# Measurement of Charged Particle Multiplicity at RHIC with PHENIX Multiplicity & Vertex Detector

Tahsina Ferdousi
University of California Riverside

November 22, 2002

# Outline

- Motivation
- Quark-gluon Plasma
- Heavy-ion Collisions at RHIC
- PHENIX Experiment at RHIC
- The Multiplicity & Vertex Detector at PHENIX
- Measurement of Charged Particle Multiplicity with MVD
- Model Comparison
- Summary

# Motivation

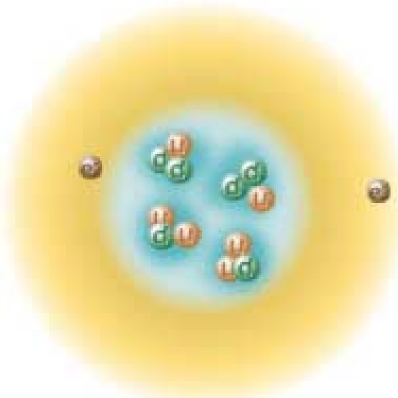
- Heavy Ion Collisions at RHIC Energies are expected to produce a new Phase of matter (Quark-gluon plasma).
  - There are a number of potential signatures to be studied for the formation a the QGP.
  - The Signatures are studied simultaneously as a function of the energy density $\varepsilon$.
- The charged particle multiplicity $dN/d\eta$ is related to $\varepsilon$ by the relation

$$\varepsilon = \frac{\sqrt{m_T^2 + \langle p_T^2 \rangle}}{\pi R^2 \tau_0} \frac{3}{2} \frac{dN}{dy}$$

  where $\langle p_t \rangle$ is the mean transverse energy of the tracks produced in the collision, $R \sim A^{1/3} \sim 6$ fm for Au and $\tau_0$ is the formation time $\sim 1$ fm/c
- Therefore the charged particle multiplicity can tell the initial energy density of formation.
- The potential signatures can be studied as a function of the $dN/d\eta$ ($dE_T/dy$), which are related to $\varepsilon$.

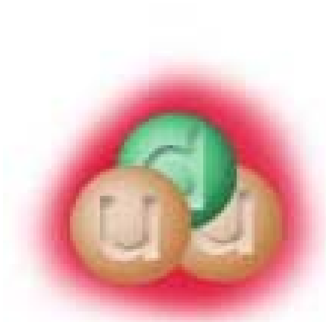
# Basic Building Block

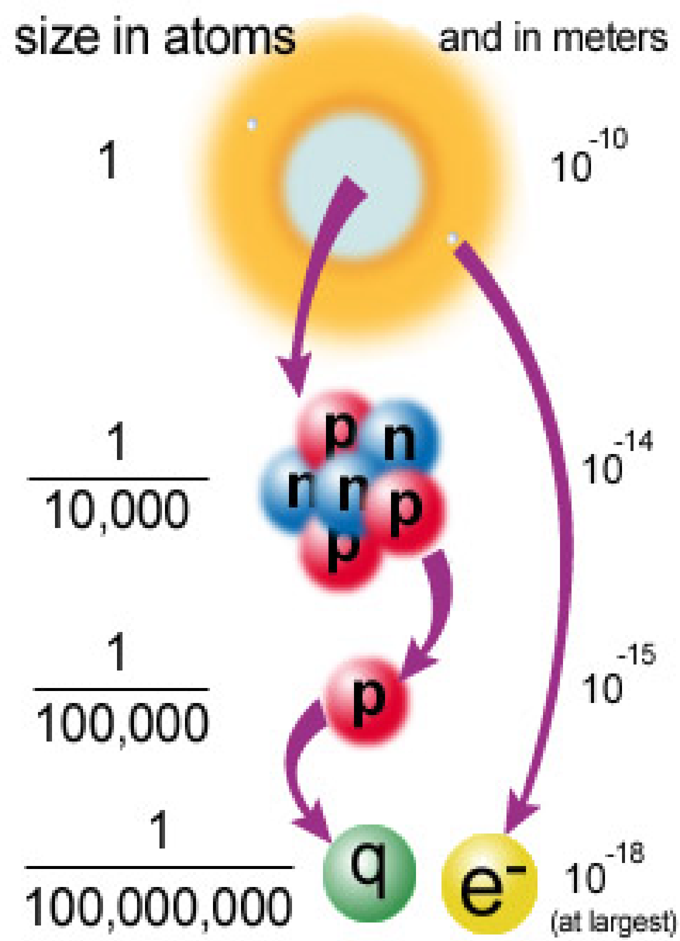
An *atom* is made up of *nucleus* and *electrons*



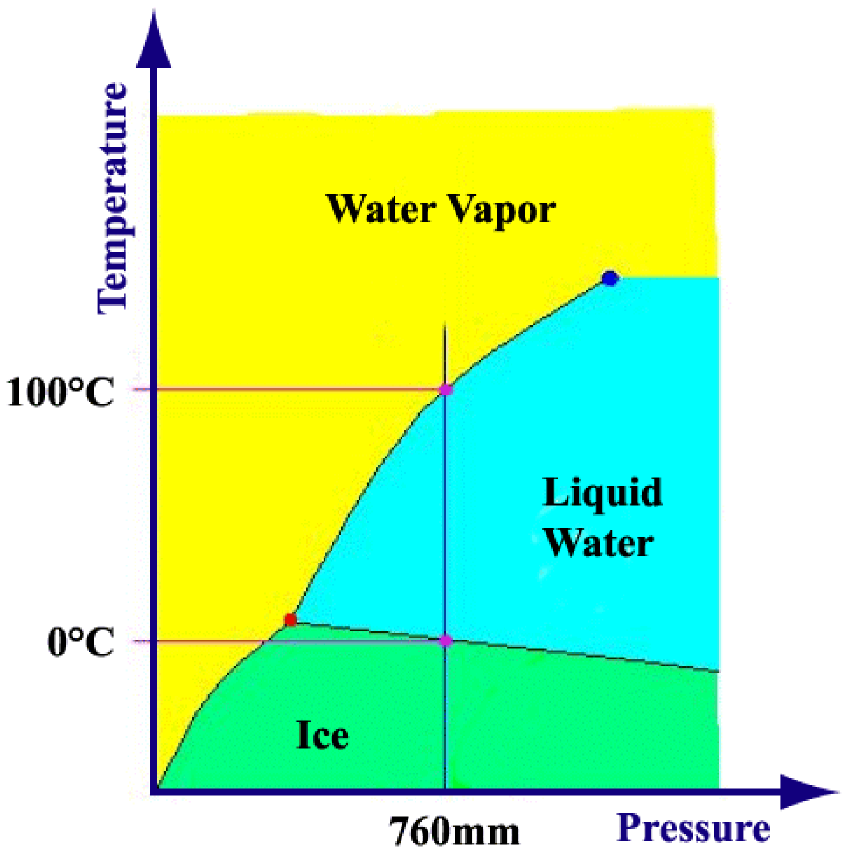
Nucleus contains *protons* and *neutrons*...

…which contain *up* and *down* *quarks*.

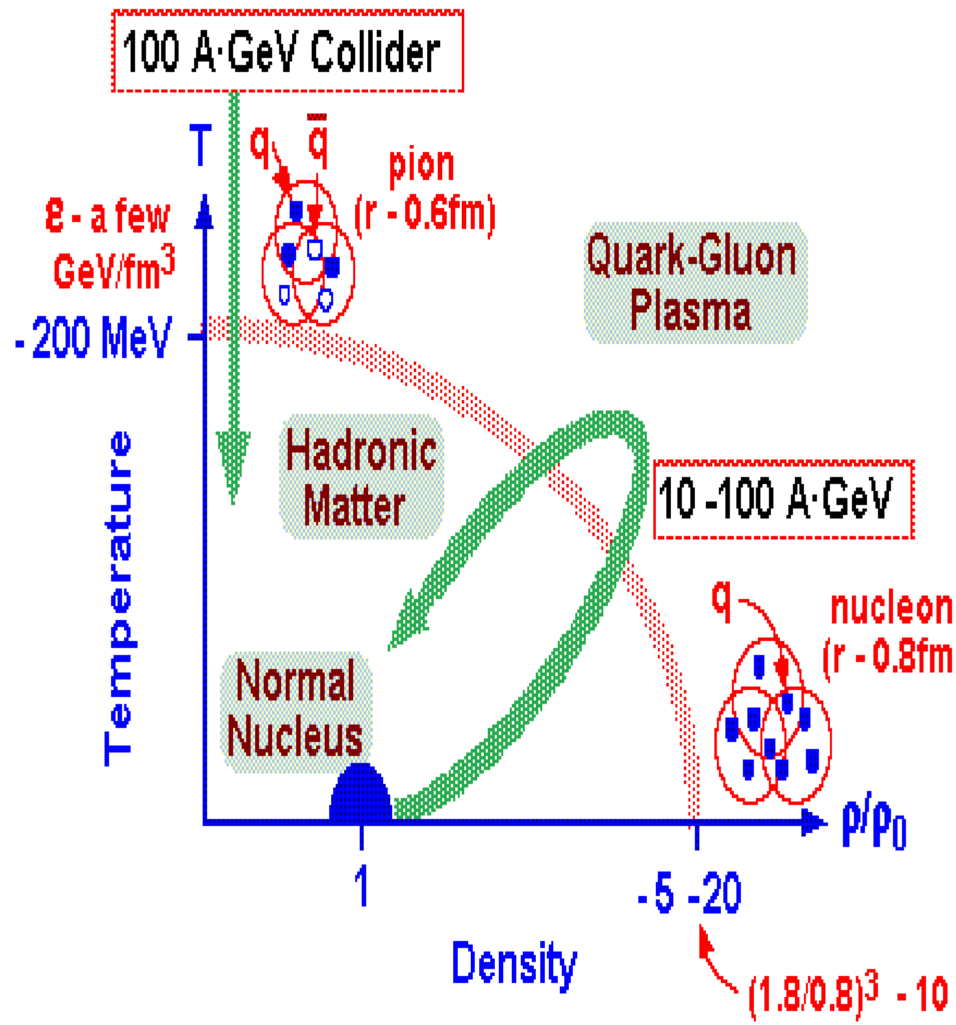




# Phase Diagram

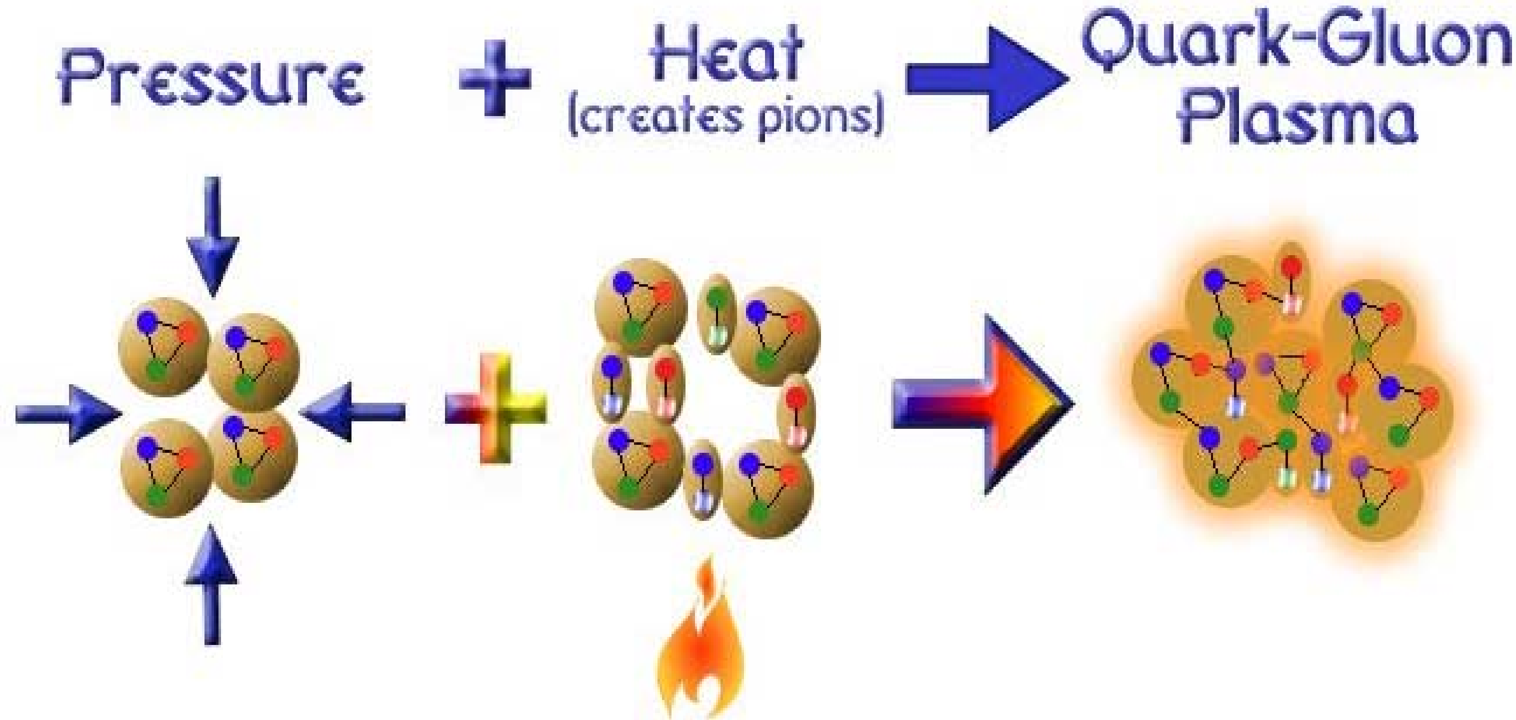



Water




Nuclear Matter

# How to Create QGP




Increase Baryon Density

(AGS/SPS)

Create hot region of high initial energy density $\varepsilon_0$ ~ few GeV/fm$^3$

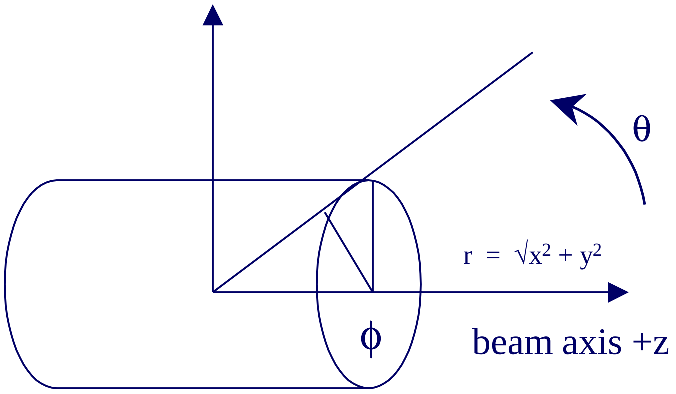
(RHIC)

Quarks and gluons become unbound to form a Quark Gluon Plasma (QGP)

# Kinematics

Transverse momentum $$p_T = \sqrt{p_x^2 + p_y^2} = p\sin\theta$$

Transverse Mass $$m_T = \sqrt{p_T^2 + m_0^2}$$




**PHENIX Coordinate System**

**Longitudinal : along z**

**Transverse : x-y plane**

Rapidity $$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right) = \frac{1}{2}\ln\left(\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right)$$

Pseudorapidity $$\eta = -\ln\left(\tan\frac{\theta}{2}\right)$$

$\eta \approx y$ when $p >> m_0$ and $\theta >> 1/\gamma$, where $\gamma = E/m$

Rapidity & Pseudorapidity

$$\eta = \frac{1}{2}\ln\left[\frac{\sqrt{m_T^2\cosh^2 y - m_0^2} + m_T\sinh y}{\sqrt{m_T^2\cosh^2 y - m_0^2} - m_T\sinh y}\right]$$

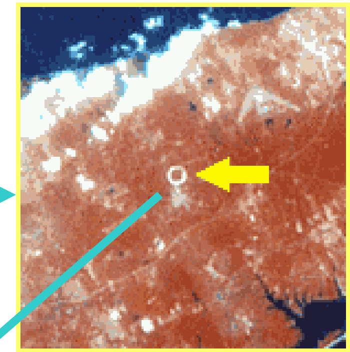
Relations between momentum and (pseudo)rapidity

$$E = m_T \cosh y$$

$$p_z = m_T \sinh y = p_T \sinh\eta$$

$$\frac{dN}{d\eta dp_T} = \sqrt{1 - \frac{m_0^2}{m_T^2\cosh^2 y}}\,\frac{dN}{dy dp_T}$$

