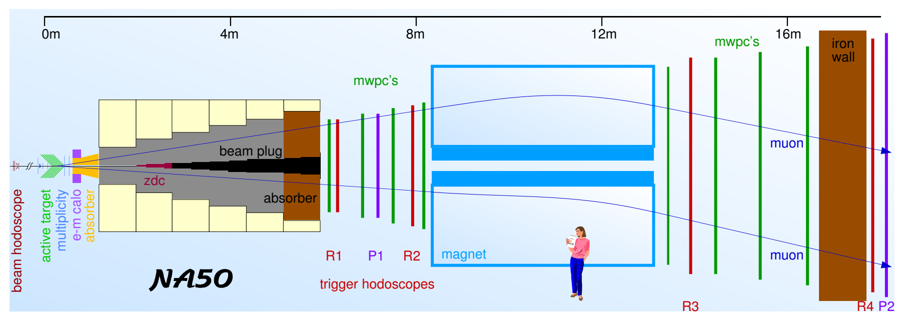
Charmonia production and suppression at SPS energies

P. Cortese for the NA50 Collaboration:

B. Alessandro, C. Alexa, R. Arnaldi, M. Atayan, S. Beolè, V. Boldea, P. Bordalo, G. Borges, C. Castanier, J. Castor, B. Chaurand, B. Cheynis, E. Chiavassa, C. Cicalò, M.P. Comets, S. Constantinescu, P. Cortese, A. De Falco, N. De Marco, G. Dellacasa, A. Devaux, S. Dita, J. Fargeix, P. Force, M. Gallio, C. Gerschel, P. Giubellino, M.B. Golubeva, A.A. Grigorian, S. Grigorian, J.Y. Grossiord, F.F. Guber, A. Guichard, H. Gulkanyan, M. Idzik, D. Jouan, T.L. Karavitcheva, L. Kluberg, A.B. Kurepin, Y. Le Bornec, C. Lourenço, M. Mac Cormick, A. Marzari-Chiesa, M. Masera, A. Masoni, M. Monteno, A. Musso, P. Petiau, A. Piccotti, J.R. Pizzi, F. Prino, G. Puddu, C. Quintans, L. Ramello, S. Ramos, L. Riccati, H. Santos, P. Saturnini, E. Scomparin, S. Serci, R. Shahoyan, F. Sigaudo, M. Sitta, P. Sonderegger, X. Tarrago, N.S. Topilskaya, G.L. Usai, E. Vercellin, L. Villatte, N. Willis, T. Wu

- Università del Piemonte Orientale/INFN, Alessandria, Italy
- LAPP, CNRS-IN2P3, Annecy-le-Vieux, France
- LPC, Univ. Blaise Pascal and CNRS-IN2P3, Aubière, France
- IFA, Bucharest, Romania
- Università di Cagliari/INFN, Cagliari, Italy
- CERN, Geneva, Switzerland
- LIP, Lisbon, Portugal
- INR, Moscow, Russia, IPN
- Univ. de Paris-Sud and CNRS-IN2P3, Orsay, France
- LLR, Ecole Polytechnique and CNRS-IN2P3, Palaiseau, France
- Università di Torino/INFN, Torino, Italy
- IPN, Univ. Claude Bernard Lyon-I and CNRS-IN2P3, Villeurbanne, France
- YerPhI, Yerevan, Armenia



SQM 2004
Cape Town, Sep. 15-20

Charmonia studies at the SPS: physics motivation

Search for the transition of nuclear matter to a deconfined phase of quarks and gluons predicted by statistical QCD at high enough temperature and density

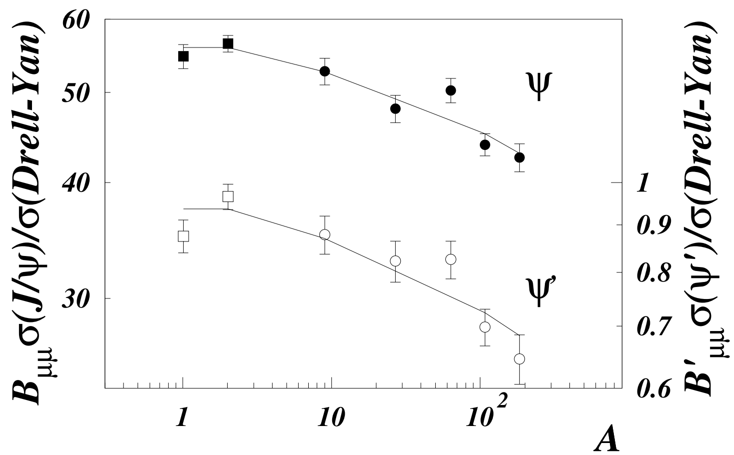
➤ Favourable environment: heavy ion collisions

Questions:

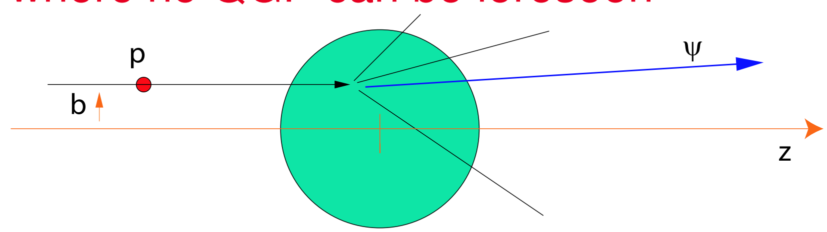
- Can it be reached at SPS energies?
- In which conditions? System size, energy density…

NA50 can study signatures of deconfinement in the dimuon channel, in particular:
➤ J/ψ suppression, first proposed in 1986 by T. Matsui and H. Satz
In this framework J/ψ production is characterized by:
hard production: $\sigma_{c\bar{c}} \propto AB$ + suppression by colour screening in the QGP

With the caveat that, even in absence of colour screening, there are other sources of charmonia suppression



J/ψ absorption is present already in p-A where no QGP can be foreseen



Charmonia production in nuclear collisions

$c\bar{c}$ resonances can be suppressed by different sources

- "Ordinary" absorption processes
  alias "normal" J/ψ suppression
  - nuclear absorption
    $\propto$ path of the $c\bar{c}$ state in nuclear matter
  - dissociation by a hadron gas
    - possible in A-B collisions
    - not possible in p-A

- Debye colour screening
  alias "anomalous" J/ψ suppression
  ➤ could be present only in heavy ion collisions

The study of different systems helps to disentangle the different contributions

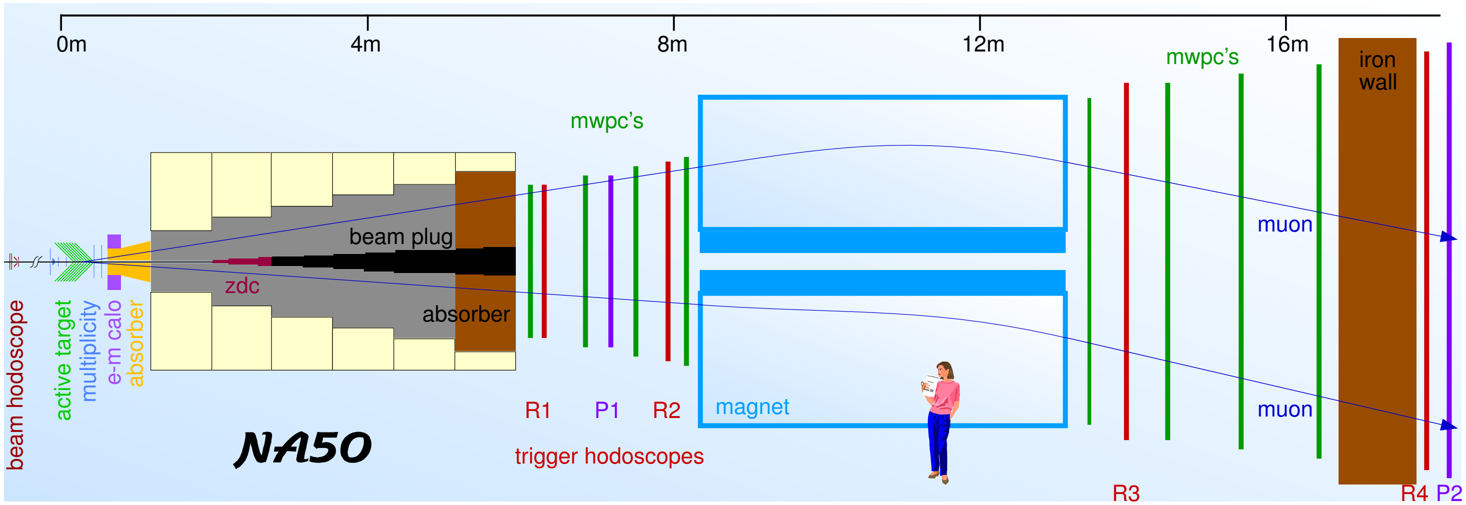
The different $c\bar{c}$ states have different binding energies:
J/ψ: 640 MeV　　χ_c: 200 MeV　　ψ': 50 MeV
$\Rightarrow$ have different sensitivity to the absorption mechanisms

