Vertex Detector Upgrade Plans for PHENIX at RHIC

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PHENIX

PHENIX Physics Goals

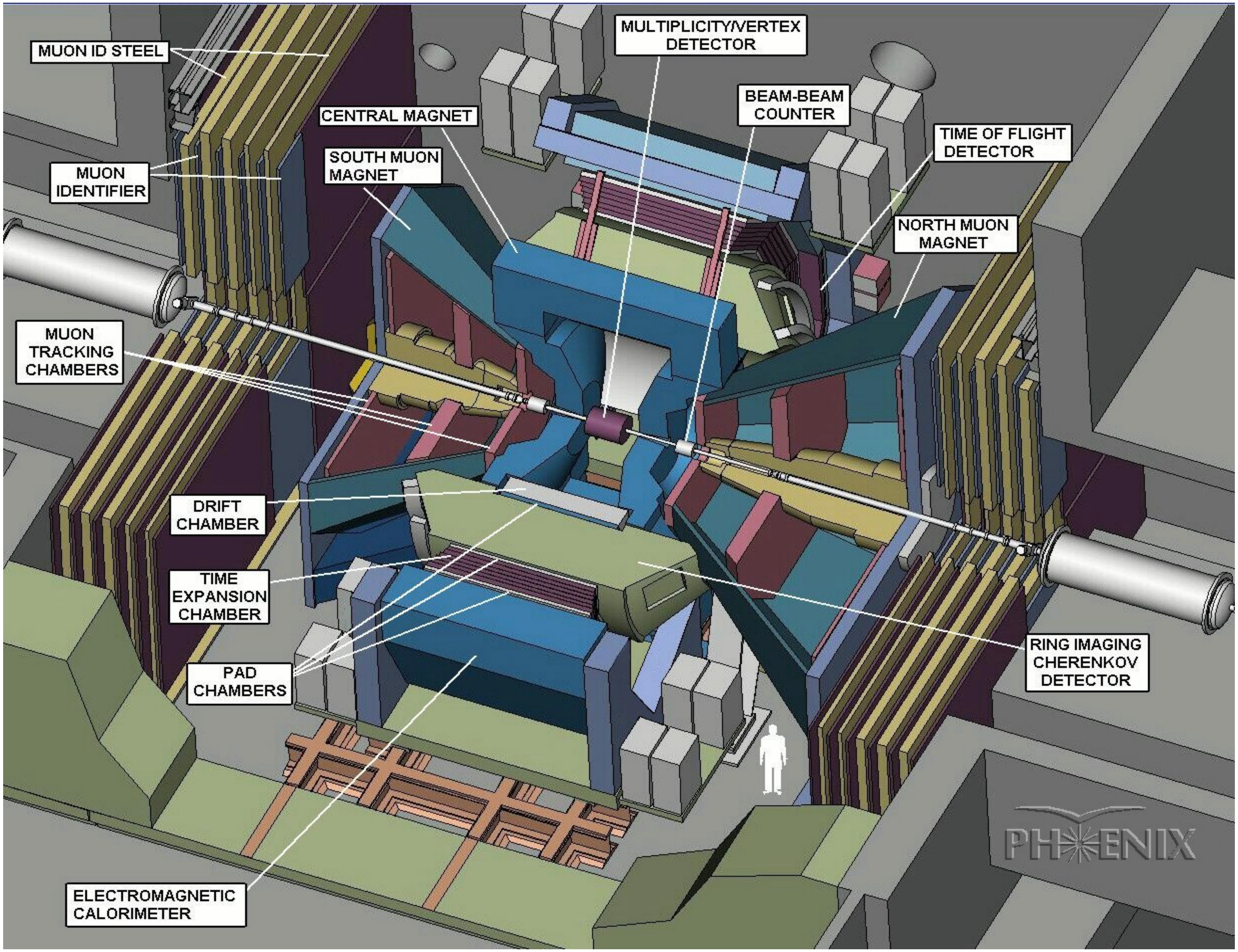
Relativistic Heavy Ion Physics:

- Detection of QGP state of nuclear matter in Au-Au-collisions at $\sqrt{s}$=200 GeV/nucleon. Measurement of its properties.
- Access leptonic and hadronic probes in the same experiment.
- Electron pairs, muon pairs, e-μ coincidences, photons, charged hadrons.
  - Lepton pairs: probe the plasma directly (vector mesons, continuum spectra)
  - Photons: probe the initial phase via prompt (thermal) photons
  - Hadrons: complementary info, hadronization phase transition

RHIC I: focus on confirmation of QGP **RHIC II:** detailed study of QGP

Spin Physics:

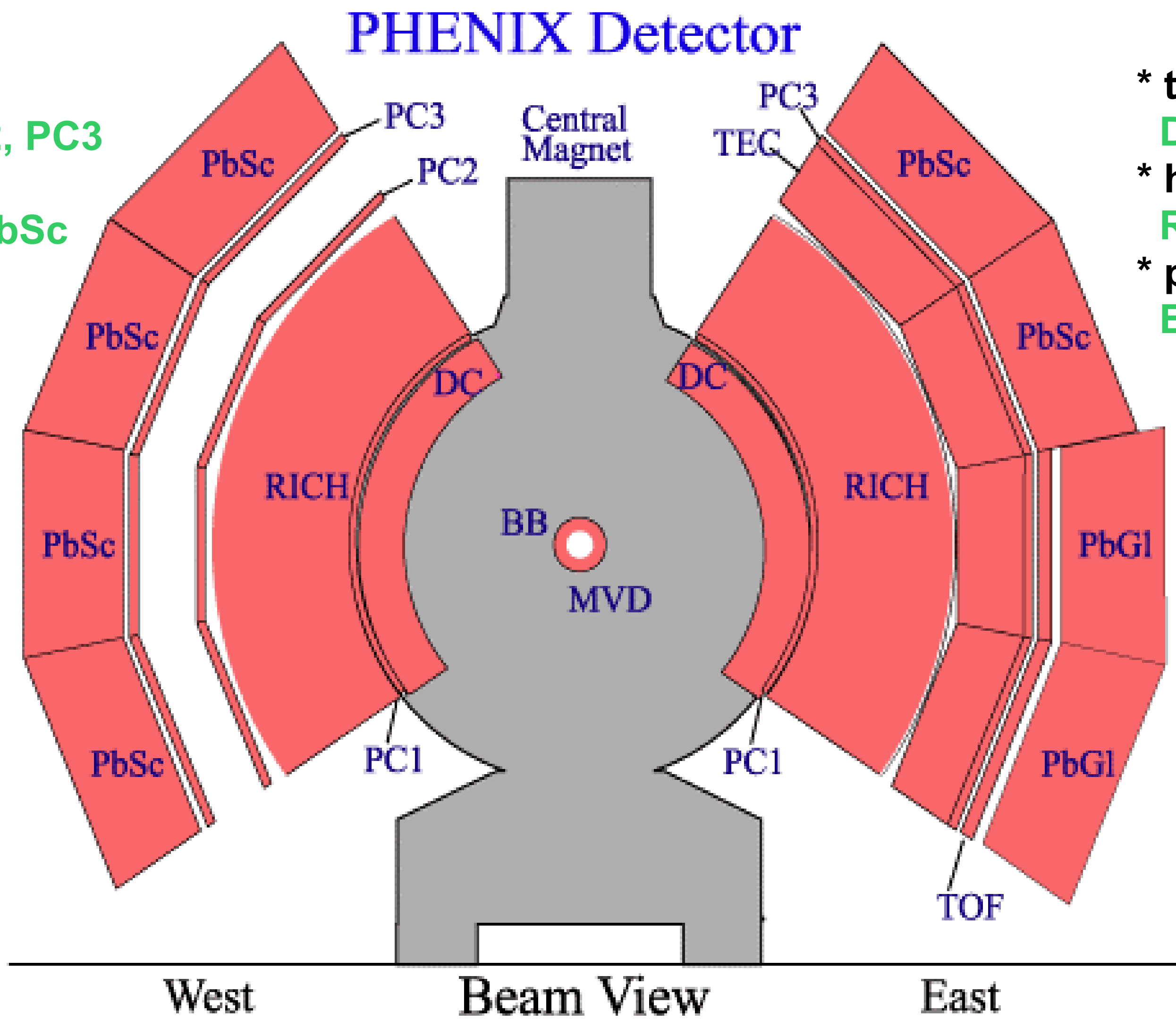
- Spin composition of proton.
- Collisions of polarized proton beams, $\sqrt{s}$=200-500 GeV
- Main goal: measurement of the gluon polarization.
- Probes: high-p_T photon production, jet and heavy flavor production.



