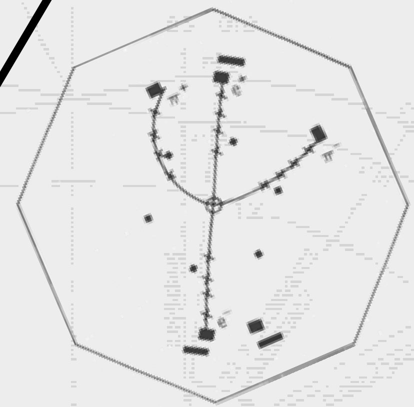
The sound [dĭng] in the chinese alphabet

丁 /



Typical event at SPEAR (SLAC) display

Heavy ions at RHIC

The J/Ψ adventure

J/Ψ simultaneously discovered in november 1974

Ting et al. at the Brookhaven National Laboratory

Richter et al. at the Stanford Linear Accelerator

Introduction

- J/Ψ (prod in A-A) has been and is studied at :
  - SPS (CERN) : NA38, NA50, NA60 (fixed target)
  - RHIC (BNL) : PHENIX (collider)
- J/Ψ studied for QGP started in 1986
  - Almost 20 years ago…
- Plan for this lecture
  - Will follow history
    - ✓ J/Ψ study at SPS
    - ✓ J/Ψ study at RHIC
    - ✓ Few words about future
  - Note : won't talk much about theory (see H. Satz's lecture)

Introduction

- Why charmonia ?
  - Bound $c\bar{c}$ state → should melt in a QGP
  - Matsui and Satz 1986
    - ✓ From their abstract (Phys. Lett. B 178 (1986) 416)
      - ✗ 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 …/… It is concluded that J/Ψ suppression in nuclear collisions should provide an unambiguous signature of quark-glun plasma formation.

Introduction

- Theoritically

Ψ'	T_C	1.0
χ_C	T_C	1.0
J/Ψ	$1.4T_C$	3.8

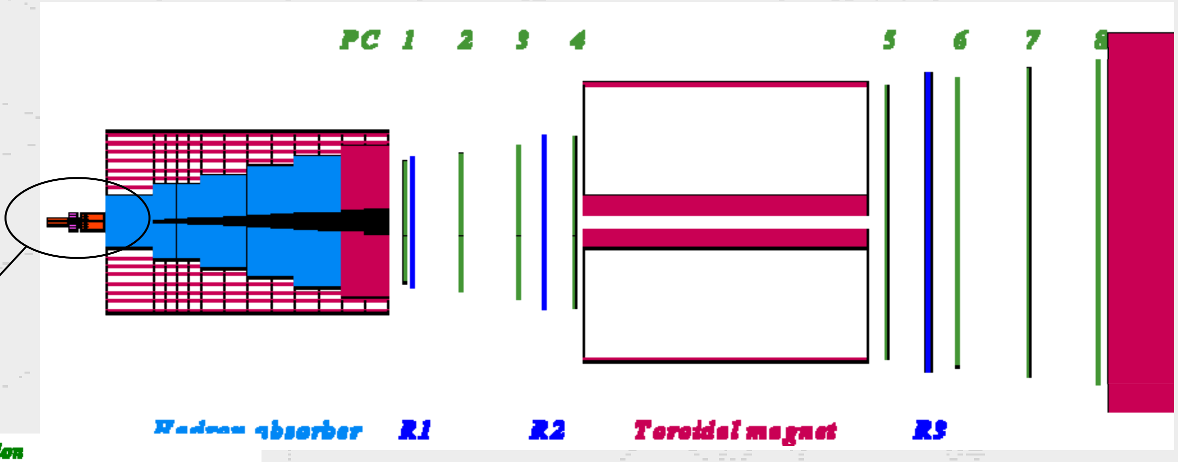
- experimentally
  - Easy to measure
    - ✓ (6%) $J/\Psi \rightarrow \mu^+\mu^-$
    - ✓ (0.7%) $\Psi' \rightarrow \mu^+\mu^-$
  - Not easy to measure
    - ✓ $\chi_C \rightarrow J/\Psi + \gamma$

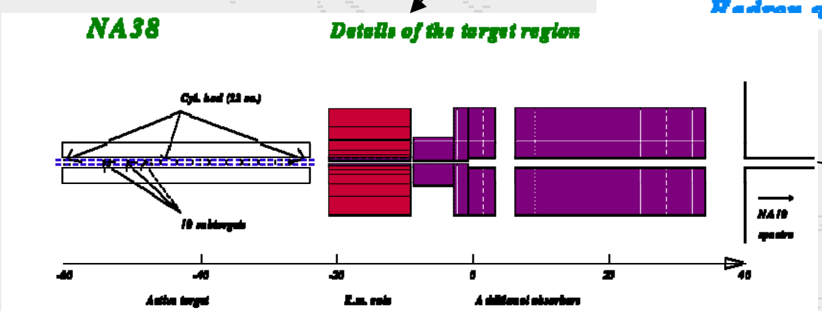
Keep in mind that :
Measured $J/\Psi \sim 0.6\ (J/\Psi) + 0.3\ (\chi_C \rightarrow J/\Psi) + 0.1\ (\Psi' \rightarrow J/\Psi)$

J/Ψ study at SPS

- NA38 : the experiment
  - Proposed in march 1985
  - Study thermal dimuon production
  - Start study J/Ψ production after Matsui-Satz's prediction

Data :
(450 GeV → √s=29.1 GeV)
(200 GeV → √s=19.4 GeV)
p-A 450 GeV (1987)
p-p, p-d 450 GeV (1992)
p-A 200 GeV (1987/1988)
A-B 200 GeV (1986/1990)





$$\varepsilon = \frac{dE_T}{dy}\Big]_{y=0} \frac{1}{S_\perp \tau}$$

First results O-U and S-U

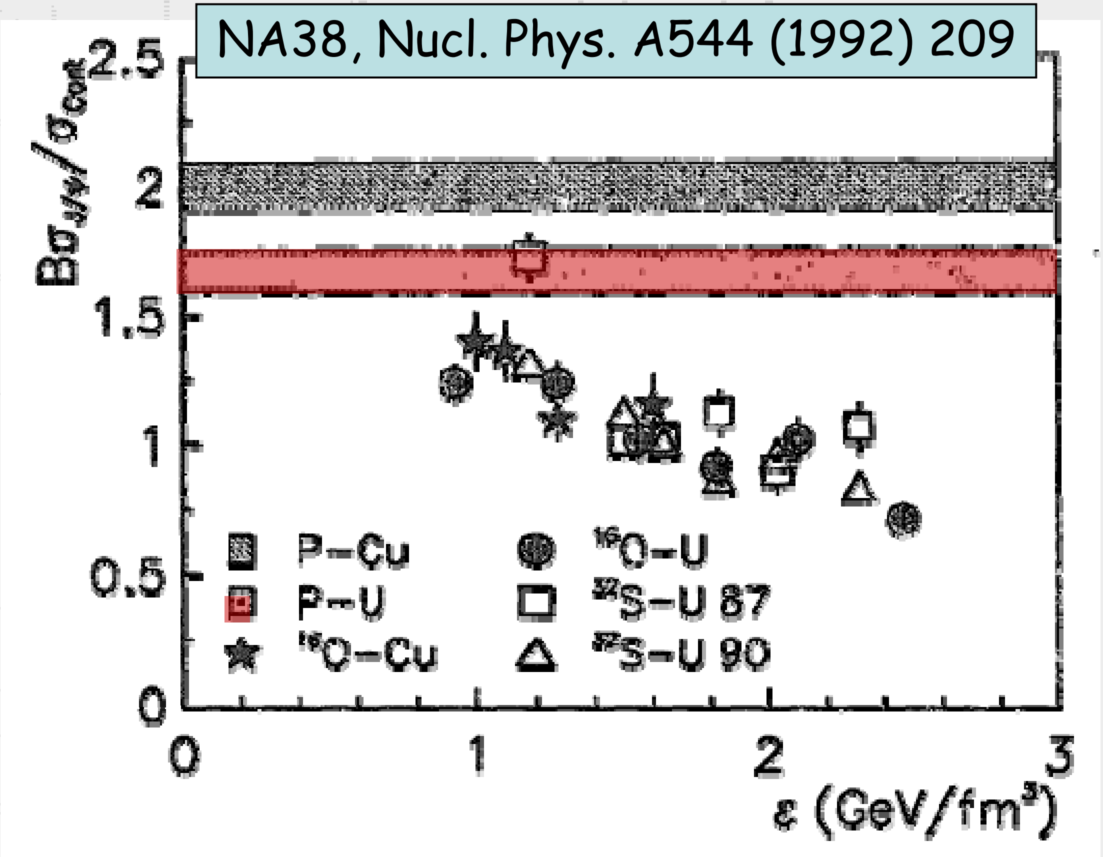
- First observation of the J/Ψ suppression

Is it a signal of QGP ?

2 issues here :

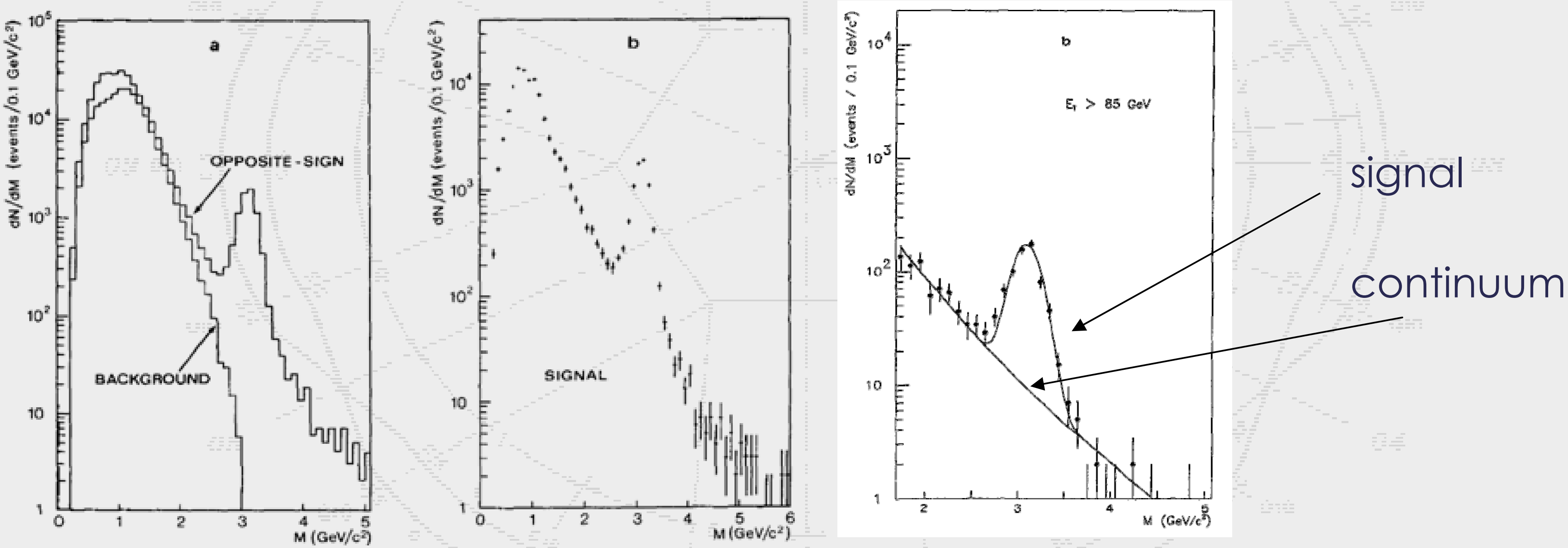
1. ***What is plotted***
   1. $\sigma_{J/\Psi}/\sigma_{cont}$
   2. What is continuum ?

- ***p-Cu ≠ p-U***
  - No plasma in p-A
  - Normal behaviour ?



1. What is plotted

- They measured signal/continuum (2.7-3.5)
  - Example : 200 GeV O-U reactions



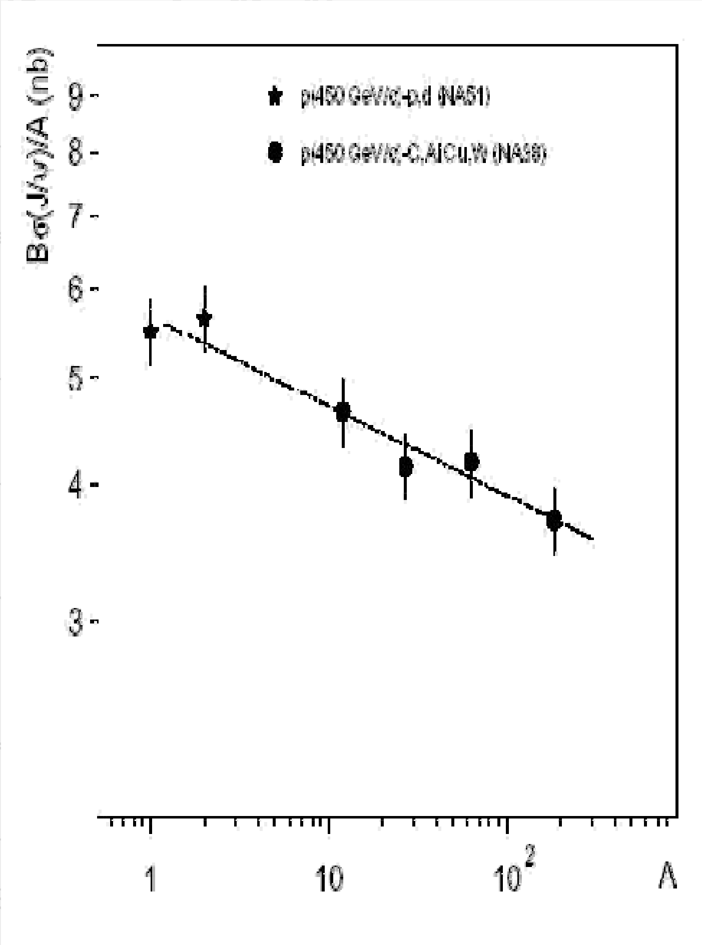
$\sigma_{AB}^{J/\Psi} \approx AB\sigma_{NN}^{J/\Psi}$ ➔ Normalise $\sigma_{J/\Psi}$ by AB

2. Proton-nucleus data

- Systematic study of p-A
  - A = p,d,C,Al,Cu,W
  - Observe a suppression

    $\sigma_{J/\psi}(pA) = \sigma_{J/\psi}(pp) \times A^{\alpha}$

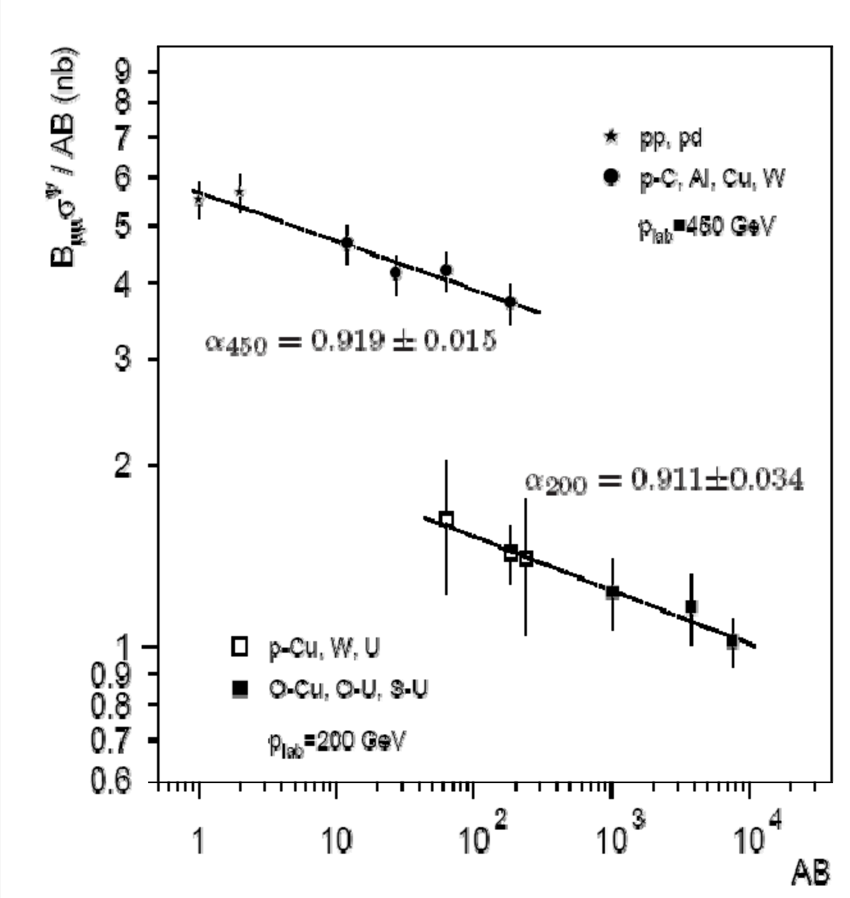
    $\alpha = 0{,}919 \pm 0{,}015$



- J/Ψ is suppressed in « normal » nuclear matter

Back to J/Ψ suppression

- All data follow the power law



p-A 450 GeV from NA38: 1st p-A sample (1987)

pp, p-d 450 GeV from NA51: collected in 1992

p-A 200 GeV secondary beam collected in 1987/88 and

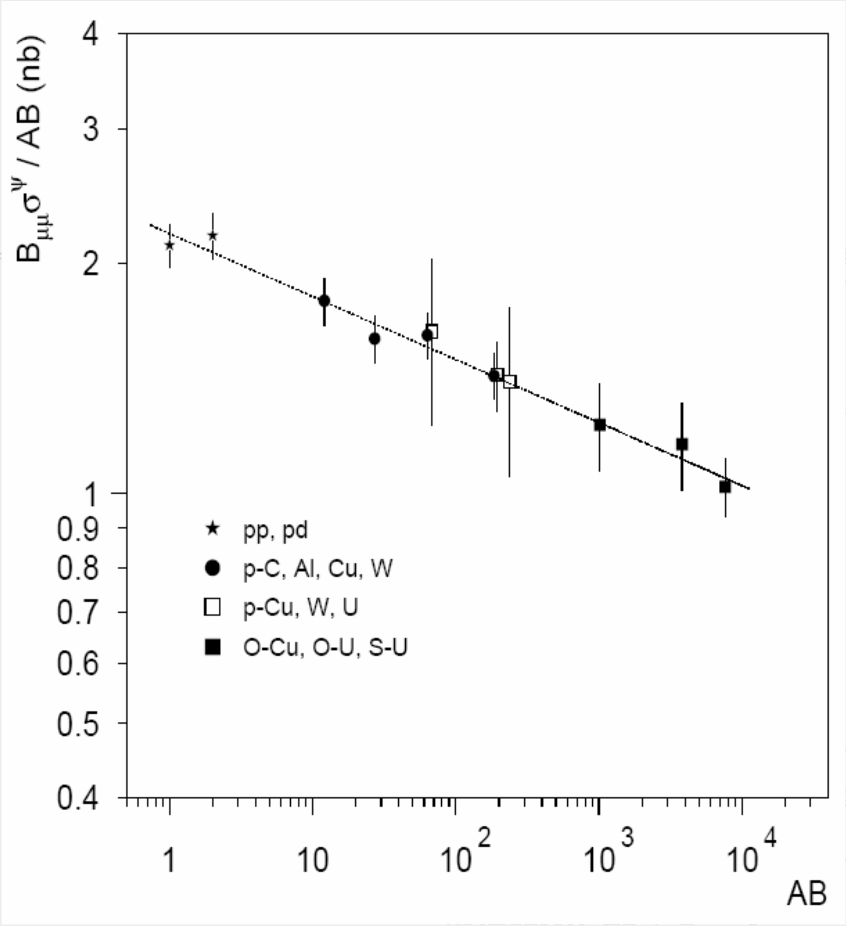
A-B 200 GeV (1986/1990)

Separate fit of $B_{\mu\mu}\sigma_0(A \times B)^{\alpha-1}$*:* α_{450} *and* α_{200} *compatible*

"Simultaneous" fit (same α*)* $\rightarrow$ *rescaling 450 ↘ 200 GeV*

Back to J/Ψ suppression

- All data follow the power law



Simultaneous fit leads to

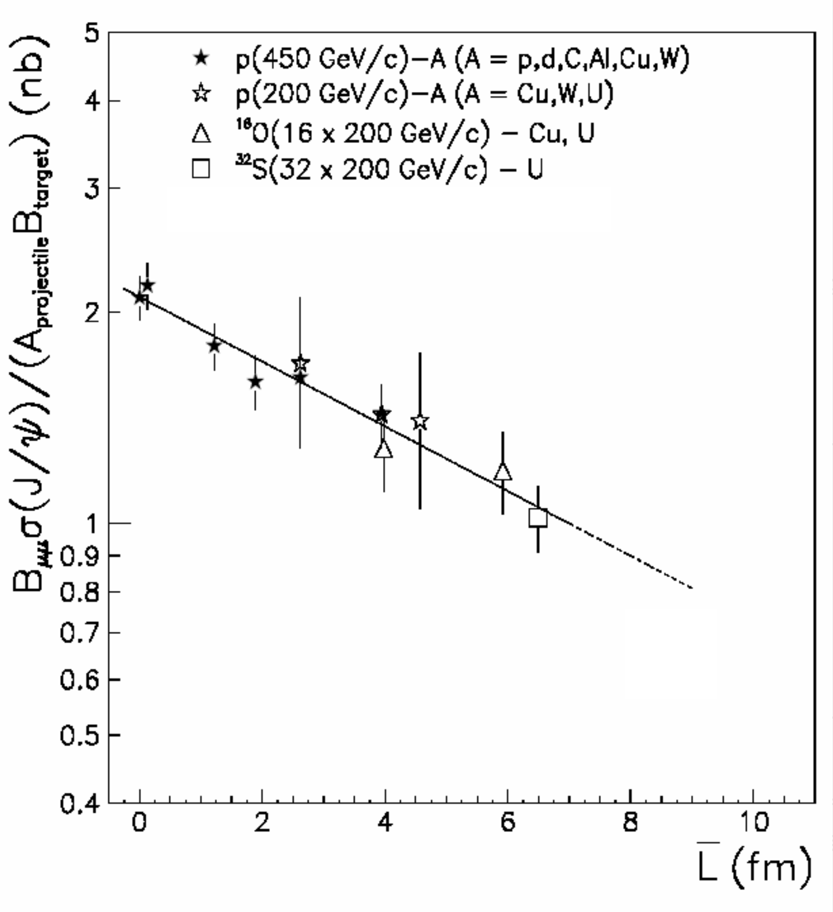
$\alpha_{sim} = 0.918 \pm 0.015$

A+A data follow p+A pattern

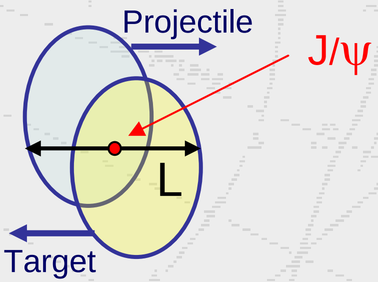
Normal suppression → No plasma

What is the normal suppression ?

