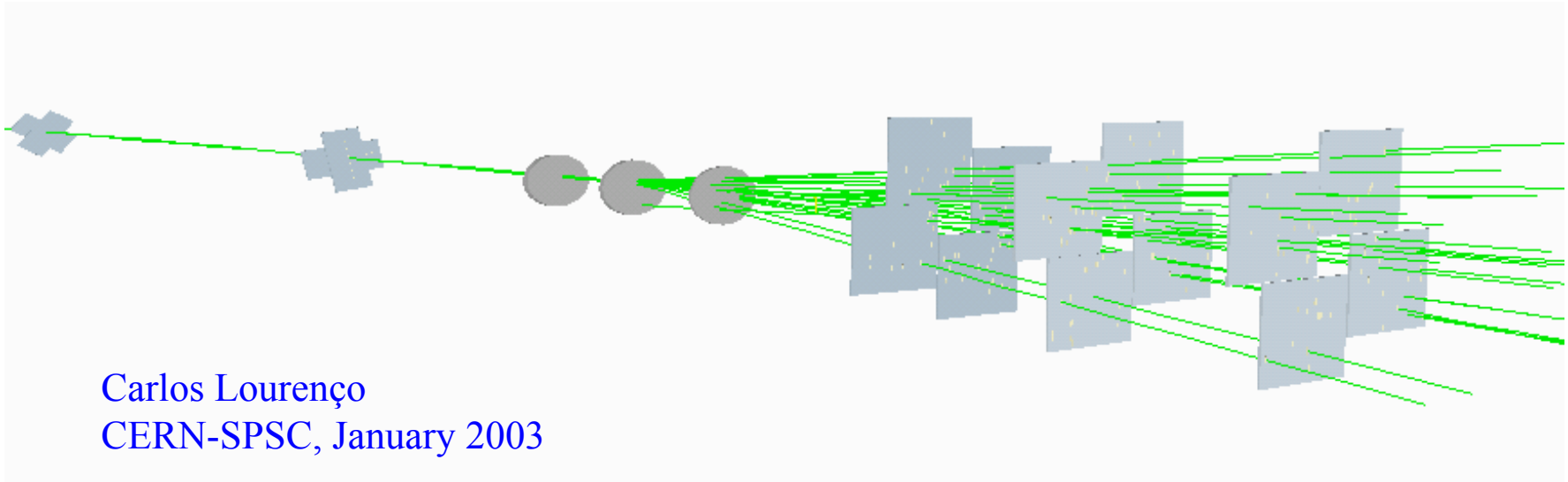
The NA60 Experiment

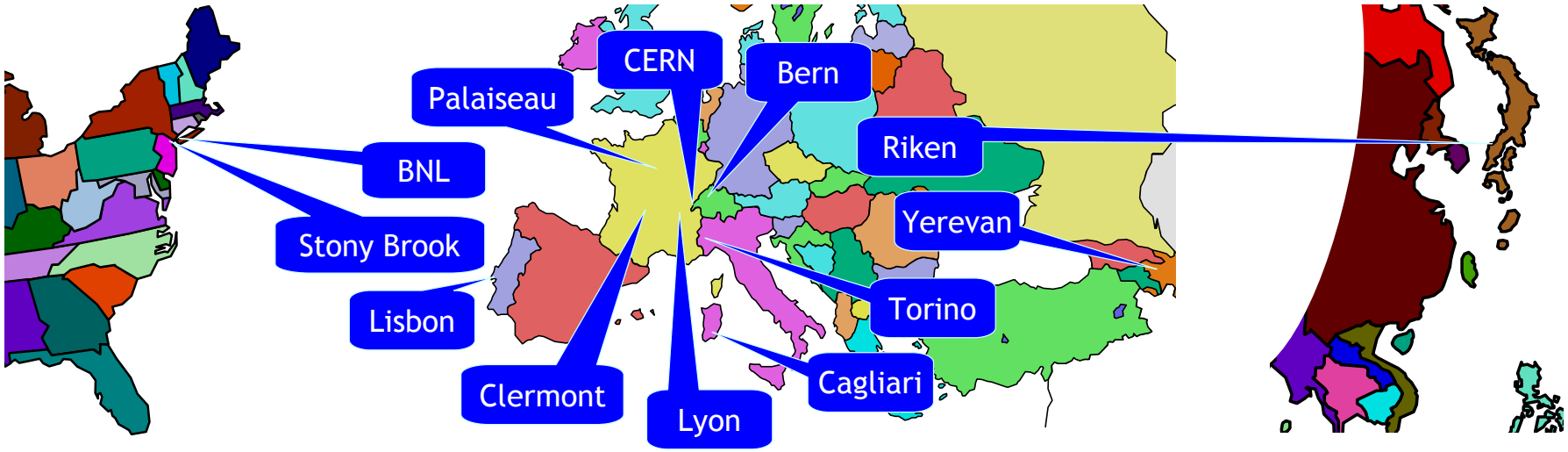
Study of Prompt Dimuon and Charm Production with Proton and Heavy Ion Beams at the CERN SPS

- Recent evolution of the apparatus
- Analysis of the 2002 data
- Perspectives



Carlos Lourenço
CERN-SPSC, January 2003

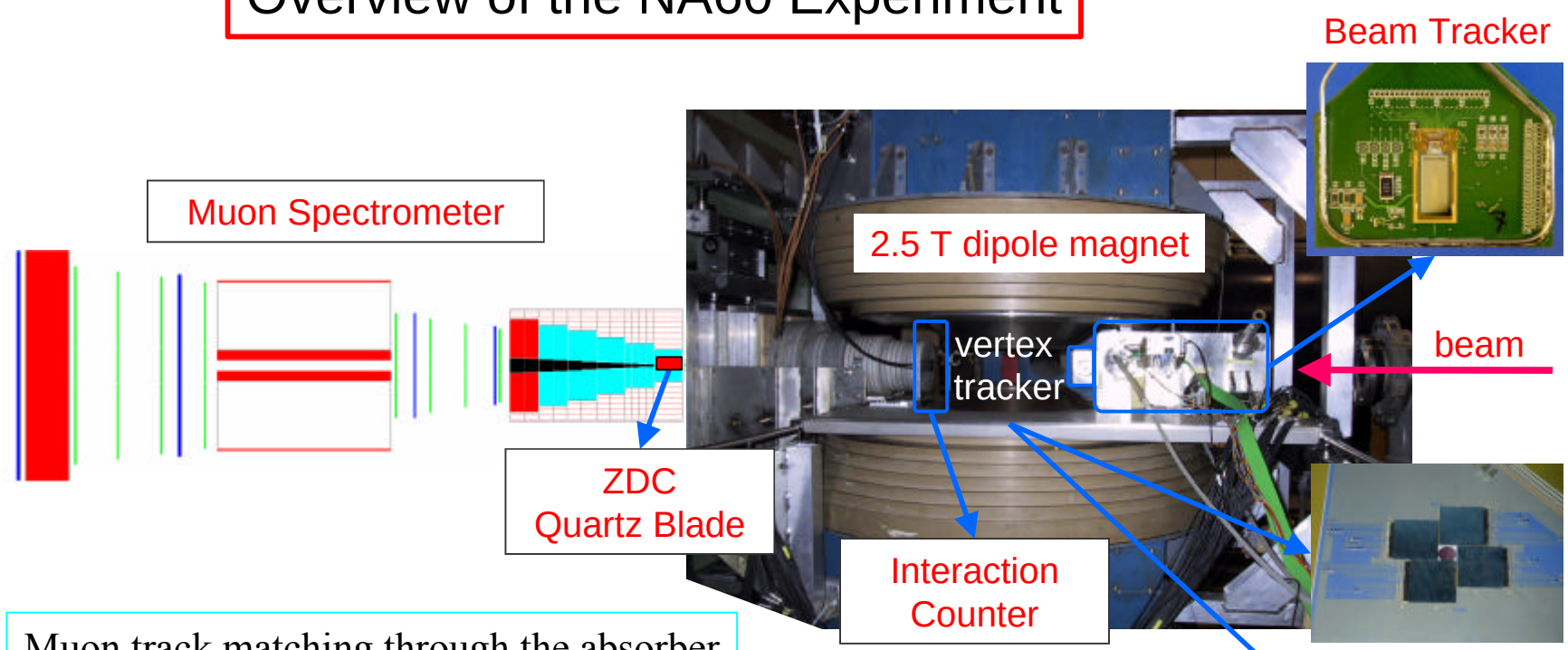
The NA60 Collaboration



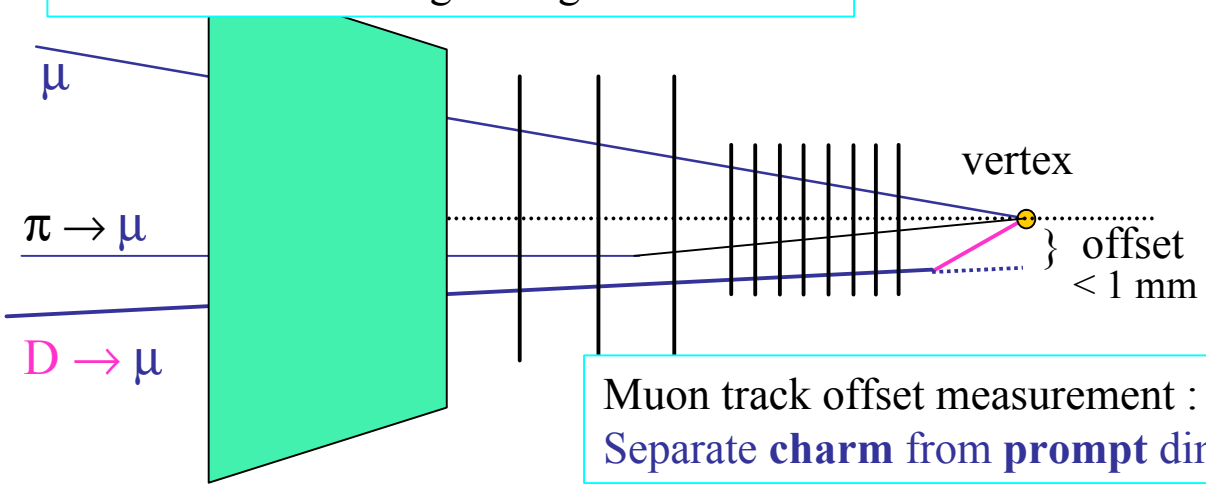
R. Arnaldi, K. Banicz, K. Borer, J. Buytaert, J. Castor, B. Chaurand, W. Chen, B. Cheynis, C. Cicalò, A. Colla, P. Cortese, A. David, A. de Falco, N. de Marco, A. Devaux, A. Devismes, A. Drees, L. Ducroux, H. En'yo, A. Ferretti, M. Floris, P. Force, A. Grigorian, J.Y. Grossiord, N. Guettet, A. Guichard,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

48 people, 12 institutes, 7 countries

Overview of the NA60 Experiment

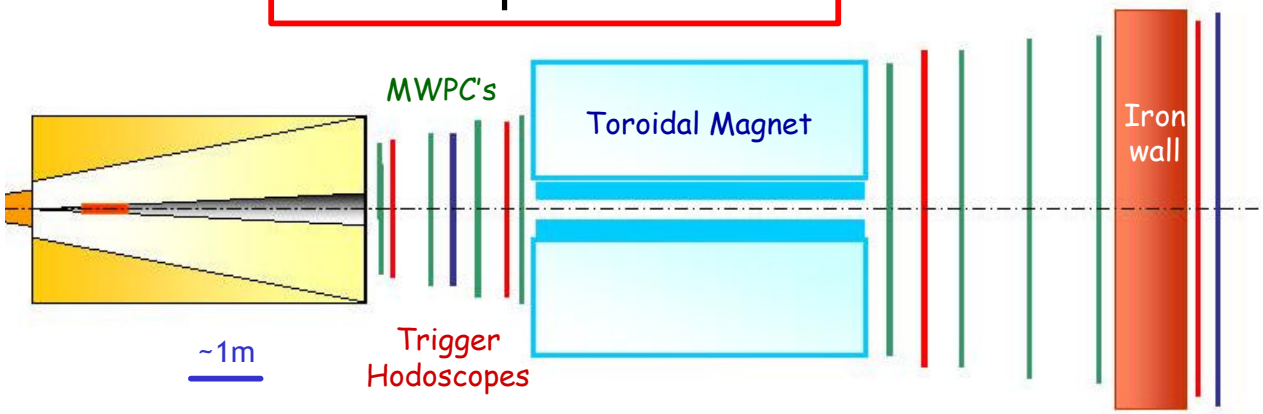


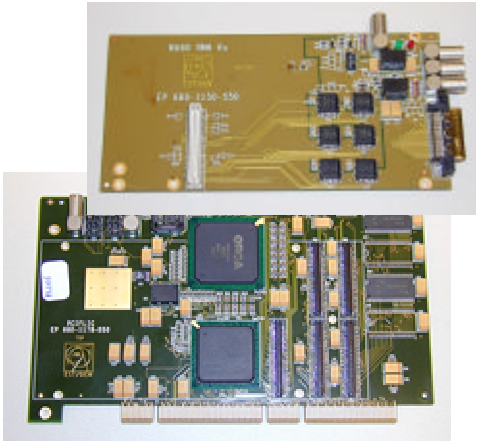
Muon track matching through the absorber



Muon track offset measurement :
Separate **charm** from **prompt** dimuons

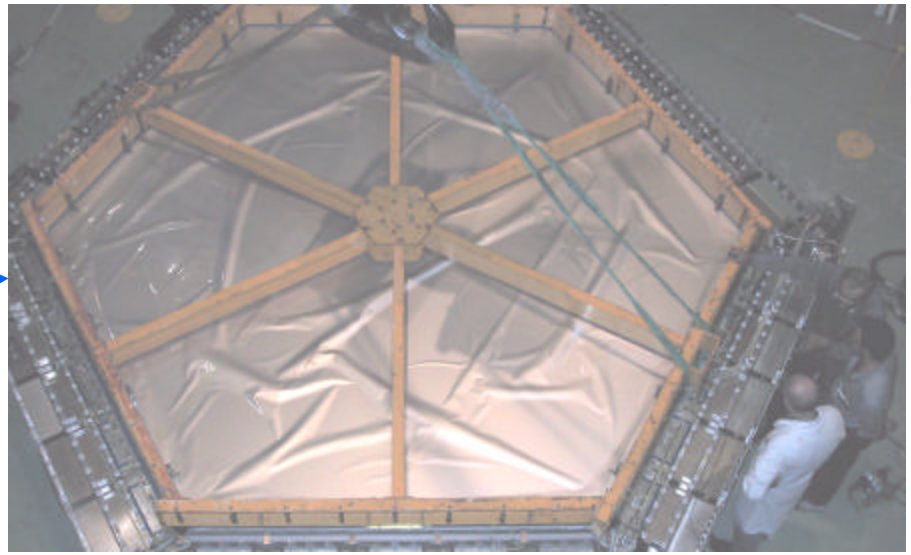
Muon Spectrometer





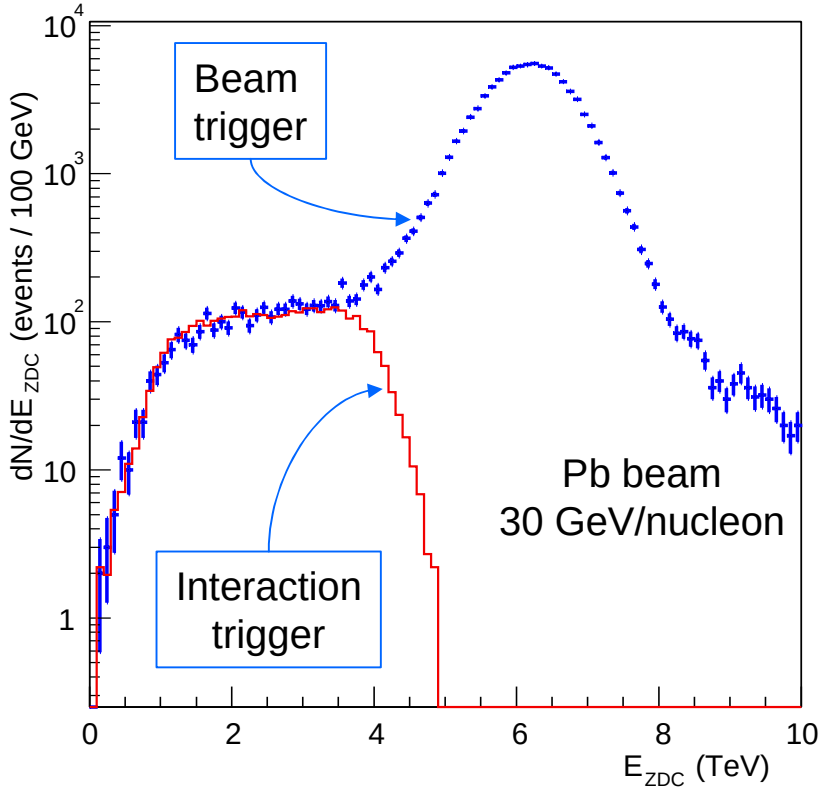
- New read-out electronics, DAQ, controls, monitoring
  - ✓ VME, transputers, VAX/VMS ➔ PCI, FLIC+RMH mezzanine, PC/Linux
  - ✓ 8x bigger spill buffer; faster readout; 2x higher trigger rate
- New gas mixture, distribution and controls for the chambers : safety requirement
- Broken wires in one tracking plane of
  - ✘ chamber 6 in October 2001
  - ✘ chambers 5 and 6 in June 2002
  - ✘ to be repaired early 2003

