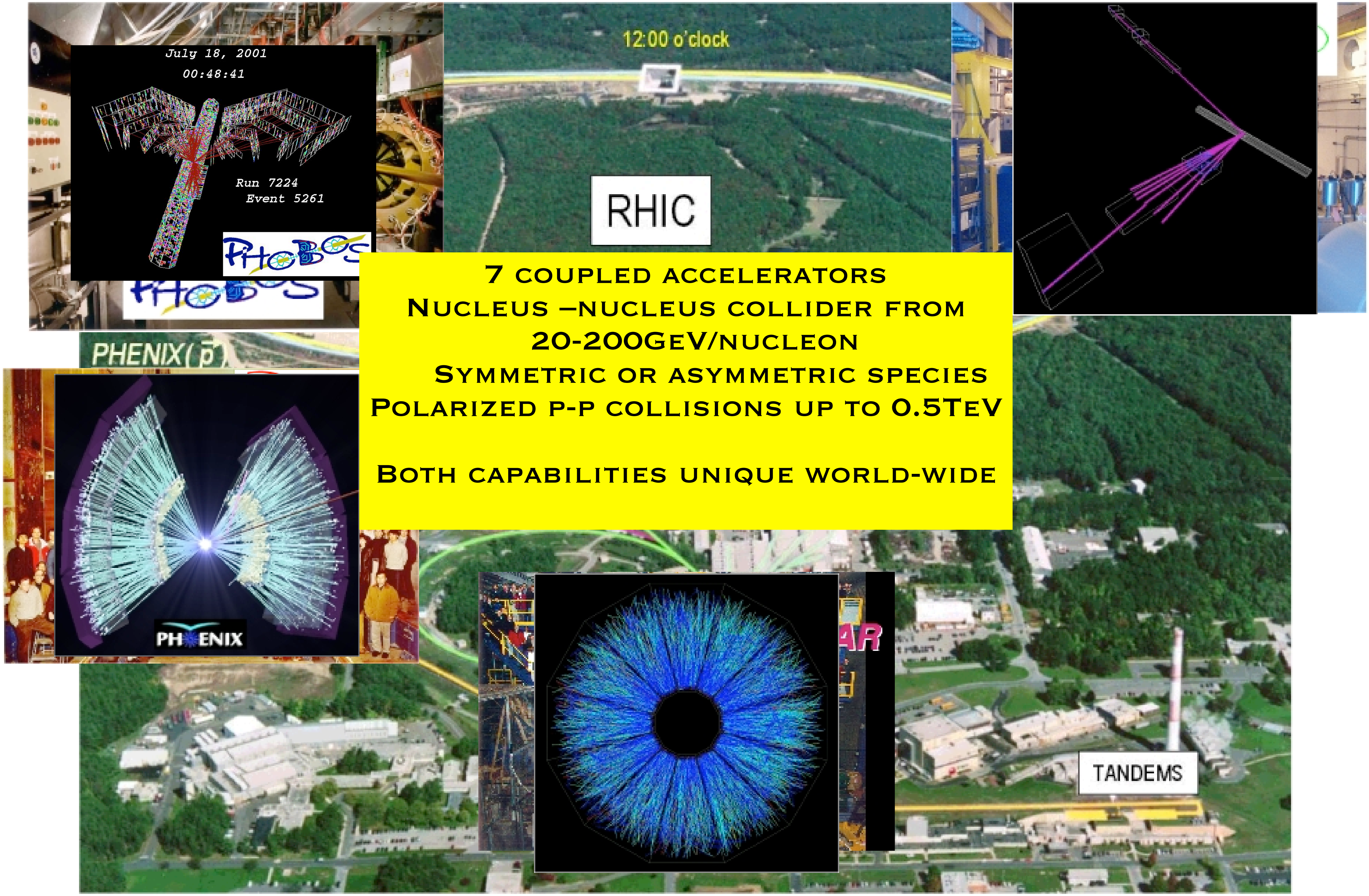
5 years of tracking Heavy Ion Collisions @RHIC

Achim Franz,
Brookhaven National Laboratory
achim@bnl.gov

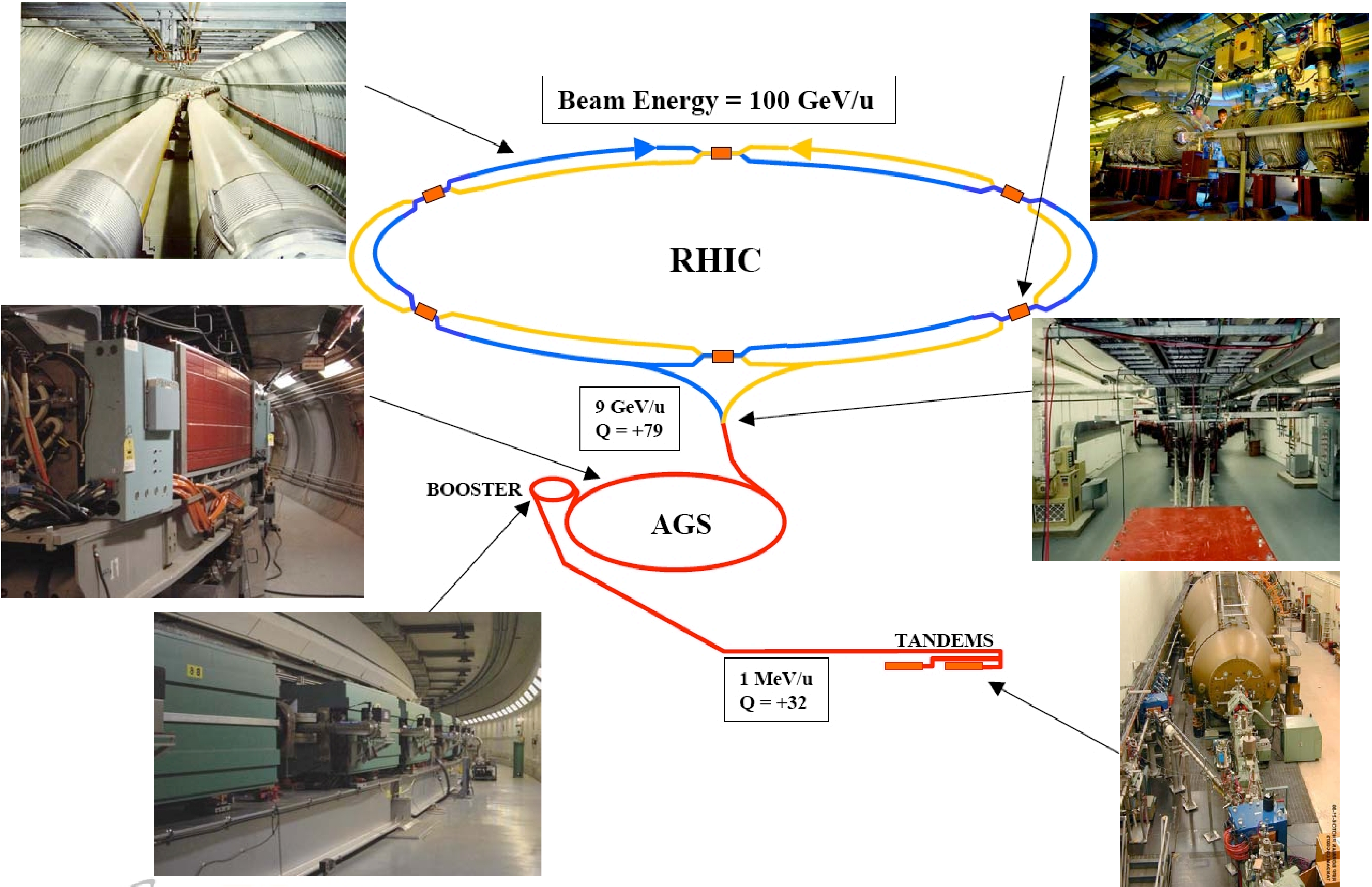
RHIC & its Experiments



7 coupled accelerators
Nucleus –nucleus collider from 20-200GeV/nucleon
Symmetric or asymmetric species
Polarized p-p collisions up to 0.5TeV

Both capabilities unique world-wide

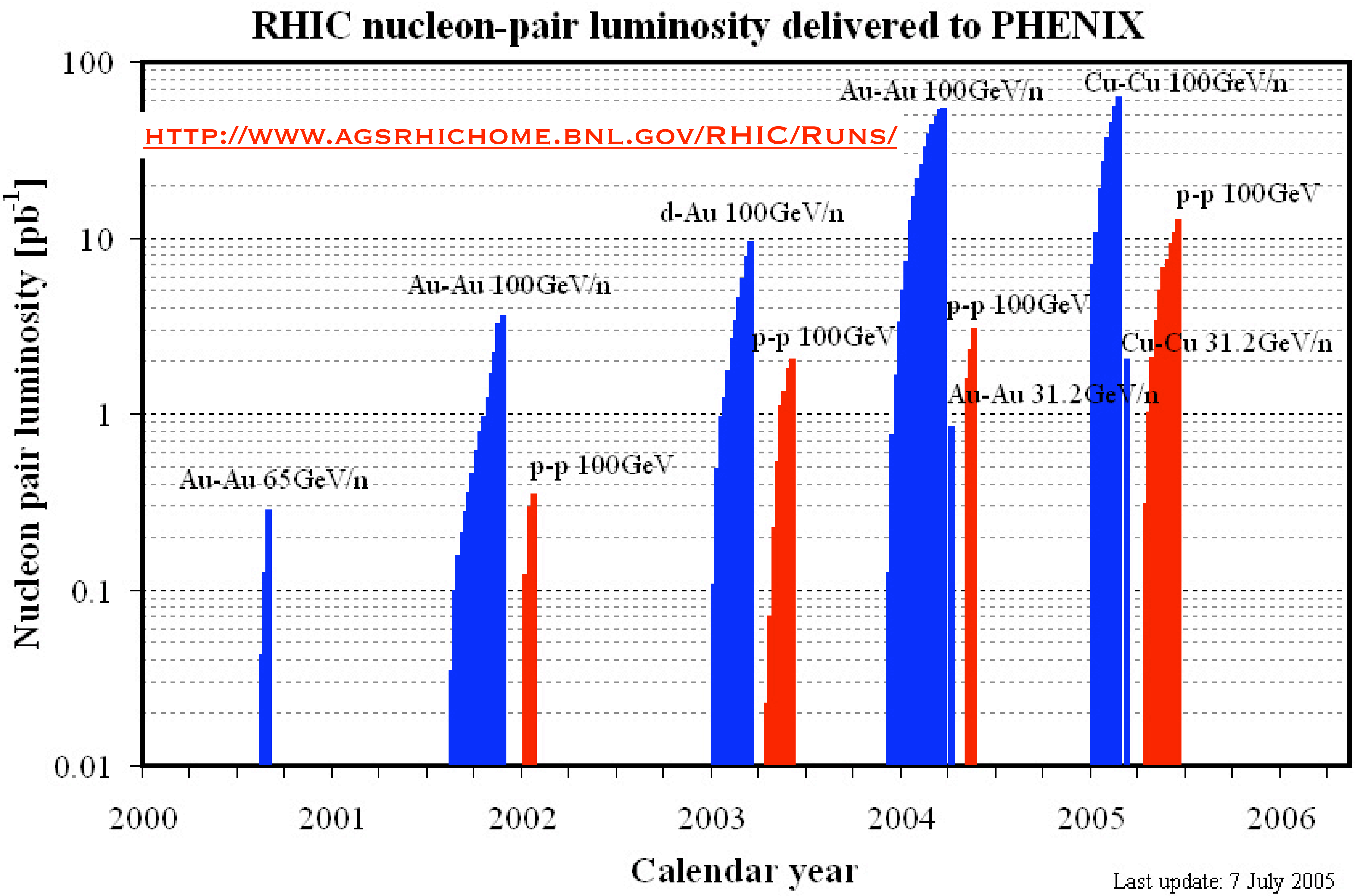
Introduction to RHIC



RHIC Summary, Runs 01 - 05

	Year			
	2001	Au-Au at 130 GeV/A	20 μb^{-1} (6 wks)	First look at RHIC collisions
	2001 – 2002	Au-Au at 200 GeV/A Comm./run pp at 200 GeV Au-Au at inj. E: 19 GeV/A	260 μb^{-1} (16wks) 1.4 pb^{-1} (5 wks) 0.4 μb^{-1} (1 day)	Global properties; particle spectra; first look at hard scattering. Comparison data and first spin run Global connection to SPS energy range
	2003	d-Au at 200 GeV/A pp at 200 GeV	74 nb^{-1} (10wks) 5 pb^{-1} (6 wks)	Comparison data for Au-Au analysis; low-x physics in cold nuclear matter Spin Development & Comparison data
	2004	Au-Au at 200 GeV/A Au-Au at 62 GeV/A pp at 200 GeV	3740 μb^{-1}(12wks) 67 μb^{-1} (3wks) 100 pb^{-1} (7wks)	"Long Run" for high statistics, rare events Energy Scan Spin Development: Commission jet target First measurements with longitudinal spin pol.
	2005	Cu-Cu at 200 GeV/A Cu-Cu at 62 GeV/A Cu-Cu at 22 GeV/A pp at 200 GeV pp at 410 GeV	42 nb^{-1} 8wks 1.5 nb^{-1} 12 days 18 μb^{-1} 39 hrs 30 pb^{-1} 10 wks 0.1 pb^{-1} 1 day	Comparison studies: surface/volume & impact parameter effects; Energy Scan Spin Development: Lum., Polarization First long data run for spin

5 YEAR SUMMARY



[HTTP://WWW.AGSRHICHOME.BNL.GOV/RHIC/RUNS/](http://www.agsrhichome.bnl.gov/RHIC/Runs/)

The nucleon-pair luminosity is defined as $\mathscr{L}_{NN} = A_1 A_2 L$, where $\mathscr{L}$ is the luminosity, and A_1 and A_2 are the number of nucleons of the ions in the two beam respectively.

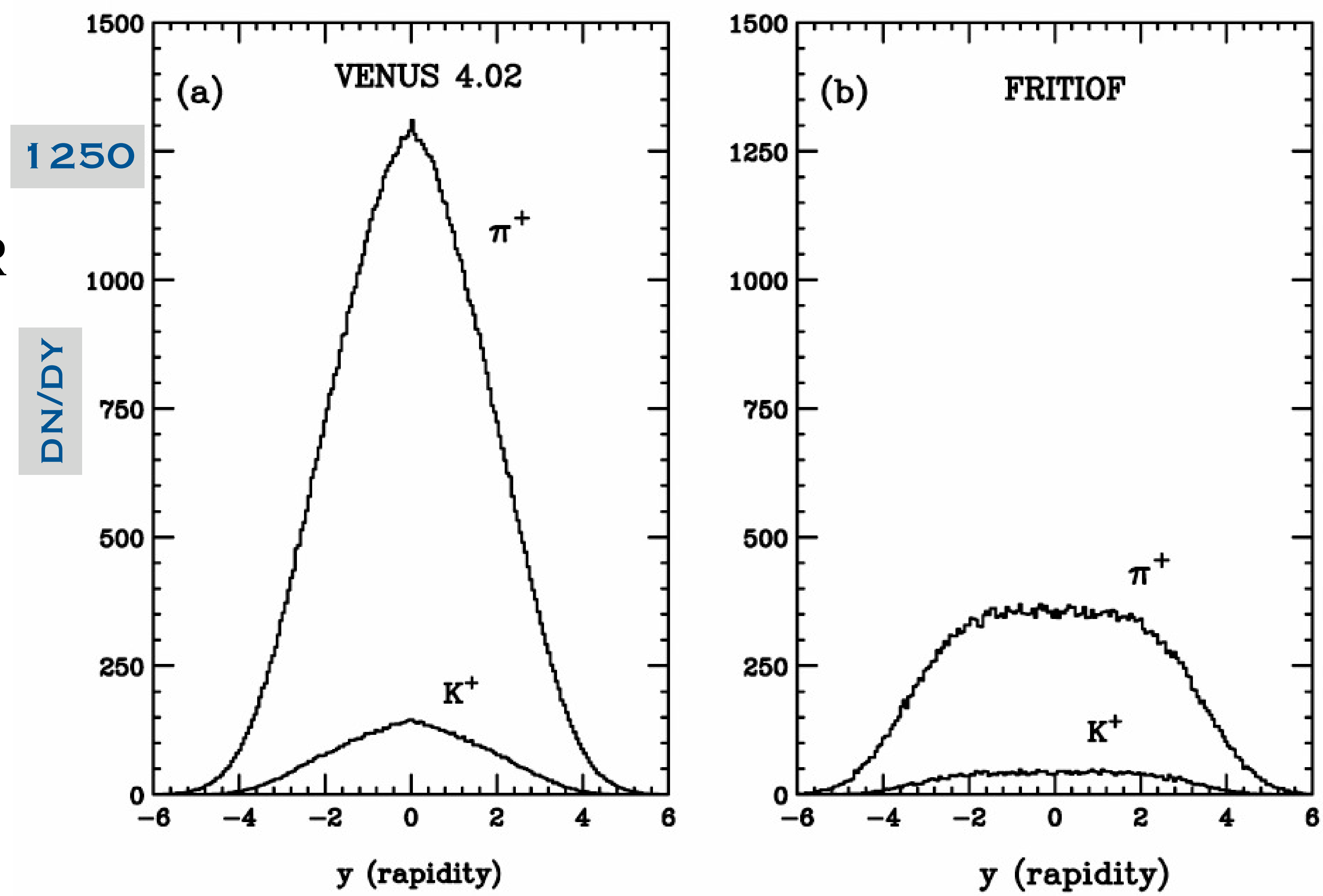
WHAT DID WE EXPECT

LOOKING BACK

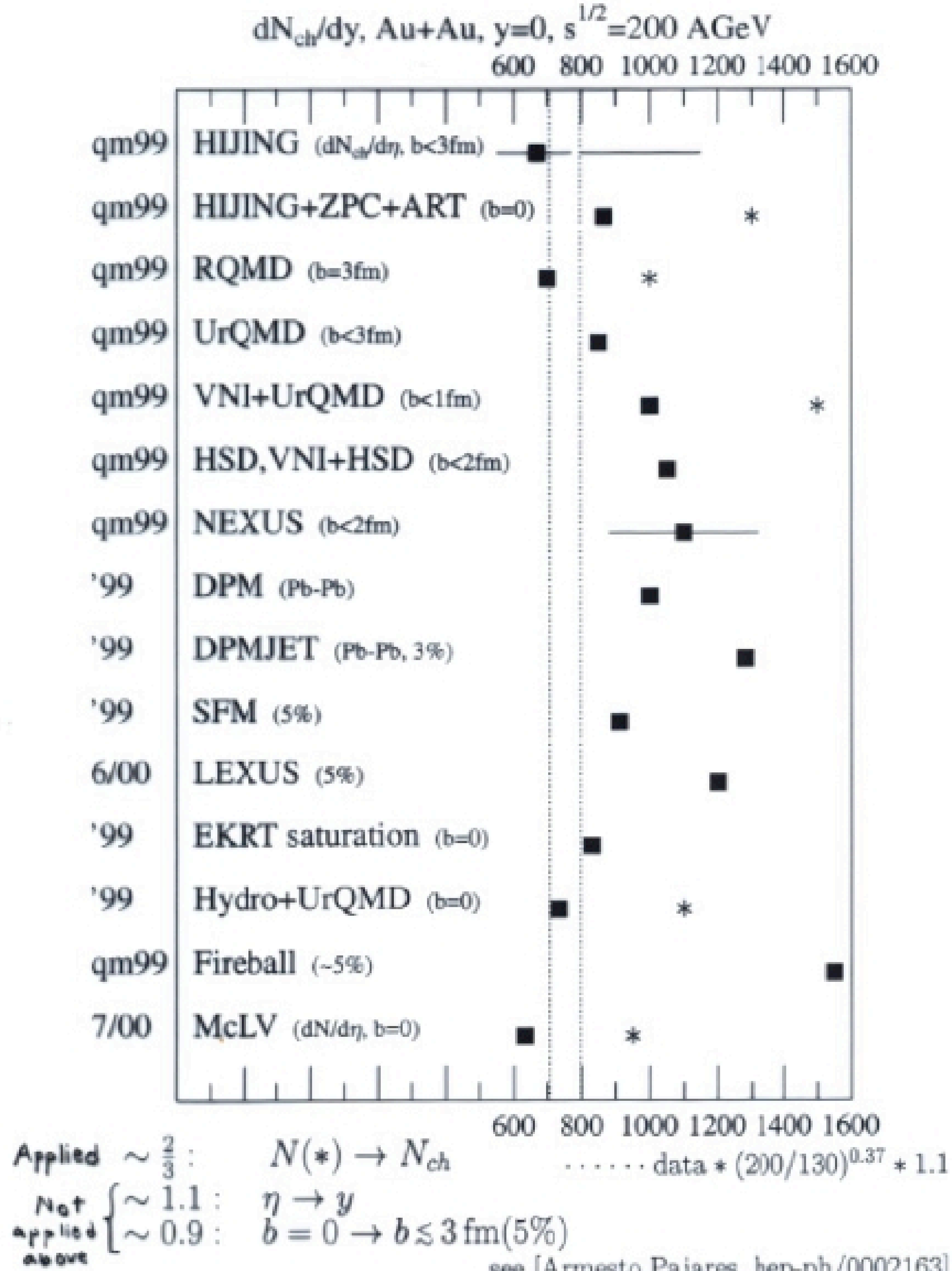
PHENIX CDR

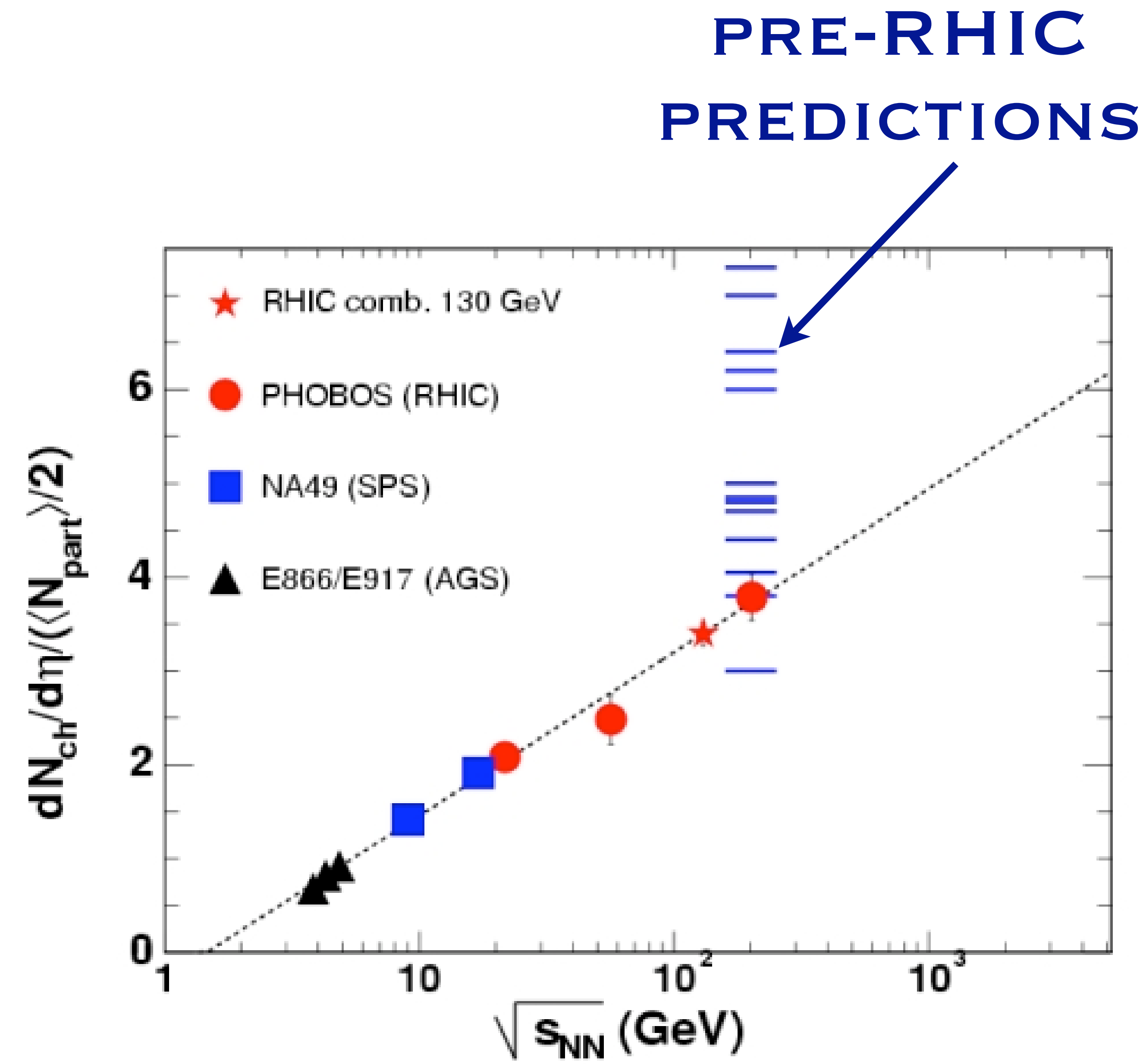
Central Au + Au collisions at RHIC will produce up to 500 charged tracks (dN_c/dy =1500) in the PHENIX fiducial volume with momenta ranging from 80 MeV/c to over 5 GeV/c. Approximately 3% of the 500 charged tracks are expected to be electrons.

BRAHMS CDR



BUT WE GOT ...

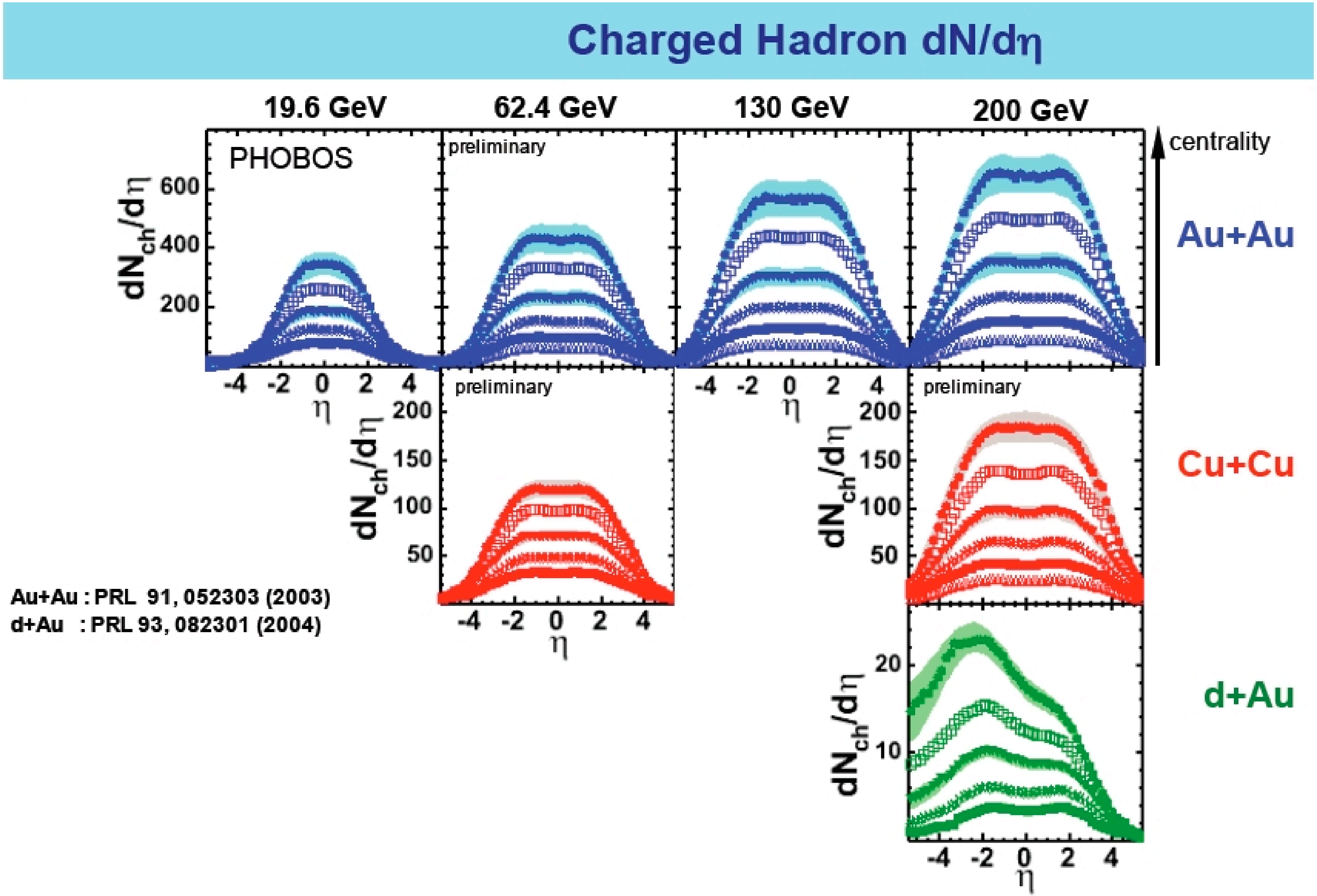




J.B.Blaizot QM01 Summary

http://www.rhic.bnl.gov/qm2001/talks/saturday_am/Blaizot.pdf

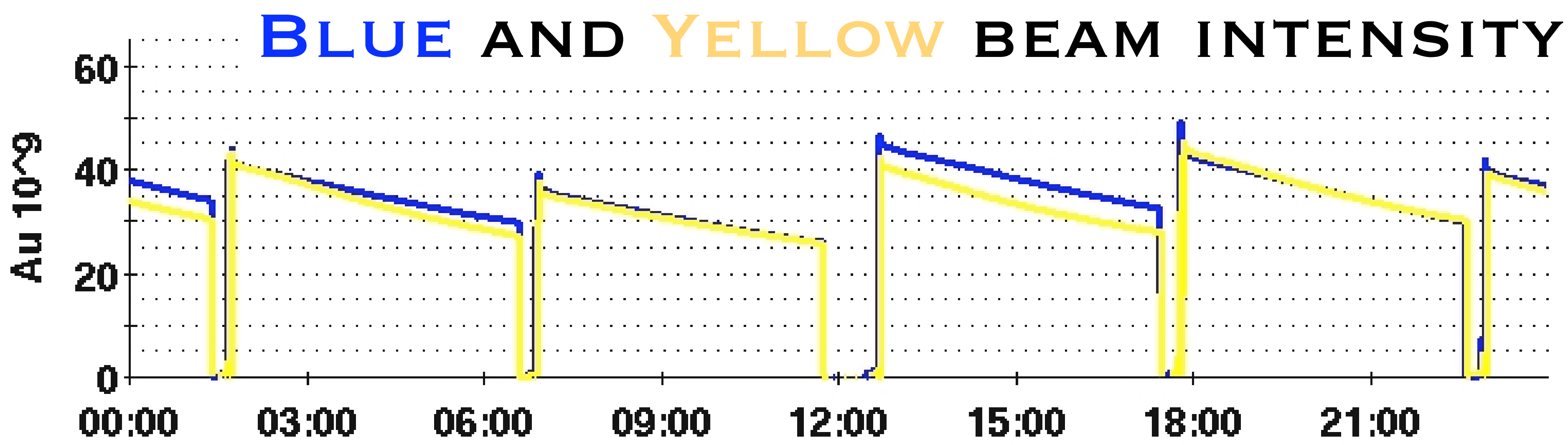
COUNTING

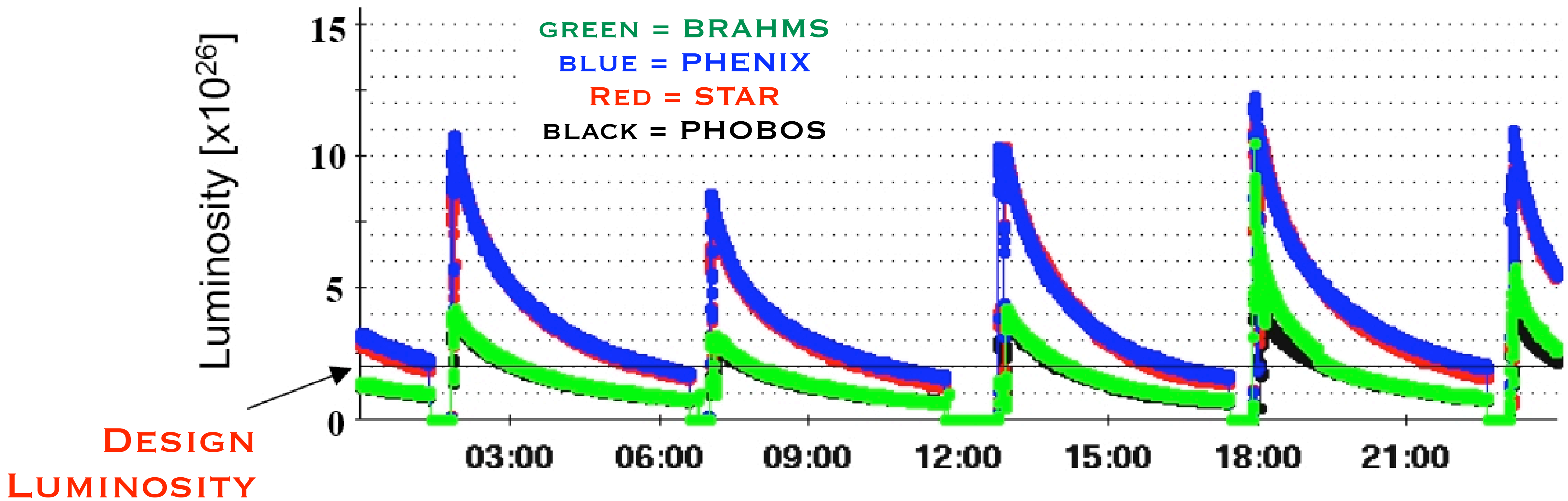


Au+Au : PRL 91, 052303 (2003)
d+Au : PRL 93, 082301 (2004)

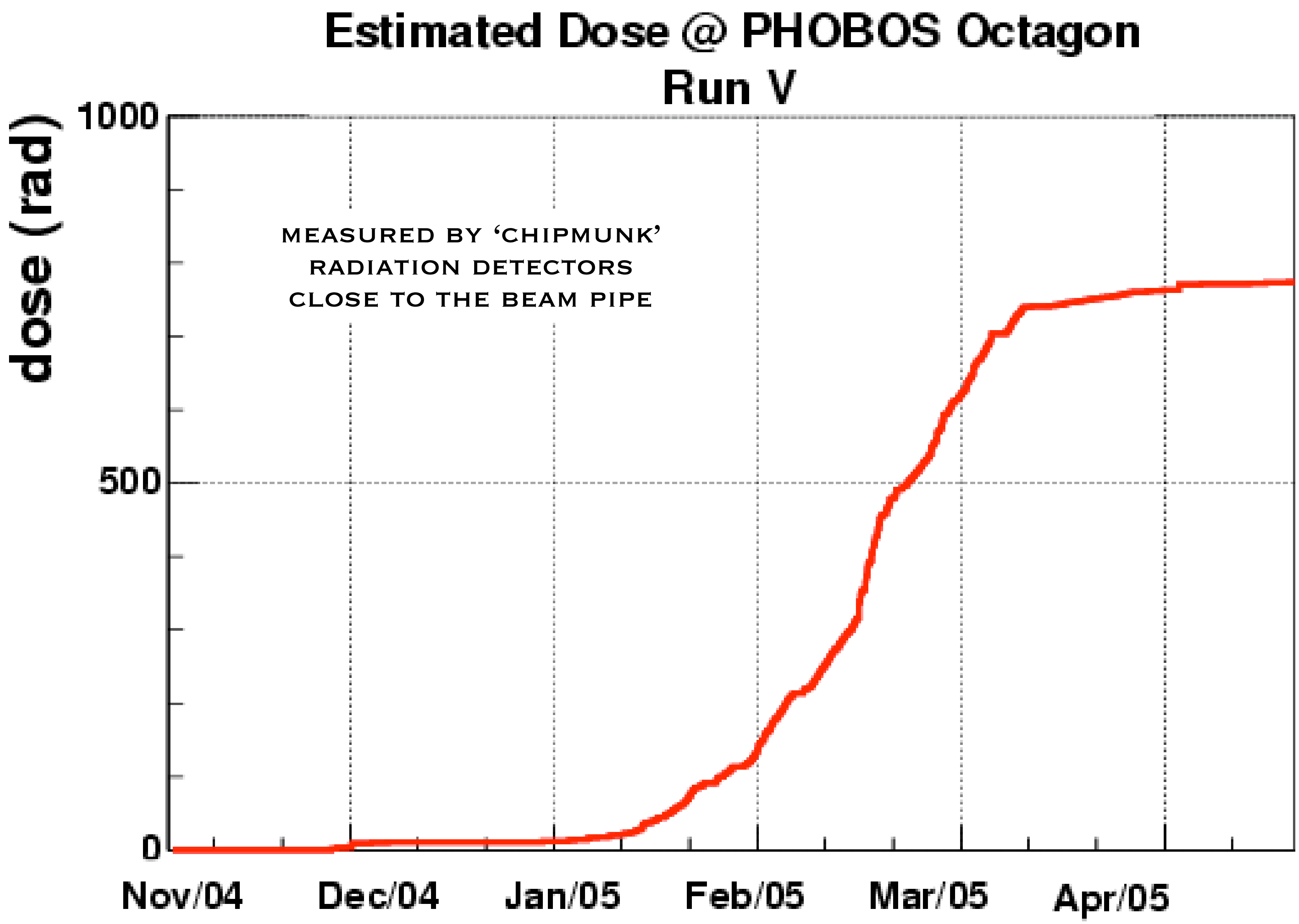
Daily life @ RHIC

A (typical) Au day at RHIC





AROUND THE RING



ESTIMATED TOTAL DOSE AT PHOBOS 2000-2005 3kRad

Shielding the Detectors

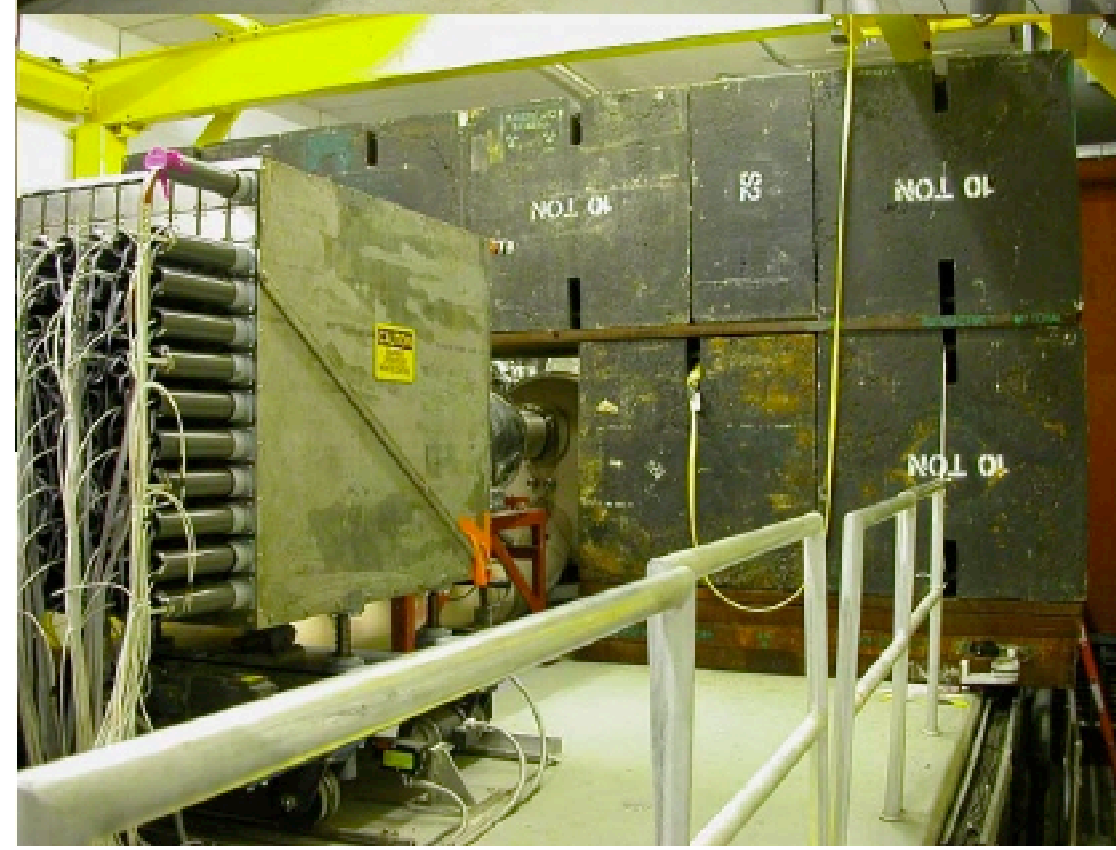
Early runs had large intra-beam-scattering and short stores with high background rates

