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September 13th, 2013

The Usual Disclaimers

- Not a comprehensive review, rather mostly a summary of experimental talks at July Jussieu workshop*
- Will only discuss LHC results, no RHIC
- Results are biased towards CMS
- I will focus strictly on jets, no mention of, high p_T spectra, correlations, etc.
- No pPb in this talk

* https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=242816

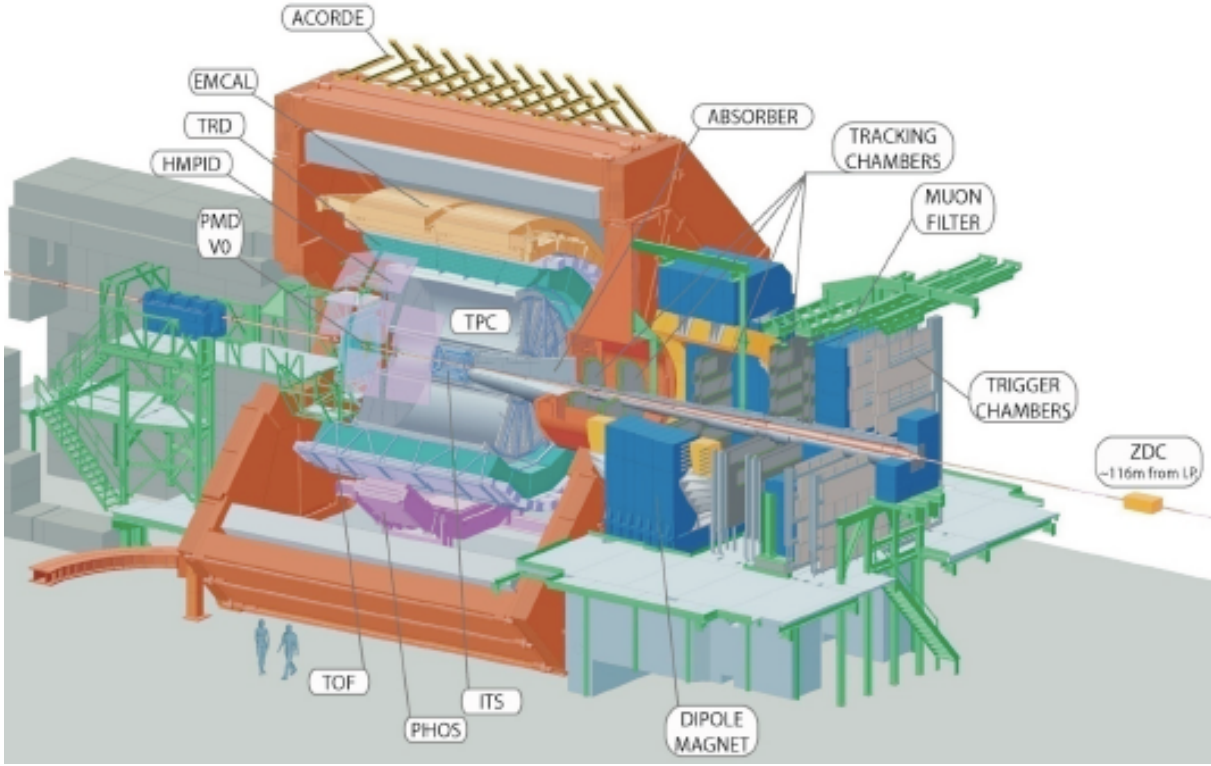
Outline

- Detector capabilities
- Jet reconstruction / Underlying event subtraction methodologies
- Results!

ALICE

Relevant Detectors

- Tracking:
  ITS + TPC
- Calorimeters:
  EMcal
  + Dcal (future)
- Also excellent PID



Pros:

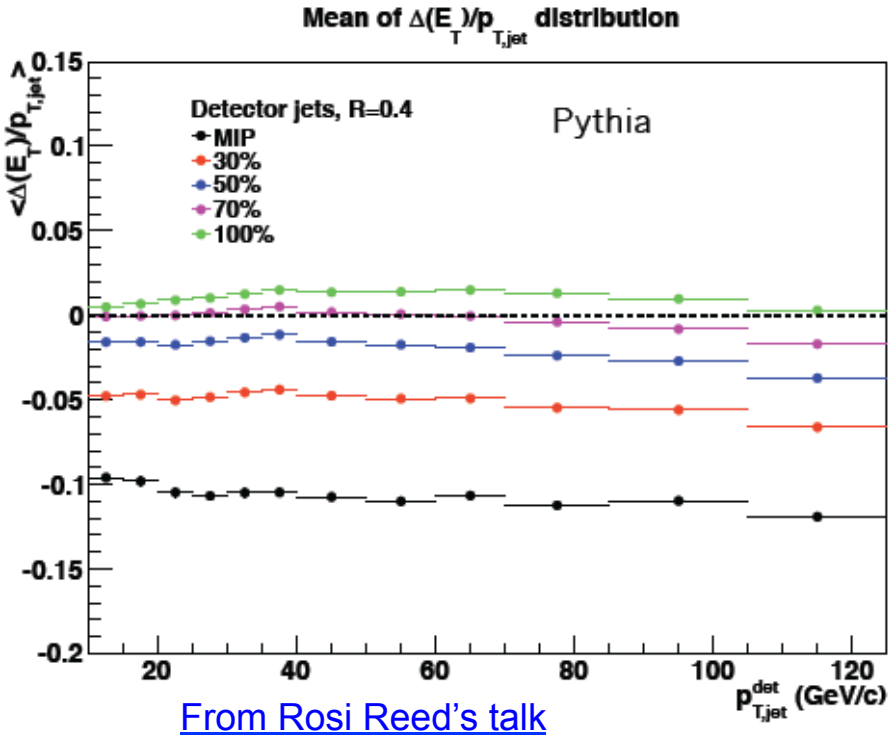
- Excellent tracking efficiency down to 150 MeV/c
- Reasonable p_T (E) resolution tracker (EMCal)
- Good shower separation in EMCal

Cons:

- No hadronic calorimetry yet
- Relatively small acceptance, low trigger rate

Photon-Track Matching in ALICE

- Including EMcal, ~90% of particles are measured
- However, charged hadron deposits in EMcal must be taking into account
- Tracks are matched to EMcal clusters and **entire** momentum is subtracted



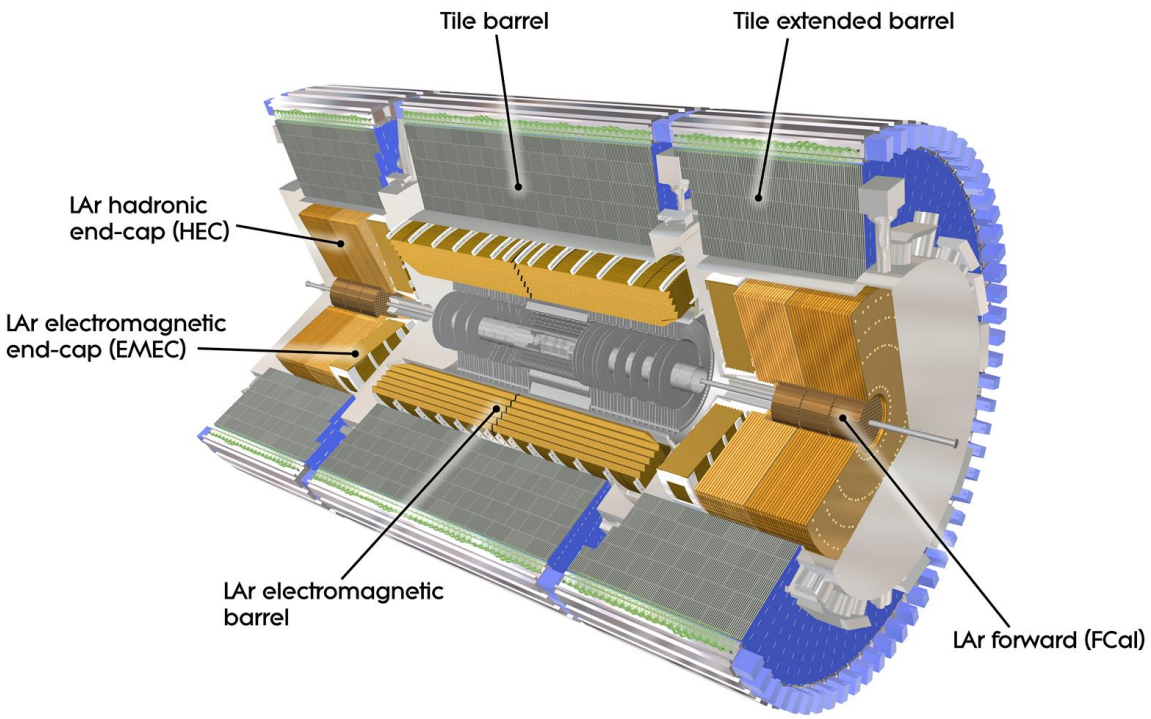
From Rosi Reed's talk

- Presumably, photons collinear with charged hadrons can be oversubtracted
- This is taken care of at the unfolding stage
- The fraction of the track momenta subtracted from the clusters is varied to assign a systematic uncertainty

ATLAS

Relevant Detectors

- Calorimeters:
- Liquid Argon (EM)
- Tile (Hadronic)



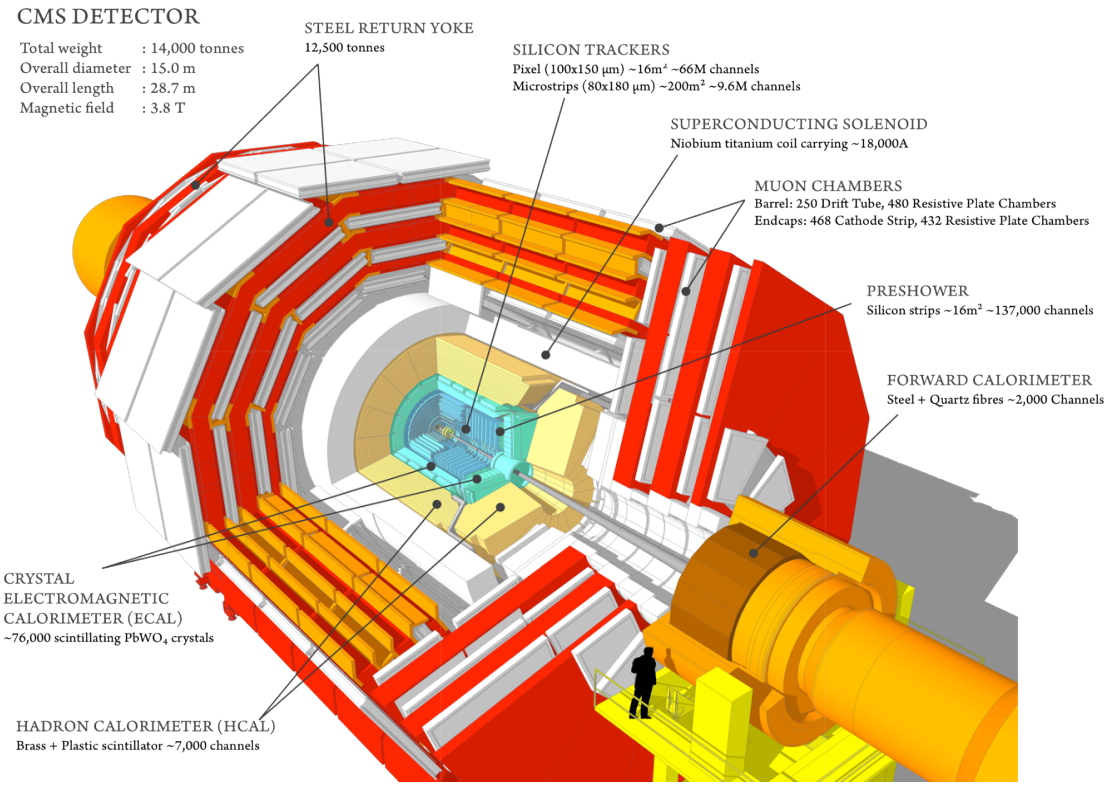
Pros:

