PHENIX Beam Beam Counter

Introduction to PHENIX Beam Beam Counter (BBC)

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Purpose of PHENIX BBC

PHENIX Beam Beam Counter

Minimum Bias Trigger
BBC & (ZDC or NTC)

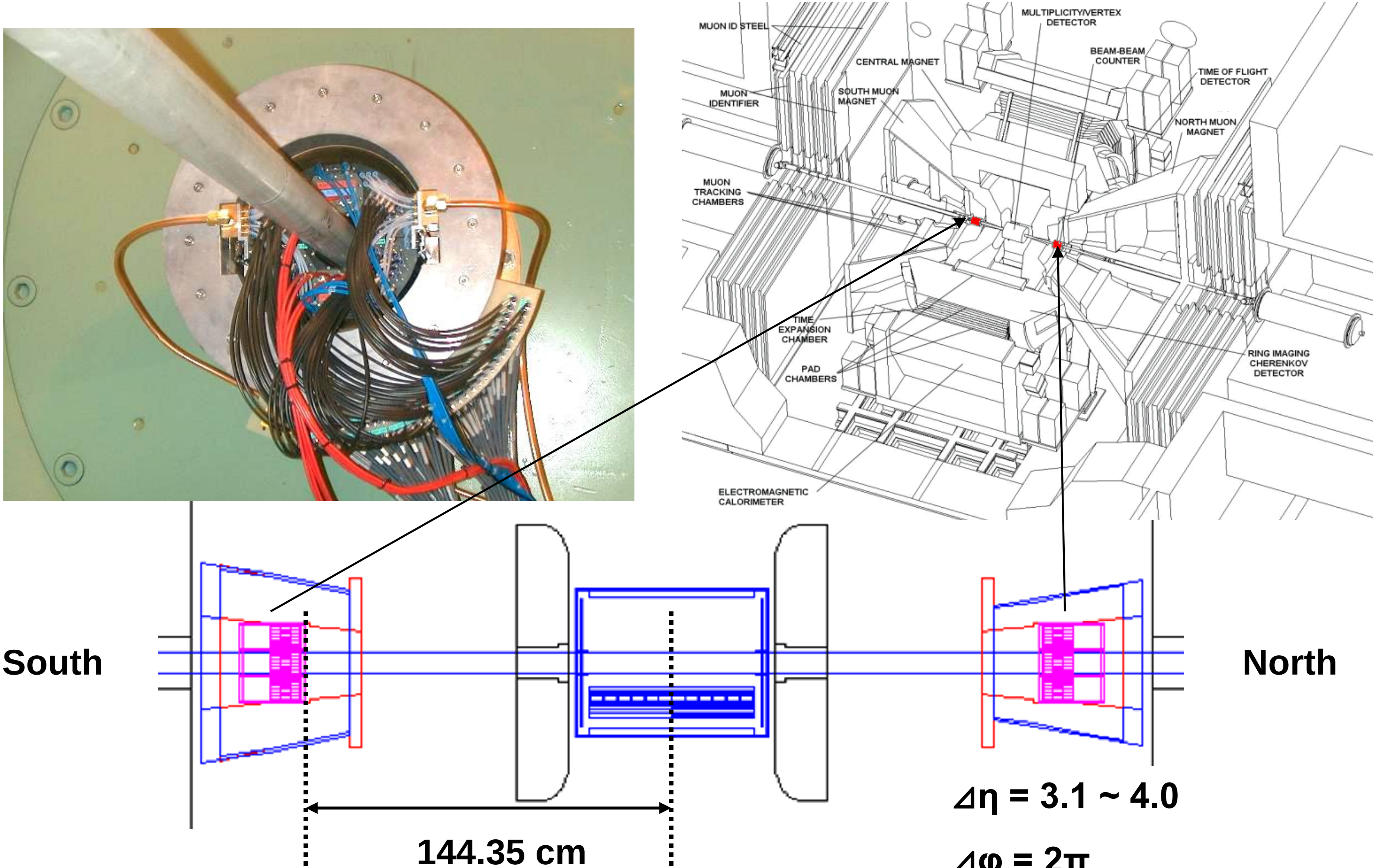
Centrality Determination
with ZDC

Time Zero
start timing for time-of-flight measurement

Collision Vertex
initial point of charged particle tracking

What is PHENIX BBC

PHENIX Beam Beam Counter

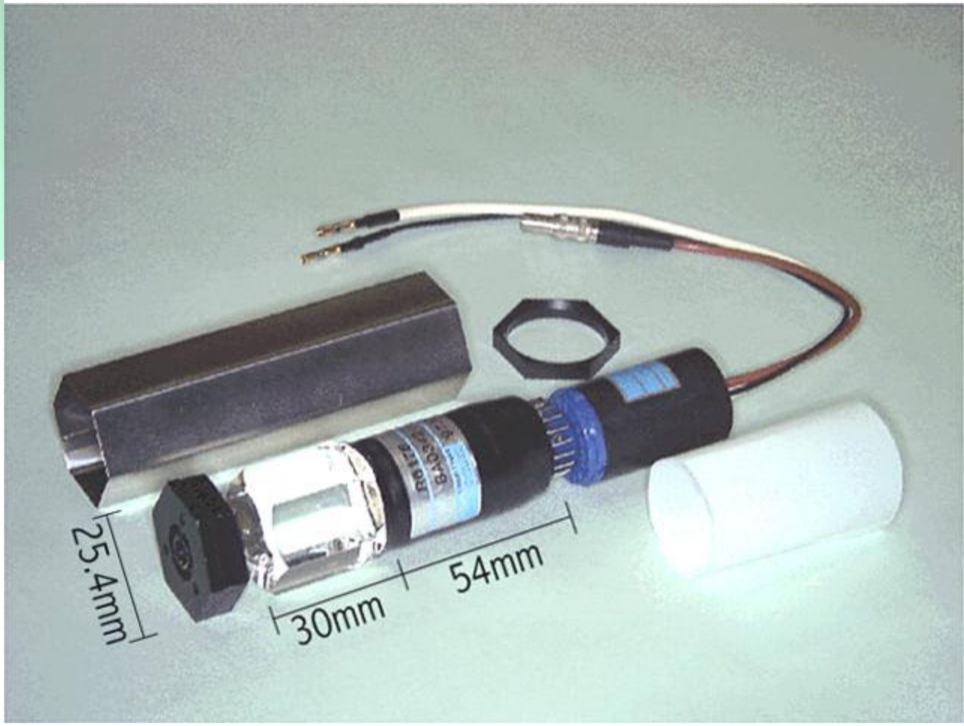


Hardware Component

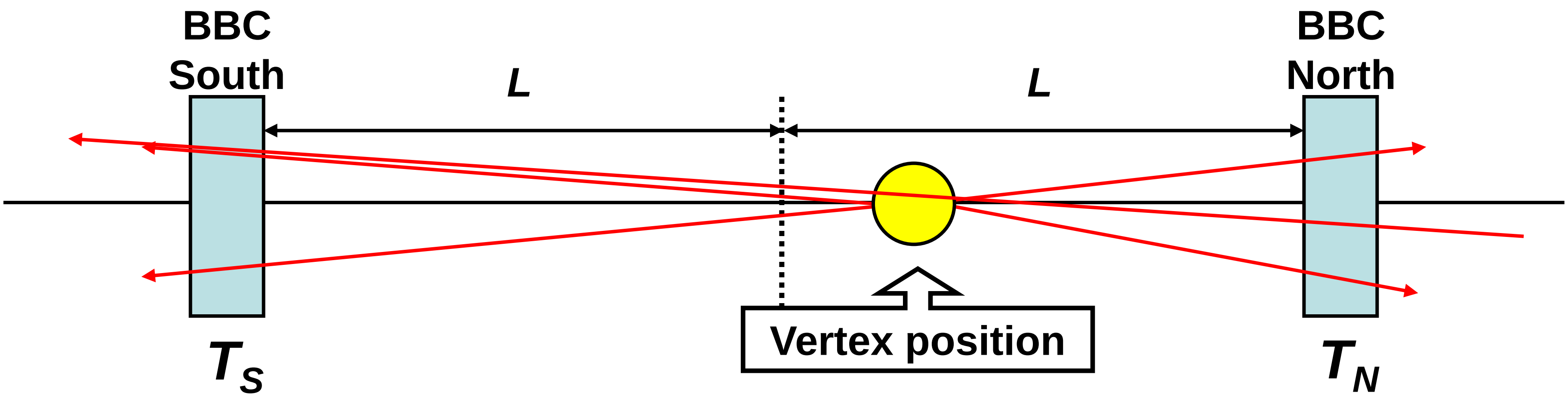
PHENIX Beam Beam Counter

BBC has 64 elements for North and South arm.

Each element consists of quartz Cherenkov radiator and meshed dynode PMT.

