Probing the QGP with ALICE at the LHC

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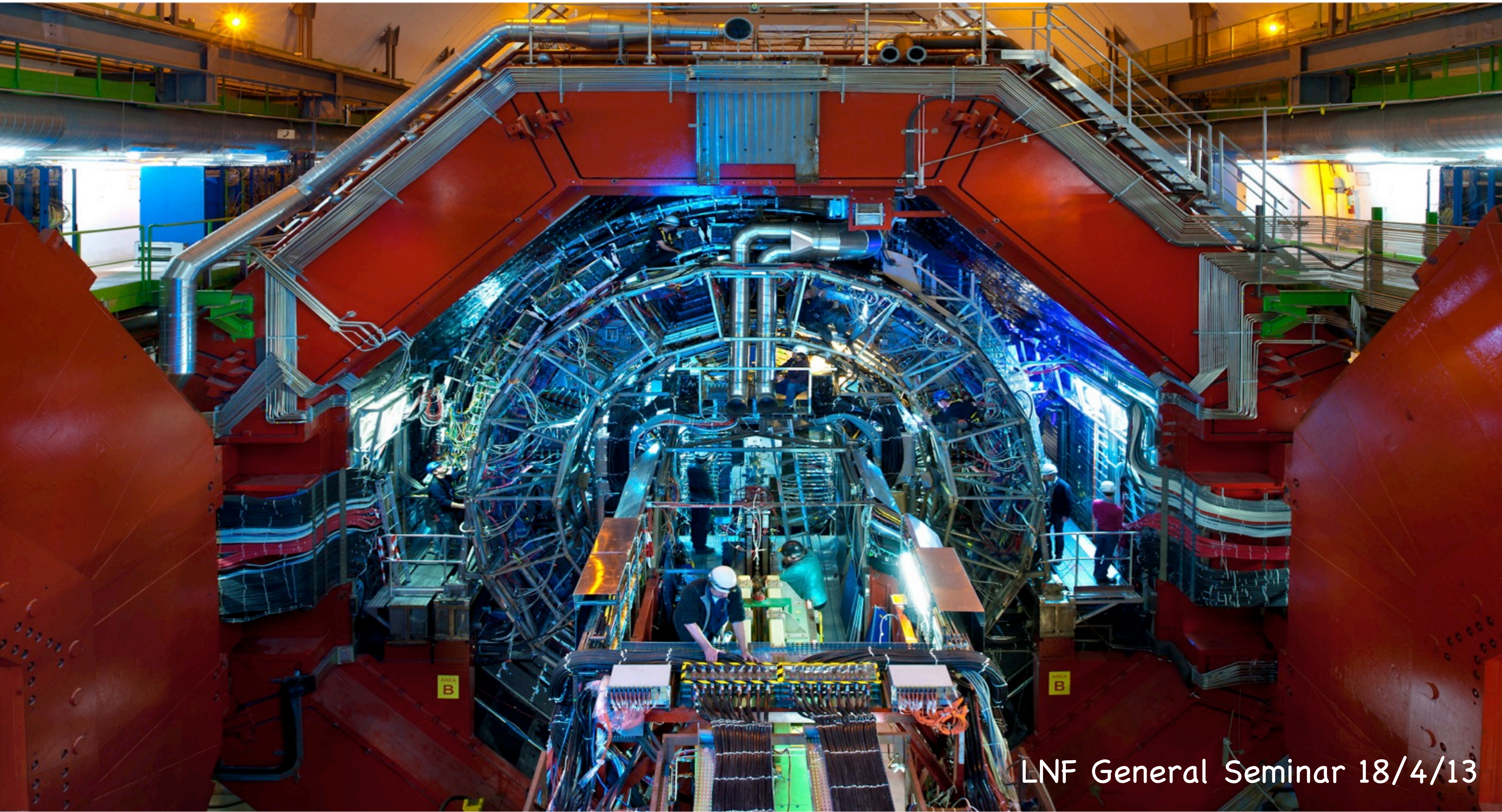
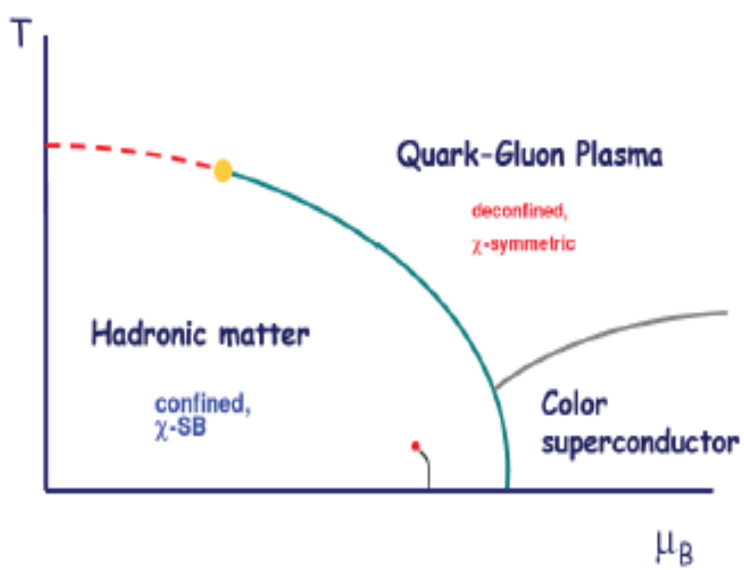


LNF General Seminar 18/4/13

Introduction: QCD & deconfinement

QCD is the standard theory for the strong interactions

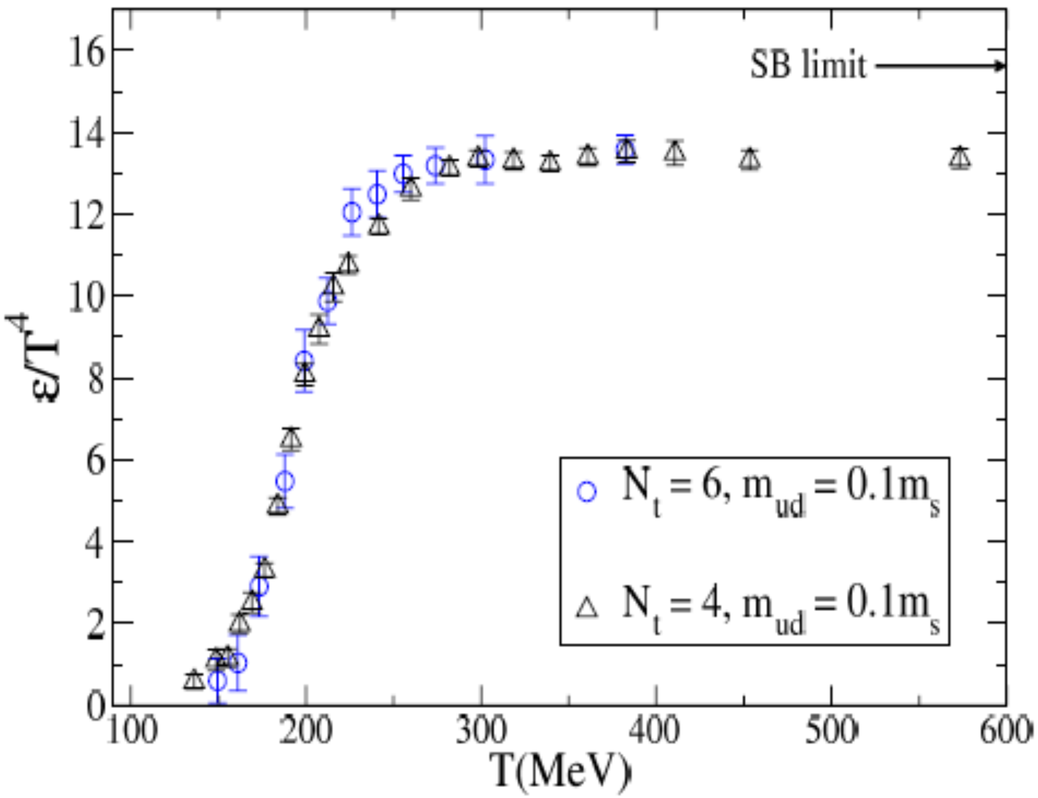
$$\alpha_s = \frac{g^2}{4\pi} \approx \frac{2\pi}{b_0 \ln\left(\mu / \Lambda_{QCD}\right)}$$



Asymptotic freedom:

at very short distances or very high energies, the forces experienced by strongly interacting particles approach zero

The expected change of nuclear matter into a deconfined state



Lattice regularized QFT

ε_C~0.3-1 GeV/fm^3

T_C~170 MeV

Stefan Boltzman: ε ~ #Degrees of Freedom (DF) in the system

Phase transition (crossover)
Low T: Hadron gas-->DF=3 pions

Asymptotically high T-->quark and gluon constituents->DF~30
(depending on # flavours considered)

Where do we expect such a deconfined partonic matter to be formed?

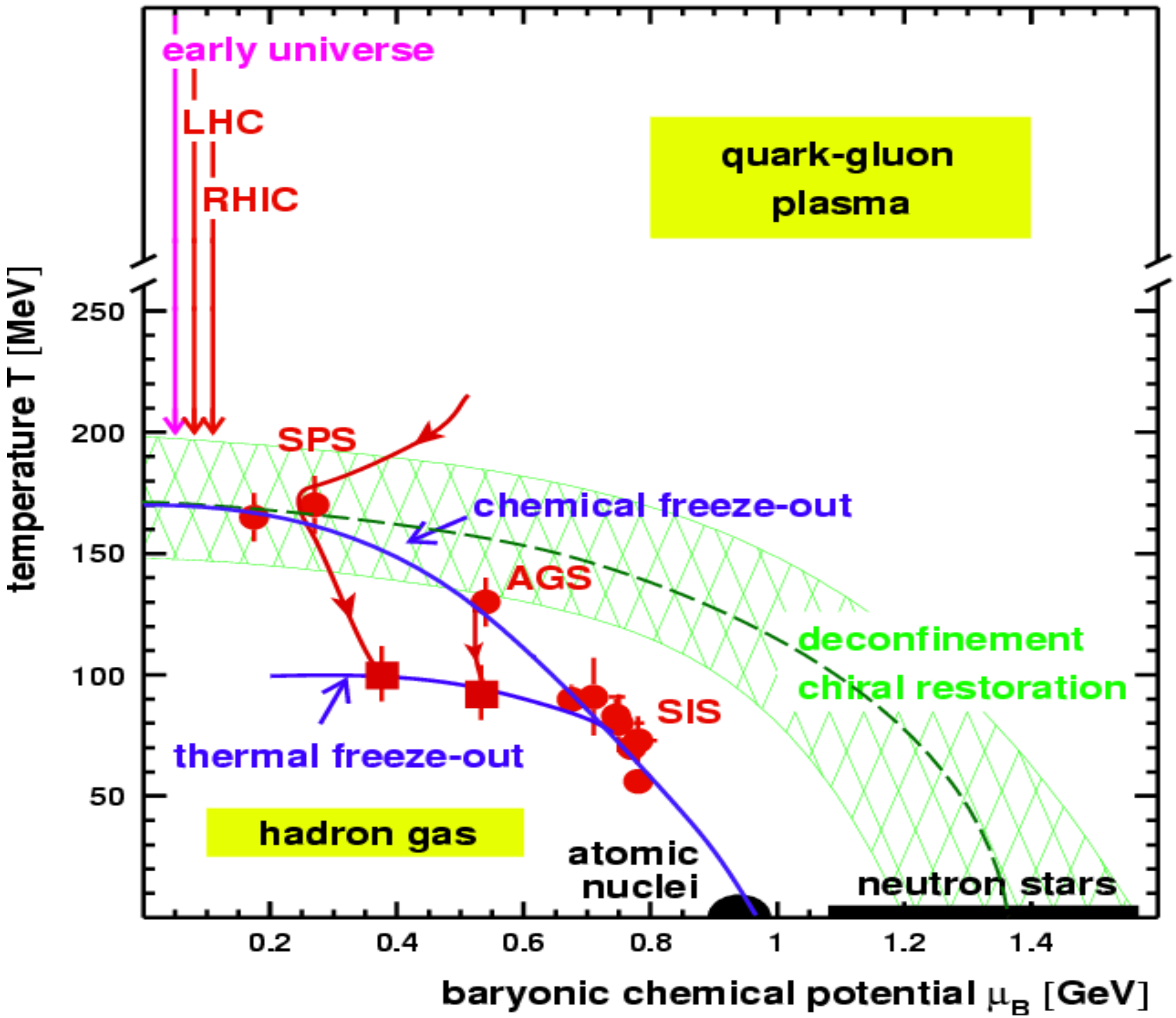
- In the hot early stages of the universe a deconfined state of quarks and gluons survives for some microseconds before the system cools down to ordinary nuclear matter.

- Neutron Stars

- High energy cosmic ray interactions

- **Relativistic Heavy Ion Colliders**

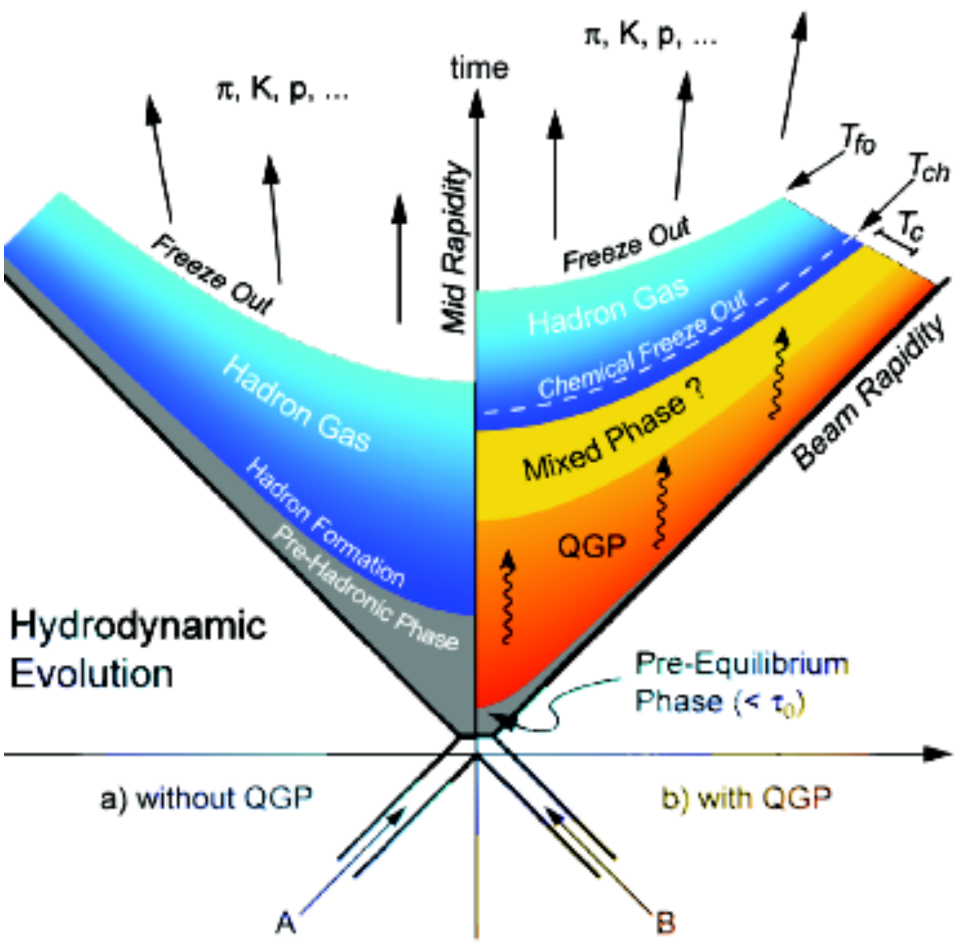
The phase diagram of nuclear matter



Hadron colliders:

zero net baryonic density at midrapidity
+
very high temperatures

The standard model of a Heavy Ion Collision



- **2 heavy nuclei collide**

$$\sqrt{s_{NN}} = 2.76 \ \ TeV @ LHC$$

- **Initial state effects**

gluon saturation,nuclear-modification of the PDFs..

- **Complex initial state conditions**

Fluctuations in the distribution of the energy density event by event.

- **Pre-equilibrium phase**

- **Thermalization? QGP?**

pQCD, hydrodynamical evolution

- **Confinement/hadronization**

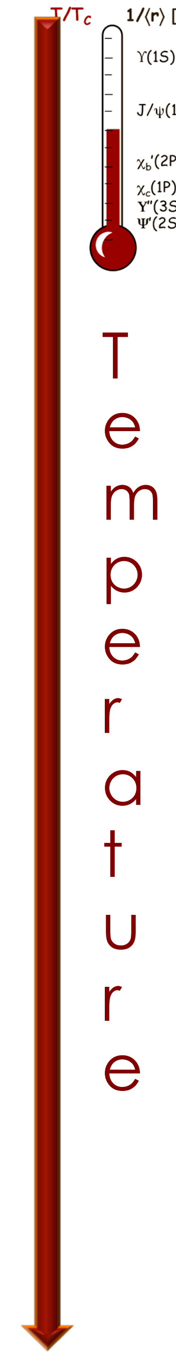
chemical freezout

- **Hadron gas**

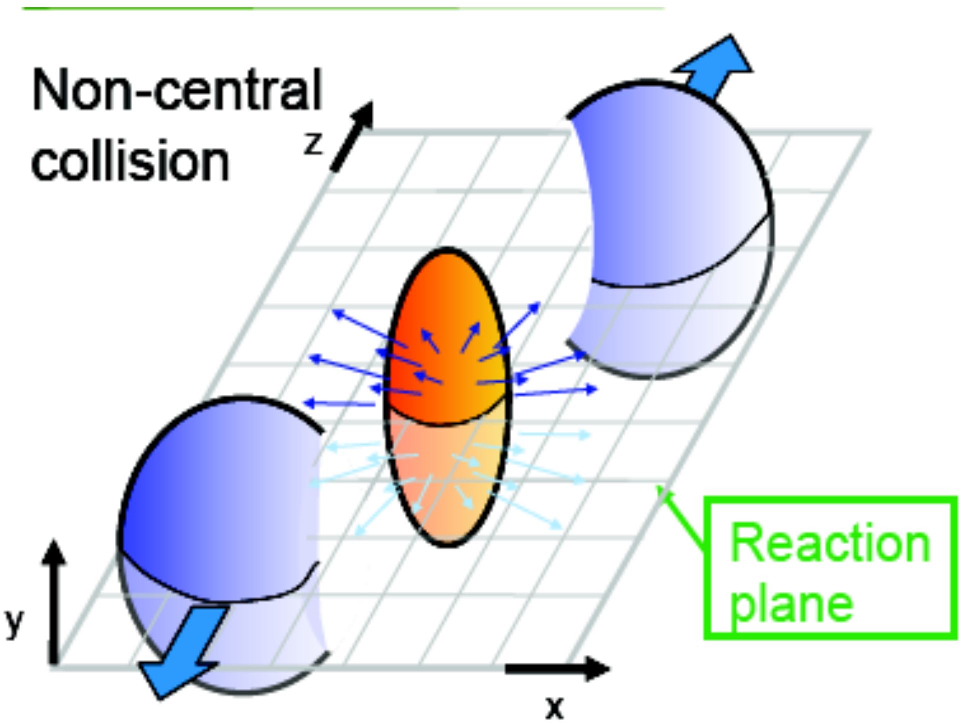
Kinetic freezout
(end of elastic interactions)

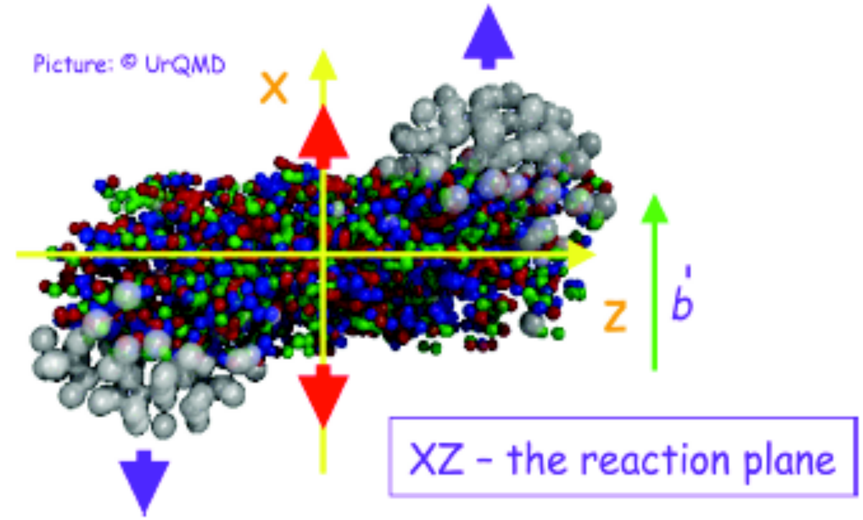
- **Final reaction products**

i.e. ~1600 particles/y per HI events



The geometry of a Heavy Ion Collision





"<u>peripheral</u>" collision ($b \sim b_{max}$)

"<u>central</u>" collision ($b \sim 0$)

Number of participants (N_{part}):

number of incoming nucleons (participants) in the overlap region

Number of binary collisions (N_{bin}):

number of equivalent inelastic nucleon-nucleon collisions

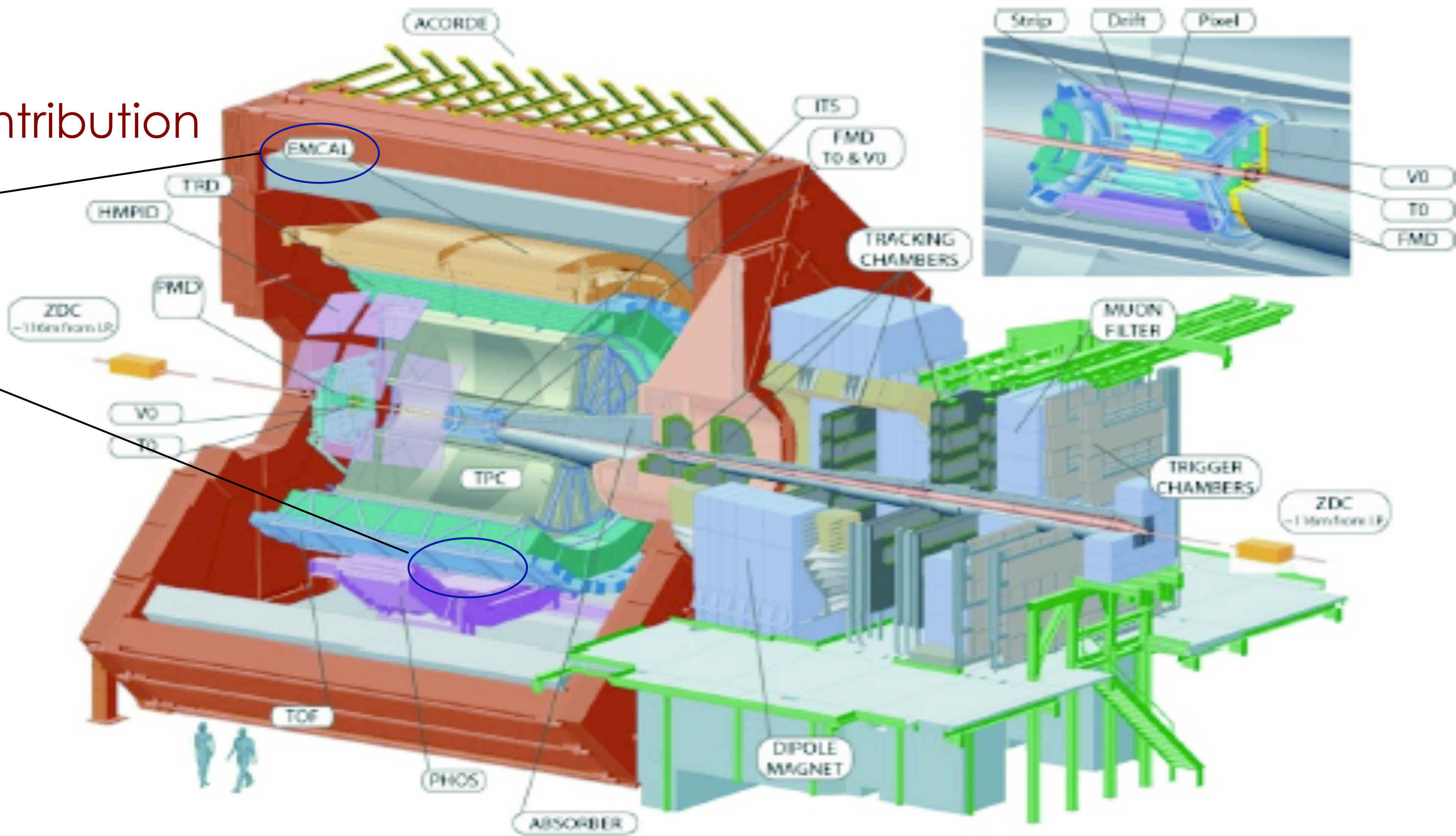
$N_{bin} \geq N_{part}$

More central collisions produce more particles

The ALICE detector

LNF hardware contribution

EMCal
DCal



ALICE excels at:

- Resolution of tracking and unique particle identification
- Bulk production coverage

Low magnetic field over a large range in momentum and full azimuth

The characterization of the QGP with ALICE

We measure the final products of the reaction to infer transport properties of the QGP

The bulk and the low p_T region (a selection of observables):

- Multiplicity: strong constraint on initial conditions
- Bose-Einstein Pion correlations: volume and lifetime of the source
- Identified particle spectra: radial velocity and temperature at the kinetic freezout
- Elliptic flow and higher harmonics: precision measurements of the shear viscosity