- Good EM energy resolution
- Excellent hadronic energy resolution
- Longitudinal segmentation

Cons:

- Relatively low/non-linear response to low p_T constituents
- Large material budget

CMS



Relevant Detectors

- Silicon Tracker
- $PbWO_4$ ECAL
- Brass-scintillator HCAL

Pros:

- Excellent p_T (E) resolution in tracker (ECAL)
- Large B field + granular ECAL suitable for particle flow

Cons:

- Modest E resolution and granularity for HCAL
- Limited tracking efficiency and low p_T reach in HI mode
- Large material budget

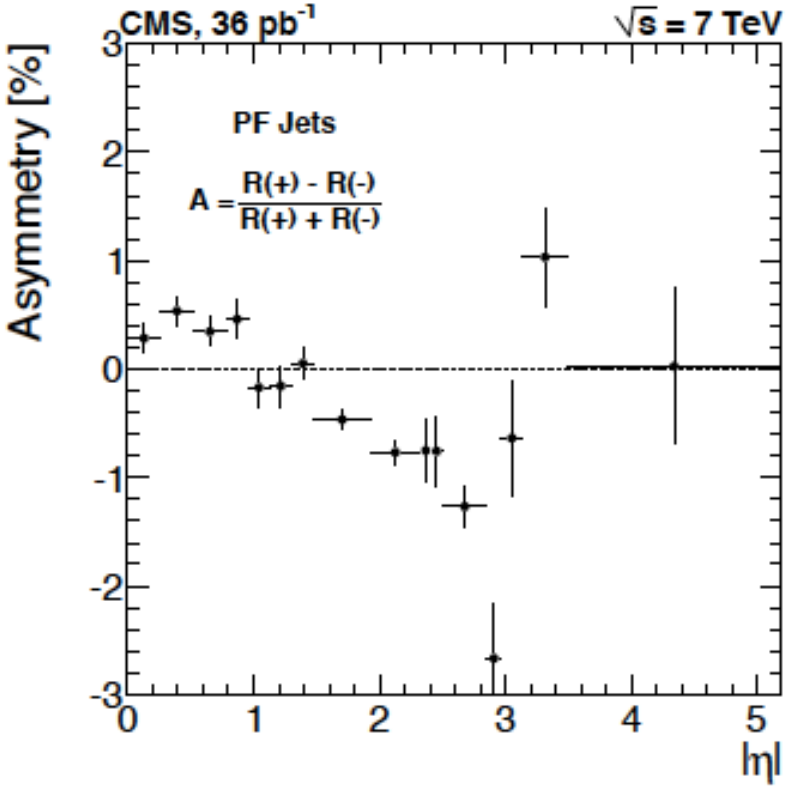
Particle Flow in CMS

- PF combines detector elements to move closer to particle level
- Minimizes jet energy corrections and reduces dependence on jet fragmentation pattern
- Uses redundancy of tracker and HCAL to linearize response to charged hadrons and reject fake tracks

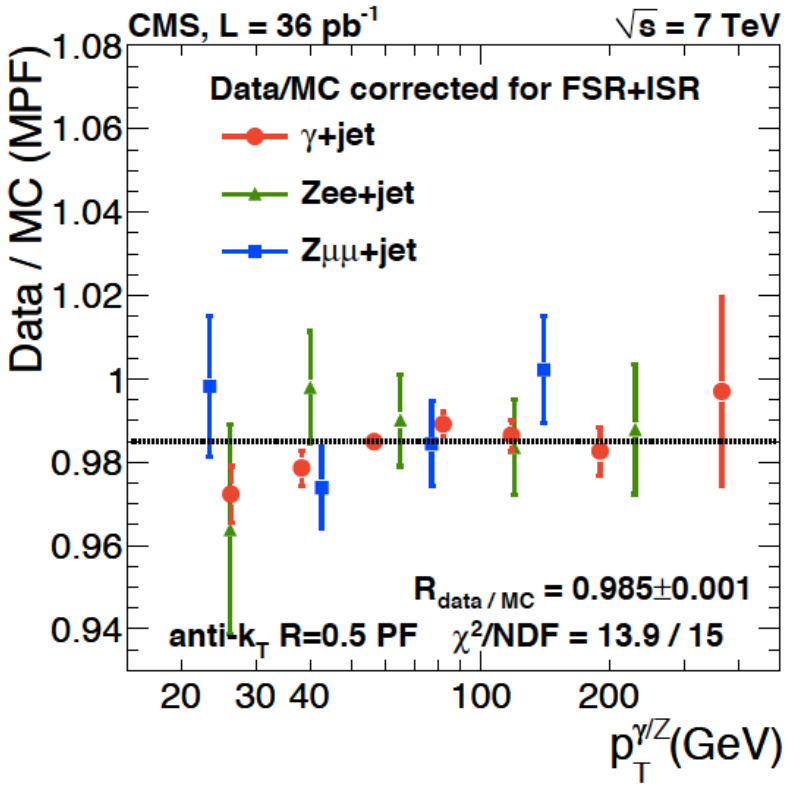
JINST 6 (2011) 11002

Jet Response Calibration

Relative response via dijet balancing



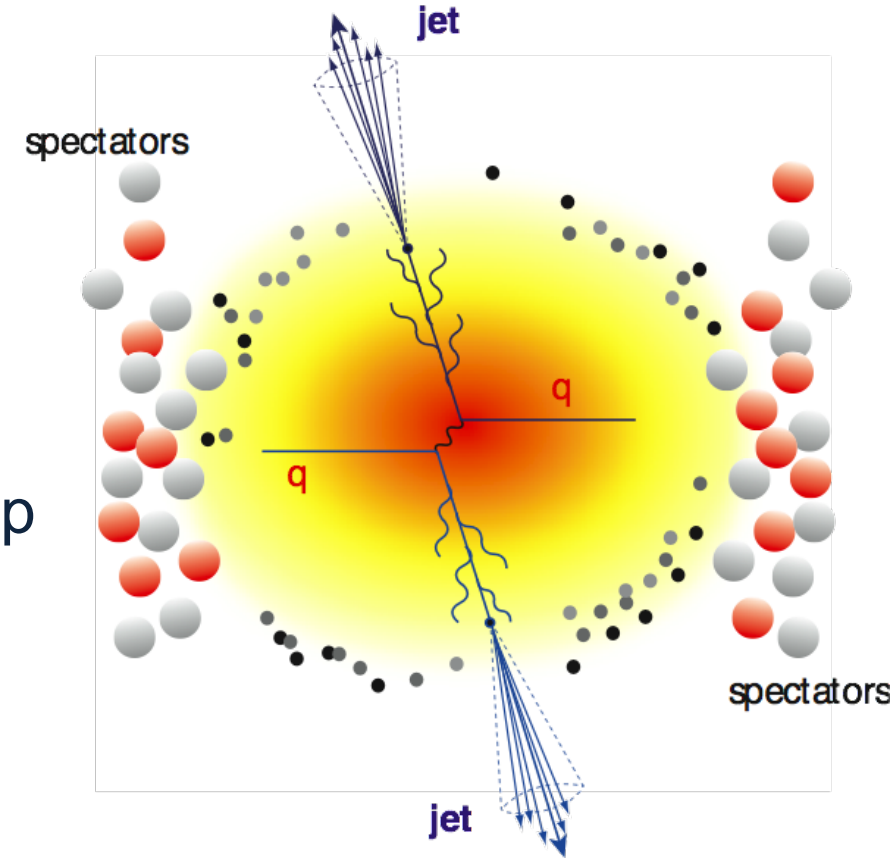
Absolute JES via γ(Z)+jet balancing



- Data-driven techniques correct for generator and simulation mismodeling
- Residual corrections on the order of 1.5% in CMS

Jets in Heavy Ions

- Q: How much energy do partons lose?
- Corollary: How does the medium respond?
- Partons not observable, but correspondence to particle-level jets well-understood in pp
- Parton-medium interaction breaks this correspondence → need model comparisons



- A good UE subtraction scheme allows to isolate the interesting physics (energy loss + medium interaction)

