Charm physics with the ALICE Experiment

Marcel Figueredo

University of Liverpool

January 29, 2014

Contents

- LHC and ALICE
- QGP – *Quark gluon plasma*
  - Open Charm as a probe of QGP
    - Some analysis of Λ_c that we have been performing
  - Charmonium as a probe of QGP.
    - J/ψ analysis with EMCal triggered events
  - Elliptic flow → v2
- ITS Upgrade
- Conclusions

LHC and ALICE

ALICE is the LHC experiment dedicated to heavy-ion physics

Due to very good tracking and PID → measurements down to low transversal momentum.

But also pp and pPb collisions are interesting for us!

- Baseline for comparison with PbPb collisions
- Check QCD predictions

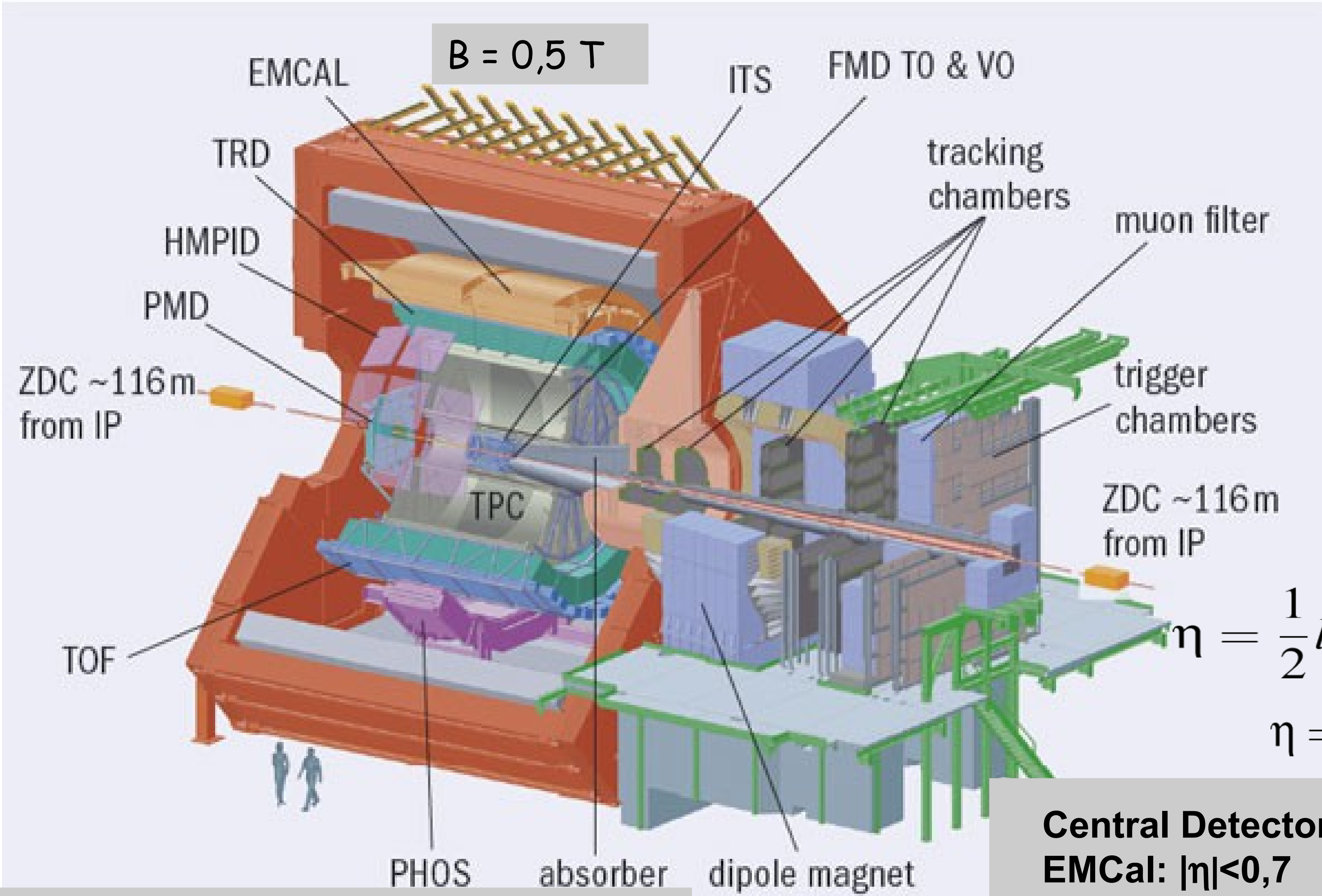
For ALICE
~100 kHz → interactions in pp
~500 Hz in PbPb

Collisions (2009--2013)

p-p @ 0.9, 2.36, 7, 8 TeV
Pb-Pb @ 2.76 TeV
p-Pb @ 5.02 TeV

Next slides
Some more details about ALICE

ALICE Experiment



$$\eta = \frac{1}{2} ln(\frac{|\vec{p}| + p_L}{|\vec{p}| - p_L})$$

$$\eta = -ln[tan(\frac{\theta}{2})]$$

Central Detectors → |η|<0,9
EMCal: |η|<0,7
Muon Chamber: 2,5 < η < 4

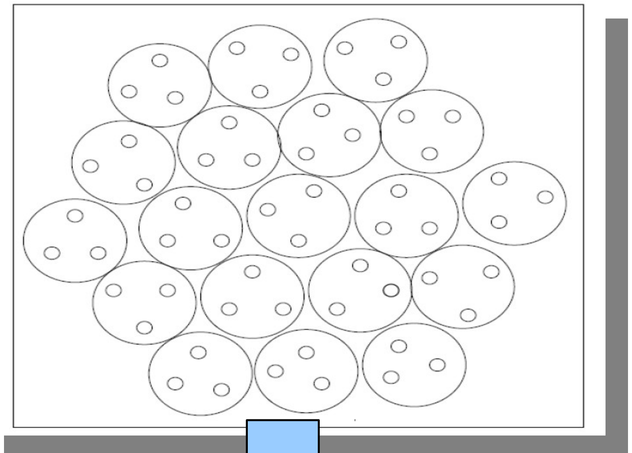
V0 → Collision trigger and multiplicity
TPC (Time projection chamber) → Tracks and Particle identification – PID)
ITS → Vertex, tracking and PID
EMCal → Energy

Let's see in details ITS, TPC and EMCal

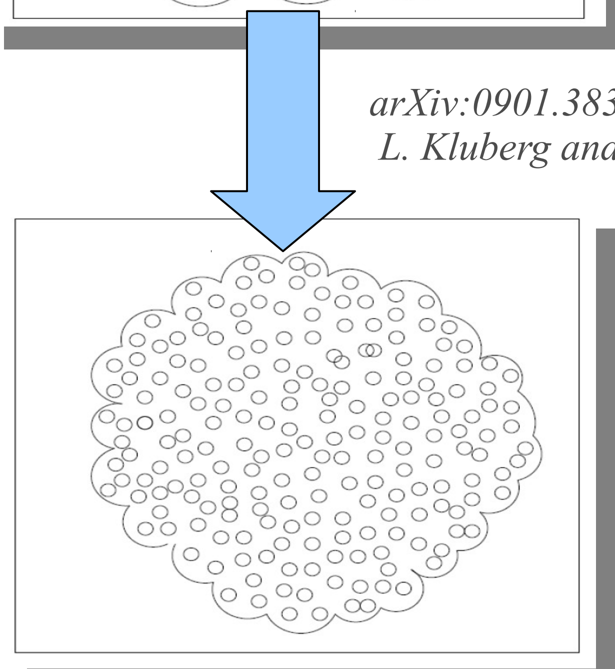
QGP – Quark Gluon plasma

Phase transition

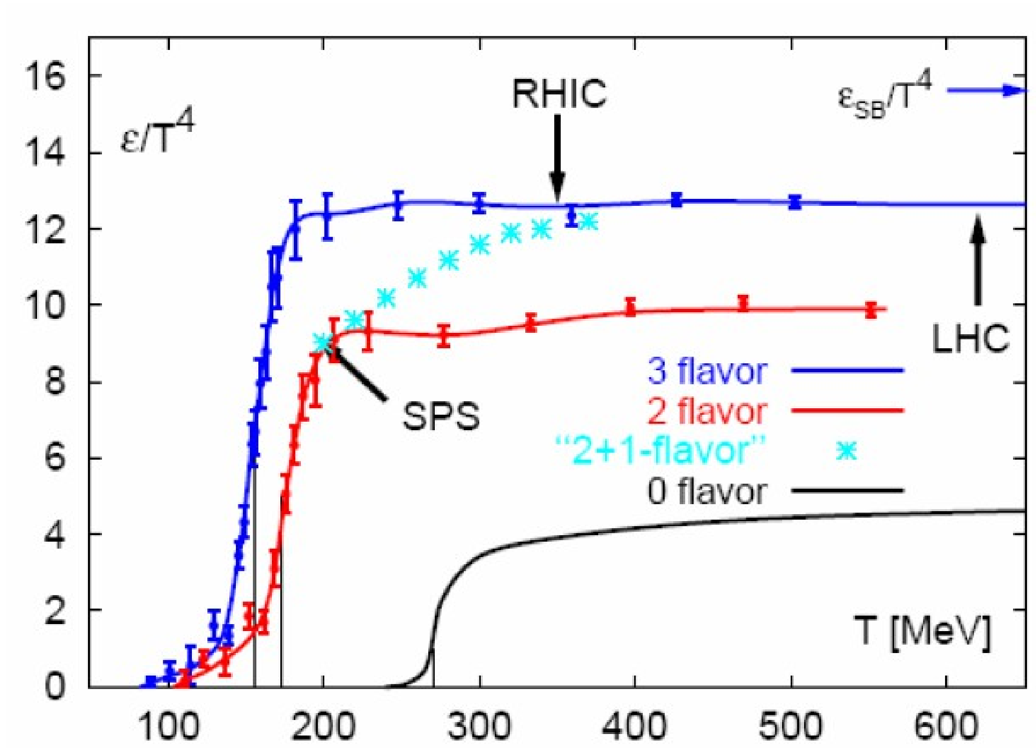
High interacting matter
Almost superposition of nucleons



arXiv:0901.3831v1 [hep-ph]
L. Kluberg and H.Satz



Partonic matter under extreme densities



Tc ~ 150-160 MeV
Energy Density ~ 1 GeV/fm^3

F. Karsch, E. Laermann and A. Peikert: Phys. Lett. B 478, 447 (2000) 8, 9

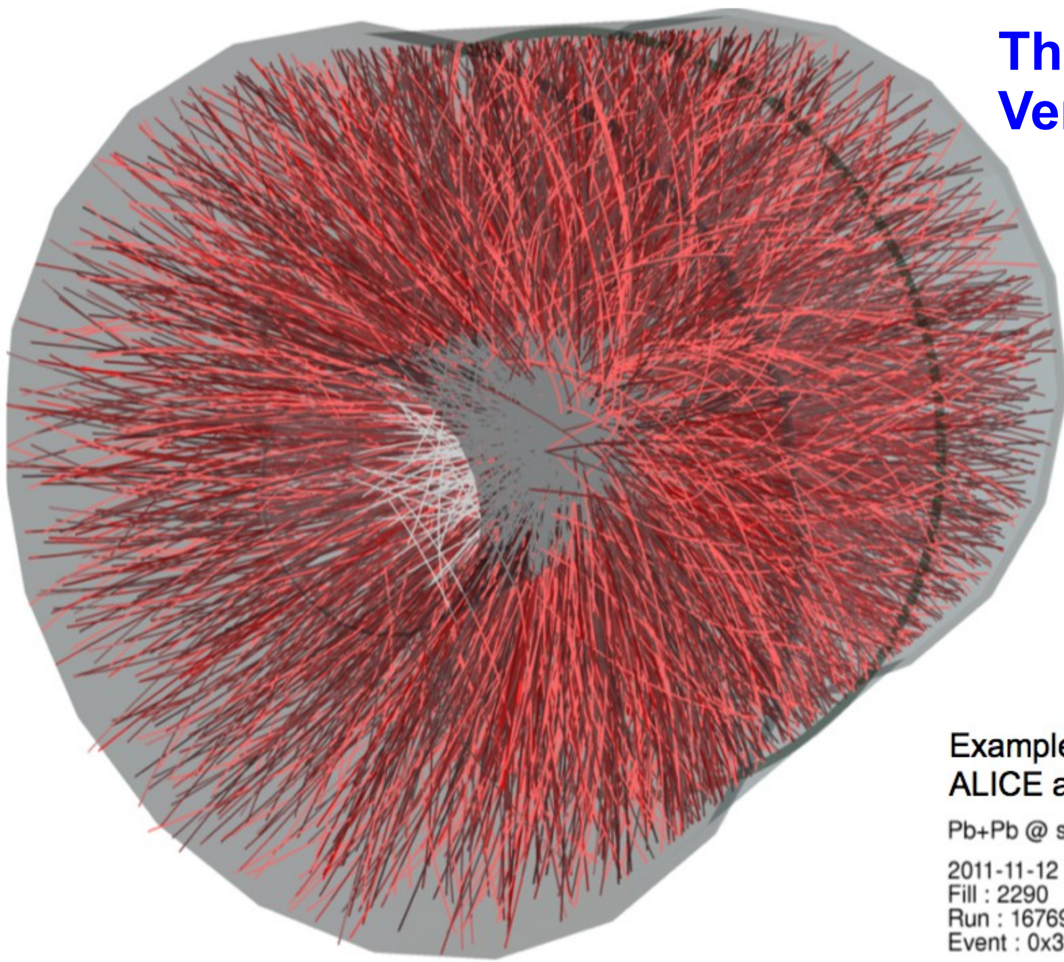
Some QGP Signatures

There are several signatures of the QGP.

Let's focus on some them:

- Elliptic flow, correlations
  - Collective expansion/behaviour of the QGP
- Heavy flavour production
  - Transport properties of the QGP
- Quarkonium production
  - Deconfinement in the QGP
  - Supression or regeneration mechanisms

Pb-Pb Collisions



Thousands of particles in a single event
Very challenging! And also exciting!

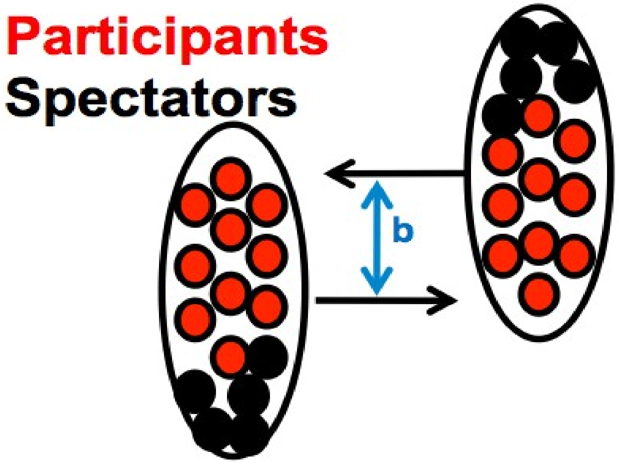
Example:
ALICE at LHC

Pb+Pb @ sqrt(s) = 2.76 ATeV

2011-11-12 06:51:12
Fill : 2290
Run : 167693
Event : 0x3d94315a

Let's discuss briefly about Centrality and RAA in PbPb

Centrality (Pb-Pb)

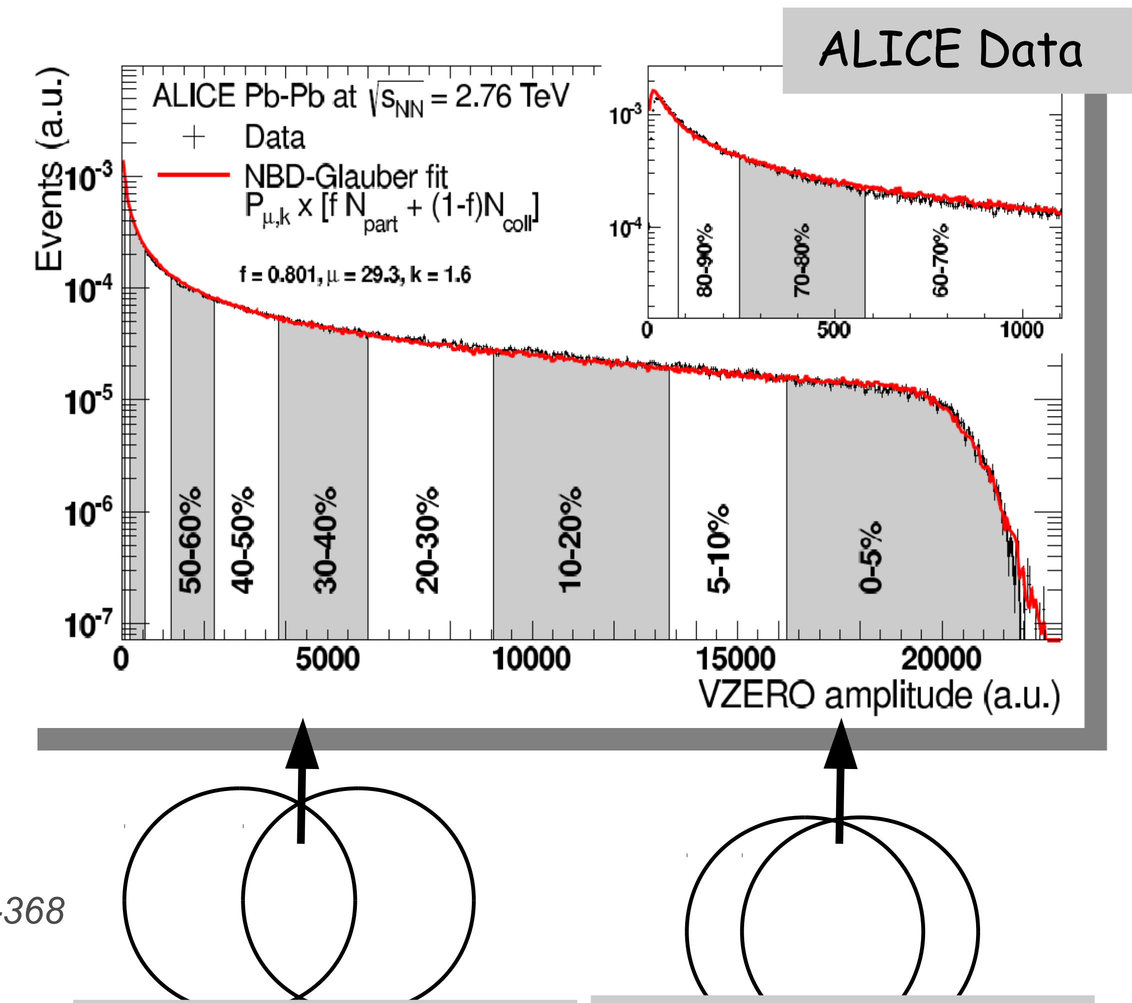


Impact parameter of Pb-Pb collisions

- **It is important for comparison among model anddifferent experiments**
- **It cannot be measured directly (Multiplicity and Glauber)**

Glauber Model:
- N_{part}, N_{coll} associated with the impact parameter b of the collision.

N_{part} → N° participants;
N_{coll} → N° binary collisions.



CERN-PH-EP-2012-368
arXiv:1301.4361v1

Peripheral collision

Central Collision

RAA

Nuclear modification factor

A good way to compare production (pp collisions) with the influence of the hot matter created in PbPb collisions.

$$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \times \frac{\mathrm{d}^2 N_{AA} / \mathrm{d}p_T \mathrm{d}\eta}{\mathrm{d}^2 N_{pp} / \mathrm{d}p_T \mathrm{d}\eta}$$

Ncoll → Number of binary collisions

RAA ~1 → There is no influence of the QGP
RAA < 1 → There is influence of the QGP
RAA > 1 → Some sort of enhancement

A similar factor RpA is used in p-Pb collisions

Disentangle the effects from cold nuclear matter: Shadowing, multiple scattering, etc.

Charm and beauty in ALICE

Open charm:

$D \rightarrow$ Hadrons

$D \rightarrow e + X$

$\Lambda_c \rightarrow \pi K p$, pK^0

Charmonium: $J/\psi \rightarrow ee$

Beauty: $B \rightarrow e + X$,

$B \rightarrow X + J/\psi$

at forward rapidity: measure with muons

Features	*What is needed to detect them*
"Rare" decays	**excellent tracking (TPC + ITS)**
Displaced secondary vertex as signature of heavy-quark decay: = 60µm – 300µm	**good vertexing + impact parameter resolution (ITS)**
High combinatorial background, Specially at low momentum	**good Particle IDentification (TPC, TOF)**

1 – I will talk about open charm, charmonium. Discuss analysis: J/ψ and Λ_c

2 – I will follow with elliptic flow for charm physics.

3 – I will discuss ITS upgrade.

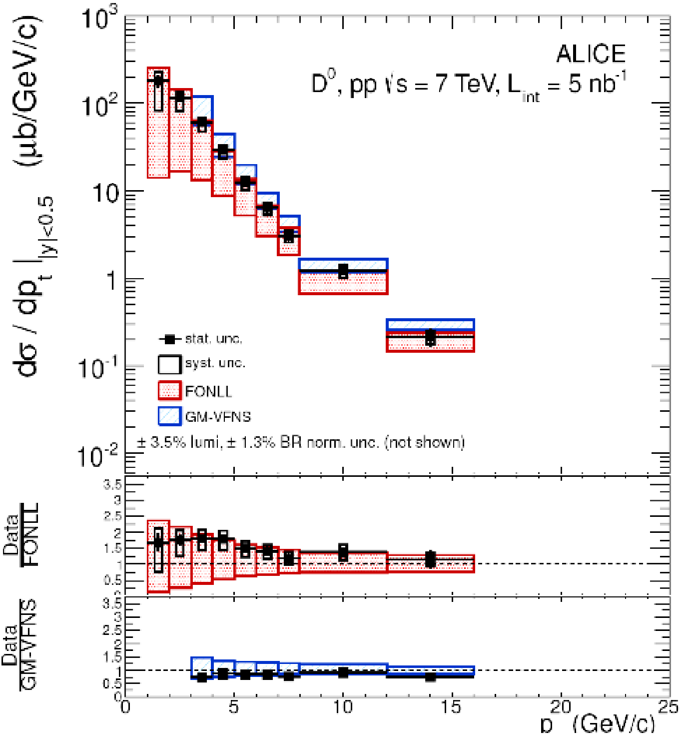
Open charm as a probe of QGP

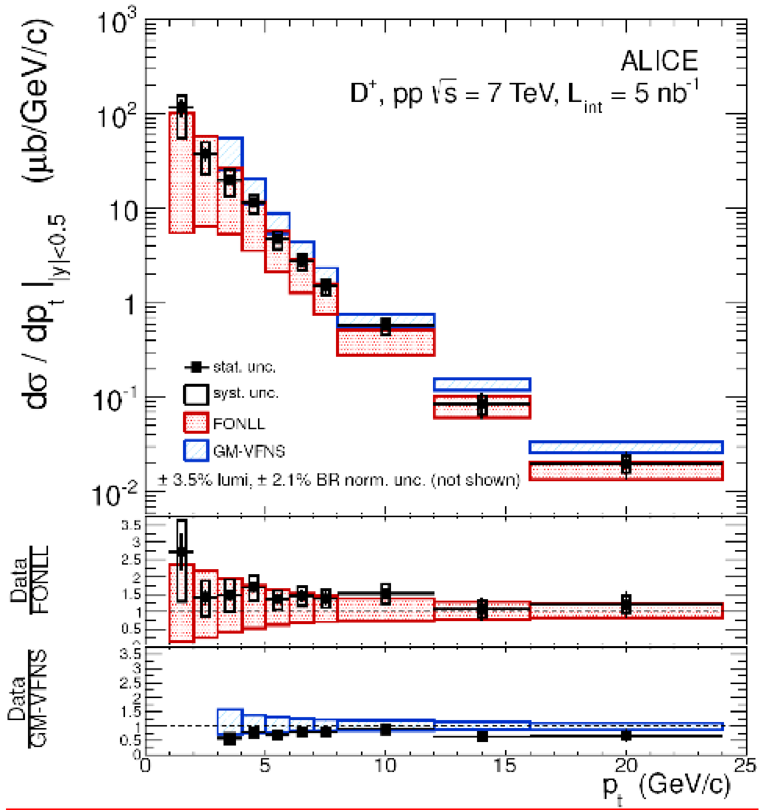
Open charm

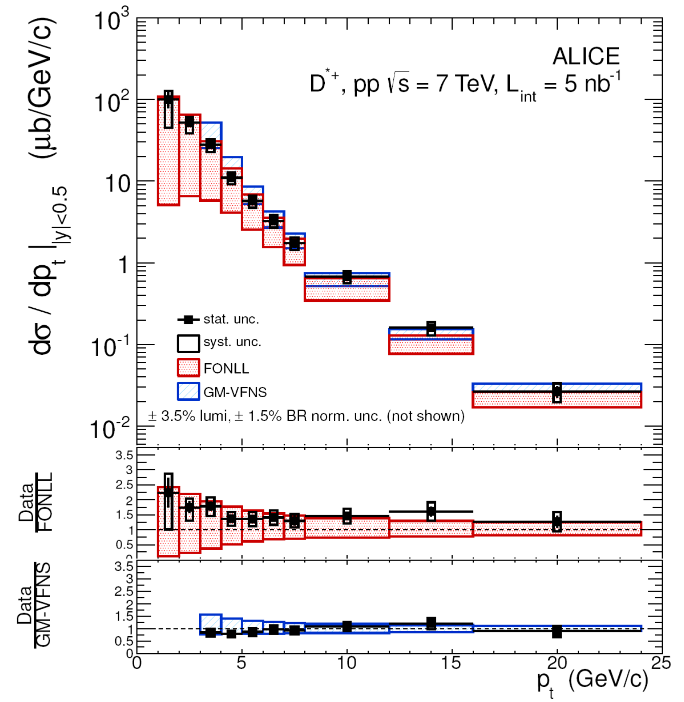
- In pp collisions
  - Baseline for a comparison with the production in Pb-Pb collisions
  - Since heavy quarks have a larger mass
  - They can be studied by pQCD
    - Due to asymptotic freedom → small α_s
- In p-Pb Collisions
  - Cold nuclear matter effects.
    - Not due to QGP formation.
    - Shadowing (changes PDFs), multiple scattering, etc.
- Pb-Pb Collisions
  - Heavy quarks are produced mainly in hard scatterings at early stage in the heavy-ion collisions
    - They are very good probes of the medium.
  - Energy loss of partons.
  - “Dead cone” effects
  - A mass hierarchy in the RAA is expected

Open charm in pp collisions (ALICE)[14]

