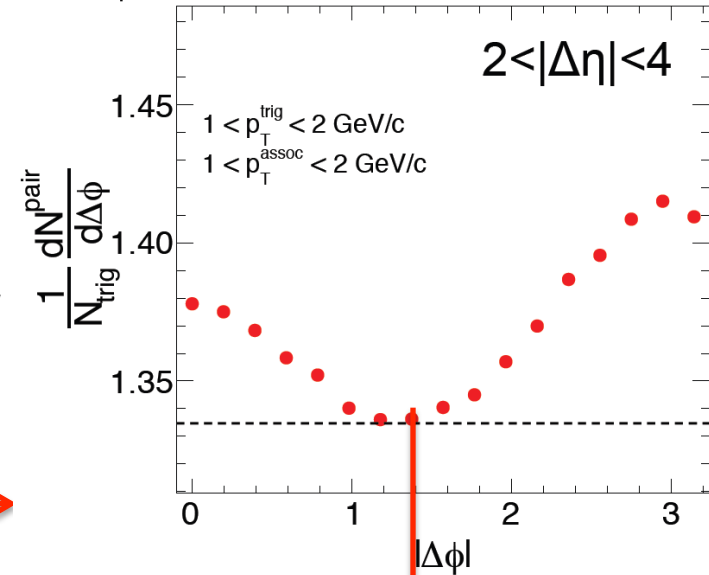
Study quantitative evolution with the same approach as in pp ridge paper for apples-“apples” comparison

CMS pPb $\sqrt{s} = 5.02$ TeV, $N \geq 110$

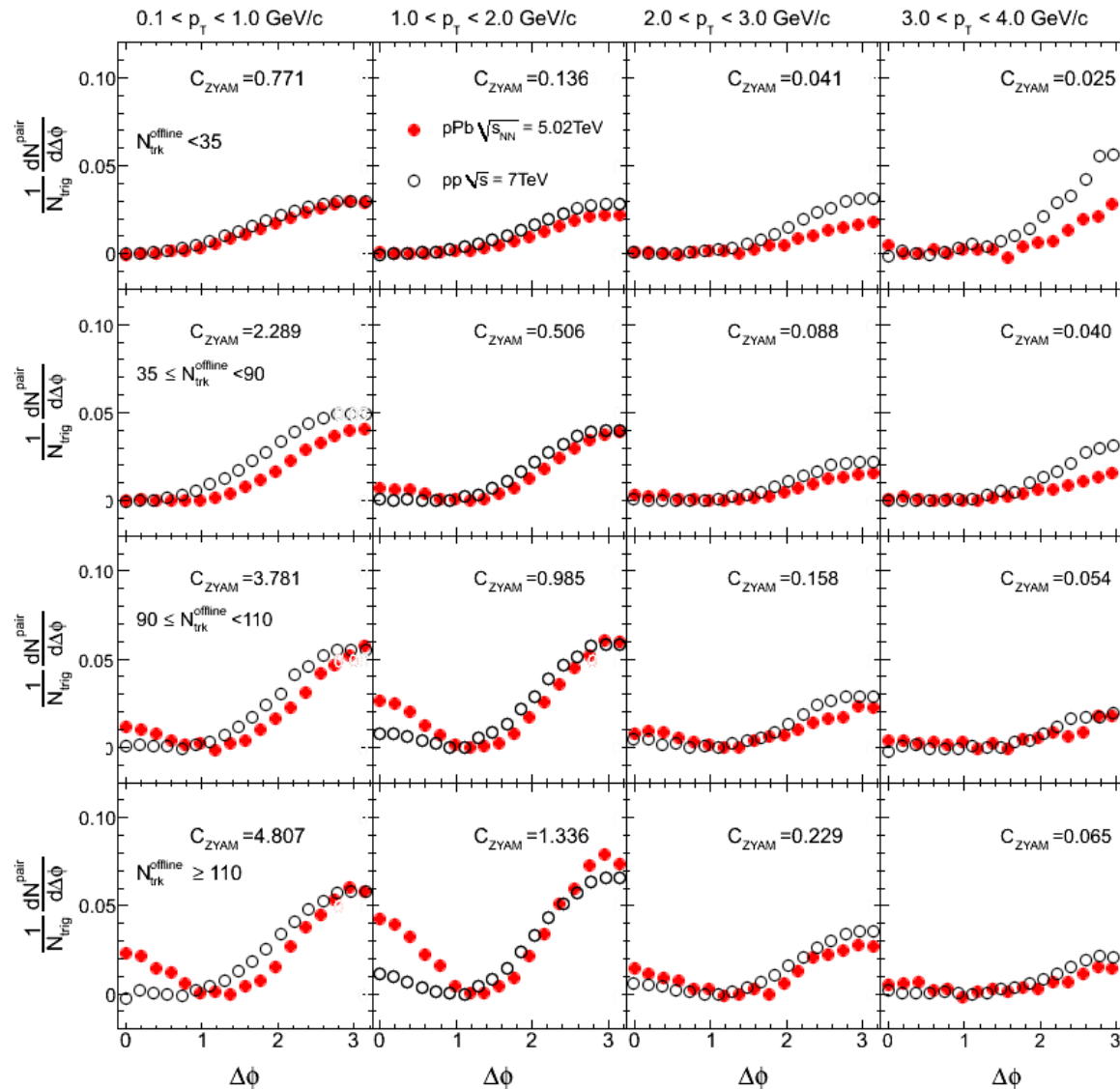
$1 < p_T^{\text{trig}} < 2$ GeV/c
 $1 < p_T^{\text{assoc}} < 2$ GeV/c



