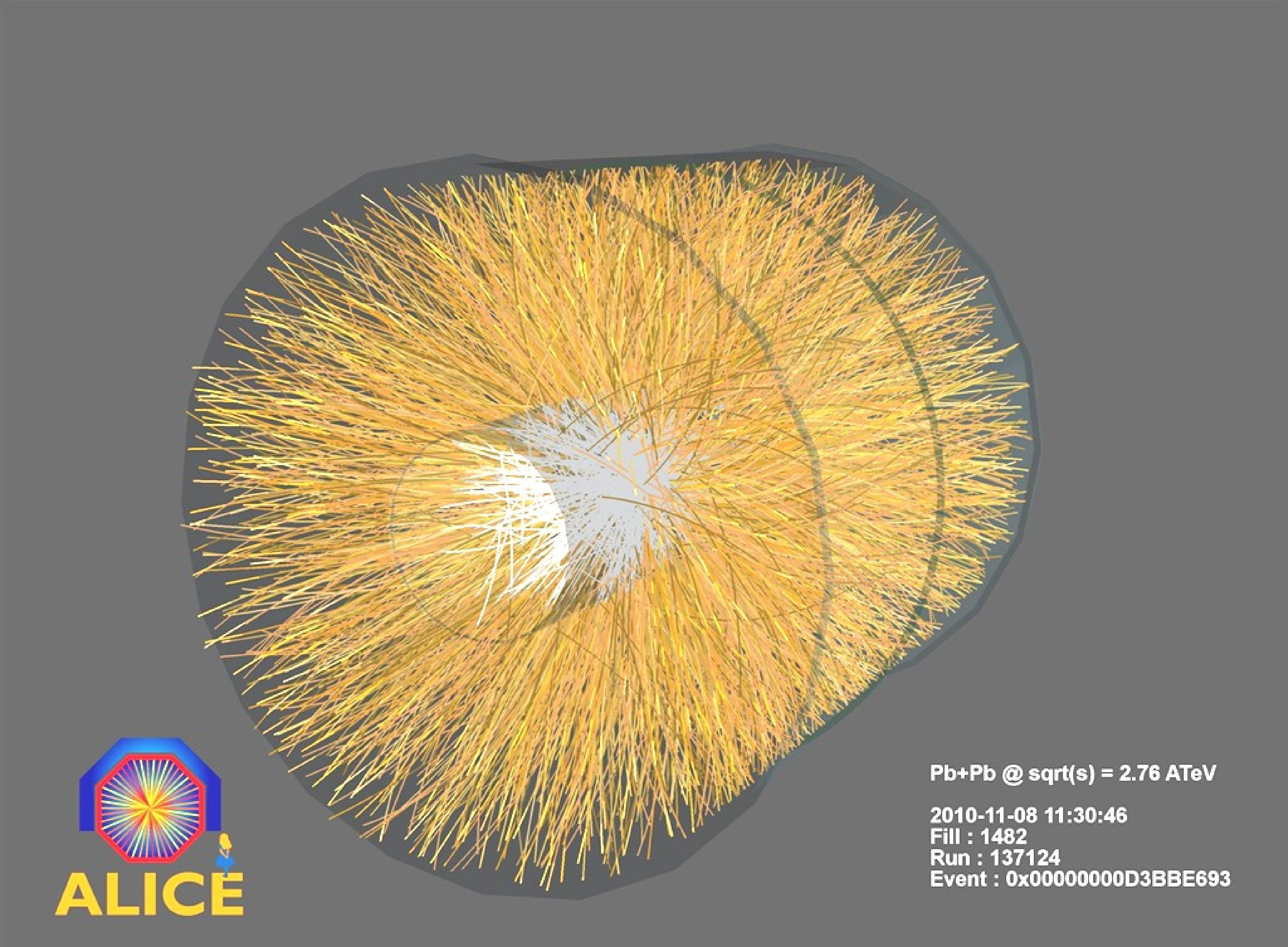

ALICE
Pb+Pb @ sqrt(s) = 2.76 ATeV
2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

QM1987 Nordkirchen

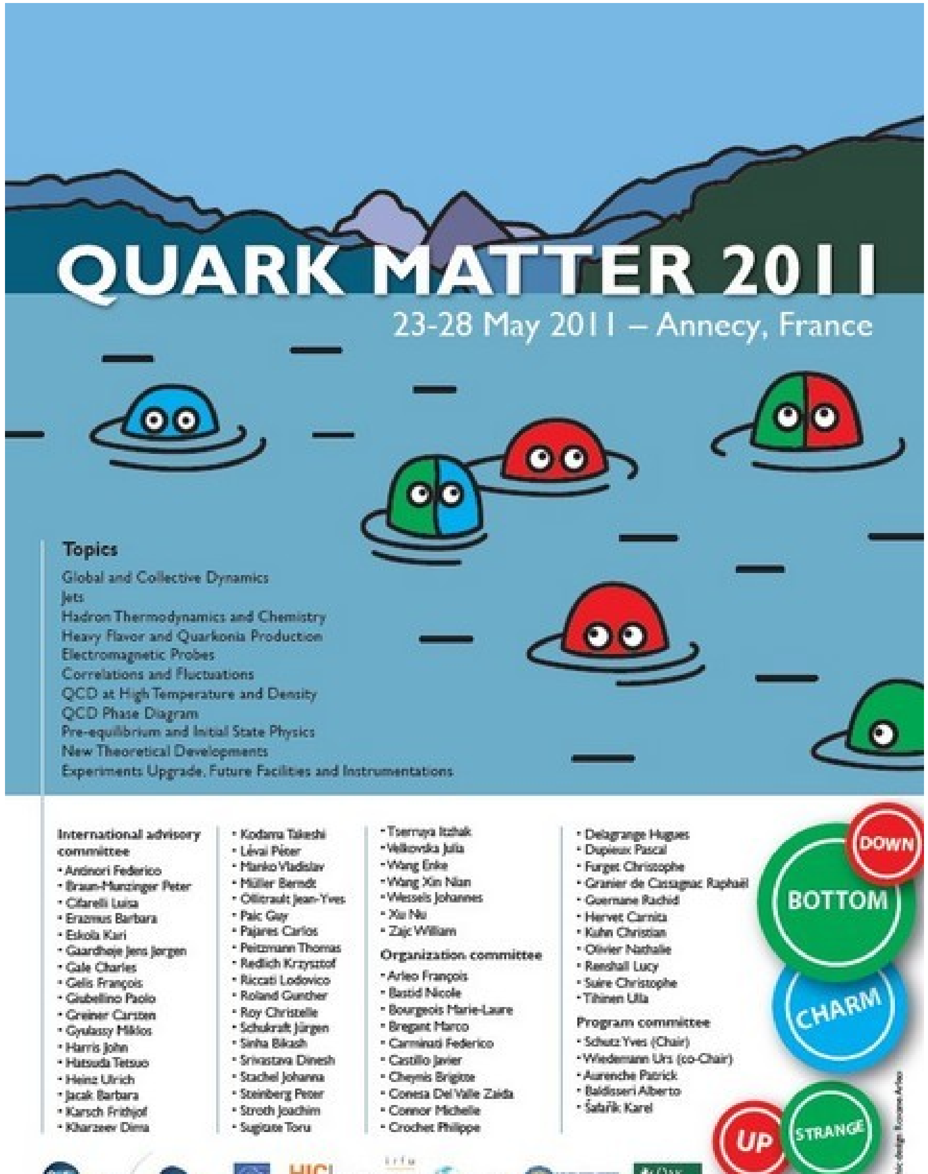
First Results from AGS/SPS

QM2001 Stony Brook

QM2001
Quark Matter 2001

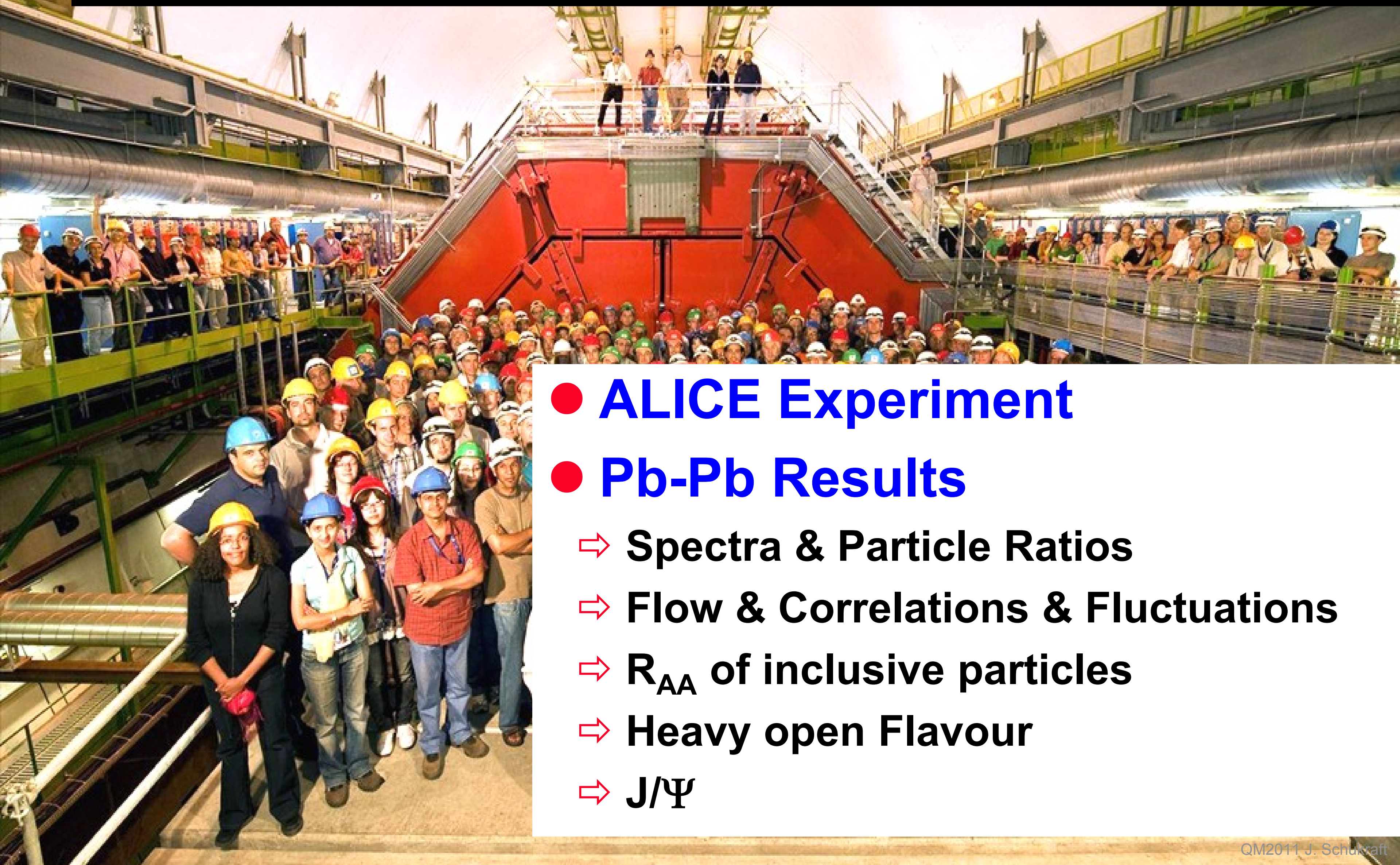
First Results from RHIC

QM2011 Annecy

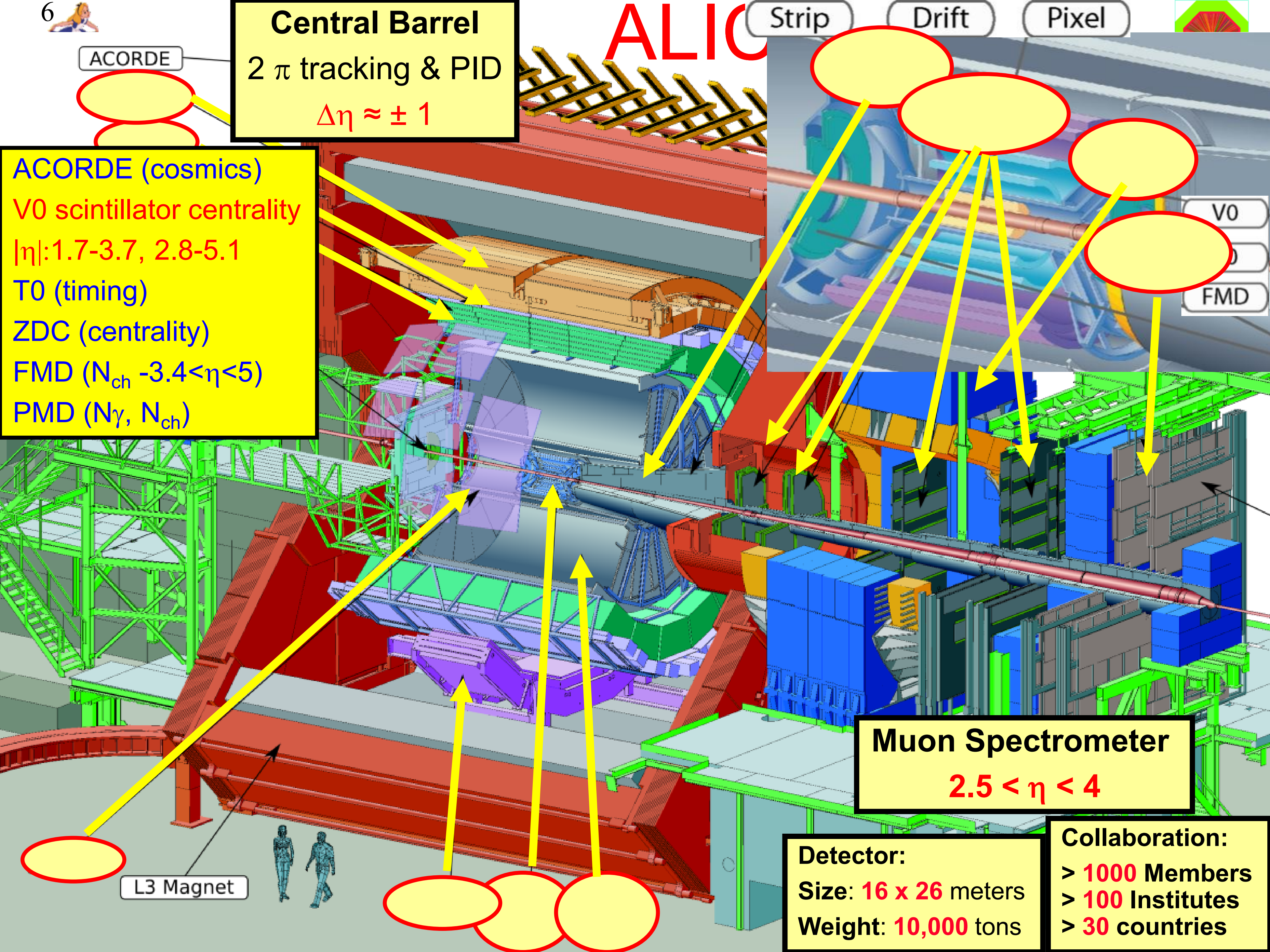


First Results from LHC

ALICE@LHC
A Large Ion Collider Experiment



- **ALICE Experiment**
- **Pb-Pb Results**
  - ⇨ **Spectra & Particle Ratios**
  - ⇨ **Flow & Correlations & Fluctuations**
  - ⇨ **R_{AA} of inclusive particles**
  - ⇨ **Heavy open Flavour**
  - ⇨ **J/Ψ**


ALIC
Central Barrel
2 π tracking & PID
Δη ≈ ± 1
ACORDE
Strip
Drift
Pixel
ACORDE (cosmics)
V0 scintillator centrality
|η|:1.7-3.7, 2.8-5.1
T0 (timing)
ZDC (centrality)
FMD (N_ch -3.4<η<5)
PMD (Nγ, N_ch)
V0
FMD
Muon Spectrometer
2.5 < η < 4
L3 Magnet
Detector:
Size: 16 x 26 meters
Weight: 10,000 tons
Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries

Detector Status

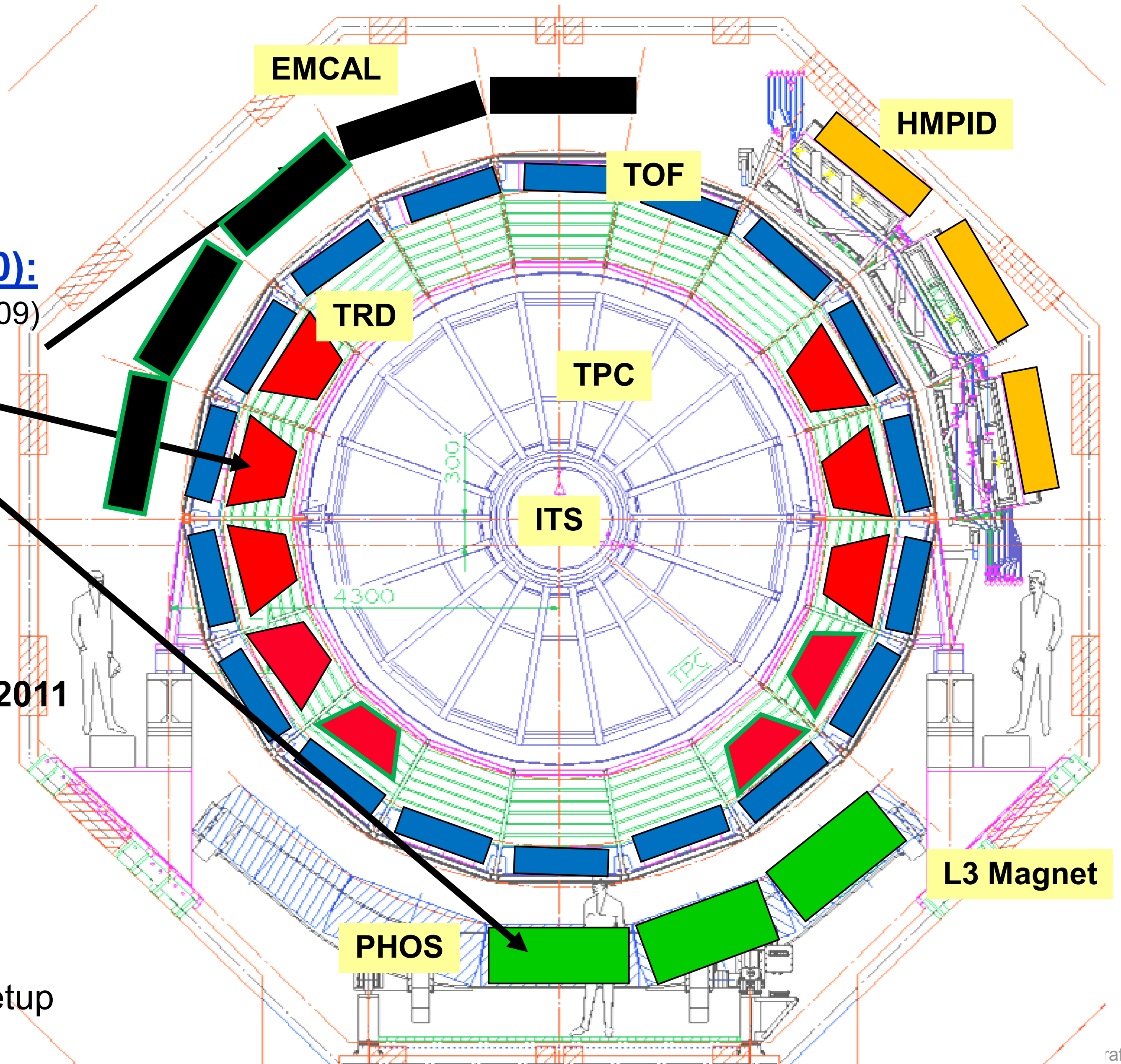
Complete since 2008:
ITS, TPC, TOF, HMPID, FMD, T0, V0, ZDC, Muon arm, Acorde PMD , DAQ

Partial installation (2010):
4/10 EMCAL* (approved 2009)
7/18 TRD* (approved 2002)
3/5 PHOS (funding)

~ 60% **HLT** (High Level Trigger)

2011
10/10 EMCAL
10/18 TRD

TRD to be completed end 2011



*upgrade to the original setup

Selected Highlights results ~~pp and~~ PbPb

ALICE Talks

Plenary:

