Jet Quenching in Heavy Ion collisions at the CMS detector

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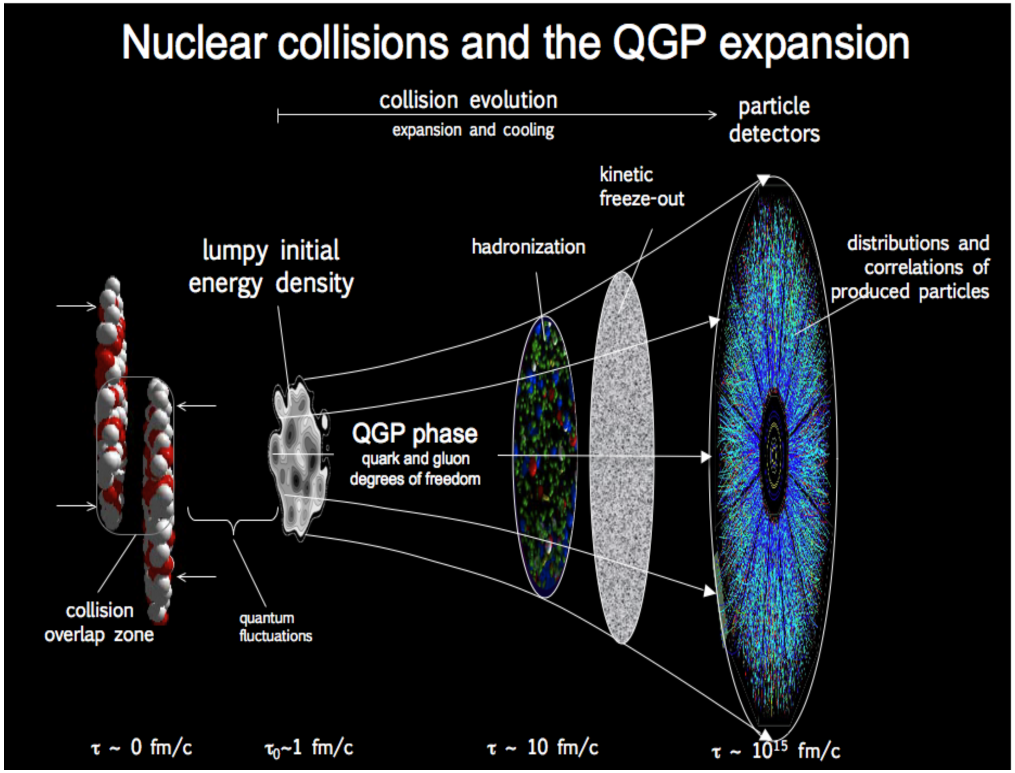
HI Collisions



QGP – Quark Gluon Plasma

The Big Bang
- Existed a few millionths of a second after.

The Little Bang
- Recreated in the lab using relativistic collisions of heavy ions

http://www.bnl.gov/rhic/news2/news.asp?a=2870&t=today

Motivations

- Jet quenching observed in AA collisions (strong interaction of medium with high-p_T particles)
  - Jet "Structure" modification ?
  - What do we know about the "lost" energy ?
  - Flavor dependence of strong coupling with the medium?
  - Jet quenching at CMS

- What can we learn from pPb collisions?
  - Initial state, Cold Nuclear Matter effects?

- Datasets:

  PbPb (2011) and pp (2013) @ 2.76 TeV

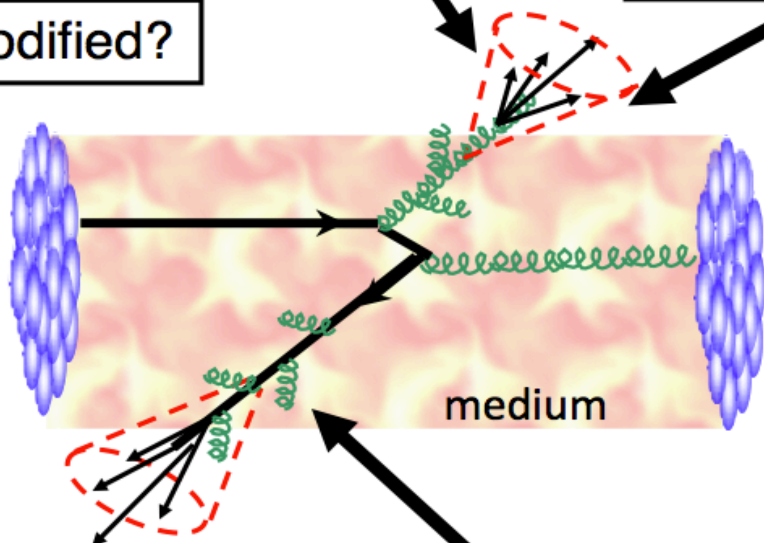
  pPb (2013) @ 5.02 TeV

Questions to be answered (pictorially)

Can we recover the lost energy by jet reconstruction?

Flavor dependence of jet quenching?

Is the initial state modified?

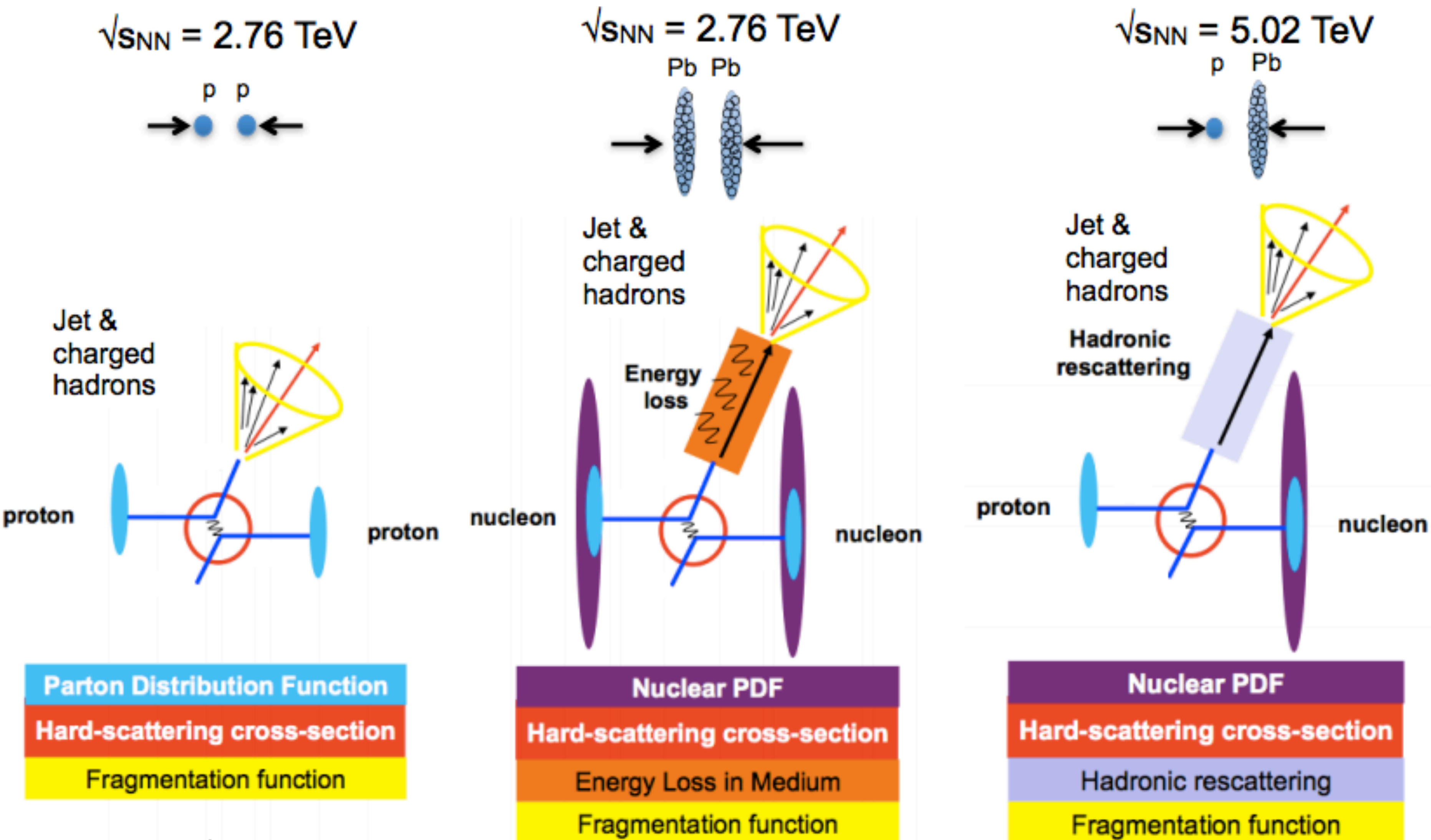


Y.J Lee QM2014

Is the jet structure modified?

