High pt and Photon Physics with ALICE at LHC

- Motivation
- The ALICE Detector
- Potential Physics Measurement
- Summary

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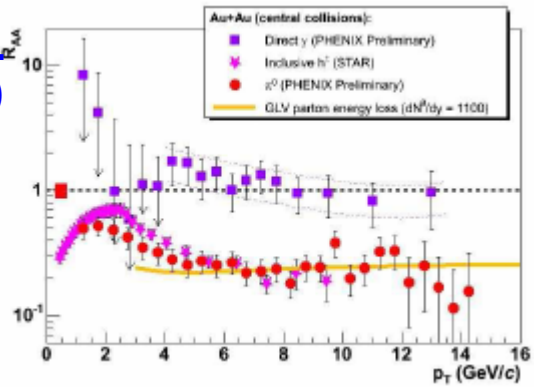
Observations at RHIC

- RHIC data have shown the importance of the high p_T and photon signal to diagnose the properties of matter formed in heavy-ion collisions.
  - Jet quenching first observed through high p_t spectra and correlation distribution suppression

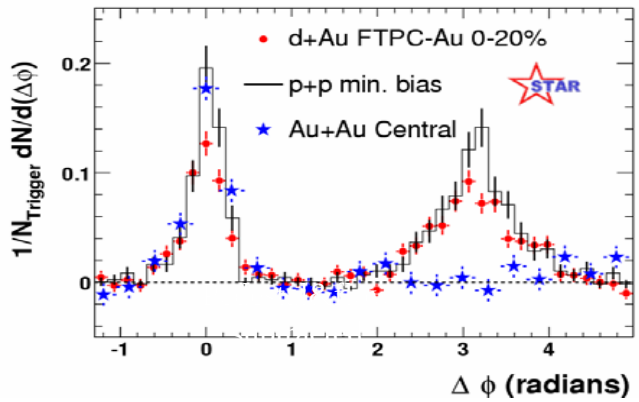
$$R_{AA} = \frac{\frac{dN^{AA}}{dp_t}}{< N_{coll} > \frac{dN^{pp}}{dp_t}}$$

  - The flow reaches the limit of hydrodynamics and scales with the number of constituent quarks
  - The QCD medium formed at RHIC has the properties of a perfect fluid

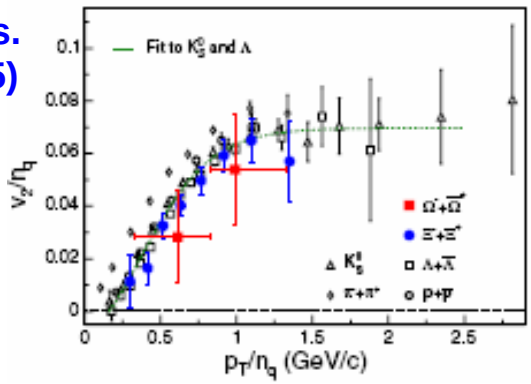
Phys. Rev. Letts. 91, 172302(2003)



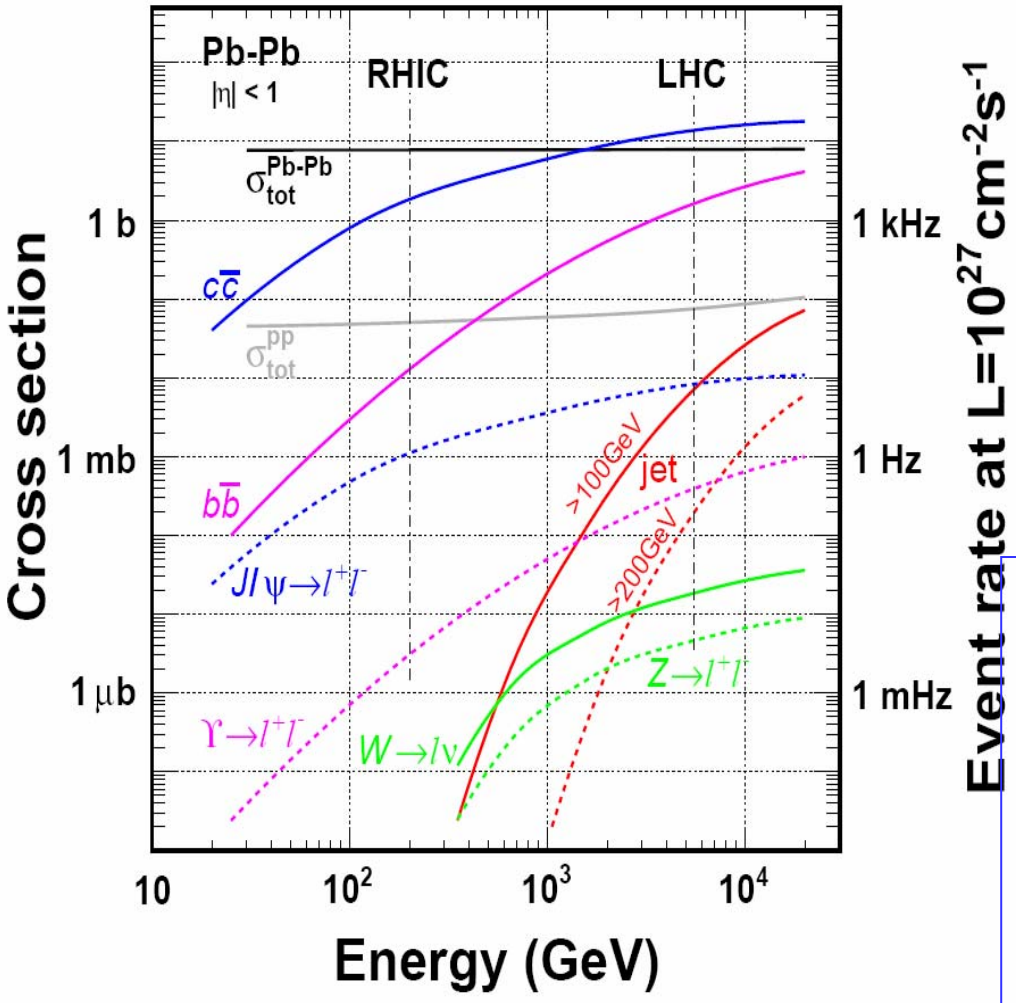
Phys. Rev. Lett. 91. 072304 (2003).



Phys. Rev. Letts. 95, 122301(2005)



LHC: hard process dominant



Hard process:
~ 2% at SPS
~ 50% at RHIC
~ 98% at LHC

Cross sections of interesting probes expected to increase by factors
~ 10 (cc)
~ 10^2 (bb)
~ > 10^5 (very high p_T jets)

Hard probes (p_T» T_{medium}, Λ_{QCD})
Probe the matter formed in HIC
Originates from the initial state
decouples from the medium,
non-equilibrate with the medium

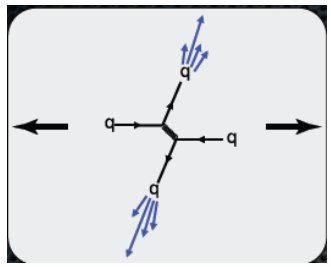
ALICE will be dedicated to the QGP detection at high temperature/density

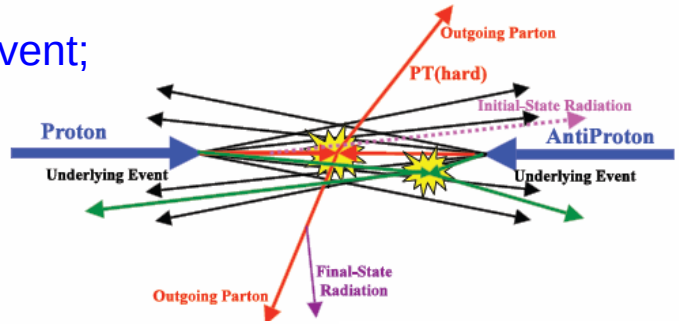
LHC: Jet and high pt yield in p-p

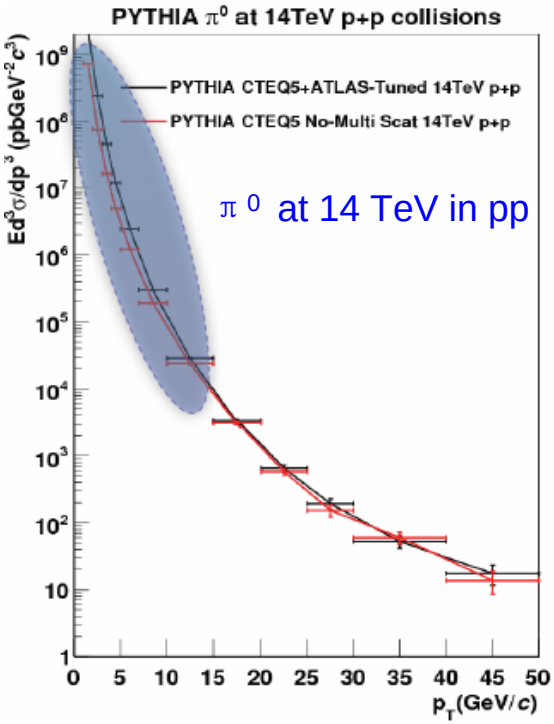
- hard scattering dominates the particle production at LHC

