ALICE - jets and photons

Physics, Physics Performance and EMCal Project Overview and Status

The Physics:

Study the QCD medium in PbPb collisions with hard probes => **jets, γ, γ^* and heavy quarks**

Exploring the Phase Diagram of QCD Matter from SPS via RHIC to LHC

Central collisions	SPS	RHIC	LHC
$\sqrt{s_{NN}}$(TeV)	17	200	5500
dN_{ch}/dy	500	850	2–8 x10^3
ε (GeV/fm^3)	2.5	4–5	15–40
V_f (fm^3)	10^3	7x10^3	2x10^4
τ_{QGP} (fm/c)	<1	1.5–4	4–10
τ_0 (fm/c)	~1	~0.5	<0.2

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RHIC => LHC Energy density 3 – 10 times higher

An entirely new region of the phase diagram

ALICE is the dedicated heavy ion experiment at the LHC

Thermodynamics - equilibruim and non-equilibrium aspects
Hydrodynamics - Flow
Quark chemistry (u,d,s,c,b) flavor dynamics
Meson/Baryon Dynamics
Quarkonium - Plasma color screening

↓

Jets photons, W, Z

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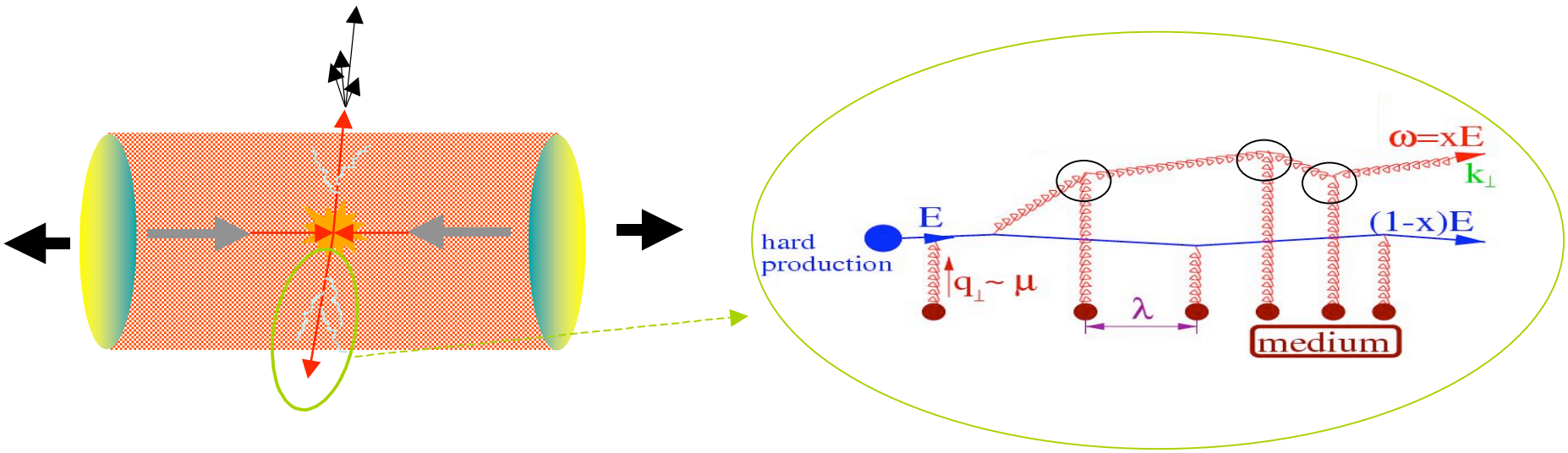
Focus of today's talk
Tomographic studies with high P_T partons

Partonic energy loss in a colored medium

Bjorken '82: jets lose energy in matter (initial idea: elastic scattering)

Main mechanism (?): medium-induced bremsstrahlung



Energy loss ΔE directly sensitive to density of the medium at the initial, hottest phase of the collision

Radiative energy loss

Medium characterized by transport coefficient:

$$\hat{q} \equiv \frac{\mu^2}{\lambda}$$

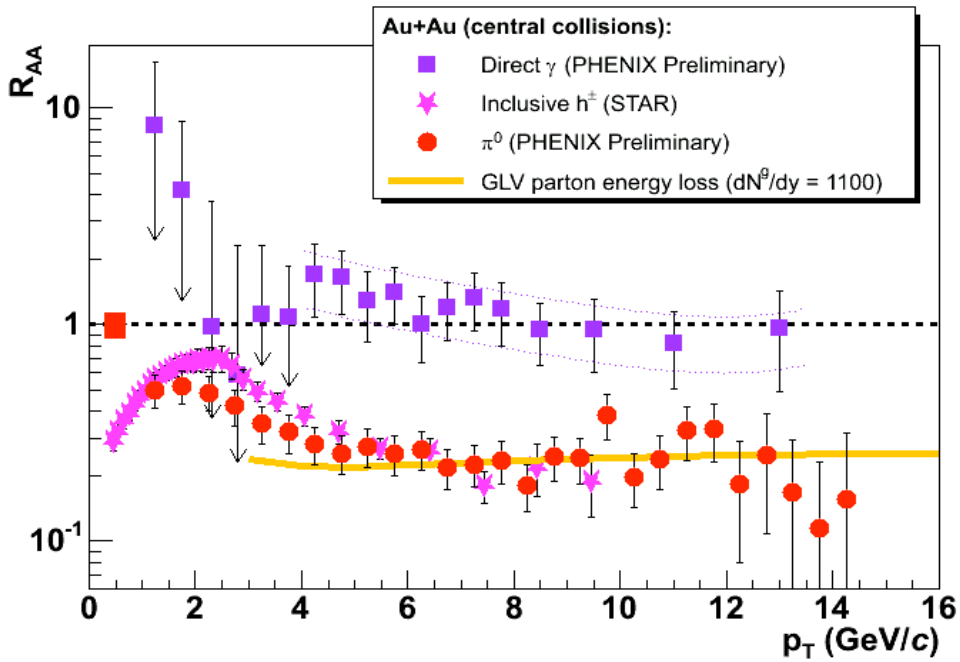
μ=typical momentum transfer
λ=gluon mean free path

Total energy loss:

$$\Delta E_{med} \sim \alpha_S C_R \hat{q} L^2$$

- $\Delta E \sim L^2$ (path length)
- ΔE linearly dependent on color charge C_R
- ΔE ~independent of partonic energy E

Jet quenching at RHIC…



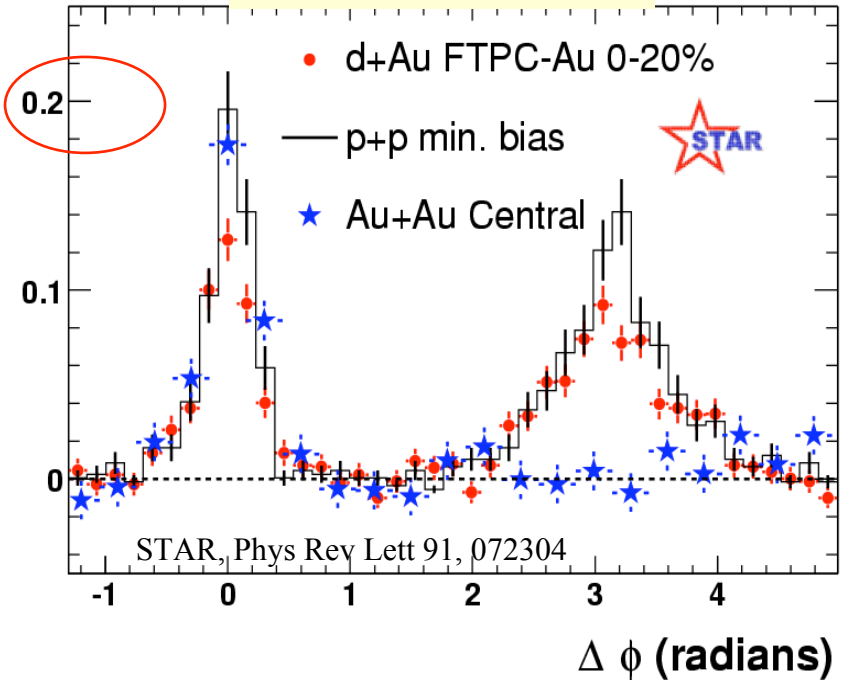
$$R_{AA}(p_t, \eta; b) = \frac{1}{\langle N_{coll}(b) \rangle} \frac{d^2 N_{AB}^{hard} / dp_t d\eta}{d^2 N_{pp}^{hard} / dp_t d\eta},$$

R_{AA} => Strong suppression of high P_T hadrons in AA compared to pp with **no** corresponding suppression of Direct Photons

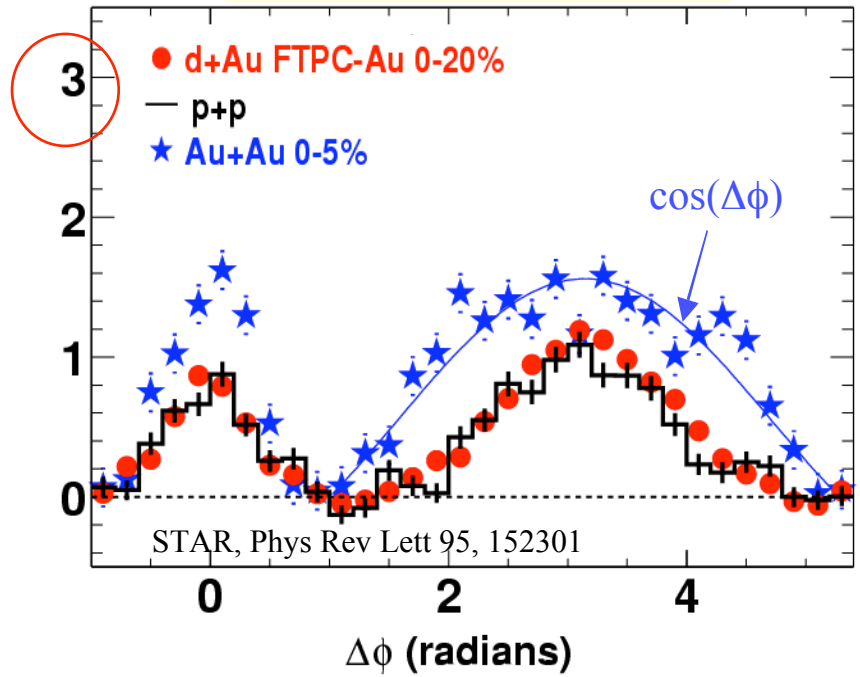
What do we see at RHIC in di-hadron correlations

$4 < p_T^{trig} < 6$ GeV

$p_T^{assoc} > 2$ GeV



$p_T^{assoc} > 0.15$ GeV



High momentum recoil suppressed ⇒ low momentum enhanced

Recoil distribution soft and broad ~ thermalized? angular substructure??

