

# 加速器 と 実験装置

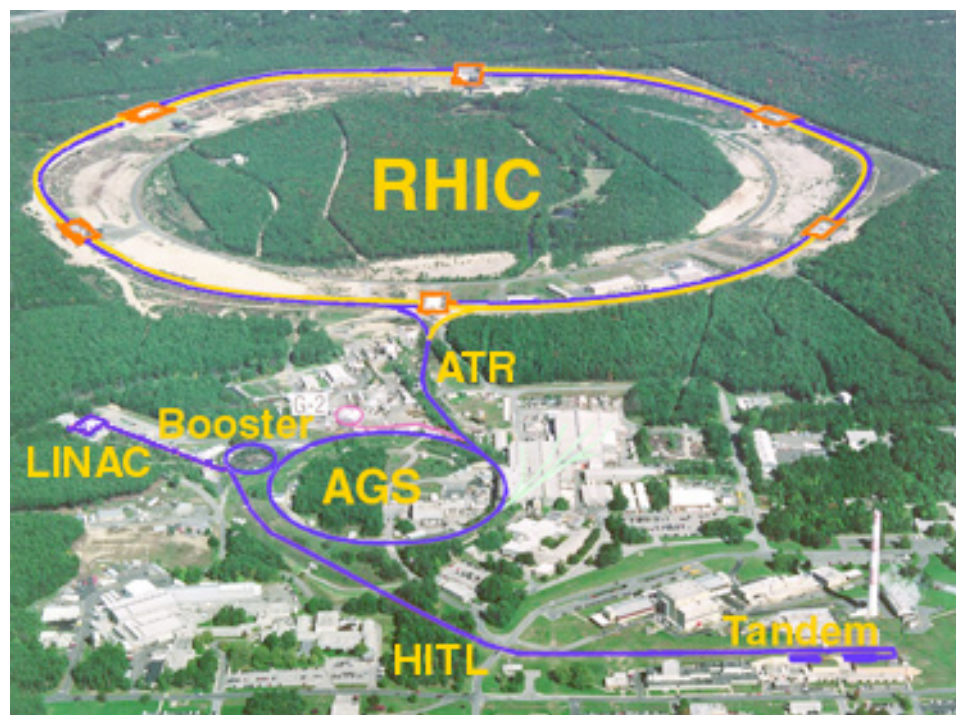
# Bevalac

- 今はもう無い
- Lawrence Berkeley Laboratory (LBL)
- Bevatron (反陽子の生成→ノーベル賞) + Hilac
- $E_{\max} = 2.1 \left( \frac{2Z}{A} \right) A \text{ GeV}$
- 1970年代中頃  
～1980年代の終わり
- 高エネルギー重イオン  
衝突実験の先駆け
  - 衝突のグローバルな様相
  - 基本的なアイデア
  - 測定方法



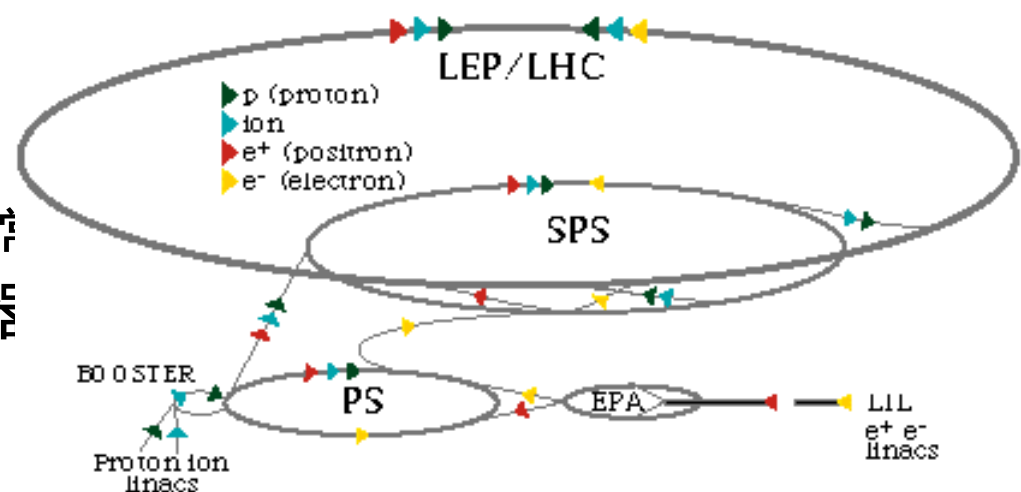
# AGS

- Brookhaven National Laboratory (BNL)
- 世界初の強収束（陽子）加速器 (三つのノーベル賞)
- $E_{\max} = 15 \left( \frac{2Z}{A} \right) A \text{ GeV}$
- 1986年～
- 主な結果
  - 大きなバリオン密度
  - ストレンジ粒子生成
  - フロー
- RHICの前段加速器
  - 同時に陽子等の実験プログラム



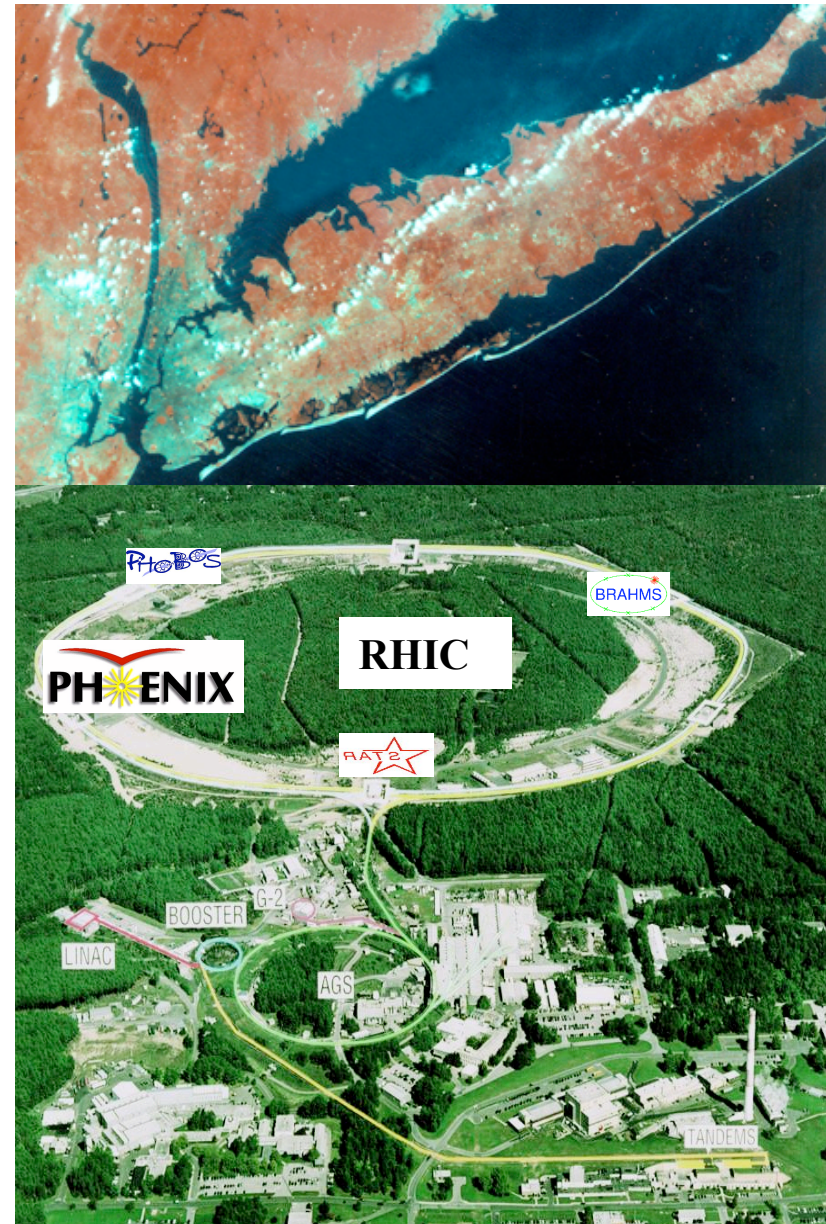
# SPS

- CERN - European Organization for Nuclear Research
- 固定標的陽子加速器  
+ 陽子・反陽子衝突型加速器
- W、Z の発見
- $E_{\max} = 400 \left( \frac{2Z}{A} \right) A \text{ GeV}$
- 1986年～
- QGPを示唆する結果
  - J/ψ 収量の異常
  - 粒子収量とスペクトル
  - 低質量レプトン対収量異常
- 将来、LHCの前段加速器

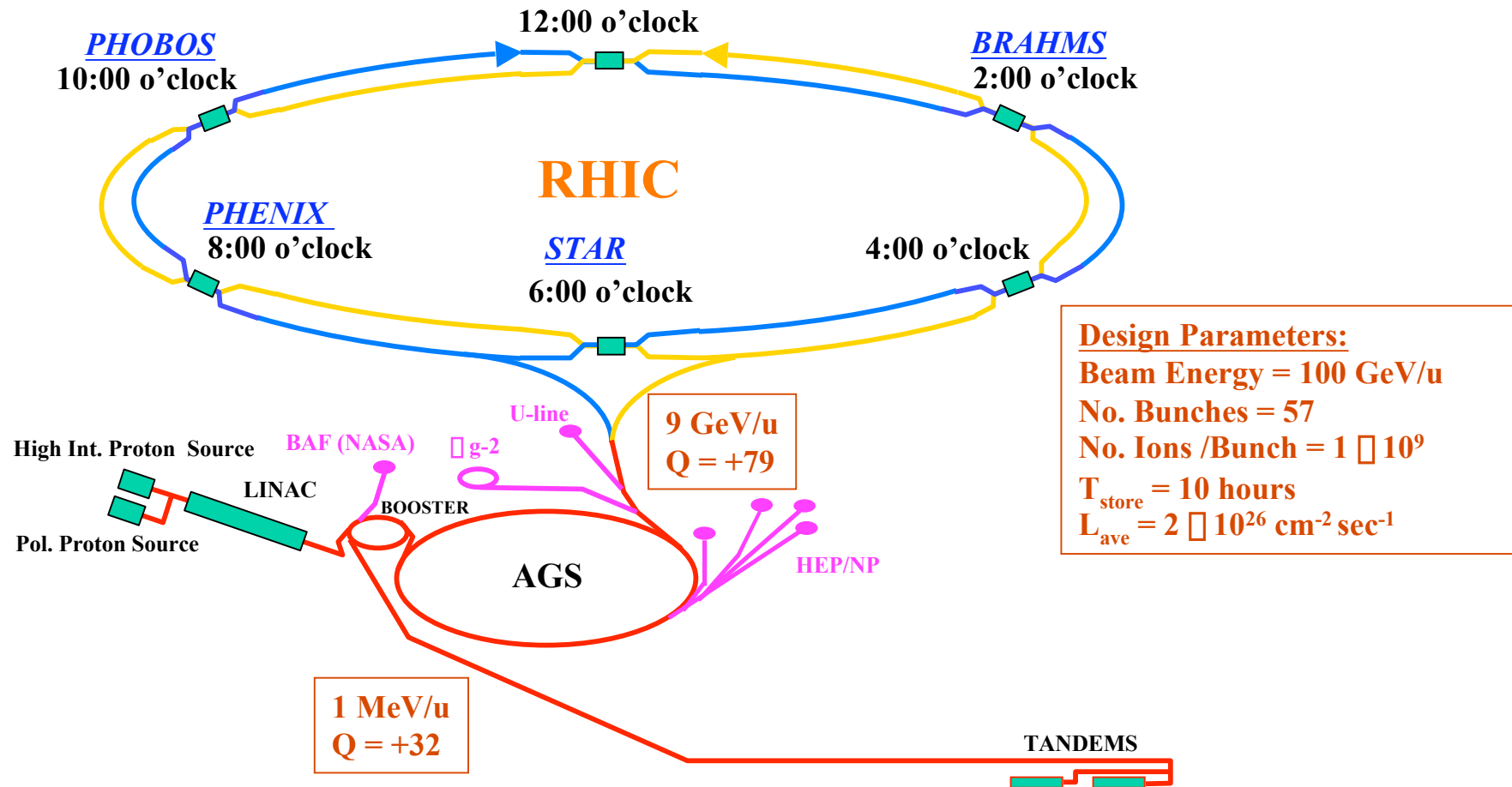


# The Relativistic Heavy Ion Collider at BNL

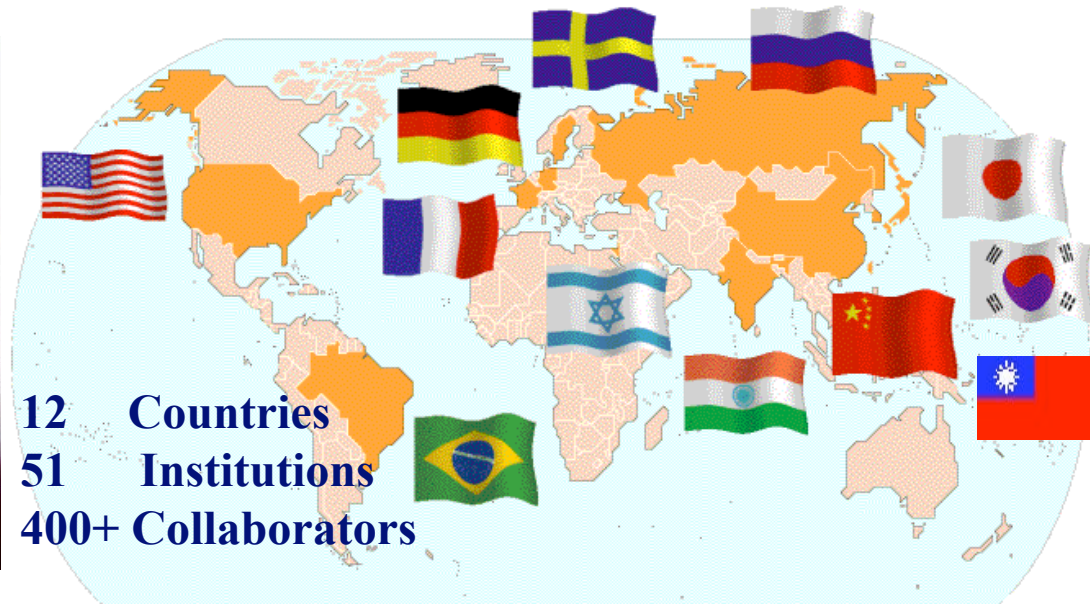
- **Two independent rings 3.83 k in circumference**
  - 120 bunches/ring
  - 106 ns crossing time
- **Maximum Energy**
  - $s^- = 500 \text{ GeV p-p}$
  - $s^- = 200 \text{ GeV Au-Au}$   
per N-N collision
- **Design Luminosity**
  - Au-Au  $2 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$
  - p - p  $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$  ( polarized)
- **Capable of colliding any nuclear species on any other nuclear species**



# the lay of the land



# The PHENIX Collaboration



**12 Countries**  
**51 Institutions**  
**400+ Collaborators**

Map No. 3003 Rev. 2 UNITED NATIONS August 1999

Department of Public Information Geographic Section

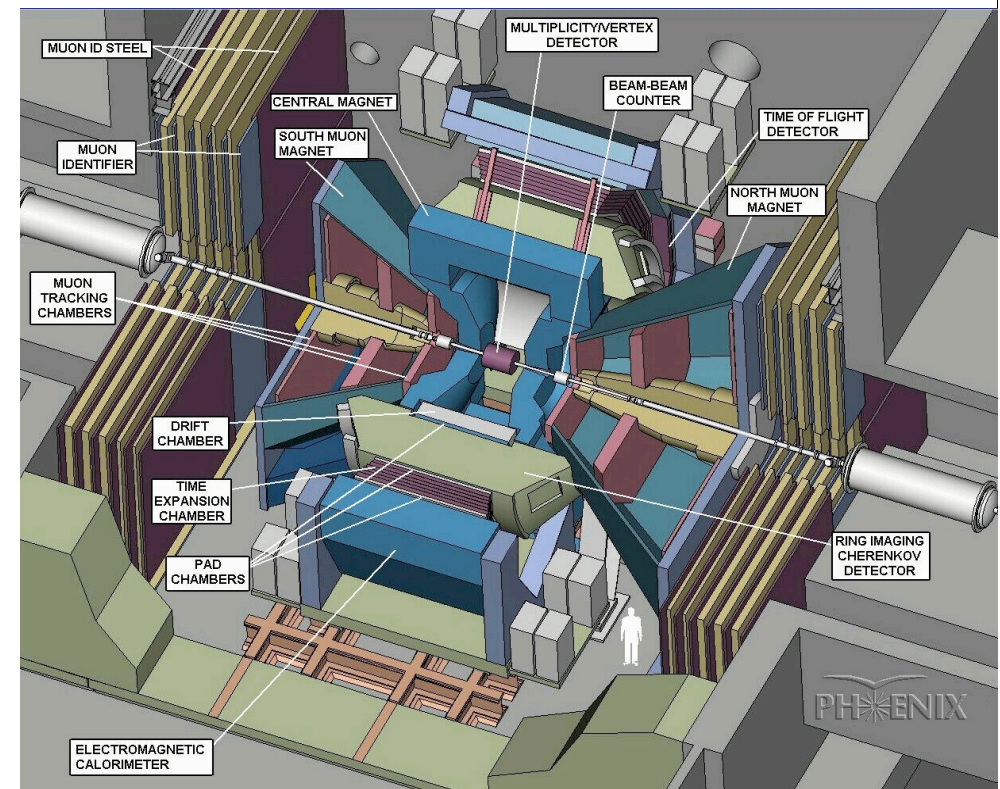
- University of São Paulo, São Paulo, Brazil
- Academia Sinica, Taipei 11529, China
- China Institute of Atomic Energy (CIAE), Beijing, P. R. China
- Laboratoire de Physique Corpusculaire (LPC), Université de Clermont-Ferrand, 63170 Aubiere, Clermont-Ferrand, France
- Dapnia, CEA Saclay, Bat. 703, F-91191, Gif-sur-Yvette, France
- IPN-Orsay, Université Paris Sud, CNRS-IN2P3, BP1, F-91406, Orsay, France
- LPNHE-Palaiseau, Ecole Polytechnique, CNRS-IN2P3, Route de Saclay, F-91128, Palaiseau, France
- SUBATECH, Ecole des Mines at Nantes, F-44307 Nantes, France
- University of Muenster, Muenster, Germany
- Banaras Hindu University, Banaras, India
- Bhabha Atomic Research Centre (BARC), Bombay, India
- Weizmann Institute, Rehovot, Israel
- Center for Nuclear Study (CNS-Tokyo), University of Tokyo, Tanashi, Tokyo 188, Japan
- Hiroshima University, Higashi-Hiroshima 739, Japan
- KEK, Institute for High Energy Physics, Tsukuba, Japan
- Kyoto University, Kyoto, Japan
- Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
- RIKEN, Institute for Physical and Chemical Research, Hirosawa, Wako, Japan
- University of Tokyo, Bunkyo-ku, Tokyo 113, Japan
- Tokyo Institute of Technology, Ohokayama, Meguro, Tokyo, Japan
- University of Tsukuba, Tsukuba, Japan
- Waseda University, Tokyo, Japan