chamber 6 repair in May 2002

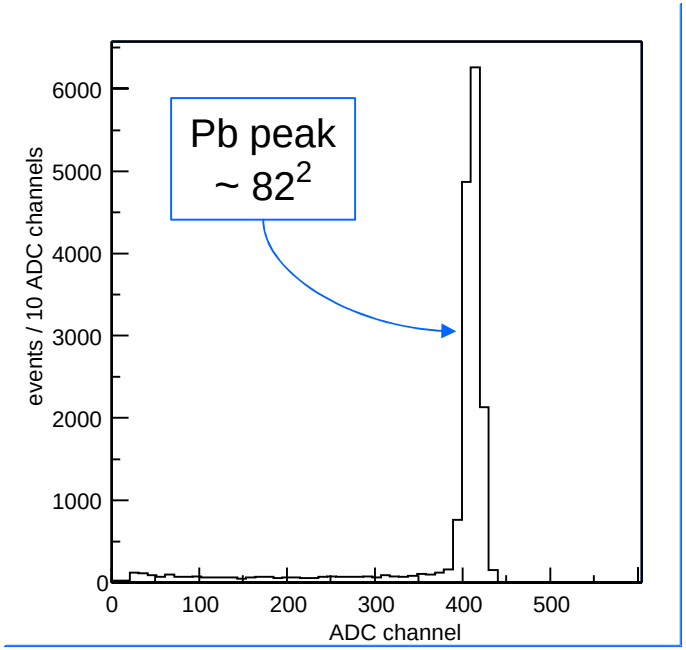


ZDC and Quartz Blade Detectors

- New read-out - DAQ interface
  - ✓ PCI-FLIC with FERA mezzanine
- New online and offline software
- The ZDC provided the trigger signal during the October 2002 Pb ion run

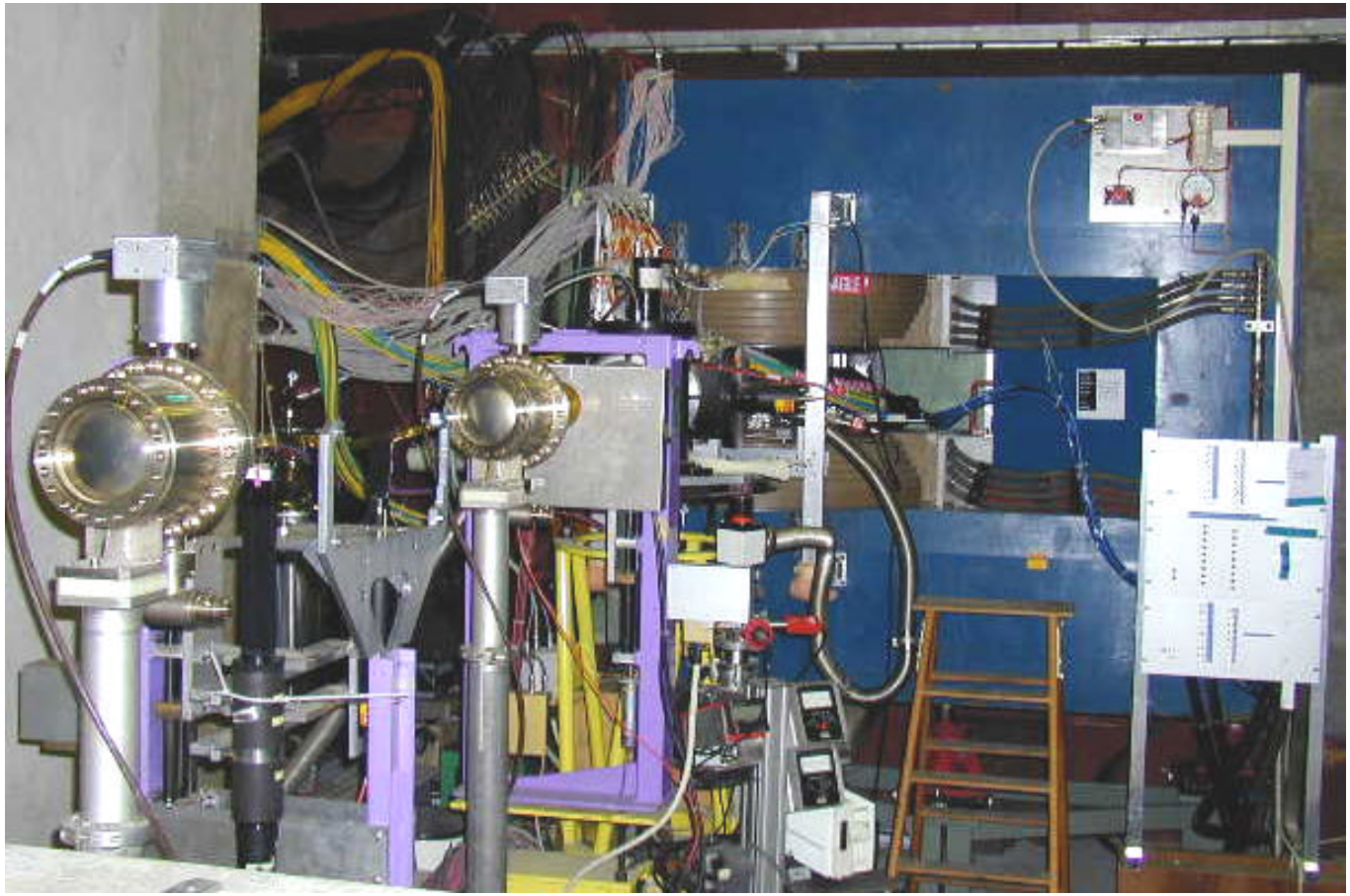


- New Quartz Blade detector
  - ✓ 40 cm long single slab of silica
  - ✓ 2% resolution on the sum of the squared charges of the beam fragments
  - ✓ worked very well with the Pb beam of 20 GeV/nucleon



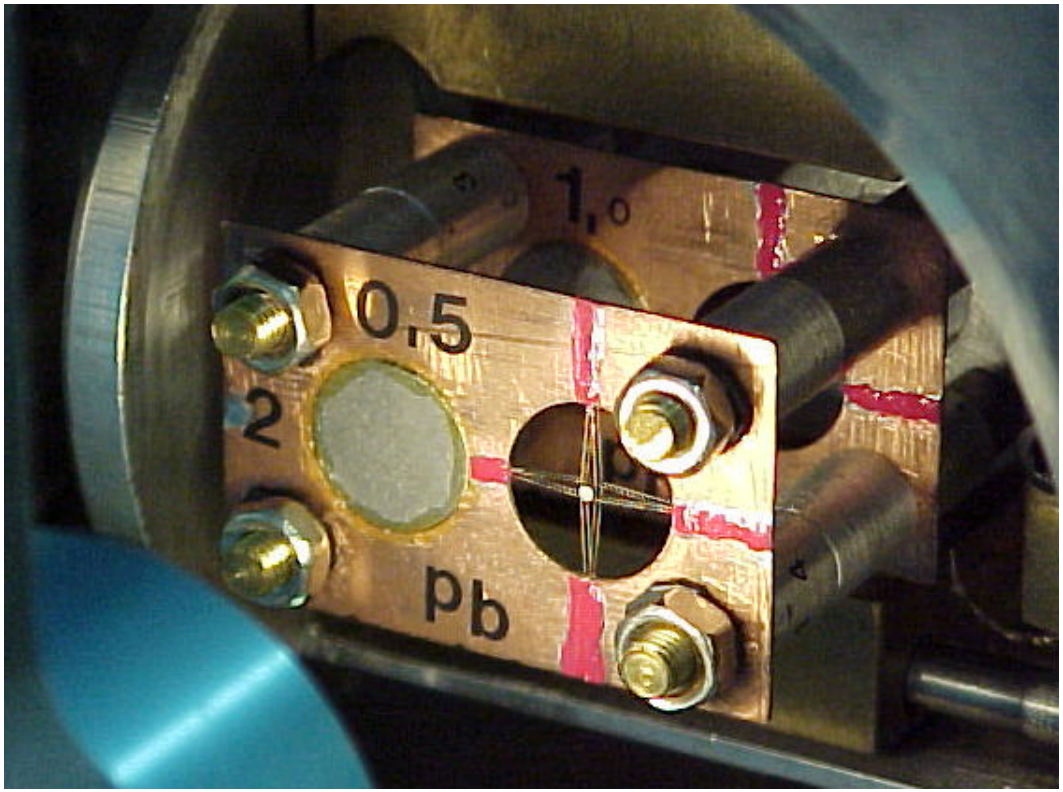
Vertex Dipole Magnet

- Operated in June 2002 at 2.5 T with both polarities
- Heating during last week of run due to problem with water cooling circuits
  - ✓ problem identified and solved in July



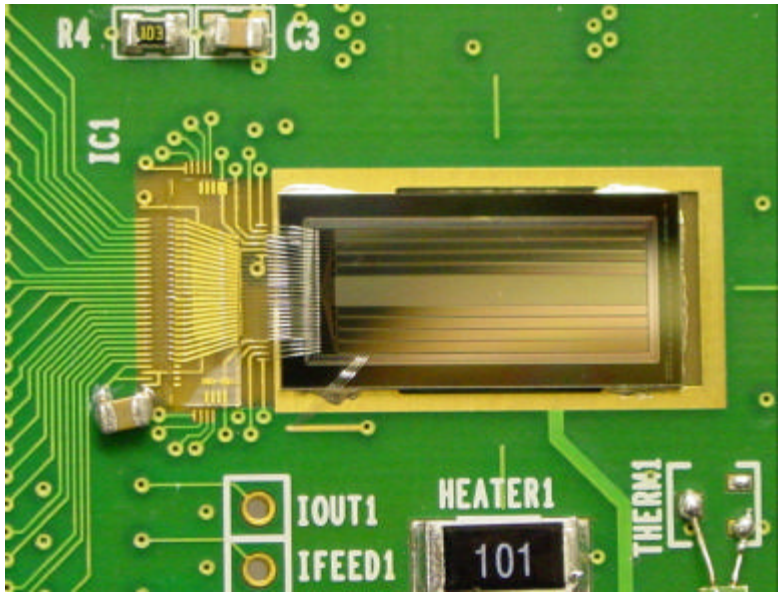
Target System

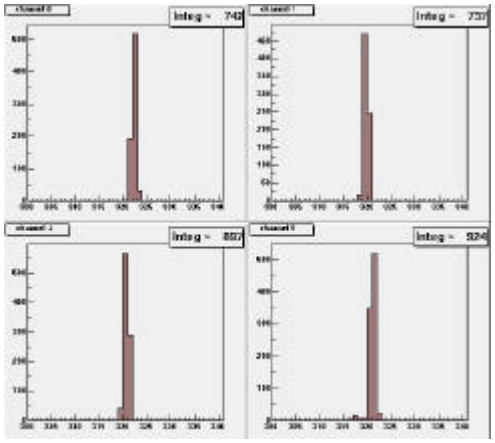
- June 2002 proton run : In, Be, Be, Be, Pb, Be
  - ✓ 2 mm thick ; 8 mm spacing ; 12 mm diameter
- October 2002 Pb run : three targets
  - ✓ 1st setup : all Pb ; 1.5, 1.0 and 0.5 mm thick ; 12 mm diameter
  - ✓ 2nd setup : In, Pb, Pb ; all 1.5 mm thick ; first 12 mm and others 1 mm diameter



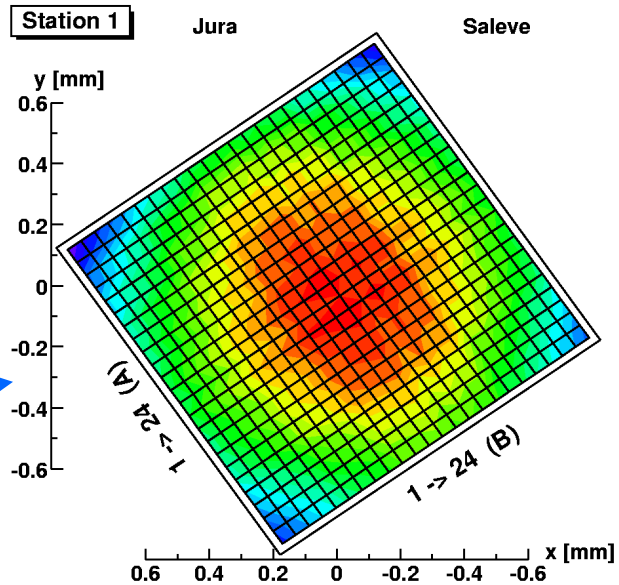
Cryogenic Silicon Beam Tracker

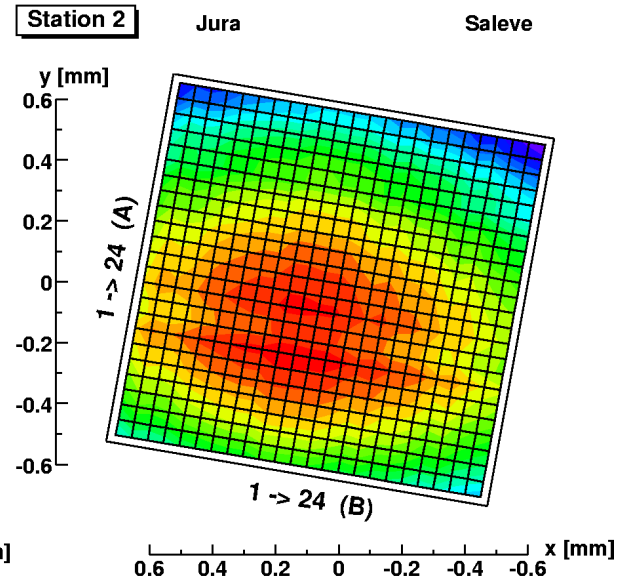
- June 2002 proton run :
  - ✓ improved electronics to fight pick-up noise
  - ✗ one of the modules did not work the last week
- October 2002 Pb run :
  - ✓ all silicon sensors worked well
  - ✓ timing spectra very clean, 1.7 ns accuracy
  - ✗ cryogenics system unstable in the last days
    - ➔ modules almost at room temperature