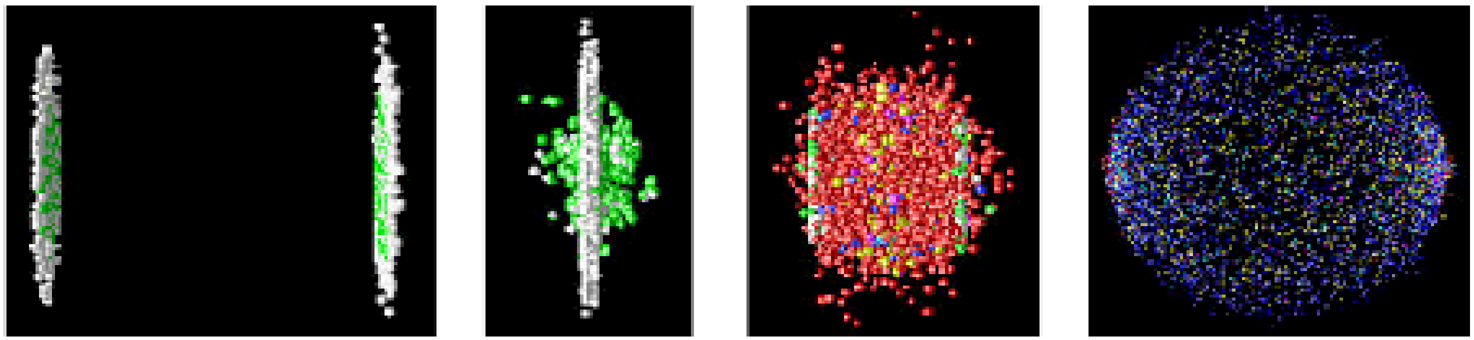
# Relativistic Heavy Ion Collider (RHIC)



Long Island, NY

RHIC Complex at the Brookhaven National Lab

# Heavy Ion Collisions at RHIC



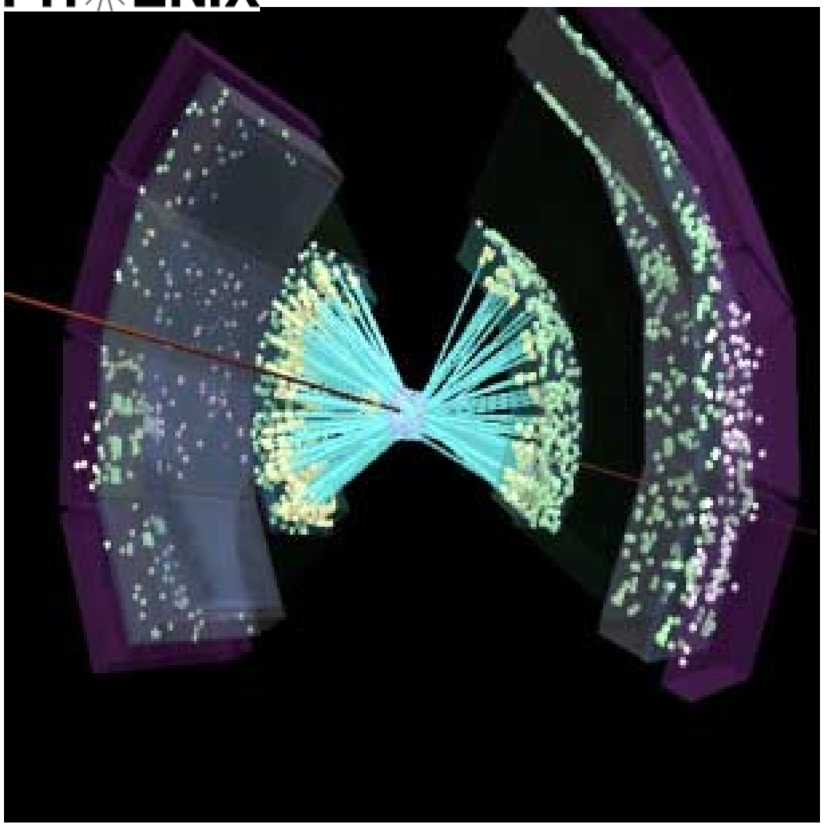
Two ions approach one another. The ions are flat, instead of spherical, because they're going 99.95% of the speed of light.

The two ions collide. If conditions are right, the collision "melts" the protons and neutrons and, for a brief instant, liberates the quarks and gluons.

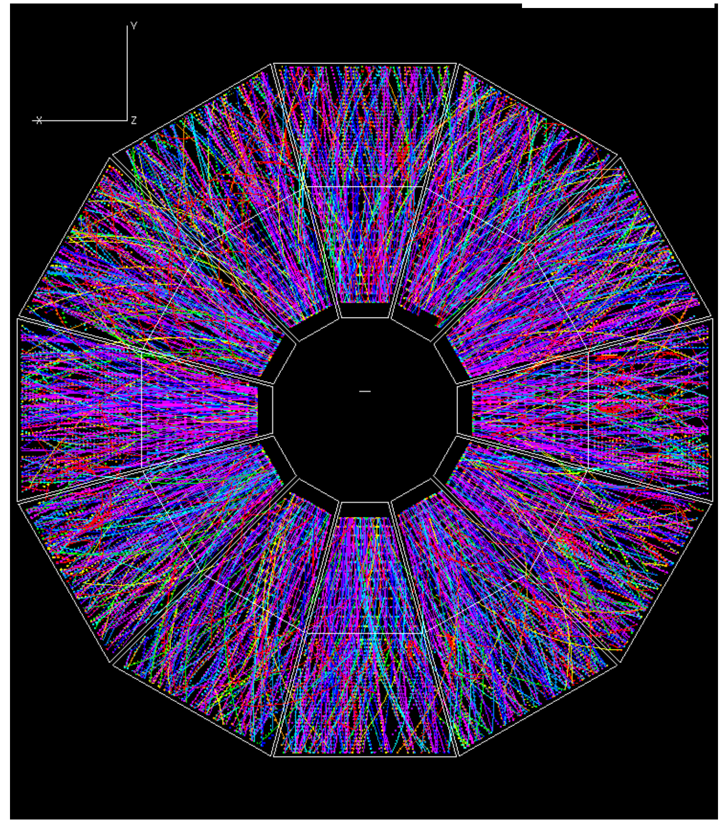
Just after the collision, thousands more particles form as the area cools off. Each of these particles is a clue to what happened inside the collision.

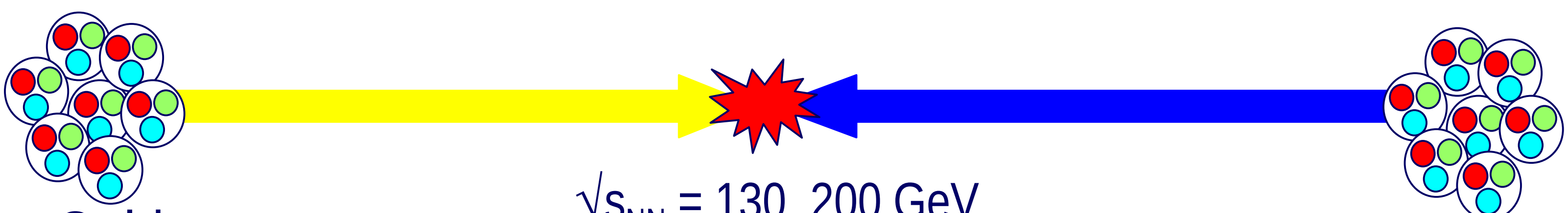
# Event Display in a Au-Au Collision

PHENIX



STAR



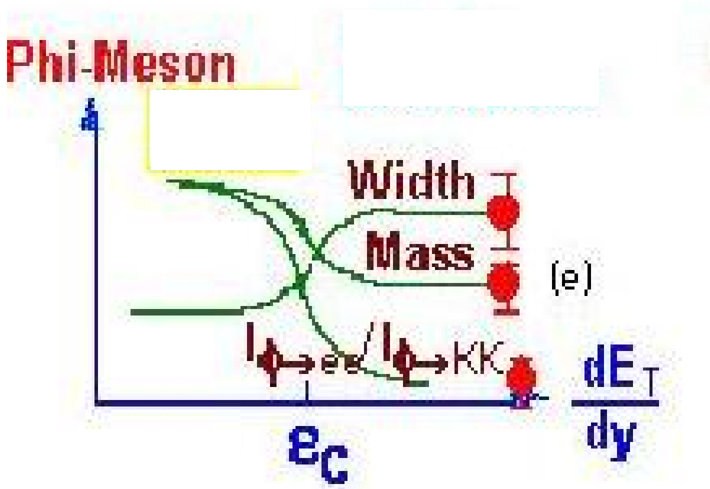


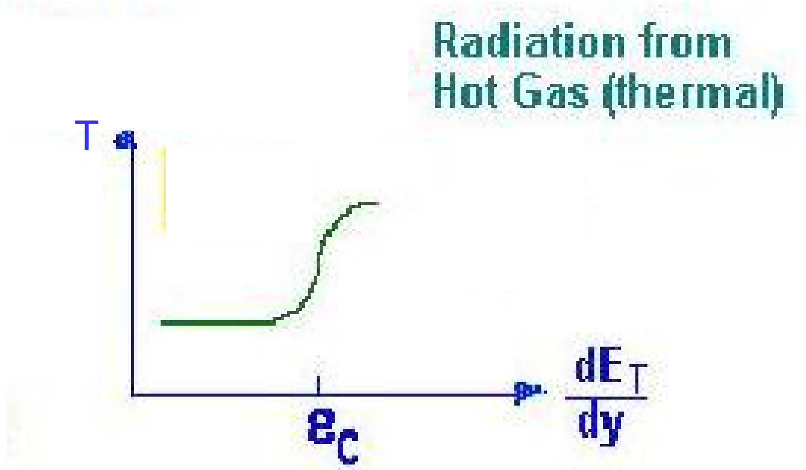
Gold

$\sqrt{s_{NN}}$ = 130, 200 GeV
(center-of-mass energy per nucleon-nucleon collision)

Gold

# Signatures of Quark-Gluon Plasma



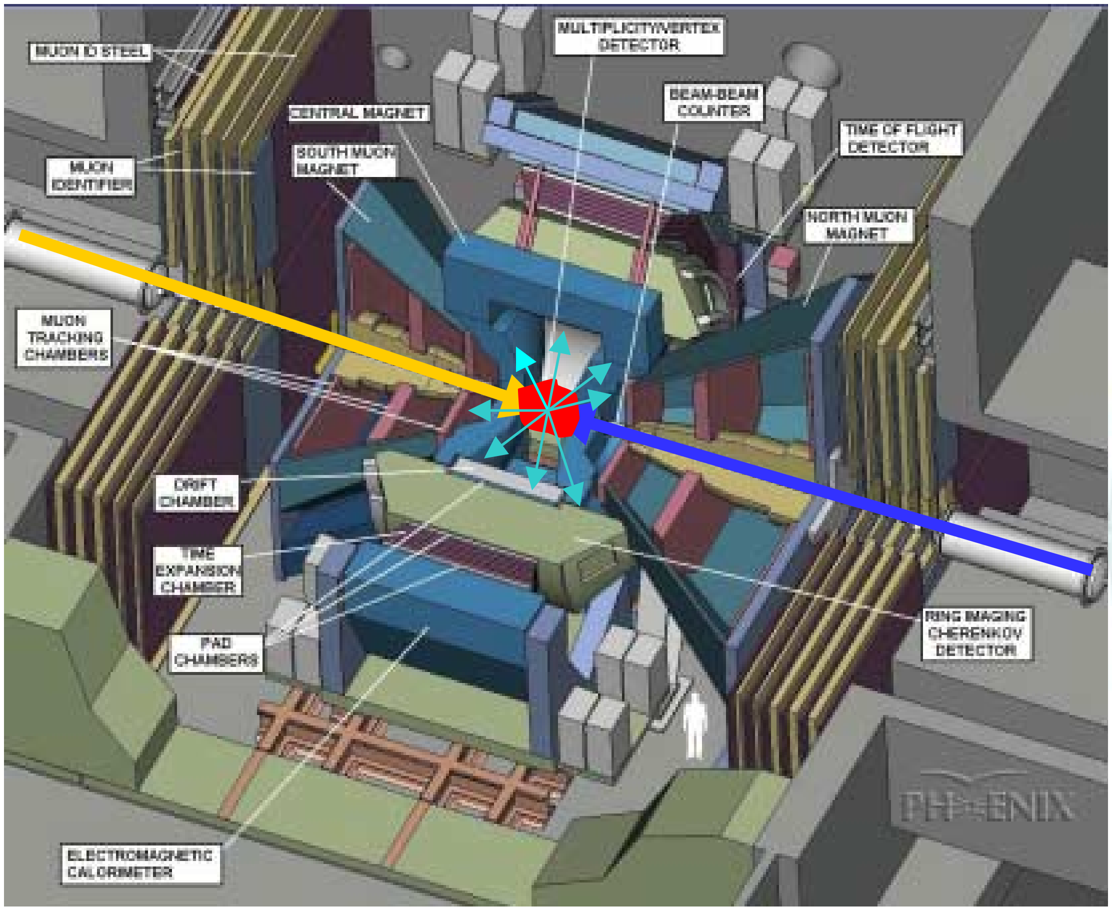




There are a number of Potential signatures for the QGP Formation.

The Heavy-ion experiments study as many signatures as possible

The potential signatures are studied as a function of the energy density $\varepsilon$ or the rapidity density of the transverse energy ($dE_T/dy$) or the pseudorapidity density of the charged particle multiplicity($dN/d\eta$)

# PHENIX Experiment at RHIC




# Design Concept

- Pair spectrometers
  - Essential for vector meson, virtual photon detection
- Good particle identification (e,$\pi$,K,p,$\gamma$,$\mu$ plus pairs e.g. $\pi^0$, $\omega$, $\phi$)
- Low occupancy of “pixels”
  - Essential for particle identification, systematic control of efficiency
- High data rate and selective multi-level triggering
- Two central arms
  - Electrons, photons, hadrons; Coverage: $\Delta\phi = \pi/2$ each, $\Delta\eta$=0.7
- Two “muon” endcaps
  - Coverage: $\Delta\phi = 2\pi$ each, $\Delta\eta$=1.15-2.44 (north), 1.15-2.25 (south) e/$\pi$, $\mu$/h rejections better than $10^{-3}$

# Physics Goals

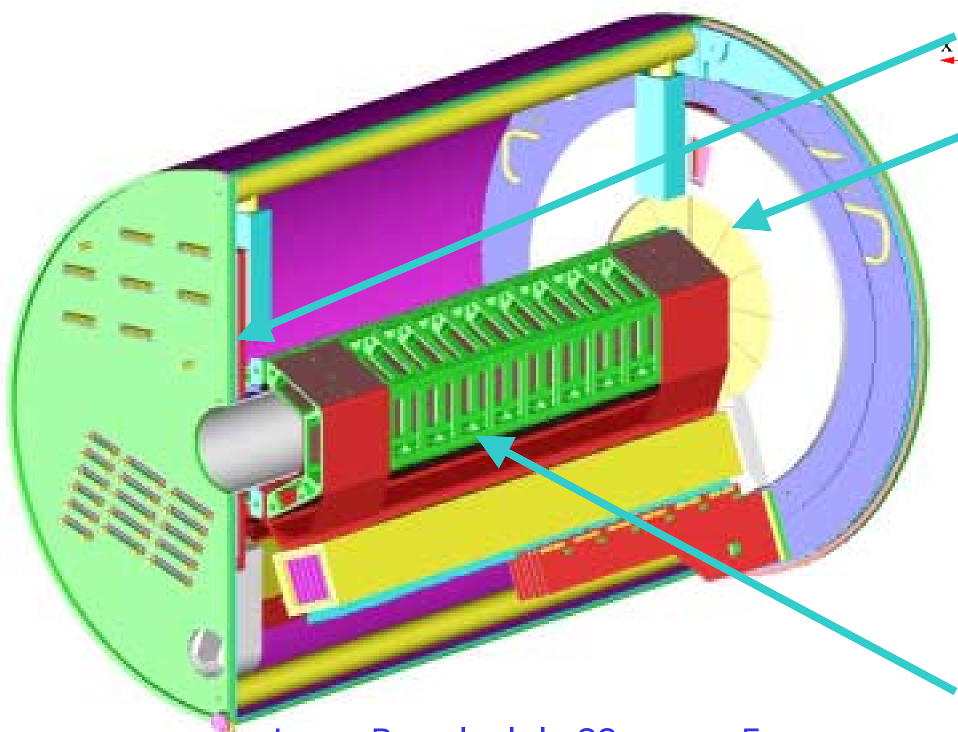
- Search for evidence of Quark-Gluon Plasma
  - Following range of probes to be covered
    - Vector mesons
    - Direct photons (real and virtual)
    - Identified hadrons
    - Collective motion and correlations
    - Global observables
  - Capability to cover A+A, p+A, p+p essential
- Study spin-structure of nucleon.