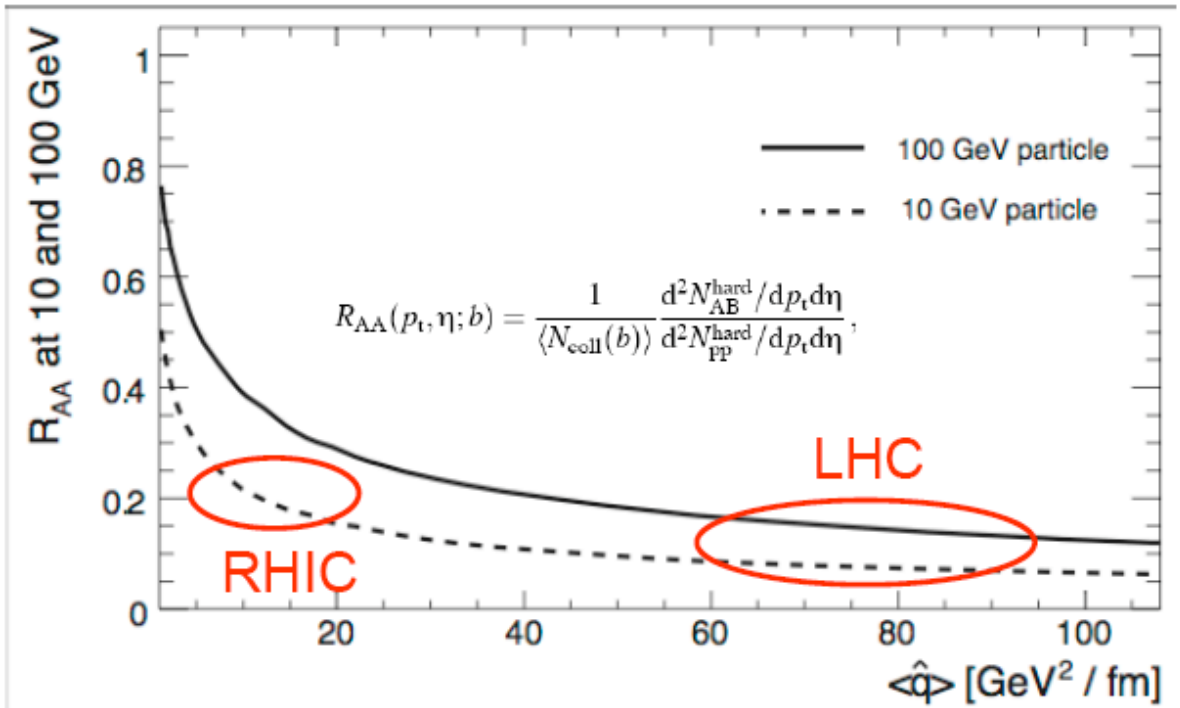
Qualitative picture consistent with jet quenching

Extension of leading particle studies to the LHC?

Initial gluon density at LHC ~ 5-10 x RHIC:

$$\hat{q}_{RHIC} \sim 10\ \mathrm{GeV}^2/\mathrm{fm} \qquad \hat{q}_{LHC} \sim 70\ \mathrm{GeV}^2/\mathrm{fm}$$

R_{AA} at the LHC from the Parton Quenching Model (PQM)



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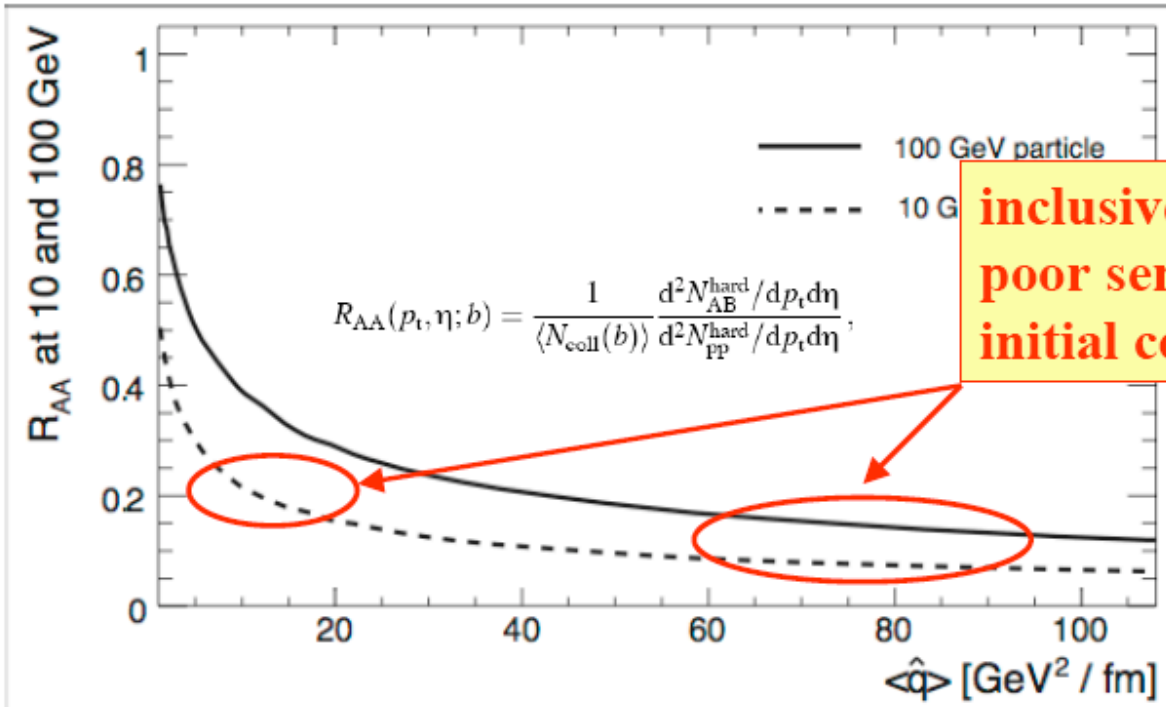


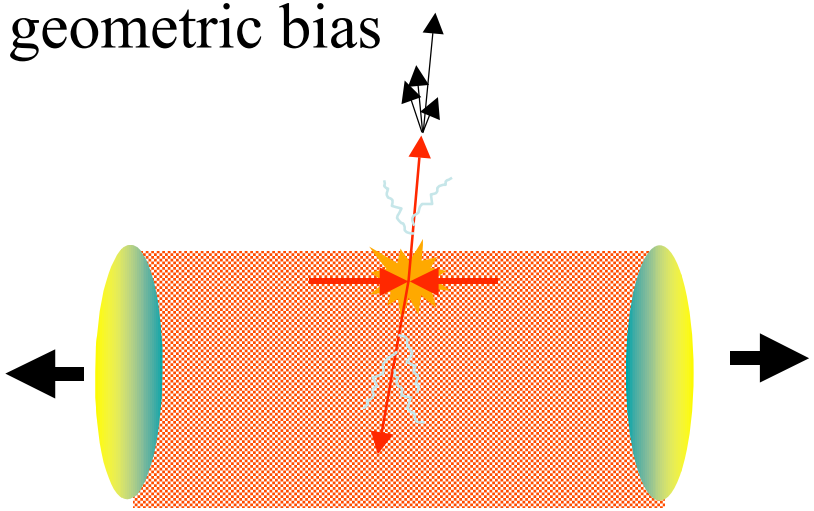
inclusive hadrons have poor sensitivity to initial conditions

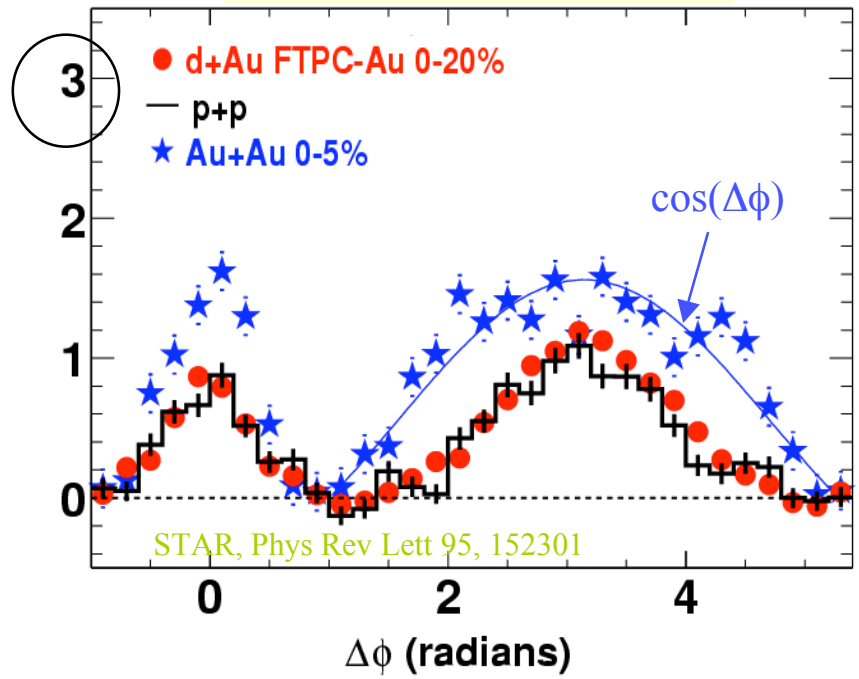
What about sensitivity of di-hadron correlations?

$4 < p_T^{trig} < 6$ GeV

$p_T^{assoc} > 0.15$ GeV

fragmentation and geometric bias





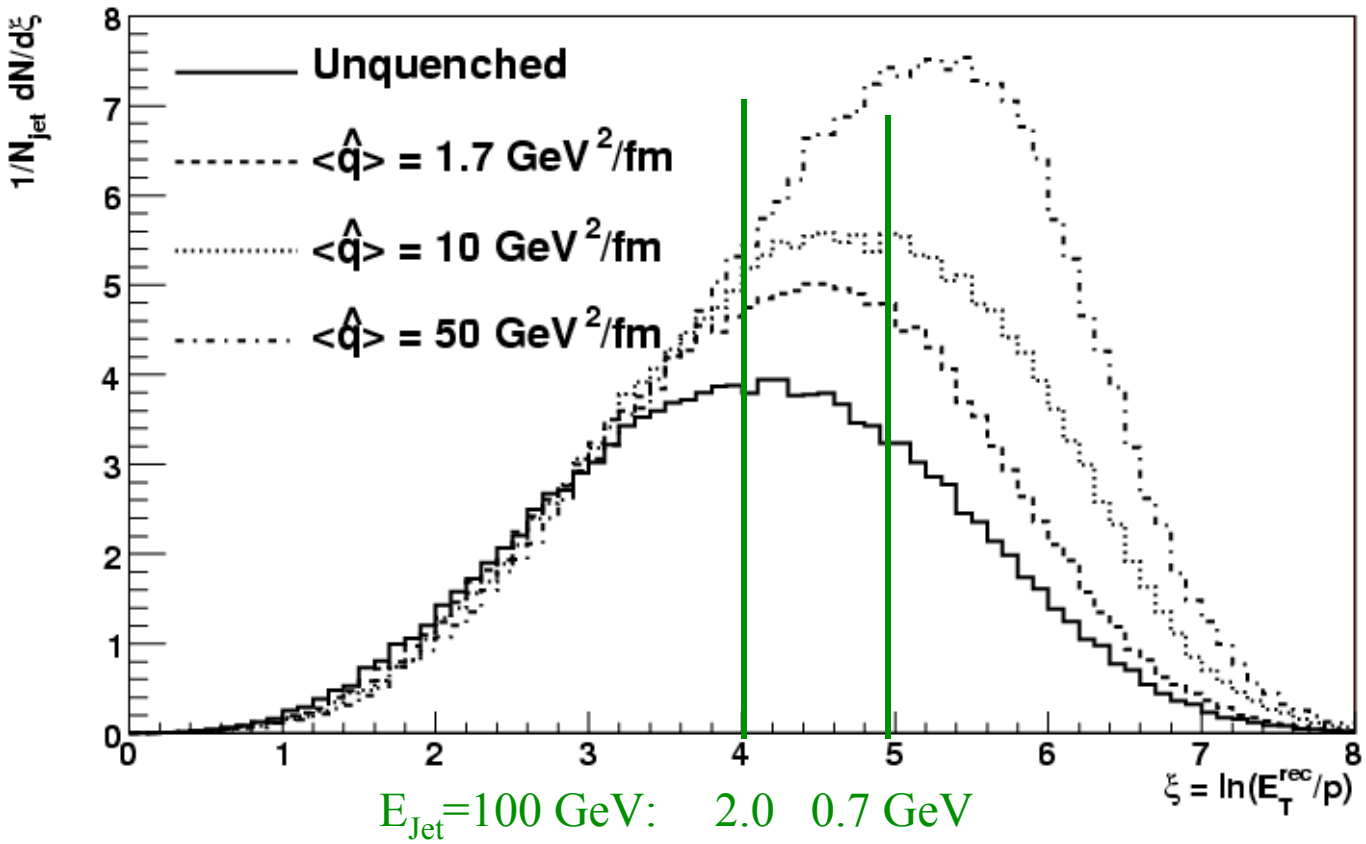
Qualitative picture from RHIC consistent with jet quenching