- Cyclotron Application Laboratory, KAERI, Seoul, South Korea
- Kangnung National University, Kangnung 210-702, South Korea
- Korea University, Seoul, 136-701, Korea
- Myong Ji University, Yongin City 449-728, Korea
- System Electronics Laboratory, Seoul National University, Seoul, South Korea
- Yonsei University, Seoul 120-749, KOREA
- Institute of High Energy Physics (IHEP-Protvino or Serpukhov), Protovino, Russia
- Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
- Kurchatov Institute, Moscow, Russia
- PNPI: St. Petersburg Nuclear Physics Institute, Gatchina, Leningrad, Russia
- Lund University, Lund, Sweden
- Ablene Christian University, Abilene, Texas, USA
- Brookhaven National Laboratory (BNL), Upton, NY 11973
- University of California - Riverside (UCR), Riverside, CA 92521, USA
- Columbia University, Nevis Laboratories, Irvington, NY 10533, USA
- Florida State University (FSU), Tallahassee, FL 32306, USA
- Georgia State University (GSU), Atlanta, GA, 30303, USA
- Iowa State University (ISU) and Ames Laboratory, Ames, IA 50011, USA
- LANL: Los Alamos National Laboratory, Los Alamos, NM 87545, USA
- LLNL: Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
- University of New Mexico, Albuquerque, New Mexico, USA
- New Mexico State University, Las Cruces, New Mexico, USA
- Department of Chemistry, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA

# Welcome to PHENIX

## Tale of the Tape:

- Begun Operation June 2000
- 12 Detector subsystems
- 4 Spectrometer arms
- Total weigh = 3000T
- 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

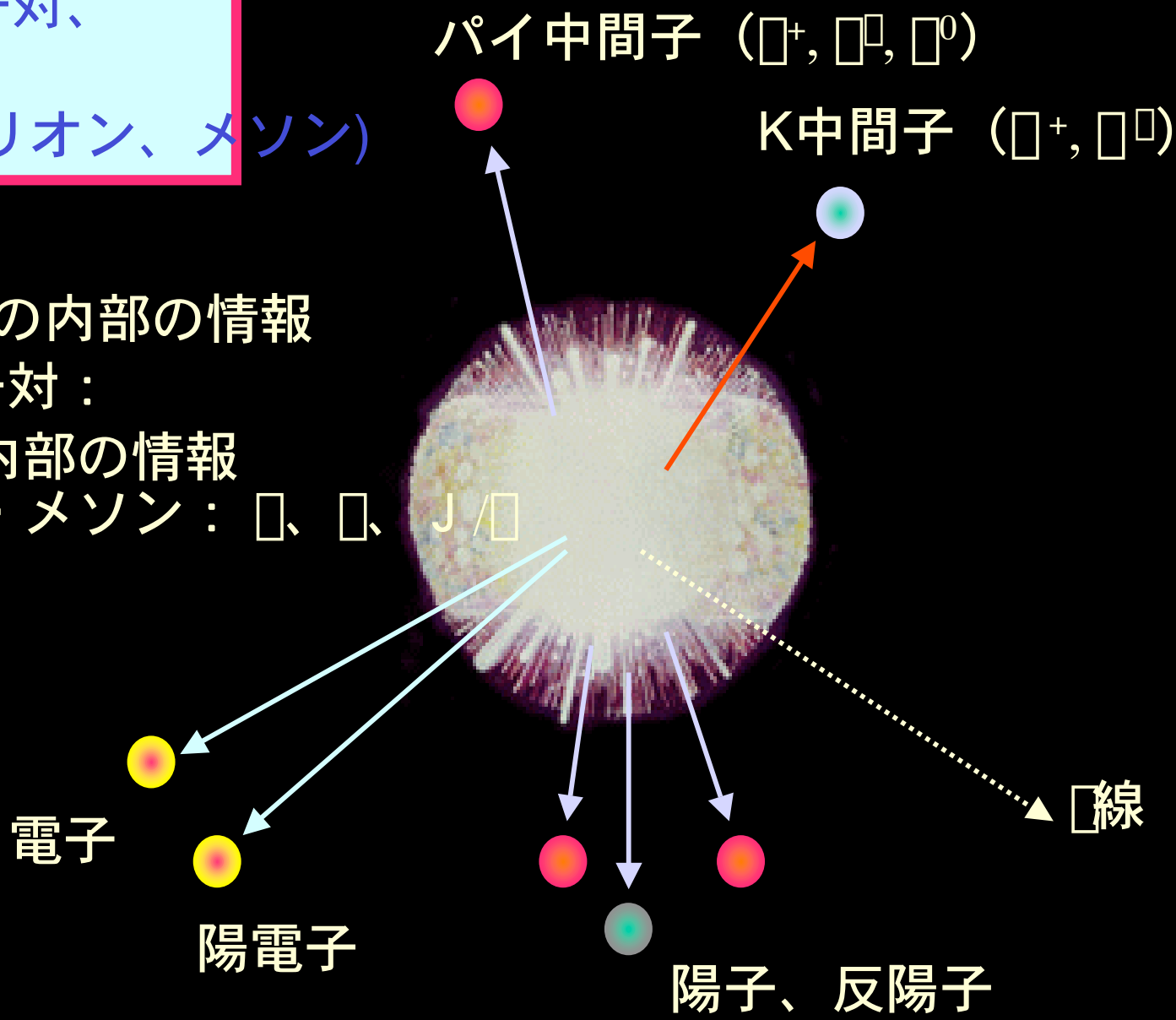
The Configuration:

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



- 電子・陽電子対、
- 光子 (γ線)、
- ハドロン(バリオン、メソン)

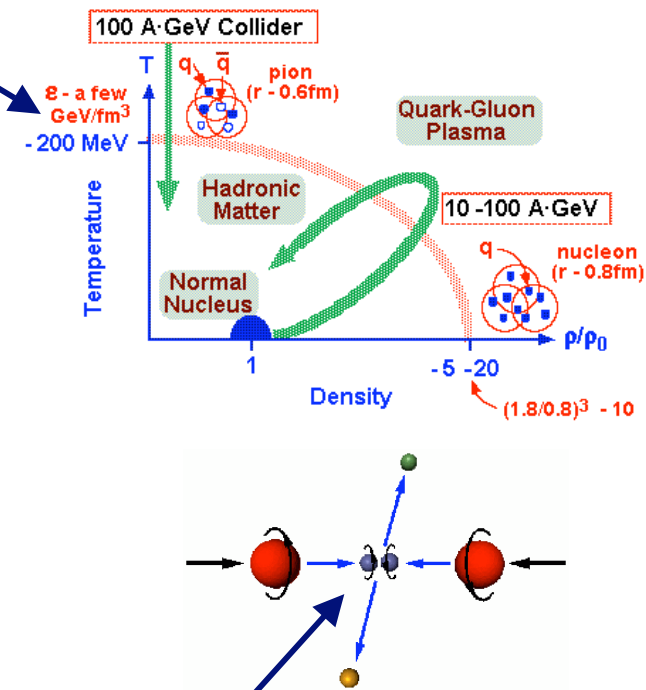
- γ線 : 火の玉の内部の情報
- 電子・陽電子対 :
  - 火の玉の内部の情報
  - ベクター・メソン : π、K、J/ψ



# The Physics of PHENIX

## QGP:

- Temperature and Energy Density
  - $dN/dy$ ,  $E_T$ , Single particle spectra
- Jet Quenching
  - High  $p_T$  jets using leading  $\pi^0$ ,  $\pi^\pm$
- Space–Time Evolution
  - HBT( $\pi\pi$ , KK,pp), Flow
  - Event by Event Fluctuations
- Deconfinement
  - $J/\psi$ ,  $\psi'$ ,  $e+e^-$ ,  $\pi+\pi^-$ ,  $\pi\pi$   $\pi\pi$
- Chiral Symmetry Restoration
  - $\pi\pi$   $e+e^-$ ,  $K+K^-$ ,  $\rho,\omega,\phi$  width/shift
  - DCC's  $\pi^0/\pi^\pm$
- Heavy Quark Production
  - $K/\psi$ ,  $\psi$ ,  $J/\psi$ ,  $\psi'$ ,  $\psi$ , D, B mesons
- Thermal Radiation
  - $\gamma$   $\pi\pi\pi$   $e+e^-$ ,  $\pi+\pi^-$

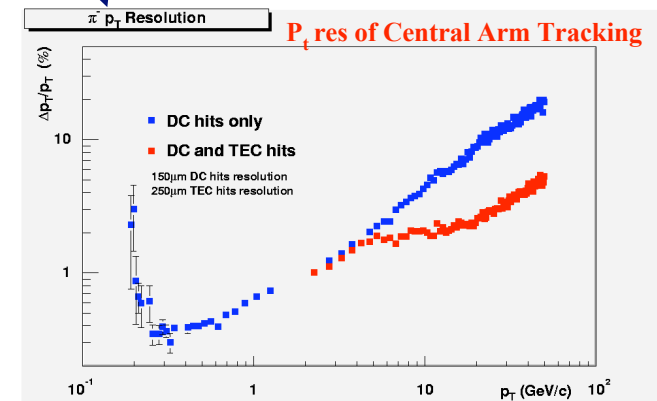
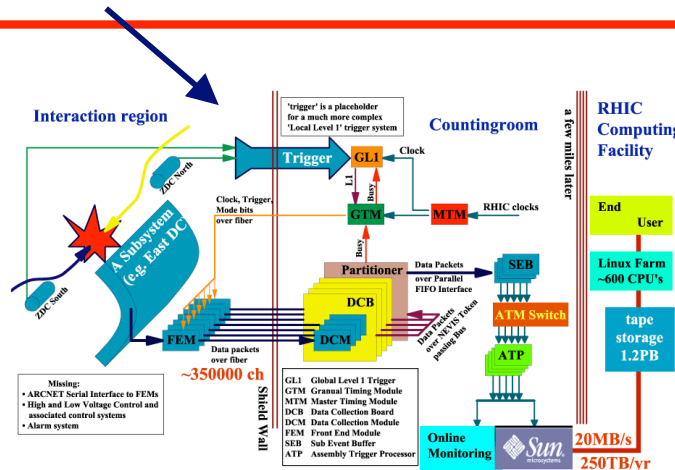
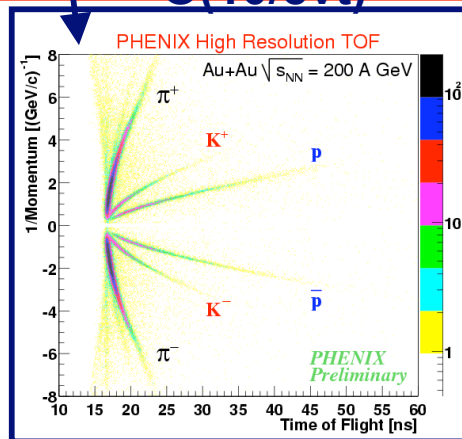
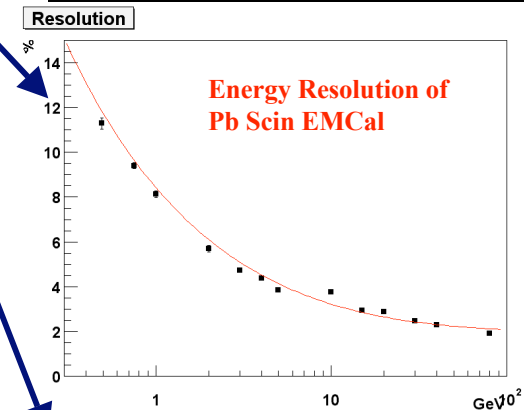
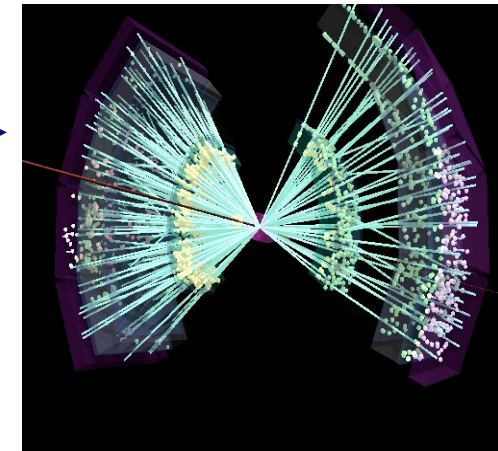


## Nucleon Spin:

- Gluon spin:  $\Delta G$ 
  - Direct  $\Delta$  high  $p_T$   $\Delta$ 's
- Sea quark spin:  $\Delta u, \Delta d$ 
  - $W^+/W^-$  production
  - Drell-Yan Polarization

# Challenges for the Detector Design

- High Particle Multiplicity/Event ( $dN_c/dy \approx 1000$ )
- Maintain performance over large dynamic range in E and  $p_t$  (300 MeV – 50 GeV)
- Significant particle ID rejections  
 $e/\pi = 10^{-4}$ ,  $\pi/\pi = 10^{-4}$ ,  $\pi/K/p = 10^{-3}$
- DAQ/Trigger operates in varying environments
  - Event rate O(10 kHz), Particle mult. O(1000/evt)
  - Event rate O(1 MHz), Particle mult. O(10/evt)



# The Detector's Design Strategy

- **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**

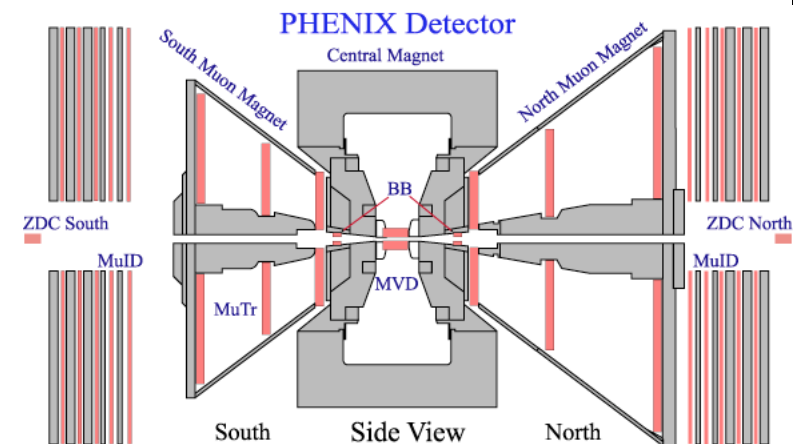
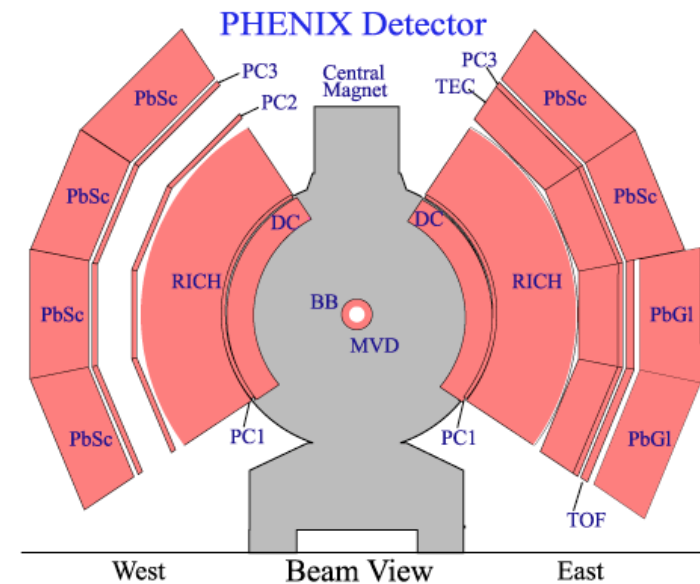
**Pb Glass**

