A promise,
not a threat

B. Mueller's challenge to the summary speakers:

(from his opening talk)

All's well that ends well.

1st slide of 69

a threat, not a promise

Experimental Summary

- **completely fair** and **totally unbiased** selection of all relevant results from ALICE (All Lhc and rhIC Experiments)
- sprinkled with random & irrelevant PR (Personal Remarks)

What' this ?

some naïve interpretation

What's Next ?

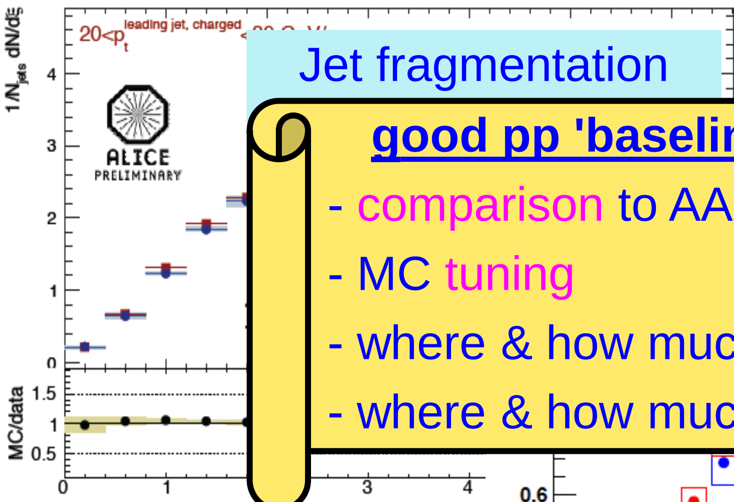
some unrealistic wish list

Many thanks to the organizers

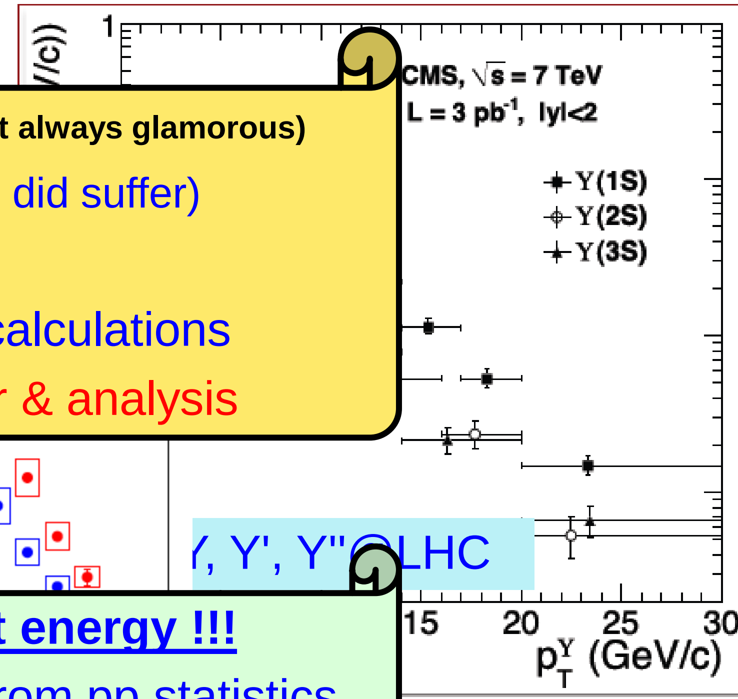
who gave me this marvelous opportunity

to loose many old friends and make plenty new enemies

pp Results



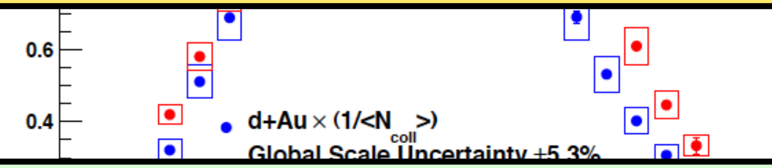
Jet fragmentation



Y, Y', Y''@LHC

good pp 'baseline' is crucial (if not always glamorous)

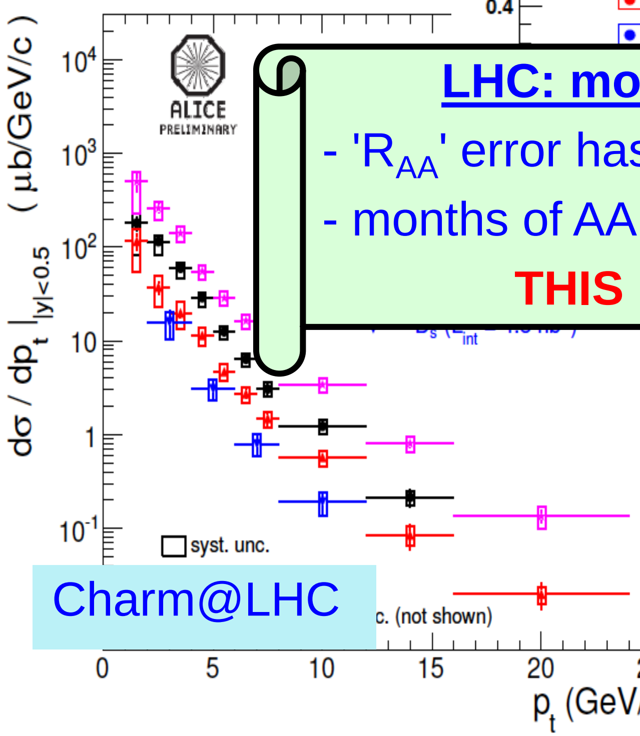
- comparison to AA (early RHIC results did suffer)
- MC tuning
- where & how much to trust pQCD calculations
- where & how much to trust detector & analysis



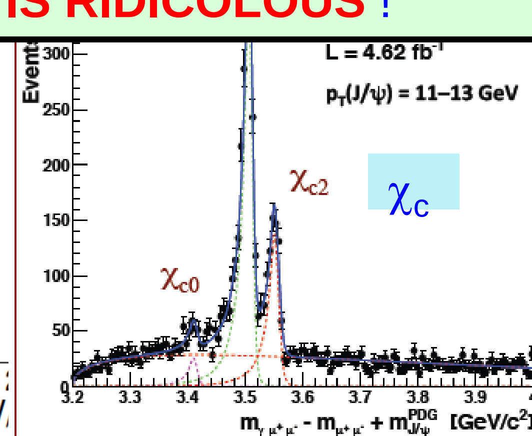
LHC: more pp at the correct energy !!!

- 'R_{AA}' error has large contribution from pp statistics
- months of AA, only days of pp@2.76TeV

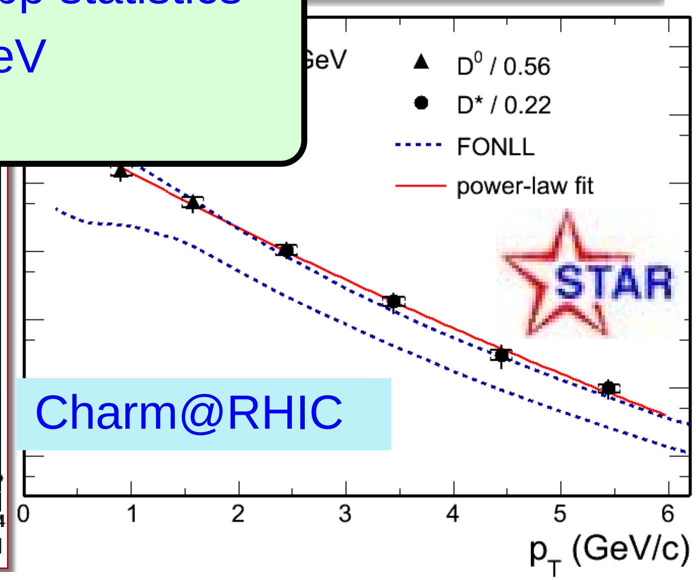
THIS IS RIDICOLOUS !



Charm@LHC



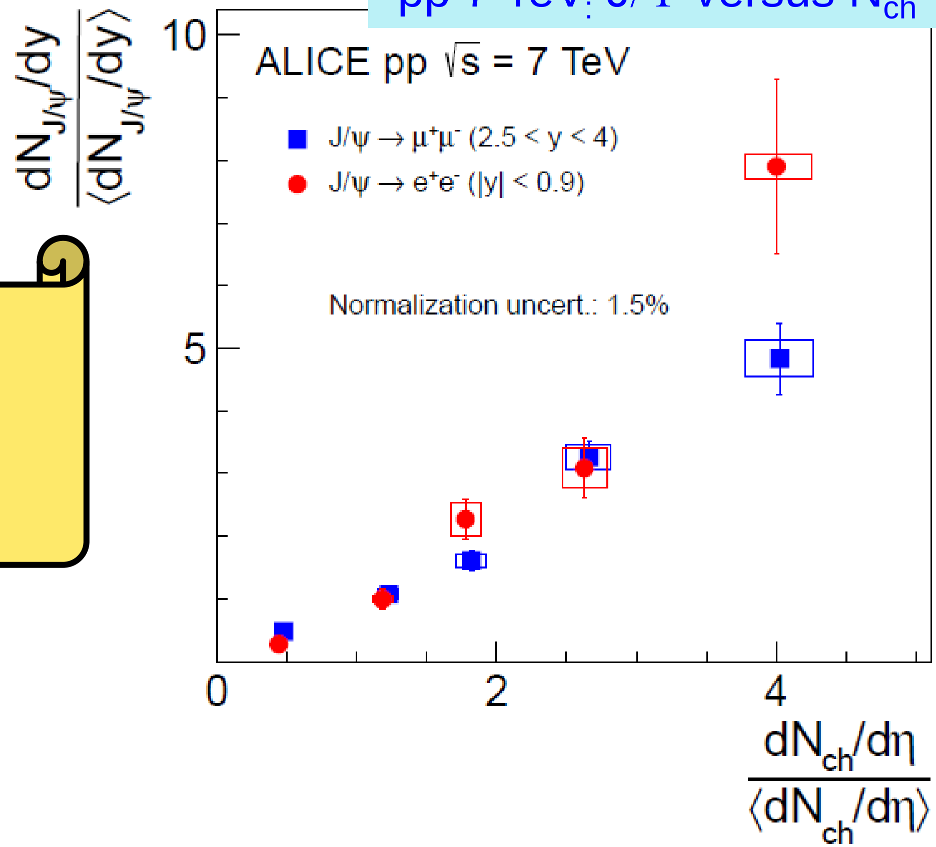
χ_c



Charm@RHIC

Parp(87) = ??

pp 7 TeV. J/Ψ versus N_{ch}

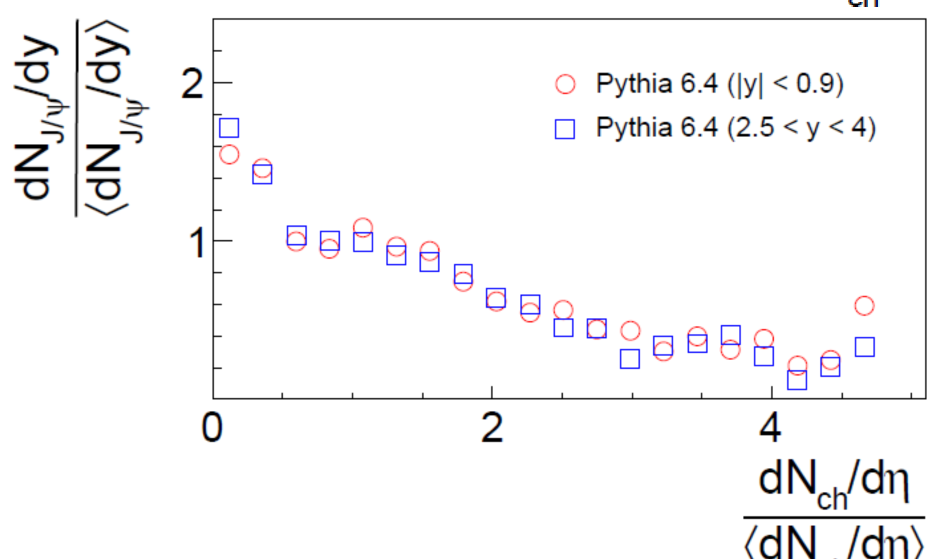


Several ways to 'read' data

- **pQCD :** Ψ associated N_{ch} > MinBias N_{ch}
- **MPI:** Ψ/event increases with N_{ch} (# MPI)
- **thermal model:** Ψ/π = constant

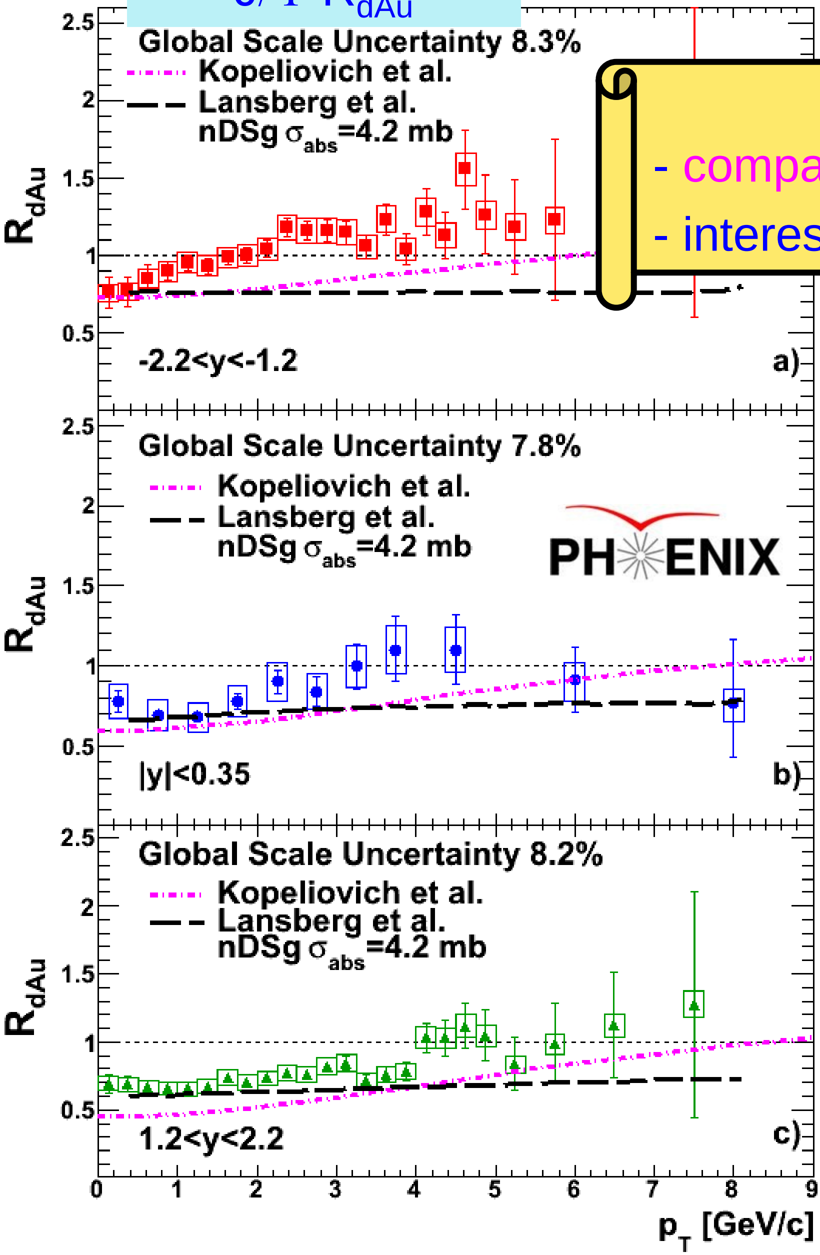
Only one way to read Phythia

more than casual tinkering may be required..



p-A Results

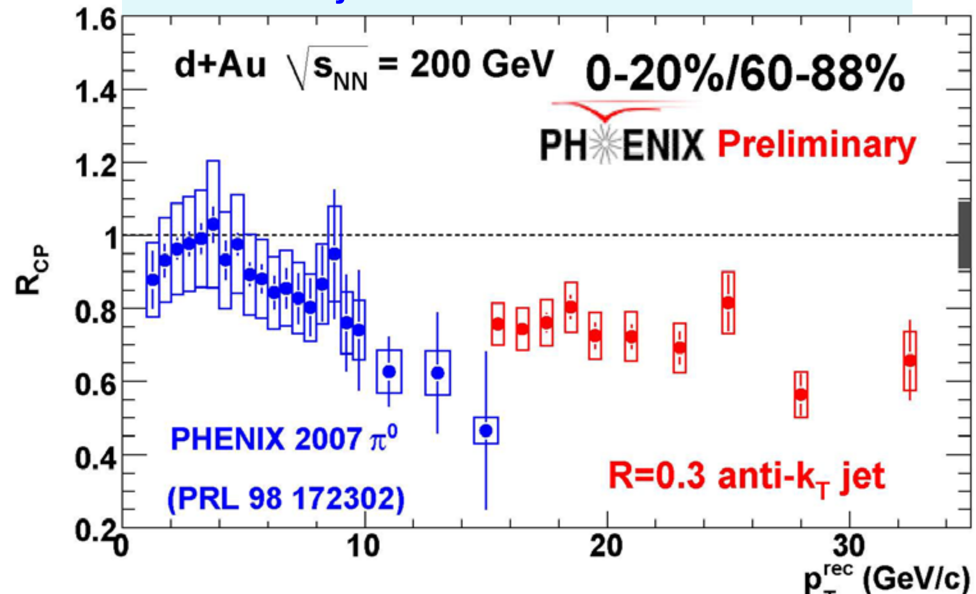
J/Ψ R_{dAu}



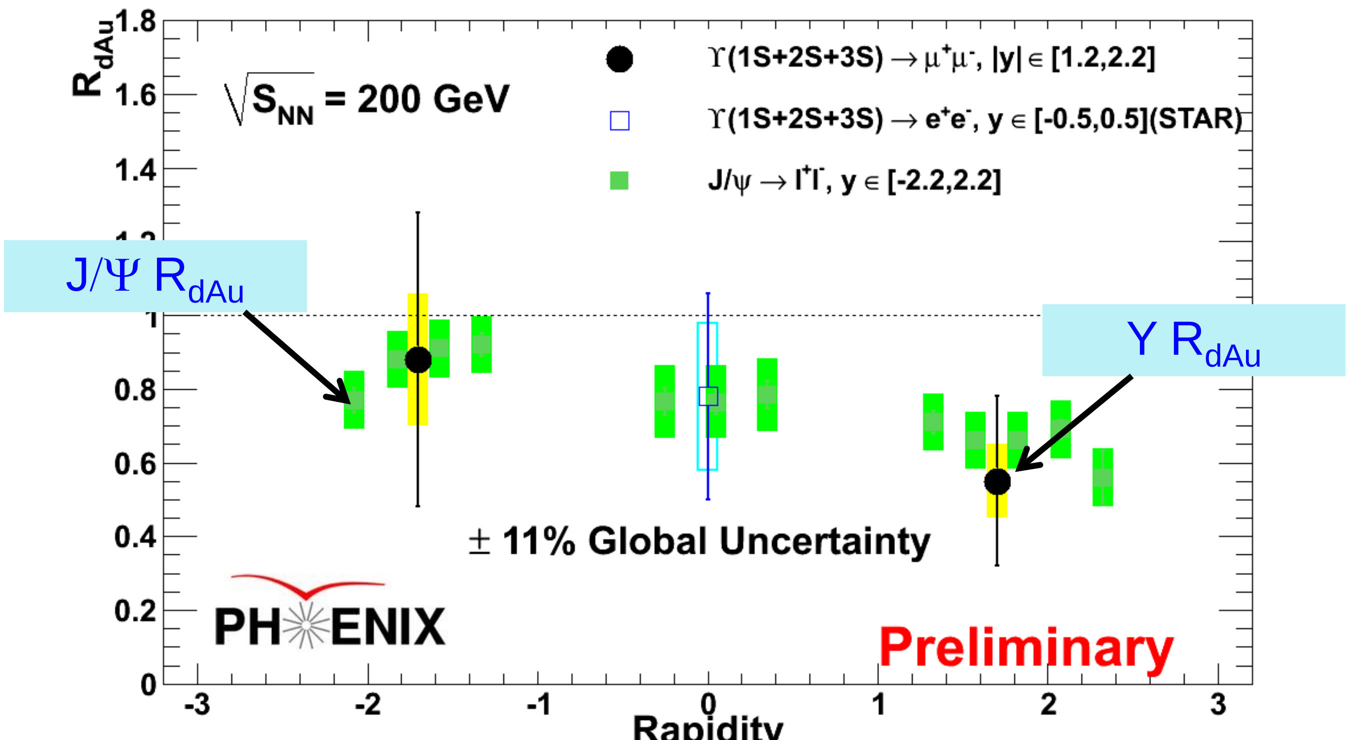
good pA 'baseline' equally crucial

- comparison to AA
- interesting for CGC/Shadowing physics

CNM for jets ?: Who ordered that ?



A doubt of Shadowing



Surprise ?

- expect << nuclear absorption for Υ than for J/Ψ (from FT pA data)
- expect << shadowing (Q²(Υ) ≈ 100 GeV²!)

No worry (yet), given the error bars, but watch out !

A measurement is ALWAYS better than even the best guess

AA: Today's Menu

- Antipasti — assorted delicacies
- Primo Piatto — **Quenched Jets**
- Secondo Piatto — **Suppressed Quarkonia**
- Dolce — **Electroweak probes**
- Fattura — **Thermal radiation**

Heavy Ion physics is tricky

- We should first agree what we actually investigate !

HARD PROBES 2012 PROGRAMME

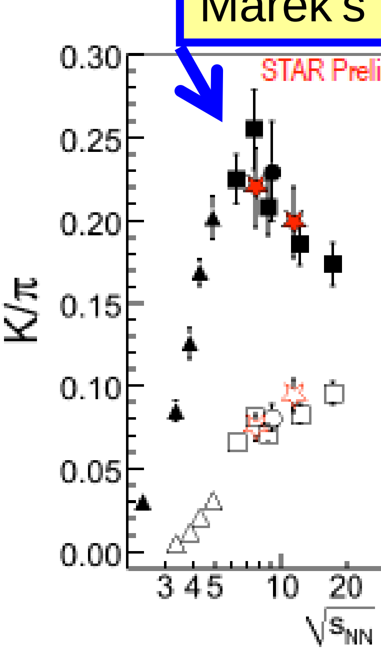
Parallel IB: Jet quenching and **enerav loss**

Parallel IVB: **Jet auenchina** and energy loss

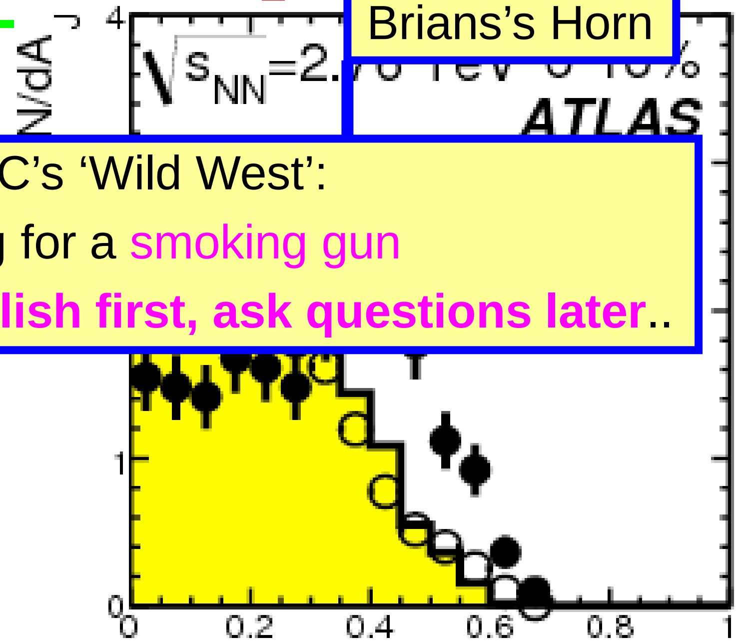
Fortunately, Carlos did not schedule another **instead-of-lunch round table** discussion

Early Days@LHC: Horny Problems

Marek's Horn



Brians's Horn

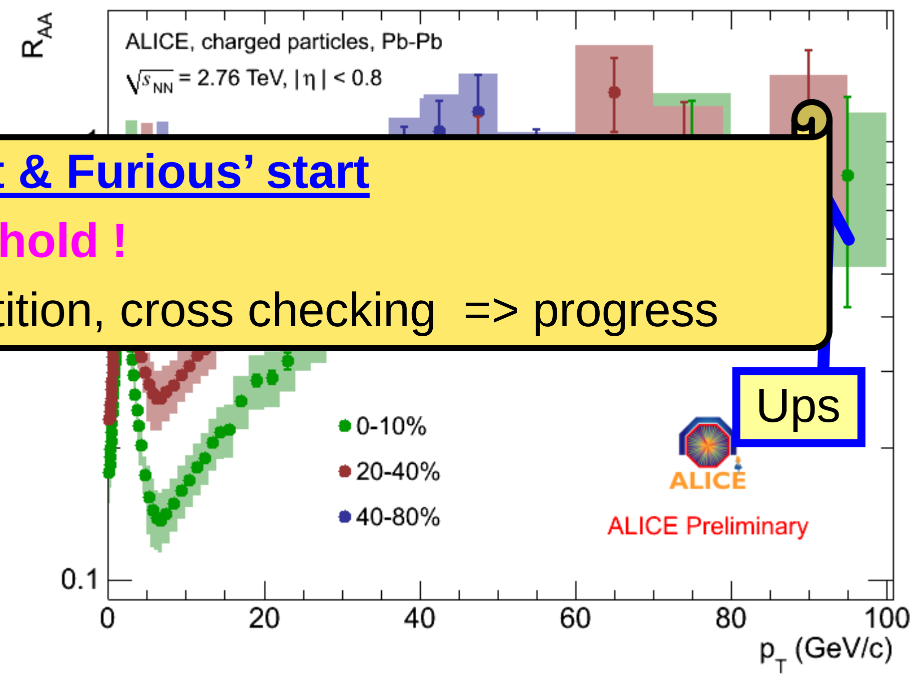


The LHC's 'Wild West':

Looking for a smoking gun

=> **Publish first, ask questions later**..

