Jet quenching: Some food for thought

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for the CMS Collaboration

CERN Workshop Summary

- GOAL: We need precision data/MC comparisons to learn about the jet quenching mechanism and extract medium properties from jet quenching data
  - Come to a "les houches accord" on how to compare data to calculations
- Many possible approaches:
  - Ideal:
    - Fully unfolded data that can be directly compared to calculations
      - Long lead times until data become available
      - Selection biases very hard to unfold
    - MC implementations of theory
      - Not ready yet
      - Full parton + medium description very challenging
      - But remember Thorstens presentation, very important to control "biases"
  - Intermediate:
    - Parameterizations of experimental resolutions + smearing of calculations
  - Alternatives
    - Choice of observables that are insensitive to details of jet definition

From Nestor's presentation at CERN

The physics we are after:
∝jet modifications
∝jet-medium interactions
as probes of medium properties.

The primary physics observables:
samples of medium-modified jets
embedded in a jet-modified medium

Problem:
∝TH limitations: unrealistic to ask for 'controlled' models
that simulate both: jet & medium in HICs

∝EXP limitation: unclear how to separate
medium-modified jet
from jet-modified medium
without introducing biases

Open questions after CERN WS

1) How to do quantitative cross-checks between experiments?
   – ATLAS/CMS show data for different R   (0.2, 0.4 vs 0.3, 0.5)
   – performance plots are shown for different kin. ranges
   – jet resolution parameterizations from different Exps.
   – Agreement on jet definition?
   – How do the jet reconstruction strategy, UE subtraction procedures and unfolding methods affect data/MC comparisons?

2) Which observables and can be compared with 'raw' theory?

3) How do we organize a systematic MC/data comparison?

4) Current working assumption:
   – The quenching effect on jets and the jet medium response factorize
   – Jet measurements unfolded for detector effects and underlying event are not strongly affected by the medium response to the jet
   – Is this a safe approach?

Answers to 1)

1) How to do quantitative cross-checks between experiments?
- – ATLAS/CMS show data for different R   (0.2, 0.4 vs 0.3, 0.5)
- – performance plots are shown for different kin. ranges
- – jet resolution parameterizations from different Exps.

$\Rightarrow$ We can try to come to an agreement between experiments
- • mostly limited by the approval process of the experiments

$\Rightarrow$ We agreed to provide resolution parameterizations or quote fully unfolded results in future measurements
- • See Yetkins presentation from earlier today
- • Simple parameterization from already published papers should already be very useful

$\Rightarrow$ Comparisons between ALICE and ATLAS/CMS inherently difficult due to very different detector capabilities

Answers to 1)

1) How to do quantitative cross-checks between experiments?

- Agreement on jet definition?
- How do the jet reconstruction strategy, UE subtraction procedures and unfolding methods affect data/MC comparisons?

$\Rightarrow$ All experiments are using the anti k_T jet algo

- UE subtraction still based on different strategies
- New CMS algo should be conceptually closer to the ATLAS prescription
  - Explicit treatment of azimuthal asymmetries
  - No more intrinsic noise suppression
- Moving in the right direction…

$\Rightarrow$ From Gavins talk on Monday:

- Confidence building!
- Scrutiny of UE subtraction algorithms from the theoretical side has shown that the current UE subtraction algo's don't do too badly
  - Some caveat's still remain
  - Remain aware of the potential artifacts of the various methods
- The key is still to define the comparison point between data and calculations
  - Final state particle level!

Answers to 2)

- 2) Which observables and can be compared with 'raw' theory?

=> Again remember Thorstens presentation
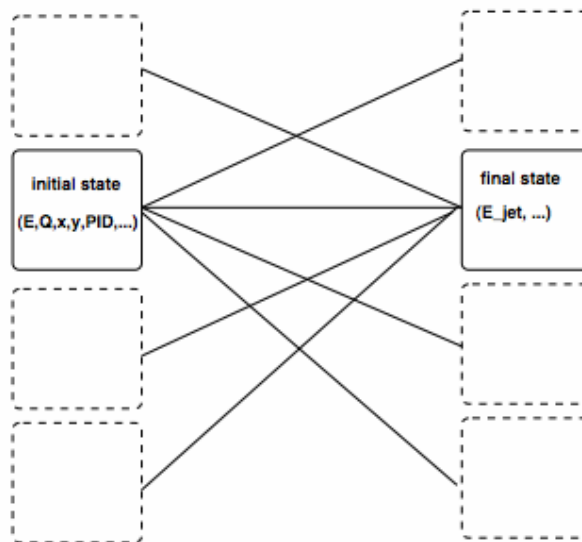
=>A correct comparison requires to compute for all initial states, taking the "biases" by the experimental observation into account
  - We have to be careful with "raw" calculations on the theory side
    - Very hard to do precise comparisons without full MC implementation
  - Resolutions and UE fluctuations need to be taken into account separately
    - see answer to 1)

Answers to 3)

3) How do we organize a systematic MC/data comparison?

