Future

PHENIX

Calorimetry and Trigger Upgrades

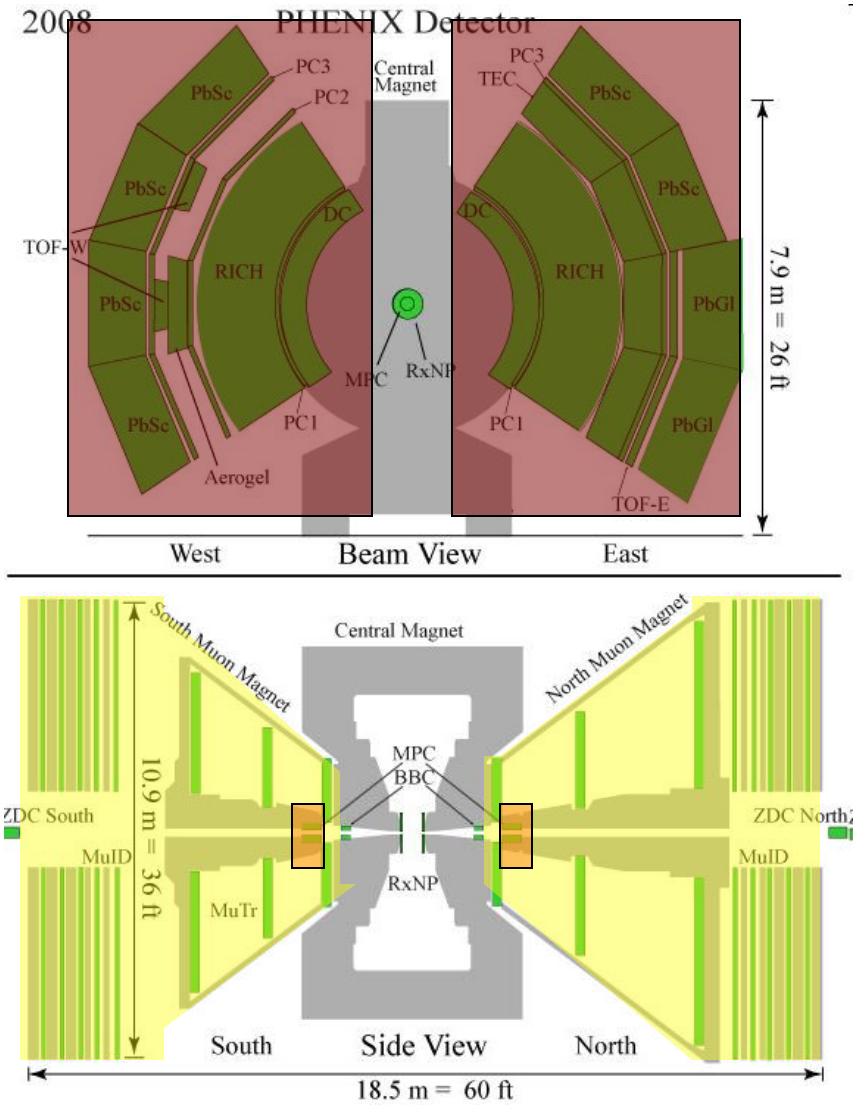
Anselm Vossen

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Outline

- Phenix now and in the next decade
- FoCal: A forward EM calorimeter
  - Gluon Densities at Low x in Nuclei
- Forward Muon Trigger Upgrade
  - Accessing Sea Quark Polarizations in W production

PHENIX Detector at RHIC



Central Arms $|\eta| < 0.35$

- Identified charged hadrons
- π^0, η
- Direct Photon
- J/Ψ
- Heavy Flavor

Muon Arms $1.2 < |\eta| < 2.4$

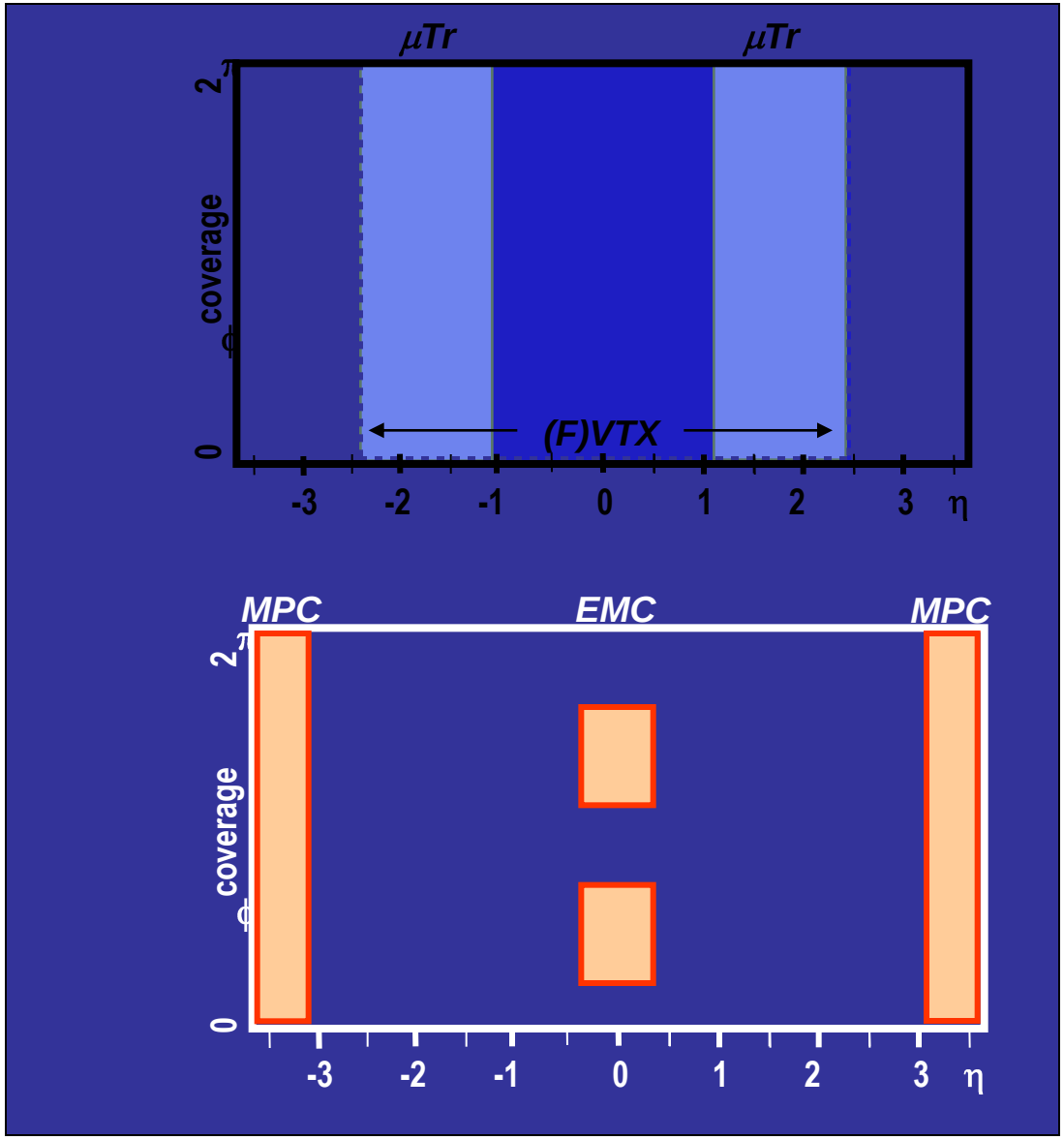
- J/Ψ
- Unidentified charged hadrons
- Heavy Flavor

MPC $3.1 < |\eta| < 3.9$

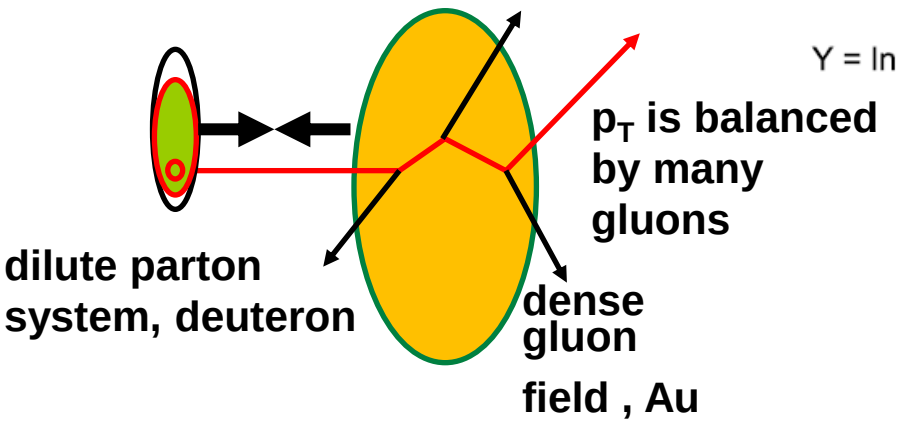
- π^0, η

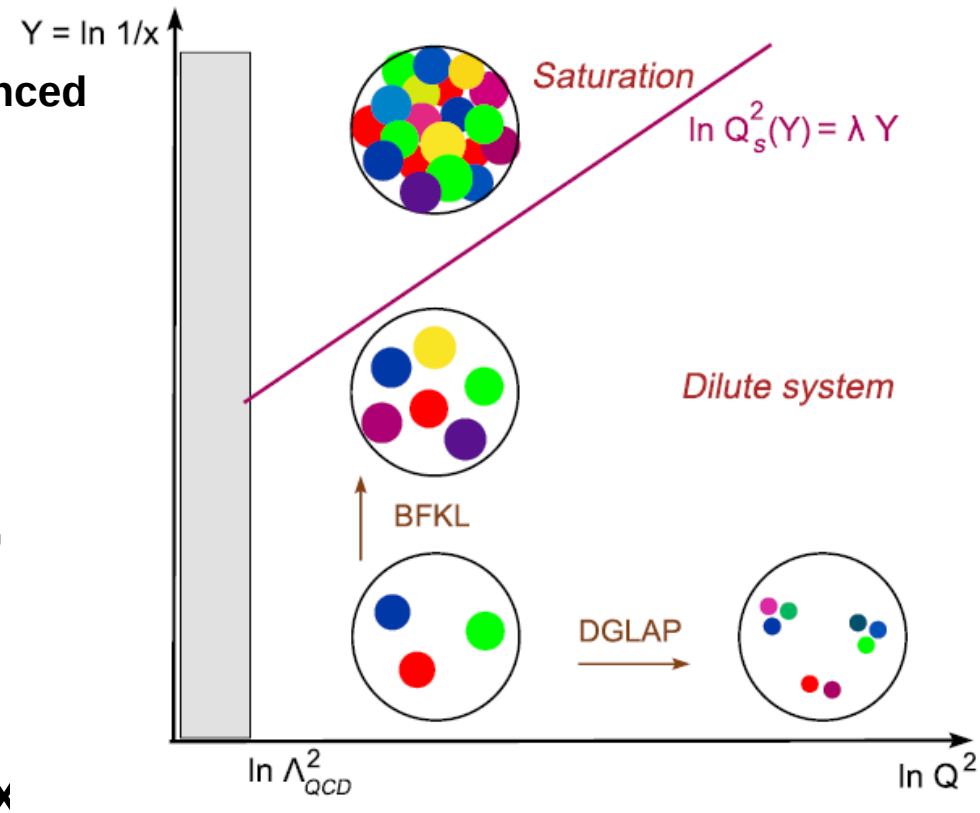
PHENIX Acceptance

- Tracking
  - Central region and forward muon arms
- Calorimetry
  - Very limited acceptance
    - In ϕ and η
- Staged Calorimeter Upgrades
- Muon Piston Calorimeter (MPC)
  - $3.1<|\eta|<3.9$
- Need more forward calorimetry



Access Low x Nuclear Gluon Distributions in d-Au

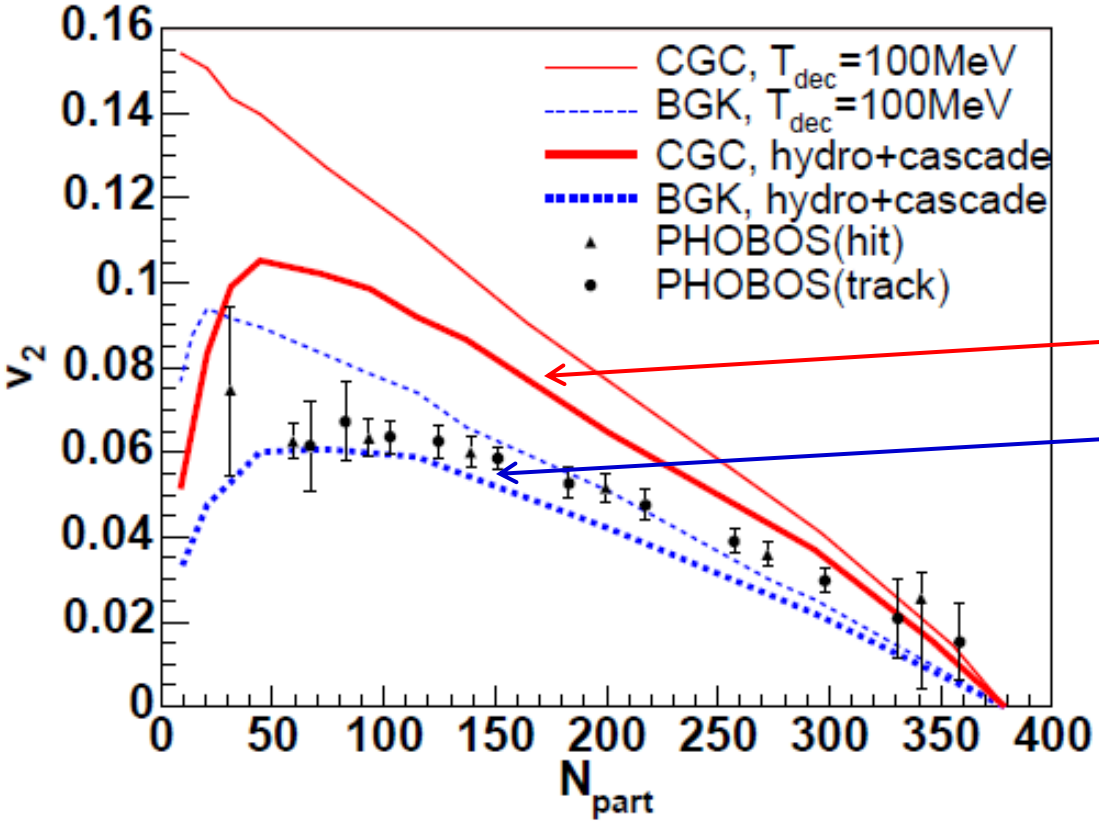




- Forward direct γ, π^0 and γ-jet correlations sensitive to low x gluons

Importance for QGP Interpretation

PHOBOS v_2 vs Hydro Calculations



T. Hirano, U. Heinz, D. Kharzeev,
R. Lacey, Y. Nara
Phys.Lett.B636:299-304,2006

Color Glass Condensate

Brodsky-Gunion-Kuhn Model

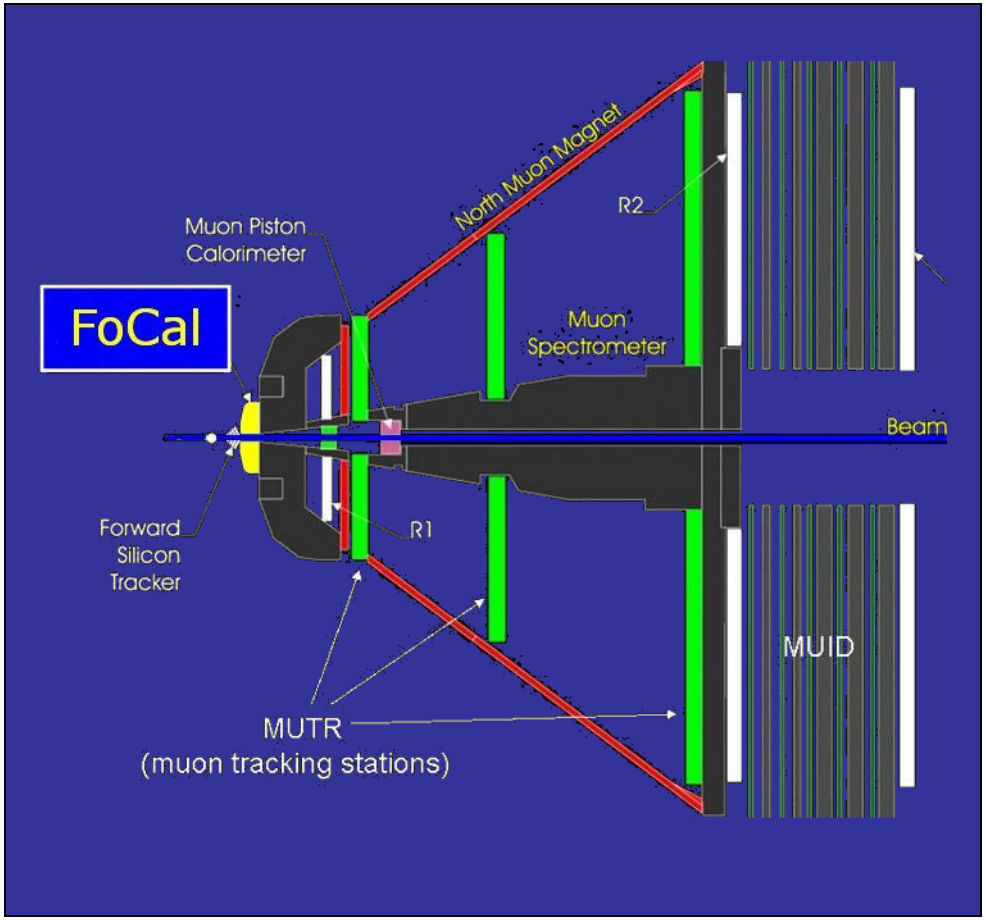
Phys.Rev.Lett.39:1120

➔

Knowledge of the initial state is important for the quantitative interpretation of experimental results in heavy ion collisions!

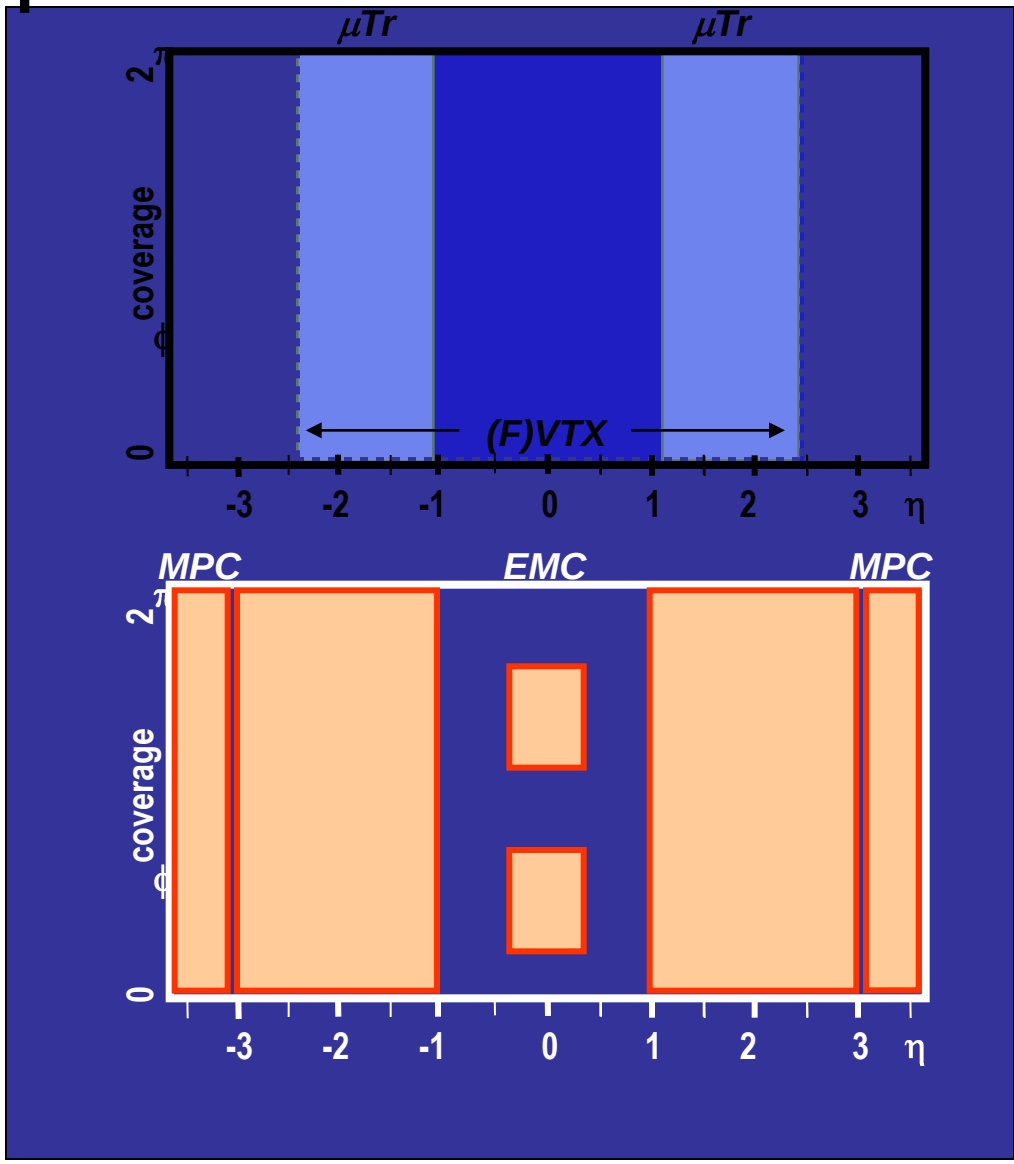
Finding space in PHENIX

- Small space in front of nosecone
  - 40 cm from vertex
  - 20 cm deep
- Calorimeter needs to be high density
  - Silicon-Tungsten sampling calorimeter