- Global properties: A. Toia
- HBT: A. Kisiel
- Flow: R. Snellings
- R_{AA}: H. Appelshaeuser
- Identified Particles: M. Floris
- Correlations (I_{AA}): Jan Fiete GO
- J/Psi: G. Martinez Garcia
- Heavy Flavour: A. Dainese

Identified hadrons

- PID methods: A. Kalweit
- π/K/p in pp: M. Chojnacki
- π^0,η in pp: K. Reygers
- Resonances: A. Pulvirenti
- Λ/K^0: I. Belikov
- Ξ, Ω pp Pb: D. Chinellato
- R_{AA} Λ/K^0 : S. Schuchmann
- ρ,ω,ϕ pp: A. de Falco

Experiments

- Upgrades: T. Peitzmann
- cross section pp: K. Oyama

Global & Collective

- N_{ch}, centrality: C. Loizides
- 'strong CP viol': P. Christakoglou
- directed flow v_1: I. Selyuzhenkov
- elliptic flow high p_t: A. Dobrin
- elliptic flow PID: M. Krzewicki
- Ultra-peripheral: C. Oppedisano
- Diffraction pp: M. Poghosyan

Correlations & Fluctuations

- Elliptic flow: A. Bilandzic
- Triggered dihadrons: A. Adare
- Untriggered dihadrons: A. Timmins
- Dihadrons pp: Y. Mao
- pT fluctuations: S. Heckel
- HBT: J. Mercado
- HBT K_0^s pp: T. Humanic

Heavy Flavour

- HF μ: X. Zhang
- HF e: S. Masciocchi
- J/Ψ pp: R. Arnaldi
- J/Ψ Pb: P. Pillot
- D mesons R_{AA}: A. Rossi

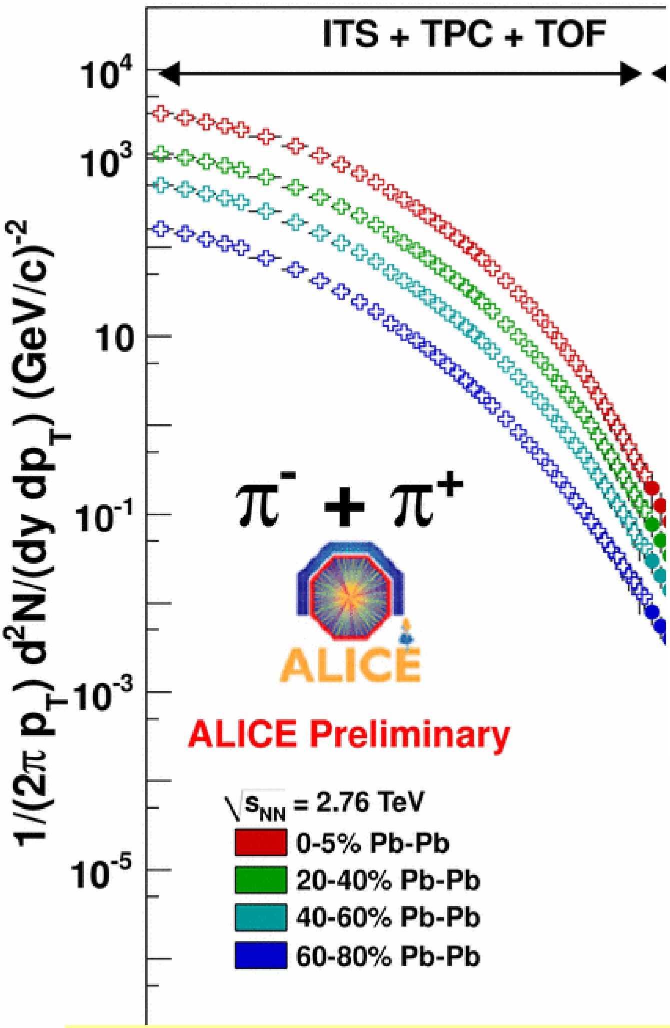
Jets

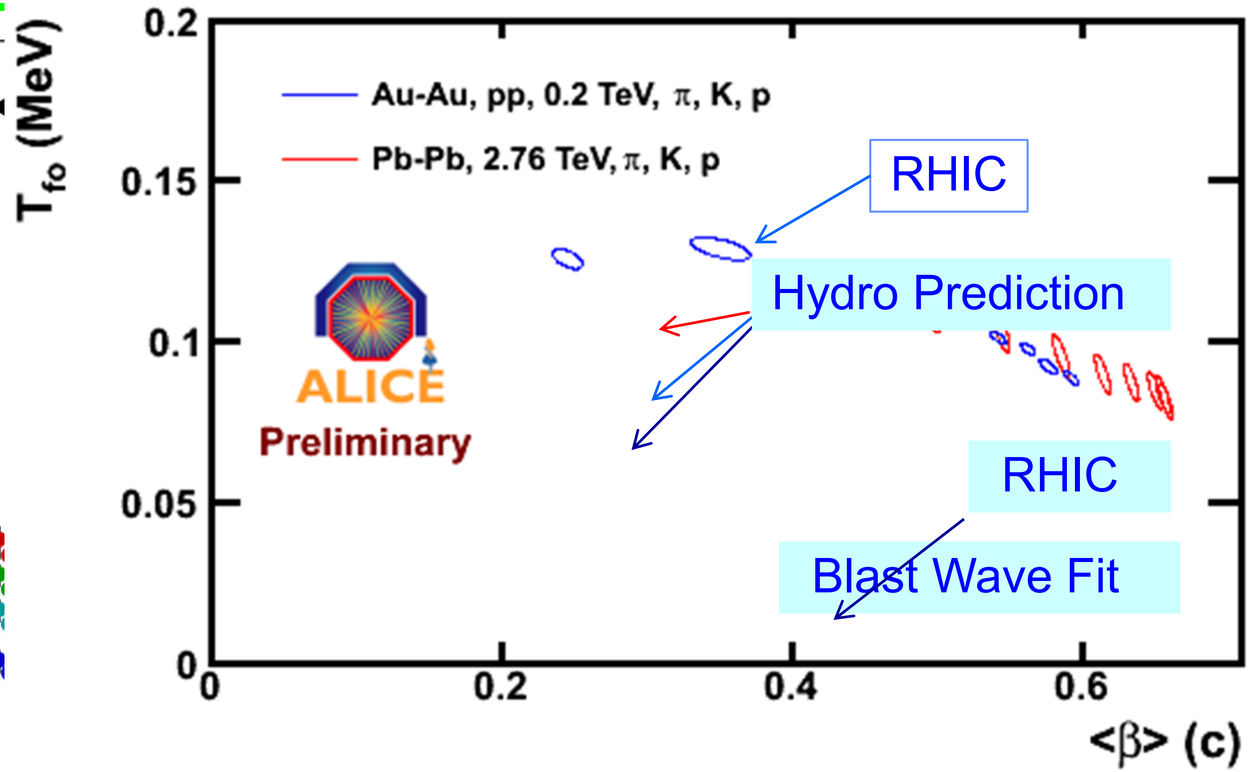
- Jet reconstruction: C. Klein-Boesing
- R_{AA} charged: J. Otwinowski
- R_{AA} π^0: G. Conesa Balbastre

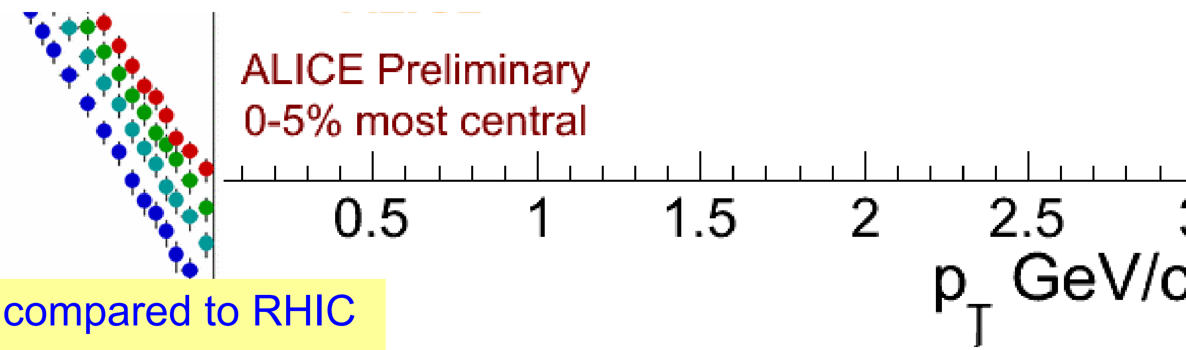
Data Samples

Beam	Energy	# of Events	
pp	900 GeV	300 k MB	2009, analysis finished
pp	900 GeV	~ 8 M MB	2010, partially analyzed
pp	2.36 TeV	~ 40 k MB	2009, only ITS, $dN_{ch}/d\eta$
pp	7 TeV	~ 800 M MB ~ 50 M muons ~ 20 M high N_{ch}	2010
PbPb	2.76 TeV/N	~ 30 M MB	2010
pp	2.76 TeV	~ 70 M MB ~ 20 nb^{-1} (rare triggers)	2011, analysis started 30 h only

Identified Particle spectra







Very significant changes in slope compared to RHIC

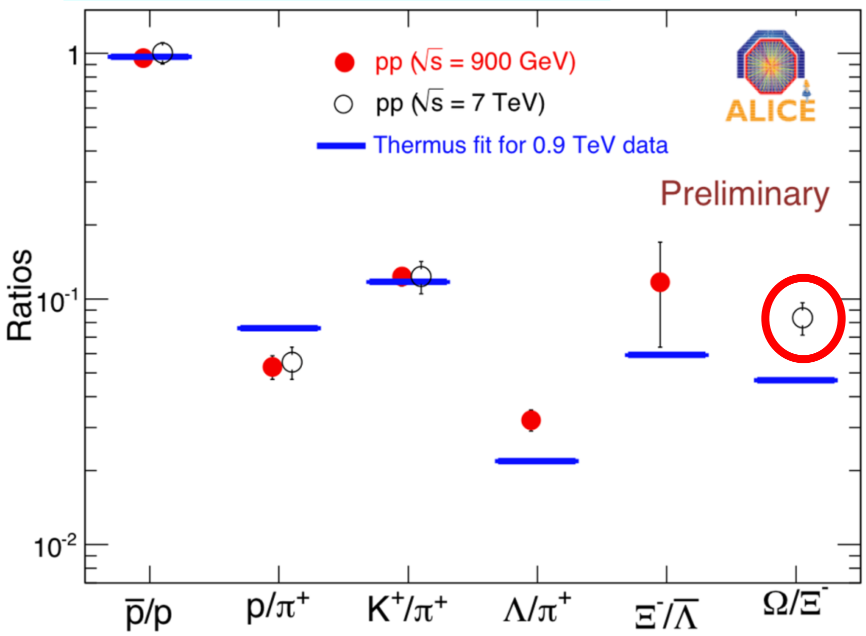
Most dramatically for protons

Very strong radial flow, $\beta \approx 0.66$

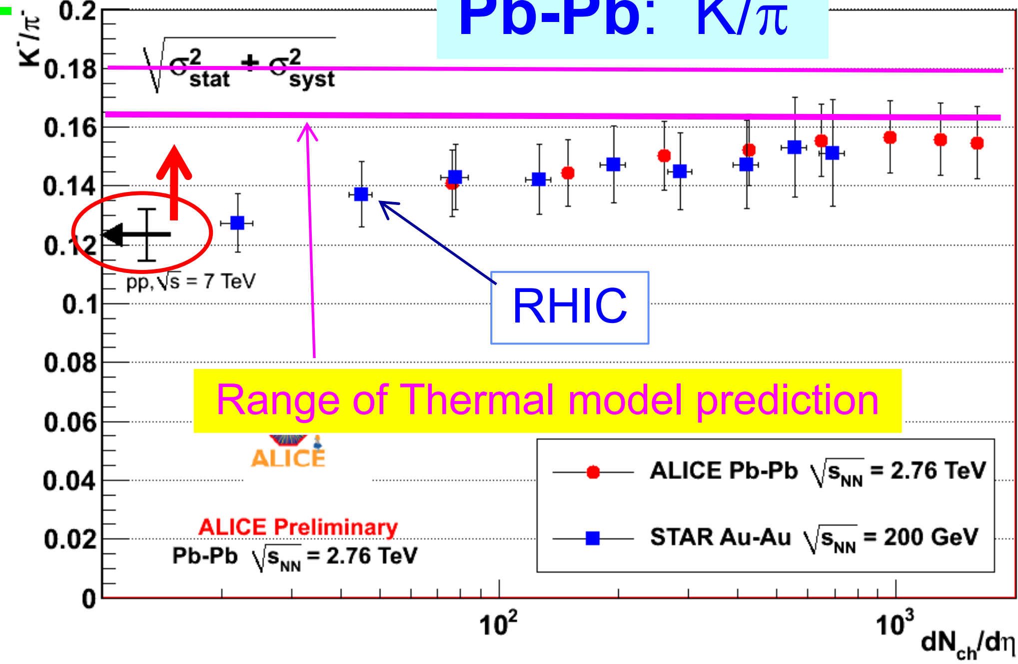
even larger than predicted by most recent hydro

Particle Ratios

pp: 900 GeV & 7 TeV



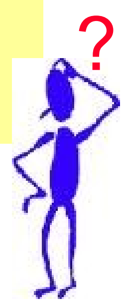
Pb-Pb: K/π



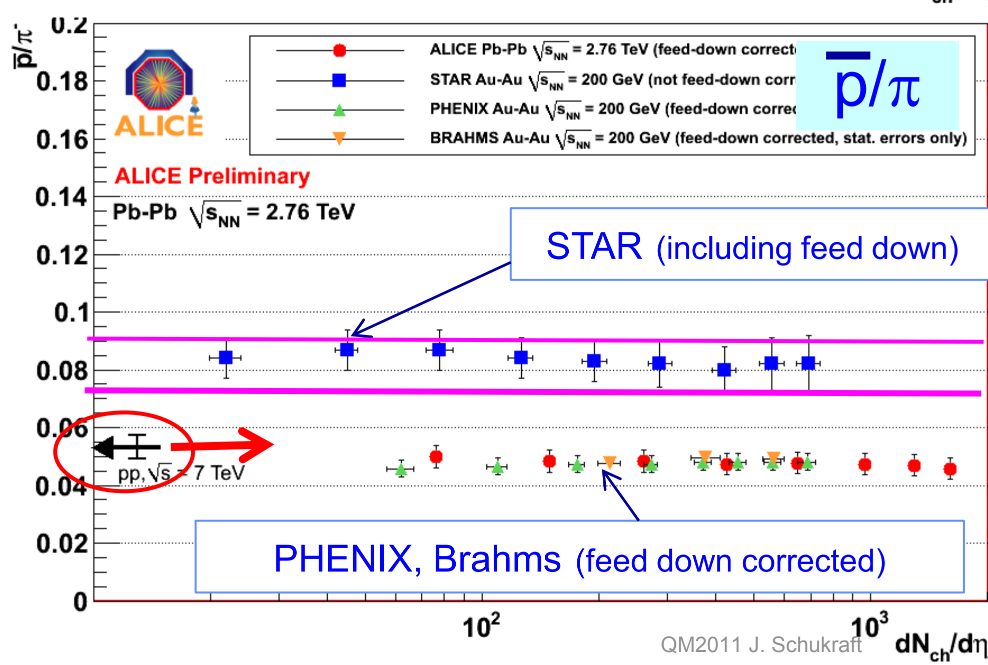
- **pp:** Thermus thermal fit rather poor
  (wasn't this better for pp at lower energies ??)
- **K/π** grows slightly from pp value
- **p/π** ≈ like pp

Pb: p/π off by factor > 1.5 from predictions !

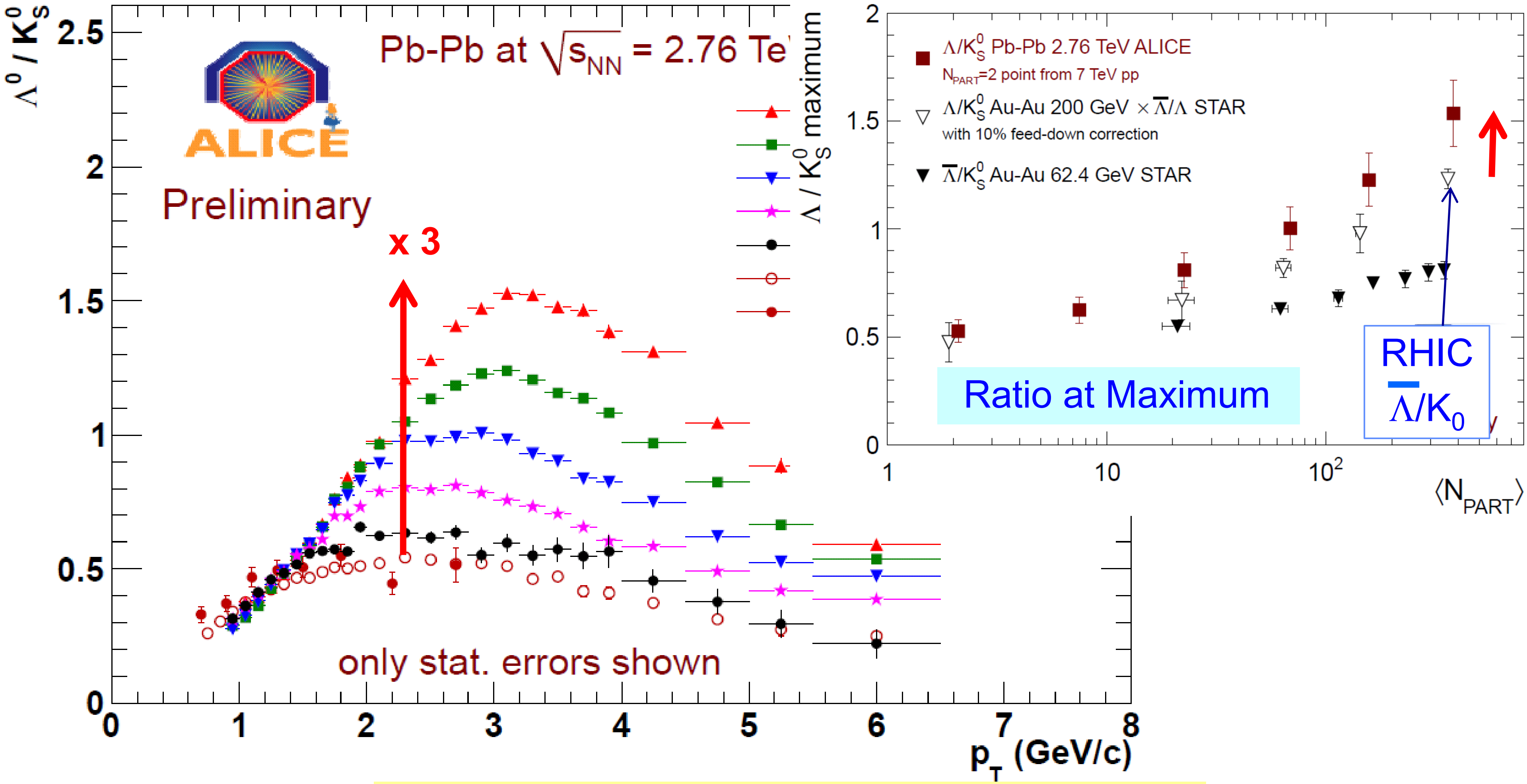
but very compatible with RHIC !!



Before we can conclude anything we need more particle species..



'Baryon anomaly': Λ/K_0



Baryon/Meson ratio still strongly enhanced

x 3 compared to pp at 3 GeV

- Enhancement slightly larger than at RHIC 200 GeV
- Maximum shift very little in p_T compared to RHIC

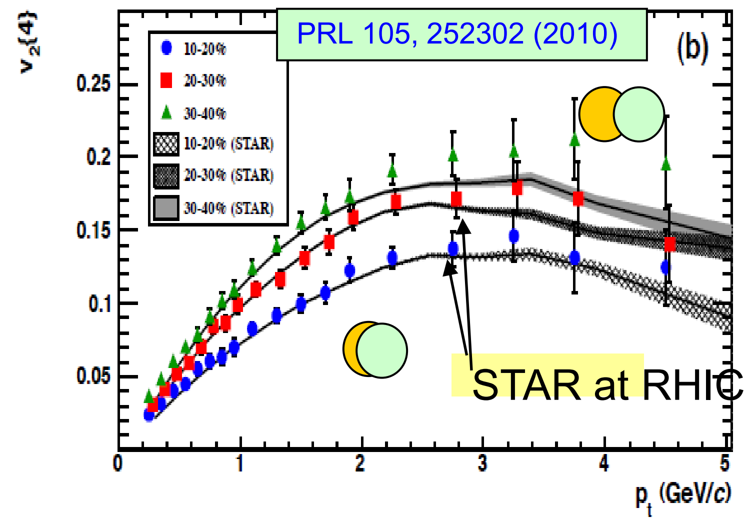
despite large change in underlying spectra !