NA50 measures $\mu^+\mu^-$:

direct ψ' production $\Leftrightarrow$ inclusive J/ψ production

J/ψ: direct J/ψ (~60%)　　J/ψ from χ_c decays (~30%)　　J/ψ from ψ' decays (~10%)

The NA50 muon spectrometer



➤ Beam detectors

- ion runs
  - beam hodoscope
  - interaction monitors
- proton runs:
  - beam monitors

➤ Centrality detectors:

- ion runs:
  - EM Calorimeter
  - ZDC
  - Multiplicity Detector

➤ NA10 Muon spectrometer

- hadron absorbers
- air toroidal magnet
- 8 tracking stations: MWPC

➤ Dimuon trigger systems

- main trigger
- redundant trigger

  $\Rightarrow$ monitor the trigger efficiency

The experiment had several upgrades along the years and its name changed from NA38 to NA50 and NA51

Coverage:
$2.9 < y_{Lab} < 3.9$
$|\cos\theta_{CS}| < 0.5$

Typical acceptances:
$A_{J/\psi} \sim 14$ %
$A_{\psi'} \sim 15$ %

Latest results from NA50

Results from year 2000 data taking

➤ improved experimental conditions

➤ improved analysis techniques

- Charmonia production in Pb-Pb collisions at 158 GeV/c

- Charmonia production in p-A at 400 GeV/c

Reanalysis of older data samples

➤ allows consistent analysis conditions of J/ψ and ψ' production when comparing different data sets

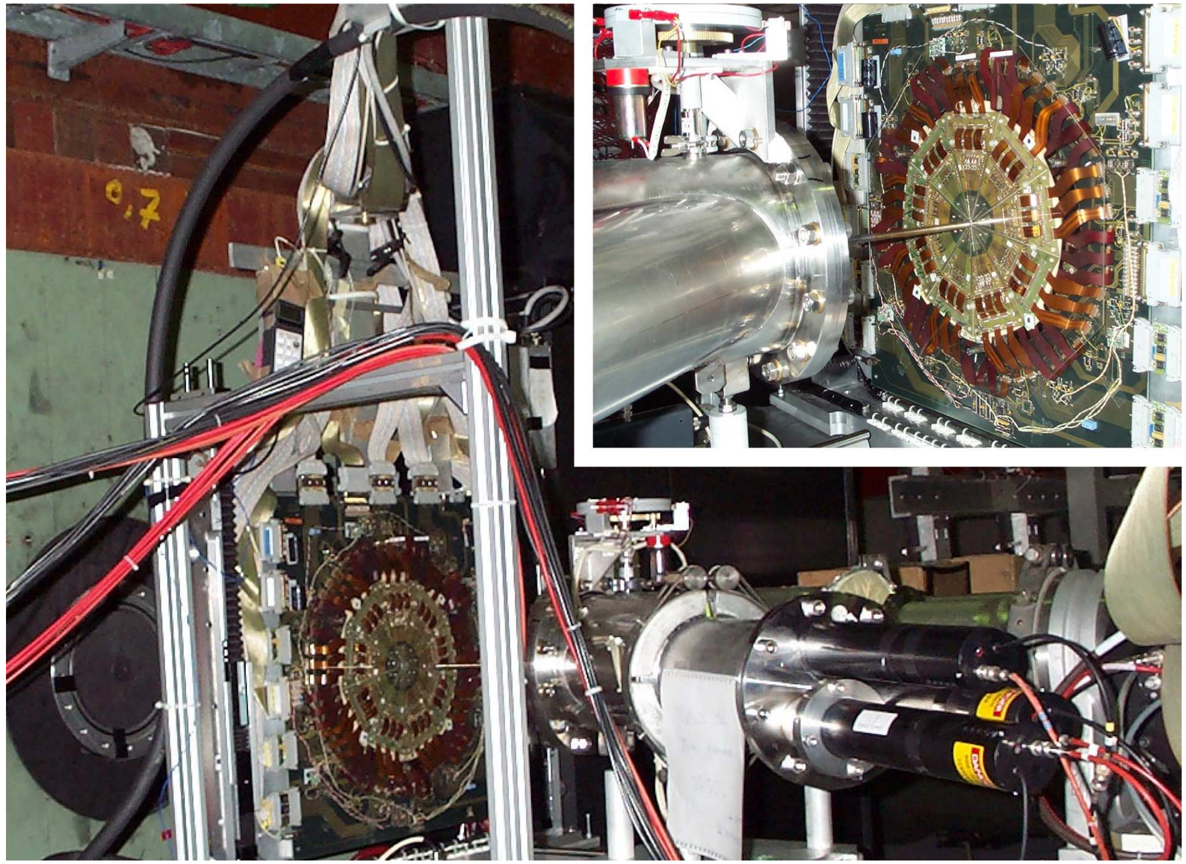
- Pb-Pb 1998 data taking at 158 GeV/c
- S-U 1992 data taking at 200 GeV/c

Improvements in the Pb-Pb experimental setup

year 1998 vs. 1995-96:
segmented target
1995: 17% λ_I and
1996: 30% λ_I

single target
1998: 7% λ_I to avoid ion re-interactions
✔ confirmation of results about central collisions

year 2000:
single target under vacuum
9.5% λ_I
✔ improved study of peripheral collisions



- Year 2000 data taking was developed in a clean environment with no Pb-Air collisions

  $\Rightarrow$ could select peripheral collisions down to $E_T = 3$ GeV
  first E_T bin $\Leftrightarrow \langle b \rangle = 11.8$ fm

The other experimental improvements

Common to pA and Pb-Pb 2000 data sets

➔ improved reconstruction program featuring a higher reconstruction efficiency

➔ improved fitting technique
✔ more accurate estimation of the small ψ' event sample

Pb-Pb 2000

➔ pile-up rejection system
pulse shape analysis of the signal of the EM calorimeter

➔ vertex identification (correlation of hits on Multiplicity Detector planes)
✔ reliable selection of peripheral interactions

p-A 2000 devoted to the accurate measurement of J/ψ nuclear absorption - baseline for the “anomalous” suppression:

- data on 6 targets with frequent target changes
  $\Rightarrow$ reduces the systematic errors on detection efficiencies

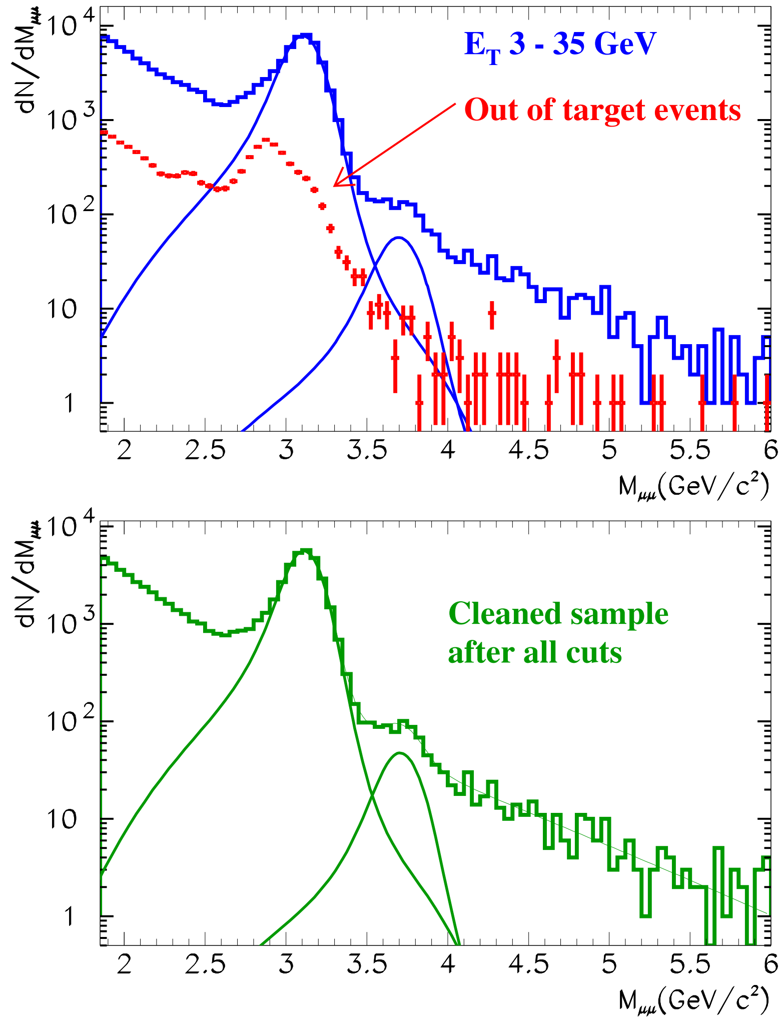
Pb-Pb 1998 and S-U 1992: analysis improvements

➔ reanalysis of previous data using more up-to-date Parton Distribution Functions in the MC
✔ reduced systematics in the comparision of different data sets