## Event Characterization:

**Multiplicity Vertex Detector (Si Strip, Pad)**

**Beam-Beam Counter**

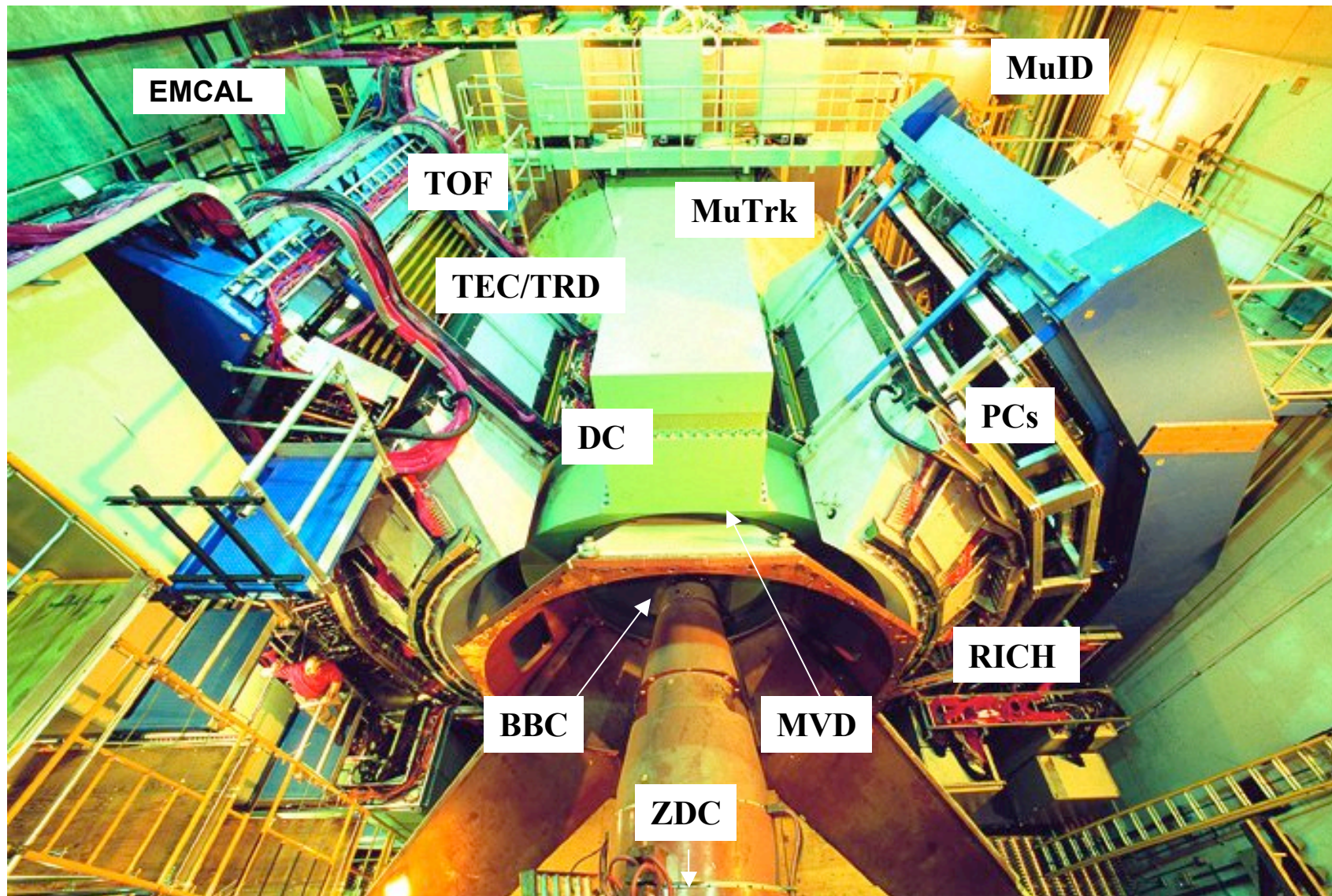
**Zero Degree Calorimeter**



# Some Unique PHENIX Technologies

- Large Area Cathode Strip Chamber with 100  $\mu\text{m}$  position resolution
- Fine-segmented EMCal (0.01  $\times$ , 0.01  $\times$ ) with  $\tau_t < 0.5$  ns
- Time Expansion Chamber that combines tracking, dE/dx and TRD
- Drift Chamber configured as focusing  $\gamma$ -jet chamber
- Ring Imaging Cerenkov Counter readout with 5000+ PMTs
- Low mass, non-projective pixel-pad wire chambers covering  $\sim 100$  m<sup>2</sup>
- Time of Flight system with  $\tau_t < 100$  ps
- Fully data-pipelined front-end electronics
- All data, timing, control and serial communication between detector and counting house is via optical link.

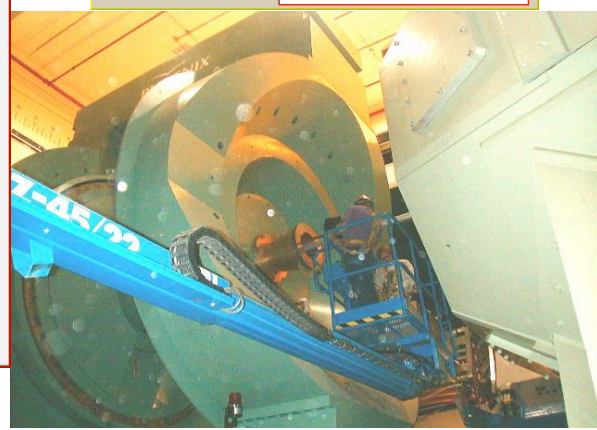
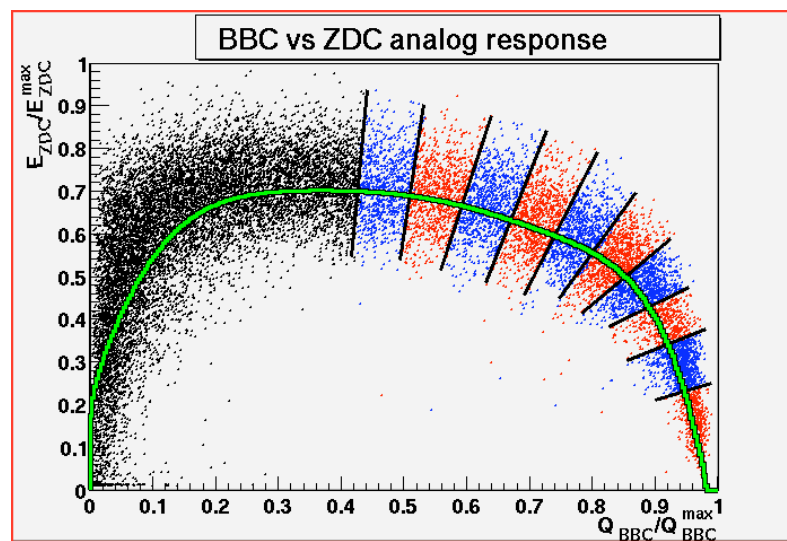
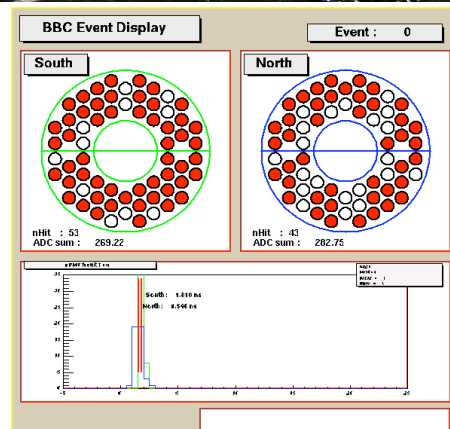
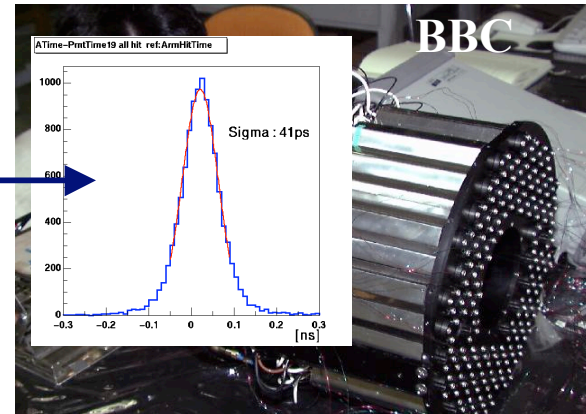
# A Crowded Experimental Hall



# Event Characterization Detectors

## Beam-Beam Counter and Zero Degree Calorimeter

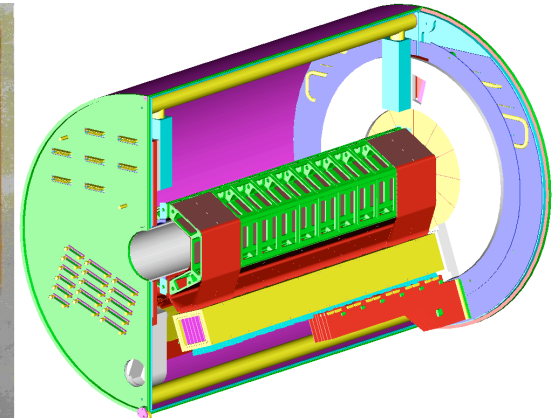
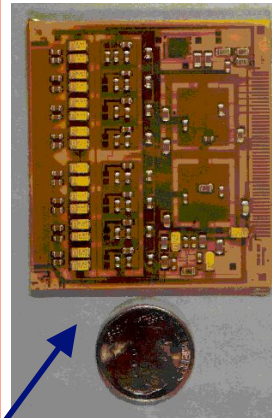
- BBC is 2 arrays of 64 PMTs with quartz radiators
  - Provides T0 for PHENIX.  $\sigma_t = 41$  ps
- ZDC is Cu-W calorimeter with fiber readout.
  - Common centrality measure for all 4 RHIC experiments
- Combined they provide the PHENIX LVL1 centrality trigger



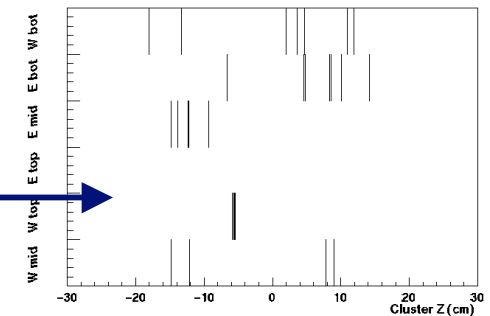
# Event Characterization Detectors

## Multiplicity Vertex Detector

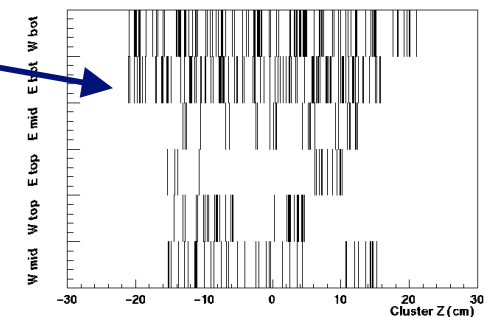
- Two concentric barrels of 300  $\mu$ m Si strips
- Two endplates of Si pads
- Total coverage of  $-2.5 < \eta < +2.5$
- 28,672 Si strips, 6048 Si pads
- Determines event vertex and measures particle multiplicity/event
- Electronics is bare die on ceramic Multi-Chip Module



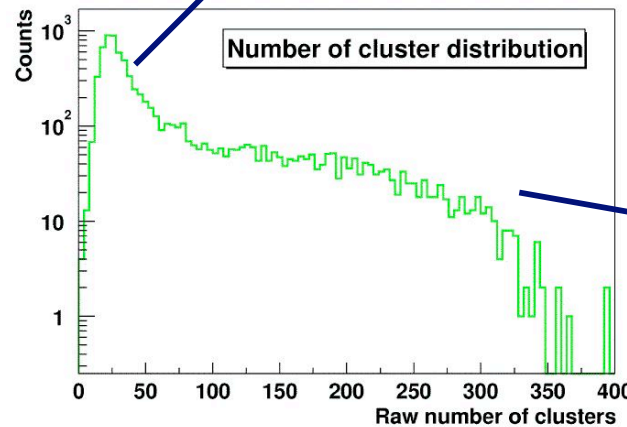
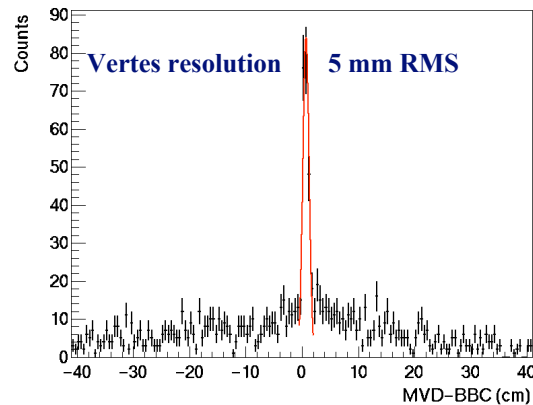
MVD inner barrel cluster position for one event



MVD inner barrel cluster position for one event



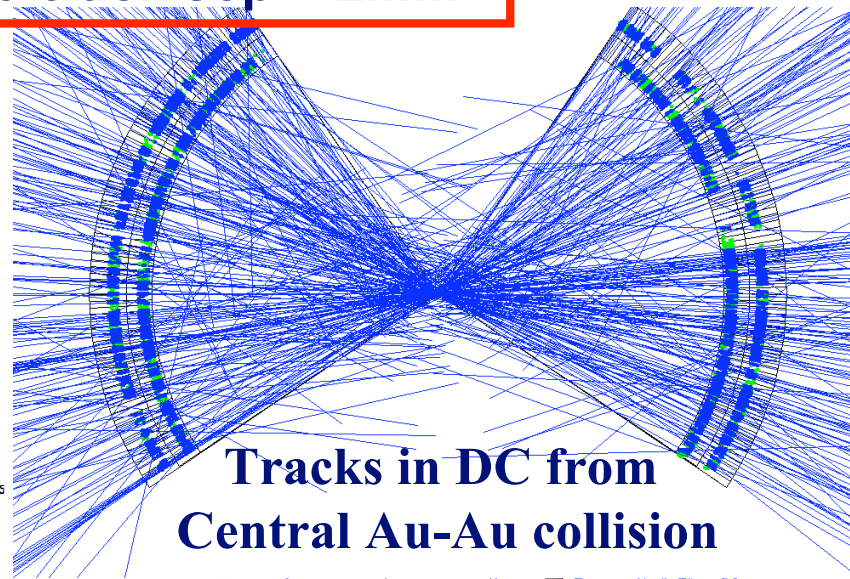
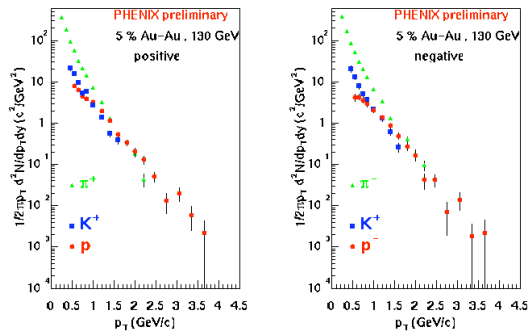
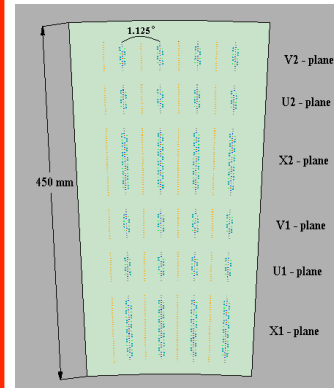
Difference between MVD and BBC vertex



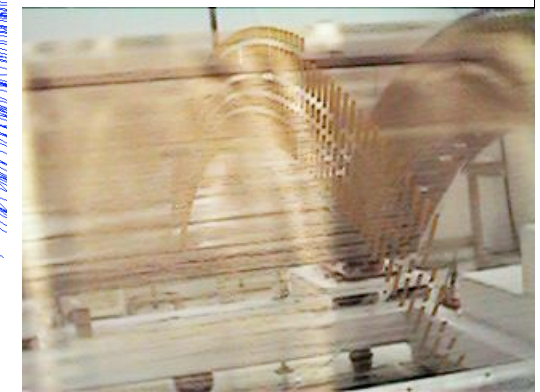
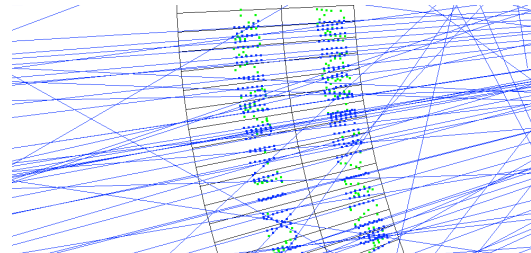


# Tracking Detectors: Drift Chamber

- Jet -chamber anode/cathode structure modified for HI high multiplicity
- Joint Russia/US design & construction
- All Titanium frame
- $\Delta x = 120 \mu\text{m}$  , two-track sep = 2mm



