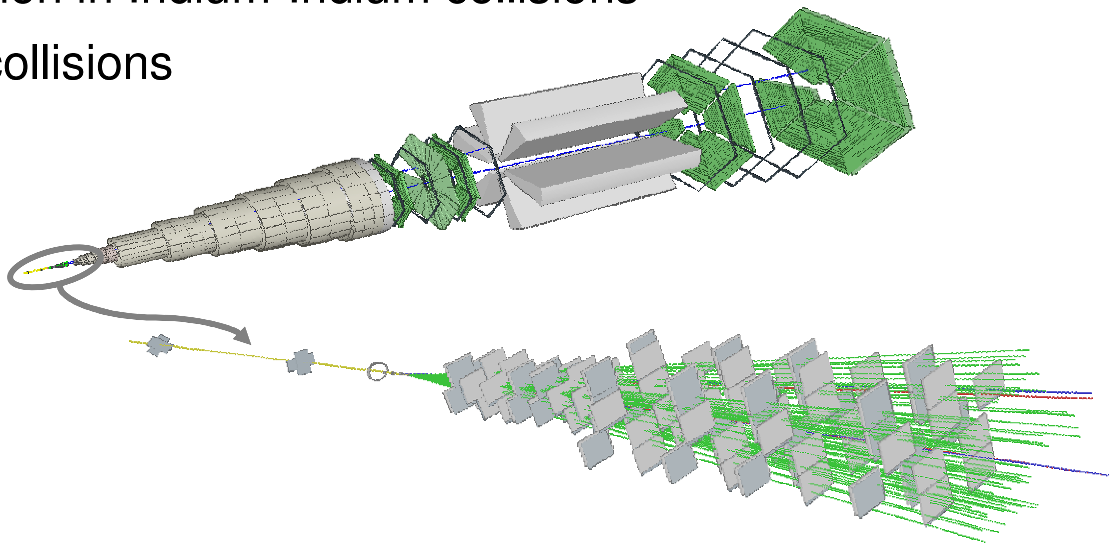
Risultati recenti dello studio sulle collisioni In-In all'SPS del CERN

IIº Congressino della Sezione INFN di Torino

Sommario:

- dimuon and charm production results obtained by NA38 and NA50
- the NA60 experiment
- first look into open charm production in Indium-Indium collisions
- J/ψ production in Indium-Indium collisions
- Low mass dimuon spectrum



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Torino, 16 Dicembre 2004

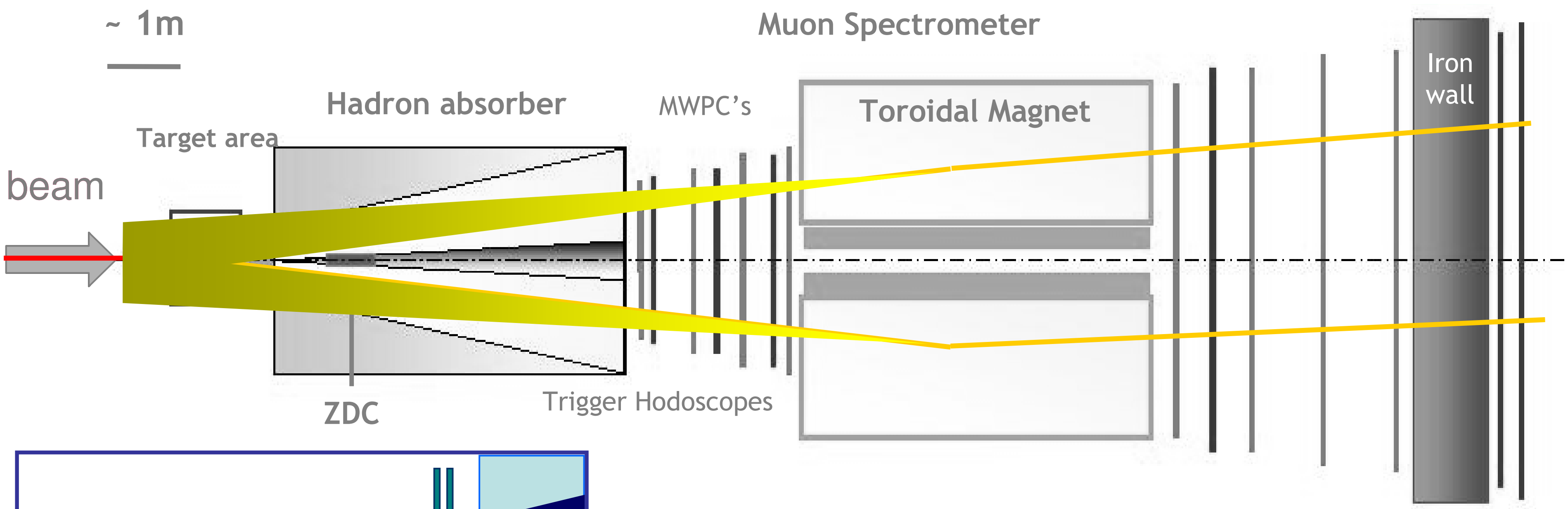
QGP phase transition and dilepton production

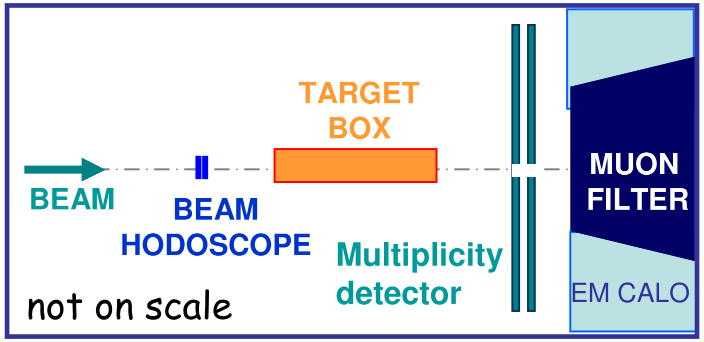
QCD predicts that, above a critical temperature or energy density, strongly interacting matter undergoes a phase transition to a new state where the quarks and gluons are no longer confined in hadrons, and chiral symmetry is restored.

Since 1986, many experiments, probing high-energy nuclear collisions at the CERN SPS, searched for this phase transition guided by theory-driven signatures.
Some these 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
- the **suppression of strongly bound heavy quarkonia states**
  dissolved when certain *critical thresholds* are exceeded
- **changes in the ρ spectral function** (mass shifts, broadening, disappearance)
  when chiral symmetry restoration is approached

The NA50 experiment





Target region:

1995: 17% λ_I segmented Pb target
1996: 30% λ_I segmented Pb target
1998: 7% λ_I single Pb target
2000: 9.5% λ_I single Pb target under vacuum

Centrality detectors:

- EM calorimeter
- ZDC calorimeter
- Multiplicity detector

Phase space window:

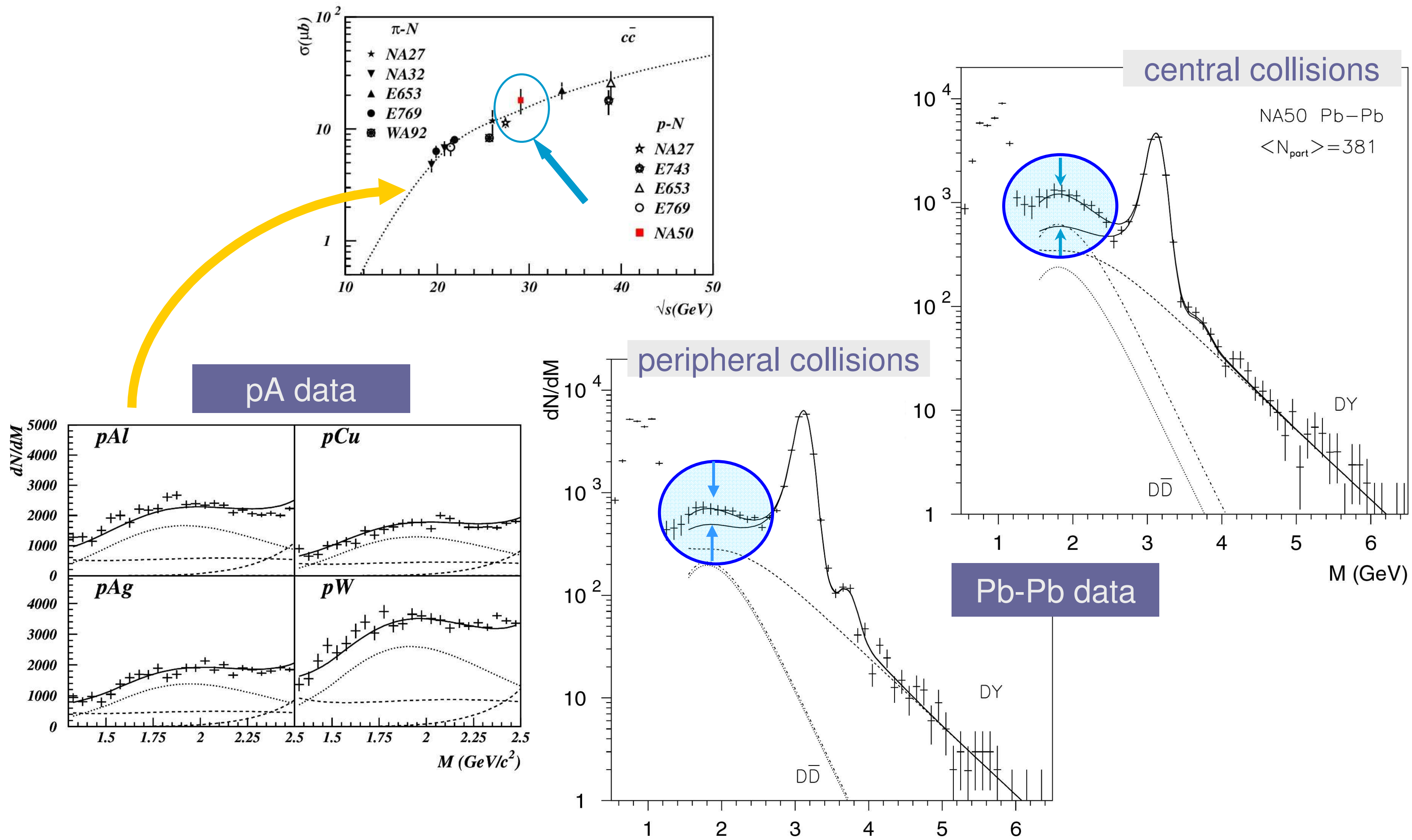
$2.9 < y_{lab} < 3.9$
$|\cos\theta|<0.5$

Typical acceptances:

$A_{J/\psi} \sim 12\%$
$A_{DY} \sim 14\%$

Intermediate mass dimuon production seen by NA38/NA50

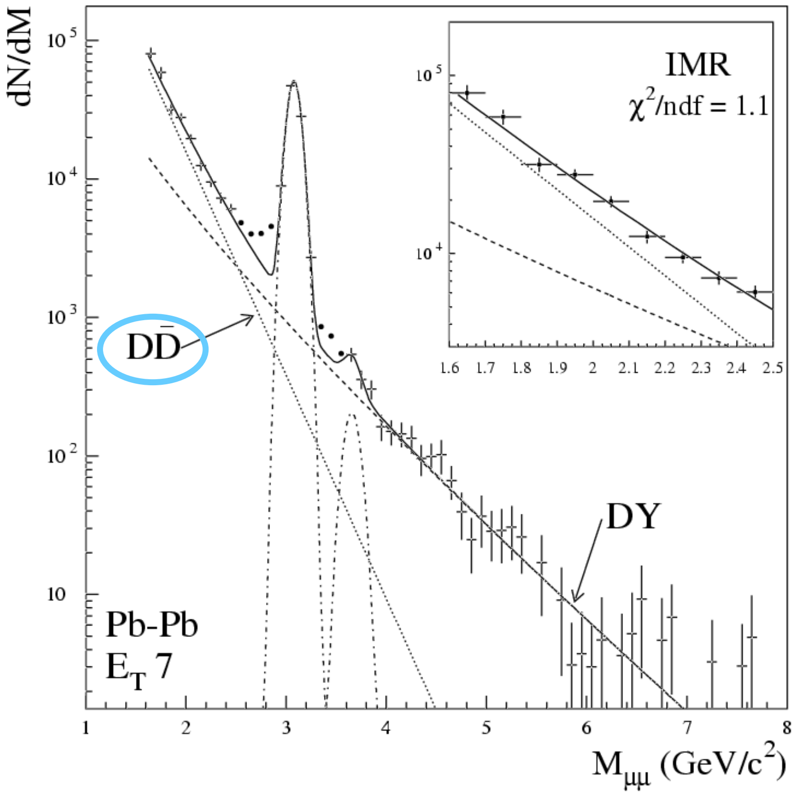
The yield of intermediate mass dimuons in heavy-ion collisions (S-U, Pb-Pb) exceeds the sum of Drell-Yan and D meson decays, which describes the proton data

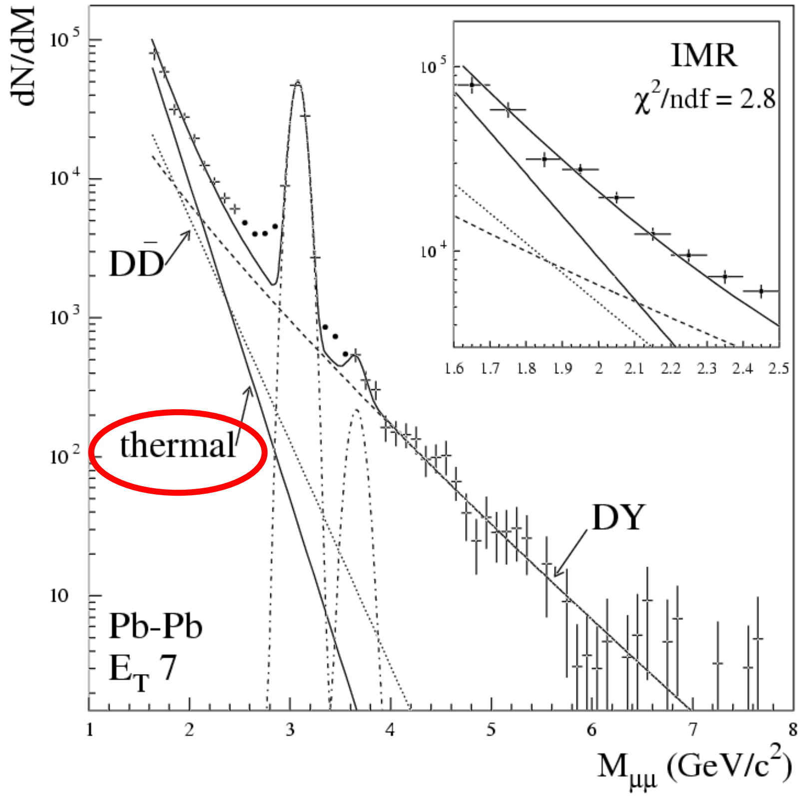


Charm enhancement or thermal dimuons ?

