Charmonium and Heavy Quarks: status and future perspectives

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Hard Probes 2004
International Conference on
Hard and Electromagnetic Probes
of High Energy Nuclear Collisions

Ericeira, November 4-10 2004

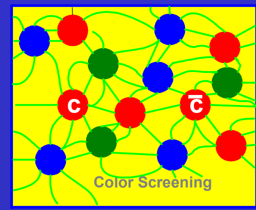
Introduction

- Heavy quarks and quarkonia
  - Probe the medium created in heavy-ion collisions
    (in fact the only hard probe investigated until recent jet studies at RHIC)

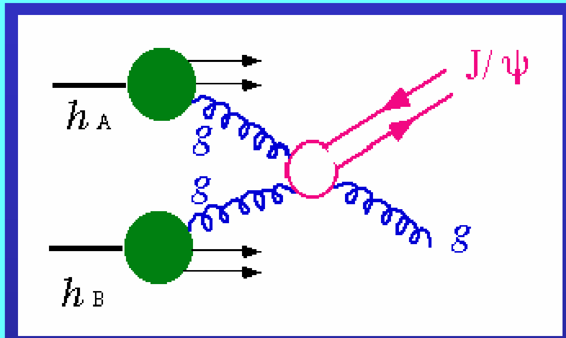
  - Clear physics motivation
    - Quarkonia
      - Sensitive to the confined/deconfined nature of the medium
    - Heavy quarks (c,b)
      - Natural reference for quarkonia studies
      - Energy loss while propagating through dense medium (quenching)

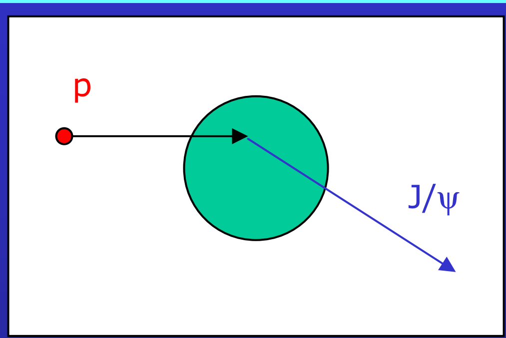
- After (almost) 20 years of investigation (from SPS to RHIC energies)
  - Starting point ? ⇒ Questions
  - Where are we ? ⇒ Answers
  - What is still missing ? ⇒ Perspectives

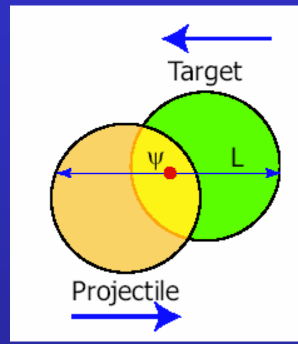
Charmonium - outline



•Can tell us if we have produced a deconfined state in A-A collisions (Matsui & Satz, Phys. Lett. B178(1986)416) but…
several prerequisites are needed







- Production
  - Initial state effects
    - Cronin effect
    - Gluon (anti)shadowing
  - $c\bar{c}$ pair production
    - pQCD
  - Propagation, hadronization
    - CSM,CEM,COM

- Interaction with the COLD nuclear medium

p-p and p-A collisions

- Interaction with the HOT nuclear medium
- Comovers and/or deconfinement

A-A collisions

- What fixed target results have taught us ?
- What is RHIC teaching us ?

Charmonium production: nuclear collisions at fixed target

- The question to be answered by studying charmonium in heavy-ion
- collisions at the SPS (talks by **L. Kluberg**, **G. Borges, R. Arnaldi**):

Is (at least part of the) suppression of charmonia that we observe in the data **NOT** due to usual hadronic processes ?

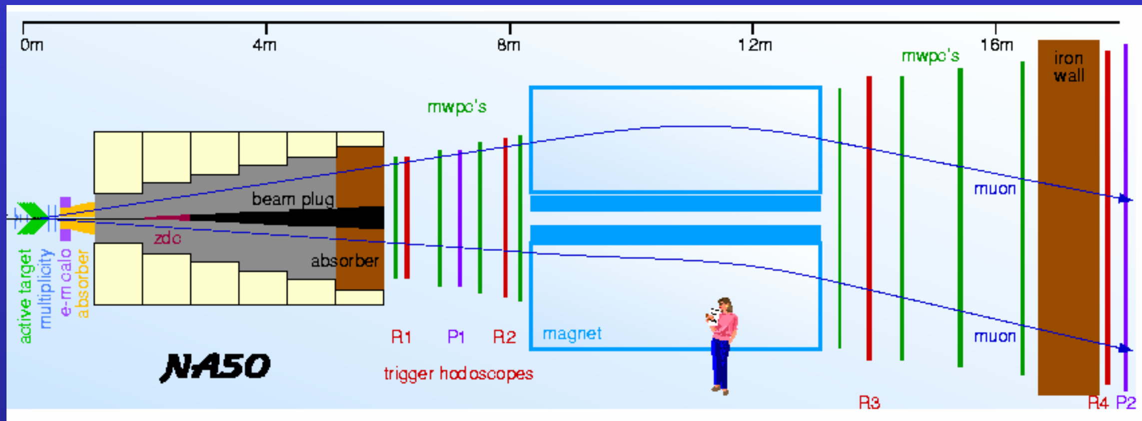
- Study carried out by NA38/NA50/NA60 at the SPS from 1986 until today
- Basic facts
  - Essentially the same experiment, although with very significant upgrades
  - Large set of results with very good statistics
  - (Lots of) systems studied, including:
    - p-p, p-d, p-Be, p-C, p-Al, p-Cu, p-Ag, p-W, p-Pb, p-U, O-Cu, O-U, S-U, In-In, Pb-Pb
  - Similar (but not identical) energy/kinematical domain between various data sets

- Very significant contributions (in a slightly higher energy range) by:
  - E866 (talk by **M. Leitch**)
  - HERA-B (talk by **A. Zoccoli**)

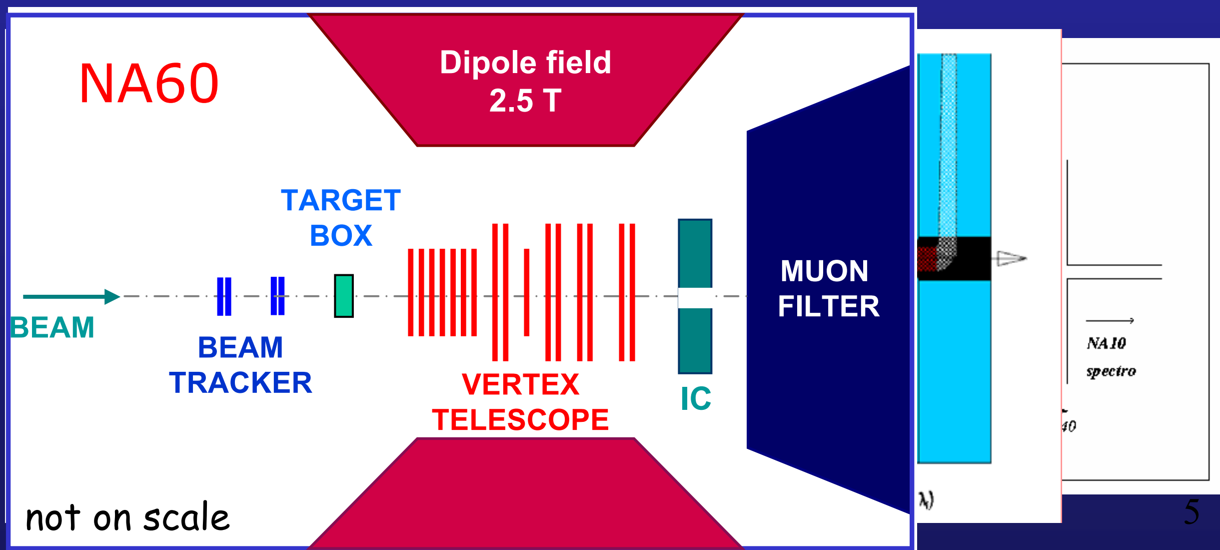
The NA38/NA50/NA60 experiments

Based on the same muon spectrometer (inherited by NA10)

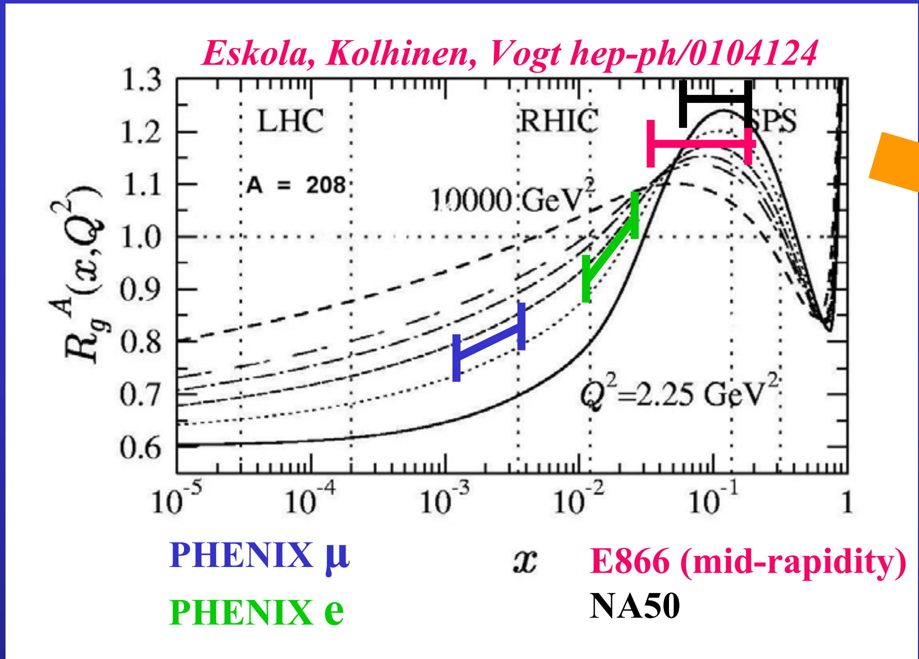
➔ no apparatus-dependent systematics

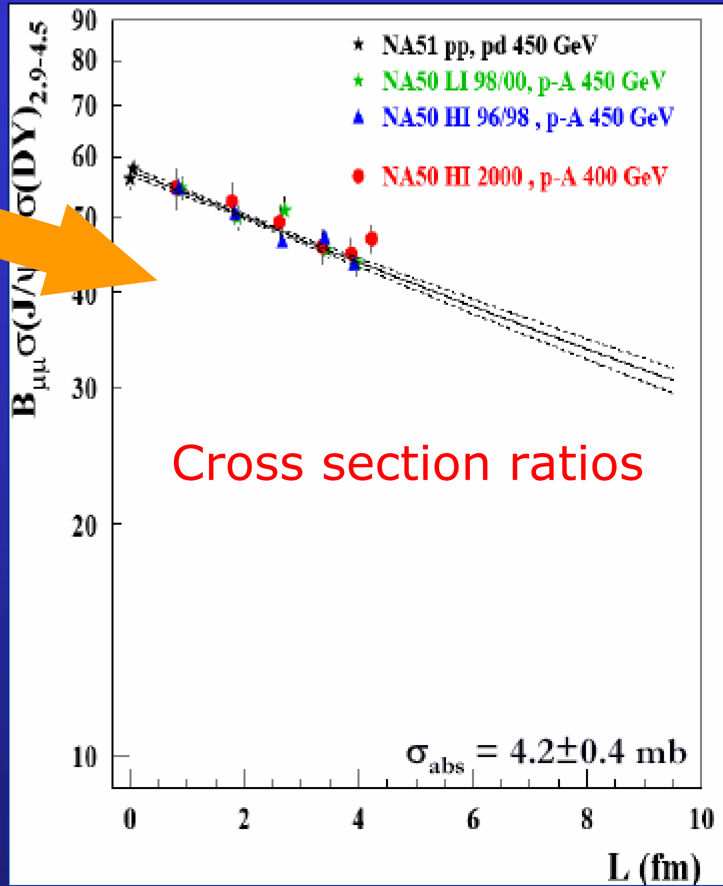


Many updates in the target region, in parallel with the availability of radiation hard detectors



SPS energy: p-p and p-A collisions





- Calculation of σ_{abs} using the Glauber model
- Several data sets (collected in ~10 years)
- Results on
  - Absolute cross section
  - Cross section ratios (J/ψ/DY)
- σ_{abs} determination looks robust

Older, higher values due to relative bias between NA51 and NA38: now corrected

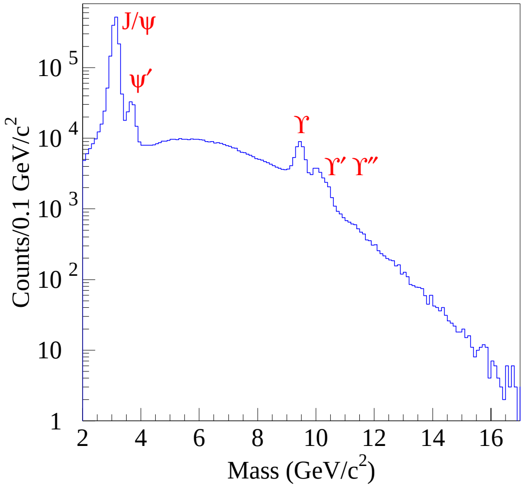
Set	P_{lab}	N_0 (nb)	σ_{abs} (mb)
NA50	450 GeV	5.6±0.1	4.1±0.4
NA50	400 GeV	5.1±0.1	
NA38 (corrected)	400 GeV	5.5±0.2	

What is $\sigma_{abs}^{J/\psi}$?

- p-A data allows us to estimate $\sigma_{abs}^{J/\psi}$
- What really is $\sigma_{abs}^{J/\psi}$?
  - Effective quantity
  - What is crossing the nucleus? $\rightarrow$ Mainly theoretical problem
    - pre-resonant $c\bar{c}$ state, fully formed resonance
  - Are we measuring primary J/ψ? $\rightarrow$ Mainly experimental problem
    - feed-down from ψ' and χ_c

- If $\sigma_{abs}^{J/\psi} \neq \sigma_{abs}^{\psi'} \neq \sigma_{abs}^{\chi}$
  - Can we use $\sigma_{abs}^{J/\psi,eff}$ obtained in p-A collisions as a baseline for nuclear absorption in A-A collisions ?
  - Could be partly biased, since the fraction of measured J/ψ coming from higher-lying resonances can vary between p-A and A-A, due to different suppression mechanisms in the two systems
  - Can this effect be quantitatively important ?

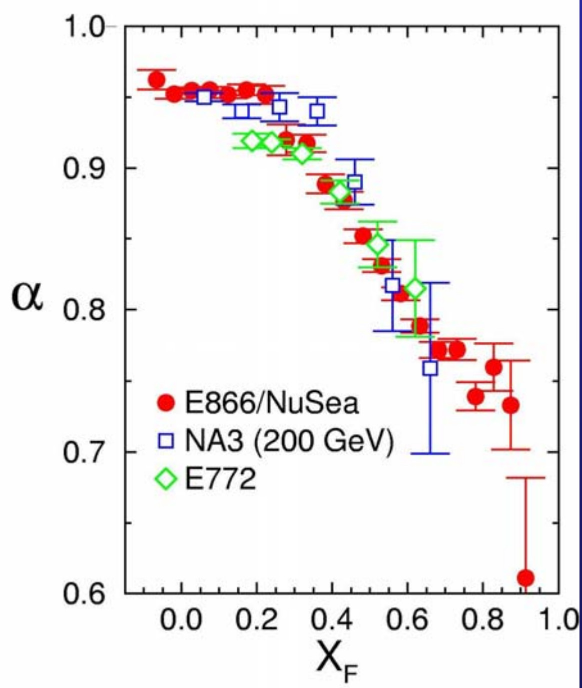
E866: charmonia nuclear absorption vs x_F



- Which data are available today to understand the situation?
  - E866 at FNAL (high statistics)
    - Study the variation of the absorption cross section (parameterized through $\sigma=\sigma_0 \cdot A^{\alpha}$) as a function of the kinematical variables x_F, p_T

- $x_F \sim 0$
  - (part of) the J/ψ hadronize
- $x_F > 0$
  - the nucleus sees a fast $c\bar{c}$ pair

- Theoretical description is notoriously difficult
- Non-trivial combination of several effects



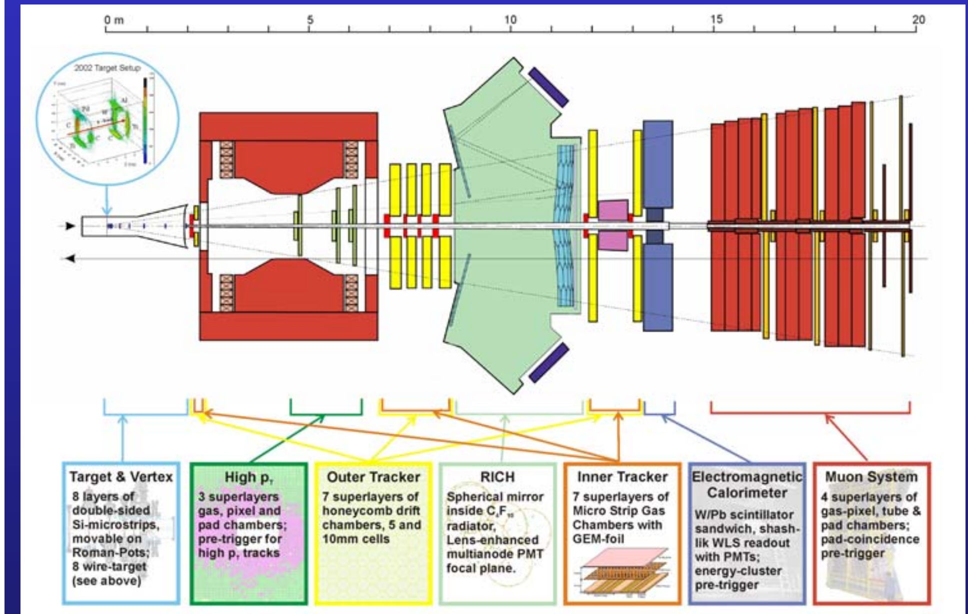
- Disagreement with NA50?
  - α_{NA50} = 0.933 ± 0.007
  - α_{E866} = 0.954 ± 0.003
- Does α depend on energy ?

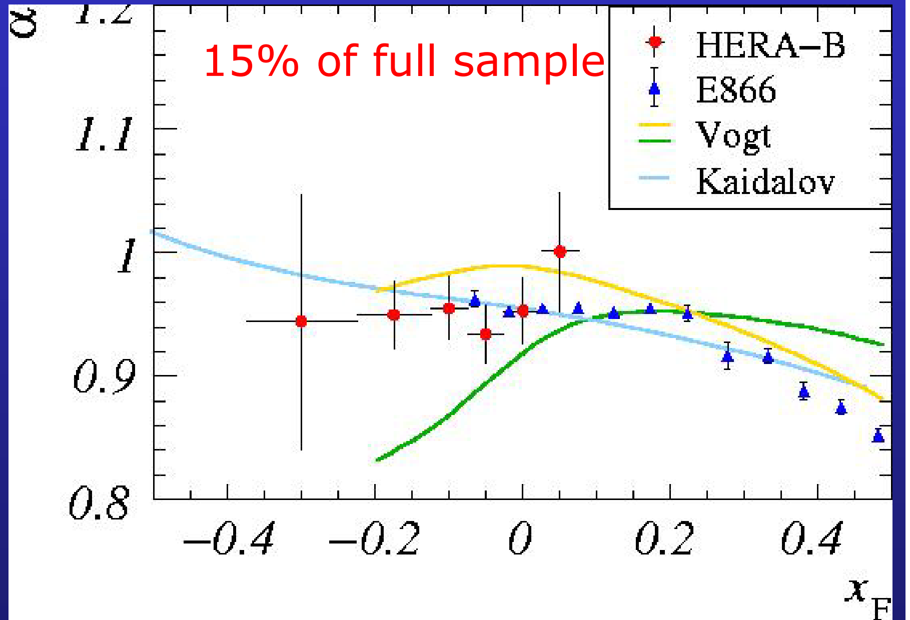
Agreement with NA3 not conclusive
p-p data used in α parameterization

What about negative x_F ?

- Region where the fully-formed resonance should interact with the nuclear medium

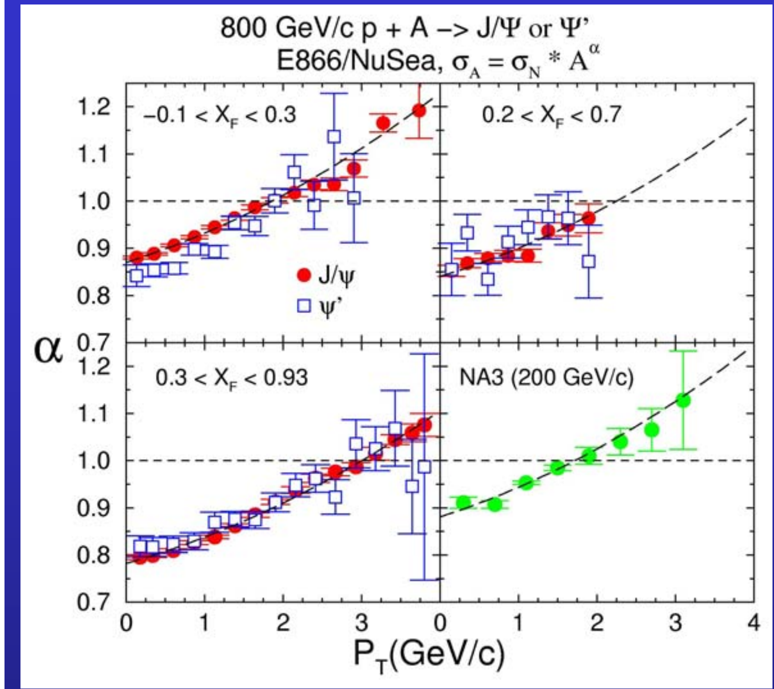
→ First recent measurements by HERA-B





- Can this result be used to sharpen our picture of the formation times of charmonium states ? What does it teach us ?
   - Would it be possible to measure α at negative x_F for the other states?