CMS pPb $\sqrt{s} = 5.02$ TeV, $N \geq 110$



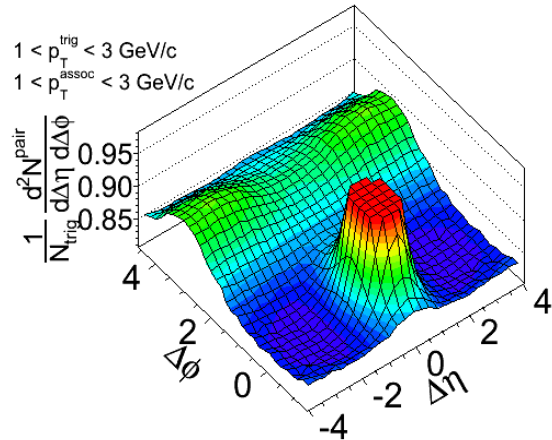
Multiplicity and p_T dependence



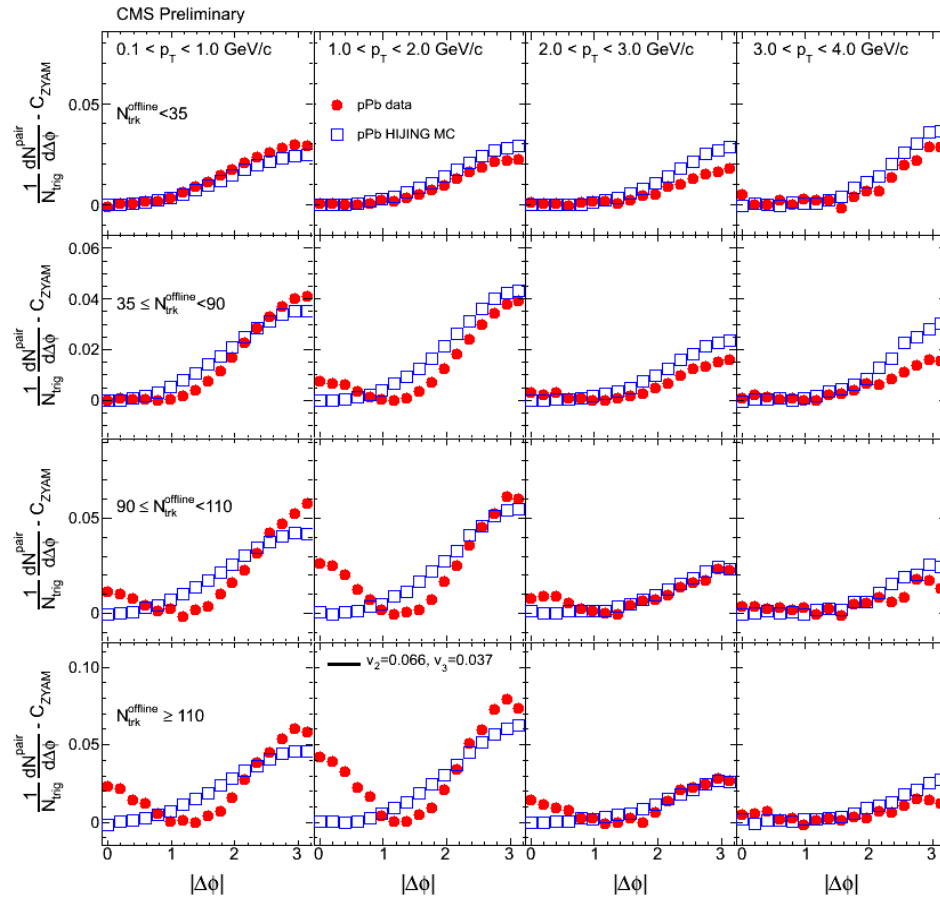
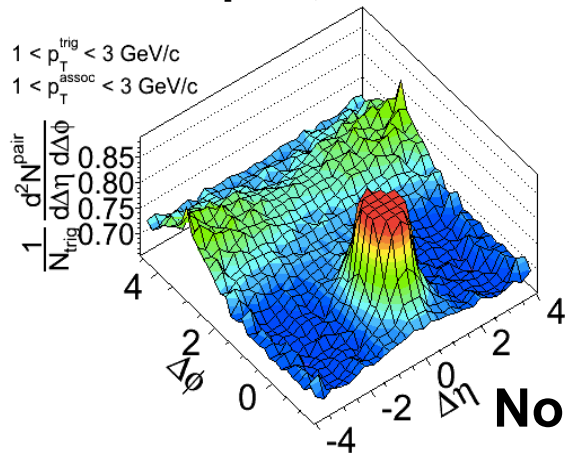
No ridge anywhere in pPb MC

