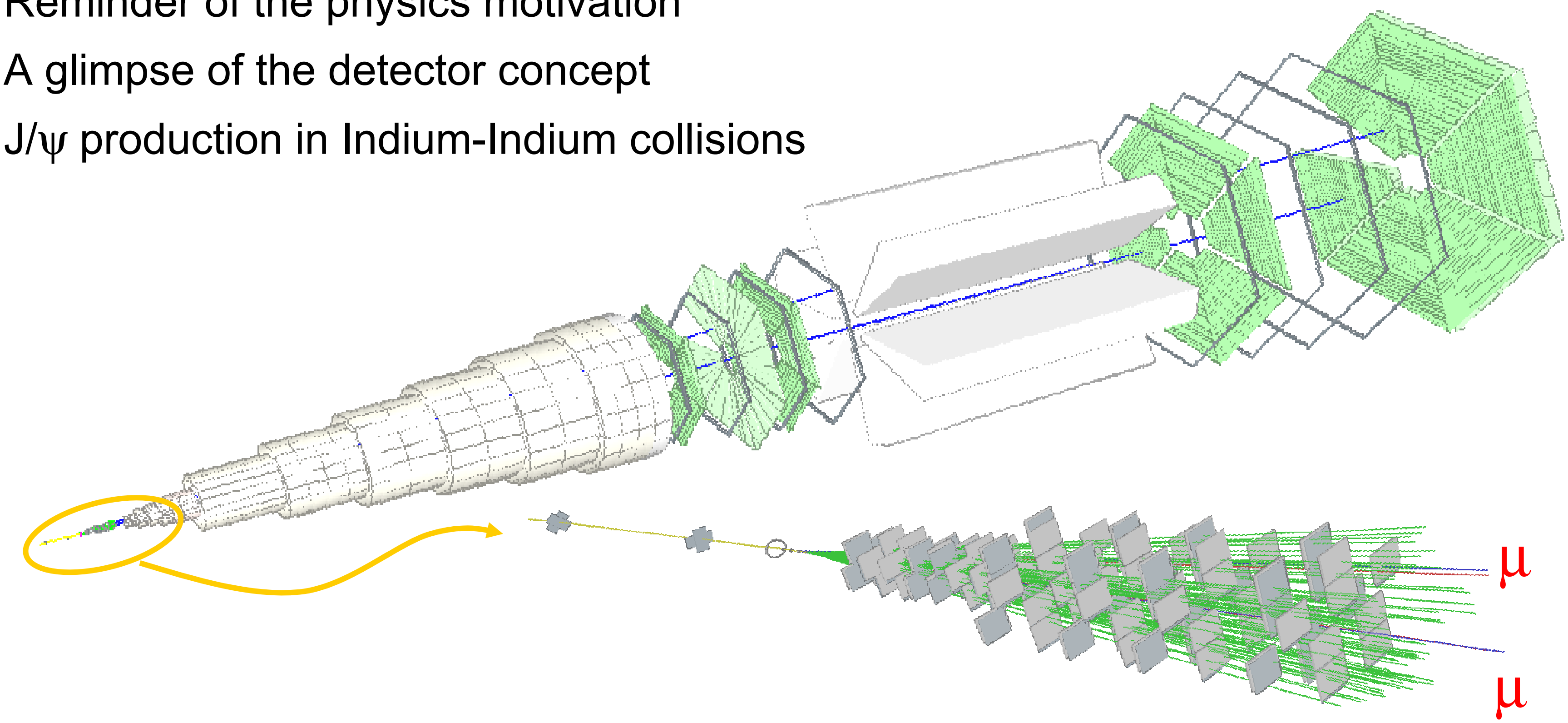
J/ψ production in Indium-Indium collisions: the NA60 experiment

Outline:

- Reminder of the physics motivation
- A glimpse of the detector concept
- J/ψ production in Indium-Indium collisions



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for the NA60 Collaboration

Hard Probes 2004, 4-10 Nov. 2004

A reminder of the physics motivation

QCD predicts that, above a critical temperature or energy density, strongly interacting matter undergoes a phase transition to a new state where the quarks and gluons are no longer confined in hadrons, and chiral symmetry is restored

Since 1986, many experiments, probing high-energy nuclear collisions at the CERN SPS, searched for this phase transition. Some of the theory-driven "signatures" required measuring lepton pairs and motivated **NA38, CERES, HELIOS-3** and **NA50**:

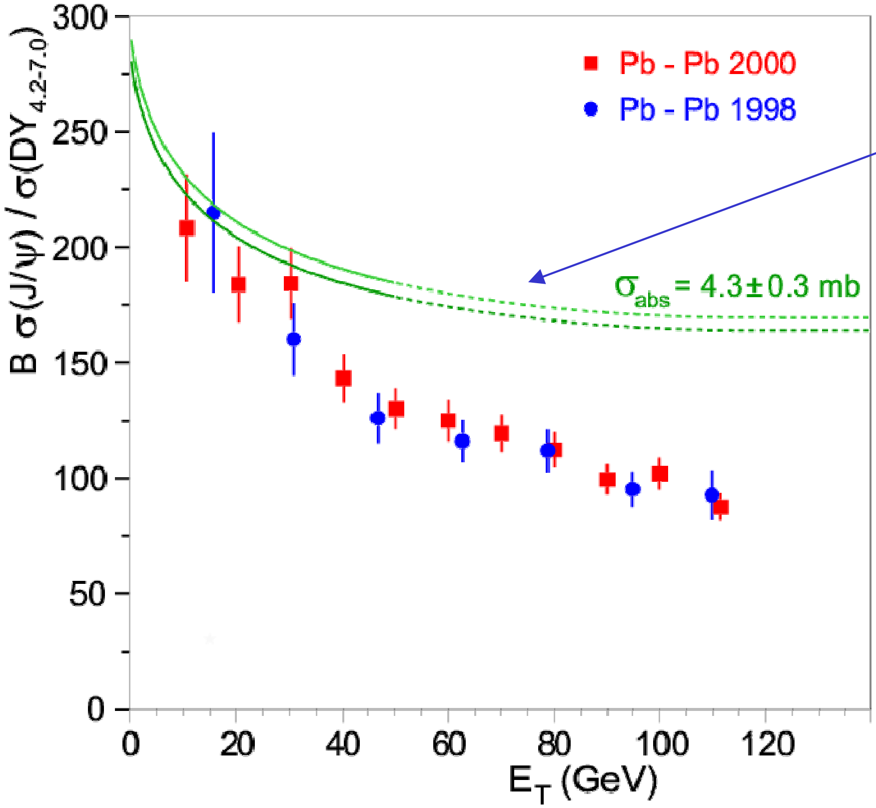
- the production of **thermal dimuons**
  directly emitted from the new phase, if in thermal equilibrium
- **changes in the ρ spectral function** (mass shifts, broadening, disappearance)
  when chiral symmetry restoration is approached
- the **suppression of strongly bound heavy quarkonia states**
  dissolved when certain *critical thresholds* are exceeded

→ This talk will be focused on the third point, in particular on the **suppression of the J/ψ**

see the talks of R. Shahoyan, H. Wöhri and G. Usai, for other interesting physics topics covered by NA60

J/ψ suppression from p-A to Pb-Pb collisions

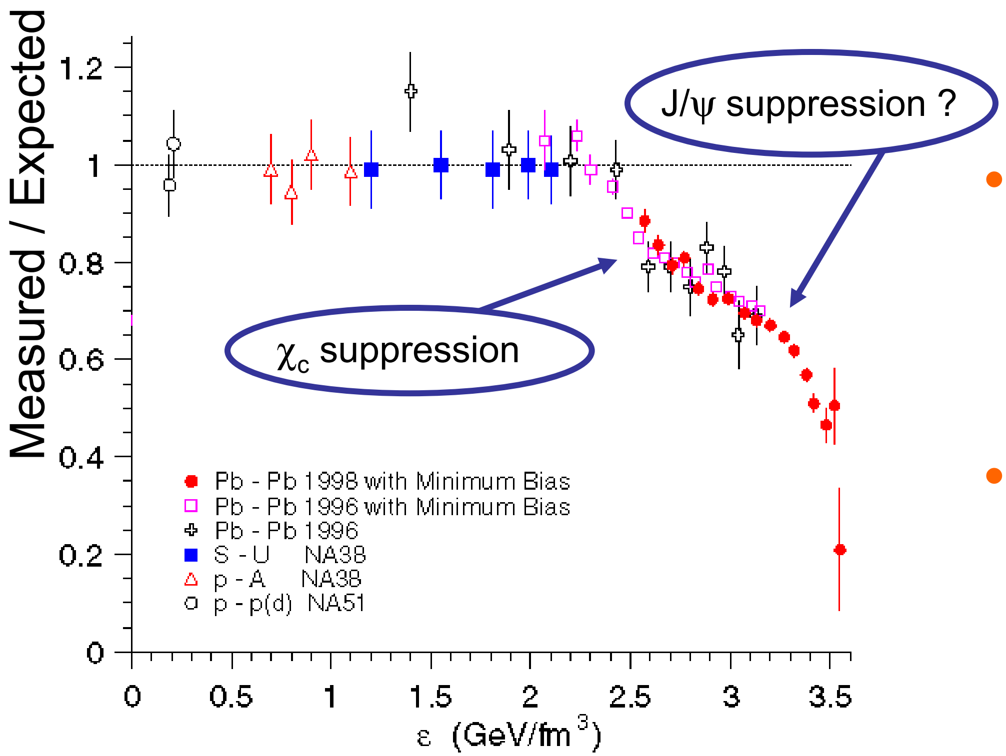
- J/ψ production has been extensively studied by the **NA38** and **NA50** experiments
  ⇒ the J/ψ is suppressed in Pb-Pb collisions
  with respect to the yields extrapolated from proton-nucleus data