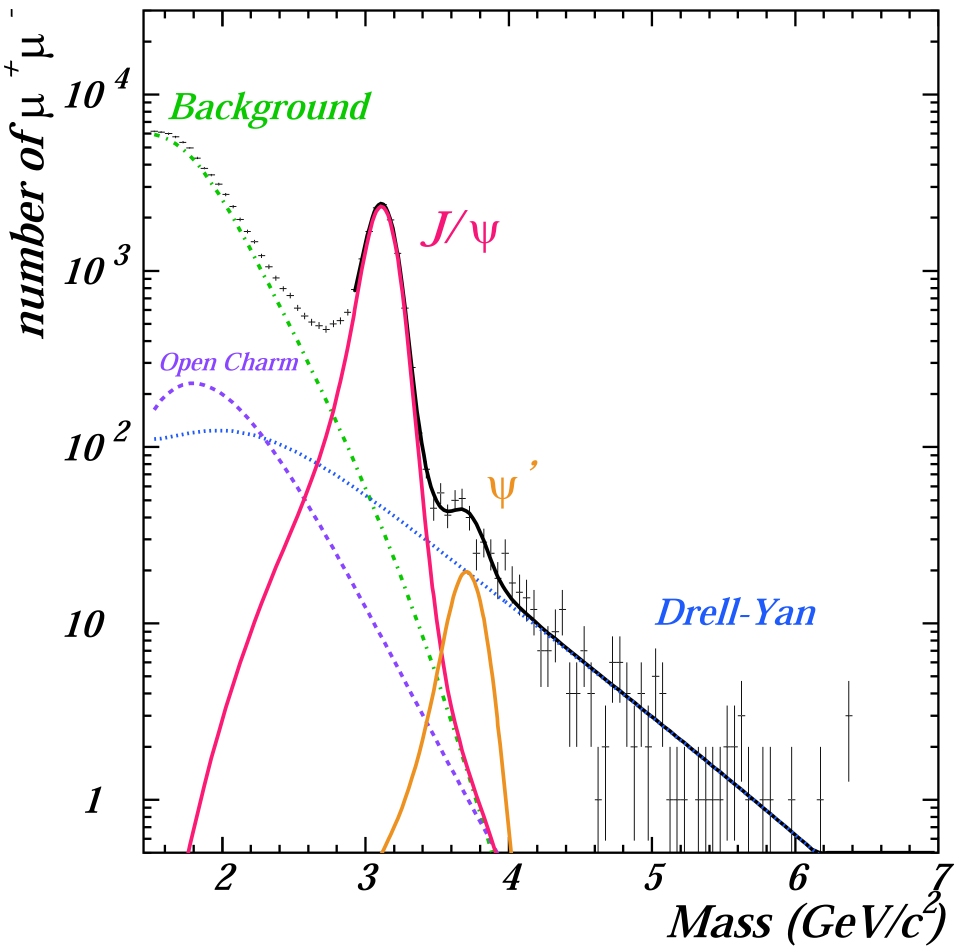
The analysis technique: data selection

- Reject dimuons produced out of target which distort the invariant mass spectrum
  - reject interactions upstream of the target using dedicated detectors (Pb-Pb)
  - identify in-target interactions using Multiplicity detector and the correlation $E_t \; vs \; E_{ZDC}$ (Pb-Pb)
  - apply track quality cuts to further reject dimuons produced in the hadron absorber (Pb-Pb and p-A)
  - subtract the empty target spectrum (p-A)
- Reject the interaction pile-up that gives a bias on the centrality measurement

✔ After all cuts a clean dimuon sample is obtained



The extraction of the signal contributions



- DY, J/ψ, ψ' and $D\overline{D}$ shapes are determined by Monte-Carlo simulation
- J/ψ, ψ' mass resolutions $\simeq$ 100 MeV
- Combinatorial background is extracted from like-sign pairs

$$\frac{dN^{+-}}{dM} = n^{DY}\frac{dN^{DY}}{dM} + n^{J/\psi}\frac{dN^{J/\psi}}{dM} + n^{\psi'}\frac{dN^{\psi'}}{dM} + n^{D\overline{D}}\frac{dN^{D\overline{D}}}{dM} + \frac{dN^{bck}}{dM}$$

Normalizations of the signals are determined with a fit to $\mu^+\mu^-$ invariant mass spectra

Outline of results

J/ψ

1 Absolute cross sections integrated on centrality

- **a)** J/ψ production in p-A 450 and 400 GeV
  - ✎ only nuclear absorption is expected
  - ➜ extract the absorption cross section of J/ψ in nuclear matter
- **b)** Compare with J/ψ suppression present in the collisions of light nuclear systems
  - ✎ additional absorption by comoving hadrons could be present
  - ➜ this additional contribution is not needed to describe data
  - ➜ extract the absorption cross section common to pA and to the collisions of light nuclei
- **c)** Investigate Pb-Pb collisions where is observed the onset of the anomalous J/ψ suppression

2 Study in more detail the J/ψ suppression investigating the centrality dependence

3 Try to disentangle which is the underlying parameter governing J/ψ absorption

ψ'

Compare absorption of the two resonances

J/ψ production in p-A collisions

- 450 GeV:
  pp, pd from NA51
  pBe, pAl, pCu, pAg, pW
  Errors include statistical + systematic errors
- 400 GeV:
  pBe, pAl, pCu, pAg, pW, pPb
  Errors include statistical and relative systematic errors. Uncertainty on the normalization (common and not plotted) is $\sim$ 3 %

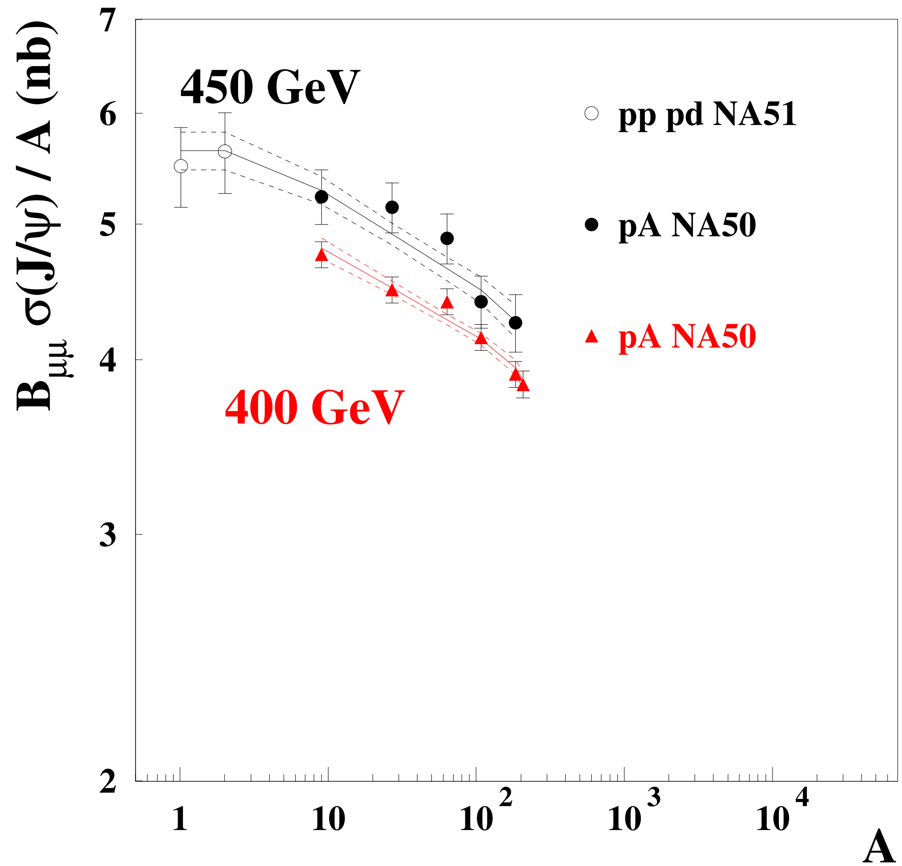
Data at 400 GeV have the smallest relative systematic uncertainty

Glauber fit to extract the J/ψ absorption cross section in nuclear matter

$\sigma_{abs\,pA}(450) = 4.5 \pm 0.8$ mb

$\sigma_{abs\,pA}(400) = 4.1 \pm 0.5$ mb

J/ψ absorption cross sections at the two energies are compatible within errors



J/ψ production in Proton, Oxygen and Sulphur induced collisions

- 200 GeV:
  pCu, pW, pU
  O-Cu, O-U, S-U from NA38
  pp and pPt from NA3 (not used in the fits)