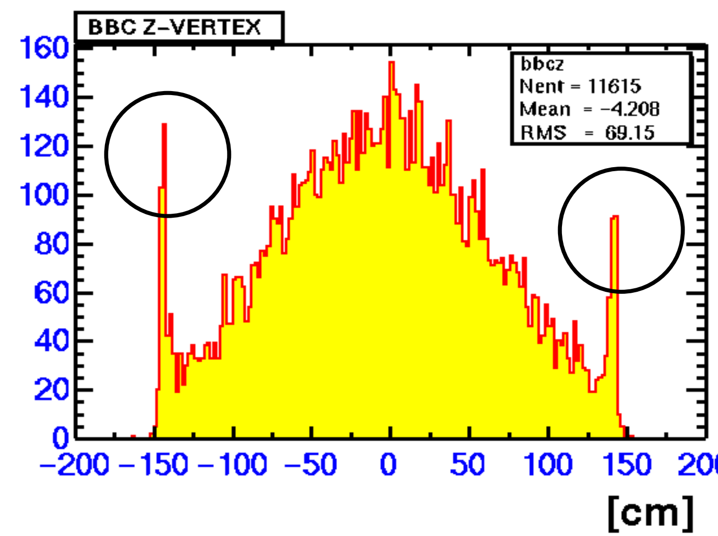


Z-Vertex and Time zero



- ***Z-Vertex*** $= \dfrac{T_S - T_N}{2} \times c$

- **Time zero** $= \dfrac{T_S + T_N - 2L/c}{2}$

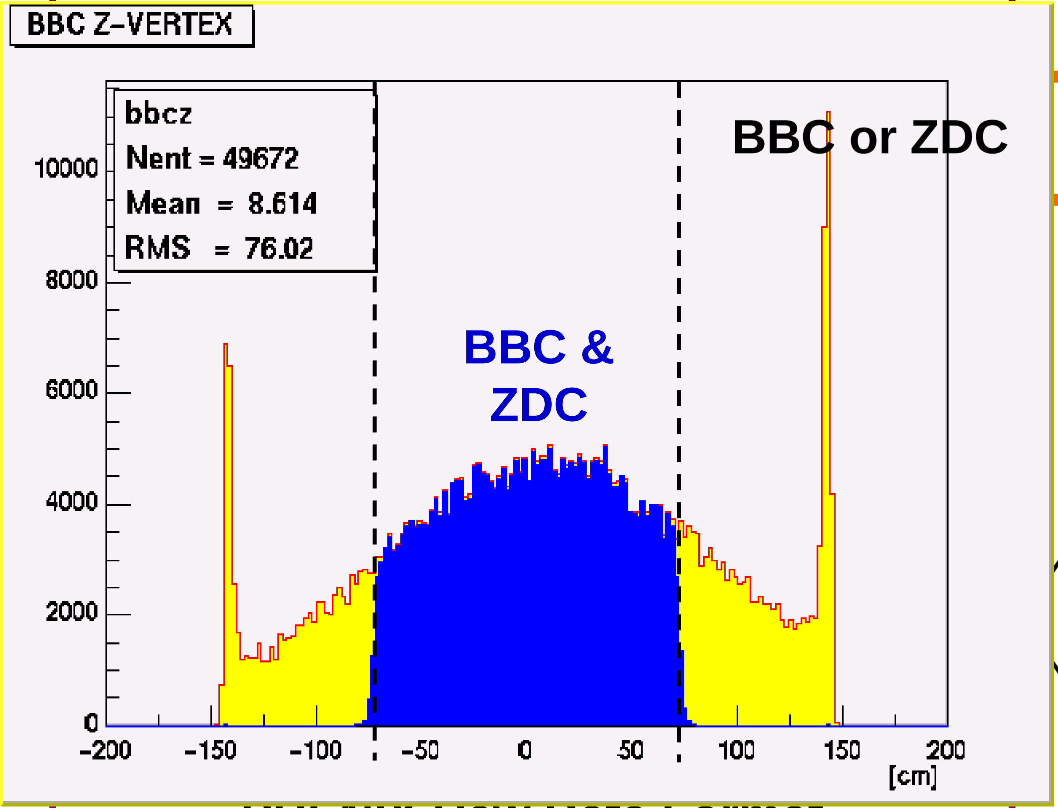


$T_{N/S}$: average hit time, c : light velocity, L : 144.35 cm

Readout

Analog signal (PMT output) from BBC

Digitized at Front End Module (FEM)



BBC Local Level 1

Global Level 1 decision

Minimum bias at Run2 (Au+Au)
(BBCN>=2 & BBCS>=2
& BBCZ<75 [cm])
&
(ZDCN & ZDCS)

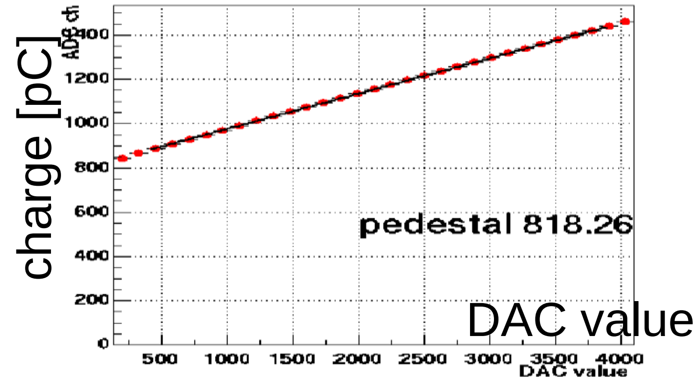
other subsystem data

PHENIX Raw Data Format

Calibration (ADC, TDC)

details in PHENIX Technical Note 393

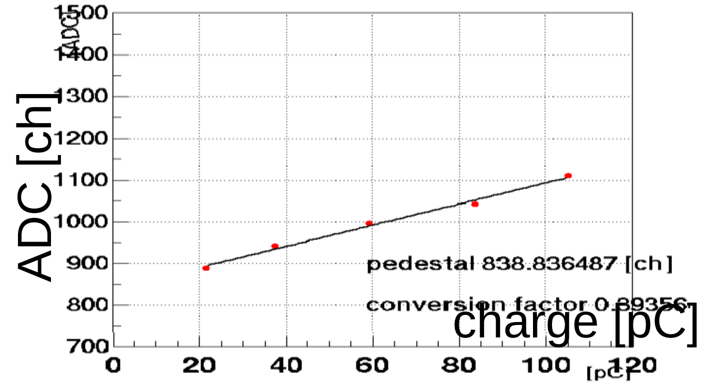
- **Pedestal of ADC was obtained by extrapolating the fit line at the zero DAC value for all 128 channels.**



- **ADC conversion factor [pC/ch] was obtained by external charge injection.**

Conversion factor : ~0.4 [pC/ch]

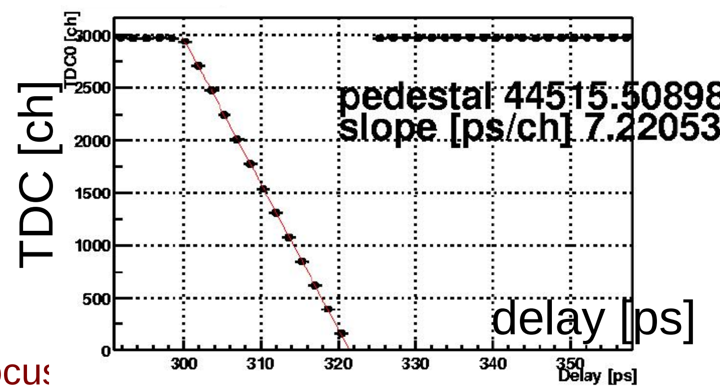
Dynamic range : ~1200pC



- **TDC conversion factor [ns/ch] was measured using test pulse delay.**

Conversion factor : ~7 [ps/ch]

Dynamic range : ~20 [ns]

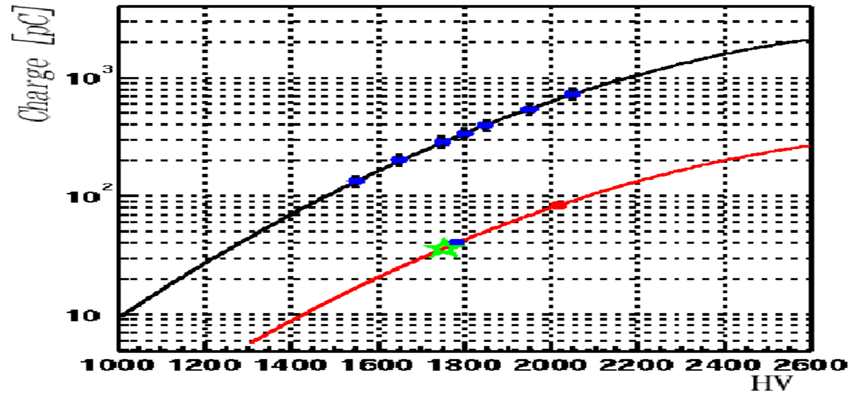


Calibration (HV, Z-offset)

PHENIX Beam Beam Counter

- Gain curve of each PMT was obtained by laser. It is scaled to measured output charge of one MIP peak. Operational HV value were determined to 40 pC for one MIP, so that the dynamic range of ADC is ~30 MIP.

details in PHENIX Technical Note 393

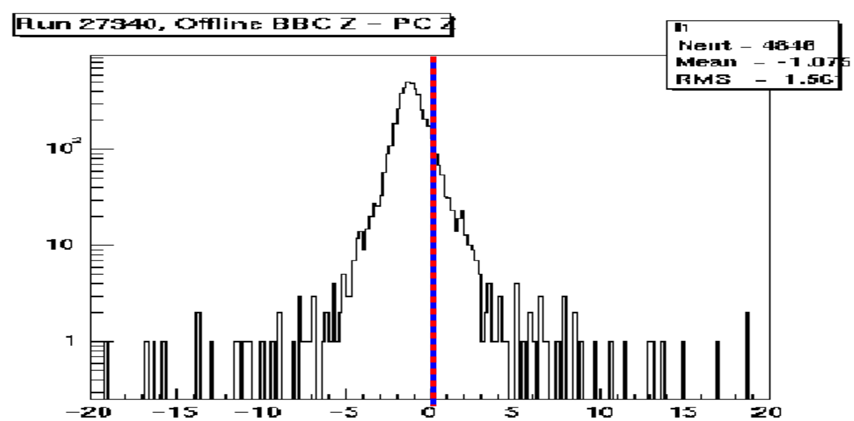


$$f(HV) = \exp(p0 + p1 \cdot HV + p2 \cdot HV^2)$$

- BBC cannot provide absolute Z-vertex positions by itself because it is calculated by the hit timings of North and South. Global offset is adjusted to PC-Z at Run2, which is geometrically adjusted center of PHENIX.

In this case, offset is 1.075cm

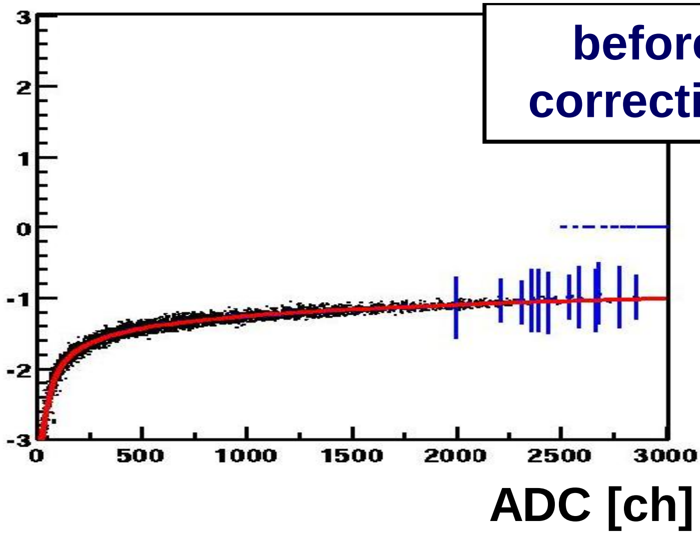
(BBC Z) - (Pad Chamber Z)



Slewing Correction

details in PHENIX Technical Note 393

(Reference time) – (PMT hit time) of typical PMT



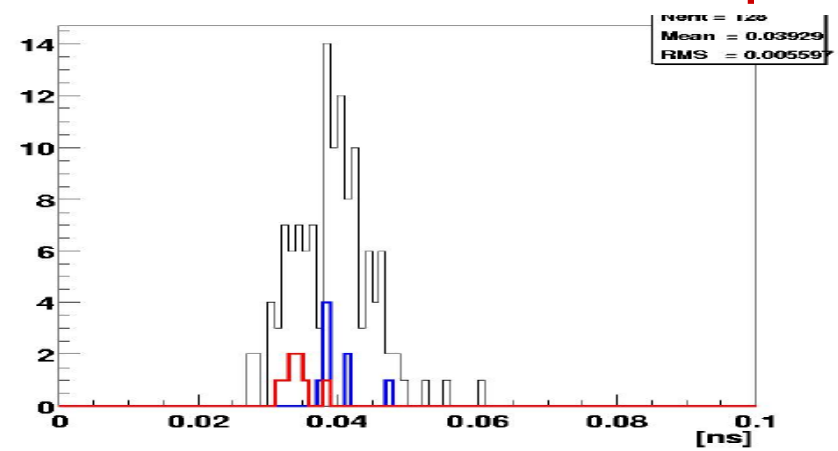
Slewing effect was corrected by this empirical function

$$f(x) = a + \frac{b}{ADC} + c \cdot \log(ADC)$$

a, b, c : constant

ADC : after pedestal subtraction

Intrinsic time resolution : 40±5ps



Resolution at RUN2 (Au+Au)

