NA50/NA60: studio della produzione di dimuoni in collisioni nucleo-nucleo

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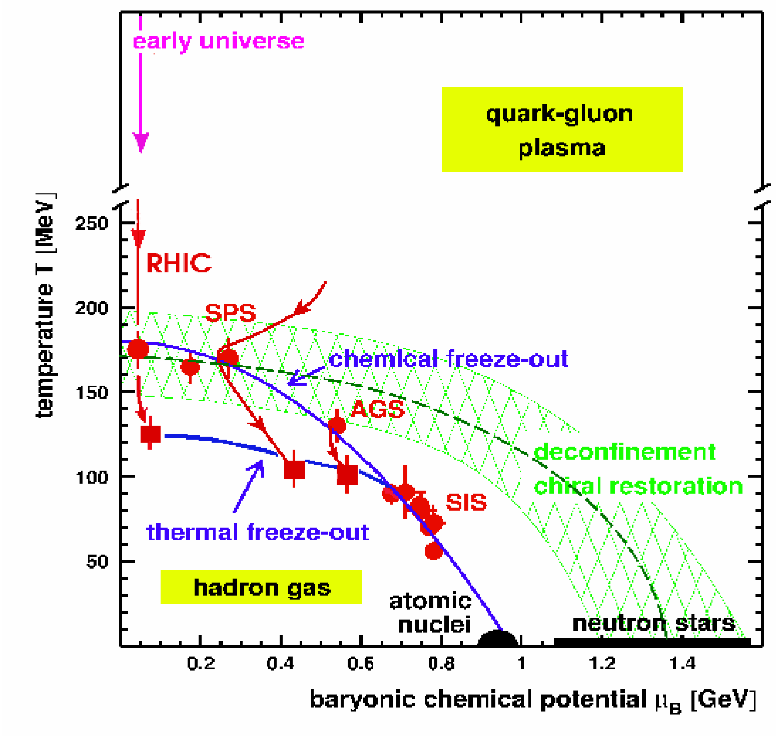
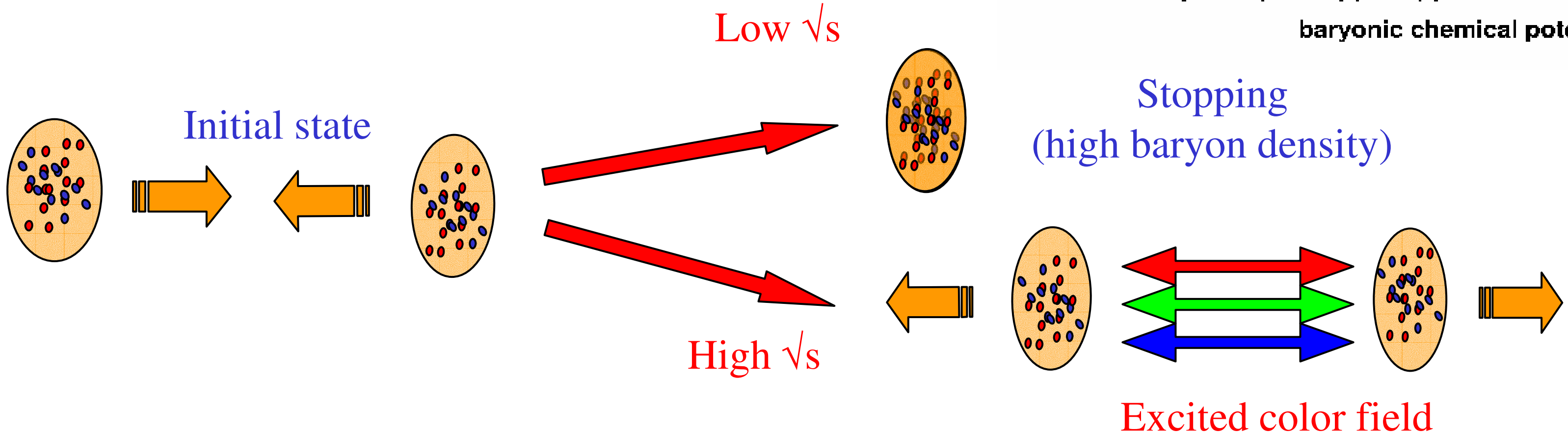
- Introduzione
  - Ricerche sperimentali del QGP
  - Il programma di fisica con ioni ultrarelativistici al CERN
- NA50: studio della produzione di dimuoni
  - Risultati
    - Basse masse: ρ/ω, ϕ
    - Masse intermedie: Dimuoni termici, open charm
    - Alte masse: J/ψ, Drell-Yan
- NA60: esperimento di seconda generazione
  - Primi risultati
- Conclusione

Looking for the Quark-Gluon Plasma

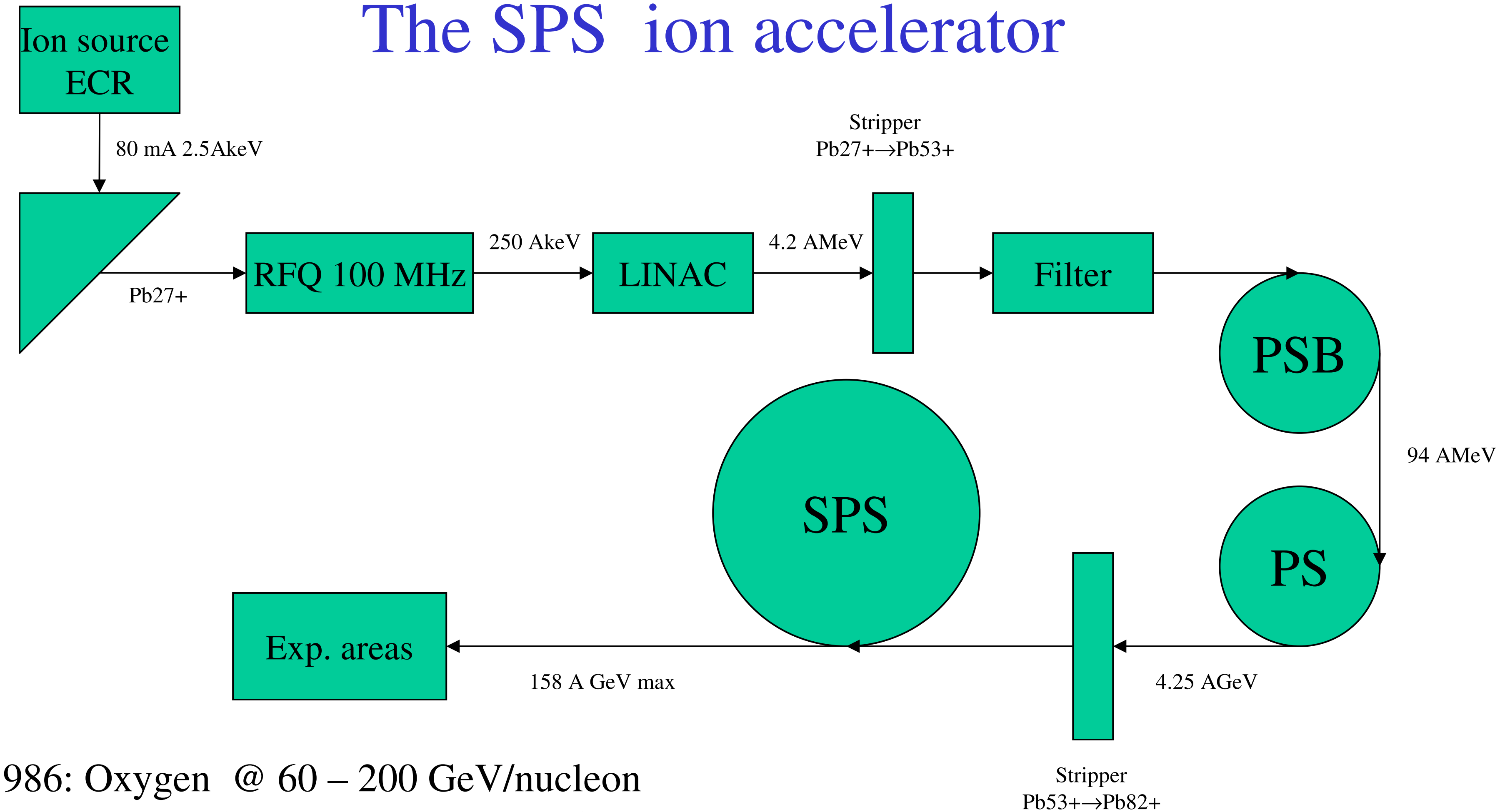
- Can we go from the normal hadronic matter to the QGP phase by doing high energy heavy ion collisions in the lab ?



- In order to reach the very high energy density required (~1 GeV/fm^3), large amounts of energy must be released in a small (but not too small) region of space in a short duration of time