Better bake-out and NEG coating of the beam pipes improved vacuum

High background particle flux made it necessary to shield the IRs

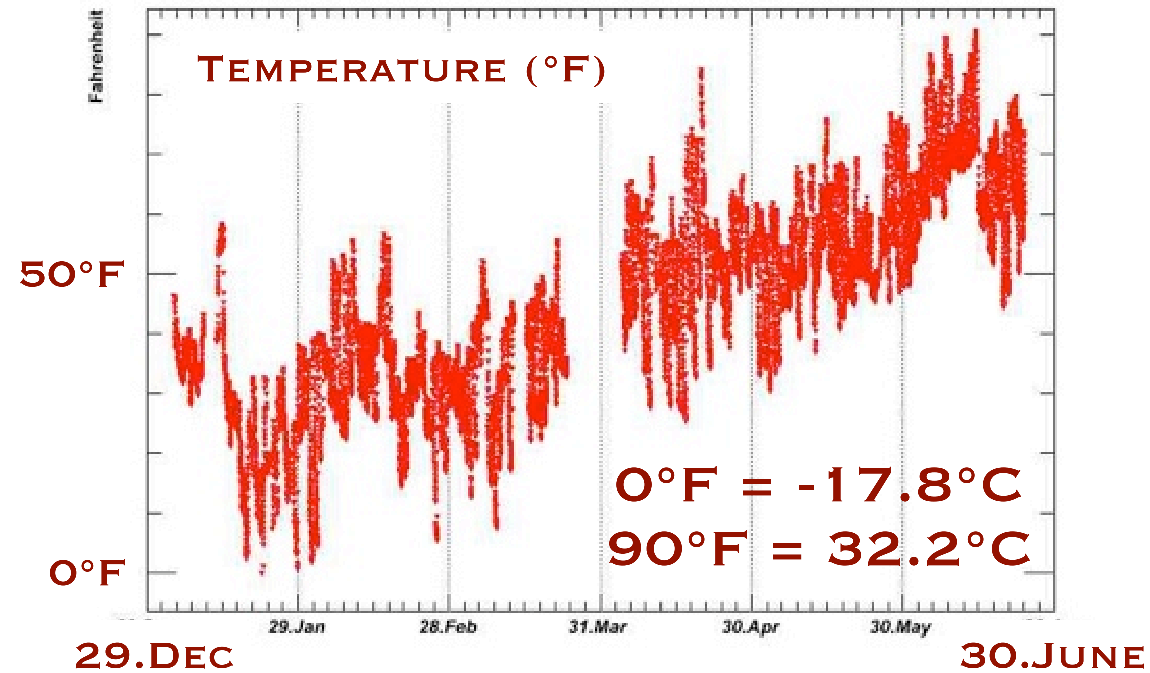
Most detectors are on standby during injection, tuning and extraction of the beam, i.e. we miss the first high intensity part of the store

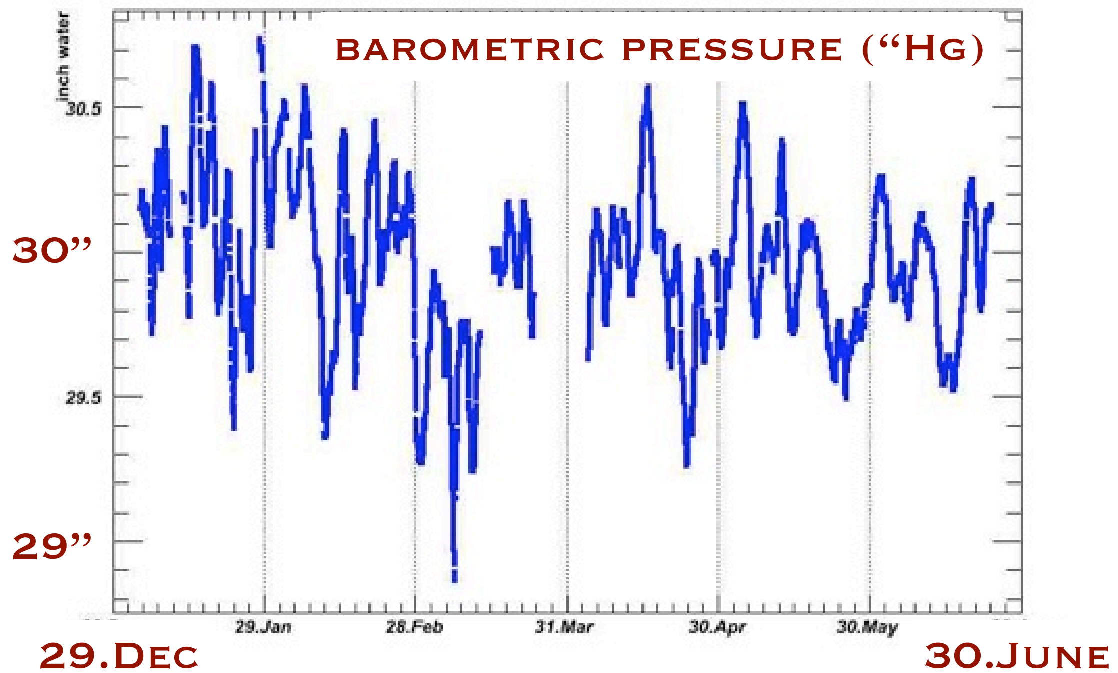
View of the tunnel close to PHENIX →

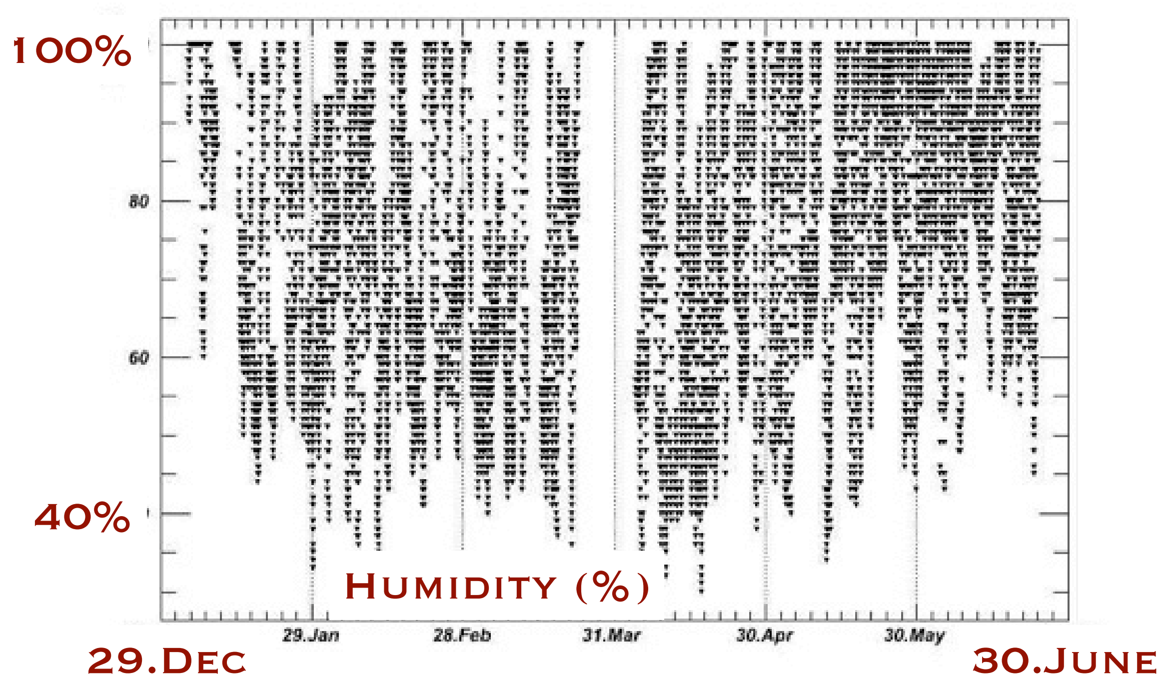


Environmental-Run05

Temperature, Barometric Pressure, Humidity and Windspeed
2004/2005 Data from BNL weather station
2005-09-20 11:53:38







large range in outside temperature

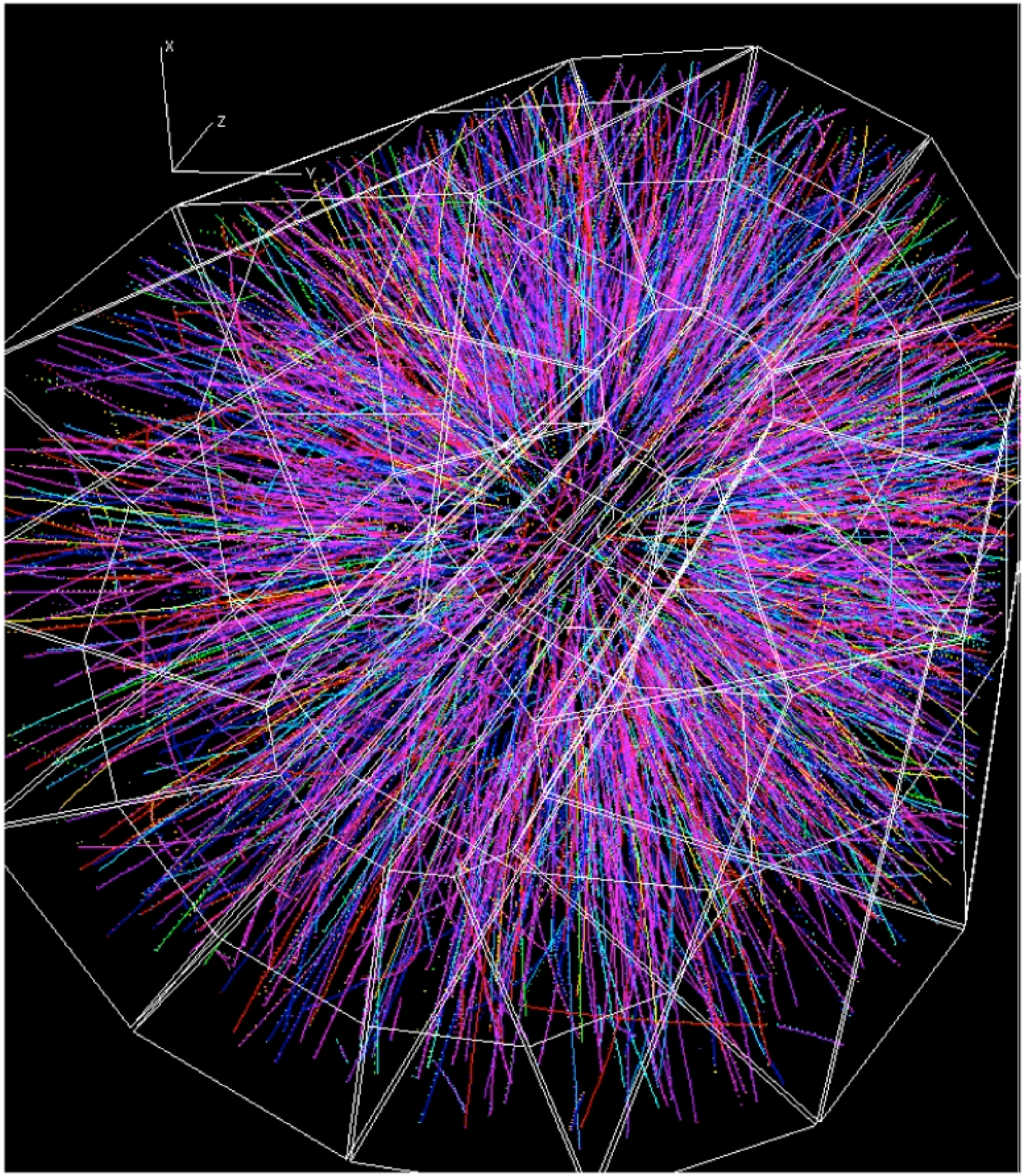
high outside humidity

not everything perfectly airconditioned

gaseous detectors need to be protected from large barometric pressure changes

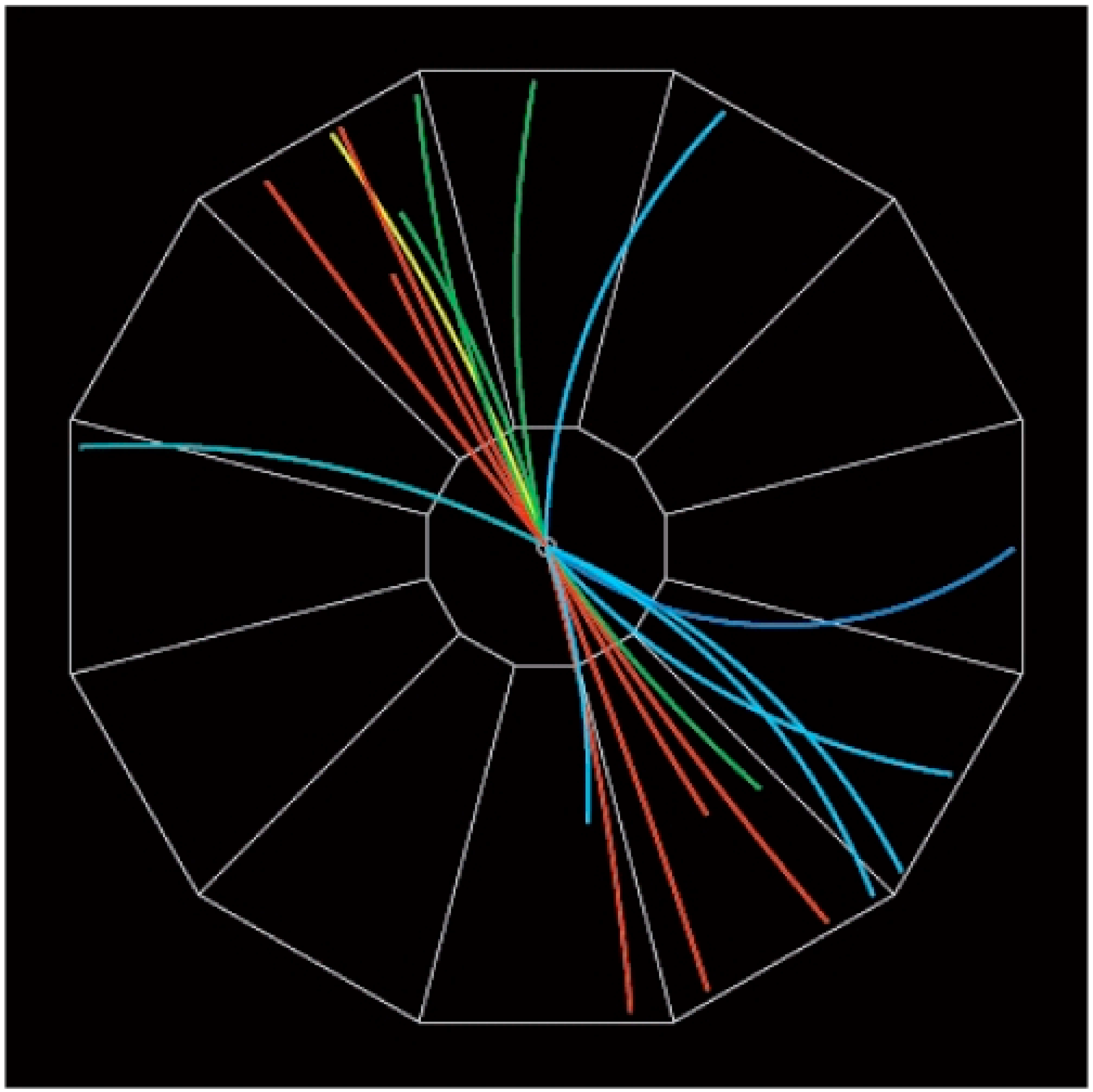
WHAT'S THE CHALLENGE

Cluster finding

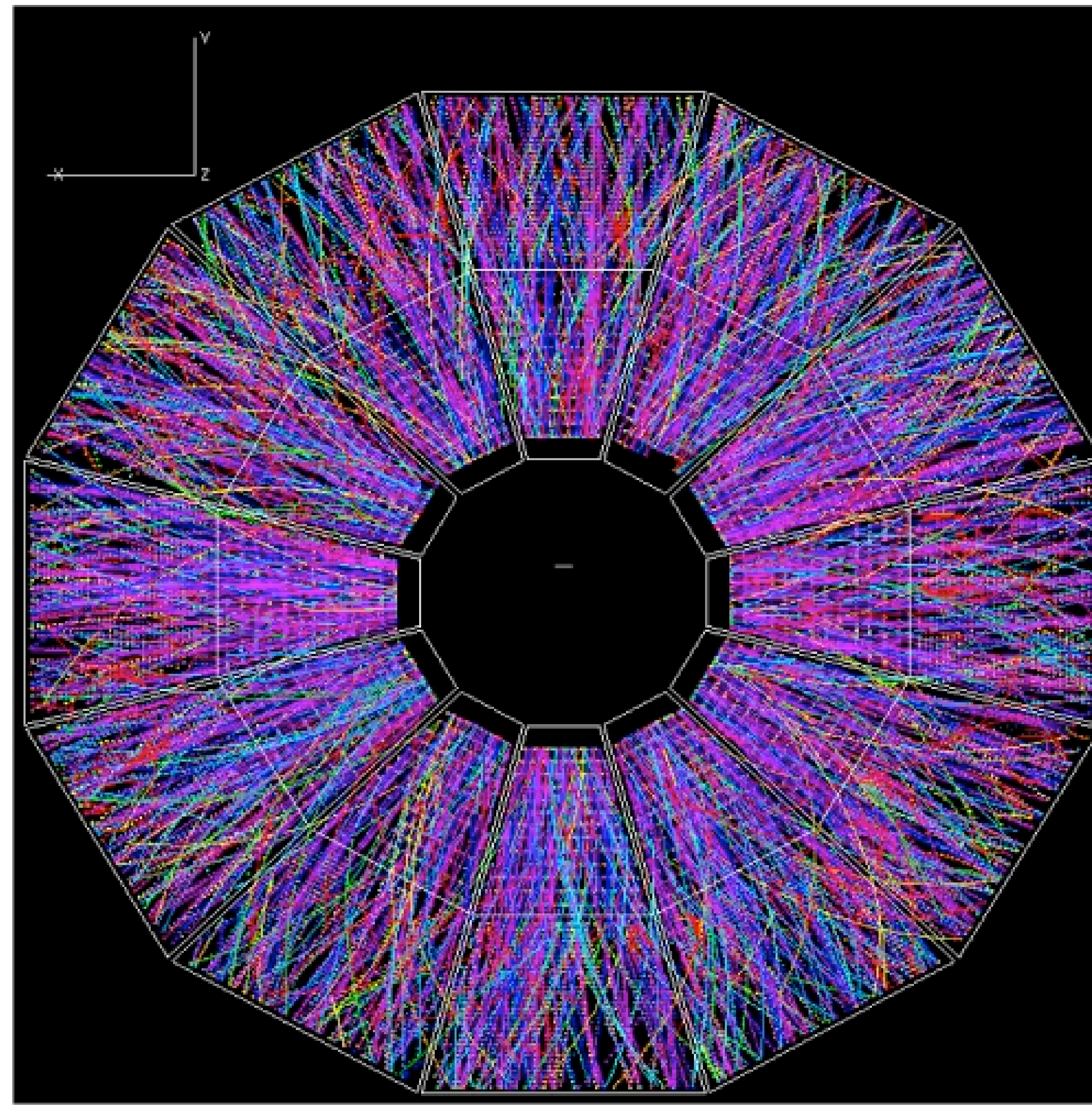


CAN YOU FIND THE JET(S)

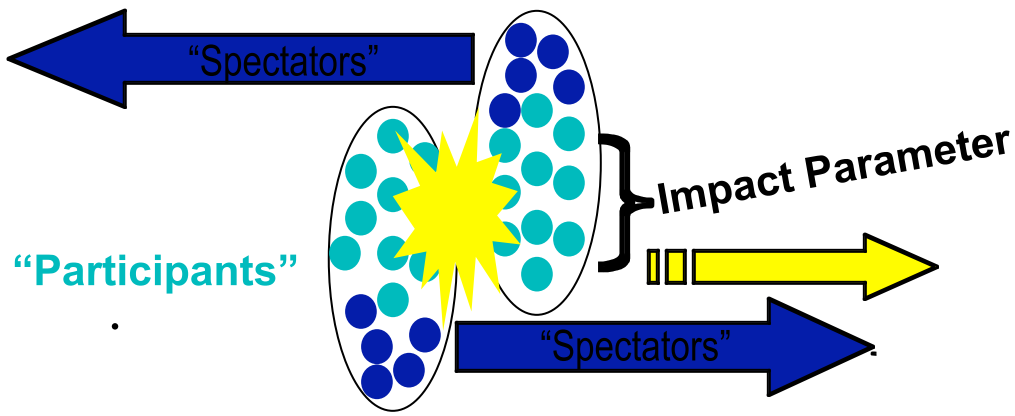
STAR PP EVENT



STAR Au Au EVENT

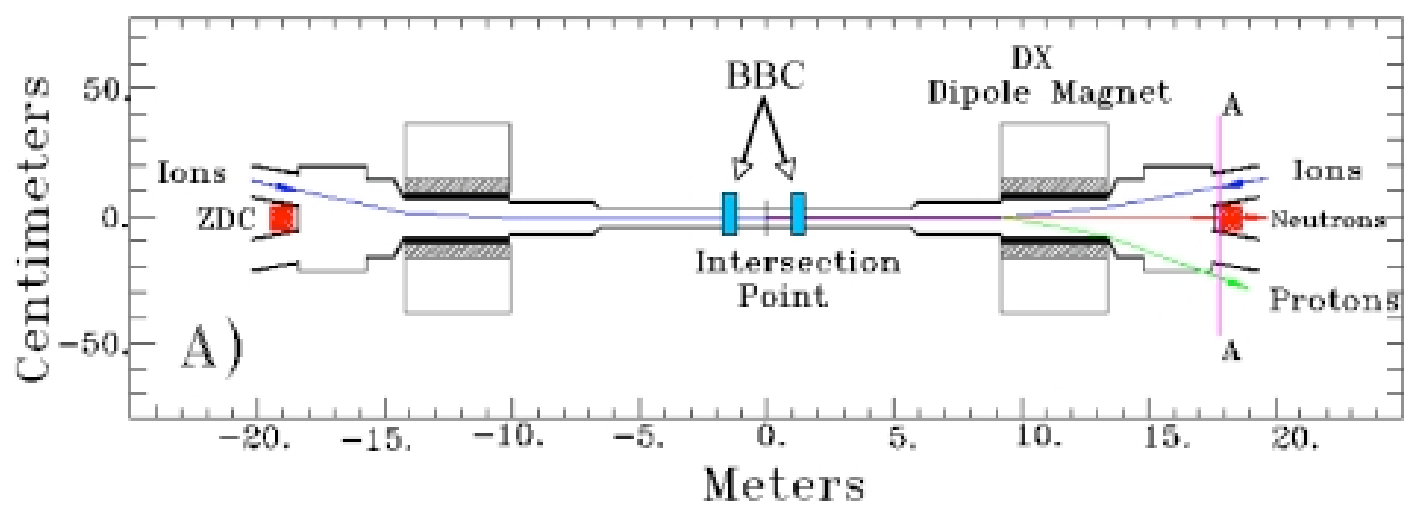


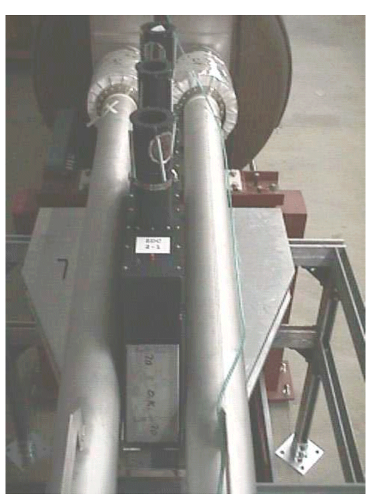
RHIC Global detectors



Luminosity/Cross-Sections
Event Characterization
 Centrality (Au+Au, d+Au)
 Event Vertex and Start-Time

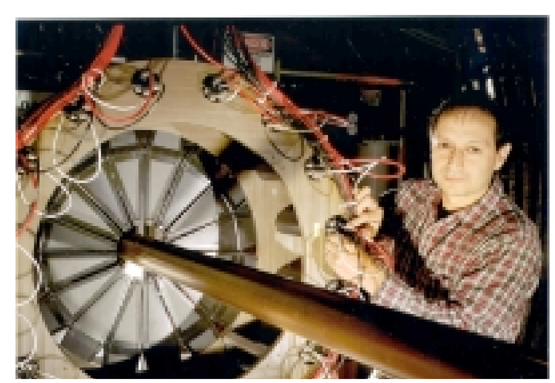
Clean Triggering
Ultra-Peripheral Coherent Interactions
Transverse Spin Asymmetry
Relative Luminosity





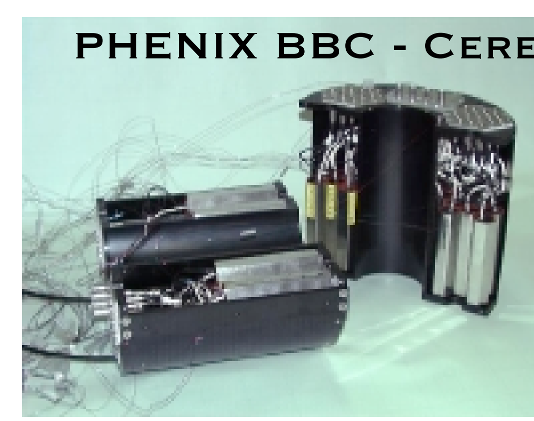
ZDC
common to all
four experiments

BBC <100ps resolution,
fast vertex trigger, timing,
centrality of collision



PHOBOS Paddle Counter

PHENIX BBC - Cerenkov



The HI Experiments

BRAHMS - COLLABORATION

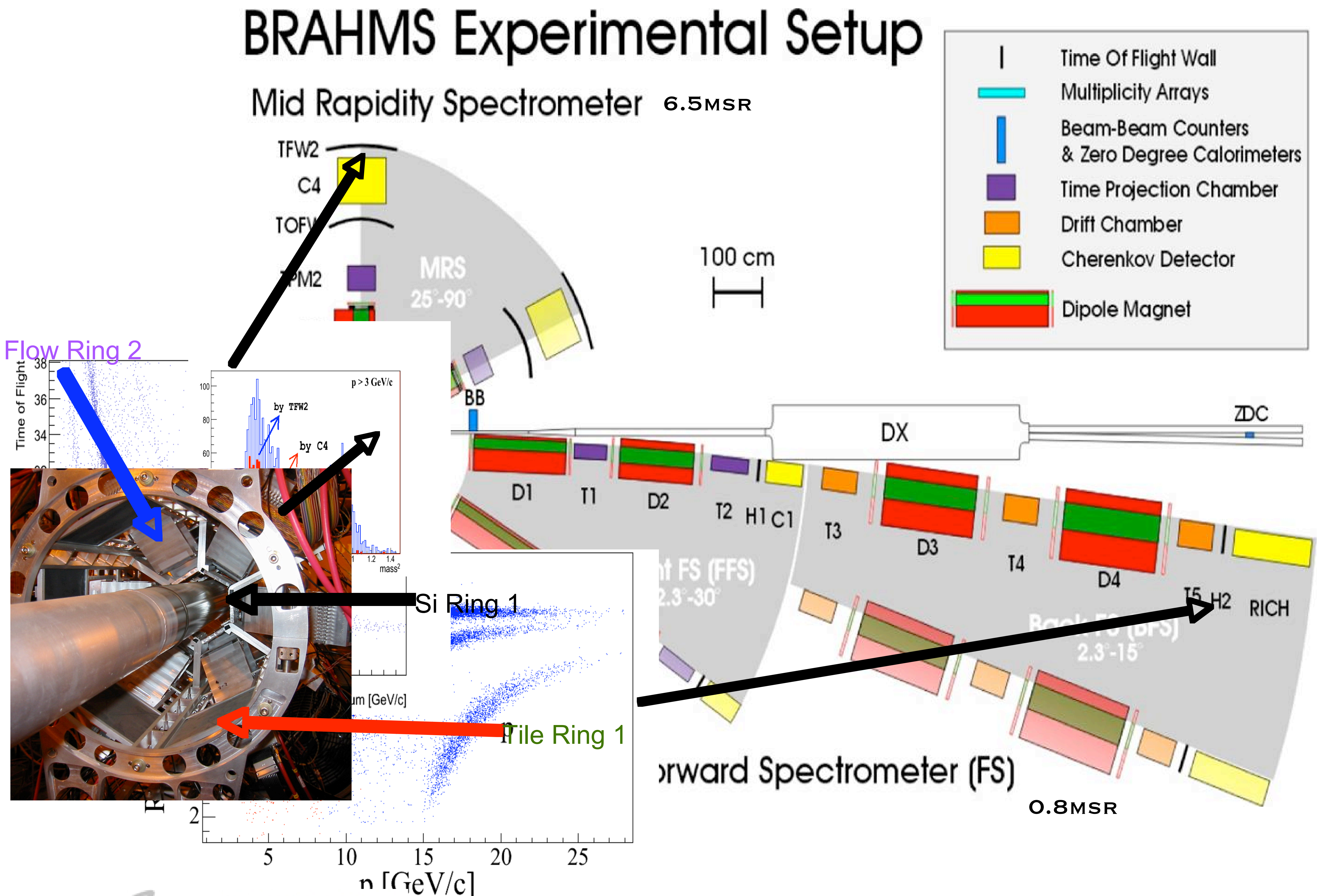
I.G. Bearden[7], D. Beavis[1], C. Besliu[10], Y. Blyakhman[6], J.Brzychczyk[4], B. Budick[6], H. Bøggild[7] , C. Chasman[1], C. H. Christensen[7], P. Christiansen[7], J.Cibor[4], R.Debbe[1], E. Enger[12], J. J. Gaardhøje[7], M. Germinario[7] , K. Grotowski[4] , K. Hagel[8], O. Hansen[7], A.K. Holme[12], H. Ito[11], E. Jacobsen[7], A. Jipa[10], J. I. Jordre[10], F. Jundt[2], C.E.Jørgensen[7], R. Karabowicz[4] , T. Keutgen[9], E. J. Kim[5], T. Kozik[3], T.M.Larsen[12], J. H. Lee[1], Y. K.Lee[5], G. Løvhøjden[2], Z. Majka[3], A. Makeev[8], B. McBreen[1], M. Mikkelsen[12], M. Murray[8], J. Natowitz[8], B.S.Nielsen[7], K. Olchanski[1], D. Ouerdane[7], R.Planeta[4], F. Rami[2], D. Roehrich[9], B. H. Samset[12], D. Sandberg[7], S. J. Sanders[11], R.A.Sheetz[1], Z.Sosin[3], P. Staszel[7], T.S. Tveter[12], F.Videbæk[1], R. Wada[8], A.Wieloch[3] and I. S. Zgura[10]

[1]Brookhaven National Laboratory, USA, [2]IReS and Université Louis Pasteur, Strasbourg, France
[3]Jagiellonian University, Cracow, Poland, [4]Institute of Nuclear Physics, Cracow, Poland
[5]Johns Hopkins University, Baltimore, USA, [6]New York University, USA
[7]Niels Bohr Institute, University of Copenhagen, Denmark
[8]Texas A&M University, College Station. USA, [9]University of Bergen, Norway
[10]University of Bucharest, Romania, [11]University of Kansas, Lawrence,USA
[12] University of Oslo Norway

56 physicists, 12 institutions, 5 countries...

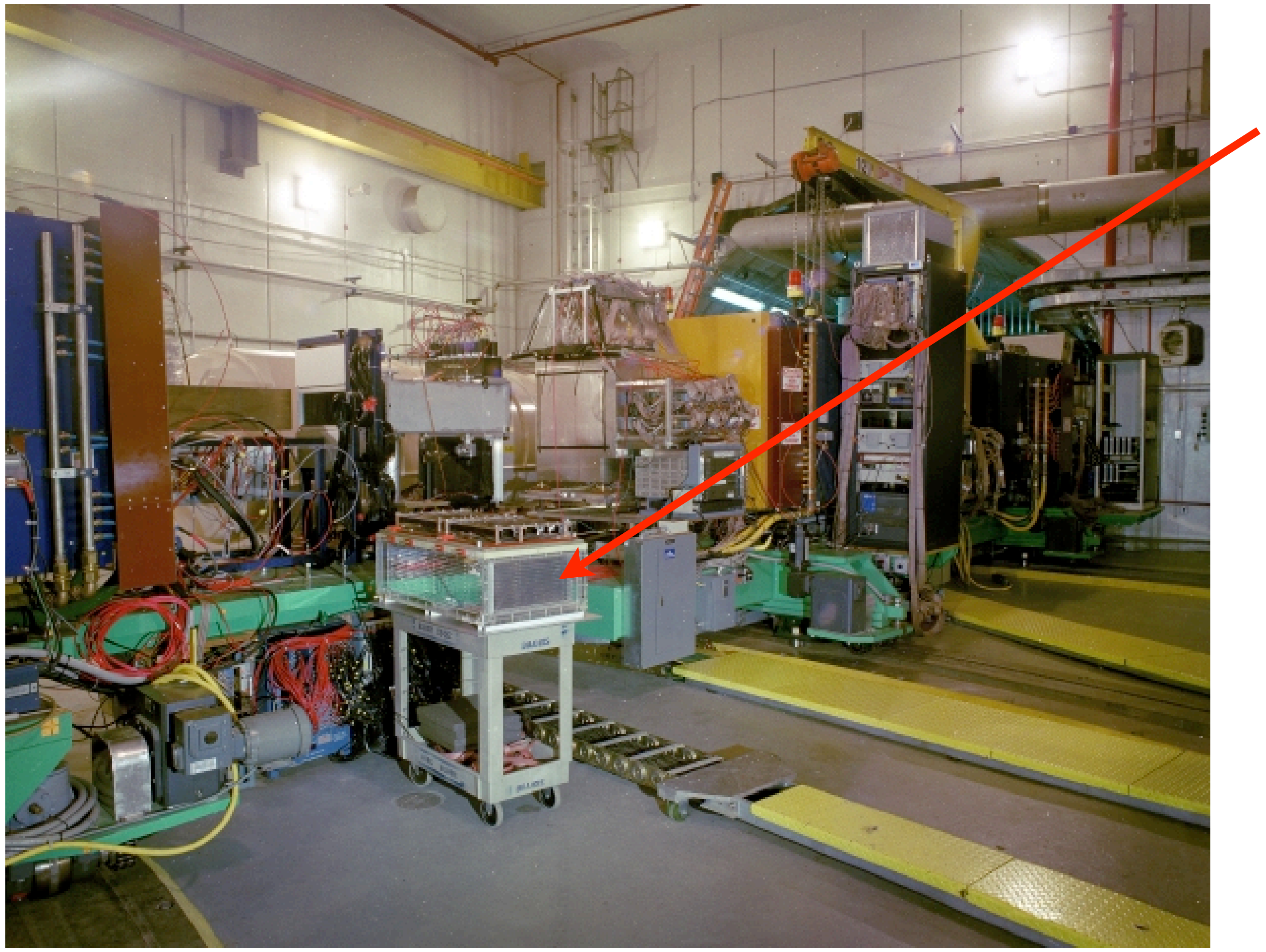
http://www.sciencedirect.com/science?_ob=HelpURL&_file=doi.htm&_acct=C000057228&_version=1&_urlVersion=0&_userid=2422869&md5=47c08f4c0830bc7a6702186224fbe1b3

BRAHMS - GENERAL



BRAHMS - SPECTROMETERS

SMALL ACCEPTANCE = SMALL DETECTORS, NO MAJOR PROBLEMS OVER THE YEARS, ONE LOOSE ANODE WIRE



TPC:
AR/CO2 (90:10)
21.8CM DRIFT, 229V/CM
1152 PADS, 158 TIME BINS EACH, STAR FEE

DC:
8(10) - HOR, VER, ±18° WIRE PLANES
AR/C4H10 (67:33), ETHANOL BUBBLER (9°C)

simple 'follow your nose' algorithm,
small track density, 0.01-0.1 part/cm^2,
Hough transforms showed no advantage

BRAHMS - DETAILS

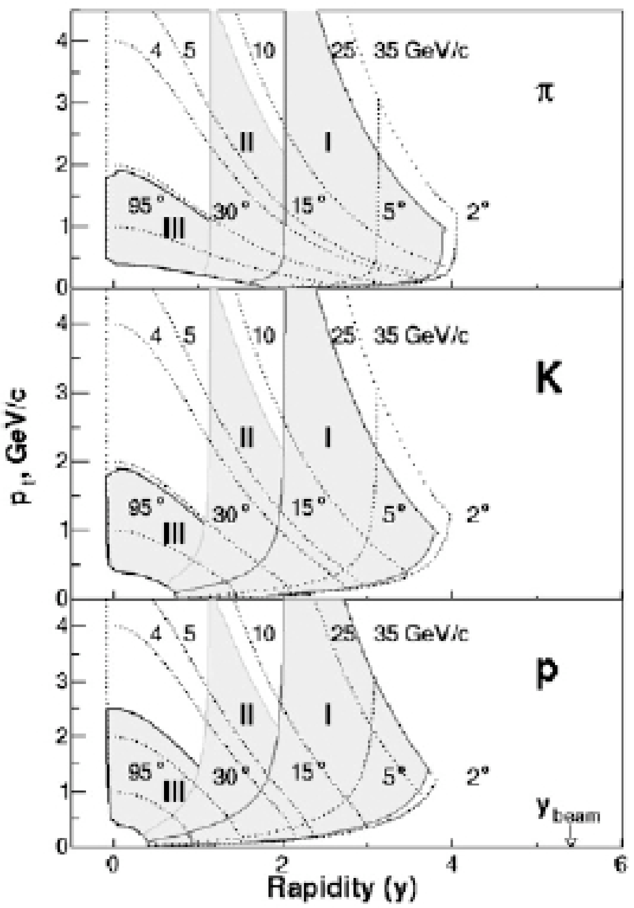


Fig. 1. BRAHMS acceptance for pions, kaons and protons. Region I and II show the acceptance of the FS with two different configurations, see below. Region III shows the acceptance for the MRS. The dotted curves marked 4, 5, 10, 25 and 35 GeV/c are curves of constant momentum, while the set marked 95°, 30°, 15°, 5°, 2° indicate curves at a constant polar angle. The fully drawn curves mark the acceptance borders.