BBCZ - PCZ **BBCZ - ZDCZ** **PCZ - ZDCZ**

$$\sigma^2_{BBC-PC} = \sigma^2_{BBC} + \sigma^2_{PC}$$

$$\sigma^2_{BBC-ZDC} = \sigma^2_{BBC} + \sigma^2_{ZDC}$$

$$\sigma^2_{ZDC-PC} = \sigma^2_{ZDC} + \sigma^2_{PC}$$

Time Zero : 20 [ps]

Z-Vertex : 0.6 [cm]

Back Ground Source

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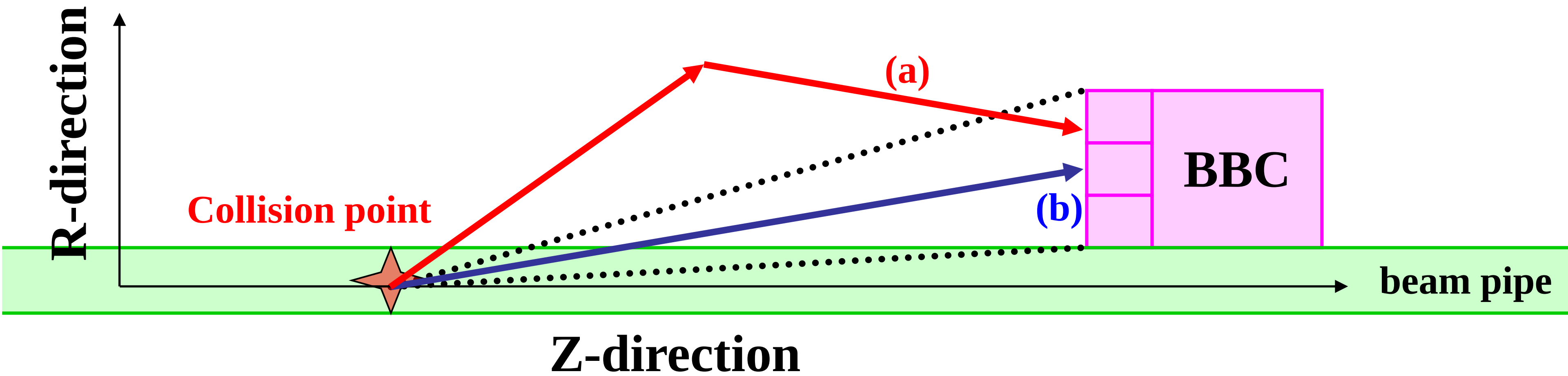
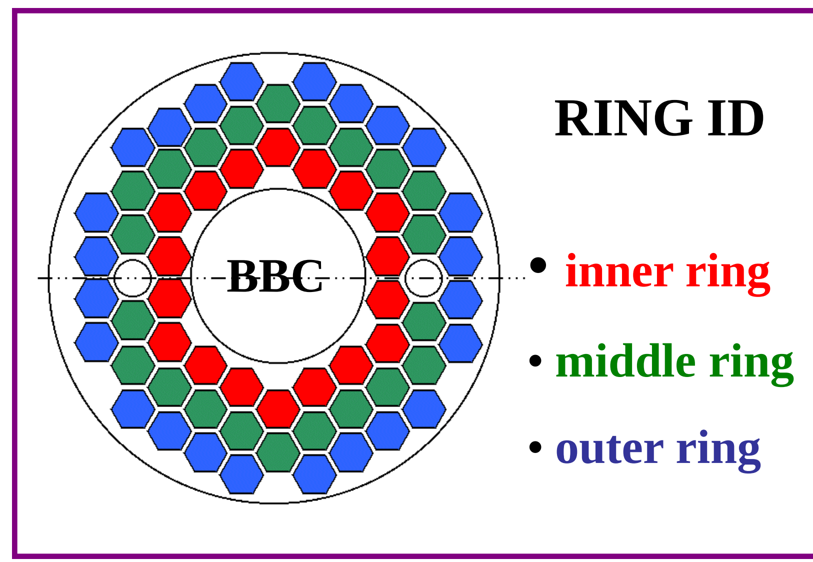


(a) : External track not coming from collision

(b) : Internal track coming from collision



- **50% of external track was estimated compared to all injected particles using HIJING Au+Au 130GeV events.**

inner ring = 43%
middle ring = 52%
outer ring = 57%

- **Main background source is beam pipe**

Beryllium (thickness 1.02 [mm]) : < 75 [cm]
Stainless Steal (thickness 1.24 [mm]) : < 200 [cm]

BBC Response in Simulation

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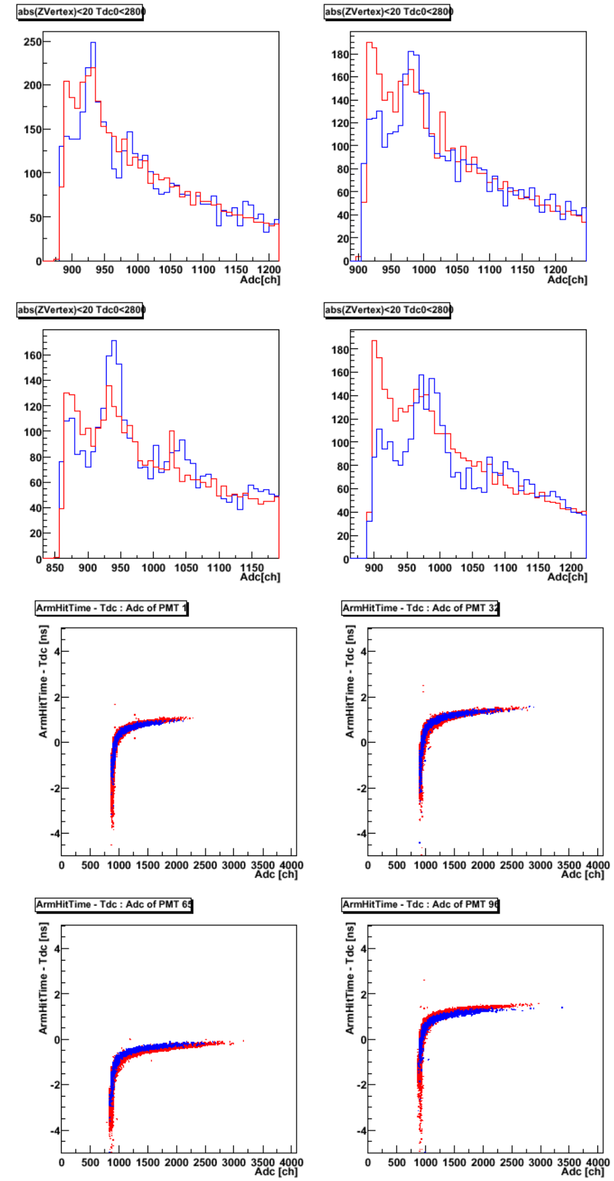
Tuned parameter for BBC response

- PMT gains based on observed MIP peak
- One sigma width of observed MIP peak
- ADC pedestal value
- ADC conversion factors [pC/ch]
- TDC overflow value
- TDC RMS of overflow value
- TDC conversion factors [pC/ch]
- TDC threshold value
- Slewing effect and parameters
- PMT intrinsic time resolution
- Relative time offset between North and South



Events for Trigger Efficiency

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• HIJING 1.35 (Au+Au 200GeV) with default options was used to obtain trigger efficiency of BBC at Run2 (Au+Au).

impact parameter < 25 [fm]

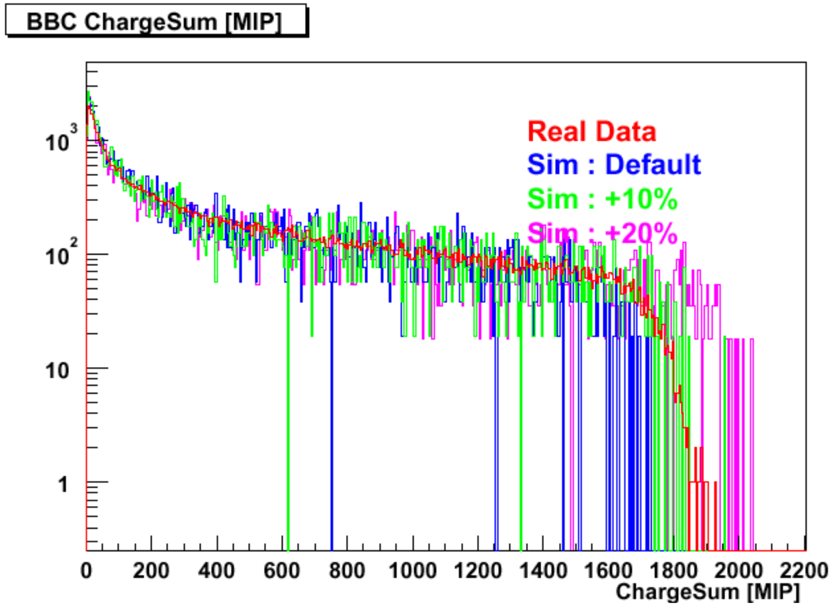
sqrt(s_{NN}) = 200 [GeV]

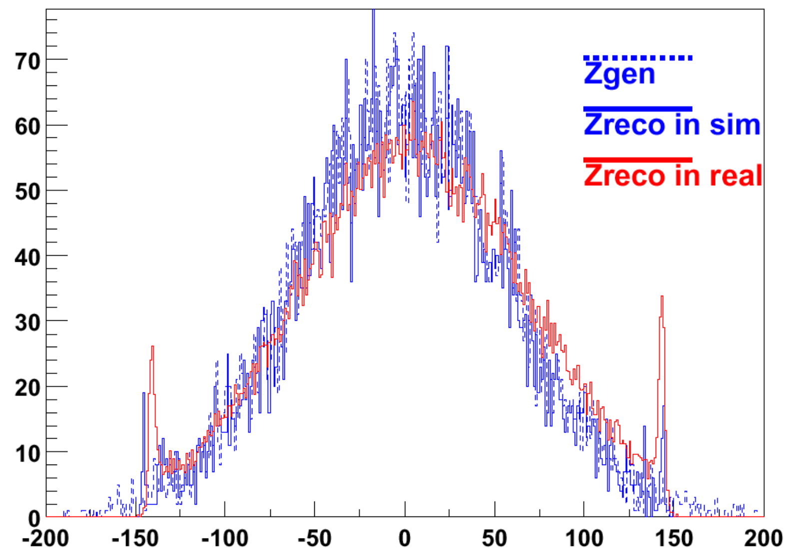
dN/dy in HIJING events are modified to evaluate systematic uncertainty because of trigger biases is model dependent.

• Z-Vertex distribution was adjusted to real data of run# 26030.