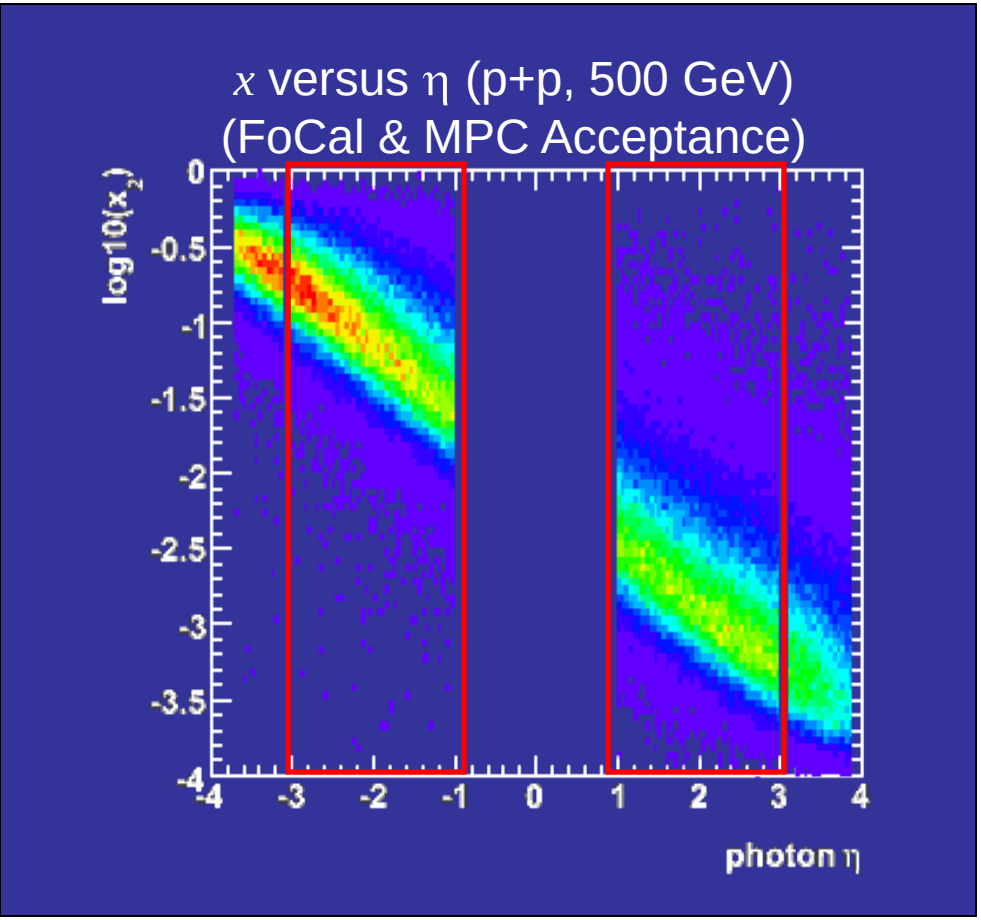


Introducing the FoCal in PHENIX Acceptance

- Acceptance
  - 1<|η|<3
- Forward gamma, pi0,
- Pi0-gamma correlations
- Access to low x



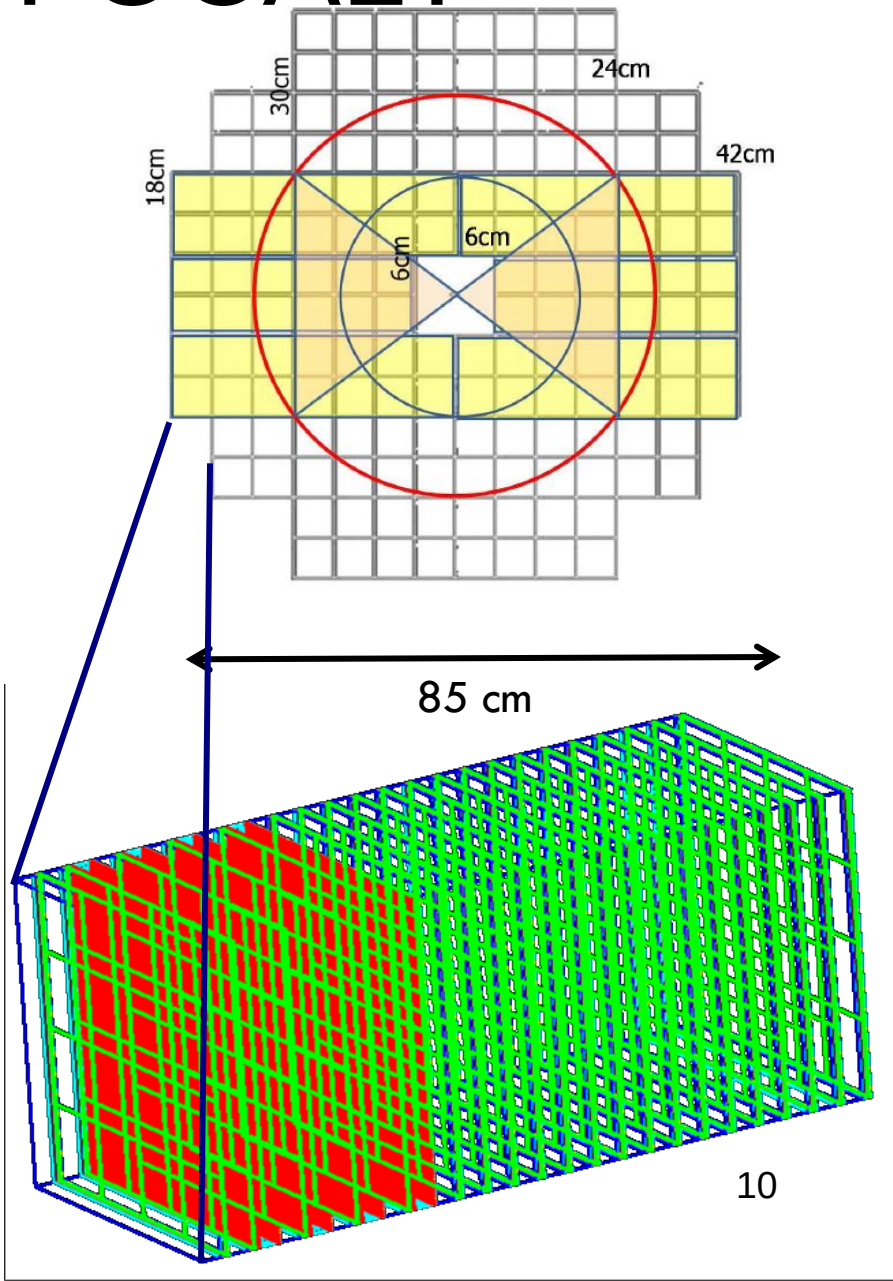
FoCal x Coverage



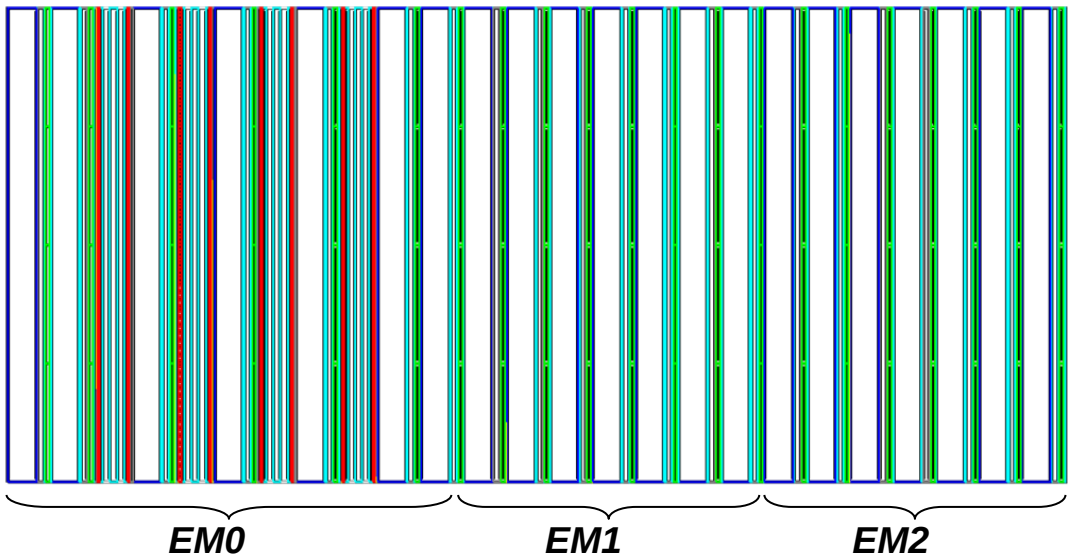
- x coverage:
  - Weak p_T dependence
  - Strong η dependence
  - FoCal complementary to MPC

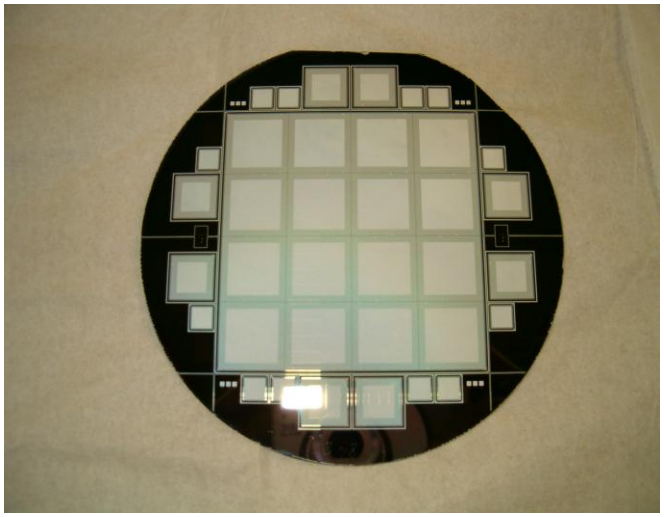
What is the FOCAL?

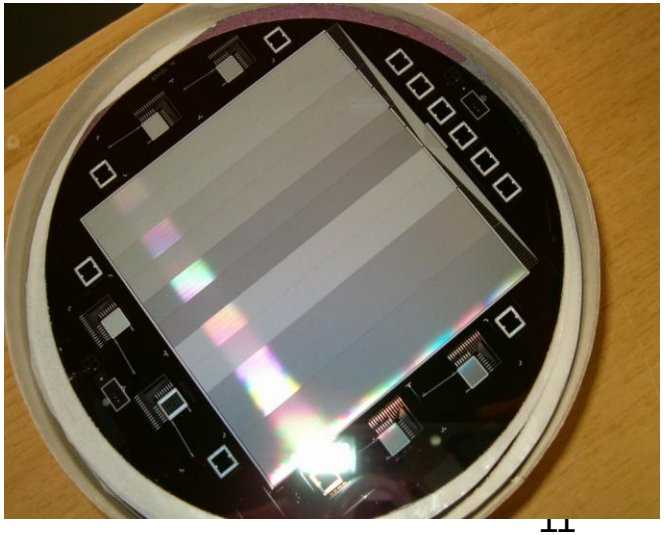
- **A compact Silicon-Tungsten (SiW) sampling calorimeter: tungsten absorber plates with silicon pad readout.**
  - **$1 < \eta < 3$**
  - **2π azimuth**
  - **21 X_0 deep**
- **Three longitudinal segments of pad readout, to reconstruct lateral and longitudinal shower profile**
- **Four layers of Si-strips within the first X_0, for γ/π^0 separation.**



Zooming in







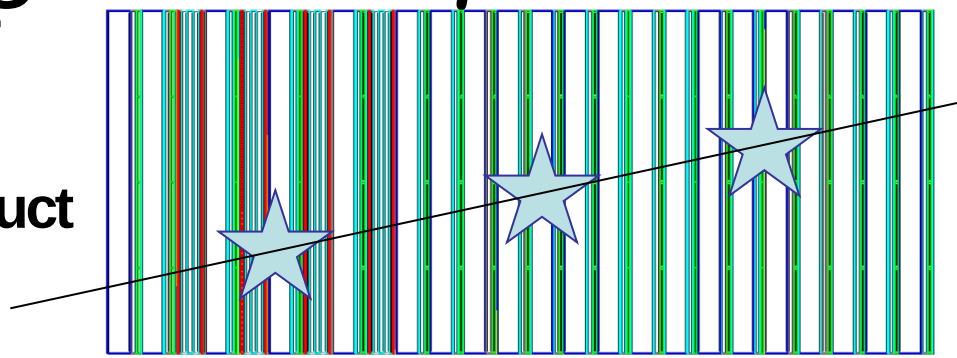
One tower:

- **4 mm thick W plates, ~21 X_0;**
- **3x7 = 21 layers of 4x4, 500 μm thick Si pads**
  - **15x15 mm^2 per pad**
- **8 layers of 300μm thick, 0.5 mm wide Si strips**
  - **4 horizontal strip layers + 4 vertical**

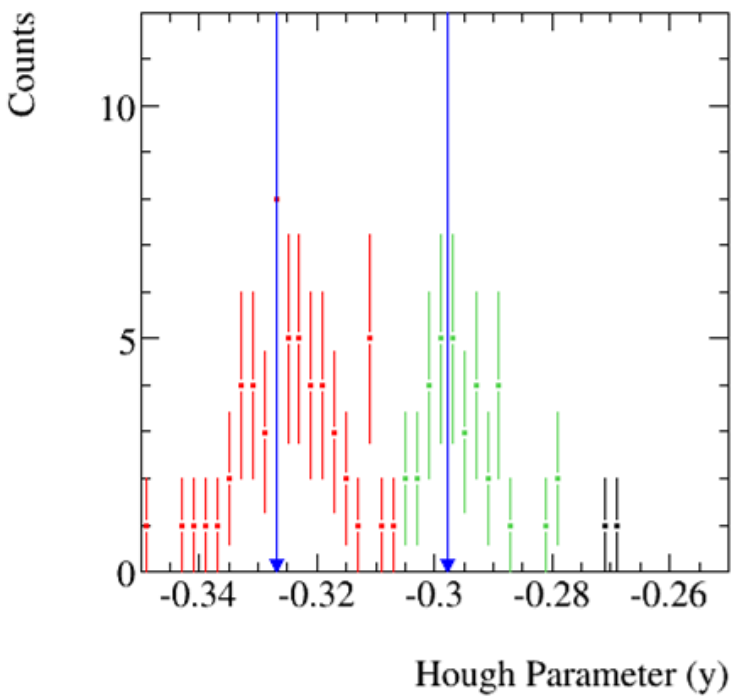
Identifying π^0 and γ

Use strip layers to track early shower development, via hough tracking;

When two tracks are found, reconstruct invariant mass.



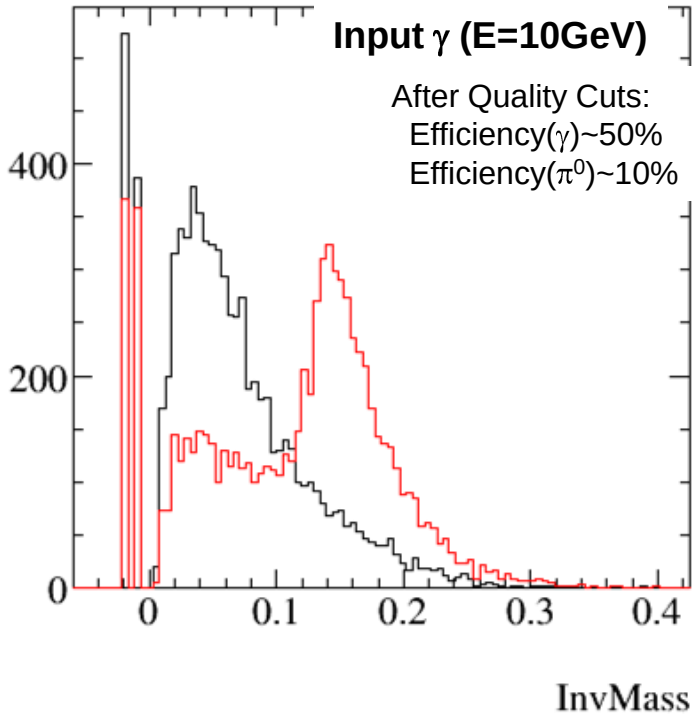
Input π^0 (E=10GeV)



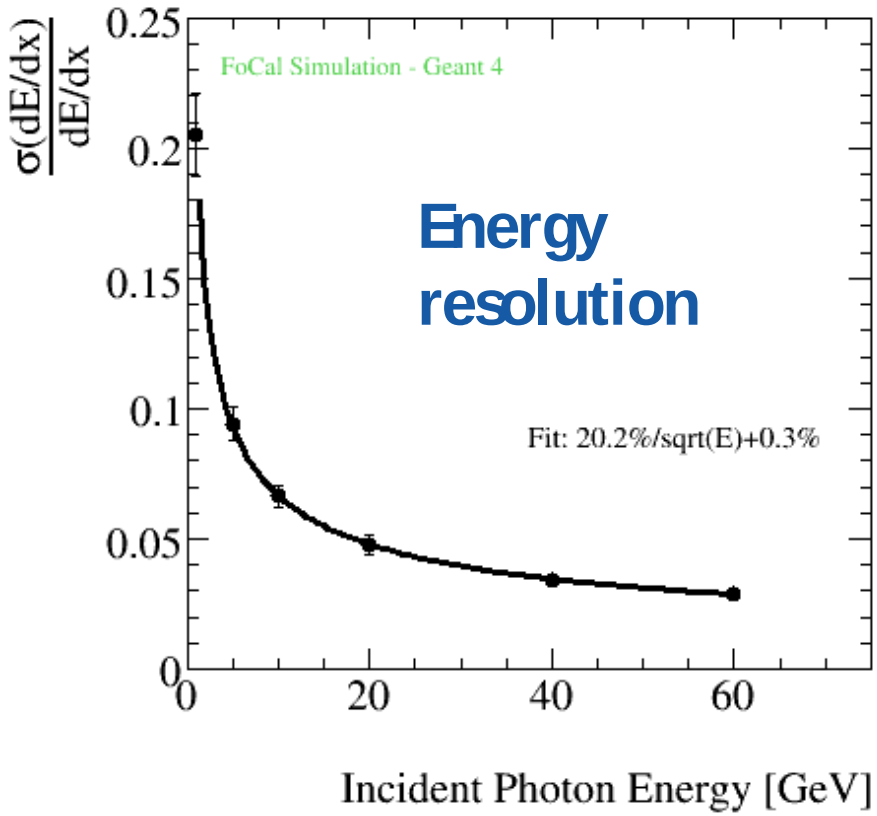
Input π^0 (E=10GeV)

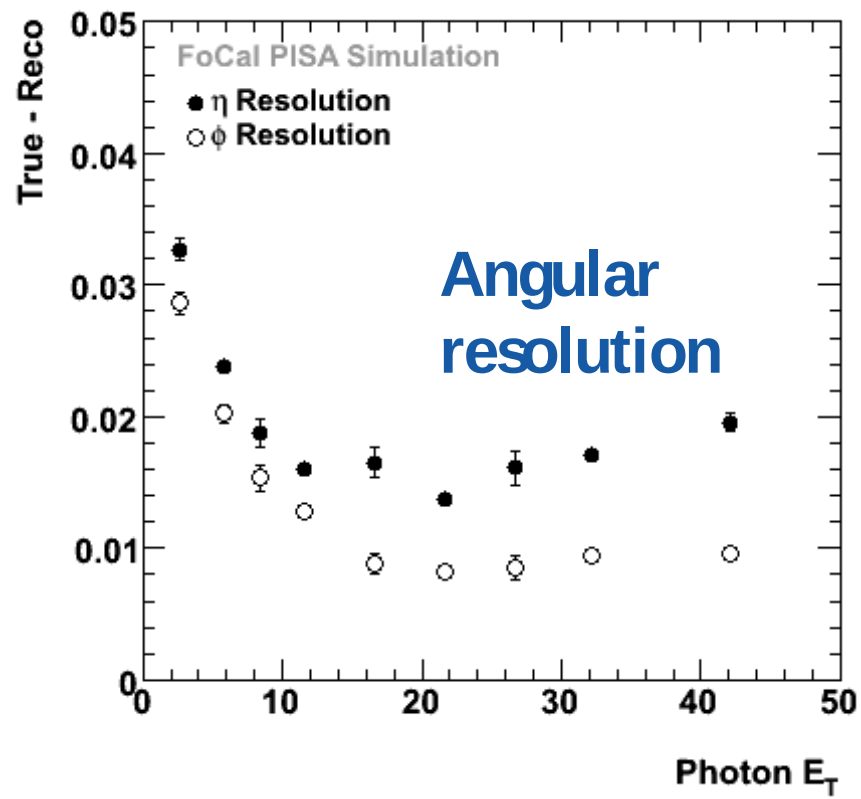
Input γ (E=10GeV)

After Quality Cuts:
Efficiency(γ)~50%
Efficiency(π^0)~10%



Detector performance studies

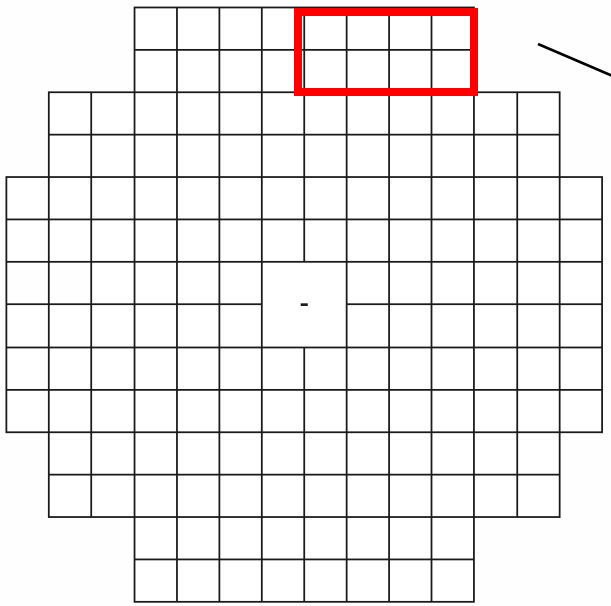




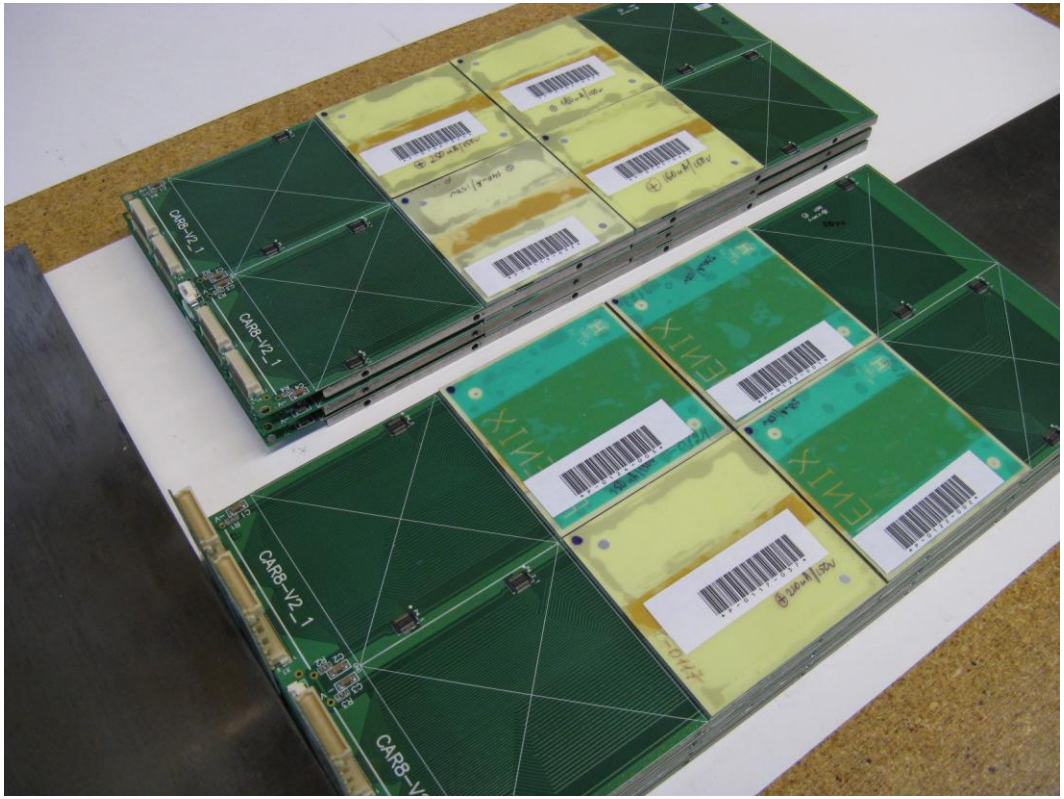
- Photon identification
  - e/γ radiation length: ~21
  - Hadronic rad. length: ~1
- Photon energy determination
  - Sampling fraction ~1.5-2.0%
  - Resolution ~ 20%/√E+0.3

- **Good angular resolution is critical for jet measurements;**
- **Results from simulation studies exceed minimum requirements**
- **Embedding jet in d+Au events has very small effect on resolution**

Beamtest with Prototype Detector



3-segment brick, with the 4 towers in the center populated with pad sensors.