NOT THANKS



the 'Fast & Furious' start

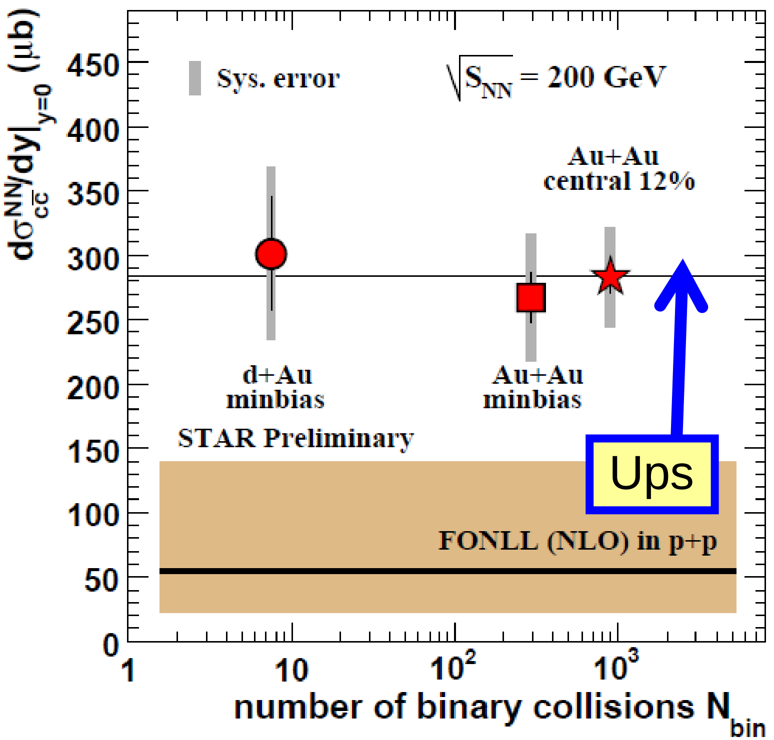
tially) **still hold !**

s, competition, cross checking => progress

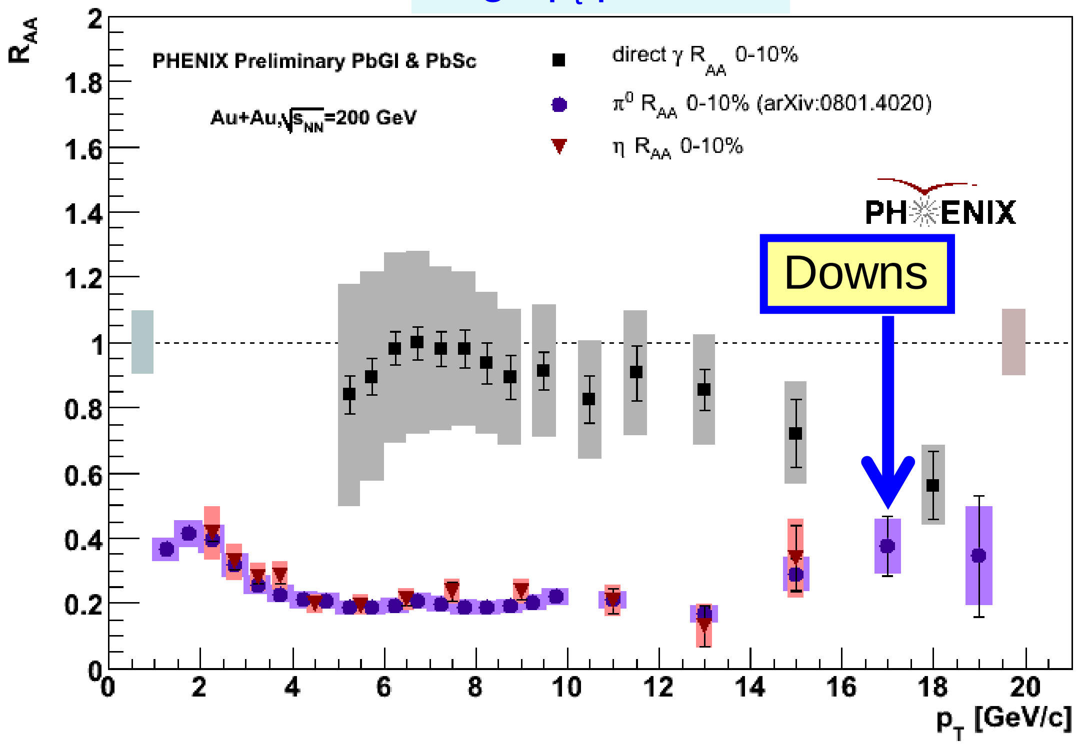
Ups

Also RHIC had its..

Early Charm results



High p_t photons



Energy Loss ('Jet-quenching')

- high energy partons loose energy ΔE when traversing a medium
  - ⇨ **jet(E) → jet (E') + soft particles(ΔE)** **(E' = E-ΔE)**
  - ⇨ energy loss ΔE expected to depend on:
    - $\hat{q}$: 'c
    - **L**: si
    - c_q: p
    - **f(*m*)** quark mass (light q > heavy Q)
    - **f(*E*)** : jet energy (ΔE = constant or ~ ln(E))

MUCW: **(my understanding of conventional wisdom)**

E-E': large, O(10-20 GeV@LHC), RHIC->LHC ~ as expected

jet(E'): ~ unmodified vacuum fragmentation **(p_t > 4 GeV, R ~ 0.4)**

ΔE: multiple soft gluons, large angle & low p_t (< 3-4 GeV)

jet quenching measures
'stopping power' of QGP
$\Delta E \sim f(m) \times c_q \times \hat{q} \times L^n \times f(E)$

Main Questions:

1) How much energy is lost ? **!**

measure jet imbalance E - E'

2) Shows expected scaling ? **!?**

vary L, m, E, .

3) Where (and how) is it lost ? **??**

measure radiated energy ΔE

..

Main Observables:

1) Inclusive single particles

R_{AA} (N_{ch}, PID, HF)

2) Two(3) particle cor

N_{ch}, PID, HF; near/away

3) Inclusive single jet

R_{AA}, long/transverse frag. functions

4) Jet correlations (jet-jet, γ(Z)-jet)

Which is better ?

None !

All give different insights !

1) Energy loss: The emerging jet

2) Scaling: Heavy flavour etc..

3) Lost energy: Intermediate p_t

Universally accepted definition of significance:

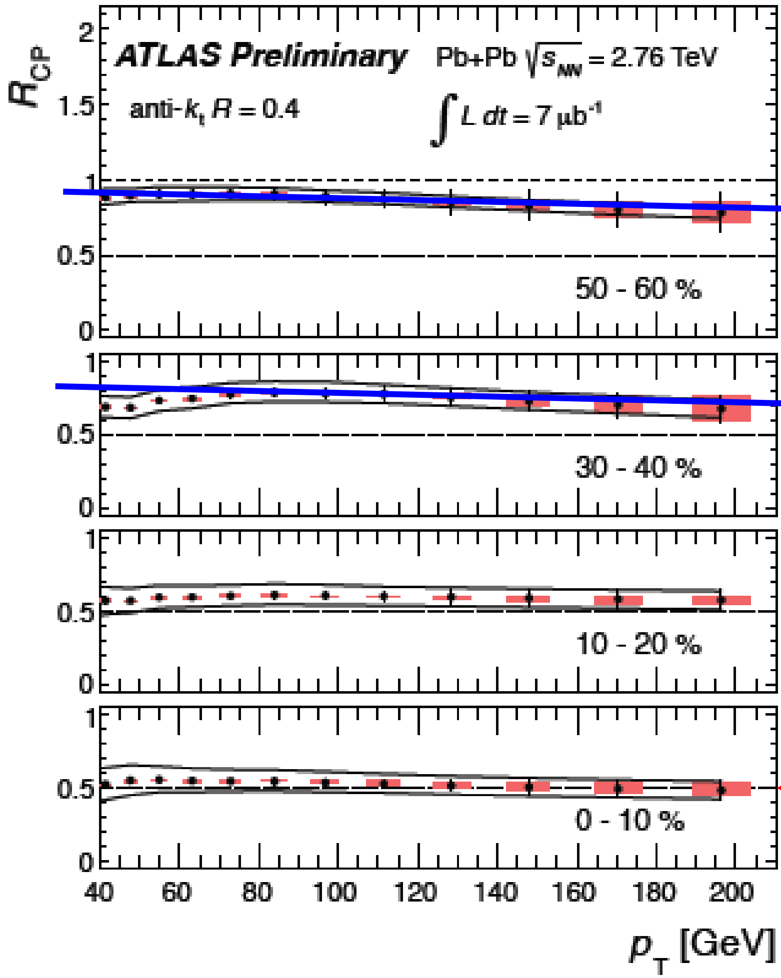
2-3 σ effect:

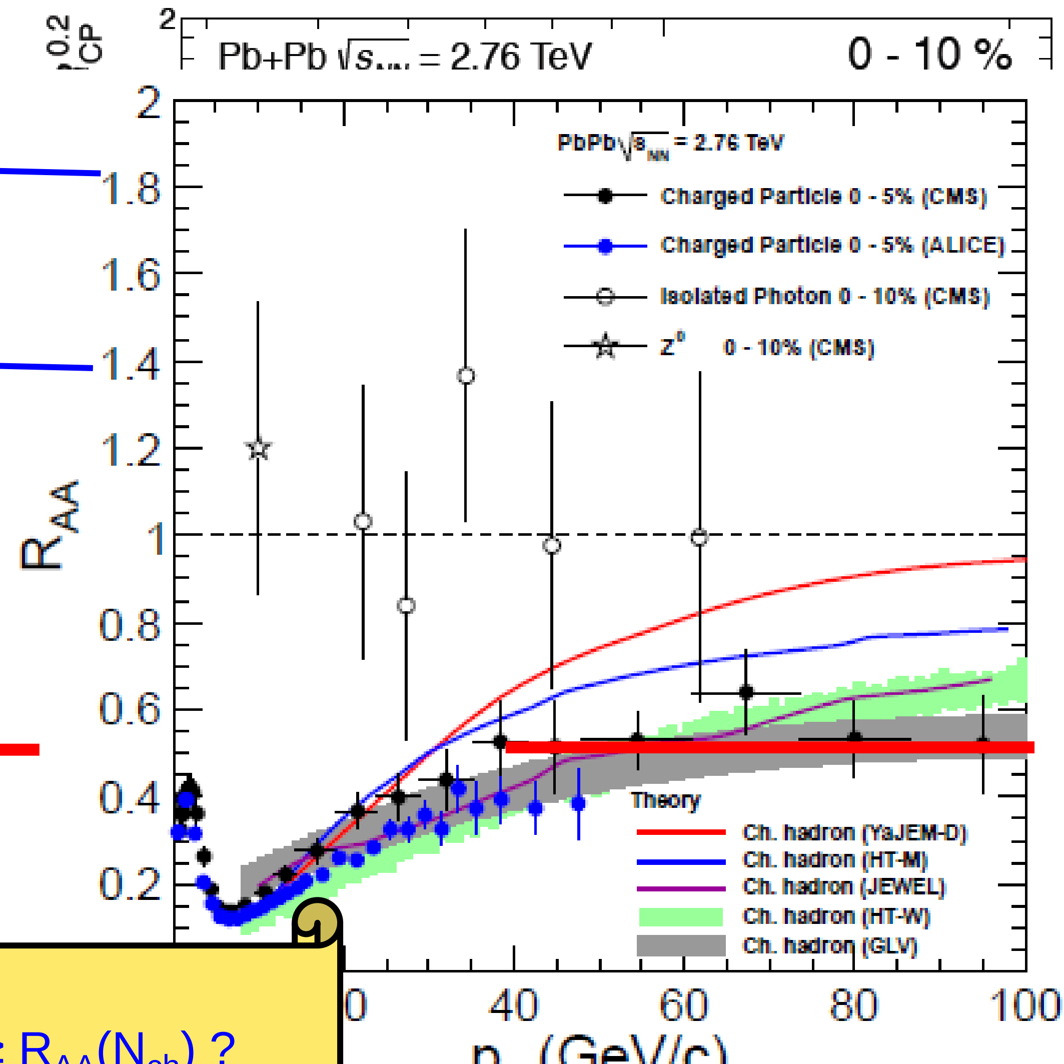
Looks Interesting ? => hint/indication ('hindication')

Looks unlikely ? => consistent within errors

liberal use of the helpful and totally innocent
'line to guide the eye'

Precision Jet R_{CP}



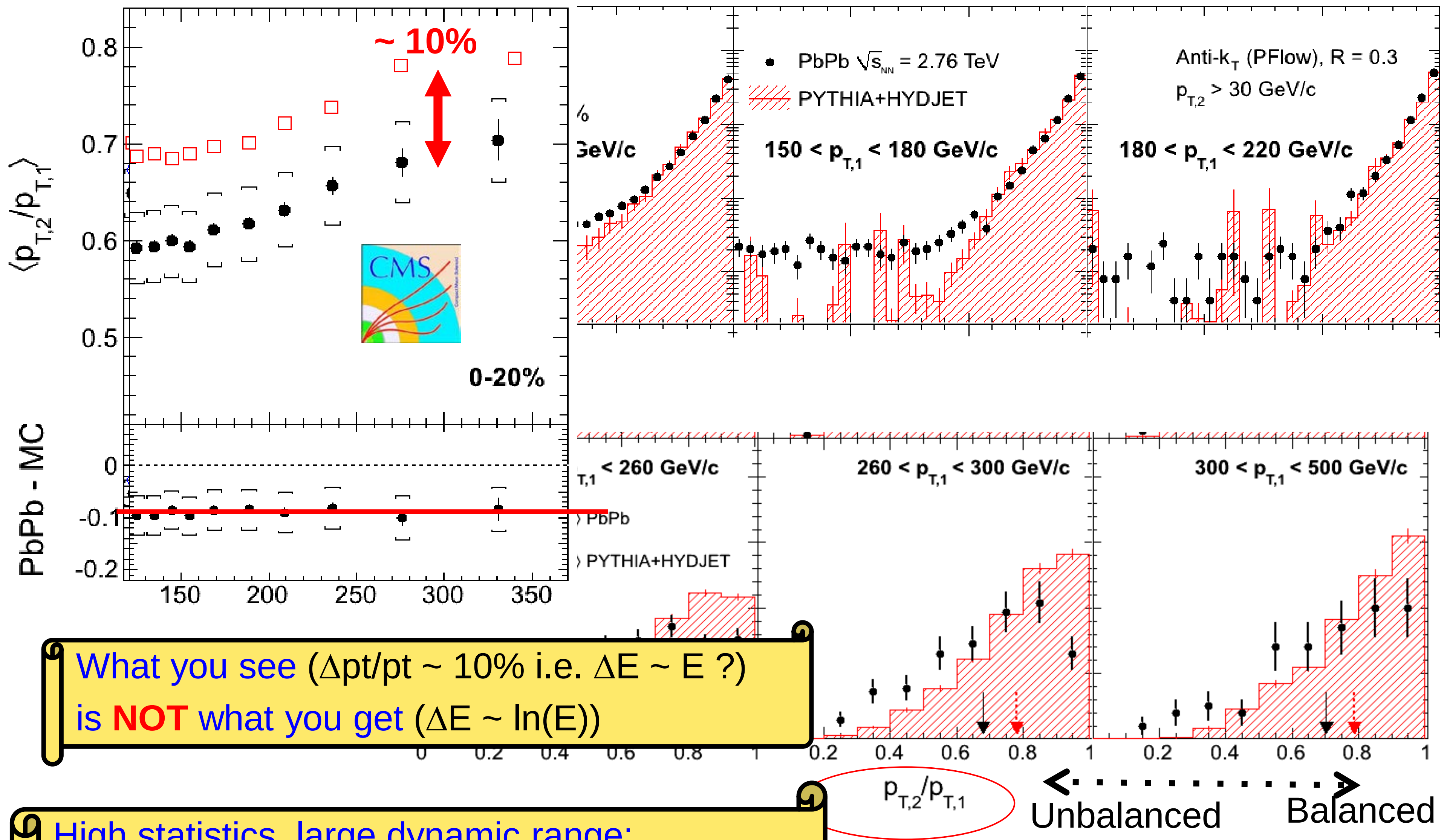


- consistent with flat 40 - 200 GeV
- $R_{CP}^{0-10} \approx R_{AA}^{0-5}(N_{ch})$ => $R_{AA}(\text{Jet}) \geq R_{AA}(N_{ch})$?
- hindication for R dependence

($R_{CP} \to 1$ for $R \to \infty$ $p_t \to 0$)

R_{CP} -> R_{AA}

On Balance



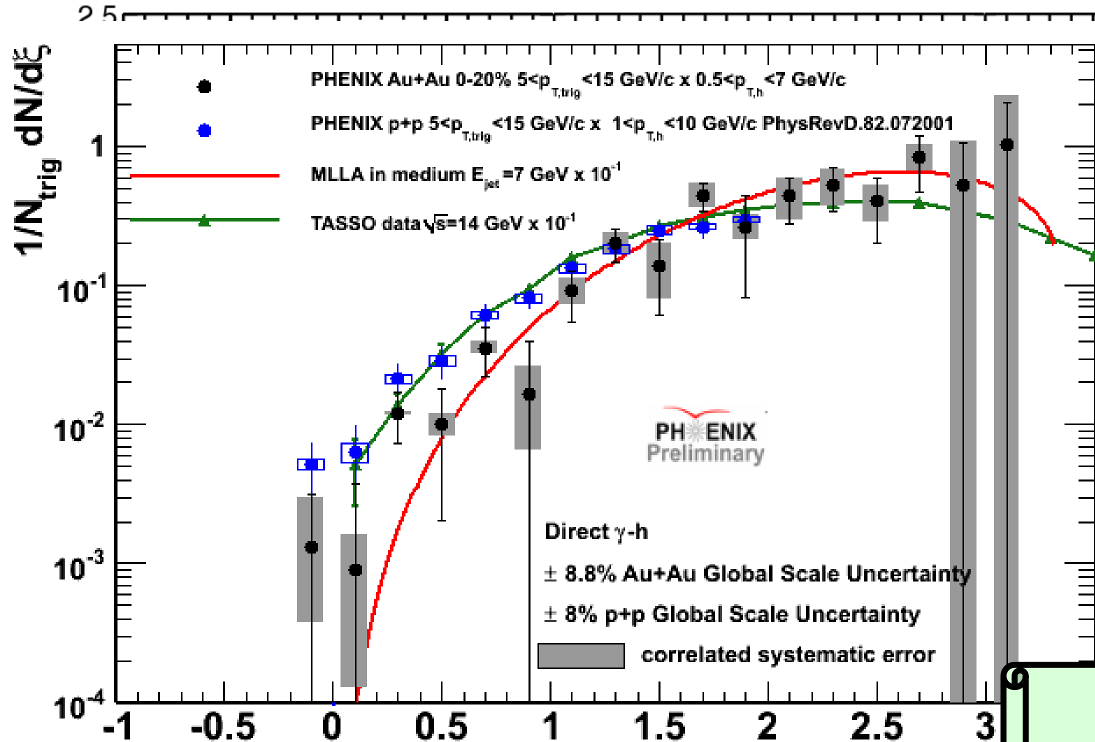
What you see ($\Delta pt/pt$ ~ 10% i.e. $\Delta E \sim E$?) is **NOT** what you get ($\Delta E \sim \ln(E)$)

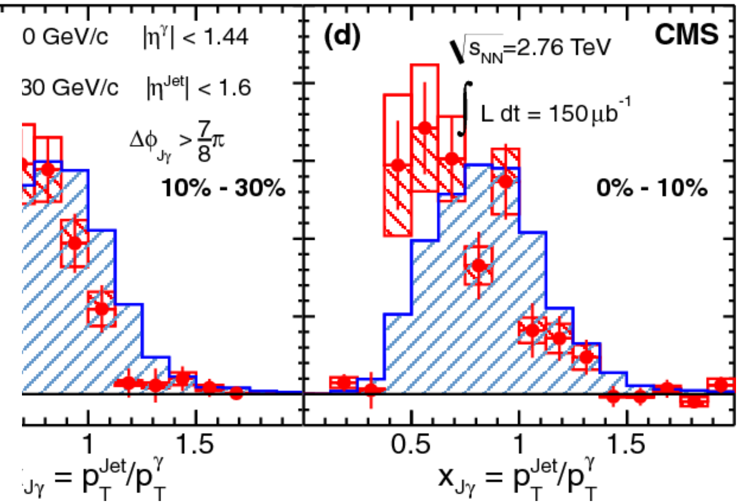
High statistics, large dynamic range:

- ~ no angular decorrelation (q_T < ISR+FSR)
- large E-loss out to the highest p_t

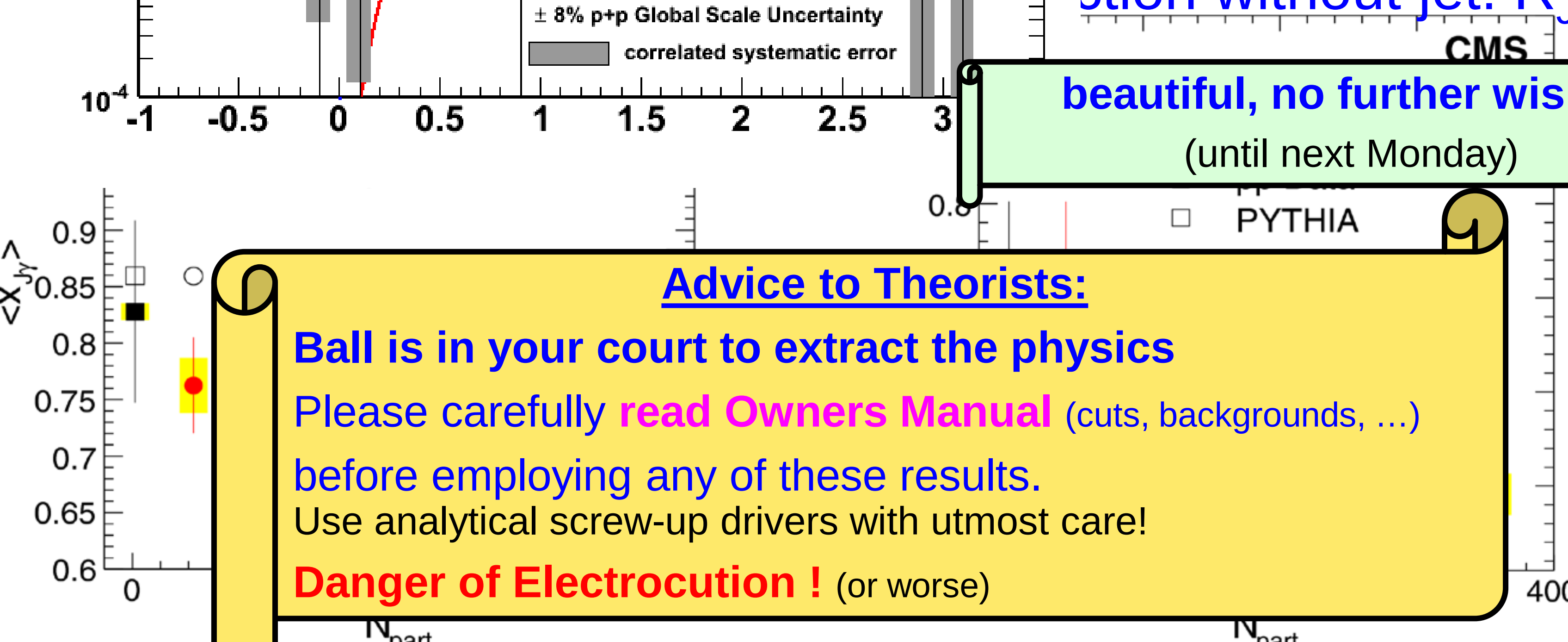
γ-Jet

(The Holy Grail of jet-quenching)





ction without jet: $R_{J\gamma}$



beautiful, no further wishes

(until next Monday)

Advice to Theorists:

Ball is in your court to extract the physics

Please carefully **read Owners Manual** (cuts, backgrounds, …)

before employing any of these results.

Use analytical screw-up drivers with utmost care!

Danger of Electrocution ! (or worse)

Heavy Flavour @ LHC

- Is charm a (somewhat light) heavy flavour (i.e. a HP) ?
  - Ener
- or a (
  - 'hyd
- or bot (depending on where and how you look) ?