- Nuclear matter absorption framework



Introducing L
L is the « length » of nuclear matter seen by the J/Ψ



$$\sigma_\psi(AB) \propto (AB)exp(-\rho_0\sigma_{abs}\bar{L})$$

ρ_0=average nucleon density
σ_{abs} = absorption cross-section

Summary of NA38

– NA38 took p-A data and O-Cu, O-U, S-U data

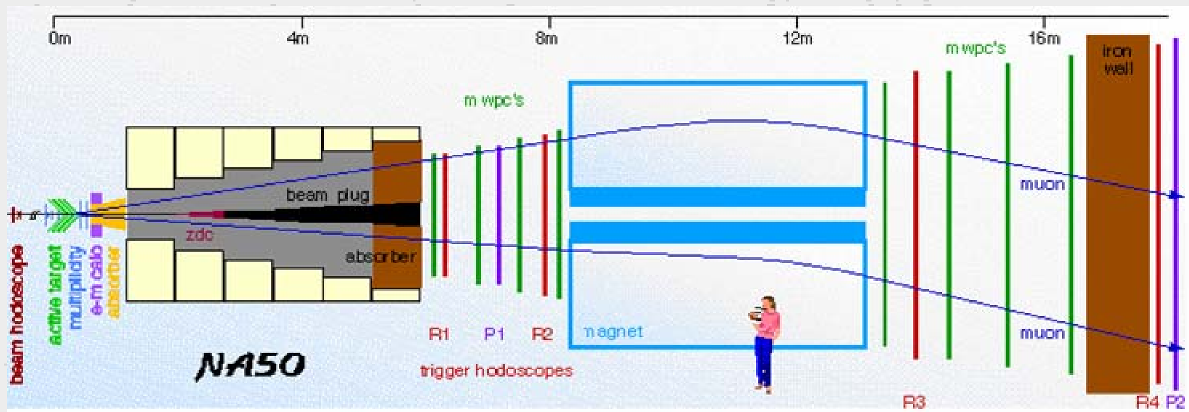
– A suppression is observed, but this suppression can be interpreted as the interaction of the J/Ψ with the nuclear matter

– We need to use a bigger system to reach the critical temperature.

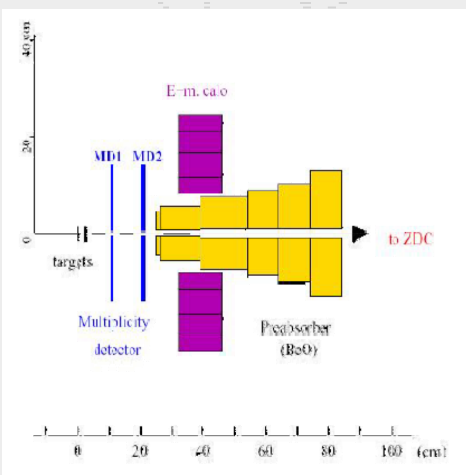
→ NA50 experiment

J/Ψ at SPS

- NA50 experiment
  - Same spectrometer as NA38
  - New detectors within target region
  - Pb-Pb data



Data :
(450 GeV $\rightarrow \sqrt{s}$=29.1 GeV)
(158 GeV $\rightarrow \sqrt{s}$=17.3 GeV)
Pb-Pb 158 GeV/A (1995-00)
p-A 450 GeV (1996-00)



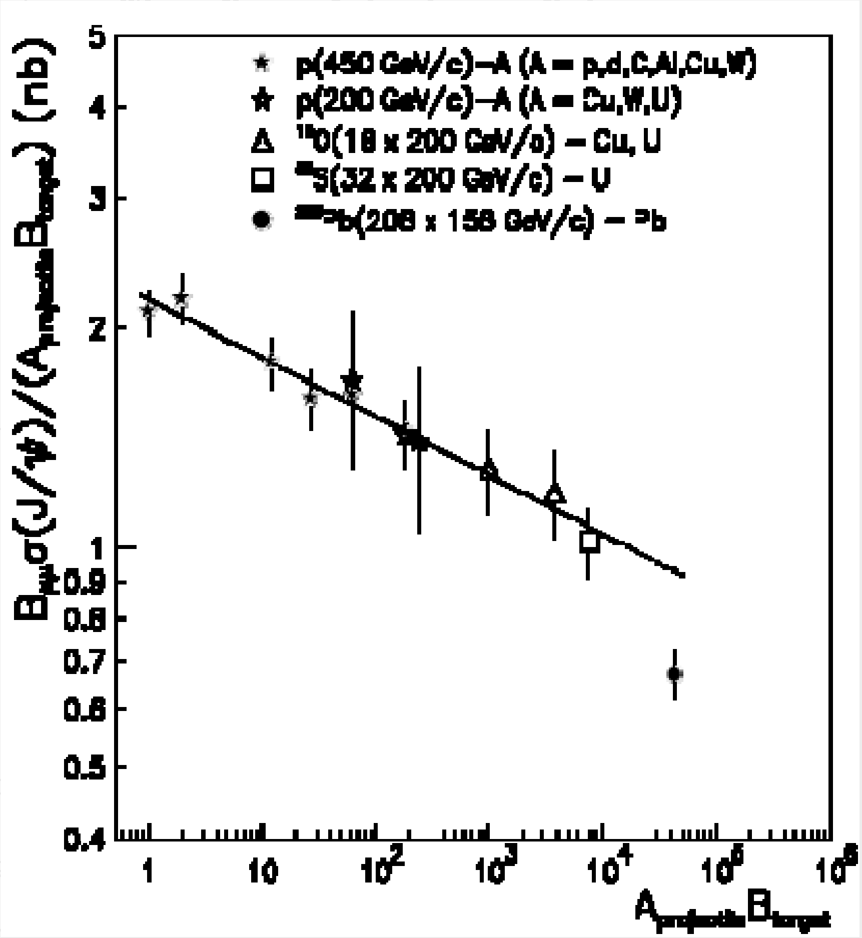
Additionnal zero degree calorimeter
Additionnal multiplicity detector

Additionnal J/Ψ suppression

- Pb-Pb data exhibit an additionnal suppression

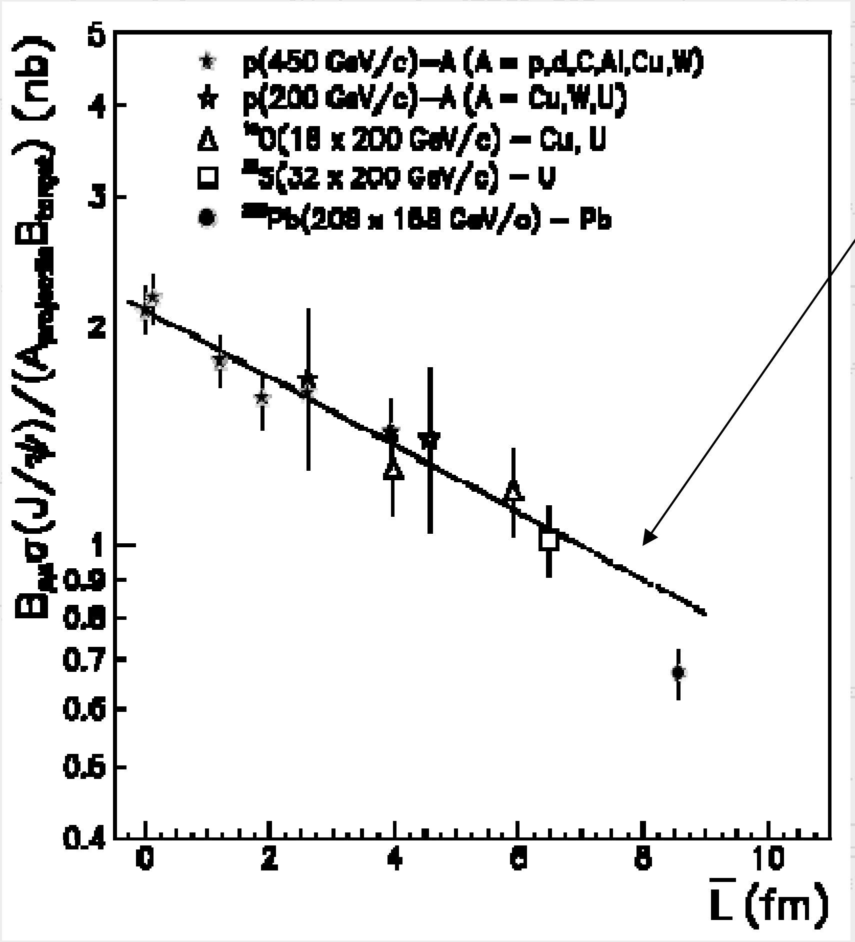
Difference between normal absorption and Pb-Pb behavior

Anomalous J/Ψ suppression in Pb-Pb interactions



Anomalous J/Ψ suppression

- Now plots as a function of L



$$\sigma_\psi(AB) \propto (AB)exp(-\rho_0\sigma_{abs}\bar{L})$$

« Normal » nuclear absorption

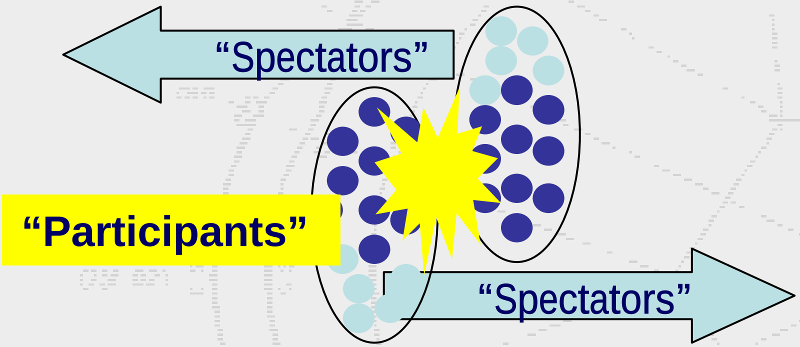
observe anomalous suppression in Pb-Pb interactions

First conclusions

- While NA38 data from p-p to S-U can be understood considering a normal J/Ψ suppression by its absorption within nuclear matter,
- NA50 Pb-Pb data exhibit an anomalous suppression which cannot be understood within the normal absorption framework.
- Can we get more information ? → look at data as a function of centrality

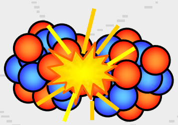
Study J/Ψ as a function of centrality

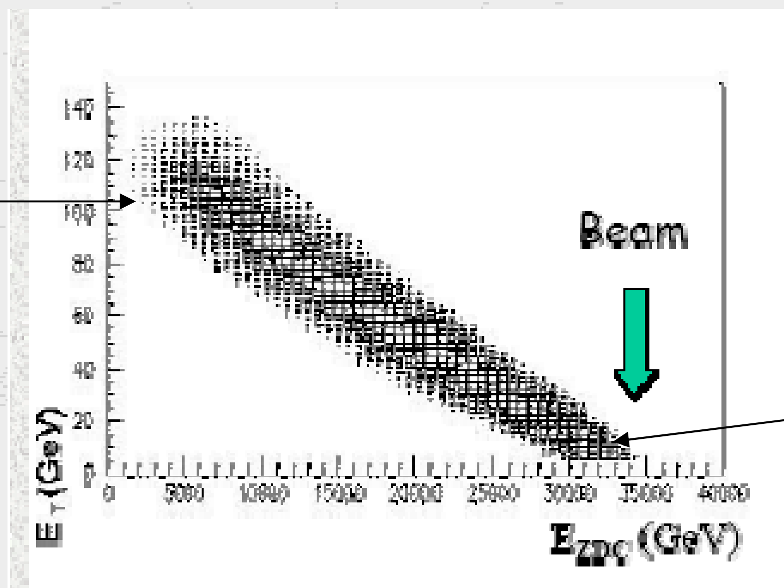
– The most central collision, the most dense matter



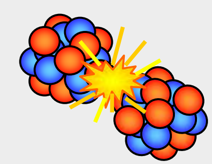
$$\varepsilon = \left.\frac{dE_T}{dy}\right]_{y=0} \frac{1}{S_\perp \tau}$$

Very central collisions



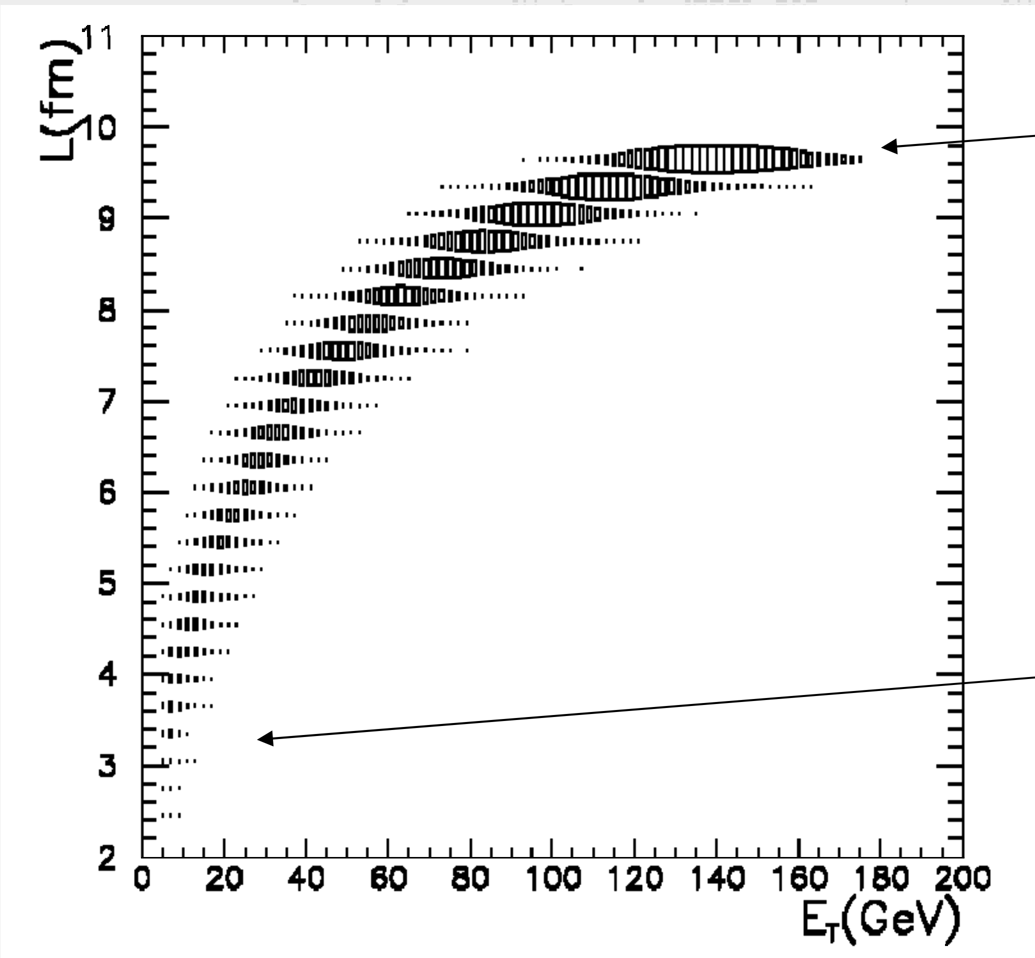


Very peripheral collisions

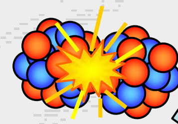


Study J/Ψ as a function of centrality

- L versus centrality

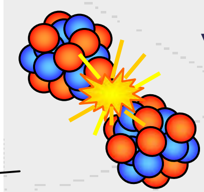


Very central collisions



Large L values

Large E_T (large density)



Very peripheral collisions

small E_T (small density)

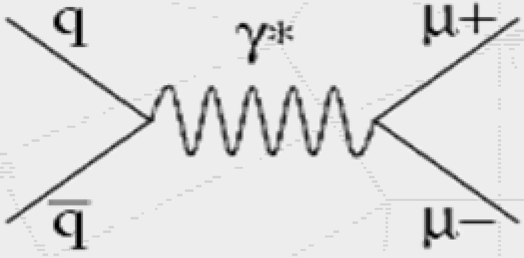
small L values

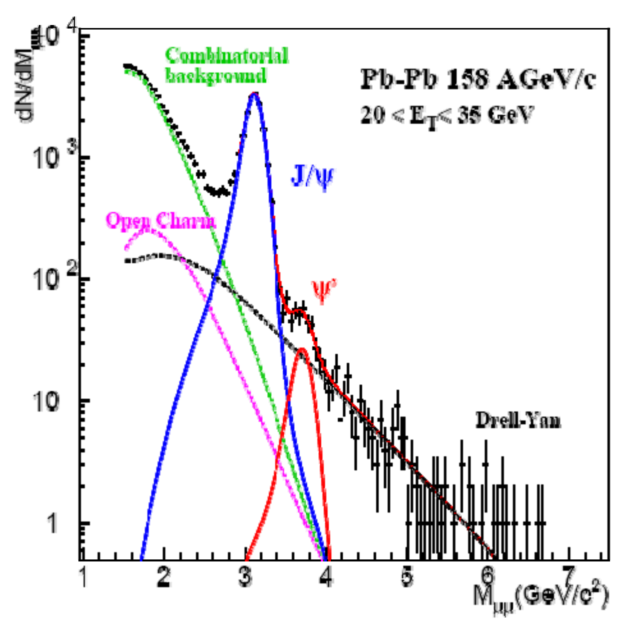
Study J/Ψ as a function of centrality

- Another requisite
  - Hard to measure Ψ cross section as a function of centrality, we have to take into account :
    - ✓ Uncertainties on luminosity measurement
    - ✓ Errors on efficiencies
    - ✓ Errors on centrality measurement
    - ✓ Effective AB calculation is model dependent
    - ✓ …
  - There is a way → go back to the mass spectrum

Study J/Ψ as a function of centrality

- Study Ψ/Drell-Yan
  - Drell-Yan is
    - ✓ a well-known process proportional to the number of elementary nucleon-nucleon collisions
    - ✓ Insensitive to the state of matter (QED process)

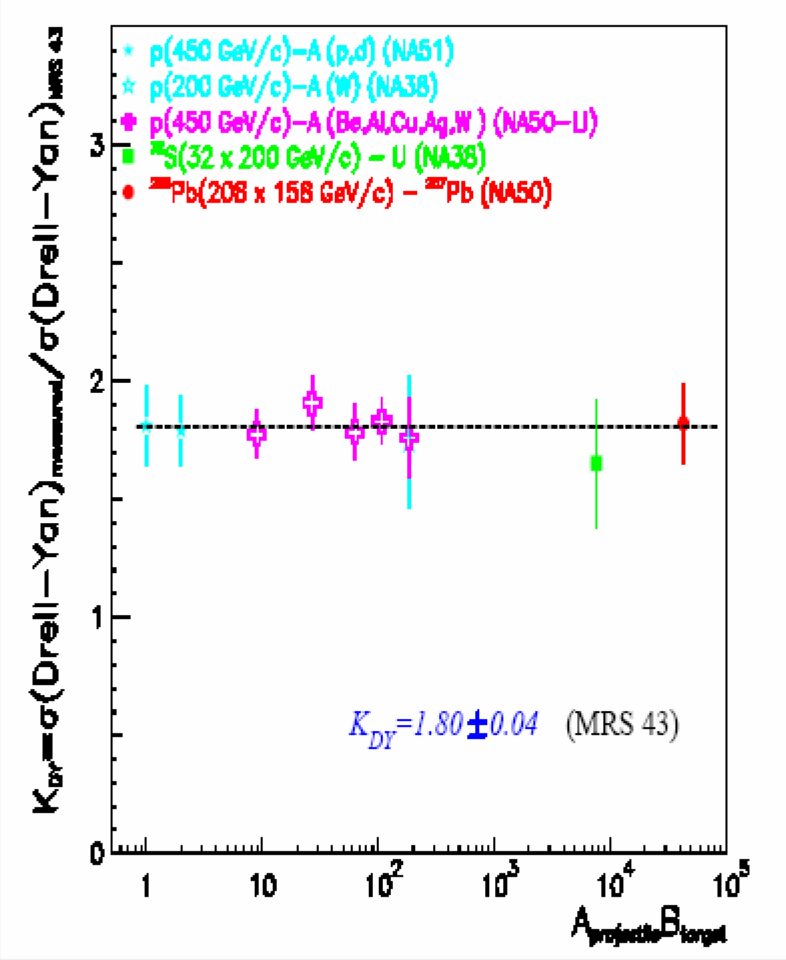




    - ✓ with the following advantages :
      - × Identical experimental biases
      - × Identical inefficiencies
      - × Identical selection criteria
      - × Identical cuts
    - ✓ Therefore, the corrections cancel out in the ratio $\sigma_{J/\Psi}/\sigma_{DY}$
    - ✓ But, there is a price : Drell-Yan statistic is small

