Jet energy-loss studies with CMS

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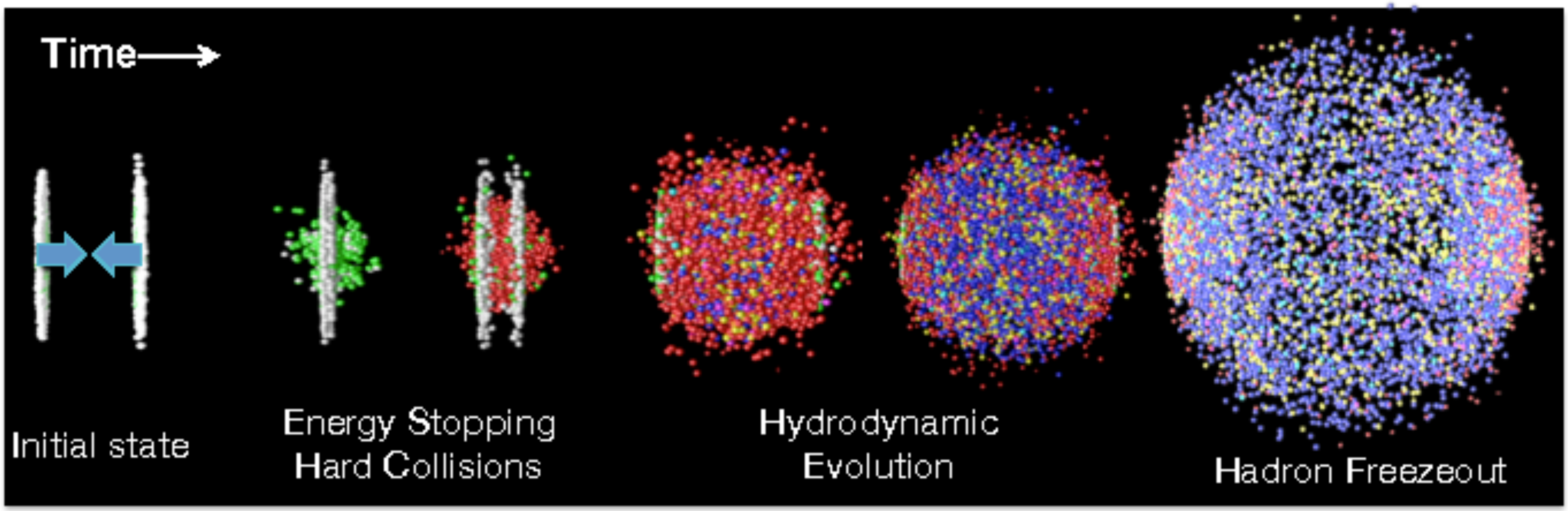
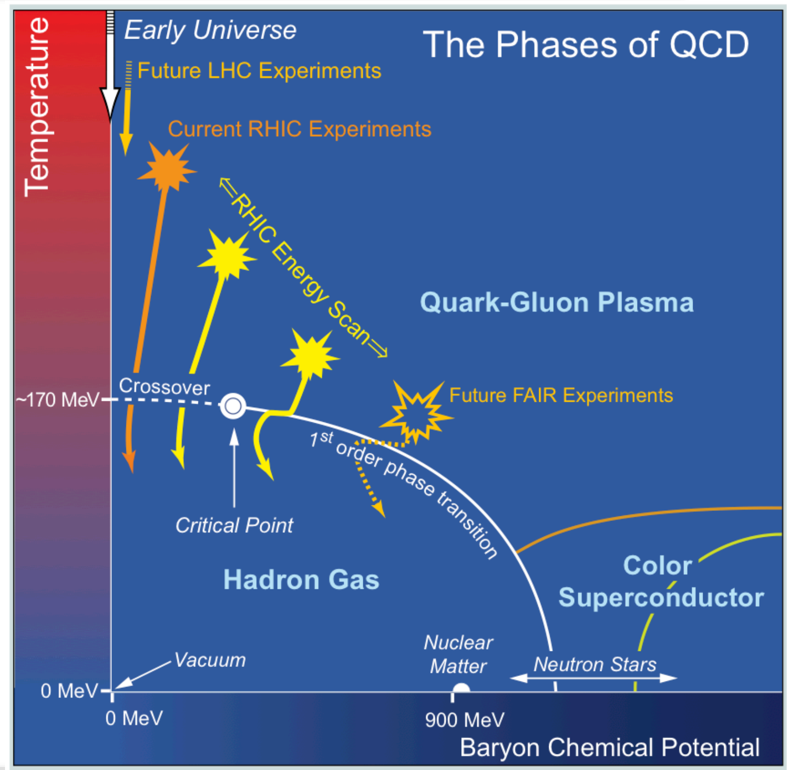
Collisions of heavy-ions

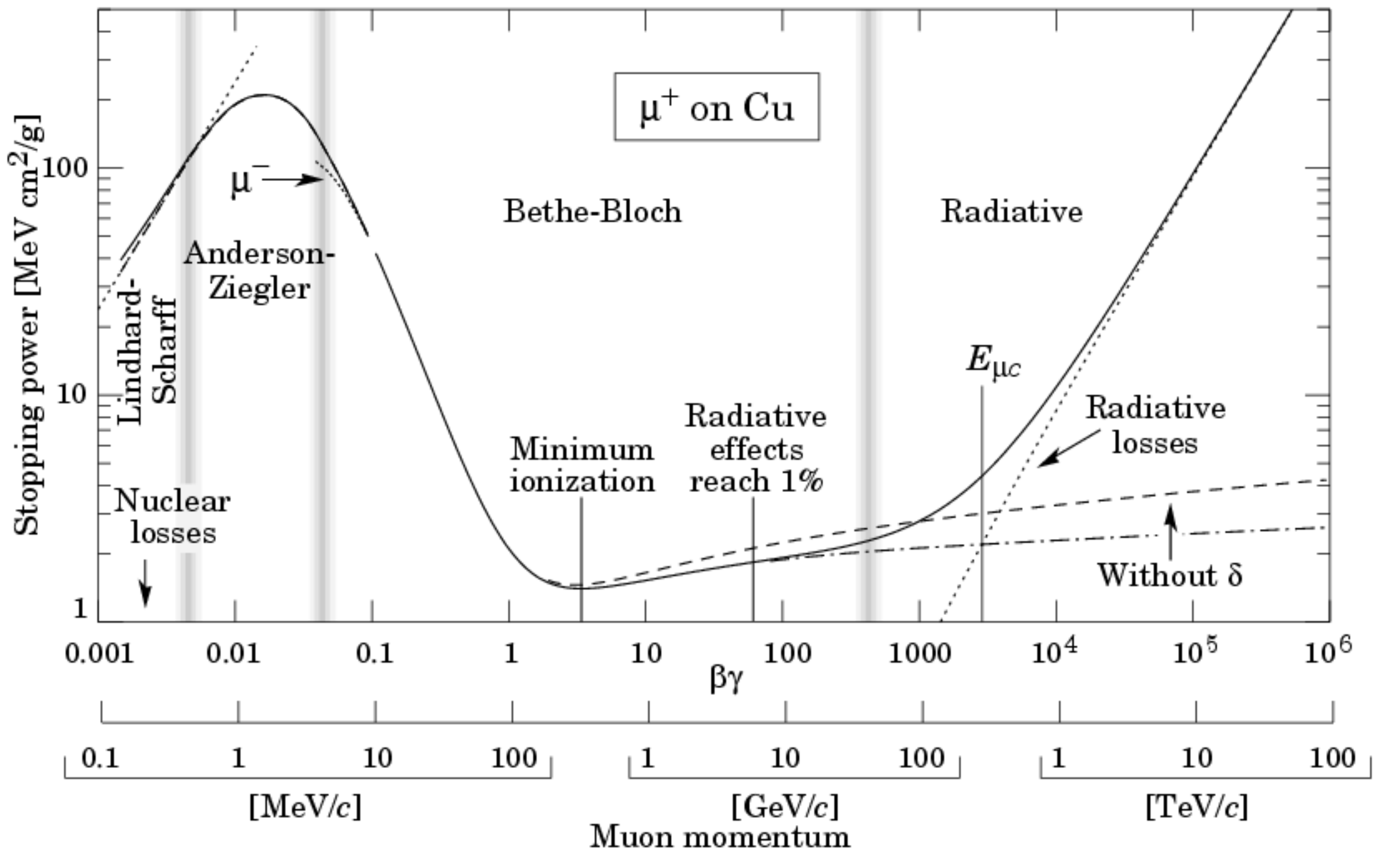


QCD matter:

- Temperature
- Mean-free-path
- Debye-mass
- dE/dx
- Viscosity

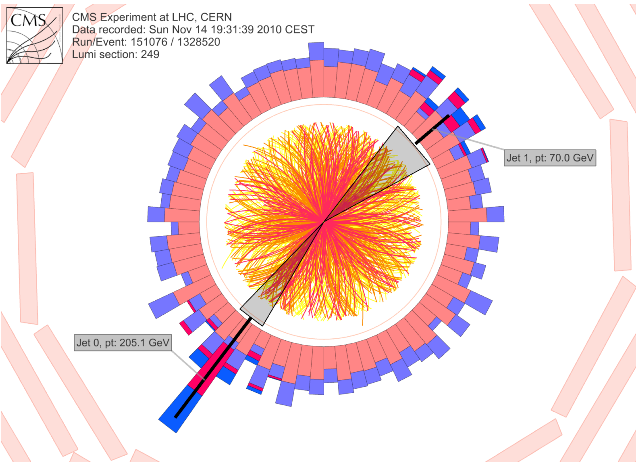


Properties of QCD medium



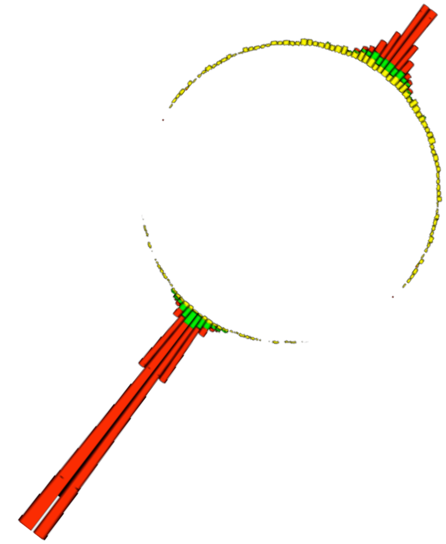
Can we build this curve for QCD interactions?

From experiment to theory



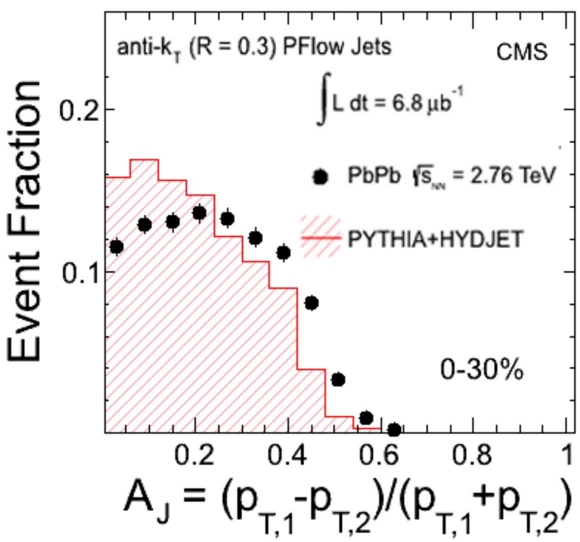
PART I

from detector to jets



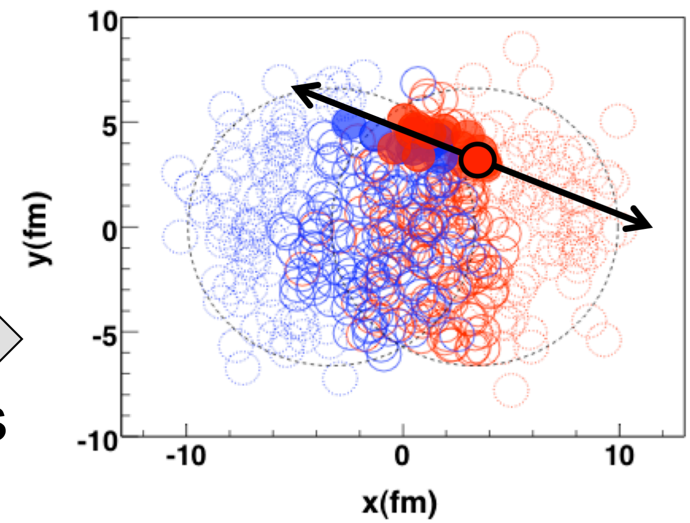
PART II

from jets to results

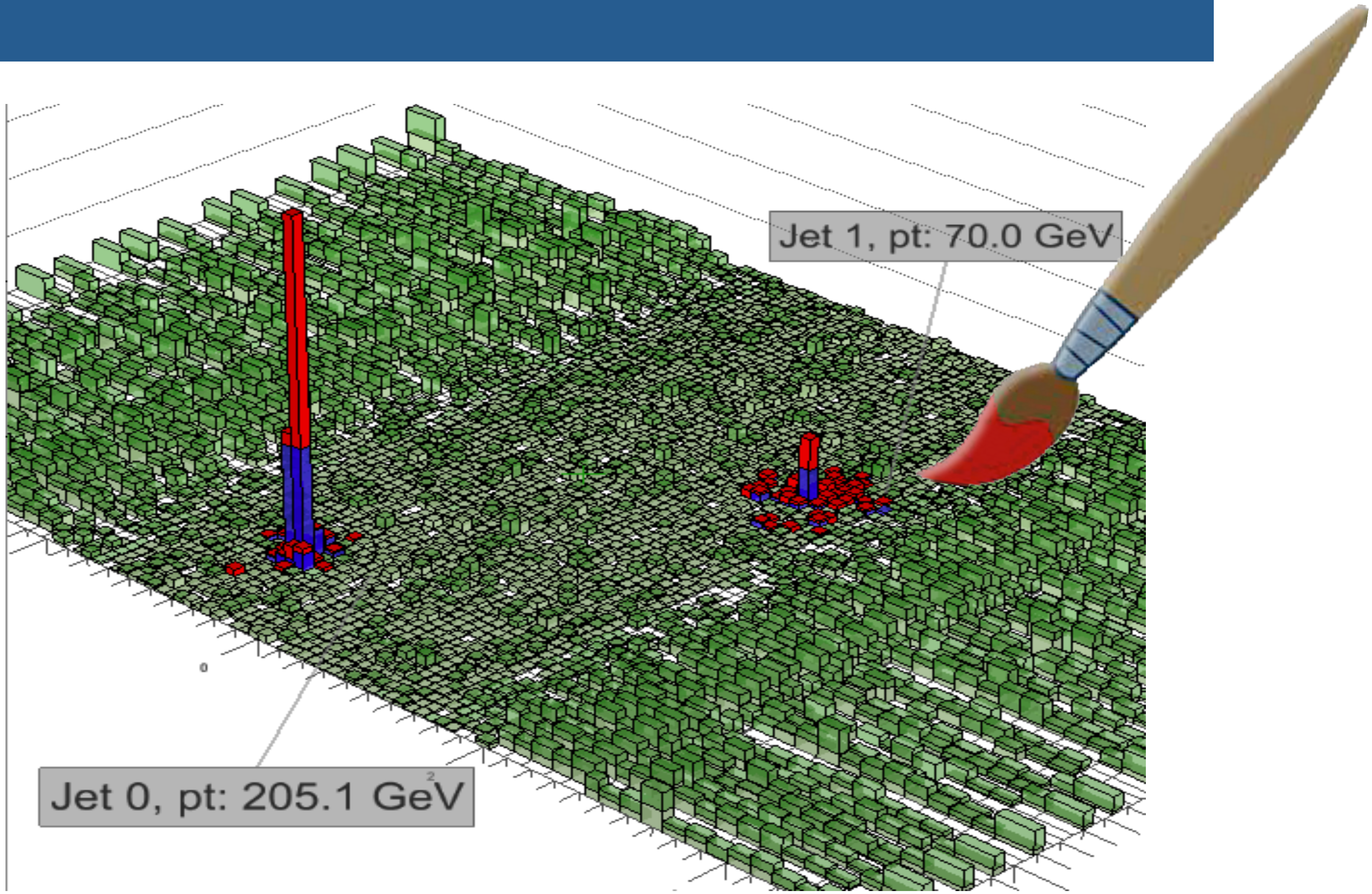


PART III

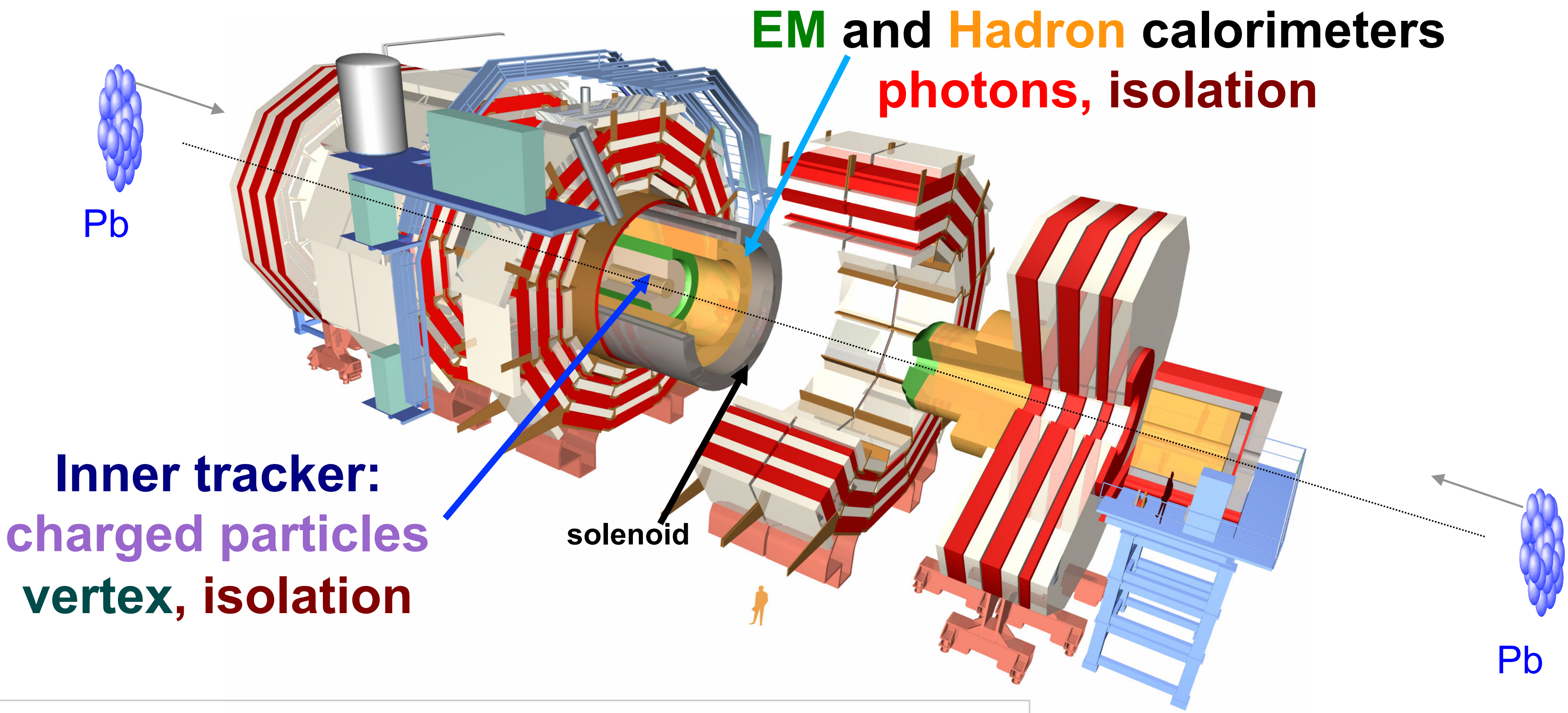
from results to physics



Part I : Jet reconstruction

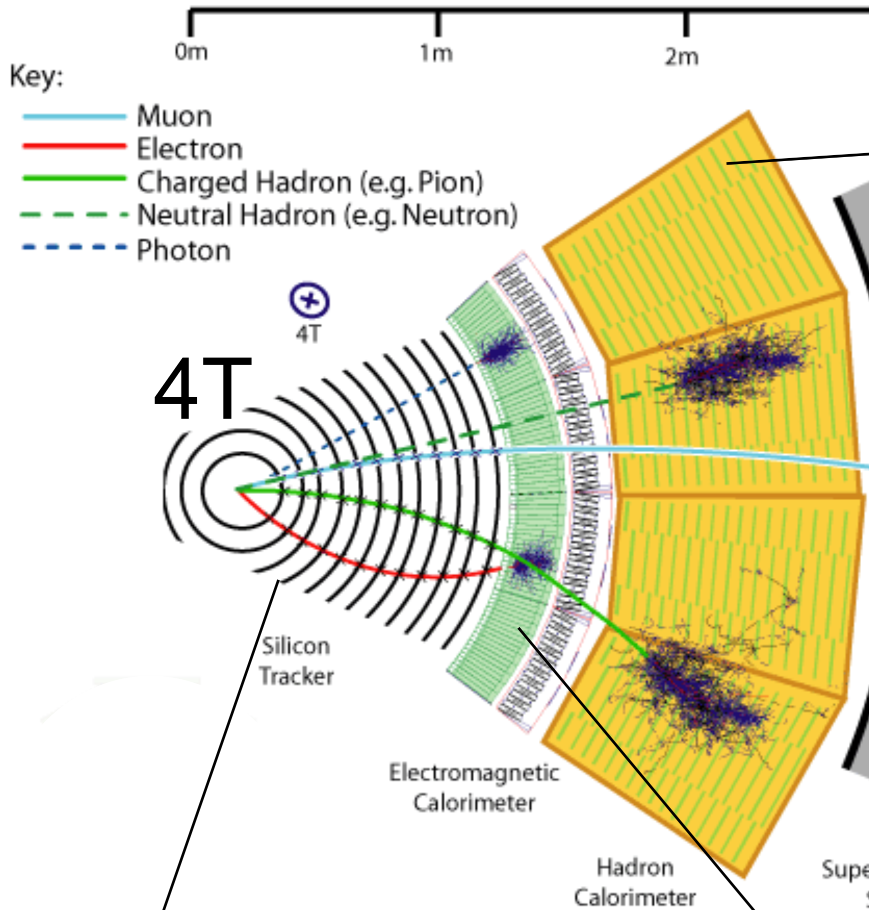


CMS detector



Muon	|η|< 2.4	
HCAL	|η|< 5.2	Calojet
ECAL	|η|< 3.0	
Tracker	|η|< 2.5	Particle Flow Jet