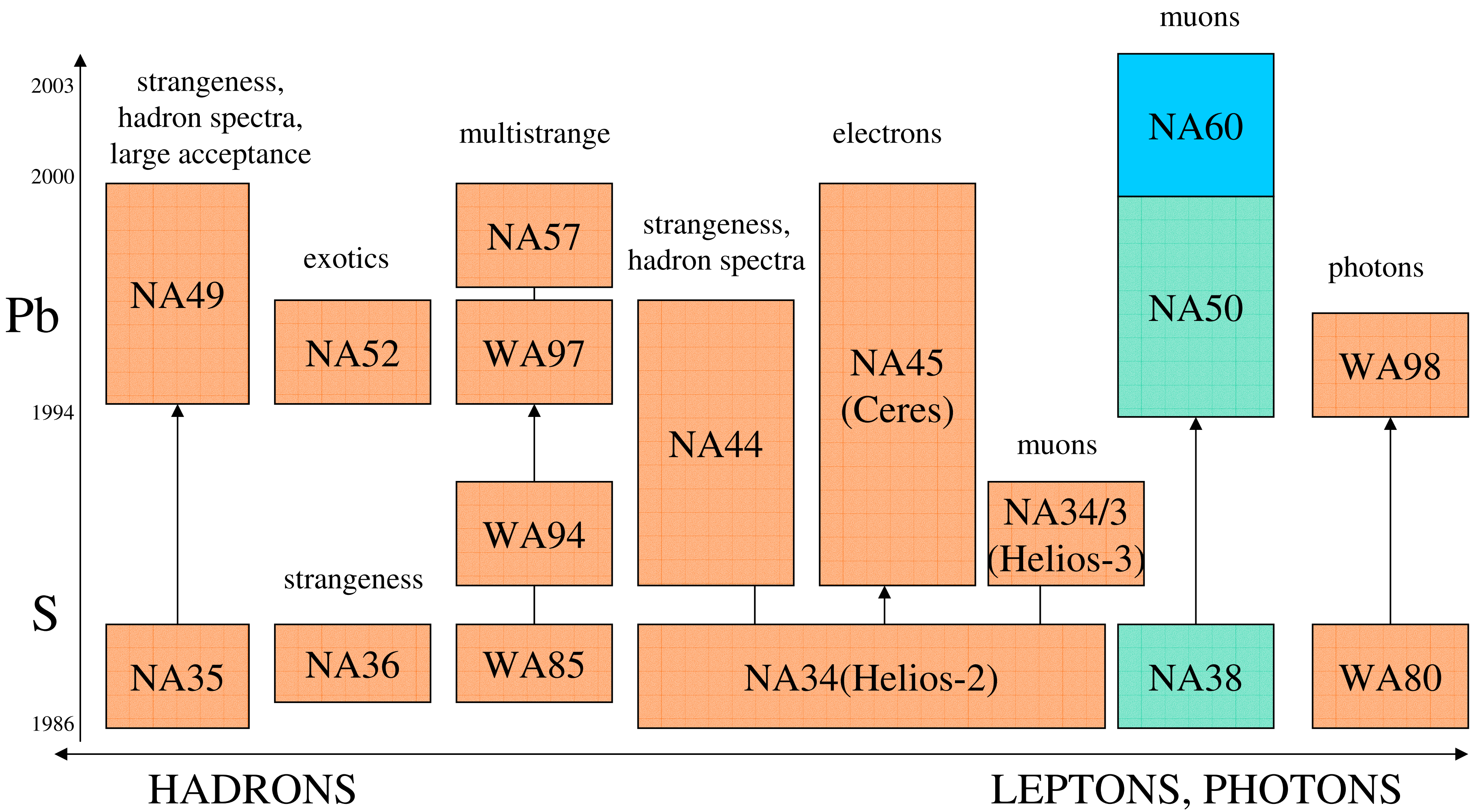
The SPS ion accelerator



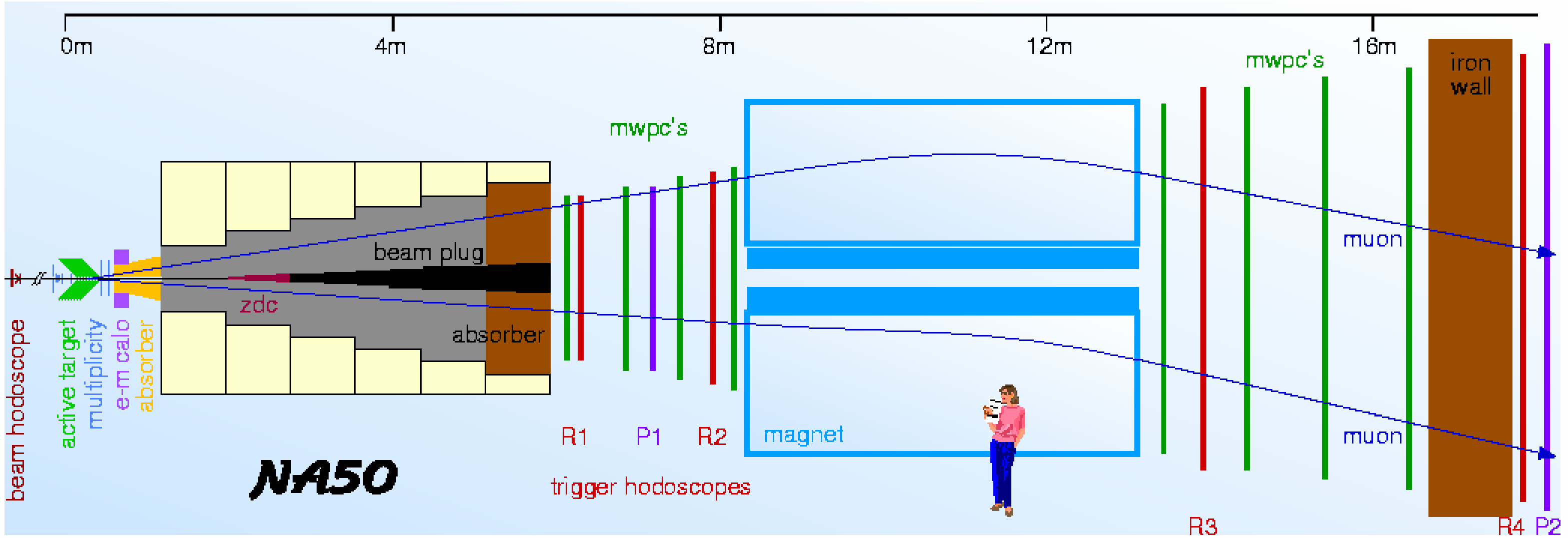
- 1986: Oxygen @ 60 – 200 GeV/nucleon
- 1987-1992: Sulphur @ 200 GeV/nucleon
- 1994-2002: Lead @ 20 – 30 – 40 – 158 GeV/nucleon
- 2003: Indium @ 158 GeV/nucleon

The SPS experiments

•25 countries, about 500 physicists involved



NA50: set-up

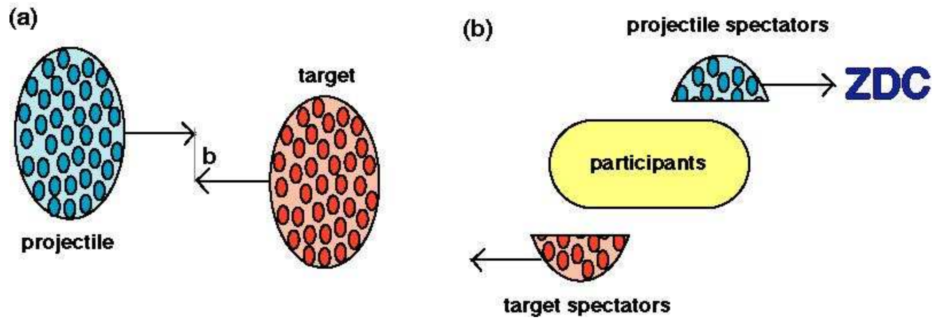


•Dimuon spectrometer : toroidal magnet + hodoscopes + MWPCs
•E_T + E_{ZDC} + N_{ch} → select events with respect to centrality
•Very small cross sections → extremely selective dimuon trigger!
•High intensity beams (>10^7/s) → radiation hard detectors

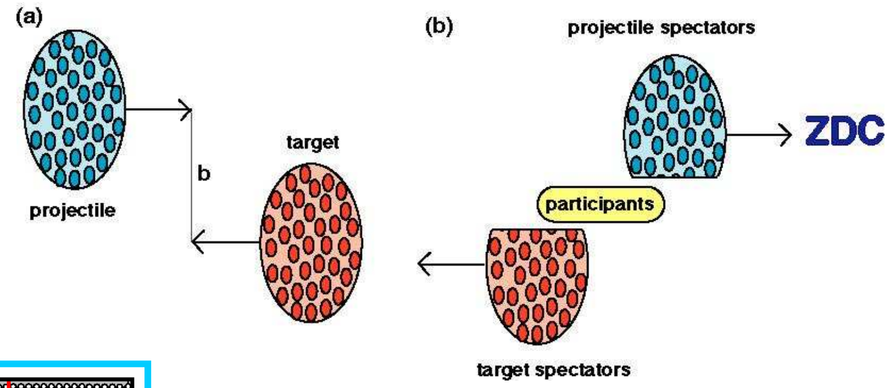
•Study of dimuon production and identification of signatures of the phase transition → QGP
•Italian responsibility on the following detectors:
- •ZDC (Torino)
- •MD (Torino)
- •Trigger hodoscopes (Cagliari)

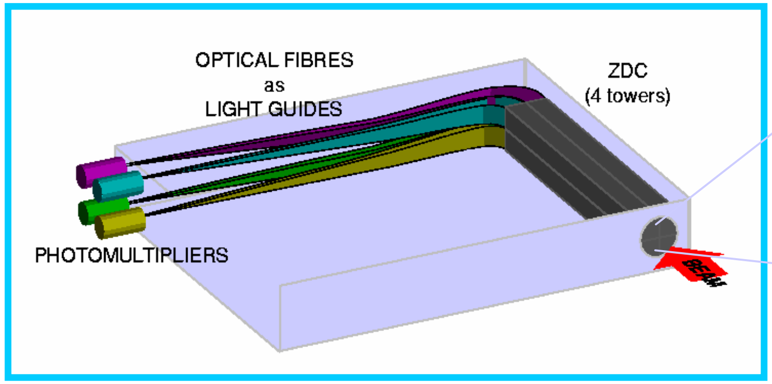
The Zero Degree Calorimeter (ZDC)

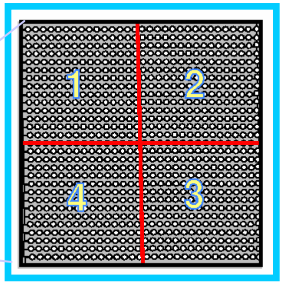
Central collision



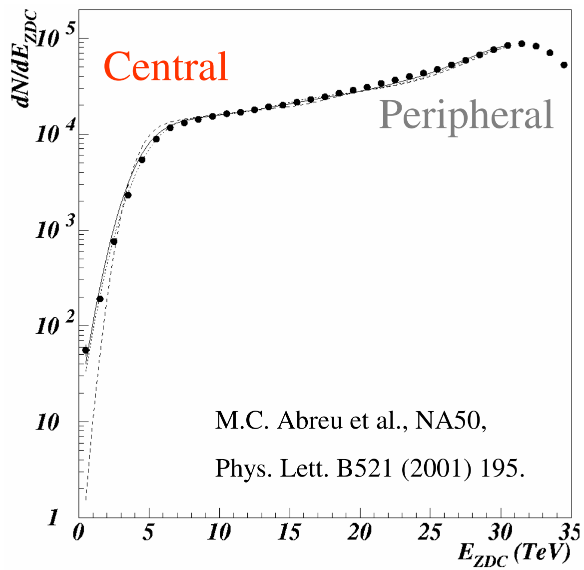
Peripheral collision



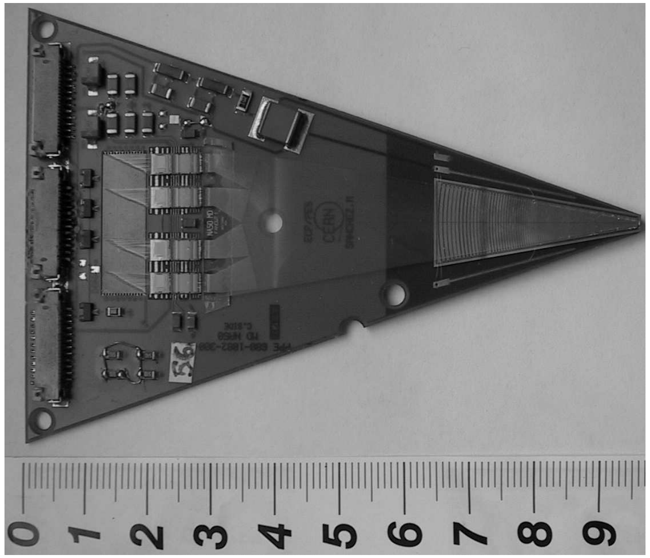


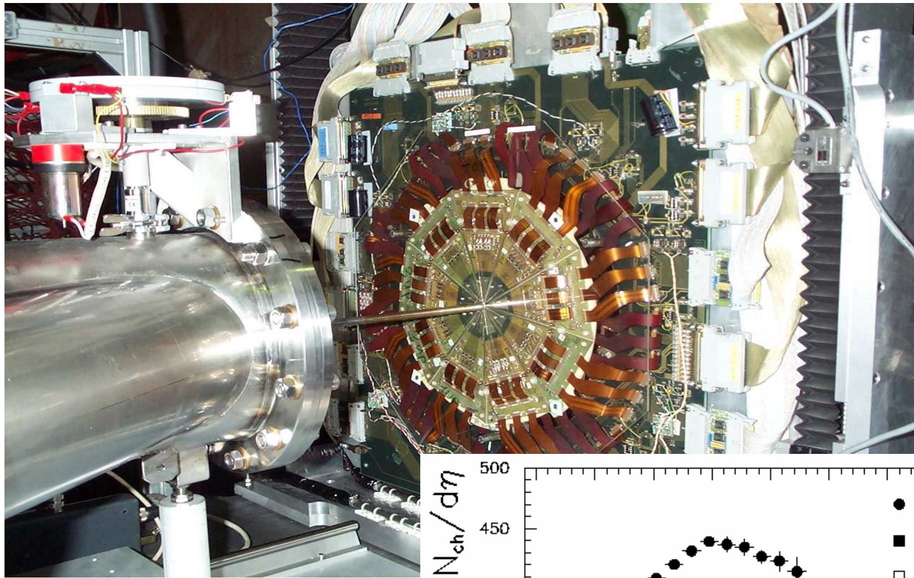


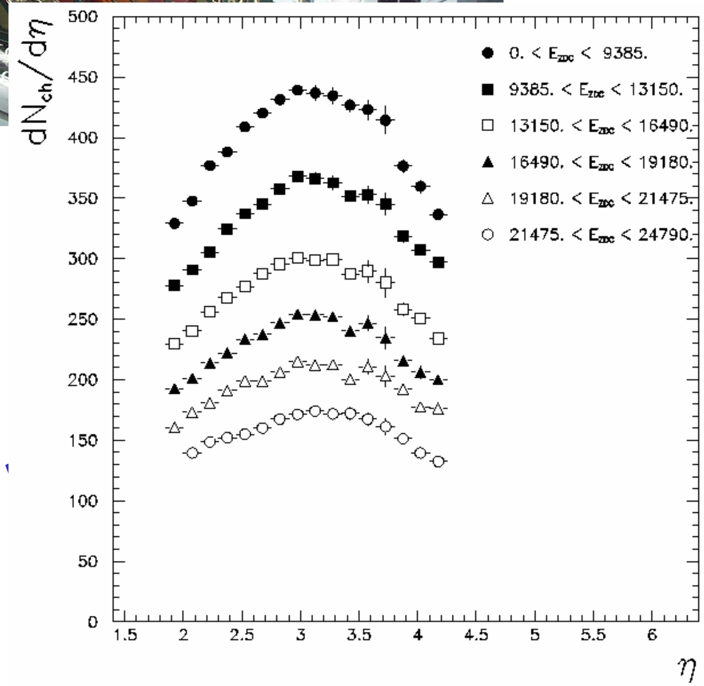
- Ta slabs + quartz fibers
- Based on Cerenkov effect
- Dimensions: 5×5×65 cm^3
- η>6.3



The multiplicity detector (MD)







- Two planes (MD1, MD2 10cm apart) of radial silicon microstrip detectors
  - Inner radius 0.5 cm,
  - Outer radius 8.5 cm
- Constant binning in pseudorapidity
  - $\rightarrow \Delta\eta = 0.02$
- Constant binning in azimuthal angle
  - $\rightarrow \Delta\Phi = 10$ degrees