Study Ψ/Drell-Yan

- Drell-Yan is under control

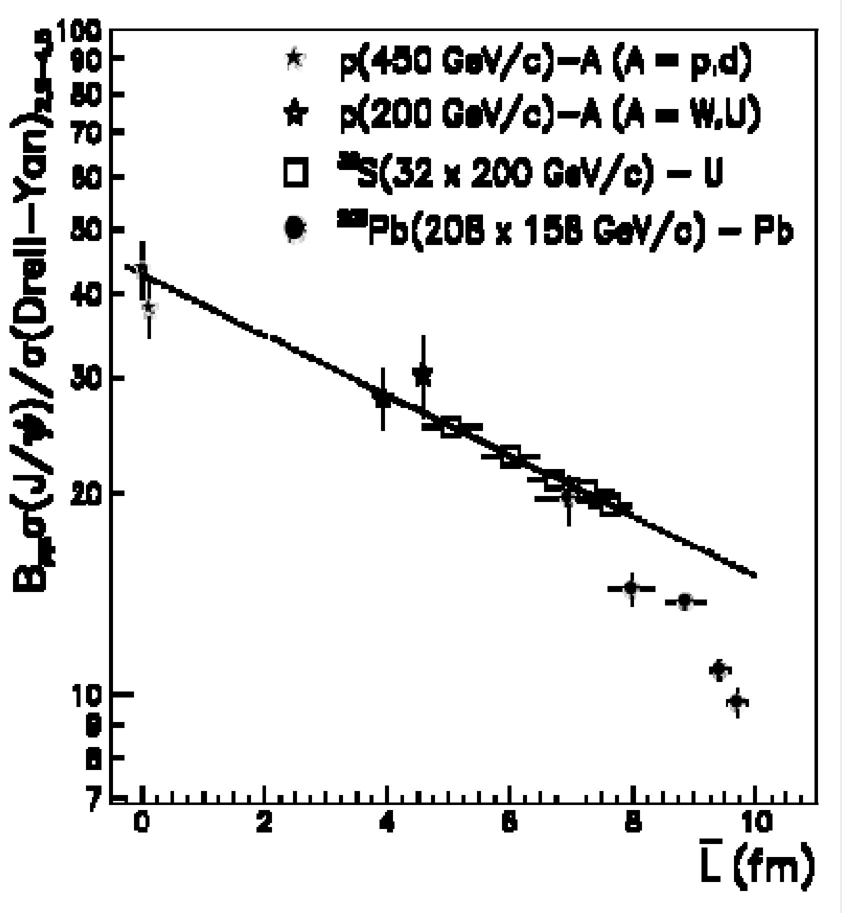


σ_{DY} is proportional to the number of nucleon-nucleon collisions from p-p up to Pb-Pb

σ_{DY} is ideal to compare different reactions

Study Ψ/drell-Yan

- Let's do it
  - Normal nuclear absorption is fitted on
    - ✓ P-p, p-d, S-U data
  - Pb-Pb data
    - ✓ Anomalous suppression
    - ✓ Peripheral Pb-Pb consistent with normal nuclear absorption
    - ✓ Suppression increases with centrality
  - But
    - ✓ Very few p-A data
      - × Not enough stat
  - Need more data
    - → new data taking



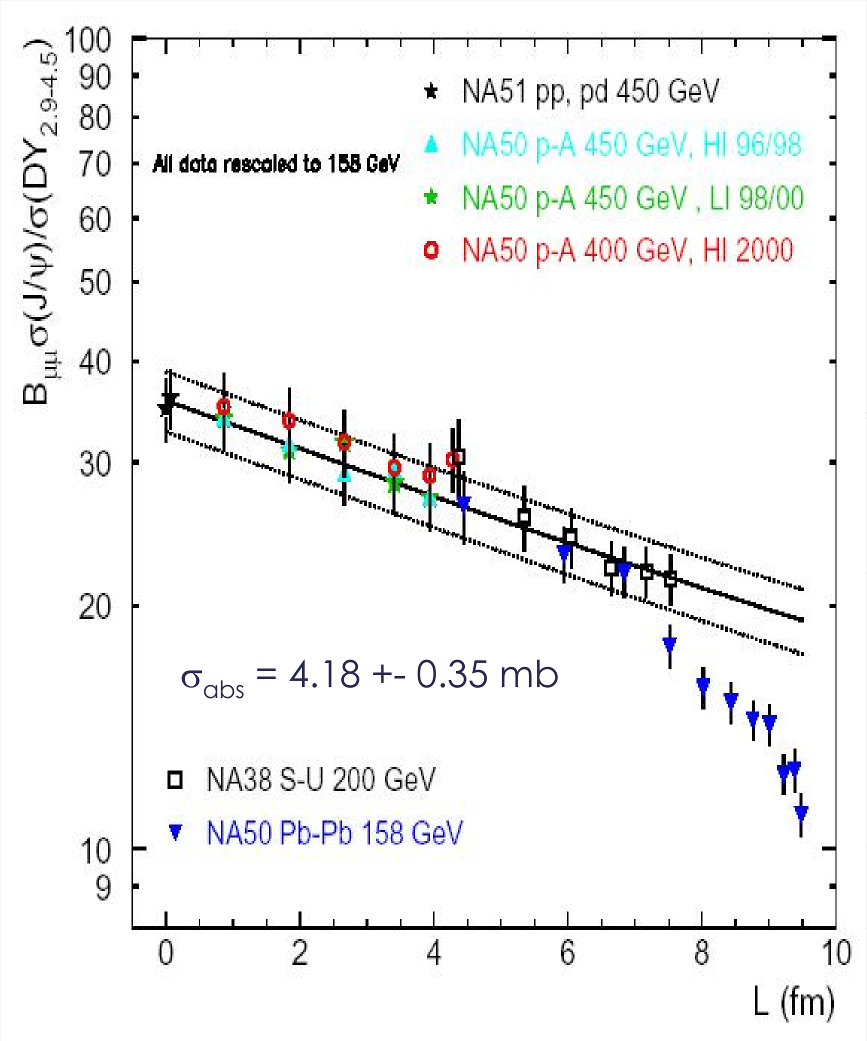
New NA50 data taking

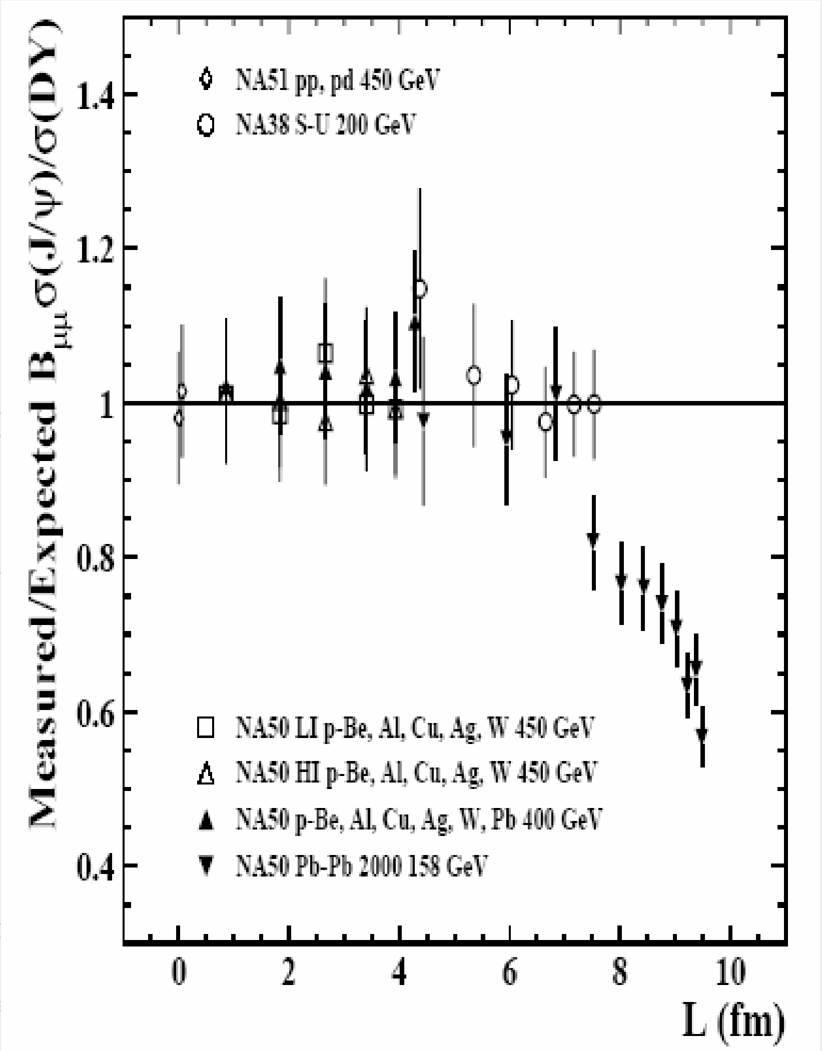
- Pb-Pb
  - ✓ Several configurations to
    - Increase statistics
    - understand issues like
      - Re-interactions within targets
      - Contamination due to Pb-air interactions

data sample	interaction length (L_T/λ_I)	number of sub-targets	beam intensity (ions/burst)	number of J/ψ
1995	17% λ_I	7 (in air)	3×10^7	50 000
1996	30% λ_I	7 (in air)	5×10^7	190 000
1998	7% λ_I	1 (in air)	5.5×10^7	49 000
2000	9.5% λ_I	1 (in vacuum)	7×10^7	129 000

- P-A
  - ✓ New high intensity (high statistics) runs

Last NA50 results

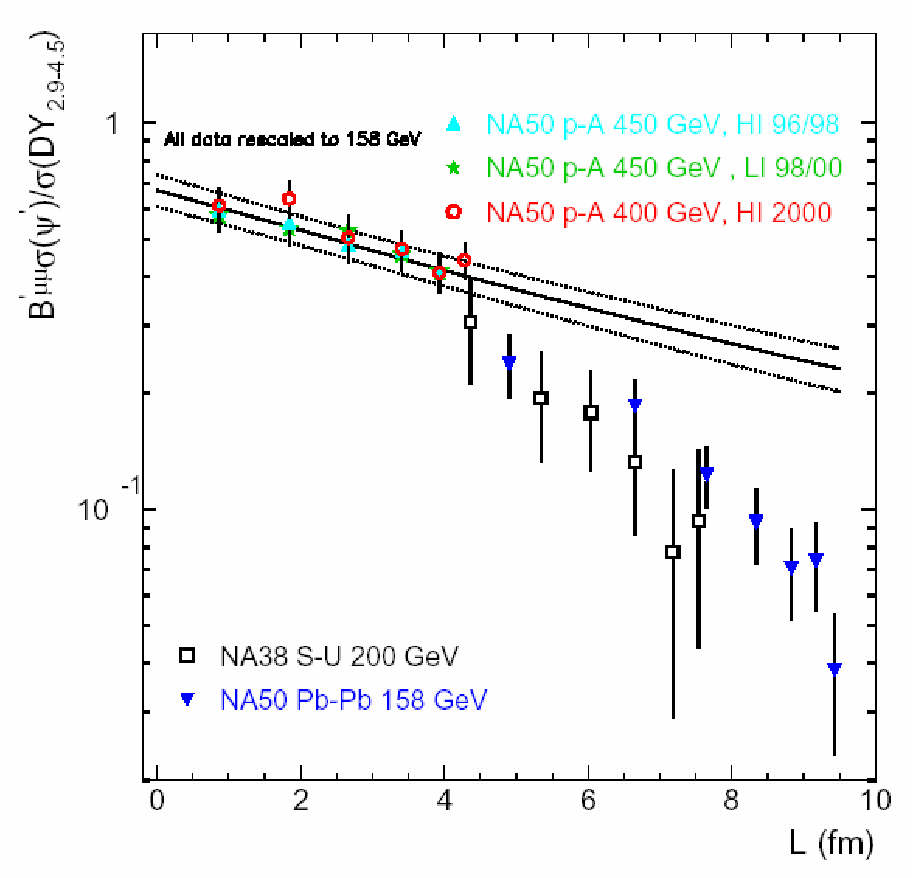




Quick look at the Ψ'

– Anomalous suppression already observed in S-U
– S-U and Pb-Pb data exhibits the same pattern

σ_{abs} = 7.6 +- 1.1 mb



Interpretations : 2 frameworks

- 1) yes, the J/Ψ suppression observed by NA50 is a signal of the QGP
- 2) no, the J/Ψ suppression observed by NA50 is NOT a signal of the QGP
  - Won't talk about 1) → see H. Satz's lecture
  - Let's have a quick look at option 2).

The alternative : comovers

- Suppression by hadron interactions

  - After the normal absorption in the nuclear environment, the survived J/Ψ's interact with secondary hadrons:

$$J/\Psi + h \rightarrow D\bar{D}$$

  - Crucial parameter : J/Ψ-hadron inelastic cross-section,
  - (σ_{co}) a very uncertain parameter !
  - Theoretical estimates : σ_{co} ~0.1-1 mb

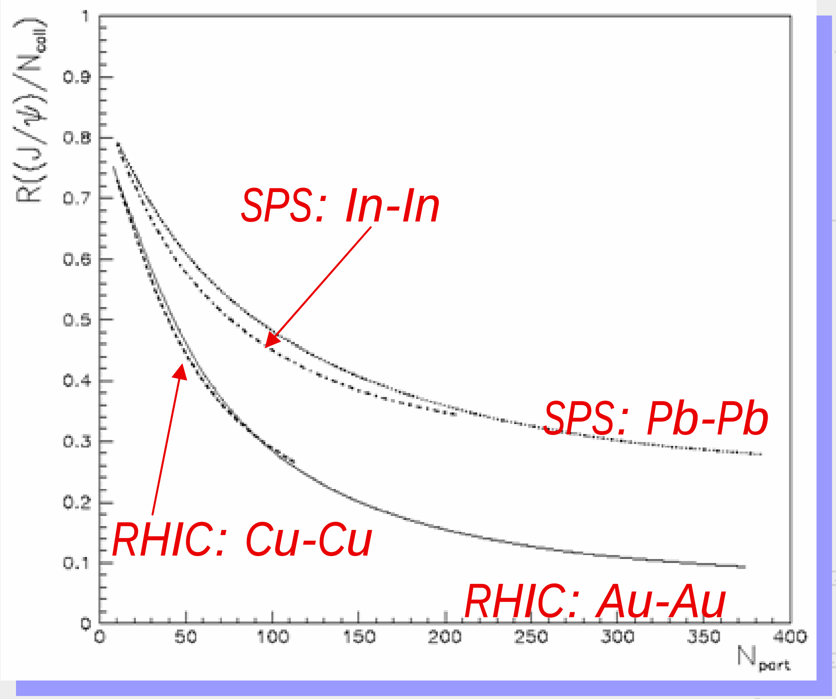
  - Common assumptions: the density of the hadron gas decreases as $1/\tau$; the interactions stop at the freeze-out.

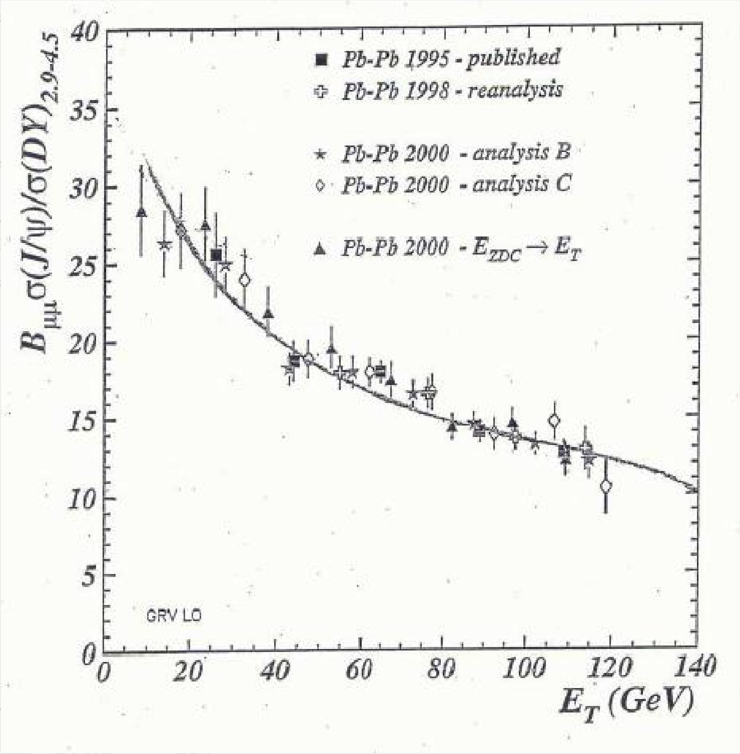
The alternative : comovers

- Comovers can fit NA50 data

σ_{abs} = 4,5 mb (pA) and σ_{co} = 0,65 mb (PbPb)

Predictions for future SPS and RHIC





→ **NA60 experiment**

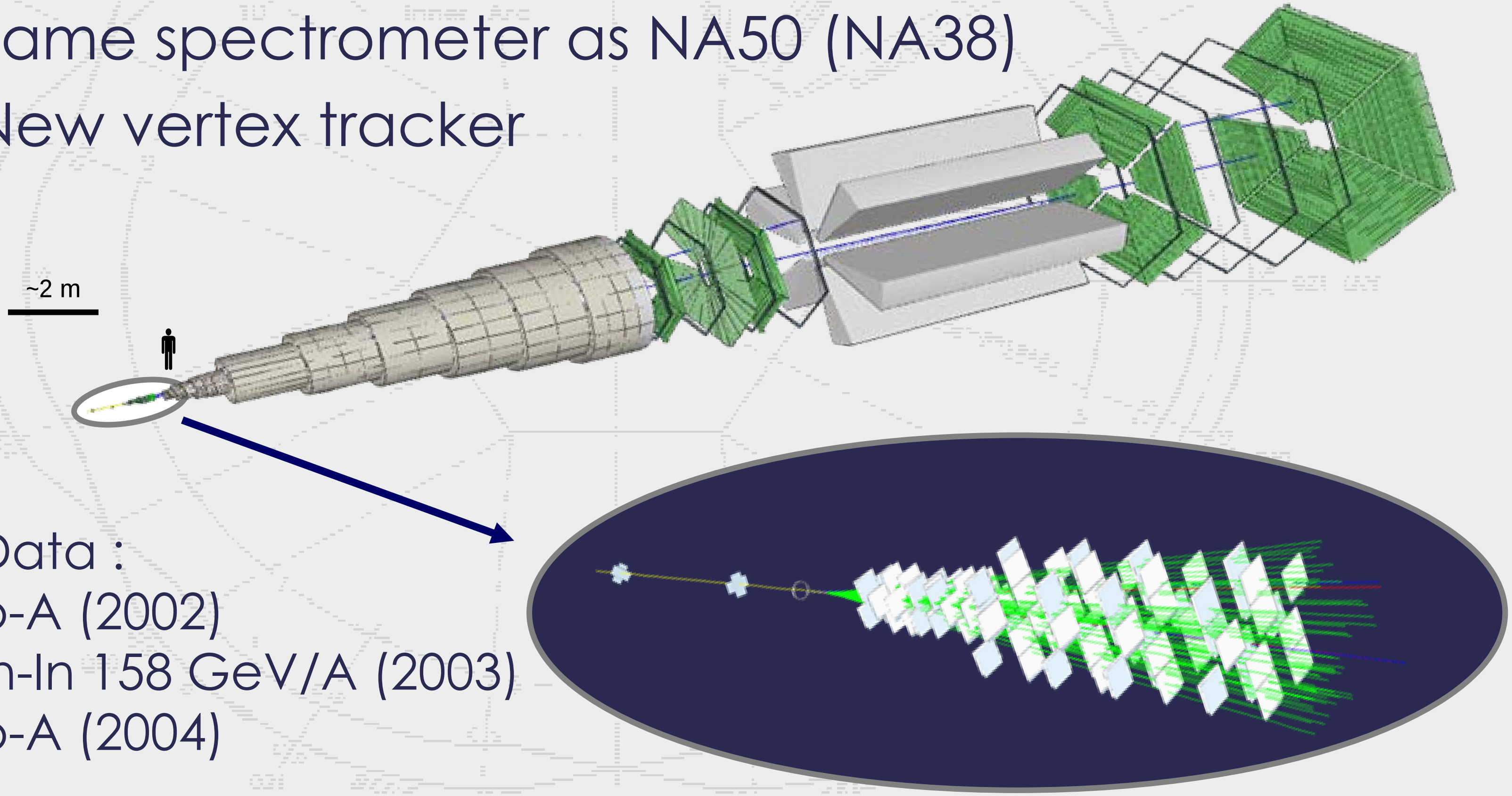
WARNING

- Starting from here, most of the results
  - are preliminary
  - Have been presented at Quark Matter 2005
  - They need to be confirmed !!