MUON ID STEEL
MULTIPLICITY/VERTEX DETECTOR
BEAM-BEAM COUNTER
CENTRAL MAGNET
TIME OF FLIGHT DETECTOR
MUON IDENTIFIER
SOUTH MUON MAGNET
NORTH MUON MAGNET
MUON TRACKING CHAMBERS
DRIFT CHAMBER
TIME EXPANSION CHAMBER
PAD CHAMBERS
RING IMAGING CHERENKOV DETECTOR
ELECTROMAGNETIC CALORIMETER
PHENIX

Baseline PHENIX – Central Spectrometers

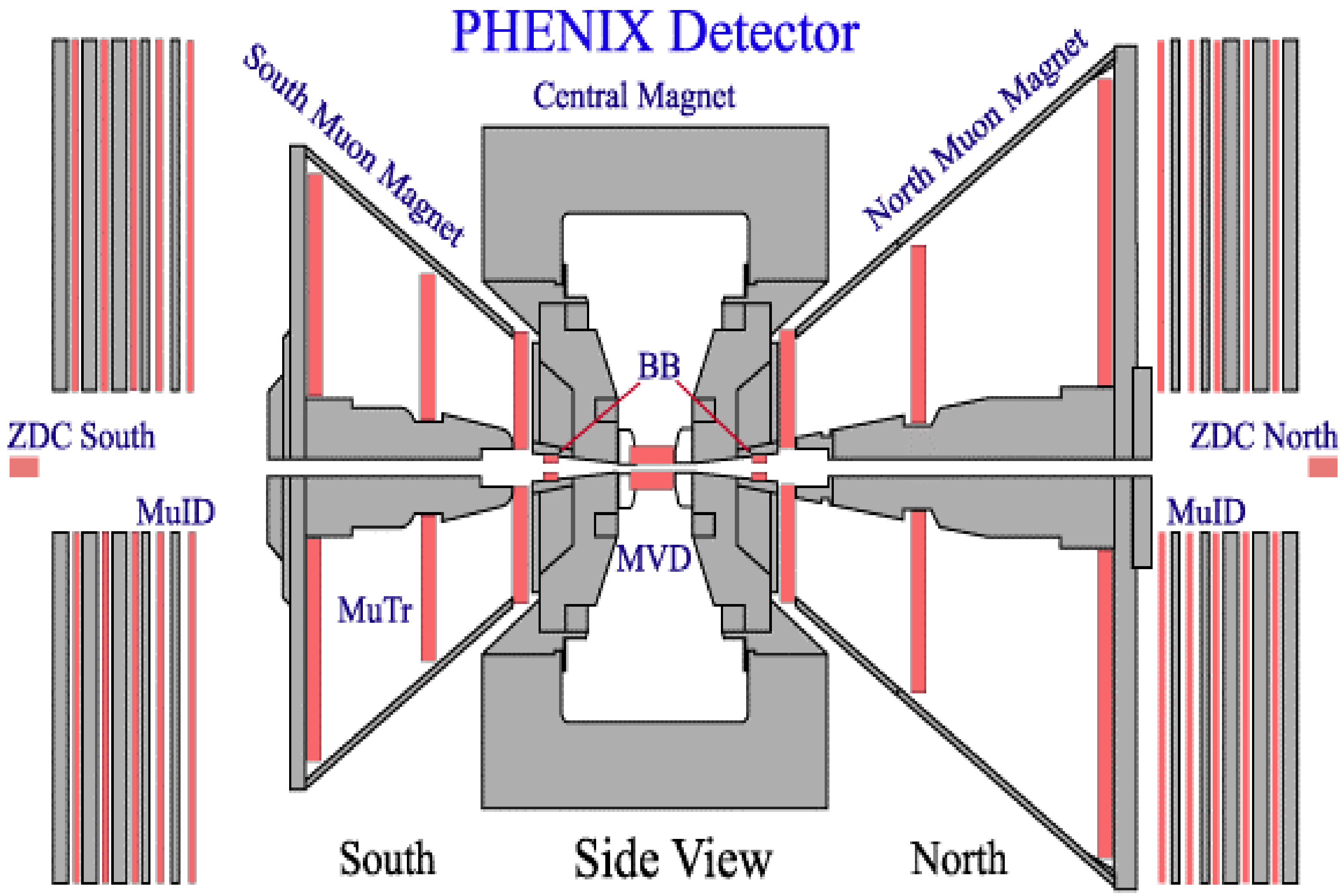
* tracking:
  DC, PC1, PC2, PC3
* electron id:
  RICH, EMC PbSc
* photons:
  EMC PbSc



* tracking:
  DC, PC1, TEC, PC3
* hadron + electron id:
  RICH, TEC, TOF, EMC
* photons:
  EMC PbSc + PbGl

vertex + centrality: ZDC, BBC, MVD

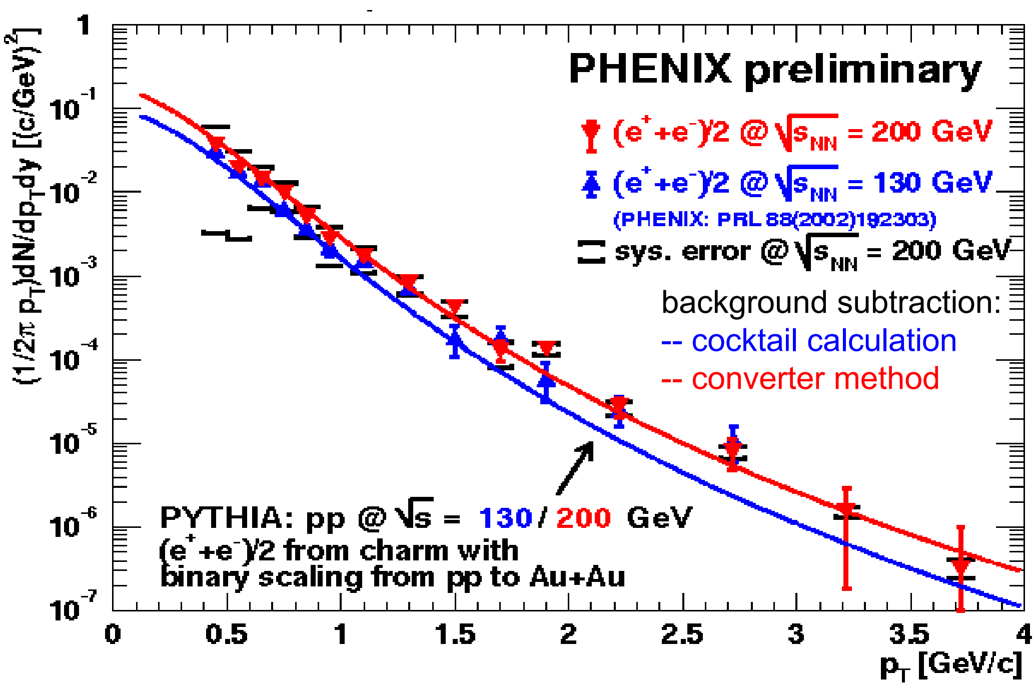
Baseline PHENIX – Forward Spectrometers



PHENIX results & new detector requirements

One example of recent PHENIX results, presented at QM2002:

"Electron production from non-photonic sources in min. bias AuAu collisions"



Direct confirmation of charm based sources via measurement of secondary vertices is not possible with baseline PHENIX.