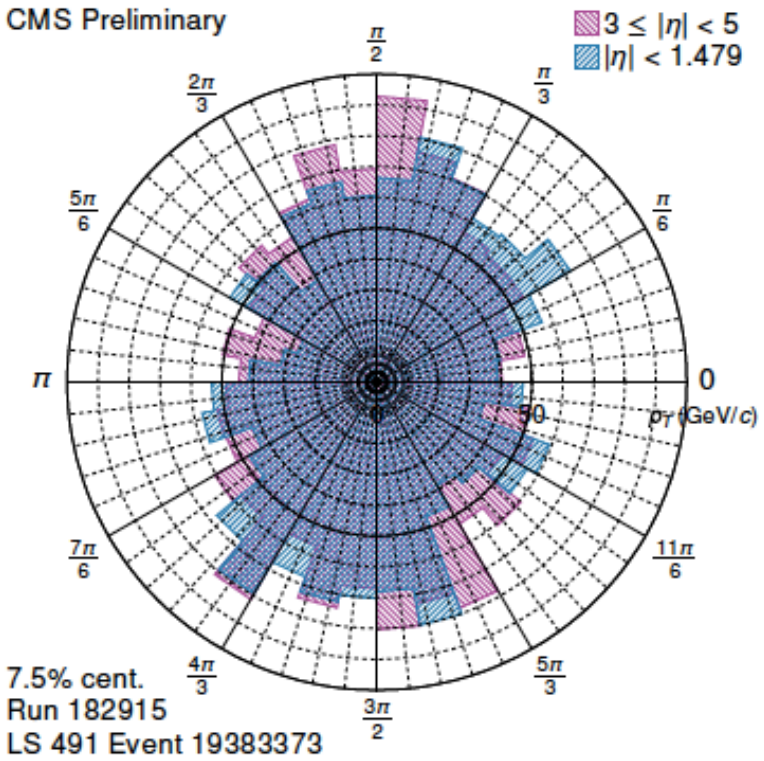
UE subtraction methods

G. Salam, et. al.

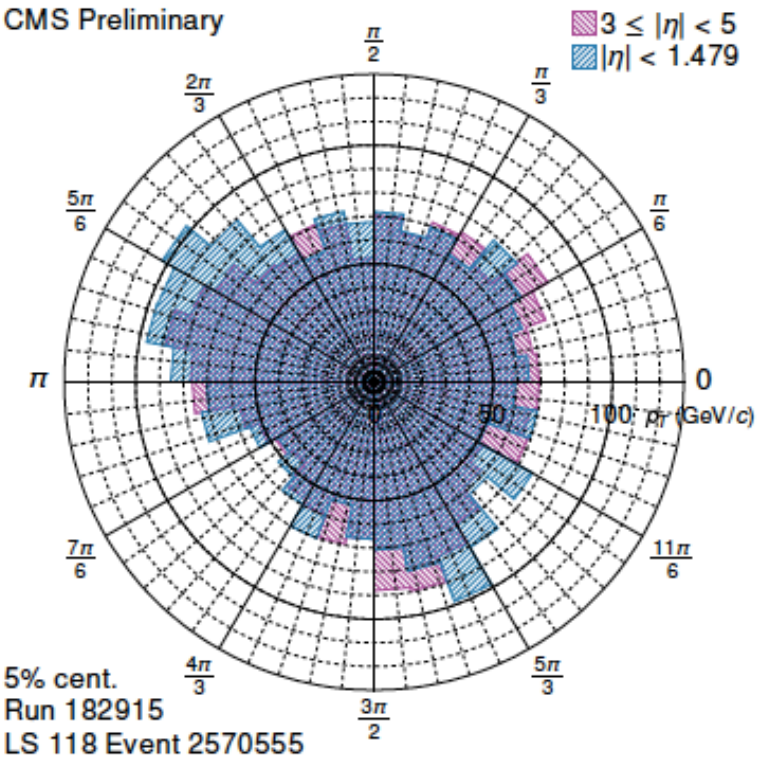
	ALICE [FastJet area/median method]	ATLAS	CMS [Iterative Cone Subtraction]
Background estimated in	whole detector [optionally: jet neighbourghood]	η strips	η strips
Hard jets excluded from bkgd estimate	by median	by p_t cut	by p_t cut
Flow corrections	no [unless use jet neighbourhood]	yes	no
Subtract bkgd from	jets [after jet clustering]	towers [after jet clustering]	towers [before jet clustering]
Noise suppression	no	no	yes [subtract ρ+σ from each tower, suppress -ve towers]

Very different strategies employed by different experiments

Influence of Flow on the UE



2nd harmonic

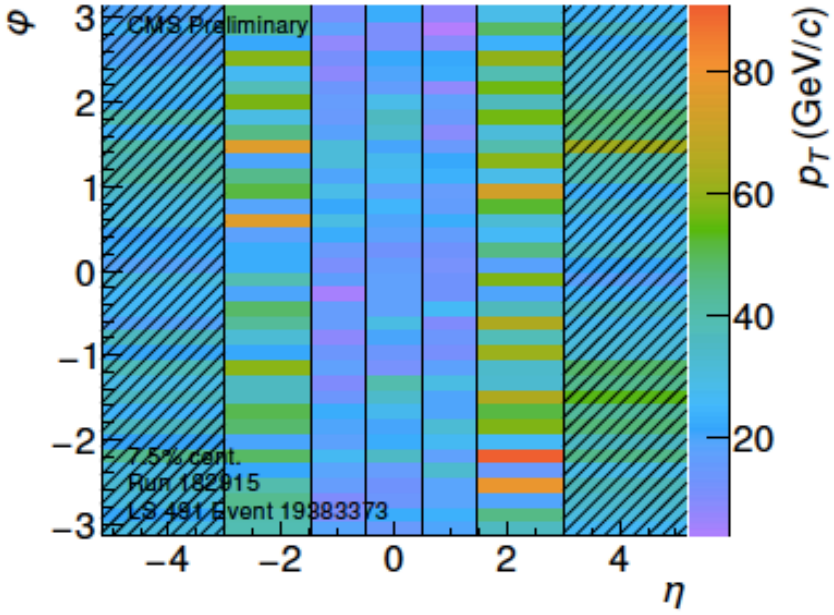


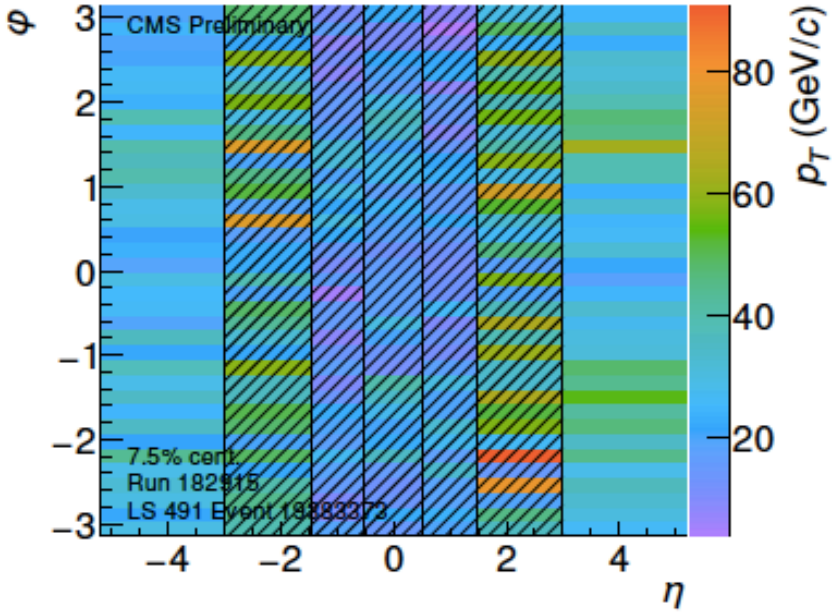
3rd harmonic

CMS-DP-2013-018

- Azimuthal anisotropy of UE already visible event-by-event
- Correlated across pseudorapidity
- Should be properly taken into account in UE subtraction

Modeling the UE in CMS



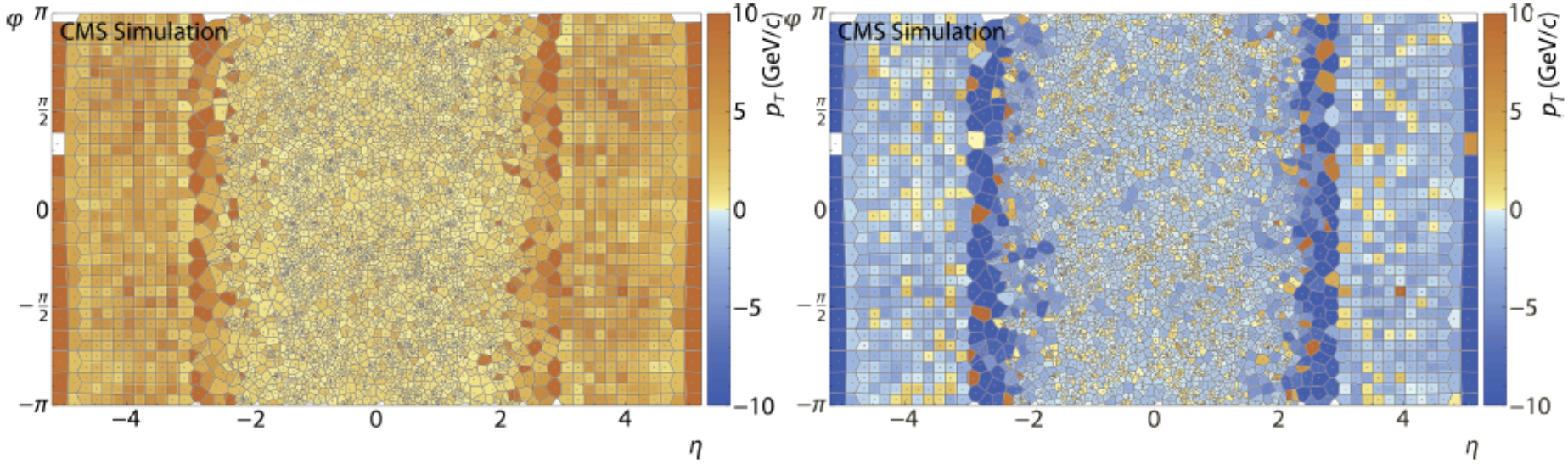


- Detector split into barrel, endcap and forward
- Barrel and endcap UE activity (including azimuthal dependence) is predicted based on forward calo. activity
- Prediction is based on fits to MinBias data

CMS-DP-2013-018

Particle-based Subtraction

CMS-DP-2013-018



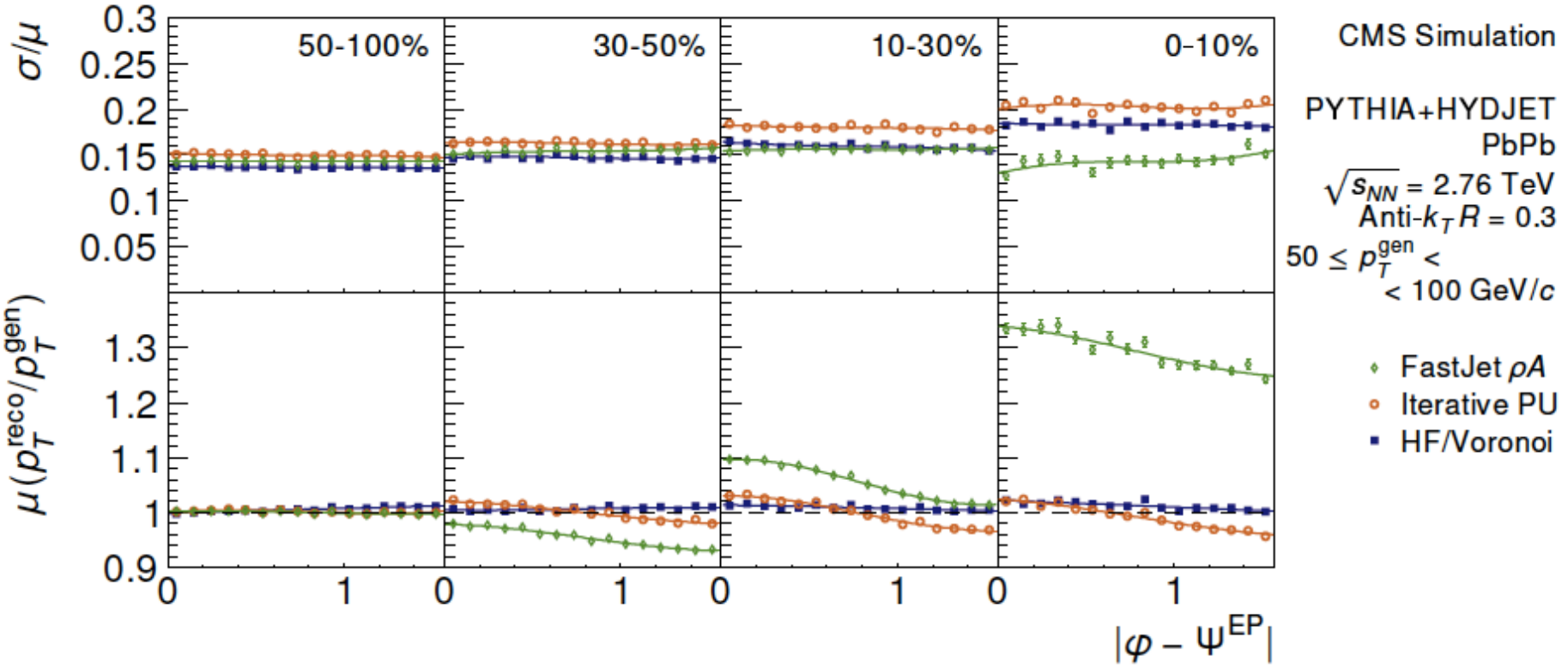
Before UE subtraction

After UE subtraction

- Voronoi diagrams are used to assign an area to each particle
- Background is estimated independently for each particle type
- Any oversubtraction is removed by an equalization procedure