D+







D^0

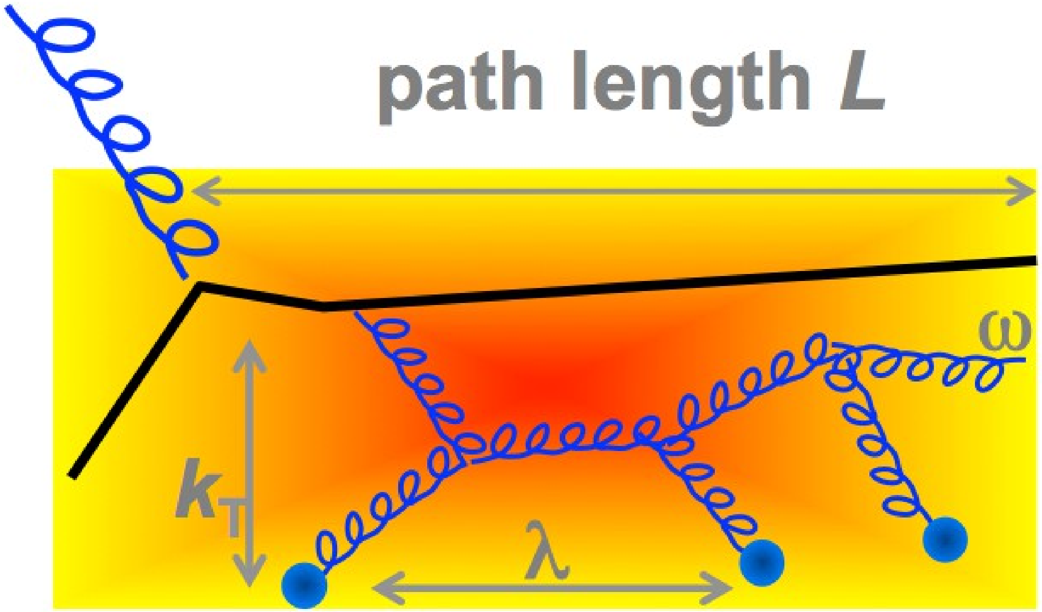
D*

pQCD predictions in agreement with data

JHEP01(2012)128 (arXiv:1111.1553)

Predictions: FONLL (CERN-PHTH/2011-227) , GM-VFNS (arXiv:1202.0439)

Radiative energy loss



$$\hat{q} = \frac{\langle k_T^2 \rangle}{\lambda}$$ Transport coefficient

BDMPS-Z formalism

$$\omega \frac{dI}{d\omega} \propto \alpha_s C_R \sqrt{\frac{\hat{q} L^2}{\omega}}$$ Distribution of radiated-gluon energy

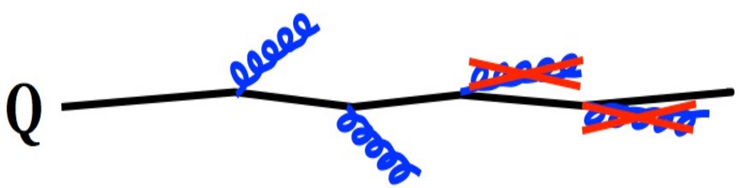
CR → Casimir coupling factor: 4/3 for quarks and 3 for gluons

Mass hierarchy → $RAA^B > RAA^D > RAA^{\pi}$

Baier, Dokshitzer, Muelle, Peigné, Schiff, NPB 483 (1997) 291
Zakharov, JTEPL 63 (1996) 952
Salgado, Wiedemann, PRD 68(2003) 014008
HCPSS2013, CERN – A. Dainese

"Dead cone" effect

Gluon radiation supressed:



$\theta < m_Q/E_Q$

It depends upon the quark mass

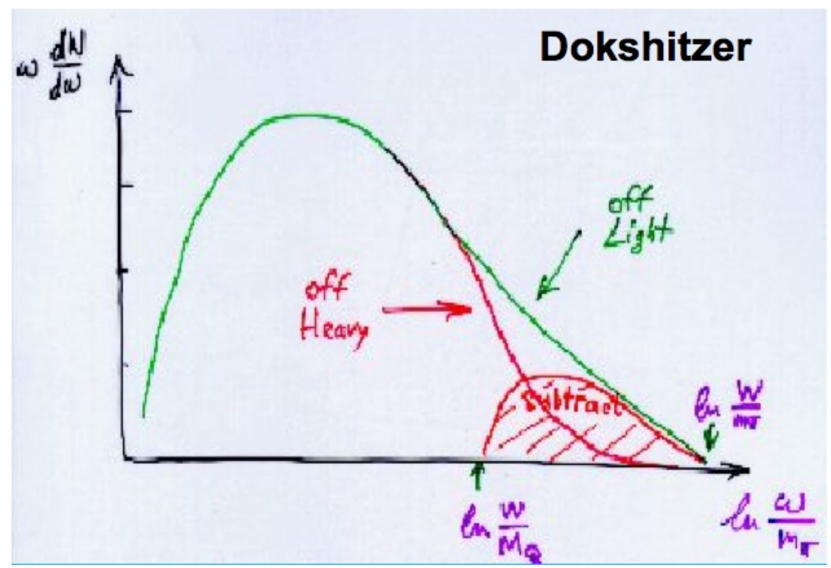
Mass hierarchy → $RAA^B > RAA^D > RAA^\pi$

Gluonsstrahlung probability

$$\propto \frac{1}{[\theta^2 + (m_Q/E_Q)^2]^2}$$

$$\omega \frac{dI}{d\omega}\bigg|_{HEAVY} = \omega \frac{dI}{d\omega}\bigg|_{LIGHT} \times \left(1 + \left(\frac{m_Q}{E_Q}\right)^2 \frac{1}{\theta^2}\right)^{-2}$$

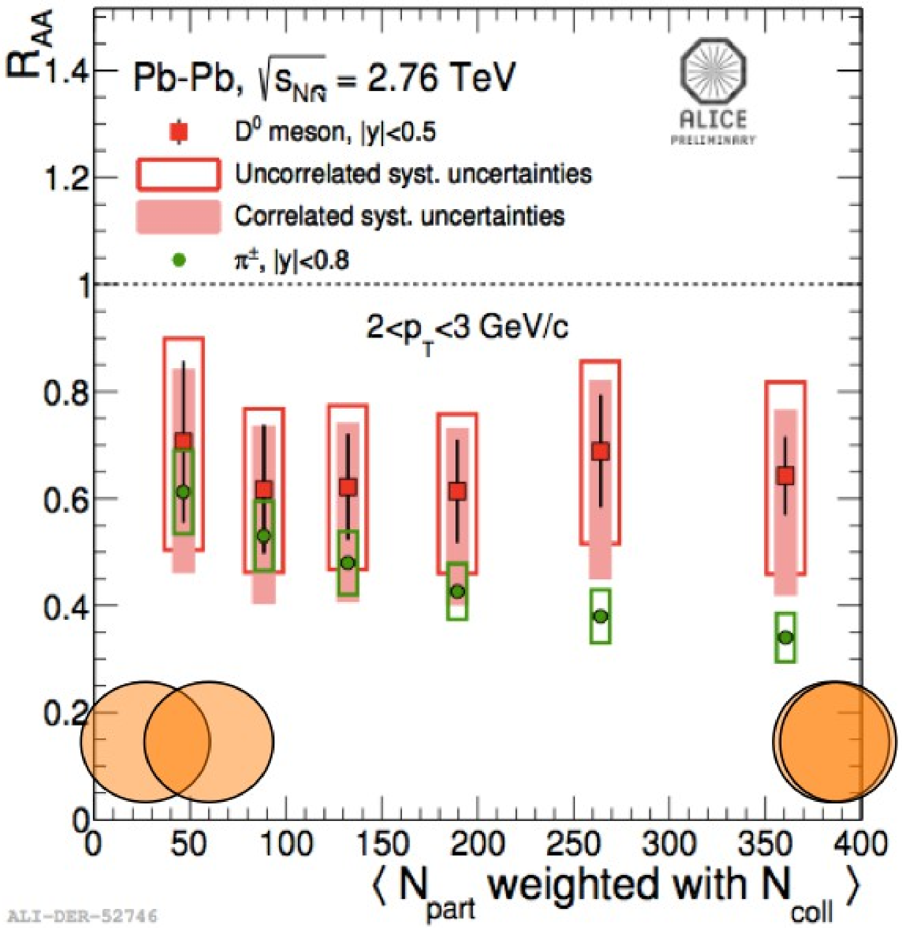
"Dead cone" effect
Lower energy loss

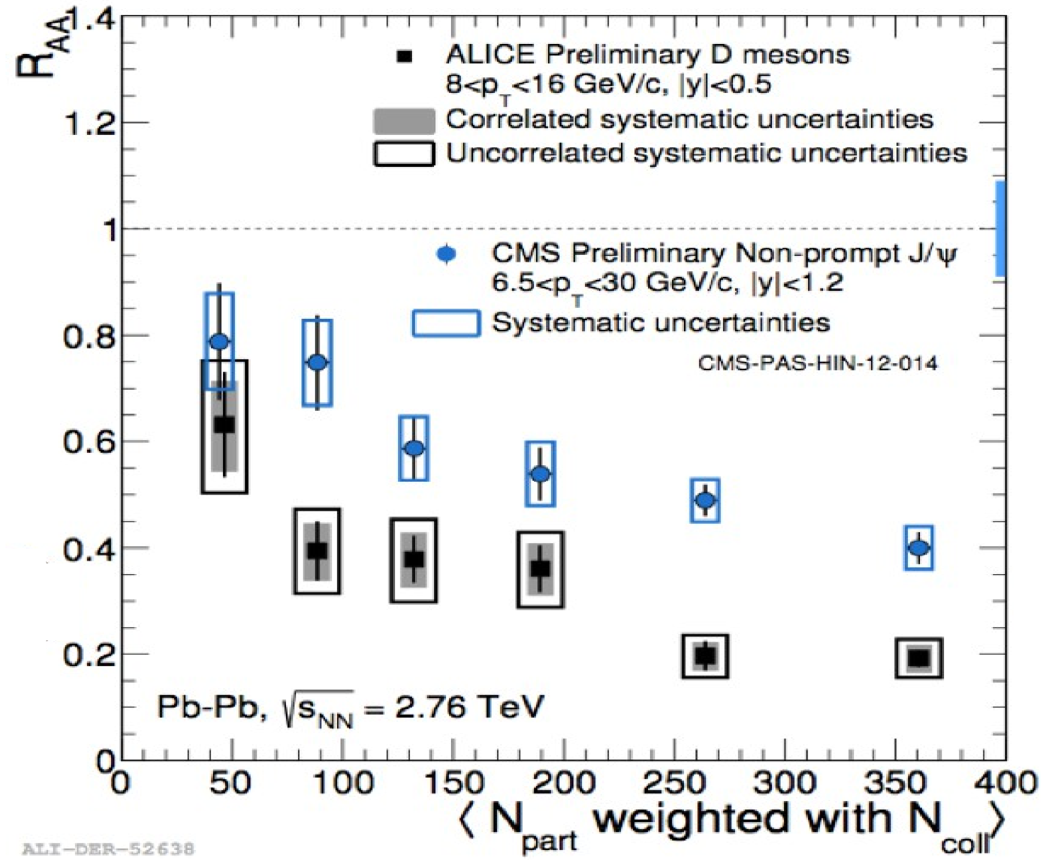


Dokshitzer, Khoze, Troyan, JPG 17 (1991) 1602
Dokshitzer and Kharzeev, PLB 519 (2001) 199

HCPSS2013, CERN – A. Dainese

RAA Measurements (ALICE)



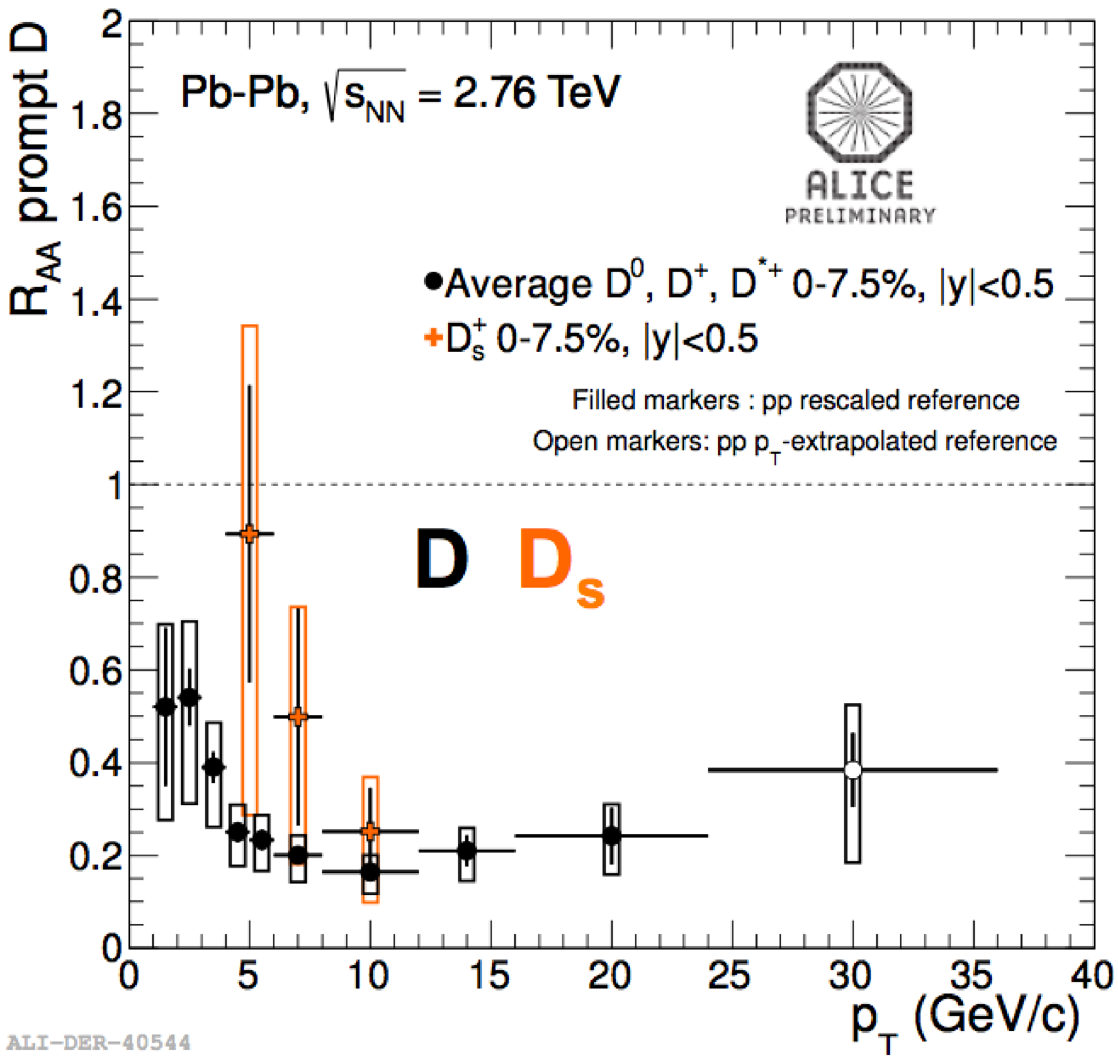


RAA of D Mesons compatible with pions, given the current statistics.

RAA of D Mesons (higher momentum) is lower than those measured for non-prompt J/ψ

Results are in agreement with it was predicted.

D_s Measurements (ALICE)



D_s RAA different from the other D mesons

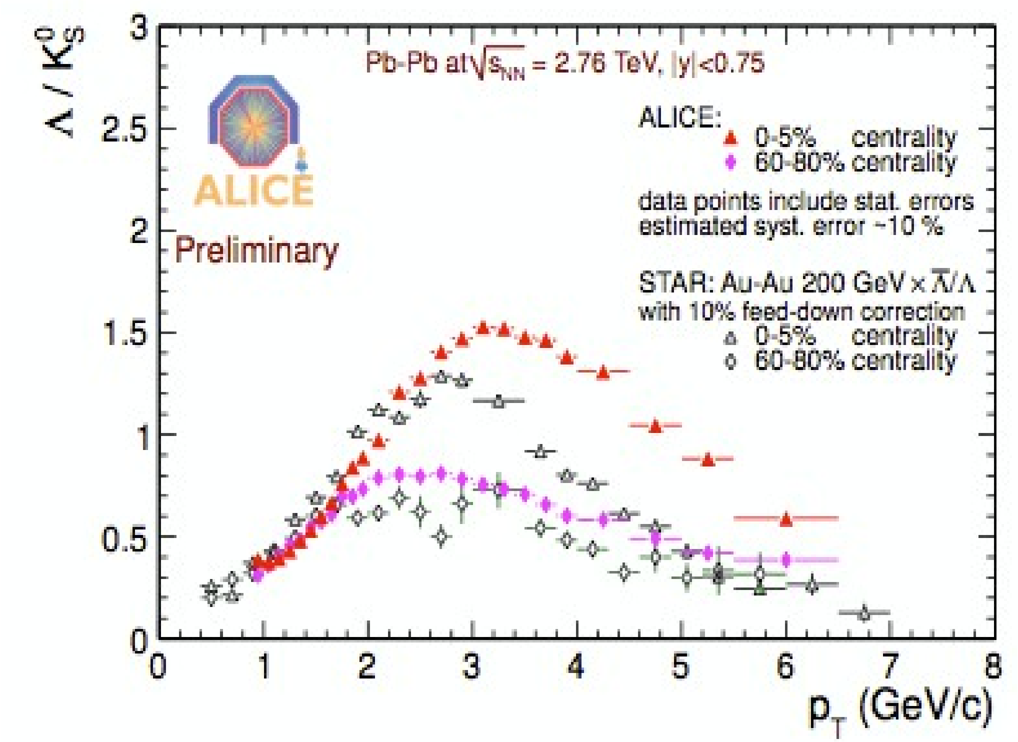
Due to strangeness enhancement?

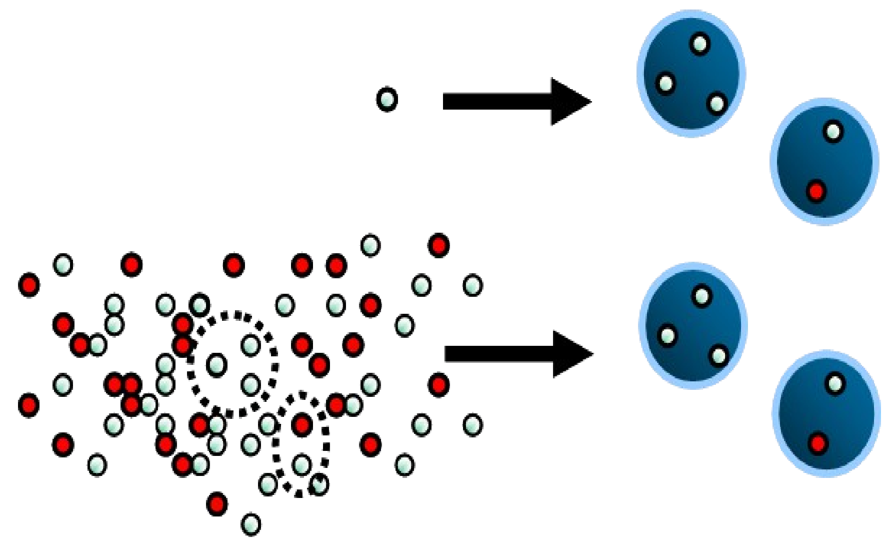
Still low statistics for D_s

$D_s \rightarrow KK\pi$ ($c\tau$~150 μm) vs. $D^0 \rightarrow K\pi$ ($c\tau$~120 μm)

Motivation Λ_C/D (ALICE)

Probe the hadronization mechanism with the baryon/meson ratio:
Λ_C/D , Λ_b/B



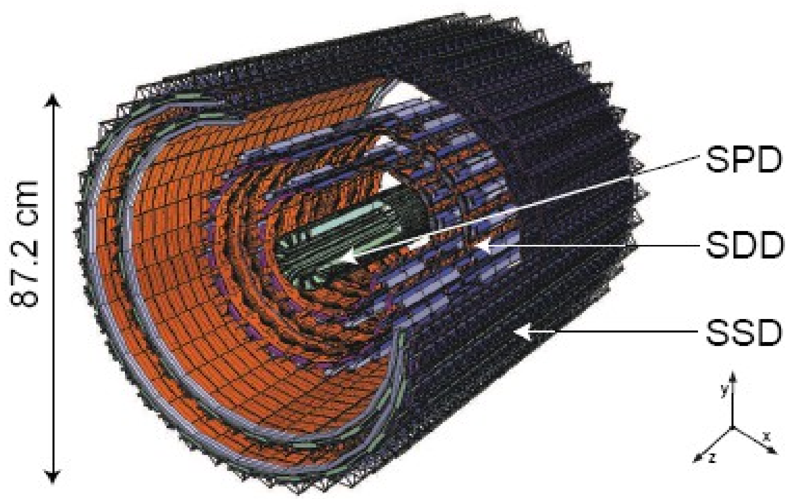


The baryon/meson ratio in the strangeness sector, suggests coalescence. Does this hold in the charm sector?

Analysis

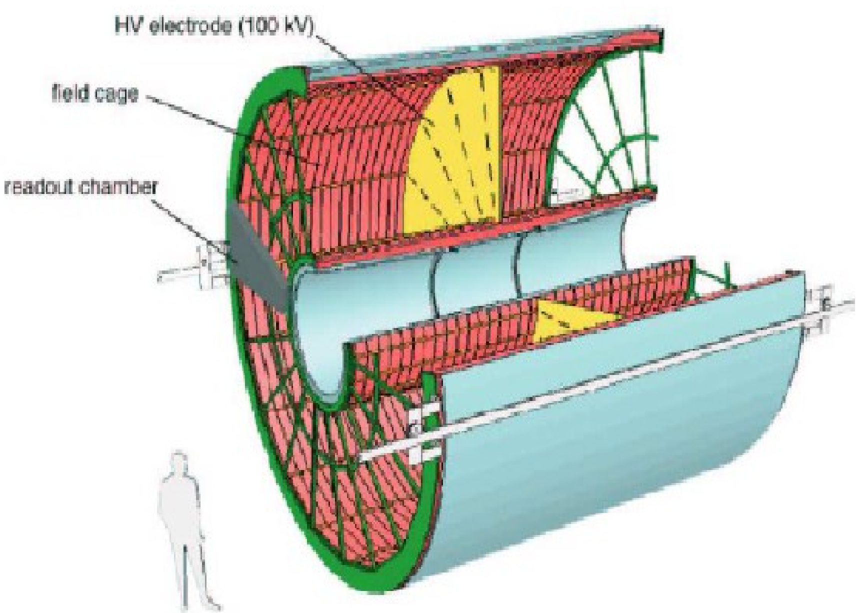
$\Lambda_c^+ \rightarrow pK^-\pi^+$

Tracking and vertexing



Good Vertexing and Impact parameter

Inner Tracking System (ITS)
SPD → Silicon Pixel Detector
SDD → Silicon Drift Detector
SSD → Silicon Strip Detector



Very good tracking
Momentum resolution close to its design
~ 8 % at p_T = 10 GeV/c
< 1% at p_T < 1 GeV/c

Up to 3000 charged particles/η
$\sigma(p_T)^2 = (0{,}01)^2 + (0{,}007.p_T)^2$

arXiv:1001.1950

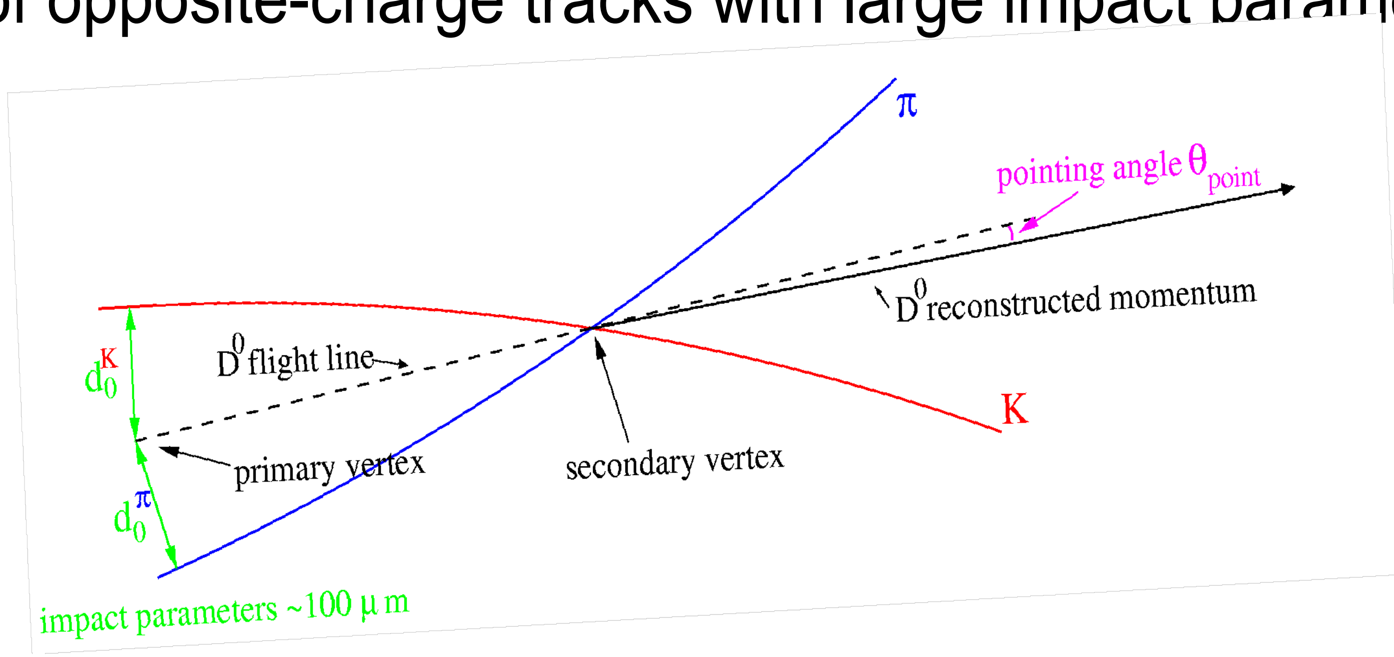
Strategy

1 – Charm Candidates (vertex analysis)
2 – In. Mass Plots (Raw Signal) → as in J/y case
3 – Corrections → Efficiencies, Acceptance and Feed-down from B