• The exactly same Level 1 emulator was applied to both real data and above simulated data.

details in PHENIX Analysis Note 107





Definition of Trigger Efficiency

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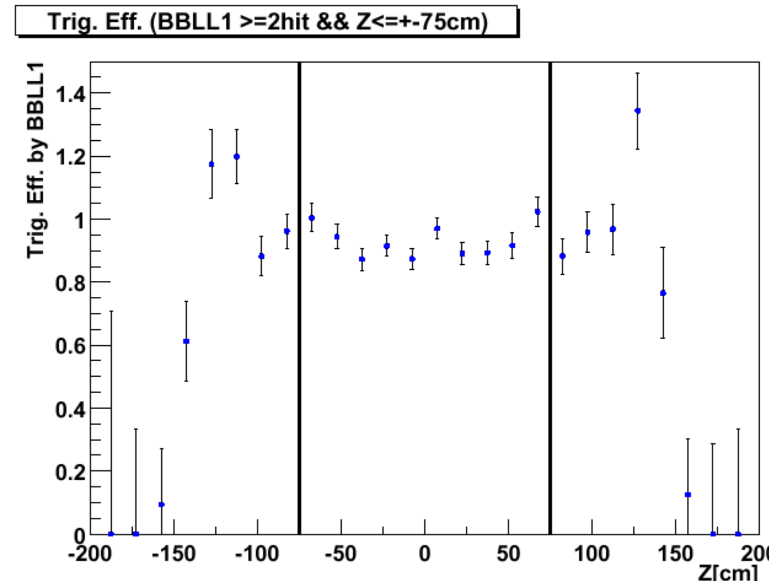
Efficiency required only BBC Local Level 1

$$eff\,(LL1) \equiv \sum_{i}^{N(LL1)} \varepsilon_i(LL1) \times w_i(LL1)$$

$$\varepsilon_i(LL1) \equiv \frac{N_i(LL1cut) \mid Z_{reco}}{N_i(generated) \mid Z_{true}}$$

$$w_i(LL1) \equiv \frac{1/N_i(generated) \mid Z_{true}}{\sum_{i}^{N(LL1)} 1/N_i(generated) \mid Z_{true}}$$

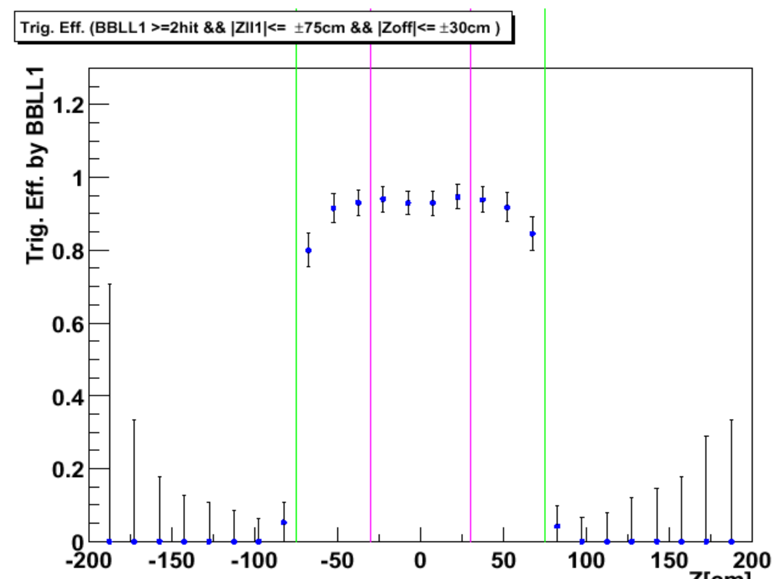


Efficiency required BBC Local Level 1 and offline vertex cut

$$eff\,(OFF) \equiv \sum_{i}^{N(OFF)} \varepsilon_i(OFF) \times w_i(OFF)$$

$$\varepsilon_i(OFF) \equiv \frac{N_i(LL1cut\,\&\,OFFcut) \mid Z_{reco}}{N_i(generated) \mid Z_{true}}$$

$$w_i(OFF) \equiv \frac{1/N_i(generated) \mid Z_{true}}{\sum_{i}^{N(OFF)} 1/N_i(generated) \mid Z_{true}}$$



Trigger Efficiency

details in PHENIX Analysis Note 107

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Systematic uncertainties

BBLL1 cut : 75cm
Offline Vertex cut : 30cm

1) Input dN/dy

used modified HIJING events as controlled samples ±1.29%

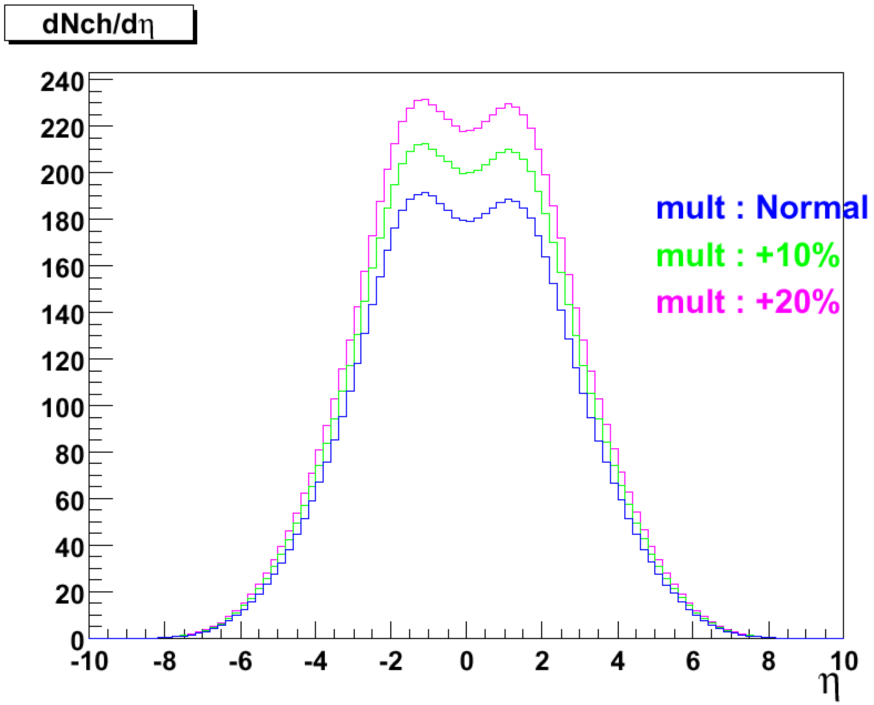
2) Input Z-vertex distributions

due to cutting edge of BBLL1 vertex cut

- 0.56%

3) Trigger threshold on TDC1

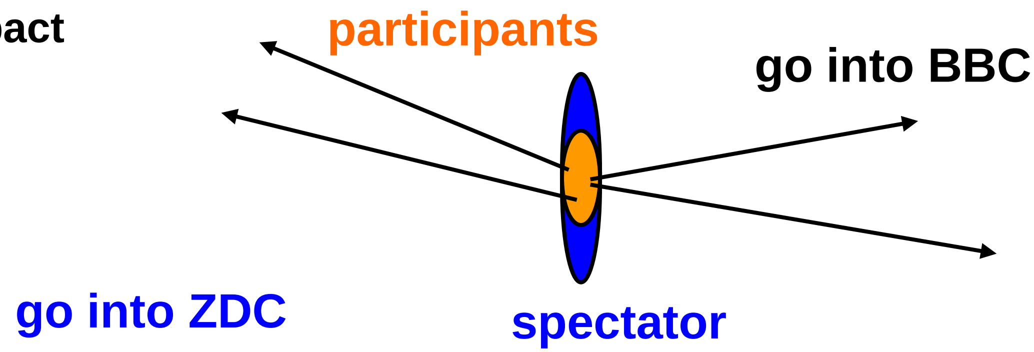
±0.75%

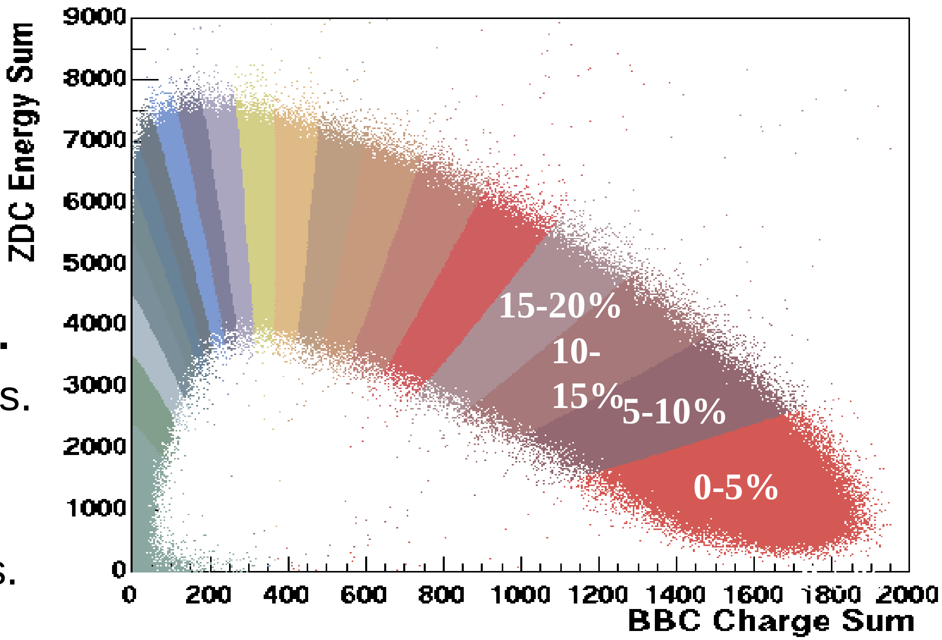


Trigger Efficiency : 93.1% ± 0.4%(stat.) ± 1.6%(syst.)

Centrality Determination

- Event characterization in terms of impact parameter (b) in Au+Au collisions.
  – Large : peripheral collision
  – Small : central collision
- Coincidence between BBC and ZDC.
  – Determine collision centrality.
  – 93 % of inelastic cross section can be seen.
- Extract variables using Glauber Model
  – Number of participants (*N_part*).
    - Number of nucleons participate in a collision.
    - Represents centrality.
    - Related with soft physics.
  – Number of binary collisions (*N_binary*).
    - Number of Nucleon-Nucleon collisions.
    - Related with hard physics.
    - Incoherent sum of N-N collisions becomes a baseline for A-A collisions.