The characterization of the QGP with ALICE

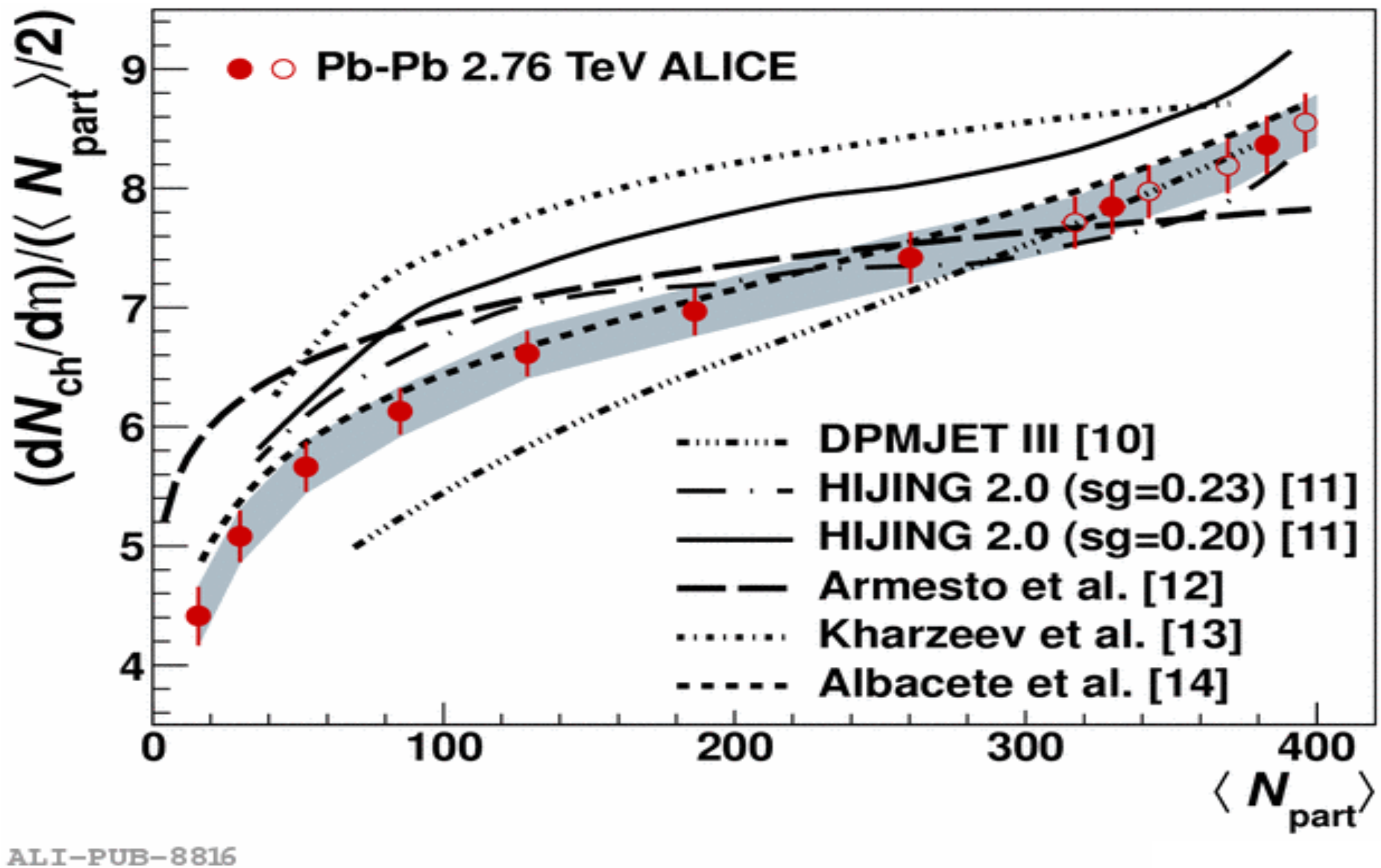
We measure the final products of the reaction to infer transport properties of the QGP

Hard probes:

- High p_T hadrons and jets-->Jet quenching-->measure medium density
- Heavy flavour: testing in medium radiation hierarchy
- Quarkonia: testing mechanisms of screening/regeneration in medium

The first observable: the multiplicity

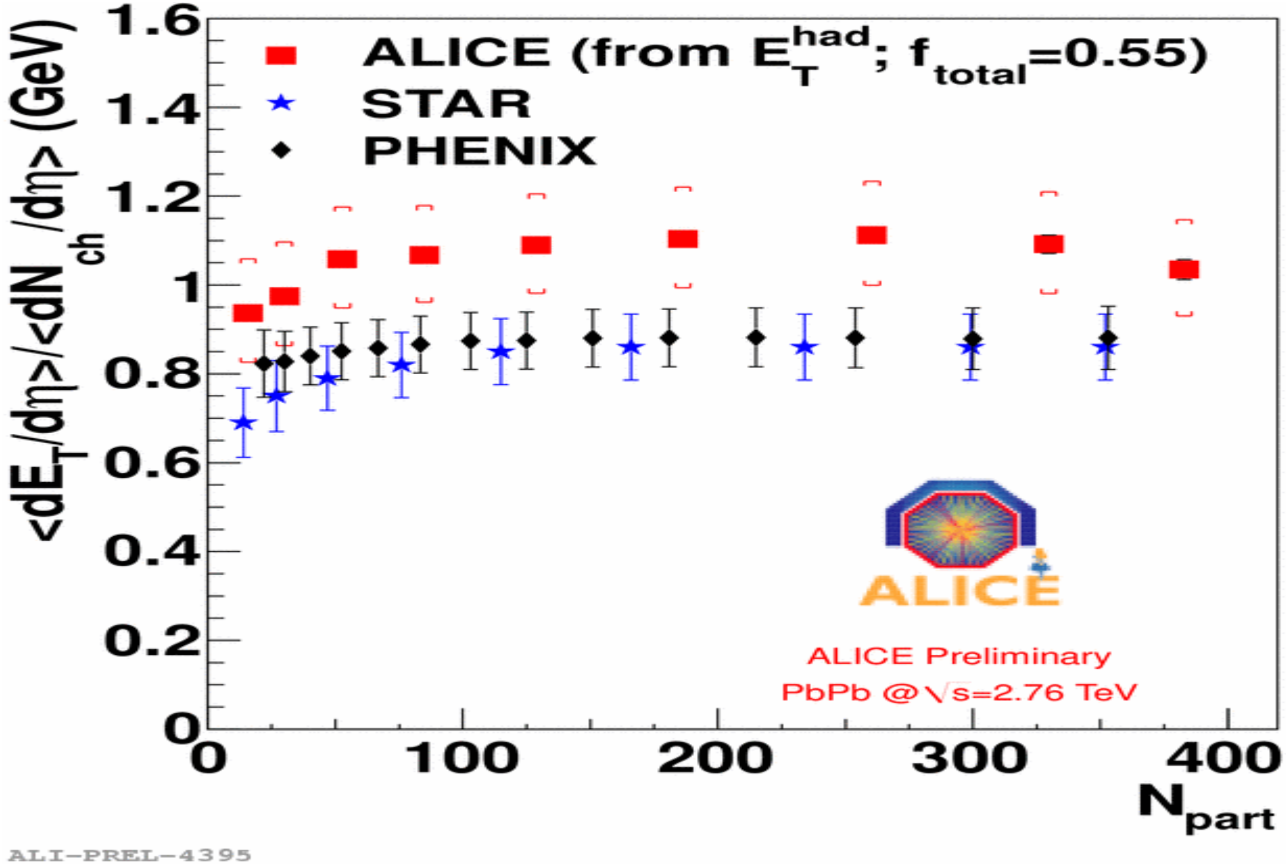
PRL 106 (2011) 032301



5% most central events:
$dN_{ch}/d\eta$ = 1584±4(stat)±76 (sys)

The centrality dependence of particle multiplicity puts strong constraints on theoretical models and initial state conditions

What is the energy density measured in ALICE?



Energy density above critical is a necessary condition for the QGP formation, but not sufficient. Many constituents needed to reach thermal equilibrium:

ε (7 TeV)$_{pp}$> ε (0.2 TeV)$_{AuAu}$

Bjorken energy density estimate:

$\varepsilon_{Bj}\ \tau \sim 16$ GeV/fm^2

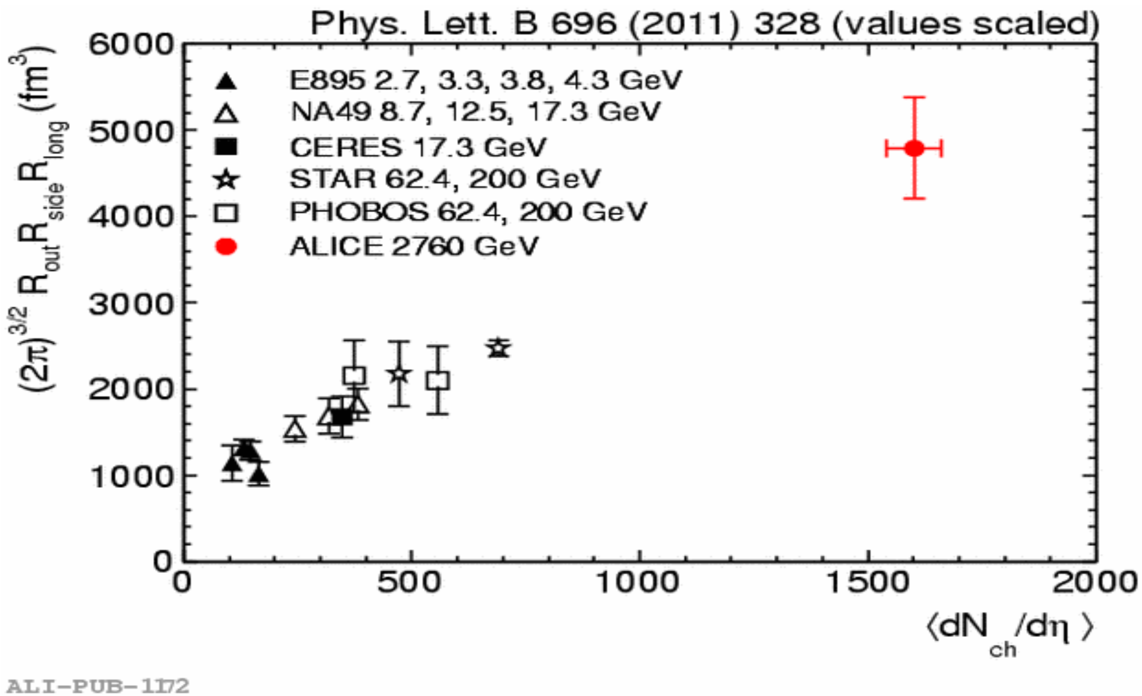
formation time, unknown, τ <1fm/c

$$\varepsilon_{Bj} = \frac{1}{\tau \pi R^2} \frac{dE_T}{d\eta}$$

area of the overlapping region

Bjorken estimate at LHC well above lattice critical density in a wide centrality range

The size & lifetime of the source: pion interferometry

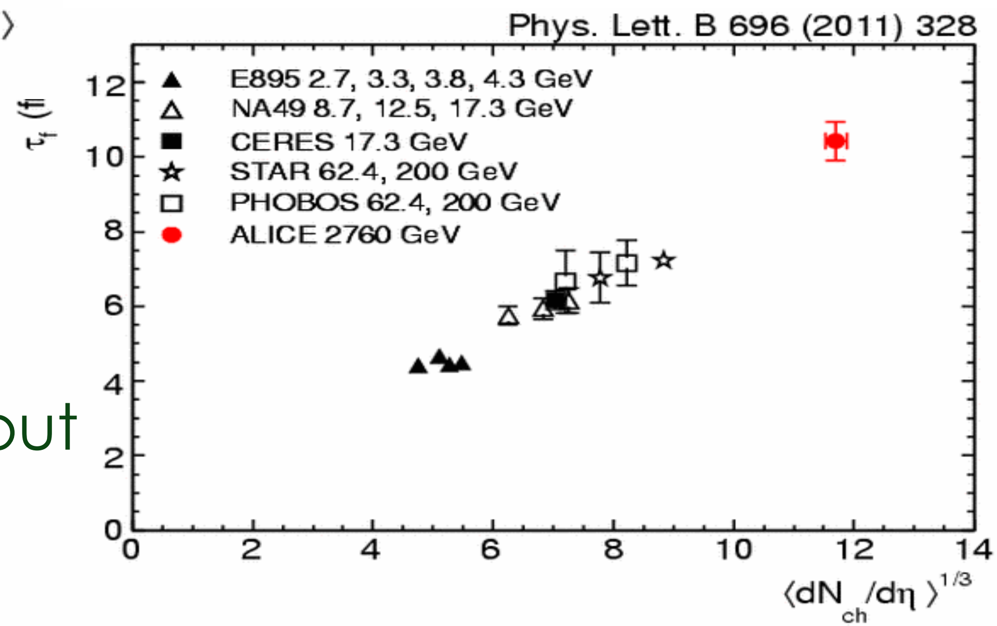


Bose-Einstein correlations: particle source volume and lifetime

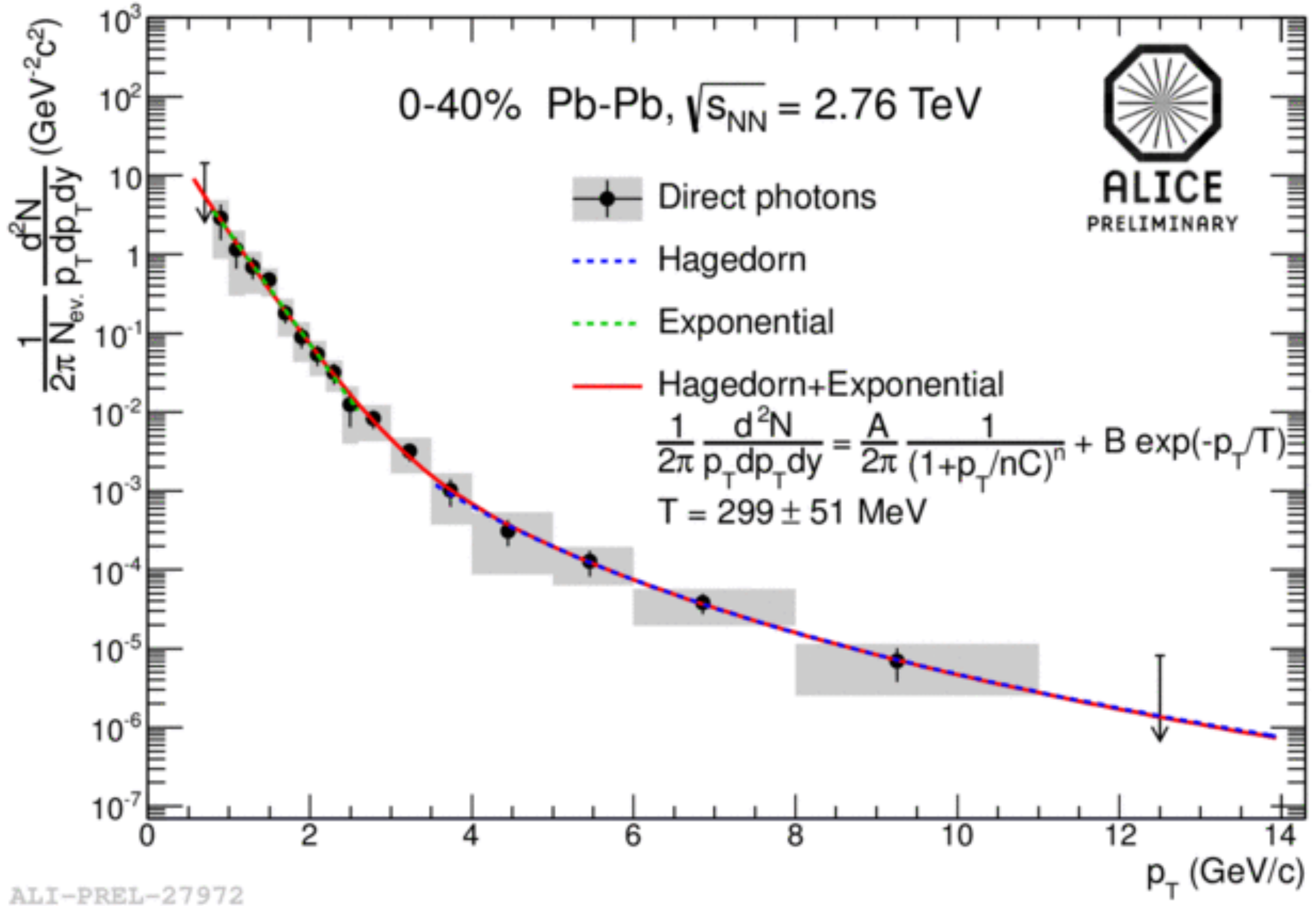
V=5000 fm^3

R_{long}~t_f=11 fm/c

t_f from bang to hadronic freeze-out



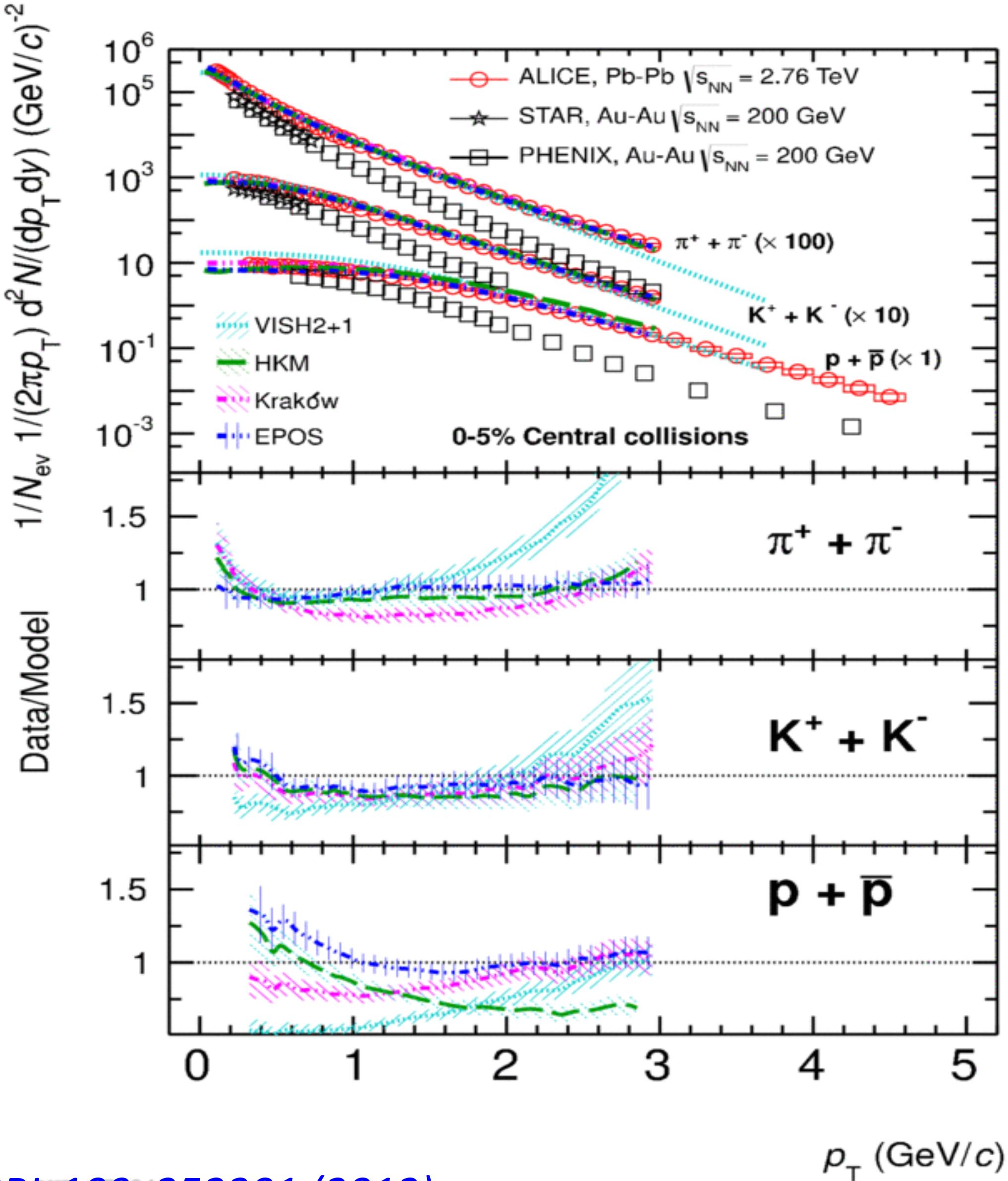
The temperature of the source



Direct photon measurement via conversions in central PbPb collisions.
A thermal system → exponential spectrum
Fit the low p_T region to a combined fit (Exponential+Hagedorn):

$T \sim 300$ MeV $\sim 2*T_{critical}$

The radial flow: collective transverse expansion

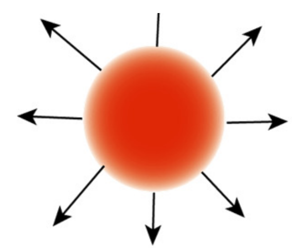


PRL 109, 252301 (2012)

Boosted thermal spectra give a very good description of the particle distributions measured in PbPb:

$$\frac{d^2N_j}{m_T dy dm_T} = \int_0^{R_0} A_j m_T \cdot K_1\left(\frac{m_T \cosh\rho}{T}\right) \cdot I_0\left(\frac{p_T \sinh\rho}{T}\right) r dr$$

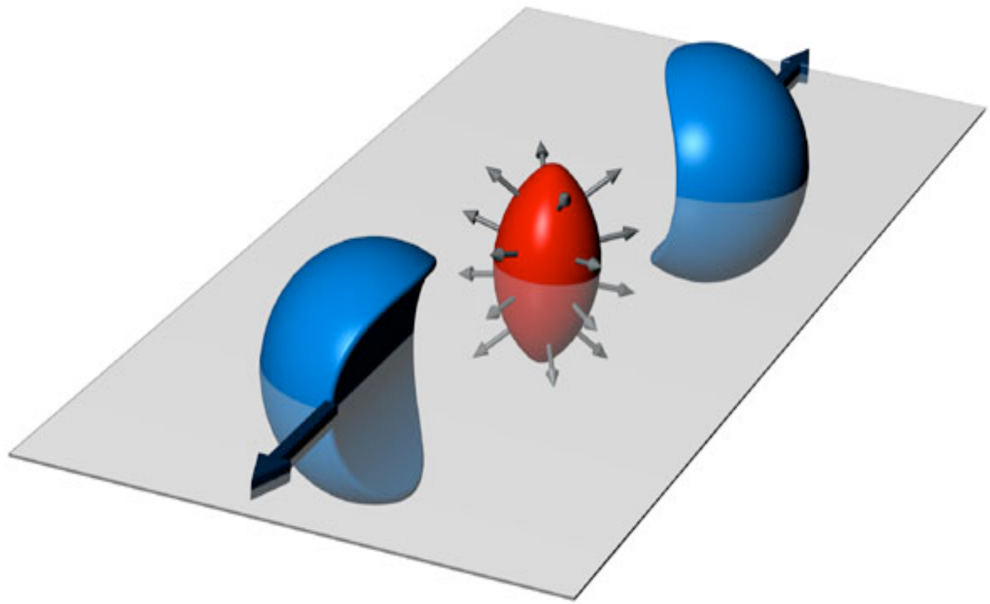
$$\rho(r) = \tanh^{-1} \beta_\perp(r)$$



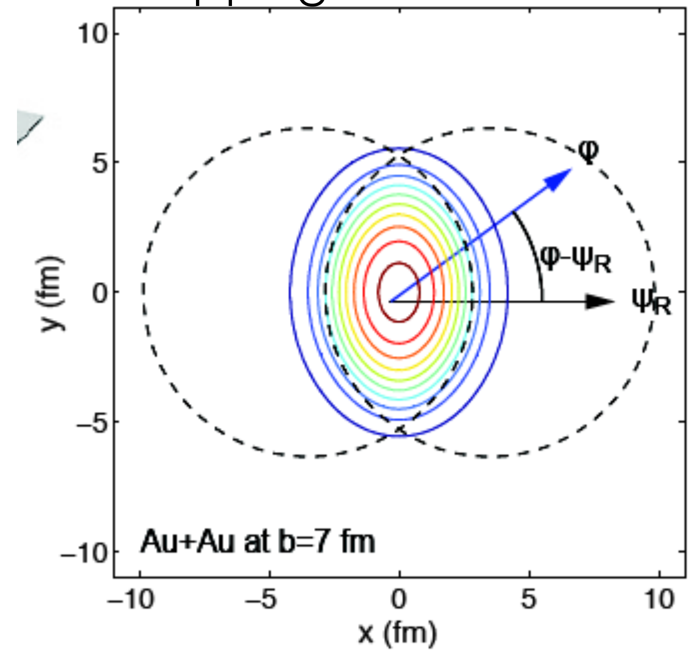
β_C (radial flow) = 0.66 c

T_{KIN} ~ 80 MeV

The elliptic flow v_2 and the perfect liquid



Overlapping transverse section



Almond shape overlapping region in coordinate space

Interactions generate pressure gradients

Anisotropy in momentum space that persists down to final particle level

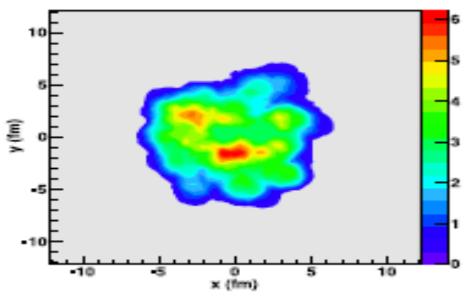
Fourier expansion to describe angular dependence of particle density wrt reaction plane

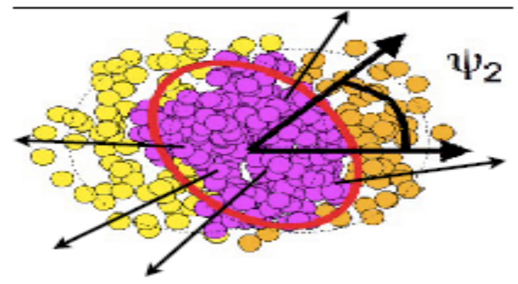
$$\frac{dN}{d\varphi} \propto 1 + 2v_2 \cos[2(\varphi - \psi_R)] + \ldots$$

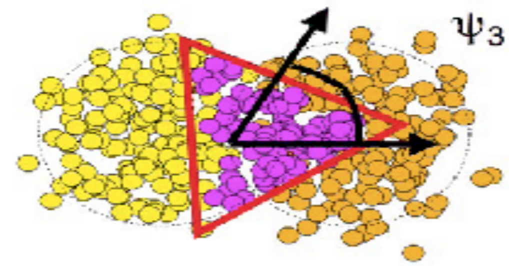
$$v_2 = \langle \cos[2(\varphi - \psi_R)] \rangle$$