Compare to AMPT and HIJING pPb

HIJING pPb, $N \geq 120$

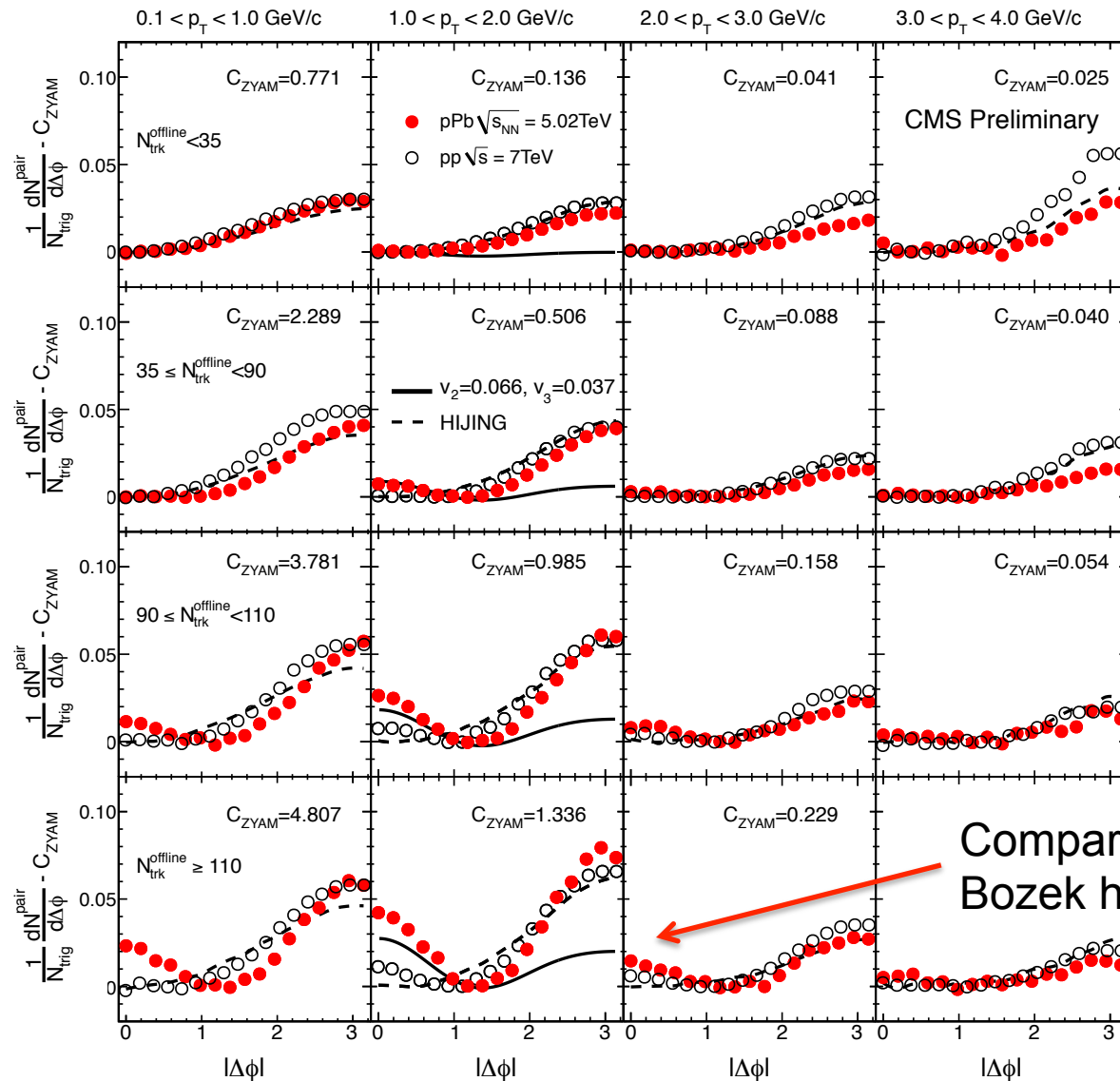


AMPT pPb, $N \geq 100$



No ridge in these pPb MC!

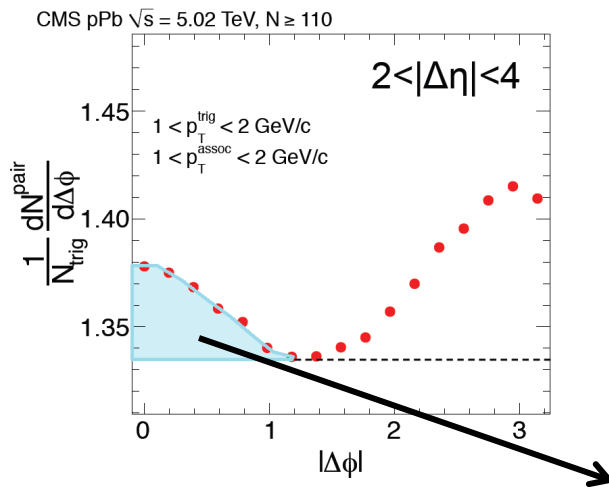
Multiplicity and p_T dependence



Compare to v₂, v₃ only from Bozek hydro prediction

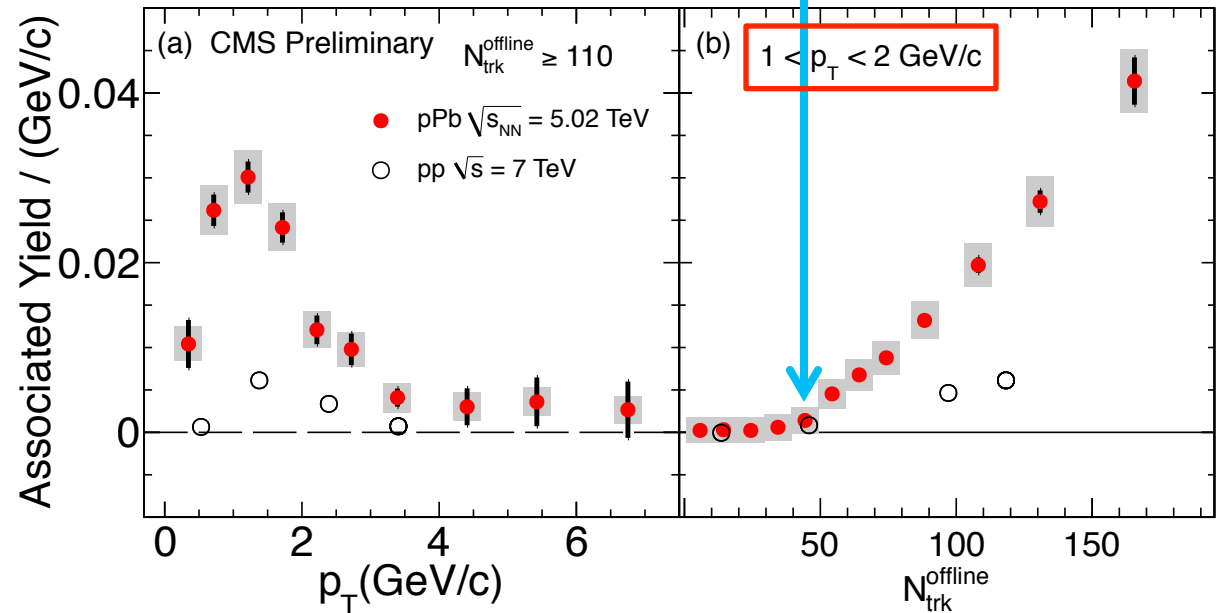
Ridge Associated Yield

ZYAM example



In the signal ($N > 110$) region, the strength of the effect rises and falls with p_T

In the p_T range where the yield is the strongest, the ridge turns on at $N \approx 40$