In addition, with increasing p_T where the beauty contribution becomes a significant or even dominant source of non-photonic electrons, charm/ beauty distinction is needed via secondary vertex reconstruction.

A detector upgraded beyond the baseline capabilities is required. Upgrades of the vertex region were already foreseen in the PHENIX concept.

Upgrade with a Vertex Spectrometer

Requirements for a new detector 'sub-system':

Heavy Ion Program:

- tracking + electron identification (p_T > 200 MeV) over $\Delta\Phi \leq 2\pi$
- additional tracking at low momenta in field-free region to preserve opening angle of background pairs.
- secondary vertex reconstruction with $\sigma_{r\Phi} \cong$ 30-50 μm in the central detector and $\sigma_z \leq$ 200 μm in the forward spectrometers.
- in high-track density environment: $dN_{ch}/d\eta|_{\eta=0} \leq 1000$

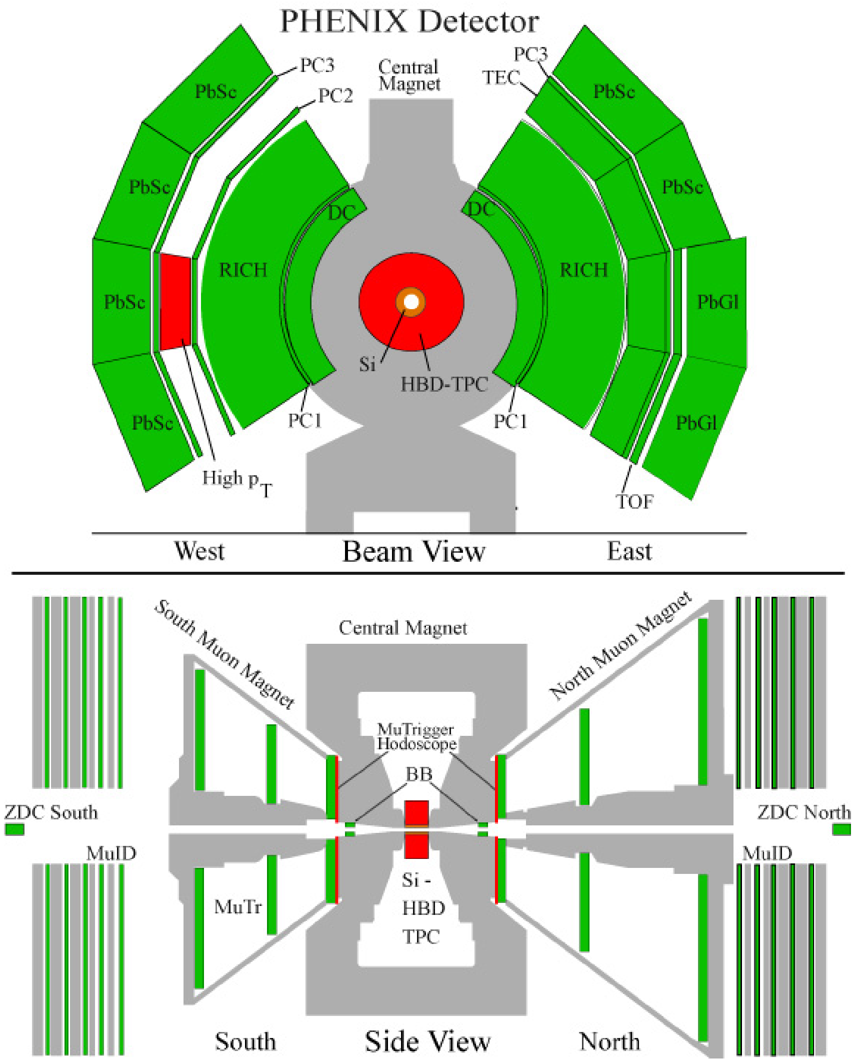
Spin Program:

- enhanced tracking acceptance $\Delta\Phi \cong 2\pi,\ \Delta\eta = \pm 1$
- precision vertex tracking (heavy flavor decay e and μ, jet measurement)

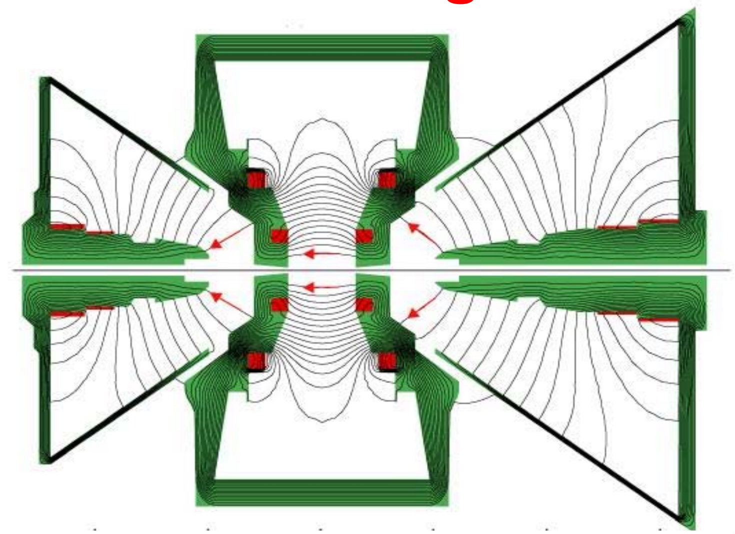
⇒ one multi-detector Vertex Spectrometer

Timeline (vertex tracking): ~ 2005/2006, primarily for spin physics schedule.

