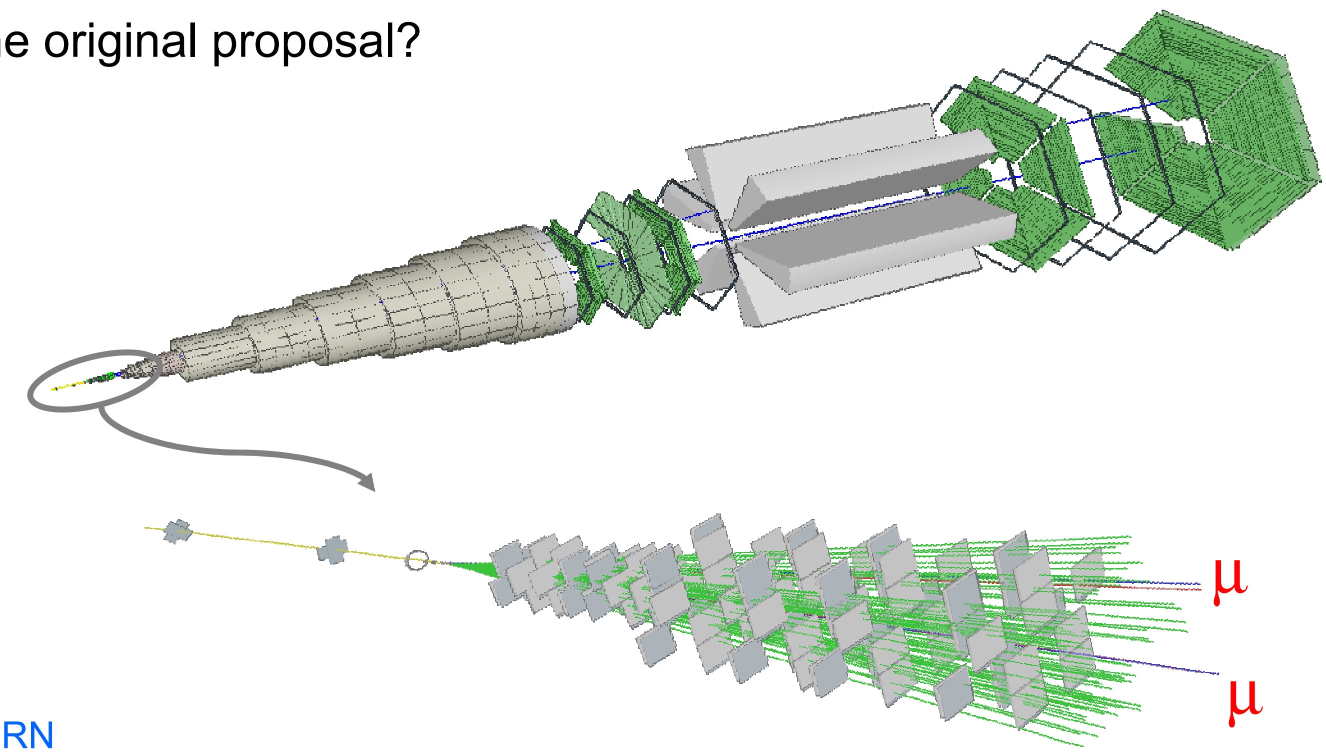
Dimuon and heavy-flavor production in p-nucleus and nucleus-nucleus collisions
The NA60 experiment

Outline:

- Why NA60 exists: a reminder of the physics motivation
- What's specific of NA60: a glimpse of the detector
- What have we done so far: performance and results from the past runs
- What's missing from the original proposal?



Carlos Lourenço — CERN
for the NA60 Collaboration

A reminder of the physics motivation

Since 1986, several SPS experiments probed high-energy nuclear collisions to search for the QCD phase transition from normal nuclear matter to a state where the quarks and gluons are no longer confined in hadrons and chiral symmetry is restored

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

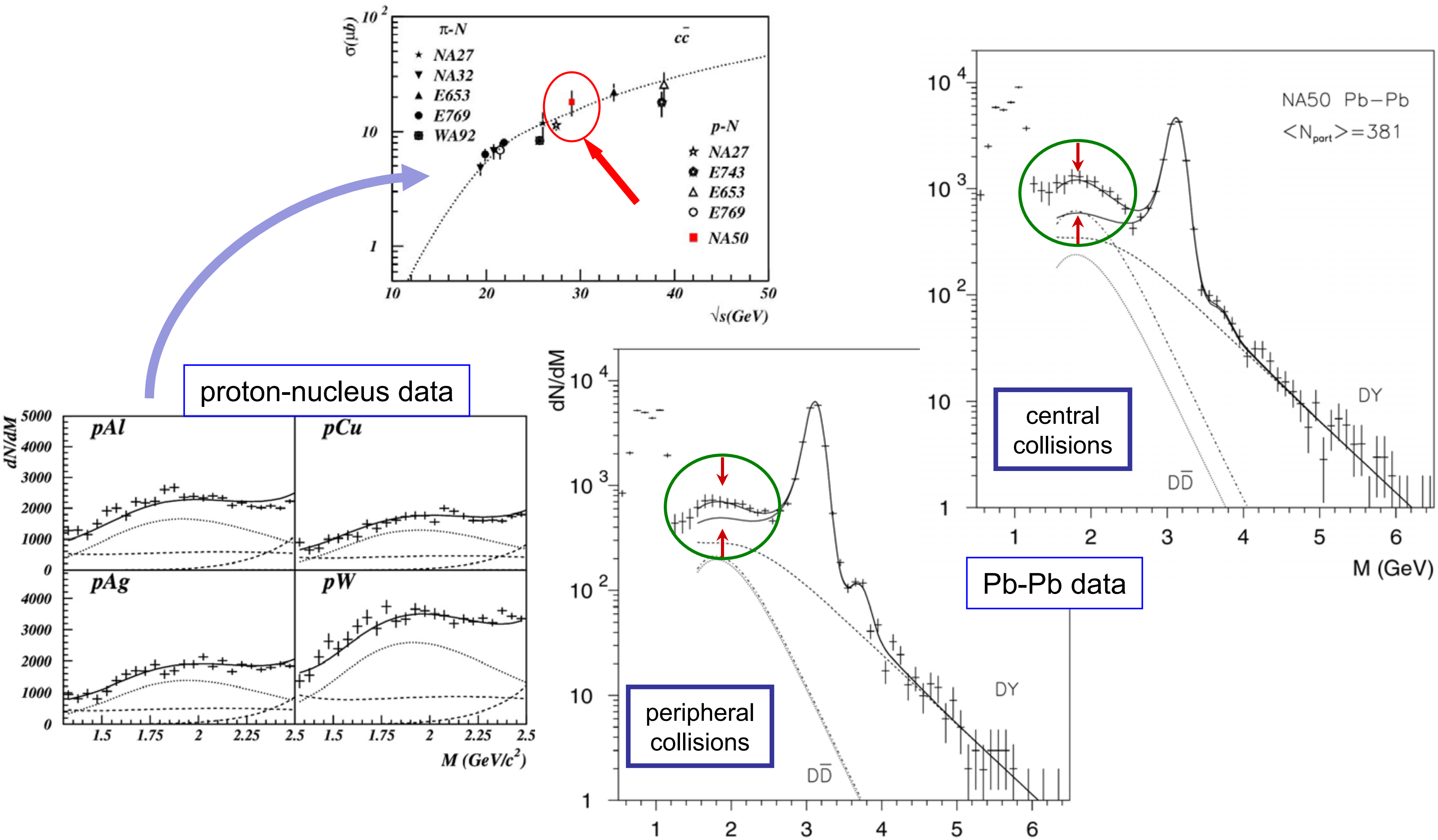
The available measurements are consistent with the expectations derived from these theory predictions: *we found what we were told to look for*

The next few slides show some of these very interesting observations, made by NA38/NA50 and CERES

Excess production of intermediate mass dimuons

NA38/NA50

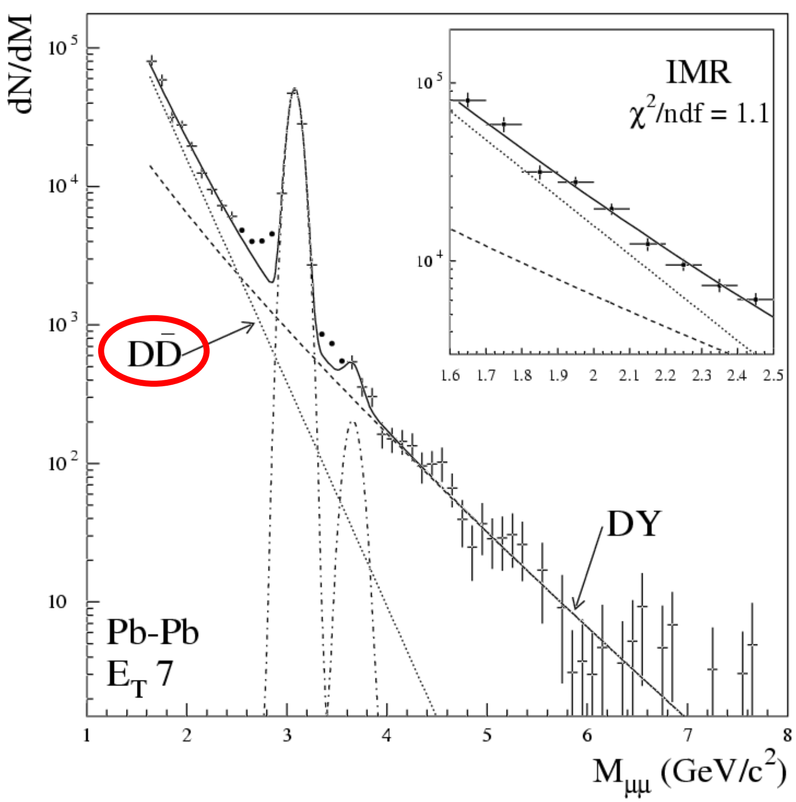
- The yield of intermediate mass dimuons seen in heavy-ion collisions (S-U, Pb-Pb) exceeds the sum of Drell-Yan and D meson decays, which describes the proton data

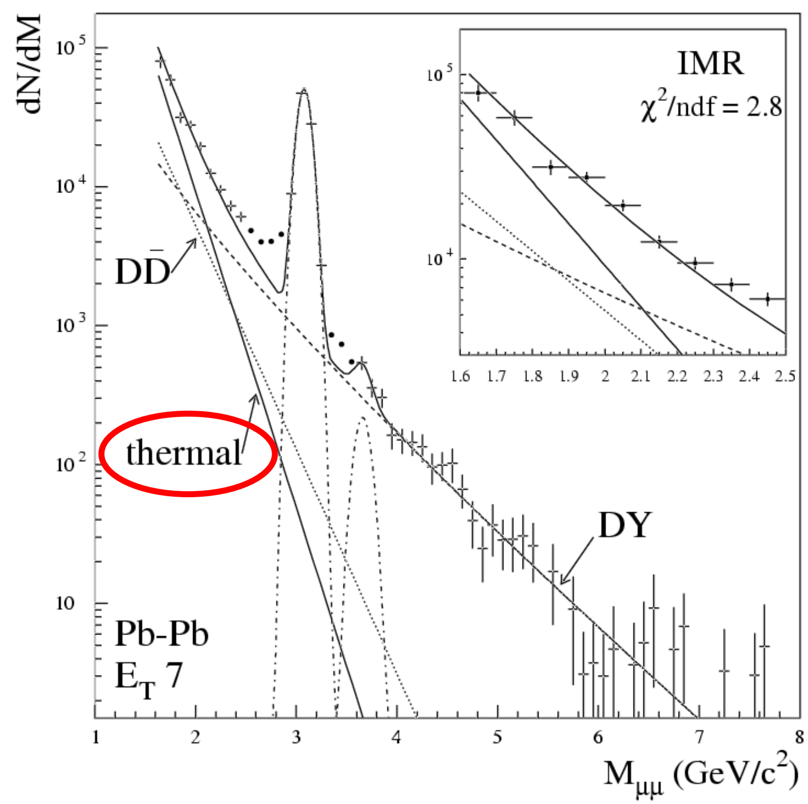


Charm enhancement or thermal dimuons ?