Summary and Conclusions

- A significant ridge is observed in high multiplicity (central) pPb collisions at 5 TeV
 - strong mechanism to produce particles in a plane
 - strength of ridge is much larger than in pp (comparable to PbPb?)
- Effect turns on slightly above average minimum bias multiplicity
- Effect rises and falls with p_T
 - similar trend as observed in both PbPb and pp ridge before

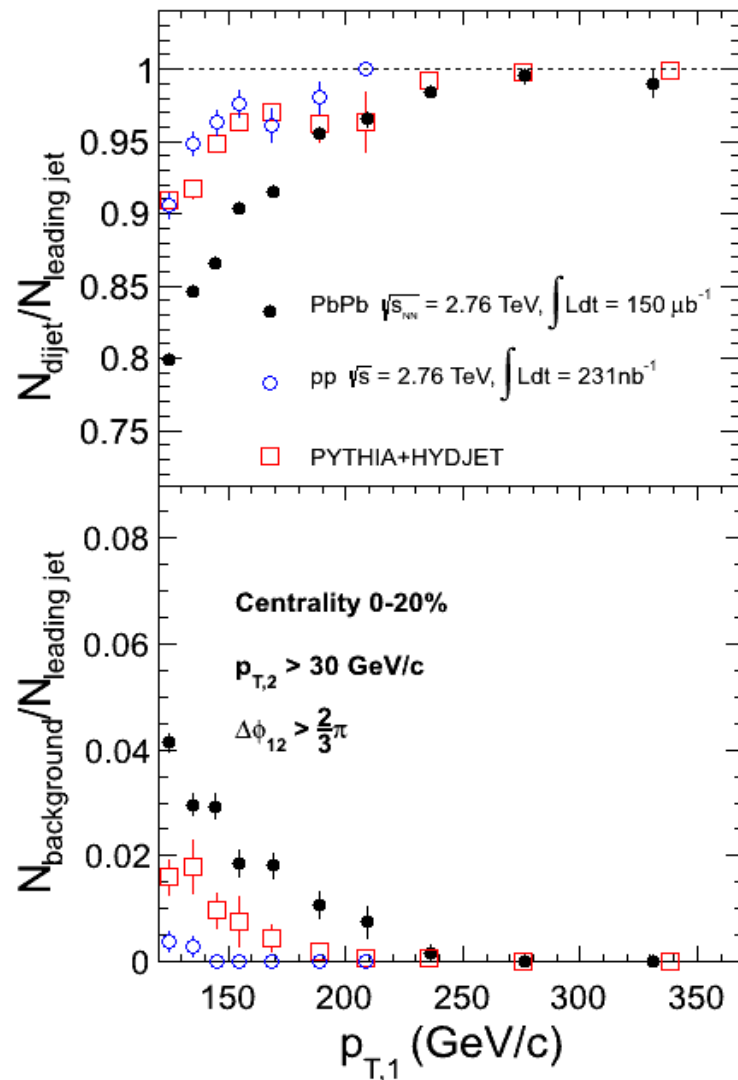




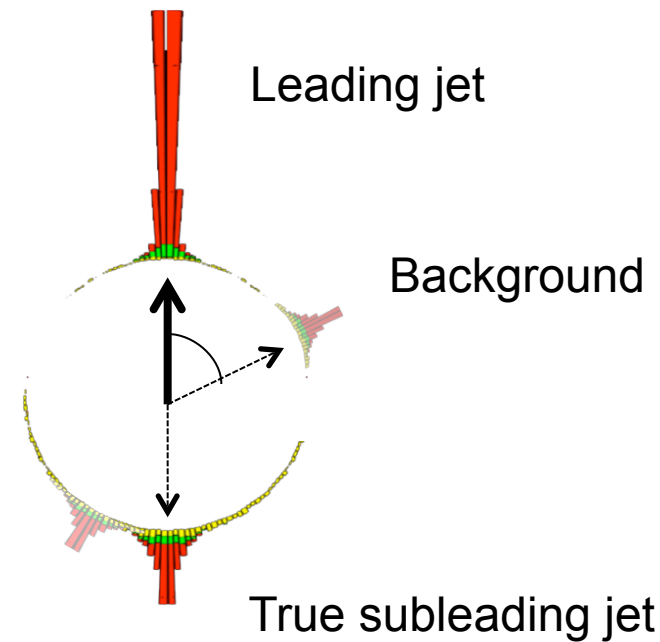
Backup



Dijet to leading jet ratio

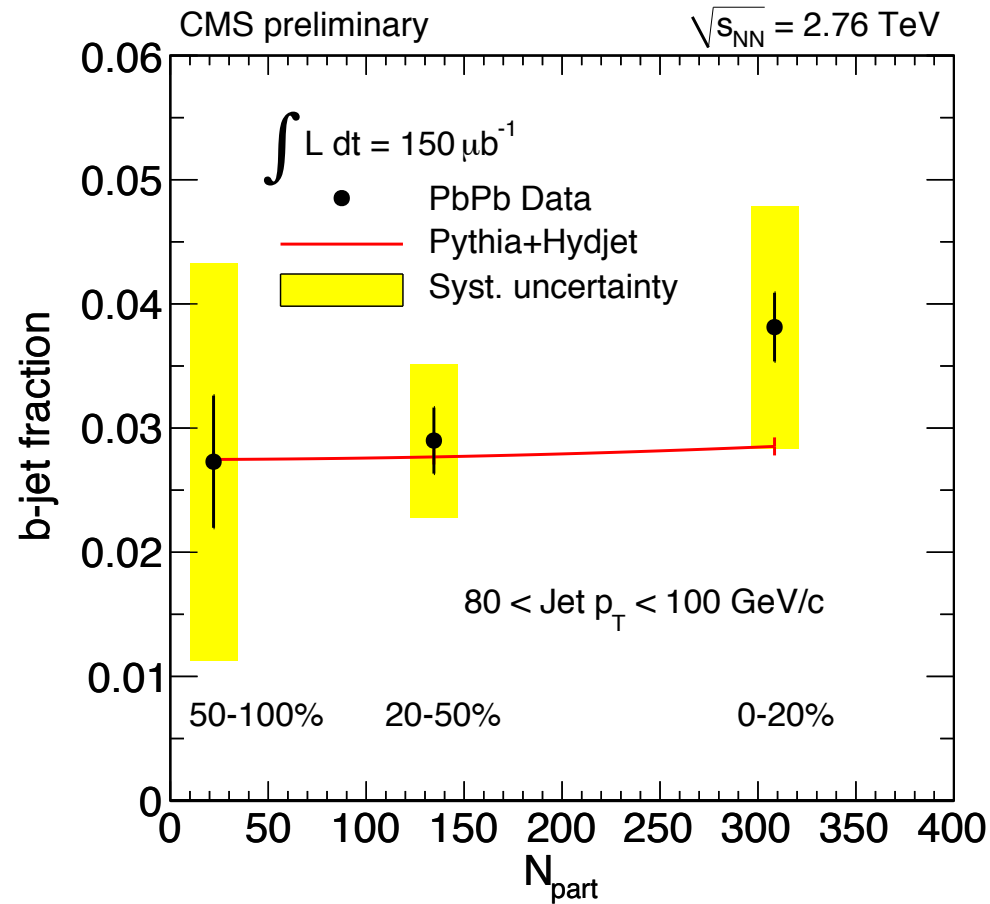


At high p_T , only very few jets get completely lost on the away side



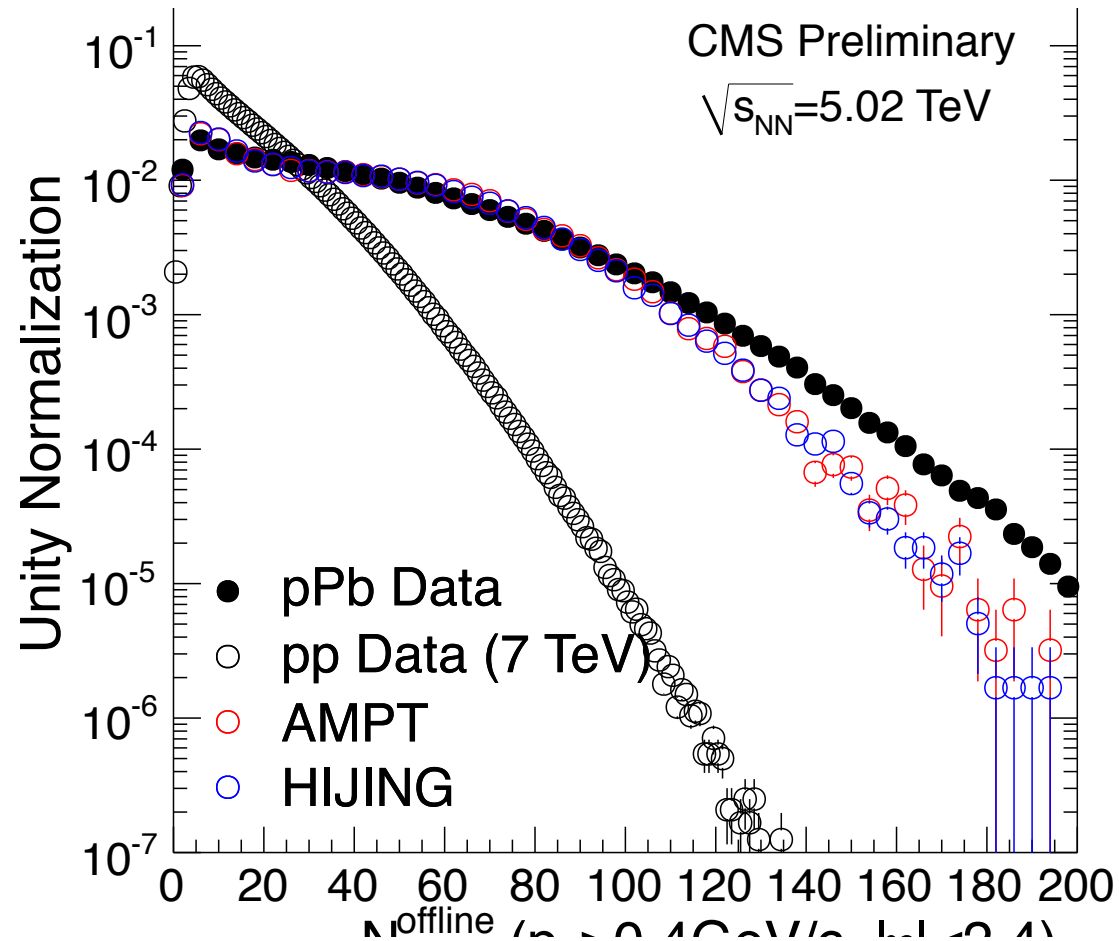
- Background amount enhanced with quenching
- However, very little at high p_T