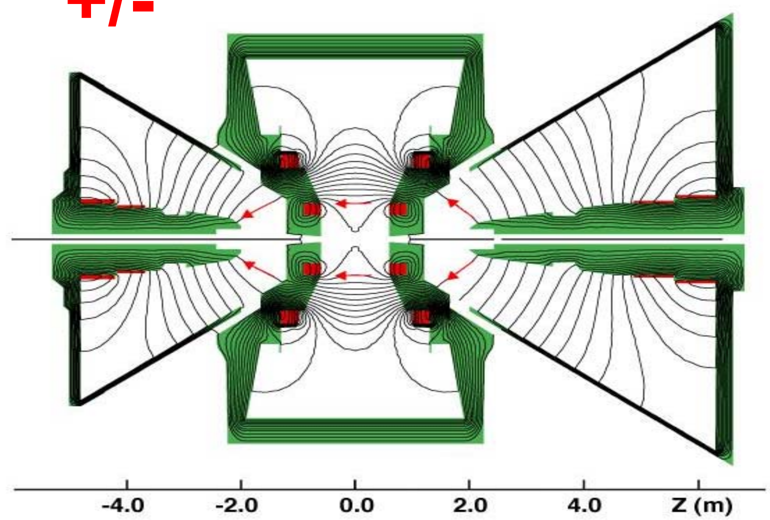
Upgrade with a Vertex Spectrometer



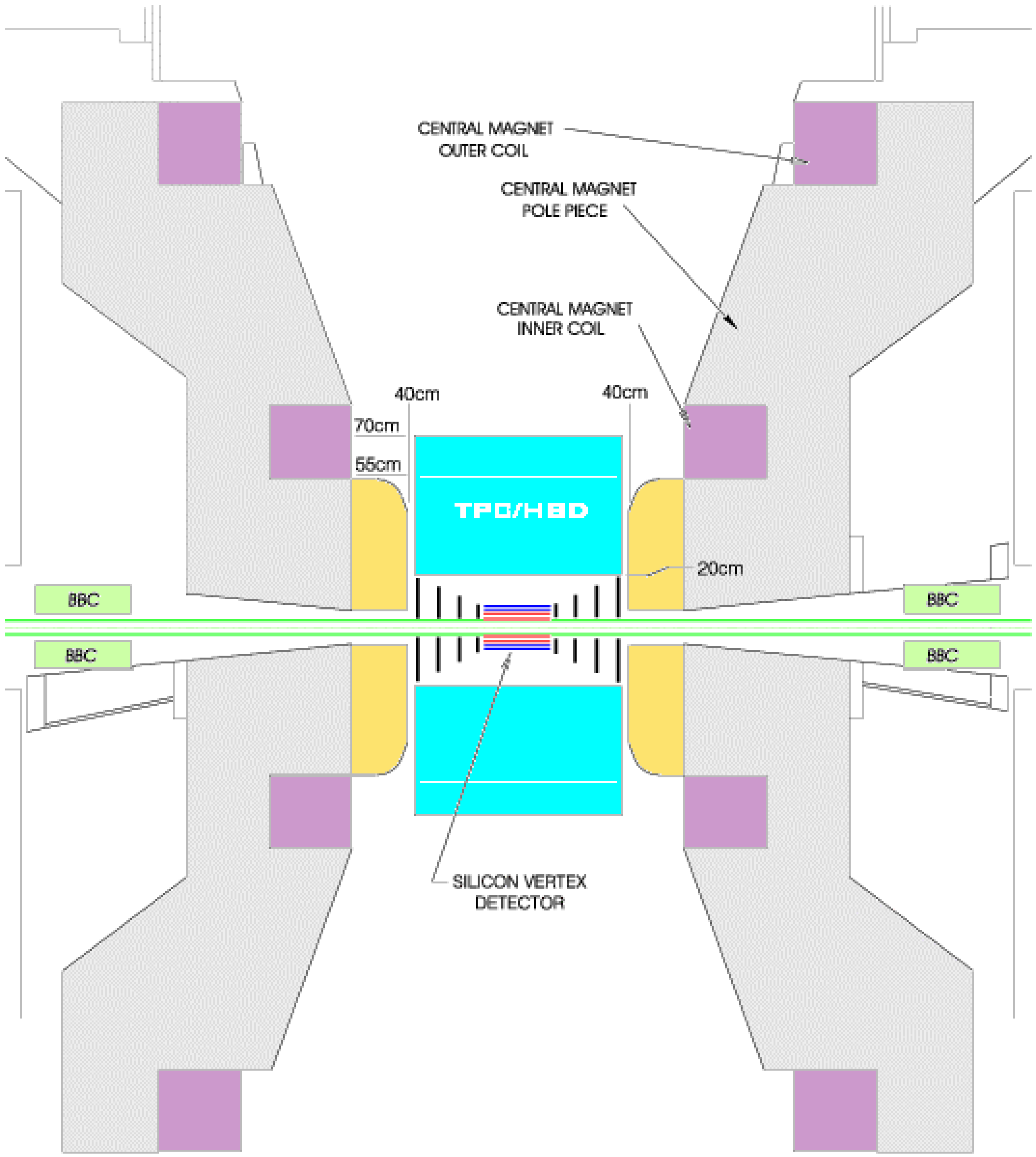
+/+ field configuration



+/-

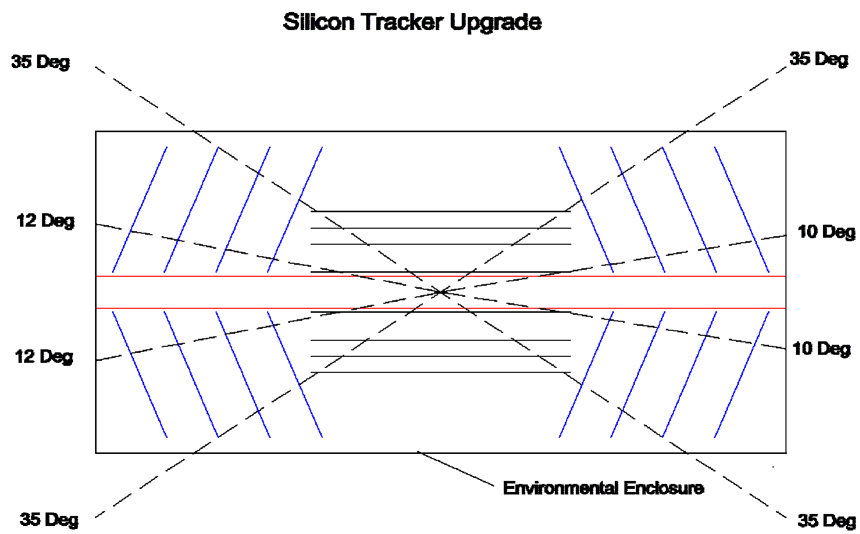


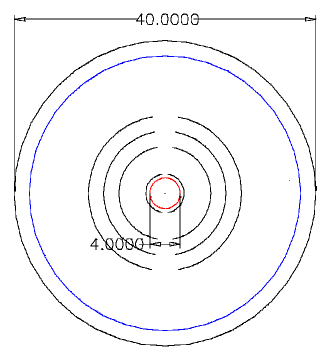
Vertex Spectrometer



- **Hadron Blind Detector**
  (Cherenkov detector w/o mirrors and windows, gas radiator, CsI photo cathodes + GEM readout chamber).
- **Time Projection Chamber**
  (HBD radiator as ionizing gas, high drift velocity, multi-stage GEM at end-plates).
- **Silicon Vertex Detector**
  (4 barrels of pixels and strips, 2 end-caps of 4 pixel disks or cones each).
- **Flexible field:** configuration of outer with new inner magnet coil (installed summer 2002).

Silicon Vertex Detector





Conceptual Mechanical Specifications

Central Barrel

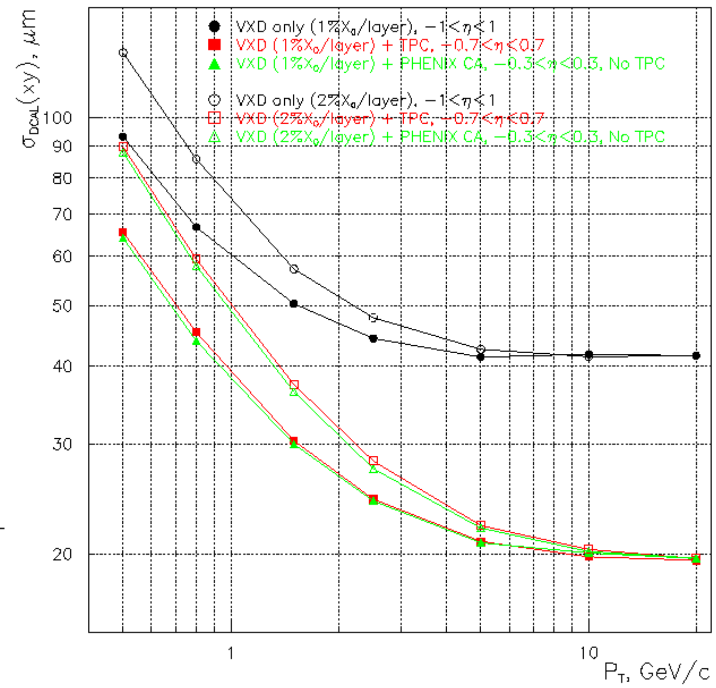
layer radius	2.5,6,8,10 cm
layer length	30 cm
pixel size	50 μm x 425 μm
strips	80 μm x 1mm (3cm)
pixels(1st layer)	~1.9M
strips(2nd,3rd,4th layer)	~165k
azimuthal coverage	320 deg

End Caps (each)

inner radius	2.5 cm
outer radius	18 cm
disk z pos.(at r_{in}= 2.5cm)	20,26,32,38 cm
pixel size	50 μm x 4 mm
total pixels	~2.0M
azimuthal coverage	360 deg