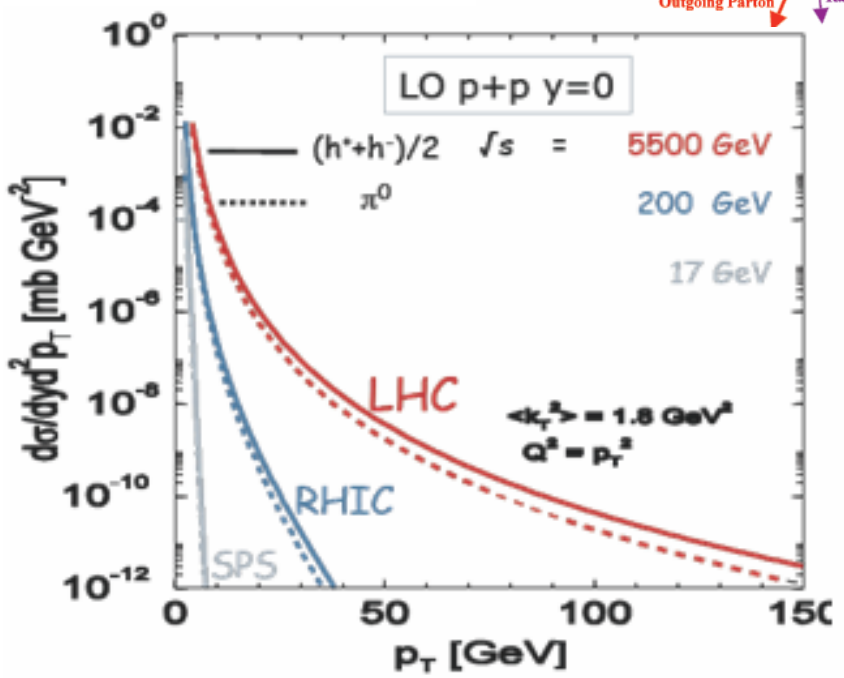
in p-p: inclusive spectra (neutral and Charged), inclusive jet and di-jet to understand and characterize the probe

-> baseline for AA, pQCD scaling test, underlying event; gluon PDF and FF of gluon jets; non pQCD: parton fragmentation, event topology; search for new physics









LHC: Jet and high pt yield in A-A

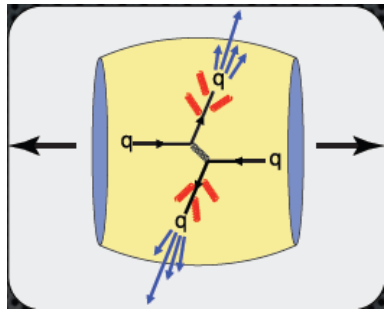
In A-A, medium effect will be significant:

Hard parton undergoes multi-scattering inside the collision region prior to hadronization

Dedicated to the measurement :

inclusive p_T spectraum, particle correlation, inclusive jet, di-jet, …

to explore the entire medium effect

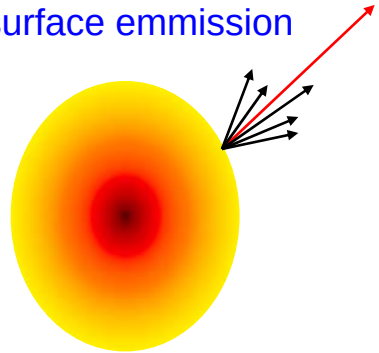


2 20 100 200 p_t (GeV)

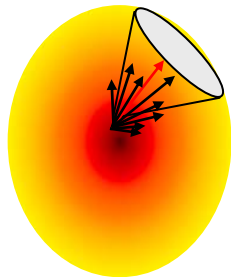
100/event 1/event

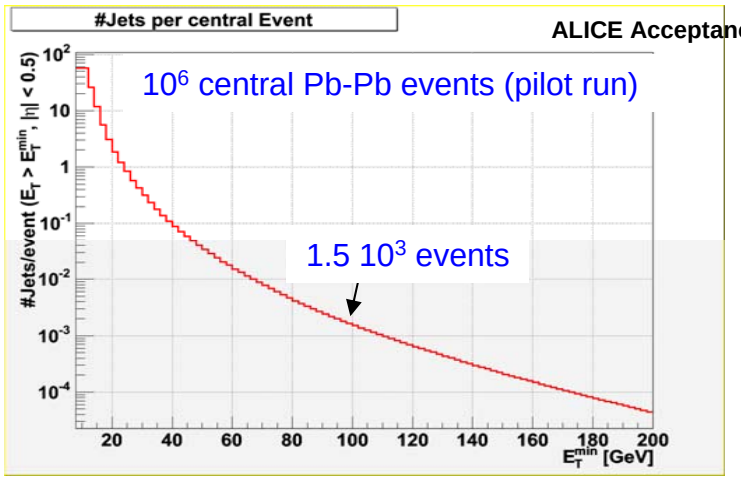
10^3 in first 10^6 Pb-Pb events

surface emmission



Reconstructed Jet

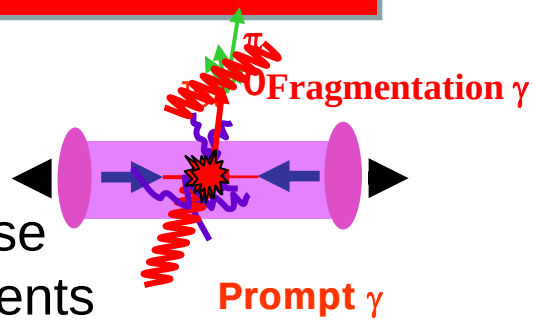




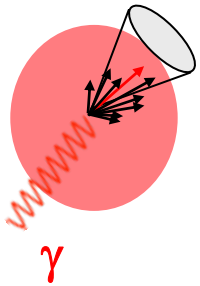
E_T threshold	N_{jets}
50 GeV	5×10^4
100 GeV	$\mathbf{1.5 \times 10^3}$
150 GeV	300
200 GeV	50

QGP probe: Photon

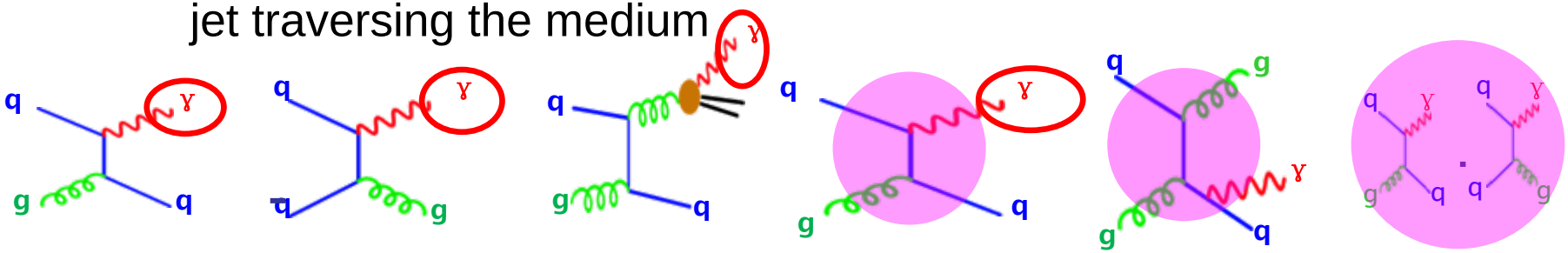
- Direct soft photons radiated from the medium
  - ⇒ Temperature reached by the dense medium
  - ⇒ Direct photon flow can be measured to diagnose the degree of thermalization of medium constituents



- Direct semi hard photons produced by hard partons interacting with the hot medium
  - ⇒ γ enhancement through bremsstrahlung and Jet-γ conversion

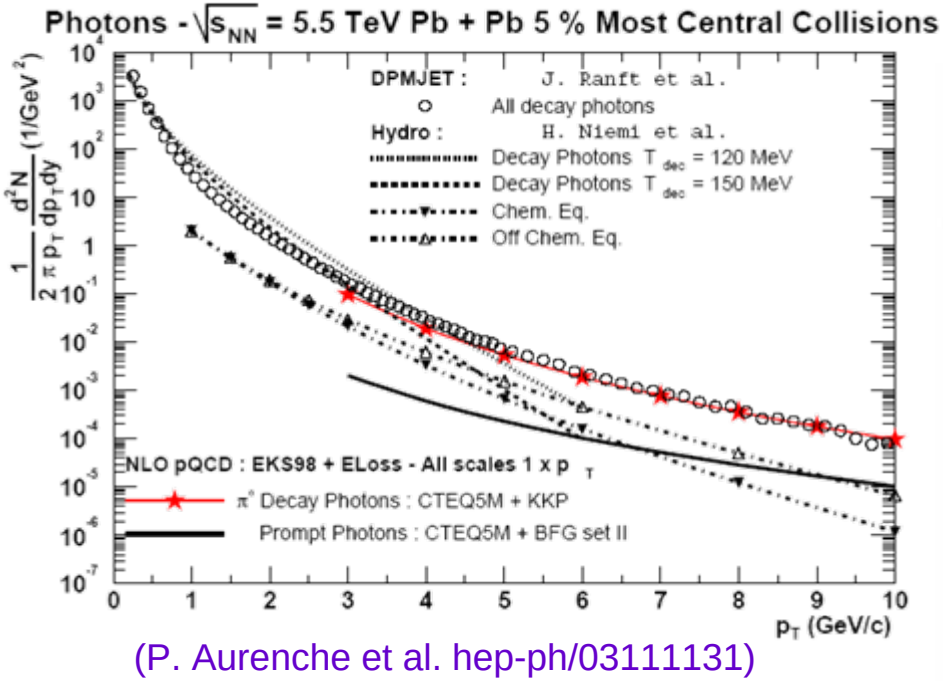


- Direct hard photons (non interacting probe)
  - ⇒ QCD scaling
  - ⇒ Jet-Quenching and fragmentation function through γ -jet correlation
- Decay photons (neutral mesons π^0, η, ω, et al.)
  - ⇒ momentum modification of the fragmentation of jet traversing the medium