  - Follow the sign →

J/Ψ at SPS

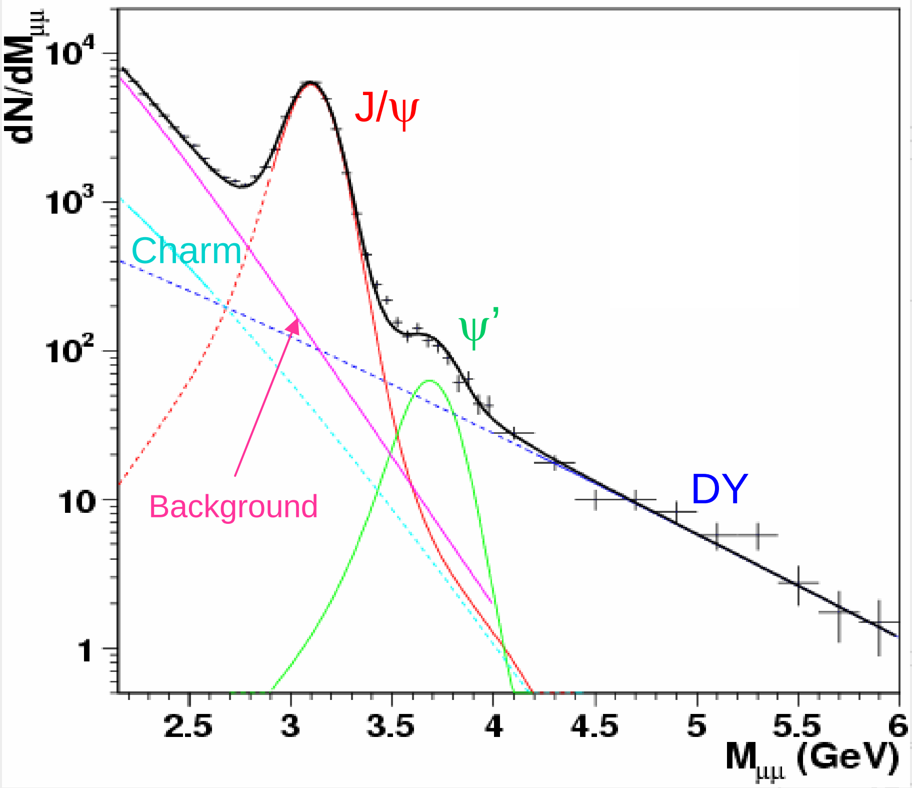
- NA60 experiment
  - Same spectrometer as NA50 (NA38)
  - New vertex tracker



Data :
p-A (2002)
In-In 158 GeV/A (2003)
p-A (2004)

Mass spectrum

- At SPS energies, the reference process commonly used to quantify J/ψ suppression versus centrality is Drell-Yan
  - → Drell-Yan production scales with the number of binary N-N collisions



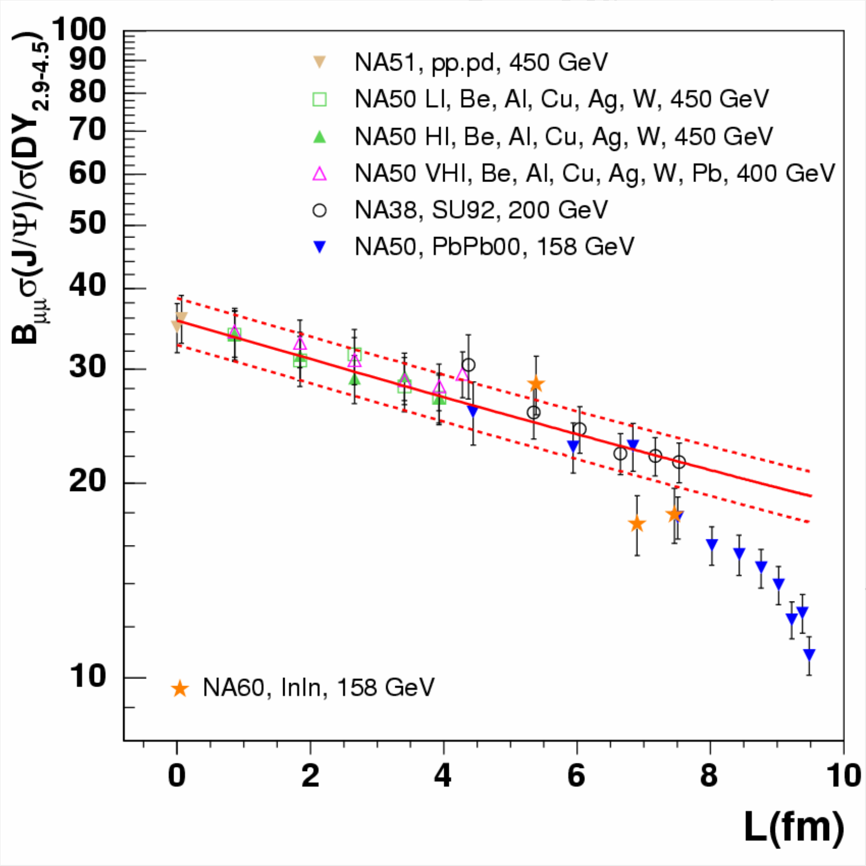
But :

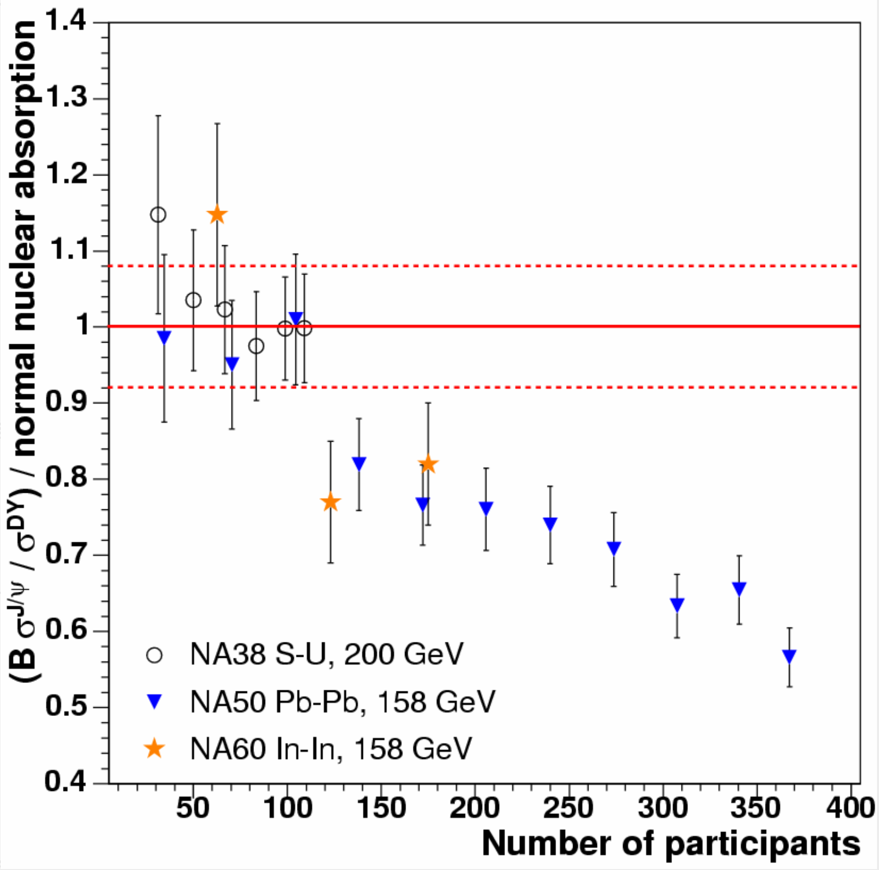
Drell-Yan statistics ($m_{\mu\mu}$ > 4 GeV/c

⇩

marginal in NA60 (~300)

J/Y standard analysis

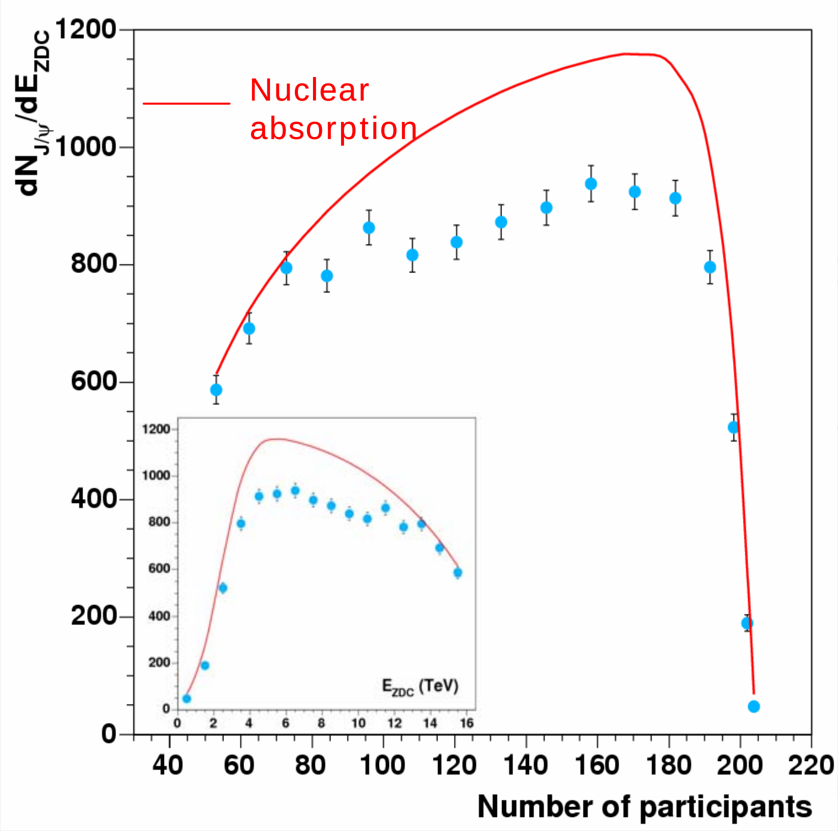


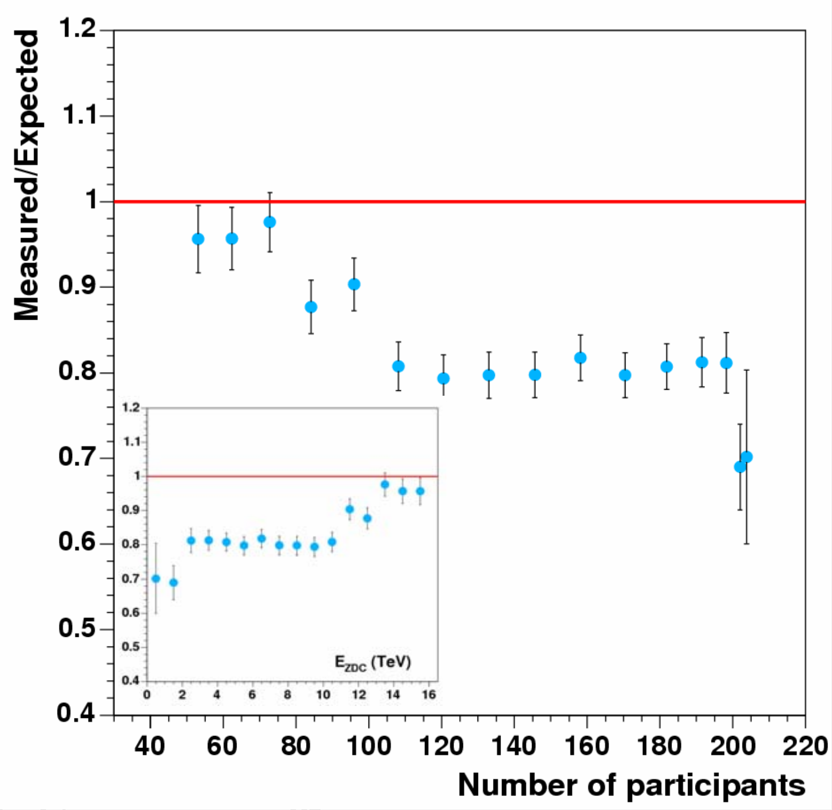


Anomalous J/ψ suppression is present in In-In collisions

Direct J/Y sample

- To overcome the problem of DY statistics, directly compare the measured J/ψ centrality distribution with the distribution expected in case of pure nuclear absorption

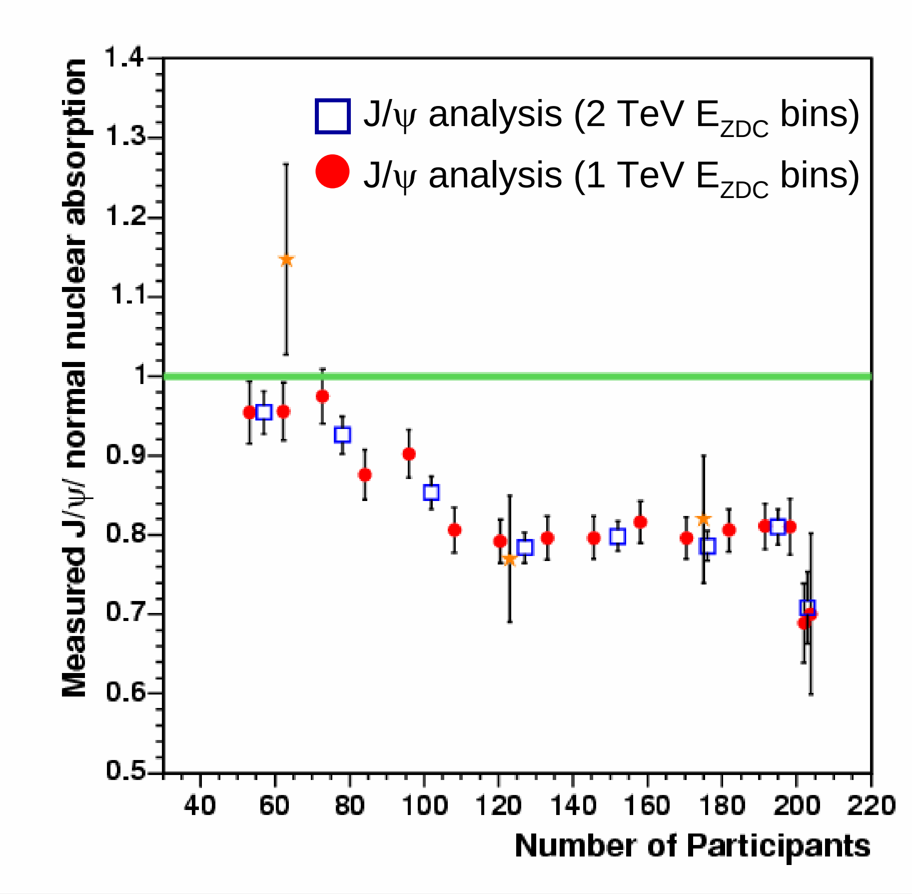




- Onset of anomalous suppression around N_{part} = 90
- Saturation at large N_{part}

Check of the method

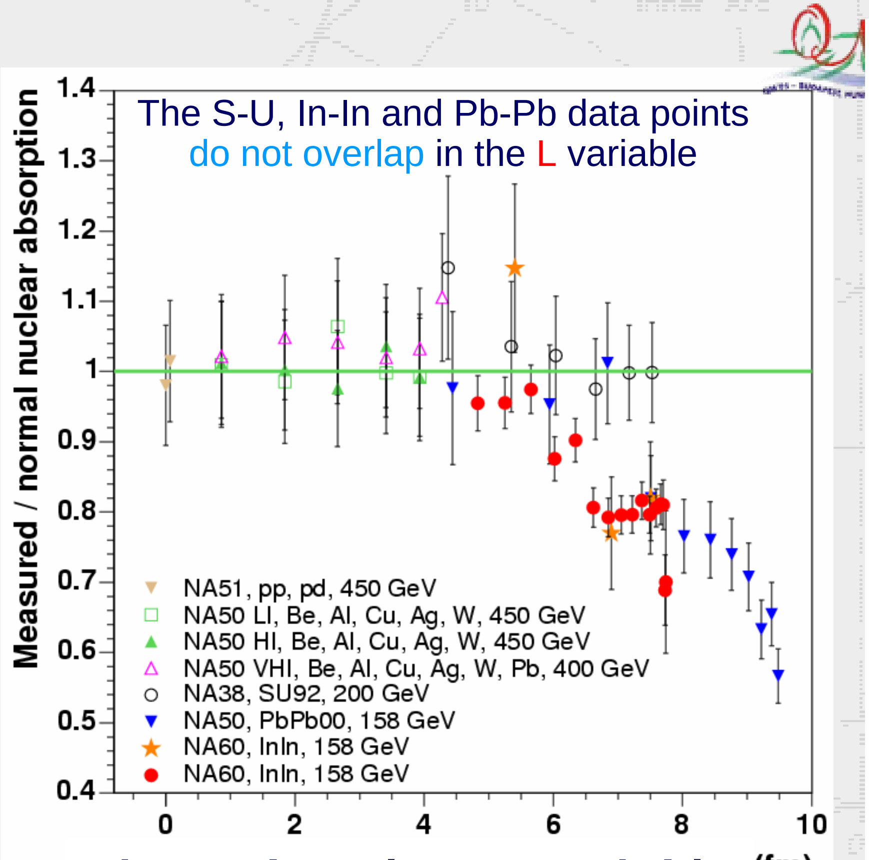
compare the new method with standard J/Ψ/Drell-Yan analysis



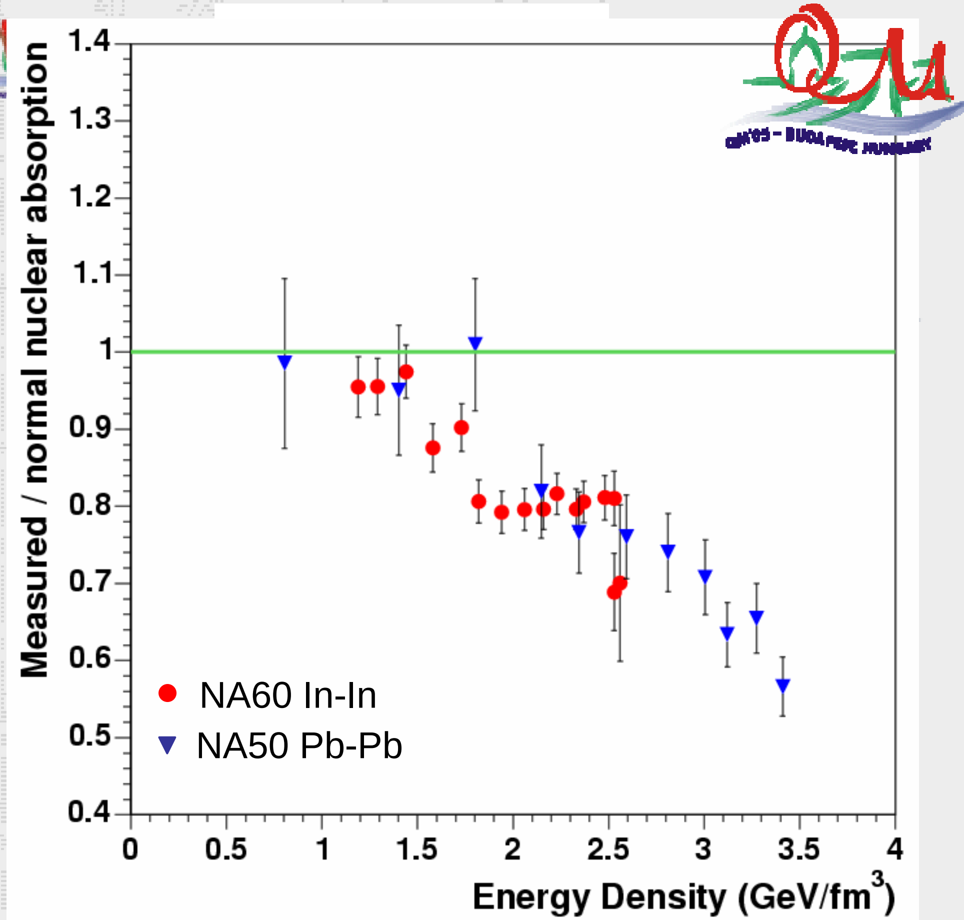
- The observed pattern is confirmed by a similar analysis with a reduced number of bins