$\sigma_{abs\, pA}(450) = 4.5 \pm 0.8$ mb

$\sigma_{abs\, pA}(400) = 4.1 \pm 0.5$ mb

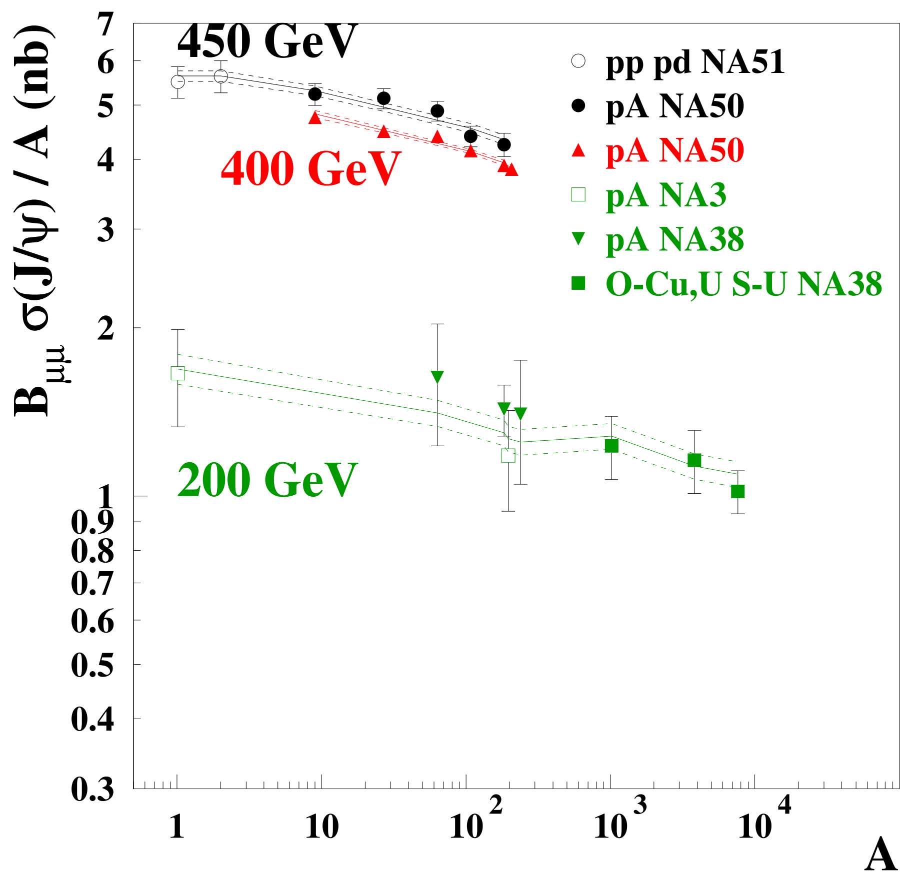
$\sigma_{abs\, pA+AB}(200) = 7.7 \pm 3.2$ mb

J/ψ absorption cross sections at the three energies are compatible within errors

- The data sets can be fitted with a common J/ψ absorption cross section

Simultaneous fit has 4 free parameters: normalizations at the 3 energies and a common absorption cross section

$\sigma_{abs} = 4.2 \pm 0.4$ mb
$\chi^2/d.o.f. = 0.48$



J/ψ production in Pb-Pb collisions

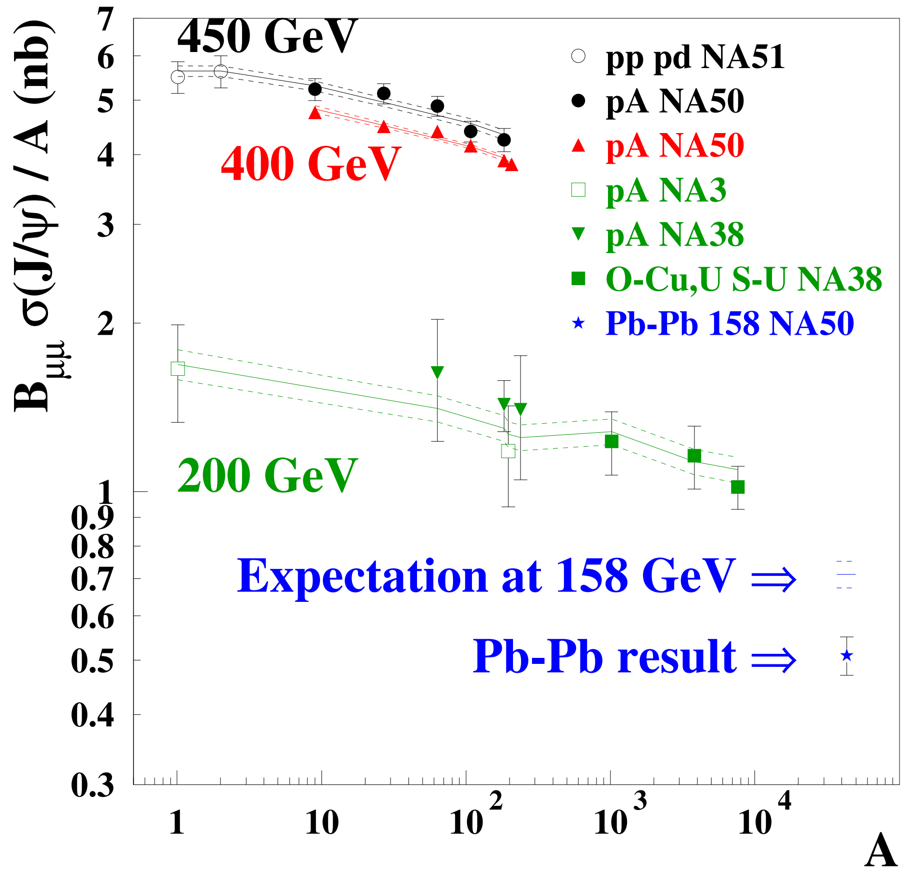
PbPb data has been taken at 158 GeV incident energy

$\Rightarrow$ rescale the J/ψ production cross section in p-p from 200 GeV to 158 GeV with a NLO calculation

$\Rightarrow$ With the Glauber model estimate the J/ψ production cross section in Pb-Pb taking into account nuclear absorption:
$\sigma_{abs} = 4.2 \pm 0.4$ mb

J/ψ production in Pb-Pb is suppressed with respect to the extrapolation from lighter systems

Expected: σ(J/ψ) $= 0.71 \pm 0.04$ nb
Measured: σ(J/ψ) $= 0.51 \pm 0.04$ nb



Centrality dependence of J/ψ production: S-U

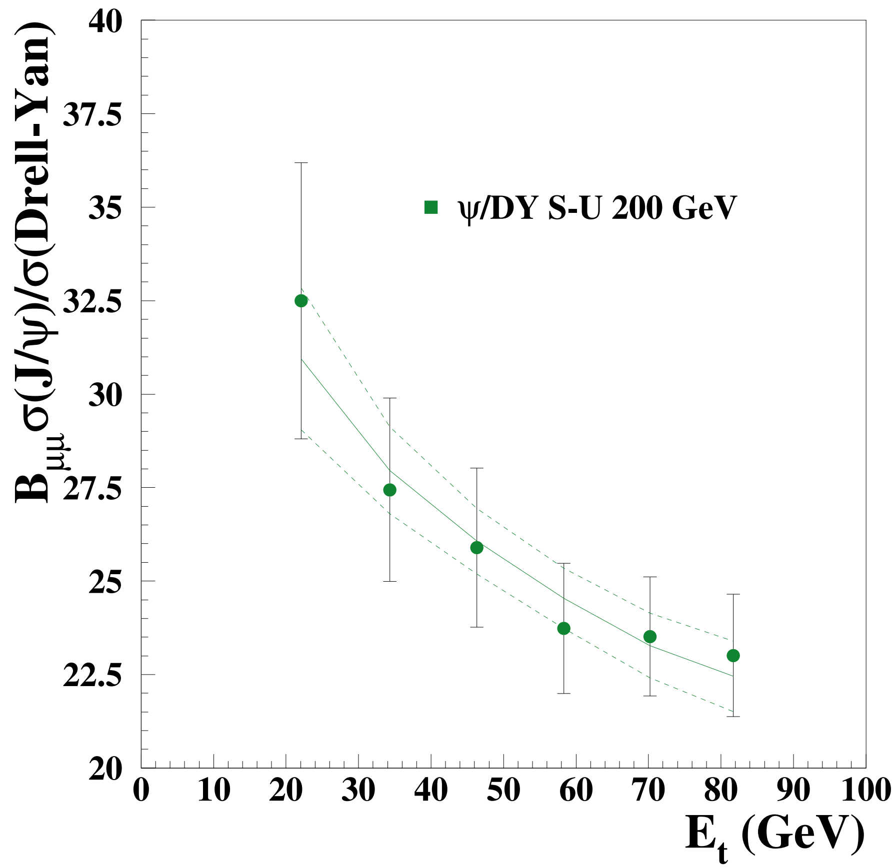
In nucleus-nucleus collisions we can study the centrality dependence of J/ψ production

S-U collisions	$\Rightarrow$	EM calorimeter		
Pb-Pb collisions	$\Rightarrow$	EM calorimeter	ZDC	Multiplicity Detector

Useful cross section ratio:
$B_{\mu\mu}\sigma(\psi)/\sigma(Drell-Yan)$

- cancels most of the luminosity uncertainties
- no shadowing is observed (or foreseen) in NA50 kinematic domain
- straightforward normalization for all systems and for every centrality bin $\sigma_{DY} \propto N_{coll}$
  $\Rightarrow$ convenient for the study of centrality dependence