J/ψ normal nuclear absorption curve

see talks of L. Kluberg
and G. Borges for details

Specific questions that remain open



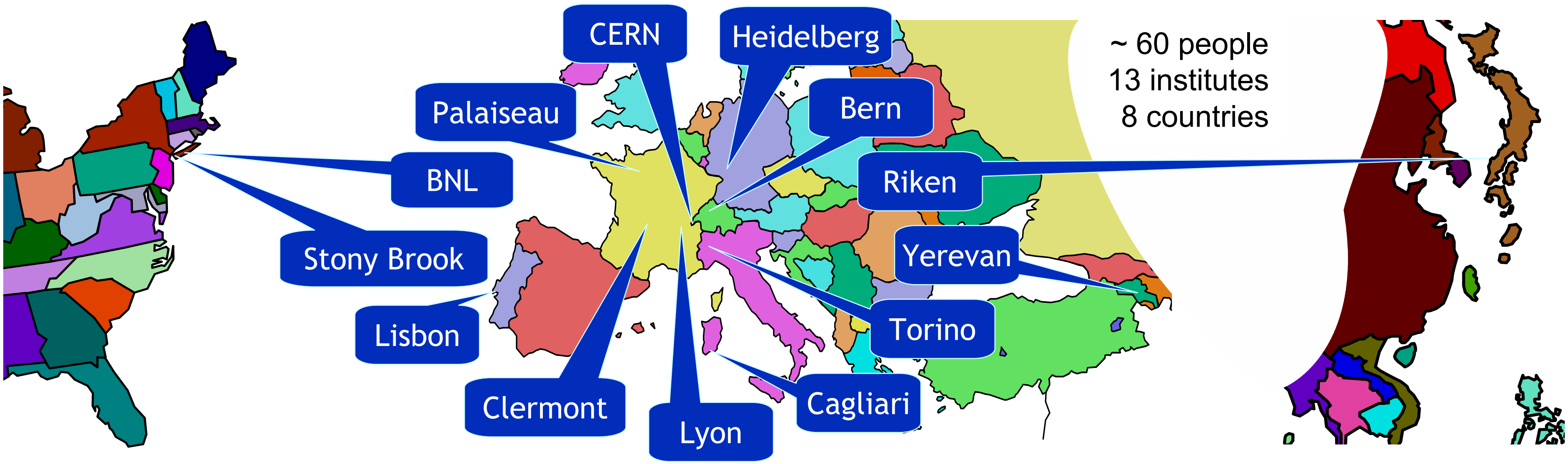
- What is the impact of the χ_c feed-down on the observed J/ψ suppression pattern?
  ⇒ Study the nuclear dependence of χ_c production in p-A collisions
- What is the physics variable driving the J/ψ suppression? L, N_{part}, energy density?
  ⇒ Measure the J/ψ suppression pattern in Indium-Indium and compare it with Pb-Pb

New and accurate measurements are needed → **NA60**

The NA60 experiment

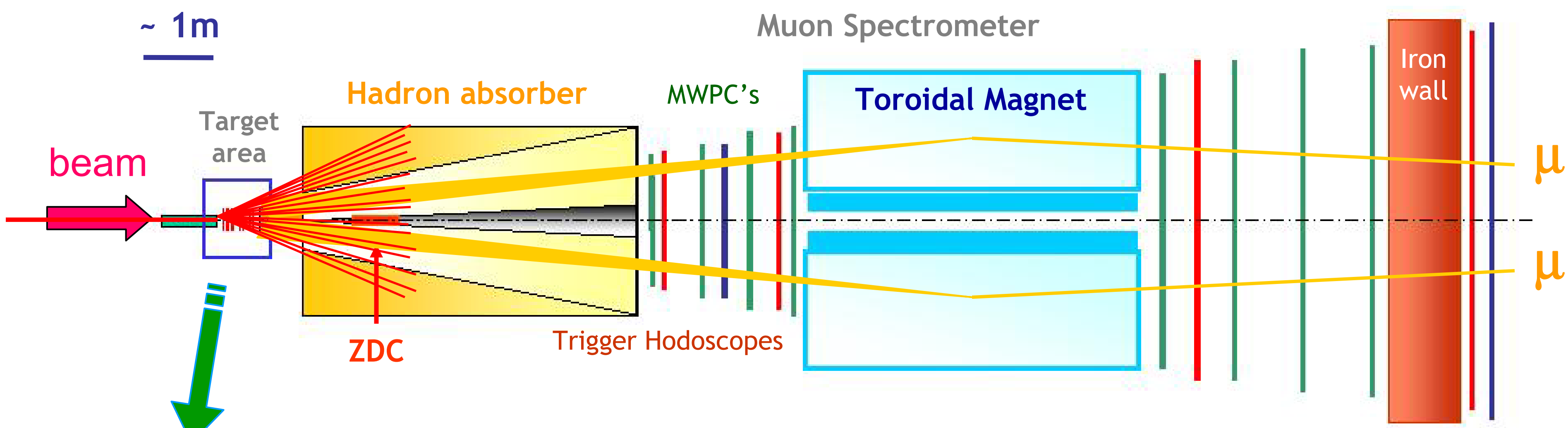
http://cern.ch/na60

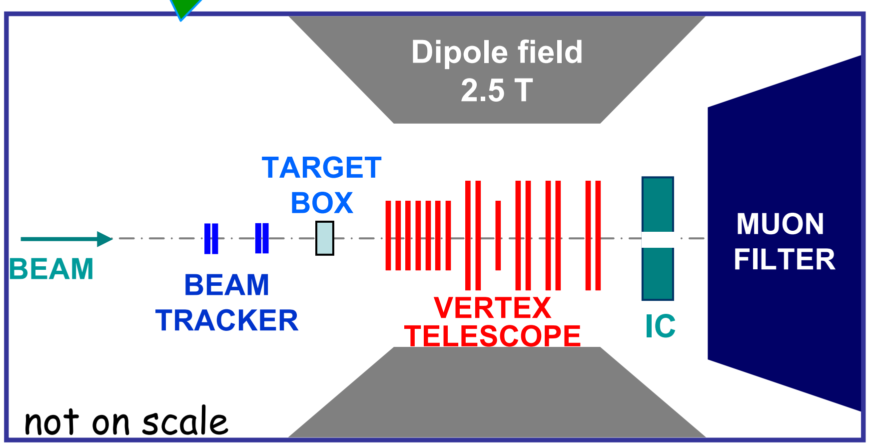
Idea: place a *high granularity* and *radiation-hard* **silicon tracking telescope** in the vertex region to measure the muons before they suffer multiple scattering and energy loss in the absorber



R. Arnaldi, R. Averbeck, K. Banicz, K. Borer, J. Buytaert, J. Castor, B. Chaurand, W. Chen, B. Cheynis, C. Cicalò, A. Colla, P. Cortese, S. Damjanović, A. David, A. de Falco, N. de Marco, A. Devaux, A. Drees, L. Ducroux, H. En'yo, A. Ferretti, M. Floris, P. Force, A. Grigorian, J.Y. Grossiord, N. Guettet, A. Guichard, H. Gulkanian, J. Heuser, M. Keil, L. Kluberg, Z. Li, C. Lourenço, J. Lozano, F. Manso, P. Martins, A. Masoni, A. Neves, H. Ohnishi, C. Oppedisano, P. Parracho, P. Pillot, G. Puddu, E. Radermacher, P. Ramalhete, P. Rosinsky, E. Scomparin, J. Seixas, S. Serci, R. Shahoyan, P. Sonderegger, H.J. Specht, R. Tieulent, E. Tveiten, G. Usai, H. Vardanyan, R. Veenhof and H. Wöhri

NA60's detector concept

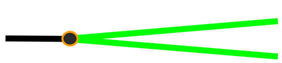




Matching in coordinate
and momentum space

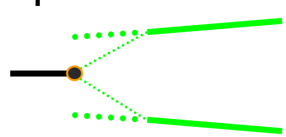
✓ Origin of muons can be accurately determined
✓ Improved dimuon mass resolution

prompt dimuon



or

muon pair from
displaced vertices

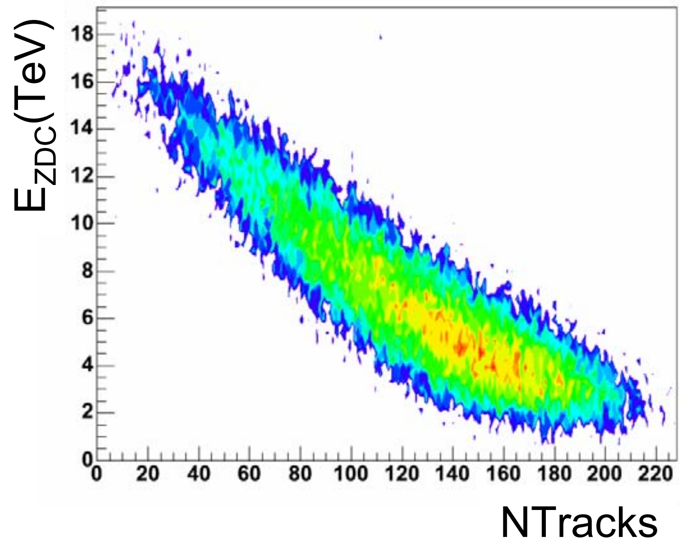


ZDC

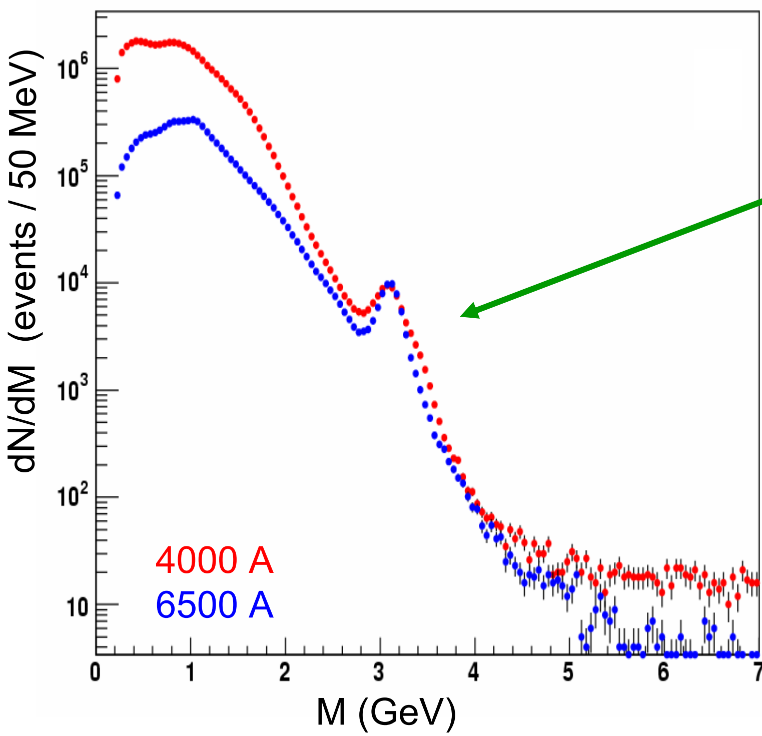
dimuon studies vs.
collision centrality

The Indium run

- 5-week long run in Oct.–Nov. 2003
- ~ 4 × 10^{12} ions delivered in total
- ~ 230 million dimuon triggers on tape



Broad centrality coverage, through two completely independent global variables: E_{ZDC} and $N_{charged}$



Opposite-sign dimuon mass distributions before event selection and muon track matching

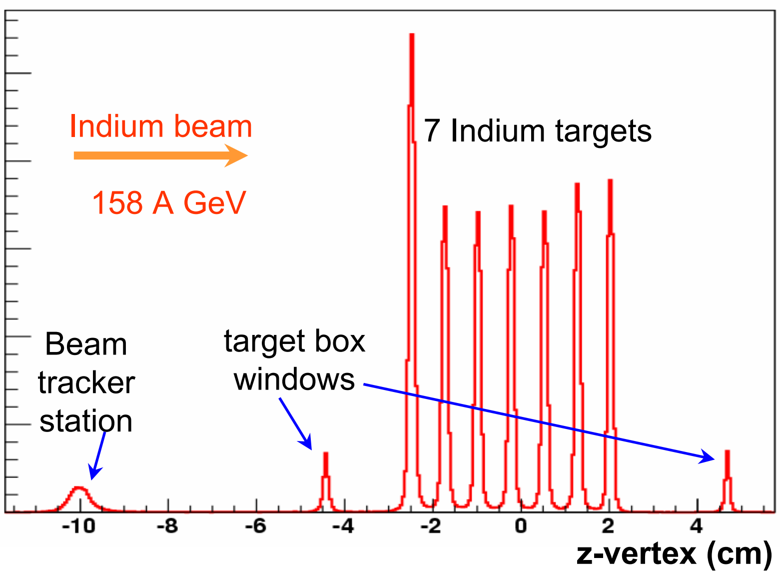
NA60 collected two data sets, with different magnet settings. Here we show the results obtained with the 6500 A sample.