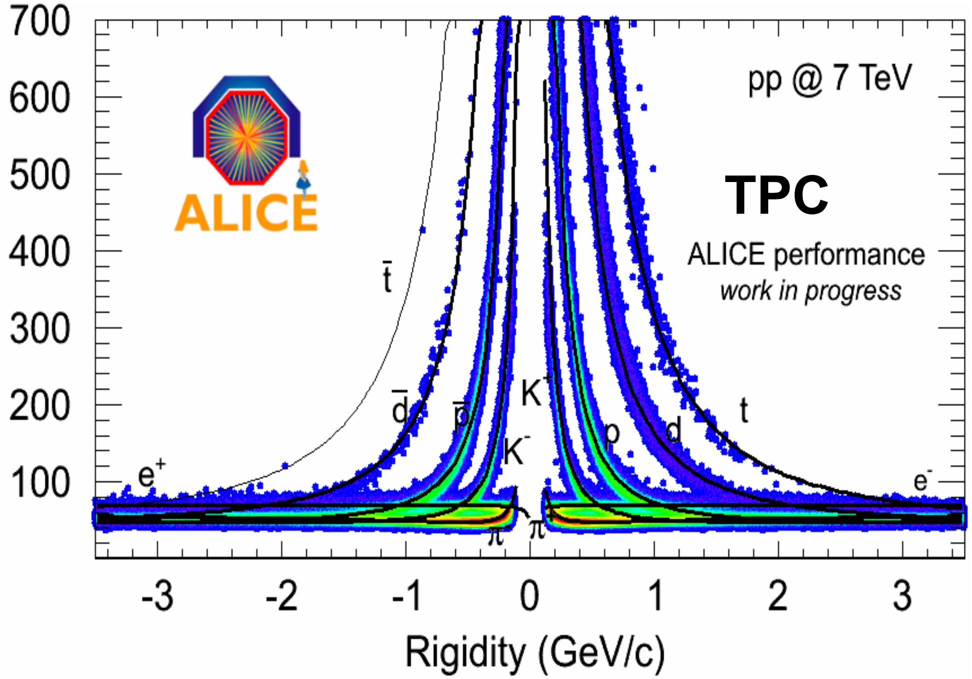
Example: $D^0 \rightarrow K^- \pi^+$:

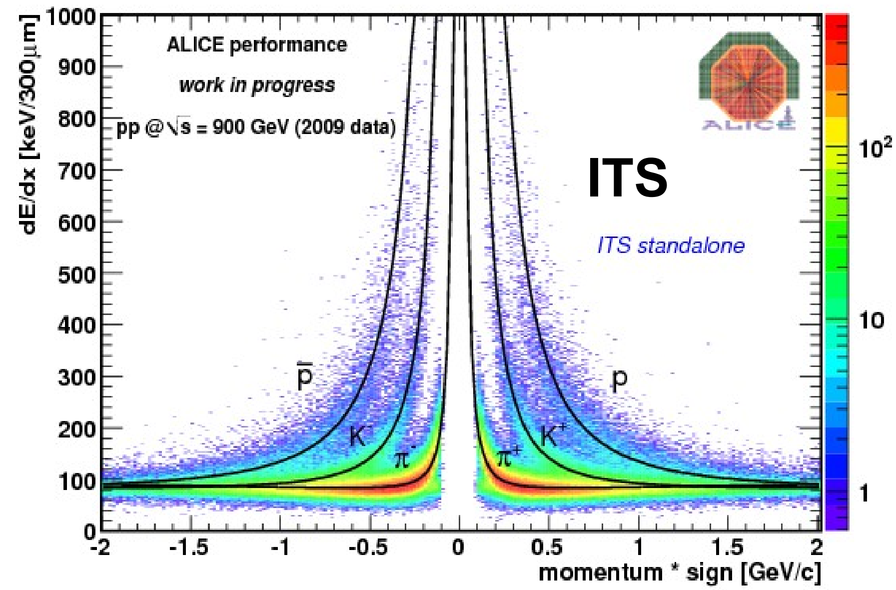
good pointing of reconstructed D momentum to the primary vertex

pair of opposite-charge tracks with large impact parameters

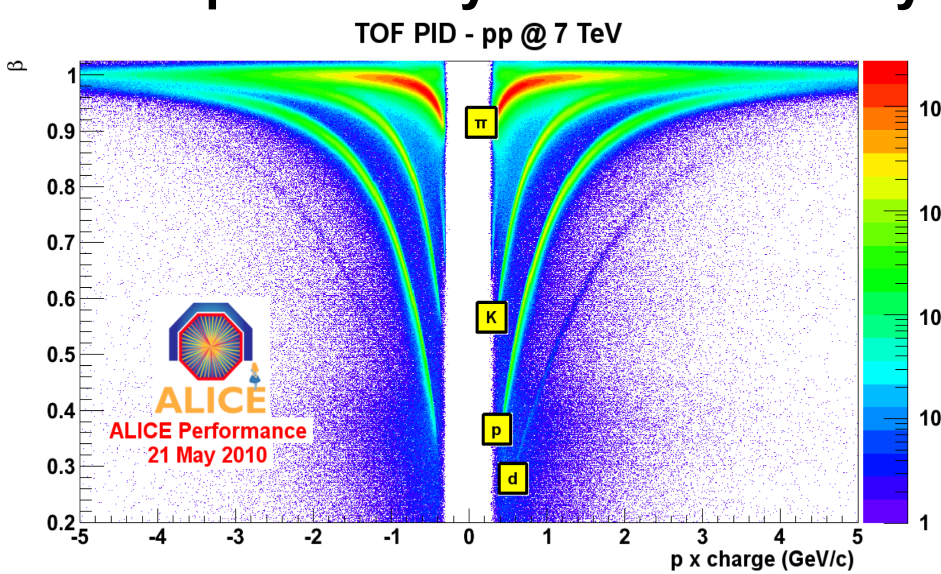


Particle Identification – PID





The detectors are complementary and cover a very good p_T range



TOF

Λ_c Measurements

- Λ_c is very interesting and challenging:
  - Need to measure the baryon to meson ratio in the charm sector
  - Useful to measure the total charm cross section → pretty unique even in pp collisions
  - Challenging: cτ = 60 μm only!
  - Not yet measured in p-p,p-Pb and Pb-Pb!
- Decay channels under study:
  - **Λ_c^+** → p K^- π^+ : B.R. 5 ± 1.3%
    - non resonant: B.R. 2.8 ± 0.8%
    - resonant: p $K^*(892)^0$: B.R. 1.6 ± 0.5%

      $\Delta(1232)^{++}$ K^- : B.R. 8.6 ± 3.0 10^{-3}

      $\Lambda(1520)$ π^+ : B.R. 1.8 ± 0.6%
  - **Λ_c^+** → K^0 p: B.R. 2.3 ± 0.6 %

    → 50% K_S^0 → $\pi^+\pi^-$ (B.R. 69.20 ± 0.05 %)

This analysis is carried out in Liverpool in 3 different collision systems:

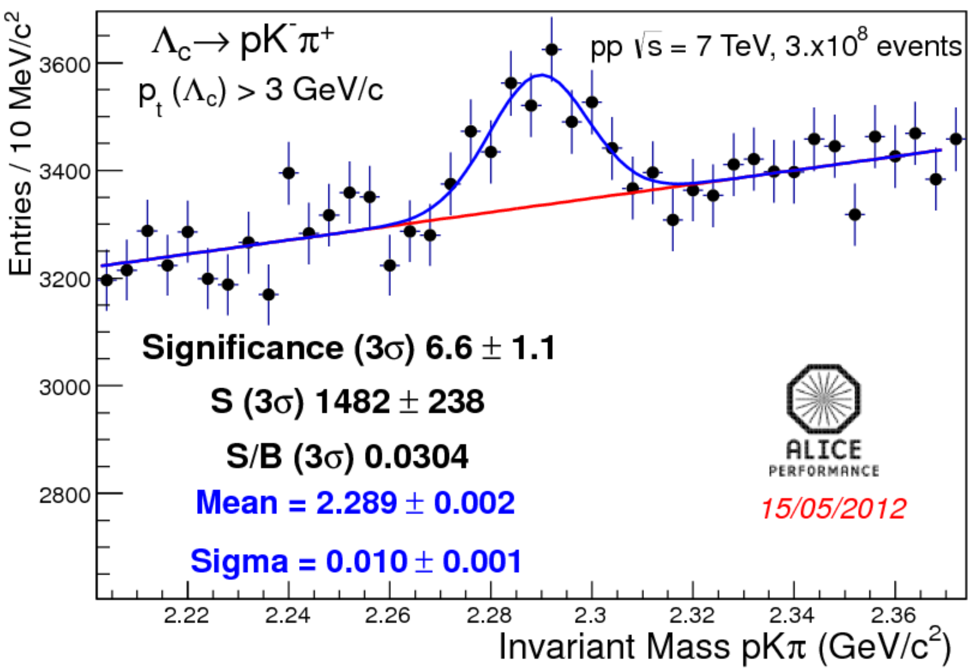
In pp, pPb and PbPb collisions

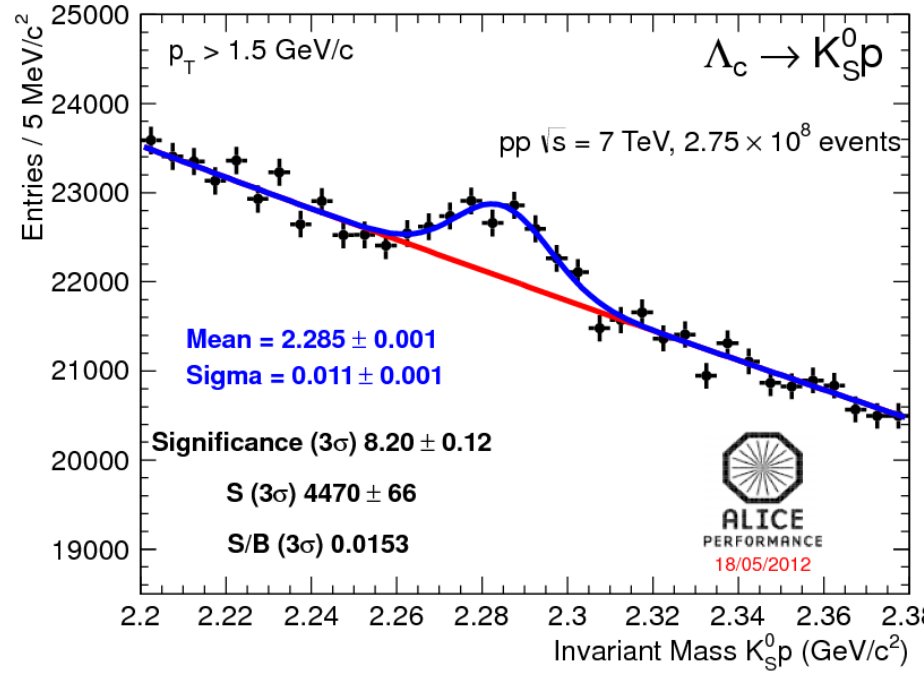
Λ_c Signal (ALICE)

Signal seen in different p_T bins

($1<p_T<6$ GeV/c), in 2 decay channels:

- **$\Lambda_c^+ \rightarrow p K^- \pi^+$: cover higher p_T**
- **Λ_c^+** $\rightarrow K^0 p$: cover lower p_T





$\Lambda_c \rightarrow pK\pi$

Large background → PID essential!

Use Bayesian PID:

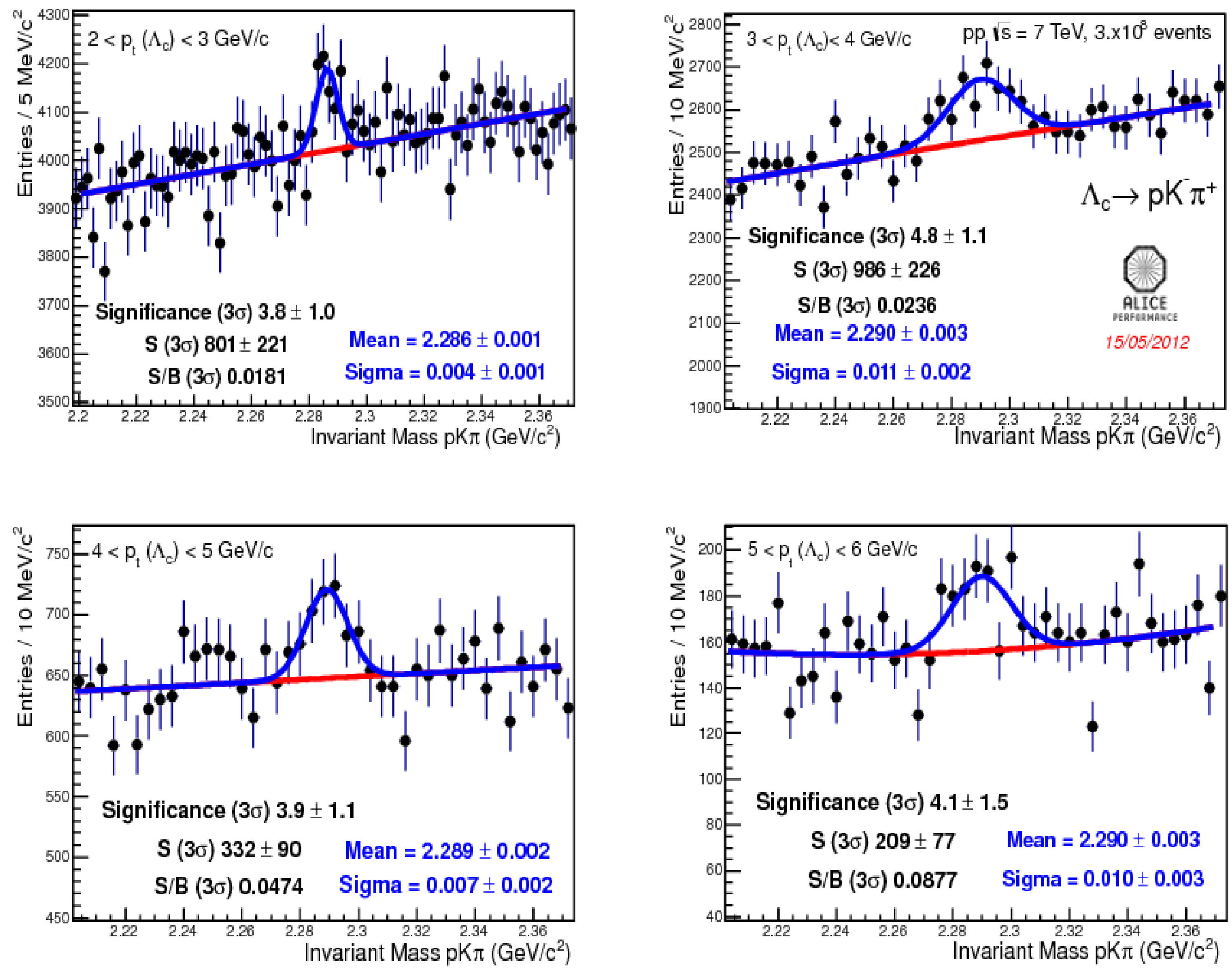
- priors from pp data
- TPC and TOF

Good results

- 300Mevts analysed
- In pp@7 TeV
- 4 p_T bins

We also have succesfully extracted the signal in p-Pb

Not asked for approval yet.

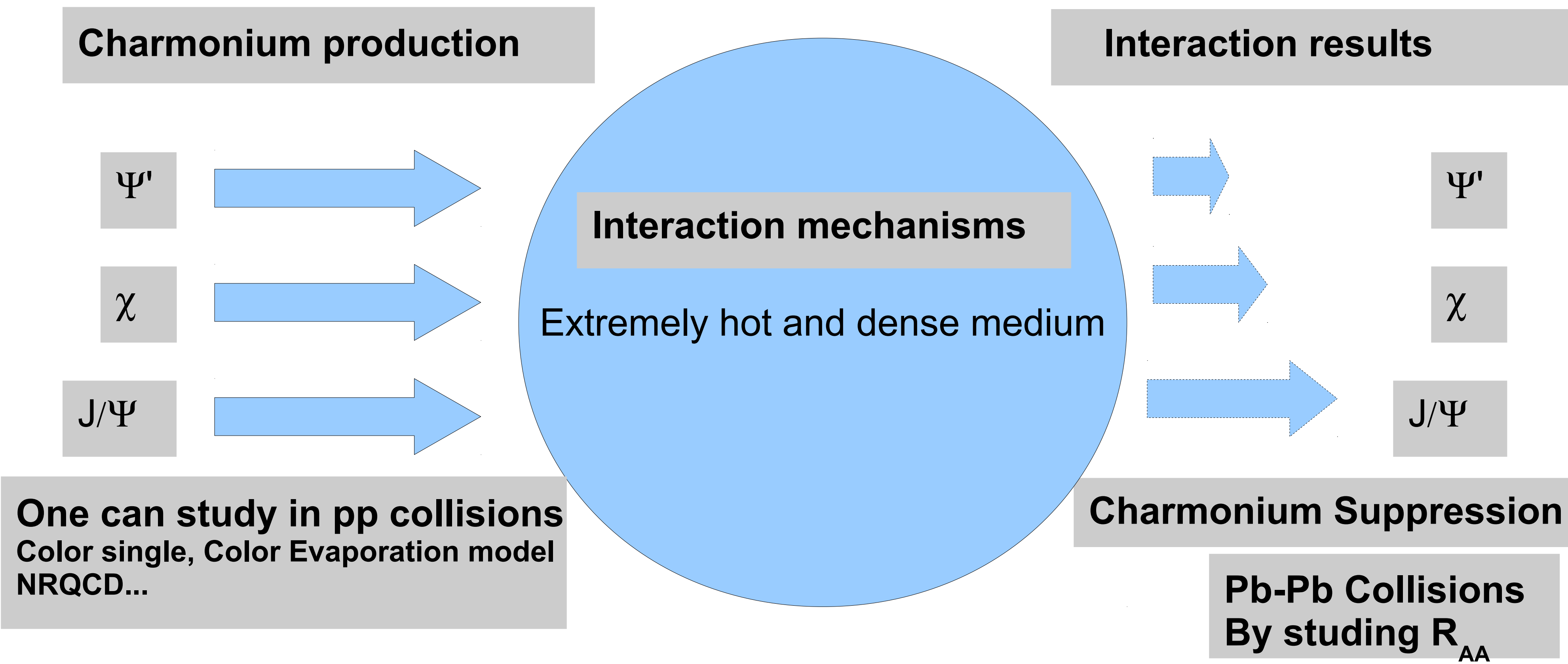


Charmonium as a probe of QGP

Charmonium as a probe of QGP

Heavy quarks are produced early in the collision.

The study of mesons composed by these quarks can be used to study their interaction with the “fireball” generated by relativistic heavy ion collisions.



Charmonium Production – pp collisions

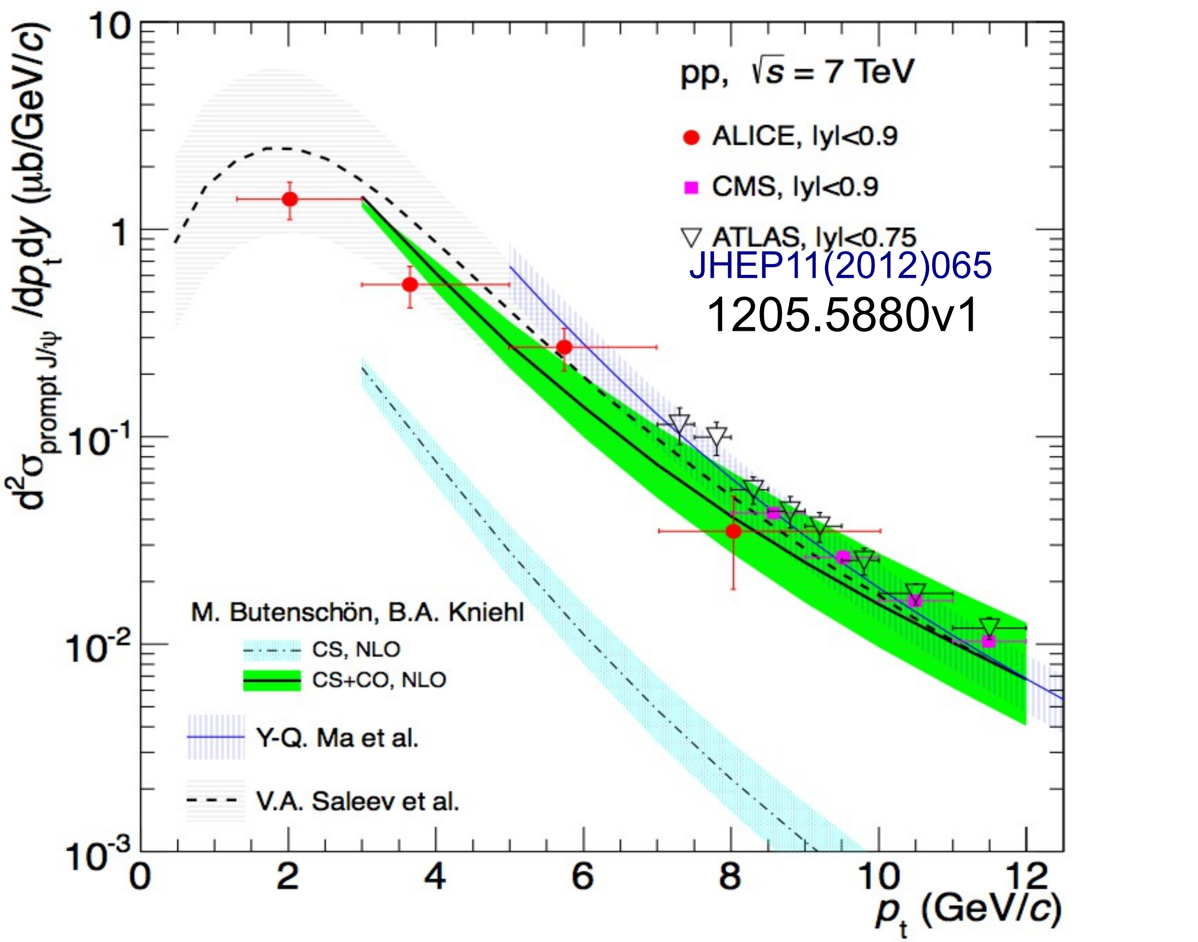
Two stages are generally considered:

Pair Q-Qbar formation; Perturbative process → pQCD

Bound state development (charmonium); Non Perturbative process

Models normally studied:

- **Color Singlet Model (CSM);**
- **Color Evaporation Model (CEM)**
- **Non-Relativistic QCD (NRQCD).**

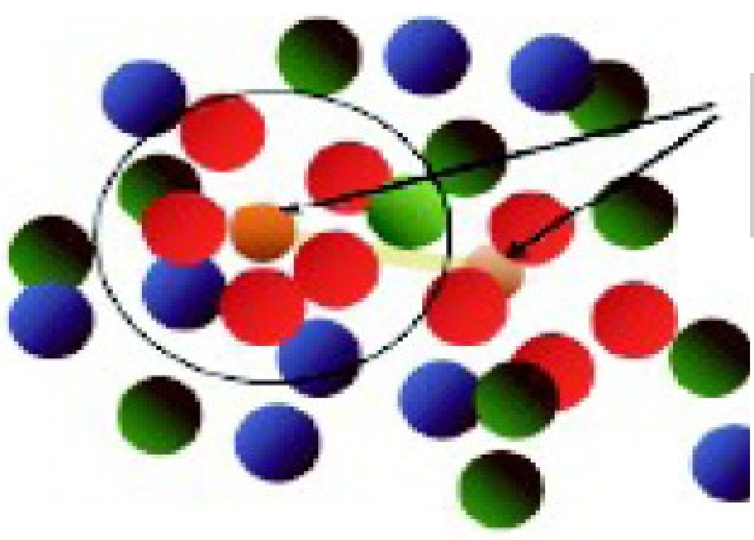


Charmonium supression/regeneration

In a environment with free quarks and gluons(QGP), heavy quarkonium states could dissociate by color screening.

Debye radius becomes < Charmonium radius (the same for bottomonium).

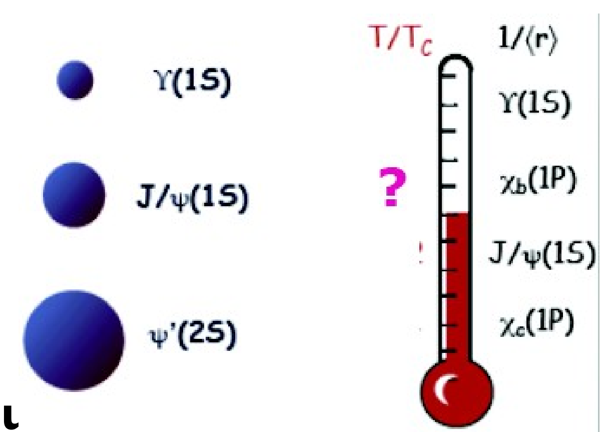
arXiv:0901.3831v1 [hep-ph]
L. Kluberg and H.Satz



Color screening
$R_D < R_{QQbar}$

Different states of heavy-quarkonium with different sizes

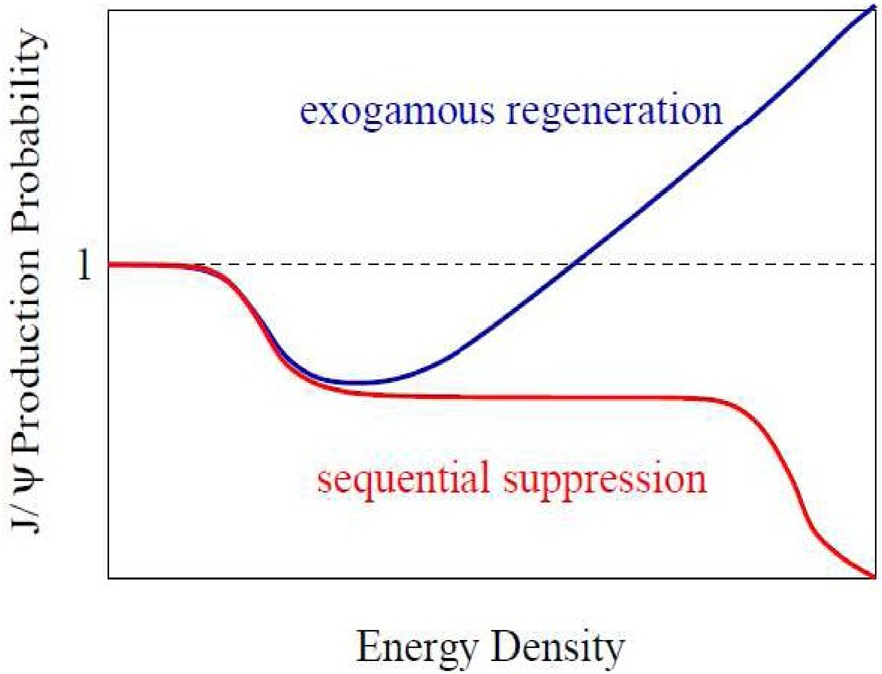
State	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
Mass (GeV)	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE (GeV)	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM (GeV)	0.02	−0.03	0.03	0.06	−0.06	−0.06	−0.08	−0.07
r_0 (fm)	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78



Heavy-quarkonium → different levels of suppression
The different bound states can be used as thermometer of the medium

Charmonium Enhancement

arXiv:0901.3831v1 [hep-ph]
L. Kluberg and H.Satz



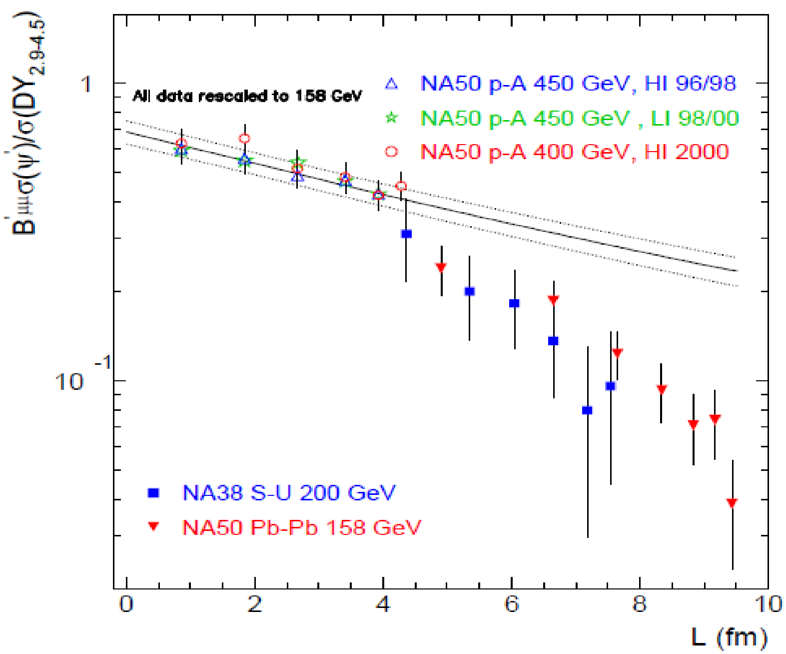
Too much more c-cbar at LHC!