But strong trigger bias -
Leading hadrons bias against what you want to measure

Full Fragmentation Function

Sensitivity to medium properties

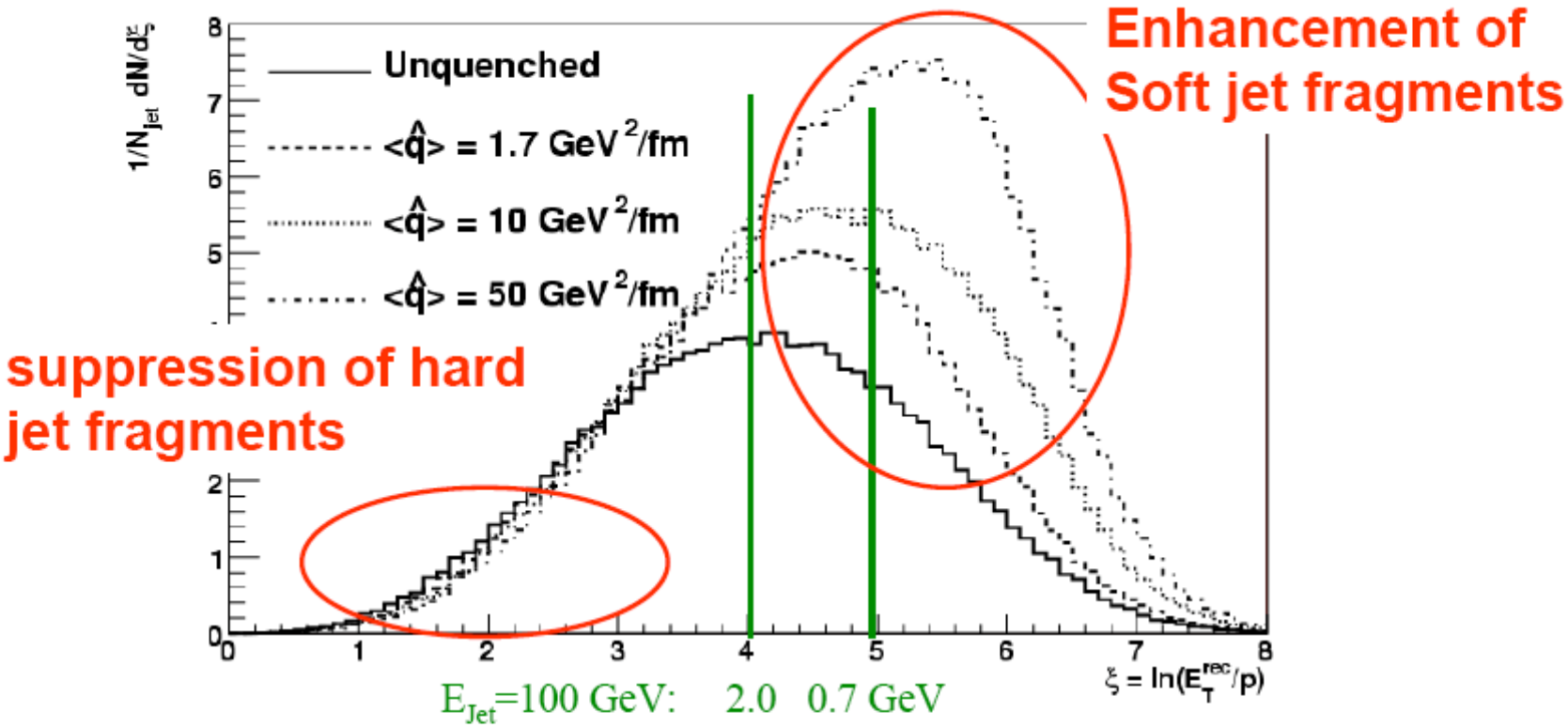
Model: MLLA + Medium, Borghini, Wiedemann



- Measurements at p_T~1 GeV are crucial

Full Fragmentation Function

Sensitivity to medium properties

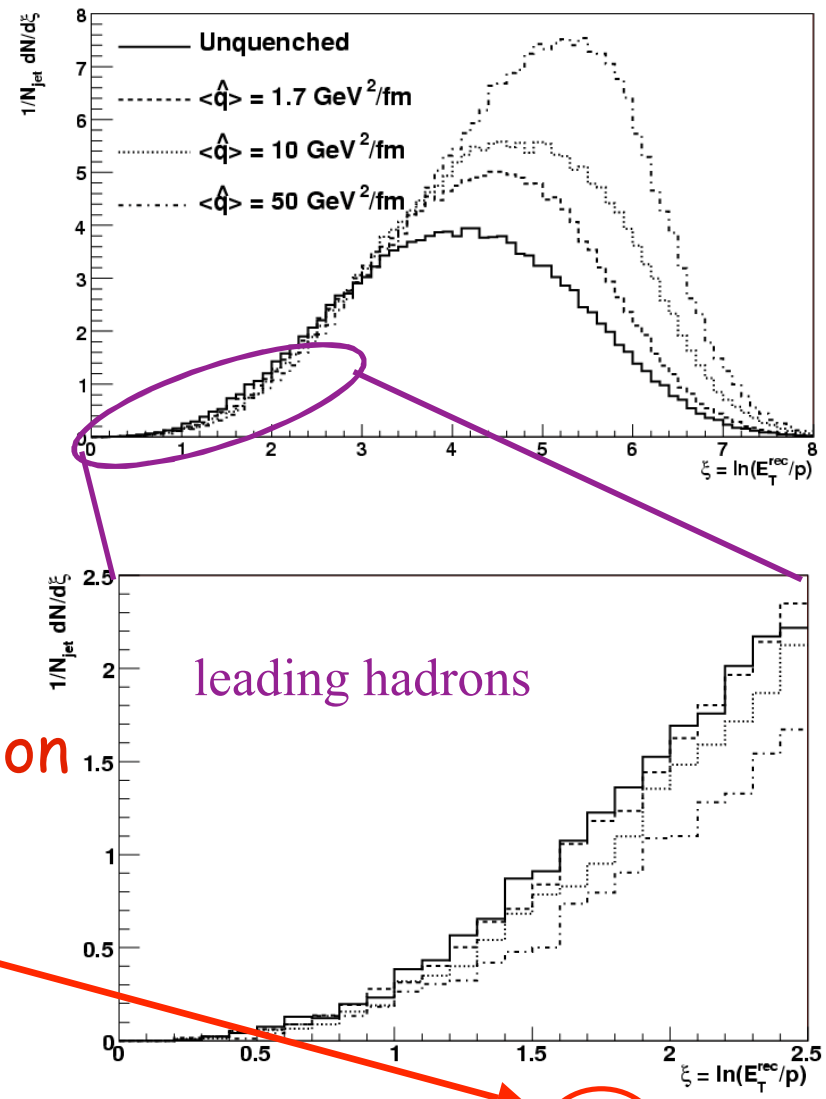


- Measurements at p_T~1 GeV are crucial

Jet reconstruction

Full characterization of fragmentation function and its modifications:

- enhancement at low p_T
- suppression at high p_T

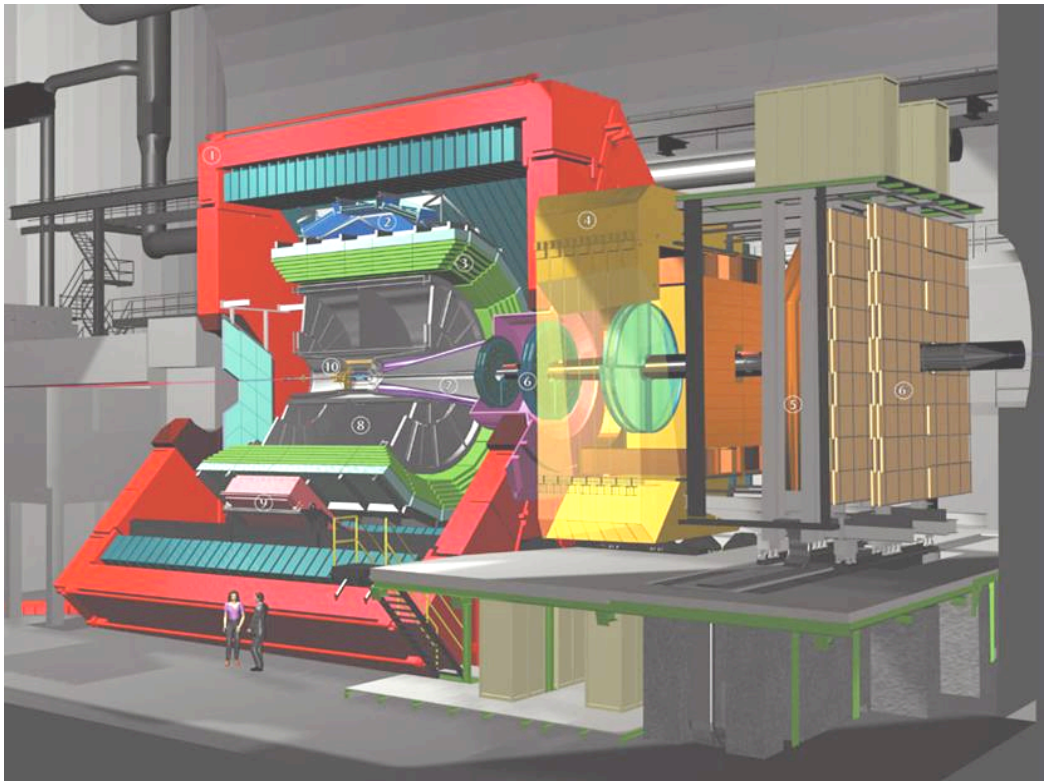


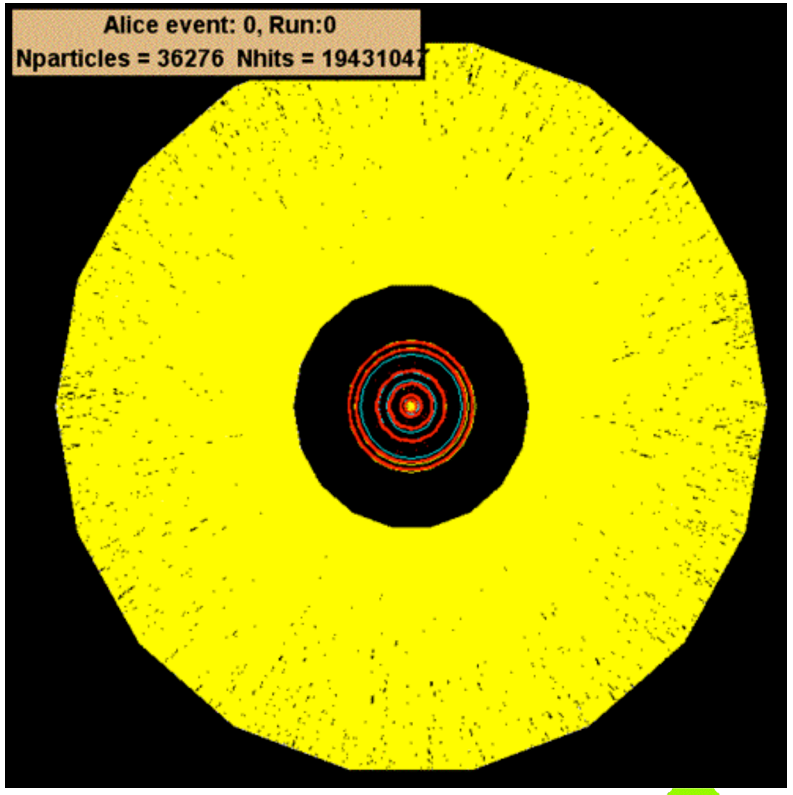
Obviously requires jet reconstruction

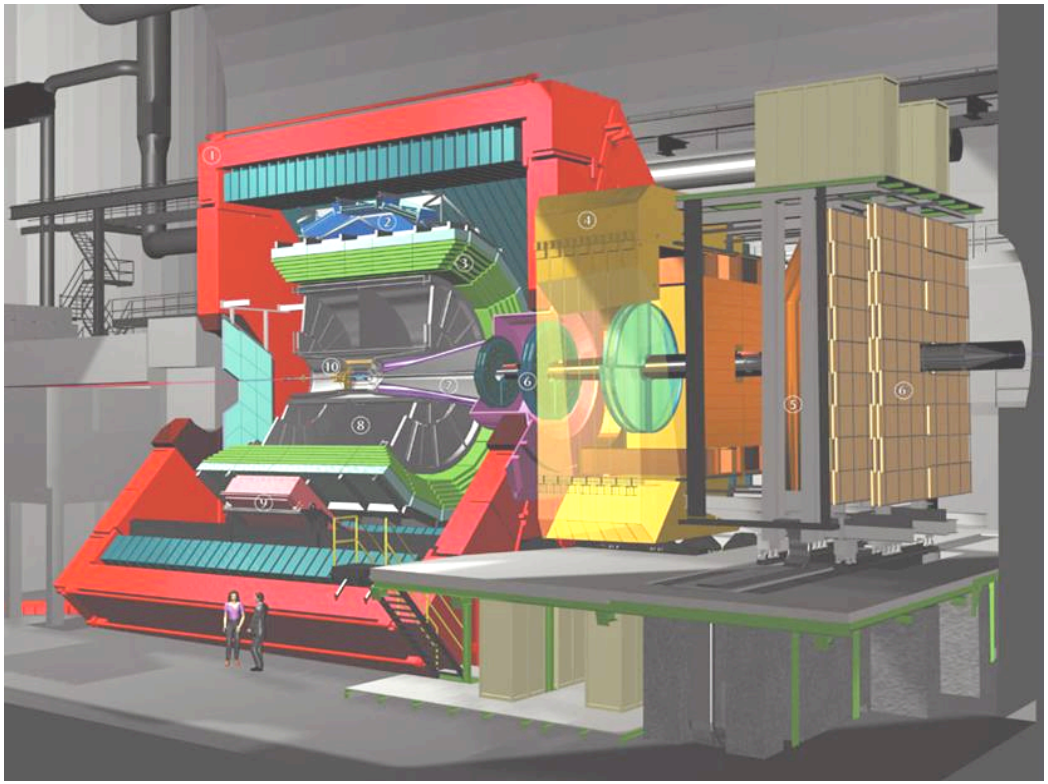
$$\xi = \ln\left(E_T^{Jet} / p^{hadron}\right)$$

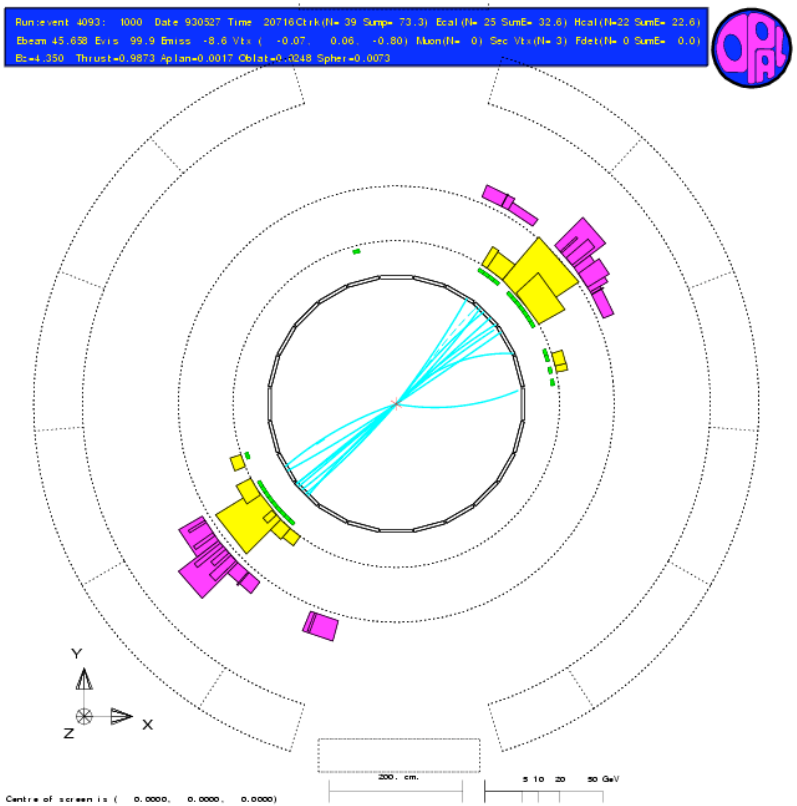
Physics Performance:

Probing QCD matter with jets in PbPb…





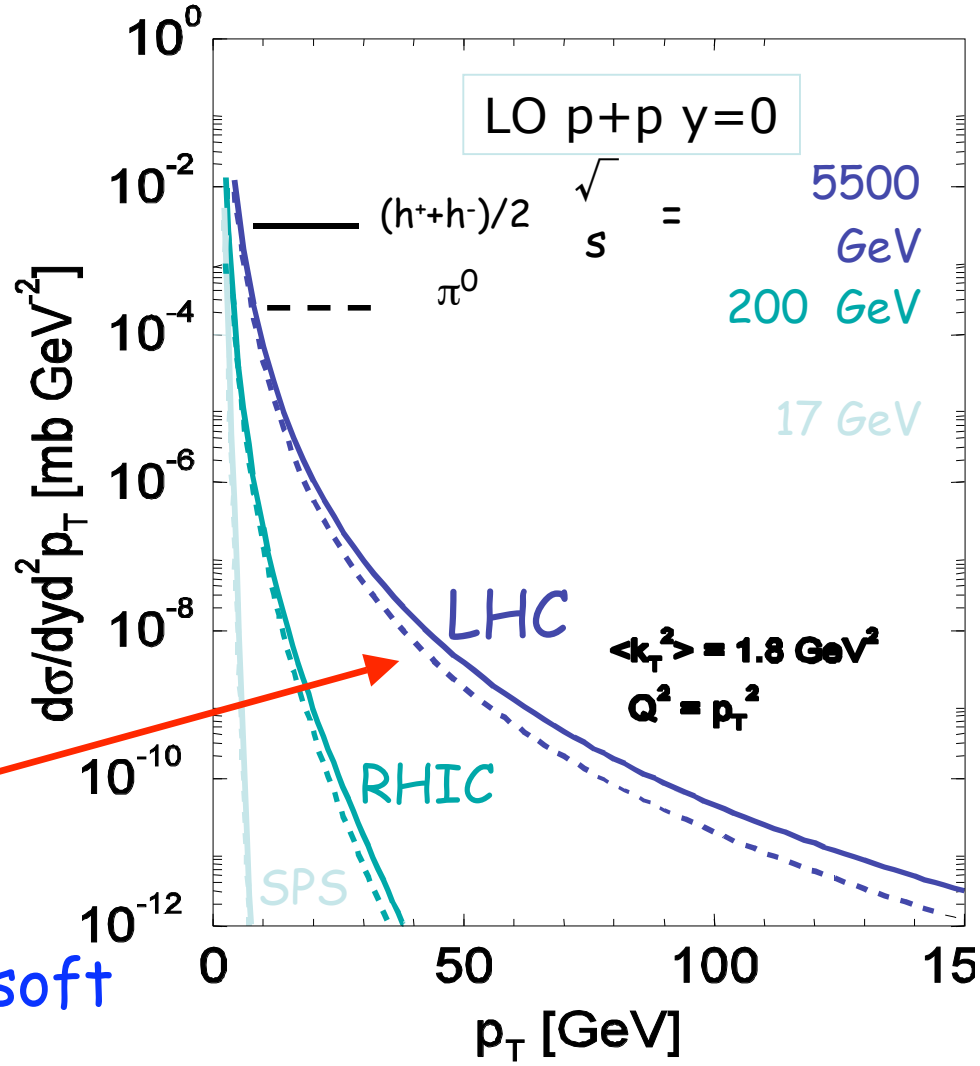



Y
X
Z
200. cm.
5 10 20 50 GeV

Jets From RHIC to the LHC…

Heavy ions at LHC:

- huge increase in yield of hard probes - many orders of magnitude at interesting P_T
- ~Logarithmic increase in the soft background



What is necessary dynamic range?