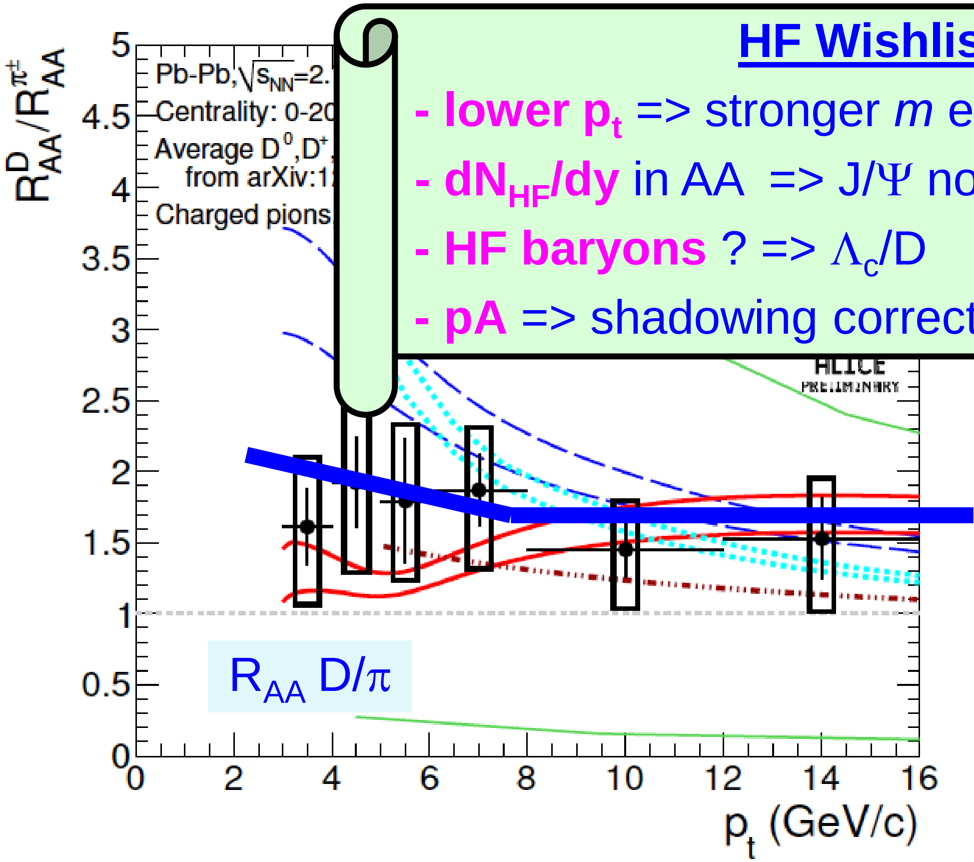
HF 'hindications':

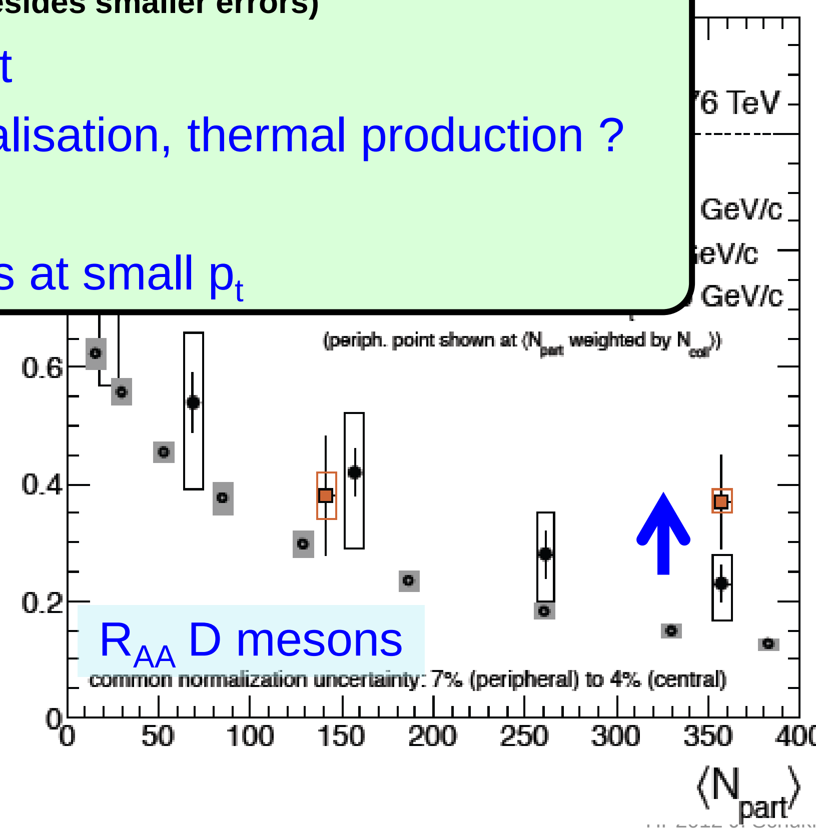
$R_{AA}(D)/R_{AA}(\pi) > 1$: colour charge and mass effect ?

$R_{AA}(b)/R_{AA}(c) > 1$: mass effect ?

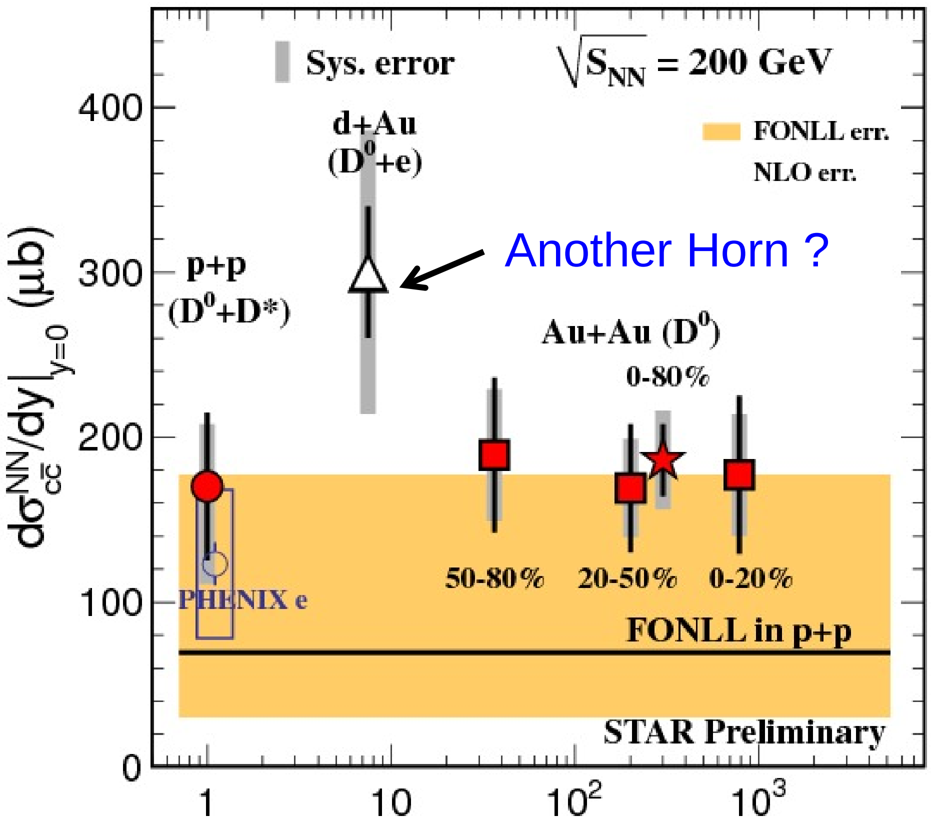
HF Wishlist (besides smaller errors)

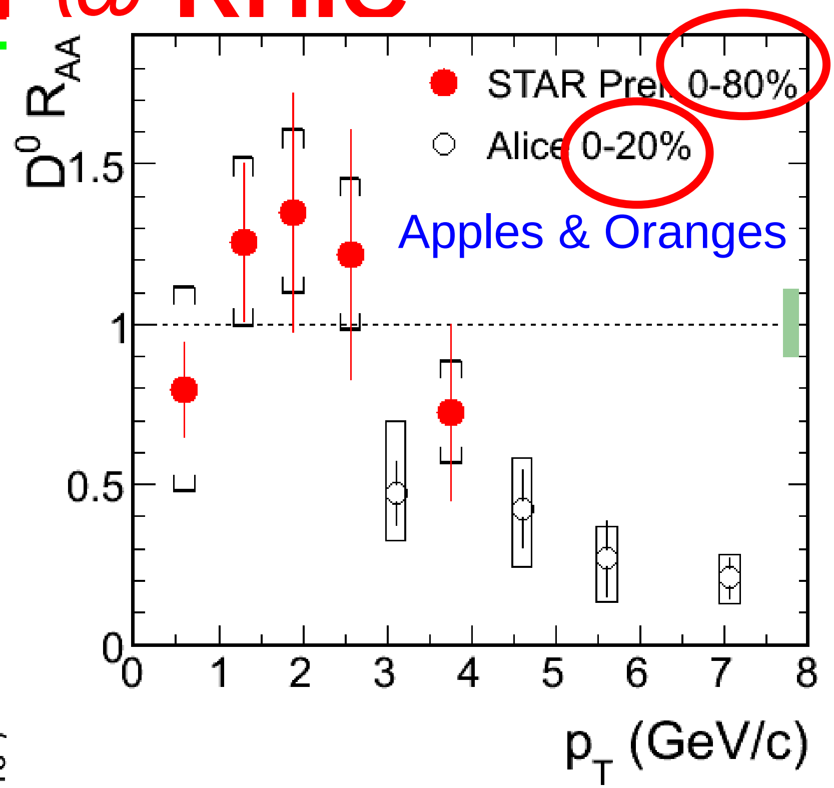
- **lower p_t** => stronger *m* effect
- **dN_{HF}/dy** in AA => J/Ψ normalisation, thermal production ?
- **HF baryons** ? => Λ_c/D
- **pA** => shadowing corrections at small p_t

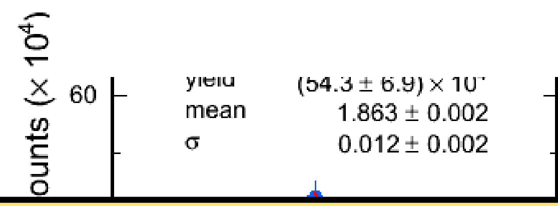




Heavy Flavour @ RHIC







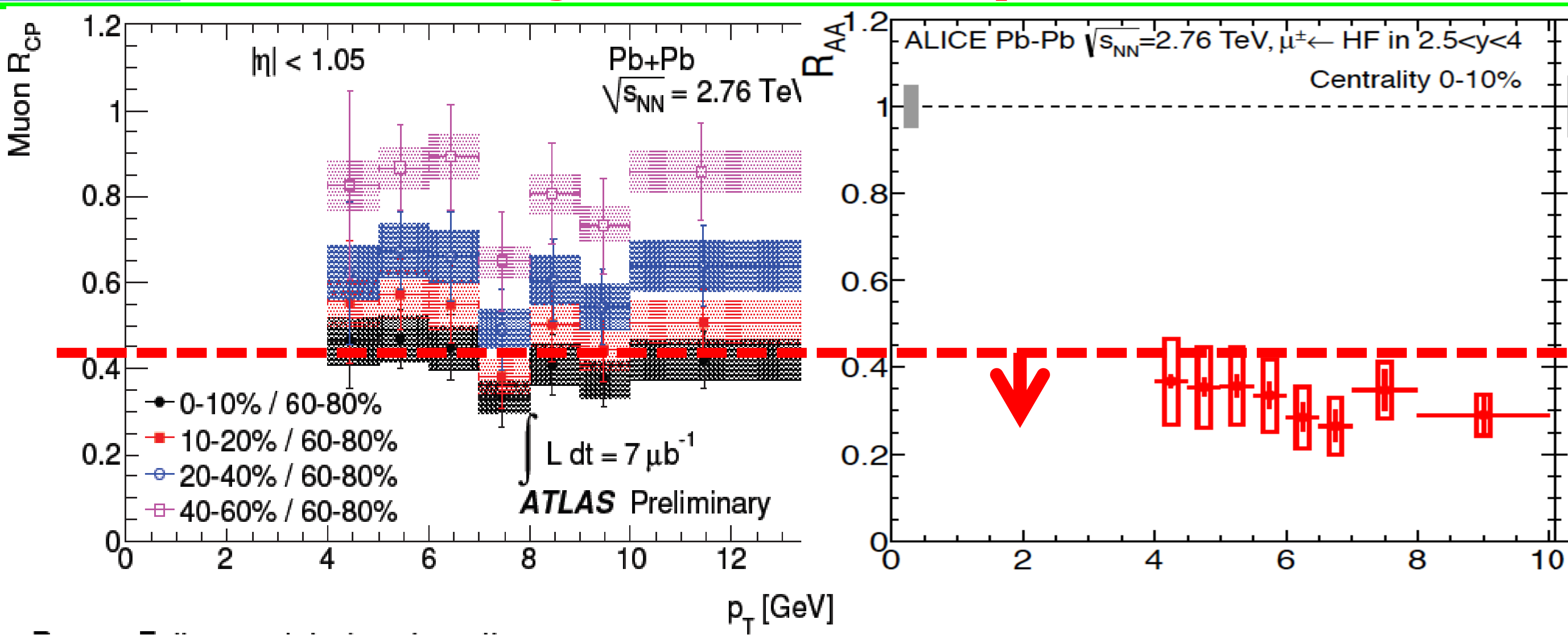
'Tour de Force' to get hadronic charm: Bravo !

- σ_c scales with N_{bin} (no visible shadowing/thermal production)
- no visible suppression at low p_t (is THIS the mass effect ?)

HF Wishlist (besides MUCH smaller errors)

- higher p_t & higher centrality => quenching region (upgrades)

Heavy Flavour leptons



- Atlas/Alice presumably consistent
(if only on could compare)

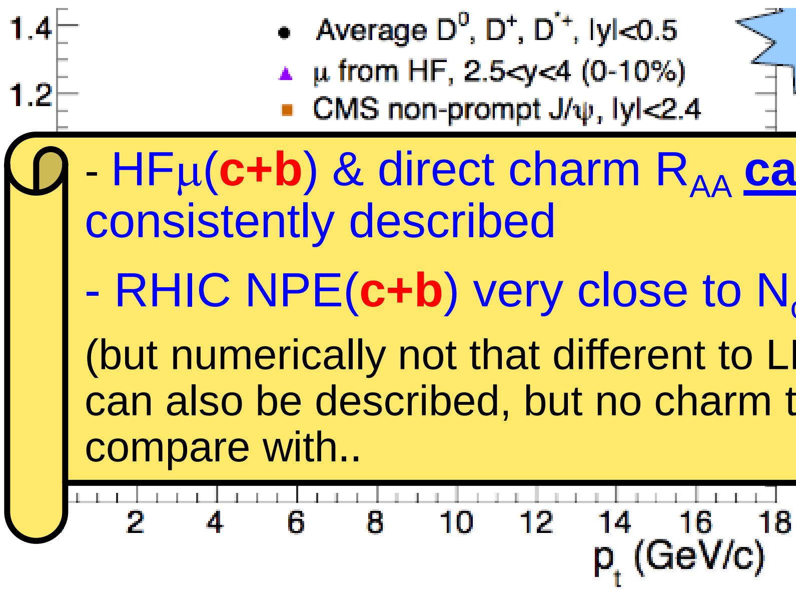
$R_{CP/PC}$ -> R_{AA}

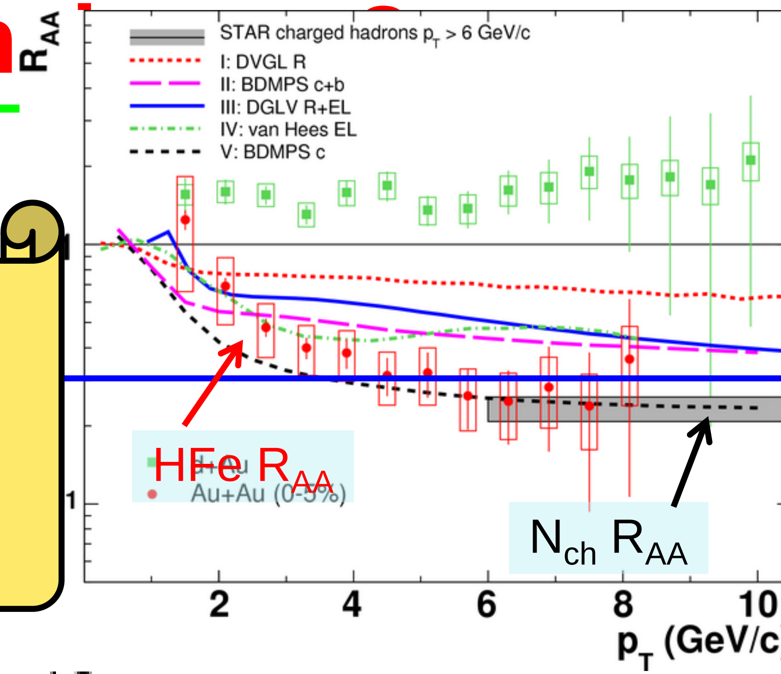
HFμ & charm con

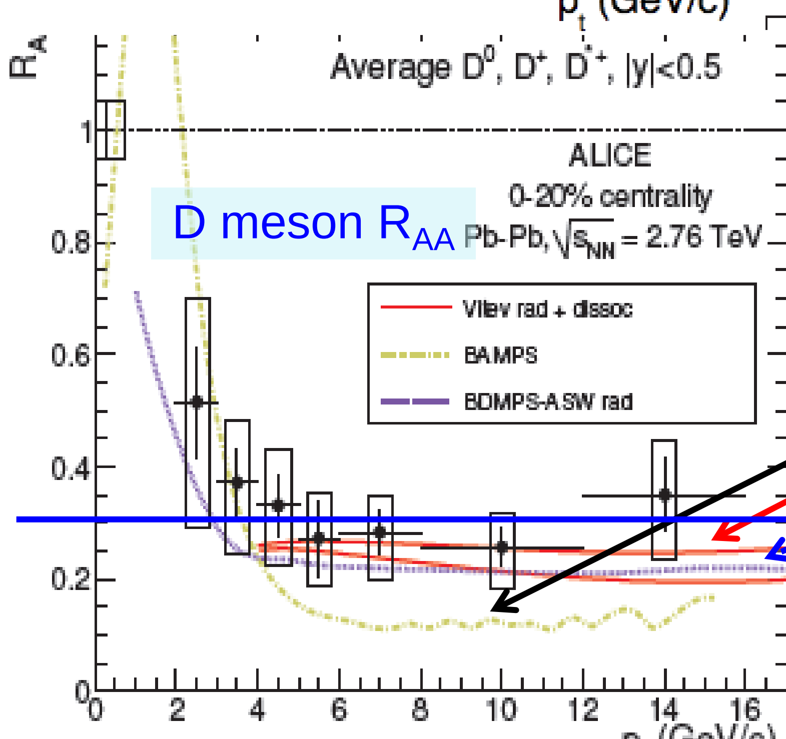
- HFμ(**c+b**) & direct charm R_{AA} **can** be consistently described

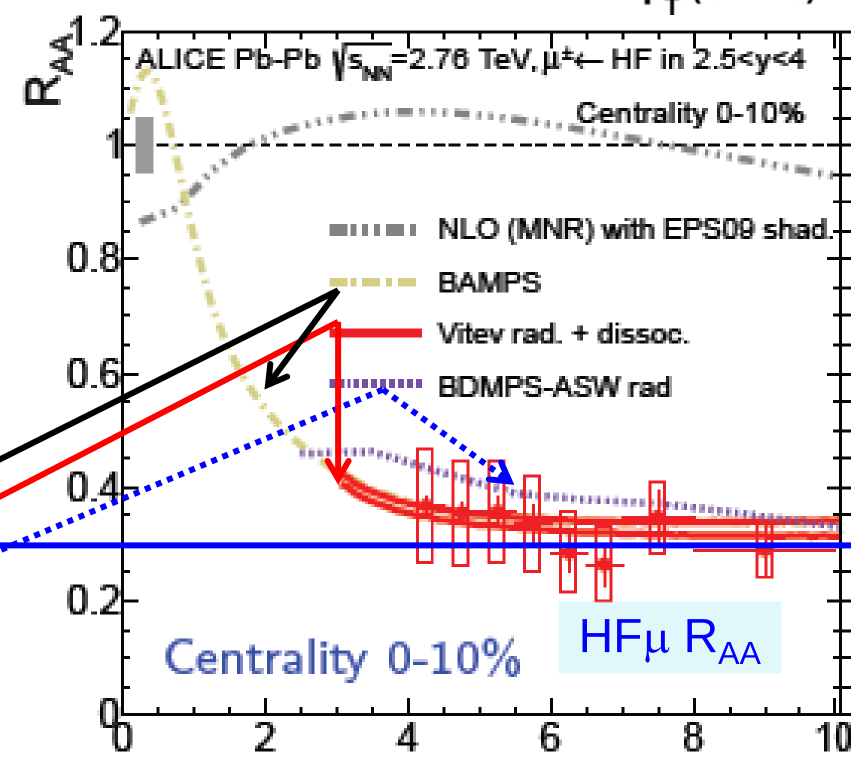
- RHIC NPE(**c+b**) very close to N_{ch}

(but numerically not that different to LHC)?
can also be described, but no charm to compare with..



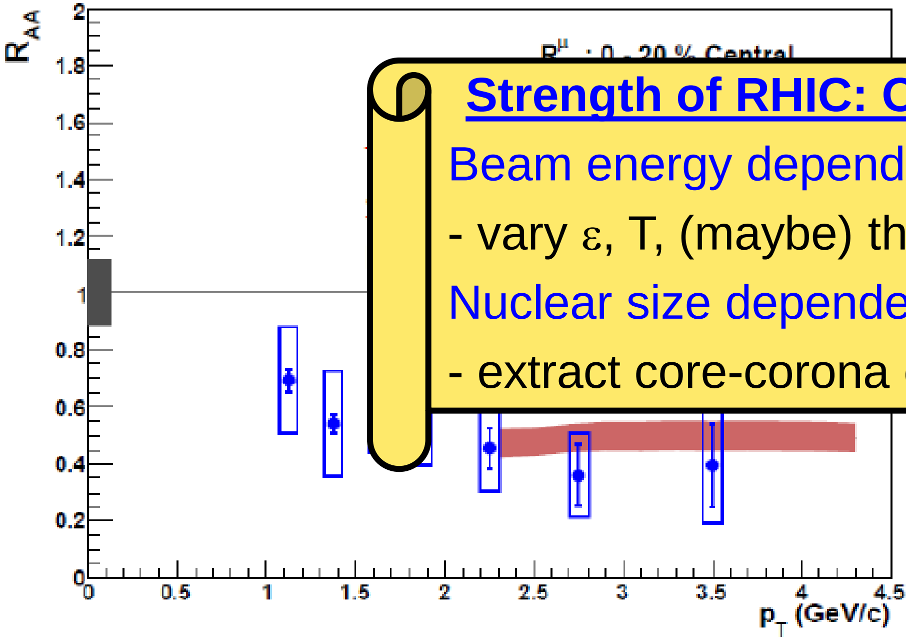




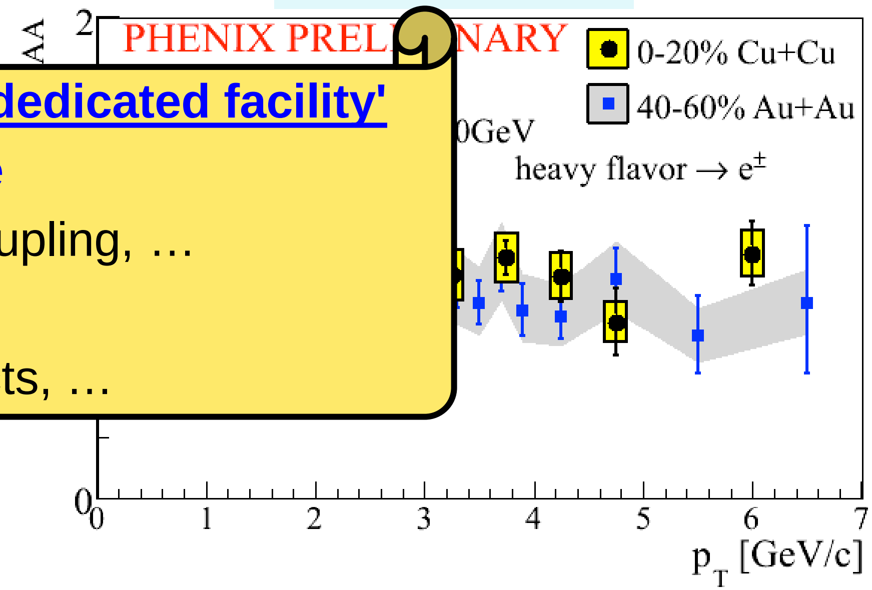


There is more to compare to..