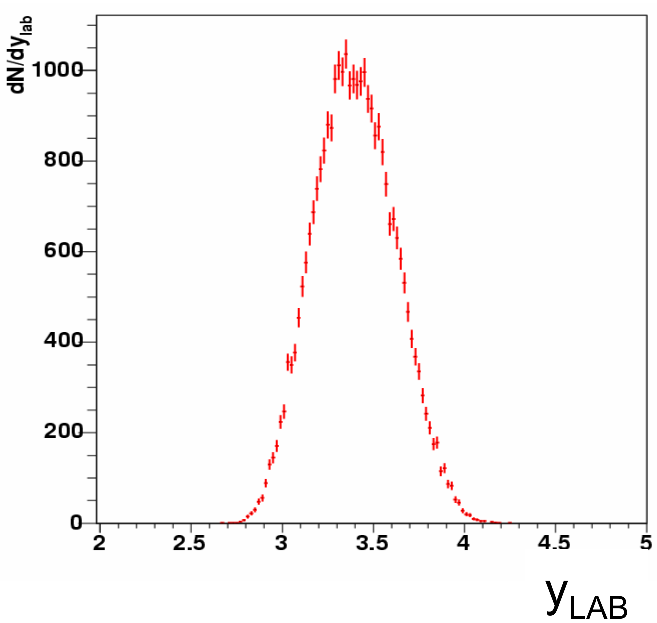
Event selection

A clean sample of events is obtained with the following requirements, profiting from the accurate determination of the interaction point and of the dimuon vertex:

- The interaction must take place in one of the seven targets; the Z-vertex of the collision is determined by the pixel telescope with ~ 200 μm accuracy

- The dimuon must be in the phase space window:
  $-0.5 < \cos\theta_{CS} < 0.5$
  $2.92 < y_{LAB} < 3.92$





To match or not to match

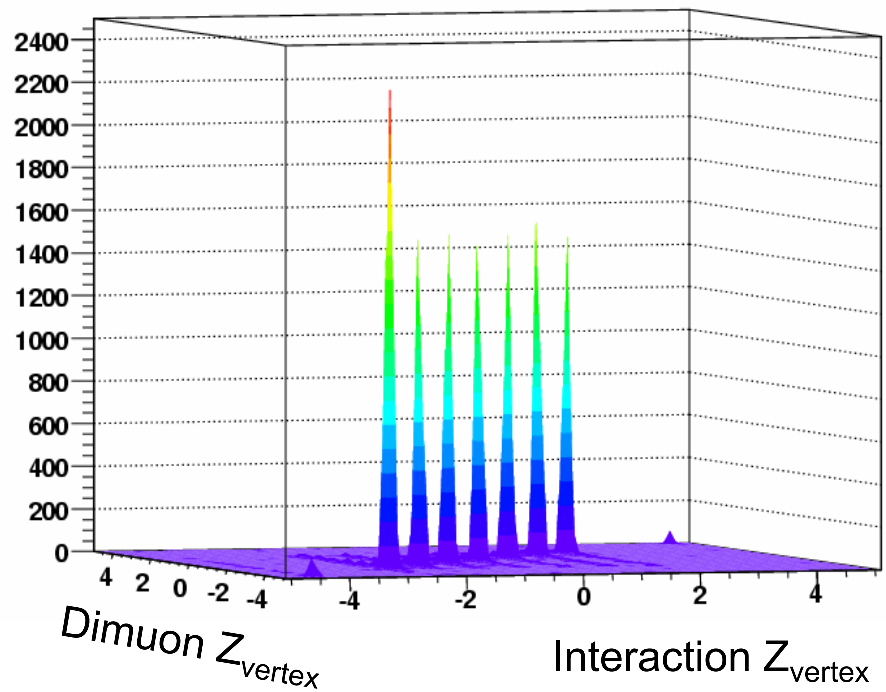
If we do not use the muon track matching:

- we keep more statistics
- we use quality cuts on the muon spectrometer data to identify dimuons produced in the target region

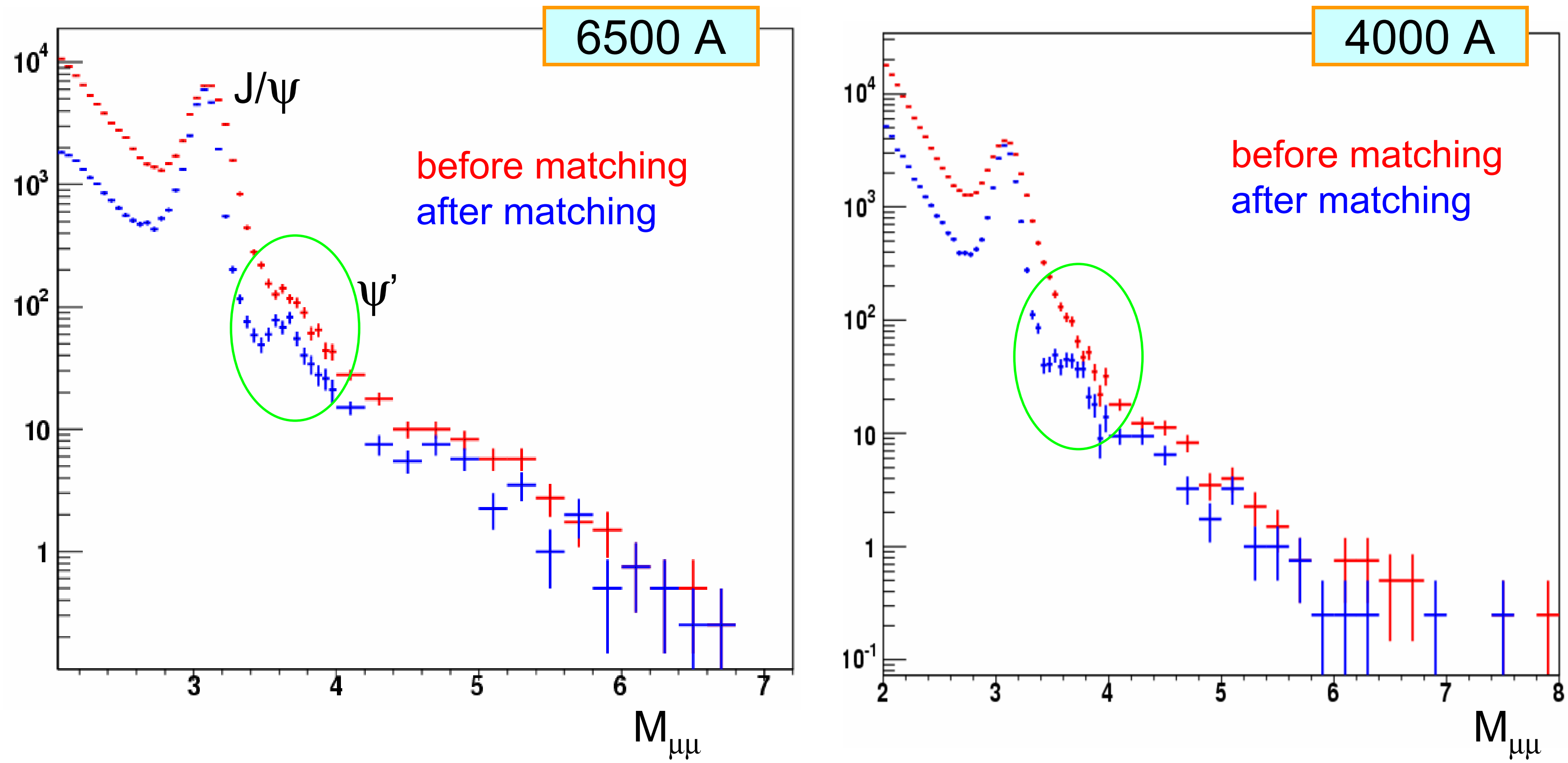
If we use the muon track matching:

- we loose statistics
- the mass resolution improves
- we can use the vertex of the dimuon in the event selection, to keep only dimuons produced in Indium-Indium collisions
- we reduce the combinatorial background

Dimuon mass above 2 GeV

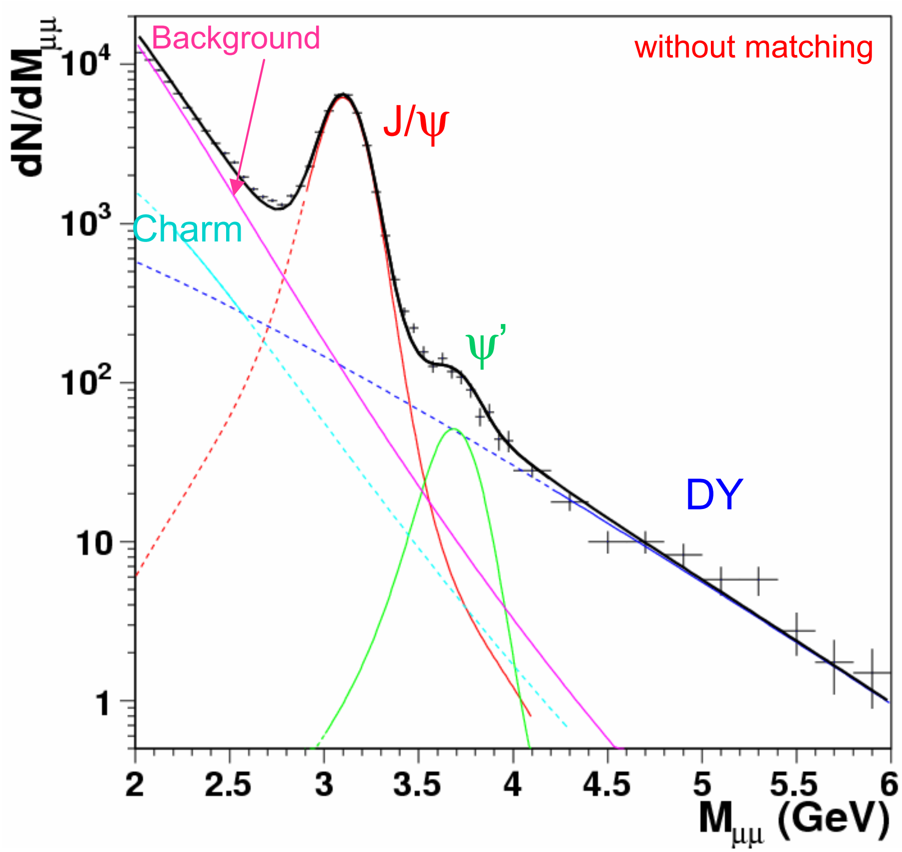


High mass dimuon spectra before and after muon track matching between the Muon Spectrometer and the Vertex Telescope