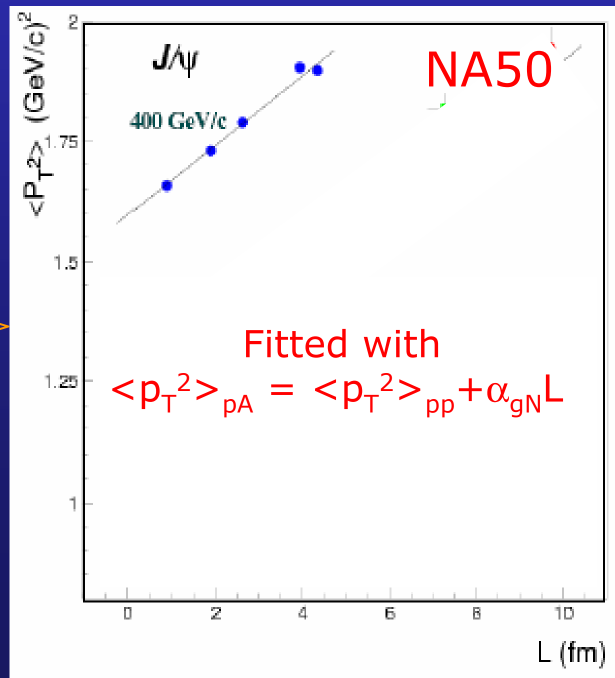
E866: charmonia nuclear absorption vs p_T



- Increase of α with p_T commonly understood as parton scattering in the initial state (E866 data)

- Effect visible in various ways
- Increase of $\langle p_T^2 \rangle$ vs A
- Linear increase vs L

α_{gN} : weak or no beam energy dependence
$\langle p_T^2 \rangle_{pp}$ depends on beam energy

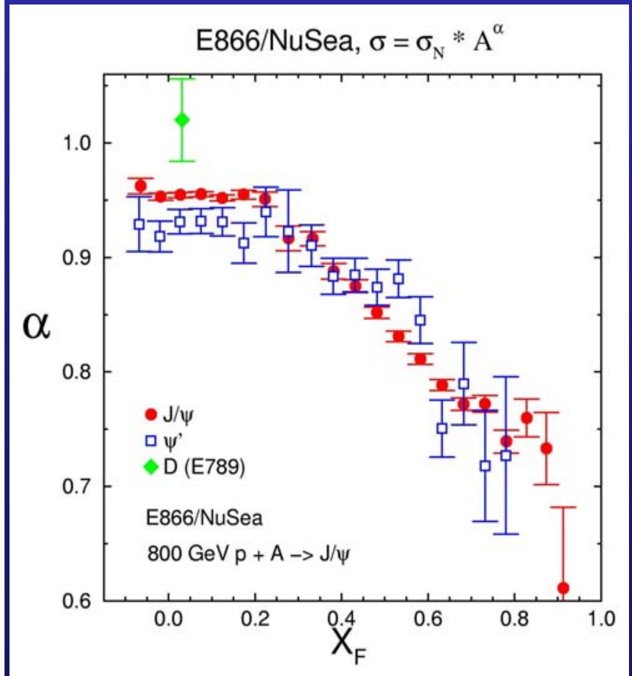


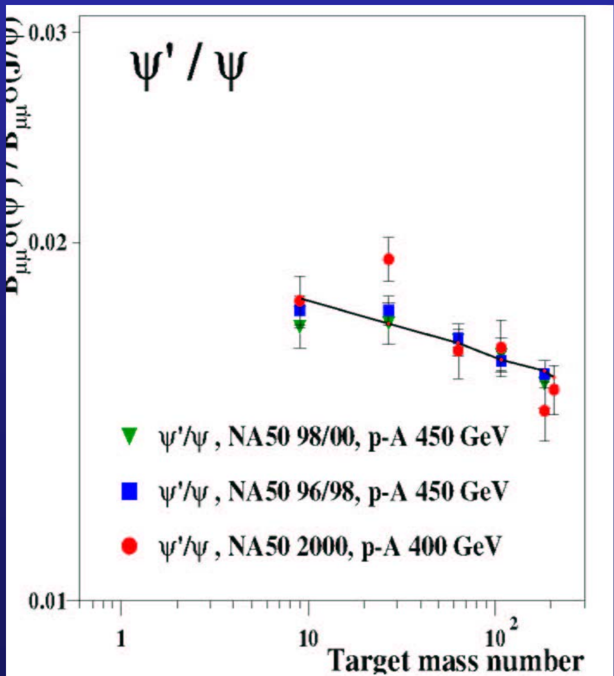
- HERA-B (920 GeV)
  $\langle p_T \rangle$ =1.29 GeV/c (p-W)
- NA50 (450 GeV)
  $\langle p_T \rangle$ =1.21 GeV/c (p-W)

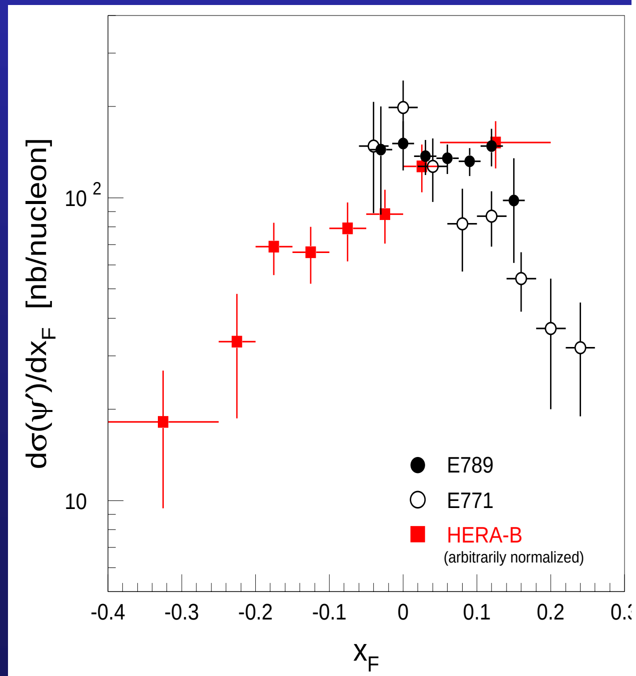
Other charmonium states: ψ'

- Important for the feed-down problem ($\psi'/J/\psi \sim 0.14$)
- Different absorption cross sections might lead to wrong extrapolations from p-A to A-A $\rightarrow$ potential problem
- ψ' more loosely bound $\rightarrow$ should be much more suppressed than J/ψ
- Studied in detail by E866, NA50 and, more recently, by HERA-B
- Around $x_F = 0$, $\sigma^{abs}_{J/\psi} \neq \sigma^{abs}_{\psi'}$ (partial hadronization ?)
- $\sigma^{abs}_{\psi'} = (7.9 \pm 0.6)$ mb (NA50) to be compared with $\sigma^{abs,eff}_{J/\psi} = (4.1 \pm 0.4)$ mb
- $\alpha_{\psi'} = 0.858 \pm 0.017 \pm 0.008$ (NA50) $\rightarrow$ significantly smaller than E866 value (~0.92)

$\rightarrow$ energy dependence ?

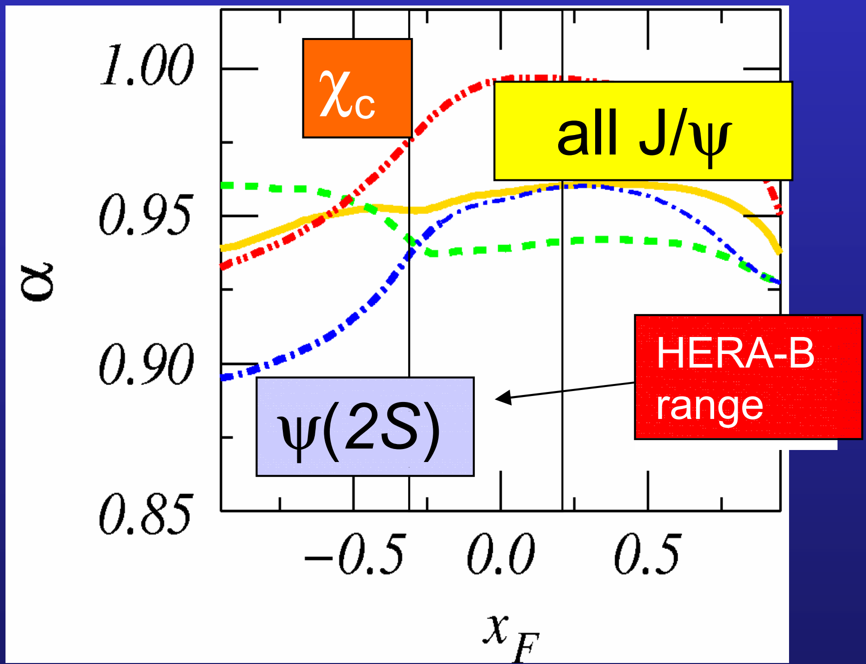






Other quarkonium states: χ_c

- Contribute very significantly to the observed J/ψ yield
- Experimentally accessible (not easy) through radiative decay $\chi_c \rightarrow J/\psi\ \gamma$
- First recent results from HERA-B



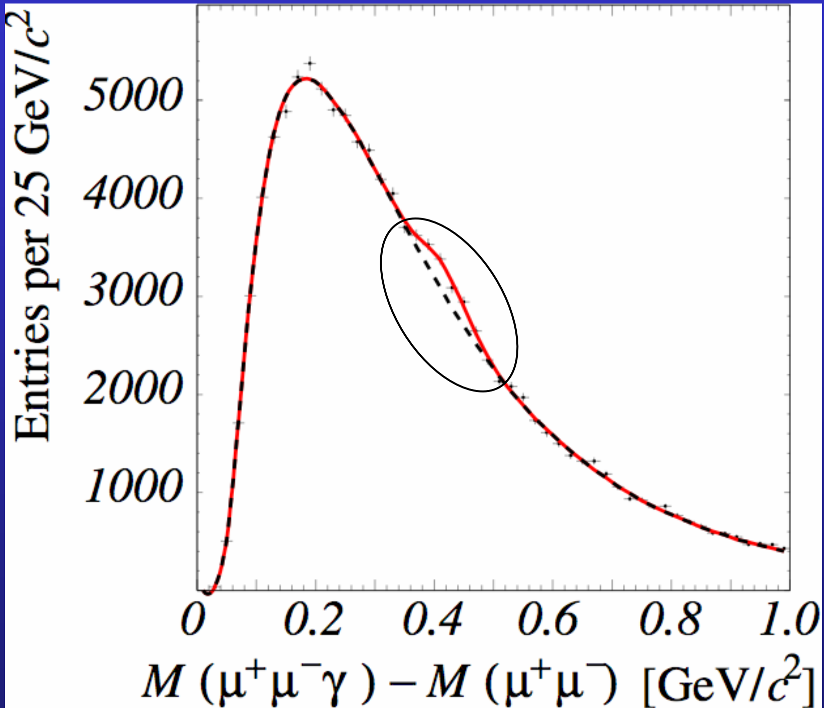
R. Vogt, Nucl. Phys. A700 (2002) 539

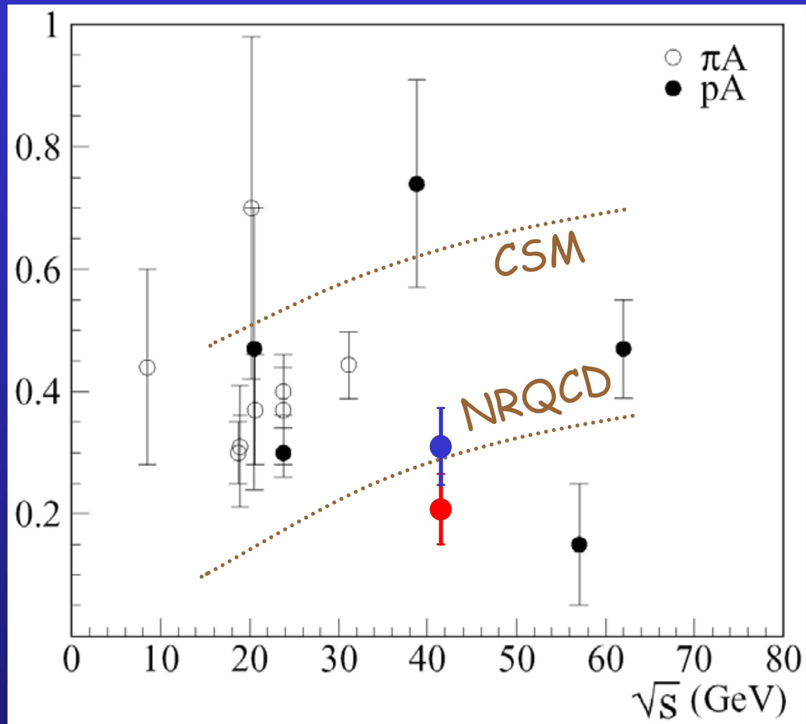
χ_c predominantly produced in a color singlet state

Expected to be sensibly less suppressed than the J/ψ

First χ_c measurements at HERA-B

- Result of 2000 (Phys.Lett. B561(2003) 61)
  - $N(\chi_c)$ = 370±74 (both $\mu^+\mu^-$, e^+e^-) → $R(\chi_c)$ = 0.32±0.06±0.04





- Preliminary result from 2002/2003 data→ $R(\chi_c)$ = 0.21±0.05 (stat.) (15% of $\mu\mu$ sample ≈ 1300 χ_c)
- Agreement with NRQCD at HERA-B energy
- What about lower energy ? Wait for results from NA60 2004 pA run

J/ψ absorption in cold nuclear matter: where are we ?

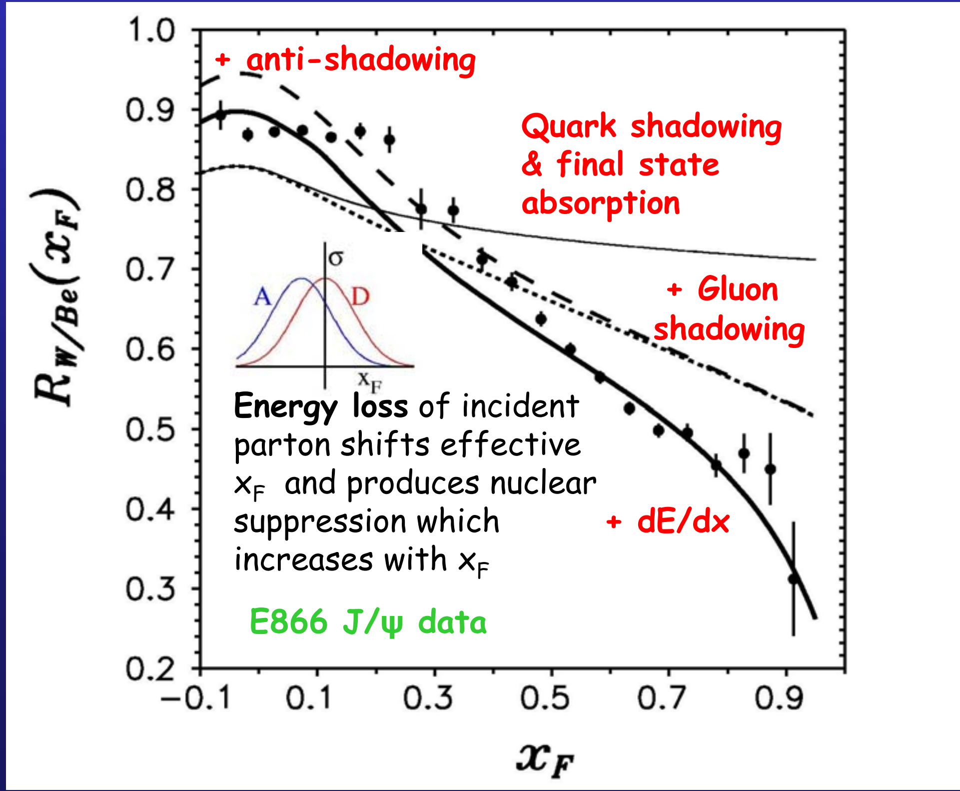
- Accurate p-A data exist, at least for J/ψ
  - 400/450 GeV, in a restricted x_F domain
  - 800 GeV, wide x_F domain
  - 920 GeV data, x_F>-0.3, final results expected soon
  - Reference for J/ψ suppression in A-A collisions established

- Theoretical description is not straightforward
- Several effects to be combined
  - Nuclear PDFs
  - Energy loss in the initial state
  - Nuclear absorption
  - Energy loss in the final state
  - Intrinsic charm

- Difficult to deduce basic input values by fitting the data

(Arleo et al.,PRC61(2000)054906 found $\tau_{8\rightarrow1}$=0.021 fm/c !)

Kopeliovich et al., NPA696(2001) 669



J/ψ absorption in cold nuclear matter: where are we ? (2)

- Feed-down is an important issue
  - ψ' knowledge is fairly good (may be improved)
  - χ_c knowledge is quite poor
    - Data on A-dependence to appear soon by HERA-B
    - To be followed by NA60 at 400 GeV

- For the next future
  - Complete x_F, p_T dependence of charmonia production in p-A exists only at one incident energy (E866)
  - Comparison NA50/E866 suggests a possible energy dependence of the various nuclear effects
  - At least another set of data at different energy would be useful

J/ψ absorption in hot nuclear matter

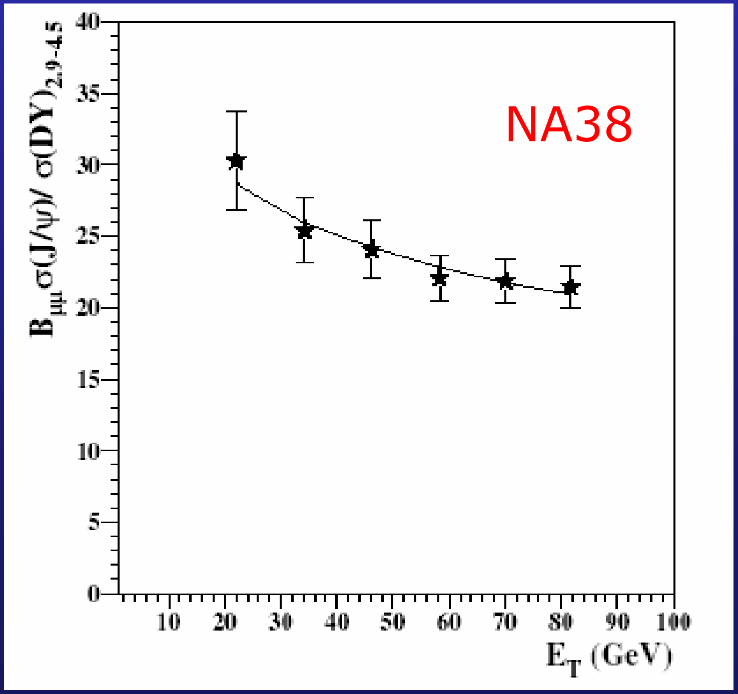
- The question:
  - Are there any "hadronic" J/ψ suppression sources in A-A (apart from nuclear absorption) ?
  - Can hadronic comovers break up the J/ψ ?

- Should be understood before claiming an anomalous suppression
- Issue very much debated by theory → no final word up to now

- Absorption by comovers: no threshold
- Already present in light ion collisions (even if the effect might be small because of the lower comover density)
- Is σ_{abs} increasing from pA to SU (NA38)?

- $\sigma_{abs}^{J/\psi,SU}$ = (7.2 ± 3.2) mb

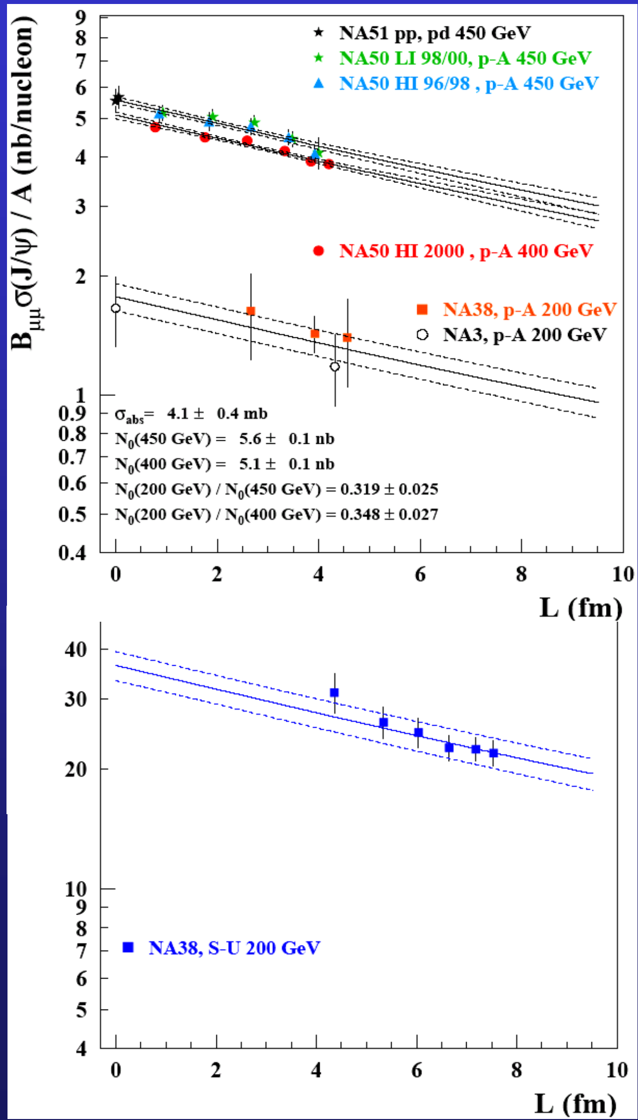
To decrease the error a very large statistics would be needed
(short lever arm of the Glauber fit)



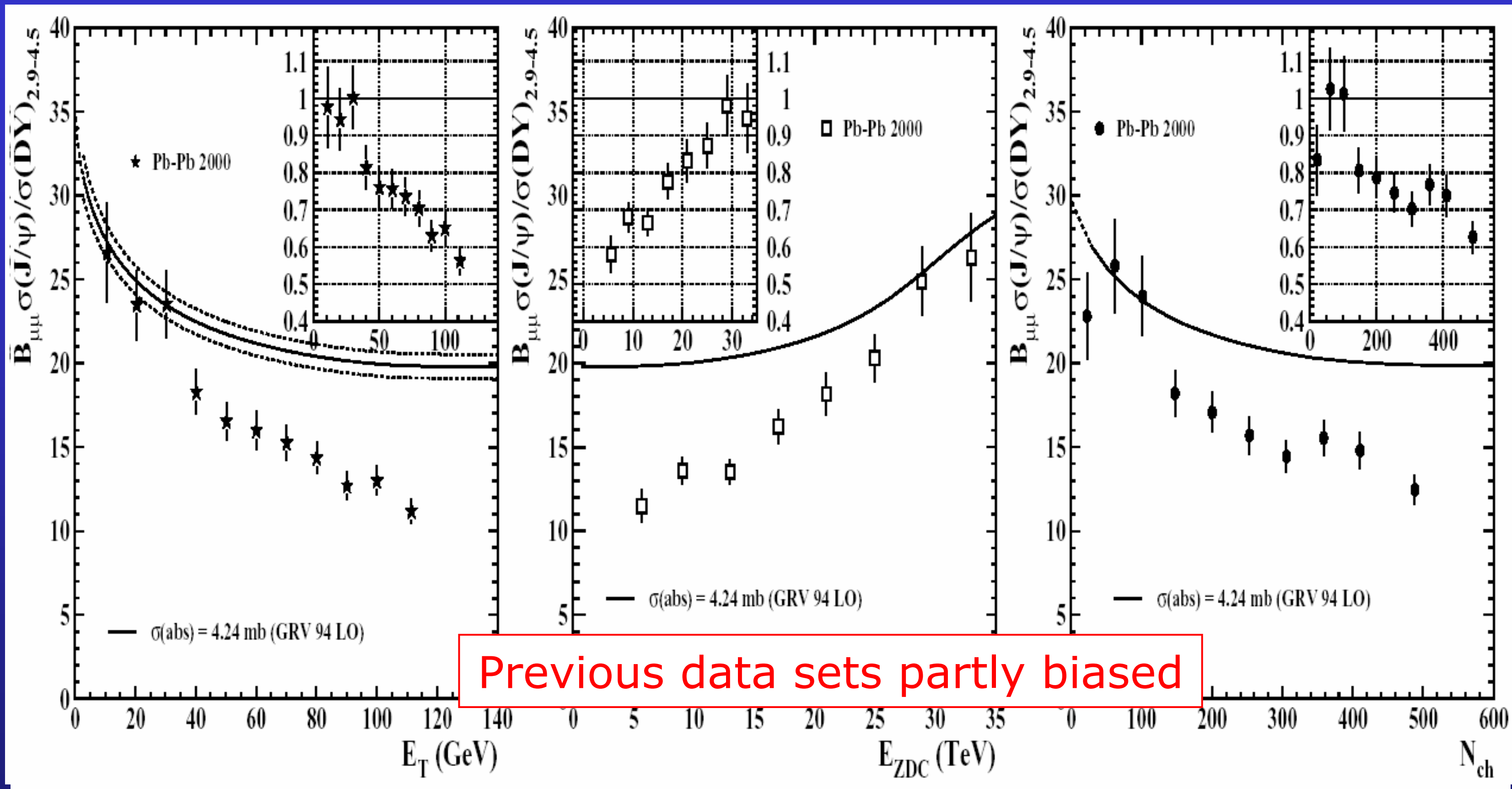
J/ψ absorption in hot nuclear matter: recent updates

- At this conference:
  - Take all the existing p-A data in the SPS energy domain
    - NA38/NA50 400/450 GeV
    - $\rightarrow$ constrain $\sigma_{abs}^{J/\psi}$
    - NA3/NA38 200 GeV
    - $\rightarrow$ constrain $\sigma_{pp}^{J/\psi}$
  - $\rightarrow$ good compatibility with the S-U data at 200 GeV
- Shows that the hadronic comovers have no sizeable effect on the J/ψ

- We also know that there is an important absorption source affecting the ψ'
  - present in S-U
  - absent in p-A



The anomalous J/ψ suppression



•Both with the new proposed reference…..