The intermediate mass dimuon yields can be reproduced :

- by scaling up the charm contribution by up to a factor of 3
  → crucial to understand J/ψ suppression: same initial state (gluons)
- or by adding thermal radiation to the DY and open charm
  explicitly introducing a QGP phase at T_c = 175 MeV (Rapp & Shuryak, Gale)
  → would be a direct evidence of thermalization of the pre-hadronization phase



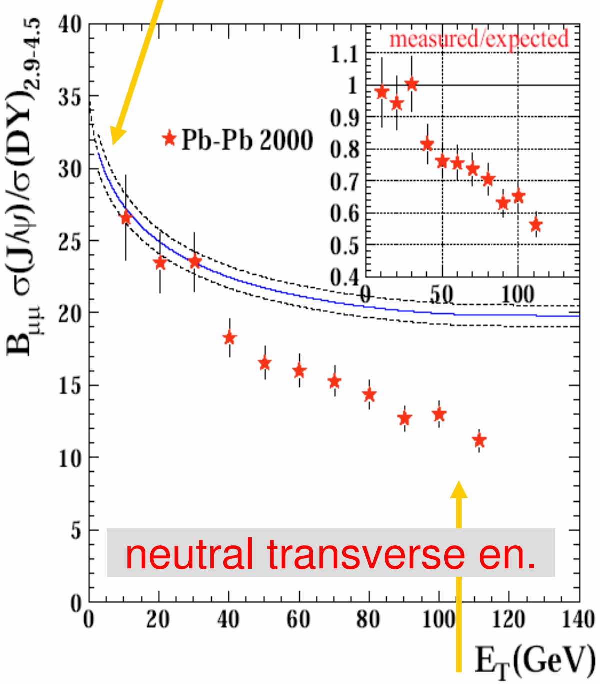


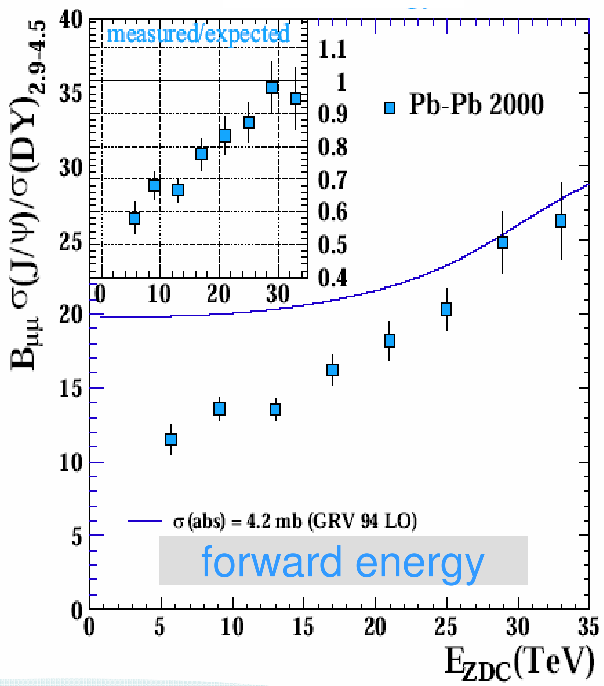
J/ψ suppression from p-A to Pb-Pb collisions

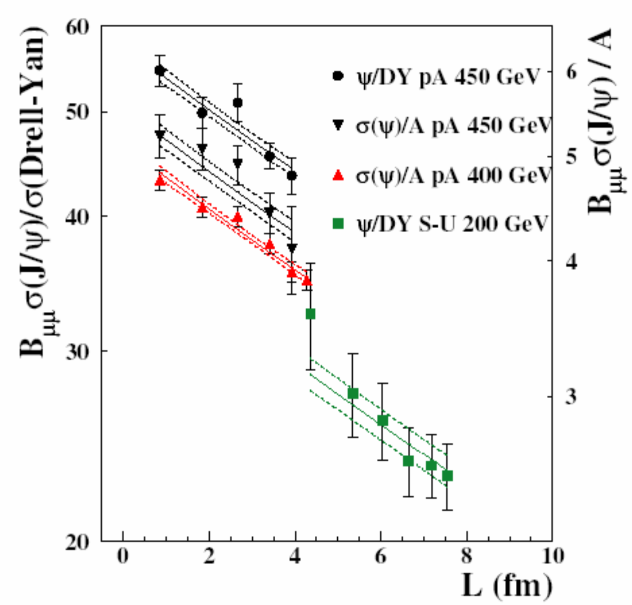
- J/ψ production has been extensively studied in pA, SU and Pb-Pb collisions
  ⇒ the J/ψ is suppressed in Pb-Pb collisions
  with respect to the yields extrapolated from proton-nucleus data

- the suppression has been studied as a function of different centrality estimators

J/ψ normal nuclear absorption curve



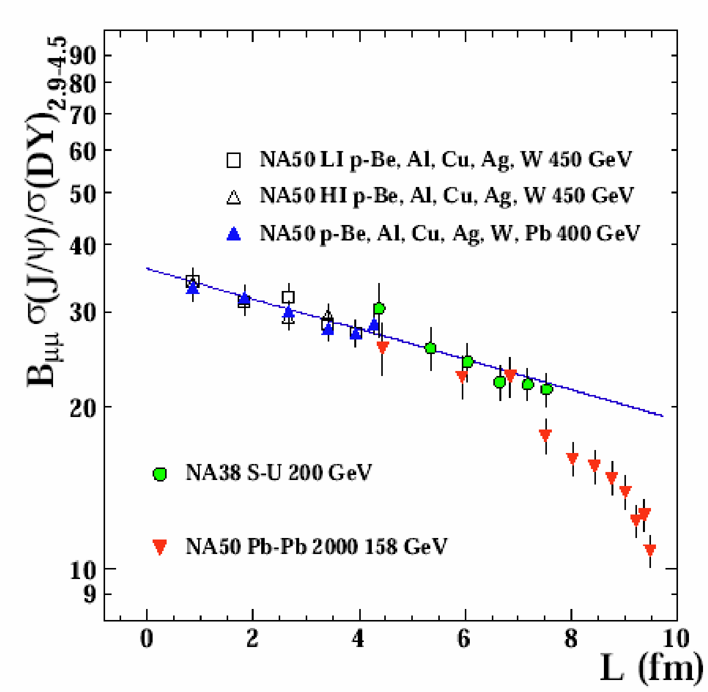


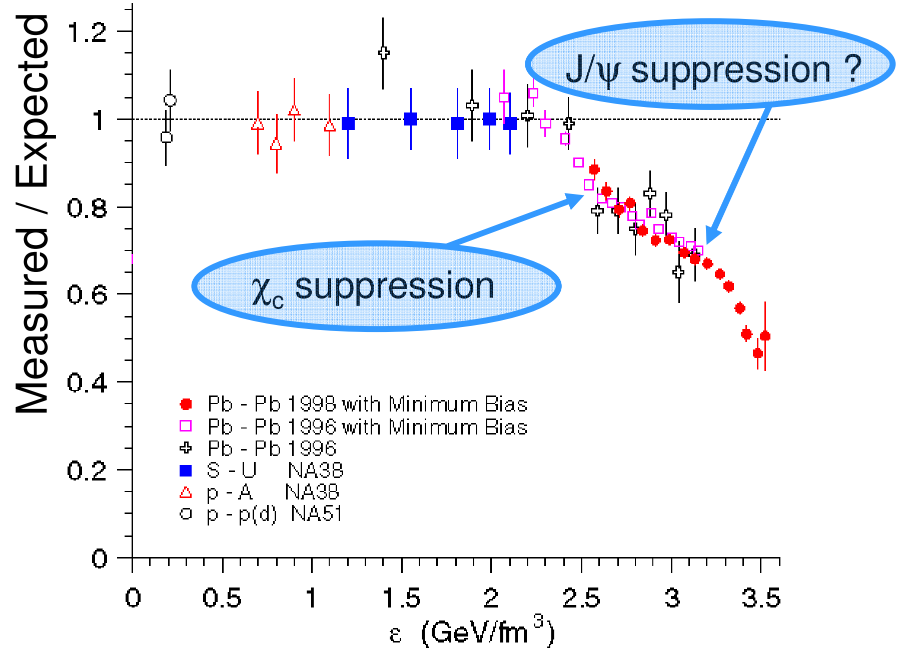


$$\sigma_{abs}^{J/\psi} = 4.2 \pm 0.4\,mb$$

J/ψ suppression in central Pb-Pb collisions

J/ψ suppression in different systems





Study of the 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, which is probably governing the “normal absorption”

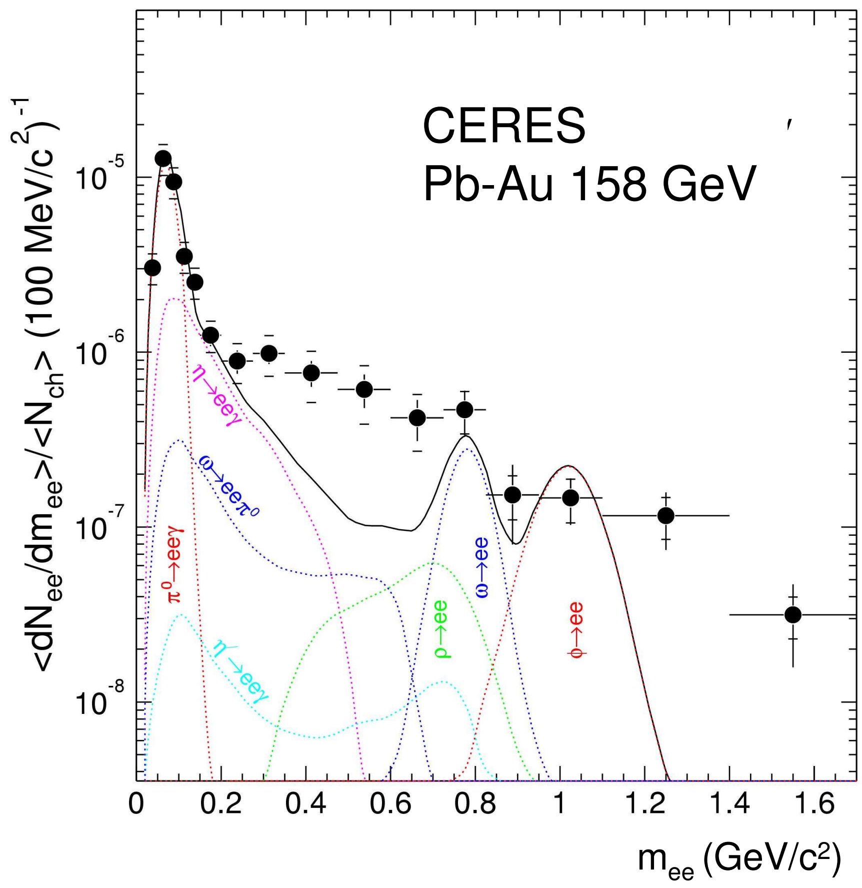
- In central Pb-Pb collisions the L scaling is broken and an anomalous suppression sets in

direct J/ψ ~ 60%

J/ψ from χ_c decay < 30%

J/ψ from ψ’ decay ~ 10%

Low mass dimuon seen by CERES



- Is the ρ meson modified by the medium produced in nuclear collisions?
- Because of chiral symmetry restoration?