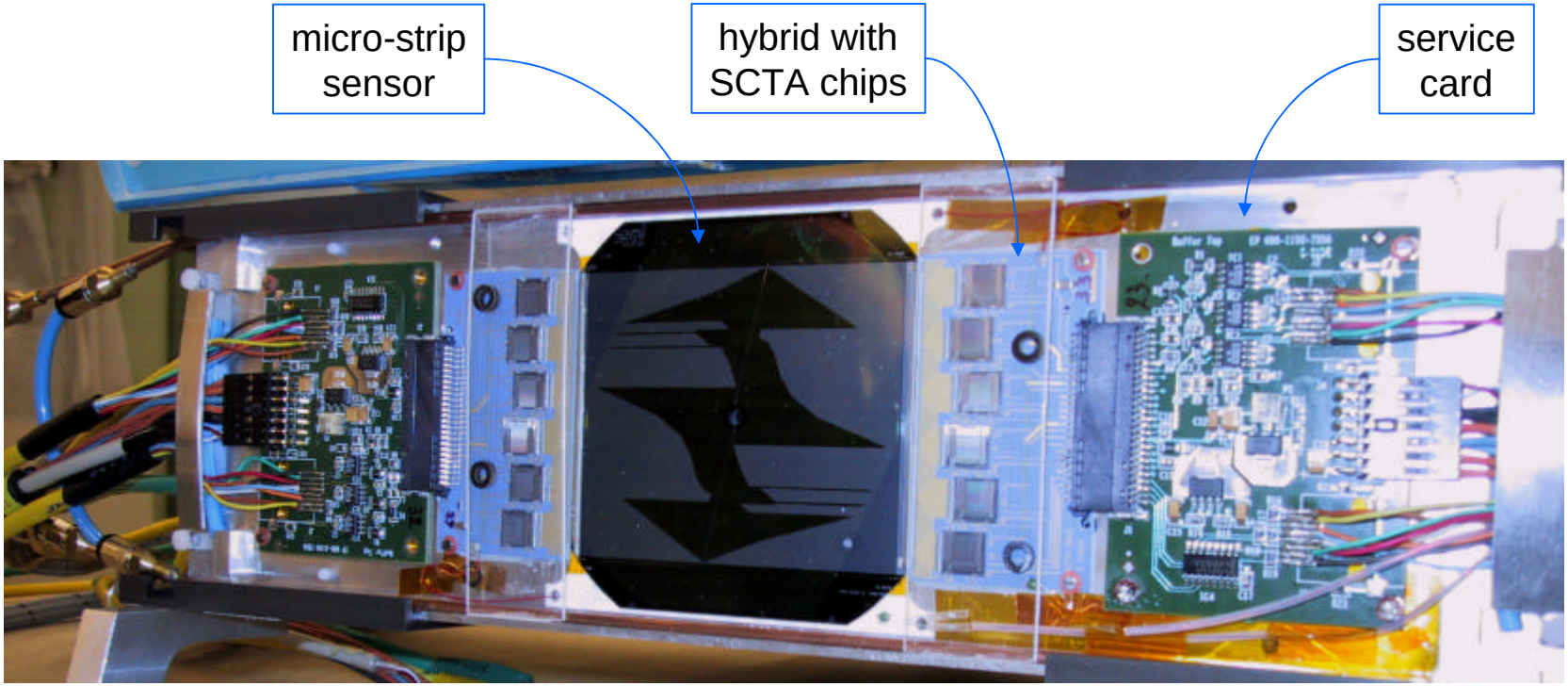
20 GeV/nucleon
Pb beam profiles
(very broad beam)





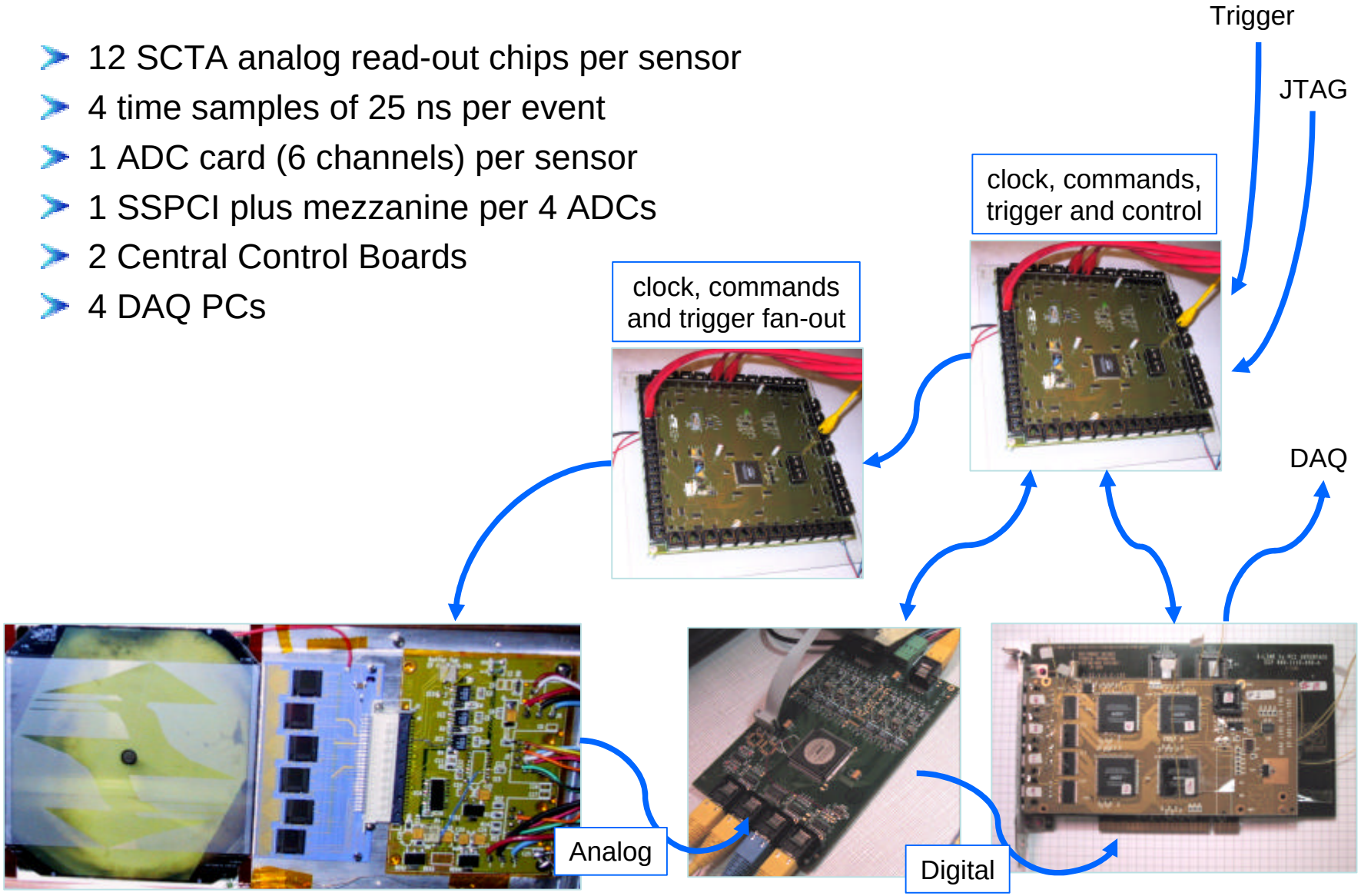
Micro-Strip Detectors

- Very special sensor design
  - ✓ divided in several regions of strip pitch = 60, 80, 135, 151, 227 µm
  - ✓ tilted lines to measure momentum and angles with good precision
  - ✓ second metal layer for the readout lines ; 12 x 128 strips per sensor
  - ✓ 90 mm diameter to cover dimuon acceptance at 40 cm from target
  - ✓ beam hole at the center of the sensor
  - ✓ 300 µm thick sensors



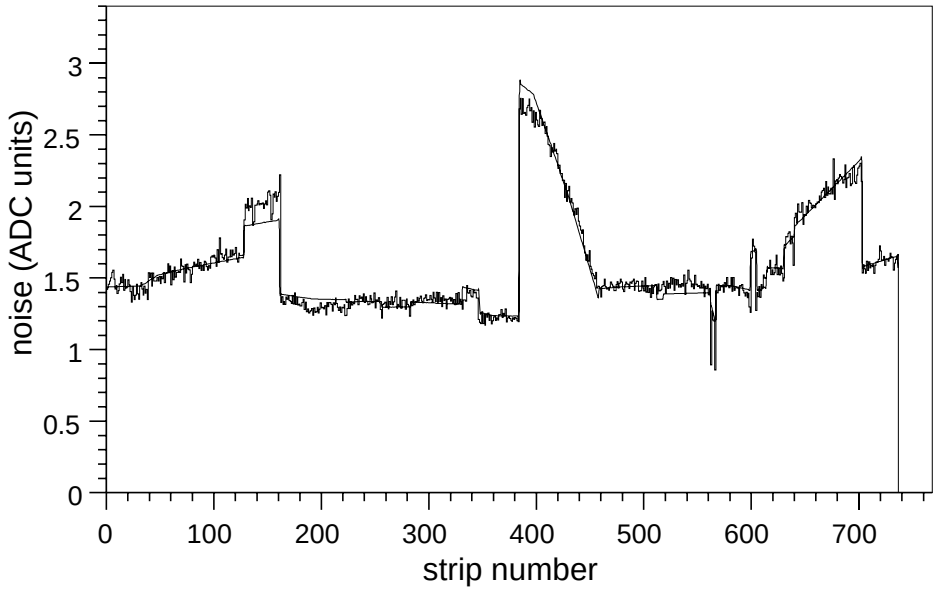
Micro-Strip Read-out Chain

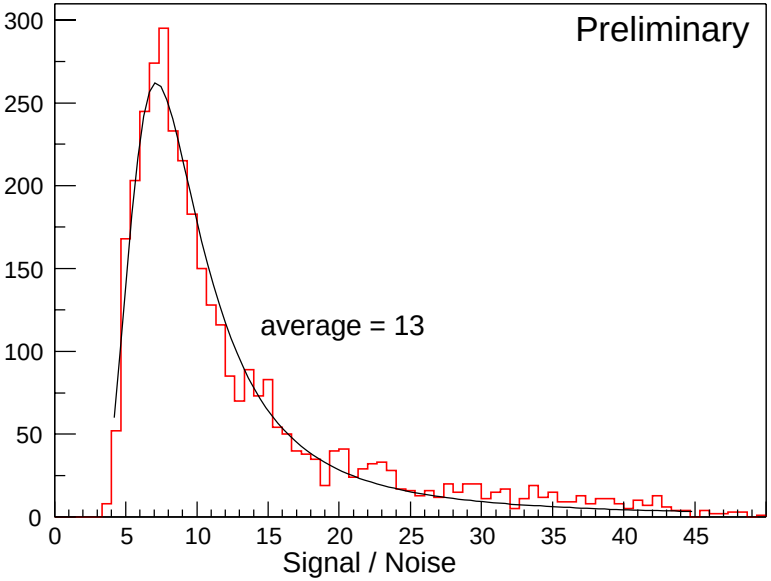
- 12 SCTA analog read-out chips per sensor
- 4 time samples of 25 ns per event
- 1 ADC card (6 channels) per sensor
- 1 SSPCI plus mezzanine per 4 ADCs
- 2 Central Control Boards
- 4 DAQ PCs



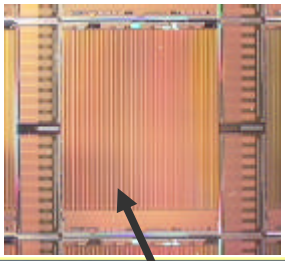
Micro-Strip Detectors : Operation

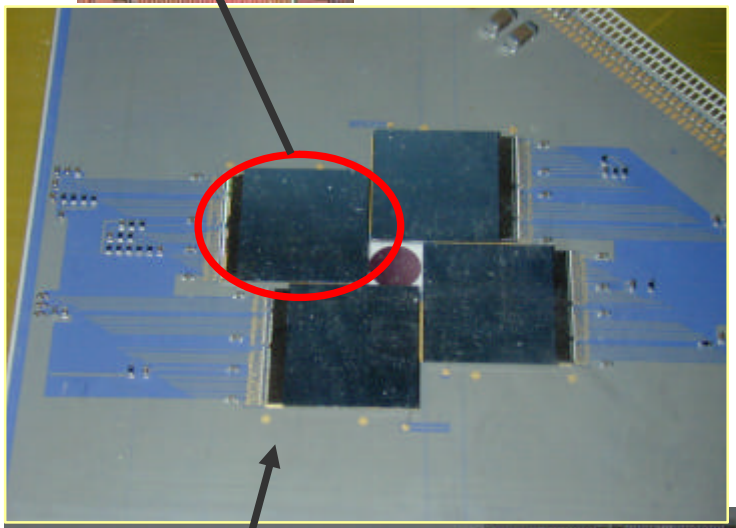
- Telescope ready for data collection only in the last week of the run due to delays in the production of the modules and read-out chain
- Only 14 planes could be read out, two of them only partially due to limited number of operational channels in one Central Control Board
- One sensor developed high leakage current and could not be depleted
- Noise pattern follows the very special geometry of the sensor
- Average signal to noise ratios around 12, depending on the region
- Cluster size around 1.5
- Performance analysis still preliminary

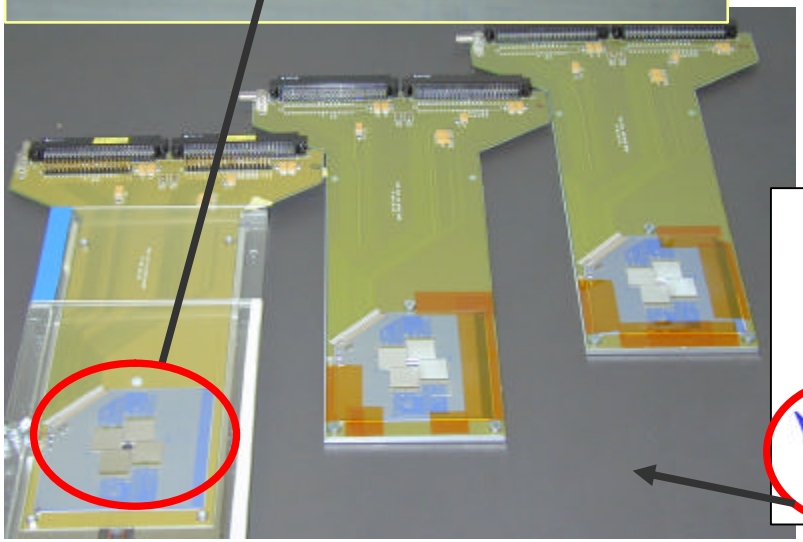




Silicon Pixel Detectors : Assembly

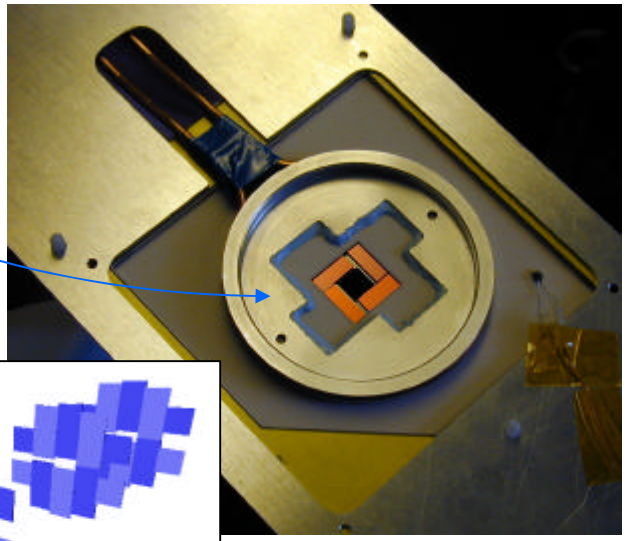


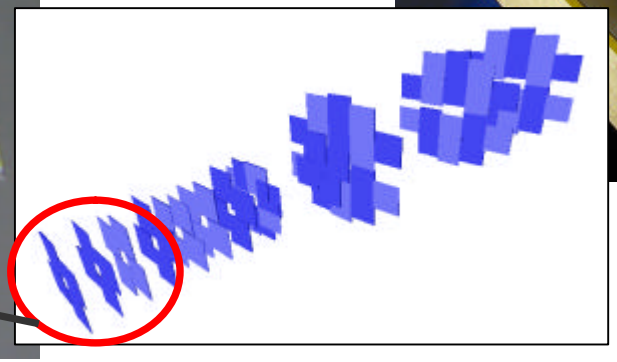




- 10 planes of 4 chips and 6 planes of 8 chips
- ALICE1LHCB read-out chips, 750 µm thick
- 8192 cells of 50 x 425 μm^2
- 300 µm thick sensors
- 2 different hybrids ; 3 different PCBs
- bump bonding : VTT, 20 µm solder bumps
- wire bonding : EP-TA1-SD