Criteria: study jet quenching over P_T range that spans from strong modification of fragmentation (low jet P_T) to negligible modification of fragmentation (high jet P_T)

$$\left.\frac{dN_g}{d\eta}\right|_{LHC} \approx (5-10)\times \left.\frac{dN_g}{d\eta}\right|_{RHIC} \Rightarrow \quad \hat{q}_{LHC} \approx 7\times \hat{q}_{RHIC}$$

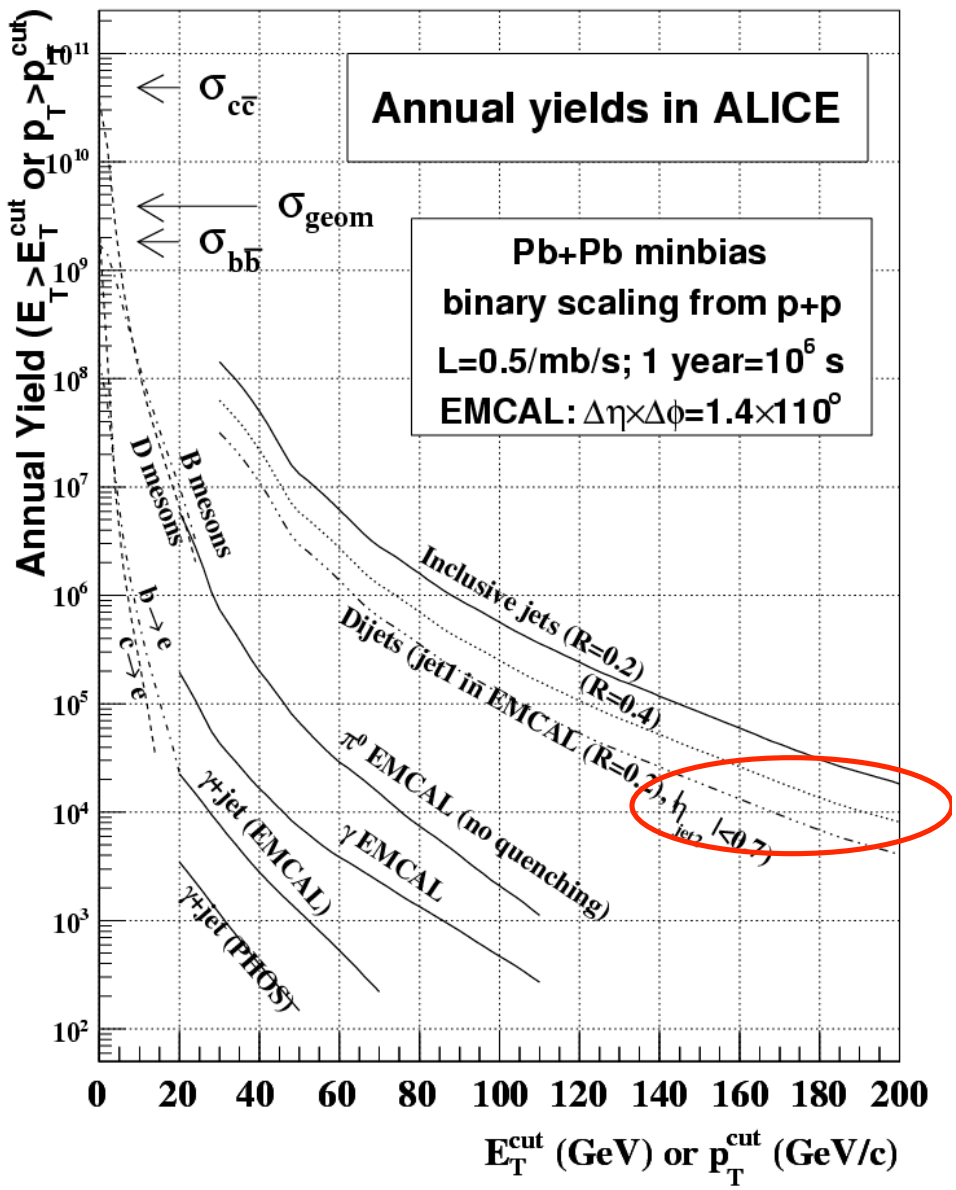
$$\Delta E_{RHIC} \sim \text{few GeV} \Rightarrow \Delta E_{LHC} \sim 35-50\ \text{GeV}$$

$\Rightarrow$ small modification to fragmentation for E_{jet}~200 GeV

$\Rightarrow$ measure E dependence of ΔE needs large lever arm

Inclusive jets and Di-Jets

Robust fragmentation function measurements to P_T ~ 200 GeV/c with trigger in the ALICE acceptance

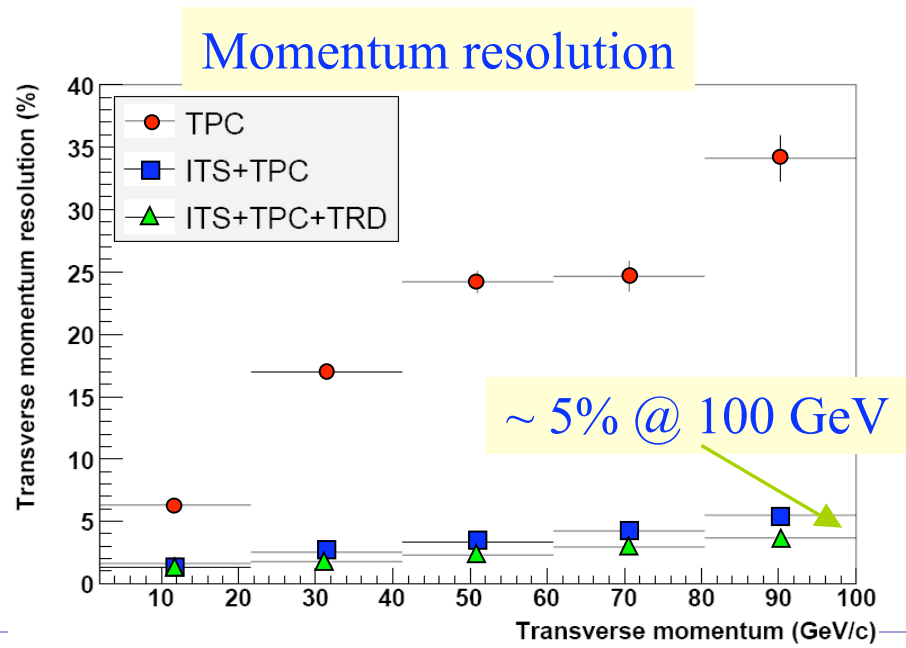


ALICE Tracking

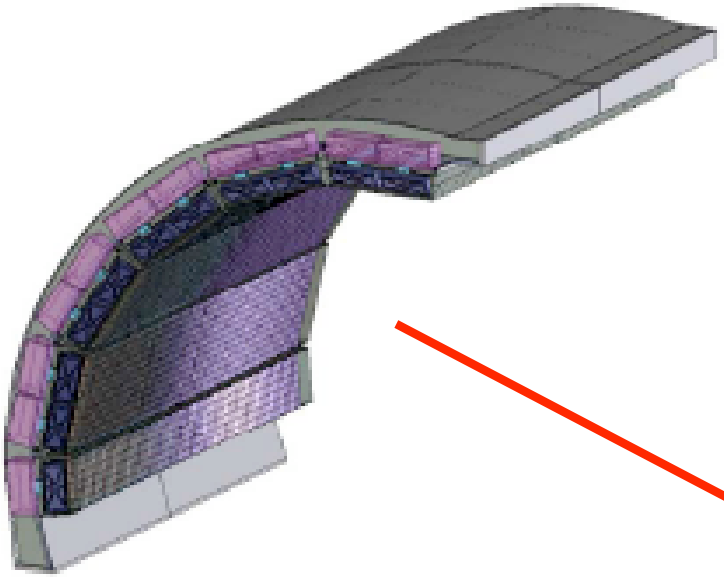
- Silicon Vertex Detector (ITS): 4 cm < r < 44 cm, 6 layers
- Time Projection Chamber (TPC): 85 cm < r < 245 cm, (159 pad rows)
- Transition Radiation Detector (TRD) 290 cm < 370 cm, 6 layers of 3 cm tracklets

- Modest solenoidal field (0.5 T) ⇒ good pattern recognition
- Long lever arm ⇒ good momentum resolution
- Small material budget: vertex→TPC outer field cage < 0.1 X_0

  ⇒ robust, redundant tracking: 100 MeV to 100 GeV



ALICE EMCal

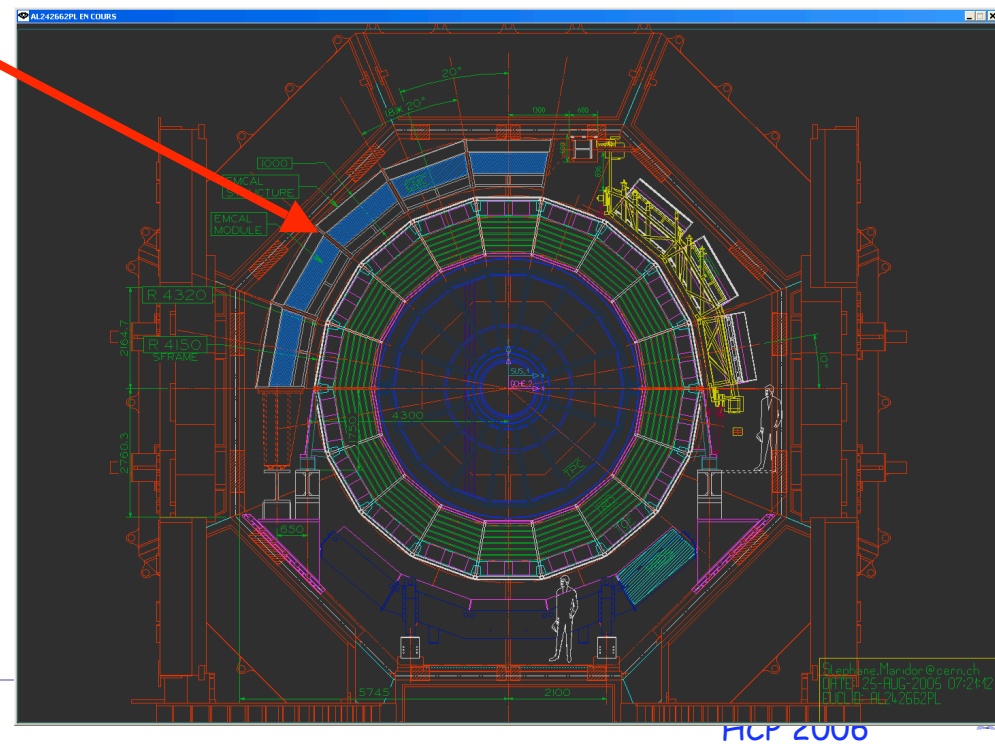


Lead-scintillator sampling calorimeter

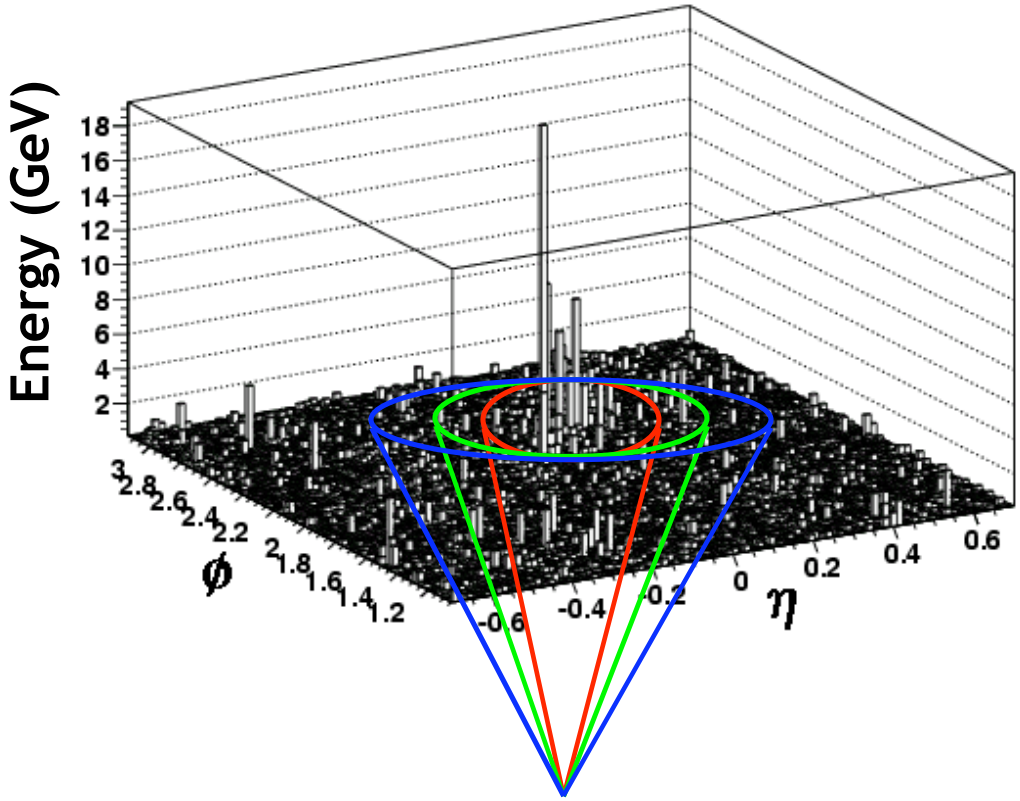
$|\eta|<0.7$, $\Delta\phi=110^{o}$

Shashlik geometry, APD photosensor

~13K towers ($\Delta\eta x\Delta\phi$~0.014x0.014)