⇒ New measurement with high statistics, good signal to background ratio and dimuon mass resolution

Specific questions that remain open

intermediate mass region

- Is the intermediate mass excess due to thermal dimuons from a QGP? or is the open charm yield enhanced in nucleus-nucleus collisions?
  $\Rightarrow$ Measure secondary vertices with ~ 50 μm precision, to separate prompt dimuons from D meson decays

low mass region

- Which is the origin of the dielectron excess below the r mass (disappearance of the ρ, mass shifts, broadening)?
  $\Rightarrow$ Increase statistics, mass resolution and S/B ratio. Study the excess as a function of centrality

high mass region

- What is the impact of the χ_c feed-down on the observed J/ψ suppression pattern?
  $\Rightarrow$ 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?
  $\Rightarrow$ Measure the J/ψ suppression pattern in Indium-Indium and compare it with Pb-Pb

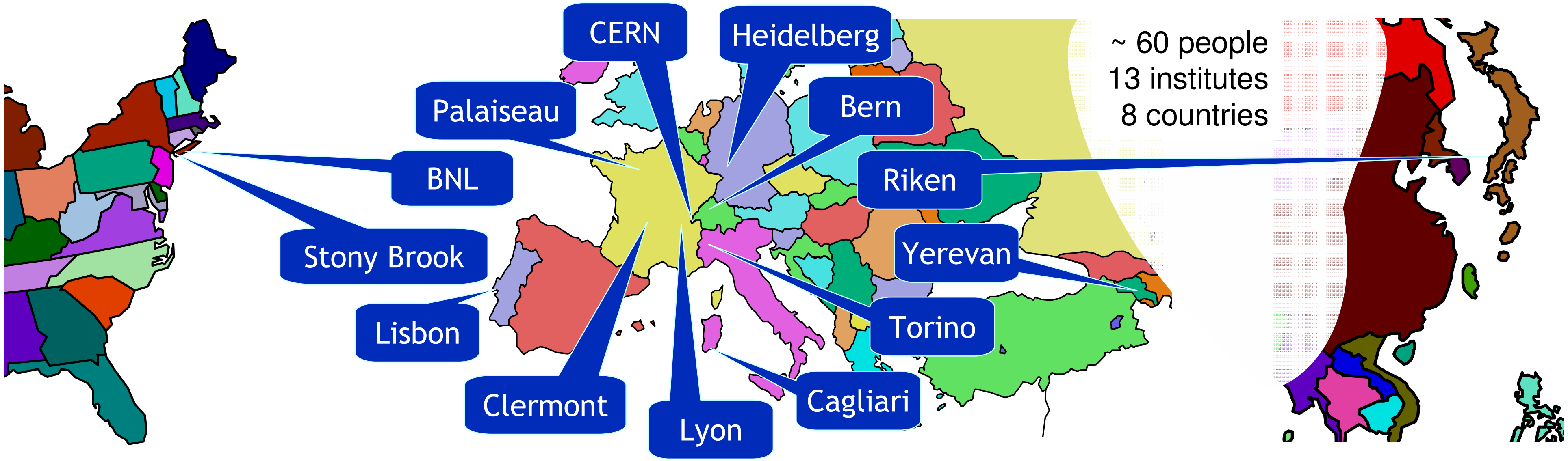
New and accurate measurements are needed

NA60

The NA60 experiment

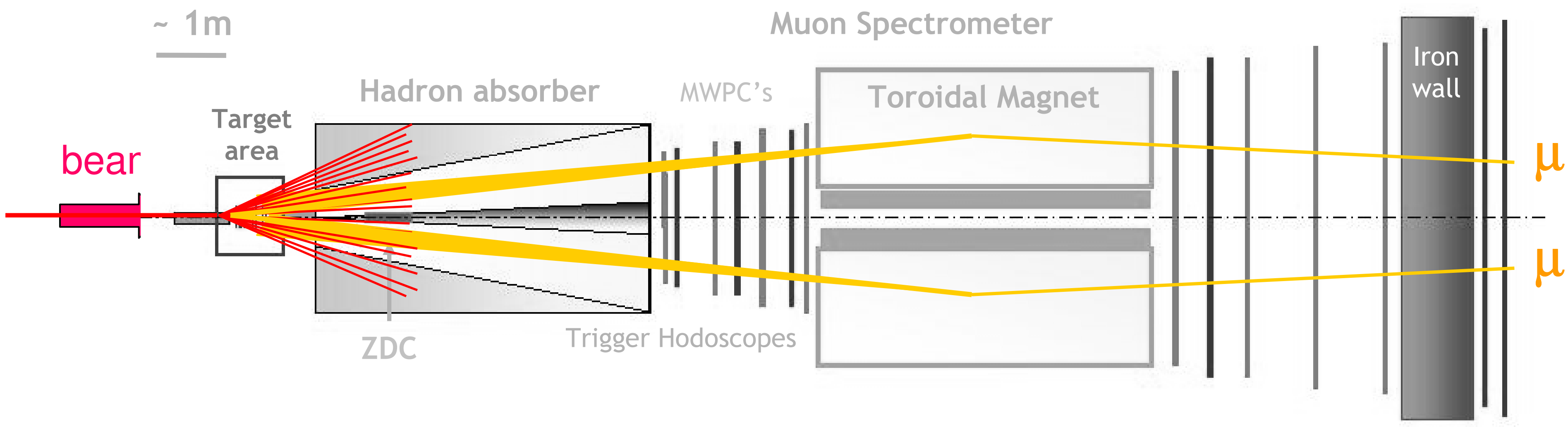
http://cern.ch/na60

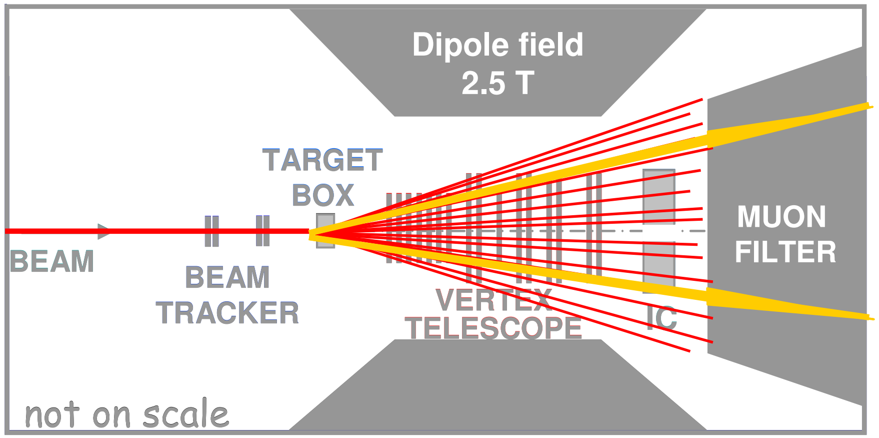
Idea: place a *high granularity* and *radiation-hard* **silicon tracking telescope** in the vertex region to measure the muons before they suffer multiple scattering and energy loss in the absorber



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 in momentum space

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

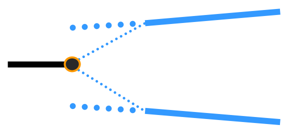
ZDC

dimuon studies vs. collision centrality

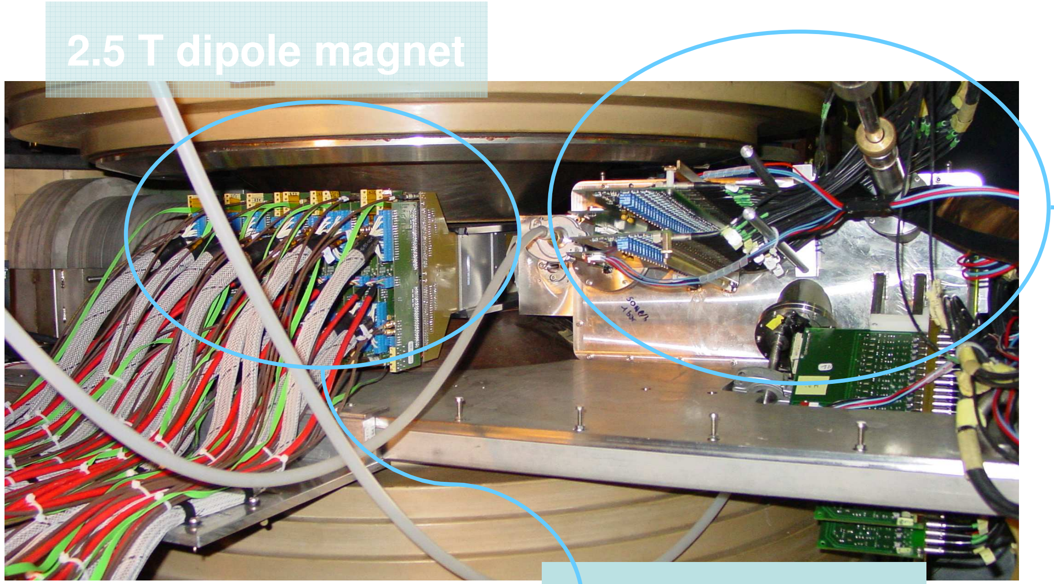
prompt dimuon

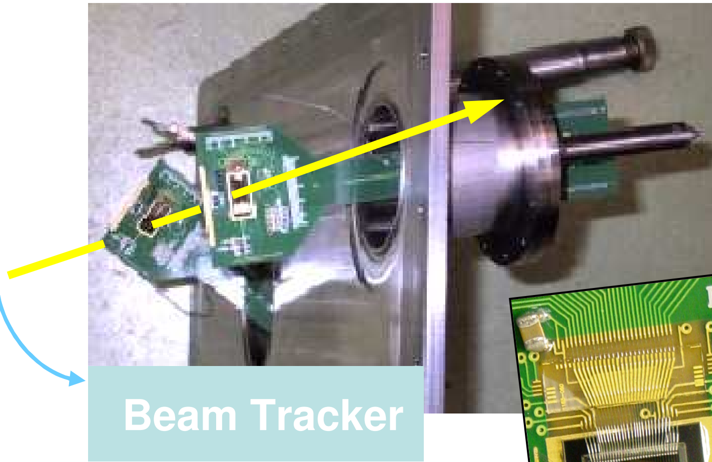
or

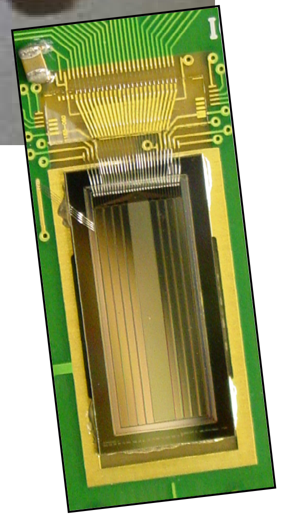
muon pair from displaced vertices



The NA60 target region in 2003

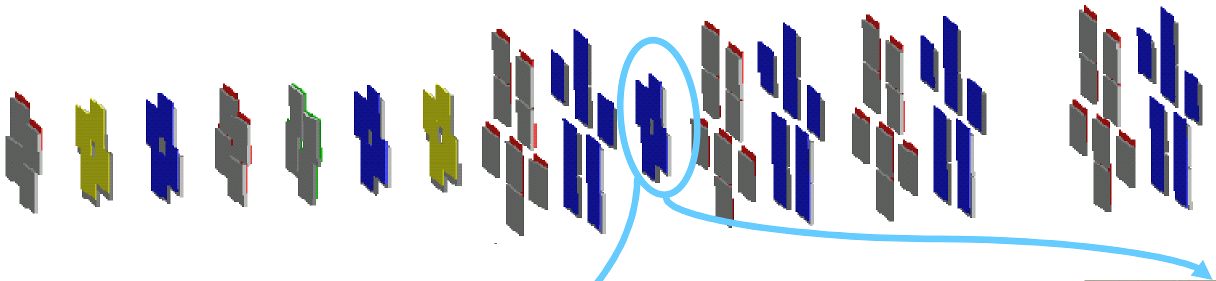


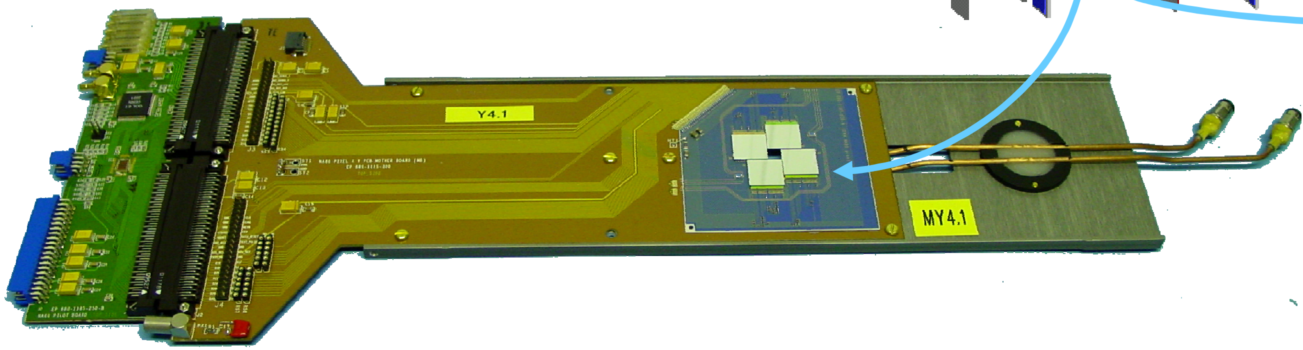


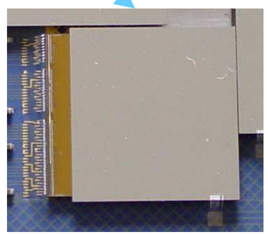


Two stations of 50 μm pitch micro-strip detectors operated at 130 K → increased radiation hardness

~ 100 pixel detectors (radiation tolerant) in 12 tracking points; cells = 50 × 425 μm^2



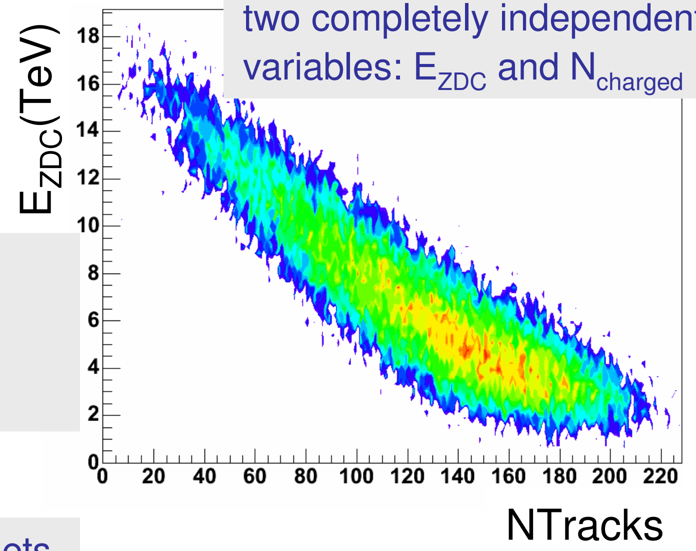




The Indium run

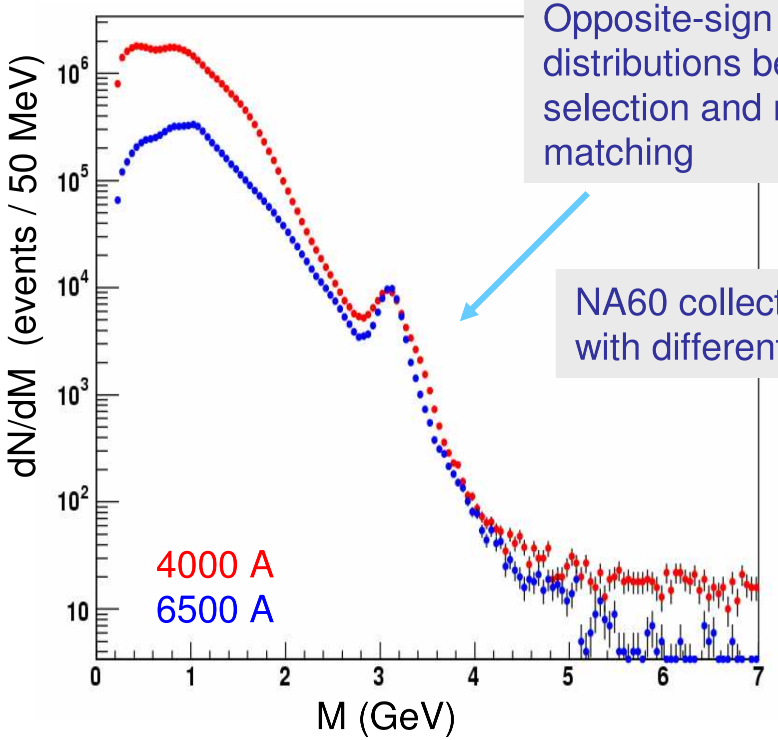
- 5-week long run in Oct.–Nov. 2003
- ~ 4 × 10^{12} ions delivered in total
- ~ 230 million dimuon triggers on tape