Tracks in DC from Central Au-Au collision

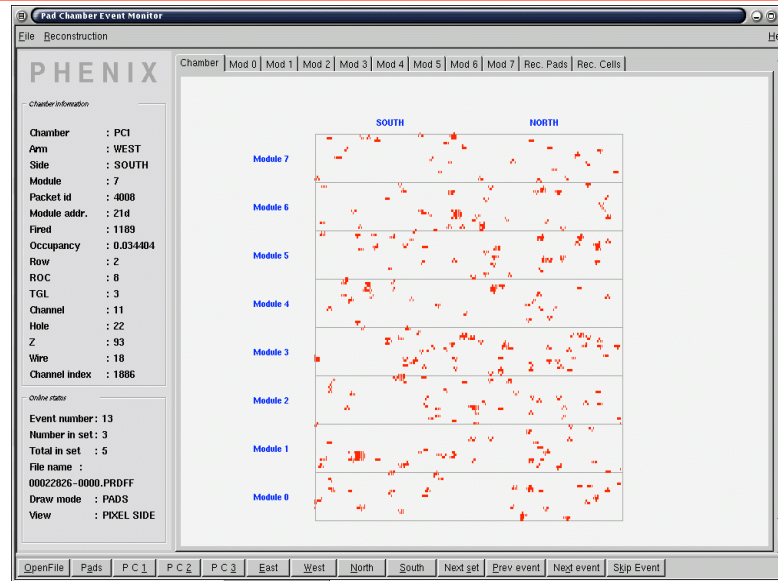
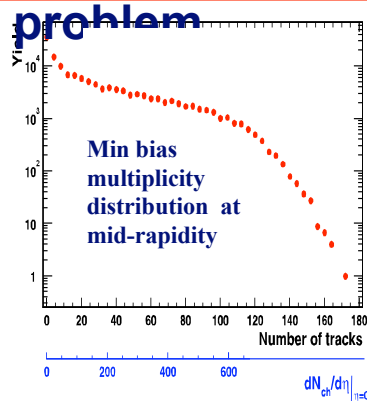
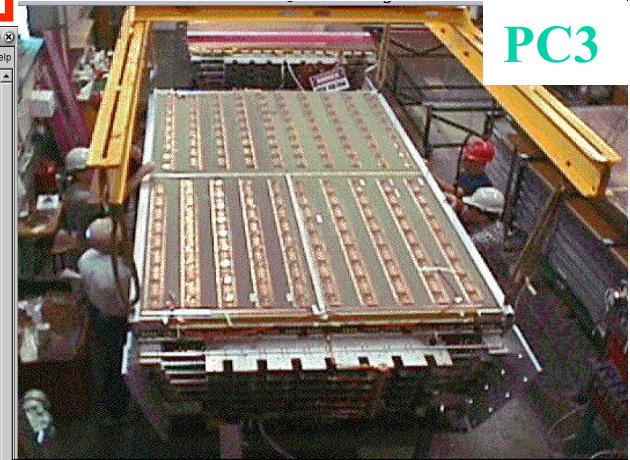
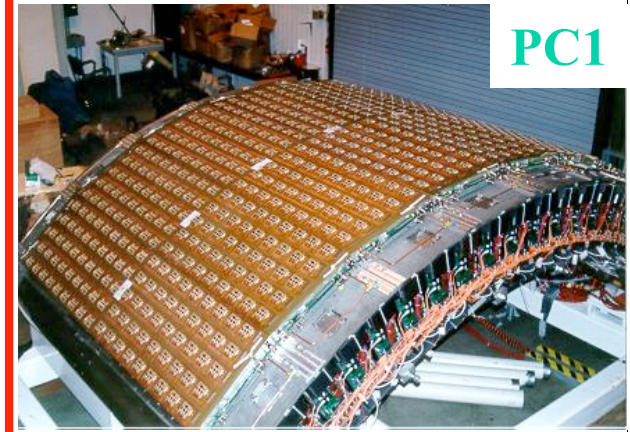


DC wires with kapton wire dividers

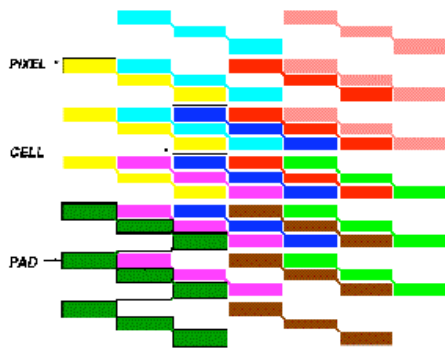
Identified particle spectra using tracking system and TOF

# Tracking Detectors: Pad Chambers

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



Pixel Pad Cathode Pattern

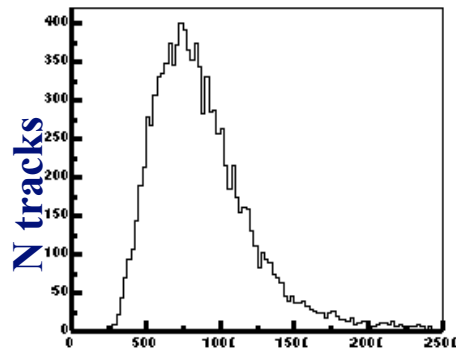


Clusters in PC from Central Au-Au collision

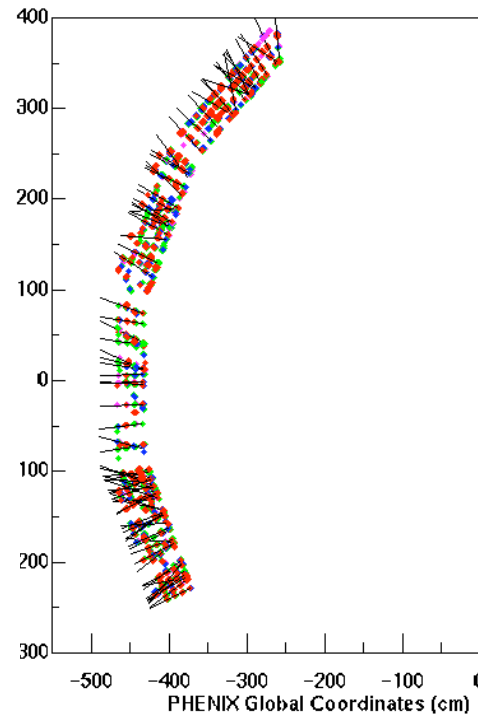


# Tracking Detectors: Time Expansion Chamber

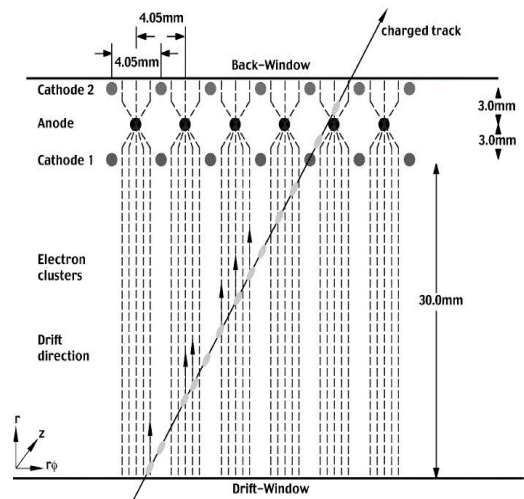
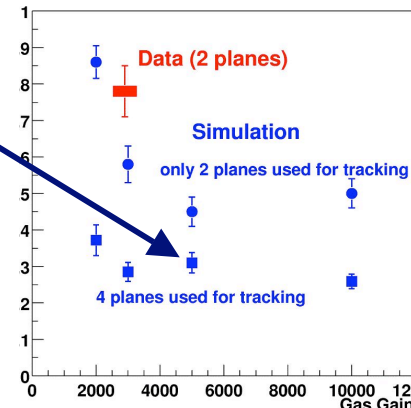
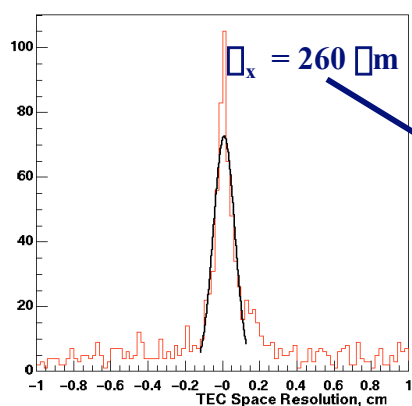
- 24 TEC Chambers arranged in 4, 6-Chamber sectors
- Used for tracking and PID ( $dE/dx, TR$ ).  $\sigma_x = 260 \mu\text{m}$
- $dE/dx$ :  $e/\pi = 5\%$  at 500 MeV/c (4 pls),  $e/\pi = 1.5\%$  (6pls) Important for momentum resolution  $p_T > 4.0 \text{ GeV}/c$
- Designed for TRD Upgrade . High momentum  $e/\pi$



Sum FADC counts/recon. track



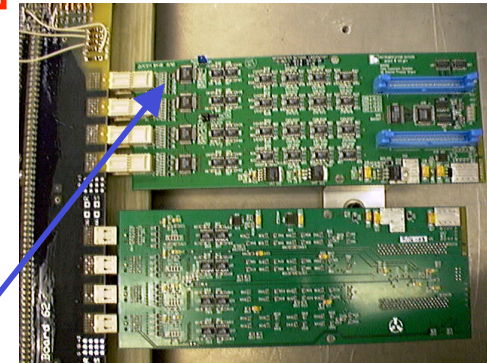
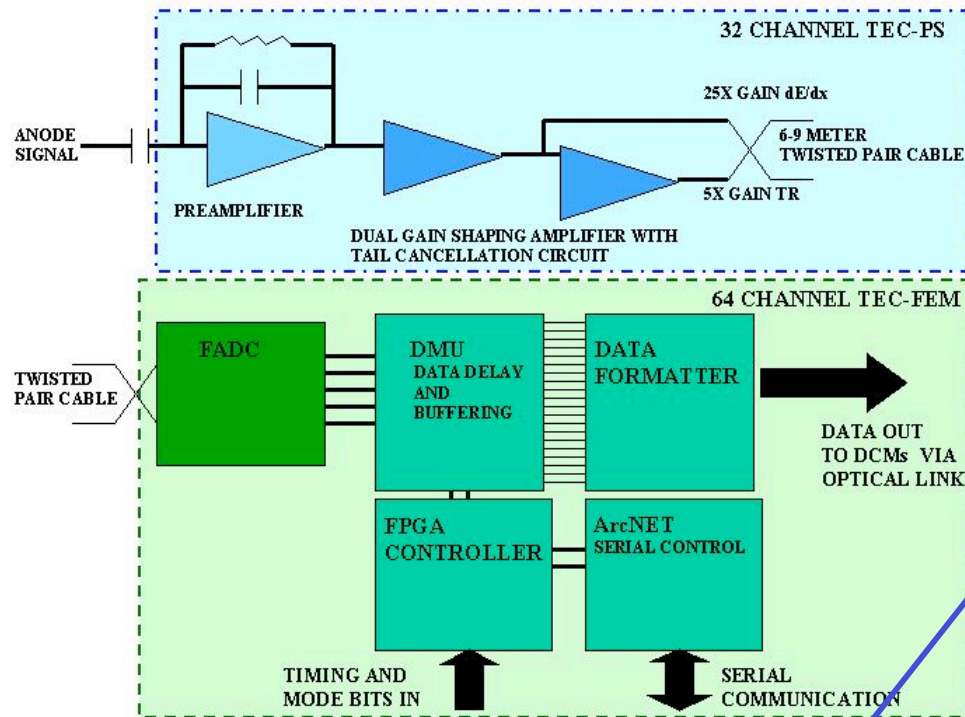
Tracks in TEC from Central Au-Au Collisions



TRD Radiator

# PHENIX TEC/TRD Electronics

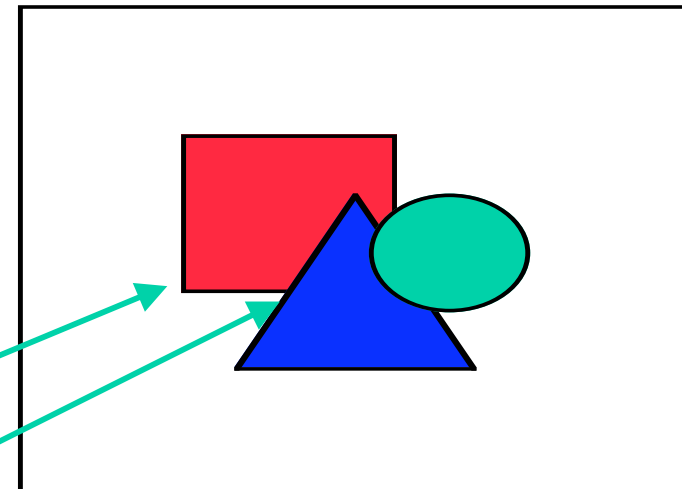
Up to 20,500 Instrumented TEC/TRD Channels



32 channel Preamp/Shaper PCB  
w/ remote calibration control  
and  $\sim 1$  fC RMS system noise

## 3 ASICs designed for TEC/TRD:

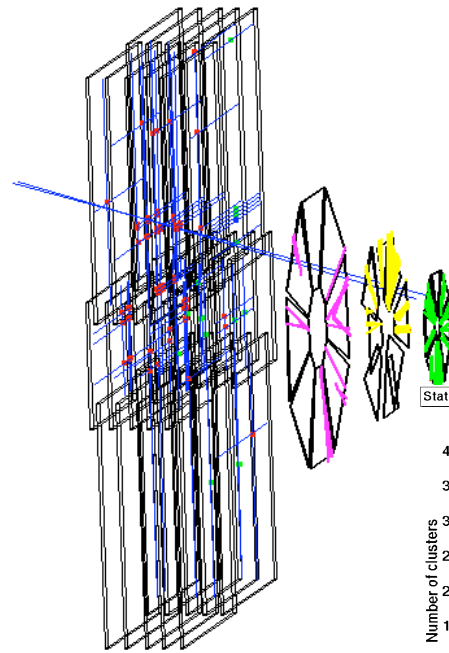
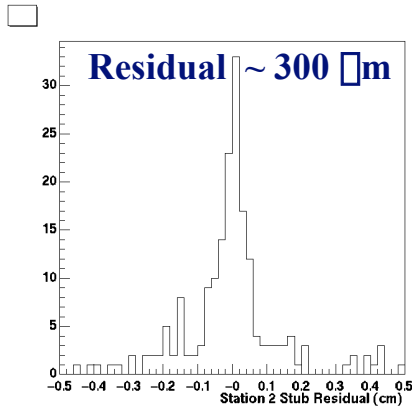
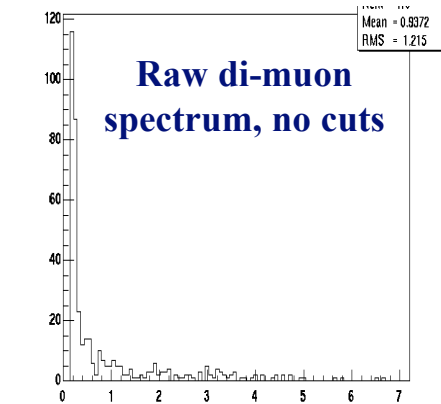
- Octal Preamp/Shaper w/ tail cancellation and dual gain for both  $dE/dx$  and TR. Full serial control of gain, shaping time and tail cancellation.
- Non-linear, 40 MHz, FADC with 9-bit dynamic range, 9-bit precision and 5-bit encoding.
- Digital Memory Unit for data formatting with programmable delay and memory depth.