Azimuthal Flow: What next ?

- ## Precision measurement of η/s:

$$\eta = \frac{\sqrt{2mkT}}{\sigma}$$

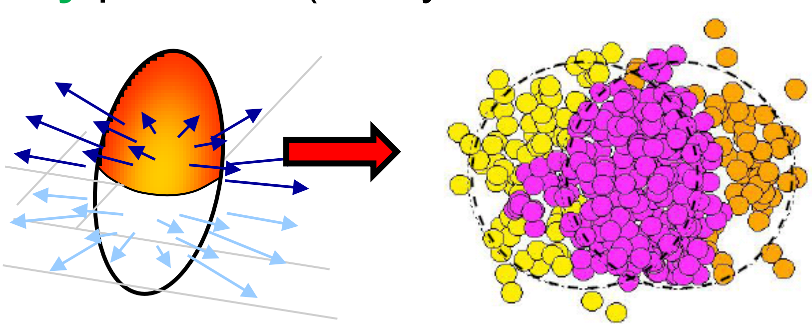
- ⇨ current RHIC limit: $\eta/S < (2\text{-}5) \times 1/4\pi$
- ⇨ $\eta/S < 1/4\pi$ => conjectured AdS/CFT limit is wrong
- ⇨ $\eta/S > 1/4\pi$ => measure σ
- ⇨ $\eta/S \approx 1/4\pi$ => quantum corrections which are O(10-30%) in AdS/CFT!
  - ✪ **20% in v_2 ~ $1/4\pi$ => need few % precision**



- ## Precision: How ?

- ⇨ fix **initial conditions** (geometrical shape is model dependent, eg Glauber, CGC)
- ⇨ quantify **flow fluctuations** σ (influence measured v_2, depending on method)
- ⇨ measure **non-flow correlations** δ (eg jets)
- ⇨ **improve theory** precision (3D hydro, 'hadronic afterburner', ...)
- ⇨ ....

$$v_n\{2\} \cong v_n^2 + \sigma_n^2 + \delta$$
$$v_n\{4\} \cong v_n^2 - \sigma_n^2$$



Elliptic Flow v_2

Non-Flow corrections

Several methods to asses (and correct for) non-flow

PID flow:

- π and p are 'pushed' further compared to RHIC

 ≈ expected from hydro, but even stronger radial flow (see spectra)

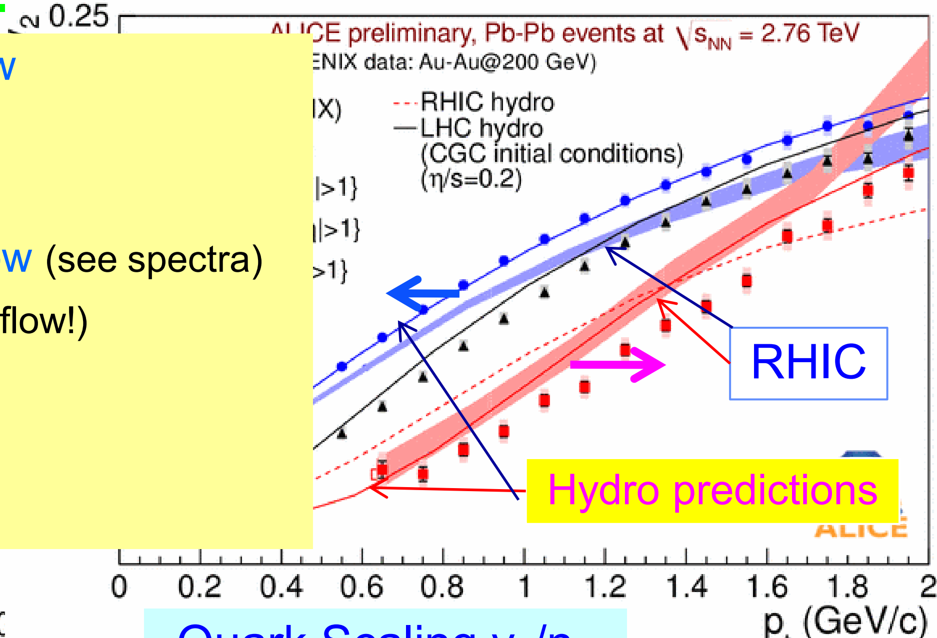
- quark scaling no longer holds at lower p_T (hadrons flow!)

Flow fluctuations:

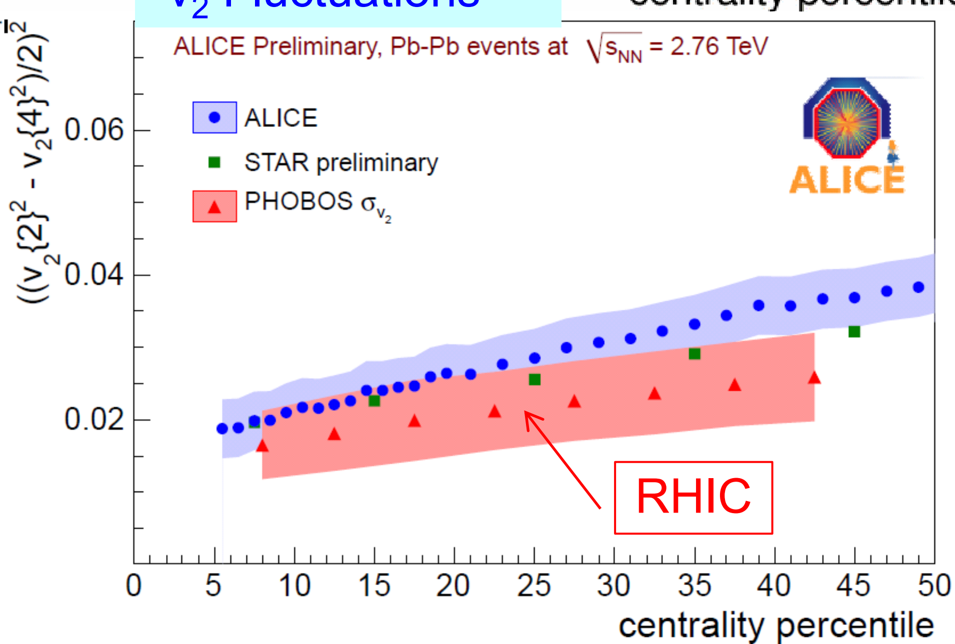
- comparable to RHIC (driven mostly by geometry)

- **measurement is needed for precision v_2**

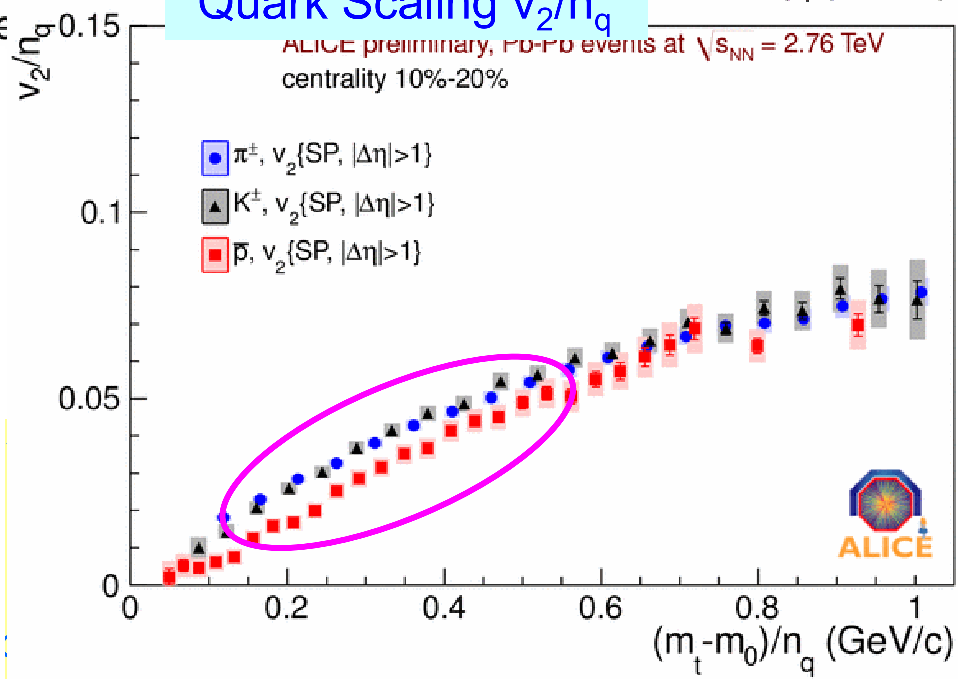
π/K/p v_2



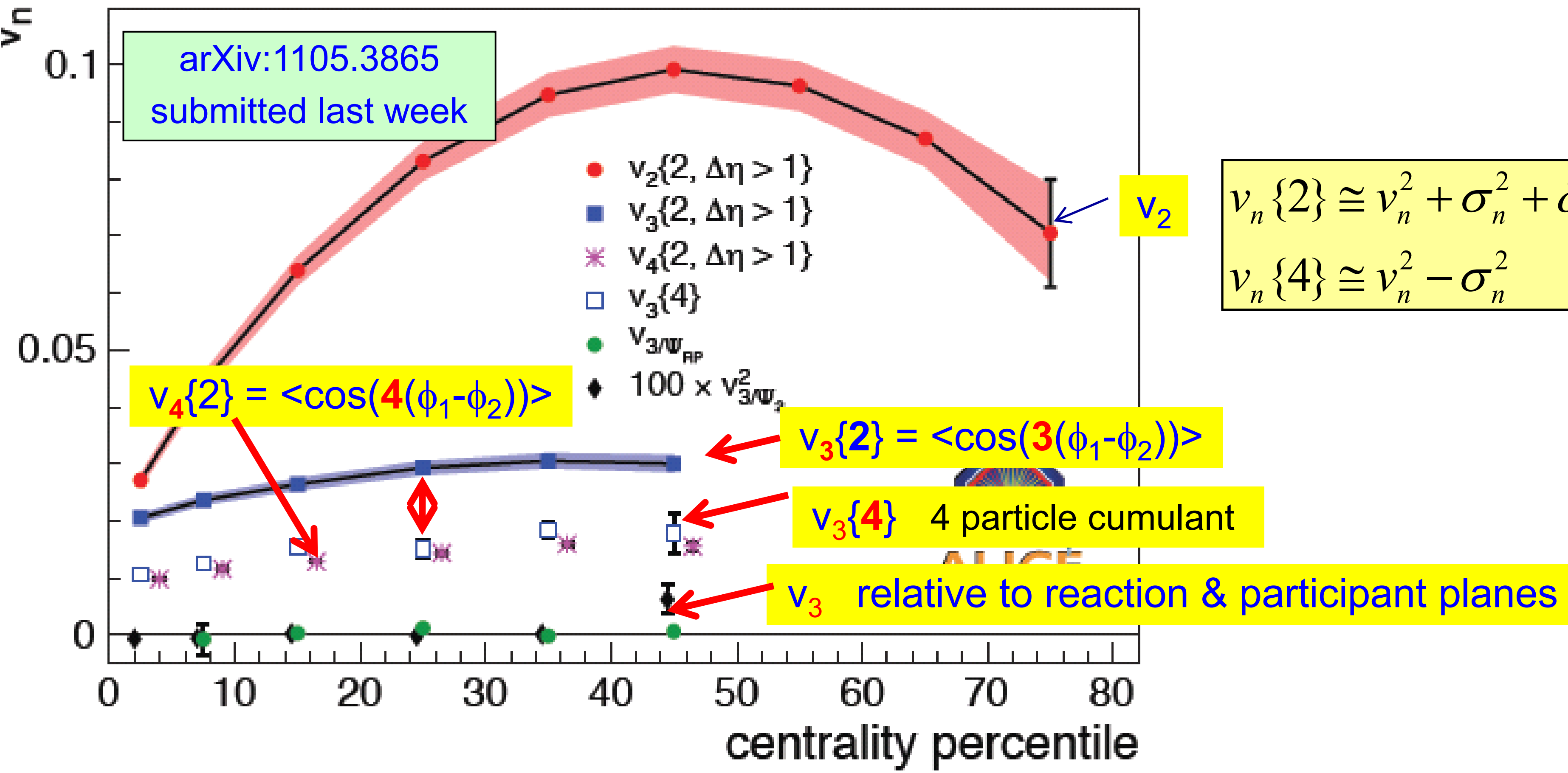
v_2 Fluctuations



Quark Scaling v_2/n_q



Higher Order Flow v_3, v_4,..



$$v_n\{2\} \cong v_n^2 + \sigma_n^2 + \delta$$
$$v_n\{4\} \cong v_n^2 - \sigma_n^2$$

V_3:

small dependence on centrality

$v_3\{4\}$ > 0 => not non-flow

$v_3\{4\} < v_3\{2\}$ => fluctuations !

v3{RP} ≈ 0 => indep. fluctuations

But is v_3 really 'Hydro' flow ?

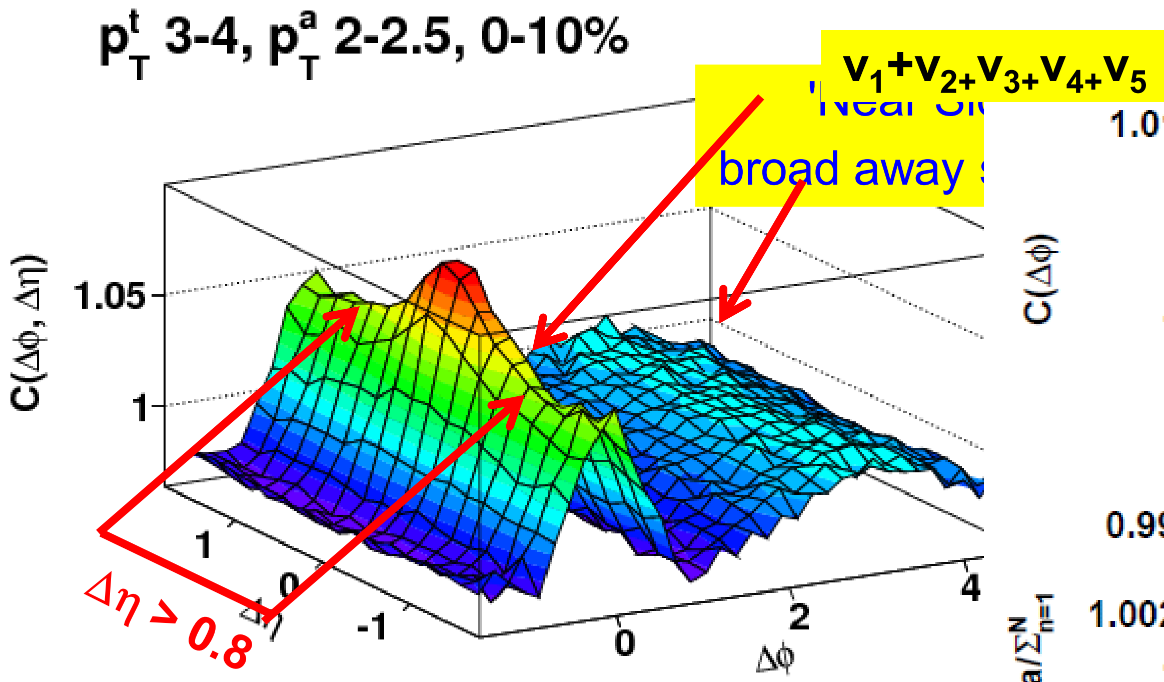
1) Is the structure 'visible' in 2 particle correlations?

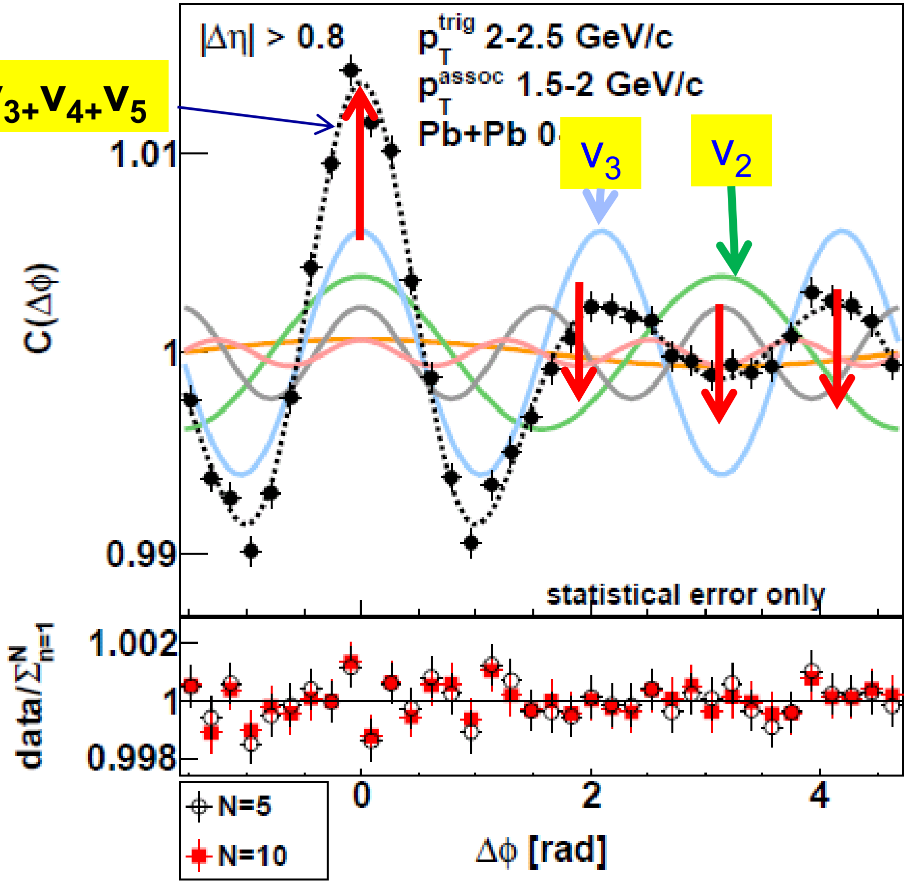
2) Is it consistent with a flow hypothesis ?

3) Does it show the expected mass dependence ?

4) Is it of the expected magnitude ?

Flow & 2 Particle Correlations





Projection on $\Delta\phi$ for $\Delta\eta$ > 0.8

Clean double Hump (aka 'Mach Cone') appears for ultra-central

(without any flow subtraction !)