CMS detector



Hcal energy

- Neutral hadrons
- Capture charged hadrons that tracking missed
- Event-by-event shower fluctuations:
  - Non-linearity
  - Wide resolution
- Acceptance limited due to B-field
- Low granularity

TRACKS

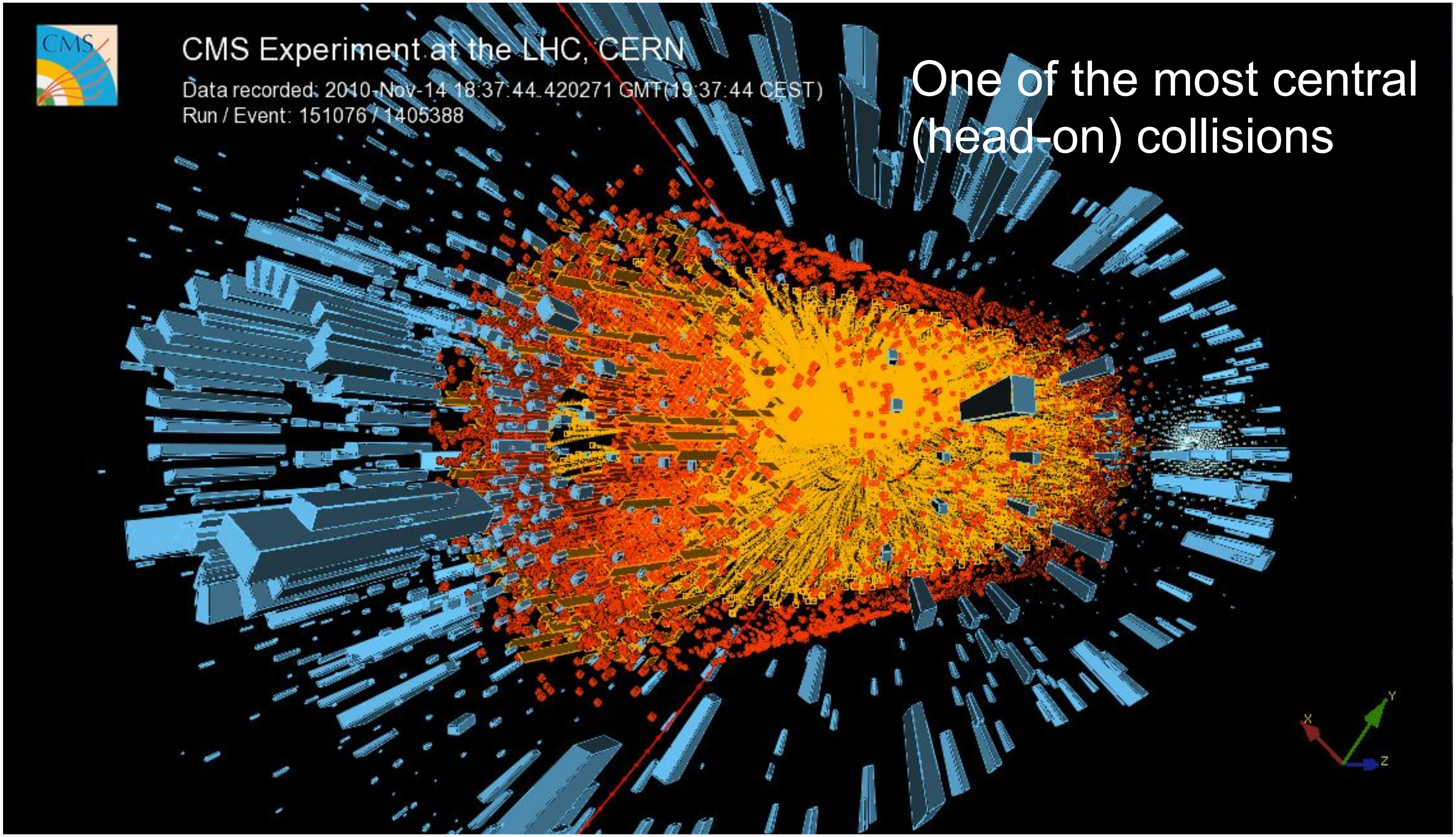
- Better resolution of p_T
- Blind to neutral energy
- Not 100% efficient
- Limited acceptance

EM candidates

- Photons

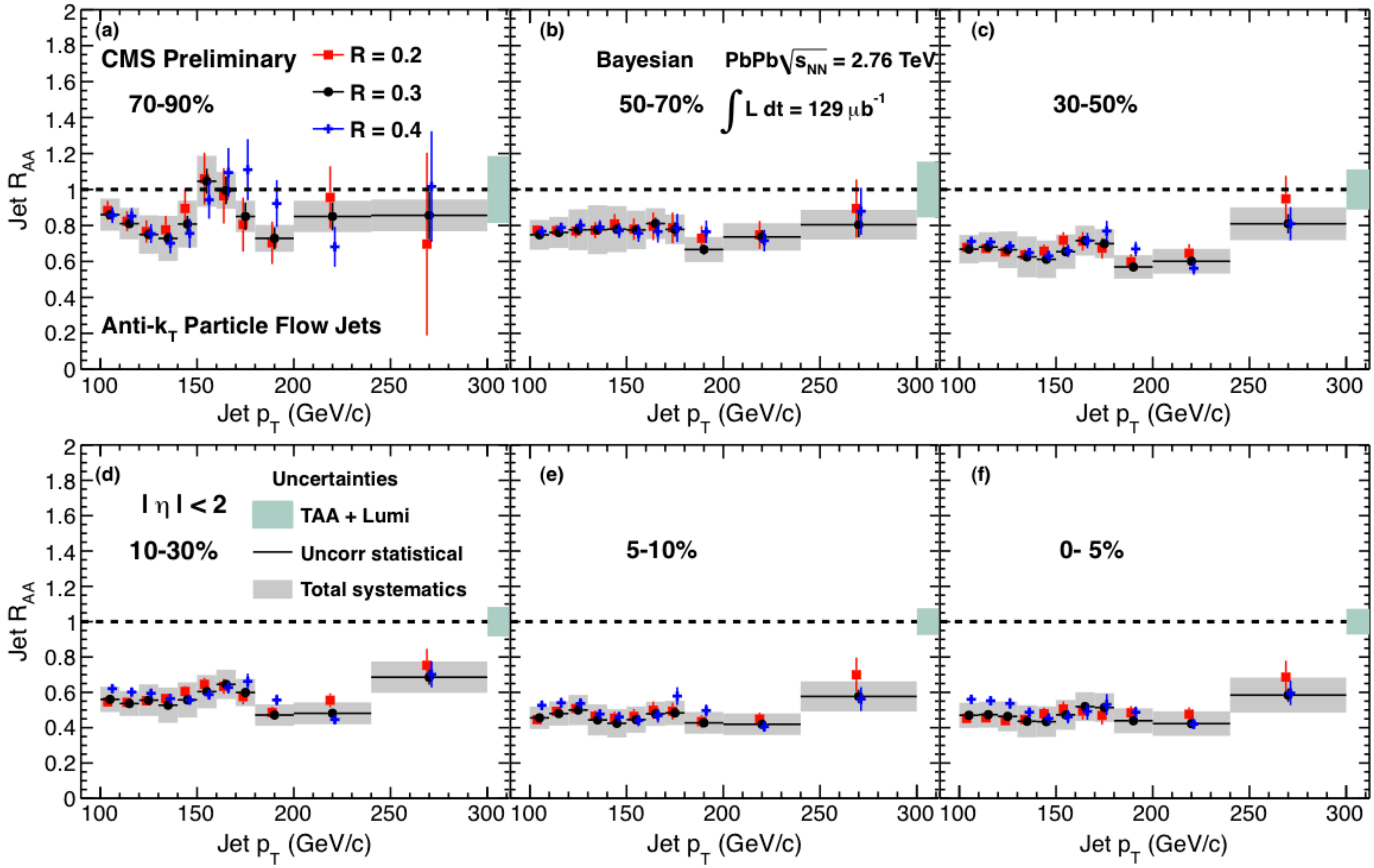
(Details: CMS-PAS-HIN-11-004)

Challenge : Underlying event in PbPb



Large background activity
Especially in most central collisions, which are most interesting

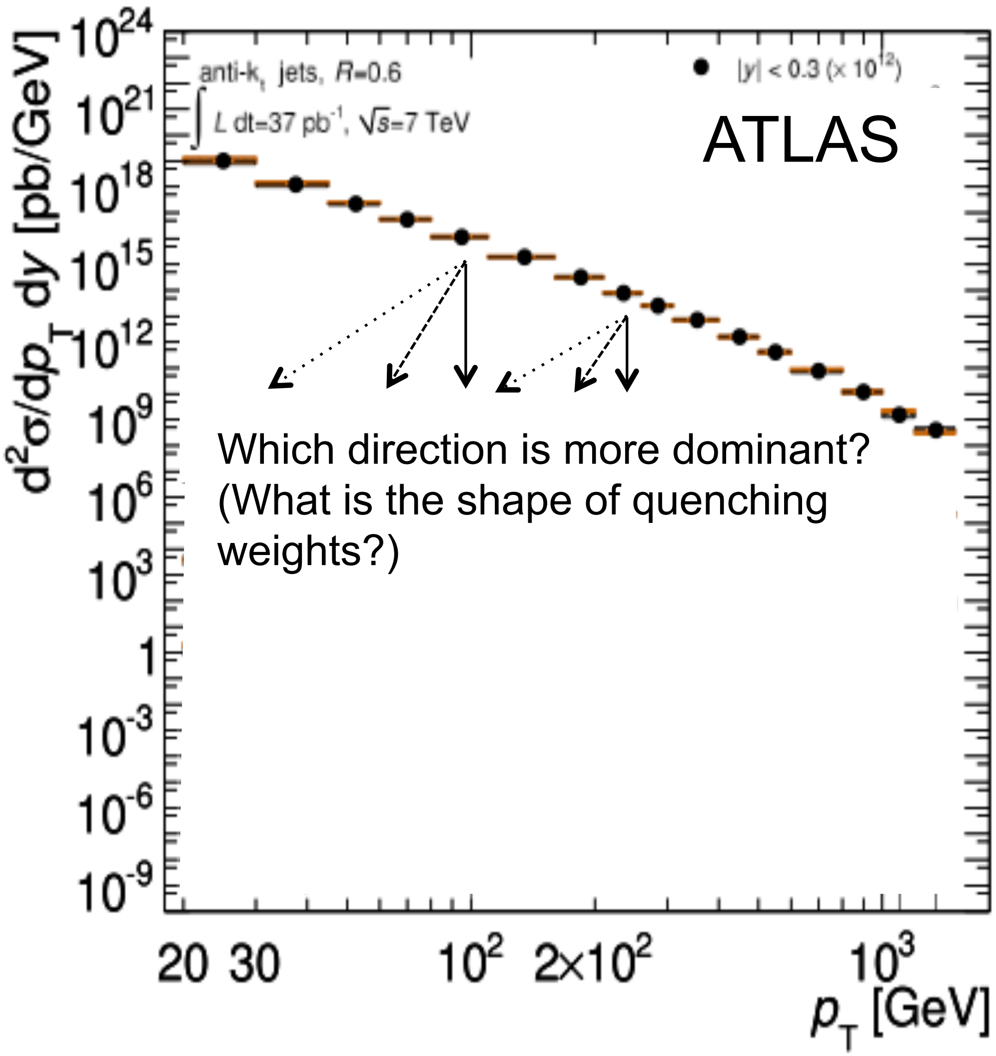
Modification of the inclusive jet spectra



CMS-PAS-HIN-12-004

Jet pT spectrum shifted
and/or
suppressed in PbPb

Interpreting R_{AA}

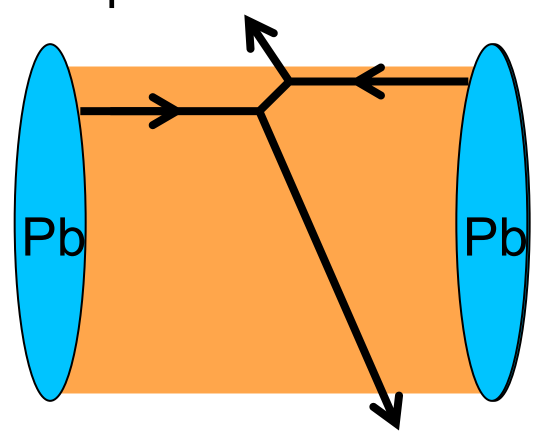


Results are unfolded for resolution effects – straightforward to compare with theory predictions.

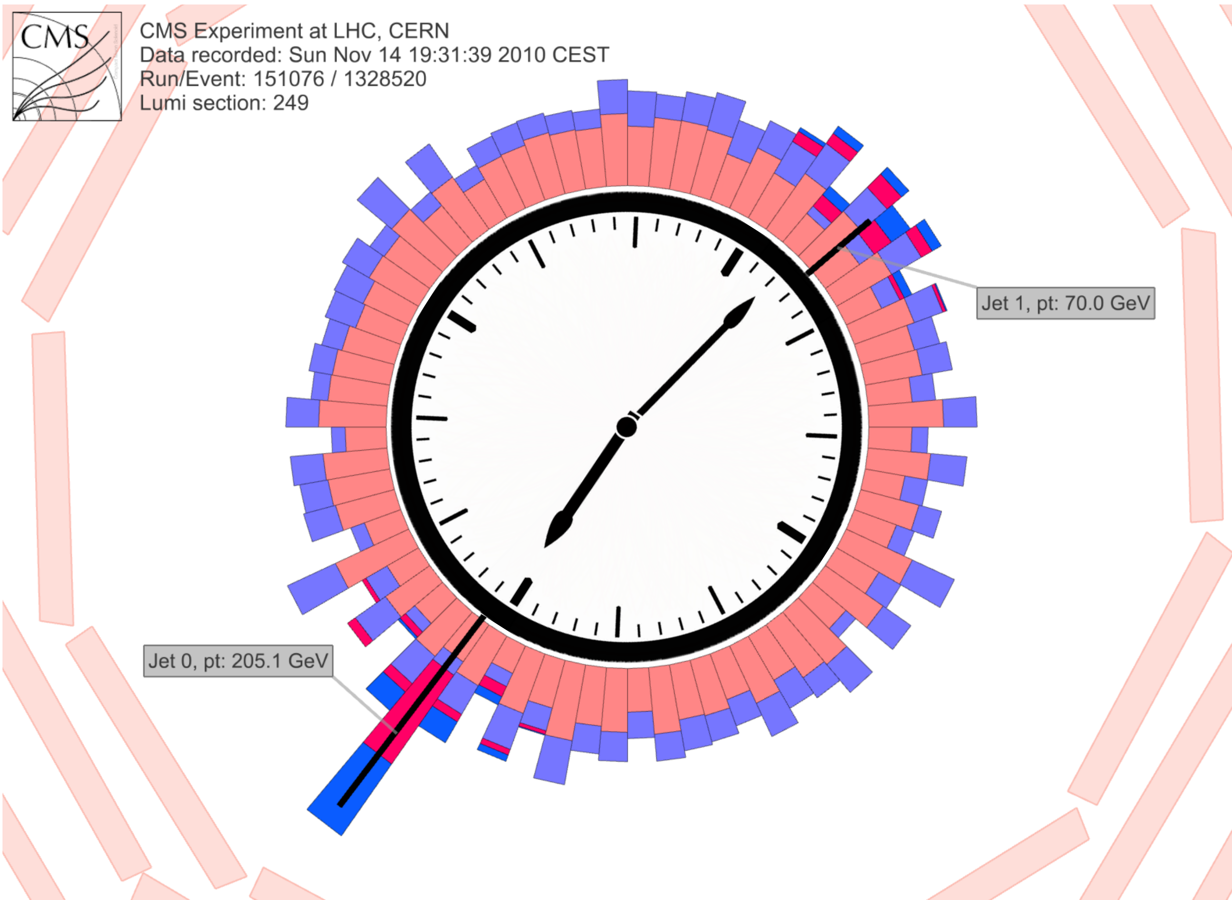
“Surface-biased” measurement:
More sensitive to the **less-quenched** jets (not saying *geometry* - yet)

Are the jets quenched often by similar amounts, or by a wide variety of values?

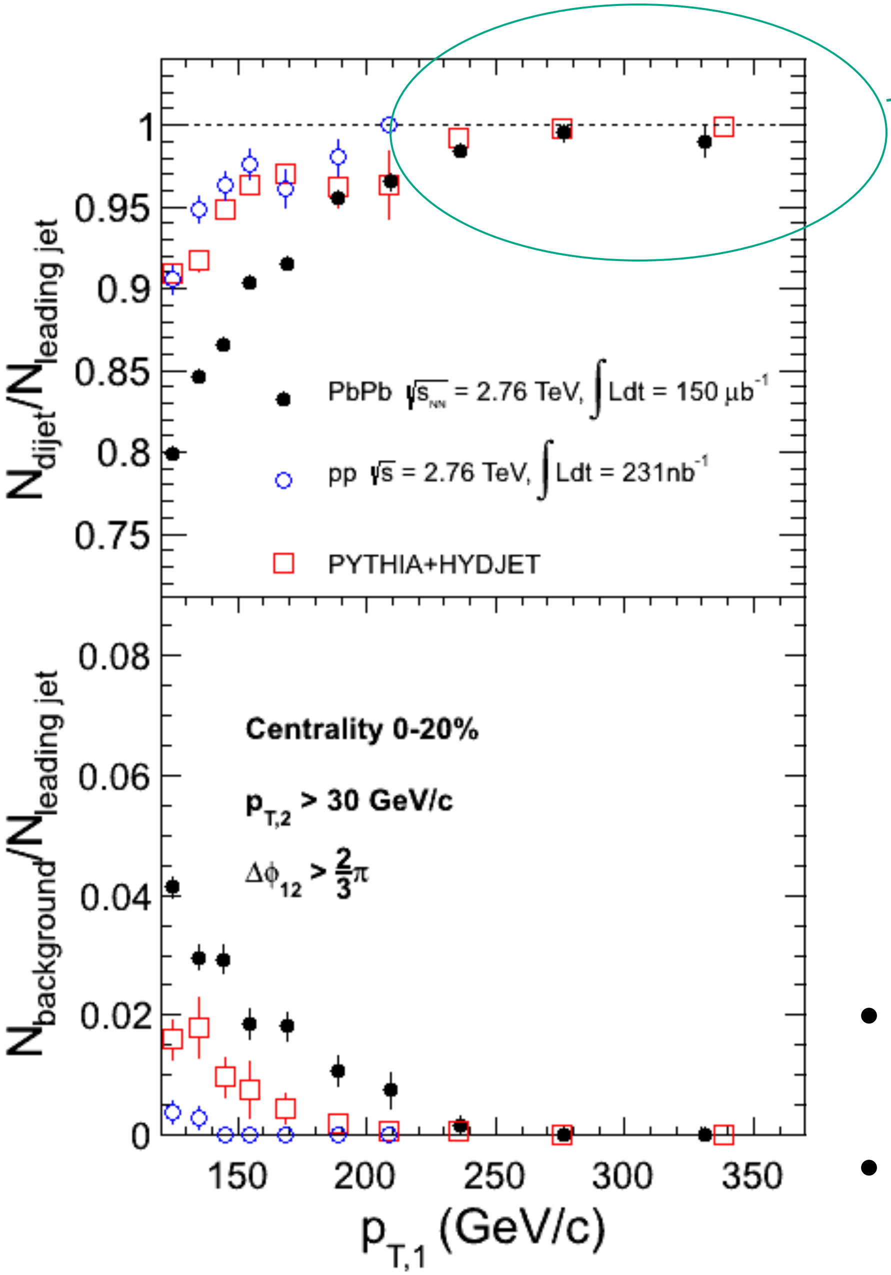
Dijet and Photon+Jet correlations can answer more questions