In-In with NA60

- Results as a function of L and N_{part}

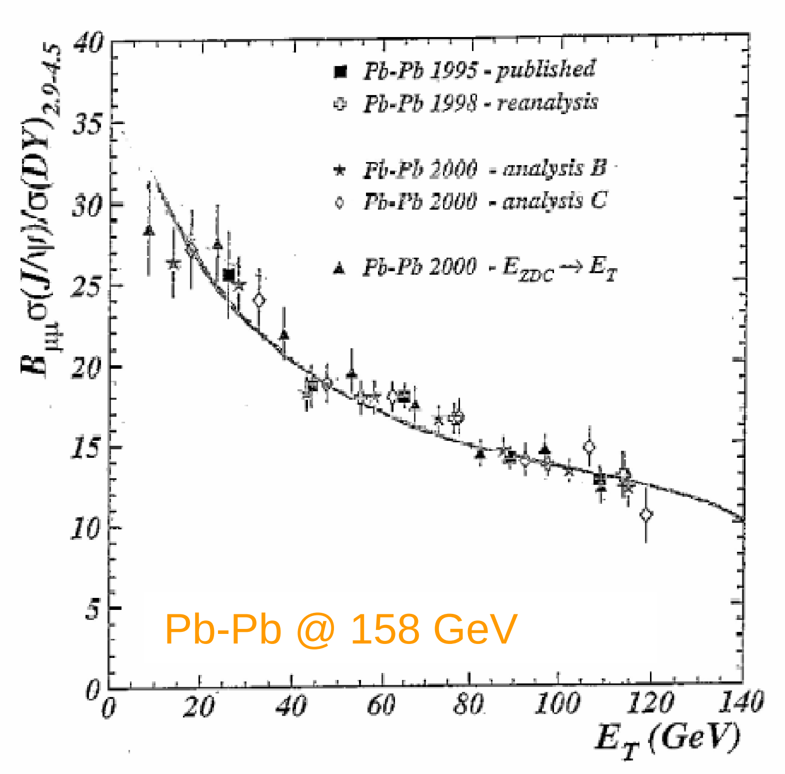


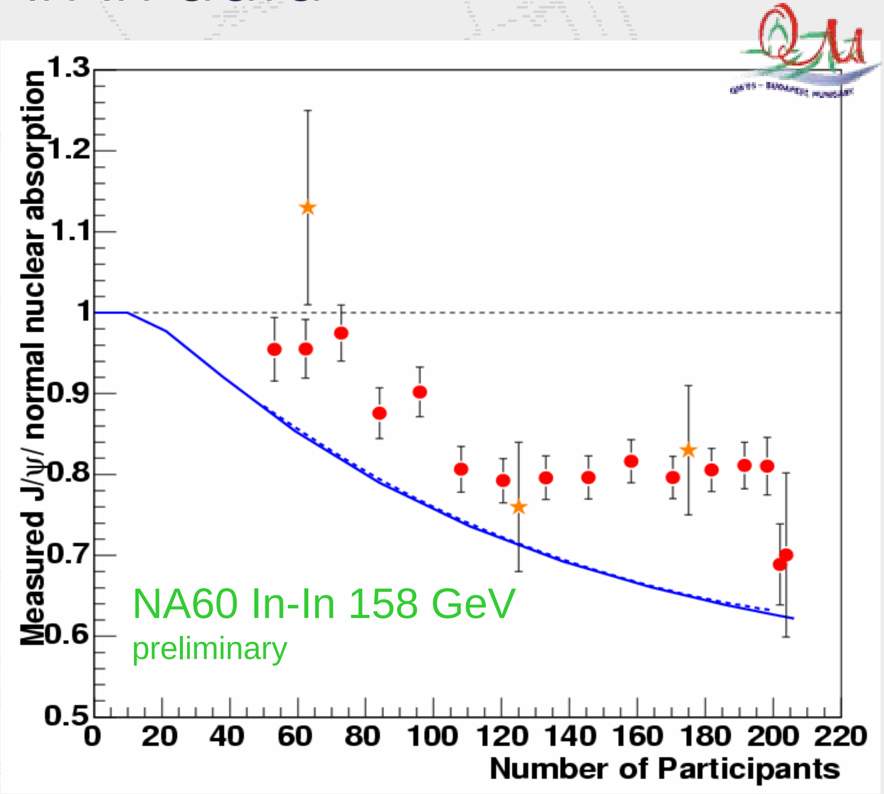
L is not the relevant variable



Comparison with comovers

- Comovers scenario
  - Can reproduce NA50 PbPb data
  - Can't reproduce NA60 In-In data





SPS summary

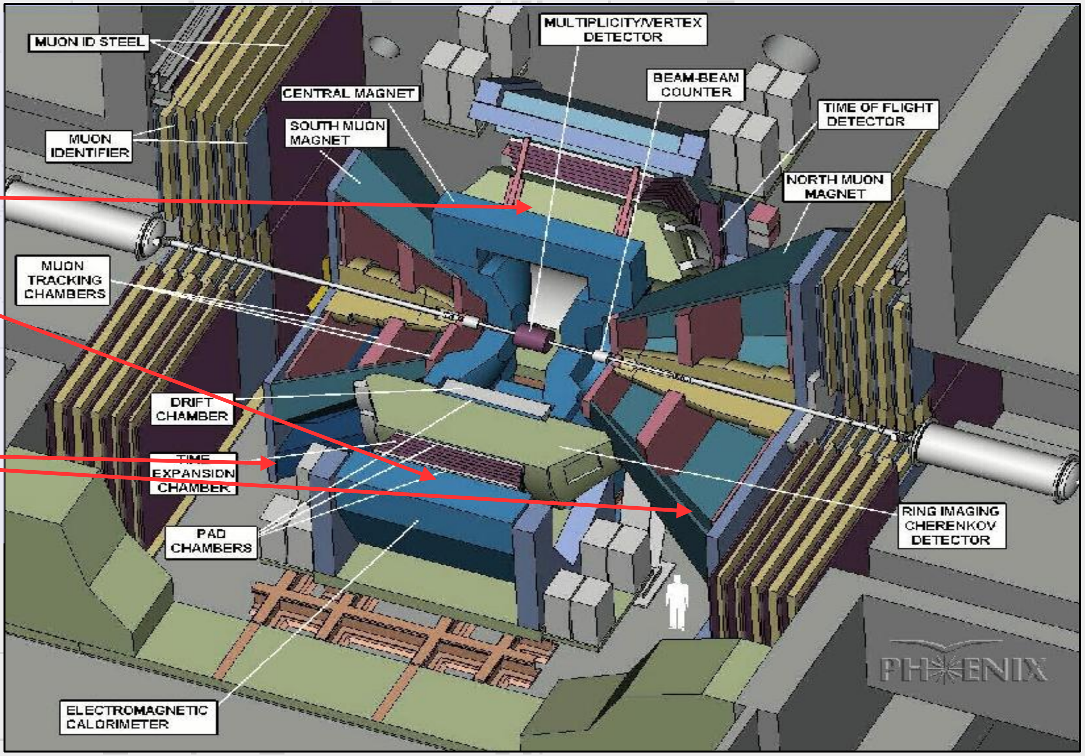
- 18 years of data (NA38, NA50, NA60)
- Observe
  - J/Ψ absorption by nuclear matter for light systems
  - Anomalous suppression in Pb-Pb data (NA50)
  - Anomalous suppression in In-In data (NA60)
- Interpretation
  - So far, hadronic scenarii can't reproduce the data
  - Room for QGP (see H. Satz lecture)
- Now : RHIC time

J/Ψ at RHIC

- J/Ψ study at RHIC done with PHENIX

Central arms:
hadrons, photons, electrons
$J/\Psi \rightarrow e^+e^-$

Muon arms:
muons at forward rapidity
$J/\Psi \rightarrow \mu^+\mu^-$

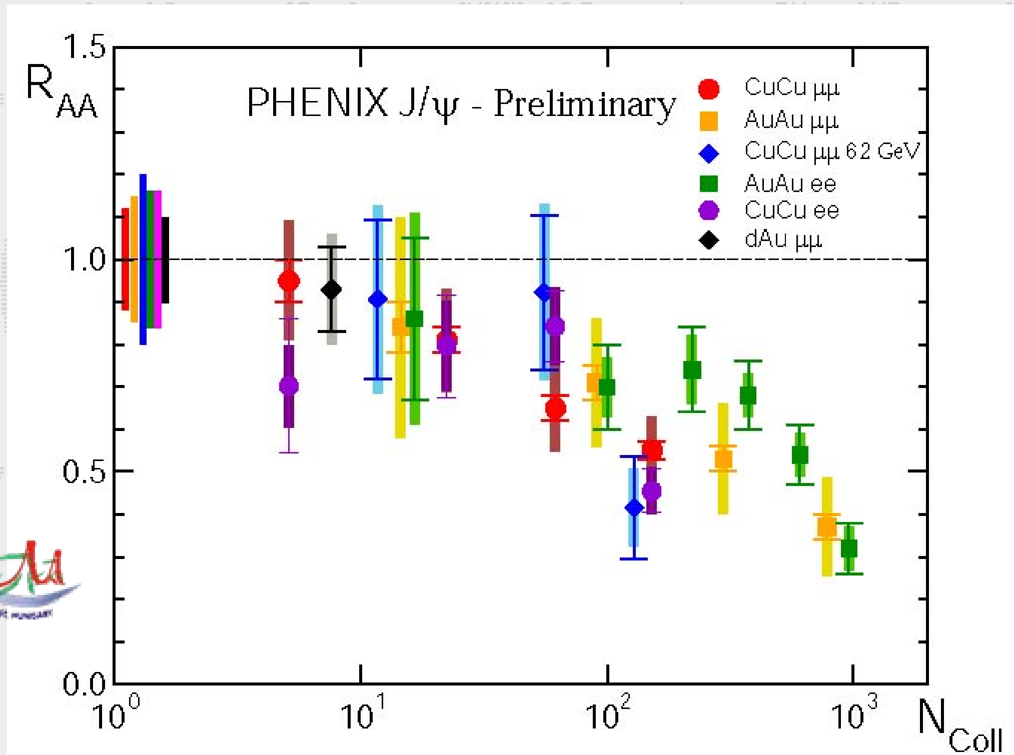


Data :

p-p	**√s=200 GeV (2000-05)**
d-Au	**√s=200 GeV (2003)**
AuAu	**√s=200 GeV (2002/04)**
Cu-Cu	**√s=200 GeV/62 GeV (2005)**

Results with PHENIX

$$R_{AA} = \frac{dN_{AA}}{< N_{coll} > \times dN_{NN}}$$ = J/Ψ yield per binary collision



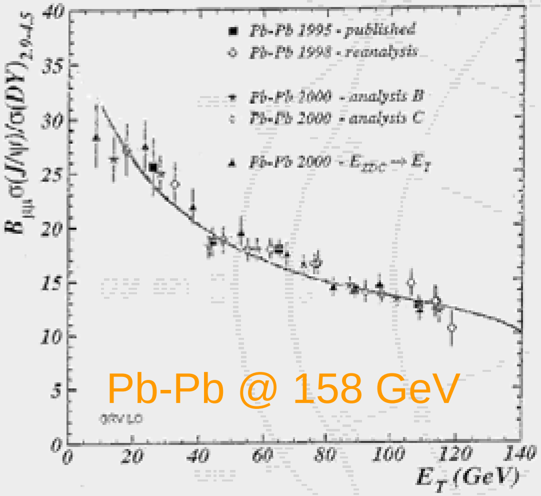
J/ψ μμ
muon arm
1.2 < |y| < 2.2

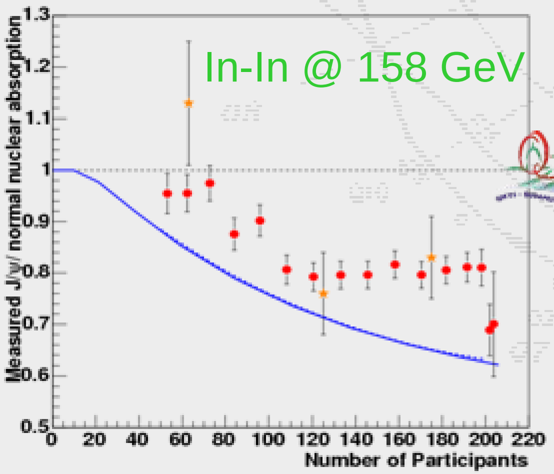
J/ψ ee
Central arm
-0.35 < y < 0.35

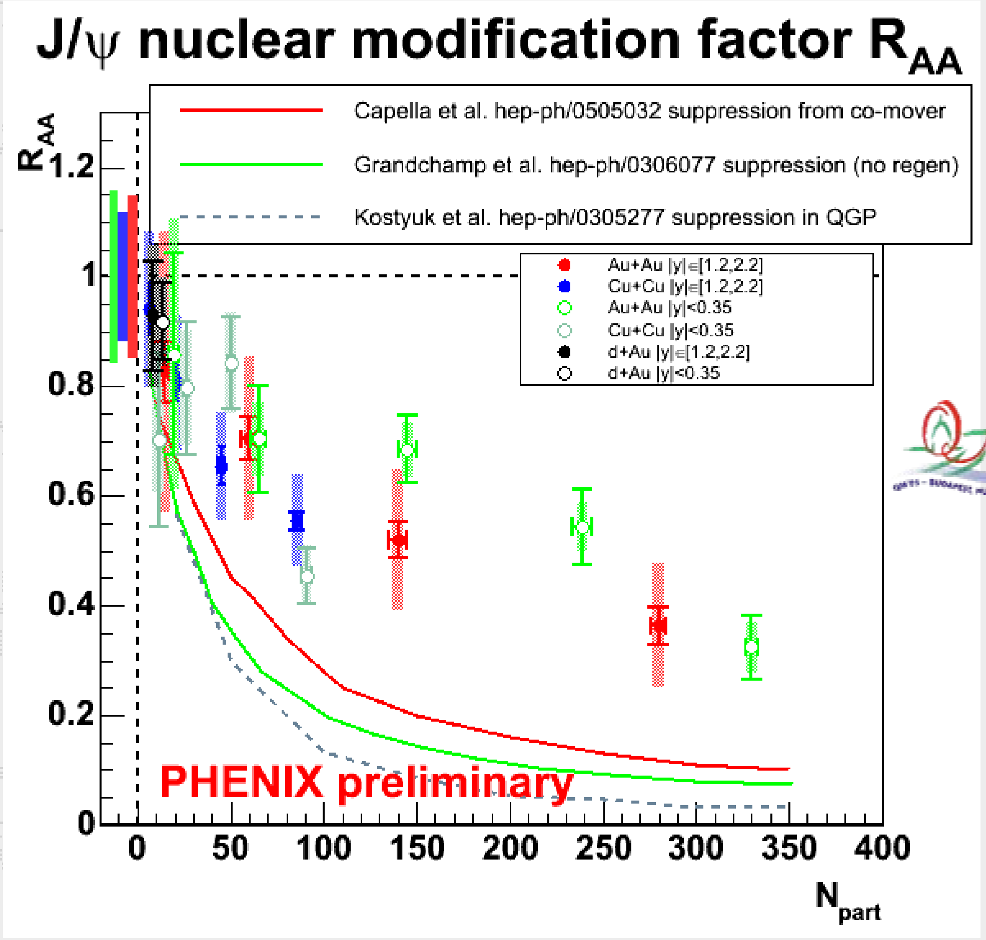
dAu	**AuAu**	**CuCu**	**AuAu**	**CuCu**	**CuCu**
μμ	**μμ**	**μμ**	**ee**	**ee**	**μμ**
200 GeV/c	**200 GeV/c**	**200 GeV/c**	**200 GeV/c**	**200 GeV/c**	**62 GeV/c**

Comparison with comovers

- Comovers don't fit the data

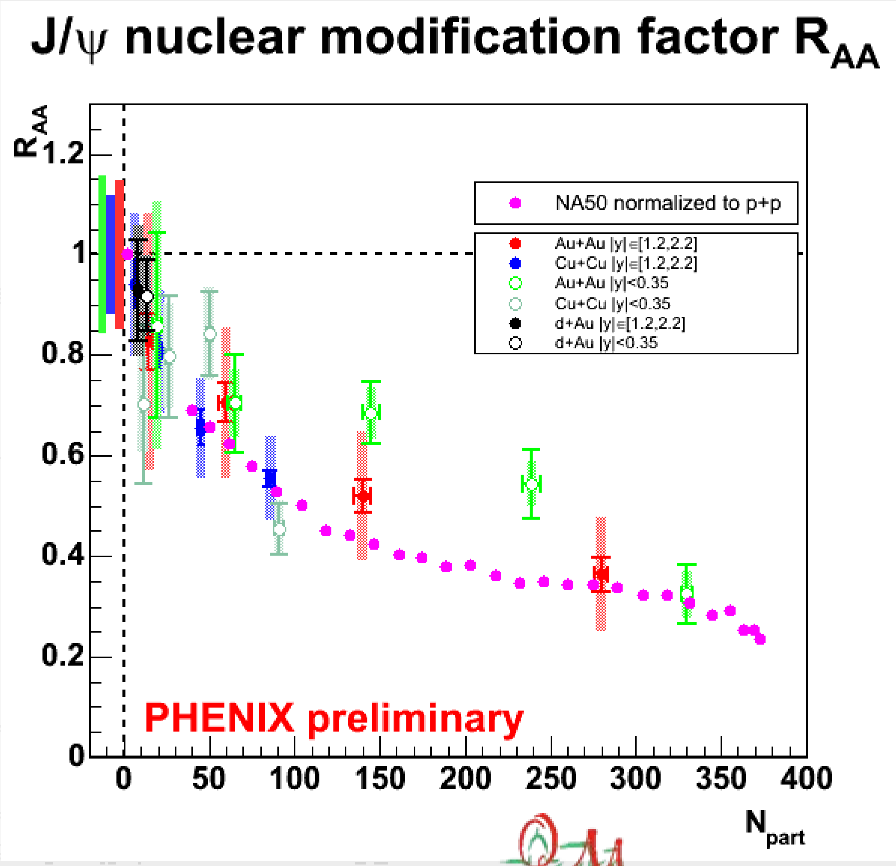






Comparing SPS and RHIC

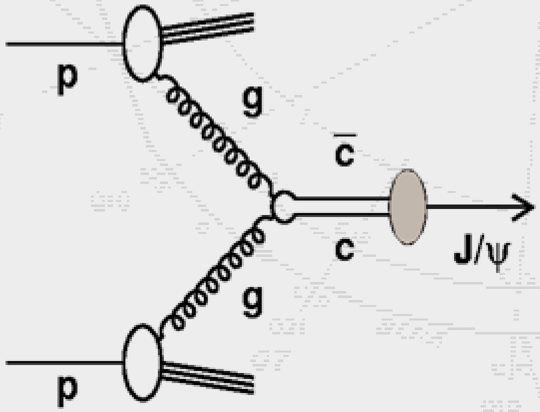
- When comparing NA50 and PHENIX
  - Suppression level is similar
- But
  - Are we comparing apple to apple ?
  - Several things are different
    - ✓ Energy
    - ✓ Rapidity window
  - Several things can change
    - ✓ J/Ψ production mechanism
    - ✓ J/Ψ suppression mechanism



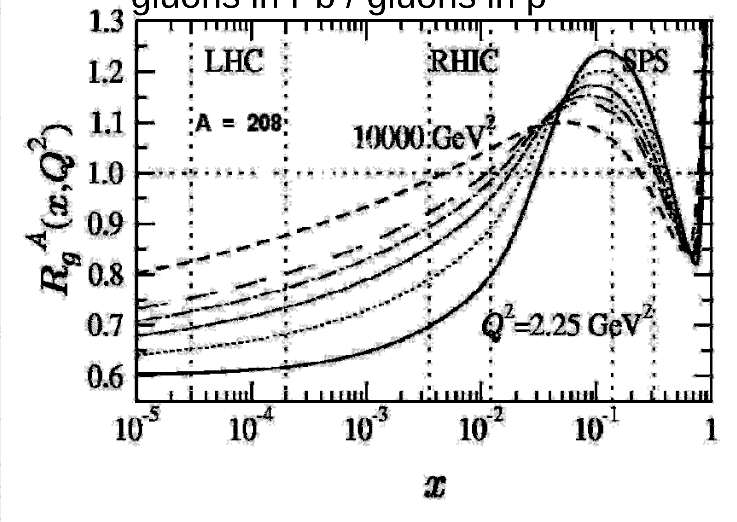
J/Ψ production mecanism

- Shadowing
  - Nuclear shadowing is an initial-state effect on the parton distributions.
  - Gluon distribution function can be different when comparing proton and nucleus.