Higher order v_n coefficients

Energy density in overlapping region

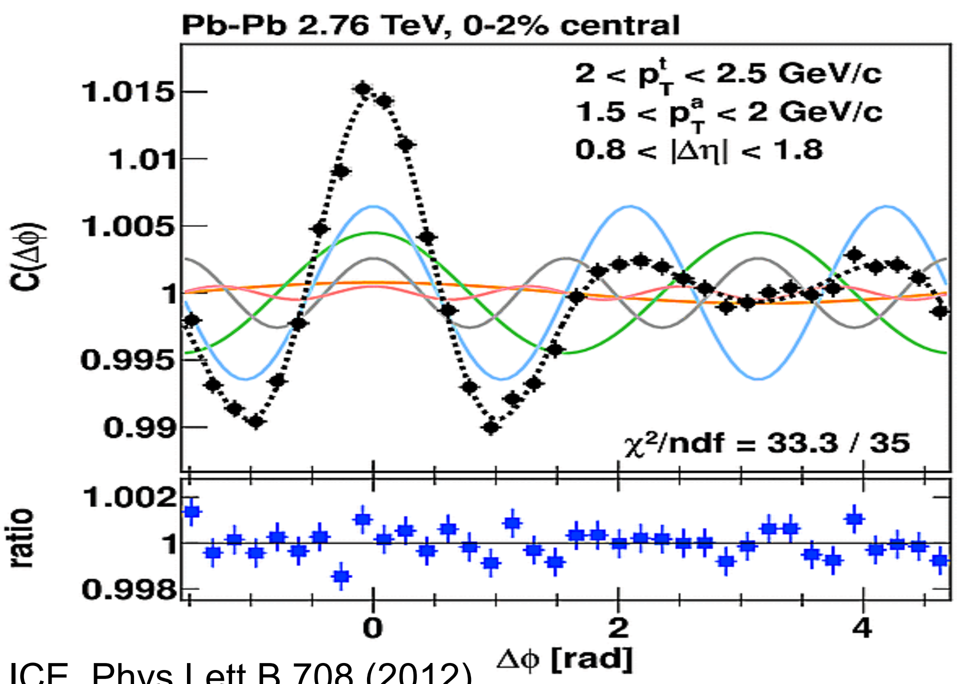


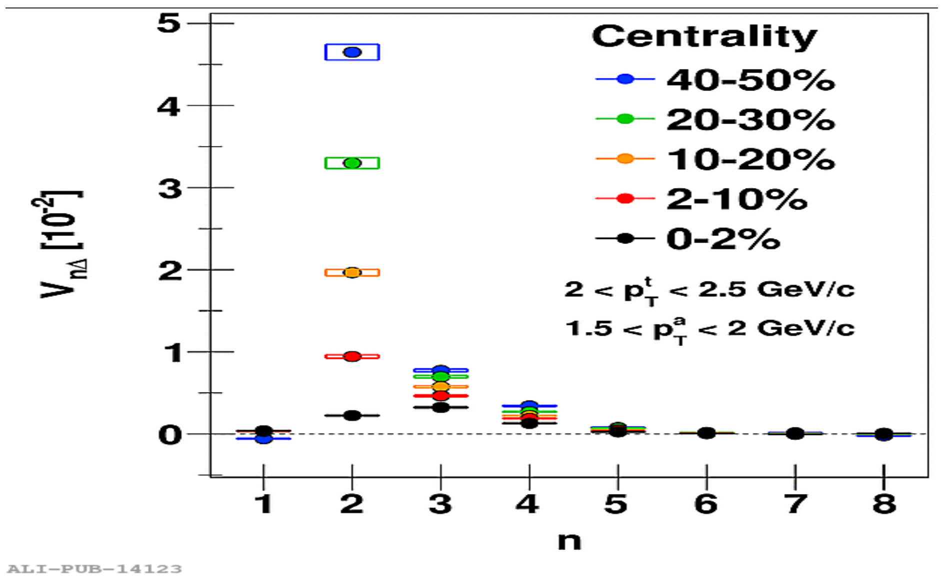




Different initial state conditions generate <u>different symmetry planes</u>
→ different flow coefficients v_n are present in the final particle distributions

Two particle azimuthal correlations

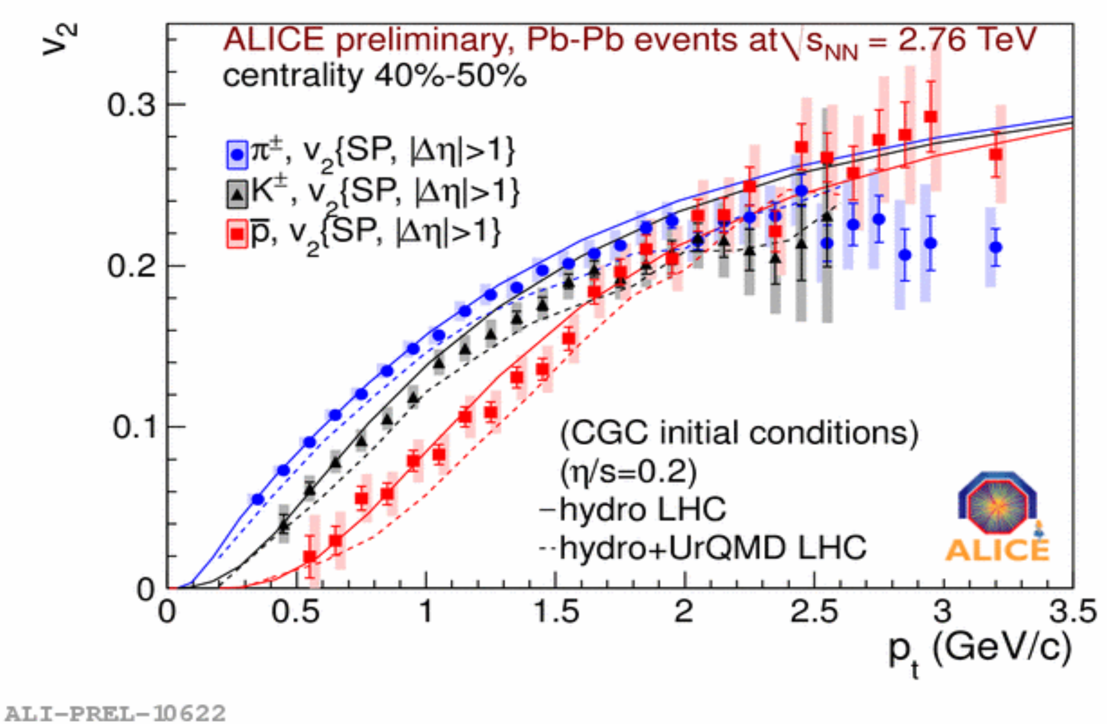


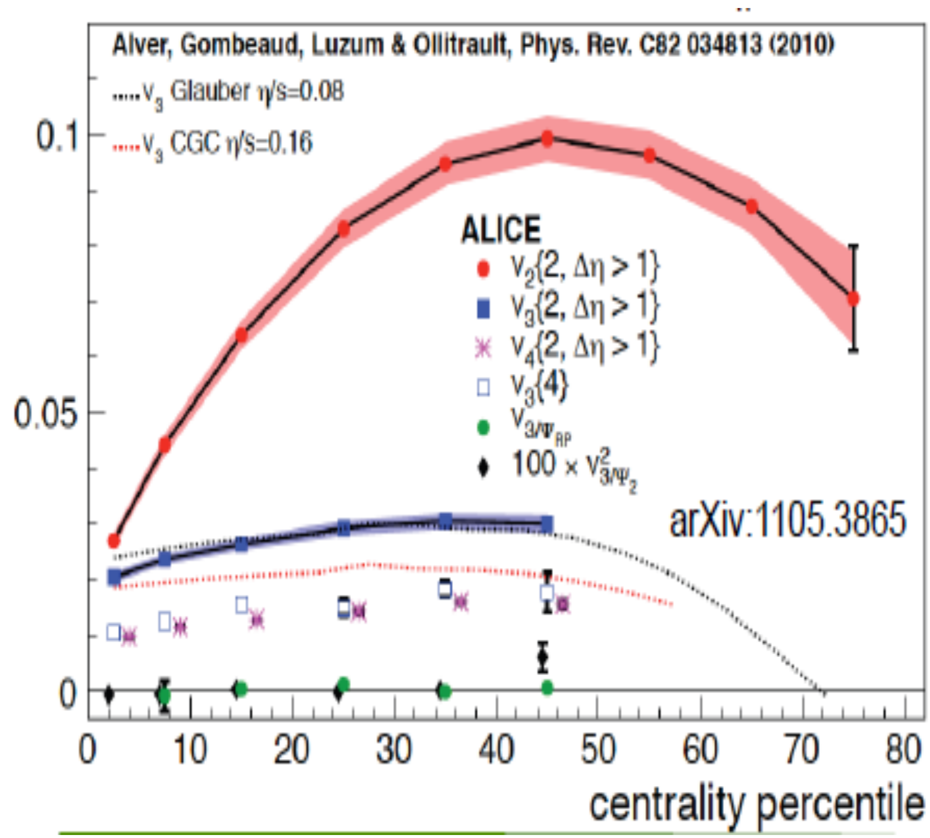


ALICE. Phys.Lett.B 708 (2012)

Particle correlations get contributions from up to n=5

Precise constraint of transport properties: shear viscosity



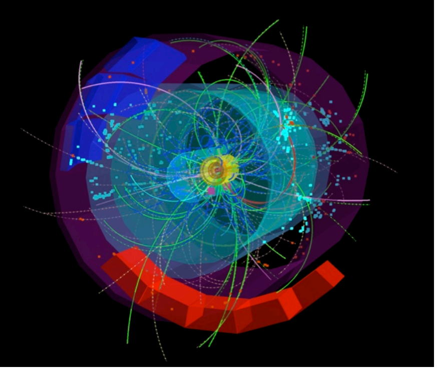


- Large v2 indicates early thermalization

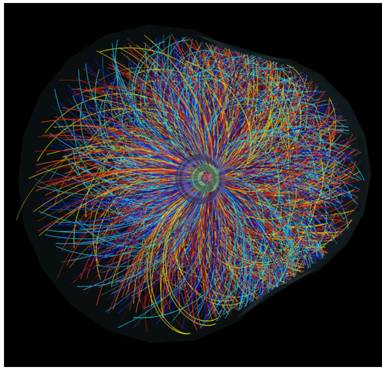
- Great success of viscous hydrodynamics: shear viscosity close to the lower bound (AdS/CFT lower bound=0.08)

Higher orders vn-->constrain initial conditions, needed for hydro calculations
→ precise determination of η /s

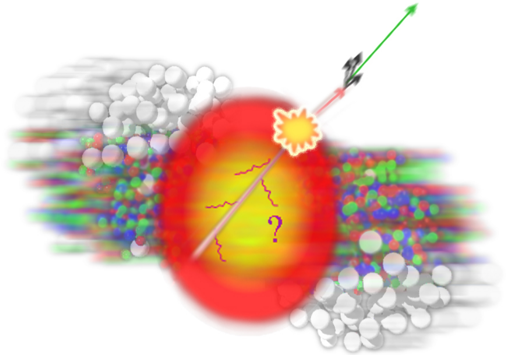
The system behaves as an almost perfect liquid, strongly coupled+low shear viscosity !



Precise characterization of the QGP: Hard Probes

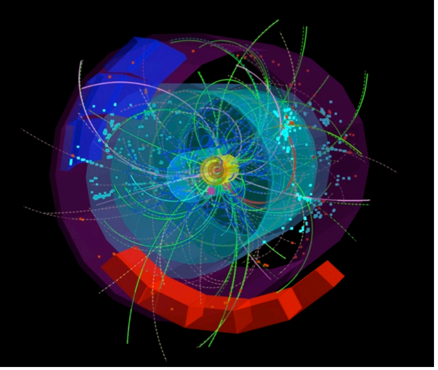


$$\sigma^{pp\to h} = f_p(x_1,Q^2)\otimes f_p(x_2,Q^2)\otimes \sigma(x_1,x_2,Q^2)\otimes D(z,Q^2) + \left(\frac{1}{Q^2}\right)^n$$



- Early production of the hard scattering: t~1/Q
- Long distance terms of the σ can be directly modified by the dense medium created in the HIC
- The probe production rate is the same as in the vacuum → well calibrated probes

Look for the attenuation/absorption of the probe



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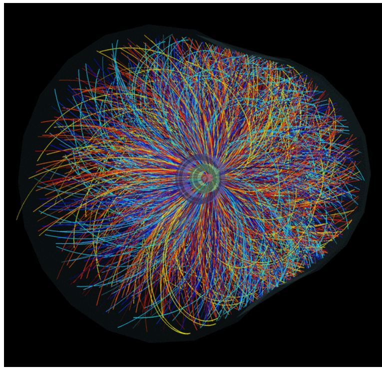
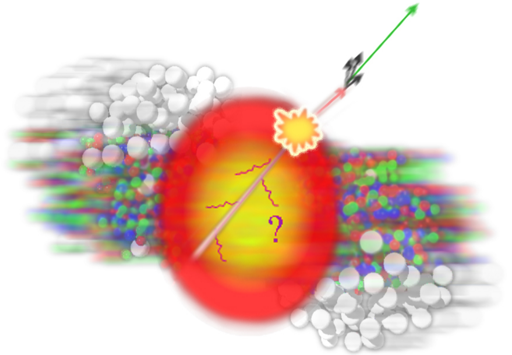


$$\sigma^{pp\to h} = f_p(x_1,Q^2)\otimes f_p(x_2,Q^2)\otimes \sigma(x_1,x_2,Q^2)\otimes \underbrace{D(z,Q^2)}_{\text{non perturbative}} + \left(\frac{1}{Q^2}\right)^n$$



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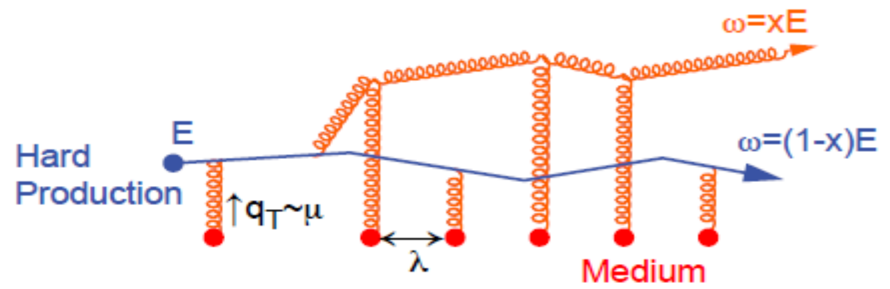
The “standard” mechanisms of energy loss in medium

Medium-induced gluon radiation, dominant mechanism of energy loss for a high energy parton traversing a colored medium.

Baier,Dokshitzer,Mueller,Peigne,Shift
Nucl. Phys. B 483 (1997) 291



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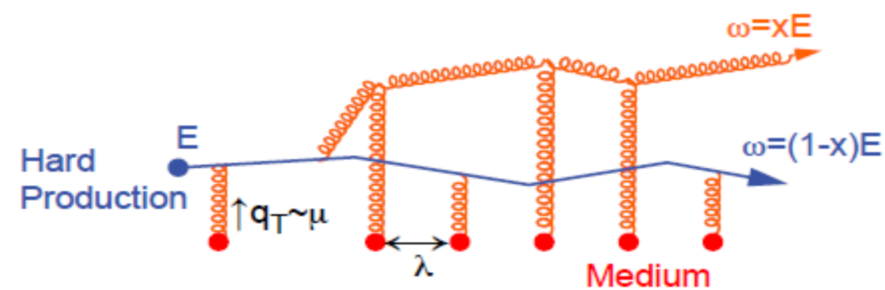
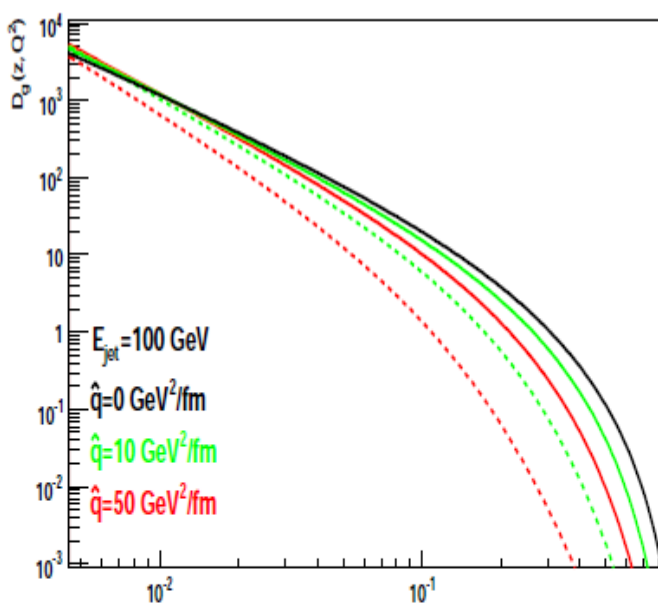
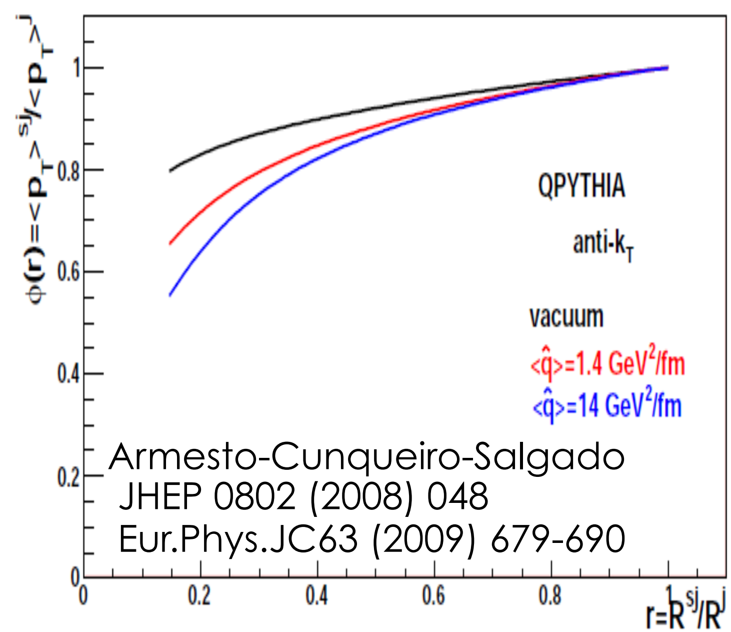


Energy loss & transverse broadening of the jet shower dynamically related by:

$$\Delta E \sim \text{qhat}\ \Delta k_T$$

qhat characterizes the medium (encodes the info about the interaction with the colored medium):
$\langle k_T \rangle$ given by the medium to the projectile per unit path length λ





Energy degradation and broadening of the transverse jet shape

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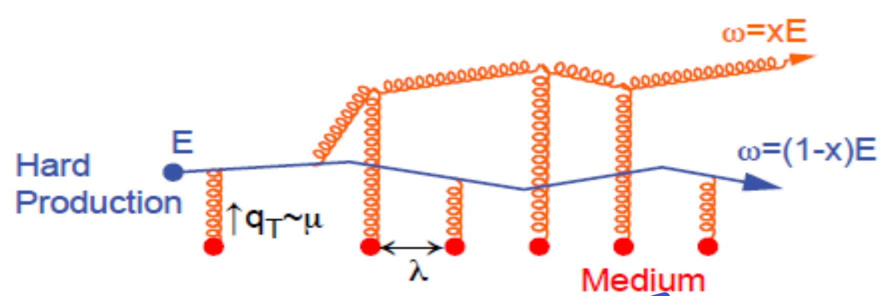
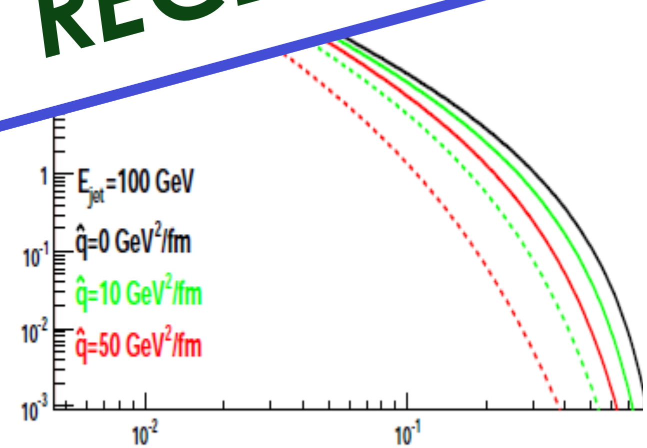
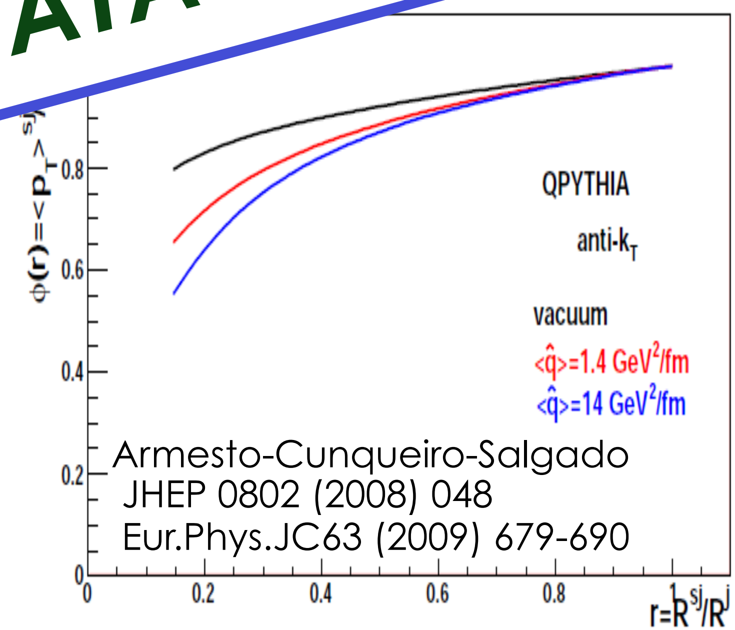


Energy loss & transverse broadening of the jet ... :

TO BE REVISITED IN VIEW OF RECENT JET DATA?

qhat characte... the me... (encod... about t... with the medium)
$<k_T>$ give... the medium to the projectile per unit path length λ





Armesto-Cunqueiro-Salgado
JHEP 0802 (2008) 048
Eur.Phys.JC63 (2009) 679-690

Energy degradation and broadening of the transverse jet shape

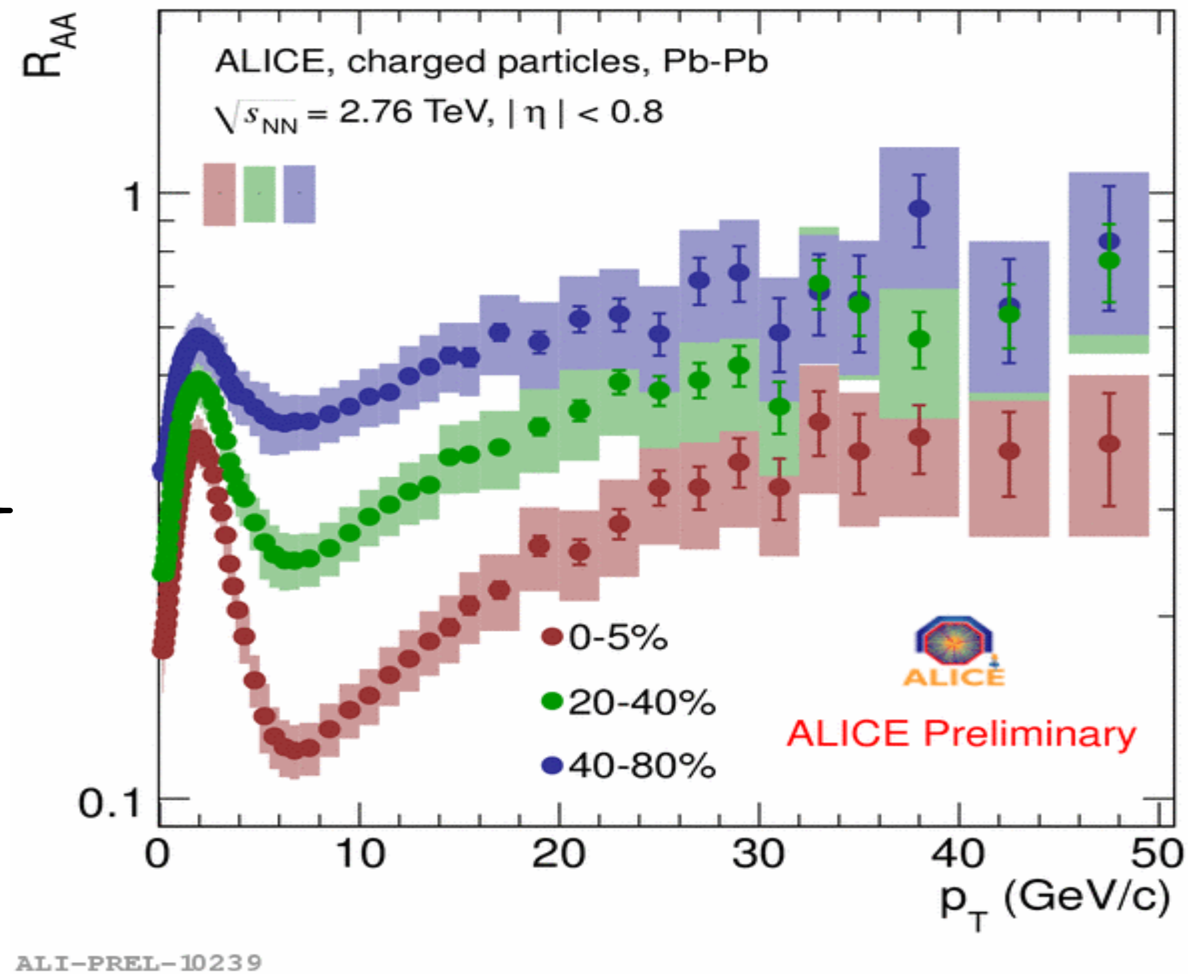
Starting with the "easy" things: high-p_T hadrons

Nuclear Modification Factor (R_{AA}):
measures the suppression of the yield in PbPb collisions with respect to the scaled yield in pp

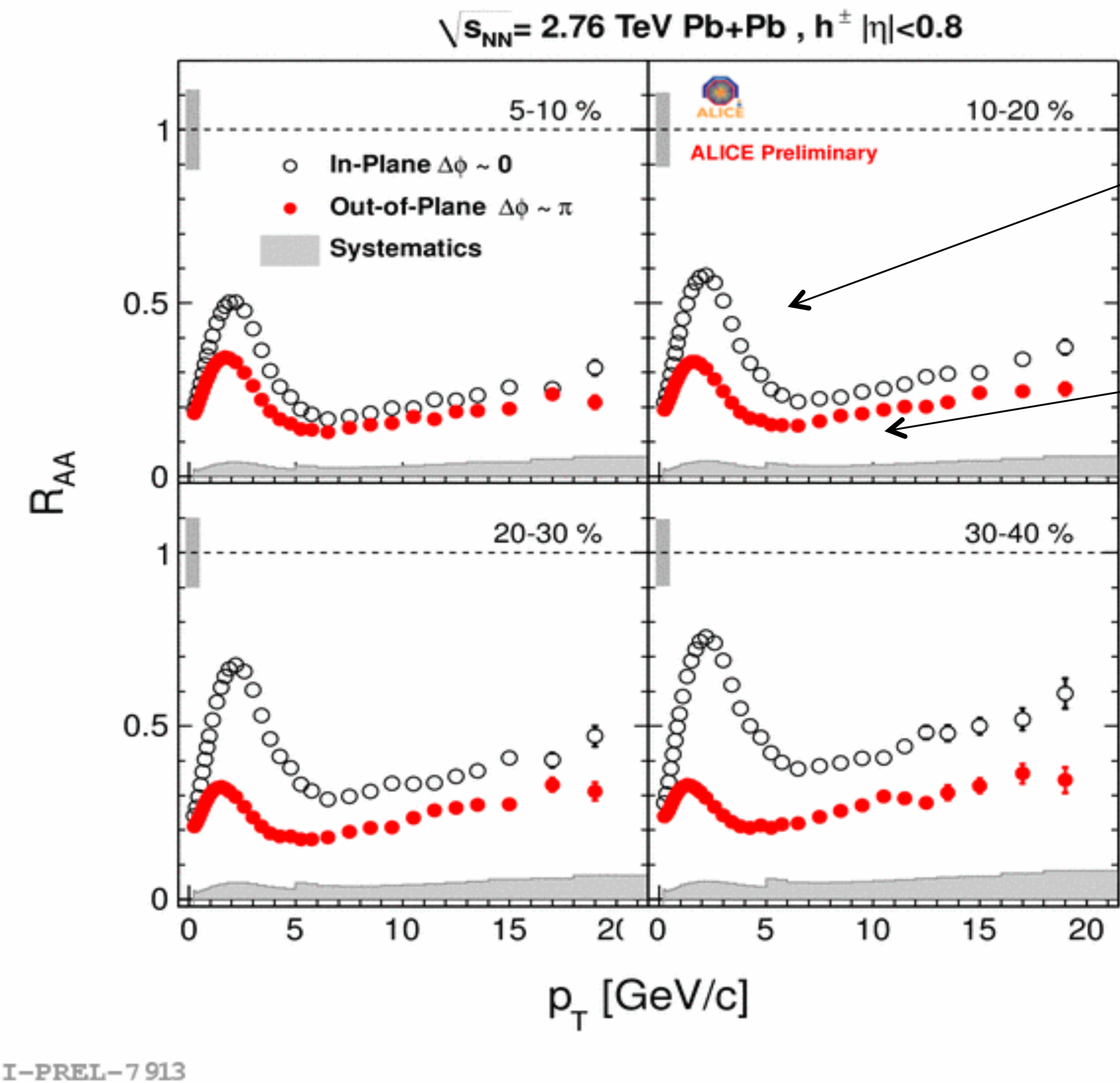
$$R_{AA}(p_T) = \frac{Yield(A+A)}{Yield(p+p) \times \langle N_{coll} \rangle}$$