•…and already with the old one…….

•The central points show a departure from the normal absorption reference

This is the more recent (and the last) set of data from NA50

What does it mean?

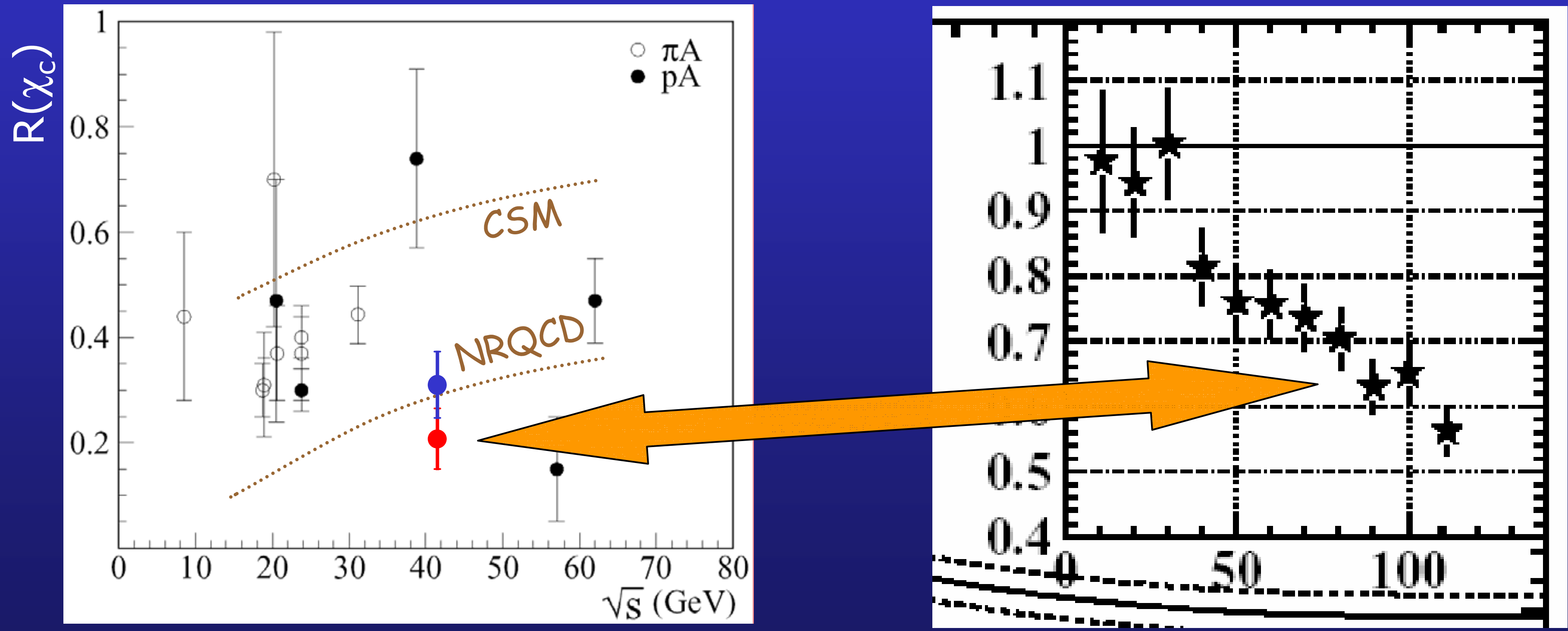
- Claimed to be (since many years) a signal of deconfinement at SPS energy

- Very much debated:
  Are we observing a threshold effect or a smooth transition ?
- Question difficult to answer (ill-posed?)
- Smearing effects in the centrality estimate, due to:
  - Finite resolution of the detectors
  - Smearing of experimental obervables vs centrality variables
- Shown to be compatible with a sharp drop (minimum bias analysis)

- Which charmonium state is being suppressed ?
- J/ψ is becoming much stronger as the years go by ($>1.5\ T_C$)
  $\rightarrow$ seems to be out of question

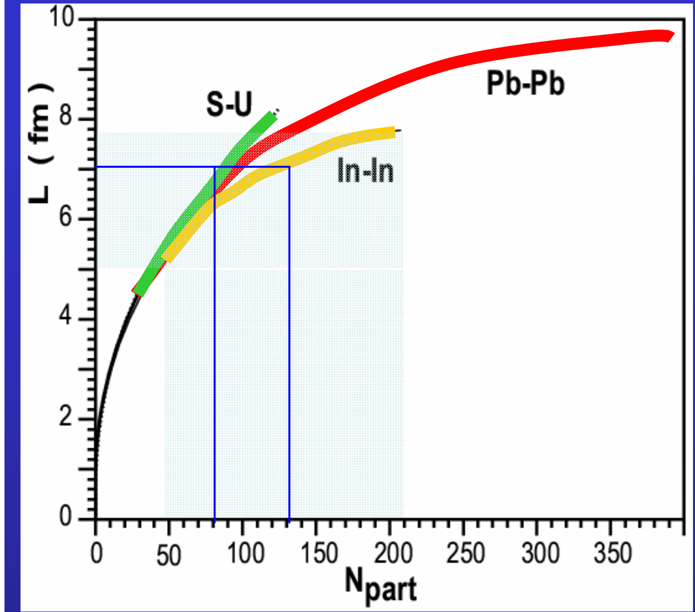
χ_c anomalous suppression

- Is it the χ_c ?
- Will recent HERA-B data on feed-down be confirmed (χ_c/J/ψ ~ 0.2) ?
- Can the χ_c be responsible for the observed suppression reaching ~40% for central PbPb events?



- Is the χ_c/J/ψ ratio energy dependent (NRQCD)?

The anomalous J/ψ suppression: NA60



- What can we learn by comparing the J/ψ suppression pattern between different systems? (talk by **R.Arnaldi**)

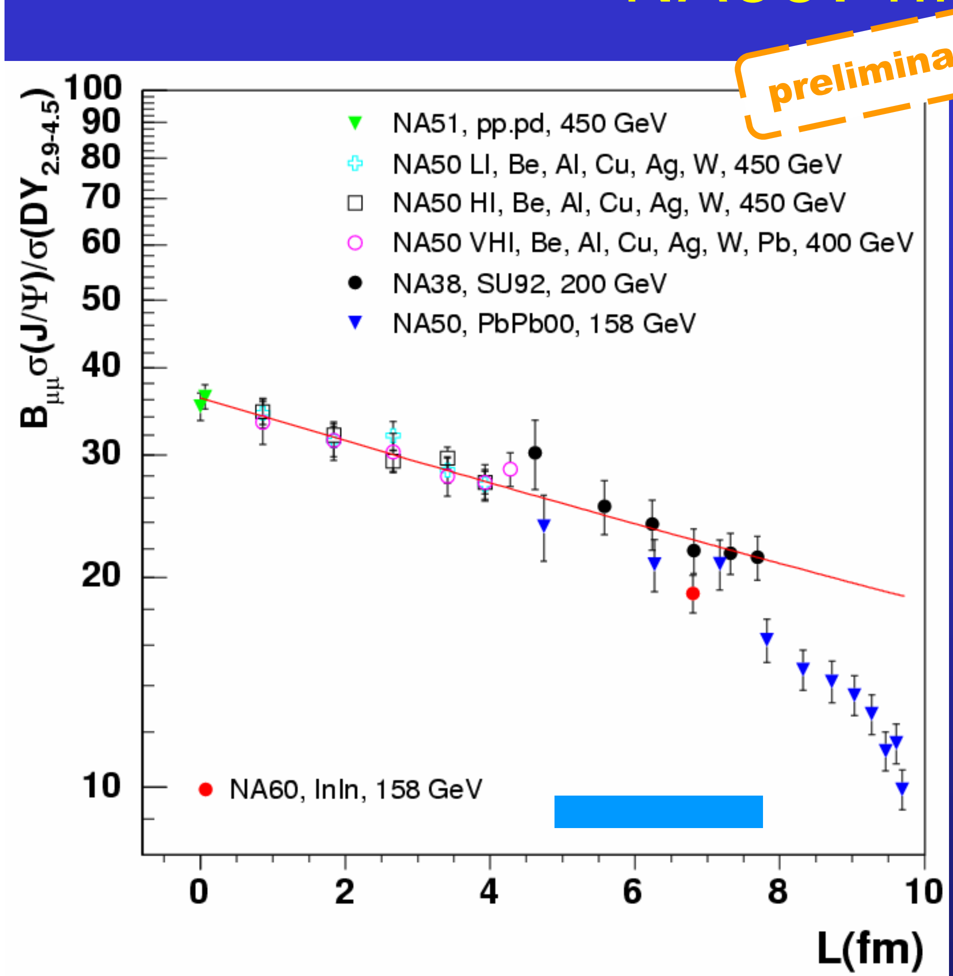
Which is the variable governing the onset of the anomalous suppression?
Discriminate between models!

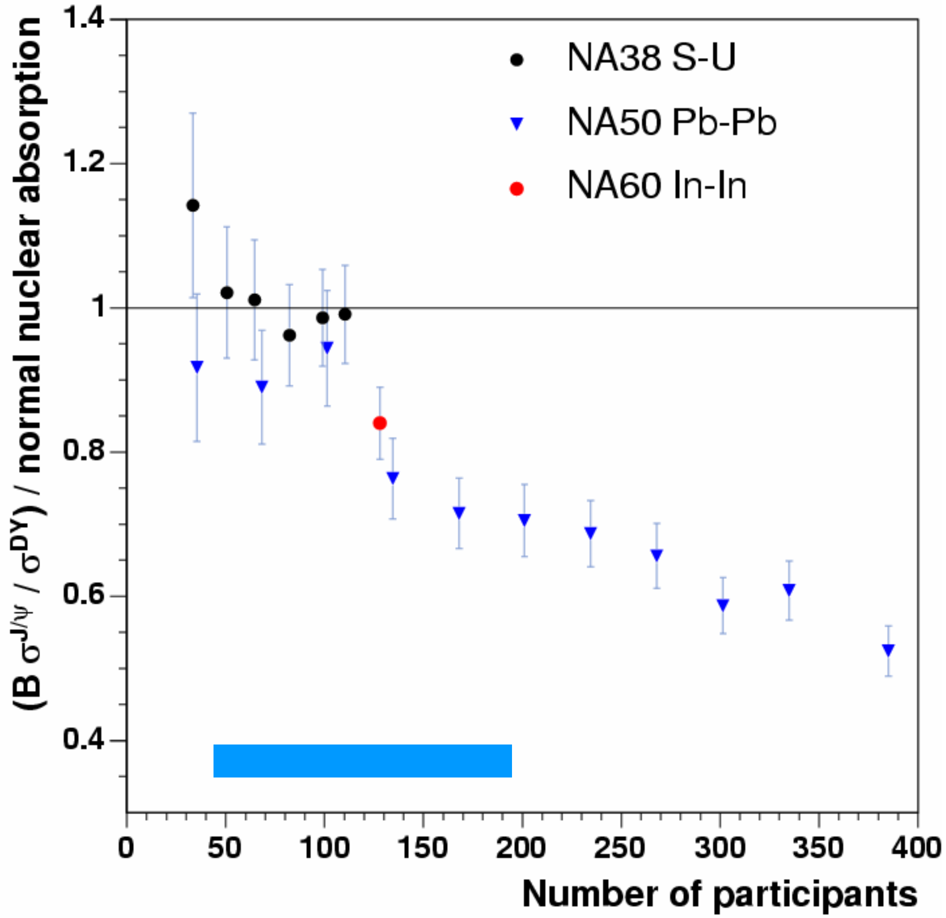
- Scaling behavior between various systems for a given centrality variable may indicate that that centrality variable is behind the observed anomalous suppression

  - For instance, for L ~ 7 fm, S-U, In-In and Pb-Pb collisions probe different values of N_{part}, ranging from 80 to 130

  →If the physics-driving variable is N_{part}, the three systems will show a different pattern

NA60: first results





- We wait for the centrality dependence……
- Should span the region across the onset of the anomalous suppression

J/ψ suppression in In-In

- Only centrality integrated result available up to now
- Can we compare it with other systems/theoretical predictions ?

→ Use $R = B_{\mu\mu}\, \sigma(J/\psi)/\sigma(DY)_{meas} / B_{\mu\mu}\, \sigma(J/\psi)/\sigma(DY)_{expected}$

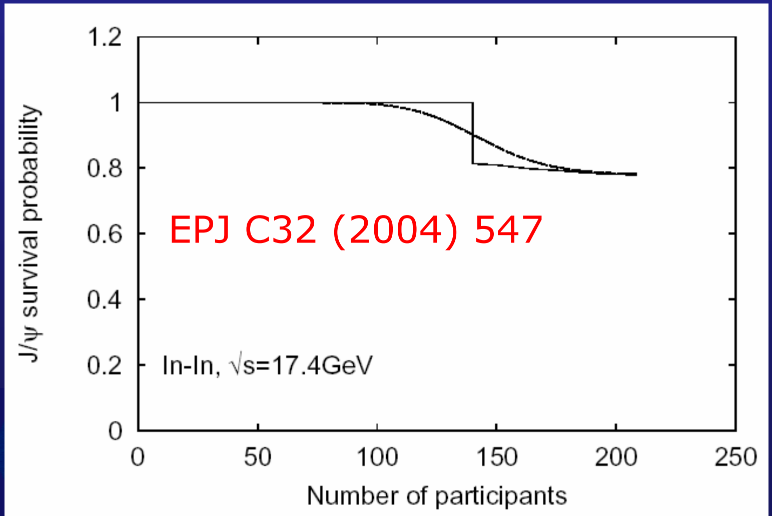
- NA50 quotes the following values:
  - R (PbPb,1995 sample) = 0.71 ± 0.03
  - R (PbPb,1996 sample) = 0.77 ± 0.04

↔

- NA60 quotes:
  - R(InIn) = 0.84 ± 0.05

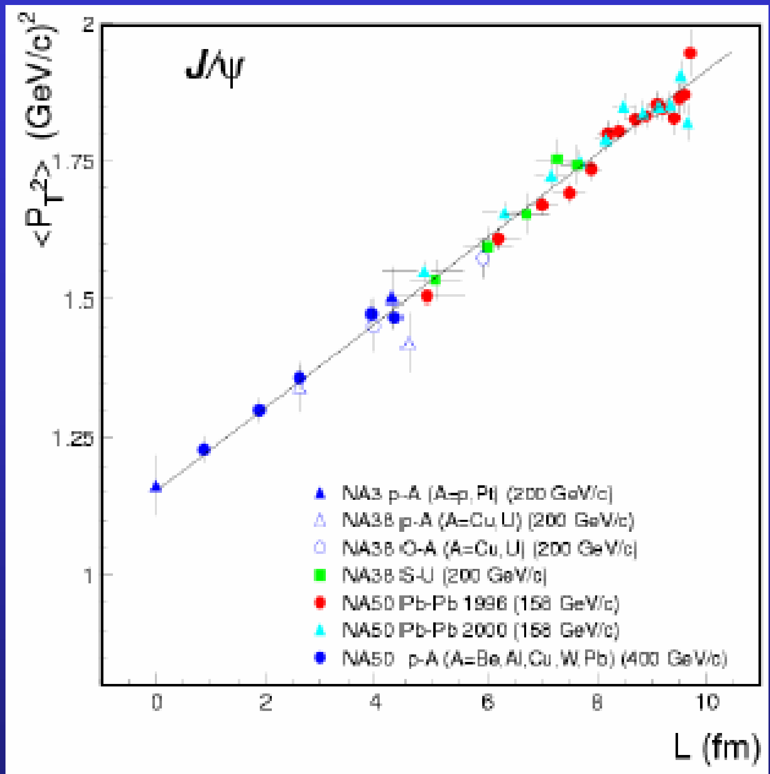
- Only two models on the market (Digal,Fortunato and Satz, Grandchamp and Rapp)

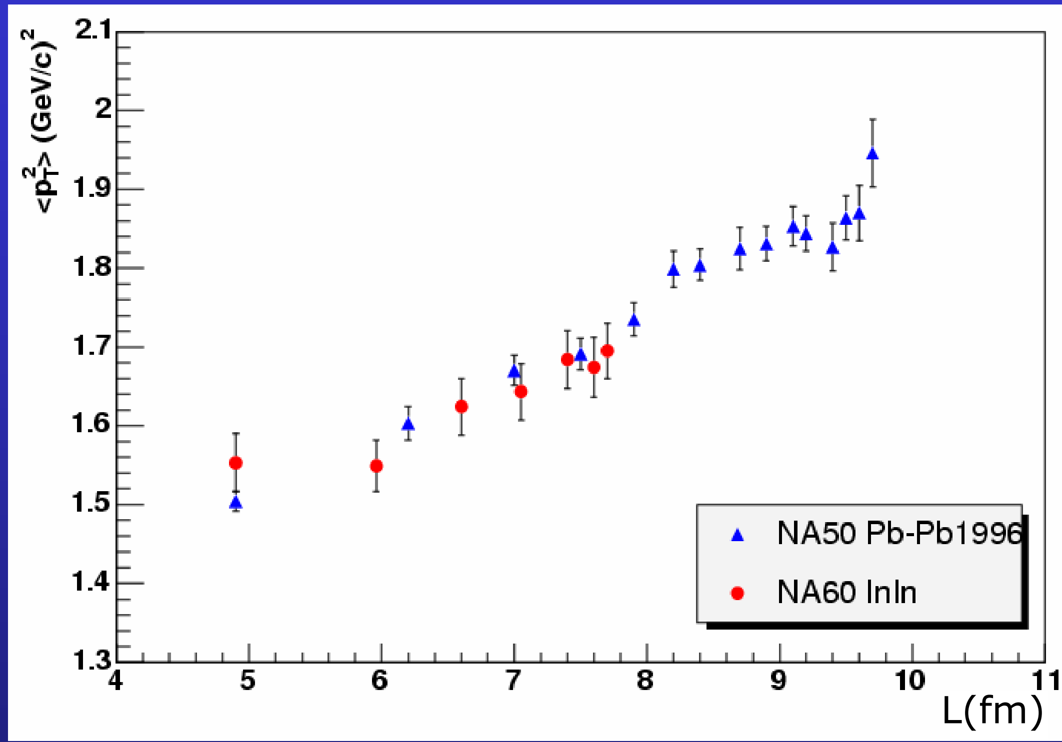
→ Need more predictions !



- Digal et al. predict, for In-In, the onset of the anomalous J/ψ suppression at N_{part} ~140
- Averaging over centrality, weighting with the correct N_{part} distribution for hard processes gives R ~ 0.90

J/ψ at fixed target: other topics, p_T





The p_T broadening (linear increase of $<p_T^2>$ with L)
is present also in A-A collisions

confirmed by NA60 for In-In collisions

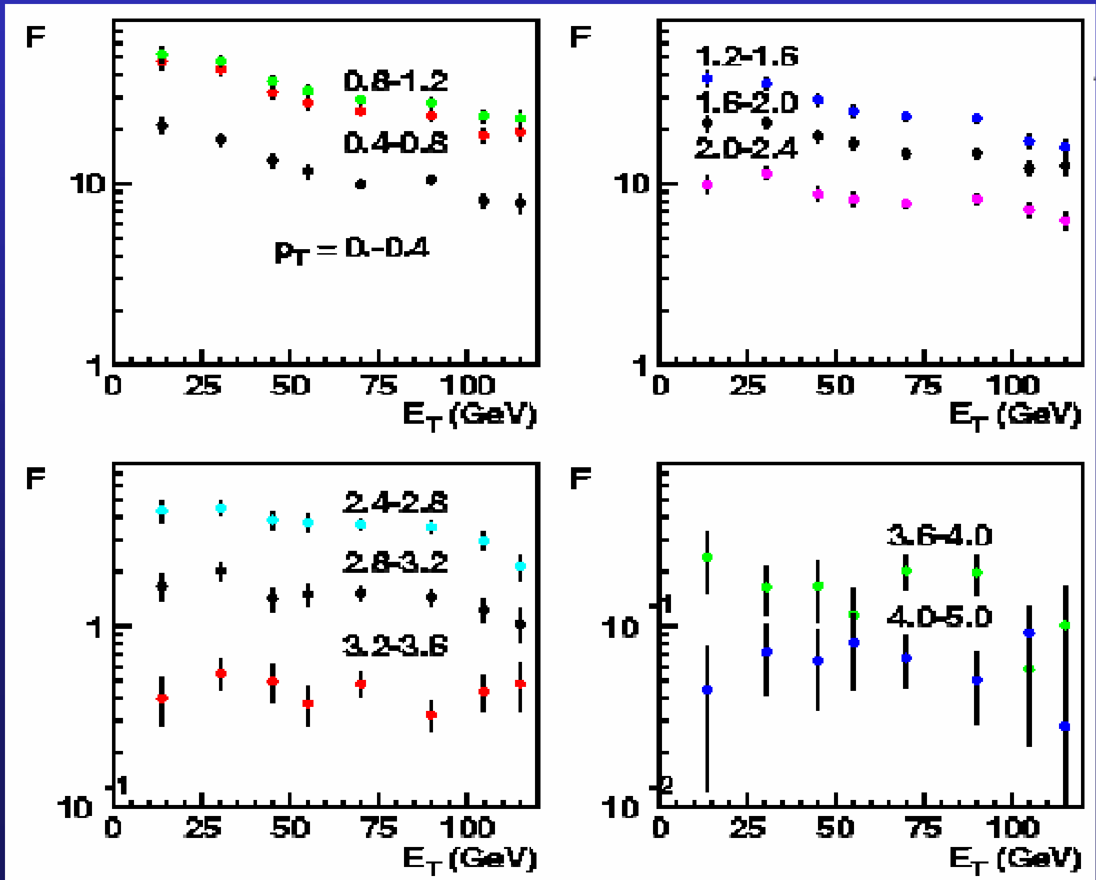
Initial state effect likely

The anomalous suppression and p_T

Has the anomalous suppression any consequence on the p_T distribution ?