✖ price to pay: low DY statistics

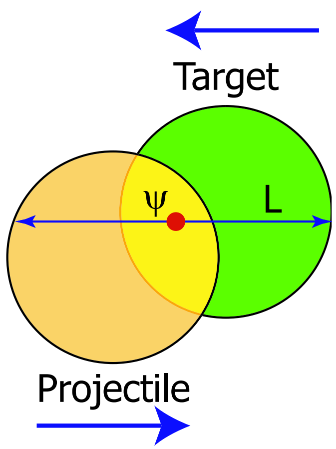


A Glauber fit to S-U data gives $\sigma_{abs\ SU} = 7.0 \pm 3.0$ mb

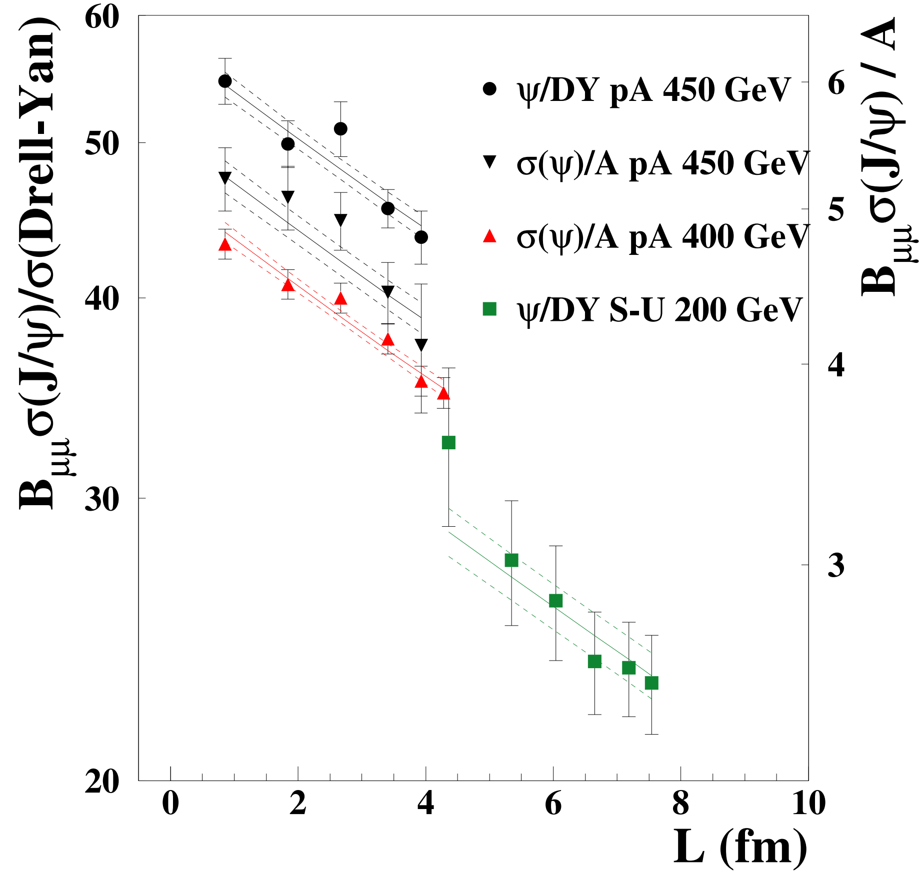
J/ψ production in p-A and S-U collisions

To compare J/ψ production pA data (integrated on centrality) with S-U data (divided into centrality bins) we use the variable L

L: path of nuclear matter crossed by the J/ψ



$$L = \frac{\#nucleons/fm^2}{0.17\, nucleons/fm^3}$$



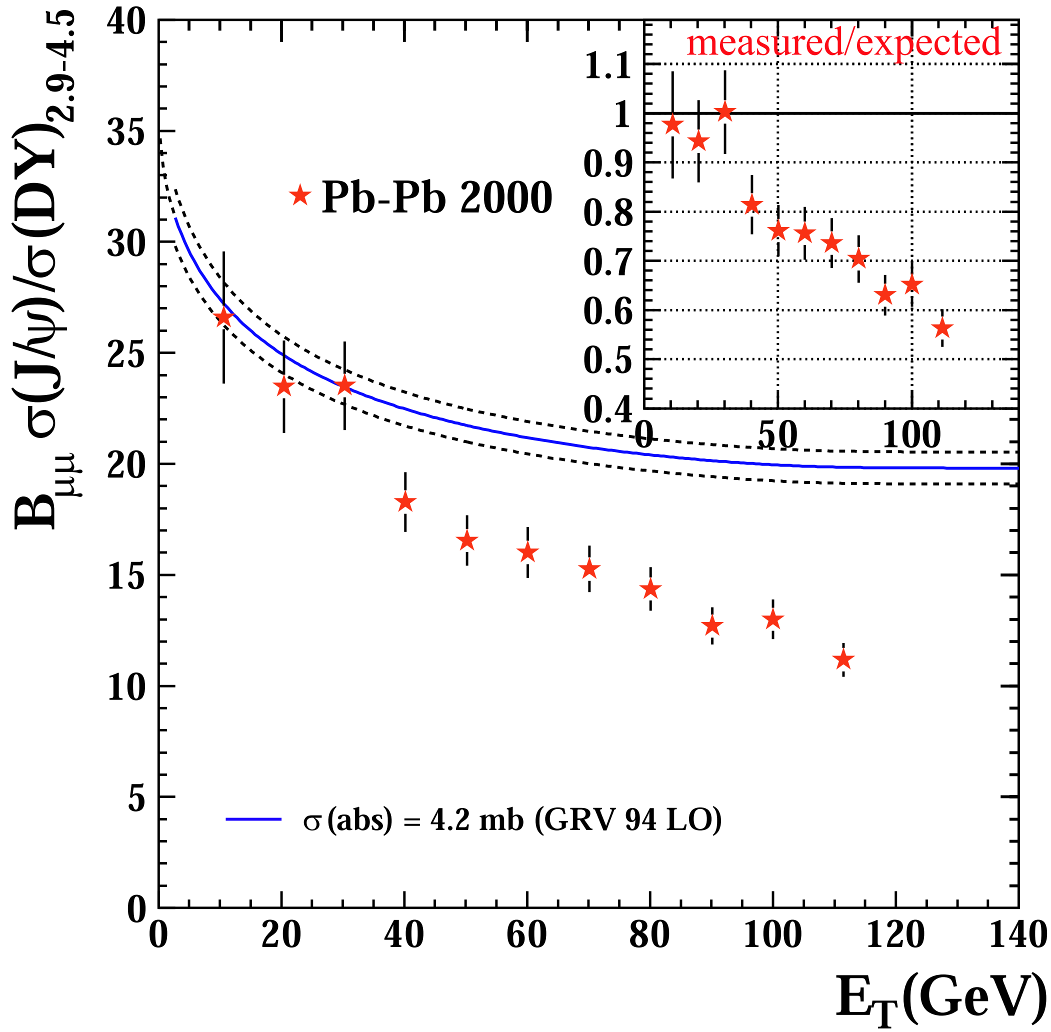
$\sigma_{abs\, pA} = 4.2 \pm 0.4$ mb (ψ/DY and σ_ψ at 450 GeV + σ_ψ at 400 GeV)
$\sigma_{abs\, SU} = 7.0 \pm 3.0$ mb

All data sets can be fitted with a common absorption cross section:
$\sigma_{abs\, pA+SU} = 4.2 \pm 0.4$ mb $\chi^2 = 0.55$

J/ψ production in Pb-Pb collisions

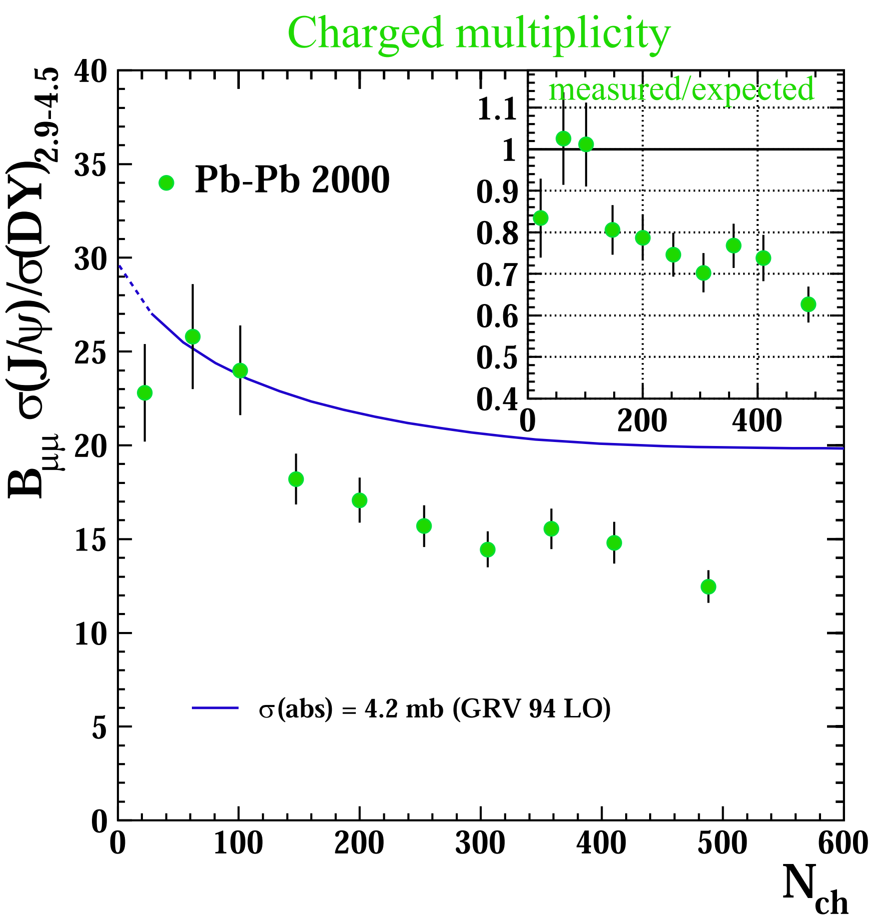
J/ψDY ratio as a function of E_T
Compare the experimental results with the nuclear absorption observed in lighter systems

