Overview of the PHENIX Experiment

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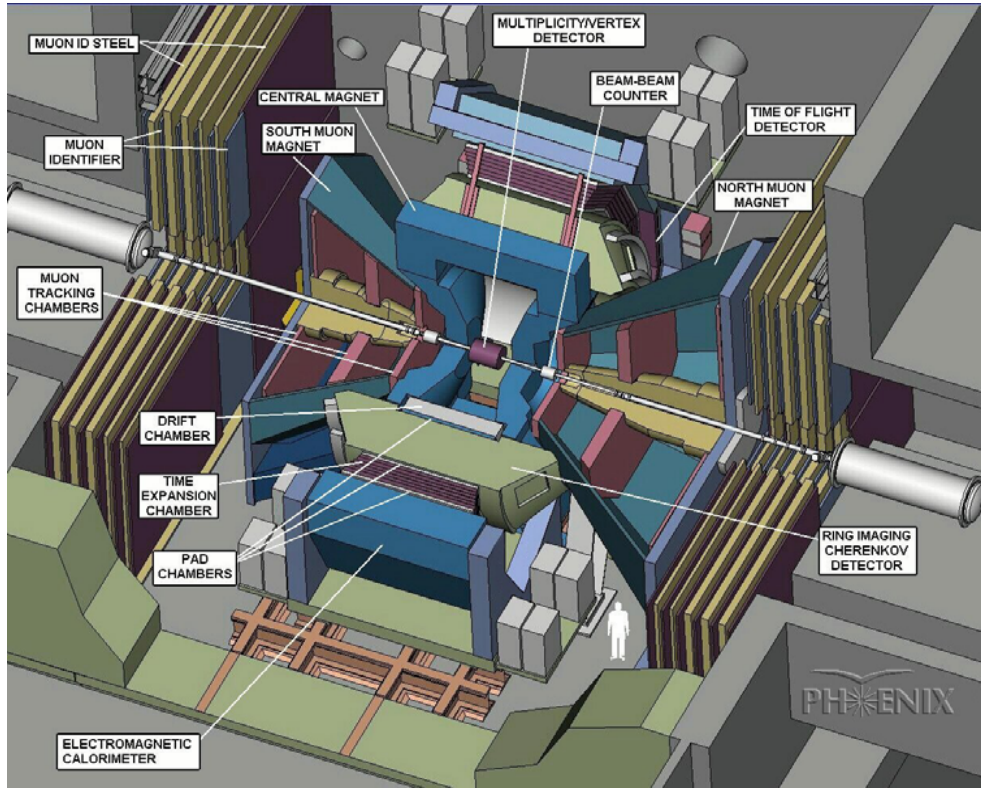
PHENIX

Welcome to PHENIX

Tale of the Tape:

- Begun Operation June 2000
- 16 Detector subsystems
- 4 Spectrometer arms
- Total weigh = 3500T
- 315,000 readout channels
- >125 Varieties of custom printed circuit boards
- 13 ASICs designed specifically for PHENIX
- Pipe-lined DAQ Front-end
- 500, GHz Optical Data Links



The PHENIX Experiment is designed to probe fundamental features of the strong nuclear force including:

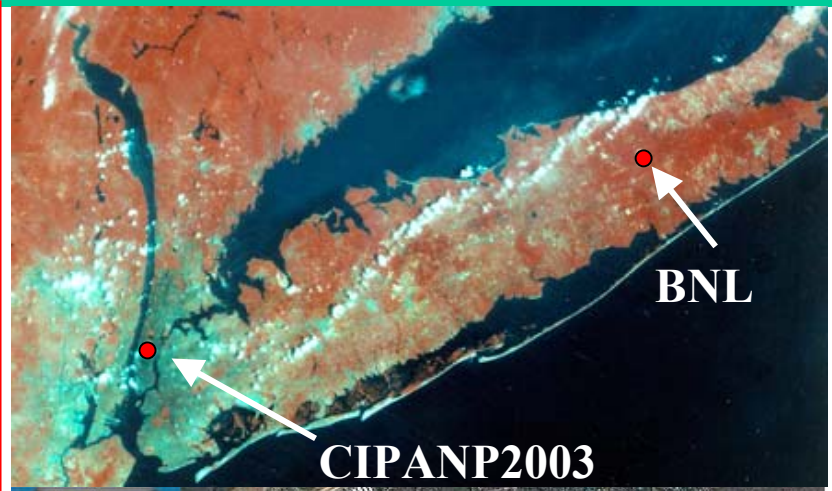
- The detection and characterization of the Quark-Gluon Plasma
- The spin structure of the nucleons
- Initial and final state nuclear effects

The Configuration:

- 2 Forward Muon Arms
- 2 Central Spectrometer Arms to measure photons, electrons, and hadrons
- Event Characterizing Detectors

The Relativistic Heavy Ion Collider at BNL

- Two independent rings 3.83 k in circumference
  - 120 bunches/ring
  - 106 ns crossing time
- Maximum Energy
  - $s^{½}$ = 500 GeV p-p
  - $s^{½}$ = 200 GeV/N-N Au-Au
- Design Luminosity
  - Au-Au $2x10^{26}$ $cm^{-2}s^{-1}$
  - p - p $2x10^{32}$ $cm^{-2}s^{-1}$ (polarized)
- Capable of colliding any nuclear species on any other nuclear species



PHENIX Runs to date: =

			$s^{1/2}$ [GeV]	$\int Ldt$	N_{tot}
Run1	2000	Au-Au	130	1 μb^{-1}	10M
Run2	2001/02	Au-Au	200	24 μb^{-1}	170M
		p-p	200	0.15 pb^{-1}	3.7G
Run3	2002/03	d-Au	200	2.74 nb^{-1}	5.5G
		p-p	200	ongoing	

PHENIX

12 Countries; 57 Institutions; 460 Participants*

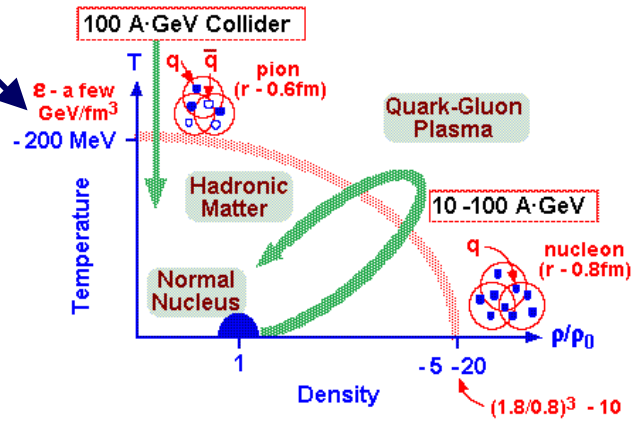
Brazil	University of São Paulo, São Paulo
China	Academia Sinica, Taipei, Taiwan
	China Institute of Atomic Energy, Beijing
	Peking University, Beijing
France	LPC, University de Clermont-Ferrand, Clermont-Ferrand
	Dapnia, CEA Saclay, Gif-sur-Yvette
	IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
	LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
	SUBATECH, Ecòle des Mines at Nantes, Nantes
Germany	University of Münster, Münster
Hungary	Central Research Institute for Physics (KFKI), Budapest
	Debrecen University, Debrecen
	Eötvös Loránd University (ELTE), Budapest
India	Banaras Hindu University, Banaras
	Bhabha Atomic Research Centre, Bombay
Israel	Weizmann Institute, Rehovot
Japan	Center for Nuclear Study, University of Tokyo, Tokyo
	Hiroshima University, Higashi-Hiroshima
	KEK, Institute for High Energy Physics, Tsukuba
	Kyoto University, Kyoto
	Nagasaki Institute of Applied Science, Nagasaki
	RIKEN, Institute for Physical and Chemical Research, Wako
	RIKEN-BNL Research Center, Upton, NY
	University of Tokyo, Bunkyo-ku, Tokyo
	Tokyo Institute of Technology, Tokyo
	University of Tsukuba, Tsukuba
	Waseda University, Tokyo
S. Korea	Cyclotron Application Laboratory, KAERI, Seoul
	Kangnung National University, Kangnung
	Korea University, Seoul
	Myong Ji University, Yongin City
	System Electronics Laboratory, Seoul Nat. University, Seoul
	Yonsei University, Seoul
Russia	Institute of High Energy Physics, Protovino
	Joint Institute for Nuclear Research, Dubna
	Kurchatov Institute, Moscow
	PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
	St. Petersburg State Technical University, St. Petersburg
Sweden	Lund University, Lund
USA	Abilene Christian University, Abilene, TX
	Brookhaven National Laboratory, Upton, NY
	University of California - Riverside, Riverside, CA
	University of Colorado, Boulder, CO
	Columbia University, Nevis Laboratories, Irvington, NY
	Florida State University, Tallahassee, FL
	Georgia State University, Atlanta, GA
	University of Illinois Urbana Champaign, Urbana-Champaign, IL
	Iowa State University and Ames Laboratory, Ames, IA
	Los Alamos National Laboratory, Los Alamos, NM
	Lawrence Livermore National Laboratory, Livermore, CA
	University of New Mexico, Albuquerque, NM
	New Mexico State University, Las Cruces, NM
	Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
	Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
	Oak Ridge National Laboratory, Oak Ridge, TN
	University of Tennessee, Knoxville, TN
	Vanderbilt University, Nashville, TN

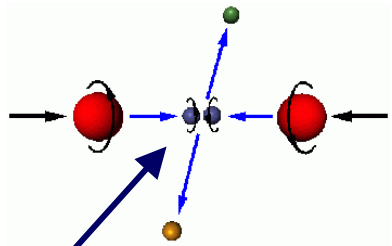
* as of May 2003

Some of the Physics of PHENIX

QGP:

- Temperature and Energy Density
  - dN/dy, E_T , Identified single particle spectra
- Jet Quenching, parton dE/dx
  - High p_T jets using leading π^o, $\pi^{\pm}$
- Space –Time Evolution
  - HBT($\pi\pi$, KK,pp), v2=Elliptic Flow
  - Event by Event Fluctuations
- Deconfinement
  - J/Ψ, Ψ'→ e+e-,μ+μ-, Υ→μμ
- Chiral Symmetry Restoration
  - φ→e+e-,K+K-, φ,ω,ρ width/shift
  - DCC's $\pi^o/\pi^{\pm}$
- Heavy Quark Production
  - K/ π , φ, J/Ψ, Ψ', Υ, D, B mesons
- Thermal Radiation
  - γ, γ*→ e+e-, μ+μ-



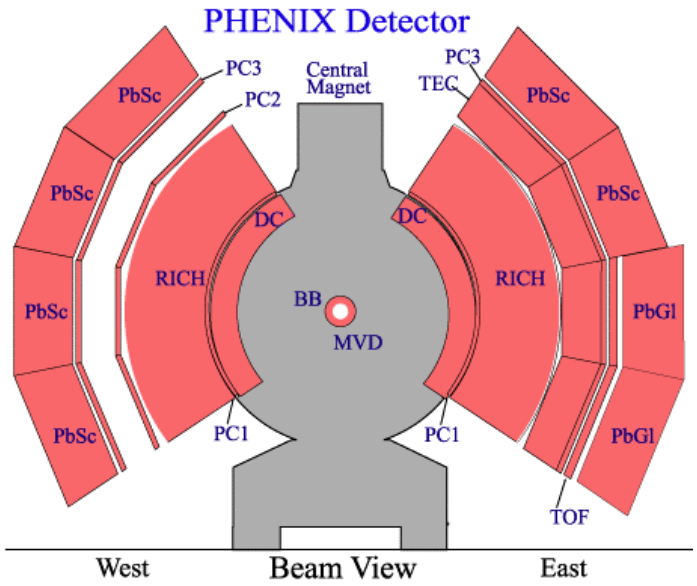


Nucleon Spin:

- Gluon spin: ΔG
  - Direct γ, high p_T π's
- Sea quark spin: $\Delta\bar{u}$, $\Delta\bar{d}$
  - W^+/W^- production
  - Drell-Yan Polarization

PHENIX Design Elements

- Detector Redundancy
- Fine Granularity, Mass Resolution
- High Data Rate
- Good Particle ID
- Limited Acceptance



Charged Particle Tracking:

- Drift Chamber
- Pad Chamber
- Time Expansion Chamber/TRD
- Cathode Strip Chambers

Particle ID:

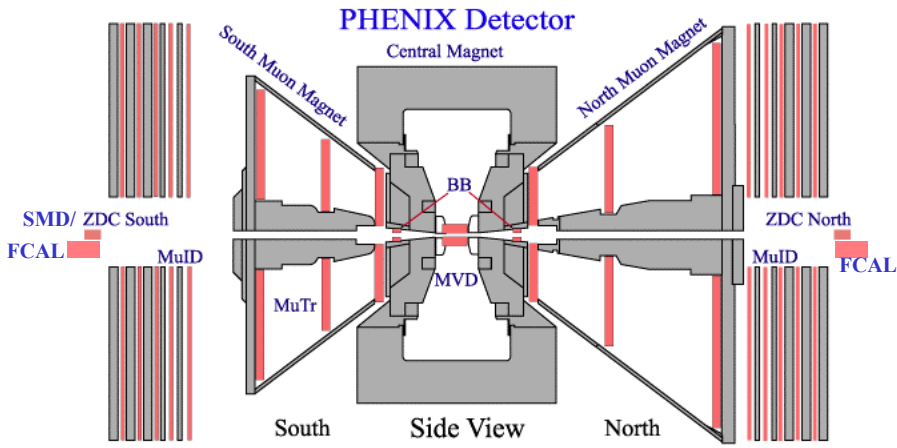
- Time of Flight
- Ring Imaging Cerenkov Counter
- TEC/TRD
- Muon ID (PDT's)

Calorimetry:

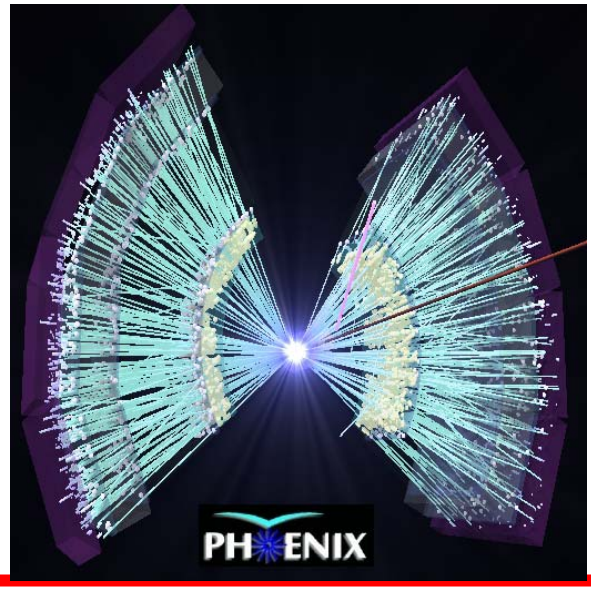
- Pb Scintillator
- Pb Glass

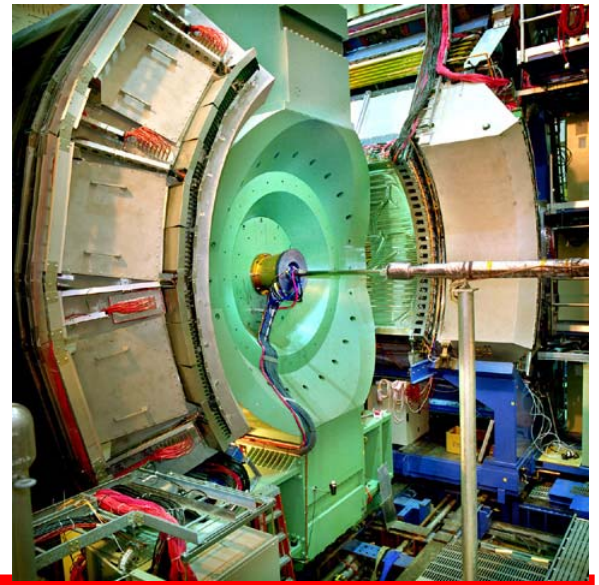
Event Characterization:

- Multiplicity Vertex Detector (Si Strip,Pad)
- Beam-Beam Counter
- Zero Degree Calorimeter/Shower Max Detector
- Forward Calorimeter
- Normalization Trigger Counters



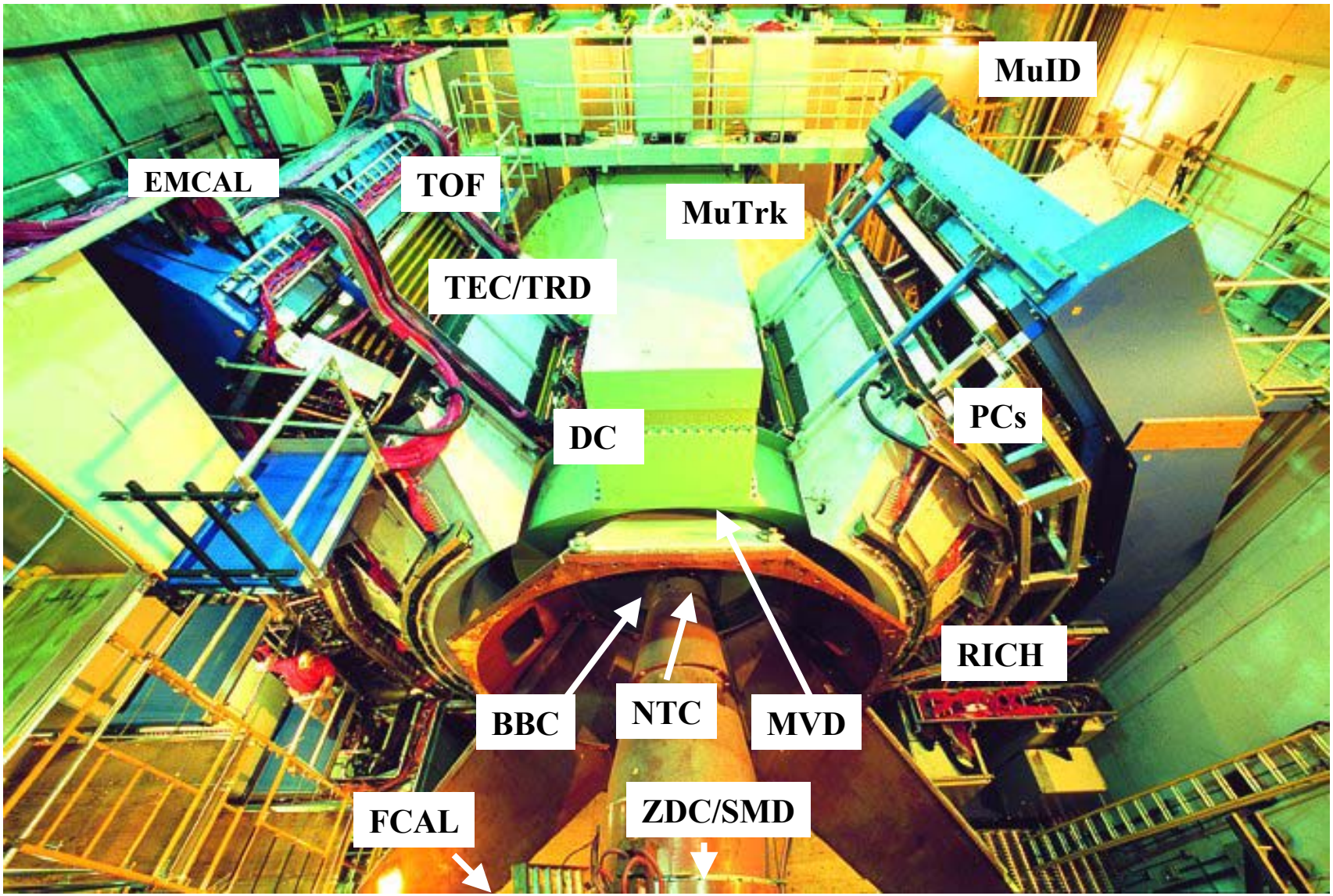
PHENIX Detector Technologies





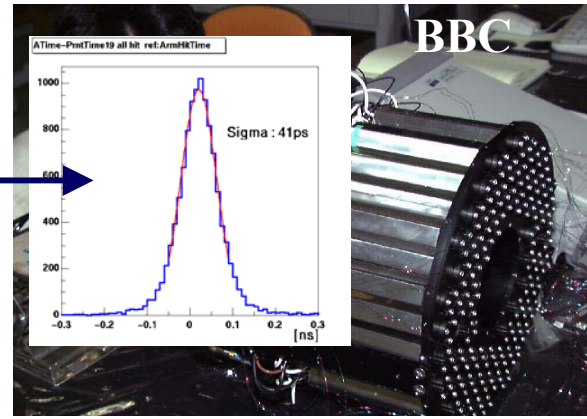
- Large Area Cathode Strip Chamber with 100 μm position resolution
- Fine-segmented EMCal (0.01 Φ, 0.01 η) with $\sigma_t < 0.4$ ns
- Time Expansion Chamber that combines tracking, dE/dx and TRD
- Drift Chamber configured as focusing –jet chamber
- Ring Imaging Cerenkov Counter readout with 5000+ PMTs
- Low mass, non-projective pixel-pad wire chambers covering ~100 m^2
- Time of Flight system with $\sigma_t < 100$ ps
- Fully data-pipelined front-end electronics
- All data, timing, control and serial communication between detector and counting house is via optical link.

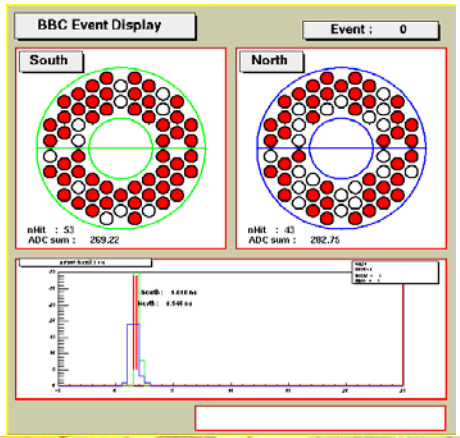
We Probably Could Have Used a Second Hall

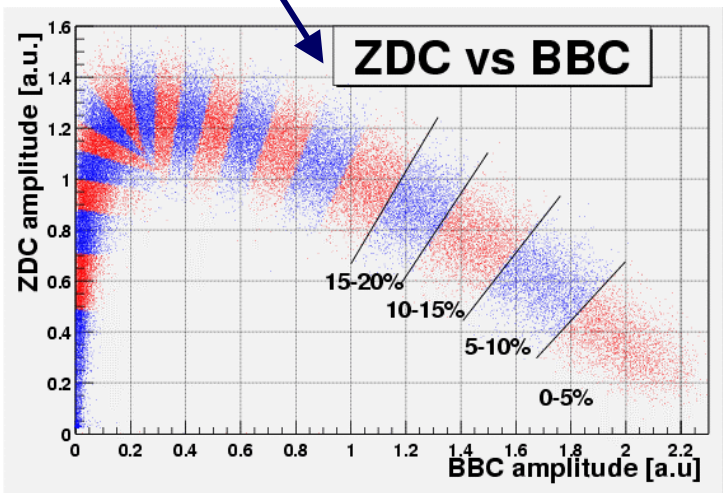


Event Characterization Detectors
Beam-Beam Counter & Zero Degree Calorimeter

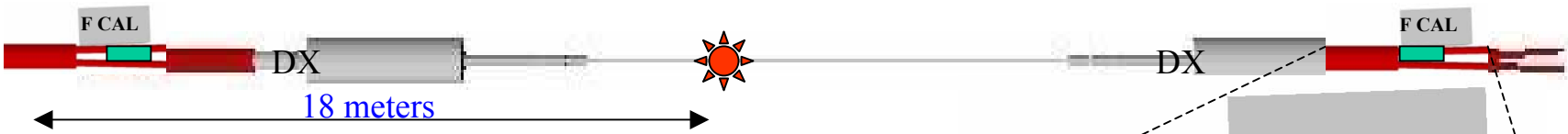
- BBC is 2 arrays of 64 PMTs with quartz radiators
  - Provides T0 for PHENIX. $\sigma_t = 41$ ps
- ZDC is Cu-W calorimeter with fiber readout.
  - Common centrality measure for all 4 RHIC experiments
- Combined they provide the PHENIX LVL1 centrality trigger