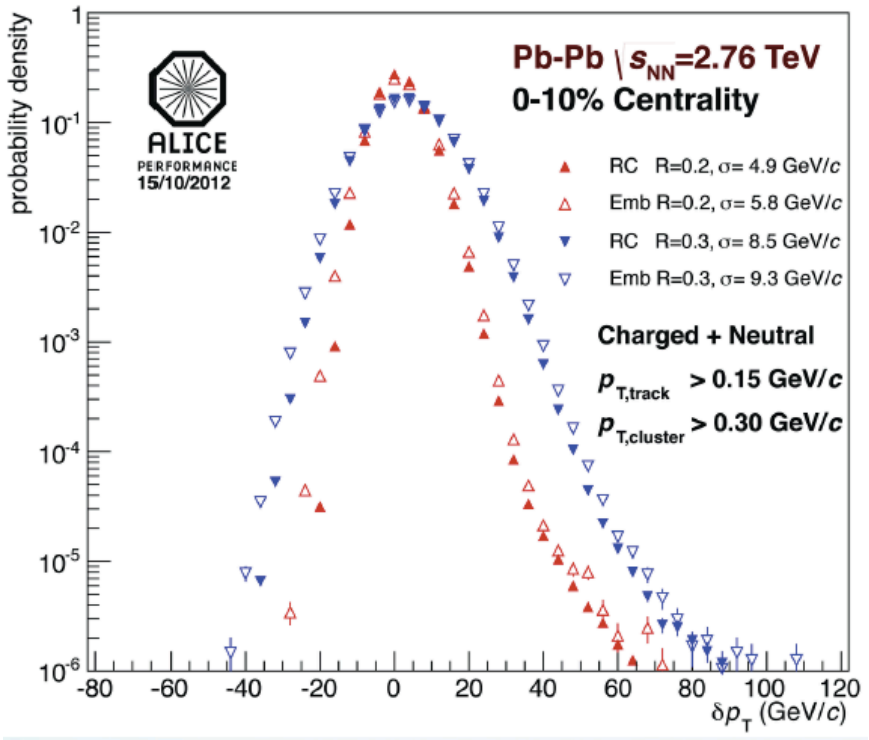
Performance vs Angle wrt Rxn Plane

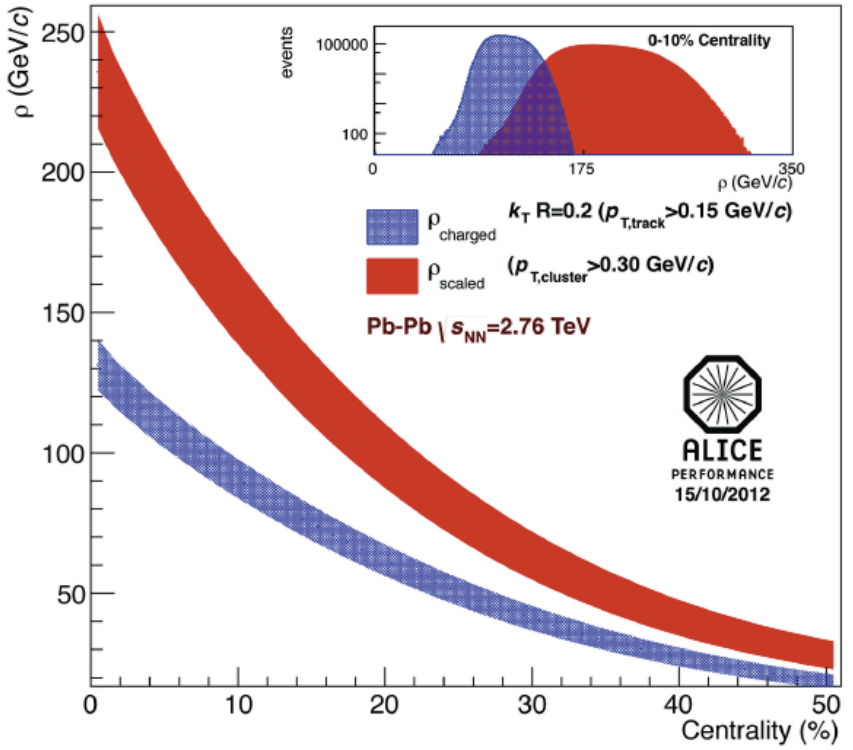
CMS-DP-2013-018



New UE subtraction removes dependence on flow orientation

Underlying Event in ALICE

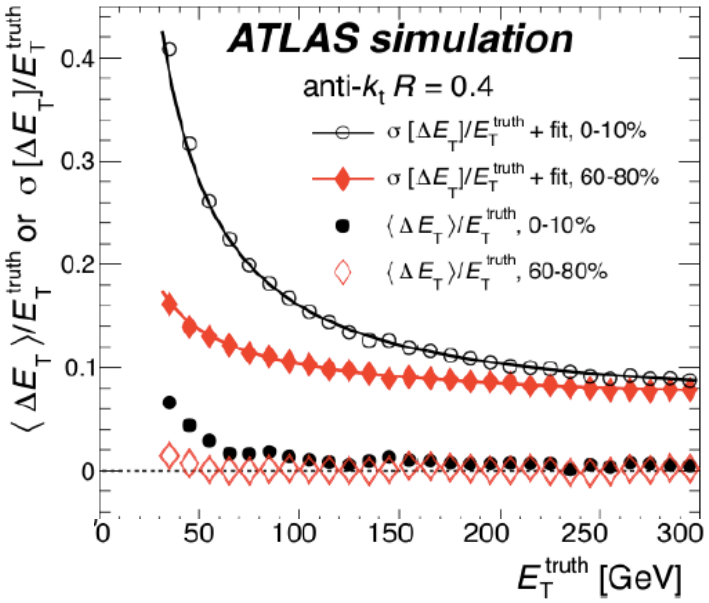


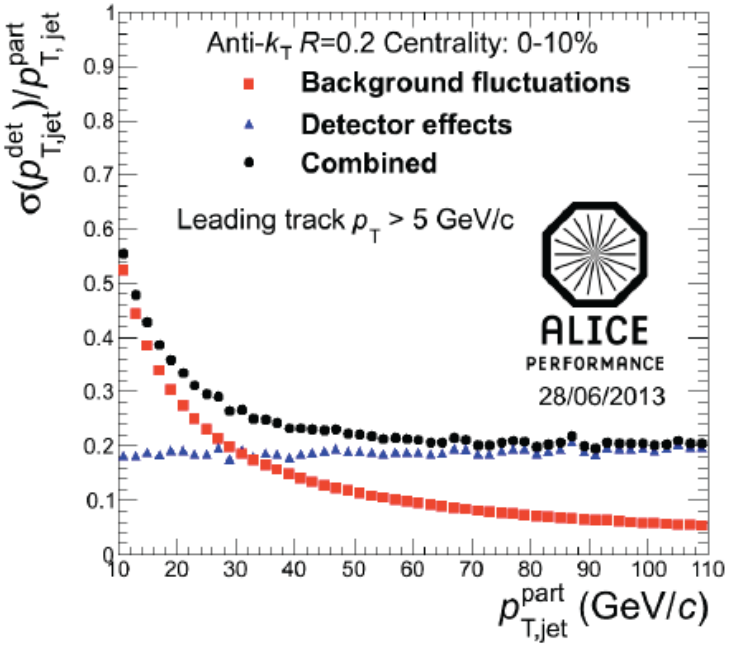


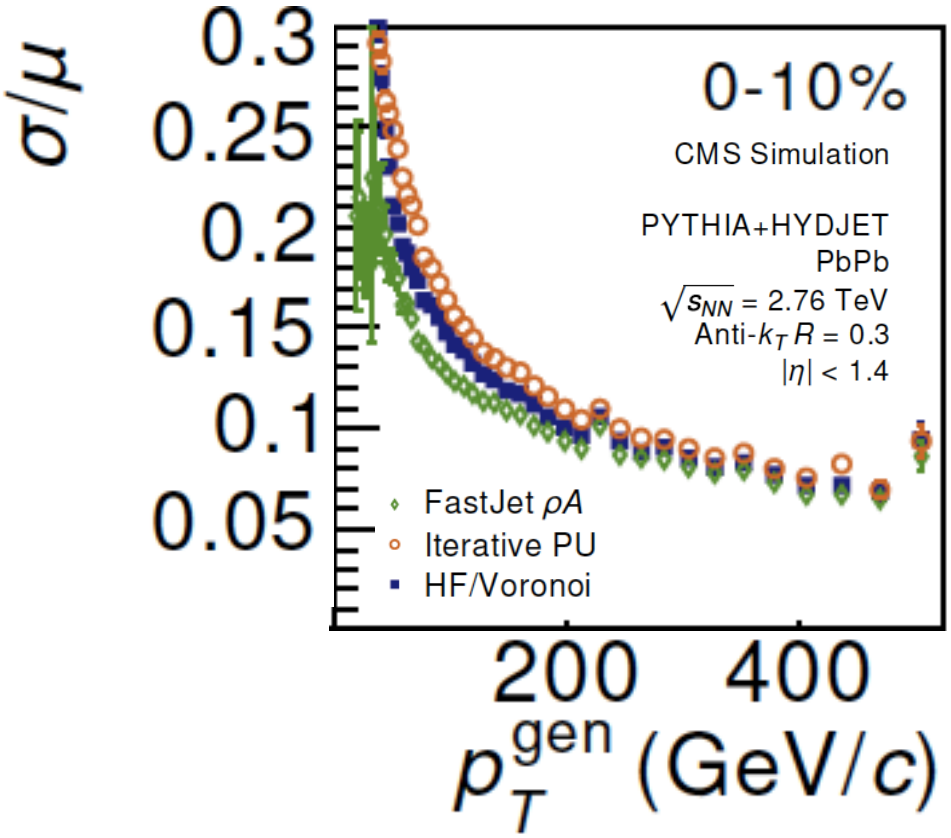
- Fluctuations evaluated by random cones, x-checked by embedding (vice-versa for CMS)
- UE density ρ depends only on centrality (i.e., global rescaling)