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)
- or by adding thermal radiation to the DY and open charm (explicitly introducing a QGP phase at T_c = 175 MeV)
  → first direct evidence of thermalization of the pre-hadronization phase: QGP

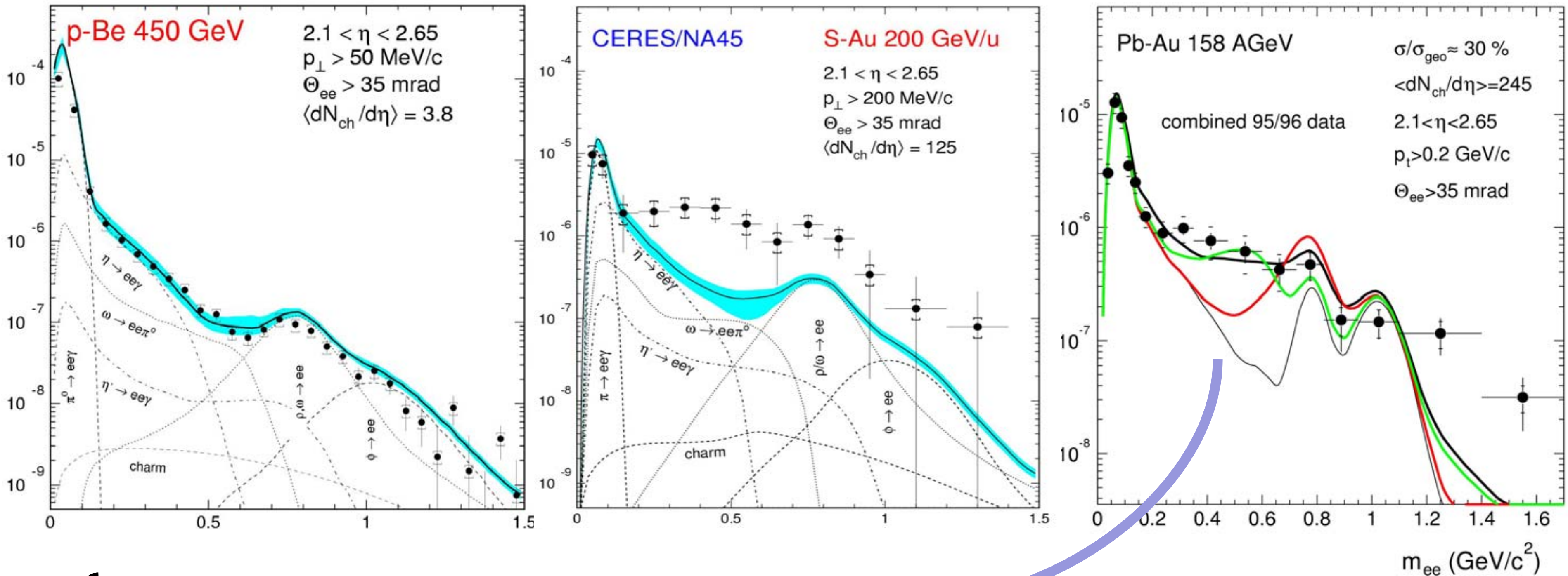




Low mass di-electron production : from p-Be to Pb-Au

CERES

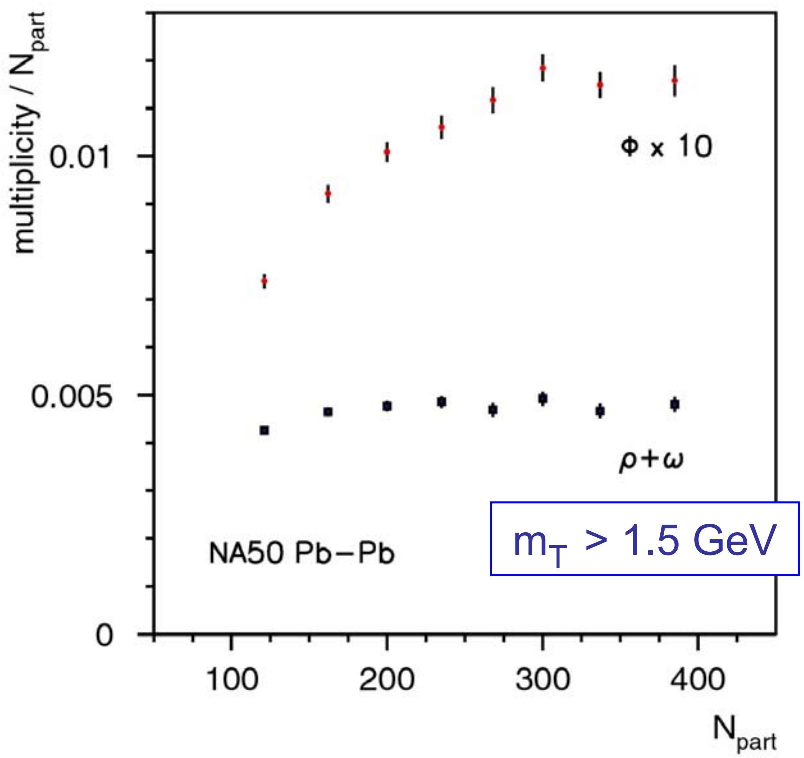
- The low mass di-electron data collected in heavy-ion collisions (S-Au, Pb-Au) exceeds the expected sum of light meson decays, which describes the proton data
- The excess electron pairs are concentrated at low p_T and scale with N_{ch}^2

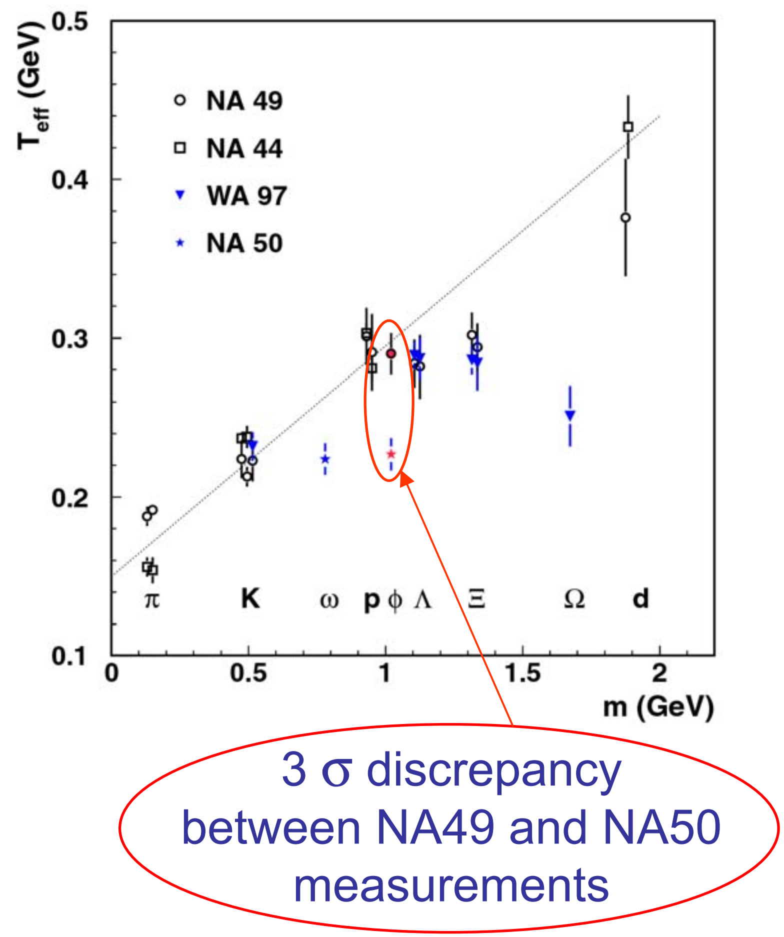


- no ρ
- vacuum ρ
- dropping ρ mass (Brown-Rho) : medium dependent chiral condensate
- broadening of the ρ spectral function (Rapp-Wambach) : ρ-hadron interactions

ϕ enhancement in Pb-Pb collisions

NA50



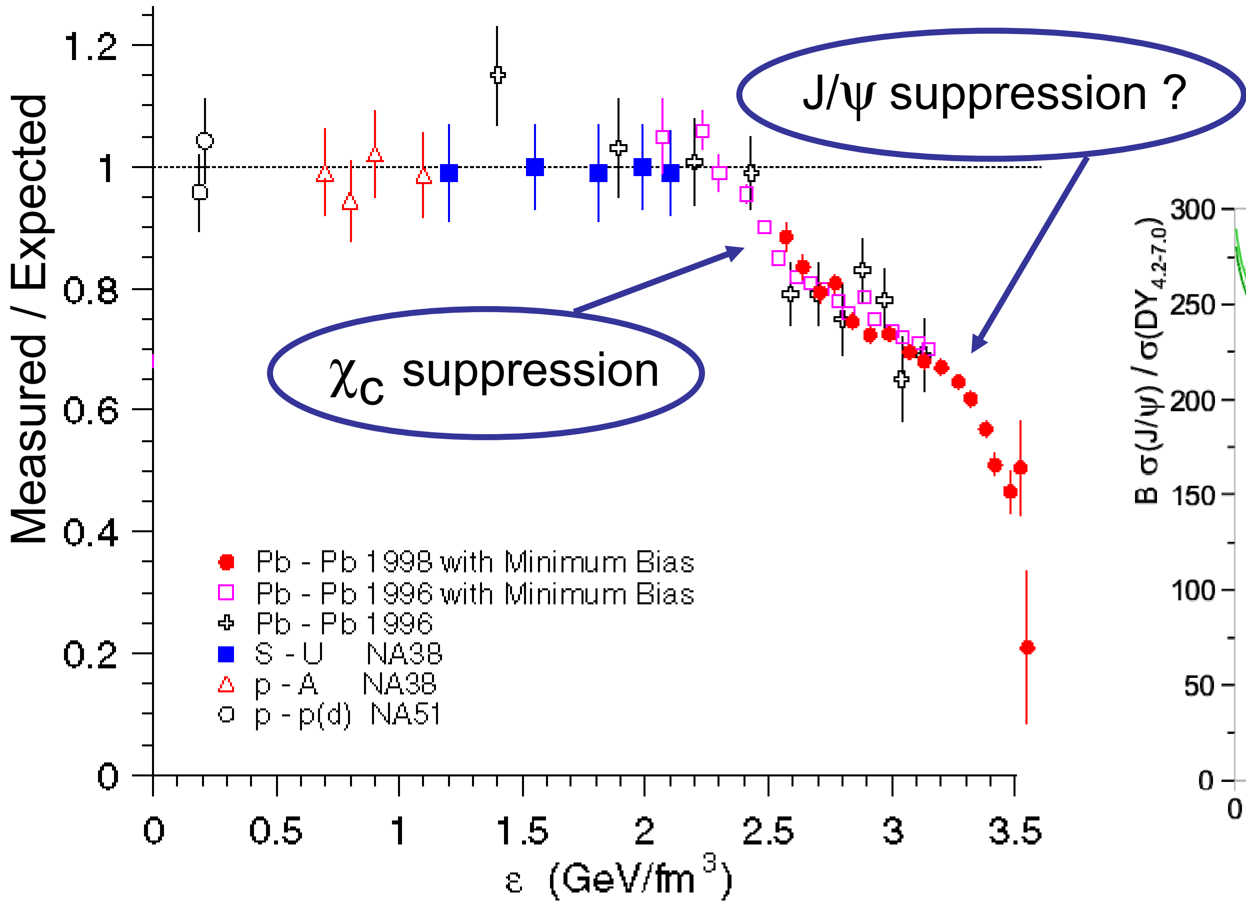


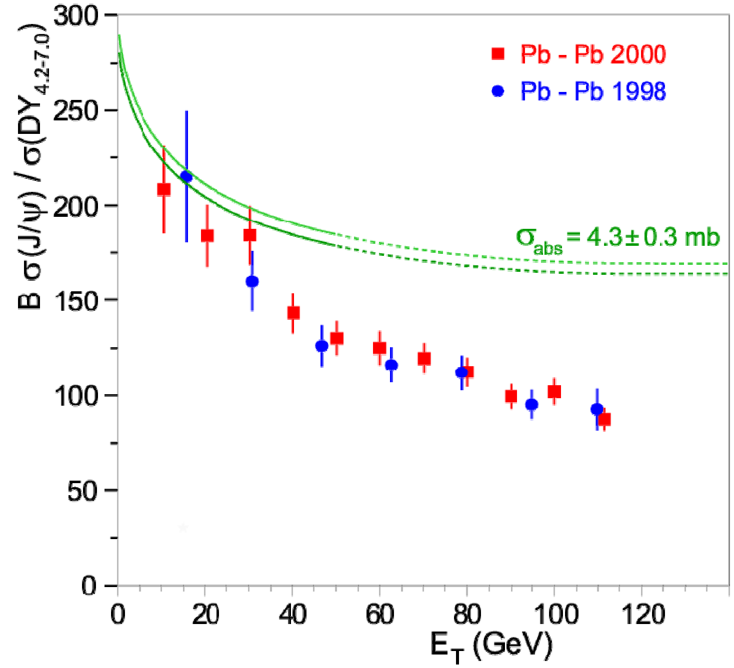
- Anomalous ϕ enhancement relative to N_{part}
- What is the value of T, the inverse slope of the p_T distribution?
- Is it different between $\phi \rightarrow KK$ and $\phi \rightarrow \mu\mu$ decays?

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

NA38/NA50

- The J/ψ production is suppressed in Pb-Pb collisions with respect to the yields extrapolated from proton-nucleus data → evidence for a deconfined QCD phase





➤ Is the deconfined phase reached through a geometrical transition (percolation) or through a thermal transition (QGP) ?

Questions raised by these interesting observations

- Is the observed low mass dielectron excess a sign of chiral symmetry restoration?

⇒ Improved statistics, signal to background ratio and mass resolution;
resolve the ω peak; study the signal versus collision centrality and p_T

- Is the observed intermediate mass excess due to thermal dimuons from a QGP?
- Or is the open charm yield enhanced in nucleus-nucleus collisions?

⇒ Measure secondary vertices with ~ 50 μm precision;
separate prompt dimuons from D meson decays

- Are the J/ψ mesons suppressed in the QGP phase or in a precursor state?
- 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

- What is the impact of the χ_c feed-down on the observed J/ψ suppression pattern?