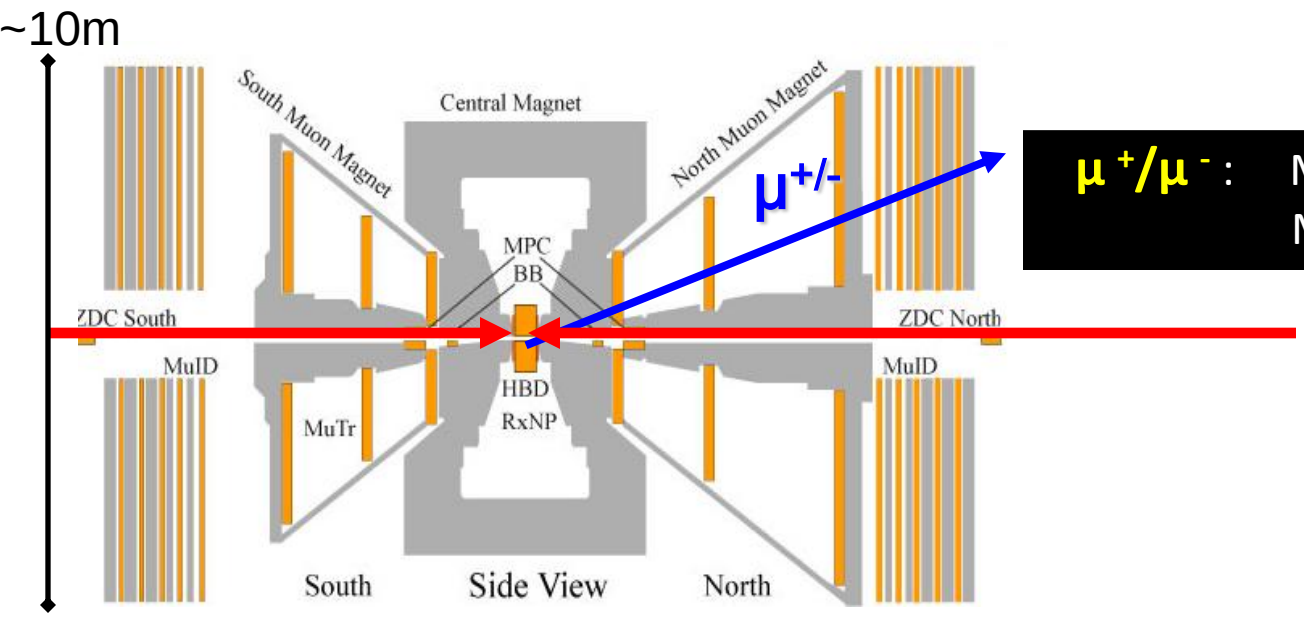


+ full readout chain, connected to standard PHENIX DAQ

Summary FoCal

- Access to small x in direct γ, π^0 correlations
  - d-Au: initial state nuclear gluon densities: CGC
  - Longitudinal polarized pp: DeltaG
- Beam test of prototype ‘bricks’ successful
- Awaiting final approval

Measurement of W Production in W->μν in the PHENIX Muon Arms in Polarized pp Collisions at $\sqrt{s} = 500\,\mathrm{GeV}$

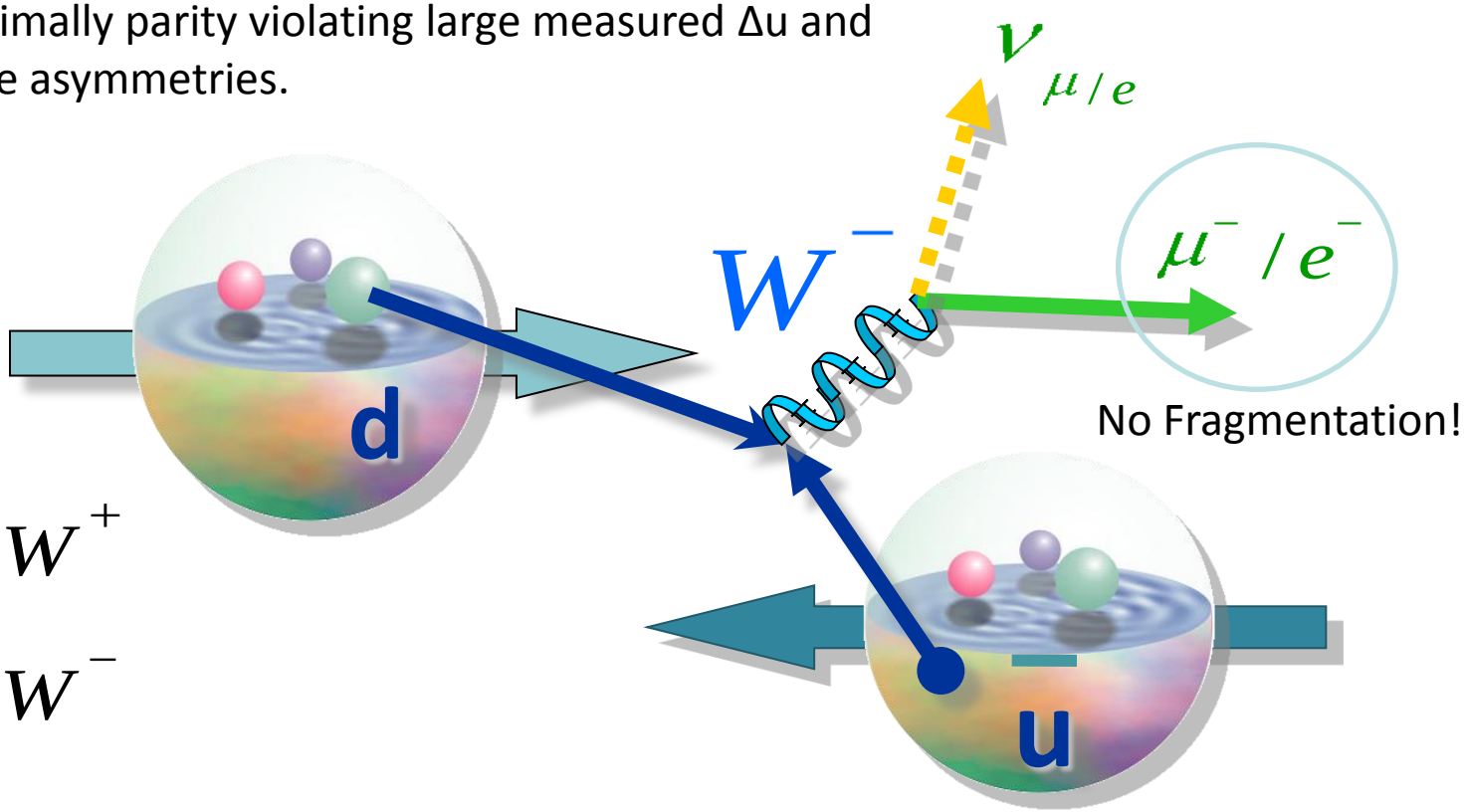


μ^+/μ^- : Muon Tracking Detector
Muon Identifier

Rapidity: $1.2 < \eta < 2.2$ (2.4)
$\Delta\phi = 2\pi$

W Production Basics

Since W is maximally parity violating large measured Δu and Δd *require* large asymmetries.



$$u\bar{d} \rightarrow W^+$$

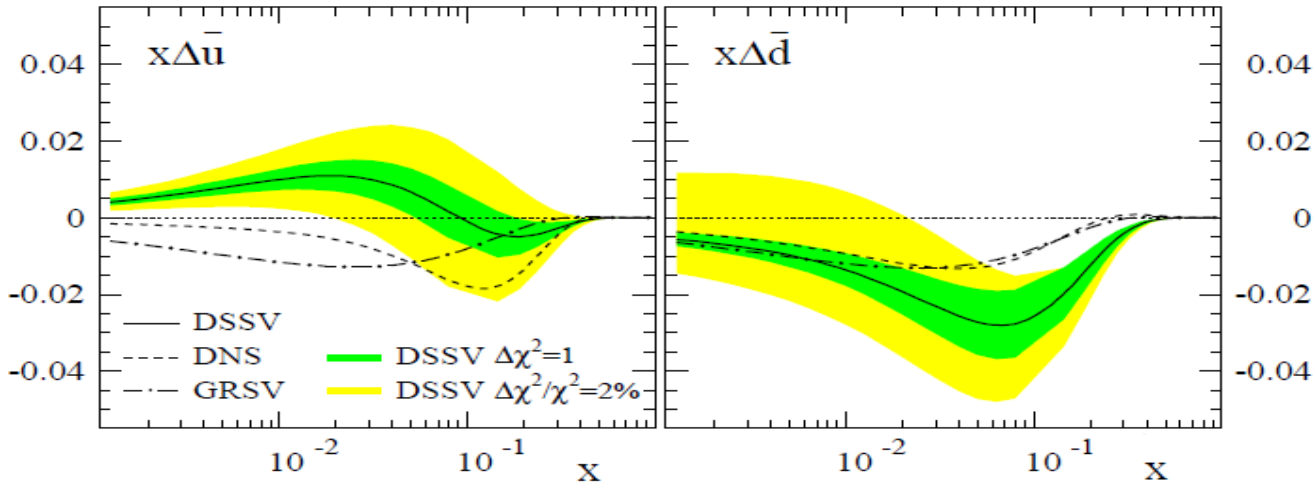
$$d\bar{u} \rightarrow W^-$$

$$A_L^{W^-} = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}} \propto \frac{\Delta\bar{u}(x_1)d(x_2) - \Delta d(x_1)\bar{u}(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

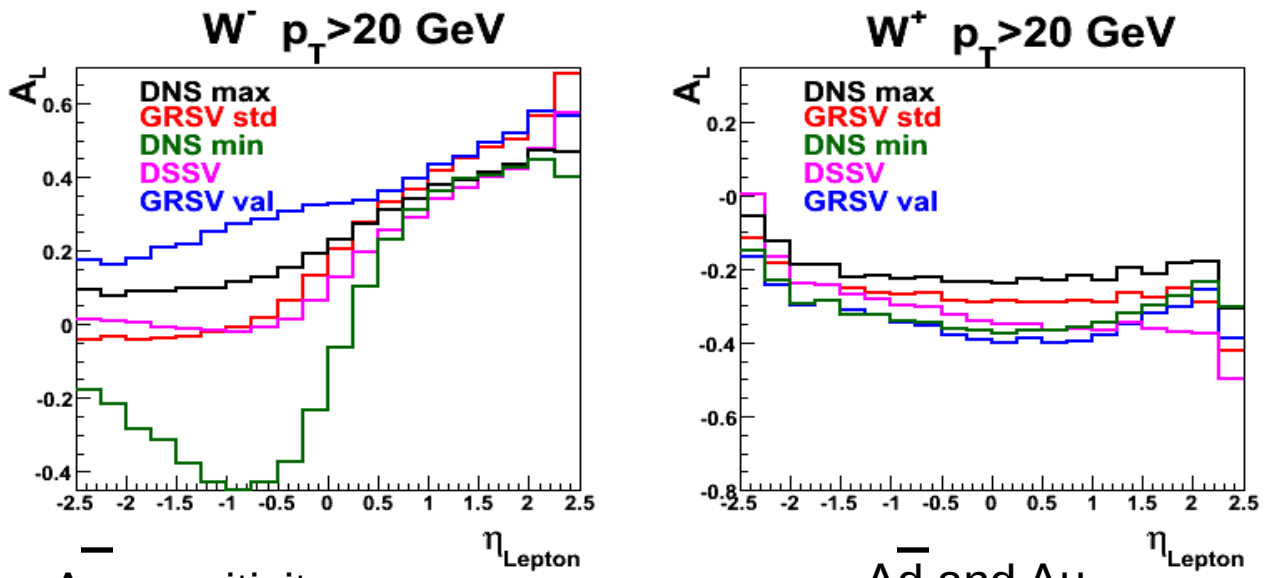
$x_1(x_2)$: momentum fraction of quark in polarized (unpolarized) proton

Similar expression for W^+ to get $\Delta\bar{d}$ and Δu…

Predicted RHICBOS forward asymmetries



- Good sensitivity in μ^- sample



$\Delta\bar{u}$ sensitivity

Δ d better known

$\Delta\bar{d}$ and Δu get mixed

W's in the PHENIX Muon Arms

A bit of development necessary…

Design Luminosity
√s = 500 GeV σ=60mb
L = 1.6 x10^{32}/cm^2/s

↓

Total X-sec rate = 9.6 MHz

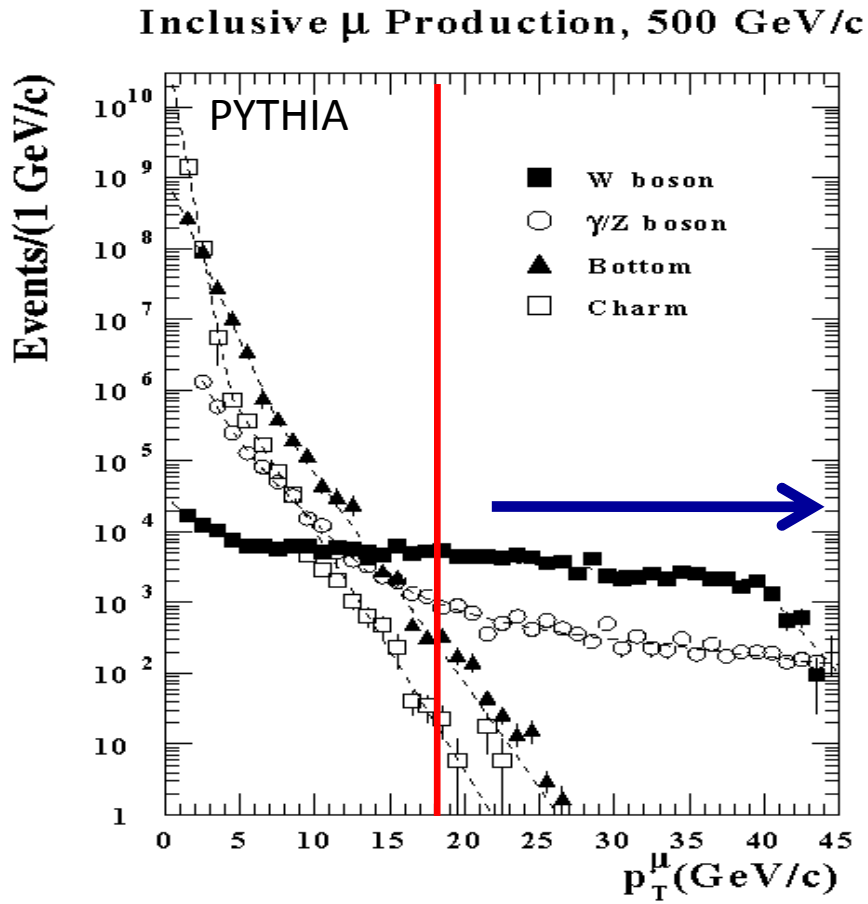
← DAQ LIMIT=1-2 kHz
(for μ arm)

↓

Required RF
10,000

↕

MuID LL1 (current trigger)
RF=200 ~ 500



Need fast level 1 trigger with momentum selectivity

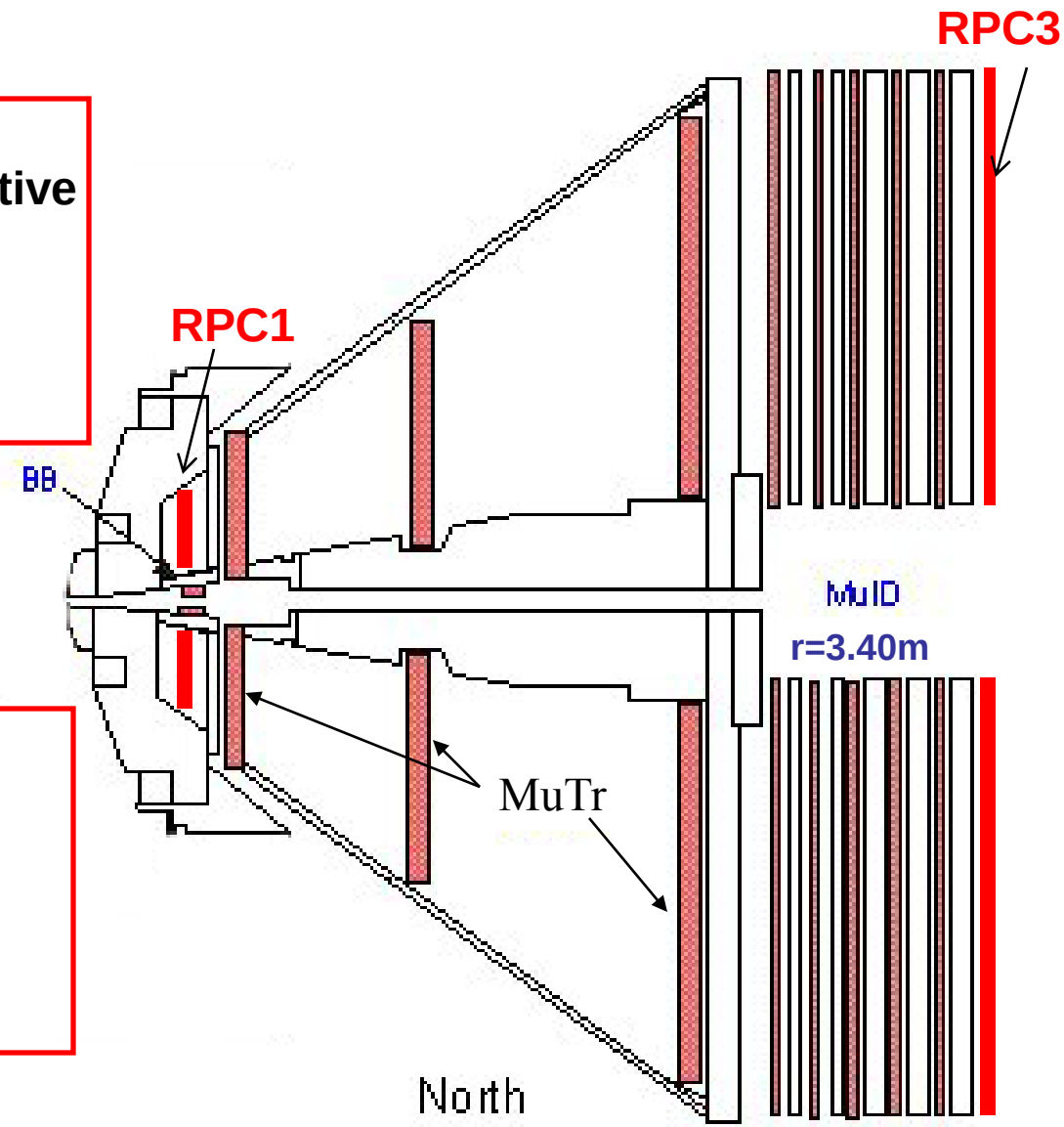
PHENIX Muon Trigger Upgrade

(I) 2 dedicated trigger Resistive Plate Chambers (RPC) stations (CMS design):