Size/Geometry



Size/Geometry



Strength of RHIC: Our 'dedicated facility'

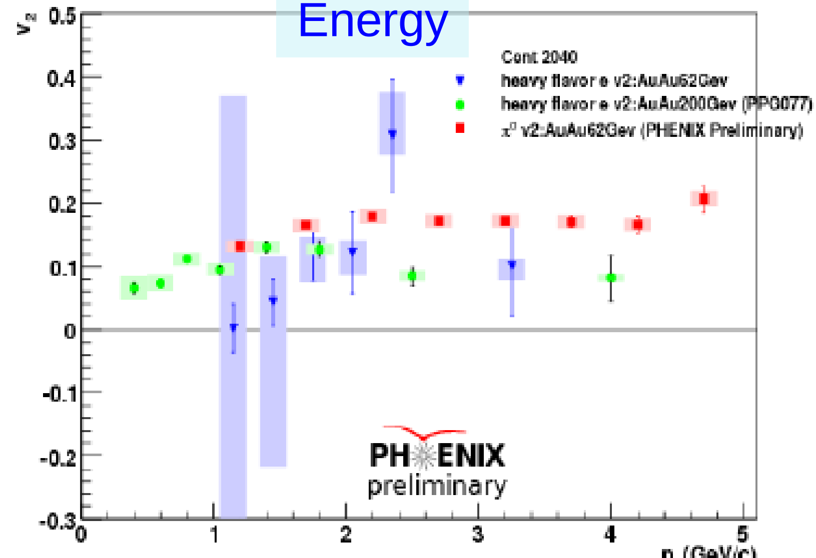
Beam energy dependence

- vary ε, T, (maybe) the coupling, …

Nuclear size dependence

- extract core-corona effects, …

Energy

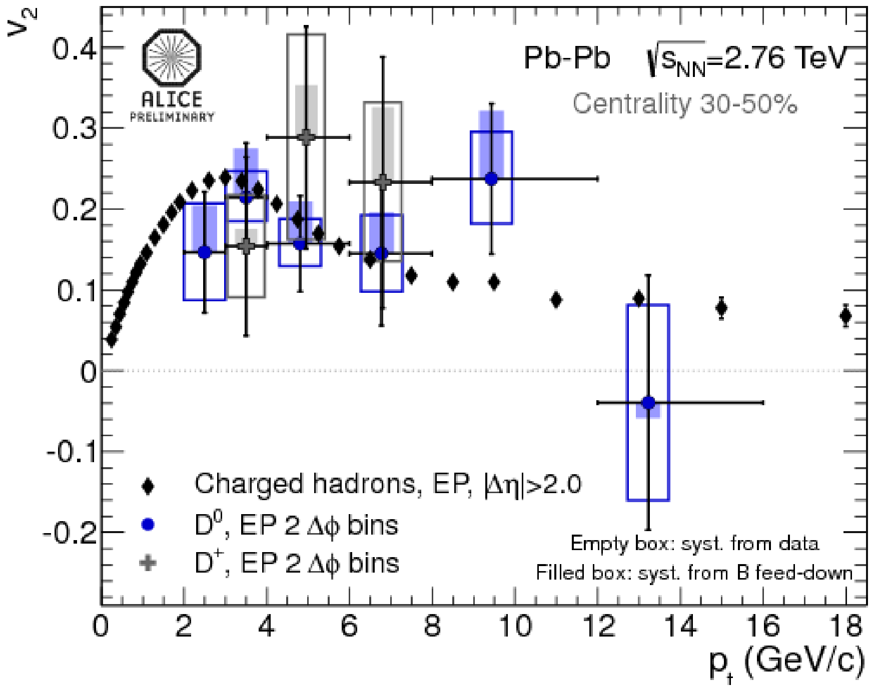


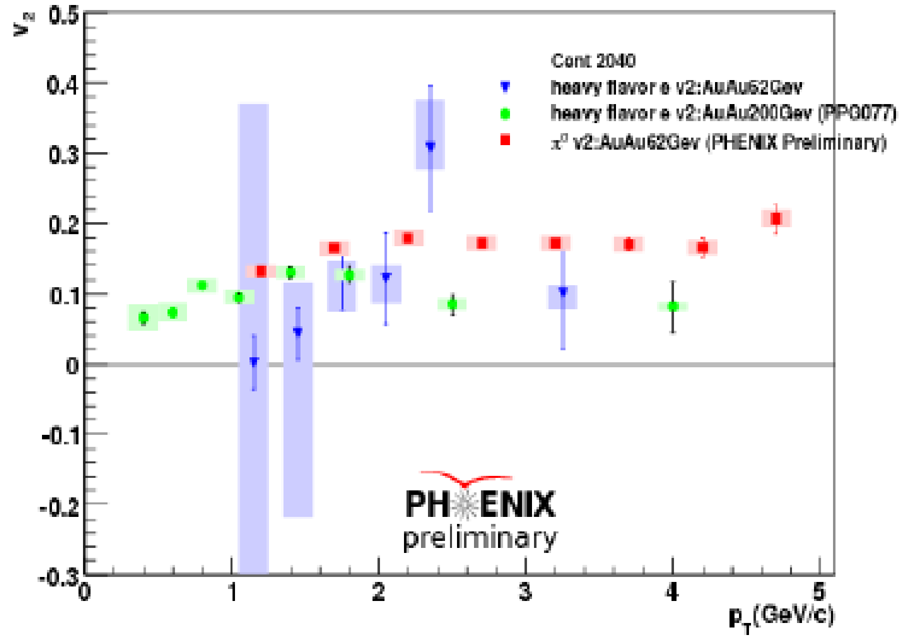
Wish for LHC:

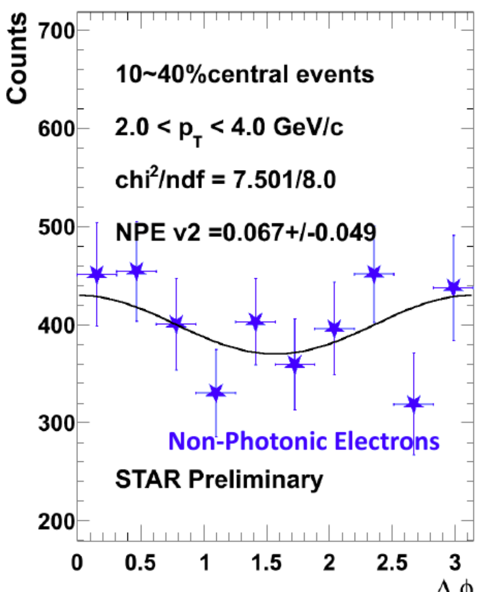
Obvious,

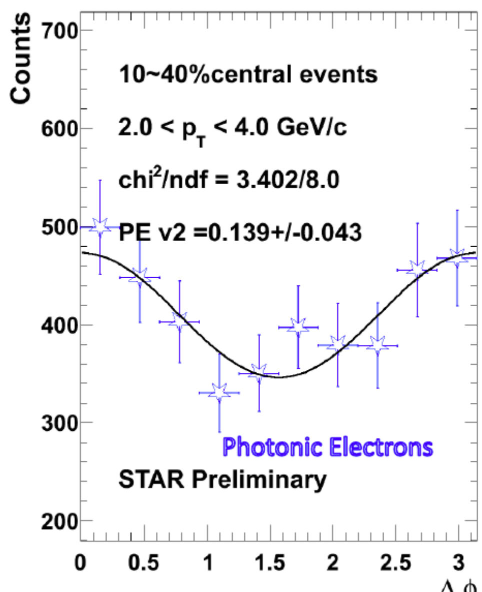
but where/when to accommodate in the limited ion time ?

Going with the flow ?









seems yes

- is it hydro flow ?

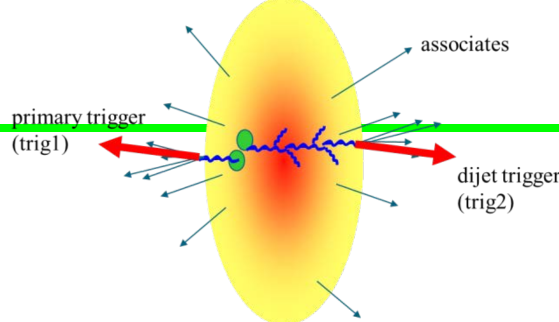
 < 2-3 GeV ?

- or quenching ?

 > 3 GeV ?

In either case, quite similar to N_{ch}

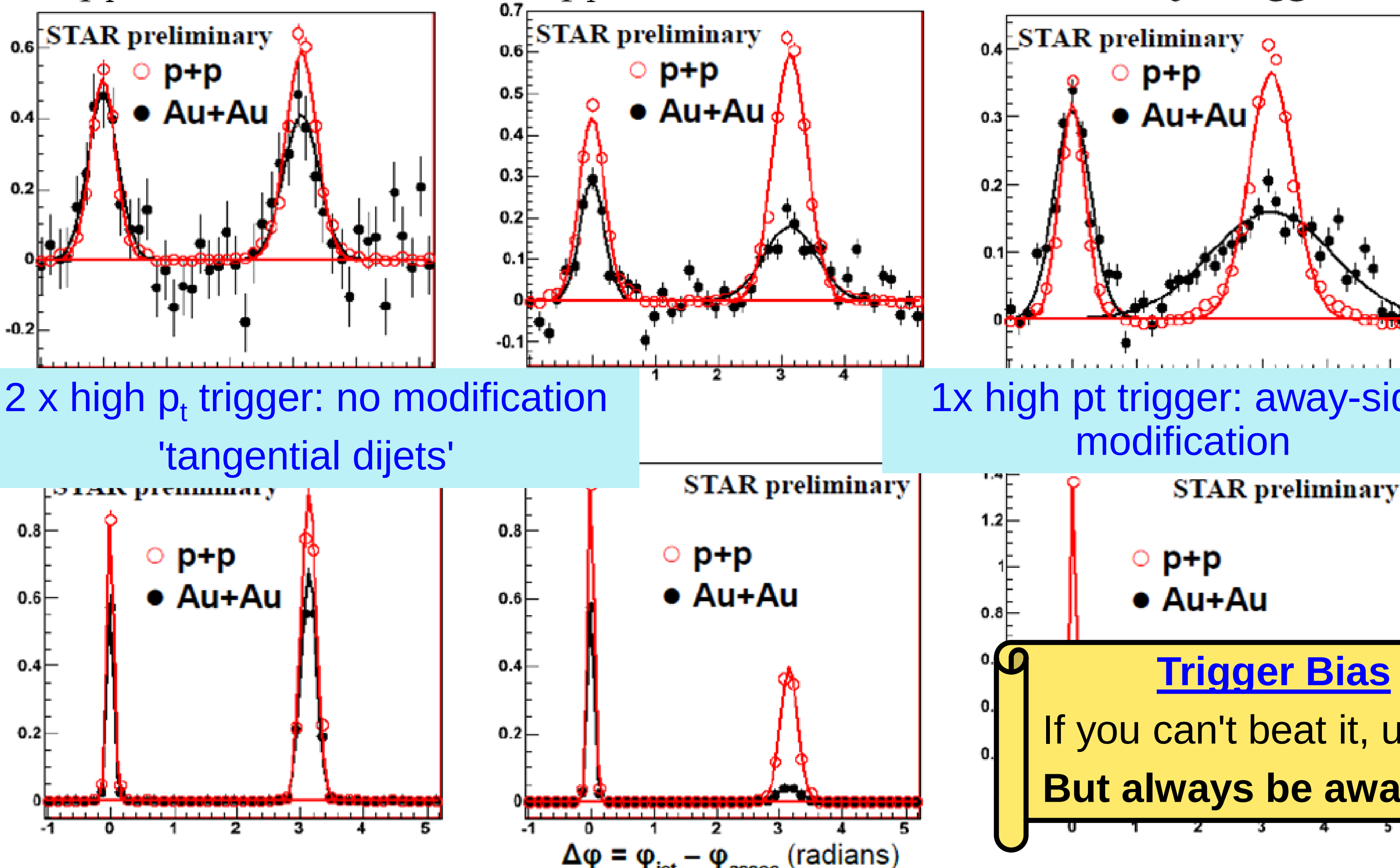
Particle Correlations



$$10 < p_T^{jet} < 20\ \mathrm{GeV}/c$$

$$|\varphi_{jet} - \varphi_{dijet\ trig}| > \pi - 0.2$$

$p_T^{dijet\ trig} > 4\ \mathrm{GeV}/c$ | $p_T^{dijet\ trig} > 2\ \mathrm{GeV}/c$ | no dijet trigger



2 x high p_t trigger: no modification
'tangential dijets'

1x high pt trigger: away-side modification

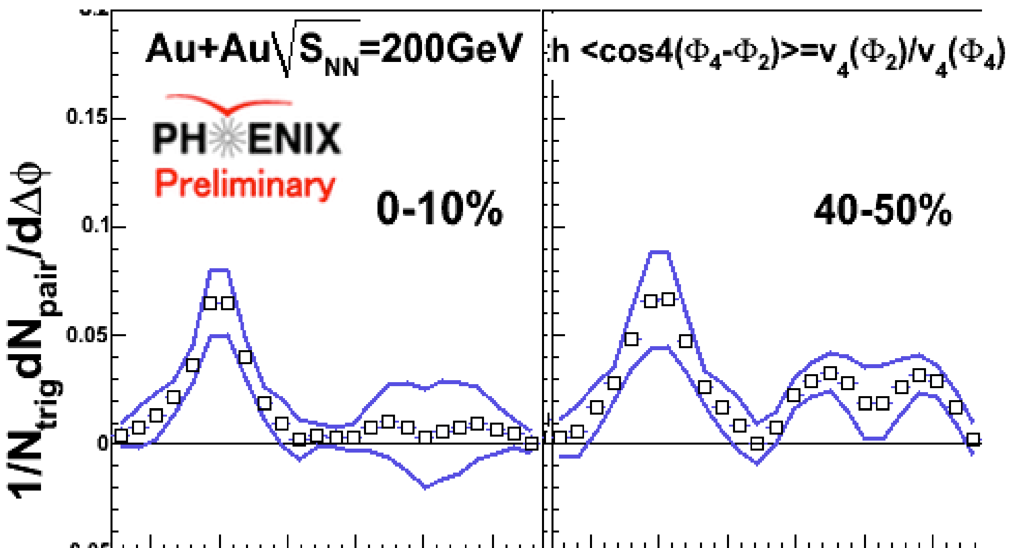
Trigger Bias

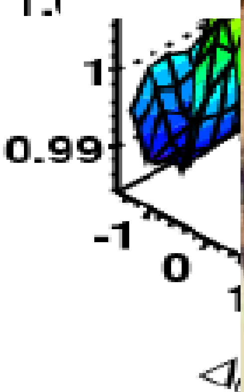
If you can't beat it, use it !

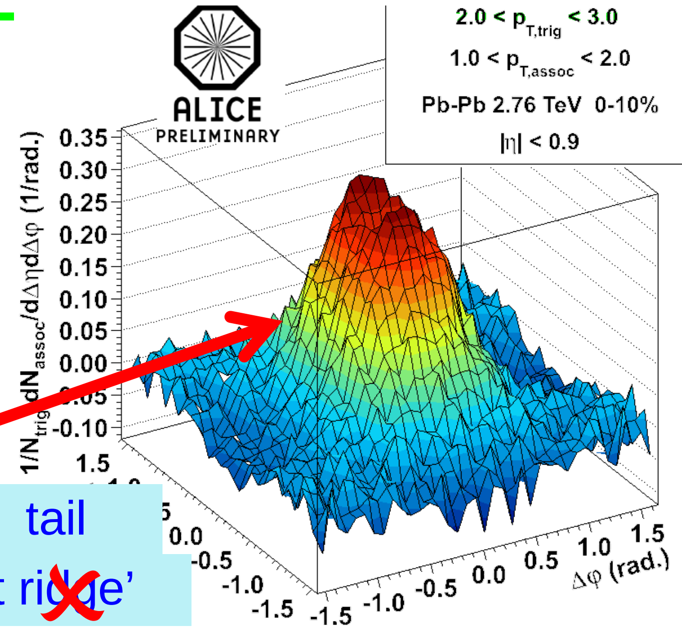
But always be aware..

Particle correlations

- 2-particle $\eta-\phi$ correlations:
  mostly Σv_n + nearside jet (+ awayside jet)



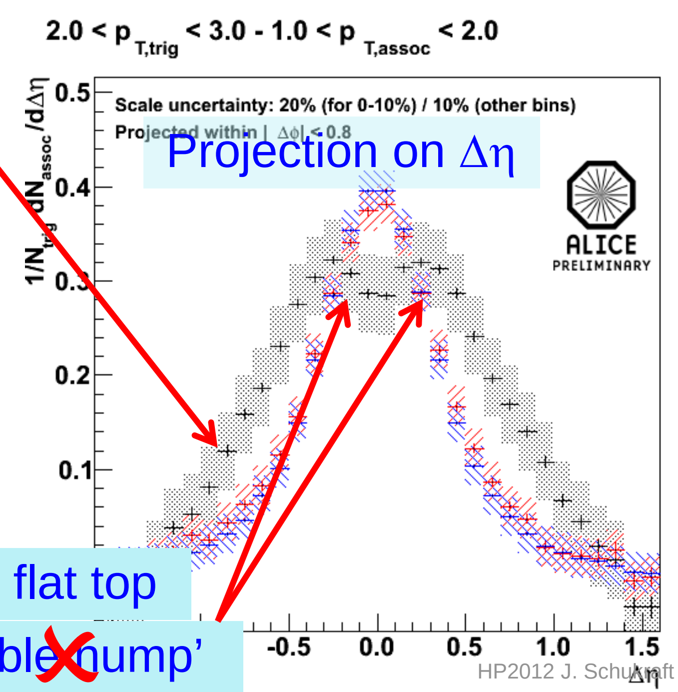




tail

ge soft ridge'

hump'



Projection on Δη

flat top

near side double hump'

HP2012 J. Schukraft

Interesting or Trivial ?

- jet a ciated, but asymmetric in η and ϕ

 ble, but not dramatic p_t dependence

medium modified jet fragments ?

jet modified medium fragments ?

- Gone with the wind ? (flow soft-hard interaction)

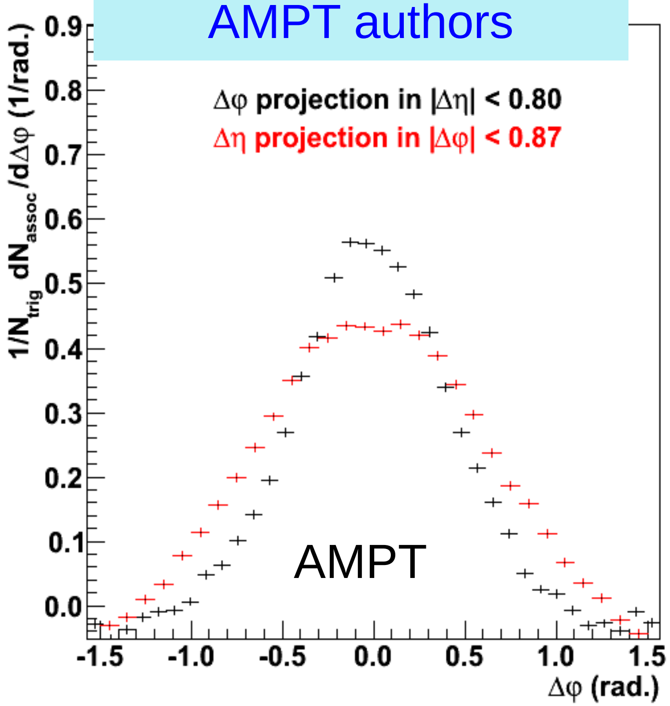
LHC: Ask AMPT

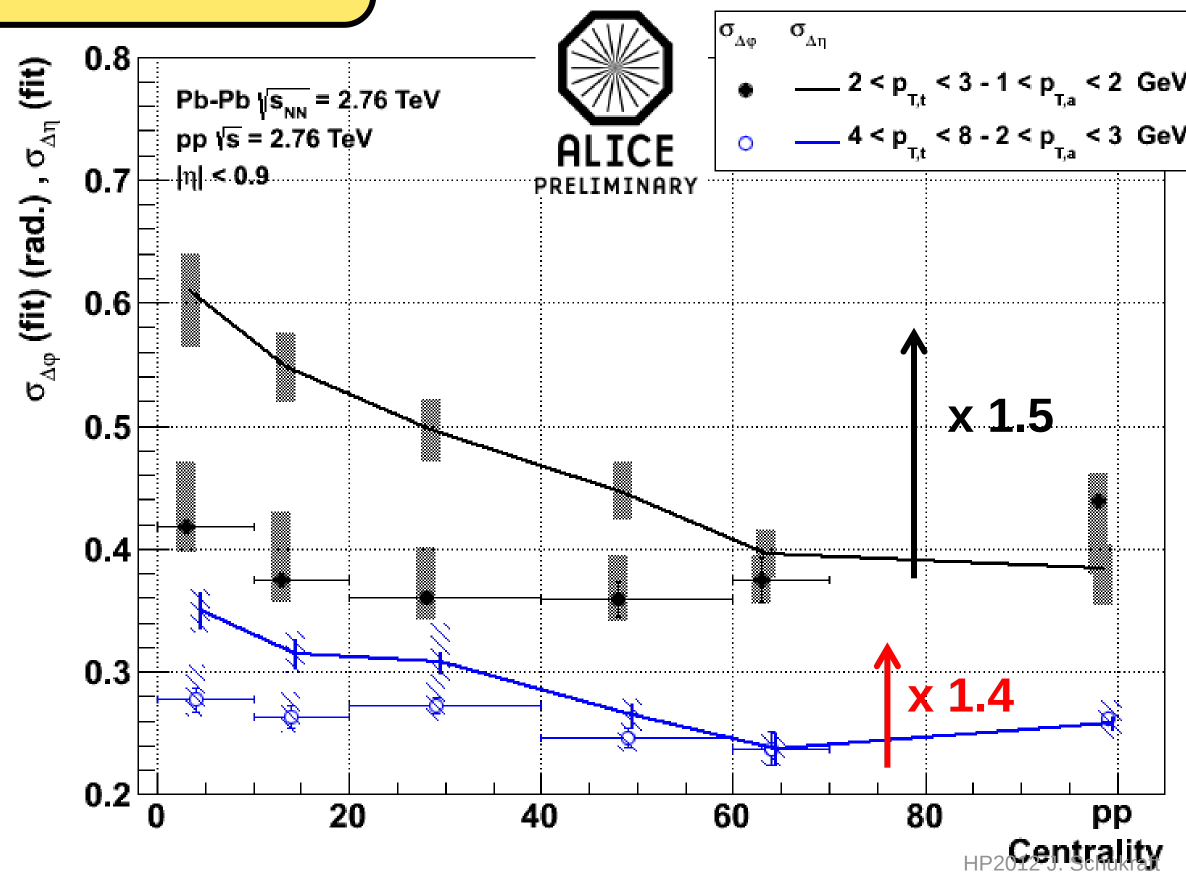
RHIC: Ask T. Trainor

explore larger p_{tT}, p_{ta} range

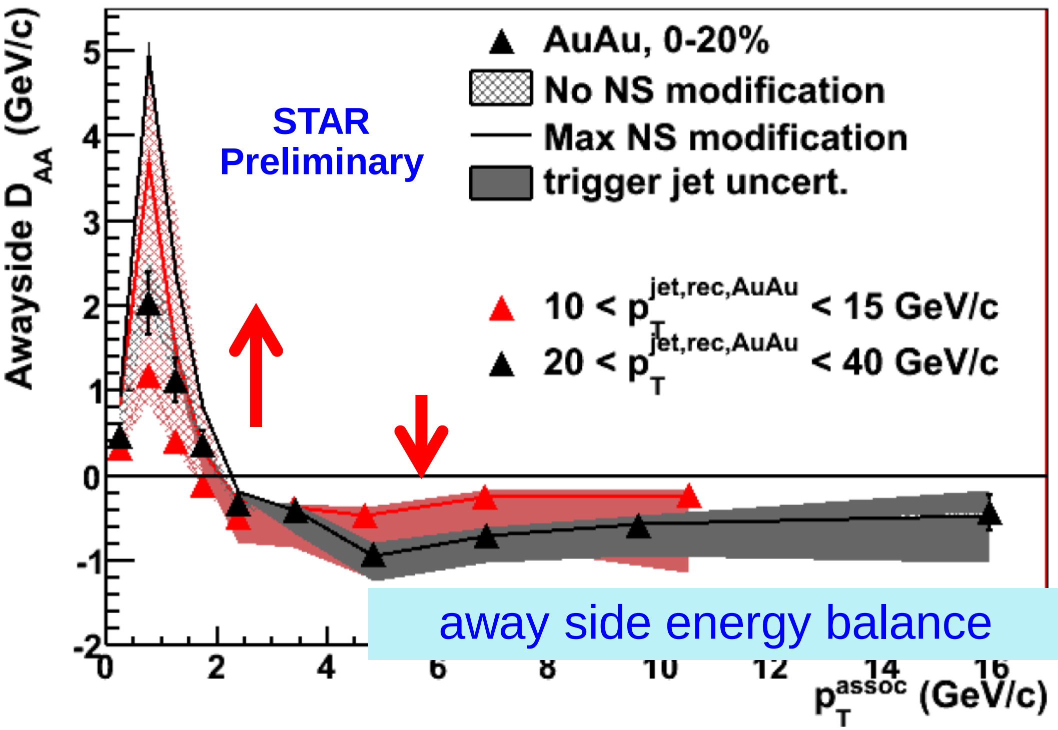
uncanny prediction,

not even known to AMPT authors





More soft modifications



away side energy balance

Another Baryon(?) Anomaly

protons from jets don't feel the bulk !

no radial flow, no coalescence, no fun..

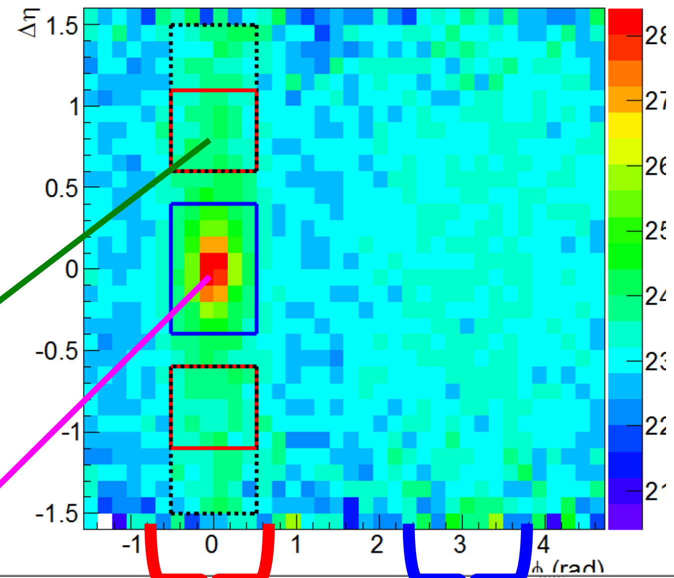
- formation time ?? (or color transparency ?)