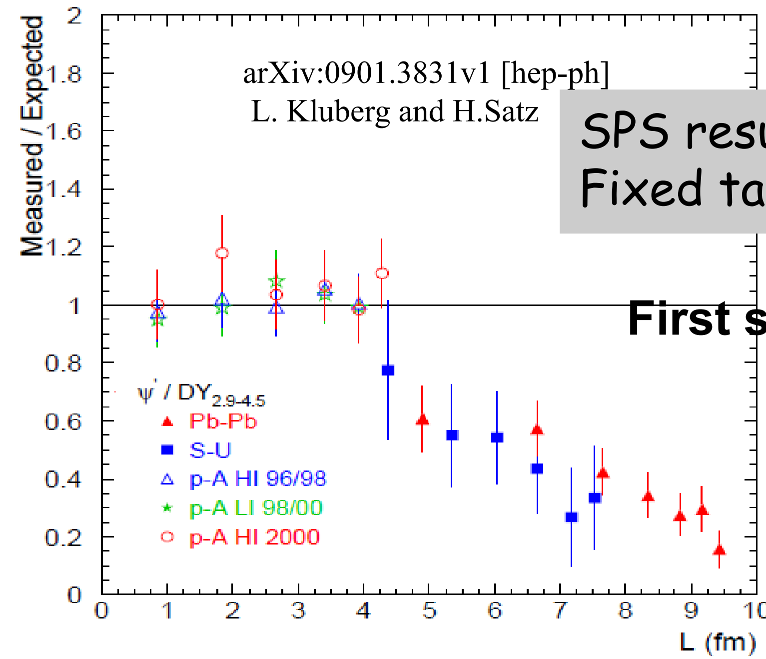
In most central A-A collisions	SPS 20 GeV	RHIC 200 Gev	LHC 2.76 TeV
N_{ccbar}/event	~0.1	~10	~100

HCPSS2013, CERN – A. Dainese

If the medium is very populated with c-cbar Random c and cbar existing in the medium can combine during hadronization → enhancement of charmonium.

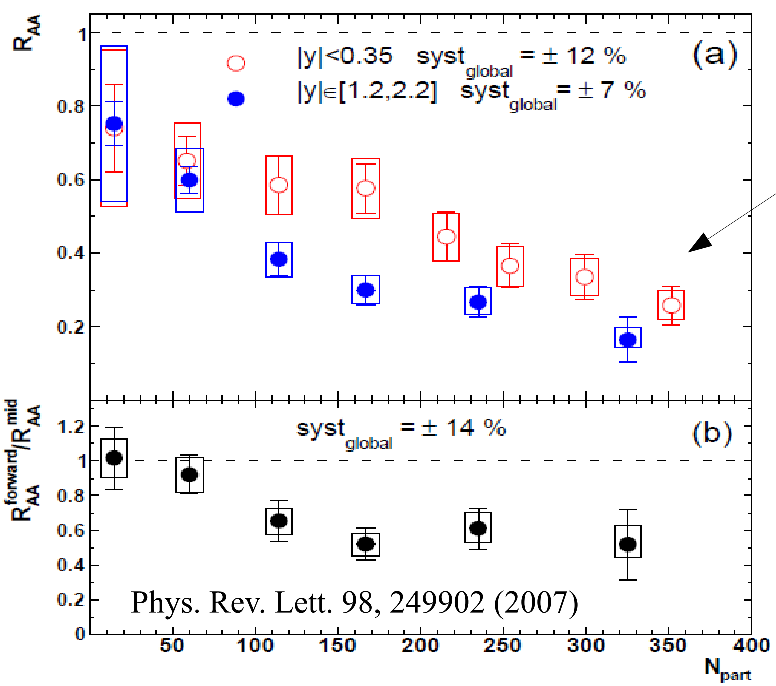
Charmonium supression?





SPS results: A-A and p-A
Fixed target experiment

First suppression seen



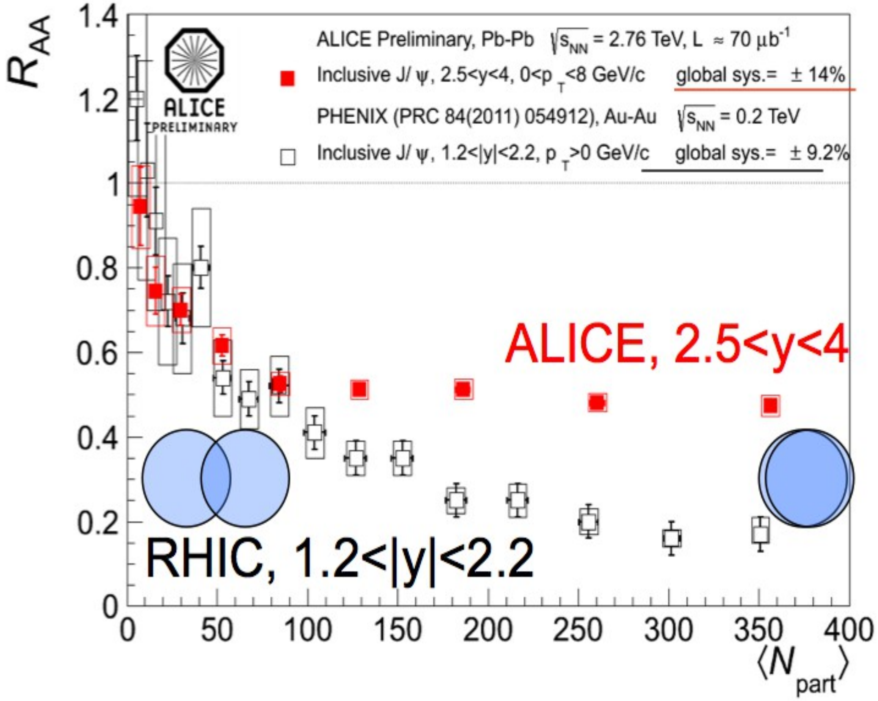
Au-Au collisions (collider) PbPb @ 200 GeV

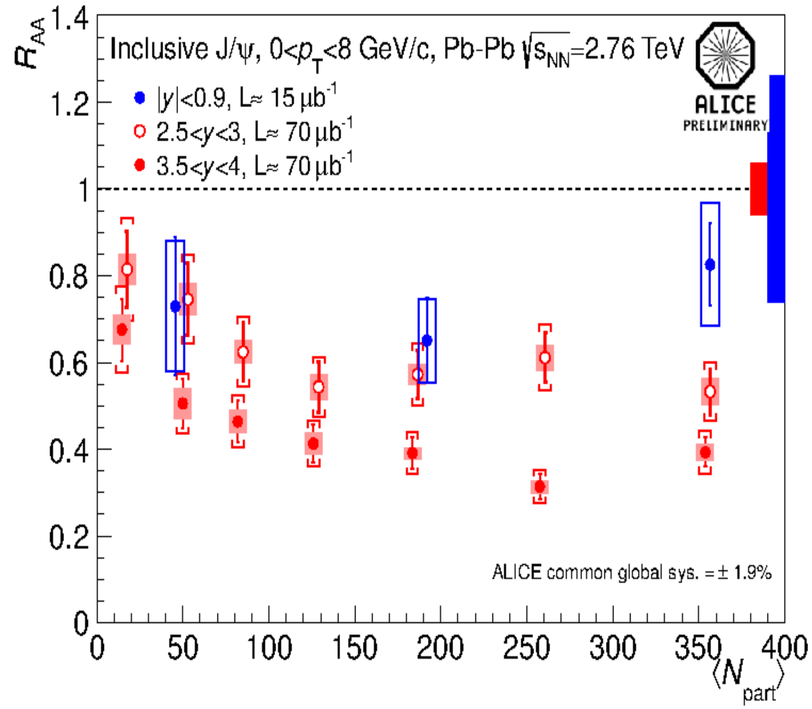
More suppressed at Forward rapidity

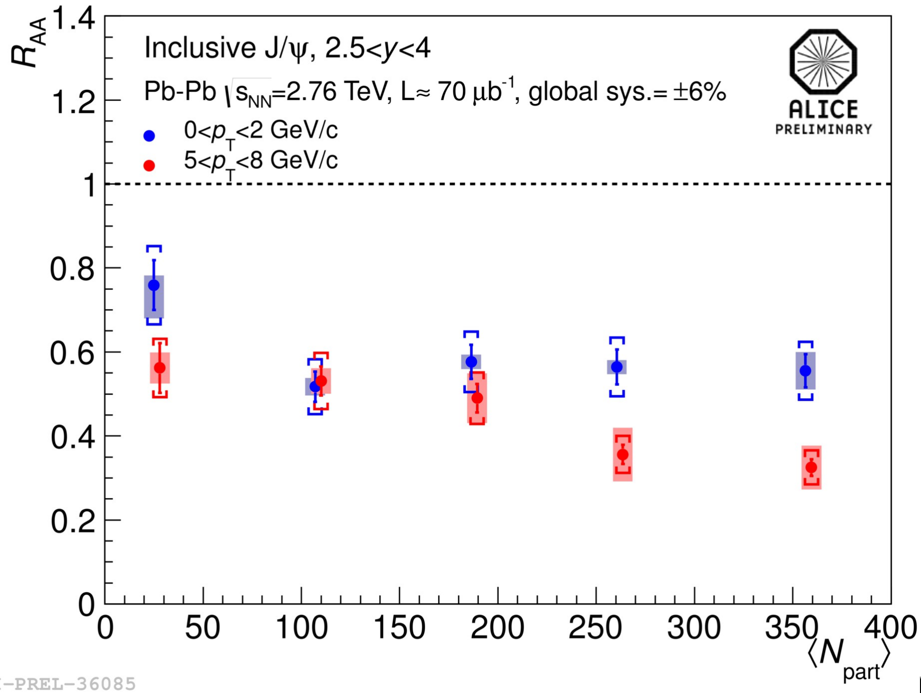
Normal supression
Not due to QGP (studied p-A or similar)

Anomolous supression
Due to QGP

RAA measurements (ALICE)







ALI-PREL-36085

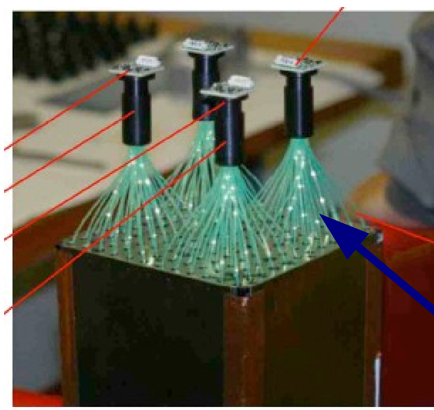
Higher energy than RHIC (PbPb at 2.76 TeV)
Supression is lower than at RHIC.
We still see rapidity dependency as RHIC
J/ψ pt dependency
RAA is lower for higher pt in most central

The results support models for enhancement

J/ψ analysis
With EMCal triggered events

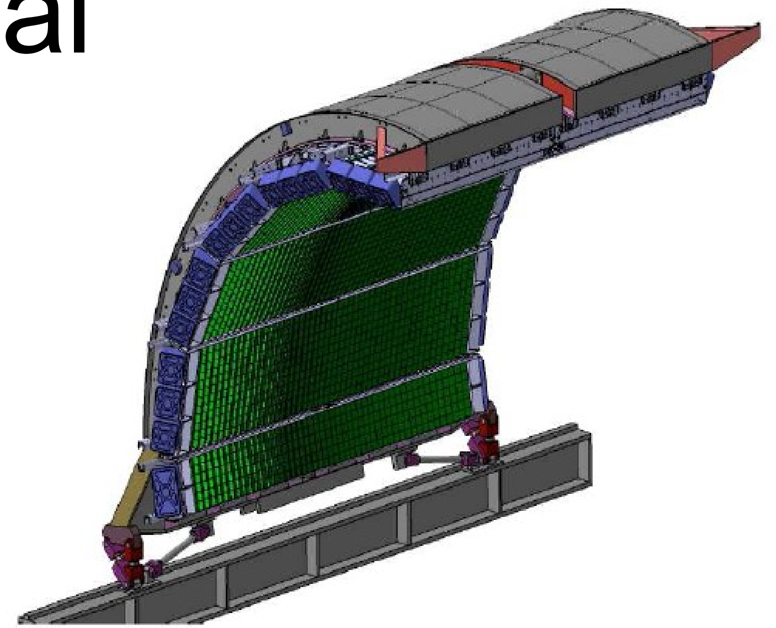
The EMCal

12 SM → $\Delta\phi$=107°, -0,7 < η<0,7;
In 2011 (10 SM) → $\Delta\phi \sim$ 100° – $\Delta E/E = 10\%/(E)^{1/2}$.

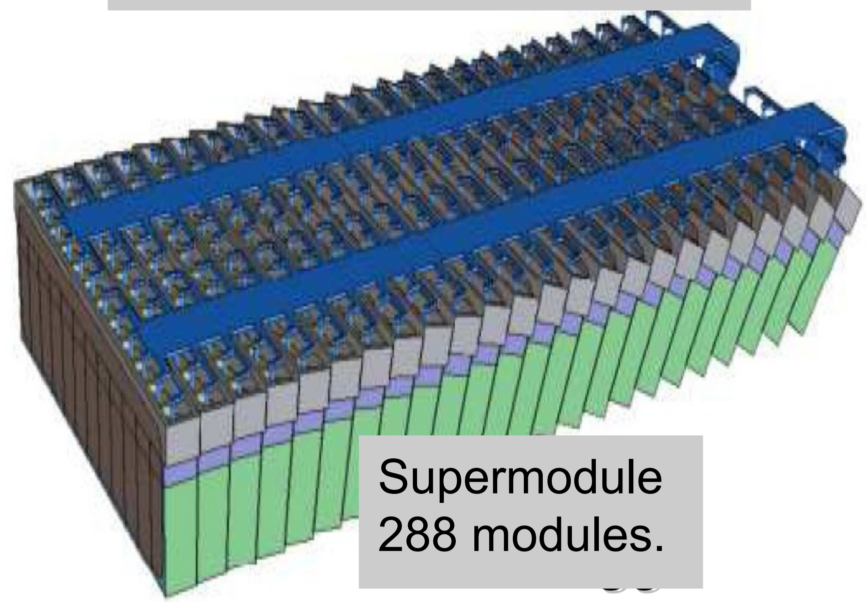


1 EMCal module (2x2 towers): Readout electronics In the back side.

1 tower ~ (6x6x24,6) cm³



Array of super modules of The EMCal

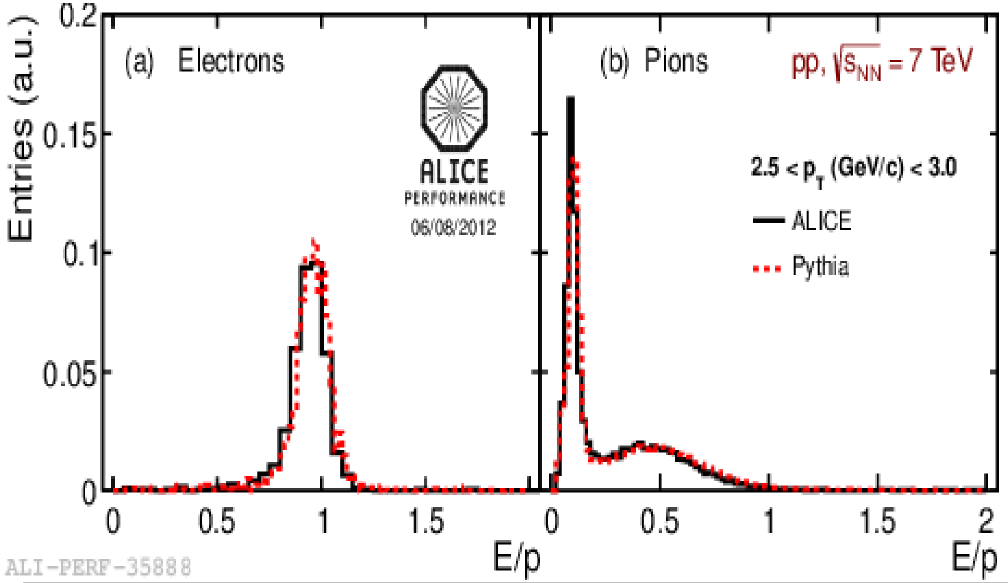


Supermodule 288 modules.

EMCal → Energy of particles photons, pion-0 and electrons.
PID for electrons→ Combination with TPC tracks
Fast trigger → High energy particles

PID:EMCal

Track → momentum;
Energy → EMCal.



E/p ~ 1 electrons;
E/p << 1 pions.

Energy from EMCal *clusters*;

Track is extrapolated to the TPC

Reconstruction strategy

J/ψ by the electron/positron decay channel

There are some challenges for the measurement.

Combination of all electrons with all positrons in a given event (p-p, Pb-Pb or p-Pb collision)

Need good electron identification

Methods for background estimation.

EMCal triggered events were studied:

Selecting events event high energy pi-0, gammas and electrons
E > 5 GeV in pp collisions
E > 5 (Peripheral) and E > 10 GeV (Central)

J/ψ – Reconstruction

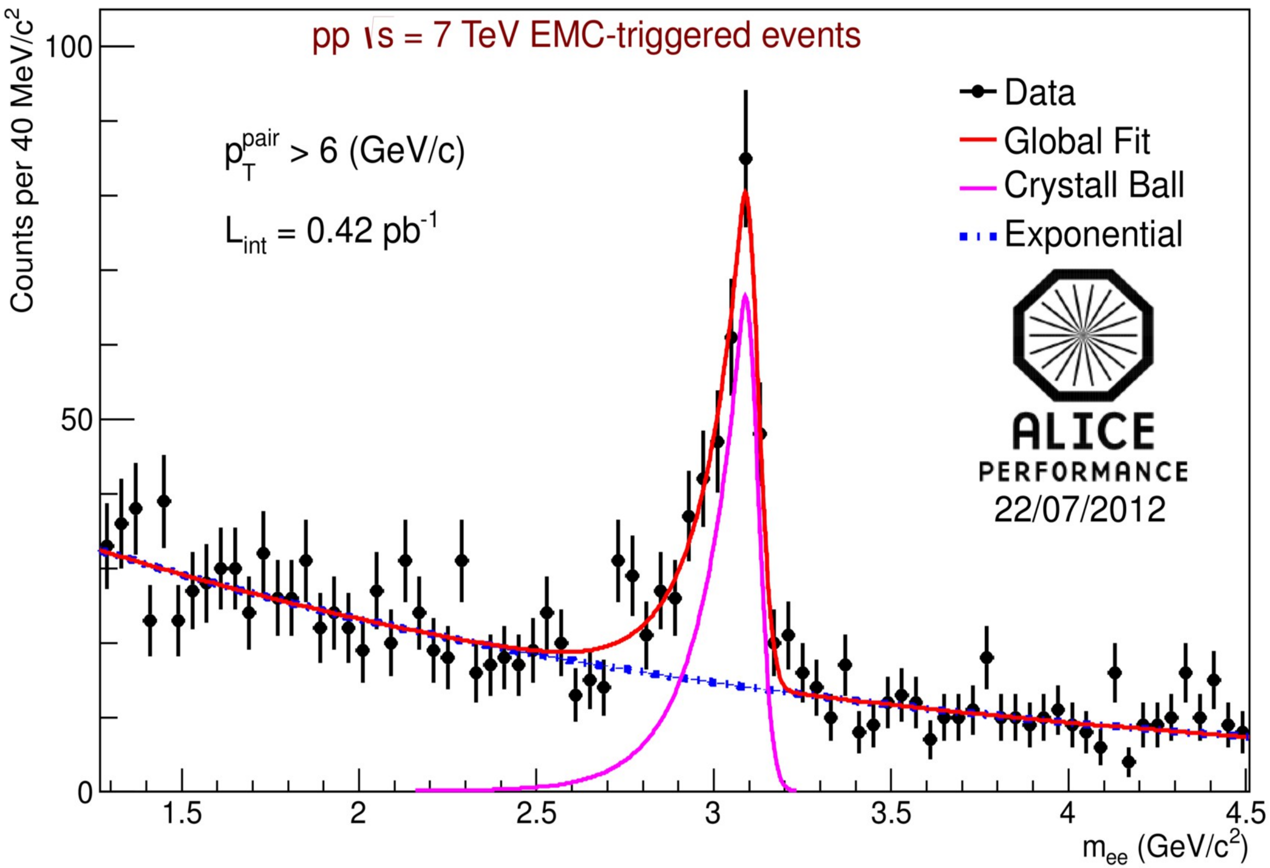
From EMCal Triggered events → pp collisions at 7 TeV

Crystal Ball(Signal) + Exponential fit (background);

Approx. 30 J/ψ per million events recorded.

Approx. 1 J/ψ per million events in Minimum Bias.

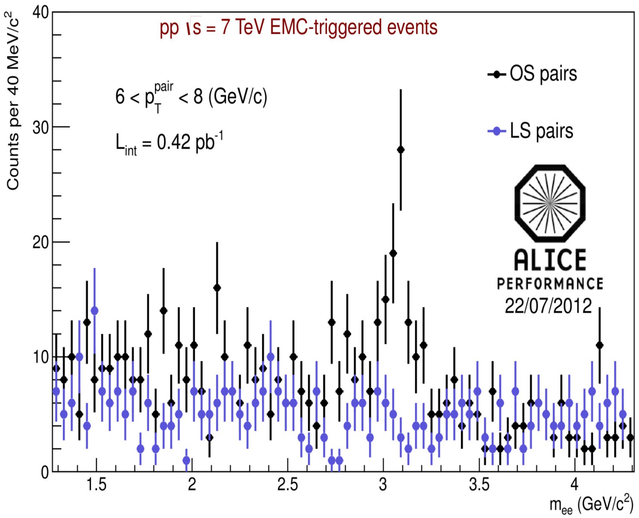
A gain of a factor of 30 per event.