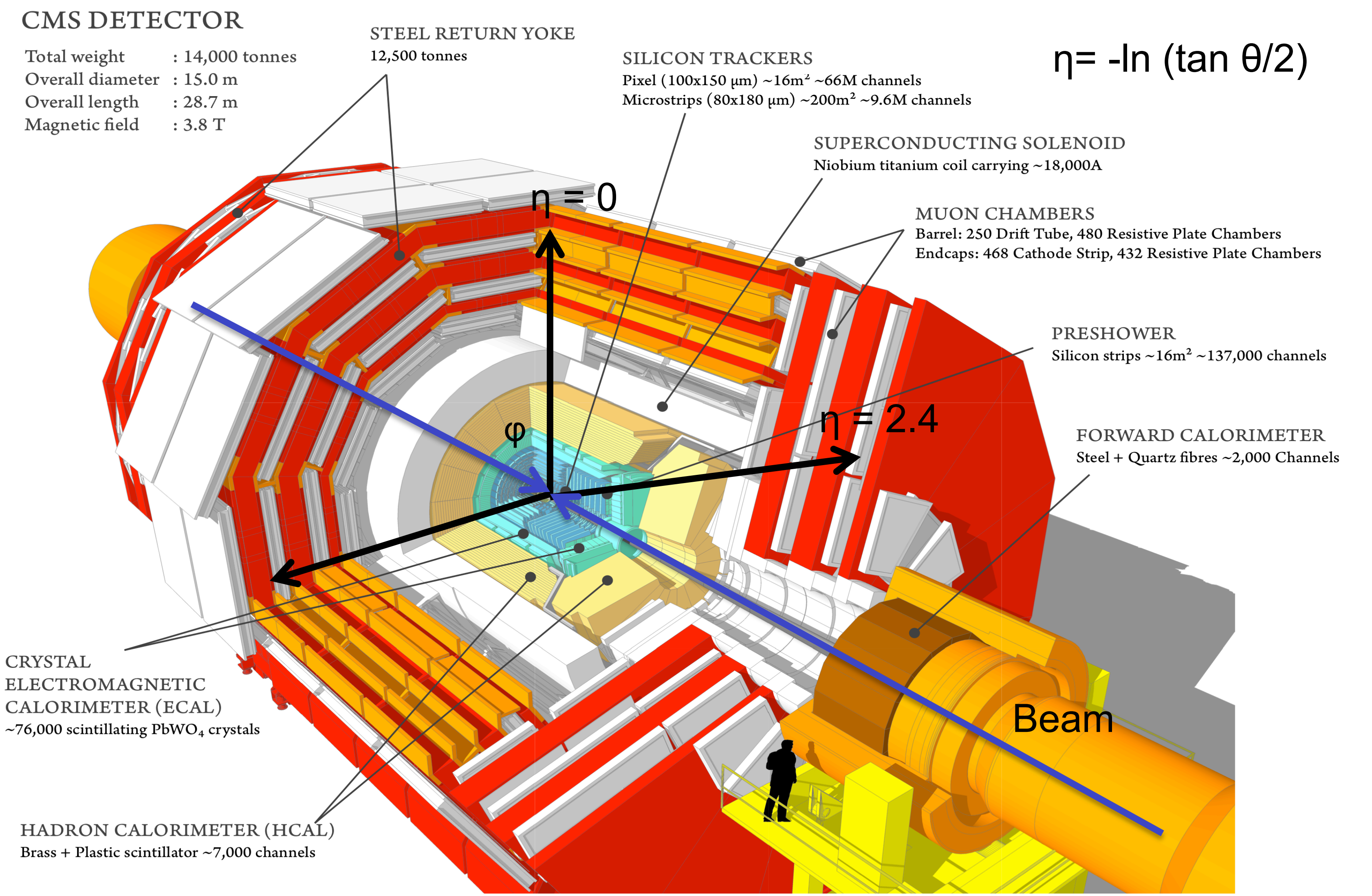
Where does the lost energy go?

What we measure

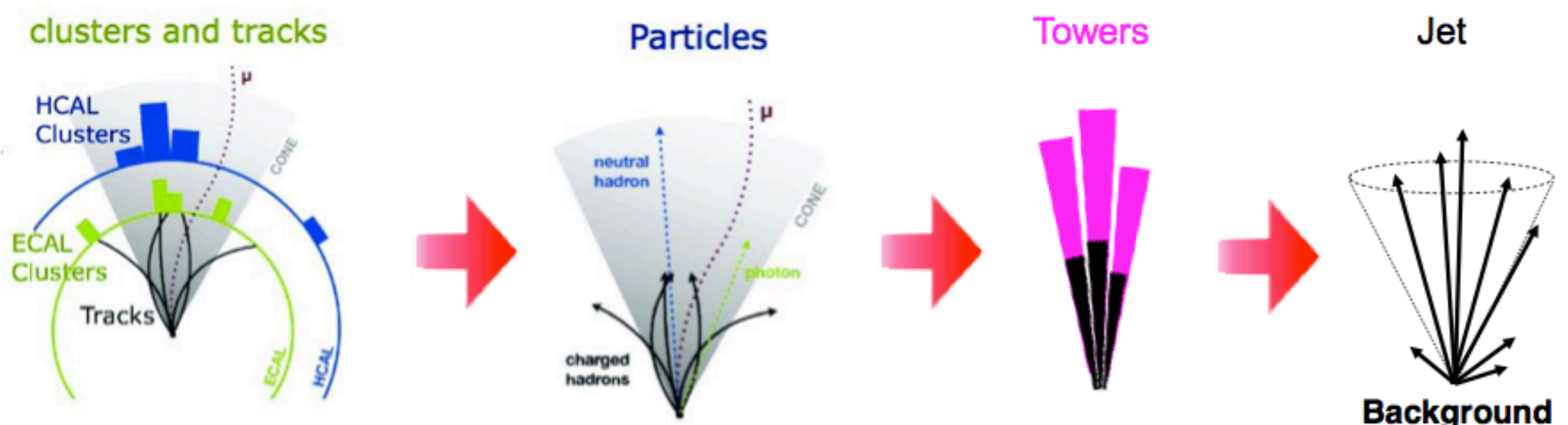


E.Applet QM2014

CMS


CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
η= -ln (tan θ/2)
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
η = 0
PRESHOWER
Silicon strips ~16m² ~137,000 channels
η = 2.4
φ
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
Beam
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

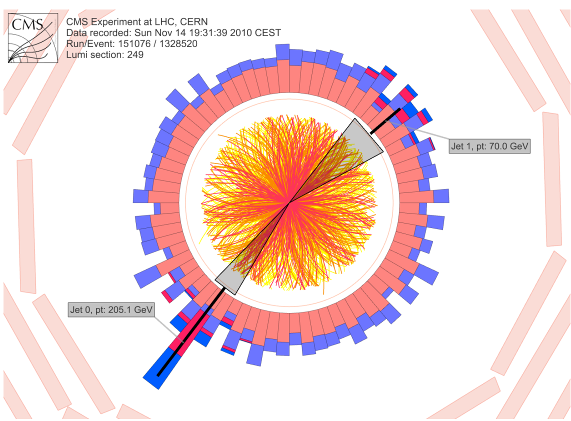
Jets in CMS



Anti-k_T algorithm is used in most of CMS publications

For instance, $\Delta\eta \times \Delta\phi$ 0.076 x 0.076 in barrel

Background subtraction and jet clustering



Calorimeter (CALO) Jets: Using Calorimeter energy deposits.
Particle Flow (PF) Jets: Combines information from all sub detectors to make PF candidates, which are then clustered.