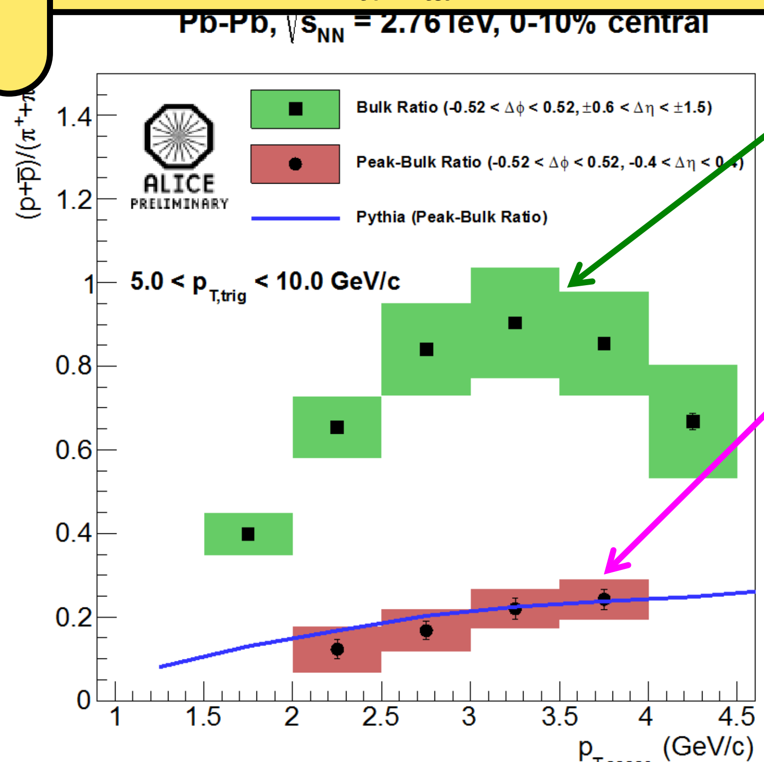
could this be used as a 'hadronization clock' ?

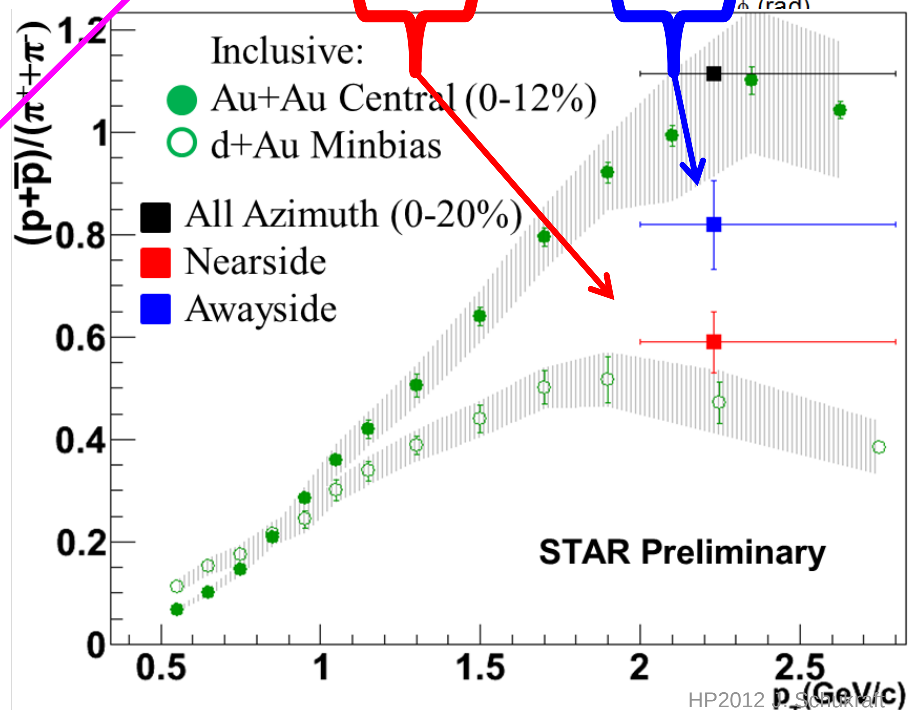
- surface bias ?

Star: a bit, but not all

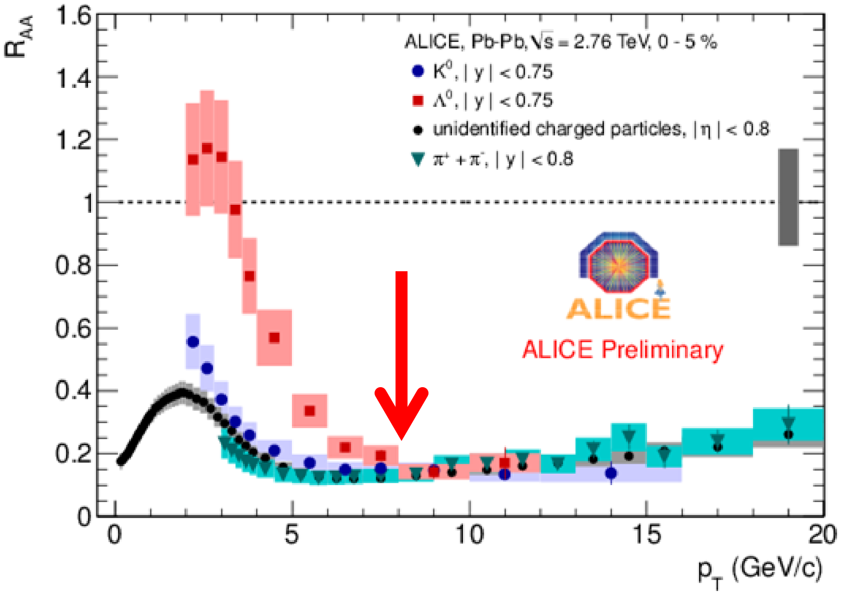
Alice: same p_{tT},p_{ta} **show** 'tail+flat top' ?

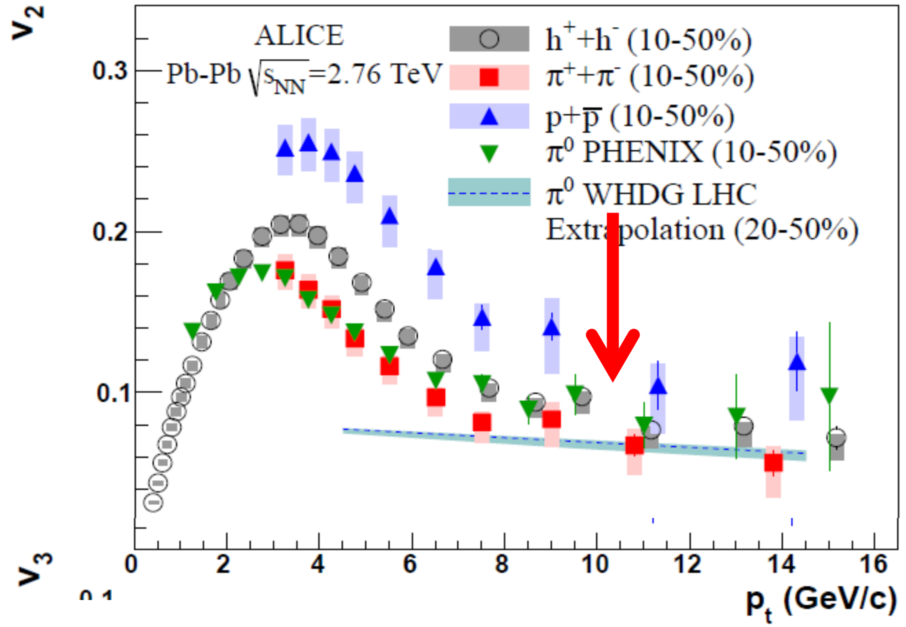






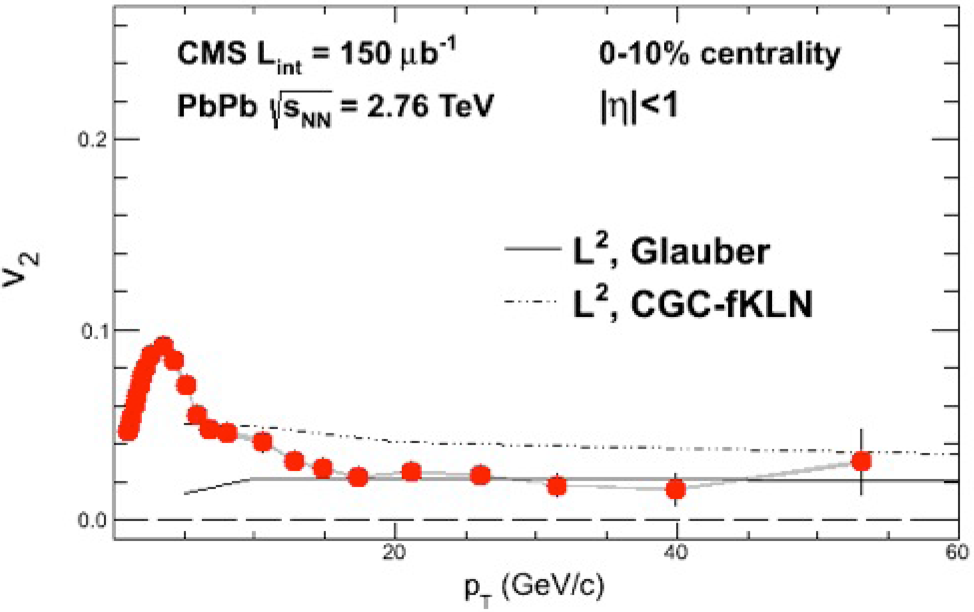
Mass (or n_q ?) Matters (up to a point)

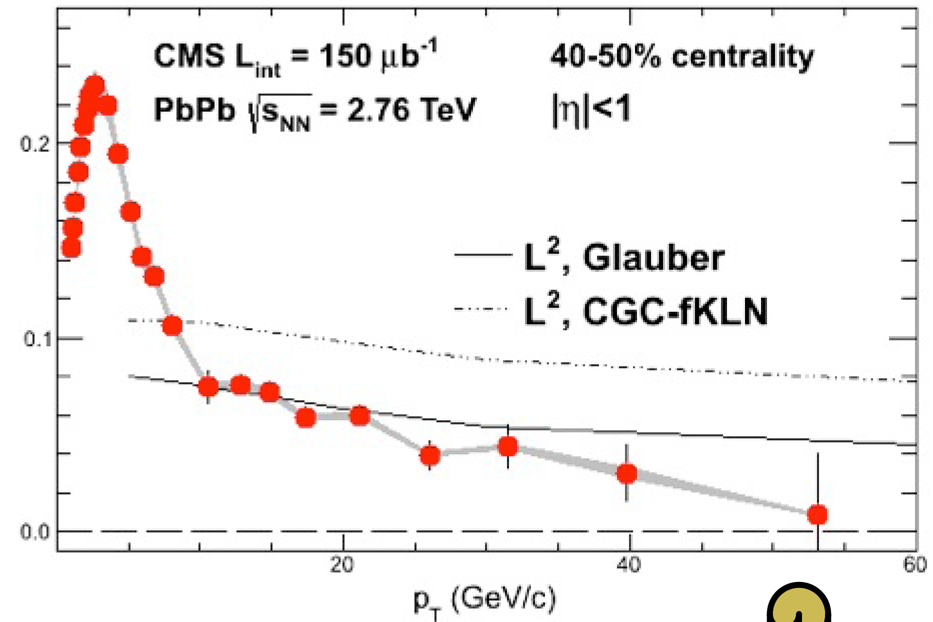




That point is around 8-10 GeV

V_2 to the limits





High p_t azimuthal anisotropy to 50 GeV: Amazing !

- quenching gets the 'ballpark' quite well

=> one of the best path-length signals ?

details to be worked out, however

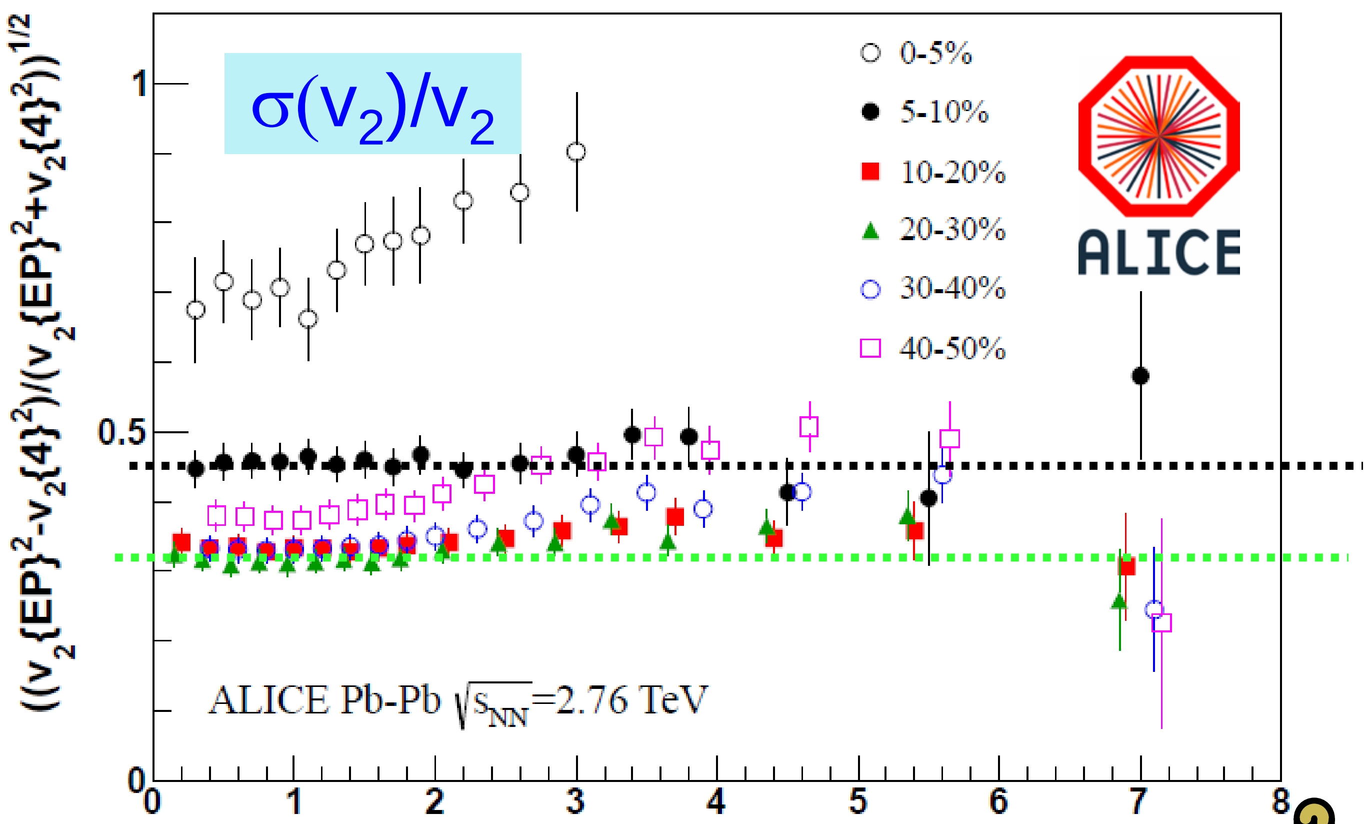
- hindication: 0-10% looks odd (flatter) ?

look into the 0-5% bin

(that may be even odder)

Another interesting observation

- Whatever it is that makes v_2 in $3 < p_t < 8$ GeV: **$\sigma(v_2)/v_2$ = constant** (5-30%)
  - ⇨ **trivial for hydro**: $\sigma(v_2)/v_2 \sim \sigma(\varepsilon_2)/\varepsilon_2$ $v_2 \sim \varepsilon_2$ independent of p_t
  - ⇨ **less trivial for quenching**: (density weighted pathlength integral)$^n \sim \varepsilon$

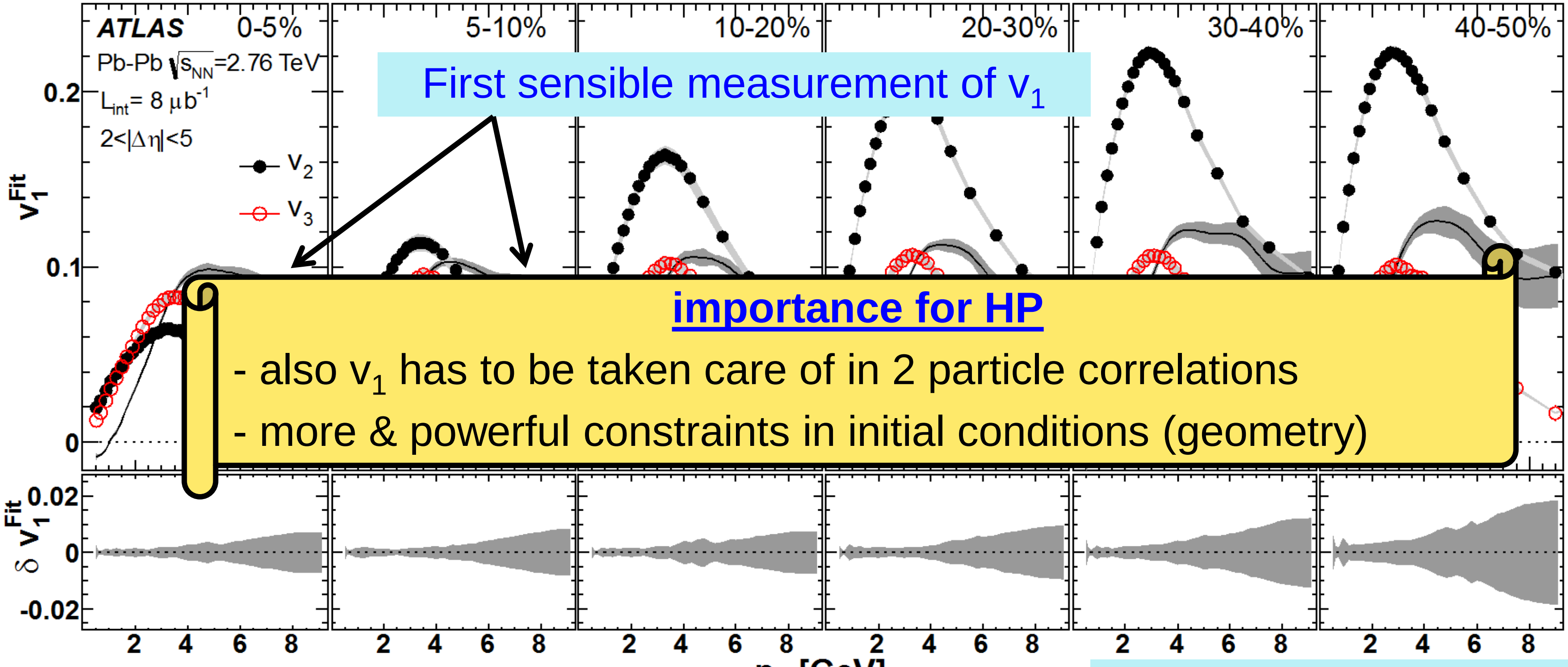


Jet another constraint on quenching models

or a hint for what makes the IM region tick (and flow) ?

Ceterum censeo: **the 0-5% bin looks odd**

Nota Bene

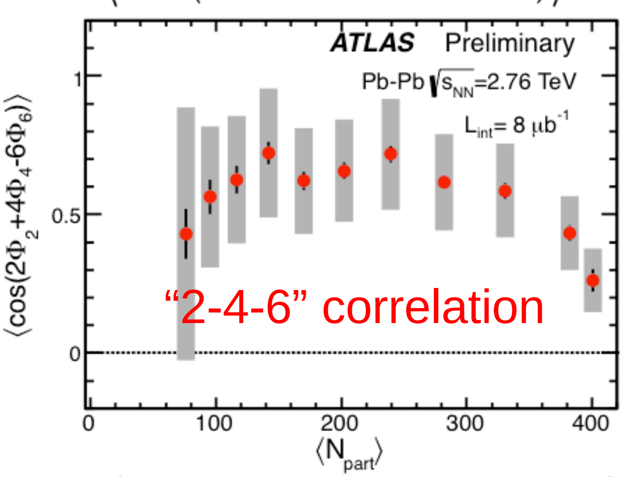


First sensible measurement of v_1

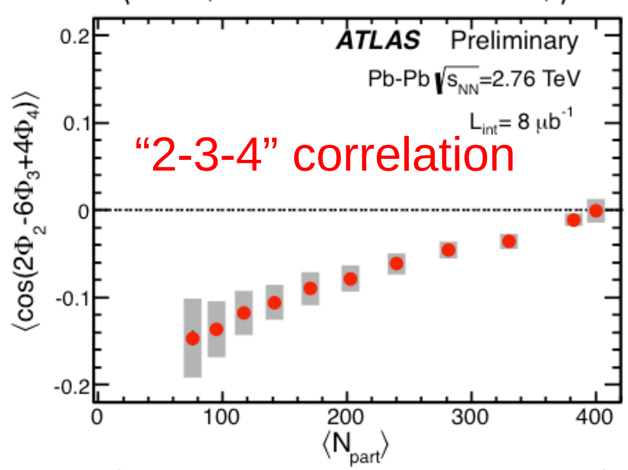
importance for HP

- also v_1 has to be taken care of in 2 particle correlations
- more & powerful constraints in initial conditions (geometry)

$$\langle \cos(2\Phi_2 + 4\Phi_4 - 6\Phi_6) \rangle$$



$$\langle \cos(2\Phi_2 - 6\Phi_3 + 4\Phi_4) \rangle$$



Amazing variety of flow plane correlations

Kama sutra of flow:

geometrical correlations I didn't even know they existed

Intermediate p_t (few - 10 GeV?)

- Facts
  - ⇨ **Mass and/or flavour matter** (PID results) up to (at least) ~8 GeV
    - R_{AA}, v_2
  - ⇨ **some** associated particles **are modified**
    - the 'tail & flat top', energy balance, …..
  - ⇨ **some aren't**
    - p/π peak 'region', near & away side
  - ⇨ whatever makes v_2, it has the **SAME ~ linear dependence on ε** as hydro flow
- Fiction
  - ⇨ n_q-scaling: **2/3 = recombination**
  - ⇨ R_{AA} 'bump' around 3 GeV **'Cronin'**

(RHIC/LHC: It's the hydro, stupid !)

the IM p_t region is important !

- that's were we **find ΔE**

- that's were we ***may* find recombination**

the IM p_t region is only starting to be explored experimentally

the IM p_t region is a theoretical desert (or minefield)?

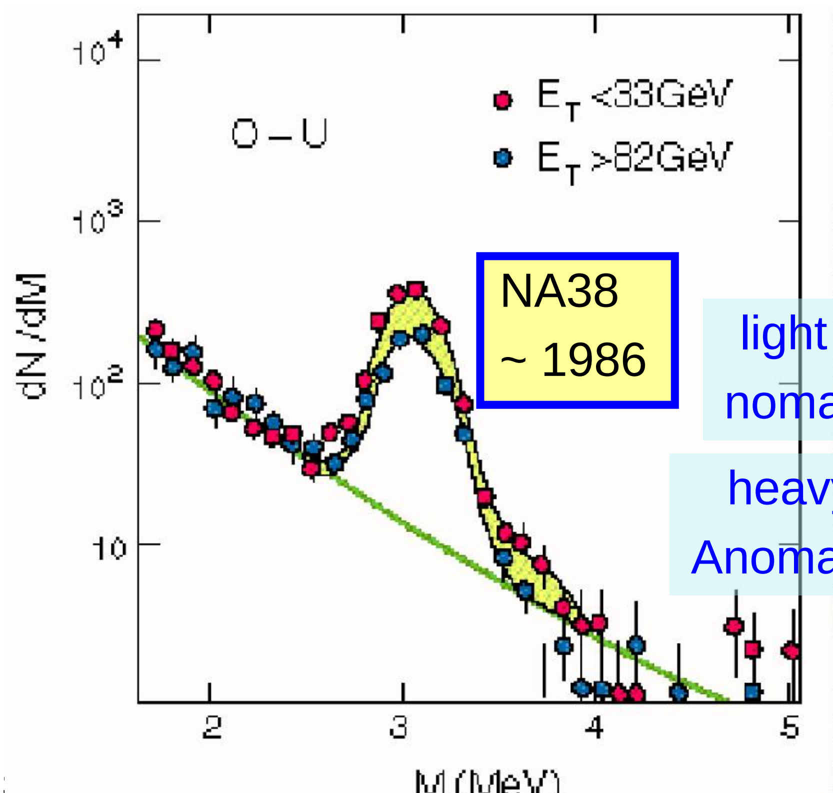
Let's do something about it (and wear flak jackets)

Quarkonium suppression

- J/Ψ, the HP par excellence: 'well calibrated (pQCD) smoking gun'

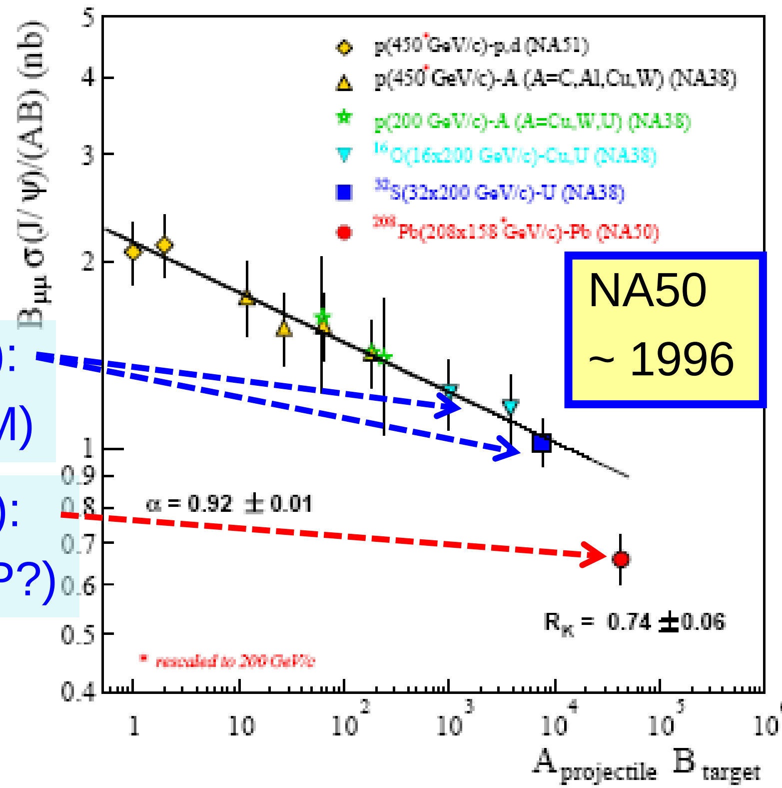
Matsui & Satz, 1986:

If high energy heavy ion collisions lead to the formation of a hot quark–gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, the temperature dependence of the screening radius, as obtained from lattice QCD, is compared with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. It is concluded that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark–gluon plasma formation.