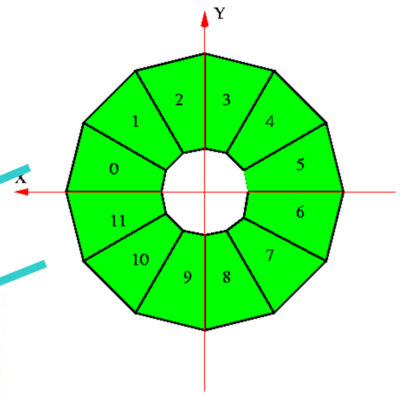
# Multiplicity & Vertex Detector

- **Dimensions : 70 cm long, 30 cm radius**
- **Weight : 11 kg**
- **34720 electronics channels**

## Physics Goals

- **Charged Particle Multiplicity**
- **Collision Vertex Position**



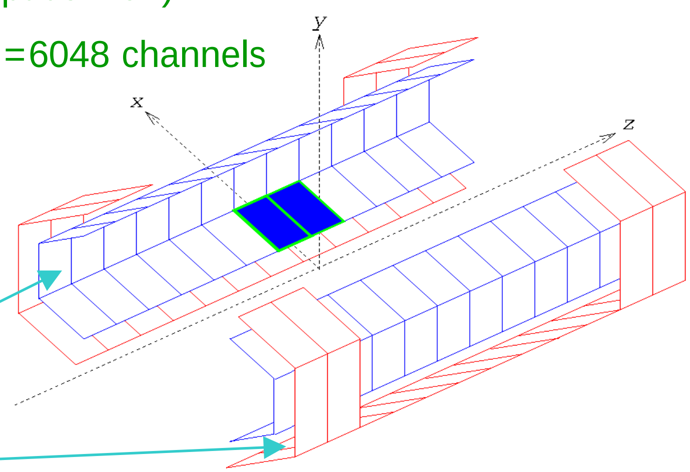



End Caps : z=±35 cm

r=5 to 12 cm

(2 end-caps*12 pads*252)

=6048 channels



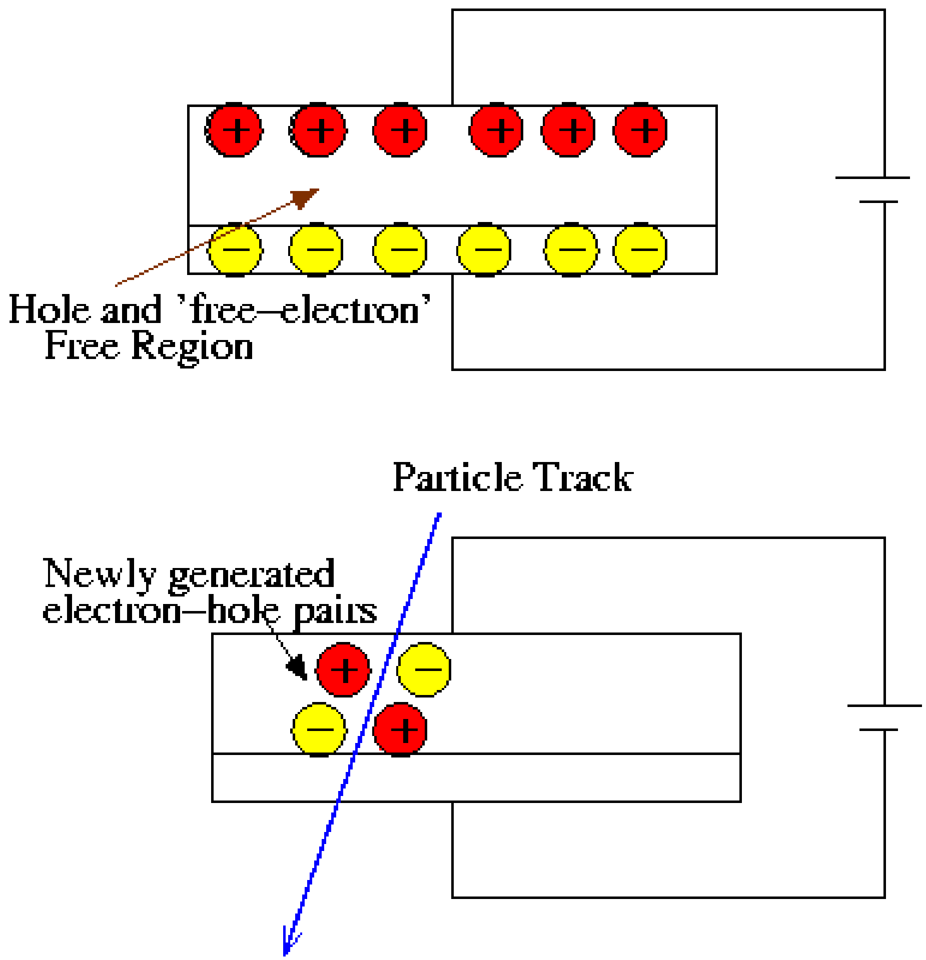

Inner Barrel : |z|<32 cm, r=5 cm

(72 panels*256strips)=18432 channels

Outer Barrel : |z|<32 cm, r=7.5 cm

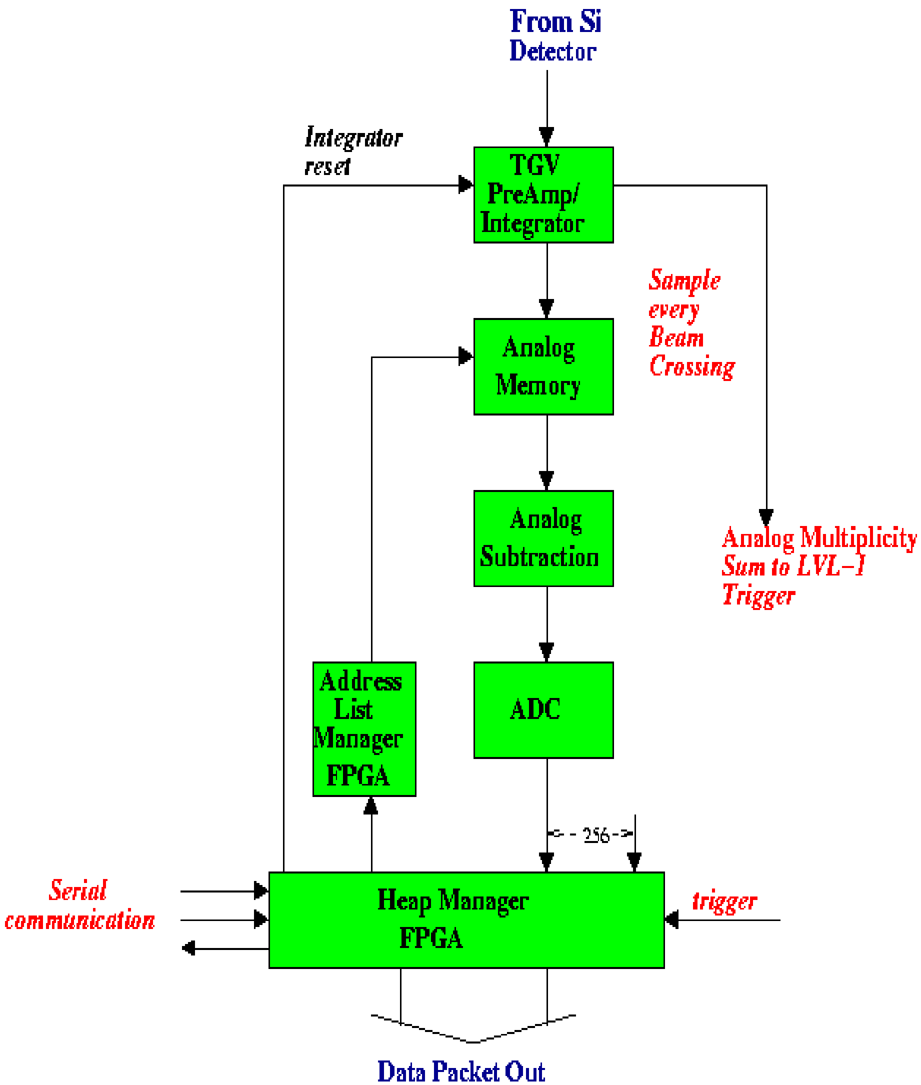
(40 panels*256 strips)=10240 channels

# How Does MVD (or any Silicon Detector) Work

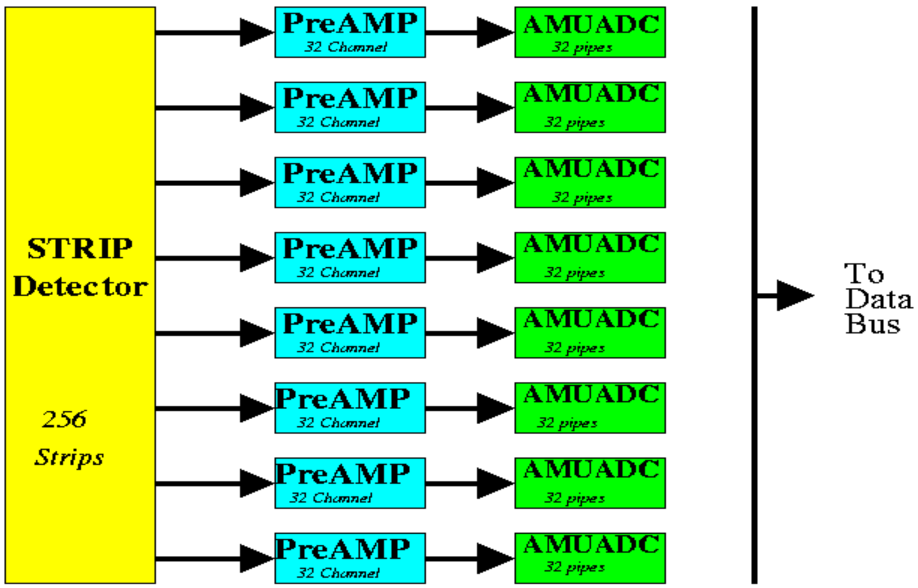



- Apply enough reverse voltage so that no free charge carriers exist
- When tracks pass through the silicon, it will deposit a fraction of its energy, which will produce free charge carriers.
- Charge carriers are attracted to the opposite terminals, and we will have signal.

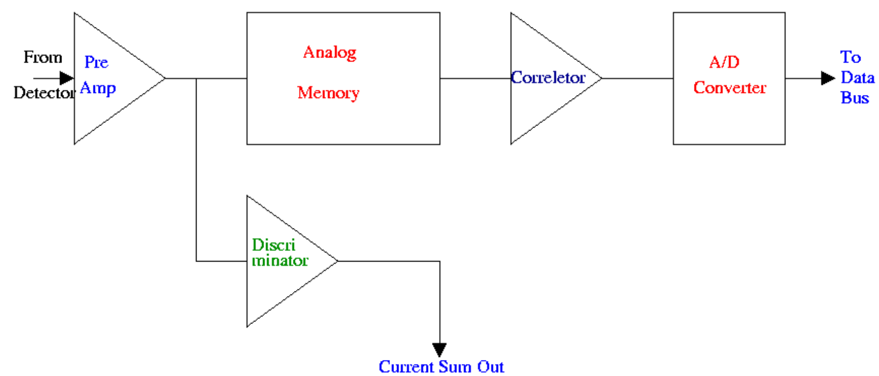
# MVD Electronics Chain

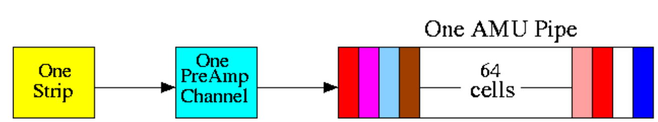



## Breakdown for one Strip Detector (256 strips)




## Breakdown for one strip

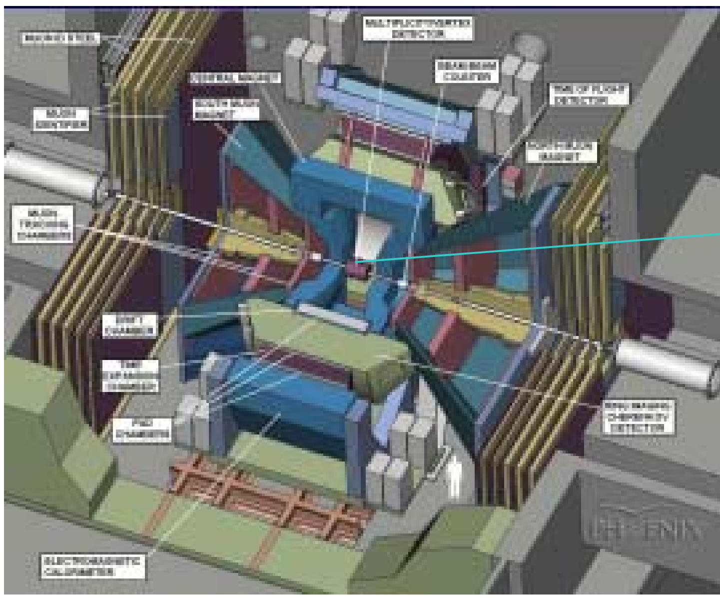


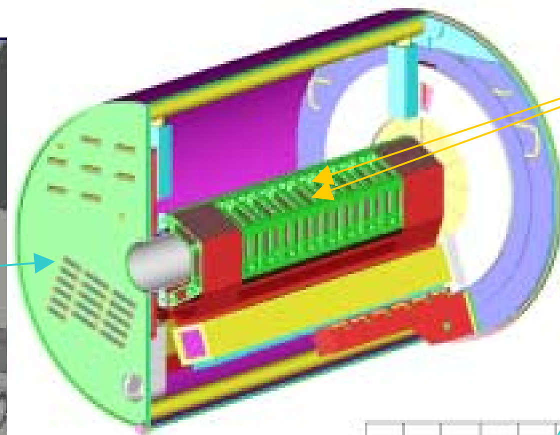



# MVD Year1 Configuration

**MCMs in MVD**

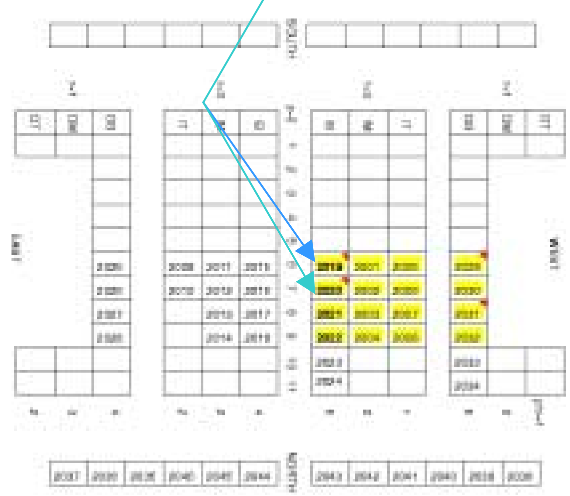
| | Inner Barrel | Outer Barrel | Pad |
|---|---|---|---|
| Design | 72 | 40 | 24 |
| Y1 | 24 | 10 | 12 |