Peripherals: $R_{AA} \rightarrow 1$

Centrals:
~1/5 suppression factor.
Larger in-medium path encountered by the hard parton



High-p_T hadron suppression vs Reaction Plane



In-plane: shorter in-medium path length L "seen" by the hard parton

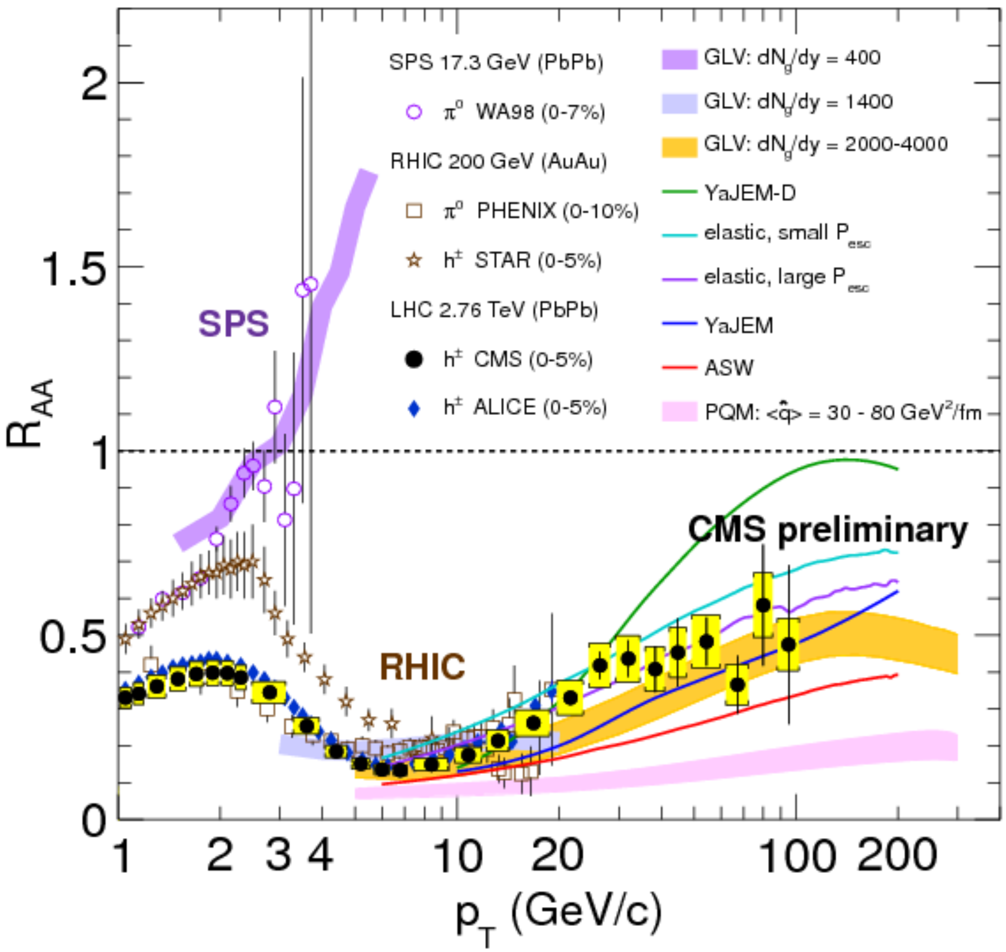
Out-of-Plane: longer in-medium path length

Test of the L dependence of the energy loss:

formalisms including LPM effect predict a ~L^2 dependence of the suppression
(~L in a expanding medium)

The full scan of high-p_T hadron suppression

Different collaborations and systems



To note:

→ Low p_T region: dominated by non perturbative processes and initial state effects

→ High p_T region: suppression due to final state effects

→ Rise with p_T: bias towards partons produced in the surface of the fireball that are not (are less) medium-modified

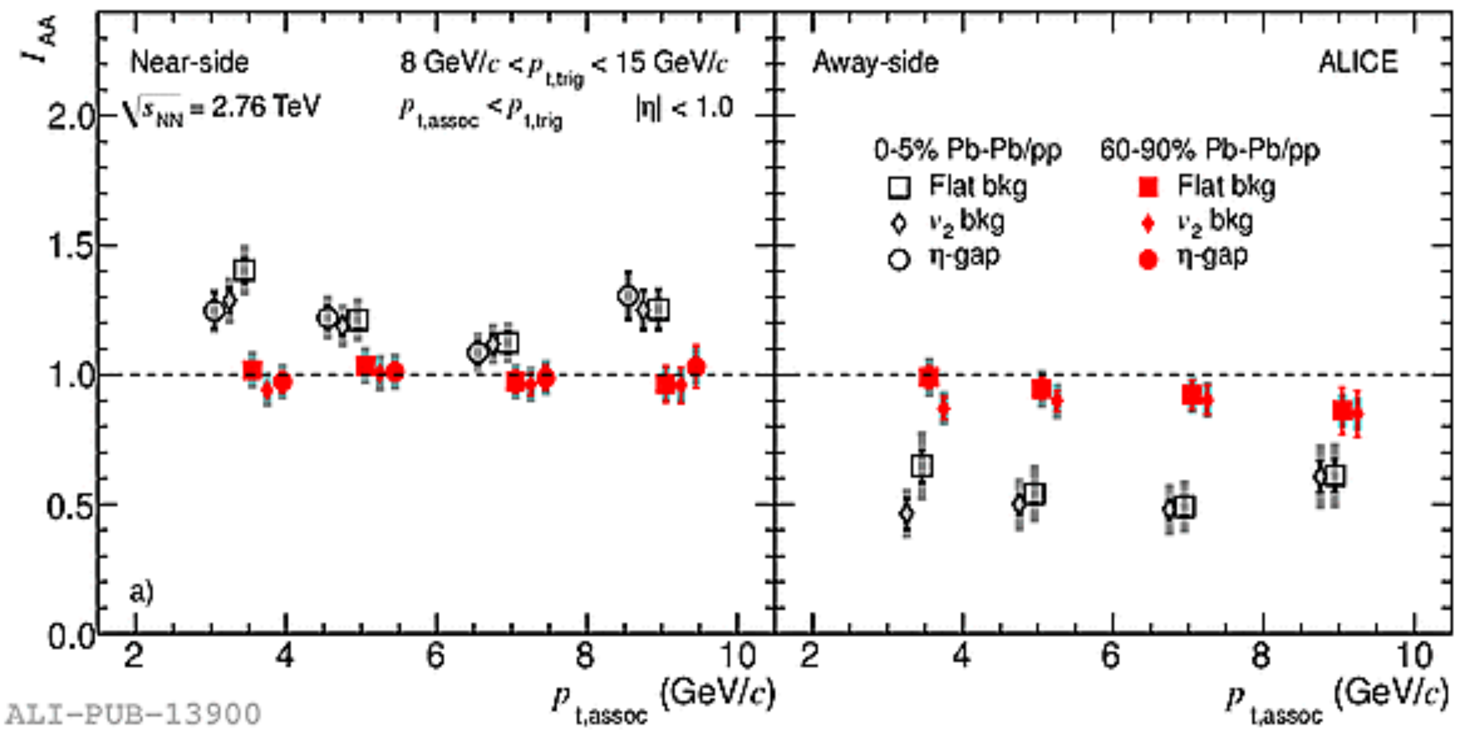
R_{AA}->not enough discriminatory power for energy loss models

Small constrain on energy loss distribution (T.Renk HP06)

Need multiple/more differential observables to constrain theory

The suppression of recoiling hadrons: I_{AA}

Trigger on a hadron with p_T^{trig} :
look to the particles with p_T^{assoc} in its near and away side



- The hadrons that are azimuthally back-to-back to the trigger are suppressed by a factor 2 (compare to ~1/5 suppression for inclusive h)

- Why is the suppression of recoiling hadrons less than that of inclusive hadrons?
-the recoil hadron spectrum is harder (flatter) and the smearing due to energy loss has less impact (the dynamical range to probe quenching is smaller)

The Heavy Flavour

Dead cone effect

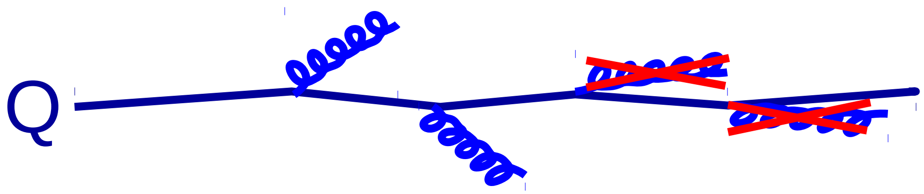
$$\omega \left.\frac{dI}{dw}\right|_{\mathrm{HEAVY}} = \frac{\omega \left.\frac{dI}{dw}\right|_{\mathrm{LIGHT}}}{\left(1 + \left(\frac{m_Q}{E_Q}\right)^2 \frac{1}{\theta^2}\right)^2}$$

Implies lower heavy quark energy loss in colored matter
Dokshitzer PLB (2001) 519 199

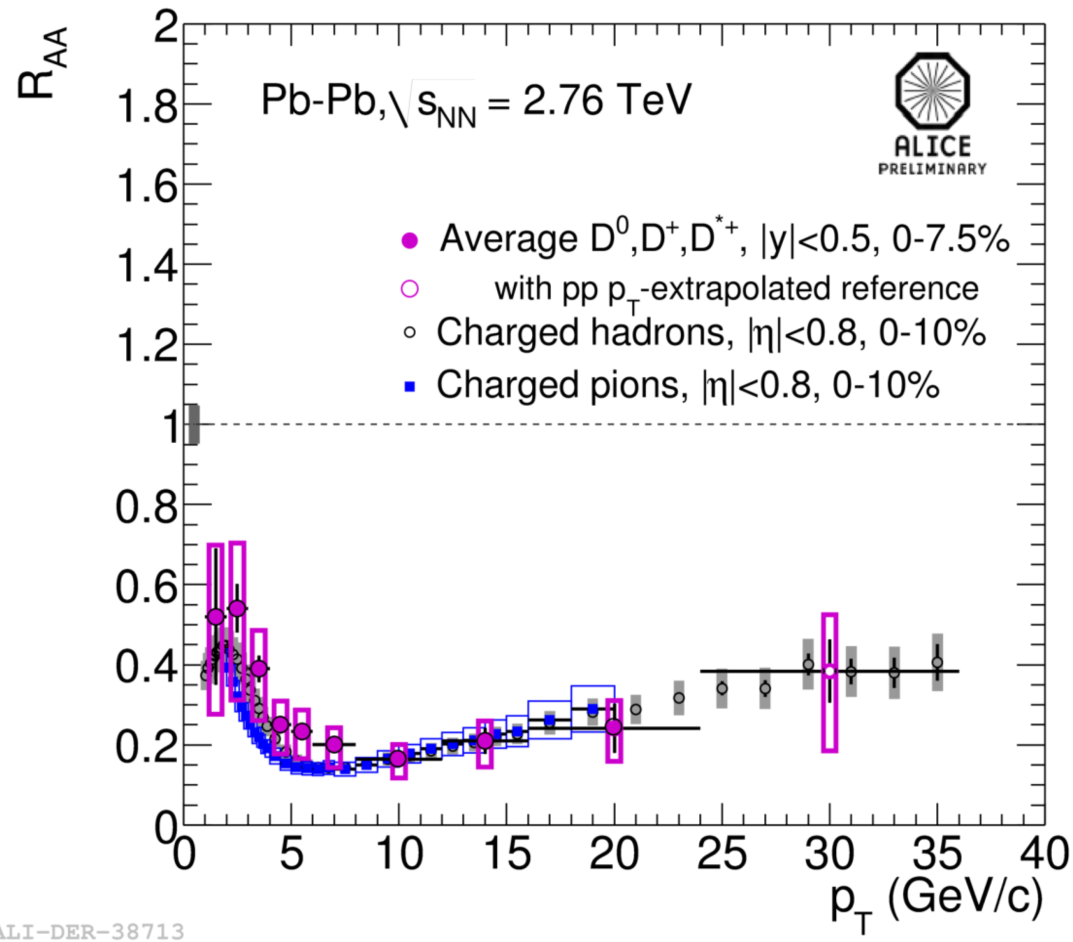
This sets a hierarchy in the energy loss of partons in a QCD medium:

ΔEloss(g)> ΔEloss(light quarks)> ΔEloss(Heavy quarks)

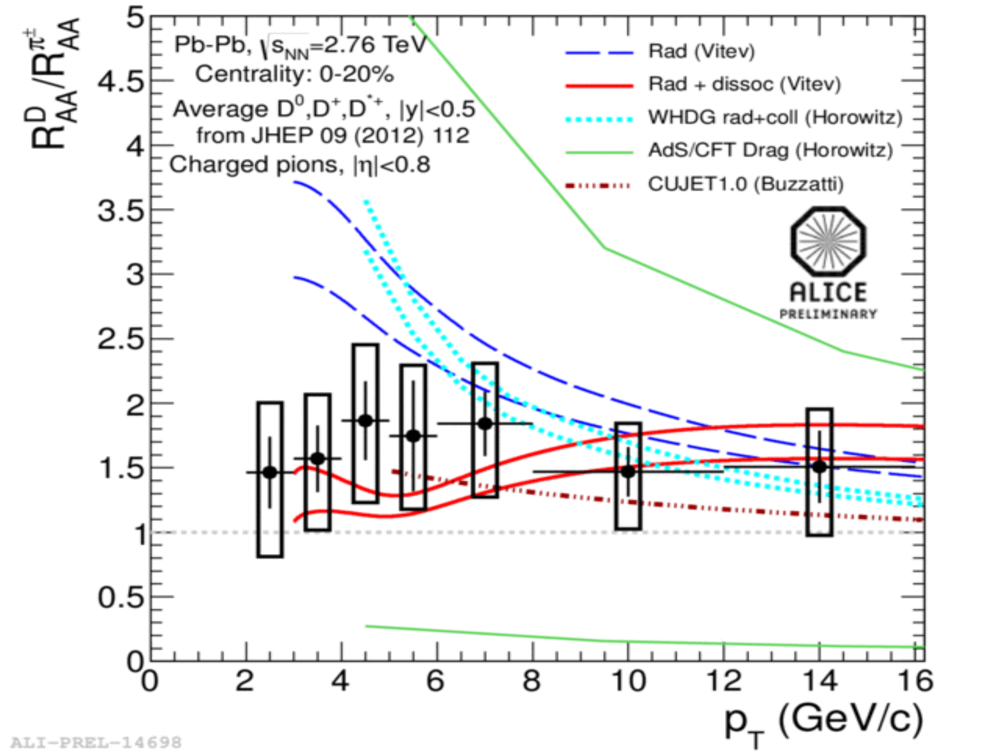
(*note that dI/dw~CF*)



The heavy flavour: R_{AA} for D mesons



Heavy (D) to light (π) suppression ratio



Note that m_D=1.9 GeV introduces mass corrections on the energy loss of ~10% for a D quark of 10 GeV

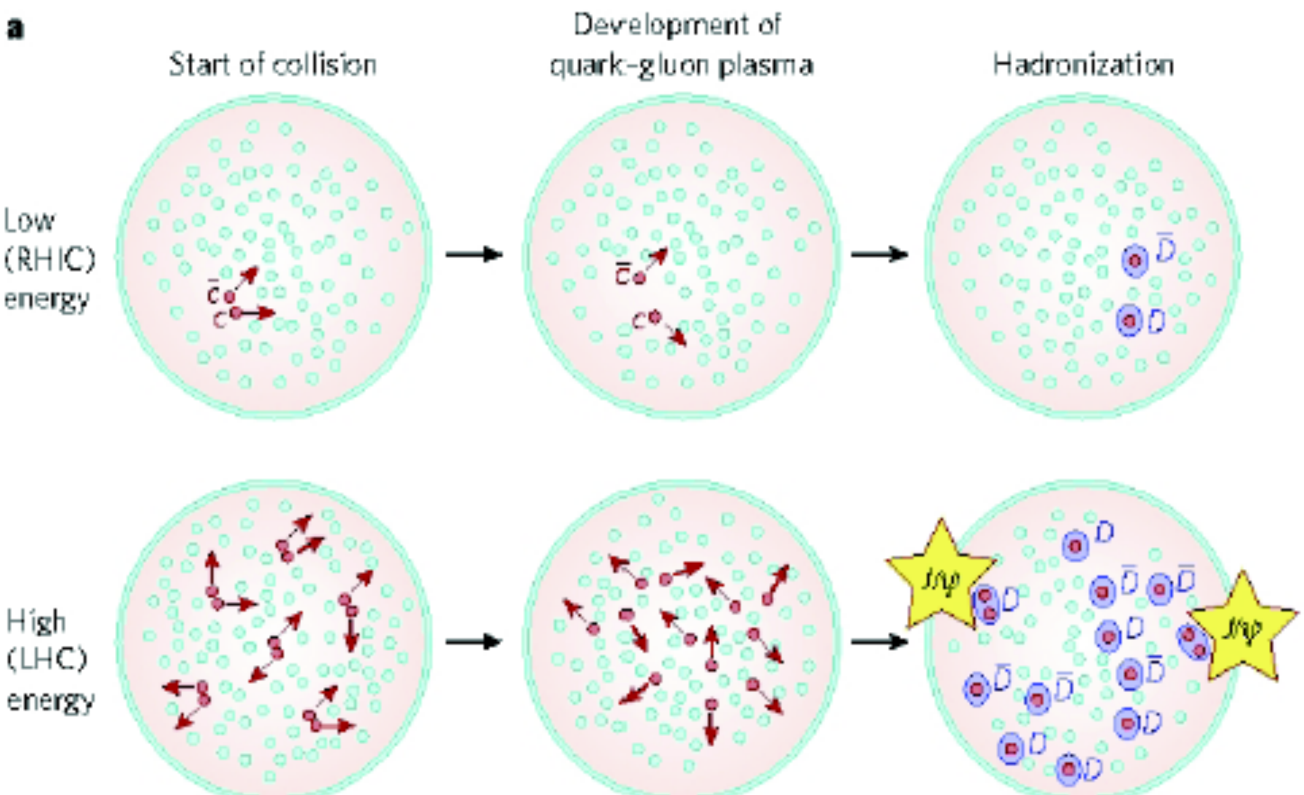
Hints for a smaller suppression of the D meson in the low p_T region

Heavier mesons with b content will allow to explore mass modification of the R_{AA} in a wider range of p_T

The heavy flavour: quarkonia

$$\sigma^{hh\to J/\Psi} = f_i(x_1,Q^2)\otimes f_j(x_2,Q^2)\otimes\sigma^{ij\to[c\bar{c}]}(x_1,x_2,Q^2)\langle\mathcal{O}([c\bar{c}]\to J/\Psi)\rangle$$

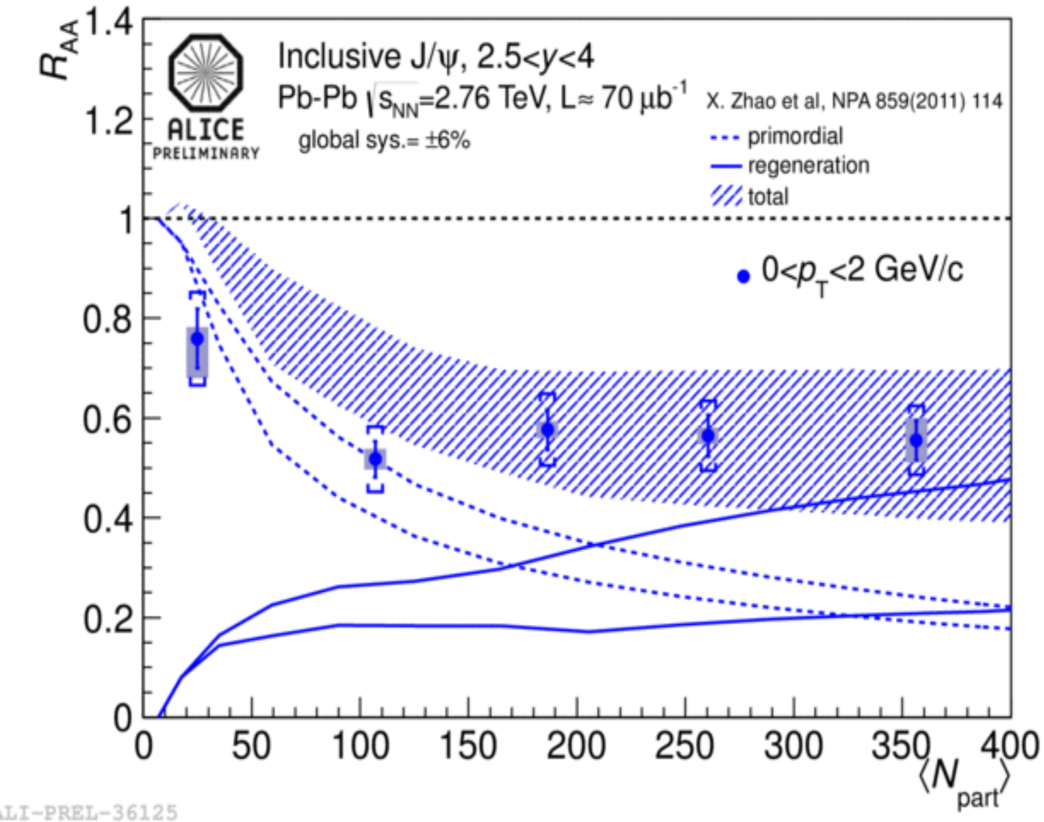
The large scale process encoded here → $\langle\mathcal{O}([c\bar{c}]\to J/\Psi)\rangle$ can suffer modification in the presence of a deconfined medium in addition to quark energy loss

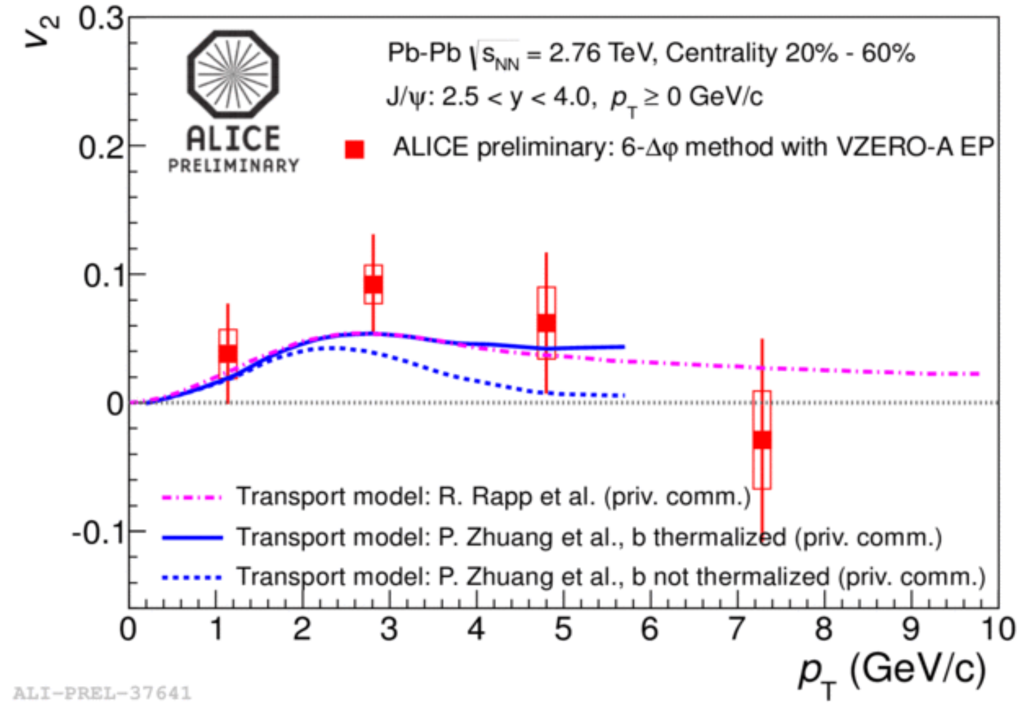


Color charge screening — feed-out

Color charge recombination — feed-in

The heavy flavour: quarkonia





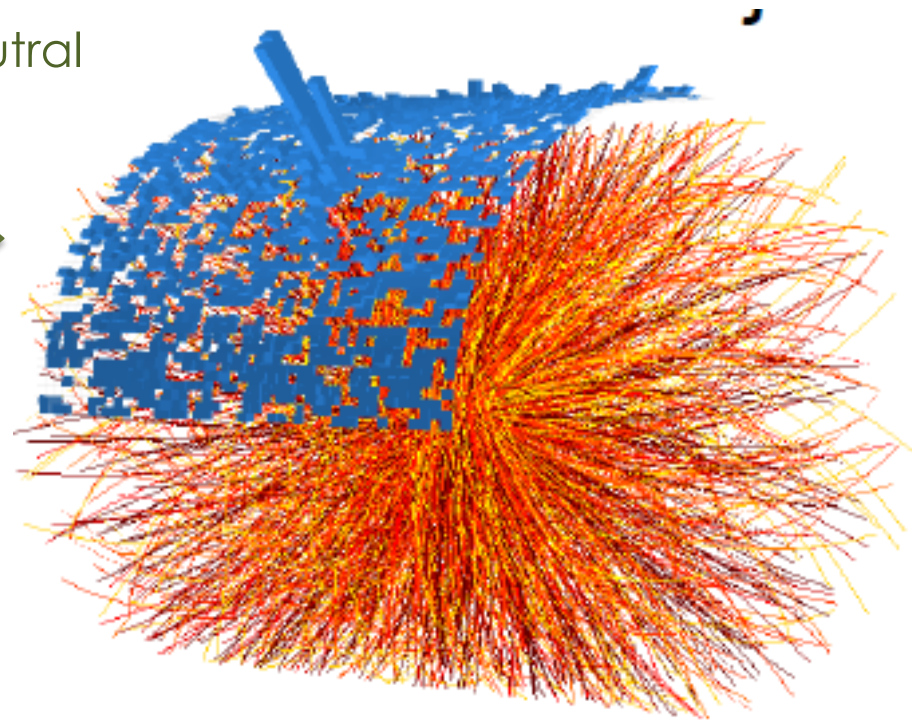
J/ψ suppression compared to theoretical models + regeneration component from deconfined charm quarks in the medium that contributes to about the 50% of the measured yield

For the first time, non zero v_2, also in qualitative agreement with models including regeneration

JETS

Single hadron measurements are limited: only sensitive to the longitudinal energy loss
Probe full dynamics of jet quenching → reconstruct jets