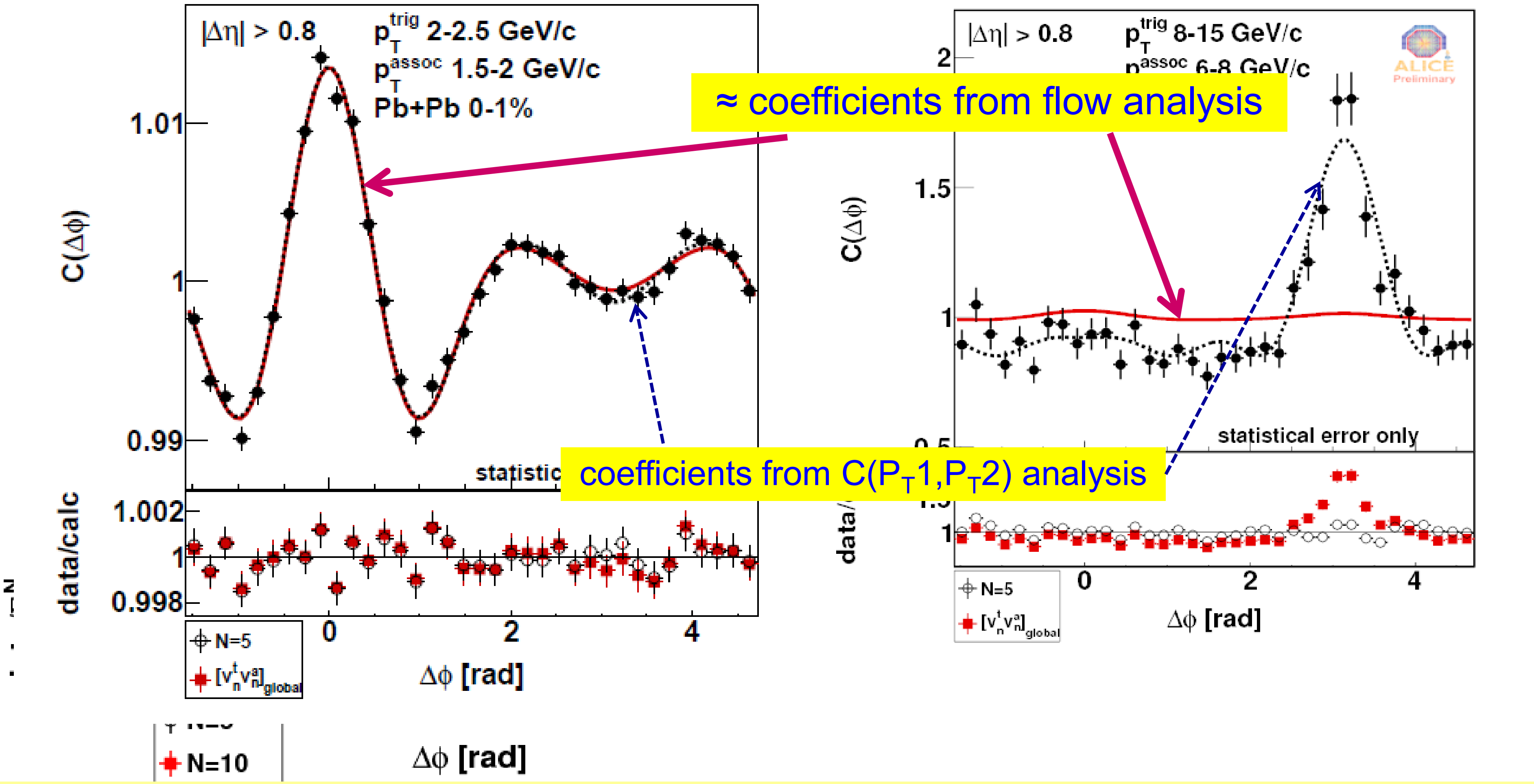
Full correlation structure described by Fourier Coefficients v_1,**v_2, v_3**, v_4,v_5 **(for |η|>0.8)**

v3 very visible, indeed, v3 ≈ v2 for very central

1) ✓

'Mach Cone' & 'Near Side Ridge' shapes evolve smooth with magnitude of v_2 and v_3

Flow & 2 Particle Correlations



Almost any structure can be described with enough coefficients !

- But not if we impose factorization **$C(p_T1, p_T2)=v(p_T1)*v(p_T2)$** (or take coefficients from flow analysis).

Correlations (|η|>0.8) can be described **consistently** with 'collective flow' hypothesis

for p_T < 3-4 GeV (consistent with 'collectivity ')

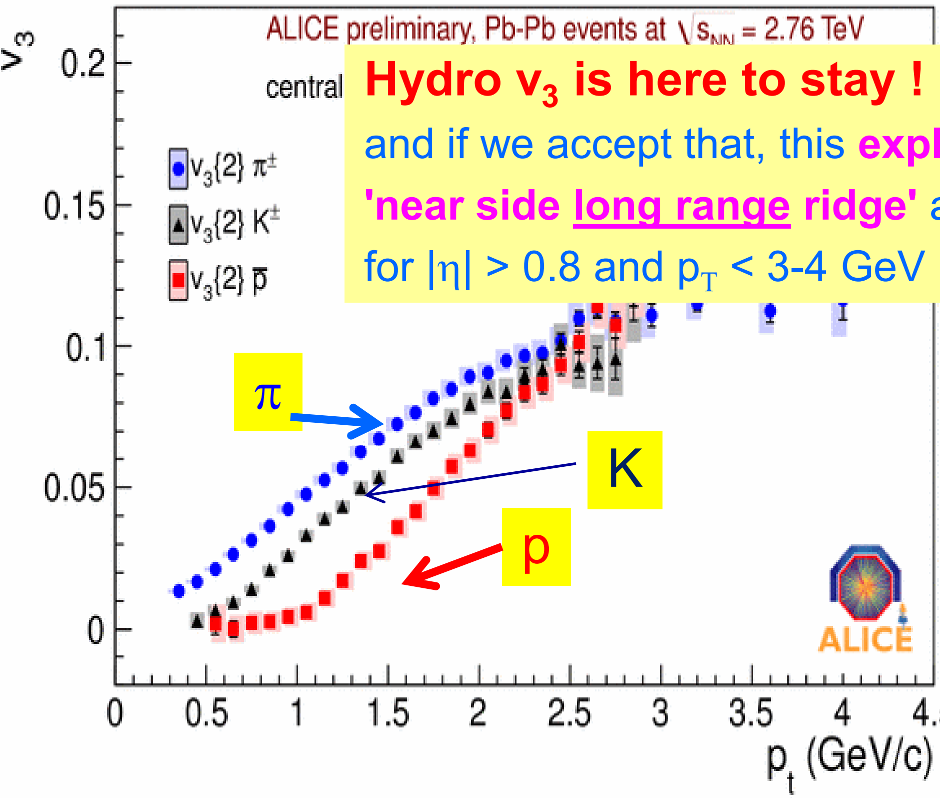
only partially or not at all for p_T > 5 GeV

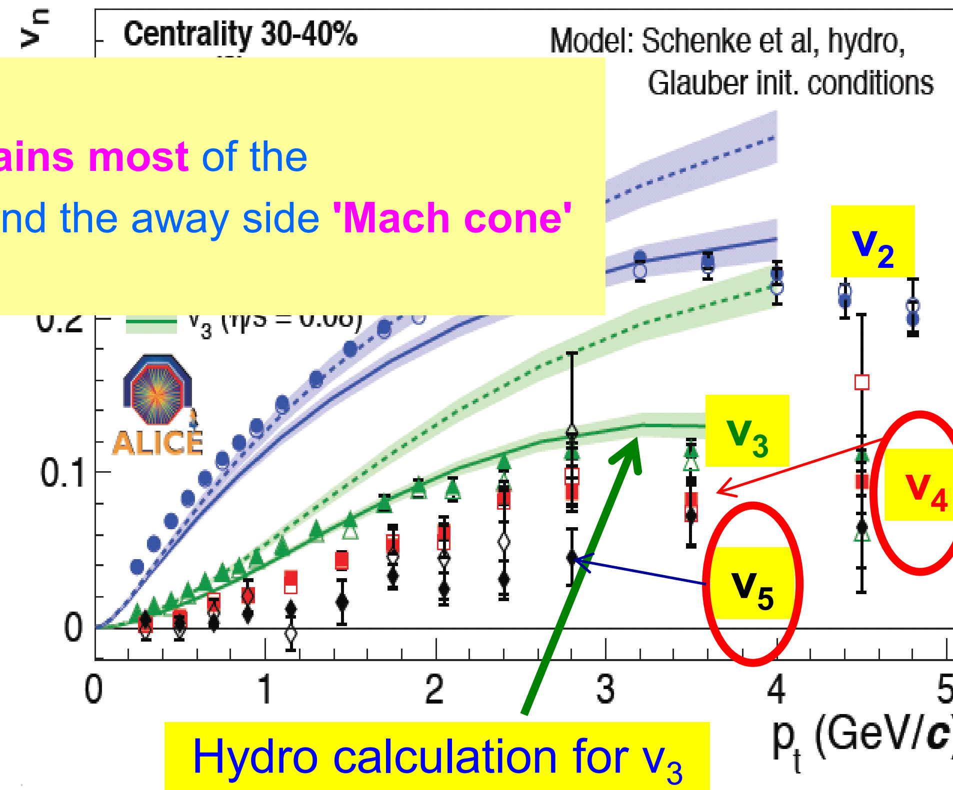
2) ✓

Triangular Flow v3

v_3 for π/K/p

v_3 v_4 v_5 versus p_T





Hydro v_3 is here to stay !

and if we accept that, this **explains most** of the **'near side long range ridge'** and the away side **'Mach cone'** for $|\eta| > 0.8$ and $p_T < 3\text{-}4$ GeV !

v_3 shows mass splitting expected from hydro flow ! 3) ✓ 4) ✓

Has the magnitude (and p_T dependence) expected from geometry fluctuations

(and has different sensitivity to η/s than v_2 !)

Initial Conditions

Comparison of

calculated eccentricities ε_n (geometrical shape, **input** to hydro)

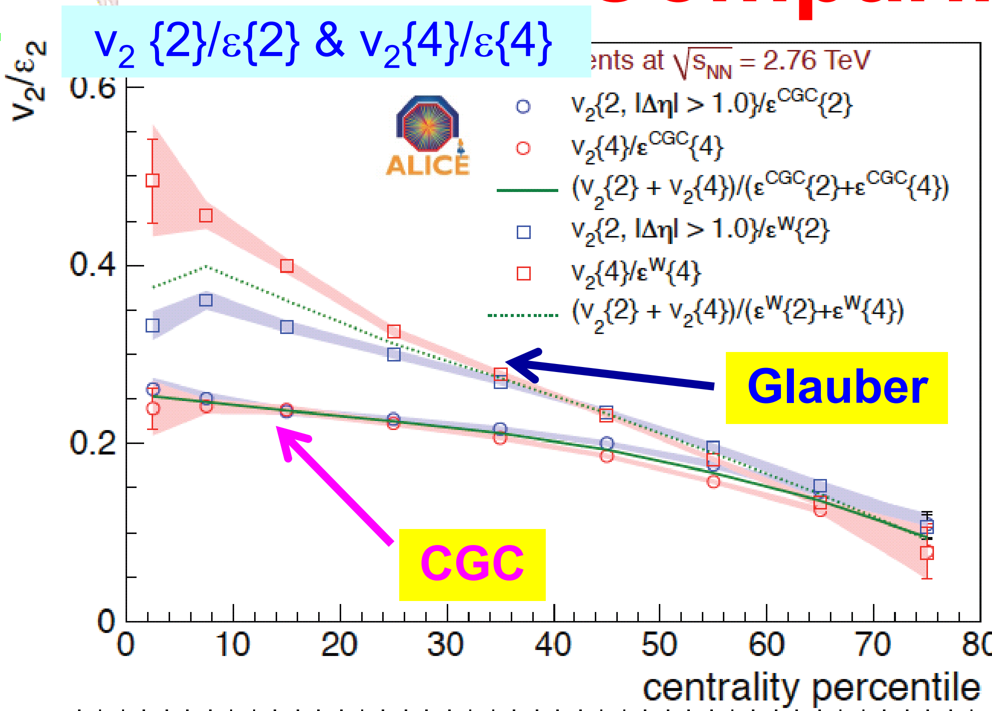
&

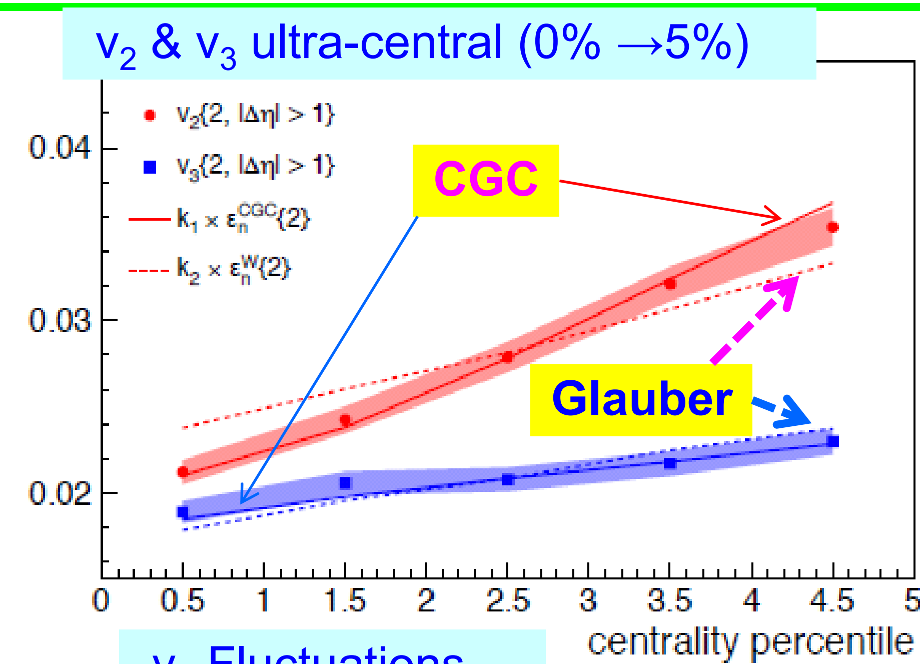
measured flow v_n (magnitude of flow, **output** of hydro)

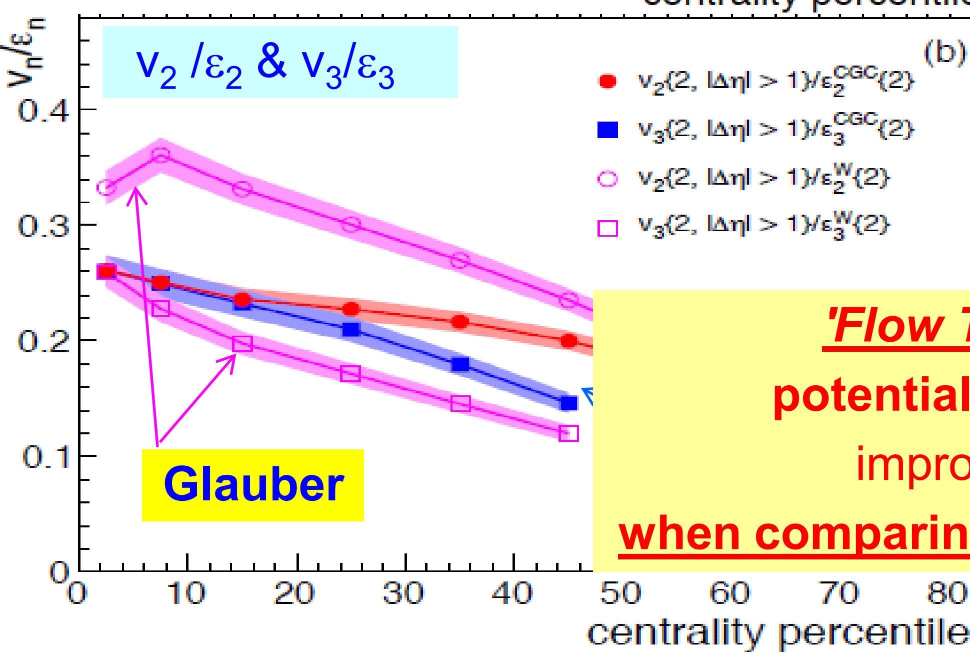
show

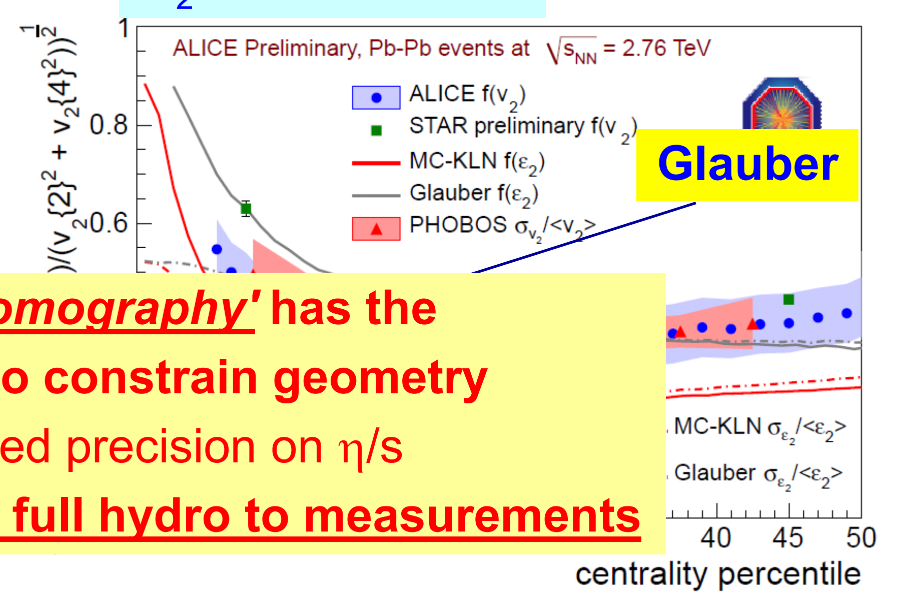
large difference between geometrical models !

Comparing v_n with ε_n









'Flow Tomography' **has the potential to constrain geometry**

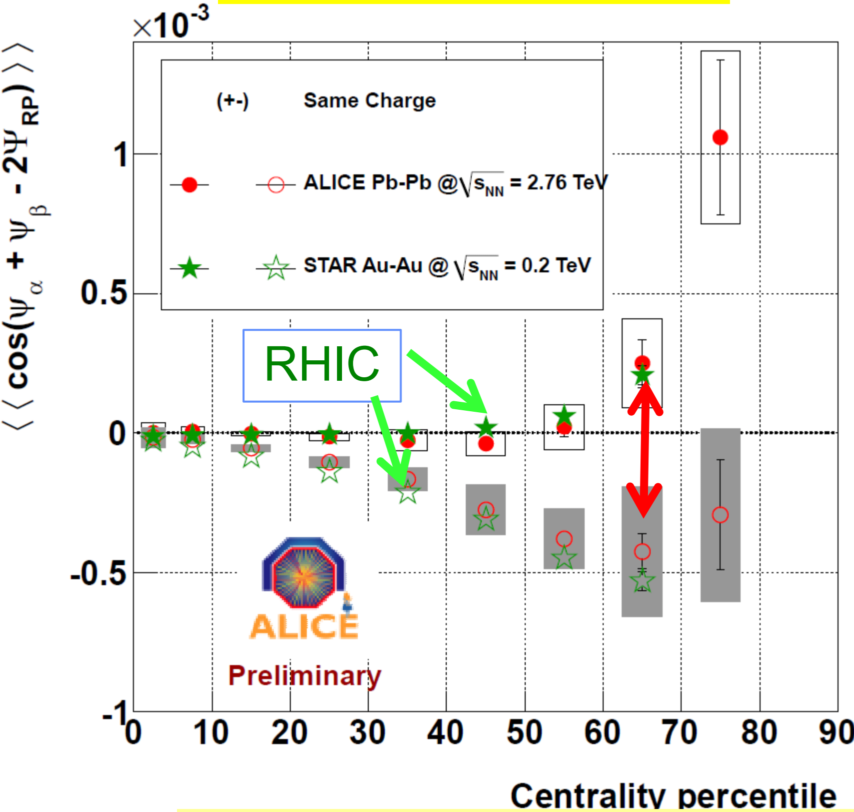
improved precision on η/s

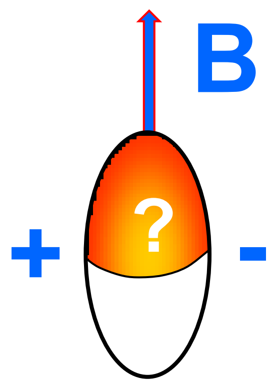
when comparing full hydro to measurements

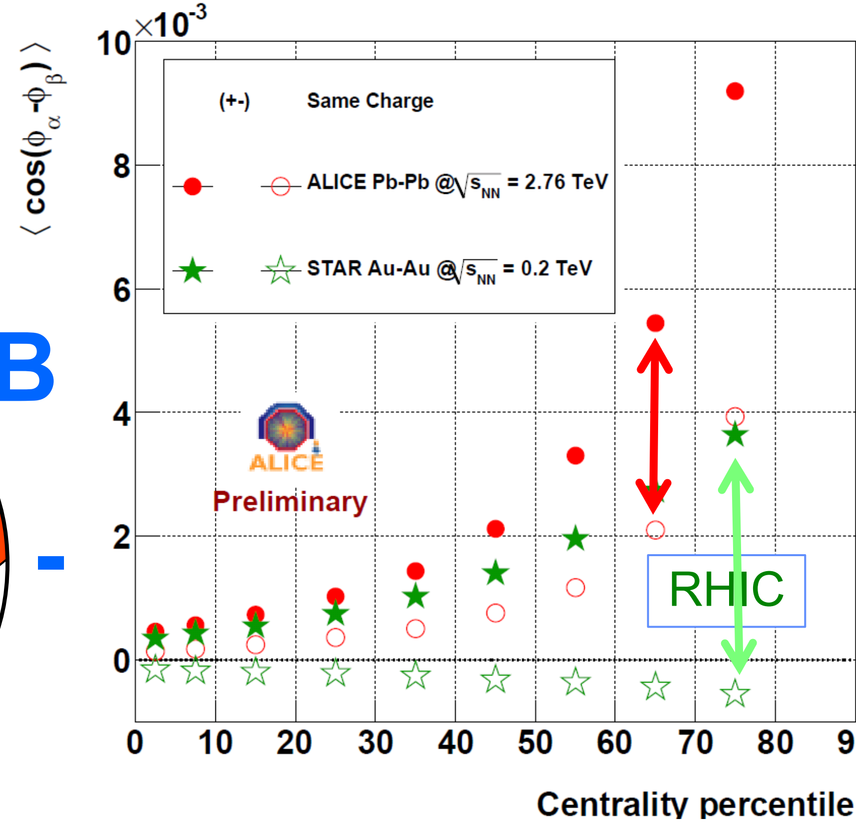
Chiral Magnetic Effect ~~('strong parity violation')~~