- We have collected a substantial amount of data already
  - Dijet energy balance, incl. p_T dependence
  - Jet R_{AA}
  - Ratio of jets without associated away side jet
- Many models can get single observables right without much effort
  - To learn which classes of models give good description of the data we need to go to multi observable comparisons
    - Simultaneous description of the centrality and p_T dependence of energy balance AND Jet R_{AA}
    - Test different models and parameter sets for tensions
  - Should be possible without full MC implementation of all different models or full availability of unfolded data

=> Propose a Workshop…

Jet Data/MC Comparison Workshop?

- Get a few MC authors and some experimentalists at the same table for ~a week
  - Produce a few million events of each flavor of MC
    - We can offer support with our computing infrastructure
    - Agree on common centrality classes glauber calculation etc.
  - Store event centrality + a list of jets in an ntuple/text file
  - Apply smearing according to experimental resolution parameterizations and apply a suitable event (trigger) selection
  - Plot dijet balance + R_{AA} on equal footing for a set of common calculations and assumptions and see how well the current state of the art models fare
- Publish a joint summary article?

Answers to 4)

4) Current working assumption:
  – The quenching effect on jets and the jet medium response factorize
  – Jet measurements unfolded for detector effects and underlying event are not strongly affected by the medium response to the jet
  – Is this a safe approach?

- From what we have seen in the data so far there does not seem to be a strong medium response effect that can distort direct jet quenching measurements
- Addressing the medium response should be an interesting candidate for the next generation of jet quenching measurements/calculations
$\Rightarrow$ In the next few slides I give a summary of my personal view of what we know so far about the medium response

My Personal picture…

Cartoon

CMS, PbPb, $\sqrt{s_{NN}}$ = 2.76 TeV, L_{int} = 6.8 μb^{-1}

● PbPb 0-30%
PYTHIA+HYDJET

Event Fraction

$$A_J = (p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2})$$
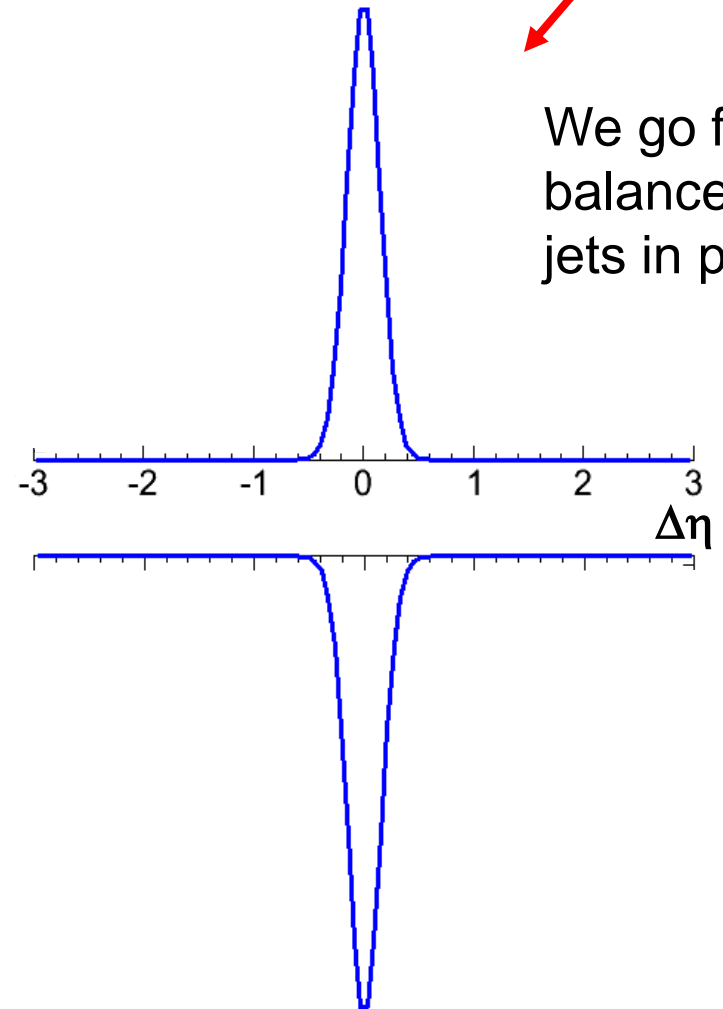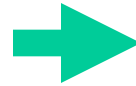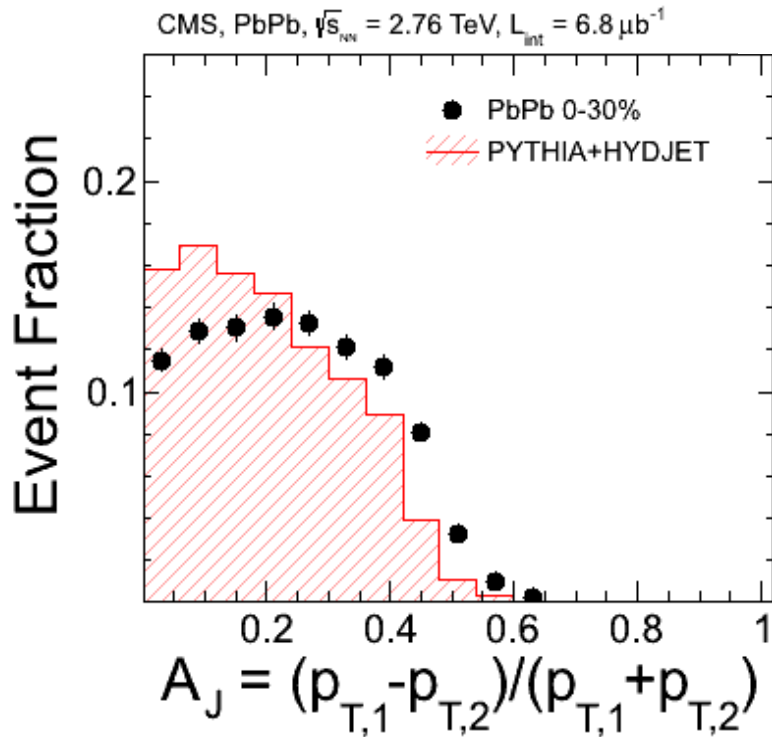
We go from balanced jets in pp…