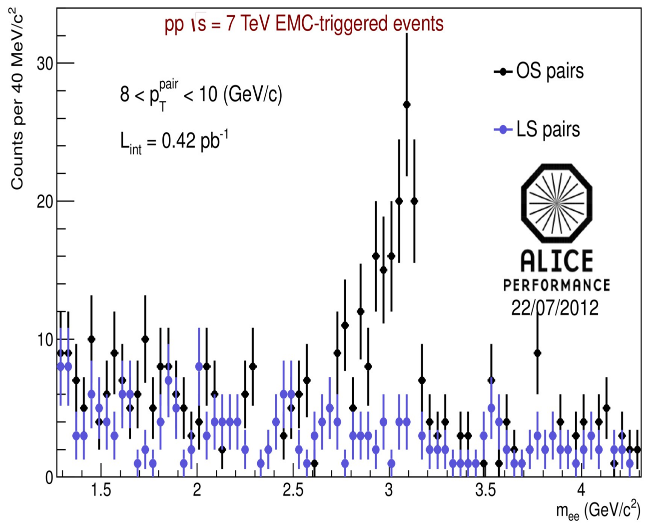
ALI-PERF-27234

Particle identification
Combination of EMCal and TPC

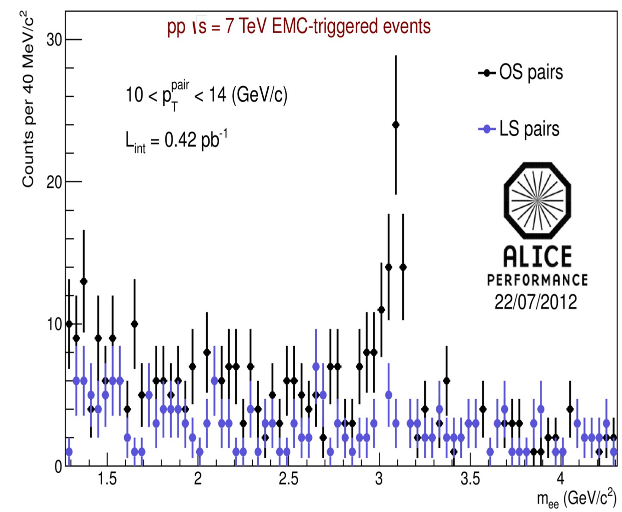
Invariant Mass Spectrum



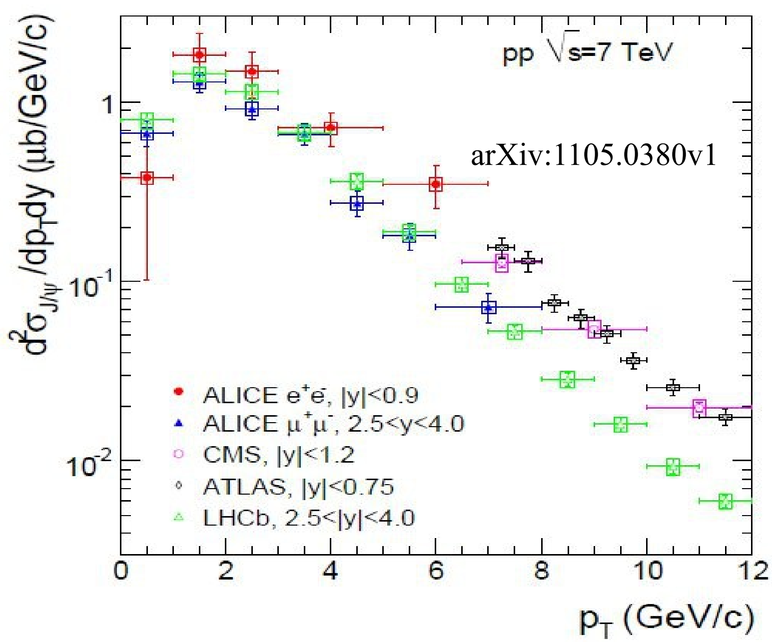
ALI-PERF-27238



ALI-PERF-27242



ALI-PERF-27246



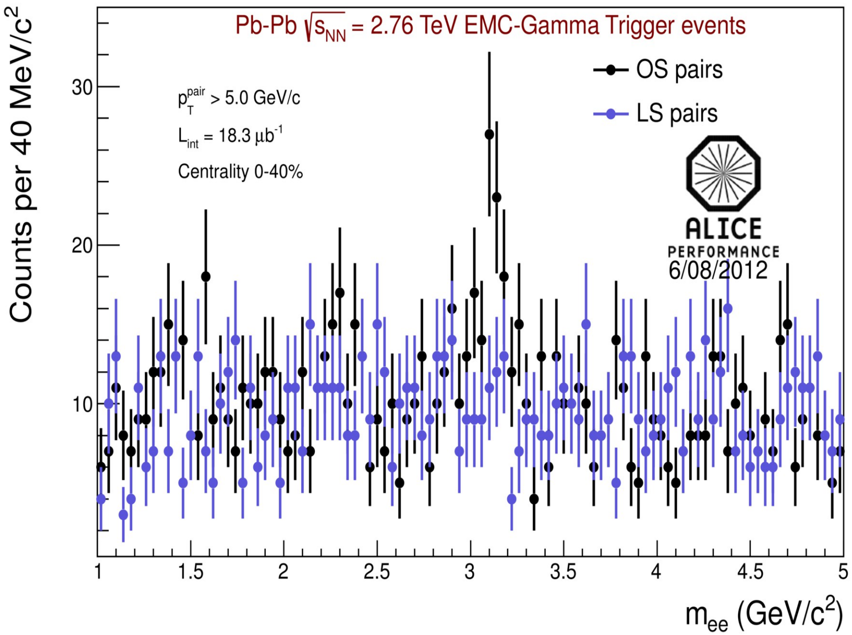
In pp@7TeV
EMCal trigger can expand ALICE measurements

We have a cross section measured
We plan to add more statistics

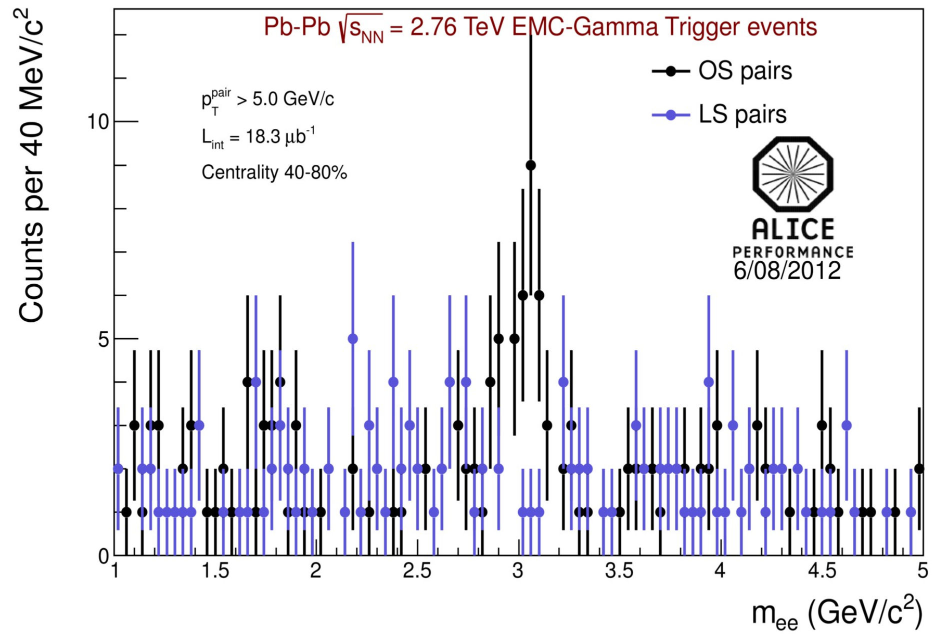
- **Significant number of events to be reprocessed with improved calibration**

Normalization LS Pairs → 3.2 – 5.0 GeV/c²

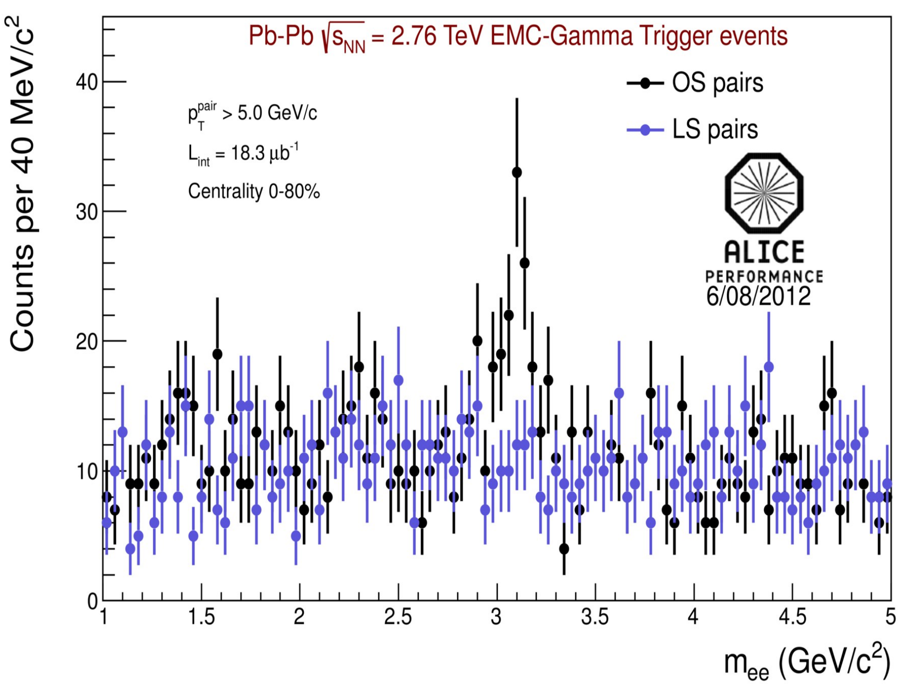
J/ψ Pb-Pb



ALI-PERF-27335



ALI-PERF-27339



ALI-PERF-27331

EMCal trigger

Also helps in PbPb collisions

One can check RAA for different pt bins also in the central rapidity.

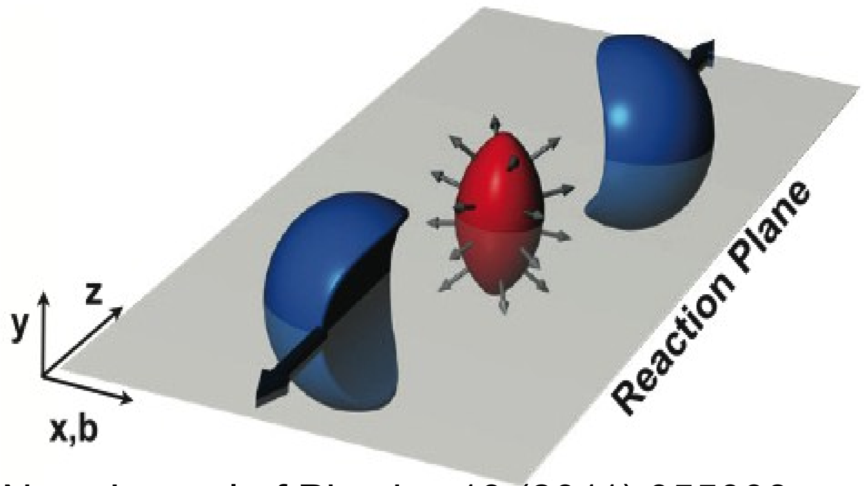
We are still working internally for a final Cross section and RAA.

Elliptic flow → v2

Elliptic flow – v2

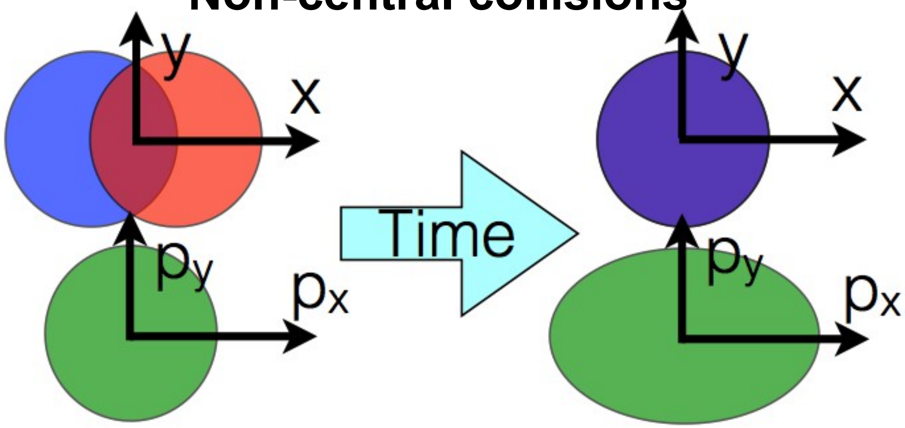
Flow represents the presence of multiple interactions between the constituents of the medium created in the heavy ion collision.

Experimentally → anisotropic flow.



New Journal of Physics 13 (2011) 055008

Non-central collisions



Pressure gradient
– initial spatial anisotropy → momentum anisotropy

$$E\frac{d^3N}{d^3\mathbf{p}} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_{RP})]\right)$$

Azimuthal distribution of particles
Fourier series

$$v_n(p_t, y) = \langle \cos[n(\varphi - \Psi_{RP})] \rangle$$

The v2 → represents elliptic flow → N=2

V2 of charmed hadrons

There are answers that we could take from the charmed meson v2 measurements.

Prompt J/ψ (c-cbar) → represents the v2 of the c quarks.

D Mesons (probably Λ_c) → also sensitive to heavy-quark hadronization mechanism (low and intermediate momentum)

At low momentum:

- Possible thermalization of heavy quarks in the medium

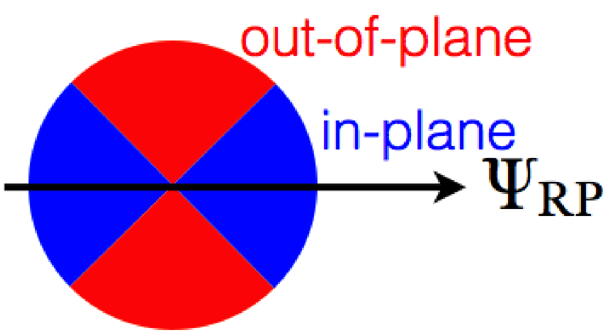
At high momentum:

- Path length dependence of heavy quark energy loss.

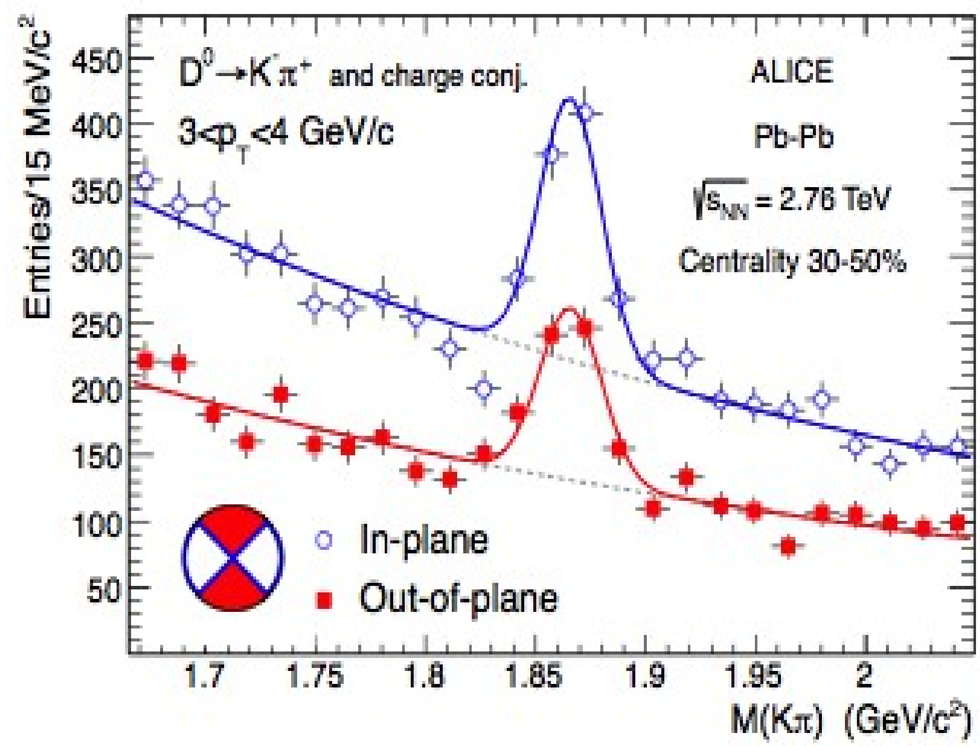
Phys. Rev. Lett. 111 (2013) 102301

V2 → E.P. Based Method

- in-plane: (0, π/4] ∪ [3π/4, π)
- out-of-plane: (π/4, 3π/4]



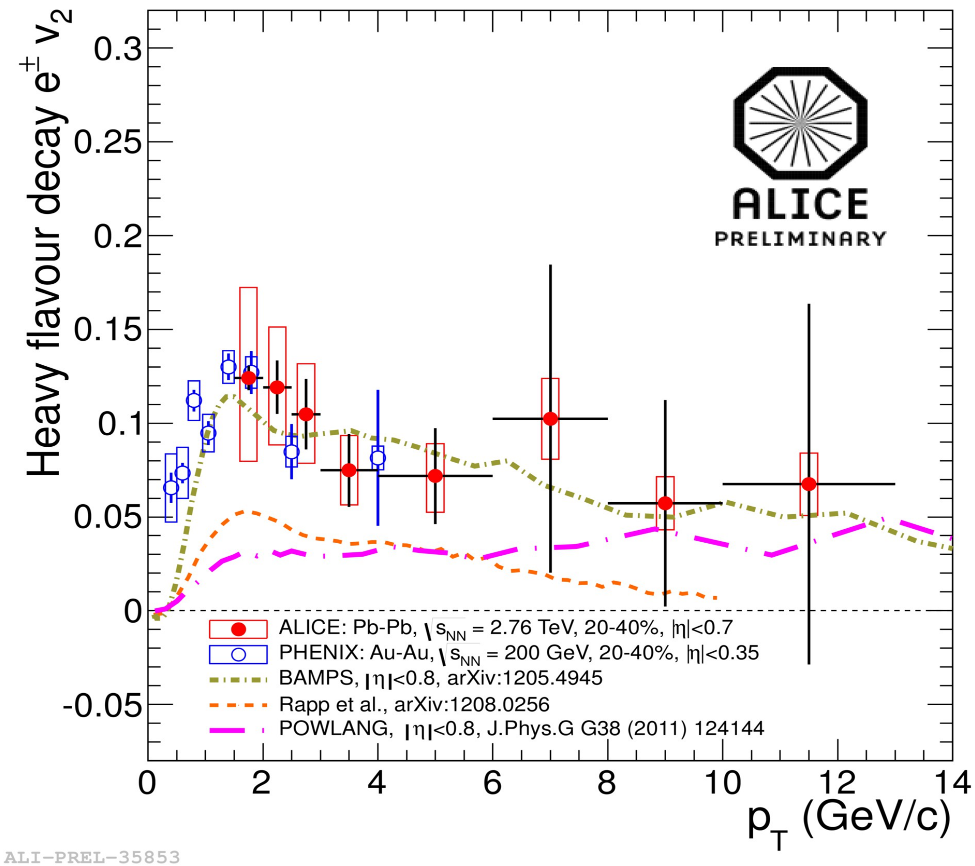
$$v_2 = \frac{1}{R_2}\frac{\pi}{4}\frac{N_{\text{in-plane}} - N_{\text{out-of-plane}}}{N_{\text{in-plane}} + N_{\text{out-of-plane}}}$$

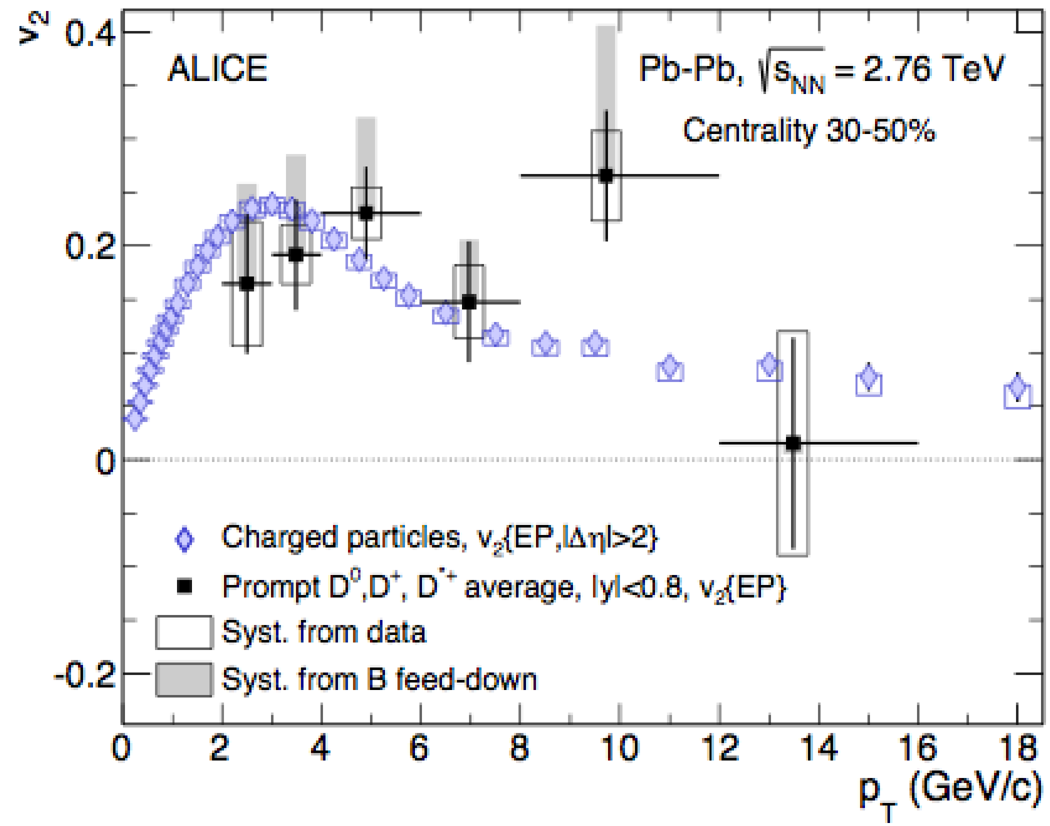


Phys. Rev. Lett. 111 (2013) 102301

Measurement of v2 with ALICE

Phys. Rev. Lett. 111 (2013) 102301

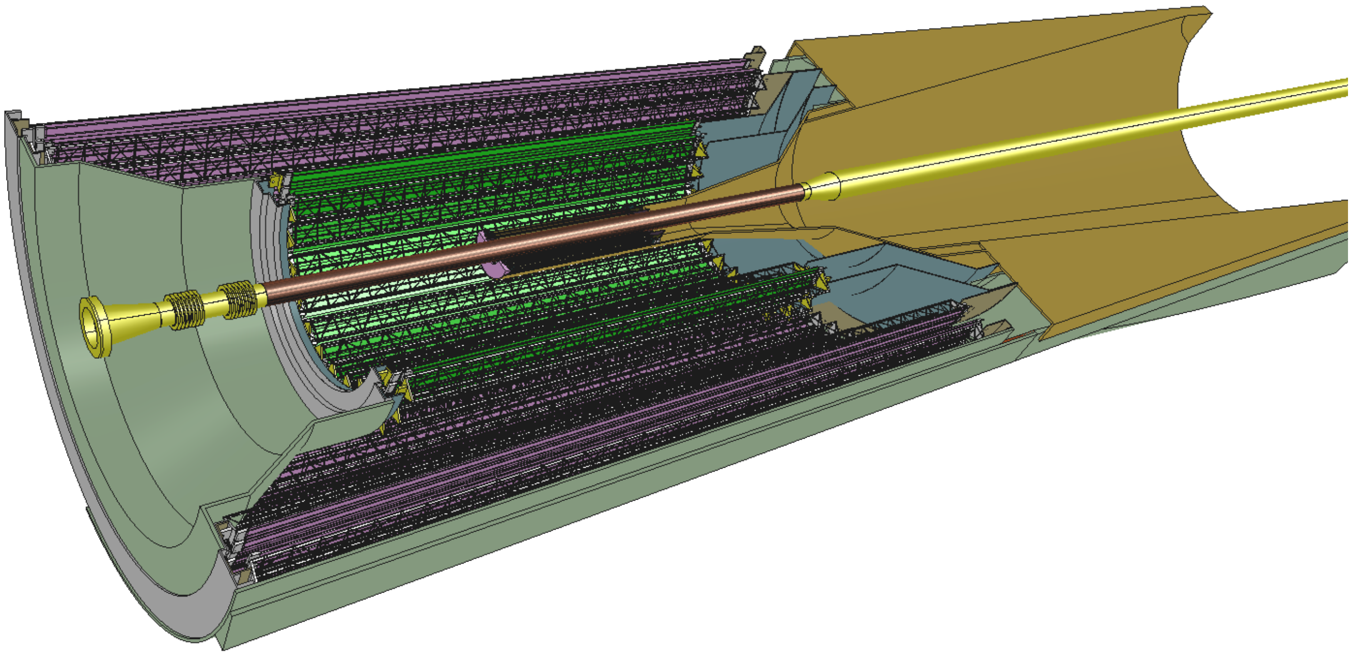




V2 measurements in the heavy-flavor sector

- **Compatible with previous PHOENIX results**
- **Compatible with charged particles v2!** (Still low statistics)
- **Persists up to higher momentum**

ITS Upgrade



ITS Upgrade

- As discussed, some measurements are limited with the current statistics and resolution
- Elliptic flow of D Mesons
- RAA of some of D Mesons
- Measurement of Lc and Ds in Pb-Pb collisions
  - Huge background in Pb-Pb collisions
  - Elliptic flow of these particles

Design

Improve impact parameter resolution by a factor of ~3

Get closer to IP (position of first layer): 39mm → **22mm**

Less material budget: X/X_0 /layer: ~1.14% → **~ 0.3%**

Reduce pixel size : currently 50μm x 425μm

Monolithic pixels: O(20μm x 20μm)

Improve tracking efficiency and p_T resolution at low p_T

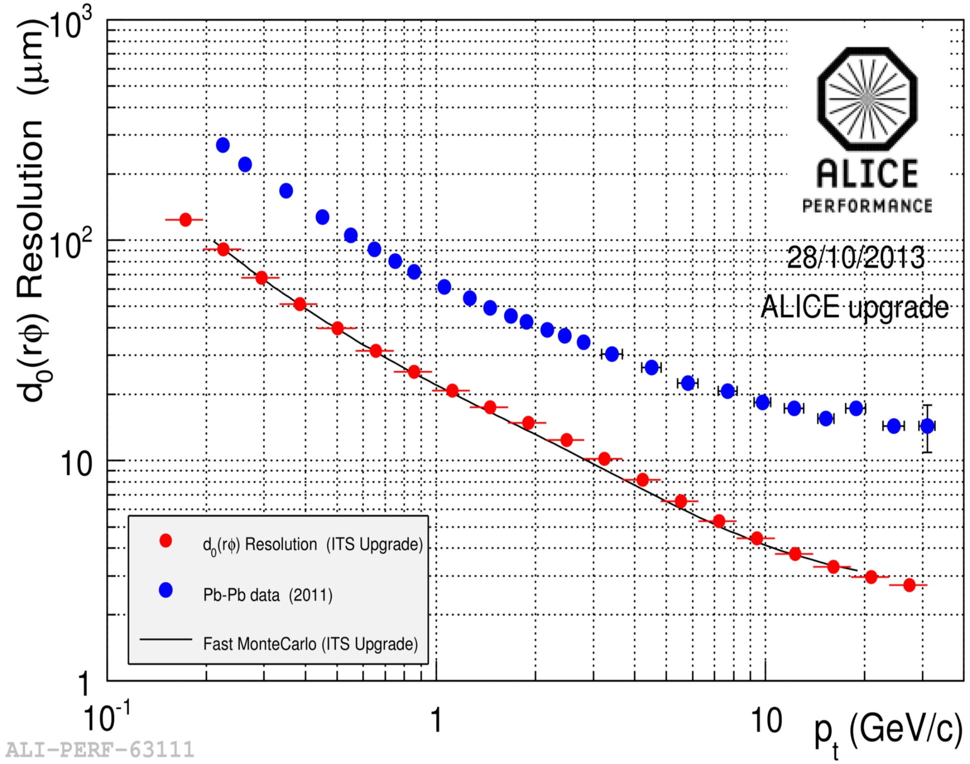
Increase granularity: 6 layers → **7 layers, reduce pixel size**