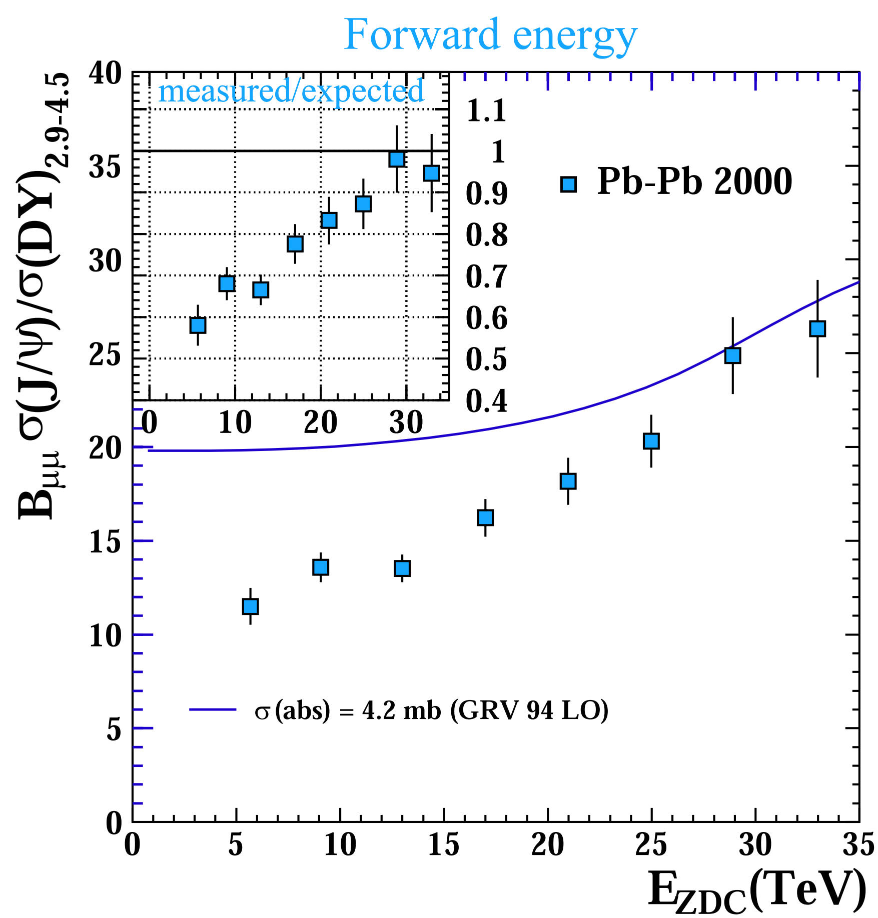
- Peripheral Pb-Pb results are in accordance with the expected nuclear absorption
- Departure from nuclear absorption at $E_T \sim 40$ GeV
- Steady decrease after 40 GeV
- No saturation for central collisions



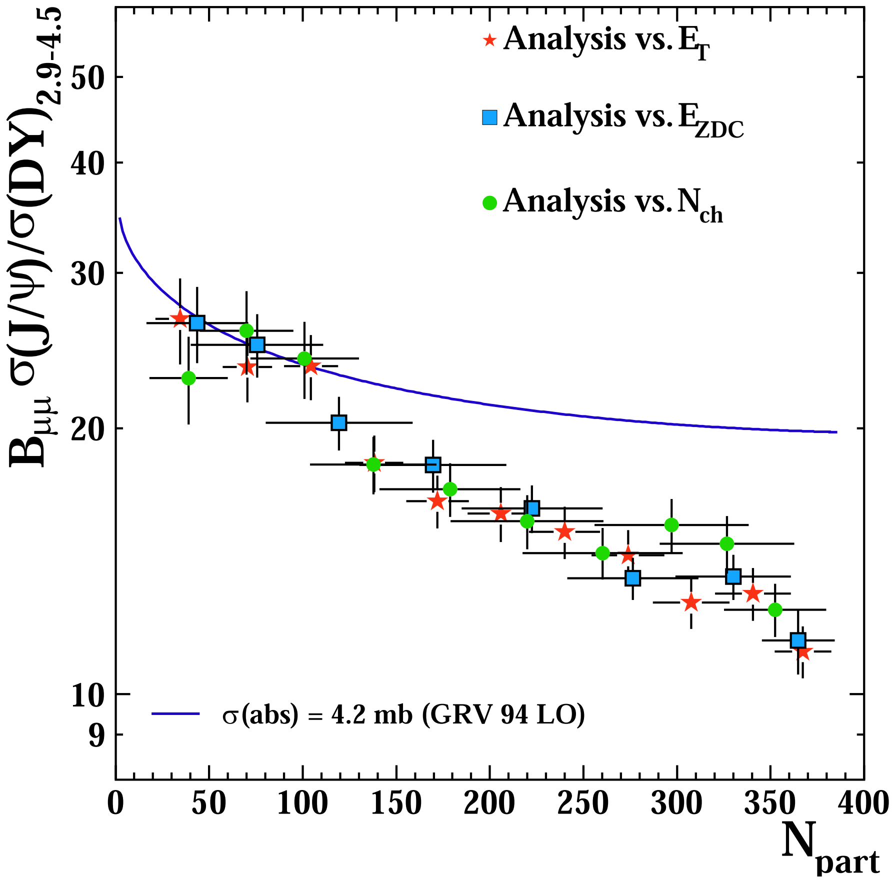
J/ψ production in PbPb (2)

Same pattern is observed with the other centrality estimators





Comparing the three analyses



- E_T, $dN_{ch}/d\eta|_{max} \propto$ number of participants nucleons
- $E_{ZDC} \propto$ number of spectator nucleons
- N_{part} allows a straightforward comparison of the three analyses

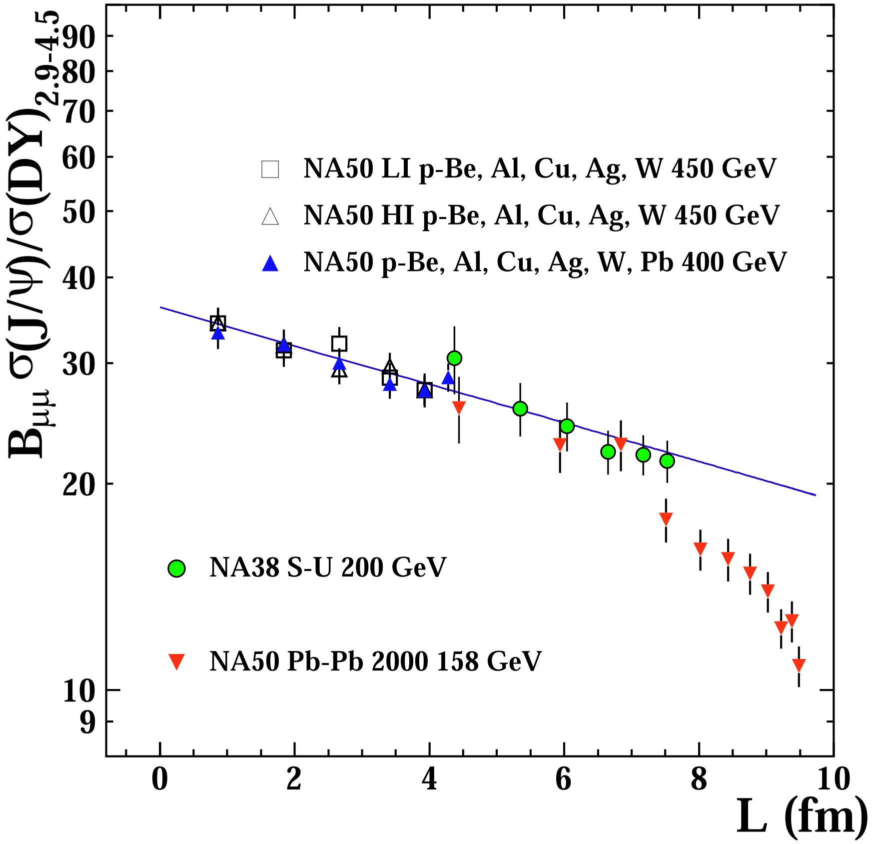
$\Delta N_{part} = RMS$ of the N_{part} distribution for each (E_T, $dN_{ch}/d\eta$, E_{ZDC}) bin