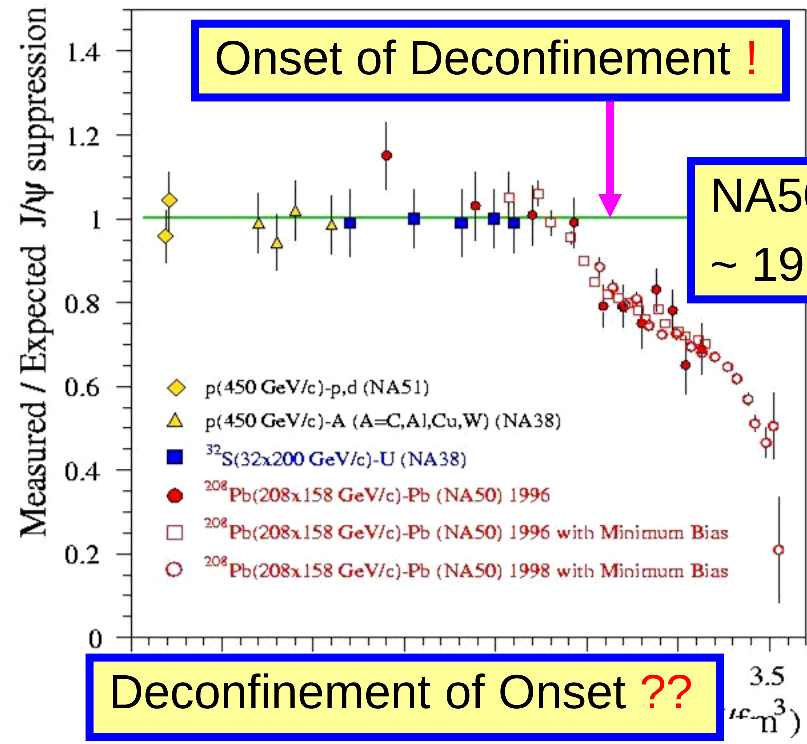
light ions (O,S): nomalous (CNM)

heavy ions (Pb): Anomalous (QGP?)

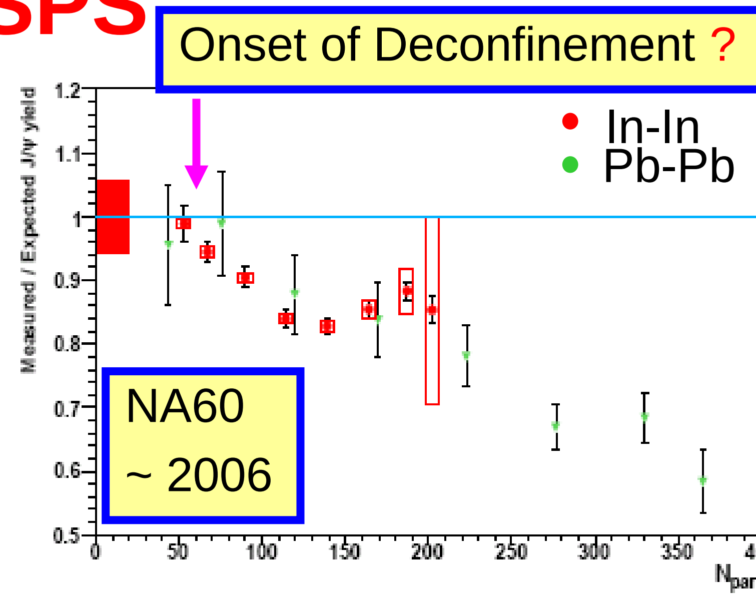


Schukraft

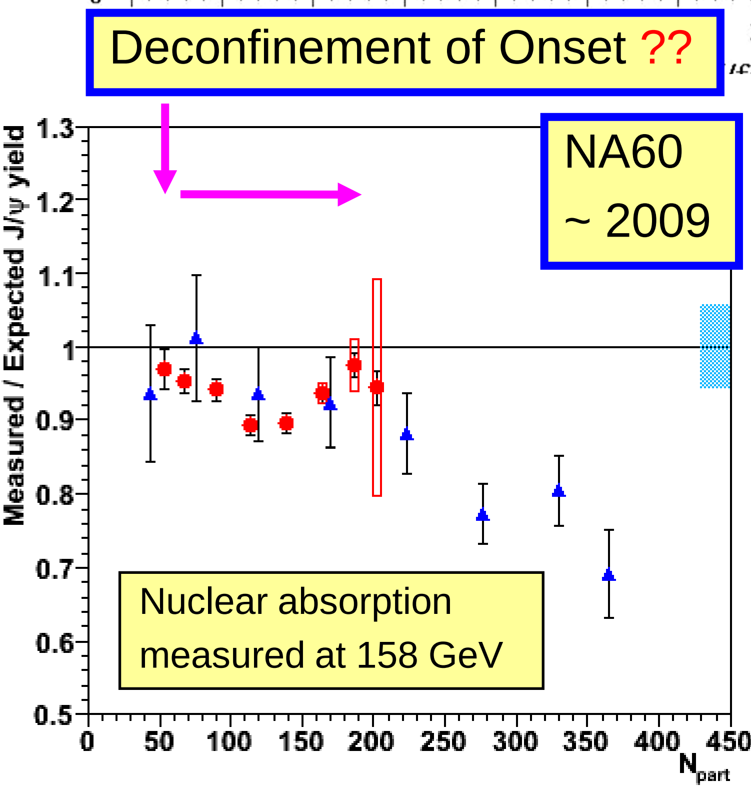
J/Ψ @ SPS



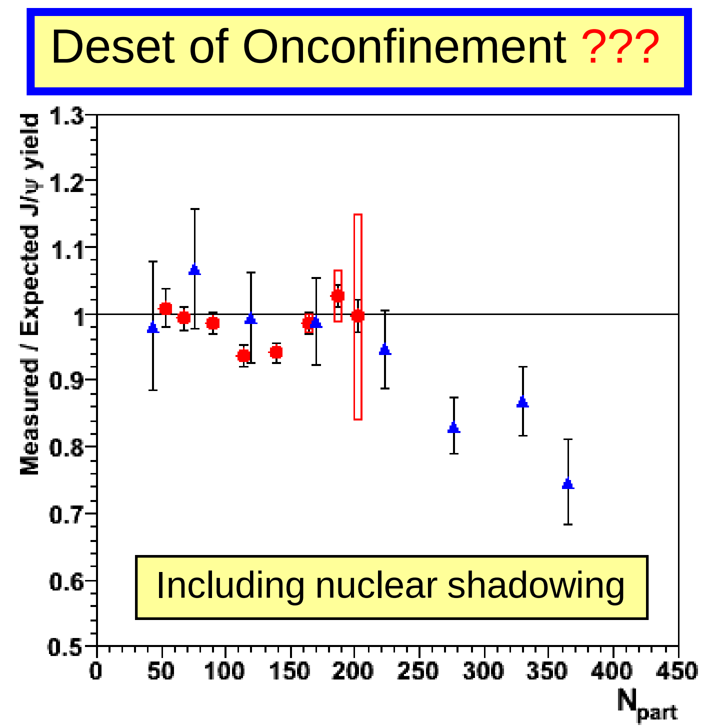
Onset of Deconfinement !
NA50
~ 1996
Measured / Expected J/ψ suppression
p(450 GeV/c)-p,d (NA51)
p(450 GeV/c)-A (A=C,Al,Cu,W) (NA38)
32S(32x200 GeV/c)-U (NA38)
208Pb(208x158 GeV/c)-Pb (NA50) 1996
208Pb(208x158 GeV/c)-Pb (NA50) 1996 with Minimum Bias
208Pb(208x158 GeV/c)-Pb (NA50) 1998 with Minimum Bias
3.5



Onset of Deconfinement ?
In-In
Pb-Pb
NA60
~ 2006
Measured / Expected J/ψ yield
N_part



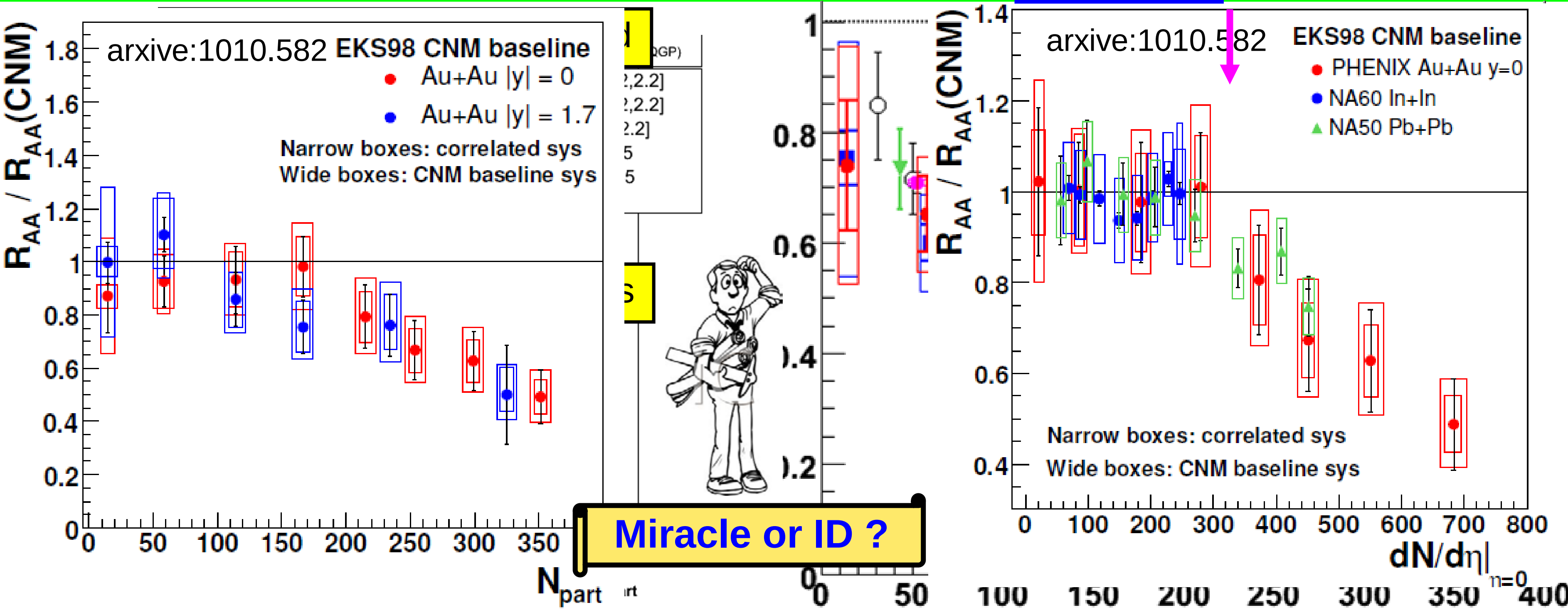
Deconfinement of Onset ??
NA60
~ 2009
Measured / Expected J/ψ yield
Nuclear absorption measured at 158 GeV
N_part



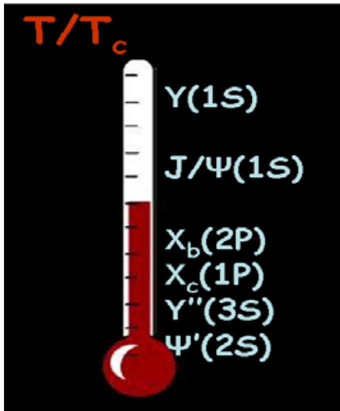
Deset of Onconfinement ???
Measured / Expected J/ψ yield
Including nuclear shadowing
N_part

J/Ψ @ RHIC

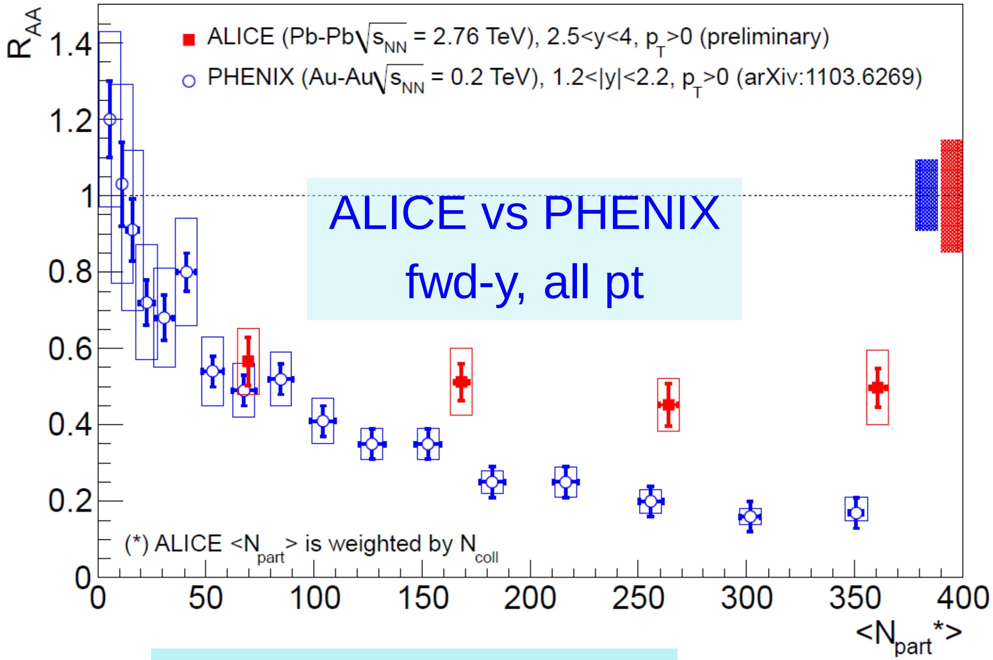
Déjà vu ?

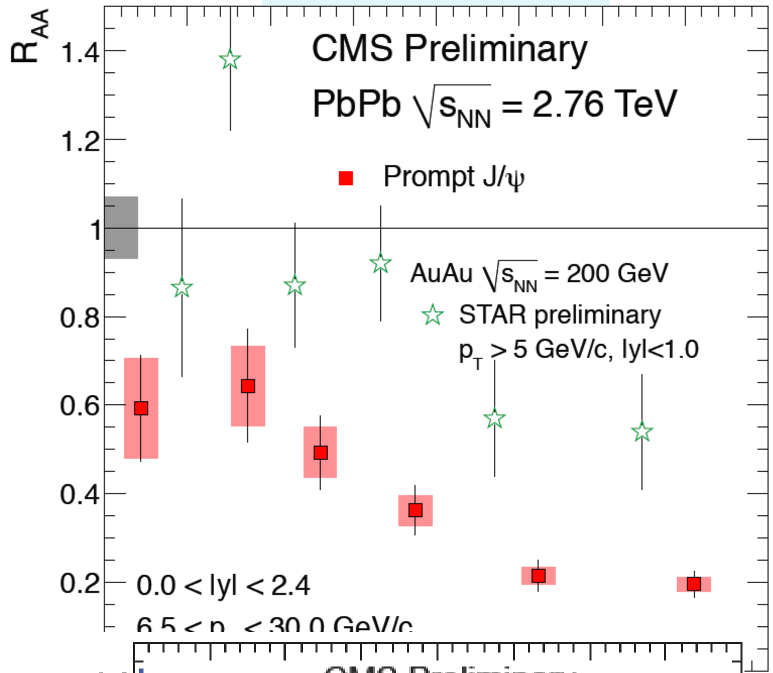


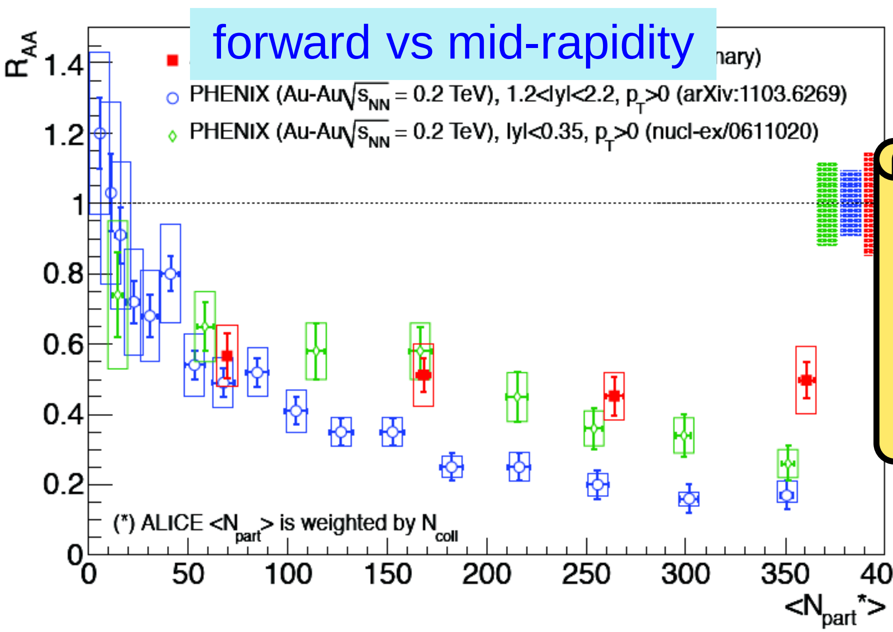
- **Expectation**: decisive answer from **RHIC**. And we even got it !
  - ⇨ (~) all predictions were wrong ! RHIC (y=0) ≈ SPS (y=0) ; RHIC(y≠0)<RHIC(y=0)!!
- Two broad classes of explanations why RHIC ≈ SPS:
  - ⇨ equal by Intelligent **Design**: same physics (Ψ', χ_c suppression only)
  - ⇨ equal by miraculous **Accident**: suppression cancelled by recombination
- **Expectation**: decisive answer from **LHC (+ Y @ RHIC)**
  - ⇨ different sensitivity to melting (T_c) and recombination (charm density)



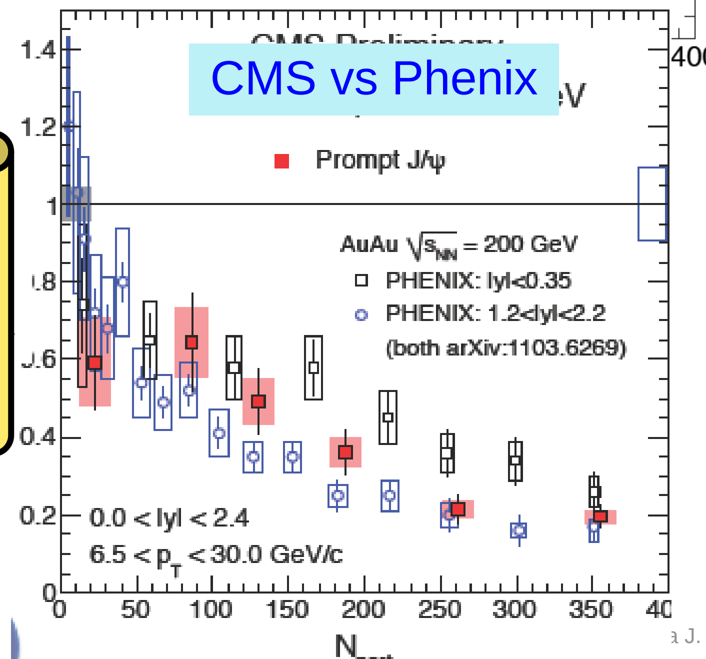
RHIC ≠ LHC (finally)



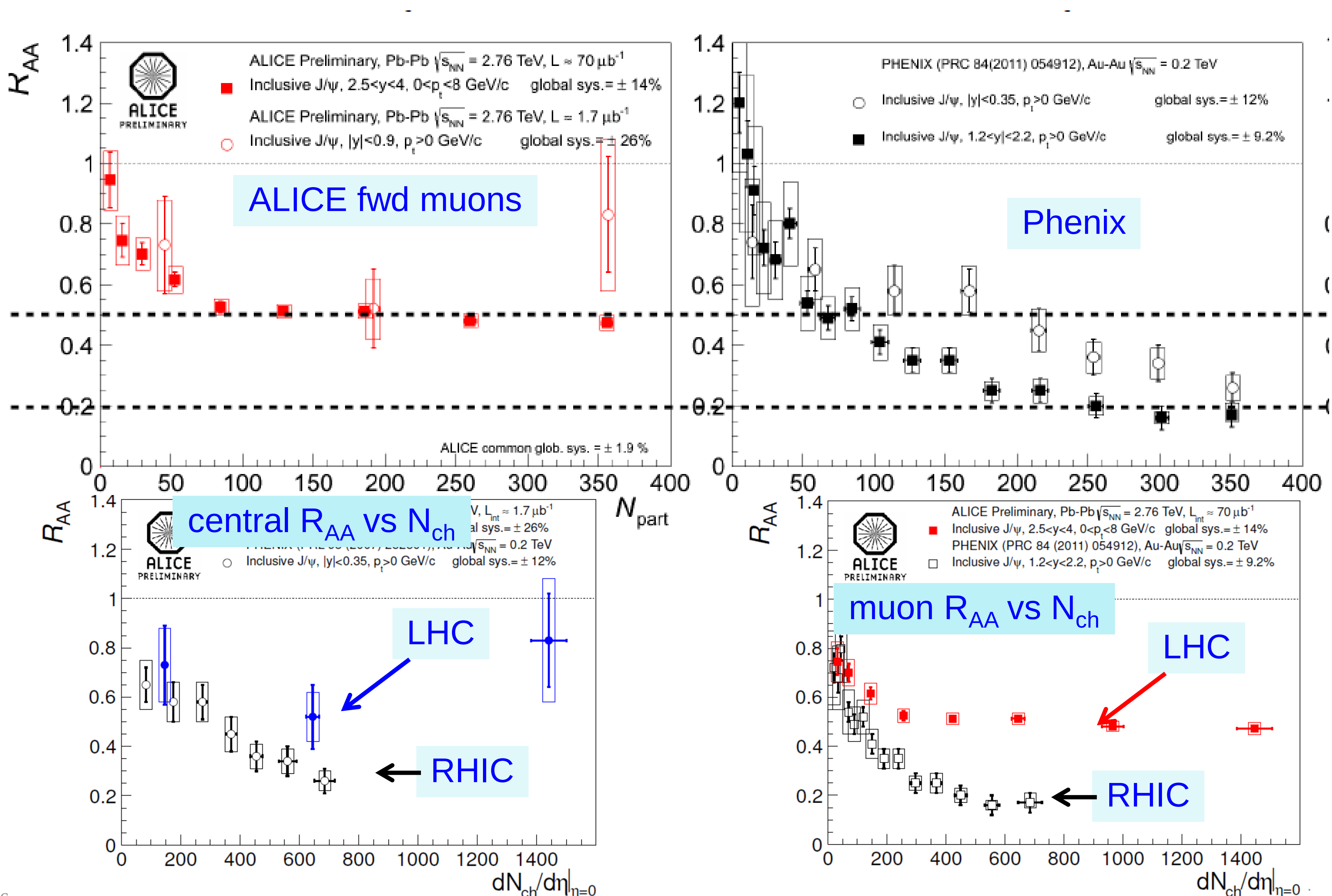




Can we really say its different ?