Time of Flight Resolution

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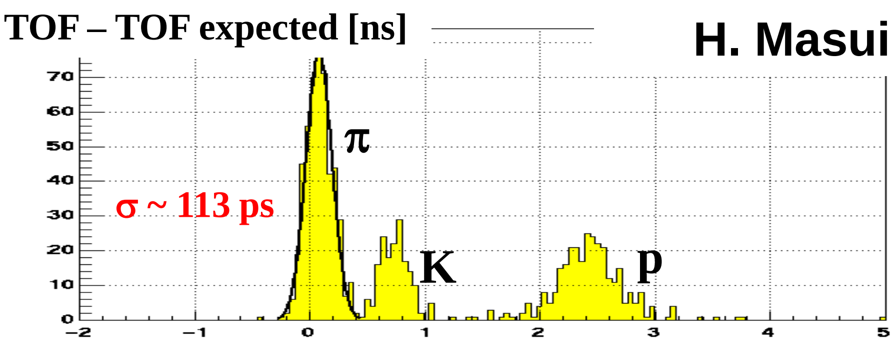
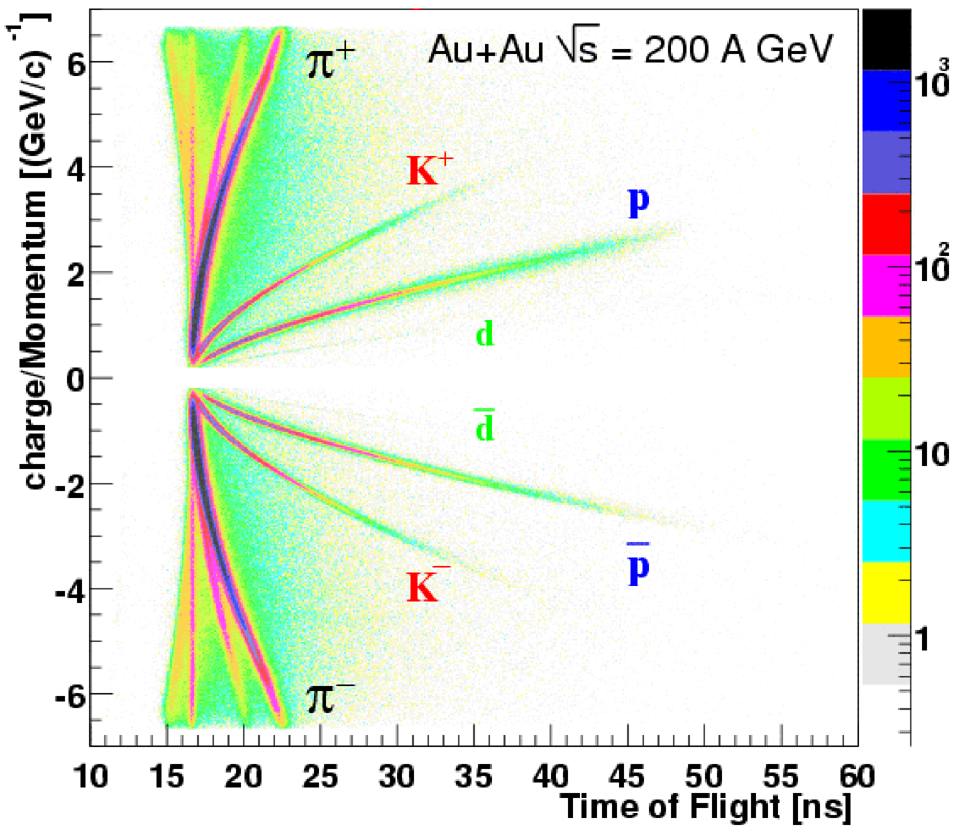




- Resolution of time zero (start timing) by BBC is 20 [ps]
- Resolution of Time of Flight is 113 [ps]

$$\sigma_{ToF} \approx \sqrt{(\sigma_{start})^2 + (\sigma_{stop})^2}$$

$$\sigma_{start} : BBC$$

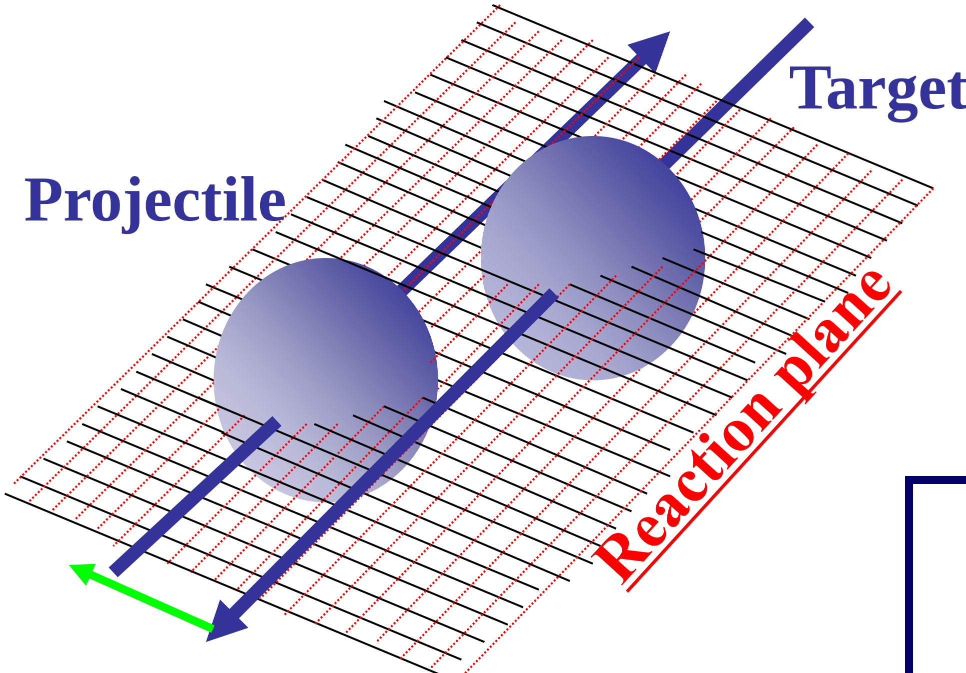
$$\sigma_{stop} : TOF$$

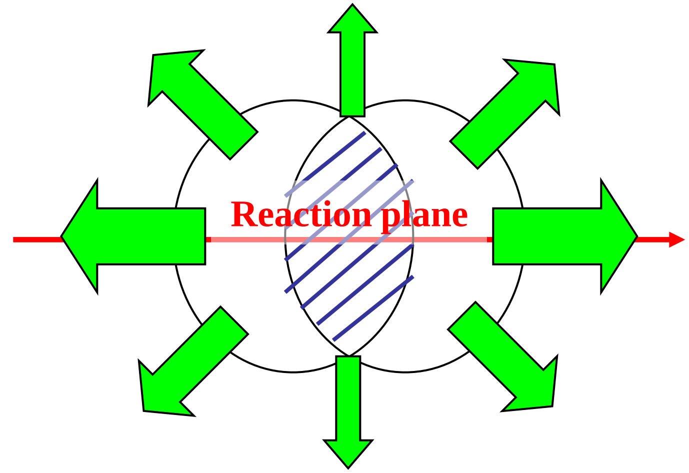
- Resolution of TOF detector (stop timing) is 111 [ps]

Reaction Plane

details in PHENIX Analysis Note 151 : S. Esumi et al. (Univ. of Tsukuba)

PHENIX Beam Beam Counter





b:impact parameter

initial geometry → final momentum anisotropy

collective flow, hard processes,
Jet-quenching and HBT radii, etc…

reaction plain (Ψ) by BBC

$$\tan(n\Psi) = \frac{\sum_{i=0}^{64} ADC_i \sin(n\phi_i)}{\sum_{i=0}^{64} ADC_i \cos(n\phi_i)}$$

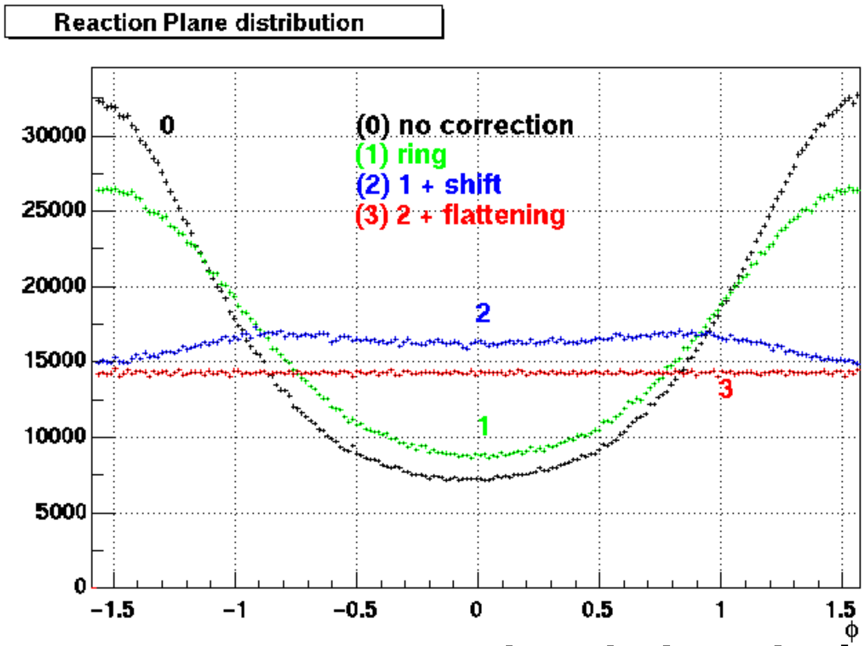
ADC_i : calibrated ADC of each PMT

Φ_i : azimuthal location of each PMT

n : order of harmonics

Reaction Plane by BBC

PHENIX Beam Beam Counter



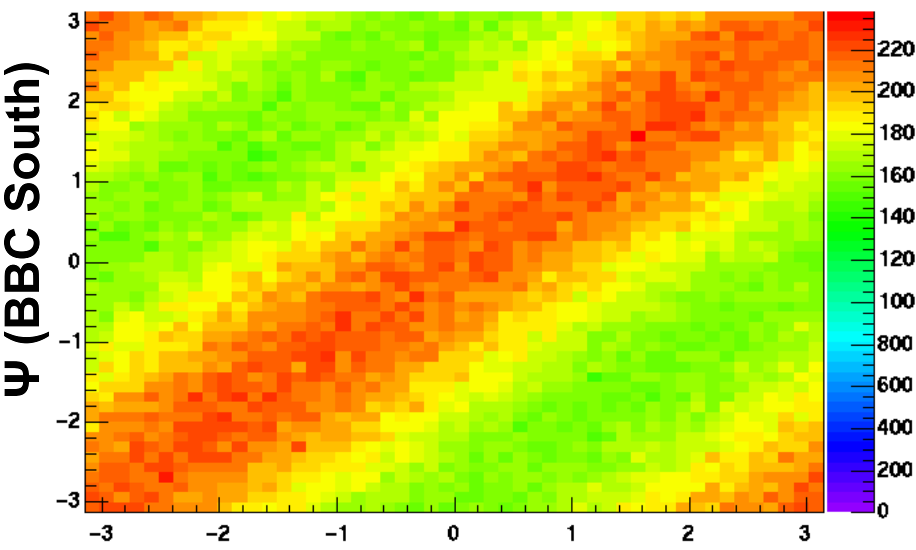
azimuthal angle Φ

details in PHENIX Analysis Note 151 : S. Esumi et al. (Univ. of Tsukuba)