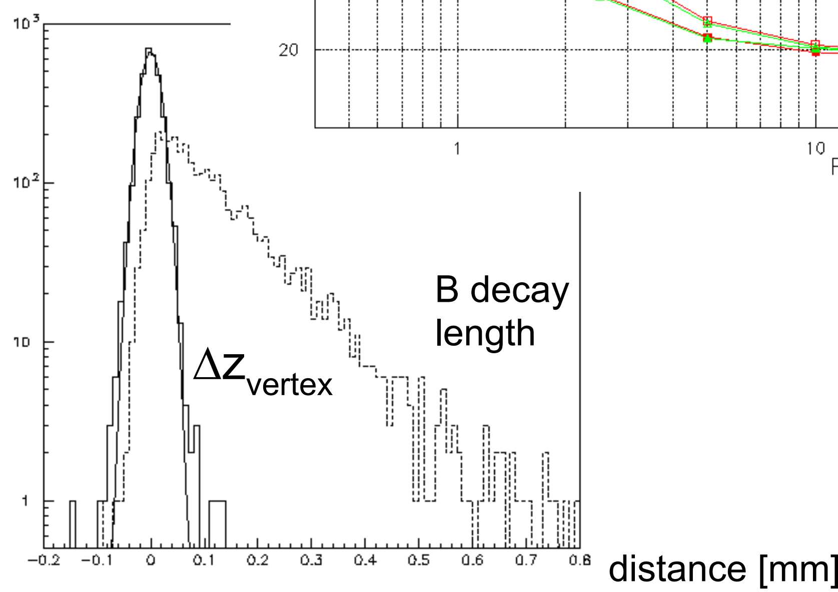
Silicon Detector Simulated Performance

Assumptions: 1% (2%) X/X_0 total per layer; 500 μm Be beam pipe.
Single tracks / heavy ion events. In Magnetic Field.



Barrel:

- occupancy: (in HI events)
  - 1st layer <1% (pixels required!)
  - 2nd layer 11.5% (strips)
  - 3rd layer 7.2% "
  - 4th layer 4.8% "
- resolution:
  - DCA(rΦ) in D→ eX <100 μm
  - (< 50 μm for p_T > 0.65 GeV/c)

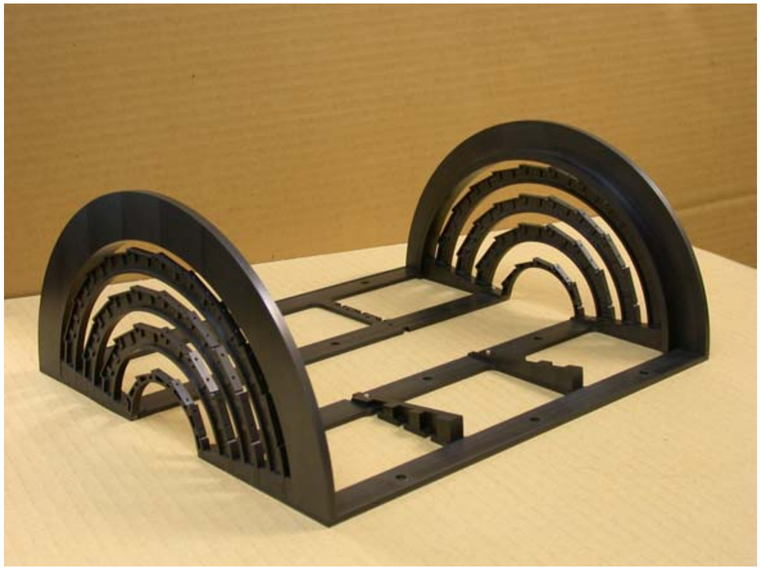


Endcaps:

- occupancy:
  - all disks <3% (pixels)
- resolution:
  - z_{vertex}, B→ J/Ψ→ μ+μ- <200 μm

Design and Prototyping – Microstrips Barrels

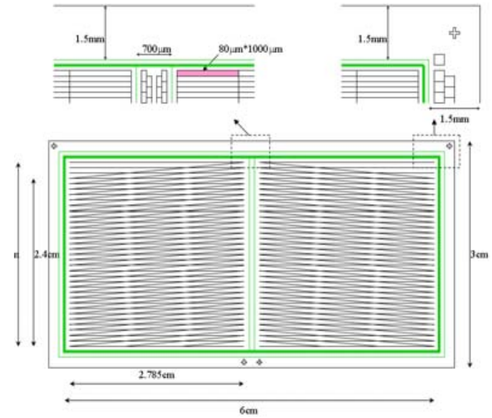
- Mock-up of Barrel Support Structure



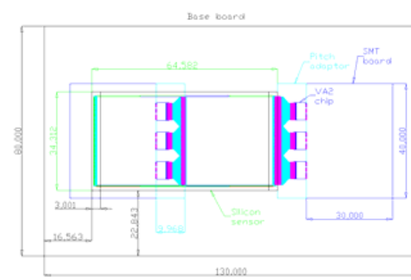
Carbon-Fiber Reinforced Polymer (June 2002)

- Microstrips

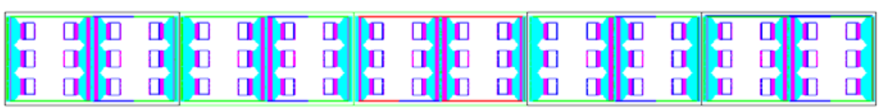
single-sided, pads of 80μm x 1mm, project-ive readout via double metal XU/V "strips" of 3cm length. Thickness 250 (400) μm.
(BNL, 2002)



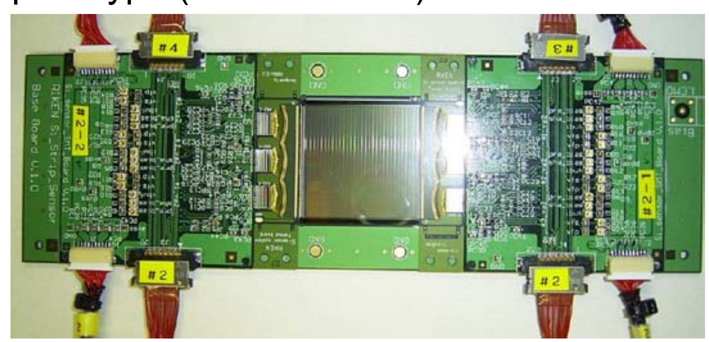
SVX4 (VA2) front-end chips



microstrips module



prototype (October 2002)



Design and Prototyping – Pixel Detectors

challenges: - module as thin as possible: minimize multiple scattering,
$\Rightarrow$ enable charm (bottom) tagging.
- track measurement at vertex with ~30-50 μm resolution.
- compatible with high PHENIX data acquisition rate.
- fit with all support, cooling, readout and cabling into PHENIX.
- allow extraction for PHENIX runs without this "converter material".
- shall be available rather soon (~ 2005, 2006).

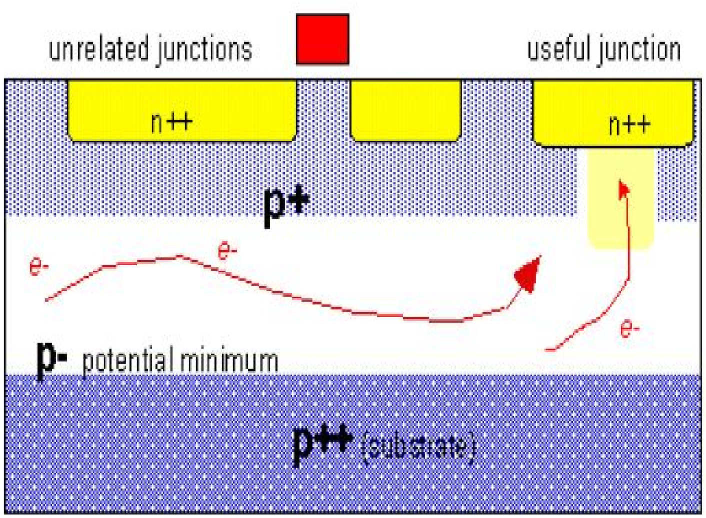
barrel/forward pixel detectors: two approaches are followed-up:

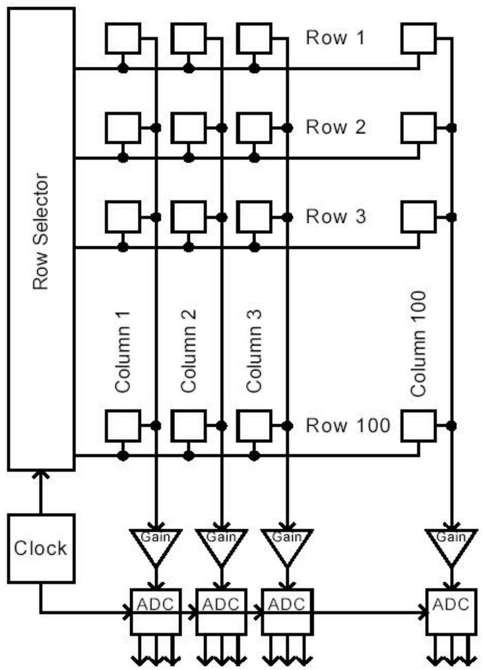
1) especially for their intrinsic low thickness: study of monolithic pixel detectors.
problem: ultimate goal, but complex devices not yet there.
2) for short-term availability and a concrete application goal:
use hybrid pixel detector technology as successfully developed at CERN during the last decade.

The forward pixel detectors might be designed and required on a somewhat different time scale than the barrel pixel detector.

Study of Monolithic Pixel Detectors

- MPDs incorporate sensor and readout electronics in one silicon chip.
- Ionization electrons from epitaxial or substrate layers below diffuse to collection well. Processed with on-pixel electronics.
- Active Pixel Sensors developed for digital imaging. First approaches towards applications in high-energy physics experiments. Custom specific CMOS processes for “thick” (≤ 20 μm) epitaxial layers.
- PHENIX studies adaptations of the LEPSI MIMOSA design to increase readout speed and suppress correlated noise. First design submitted Summer 2002.





Hybrid Silicon Pixel Detectors

- Development at CERN since ~ 10 years. Advanced technology.
- Large-scale application in ALICE upcoming. Similar to PHENIX environment. Detector building blocks available/being finalized. Attractive !!

⇒ PHENIX/RIKEN: Technical collaboration with ALICE (agreement to be signed these days) on a shared production of detectors ladders.

- Help of ALICE/CERN groups with the development of a pixel detector module suited for PHENIX: bus, module controller and assembly.
- Most important to PHENIX: Thinning and high bump-bonding yield.
- Target thickness: electronics 150 μm, detectors 200 μm, radiation length per fully integrated detector layer: ~ 1% X/X_0.

⇒ First step: On a smaller scale, participation of two PHENIX groups in the NA60 experiment at CERN was started up already earlier. NA60 uses ALICE/CERN pixel technology, builds a vertex spectrometer for the final heavy-ion runs of the SPS. Interesting physics. Setup resembles a PHENIX muon spectrometer.

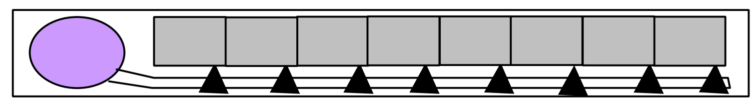
Hybrid Pixel Detector: Plan for PHENIX Modules

ALICE1LHCb readout chip:

- pixel: 50 μm x 425 μm
- channels: 256 x 32, 10 MHz r/o clock
- size: 1.28 cm x 1.36 cm

half-stave (2 hybrid ladders à 4 chips + Pilot MCM):

- 1.28 cm x 10.9 cm



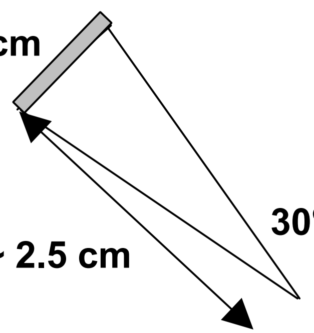
2 half-staves in z-direction (north and south sides):

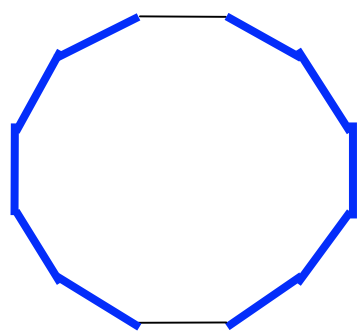
- Δz = 21.8 cm

⇒ **20 half-staves, 160 chips**

dodecagon in rΦ direction, resembling the central arms structure of PHENIX:

- 5 half-staves (x2) east, 5 half-staves (x2) west, radius ~ 2.5 cm
- measurement in rΦ with ~14 μm r.m.s. detector resolution.





The NA60 Experiment

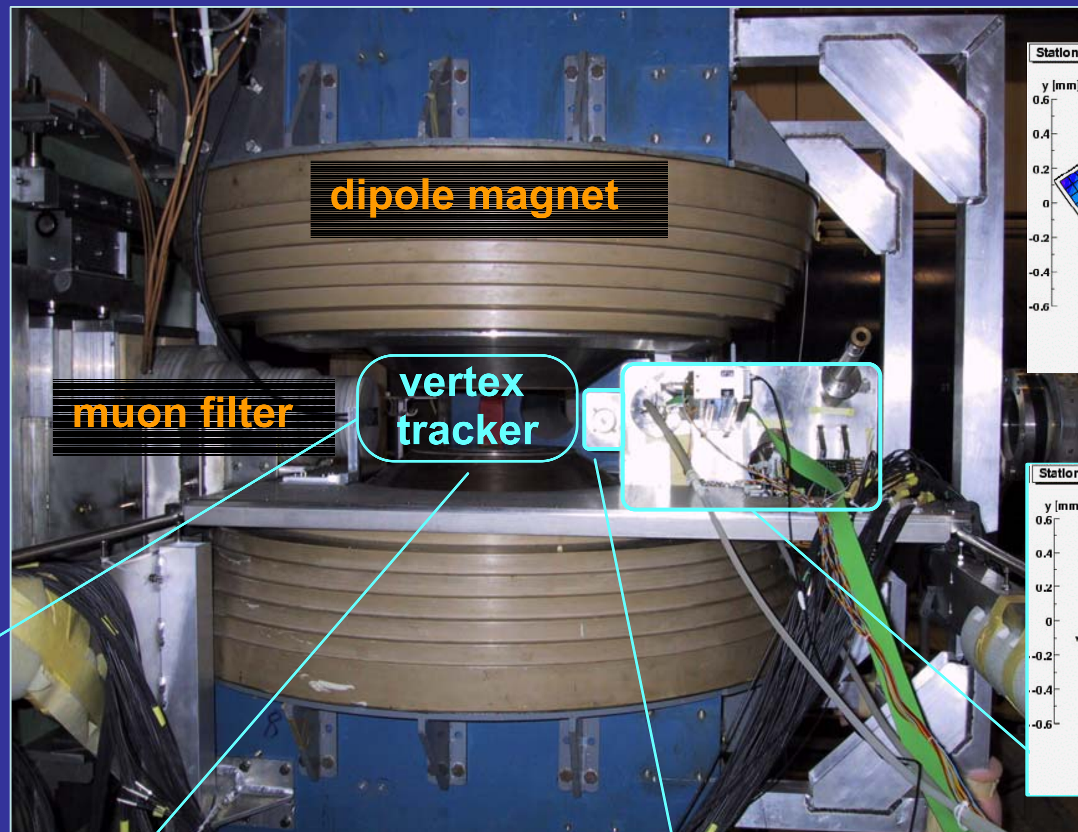
(NA50 di-muon spectrometer + additional vertex spectrometer)

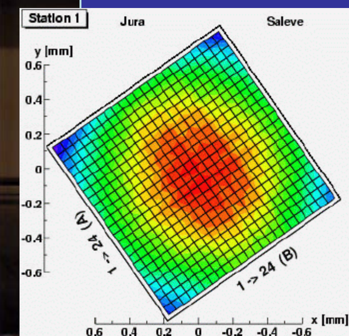
"Study of open charm and prompt dimuon production in proton-nucleus and heavy ion collisions"