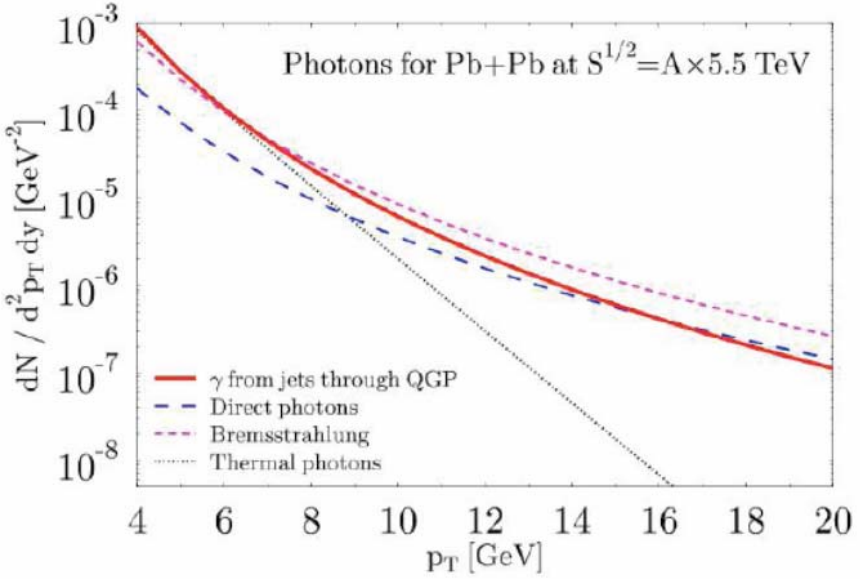
Challenge for Photon measurement at LHC

Extending the photon measurement in a very hard regime ~ 250 GeV/c



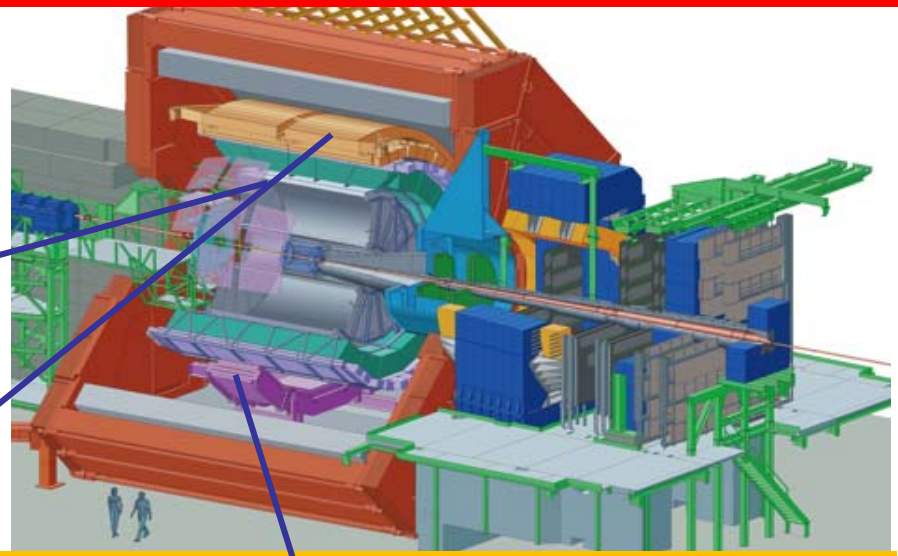
(P. Aurenche et al. hep-ph/03111131)

R.J. J. Fries, B.Muller, PRL 90 (2003) 132301



ALICE detector for jet and γ Identification

- **ITS+TPC+TOF+TRD+HMPID**
  - Charged particles $|\eta| < 0.9$
  - Excellent momentum resolution up to ~100 GeV/*c* ($\Delta p/p < 6\%$)
  - Tracking down to 100 MeV/*c*
  - Excellent Particle ID and heavy flavor tagging
  - Mass resolution: σ_π~3.3 MeV



- **EMCal**
  - Lead-scintillator sampling EMCal, 13k towers of $\Delta\eta \times \Delta\phi = 0.014 \times 0.014$
  - $\Delta\phi = 107°$, $|\eta| < 0.7$,
  - Energy resolution *~10%/ √E*
  - Mass resolution: σ_π ~ 16 MeV
  - High pt triggers: γ, π^0, e
  - pt measured up to ~250 GeV/c

- **PHOS**
  - High resolution photon spectrometer ($PbWO_4$ crystals 56x64x5): $\Delta E/E$~3%/ *√E*
  - $|\eta| < 0.12$, $220° < \phi < 320°$
  - Energy and position resolution (E in GeV):

$$\frac{\Delta E}{E} = \sqrt{\frac{a^2}{E^2} + \frac{b^2}{E} + c^2}, (a = 0.03, b = 0.03, c = 0.01)$$

$$\Delta x = \frac{A}{\sqrt{E}} + B, (A = 3.26mm, B = 0.44mm)$$

  - Mass resolution: σ_π ~ 4.7 MeV
  - high pt trigger : γ, π^0, e
  - pt measured from ~100MeV/c to ~100 GeV/c

LHC/ALICE: Running Scenario

- data taking for p+p collisions with energy at 7, 10, 14 and 5.5 TeV with Lint=10pb-1 from end of 2009
- Pb+Pb at ~4 TeV (10x82/208) per nucleon pair with $\int Ldt = 0.5$ nb-1 from end of 2010
- Pb+Pb at 5.5 TeV (14x82/208) per nucleon pair with $\int Ldt = 0.5$ nb-1 after 2010
- p-Pb at 5.5 TeV, Ar-Ar at 7 TeV, after 2010
- then O, Kr, Sn collisions

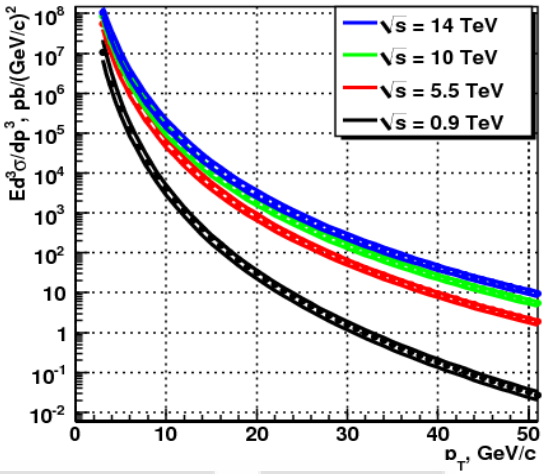
Inclusive neutral meson yield with PHOS in pp first run

measure inclusive spectrum to test NLO pQCD, provide reference for heavy ion collision

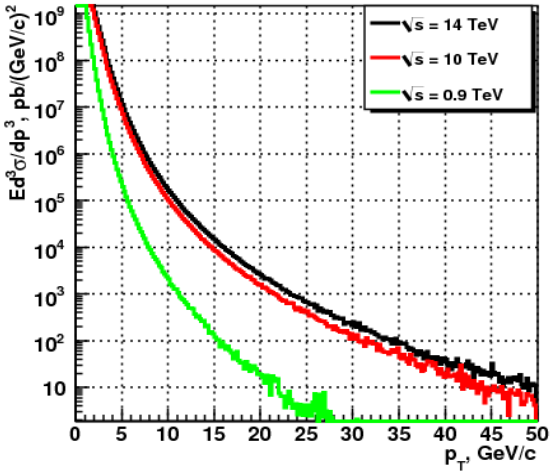
same as for $\pi 0$; measure $\eta/\pi 0$ ratio; test m_T scaling

same as for η; provide reference for vector meson mass modification in HIC qq

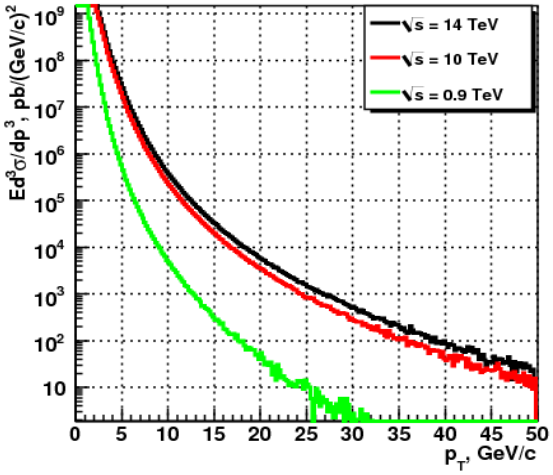
$pp \rightarrow \pi^0 X$

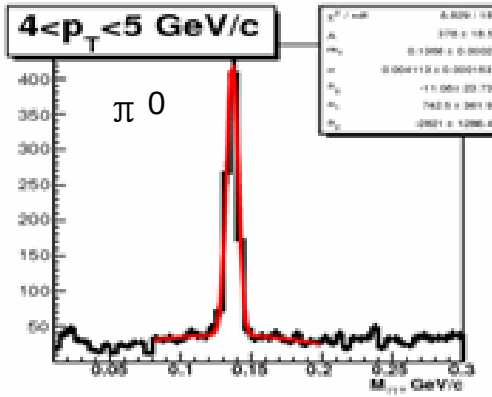


$pp \rightarrow \eta X$

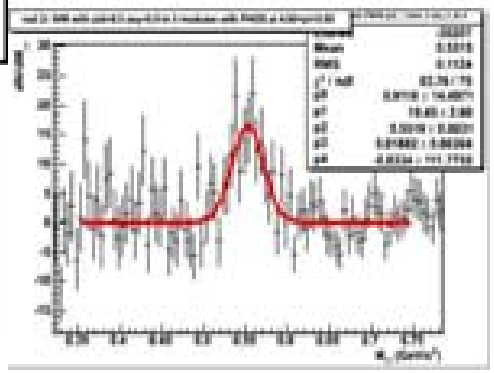


$pp \rightarrow \omega X$

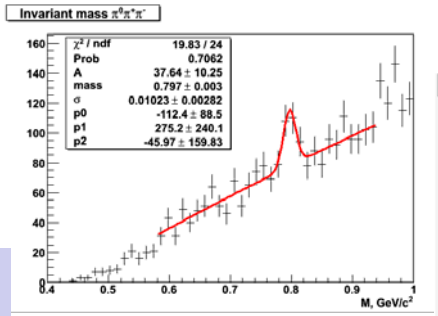


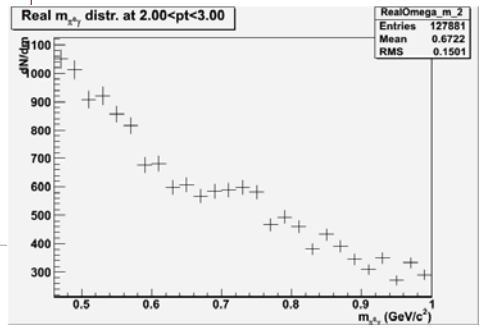


η



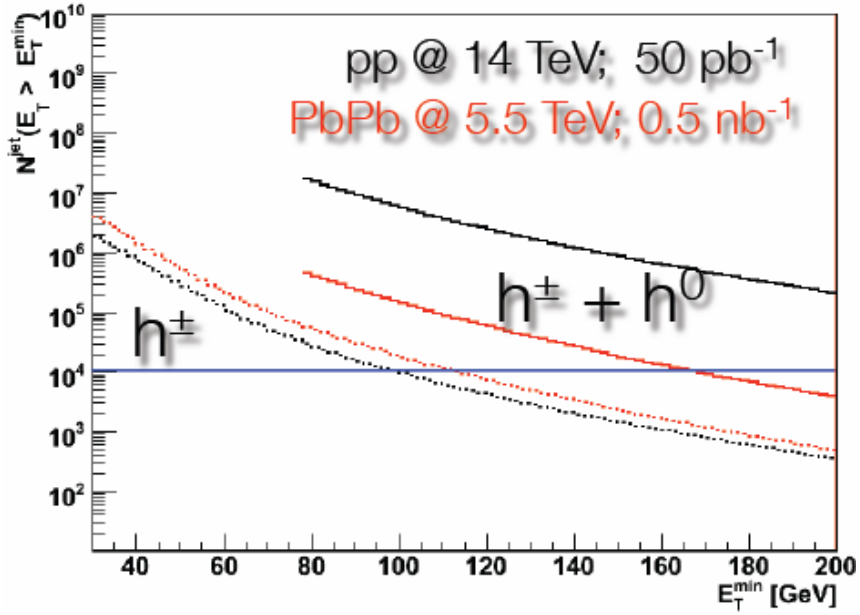
$pp \rightarrow \omega X$: $\omega \rightarrow \pi^0\pi^+\pi^-$, $\omega \rightarrow \pi^0\gamma$