$\Delta\eta$

From QM2011:
Parton Energy Loss observed
as Dijet Momentum Imbalance

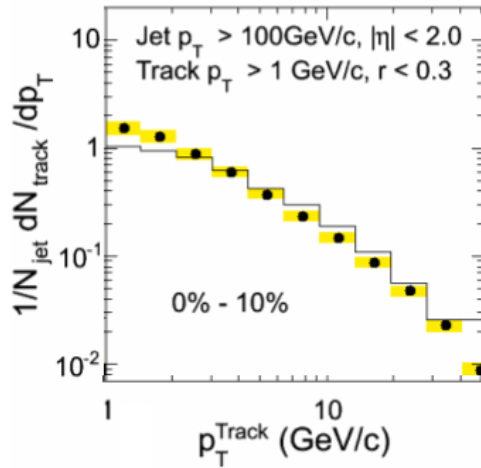# Jet Medium Interactions

My Personal picture…

CMS, PbPb, $\sqrt{s_{NN}}$ = 2.76 TeV, L_{int} = 6.8 μb^{-1}

- ● PbPb 0-30%
- PYTHIA+HYDJET

Event Fraction

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

…to imbalanced jets in PbPb
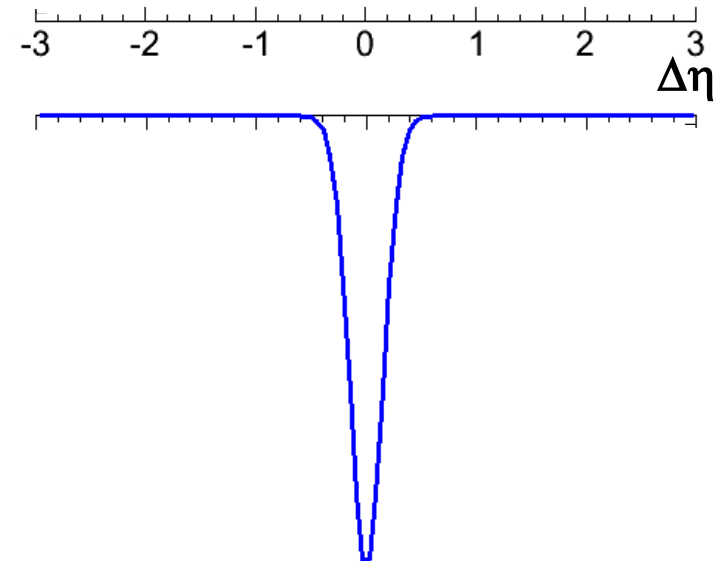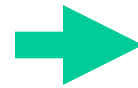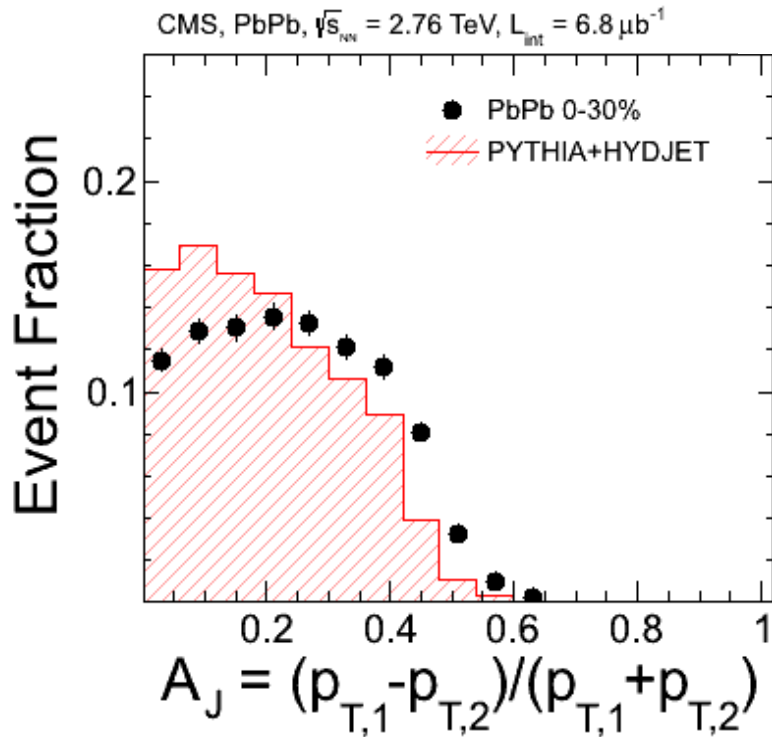