Background subtraction

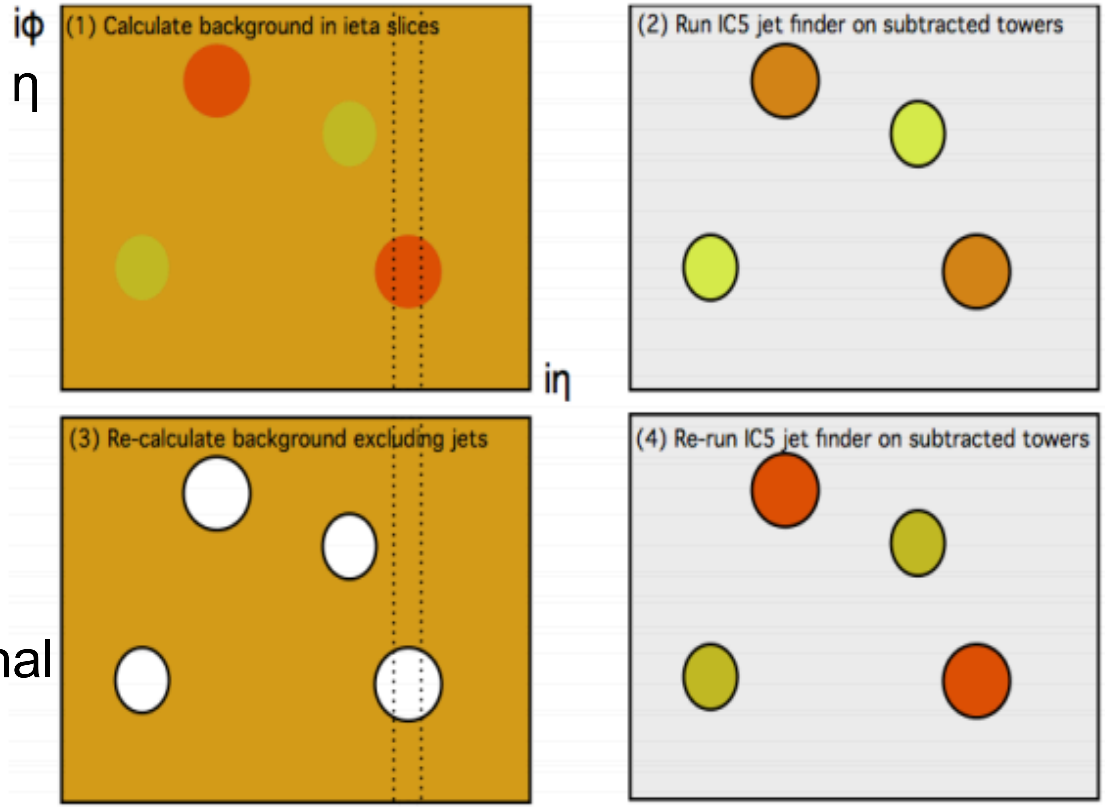
EPJC (2007) 117.

1. Background (bkg) energy per tower calculated in strips of η

2. Jet finder run on subtracted (sub) towers

3. Background energy recalculated excluding jets

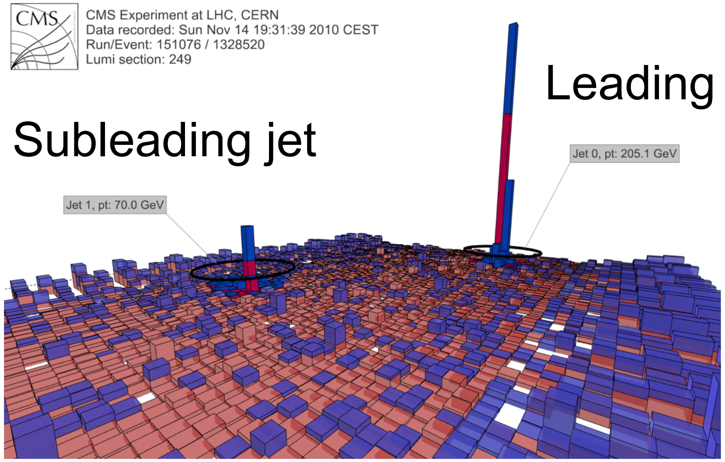
4. Rerun Jet algo on bkg-sub towers without jets -> get the final jets.

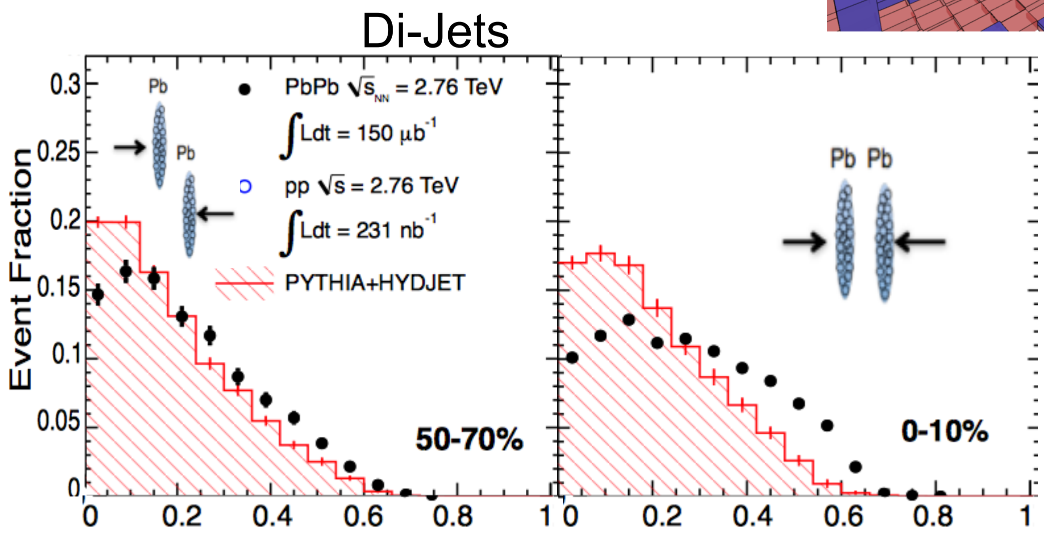


Jet Quenching: Observation

PLB 712 (2012) 176

- Strong jet-quenching in PbPb collisions
- Dijet p_T imbalance observed
- subleading jets quenched more than leading jets



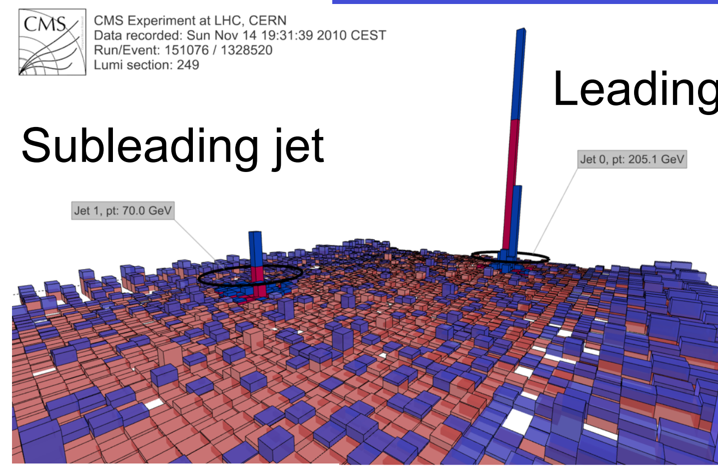


contd.