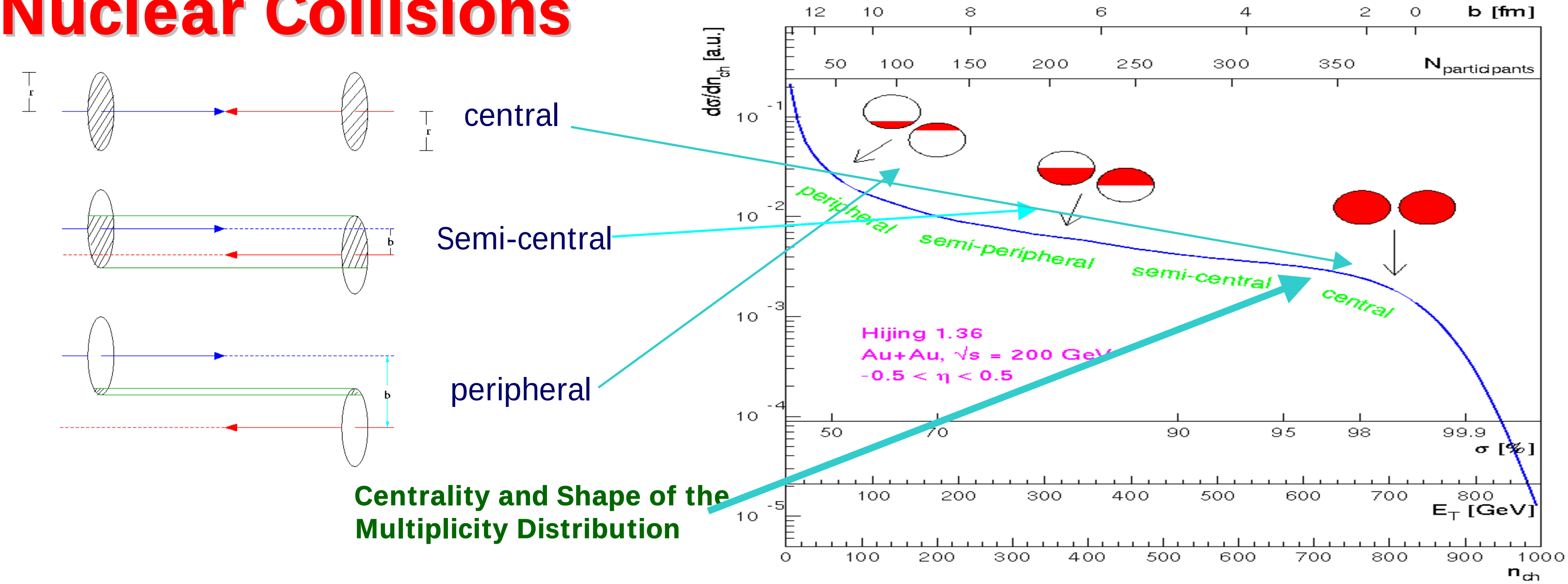
Only 2 good MCM,
512 Channels

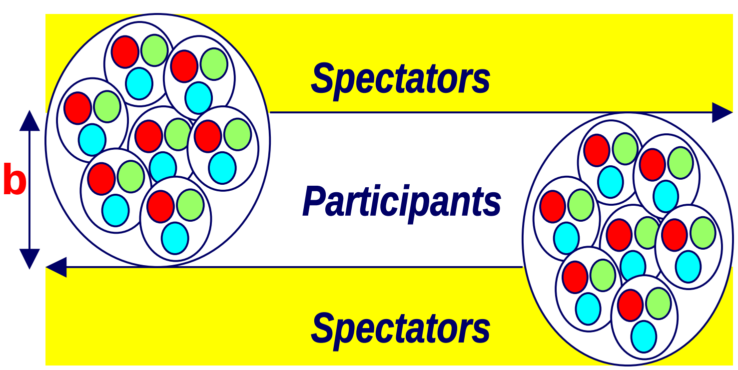
But Still has the
largest η coverage
|η|<1.48 at |z|=0.



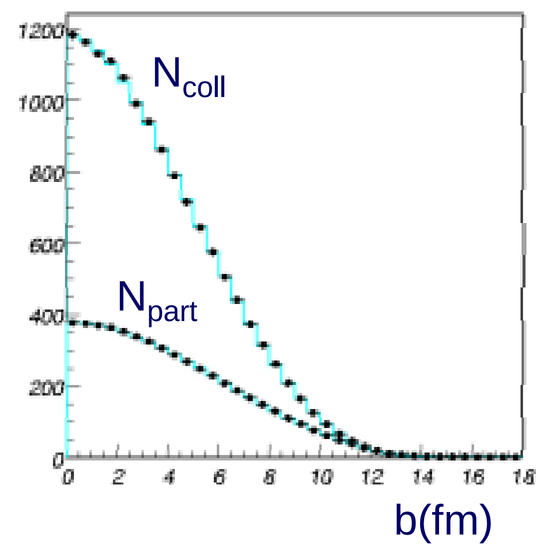
- Participated in 2 Runs :
  - #12397 : 78 segments
  - #12399 : 3 segments
- About 120,000 Events

# Nuclear Collisions



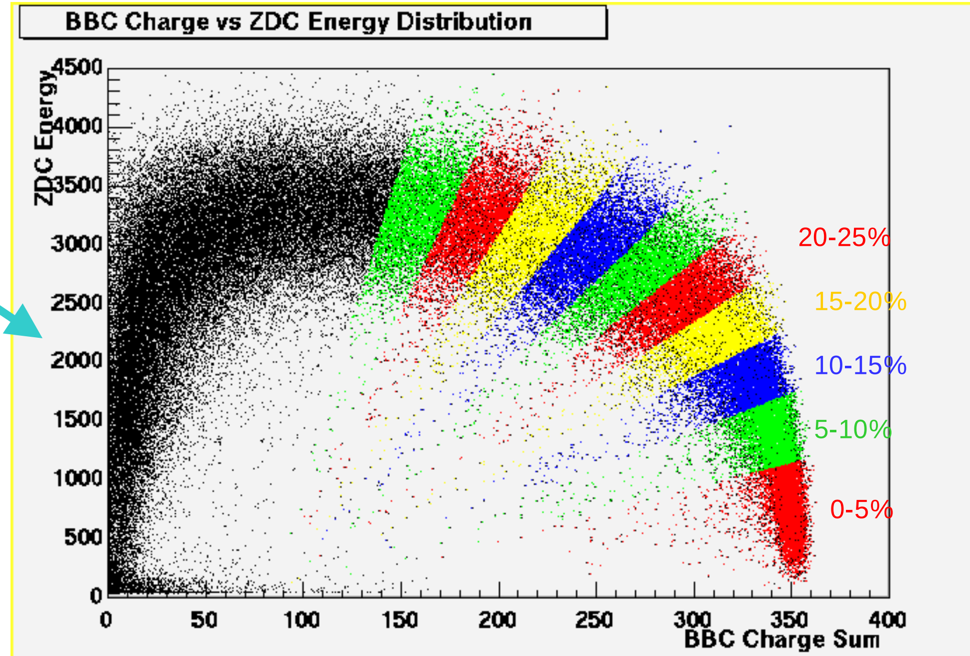




- Geometrical model
  - Binary collisions ($N_{coll}$)
  - Participants ($N_{part}$) : Nucleons that interact
  - Spectators ($2A - N_{part}$) : Nucleons that do not interact



# Centrality Selection

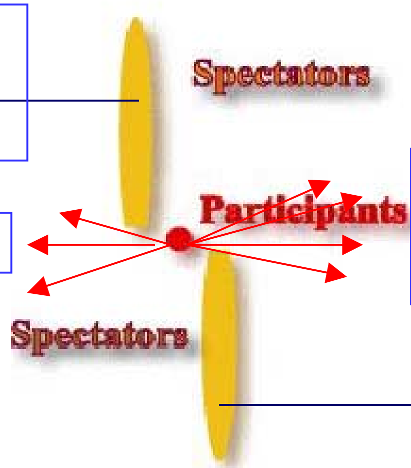
Centrality Selection based on BBC Charge Q and ZDC Energy E




$$\phi_{cent} = \tan^{-1}[((Q-Q_0)/Q_{max})/(E-E_{max})]$$

Zero Degree Calorimeter

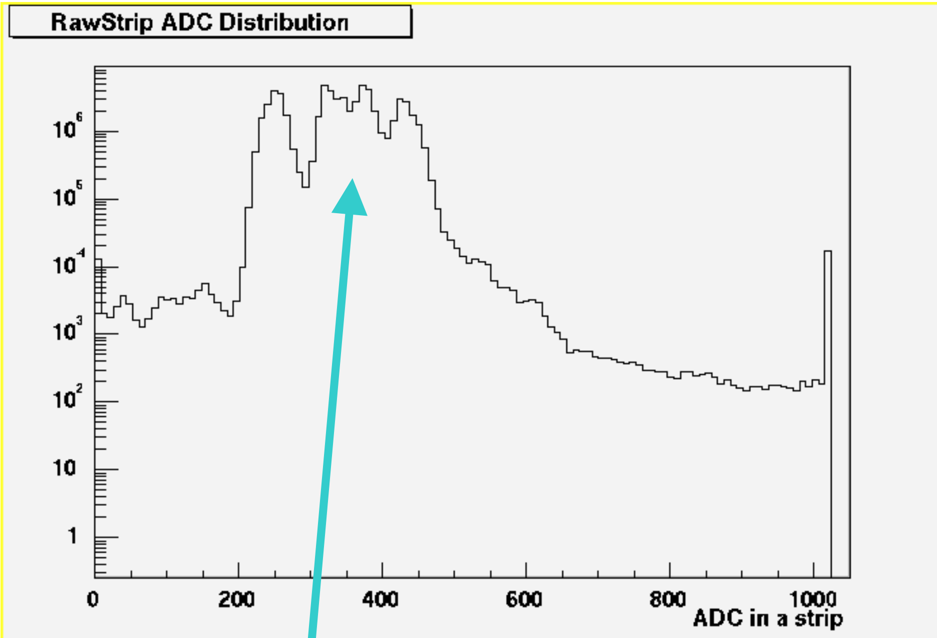
BBC




Charge of the tracks detected in BBC

Energy of the Spectators measured in ZDC

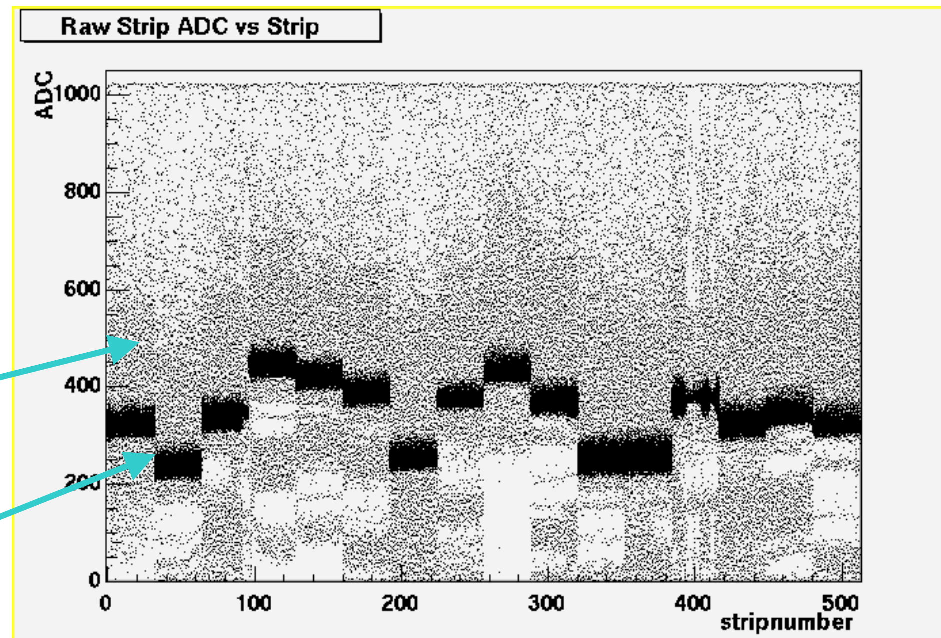
# Raw ADC Distribution for All Channels




No Calibration

**Two Major Complications:**

1. **Event by event jumping of pedestals**
2. **AMU cell dependence of pedestals**



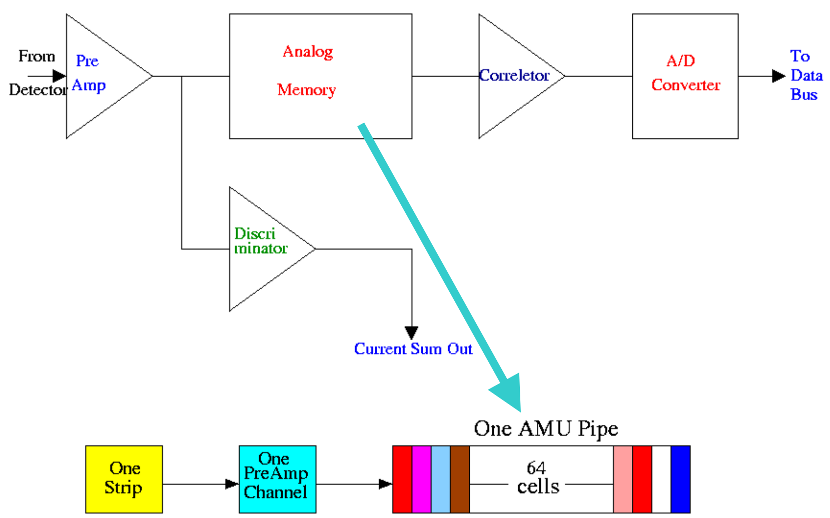

Are these Mips ?

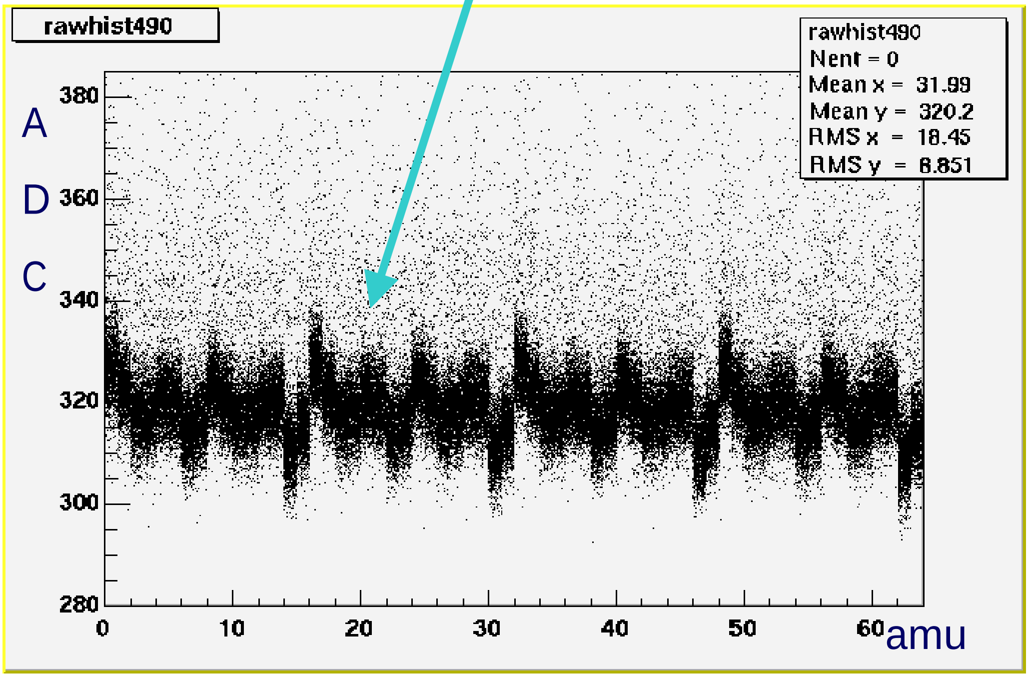
Very Wide Pedestal

# AMU Cell Dependence of Pedestals

- AMUs are analog equivalent of RAM
- Each Memory Cell is a small Capacitor
- Each Strip has one-to-one correspondence with a memory pipe
- Each pipe is 64 cell deep