b-jet Fraction vs. Centrality

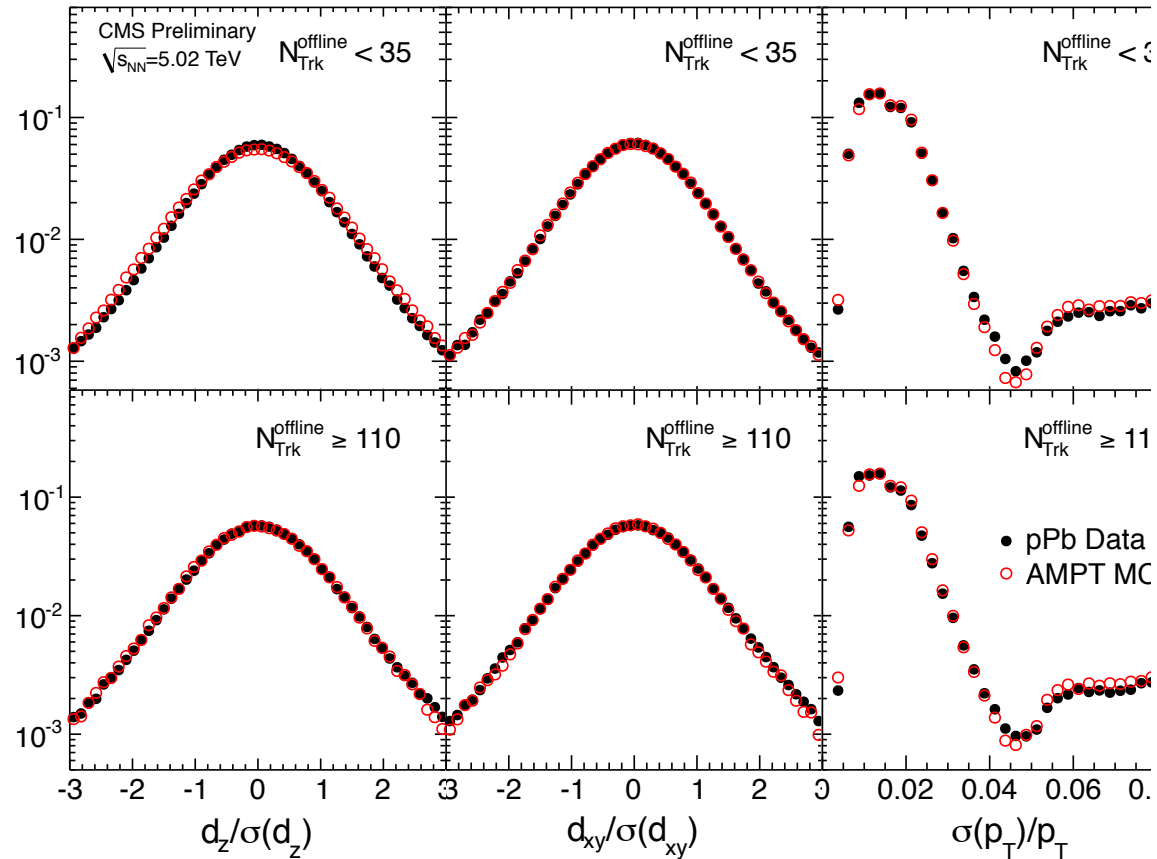


b-jet fraction does not show a strong centrality dependence

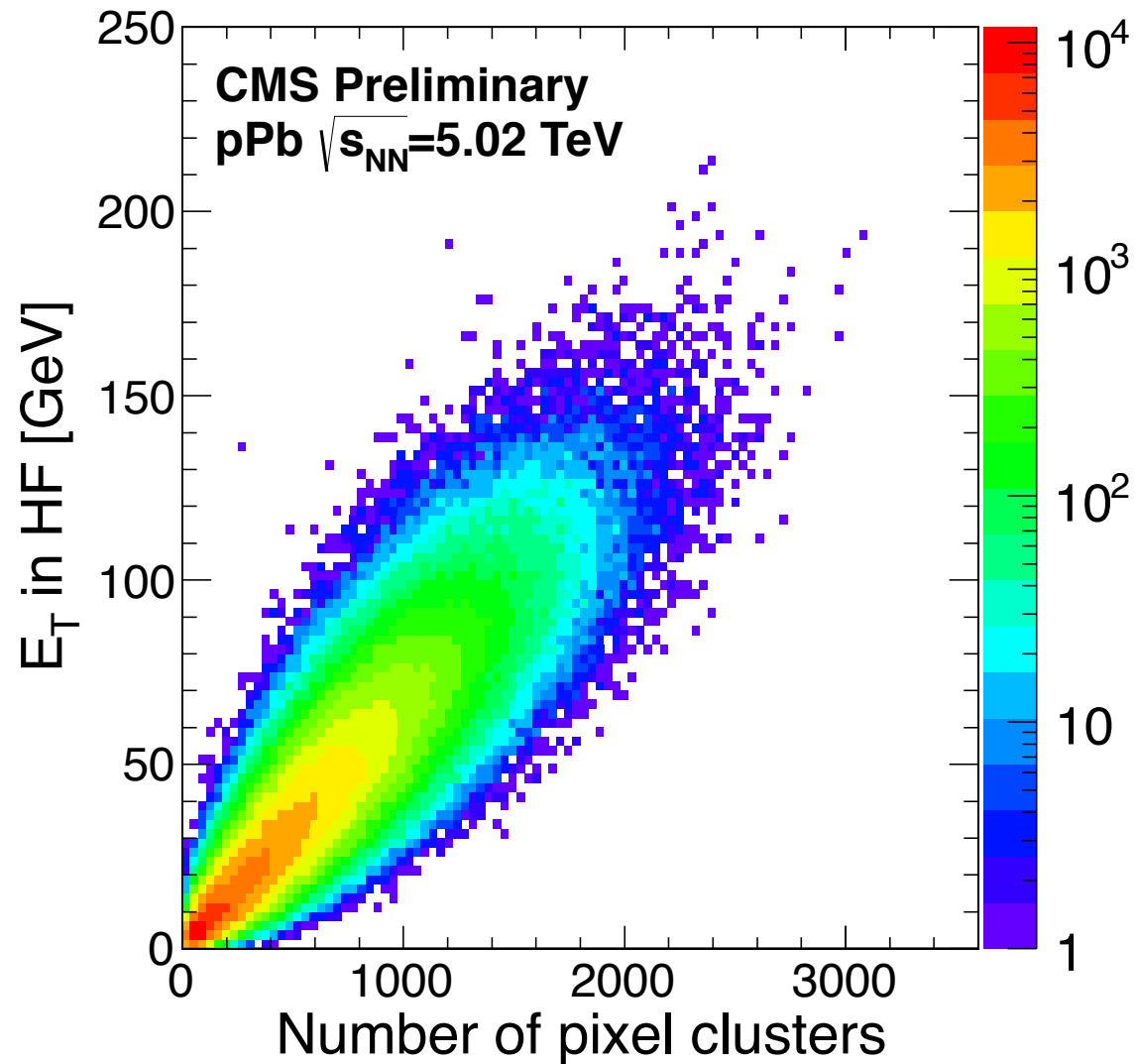
RAW multiplicity distribution



Track quality cuts

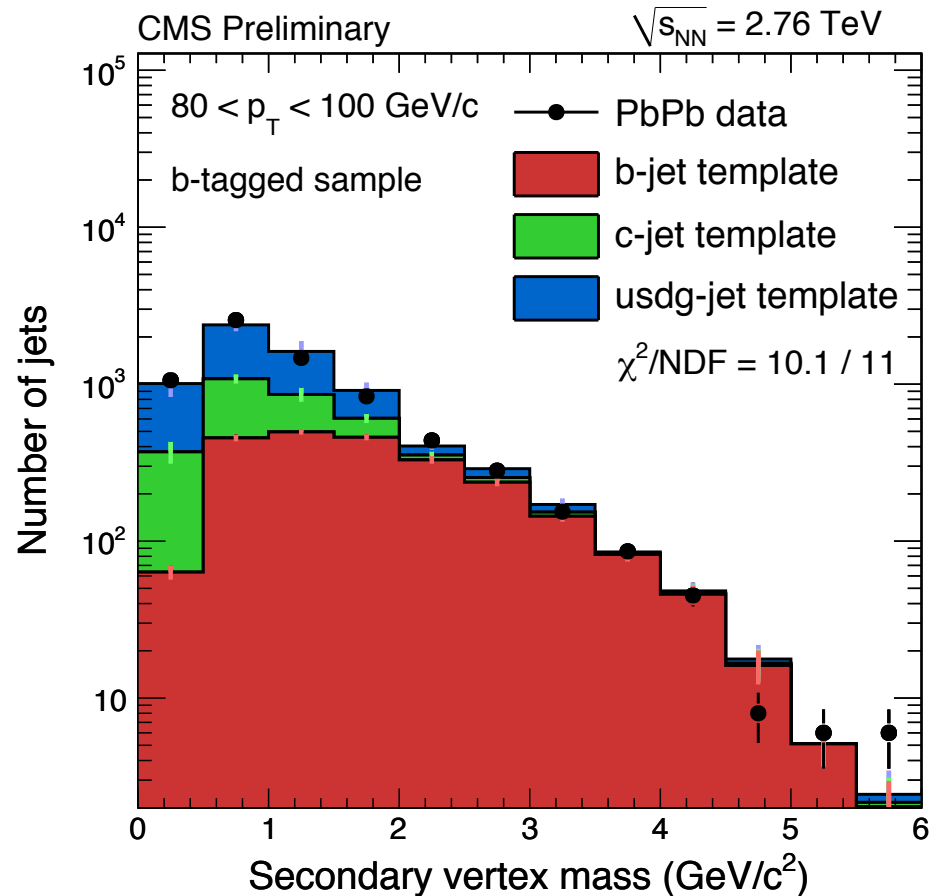


Event Selection

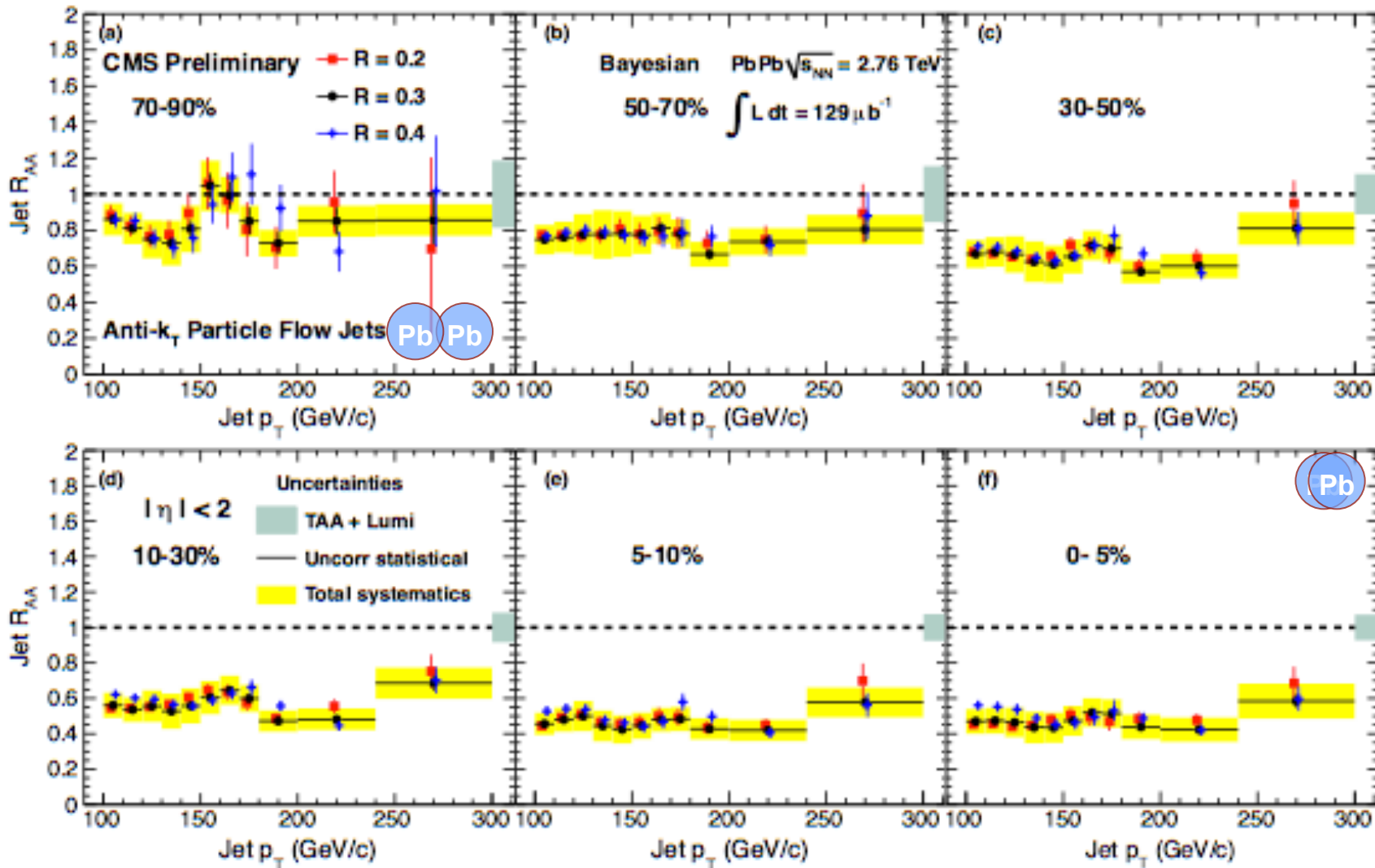


Secondary Vertex Mass Fits