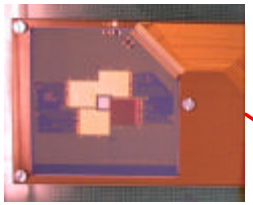
water cooling : copper pipe on aluminum ring



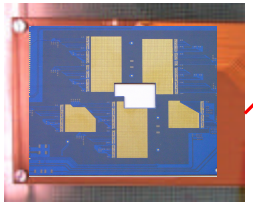


Silicon Pixel Detectors : Read-Out

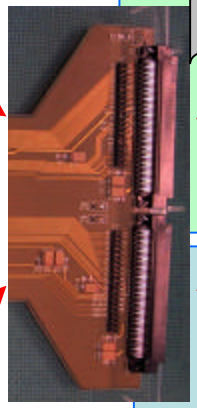
- 10 MHz chip clock
- 200 ns read-out strobe
- around 140 MB/burst



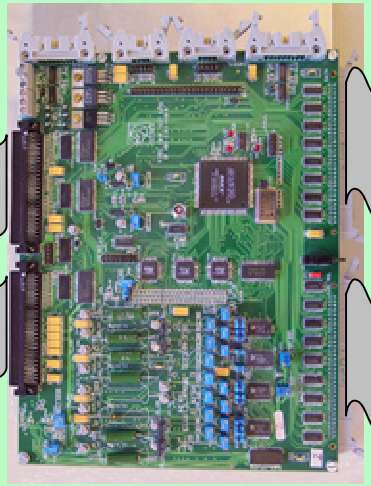
Hybrids



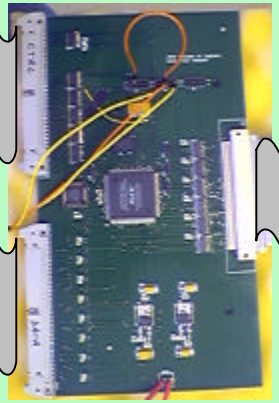
PCB



MB card



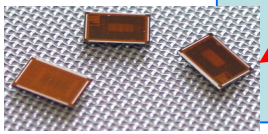
Adapter card



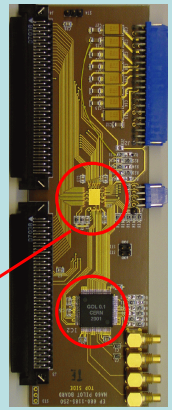
PRB mezzanine

2002

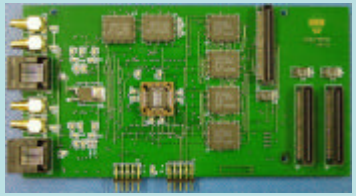
2003



Pilot chips



Pilot + GOL PCB

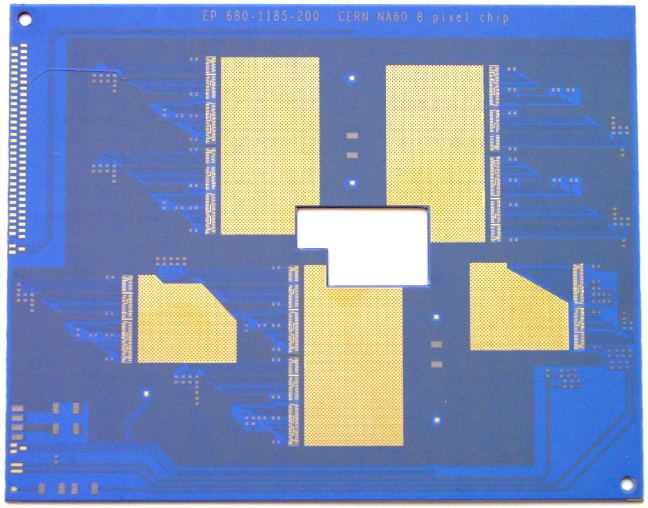


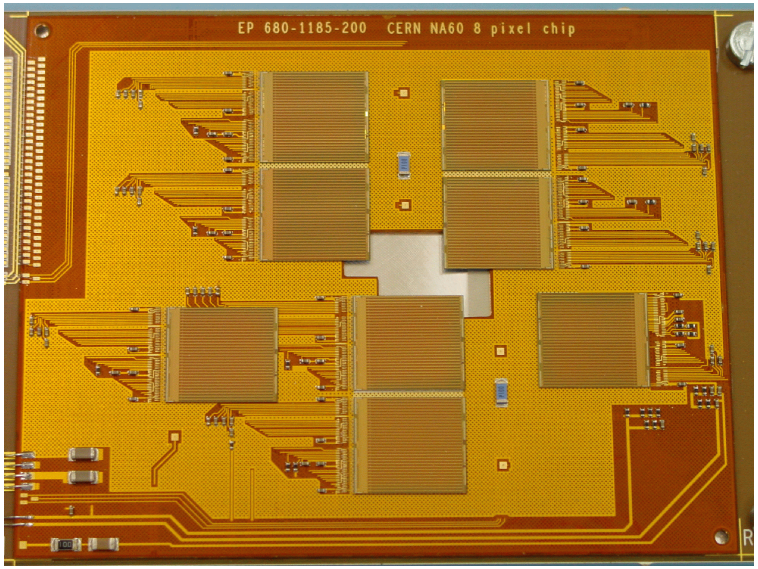
Pilot Mezzanine

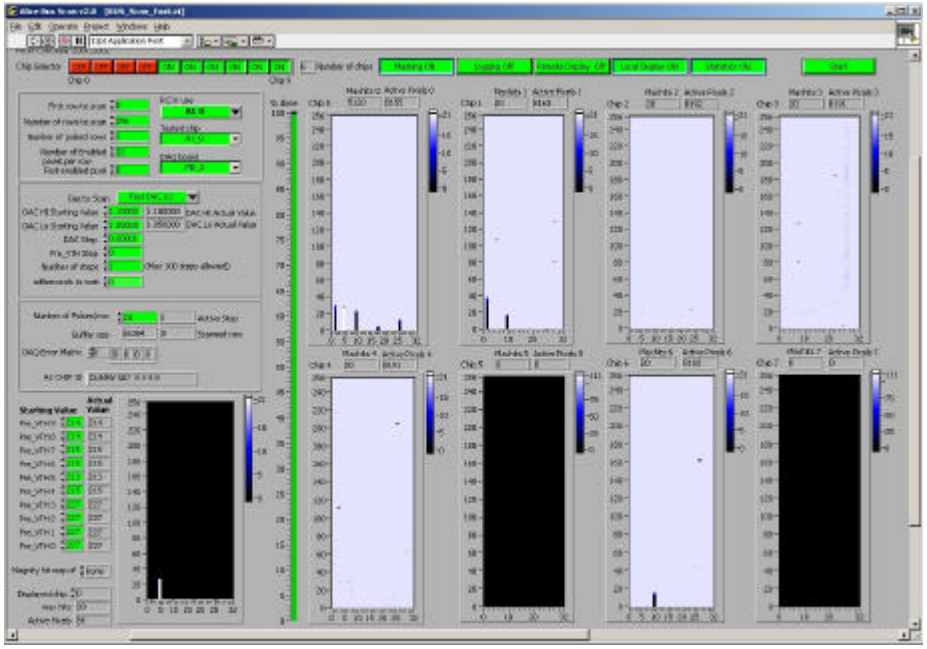
Silicon Pixel Detectors : Large Planes

- Final hybrids in Al N
  - ✓ Improved heat dissipation

- Copper hybrid for preliminary tests
  - ✓ 8 read-out chips mounted
  - ✓ 6 wire-bonded and working

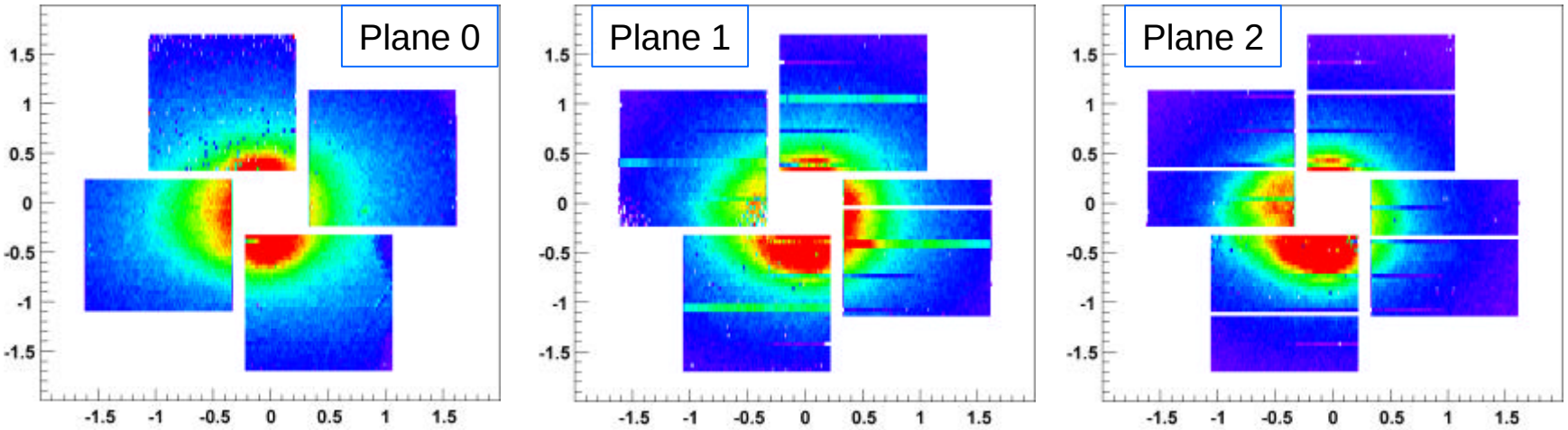




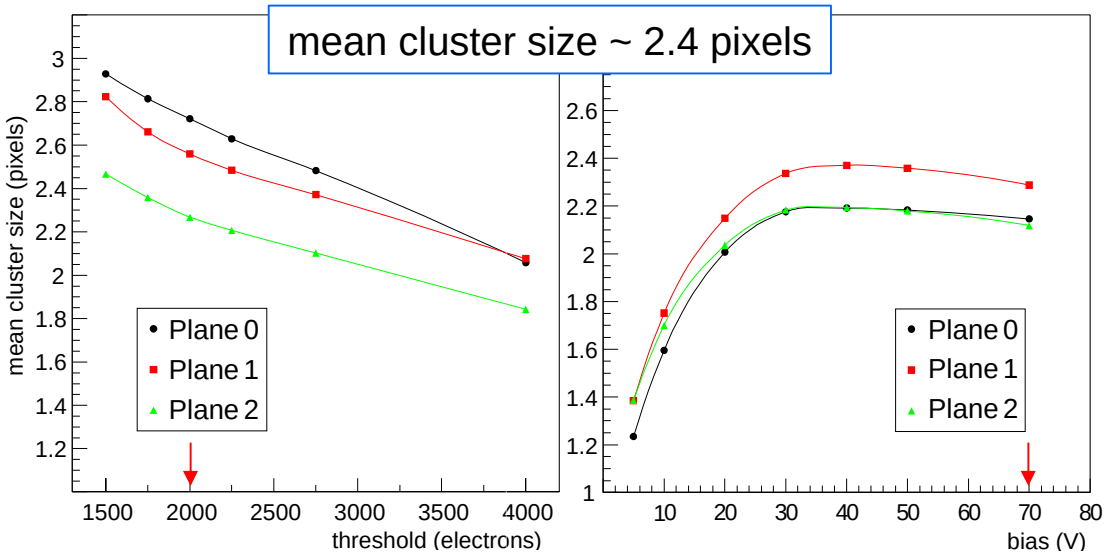


Silicon Pixel Detectors : Operation

- Hit-maps integrated over ~ 1 hour of Pb running :

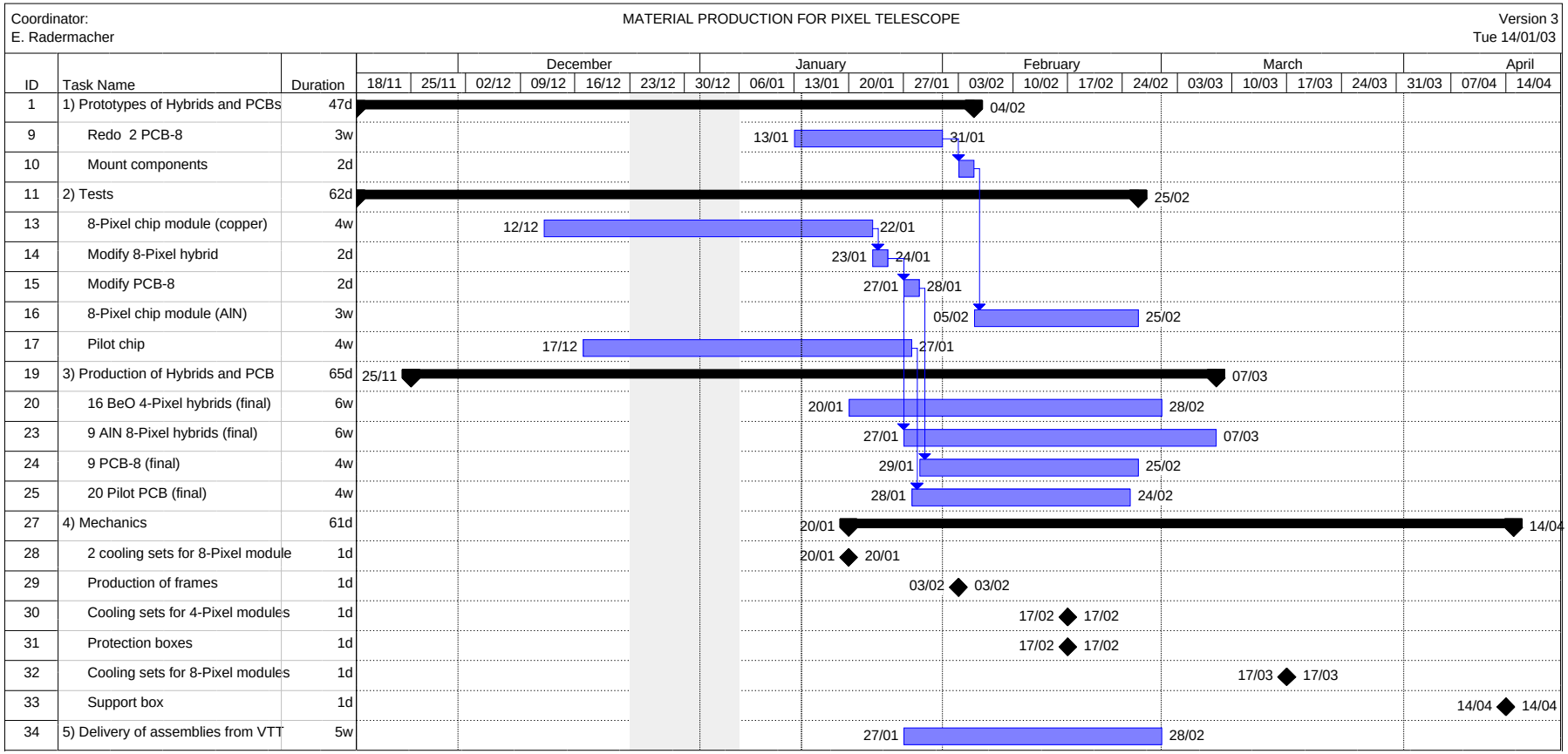


- ✓ The 3 planes worked very well
- ✓ Less than 0.5 % noisy pixels
- ✓ Same dead pixels as in the lab
- ✓ Data cables 5 m long :
  - × 1 open channel
  - × 2 wires shorted
- × Test columns were half efficient in planes 1 and 2