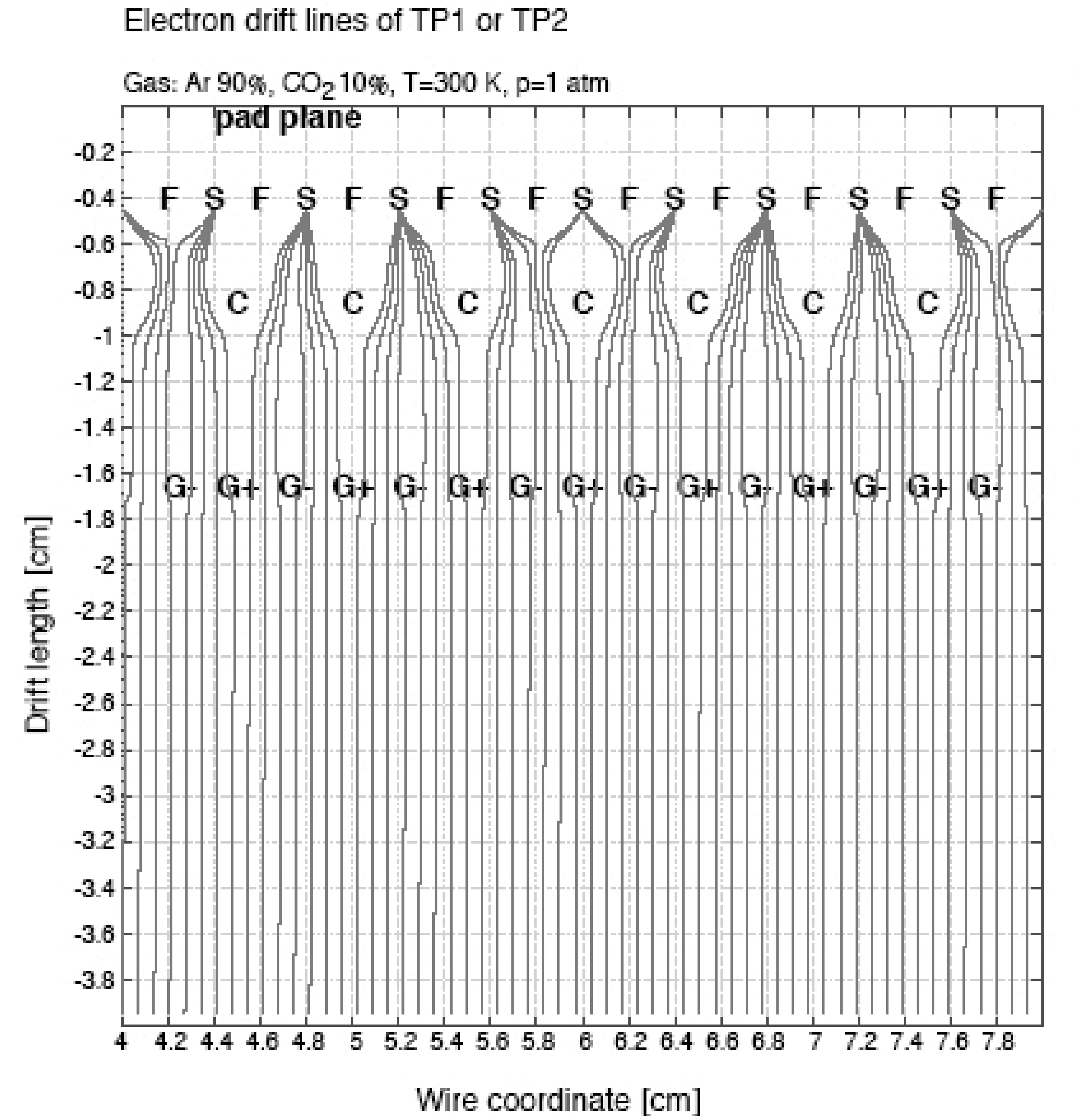


Fig. 10. Electric field lines near the TPC read-out chamber. All

TPCs main characteristics

TPC	Dist. to vertex (cm)	Overall (x, y, z) cm^3	Active (x, y, z) cm^3	Pad rows	Pads per row	Pad size (mm^2)
T1	500	$45 \times 30 \times 70$	$33 \times 22 \times 56$	14	96	27.5×3
T2	810	$50 \times 30 \times 88$	$2 \times (39 \times 22 \times 31.5)$	2×8	112	27.5×3
TPM1	95	$67 \times 34 \times 67$	$37.5 \times 21 \times 36$	12	96	29.5×3.4
TPM2	285	$82 \times 30 \times 61$	$50 \times 22 \times 67.5$	20	144	24.5×4.2

PHOBOS - COLLABORATION

Burak Alver, Birger Back, Mark Baker, Maarten Ballintijn, Donald Barton, Russell Betts, Richard Bindel, Wit Busza (Spokesperson), Zhengwei Chai, Vasundhara Chetluru, Edmundo Garcia, Tomasz Gburek, Kristjan Gulbrandsen, Clive Halliwell, Joshua Hamblen, Ian Harnarine, Conor Henderson, David Hofman, Richard Hollis, Roman Hołyński, Burt Holzman, Aneta Iordanova, Jay Kane, Piotr Kulinich, Chia Ming Kuo, Wei Li, Willis Lin, Constantin Loizides, Steven Manly, Alice Mignerey, Gerrit van Nieuwenhuizen, Rachid Nouicer, Andrzej Olszewski, Robert Pak, Corey Reed, Eric Richardson, Christof Roland, Gunther Roland, Joe Sagerer, Iouri Sedykh, Chadd Smith, Maciej Stankiewicz, Peter Steinberg, George Stephans, Andrei Sukhanov, Artur Szostak, Marguerite Belt Tonjes, Adam Trzupek, Sergei Vaurynovich, Robin Verdier, G‡bor Veres, Peter Walters, Edward Wenger, Donald Willhelm, Frank Wolfs, Barbara Wosiek, Krzysztof Woźniak, Shaun Wyngaardt, Bolek Wyslouch

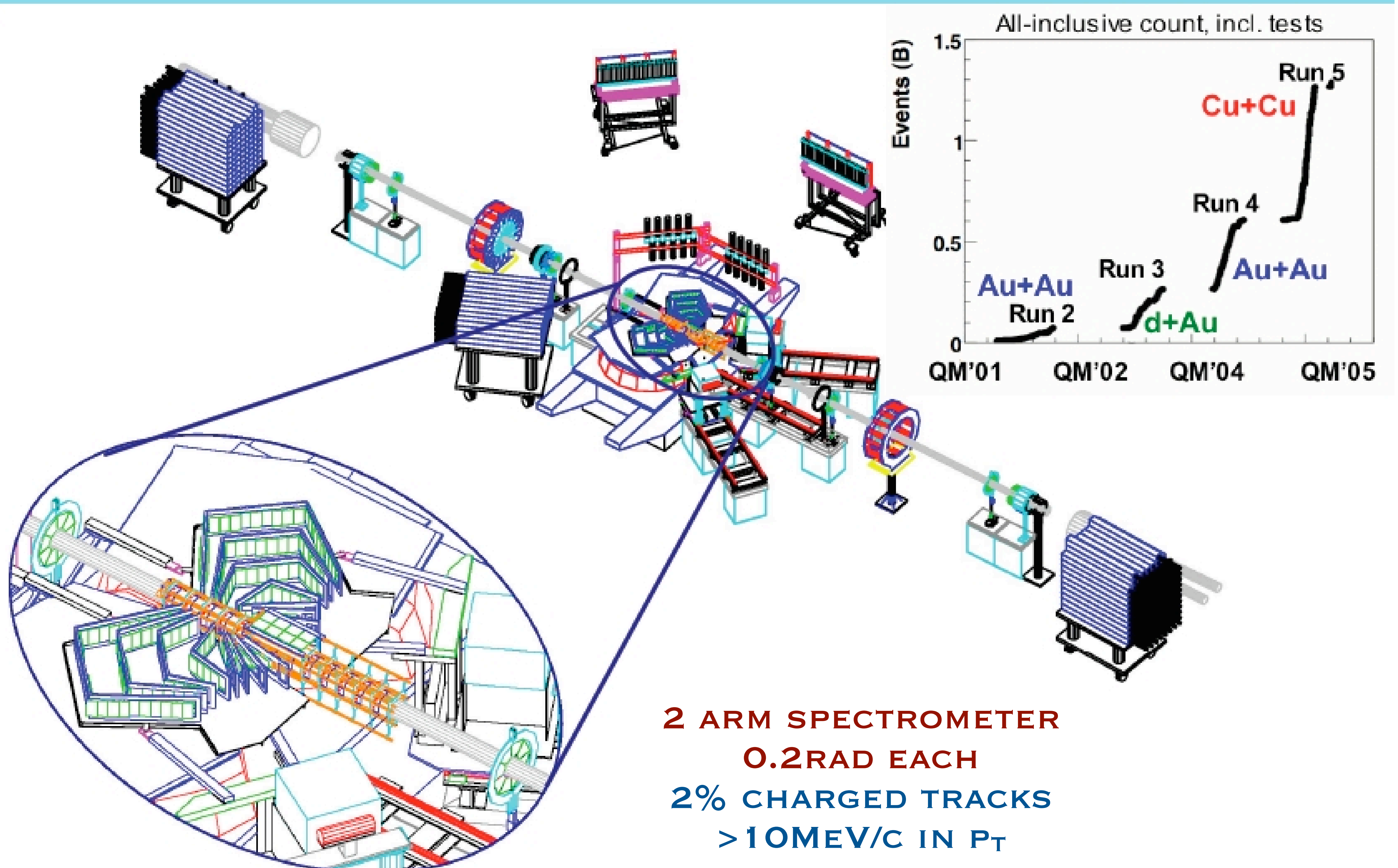
ARGONNE NATIONAL LABORATORY
BROOKHAVEN NATIONAL LABORATORY
INSTITUTE OF NUCLEAR PHYSICS PAN, KRAKOW
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
NATIONAL CENTRAL UNIVERSITY, TAIWAN
UNIVERSITY OF ILLINOIS AT CHICAGO
UNIVERSITY OF MARYLAND
UNIVERSITY OF ROCHESTER

63 physicists, 8 institutions, 3 countries...

http://www.sciencedirect.com/science?_ob=HelpURL&_file=doi.htm&_acct=C000057228&_version=1&_urlVersion=0&_userid=2422869&md5=47c08f4c0830bc7a6702186224fbe1b3

PHOBOS - GENERAL

PHOBOS Experiment - Run 5

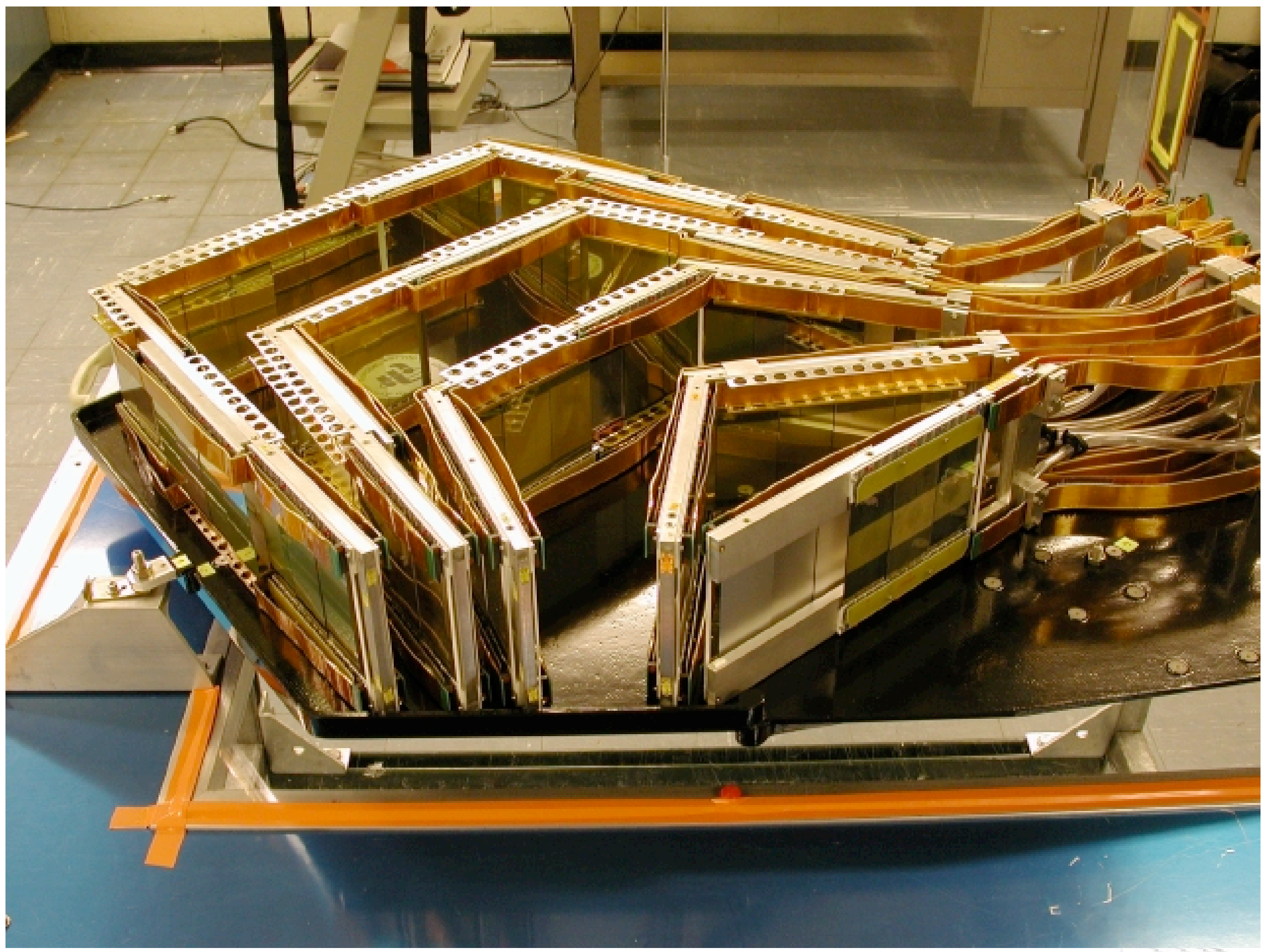


2 arm spectrometer
0.2rad each
2% charged tracks
>10MeV/c in p_T
wide rapidity coverage

PHOBOS - Silicon

B.B. Back et al. / Nuclear Instruments and Methods in Physics Research A 499 (2003) 603–623

9 different Si-pad wafer designs
300-340μm thickness



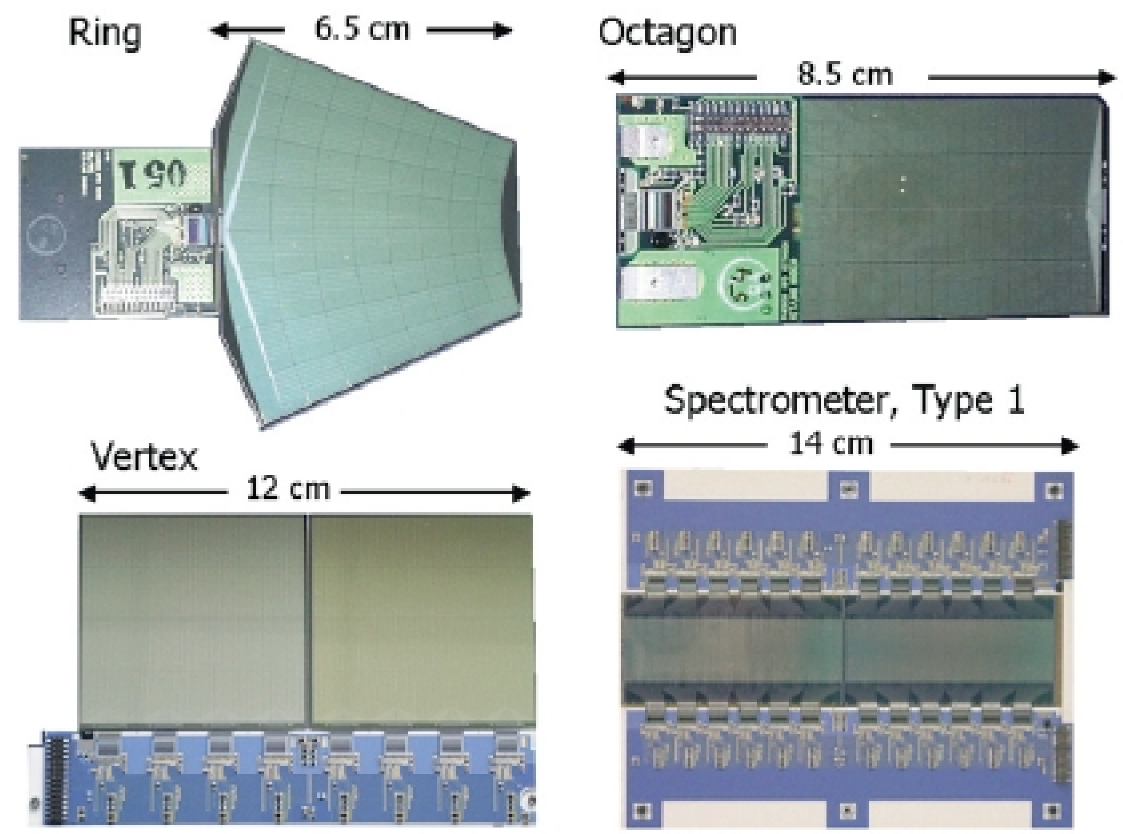


Fig. 6. Photographs of different detector modules.

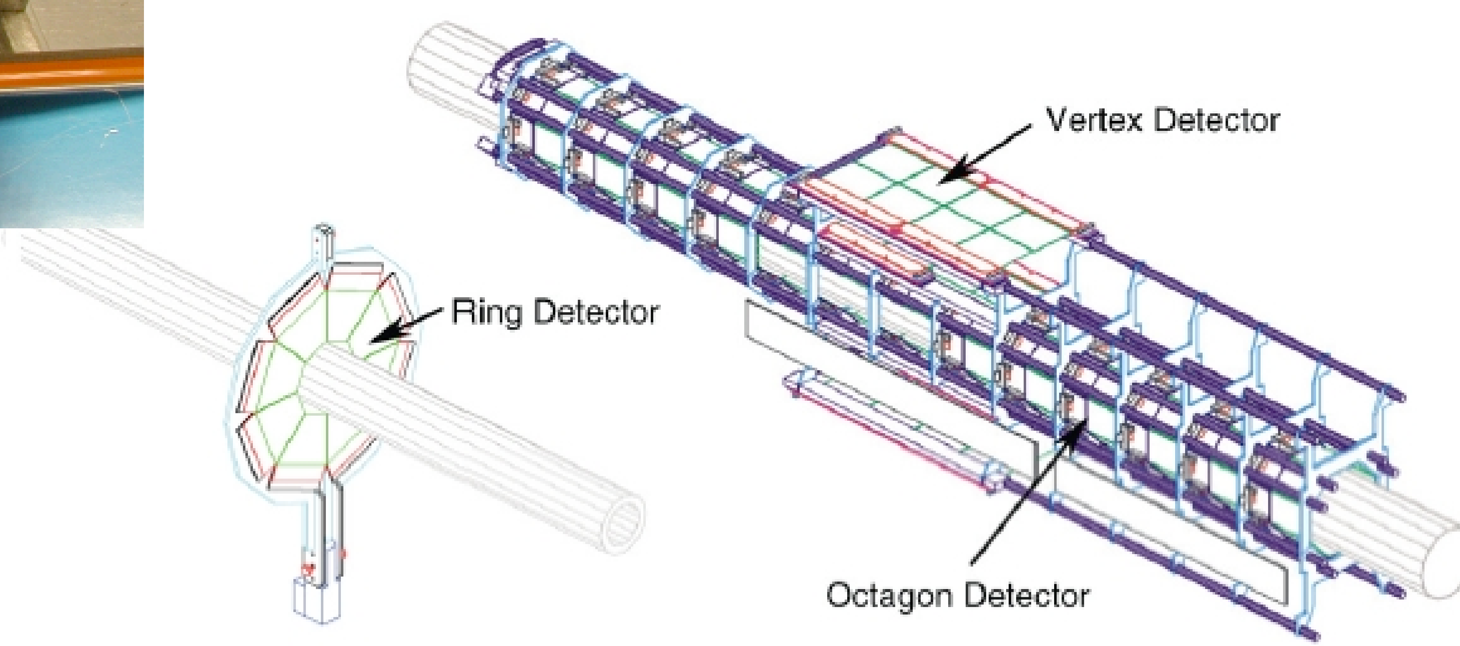


Fig. 8. Isometric drawing of the Octagon frame with detector modules and a complete Ring detector.

water cooled frames
0-2T field region
135k channels

PHOBOS - TRACKING

SPECTROMETER TRACKS:

OUTSIDE FIELD:

- ROAD-FOLLOWING ALGORITHM IN FIRST 6 FIELD FREE LAYERS

INSIDE FIELD:

- MAP TWO-HIT COMBINATIONS IN (1/P, Θ) SPACE
- APPLY CLUSTER ALGORITHM

MATCH TWO TRACK INFORMATION BY Θ, A FIT IN THE YZ PLANE AND DE/DX CONSISTENCY

FOR MORE DETAILS ASK C.ROLAND, WHO SPEAKS LATER IN THIS SESSION

TALK BY K. WOZNIAK
"VERTEX RECONSTRUCTION ALGORITHMS IN THE PHOBOS EXPERIMENT AT RHIC", AT 17:25

PHOBOS - DETAILS

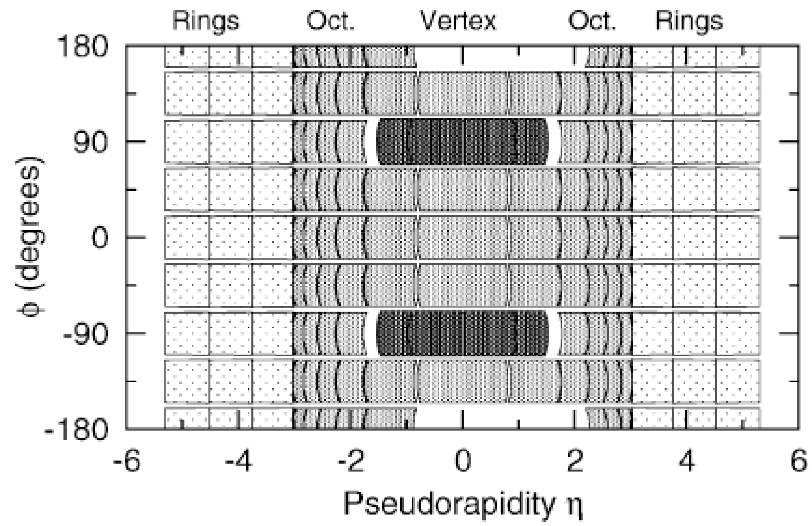


Fig. 2. The geometrical acceptances of the Ring (light), Octagon (medium) and Inner Vertex (dark) detectors for particles emitted from the nominal interaction point are shown as a function of η and ϕ.

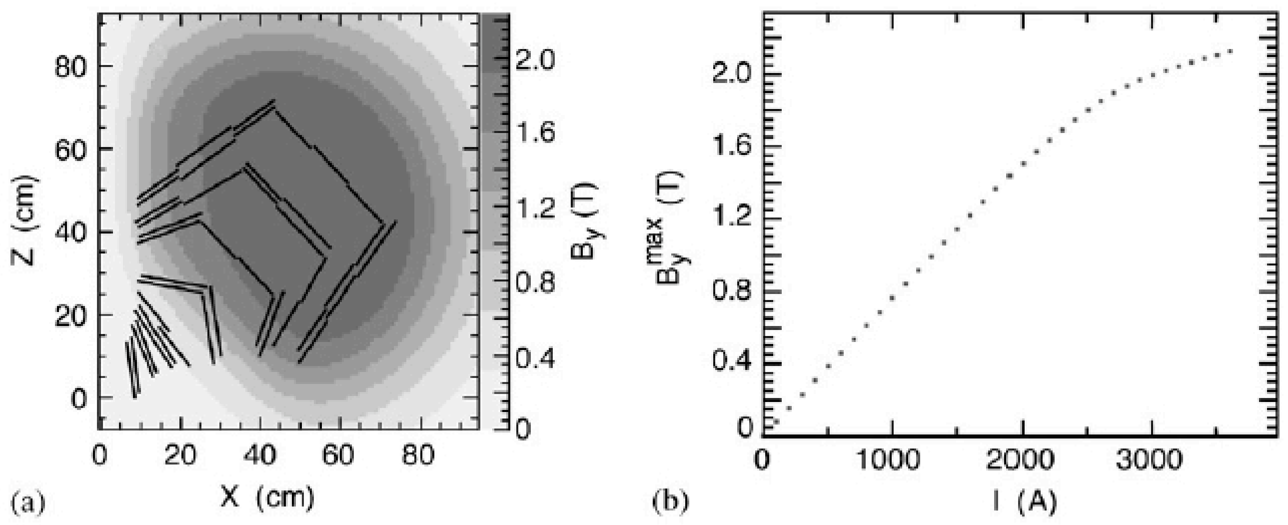


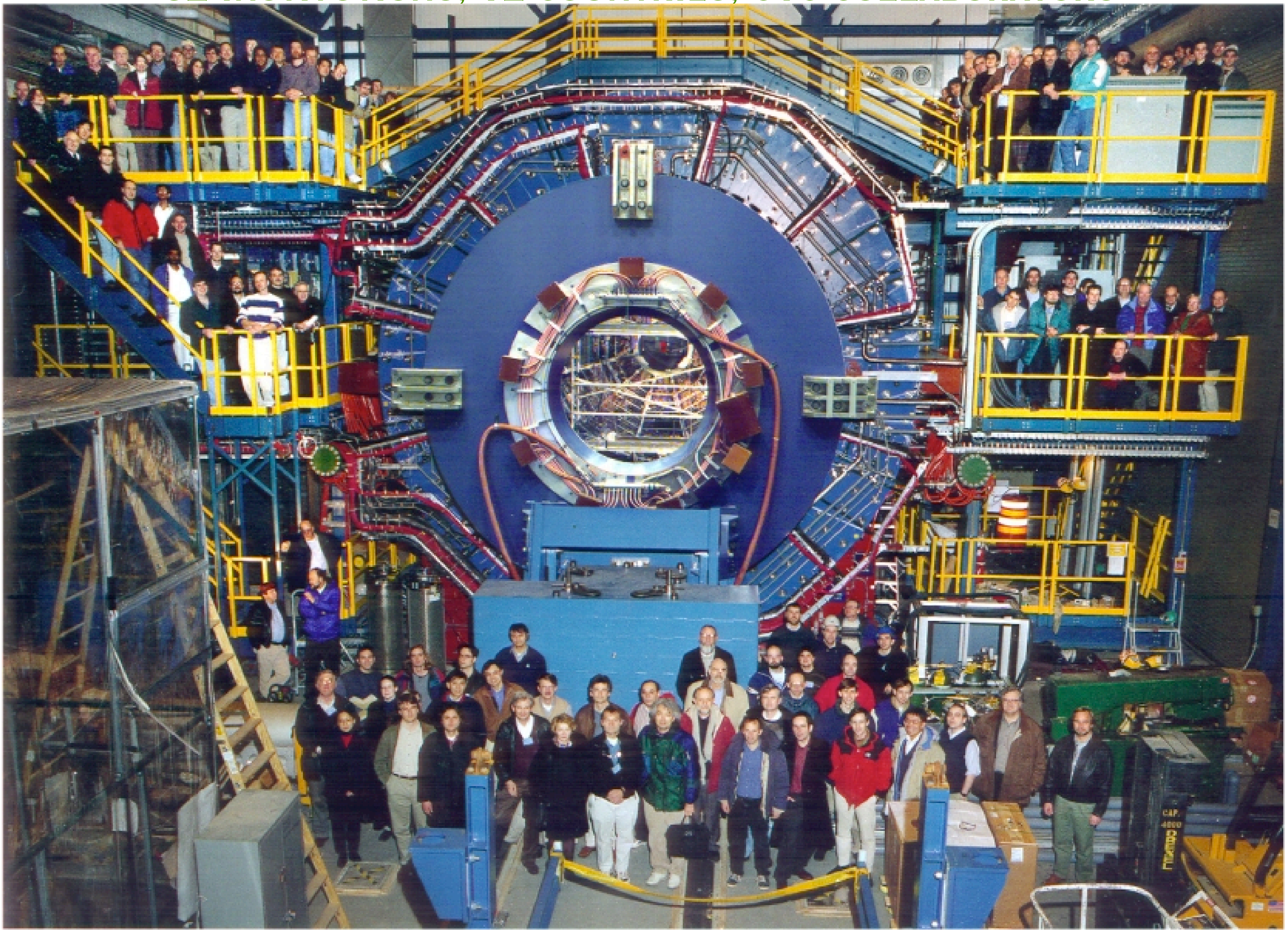
Fig. 4. (a) B_y component of the magnetic field in the mid-plane as a function of the x and z coordinates. In the PHOBOS coordinate system the beam line is located along z, at $x = y = 0$. The outlines of the Spectrometer silicon detectors are also indicated. The maximum magnetic field is 2.18 T. (b) The maximum B_y component is shown as a function of excitation current. The nominal excitation current is 3600 A.

Table 1
Physical characteristics for the PHOBOS silicon pad sensors

Detector system	Sensor type	Active area (mm^2)	Number of pads	Pad size (mm^2)
Spectrometer	1	70.000×22	70×22	1.000×1.0
	2	42.700×30	100×5	0.427×6.0
	3	42.688×60	64×8	0.667×7.5
	4	42.688×60	64×4	0.667×15.0
	5	42.688×76	64×4	0.667×19.0
Multiplicity	Octagon	34.880×81.280	30×4	2.708×8.710
	Ring	≈ 3200	64	≈ 20–105
Vertex	Inner	60.584×48.180	4×256	0.473×12.035
	Outer	60.584×48.180	2×256	0.473×24.070

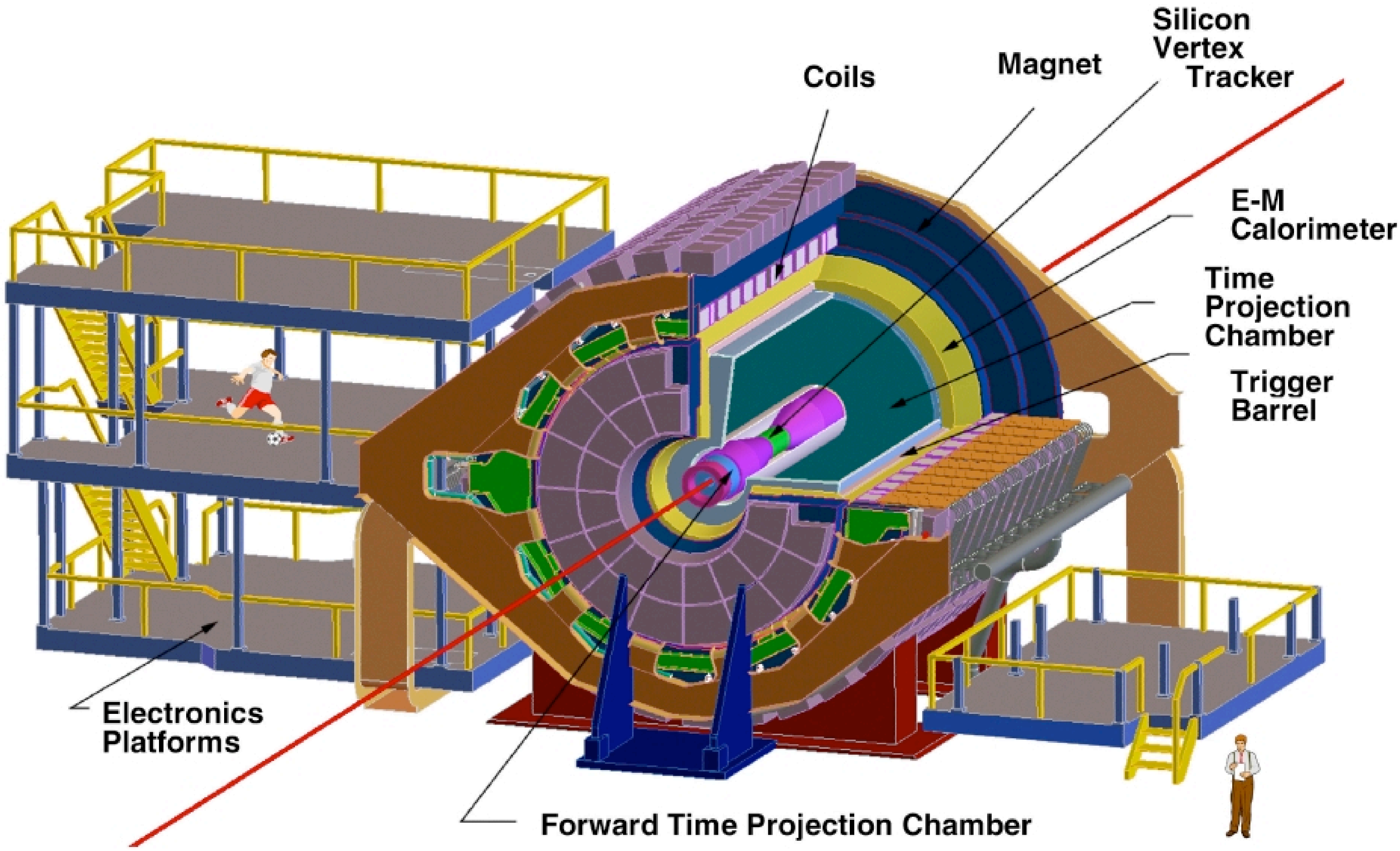
STAR

52 institutions, 12 countries, 616 collaborators

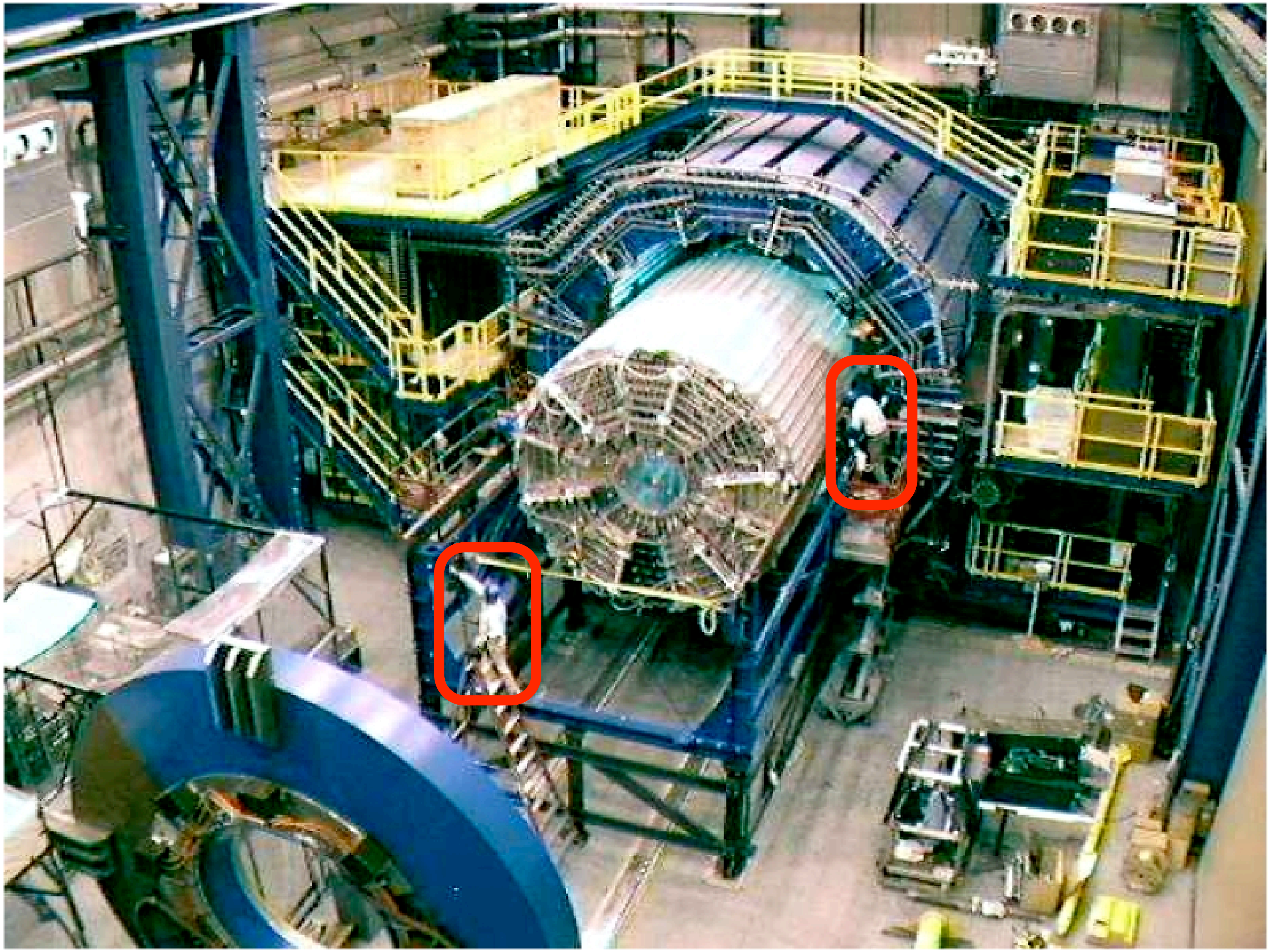


http://www.sciencedirect.com/science?_ob=HelpURL&_file=doi.htm&_acct=C000057228&_version=1&_urlVersion=0&_userid=2422869&md5=47c08f4c0830bc7a6702186224fbe1b3

STAR - general



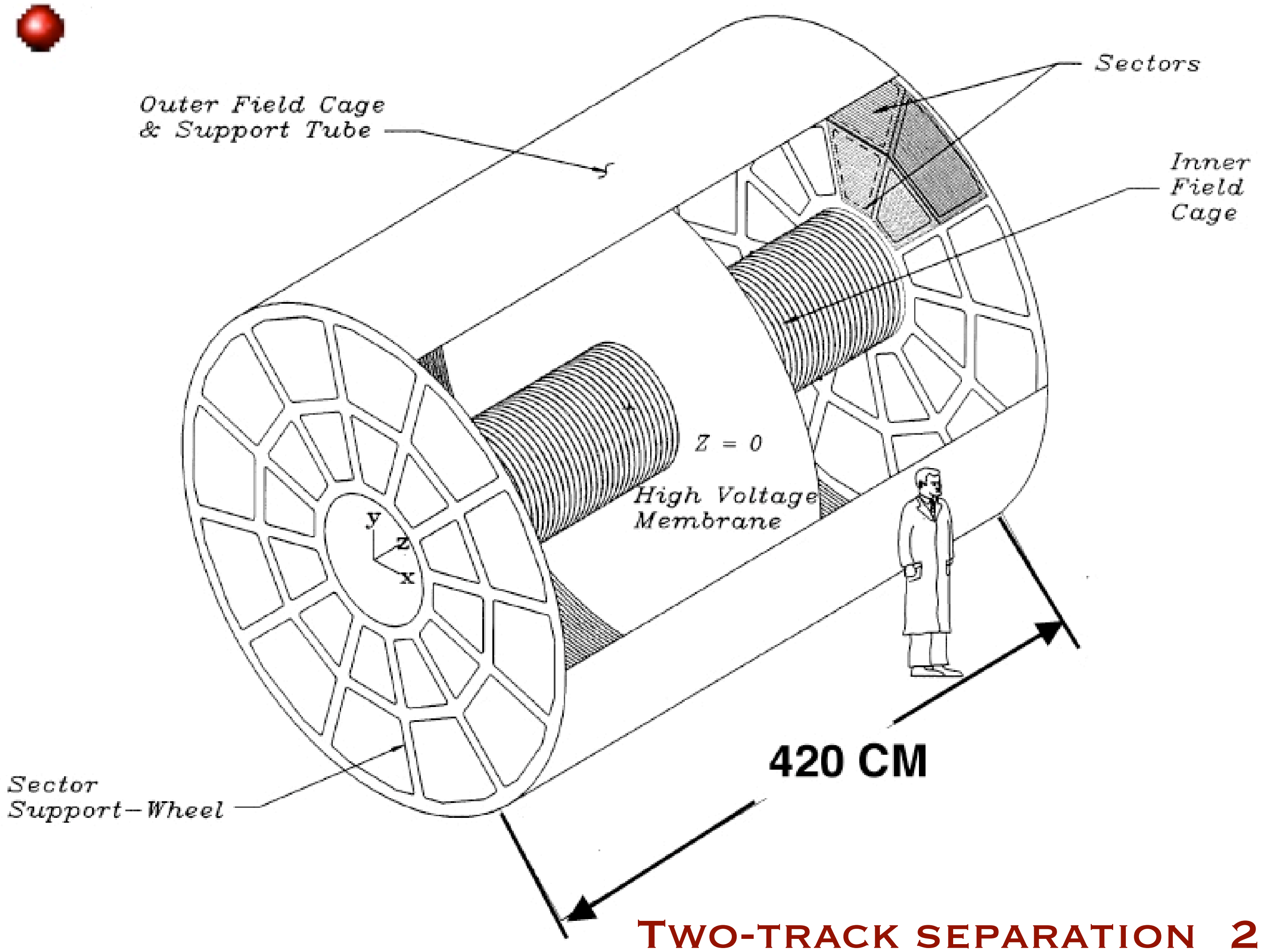
STAR - TPC



Magnetic Field
0.0 G
± 2.5 kG
± 5.0 kG

Gas: P10 ($Ar\text{-}CH_4$ 90%-10%) @ 1 atm
Voltage : - 28 kV at the central membrane 135 V/cm over 210 cm drift path