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

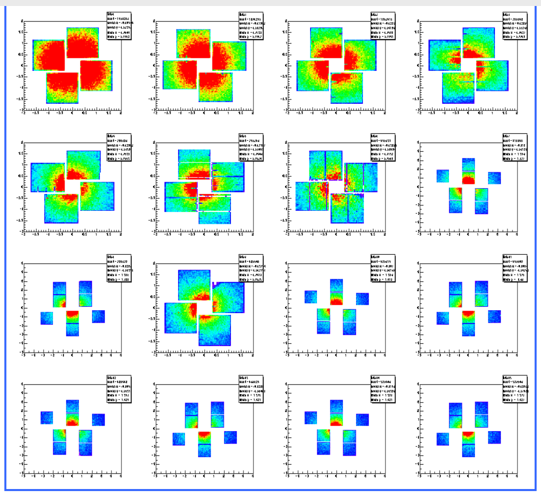


Opposite-sign dimuon mass distributions before event selection and muon track matching

NA60 collected two data sets, with different magnet settings.



16 pixel planes fully operational



Other physics performances will be introduced in the next slides

How to measure open charm in NA60 ?

Lifetime of the D mesons:

$D^+ : c\tau = 312\ \mu m$
$D^o : c\tau = 123\ \mu m$

Select muons from $D \rightarrow \mu + X$ which do not converge to the interaction vertex.

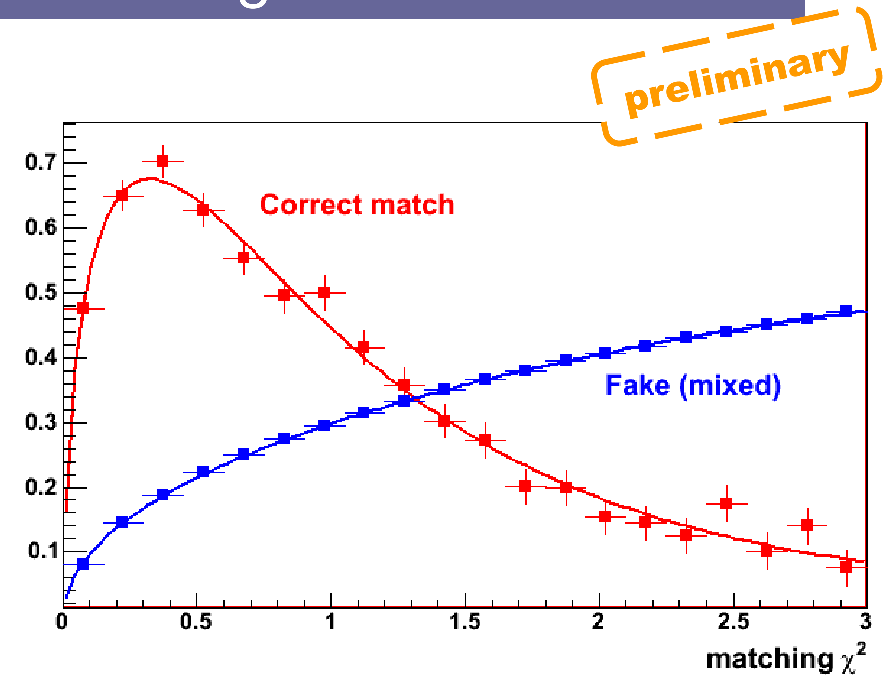
This requires:

- precise knowledge of the vertex position
- good resolution on the track impact point at the vertex plane

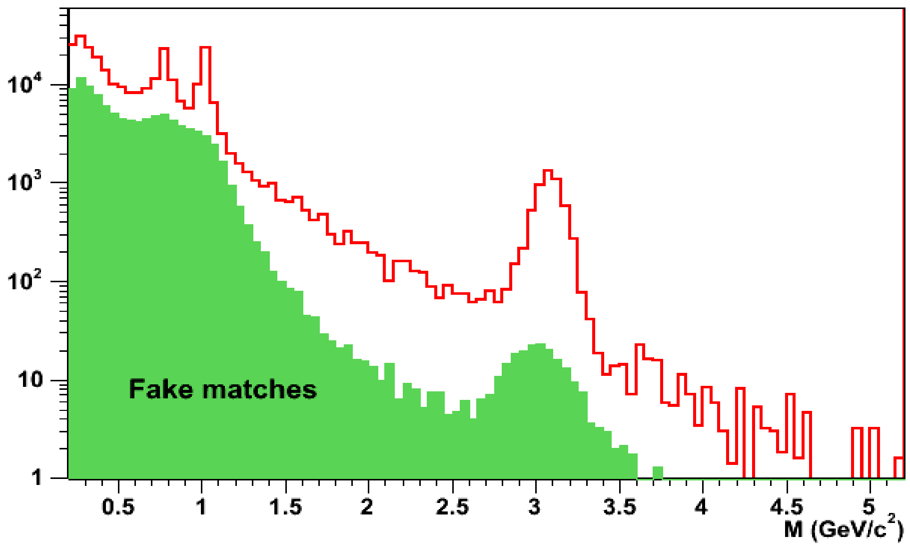
Inverse: picking only muons strictly converging to the vertex we select prompt dimuons

Muon Track Matching

Matching between the muons in the Muon Spectrometer and the tracks in the Vertex Telescope is done estimating the weighted distance (χ^2) in slopes and inverse momenta.



If a certain fraction of muons is matched to closest non-muon tracks a source of background is introduced: fake matches ⇒ deteriorates kinematics and offset resolution.



Fake matches are subtracted by a mixed events technique: the muons are matched to tracks from different events (work in progress...)

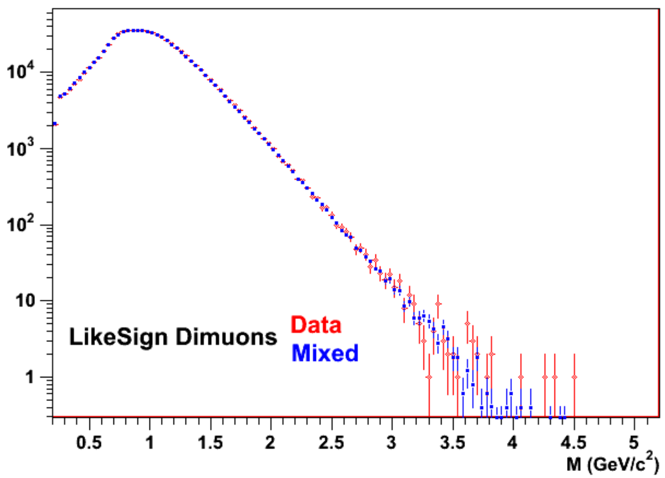
In the present study the fakes are not subtracted

Combinatorial Background from π,K→μ decays

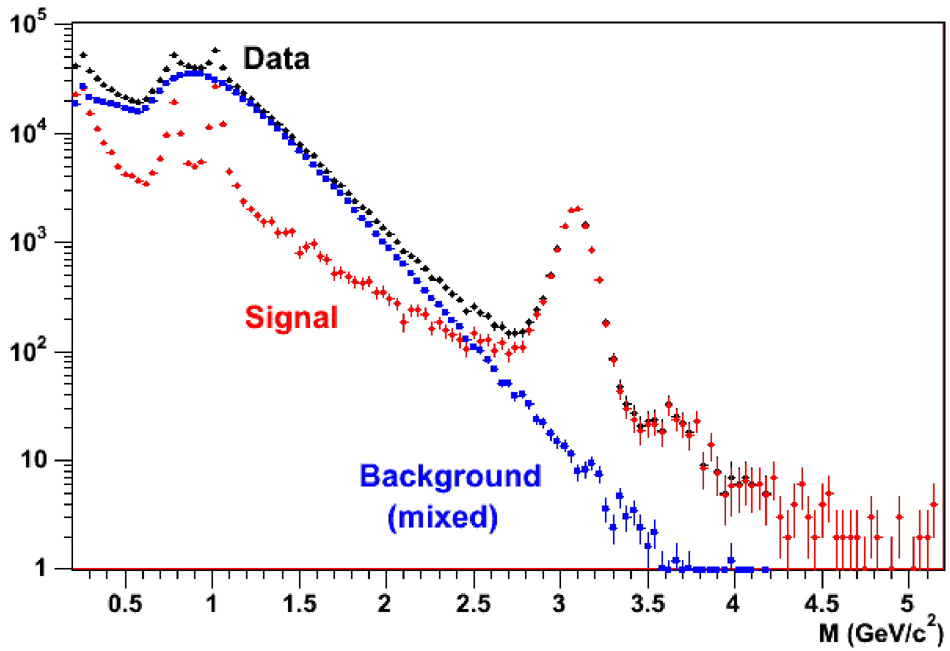
Muons coming from π and k decays are another source of background: the combinatorial background

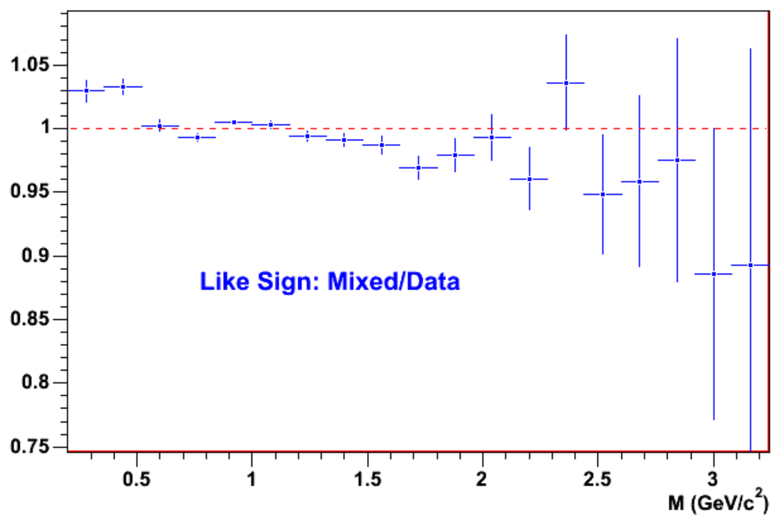
⇩

Subtracted by mixed event technique, building a sample of μμ pairs using muons from different events.



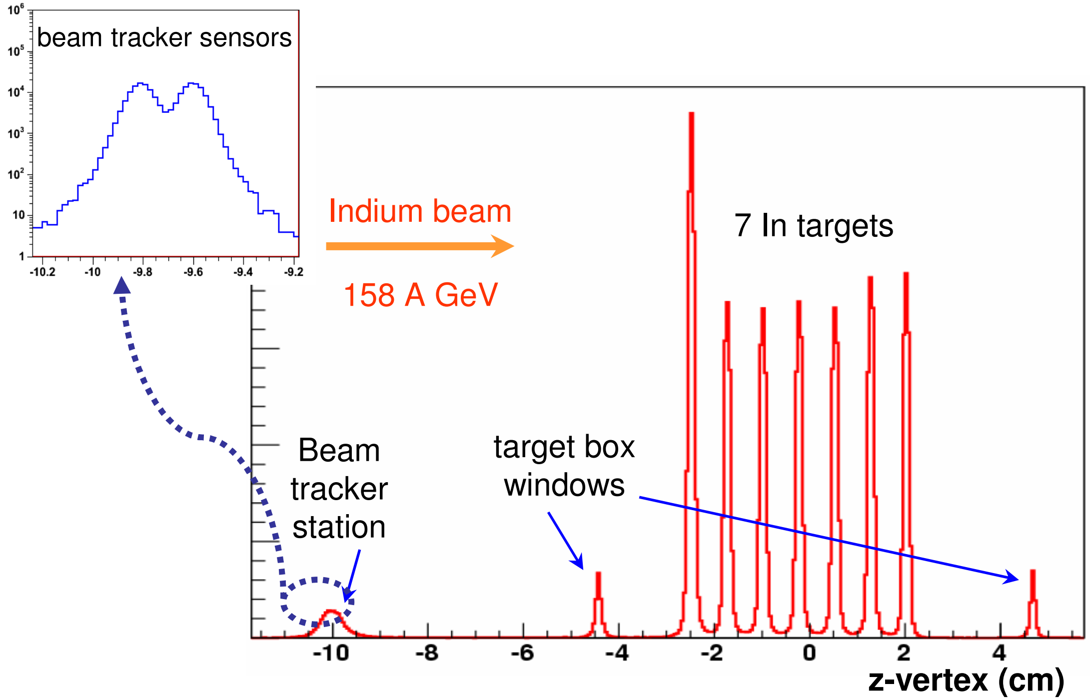
The technique may be controlled by comparing the built **mixed** event Like Sign dimuon spectra to the corresponding measured **data**.