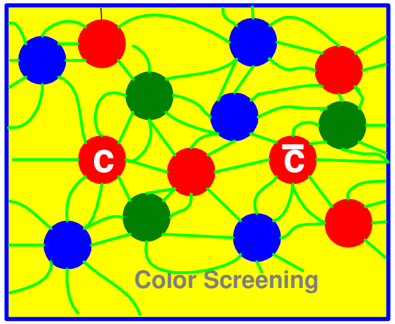
- binary readout
- 13864 channels
- 50MHz sampling

- dN/dη distributions for various centrality bins

Charmonia suppression as a signature of deconfinement

$c\bar{c}$ pairs are produced very early in the collision by gluon fusion ⇨ probe the medium they cross

- Confined medium
  - Strongly bound states are not easy to break in the (relatively) soft interactions with comoving hadrons. Anyway they can interact with nuclear matter from target/projectile
    ⇨ Effect to be estimated experimentally



Matsui and Satz ,
Phys. Lett. B178 (1986) 416

- Deconfined medium
  - The charm quarks are screened in the partonic color field
    ⇨ Successive melting of charmonium states

Hierarchy of suppression

Binding energy:

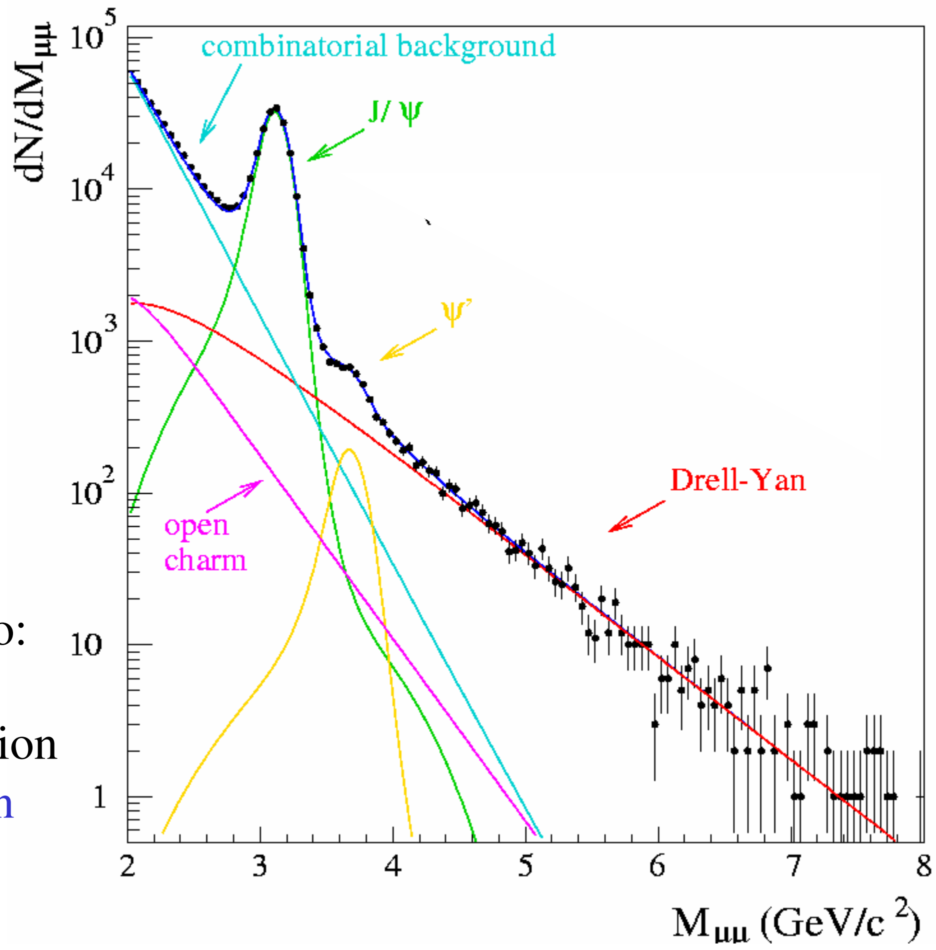
$J/\psi \approx 650$ MeV	$T_d/T_c = 1.10$
$\chi_c \approx 250$ MeV	$T_d/T_c = 0.74$
$\psi' \approx 50$ MeV	$T_d/T_c = 0.1\text{-}0.2$

Infer the temperature of the medium from the suppression pattern

Charmonia detection in NA50

- Dimuon detection: $J/\psi \to \mu^+\mu^-$
- Estimate of the size of the various known sources via a fit to the invariant mass spectrum
- Calculate the ratio:

$$\frac{B_{\mu\mu}\,\sigma(J/\psi)}{\sigma(DY)}$$



- Comparison of J/ψ production with DY allows to:
  - Cancel most systematic uncertainties on detection efficiency and luminosity calculation
  - Study J/ψ cross section per nucleon-nucleon collision (since $\sigma(DY) \propto N_{coll}$)

The "normal" J/ψ suppression

- First consider pA collisions, where no QGP formation is expected
- To extract J/ψ absorption cross section, fit the data with the simple function

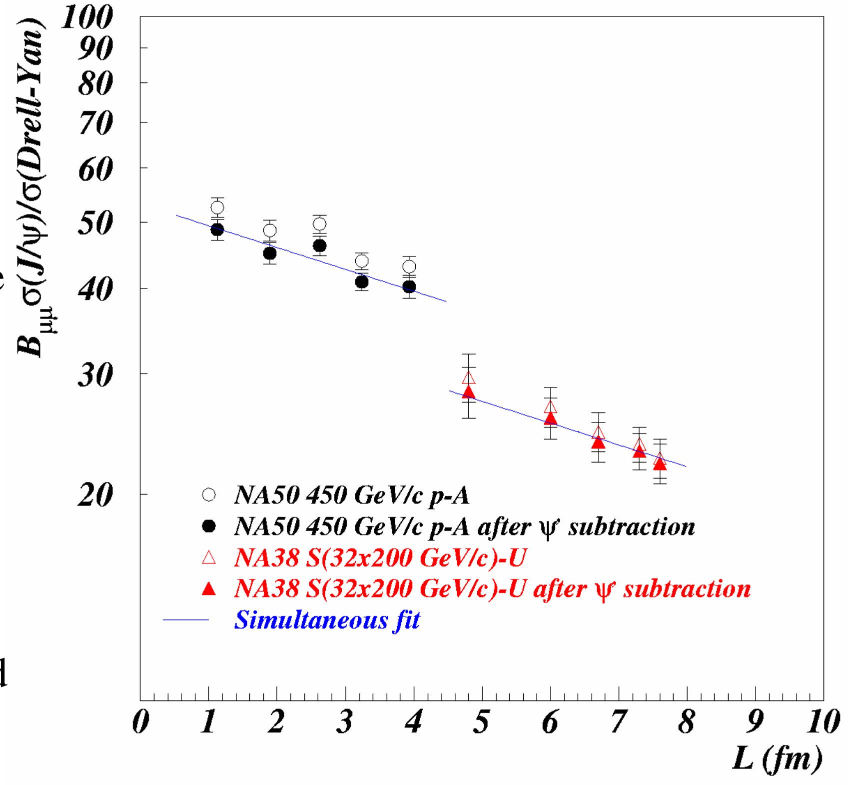
$$\frac{\sigma_{J/\psi}}{\sigma_{DY}} \propto e^{-\sigma\rho L}$$

where $L = \langle\rho L\rangle/\rho_0$ is the average path of the resonance in nuclear matter

- Get $\sigma_{J/\psi\text{-}N} = 4.4 \pm 0.9$ mb

(a more detailed approach, using the Glauber model, gives compatible results)

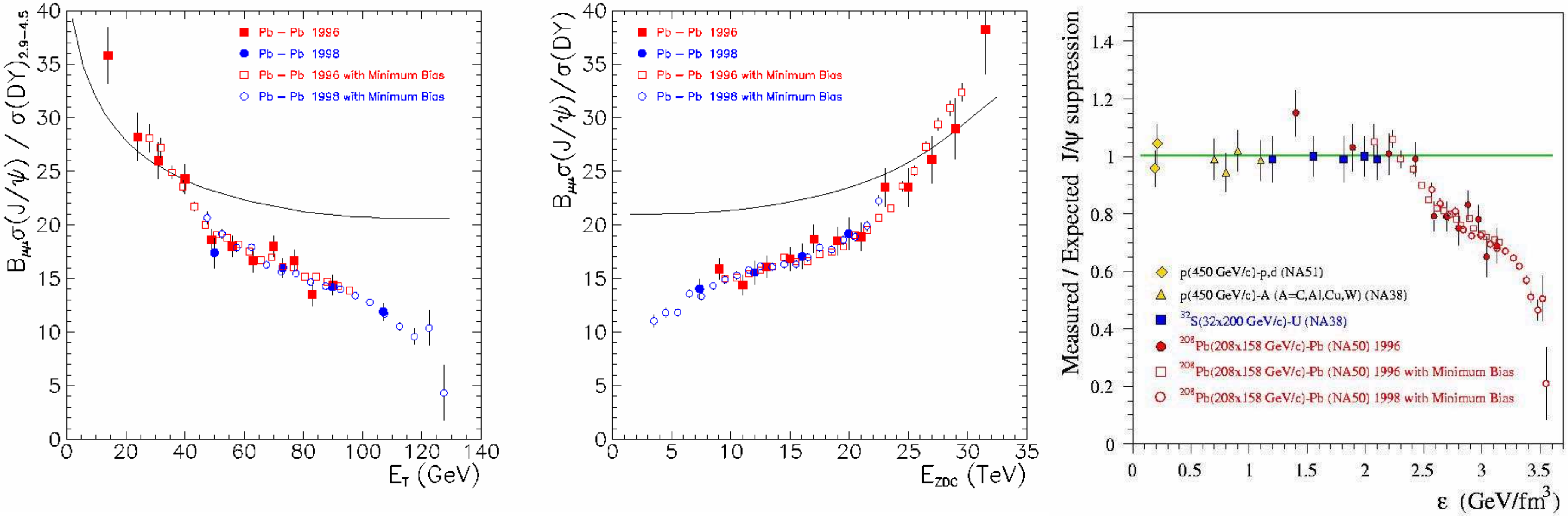
- Then consider S-U collisions. Can they be described by the same value of the absorption cross section ?
- A simultaneous fit to p-A and S-U data gives $\sigma_{J/\psi\text{-}N} = 4.7 \pm 0.8$ mb with $\chi^2/dof = 0.96$



E. Scomparin et al., Nucl. Phys. A698(2002) 543c

We have experimentally determined a "normal" J/ψ suppression, which can be used as a reference in the study of J/ψ production in heavy-ion collisions (Pb-Pb)

The “anomalous” J/ψ suppression

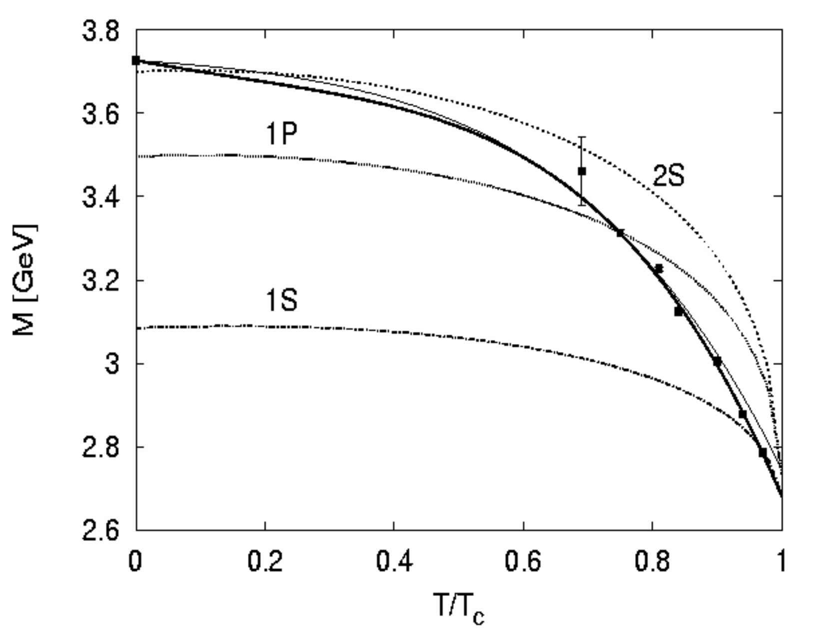


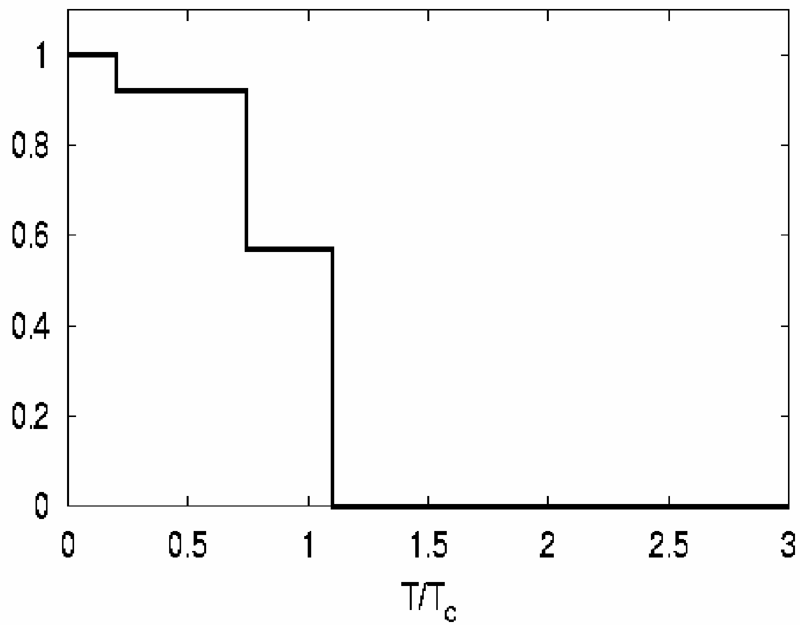
- Peripheral Pb-Pb collisions follow the behavior observed in p-A and S-U
- Clear departure from “normal” absorption at E_T~ 35 GeV (E_{ZDC}~ 26 TeV), corresponding to N_{part}~ 150
- Suppression pattern compatible with two sharp steps in the N_{part} variable
- In a deconfinement scenario such a behavior can be attributed to:
    - χ_c melting in semi-peripheral Pb-Pb collisions