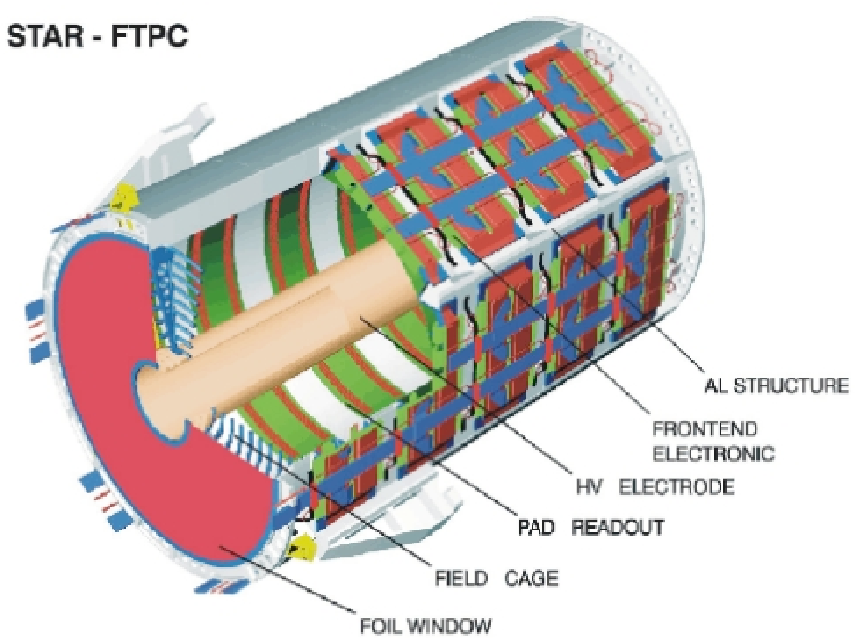
STAR - TPC



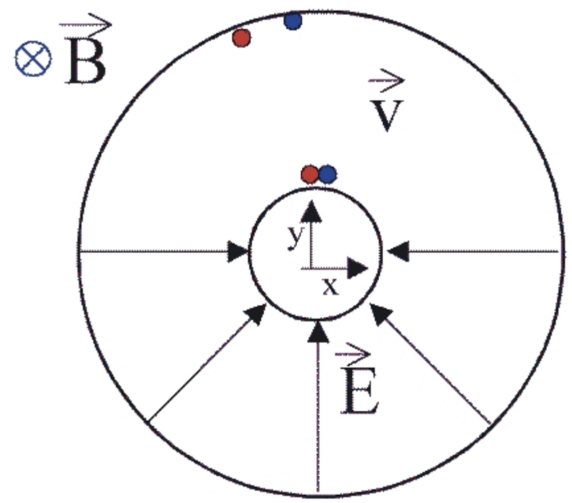
- Two-track separation 2.5 cm
- Momentum Resolution < 2%
- Space point resolution ~ 500 μm
- Rapidity coverage $-1.8 < \eta < 1.8$
- Typically 1000 to 2000 tracks per central event
- >90% eff. @ medium centrality
- Kalman filter & hough transform, point back to SVT

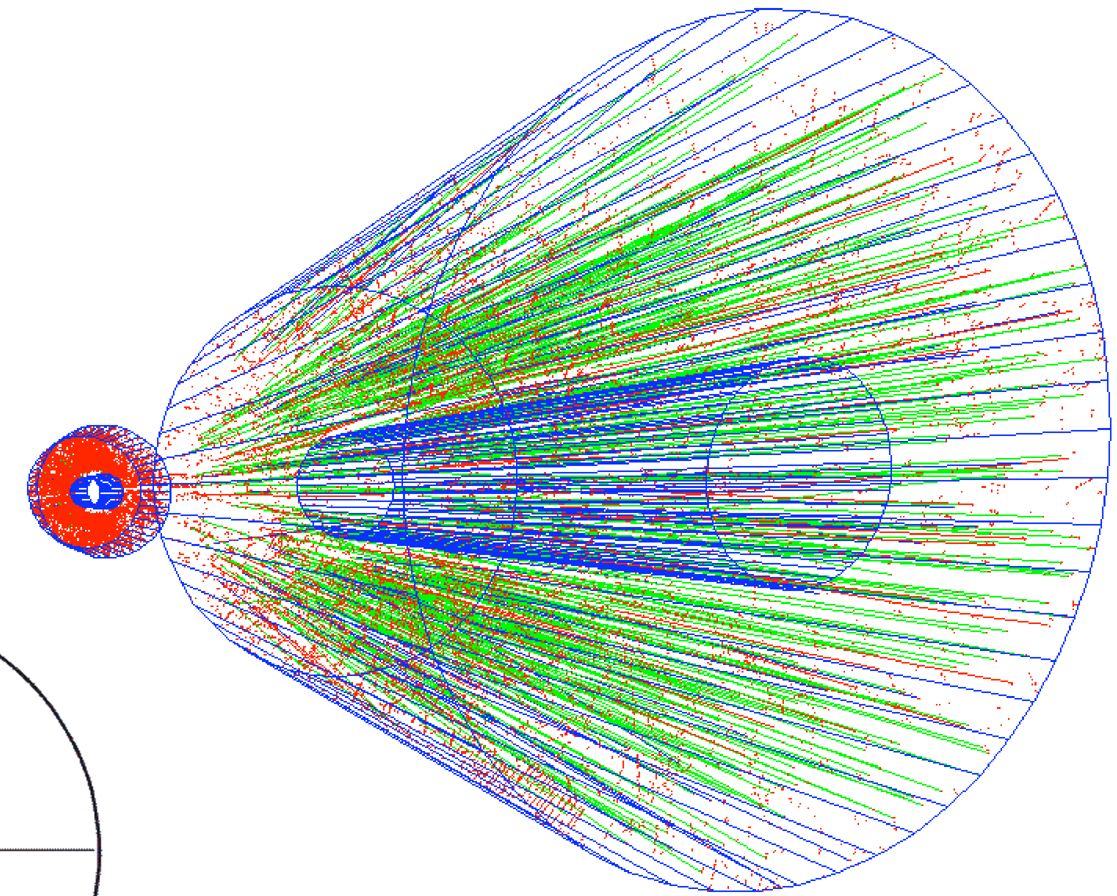
Talk by Gene van Buren,
"Correcting for distortions due to ionization in the STAR TPC", Thursday 14:35h

STAR - fTPC



Volume	
inner radius	7.73 cm
outer radius	30.05 cm
chamber length	120 cm (|z| = 150 – 270 cm)
acceptance	η=2.5 –4.0 (θ=2° - 9°)
Field properties	
drift cathode voltage	10-15 kV
drift electrical field	240-1400 V/cm (radial, ⊥ beam)
Solenoid magnetic field	0.5 T (|| beam)
Gas properties	
gas mixture	Ar(50%)-CO_2(50%)
drift velocity	0.3 – 2.0 cm/μs
trans. Diffusion DT	100-130 μ m/$\sqrt{}$cm
long. Diffusion DL	100-130 μ m/$\sqrt{}$cm
Lorentz angle	4 deg.





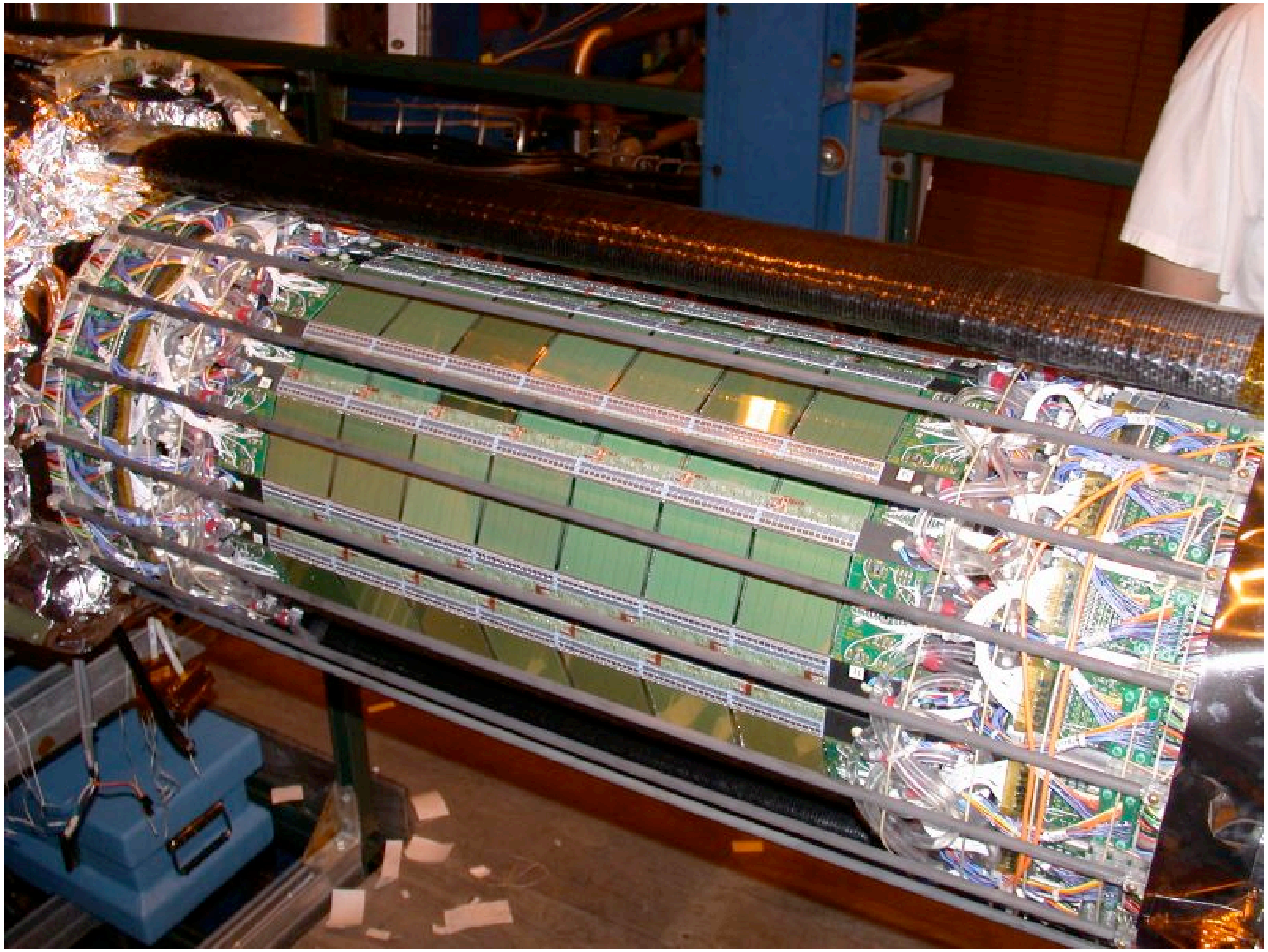
High track density ~ 500 charged particles in each FTPC.

Occupancy of ~30-35% at the inner radius.

Some FEE trouble over the years

compare TPC and fTPC vertex for calibration

STAR - SVT



3 barrels, 8, 12, and 16 ladders
total of 216 wafers

R = 5.97cm, 10.16cm and 14.91cm
Zmax = 44.1cm
$|\eta| = 1$

280μm thick, 6cm x 6cm silicon
total average radiation length
4.5% including FEE

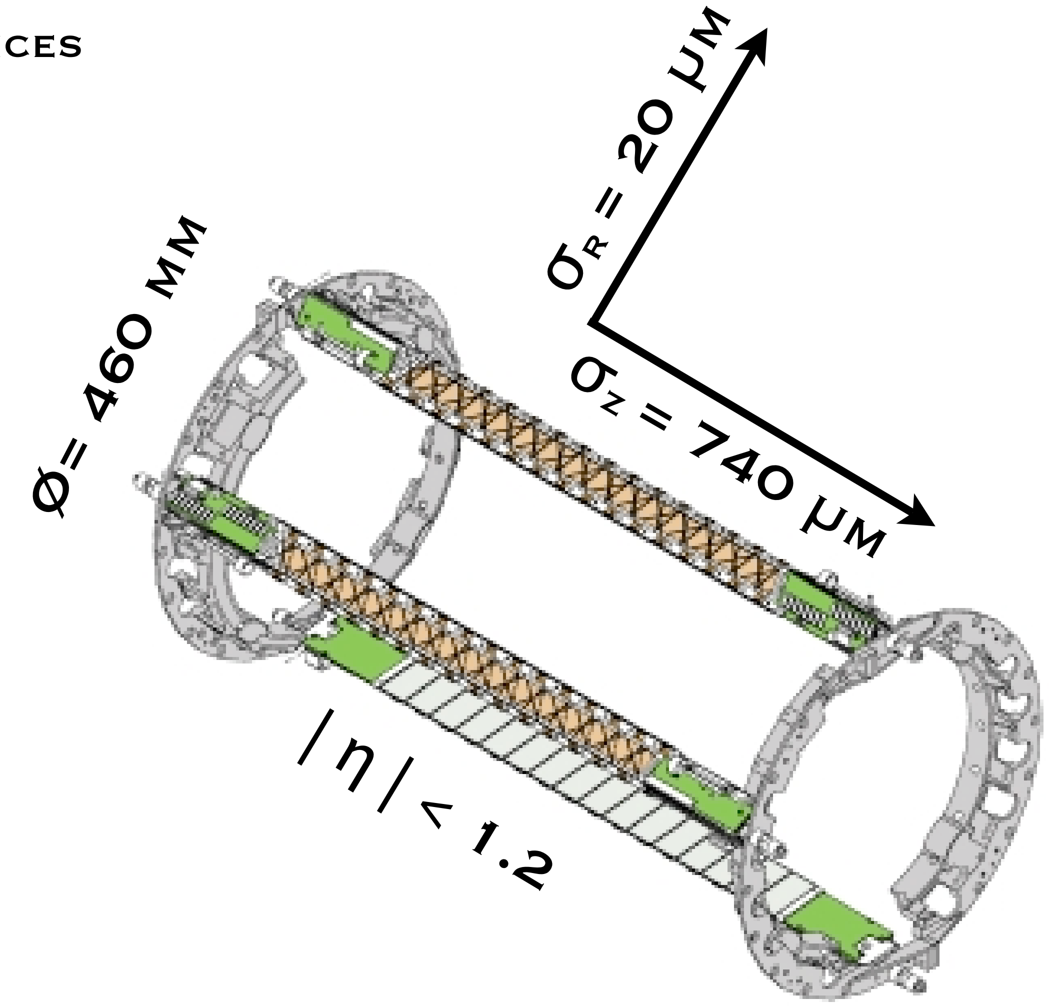
read out at both ends.
480 anodes per wafer.
each anode is sampled and stored
with a Switched Capacitor Array
(SCA) with a depth of 128
capacitors.

	Percent bad channels	
Initial 36 ladders built	< 1%	
RunII-pp	~3.7%	
RunIII Commissioning	~10.5%	
Beginning RunIII-pp	~12.7%	
Beginnin of RunIV	~12.6%	Jan 2004
Last day data taking RunIV	~15.9%	May 2004

STAR - SSD

Summary of the SSD characteristics and performances

General layout	
Radius	230 mm
Ladder length	1060 mm
Acceptance	$\lvert\eta\rvert < 1.2$
Number of ladders	20
Number of wafers per ladder	16
Total number of wafers	320
Silicon wafers characteristics	
Number of sides per wafer	2
Number of strips per side	768
Total readout channels	491520
Silicon wafer sensitive area	73 x 40 mm
Total silicon surface	0.98 m^2
Wafer pitch	95 μm
rf Resolution	20 μm
z Resolution	740 μm
Operating voltage	20–50 V
Leakage current for one wafer	1–2 μA
Readout front-end electronics	
Number of input channels per circuits	128
Total number of circuits	3840
Dynamical range	±13 MIPs
Shaping time	1.2–2 μs
Signal/noise	30–50
SSD total readout time	<5 ms
Expected performances	
Dead channels level	~2%
Hit reconstruction efficiency	~95%
Hit reconstruction purity	~98%

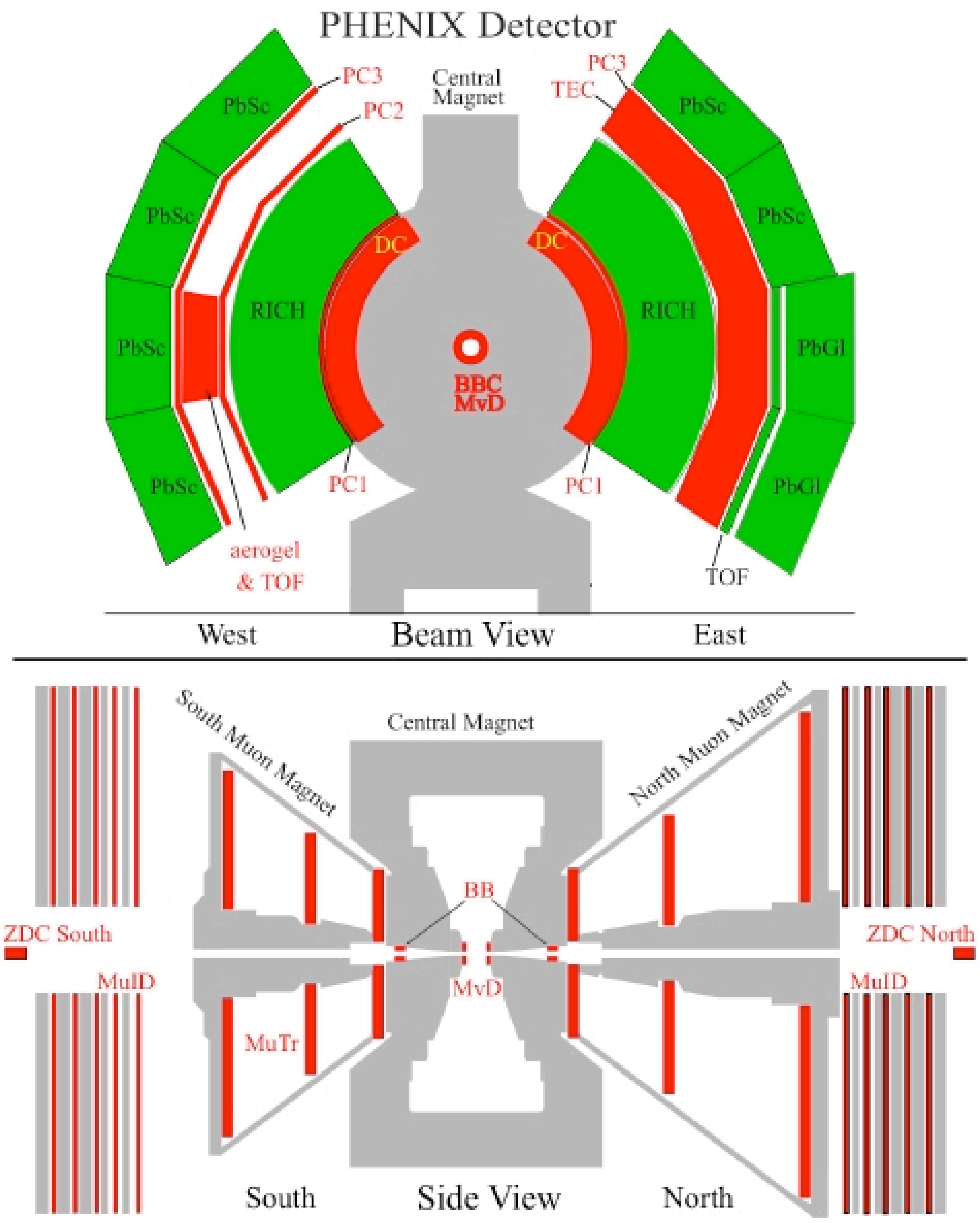


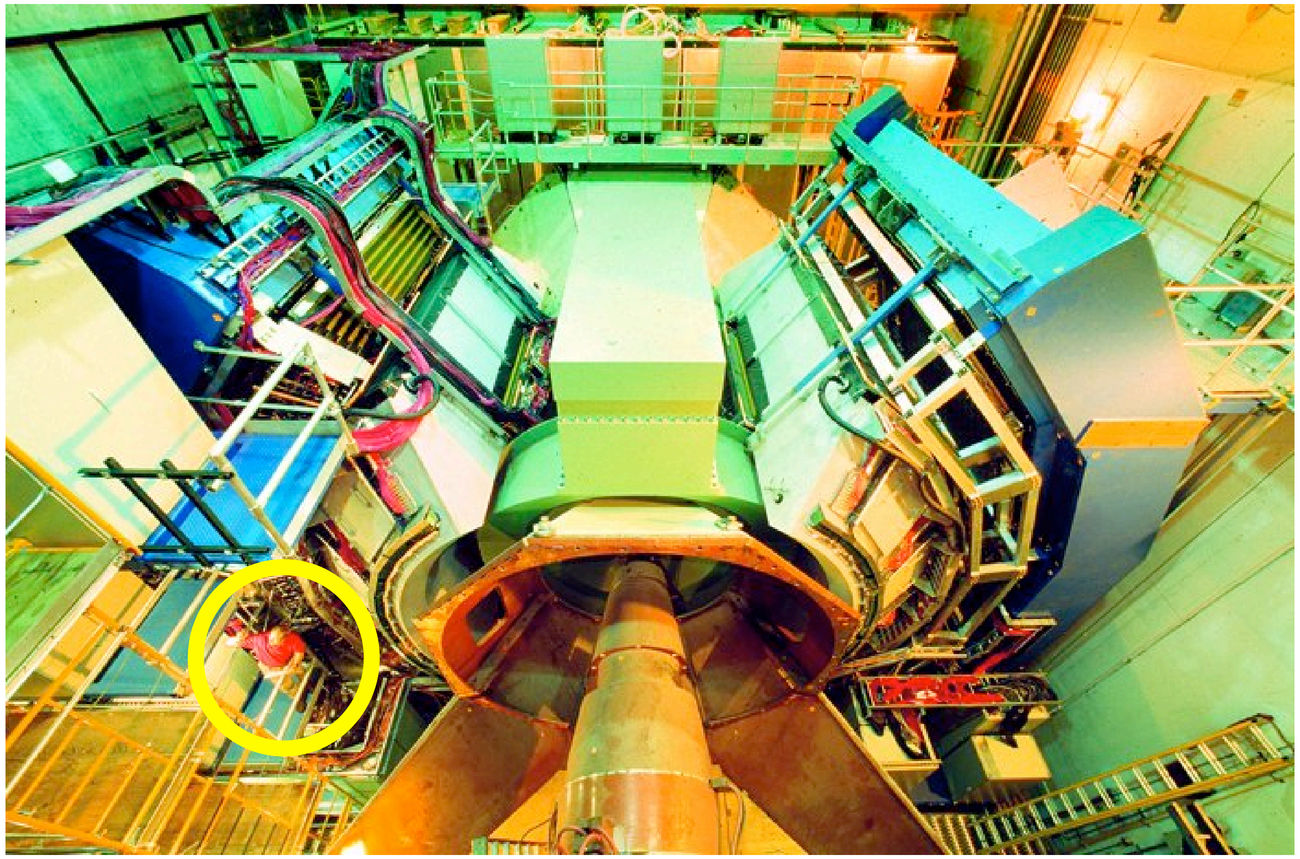
PHENIX

62 institutions from 13 countries, with a total of 498 scientists

http://www.sciencedirect.com/science?_ob=HelpURL&_file=doi.htm&_acct=C000057228&_version=1&_urlVersion=0&_userid=2422869&md5=47c08f4c0830bc7a6702186224fbe1b3

PHENIX-GENERAL



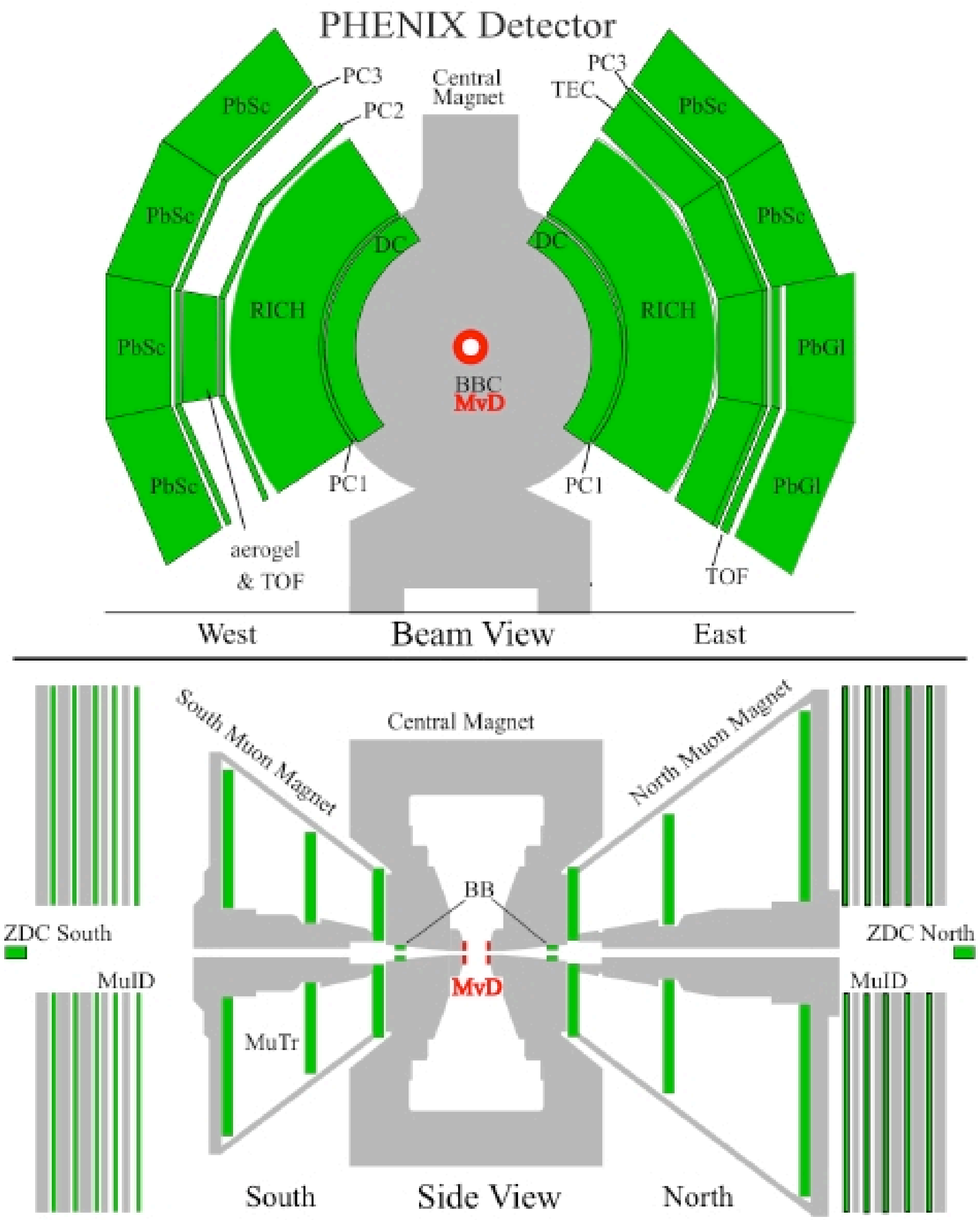


6 different chamber types

Beam-Beam Counter (BBC) and ZDC for Vertex/Start-time trigger and offline cuts

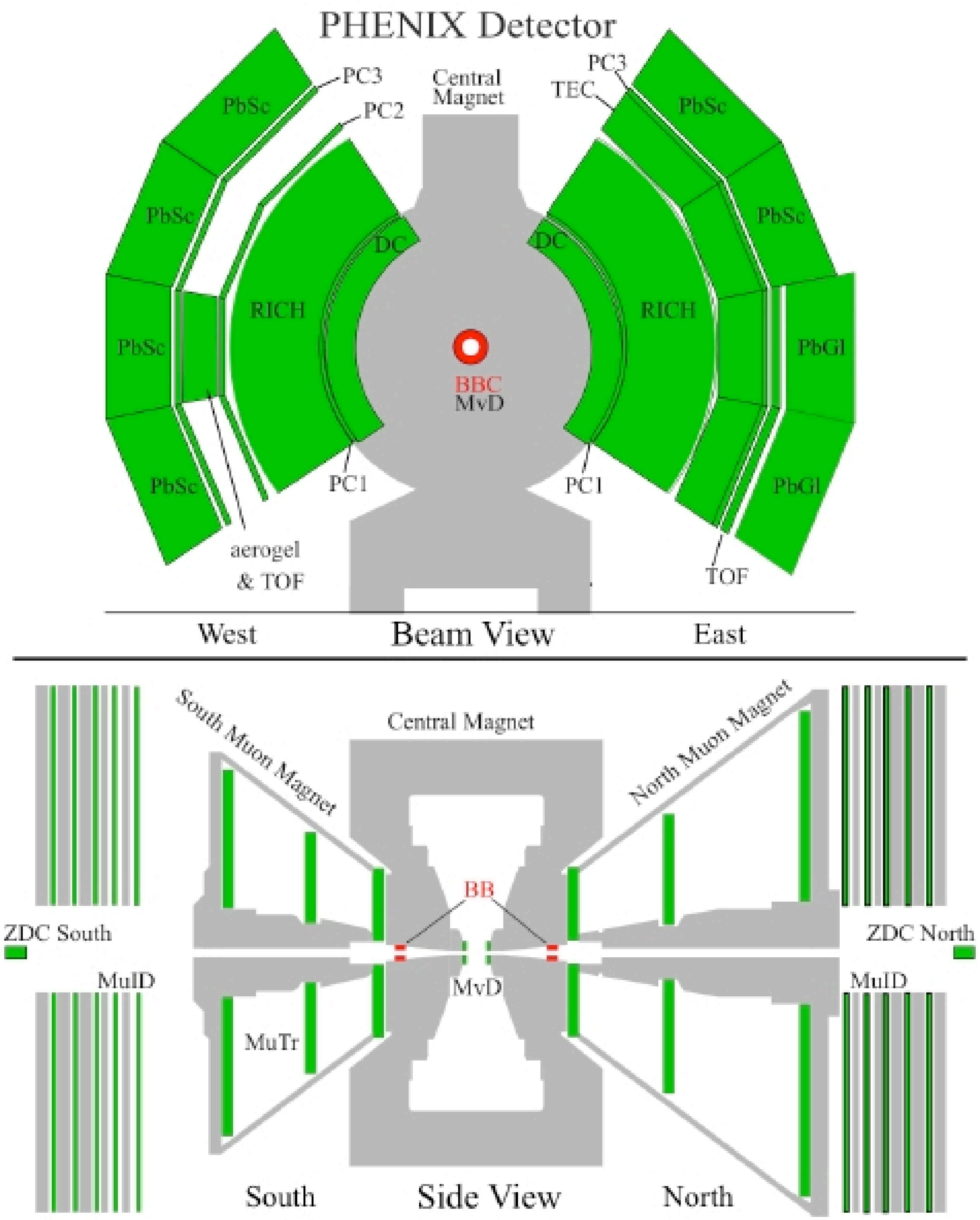
Si-Multiplicity Vertex Detector (MvD)

PHENIX - MvD

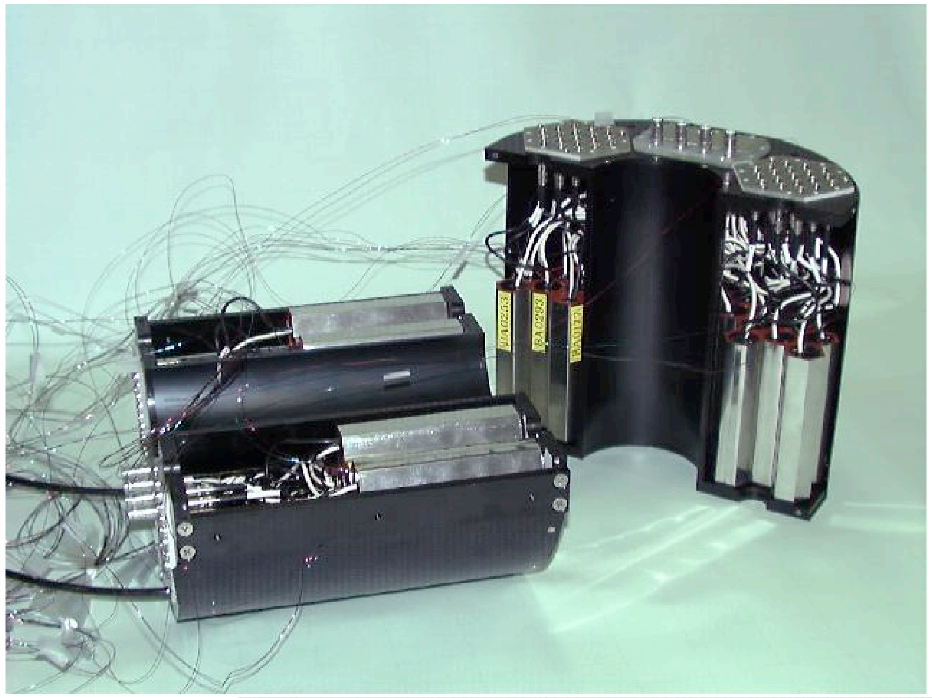


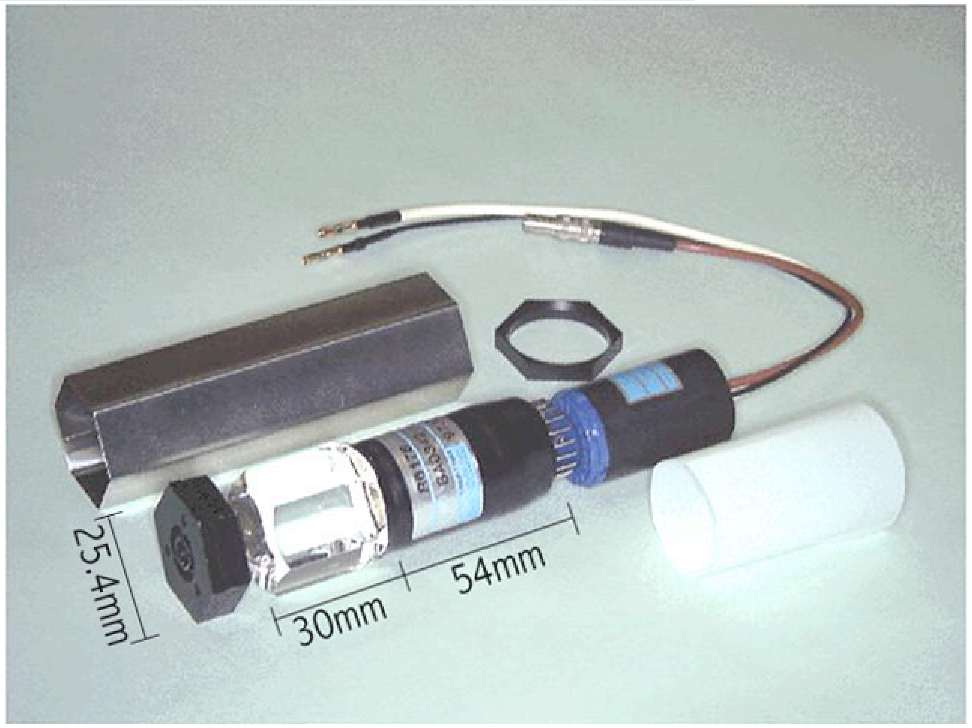
Multiplicity-Vertex detector MvD,
single layer strip/pixel detector,
FEE/noise problems
Not always in data stream
has been removed in stages

PHENIX - BBC

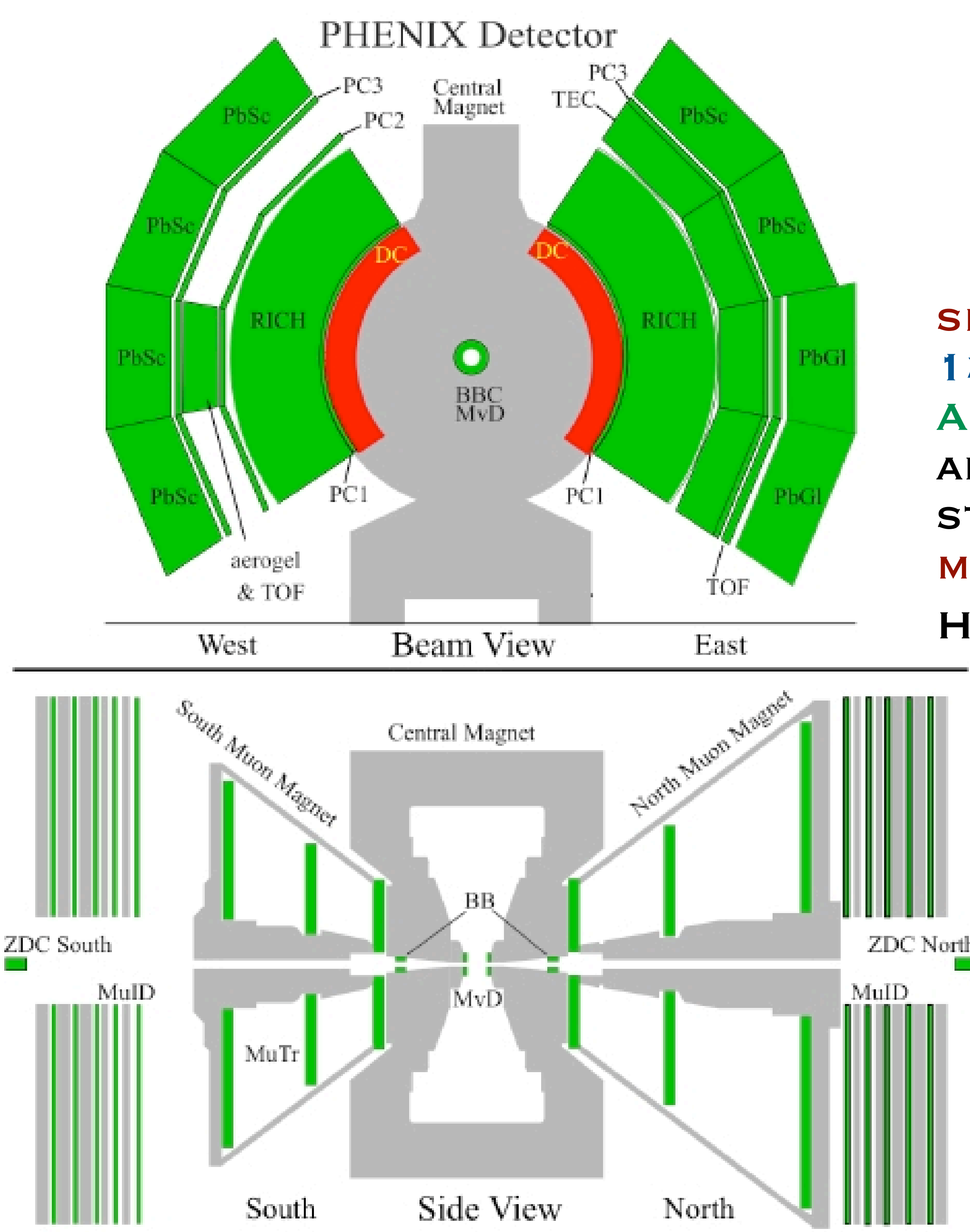


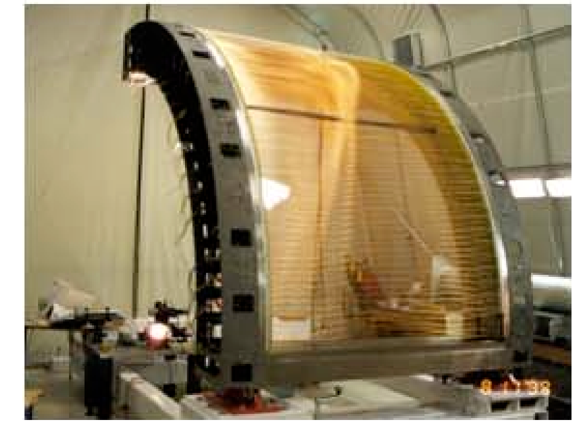
- BBC, quartz Cerenkov
- 64 PMs each side
- vertex trigger and start timing
- event centrality
- reaction plane





PHENIX- DRIFT CHAMBER





SEGMENTED DRIFT CHAMBER

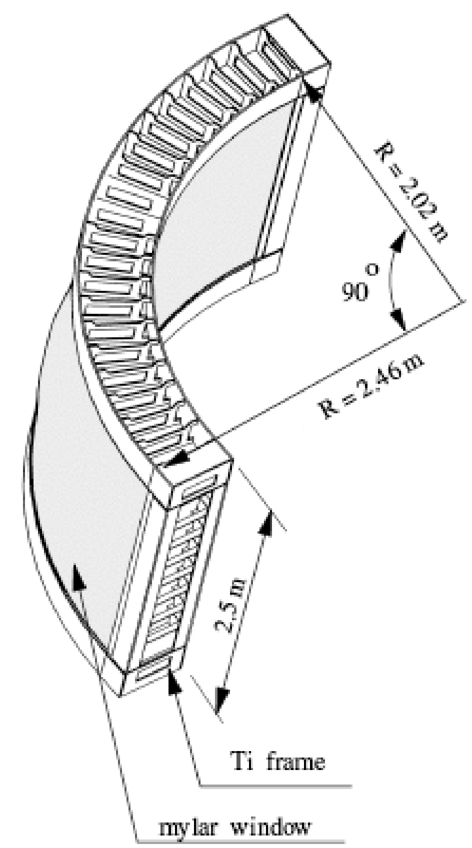
13K CHANNELS, ~98% TRACKING EFF.