Jet Reconstruction event by event…



Combined information from TPC/EMCal

with track-by-track P_T cut

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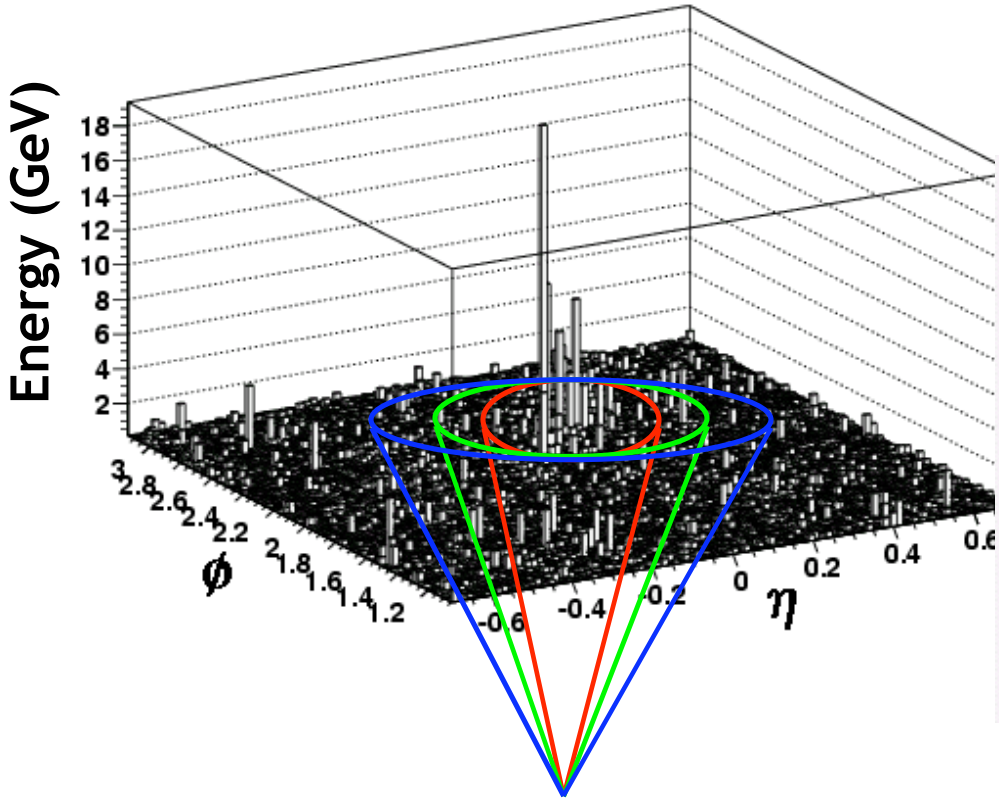
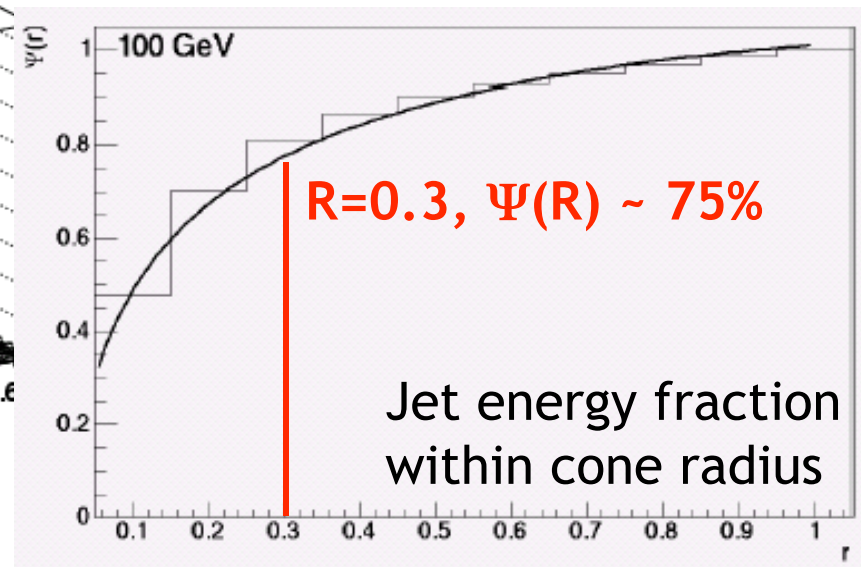
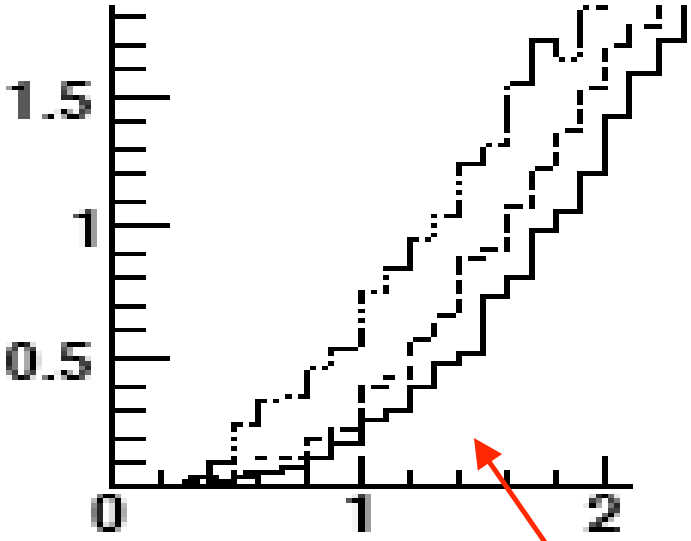




$$R = \sqrt{\eta^2+\phi^2}$$

Underlying Event Dictates Small Jet Reconstruction Cone => Resolution

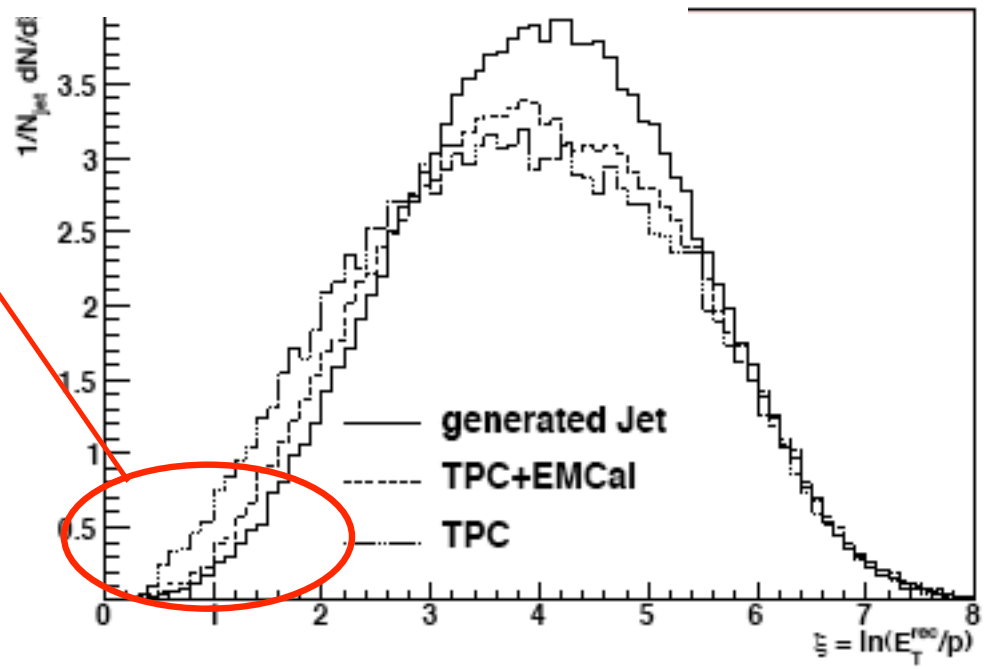


~1.0 ~0.35

$z = p/E_{jet}$

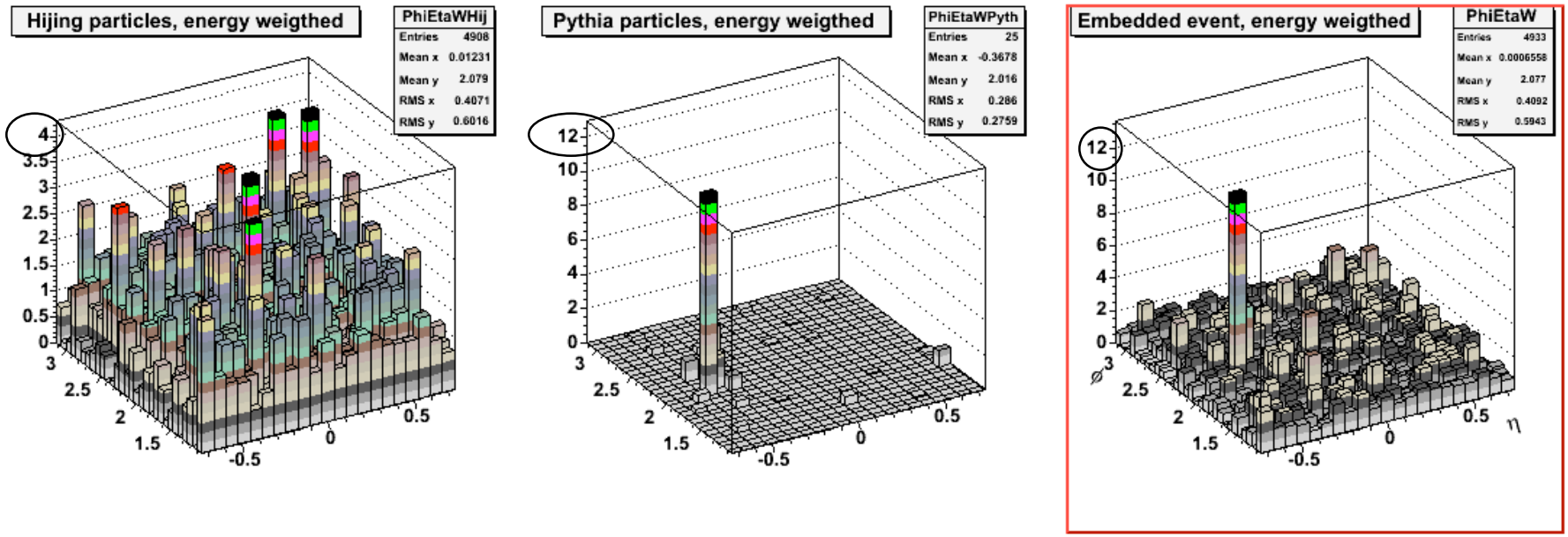
Jet Reconstruction with EMCal+TPC:

Impact on measured fragmentation functions



Jet trigger in heavy ion collisions

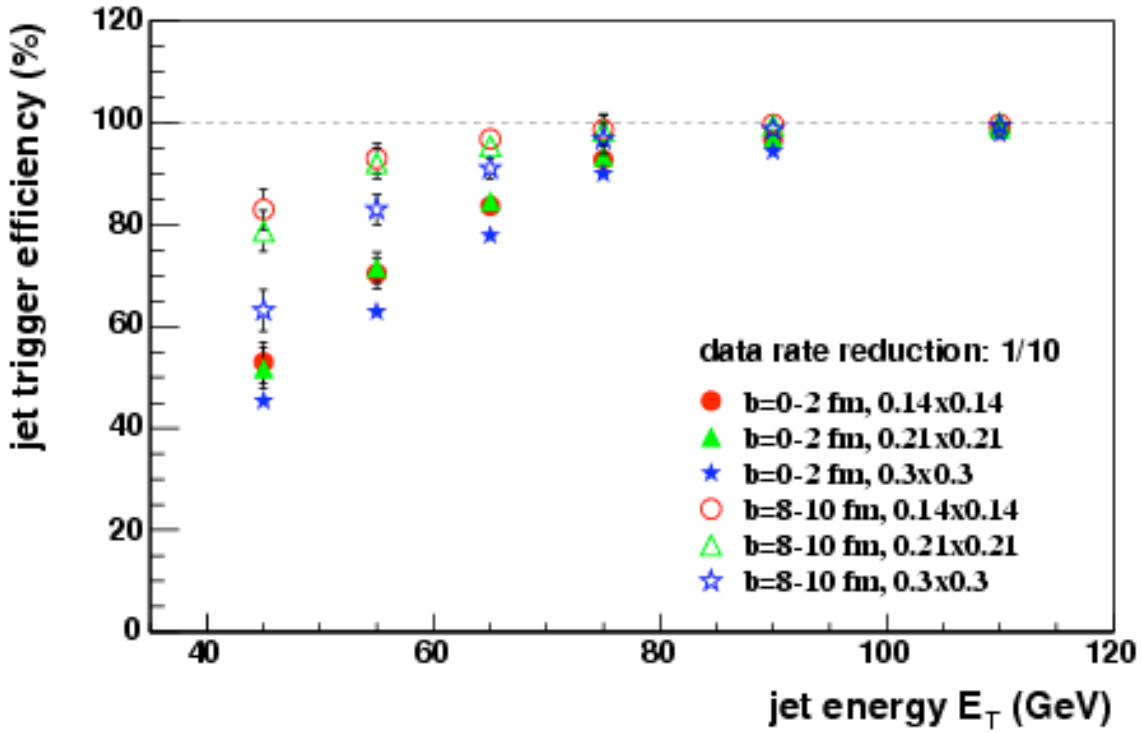
50 GeV jet with background from central Pb+Pb



Jet structure clearly visible but rate is low:
⇒ need to trigger efficiently

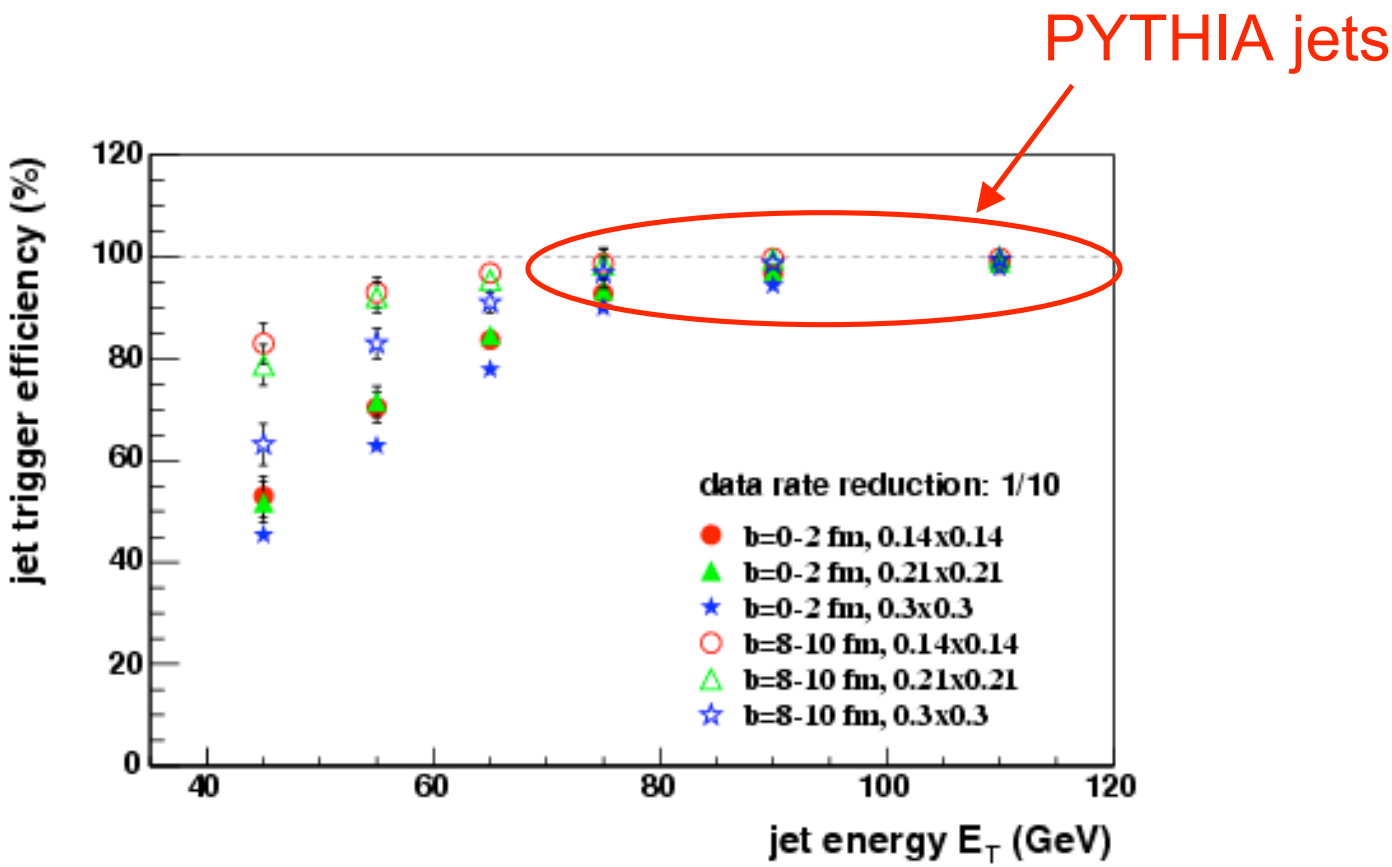
Trigger efficiency / Trigger Bias

Background rejection set to factor 10 => HLT
Centrality dependent threshold

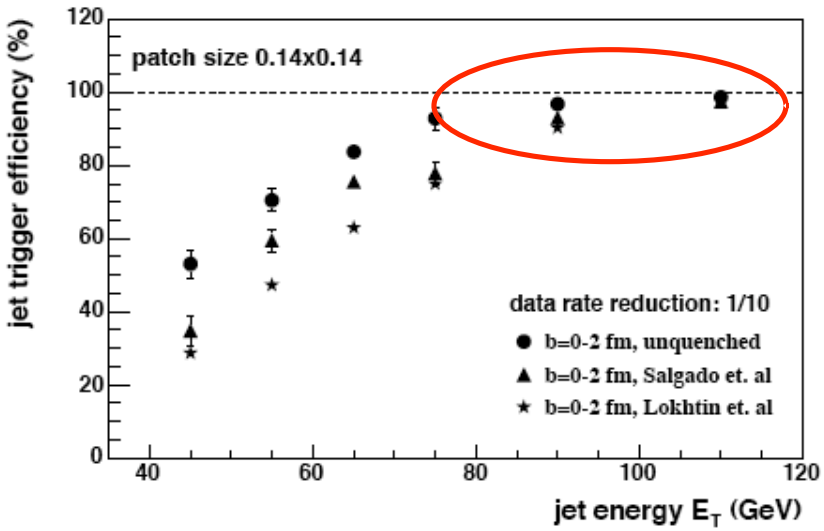


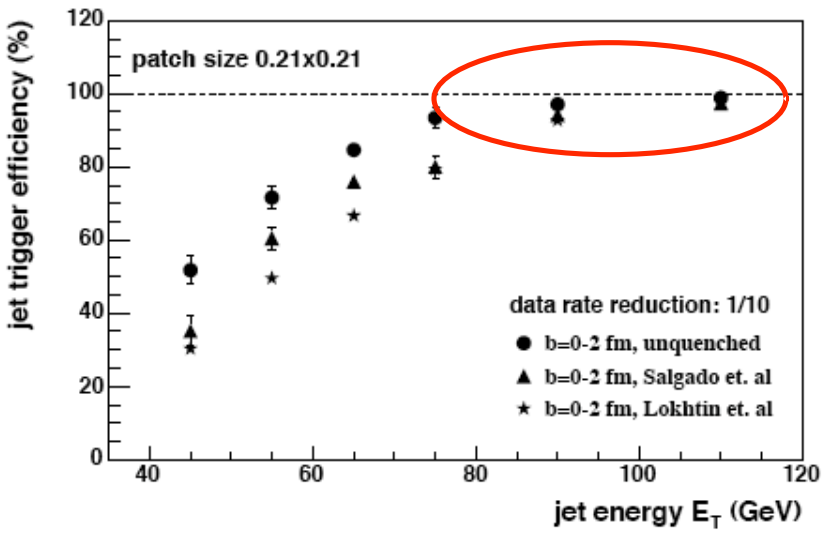
- good efficiency above ~50 GeV
- 0.3 x 0.3 larger than optimal for PYTHIA+HIJING

Trigger efficiency / Trigger Bias



Trigger bias versus physics …..





Very small trigger bias versus quenching physics model.