EMCal for the neutral component



TPC for the charged particles

Jet reconstruction in Heavy Ion Collisions is challenging!
Complex interplay between
medium modifications ←→ background ←→ jet finding

LNF group is main contributor to jet physics@LHC

1. ALICE JET RESULTS:

-ALICE first publication on Heavy Ion Jets,
"Measurement of event background fluctuations for charged particle jet reconstruction in PbPb collisions at 2.76 TeV"
JHEP 1203 (2012) 053.[Cunqueiro primary author]

-Charged jet spectrum, upcoming publication

-Full jet spectrum, upcoming publication

-Hadron-jet and recoil jet spectrum, upcoming publication,
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2. <u>Detector and online development for jet physics in the LNF group:</u>

-Calorimeter construction: EMCAL/DCAL proyect
To recover the full jet energy and to study correlations
-Online High Level Trigger
To select jetty events and increase statistics

Large LNF effort, not discussed here

LNF group is main contributor to jet physics@LHC

3. Phenomenological studies of jet quenching and first interpretation of LHC data, Collaboration with Santiago de Compostela theory group and with LNF theory department:

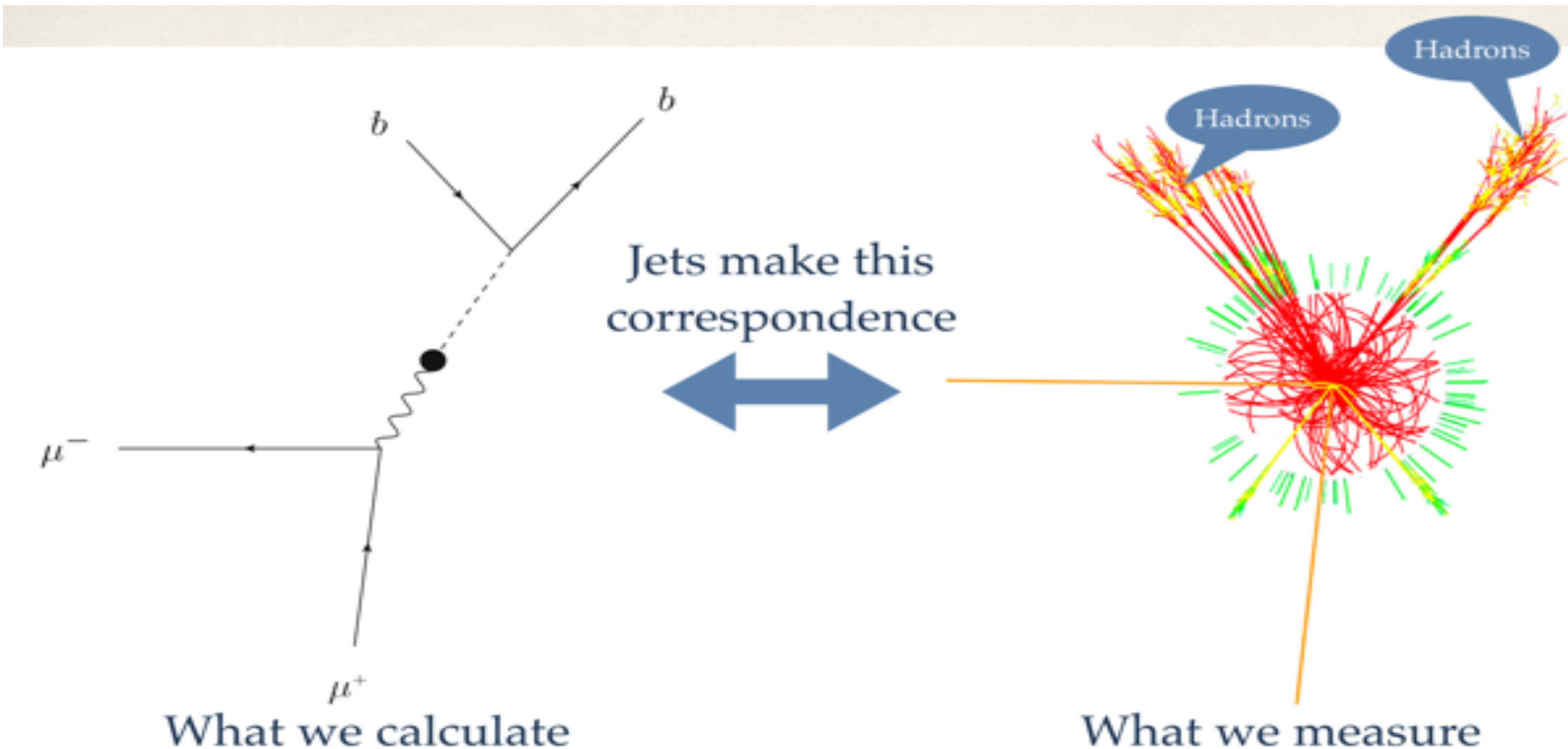
"Medium evolved fragmentation functions"
[Armesto,Cunqueiro,Salgado,Xiang]JHEP 0802 (2008)

"*QPYTHIA:a medium-modified implementation of final state radiation"*
[Armesto,Cunqueiro,Salgado],Eur.Phys.Jour C61(2009)

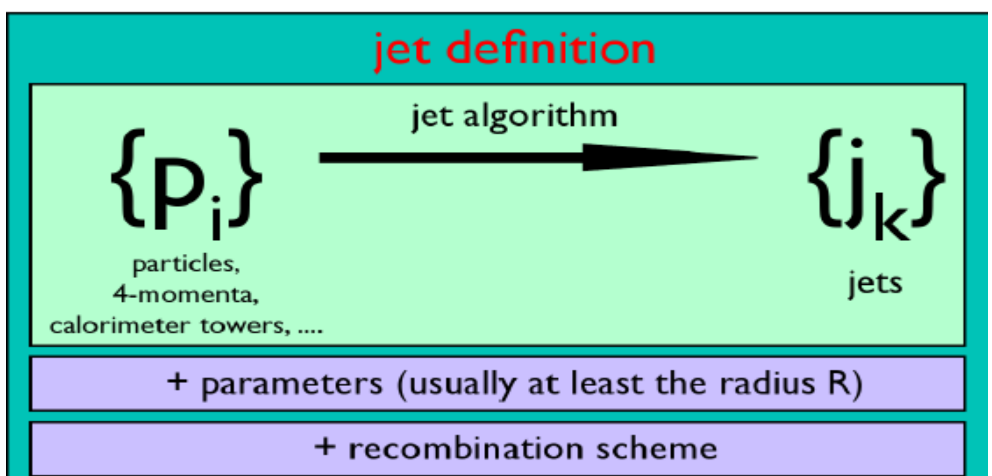
"*Angular-ordered parton showers with in-medium modified splittings"*
[Armesto,Corcella,Cunqueiro,Salgado],JHEP0911 (2009)122

"Analysis of the influence of background subtraction and quenching on jet observables"
[Apolinario,Armesto,Cunqueiro] JHEP1302 (2013)022

What is a Jet?



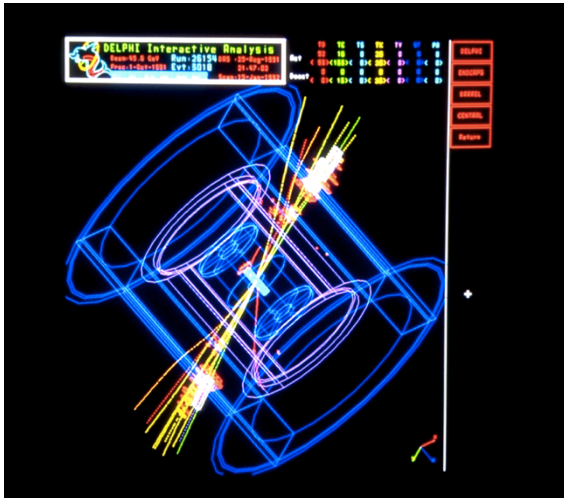
b
b
Hadrons
Hadrons
Jets make this correspondence
μ^-
μ^+
What we calculate
What we measure

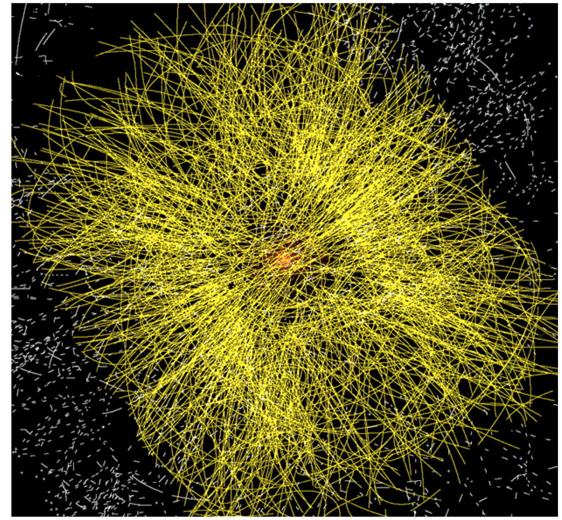


jet definition
jet algorithm
$\{p_i\}$
particles,
4-momenta,
calorimeter towers, ...
$\{j_k\}$
jets
+ parameters (usually at least the radius R)
+ recombination scheme

What is a Jet in a Heavy Ion Collision?

@LEP →





← In ALICE

How is a pp jet's p_t modified by the HI background?

$$p_t^{AA} - p_t^{pp} =$$

$$= \boxed{\rho A \pm (\sigma\sqrt{A} + \cancel{\sigma_\rho A} + \cancel{\rho\sqrt{\langle A^2\rangle - \langle A\rangle^2}})}$$

Background momentum density (per unit area)

jet area

background fluctuations

'susceptibility'
(background contamination, gain of **UE** particles)

$$+ \boxed{\Delta p_t^{BR} \pm \sigma^{BR}}$$

'resiliency'
(backreaction, gain or loss of **hard** particles)

event-by-event and jet-by-jet background determination and subtraction will eliminate these two contributions to dispersion

Jet Finder and inputs (only for experts)

- Anti-k_T Algorithm from FastJet[*] package
  - Resolution parameter R = 0.2, 0.3, 0.4
  - Area cut A > 0.1-0.4 avoids extremes
  - Jet vector from boost invariant p_T recombination scheme
- Charged Jets
  - Input: tracks with p_T > 150 MeV/c
  - Advantage: full azimuth (φ) coverage
- Fully reconstructed jets
  - Input
    - Tracks with p_T > 150 MeV/c
    - EMCAL clusters E_T^{clus} > 150 MeV after correction for energy from charged particles
    - Jet required to be fully contained in EMCAL acceptance
  - Advantages: trigger capability, higher $p_{T,Jet}$ reach, unbiased fragmentation

[*] M. Cacciari, G.P. Salam and G. Soyez, Eur.Phys.J. C72 (2012) 1896 [arXiv:1111.6097]

Distance Definition

$$D_{ij} = \min\left(p_{Ti}^{2p}, p_{Tj}^{2p}\right)\frac{\Delta R_{ij}^2}{R^2};\ D_i = p_{Ti}^{2p}$$

$$k_T\,(\mathrm{anti}\,k_T): p = 1\,(-1)$$

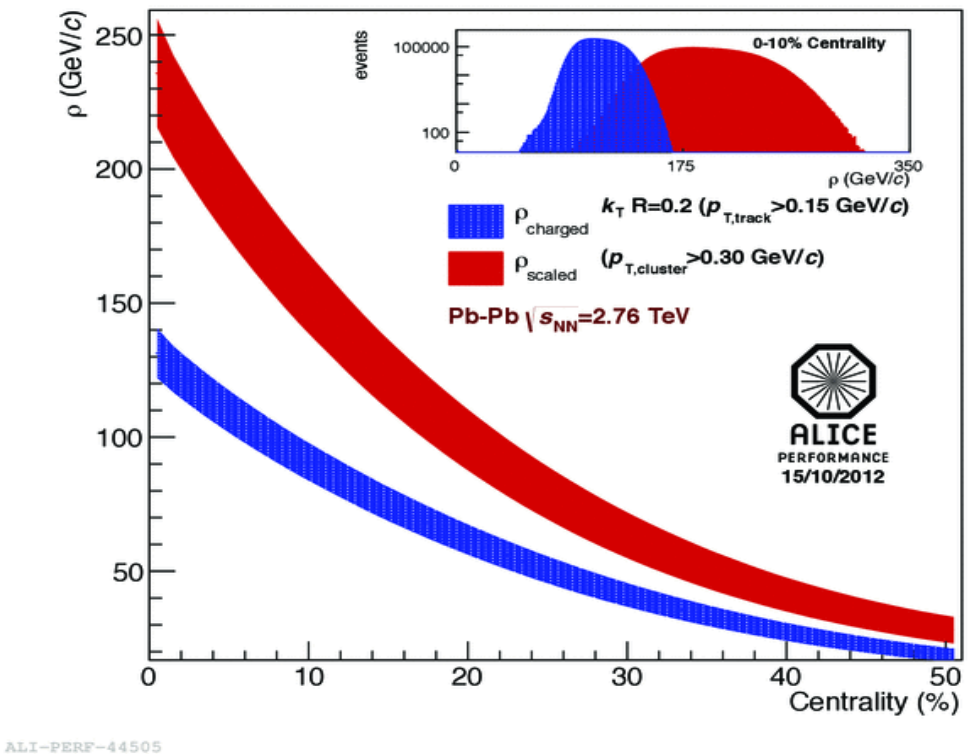
Compute all D_{ij}, D_i, $d = \min(D_{ij}, D_i)$

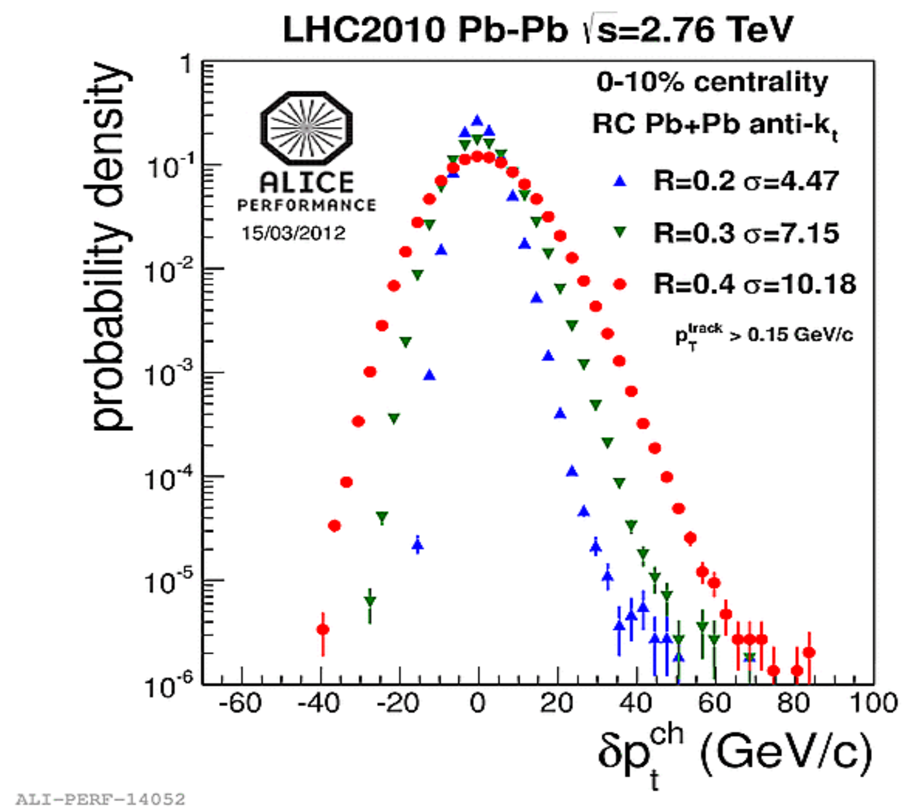
if $d = D_{ij}$: combine i with j

if $d = D_i$: i is final state jet

Jets in ALICE

ALICE JHEP 1203 (2012) 053



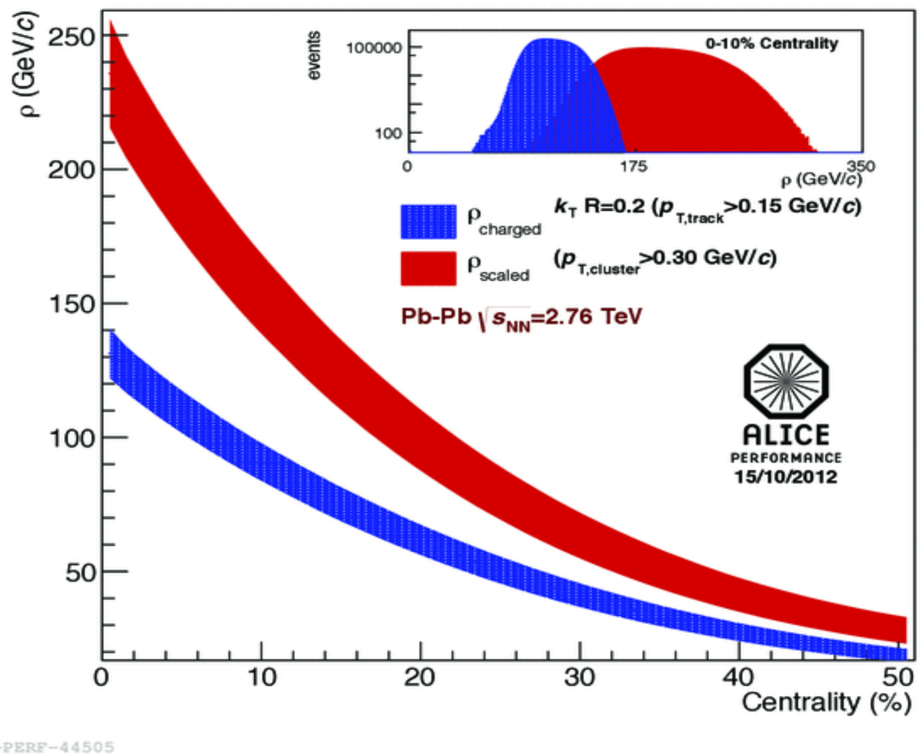


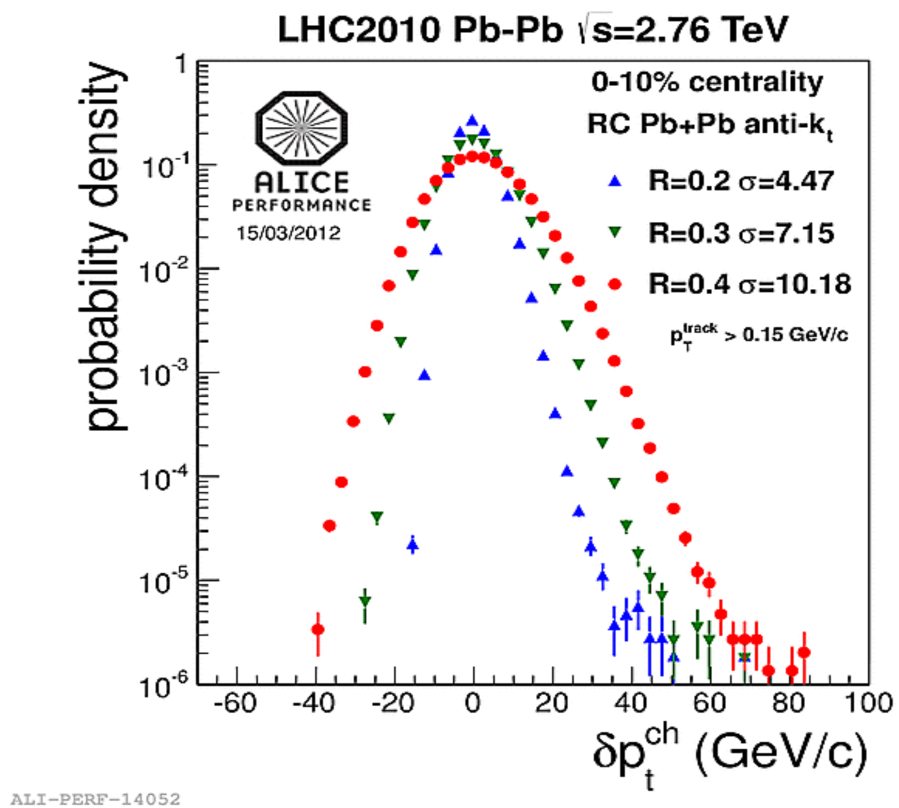
ρ ~140 GeV/area in a 0-10% central collision

means 70 GeV of background contamination inside the jet

Jets in ALICE

ALICE JHEP 1203 (2012) 053





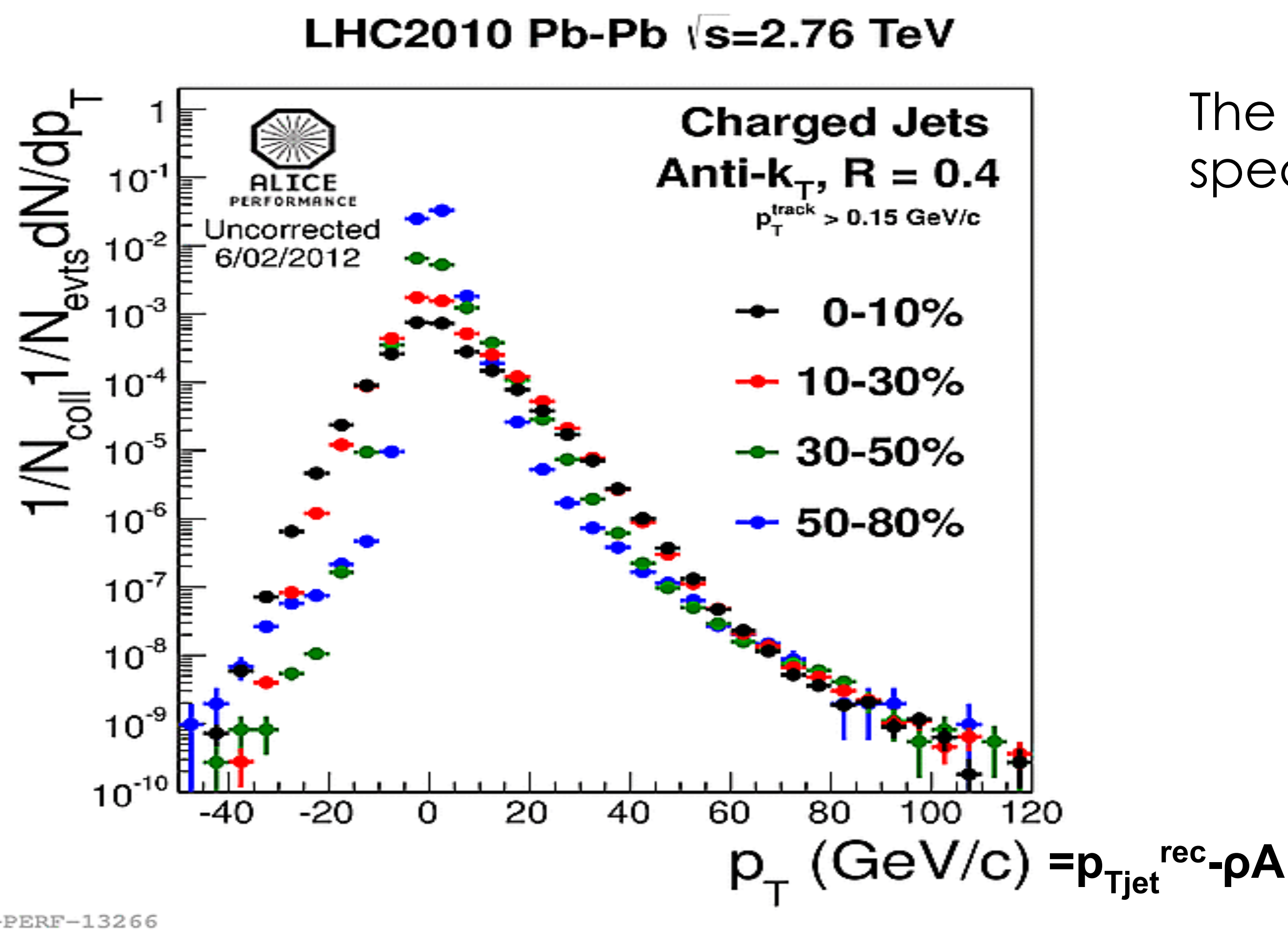
ρ ~140 GeV/area in a 0-10% central collision

means 70 GeV of background contamination inside the jet

Background not homogeneous:
→ region-to-region deviations from the average ρ displaying a non gaussian shape with σ=11 GeV for R=0.4.

Tail to the right, source of large upward fluctuations on the jet energy.

Jets in ALICE

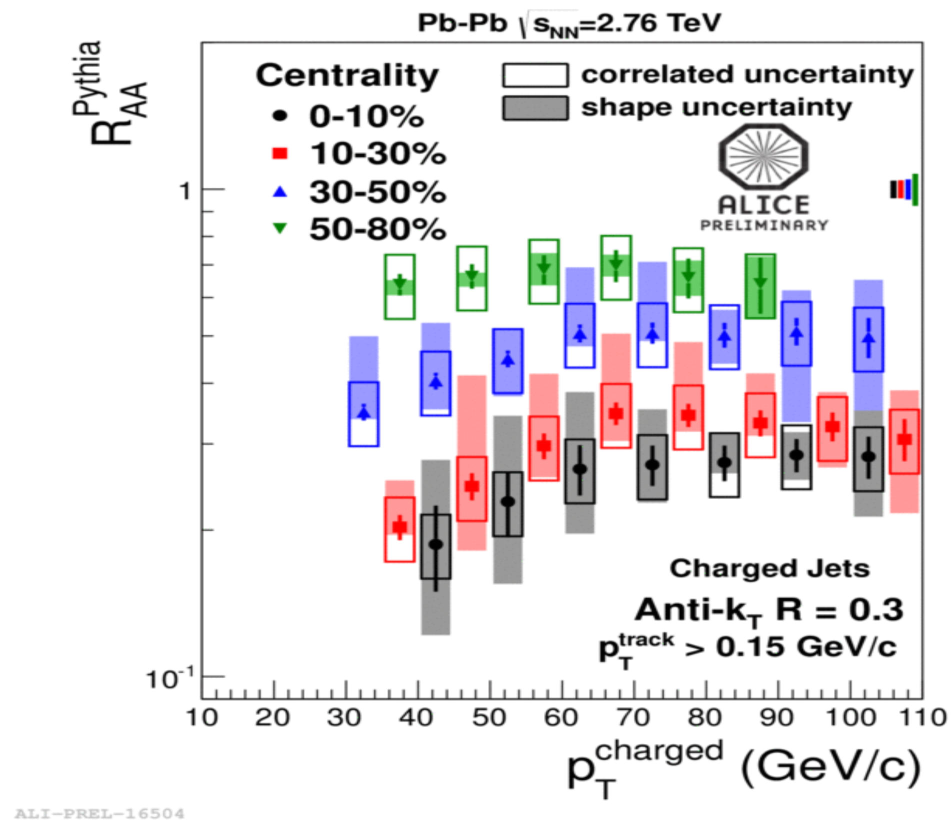


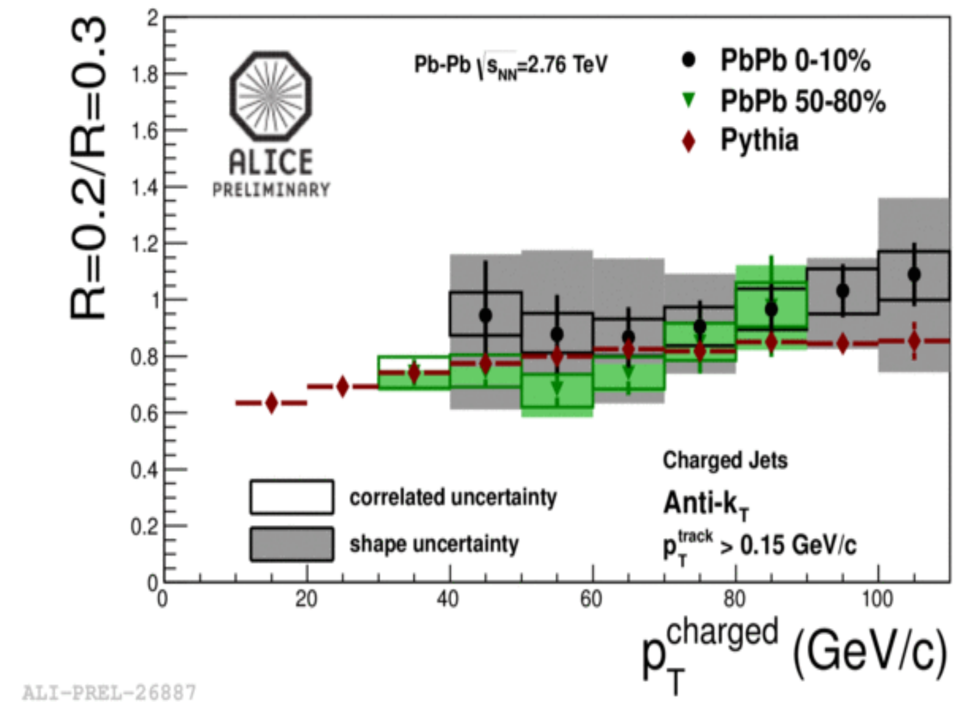
The raw charged jet spectrum

- Fluctuations smear the jet energy enhancing the jet yield up to high jet p_T
- Low-moderate jet p_T is dominated by fakes
  →correct by unfolding

ALICE is the only experiment that reconstructs jets using a minimum cutoff on particles of 0.15 GeV → least fragmentation bias on the jet population!