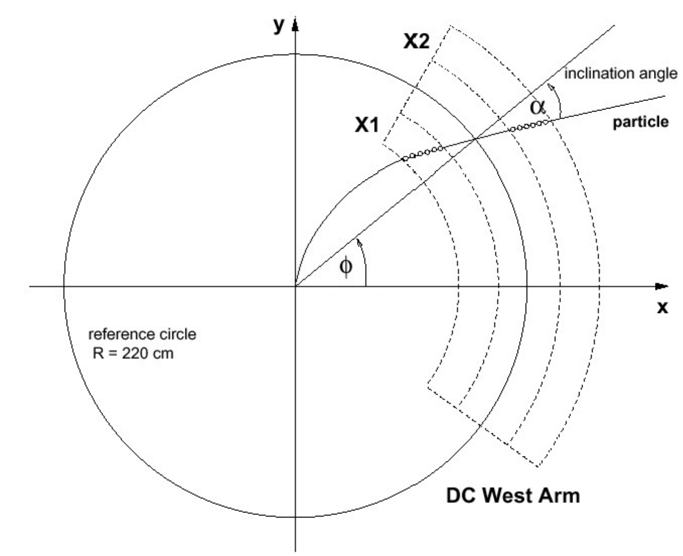
AR/C2H6, 50:50, 0°C ETHENOL BUBBLER

ADDED BUBBLER (1.5%) 2002 AFTER HV STABILITY PROBLEMS

MAIN TRACKING DEVICE FOR CENTRAL ARM

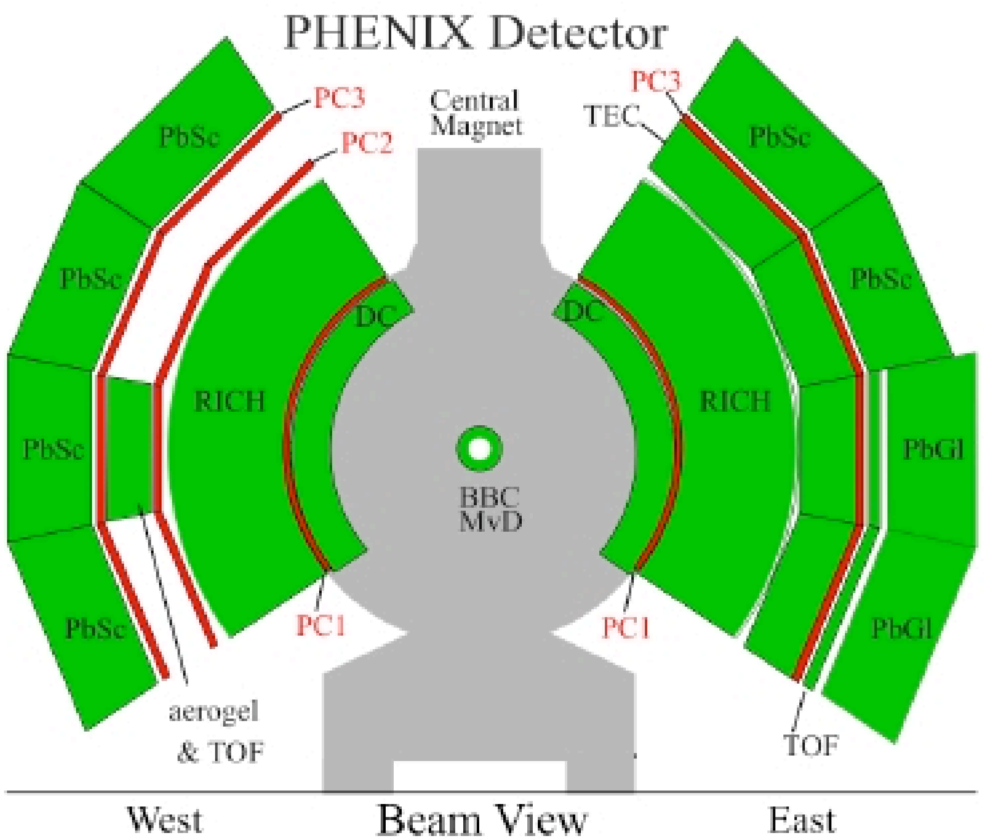
HOUGH TRANSFORM, α, φ

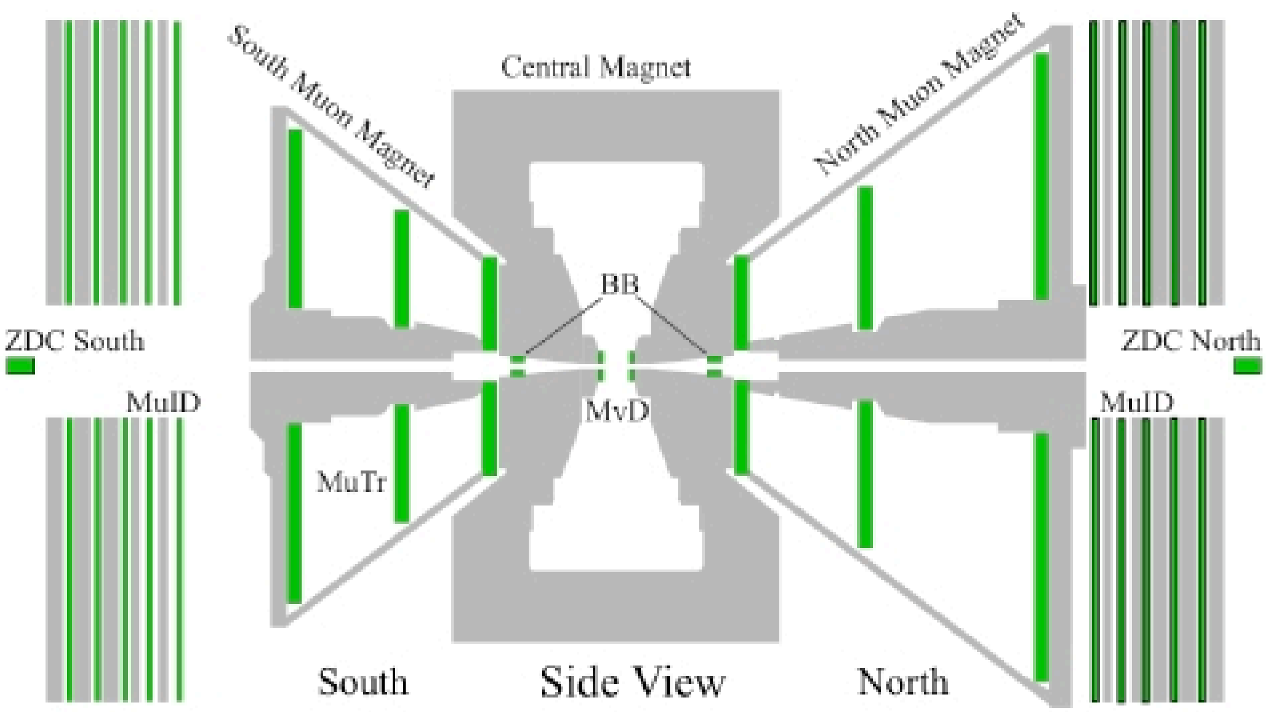




PHENIX - PAD CHAMBERS

- WIRE CHAMBER WITH THRESHOLD PAD READOUT
- AR/C2H6 50:50
- 3(2) PLANES
- PROVIDE 3D SPACE-POINT FOR TRACKING
- ~99% EFFICIENCY





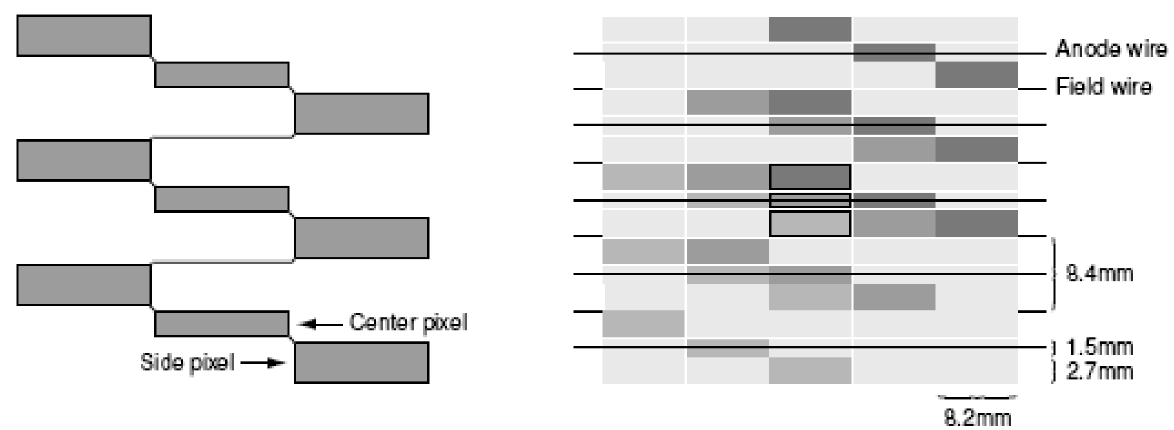
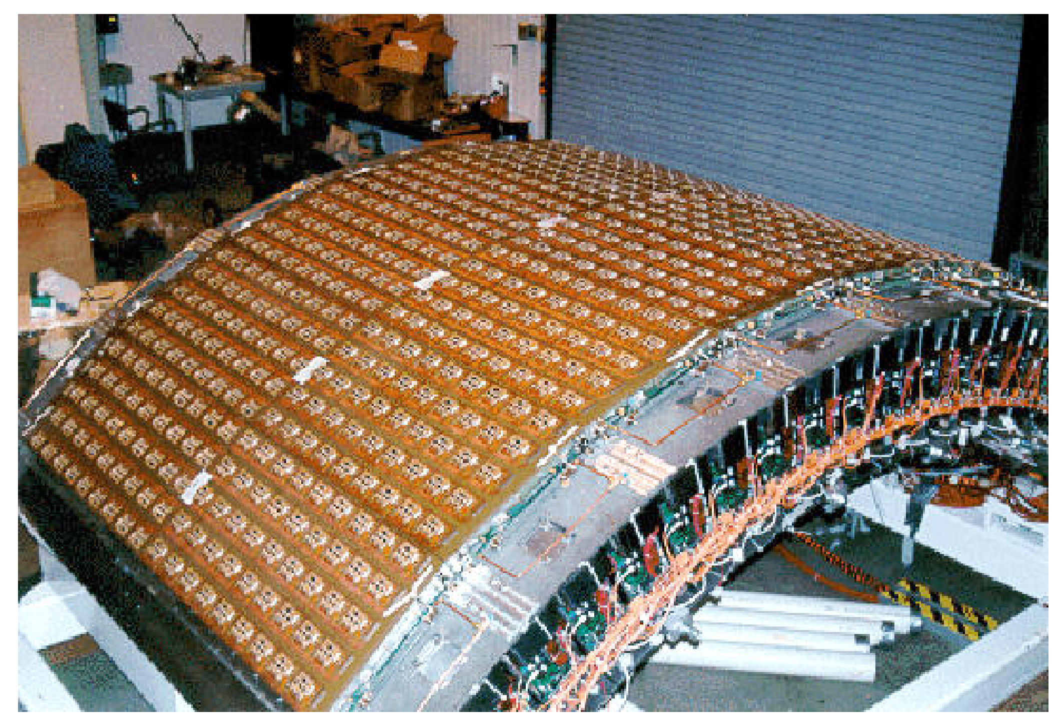
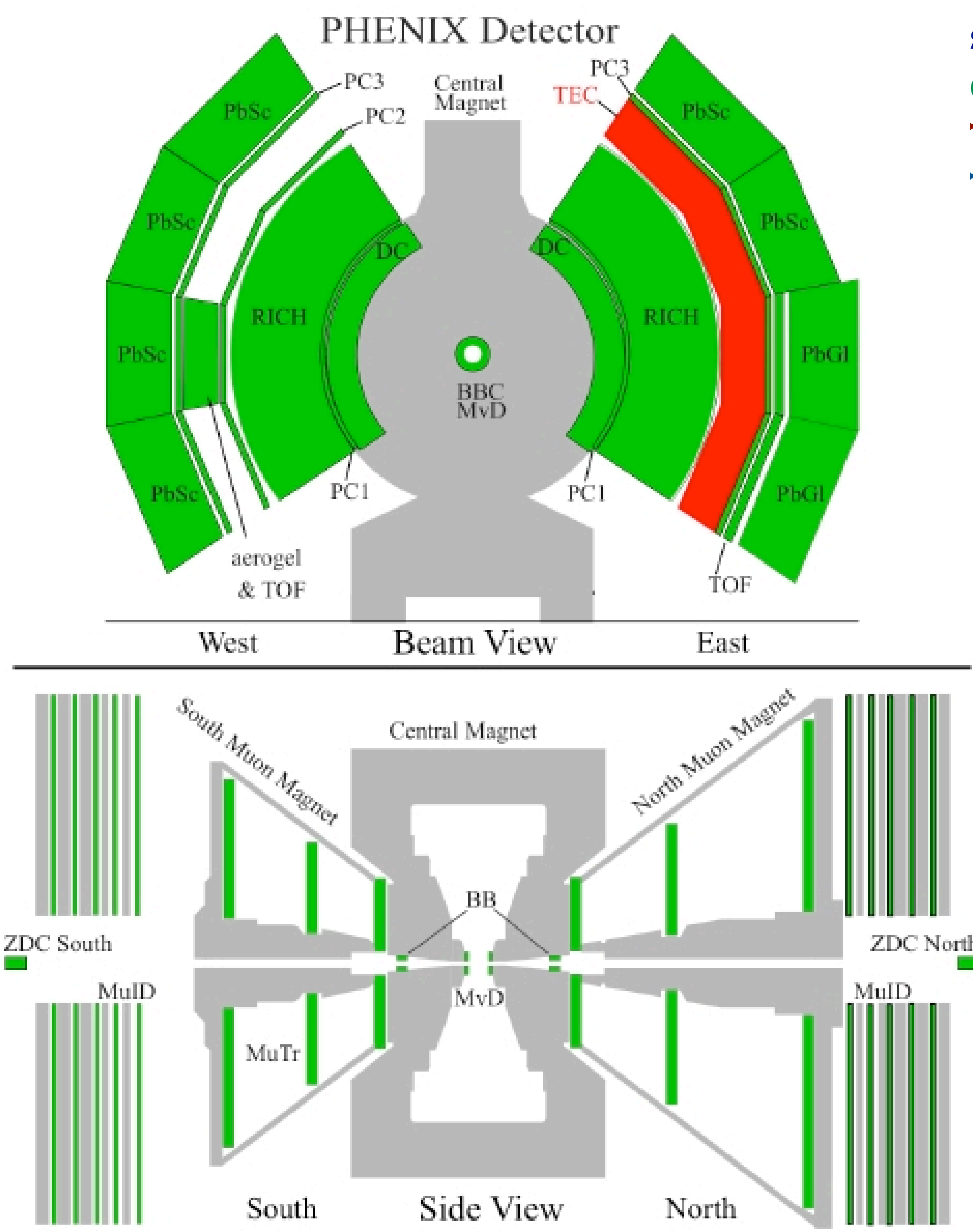


Fig. 6. The pad and pixel geometry (left). A cell defined by three pixels is at the center of the right picture



PHENIX - TEC/TRD



TRACKING AND ELECTRON IDENTIFICATION,

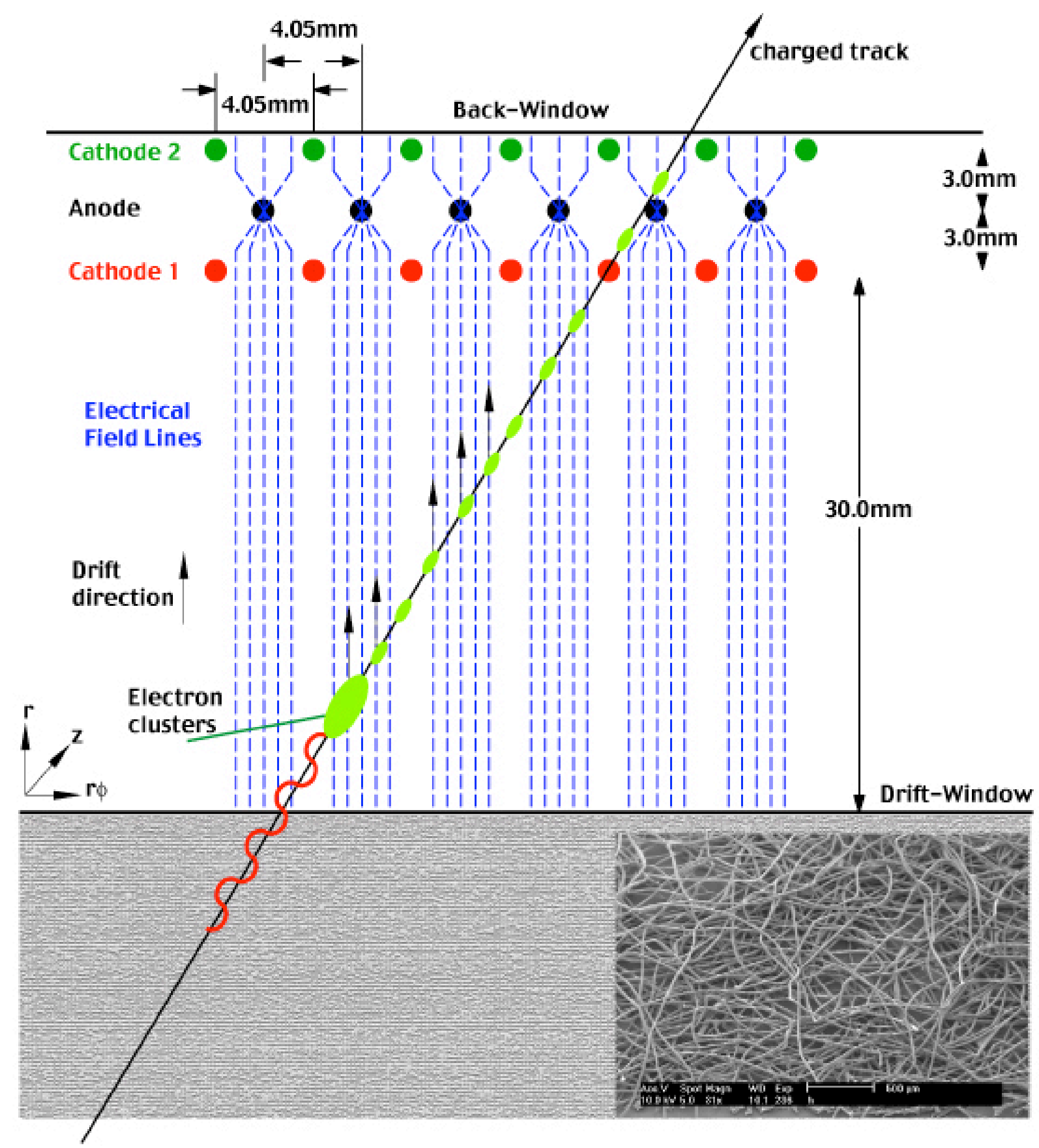
SLOPE-INTERSECTION HOUGH TRANSFORM

6 PLANES

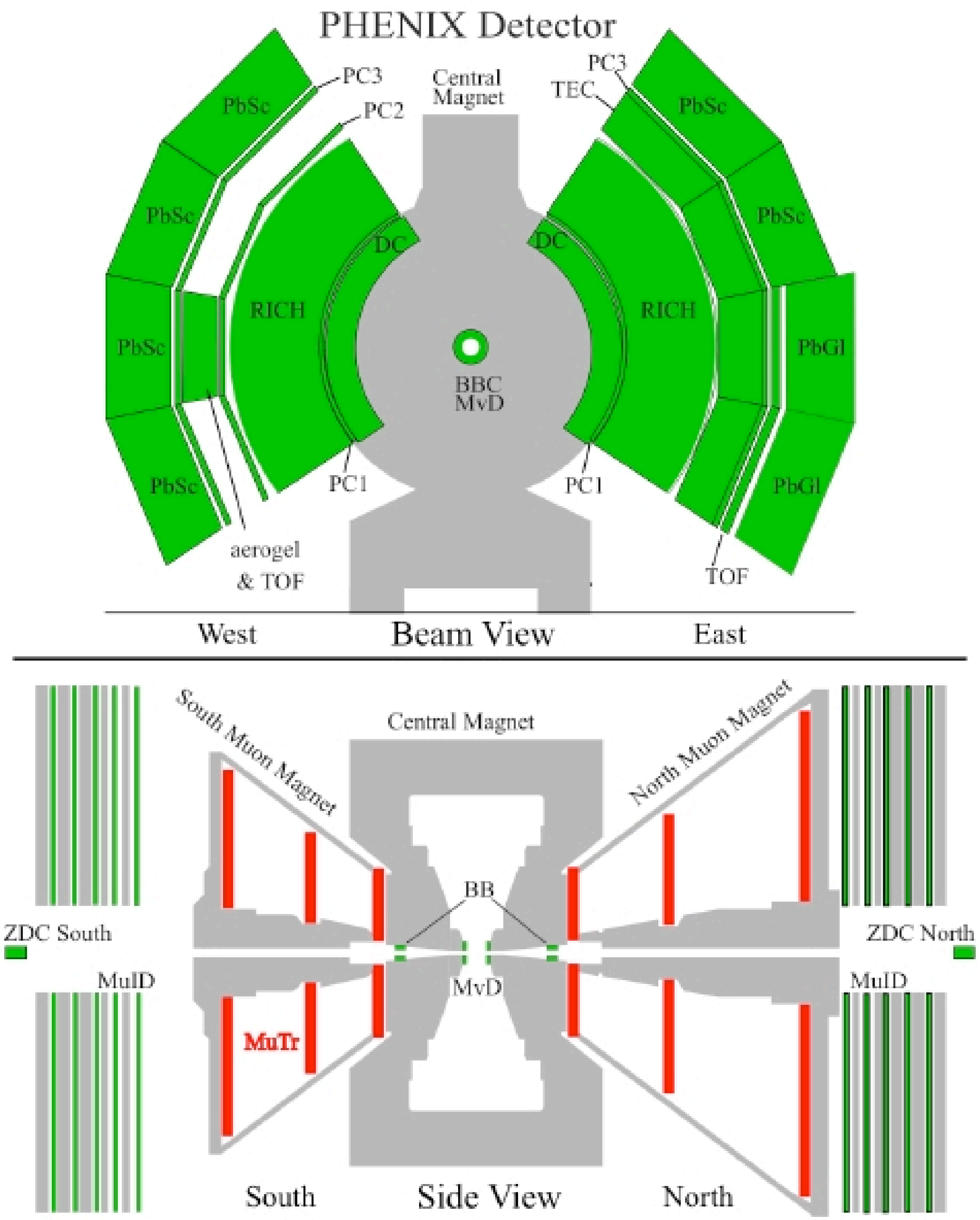
TEC (2000-2002), AR/CH4 90:10

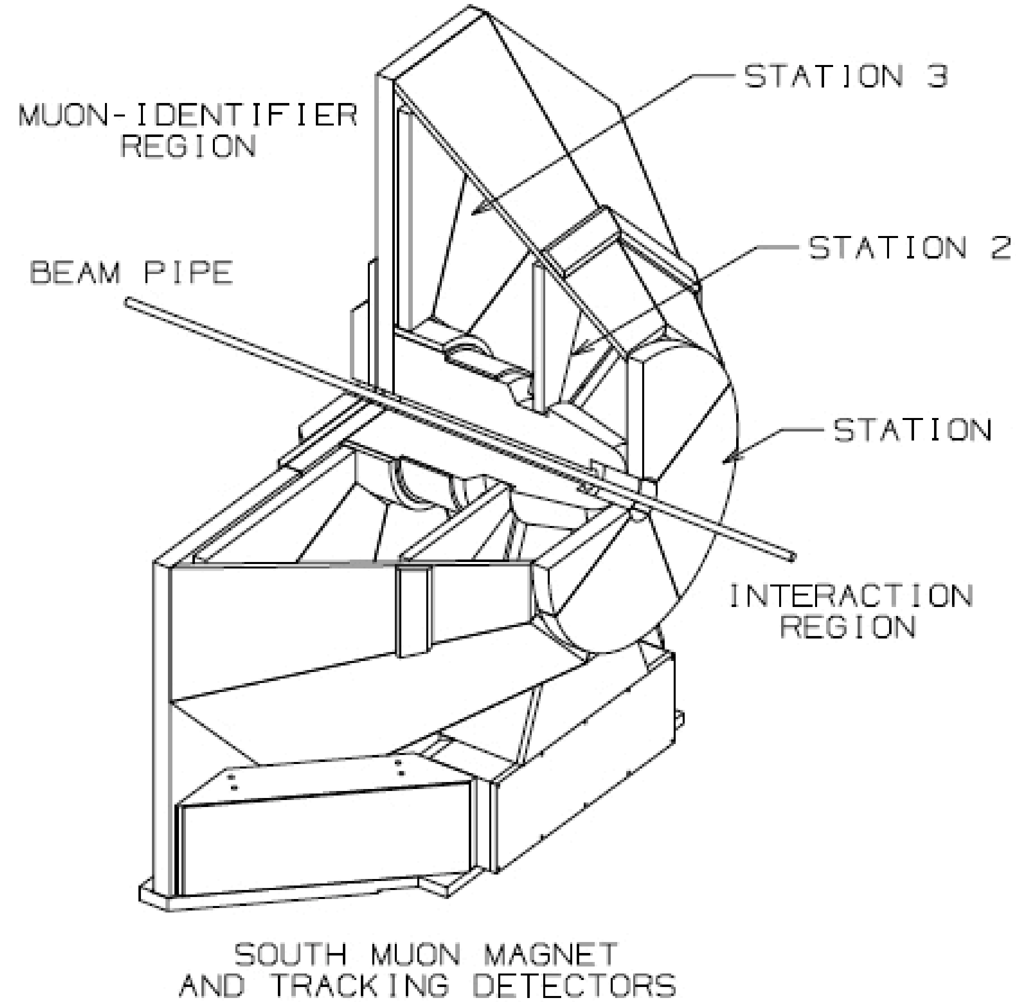
TRD (2003-), XE/HE/CH4 45:45:10

17 μM POLYPROPYLENE FIBER RADIATOR

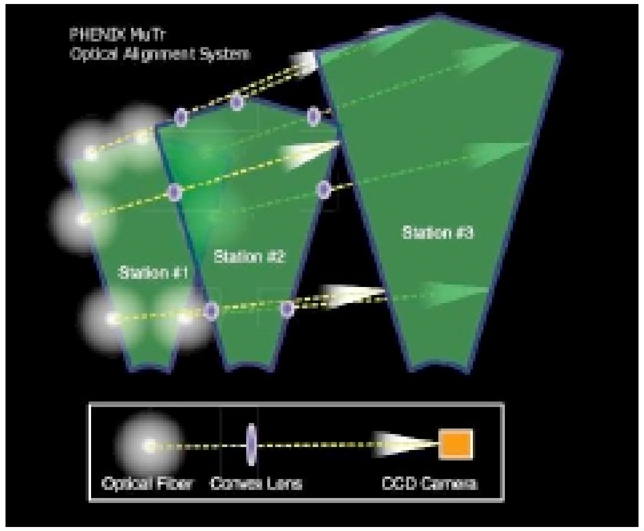


PHENIX - MuTR

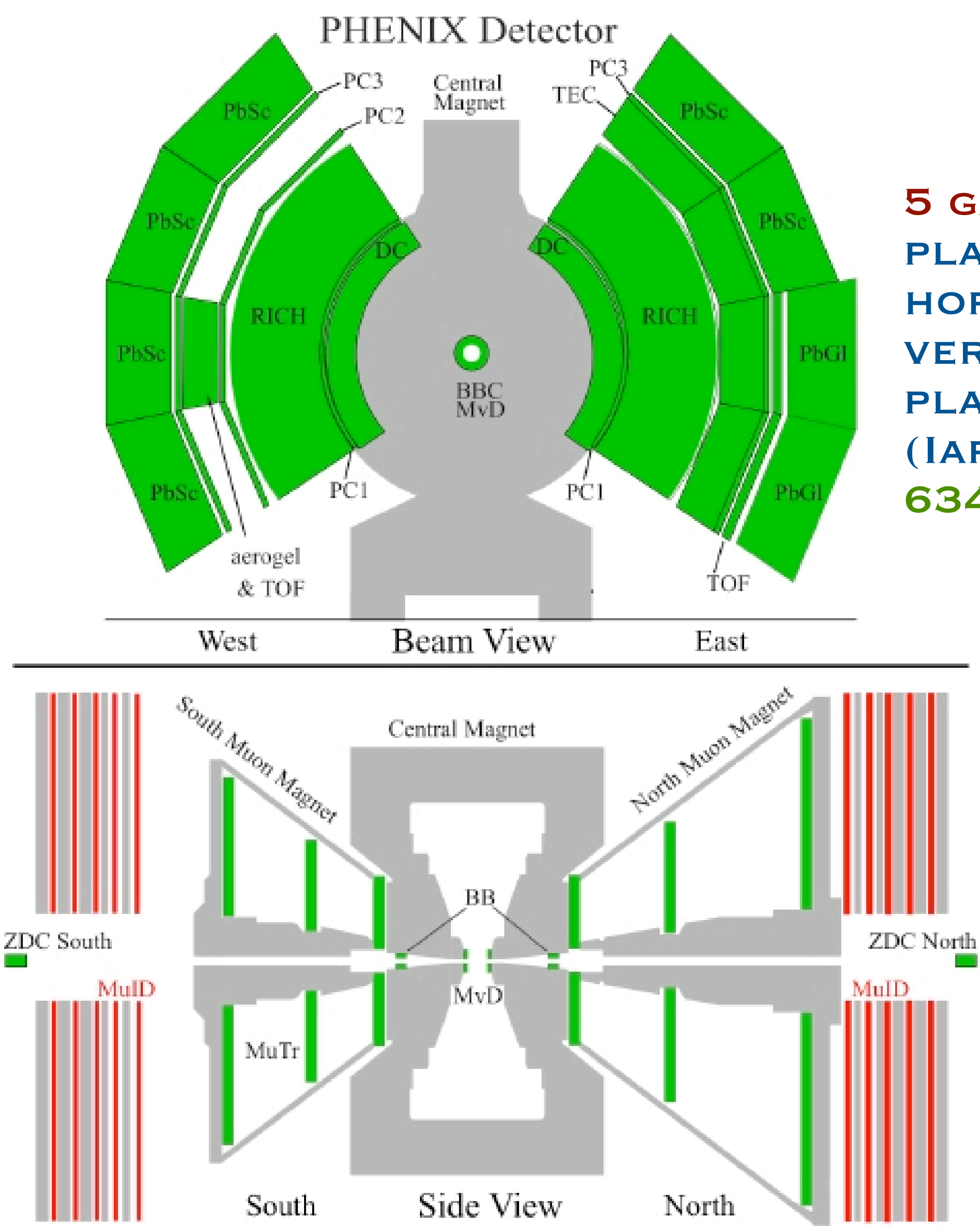


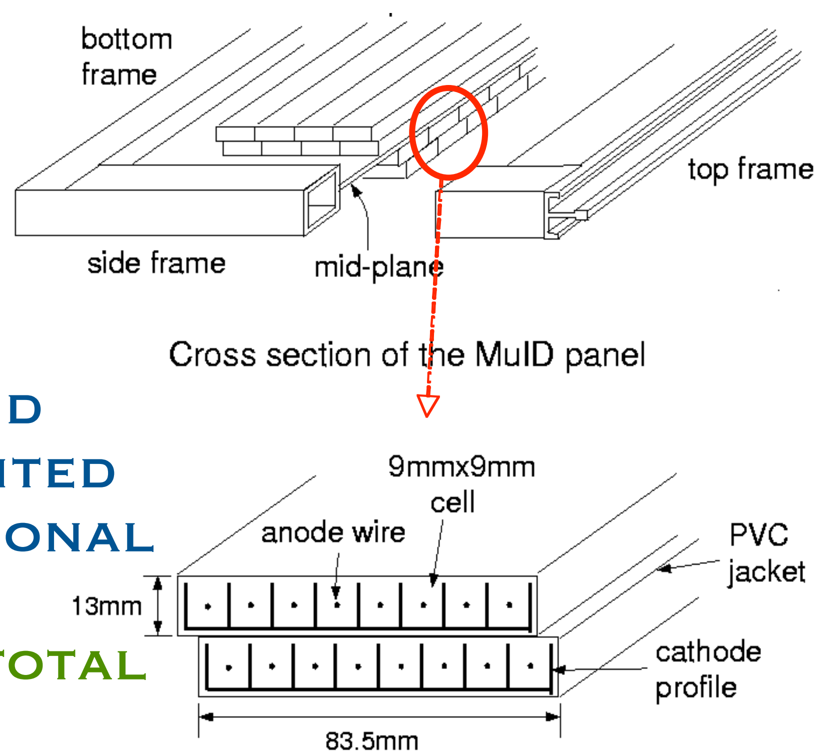


3 PLANES OF STRIP CHAMBERS INSIDE MUON MAGNETS,
AR/CO2/CF4, 50:30:20
OPTICAL ALIGNMENT



PHENIX - MuID





5 gaps per arm

planes of horizontally and vertically oriented plastic proportional (Iarocci) tubes

6340 channels total

Summary, the last 5 years

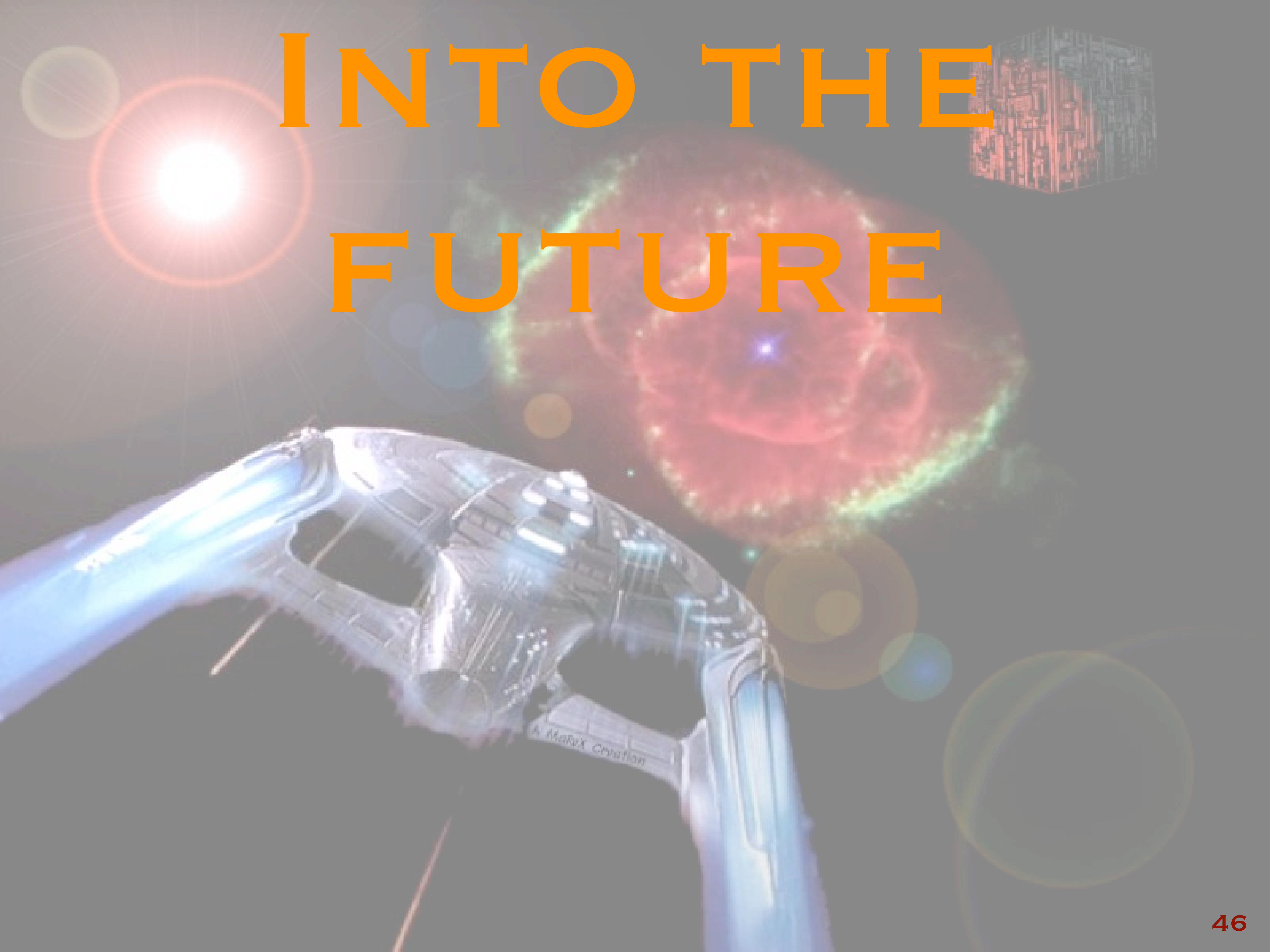
- very successfull
- ever increasing luminosity
- p-p, d-Au, Cu-Cu and Au -Au collisions @ various √s
- >100 publications,
  white papers (NIM A499, Issues 2-3, Pages 235-880 (1 March 2003)
  > 60 submitted or in preparation
- >100 PhD Thesis

- initially high backgrounds, beam-beam interactions, bad vacuum
- forced experiments to wait out first high intensity part of the store
  up to 60min
- needed extra shielding in the tunnel

- Better vacuum, bake-out, NEG coating
- faster times between stores,
- nearly automatic tuning and collimation, more feedback from experiments
  vbbb n

- no sign of aging in most tracking detectors
- integrated radiation level (@PHOBOS) a ~1 kRad / year

Into the future



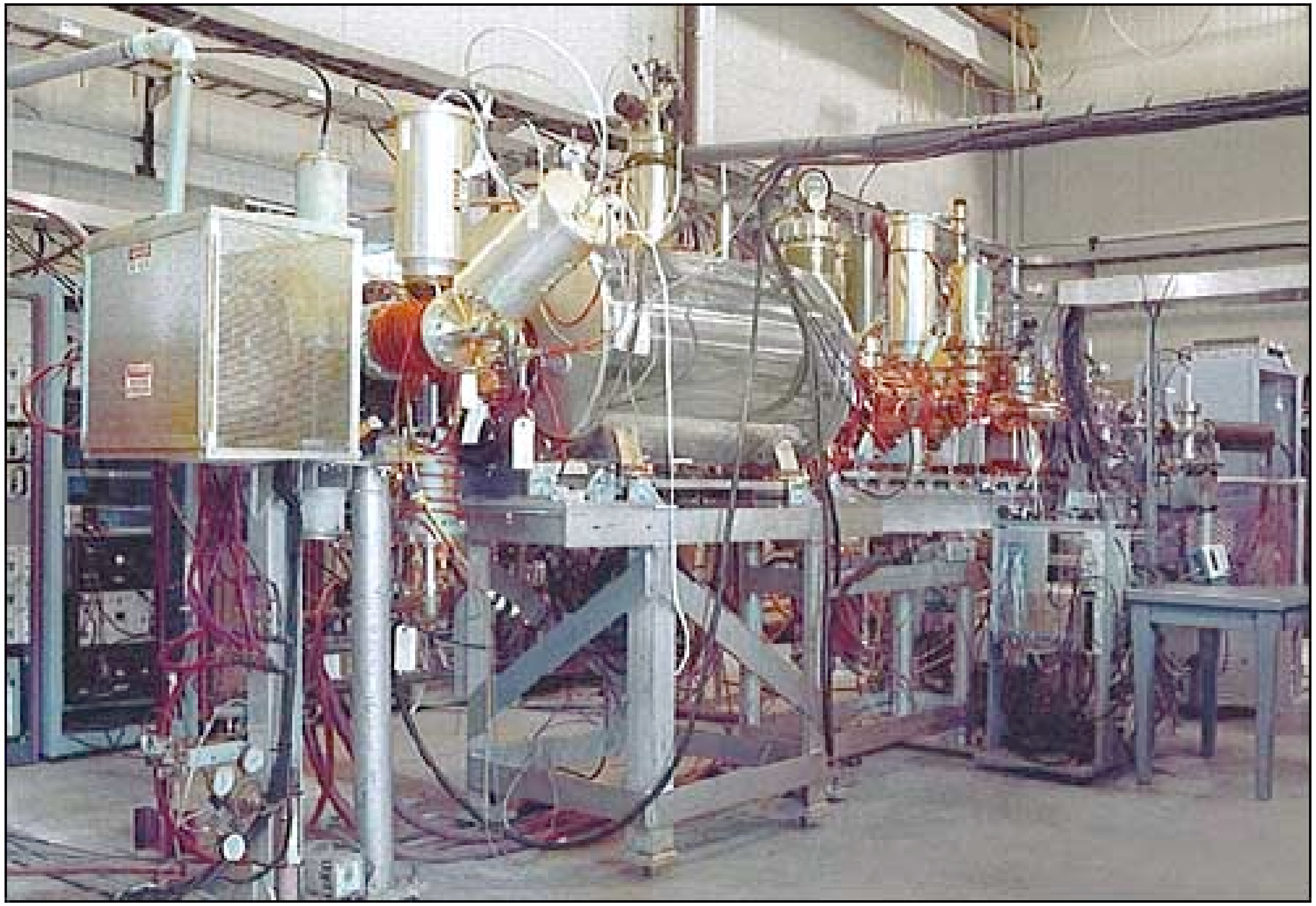
Upgrades - RHIC - EBIS

electron beam ionization source, followed by a linac.