Invariant mass spectra show clear peaks and available measurement of π^0, η and ω

Inclusive jet spectrum comparing A-A with p-p collisions



Need EMCAL trigger for reference data

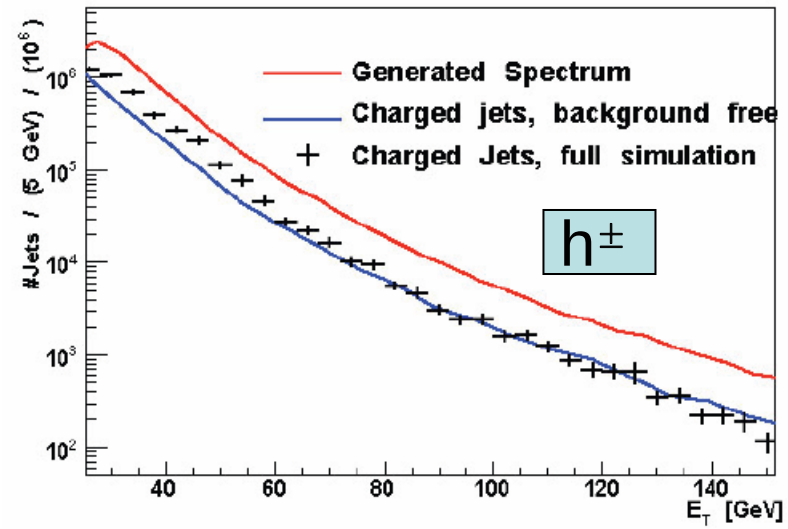
For the charged particles spectrum h± in first PbPb @ 5.5 TeV with low luminosity (L~50 μ b-1):
pT reach is ~100 GeV/*c*

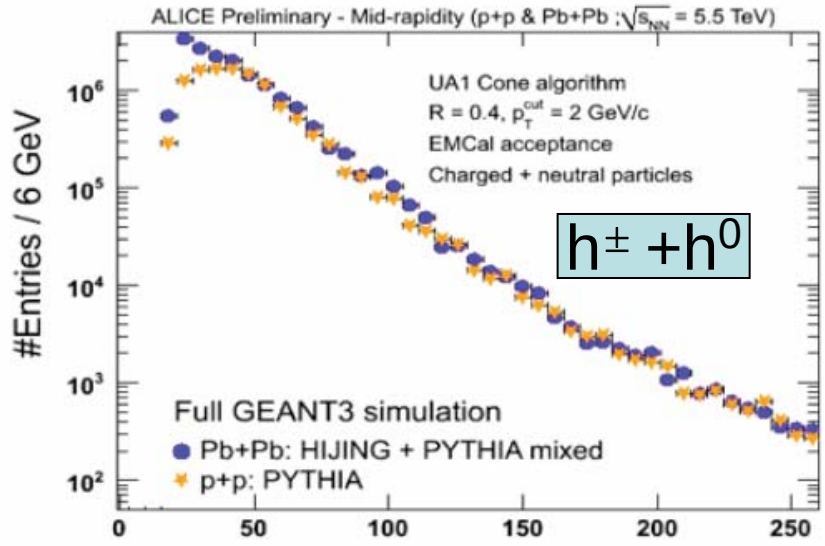
Plusing neutral hadron h0 and trigger(EMCal):
pT reach can be extended to ~200 GeV/*c*

Reconstructed jet spectrum in Pb-Pb

Jet yield with only charged and (Charged+neutral) particles from 10^7 central events with cone R = 0.4 and pt cut=2 GeV in EMCal acceptance

With statistics of one month of Pb-Pb collisions at 5.5 TeV





Jet reconstruction in HIC possible for E>40 GeV;

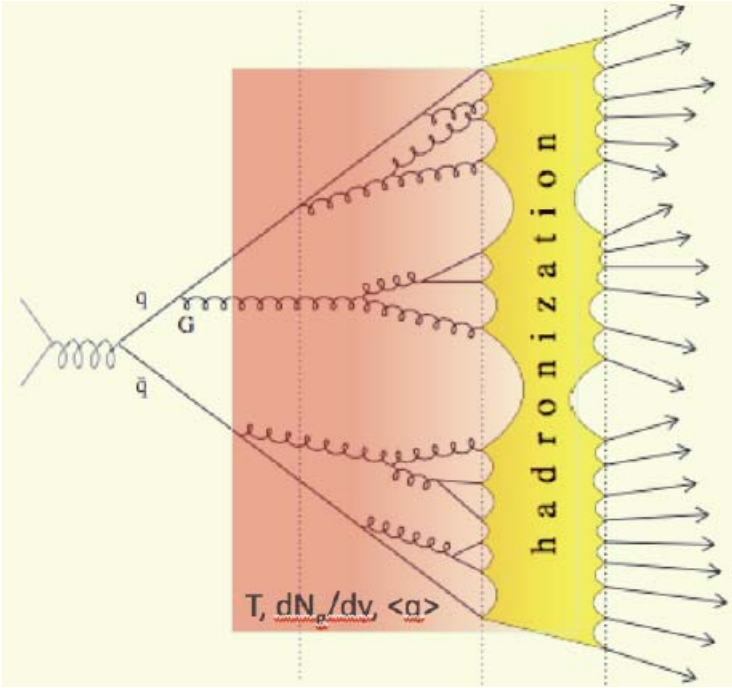
Hump-backed plateau analysis up to E~150 GeV;

Jet : explore medium effect and modification

Because of dense medium , the evolution of the parton shower changes :
Like gluon radiation, jet broadening, Multiplicity redistribution

The fragmentation process might be modified

To measure energy loss and phase space distribution of radiated energy over a wide range of jet energies



Medium modification effect and observables

- Decrease the p_T of leading particle, disappearance of back-to-back high p_T hadron correlation: R_{AA}

- Increase number of low p_T particles: reappearance of back-to-back low p_T hadron correlation

- Increase of j_T (momentum transverse to jet axis), broadening of jet, out of cone radiation: jet quenching in R_{AAjet}

- Increase di-jet imbalance and acoplanarity: γ –jet, hard parton fragmentation, hadron–jet correlations

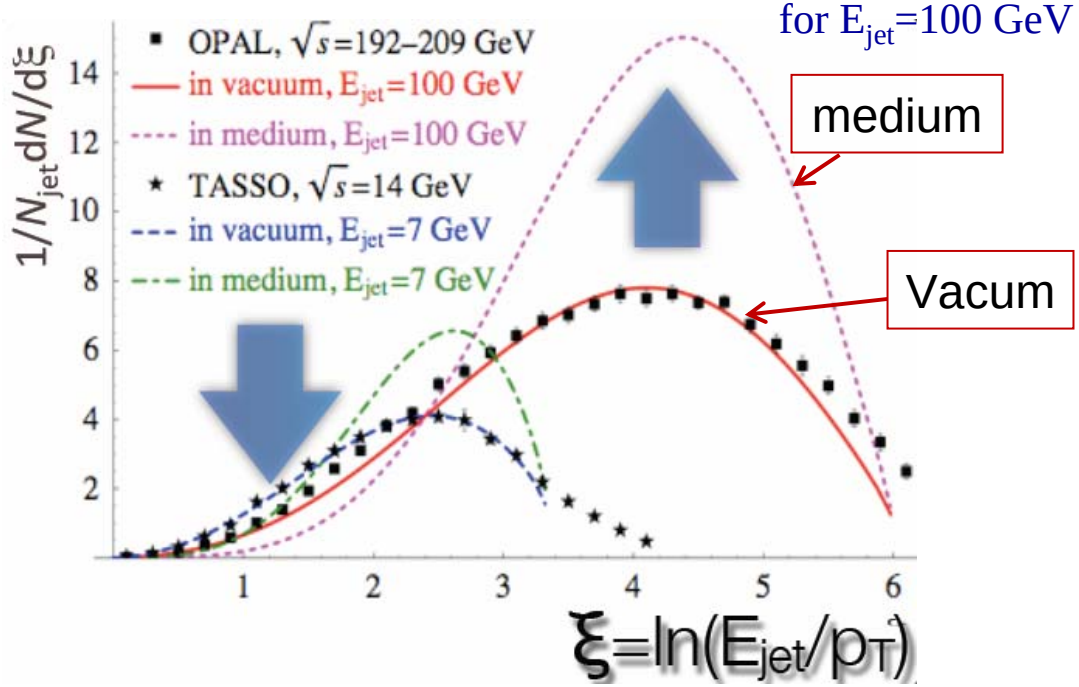
New sources of high p_T photons: γ spectrum, $R_{AA\,\gamma}$ and flow

Measure Jet fragmentation function

Borghini & Wiedemann, arXiv:jep/ph/0506218

Merge p+p and Pb+Pb events
Compare jet reco event-wise

p_T^{hadron}~2 GeV
for E_{jet}=100 GeV



Jet-QGP interaction:

Searching for

Suppression at low ξ ;

Enhancement at high ξ ;

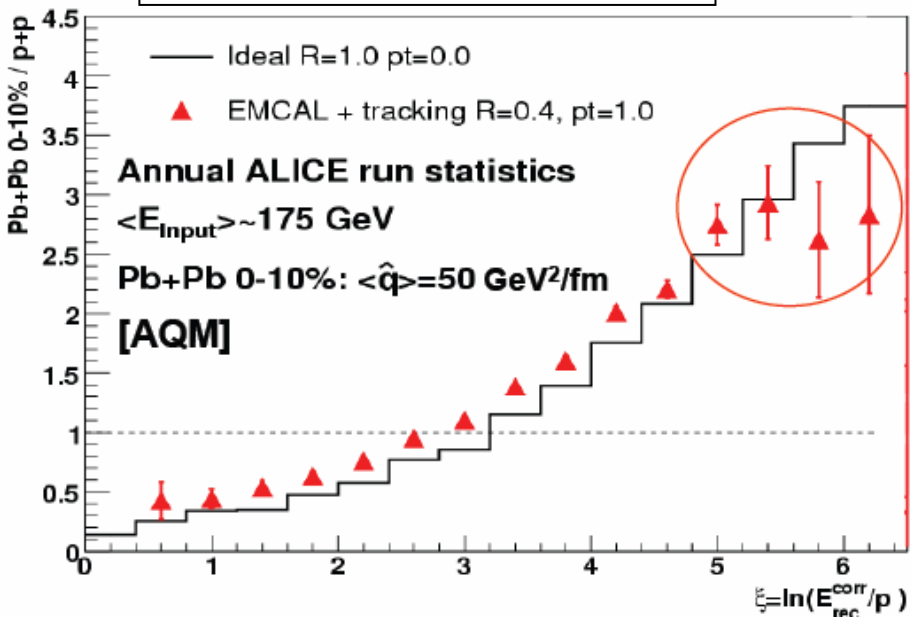
Jet broadening & radiation out of cone;

Increase of di-jet energy imbalance and acoplanarity

Medium modification factor

$$R_{AA}(\xi) = \frac{1/N_{jet}^{AA}\, dN^{AA}/d\xi}{1/N_{jet}^{pp}\, dN^{pp}/d\xi}$$

Ratio of Fragmentation Fns: quenched/unquenched



Robust signal, but:
underestimation (R, pTcut) of jet energy biases z=pT/Ejet toward lower values

Need complementary measurements:

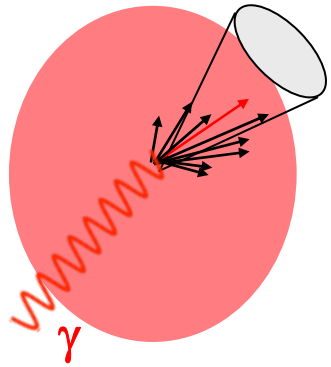
Jet shape (out of cone radiation)

Jet RAA

Calibrated jets (γ –jet)

Golden measurement: γ -tagging jet – calibrate jet energy

Tag jet with **direct prompt photon** γ or **very high pt** π^0 emitted back-to-back: $E_\gamma = E_{jet}$



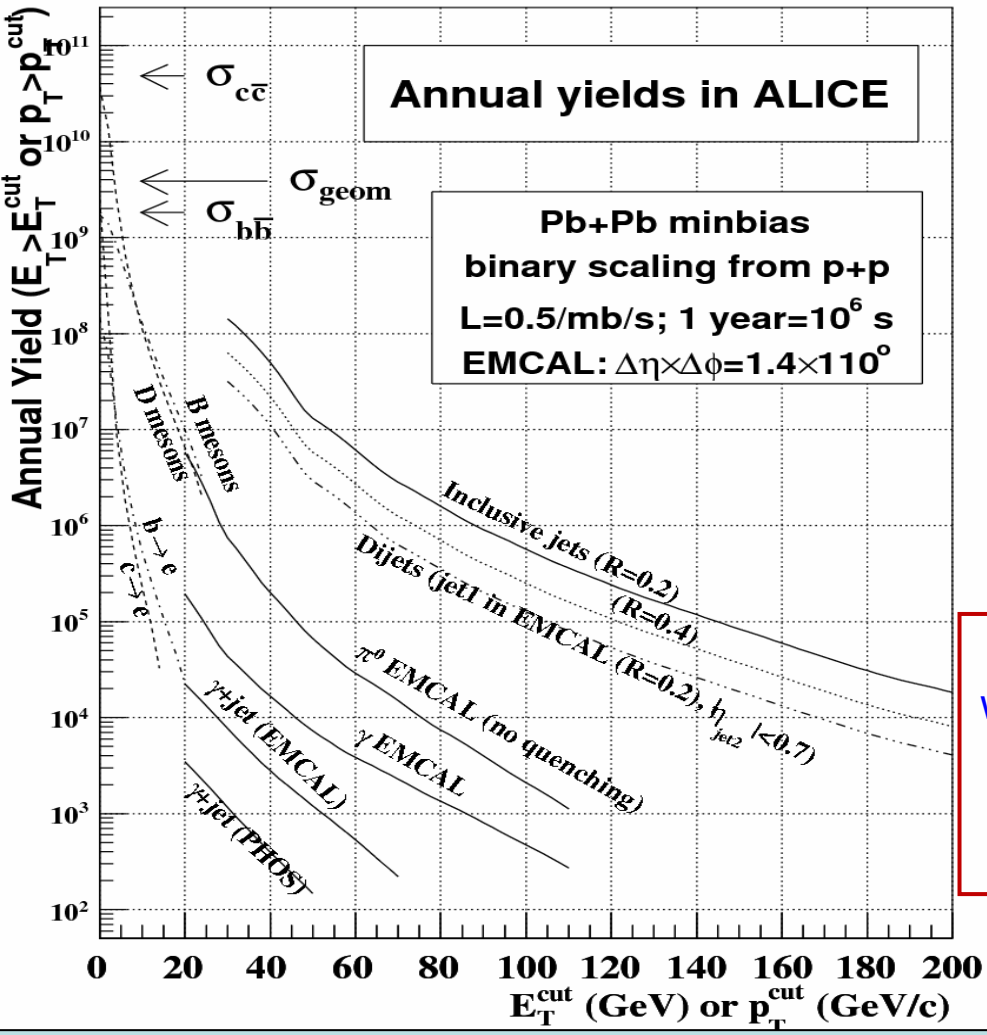
To solve the jet energy calibration problem

To give access to low energy jets: $E_{jet} < 50$ GeV/*c*

Measure the jet fragmentation function of the photon-hadrons imbalance distribution: $x_E = -p_{T_h} \cdot p_{T\gamma} / |p_{T\gamma}|^2$

One can also tag jet with isolated high p_T hadrons (hard fragmentation)

Photon and jet yield related to PHOS and EMCal



ALICE EMCAL TDR 2008-014, p5

More detailed discussion will be by Yaxian Mao's talk at the meeting for the gamma-jet and gamma-hadron correlation

Prediction of annual yields in ALICE electromagnetic calorimeter which are related to the observations of γ, π^0, γ-jets, jets, Di-jets, heavy quark-tagged jets (b,c—>e). Their observations will provide the definitive understanding of the interaction between partons and medium

Conclusions

- Jets and high pt particles and photons will be copiously produced in HIC at LHC
  - Jets can be reconstructed over the background from the underlying event
  - Sufficient dynamic range (50 – 250 GeV) to make systematic studies of energy dependence.
  - CF analysis through γ -hadron correlation make the jet measurement down to pt~20 GeV

- Background requires jet identification and reconstruction in reduced domain $R = 0.4$

- ALICE will measure inclusive particle spectrum, γ -hadron correlation, γ -jet and jet-jet structure observables (j_T, fragmentation function, jet-shape) , and heavy quark-tagged jets (b, c->e), to diagnose the QGP signal and its properties

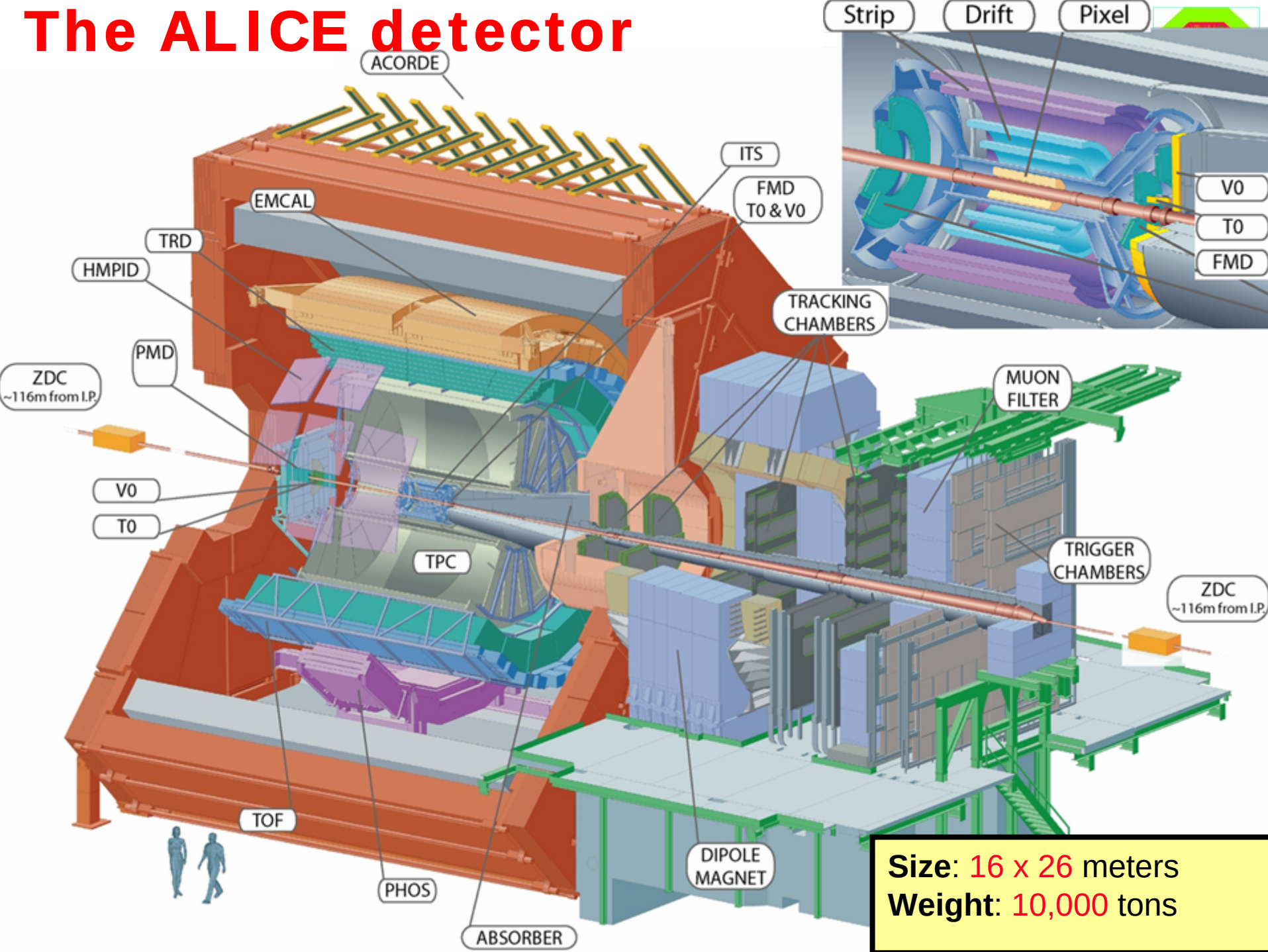
Thanks!