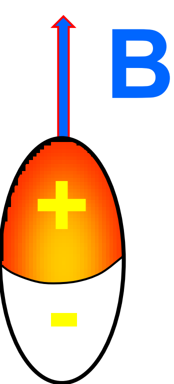
$$\left\langle \cos\left(\varphi_\alpha + \varphi_\beta - 2\Psi_{RP}\right)\right\rangle$$

$$\left\langle \cos\left(\varphi_\alpha - \varphi_\beta\right)\right\rangle$$









Same charge correlations **positive**

Opposite charge correlations **negative**

RHIC ≈ LHC

s

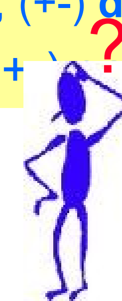
Local Parity Violation

in strong magnetic Field ?

may decrease with √s

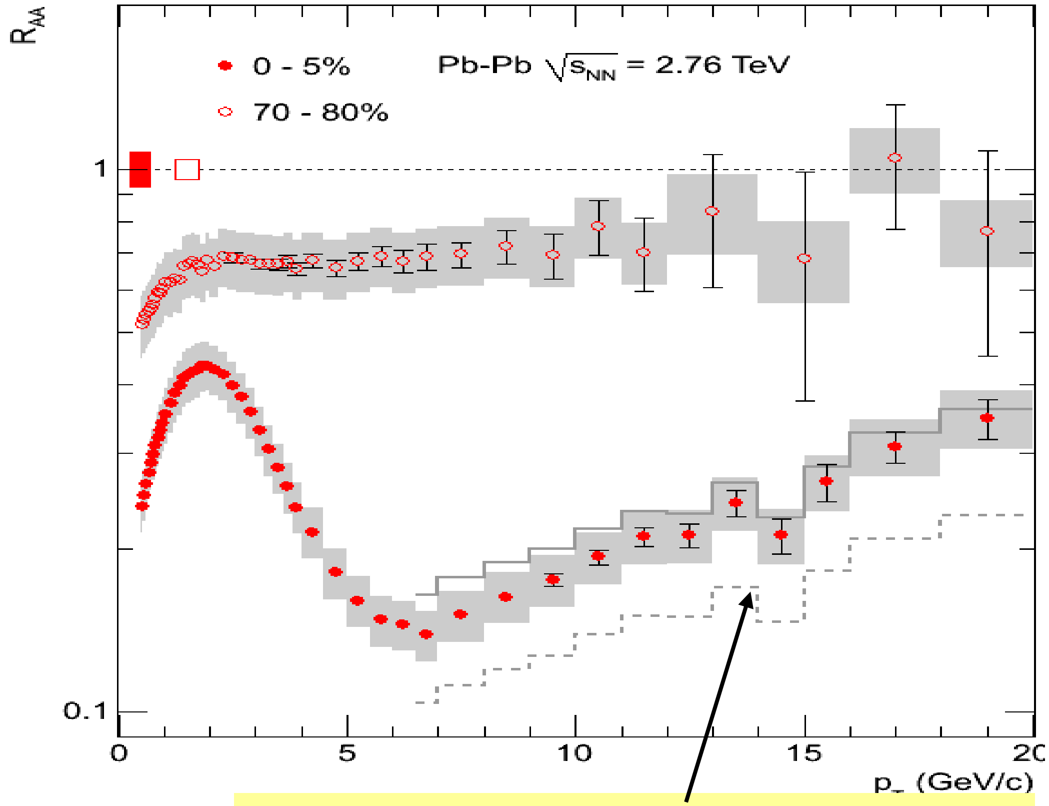
RHIC : (++), (+-) **different sign** and magnitude

LHC: (++),(+ … **me sign**, similar magnitude



Charged Particle R_{AA}

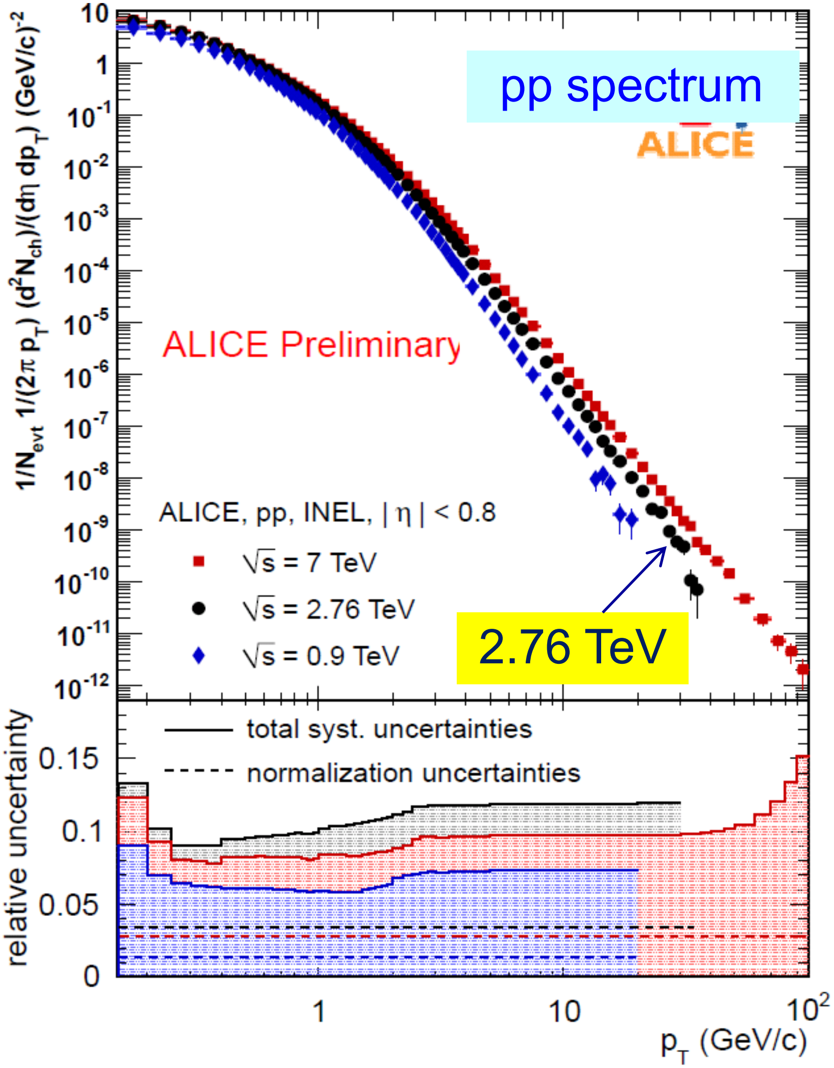
PLB 696 (2011) 30-39

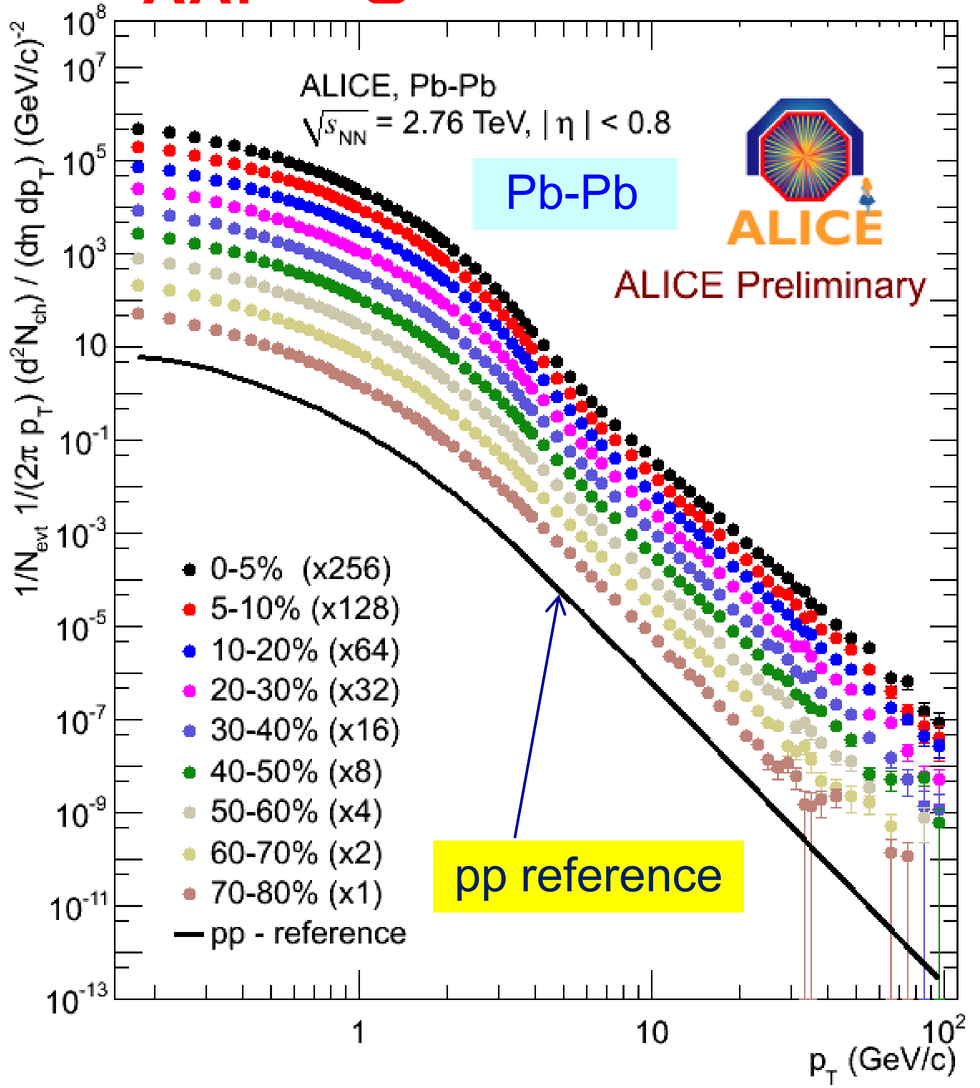


Extrapolated reference
=> large syst. error

$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta dp_T}{\langle N_{coll}\rangle (1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta dp_T}$$

Charged Particle R_{AA}: Ingredients





Measured reference, still needs extrapolation for p_T> 30 GeV

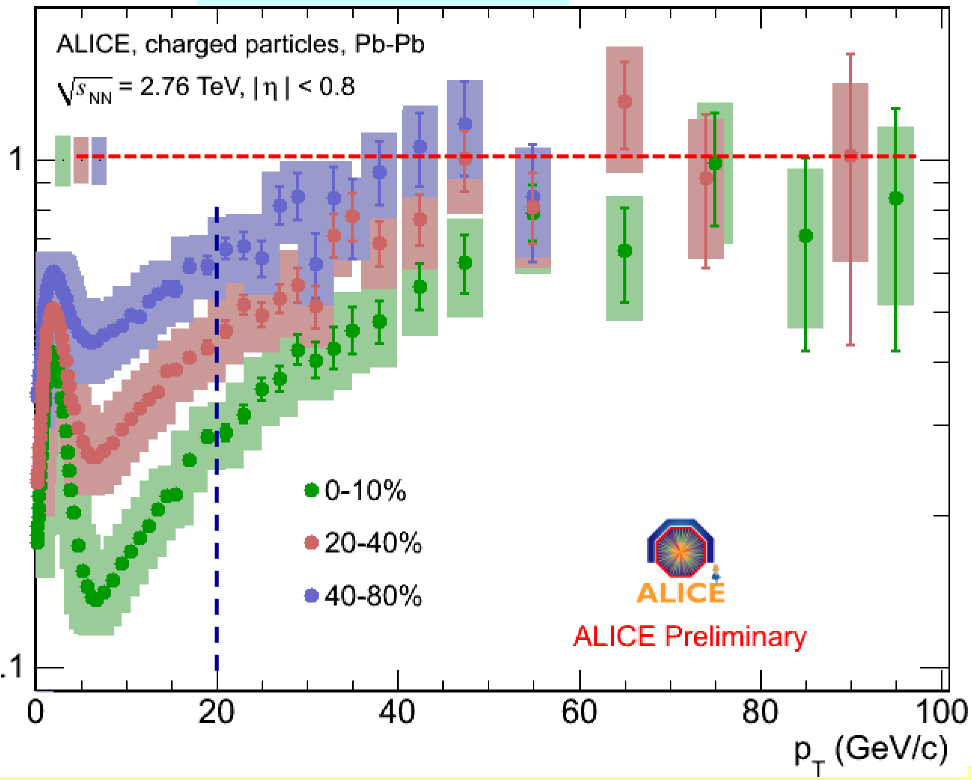
(but not in √s => smaller syst. error)

Note: measured spectrum somewhat different than previous extrapolation

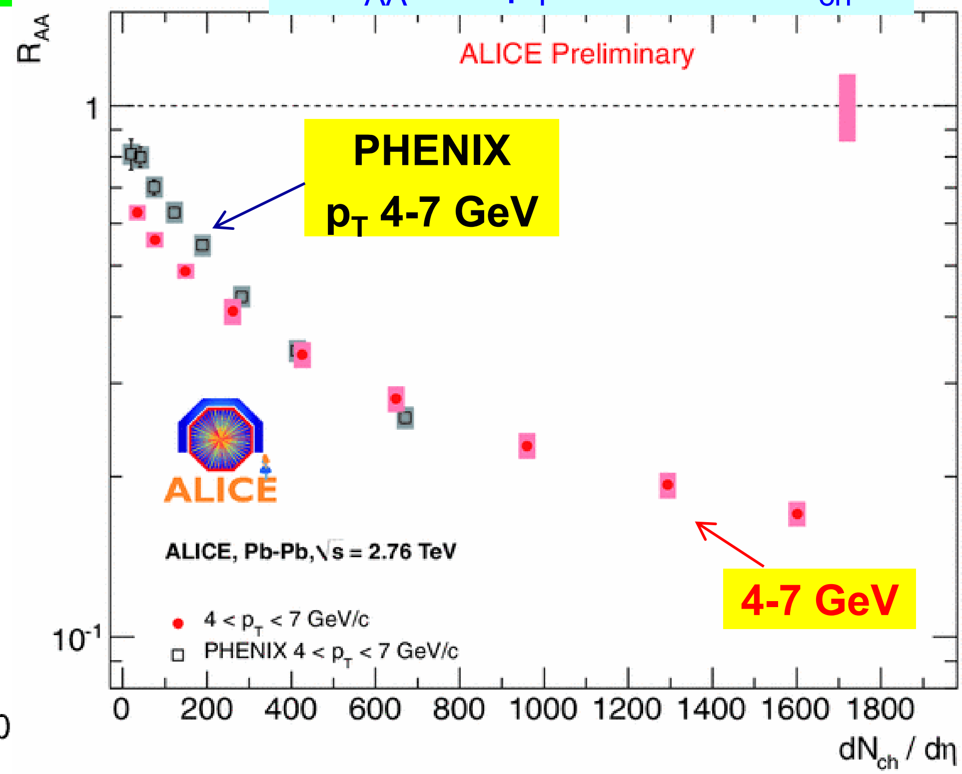
(**R_{AA} goes down**, but stays well within old systematic error bands)

R_{AA}: Results

R_{AA} versus p_T



$\langle R_{AA} \rangle$ in p_T bins vers. N_{ch}



Rise continues beyond 20 GeV

Gradual change of slope above 30-40 GeV

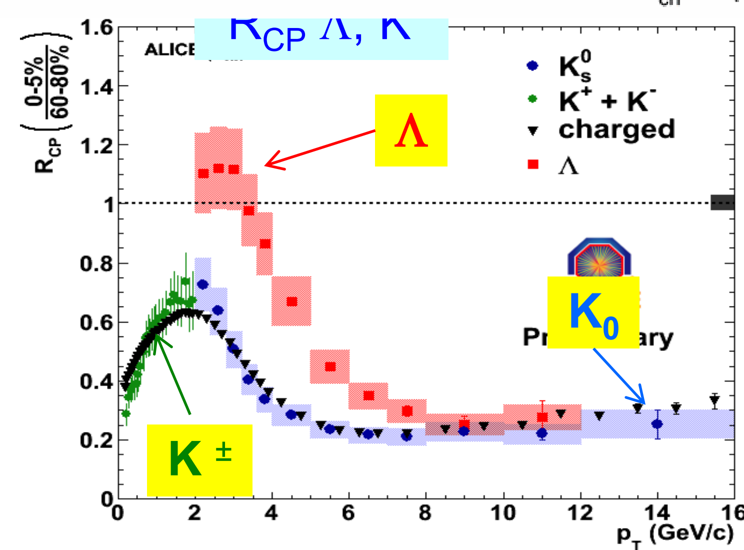
with increasing p_T

- less centrality dependence, less suppression

Note: centrality dependence is independent of reference spectrum !

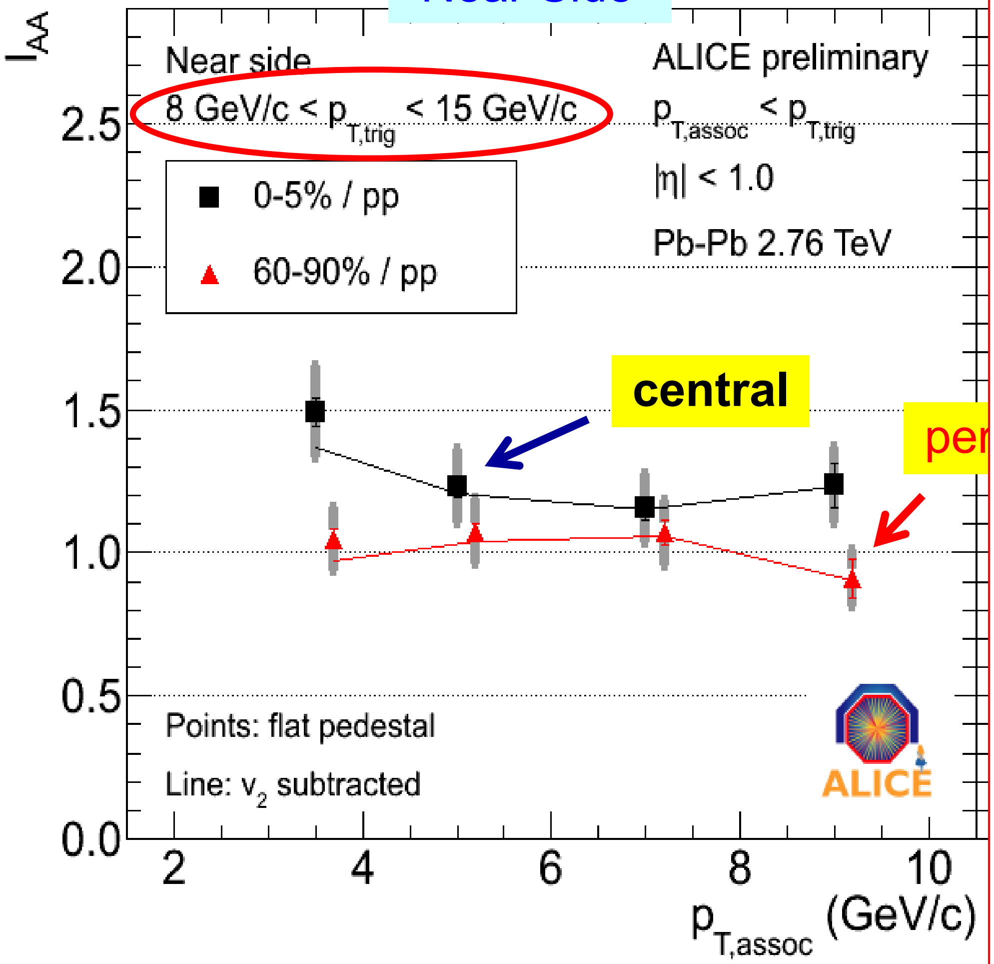
Identified particle R_{AA}(K/Λ):