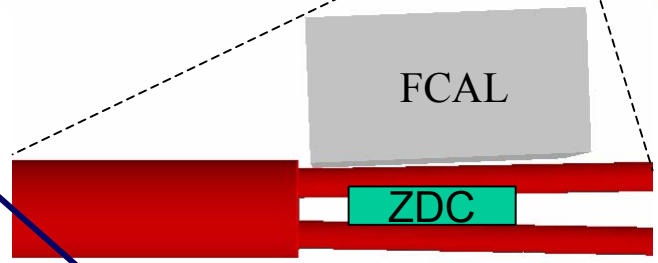


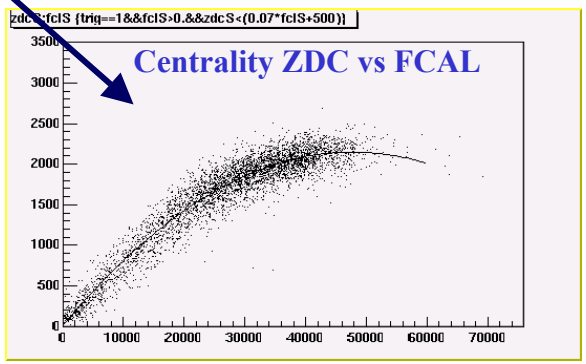


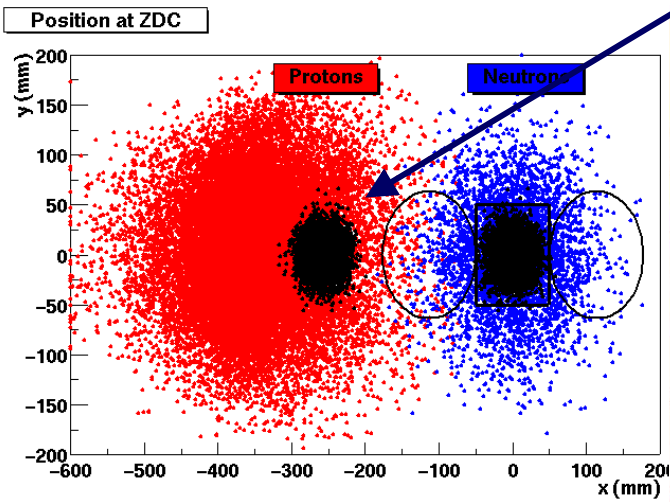
Event Characterization in dAu Run
Forward Calorimeter

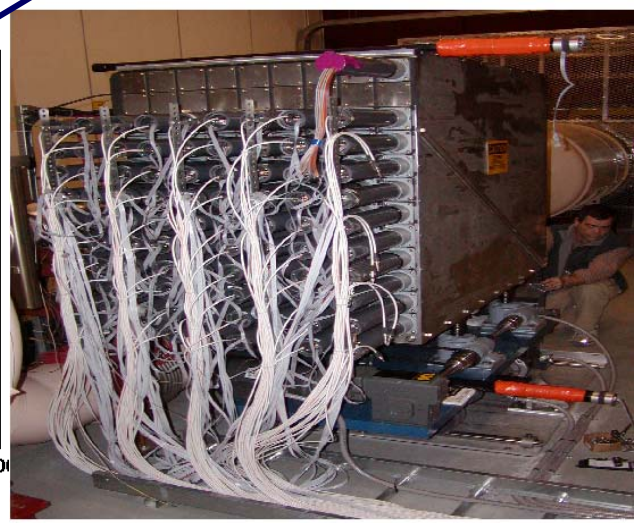


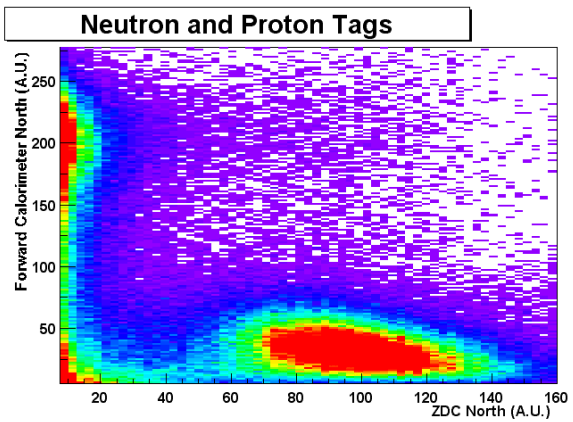
- Used to determine centrality in d Au events
- 2 stacks of 90 hadronic calorimeter modules
  - Pb + Scintillating fiber
  - Located in both d and Au direction
- Primarily sees forward going protons





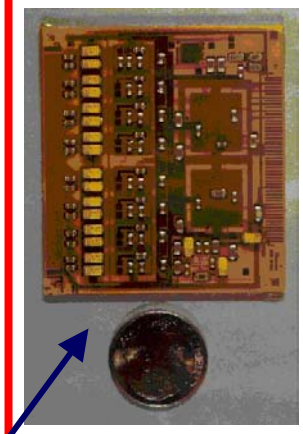


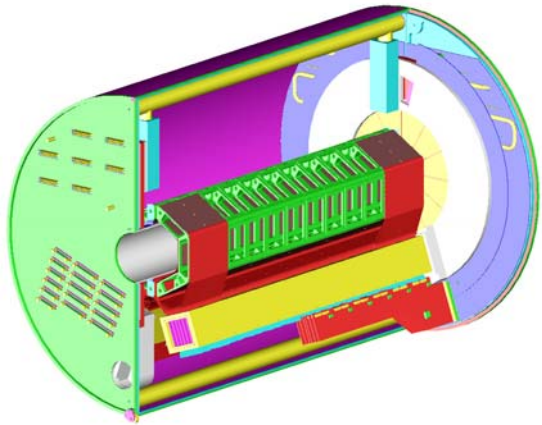




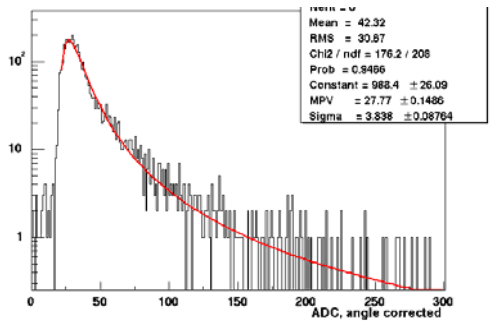
Event Characterization Detectors
Multiplicity Vertex Detector

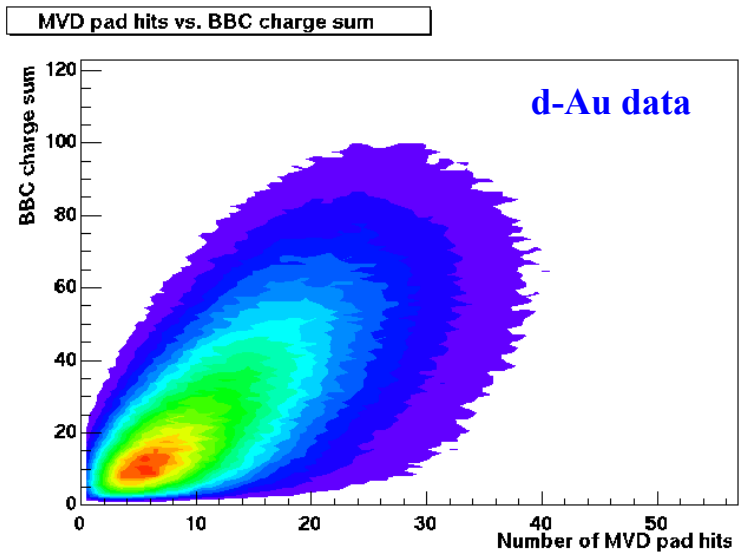
- Two concentric barrels of 300μm Si strips
- Two endplates of Si pads
- Total coverage of $-2.5 < \eta < +2.5$
- 28,672 Si strips, 6048 Si pads
  - ~75% instrumented
- Determines event vertex and measures particle multiplicity/event
- Electronics is bare die on ceramic Multi- Chip Module





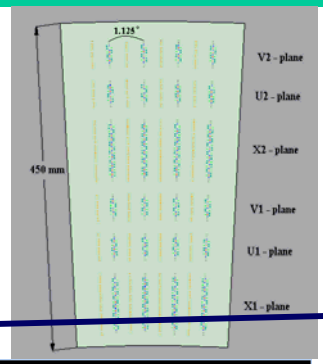
Min ionizing peak dist from single pad

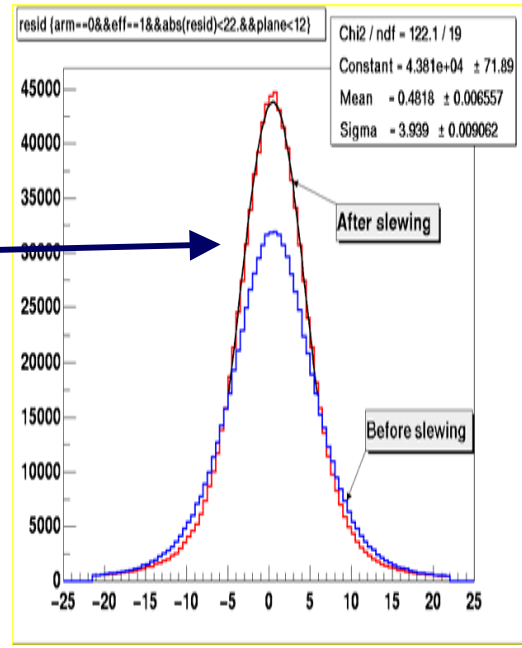




Central Tracking: Drift Chamber

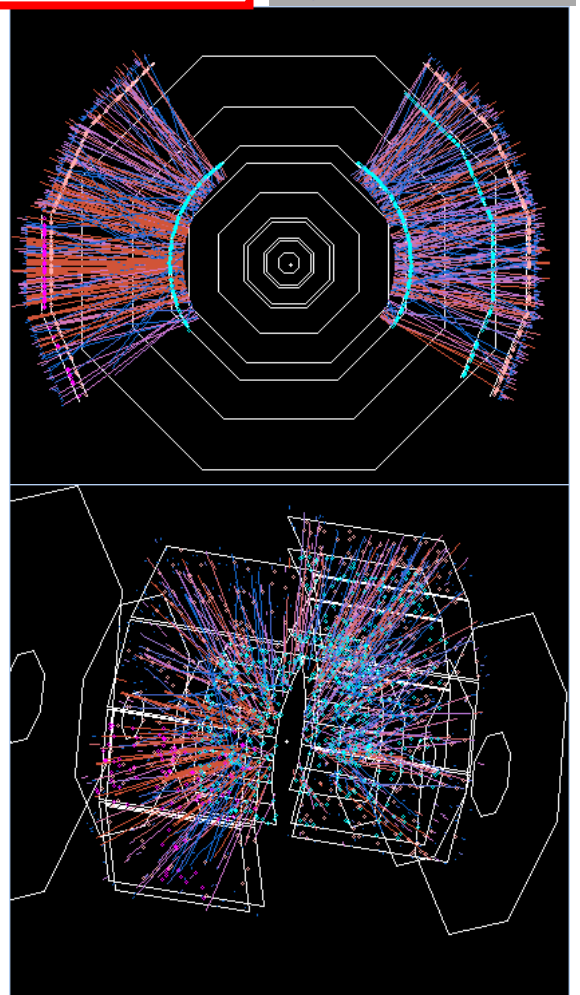
- Jet -chamber anode/cathode structure modified for HI high multiplicity
- Joint Russia/US design & construction
- All Titanium frame
- σ_x = 120 μm , two-track sep = 2mm

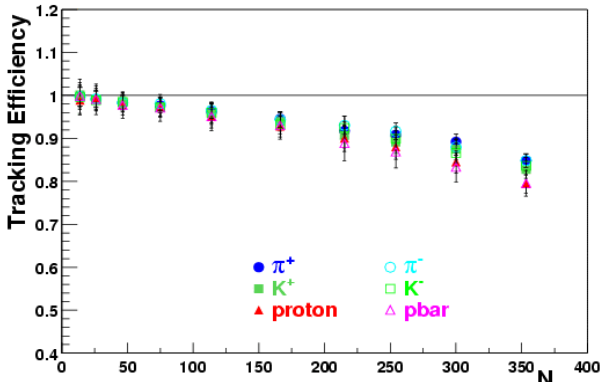




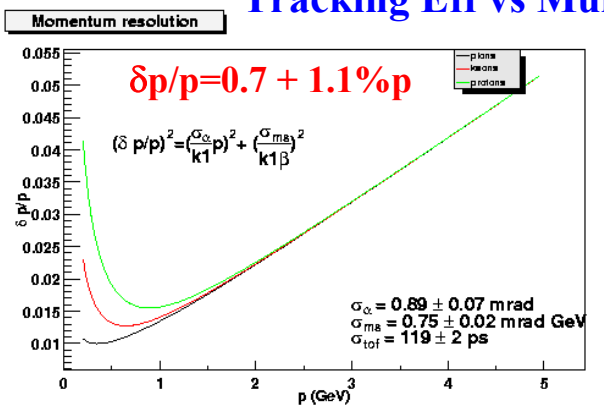
DC Position Resolution

Central Au Au Event





Tracking Eff vs Mult.