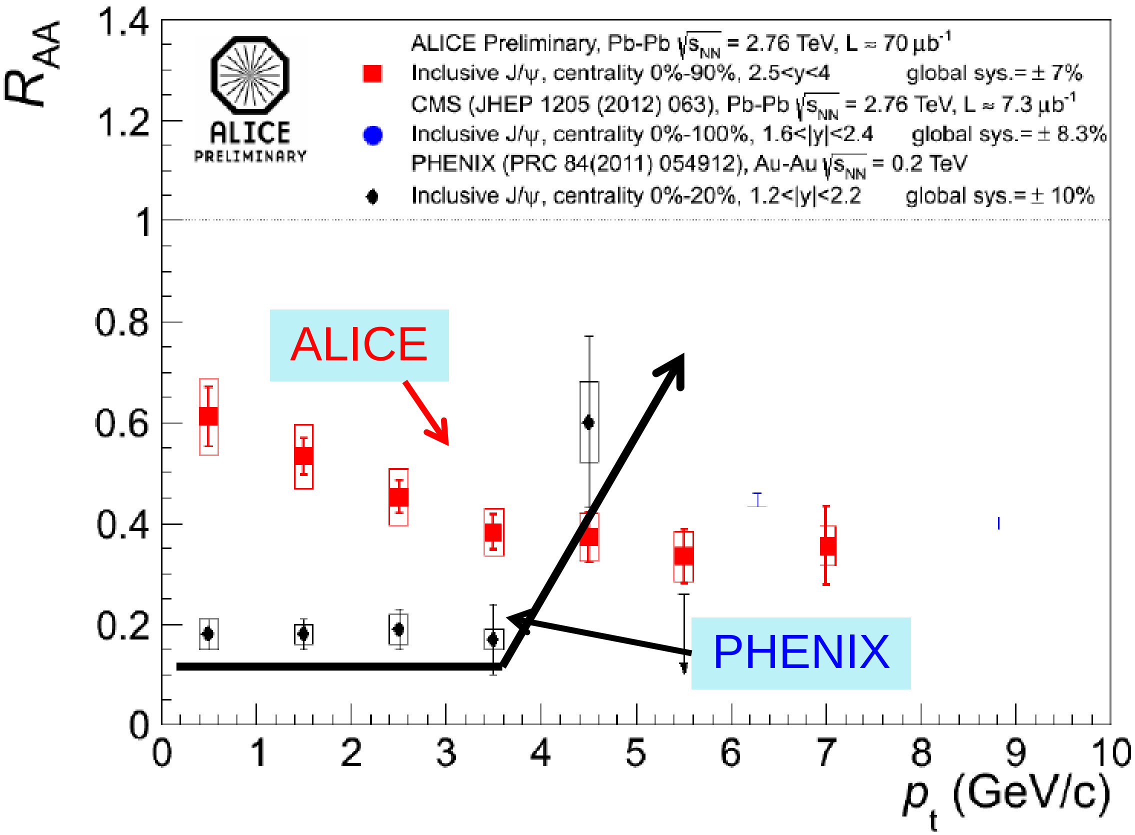


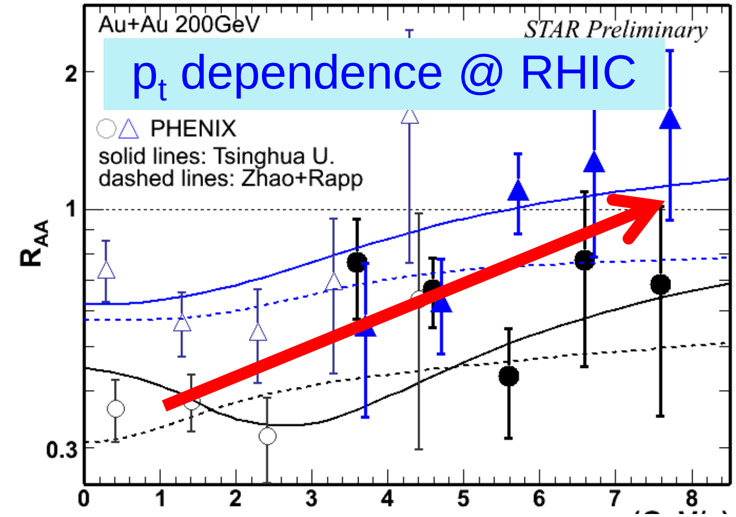
Yes, we can !

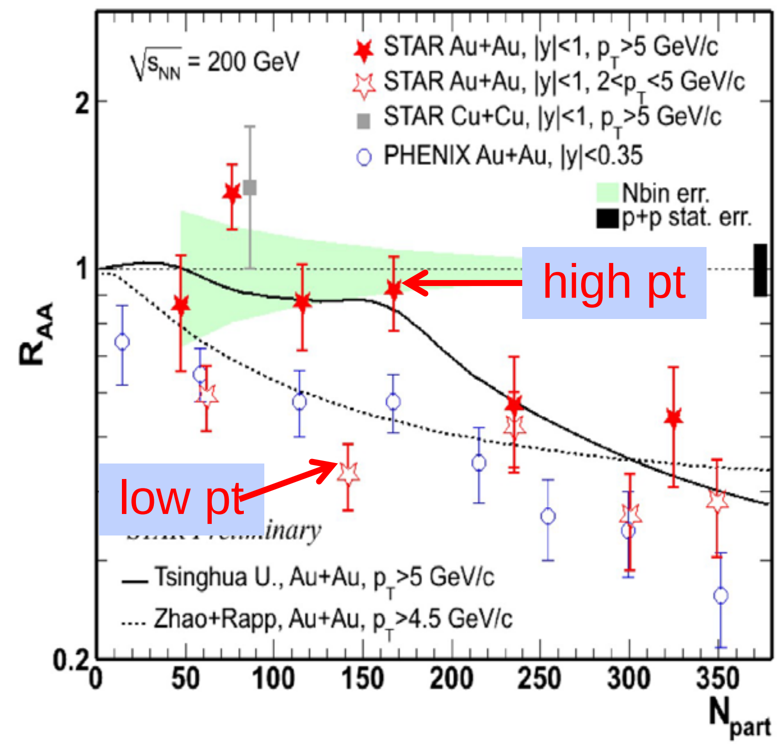


Schukraft

J/Ψ R_{AA}: p_t dependence



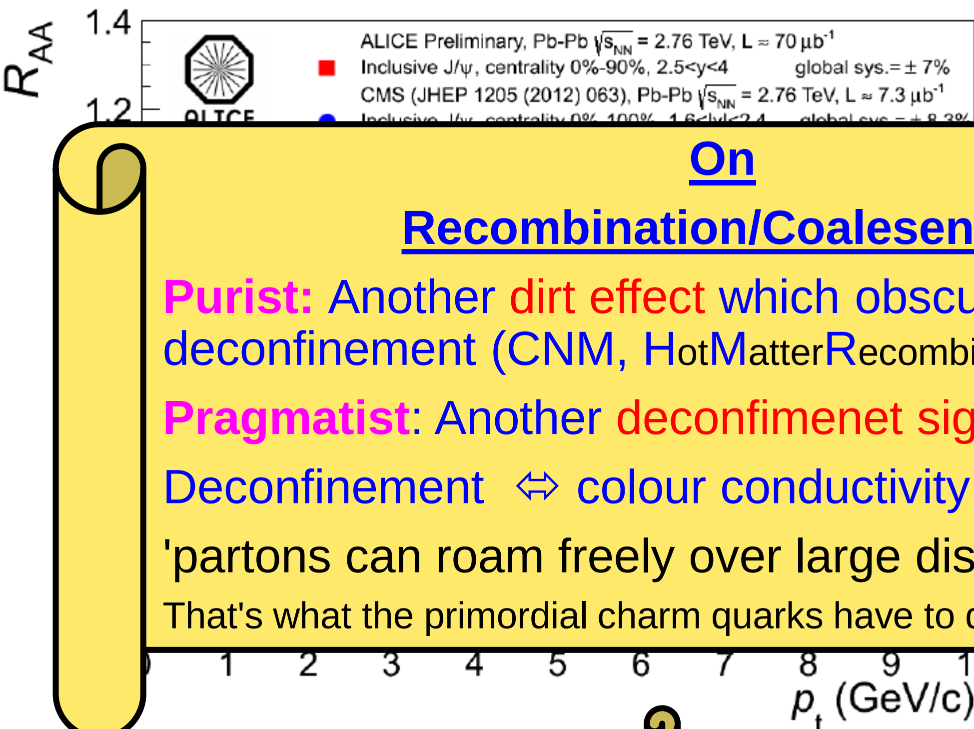


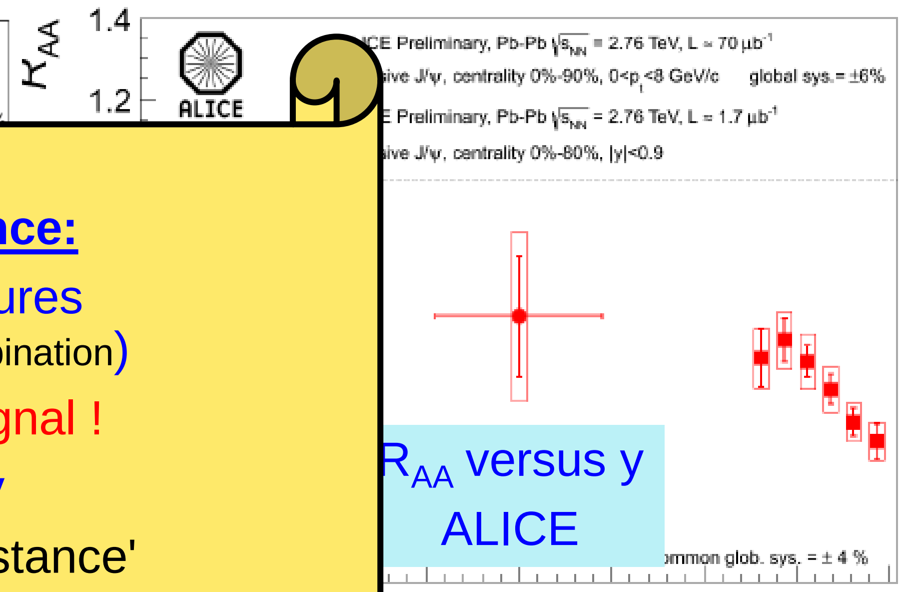


J/Ψ suppression IS different @ LHC

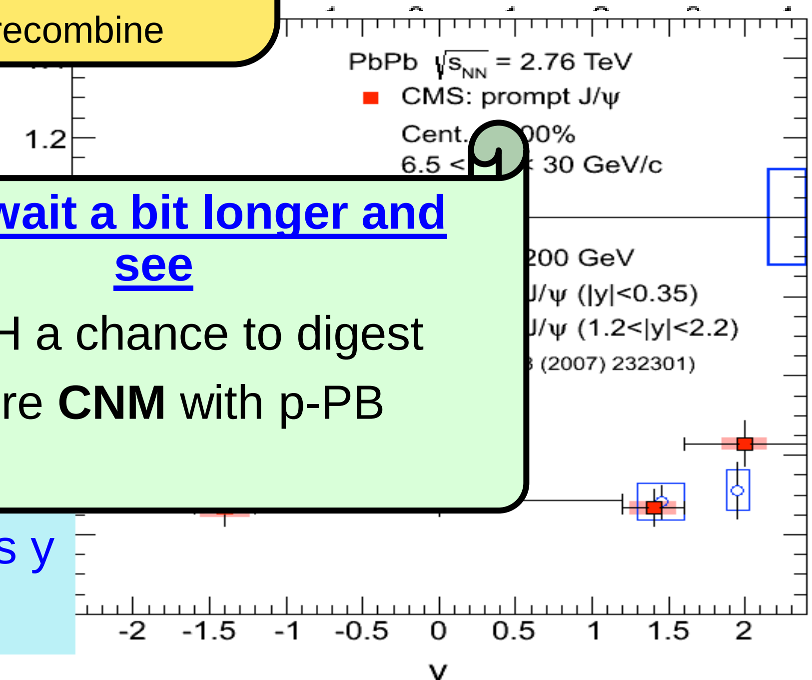
unless CNM plays very dirty, unexpected tricks

CMS-ALICE puzzle solved





R_{AA} versus y ALICE



R_{AA} versus y CMS

On Recombination/Coalesence:

Purist: Another dirt effect which obscures deconfinement (CNM, HotMatterRecombination)

Pragmatist: Another deconfimenet signal !

Deconfinement ⇔ colour conductivity

'partons can roam freely over large distance'

That's what the primordial charm quarks have to do to recombine

Consistent in regions of overlap

the p_t did it, not the y !!

Have we solved the fundamental dispute ?

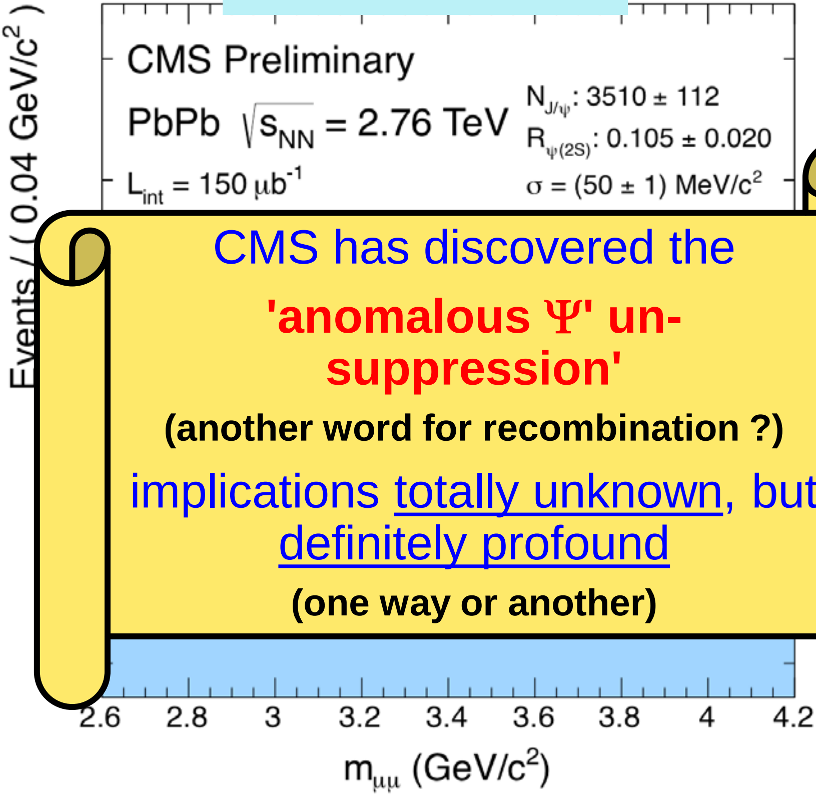
I don't believe in Miracles, but if the alternative is ID..

Let's wait a bit longer and see

- give TH a chance to digest
- measure **CNM** with p-PB
- Ψ'

Weirdo !

J/Ψ & Ψ' in PbPb



CMS has discovered the

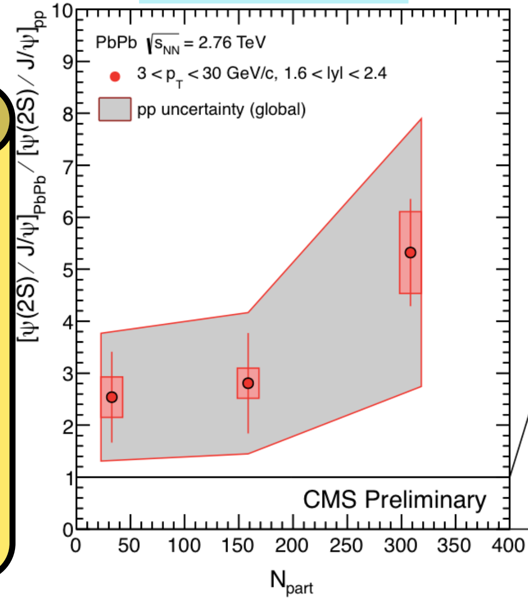
'anomalous Ψ' un-suppression'

(another word for recombination ?)

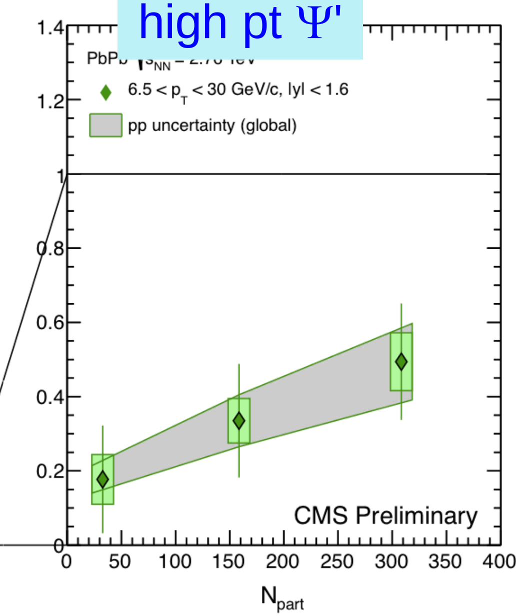
implications <u>totally unknown</u>, but <u>definitely profound</u>

(one way or another)

lower pt Ψ'



high pt Ψ'



- "R_{AA}" ; i.e. double ratio Ψ'/Ψ(Pb) / Ψ'/Ψ(pp)
  - ⇨ high pt: "R_{AA}"< 1 (Ψ' suppression stronger), but (small hindication) **rising with N_{part} ??**
  - ⇨ lower pt: **"R_{AA}" > 1!!!** (Ψ' enhancement), **rising** with N_{part} !!

- use scaled 7 TeV as reference ?

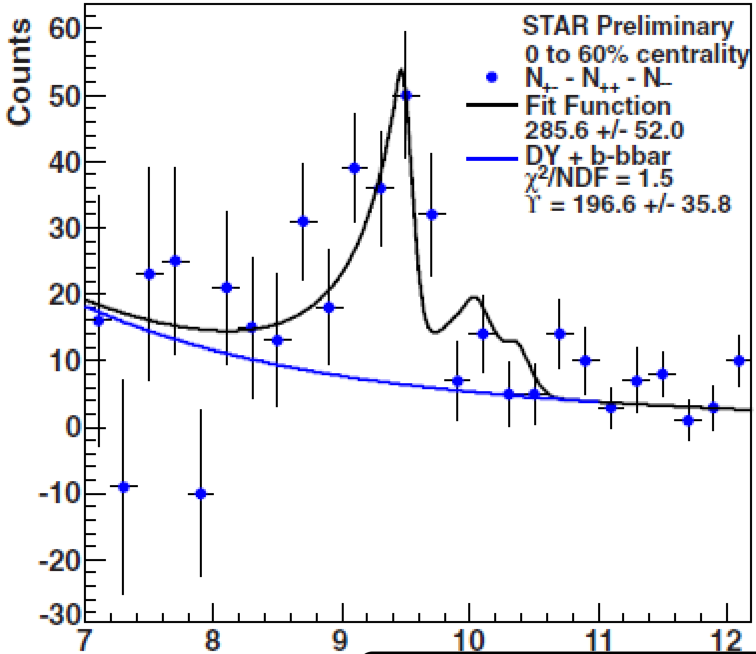
- Alice/Atlas ?

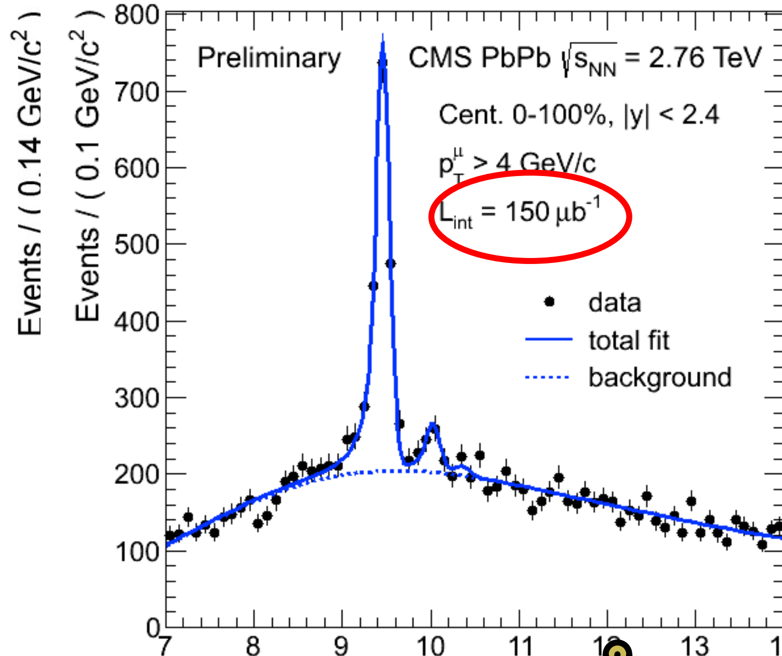
- Christoph, did you check the cables ?

After Opera, the 2nd experiment which proves Einstein wrong !

'***Subtle is the Lord***, but ***malicious*** He is not.'

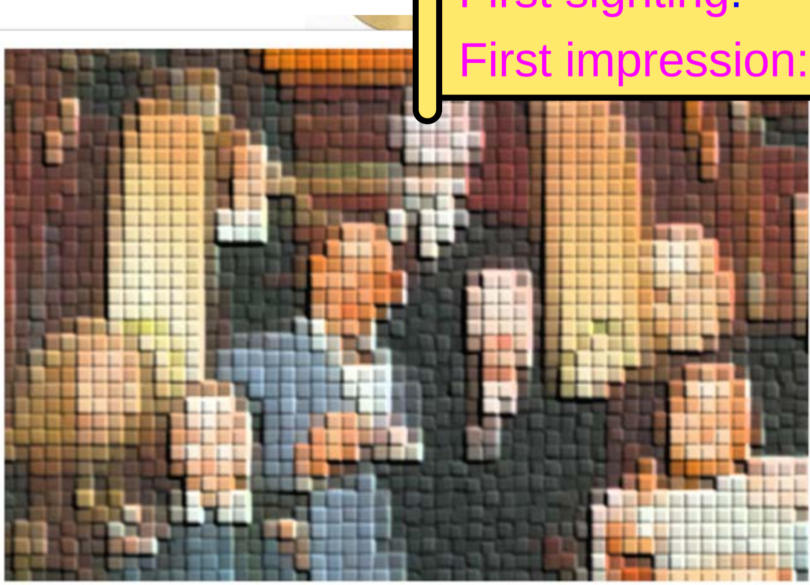
Welcome to the Upsilon Family



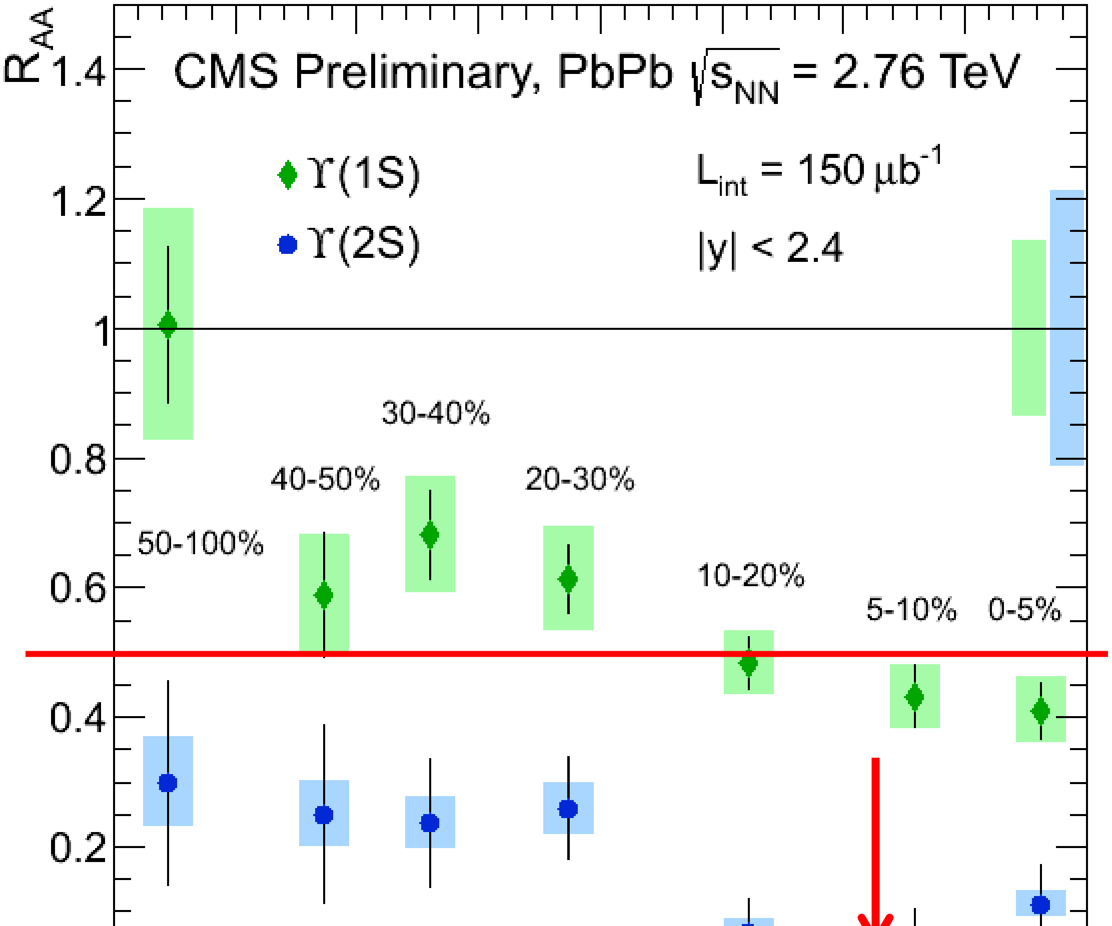


First sighting: QM2012

First impression: ~ equally suppressed at RHIC&LHC



ConSequential Υ suppression

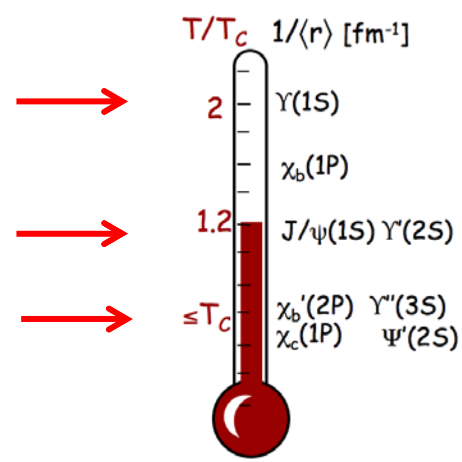


- Υ(1S), ~ 50% direct
  - ⇨ ~ consistent with (complete !) higher state suppression
    - ✪ some hindication for more ?
- Υ(2S) (~ J/Ψ)
  - ⇨ up to 5 x stronger suppression than Υ(1S)
- Υ(3S) gone (thankfully)
  - ⇨ Υ(3S)/Υ(1S) < 0.1 (95%CL)