Planning of the Pixel Telescope Production

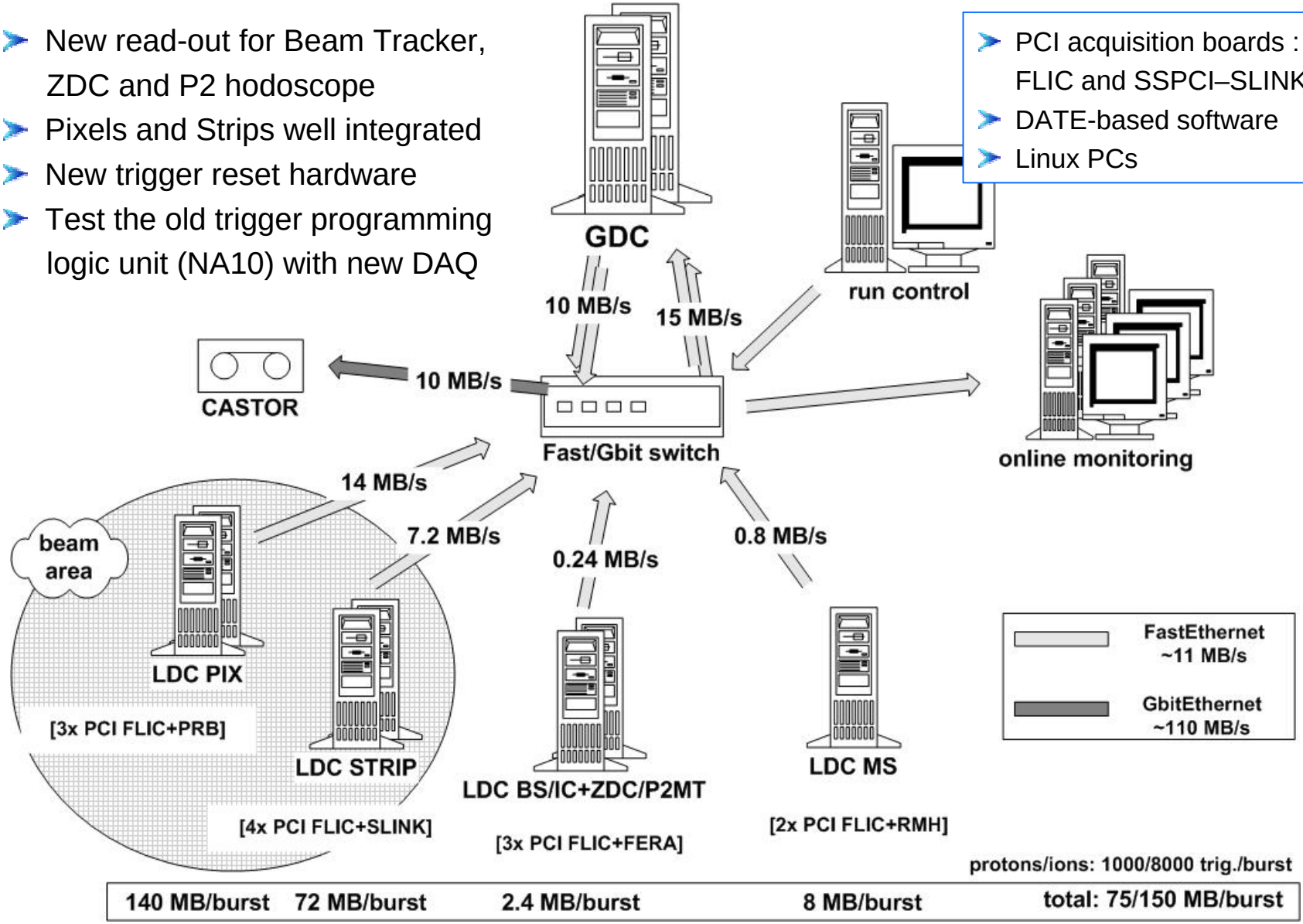
- Four read-out chip wafers and five sensor wafers being bump-bonded
- All hybrids, PCBs, support frames, etc., should be ready in April



Data Acquisition System and Trigger

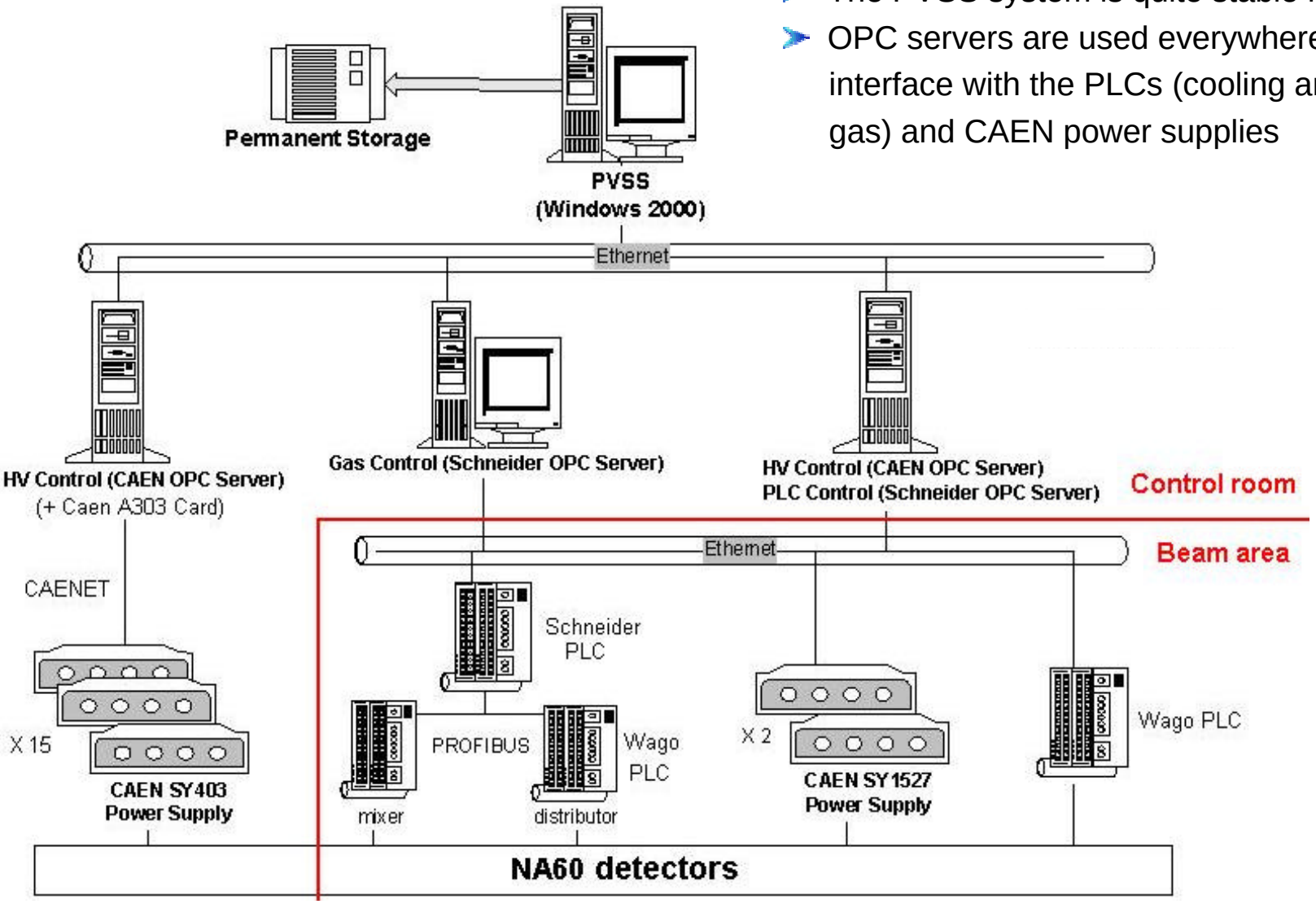
- New read-out for Beam Tracker, ZDC and P2 hodoscope
- Pixels and Strips well integrated
- New trigger reset hardware
- Test the old trigger programming logic unit (NA10) with new DAQ

- PCI acquisition boards : FLIC and SSPCI–SLINK
- DATE-based software
- Linux PCs



Detector Control System

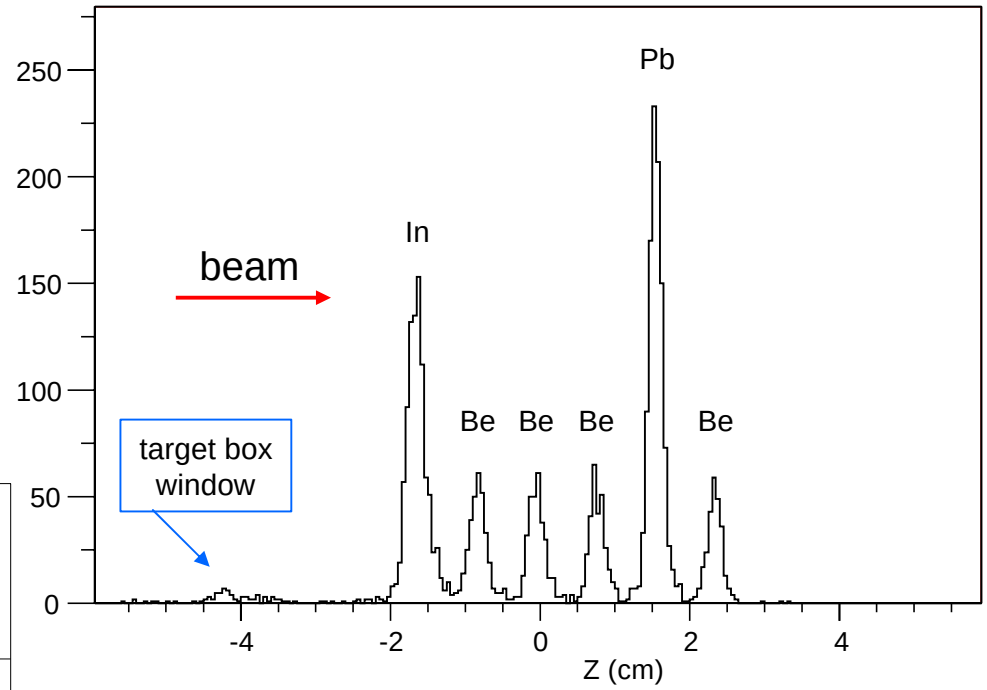
- Important evolution during 2002
- The PVSS system is quite stable now
- OPC servers are used everywhere to interface with the PLCs (cooling and gas) and CAEN power supplies

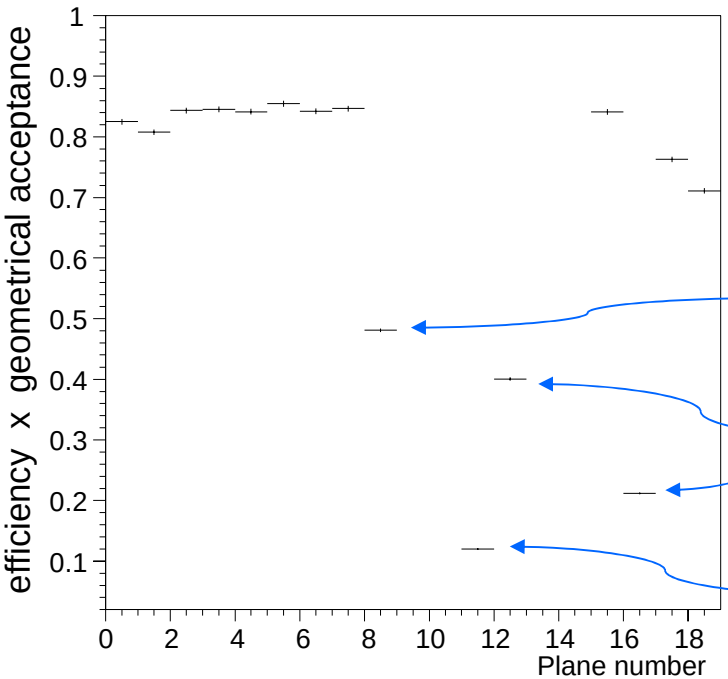


Analysis of the June p-A Data : Tracking

- Z-vertex resolution ~ 900 µm
- 2 mm thick targets clearly seen

- Sensor efficiencies around 85 %
- Analysis procedure still evolving





Small pixel plane

Sensors partially read out

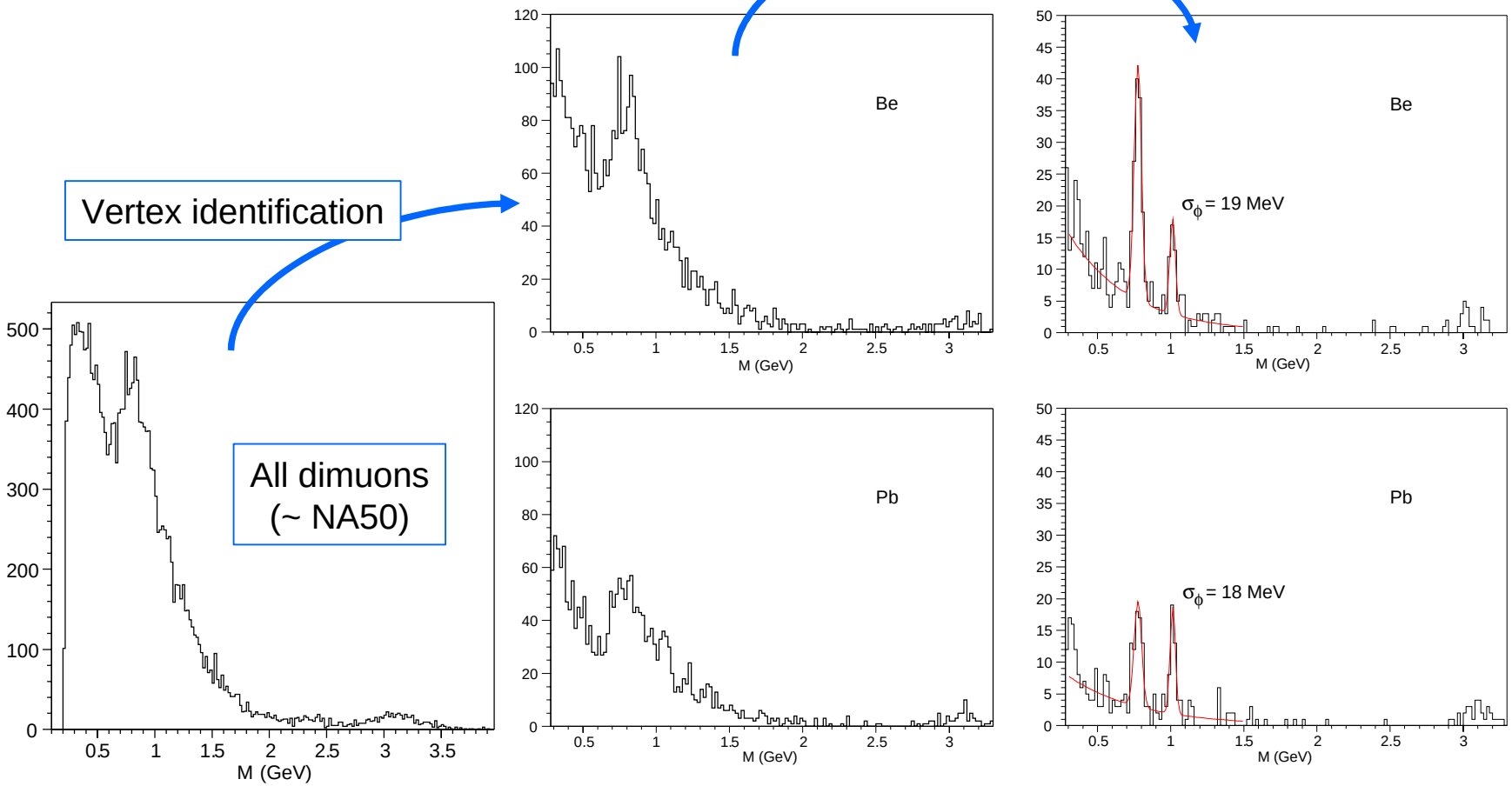
Sensor not depleted

Analysis of the June p-A Data : Dimuons

- Dimuon mass resolution : ~ 20 MeV at the ϕ mass
- Very preliminary results
  - ✓ ~ 10 % of collected statistics
  - ✓ still evolving algorithms