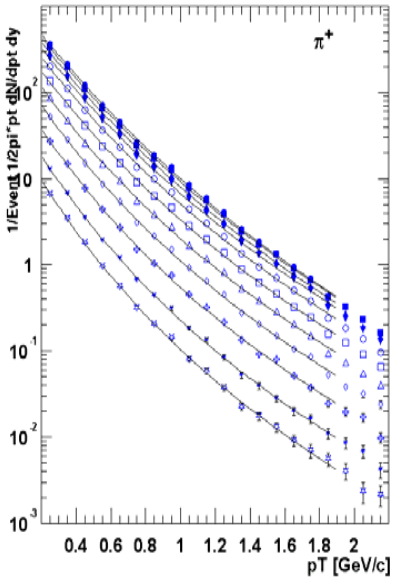


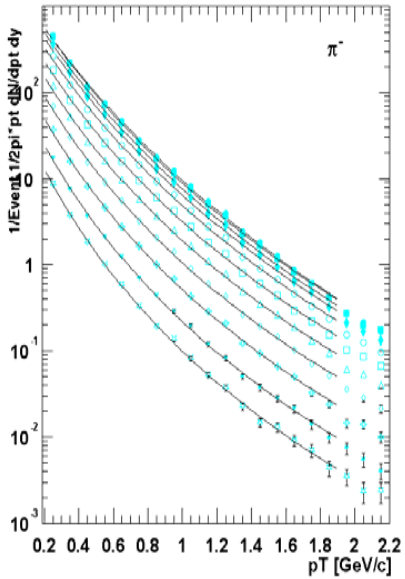
Momentum Resolution

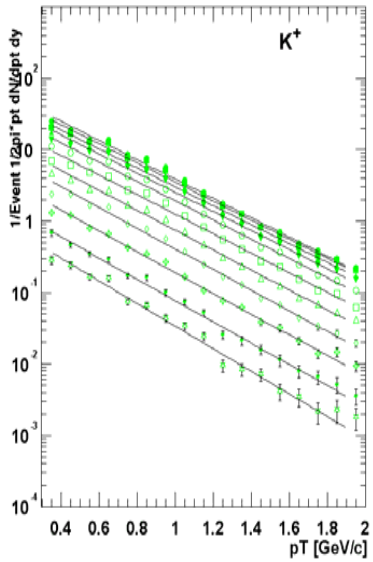
DC wires with kapton wire dividers

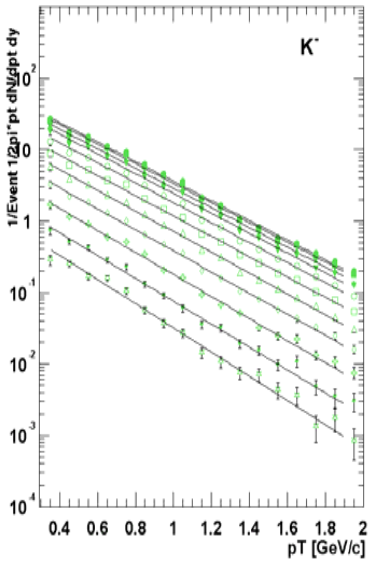
Central Tracking Physics Spectra

Au+Au at √s = 200 GeV PHENIX preliminary



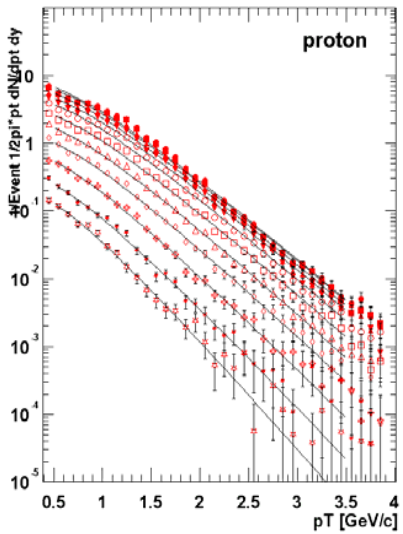


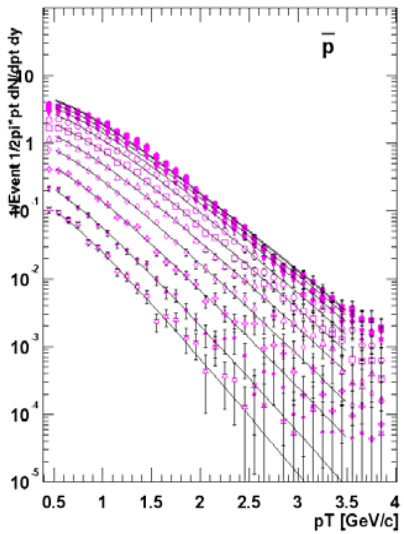




Centrality

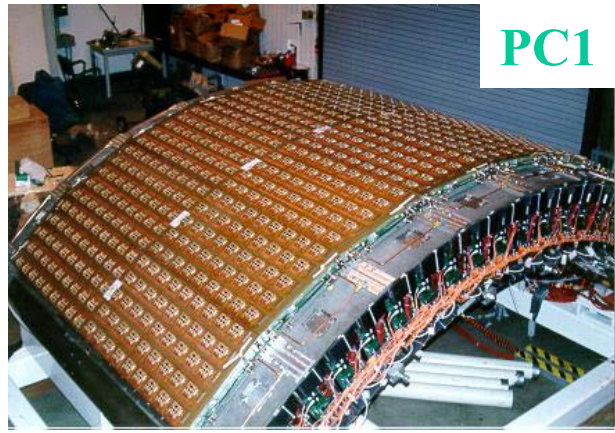
0 – 5 %
5 -10 %
10- 15 %
15 – 20 %
20 – 30 %
30 – 40 %
40 – 50 %
50 – 60 %
60 – 70 %
70 – 80 %
80 – 93 %

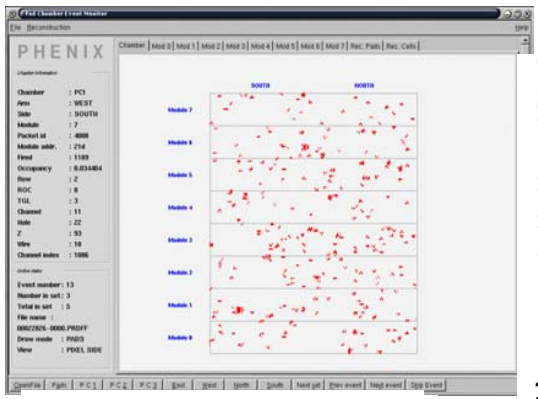




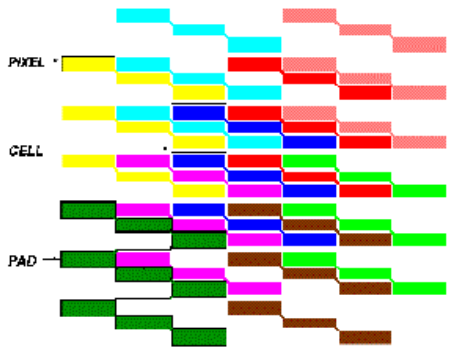
Central Tracking: Pad Chambers

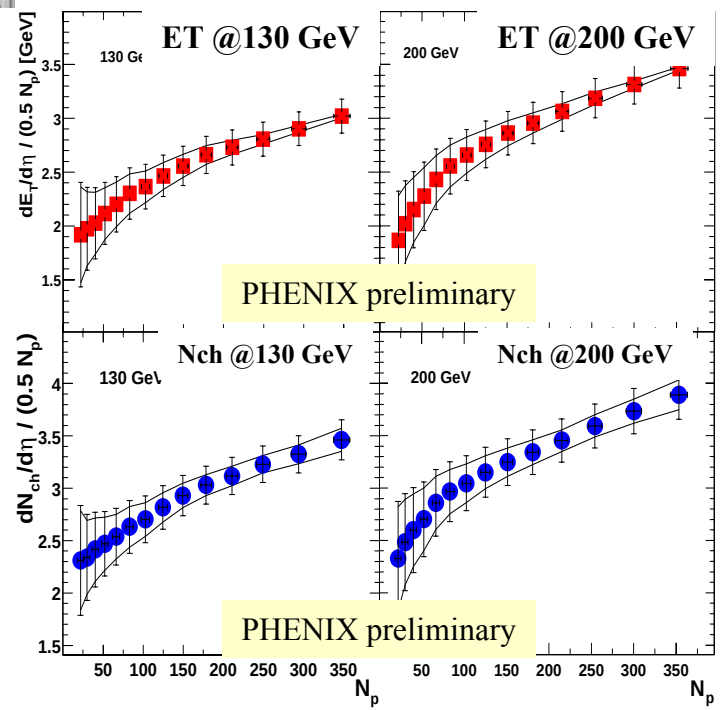
- Cathode wire chambers using fine granularity pixel pad readout
  - 2-D hit position, $\sigma_x = \sigma_y \sim O(\text{mm})$
  - 173k channels total, ~ 100 m^2 detector coverage
- Low-mass , rigid honeycomb/circuit board construction
- All signal digitization takes place on-board in detector active region. Solves interconnect problem.





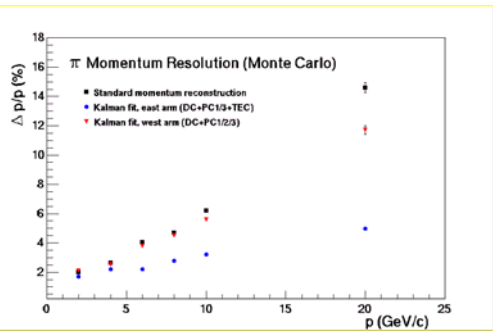
Pixel Pad Cathode Pattern



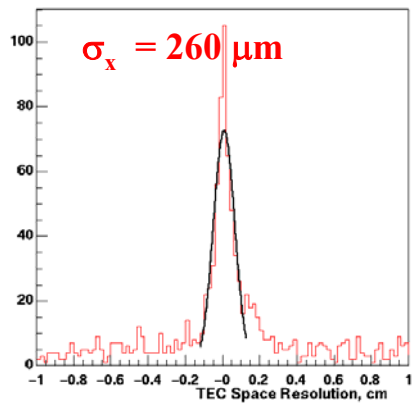


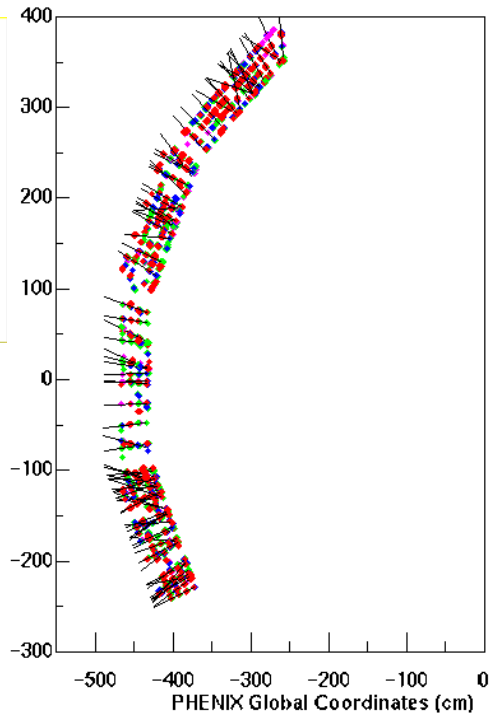
Central Tracking: Time Expansion Chamber

- 24 TEC Chambers arranged in 4, 6-Chamber sectors
- Used for tracking and PID (dE/dx,TR). σ_x = 260 μm
- dE/dx: e/π = 5% at 500 MeV/c (4 pls), e/π = 1.5% (6pls)
  Important for momentum resolution $p_T > 4.0$ GeV/c
- TR polypropylene fiber/foam radiator packs installed