- dimuon matching efficiency: ~ 65% at the J/ψ
- the mass resolution at the J/ψ improves from ~105 MeV to ~70 MeV
- the combinatorial background decreases from ~3% to ~1% in the J/ψ region
- out-of-target events are rejected ➡ cleaner spectrum

J/ψ production in Indium-Indium collisions



Dimuon data from the 6500 A event sample

Combinatorial background from π and K decays estimated from the measured like-sign pairs

Signal mass shapes from Monte Carlo:

- PYTHIA and MRS A (Low Q^2) parton densities
- GEANT 3.21 for detector simulation
- reconstructed as the measured data

Acceptances from Monte Carlo simulation:

- for J/ψ : 12.4 %
- for DY : 13.4 % (in mass window 2.9–4.5 GeV)

A multi-step fit (max likelihood) is performed:

a) **M > 4.2 GeV** : normalize the DY → DY yield = 253 ± 16
2004 ± 128 in range 2.9–4.5 GeV

b) **2.2 < M < 2.5 GeV**: normalize the charm (with DY fixed)

c) **2.9 < M < 4.2 GeV**: get the J/ψ yield (with DY & charm fixed) → J/ψ yield = 35630 ± 361

… and the result is …

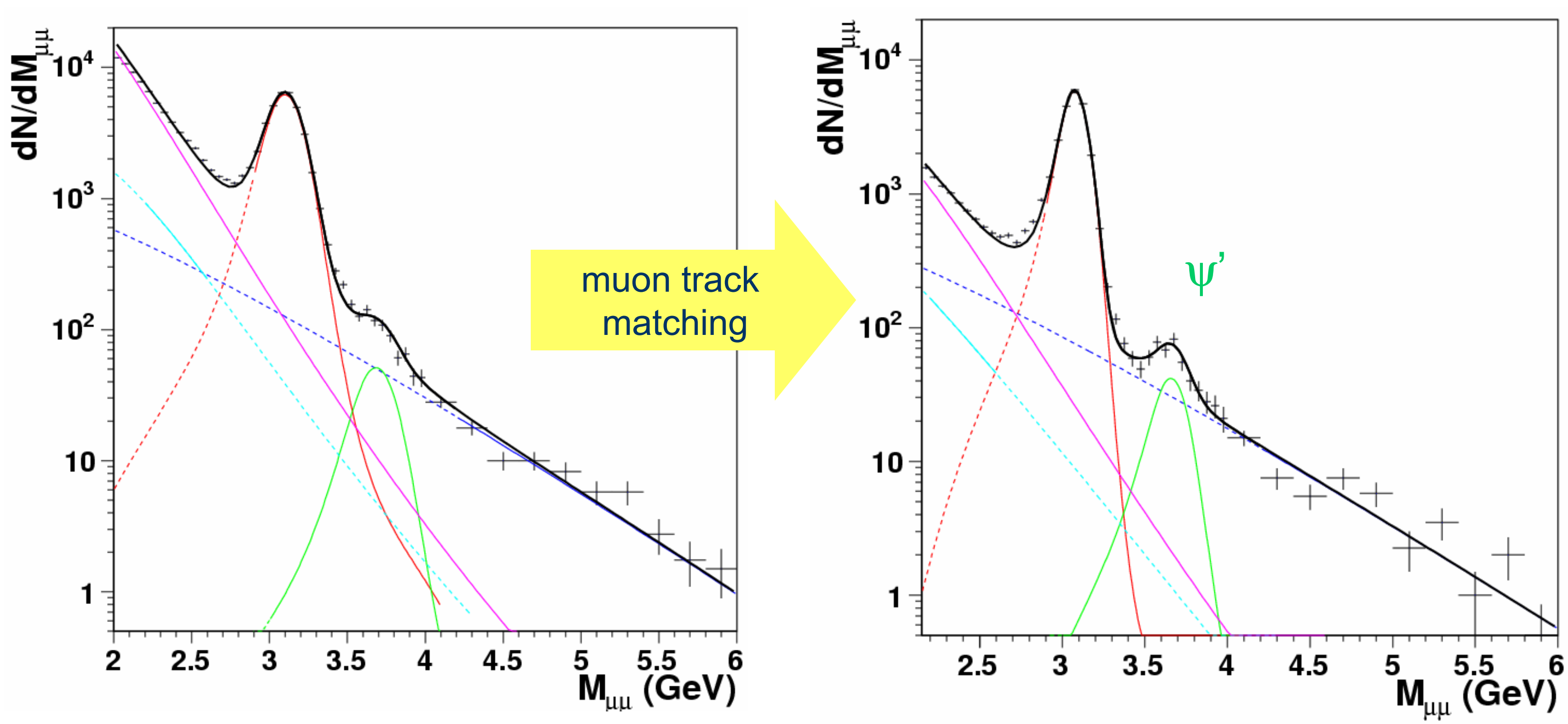
From the J/ψ and Drell-Yan yields obtained from the previous fit, after the acceptance corrections, we extract the J/ψ / DY cross-section ratio.

The Drell-Yan cross-section must be defined in a given mass window. We choose the region $2.9 < M_{\mu\mu} < 4.5$ GeV, so that our value can be directly compared with previous NA50 results. And the value is

$$B\ \sigma(J/\psi) / \sigma(DY) = 19.2 \pm 1.2$$

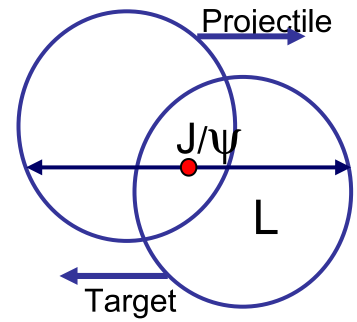
Stability checks

In order to evaluate the sensitivity of our result to the data analysis procedure, we have redone it, changing several steps. We found that the result is almost insensitive to (reasonable) changes in the background normalization, different event selection criteria and different fitting procedures. Systematical uncertainties are still under study but a value around 5% seems to be within reach.
Furthermore, the analysis of the dimuon mass spectra after muon track matching leads to essentially the same numerical values.



Looking for the physics behind the suppression

The study of the J/ψ suppression pattern as a function of different centrality variables, including data from different collision systems, should allow us to understand which is the physics variable driving the disappearance of the J/ψ

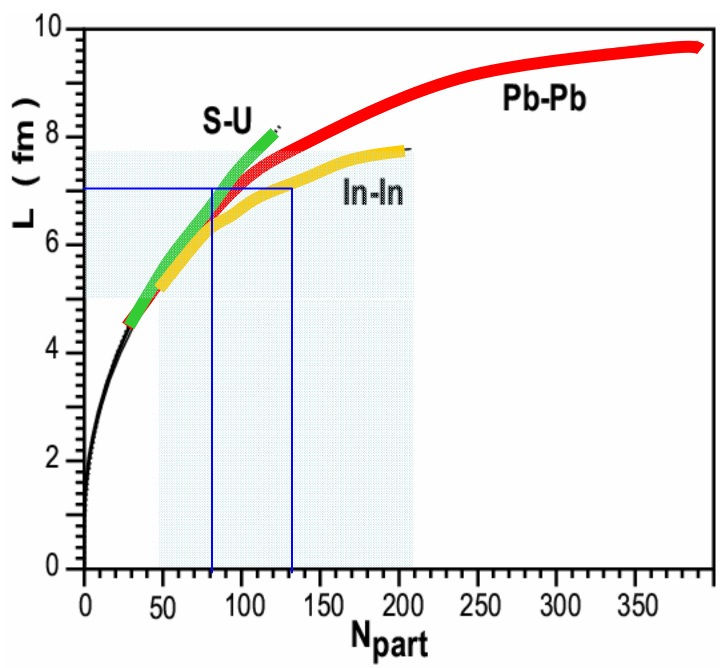


In the absence of "new physics", the J/ψ suppression patterns measured in different collision systems should overlap when plotted as a function of L (it is the case between p-A and S-U).

If the J/ψ is suppressed because of a geometrical phase transition, such as percolation, the scaling variable should be N_{part}

$$S(J/\psi) \propto e^{-\rho\sigma_{abs}L}$$

If, on the other hand, the J/ψ is dissolved by a thermal medium, the QGP, the physics variable should be the (local) energy density.