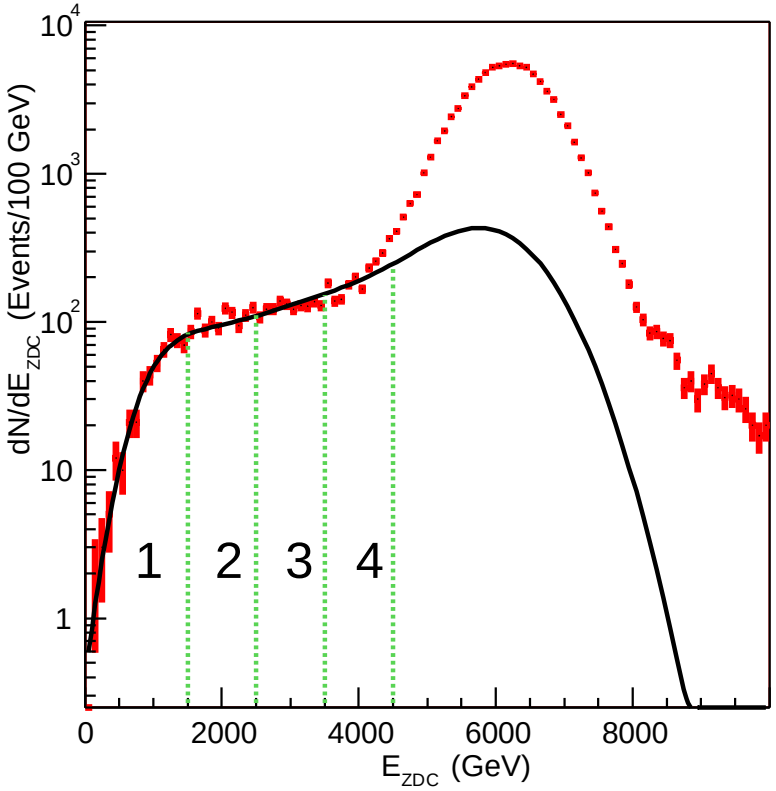
Muon track matching

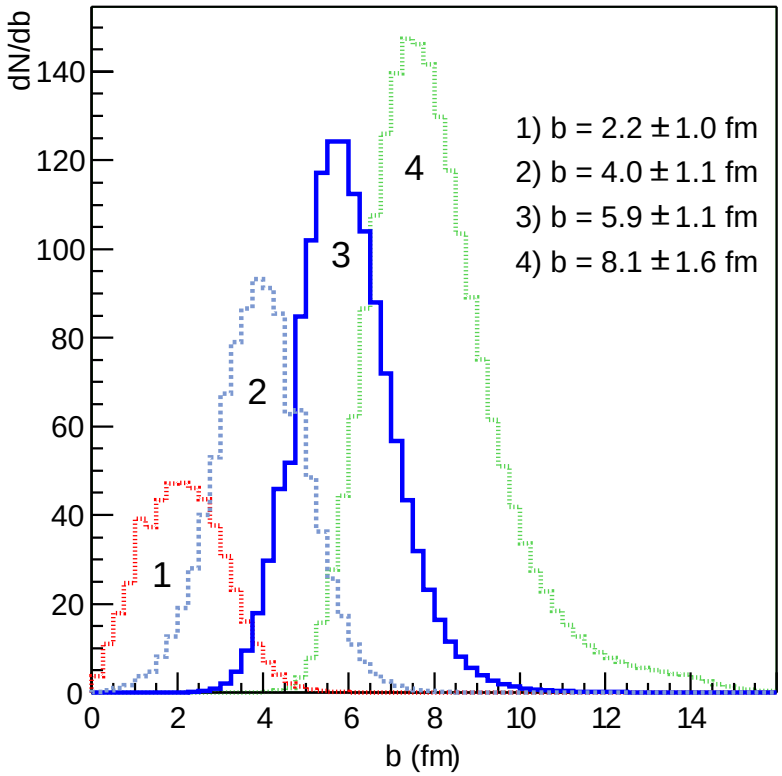
Vertex identification



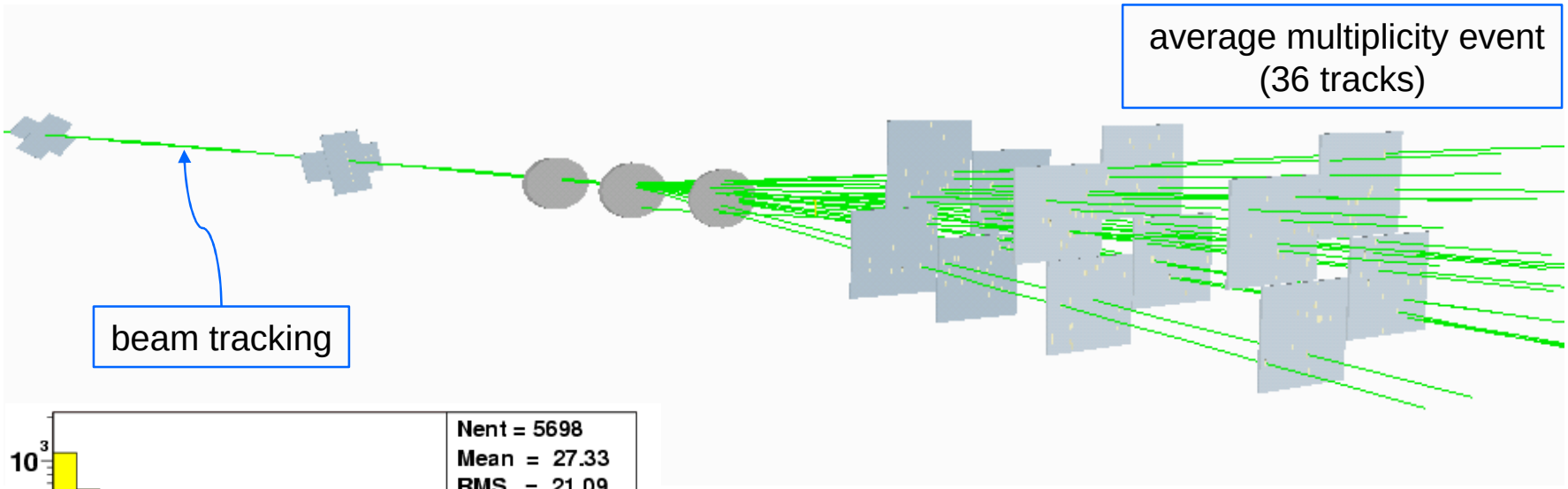
October Pb-Pb Data : Centrality Determination

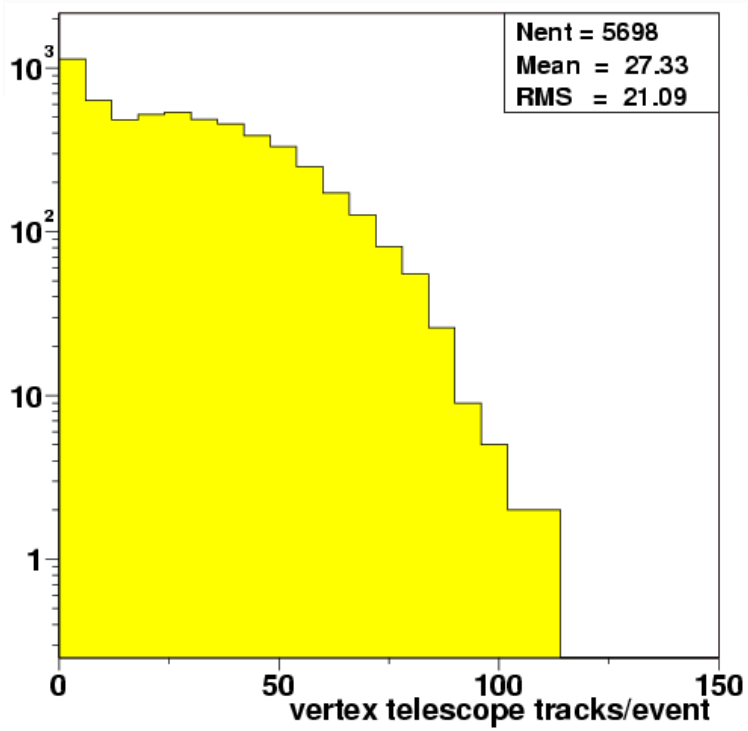
- The resolution of the ZDC energy measurement depends on the beam energy
  - ✓ ~ 10% for 30 GeV/nucleon
  - ✓ ~ 15% for 20 GeV/nucleon
- The Glauber model of Pb-Pb interactions describes the measured spectra away from the peak of non-interacting beam ions
  - ✓ 4 centrality bins for the 30 GeV/n data and 3 for the 20 GeV/n data





Analysis of the October Pb-Pb Data : Tracking

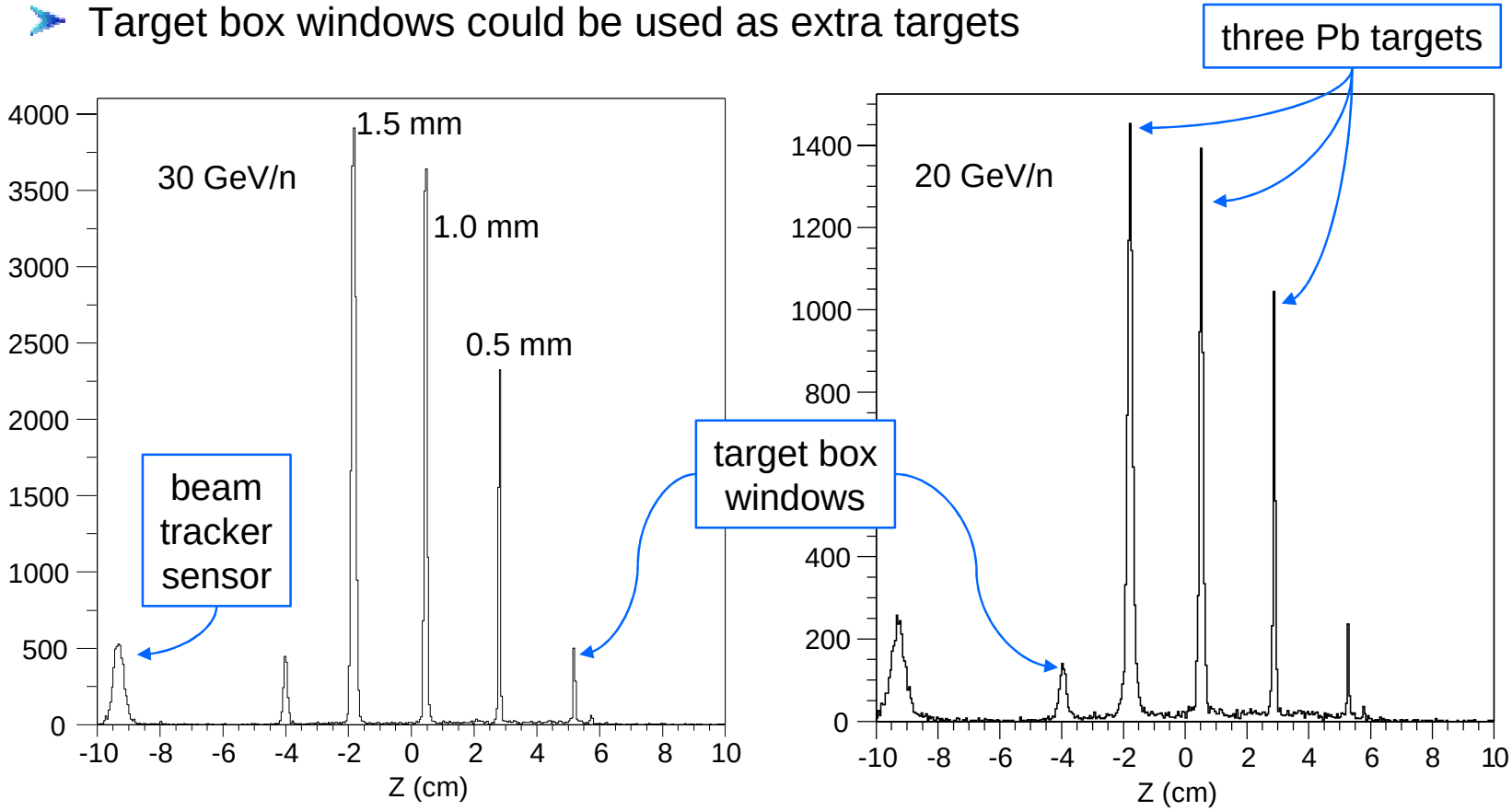




- Setup accurately aligned (offline)
  - ✓ sensitive to the temperature of the beam tracker modules
- Tracking procedure works very well
- Almost all the collected data has already been processed (using our DAQ PCs)

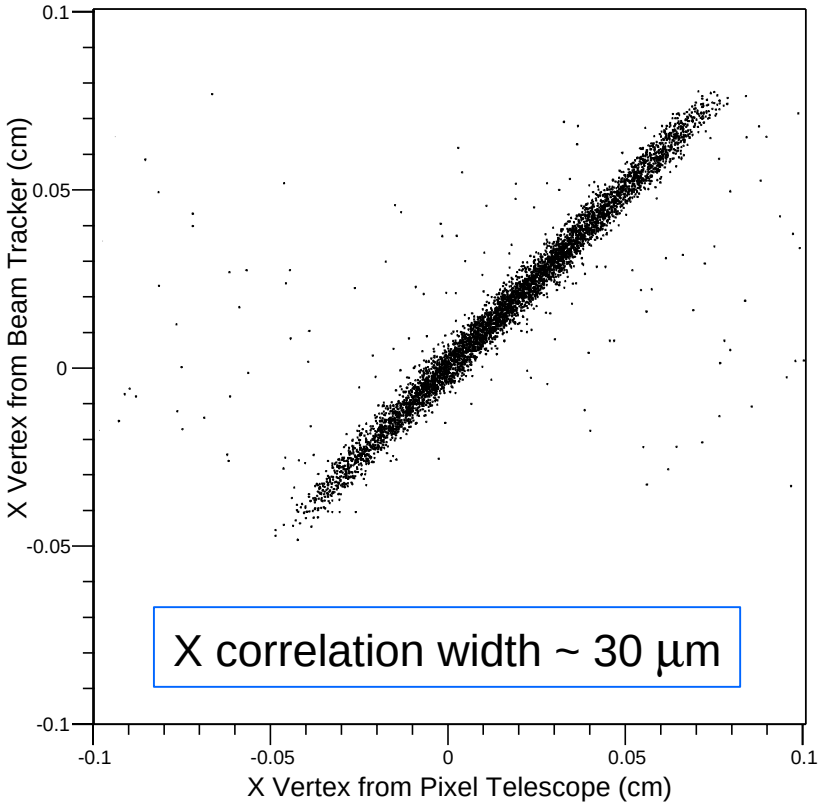
October Pb-Pb data : Z-vertex

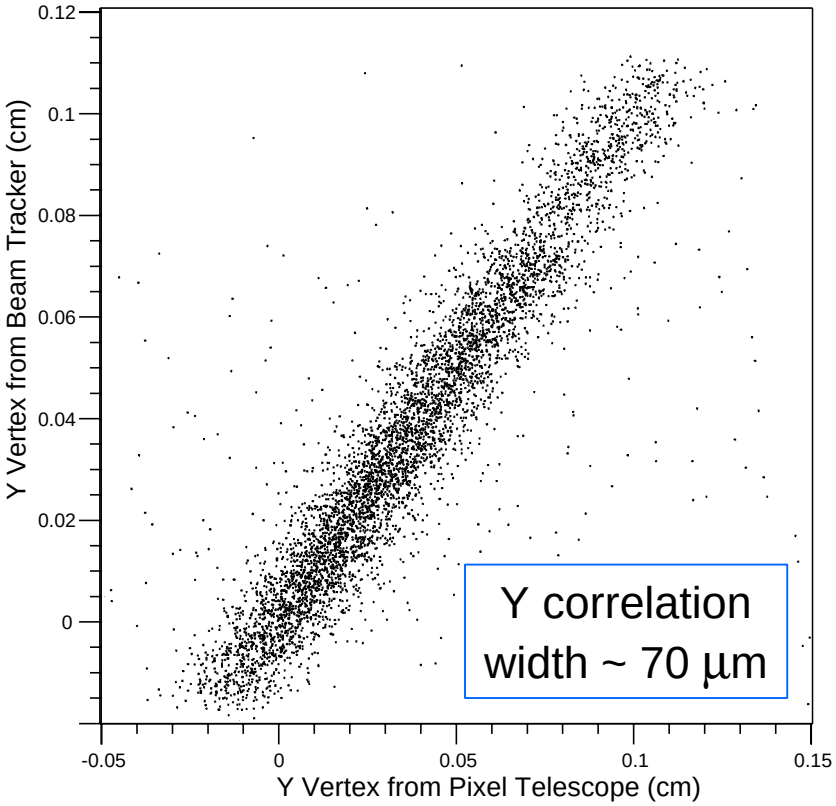
- The Z coordinate of the interaction vertex is reconstructed with
  - ✓ ~ 190 μm resolution for 30 GeV/nucleon
  - ✓ ~ 320 μm resolution for 20 GeV/nucleon
- The accuracy will be even better with more tracking planes
- Target box windows could be used as extra targets