Much debated issue in the past
No clear answer up to now

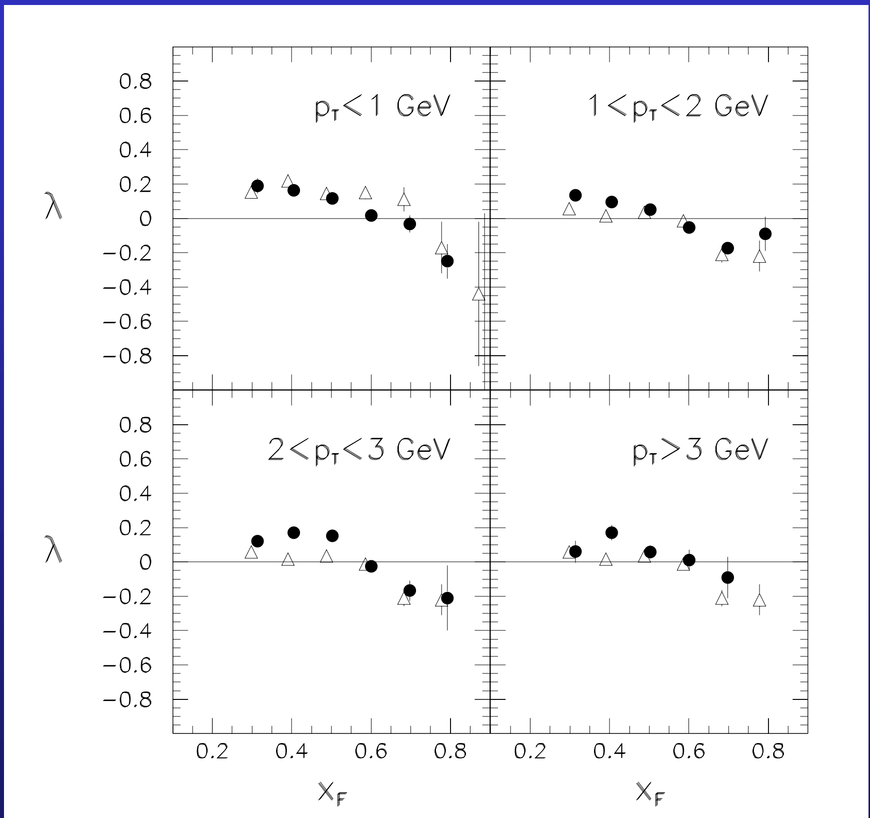
- Data from 2000 PbPb data taking presented at this conference

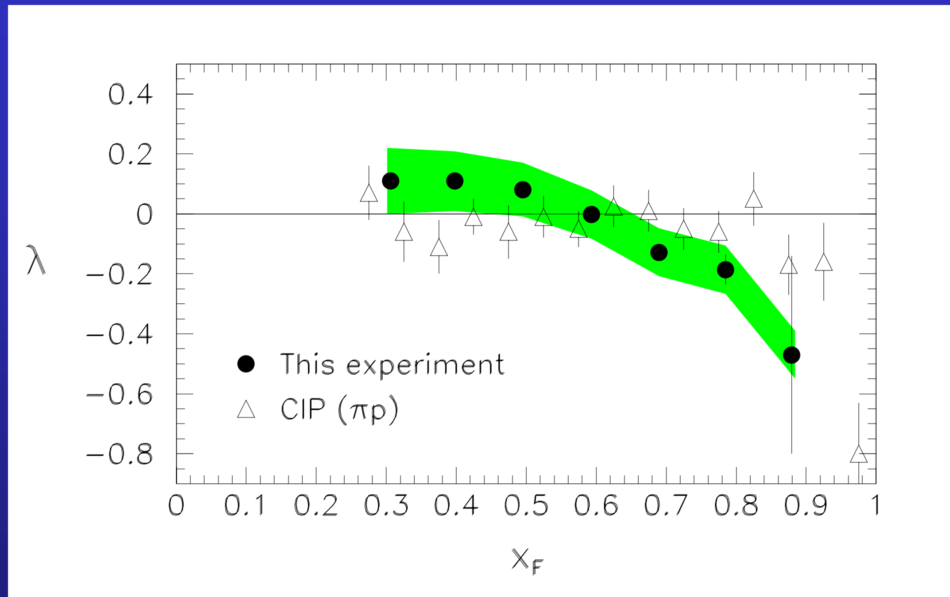


Can this result be relevant for the understanding of the anomalous suppression?

J/ψ at fixed target: other topics, polarization

- Reference measurement: E866 → 9 million J/ψs!
  - Study vs x_F, p_T





Should help significantly in discriminating between models

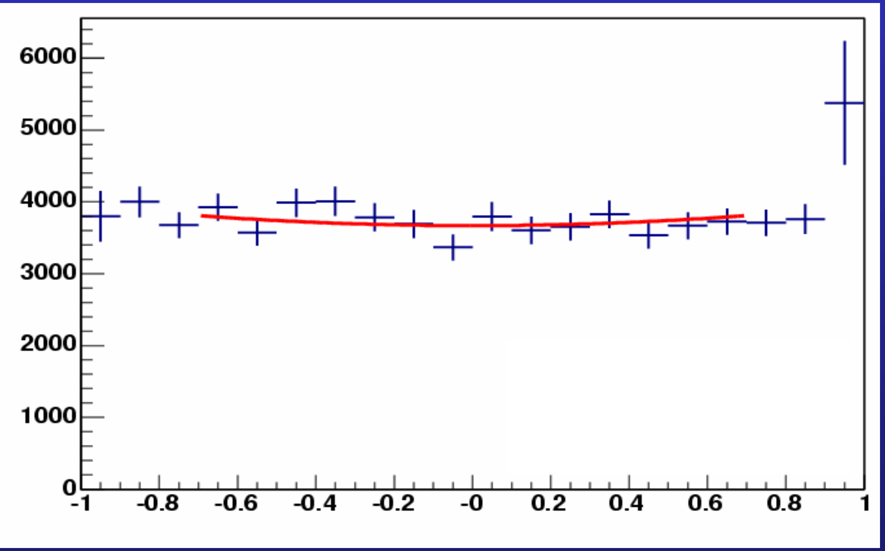
COM (successful in many respects) predicts large polarization at high p_T

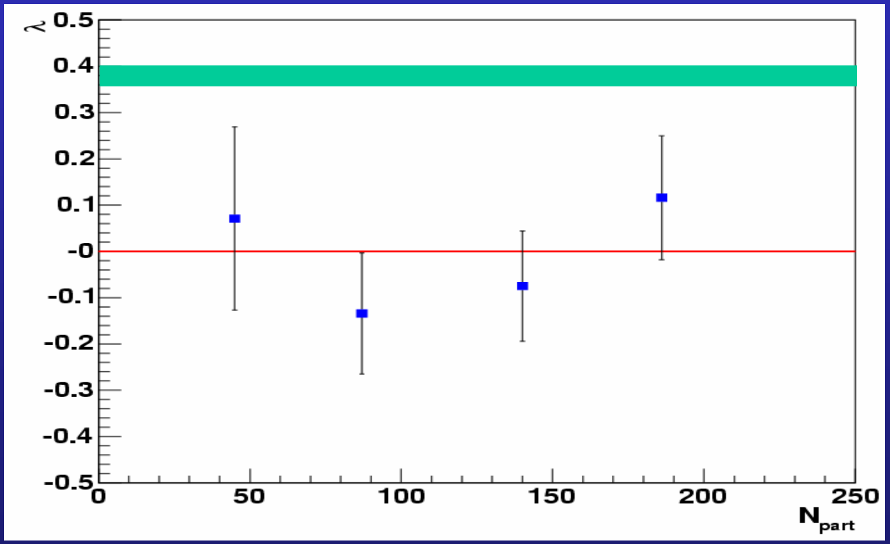
NOT seen in the data

Polarization: a new QGP signature ?

- Recent prediction by Ioffe and Kharzeev (Phys. Rev. C68(2003) 061902

- QGP screens away non-perturbative effects, quarkonia which escape from the plasma should be polarized $\rightarrow$ $\alpha \sim 0.35 \div 0.4$





- First preliminary results shown by NA60 at this conference
- Although with rather large errors no polarization seems to be present in Indium-Indium collisions

J/ψ suppression at fixed target: what have we learned?

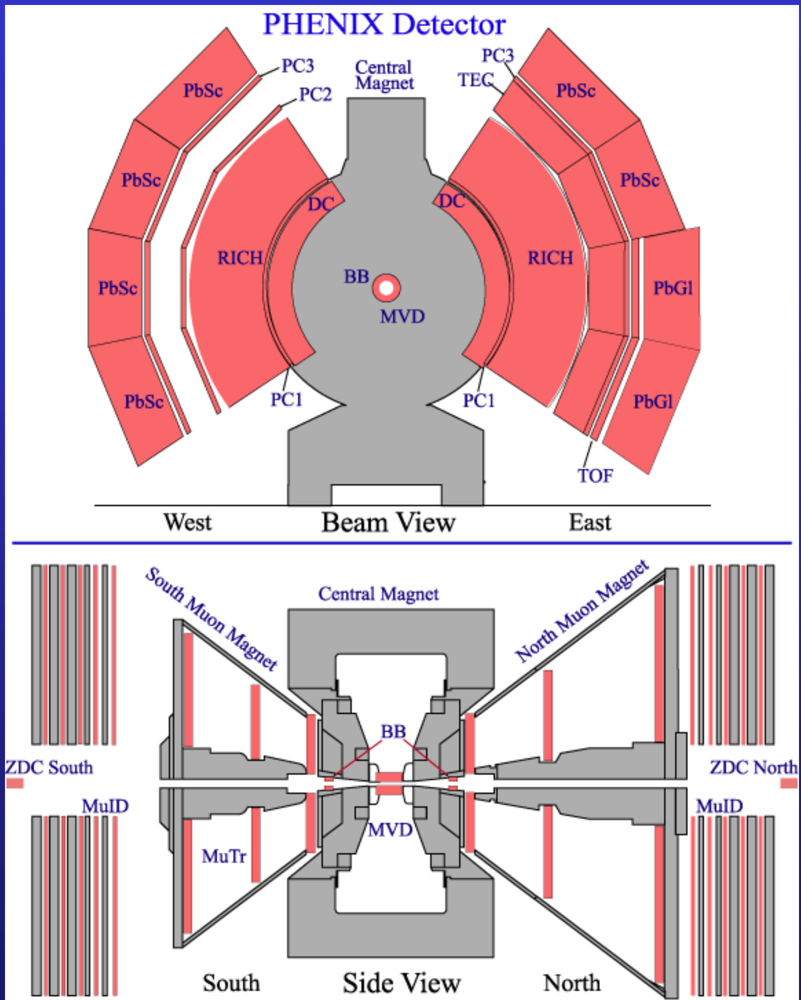
- Although we are dealing with a hard process, quantitative calculations of the production and hadronic suppression are difficult

- Fortunately, very good quality data exist from p-p to Pb-Pb collisions (NA50, E866, HERA-B)

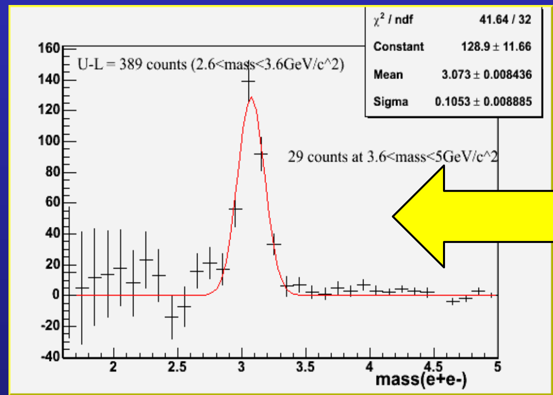
- Baseline for the interpretation of A-A data

- High statistics A-A data
  - Physics interpretation still evolving, but anomaly confirmed by the most recent NA50 data
  - An important reference has been set for higher energy experiments at RHIC and LHC

Charmonium production at RHIC

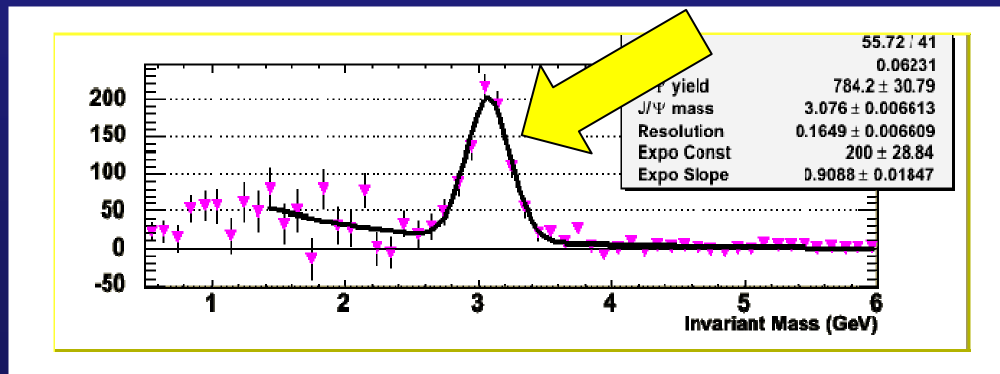


- PHENIX experiment
  - $e^{\pm}$ ($|\eta| \leq 0.35$, $p \geq 0.2$ GeV/c)
  - $\mu^{\pm}$ ($1.2 < |\eta| < 2.4$, $p \geq 2$ GeV/c)
- Larger kinematical domain with respect to the SPS
- Simultaneous measurement of e and μ



σ_m^{ee}=105 MeV

$\sigma_m^{\mu\mu}$=165 MeV



see talk by **M. Rosati**

Charmonium at RHIC: questions

- The basic question addressed is the same we had to answer at SPS, but the interpretation of the results will probably be more challenging

- New production mechanisms
  - $\sigma_{c\bar{c}}$ (RHIC) ~ 50 $\cdot\sigma_{c\bar{c}}$ (SPS) $\rightarrow$ $N_{c\bar{c}}$ (RHIC) ~ 10^1
  - May lead to enhancement from $c\bar{c}$ coalescence as the collision volume cools

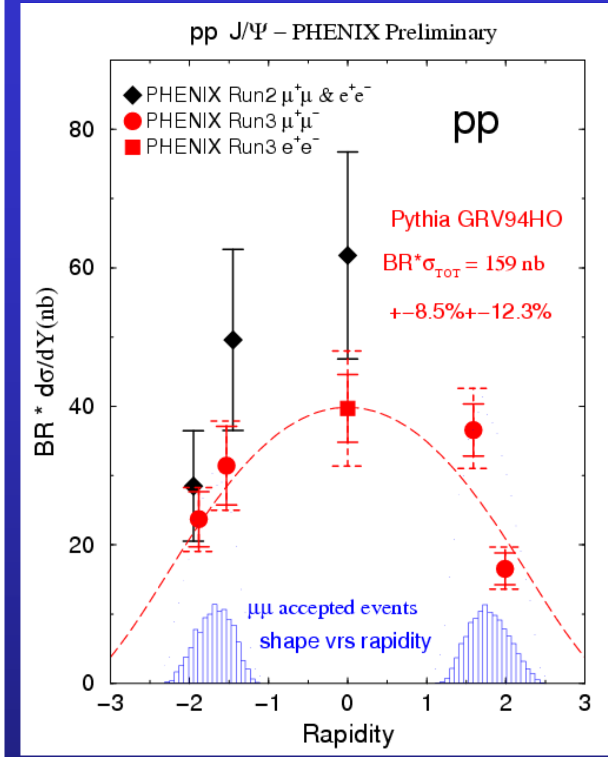
- New backgrounds
  - Feed-down from B-decays

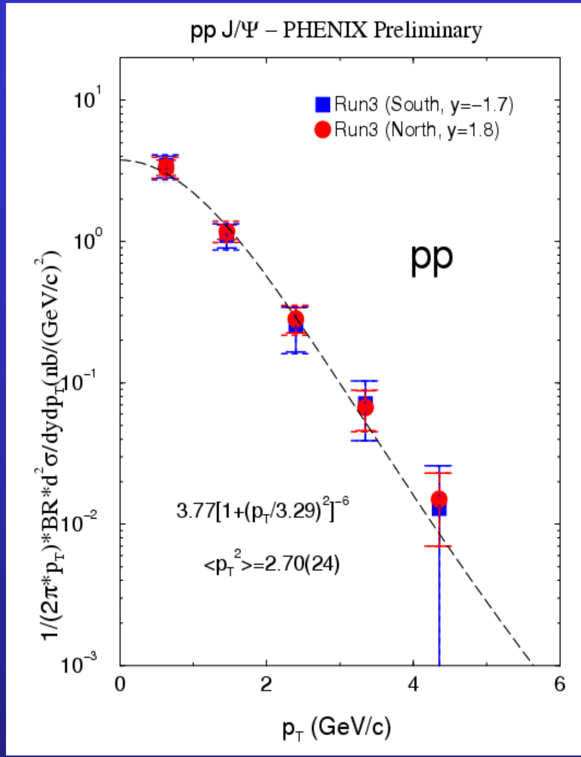
- The baseline should be studied as accurately as at SPS
  - d-Au vs p-p to understand shadowing/absorption

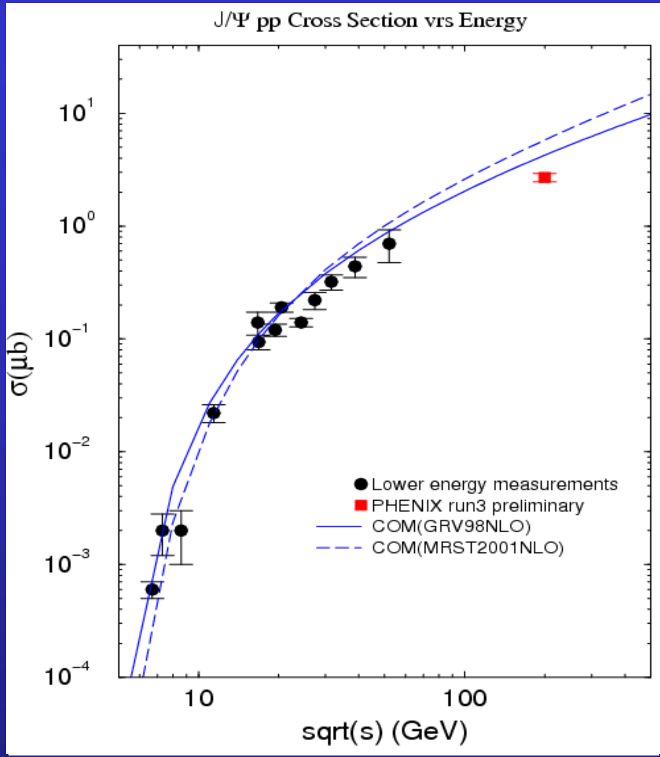
- The nuclear suppression (A-A) should be studied for many systems to help unraveling the effects not connected with deconfinement

- Small statistics: can (up to now) only distinguish gross features in the data $\rightarrow$ Detailed understanding still to come

Setting the baseline: pp collisions



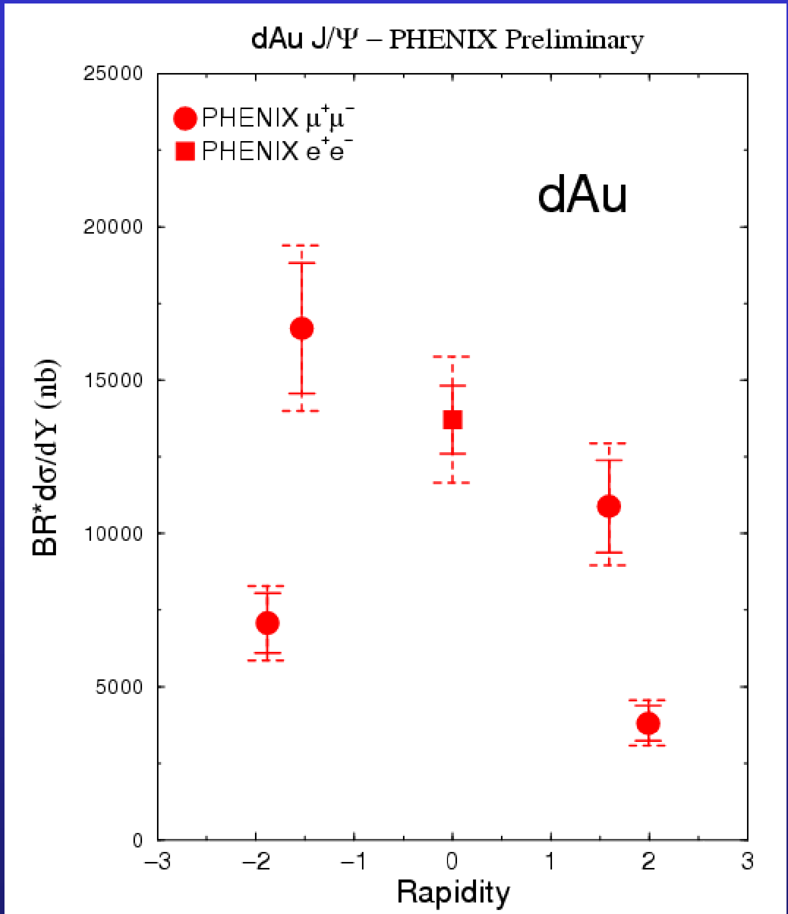


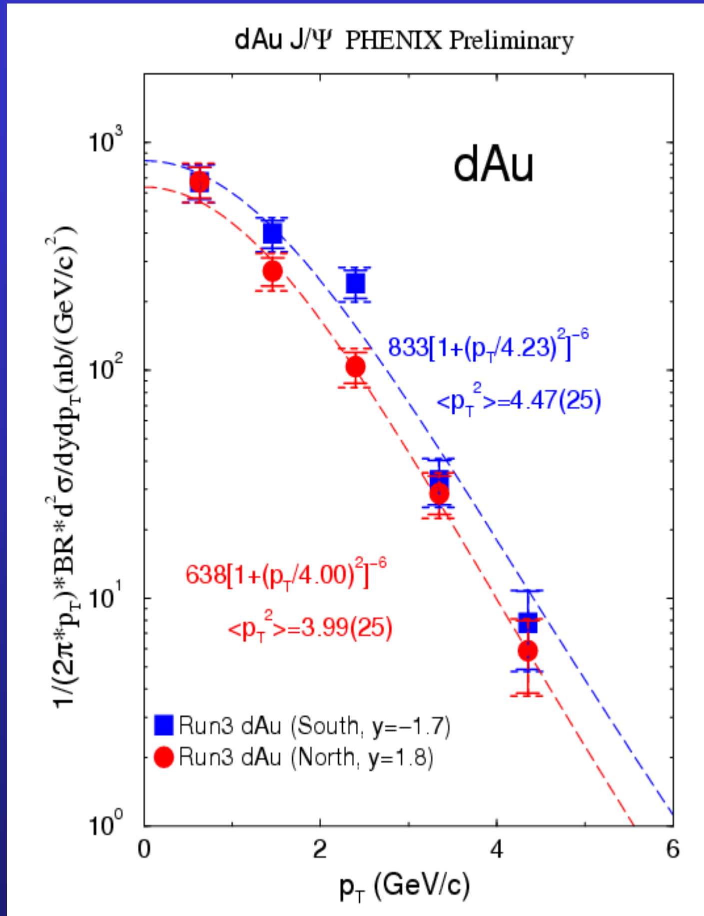


- p-p studies also important to constrain production models
- Rather wide y and p_T coverage (electrons + muons), contrarily to other collider experiments

  - Total cross section can be estimated
    - Run2: $BR.\sigma_{tot}$ = 234 ± 36(stat) ± 34(sys) ± 24(abs) nb
    - Run3: $BR.\sigma_{tot}$ = 159 nb ± 8.5 % ± 12.3 %