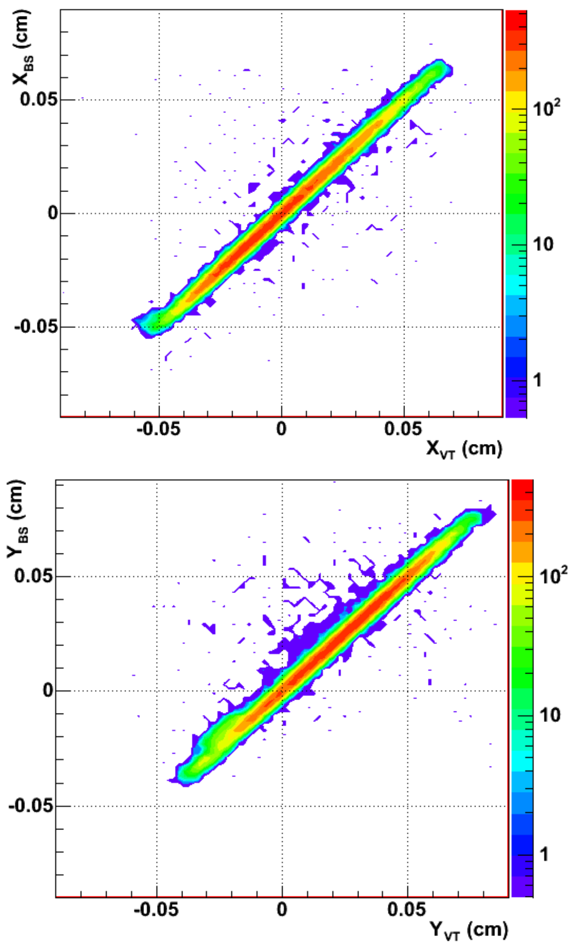
Vertexing

- Robust algorithm resolves multiple vertices (provided they are on different targets)
- Good target identification even for the most peripheral collisions (≥ 4 tracks)



Z-vertex of the interaction determined by the pixel telescope with ~ 200 µm accuracy

Beam Tracker measurement vs. reconstructed vertex

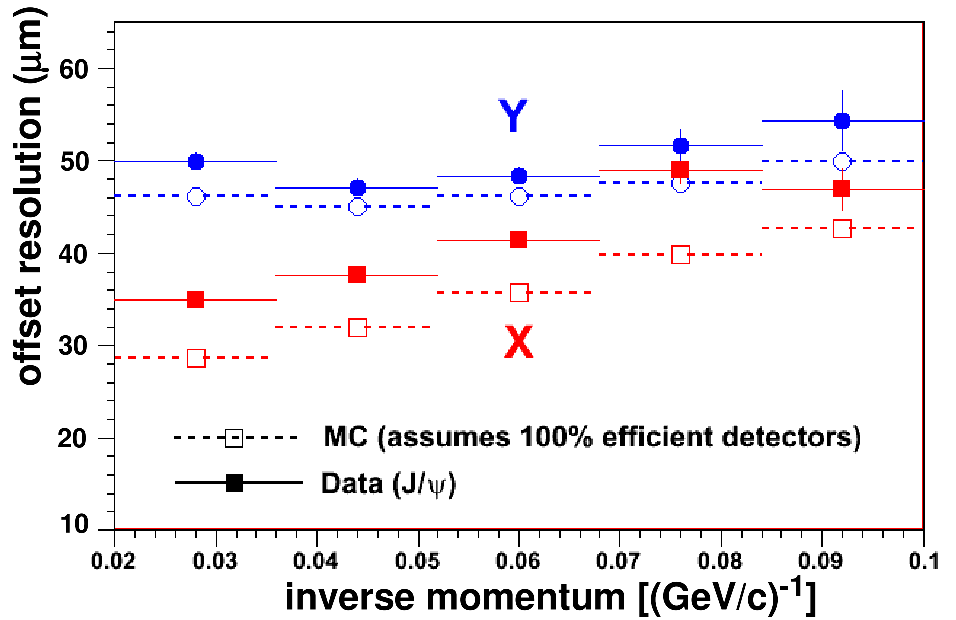


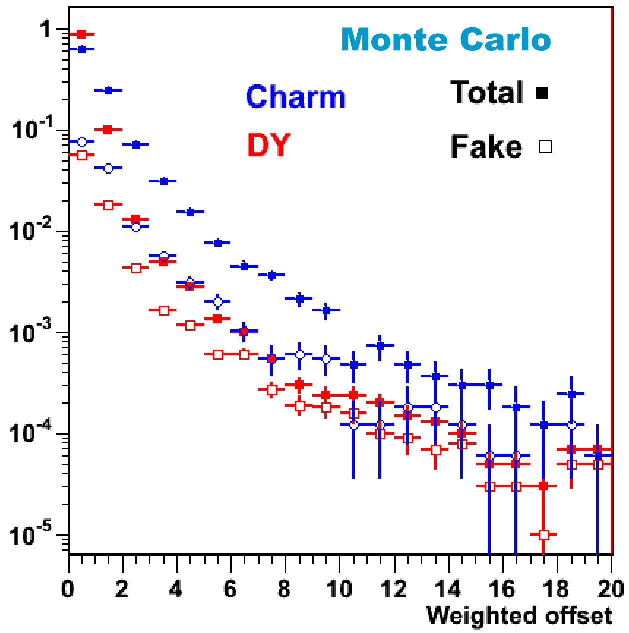
Vertex transverse coordinates determined with better than 20 µm accuracy from the pixel telescope and beam tracker

Measuring the muon track offset at the vertex

Offsets: ΔX, ΔY between the vertex and the track impact point in the transverse plane at Z_{vertex}.

Resolution depends on track momentum

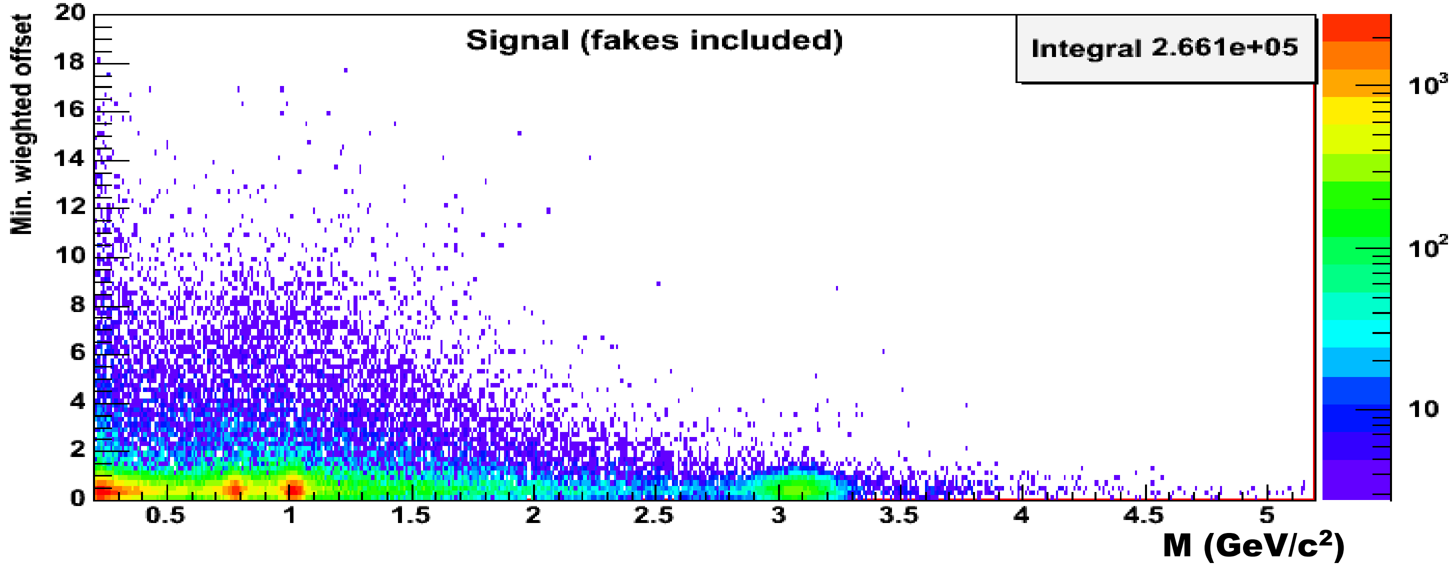




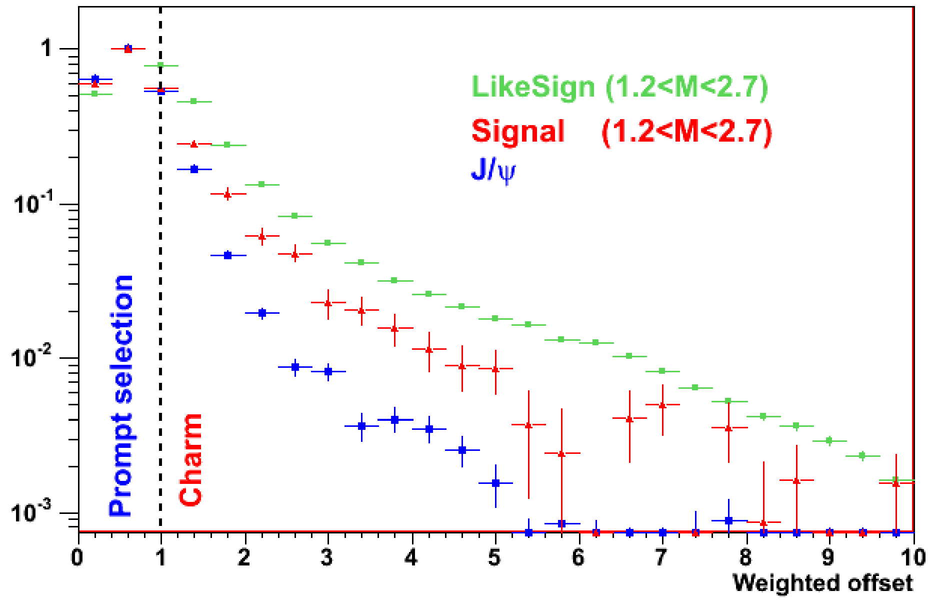
Fake matches tend to have large offsets: they degrade the charm selection capability.

Problem will be solved once their subtraction is under control

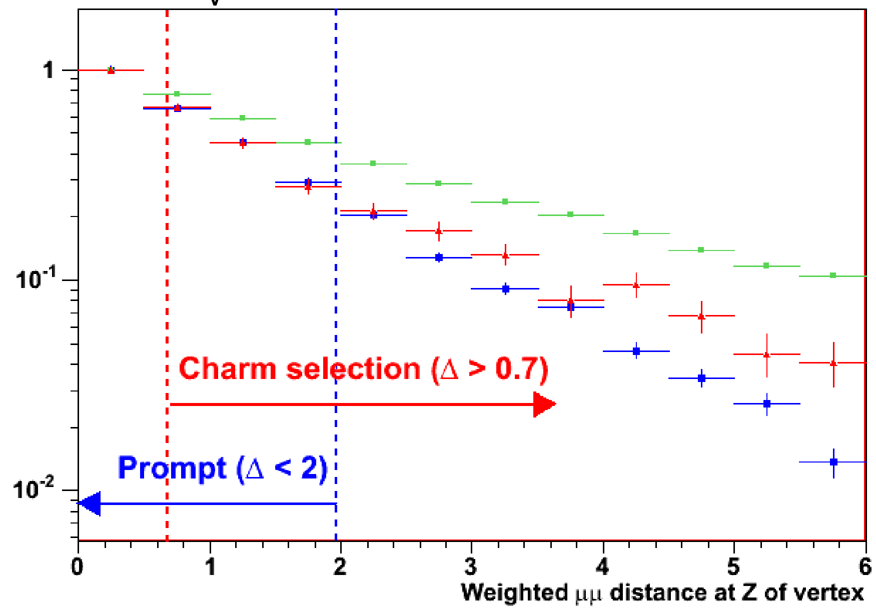
Prompt versus offsetted dimuon separation



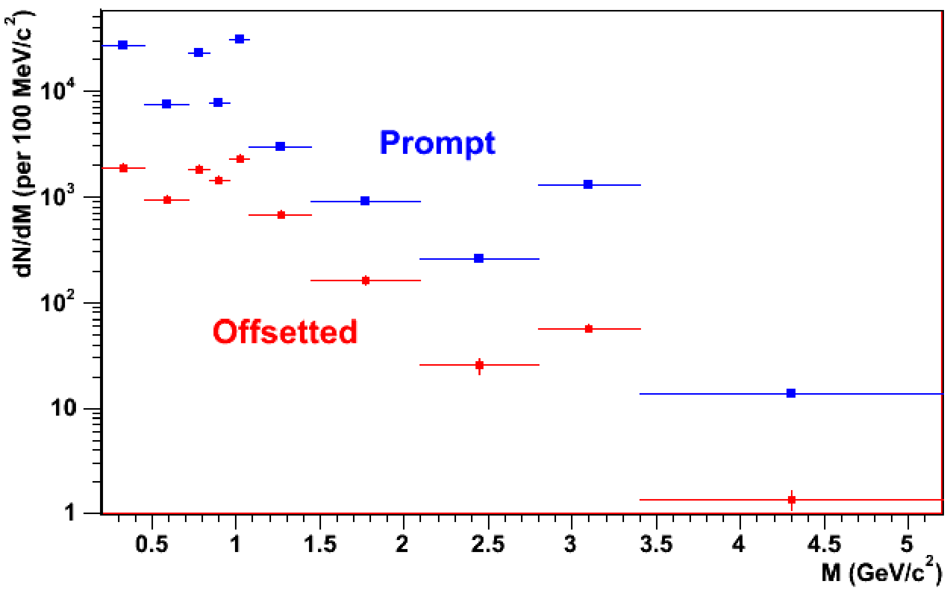
Cut on the weighted offset of the muon closest to the vertex