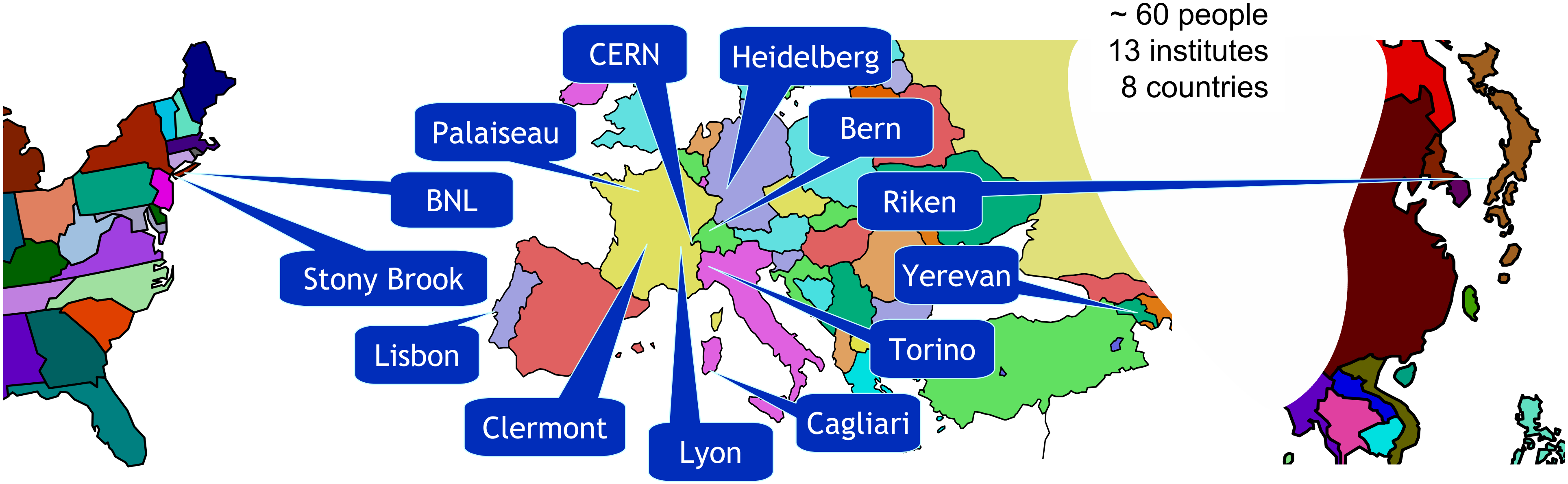
⇒ Study the nuclear dependence of χ_c production in p-A collisions

New and accurate measurements are needed → NA60

The NA60 Experiment

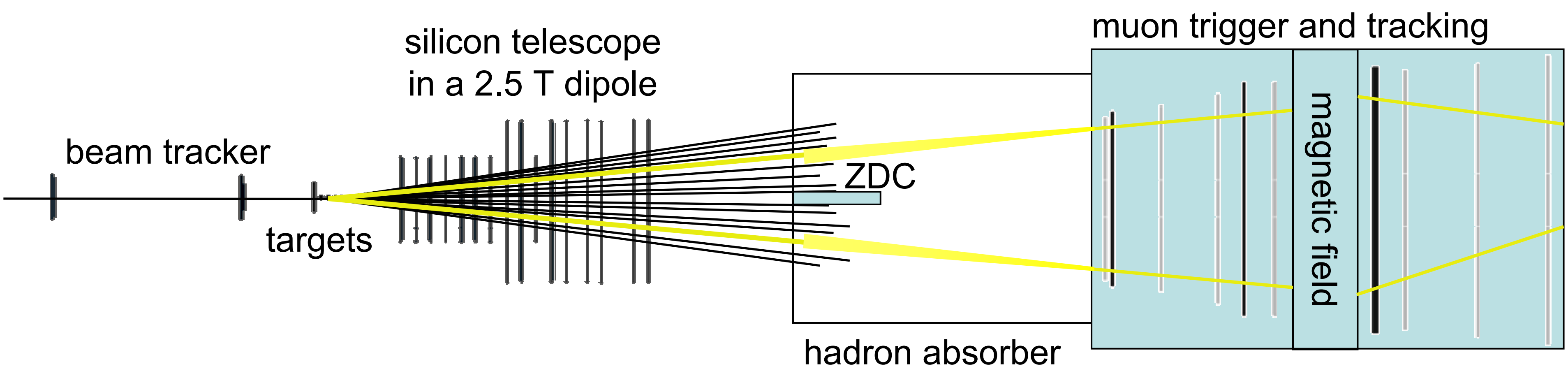
Place a *high granularity* and *radiation-hard* silicon tracking telescope in the vertex region to measure the muons before they suffer multiple scattering and energy loss in the hadron absorber

… a unique detector
for a unique machine



http://na60.cern.ch

What's original in NA60: measuring dimuons in the target region

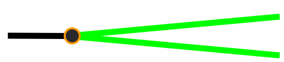


Matching in coordinate
and momentum space

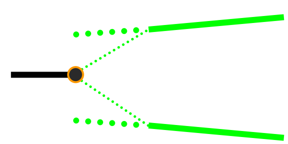
Origin of muons can be accurately determined

Improved dimuon mass resolution

prompt dimuon



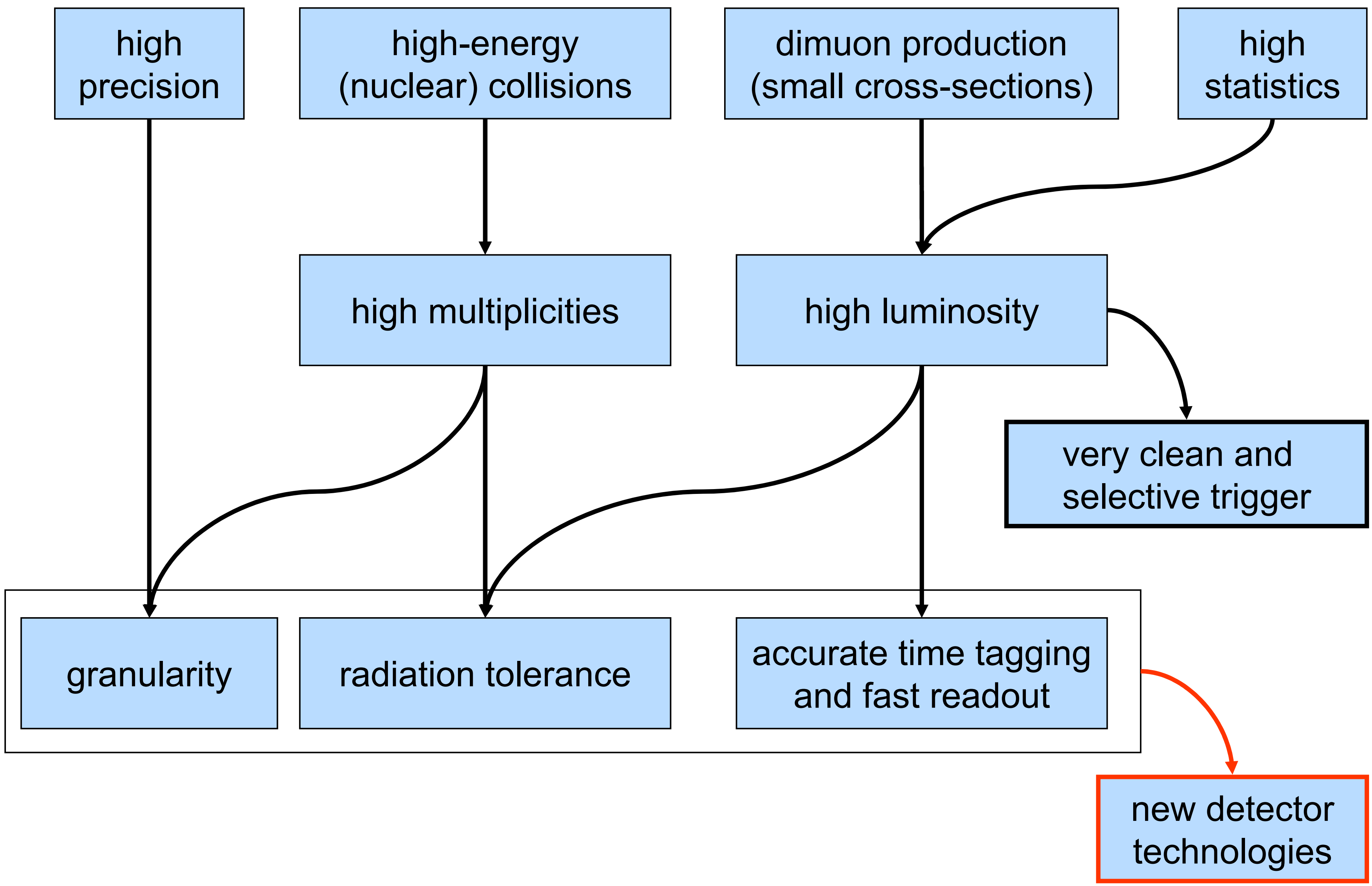
or



muon pair from
displaced vertices

ZDC: dimuon studies vs.
collision centrality

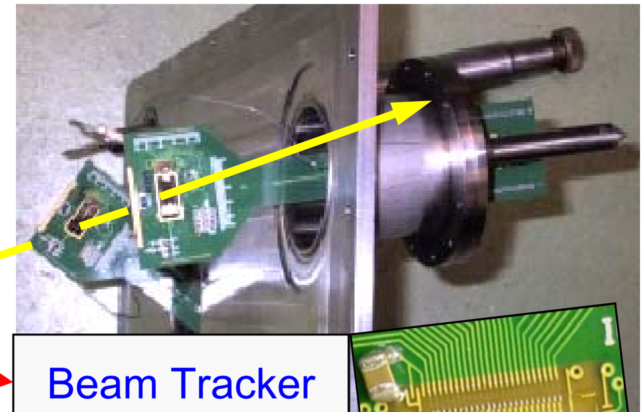
Requirements

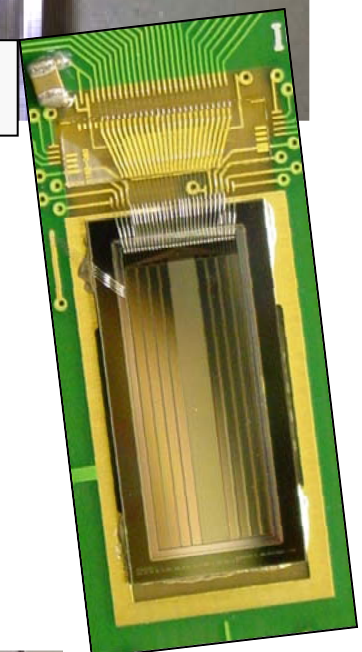


The NA60 target region in 2003

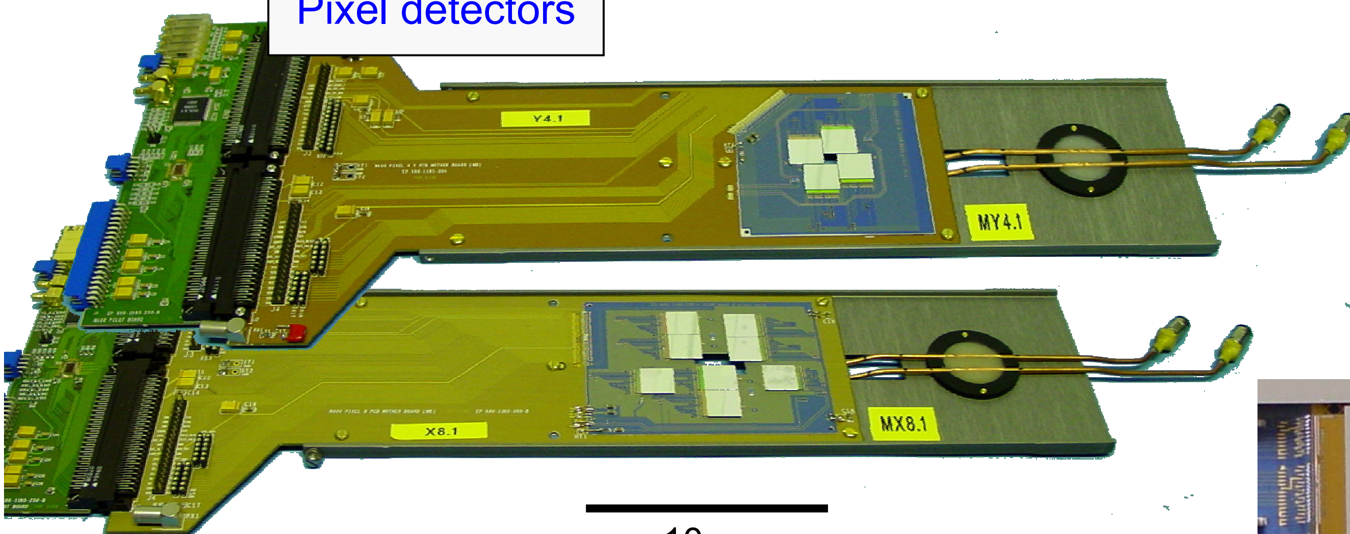
2.5 T dipole magnet

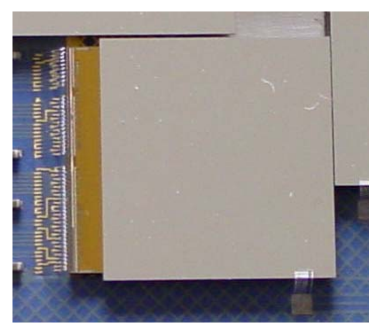
Beam Tracker





Pixel detectors

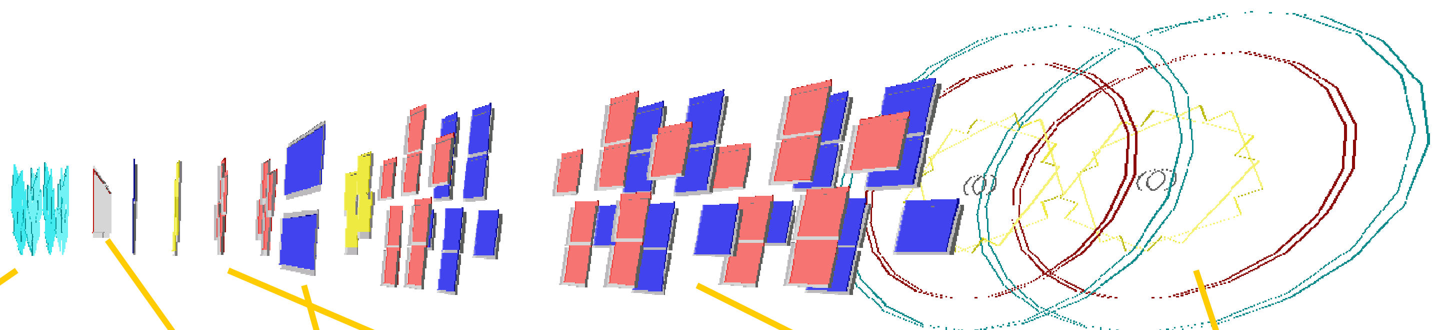


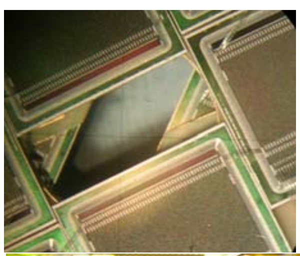


The NA60 target region in 2004

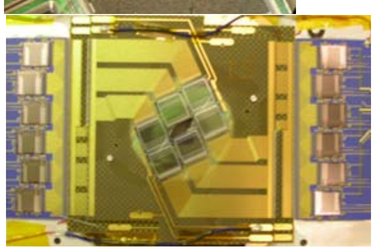
- New cooling to run the silicon detectors at lower temperatures (around 0 C), imposed by the high radiation levels
- New tracking planes, based on ATLAS detectors, operated at 40 MHz, imposed by high luminosity