<u>**Beautiful data. Even seem to make sense !!**</u>

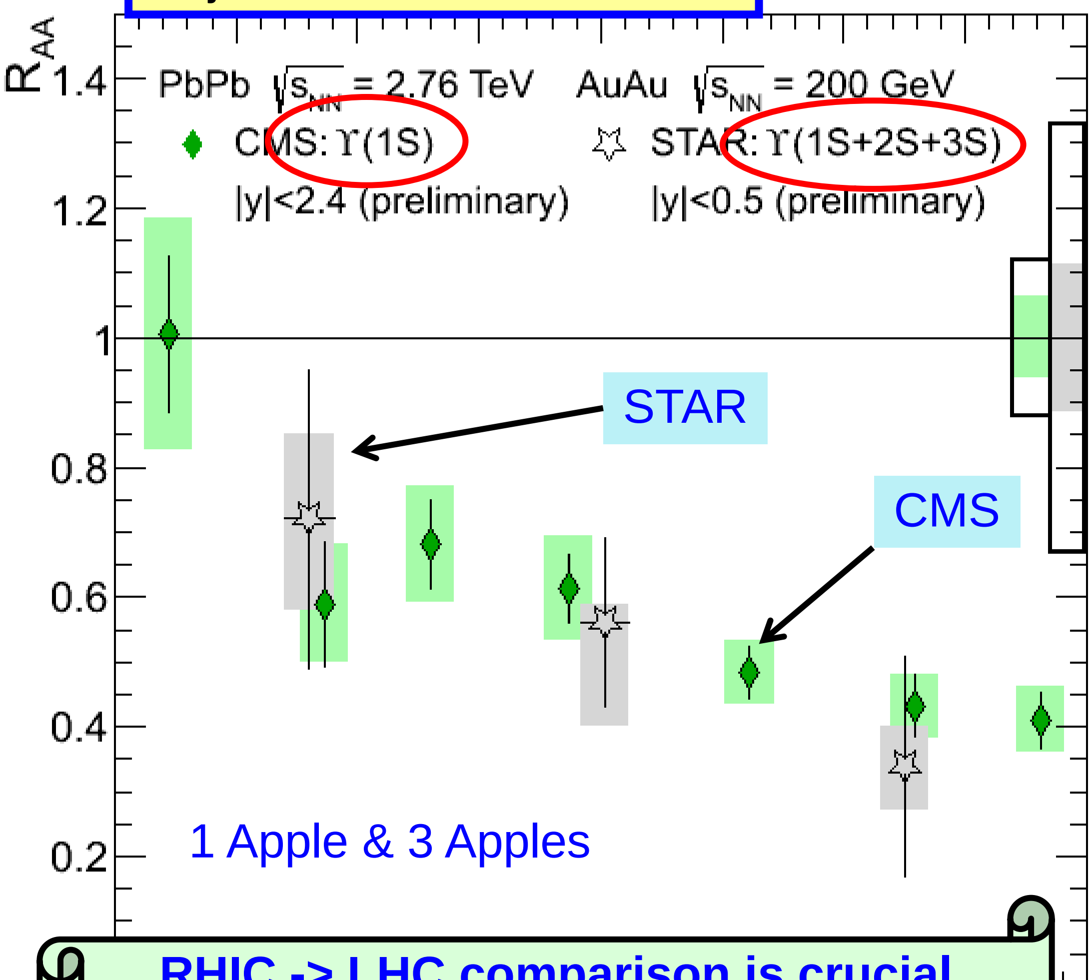
Quote from the Owners Manual:

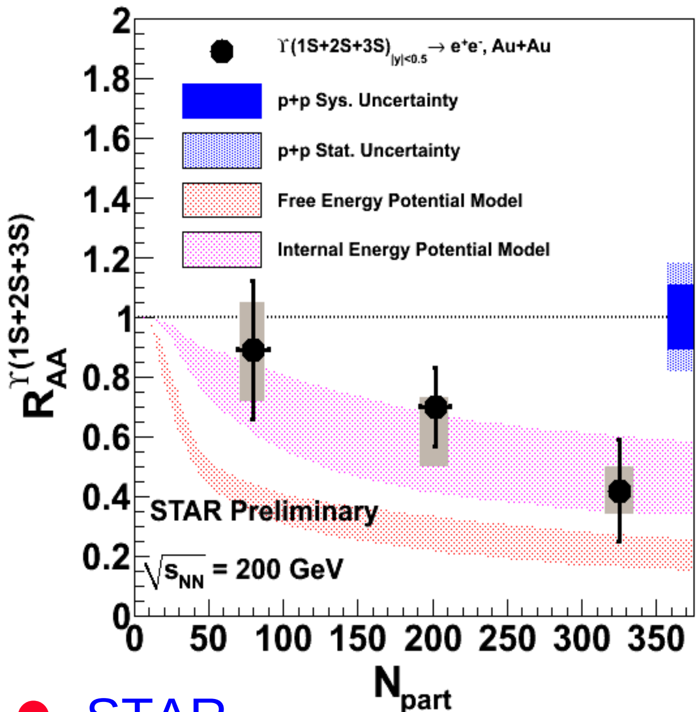
- Raw ratios, with non-uniform pt acceptance
- beware of feed-downs
- **check CNM** (none expected, but…)



Is the First Impression correct ?

Déjà vu ? J/Ψ: RHIC = SPS





- STAR
  - ⇨ $R_{AA}(1+2+3)$ **= 0.56$^{+0.22}_{-0.26}$**
- CMS
  - ⇨ $R_{AA}(1+2+3)$ = **0.32**

RHIC -> LHC comparison is crucial

- we need to raise the temperature

Yet another clear-cut case for
'long live the RHIC'

< 1 σ

Consistent with Hindication

No Title

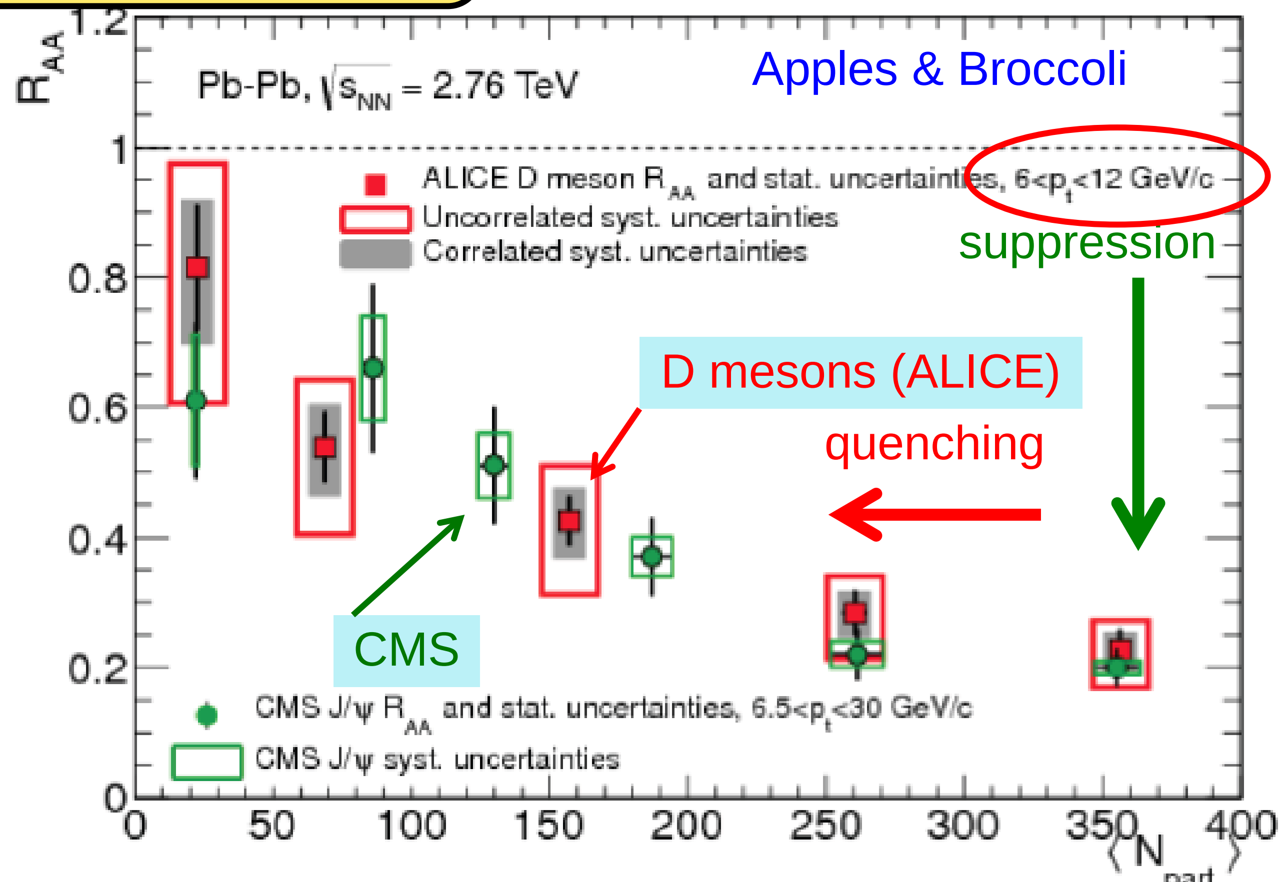
ALICE/CMS: Amazing agreement !

However, they shouldn't !!!!

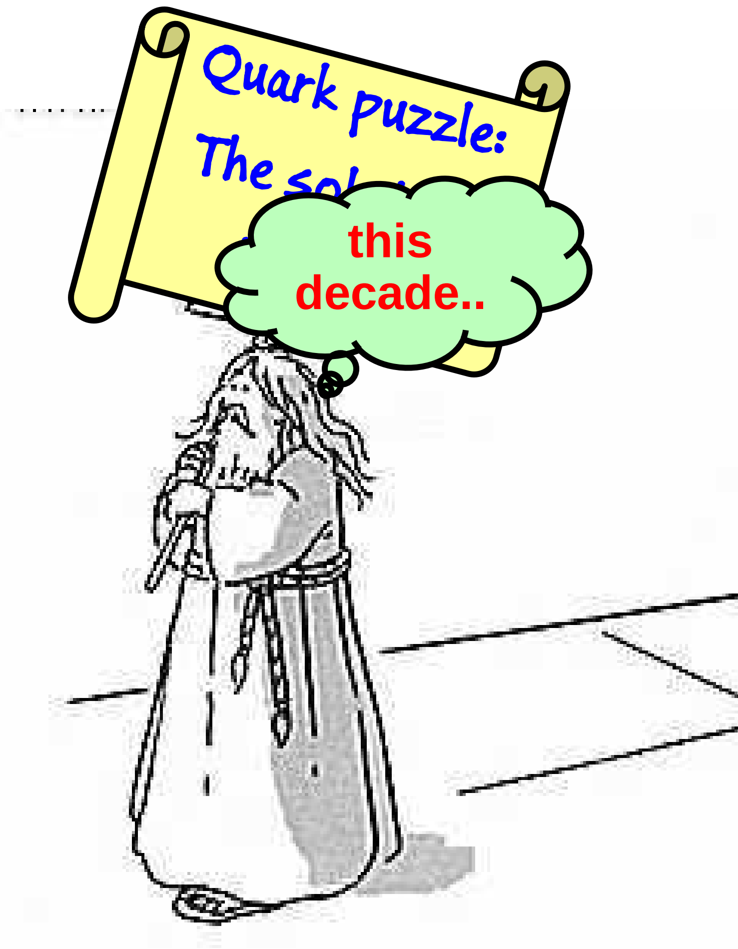
If these would be p_t-integrated, the answer would be clear & unpleasant:

No J/Ψ suppression, no regeneration
(open/hidden charm=constant)

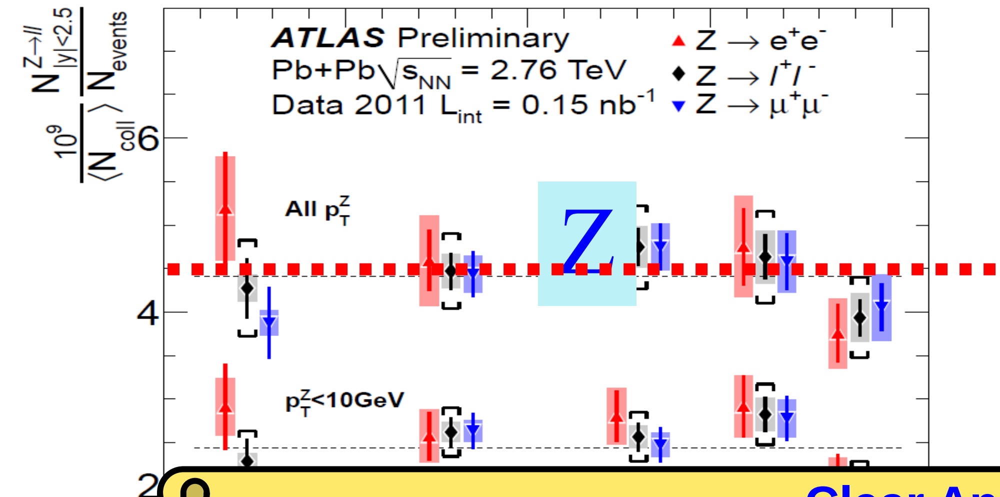
Miracle or ID ?

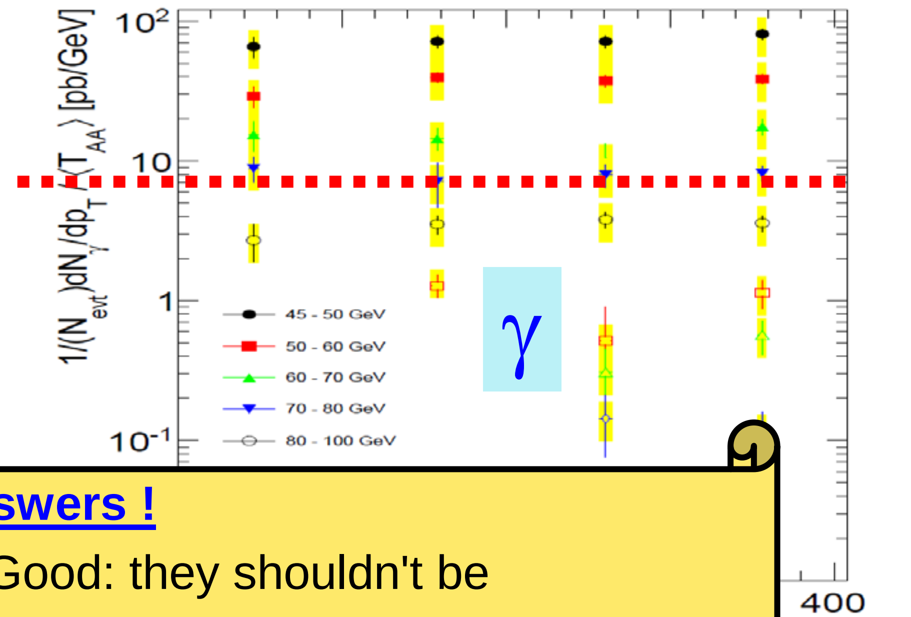


Prophecy..



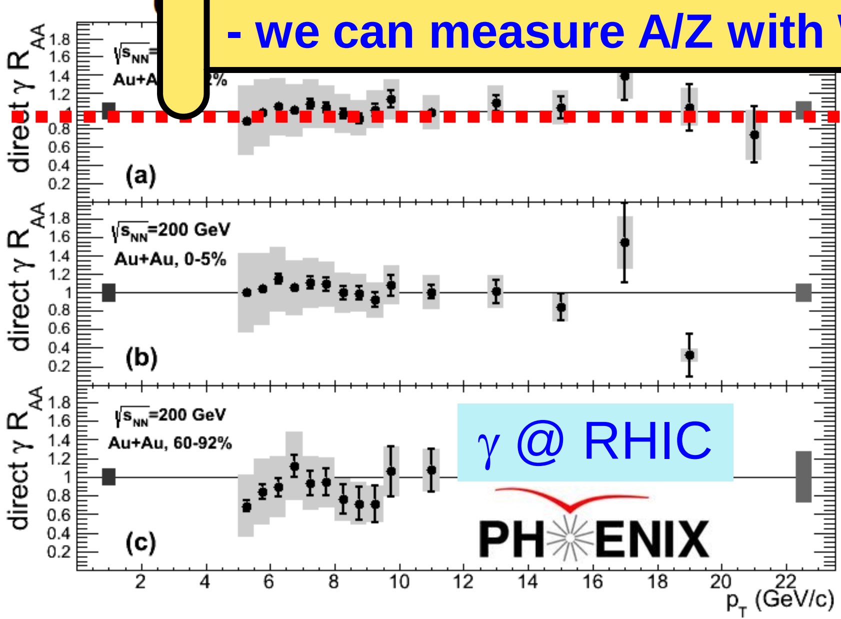
ElectroWeak: Clear Questions

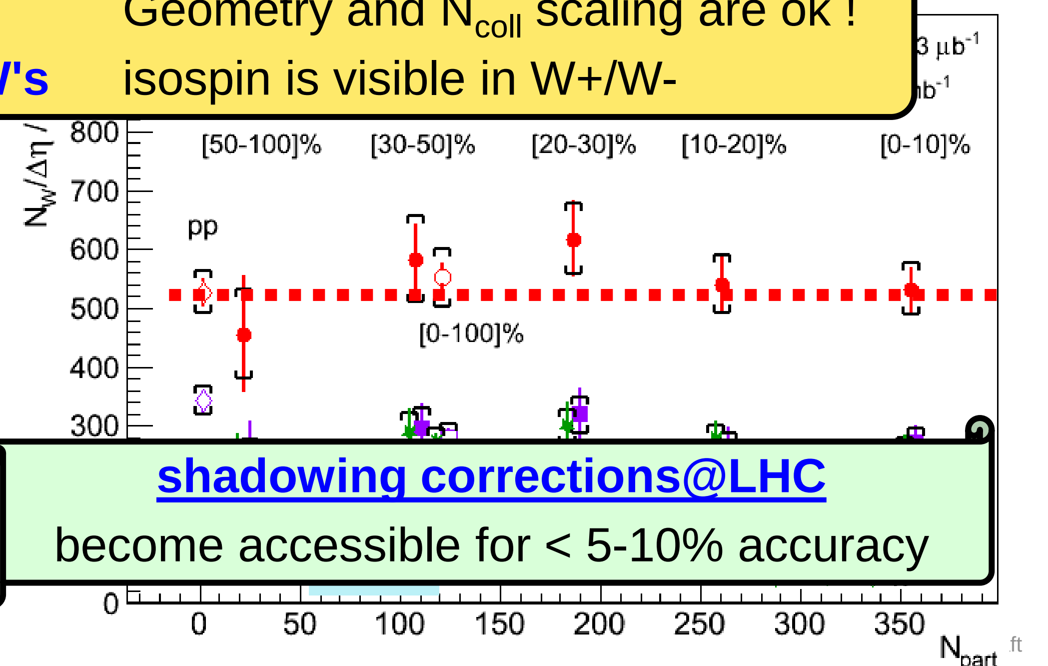




Clear Answers !

- γ, Z, W are NOT modified — Good: they shouldn't be
- we can count up to 400 — Geometry and N_{coll} scaling are ok !
- we can measure A/Z with W's — isospin is visible in W+/W-





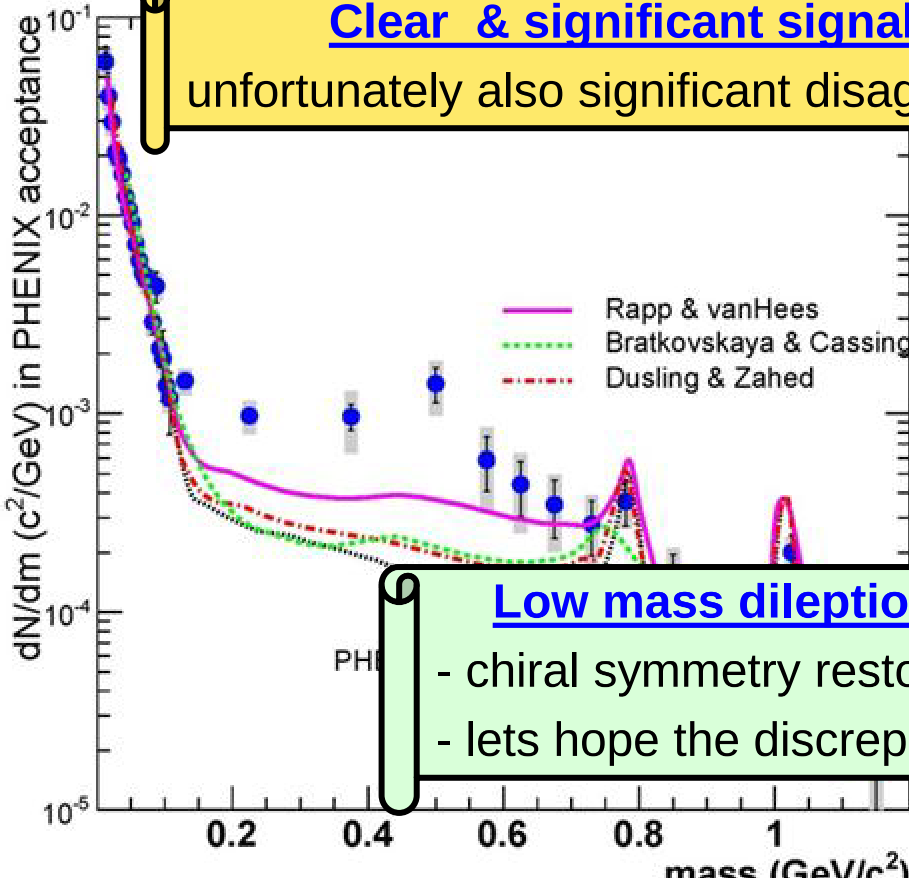
shadowing corrections@LHC

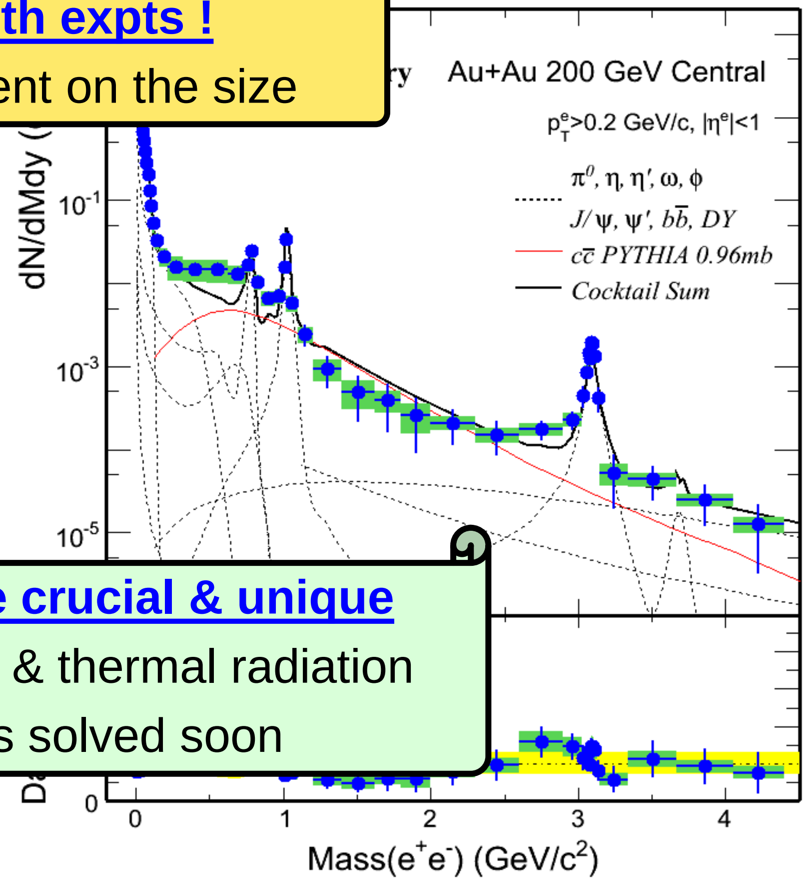
become accessible for < 5-10% accuracy

Thermal Radiation

Clear & significant signal in both expts !

unfortunately also significant disagreement on the size





Low mass dileptions are crucial & unique

- chiral symmetry restoration & thermal radiation
- lets hope the discrepancy is solved soon

PHENIX data on E&M probes seems INCONSISTENT with standard hydro space-time evolution!

And exhibits UNKOWN additional sources!

	Minbias (value ± stat ± sys)	Central (value ± stat ± sys)
STAR	1.53 ± 0.07 ± 0.41 (w/o ρ) 1.40 ± 0.06 ± 0.38 (w/ ρ)	1.72 ± 0.10 ± 0.50 (w/o ρ) 1.54 ± 0.09 ± 0.45 (w/ ρ)

- **HP 2012: (my) Expectations versus Reality**
  - ⇨ Summary talk: lousy ☑
  - ⇨ Italian weather: good ☑
  - ⇨ Italian wine: very good ☑
  - ⇨ Italian cuisine: even better ☑
  - ⇨ HP Organization: Italian ☑
  - ⇨ **HP physics: excellent** ☑

B. Mueller's consolation for the summary speakers: → If all is not well, it's not the end!

Usual Summary Talk Disclaimer

- **don't use any plots** from this talk, they have all been hacked & modified
- any misrepresentation is **MY fault**

(**but YOU didn't explain well enough**)

- I intended to cover **your important result** (**but unfortunately ran out of time**)
- by listening to this talk you agree

to abide by all its terms and conclusions

- if you try to read the fineprint you are wasting your time, it's always unintelligible