Trigger efficiency does not depend strongly on the details of fragmentation softening

Other features of the ALICE Jet Program:

- **Event topology** - reaction plane
- particle ID (π/**K/p** to ~ 50 GeV/c)
- Hyperons - for meson/baryon
- Open Charm
- b-tagging
- γ + jet

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Heavy Quark dE/dx

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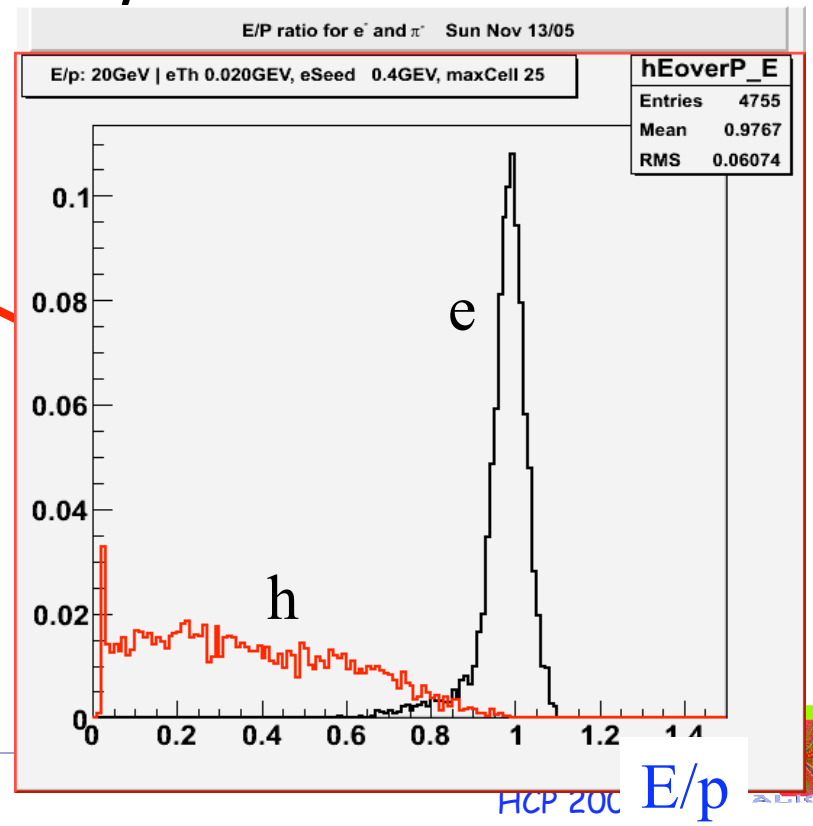

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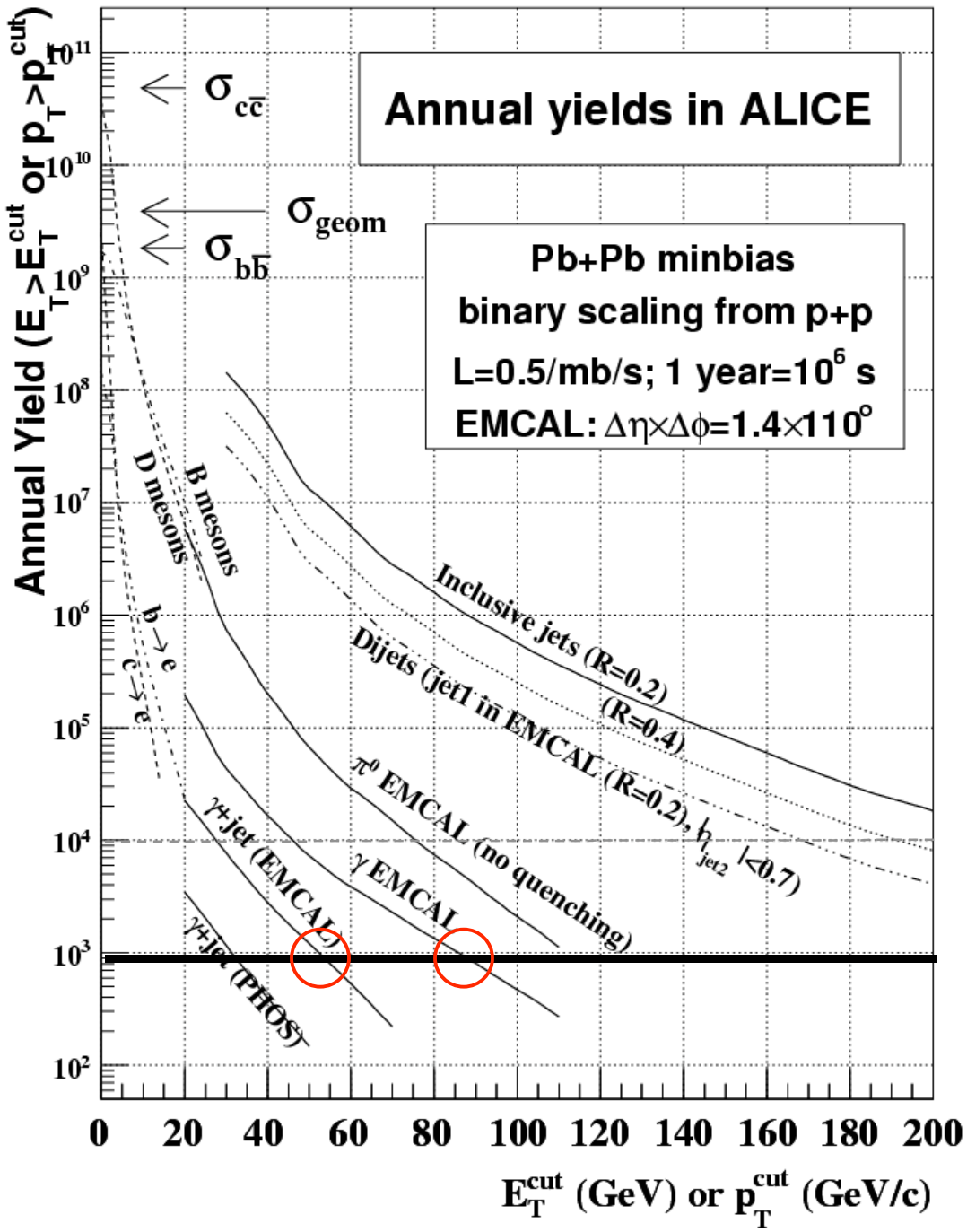
Allows study of light <u>quark</u> energy loss

Inclusive jets study <u>gluon</u> energy loss

Kinematic reach of ALICE+EMCal for direct γ and γ+jet

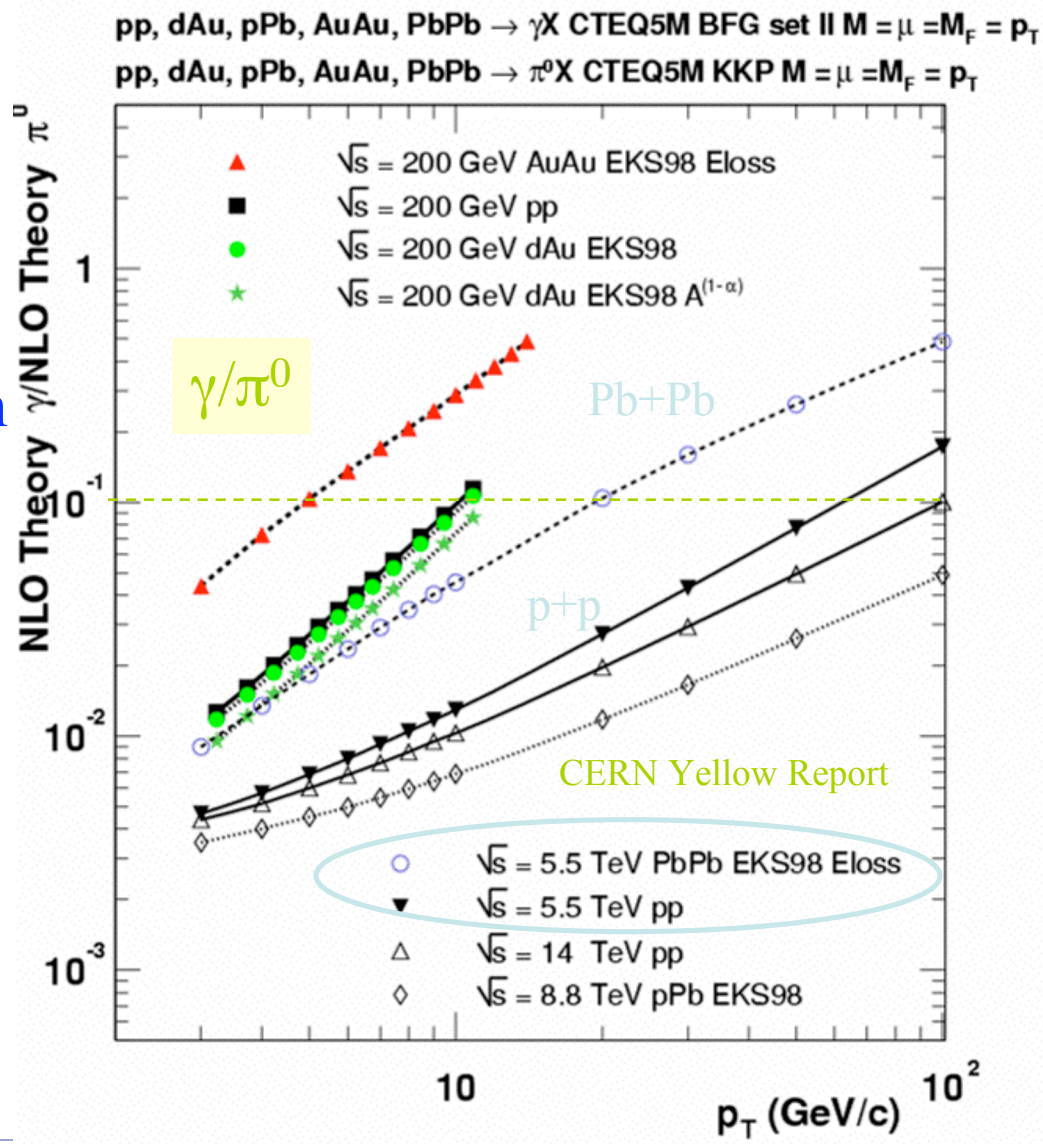


Direct photons at the LHC

Not an easy measurement, however:

- $\gamma/\pi^0 < 0.1$ for p+p (expected to be better in central Pb+Pb due to hadron suppression)

- QCD bremsstrahlung photons significant for p_T<50 GeV/c
  ⇒ isolation cuts in heavy ion collisions?



Conclusions

ALICE is preparing study QCD matter in the new regime of temperature and density produced at the LHC with reconstructed jets and the full power of the ALICE central detector.

To be continued …..

ALICE+EMcal in the larger LHC context

- main fragmentation modifications are at p_T<~few GeV even for the highest energy jets
- interaction with medium is per definition soft physics
- hadronization effects may be a central issue ⇒ particle ID
- 200 GeV jets exhausts the physics

ALICE+EMCal effectively trade acceptance/rate in favor of robust tracking and PID over a broad kinematic range

There are significant measurements that ALICE+EMcal cannot do:
3-jet events, forward rapidity, Z+jet,…

Conclusions

To be continued …..

Extra Slides:

Full Project Scope:

11 Effective Super Modules

Preliminary Planning

~ 3 **France + Italy**

~ 8 **USA**

France (Grenoble, Nantes, Strassbourg)

Italy (Catania, Frascati)

Switzerland (CERN)

USA (University of California Davis, University of California Los Angeles, Creighton University, University of Houston, Kent State University, Lawrence Berkley National Laboratory, Lawrence Livermore National Laboratory, Michigan State University, Oak Ridge National Laboratory, Ohio State University, Purdue University, University of Tennessee, University of Texas, Austin, University of Washington, Seattle, Wayne State University, Yale University)

EMCal support rails
average Frenchman
EMCal: 120 tons, 50 m^2
~same area and weight as STAR barrel calorimeter

Physics Driven EMCal schedule

First super module in for **2008 run**

Nov 2007 installation test, commission software/hardware, first physics

Have reasonable acceptance (up to 50%) for **2009 run**

Install Nov 2008

Have complete acceptance for **2010 run**

Install Nov 2009