~ 1 degree pitch in φ

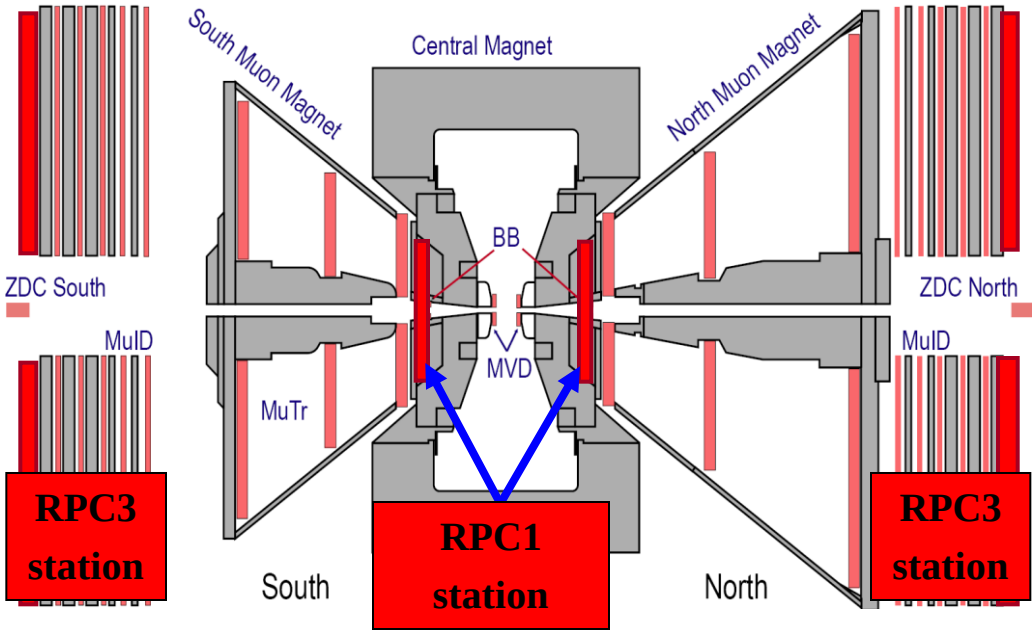
(II) MuTr front end electronics

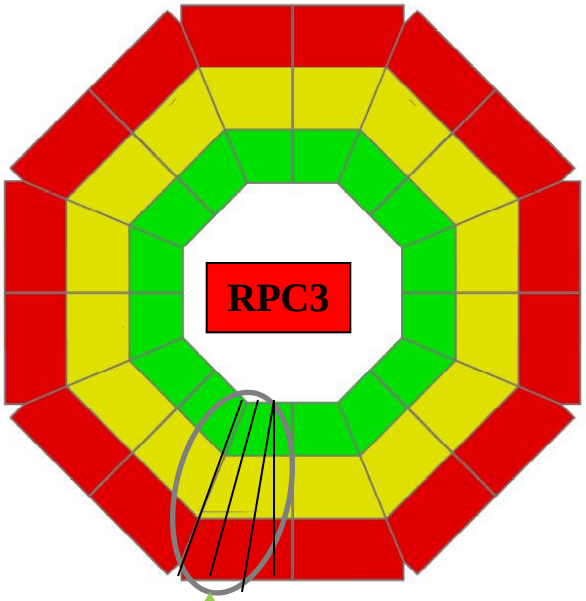
(MuTr-FEE Trigger)



Additional absorber necessary for offline background rejection

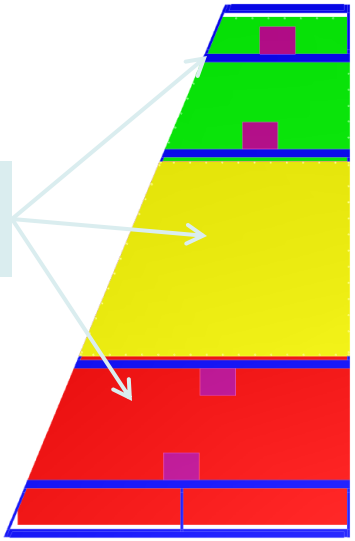
Resistive Plate Chambers (RPC) at PHENIX





half octant

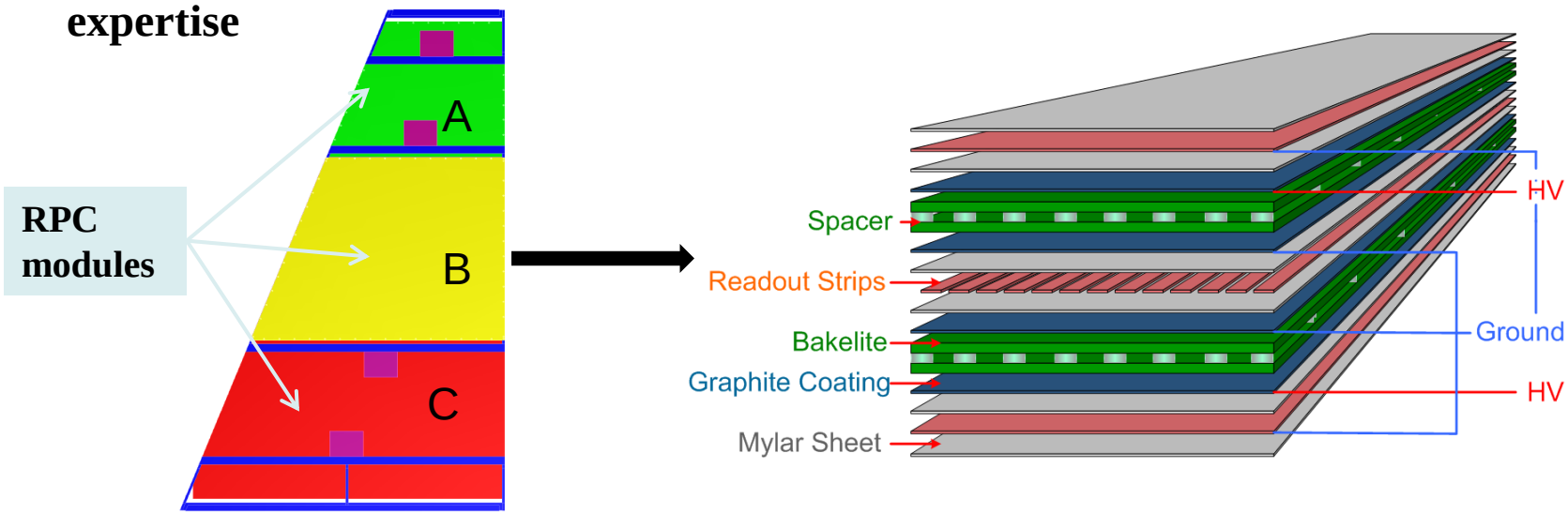
Use already established CMS Bakelite RPC technology and expertise

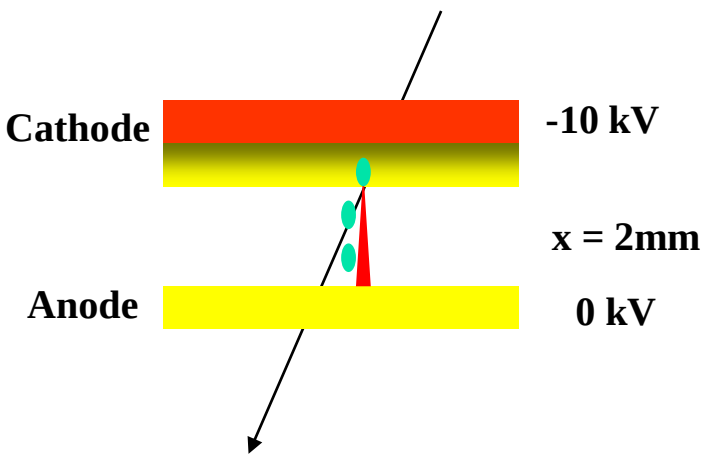


RPC modules

RPC Technology

Use already established CMS Bakelite RPC technology and expertise





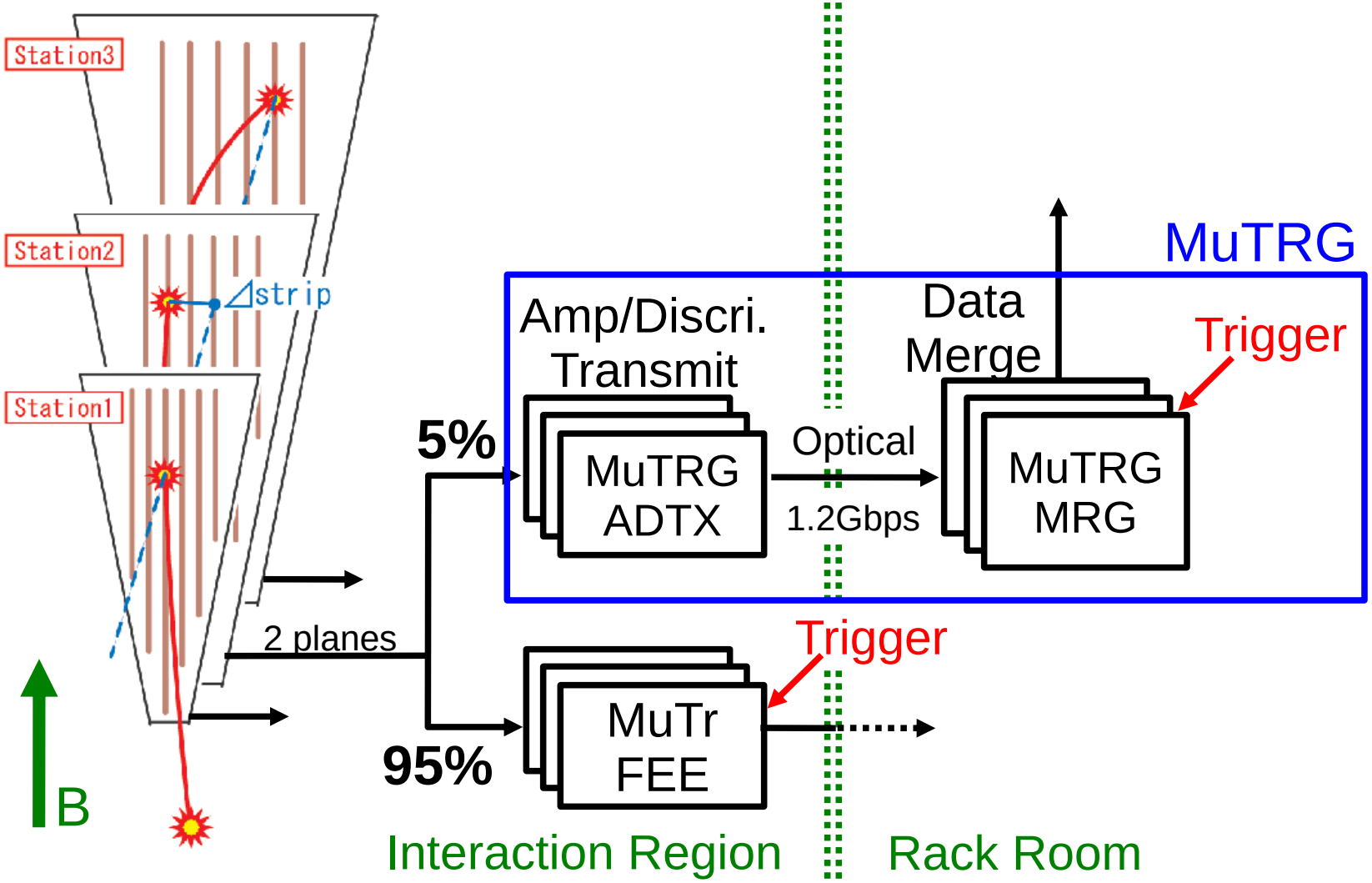
Trigger RPC (Muon RPC)

PHENIX RPC requirements

Time resolution	≤ 3 ns
Average cluster size	~ cm
Efficiency	> 95%
Rate capability	0.5 kHz/cm^2

W Trigger System

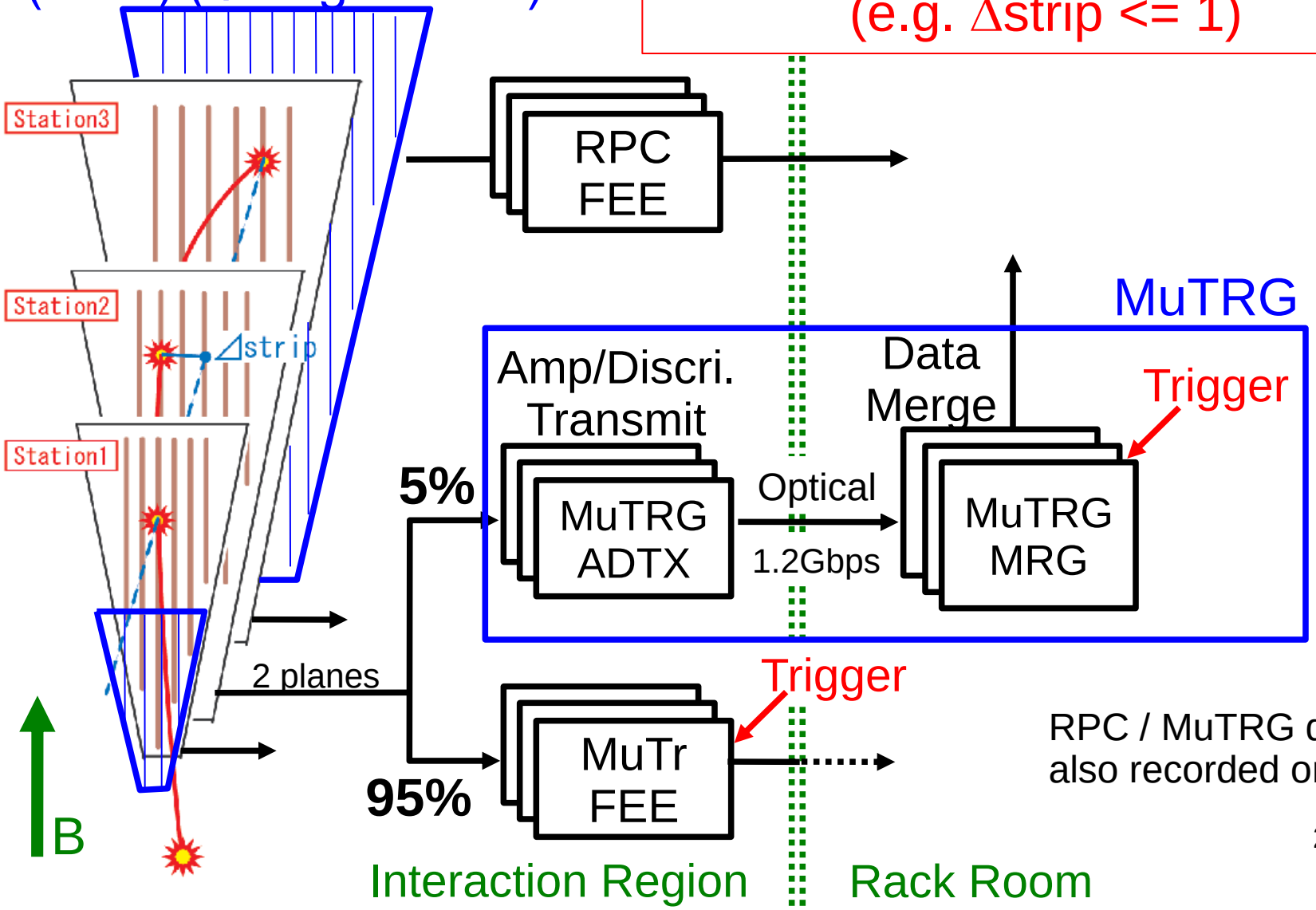
Trigger events with straight track
(e.g. Δstrip <= 1)



W Trigger System

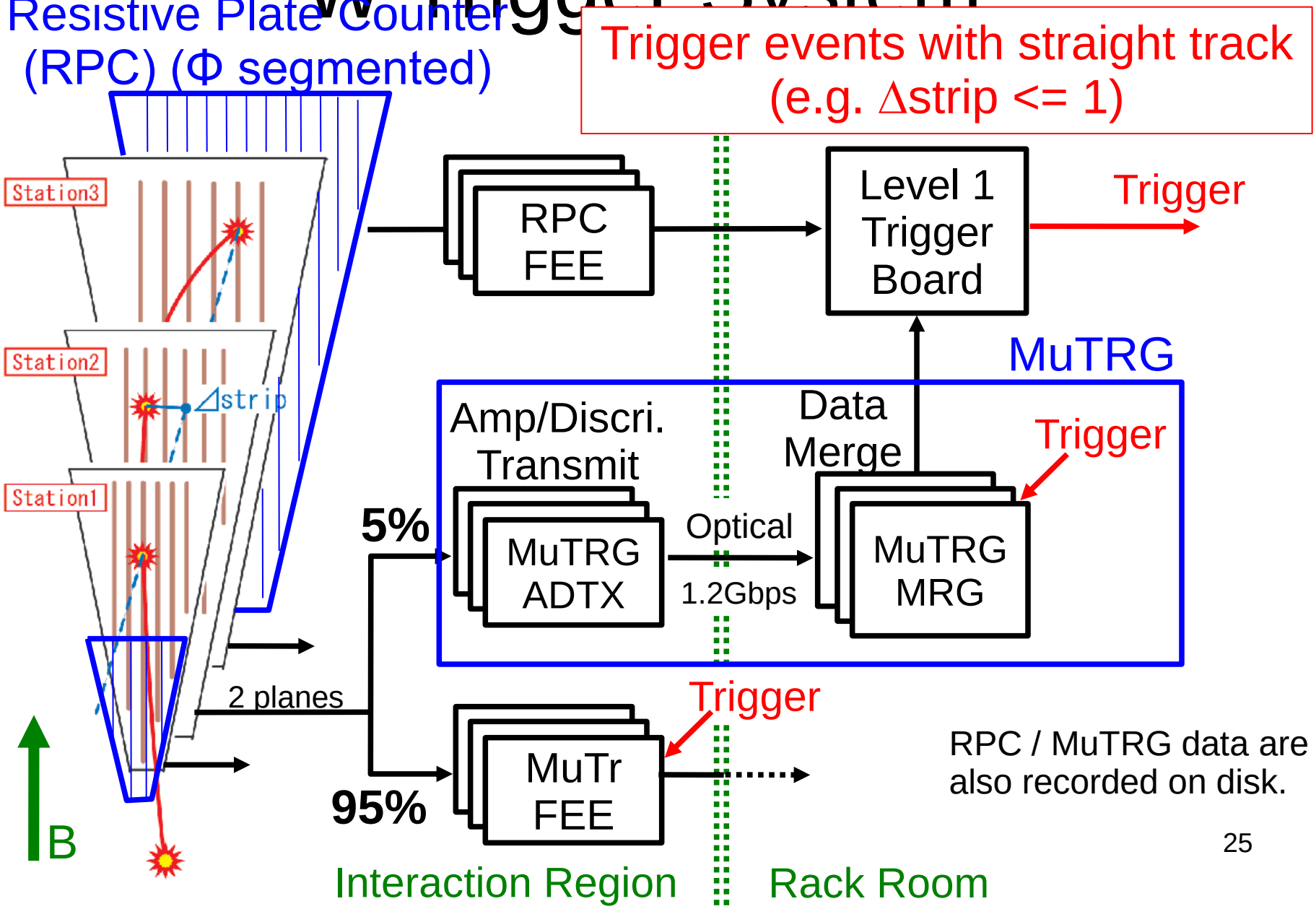
Resistive Plate Counter (RPC) (Φ segmented)

Trigger events with straight track (e.g. Δstrip <= 1)



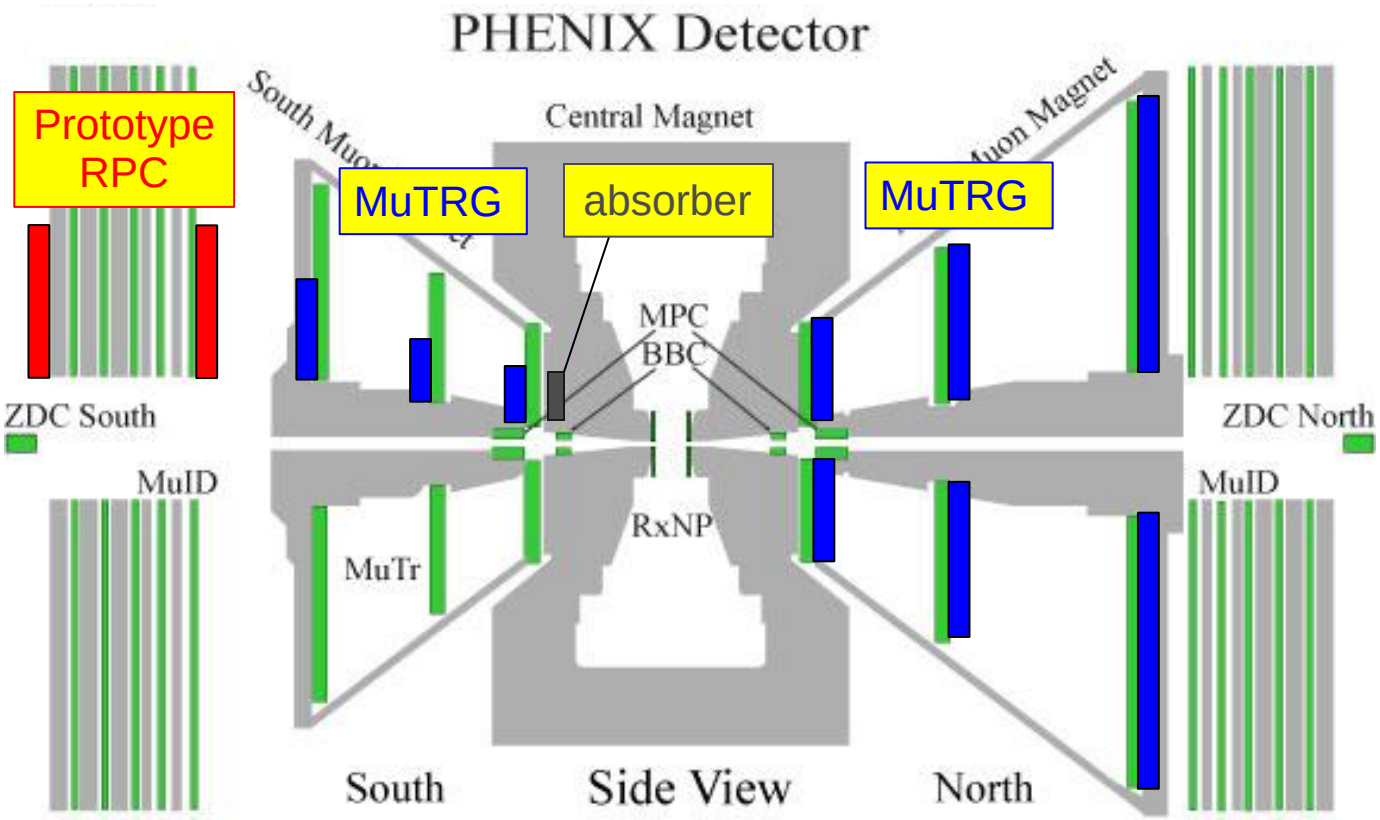
RPC / MuTRG data are also recorded on disk.