(depends on detector resolution + experimental smearing)

The absorption pattern does not depend on a particular centrality estimator

Departing from normal nuclear absorption between $N_{part} \sim 100$ and 150

Physics processes governing J/ψ suppression: nuclear absorption



- Rescale all data sets to 158 GeV
- Correct DY for isospin effects

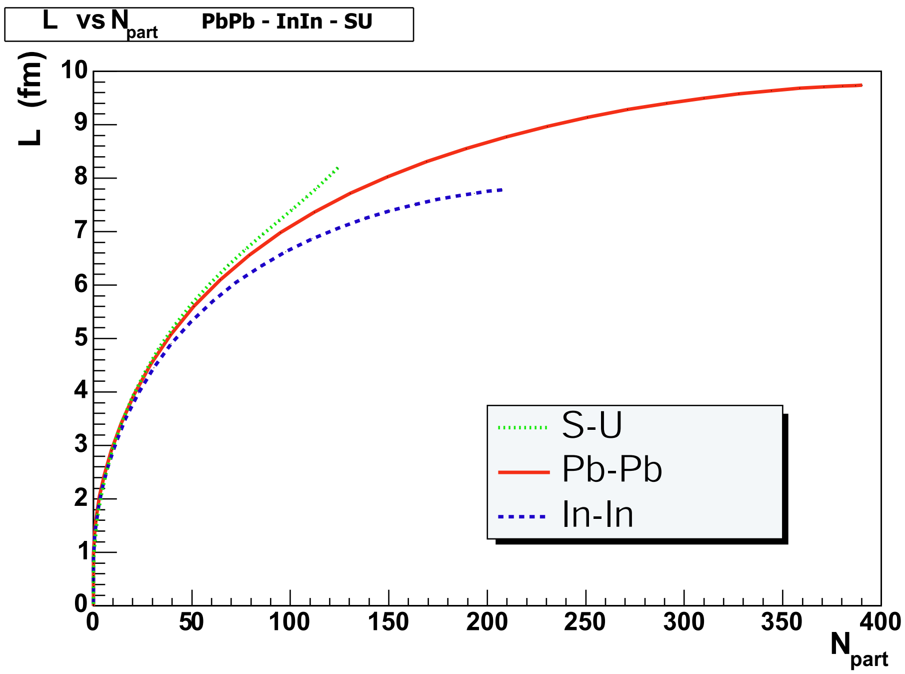
Study J/ψ production as a function of L: the length of nuclear matter crossed by the J/ψ

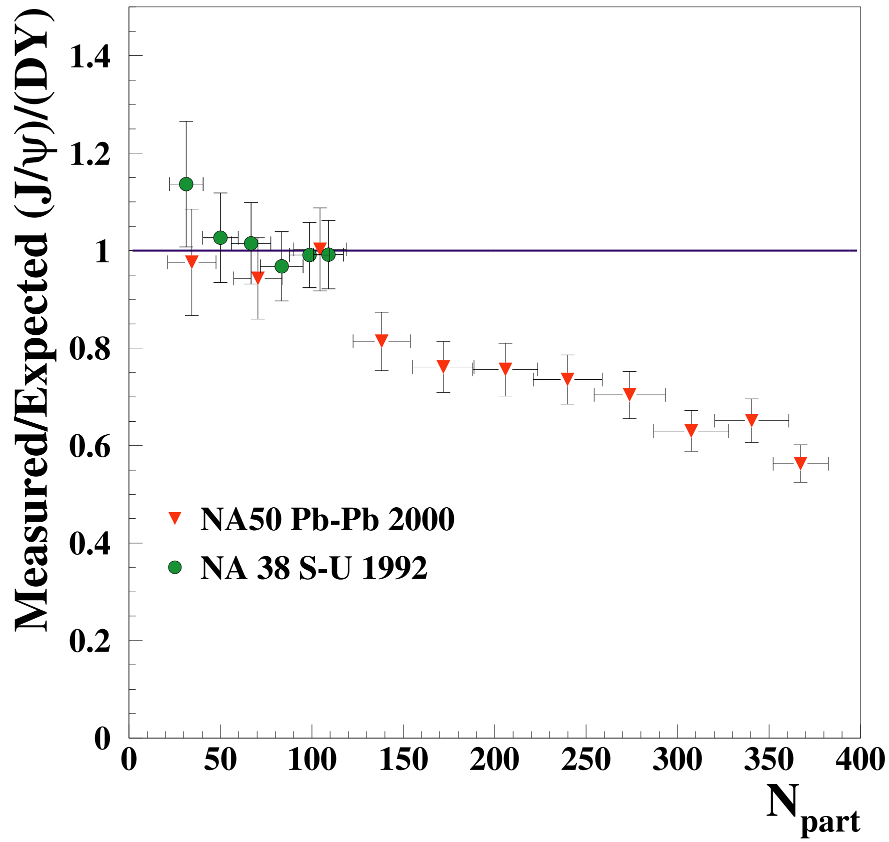
- In light systems and peripheral Pb-Pb collisions the J/ψ absorption scales with L
  - L very probably is governing the normal absorption
- In Pb-Pb collisions the L scaling is broken
  - The anomalous suppression sets in

J/ψ suppression vs. the number of participants nucleons

Measured ψ/DY compared with expectations of nuclear absorption from a Glauber model

Collisions of different systems allow to explore different ranges of L and N_{part}





The departure from normal absorption is compatible with a onset in the N_{part} variable

J/ψ suppression vs. energy density

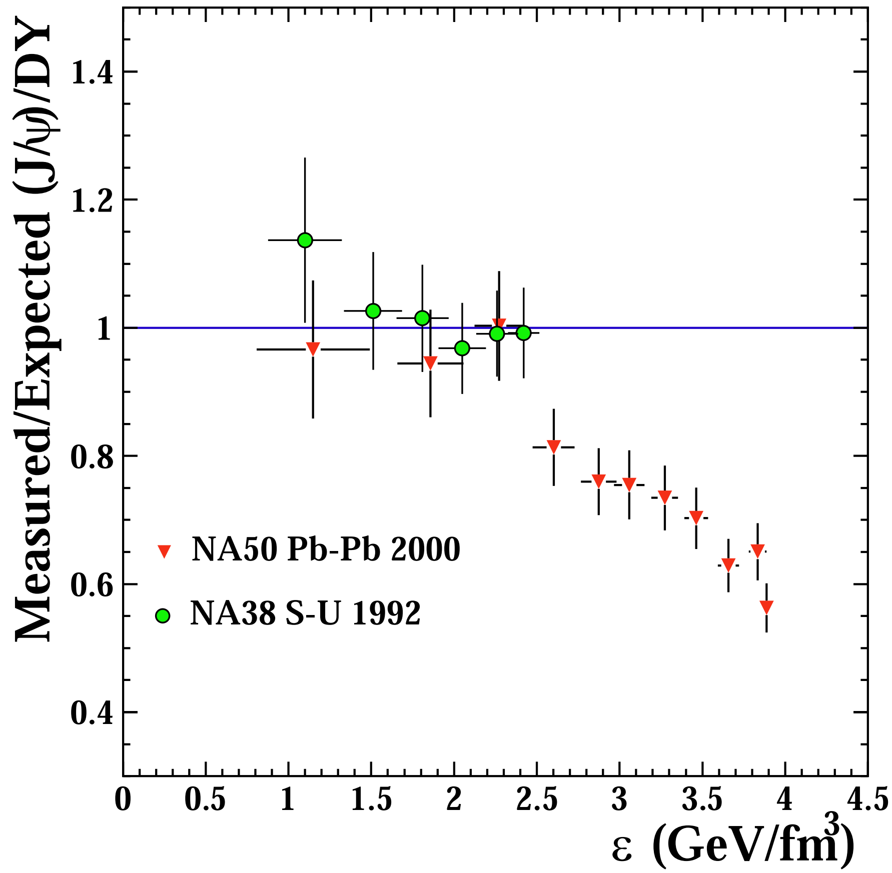
Measured ψ/DY compared with expectations of nuclear absorption from a Glauber model

Energy density computed with the Bjorken estimate:

$$\varepsilon = \frac{dE_T/d\eta\big|_{max}}{c\,\tau\,A_T}$$

- useful comparison between different colliding systems

The departure from normal absorption is compatible with an onset in energy density