- Interesting differences < 6 GeV
- **R_{AA} universal > 6 GeV**



I_{AA} (PbPb/pp for near and away side Yields)

Near Side



- Near-side of central events slightly enhanced

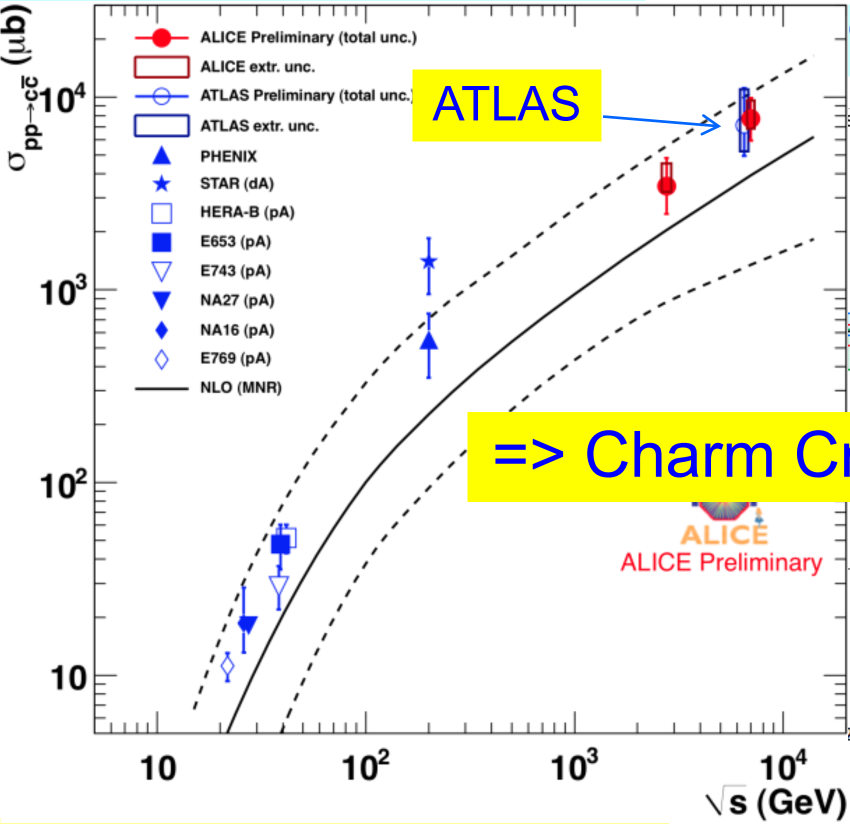
  I_{AA} ~ 1.2 … unexpected and interesting
- Away side of central events suppressed:

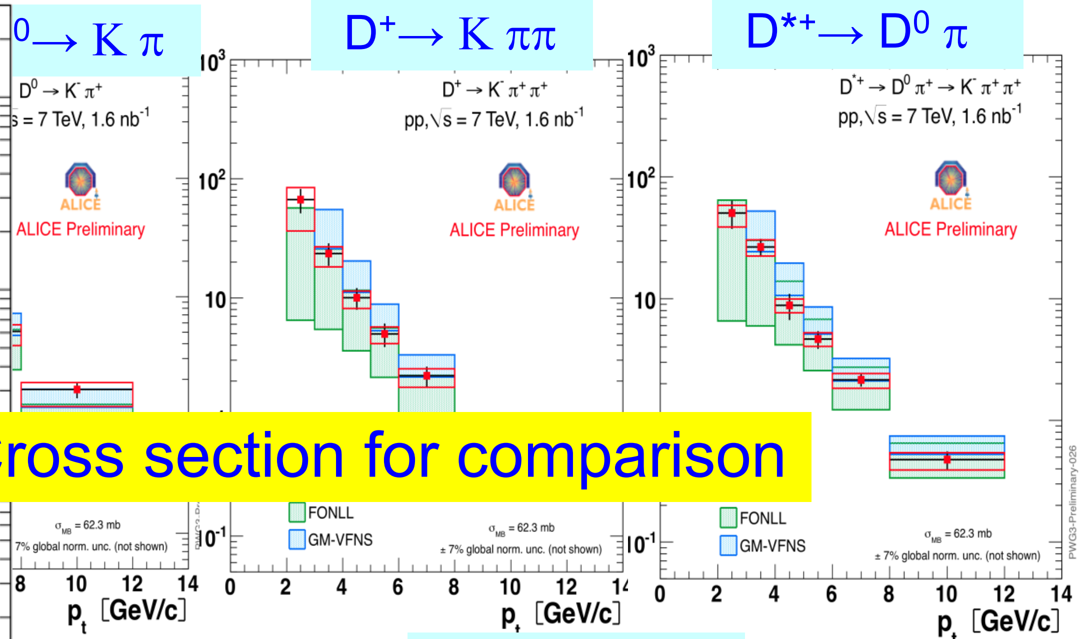
  I_{AA} ~ 0.6 … expected from in-medium energy loss

- Peripheral events consistent with unity

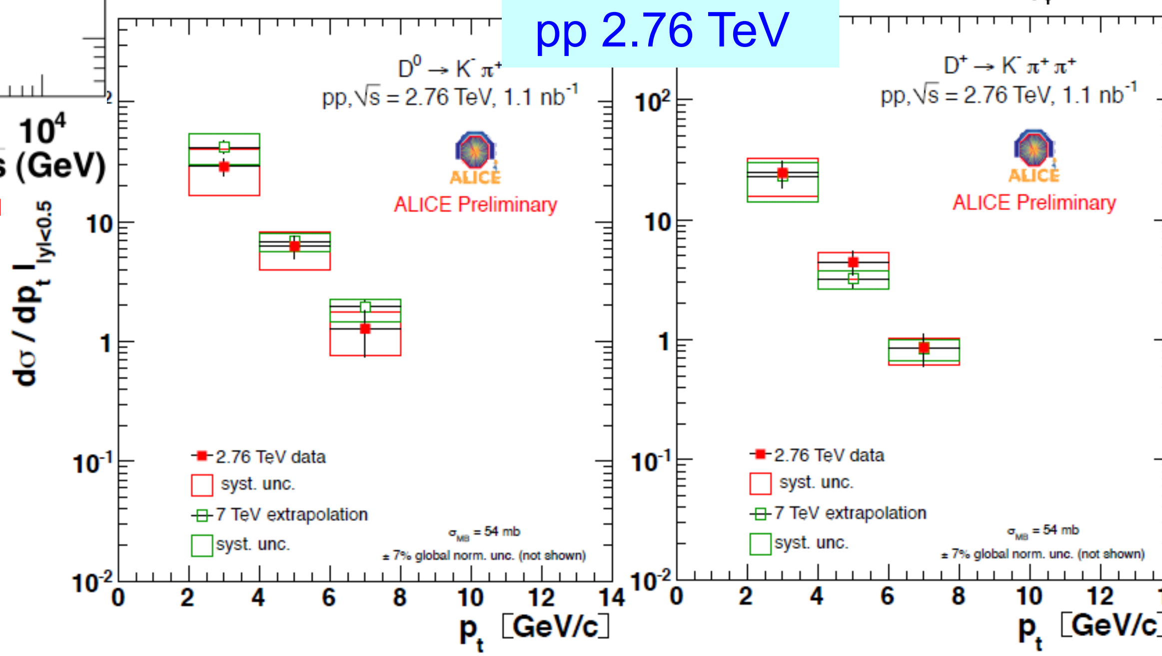
Charm R_{AA}: Ingredients

Total Charm cross section





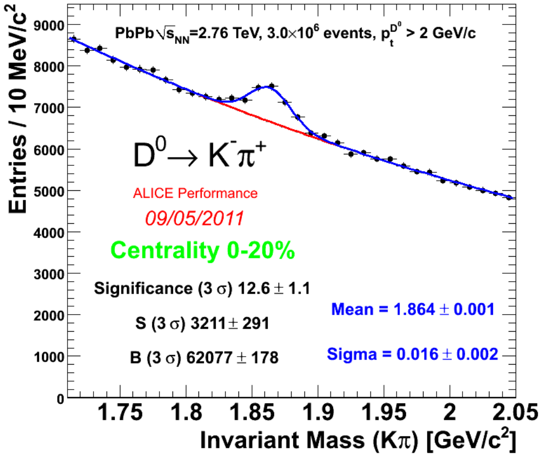
=> Charm Cross section for comparison



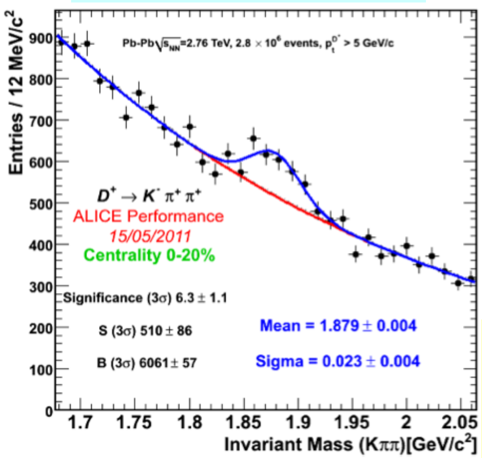
- charm in **pp @ 7 TeV**
- subtract B feed down
- absolute cross section
- scale (FONLL) to 2.76 TEV
- check with data @ 2.76 TeV
- compare with other expts

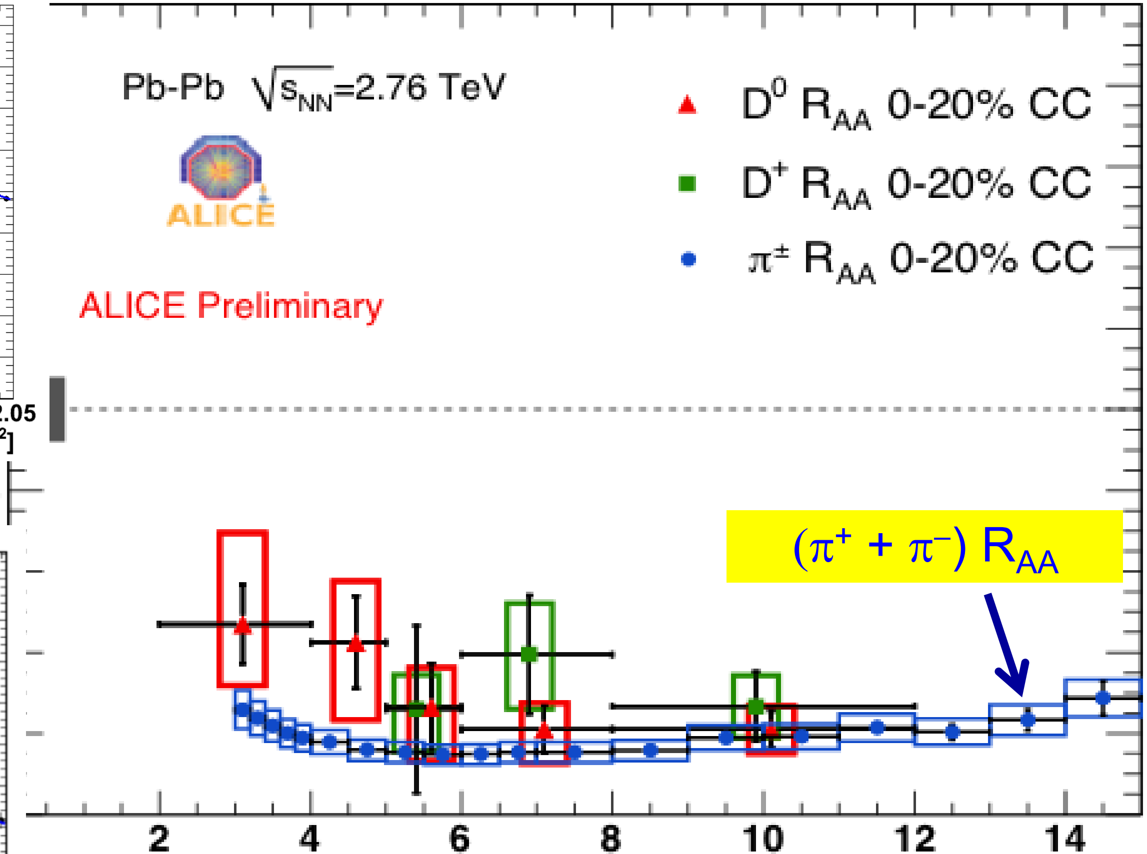
Charm R_{AA}: Results

$D^0 \rightarrow K\pi$



$D^+ \rightarrow K\pi\pi$





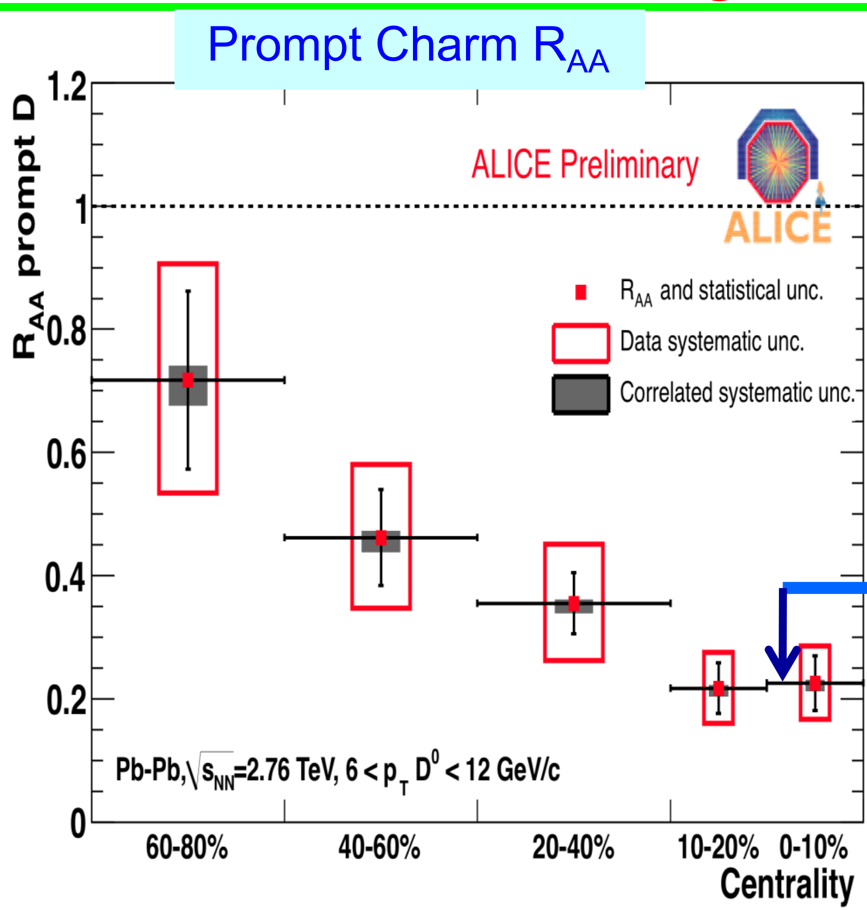
- R_{AA} **prompt charm ≈** R_{AA} **pions for** p_T **> 5-6 GeV**
- R_{AA} charm > R_{AA} π for p_T < 5 GeV ?

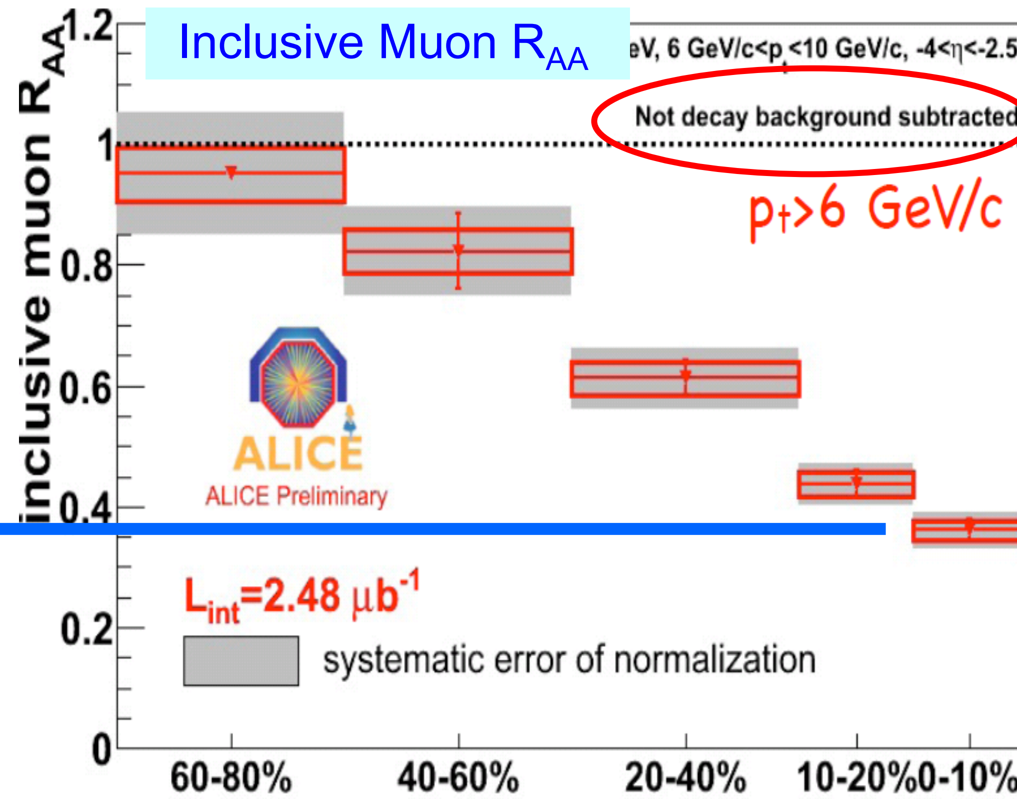
Qualitative expectation: R_{AA} **Charm >** R_{AA} **Mesons**

- ΔE gluon > ΔE quark (**Casimir factor**)
- ΔE massless parton > ΔE massive quark (**'dead cone'**)

Needs quantitative comparison with quenching calculations

Heavy Flavour muons





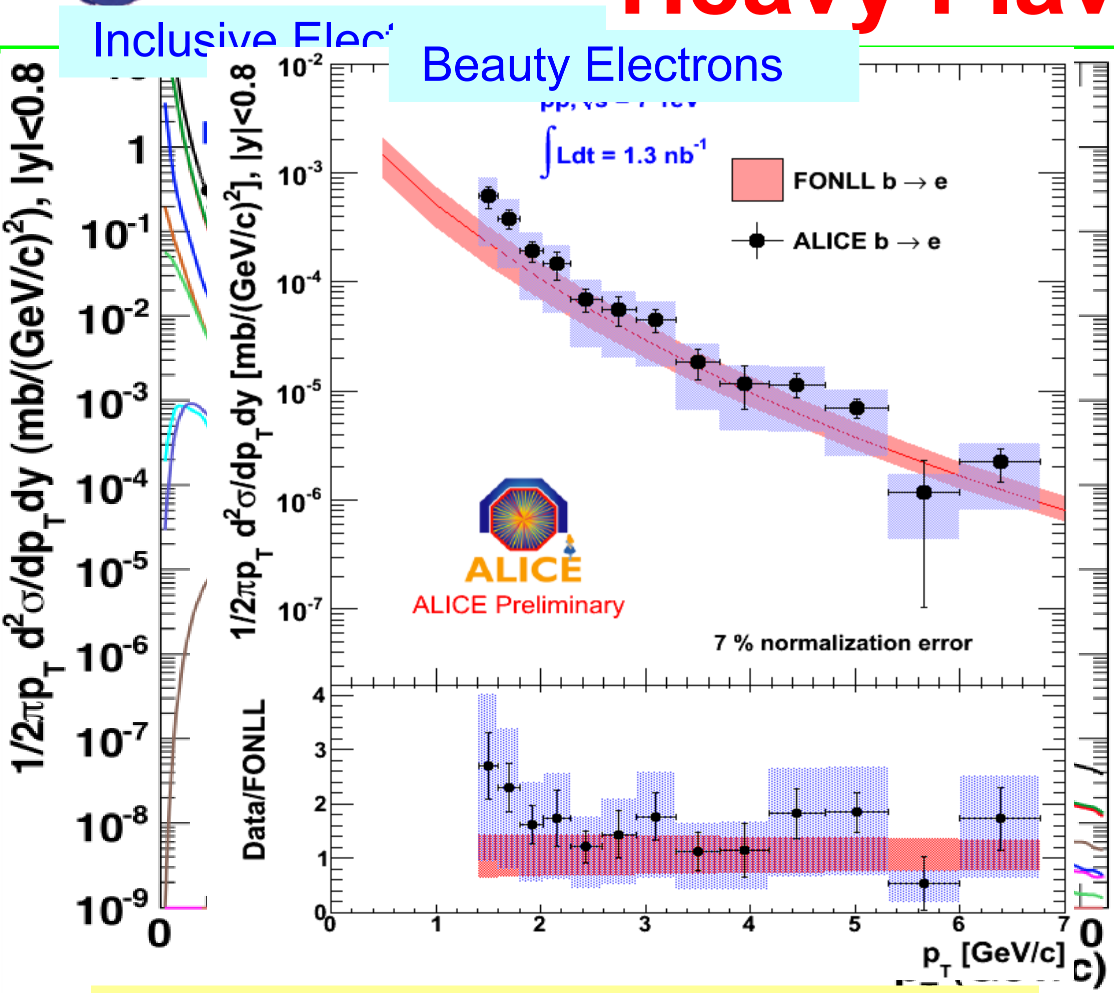
- single prompt muon cross section (c,b) **pp @ 7 TeV**
- scaled (FONLL) to 2.76 TEV
- R_{AA} (p_T, centrality) with inclusive muons