Setting the baseline: dAu collisions

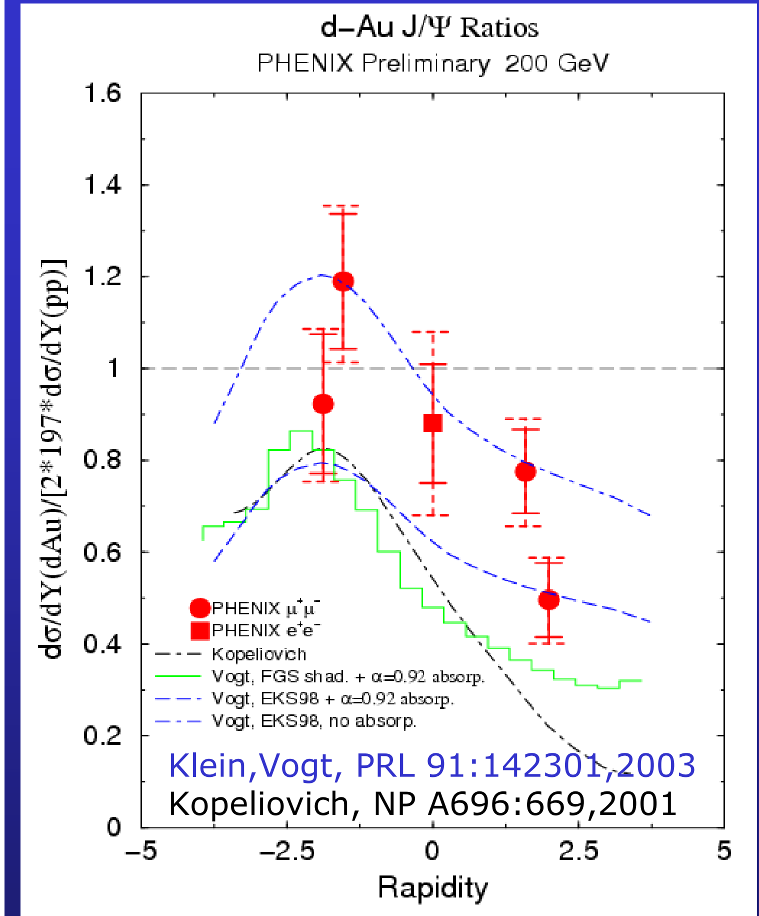


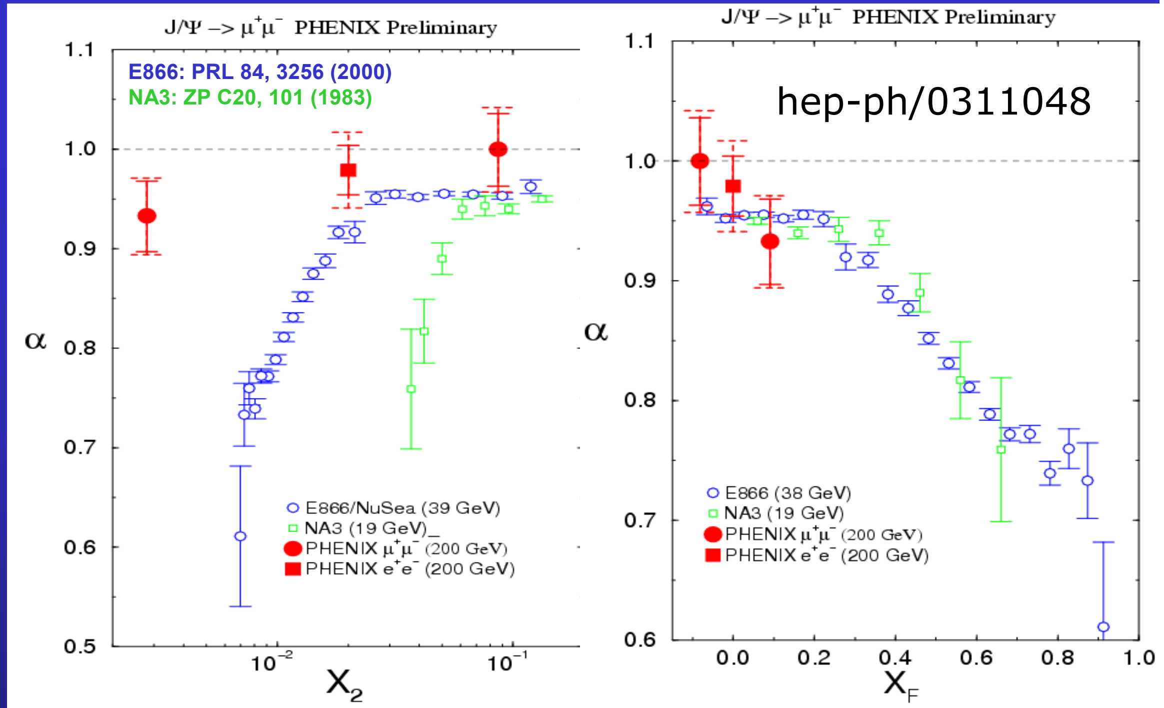


- Clear asymmetry observed in the rapidity dependence
  - $y>0$ small x_2 (~0.003) → shadowing
  - $y<0$ large x_2 (~0.09) → anti-shadowing

- p_T broadening observed
  - $\Delta\langle p_T^2\rangle$ $y>0 \rightarrow 1.29\pm0.35$ $(GeV/c)^2$
  - $\Delta\langle p_T^2\rangle$ $y<0 \rightarrow 1.77\pm0.35$ $(GeV/c)^2$

Shadowing vs absorption in dAu collisions

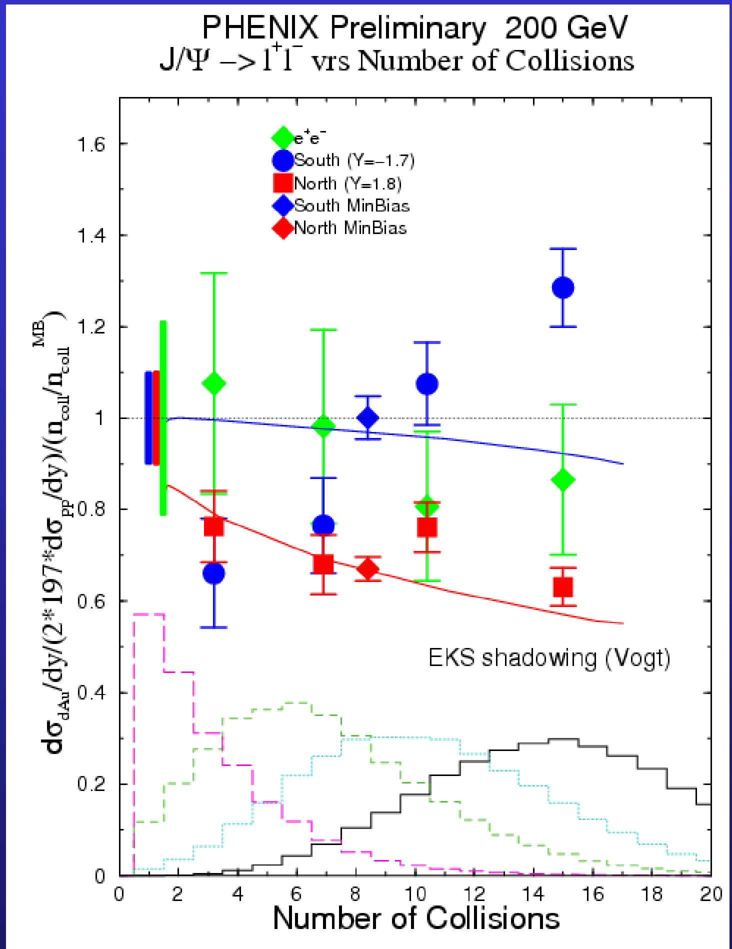




- Data seem to show that shadowing/absorption plays a (small) role when comparing d-A to p-p
  - How much is shadowing? No x_2 scaling
  - How much is nuclear absorption?
    - $\rightarrow$ Need more data

Total effect possibly weaker than at fixed target energy

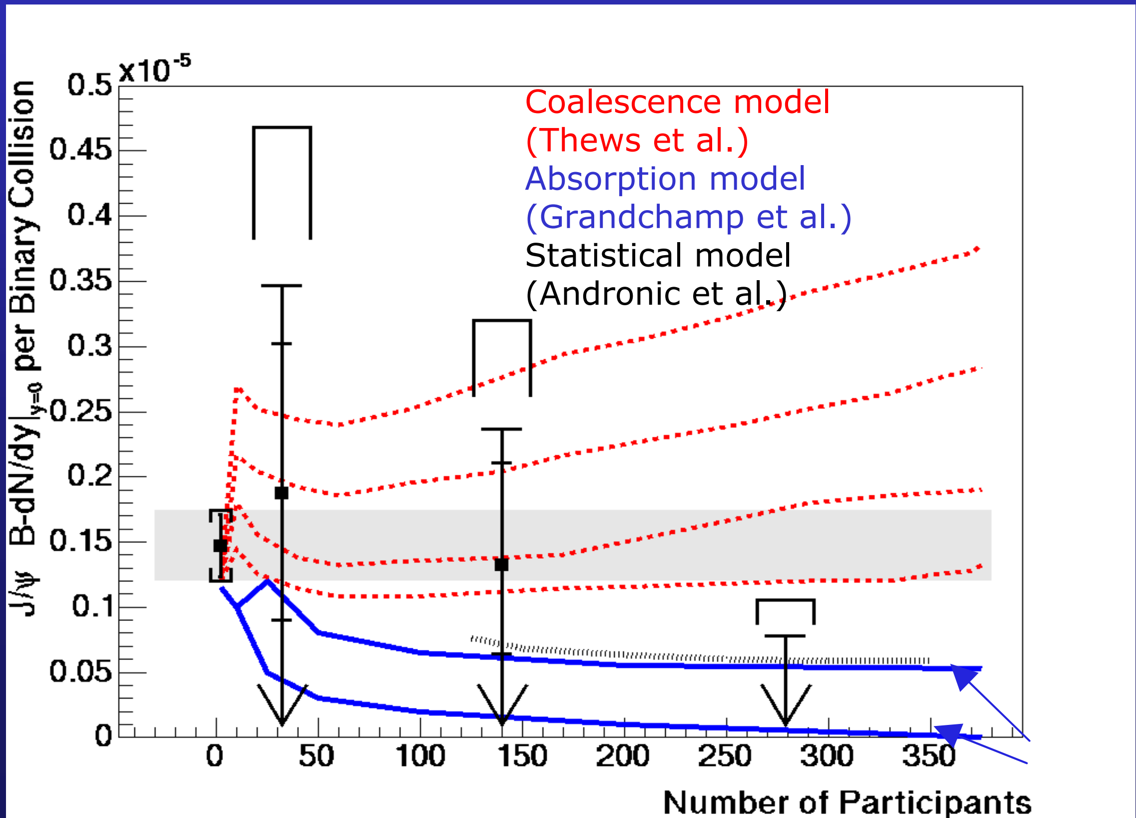
Puzzling observations



•Strong increase of J/ψ yield vs centrality for backward production reported at QM

Au-Au collisions: first results

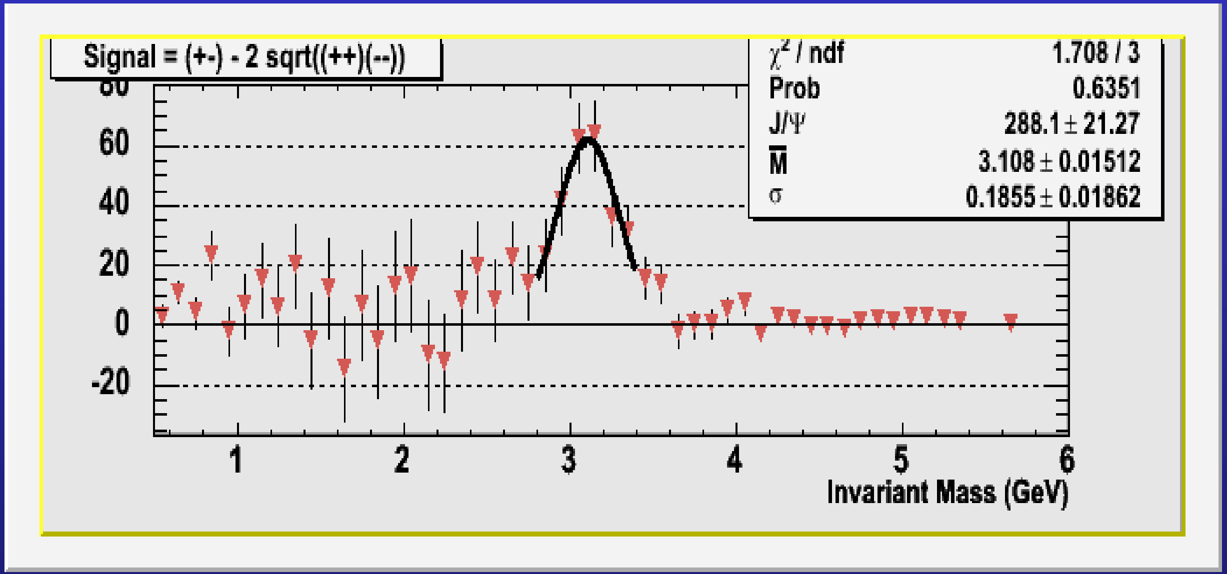
- Only very low statistics Run2 results available for the moment
- Several models, predicting anything from strong suppression to large enhancements can be compared (successfully) with the data
- Same model, with different parameter tuning, may lead to very different predictions (can they be fixed independently of data?)
- May a comparison between various projectile/target combinations help in establishing the importance of various effects ?



Eagerly waiting
For Run-4 results !

Au-Au collisions: what next ?

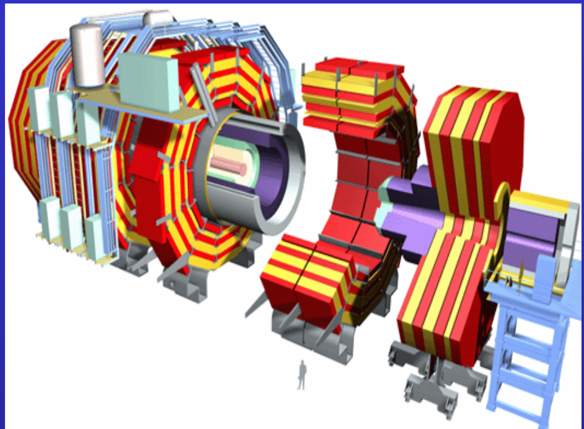
- RHIC run-4 expected statistics = 50 $\times$ run-2
  - ~3000 J/ψ expected
  - Supposing to do 5 centrality bins (as for first NA50 runs)
    $\rightarrow$ stat. error ~ 4%



- What about normalization of results ?
- Which unsuppressed reference is best suited ?
- SPS solution (Drell-Yan) does not appear possible
- Open charm would be fine, but still has significant systematic errors

Quarkonia at LHC

CMS: strong heavy ion program

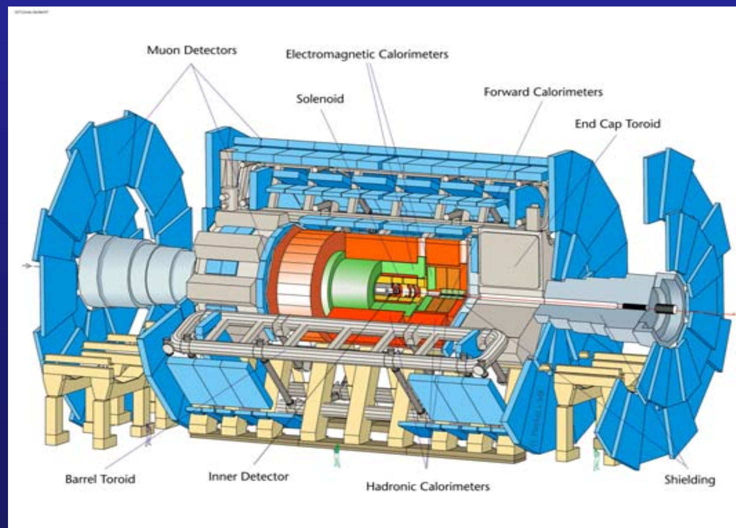


- All large experiments have physics capabilities in the quarkonium sector
- Complementary approach

- Very interesting for the study of the Υ family
  - No possibility at SPS
  - Apparently out of present RHIC reach

ALICE: the dedicated heavy ion experiment

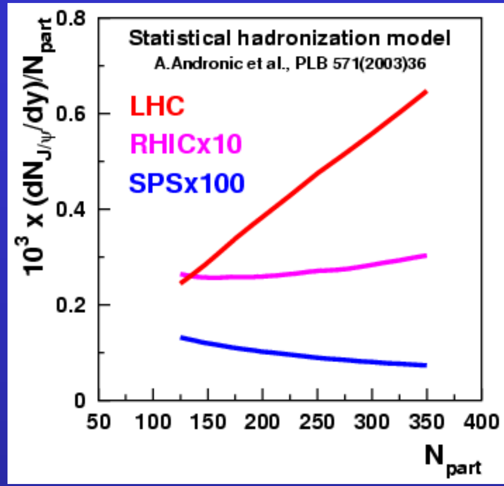
ATLAS: heavy ion LOI (2004)



Quarkonium at ALICE

N(qq̄) per central PbPb (b=0)	SPS	RHIC	LHC
charm	0.2	10	120
bottom	---	0.05	5

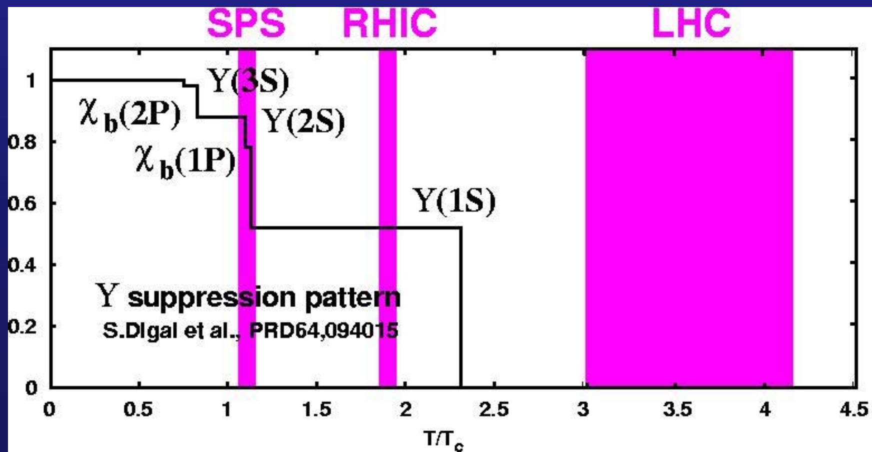
Charmoniun physics dominated by statistical production



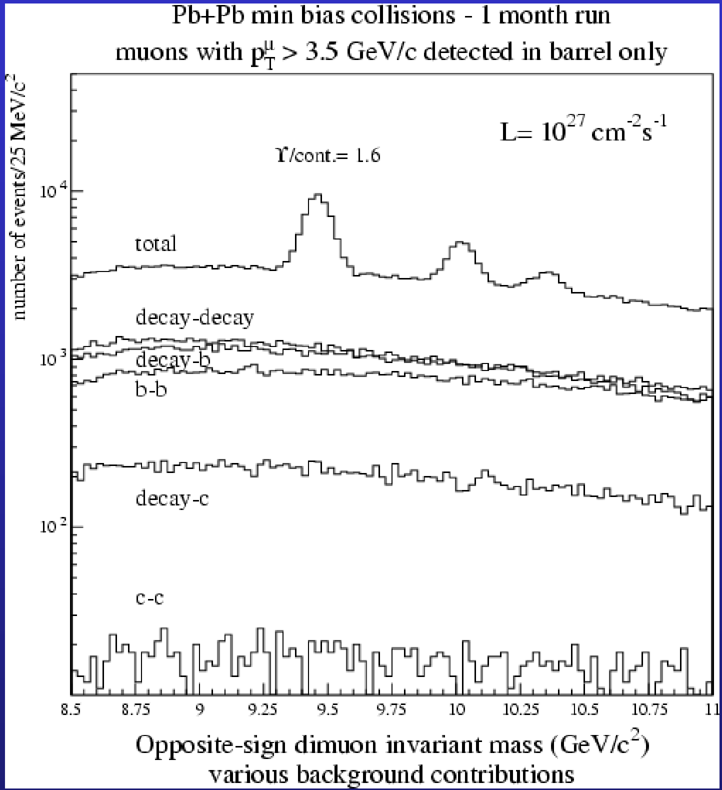
PbPb, $\sqrt{s}$ = 5.5TeV, L = 5.10^{26} cm^{-2}s^{-1}, T=10^6s,
2σ mass-cut, ε assumes dN$_{ch}$/dy = 4000 @ y = 0 in central

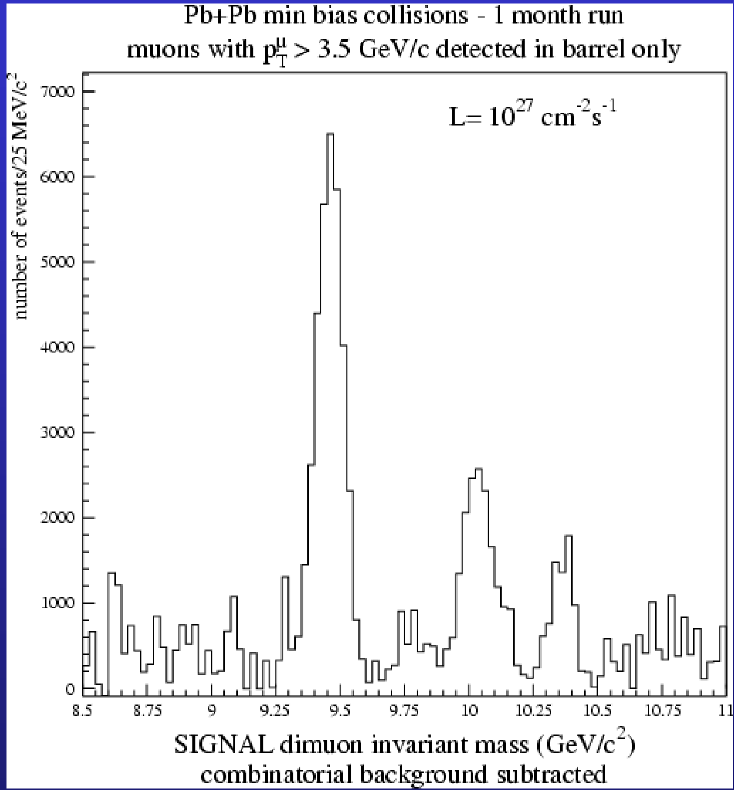
	b (fm)	0-3	3-6	6-9	9-12	12-16	min. bias
	ε (GeV/fm^3)	32	30	28	16	5	
J/ψ	S (x10^3)	86.48	184.6	153.3	67.68	10.46	502.4
	S/B	0.167	0.214	0.425	1.237	6.243	0.28
	S/√S+B	111.3	180.4	213.8	193.4	94.95	331.5
ψ'	S (x10^3)	1.989	4.229	3.547	1.565	0.24	11.57
	S/B	0.009	0.011	0.021	0.063	0.273	0.015
	S/√S+B	4.185	6.902	8.604	9.641	7.171	12.95
Υ	S (x10^3)	1.11	2.376	1.974	0.83	0.118	6.408
	S/B	2.084	2.732	4.31	7.977	12.01	3.246
	S/√S+B	27.39	41.71	40.03	27.16	10.42	69.99
Υ'	S (x10^3)	0.305	0.653	0.547	0.229	0.032	1.766
	S/B	0.807	1.043	1.661	2.871	4.319	1.243
	S/√S+B	11.68	18.26	18.48	13.02	5.077	31.28
Υ''	S (x10^3)	0.175	0.376	0.312	0.13	0.019	1.012
	S/B	0.566	0.722	1.18	1.936	3.024	0.867
	S/√S+B	7.951	12.55	13	9.274	3.73	21.67