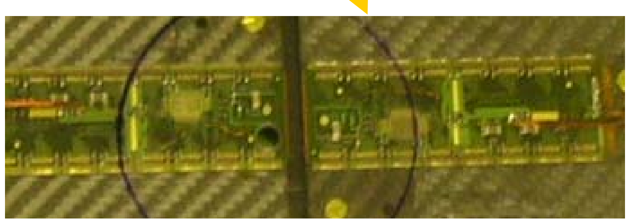
7 different nuclear targets

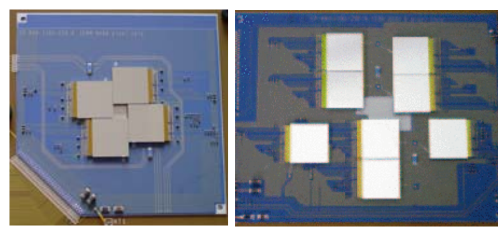




NA60-ATLAS
strip and pixel planes
(new, 40 MHz)

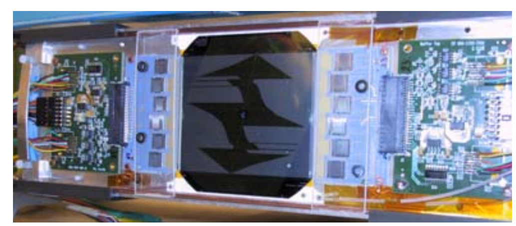




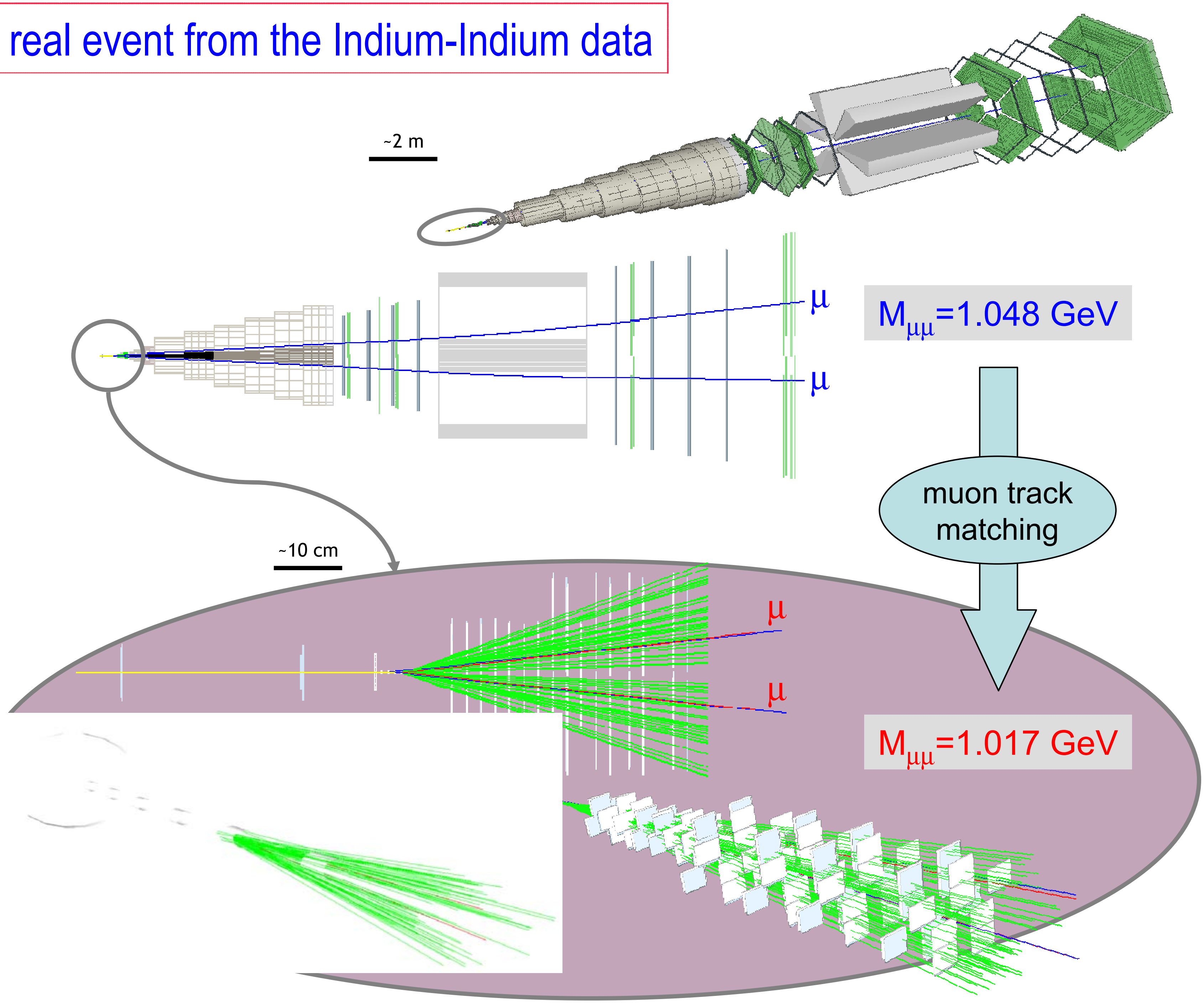


NA60-ALICE
pixel planes
(used in 2003)

NA60-BNL
strip planes
(used in 2002)



A real event from the Indium-Indium data



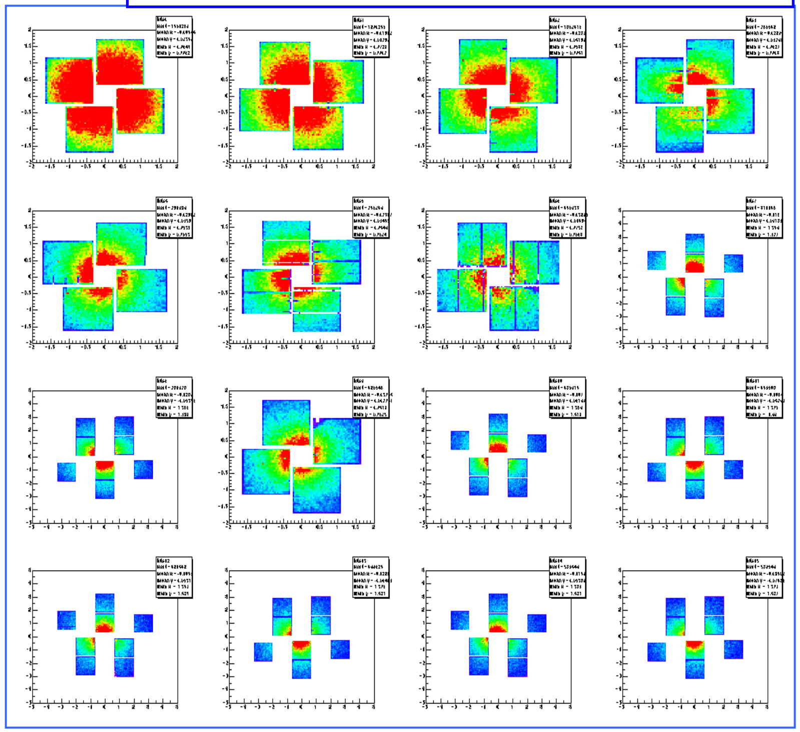
Run 6935
Burst 33
Event 5987

Physics performance in the Indium run (summary)

- Good statistics, especially for low mass dimuons
- Broad centrality coverage, through E_{ZDC} and $N_{charged}$ variables
- Good vertexing of the interaction and of the dimuon production point
- Good dimuon mass resolution and signal to background ratio
- Good acceptance down to low p_T, even for low mass dimuons
- Good muon offset resolution

The next slides illustrate many of these points

16 pixel planes fully operational

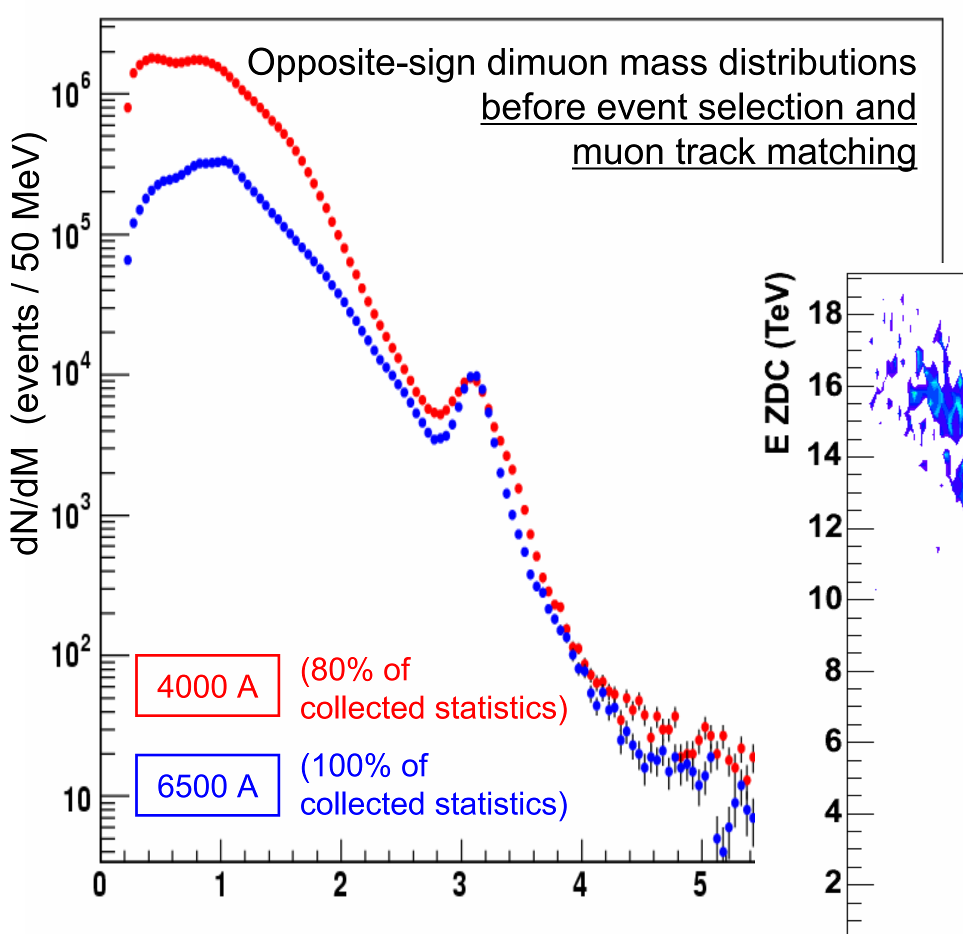


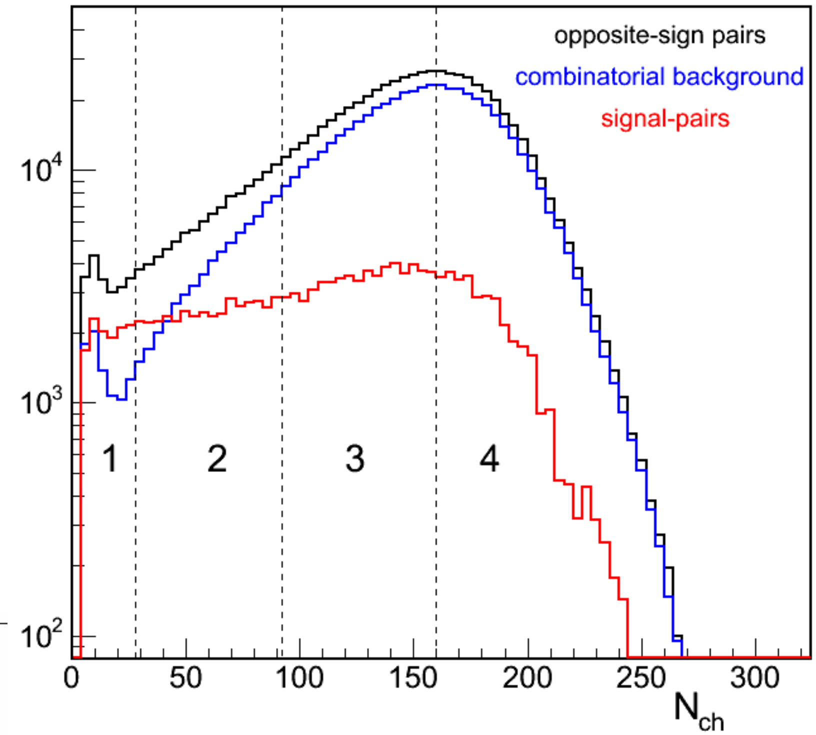
Reminder of the Indium run:

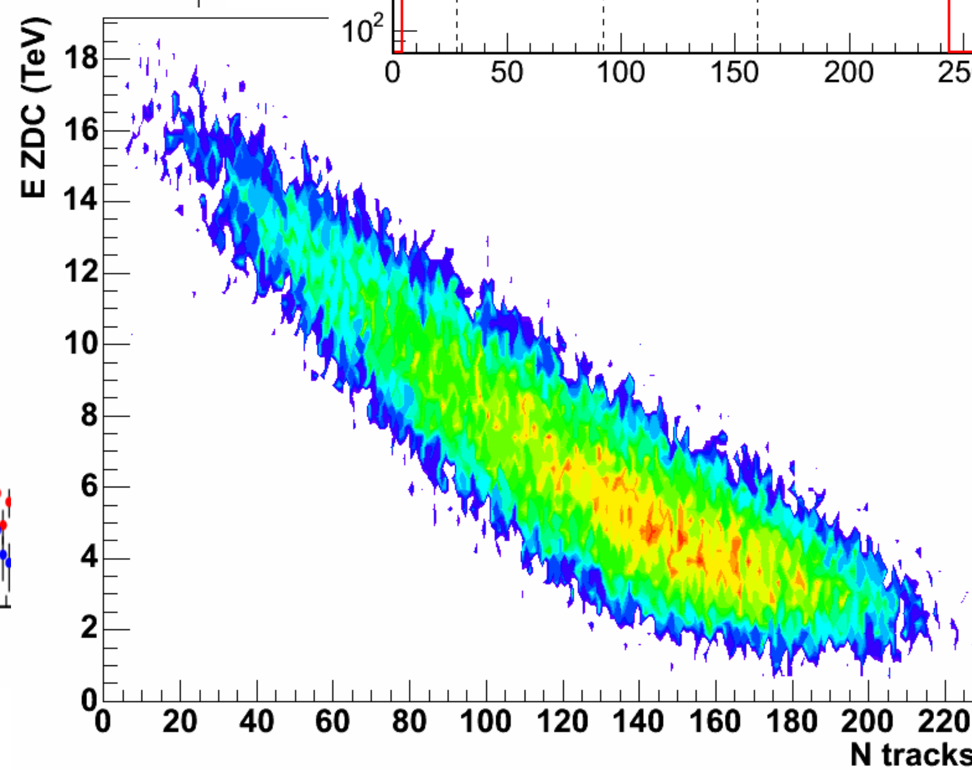
- 5-week long run in Oct.–Nov. 2003
- ~ 4×10^{12} ions delivered in total
- ~ 230 million dimuon triggers on tape

Statistics and centrality coverage

Good statistics and broad centrality coverage measured by the ZDC and by the number of tracks seen in the pixel telescope

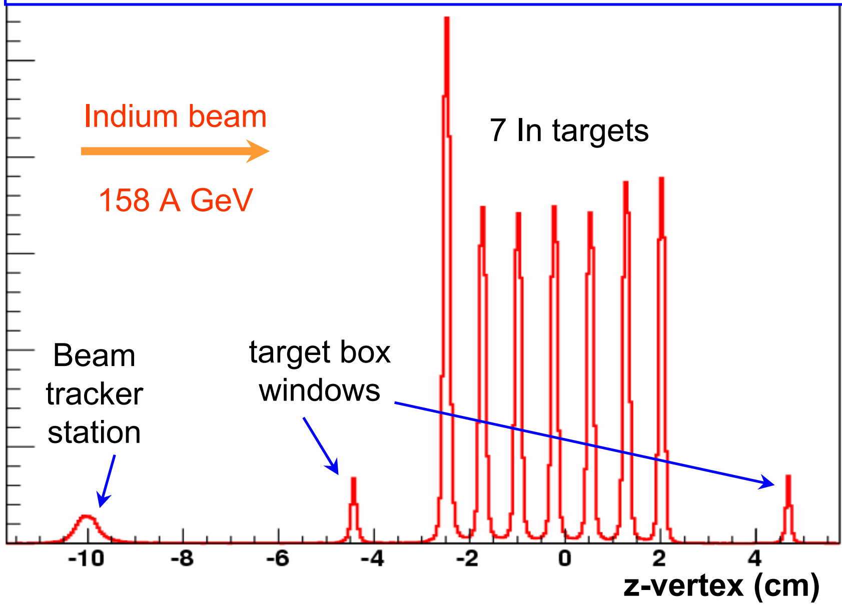


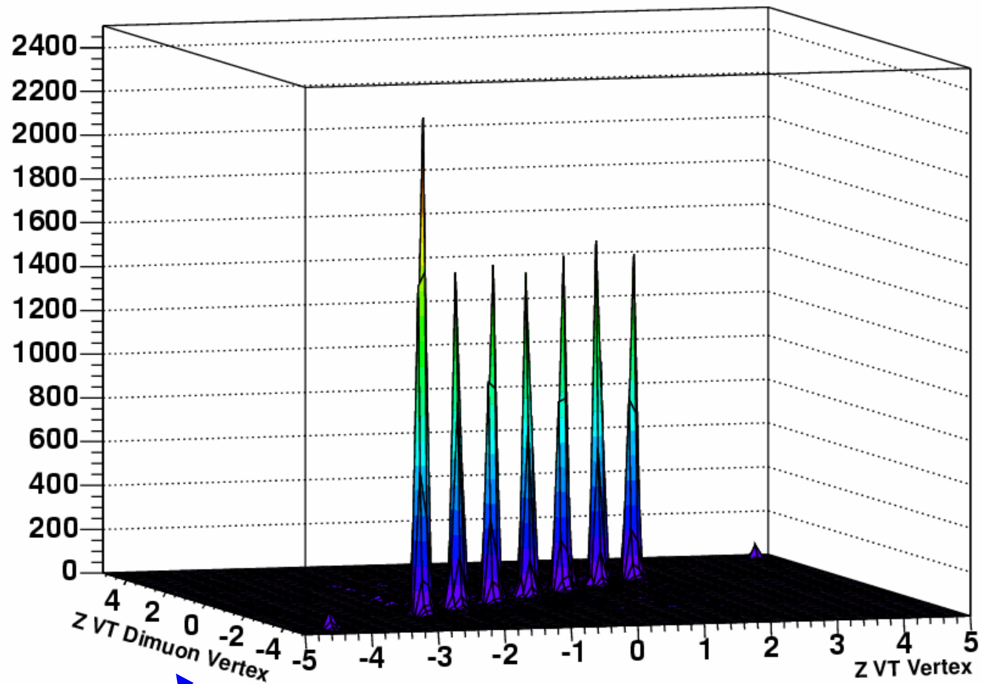




Vertexing capabilities

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

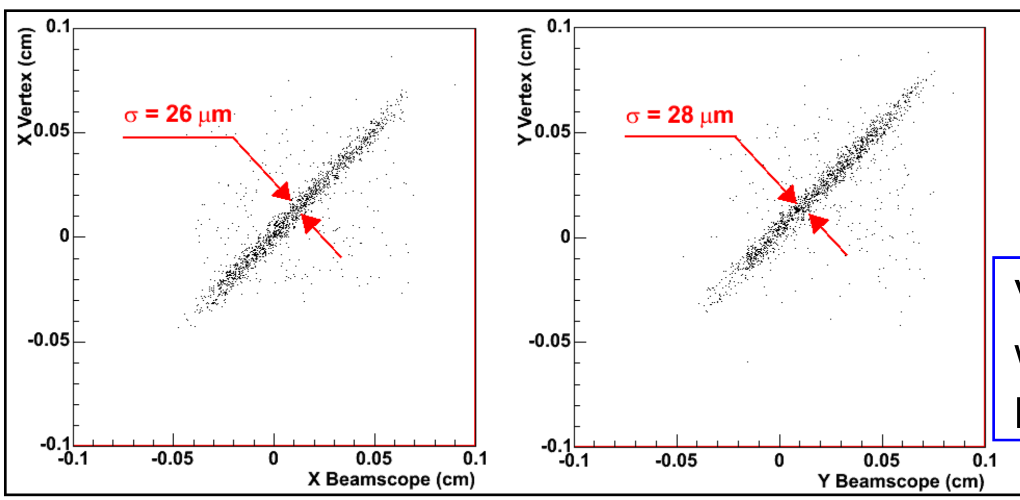




Dimuon vertex

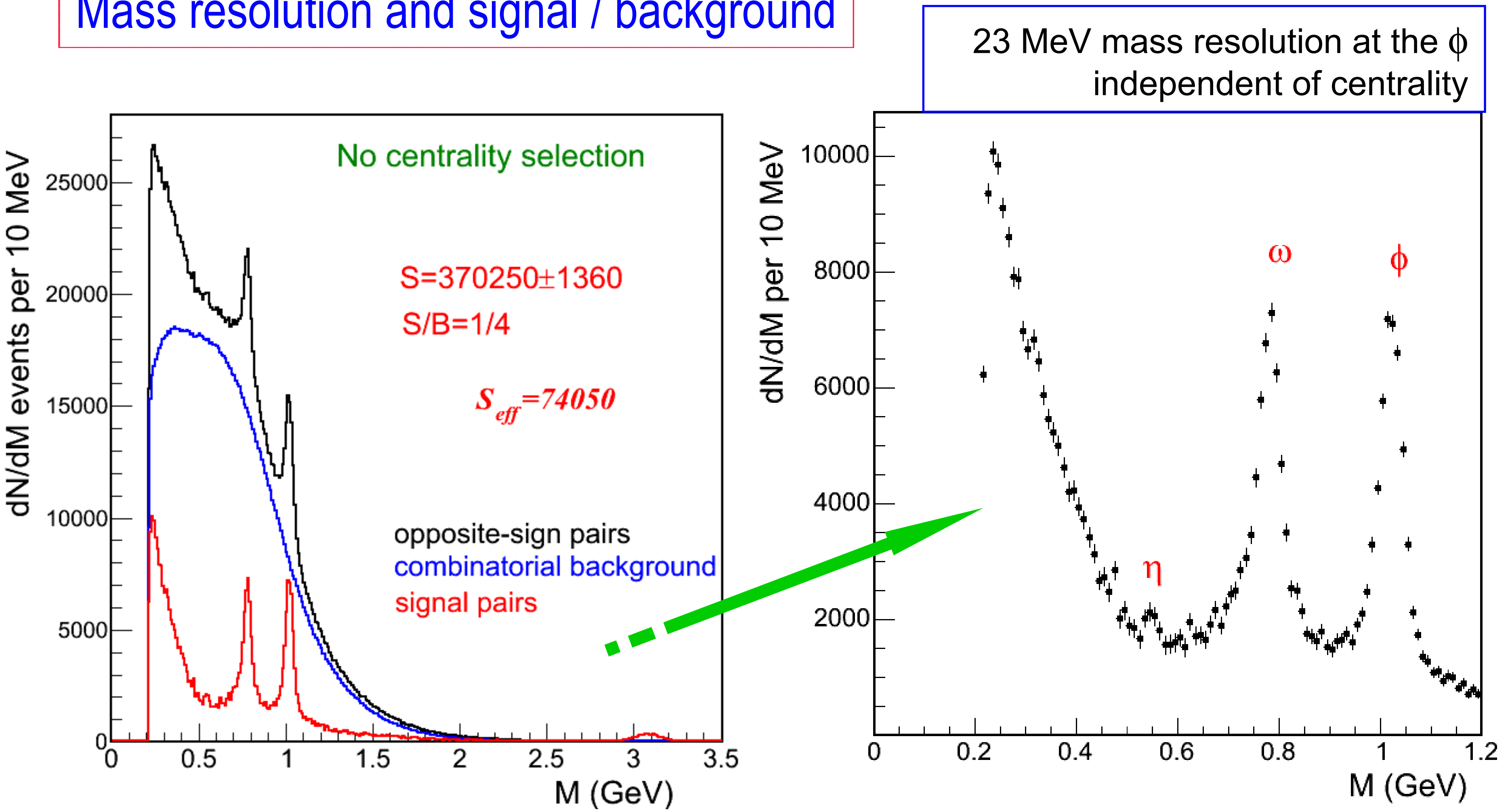
(mass above 2 GeV)

Hadronic vertex



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

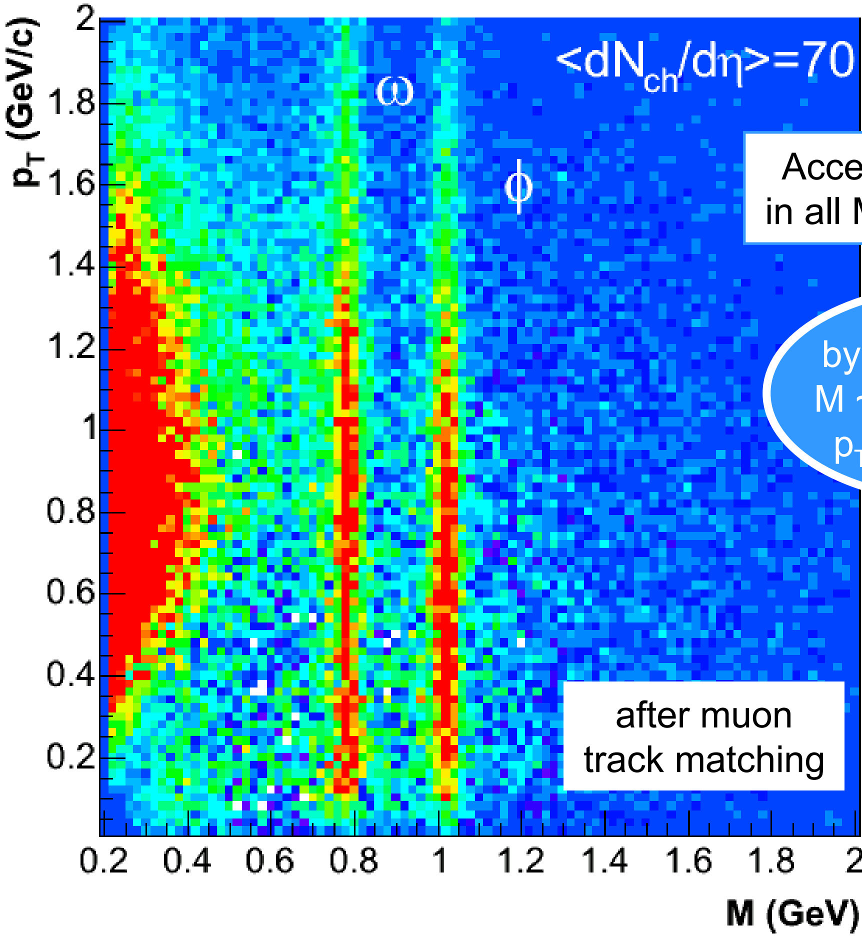
Mass resolution and signal / background



- 37000 signal events in the ϕ peak, similar ω statistics
- Combinatorial background estimated through a mixed-event technique, using like-sign muon pairs. Subtraction of fake matches is in progress.
- The $\eta \to \mu\mu$ channel is also visible (for the first time in nuclear collisions)