W Trigger System



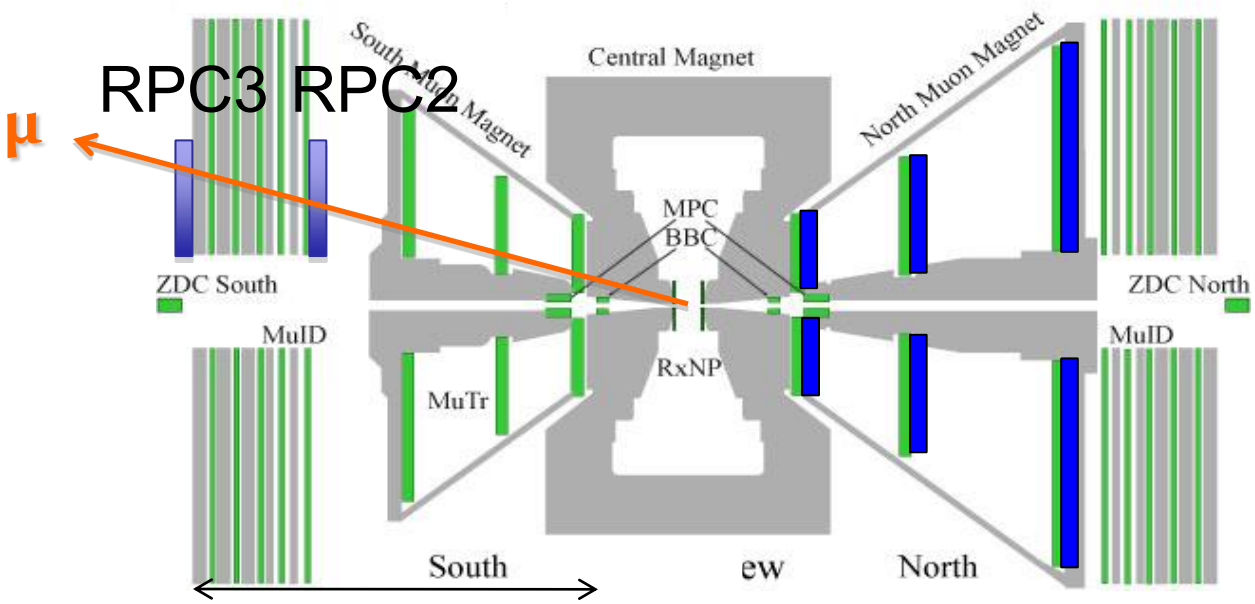
RPC / MuTRG data are also recorded on disk.

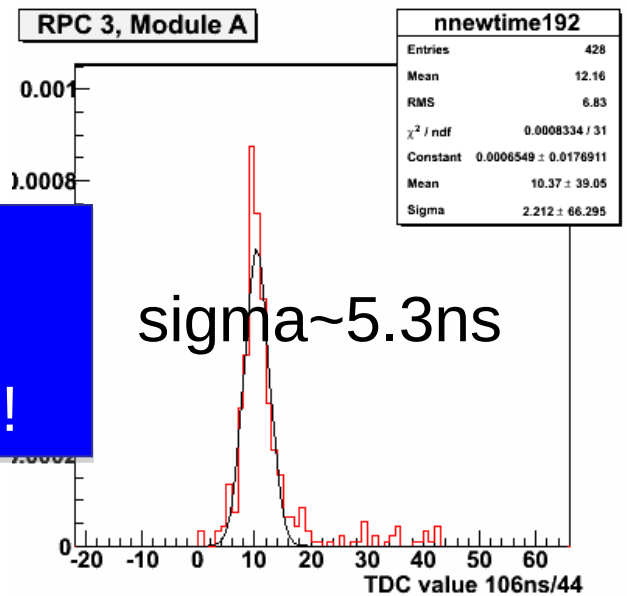
Instrumentation in 2009 run

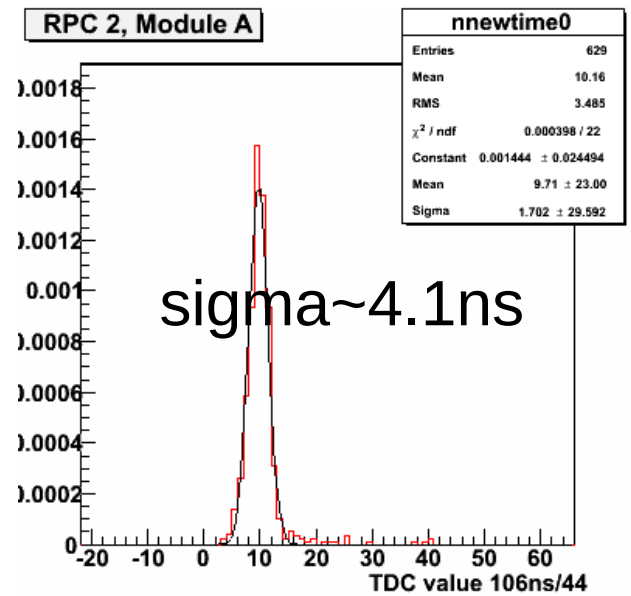


- Full Installation to North Arm, 1/2 octant installed to South
- Demonstrate performance of RPC and MuTRG with beam of $\sqrt{s}$=500 GeV.

Prototype RPC Performance @ Run9







Demonstrated satisfactory Timing Resolution w/ beam!

Work during last Shutdown

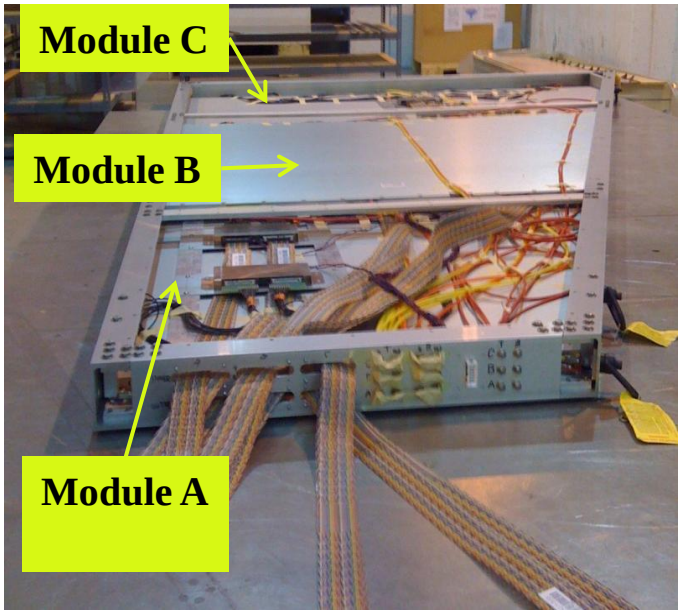
- Installation of MuTRIG FEE in South
- Installation of RPC3 North

RPC Detector Module Test and Production at BNL

cosmic ray trigger (10 scintillators readout both sides)

10 shelves for RPCs

cosmic ray trigger (12 scintillators readout both sides)



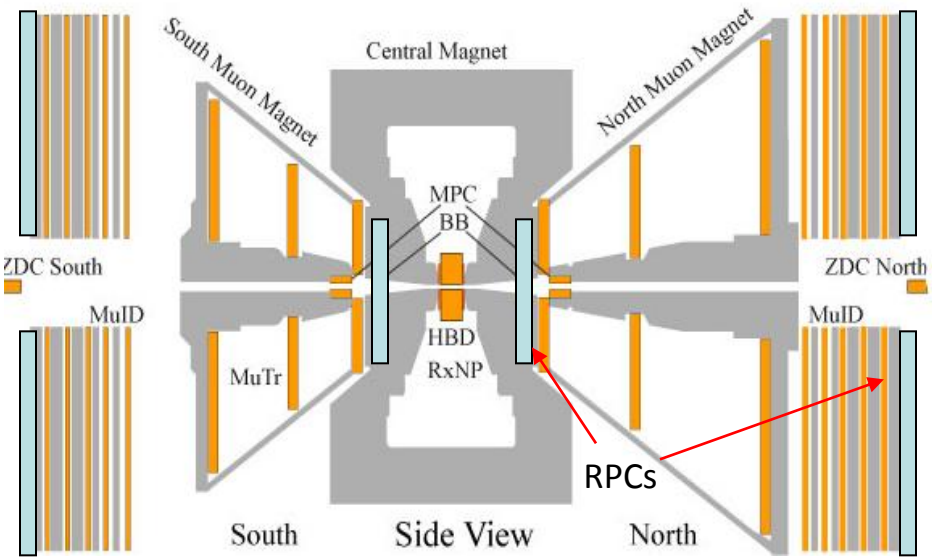
cosmic ray test stand at RPC factory

We are measuring: Noise rate, Total (2D) and strip efficiencies, Position and time resolutions, Cluster size

RPC3 North Installation (Nov.'09)

RPC3 North Completed Installation

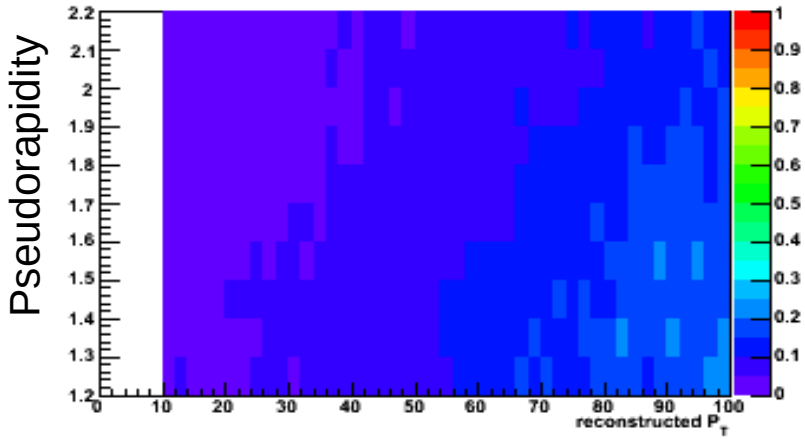
Status of Software



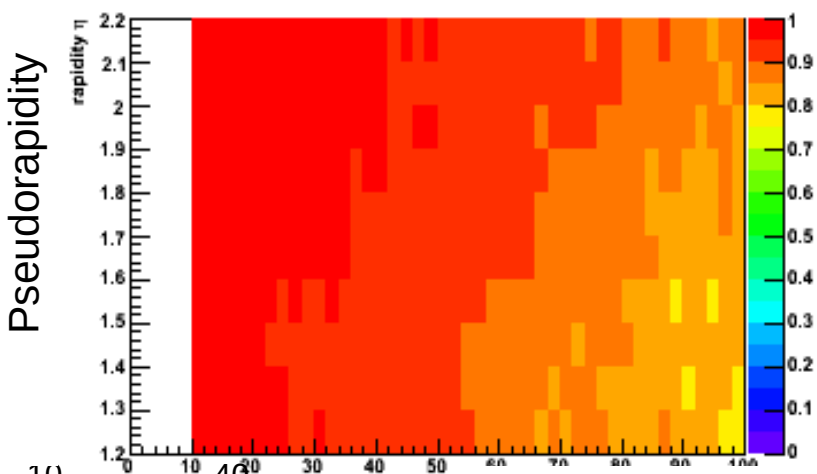
- Reconstruction
  - RPC included
  - Offline MuTr stations exists
- Simulation
  - Efficiencies
  - Smearing
    - Momentum
    - Charge identification
  - Background simulation
    - Hadronic background
      - Punch through
      - Decay hadrons faking straight high momentum track
    - S/N assumption: 3:1
      - Reachable with absorber (2011) or future vertex tracker (>2012)
  - Absorber effects
    - Background suppression
    - Impact on momentum reconstruction

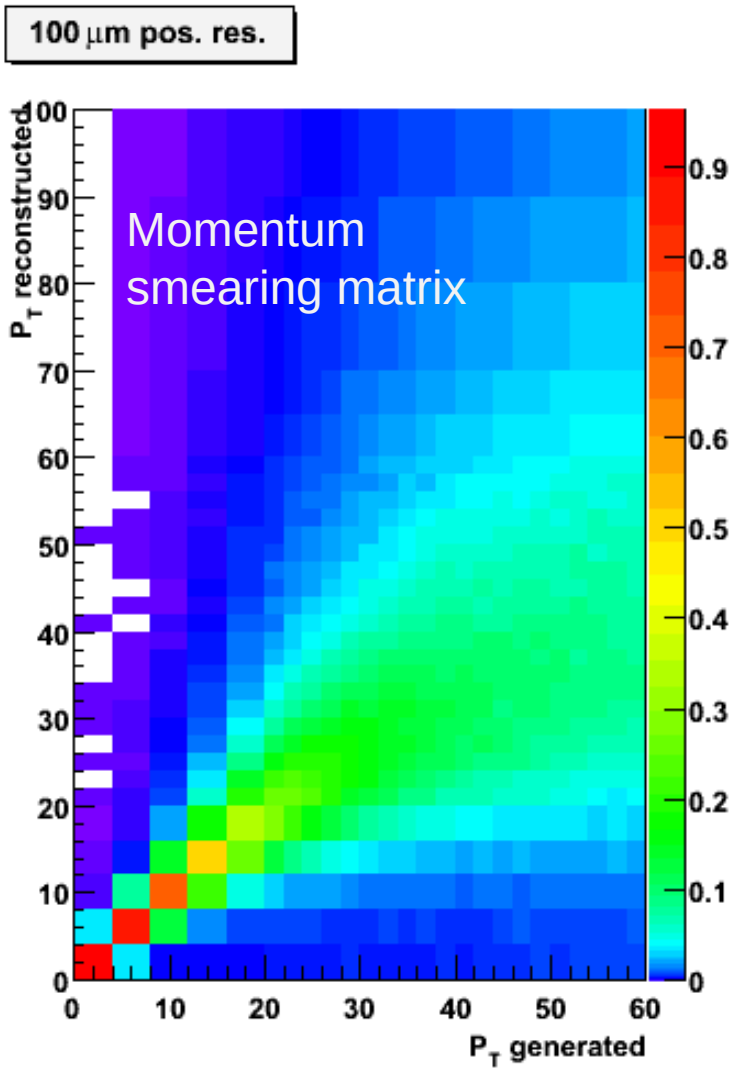
Charge reconstruction and Momentum Smearing in Simulations

Wrong charge



Correct charge





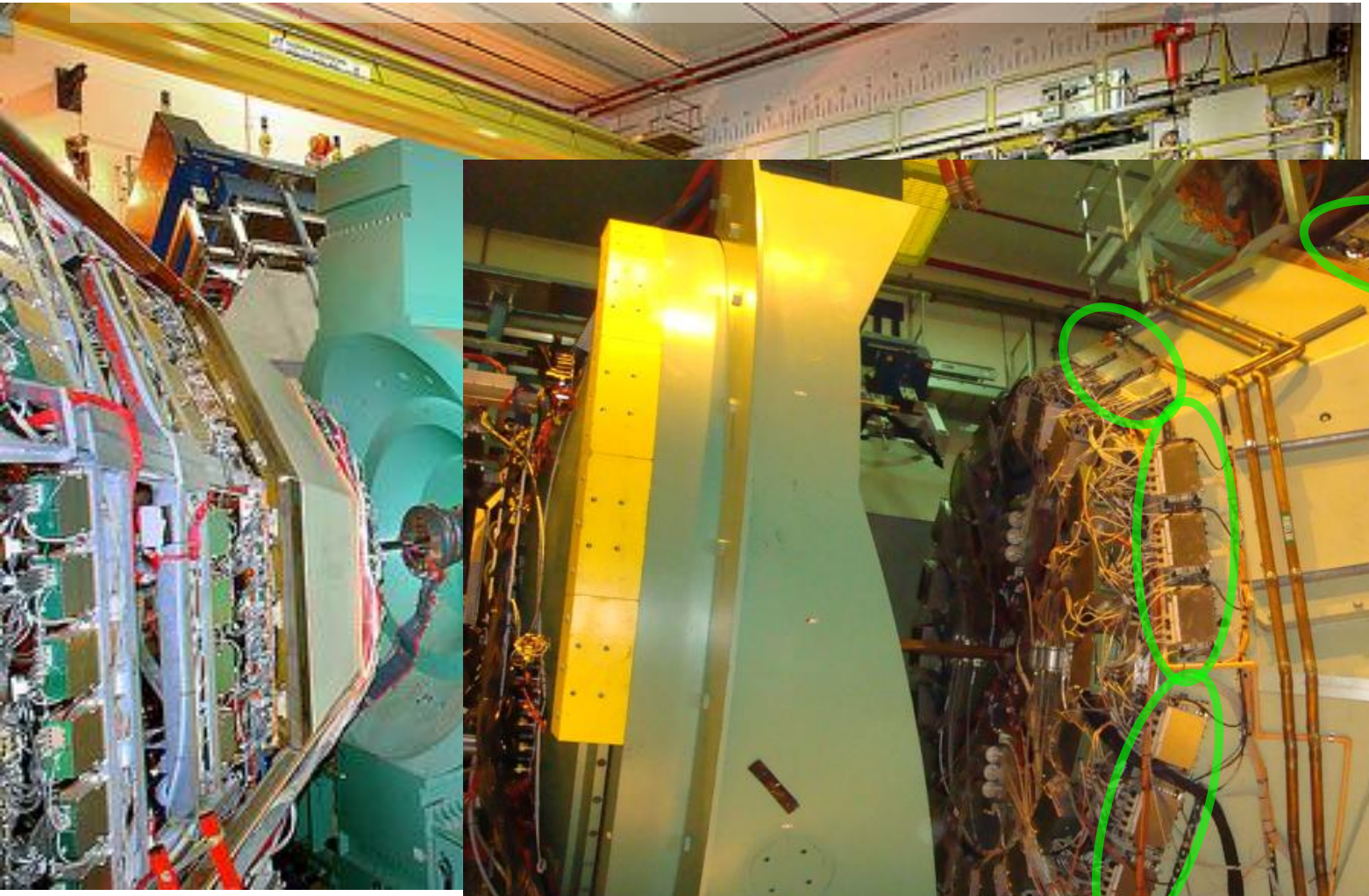
Reconstructed Pt

Summary and Outlook Forward Upgrade

- Forward asymmetries provide essential information about sea quark polarizations
- No uncertainty due to fragmentation
- PHENIX forward upgrade will enable measurements in unique kinematic region
- Hardware and software in place for polarized pp collisions at $\sqrt{s}$ = 500GeV in run11
- Completion of RPC stations during shutdowns in
  - 2010 RPC3 South
  - 2011 RPC1 North & South