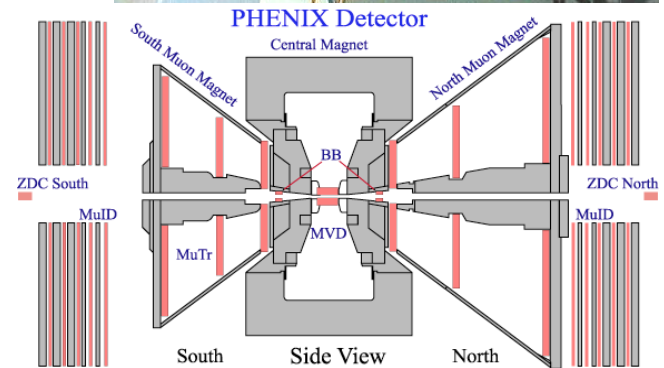
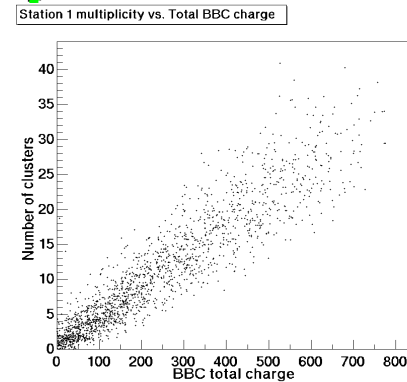
64 channel Front End Module(FEM)  
w/ digitizing , data formatting and  
optical data transmission

# Tracking Detectors: Cathode Strip Chambers

- First cathode-strip chambers (CSC) used in an experiment
- Low mass honeycomb-printed circuit board and etched metalized-mylar design
- Each CSC station has a position resolution of  $\sigma_x = 100 \mu\text{m}$
- 20k electronics channels/spectrometer arm

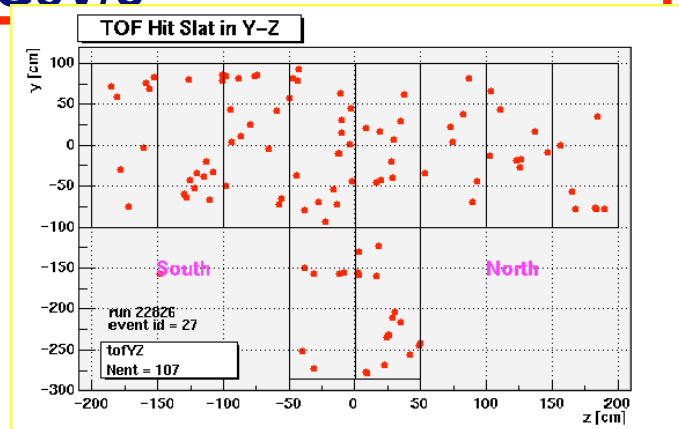
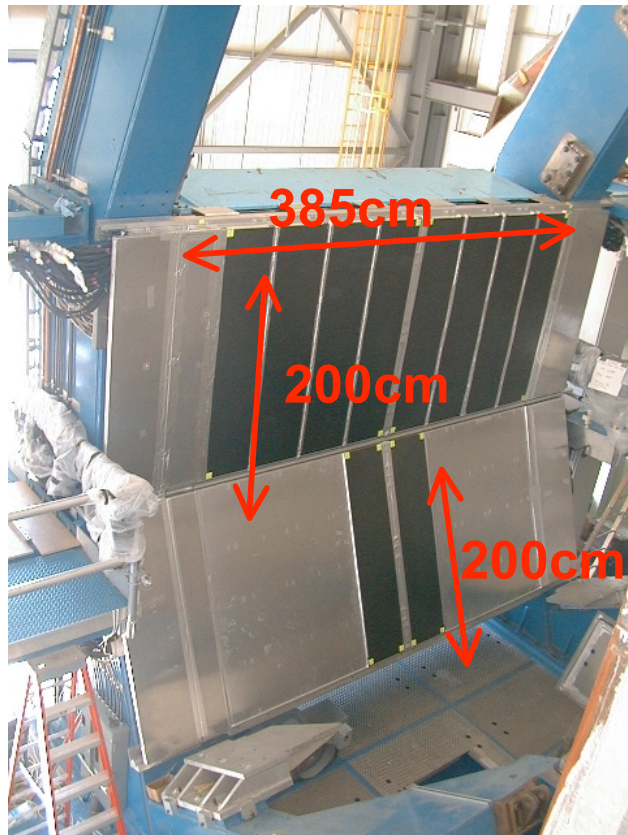
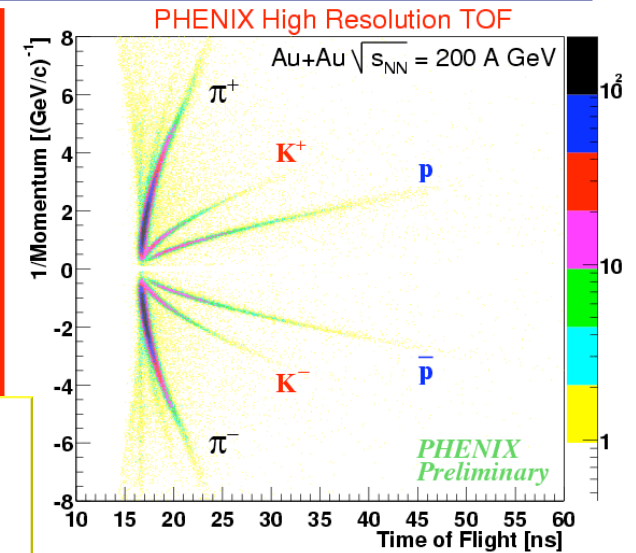


Reconstructed muon  
In Au-Au Collision

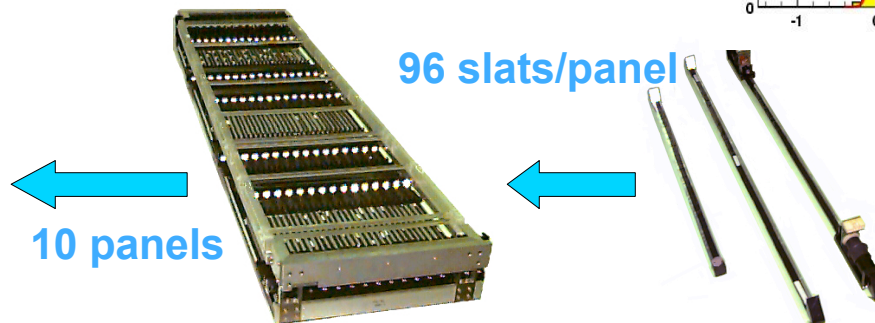
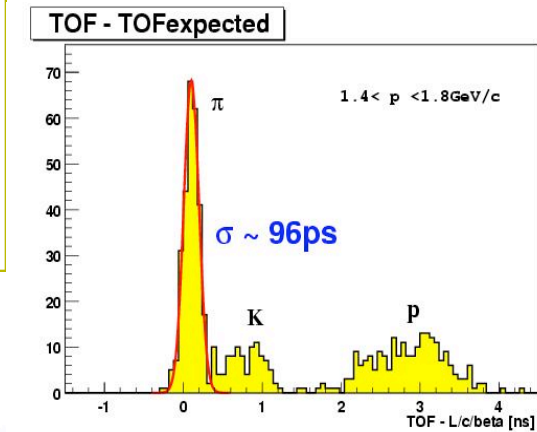


# Particle ID Detectors: Time of Flight

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

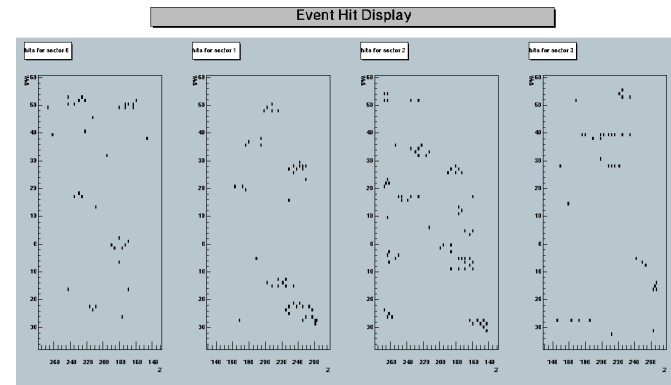
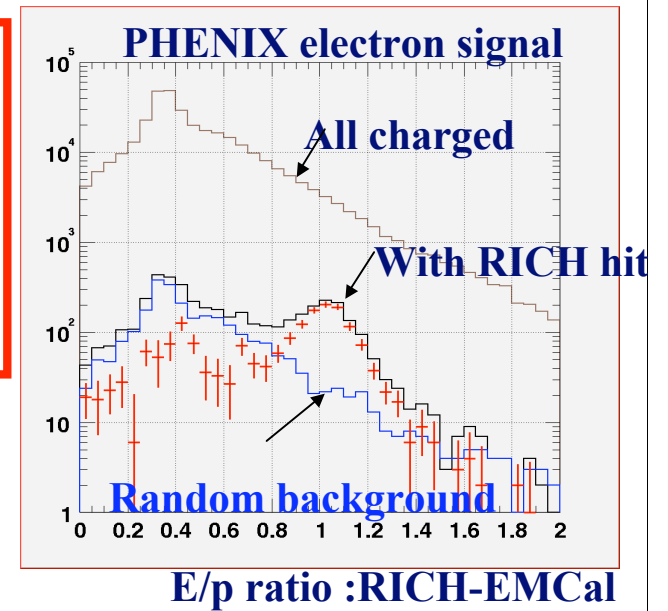


Clusters in TOF from Central Au-Au collision

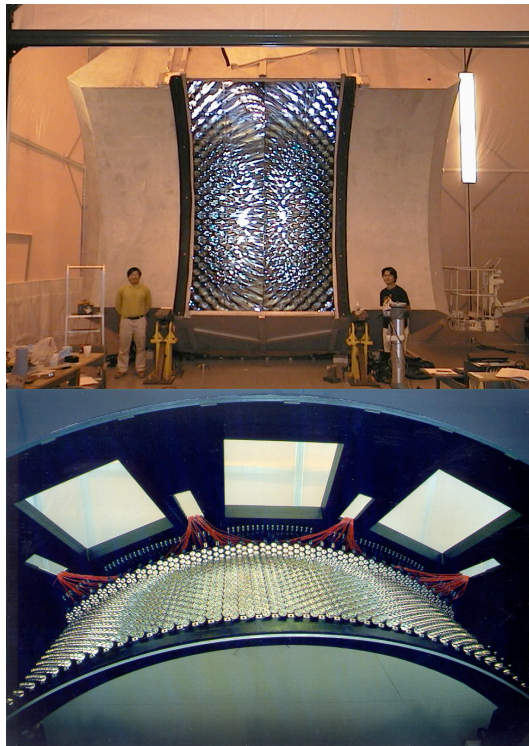
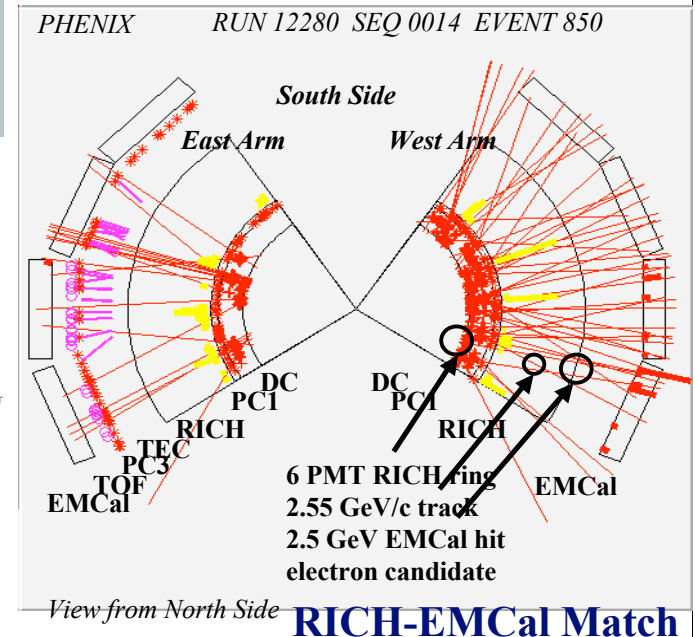
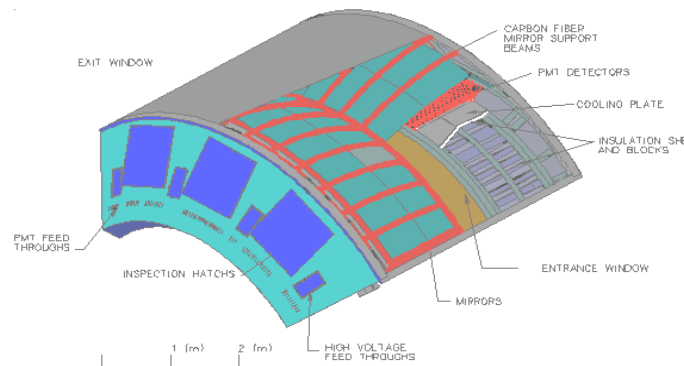


# Particle ID Detectors: Ring Imaging Cerenkov Counter

- Gas radiator CO<sub>2</sub>, e/p separation for p < 5 GeV/c
- 5120 PMTs sensitive to single photoelectrons,  $\tau_t < 1$  ns
- Ring resolution  $\sim 1^\circ$  in both  $\theta$  and  $\phi$



**Rings in RICH from Central Au-Au collision**

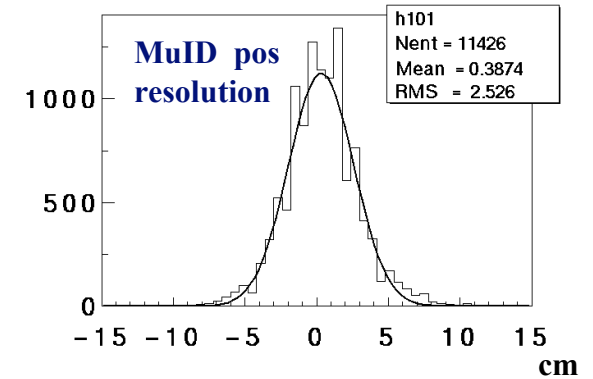
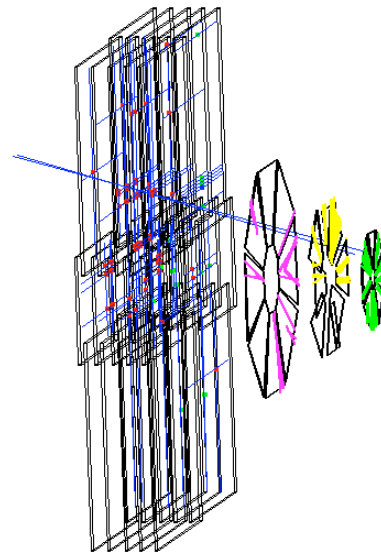
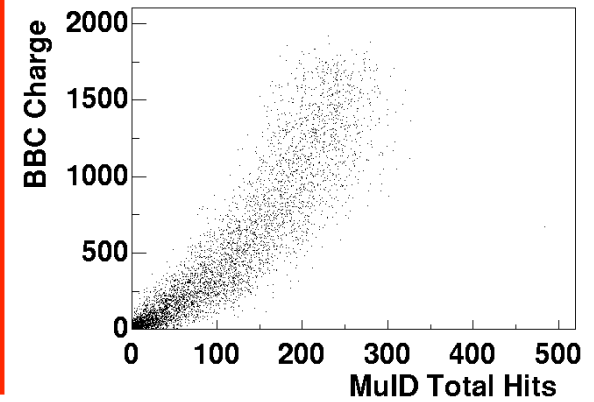




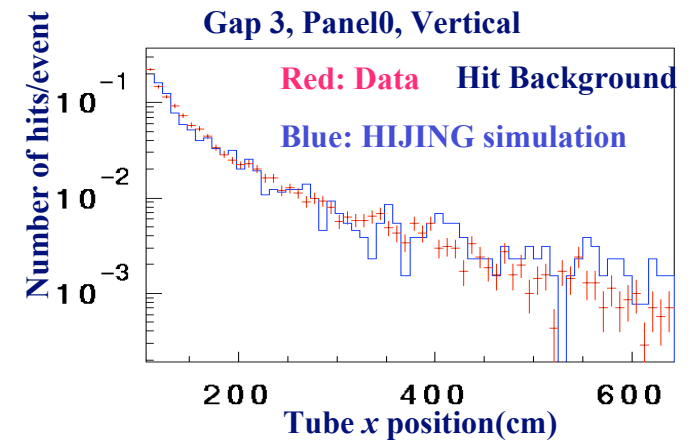


# Particle ID Detectors: Muon ID

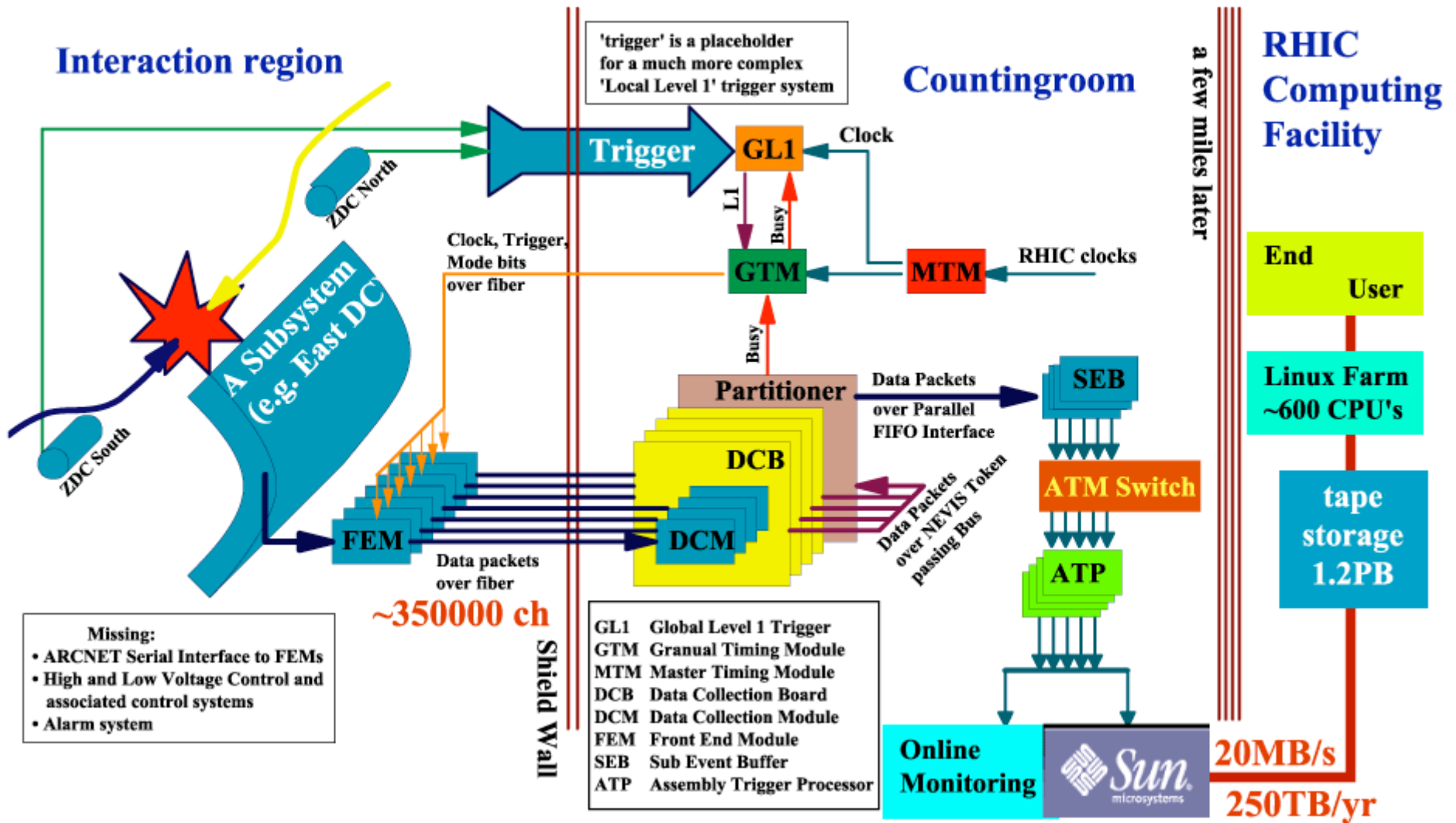
- 5 layers of steel absorber plate interleaved with 5 layers of larocci tubes (2x,2y 4 planes/layer)
- Active cross section of each wall 10m x 10m
- Muon low energy cutoff off 1.9 GeV/c
- Permanently sealed in place behind shield