Strong Dependence on AMU cell position



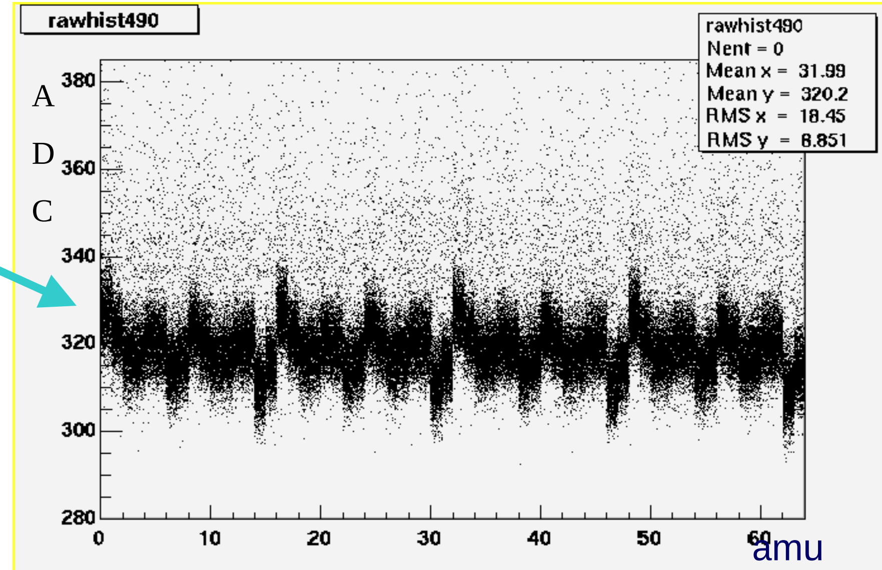



# Correction for the AMU Cell Dependence of Pedestals

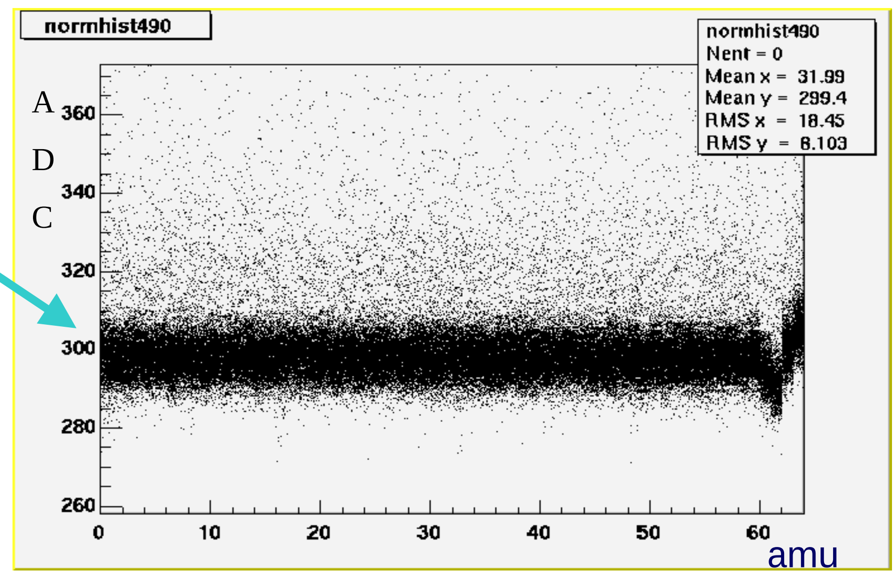
- Plot an 1-D plot for each channel for each amu.
- For each plot find the mean of the ADC
- Normalize ADC around 300.

  ADC(normalized)=(ADC(raw)/mean)*300

**Before Correction**




**After Correction**



# Event by Event Correction

## Objective

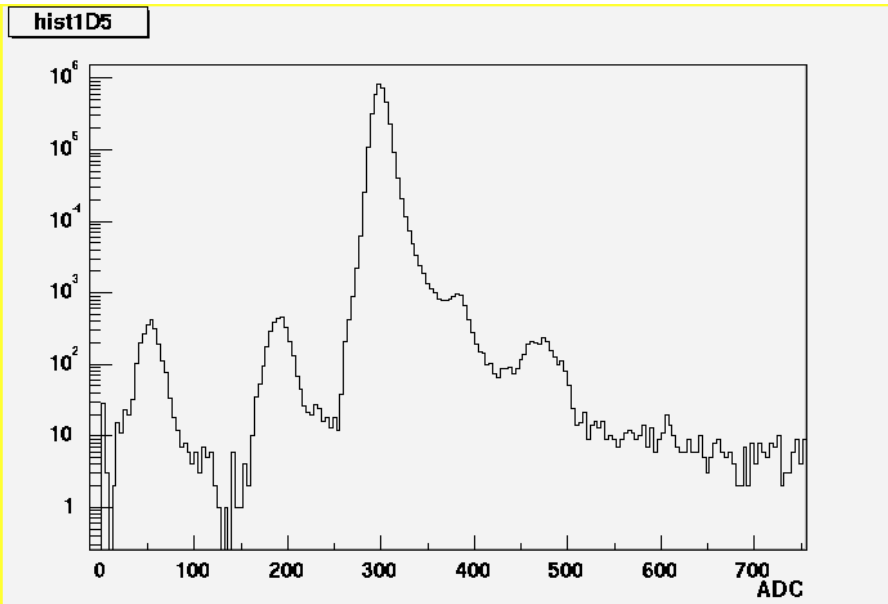
- In each event Identify the “true” pedestals.
- Once identified, find the mean. This mean contains the amount the pedestals “jumped” in that event.
- Then subtract the mean from all the measurements in that event. This eliminates the pedestals jumping.

## Procedure

- Step1 : Find the lowest 30% entries in each event. These entries are undoubtedly pedestals. Plot them and get Mean and RMS.
- Step2 : Extend the window. We find the entries that are less than (Mean+ 2*RMS). Plot them and get Mean and RMS.
- Step3 : Extend the window even further. Find entries that are less than (Mean + 3*RMS) (from step2). THESE ENTRIES ARE IDENTIFIED PEDESTALS. Plot them and get the Mean.
- Step4 : Subtract this Mean from all ADC.

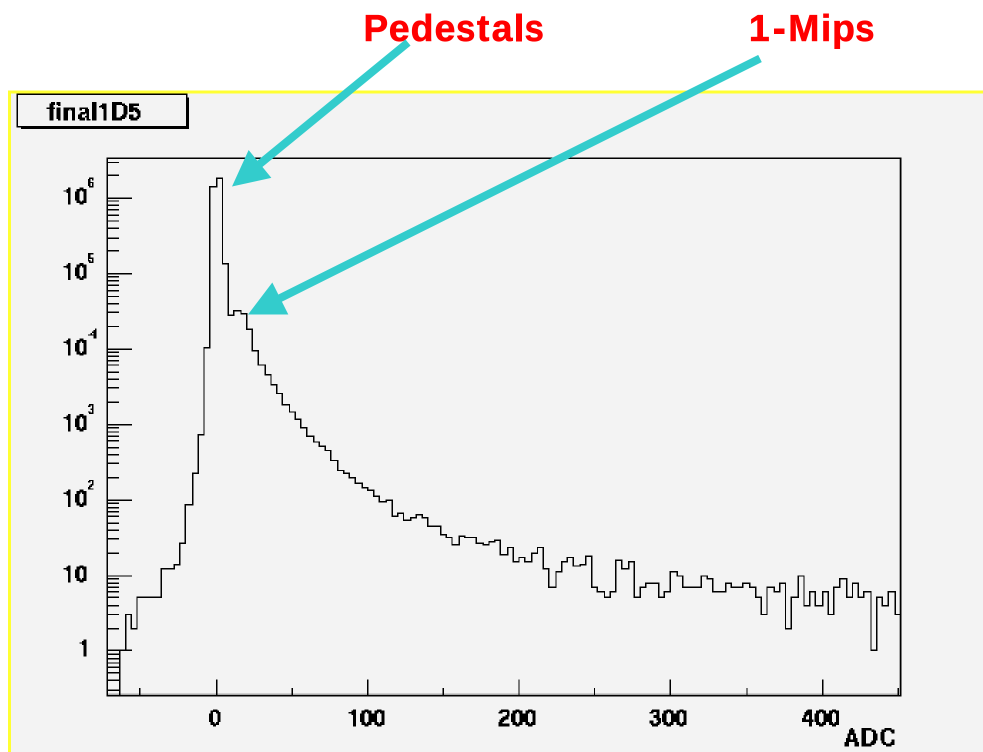
The process is repeated for all events.

# Event by Event Correction Applied to Data



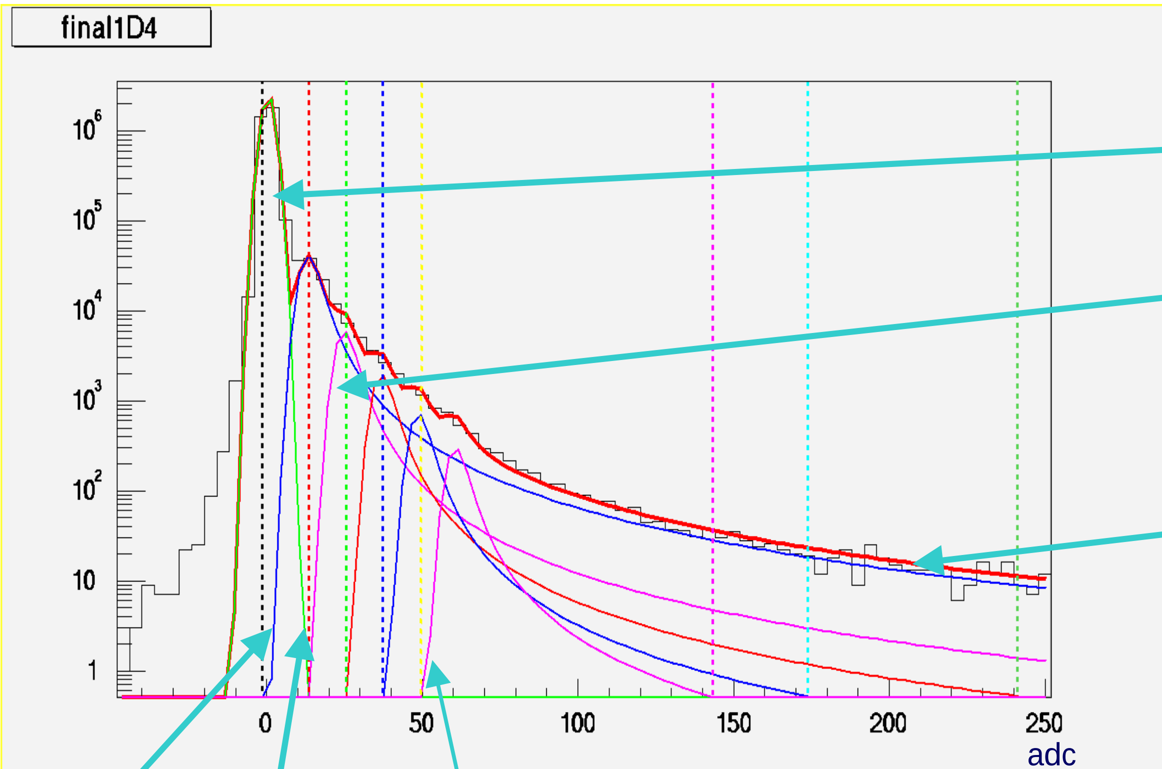

Before correction

ADC of channels 128-159
from all Data Sample




After correction

# Fitting and Track Selection




Pedestals are Fitted With a Gaussian

Tracks are Fitted with a Landau convoluted with a gaussian

Total Distribution is Fitted with

Total = Gaus + Gaus*Landau

1-track

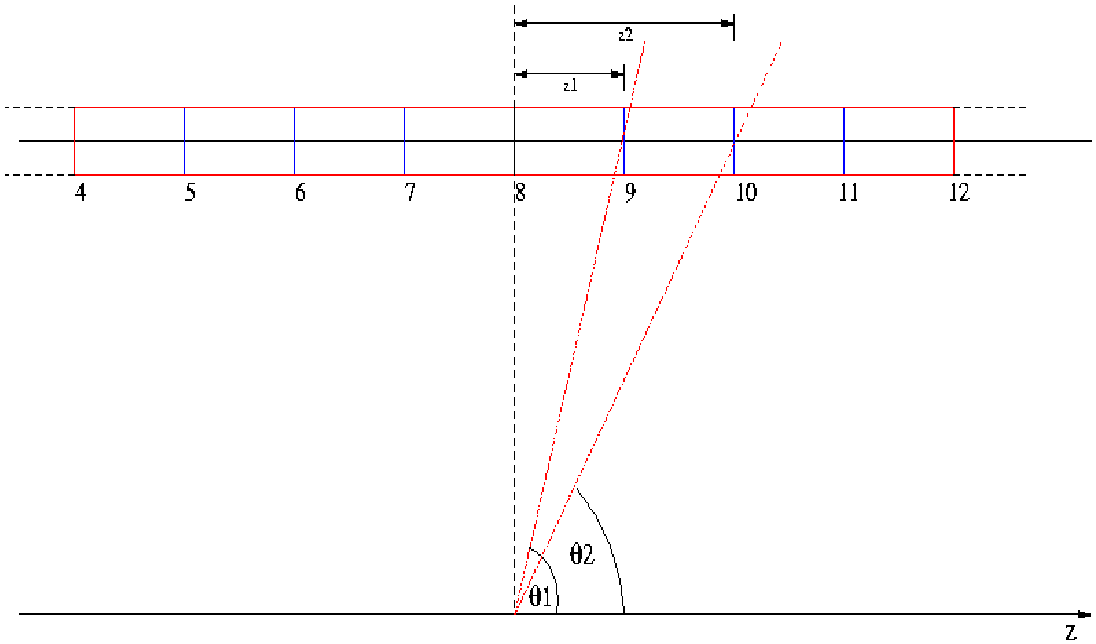
2-tracks

5-tracks

If $p_0$ is the probability to be pedestal and $p_i$ is the probability to be a i-track, then the number of track associated with an ADC is:

$$n = 0*p_0+1*p_1+2*p_2+3*p_3+4*p_4+5*p_5$$

# Strategy to Calculate dN/d$\eta$



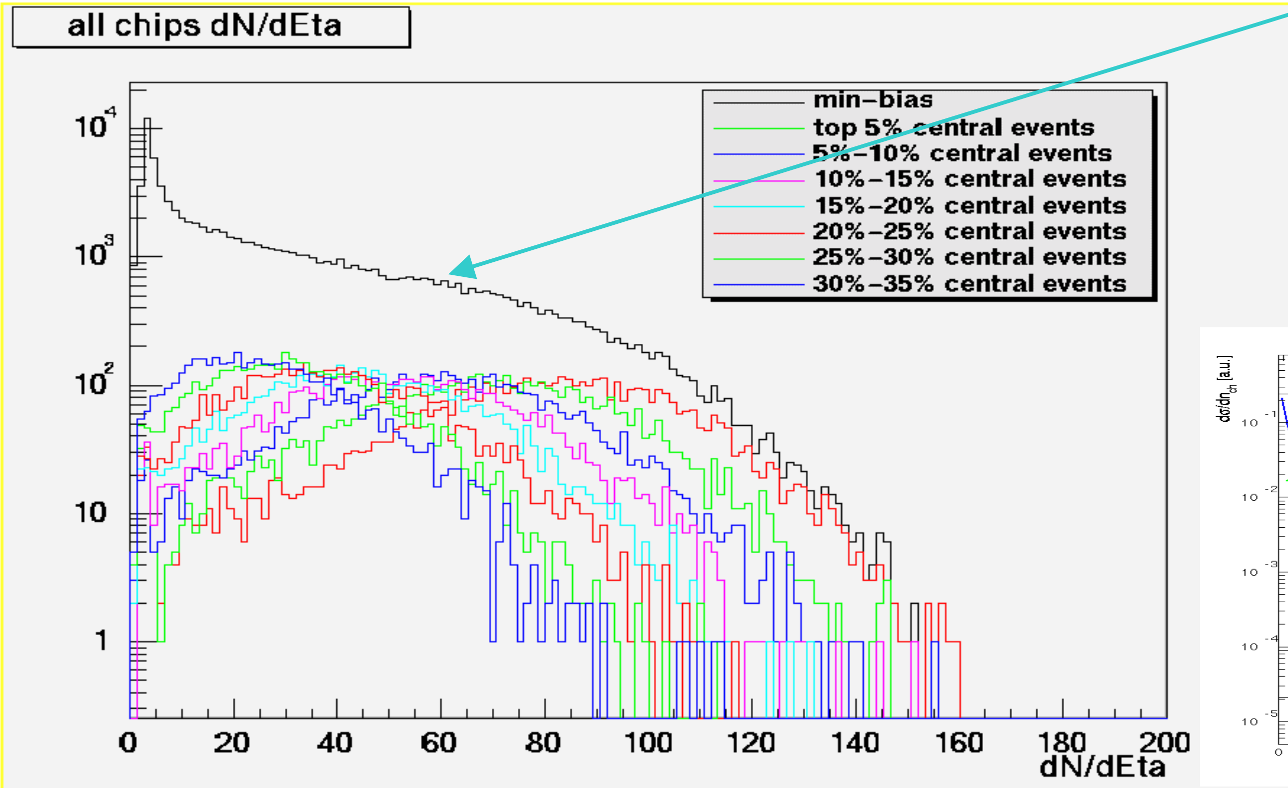

Measurement is done chip-by-chip (32 channels)