Detailed discussion of ALICE UE subtraction in JHEP 1203 (2012) 053

Jet Resolution

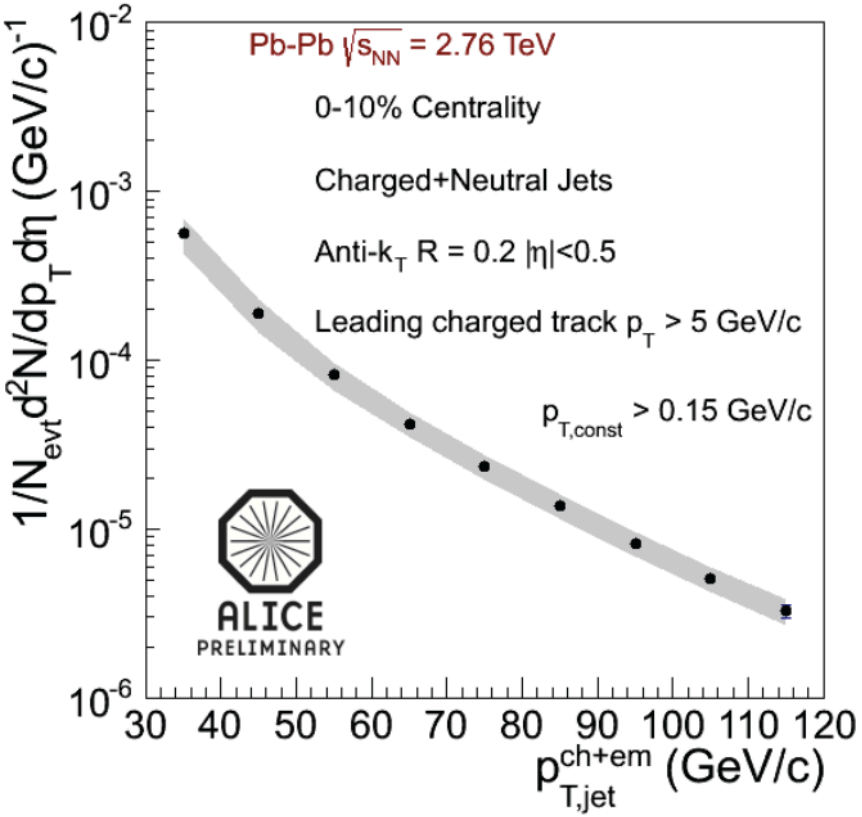


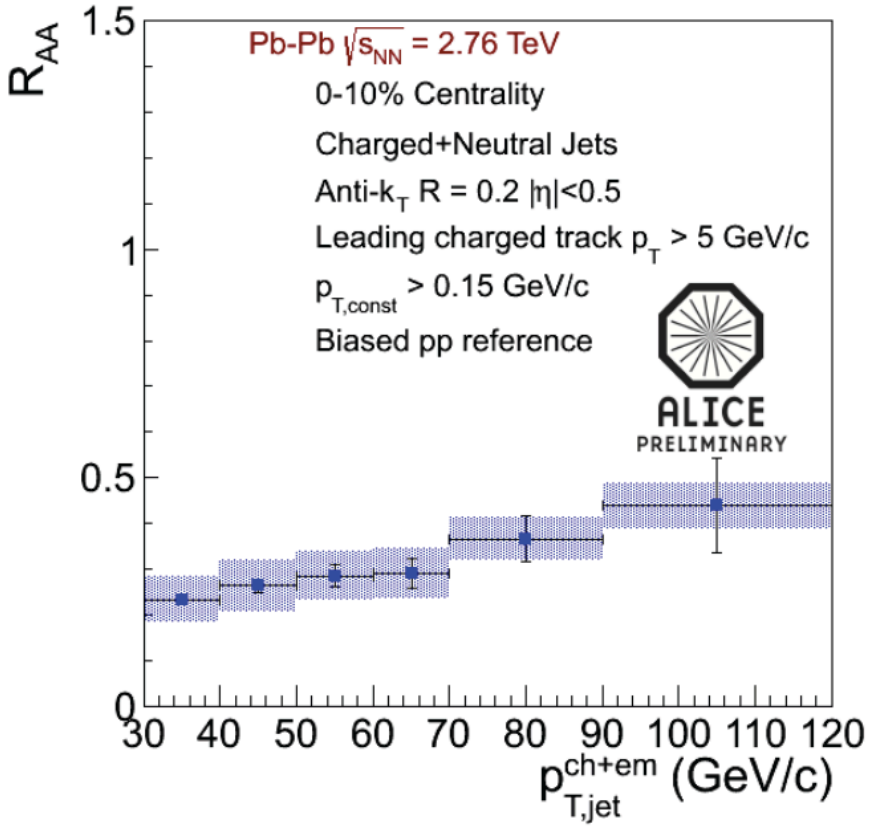




- Same centrality selection
- Different R values

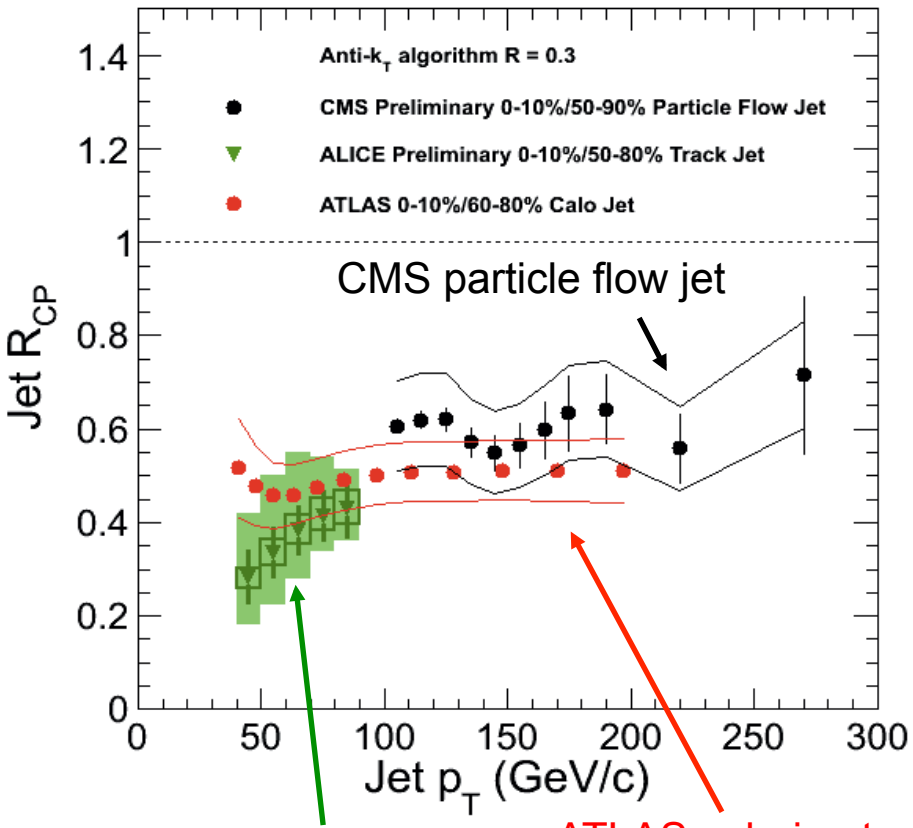
Jet x-section, R_{AA}

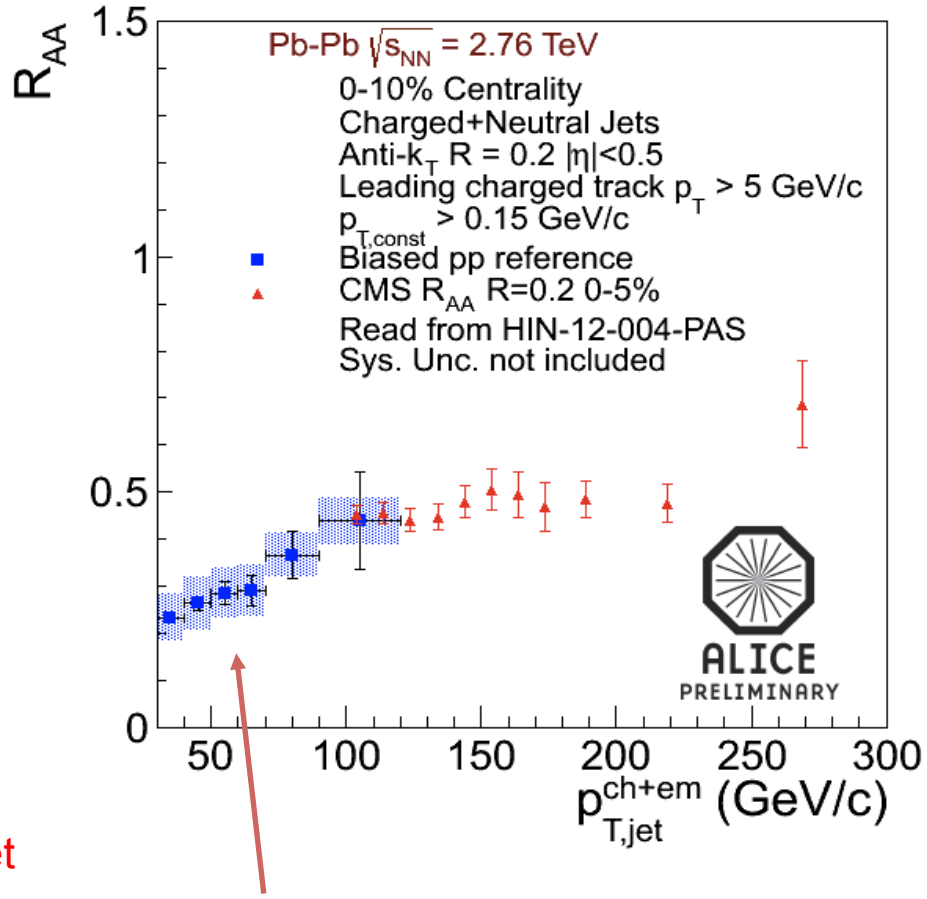




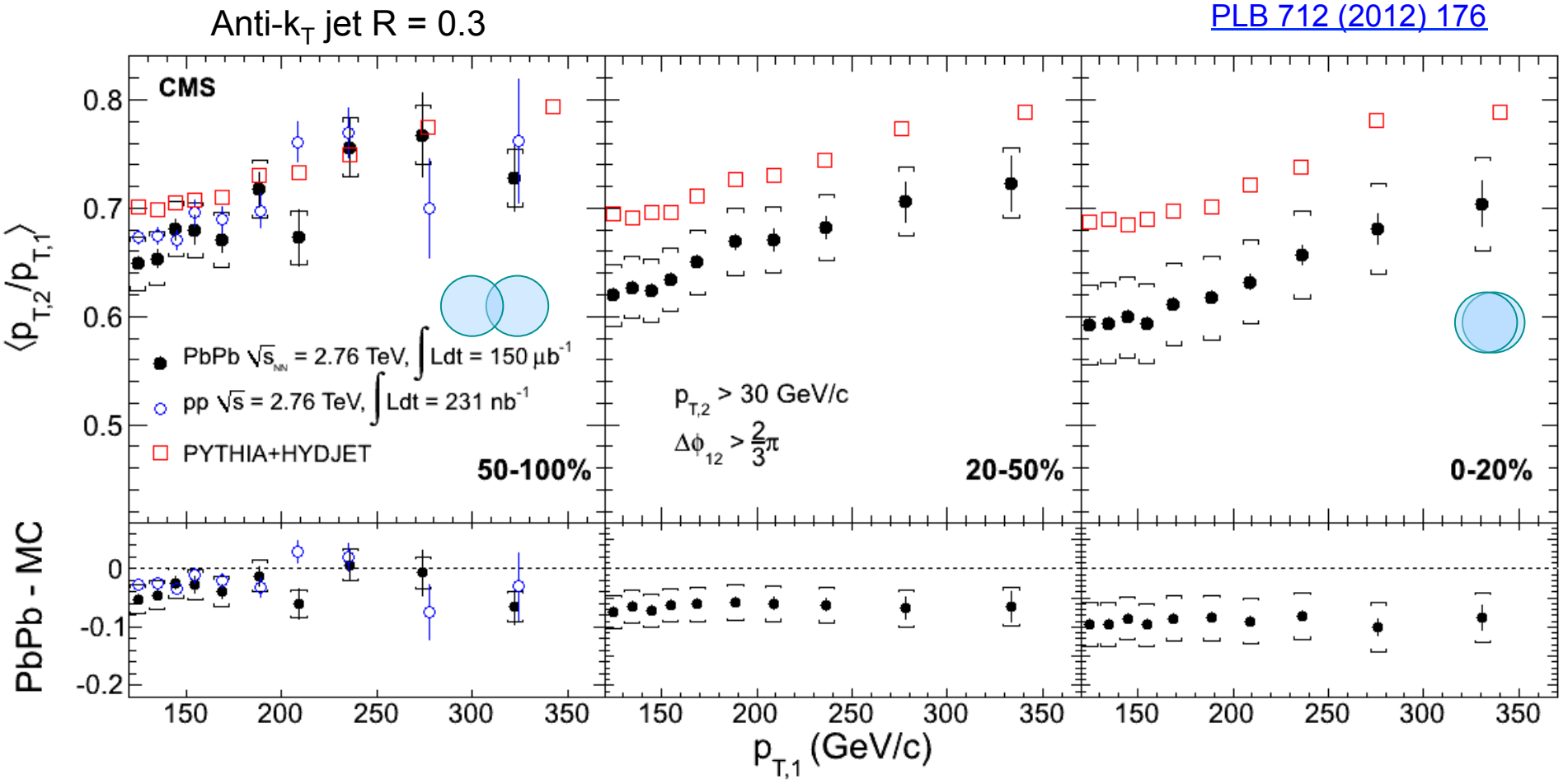
R_{AA} of jets down to low p_T!

Inter-experiment Comparisons





Dijet p_T Ratio (p_{T2}/p_{T1})



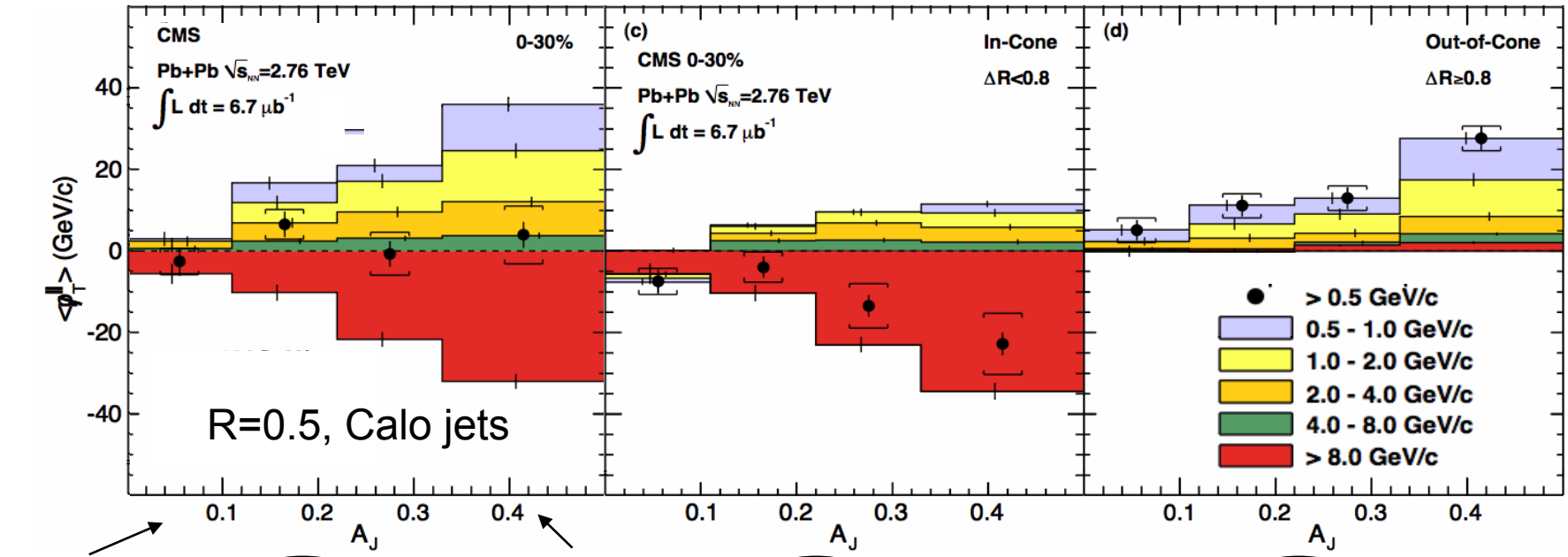
- Energy imbalance increases with centrality
- Jet quenching persists to very high p_T