Special thanks to:

- Yves Schutz, Andreas Morsh, Yaxian Mao, Renzhuo Wan, Vladislav Manko, Thomas Commier, Gustavo Conesa, Yuri Kharlov, Peter Jacobs, Peter Levai, Ana Marin, Gines Marinez, Hans-Ake Gustafsson, Jurgen Schukraft and Paolo Giubellino
- PWG4, PHOS and EMCal teams
- And ALICE collaboration

Backup

The ALICE detector

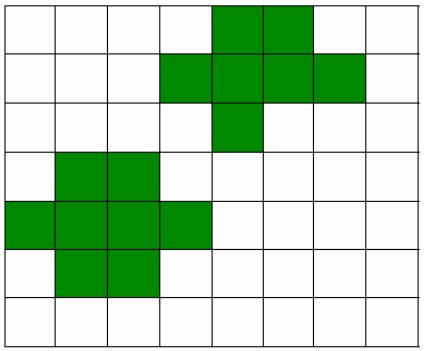


Size: 16 x 26 meters
Weight: 10,000 tons

Invariant Mass Analysis + Shower Shape Analysis + Isolation Cut of γ and mesons measurement

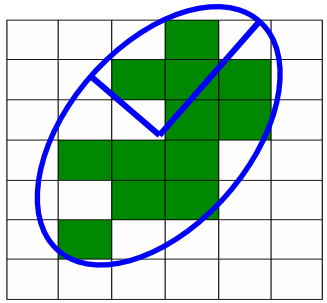
well separated clusters
➔ invariant mass analysis

< 10 GeV/c in **EMCal**
< 30-50 GeV/c in **PHOS**



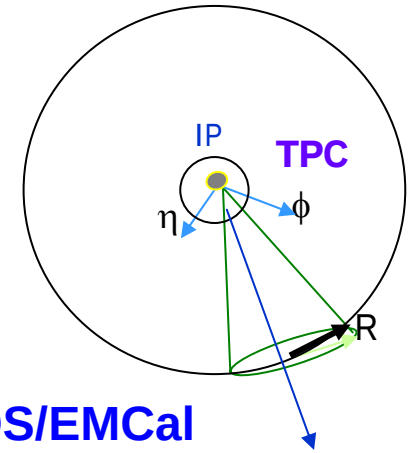
merged clusters not spherical
➔ shower shape analysis

10 - 30 GeV/c in **EMCal**
50 - 100 GeV/c in **PHOS**



If the high pt γ and π0 with opening angle << 1
➔ isolation cut
NIM A(580)2007, 1446-1459
Gustavo Conesa et.al

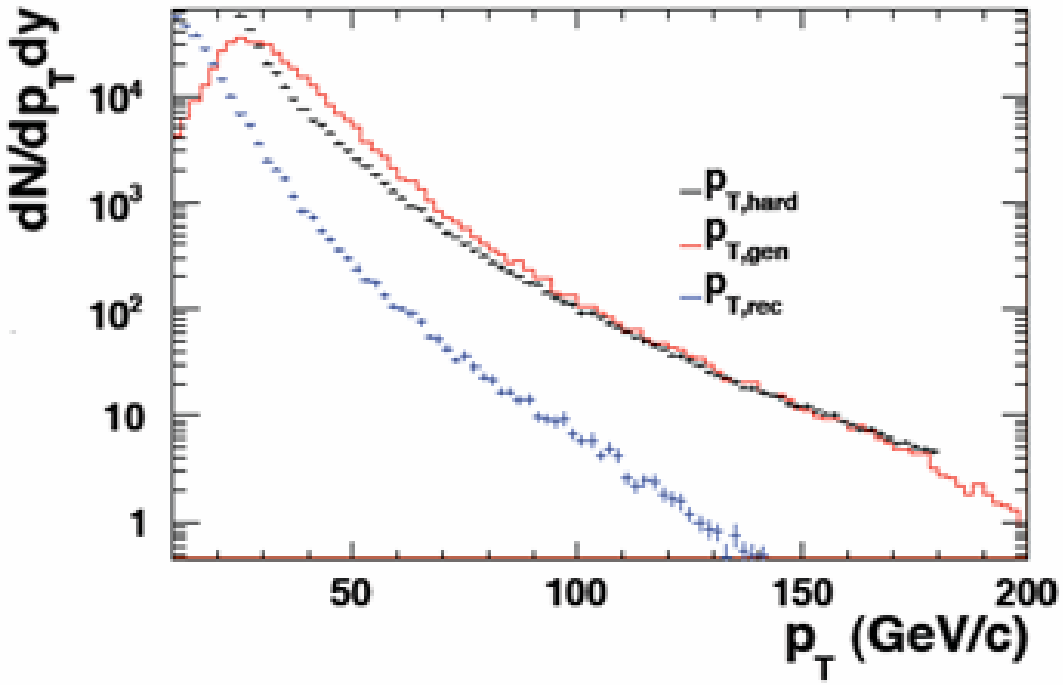
>30 GeV/c, which is the only method in EMCal for high pt π0



PHOS/EMCal

Inclusive jet spectrum in p-p

Charged particles spectrum with minimum bias trigger: h±

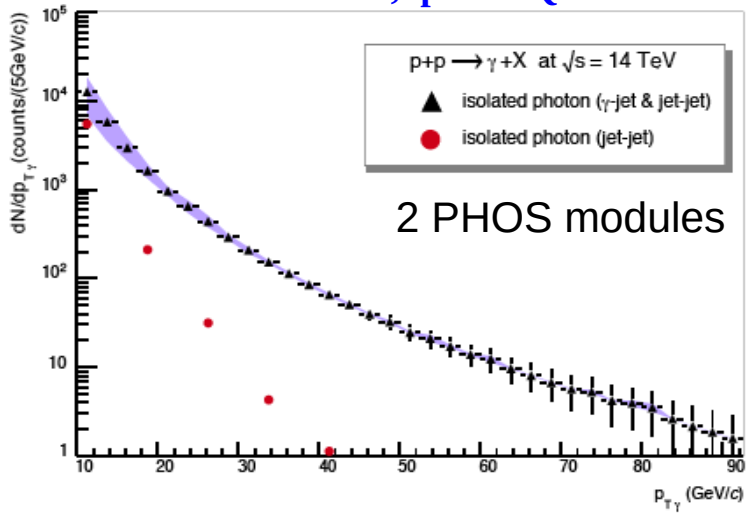


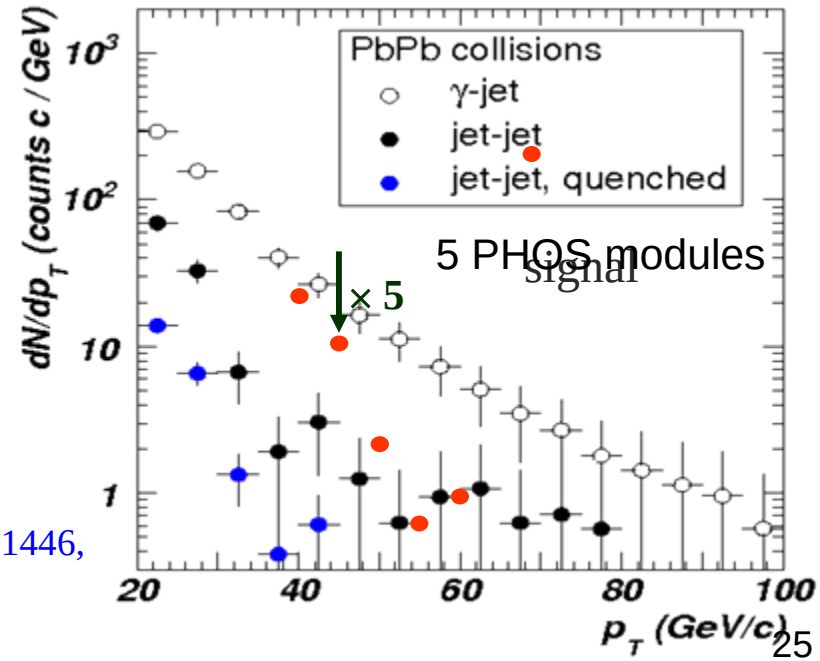
Isolated prompt γ spectra from p-p and Pb-Pb in PHOS

PYTHIA γ-jet (signal) and jet-jet (π 0–hadron background) events simulated and reconstructed in ALICE, full material budget.