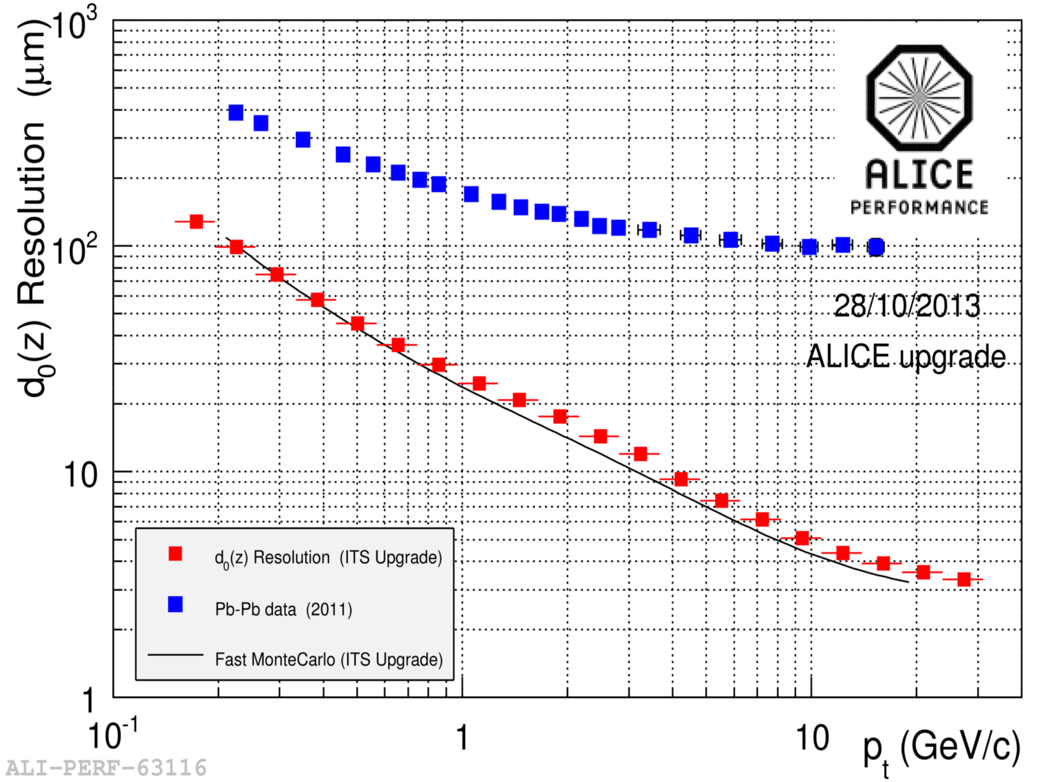
Increase radial extension: 39-430 mm → **22–430 (500) mm**

Fast readout of Pb-Pb interactions **at > 50 kHz** and pp interactions at **~ several MHz** → **Currently, PbPb ~ 500 Hz and pp ~ 100kHz**
Fast insertion/removal for yearly maintenance

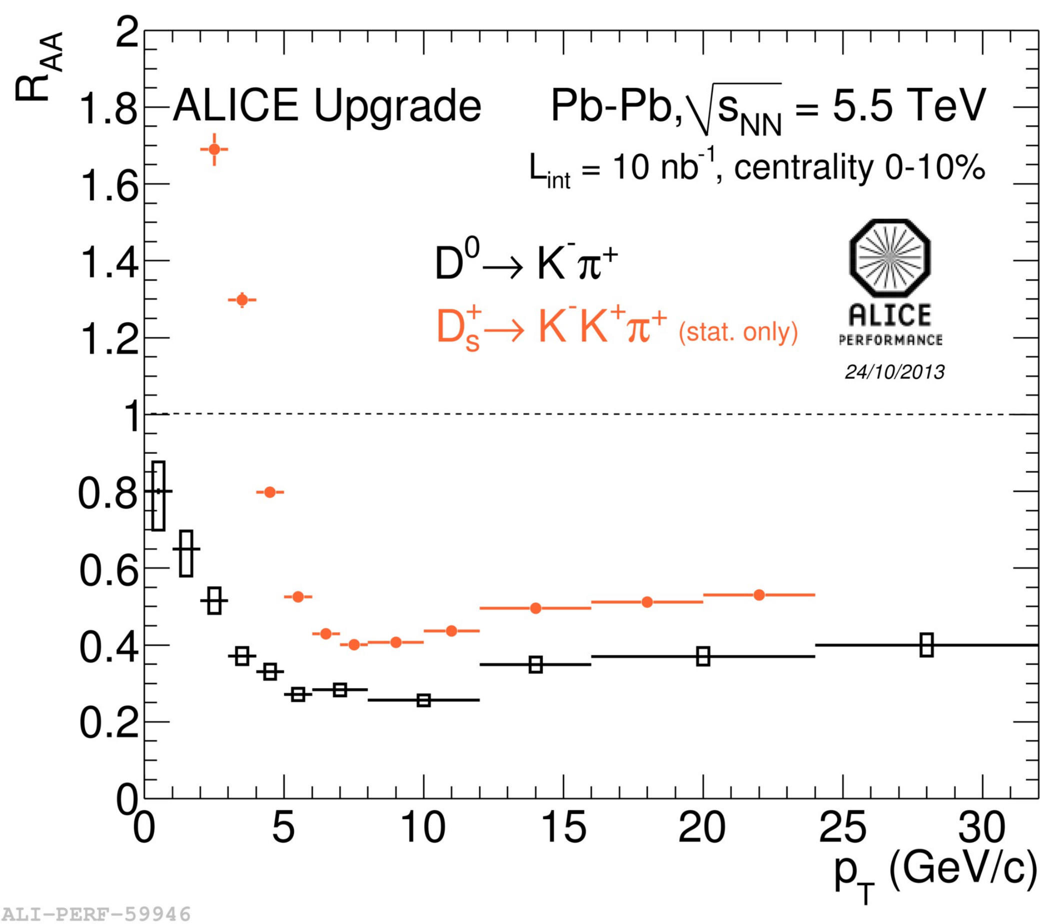
Vertex resolution – ITS Upgrade

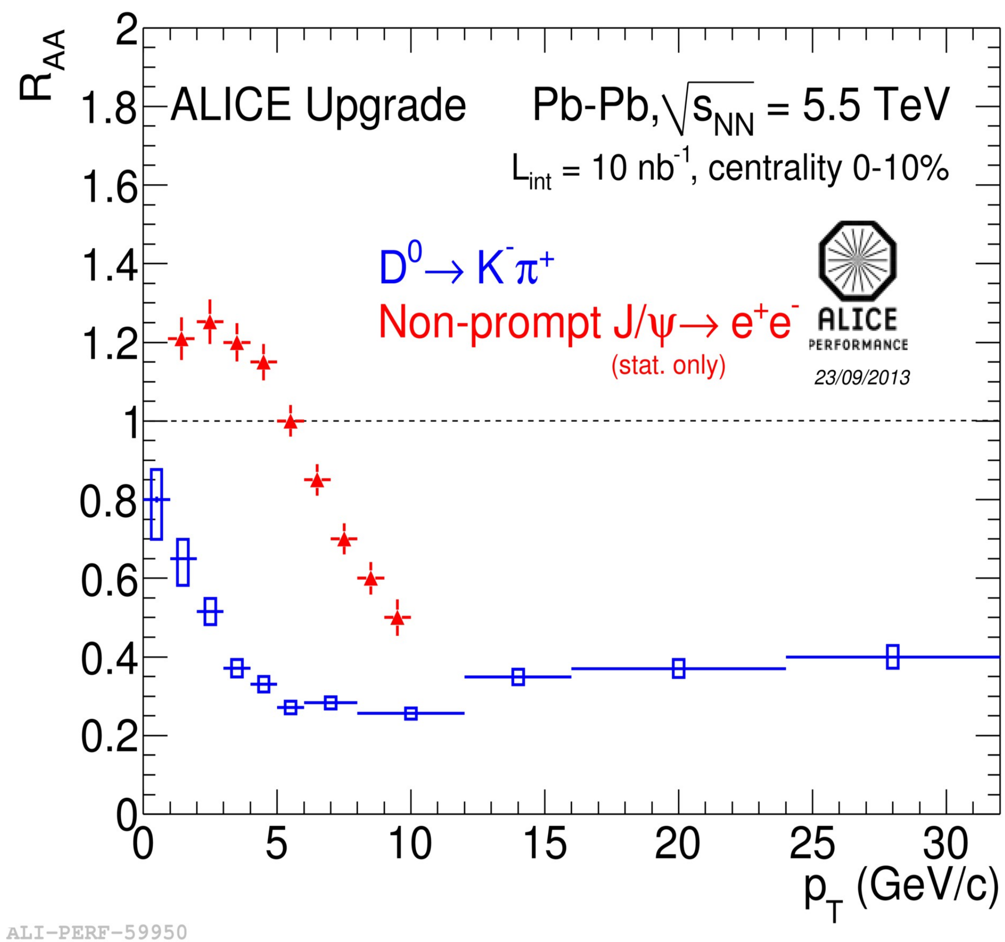
ITS upgrade will bring an improvement of a factor of 3 in resolution for impact parameter.
This will significantly in order to reduce background.





RAA D Mesons



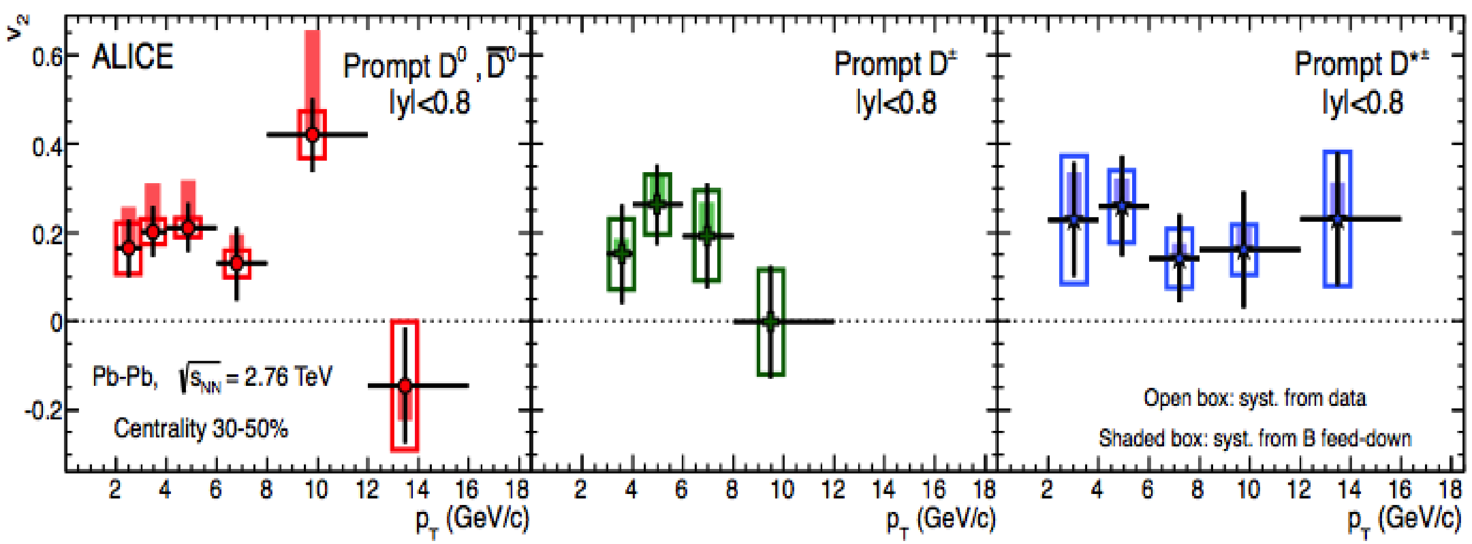


D_s and non-prompt J/psi will be measured with very low statistical uncertainties

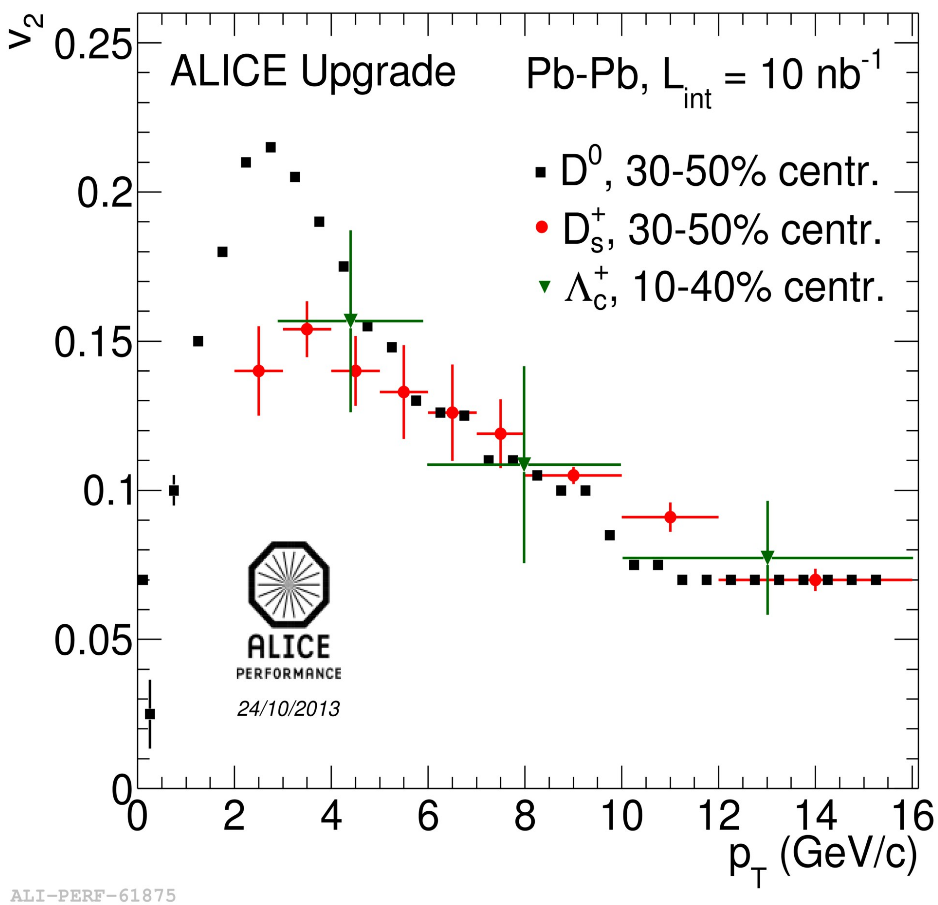
V2 → Current ITS

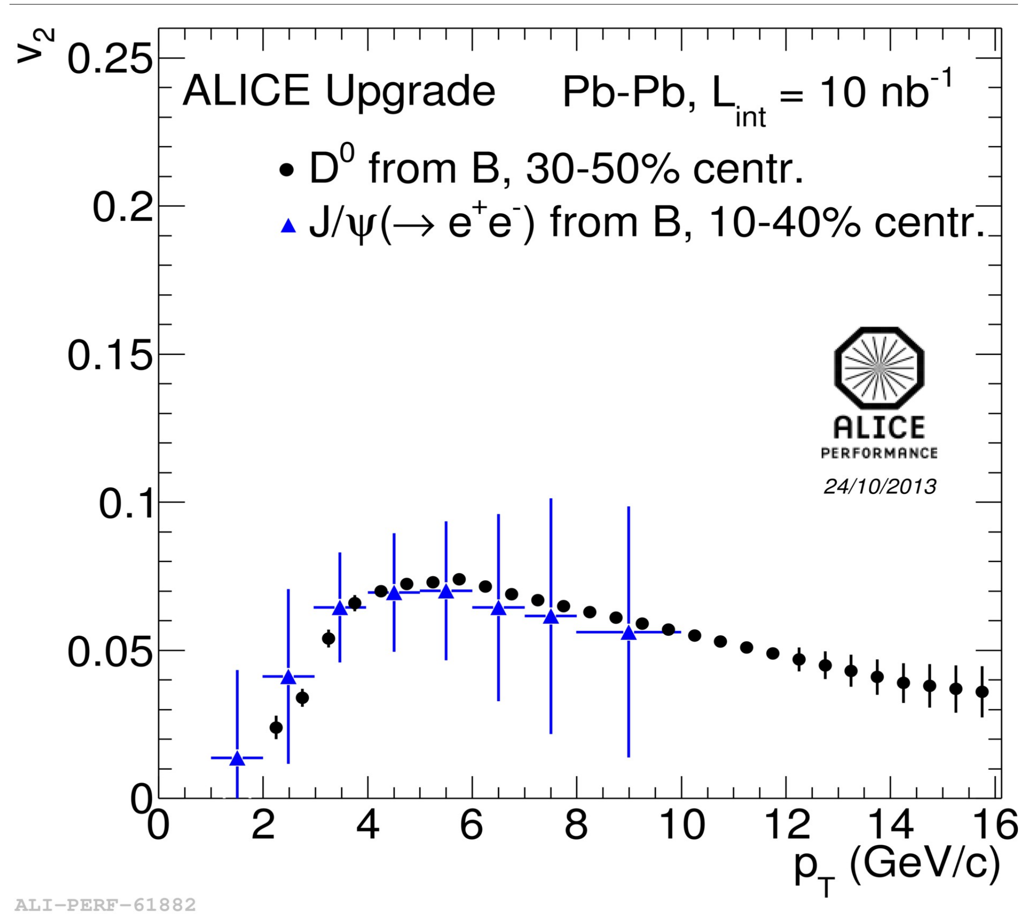
- Current scenario is difficult
  - Even for D mesons → limited statistics
    - Error bars are very big.
  - Lc and D_s v2 not yet measured
    - Upgrade ITS will help in the signal extraction of Lc.

Phys. Rev. Lett. 111 (2013) 102301



V2 with the ITS upgrade

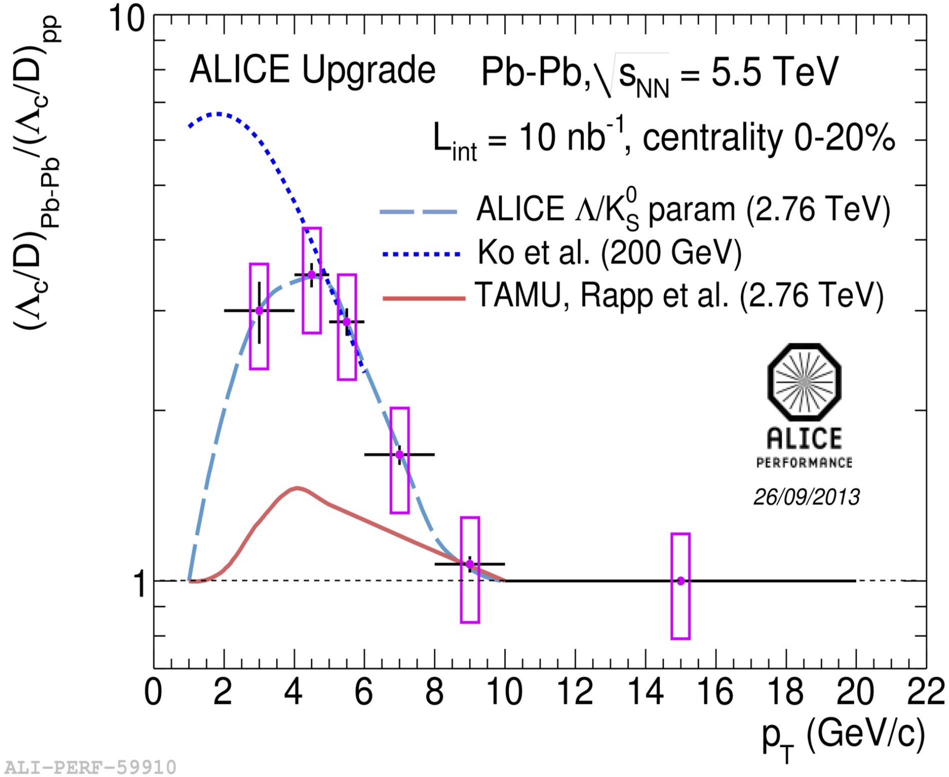


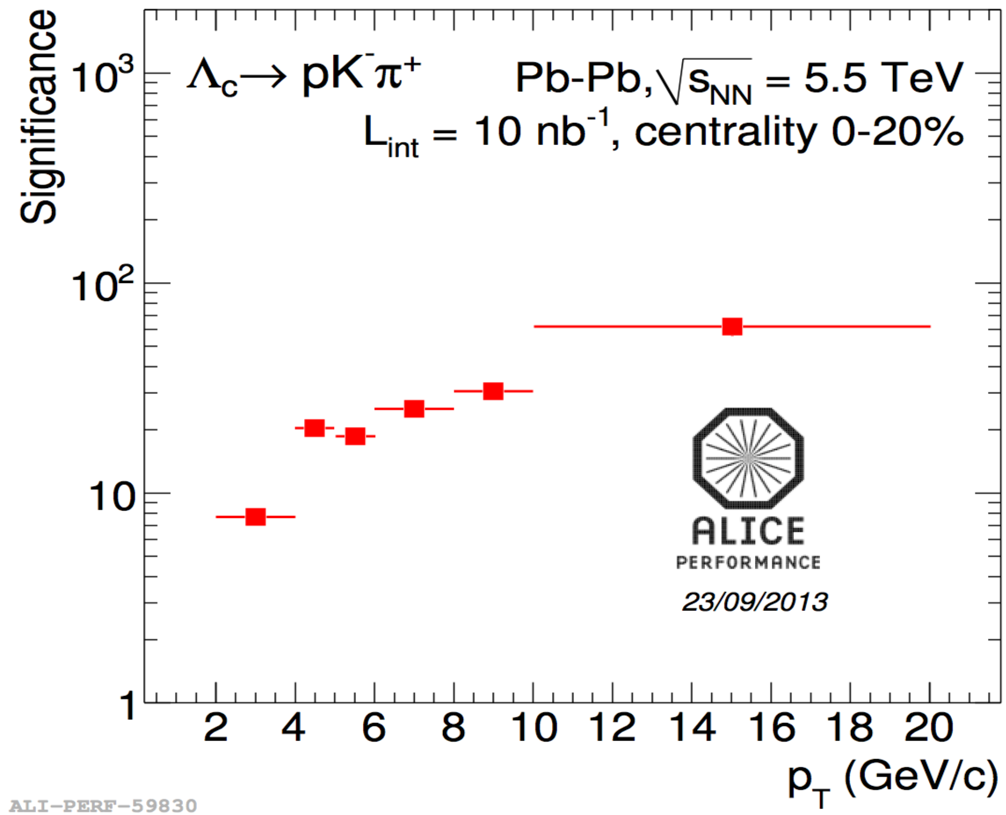


The results were taken using a dedicated simulation of PbPb collisions in ALICE with the ITS upgrade. The v2 assumptions come from models (BAMPS arxiv:1205.4945)

We expect to improve the v2 measurements for open charm and charmonium physics.

Λ_c/D ratio





The Ratio Λ_c/D will also be measured (Λ_c will be measured with good significance)

Check baryon/meson ratio for heavy quarks as well.

Hadronization mechanisms → Coalescence for instance

Conclusions and Outlook

- Heavy quarks (specially charm) are a very important probe for the QGP
- In ALICE
  - D Mesons, Λ_c and J/ψ
- Results so far:
  - Open charm → Results consistent with energy loss mechanisms proposed
  - Charmonium → Results are still suggesting enhancement
  - V2 of heavy flavour → Not high statistics, but seem similar to those of charged particles
- ITS upgrade will help the measurement of charm:
  - First measurement of Λ_c and improvement of D_s;
  - V2 measurement with higher statistics
  - V2 measurement for Λ_c and D_S
- EMCal trigger improves the J/ψ analyses in ALICE
- Λ_c can be measured in pp collisions
  - Very promising in pPb collisions
  - Very promising with the ITS upgrade

Backup slides

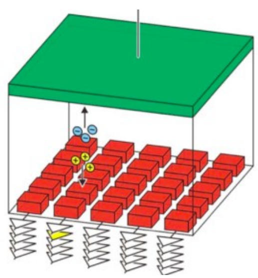
ITS Upgrade options

Two design options have being studied

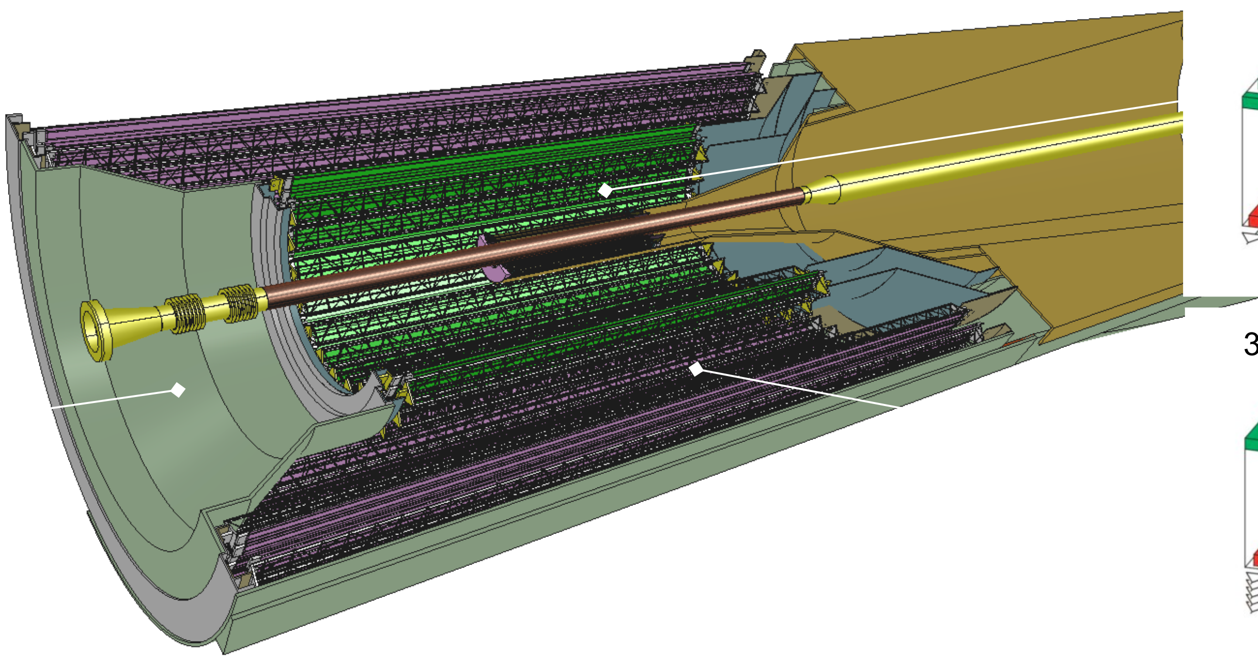
1 → 7 layers of pixel detectors (baseline)

2 → 3 inner layers of pixel detectors and 4 outer layers of strip detectors

7 layers of pixels



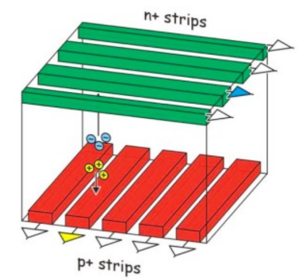
Pixels: O(20x20μm^2)