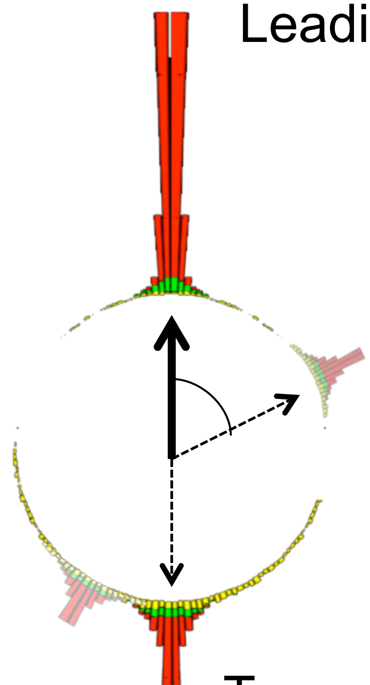
Part II : Studying dijet correlations



Dijet correlation and background

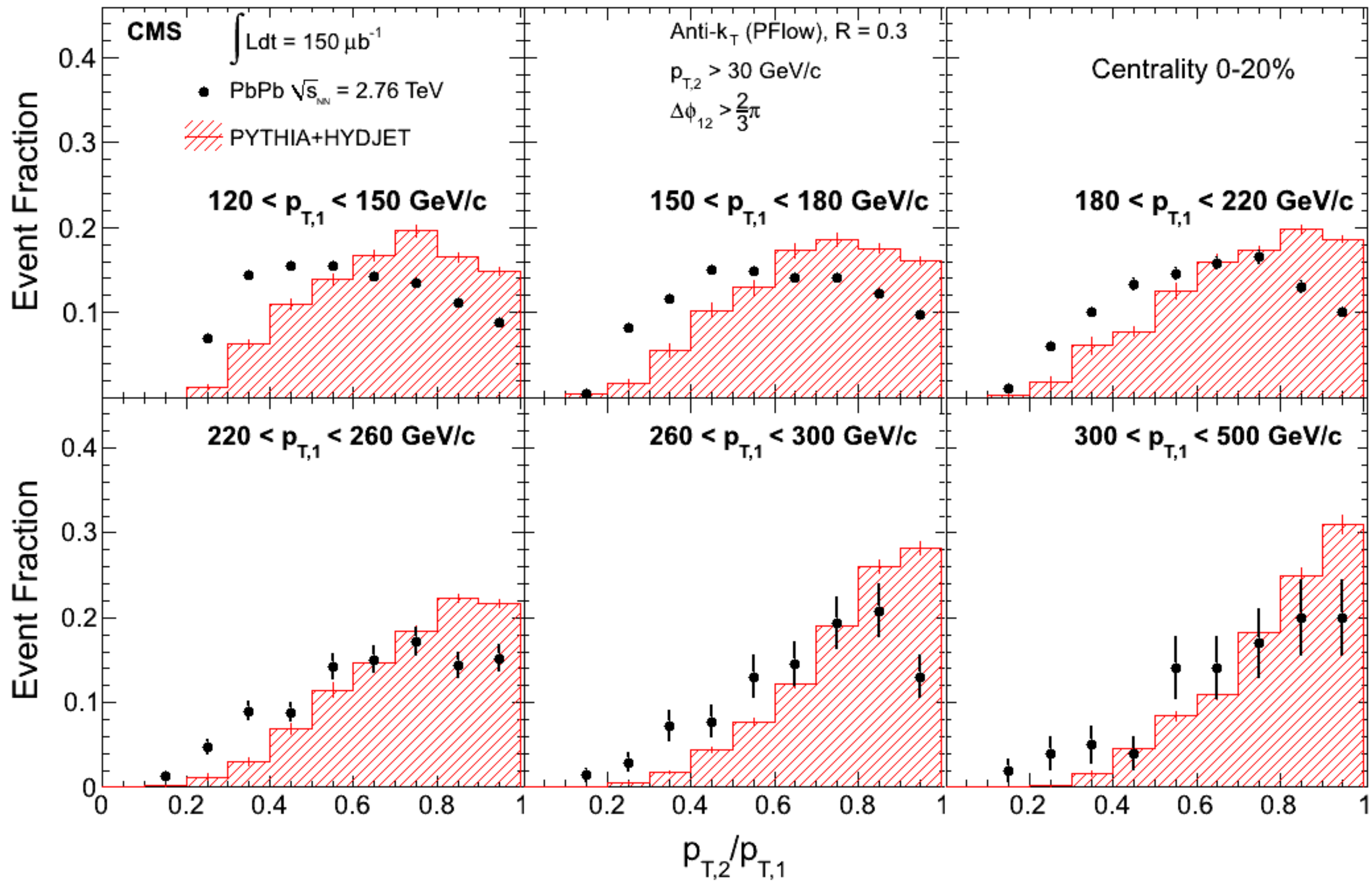


At high p_T, only very few jets get completely lost on the away side



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

p_T-dependence of the dijet imbalance

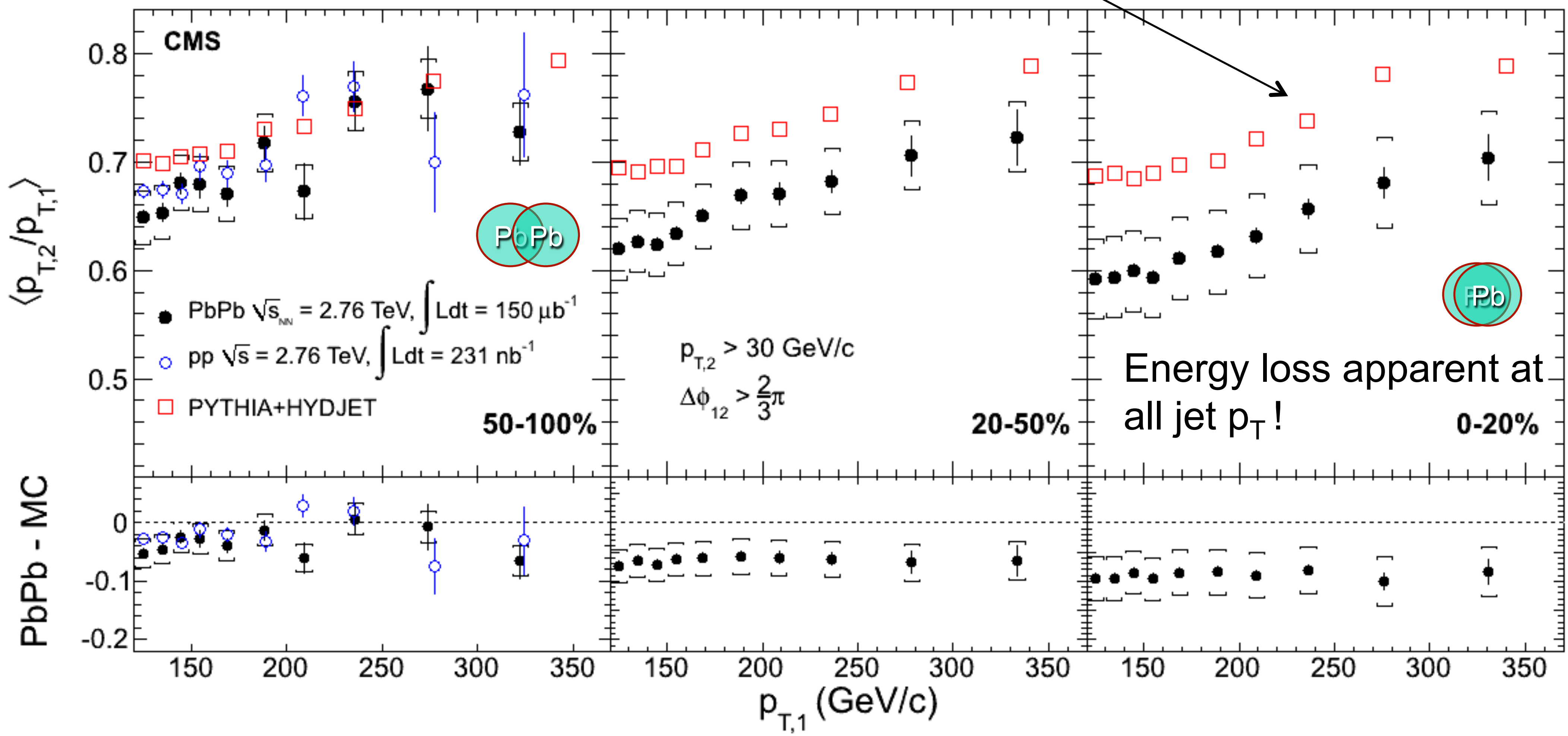


Dijets in PbPb are more imbalanced than Pythia at **all bins of leading jet p_T**

p_T-dependence of the dijet imbalance

Reference itself has an increasing trend

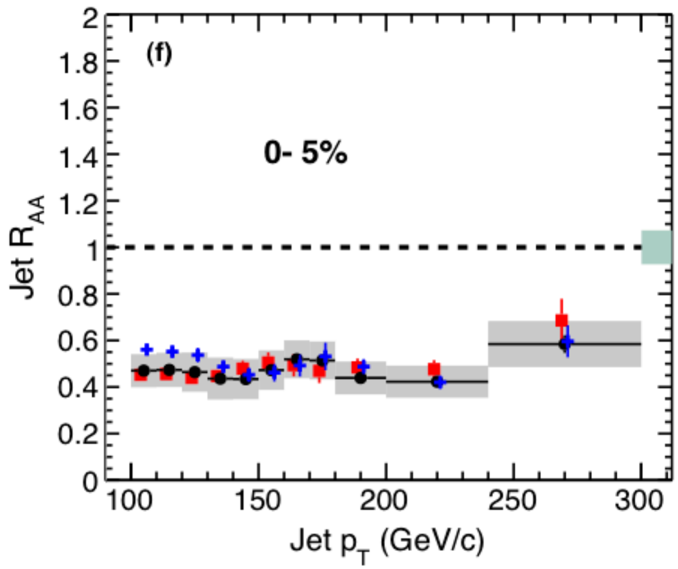
Phys. Lett. **B**712 (2012) 176-197



The leading jet has also suffered energy-loss

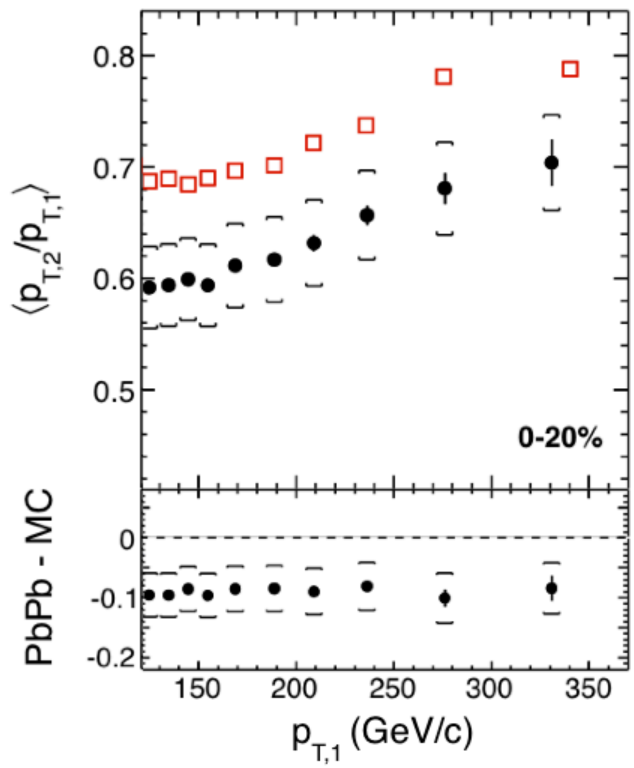
Modeling is needed to extract the exact p_T dependence

Part III : Putting the results together

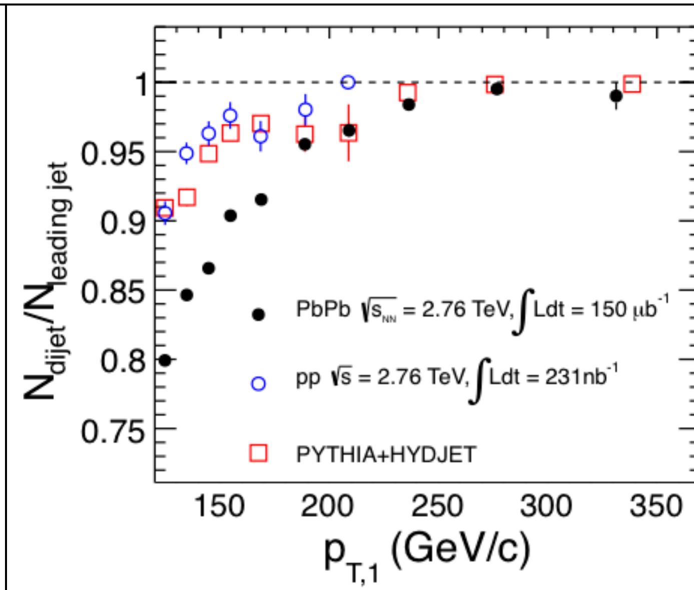


CMS-PAS-HIN-12-004

How much energy is lost on average



How much on average the away-side loses further



Phys. Lett. **B**712 (2012) 176-197

What is the maximum amount of energy-loss

Following slides present a simple modeling attempt in order to:

- illustrate a correct approach for comparison the data
- get a physical intuition, although not as precisely as from a realistic calculation

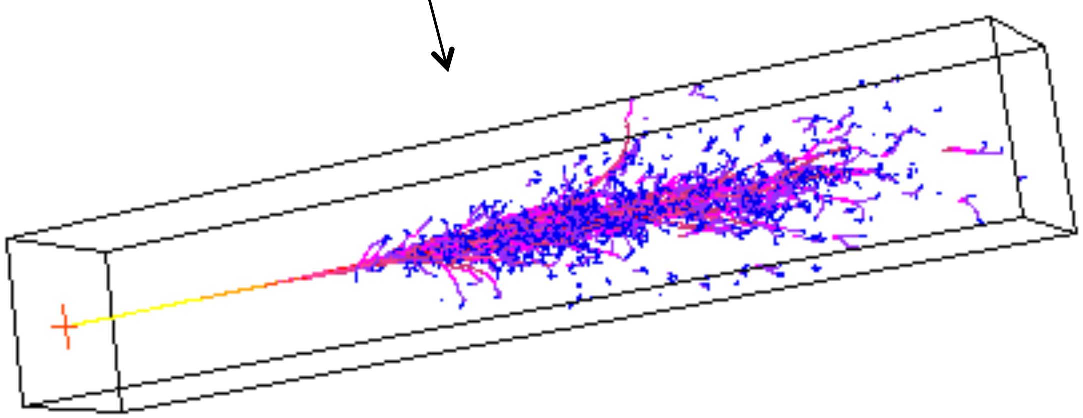
Jet resolution effects on imbalance

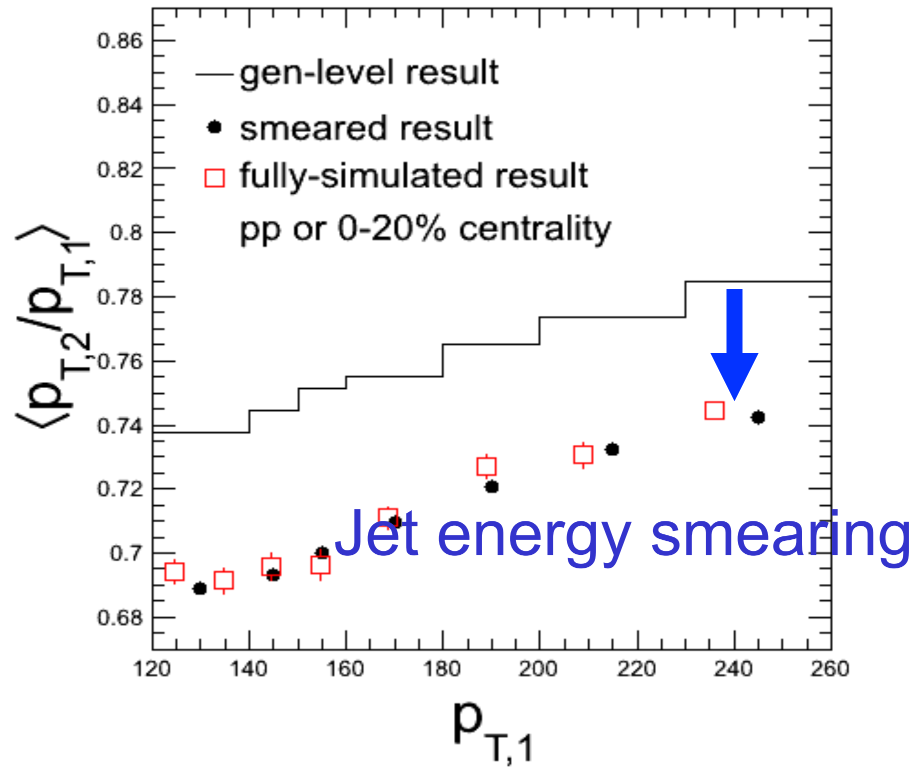
$$\sigma\left(\frac{p_T^{\mathrm{Reco}}}{p_T^{\mathrm{Gen}}}\right) = C \oplus \frac{S}{\sqrt{p_T^{\mathrm{Gen}}}} \oplus \frac{N}{p_T^{\mathrm{Gen}}},$$

The model calculation has to take into account the resolution effects when comparing with convoluted data

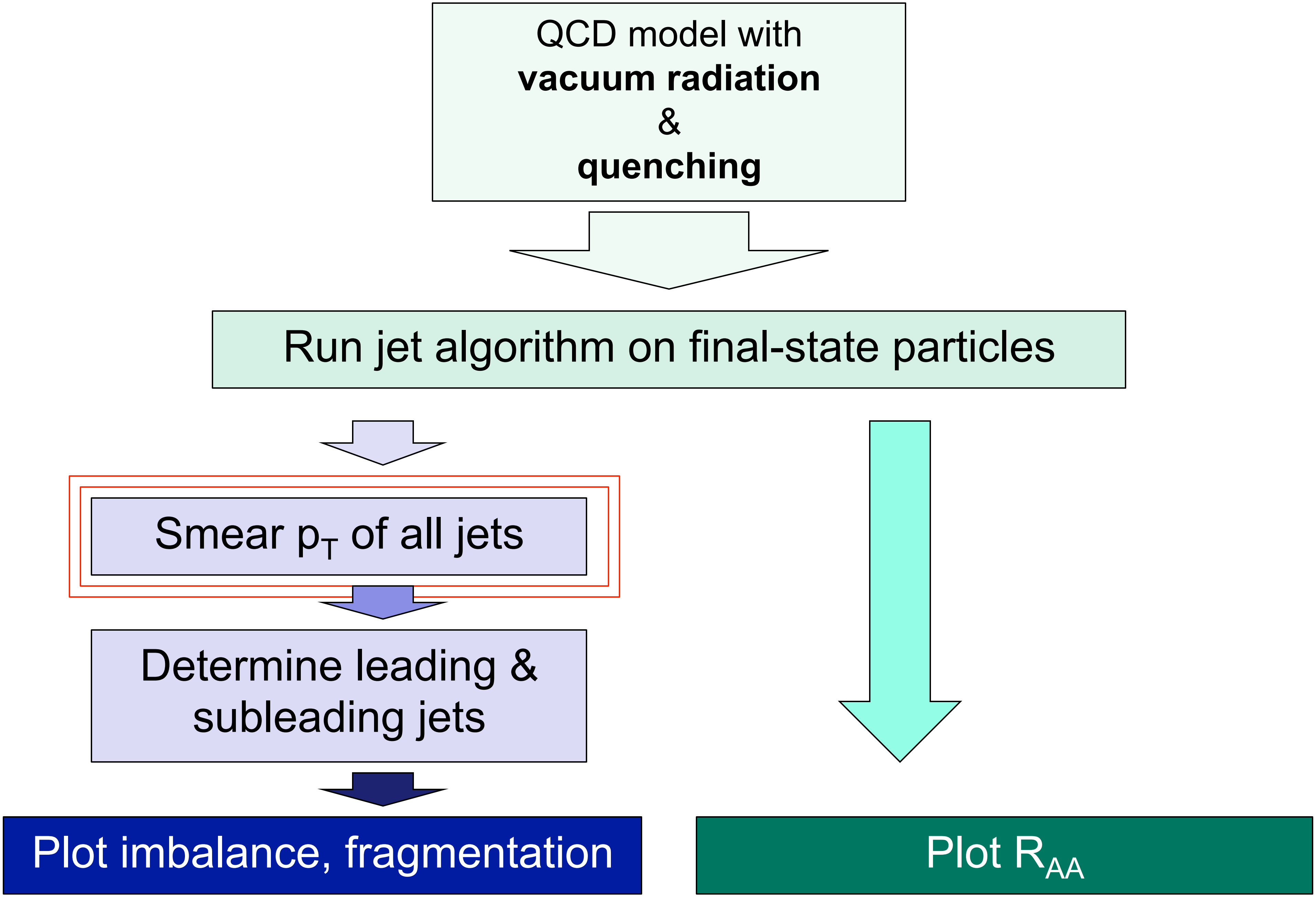
C	S	N (pp)	N (50–100%)	N (30–50%)	N (10–30%)	N (0–10%)
0.0246	1.213	0.001	0.001	3.88	5.10	5.23