-- no correction
-- ring-by-ring gain correction
-- average subtraction (shift correction)
-- fluttening

after collection

Reaction plane correlation



Reaction Plane Resolution

PHENIX Beam Beam Counter

$$\sigma \equiv <\cos(n(\Psi_{measured} - \Psi_{true}))>$$

$$<\cos(n(\Psi_A - \Psi_B))> = <\cos(n(\Psi_A - \Psi_{real}) - (\Psi_B - \Psi_{real}))>$$

$$= <\cos(n(\Psi_A - \Psi_{real})><\cos(n(\Psi_B - \Psi_{real})>$$

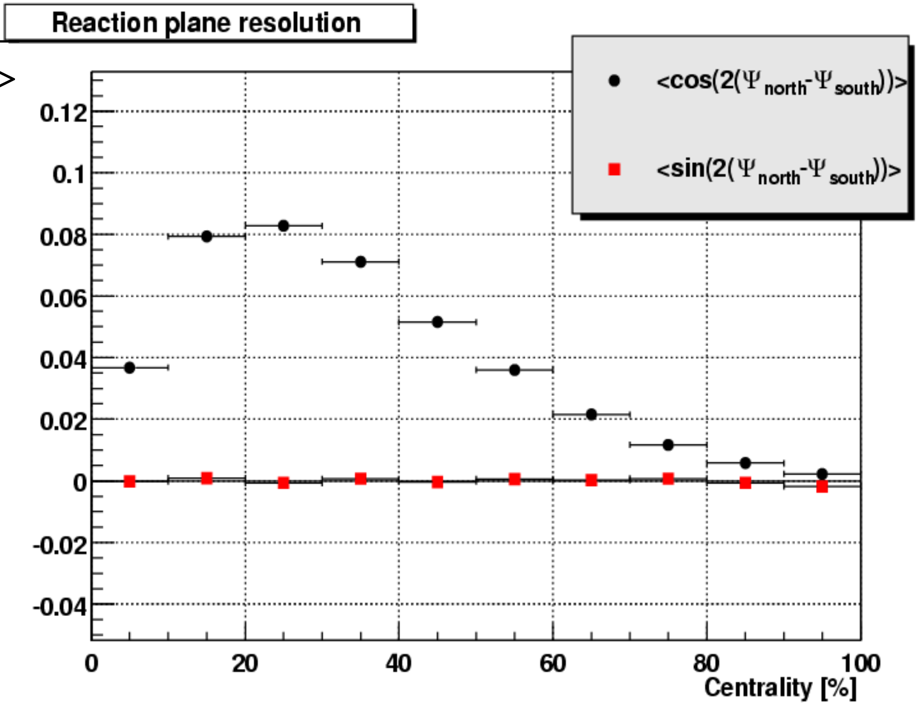
$$+ <\sin(n(\Psi_A - \Psi_{real})><\sin(n(\Psi_B - \Psi_{real})>$$

$$= <\cos(n(\Psi_A - \Psi_{real})><\cos(n(\Psi_B - \Psi_{real})>$$

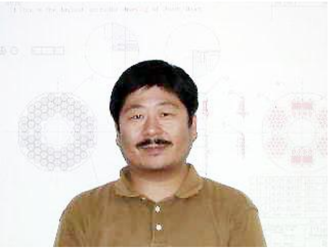
$$<\cos(n(\Psi_A - \Psi_{real})> = \sqrt{<\cos(n(\Psi_A - \Psi_B))>}$$

details in PHENIX Analysis Note 151 : S. Esumi et al. (Univ. of Tsukuba)

- **central region : small elliptic flow**
- **mid-central region : best resolution**
- **peripheral region : low number of tracks**



BBC People (current member)



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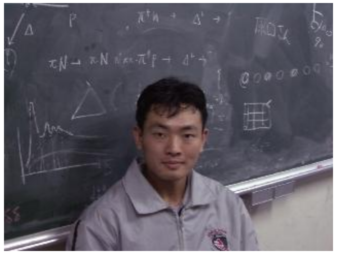

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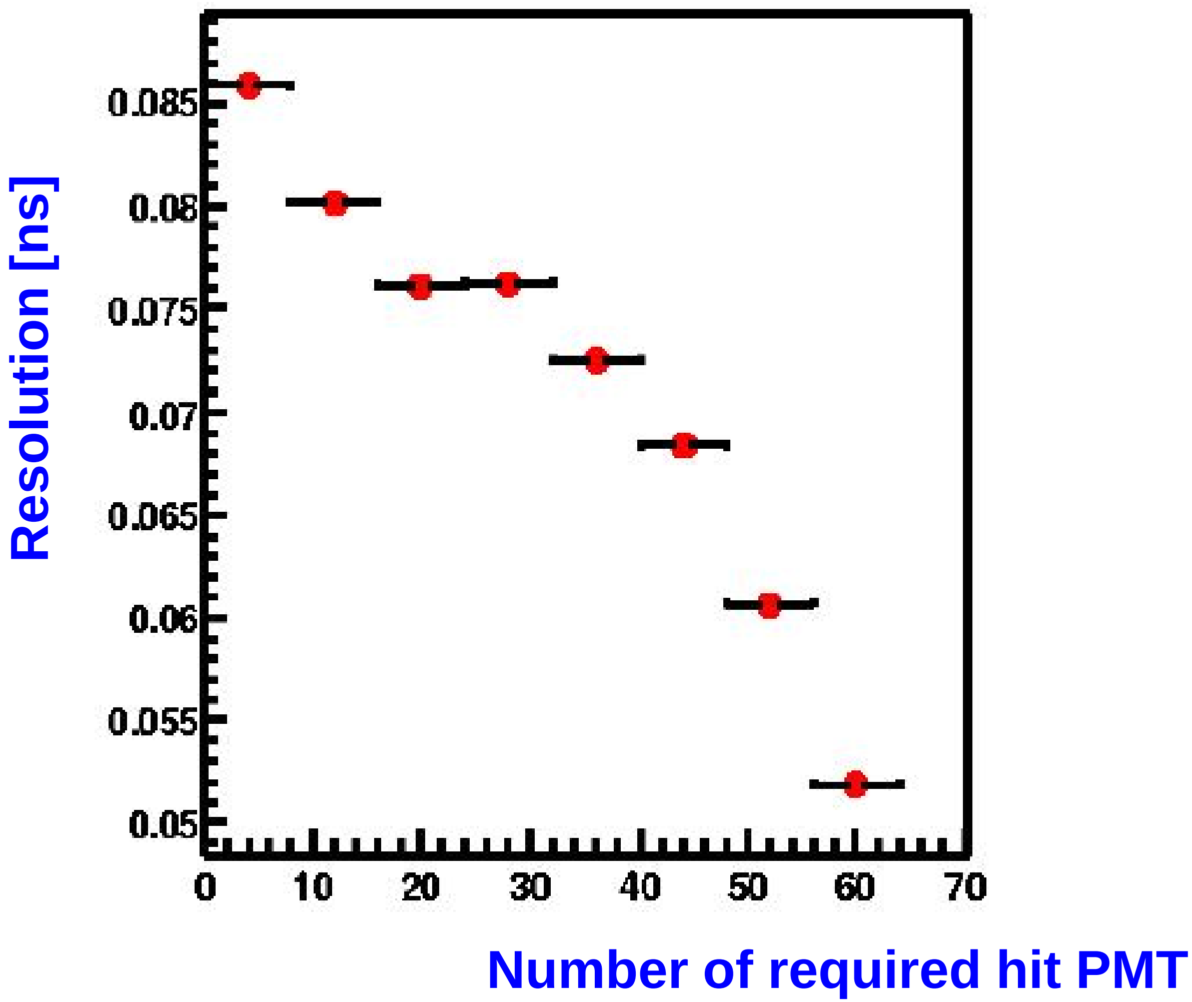
Backup

Multiplicity dependence of Intrinsic time resolution

PHENIX Beam Beam Counter

Typical PMT



Injected particles to BBC

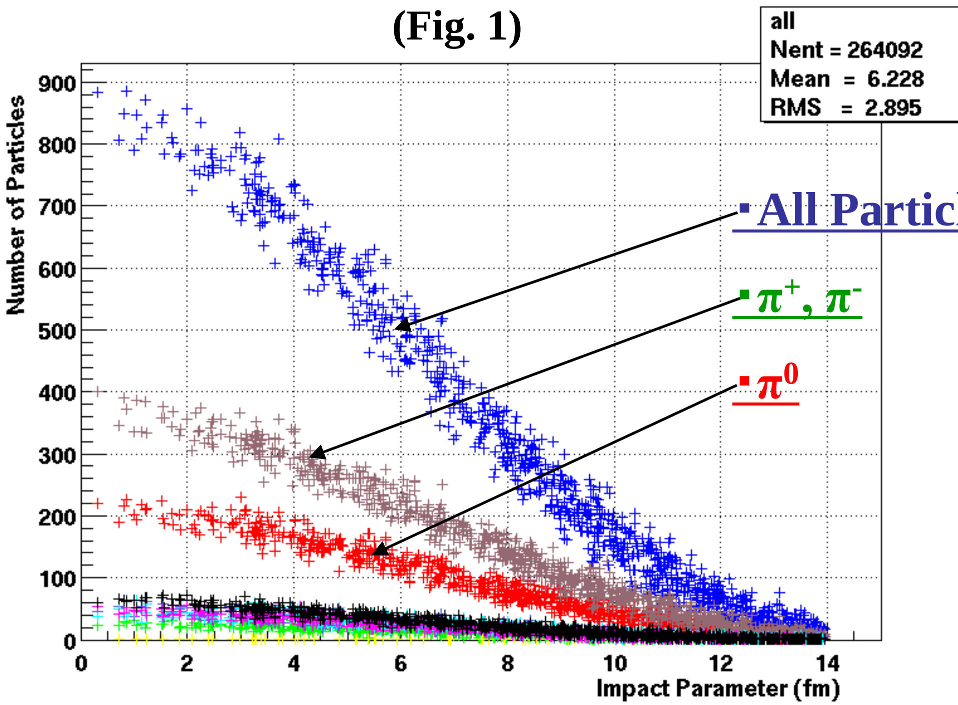
PHENIX Beam Beam Counter

HIJING Au+Au √s 130 A GeV
minimum bias (0<b<14 fm)

HIJING emits 0~900 particles in the acceptance of BBC.

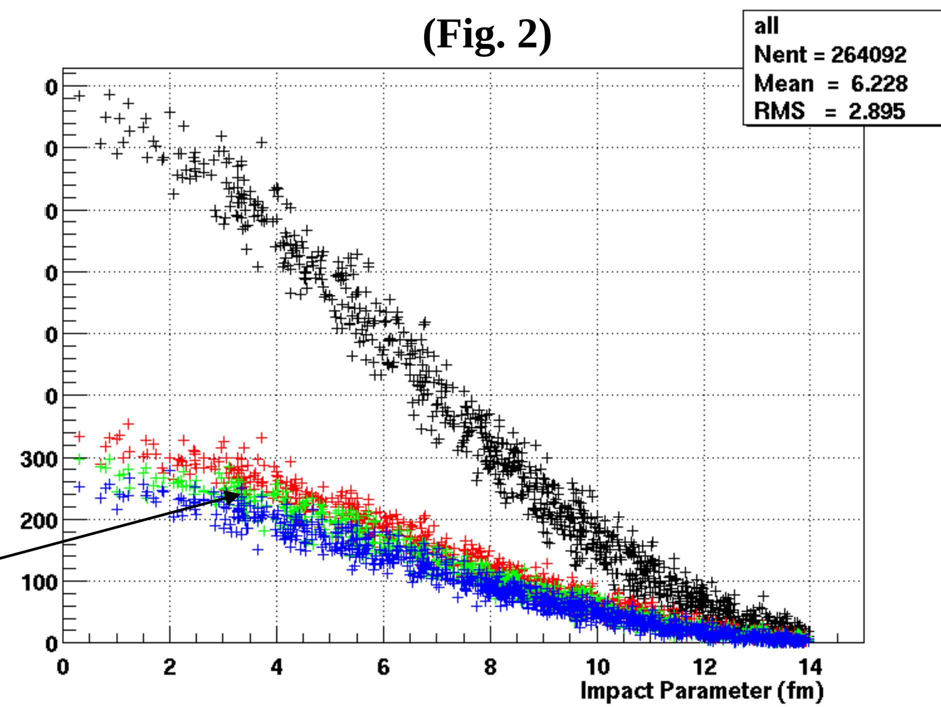
- Fig. 1 : (Number of Particles vs. Impact Parameter) by PID
- Fig. 2 : (Number of Particles vs. Impact Parameter) ring by ring of BBC