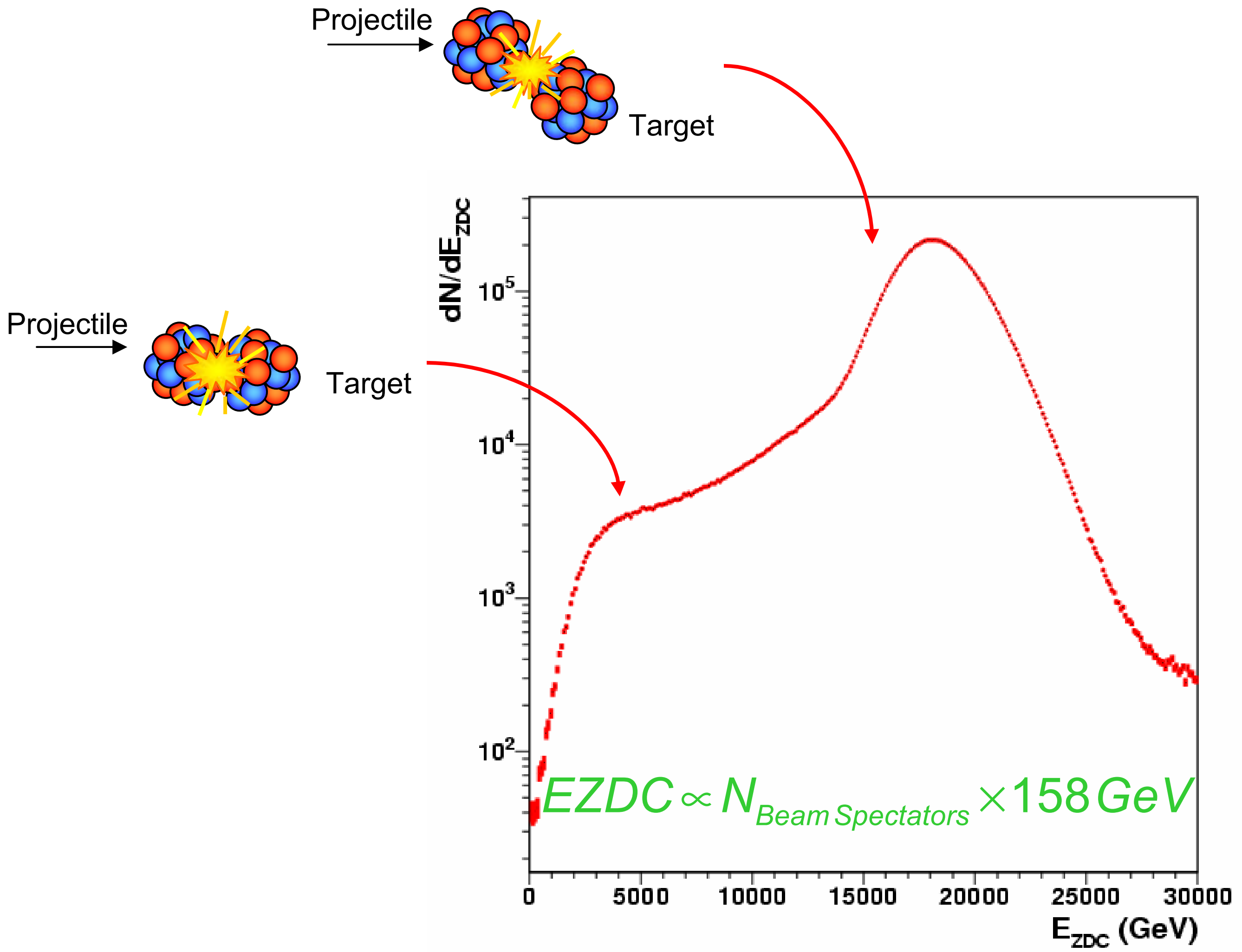


For instance, for L ~ 7 fm, S-U, In-In and Pb-Pb collisions probe different values of N_{part}, ranging from 80 to 130

→ If the physics-driving variable is L, the three systems will overlap

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

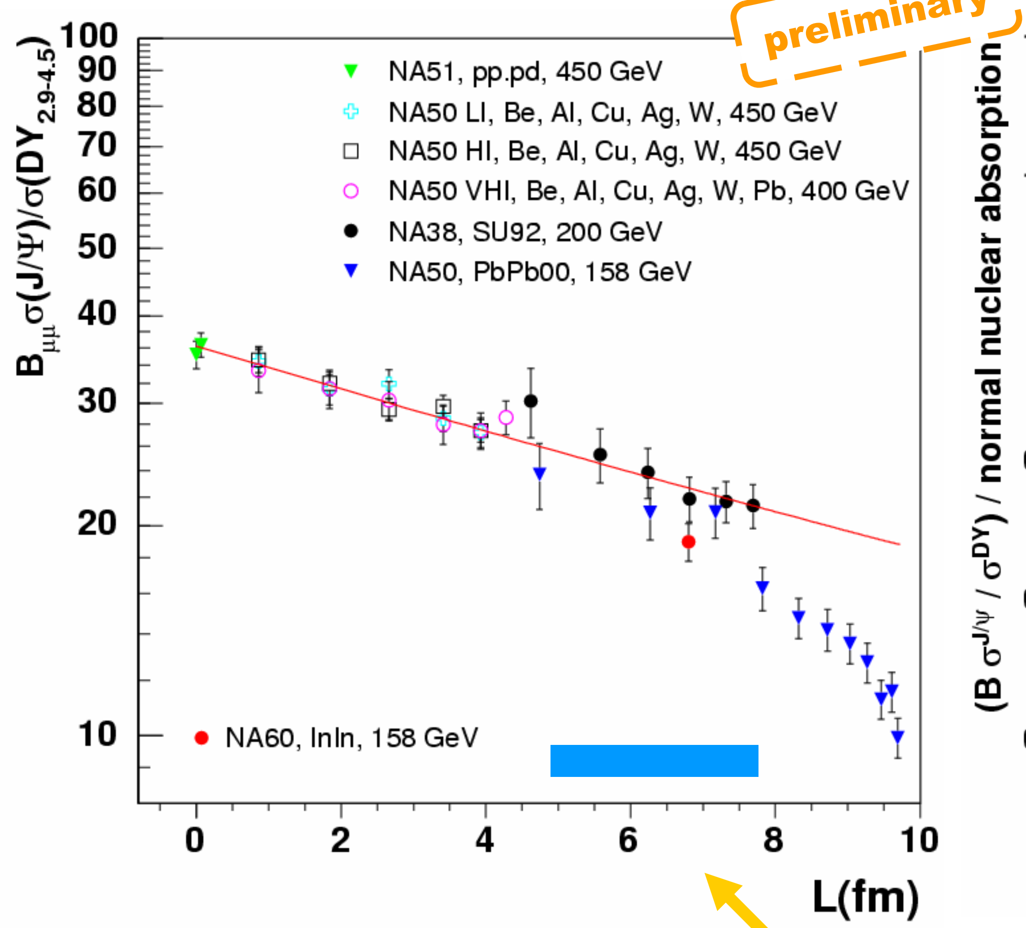
The values of L and N_{part}, integrated over all the centralities, are extracted from a Glauber calculation which fits the E_{ZDC} spectrum

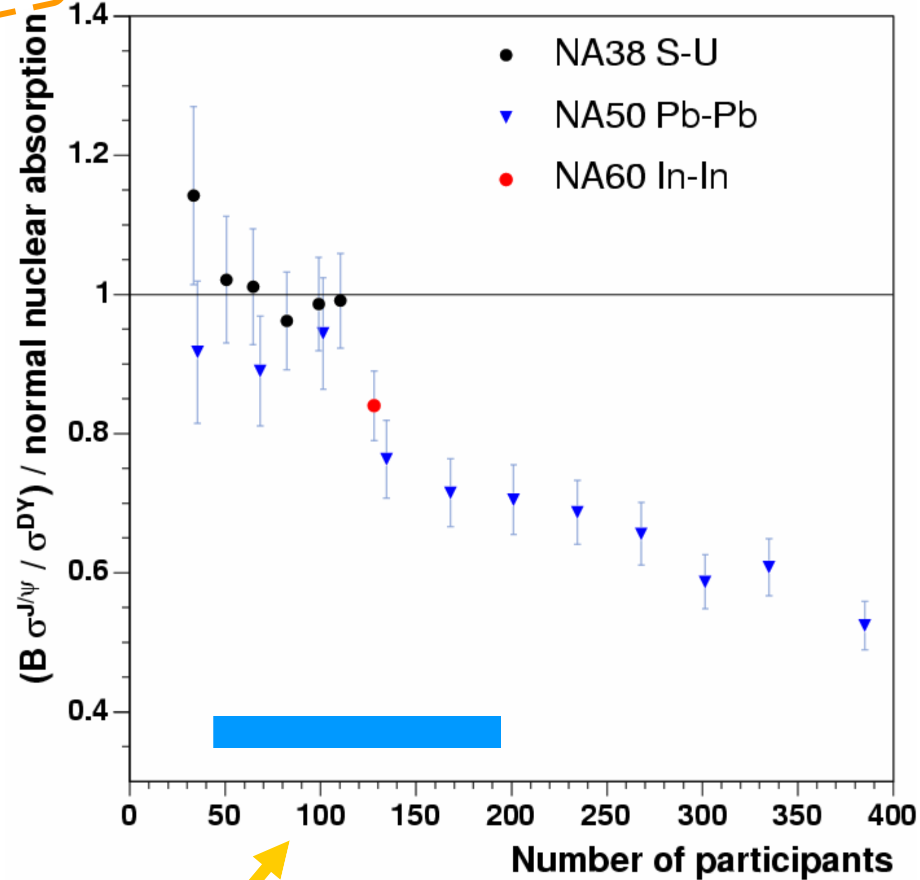


L = 6.8 fm

N_{part} = 128

Dividing the J/ψ / DY result by the normal nuclear absorption curve ⇒ 0.84 ± 0.05





regions that will be exploited by the centrality study in Indium-Indium collisions

Theoretical predictions for the pattern as a function of centrality are welcome!

Study of the kinematical variables of the J/ψ

From the Indium data, we have also extracted information on

- the transverse momentum
- and the polarization angle   of the J/ψ

To extract the "true" angular or transverse momentum distributions from the measured ones, we have to know the **acceptance** of the experimental apparatus as a function of the kinematical values of the produced dimuon

Method:

Since the different kinematical variables are related, the acceptance in one variable can have a strong dependence on other variables. To take into account these correlations