$\Delta\eta$

From QM2011:
Parton Energy Loss observed
as Dijet Momentum Imbalance

Jet Medium Interactions

Jet p_T > 100GeV/c, |η| < 2.0
Track p_T > 1 GeV/c, r < 0.3

0% - 10%

My Personal picture…

Cartoon

$\Delta\eta$
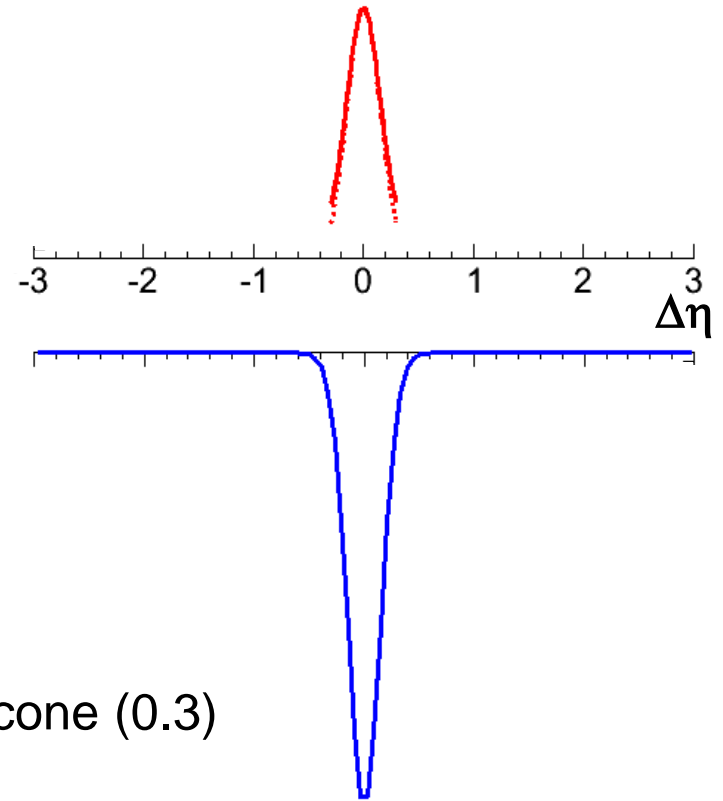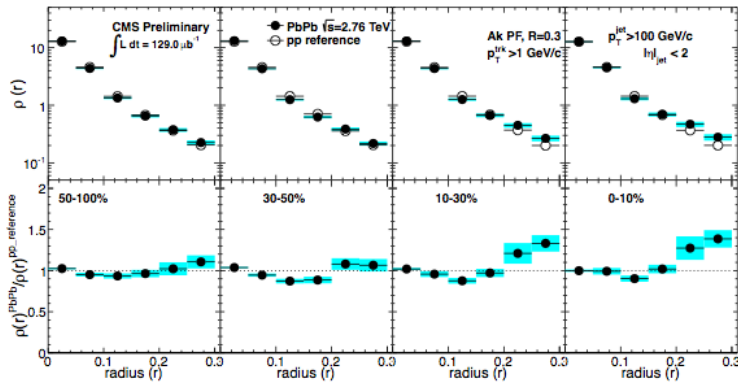
From jet shapes and FF measurements:
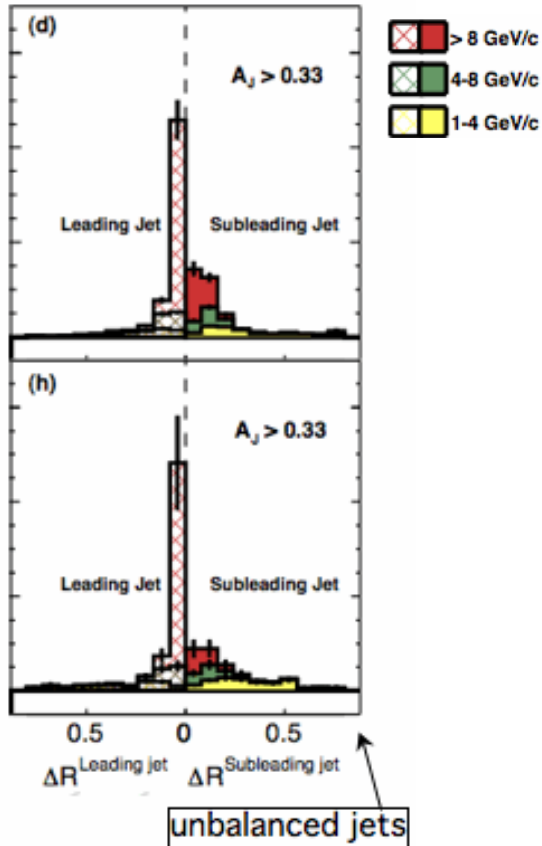Little change of the jet structure inside the jet cone (0.3)