Stochastic term dominant at high-p_T



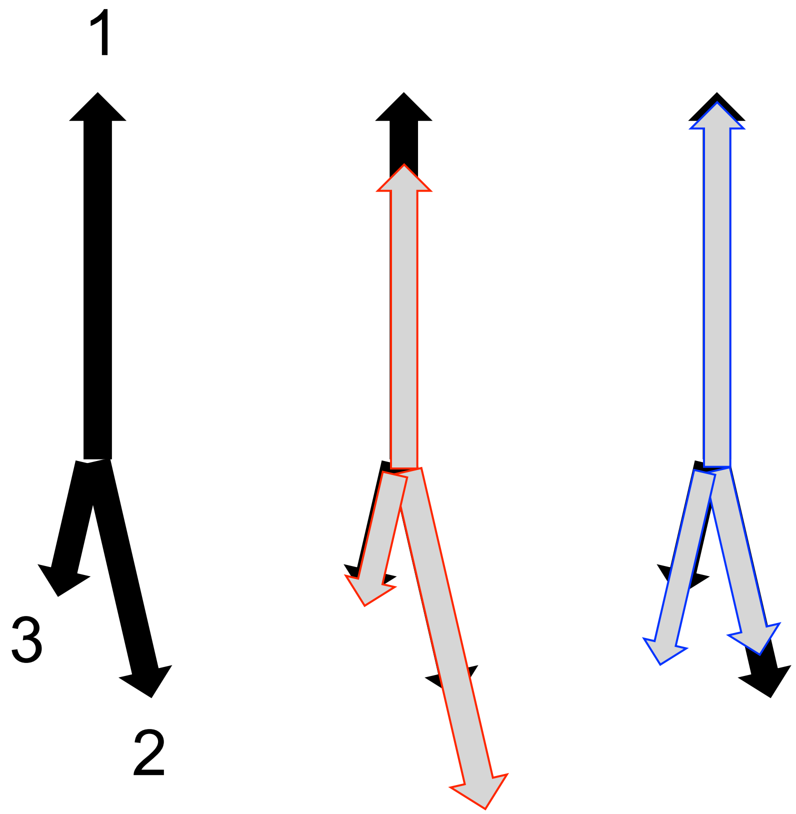


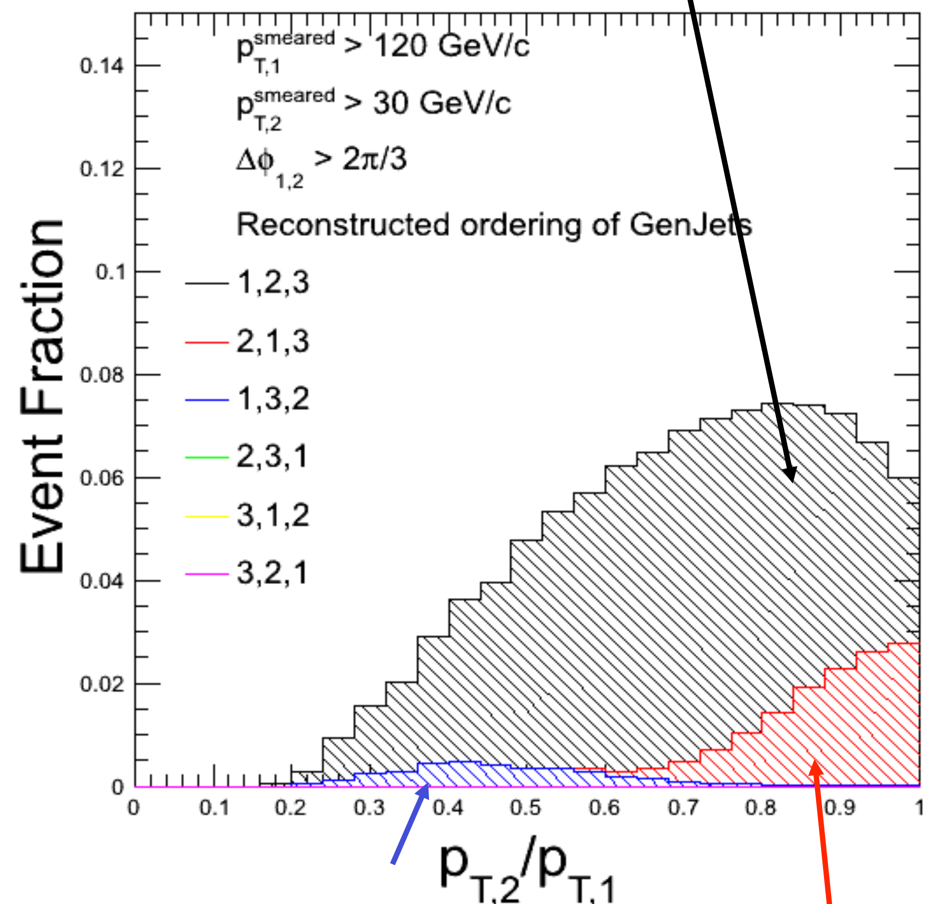
Good Data-MC comparison recipe



Resolution effects on jet selection

Generator level leading and subleading jets matches reco level

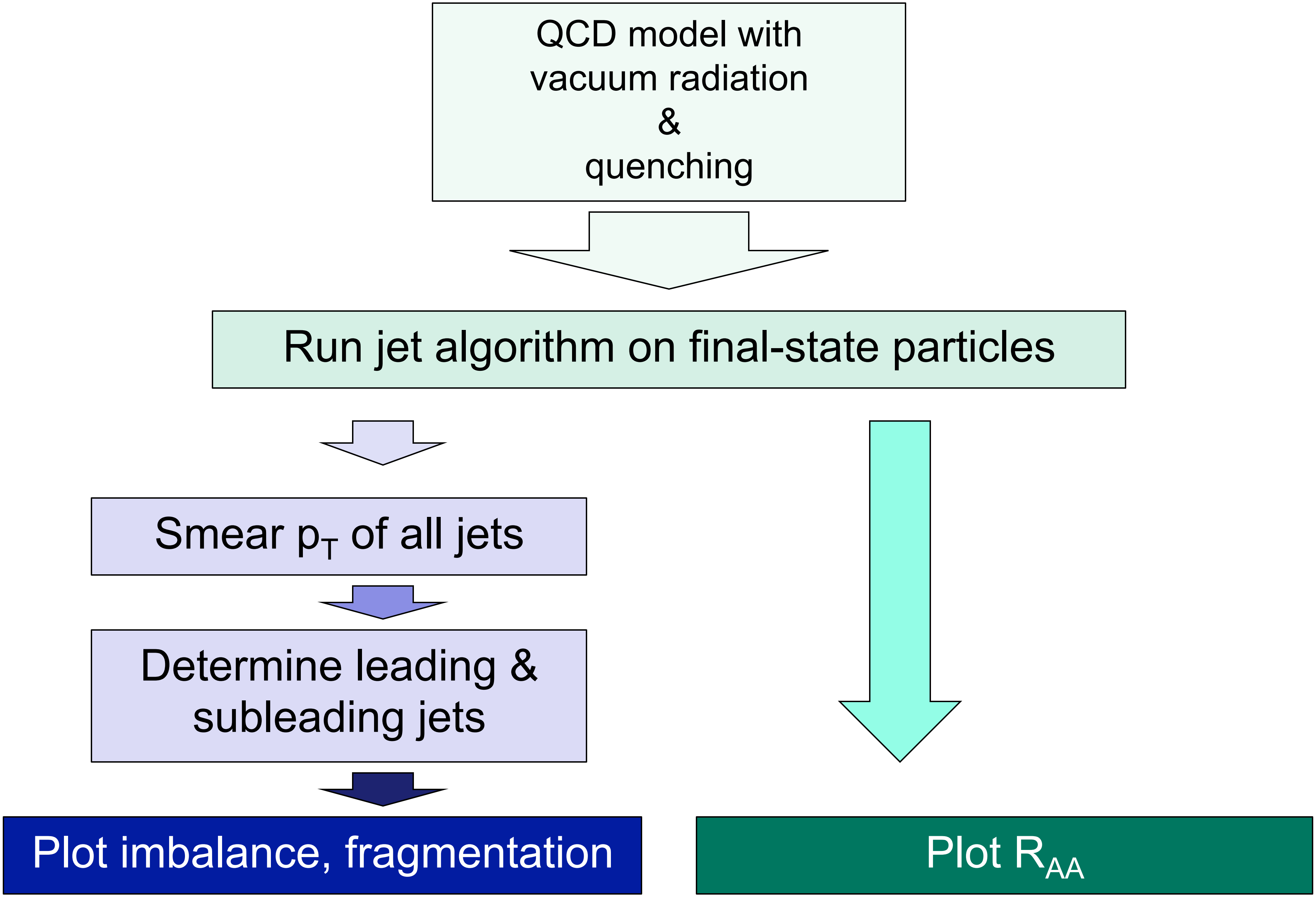




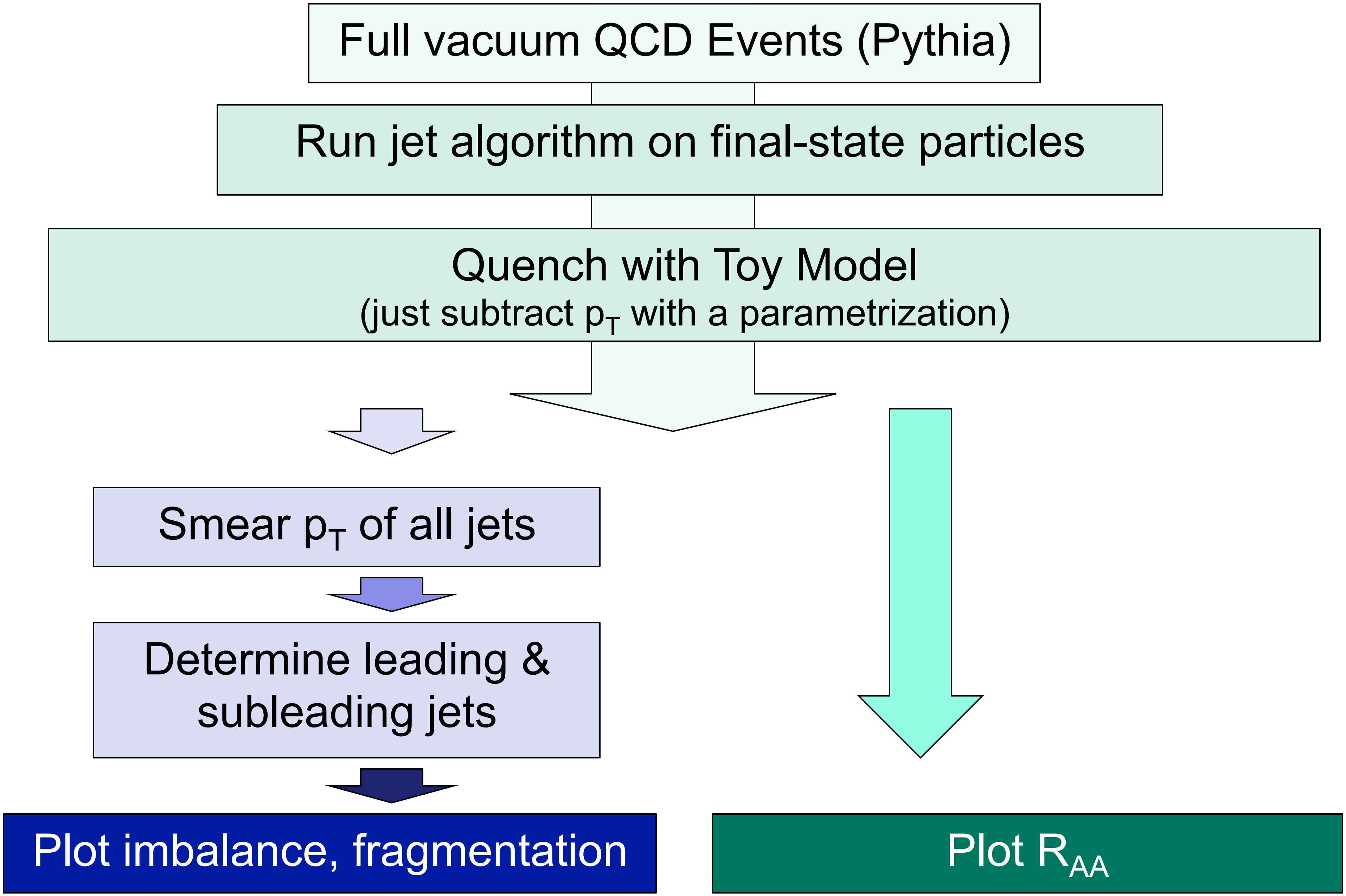
Third jet supersedes second

Swapped leading and subleading jet

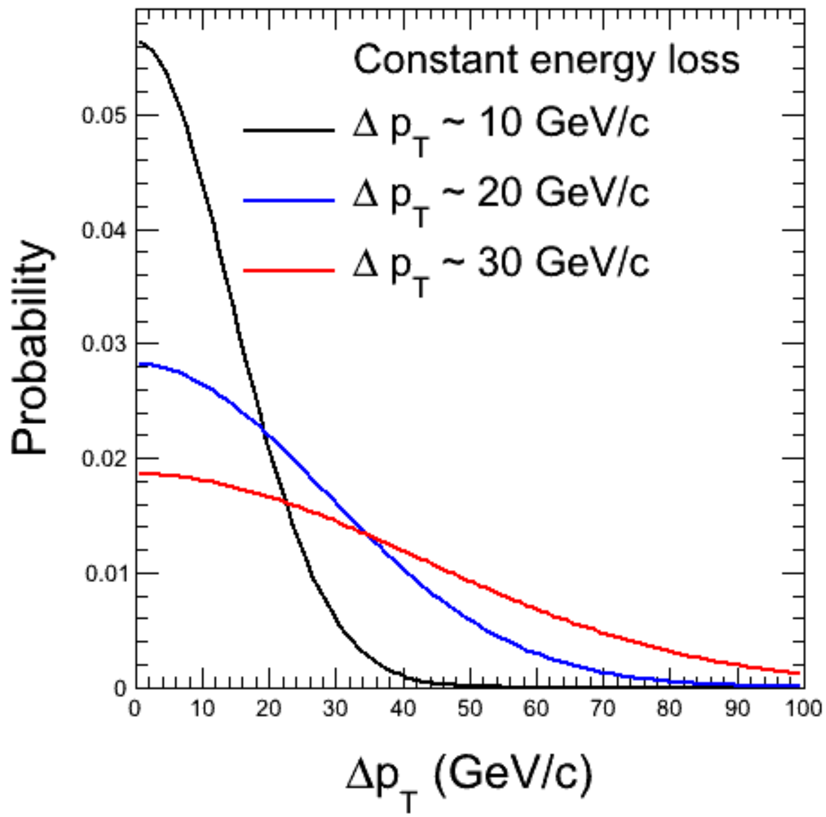
Good Data-MC comparison recipe



Toy model


Full vacuum QCD Events (Pythia)
Run jet algorithm on final-state particles
Quench with Toy Model
(just subtract p_T with a parametrization)
Smear p_T of all jets
Determine leading & subleading jets
Plot imbalance, fragmentation
Plot R_{AA}

Simple Toy Model: Independent quenching



An artificial energy-loss is applied on particle-jets in Pythia generated events

Each jet suffers a random energy-loss, completely independent on other jets in the event

No difference between quark vs gluon jets

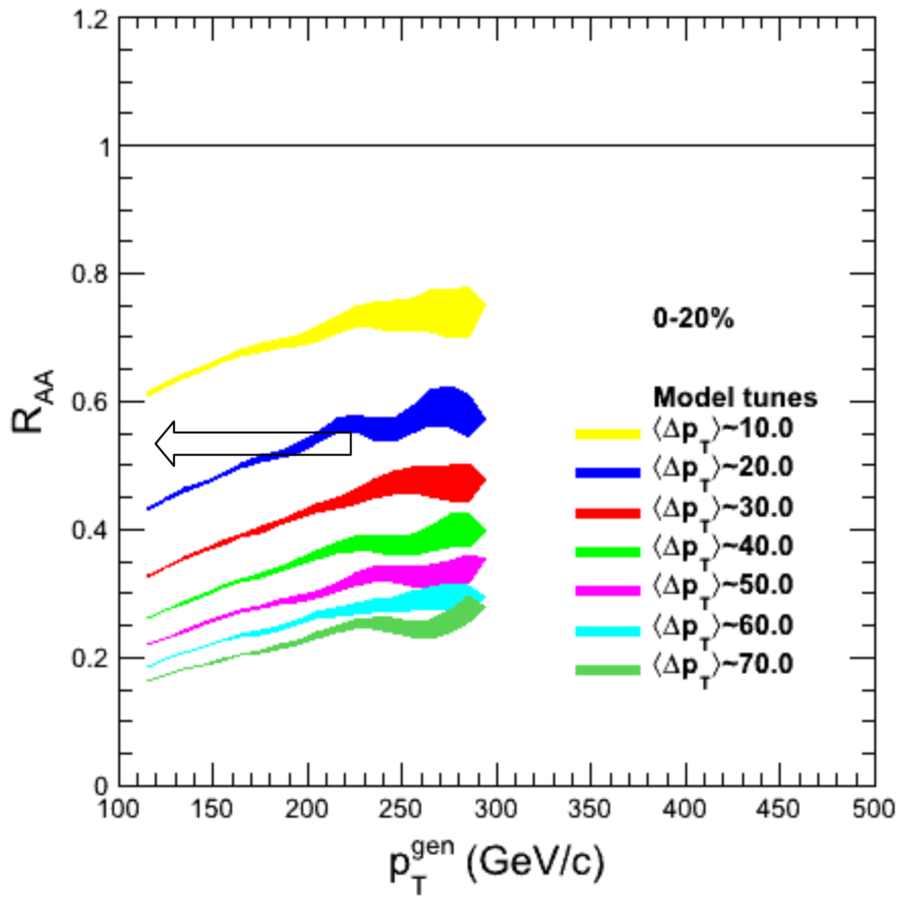
The probability distribution of energy-loss is modulated by

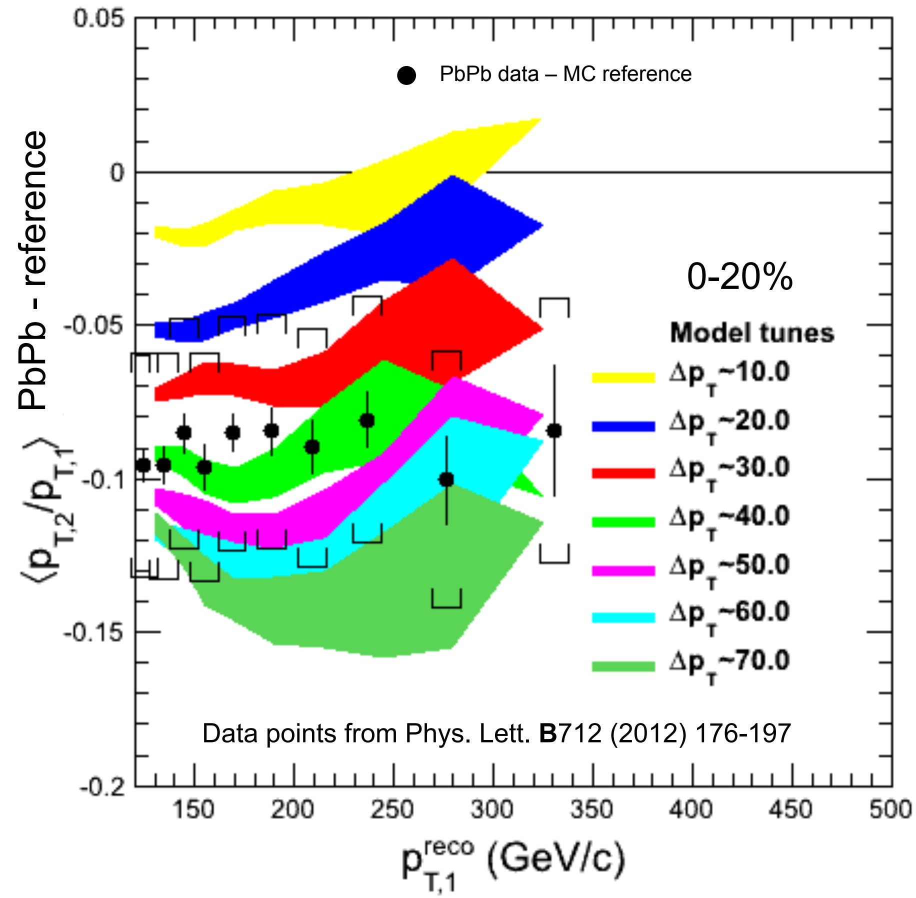
- the tuned mean amount

and

- momentum dependence

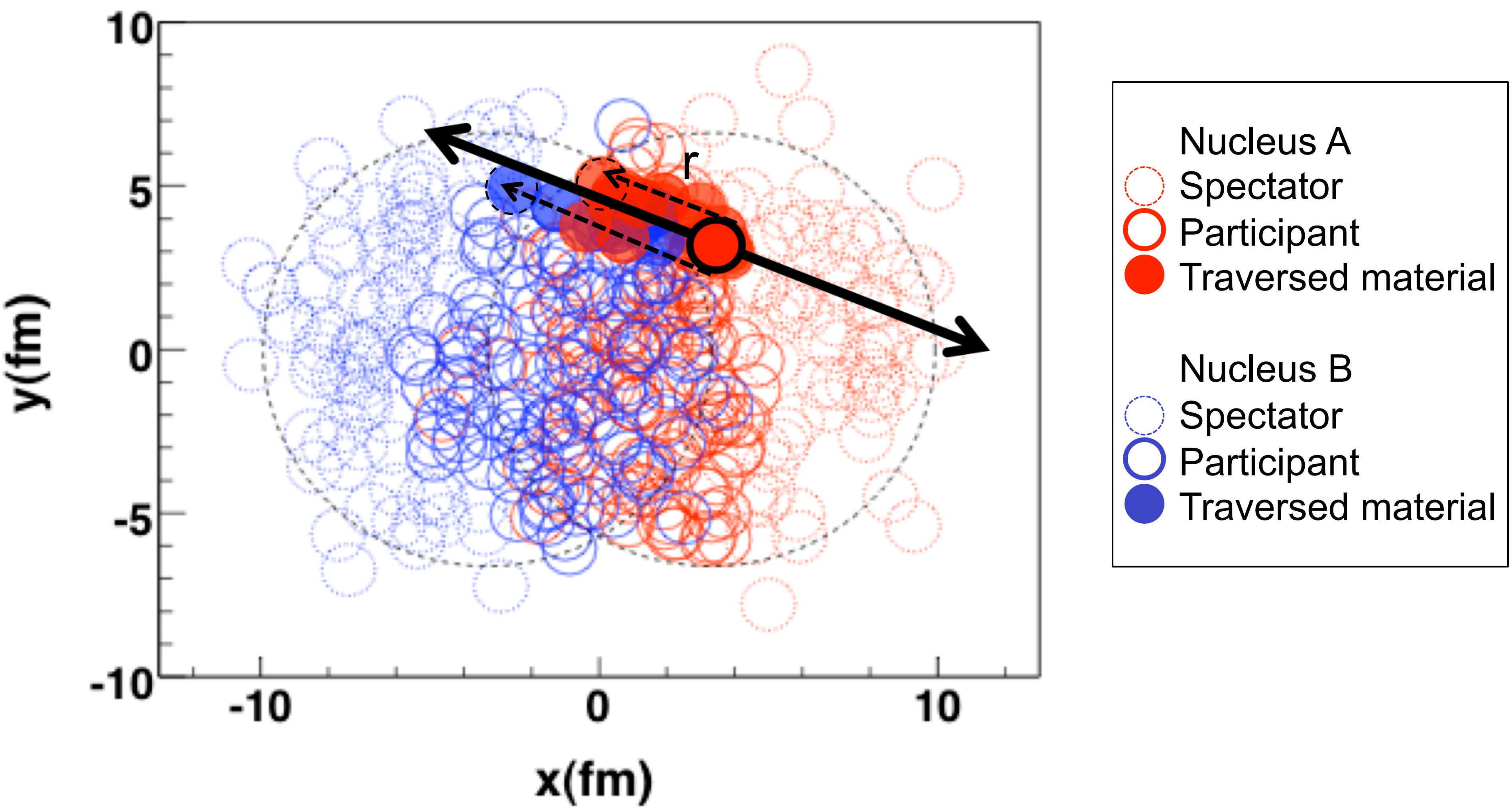
Simple model: Independent quenching





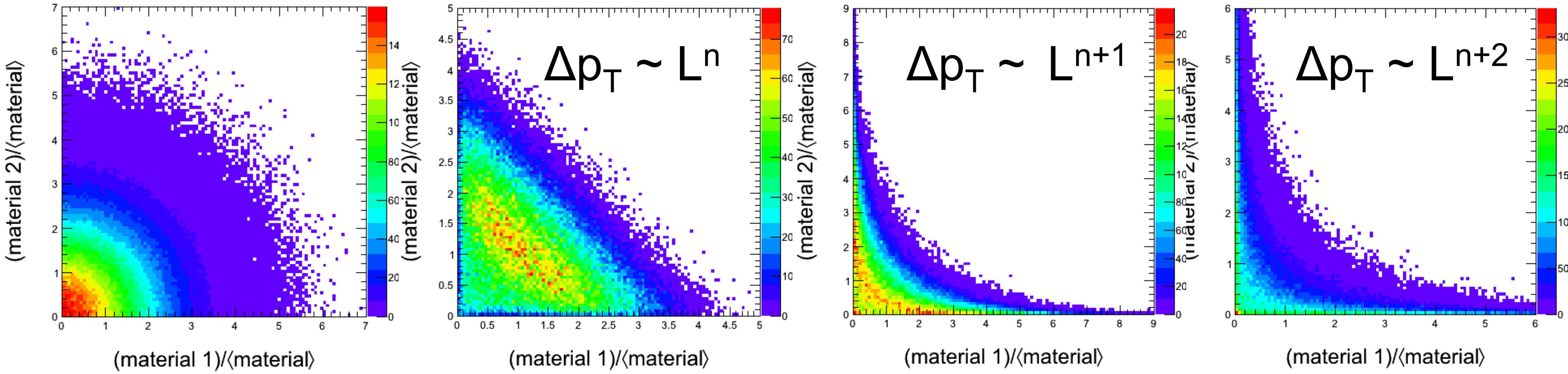
- Jet RAA suggests that about 20 GeV is lost on average
- This is not sufficient to cause imbalance as seen in data
- There should be a further anti-correlation between the two jets