PLB 712 (2012) 176

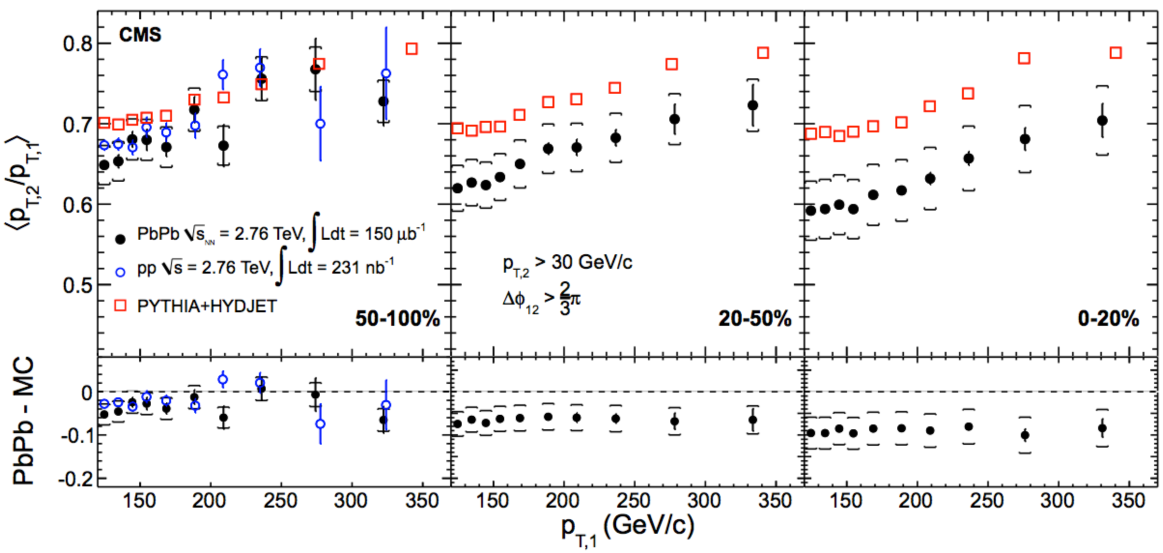
- Strong jet-quenching in PbPb collisions
- Dijet p_T imbalance observed

Miraculously flat over the p_T range observed!



Subleading jet

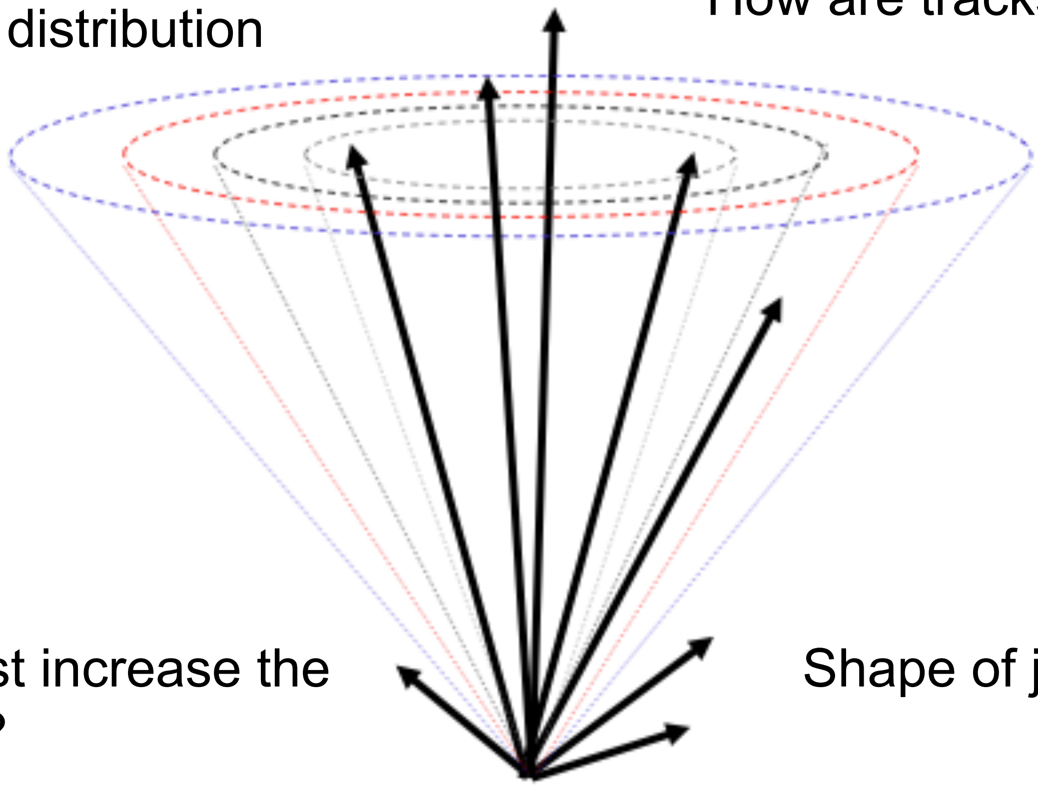
Leading jet



What do we learn from jets?

Track energy distribution
Inside jet ?

How are tracks aligned?



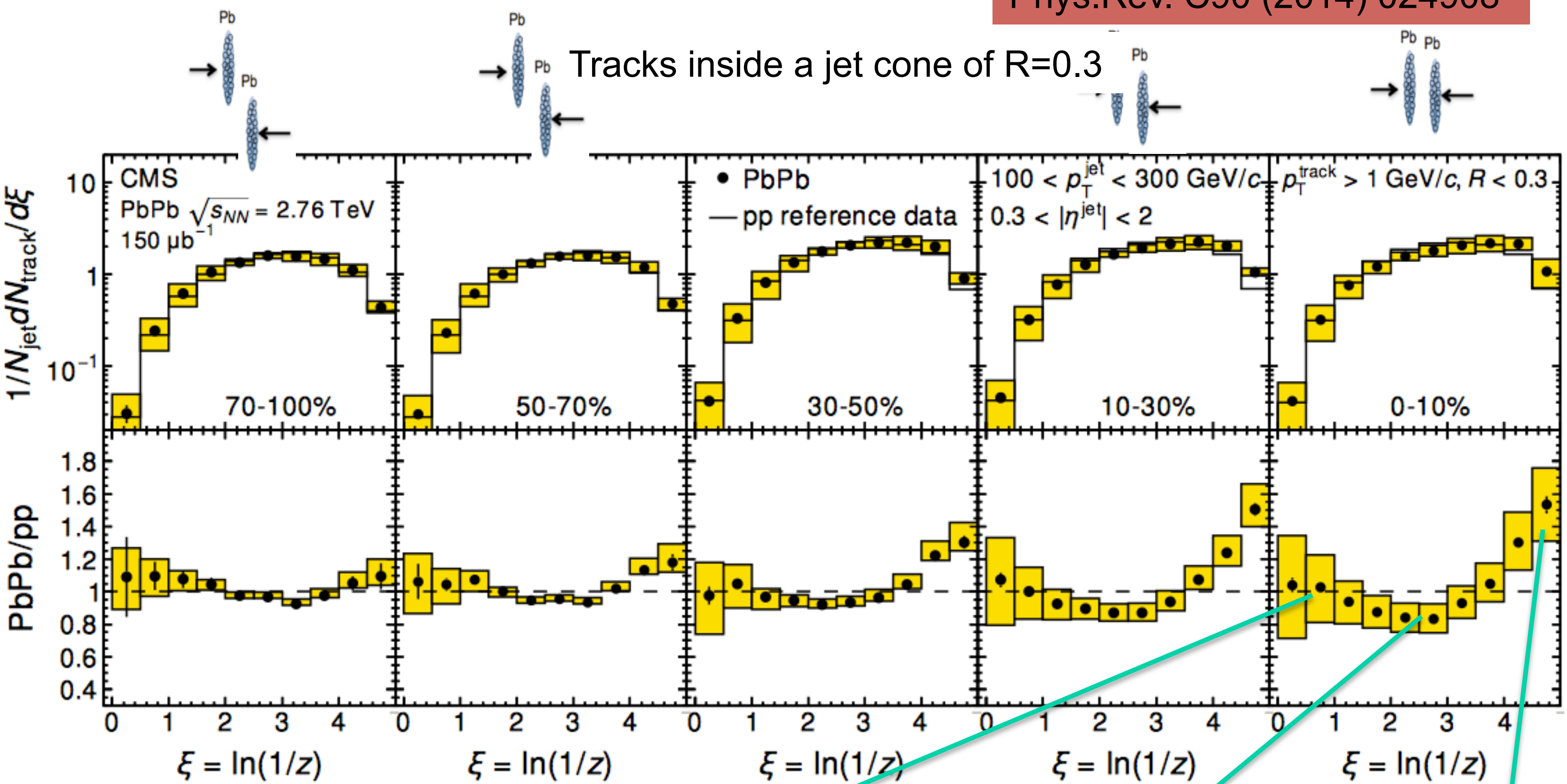
Can we just increase the
Jet radius?