      (J/ψ from $\chi \rightarrow J/\psi+\gamma$ are not seen any more)
    - Direct J/ψ melting in central Pb-Pb collisions
- Purely hadronic effects (J/ψ interaction with comoving hadrons) cannot produce neither thresholds nor successive steps in the suppression!

Present understanding of J/ψ suppression

- Temperature behavior of the heavy quark potential has been recently obtained in finite temperature lattice QCD
- Open charm threshold lowers when approaching T_c
- χ_c melts below $T_c \rightarrow$ not a signal for deconfinement, rather the approach of chiral symmetry restoration (decrease of constituent quark mass)





- The cc state is destroyed by a precursor of the QGP (deconfined partons not yet in thermal equilibrium)

$\rightarrow$qualitatively predicts two drops in J/ψ yield in PbPb at N_{part}~ 150 and N_{part}~ 250

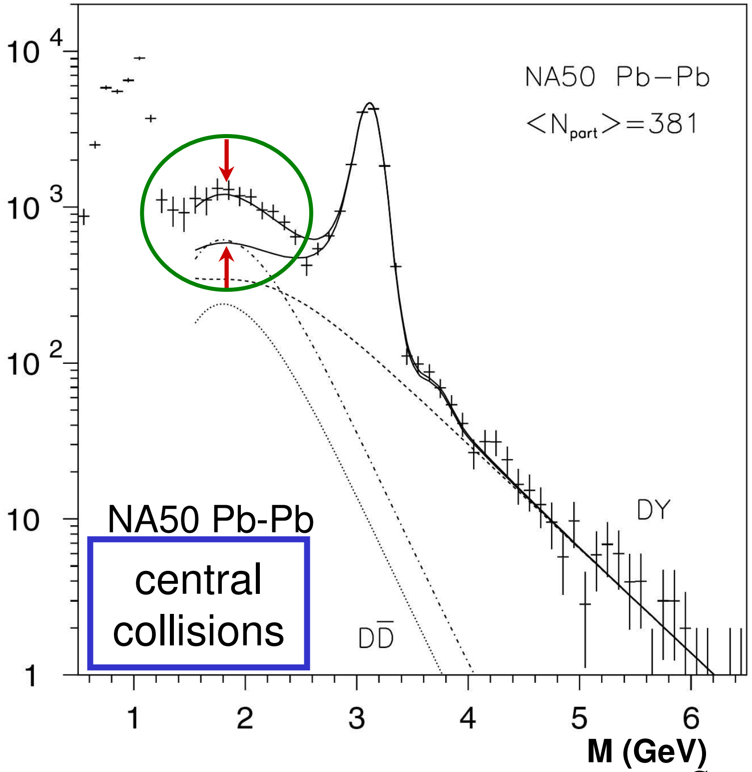
(Digal, Fortunato, Petreczky and Satz, hep-ph/0207264)

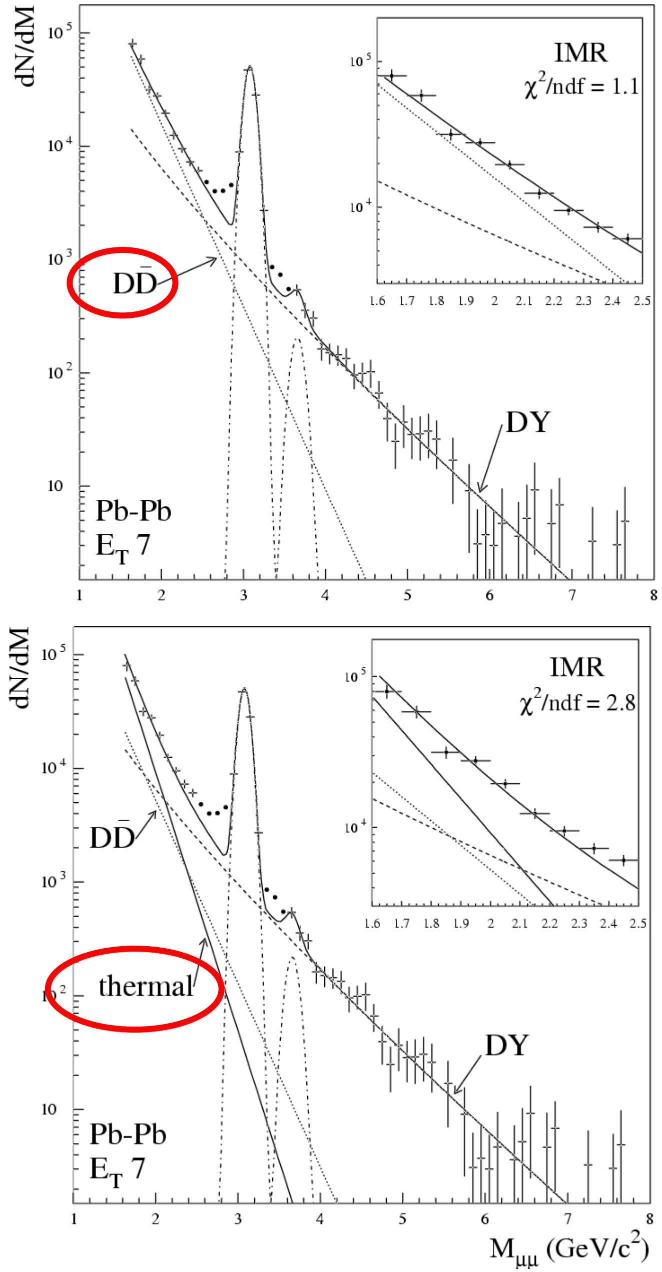
The intermediate mass region ($m_{\phi} < m_{\mu\mu} < m_{J/\psi}$)

•In Pb-Pb collisions dimuon production is enhanced with respect to known sources, i.e.Drell-Yan and semi-leptonic decays of D-meson pairs

•NA50 data in the intermediate mass region can be explained assuming that:

- D-meson production in Pb-Pb is larger up to a factor 3 with repect to pQCD predictions
- In the QGP phase thermal dimuons are produced





Open questions

- The experimental observations by NA50 represent up to now one of the most interesting results of the whole scientific program with ultrarelativistic heavy-ions (AGS, SPS, RHIC)

- Together with strangeness enhancement results they give many hints suggesting that in central Pb-Pb collisions at 158 GeV/nucleon the deconfinement of quarks and gluons has been observed

- Anyway many aspects of the interpretation of these results are still not clear

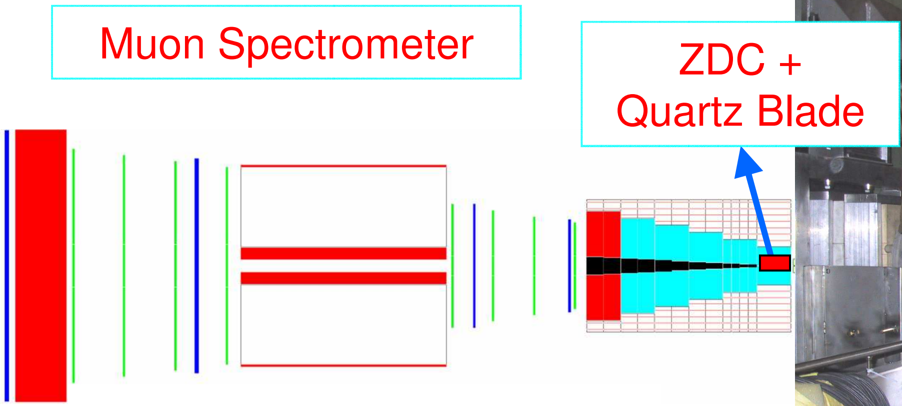
- Interpretation of the dimuon excess in the intermediate mass region:
  - Thermal production or open charm enhancement ?

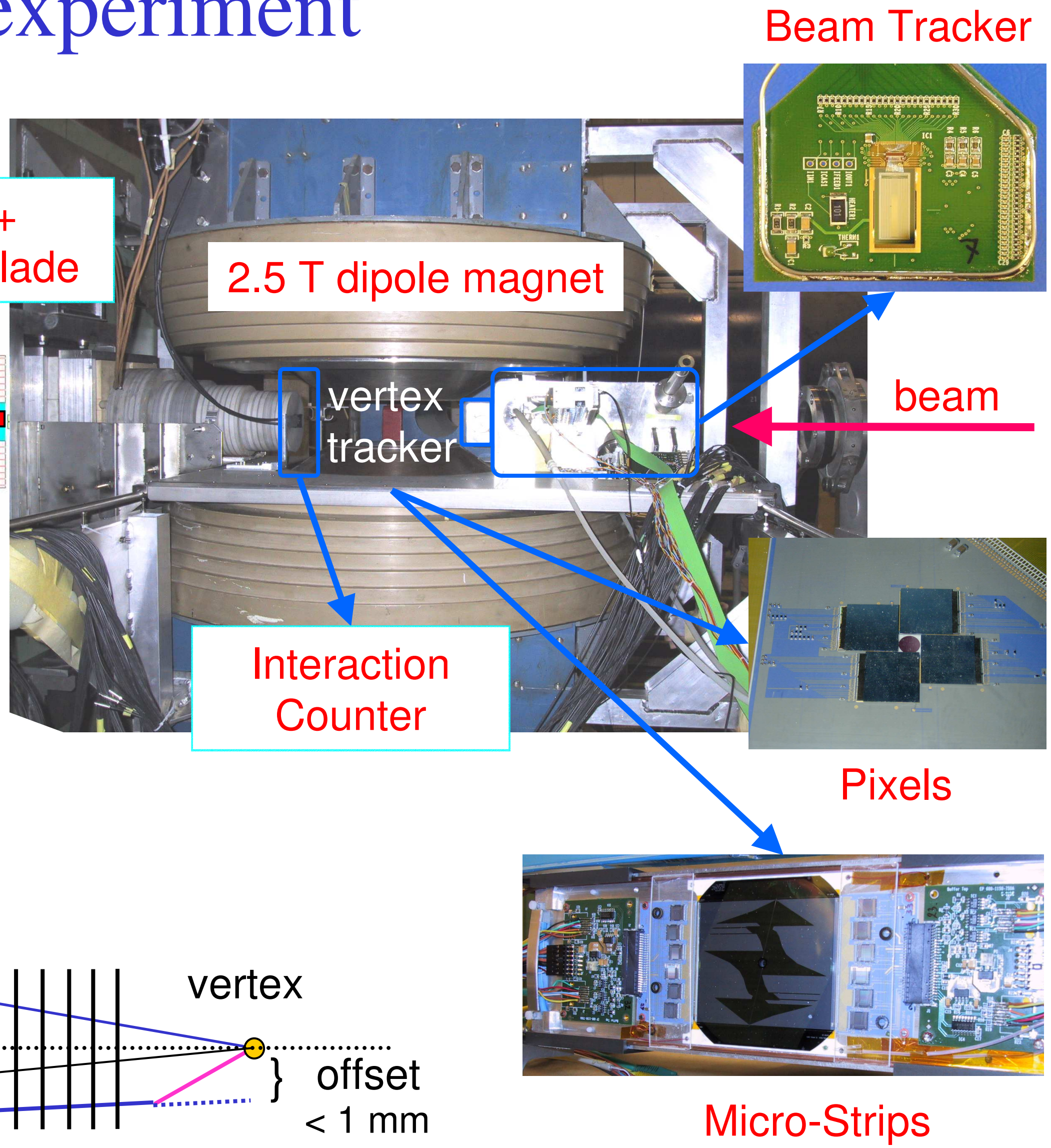
- Anomalous J/ψ suppression:
  - Probably we observe χ_c suppression (we detect its J/ψ decay)
  - The energy density where we see such a suppression is $\varepsilon \sim 2$ GeV/fm^3
  - Lattice QCD predicts $\varepsilon \sim 0.7$ GeV/fm^3 for the phase transition towards a QGP
  - Which variable actually governs the onset of the anomalous suppression ?