Geometry-inspired toy-model

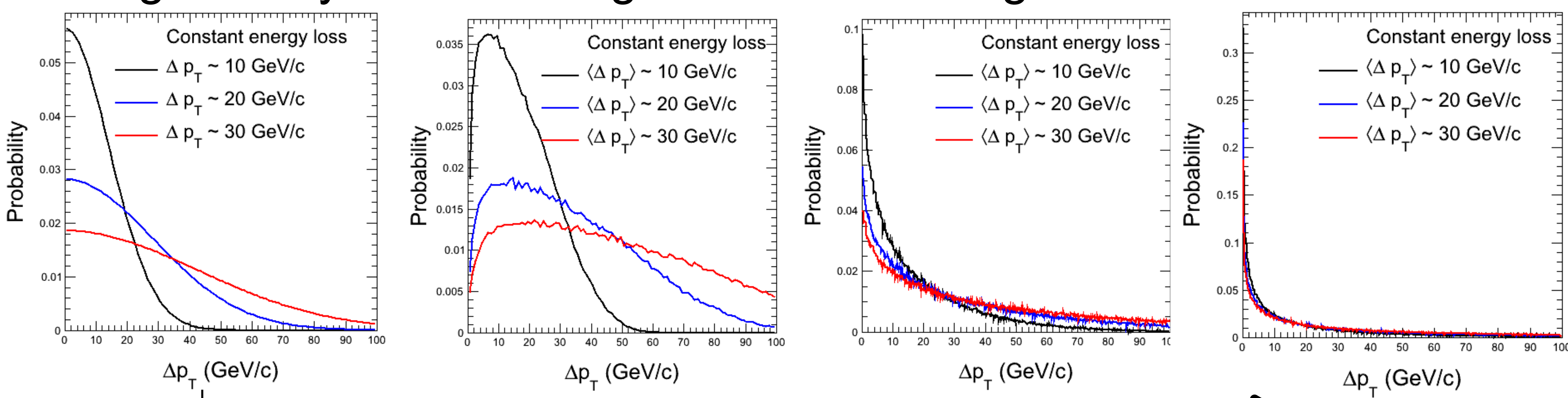


- The material along the trajectory of the jet is summed, weighted by a power of r
- r = distance between target nucleon and jet origin
- Static medium

Correlation between two jets



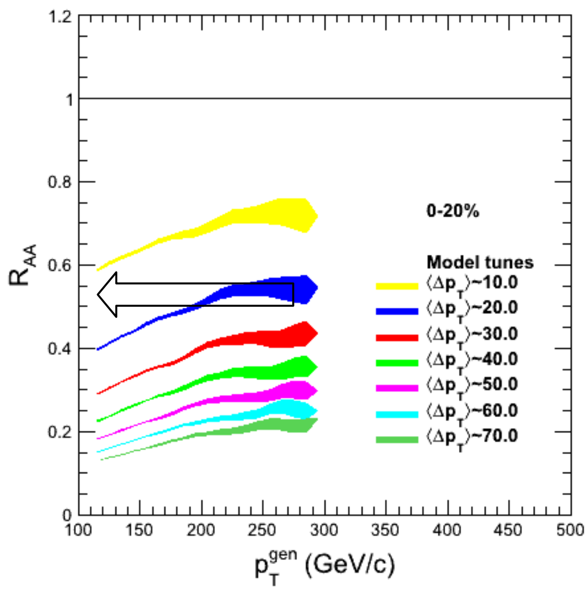
no geometry | r^0-weighted | r^1-weighted | r^2-weighted

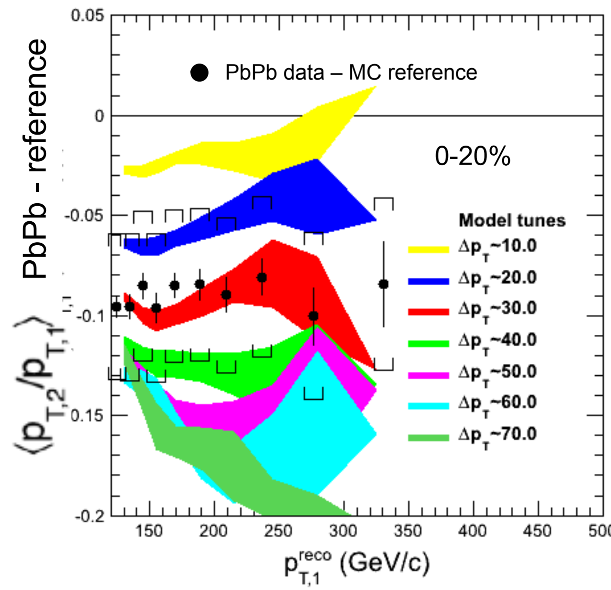


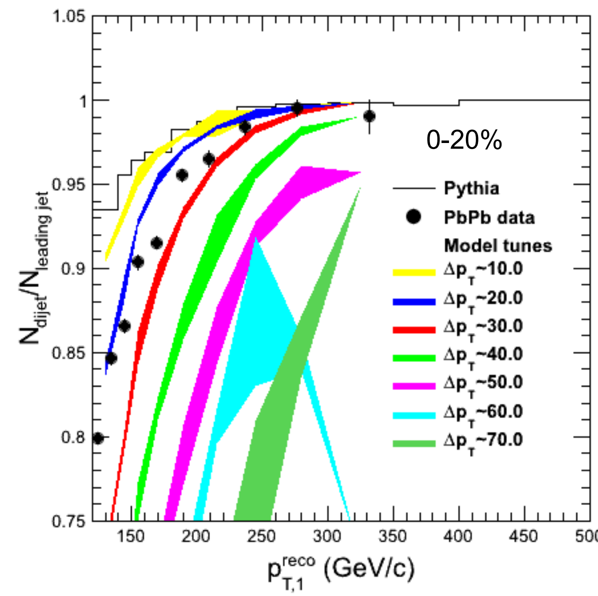
did not work

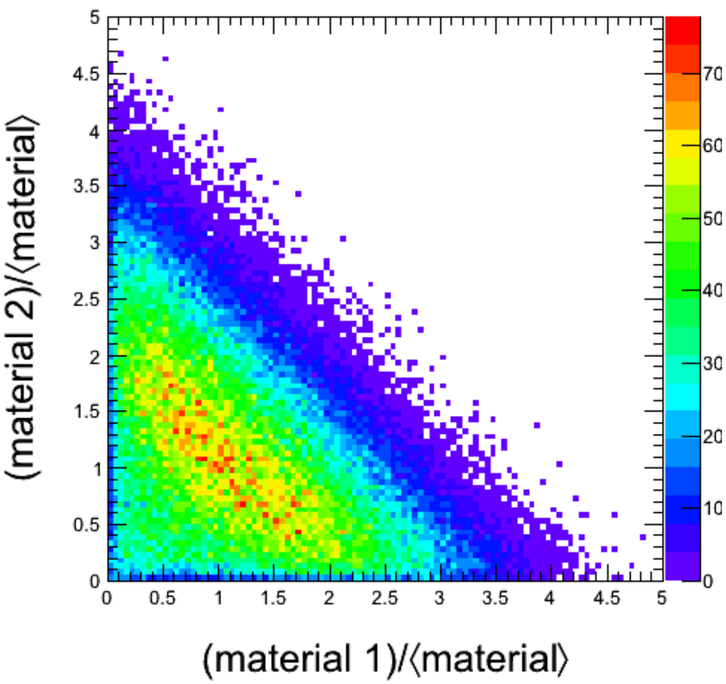
more anti-correlation induced

Material weighted by r^0



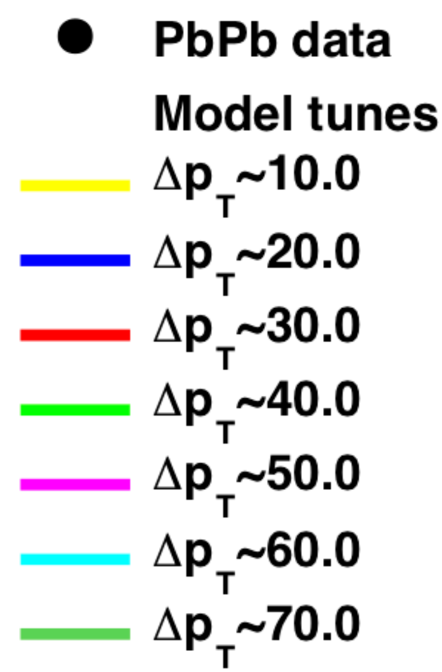




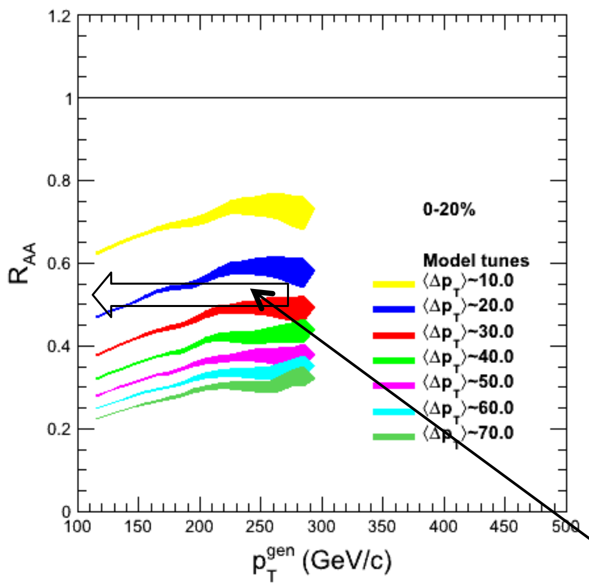


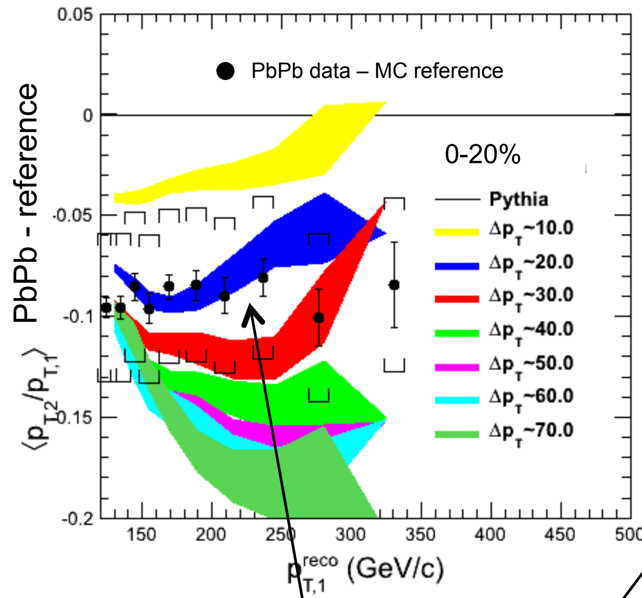
Moving towards more imbalance compared to independent quenching

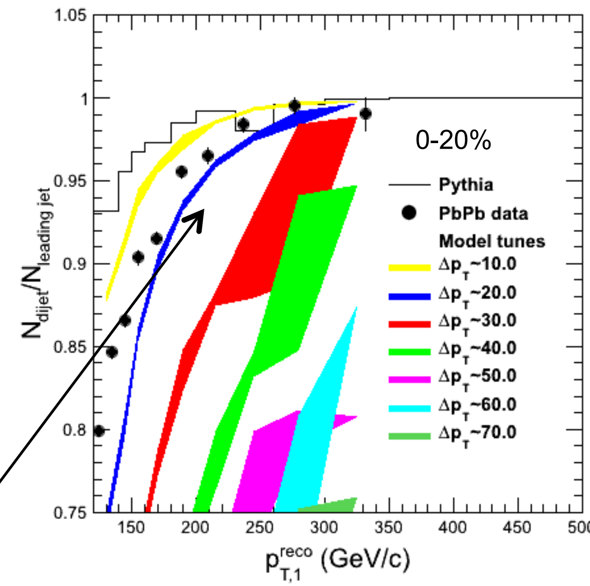
Blue is consistent with R_{AA} but
Red is better with $\langle p_{T,1}/p_{T,2} \rangle$

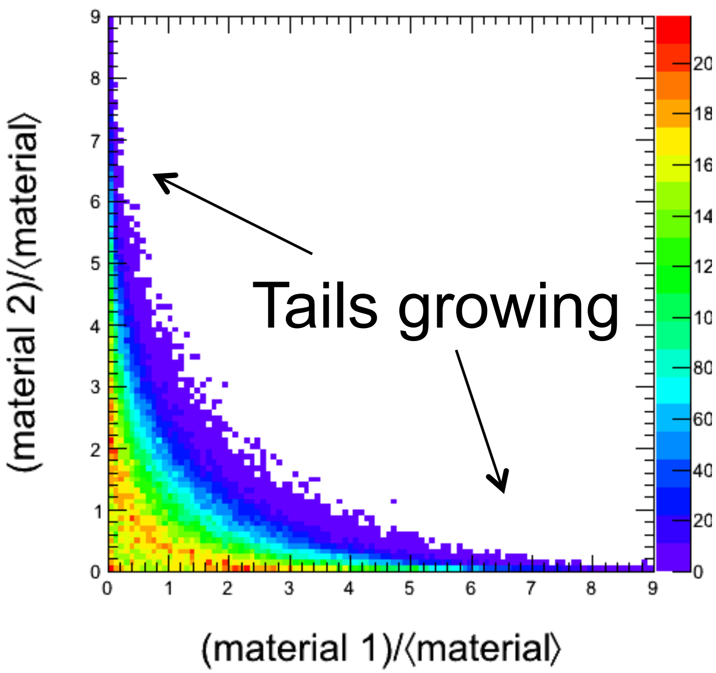


Material weighted by r¹









Tails growing

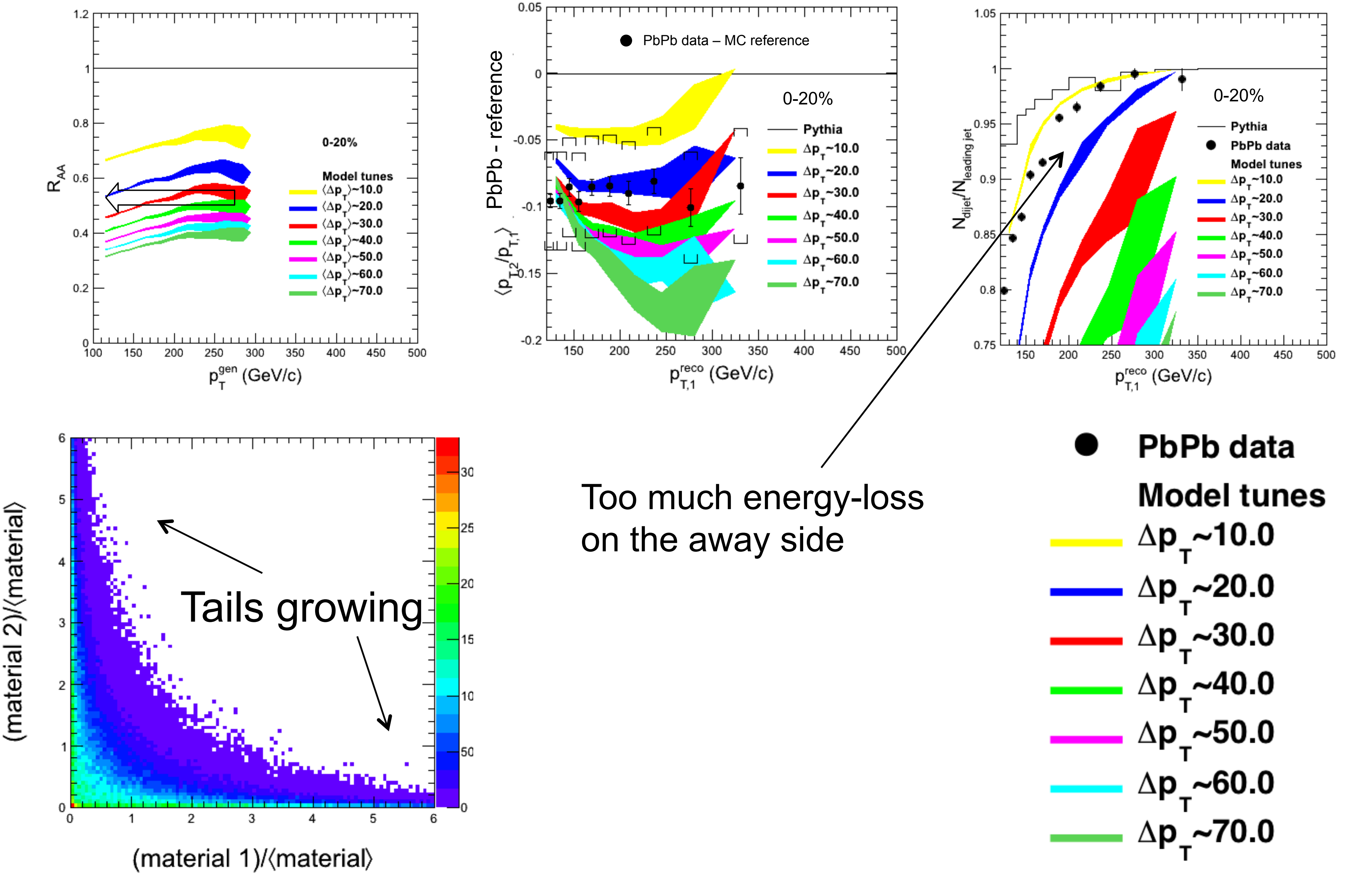
Starting to be compatible in all observables

● PbPb data

Model tunes

- Δp_T~10.0
- Δp_T~20.0
- Δp_T~30.0
- Δp_T~40.0
- Δp_T~50.0
- Δp_T~60.0
- Δp_T~70.0

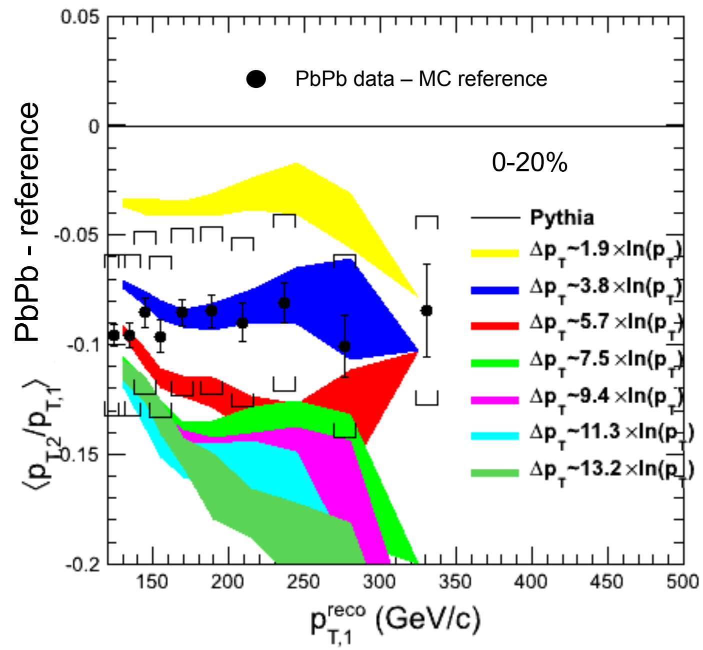
Material weighted by r^2

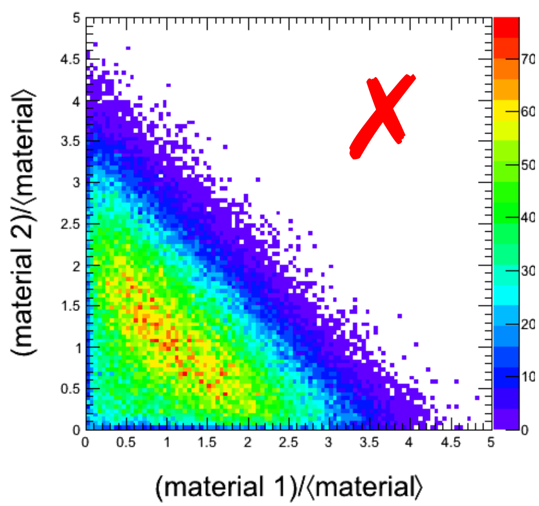


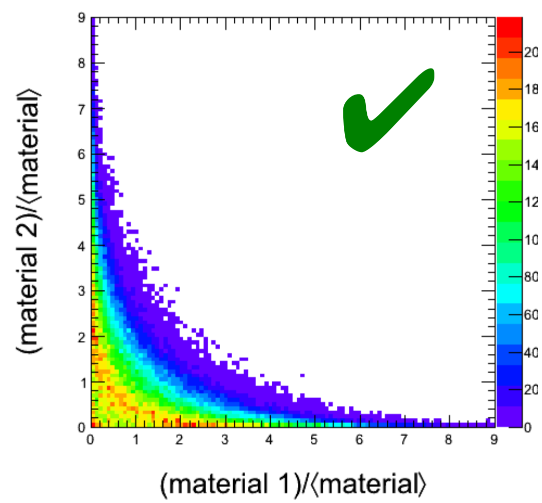
Model study

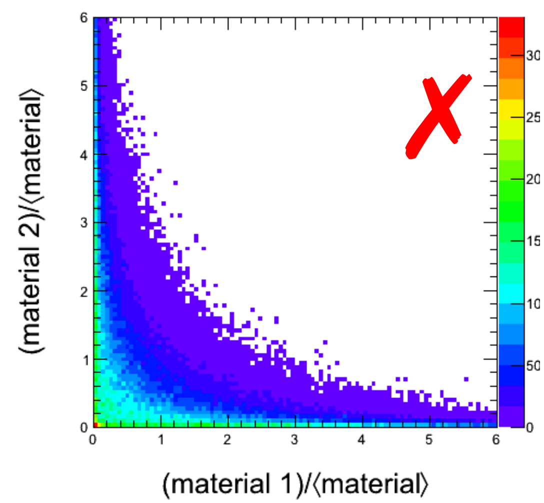
The trends observed in model with
r-weighted material,
with not much (perhaps logarithmic) p_T dependence,
resulting in ~20 GeV/jet energy-loss,
are consistent with data;