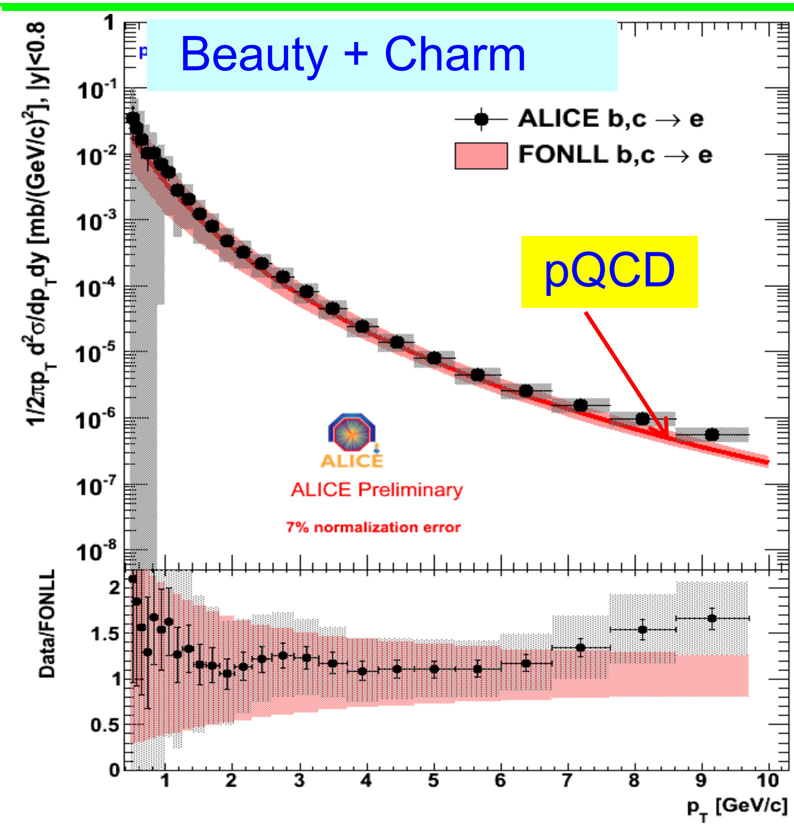
R_{AA} Muon > R_{AA} Charm

Comparing R_{AA}-D and R_{AA}-HFμ via quenching models

the two spectra seem **fully consistent**

Heavy Flavour Electrons



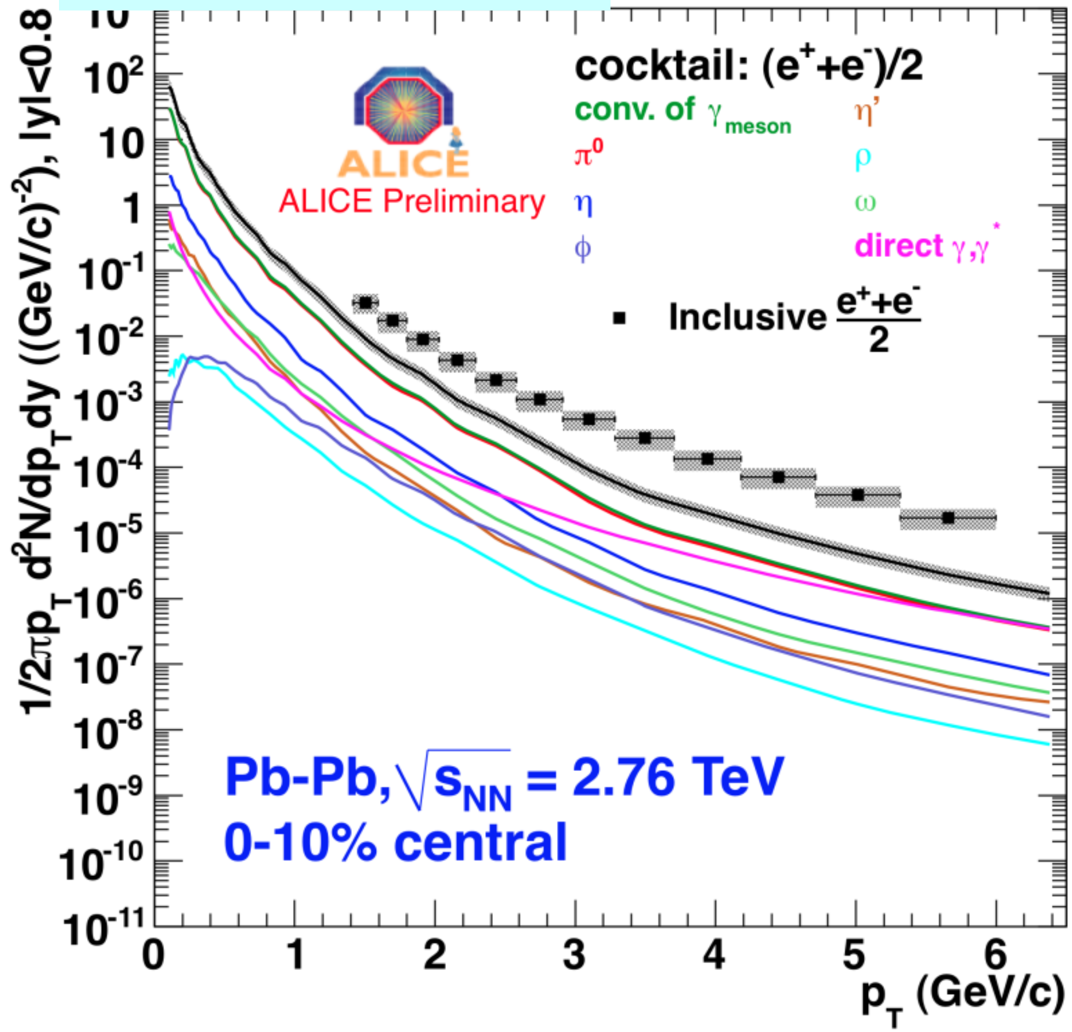


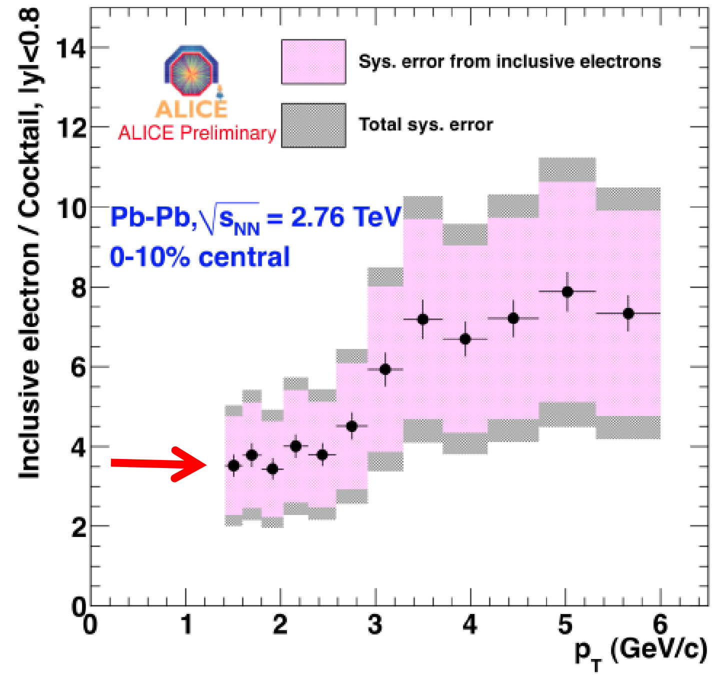
Inclusive electron spectrum **pp 7 TeV**
Background 'cocktail' based on measured $\pi^{\pm}$
subtract => heavy flavour electrons **(c, b)**
consistent with pQCD (and measured charm!)
impact parameter cut => select **beauty**
consistent with qQCD

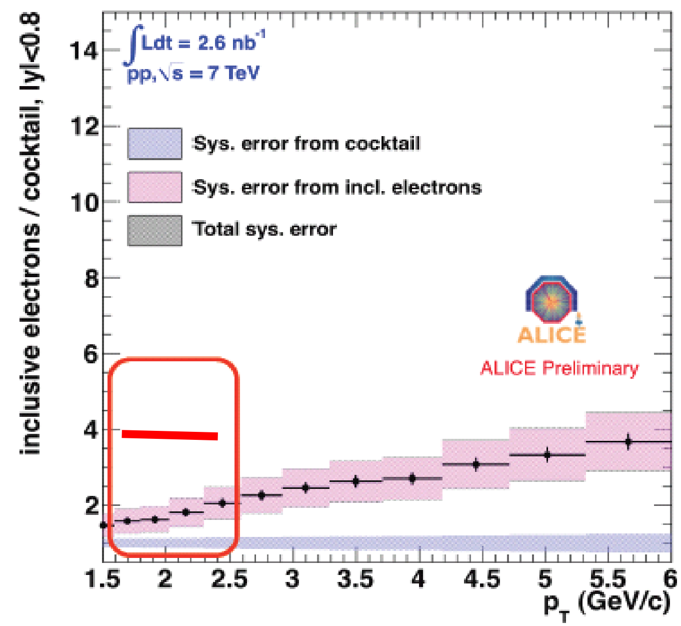
=> Good analysis check
c, b measurement in pp

Heavy Flavour Electrons

Inclusive Electrons **Pb**







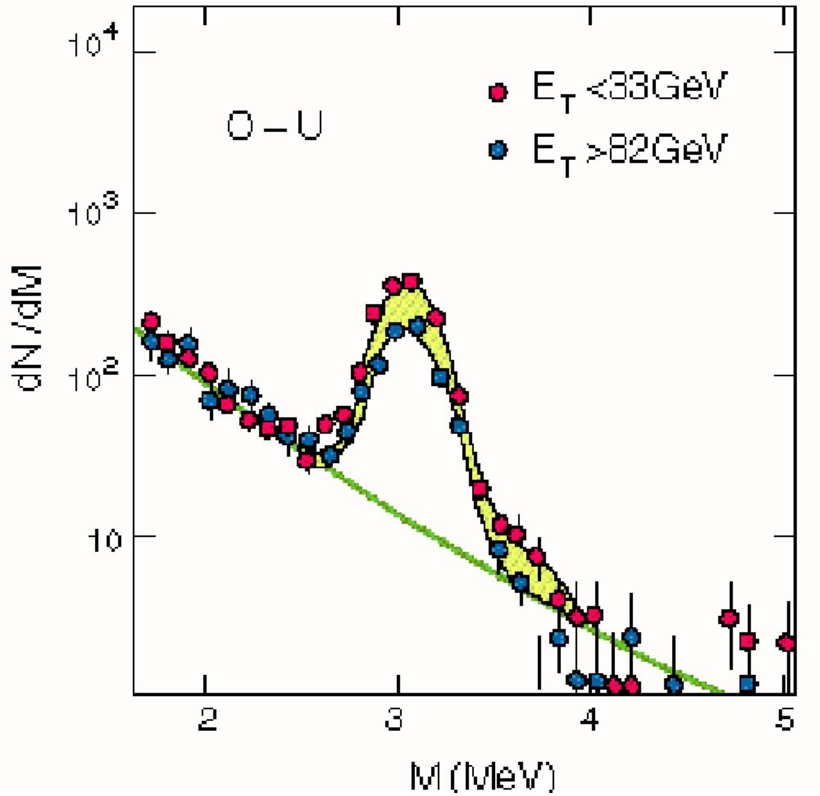
Data / Background => hint of excess around 2 GeV

interesting region (thermal radiation ?)

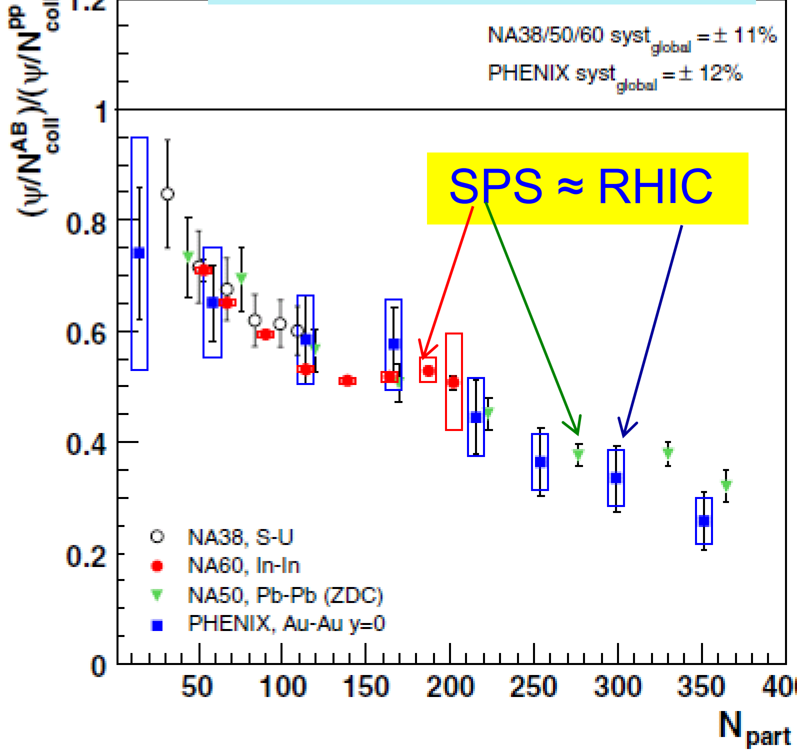
Resulting HFe R_{AA} consistent wit HFμ for p_T > 3-4 GeV

The J/Ψ Saga

QM 1987 Nordkirchen NA36: (A. Bussiere)



QM 2008 Goa (P. Seyboth)



- Can LHC solve the puzzle (measuring J/Ψ and Υ families) ?

	Ψ'	χ	Υ''(3S)	Υ'(2S)	J/Ψ	Υ
T_d/T_c	1-1.2	1-1.2	1.1-1.3	1.2-2	1.5-2.5	3-5

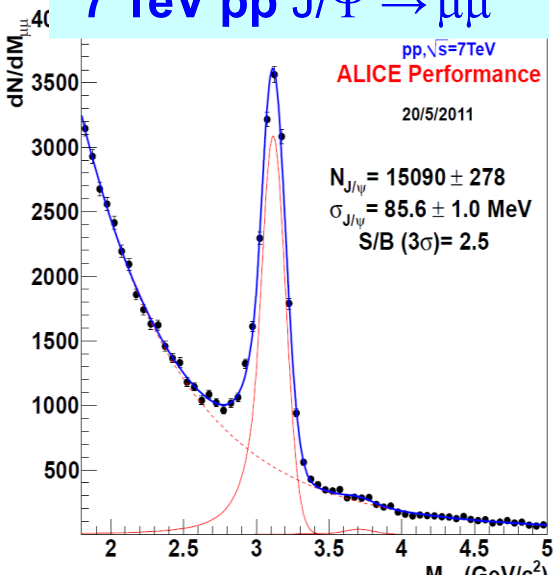
Lattice QCD based predictions of 'melting' temperature T_d (a bit dated..)

⇨ **suppression** only: suppression for Υ'(2S) ≈ Ψ', Υ''(3S) ≈J/Ψ

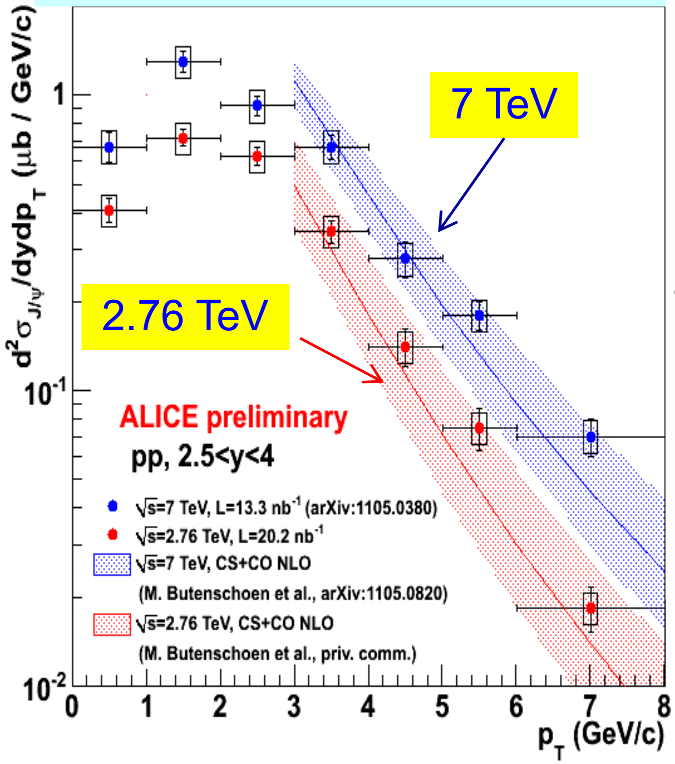
⇨ **suppression + recombination:** Υ', Υ'' ~**unaffected**, J/Ψ **less** suppression than @ RHIC

J/Ψ suppression: Ingredients

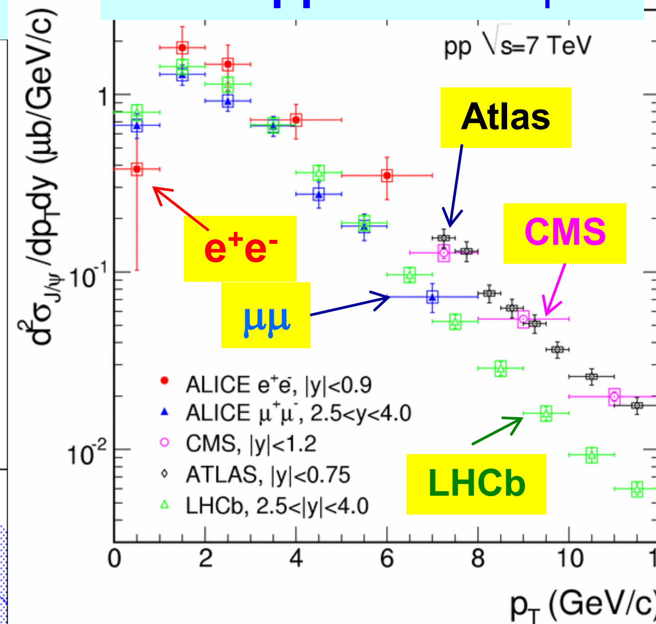
7 TeV pp J/Ψ → μμ



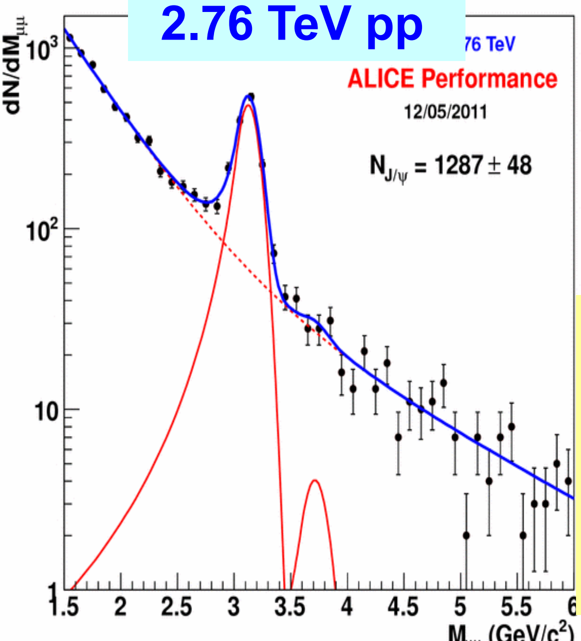
pp J/Ψ Cross Section



7 TeV pp 4 LHC expts



2.76 TeV pp



J/Ψ cross section $d\sigma/dydp_T$

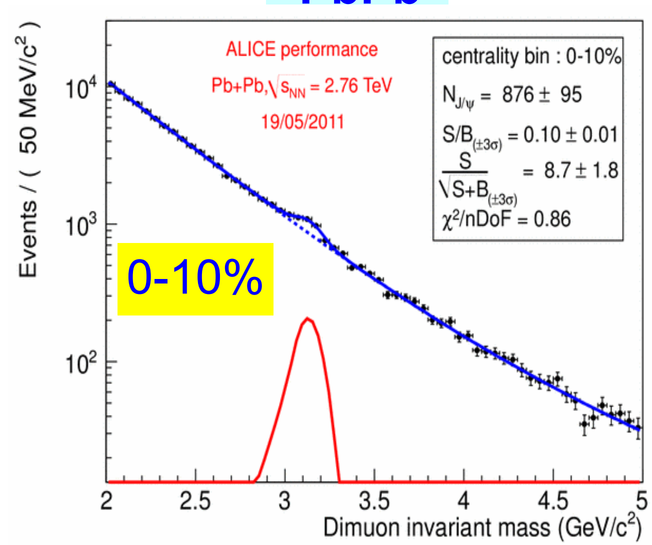
7 TeV & 2.76 TeV

agreement with pQCD

ALICE≈ATLAS≈CMS≈LHCB

(in region of overlap)