Inclusive charged jet spectra and R_{AA}



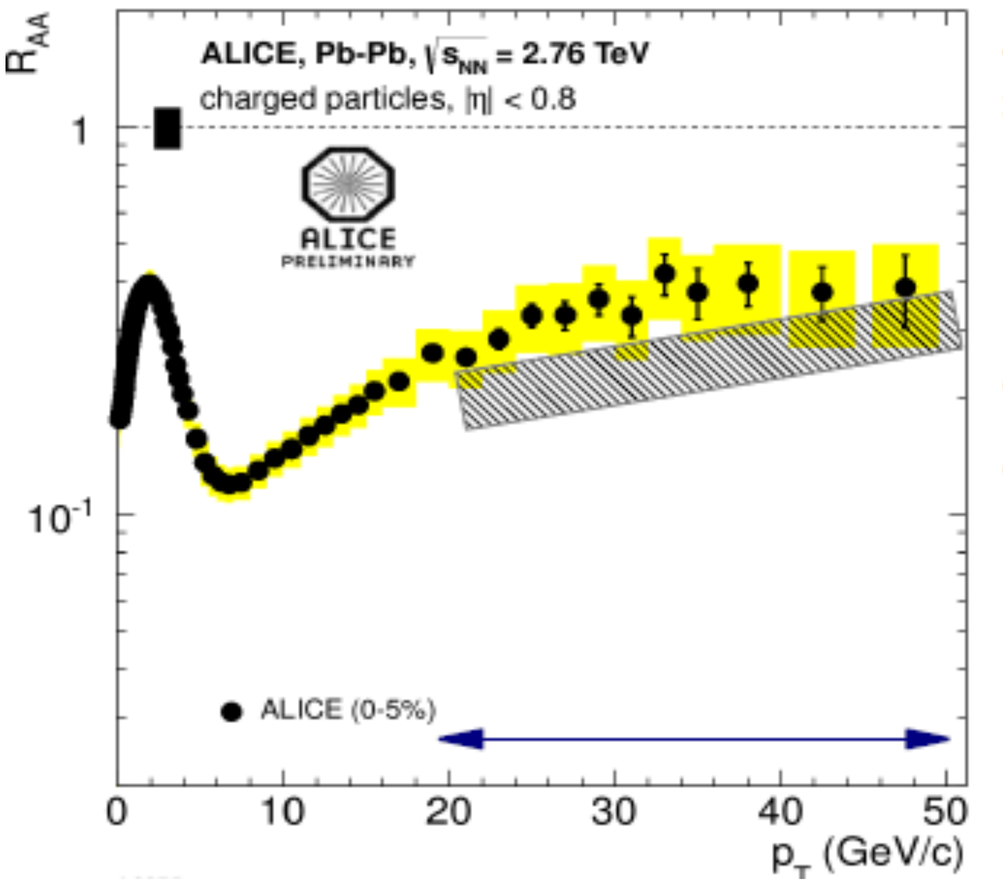


I: R_{AA} for R=0.3 is not very different to R_{AA} for single hadrons!

II: Energy distribution within a cone of R=0.3 is not very different (within large systematic errors) from PYTHIA's

To Note: lower limits in jet p_T are set by the unfolding instabilities due to fake jets

A possible interpretation



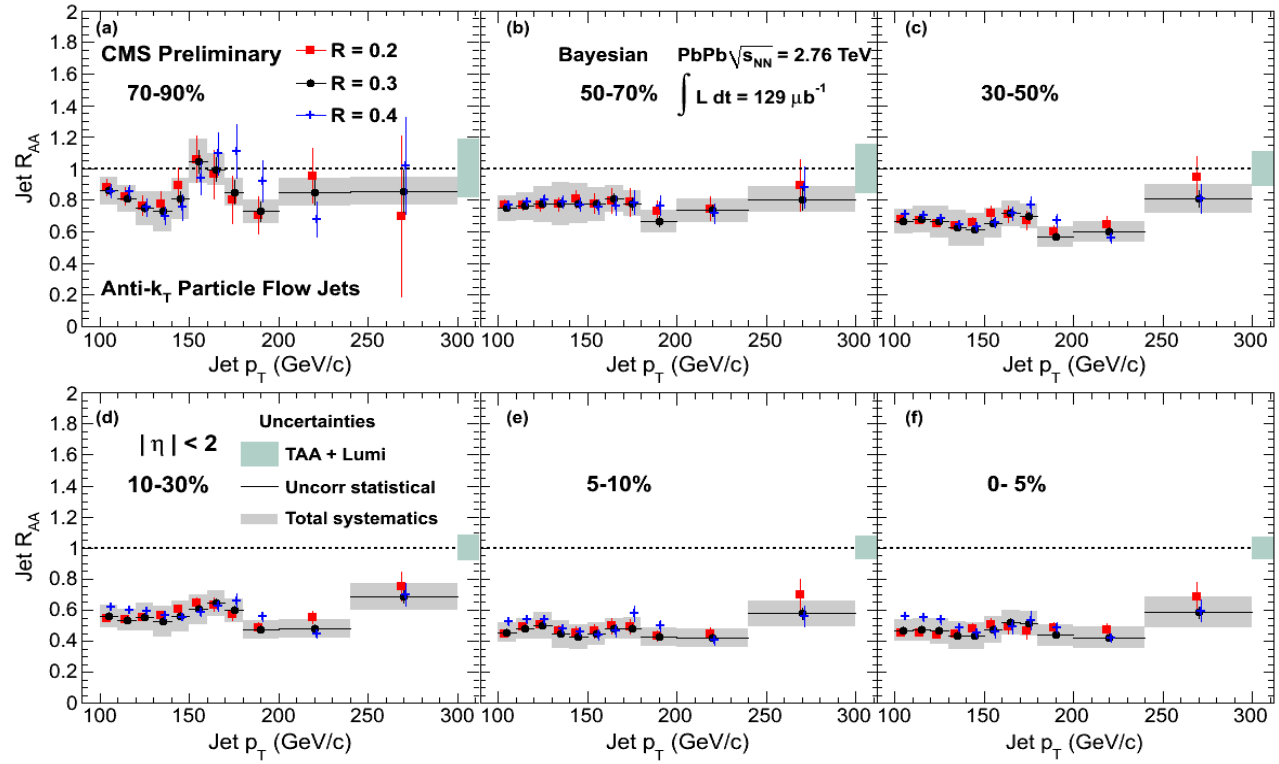
- Jet suppression comparable to hadron suppression
- No hints of broadening inside the cone

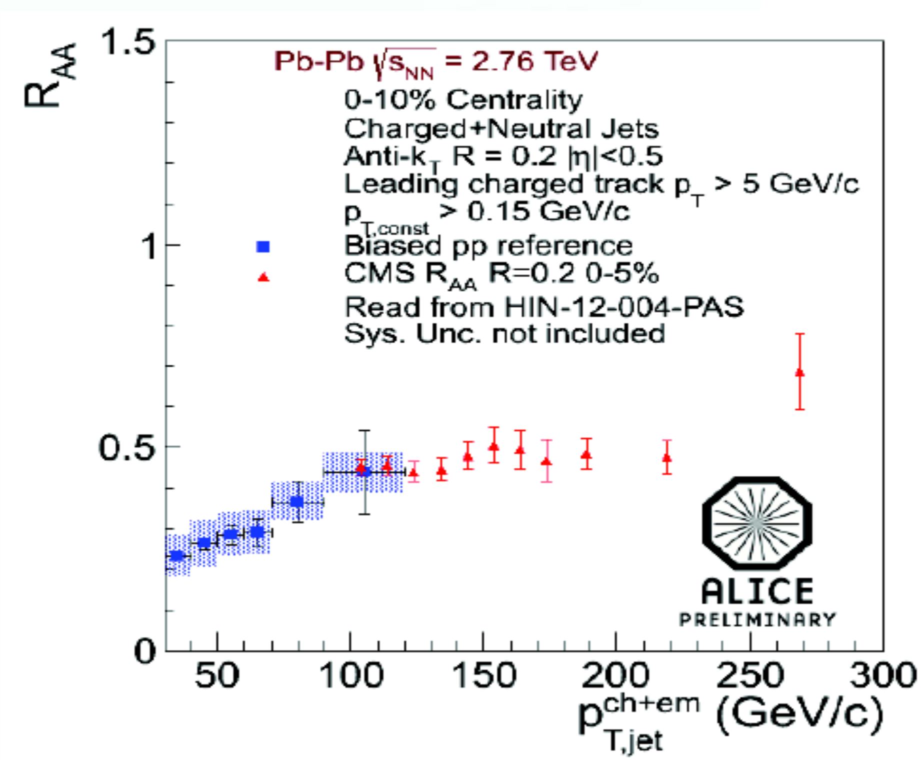
?

- Radiation happens outside the jet cone
- Jet constituents loose energy proportionally to the fraction of the jet energy they carry:

$$\Delta E_{part} = z \Delta E$$

Comparison to CMS





- CMS measures compatible suppression for high energy jets
- CMS high energy jets exhibit a flat dependence with jet p_T
- ALICE lower energy jets show p_T dependent suppression

The yield of 300 GeV jets is suppressed in a factor 2!

ALICE recoil jets and jet structure

<u>Goal</u>: precise measurement of jet structure and modifications due to quenching

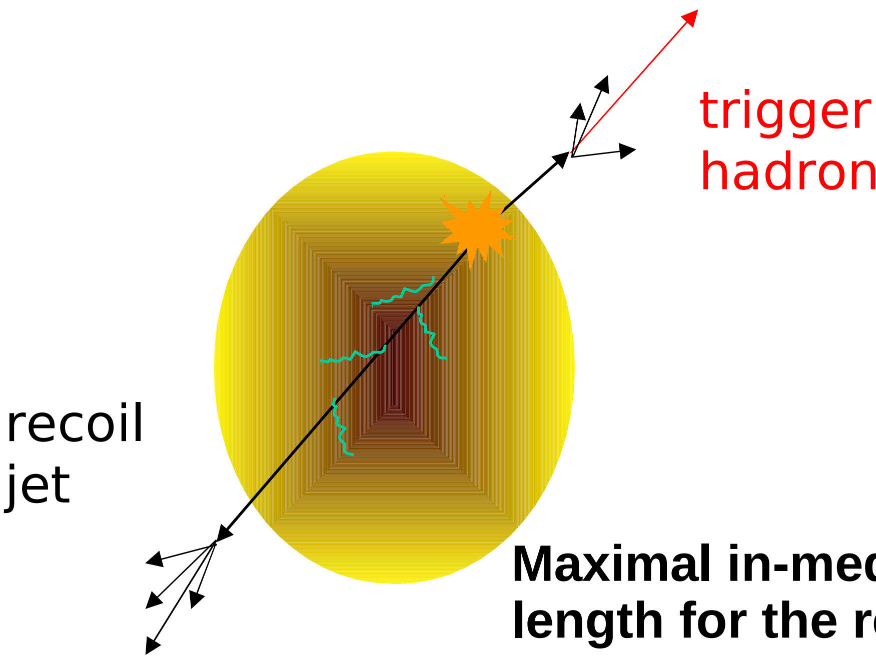
→ minimize fragmentation bias on jet population

Hadron trigger: highest particle p_T in event

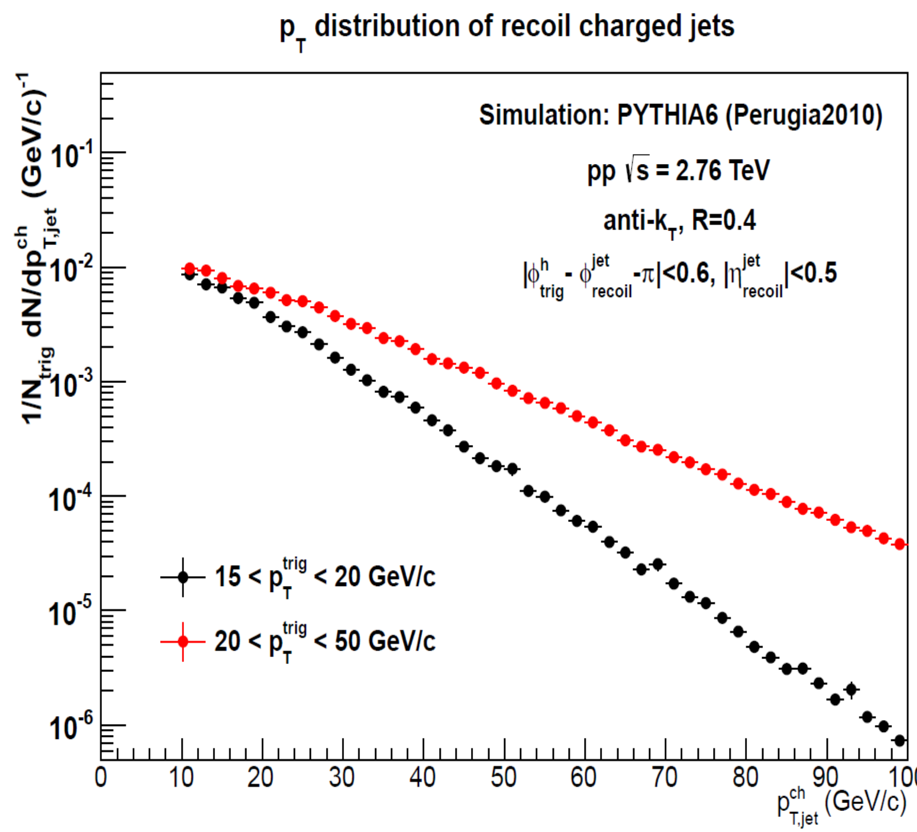
Count number of reconstructed jets in recoil azimuth

$|\varphi_{recoil}^{jet} - \varphi_{trig}^{h}| < \pi - 0.6 \quad |\eta_{recoil}^{jet}| < 0.5$

Normalize to number of triggers

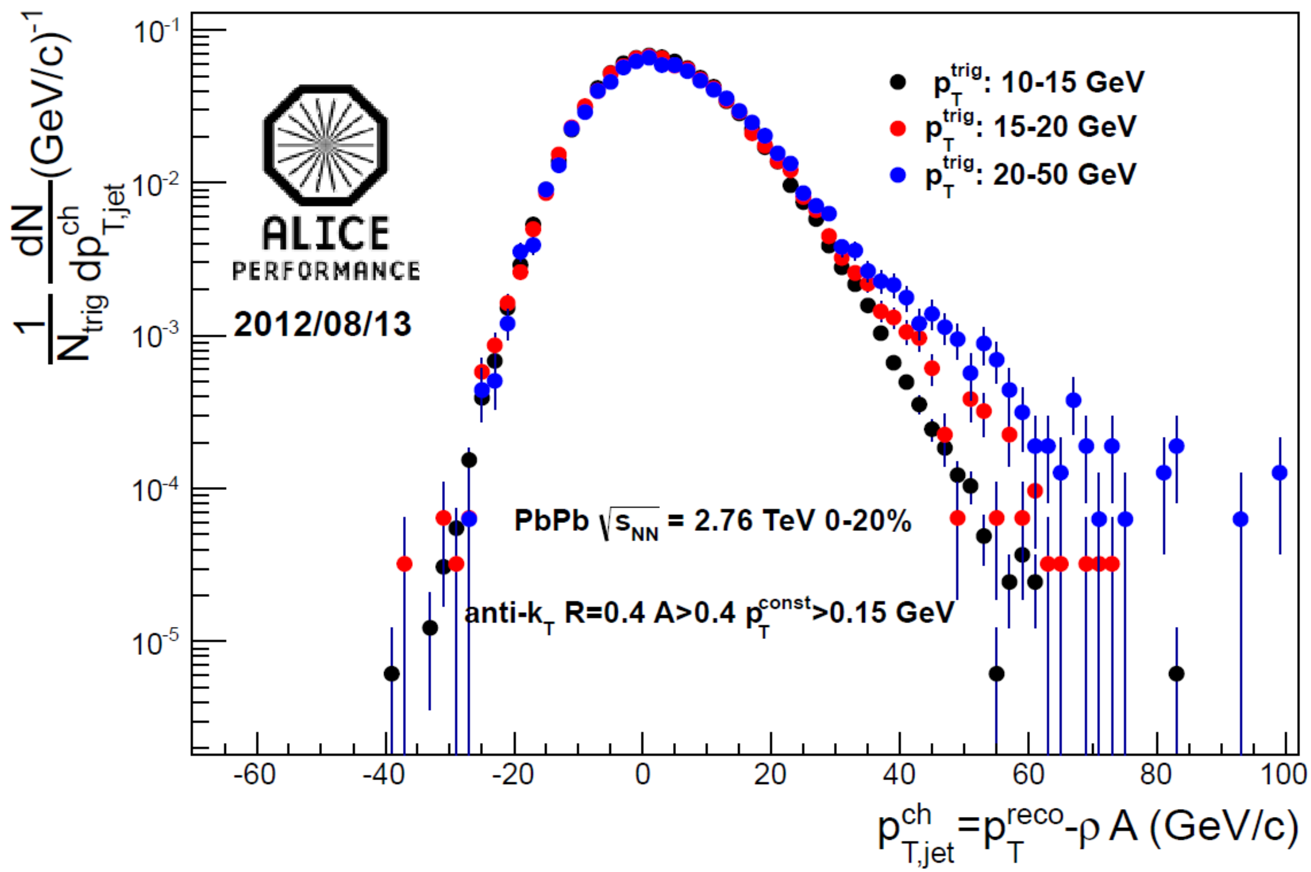


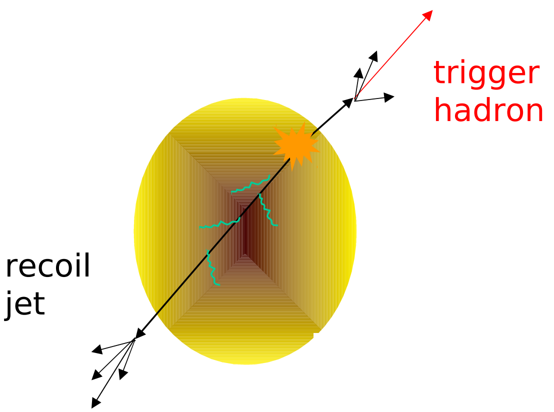
Maximal in-medium path length for the recoil jets



ALICE recoil jets and jet structure

<u>Conjecture</u>: combinatorial background distribution is independent of trigger p_T





$p_{T,jet}$< 20 GeV/c: uncorrelated with trigger p_T

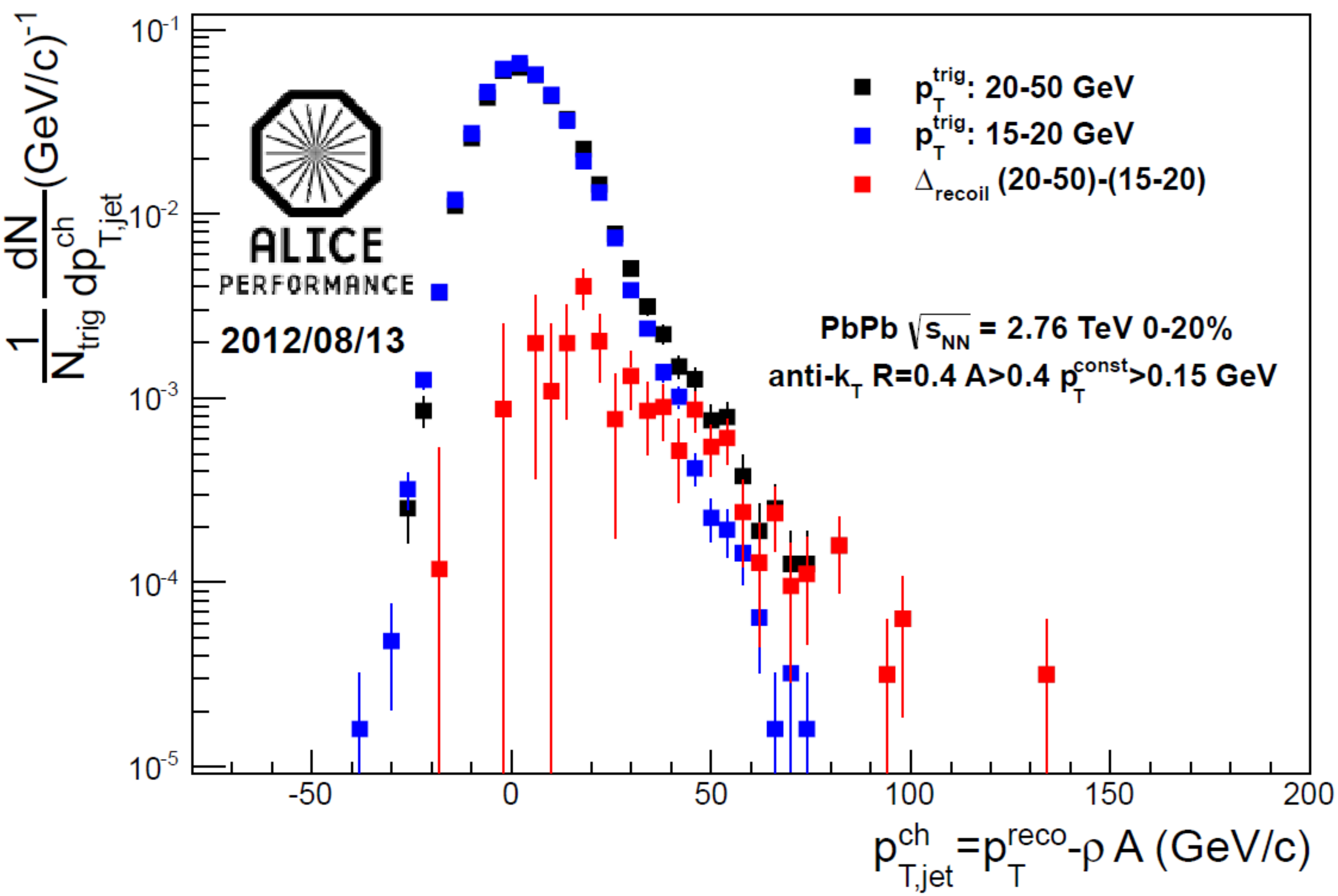
-consistent with dominance by combinatorial jet contribution

$p_{T,jet}$>20 GeV/c: correlated with trigger p_T

-consistent with dominance by hard jets from the same hard scattering

ALICE recoil jets and jet structure

1. Combinatorial background distribution is independent of trigger p_T
   Opportunity: removal of combinatorial jets via DIFFERENCE of triggered distributions: Δ_{recoil}

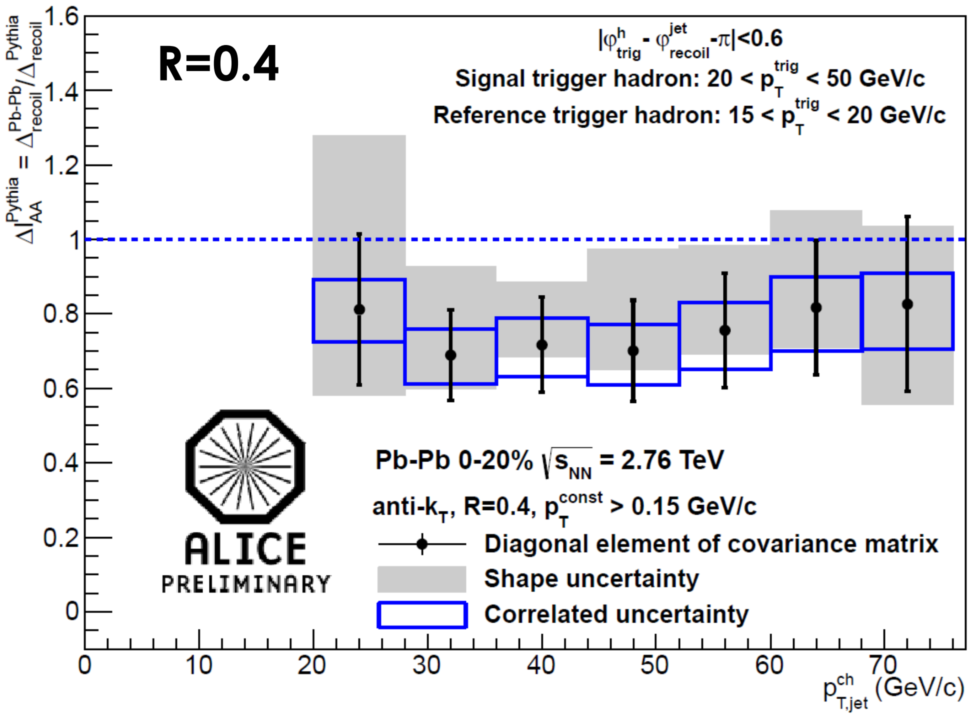


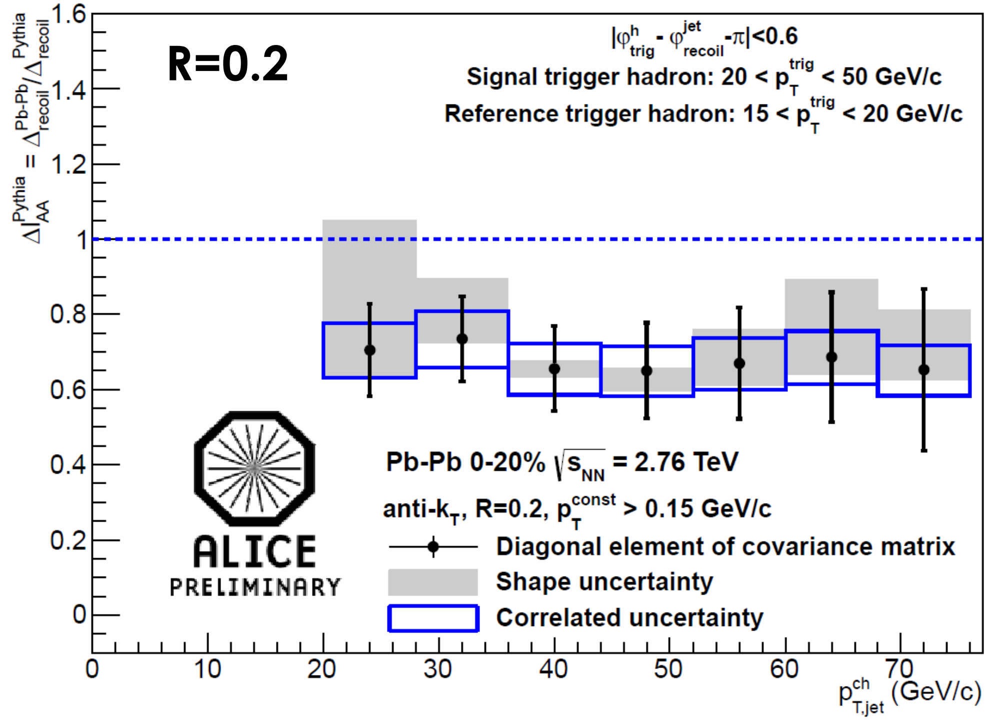
$$\Delta_{recoil}\left(p^{ch}_{T,Jet}\right) = \frac{1}{N_{trig}} \frac{dN\left(p^{ch}_{T,Jet}; p^{min}_T, p^{max}_T\right)}{dp^{ch}_{T,Jet}} - \frac{1}{N_{trig,ref}} \frac{dN\left(p^{ch}_{T,Jet}; p^{min}_{T,ref}, p^{max}_{T,ref}\right)}{dp^{ch}_{T,Jet}}$$

Reference spectrum (15-20) scaled by ~0.96 to account for conservation of jet density.