- Υ suppression
  - one of the most promising physics observables
  - Good statistics and resolution
  - Use bottomonium suppression pattern as a thermometer of the medium



Quarkonium at CMS



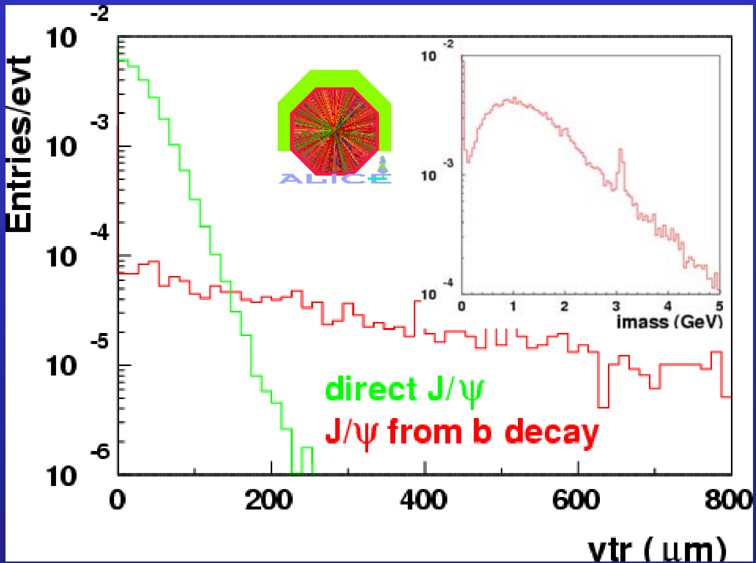


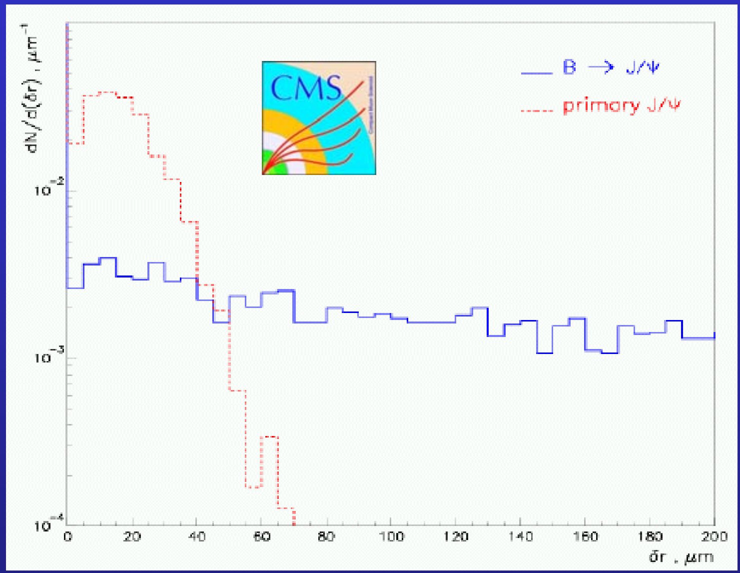
- Expected yield: $2.4 \cdot 10^4$ J/ψ, $1.8 \cdot 10^4$ ϒ, $5.4 \cdot 10^3$ ϒ′
- only high p_T

(one month at 50% running efficiency)

B-tagging

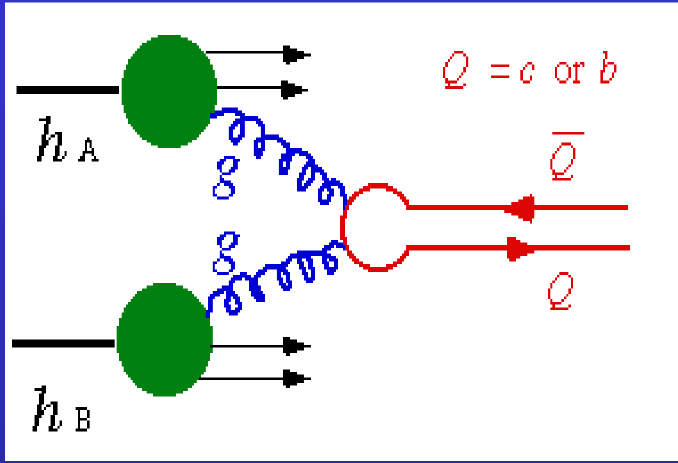
- Essential prerequisite for any charmonium physics at LHC





- Possible at both ALICE (for electrons) and CMS
- Good vertexing capabilities, with accuracy better than 100 μm

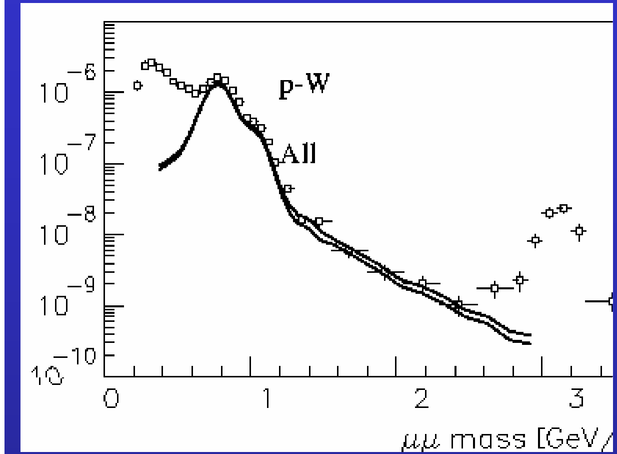
Moving to open charm



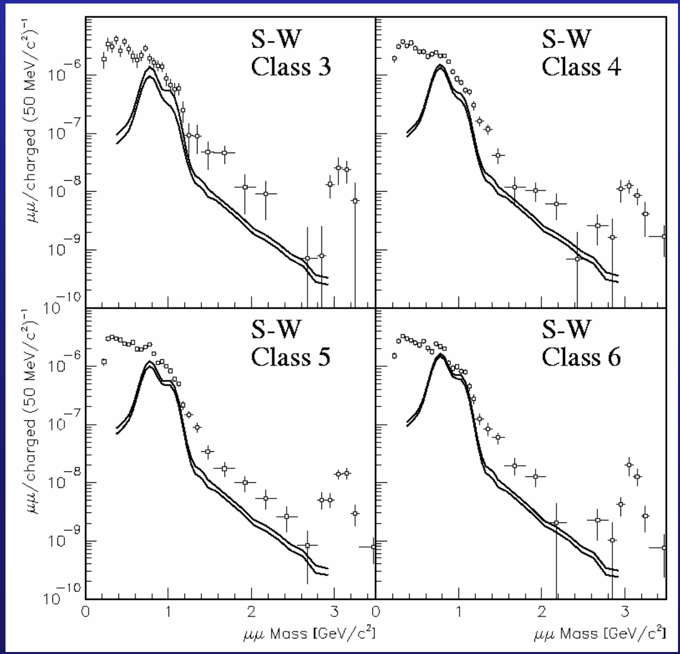
- Interesting in several respects
  - As a normalization for charmonia study
    - Share the same initial state
      - Ideal reference
  - Per se
    - Do heavy quarks suffer « quenching », as light flavors do?
    - Complementary results with respect to quenching of high p_T light hadrons (RHIC only)
    - Do heavy quarks flow ?

- From the experimentalist point of view
  - Direct measurement in A-A collisions much more difficult than for charmonium
  - Needs less luminosity but "anonymous" decay mode requires very accurate track reconstruction (vertex offset)
  - Indirect measurements not ideal, affected by large systematics

Open charm at fixed target HI experiments: Helios-3



- HELIOS-3→ dimuon trigger, but could not run at high beam intensities
- Open charm modeled through PYTHIA
- Significant uncertainty on absolute normalizations

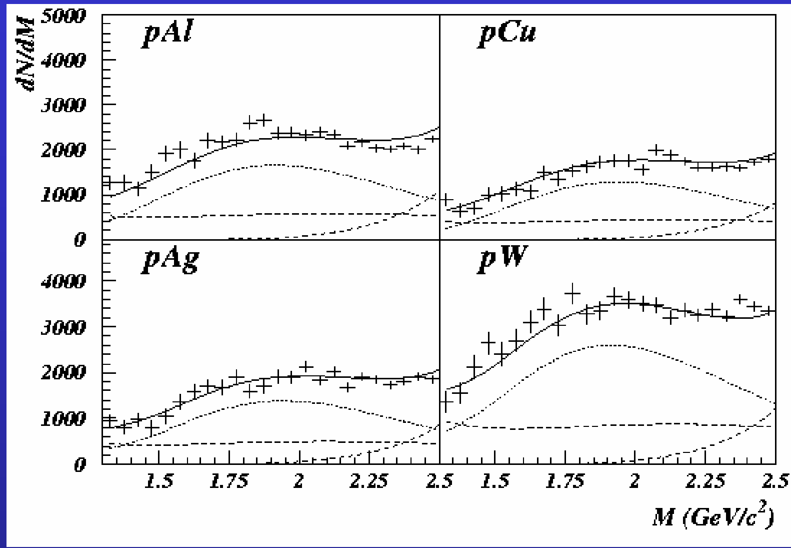


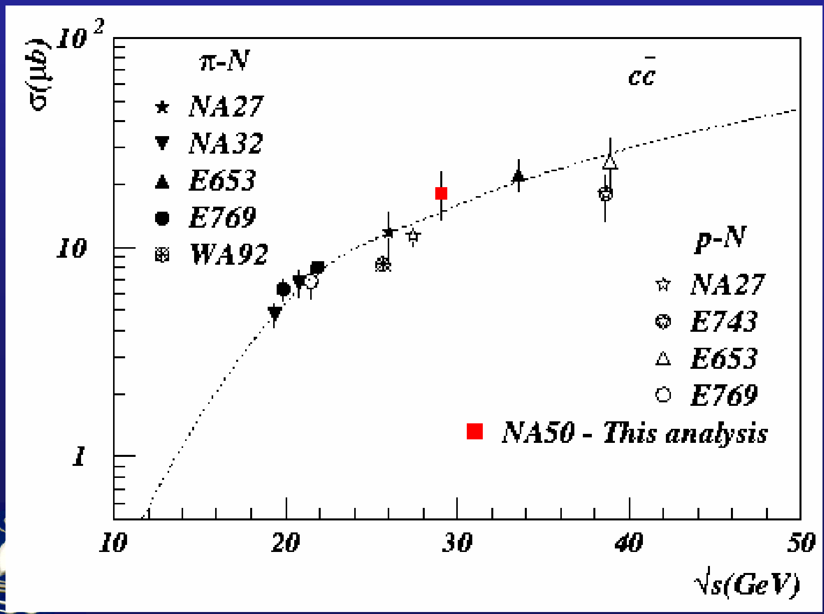
- The amount of open charm needed to describe p-A data is in agreement with direct measurements of open charm…
- …but A-A data show a large excess

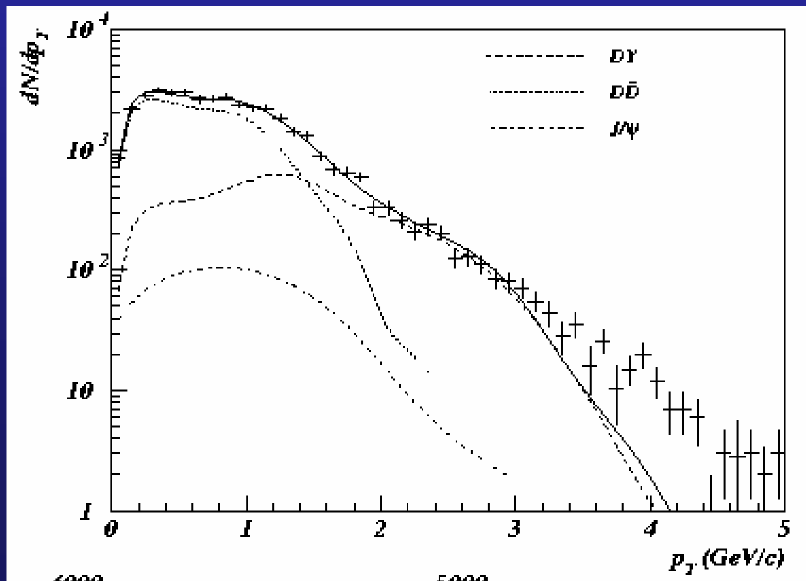
- What is the origin of the dimuon excess in the IMR? May it be related to open charm ?

Open charm at fixed target HI experiments: NA38/NA50

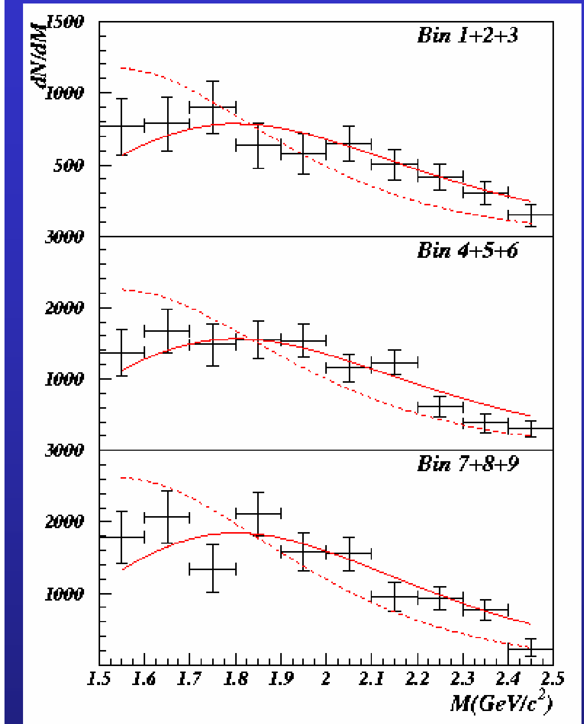
- NA50: large statistics, many p-A systems studied
- IMR can be described including an open charm source
- Both absolute and differential yields of open charm agree with expectations

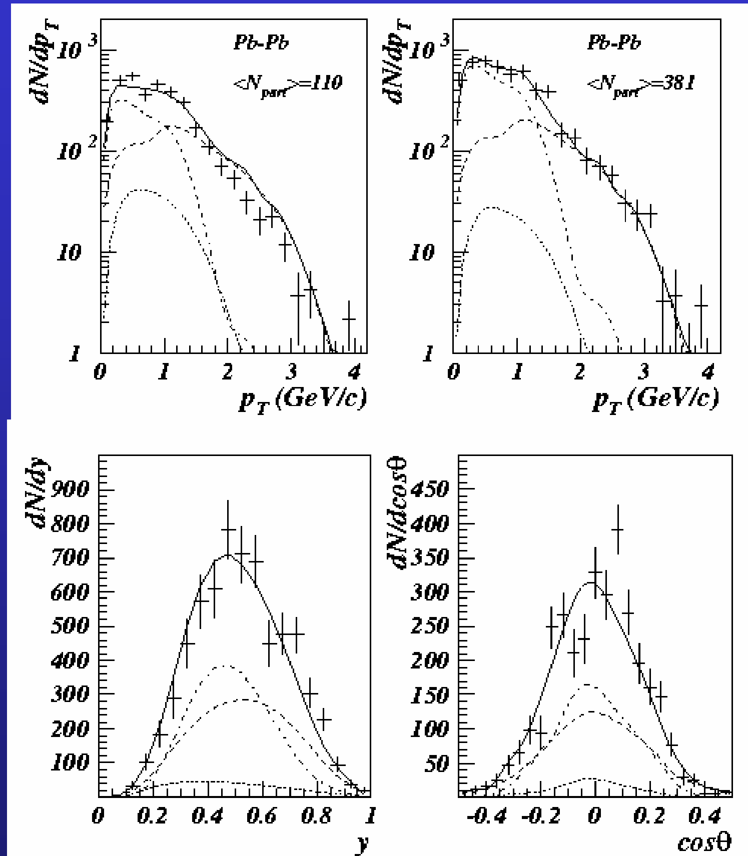






The NA50 IMR puzzle:
open charm, thermal dimuons, … ?





The Pb-Pb IMR is compatible with an enhanced open charm source

× 3 in central Pb-Pb

- The absence of vertexing capabilities prevents any stronger conclusion.
- A new experiment is needed

NA60

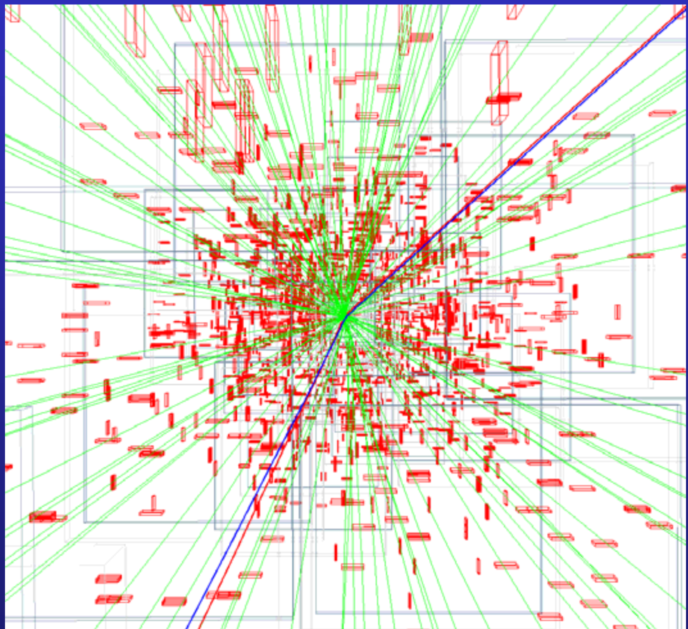
NA60: disentangling the IMR contributions

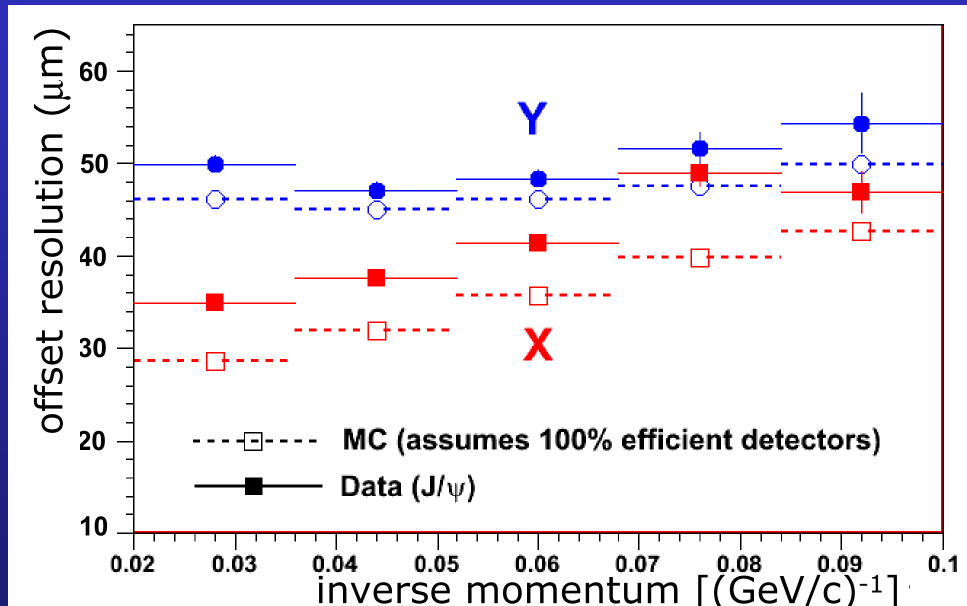
(see talk by **R. Shahoyan**)

•Couple the NA50 muon spectrometer to a new vertex detector

•Measure the transverse offset of the muons wrt the interaction point

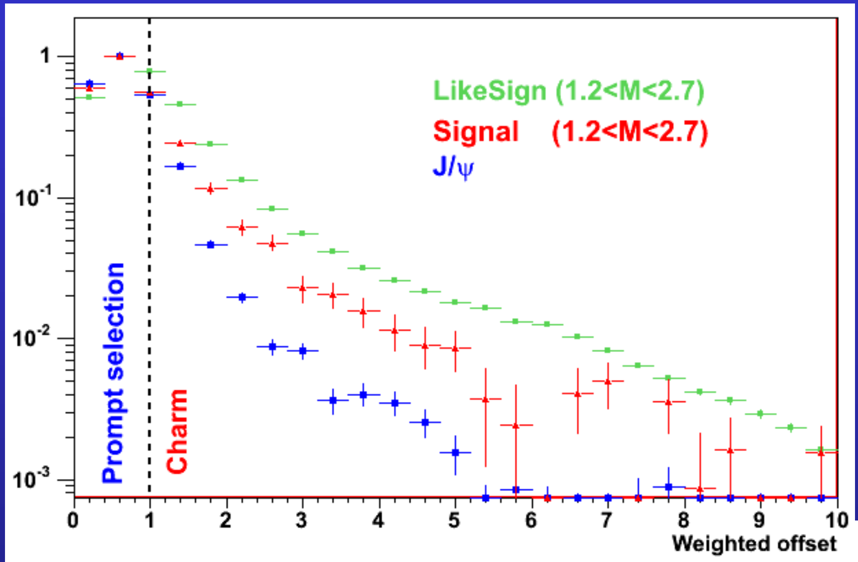
•Needs a resolution ~ 50 μm……





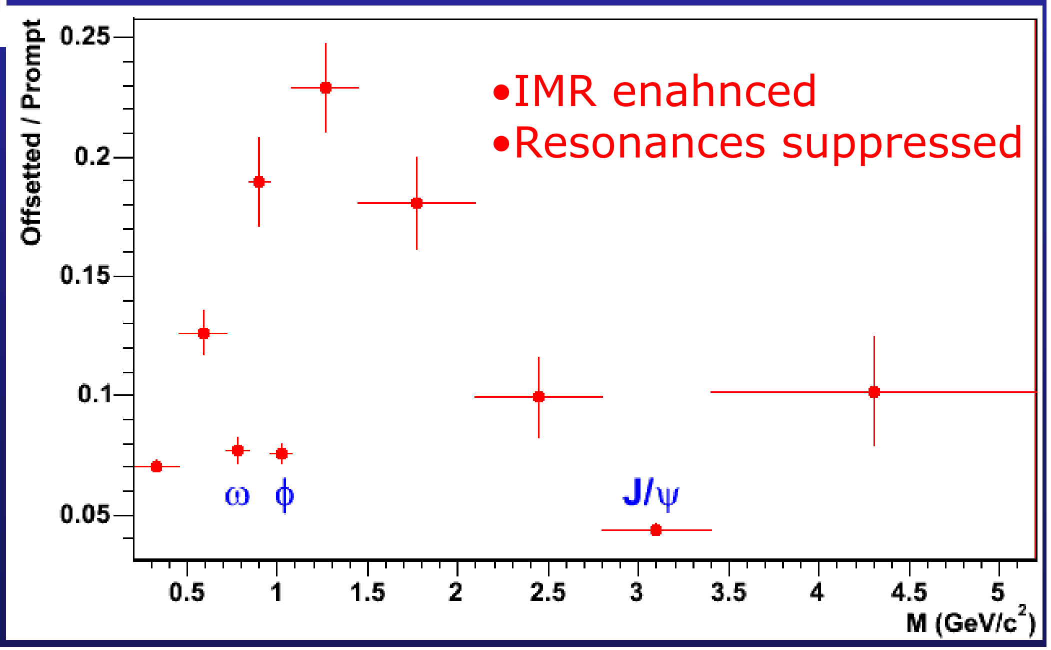
..that seems confirmed by preliminary results