Christof Roland   13   Jet Workshop 2013, Paris

My Personal picture…

Cartoon

Phys. Rev. C84 (2011) 024906

MC

	> 8 GeV/c
	4-8 GeV/c
	1-4 GeV/c

(d)

$A_J > 0.33$

Leading Jet   Subleading Jet

Data

(h)

$A_J > 0.33$

Leading Jet   Subleading Jet

0.5   0   0.5

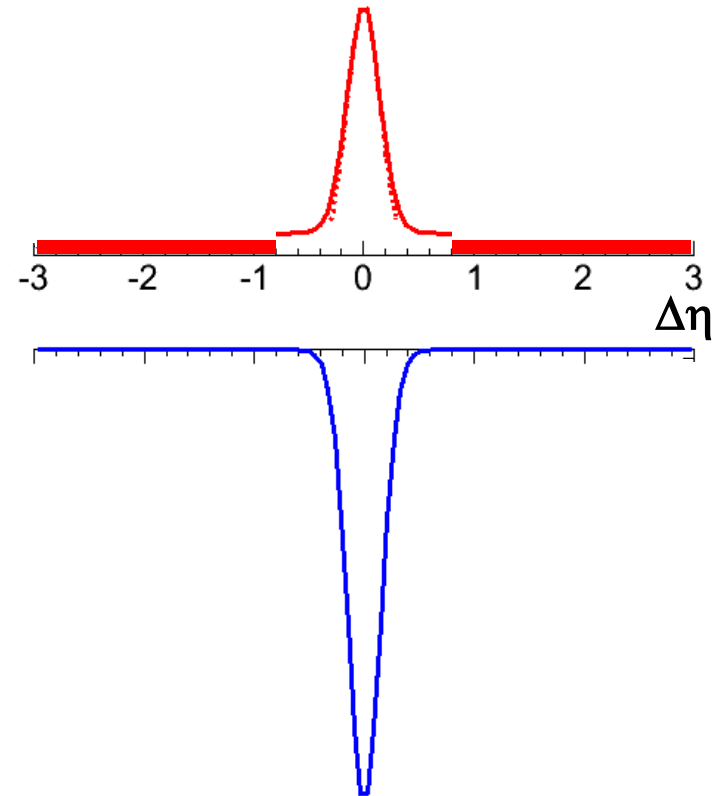$\Delta R^{Leading\ jet}$ $\Delta R^{Subleading\ jet}$