Additional cut on weighted distance, Δ, between muons at Z_V to reduce influence of bad vertices



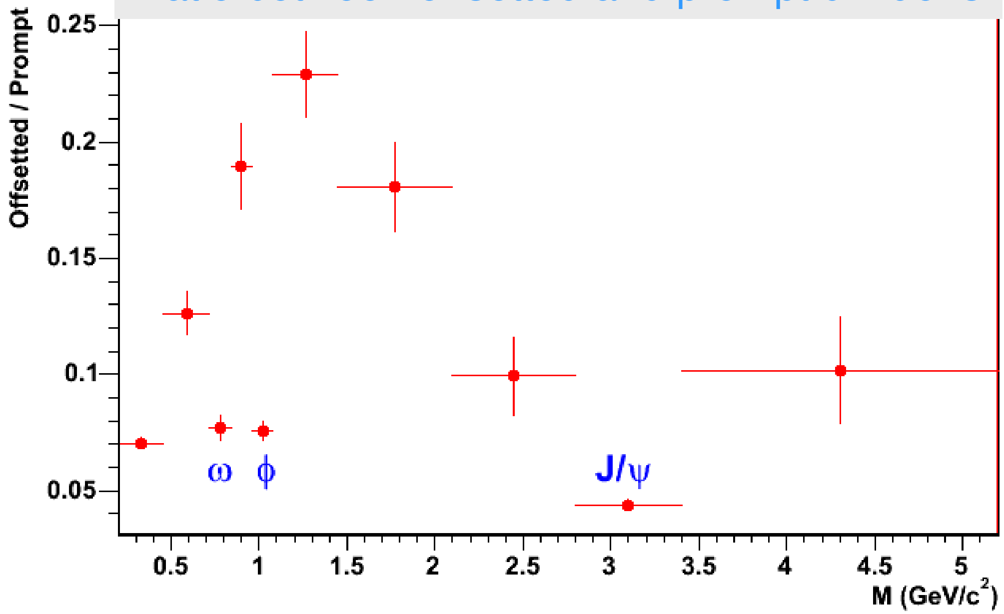
Prompt versus offsetted dimuon separation



- Only ~20% of the total statistics is used
- The selection cuts are still to be optimized (once the subtraction of the fake matches is available)

- Strong reduction in the offsetted sample of the dimuon yield at the masses corresponding to the prompt ω, φ and J/ψ resonances
- Clearly visible "excess" in the offsetted dimuon sample in the mass window where the charm decays contribute the most

Ratio between offsetted and prompt dimuons



J/ψ production in Indium-Indium: 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
- The dimuon must be in the phase space window:
  $-0.5 < \cos\theta_{CS} < 0.5$ & $2.92 < y_{LAB} < 3.92$
- The matching between the muon spectrometer and the vertex telescope tracks can also be required with the following advantages/disadvantages:

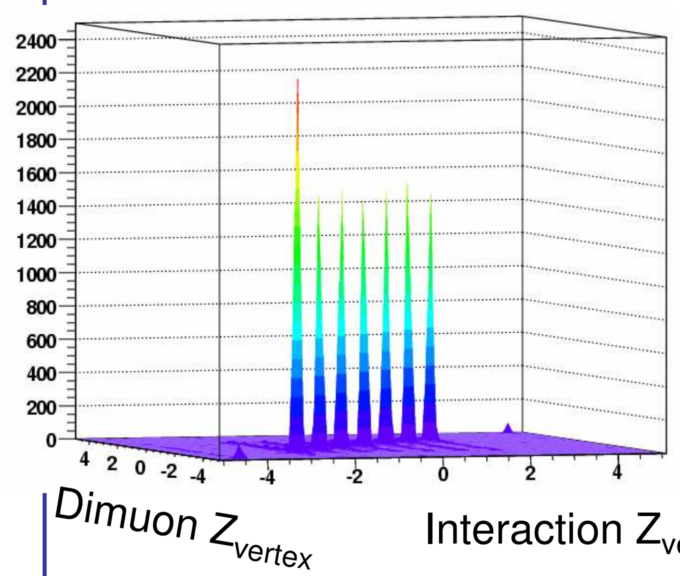
Without the muon track matching:

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

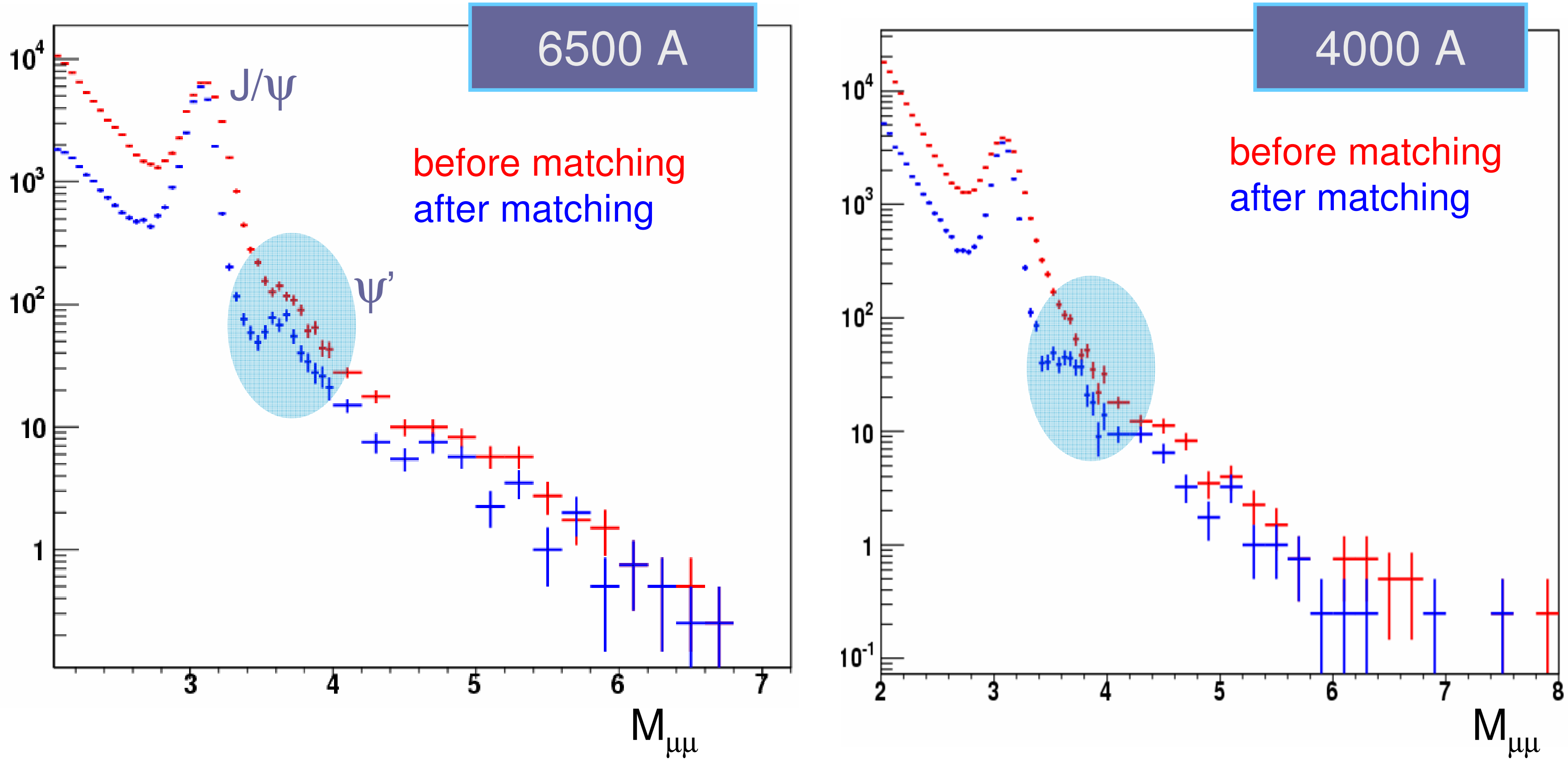
With the muon track matching:

- ☹ we lose 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



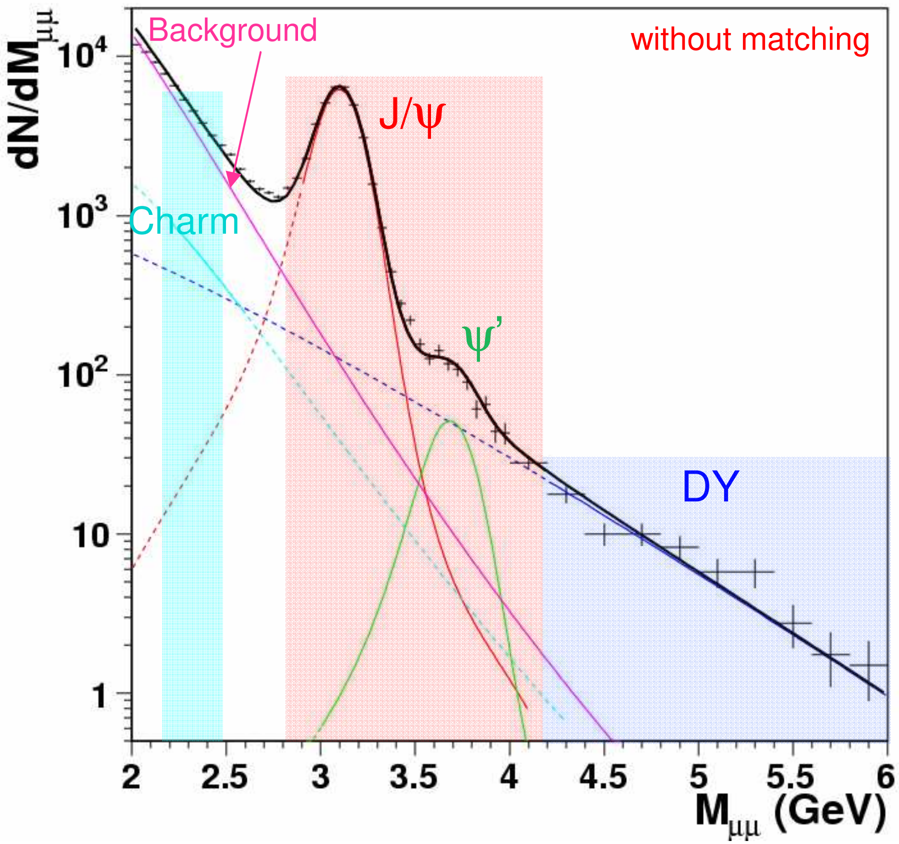
High mass dimuon spectra before and after muon track matching between the Muon Spectrometer and the Vertex Telescope



- 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

J/ψ/DY

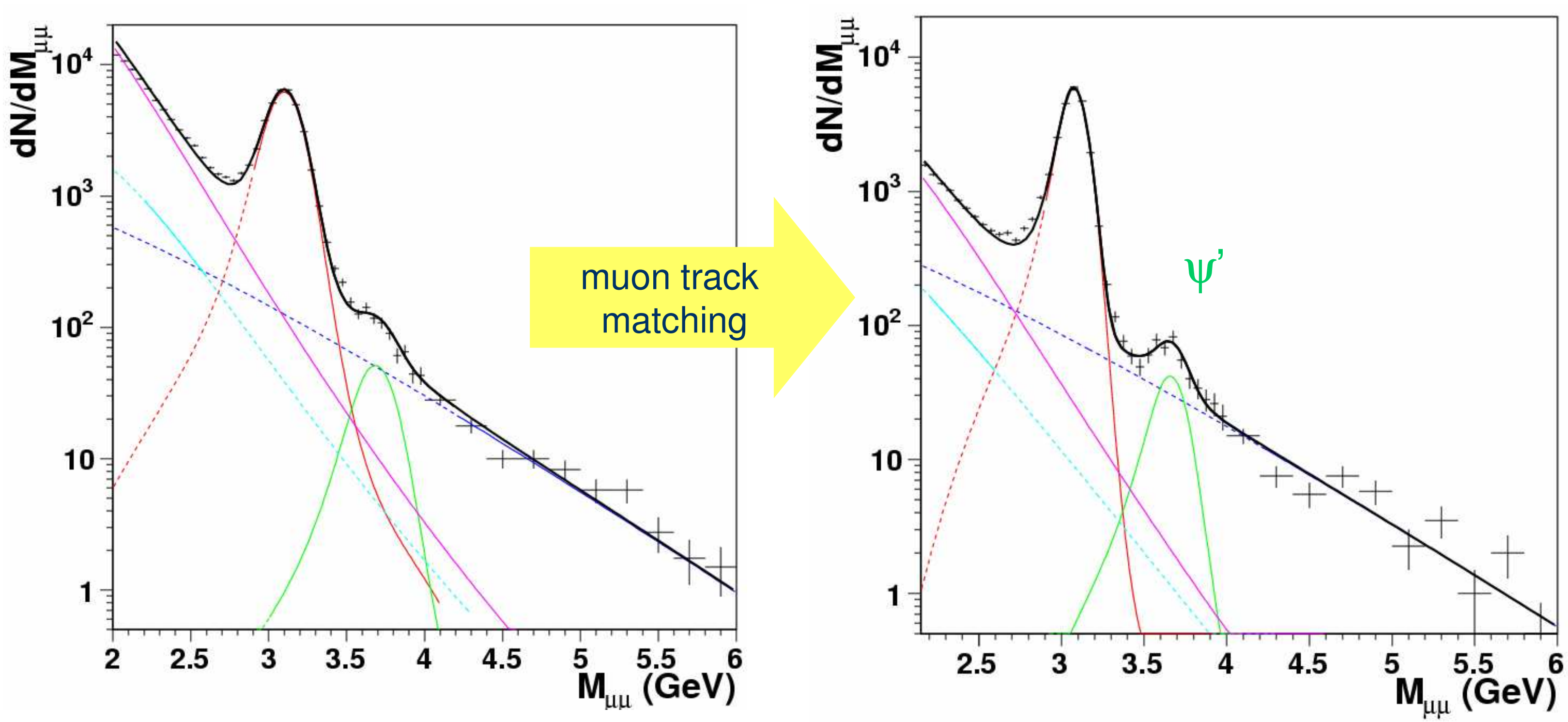
From the J/ψ and Drell-Yan yields obtained from the previous fit, after the acceptance corrections, we extract the J/ψ / DY cross-section ratio.