"small momentum quarks and gluons, because of the uncertainty principle, spread over a distance comparable to the nucleon-nucleon separation. Quarks and gluons from different nucleons can overlap spatially and fuse, thus increasing the density of high momentum partons *[anti-shadowing]* at the expense of that of lower momentum ones *[shadowing]*"



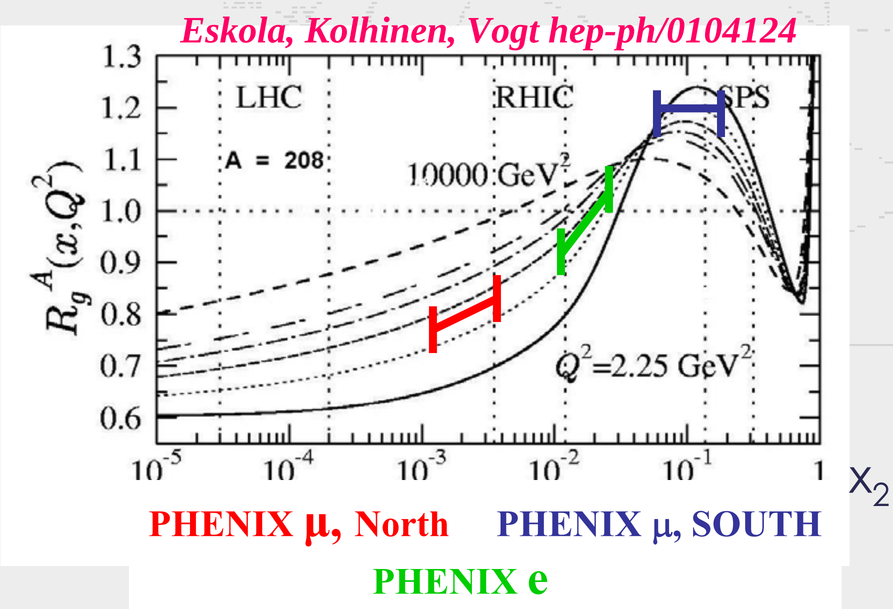
gluons in Pb / gluons in p

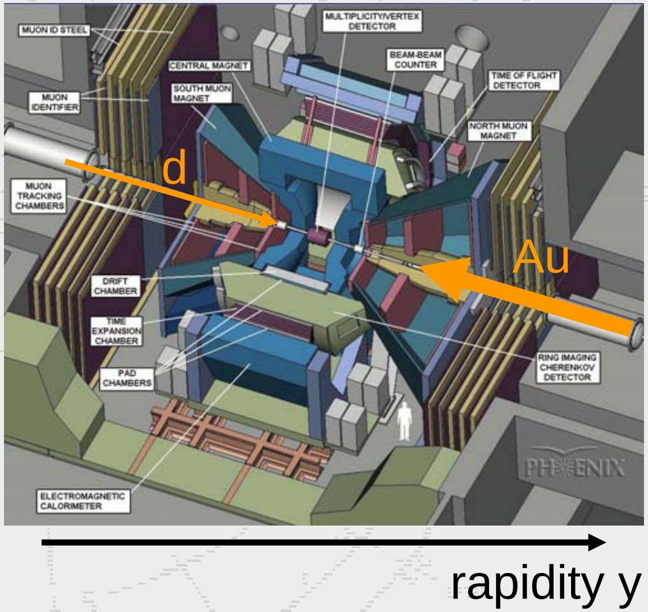


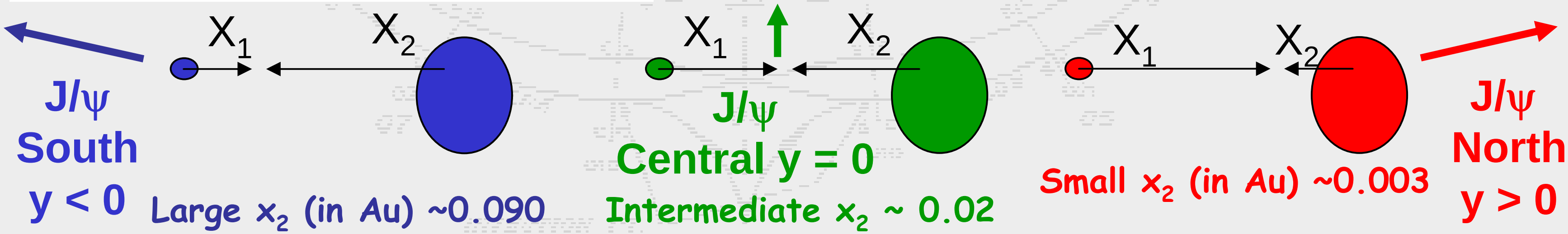
x is the momentum fraction of the nucleon that a parton (quark or gluon) carries.

Shadowing at RHIC

- Using d-Au data
  - PHENIX measurements cover expected shadowing, anti-shadowing range

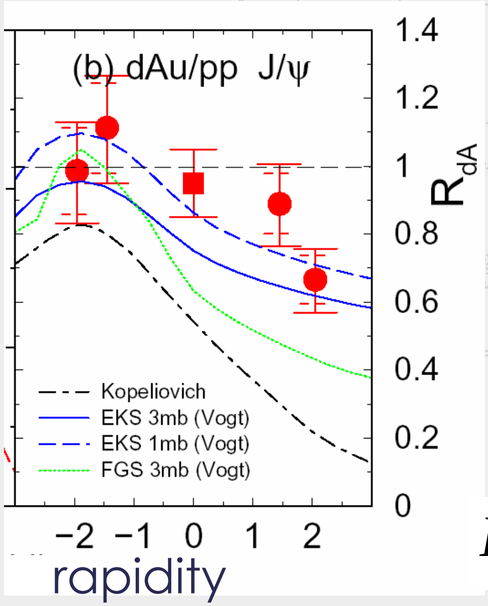






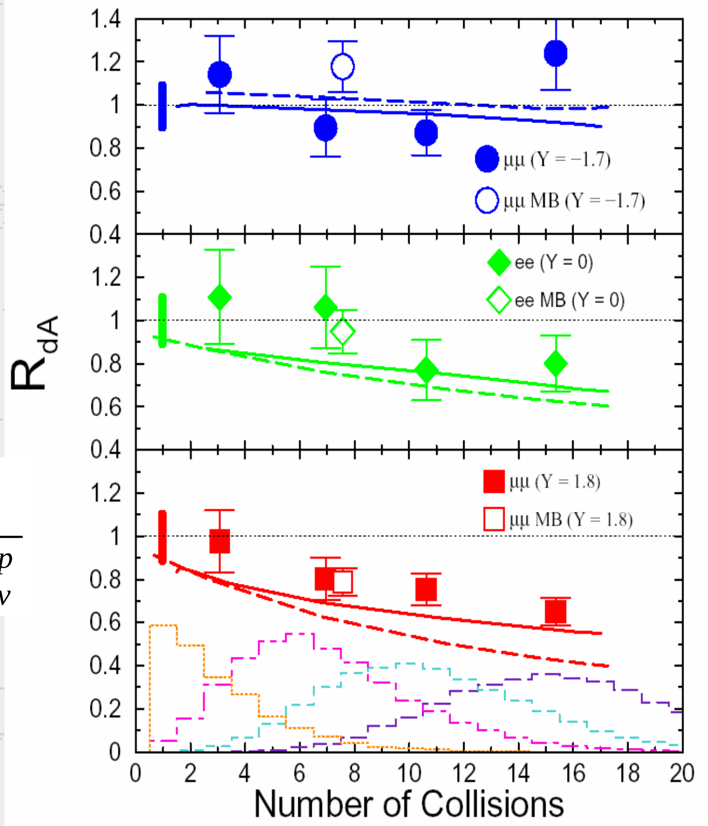
Shadowing at RHIC

- PHENIX d-Au results
  - Some gluon (anti)shadowing is « visible » in d-Au data
  - What about SPS ?
  - σ_{abs} seems lower than @ SPS
    - ✓ ~1 mb (~4mb at SPS)
  - Dependance with centrality
    - ✓ Will affect Au-Au and Cu-Cu data



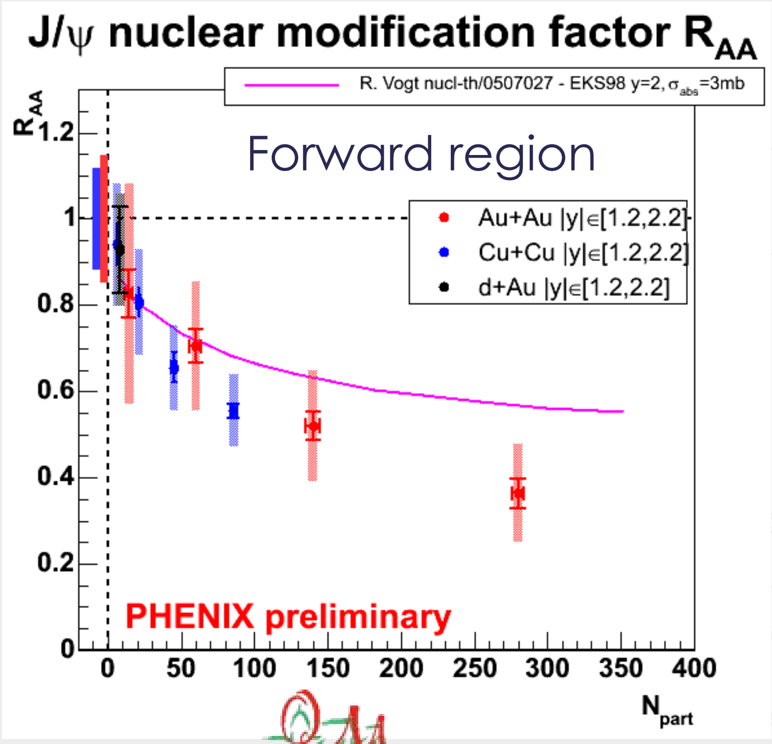
$$R_{dA} = \frac{Yield^{dA}_{inv}}{< N_{coll} > Yield^{pp}_{inv}}$$

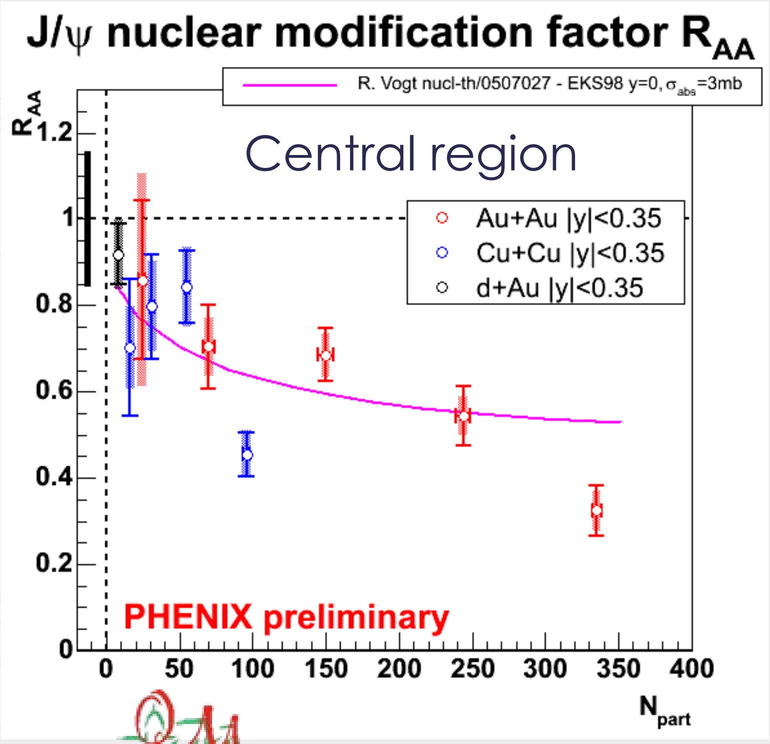
$$R_{dA} = \sigma_{dA} / (2 \times 197 \times \sigma_{pp})$$



Shadowing at RHIC

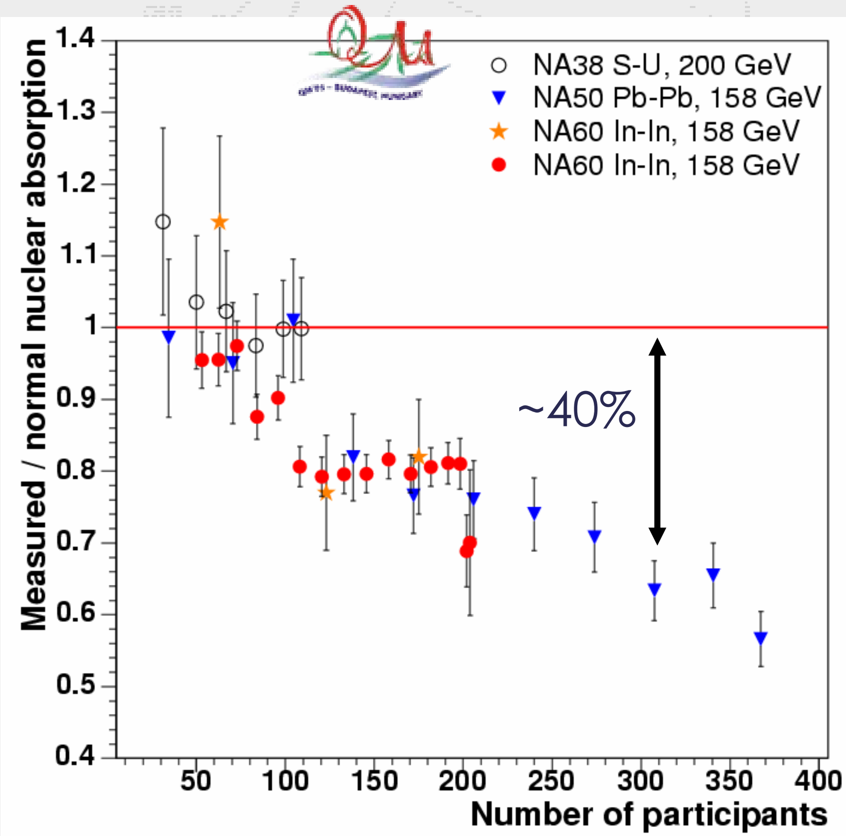
- PHENIX Au-Au and Cu-Cu results
  - Curve Includes nuclear absorption and gluon shadowing.
    - ✓ But here σ_{abs} is taken too large (3 mb)

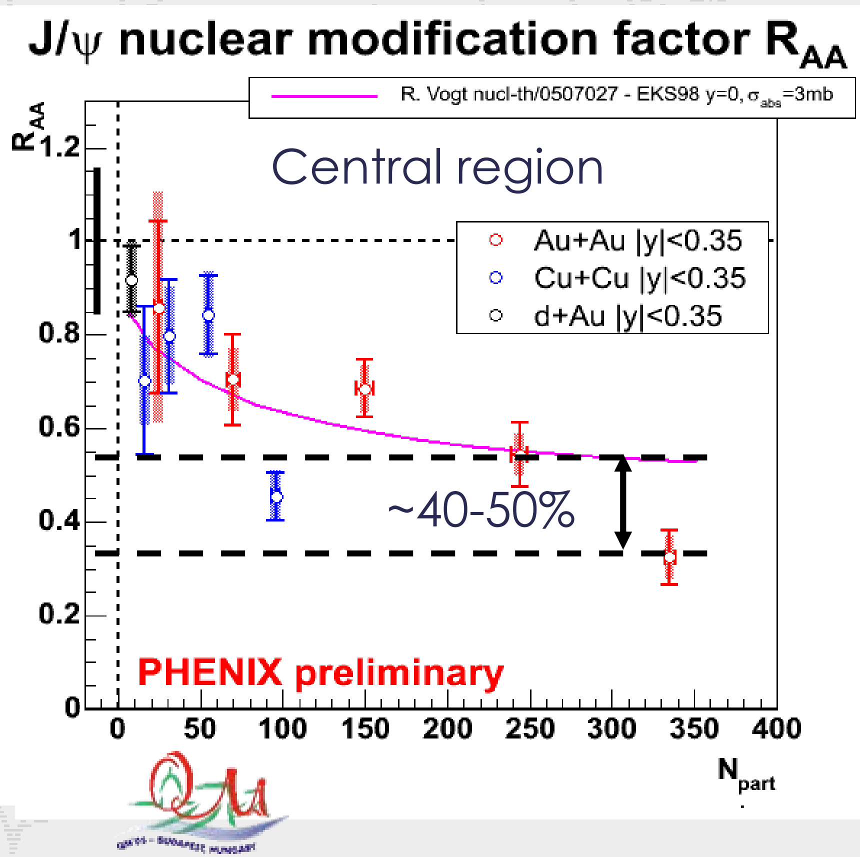




Comparing SPS and RHIC

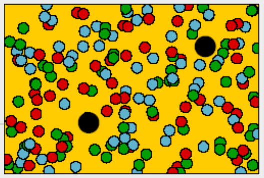
- ~ same suppression at SPS and RHIC
  - We expected a much bigger suppression at RHIC





Recombination

- At RHIC energies
  - Number of $c\bar{c}$ up to 14 in central collision
    - ✓ A c can combine with a $\bar{c}$ to form a J/Ψ
    - → increase J/Ψ production cross-section



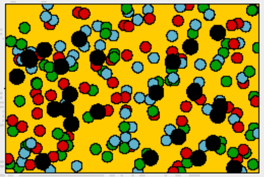
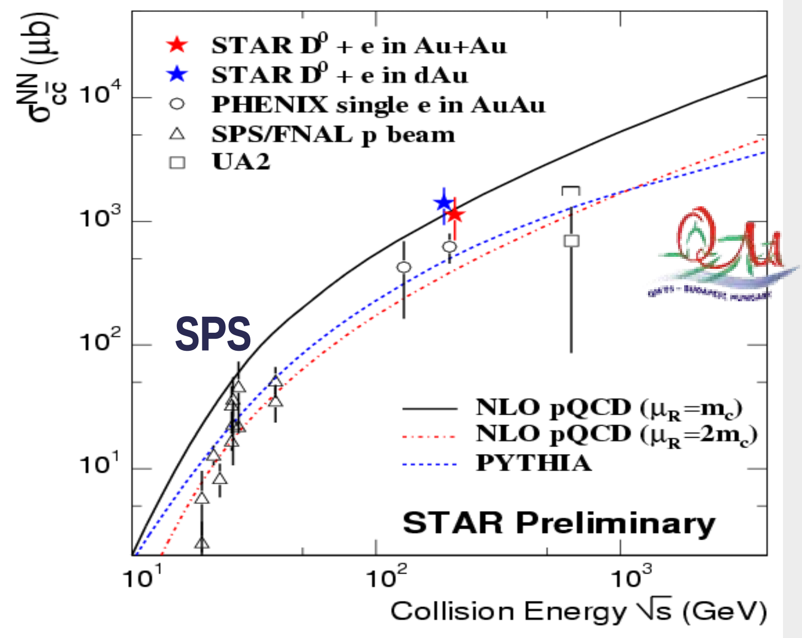


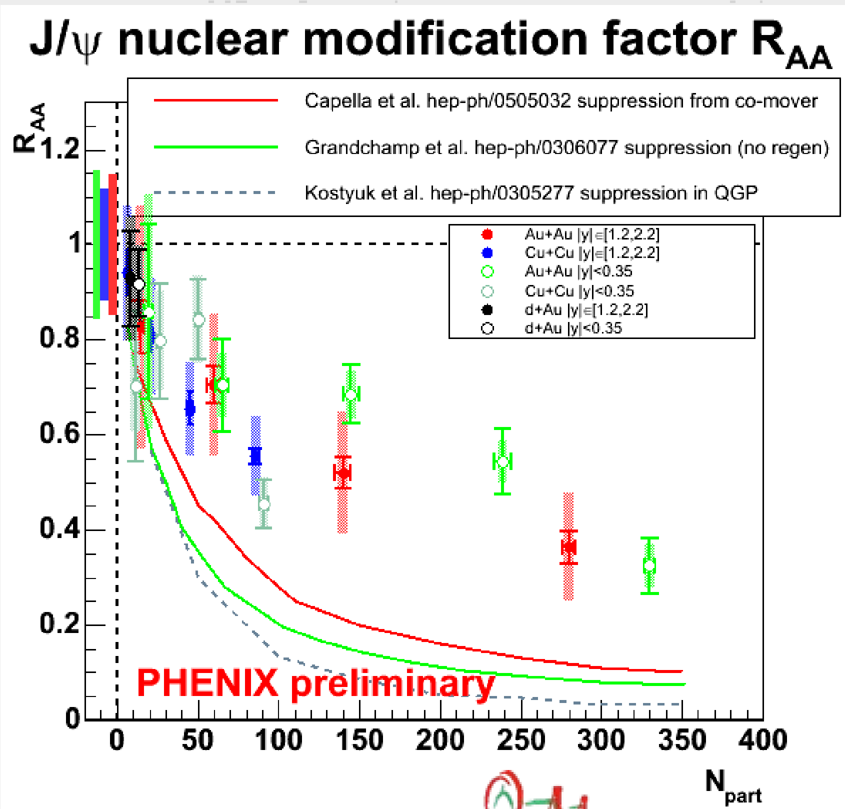
TABLE I: Centrality bin, number of NN collisions, nuclear overlap function, charm cross section per NN collision, and total charm multiplicity per NN collision, in $\sqrt{s_{NN}}$ = 200 GeV Au+Au reactions.

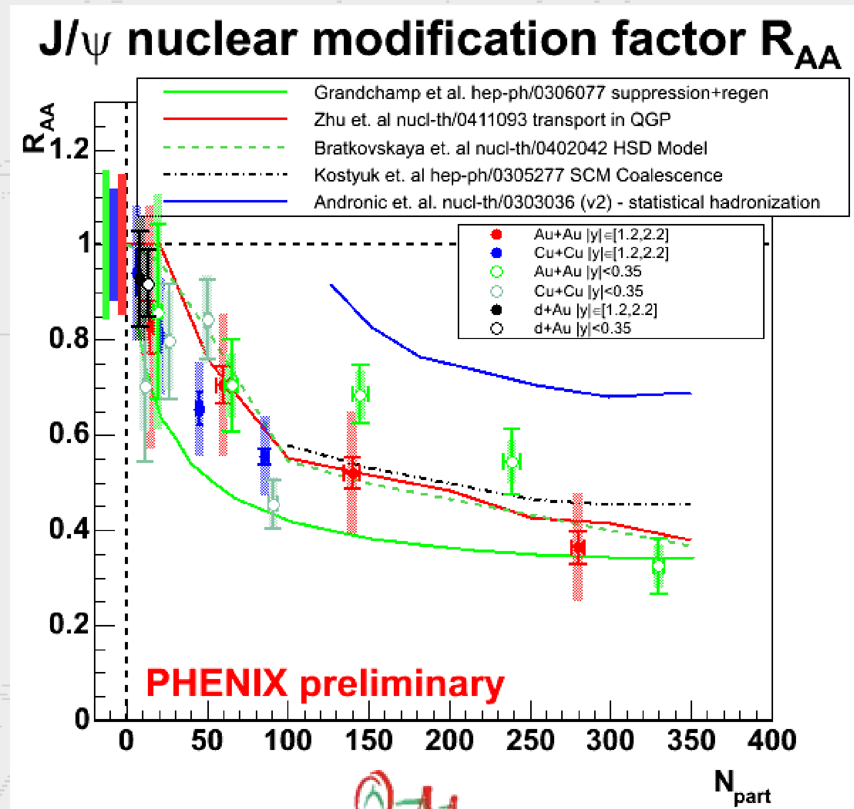
Centrality	N_{coll}	T_{AA} (mb^{-1})	$\frac{1}{T_{AA}}\frac{dN_{c\bar{c}}}{dy}\vert_{y=0}$ (μb)	$N_{c\bar{c}}/T_{AA}$ (μb)	N_{cc}
min. bias	258±25	6.14±0.45	143±13±36	622±57 ±160	3.8
0–10 %	955±94	22.8±1.6	137±21±35	597±93 ±156	**13.6**
10–20 %	603±59	14.4±1.0	137±26±35	596±115±158	8.6
20–40 %	297±31	7.07±0.58	168±27±45	731±117±199	5.2
40–60 %	91±12	2.16±0.26	193±47±52	841±205±232	1.8
60–92 %	14.5±4.0	0.35±0.10	116±87±43	504±378±190	0.2



Recombination ?