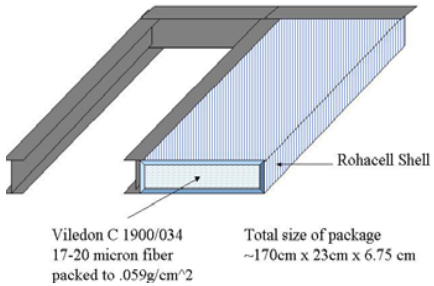


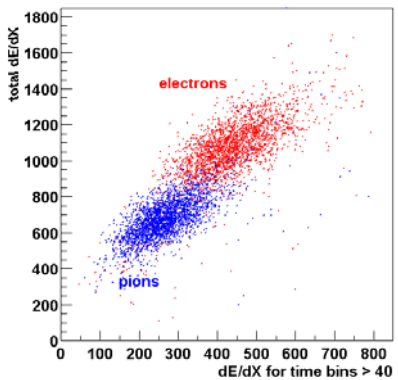
Momentum Resolution



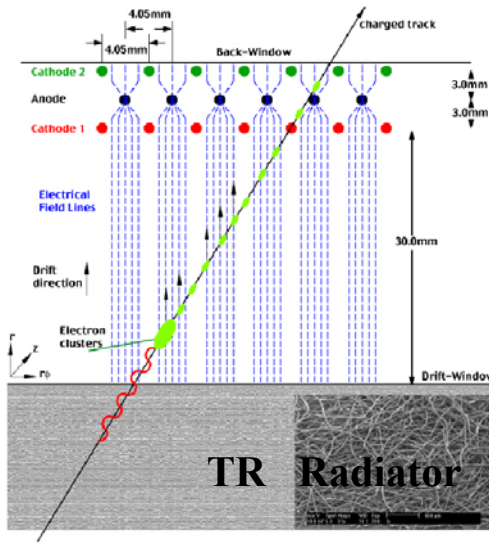


Tracks in TEC from Central Au-Au Collisions



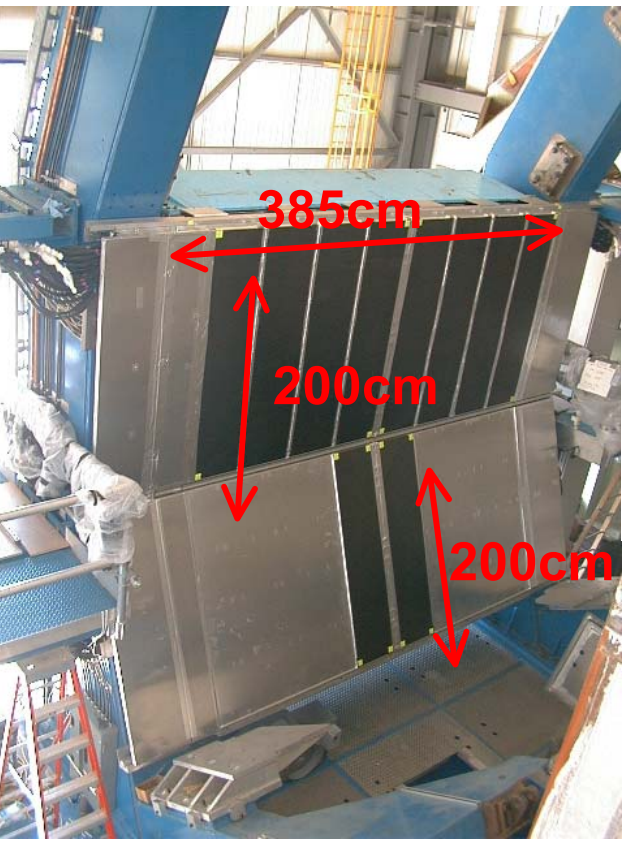


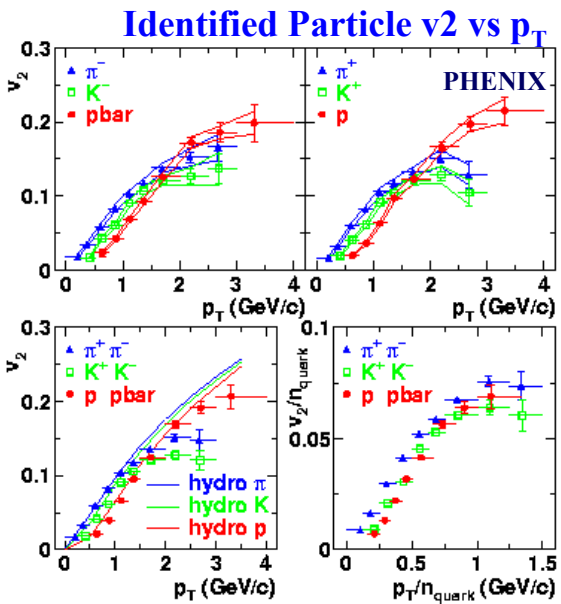
e/π Separation using TR & dE/dx

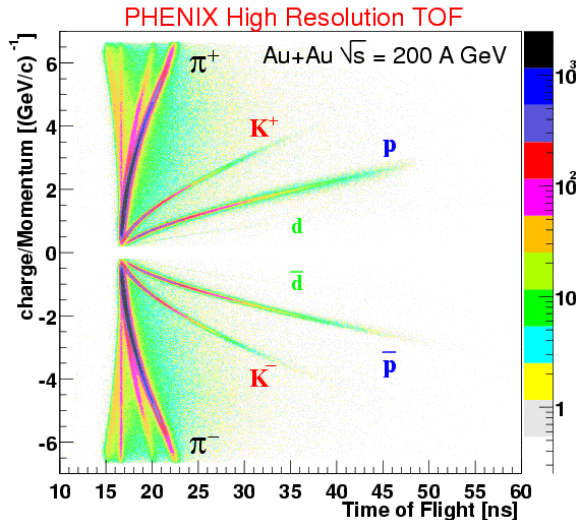


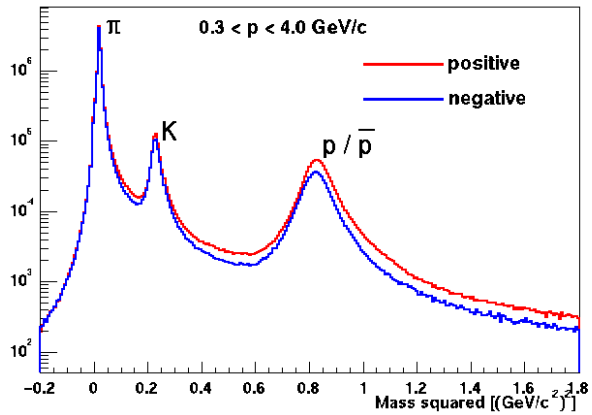
Particle ID Detectors: Time of Flight

- 1000 finely segmented slats readout w/ 2000 PMTs
- Combines with BBC timing for an overall time resolution of $\sigma_{TOF} < 96$ ps
- K/π separation <~ 2 GeV/c
- p/K separation <~ 4 GeV/c



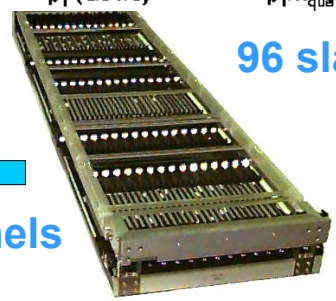






96 slats/panel

Mass ^{2} resolution

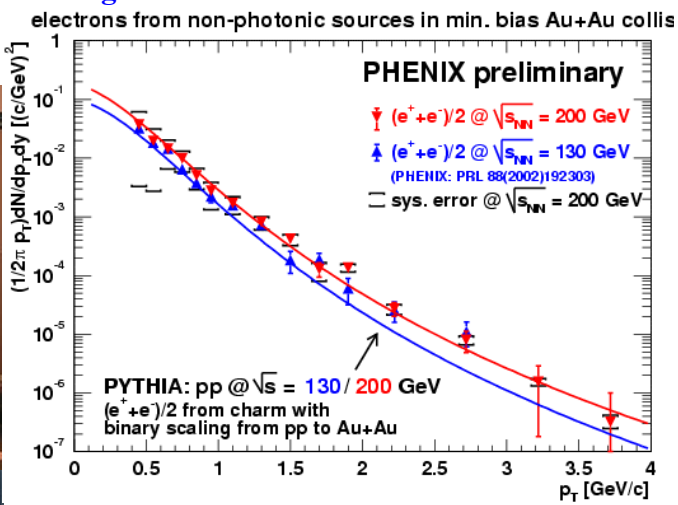


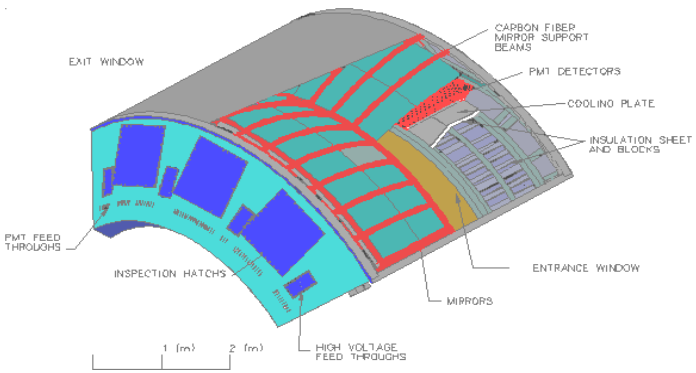
10 panels

Particle ID Detectors: RICH

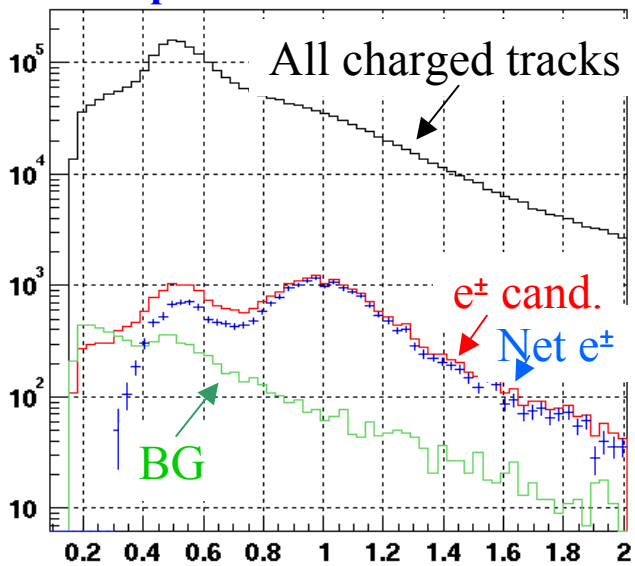
- Gas radiator CO_2, e/π separation for $p < 5$ GeV/c
- 5120 PMTs sensitive to single photoelectrons, $\sigma_t < 1$ ns
- Ring resolution ~1° in both Φ and η

Charm signal measured in PHENIX Central Arms



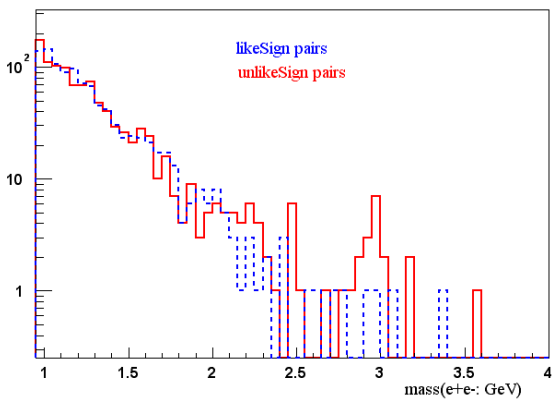


E/p ratio :RICH-EMCal



Energy/momentum (E/p)

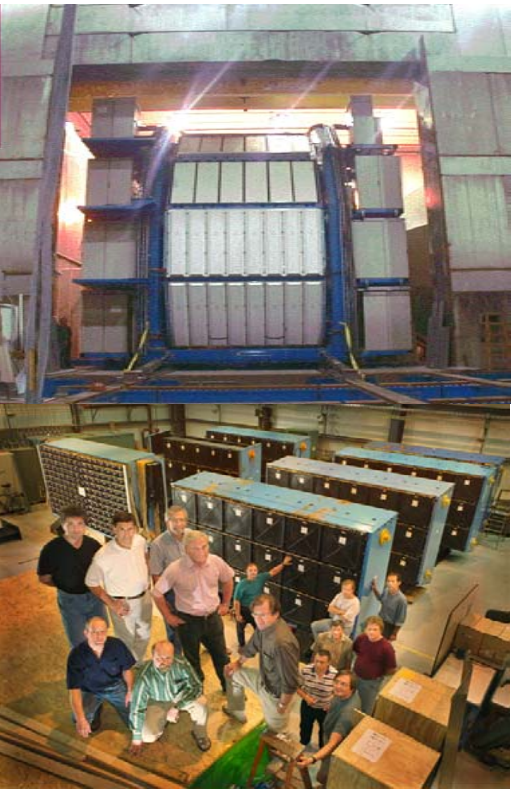
Online Data Reconstruction d Au



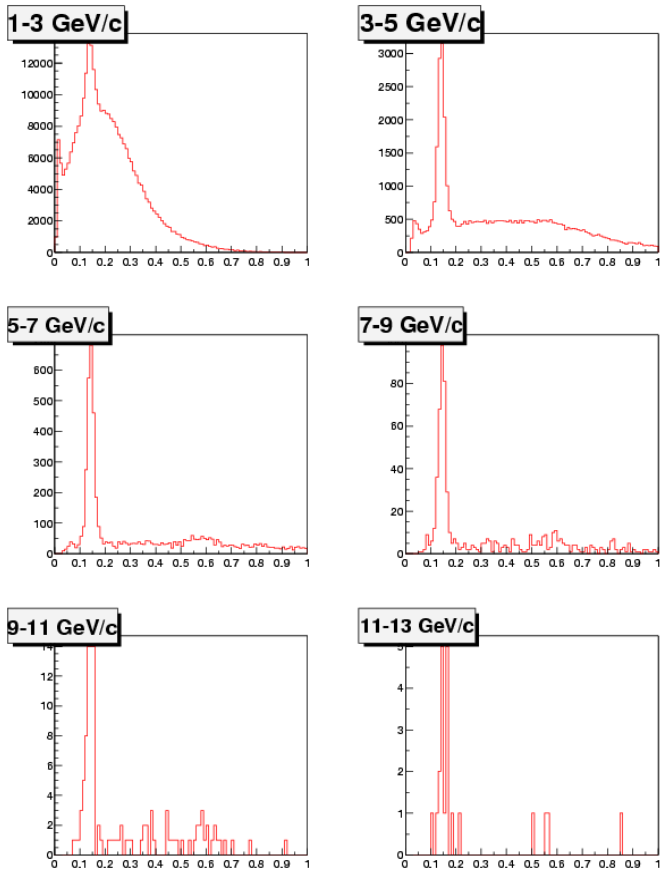
Particle ID Detectors: EM Calorimeter

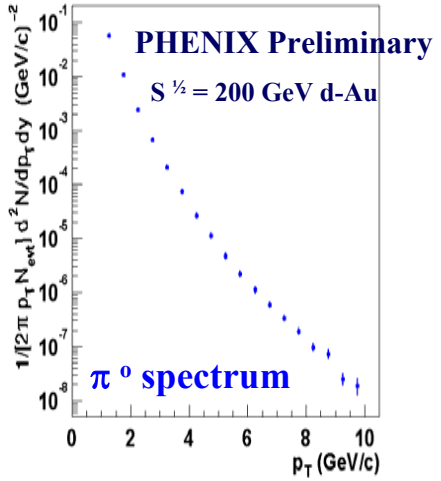
- 60 m^2 of calorimeter (6 Sectors Pb Scin, 2 Sectors PbGlass)
- Very Fine Segmentation .01 x .01 ($\Delta\Phi$ x $\Delta\eta$)
- Timing $\sigma_t \sim 340$ ps Pb Scin $\sigma_t \sim 600$ ps Pb Glass
- $\sigma_E = 10\%/\sqrt{E}+6.5\%$ Pb Scin, $\sigma_E = 8.5\%/\sqrt{E}+9.0\%$ Pb Glass