- pp
  - $R = 0.3$, $\Sigma p_T < 2$ GeV/c
  - Efficiency: 70%
  - Background rejection: 1/100
  - Integral Luminlosity (10 pb^{-1})
    - 3000 γ ($E\gamma > 20$ GeV)
- PbPb
  - $R = 0.2$, $p_T^{thresh} = 2$ GeV/c
  - Efficiency: 50%
  - Background rejection: 1/14
  - One month of running
    - 2000 γ ($E_\gamma > 20$ GeV)

Y. X. Mao et al, E.P.J.C57:613-619,2008
ALICE-INT-2007-021; poster QM2008



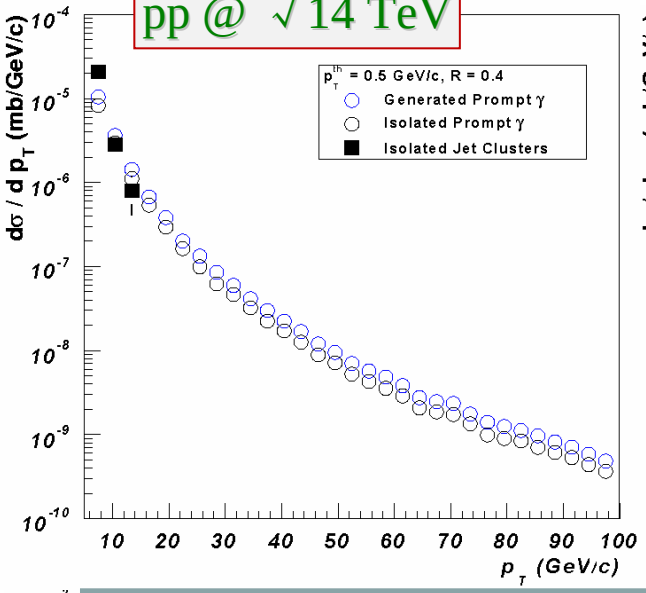


G. Conesa et al., NIM A 580(2007) 1446,
NIM A 585(2008) 28

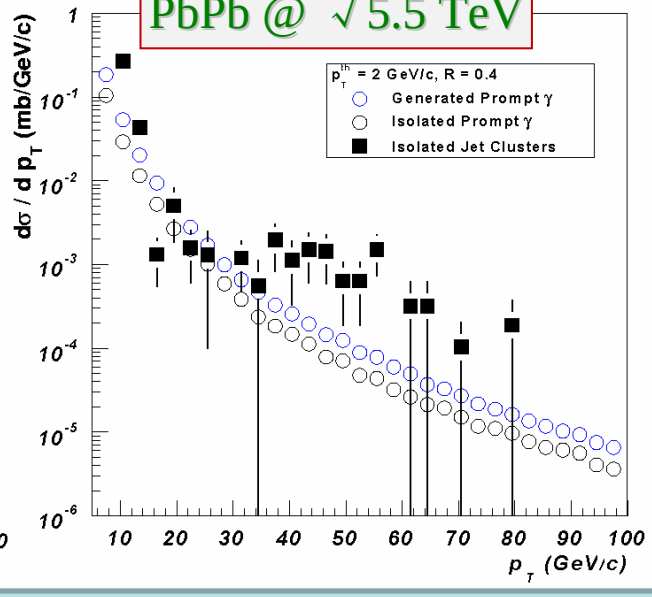
Isolated spectra in EMCAL

pp = PYTHIA
PbPb =PYTHIA (signal) +HIJING (UE)
Full reconstruction in ALICE

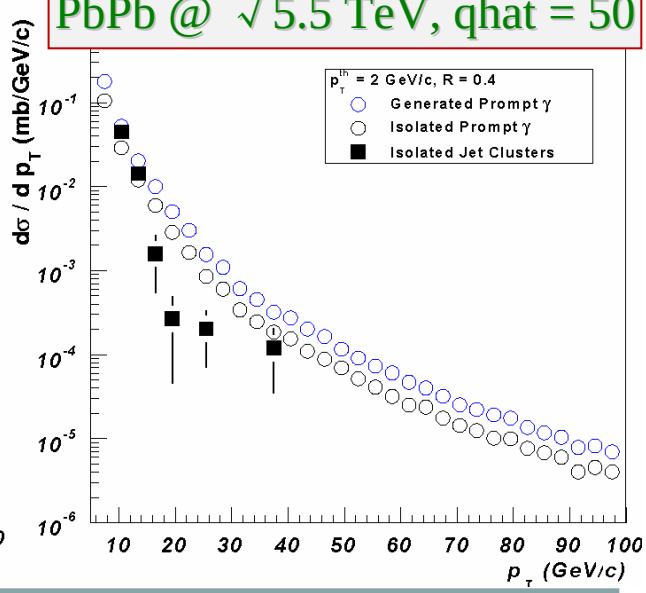
pp @ √14 TeV



PbPb @ √5.5 TeV

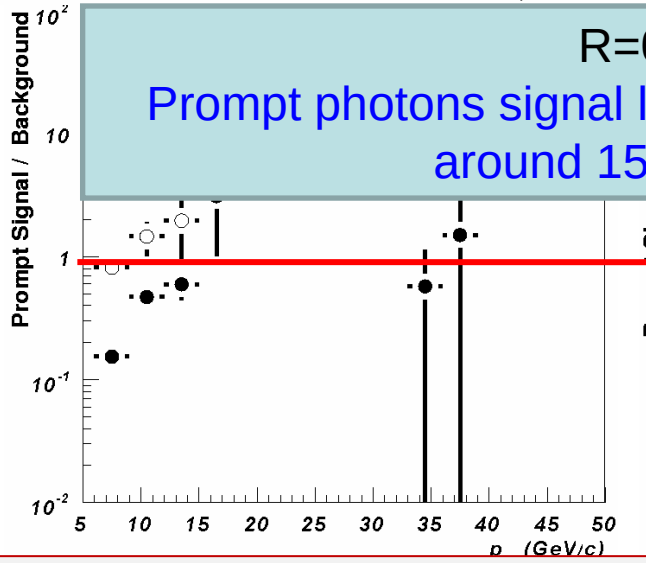


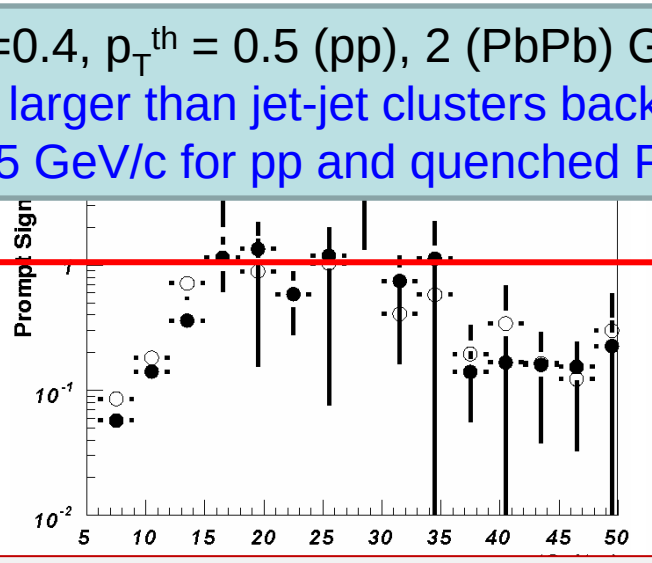
PbPb @ √5.5 TeV, qhat = 50

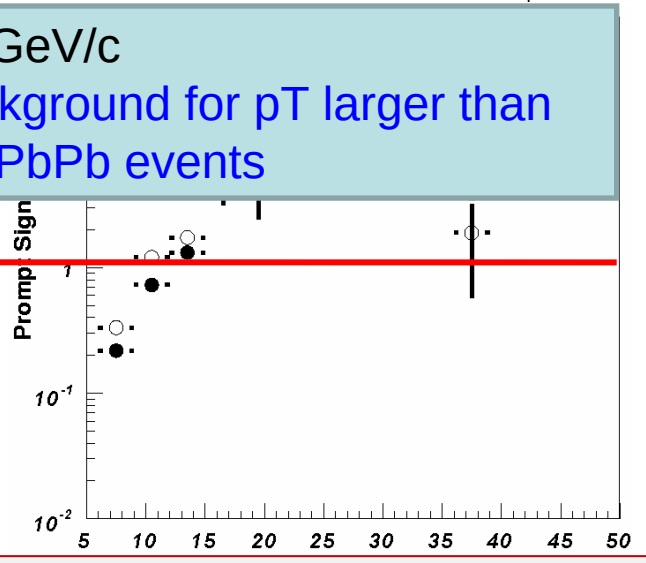


R=0.4, p_T^{th} = 0.5 (pp), 2 (PbPb) GeV/c

Prompt photons signal larger than jet-jet clusters background for pT larger than around 15 GeV/c for pp and quenched PbPb events

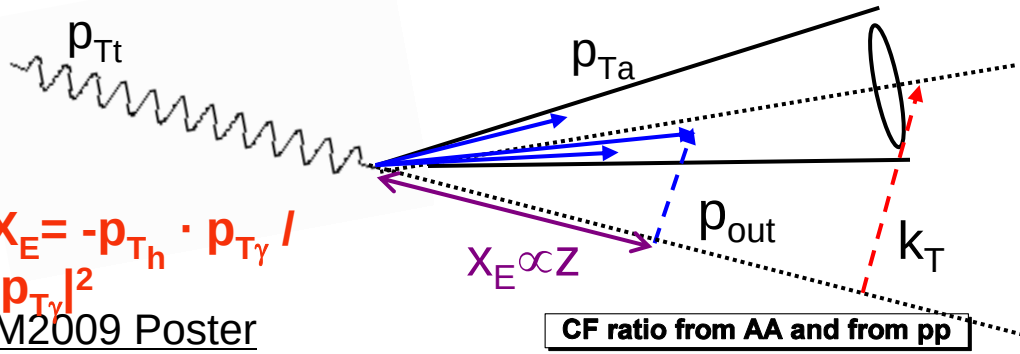






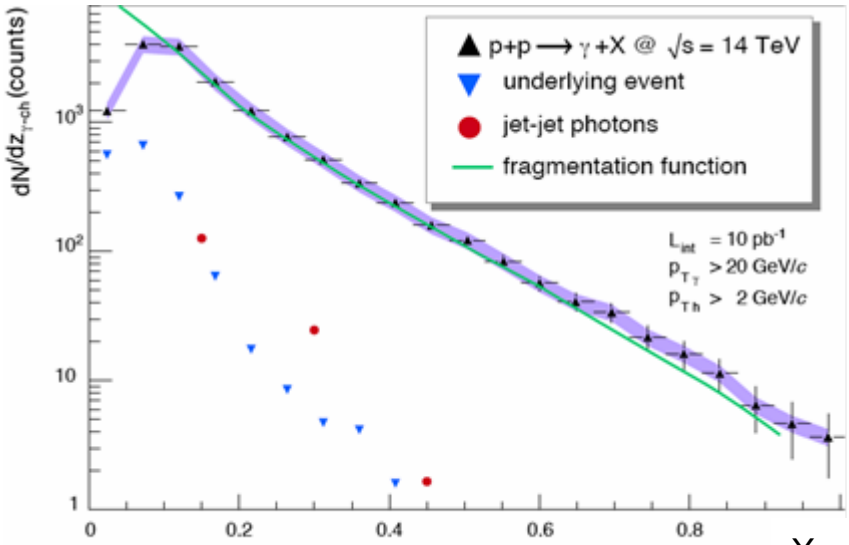
Isolated clusters in γ -jet and jet-jet (π^0 -hadron background) with PID $\lambda^2_0 < 0.25$