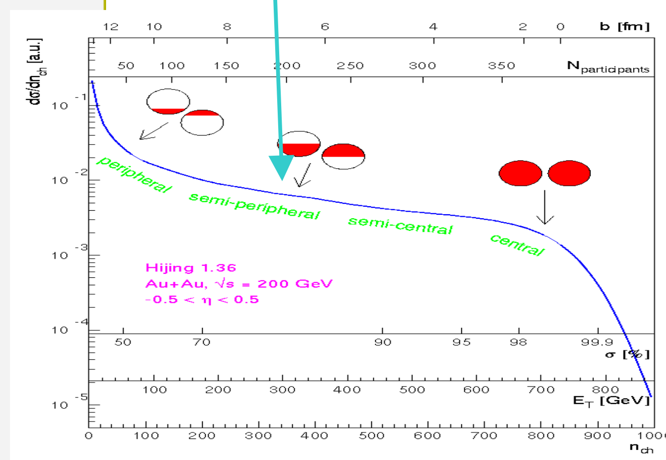
In any event

- Find the vertex position
- Find $d\eta = \eta_{max}-\eta_{min}$ of the chip
- Find $\eta$ at the center of the chip
- Find the total number of tracks in the chip in that event. This is dN
- Find dN/d$\eta$

# Charged Particle Multiplicity in MVD

Min-bias Distribution Resembles the theoretical shape

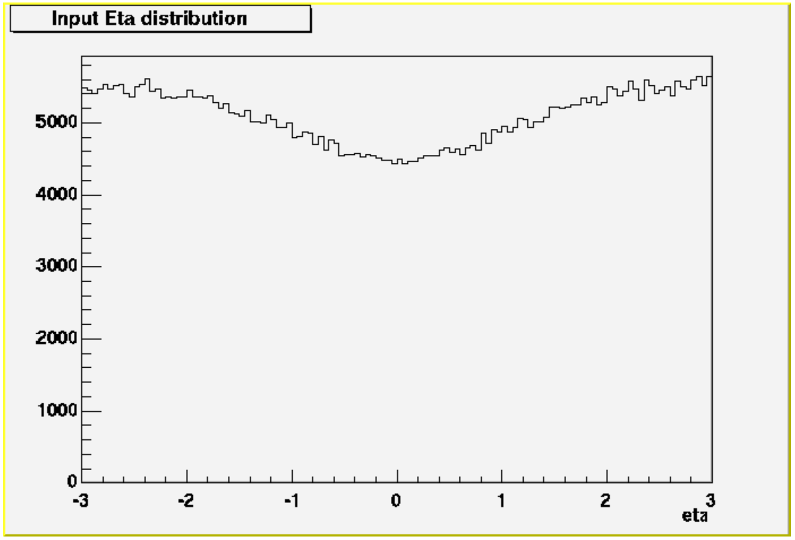


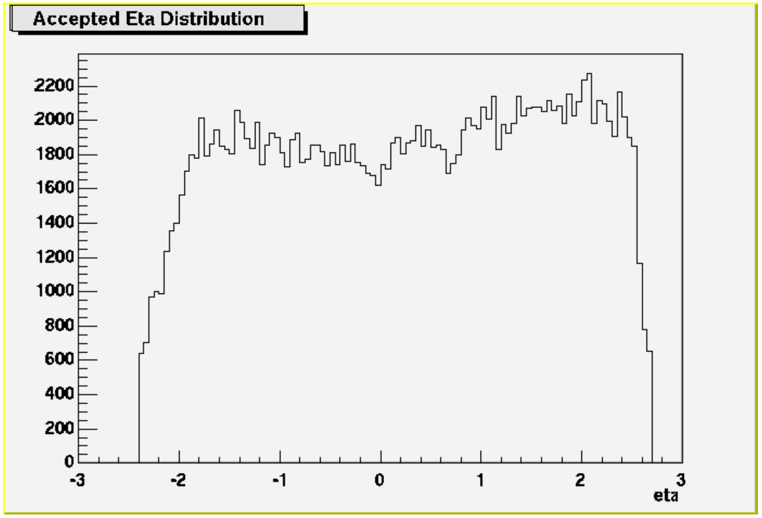



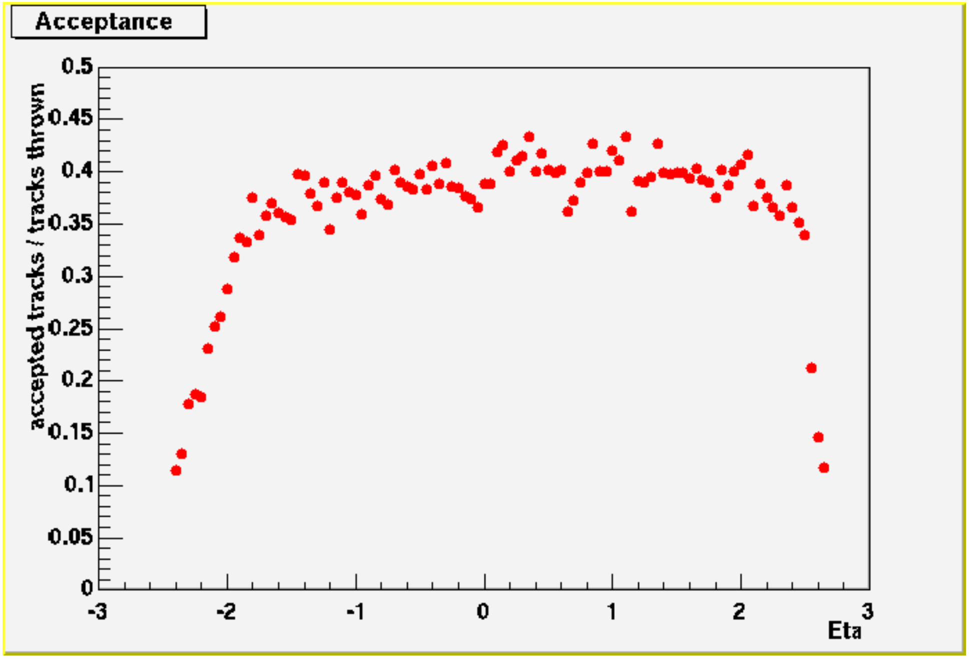
# Acceptance Correction

## Input Particles

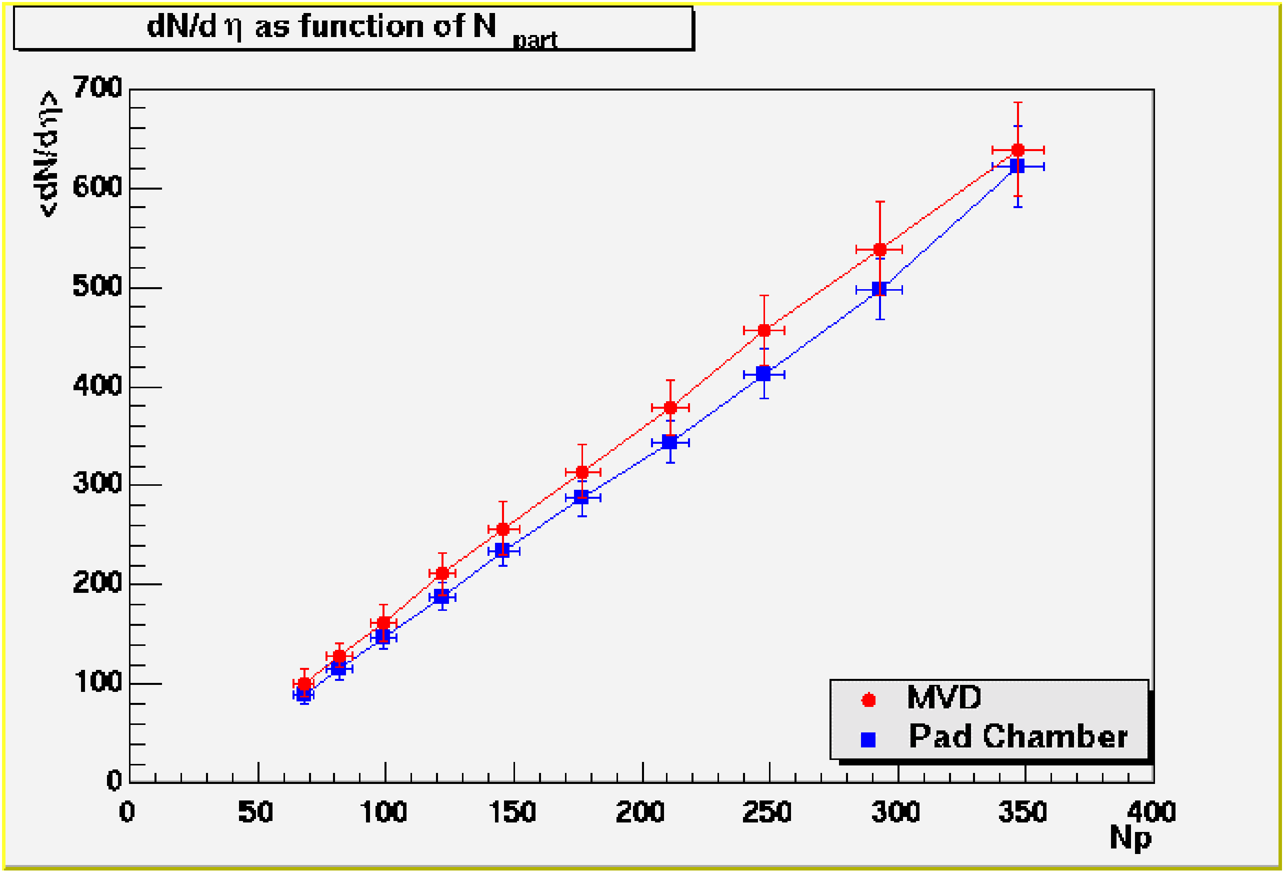
- Flat in Rapidity $|y|<3$
- Random in azimuth $0<\phi<2\pi$
- Exponential in $m_t$
  - $(1/m_t)\,(dm_t/dy) = \exp(-(m_t-m_0)/T)$
  - $T = 220$ MeV



# Charged Particle Multiplicity in MVD and Comparison with other Measurements in PHENIX

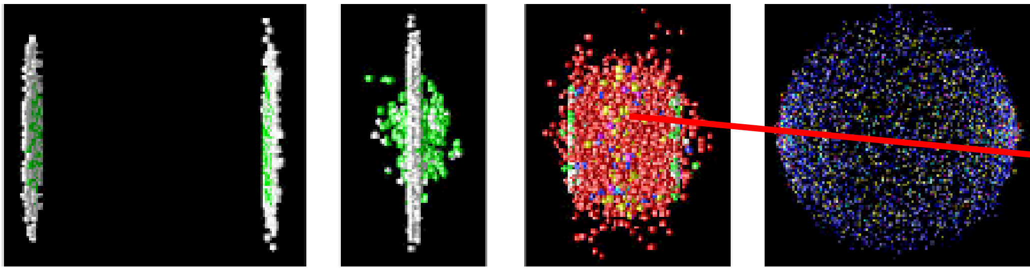



**dN/dη as a function of number of participants in PHENIX MVD compared with the measurements from Pad Chambers**

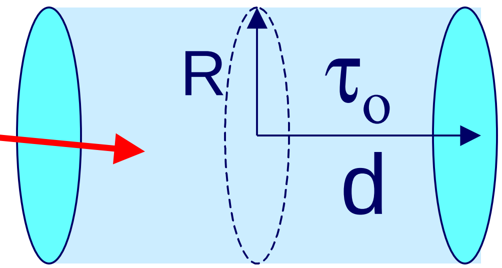
**Corrections:**

- AMU-cell dependence
- Event by event pedestal jumping
- Correction for multiple counting of tracks
- Acceptance Correction

# Energy Density of the Collision



Two ions approaching | collision | Fireball | Particle Produced mainly in the transverse direction




Bjorken Estimate

**Fireball expands longitudinally**

**After time $\tau_0$, fireball cools of and particles are produced**

**Particles are produced mainly in the transverse direction**

**Transverse Energy**

$$E_T = \langle E \rangle N = \sqrt{m_T^2 + \langle p_T^2 \rangle}\, N$$

**Total energy of the Fireball**

$$E = \int_{-d}^{d} \frac{dE_T}{dz} dz = \frac{dE_T}{dy} \frac{2d}{\tau_0}$$

**Volume of the Fireball**

$$V = \pi R^2 (2d)$$

**Energy Density**

$$\varepsilon = \frac{E}{V} = \frac{1}{\pi R^2 \tau_0} \frac{dE_T}{dy} = \frac{\sqrt{m_T^2 + \langle p_T^2 \rangle}}{\pi R^2 \tau_0} \frac{dN}{dy}$$

**Particles are mostly pions.**

**$N \approx (N_{\pi+} + N_{\pi-} + N_{\pi 0}) \approx 3/2\ (N_{\pi+} + N_{\pi-})$**

$$\varepsilon = \frac{E}{V} = \frac{1}{\pi R^2 \tau_0} \frac{dE_T}{dy} = \frac{\sqrt{m_T^2 + \langle p_T^2 \rangle}}{\pi R^2 \tau_0} \frac{3}{2} \frac{dN_{ch}}{dy}$$

**$\langle p_t \rangle$ is measured at PHENIX for $\sqrt{s}$=130 GeV for hadrons.**

**dN/dy = dN/dη . dη/dy = 1.13 dN/dη**

**R ~ $A^{1/3}$ ~ 6 fm**

**$\tau_0$ is the formation time ~ 1 fm/c**

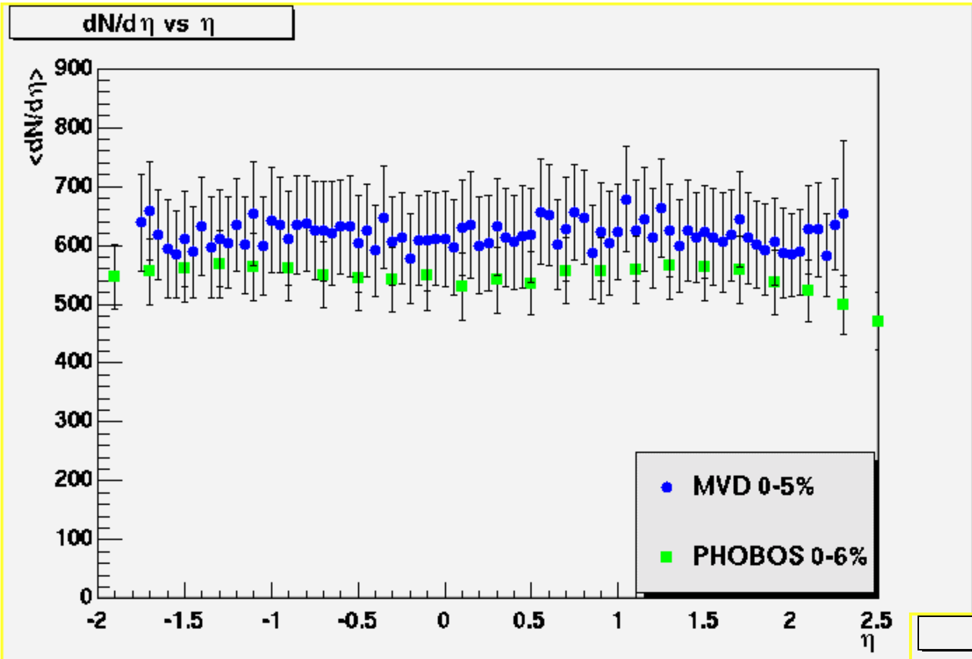
**dN/dη for the top 5% central events is 639**