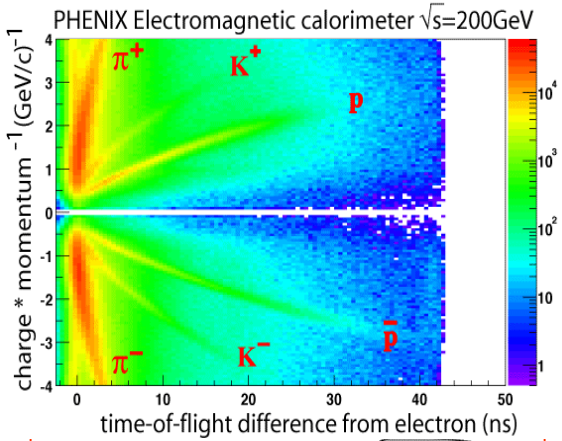
24,768 channels total, all PMTs

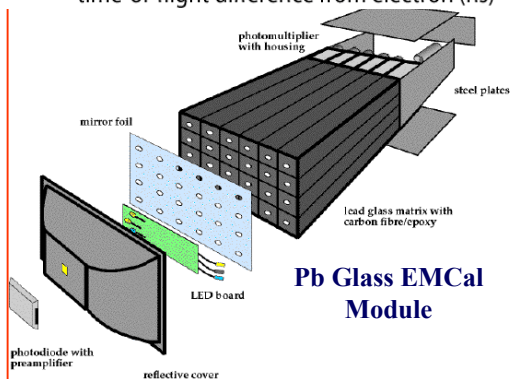


π^0 's from d Au events





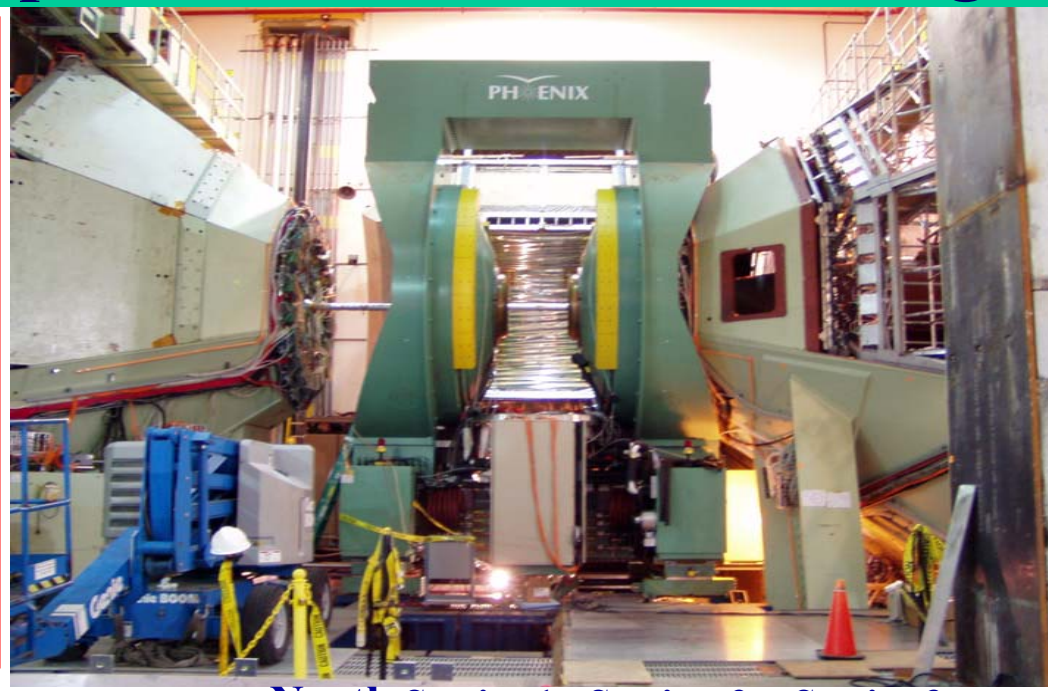




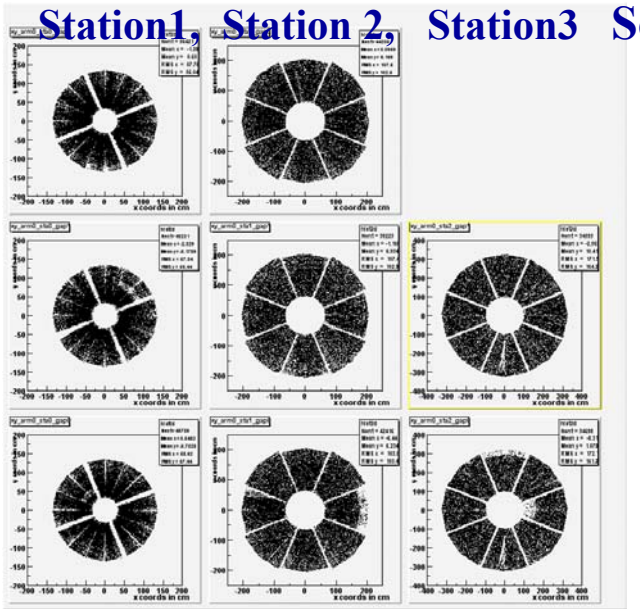
Pb Glass EMCal Module

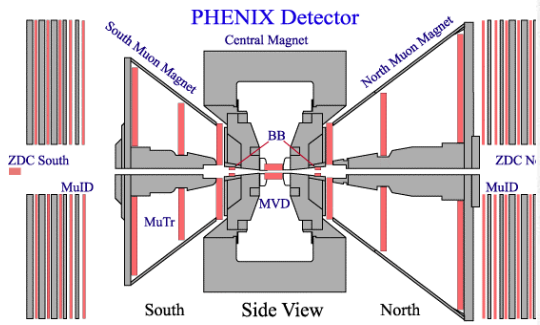
Forward Spectrometers: Muon Tracking

- First large cathode-strip chambers (CSC) used in an experiment (1 m x 2.5 m octant)
- Low mass honeycomb-printed circuit board and etched metalized-mylar design.
- Each CSC station has a pos. resolution of σ_x=100 μm
- ~20k elec. channels/ arm

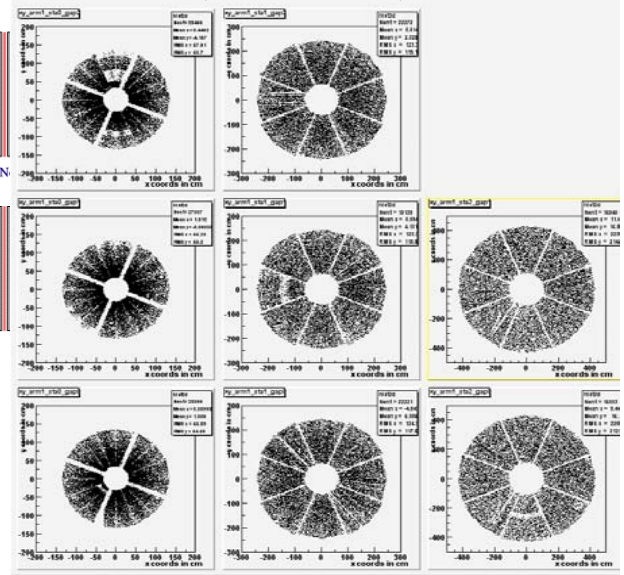


Station1, Station 2, Station3 South





North Station1, Station 2, Station3



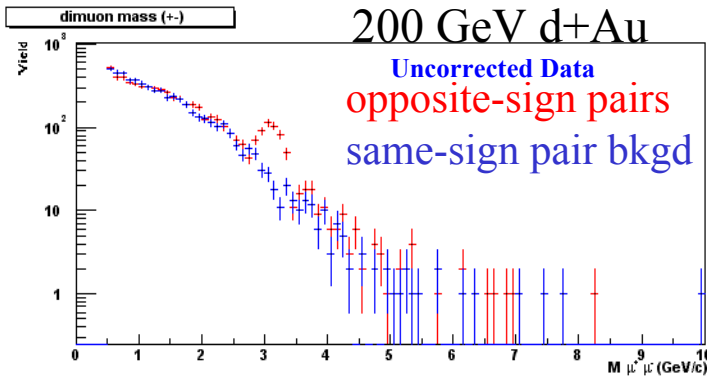
Particle ID Detectors: Muon ID

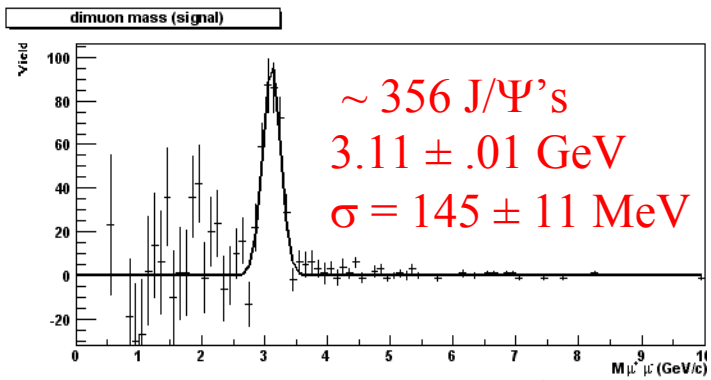
- 5 layers of steel absbr plate interleaved w/ 5 layers of Iarocci tubes (2x,2y 4plns/layer)
- Active cross section of each wall 10m x 10m
- Muon low energy cutoff off 1.9 GeV/c. Interact 99% of the π's

PHENIX Online Analysis

North

200 GeV d+Au

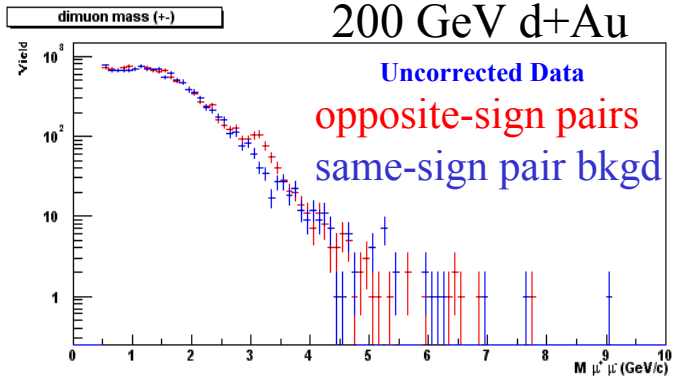


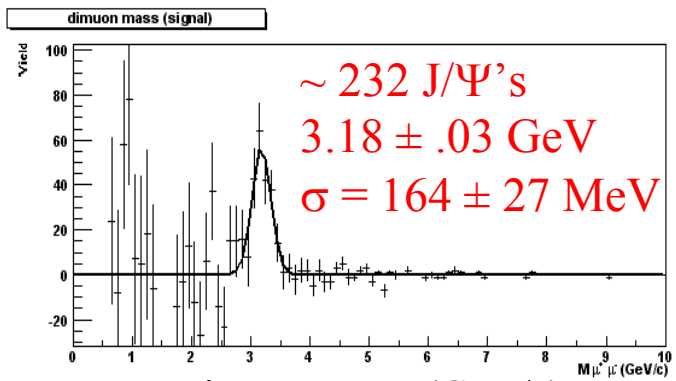


Dimuon Mass (GeV/c)