It will provide all stable ion species from deuterons to uranium.

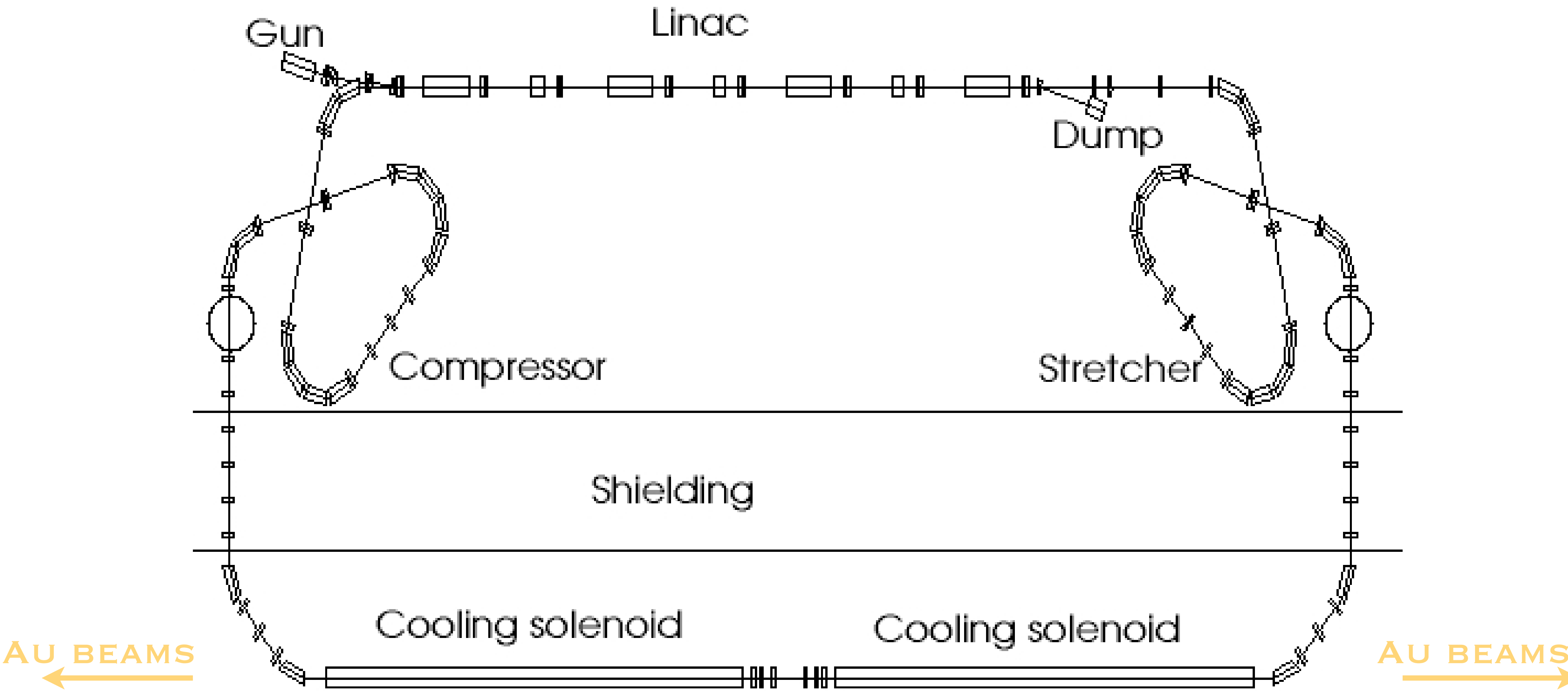
EBIS will be able to switch different ion beams to the Booster, AGS, and RHIC on a timescale of one second.

EBIS is expected to be operational in 2009.



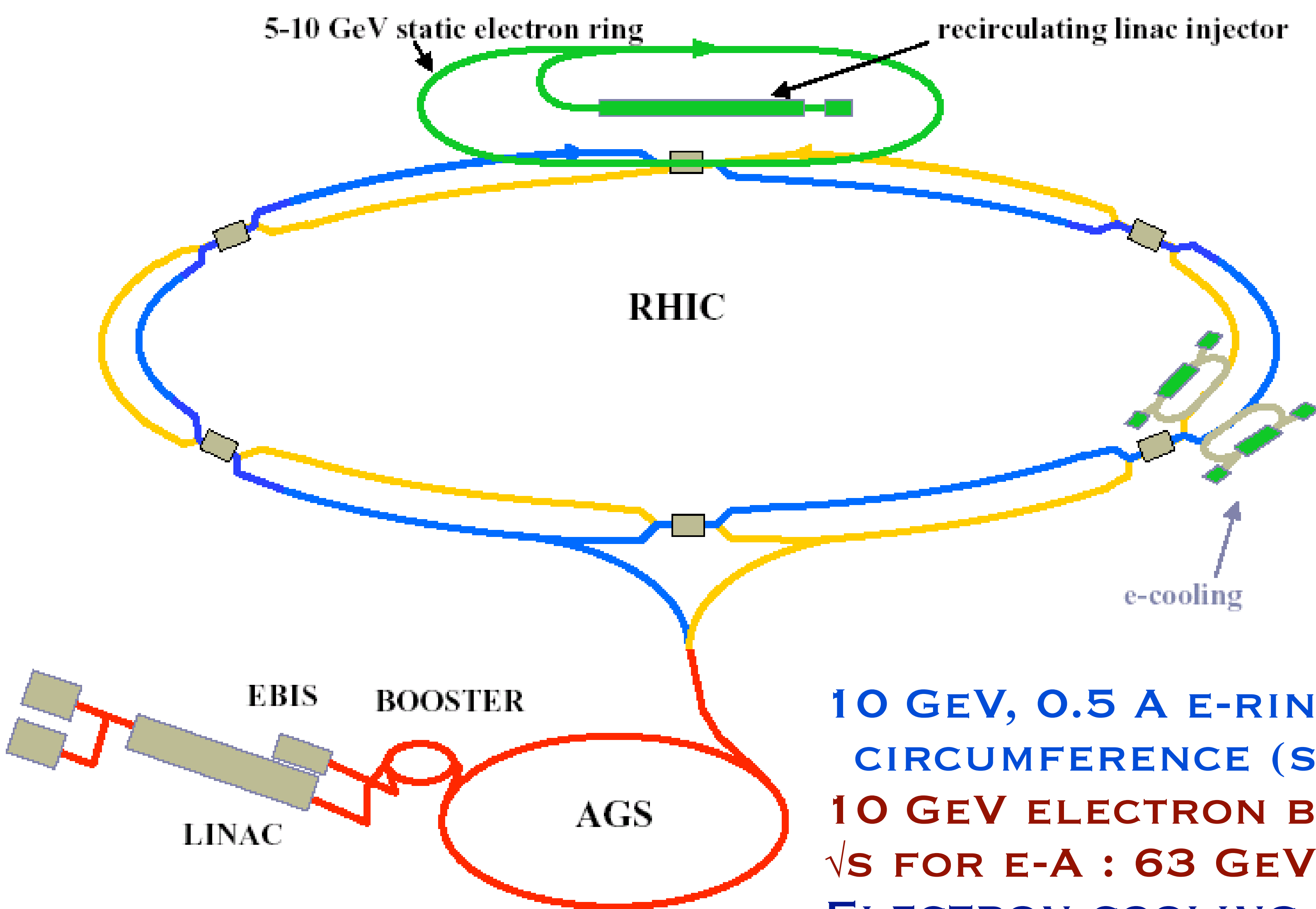
http://www.bnl.gov/bnlweb/facilities/EBIS.asp

Upgrades - RHIC - e-cooling



Gold collisions (100 GeV/n x 100 GeV/n)	w/o e-cooling	with e-cooling
Emittance (95%) pmm	15→40	15→3
Beta function at IR [m]	1.0	1.0→0.5
Number of bunches	112	112
Bunch population [10^9]	1	1→0.3
Ave. store luminosity [10^{26} cm^{-2} s^{-1}]	8	70

Upgrades - RHIC - eRHIC



- 10 GeV, 0.5 A e-ring with 1/3 of RHIC circumference (similar to PEP II HER)
- 10 GeV electron beam
- √s for e-A : 63 GeV/u; √s for e-p: 100 GeV
- Electron cooling required for high luminosity e-A and low energy e-p collisions
- Polarized e-He3 (e-n) collisions with EBIS
- Existing RHIC interaction region allows for typical asymmetric detector
- Luminosity: up to 10^{33} cm^{2}s^{1} per nucleon (10^{34} cm^{2}s^{1} with linac – ring scheme)

Detector Upgrades Timeline

Strawman schedule: depends on funding (TBD)*

FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012

EBIS construction

RHIC II: construction operation

RHIC Accelerator & Detector R&D

TOF and VTX construction; Muon trigger
+ "Small" upgrades: HBD, FMS, DAQ

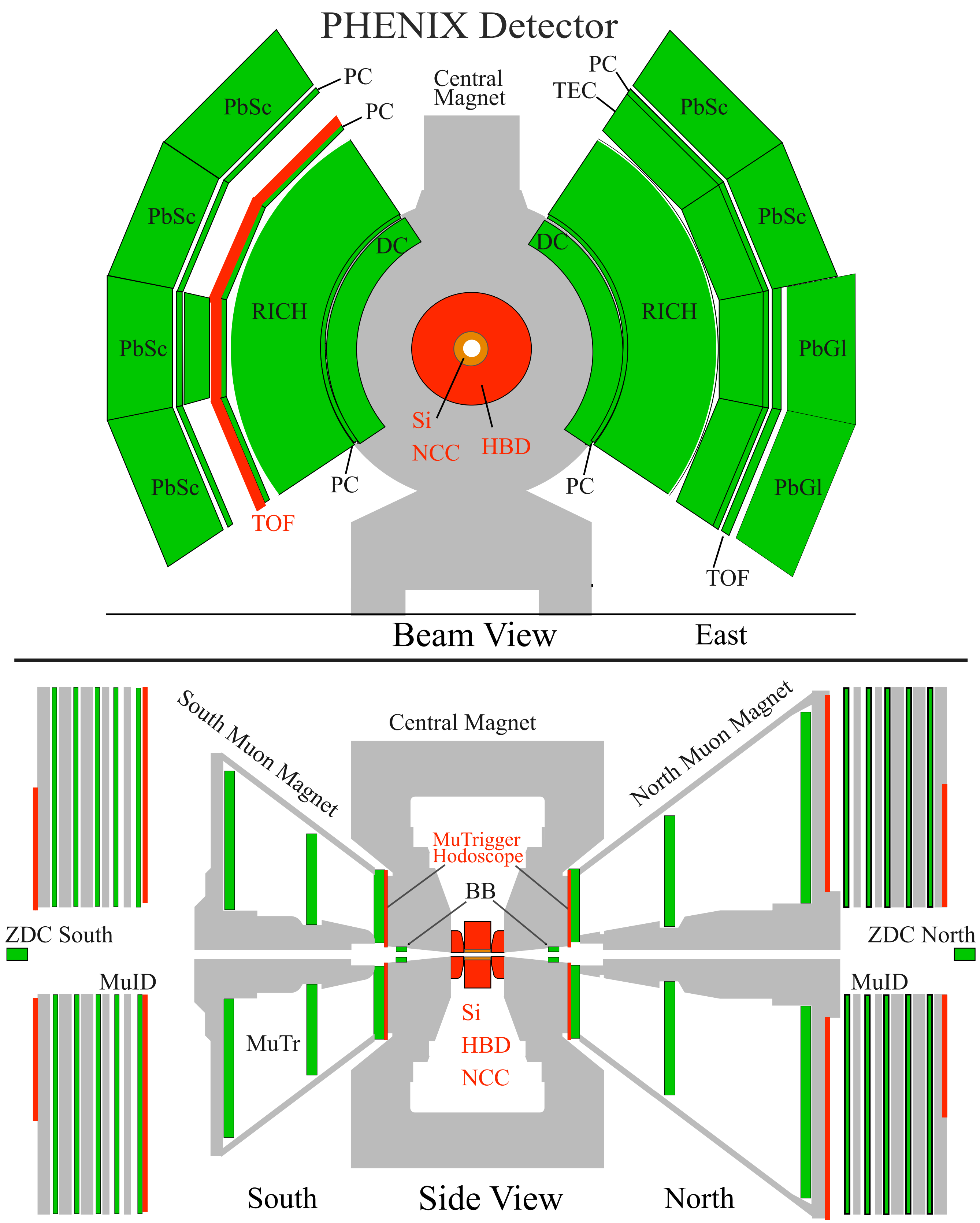
STAR HFT & PHENIX FVTX

Next Generation Detector Upgrades
STAR Forward/Inner Tracker System
PHENIX Inner Tracker and Nosecone Cal
Other approaches?

LHC Heavy Ion Program

*Target for presenting a plan to DOE: January 2006

Upgrades - PHENIX



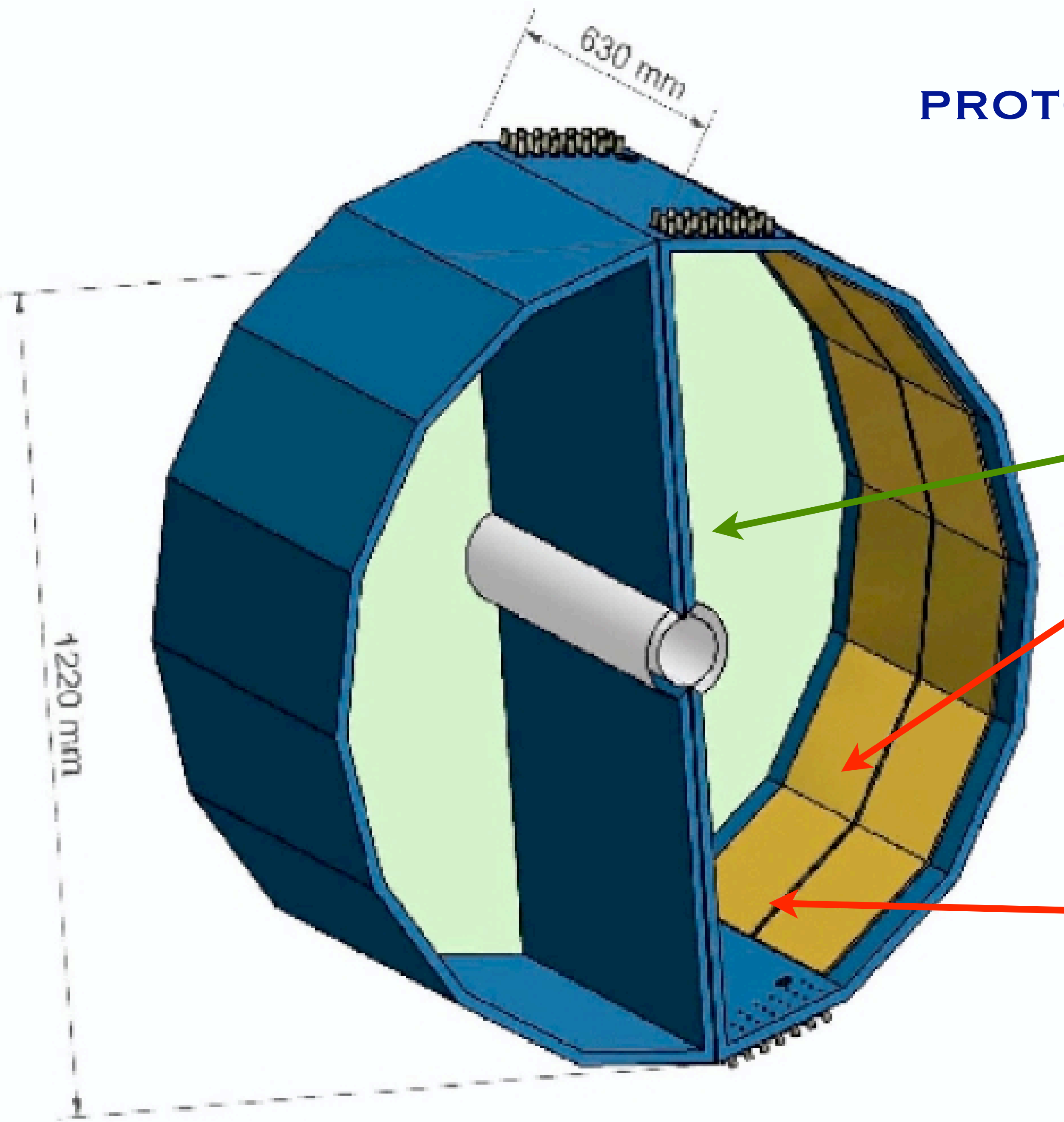
Displaced vertex:
VTX: silicon tracker

Jet measurement:
NCC: nose cone calorimeter

Other detectors:
HBD: hadron blind detector
Muon trigger
PID in west arm

Upgrades - PHENIX - HBD

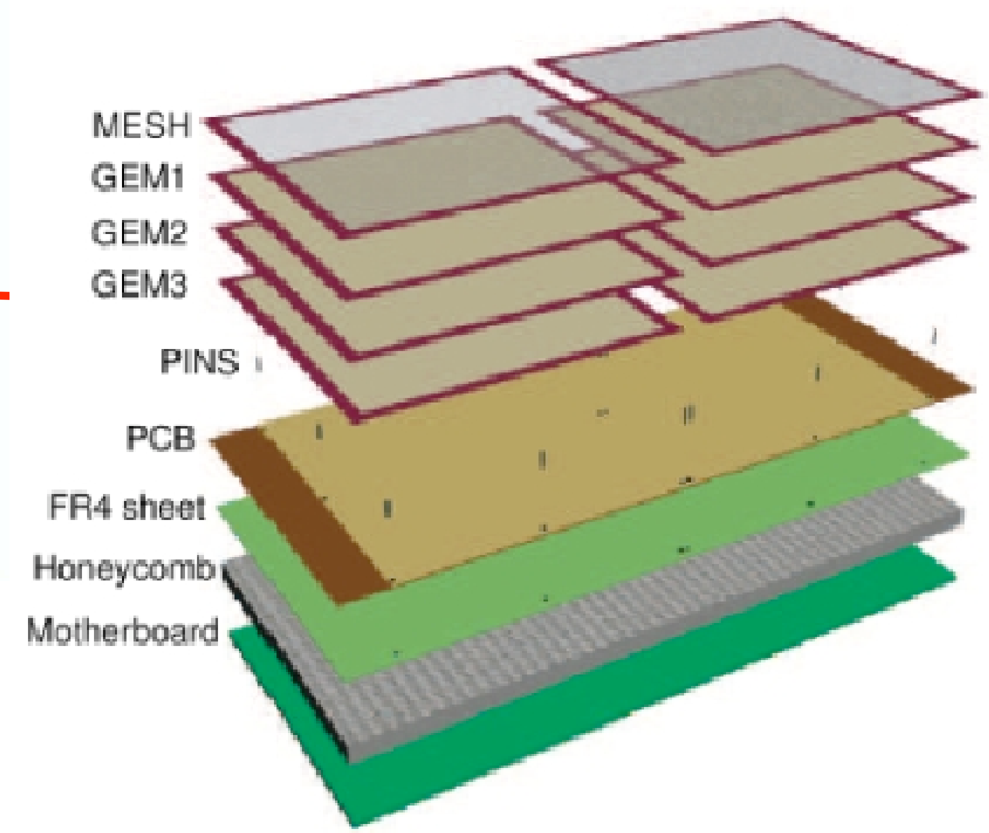
Proximity focused Cherenkov detector
Hadron Blind
prototype to be installed this fall



Uses deep UV transmitting gas (CF_4) with no gas window to detect Cerenkov light from low momentum electrons

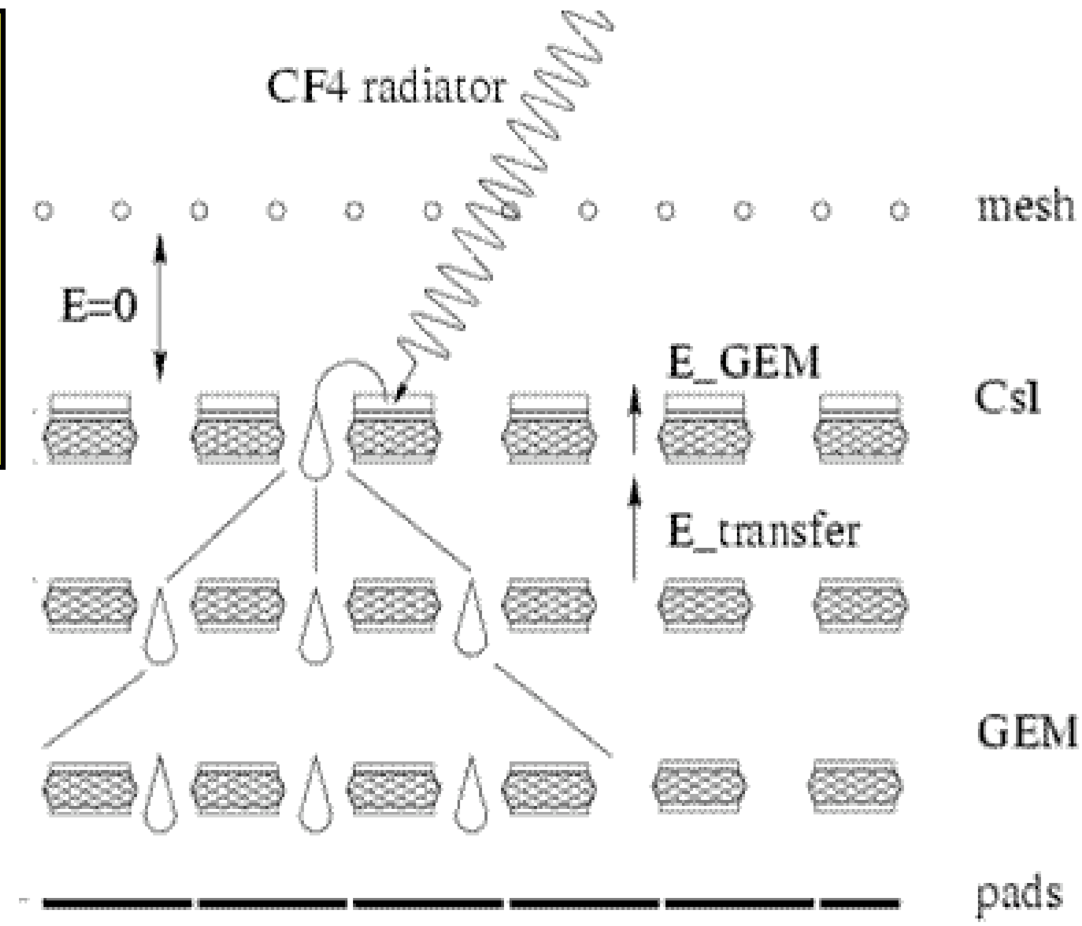
50 cm of CF_4 radiator

GEM detectors with CsI photocathodes to detect Cherenkov light



UPGRADES - PHENIX - HBD

HBD concept:
- windowless Cherenkov detector (L=50 cm)
- CF_4 as radiator and detector gas
- CsI reflective photocathode
- Proximity focus: detect blob not ring
- Triple GEM with pad readout



Very attractive features:

- Unprecedented N_0
  bandwidth 6 - 11.5 eV → $N_0 \approx 800\ cm^{-1}$ → ~35 p.e. in a 50 cm radiator
- Reflective photocathode
  no photon feedback
- Pad size comparable to blob size (~10 cm^2)
  hadrons: single pad hit, electrons: more than one pad hit
- Low granularity
  ~1000 pads to cover central arm acceptance
- Low gain
  primary charge of at least 10 e/pad → gain of ~10^4 is enough

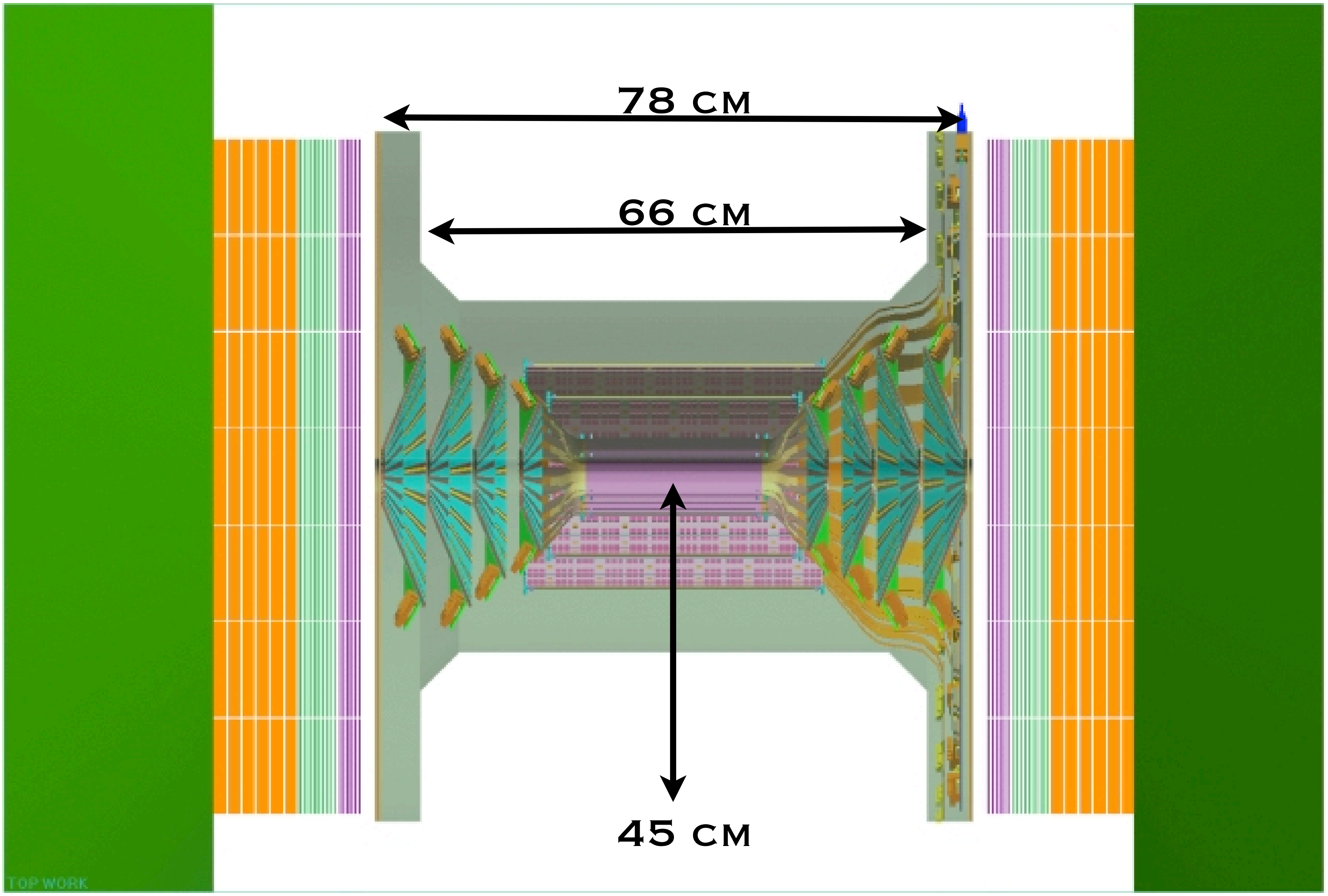
But many open questions!

Extensive R&D was needed!

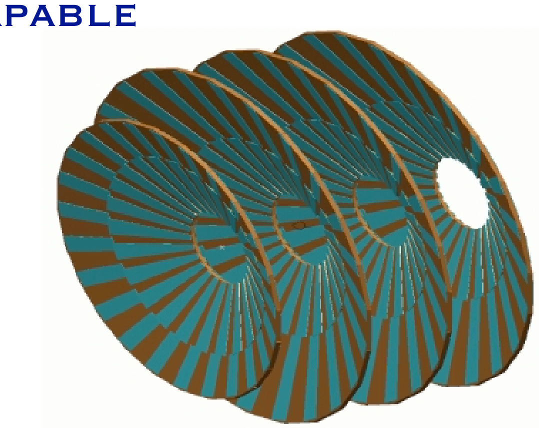
Comprehensive R&D studies have been carried out over the past two years. The results are published in two NIM papers:
1. NIM A523, 345, 2004
2. NIM A546, 466, 2005

The short summary of these results will be given in the next slides

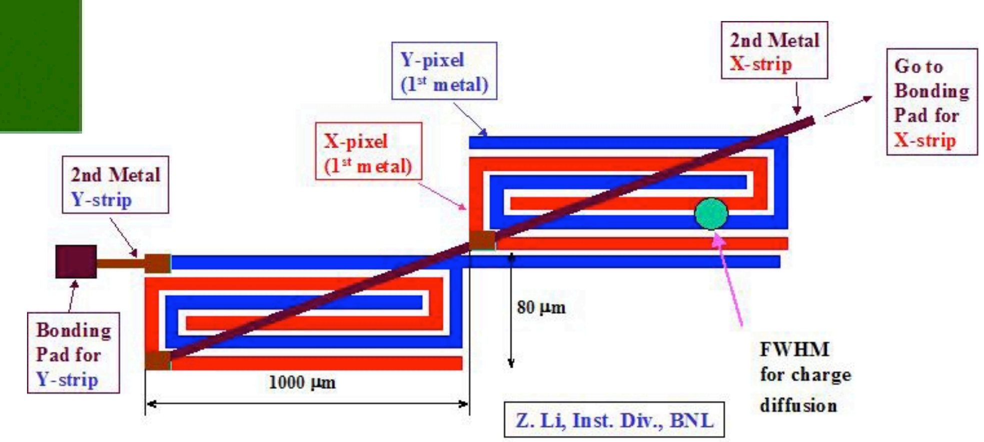
Upgrades - PHENIX - VTX



- Barrel region
  - $|\eta|<1.2$, almost 2π in fφ
  - Pixel sensor at inner 2 layers
  - R = 2.5 cm, 5 cm
  - Strip sensors at outer 2 layers
  - R = 10 cm, 14 cm
- Forward region, umbrella shape
  - $1.2<|\eta|<2.7$, 2π in φ
  - 4 layers of mini strip
  - Z ~ 20 cm, 26 cm, 32 cm, 38 cm
  - (50 x 2000 to 11000 mm)
  - Trigger capable

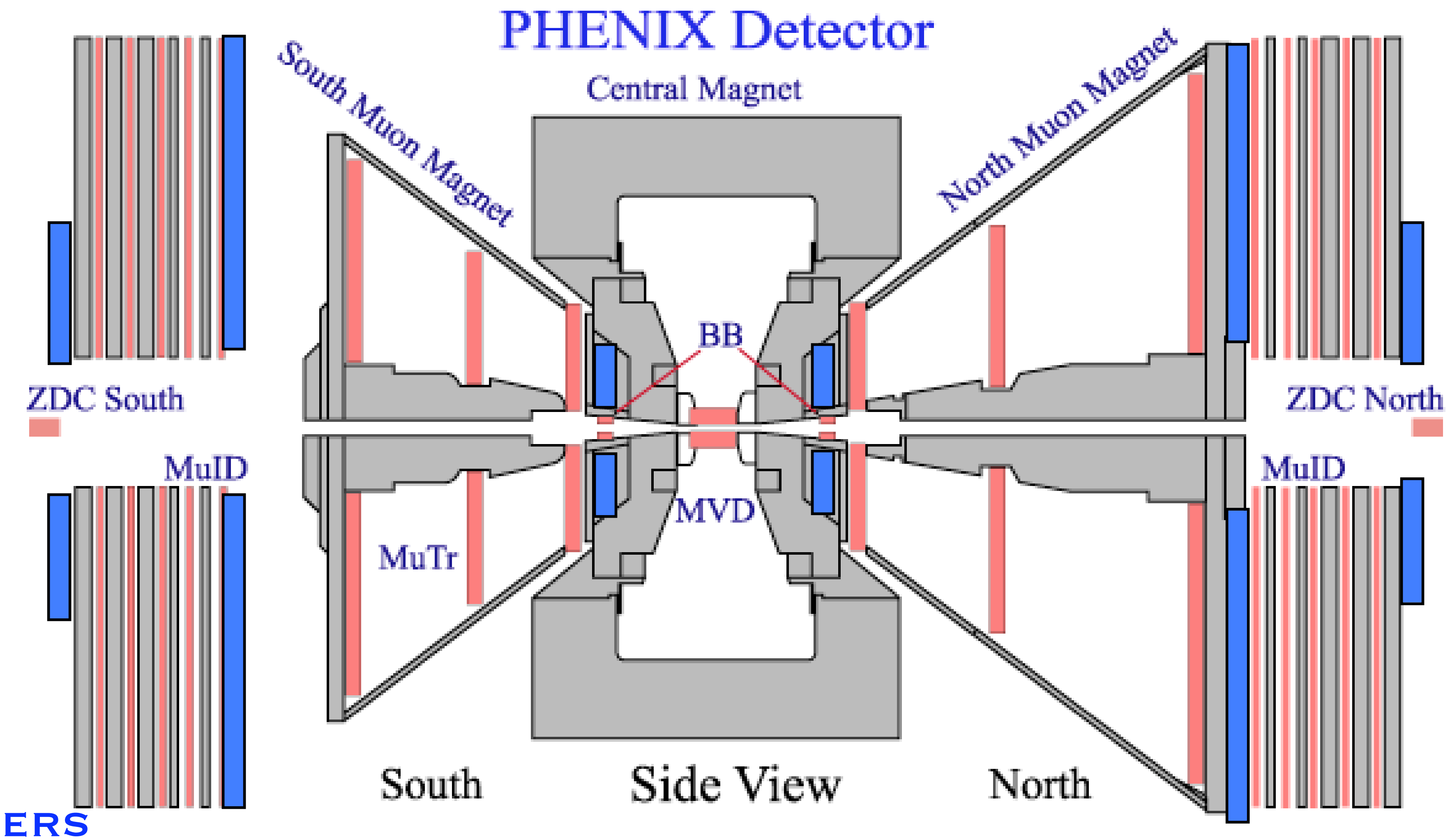


- High precision tracking for displaced vertex measurement.
  - 40μm displaced vertex resolution, c_T ~ 100μm(D), ~400μm(B)
- Large coverage tracking capability with momentum resolution
  - ($|\eta|<1.2$, over 2π in φ, with σ/p ~ 5%p)
- High charged particle density 'dN/dη' ~ 700 @η=0
- High Radiation Dose ~100KRad@10Years
- High Luminosity @pp -> High rate readout
- Low Material Budget <- avoid multiple scattering and photon
  - conversion for electron measurement by outer detectors.