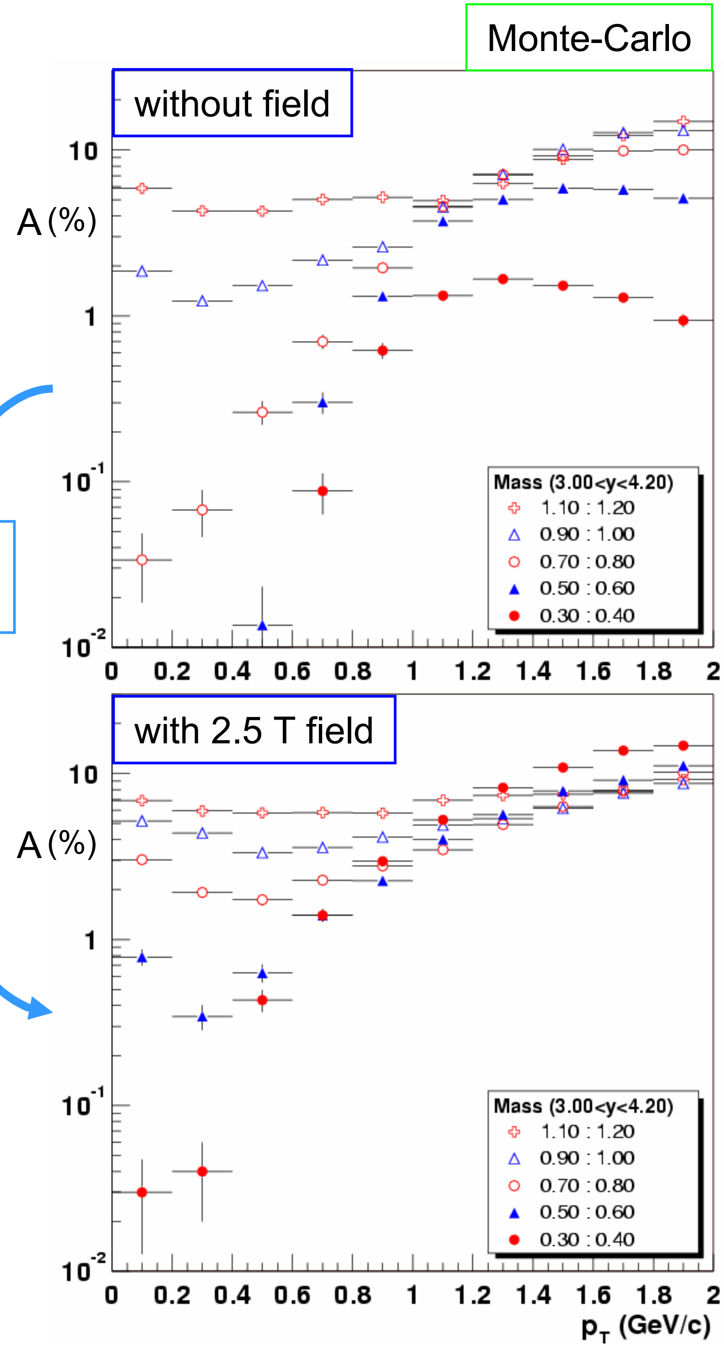
Acceptance down to low p_T at low masses

The dipole field in the target region leads to much better p_T coverage than previous dimuon measurements
⇒ competitive with respect to dielectron measurements



Acceptance improves in all M and p_T windows

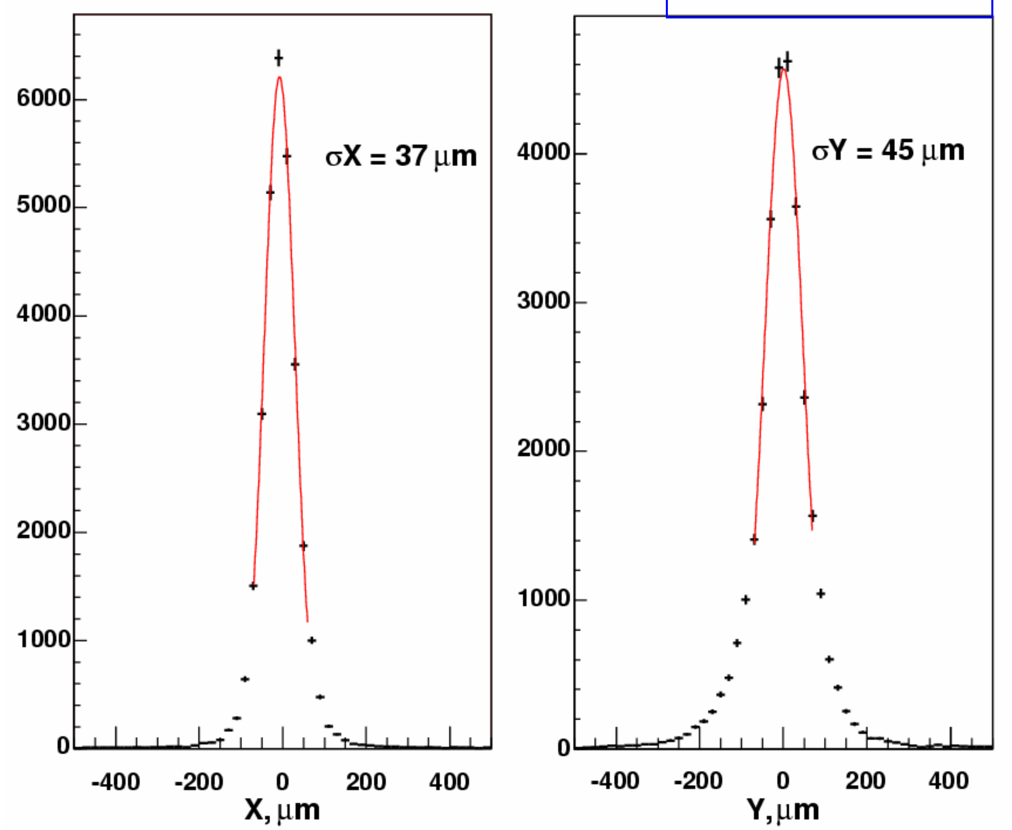
by a factor 50 for M ~ 500 MeV and p_T ~ 500 MeV/c



Muon offset resolution

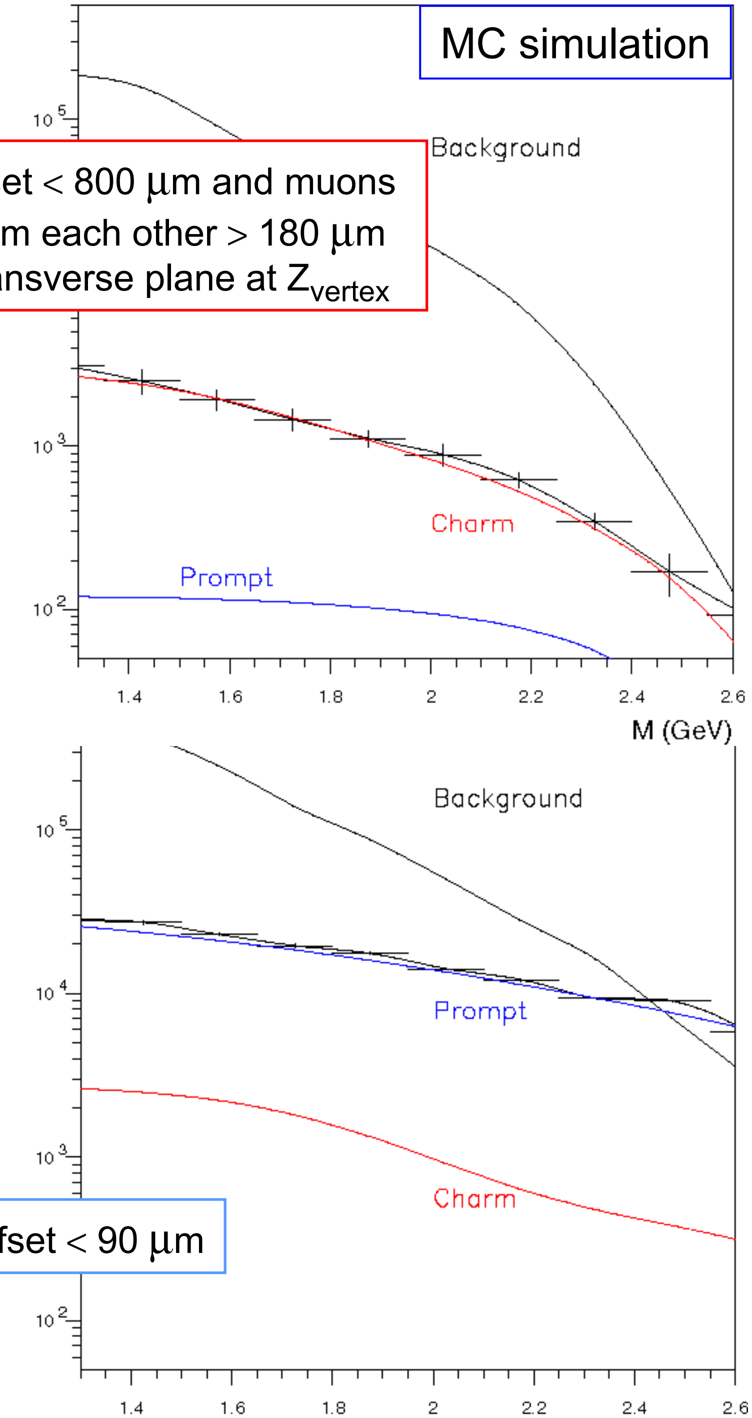
Presently, the muon track offset is measured with an accuracy around 40 μm, as deduced from the distance between the J/ψ and the interaction vertices

measured data



MC simulation

90 < offset < 800 μm and muons away from each other > 180 μm in the transverse plane at Z_{vertex}



offset < 90 μm

A first look into interesting physics issues

- Progress in understanding low mass dimuon production (resonances and continuum)
  - Nuclear dependence in p-A collisions (from the June 2002 run)
  - Ratio ϕ / ω versus centrality in Indium collisions
  - Inverse p_T slope of the ϕ versus centrality in Indium collisions
- J/ψ suppression in Indium-Indium collisions