**Which gives**

**$\varepsilon_0 \tau_0$ = 4.97 GeV/($fm^2$.c)**

**The energy density is well above the energy density needed to induce a phase transition from lattice calculations**

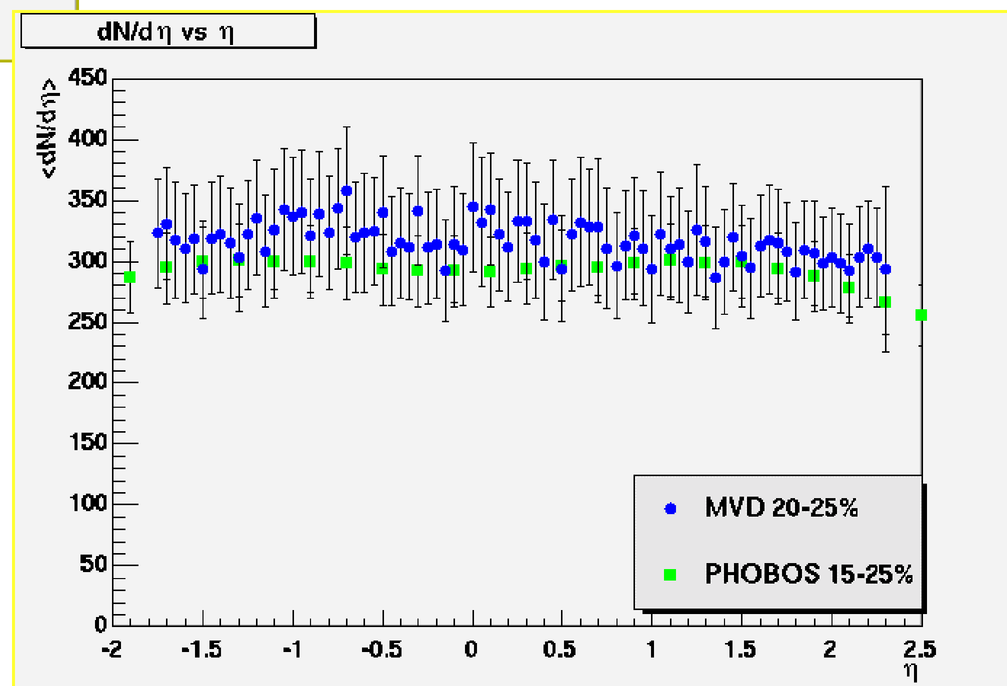
# Centrality Dependence of Multiplicity as a Function of $\eta$




**dN/d$\eta$ as vs $\eta$ plots for different centralities**

**As examples, plots for the most central (top 5%) events and mid-central (20%-25%) events are shown.**

**A comparison is made with the PHOBOS data.**



# Theoretical Models

## HIJING Monte-Carlo Model (Gyulassy & Wang)

(HIJING = Heavy Ion Jet INteraction Generator)

Particle produced in a heavy-ion collision has two components

- From soft interactions, which scales linearly with $N_p$
- From hard process, which scales with $N_c$.

$dN/d\eta = a\langle N_p\rangle + b\langle N_c\rangle$

## Saturation Model (Kharzeev & Nardi)

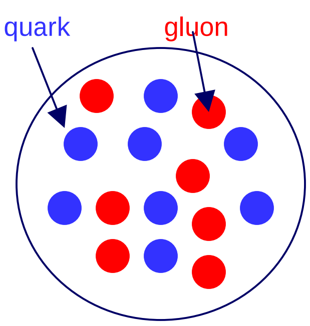
The initial parton density determines the number of produced charged particle. Naively it can be said that

$dN/d\eta \propto$ Number of Partons

The Partons Density is Derived from the following scenario :

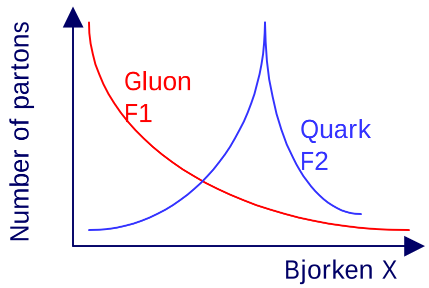
Nucleus is Lorentz contracted. Partons lie on a thin sheet in the transverse plane. Area of the transverse plane $S_A \sim \pi R^2$.

The Parton density keeps growing until all the available nuclear interaction transverse area is filled – the parton density saturates.

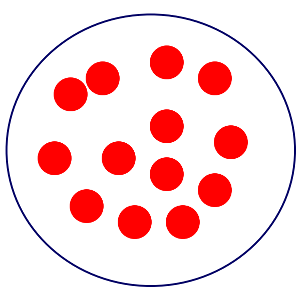



Parton Structure function.

At small Bjorken X, number of gluons are much much higher than the number of quarks

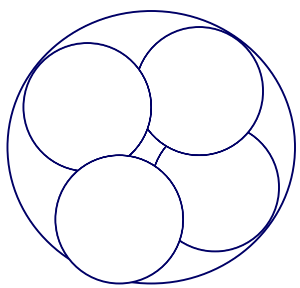



Partons having small Bjorken X will come to the transverse plane. Which means GLUONS

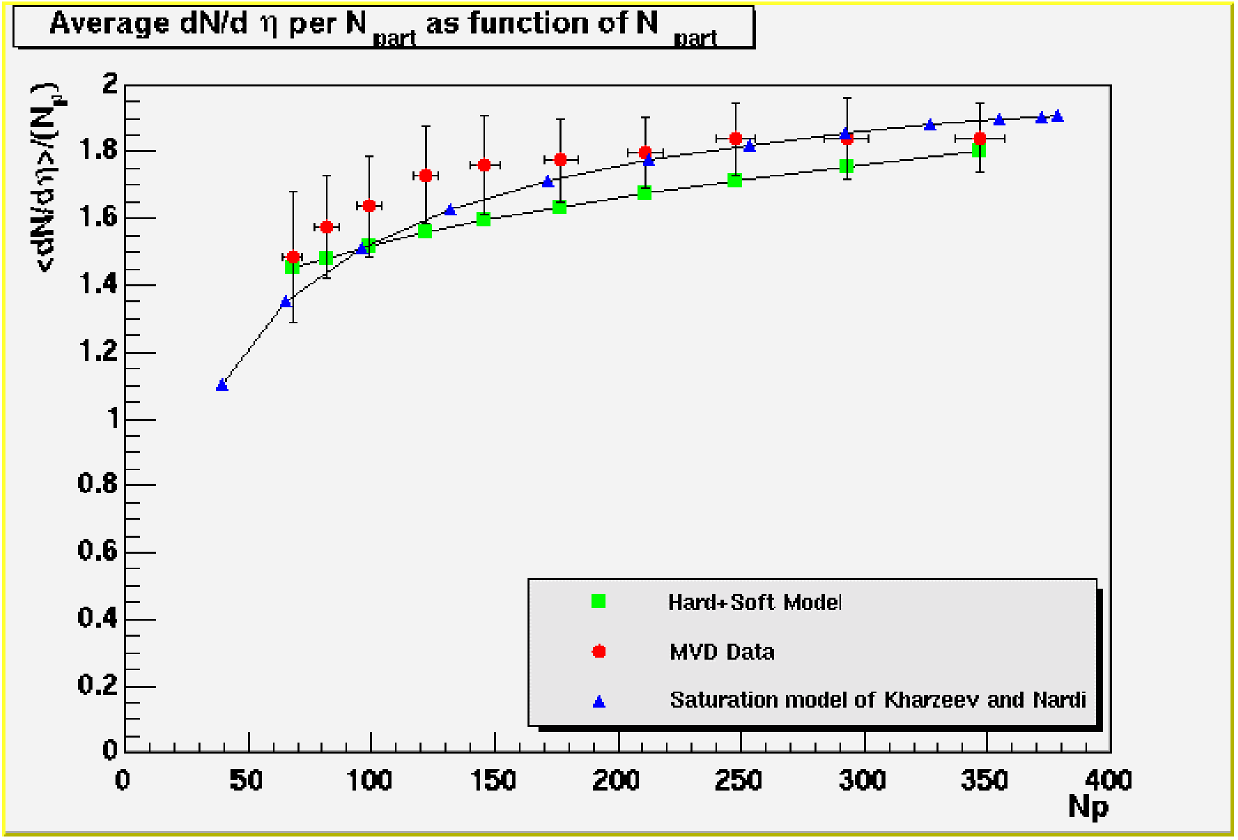


$\Delta x \Delta p \sim 1$, small p means large size.

The gluons grow big and saturates the area



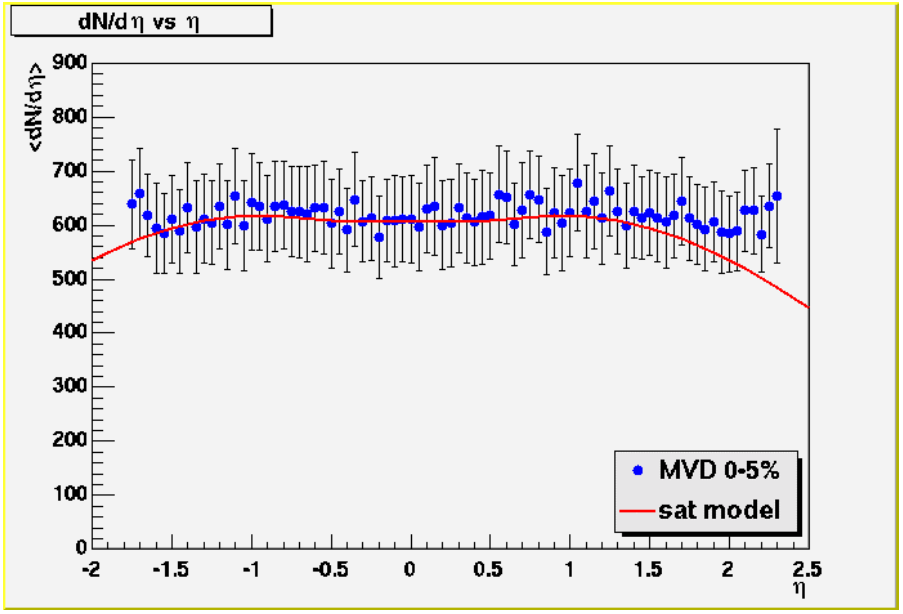
# Model Comparison of Data




**Both models agrees with the data within the error bars.**

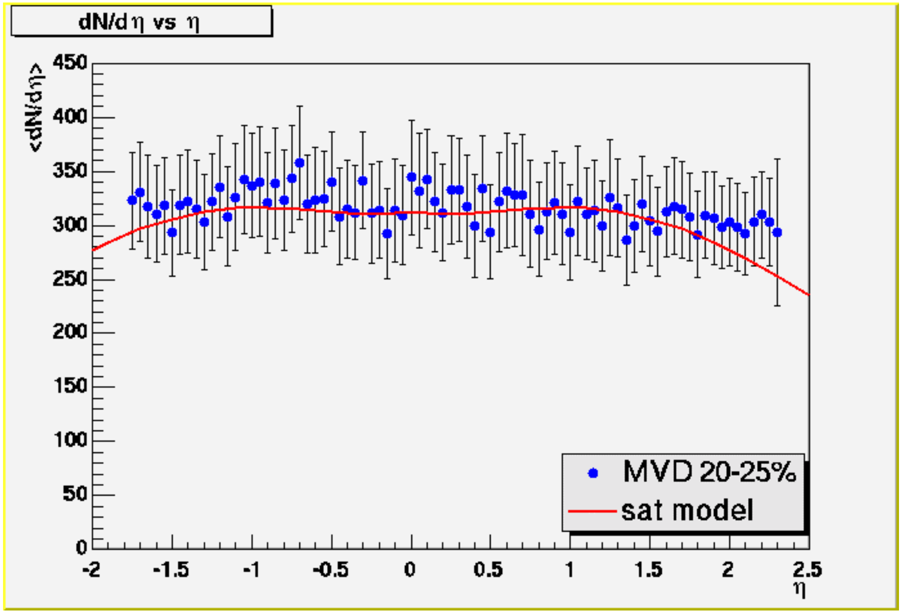
**The Saturation Model describes the shape of the distribution better**

# Centrality Dependence of Multiplicity : Model Comparison




**dN/dη as vs η plots for different centralities**

**As examples, plots for the most central (top 5%) events and mid-central (20%-25%) events are shown.**



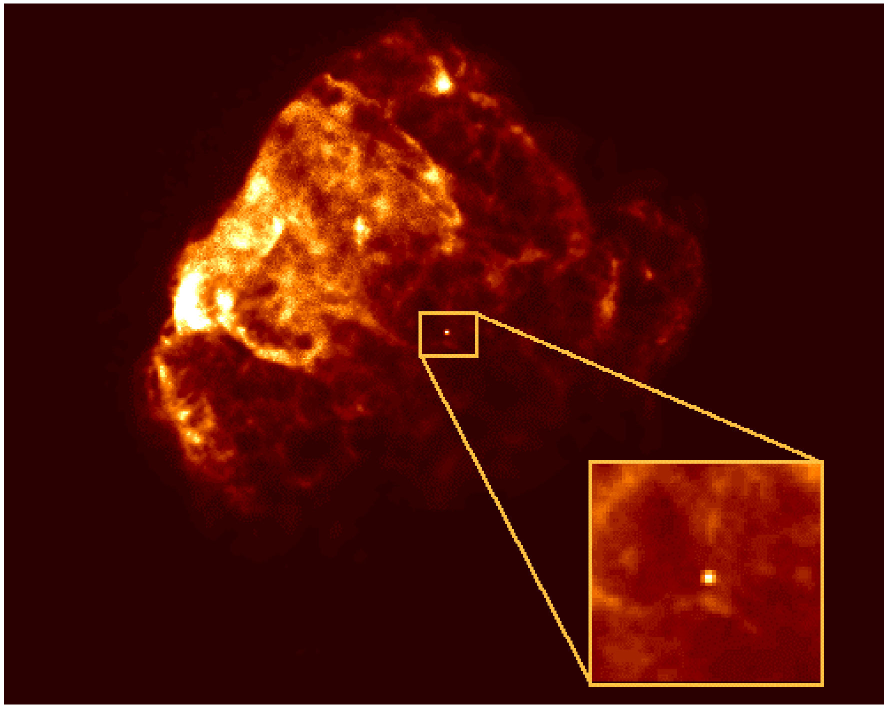

**A comparison is made with the Saturation Model Calculation. The Saturation model describes the data well.**

# Summary

- The charged particle multiplicity for the Au-Au collisions at $\sqrt{s}$=130GeV is measured with the MVD at PHENIX at RHIC.
  - For the top 5% central events $dN/d\eta$ = 639±48(*syst*)±10(*stat*)
  - The energy density $\varepsilon_0\tau_0$= 4.97 GeV/(fm$^2$c)
- The charged particle multiplicity measured with MVD agrees well with the PHENIX Pad Chamber.
  - The $dN/d\eta$ as a function of $\eta$ agrees well with the PHOBOS measurements.
- The centrality dependence of the charged particle multiplicity is compared with the HIJING soft+hard model and the Saturation model. Both the models fits the data within the error bar. Saturation model describes the shape of the distribution better.