NA60: first open charm signal in A-A collisions



- Suppress prompt production by appropriately cutting on the weighted offset of the muon closest to the vertex….
  …also cut on the weighted distance, Δ, between muons at Z_V, to reduce influence of bad vertices

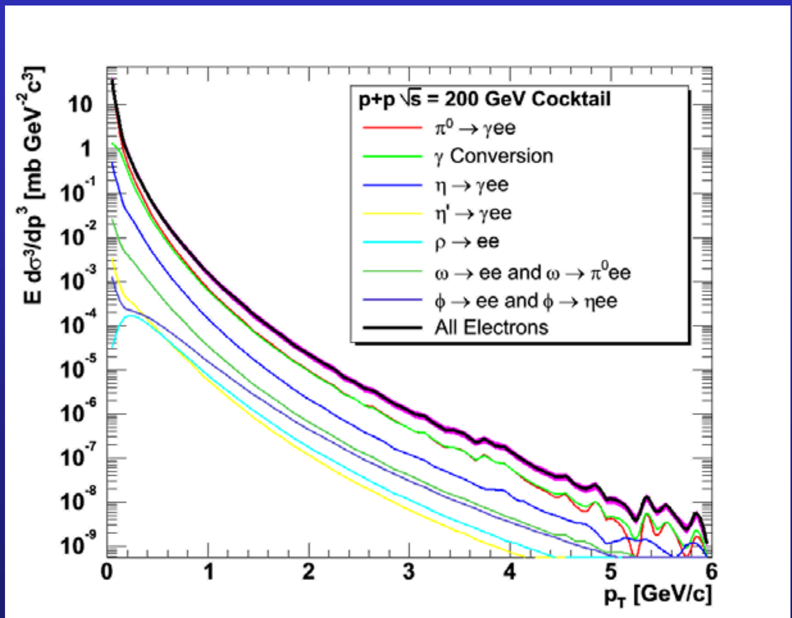
Ratio between off set and prompt dimuons

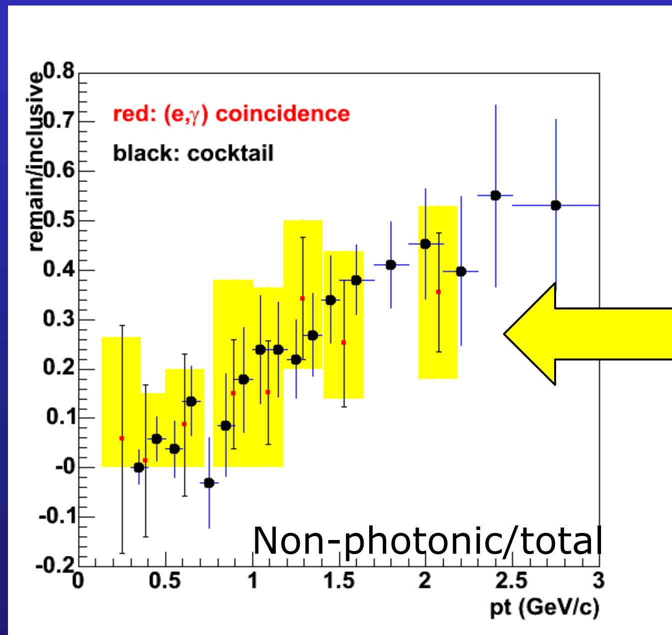


Next step:
open charm cross section
for In-In at the SPS

Open charm at PHENIX: technique

- Only indirect measurements performed up to now
  - $\rightarrow$ via single electrons from semi-leptonic decay
- Need to subtract a large background, especially at low p_T
- Systematic errors on total yields are important
- More sensitive to possible quenching effects





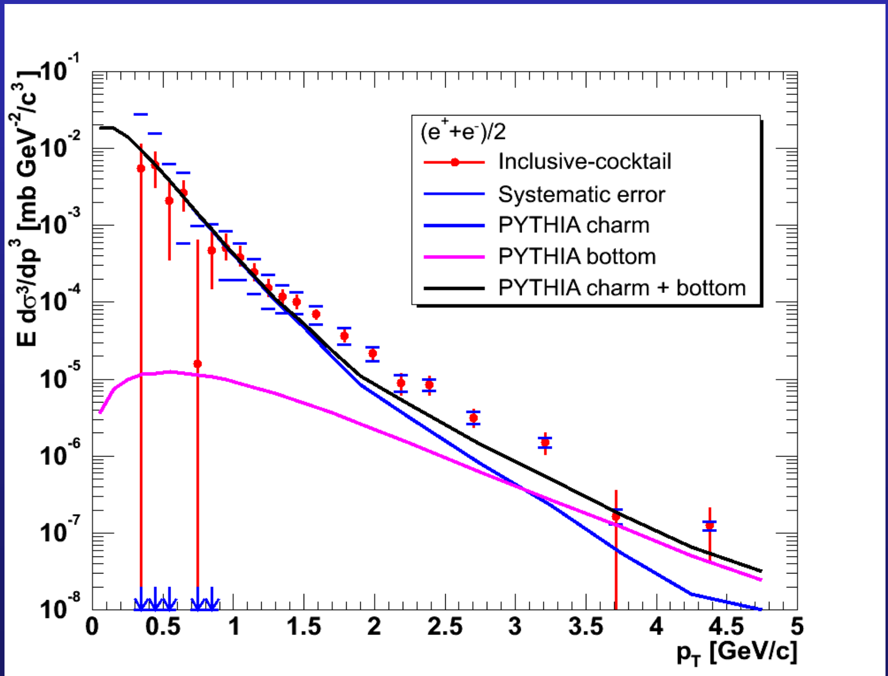
Signal is significant only beyond $p_T \sim 1.5$ GeV/c

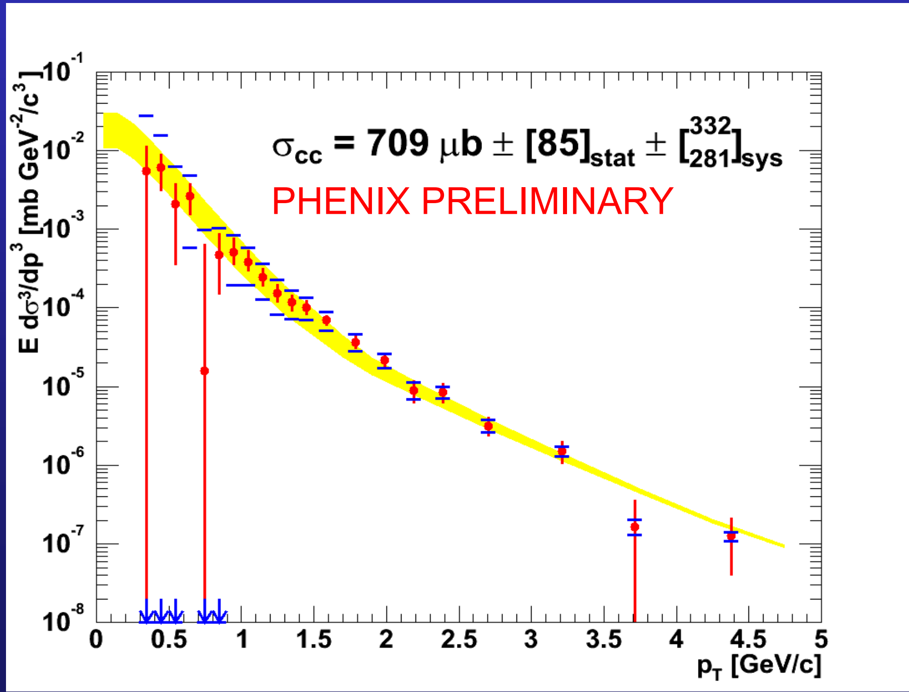
- Sophisticated background subtraction (see talk by **O.Drapier**)
  - Subtract photonic contribution (validated with converter method)
  - Subtract $K \rightarrow \pi e \nu$, $\rho,\omega,\phi \rightarrow e^+e^-$

Open charm at PHENIX: p-p

- In spite of the huge background, several interesting physics hints have been obtained

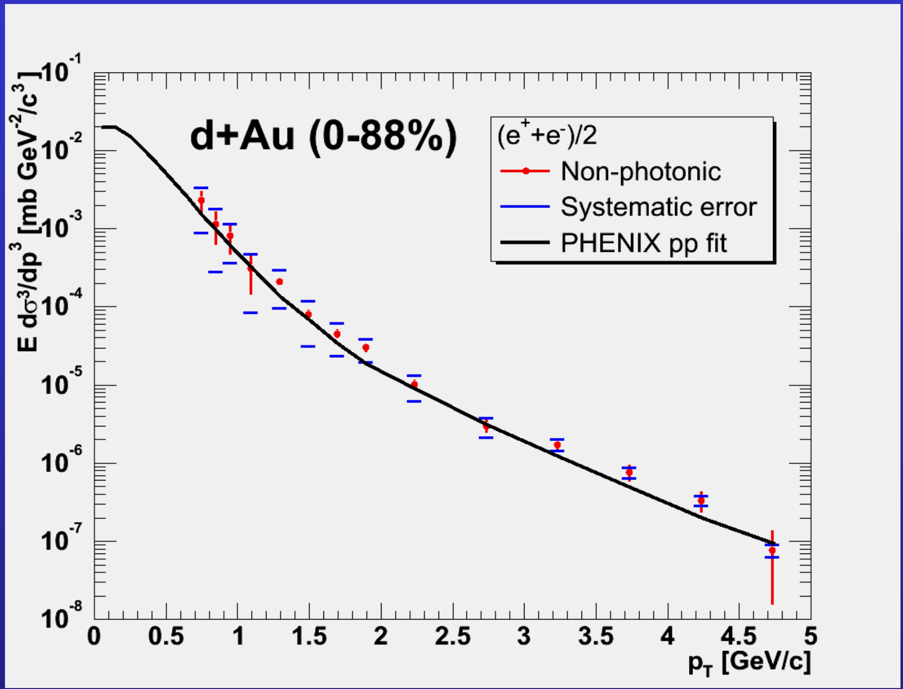
- PYTHIA is not able to reproduce the differential p-p single-electron spectra
- PHENIX spectrum is harder for p_T>1.5 GeV/c (where signal is significant)
- Indication for an open beauty contribution…

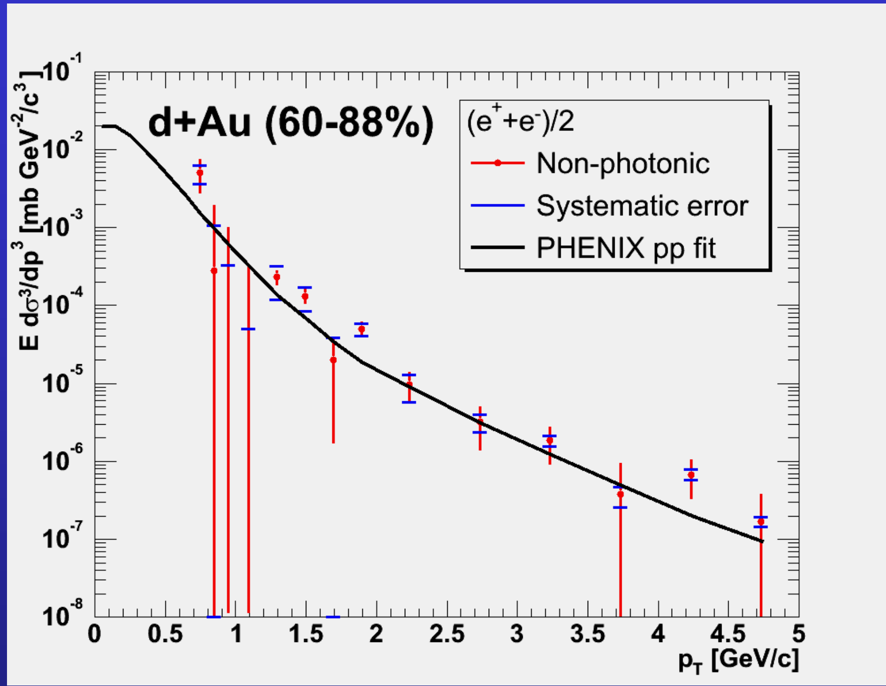




Phenomenological fit to extract σ_{tot}

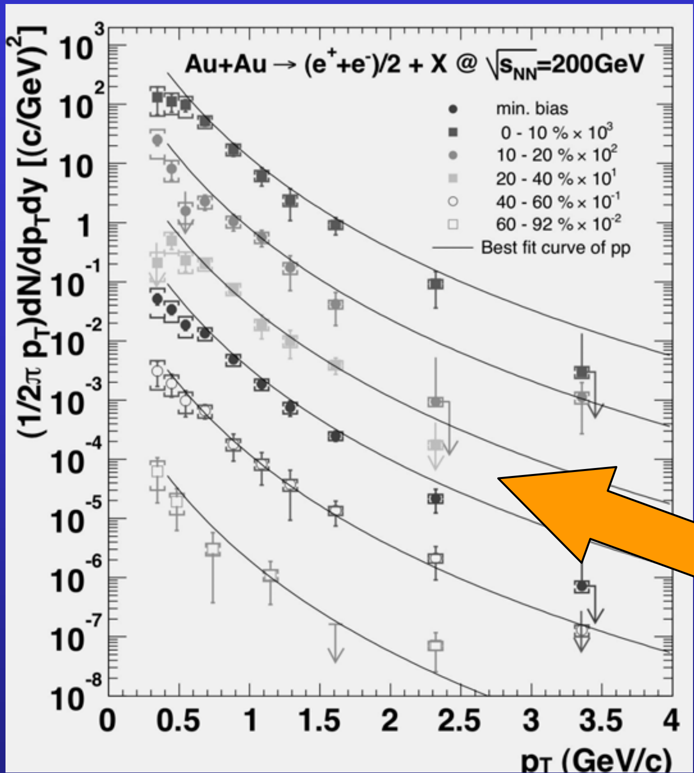
Open charm at PHENIX: d-Au





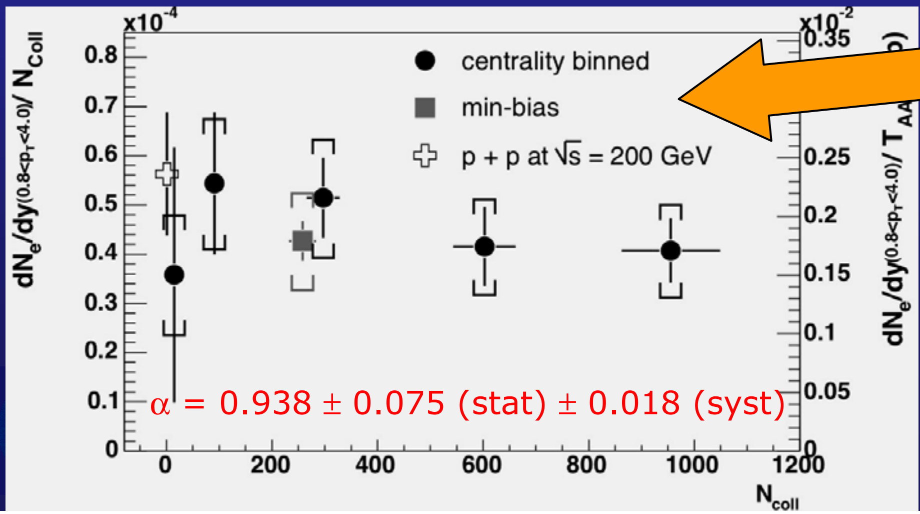
- d-Au data scaled by $1/N_{coll}$ and plotted against phenomenological p+p fit to data
- No significant nuclear effects (as in fixed target data, see E866)
- No indication of shadowing effect at mid-rapidity (as already seen in $J/\psi \rightarrow e^+e^-$)
- Binary scaling seems to hold for every centrality bin

Open charm at PHENIX: Au-Au



- Two important physics questions:
  1) Is there quenching at high p_T ?
     (as observed in light quark sector)
  2) Is the N_{coll} scaling violated?
     (as could have been observed at SPS…)

Question 1
No answer for the moment

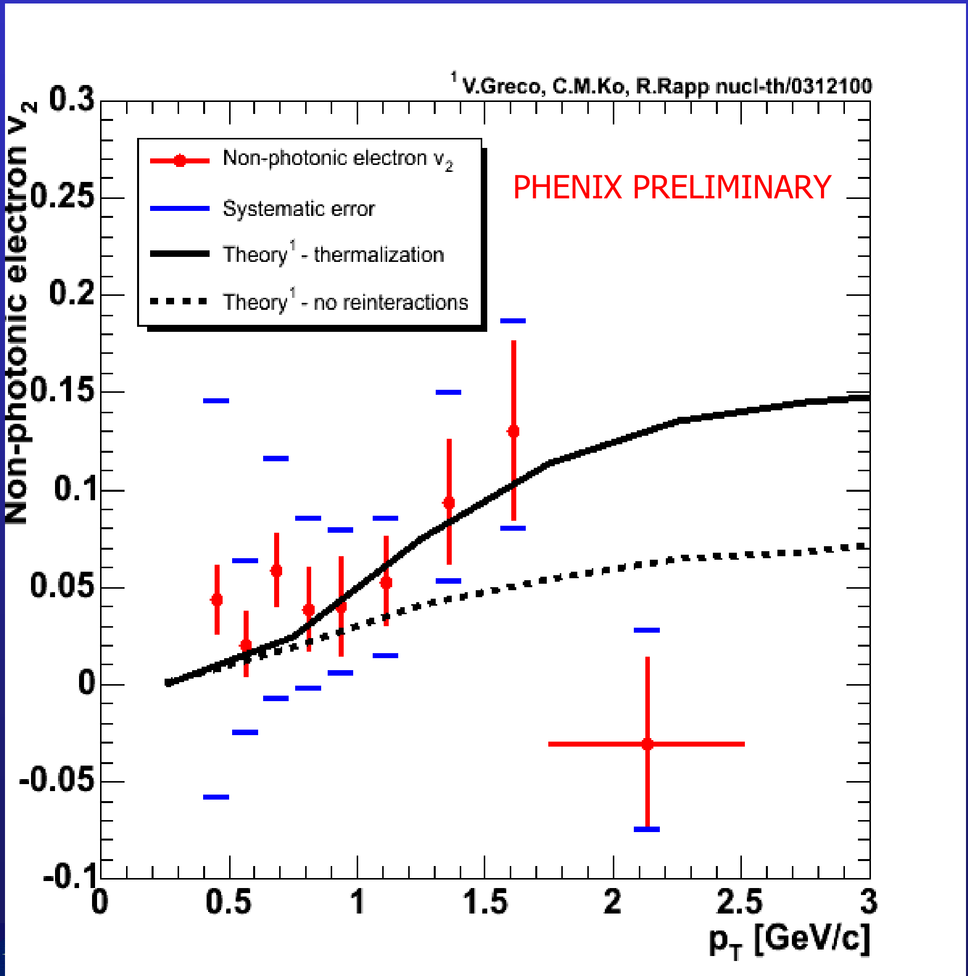


Question 2
No evidence for open charm anomalous enhancement
(same indication at $\sqrt{s}$=62.4 GeV)

Is the factor-3 enhancement seen at SPS not due to open charm ?

Charm flow?

- Single electron p_T spectra insensitive to (possible) thermalization of heavy quarks with respect to a scenario without final state interactions



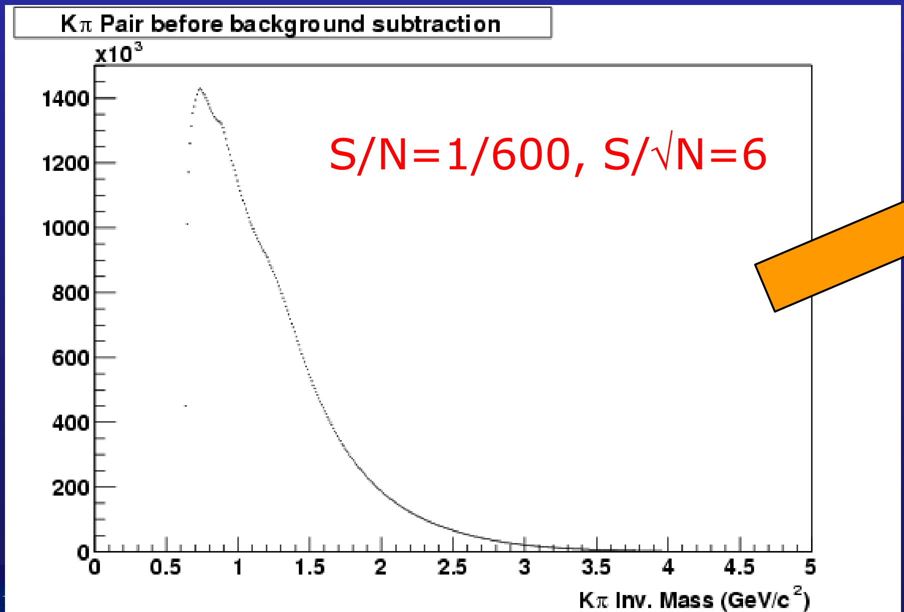
- Charm quark v_2 expected to be zero if there is no energy loss

- No clear conclusion can be drawn from PHENIX Run-2 results
- Wait for more statistics

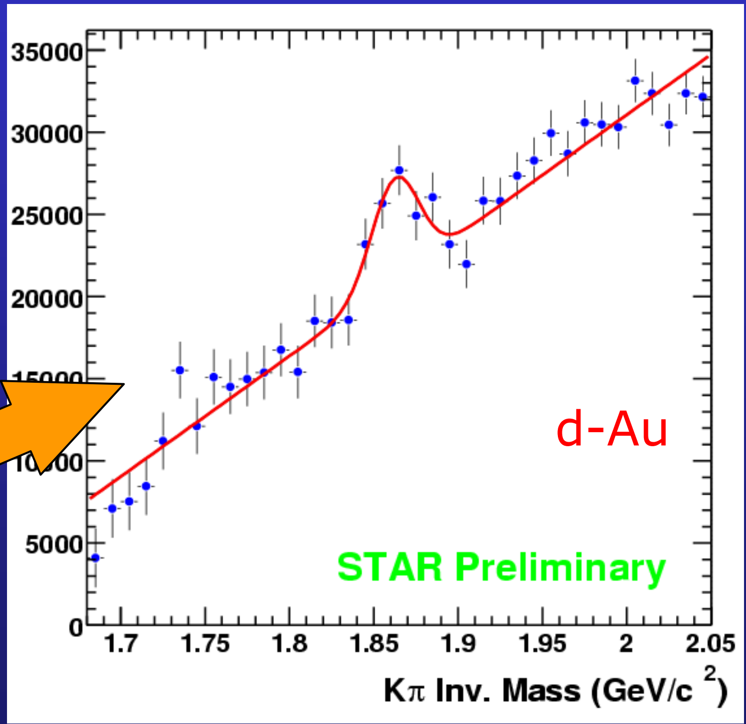
Open charm at STAR

- A direct open charm measurement is very useful, in order to validate the set of results obtained through single electrons