(Fig. 1)



- All Particles
- π^+, π^-
- π^0

(Fig. 2)

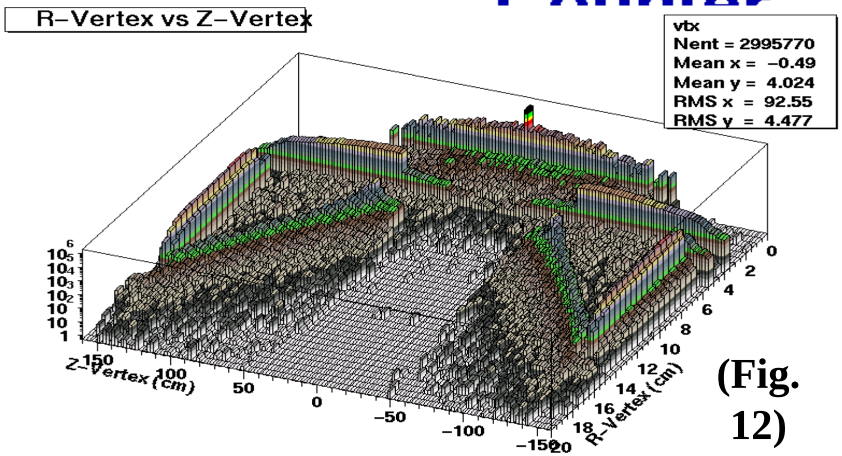


Initial velocity > 0.7 c

- Inner Ring (2.98 < |η| < 3.50)
- Middle Ring (3.20 < |η| < 3.50)
- Outer Ring (3.50 < |η| < 3.92)

Background Source

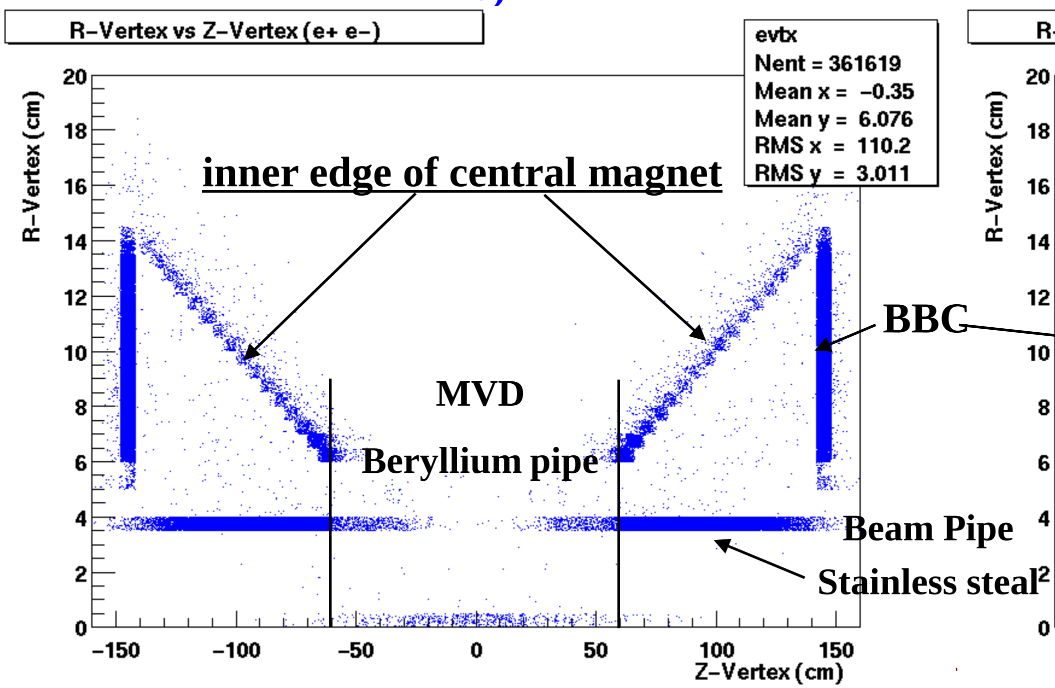
This is all vertex position of each secondary particles that are injected to BBC. Fig.10 is electron or positron at each vertex position. Fig.11 is charged pion. Almost of electron and positron are produced at beam pipe of Stainless steal.

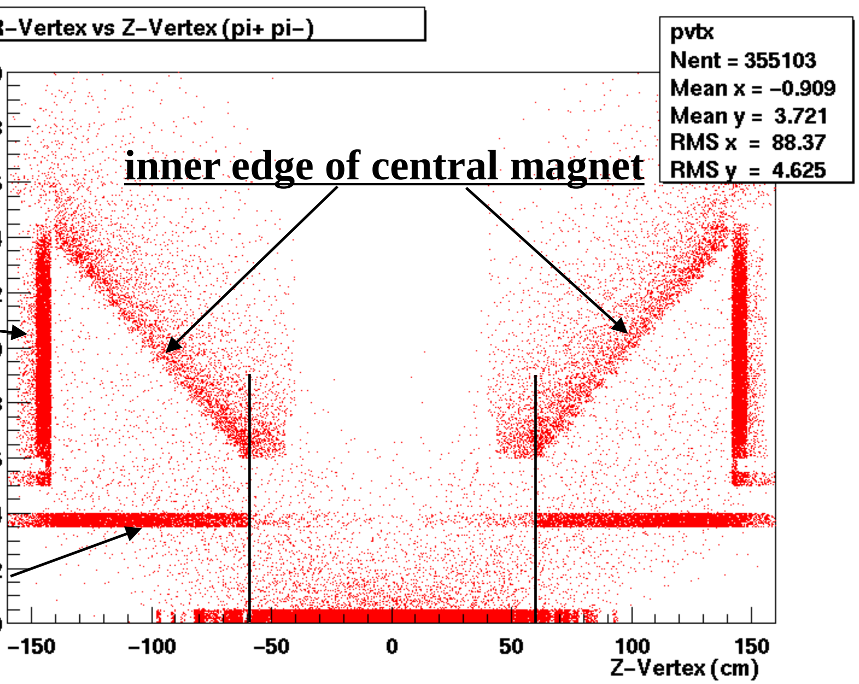


(Fig. 12)

electron, positron at each position (Fig. 10)

π^+, π^- at each position (Fig. 11)





Material Contribution

PHENIX Beam Beam Counter

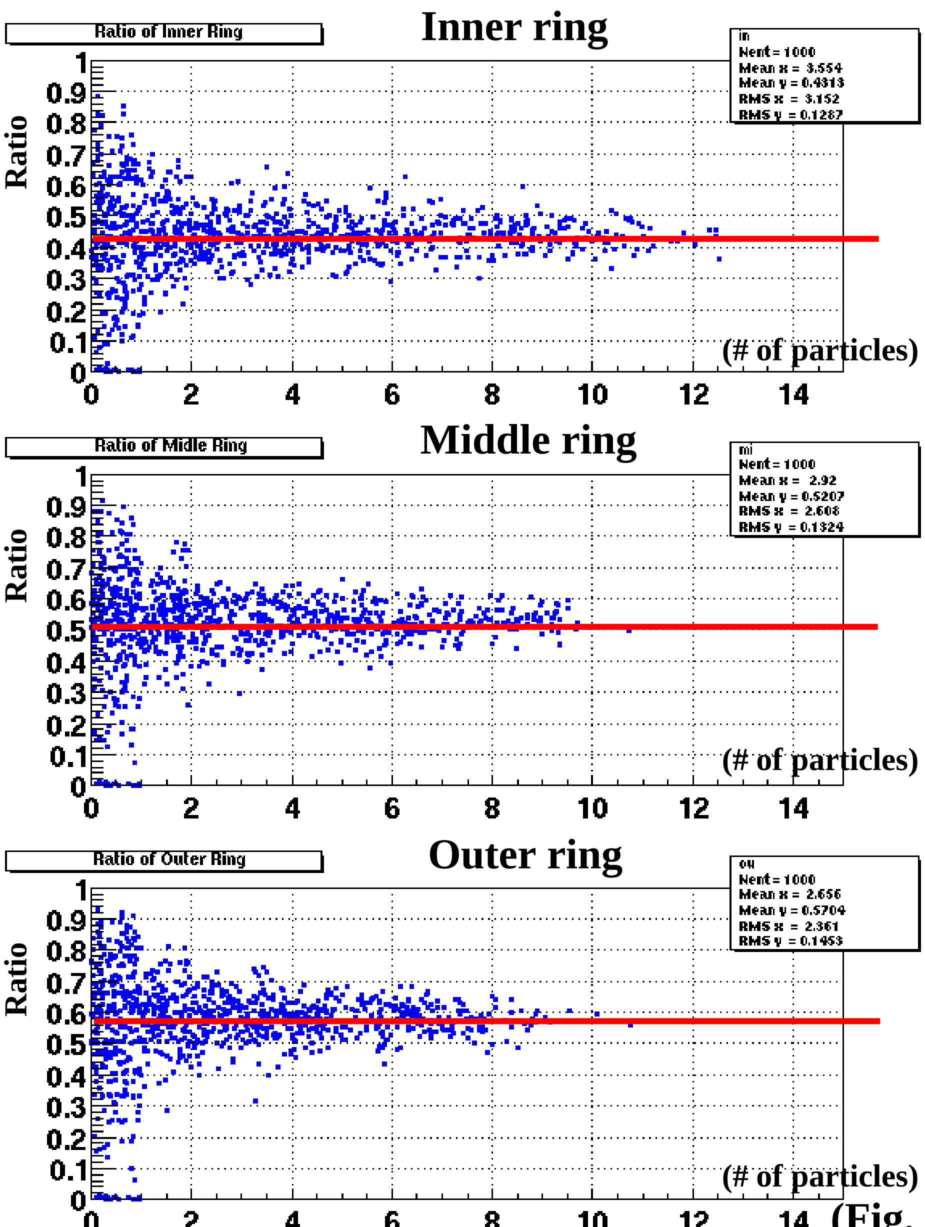
Ratio of external particles (External/All Injected)

vs. Number of particles per one PMT

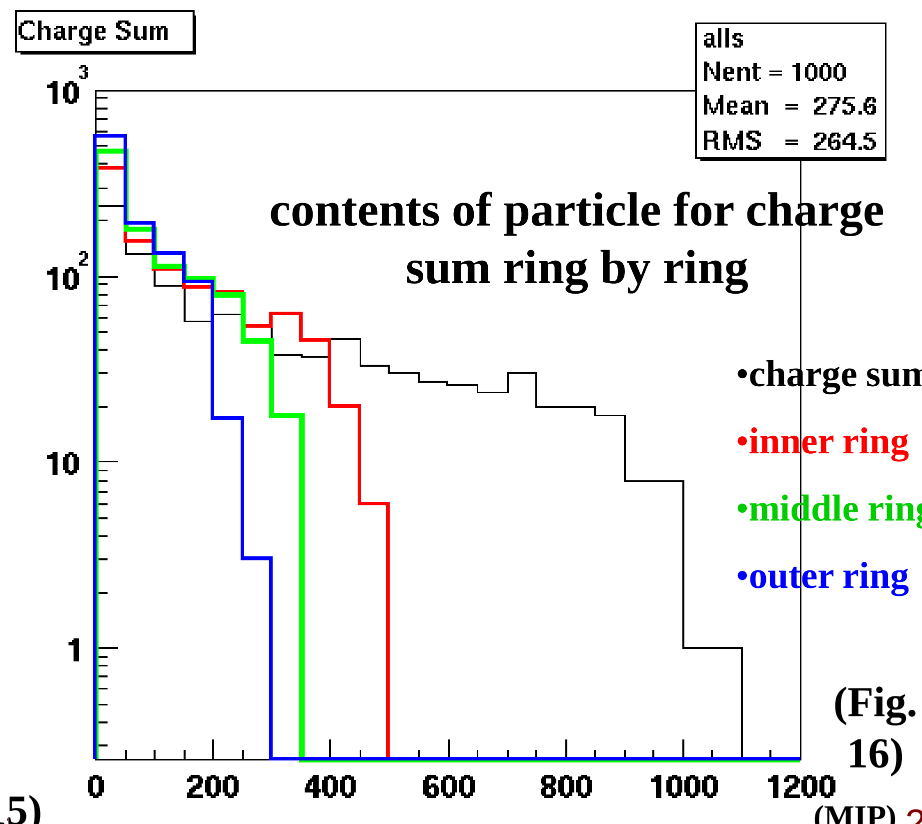
- **HIJING Au + Au $\sqrt{s}$ = 130 A GeV**

  minimum bias (0<b<14 fm)