unbalanced jets
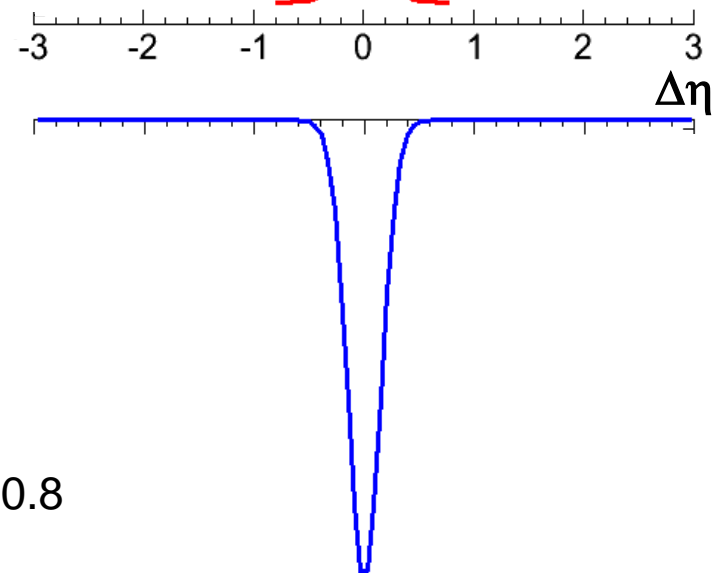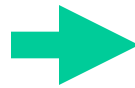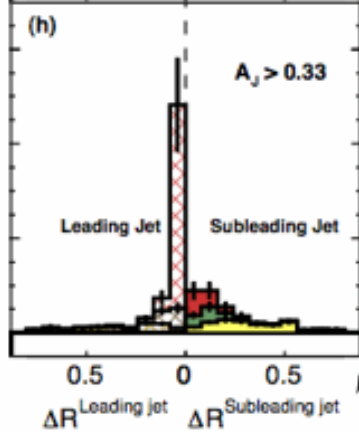
From jet track correlations:

Little extra energy in the vicinity of the jet $0.3 < R < 0.8$

$\Delta\eta$

-3   -2   -1   0   1   2   3

Jet Medium Interactions

My Personal picture…

Cartoon

in-cone

out-of-cone

0-30% Central PbPb

CMS   Pb+Pb $\sqrt{s_{NN}}$=2.76 TeV   0-30%
$\int L\,dt = 6.7\ \mu b^{-1}$

- > 0.5 GeV/c
- 0.5 - 1.0 GeV/c
- 1.0 - 2.0 GeV/c
- 2.0 - 4.0 GeV/c
- 4.0 - 8.0 GeV/c
- > 8.0 GeV/c

In-Cone $\Delta R < 0.8$

Out-of-Cone $\Delta R < 0.8$

Phys. Rev. C84 (2011) 024906

balanced jets   unbalanced jets

$\Delta\eta$
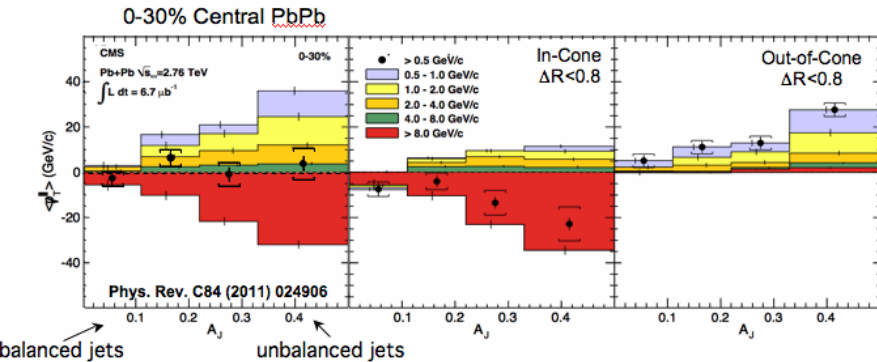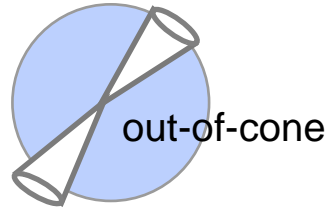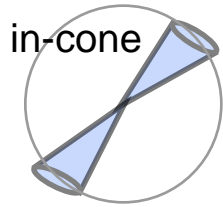
From the missing p_T analysis:
The "lost" energy can be found in form
of low p_T particles at R> 0.8

Jet Medium Interactions

My Personal picture…

- The cartoon sums up our incomplete knowledge how the "lost" energy gets redistributed
  - Is pattern directly related to radiation off of the parton
  - Is this energy completely thermalized by the medium and the shape should rather be considered a medium response?
  - All current model agree these days that the energy should go to large angles
    - But how large?
- Now would be a good time for predictions!