South

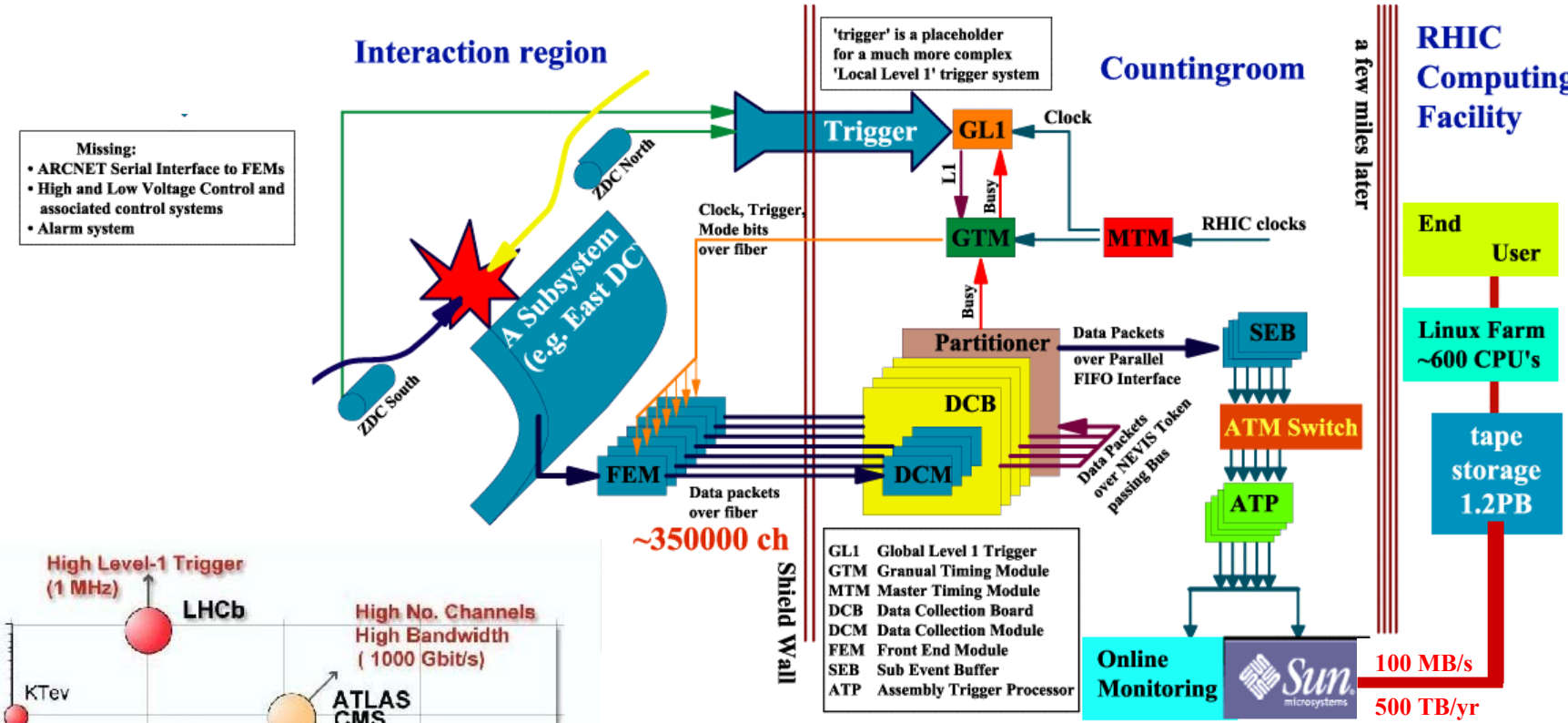
200 GeV d+Au

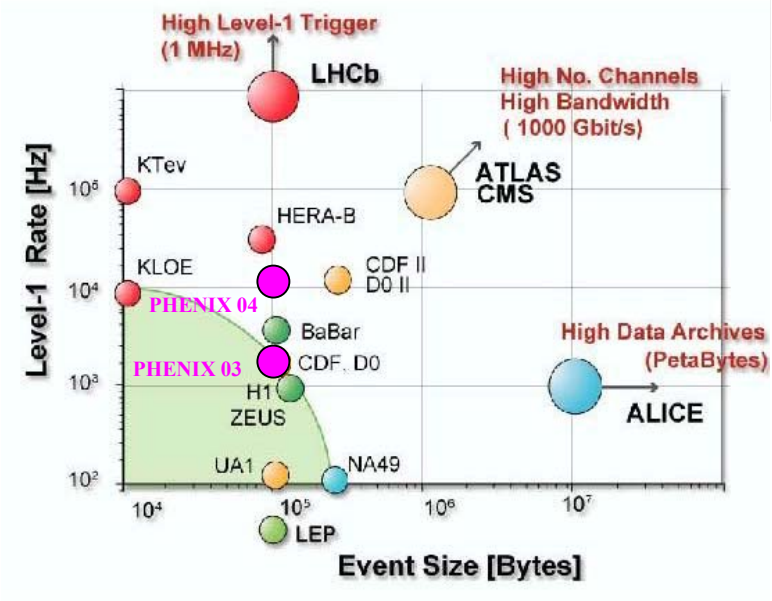




Dimuon Mass (GeV/c)

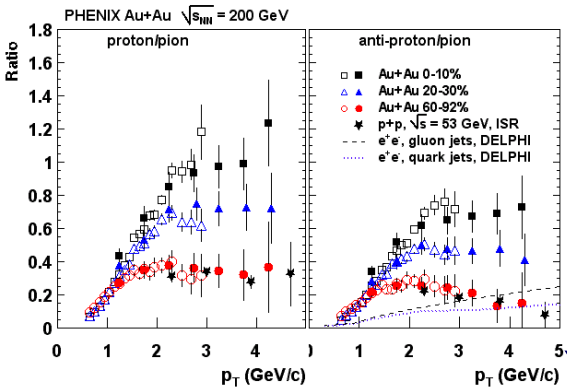
PHENIX DAQ and Trigger

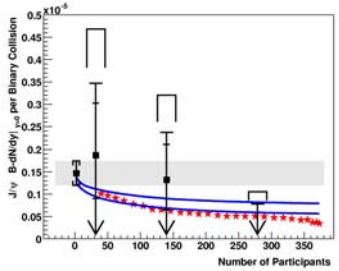


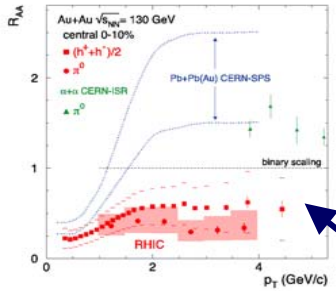


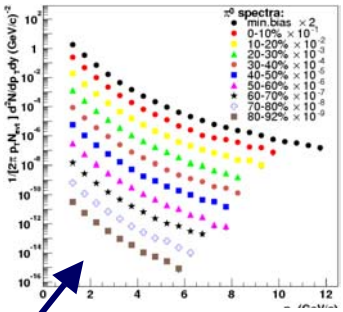
- Pipelined DAQ with multi-event buffering
- Two levels of triggering
  - Level1 Hardware (few μsec)
  - Level2 Processors (few msec)
- Fully partitioned system w/ 32 partitions
- Archive @ 100 MB/s, ~1kHZ event rate
- Events Built @ 2KHz (8 KHz for 2004)

A Variety of Physics Results

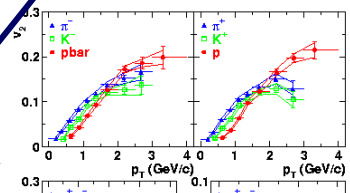


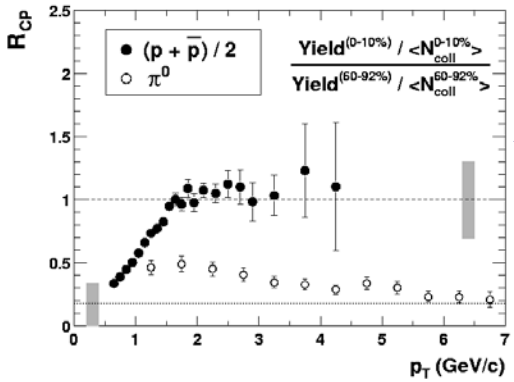


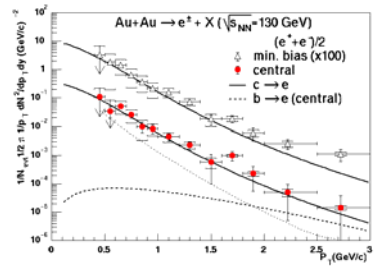


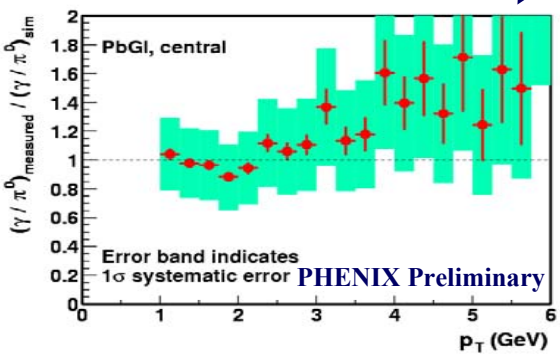


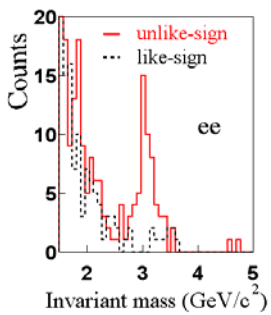
- J/Ψ production vs Centrality $\sqrt{s_{NN}}$ = 200 GeV AuAu
- High pT hadron suppression. $\sqrt{s_{NN}}$ = 130 GeV AuAu
- Spectra of πo to 12 GeV/c . $\sqrt{s_{NN}}$ = 200 GeV AuAu
- Particle composition $\sqrt{s_{NN}}$ = 200 GeV AuAu
- v2 of identified particles $\sqrt{s_{NN}}$ = 200 GeV AuAu
- Central/peripheral for proton/pions 200GeV AuAu
- Charm signal Central & MB $\sqrt{s_{NN}}$ = 130 GeV AuAu
- Limit of Direct photon production $\sqrt{s_{NN}}$ = 200 GeV AuAu
- J/Ψ production $\sqrt{s}$ = 200 GeV pp

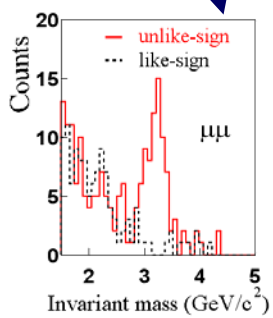


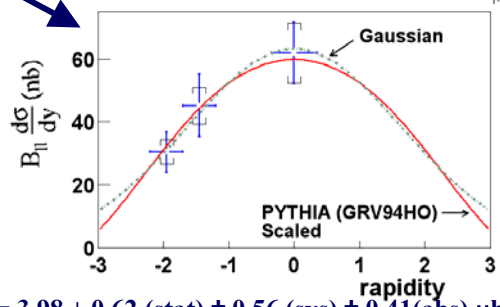








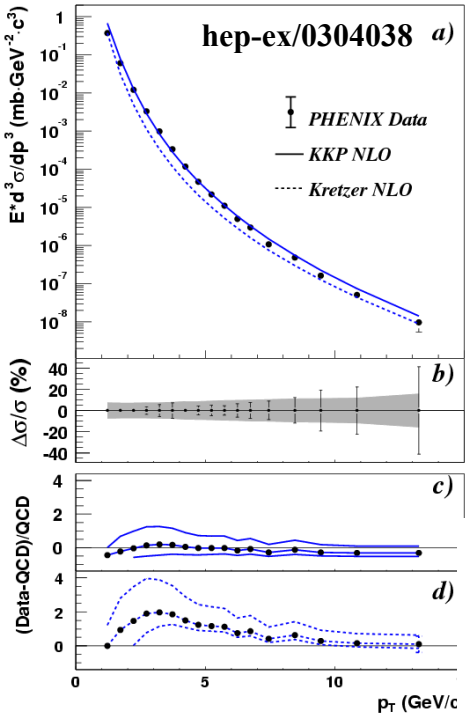




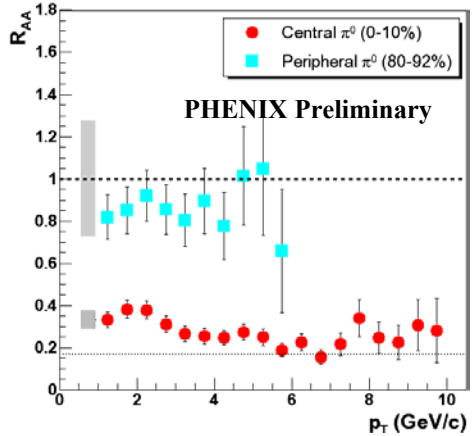
σ = 3.98 ± 0.62 (stat) ± 0.56 (sys) ± 0.41(abs) μb