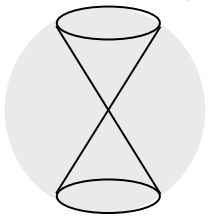
Missing p_T

$$\not{p}_{\mathrm{T}}^{\parallel} = \sum_{\mathrm{Tracks}} -p_{\mathrm{T}}^{\mathrm{Track}} \cos\left(\phi_{\mathrm{Track}} - \phi_{\mathrm{Leading\ Jet}}\right)$$

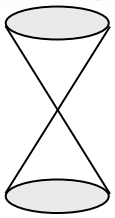
PRC84 (2011) 024906

0-30% Central PbPb

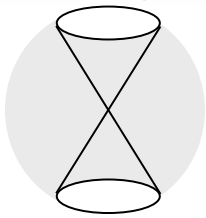




All tracks



Tracks in the jet cone $\Delta R<0.8$

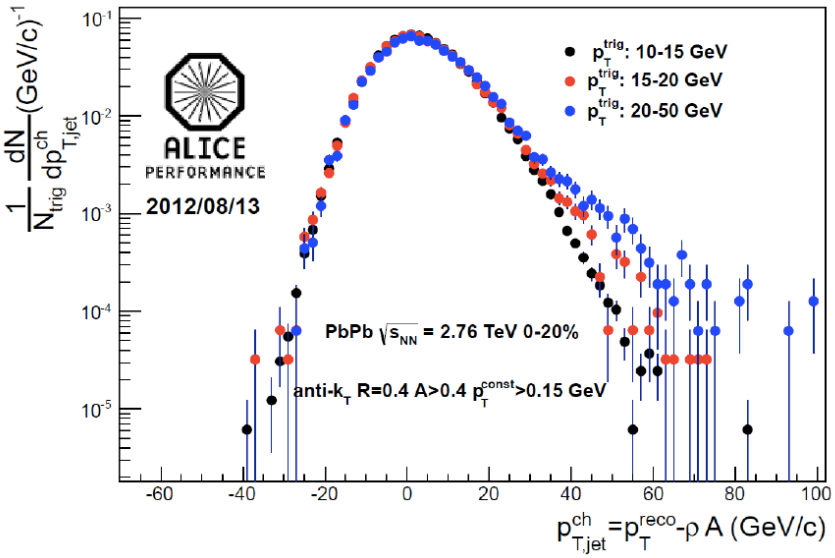


Tracks out of the jet cone $\Delta R>0.8$

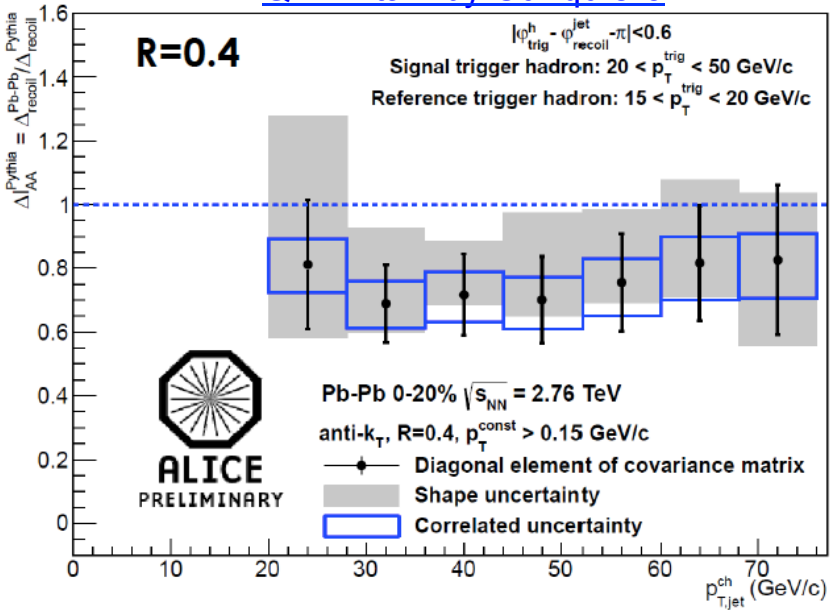
The momentum difference in the dijet is balanced by low p_T particles outside the jet cone