- After enriching sample in b-jets with the SSVHE tagger, we fit the SV mass distribution
- Shapes of b and non-b templates taken from MC, normalizations allowed to float
- The shapes of the non-b templates are cross-checked with a data-driven method
- The stability of the fits and the shapes of the templates are the dominant sources of systematics uncertainty



Different jet cone size

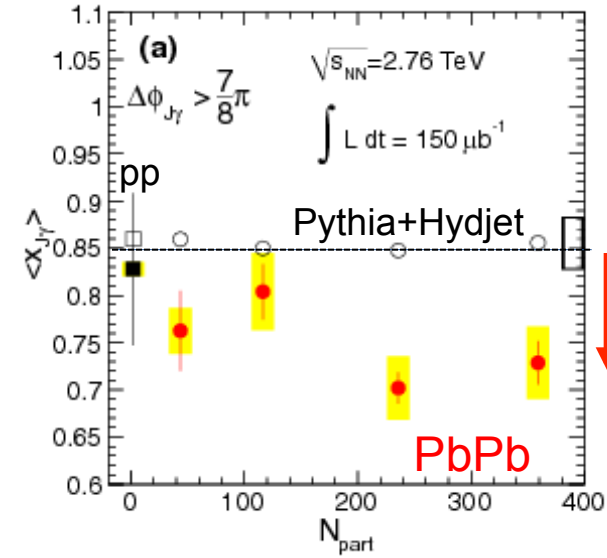
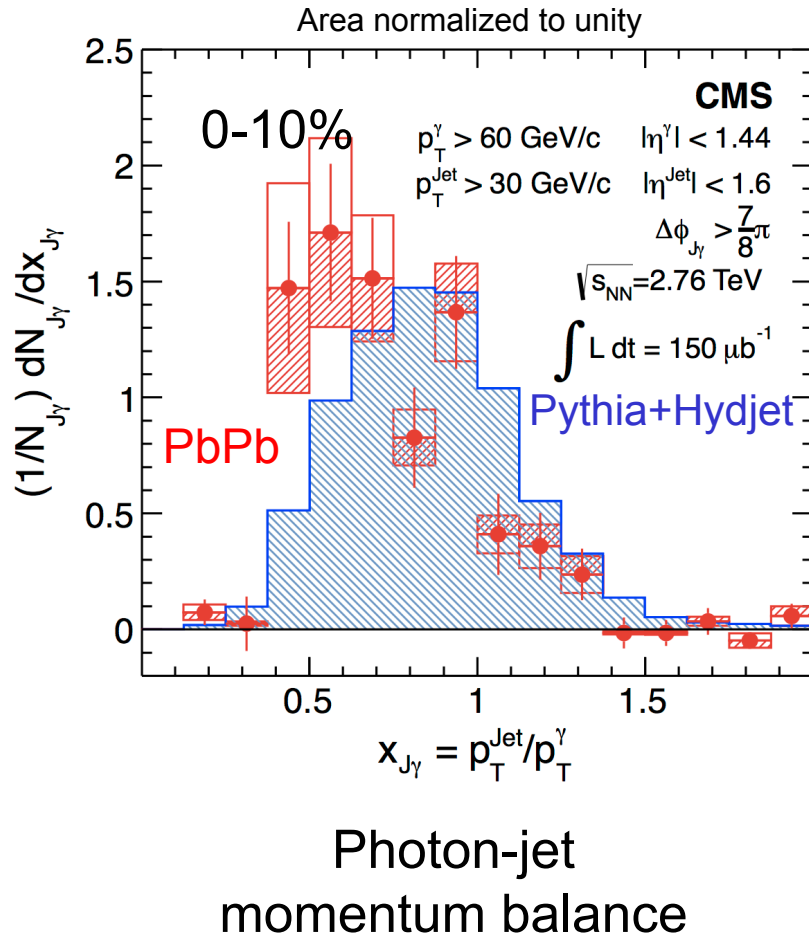


total
systematic
 $R=0.3$

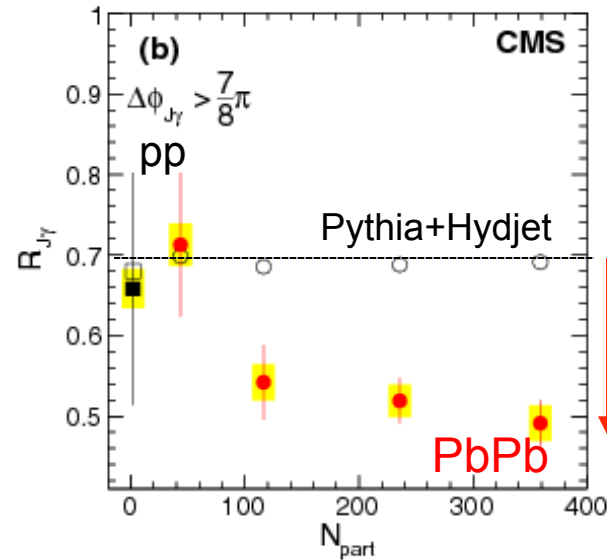
- No strong dependence on jet radius

γ +jet: u,d quark energy loss

arXiv:1205.0206



Jet-photon p_T balance drops by 14%



20% of photons lose jet partner

Parallel talk
 Yue Shi Lai (Tue)



Jet RAA systematics