Shape of jet ?

Jet Fragmentation

Phys.Rev. C90 (2014) 024908

Tracks inside a jet cone of R=0.3



$z = p^{track}_{||} / p_{jet}$

High p_T – no modification

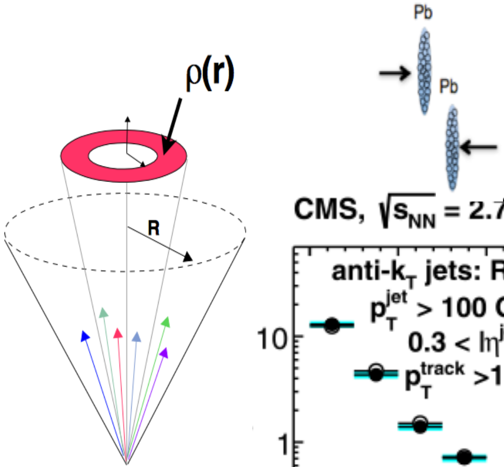
Suppression of intermediate p_T in the cone

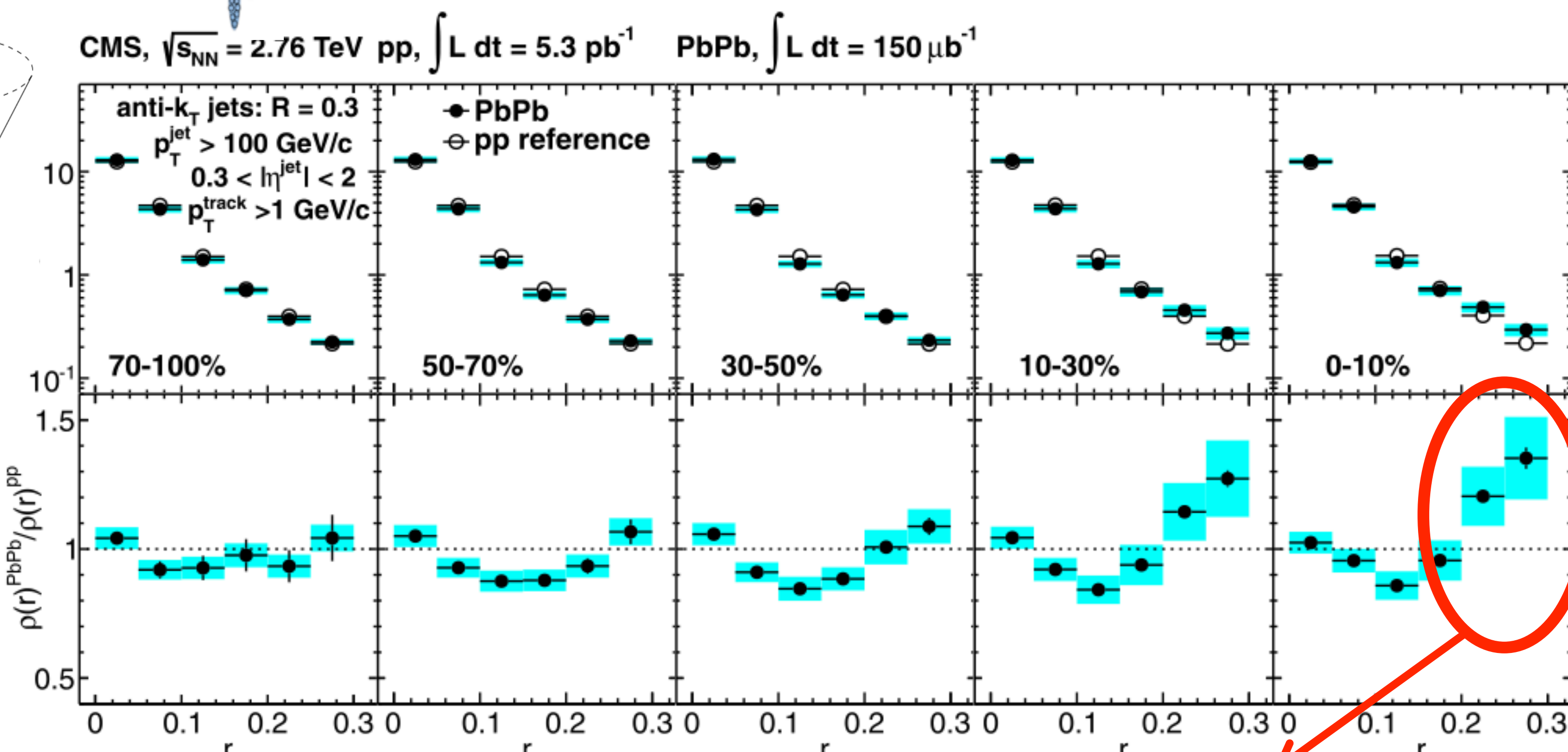
Enhancement at low p_T

Shape modification?

PLB 730 (2014) 243

First experimental Jet Shapes in HI





$$\rho(r) = \frac{1}{f_{ch}} \frac{1}{\delta r} \frac{1}{N_{jet}} \sum_{jets} \frac{p_T(r - \delta r/2, r + \delta r/2)}{p_T^{jet}}$$

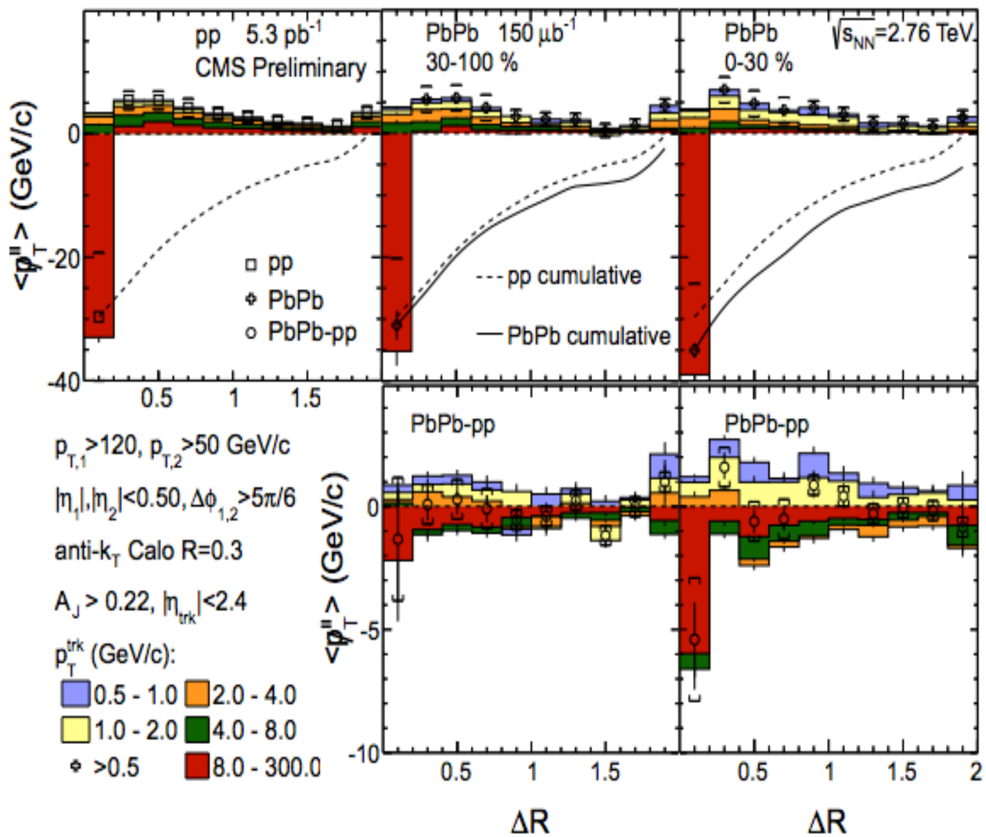
Broader jet shapes in PbPb in most central collisions

Where does the energy go?