- Low mass region ($m_{\mu\mu}<m_{\phi}$): CERES finds a considerable dilepton excess (in e^+e^-)
  - Large statistical and systematical errors

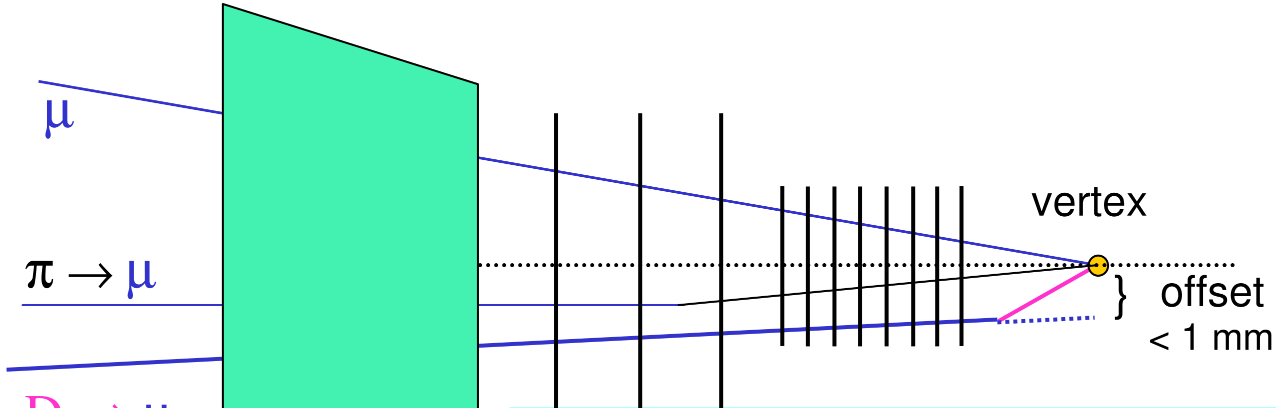
- Many question can be answered by an experiment which detects dimuons BEFORE they suffer multiple scattering in the hadron absorber $\rightarrow$ **NA60**

The NA60 experiment



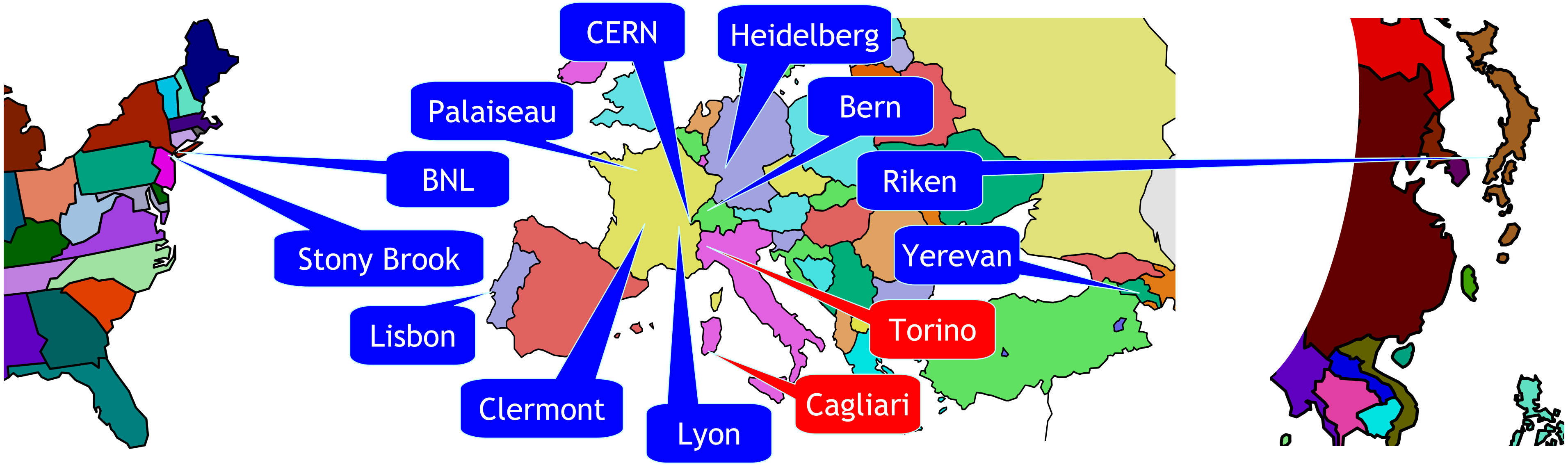


- Muon matching through hadron absorber
  - Better mass resolution
  - Better signal/background ratio



- Measurement of the dimuon offset
  - Distinguish open charm and “prompt” dimuons

NA60: brief history



•May 1999:
Letter of intent
CERN/SPSC 1999-15

•March 2000: Proposal
CERN/SPSC 2000-010

•March 2000:
SPSC approval

•June 2000:
Research Board approval

•October 2001:
Commissioning run (p)
muon spectrometer

•June 2002:
Proton run
1 pixel plane +16 strip planes

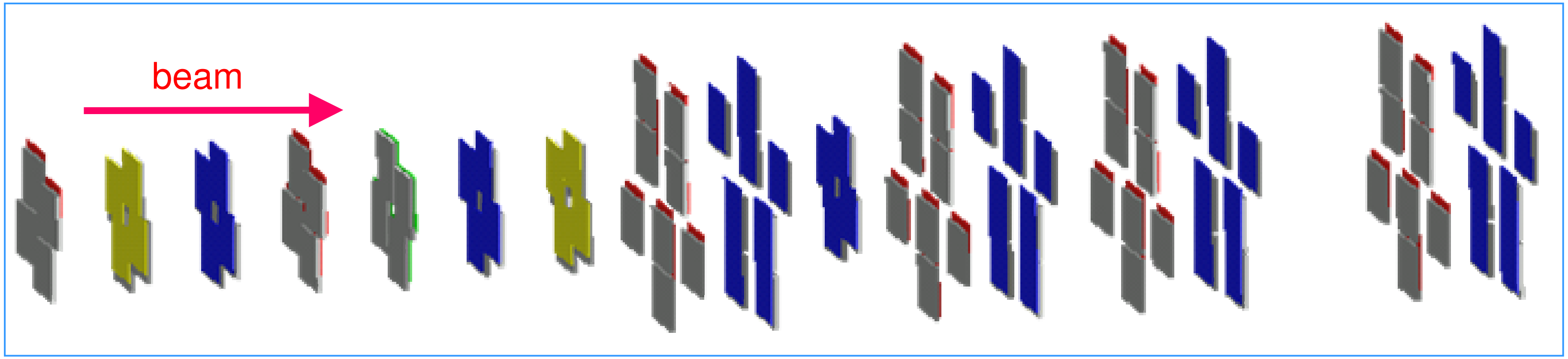
•Summer 2002:
Cancellation Pb run
@158 GeV/nucleon
(bump bonding problems)

•October 2002:
Pb run @ 20-30
GeV/nucleon
3 pixel planes

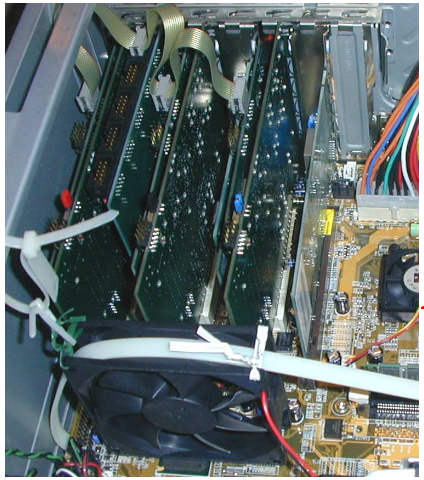
•August 2003:
Pixel telescope
completed

•October-November 2003:
Physics data taking with In beam

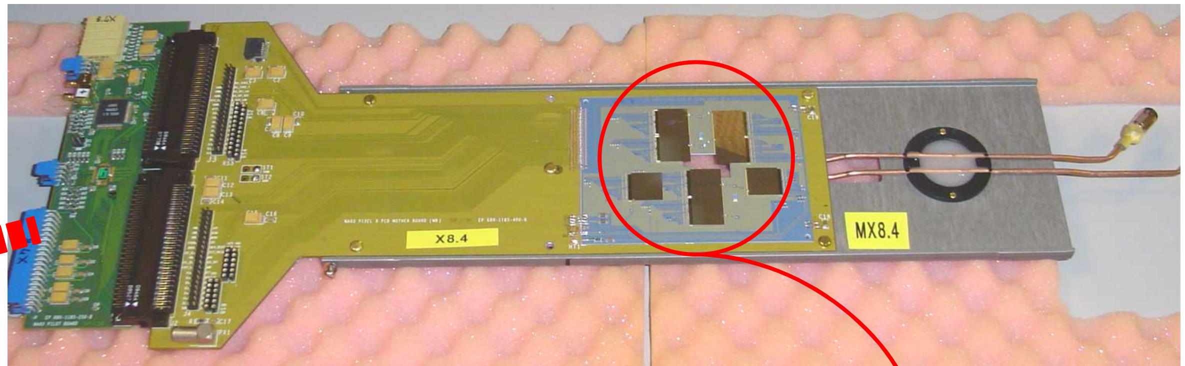
Vertex telescope (pixel)



- 8 4-chip planes (small) and 8 8-chip planes (large): good angular acceptance and tracking efficiency
- 8192 pixel ($50 \times 450\ \mu m^2$) per chip
- Total thickness: 750 µm (read-out chip) + 300 µm (sensor) + hybrid (ceramic) ~ $0.03\ X_0$
- Read-out chip ALICE1LHCB : 10 MHz clock



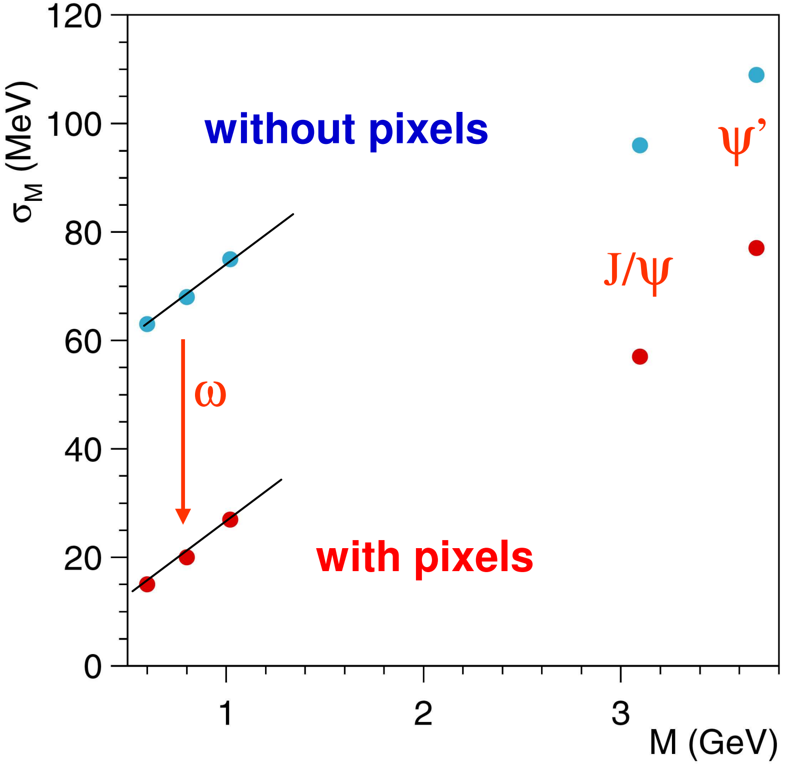
DAQ PCs with CFD card and mezzanine (~140 MB/burst)