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. The value is

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

Stability checks

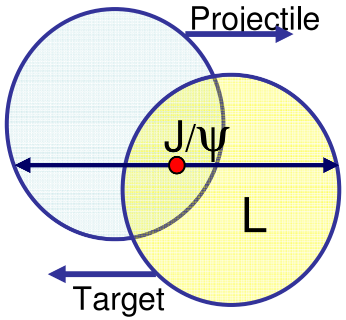
In order to evaluate the sensitivity of our result to the data analysis procedure, we have redone it, changing several steps. We found that the result is almost insensitive to (reasonable) changes in the background normalization, different event selection criteria and different fitting procedures. Systematical 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

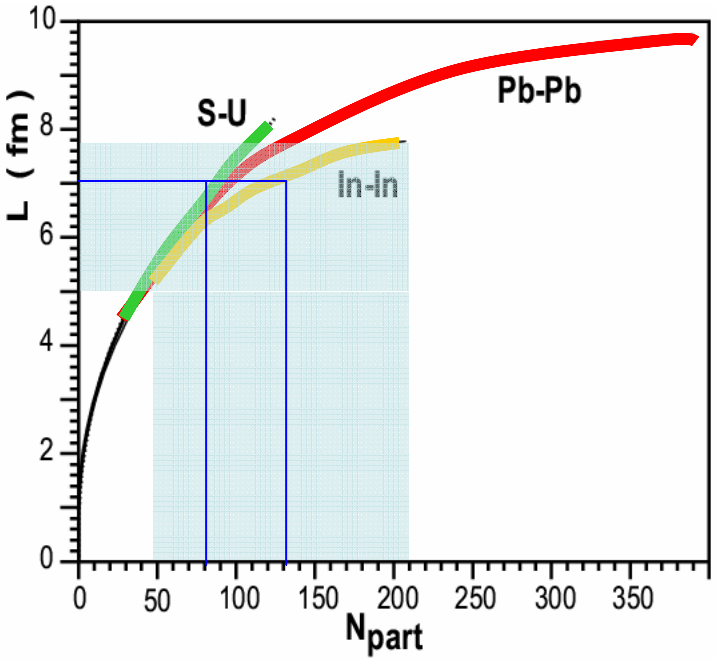
In the absence of "new physics", the J/ψ suppression patterns measured in different collision systems should overlap when plotted as a function of L (it is the case between p-A and S-U).



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

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.

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



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

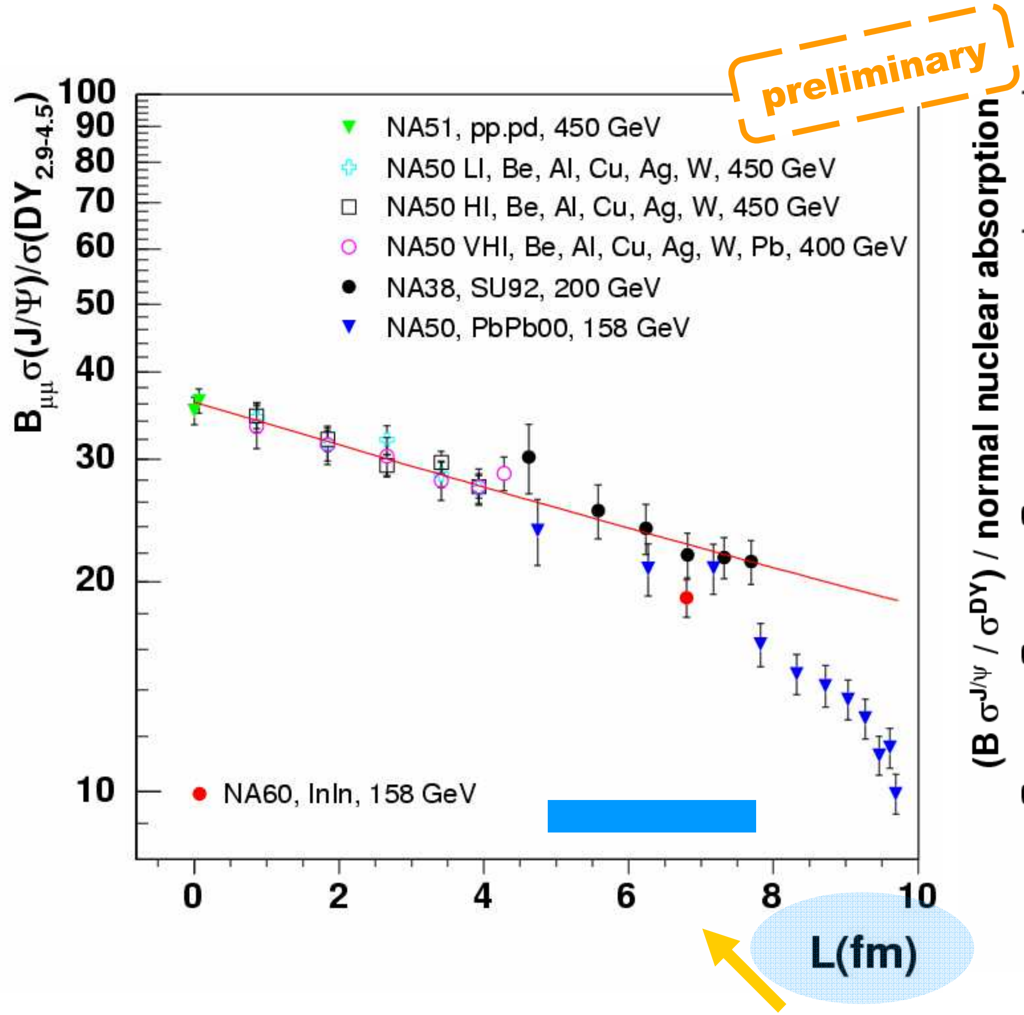
→ If the physics-driving variable is L, the three systems will overlap

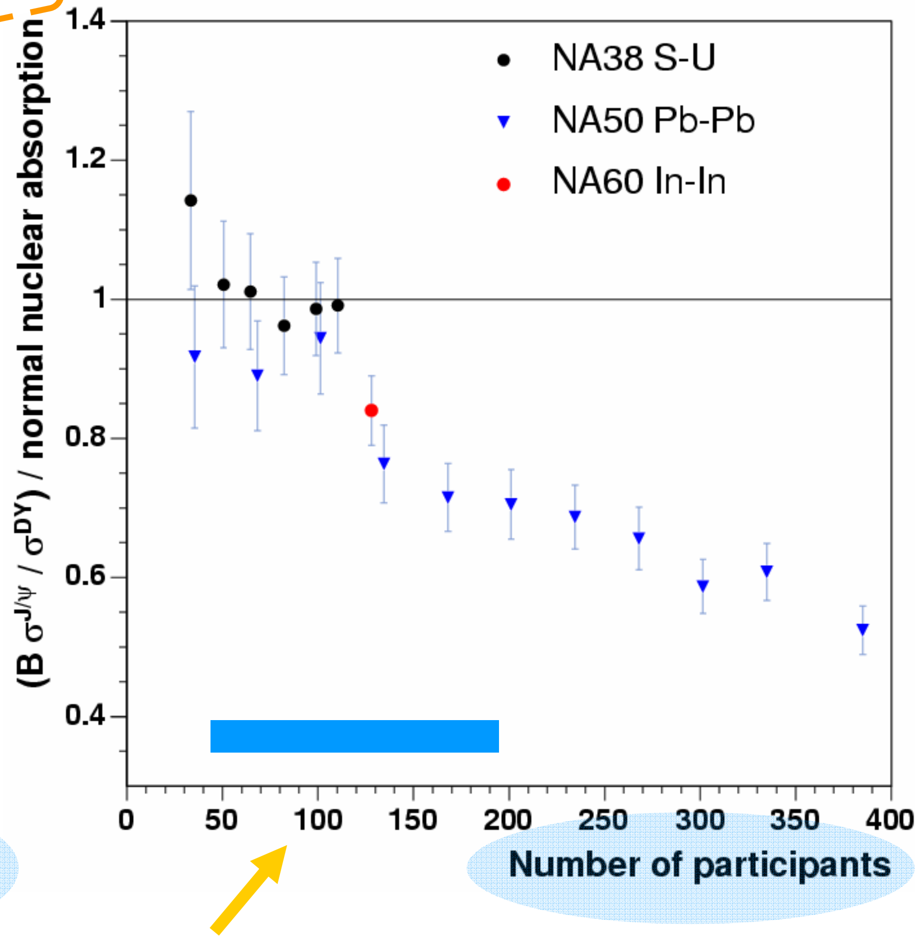
→ If the physics-driving variable is N_{part}, the three systems will show a different pattern

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

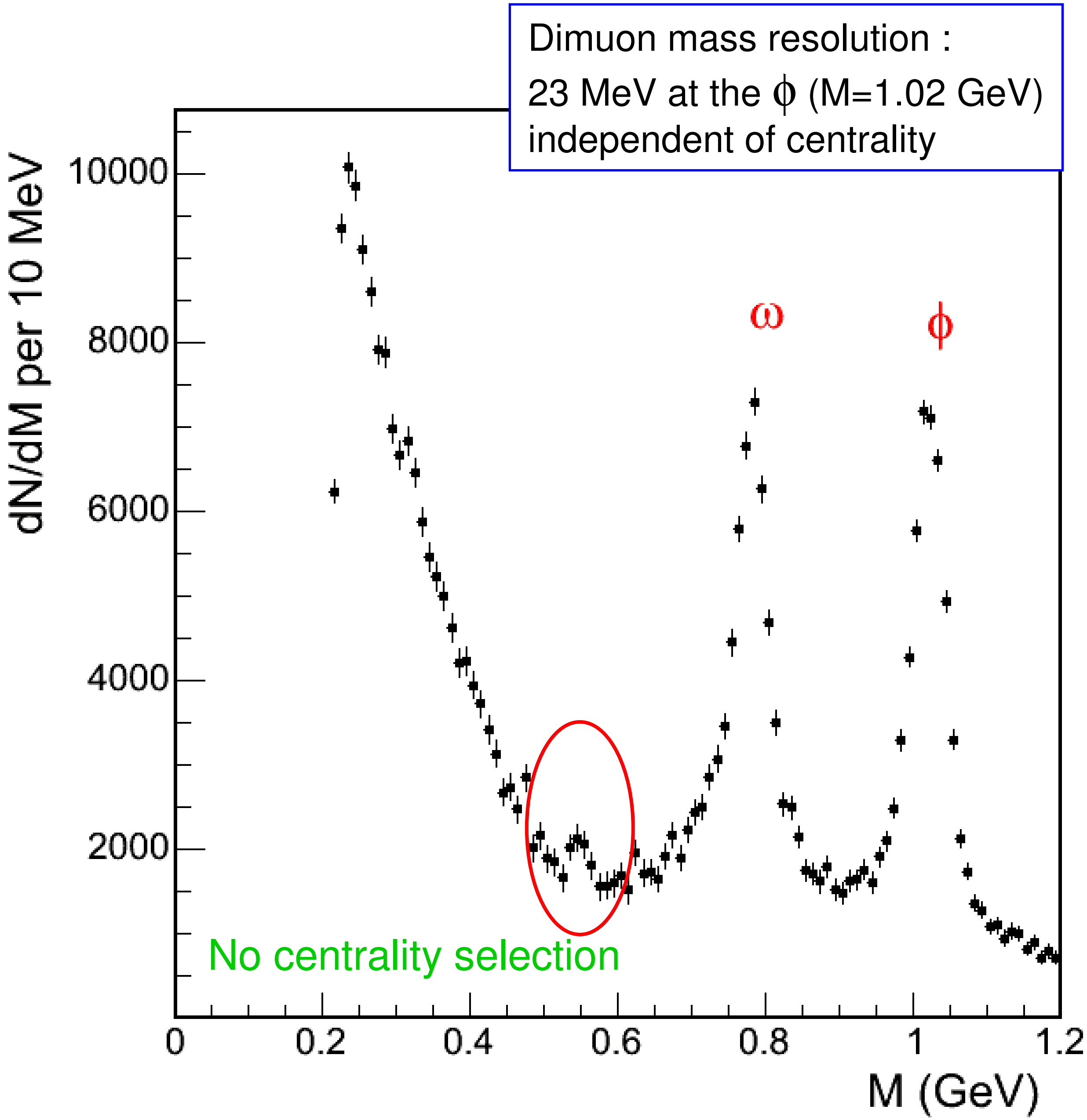
Dividing the J/ψ / DY result by the normal nuclear absorption curve $\Rightarrow$ 0.84 ± 0.05