↓

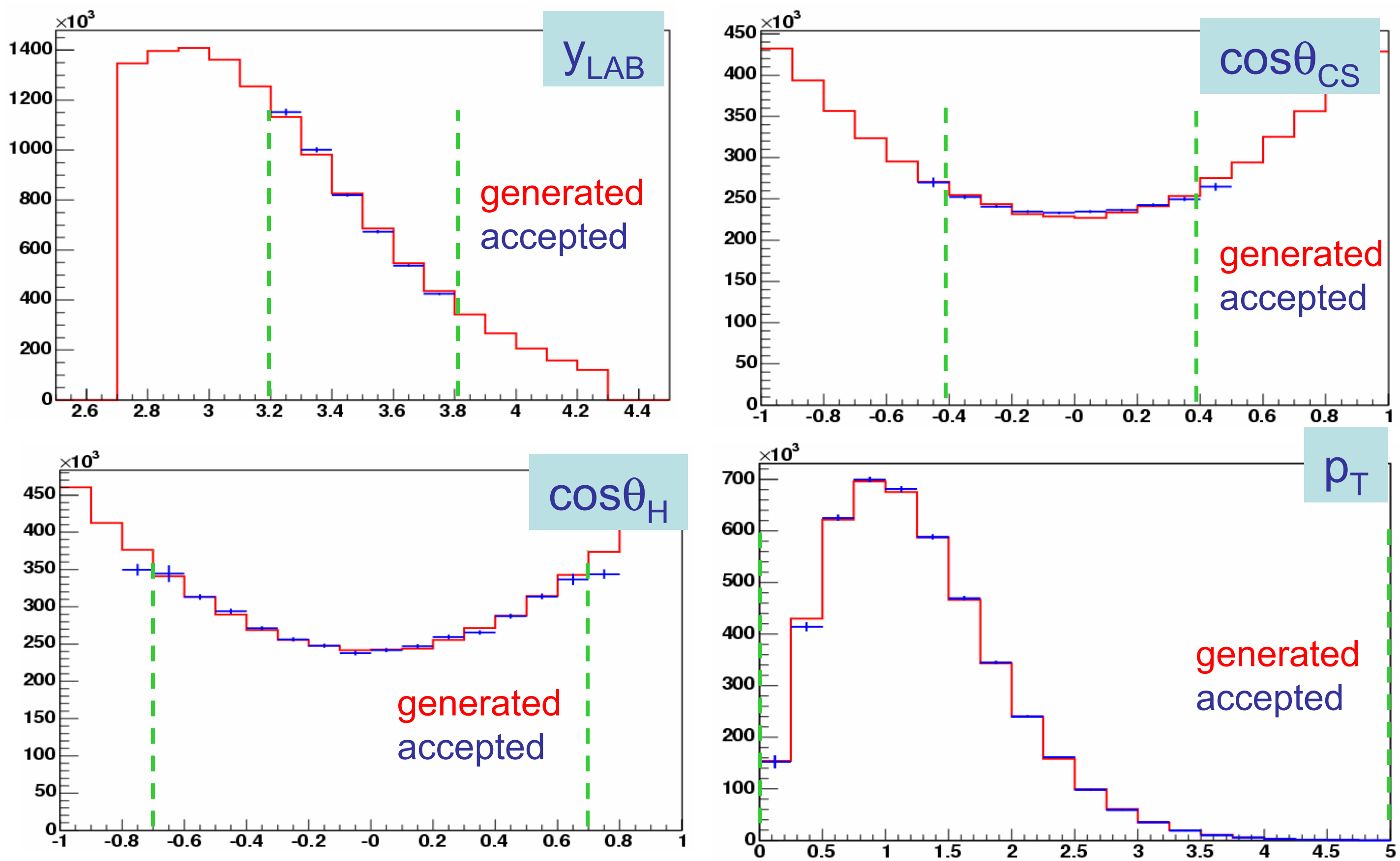
a **3D method** for the acceptance calculation has been developed.

Monte Carlo data have been generated according to flat p_T, $\cos\theta$ and y_{LAB} distributions; the MC events were tracked through the experimental apparatus and then reconstructed using the same procedures as the real data.

↳ acceptance matrices are obtained from the ratio between the reconstructed and the generated events

The procedure has been checked by injecting realistic p_T, y_{LAB} and cosθ distributions as inputs for the Monte Carlo simulation.

→ Very good agreement, except in the edges of the probed phase space, between the reconstructed and acceptance-corrected MC and the injected distributions.



Preliminary results are obtained in the following phase space windows →

- $0 < p_T < 5$ GeV/c
- $3.2 < y_{LAB} < 3.8$
- $-0.7 < \cos\theta_H < 0.7$
- $-0.4 < \cos\theta_{CS} < 0.4$

Transverse momentum of the J/ψ

NA50 studied the transverse momentum distributions of the J/ψ from p-A up to Pb-Pb collisions.

The observed increase of the $\langle p_T^2 \rangle$ values has been interpreted in terms of

initial-state parton multiple scattering:

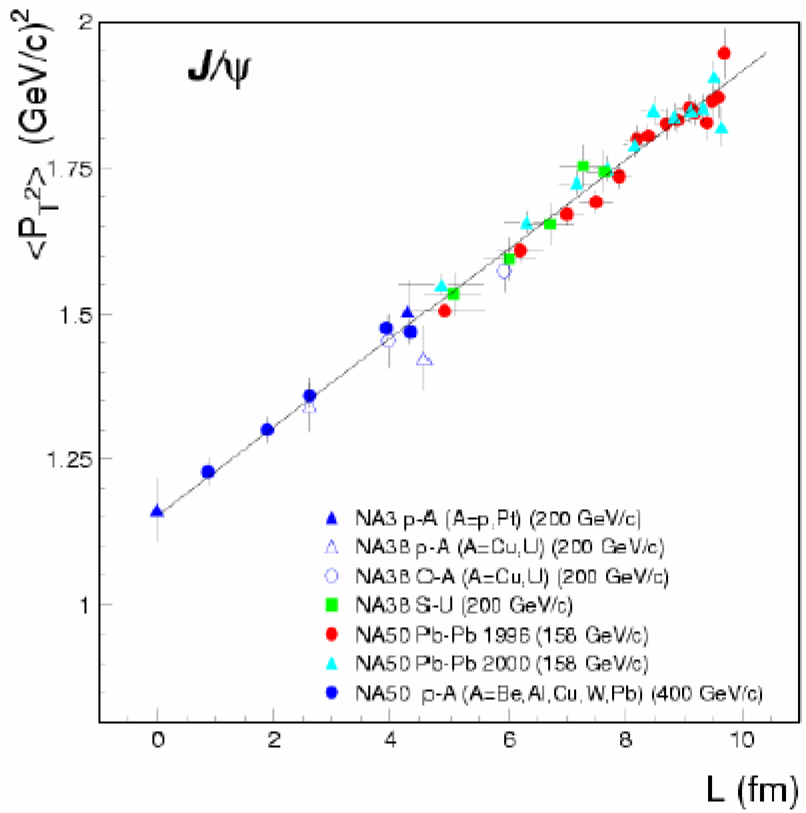
if the length of the crossed nuclear matter L increases, the number of possible g-N scattering grows linearly, resulting in a higher $\langle p_T^2 \rangle$ for the J/ψ

$$\langle p_T^2 \rangle = \langle p_T^2 \rangle_{pp} + a_{gN} L$$

$\langle p^2_T \rangle_{pp}$ is the value that a $c\bar{c}$ pair has in absence of any scattering

L: length of crossed nuclear matter

N. Topilskaya (NA50) – Quark Matter 2002



NA3 + NA38 + NA50 data rescaled to 158 GeV

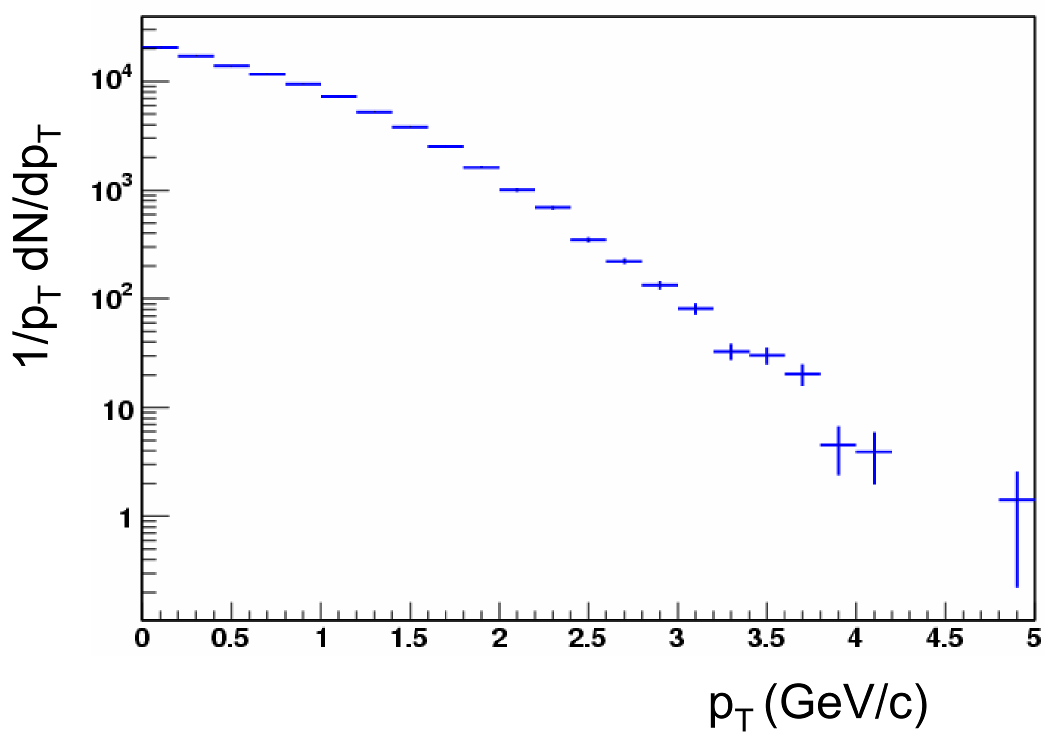
$a_{gN} = 0.077 \pm 0.002$ GeV^2/c^2/fm^{-1}

$\langle p^2_T \rangle_{pp} = 1.15 \pm 0.02$ GeV^2/c^2

Transverse momentum of the J/ψ in Indium-Indium

For these studies we count the events in the range $2.9 < M_{\mu\mu} < 3.3$ GeV/c^2 (without matching)

- $0 < p_T < 5$ GeV/c
- $3.2 < y_{LAB} < 3.8$
- $-0.4 < \cos\theta_{CS} < 0.4$



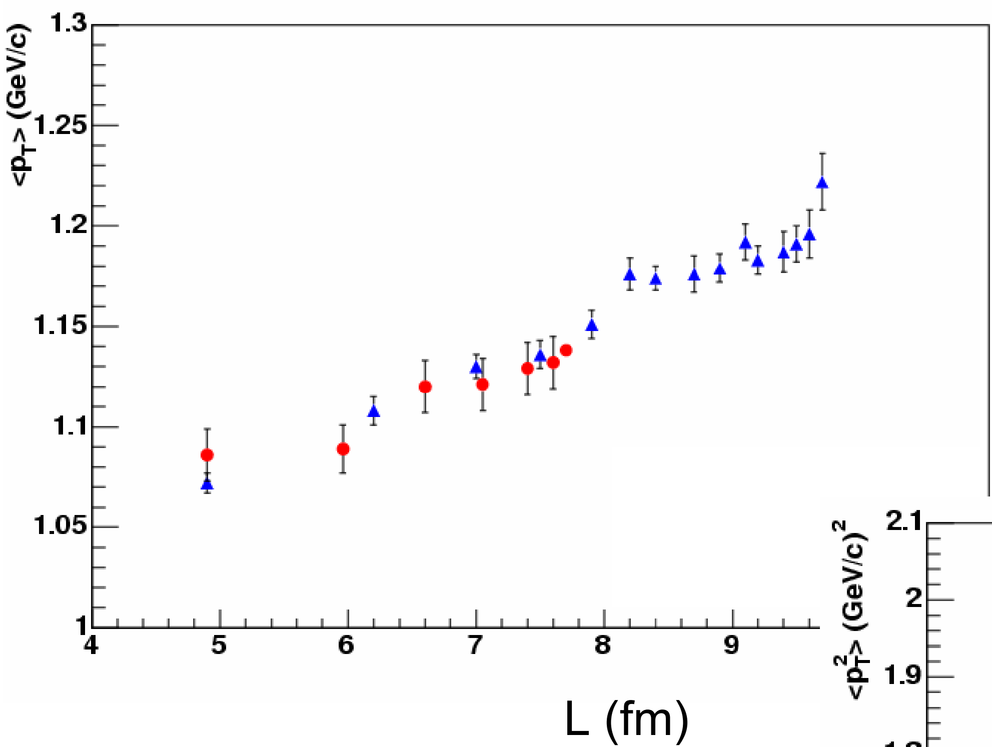
$\langle p_T \rangle = 1.117 \pm 0.005$ GeV/c