Backup

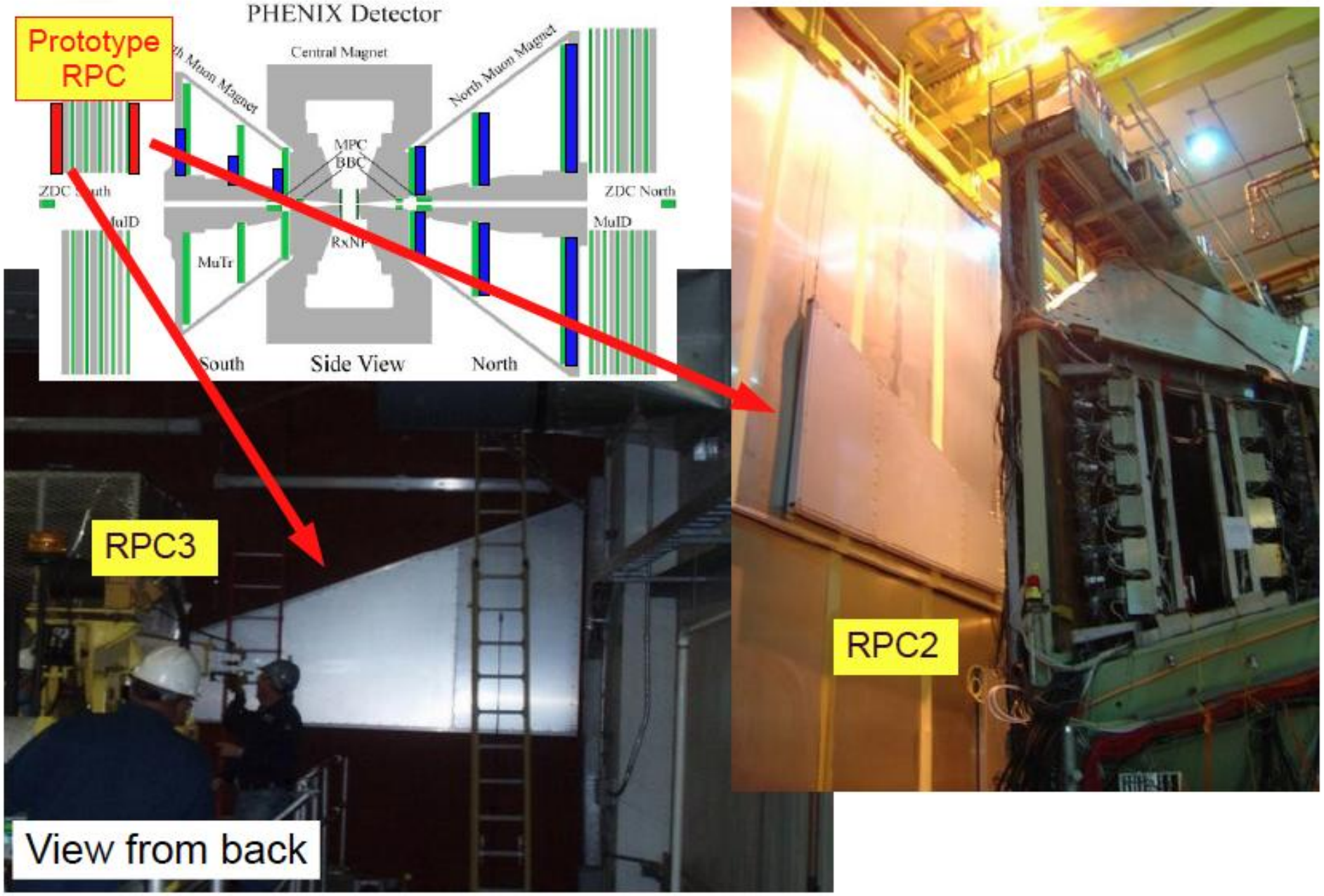
New MuTRIG-FEE in North Arm



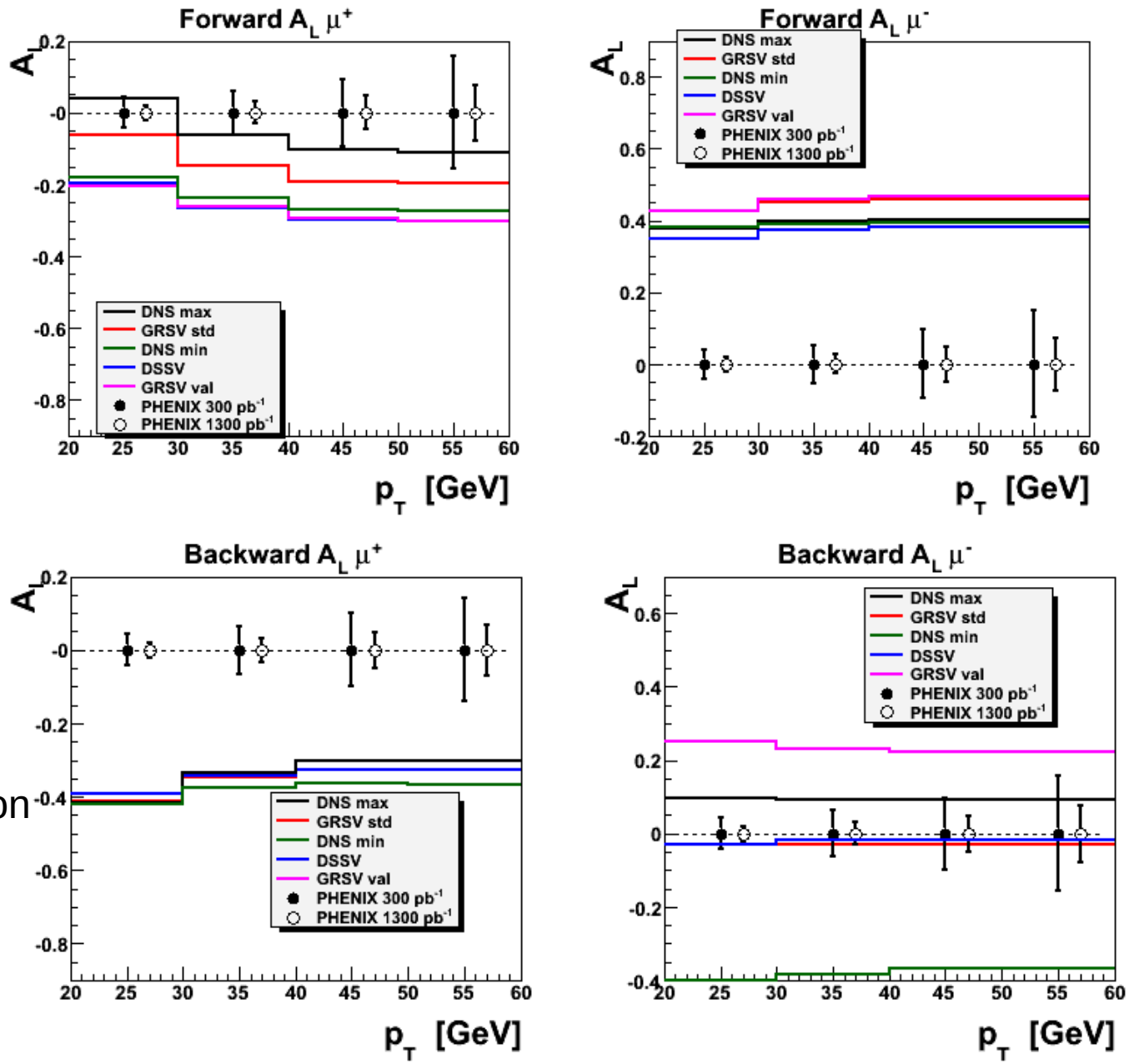
↑ Before Install

2008 Install➔

Prototype RPC installed in 2009 run

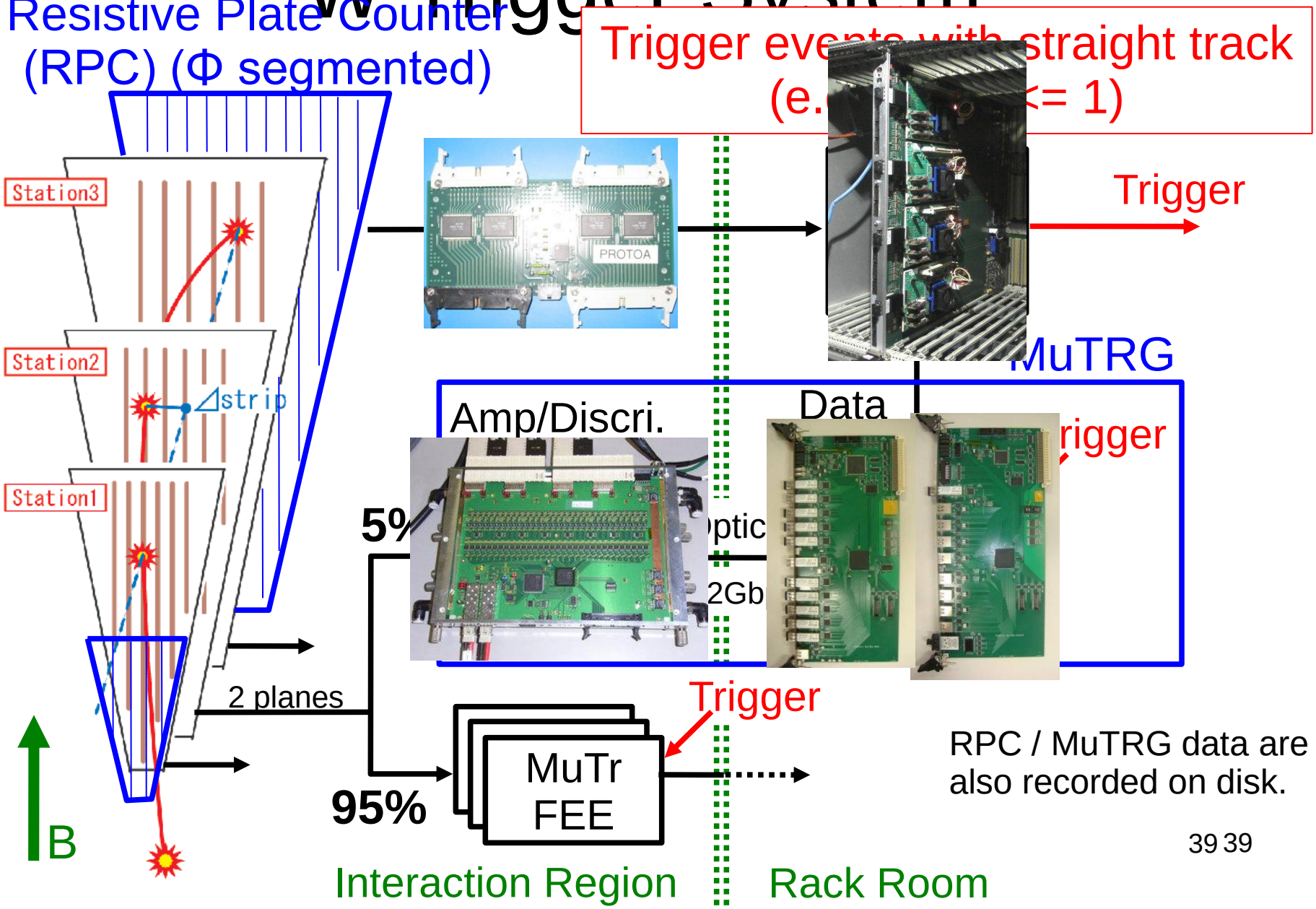


Simulated Asymmetries for 1.2 <|η|< 2.4



Including
- smearing
- S/N of 3:1
- efficiencies
- 70% polarization

W Trigger System



RPC / MuTRG data are also recorded on disk.

Flavour Separation->Increased Sensitivity in the Forward Direction

- Asymmetric x_1, x_2 helps disentangle asymmetries
- Sea quark distributions vanishes at high x
- W in forward/backward rapidities

$$A_L^{W^-} = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}} \propto \frac{\Delta\bar{u}(x_1)d(x_2) - \Delta d(x_1)\bar{u}(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

suppressed

$x_1 << x_2$
(W is produced in backward direction)

Installation to South Muon Arm

- Post Run9 Shutdown
- **Completed!**
- Under Commissioning in Run10 Au-Au Run

Work during last Shutdown

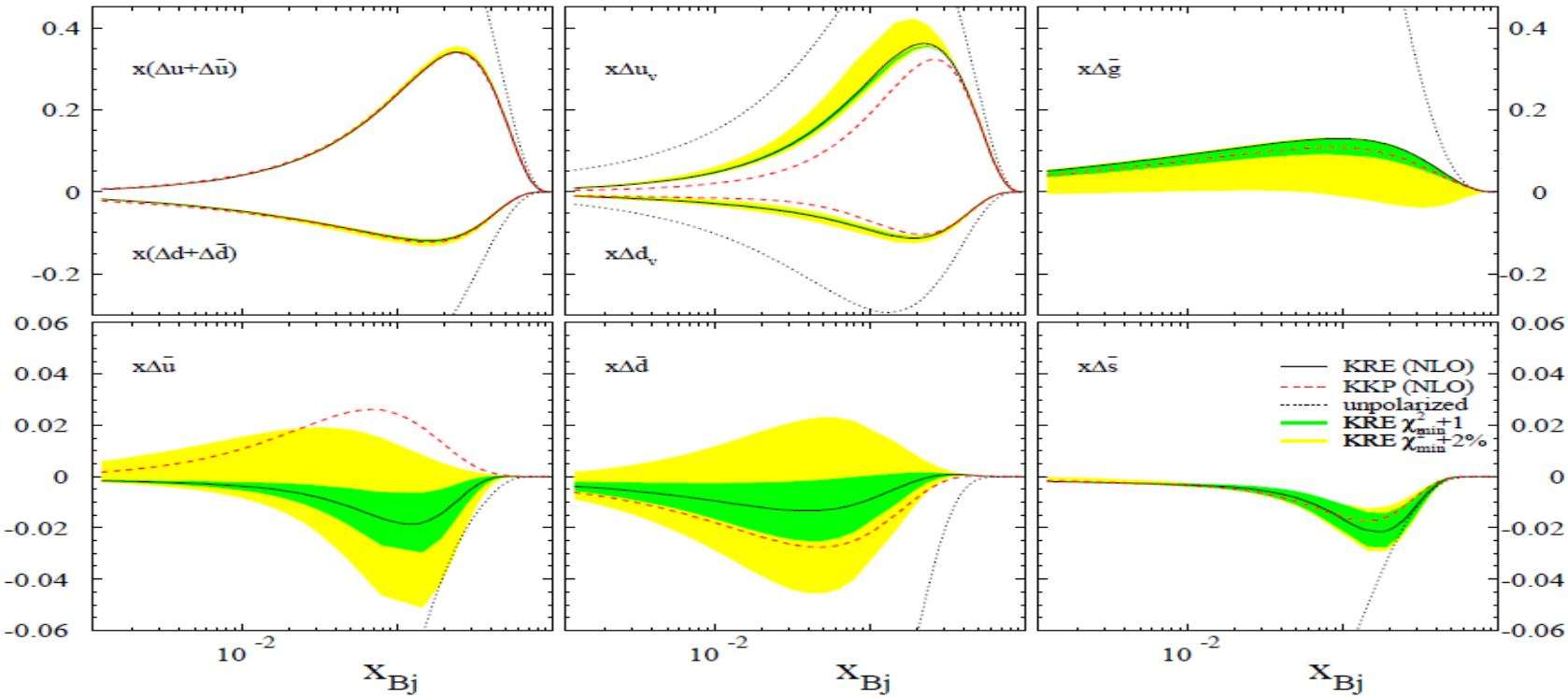
- Installation of MuTRIG FEE in South
- Installation of RPC3 North

Impact of Fragmentation Functions in SIDIS data

D. De Florian et al. PRD71:094018,2005

NLO @ Q^2=10 GeV^2

	χ^2_{DIS}	χ^2_{SIDIS}	Δu_v	Δd_v	$\Delta\bar{u}$	$\Delta\bar{d}$	Δs	Δg	$\Delta\Sigma$
Kretzer	206	225	0.94	–0.34	–0.049	–0.055	–0.051	0.68	0.28
KKP	206	231	0.70	–0.26	0.087	–0.11	–0.045	0.57	0.31



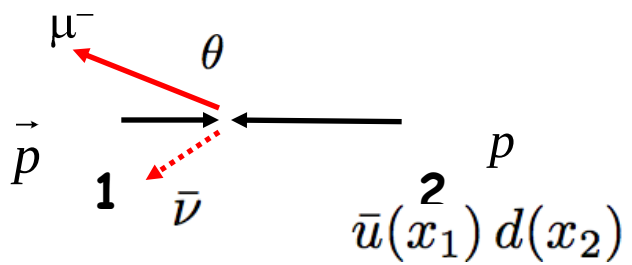
- Kretzer FF favors SU(3) symmetric sea, not so for KKP
- DS ~30% in all cases

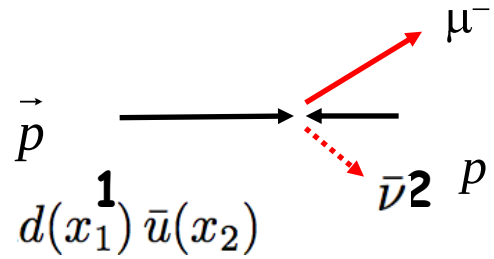
A new experimental Approach in p-p

- Accessing sea quark polarization in W production
  - High Q^2
  - No u quark dominance
  - Only single spin asymmetries
  - No uncertainty due to fragmentation
  - No nuclear corrections of measurements

W Decay Kinematics

W^- :

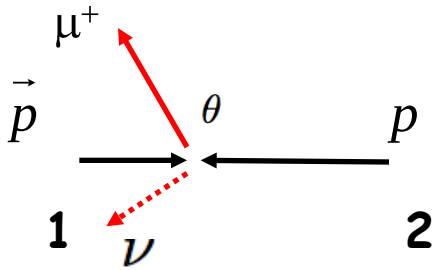


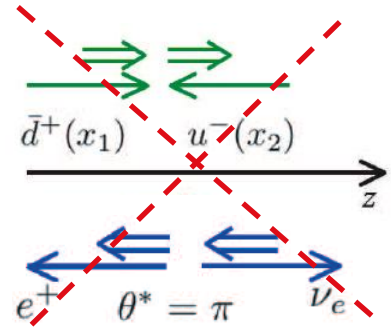


$$\sigma^{W^-} \propto \bar{u}(x_1)\, d(x_2)\, (1-\cos\theta)^2 + d(x_1)\, \bar{u}(x_2)\, (1+\cos\theta)^2$$

W^+ :

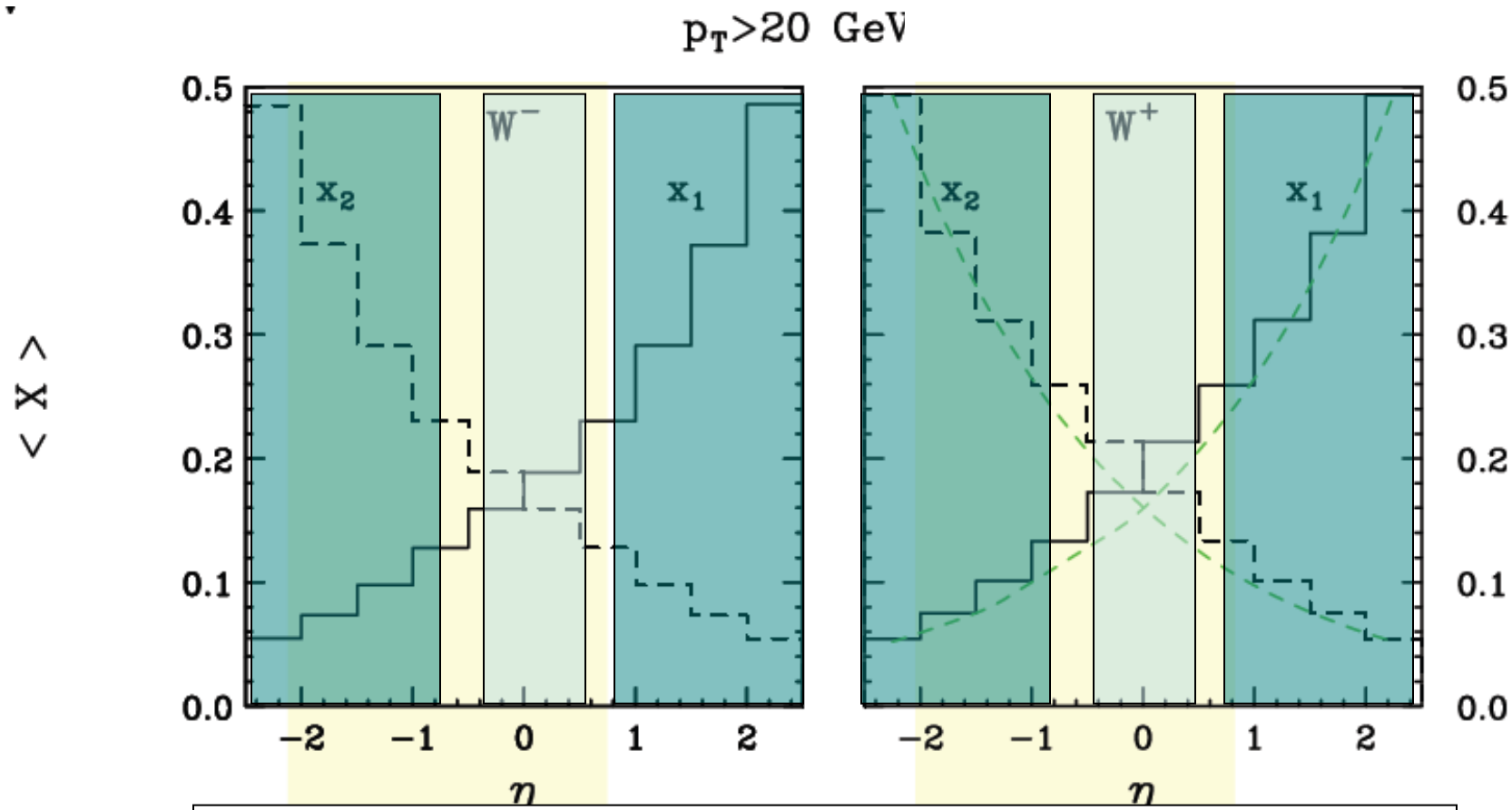
$$\sigma^{W^+} \propto \bar{d}(x_1)\, u(x_2)\, (1+\cos\theta)^2 + u(x_1)\, \bar{d}(x_2)\, (1-\cos\theta)^2$$





Decay kinematics lead to decreased separation for W^+

High |η| leads to sea/valence separation



PHENIX Central Arms

PHENIX Muon Arms

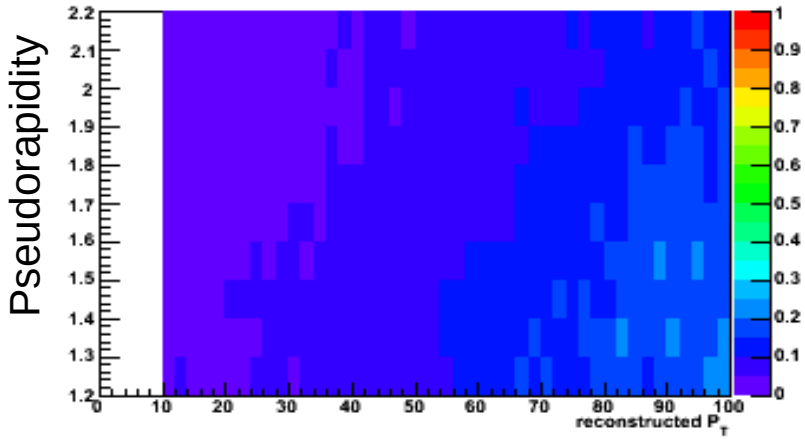
Unique kinematic domain!