$\Delta\eta$
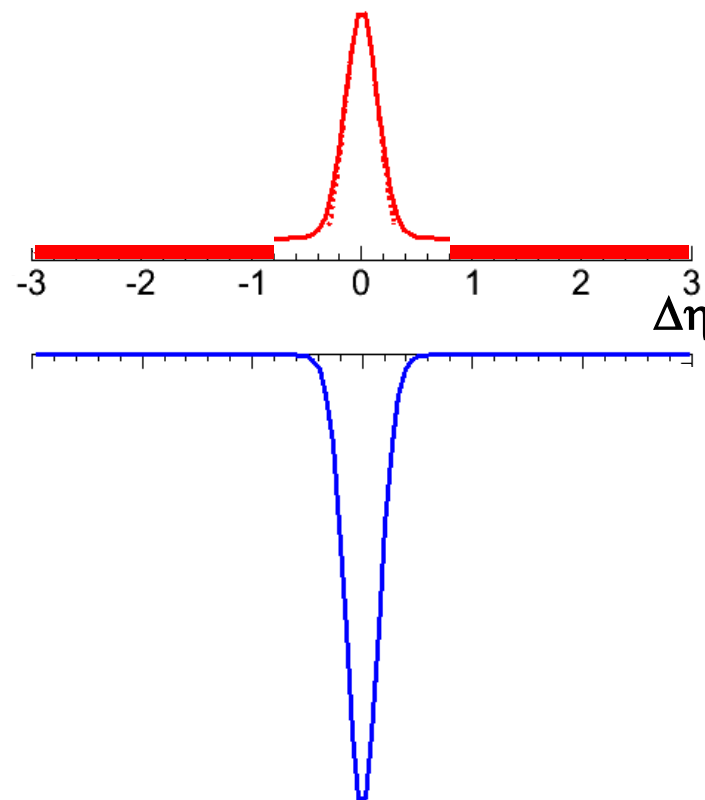
Jet Medium Interactions

My Personal picture…

Cartoon

- We should be able to measure this shape in the near future, e.g by
    - Jet track correlations
    - Energy flow relative to the jet axis
    - Missing p_T vs cone size
    - There is still time to predict the width ;-)

- Can we distinguish many soft particles emitted early (or late?) from the parton from few harder gluons that get thermalized?
    - Event by event observables?
    - HBT analysis in and out of the jet cone to see in which kinematic region jet related particles are coherent with the medium?

- Measure the bethe bloch curve of the QGP analogous to the QED problem
    - ΔE vs. specific ionization
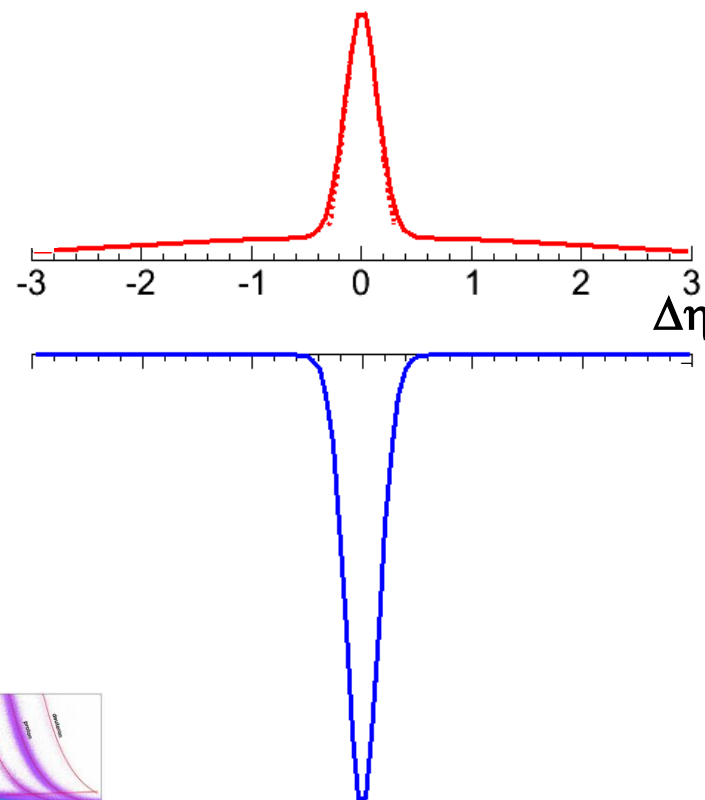
Flavor dependence of jet quenching

- ## More opportunities for predictions!
  - Dijet vs gamma-jet energy balance should already now give some handle on gluon vs quark dominated processes
  - b-Jet momentum balance, b-Jet R_{AA}
    - Perform similar exercise as with the current dijet analysis
  - Quark to gluon jet ratios via fragmentation functions
    - Extract quark and gluon FF's from pp
      - Three jet events, gamma jet events etc
    - Fit the quark/gluon ratio or even unfold the parton spectrum in dijet events
  - 3 jet events in PbPb
    - Can we learn something about gluon energy loss?
    - Can we use the energy of the 3rd jet to control the virtuality?