NIM A535 (2004) 404-409, NIM A541 (2005) 21-28

Upgrades - PHENIX - μ



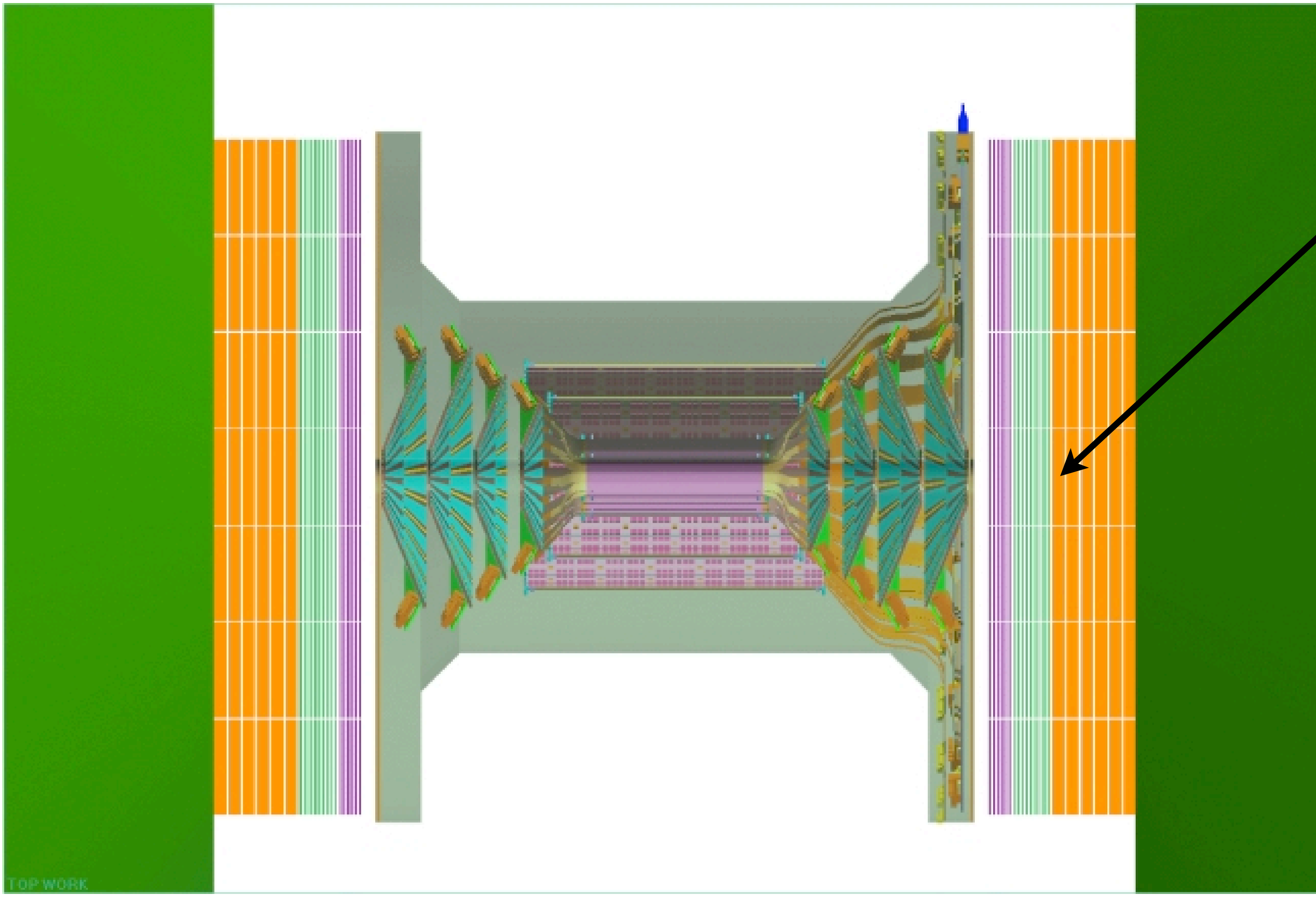
Trigger RPC Locations

μ trigger
Resistive Plate Chambers
use CMS R&D
timing information
- reject beam background
- assign tracks to correct bunch

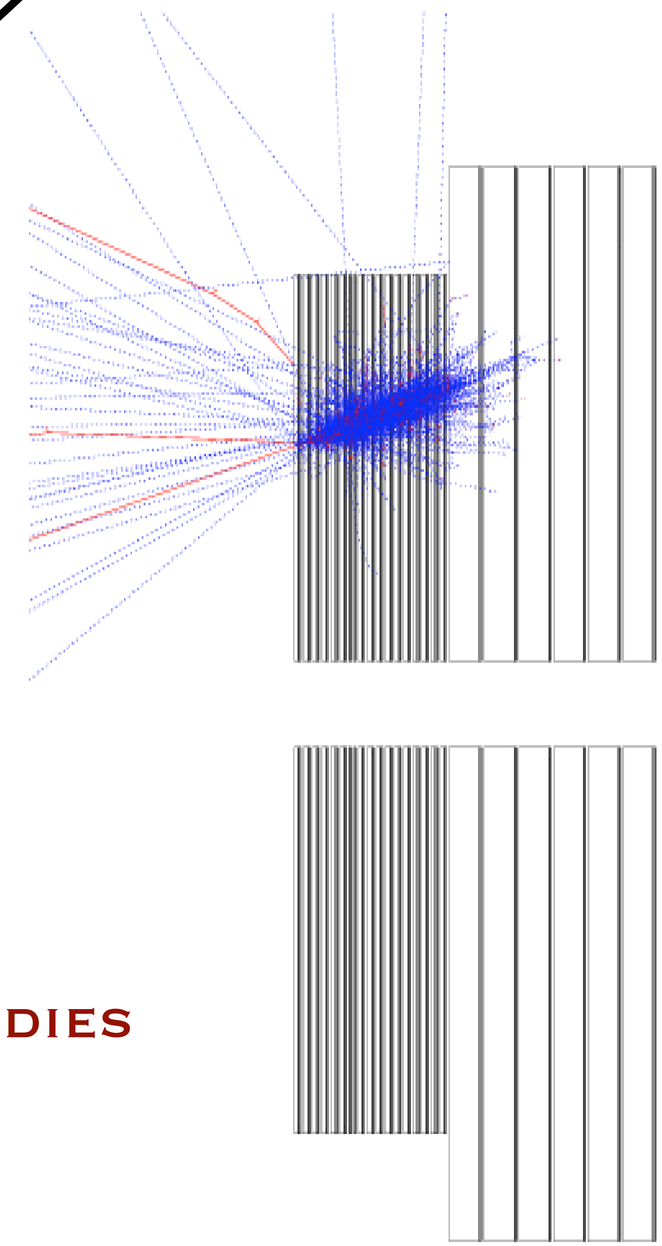
small prototype tested in 2005

NSF funded

Upgrades - PHENIX - NCC



W-silicon sampling calorimeter

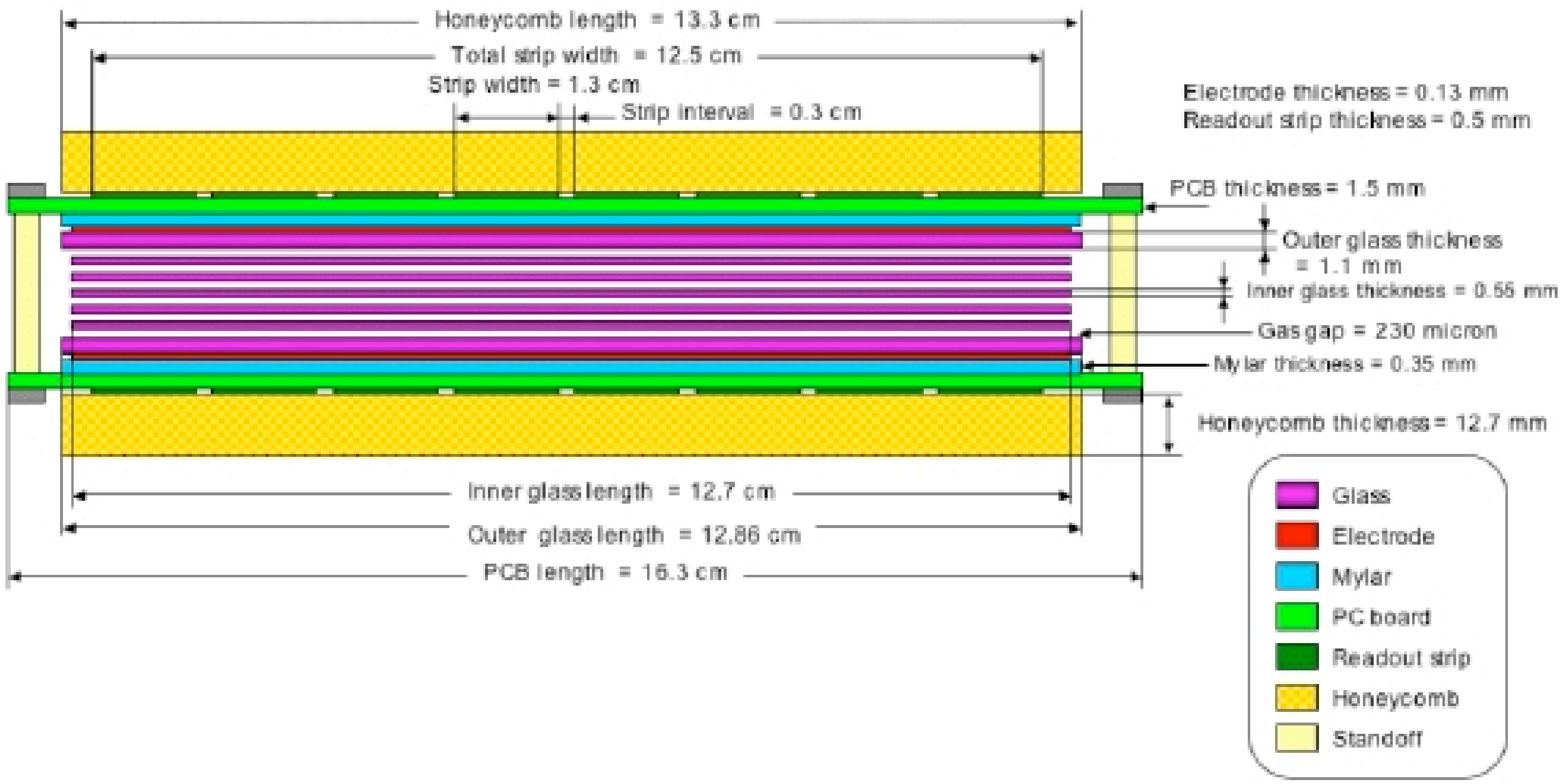


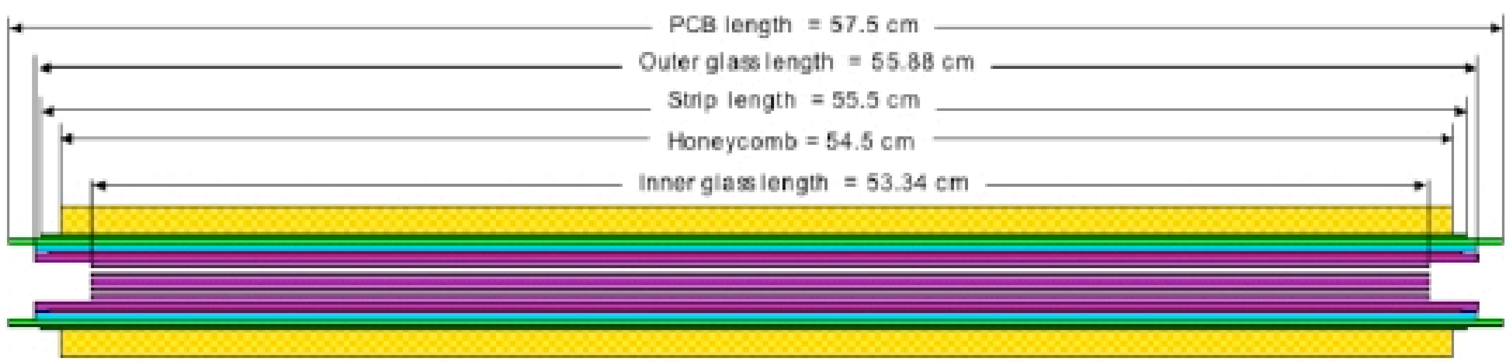
A forward calorimeter to provide photon+jet studies over a wide kinematic range

EM calorimeter ~40 X/X_0
hadronic section (1.6 λ/λ_0)

work in progress

Upgrades - PHENIX - ToFW





Time of Flight MRPCs

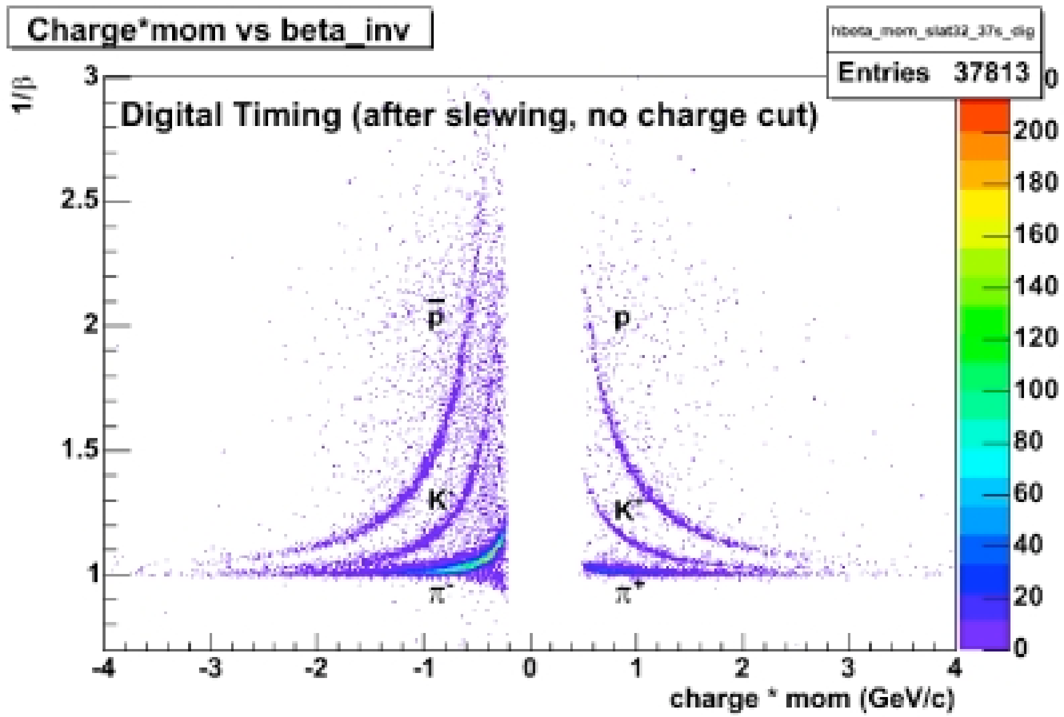
$R134a/C_4H_{10}$ 95:5

STAR design

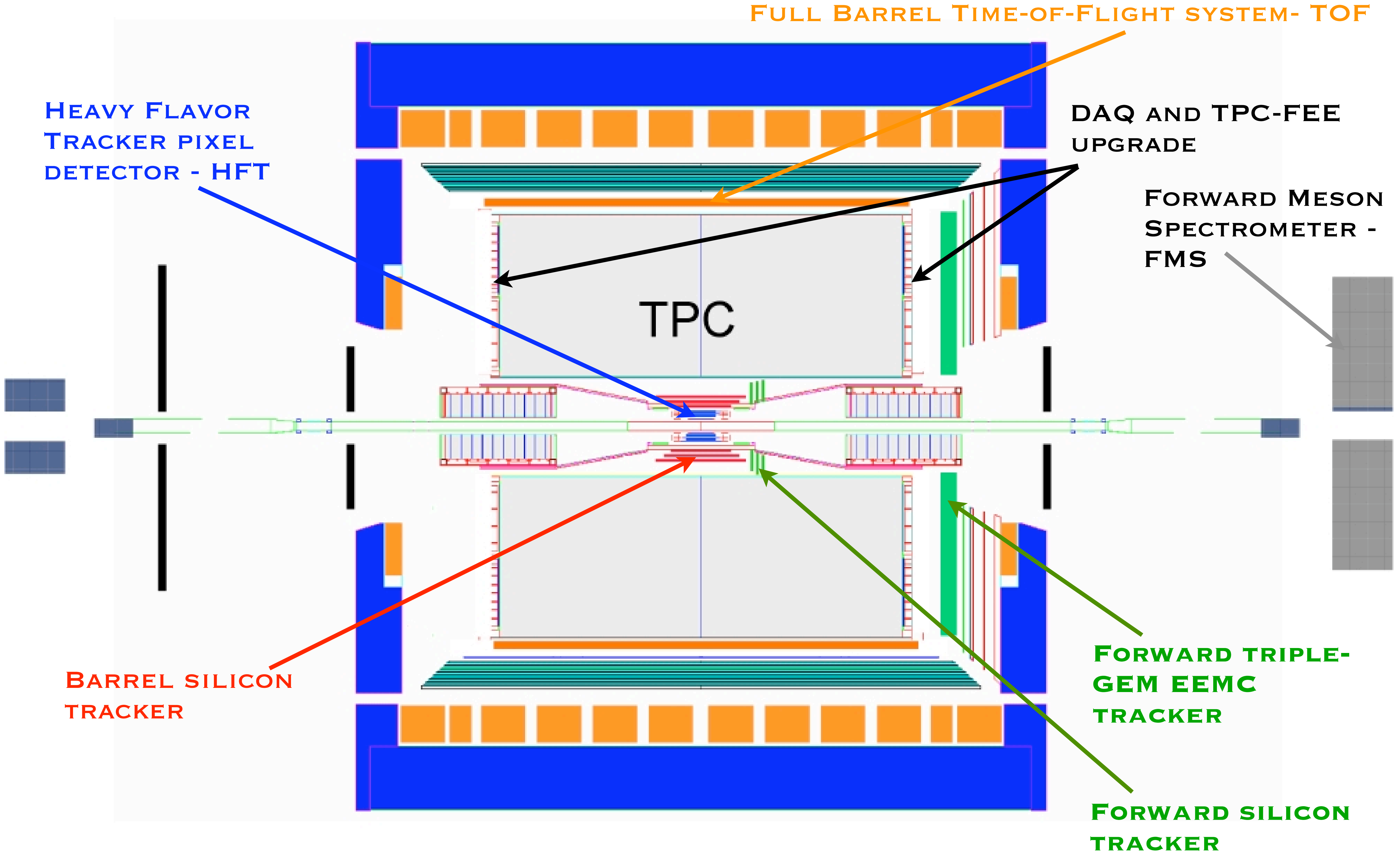
very limited depth
(2" including cables)

prototype in Run05

full arm 2006



Upgrades - STAR



BROOKHAVEN NATIONAL LABORATORY

Office of Science U.S. Department of Energy

Upgrades - STAR - MRPC ToF

MRPC technology, 2007/08

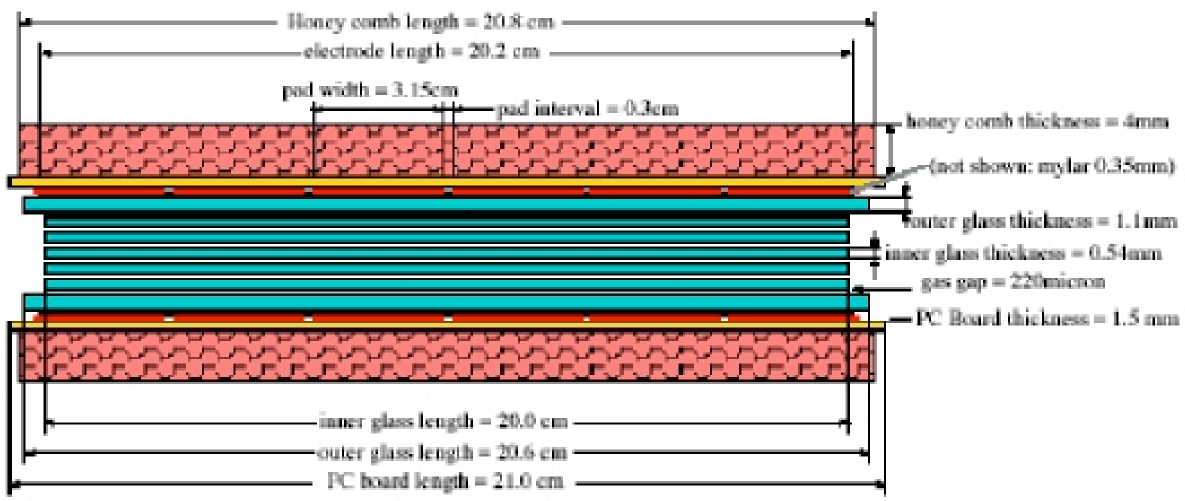
3800 modules, 23,000 channels to cover TPC barrel

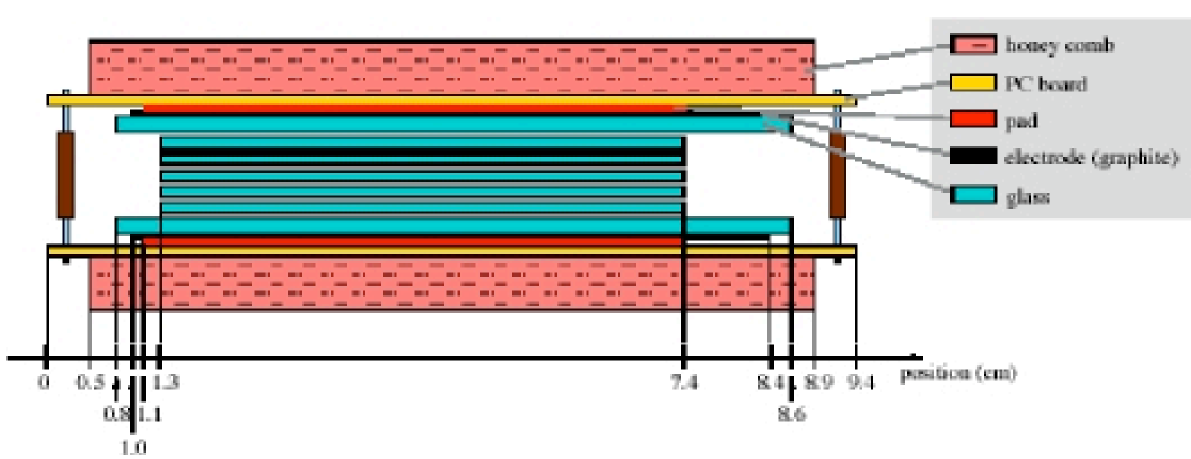
Large coverage $-\pi<\varphi<\pi$, $-1<\eta<1$, $R\approx 2.1$ m, $\Delta t < 100$ ps

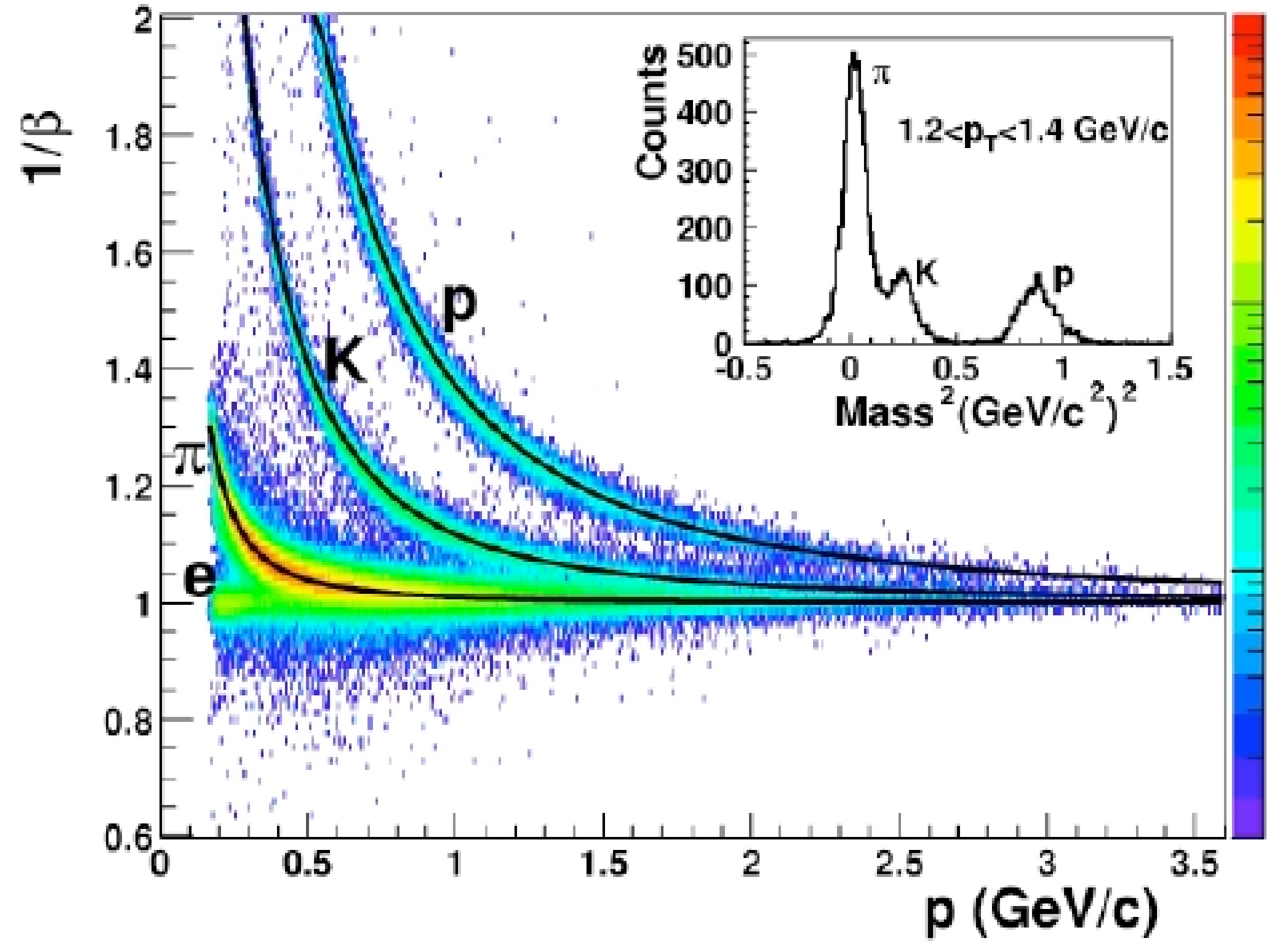
95% of charged particles in acceptance identified

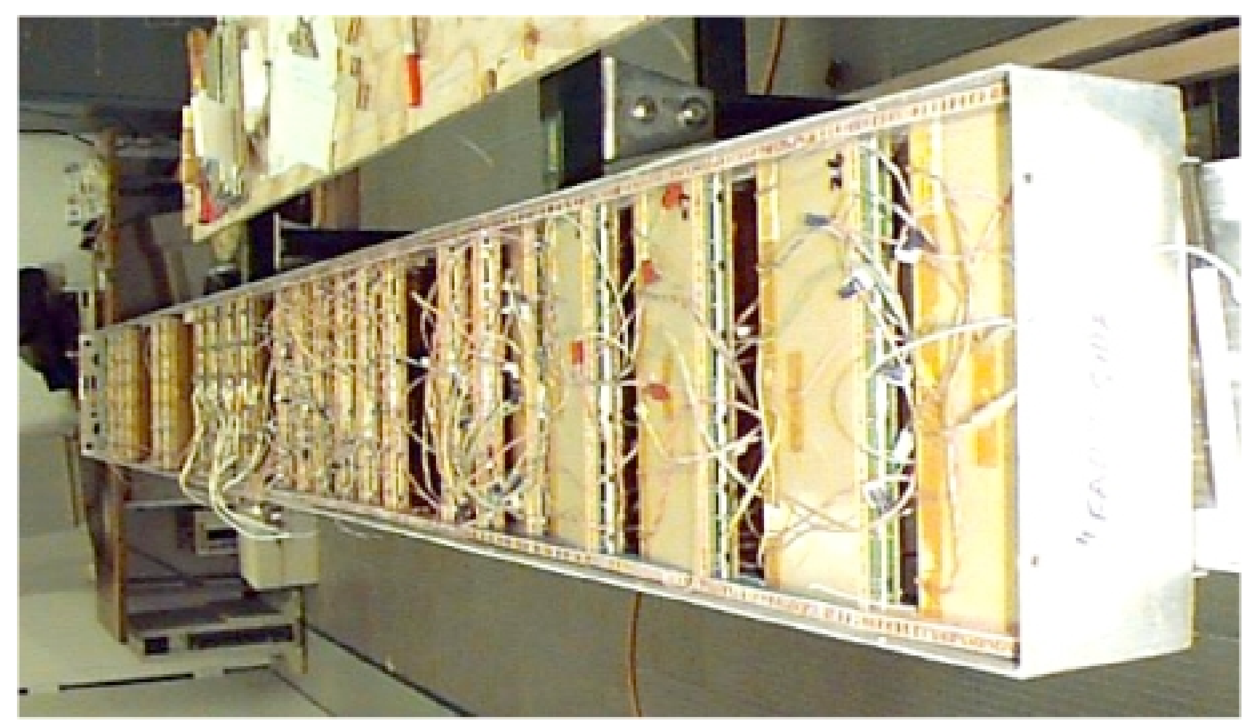
Fast detector with high granularity

Prototype running since 3 years





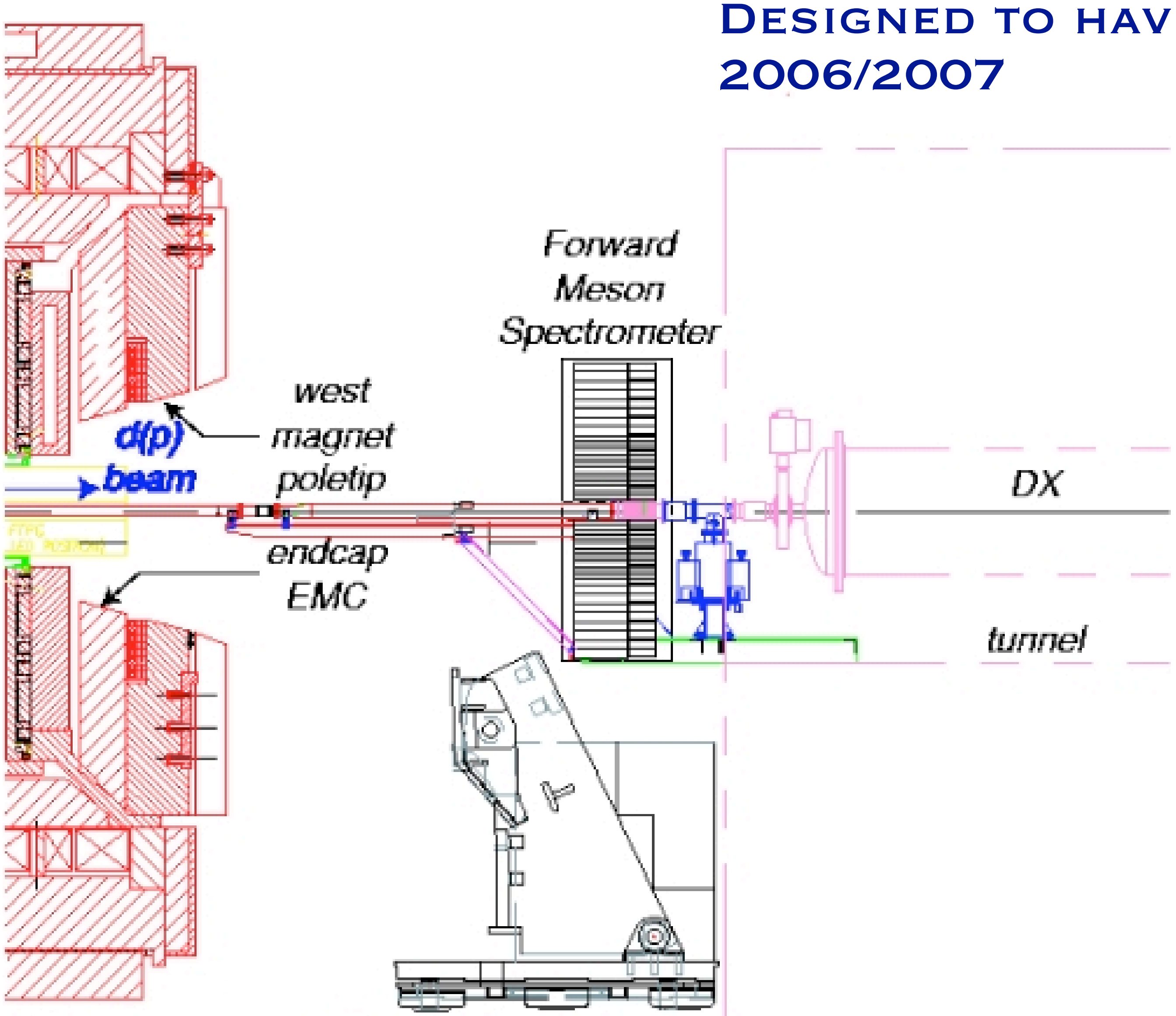


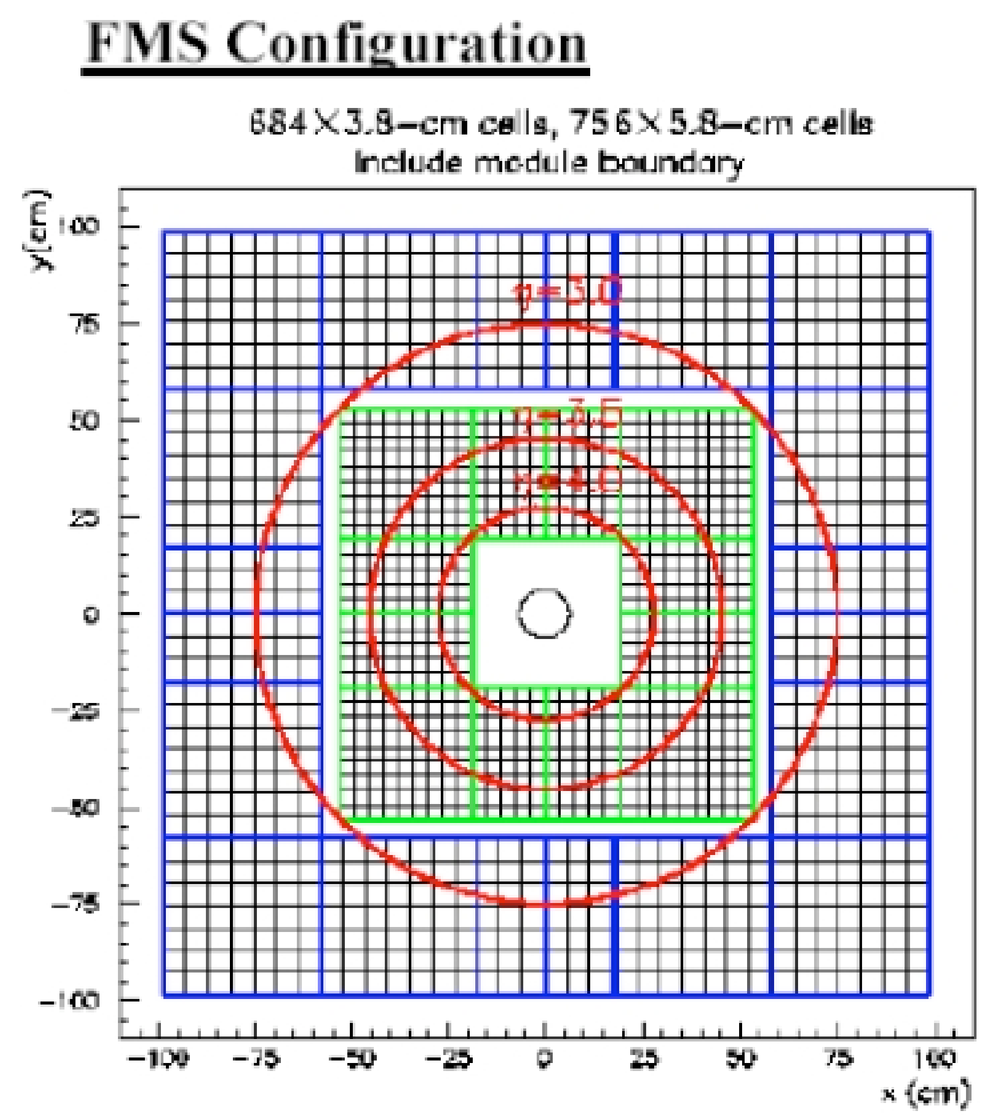


Upgrades - STAR - FMS

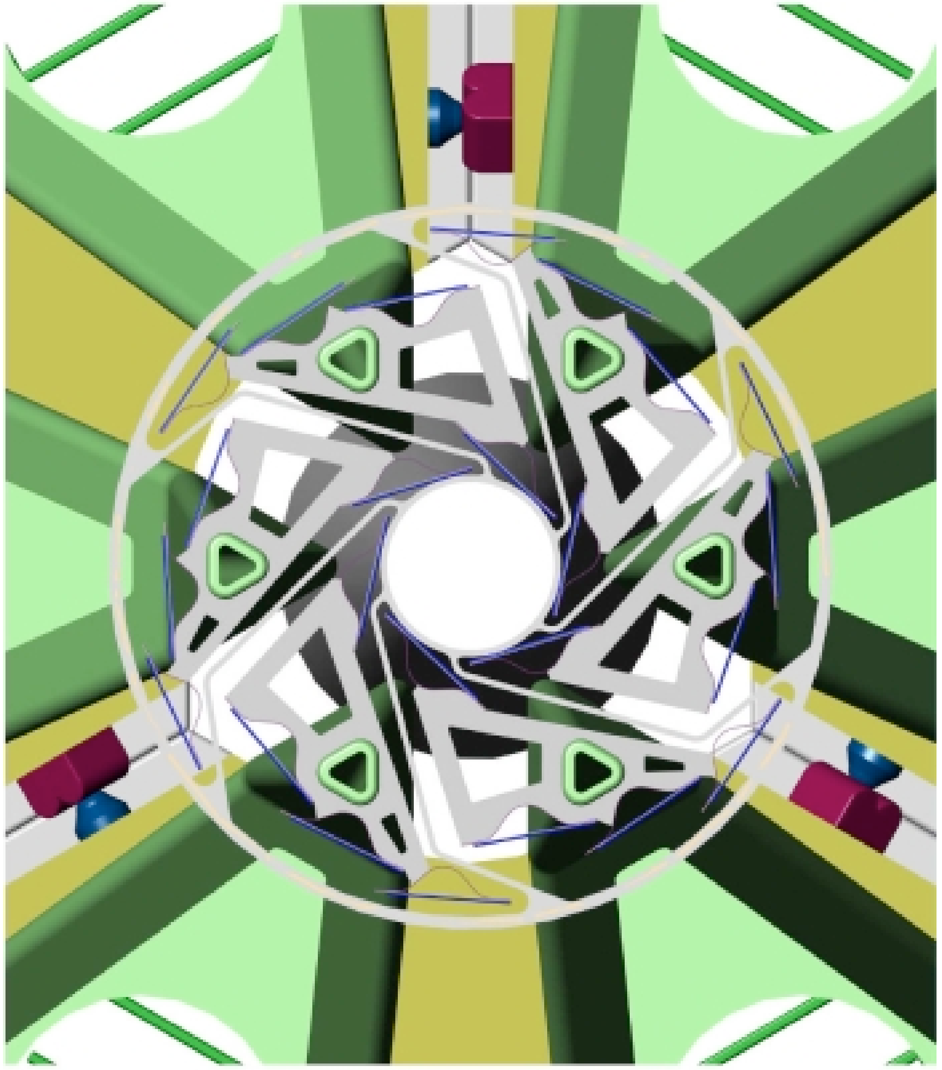
Electromagnetic calorimeter with full azimuthal coverage, 2.5<η<4.0

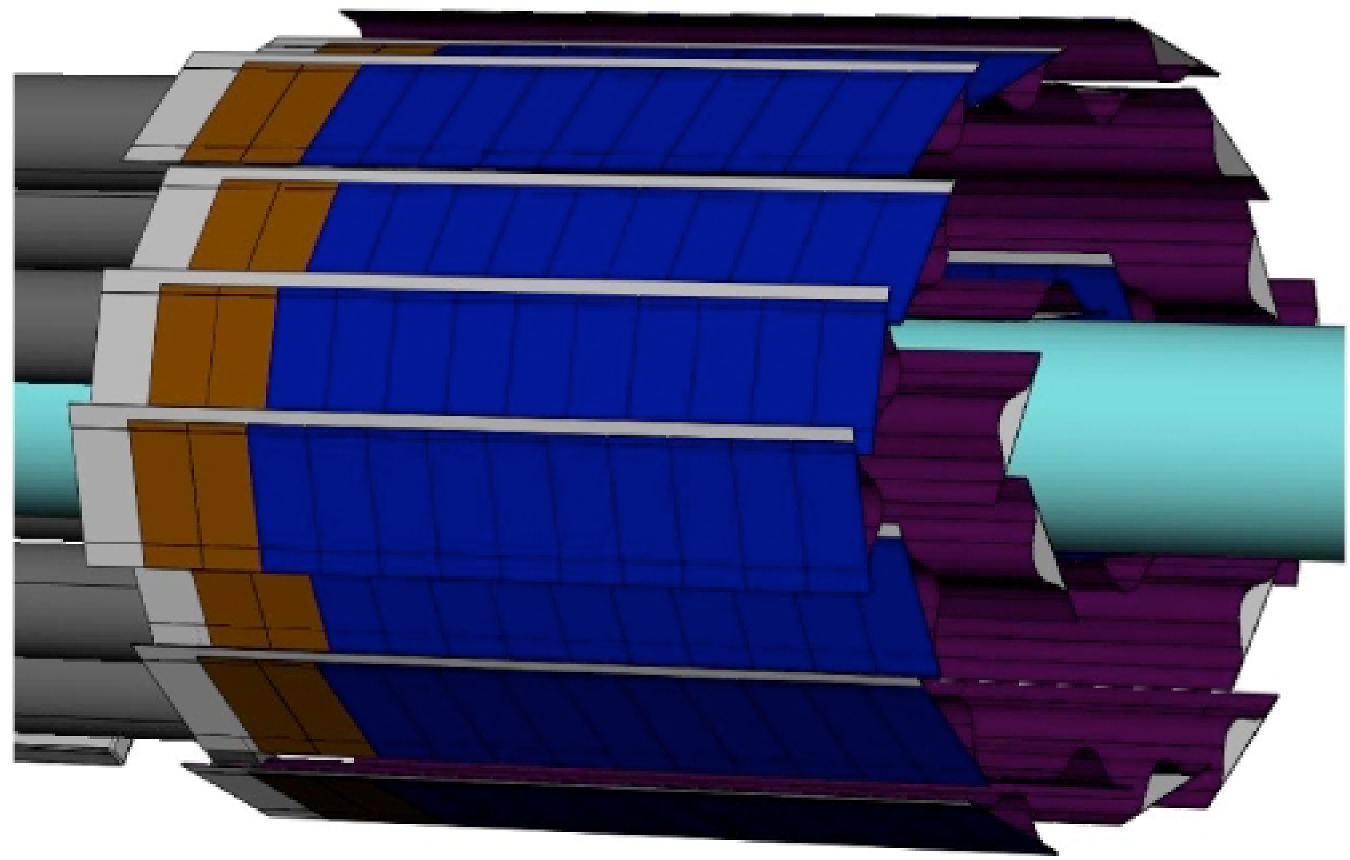
- Located at tunnel exit on west side
- Inner: 684 blocks, 3.8^2 x 45 cm
- Outer 756 blocks, 5.8^2 x 60 cm
- Use existing Pb Glass,
- PMT, bases Need R/O.
- Designed to have trigger capability
- 2006/2007