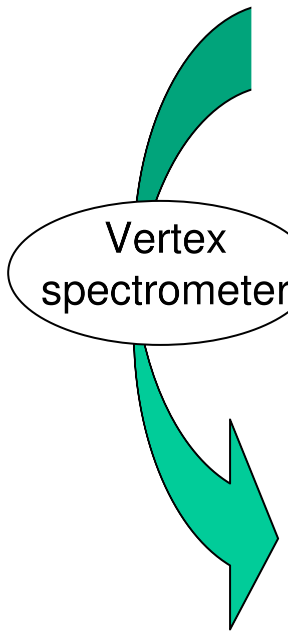


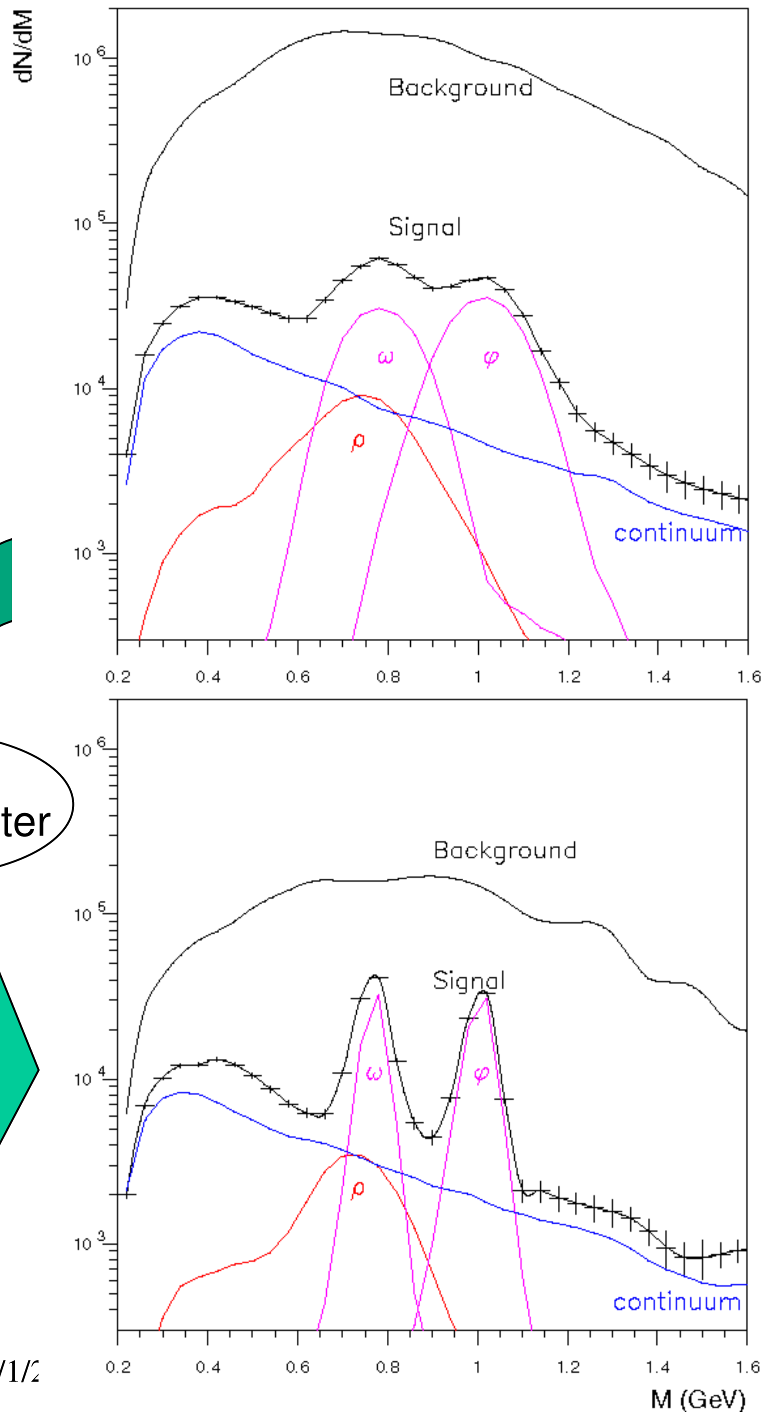
Detector

Invariant mass resolution

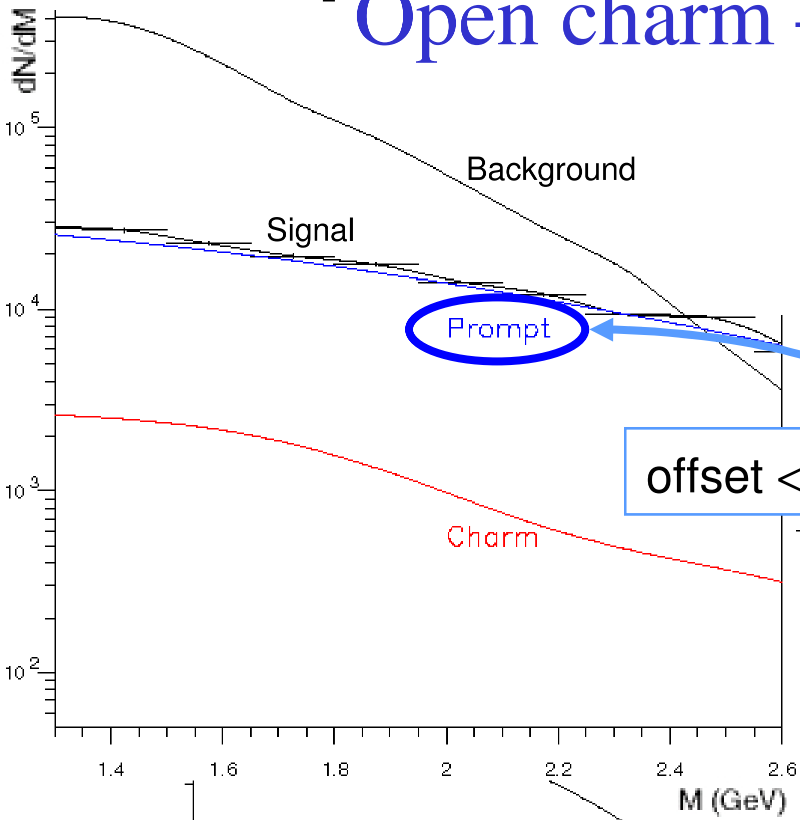
•Clear upgrade, especially in the low mass region
(at the ω peak , from 70 to 20 MeV)





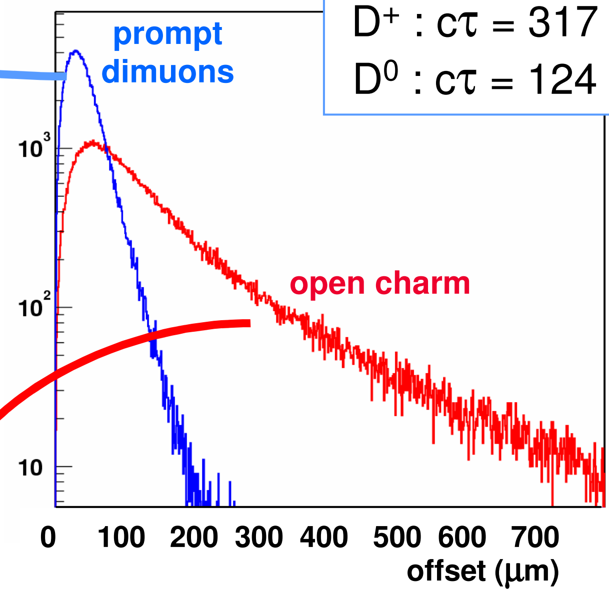


Open charm – prompt separation

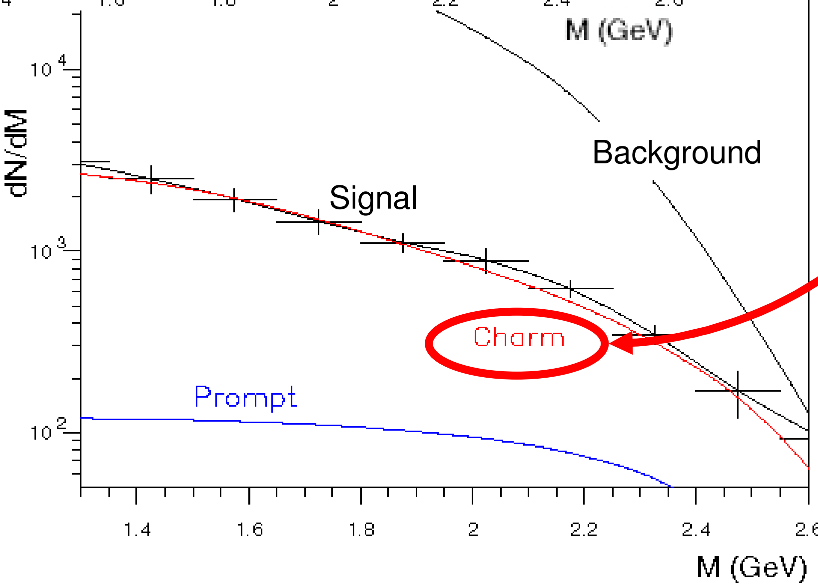


offset < 90 µm

Offset resolution
< 35 µm per p > 15 GeV/c



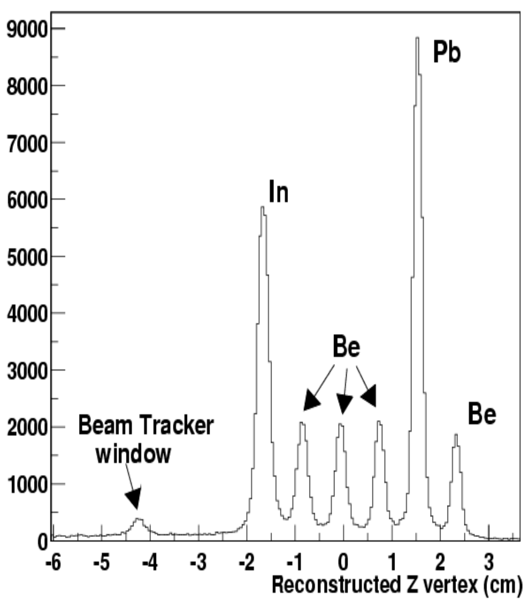
D^+ : $c\tau$ = 317 µm
D^0 : $c\tau$ = 124 µm

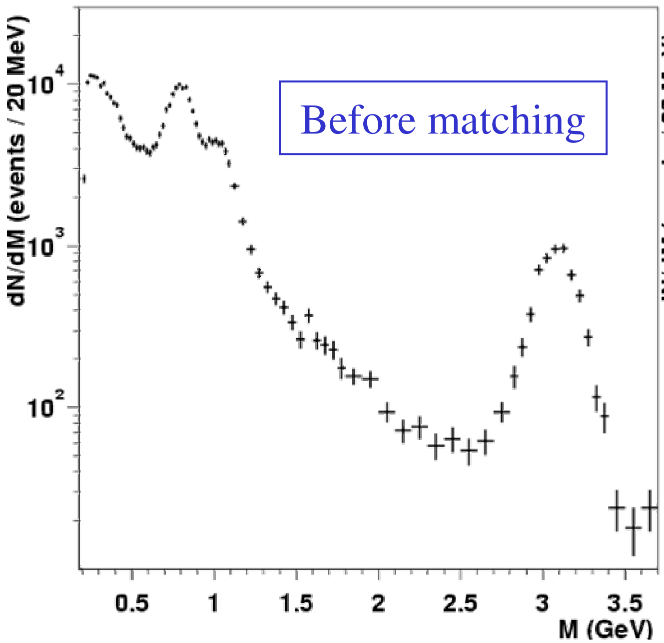


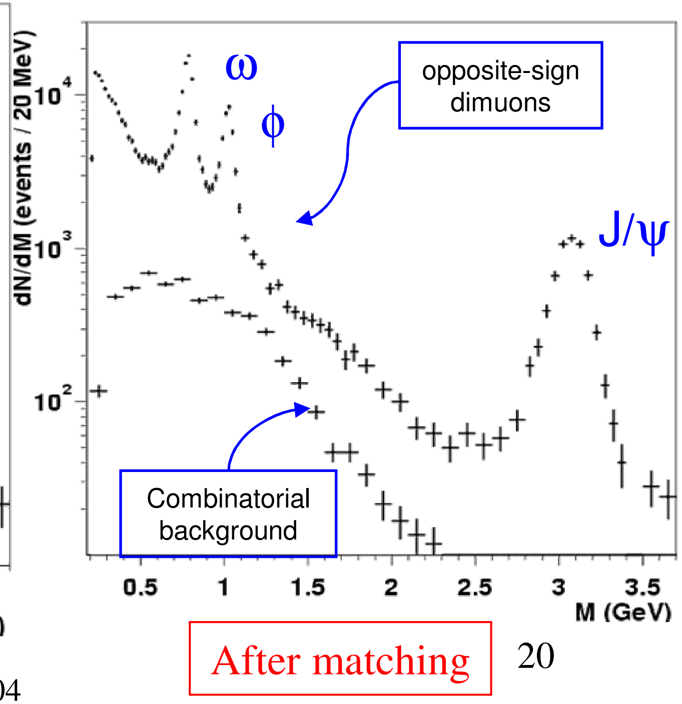
90 < offset < 800 µm and distance between muons > 180 µm in the transverse coordinate at Z_{vertex}