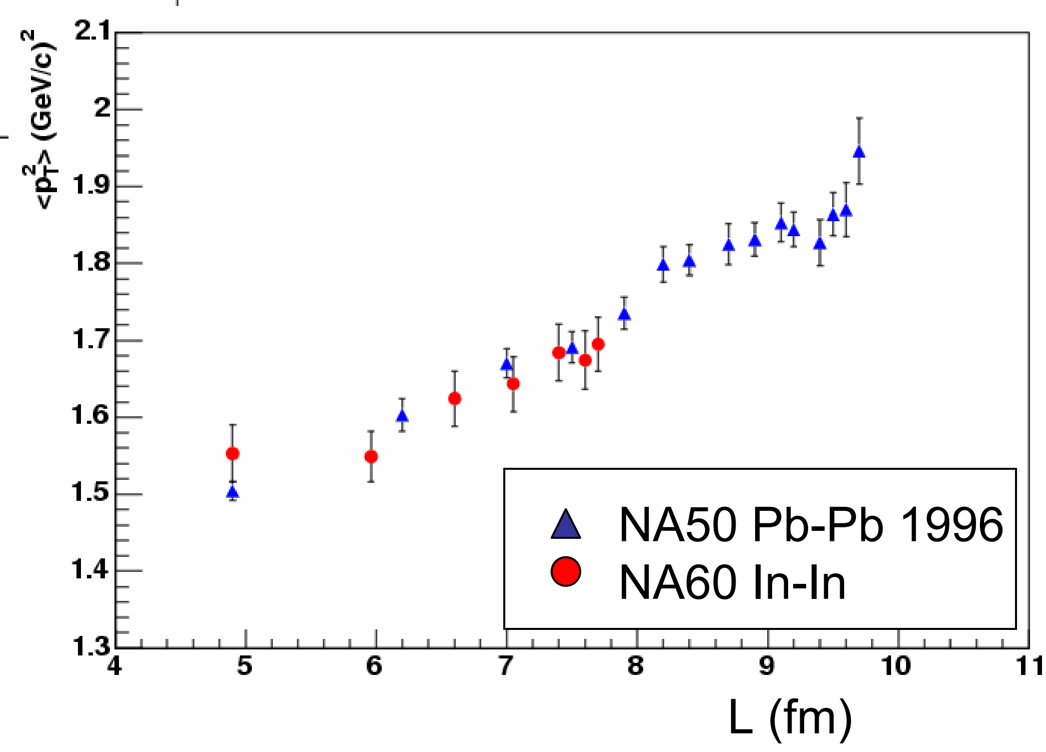
$\langle p_T^2 \rangle = 1.63 \pm 0.01$ (GeV/c)^2

(integrated on all centralities)

→ 7 centrality bins have been defined
(the centrality information is extracted from the E_{ZDC})

Transverse momentum of the J/ψ in Indium-Indium





Polarization of the J/ψ

The polarization of the J/ψ provides a detailed test of quarkonium production

Quarkonium polarization:

- **CSM**: predicts transverse polarization
- **CEM**: predicts no polarization
- **NRQCD**: predicts transverse polarization at large p_T

Results up to now (E866, CDF…) do not show an increase of the polarization for high p_T

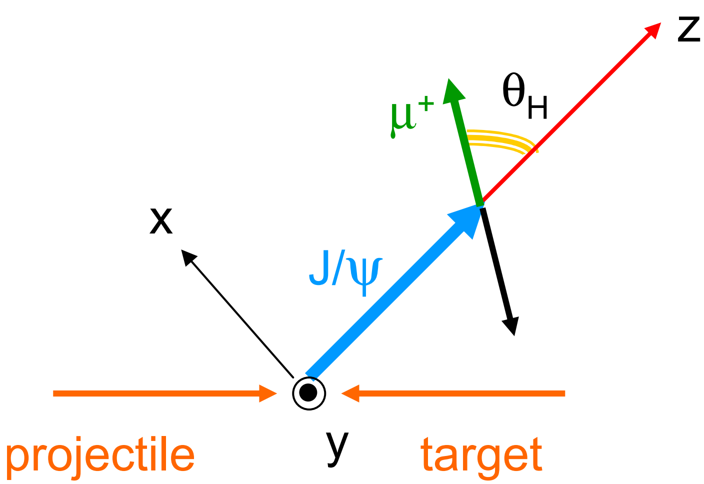
Moreover, the recent paper
B.L. Ioffe and D.E. Kharzeev: hep-ph/0306176: "Quarkonium Polarization in Heavy-ion collisions as a possible signature of the QGP"
predicts an increase of J/ψ polarization in heavy-ion collisions in case of QGP:

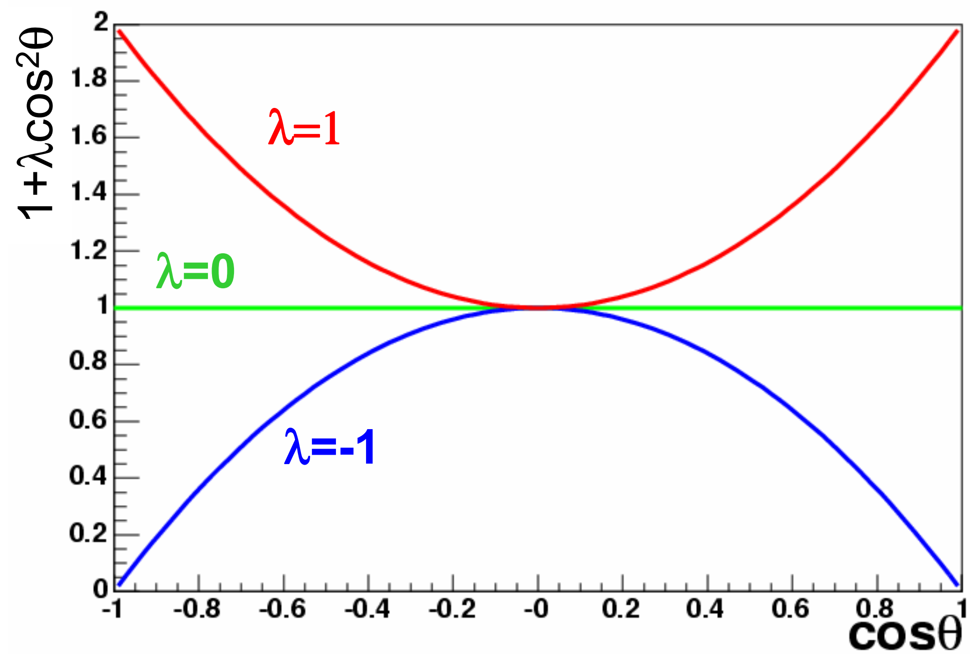
> "…polarization exhibits strong non-perturbative effects. The QGP is expected to screen away the non perturbative physics: the J/ψ which escape from the plasma should possess polarization as predicted by perturbative QCD…"

Experimentally, the polarization of the J/ψ is obtained from the angular distribution of the μ^+ from $J/\psi \rightarrow \mu^+\mu^-$

$$\frac{d\sigma}{d\cos\theta} \sim 1 + \lambda\cos^2\theta_H$$

θ_H is the emission angle of the μ^+ in the J/ψ rest frame.
There are various ways one can choose axes for the J/ψ rest frame. According to hep-ph/0306176 we choose the z axis to be coincident with the J/ψ direction in the center of mass frame.





$\lambda < 0$ Longitudinally polarized

$\lambda = 0$ Unpolarized

$\lambda > 0$ Transversely polarized

Polarization of the J/ψ in Indium-Indium

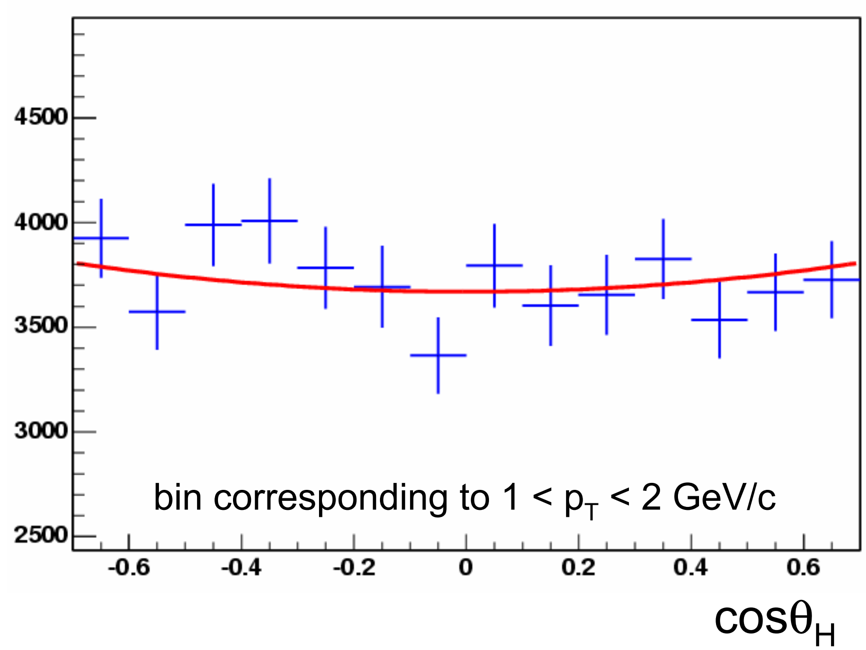
For these studies we count the events in the range $2.9 < M_{\mu\mu} < 3.3$ GeV/c^2 (without matching)

- $0 < p_T < 5$ GeV/c
- $3.2 < y_{LAB} < 3.8$
- $-0.7 < \cos\theta_H < 0.7$

The $\cos\theta_H$ distribution is fitted with

$$\frac{d\sigma}{d\cos\theta_H} \sim 1 + \lambda \cos^2\theta_H$$

where from the λ is extracted



The results are given as a function of:

- transverse momentum
- number of participant nucleons
- x_F

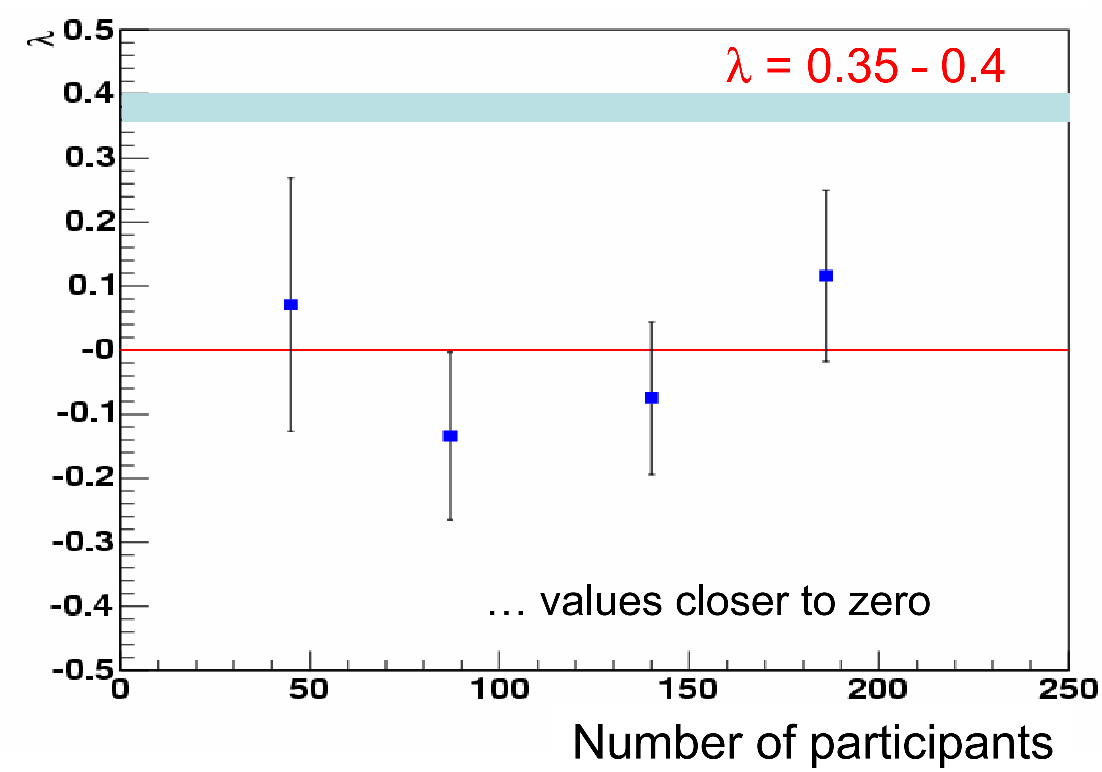
Polarization of the J/ψ in Indium-Indium

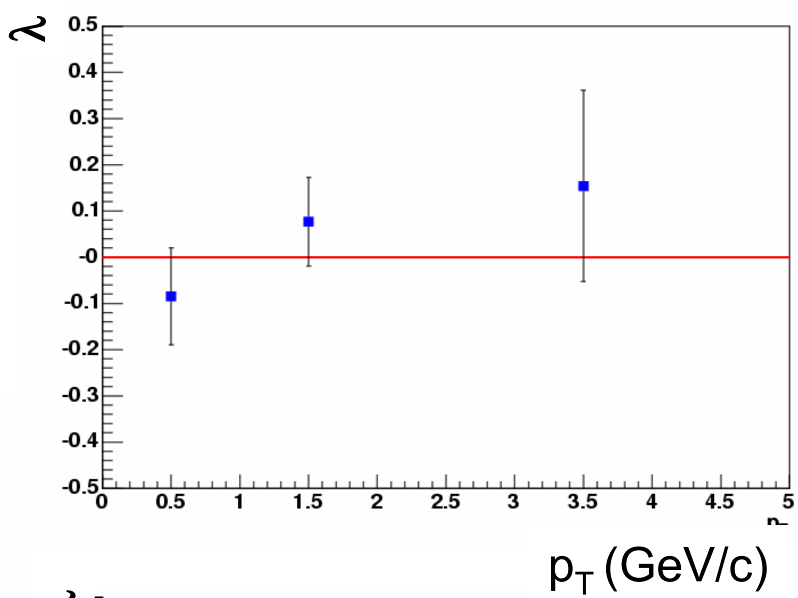
Preliminary

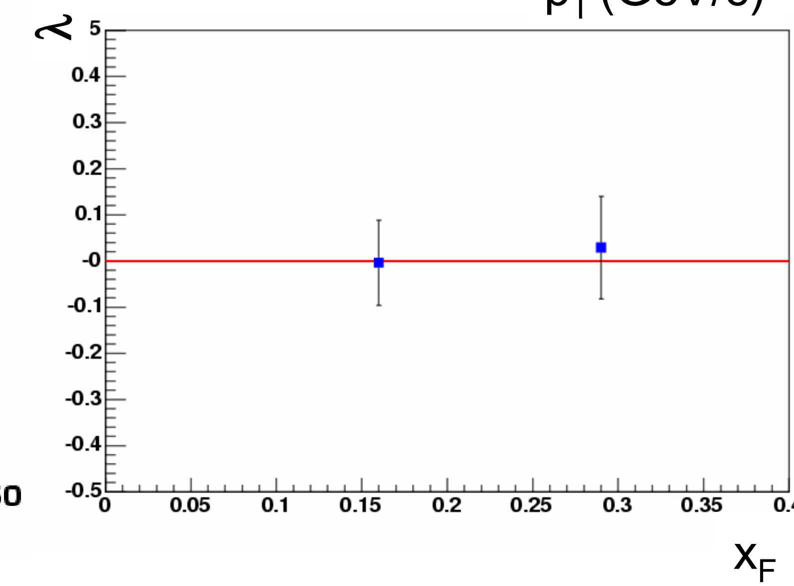
According to hep-ph/0306176, in case of QGP formation the expected value for the polarization is

$\lambda = 0.6$ (for $p_T \sim 0$)

and even taking into account the initial transverse momentum of gluons, λ remains significantly higher than zero:







Summary and outlook

We presented the cross section ratio J/ψ / DY in Indium-Indium collisions, integrated over all centralities, together with a preliminary study of two J/ψ kinematical variables: p_T and polarization angle

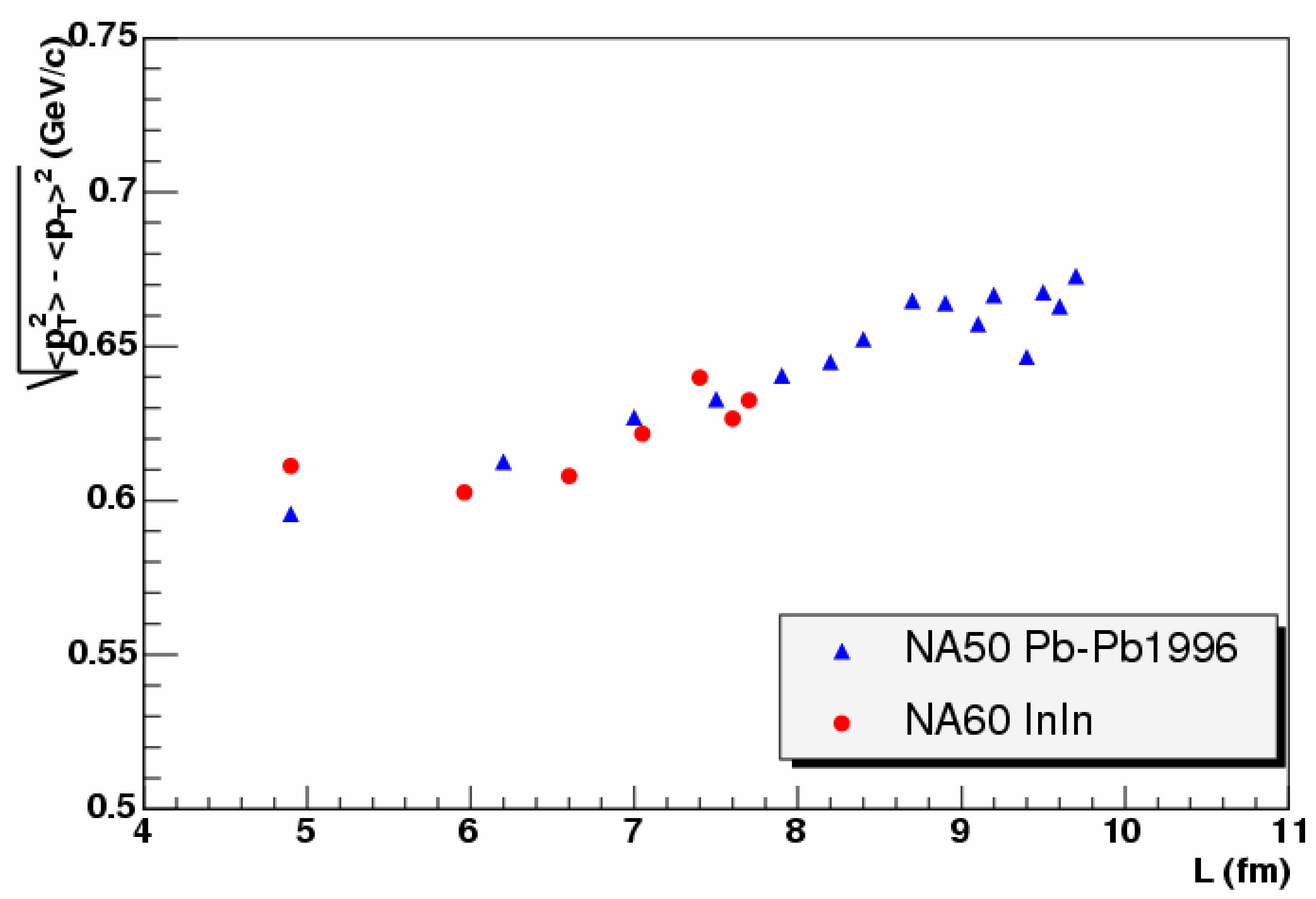
To better understand the heavy-ion results, a solid reference baseline from proton-nucleus data is needed

NA60 is now taking data with 400 GeV protons incident on 7 different nuclear targets, at high beam intensities (~ 2 × 10^9 p/burst), to study the impact of χ_c production on the J/ψ suppression

We have also taken a small sample of proton-nucleus data at 158 GeV, in order to extract the normal nuclear absorption of the J/ψ at the energy of the heavy ion data

This will improve our understanding of the production and suppression of charmonium states

backup



$\sqrt{<p_T^2> - <p_T>^2}$ (GeV/c)
0.75
0.7
0.65
0.6
0.55
0.5
4
5
6
7
8
9
10
11
L (fm)
NA50 Pb-Pb1996
NA60 InIn