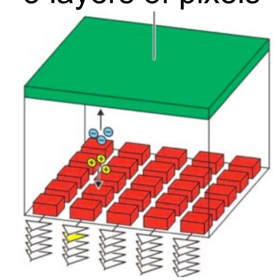
700 krad/ 10^{13} n_{eq}

Includes safety factor ~ 4

4 layers of strips

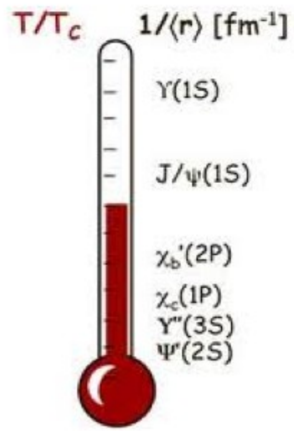


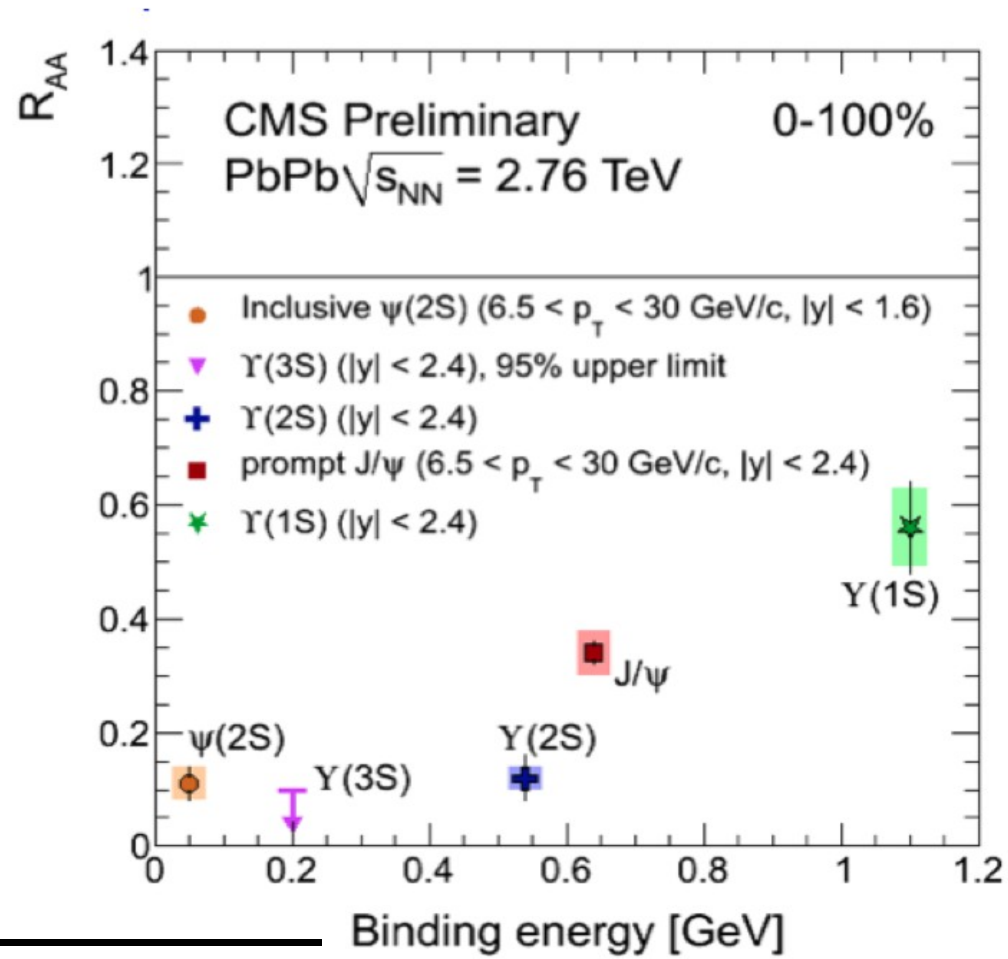
3 layers of pixels



Pixels: O(20x20μm^2)
Strips: 95 μm x 2 cm, double sided

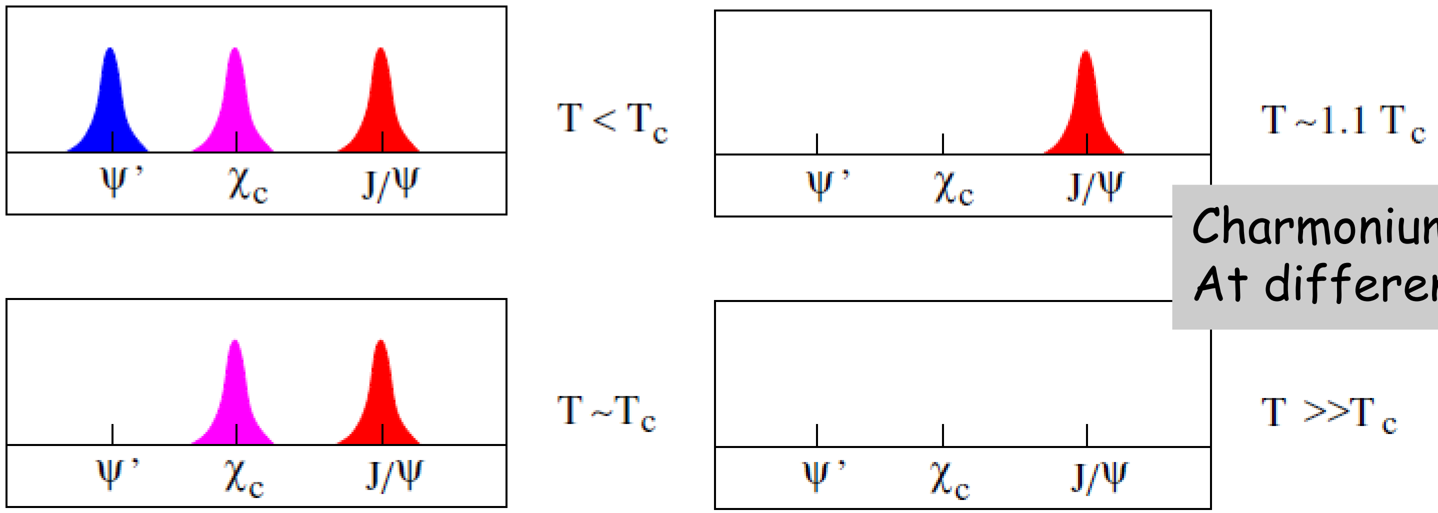
Thermometer?



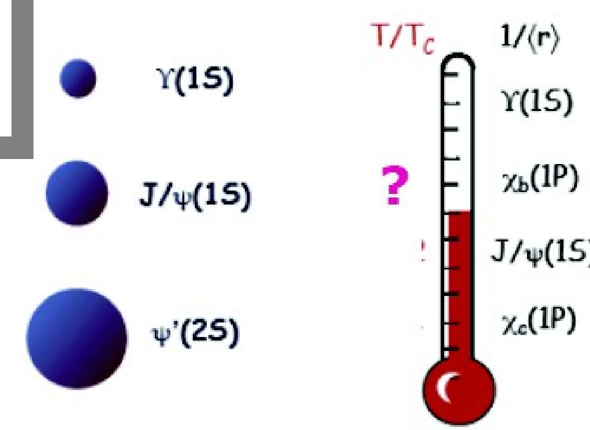


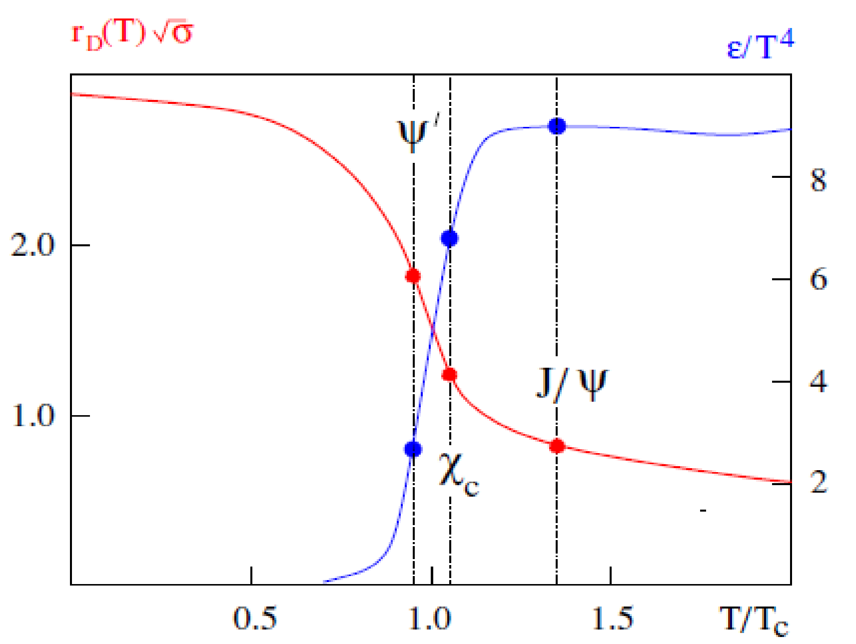
State	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
Mass (GeV)	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE (GeV)	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM (GeV)	0.02	−0.03	0.03	0.06	−0.06	−0.06	−0.08	−0.07
r_0 (fm)	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

Charmonium as a thermometer



Charmonium spectra
At different temperatures





Charmonium dissociation x temperature
And energy density

arXiv:0901.3831v1 [hep-ph]
L. Kluberg and H.Satz

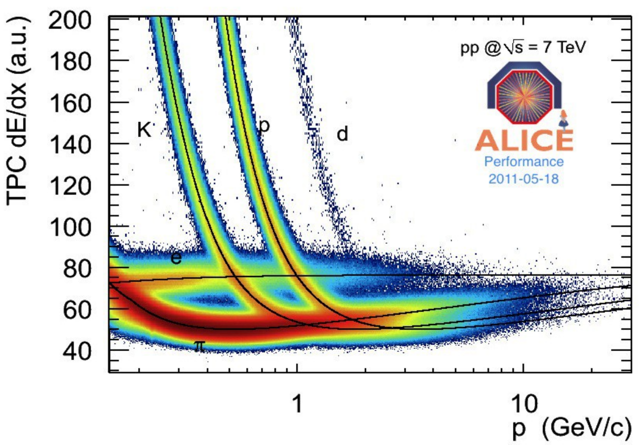
PID Baysian

p, K, π are identified with the Bayesian PID approach:

The probability for a track to be of the specie *i* :

$$W(i|s_1, s_2, ..., s_N) = \frac{C_i \prod_{j=1}^{N} r(s_j|i)}{\sum_{k=e,\mu,\pi,...} C_k \prod_{j=1}^{N} r(s_j|k)}$$

Detectors signals



Detectors: TPC, TOF

Priors: our a priori knowledge of the sample composition

59

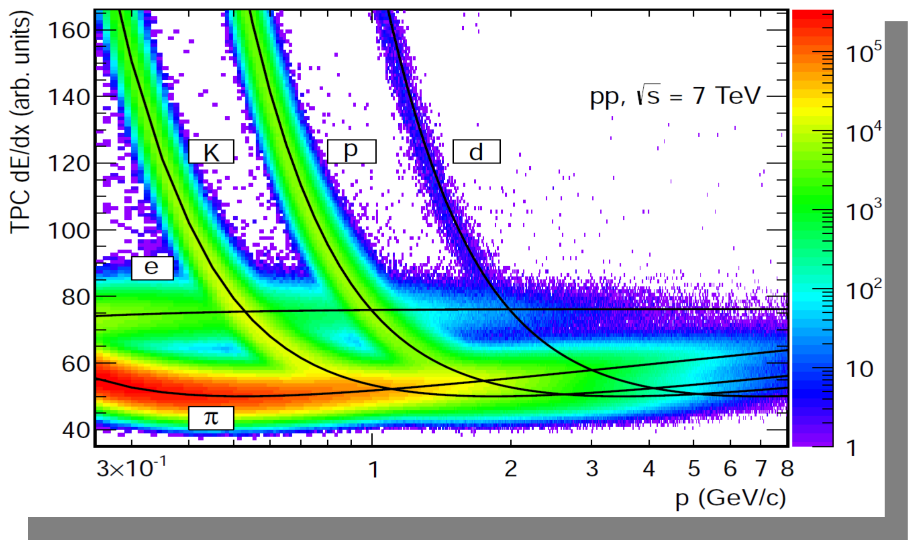
TPC and TOF separate well hadrons in complementary p ranges

EMCal HLT

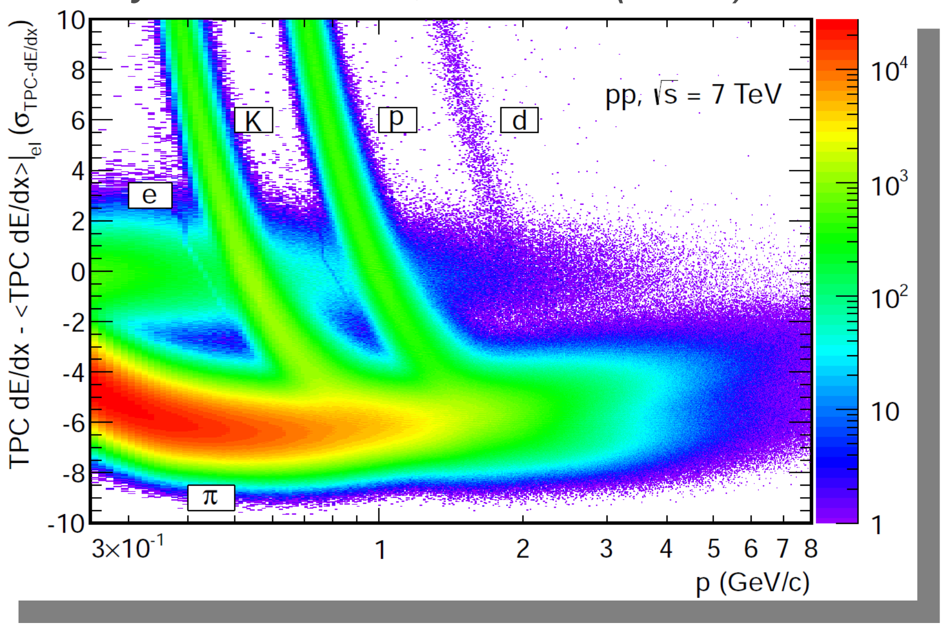
- Some developments regarding the EMCal High Level Trigger 2011:
  - 3 components created
  - Jet trigger, cluster energy trigger and electron trigger
  - Electron trigger was my main focus.
- Scenario in 2011:
  - In p-p:
    - 100kHz interaction ratio
    - TPC gate limited to about 0.5-1 kHz
    - Minimum bias data taking → up to 100 Hz
    - 20-40 Hz Bandwidth (for EMCal trigger)
      - Trigger rejection to match this ~ 5 GeV.
    - HLT could achieve
      - There were some proposals for 2012:
      - EMCal L0 at 1.8 or so + HLT Electron trigger.

PID: TPC

Phys. Rev. D 86, 112007 (2012)



Phys. Rev. D 86, 112007 (2012)



- TPC dE/dx;
- 5 charged particles can be distinguished;
- BetheBloch equation.

ALICE: Physics Performance Report, Volume I
http://stacks.iop.org/0954-3899/30/i=11/a=001

Particle velocity

$$\left\langle \frac{dE}{dx} \right\rangle = \frac{C_1}{\beta^2}\{\ln(C_2\beta^2\gamma^2) - \beta^2 + C_3\}$$

$$\gamma = 1/\sqrt{1-\beta^2}$$

C1, C2 e C3 detector dependent constants.

- Em análise:

Measured value **Mean value**

$$N\sigma_{ele}^{TPC} = \frac{dE/dx - \langle dE/dx \rangle_{ele}}{\sigma_{ele}}$$

Width

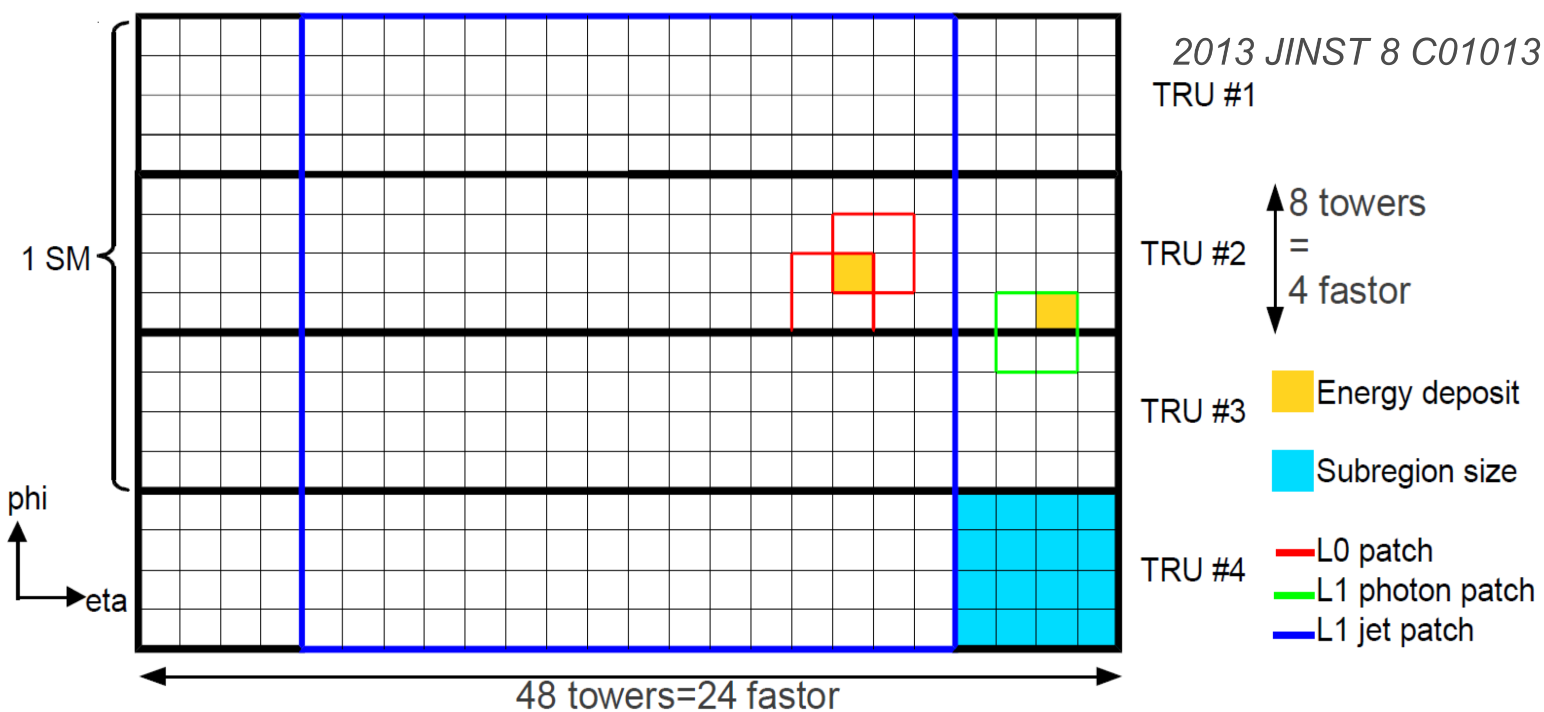
EMCal Triggers
L0, L1 and HLT

EMCal trigger: L0 e L1

Level 0 (L0) – Fast and efficient (used in pp collisions);

Level 1 (L1) – Algorithm more robust (used in Pb-Pb collisions).

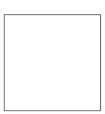
L0 e L1 – Select events with high energy pions-0, photons and electrons.



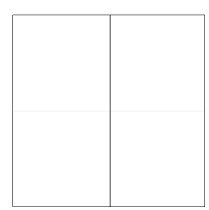
L0:do not combine TRU's.

Trigger Region Unit

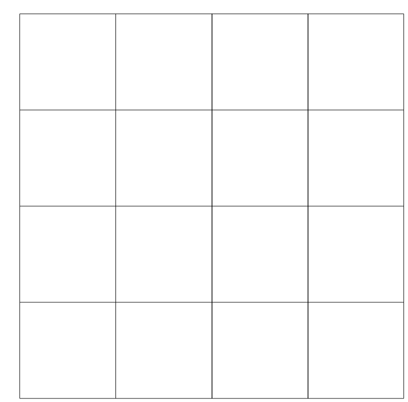
L1: Combine TRU's.



1 tower
6x6 cm^2



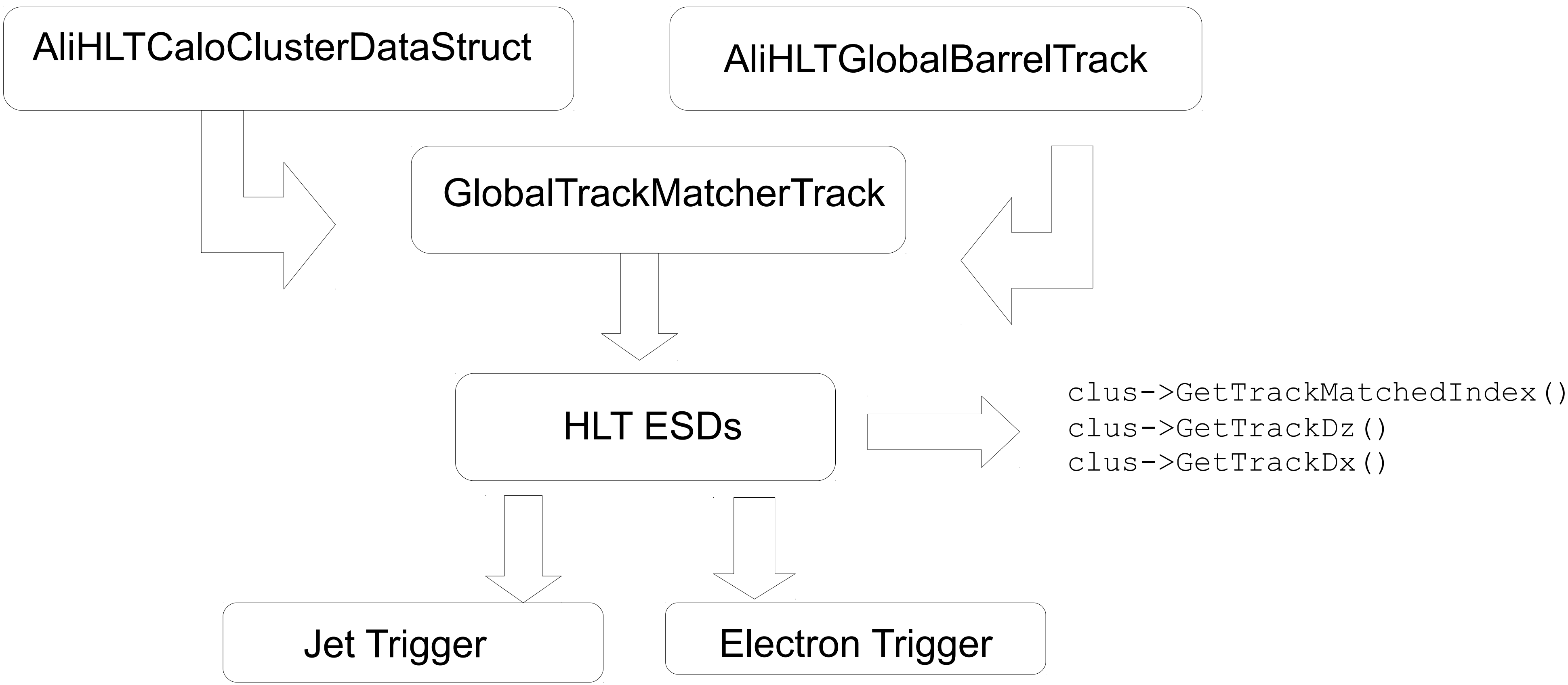
1 Module (fastOr): 2x2 towers



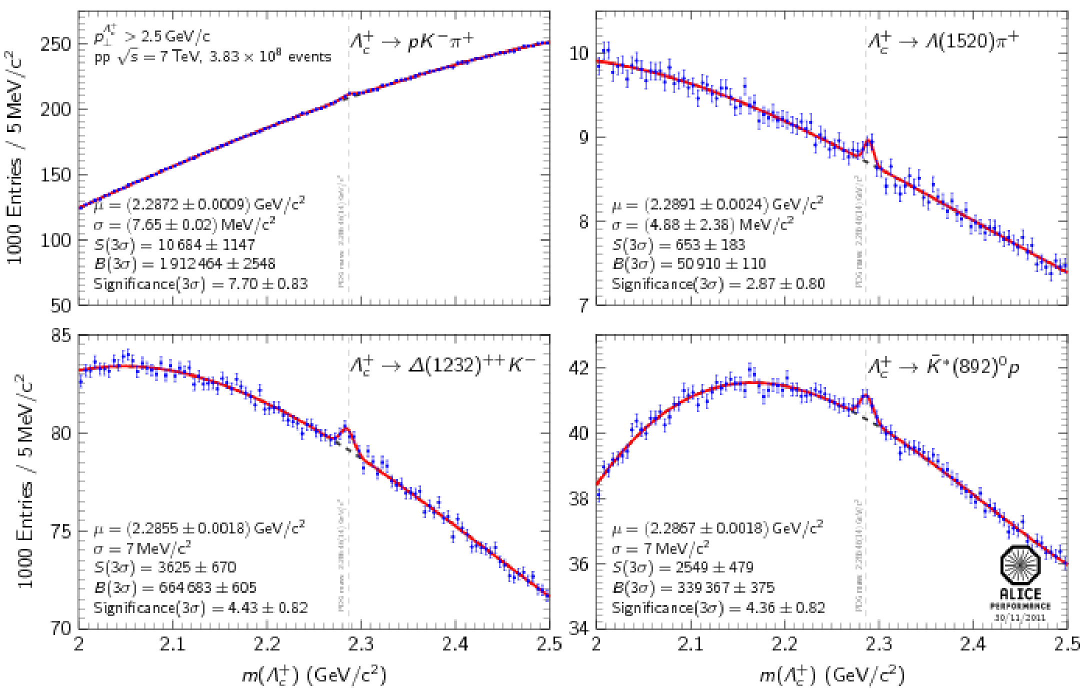
Trigger system used:
4x4 towers > Threshold

HLT EMCal Electron

- Track-cluster matching.
  - AliHLTGlobalTrackMatcher.
  - Implemented functions from AliEMCalRecoUtils:ExtrapolateTracktoCluster (Official EMCal Matching code).