Dimuon matching

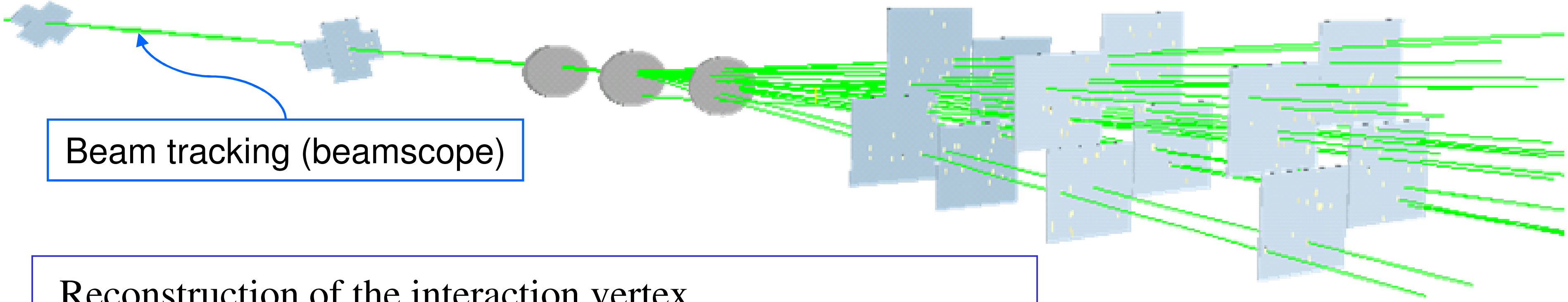
- 5 days of proton beam (intensity 2×10^{8} p/burst)
- Statistics: 335 000 reconstructed dimuons (~ 50% from the target region)
- Matching for ~ 30% of the signal $\mu^{+}\mu^{-}$ pairs (only ~ 6% for like-sign dimuons);
  after further quality cuts ~ 25 000 dimuons
- Like-sign / opposite-sign : ~ 25% $\Rightarrow$ ~ 7% after matching
- **Mass resolution at the ω/ϕ: ~ 70 MeV (NA50) $\Rightarrow$ 25–30 MeV ;**
  at the J/ψ : 125 MeV (NA50) $\Rightarrow$ 90 MeV (assorbitore)





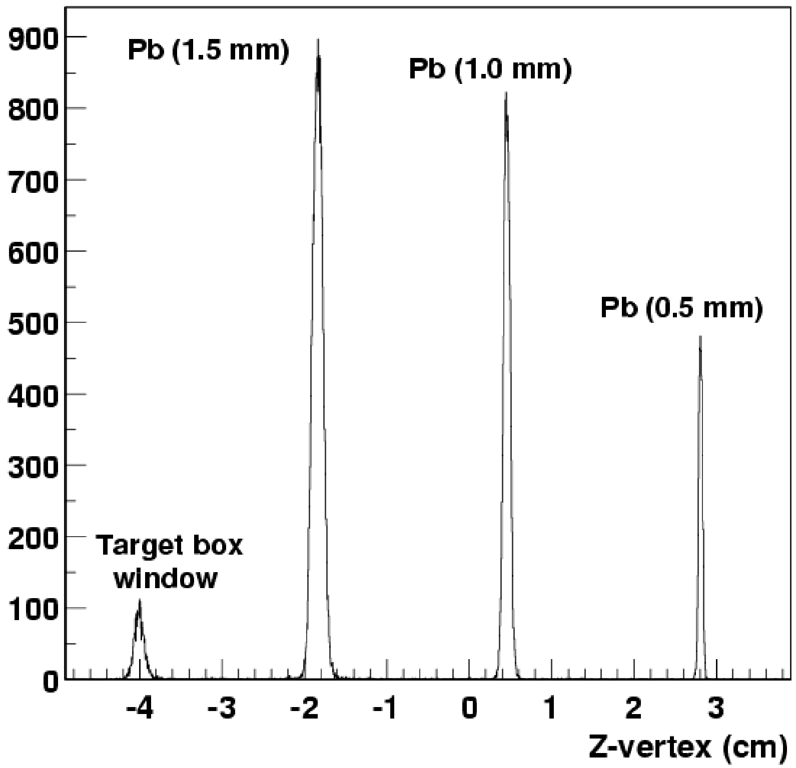


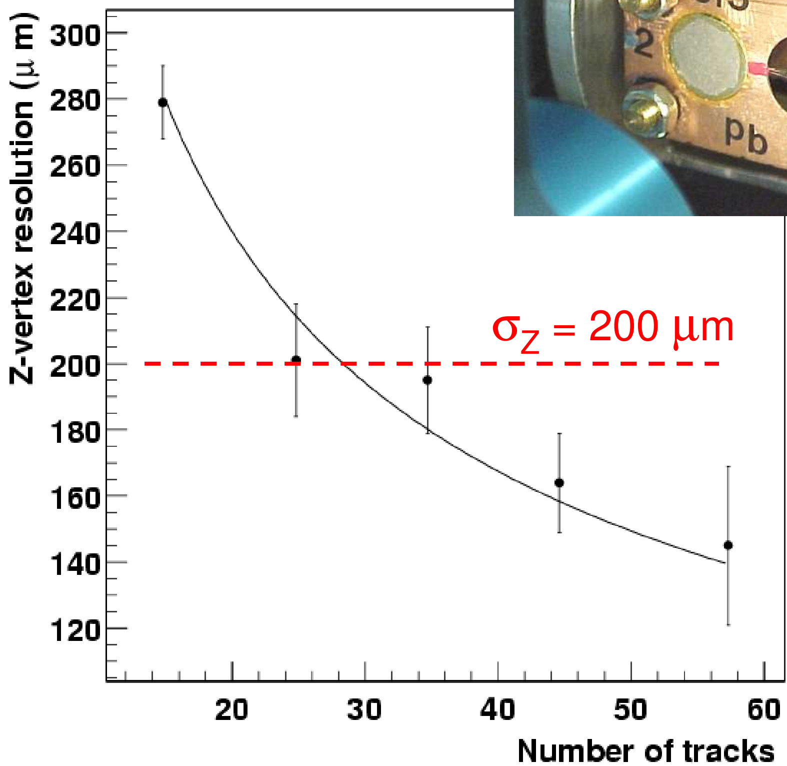
October 2002 run: Pb-Pb @ 20-30 GeV/nucleon

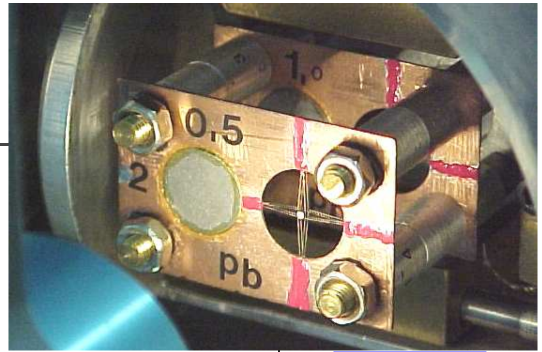


Reconstruction of the interaction vertex

$\sigma_Z = 200\ \mu m$ and $\sigma_X = 20\ \mu m$ (with only three pixel planes!)





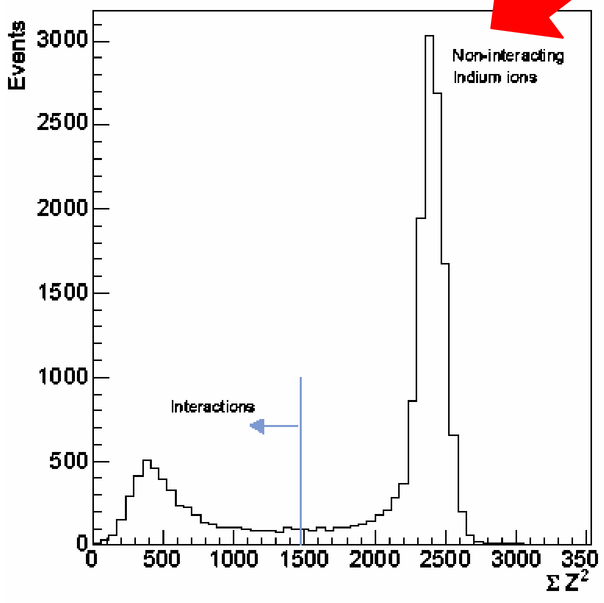


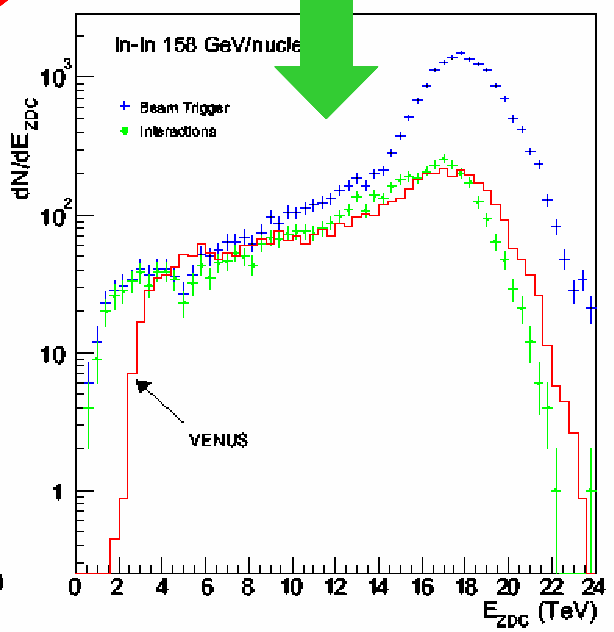
target

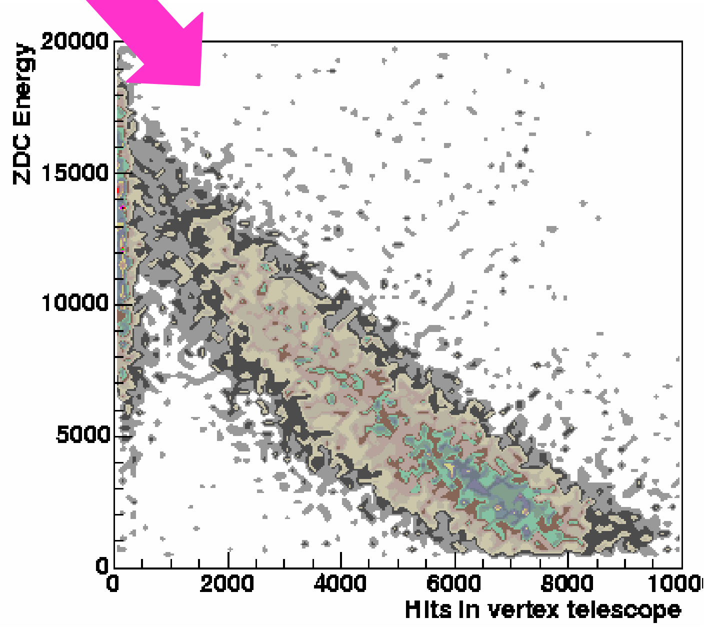
The first physics run: In-In @ 158 GeV/nucleon (1)

- Intermediate mass ion (A=115): complement information obtained with Pb ion runs
- Beam intensity ~ 10^7 In ions/s
- Running time: 39 days