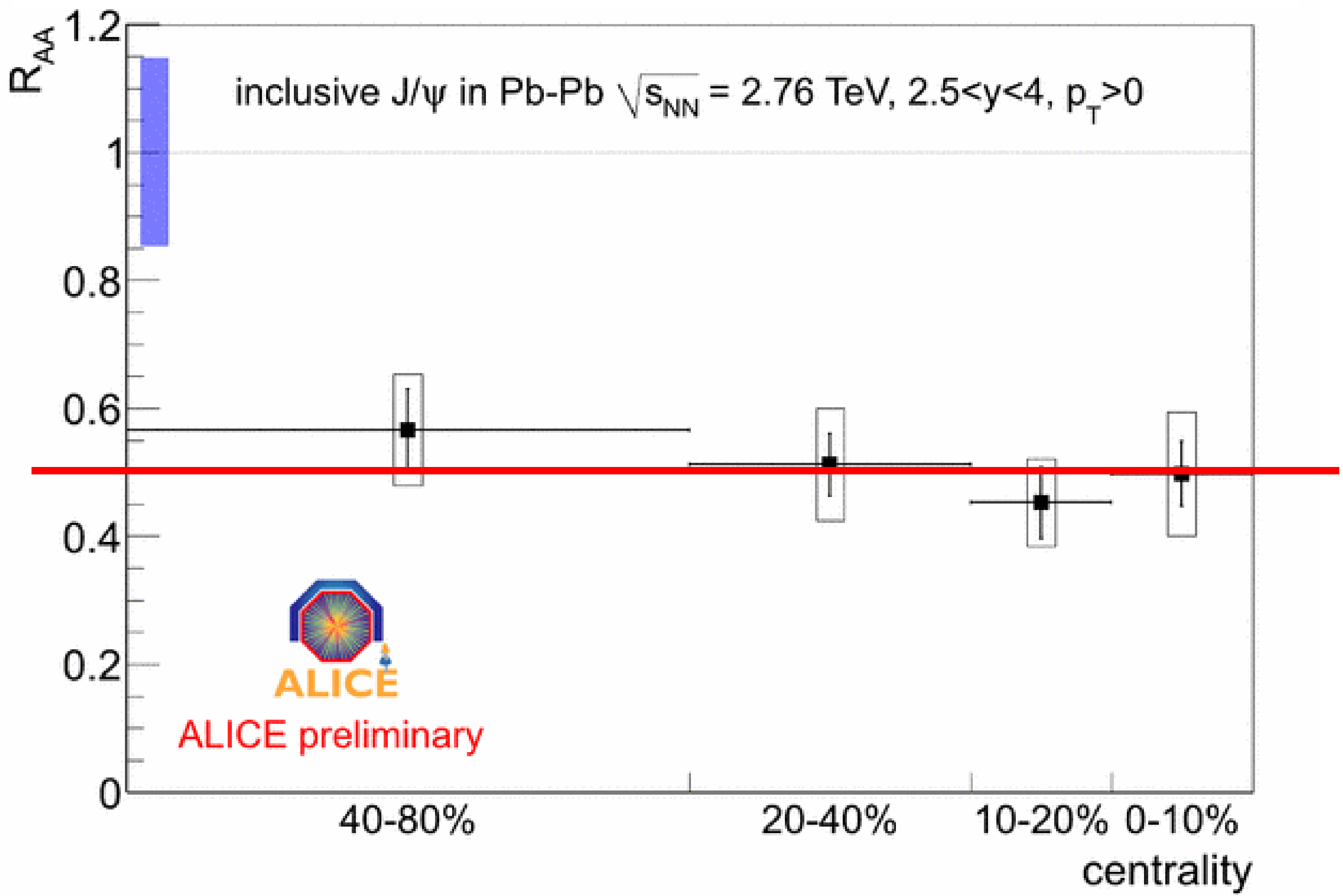
PbPb



ALI-PERF-4502

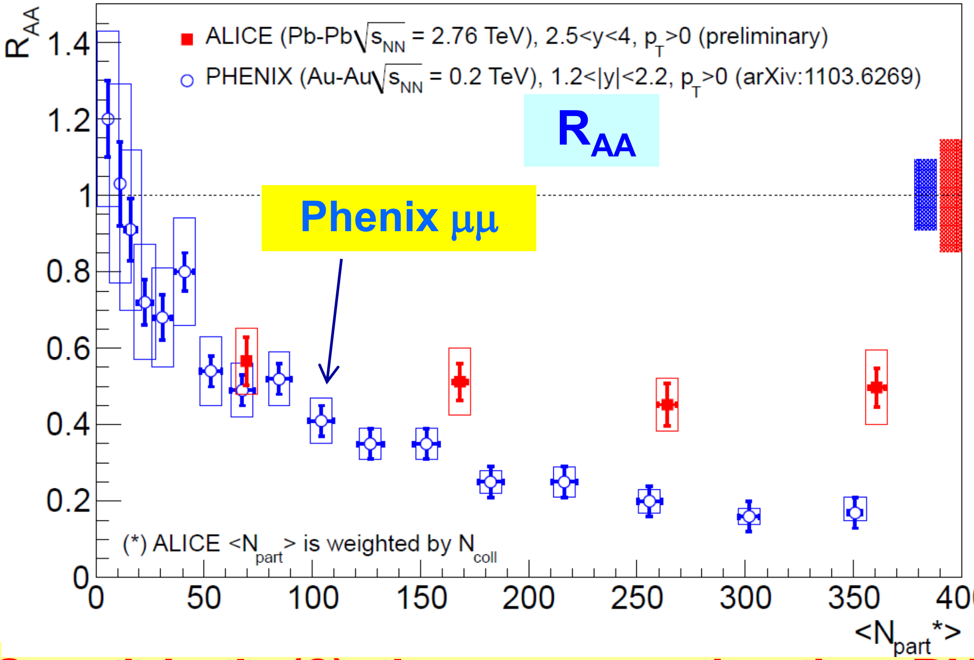
J/Ψ suppression: Results

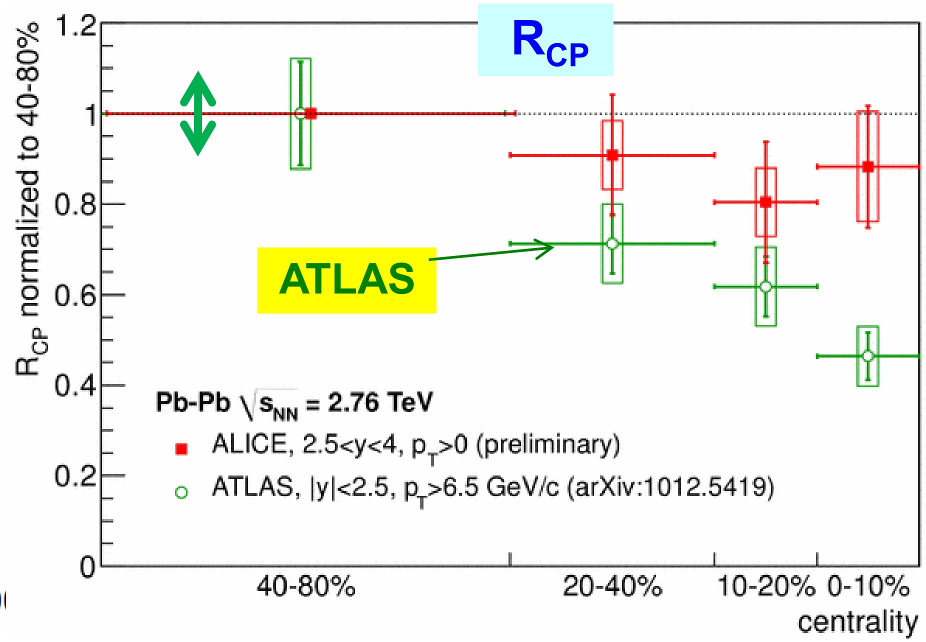
Inclusive J/ψ $R_{AA}^{0-80\%}$ = ± 0.03 (stat.) ± 0.08 (sys.)



Rather small suppression & centrality dependence

J/Ψ suppression: Compared to..



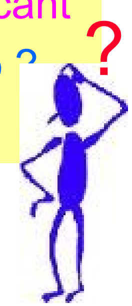


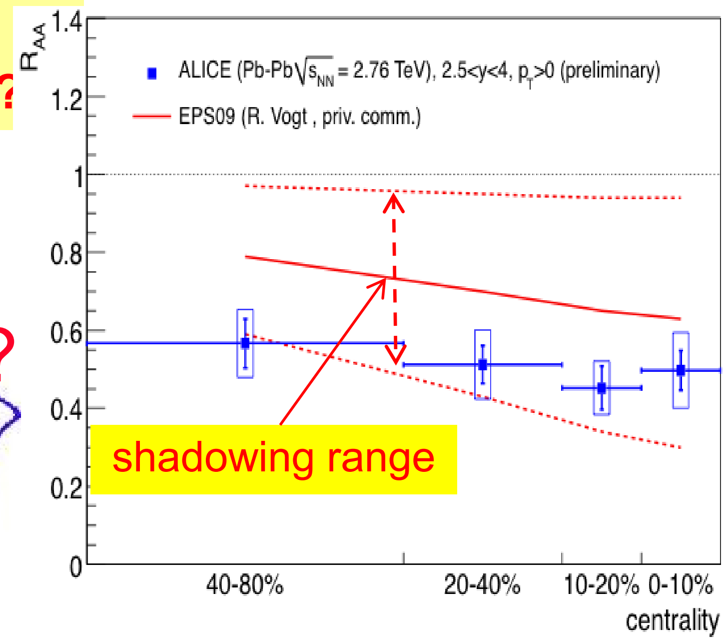
Surprisingly (?) : less suppression than RHIC !

R_{CP}(Alice/Atlas): suppression stronger at high p_T ??

Caveats:

- **J/Ψ (B) ≈ 10%** (LHCb) => R_{AA}(prompt) lower by ≈ 0.05
- compare to Phenix e^+e^- ? => less difference, still significant
- shadowing(LHC) > shadowing(RHIC) ? => R_{AA} goes up ?
- cold nuclear matter suppression ?





Very intriguing, nevertheless ..

ALICE Talks

Plenary:

Global properties: A. Toia
HBT: A. Kisiel
Flow: R. Snellings
R_{AA}: H. Appelshaeuser
Identified Particles: M. Floris
Correlations (I_{AA}): Jan Fiete GO
J/Psi: G. Martinez Garcia
Heavy Flavour: A. Dainese

Identified hadrons

PID methods: A. Kalweit
π/K/p in pp: M. Chojnacki
π^0,η in pp: K. Reygers
Resonances: A. Pulvirenti
Λ/K^0: I. Belikov
Ξ, Ω pp Pb: D. Chinellato
R_{AA} Λ/K^0 : S. Schuchmann
ρ,ω,ϕ pp: A. de Falco

Experiments

Upgrades: T. Peitzmann
cross section pp: K. Oyama

Global & Collective

N_{ch}, centrality: C. Loizides
'strong CP viol': P. Christakoglou
directed flow v_1: I. Selyuzhenkov
elliptic flow high p_t: A. Dobrin
elliptic flow PID: M. Krzewicki
Ultra-peripheral: C. Oppedisano
Diffraction pp: M. Poghosyan

Correlations & Fluctuations

Elliptic flow: A. Bilandzic
Triggered dihadrons: A. Adare
Untriggered dihadrons: A. Timmins
Dihadrons pp: Y. Mao
pT fluctuations: S. Heckel
HBT: J. Mercado
HBT K_0^s pp: T. Humanic

Heavy Flavour

HF μ: X. Zhang
HF e: S. Masciocchi
J/Ψ pp: R. Arnaldi
J/Ψ Pb: P. Pillot
D mesons R_{AA}: A. Rossi

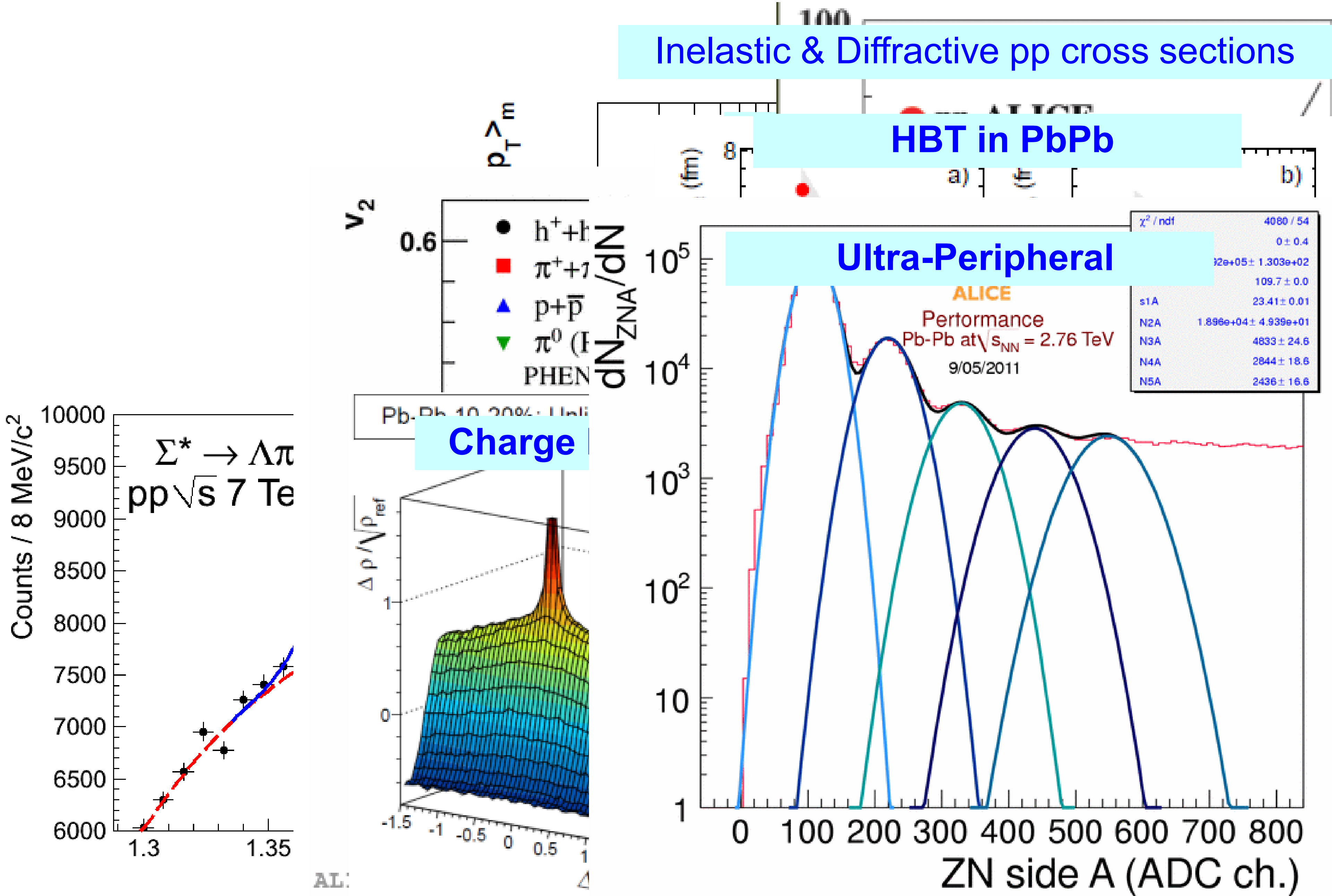
Jets

Jet reconstruction: C. Klein-Boesing
R_{AA} charged: J. Otwinowski
R_{AA} π^0: G. Conesa Balbastre

> 70 Posters

Feasibility study for a Muon Forward Tracker in ALICE
Measurement of Low Mass Electron-Positron Pairs with ALICE
Measurement of the Multiplicity Dependence of J/ψ→e+e− Production in √s = 7 TeV pp Collisions with ALICE at the LHC
Hadron-Resonance Correlation in pp collisions at the LHC with ALICE
Prompt and detached J/ψ production in pp collisions at √s = 7 TeV with the ALICE detector

Appetizers..


Inelastic & Diffractive pp cross sections
HBT in PbPb
Ultra-Peripheral
Charge
$\Sigma^* \to \Lambda\pi$
pp $\sqrt{s}$ 7 Te
Counts / 8 MeV/c^2
v_2
PHEN
ALICE
Performance
Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV
9/05/2011
dN_{ZNA}/dN
ZN side A (ADC ch.)

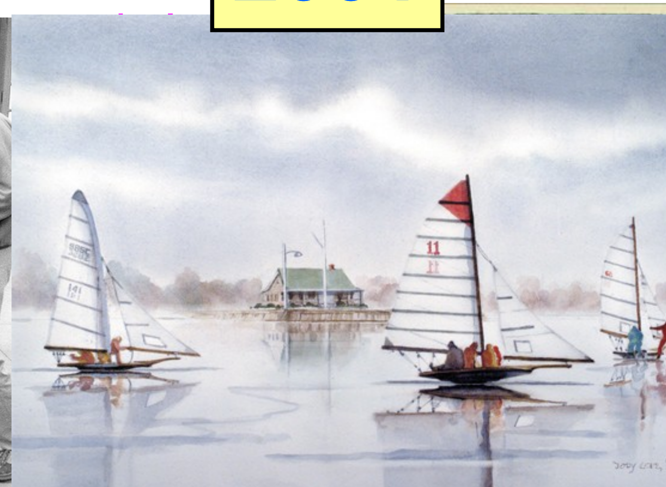
Conclusions

- Our Field has come a long way
  - ⇨ and we are just at the beginning of LHC, < 6 months after the first Pb-Pb collision
- In regions of overlap RHIC/LHC
  - ⇨ some signals are very similar
  - ⇨ some qualitatively similar, but quantitatively different
  - ⇨ first hints of surprises
  - ⇨ **Comparing RHIC & LHC will tell us more than either alone !**
    - ✪ **RHIC** and its detector (**STAR/PHENIX**) are **going strong as ever !**
- In reg… que to LHC (low… , m, ε,)

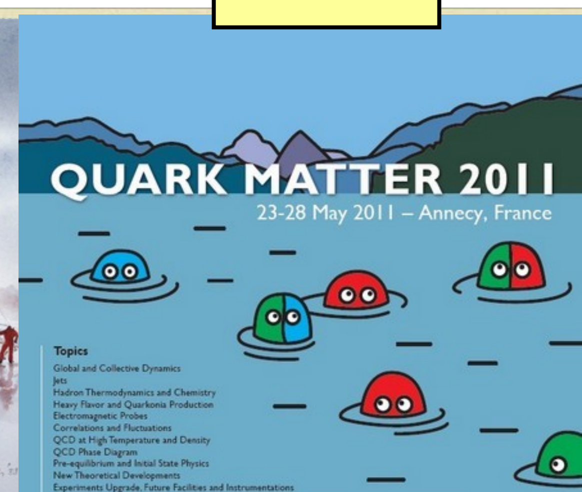
Big THANKS to the
CERN Accelerator crew
from ion source all the way to LHC
which made all this possible !

1987

2001



2011



for a loooooong time !