**Reconstructed muon  
In Au-Au Collision**



# Data Acquisition System/Trigger



# Data Acquisition System/Trigger

## Run Control Display

Run Control Display for BigPartition

ions Mode

Configured BB LL1 Status North Glink South Glink

Run Number: 310 58  
 Data Taking Mode: Production  
 Run Control State: Run Started  
 Granule State: GTM.MUID.5 Started  
 Outstanding Granule Count: 0  
 Time In Run: 0:08:01  
 Data Path: none  
 Data File Directory: /buffer/eventdata  
 Data File Name: EVENTDATAxxx\_P01-0000310 58--SEQ#.PRDF  
 Buffer Box: phnxbx2.phenix.bnl.gov

Run Control Log

```

Issuing command: set runtime physics
Issuing command: scaler read activate
Issuing command: scaler etattach
Issuing command: start
Issuing command: scaler write activate
  
```

GTM Status			DCM Status			SEB Status			ATP Status			EBC Status											
L1	Run	Busy	OK	L1	Busy	Glink	OK	Name	#Events	Event Size	Data Rate	Busy	OK	Name	#Events	#L2Accept	#Read	Err	Assem Rate	Ave Data Rate	ATP OK	ET OK	EBC.0
16316								SEB.BB.0	117325	1.692 KB	0.413 MB/s			ATP.0	4029	1999	1		8.502/s	1.523 MB/s			EBC OK
16322								SEB.ZDC.0	117221	0.192 KB	0.043 MB/s			ATP.1	4021	1951	0		8.833/s	1.479 MB/s			#Received 116263
16330								SEB.MVD.0	117301	8.725 KB	1.908 MB/s			ATP.2	4090	1996	2		7.084/s	1.336 MB/s			#Assigned 116265
16336								SEB.MVD.1	117254	7.260 KB	1.967 MB/s			ATP.3	3917	1894	0		8.282/s	1.392 MB/s			#Completed 116179
16336								SEB.DC.W.0	117243	10.471 KB	2.825 MB/s			ATP.4	4133	2016	0		7.431/s	1.376 MB/s			Avg Event Rate 266.617/s
16336								SEB.DC.W.1	117321	9.237 KB	2.425 MB/s			ATP.5	4116	2020	0		10.312/s	1.742 MB/s			Avg Assem Lat 0.339 s
16336								SEB.PC.W.0	117294	8.498 KB	2.128 MB/s			ATP.6	4110	1983	0		7.856/s	1.404 MB/s			Avg ATP Load 0.000
16336								SEB.RICH.W.0	117332	2.622 KB	0.610 MB/s			ATP.7	4159	2030	0		7.752/s	1.439 MB/s			
16343								SEB.EMC.W.B	117214	6.328 KB	1.289 MB/s			ATP.8	4187	2063	0		9.988/s	1.652 MB/s			
16347								SEB.EMC.W.T	117243	7.122 KB	1.751 MB/s			ATP.9	4160	2057	0		8.492/s	1.491 MB/s			
16347								SEB.DC.E.0	117323	11.664 KB	2.910 MB/s			ATP.A	3921	1919	0		8.363/s	1.467 MB/s			
16352								SEB.DC.E.1	117235	10.664 KB	2.958 MB/s			ATP.B	4112	2059	1		9.932/s	1.663 MB/s			
16352								SEB.PC.E.0	117331	6.939 KB	1.648 MB/s			ATP.10	4111	1967	0		9.304/s	1.587 MB/s			
16357								SEB.TEC.E.0	117254	6.894 KB	1.808 MB/s			ATP.11	4202	2005	0		9.399/s	1.620 MB/s			
16357								SEB.TEC.E.1	117254	6.592 KB	1.726 MB/s			ATP.12	3887	1860	2		8.364/s	1.457 MB/s			
16360								SEB.TEC.E.2	117280	7.245 KB	1.824 MB/s			ATP.13	4040	1936	0		9.469/s	1.543 MB/s			
16360								SEB.TEC.E.3	117294	7.524 KB	1.876 MB/s			ATP.14	3904	1896	0		10.294/s	1.692 MB/s			
16363								SEB.TO.F.E.0	117345	4.537 KB	0.905 MB/s			ATP.15	3903	1891	0		10.431/s	1.638 MB/s			
16363								SEB.RICH.E.0	117294	2.595 KB	0.659 MB/s			ATP.16	3976	1937	0		10.973/s	1.732 MB/s			
16376								SEB.EMC.E.T	117243	6.705 KB	1.655 MB/s			ATP.17	3934	1912	0		7.759/s	1.435 MB/s			
16381								SEB.EMC.E.B.0	117252	4.671 KB	0.957 MB/s			ATP.18	4024	1937	0		7.683/s	1.396 MB/s			
16387								SEB.EMC.E.B.1	117323	5.298 KB	1.358 MB/s			ATP.19	3834	1882	0		8.255/s	1.463 MB/s			
16387								SEB.MUTR.S.ST1.0	117323	7.603 KB	1.810 MB/s			ATP.1A	3864	1905	0		8.397/s	1.405 MB/s			
16387								SEB.MUTR.S.ST2.0	117283	11.352 KB	2.914 MB/s			ATP.1B	4990	2445	0		11.897/s	1.976 MB/s			
16387								SEB.MUTR.S.ST3.0	117314	4.849 KB	1.053 MB/s			ATP.1C	4919	2412	1		11.727/s	1.965 MB/s			
16387								SEB.MUTR.S.ST3.1	117310	4.343 KB	1.201 MB/s			ATP.1D	5011	2438	0		10.744/s	1.812 MB/s			
16392								SEB.MUID.5.0	117334	0.963 KB	0.224 MB/s			ATP.1E	5090	2485	1		12.754/s	2.043 MB/s			
								Sum		172.585 KB	42.846 MB/s			ATP.1F	0	0	0		0.000/s	0.000 MB/s			

Scaler Monitor

Trig	Status	Raw	Live	Scaled	Raw Rate	Live Rate	Scaled Rate	Live Time	Live Time(RA)
BBLL1>=1	Disabled	152768	0	0	304.853 Hz	0.000 Hz	0.000 Hz	0.000	0.000
ZDCNS	Enabled	430580	285803	28580	877.161 Hz	595.906 Hz	59.586 Hz	0.664	0.679
BBCLL1>=1*ZDCNS	Disabled	141092	0	0	282.745 Hz	0.000 Hz	0.000 Hz	0.000	0.000
BBPhTubMult	Disabled	1859746	0	0	3.709 KHz	0.000 Hz	0.000 Hz	0.000	0.000
BBVertex	Disabled	632477	0	0	1.242 KHz	0.000 Hz	0.000 Hz	0.000	0.000
BBLL1>=2	Disabled	152768	0	0	304.853 Hz	0.000 Hz	0.000 Hz	0.000	0.000
MUID15	Disabled	1552604	0	0	2.711 KHz	0.000 Hz	0.000 Hz	0.000	0.000
MUID25	Disabled	839441	0	0	1.390 KHz	0.000 Hz	0.000 Hz	0.000	0.000
MUID1D	Disabled	900152	0	0	1.087 KHz	0.000 Hz	0.000 Hz	0.000	0.000
MUID1D15	Disabled	712162	0	0	909.502 Hz	0.000 Hz	0.000 Hz	0.000	0.000
MUID2D	Disabled	586600	0	0	611.134 Hz	0.000 Hz	0.000 Hz	0.000	0.000
DC.W FA	Disabled	37771724	0	0	78.188 KHz	0.000 Hz	0.000 Hz	0.000	0.000
DC.E FA	Disabled	37771724	0	0	78.188 KHz	0.000 Hz	0.000 Hz	0.000	0.000
PC.W FA	Disabled	37397748	0	0	77.414 KHz	0.000 Hz	0.000 Hz	0.000	0.000
PC.E FA	Disabled	37397748	0	0	77.414 KHz	0.000 Hz	0.000 Hz	0.000	0.000
BBCHits*ZDCNS*MUID1D	Disabled	39469	0	0	118.764 Hz	0.000 Hz	0.000 Hz	0.000	0.000
ZDCNS*MUID1D	Disabled	39684	0	0	118.907 Hz	0.000 Hz	0.000 Hz	0.000	0.000
MUID1D*BBCHits*ZDCNS	Disabled	52053	0	0	108.259 Hz	0.000 Hz	0.000 Hz	0.000	0.000
ZDCNS*BBCHits	Disabled	138154	0	0	281.846 Hz	0.000 Hz	0.000 Hz	0.000	0.000
ZDCNS*BBCLL1>=2	Disabled	141092	0	0	282.745 Hz	0.000 Hz	0.000 Hz	0.000	0.000
BBCLL1>=2*ZDCNS	Disabled	11676	0	0	22.108 Hz	0.000 Hz	0.000 Hz	0.000	0.000
MUID1D*BBCLL1>=2	Disabled	21556	0	0	67.229 Hz	0.000 Hz	0.000 Hz	0.000	0.000
MUID2D*BBCLL1>=2	Disabled	49	0	0	0.000 Hz	0.000 Hz	0.000 Hz	0.000	0.000
BBCLL1>=2(copy)	Enabled	152768	97412	97412	304.853 Hz	199.492 Hz	199.492 Hz	0.638	0.654
PPG(Pedestal)	Disabled	4806	0	0	9.985 Hz	0.000 Hz	0.000 Hz	0.000	0.000
PPG(Test Pulse)	Enabled	401	270	270	0.856 Hz	0.524 Hz	0.524 Hz	0.673	0.611
PPG(Laser)	Enabled	400	255	255	0.808 Hz	0.475 Hz	0.475 Hz	0.638	0.588
PPG(LED)	Disabled	401	0	0	0.856 Hz	0.000 Hz	0.000 Hz	0.000	0.000

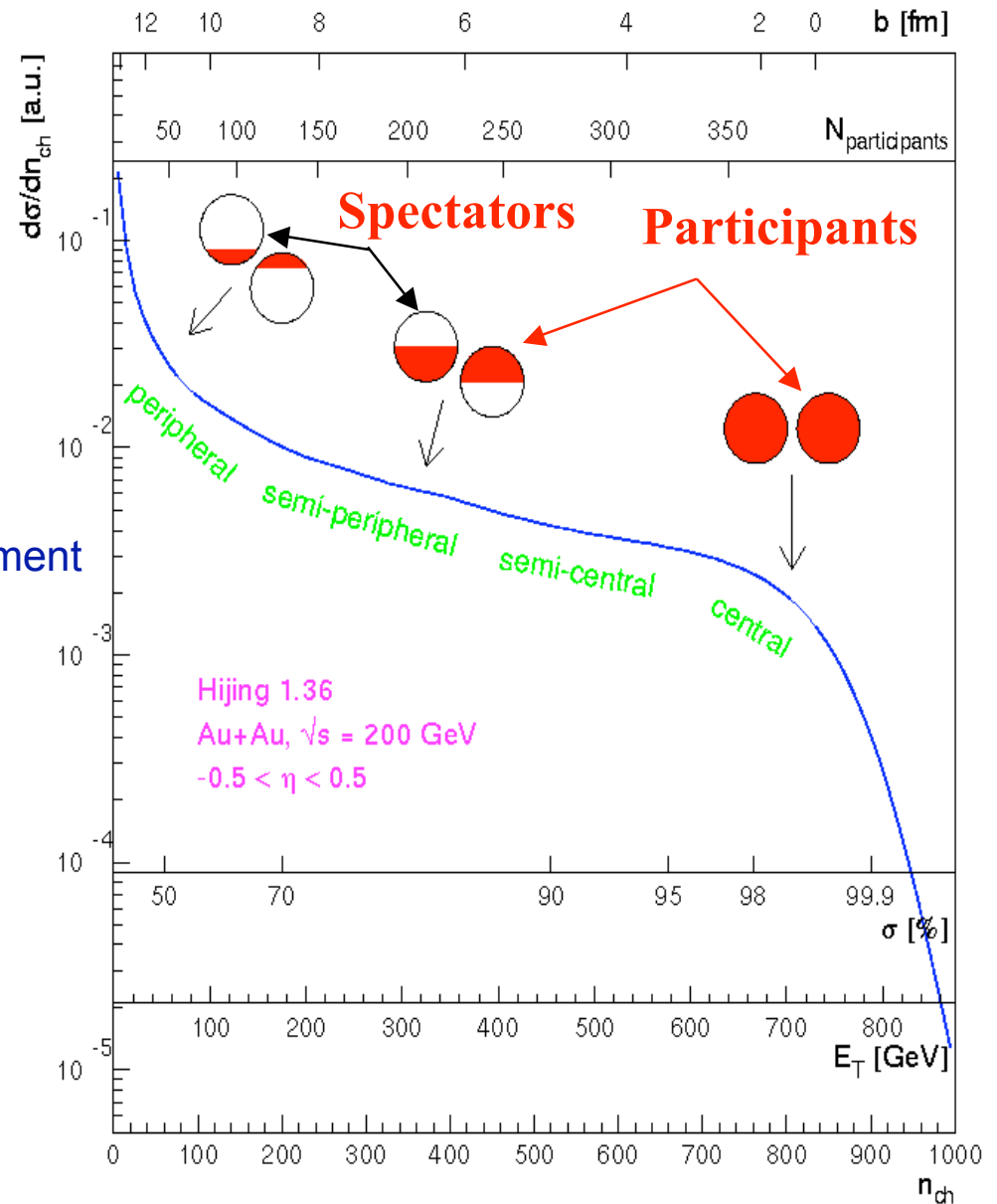
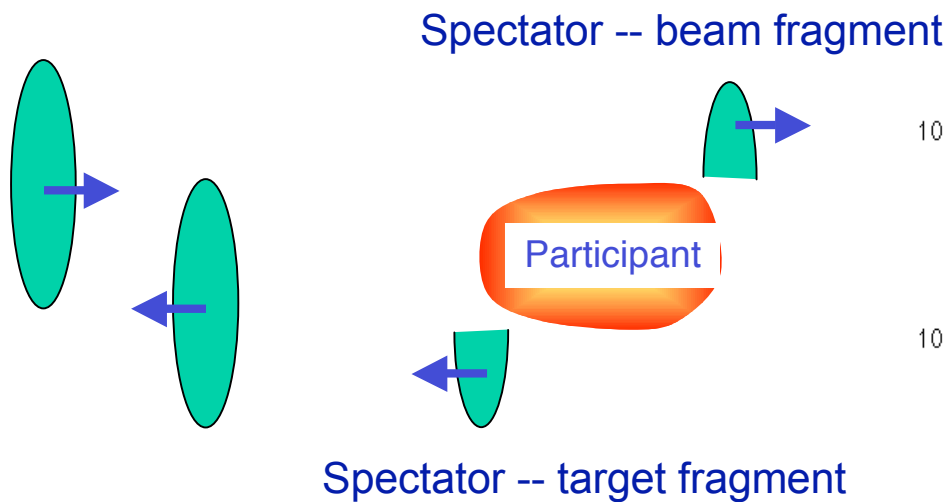
# Participant-spectator model