2. Difference distribution Δ_{recoil} contains only correlated hard jet component
3. Still smeared in energy by the underlying event → correct by unfolding

Recoil jet structure: ΔI_{AA}^{PYTHIA} and R dependence





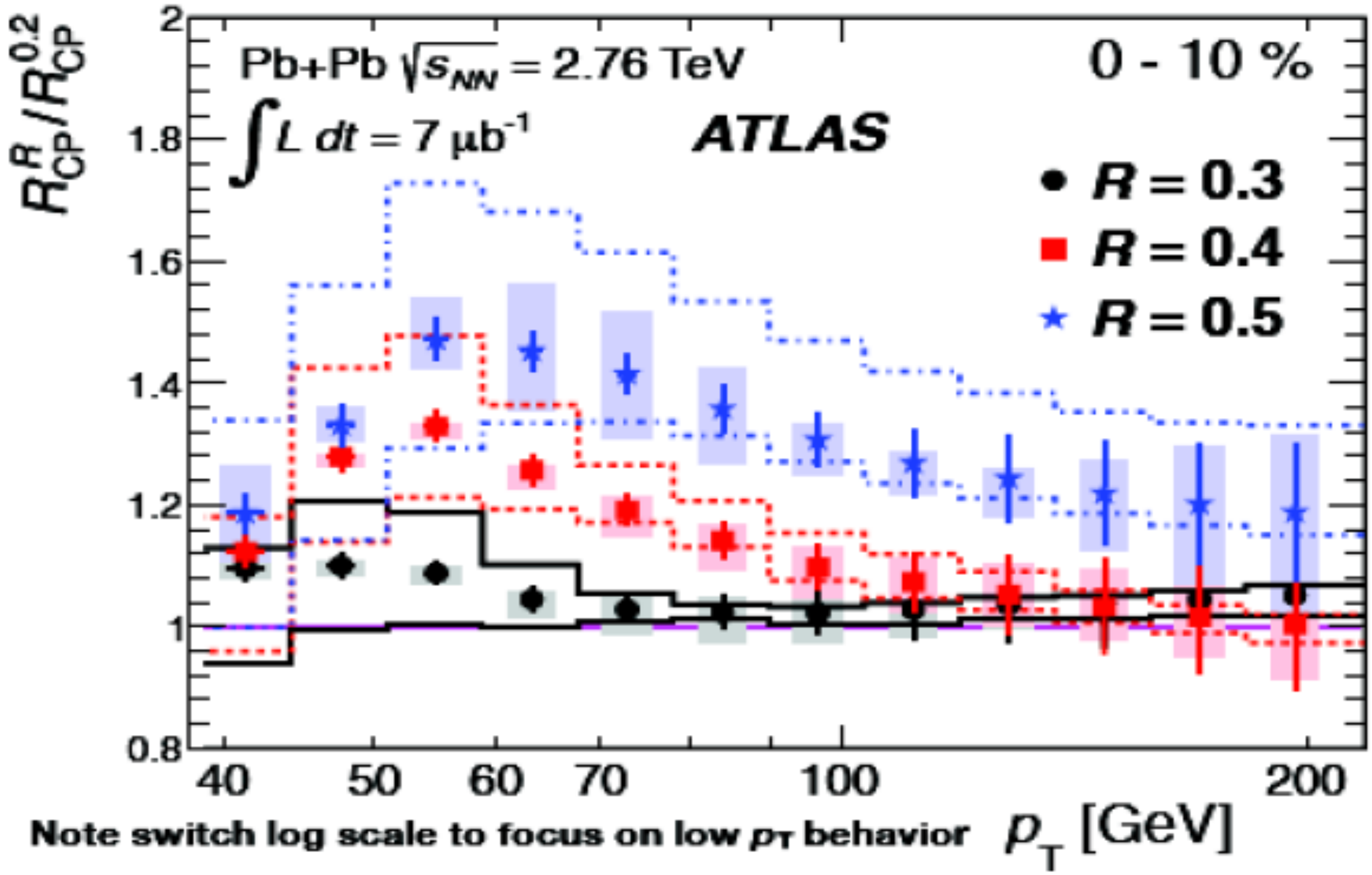
Similar ΔI_{AA}^{PYTHIA} for R=0.2 and R=0.4

→ little, if any, energy redistribution within R=0.4 relative to PYTHIA reference

Working on reducing the systematics!

Competing measurements on the jet structure

ATLAS MEASUREMENTS of low pT JET STRUCTURE



Clear evidence for energy redistribution at low jet p_T<40 GeV

Note that ATLAS has an hadronic calorimeter and thus the jet finding input has a higher minimum energy cutoff than ALICE tracks

The picture for jet quenching that emerges from data

1. Different collaborations:

different jet p_T ranges, different minimum p_T cut-off, different biases, different jet finding algorithms, different input to jet finding, different background subtraction techniques, different interplay between the detector and background response....

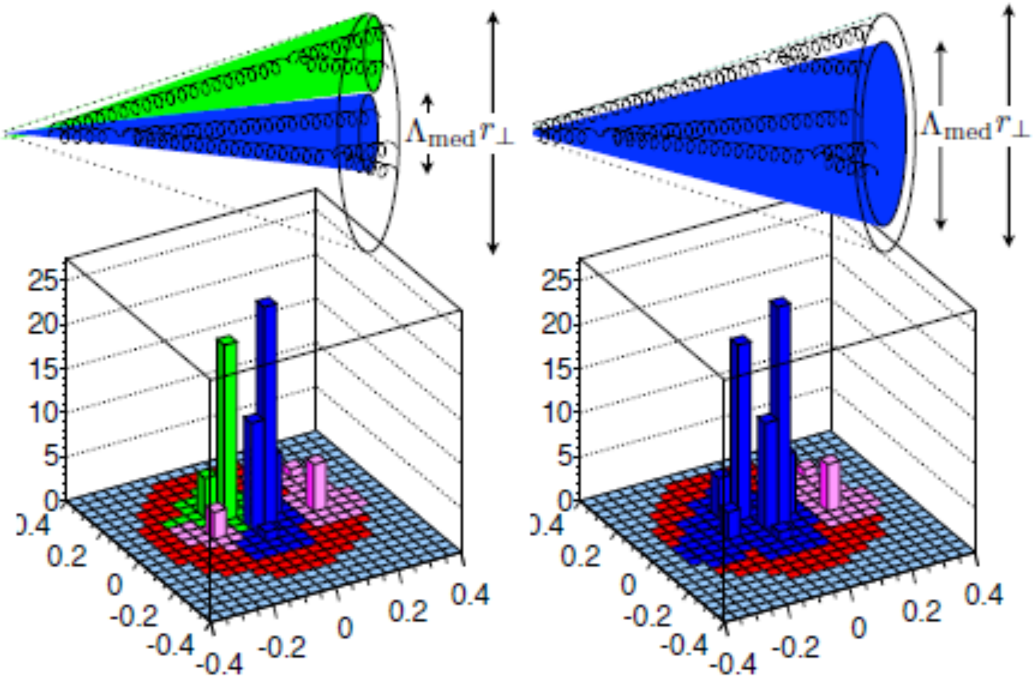
The picture for jet quenching that emerges from data

2. What is observed so far:

- The jet energy is not recovered within R=0.3,0.4 (ALICE)
- No apparent signals of broadening within R=0.3,0.4 in high energy jets (ALICE)
- Hints for transverse modifications of jets at low jet energies (ALICE-ATLAS)
- Excess of events with large momentum imbalance where the energy is recovered at very large angle (R>0.8) in the form of very soft particles (CMS)
- Coplanarity of dijets: the subleading looses energy but does not change direction (CMS)

The picture for jet quenching that emerges from data

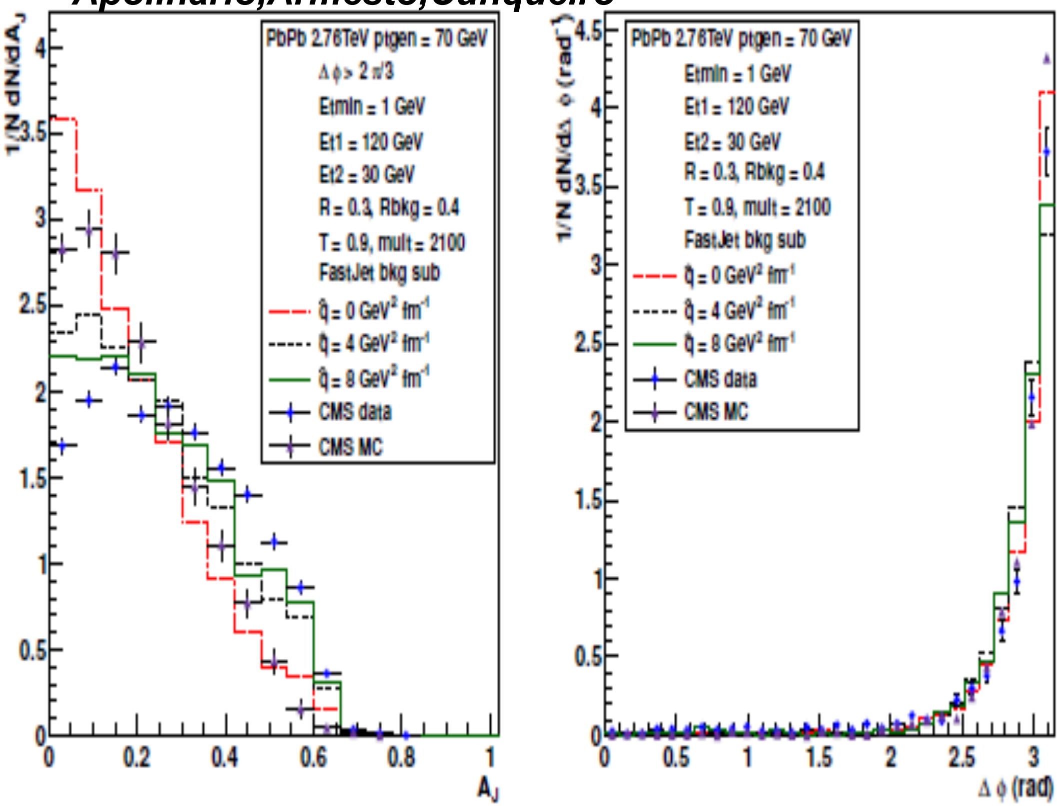
3. Interesting new pictures arising from theory:
[Salgado et al,arXiv:1210.7765v2]



4. Comparisons to theory ongoing: lot's of joint effort to define strategies and observables

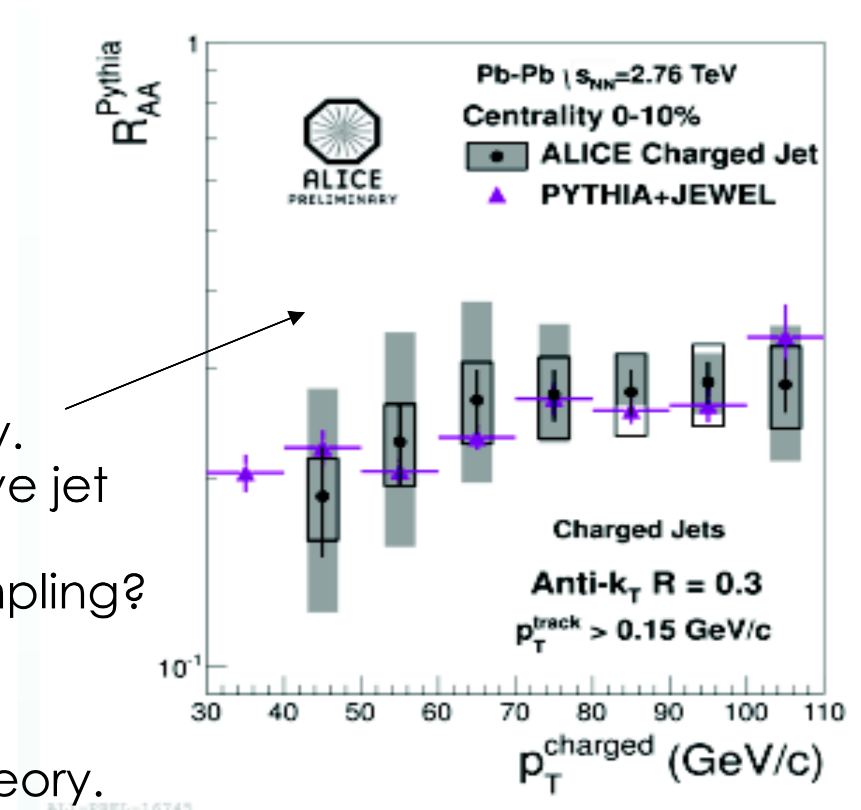
Theory-experiment comparisons

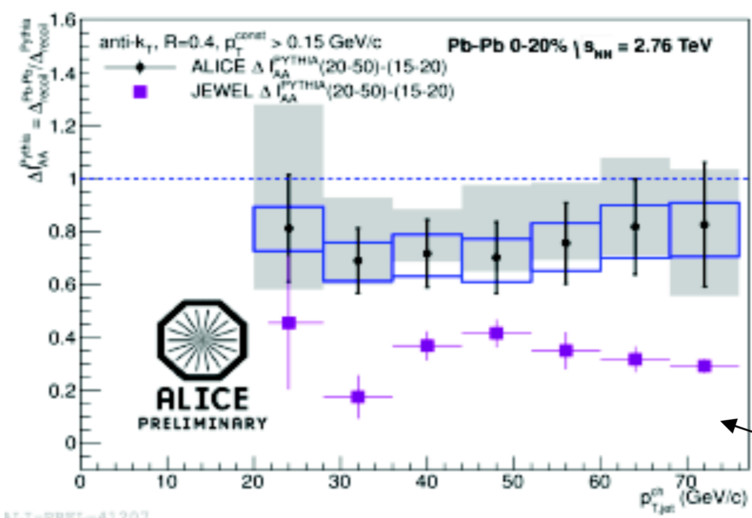
Apolinario,Armesto,Cunqueiro



The LHC experiments provide a wide set of observables to constrain theory models.

Work is in progress...





azimuthal correlation.

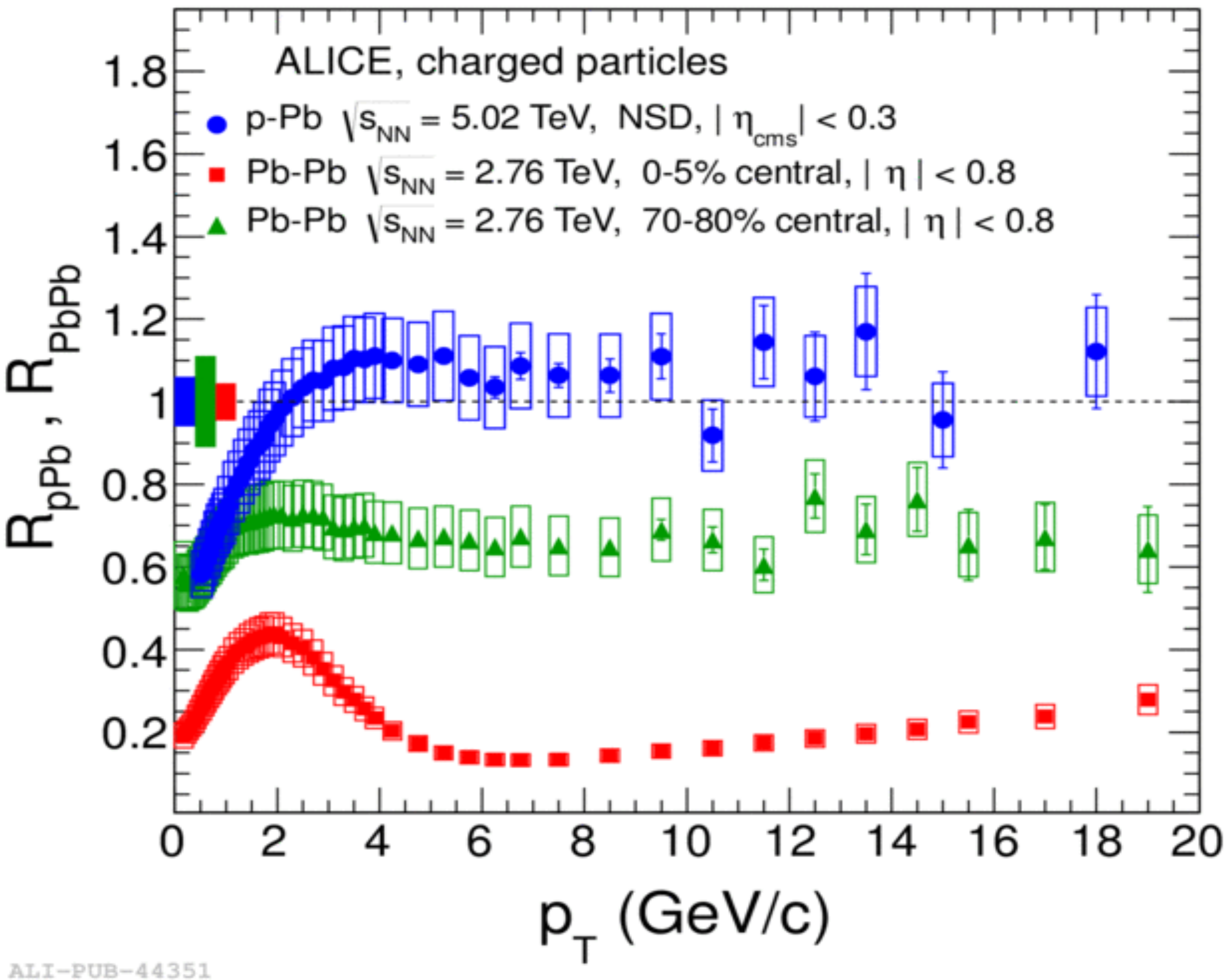
Constrain theory.
JEWEL vs inclusive jet spectrum.
Path length sampling?

Constrain theory.
JEWEL vs recoil. Path length sampling?

ALICE most recent results: pPb collisions

First data ever collected

pPb collisions are the major benchmark for PbPb collisions as they address cold nuclear effects

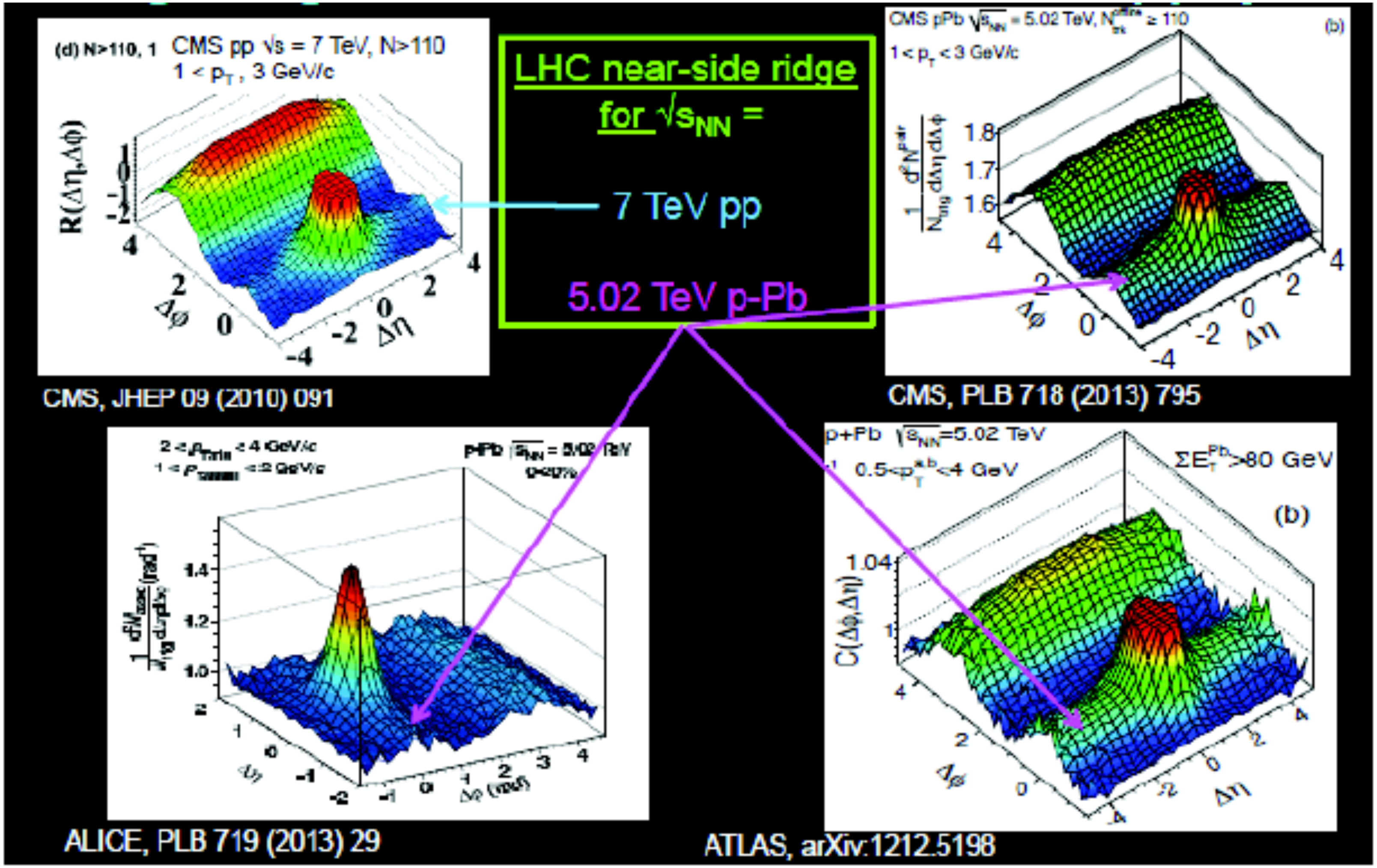


- R_{pPb} compatible with 1 above 2-3 GeV
- No high p_T-suppression due to initial state effects

pPb collisions ... not only a benchmark for PbPb

- They probe nucleus structure at unprecedent QCD regime of very low x
- The double ridge seen by ALICE makes pPb collision an interesting physics topic on its own

→ **pPb: long range dihadron correlations!**

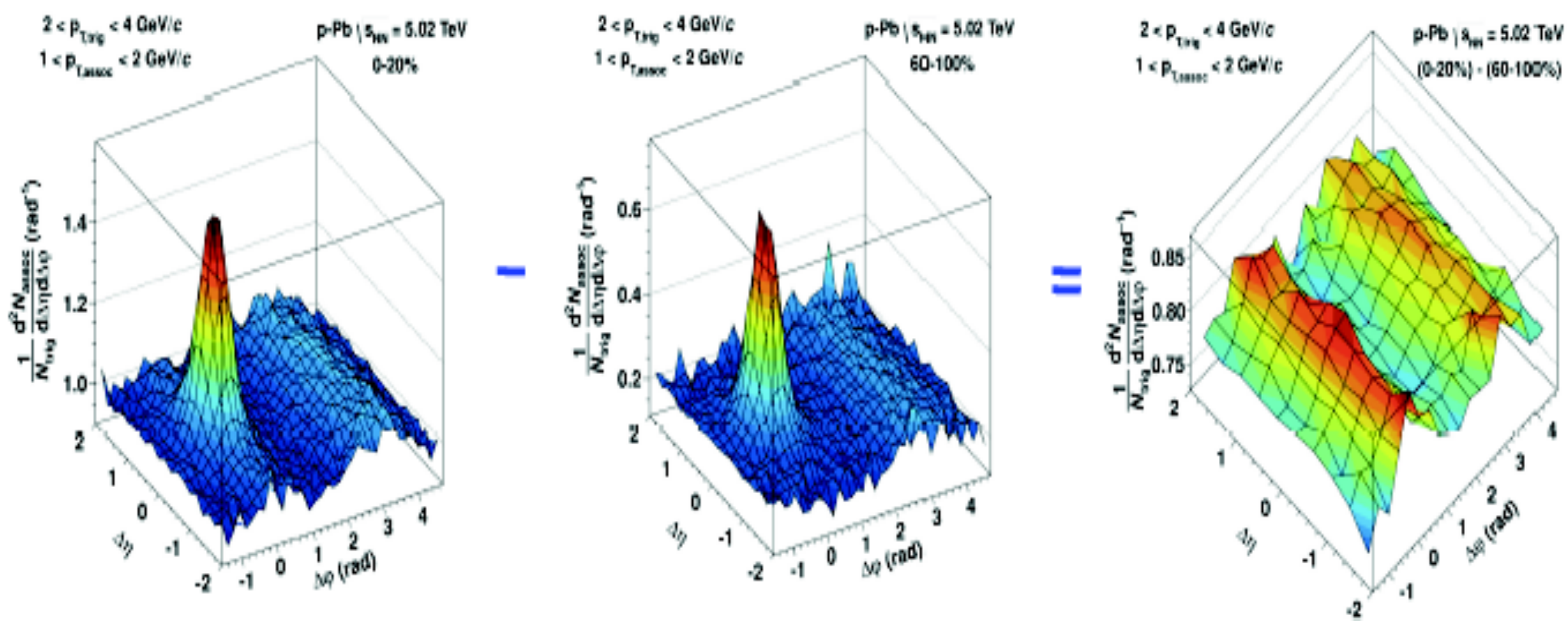


pPb collisions...not only a benchmark for PbPb

High multiplicity pPb

Low multiplicity pPb, pp-like

Double ridge structure



Long dihadron correlations in the near side and in the away side

Phys.Lett. B 719 (2013)

CCG? Hydrodinamics? Origin not yet understood....