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

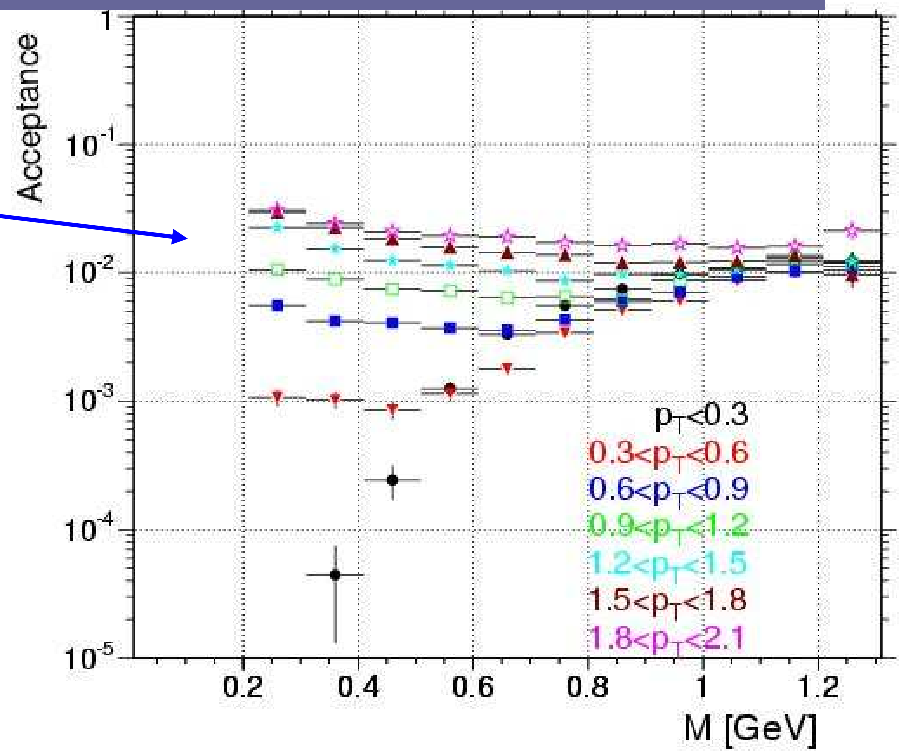
Signal spectrum in the low mass region

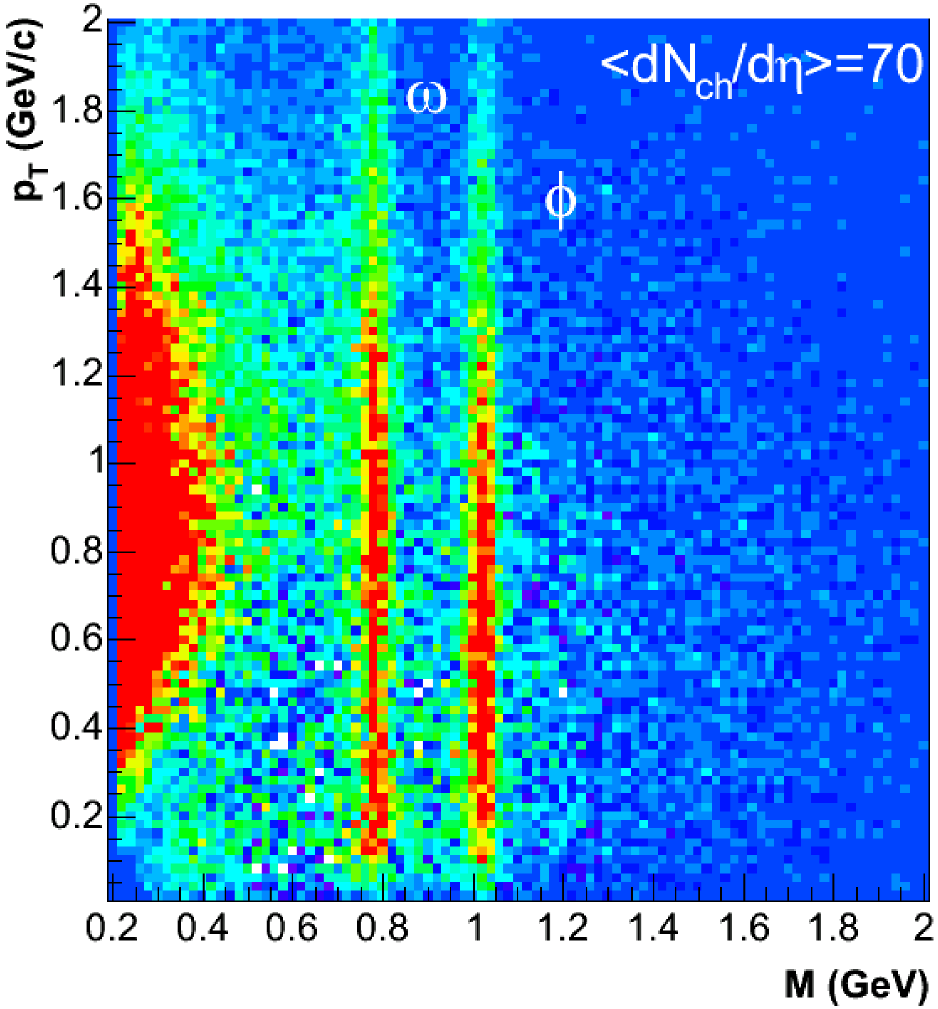


- 37000 ϕ events
- Similar ω statistics
- The η → μμ channel is also visible (for the first time in nuclear collisions)

Phase space coverage of low mass dimuons

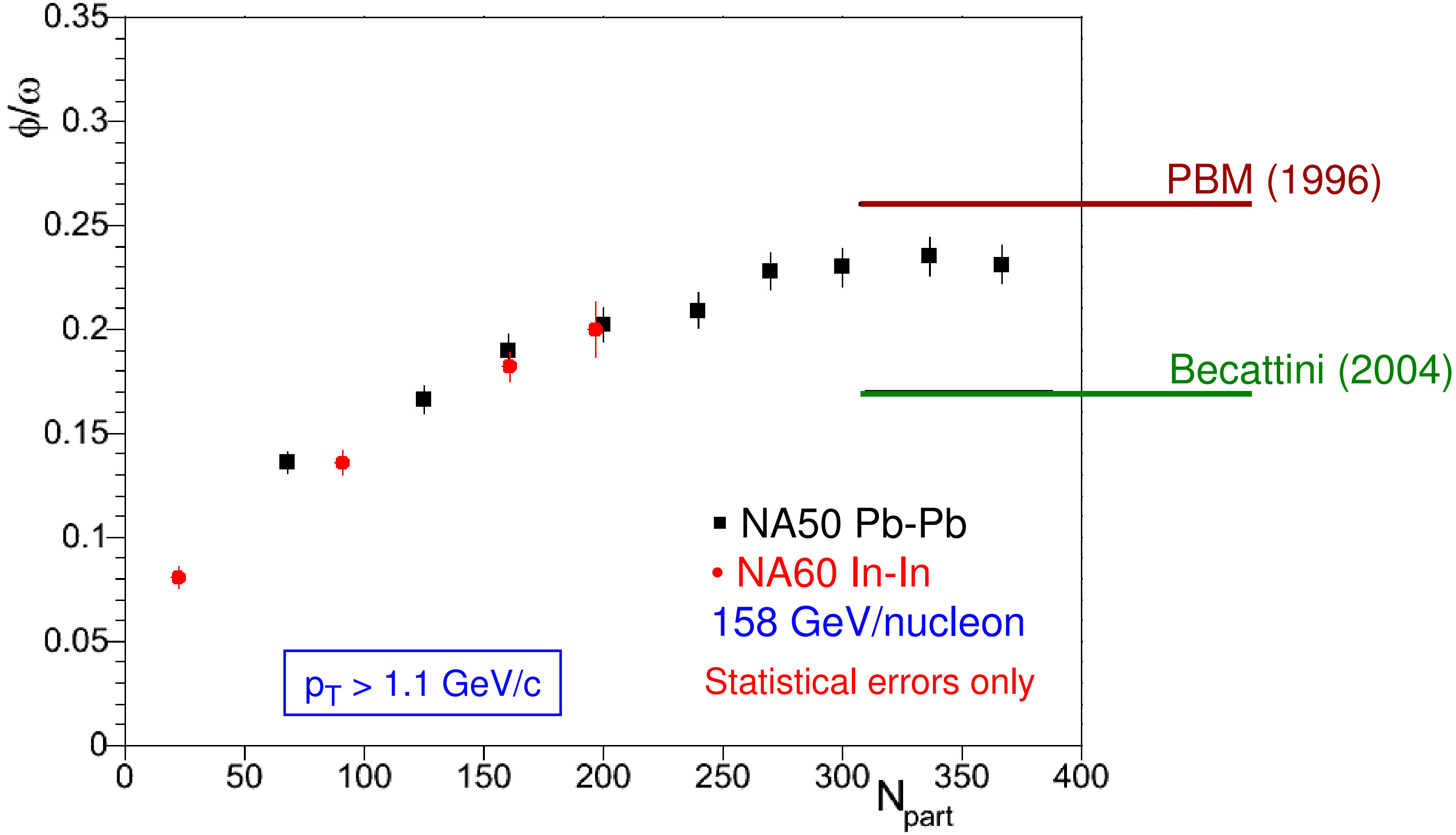
The NA60 acceptance extends, in contrast to NA38/NA50, down to small M and p_T





- Net spectrum after muon track matching and subtraction of the combinatorial background
- The ω and φ vector mesons are well resolved over the whole p_T range

ϕ/ω cross section ratio vs. centrality

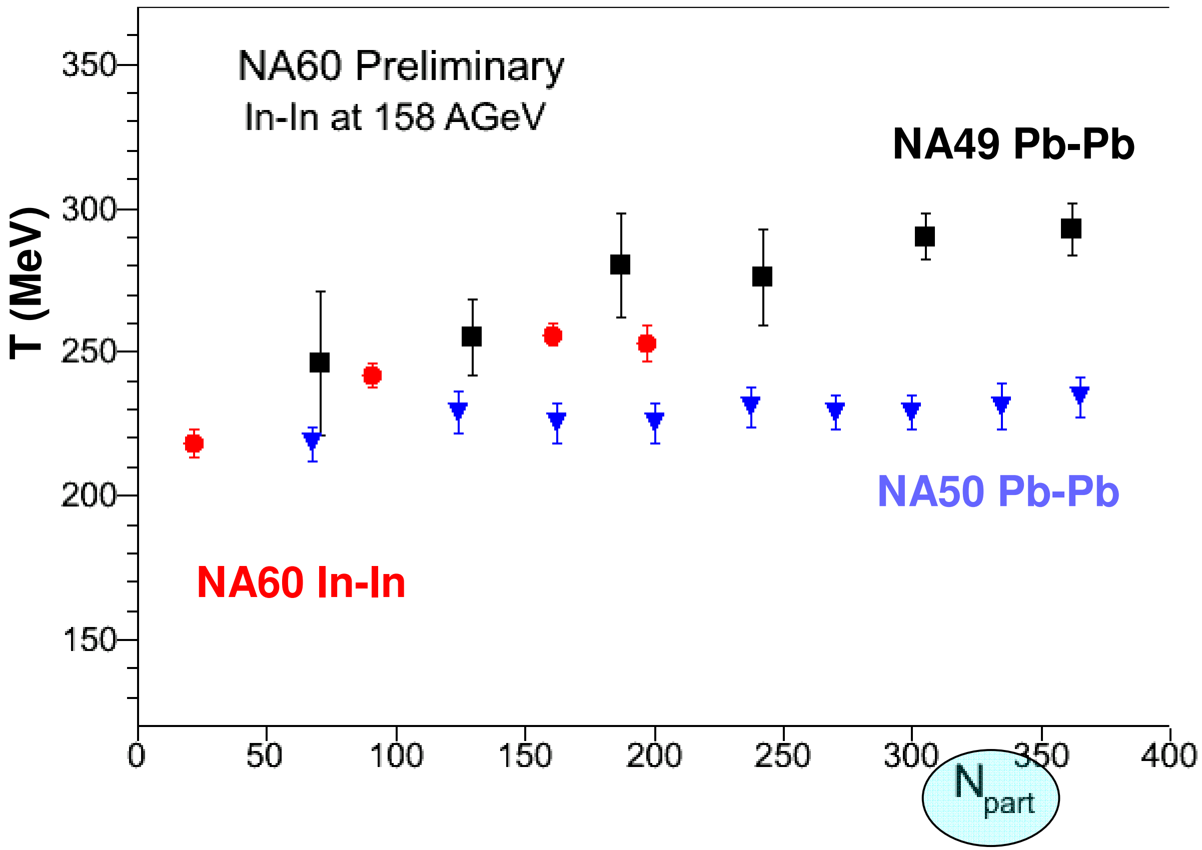


Very good agreement between the In-In and Pb-Pb colliding systems

$\rightarrow$ N_{part} seems to be the appropriate scaling variable for ω and ϕ production

- The NA50 $\phi/(\rho+\omega)_{\mu\mu}$ published values were corrected for BR, assuming $\rho/\omega = 1$, and extrapolated from $m_T > 1.5$ GeV to $p_T > 1.1$ GeV using T = 228 MeV
- The NA60 systematic uncertainties are expected to be < 10%

T(φ): NA60 versus NA50 and NA49



Average T(φ) In-In values

1) all p_T
   252 ± 3 MeV

2) p_T < 1.5 GeV (NA49 range)
   256 ± 6 MeV

3) m_T > 1.65 GeV (NA50 range)
   245 ± 5 MeV

→ Always ~ 250 MeV

Systematic errors still under investigation
Expected to be less than 10 MeV

Summary and outlook

We presented the cross section ratio J/ψ / DY in Indium-Indium collisions, integrated over all centralities, together with first results of a feasibility study of the intermediate and low mass region of the dimuon spectrum

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

⇩

In autumn 2004, NA60 has taken data with 400 GeV protons incident on 7 different nuclear targets, at high beam intensities (~ 2×10^9 p/burst)

The expected statistics is of the order of

~ 500 000 J/ψ
similar amount of open charm at $1.2 < M < 2.7$ GeV/c^2

NA60 has 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

Summary and future perspectives

- A total of ~1 million signal low mass dimuons, from In-In collisions, after muon track matching.
  About 35% of this statistics has been analysed by now.
  - 23 MeV dimuon mass resolution at the ϕ mass
  - good signal to background ratio

- First results on:
  - the ϕ/ω cross section ratio
  - the inverse slope parameter T of the ϕ
  - the ϕ mass

  } … as a function of centrality

<u>What's next:</u>

- Analysis of the full data sample
- Fake matches subtraction

continuum physics
in the low mass and intermediate mass region