Any model, inducing similar correlations
(a combination of
geometry & radiation & parton-type
effects)
may be successful in description of data





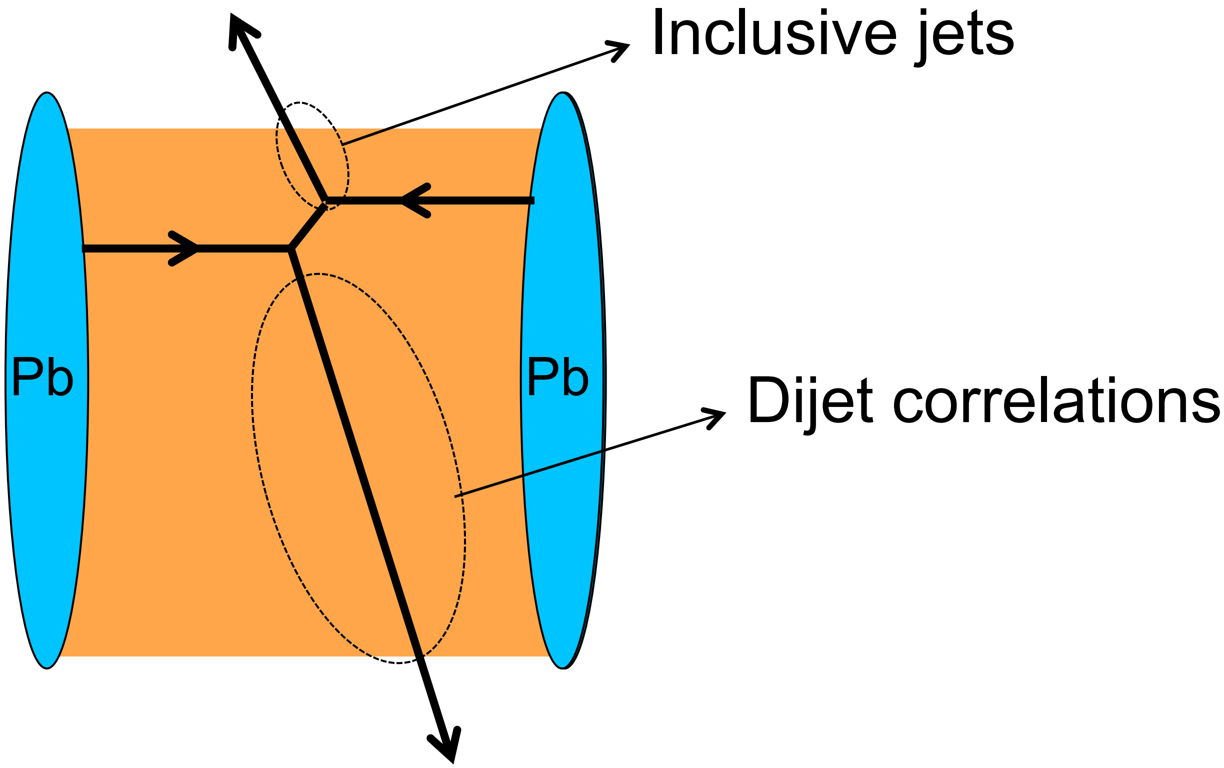


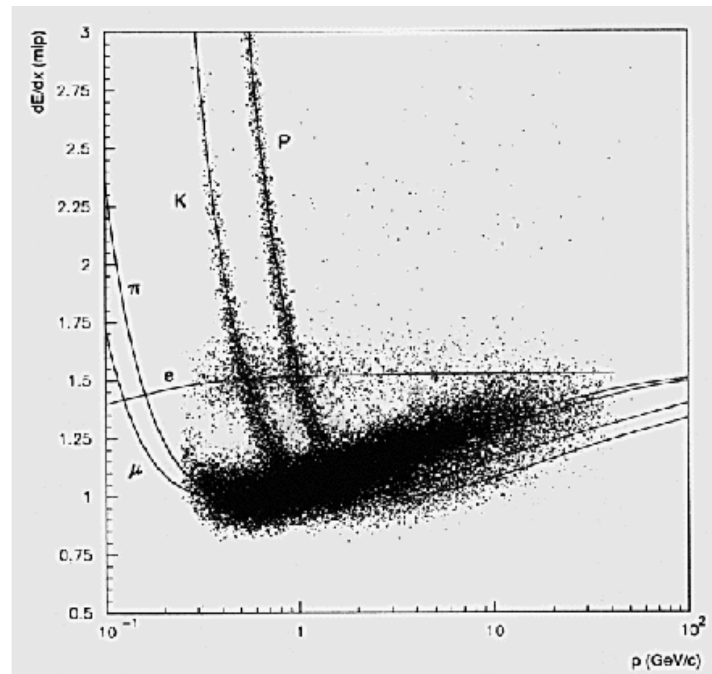


Conclusions

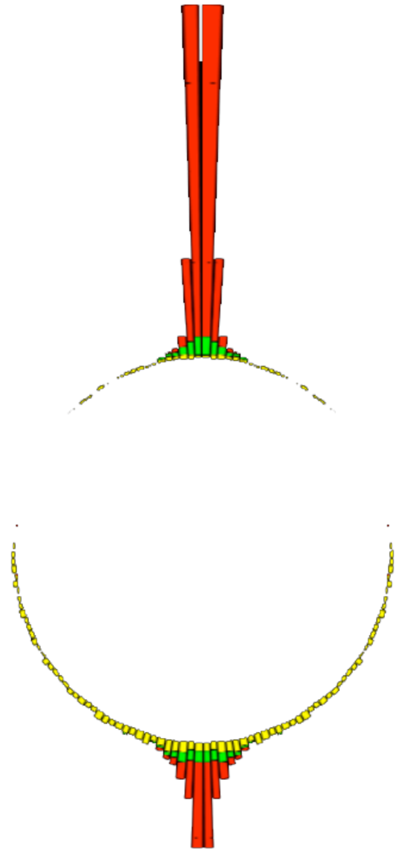
Inclusive jet R_{AA} and dijet imbalance provide complementary information on the energy-loss dynamics, which may be combined in order to isolate medium geometry-sensitive effects

Different species, different geometry and widened kinematics range will all add to this picture!



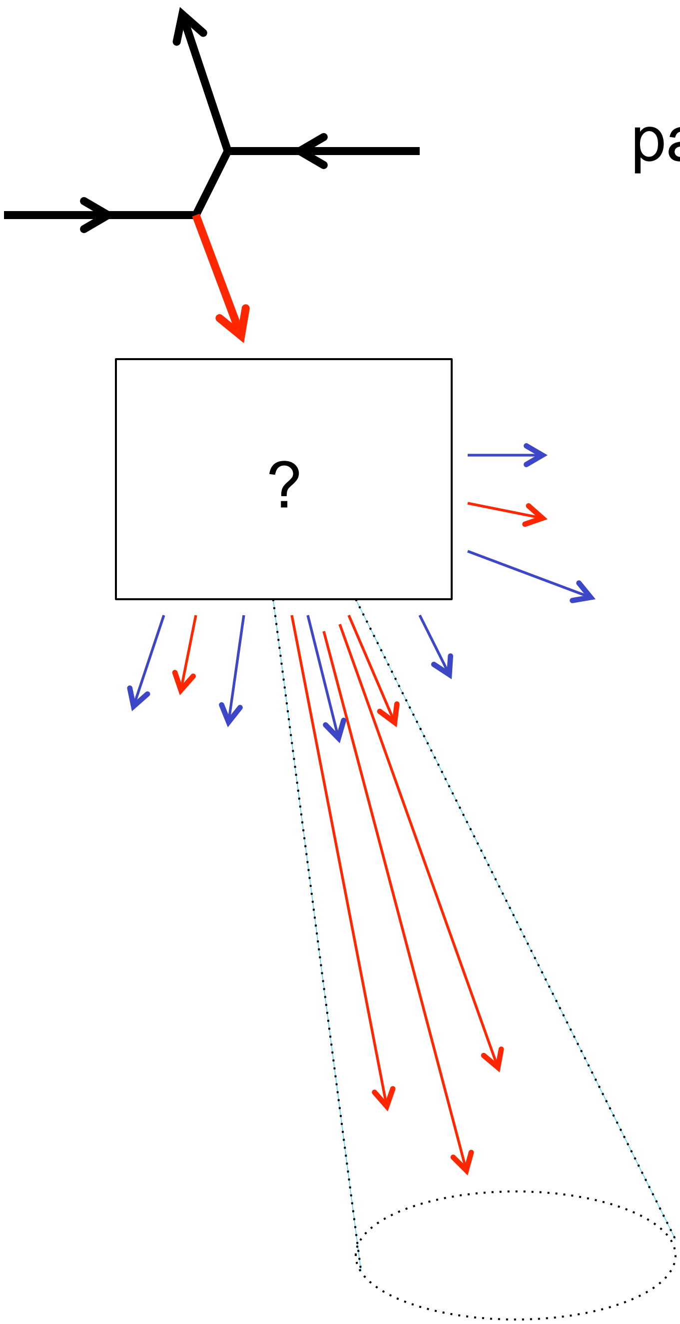


The end



Next : back-up slides

What do we want to reconstruct?



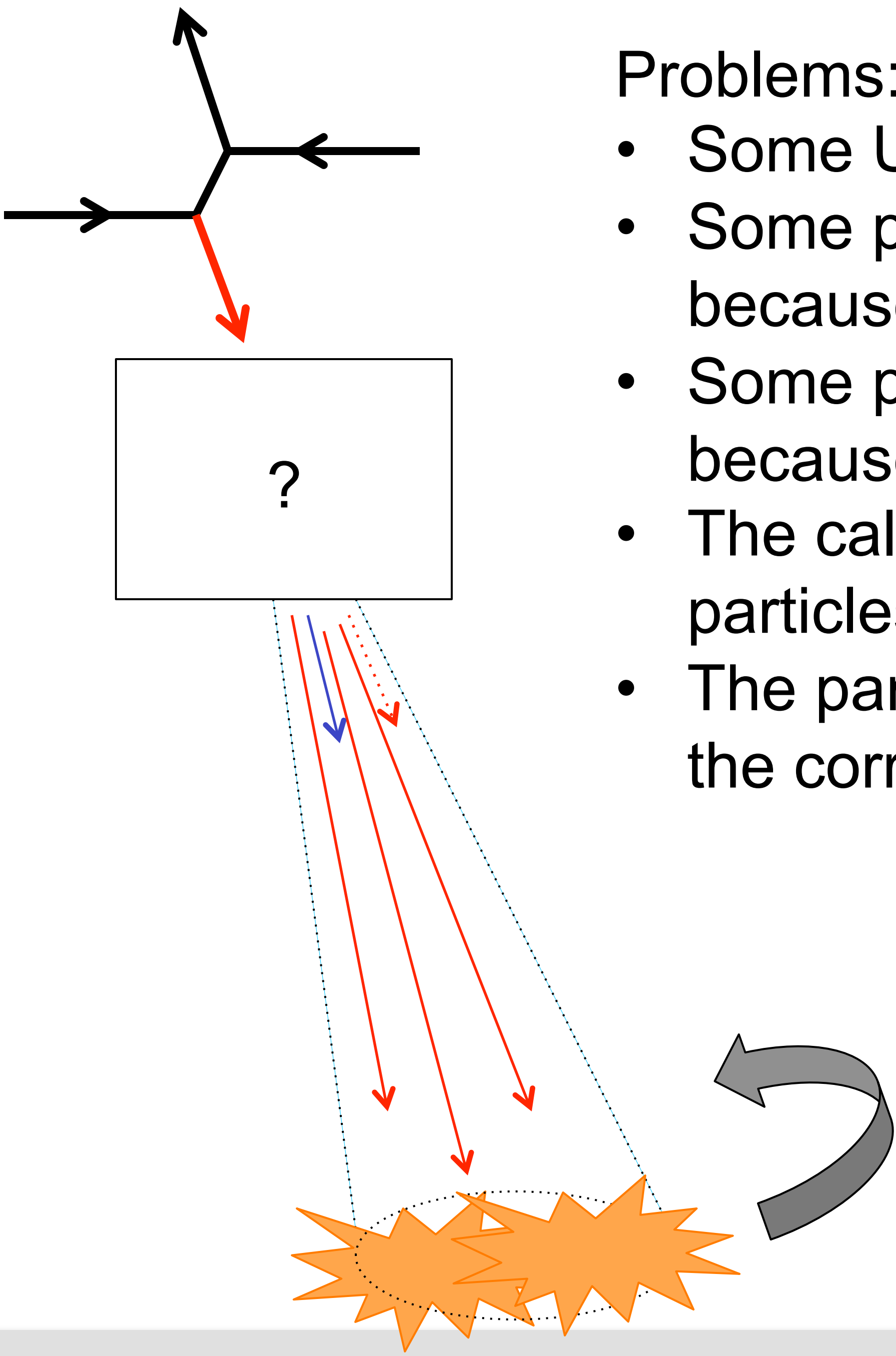
partons+Underlying Event(UE)

hadrons:
UE-associated : What energy would be in this cone if the hard scattering did not happen
parton-associated : What the hard scattering added into the event

JETS:
well defined by the clustering algorithm, FastJet anti-k_T, R = 0.3

Energy-corrected to particle-level (PYTHIA) jets
NO constituent p_T threshold

What do we want to reconstruct?

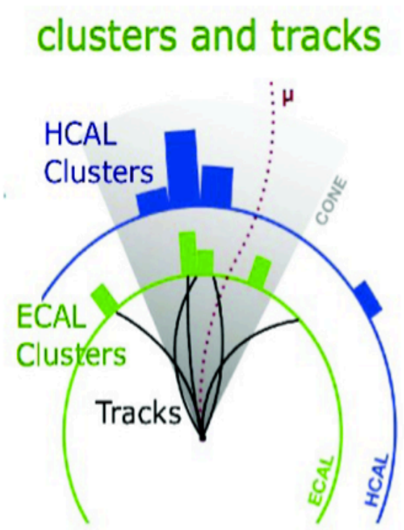


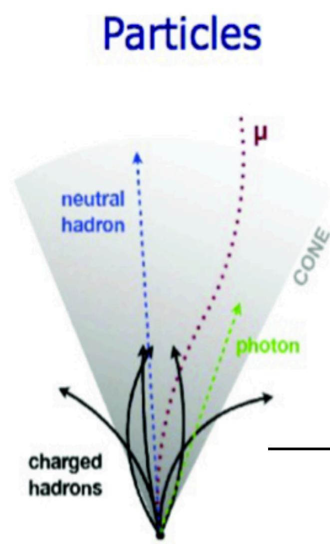
Problems:

- Some UE may still be there
- Some parton associated particles are lost because of reconstruction
- Some parton associated particles are lost because of bkg subtraction
- The calorimeter energy deposit of the final particles fluctuates
- The particle composition is different from what the corrections assume

Corrected to this level,
based on pythia and pp data

ParticleFlow algorithm





Towers

Background subtraction and jet clustering

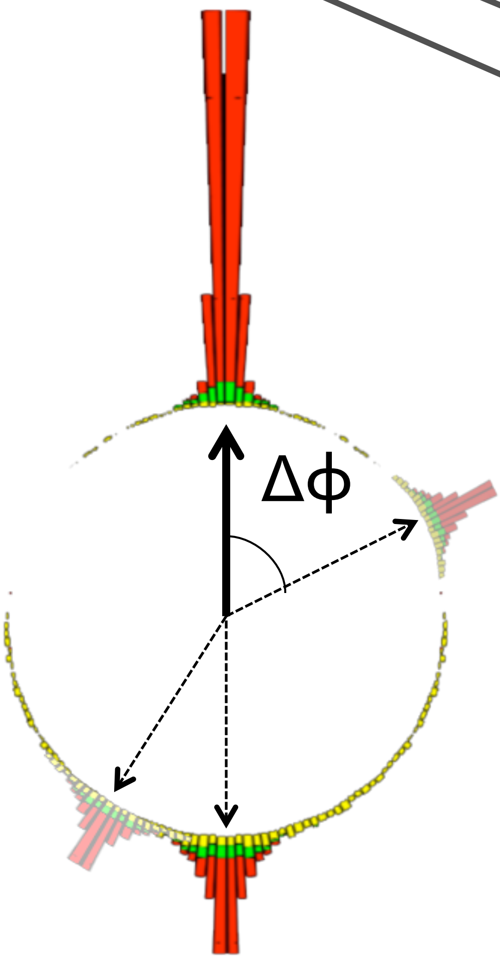
(Tracking for only the primary vertex)

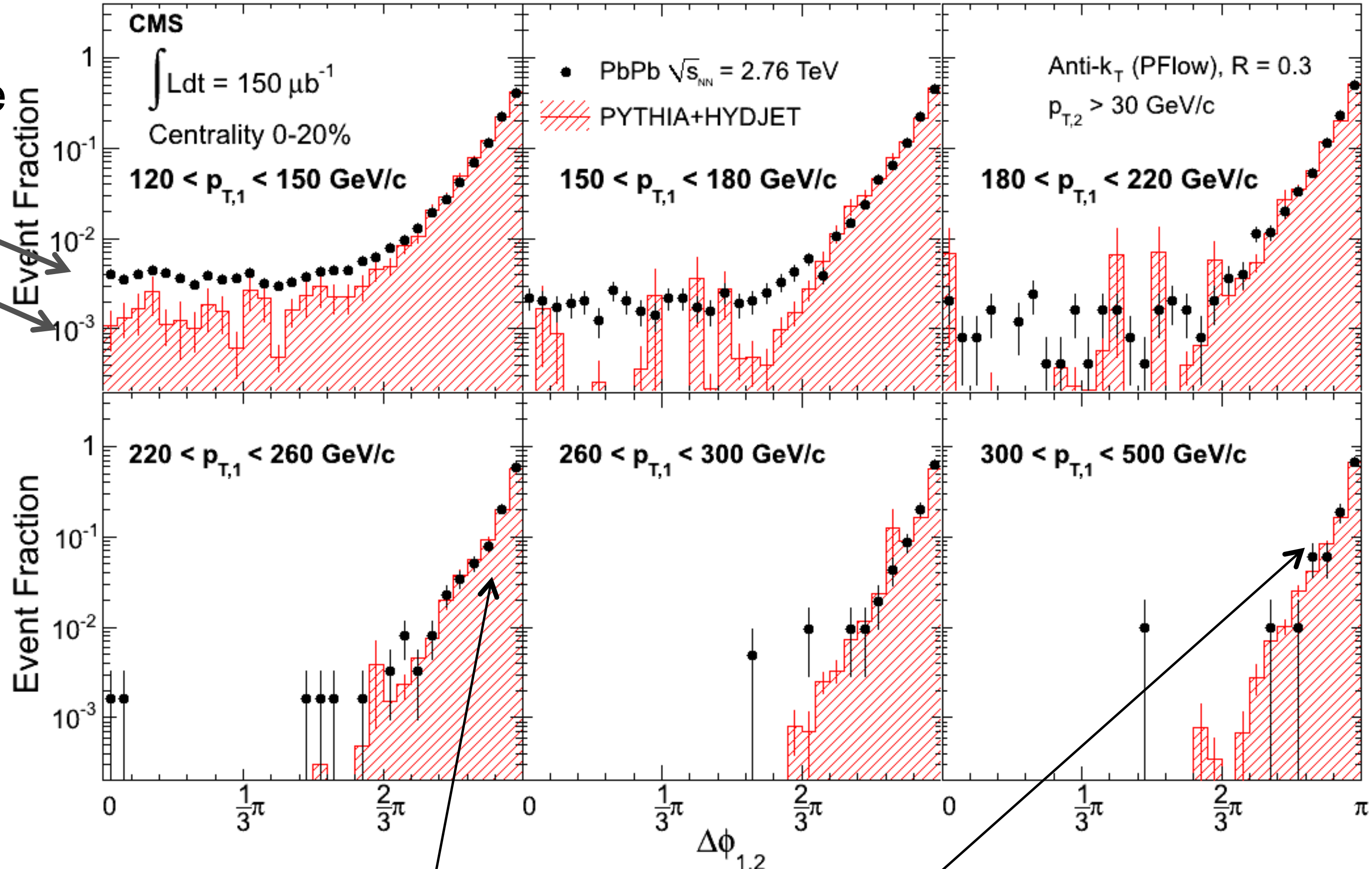
$\Delta\eta \times \Delta\phi$
0.076 x 0.076
in barrel

Calorimeter clusters and tracks are matched
(Details: CMS-PAS-HIN-11-004)
The candidates are merged into pseudo-towers in order to subtract background per segmentation