Physics Perpectives (for LNF)

LNF group is now participating in the Inner Tracking System upgrade, it will be the national production center coordinating the assembly of the detector

Outer Barrel (OB): 4 layers pixels

Radial position (mm): 200, 220, 410, 430

Length in z (mm): 843, 1475

Nr. of modules: 48, 52, 96, 102 → 298

Nr. of chips/module: 28, 28, 52, 52

Nr. of chips/layer: 2688, 2912, 9600, 10200

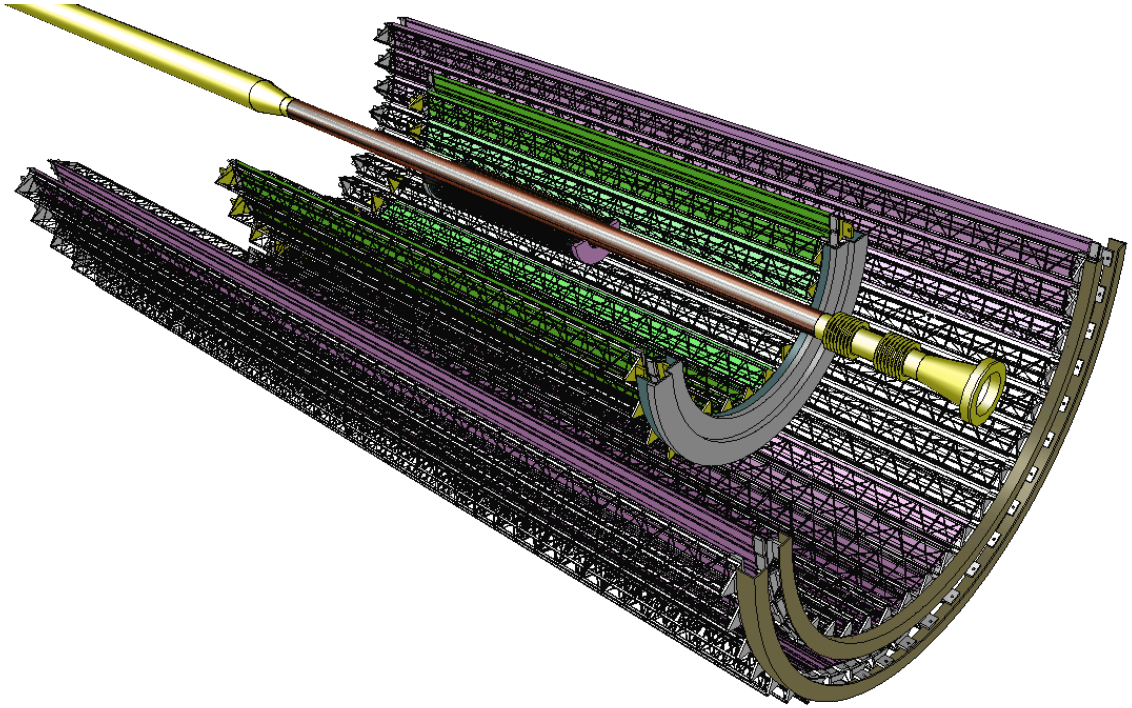
→ 25400

Pixel size: ~ 20 μm x 20 μm or bigger

Material thickness: ~ 0.8% X_0

Power density: ?

Throughput: < 6 Mbit / sec·cm^2



New interesting possibilities for heavy flavour jet tagging

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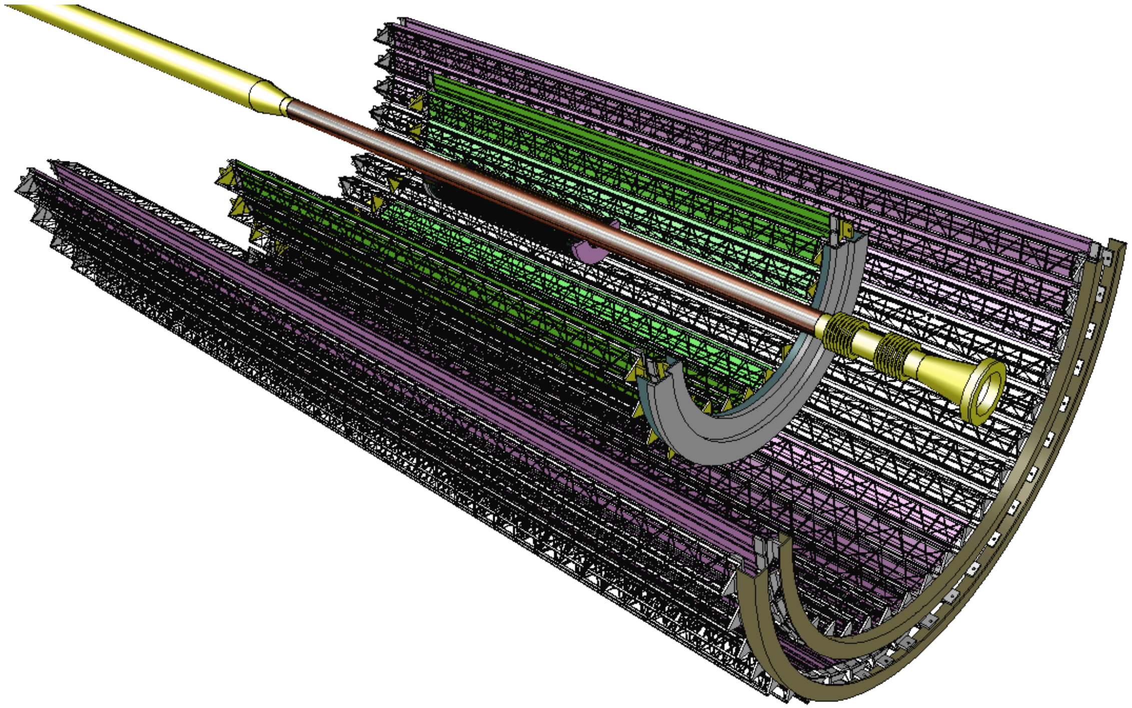

The upgrade will allow for:

- High read-out rate
- Improved resolution
- New possible charm and beauty measurements:
  - -D down to p_T~0
  - -B meson
  - -Δ_b, Δ_c baryons
  - -…

New interesting possibilities for heavy flavour jet tagging

Summary and outlook

- LHC measures a larger, hotter, denser, longer lived and more opaque source than at RHIC

- The measurements of bulk properties confirm the great success of hydrodynamics in Heavy Ion Collisions.
  →precision measurements of shear viscosity η/s

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ALICE jet program is fully competitive.
Unique/new analysis ongoing and interesting new results foreseen

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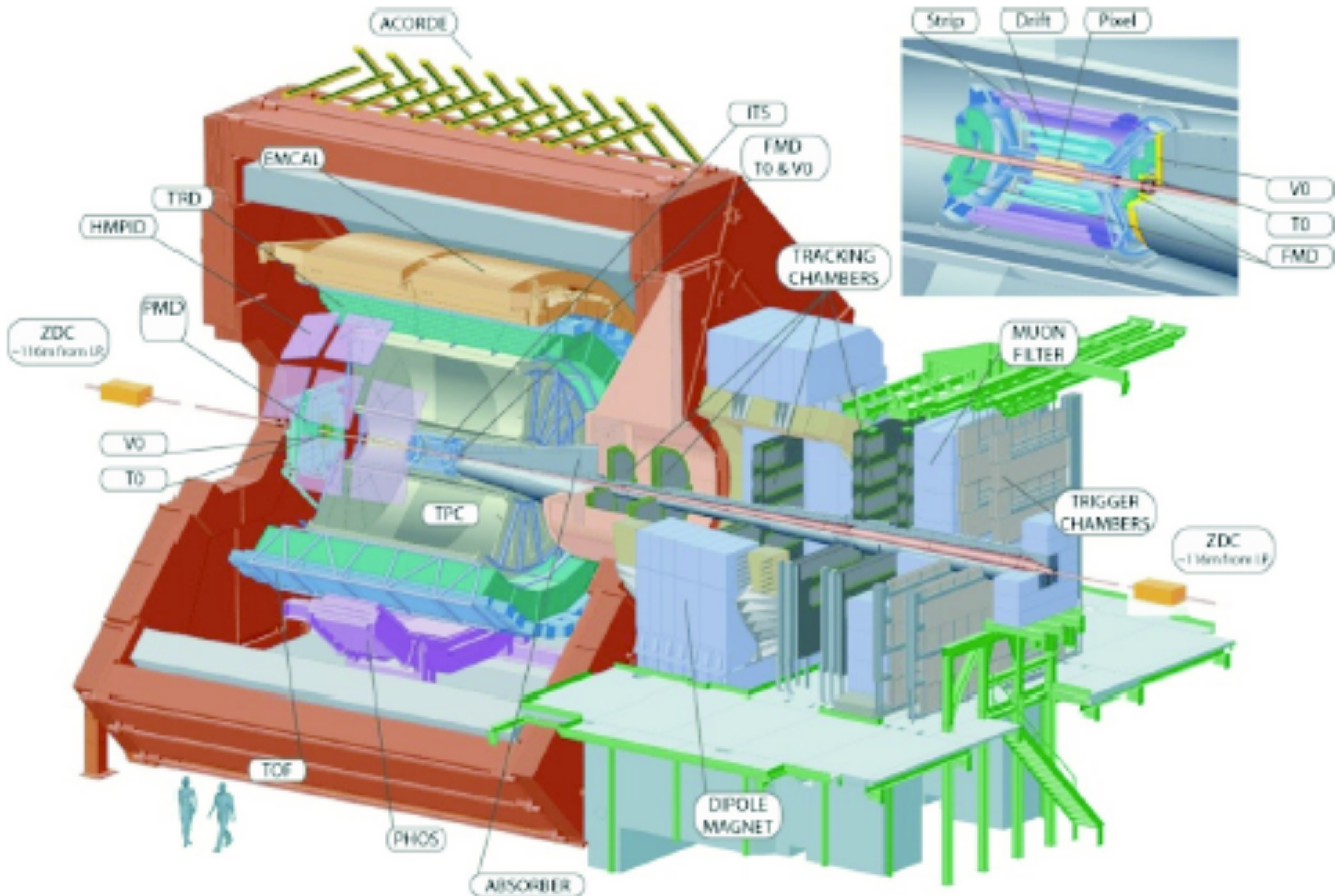
Towards a quantitative characterization of the fundamental "transport" properties of the medium:qhat

→Jets are great tools but there is a long road ahead

The ALICE experiment



How we reconstruct jets in ALICE (only for experts)

Input: a) charged tracks fromt TPC and ITS p_T>0.15 GeV
Low p_T cut-off allows for an unbiased jet reconstruction

b) charged tracks+EMCAL clusters

-Emcal towers (E_T>0.05 GeV) are grouped into clusters.
-Only one local maximum is accepted per cluster
-A minimum energy per cluster is required $E_{cluster}$>0.3 GeV
-Emcal clusters are matched to tracks and the double counting due to charged particle shower energy is removed.

Jets are reconstructed using antik_T using a p_T boosted recombination scheme.

Only jets that are **fully contained in the acceptance are accepted**:

$|\varphi_{jet}|<\varphi_{acceptance}-R$
$|\eta_{jet}|<\eta_{acceptance}-R$

Background contamination is corrected on an event by event basis usign area-based method ***Cacciari et al arXive:0802.1189***

Background fluctuations and detector effects (tracking efficiency main contribution to JES,5%) are corrected via unfolding

The dependence on the jet R

δp_T measures the difference between the measured jet p_T and the original parton p_T

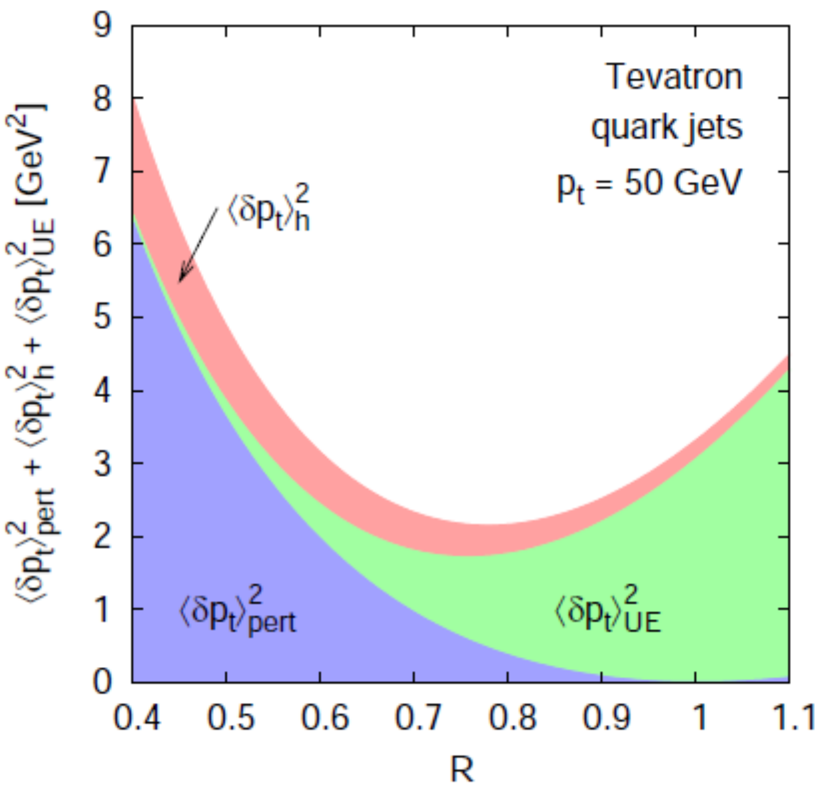
$$< \delta p_T > = < \delta p_T^H > + < \delta p_T^P > + < \delta p_T^{UE} >$$

Har radiation, UE and hadronization splash out

$$< \delta p_T^P > \approx \log R + \mathcal{O}(1)$$

$$< \delta p_T^{UE} > \approx R^2 + \mathcal{O}(R^4)$$

$$< \delta p_T^H > \approx -\frac{1}{R} + \mathcal{O}(R)$$



Note that the UE (*underlying event:energy in the pp event which is not correlated with the hard scattering*) enters as ~R^2
In heavy ions, this constraints us to low-moderate jet R~0.4
In pp, no limit (except for acceptance) on maximum R.

Combinatorial background and unfolding

The unfolding is a **linear** method that **conserves** total number of jets.

If in your measured sample at a certain jet p_T you have large contribution from **fake jets** (soft particles clusterd by the algorithm, uncurrelated with hard processes) and they enter the unfolding,
then the **unfolded solution will be wrong.**

I HIC we are interested on looking to low energy jets, which are expected to be modified more by the medium, and we are interested on large R to explore energy redistirbution at large angles.

-the unfolding of the inclusive spectrum is limited in min p_T and R

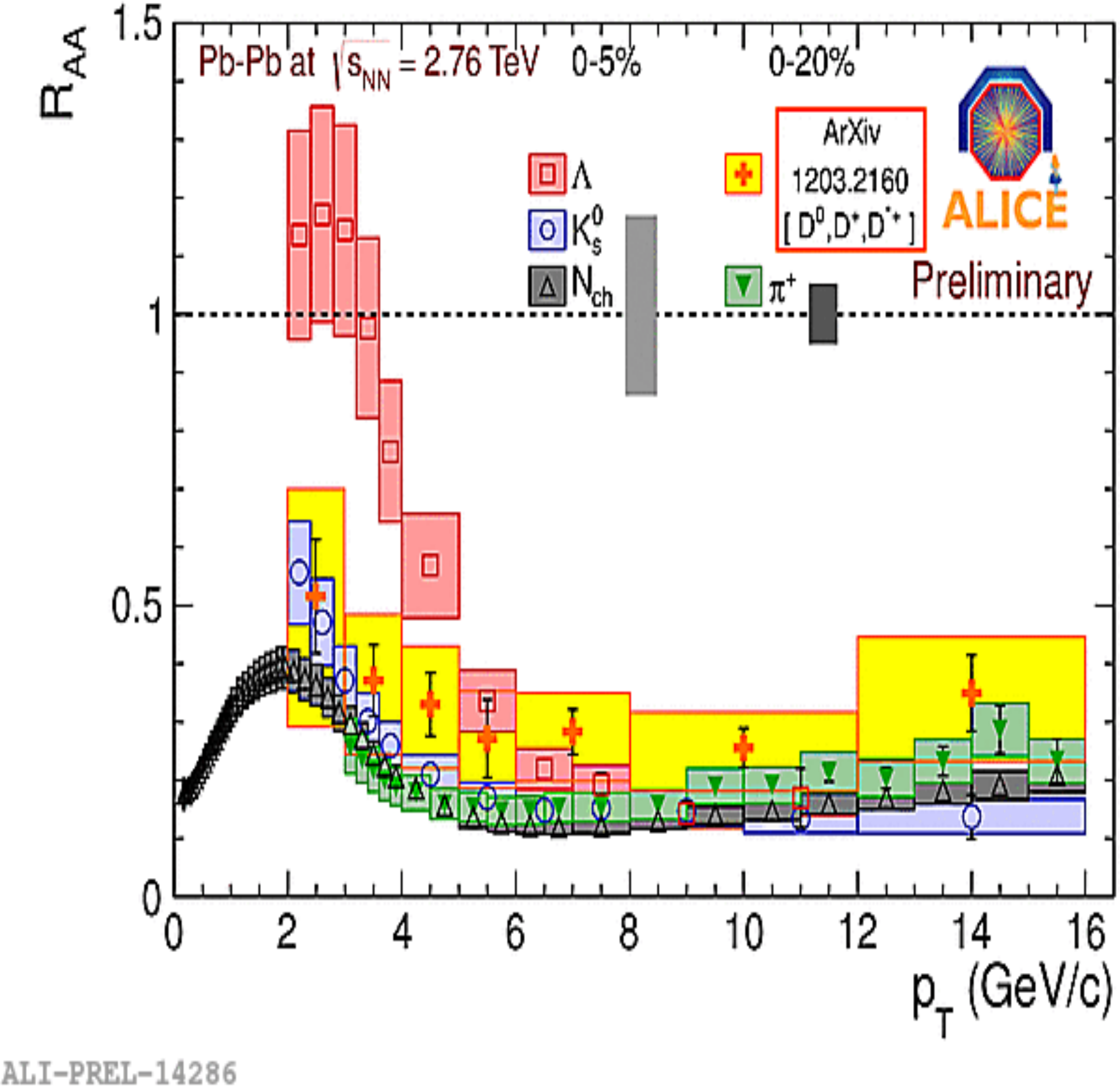
Different approaches to the problem:

-Introduce biases: require a leading hadron of more than X GeV
(but this biases your jet fragmentation)

-consider correlation measurements to suppress combinatorial background

-tagging on heavy flavour jets?

PID RAA



Dead cone effect?

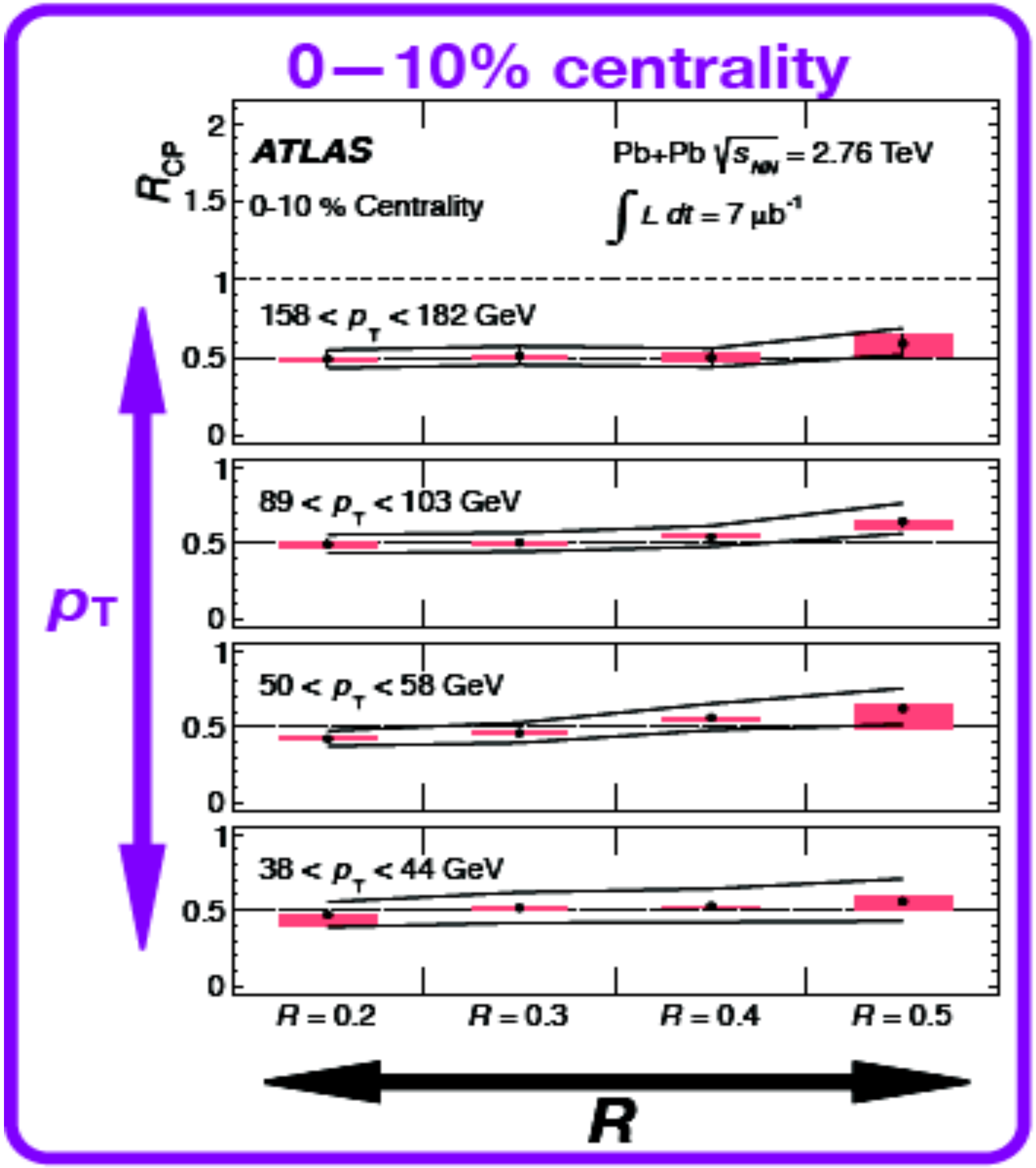
$$\omega \left.\frac{dI}{dw}\right|_{\text{HEAVY}} = \frac{\omega \left.\frac{dI}{dw}\right|_{\text{LIGHT}}}{\left(1+\left(\frac{m_Q}{E_Q}\right)^2 \frac{1}{\theta^2}\right)^2}$$

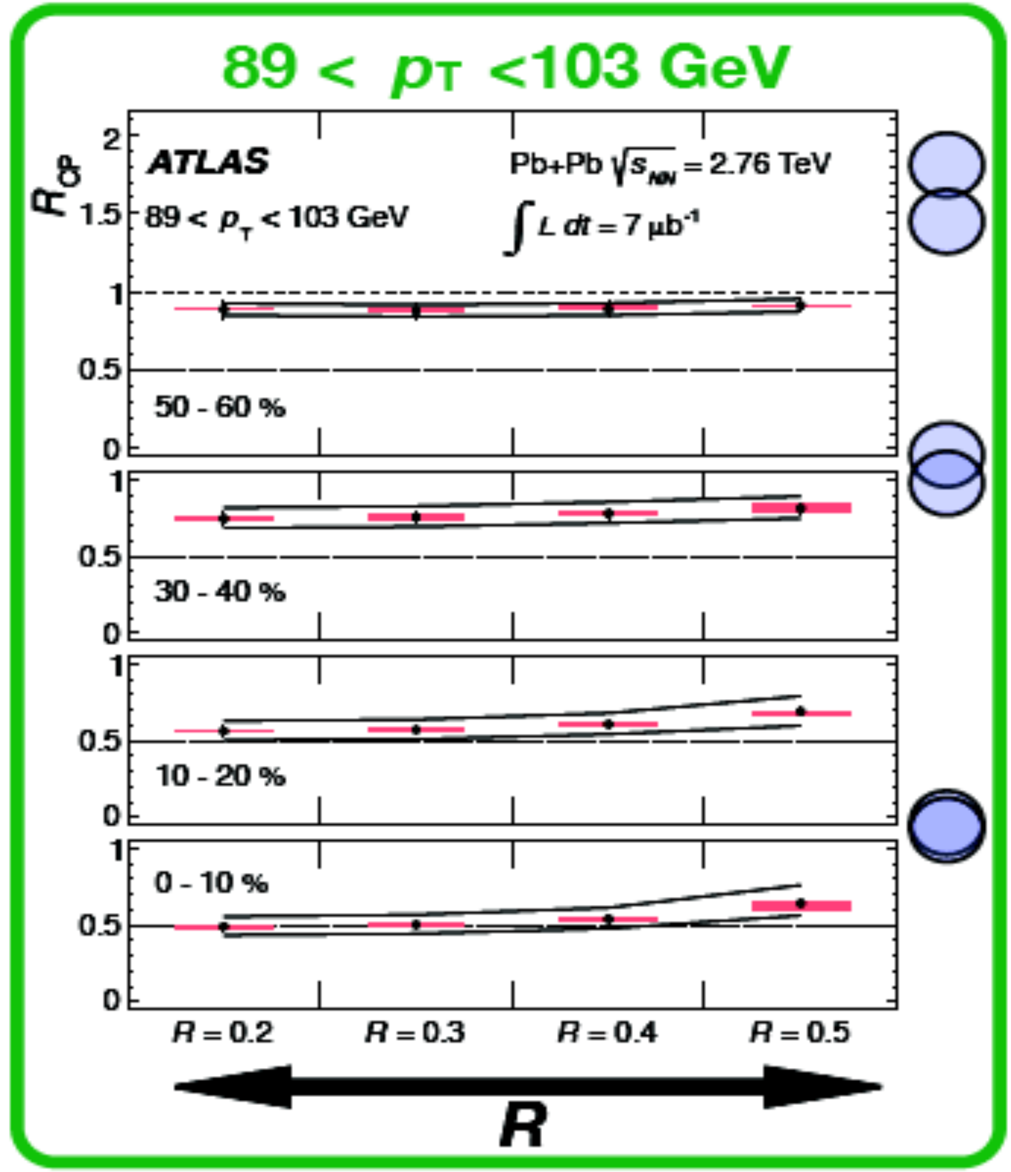
Implies lower heavy quark energy loss in matter

Dokshitzer PLB (2001) 519 199

Similar suppression at high p_T for all particle species, including charm.

ATLAS RCP and R dependence





Some change in the suppression observed at larger R~0.5-->but also large systematics