October Pb-Pb Data : Transverse Coordinates of the Vertex

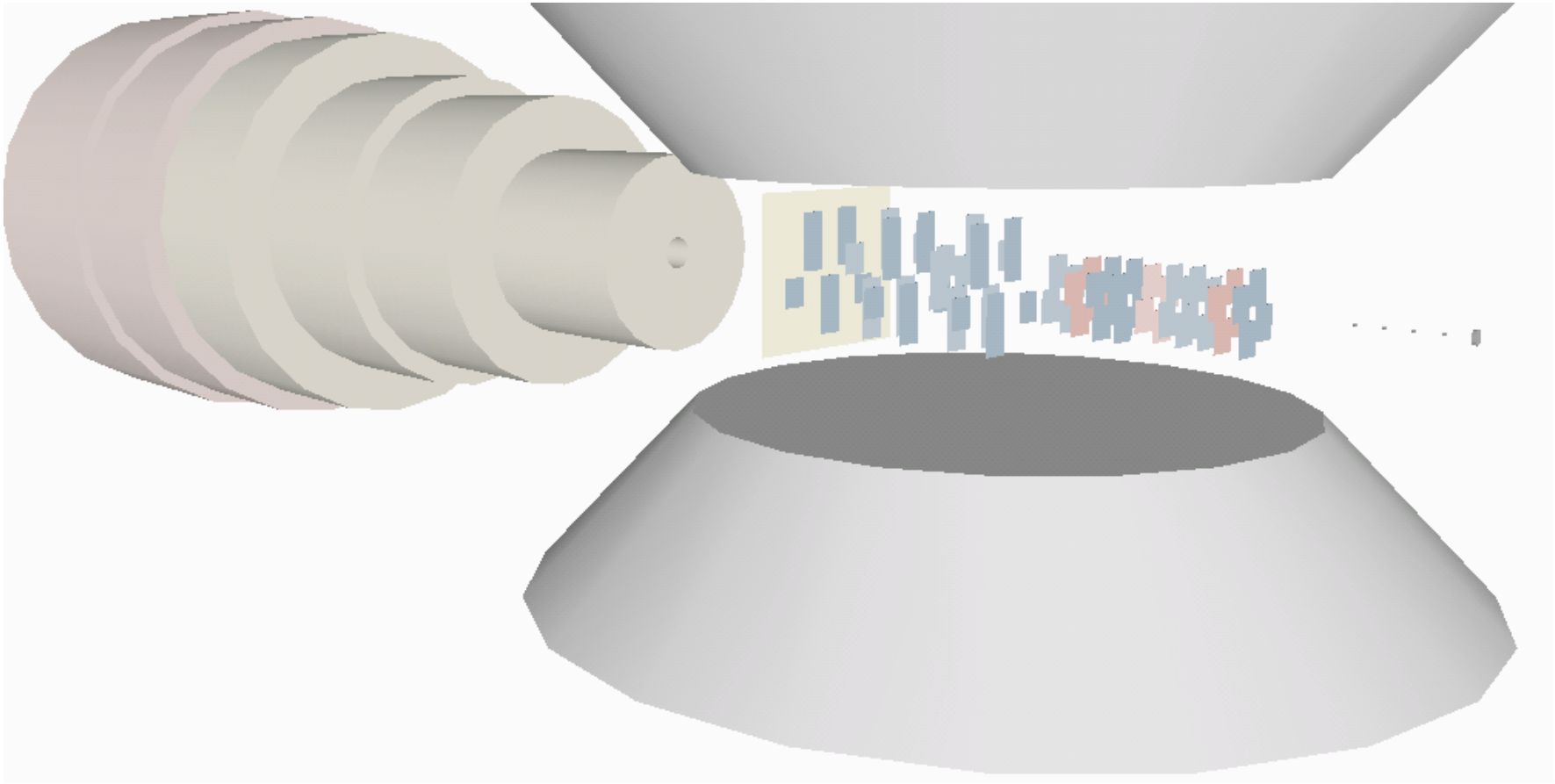
- The X coordinate of the interaction vertex is reconstructed by the 3-plane pixel telescope with an accuracy of ~ 20 µm
- The accuracy of the Y coordinate is not as good because all the planes are of the X kind
- Resolutions around 10 µm should be reached with the full telescope





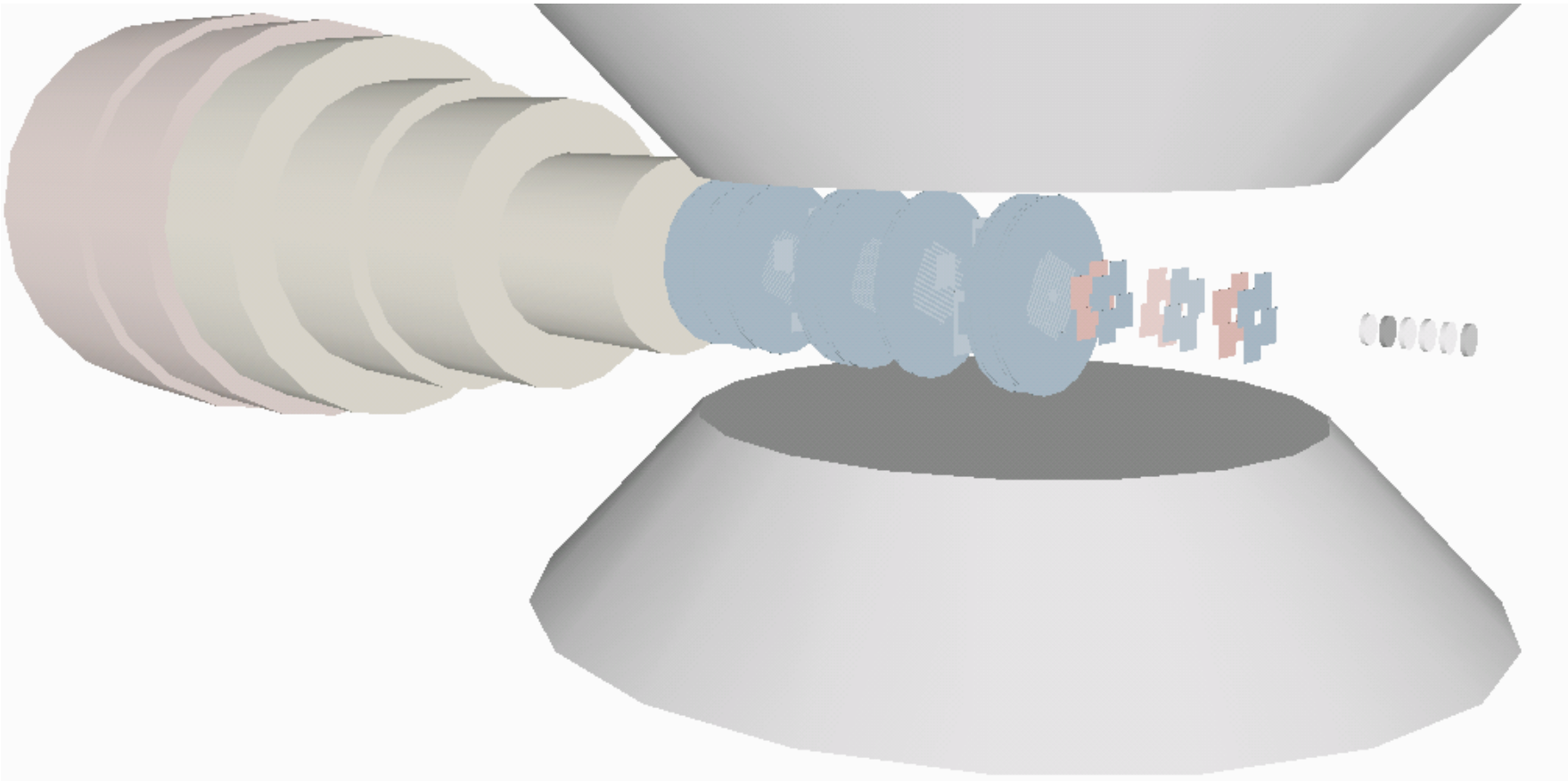
Silicon Pixel Telescope for In-In Run

- Ten 4-chip and six 8-chip pixel planes (grouped in three stations)
- Last tracking plane at 32 cm from the center of the target
- Acceptance coverage optimized for dimuons from ω or J/ψ decays



Silicon Tracking Telescope for Next Proton Runs

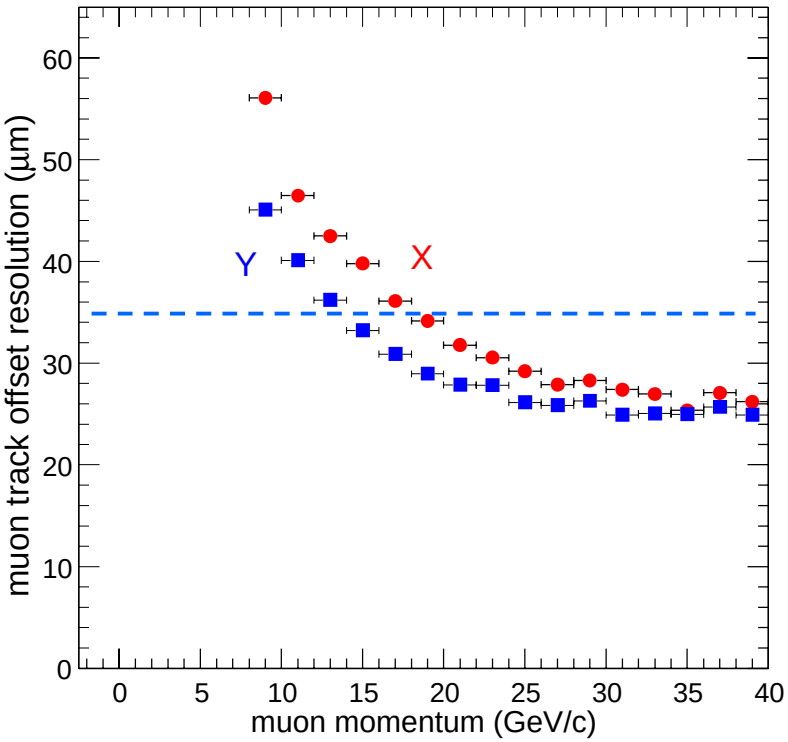
- Mixed setup : 8 strip tracking stations complemented by pixel planes
- Strip planes : faster read-out, less material and bigger angular coverage
- Pixel planes : much better granularity and signal to noise ratio
- Target system : Be, In and Pb, complemented with Al windows



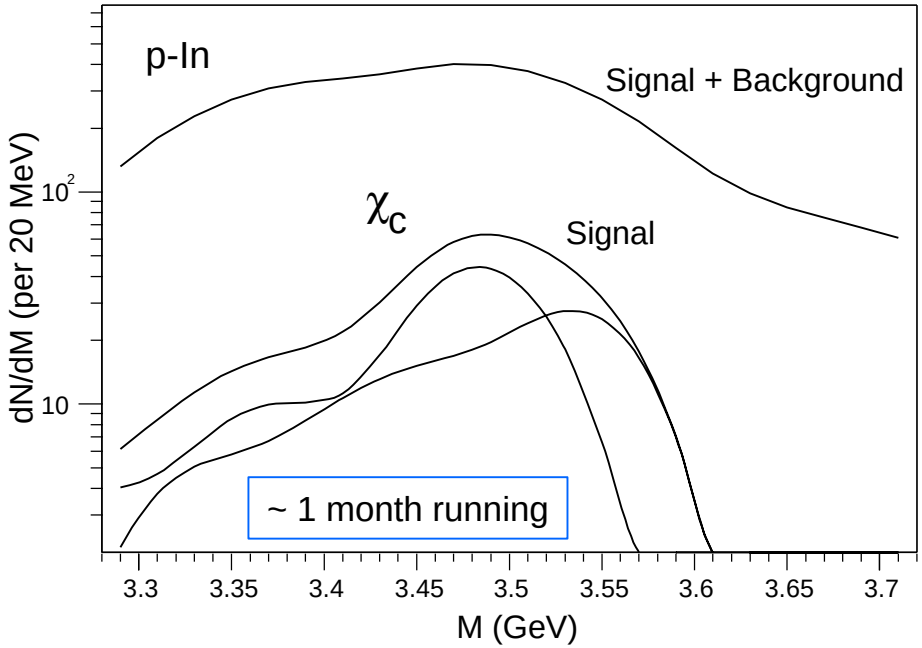
Physics Performance Simulations

- We are presently re-evaluating the physics performance of the experiment
  - to account for the changes with respect to the proposal
  - to incorporate what we learned with the 2002 runs

muon track offset resolution
better than 35 μm for p>15 GeV/c



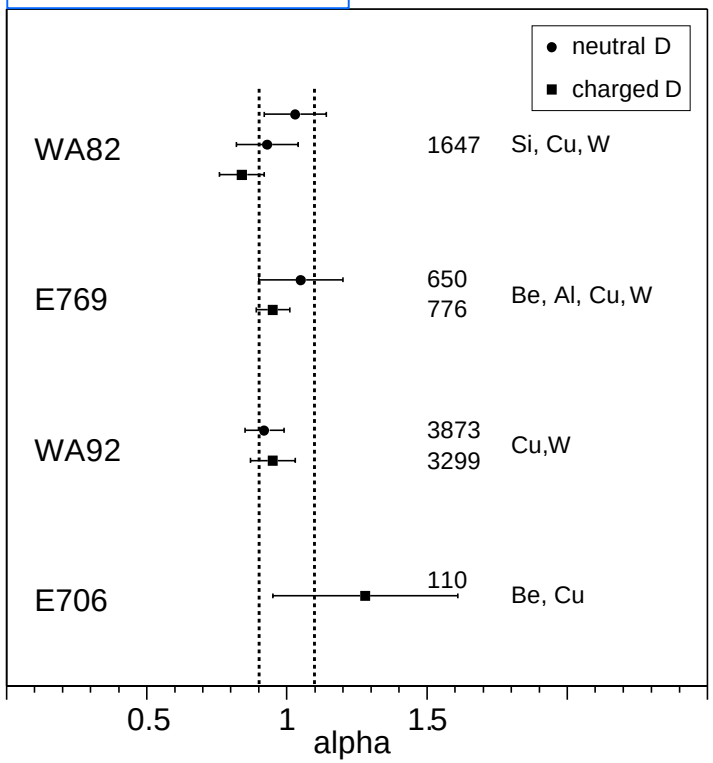
thicker pixels :
increased background from conversion of photons uncorrelated with the χ_c decay
$\Rightarrow$ increased luminosity needed !