D. de Florian at RSC meeting, Berkeley 2009

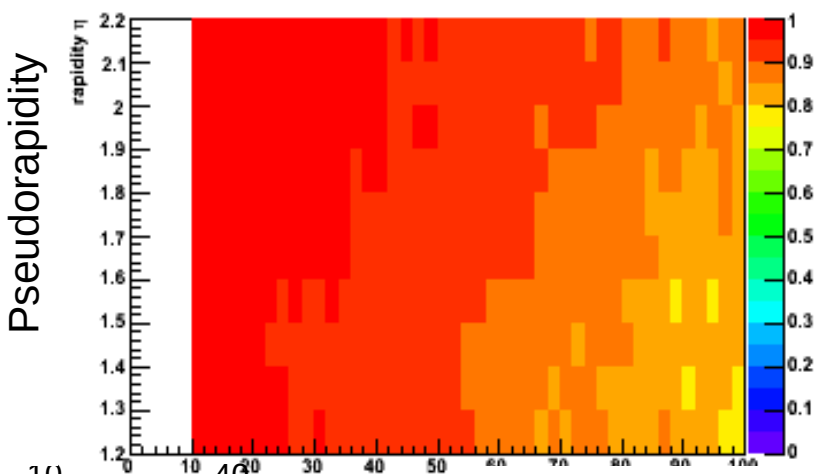
Large η-coverage: also important for sea/ valence asymmetry

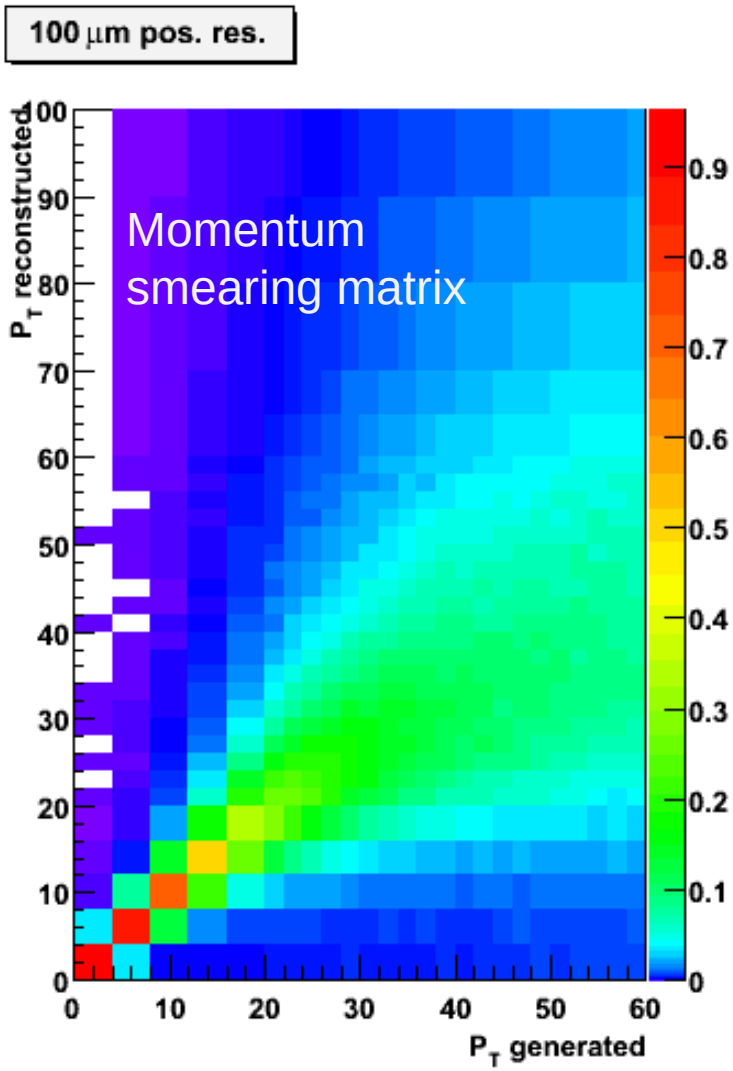
Charge reconstruction and Momentum Smearing in Simulations

Wrong charge



Correct charge





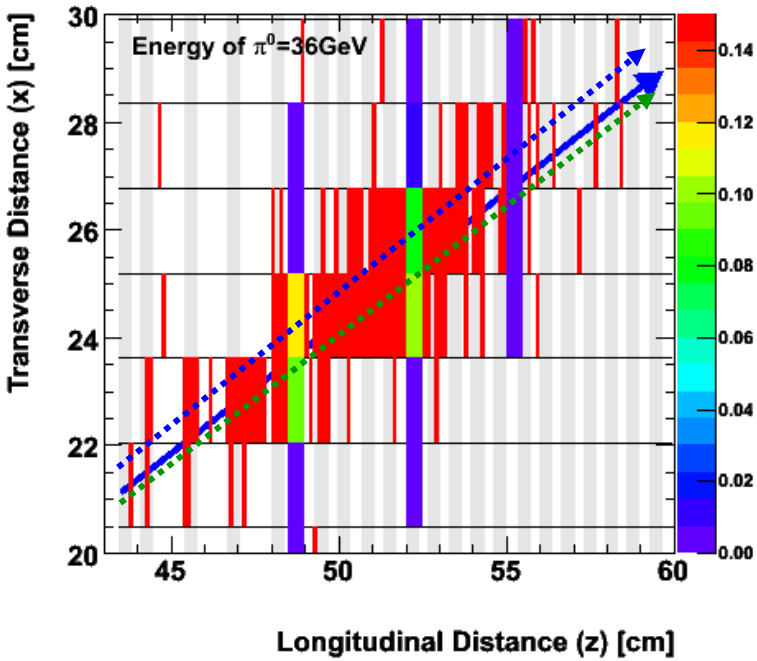
Reconstructed Pt

What about direct γ identification?

- Important for our measurements in the next decade in
  - Spin
  - d+Au
  - Au+Au

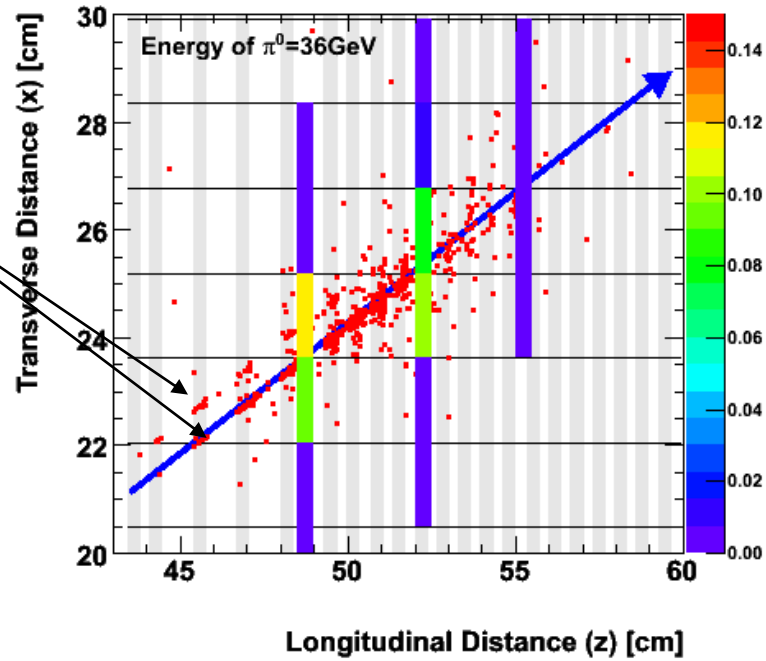
High energy π^0 shower

- Origin of all shower particles (red)
  - Shown with effective resolution of pads
- Individual tracks not distinguishable



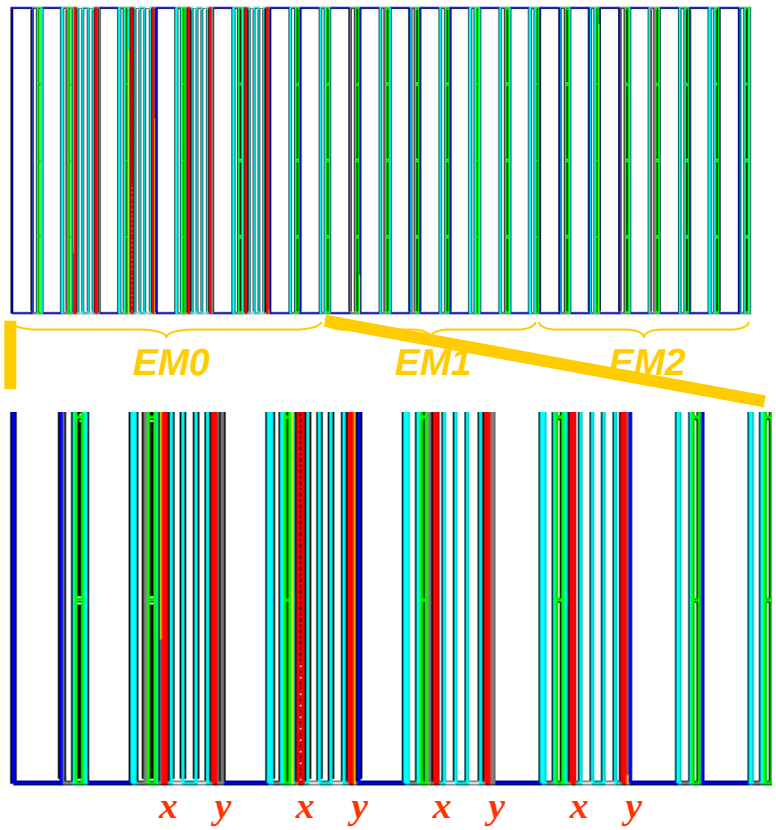
High energy π^0 shower

- Finer resolution could "see" individual tracks from π^0
  - Up to ~50GeV
- Make the whole detector with finer resolution!!
  - Not realistic → what can be designed?



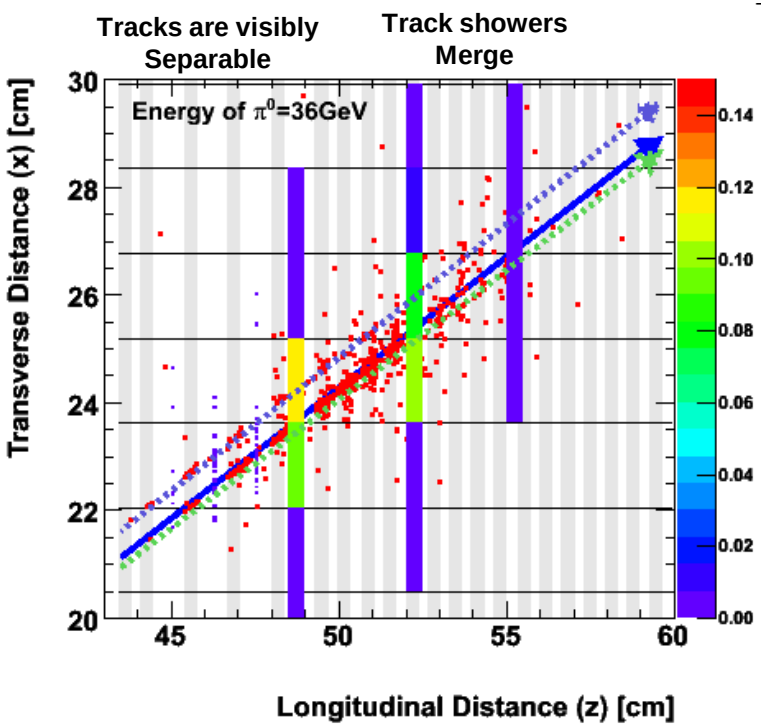
High energy π^0 shower

- Finer resolution could "see" individual tracks from π^0
  - Up to ~50GeV
- Make the whole detector with finer resolution!!
  - Not realistic → what can be designed?
- Add highly segmented layers of *x/y* strips into first segment.
  - Measure the development of the shower at its infancy
  - With a resolution to distinguish individual γ tracks



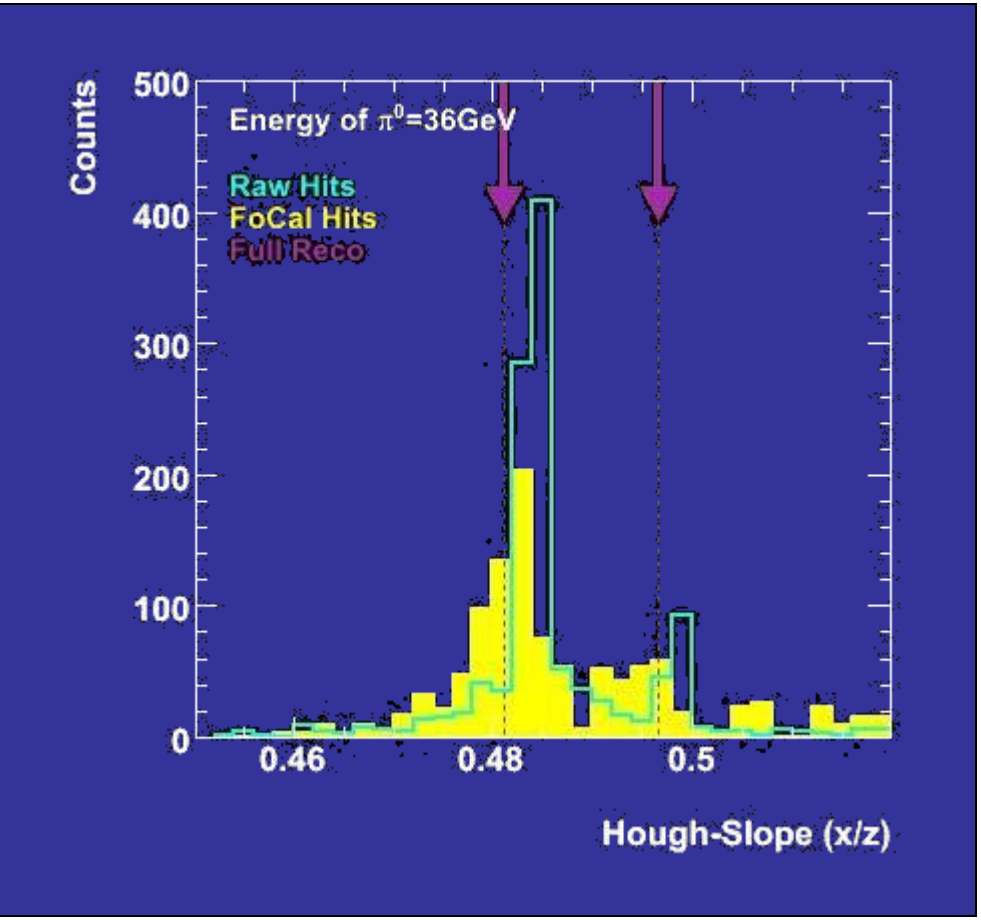
High energy π^0 shower

- Finer resolution could "see" individual tracks from π^0
  - Up to ~50GeV
- Make the whole detector with finer resolution!!
  - Not realistic → what can be designed?
- Add highly segmented layers of *x/y* strips into first segment.
  - Measure the development of the shower at its infancy
  - With a resolution to distinguish individual γ tracks



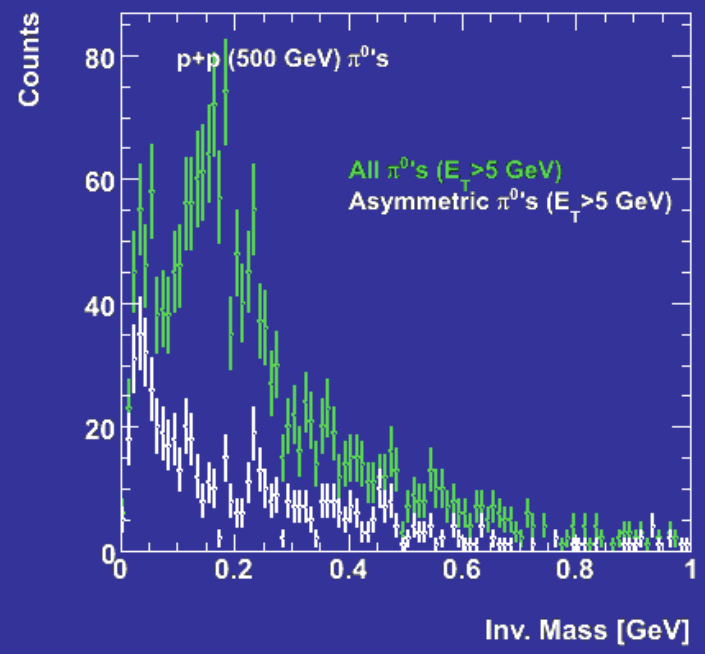
Catch the shower, before it's too late

High energy π^0 shower

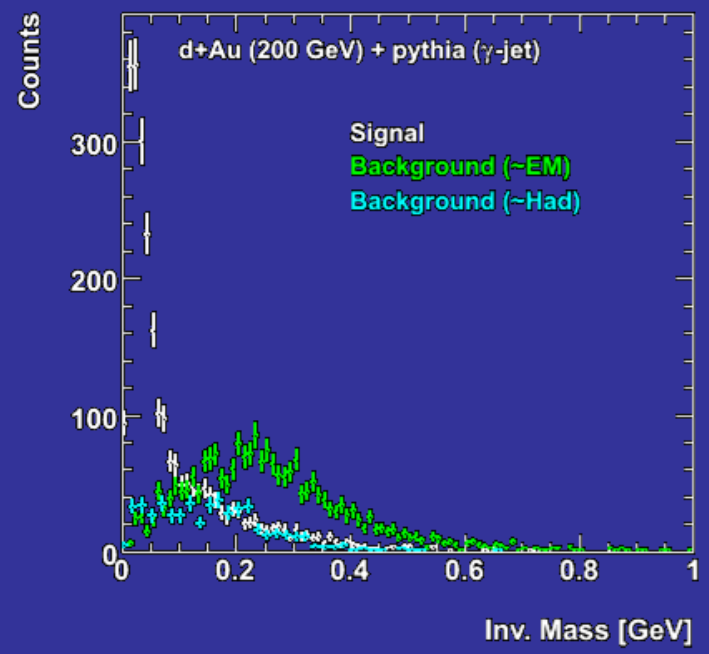


- Using a Hough Transform,
  - Transverse/longitudinal coordinate
  - Find the best track as most frequently occurring Hough-slope
- Use each track vector, full track energy → calculate invariant mass

Performance of FoCal Reconstruction

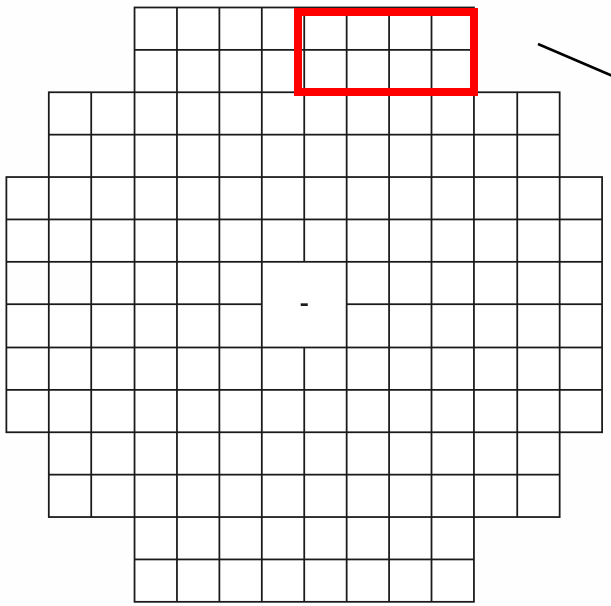


Reconstruction of π^0
(p+p 500 GeV minimum bias pythia)

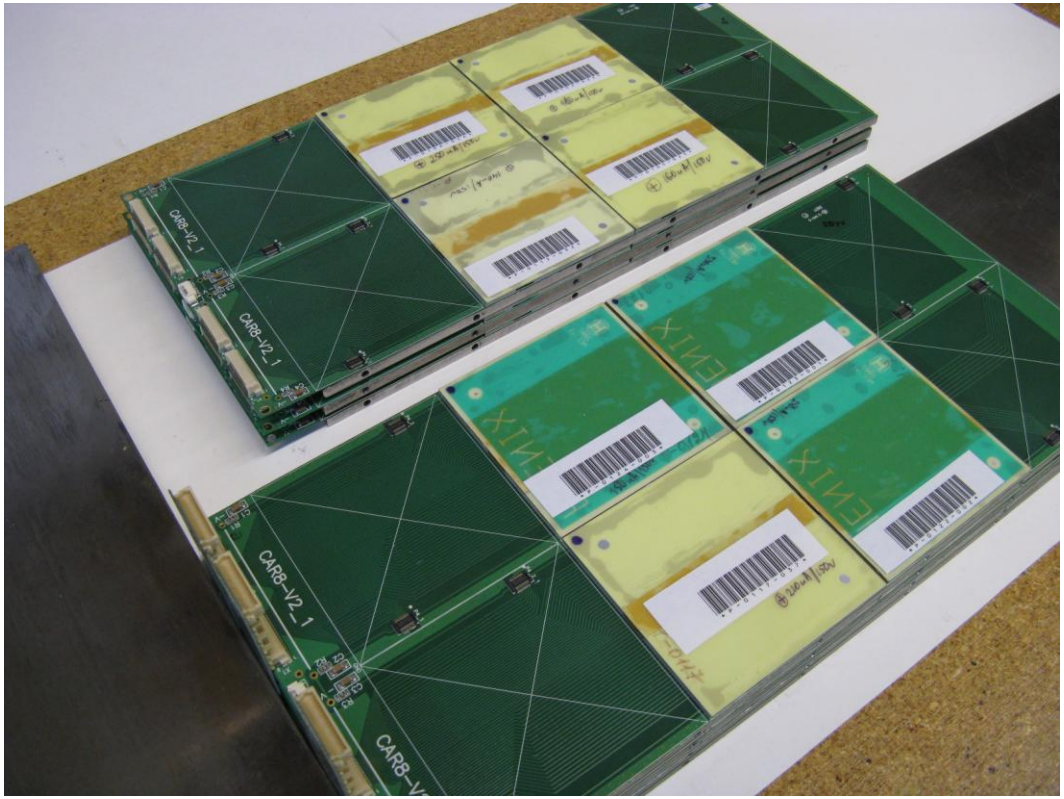


Signal reconstruction
(d+Au 200 GeV minimum bias + embedded pythia γ+jet signal)

The prototype detector

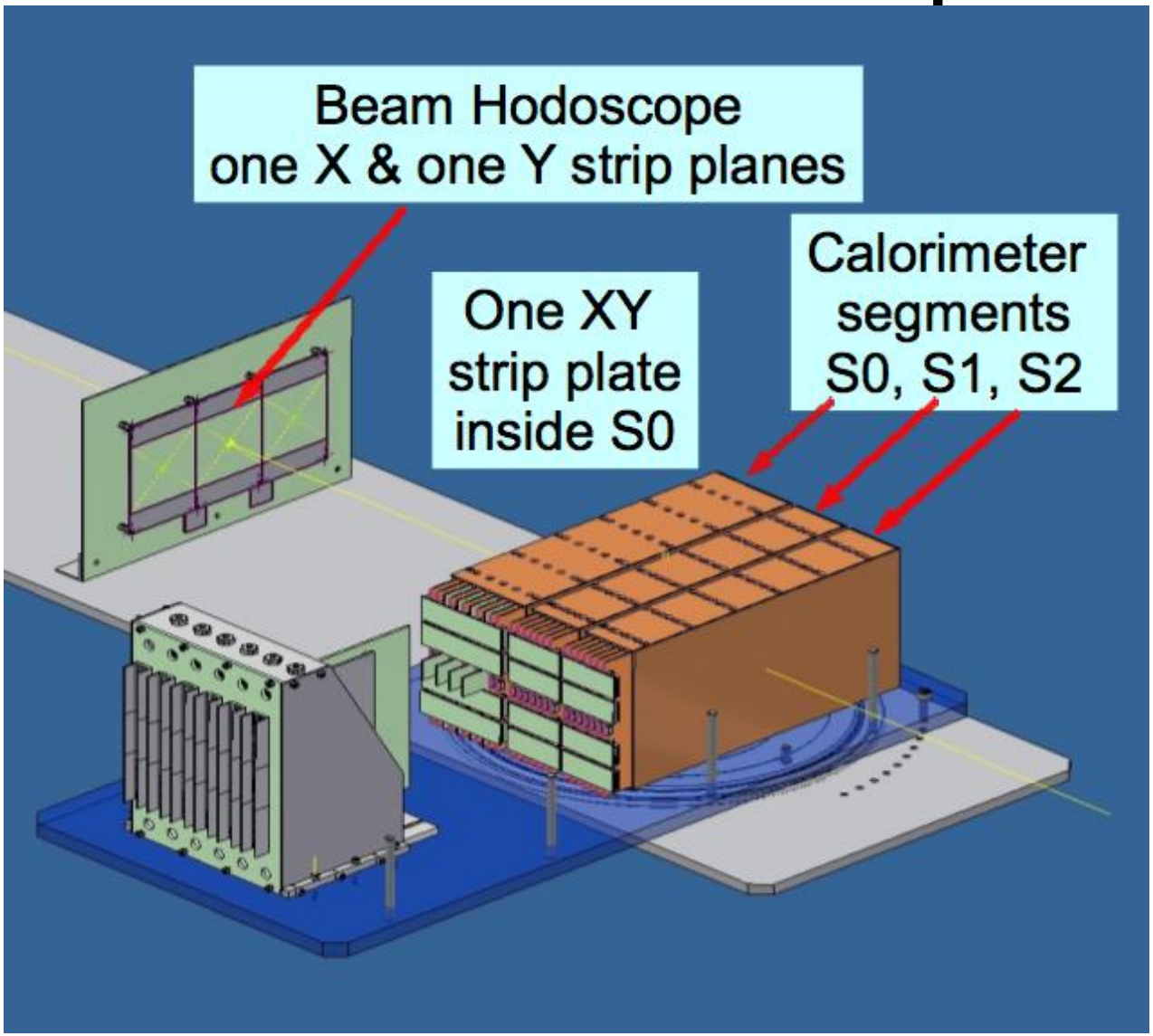


3-segment brick, with the 4 towers in the center populated with pad sensors.