The ψ' study

Challenging analysis

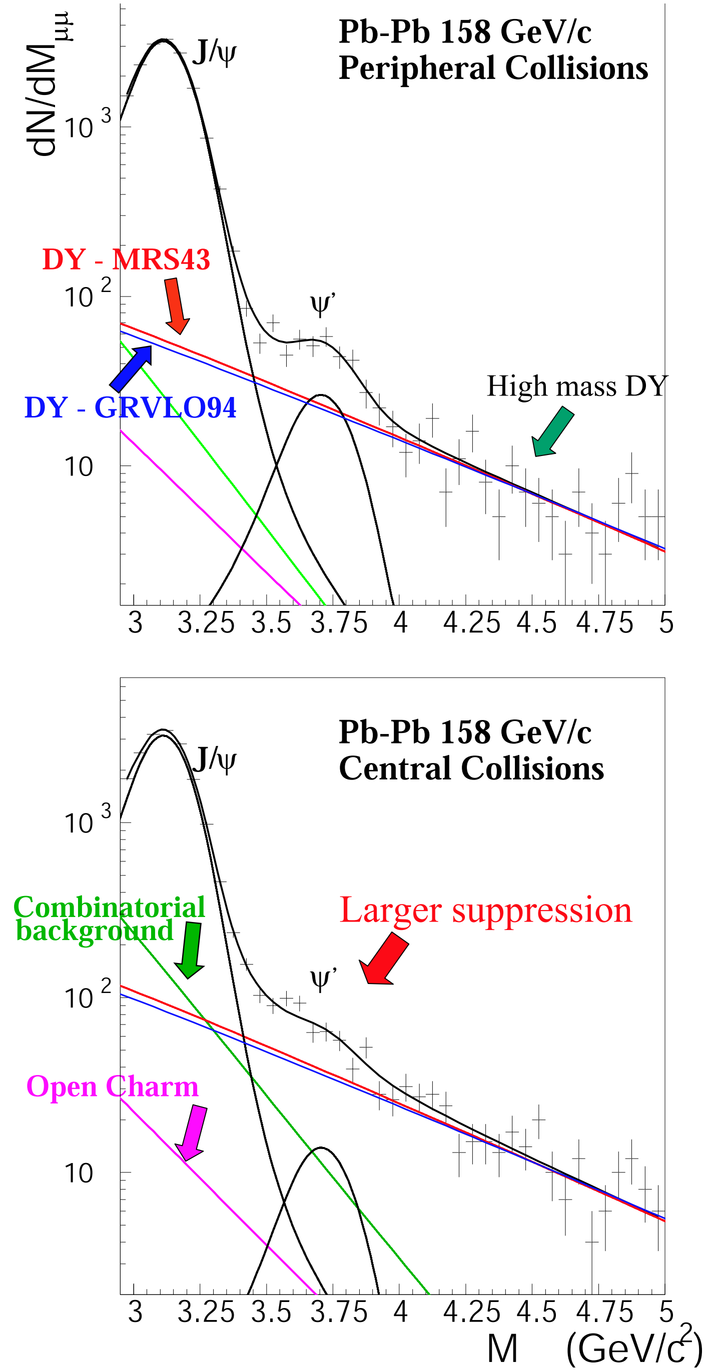
- small cross section and branching ratio
- large suppression
- several dimuon sources in the invariant mass spectrum range

Main systematics:

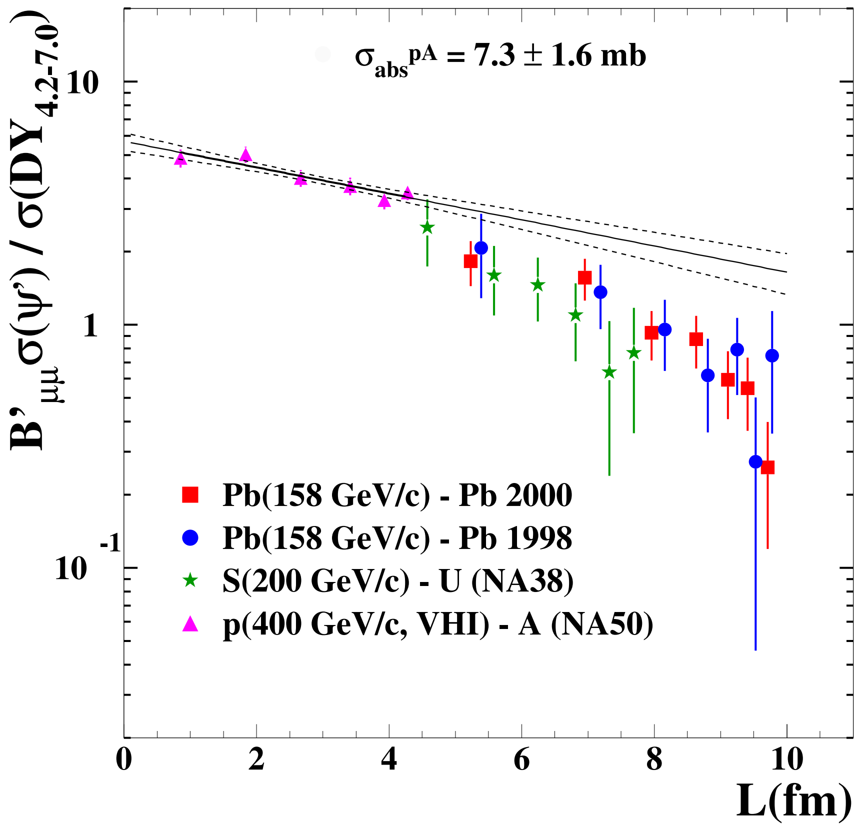
✖ Different PDFs for Drell-Yan simulation introduce $\sim$ 10% difference on ψ' normalization (GRV LO/MRS A)

$\Rightarrow$ consistent analysis of the different data sets

$\Rightarrow$ use high-mass DY as a reference



ψ'/DY as a function of L



ψ' is suppressed w.r.t. Drell-Yan

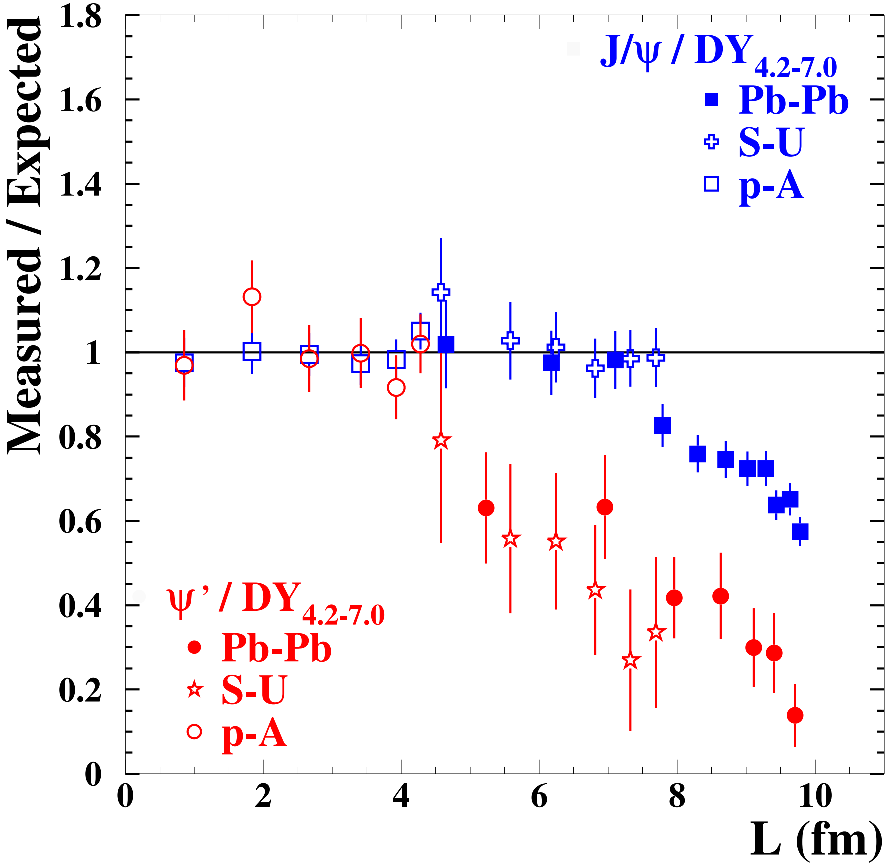
- absorption in p-A $\ll$ S-U and Pb-Pb
- strong suppression between peripheral and central A-B collisions (a factor $\sim$ 7 in Pb-Pb)
- absorption in S-U and Pb-Pb are compatible when considered as a function of L

With an exponential fit we estimate the ψ' break up cross section: σ_{abs}

p-A: $\sigma_{abs}^{\psi'} = 7.3 \pm 1.6$ mb

A more accurate Glauber fit (that includes also other NA50 ψ' published results) gives: $\sigma_{abs}^{\psi'} = 7.7 \pm 0.7$ mb

Summary: measured/expected



Measured:
(J/ψ)/DY and ψ'/DY
Expected:
predictions from a Glauber model:

- for J/ψ
  $\sigma_{abs}^{J/\psi} = 4.2$ mb (p-A and S-U)
- for ψ'
  $\sigma_{abs}^{\psi'} = 7.7$ mb (p-A)

Conclusions

p-A

J/ψ and ψ' undergo nuclear absorption

$\sigma_{abs}^{J/\psi} = 4.2 \pm 0.4$ mb $\qquad$ $\sigma_{abs}^{\psi'} = 7.7 \pm 0.7$ mb

S-U

- J/ψ production can be described with the same nuclear absorption observed in pA
- Departure from nuclear absorption for the ψ'

Pb-Pb

- For the J/ψ: clear onset of the anomalous suppression
- The ψ' follows the same trend already observed in S-U collisions
  $\Rightarrow$ points to towards a common origin of ψ' suppression in Pb-Pb and S-U