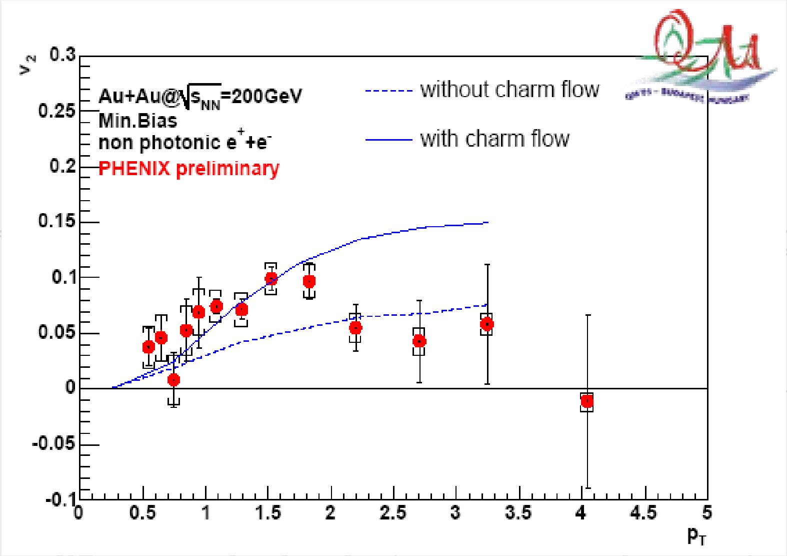
- Seems to work
  - How can we test ?

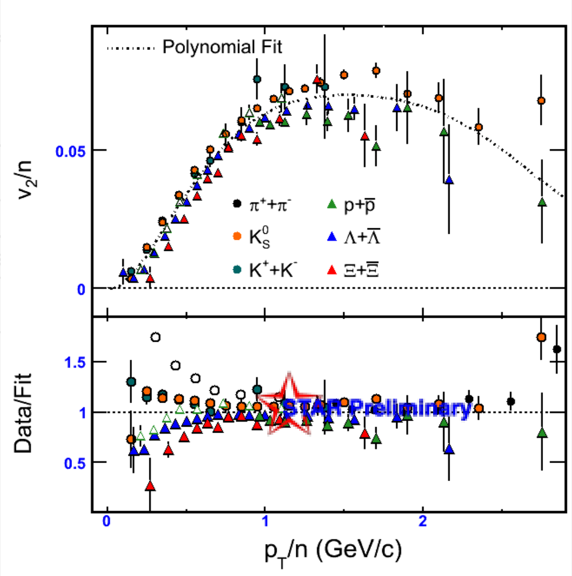




Testing recombination

- J/Ψ flow
  - From v_2 measurement, we know that charm flows

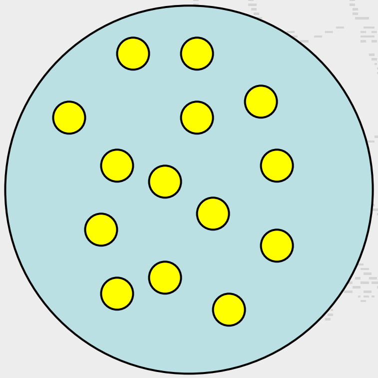




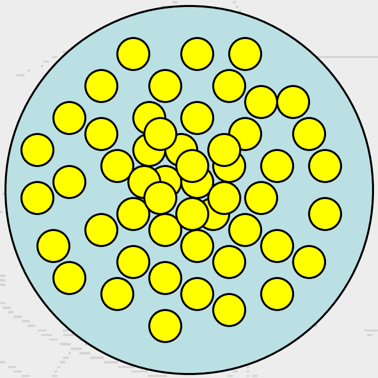
  - If charm flows, J/Ψ from recombination should flow.
  - Directly produced J/Ψ shouldn't flow.
  - Need to measure J/Ψ v_2 and compare to charm v_2

Percolation ?

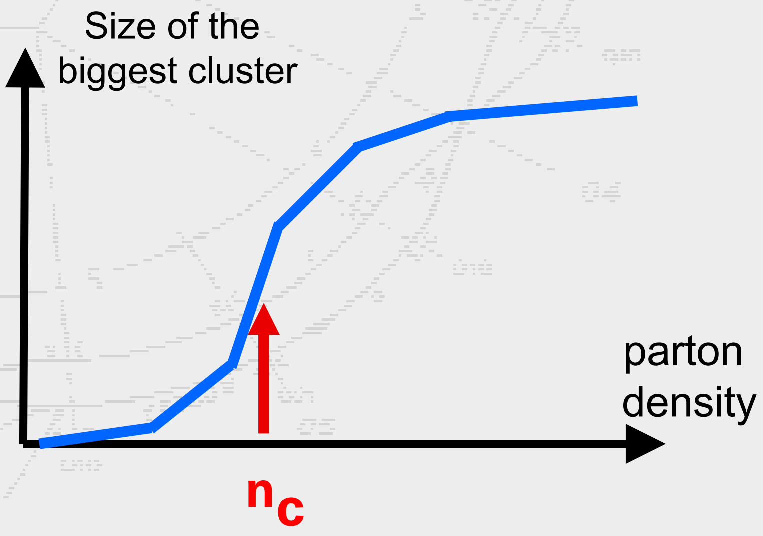
– See H. Satz's lecture
  - ✓« parton percolation is a geometric, pre-equilibrium form of deconfinement »
  - ✓« an essential prerequisite for QGP production is cross-talk between the partons from different nucleons »



Low parton density



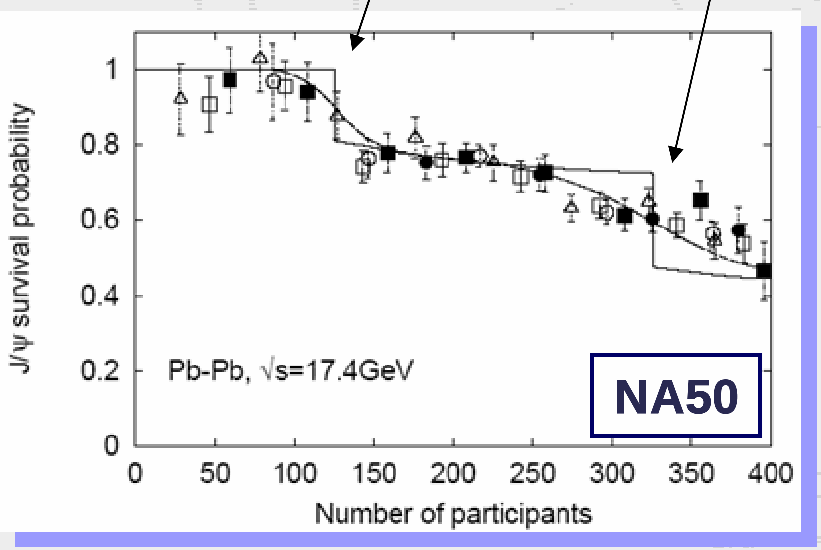
High parton density

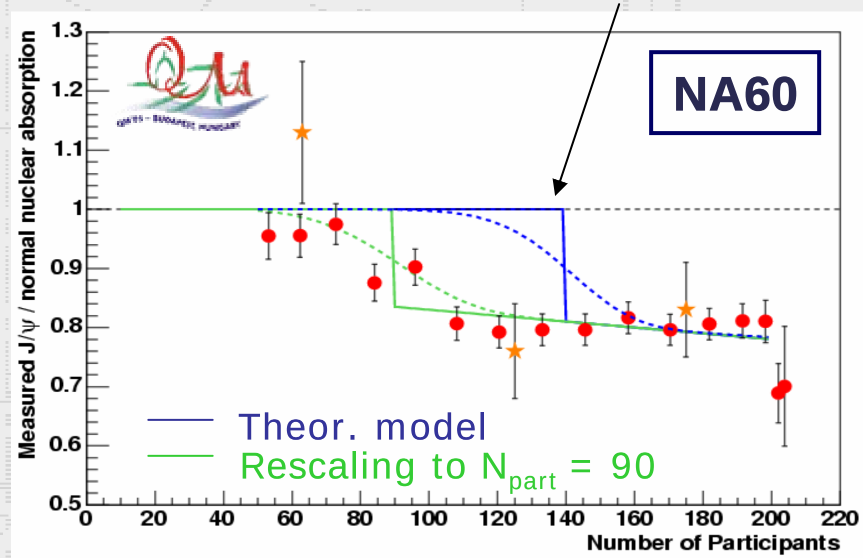


Percolation at SPS

– See H. Satz's lecture
– J/Ψ ~ 0.6 (J/Ψ)+ 0.3 (χ_c→J/Ψ)+ 0.1 (Ψ'→J/Ψ)
  ✓ χ_c and Ψ' are broken at percolation, J/Ψ later

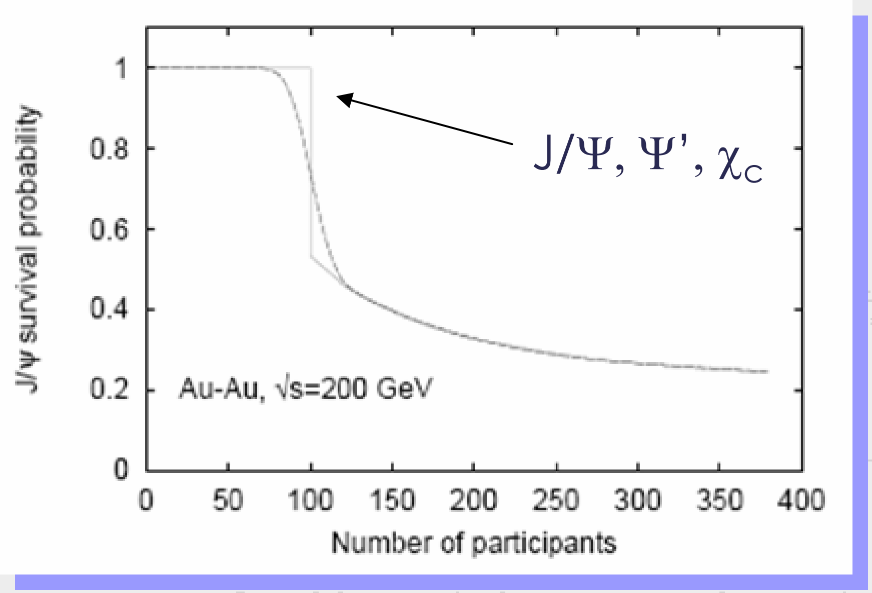
χ_c+Ψ'   J/Ψ χ_c+Ψ'

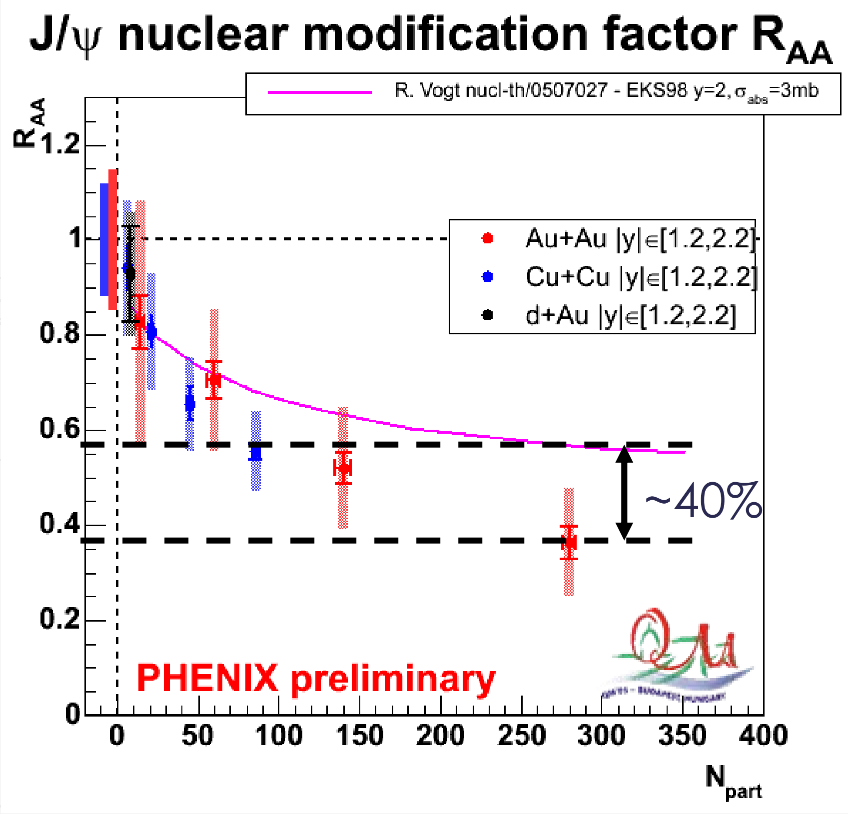




Percolation at RHIC

- See H. Satz's lecture





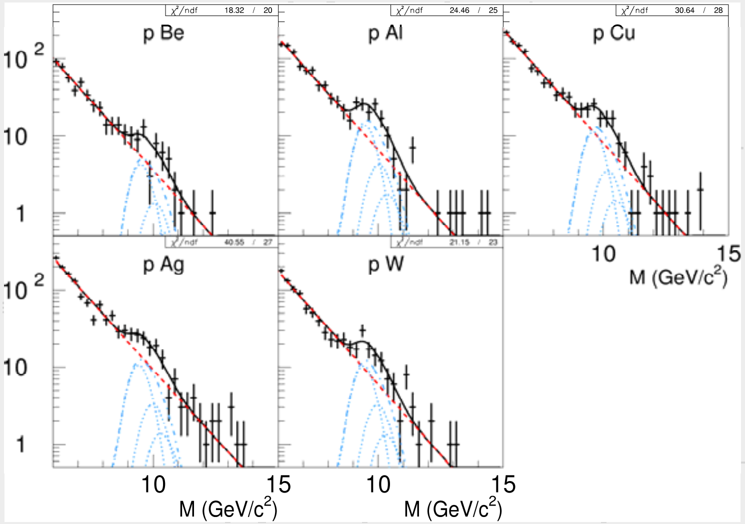
- Percolation doesn't match
- OK, but new lattice QCD calculations predict that direct J/Ψ are dissolved at ~2 T_C ...

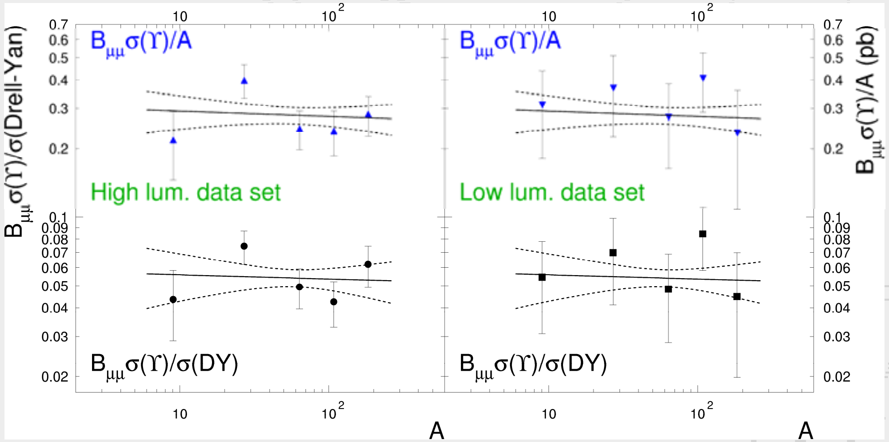
RHIC summary

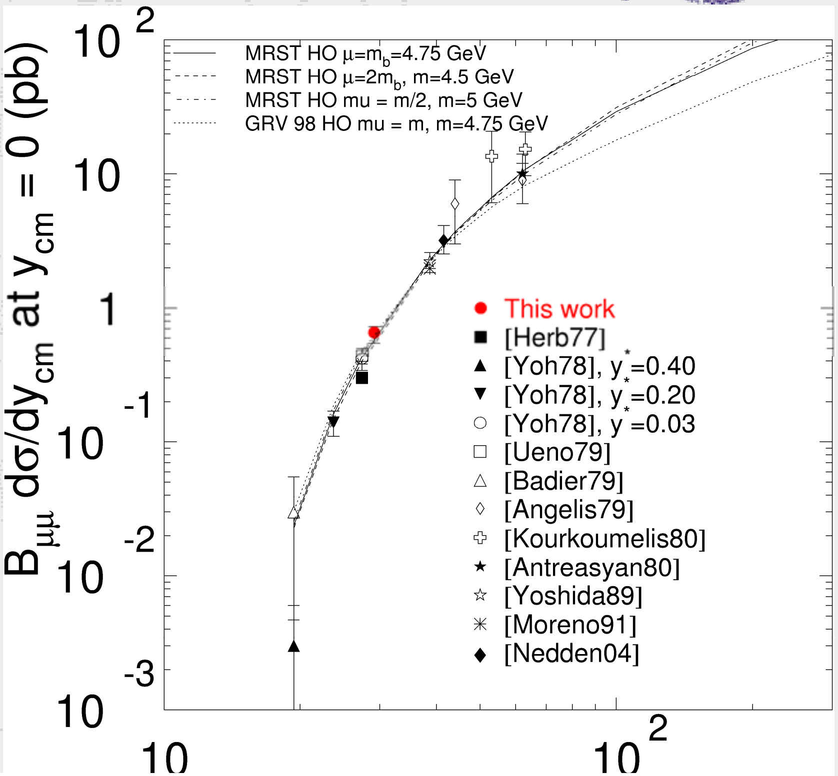
- A lot of new (exciting) results at QM05
  - Comovers seem to be ruled out
  - Some gluon shadowing seems to be observed with d-Au data
  - Suppression observed in AuAu and CuCu data
    - ✓ Same magnitude as SPS suppression
    - ✓ Models without recombination of charm quarks are enable (so far) to account for the data
- More work to do
  - For theorists
  - For experimentalists

What about ϒ ?

- Some ϒ seen by NA50 in p-A







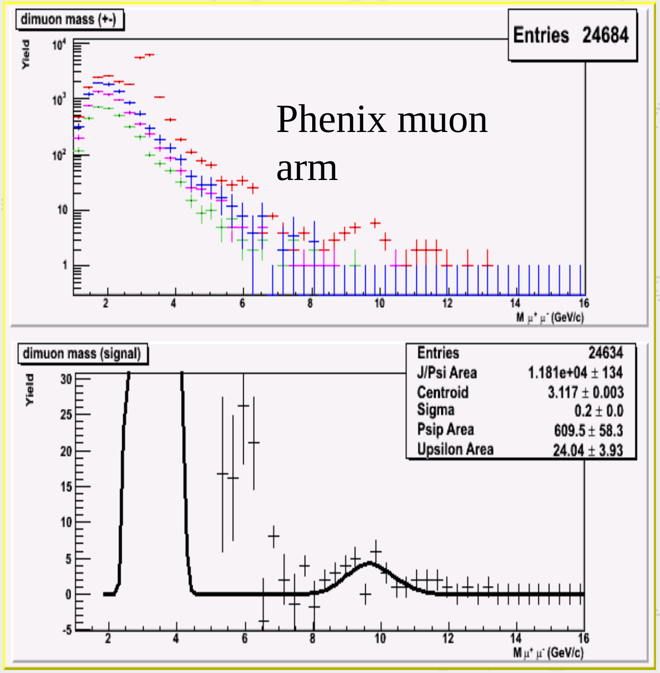
$\alpha_\Upsilon = 0.98 \pm 0.08$ (χ^2/dof = 0.8)

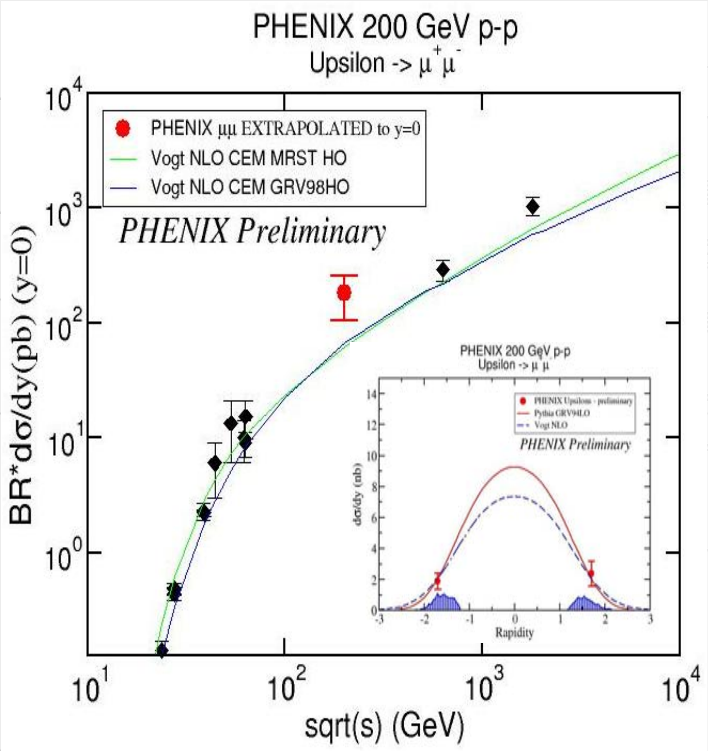
$\alpha_{\Upsilon/DY} = 0.98 \pm 0.09$ (χ^2/dof = 0.9)

By imposing $\alpha \equiv 1$ they get χ^2/dof = 0.8

What about Υ ?