Tracking:
- precise beam tracking
- accurate track + vertex reconstruction in high multiplicity environment, in magnetic field

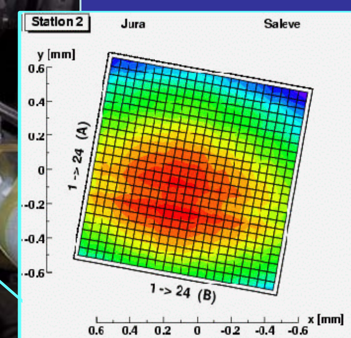
muon spectrometer

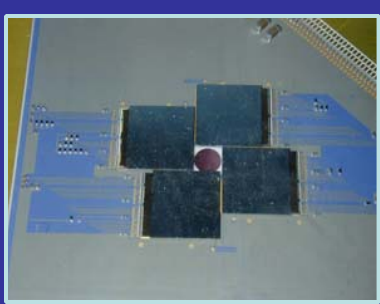
Innovative Si detectors:
- cryogenic silicon strips
- rad-hard pixel detectors





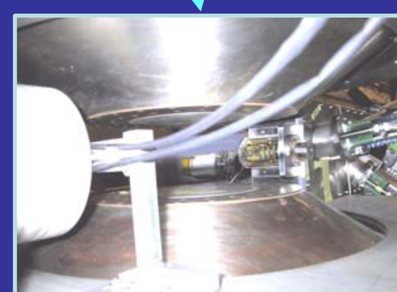
beam



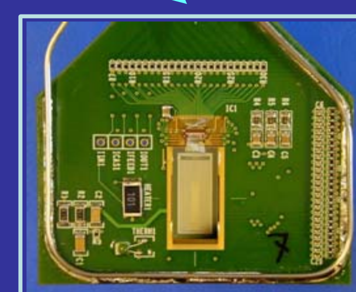


16 pixel planes

(microstrip planes in pA)



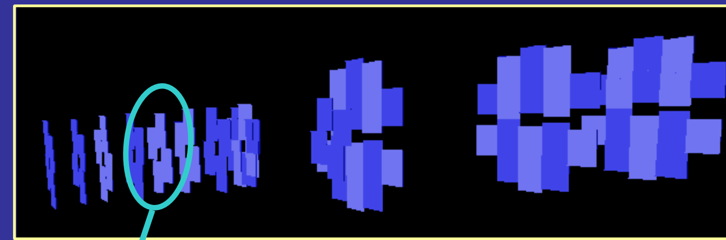
up to 5 targets



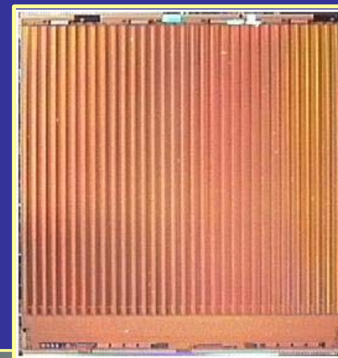
2 beamscope stations

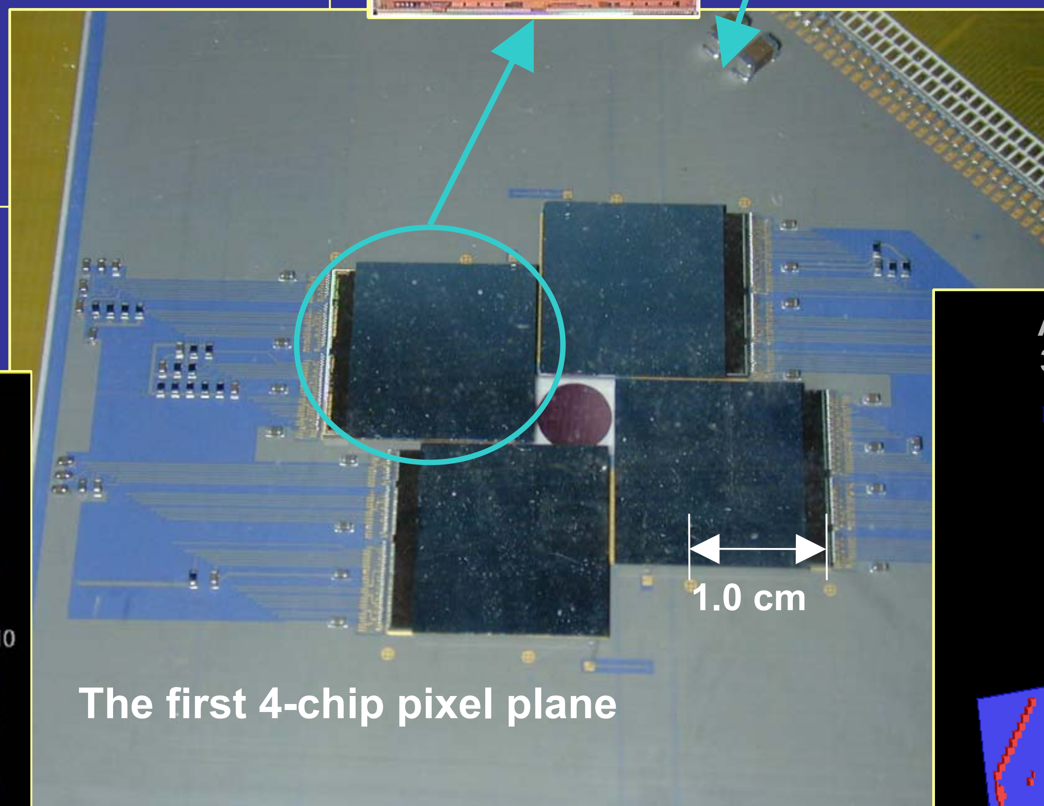
The NA60 Pixel Detector

- pixel detector developed at CERN for application in ALI CE and LHCb.
- ALICE1LHCb chip: 8192 pixels of 50 µm x 425 µm, radiation hard.
- 16 NA60 specific 4- and 8-chip planes, 10 MHz clk, 200 ns strobe.
- acceptance $3 < \eta < 4$.
- PCI readout by NA60.
- Linux based DAQ.