CMS-HIN-14-010

Sum charged particles for unbalanced A_J>0.22 dijets in central (0-30%) PbPb

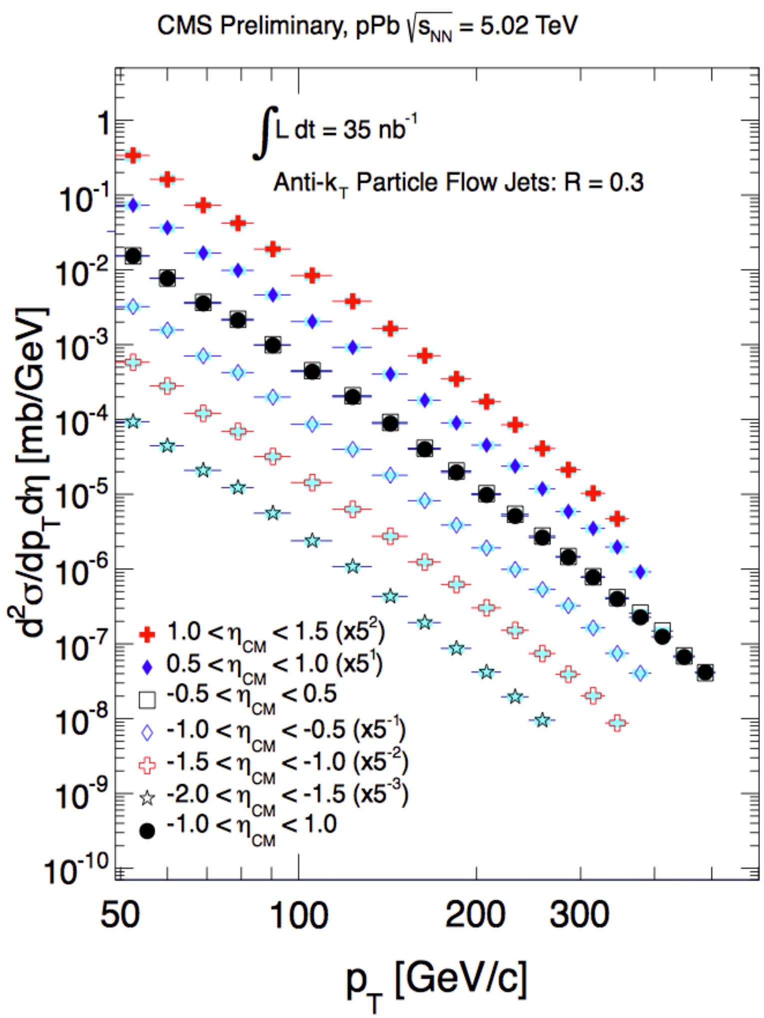
- 35 GeV/c of high p_T tracks missing from away side jet at ΔR=0.2
- Balanced by low p_T particles up to very large ΔR=2.0
- PbPb-pp : result shows a different p_T distribution
- Take the p_T cumulative of all tracks – total angular pattern is similar in PbPb and pp

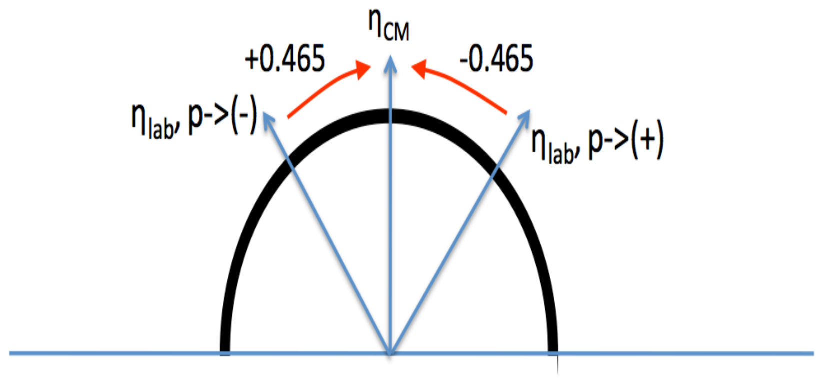


Able to recover the lost energy by going to Large ΔR in the away side jet

Initial State effects - pPb

CMS-HIN-14-001





- pPb collisions are natively asymmetric
  - E(proton) = 4 TeV, E(Pb) = 1.58 TeV/N
  - Distributions of jets are centered around ±0.465 units in η
- η distributions are corrected to the center-of-mass eta
- Pbp η distribution is "mirrored" (η -> -η)
  - This ensures consistency when pPb and Pbp results are used together

Nuclear modification factors

$$R_{AA} = \frac{dN^{AA}_{jets}/dp_T}{\langle N_{coll} \rangle \, dN^{pp}_{jets}/dp_T} = \frac{dN^{AA}_{jets}/dp_T}{\langle T_{AA} \rangle \, d\sigma^{pp}_{jets}/dp_T}.$$