- Some Υ seen by PHENIX in p-p

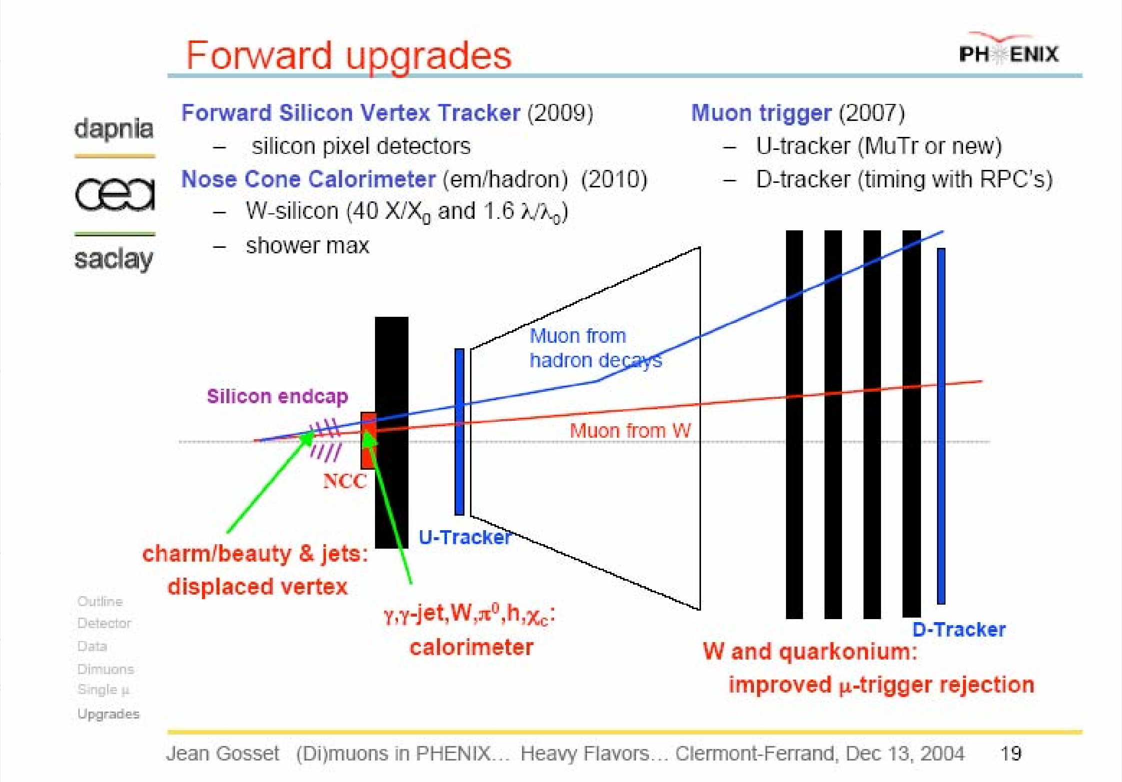




1st Upsilons at RHIC !

The future at RHIC

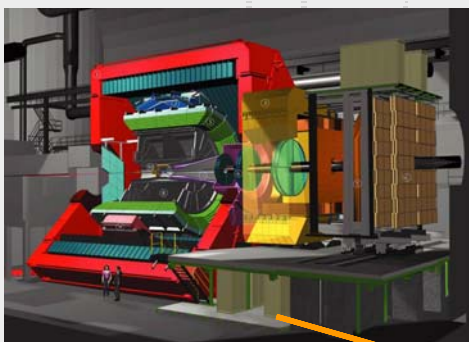
- Next 4 years plan (before RHIC II)
  - Factor 2 increase in heavy ion luminosity
  - Factor 6 increase in proton luminosity
- Detector upgrades



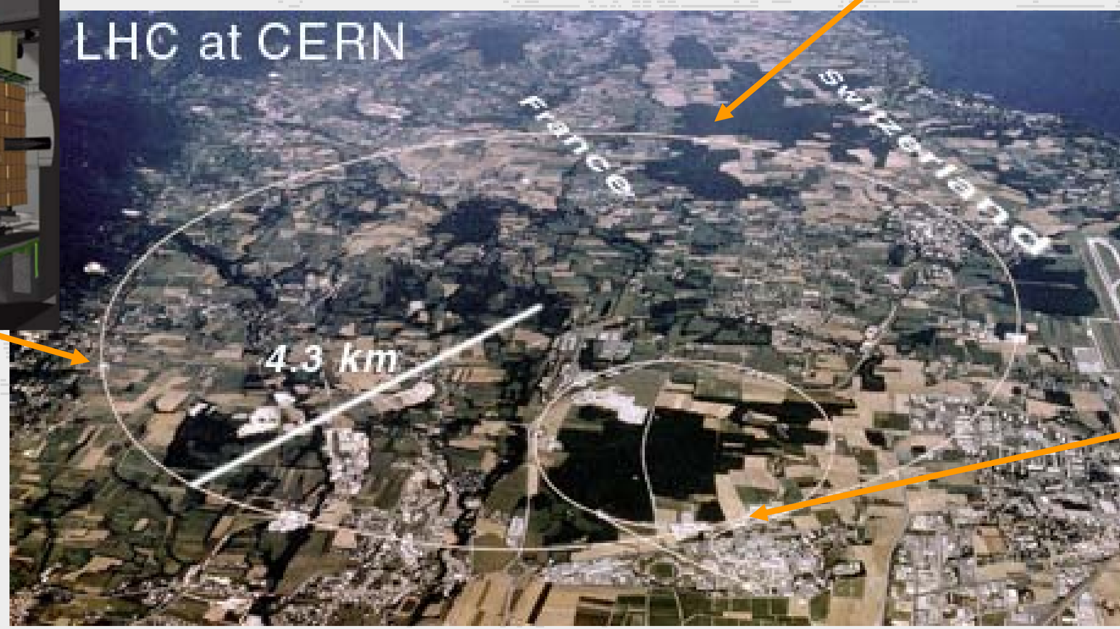
Heavy ions at LHC

- Large hadron collider
  - pp @ 14 TeV (10^7 s/year)
  - PbPb @ 5.5 TeV (10^6 s/year)
  - pA, lighter ions and energies

CMS



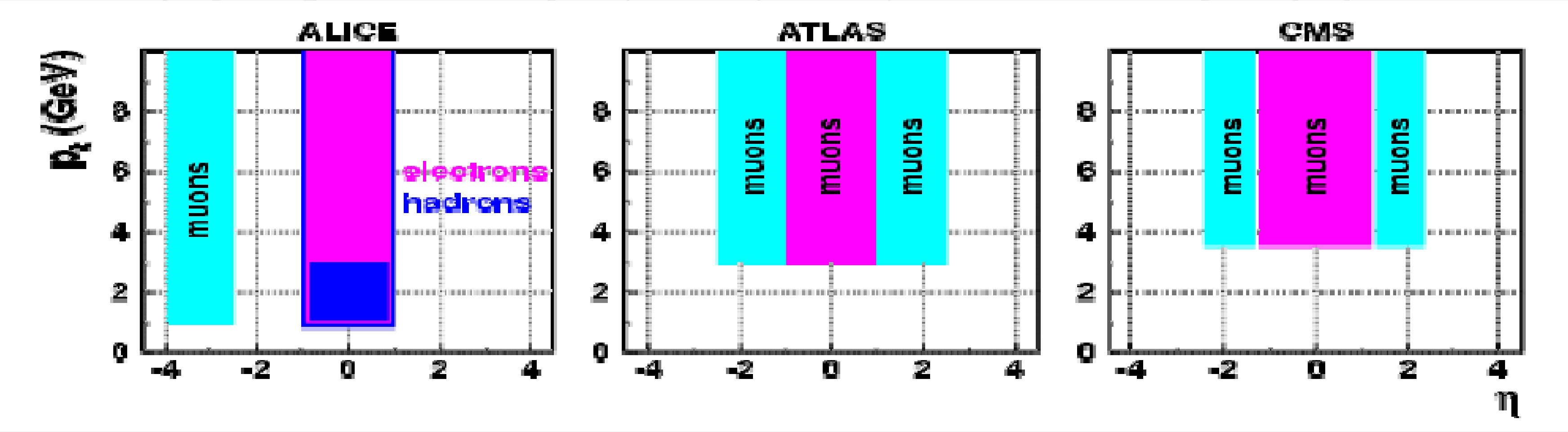
ALICE



ATLAS

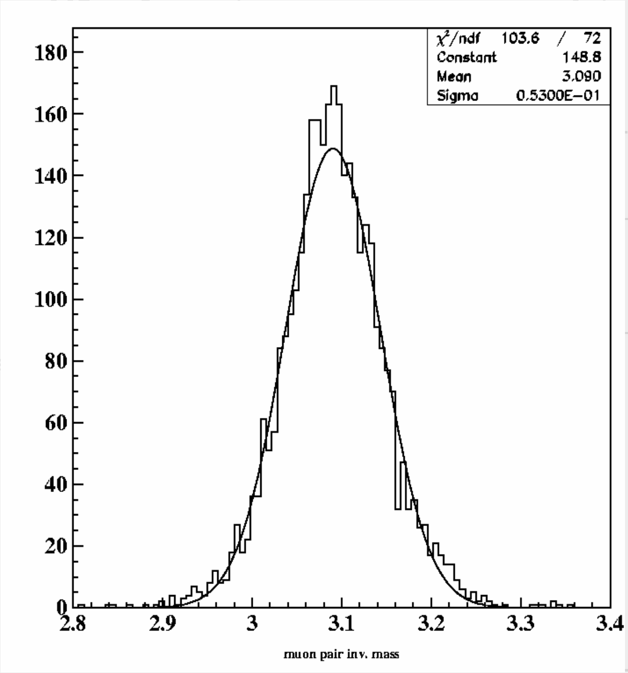
Heavy flavor measurements

- Acceptance
  - Complementarity between the 3 experiments
  - ATLAS & CMS acceptance is large in η & limited to high p_T
  - ALICE is limited in η but cover down to very low p_T



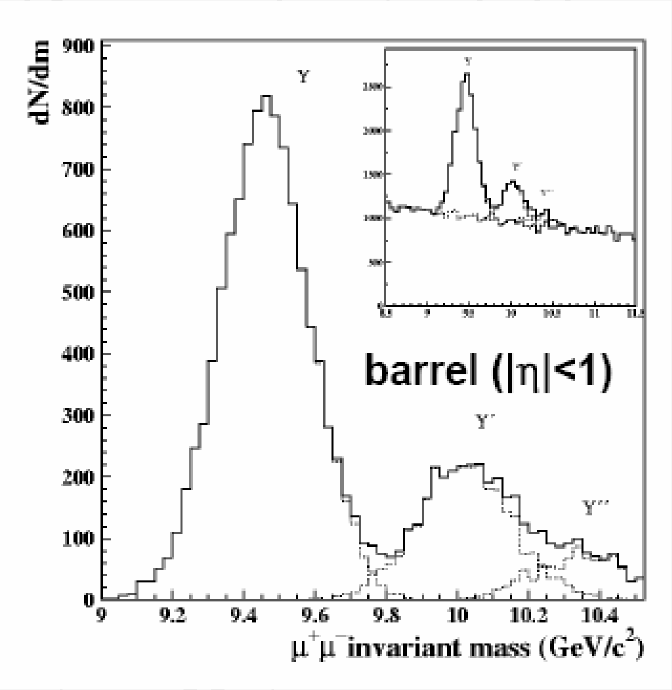
Quarkonia measurements in ATLAS

$J/\psi \rightarrow \mu^+\mu^-$



Rate/month ~ 100k
~ 50 MeV resolution

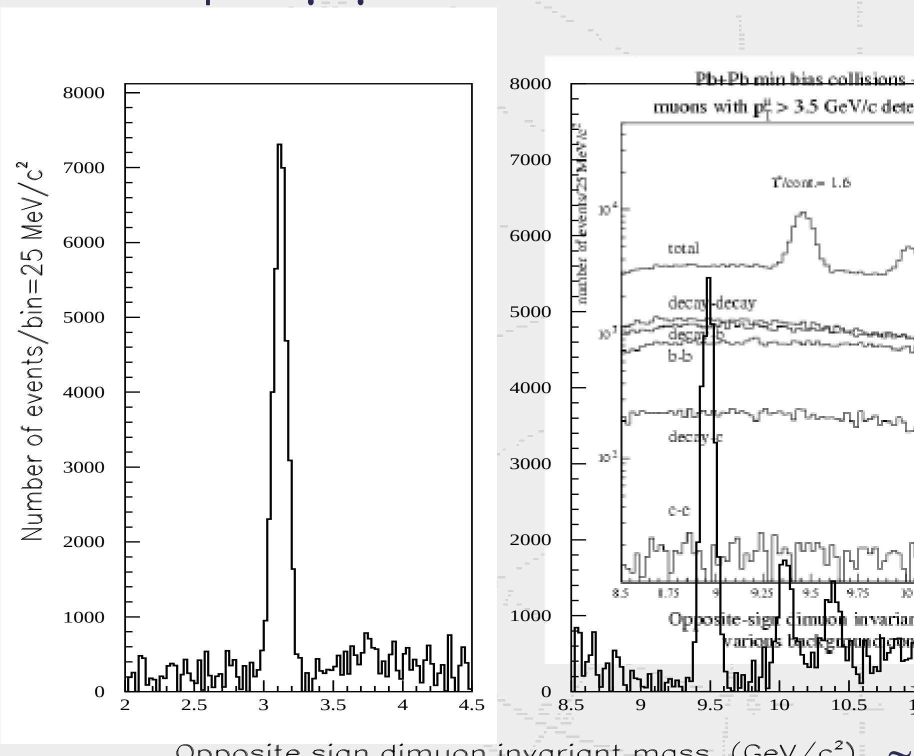
$\Upsilon \rightarrow \mu^+\mu^-$



Rate/month ~ 10k
~ 120 MeV resolution

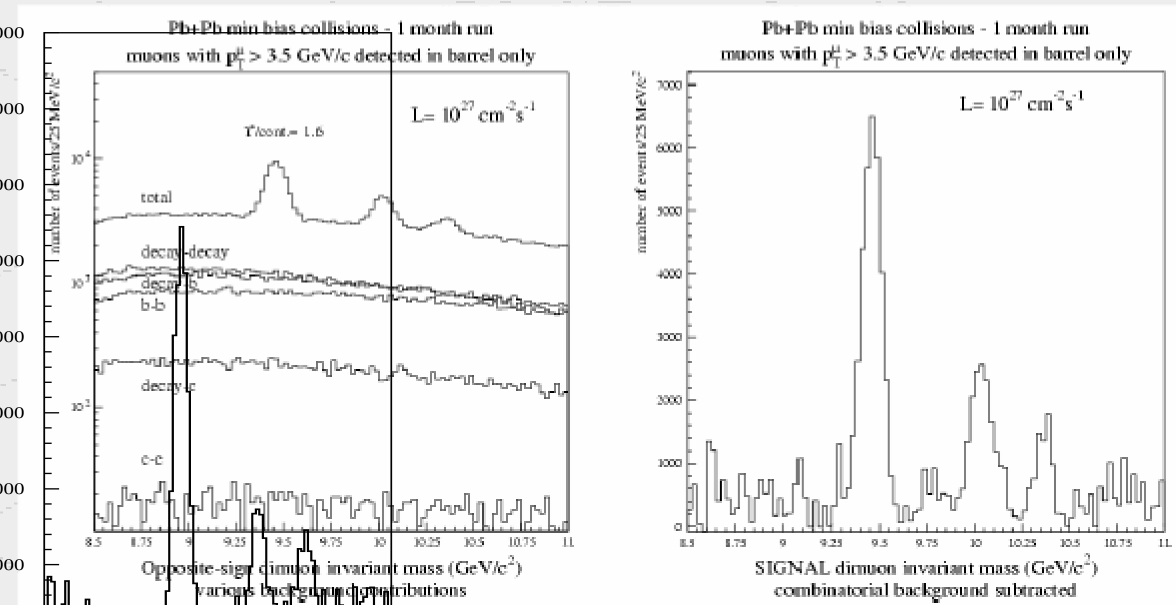
Quarkonium measurements in CMS

J/ψ → $\mu^+\mu^-$



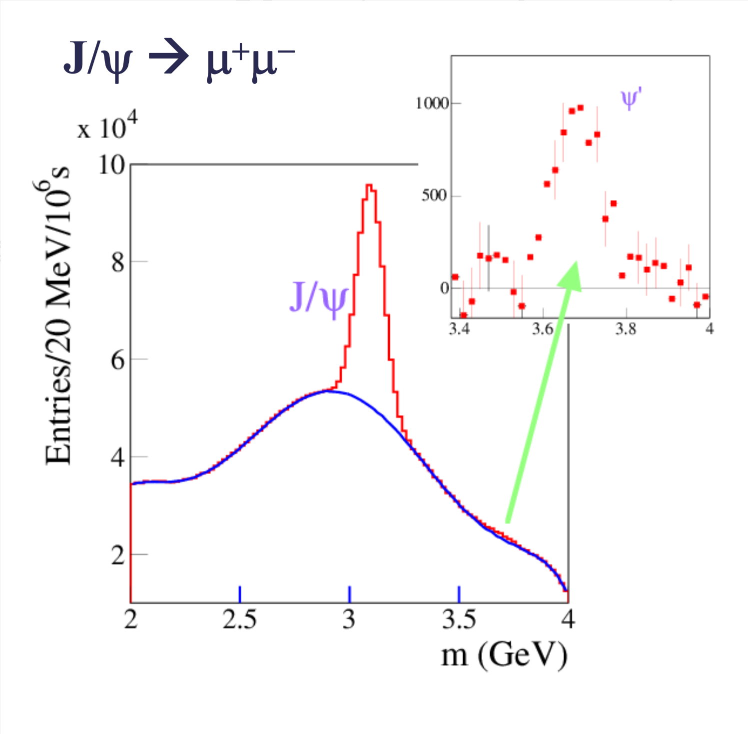
Rate/month ~ 24k
~ 50 MeV resolution

Υ → $\mu^+\mu^-$

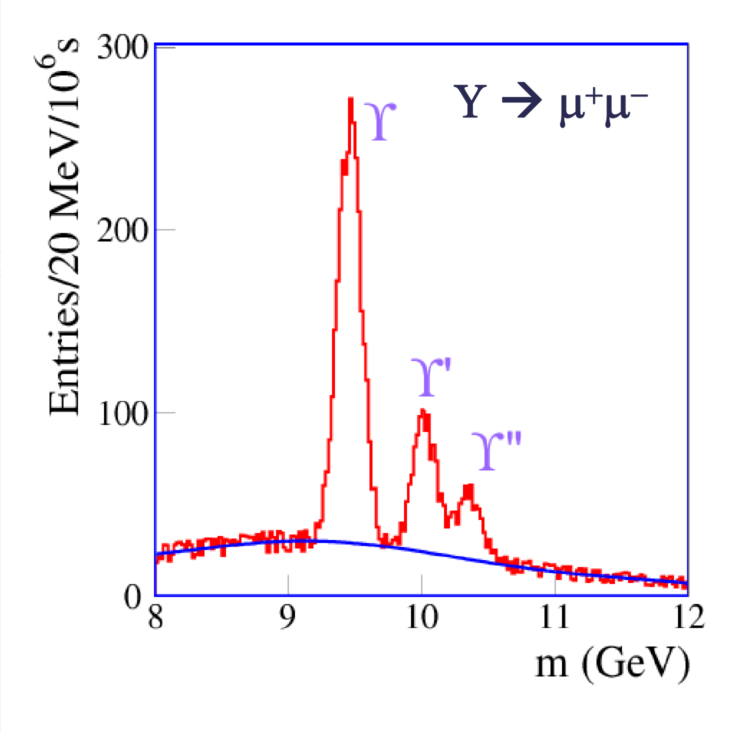


Rate/month ~ 15k
~ 60 MeV resolution

Quarkonium measurements in ALICE



Rate/month ~ 100k
~ 70 MeV resolution



Rate/month ~15k
~ 130 MeV resolution

Conclusion

- 20 years of results
  - Big experimental effort @ SPS and RHIC
  - Big theoretical effort (melting, recombination, percolation, comovers…)
  - Lot of things still need to be done (both in theory and experiments)
  - Future : psi and upsilon adventure
    - ✓ RHIC and LHC