γ-hadron correlation function measurement



$x_E = -p_{T_h} \cdot p_{T\gamma} / |p_{T\gamma}|^2$

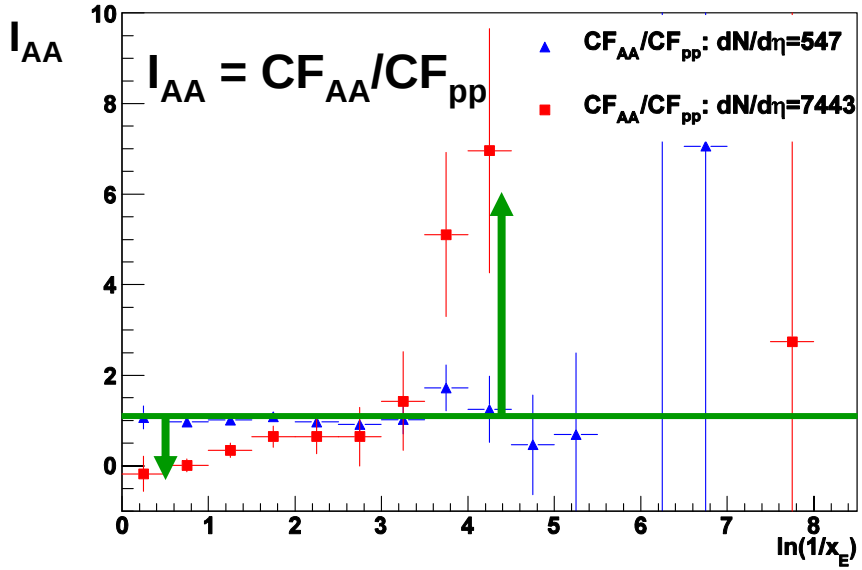
Y.X. Mao et al., EPJC (2008) 57; QM2009 Poster



- Statistical errors correspond to one standard year of data taking with 2 PHOS modules.
- Systematic errors from decay photon contamination and hadrons from underlying events.

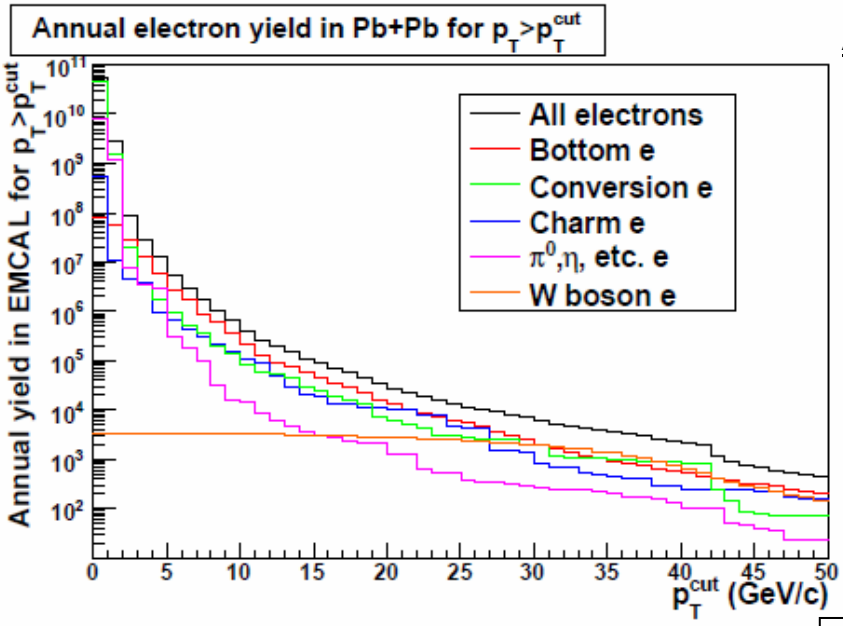
PYQUEN

CF ratio from AA and from pp

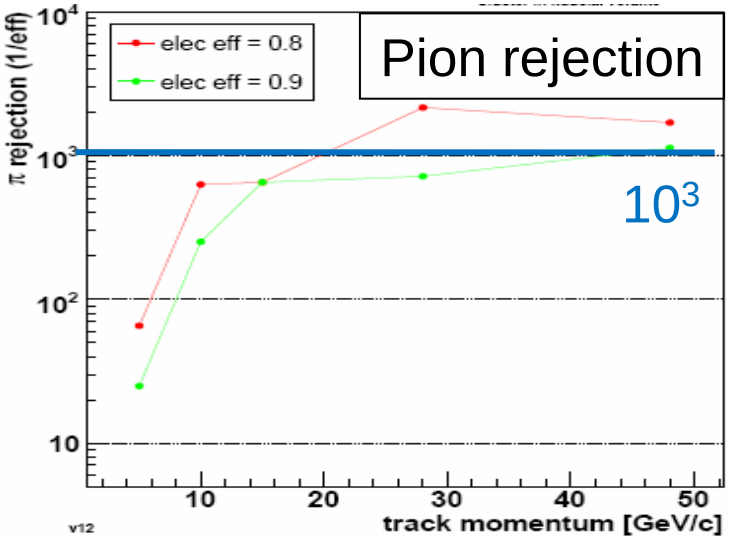


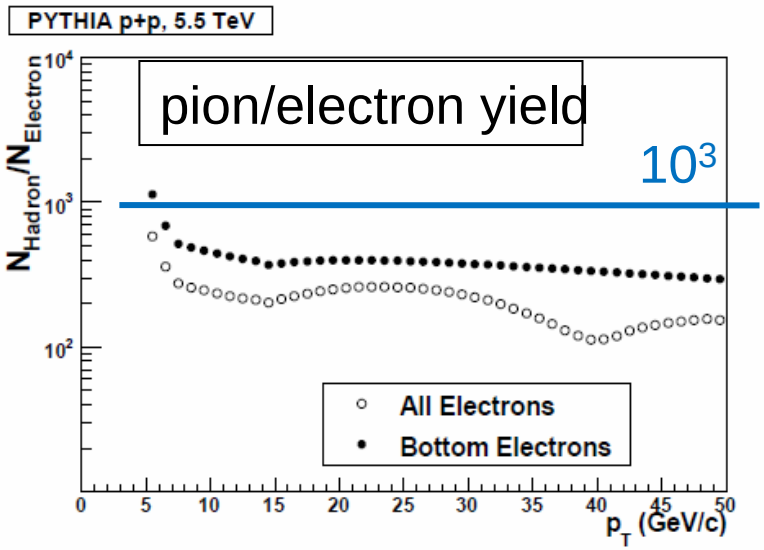
- Medium modification factor I_{AA} calculated from the γ - hadrons correlation (CF) distribution.
- Enhancement at low x_E and suppression at large x_E

High p_T electron yields in EMCal



ALICE EMCAL TDR 2008-014





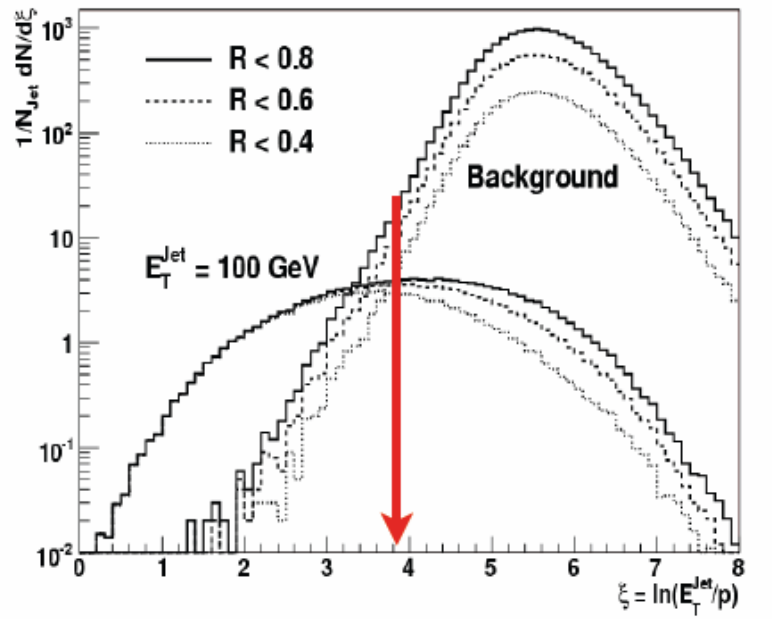
- Accumulated annual yield of all electrons from 5.5 TeV mini. bias PbPb collisions

=> Measure heavy quark energy loss and dead cone effect through heavy quark-tagged jets

- **Heavy flavor-tagged jet measurement is available**
- **Sufficient hadron rejection is achievable**

Soft underlying event

In heavy-ion the high multiplicity soft background hides the medium induced soft jet-particles enhancement



2 GeV/*c*

Understand

background subtraction

relative jet energy calibration
in pp @ 14 TeV and AA @ 5.5 TeV