- **Z-Vertex (0 cm)**



(Fig. 15)



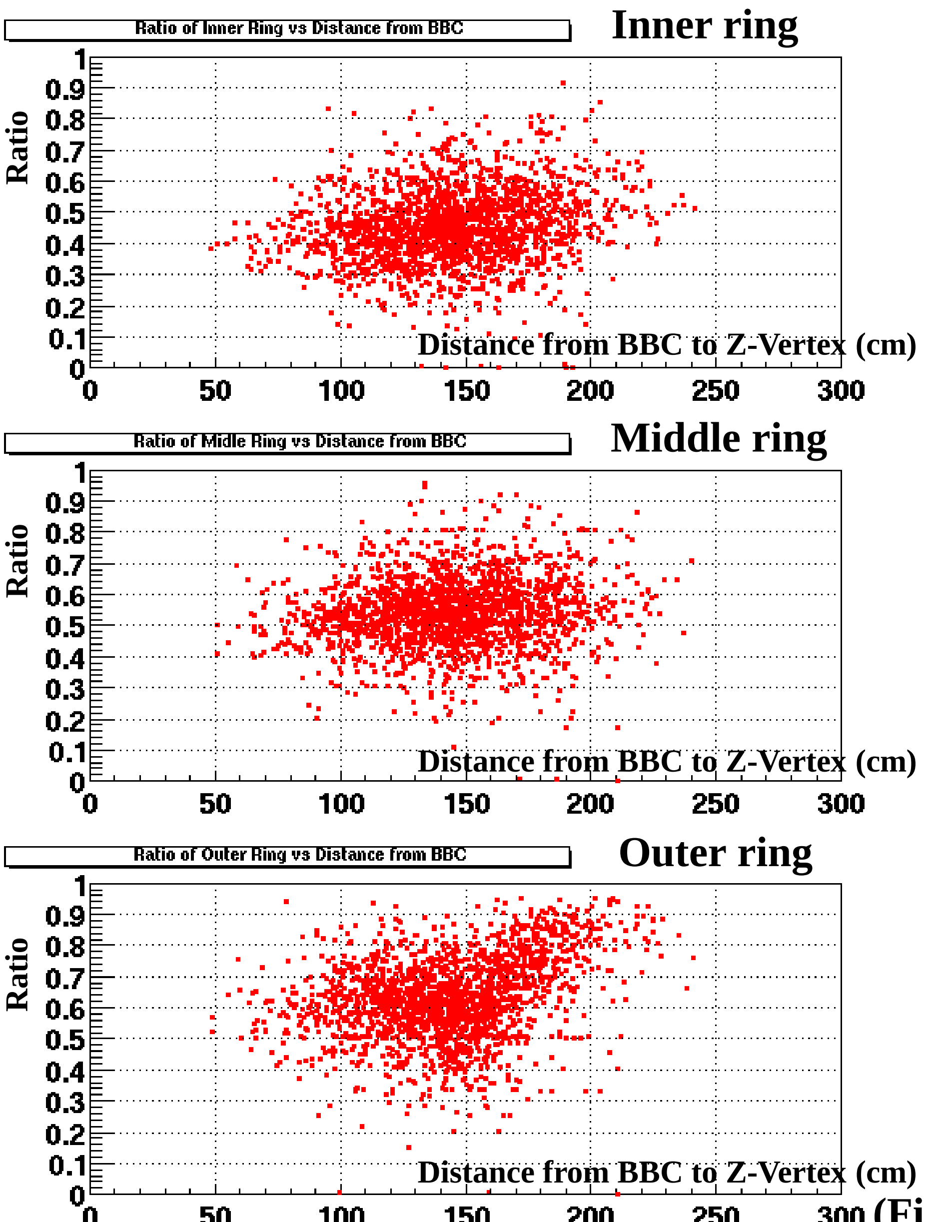
(Fig. 16)

Z-vertex dependence

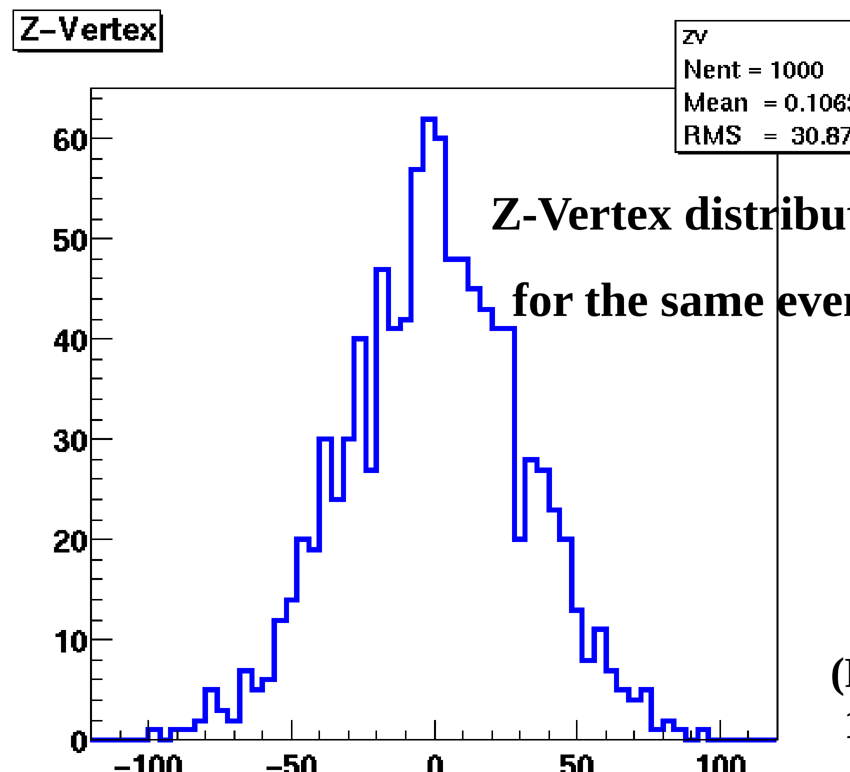
PHENIX Beam Beam Counter

Ratio of external particles (External/All Injected) **vs. Distance from BBC to Z-Vertex point** (cm)

- HIJING Au + Au $\sqrt{s}$ = 130 A GeV
  minimum bias (0<b<14 fm)
- Z-Vertex (RMS = 30 cm)



(Fig. 17)



(Fig. 18)

BBC Response (ADC)

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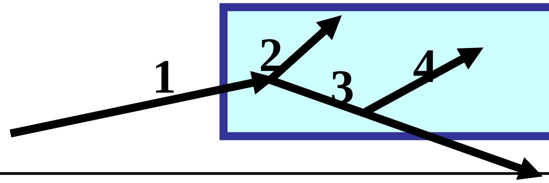
At Cherenkov detector, number of produced photo electron is calculated by this formula.

$$N_{photo\_electron} = L \cdot \frac{\alpha^2 \cdot z^2}{r_e \cdot m_e \cdot c^2} \int \varepsilon_c \cdot \varepsilon_d \cdot \sin^2 \theta dE$$

$$\frac{\alpha^2 \cdot z^2}{r_e \cdot m_e \cdot c^2} = 370 cm^{-1} eV^{-1}$$

BBC quartz



$$N_{photo\_electron} = L \cdot N_0 < \sin^2 \theta_c >$$

L : path length of particles in quartz

ε_c : collecting Cherenkov light efficiency

ε_d : quantum efficiency of photo electron conversion

β>0.7 and incident angle>±45°

$$N_{photo\_electron} = \sum_{i=1}^{ntracks} L_i \cdot N_0 \cdot (1 - 1/(\beta_i \cdot Index)^2)$$

Charge value of PMT output is calculated by PMTGainFactor and # of Photoelectron.

$$PMToutput[pC] = N_{p.e.} \cdot PMTGainFactor \cdot e$$

ADC input value is split in FEM.

$$ADCinput[pC] = N_{p.e.} \cdot e \cdot PMTGainFactor \cdot SplitInFEM$$

BBC Response (ADC)

PHENIX Beam Beam Counter

- **Charge value for ADC input is summarized by this constant value.**

$$ADCinput[pC] = Const \cdot \sum_{i=1}^{ntracks} L_i (1-(1-\beta \cdot Index)^2)$$

$$Const = N_0 \cdot e \cdot PMTGainFactor \cdot SplitInFEM$$

- **This constant value is tuned by 1 MIP peak of real data for 128 ADC channel.**
- **This ADC charge value is randomized by Gauss function with width of 1 MIP, channel by channel.**

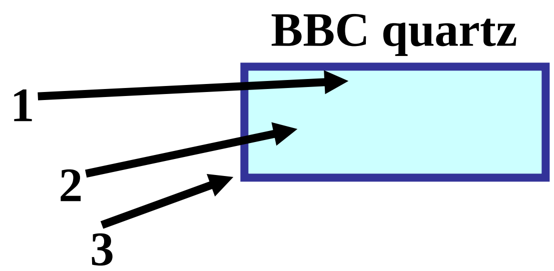
$$ADC[ch] = ADCinput / ADCChannelGain + Pedestal$$

- **After randomization, charge value is converted to ADC[ch] by ADC conversion factor [pC/ch] and pedestal, which is obtained by internal charge injection.**

BBC Response (TDC)

PHENIX Beam Beam Counter

• **Time of Flight is extracted from GEANT as fastest track** $\beta > 0.7$
and incident angle>±45



• **Threshold was applied for each TDC**
TDC1 (ADC>5pC), TDC1 (ADC>15pC)

• **Slewing effect is implemented**

TDC[ns] = TOF – (SlewParA + SlewParB/ADC_without pedestal

+ SlewParC*log(ADC without pedestal))

• **Intrinsic timing resolution was added for each channel.**
Timing offset was added.

TzeroOffset=(BBC_Zvertex-PC_Zvertex)/2 (North+, South-)

TDC[ch] = (TDC+TzeroOffset)/Conversion_factor + GlobalTimingoffset

• **Global timing offset set to 1500 [ch], which is center of time window of TDC.**