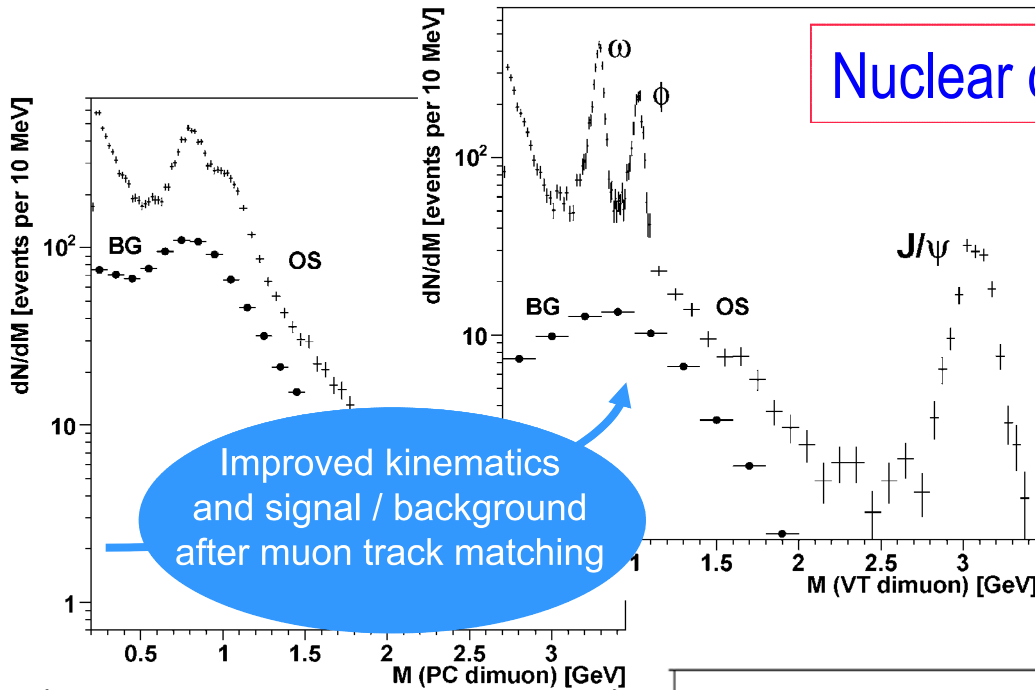
Nuclear dependence of low mass dimuons

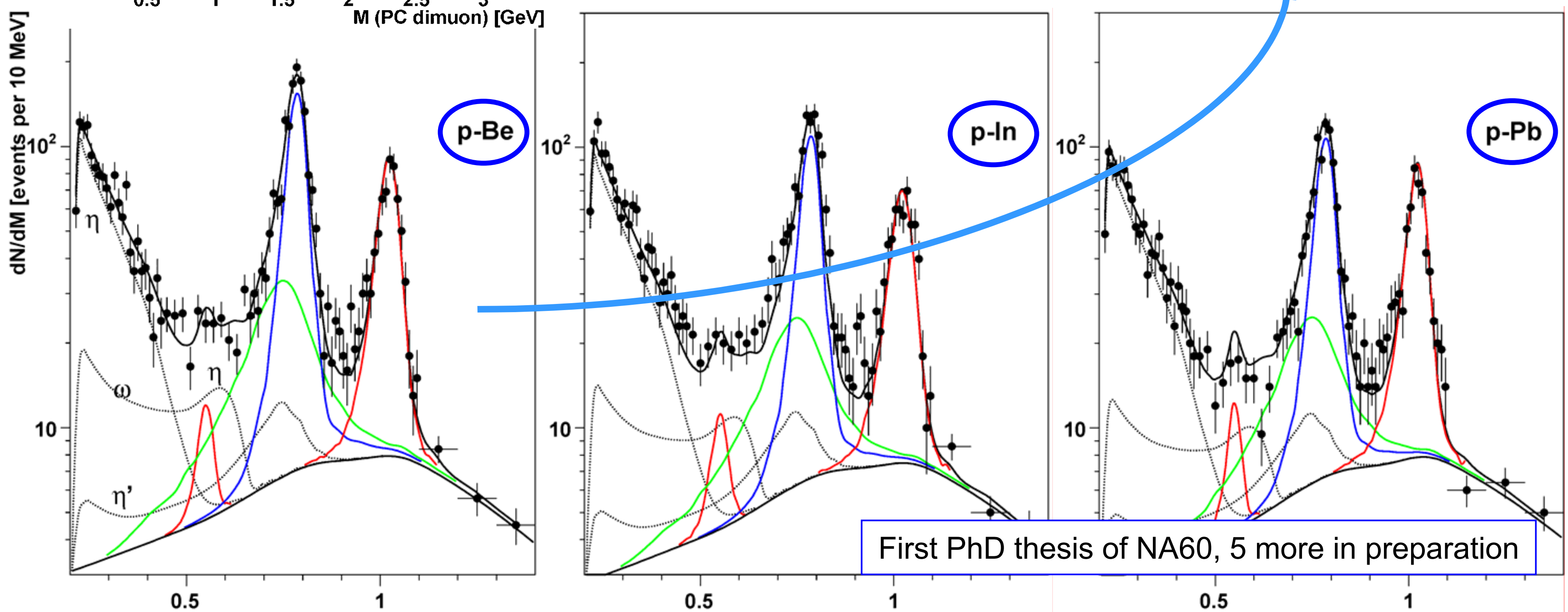
p-A at 400 GeV; Be, In and Pb targets

Data collected during one week in 2002

$$\sigma_{pA} = \sigma_0 \, A^{\alpha}$$

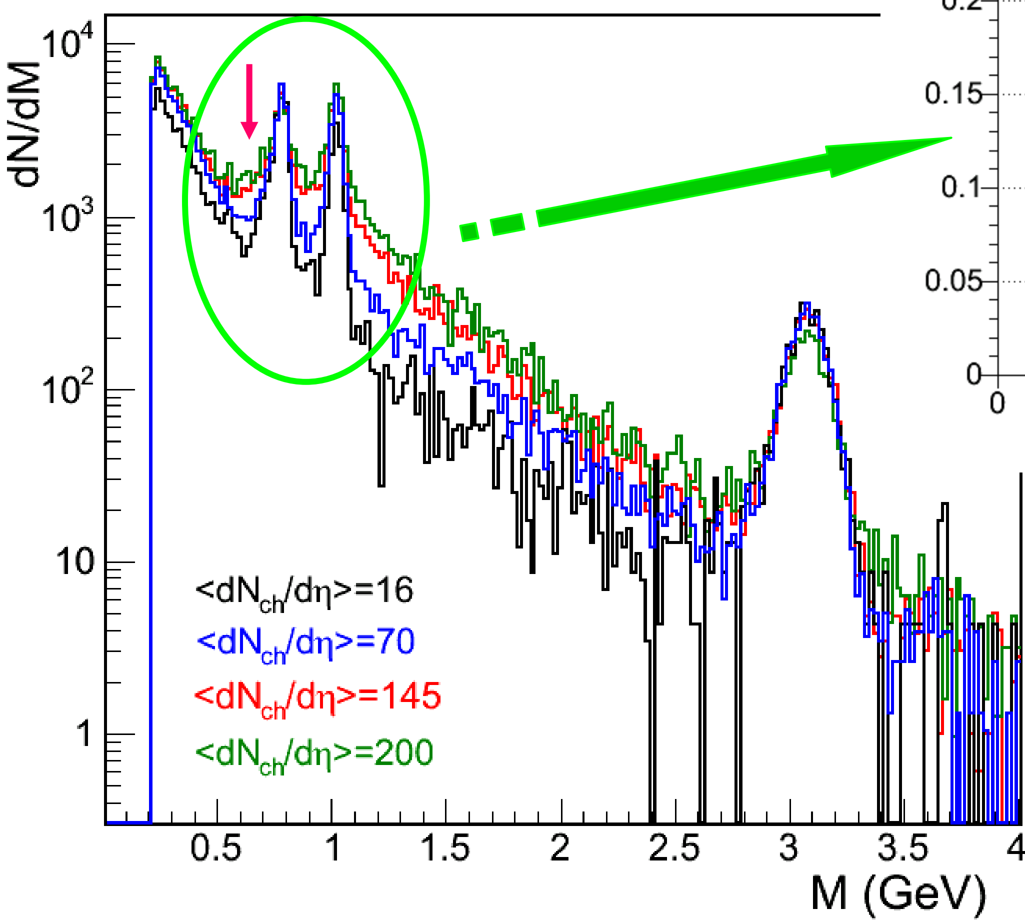
	α
ω	0.82 ± 0.01
φ	0.91 ± 0.02
η	0.93 ± 0.02

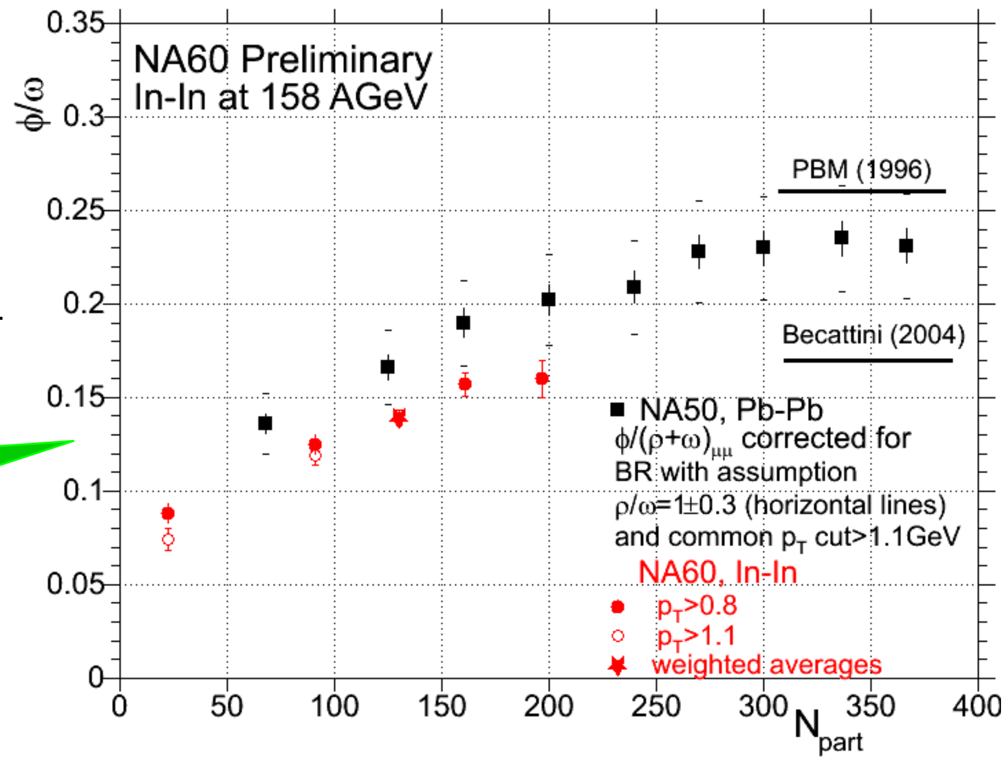




Ratio of ϕ / ω production cross-sections in Indium collisions

- ϕ / ω production cross-section ratio increases with $\langle dN_{ch}/d\eta \rangle$
- full statistics → more centrality bins

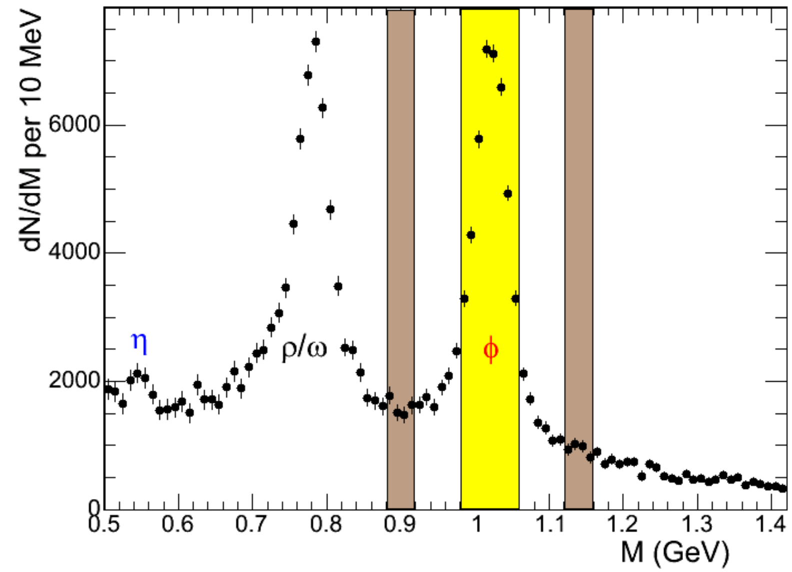


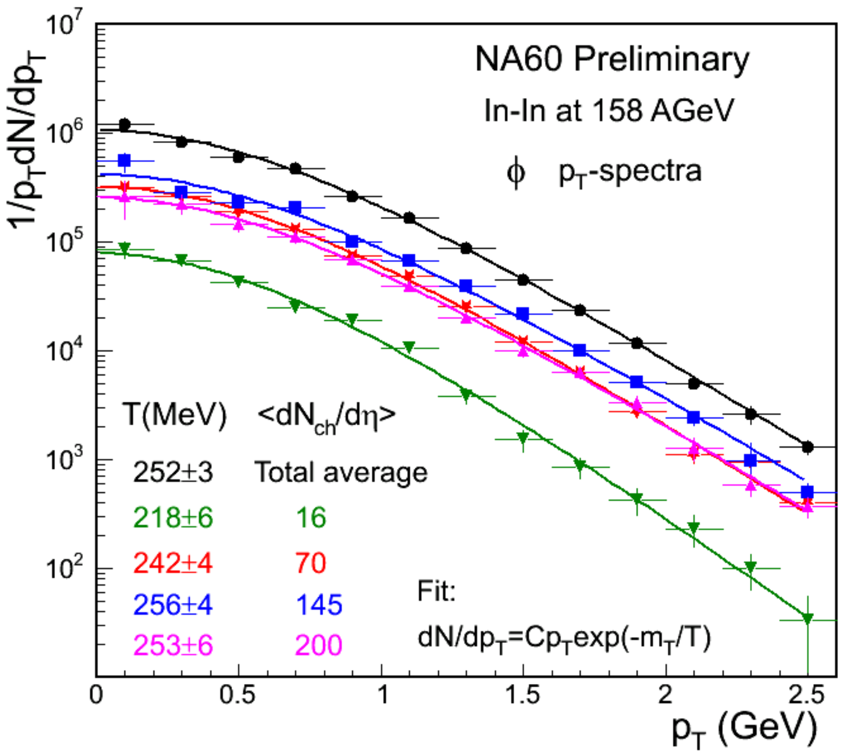


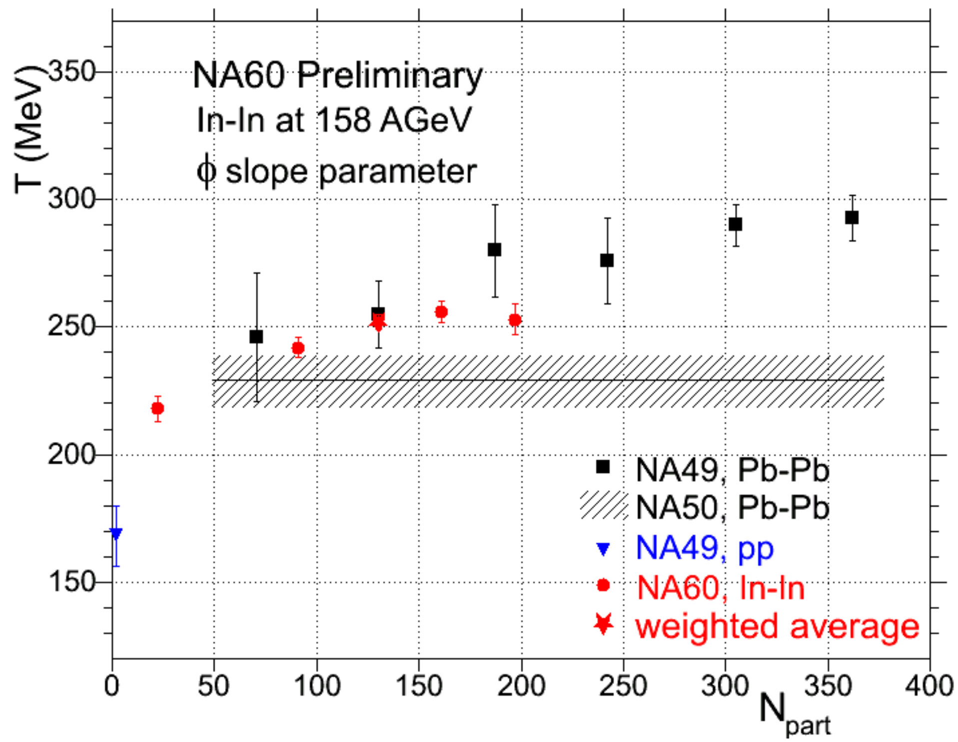
Is the ρ increasing faster than the ω as a function of multiplicity ?
More home work needed…