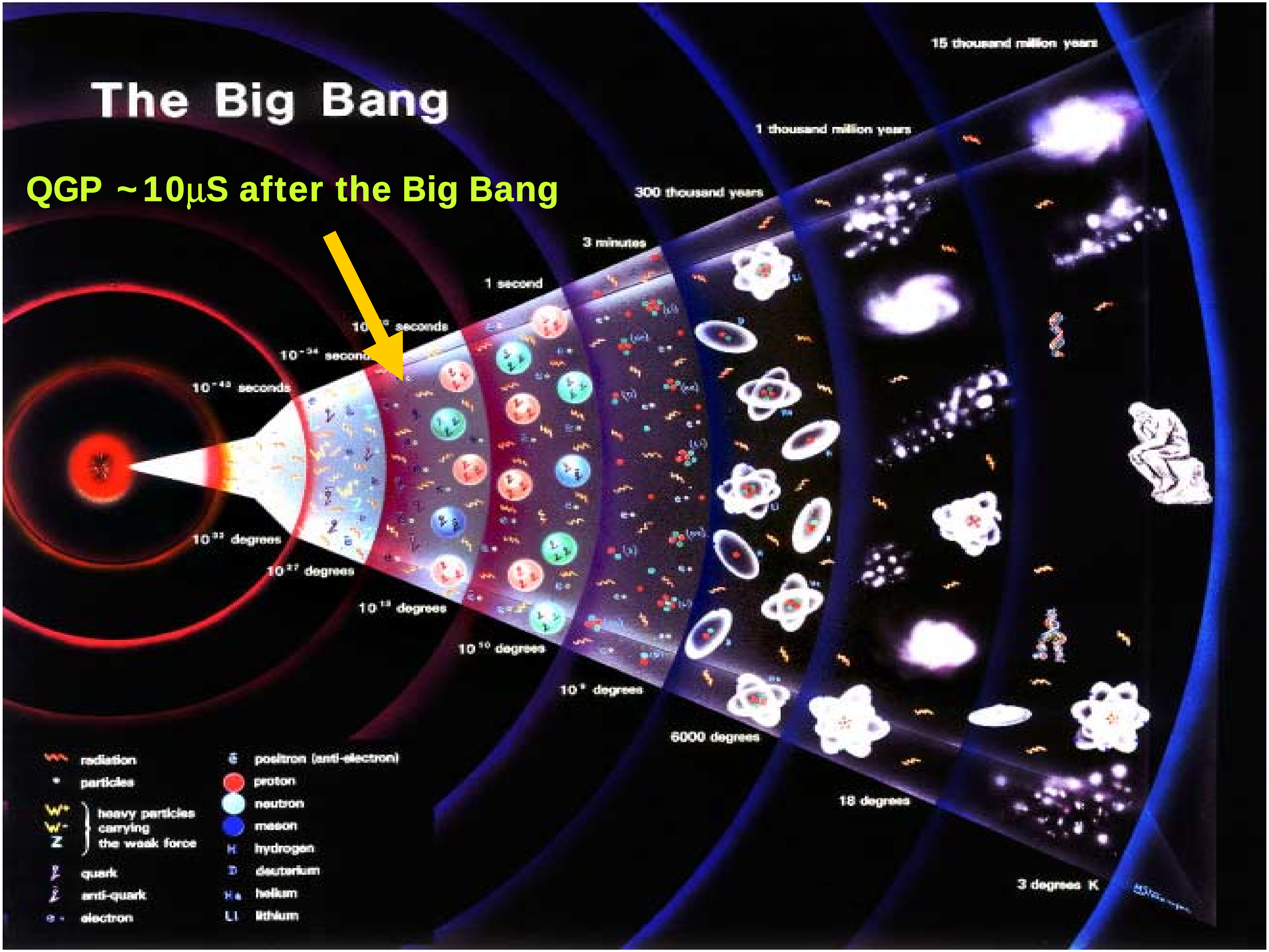
# Back-up Slides

# QGP in the Universe



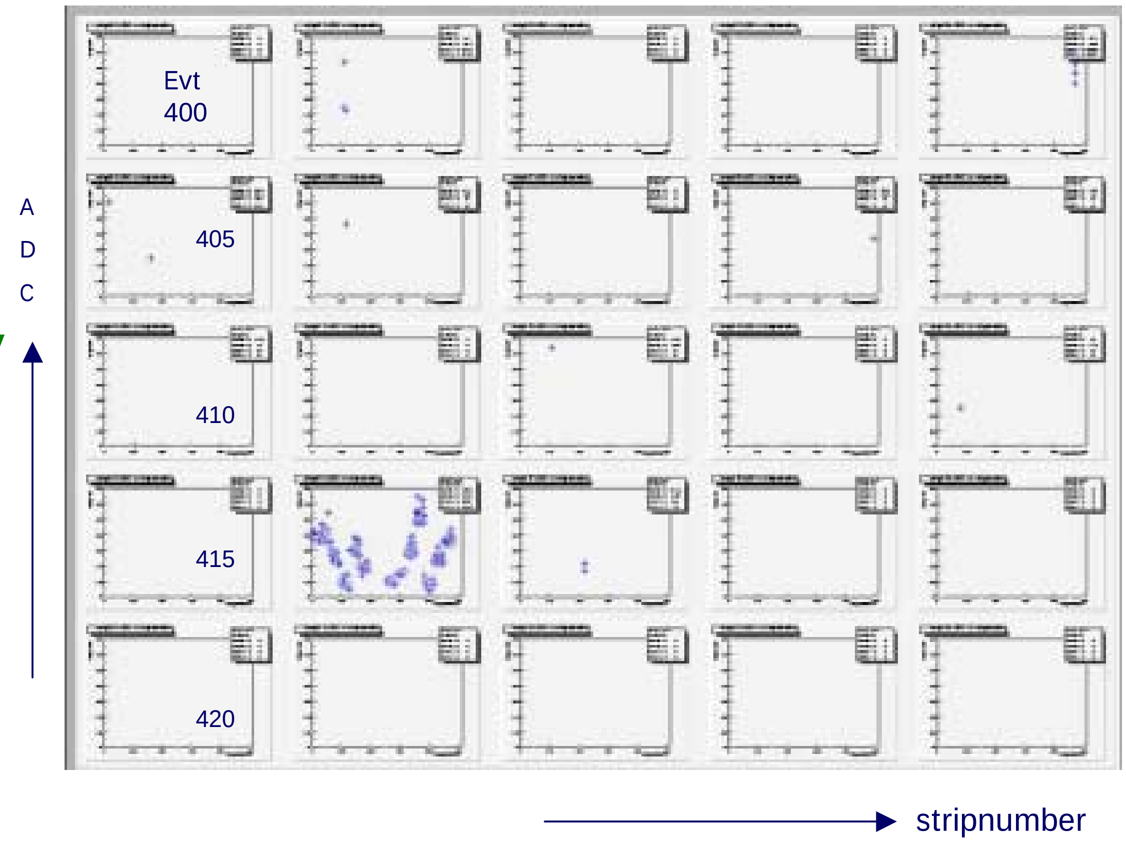

Neutron stars are the collapsed cores of a massive star.

They pack the mass of the sun into the size of a city.


The Big Bang
QGP ~10μS after the Big Bang
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
$10^{-43}$ seconds
$10^{32}$ degrees
$10^{27}$ degrees
$10^{15}$ degrees
$10^{10}$ degrees
$10^{9}$ degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium

# Event by Event Pedestal Jumping

- Pedestals "jump" in event to event!!
- Jumping could be such that the pedestals can occupy the ADC range that could be that of a track (meaning they can screen the tracks)
- WE NEED TO IDENTIFY THE PEDESTALS BEFORE WE DO ANYTHING.




**2D plot of ADC in y-axis and stripnumber in x axis.**

**The plots are for events 400-424.**

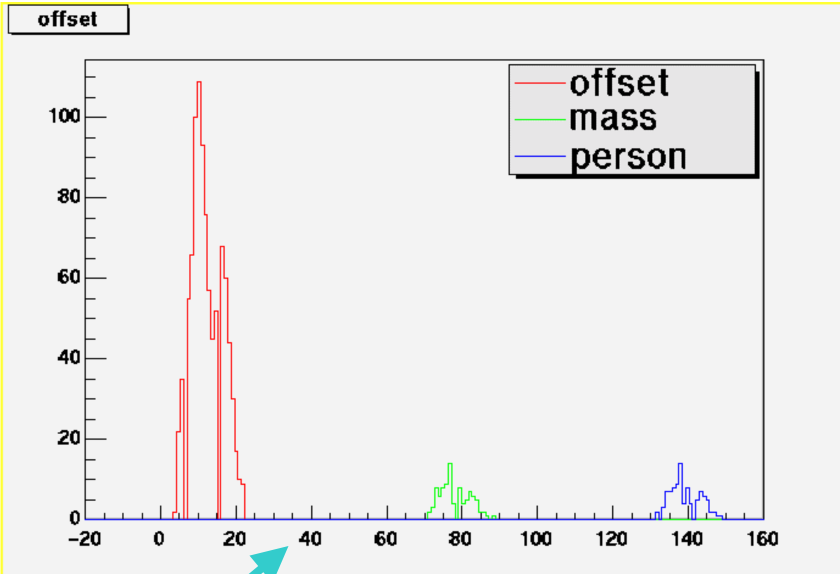
**Look at event 416. All the strips have high ADC.**

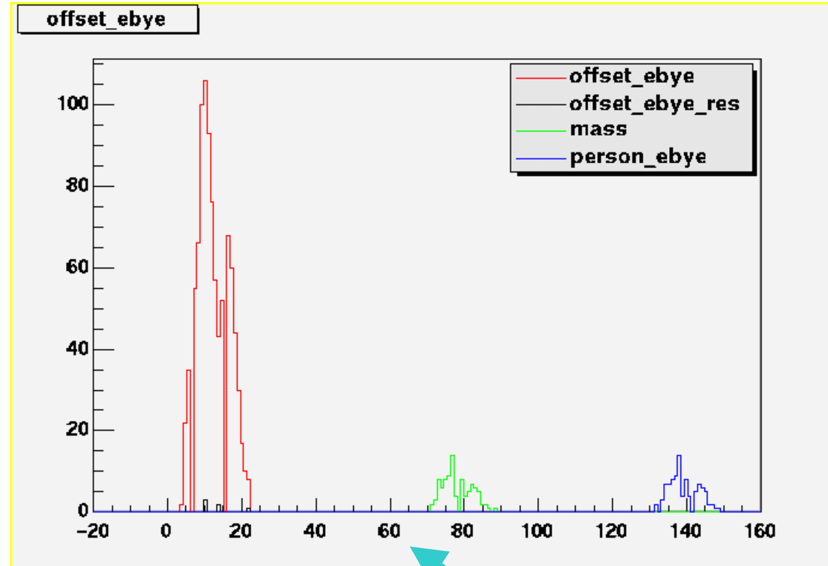
# Event by Event Correction Procedure : Does it Work?

- We do a simple test
  - measure two quantities on a scale that ‘s offset changes in each measurement.
  - Think of an “event” where we change the offset and record offset 10 times, and measure a block and a persons weight once. So each event has 12 entries.
  - Lets do about 100 events.

    Pass the events through the event by event correction procedure.
  - If the procedure works, we will see very narrow distributions .

# Test Result

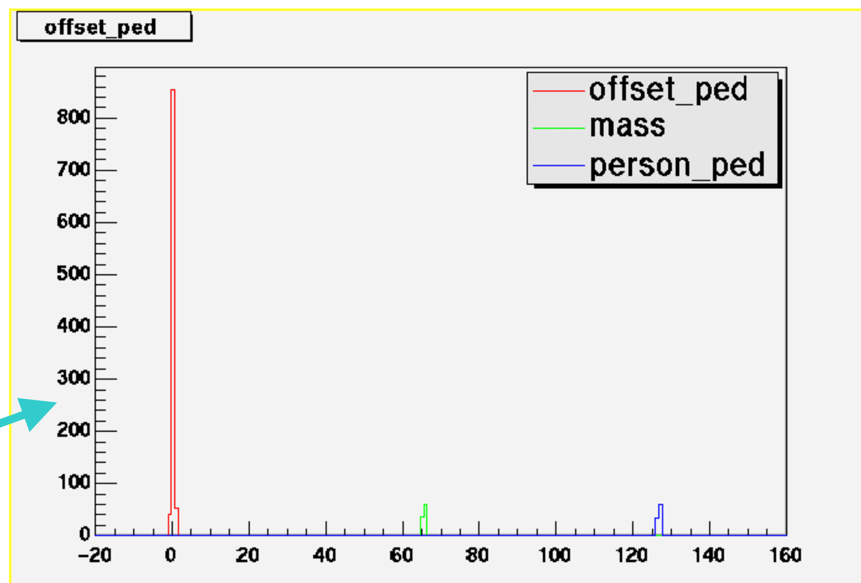



Raw

All are 1D plots of weights in x-axis

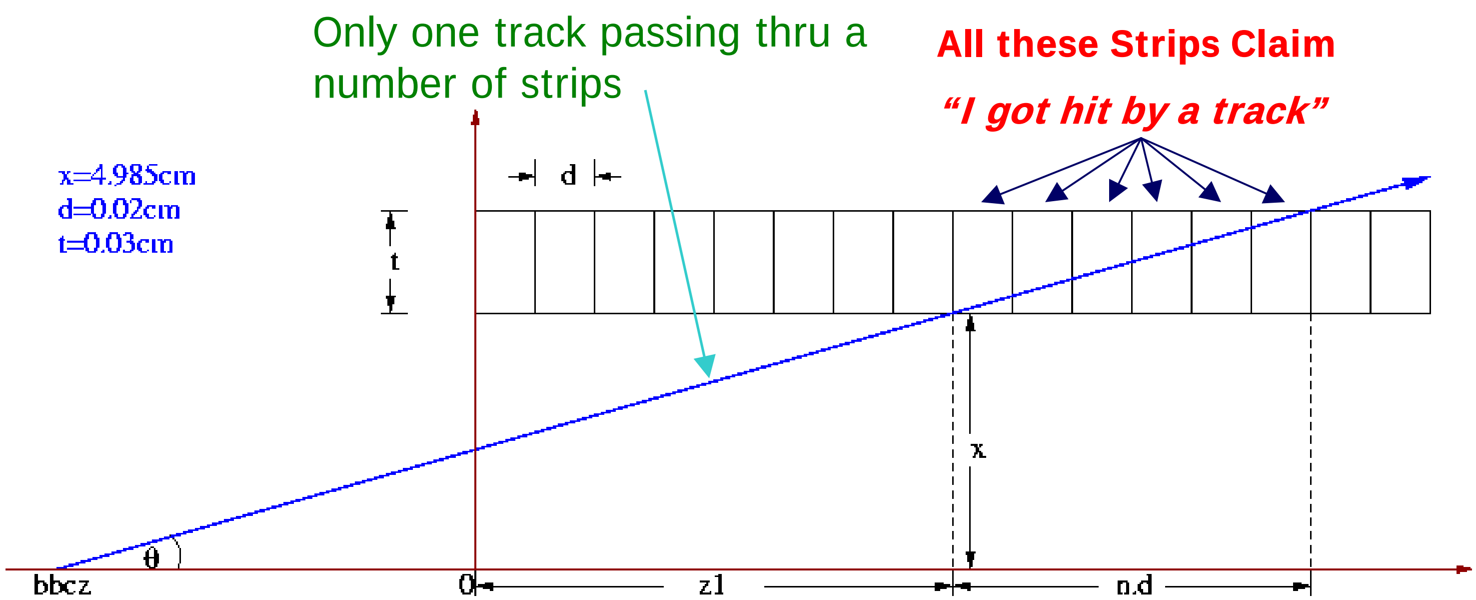
After ebye pedestal identification




After event-by-event pedestal subtraction

**WORKS!**

# Corrections for Multiple Counting of Tracks



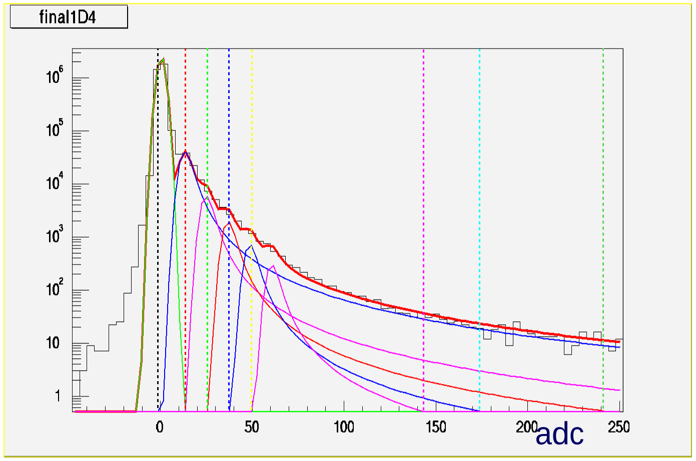

Pathlength inside MVD is $\sqrt{(t^2+n^2d^2)}$

A pathlength of t corresponds to an ADC for a MIP

Pathlength $\sqrt{(t^2+n^2d^2)}$ corresponds to $\sqrt{(t^2+n^2d^2)}/t$ tracks

So the correction factor is $t/\sqrt{(t^2+n^2d^2)} = \mathrm{Sin}\theta$

# Systematic Error from Fitting




If $p_0$ is the probability to be pedestal and $p_i$ is the probability to be a i-track, then the number of track associated with an ADC is:

$n = 1*p_1+2*p_2+3*p_3+4*p_4+5*p_5$

Imagine that an ADC is really due to 2-tracks. Using above relation, we are undercounting the track by

$e_2 = -1*p_1+0*p_2+1*p_3+2*p_4+3*p_5$

We counted the number of 1-tracks, 2-tracks etc.

So, if there are $N_2$ 2-tracks in a total of N tracks, the error for such tracks are

$err_2 = (-1*p_1+0*p_2+1*p_3+2*p_4+3*p_5)*p_2*100\%$

Where $p_2 = N_2/N$