Dijet imbalance studies

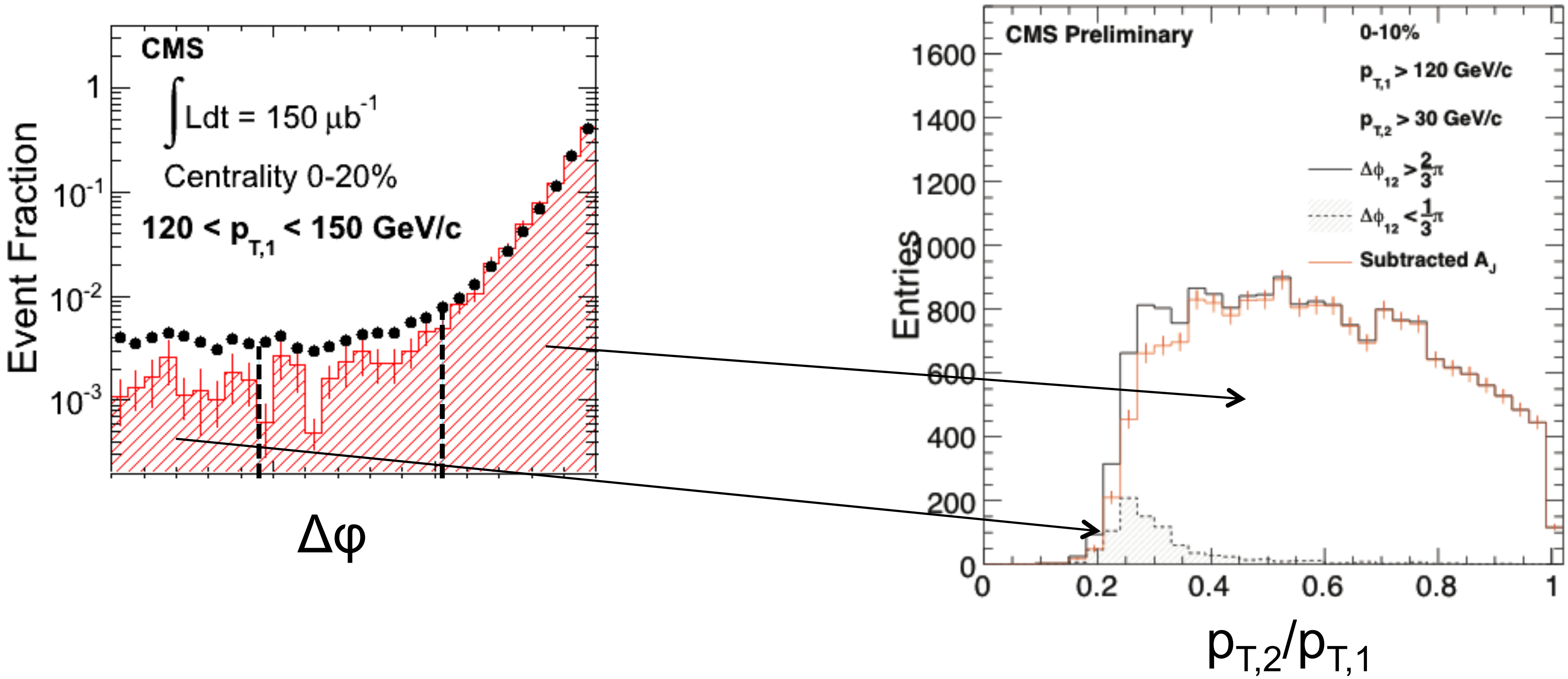
Background fluctuations supersede the recoil jet more often in data





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

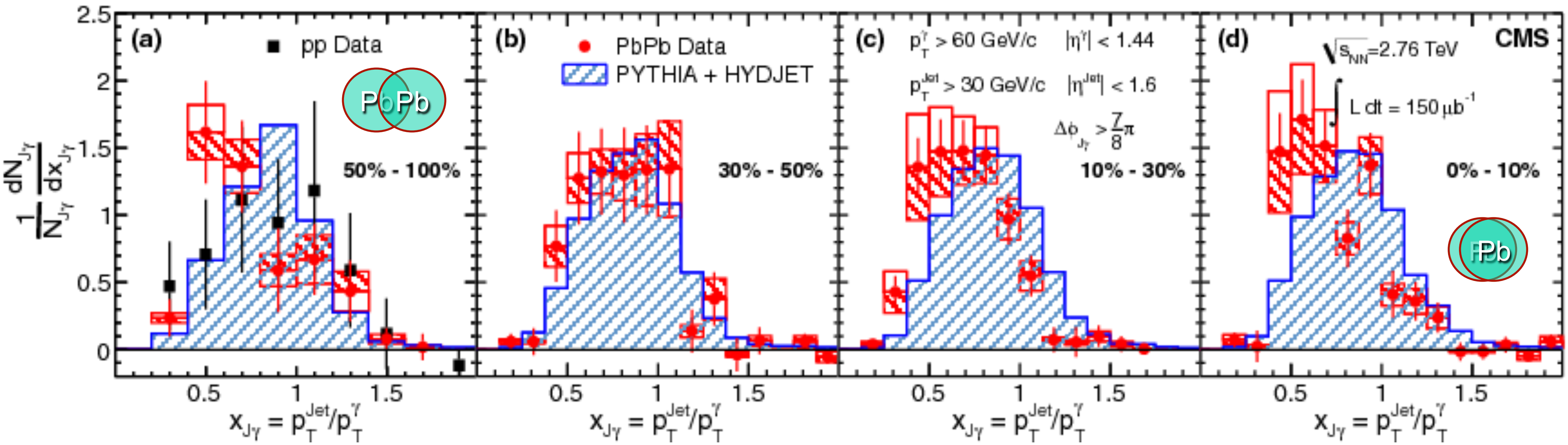
Subtraction of background jets

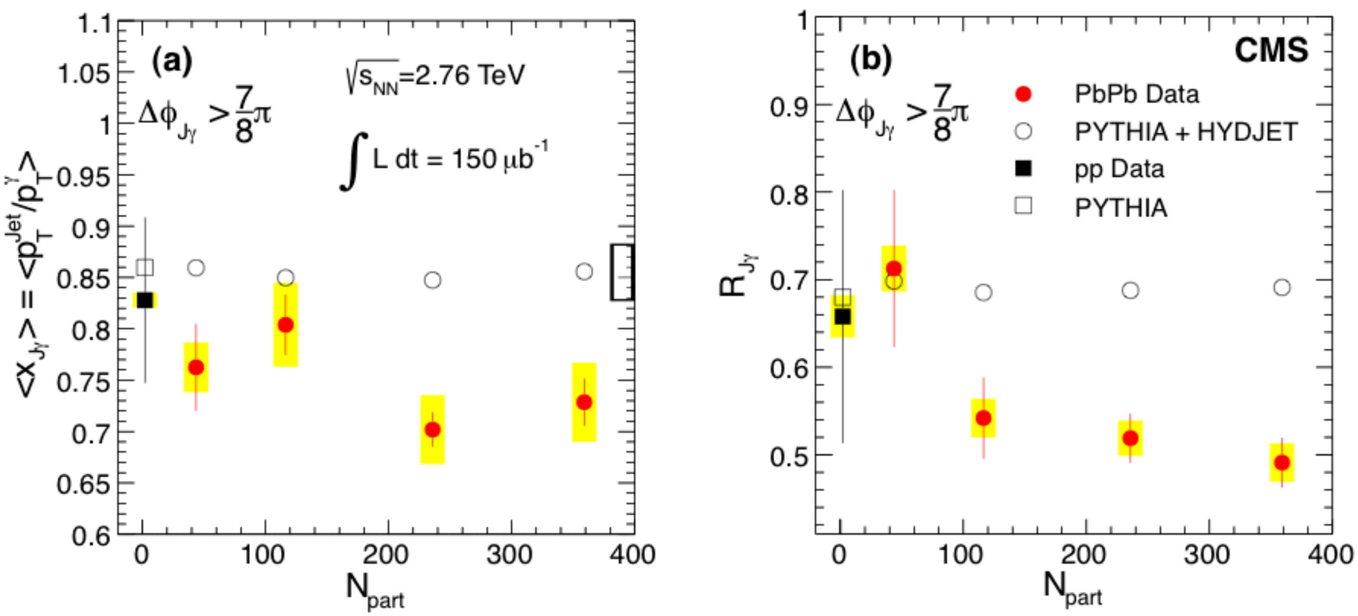


Bkg fluctuations peak at cut-off (30 GeV) → $p_{T,2}/p_{T,1}$ (bkg) ~ 0.25
This distribution is subtracted in all later plots

Photon-Jet correlations

Phys. Lett. **B** 718 (2013) 773



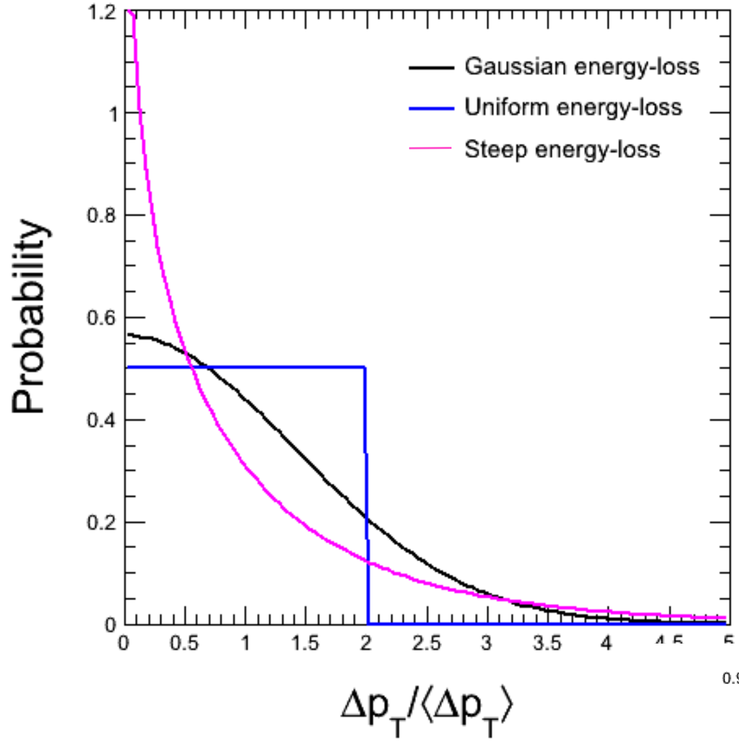


Equivalent information with jet R_{AA} and imbalance
-shift
-(potential) widening

Complementary:
-Different initial geometry
-Quark dominated

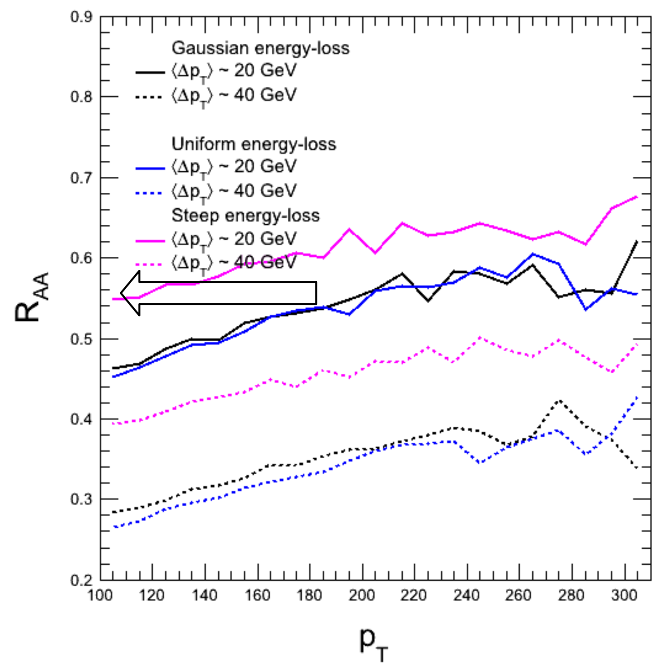
Same smearing procedure (for jet only) needed!

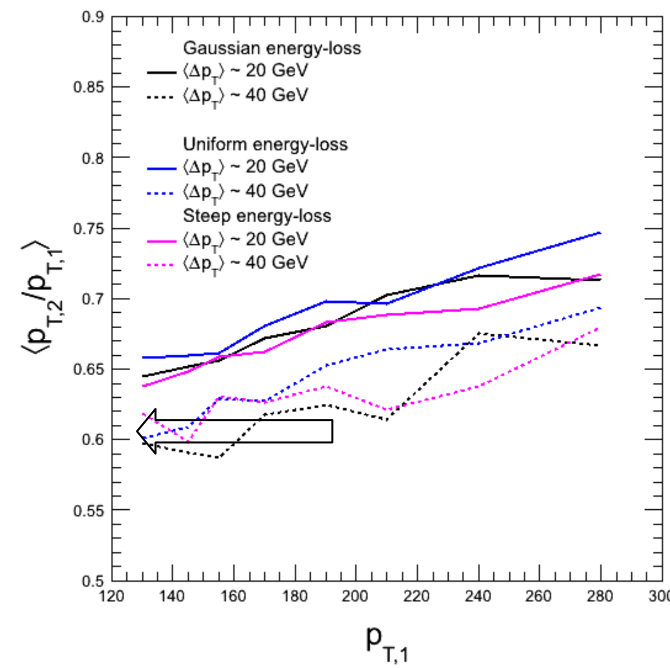
Tuning Quenching Weights



Try a different functional form for the probability distribution

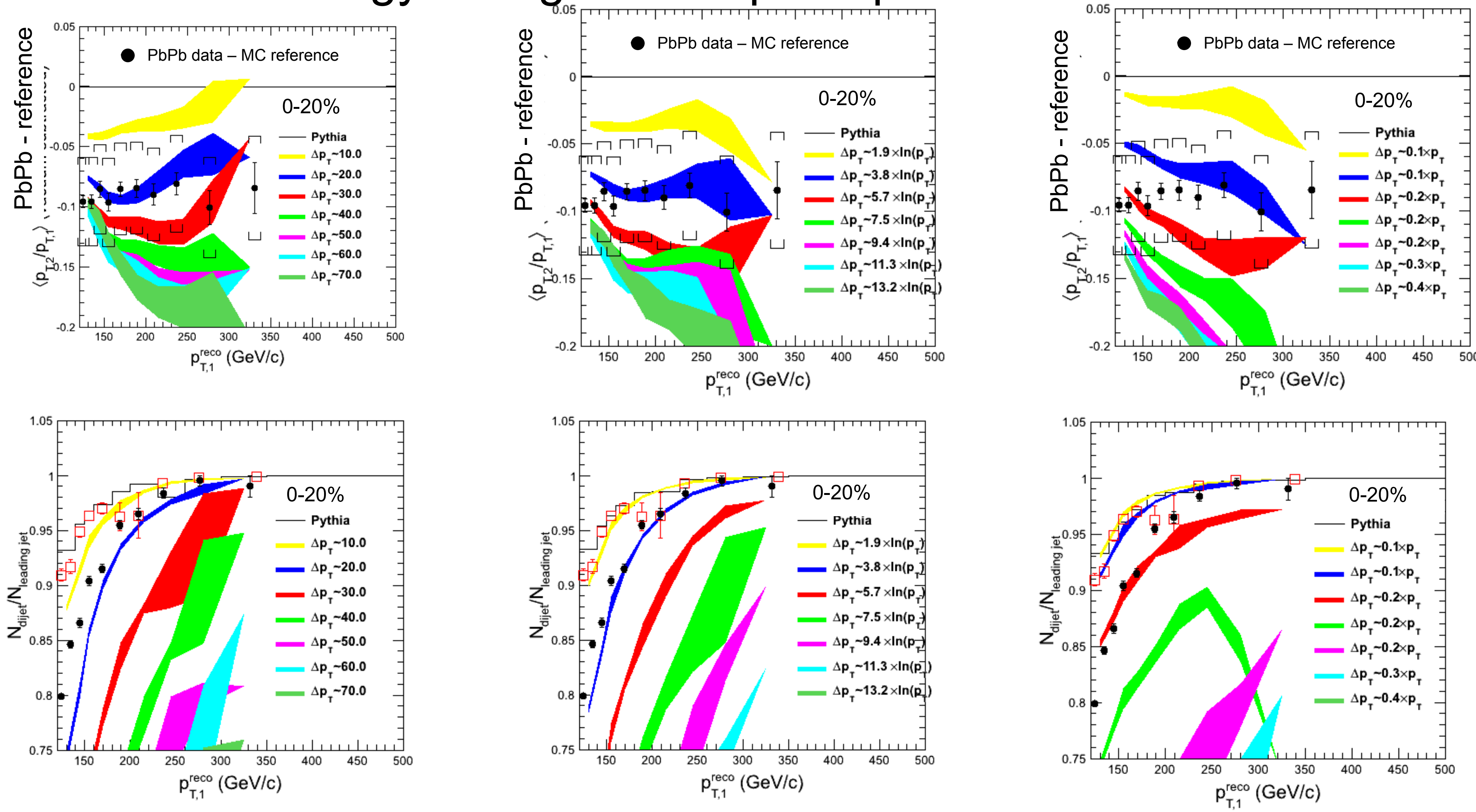
Not enough impact on results to account for the observed imbalance





p_T dependence of energy-loss

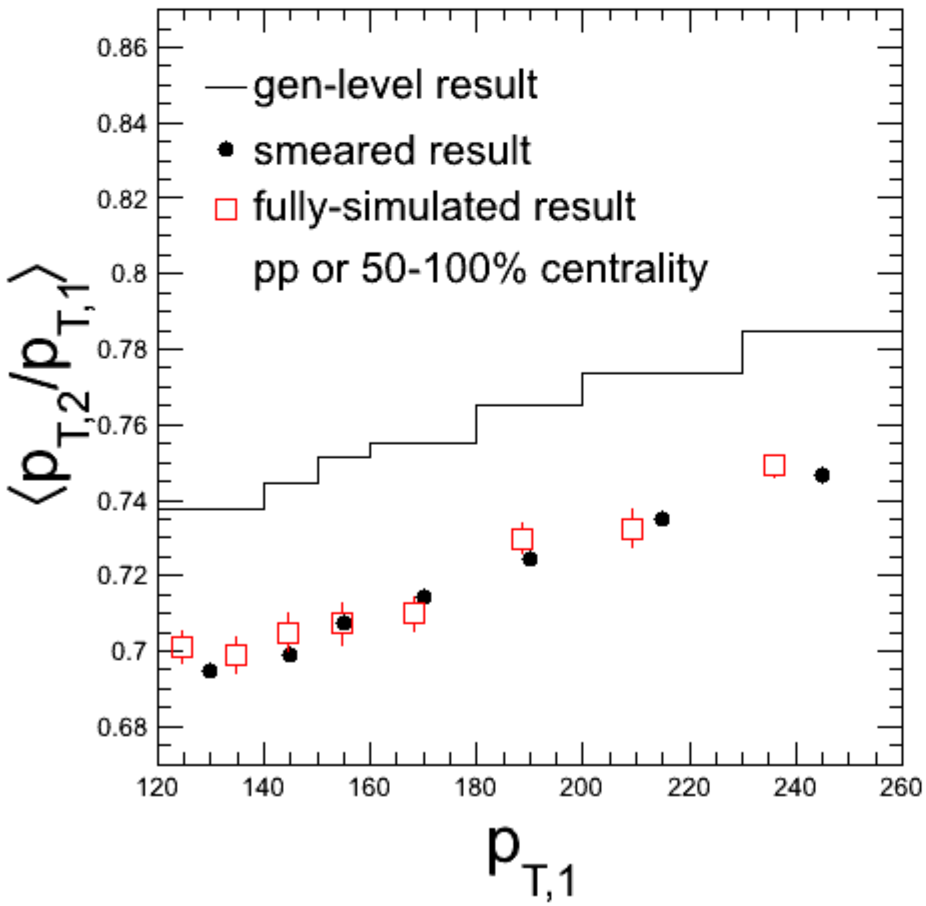
constant energy | logarithmic pT dependence | constant fraction



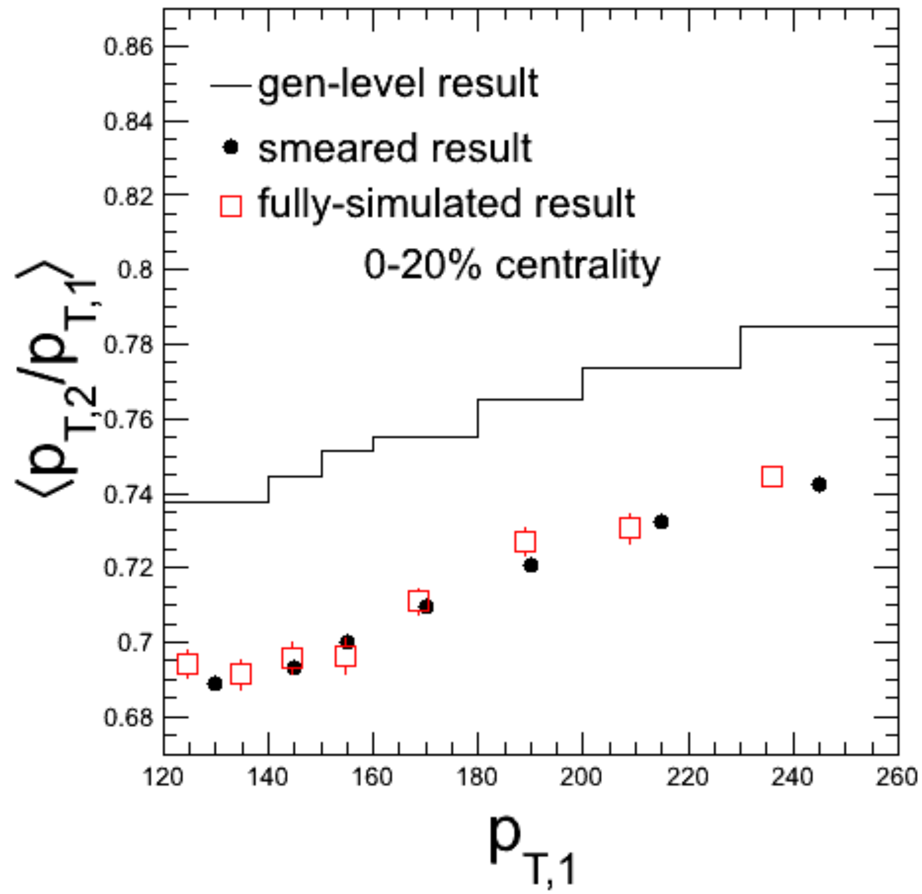
Mild p_T dependence, the first two parameterizations survive.
Similar lesson from other geometry models.