Recoil Jets in ALICE

- Studying jets recoiling from a high p_T charged hadron
- Large UE event background for low p_T recoil jets



QM12 talk by Cunquiero

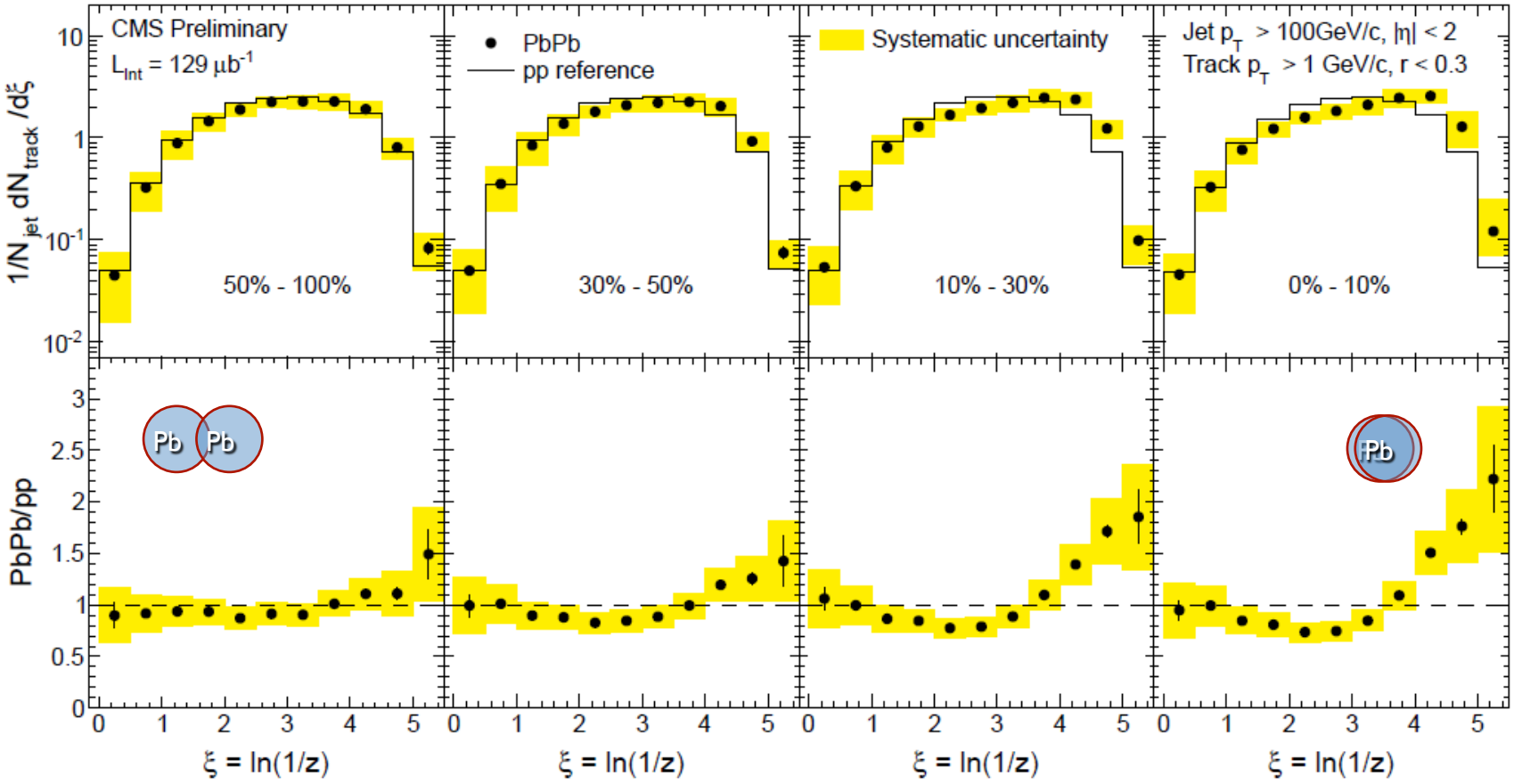


- UE event appears to be independent of hadron p_T
- Use low p_T trigger associated yield to subtract UE
- Able to observe suppression of recoil jet in I_{AA}

“Fragmentation Functions”

CMS-PAS-HIN-12-013

Defined w.r.t. reconstructed jet



- Deficit at intermediate z compensated at low z
- Consistent results from ATLAS

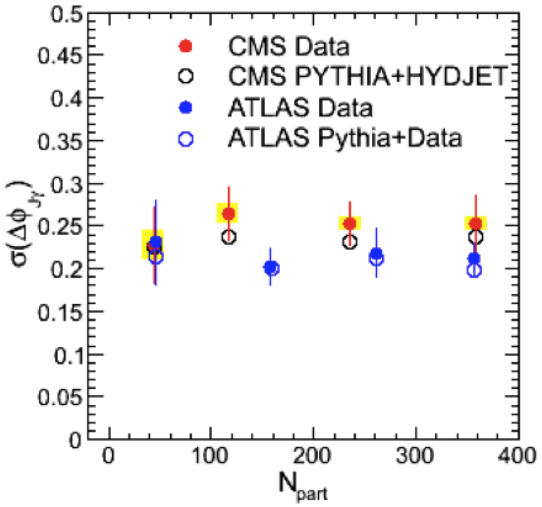
$$z = \frac{p_{\parallel}^{\text{track}}}{p^{\text{jet}}}$$

Photon+Jet

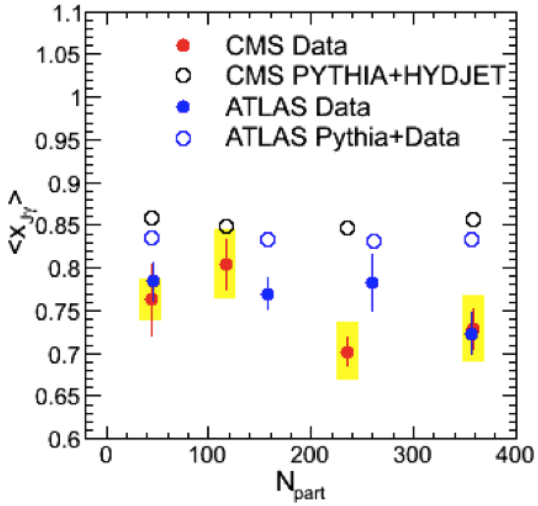
- γ p_T > 60 GeV/c
- Jet p_T > 30 GeV/c
- $\Delta\phi$ > 7/8 π

CMS: PLB 718 (2013) 773
ATLAS-CONF-2012-121

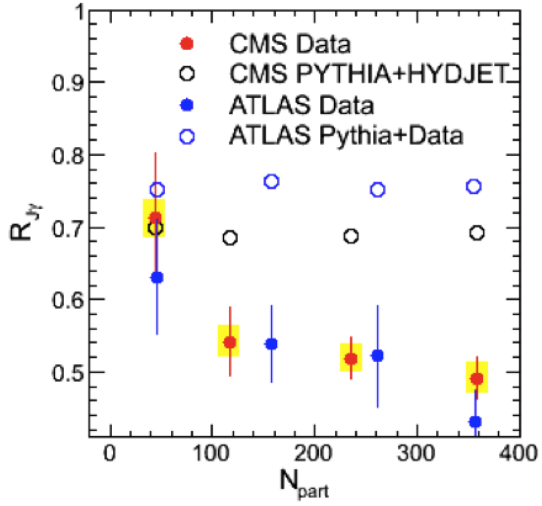
Azimuthal correlation



Jet p_T / photon E_T

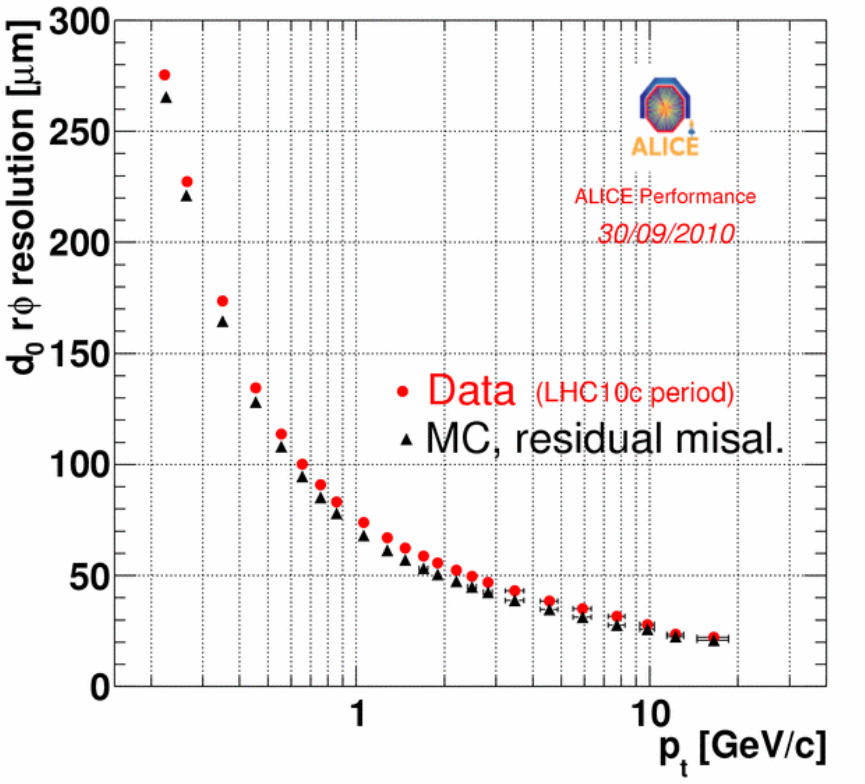


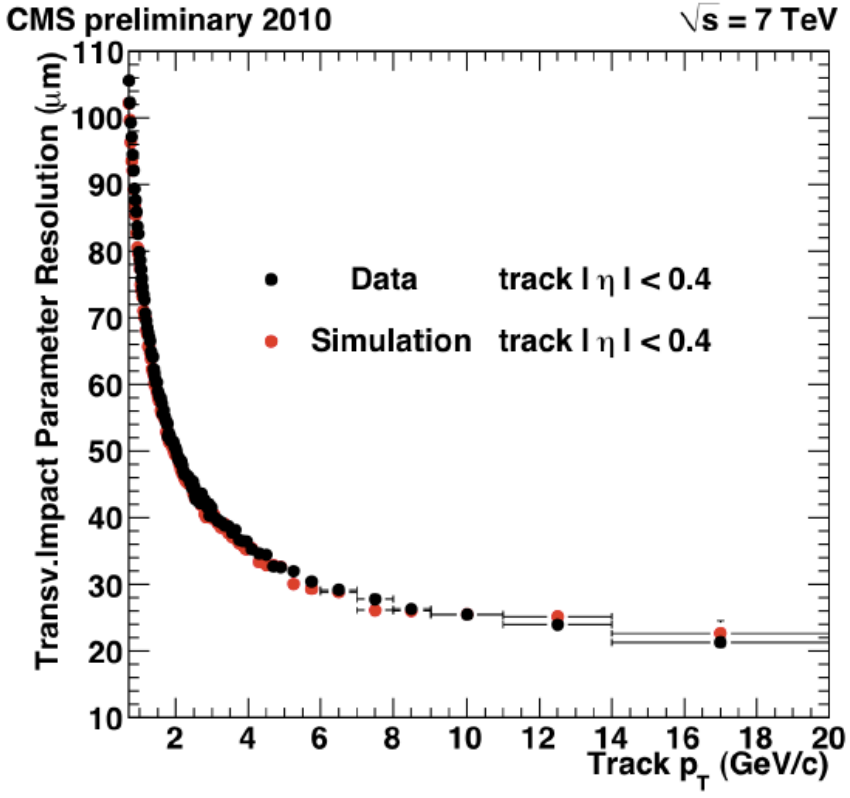
Fraction of found jets



- Photon ID based on isolation and shower shape
- CMS and ATLAS consistent within errors / experimental effects
- Also Z+jet from ATLAS