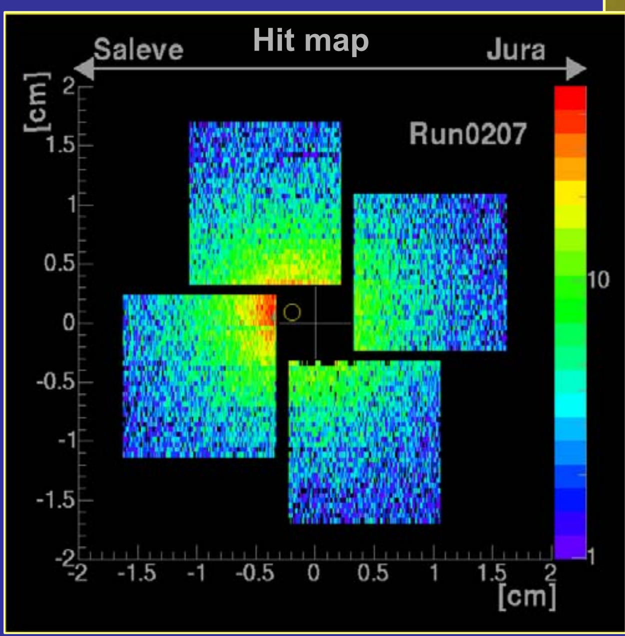


16-plane pixel detector telescope



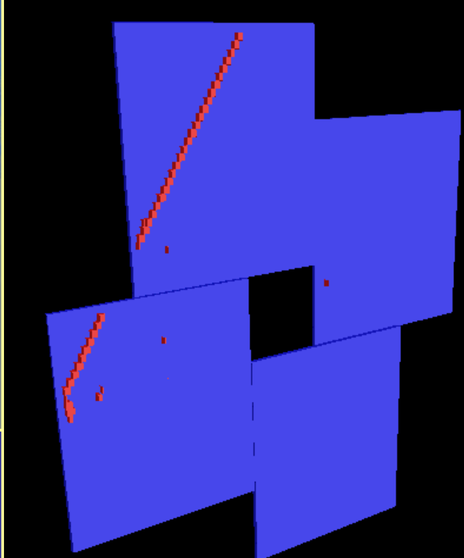


The first 4-chip pixel plane



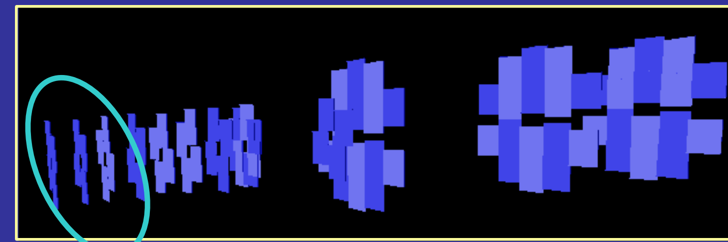
June 2002 : the first 4-chip plane in 400 GeV/c proton beam

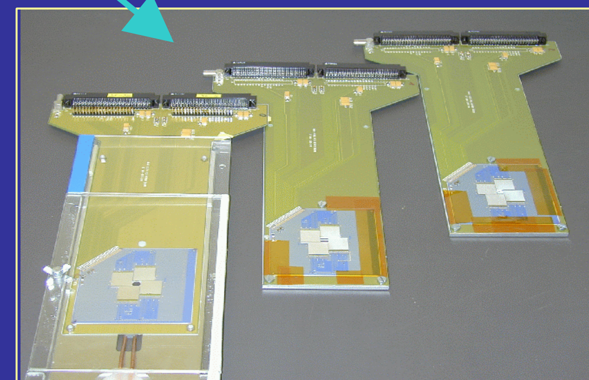
A cosmic ray in the 300 µm thin plane?

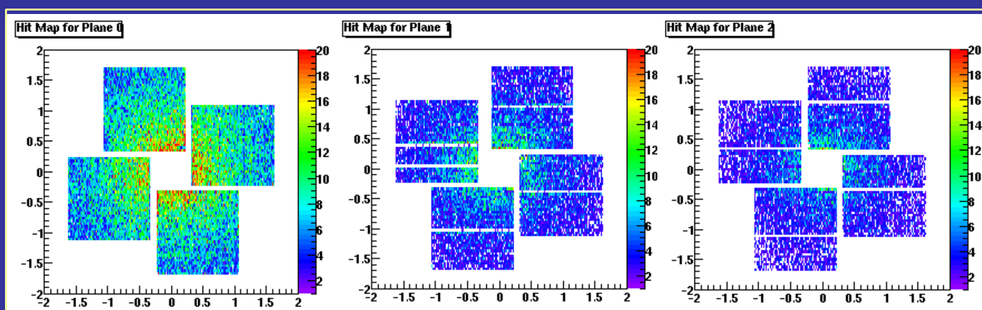


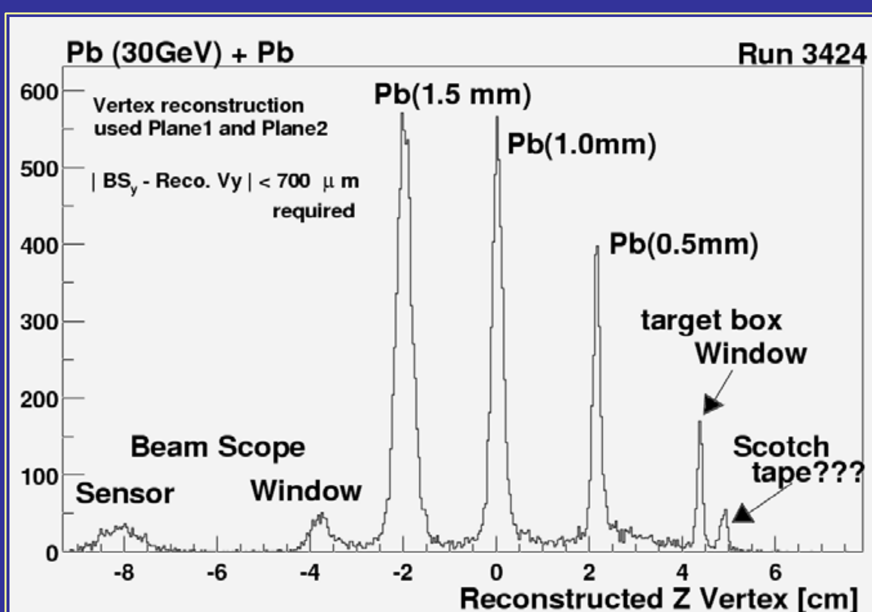
NA60 Pixels – October 2002

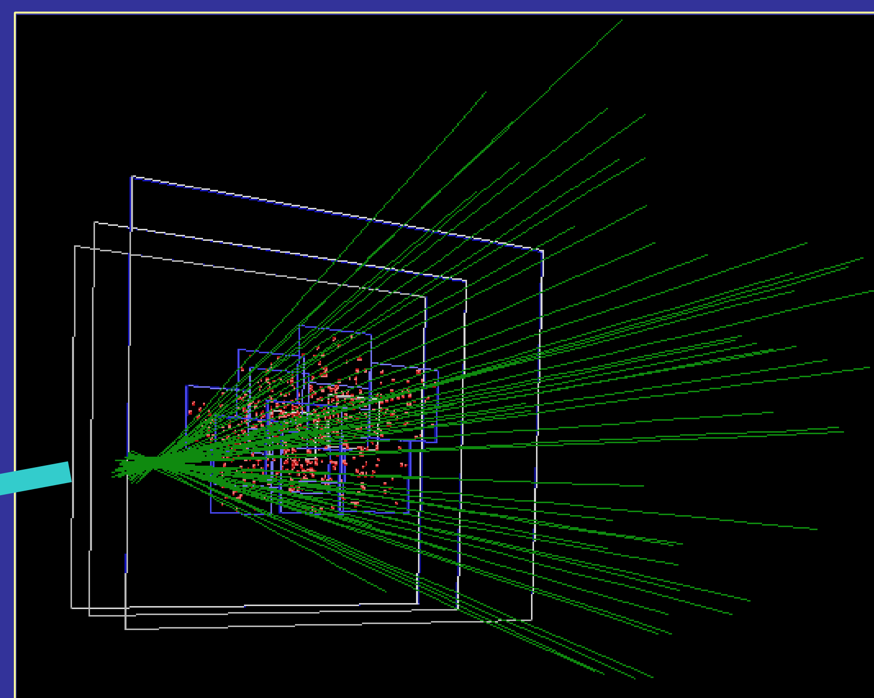
- first three 4-chip pixel planes constructed.
- test of vertex spectrometer with 20 and 30 GeV/c Pb beams on Pb targets, preparing for physics run in 2003.
- tracking and vertex reconstruction with pixel planes.











Summary

- The PHENIX Collaboration is developing a plan to upgrade the experiment's baseline setup and to extend the physics reach well beyond the first, discovery phase of RHIC. The enhanced physics program is intended to begin in the second half of this decade.

- A vertex spectrometer consisting of a silicon vertex detector for precision vertex tracking and a Dalitz rejector (HBD for electron identification and TPC for tracking) is the main new detector system foreseen.

- A possible layout of the vertex detector was presented, building on silicon microstrips and pixel detectors. Simulation studies are being performed to optimize the overall design and to insure the required physics capabilities of the complex device.

- Different detector technology options are being evaluated. Activities reach from the study of new approaches (monolithic pixel detector) for an application more distant in time, to the construction and evaluation of concrete prototypes (microstrips, hybrid pixel detectors) based on latest but existing technologies for rather short-term availability.