- ## Should all be possible measurements in the near future (I.e. before 2015)

And most important of all…

- When is the next Workshop?

- The February Workshop at CERN and this one Paris were already a very good start towards our goal to learn about the medium using jets
  - How should we continue?
  - Time line for the next meeting?
  - Any volunteers to organize it?
  - Peter Steinberg suggested a WS in New York

Backup

Jet Fragmentation in pp and PbPb

$\xi = \log (1/z)$
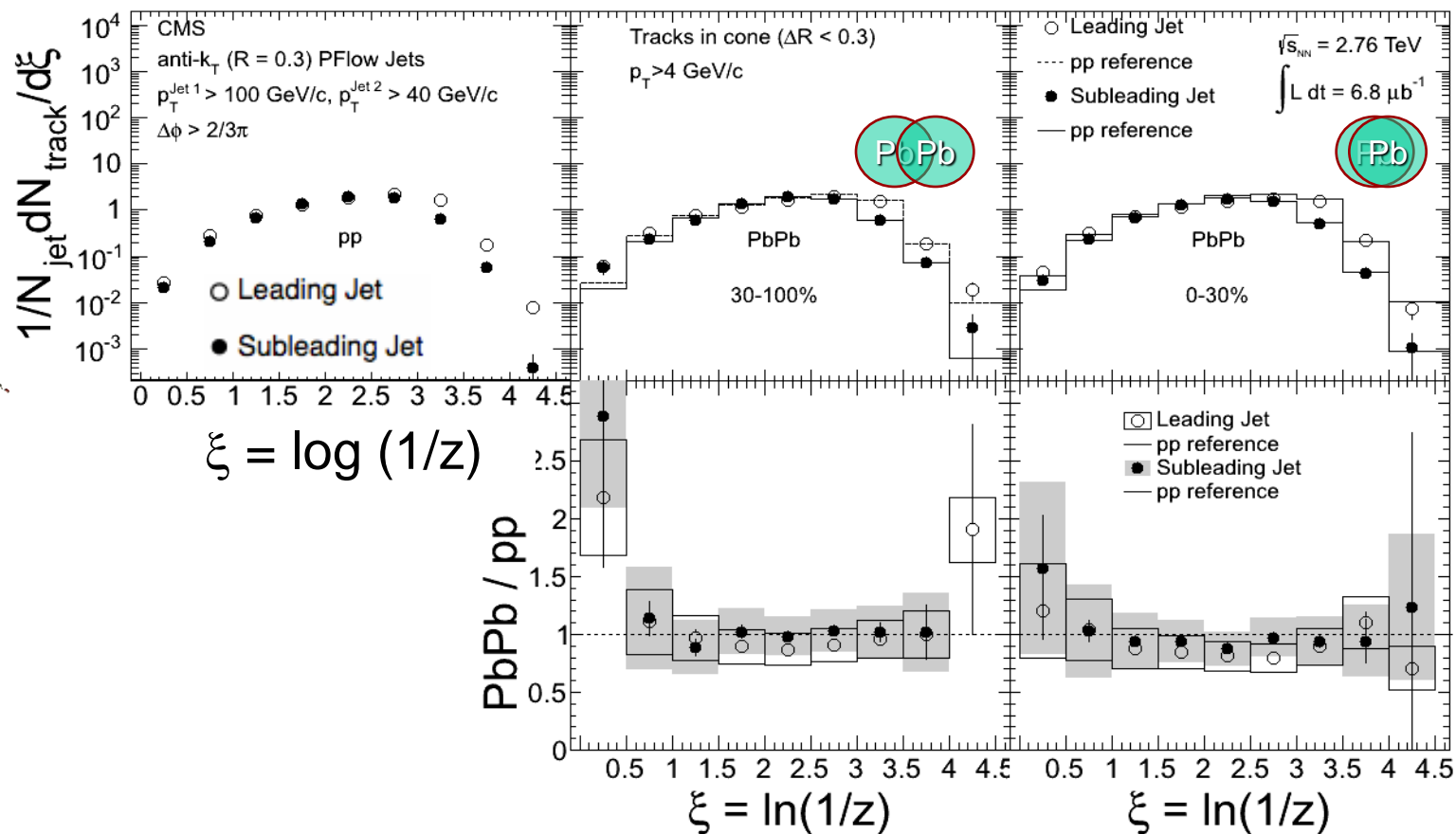
Leading and subleading jet in PbPb fragment like jets of corresponding energy in pp collisions

Yetkin Yilmaz, Parallel IVB, Thursday 14:00

CMS, PbPb, $\sqrt{s_{NN}}$ = 2.76 TeV, L$_{int}$ = 6.8 μb^{-1}