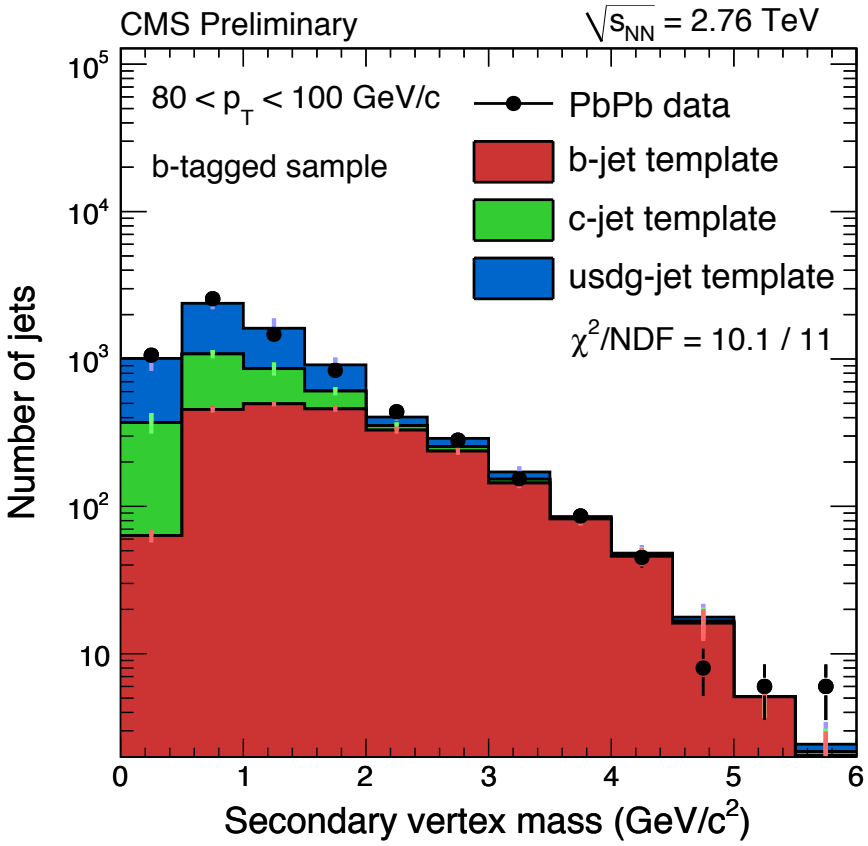
Impact Parameter Resolution



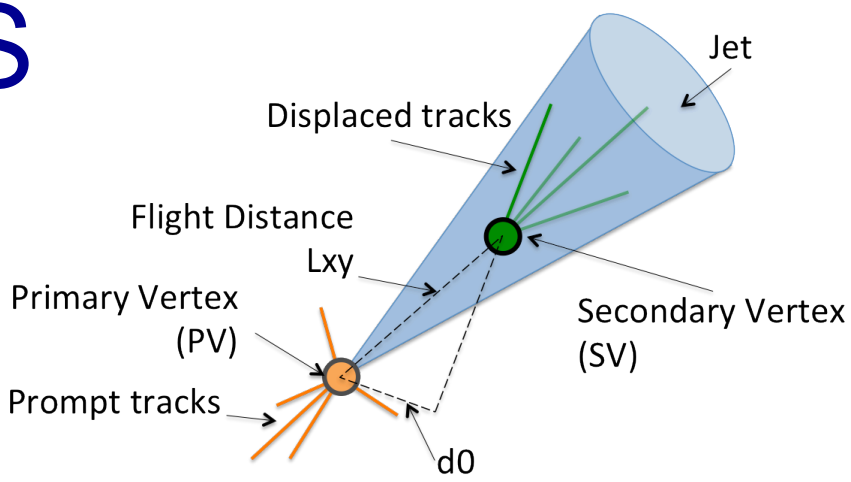


- Good IP resolution is the key to b-tagging
- Similar b-tagging performance from ATLAS and CMS
- ALICE offers best IP resolution at the LHC

b-Tagging in CMS



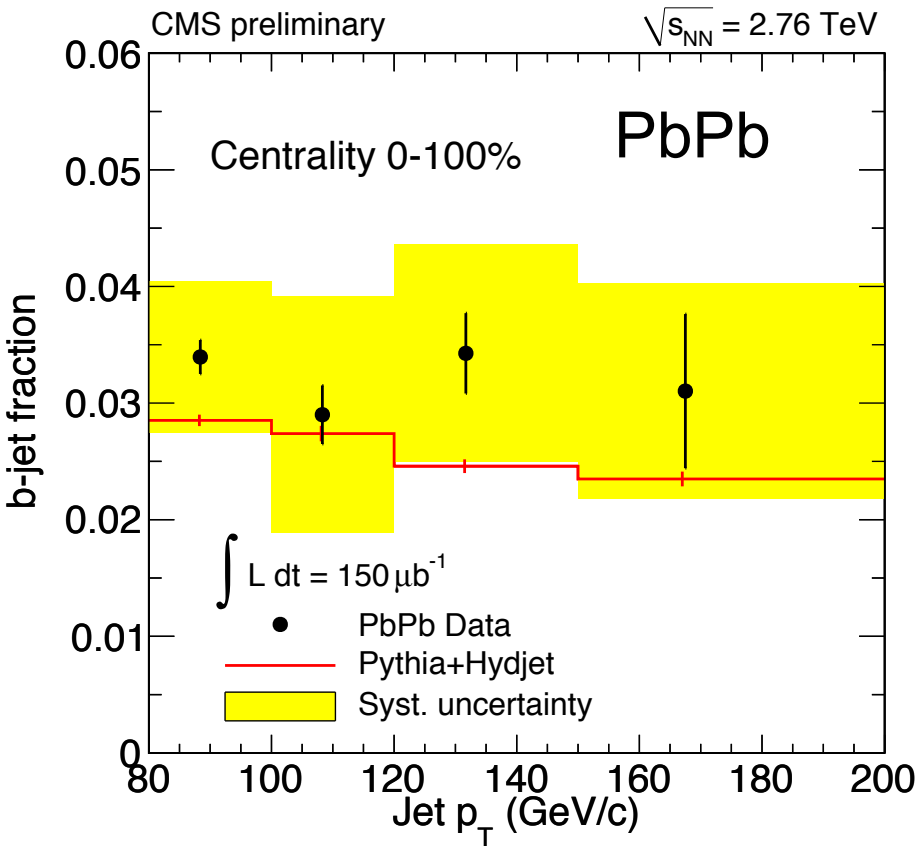
CMS-PAS-HIN-12-003

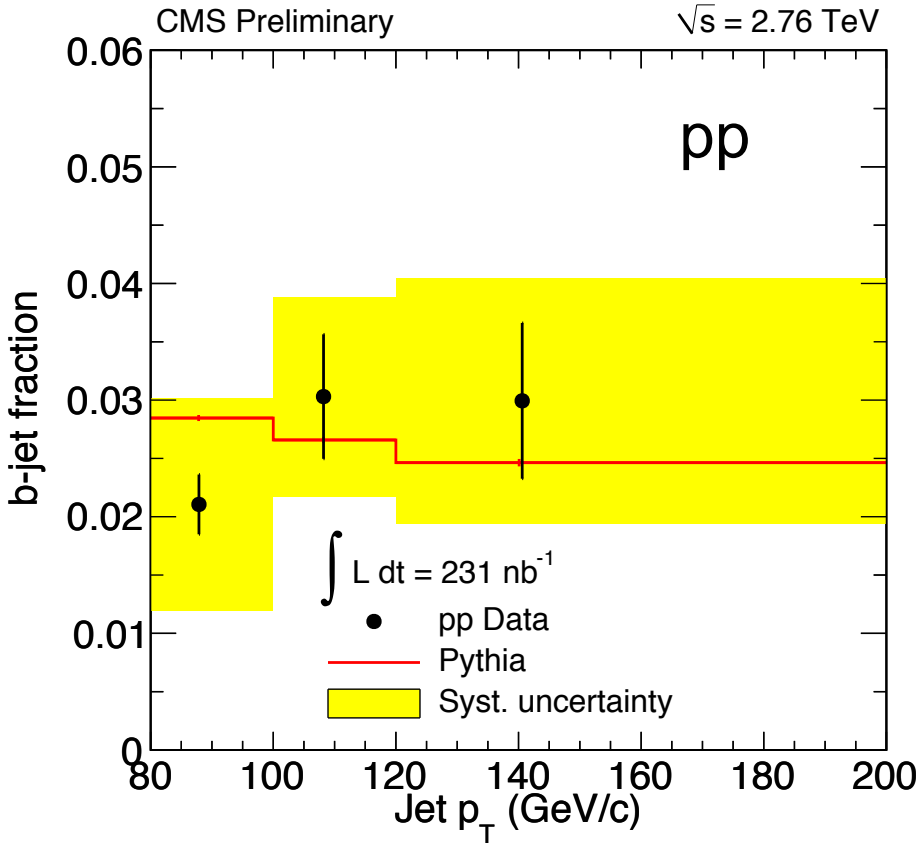


- Jets are tagged by direct reconstruction of secondary vertices
- A selection is made on the flight distance significance
- The b-jet purity is extracted via a template fit

b-Jet Fraction

CMS-PAS-HIN-12-003





- Ratio of b-jets to inclusive jets
- pp data consistent with PYTHIA
- PbPb b-jet fraction unmodified → b-jets suppressed like light jets

Outlook

- LHC Run 1 provided a number of firsts for HI
  - Clean jet measurements
  - Photon-jet and Z-jet
  - b-Tagging
- Now that the landscape has been mapped out careful studies are in order
  - Coordination of methodologies amongst experiments and with theory
  - Beating down systematics
- The luminosity will continue to increase, it's up to us to take advantage of it