Centrality dependence of smearing

pp & peripheral

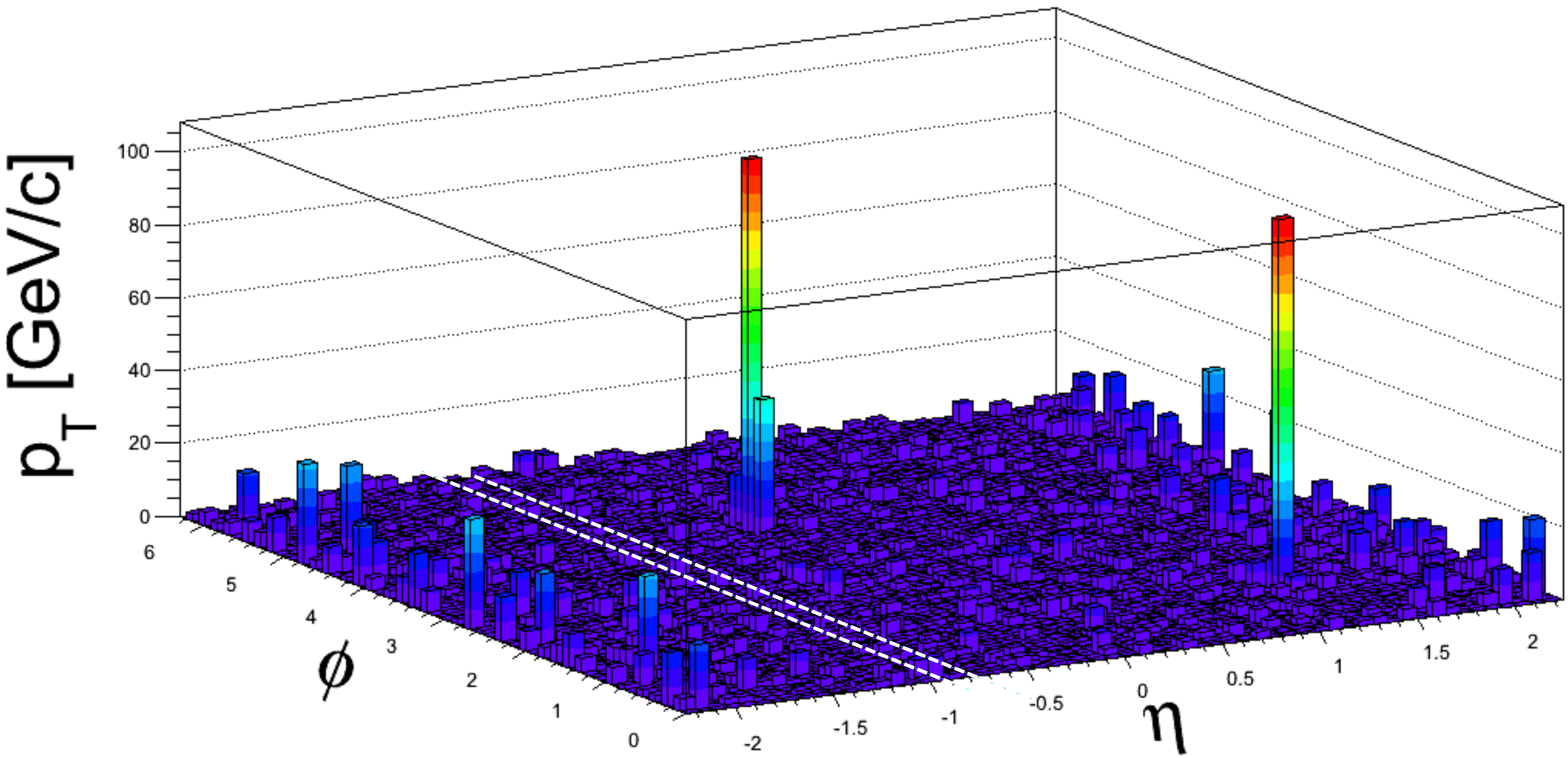


central



Smearing important in pp and peripheral PbPb
as much as in central PbPb!

PU-subtraction algorithm



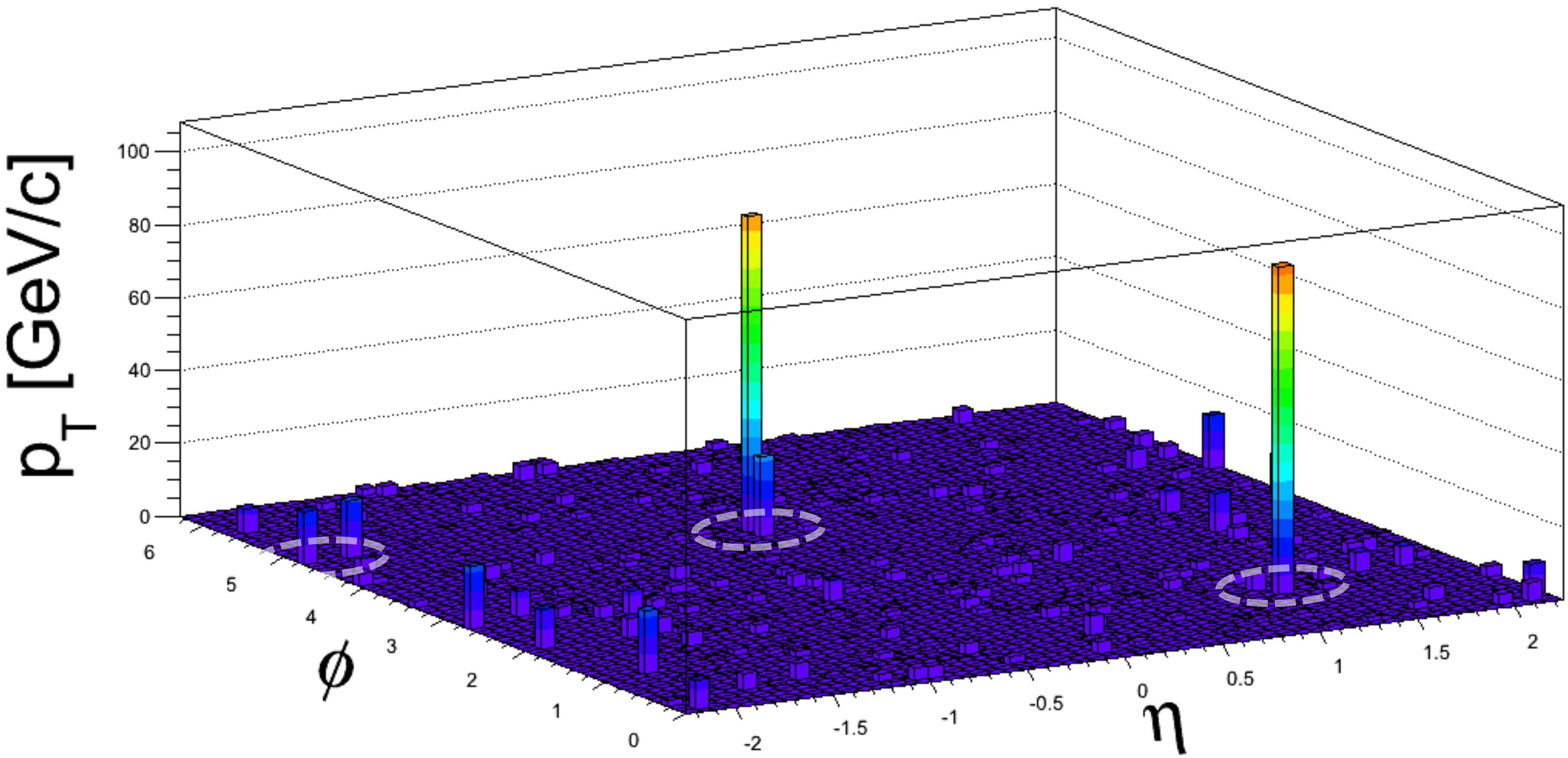
Estimate background
for each tower ring of constant η
estimated background = $\langle p_T \rangle + \sigma(p_T)$

- Captures dN/dη of background
- Misses ϕ modulation – to be improved

Tunable parameters:

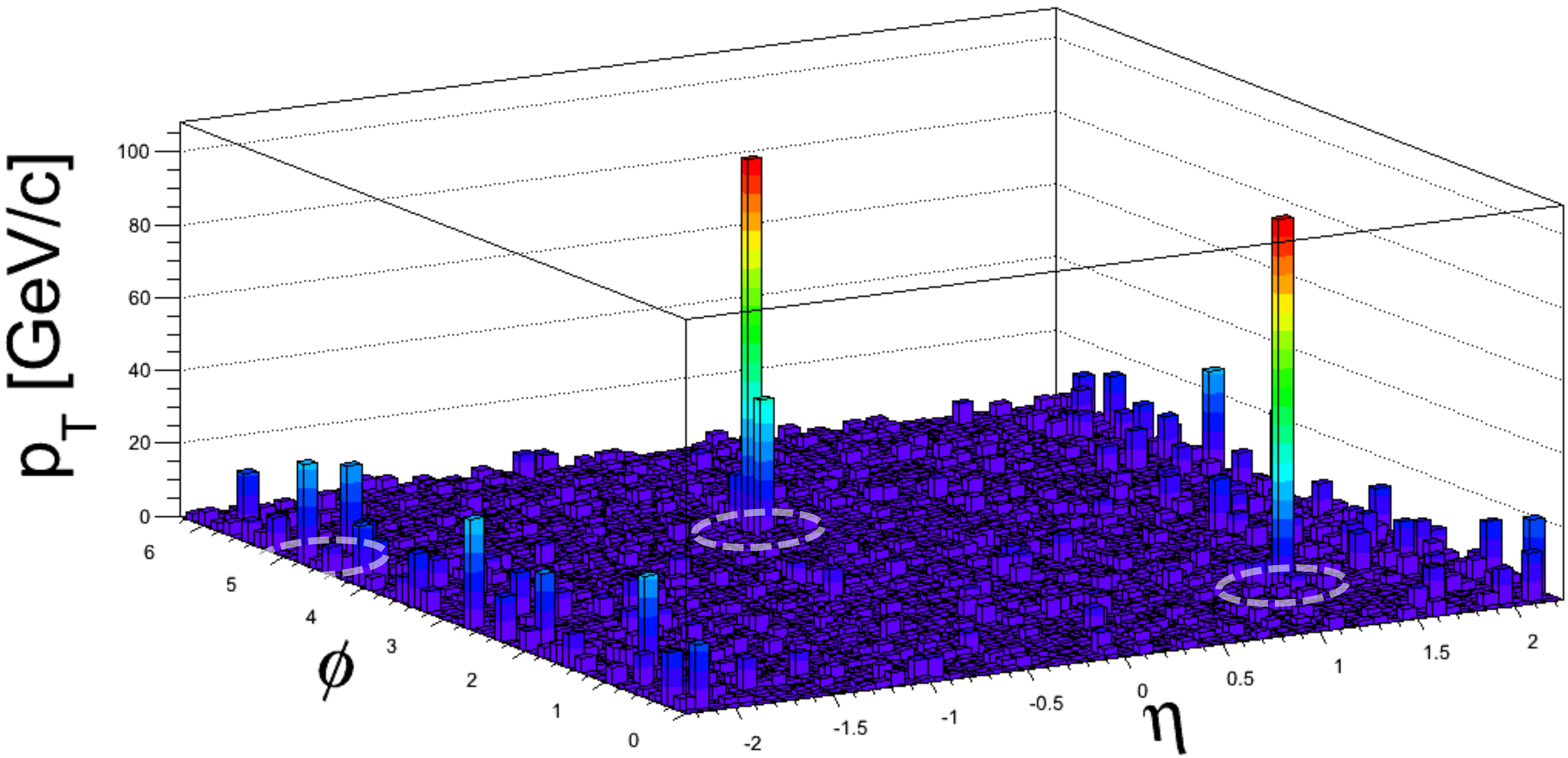
- Coefficient of RMS

PU-subtraction algorithm



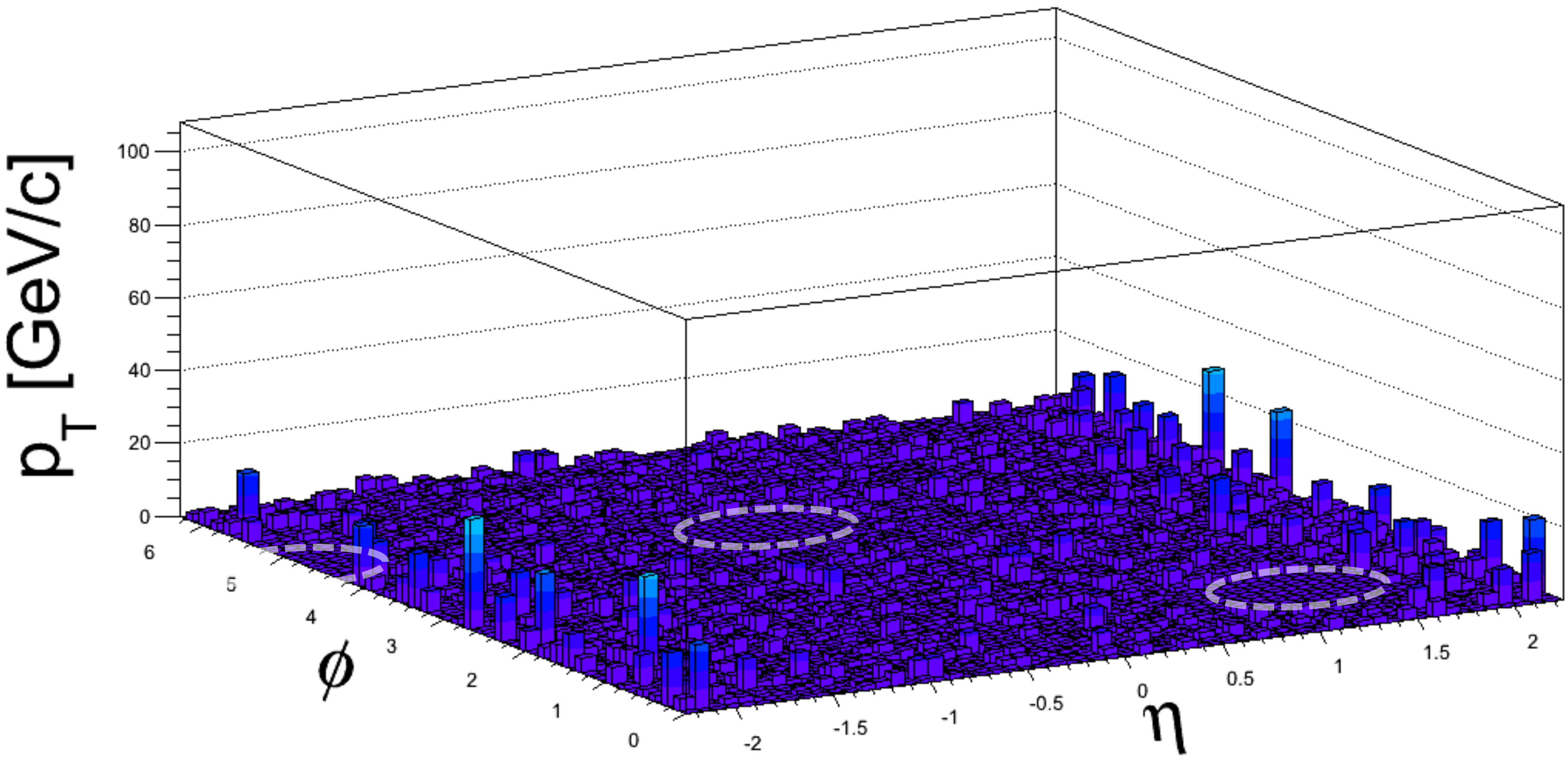
Subtract background from all towers
Run the clustering algorithm (anti-k_T)

PU-subtraction algorithm



Start over, knowing where the jets roughly are

PU-subtraction algorithm



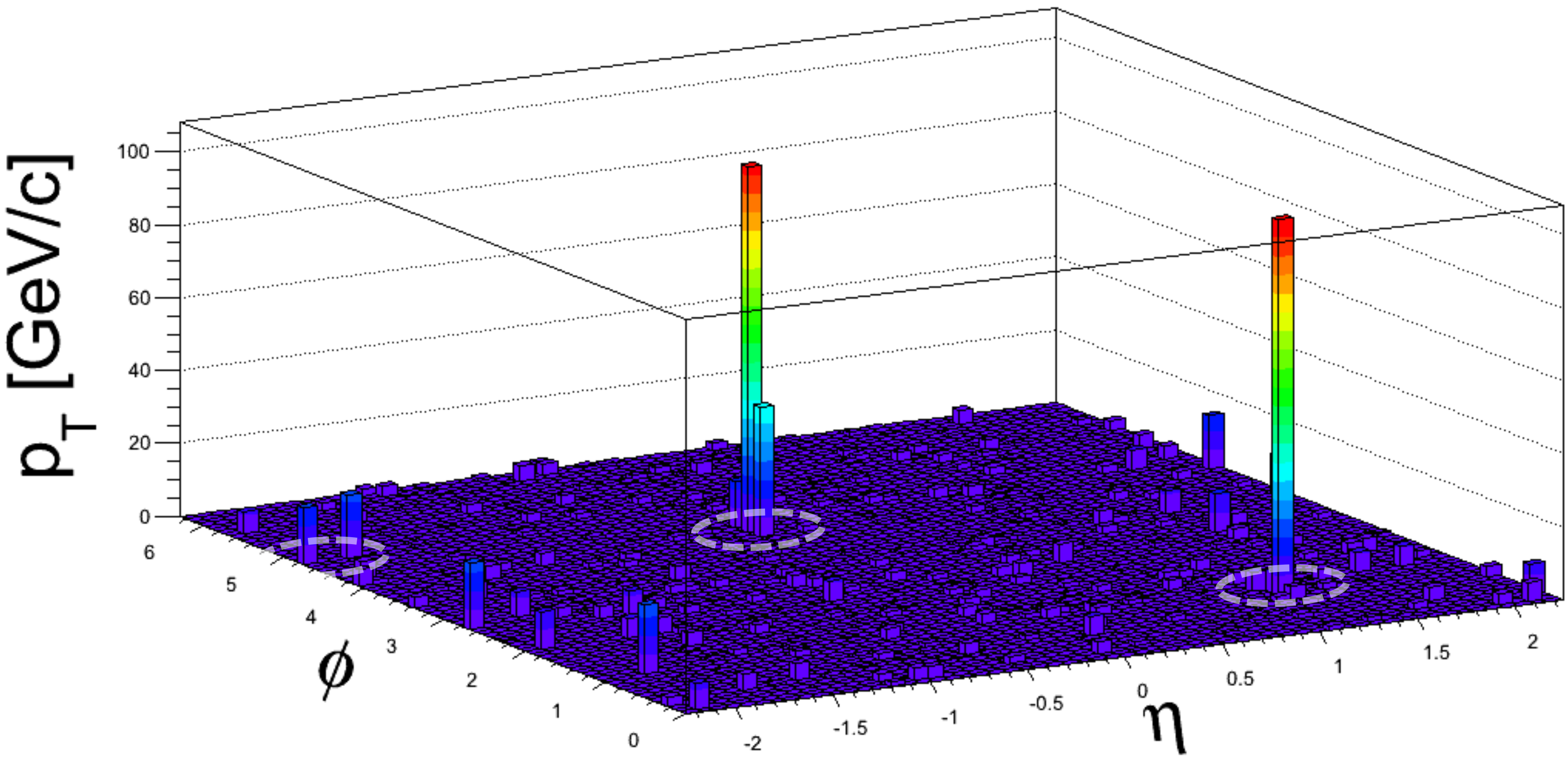
Start over, knowing where the jets roughly are
Exclude a certain area around the jets
Re-estimate the background for all towers

Tunable parameters:

- Coefficient of RMS
- Raw jet threshold
- Radius of exclusion

(not necessarily = R)

PU-subtraction algorithm



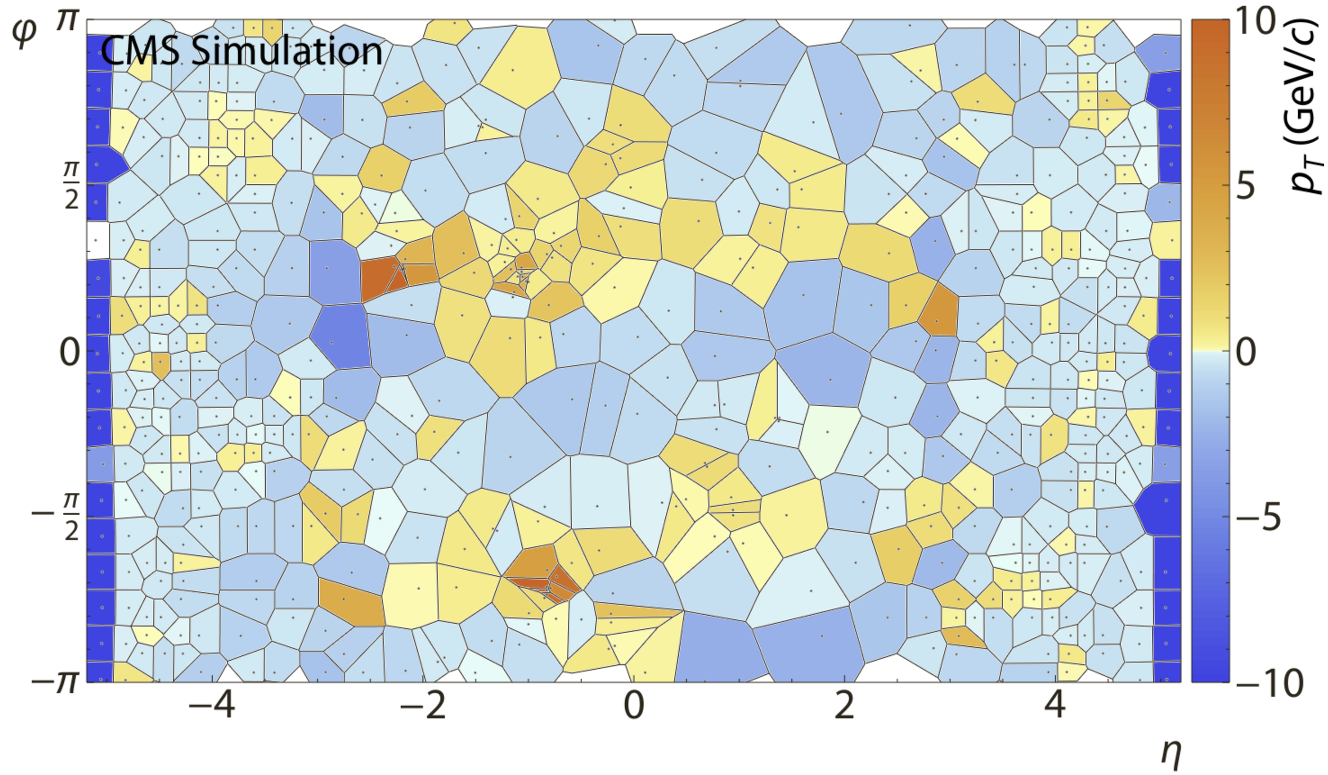
Start over, knowing where the jets roughly are
Exclude a certain area around the jets
Re-estimate the background for all towers
Subtract final background
Cluster jets

Tunable parameters:

- Coefficient of RMS
- Raw jet threshold
- Radius of exclusion

(not necessarily = R)

Preview: New UE subtraction



Underlying event characterized by forward calorimeters and tuned with minimum-bias data

Subtraction can be modulated based on azimuthal harmonics

Stay tuned...