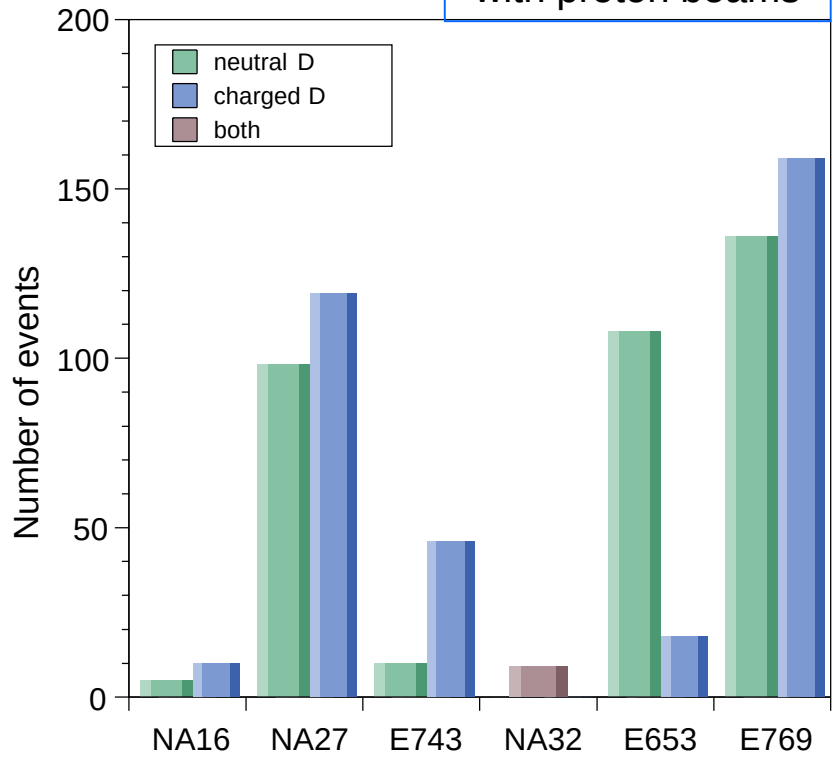
A-dependence of open charm in p-A collisions

- Establish an accurate reference baseline to compare with the heavy-ion results
- Measure the nuclear dependence of open charm production with p beams
  - Existing measurements done only with pion beams : $\alpha \sim 0.9–1.1$
  - Experiments with proton beams have very poor statistics ($\leq$160 events)

α measurements with pion beams

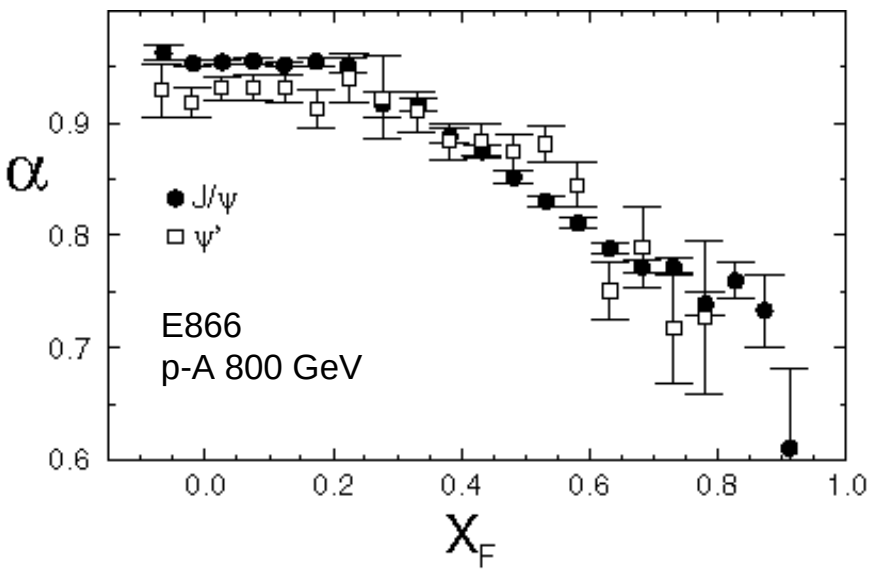


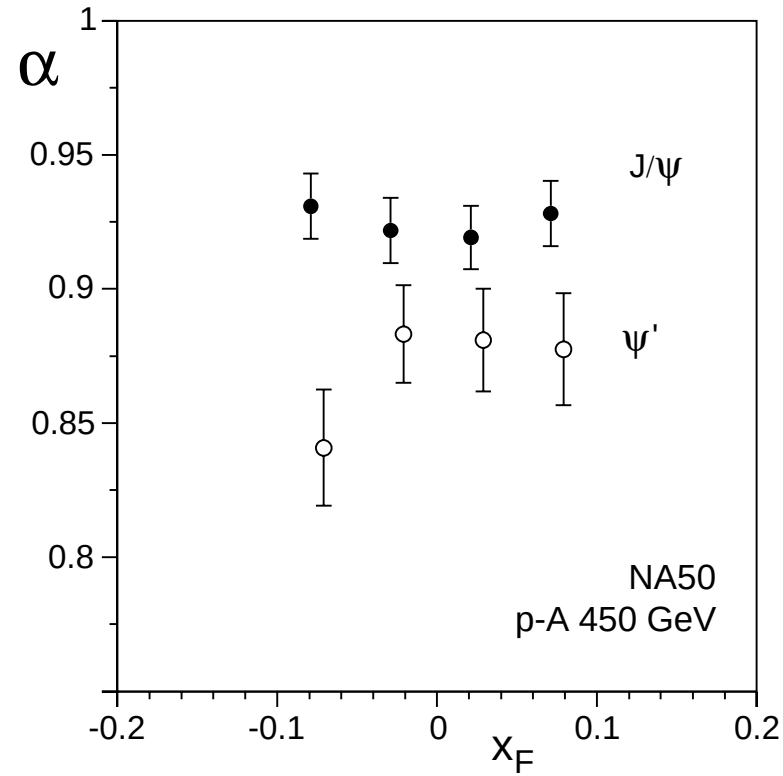
Charm experiments with proton beams



Charmonium production in p-A collisions

- E866 and NA50 : stronger nuclear absorption for ψ' than for J/ψ (for low xF)





NA50 : $\alpha(\psi') - \alpha(J/\psi) = -0.045 \pm 0.007$

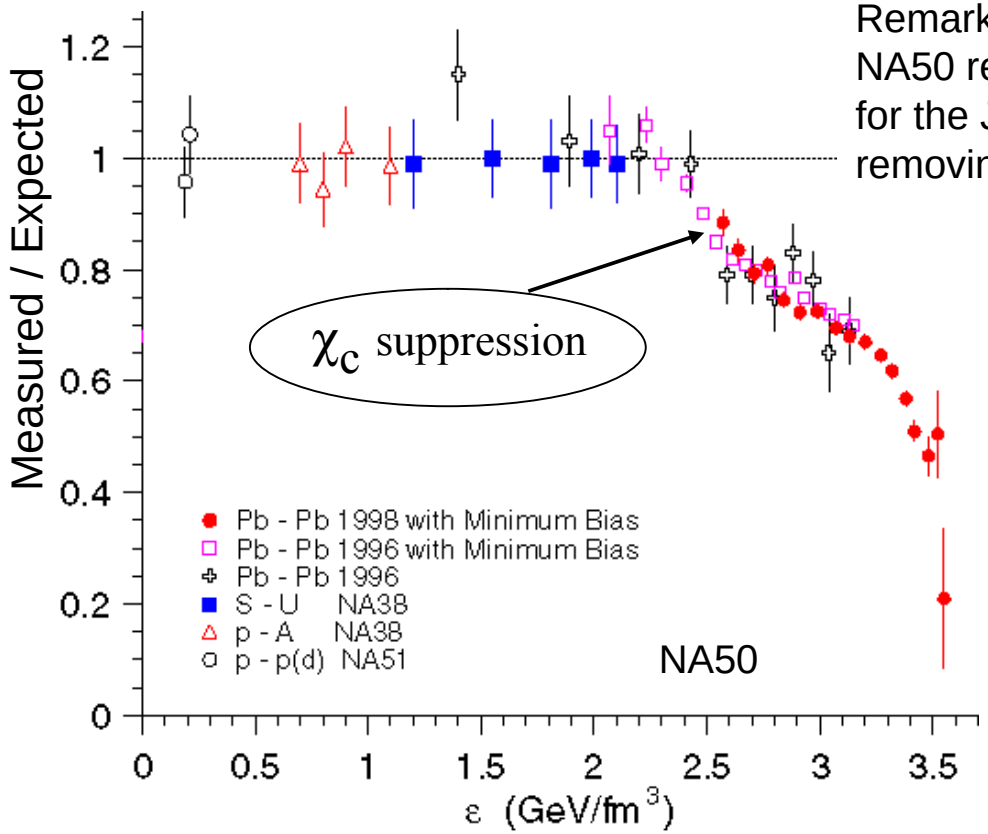
Remark :

With much less statistics, NA38 published : $\alpha(\psi') - \alpha(J/\psi) = +0.016 \pm 0.009$

Charmonium suppression in heavy-ion collisions

- NA50 : the χ_c is suppressed in semi-central Pb-Pb collisions with respect to the normal nuclear absorption of the J/ψ

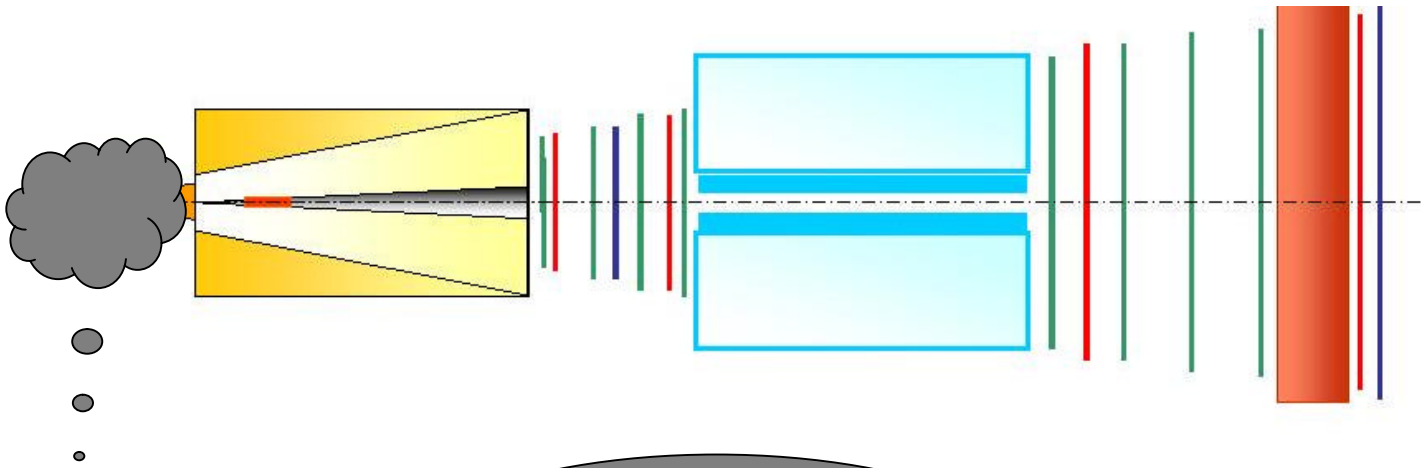
➔ Measure the χ_c / ψ production cross-section ratio and its nuclear dependence



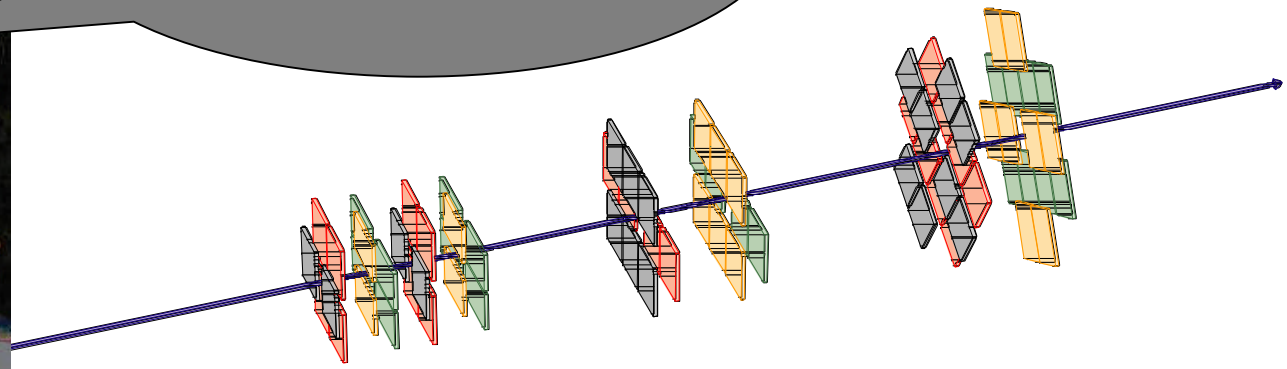
Remark :
NA50 recently published $\sigma_{abs} = 4.3 \pm 0.6$ mb for the J/ψ nuclear absorption cross-section after removing (10%) feed-down from ψ' decays
(it used to be 6.4 mb)

Open questions :
⇒ Onset of what exactly ?
⇒ As a function of which variable ?
⇒ Is there really a second step ?

From a dream in 1996 : upgrade NA50 …



Let's add silicon detectors to track the muons before they traverse the hadron absorber



… to the reality in 2003

- Completely new in NA60 :
  - ✓ Cryogenic Silicon Beam Tracker
  - ✓ Silicon Pixel Detectors
  - ✓ Silicon Micro-Strip Detectors
  - ✓ 2.5 T Vertex Dipole Magnet
  - ✓ Multiple Target (in vacuum)
  - ✓ Interaction Counter
  - ✓ Quartz Blade
  - ✓ DAQ System
  - ✓ Read-out – DAQ Interfaces
  - ✓ Online Monitoring
  - ✓ Detector Control System
  - ✓ Offline Software
  - ✓ ***Most of the people…***

- Effectively, NA60 is a new experiment, with state-of-the-art detectors, read-out electronics, DAQ, controls and offline

- NA60 is now ready for precision p-A and nucleus-nucleus studies based on a 15-year long learning curve

- But open charm and heavy quarkonia are rare processes ; their study requires good statistics and controlled systematics

- Good physics requires beam time

Beam Time Request for the Indium run

- In what concerns charmonia production and suppression, the SPS is more than just competitive w.r.t. RHIC – it is the ideal tool to study the onset of suppression patterns. To study the critical region, RHIC would have to either decrease the energy or use lighter nuclei or both, and would still suffer from luminosity (never do in a collider what can be done in a fixed-target experiment).

- A detailed and improved study of some NA50 observations
  - charmonia suppression
  - open charm enhancement vs. thermal dimuon production
  - ϕ enhancement

requires running the full indium beam period at 158 GeV/nucleon

- *Extraordinary claims require extraordinary evidence*

Beam Time Request for the proton run

- To distinguish open charm enhancement from thermal dimuon production we need a robust baseline established with p-A data

- The study of the χ_c production is crucial to
  - understand the χ_c suppression seen in Pb-Pb collisions
  - determine the charmonium formation process in space and time (major open issue in QCD), together with the ψ and ψ' nuclear absorption patterns

- We need to run two weeks in 2003, just before the ion run, to get started and 60 days in 2004 to complete our p-A physics program

➔ In the NA60 proposal we requested 60 days of protons for physics between 2002 and 2003

➔ We believe that running NA60 in 2004 is the only way to accommodate the beam time needs of NA48 and NA60

Many people helped converting the dream into reality

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