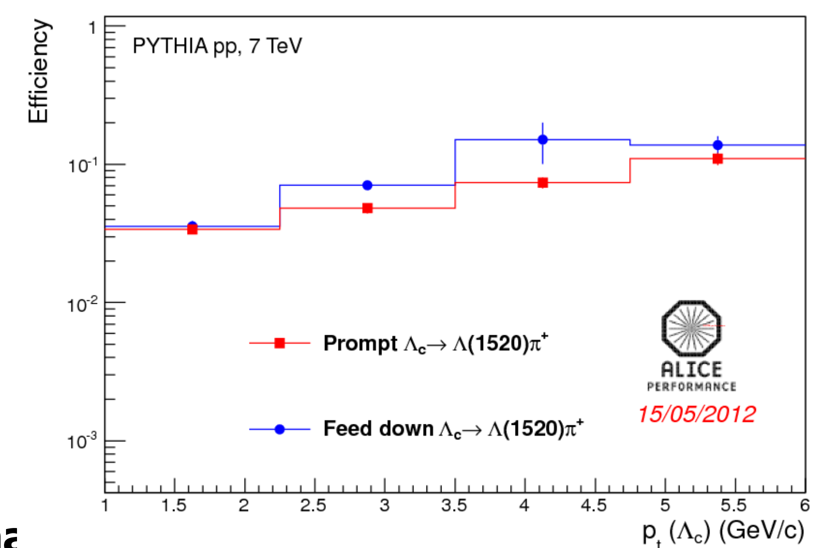


$\Lambda_c \rightarrow p\, K\, \pi$



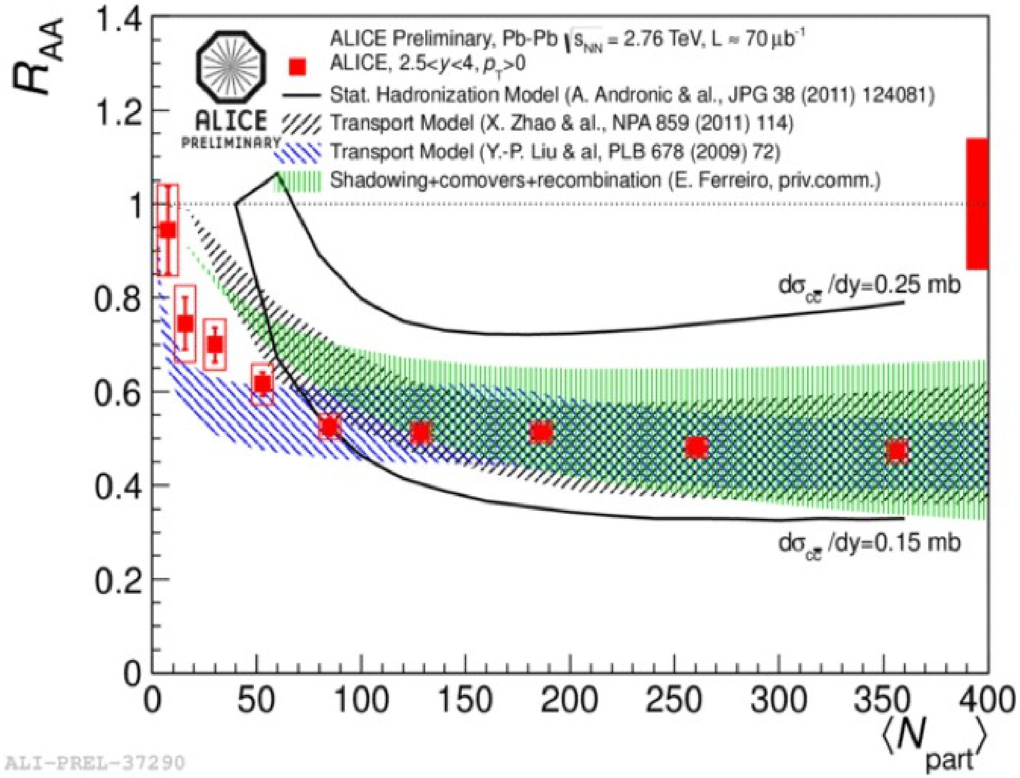
- Possible to distinguish between the different resonant decay channels

- Effiencency to be computed decay channel by decay channel



Enhancement of charmonium

Uncorrelated c-cbar forms a charmonium during hadronization



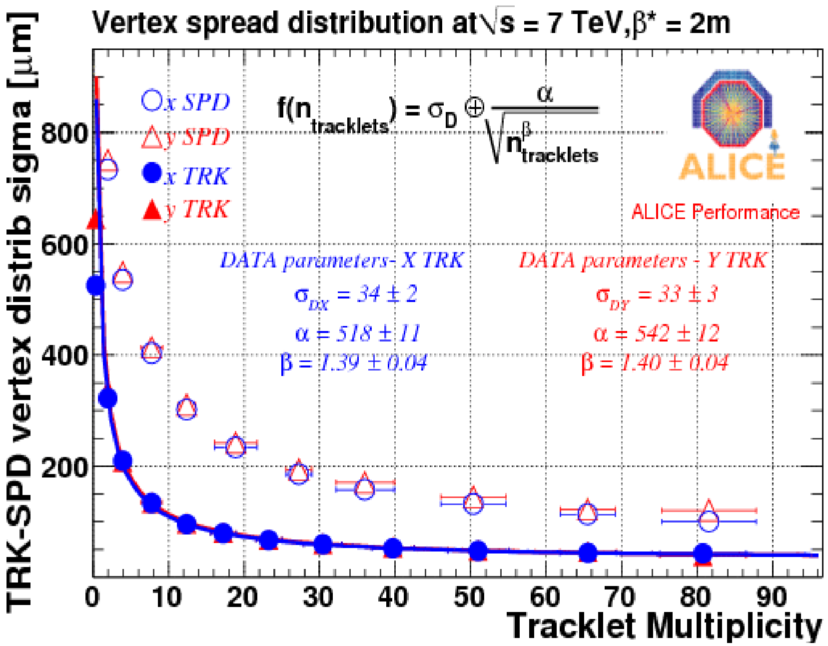
Some stat. hadronization and transport models describe partially the Behavior.

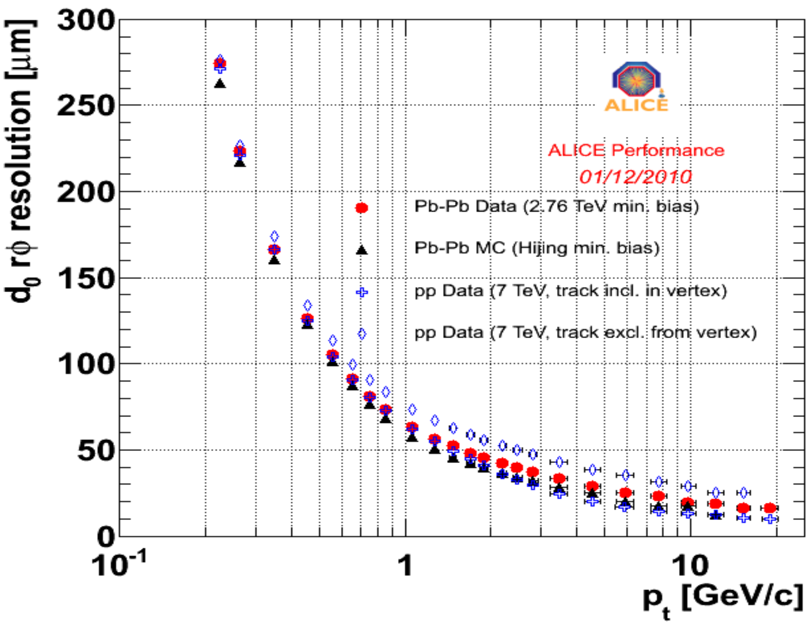
P. Braun-Muzinger and J. Stachel, Phys.Lett. B490(2000) 196
R. Thews et al, Phys.Rev.C63:054905(2001)

Tracking and vertexing

Inner T vracking System (ITS)
SPD → Silicon Pixel Detector
SDD → Silicon Drift Detector
SSD → Silicon Strip Detector

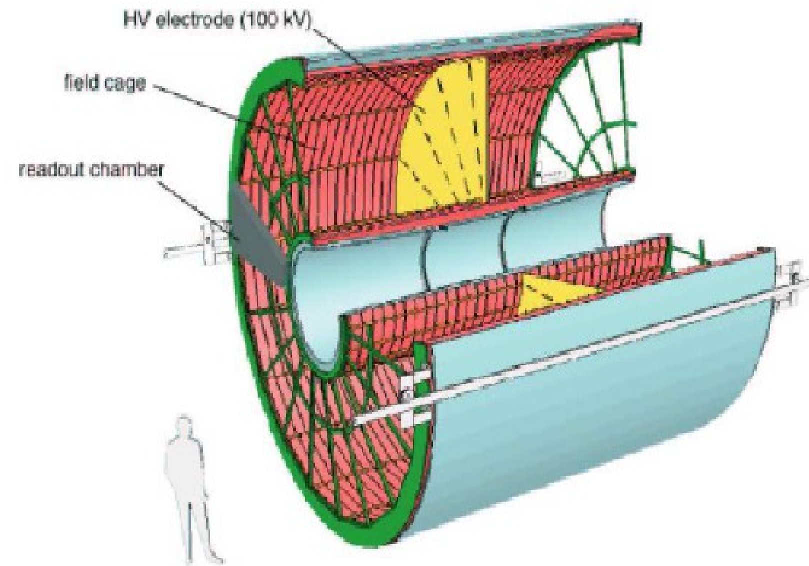
Good Vertexing and Impact parameter



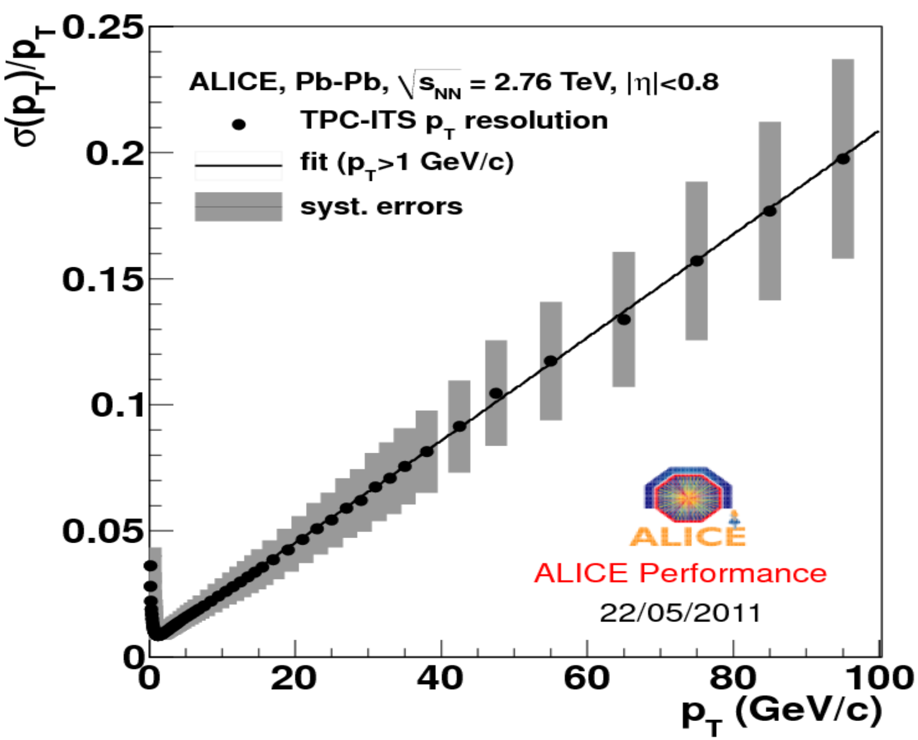


Time Projection Chamber

Charged particle tracking reconstruction
I can reconstruct up to 15000 particles in a given event
The dE/dx is used for PID purposes



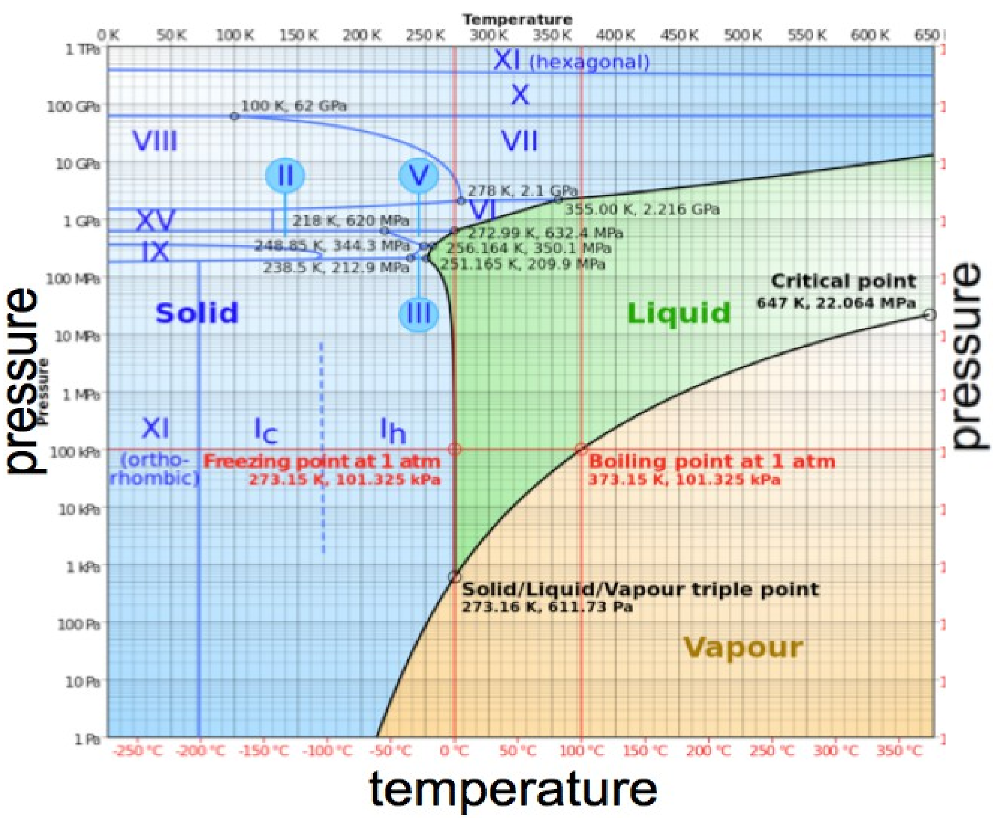
arXiv:1001.1950



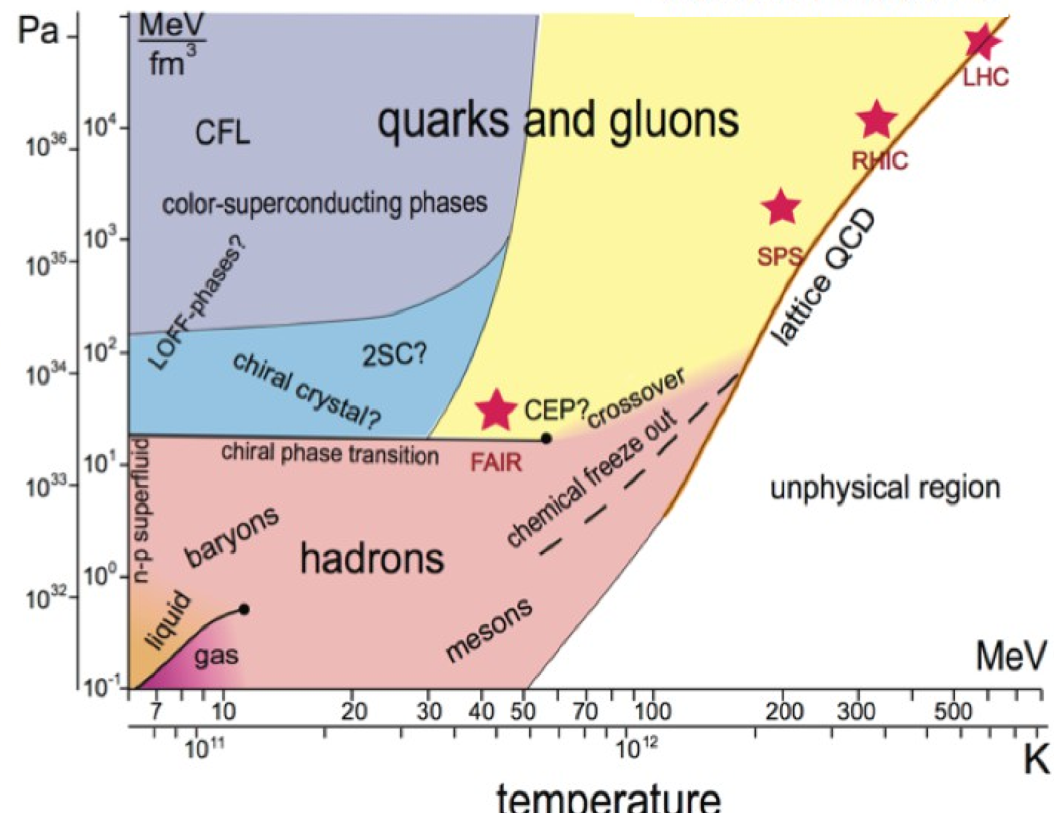
Momentum resolution close to its design
7 % at pT = 10 GeV/c
< 1% at pT < 1 GeV/c

QGP

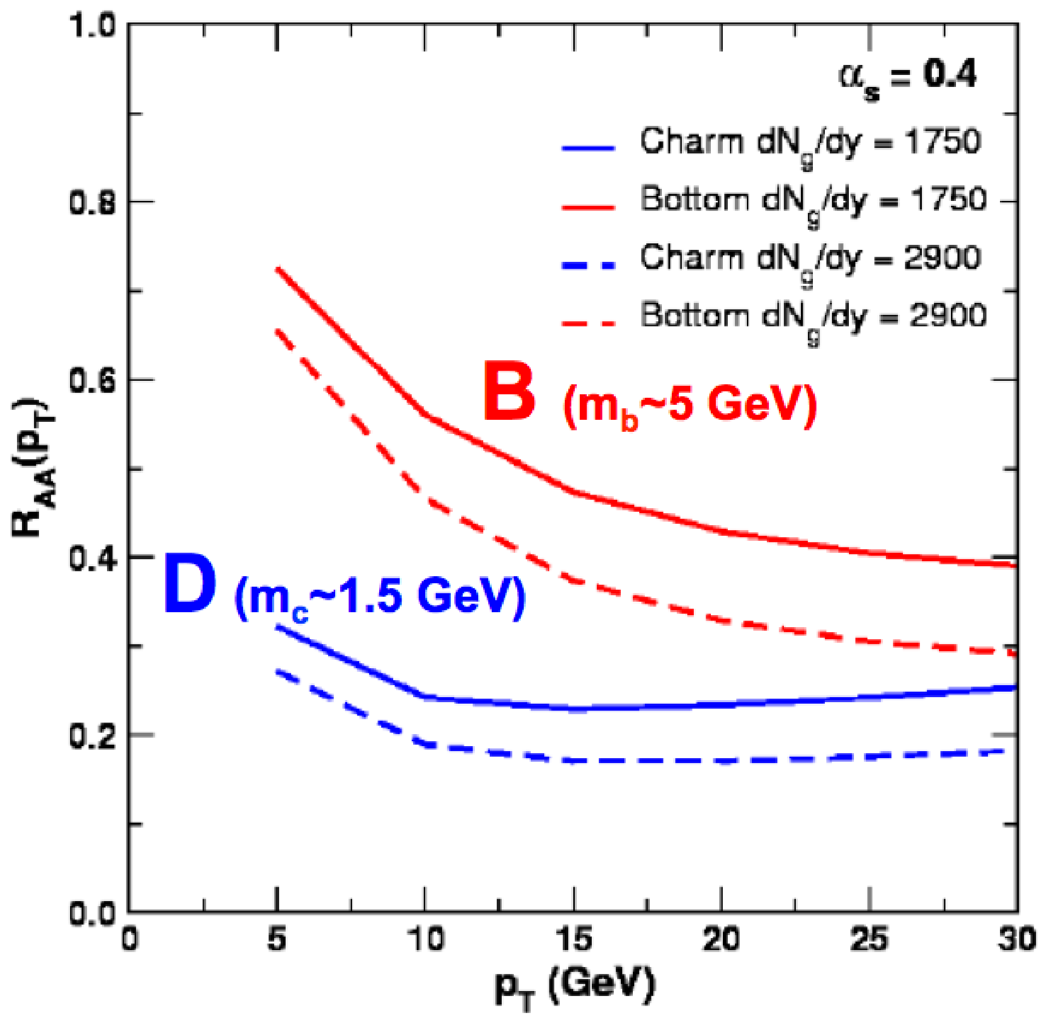
Another way is to look into the pressure x temperature diagram
Here's also the water phase diagram.



arXiv:1111.5475



B and D Predictions



The prediction before the LHC started
RAA for B Mesons > D Mesons

Wicks Gyulassy, "Last Call for LHC Predictions"(workshop, 2007)
HCPSS2013, CERN – A. Dainese

Energy loss

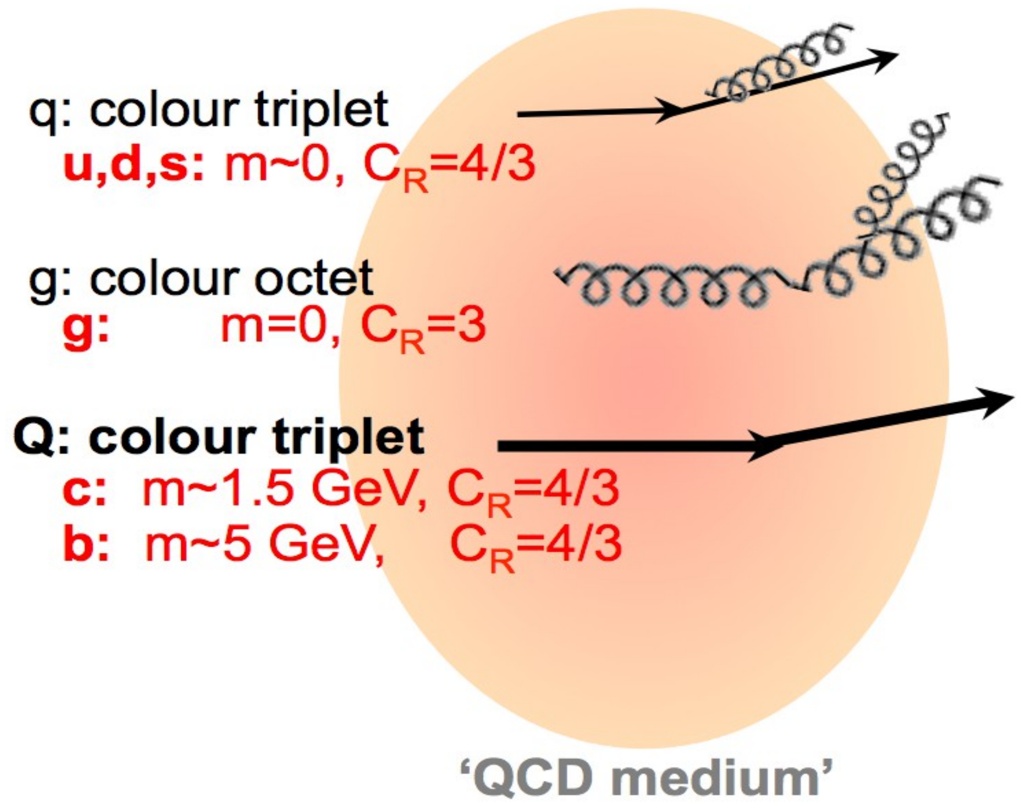
Parton Energy Loss by

Medium-induced gluon radiation
Collisions with medium gluons

$$\Delta E(\varepsilon_{medium};C_R,m,L)$$

$$\Delta E_g > \Delta E_{c\approx q} > \Delta E_b$$

$$R_{AA}^{B} > R_{AA}^{D} > R_{AA}^{\pi}$$

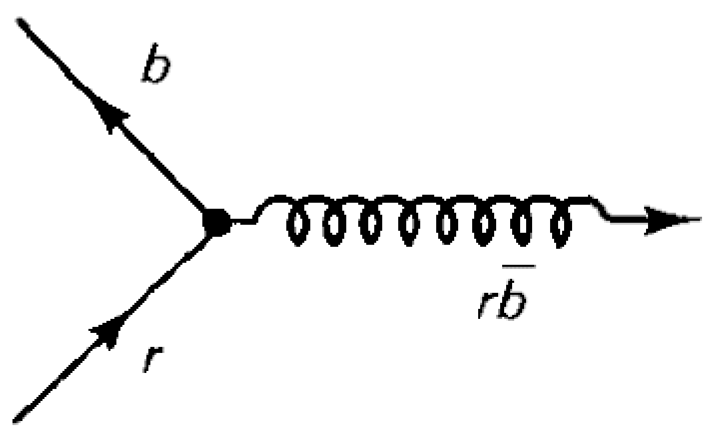


HCPSS2013, CERN – A. Dainese
Arnesto, Salgado, Wiedemann, PRD 69 (2004) 114003
Dokshitzer and Kharzeev, PLB 519 (2001) 199
Djordjevic, Gyulassy, Horowitz, Wicks, NPA 783 (2007) 493

Colour Singlet x Octet

Colour Octet (Um valid representation) From Griffiths Particle physics

$$\left\{ \begin{array}{ll} |1\rangle = (r\bar{b} + b\bar{r})/\sqrt{2} & |5\rangle = -i(r\bar{g} - g\bar{r})/\sqrt{2} \\ |2\rangle = -i(r\bar{b} - b\bar{r})/\sqrt{2} & |6\rangle = (b\bar{g} + g\bar{b})/\sqrt{2} \\ |3\rangle = (r\bar{r} - b\bar{b})/\sqrt{2} & |7\rangle = -i(b\bar{g} - g\bar{b})/\sqrt{2} \\ |4\rangle = (r\bar{g} + g\bar{r})/\sqrt{2} & |8\rangle = (r\bar{r} + b\bar{b} - 2g\bar{g})/\sqrt{6} \end{array} \right\}$$



Colour octet - Gluons

$$|9\rangle = (r\bar{r} + b\bar{b} + g\bar{g})/\sqrt{3}$$

Colour singlet → Physics states

NRQCD

Matrix element fo NRQCD
soft factor → v scale

$$d\sigma[H] = \sum_n d\hat{\sigma}[c\bar{c}(n)]\ \langle \mathcal{O}_n^H \rangle$$

v(apr. 1/3 charmonium)
v(apr. ~1/10 bottomonium)

Partonic cross section
Hard factor → $\alpha_s(m_c)$

V → is the quarks relative
Velocity in the Q-Qbar pair

Expansion in multipoles

- Transitions E1: ΔL=1, ΔS=0, amplitude ~v
- Transitions M1: ΔL=0, ΔS=1, amplitude ~v^2

$$|J/\psi\rangle = \mathcal{O}(1)\ |c\bar{c}(\underline{1}\ {}^3S_1)\rangle + \mathcal{O}(v)\ |c\bar{c}(\underline{8}\ {}^3P_J) + g\rangle + \mathcal{O}(v^2)$$

Singlet

S-waves: $\langle \underline{1}\ {}^3S_1\rangle, \langle \underline{8}\ {}^3S_1\rangle, \langle \underline{8}\ {}^1S_0\rangle, \langle \underline{8}\ {}^3P_J\rangle$

P-waves: $\langle \underline{1}\ {}^3P_J\rangle, \langle \underline{8}\ {}^3S_1\rangle$

arXiv:hep-ph/9407339v2