- Notoriously difficult
  - short lifetime
  - low production rates
  - large combinatorial background
- Pair EACH oppositely charged kaon and pion in the event



After mixed event subtraction

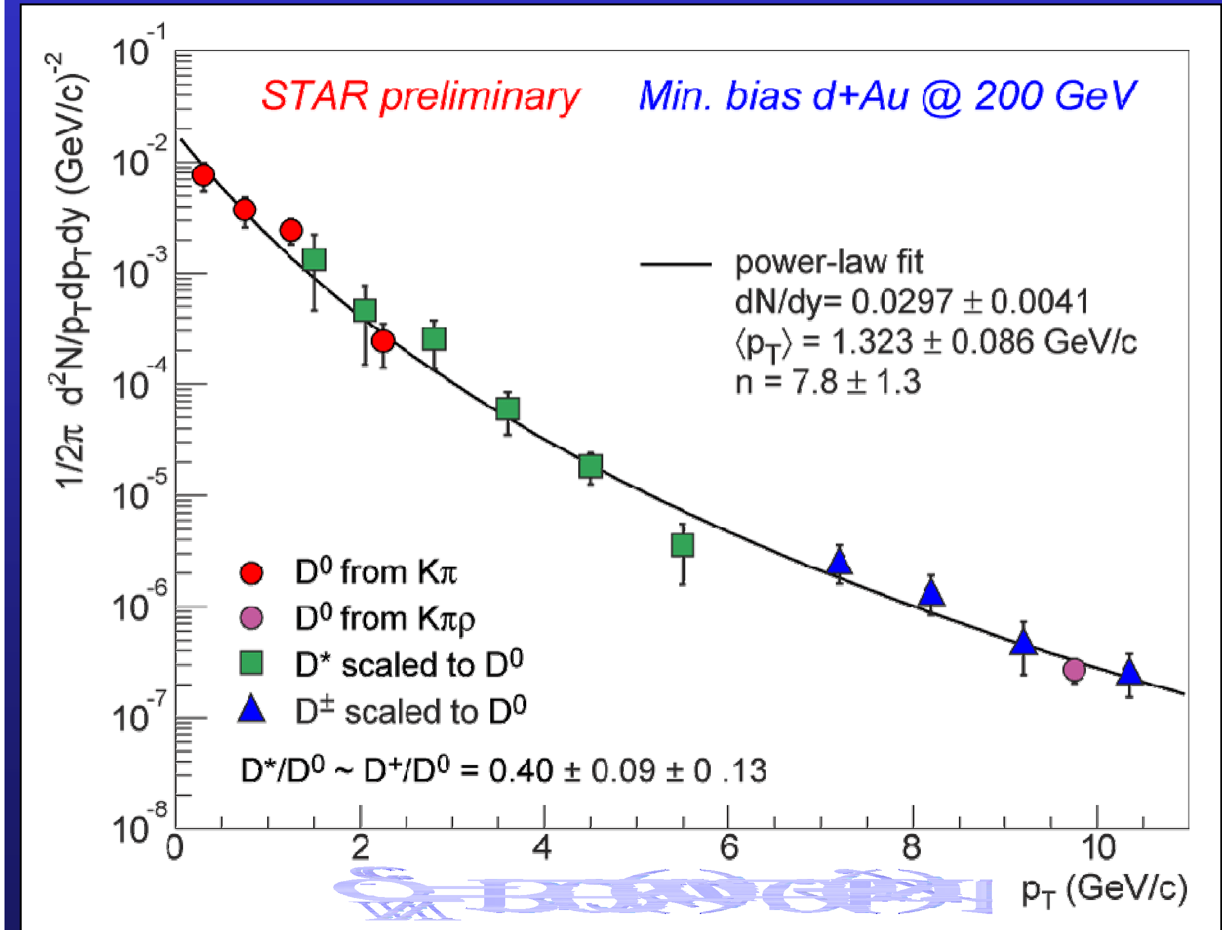


- $D^0 \rightarrow K^-\pi^+$ +c.c.
- $D^0 \rightarrow K^-\pi^+\rho^0$
- $D^{*\pm} \rightarrow D^0\pi$
- $D^\pm \rightarrow K\pi\pi$

See talk by **M. Calderon**

d-Au: absolute cross sections

- Assume σ(D*) = σ(D±)
- Scale σ(D*) and σ(D±) to match D^0 by $D^*/D^0=0.40$



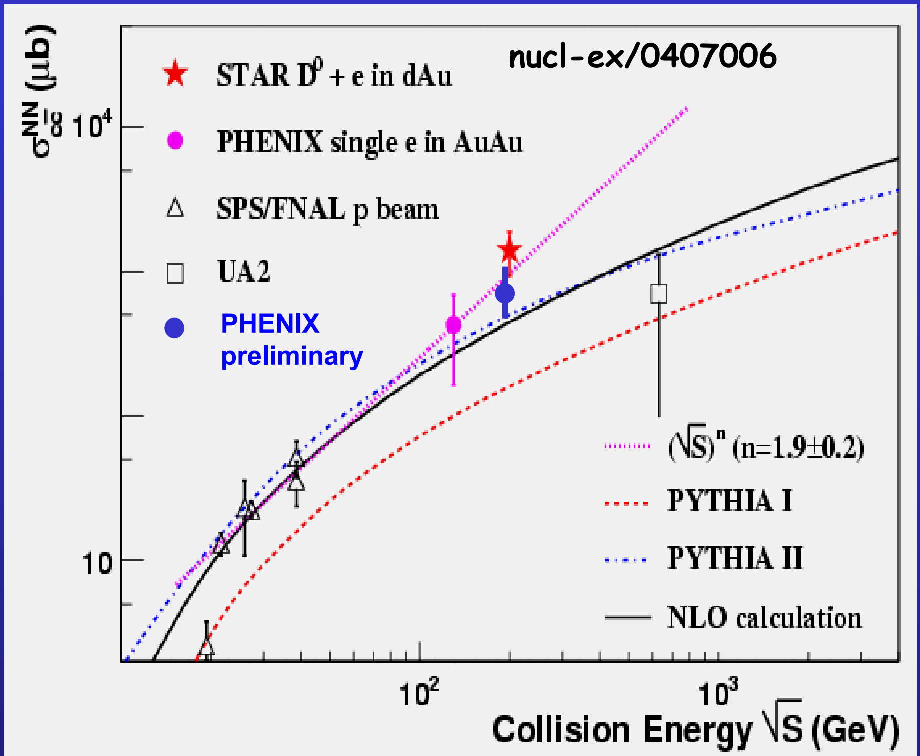
Combine with electron analysis

- Check relative systematics
- Better determination of σ_{tot}

$$\sigma_{c\bar{c}}^{NN} = 1.4 \pm 0.2(stat) \pm 0.4(sys)\ \text{mb}$$

Within errors consistent with binary scaling

Cross section comparisons

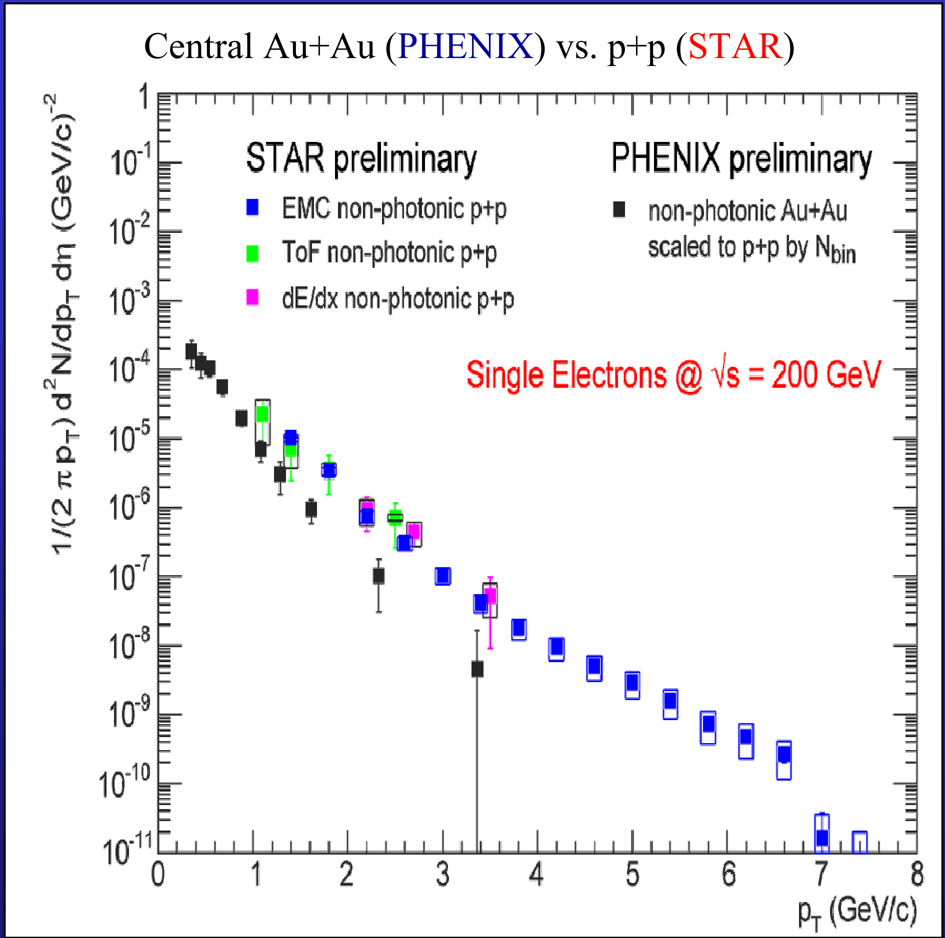


- PHENIX e (pp) σ ~ 0.7 ± 0.1 ± 0.3 mb
- STAR D (dAu) σ ~ 1.3 ± 0.2 ± 0.4 mb
- STAR D+e (dAu) σ ~ 1.4 ± 0.2 ± 0.4 mb

Still not worried about discrepancy (less than 2σ)

- NLO calculations seem to underpredict the data (STAR, in particular)
- However, still large uncertainties in the extrapolations…

From d-Au to Au-Au: suppression ?



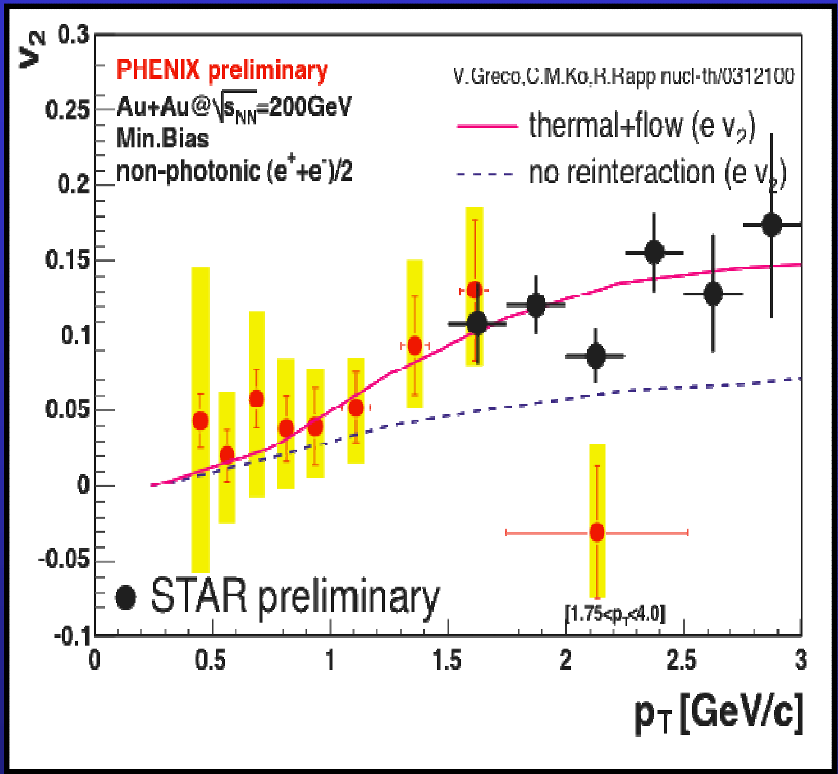
STAR p-p electrons
vs
PHENIX Au-Au electrons

Might indicate suppression in Au-Au collisions ?

Still early to draw any definite conclusion…….

(see talk by **A. Suaide**)

Charm flow at high p_T ?



- Direct measurement still not possible
- Does electron flow reflect D's flow?

- Still a long way to go
  - Centrality dependence
  - Understand systematics
  - Improve statistics

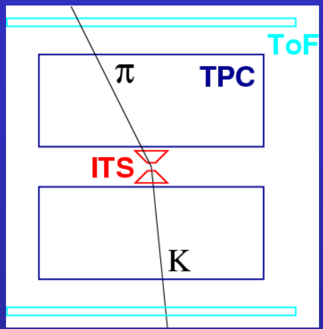
Open charm at SPS/RHIC: what have we learned?

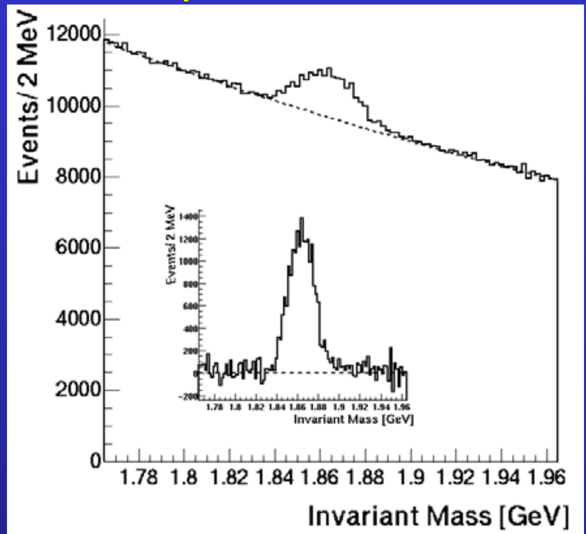
- SPS
  - p-A dimuon data indicate an open charm yield scaling with the number of collisions
  - Absolute yield consistent with direct open charm measurements
  - Anomaly in A-A
    - Open charm enhancement seems theoretically unlikely
    - Thermal dimuons?
  - NA60 expected to give an answer soon

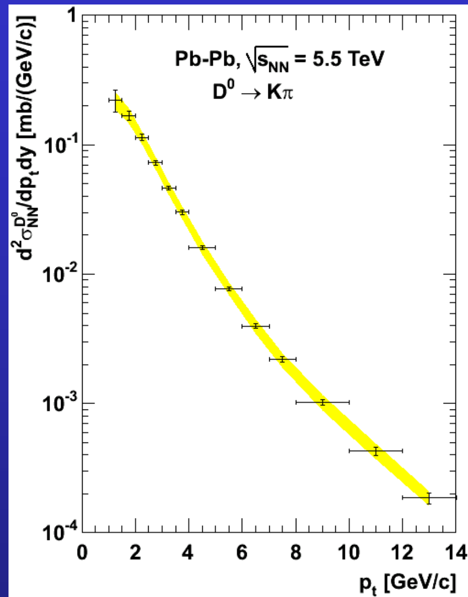
- RHIC
  - Scaling with number of collisions holds for d-Au compared to p-p (shadowing not important)
  - Scaling with number of collisions holds for Au-Au compared to p-p
    - What about the SPS excess?
  - Do p_T spectra in Au-Au indicate any suppression?
  - Do charm quarks flow?
    - No final conclusion for the moment

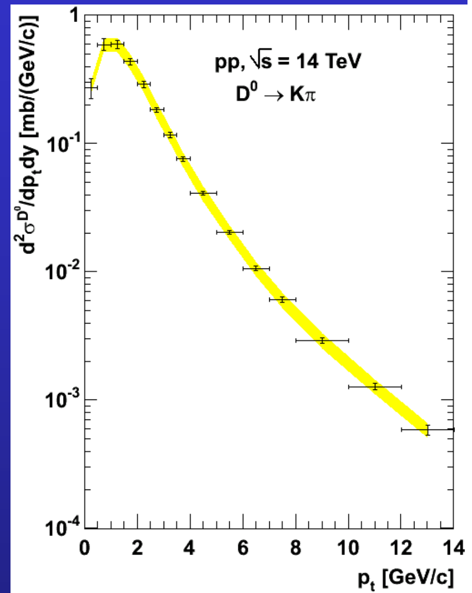
Open charm at ALICE: feasibility

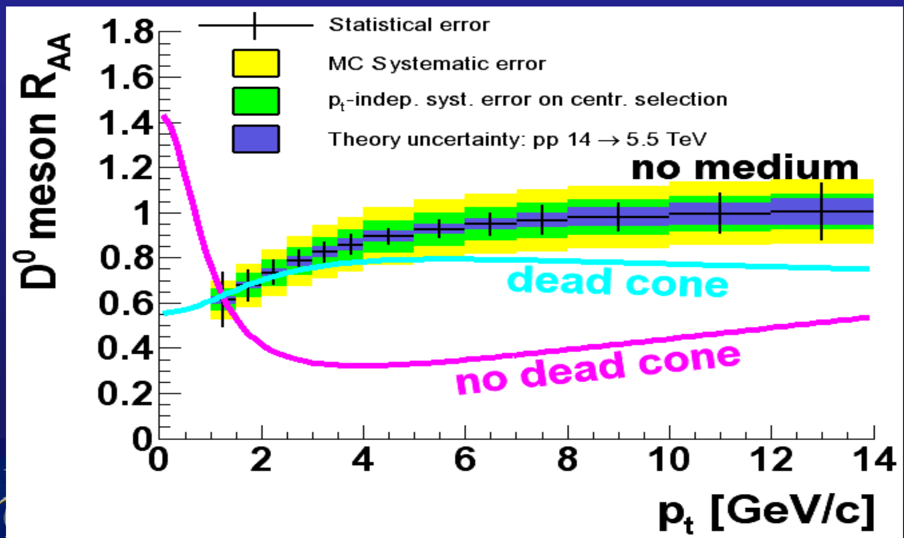
- One of the most detailed physics performance studies carried out up to now
- Direct measurement possible









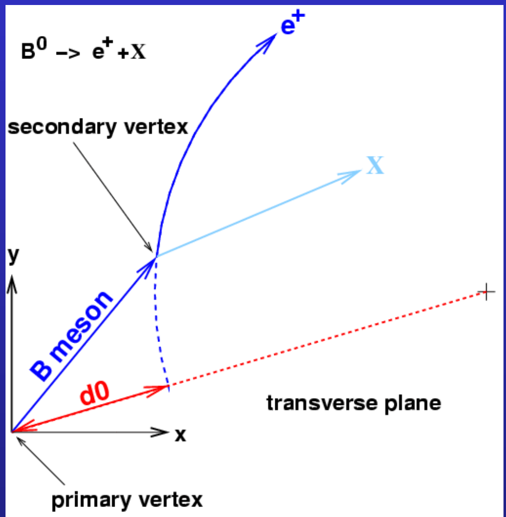


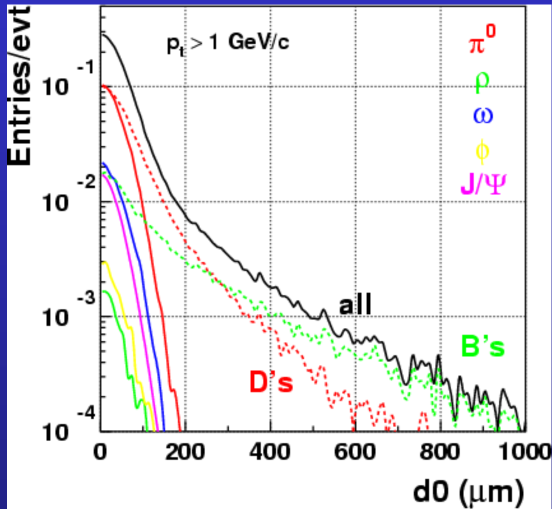
	S	S/B (%)	$S/\sqrt{S+B}$
PbPb	13000	11	37
pp	19000	11	44

Statistics expected for 1 LHC year, 1σ mass cut

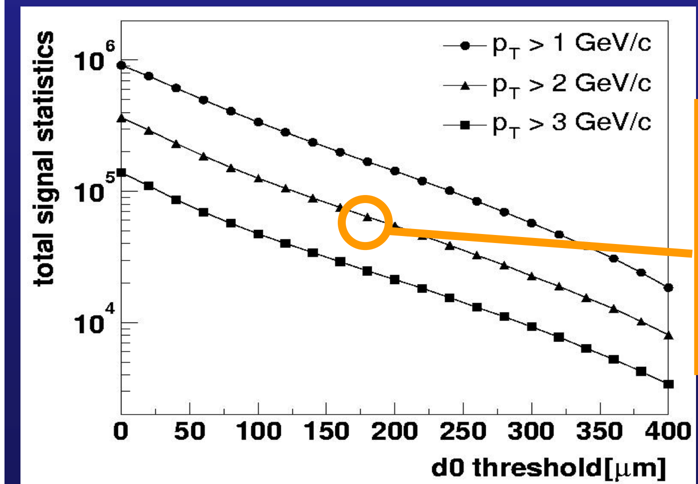
Open bottom at ALICE: feasibility

- Various possibilities (central barrel, muon arm)
- One of the most promising: single electrons in the TRD, coupled to displaced vertex

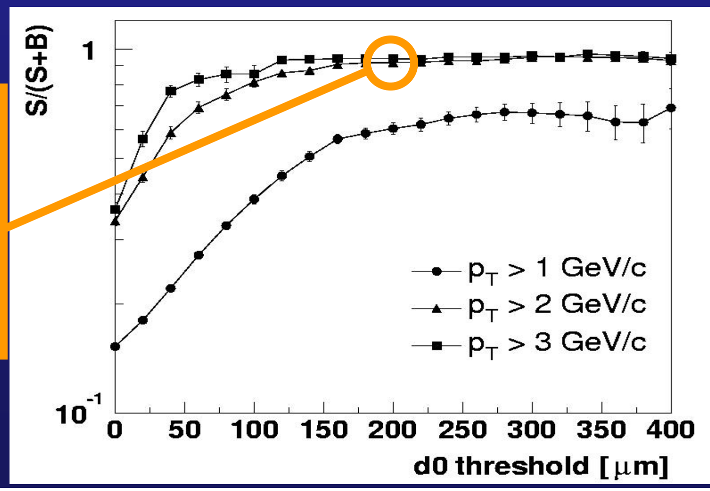




- D0<d0cut
  - Improve S/B for resonances
- D0>d0cut
  - Measure electrons from D & B



$B \to e^{\pm}$ in ITS/TPC/TRD
$p_T > 2$ GeV/c,
d0 > 180 μm:
50000 $e^{\pm}$,
S/(S+B) = 90%



Conclusions

- Heavy quarks and quarkonia
  - After 25 years still a hot and lively physics topic
- Charmonium
- A-A
  - NA50, NA60 $\rightarrow$ Anomalous J/ψ suppression
  - PHENIX $\rightarrow$ Au-Au run-4 results are approaching
- p-p, p-A (d-A)
  - E866, HERA-B $\rightarrow$ fundamental systematics

- Open charm
- Real data start to be available only now
  - NA60 $\rightarrow$ displaced vertices identified
  - PHENIX, STAR $\rightarrow$ indirect measurement
    - $\rightarrow$ N_{coll} scaling
    - $\rightarrow$ quenching, flow ?

- LHC
- A window above T_c
- New probes: B, Υ

Many important results have been achieved…

…still many exciting results in front of us !