$\langle N_{coll} \rangle$ - No of participating nuclei per event

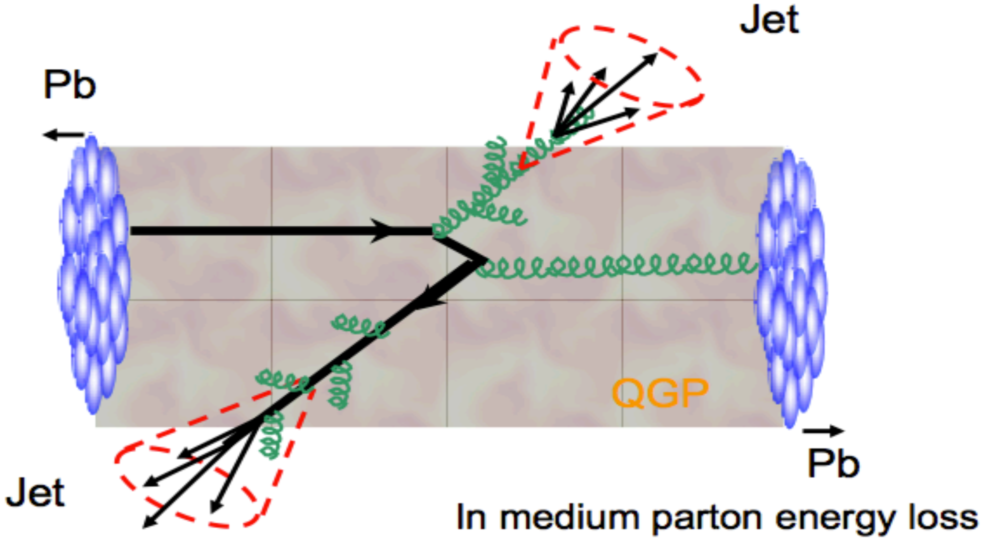
σ - cross section

$\langle T_{AA} \rangle$ - Average value of the nuclear 'thickness' function

$R_{AA} > 1$: Enhancement

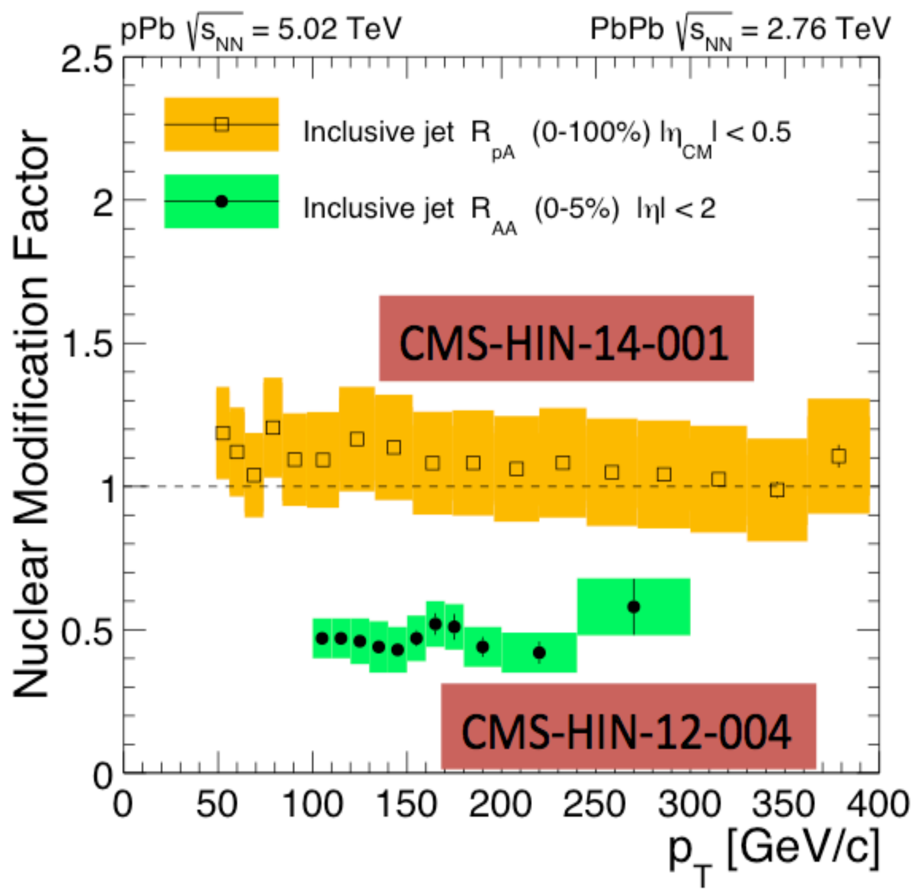
$R_{AA} = 1$: no medium effect

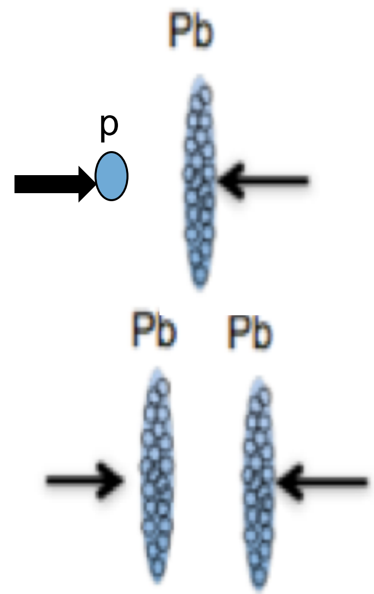
$R_{AA} < 1$: Suppression/ quenching



In medium parton energy loss
→ "Jet quenching"

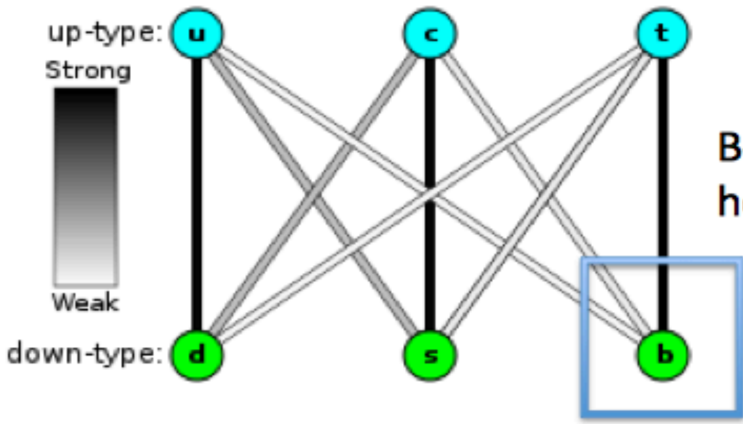
Modification in PbPb vs pPb for light and heavy jets



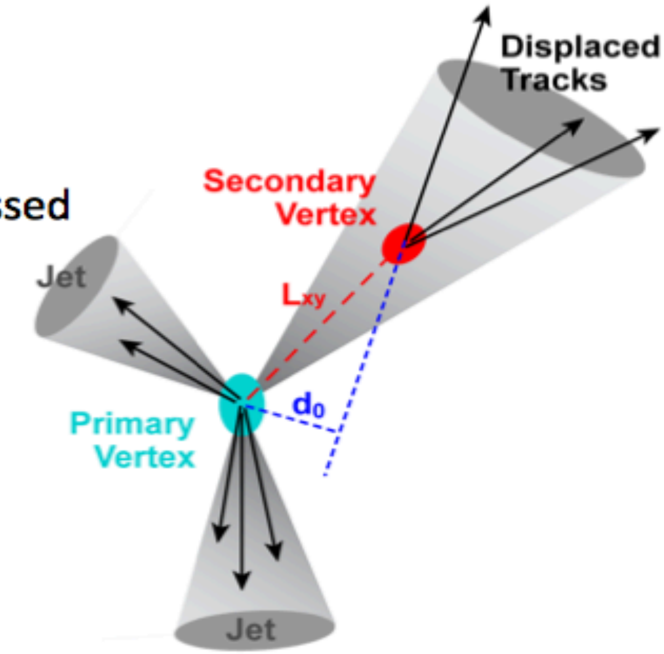


We do not observe any quenching for in the pPb case but a large suppression factor in the most central PbPb collisions

Heavy flavor Jets



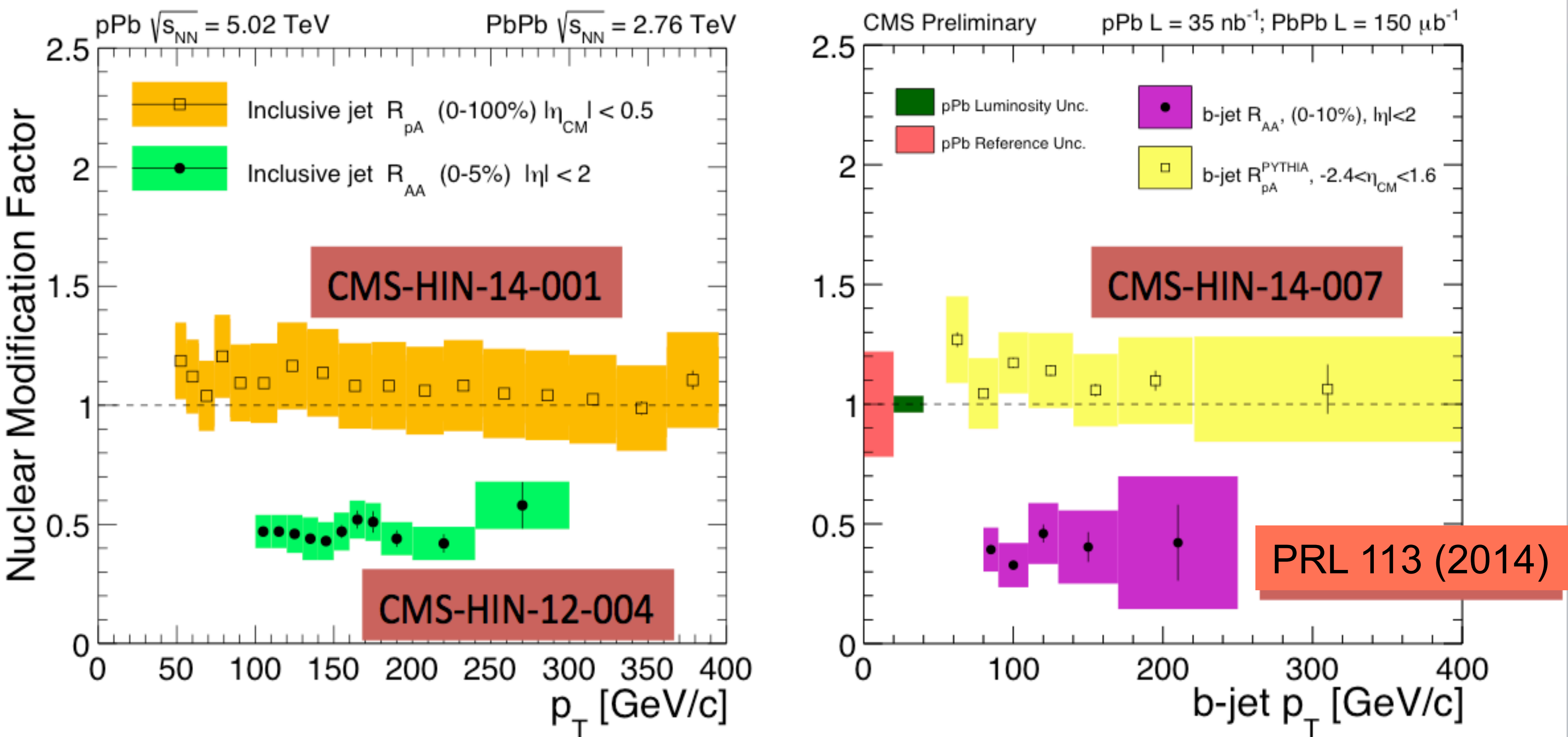
B-quark decays are heavily CKM-suppressed
-> Long lifetimes