Upgrades - STAR - HFT





Two layers of CMOS pixel detector around a new thin (0.5mm) small radius (14 mm) beam pipe

10^8 pixels, $(30\ \mu m)^2$

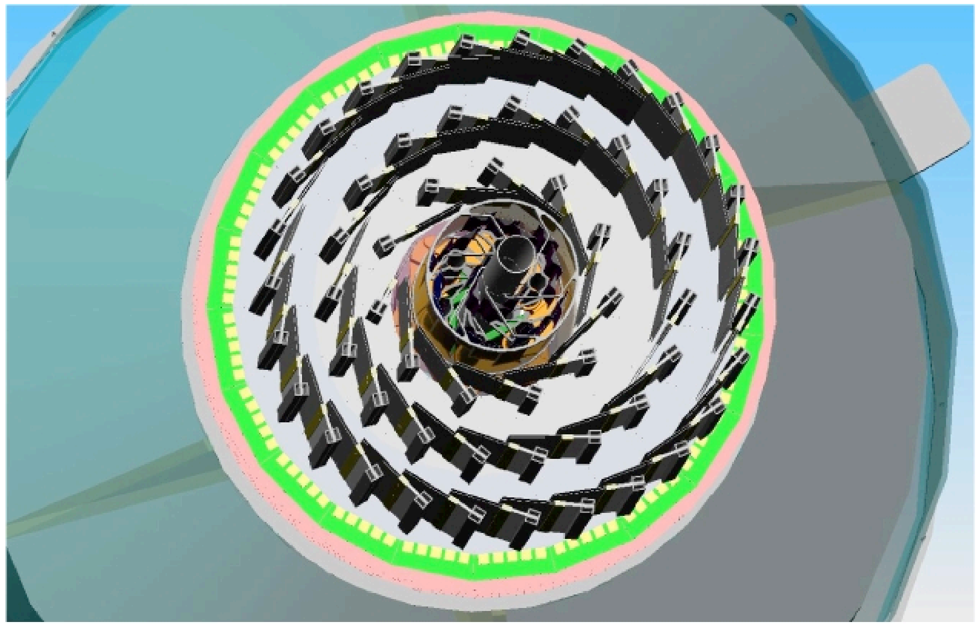
50 μm thick
10 μm point resolution

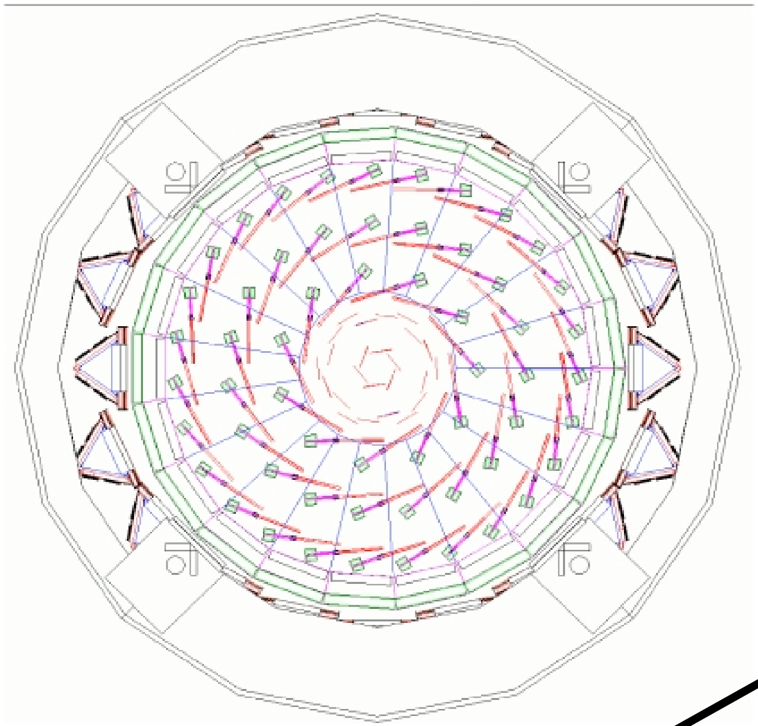
Upgrades - STAR - TUP

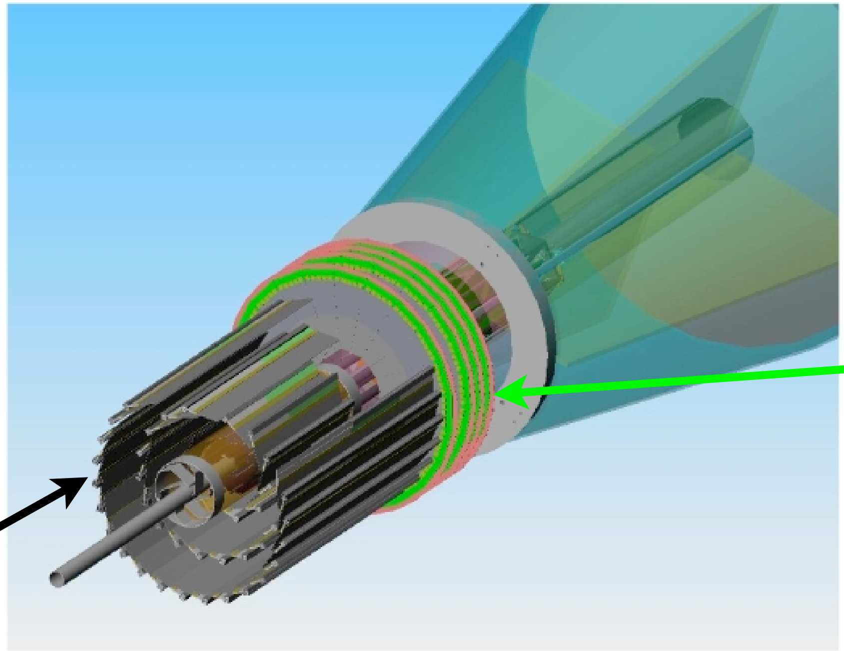
Replaces SVT – remove SVT infrastructure in $1<\eta<2$ region for $W^{+(-)}\rightarrow e^{+}(e^{-})$ (sea anti-quark contribution to proton spin), and provides part of the $1<\eta<2$ tracking

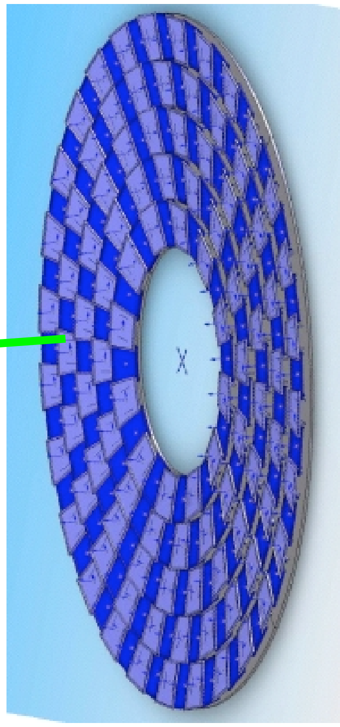
Forward Tracking Upgrade:

High precision Tracking in $1<\eta<2$ to discriminate charge sign in $W^{+(-)}\rightarrow e^{+}(e^{-})$ - 10's of GeV $e^{\pm}$









Barrel:

Three double layers of single sided silicon strip detectors

Forward:

4 Silicon strip discs plus GEM layer on End Cap

Common readout (AVP-25) used for silicon and GEM

Upgrades - STAR - DAQ/TPC RO

Goal:

(1) replace TPC FEE with version based on ALICE ALTRO chip;
(2) replace TPC DAQ system with one based on storage of only cluster information extracted in fast hardware;
(3) upgrade EMC Level 2 Receiver Boards and use for other new subsystems as well.

Increase Data rate for most detectors to ≥ 1kHz

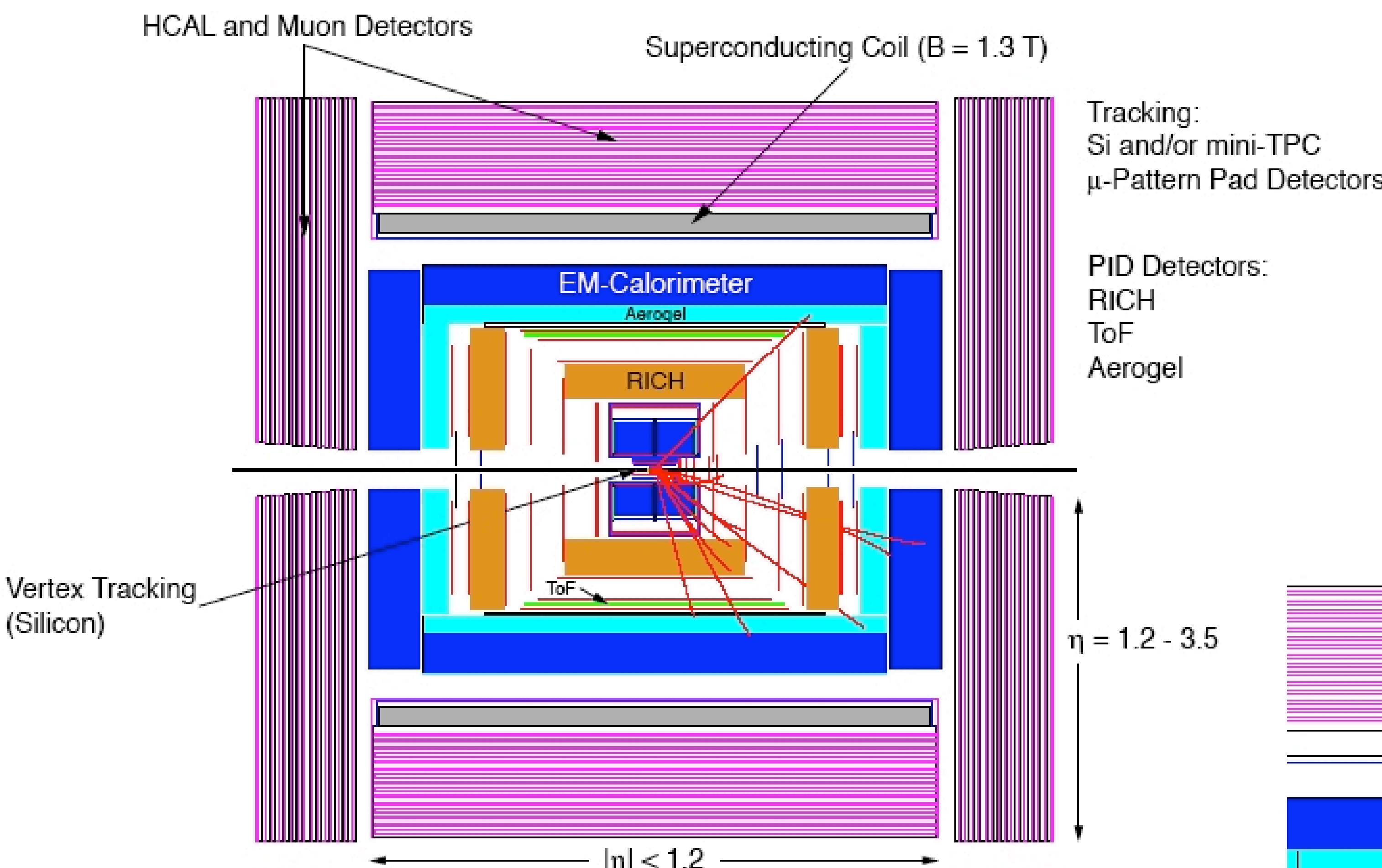
Make use of CERN developments for ALICE/LHC
PASA (preamp/shaper amp)
ALTRO (digitizer, digital filter, zero suppression, buffer)
SIU (Optical data sender)
D-RORC (PCI optical receiver board)

Schedule:
Nov. 2005 Small prototype in STAR
Nov. 2006 Two Sectors in STAR
Nov. 2007 Full TPC readout in STAR

R2D

HTTP://QM2005.KFKI.HU/TALKS/081/AUG6/1420//1420_R2D-QM-V4.PPT

HTTP://ARXIV.ORG/ABS/NUCL-EX/0503002



Subsystem	Channel Count	Comments
Vertex Tracker	388,000,000	40 by 40 μm pixels
Main Barrel Tracker	3,000,000	100 μm pitch strips (double-sided)
High pt Barrel Tracker	2,200,000	pad sizes (0.04 by 4, 0.04 by 10 cm)
Endcap Tracker	800,000	pad sizes (0.04 by 10 cm)
Forward Tracker	800,000	various technologies (see text)
Barrel EMCal	34,400	based on SLD layout
Endcap EMCal	9,600	based on SLD layout
Forward EMCal	200	based on CLEO crystals
Barrel HCal	9,800	based on SLD layout (towers)
Endcap HCal	110,800	based on SLD layout (strips)
Barrel TOF	50,000	based on STAR layout
Barrel RICH	260,000	6 by 6 mm pads

Table 10: preliminary channel count based on the proposed technologies for the main detector components.

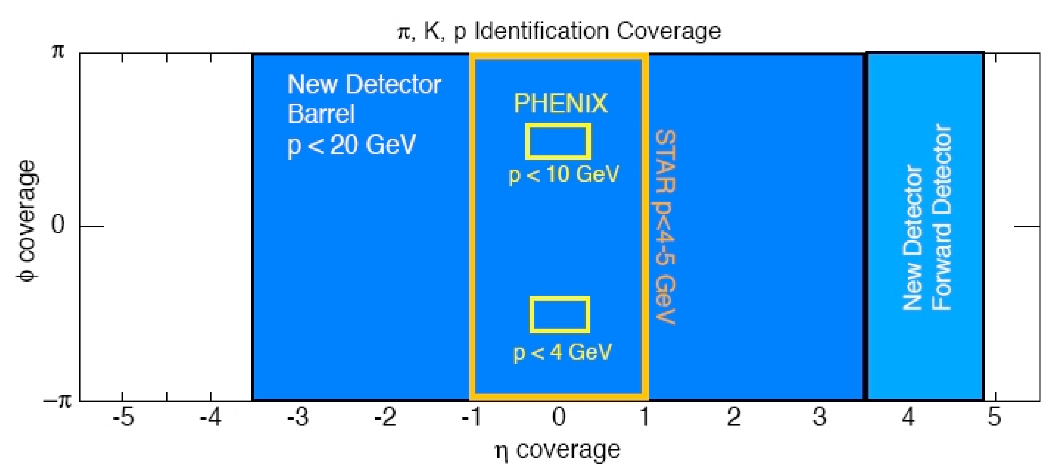
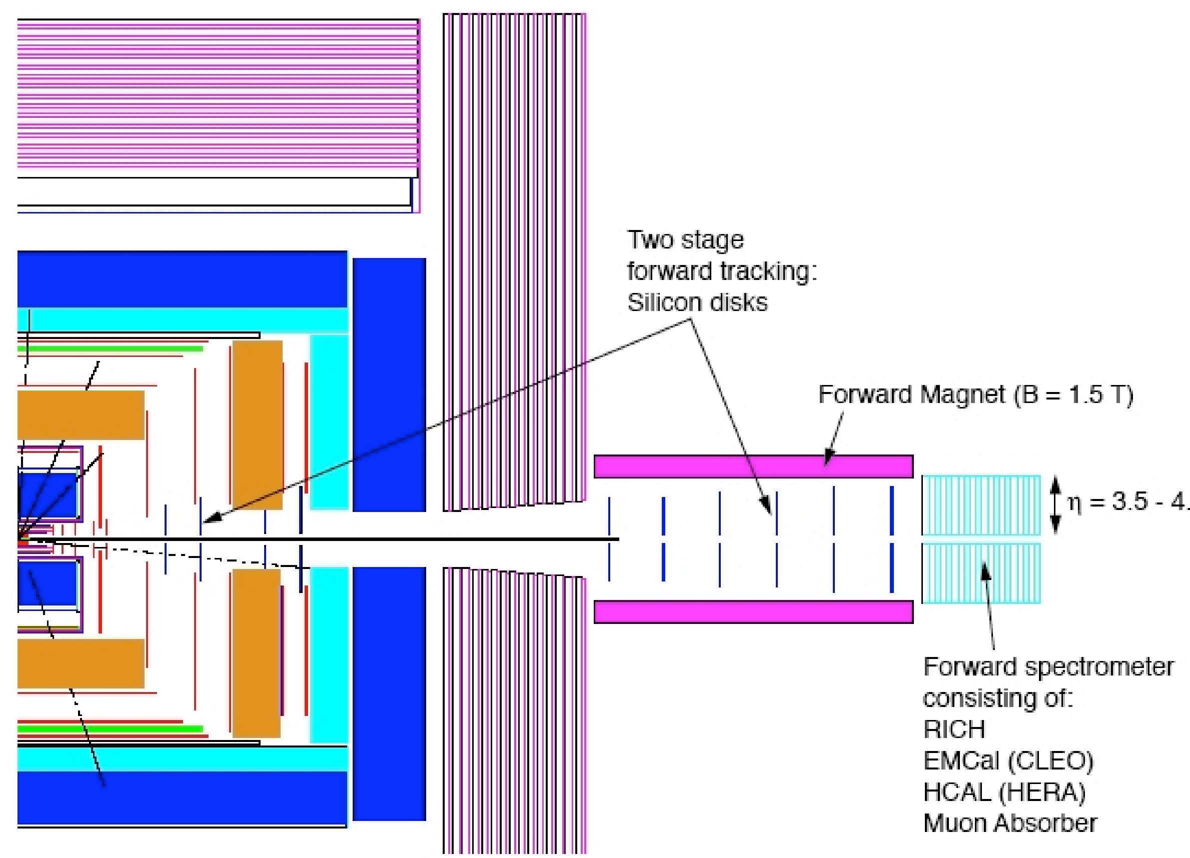


Figure 14: Comparison of particle identification capabilities in the new detector and the upgraded RHIC-I detectors as a function of pseudorapidity coverage and φ. The boxes show STAR and PHENIX, the blue shaded area shows the new detector coverage. The maximum transverse momentum for which particle identification is possible is indicated by the values in the boxes.



Summary II

bright future for RHIC, RHIC II, mixed HI species and √s, spin program and eRHIC unique

many experimental and collider updates on the way for the next phase of HI and spin physics

still a challenging environment

Tracking In High Multiplicity Environments

03 – 07 October 2005 Zurich, Switzerland

Encourage dialogue between hardware and software experts

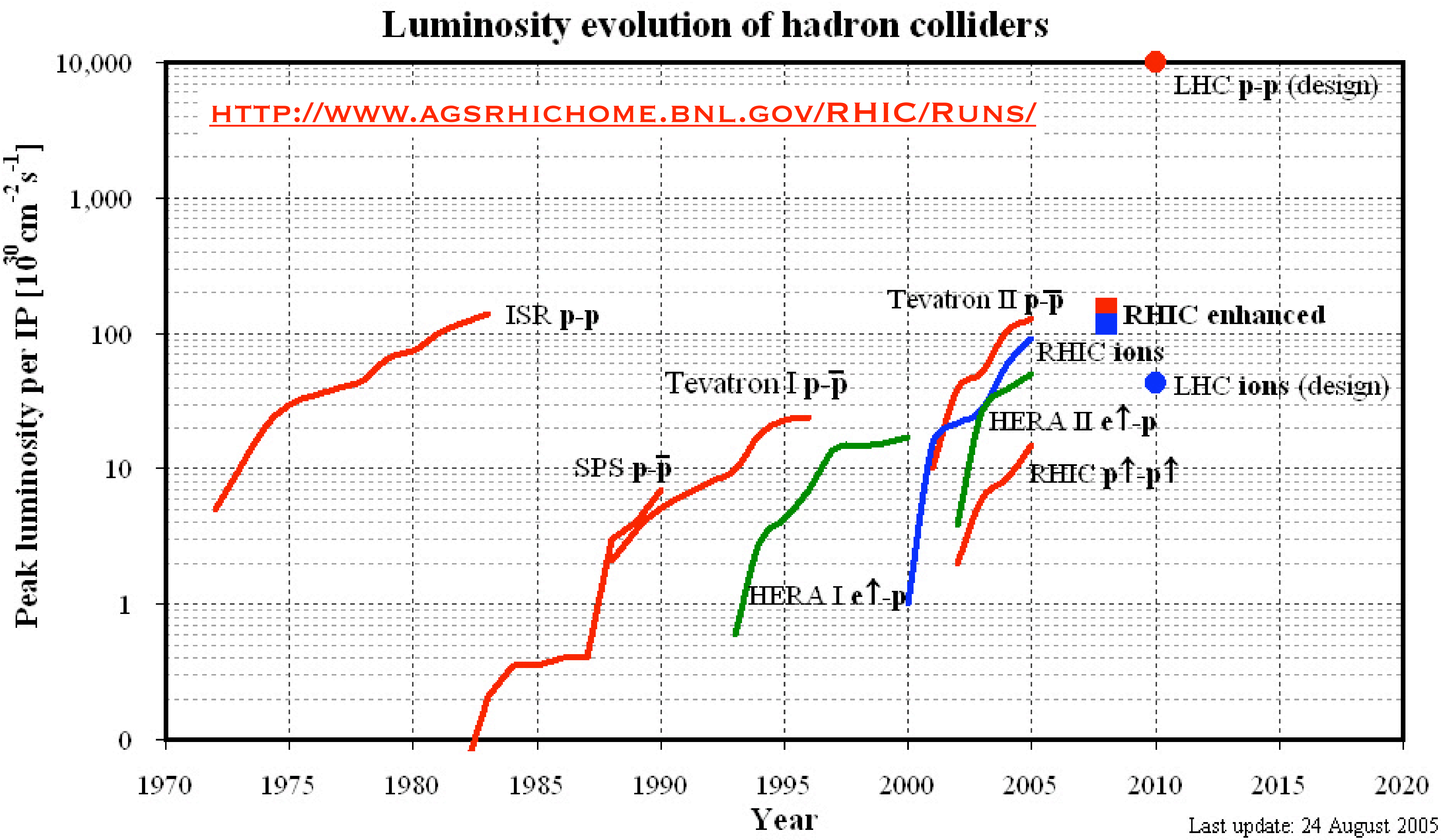
Transfer knowledge from running to future experiments

SOME ON:

HTTP://WWW.PHENIX.BNL.GOV/WWW/PUBLISH/AFRANZ/TIME05/

Backup slides

Comparison to other colliders



Note 1: For ion collisions the nucleon-pair luminosity is shown. The nucleon-pair luminosity is defined as $L_{NN} = A_1 A_2 L$, where L is the luminosity, and A_1 and A_2 are the number of nucleons of the ions in the two beam respectively.
Note 2: An upward arrow next to a particle symbol denotes polarized beam.

RHIC summary Run 03-05

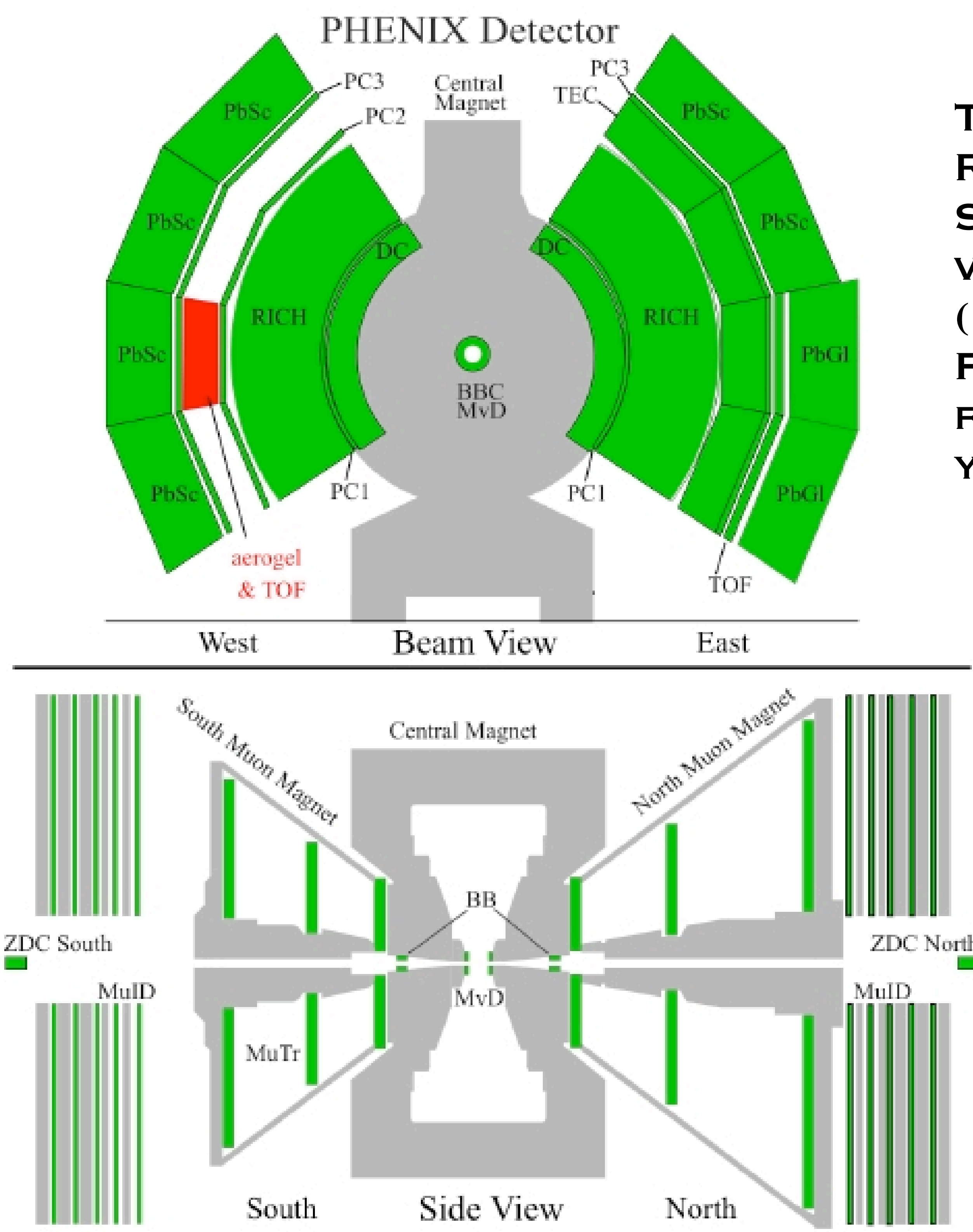
Table 1: Achieved beam parameters and luminosities ($\mathcal{L}$) for Au-Au (Run-4), Cu-Cu (Run-5), d-Au (Run-3), and p-p (Run-5). All numbers are given for operation at a beam energy of 100 GeV/n.

Mode	# bunches	Ions/bunch [10^9]	β^* [m]	Emittance [μm]	$\mathcal{L}_{peak}$ [$cm^{-2}s^{-1}$]	$\mathcal{L}_{store\ ave}$ [$cm^{-2}s^{-1}$]	$\mathcal{L}_{week}$
Au-Au	45	1.1	1	15-40	15×10^{26}	5×10^{26}	160 μb^{-1}
Cu-Cu	37	4.5	0.9	15-30	2×10^{28}	0.8×10^{28}	2.4 nb^{-1}
d-Au	55	110d / 0.7Au	2	15	7×10^{28}	2×10^{28}	4.5 nb^{-1}
p↑-p↑ *	106	90	1	30-35	10×10^{30}	7×10^{30}	1.9 pb^{-1}

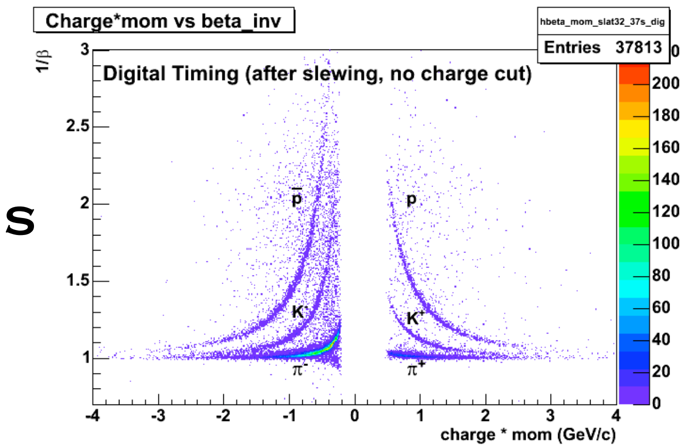
* Blue ring average polarization of 49%, Yellow ring average polarization of 44% in RHIC stores at 100GeV.

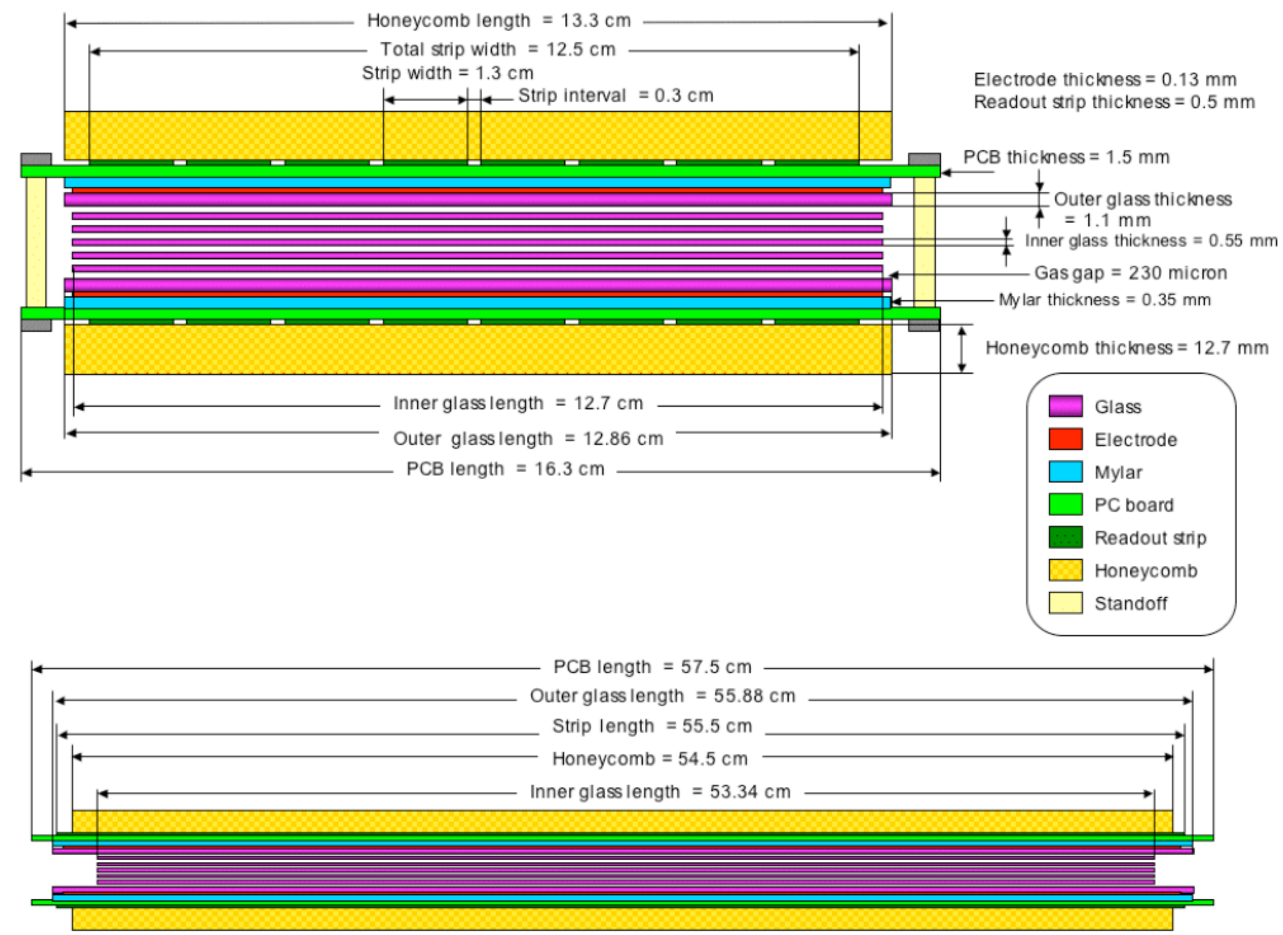
http://www.agsrhichome.bnl.gov/RHIC/Runs/

PHENIX - MRPC



Time of Flight MRPCs
R134a/C4H10 95:5,
STAR design,
very limited depth
(2" including cables)
Prototype successful,
full installation this
year





BROOKHAVEN NATIONAL LABORATORY
Office of Science U.S. DEPARTMENT OF ENERGY

PHENIX - Gas Summary

	Mixture	%	in liters	Flow rates (lpm)
TEC	Ar/CH4	90/10	6000	15.100
TEC/TRD	Xe/He/CH4	45/45/10	6000	XX
DC	Ar/C2H6	50/50	6000	12.000
PC	Ar/C2H6	50/50	1075	4.700
MuTR	Ar/CO2/CF4	50/30/20	3000	8.000
MuID	CO2/C4H10	10.111	50000	25.000
RICH	CO2	100.000	80000	2.000
He Bag	He	100.000	9060	1.000
TOF West	R134a/ C4H10	95 / 5	225	0.625
TRD Purifier	Ar/H2	95 / 5	7	0.050
HBD	CF4	100.000	200	2.000

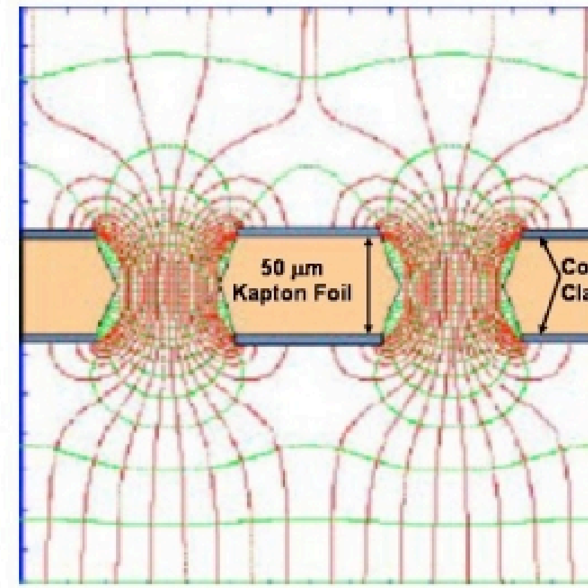
GEMs

GEM =Gas Electron Multiplier

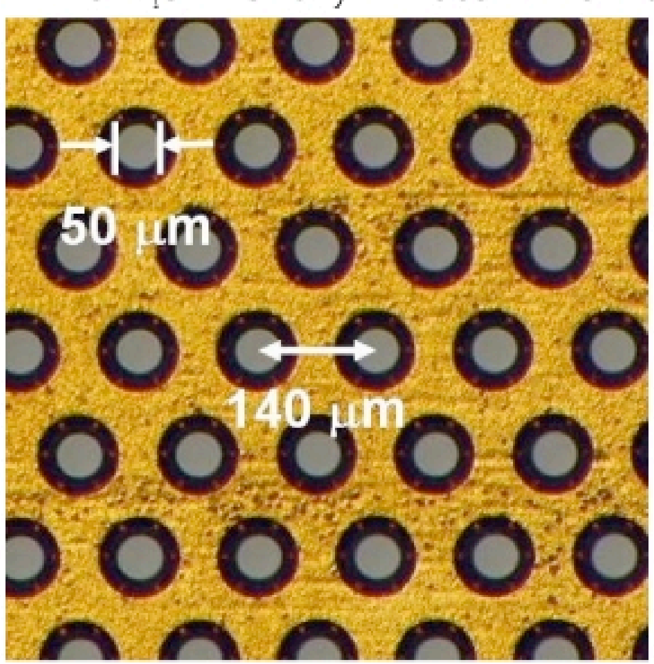
A micropattern structure produced in 50μm thick copper clad kapton using lithographic techniques.

55μm holes on ~140μm centers

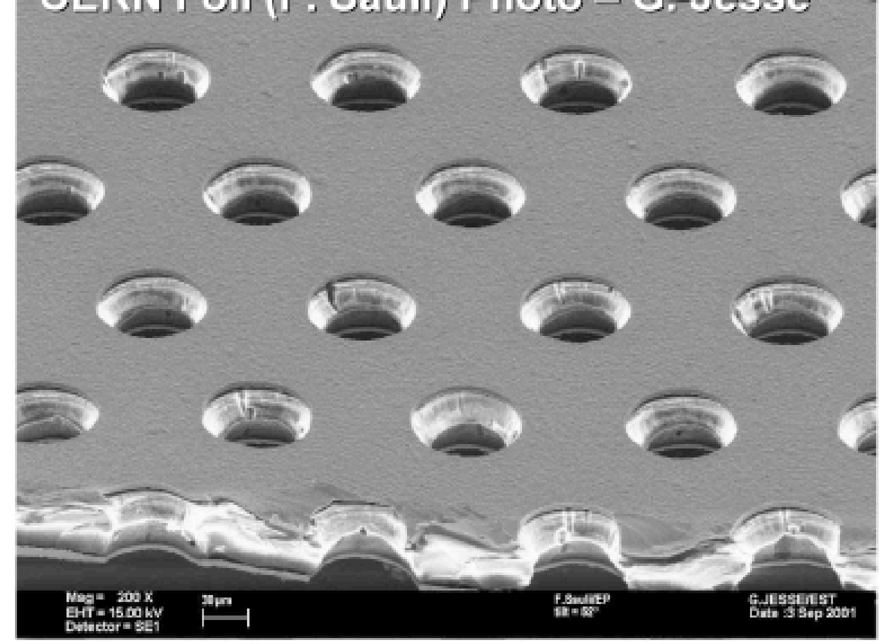
Gain up to ~10^3 for single foil



3M Foil (J. Collar) Photo – Bo Yu, BNL



CERN Foil (F. Sauli) Photo – G. Jesse



RHIC UPGRADES

RHIC Upgrades Overview

Upgrades	High T QCD				Spin		Low x
	e+e-	heavy flavor	jet tomography	quarkonia	W	ΔG/G	
PHENIX							
hadron blind detector (HBD)	x						
Vertex tracker (VTX and FVTX)	x	x	o	o		x	o
μ trigger				o	x		
forward calorimeter (NCC)			o	o	o		x
STAR							
time of flight (TOF)		o	x	o			
Heavy flavor tracker (HFT)		x		x			
tracking upgrade		o			x	o	
Forward calorimeter (FMS)						o	x
DAQ		o	x	x	o	o	o
RHIC luminosity	o	o	x	x	o	o	o