First event selection: use quartz blade, ZDC and pixel multiplicity information



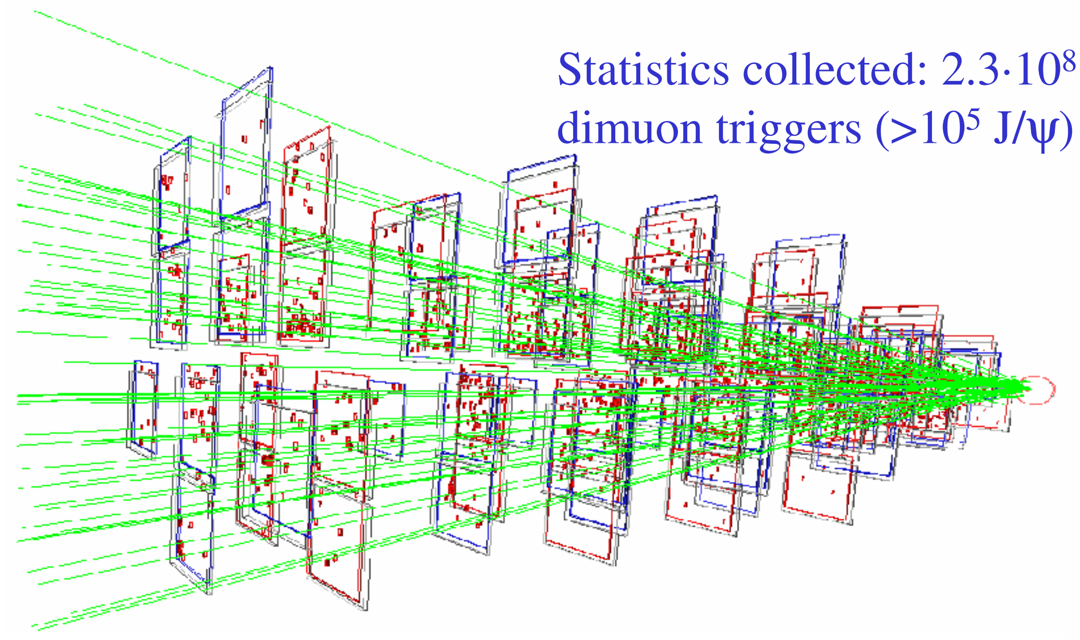




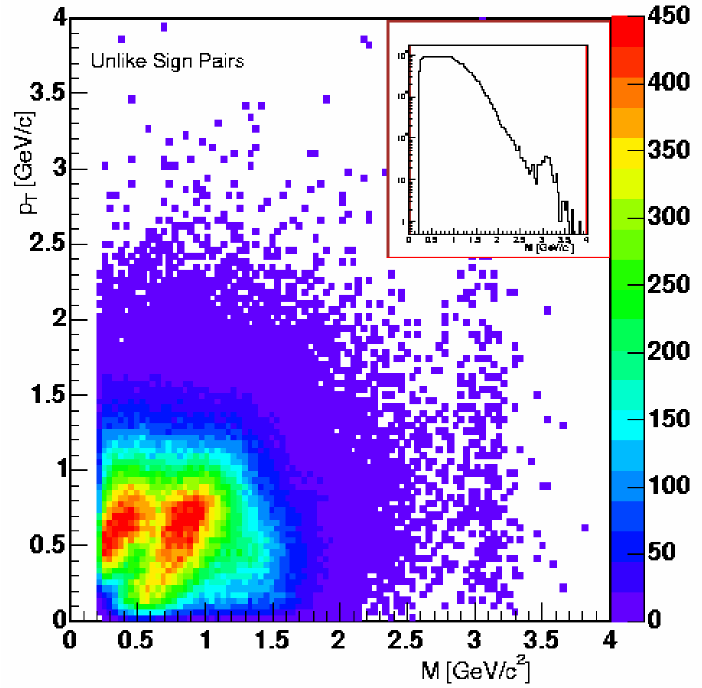
The first physics run: In-In @ 158 GeV/nucleon (2)

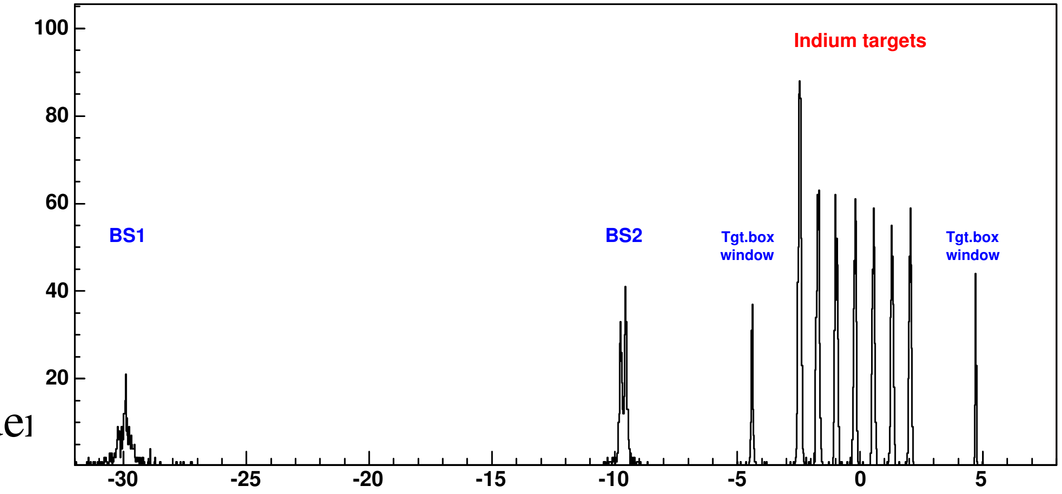
•Semi-peripheral event as reconstructed by the complete vertex telescope

Statistics collected: $2.3 \cdot 10^8$ dimuon triggers ($>10^5$ J/ψ)



•Opposite sign dimuon invariant mass spectrum (muon spectrometer only)





•Production of reconstructed events under way (CERN, Lyon, Cagliari, Torino)

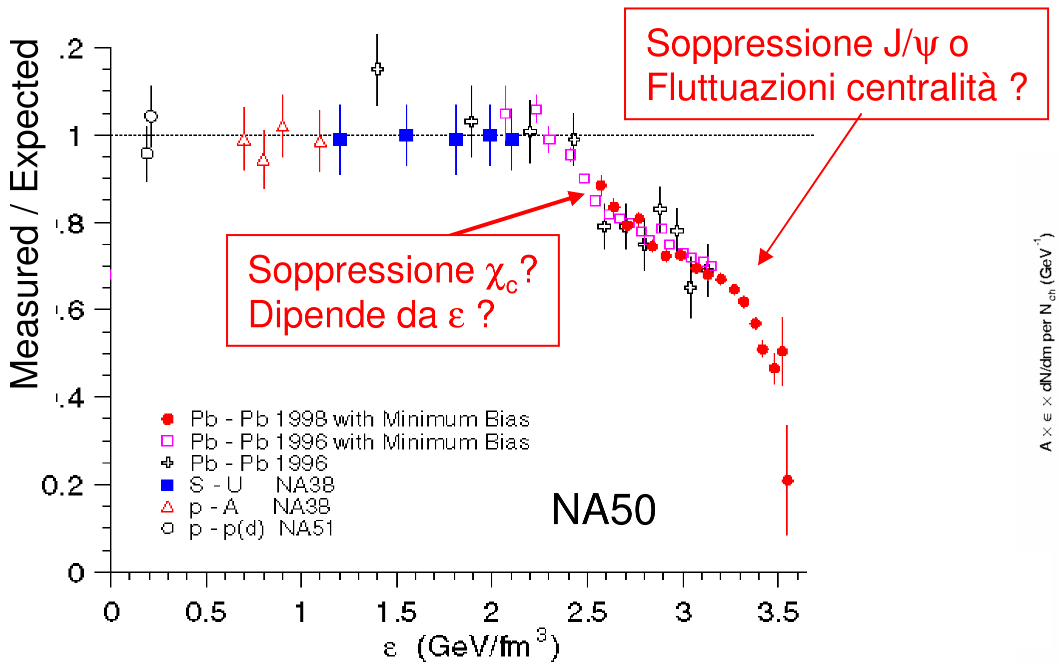
•First physics results expected by spring/summer 2004

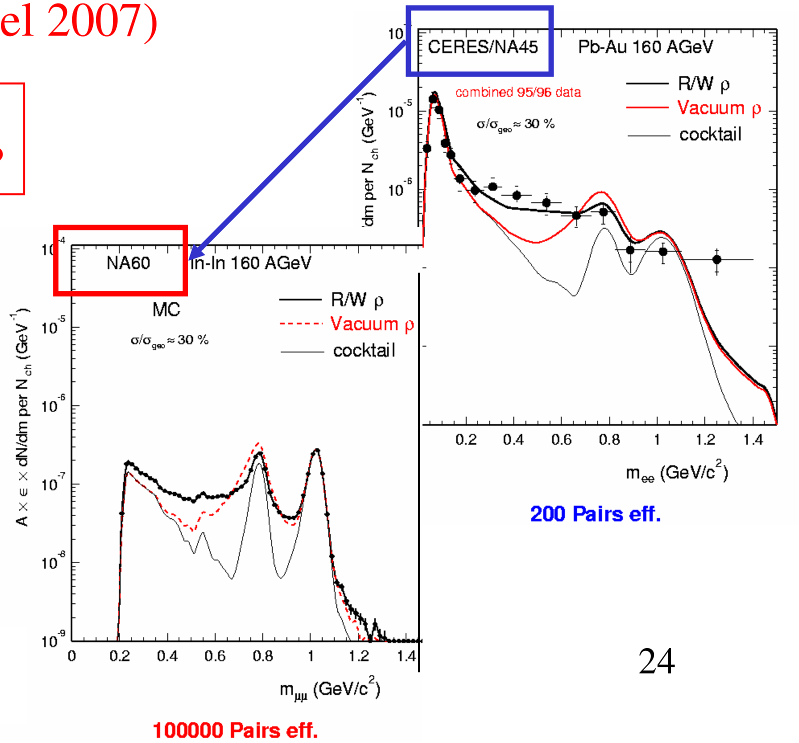
Conclusioni

•NA50 ha fornito, negli anni ’90, risultati molto interessanti (soppressione anomala J/ψ, eccesso masse intermedie), alla base dello “statement” del CERN sulla scoperta dello stato deconfinato di quark e gluoni (Febbraio 2000)

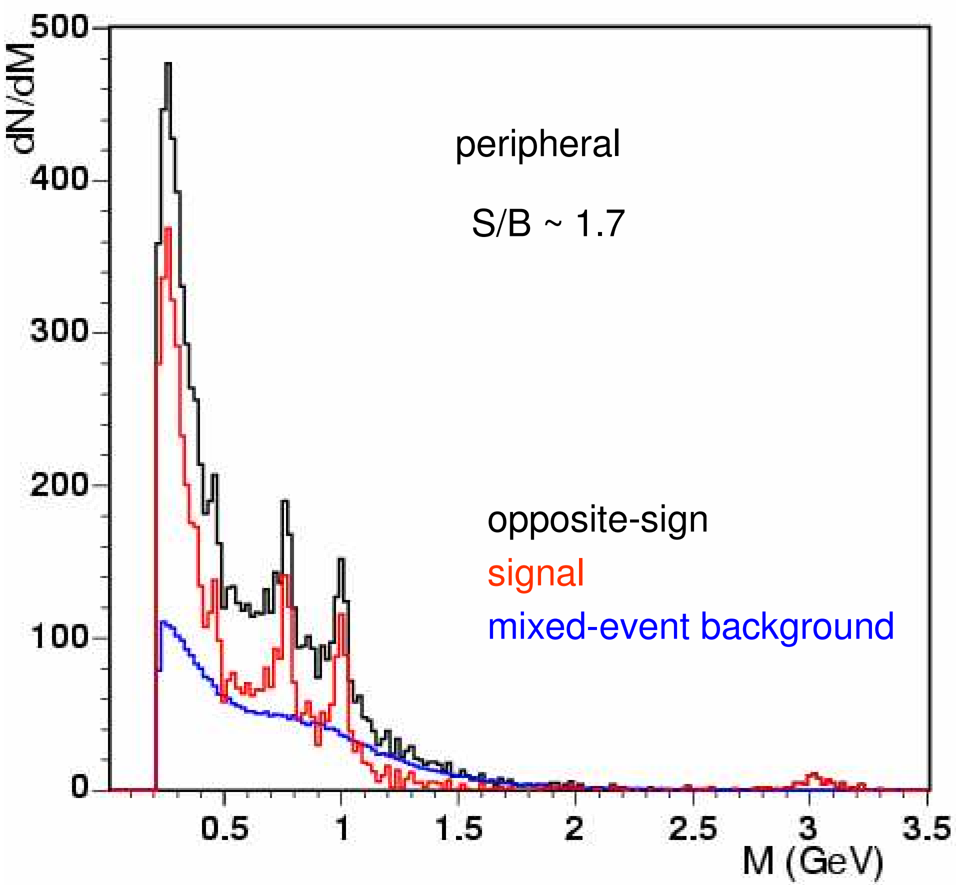
•NA60 raccoglie l’eredità di NA50 nel campo della fisica dei dimuoni, permettendo di:

- •Chiarire diverse questioni irrisolte nel campo della fisica del QGP alle energie dell’SPS
  - •Interpretazione soppressione anomala J/ψ
  - •Dimuoni termici nella zona delle masse intermedie ?
  - •Ripristino simmetria chirale (“sparizione” ρ) ?
- •Mantenere competitivo il CERN ripetto a BNL nel settore della fisica degli ioni ultrarelatvistici (aspettando l’inizio di ALICE, nel 2007)





5000 signal events
for M < 1.2 GeV
(less than 1 % of total statistics)



mass resolution :
~ 20 MeV at M ~ 1 GeV