- Primary identification method is using a **Secondary Vertex**
  - Long lifetime of b = mm or cm vertex displacement
- Flight distance (L_{xy}) of the secondary vertex used as a discriminating variable
- Tagging methods independent of secondary vertex reconstruction used as cross-check

Algorithms described in:
JINST 8 (2013) P04013

Modification in PbPb vs pPb for light and heavy jets



No observable difference between inclusive and b-jets in the explored p_T range

Conclusions

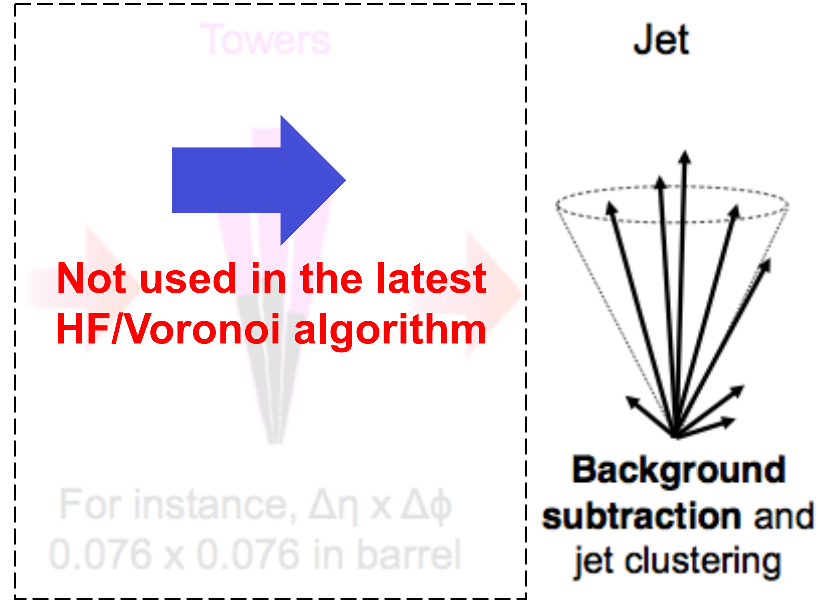
- Many observables showing independent confirmation of modification of jets in the medium (final state interactions)
- Jets are heavily quenched in most central PbPb collisions
- Jet Structure modification:
    - Excess of low p_T particles inside the jet cone (A_J measurements)
    - Observe quenching of intermediate range p_T particles (Jet Fragmentation)
- Quenched energy recovered by going to higher radii.
    - Lost energy carried away by low p_T particles away from the jet cone (Jet+Track measurements)

- Flavor dependence: So far no glaring differences between tagged and inclusive jets (in the explored p_T range). Need results from fully reconstructed D, B mesons (in both PbPb and pPb) to extend the pT range.

- Initial state in pPb collisions can be described by nPDF
    - Inclusive jets are not quenched

Back up Slides

Jets in CMS – part 2



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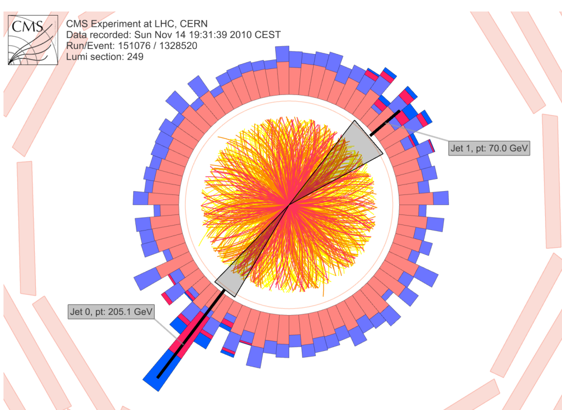
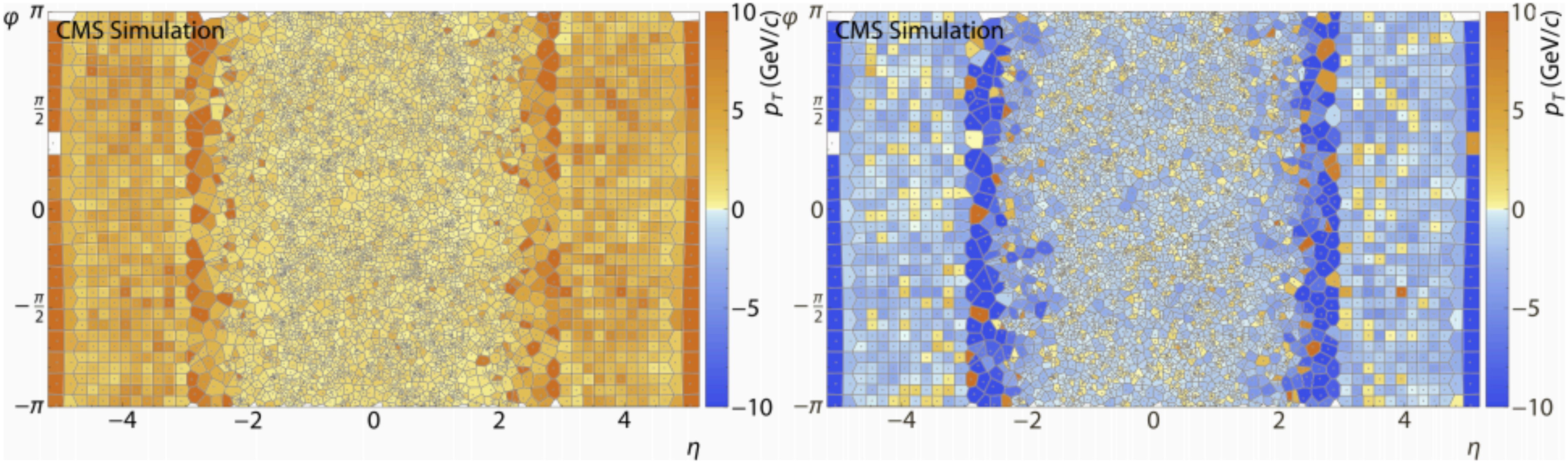


Calorimeter (CALO) Jets: Using Calorimeter energy deposits.
Particle Flow (PF) Jets: Combines information from all sub detectors to make PF candidates, which are then clustered.

HF/Voronoi algorithm

CMS-DP-2013-018

A Voronoi diagram in the (eta, phi)- plane is used to associate an unique area to each particle such that the UE density can be removed particle-by-particle



Voronoi tessellated HYDJET/GEANT particle-flow event (combined tracks and calorimeter towers) before (left) and after (right) subtraction.

Non physical negative particle/areas are "equalized" to maximally approximate to the original (real) jet distribution of radius R. (backup slides)

Flow (v2,..,v5) accounted for by projecting the expectation from the HF