と

# 衝突係数

# Participant-spectator 描像

- impact parameter (衝突係数) によって、衝突の様相が決まる

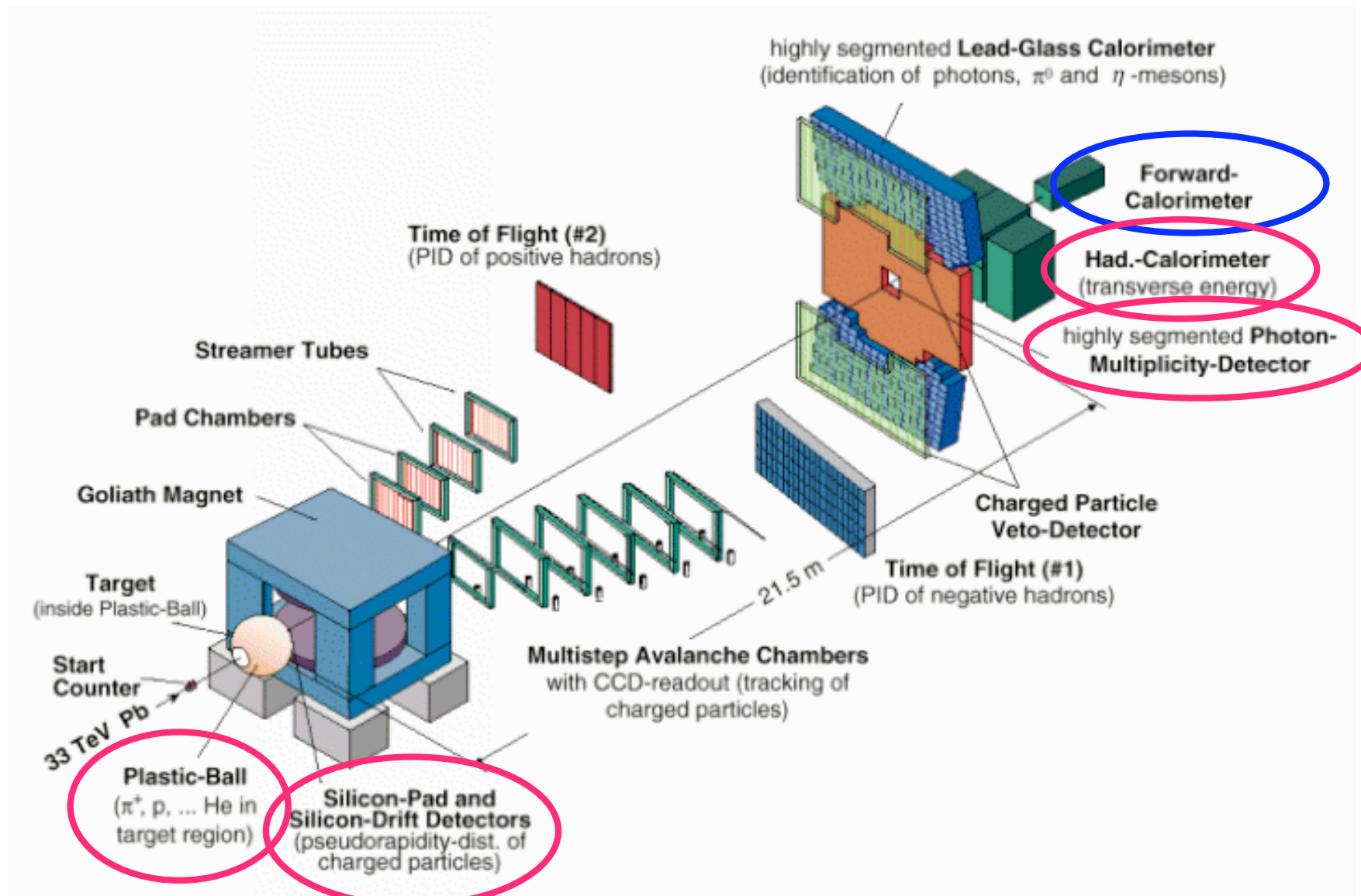


# 衝突係数の決定

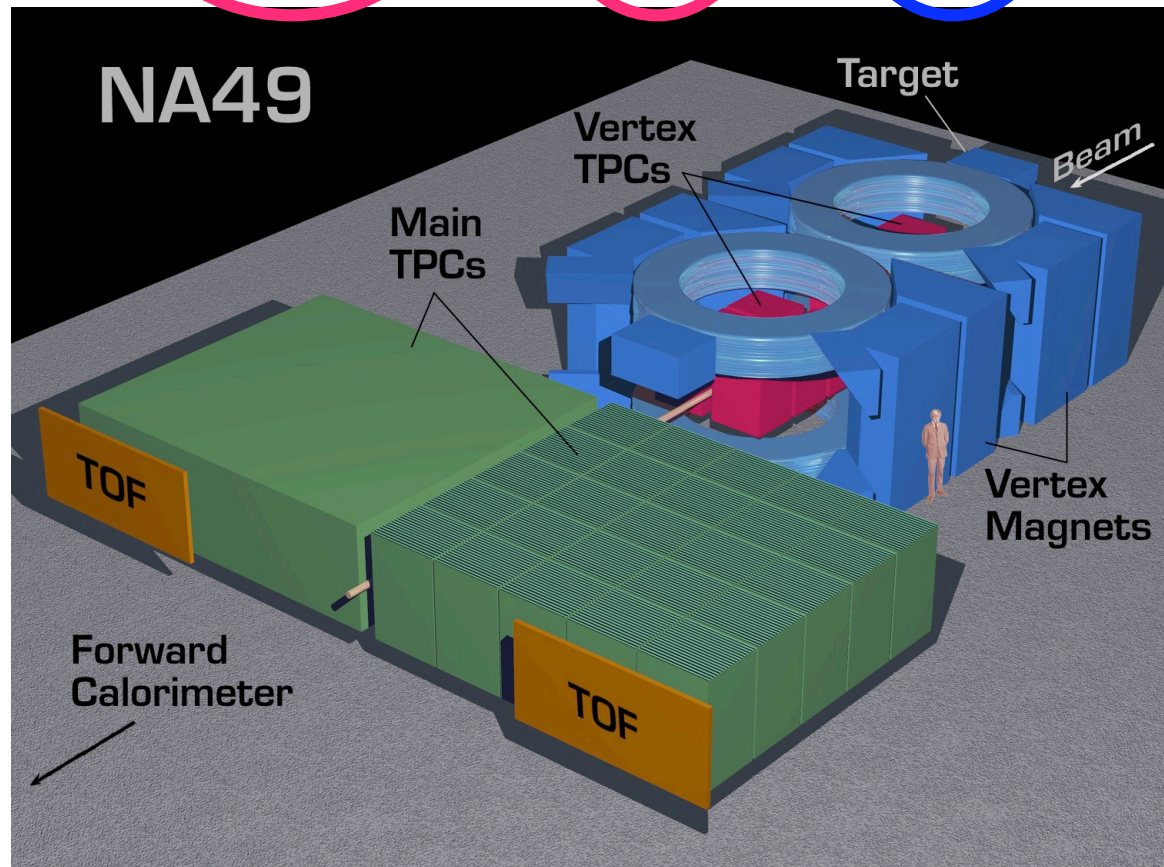
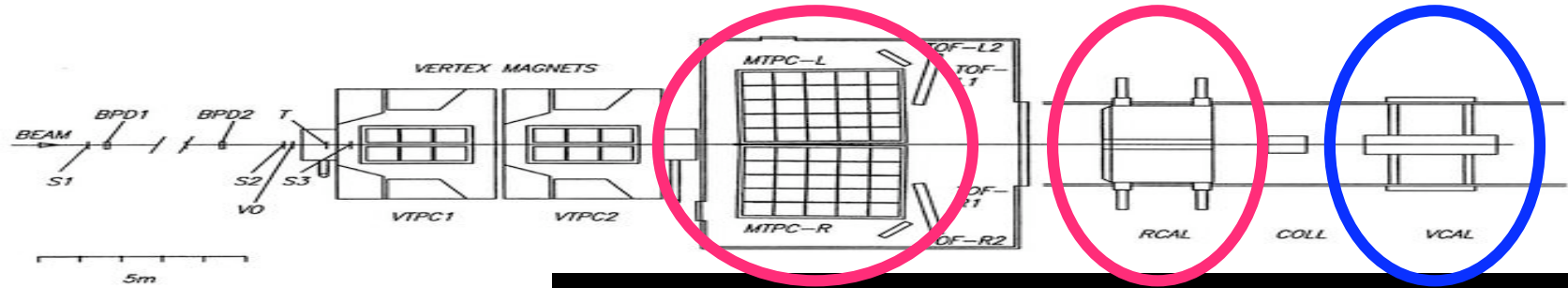
## Participant-spectator 描像を利用する

- Beam fragment の運動エネルギー
  - ハドロンカロリメータ
    - $\propto A_F E_N \rightarrow$  fragment の核子数
- 横エネルギー ( $E_T$ )
  - ハドロンカロリメータ、電磁カロリメータ
    - Participant 領域からの放出エネルギー
- 粒子多重度
  - 荷電粒子検出器
    - Participant 領域からの放出粒子数

# CERN-SPS WA98 実験



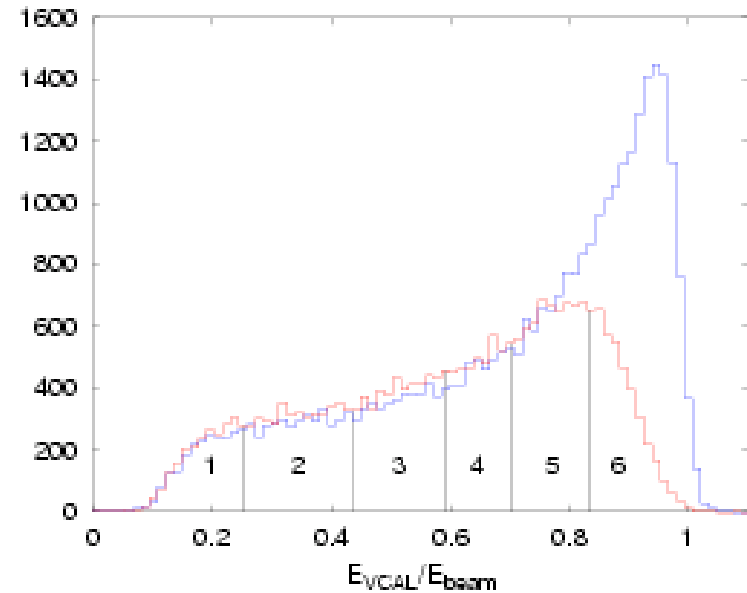
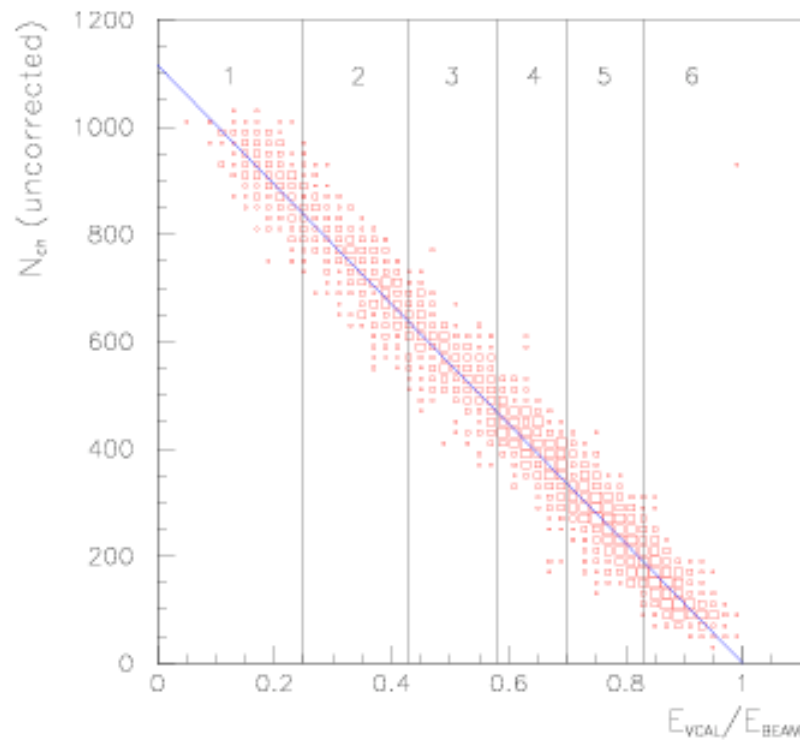
# CERN-SPS NA49 実験





# Centrality の決定 (NA49)

- 前方ハドロンカロリメー;  
(VCAL)



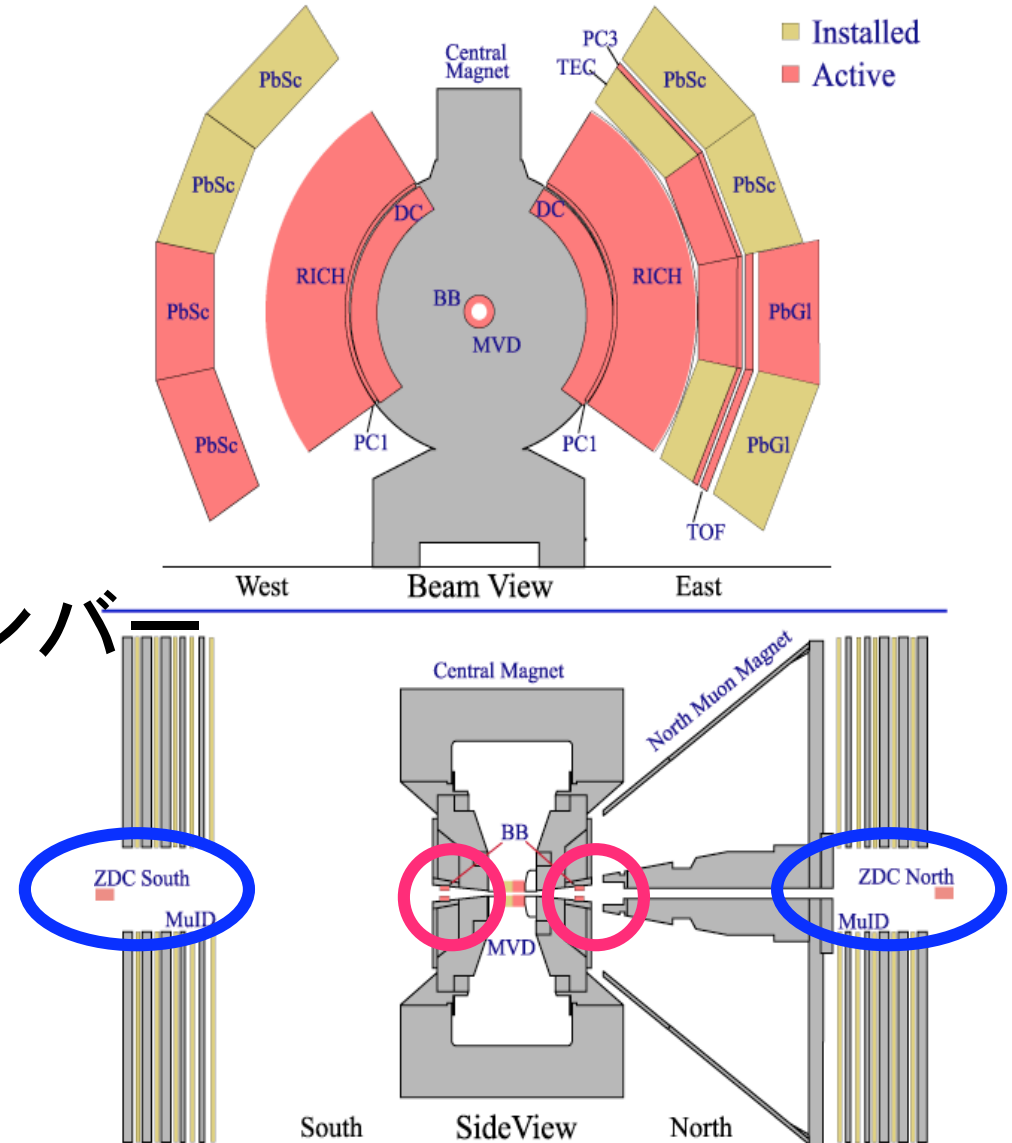
$E_{VCAL}$  vs.  $N_{ch}$

- $N_{ch}$  : TPC でのトラックの数
- 強い反相関

# Centrality (PHENIX)

- BBC
- ZDC
- EMCal
  - PbSc+PbGl
- トラッキングチェンバ
  - PC1,PC2,PC3
  - DC
  - TEC

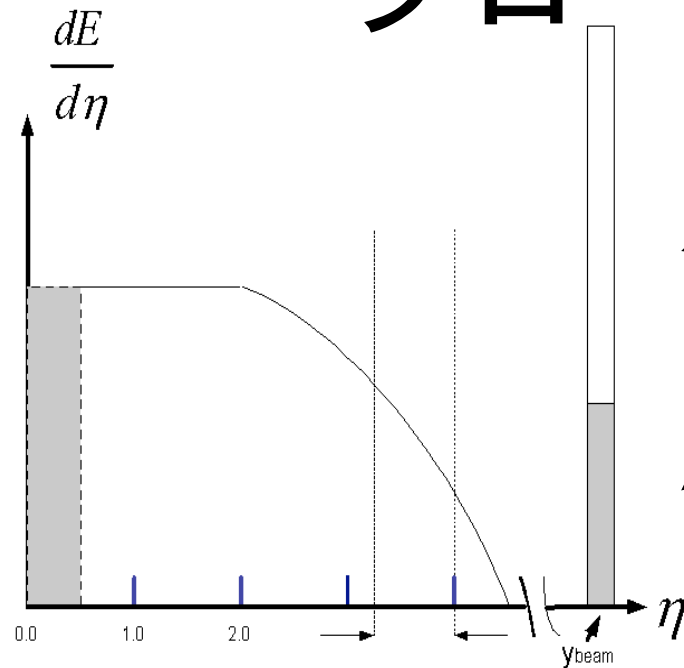
PHENIX Detector - First Year Physics Run