New Results on High p_T Suppression

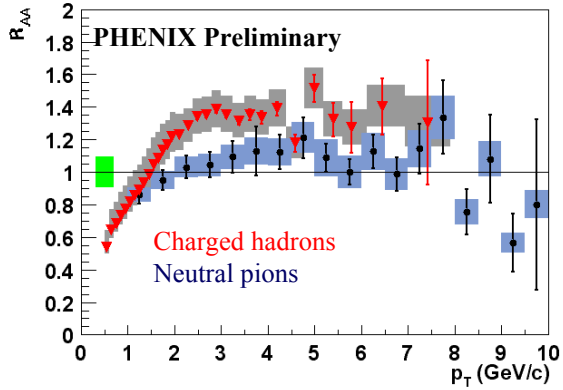
π^0 spectrum pp $s^{1/2}$= 200 GeV



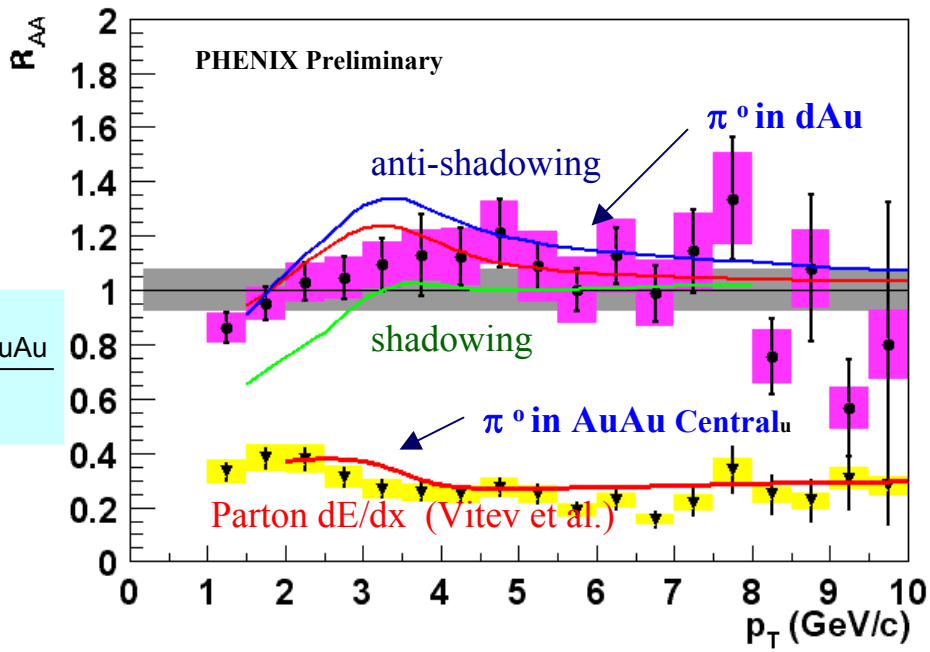
R_{AA} for π^0 AuAu $s_{NN}^{1/2}$= 200 GeV



R_{AA} dAu $s_{NN}^{1/2}$= 200 GeV



$$R_{AA} = \frac{\text{Yield}_{AuAu} / \langle N_{binary} \rangle_{AuAu}}{\text{Yield}_{pp}}$$



- Certain processes are observed to scale w/ # of collisions (N_{coll})
- PHENIX observes π^0 production in AuAu peripheral/N_{coll} to agree with π^0 production in pp
- All previous exper. at other $\sqrt{s_{NN}}$ observed π^0 production enhancement in central AuAu coll. due to Cronin effect.
- At RHIC PHENIX observes a suppression not enhancement in central collisions!

PHENIX

Summary

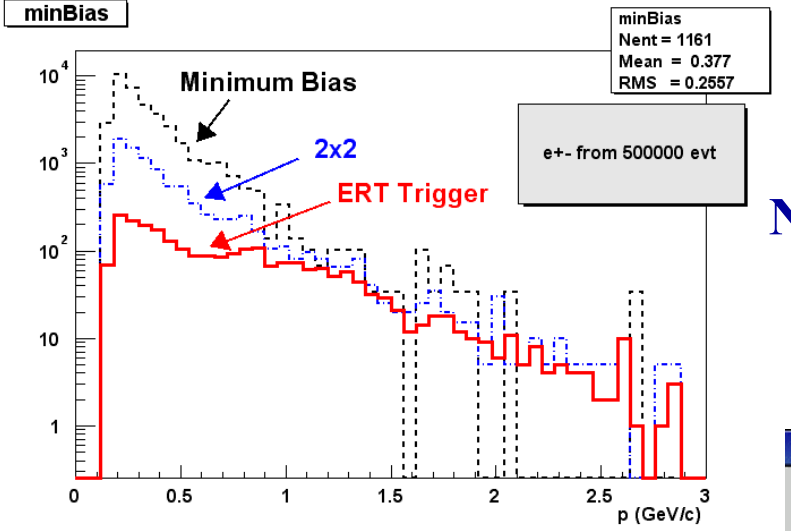
- RHIC and PHENIX are just finishing the third year of physics runs.
- PHENIX was operated in its completed configuration for the first time in the current run.
  - All 4 spectrometer arms complete. Commissioning of North Muon Arm for Run 3 was very rapid
  - The experiment is operating smoothly. All 16 detector subsystems OK.
- There has been significant physics production to date. The variety of physics results is remarkable.
  - AuAu, pp, dAu
- We are observing some very intriguing effects in our data and we are only a fraction of the way through our physics program.
- We are looking forward to a long AuAu run in 2004.

PHENIX

Backup

Full Complement of Level1 Triggers Now Running

New LVL1 Triggers for Emcal/Rich and MuID including commissioning of LL1 Boards



LVL1 Trigger Scalers

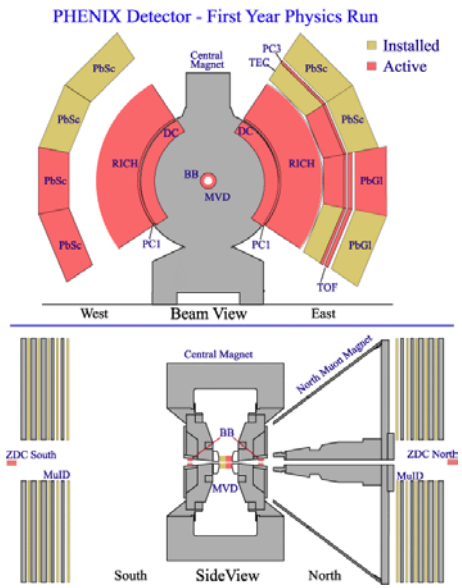
Scaler Monitor

Trig	Status	Raw	Live	Scaled	Raw Rate	Live Rate	Scaled Rate	Live Time	Live Time(RA)
Clock	Enabled	-1431425711	-585932078	19014	9.383 MHz	6.984 MHz	16.554 Hz	0.409	0.737
BBCLL1>=1	Enabled	2185406	1522644	380661	1.702 KHz	1.263 KHz	315.684 Hz	0.697	0.736
ZDCNS	Enabled	2189343	1531590	76579	1.728 KHz	1.285 KHz	64.237 Hz	0.700	0.737
ERT_2x2	Disabled	8994828	0	0	7.479 KHz	0.000 Hz	0.000 Hz	0.000	0.000
ERT_2x2&BBCLL1	Enabled	502730	352006	8585	395.028 Hz	295.808 Hz	7.244 Hz	0.700	0.744
ERT_Gamma1	Disabled	29320	0	0	22.409 Hz	0.000 Hz	0.000 Hz	0.000	0.000
ERT_Gamma1&BBCLL1	Enabled	11233	7900	7900	8.906 Hz	6.783 Hz	6.783 Hz	0.703	0.756
ERT_Gamma2	Enabled	16934	8206	8206	14.750 Hz	7.927 Hz	7.927 Hz	0.485	0.523
ERT_Gamma2&BBCLL1	Enabled	3026	2114	2114	2.814 Hz	2.357 Hz	2.357 Hz	0.699	0.816
ERT_Electron	Disabled	110477	0	0	89.363 Hz	0.000 Hz	0.000 Hz	0.000	0.000
ERT_Electron&BBCLL1	Enabled	29588	20440	20440	22.597 Hz	17.008 Hz	17.008 Hz	0.691	0.745
MUIDLL1_S_Vertical	Disabled	0	0	0	0.000 Hz	0.000 Hz	0.000 Hz	--	--
MUIDLL1_S_Vert&MUIDS_1D	Disabled	0	0	0	0.000 Hz	0.000 Hz	0.000 Hz	--	--
ERT_Phi&BBCLL1	Enabled	122626	85701	85701	94.515 Hz	69.805 Hz	69.805 Hz	0.699	0.731
ERT_Gamma3&BBCLL1	Enabled	60870	42061	42061	47.462 Hz	34.788 Hz	34.788 Hz	0.691	0.729
MUIDS_1D	Disabled	58528792	0	0	47.121 KHz	0.000 Hz	0.000 Hz	0.000	0.000
MUIDS_1D&BBCLL1	Enabled	71875	50077	50077	60.641 Hz	45.128 Hz	45.128 Hz	0.697	0.743
MUIDLL1_S_Vert&Hor	Disabled	0	0	0	0.000 Hz	0.000 Hz	0.000 Hz	--	--
MUIDS_1D1S*BBCLL1	Enabled	44858	31148	31148	39.630 Hz	29.665 Hz	29.665 Hz	0.694	0.749
MUIDN_1D	Disabled	27779267	0	0	21.561 KHz	0.000 Hz	0.000 Hz	0.000	0.000
MUIDN_1D&BBCLL1	Enabled	38625	26708	26708	30.259 Hz	22.167 Hz	22.167 Hz	0.691	0.733
BBCLL1_SyncErr	Disabled	81341	0	0	3.238 Hz	0.000 Hz	0.000 Hz	0.000	0.000
MUIDN_1D1S*BBCLL1	Enabled	21333	14627	14627	17.246 Hz	12.581 Hz	12.581 Hz	0.686	0.726
ZDCS|ZDCN	Enabled	16886879	11817521	39390	13.416 KHz	10.000 KHz	33.292 Hz	0.700	0.739
BBCLL1&ZDCNS	Disabled	483439	0	0	367.235 Hz	0.000 Hz	0.000 Hz	0.000	0.000
NTCNSwide	Enabled	10453210	7310459	235820	8.310 KHz	6.188 KHz	199.611 Hz	0.699	0.739
PPG(Pedestal)	Enabled	12139	8470	8470	9.964 Hz	7.476 Hz	7.476 Hz	0.698	0.753
PPG(Test Pulse)	Enabled	12138	8536	8536	9.918 Hz	7.334 Hz	7.334 Hz	0.703	0.731
PPG(Laser)	Enabled	12139	8530	8530	9.957 Hz	7.555 Hz	7.555 Hz	0.703	0.747
BBCLL1>=1(noVertexCut)	Enabled	7483172	5211739	13028	5.905 KHz	4.375 KHz	10.930 Hz	0.696	0.735

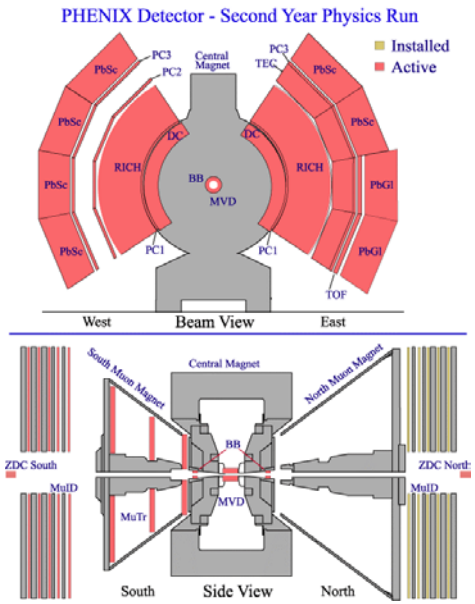
PHENIX: Run History

Run	Year	Species	$s^{1/2}$ [GeV]	∫Ldt	N_{tot}
01	2000	Au-Au	130	1 μb^{-1}	10M
02	2001/2002	Au-Au	200	24 μb^{-1}	170M
		p-p	200	0.15 pb^{-1}	3.7G
03	2002/2003	d-Au	200	2.74 nb^{-1}	5.5G
		p-p	200	ongoing	

2000



2001/2002



2002/2003