p_T distribution of ϕ dimuons

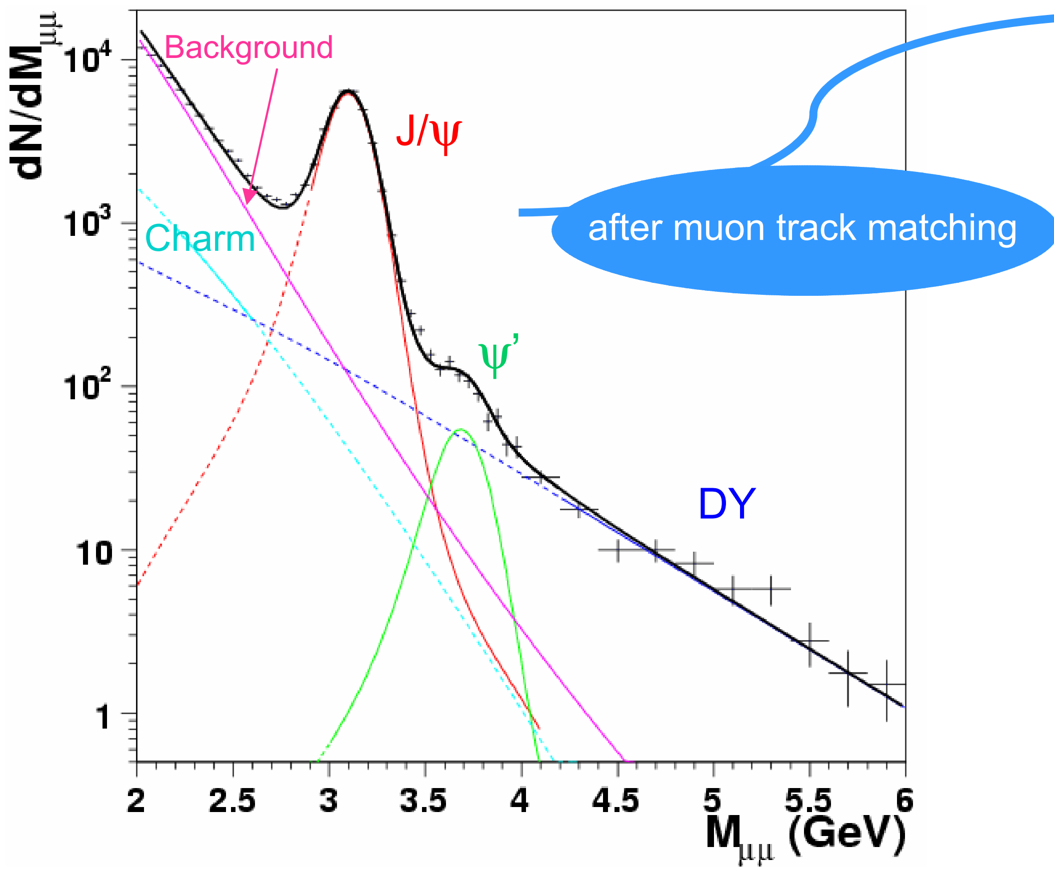
- Inverse slope parameter, T, increases with $<dN_{ch}/d\eta>$
- Extension to 3.5 GeV/c should be feasible with the full statistics

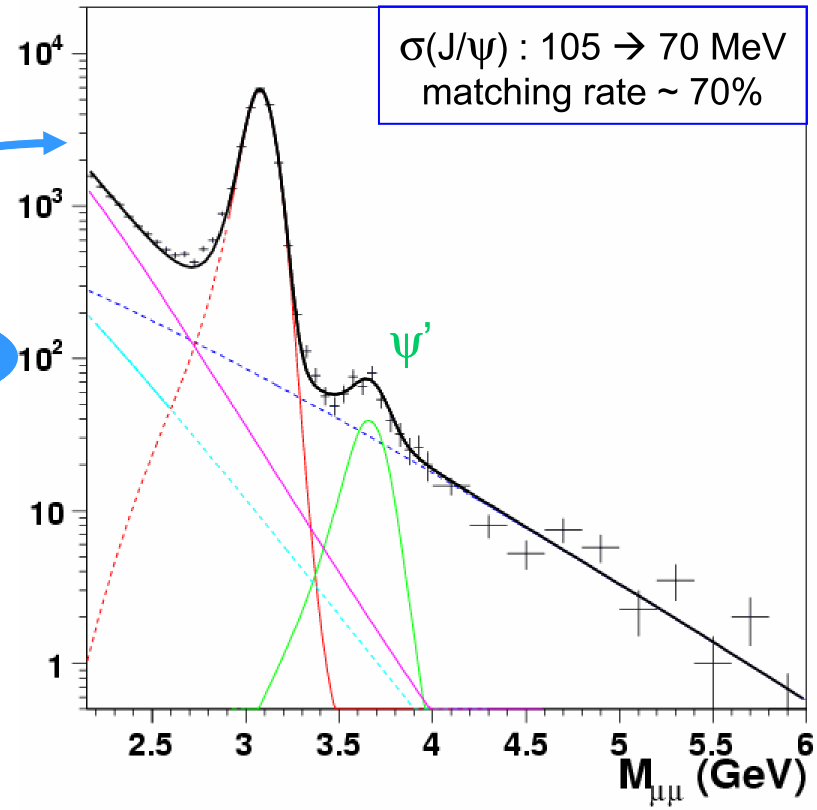






J/ψ production in Indium-Indium collisions





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

a) M > 4.2 GeV : normalize the DY

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)

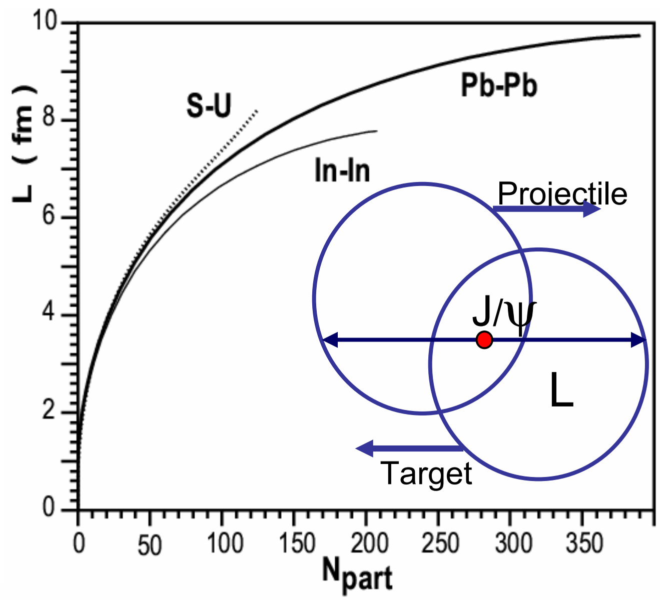
→ DY yield = 253 ± 16
1964 ± 126 in range 2.9–4.5 GeV

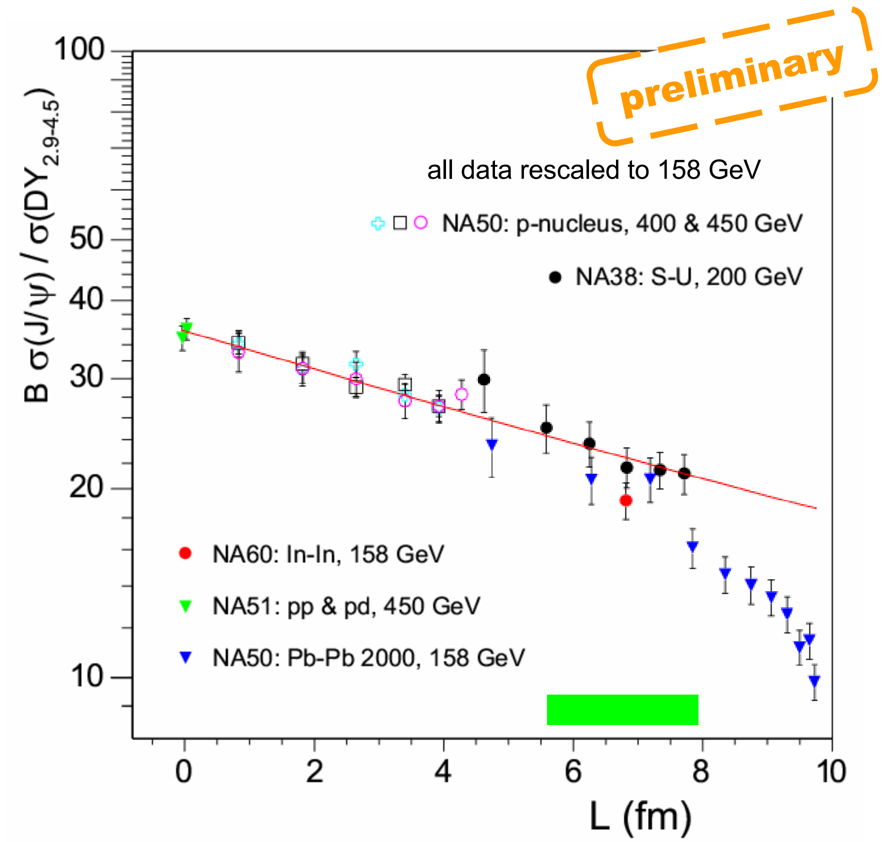
→ J/ψ yield = 35626 ± 361

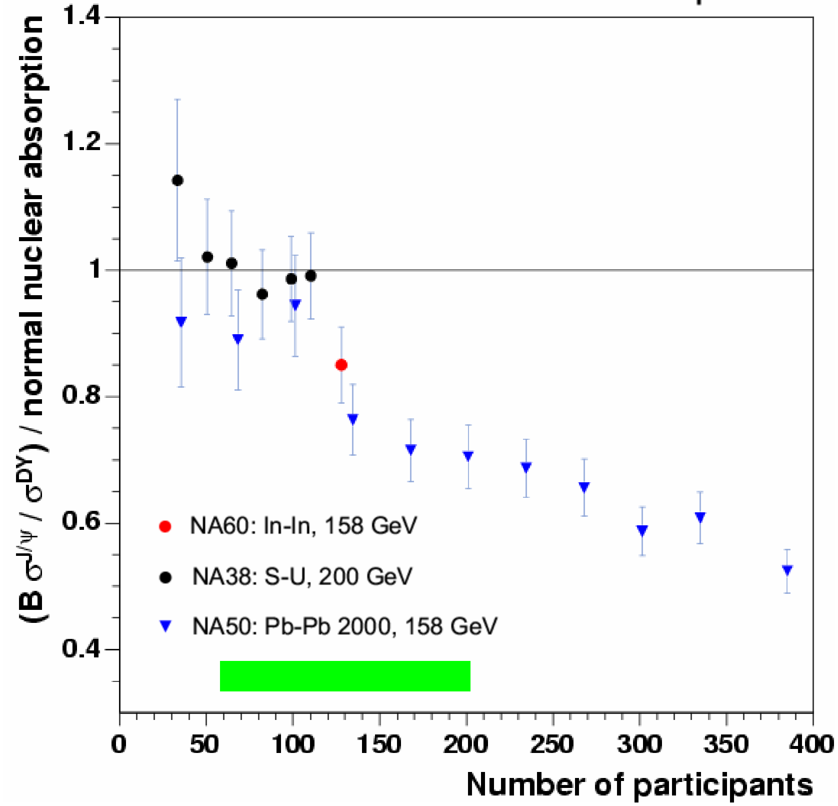
J/ψ / Drell-Yan in Indium-Indium collisions

$B\,\sigma(J/\psi) / \sigma(DY) = 19.6 \pm 1.3$ $\Rightarrow$ 0.85 ± 0.06 w.r.t. the normal nuclear absorption

for $L = 6.8$ fm or $N_{part} = 128$







What's missing from the original proposal?

High-energy Pb-Pb collisions

a new data taking period is needed

- Approved and scheduled for 2002
- Cancelled because of delays in the production of bump-bonded pixel detectors
- Important for the study of
  - thermal dimuon and open charm production up to the highest energy densities which can be produced at the SPS
  - ρ meson modifications in collisions similar to those of the CERES observations
  - ϕ and ψ' production in much better experimental conditions than before

Proton-nucleus collisions

- Presently taking data with 7 different nuclear targets, to study:
  - the impact of χ_c production on the J/ψ suppression
  - the nuclear dependence of open charm production
  - the intermediate mass *prompt* dimuons
  - low mass dimuon production with unprecedented accuracy

being done now at ~ 40 MHz interaction rate

- Around 3 days of 158 GeV protons will take place next month to study the J/ψ normal nuclear absorption at the energy of the heavy-ion data

Summary and outlook

Harvest from the 5-week long Indium run in Oct.–Nov. 2003 :

- ~ 100 000 reconstructed J/ψ events
- ~ 1 million signal low mass dimuons (after track matching)
- mass resolution ~ 20 MeV at the ω mass
- muon track offset resolution ~ 40 μm in X and Y

A first look at the collected data has been presented in what concerns

- the production of low mass dimuons, including the ρ, ω and ϕ resonances
- the production of the J/ψ meson

To understand the cause of the excess of intermediate mass dimuons in heavy-ion collisions we need further progress in the data analysis

Together with the proton run of 2004, NA60 should be able to :

- study the medium effects on the ρ, ω and ϕ resonances
- clarify the intermediate mass dimuons excess
- measure the production of D mesons
- search for thermal dimuons
- improve the understanding of the production and suppression of charmonium states

Concluding remarks

- The physics being studied by NA60 justified several experiments at the SPS (NA38, CERES, HELIOS-3, NA50) and is high in the *future* agenda of RHIC and LHC experiments.

- NA60 remains very competitive with respect to RHIC experiments in what concerns the study of charmonia suppression (J/ψ, ψ' and χ_c), the search for thermal dileptons, the measurement of open charm production, and the study of low mass dilepton production.

- The luminosity capabilities of NA60 keep it in the front line in the study of rare processes. The vertexing and muon track matching capabilities are also unique to NA60.

- Around 5-6 weeks of high-energy Pb ions at the SPS should be sufficient to conclude the (approved) heavy-ions physics program of NA60.

- The 25 year old muon spectrometer needs to be refurbished: new trigger and read-out electronics have been designed; tracking MWPCs need repair.

- NA60 would like to measure charmonia production in p-A collisions, up to $x_F \sim 0.7$, and to search for the rare decay $D^0 \rightarrow \mu^+\mu^-$. Details on the Heavy Flavors session (Monday).

- NA60 is a small but complex experiment, at the edge of technology in terms of radiation hardness and time accuracy of silicon tracking detectors. It is an ideal place, at CERN, for training young HEP experimental physicists.