# グローバル用検出器

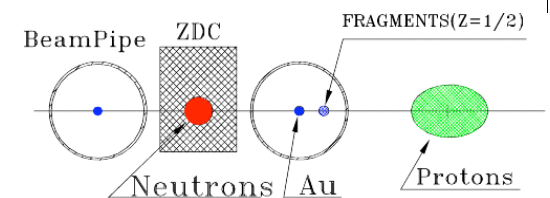
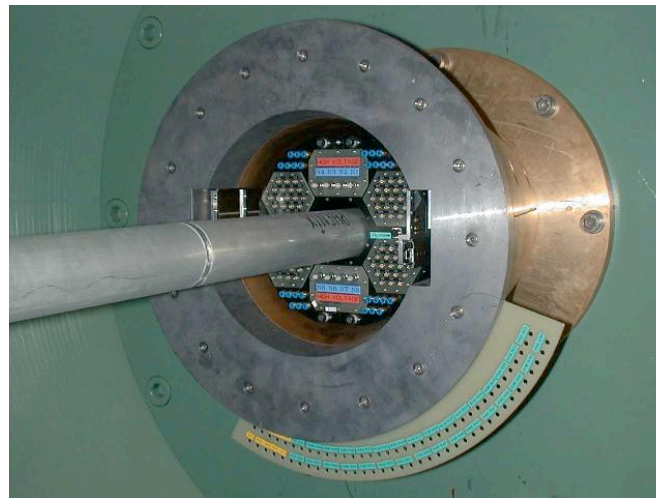
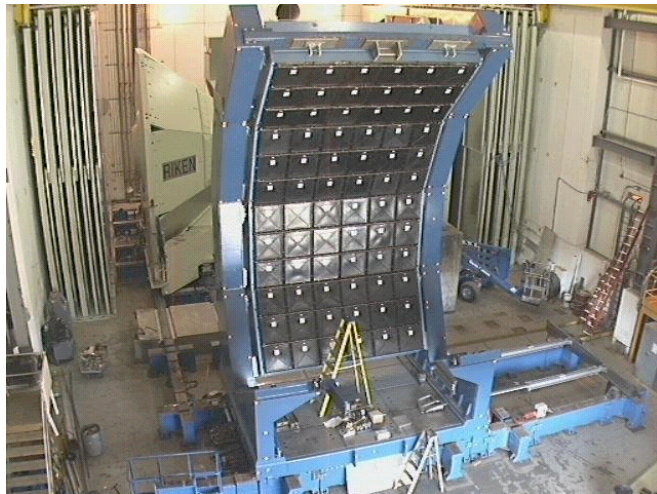
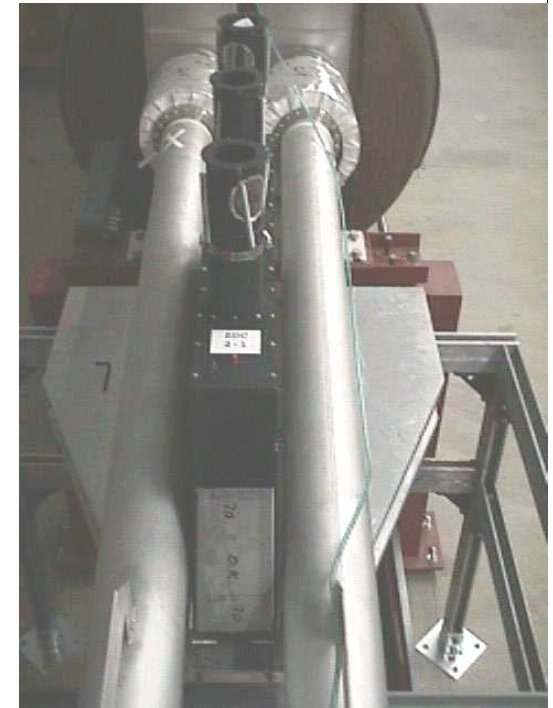
Forward, spectator Energy  
charged, neutral

Zero Degree Calorimeter



Beam-Beam  
Counter

EMCal

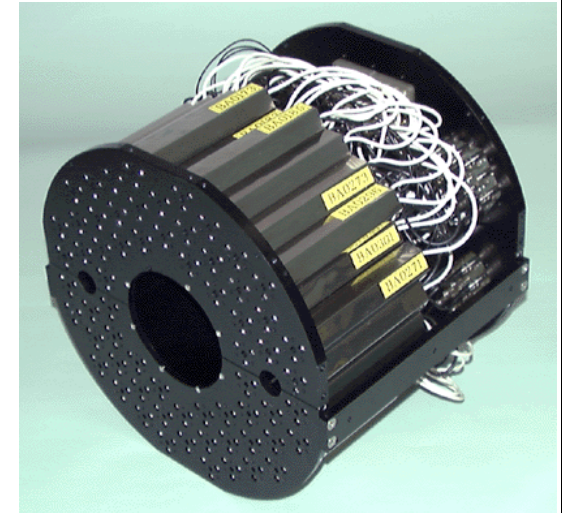


# ビーム・ビーム検出器 (BBC)

Hiroshima U, Columbia, LANL, and BNL

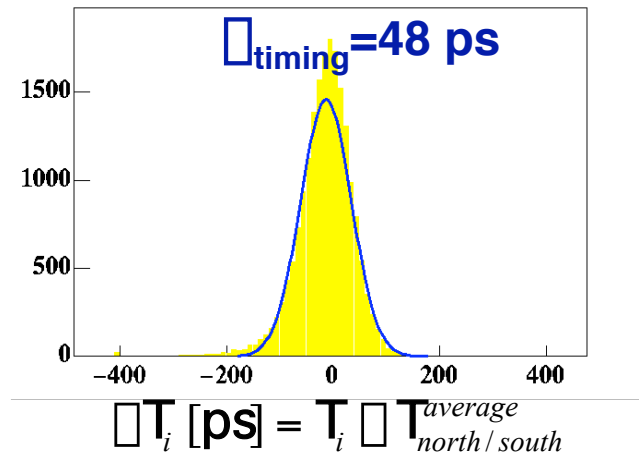


- 一対：ビーム軸に沿って超前方  
( $3.0 < \theta < 3.9$ )に設置
- ビーム衝突事象を検出  
→ 衝突位置、衝突時間、  
衝突係数を与える
- 64個の検出素子
- 各素子：  
チェレンコフ輻射体（石英）  
+ 1インチ径メッシュ型  
PMT

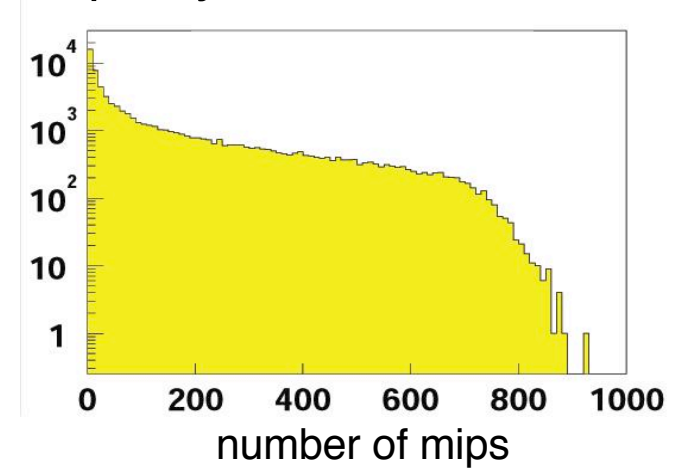


# BBC Performance in Year-1

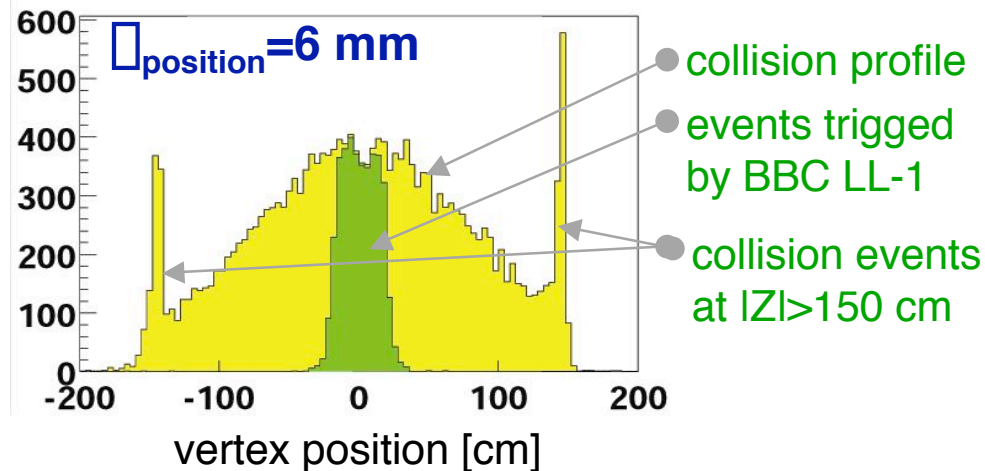
## Timing resolution of an element



## Multiplicity distribution at BBC

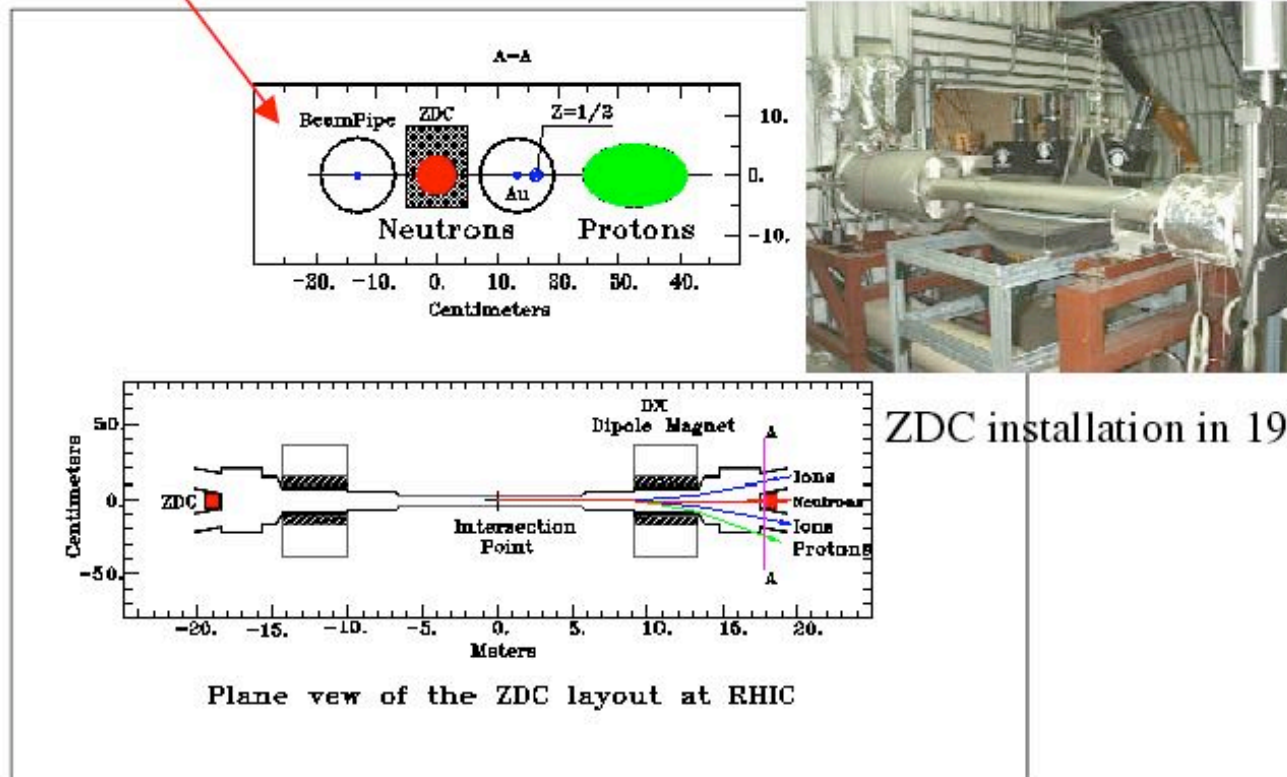


## Online Vertex selection in LL-1



# ZDC Layout

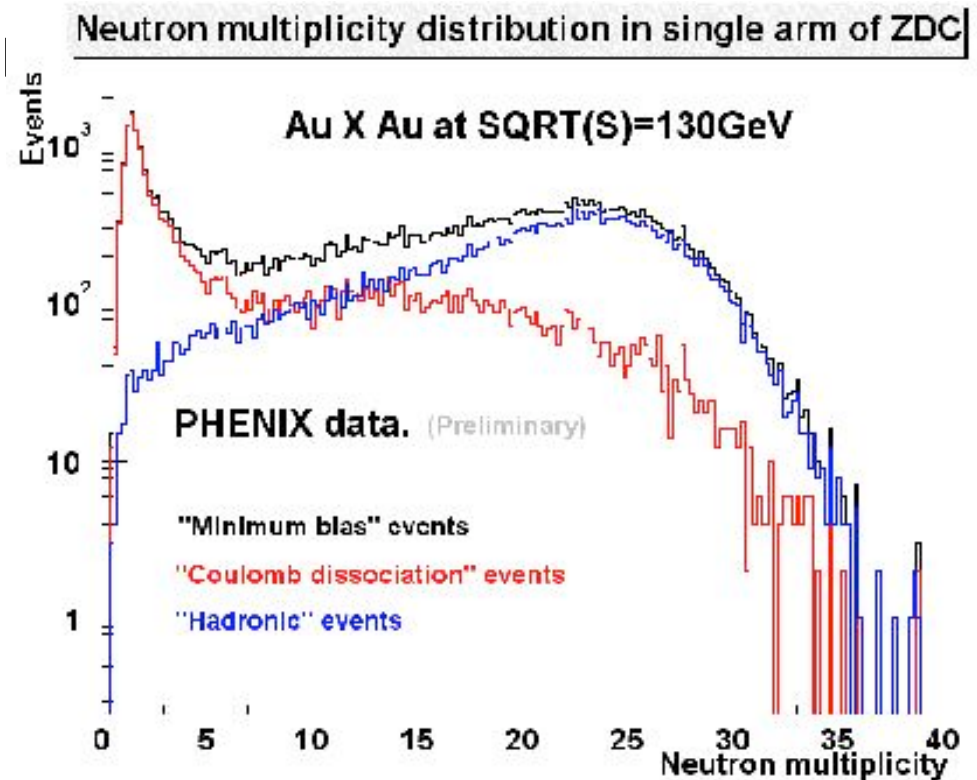
“Beam-eye” view of the ZDC location



- ハドロンカロリメータ：RHIC の 4 実験に共通
- 衝突型加速器では、spectator 全体を捕らえることは困難
- 0度方向の中性子数 → 衝突の中心度の単調関数ではない

# ZDCからのデータ

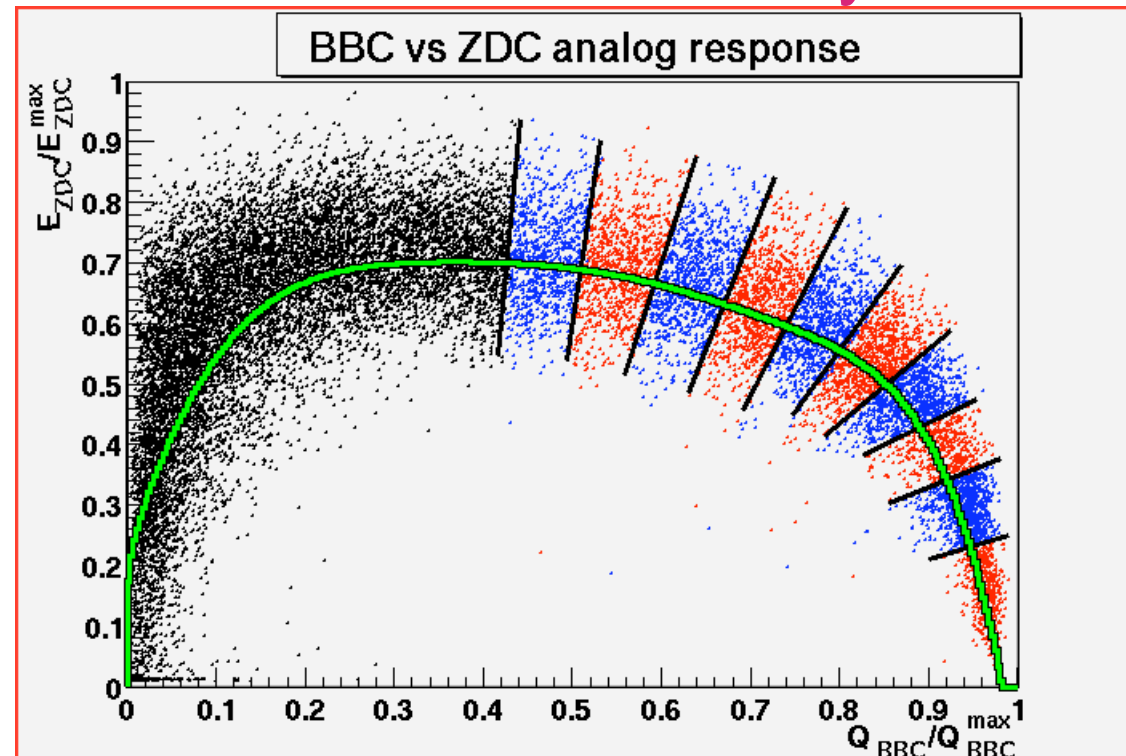
- 0度方向の運動エネルギー → 中性子の数
- 金・金衝突
  - 全体の1/3は Coulomb



# Centrality の決定 (PHENIX)

- BBC-ZDC プロット
  - ZDCエネルギー ( $\propto$ 中性子数) は中心衝突と周辺衝突で減少
  - 総ハドロン断面積に対する割合  $\rightarrow$  centrality の決定

- Glauber model
  - $N_p$ 、 $N_{coll}$  を計算





# $N_p$ と $N_{\text{coll}}$

- $N_p$  : 関与部の核子数
  - 主に衝突係数によって決まる
  - Wounded nucleon 模型の wounded nucleon 数
    - 一度しかカウントしない
  - p-p 衝突では  $N_p = 2$
- $N_{\text{coll}}$  : 核子の総衝突回数
  - 繰り返しを許す
  - 1個あたりの平均衝突回数 :  $\bar{n} \sim N_{\text{coll}} / (0.5N_p)$
  - ハードプロセスの場合、 $N_{\text{coll}}$  が良い指標