+ full readout chain, connected to standard PHENIX DAQ

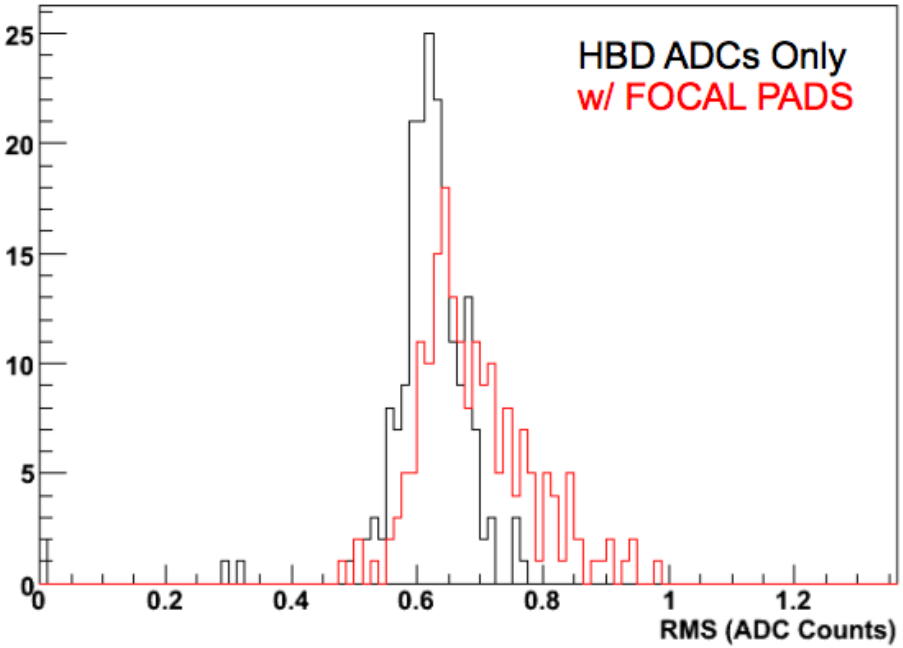
Test Beam setup

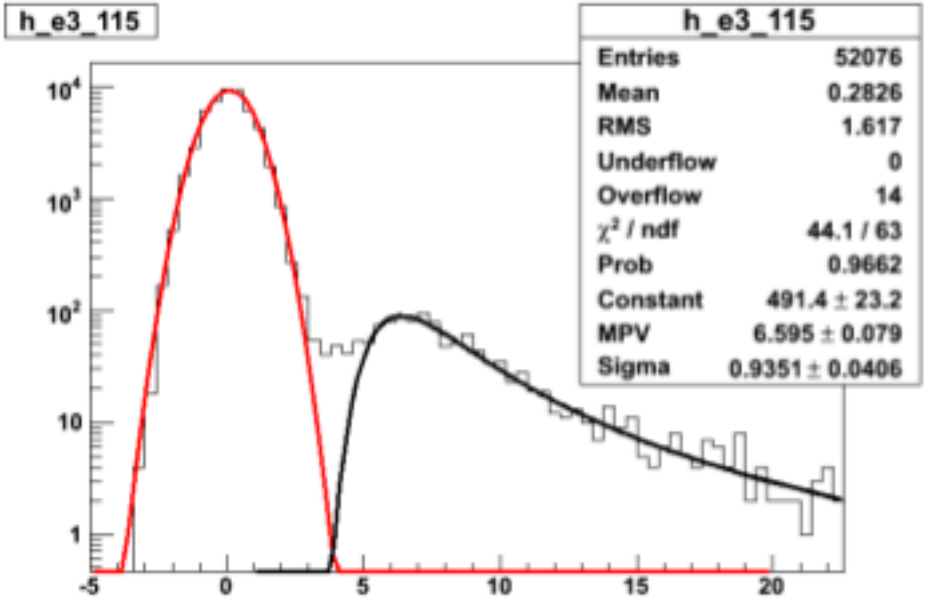


Prototype performance

Pedestals: very low noise,

Connecting the pad modules increases RMS by only ~ 0.2 ADC counts



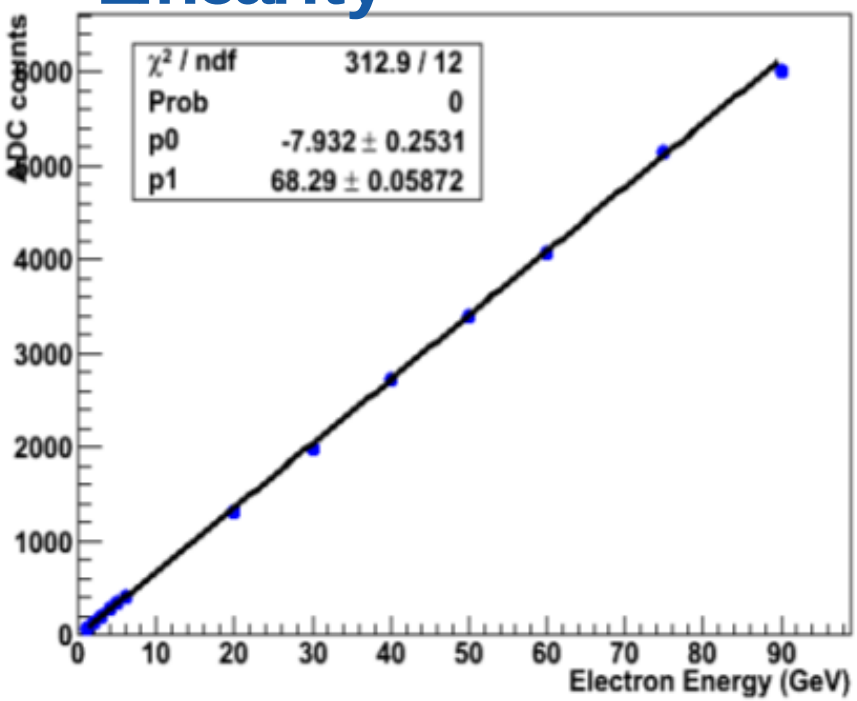


Muon beam: clear MIP peak

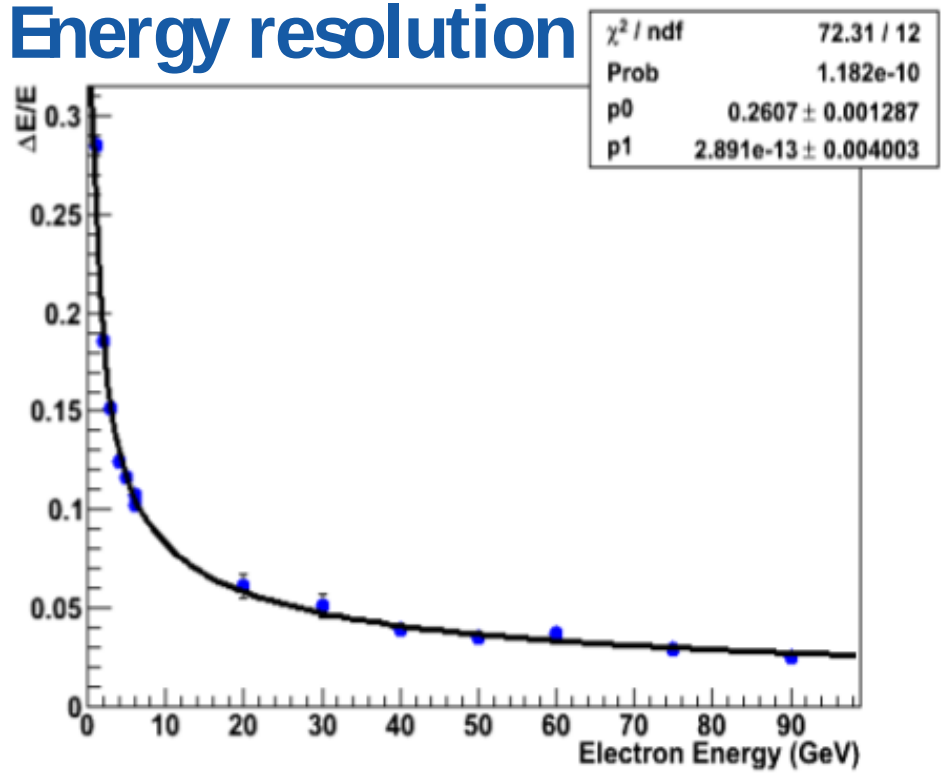
Response well described by Gaussian pedestal + Landau function

Prototype performance: response to electron beams

Linearity



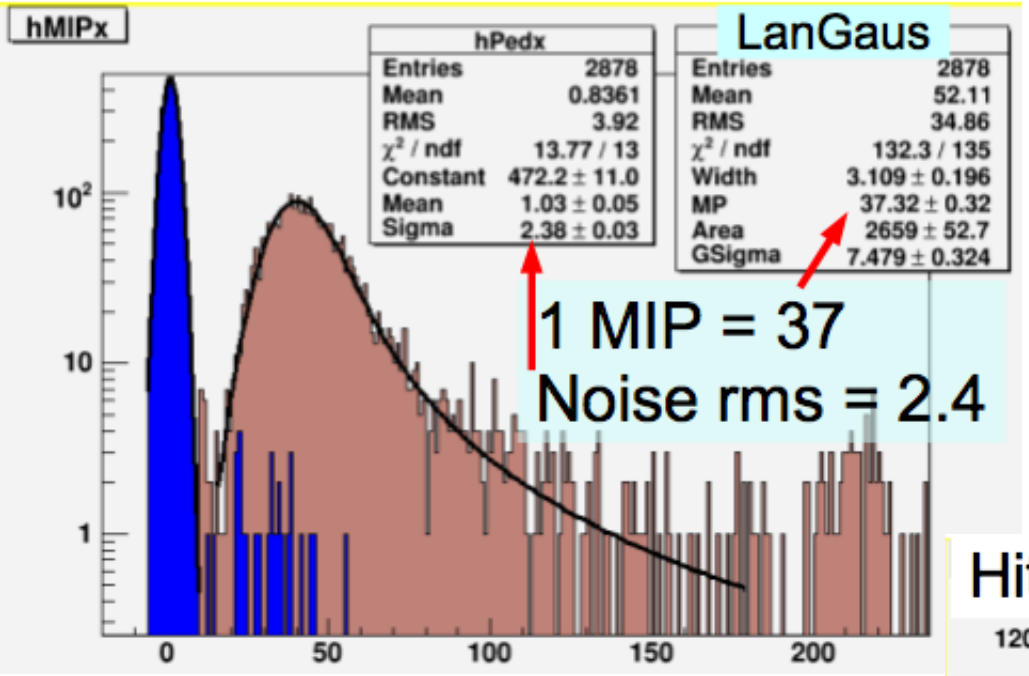
Energy resolution

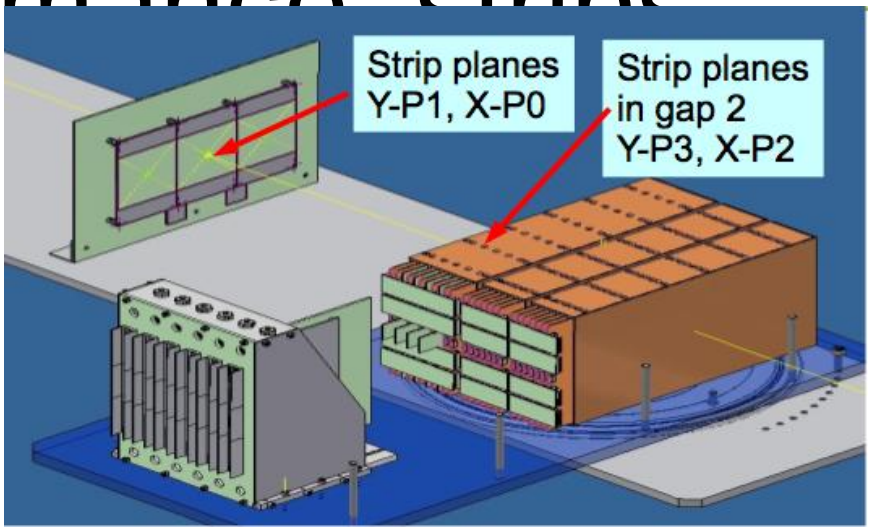


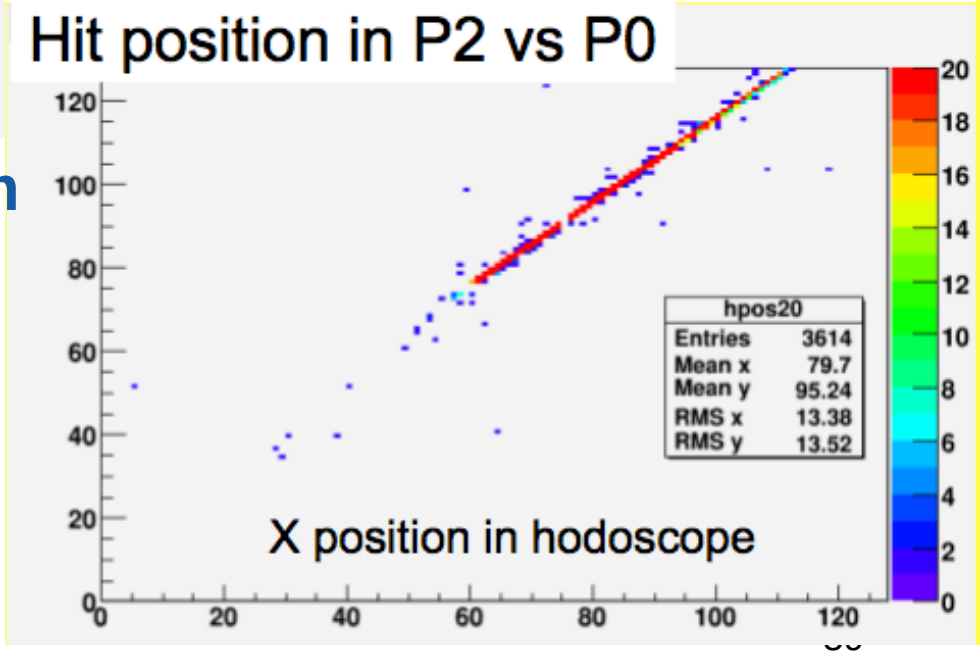
Good linearity up to ~90GeV, and down to very low PS beam energy

Energy resolution currently at ~26% / √E, but this still can be improved; design value is 23% / √E

Prototype performance: strips



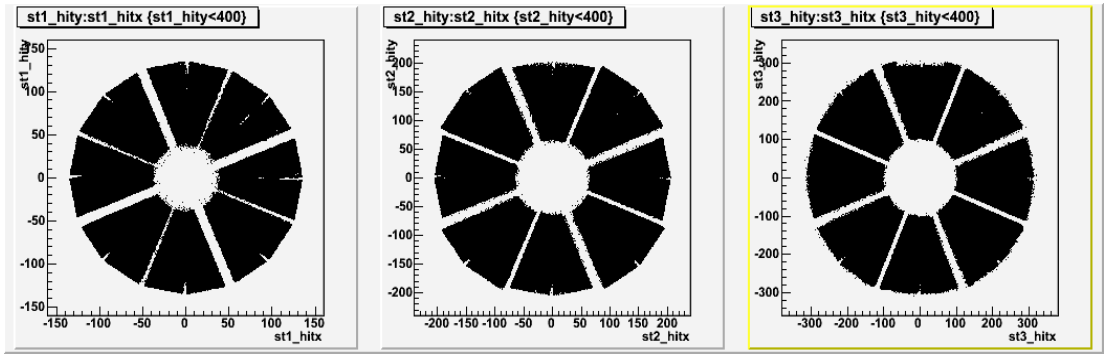




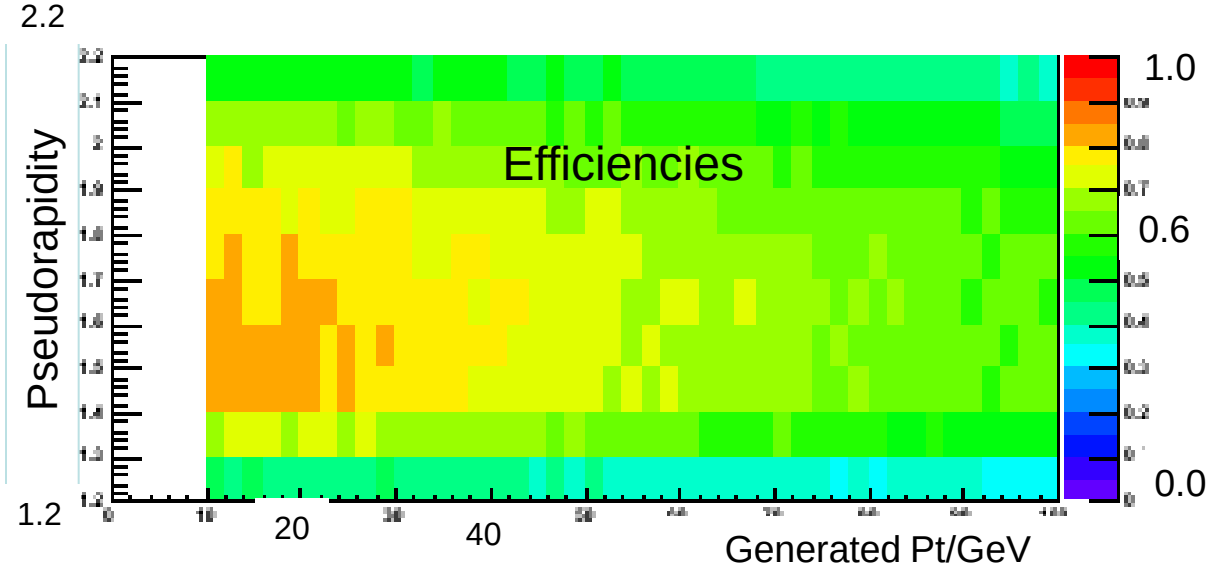
MIP peak clearly separated from pedestal; obtained by adding amplitudes of 3 strips around hit.

Good correlation between the two planes of strips

Muon Signal Efficiencies and Smearing from Simulations



MuTr Radiographs

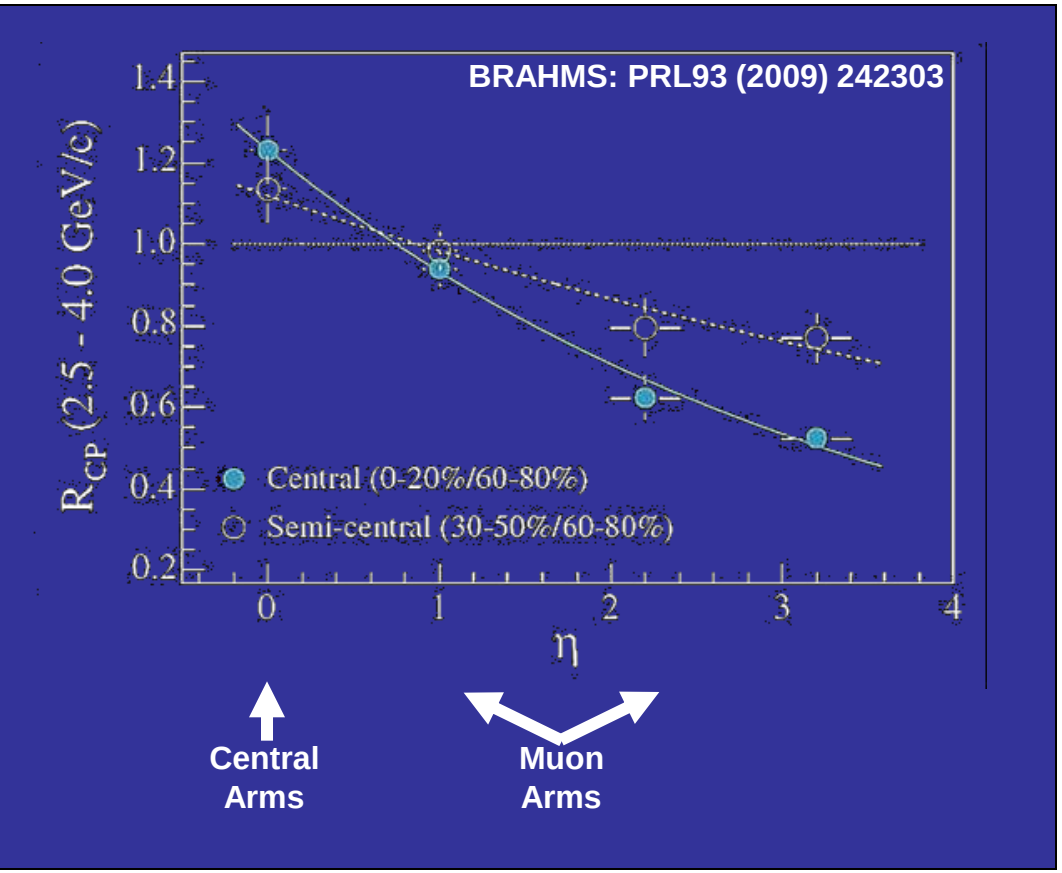


- Note:
  - Start at 5GeV

Abstract

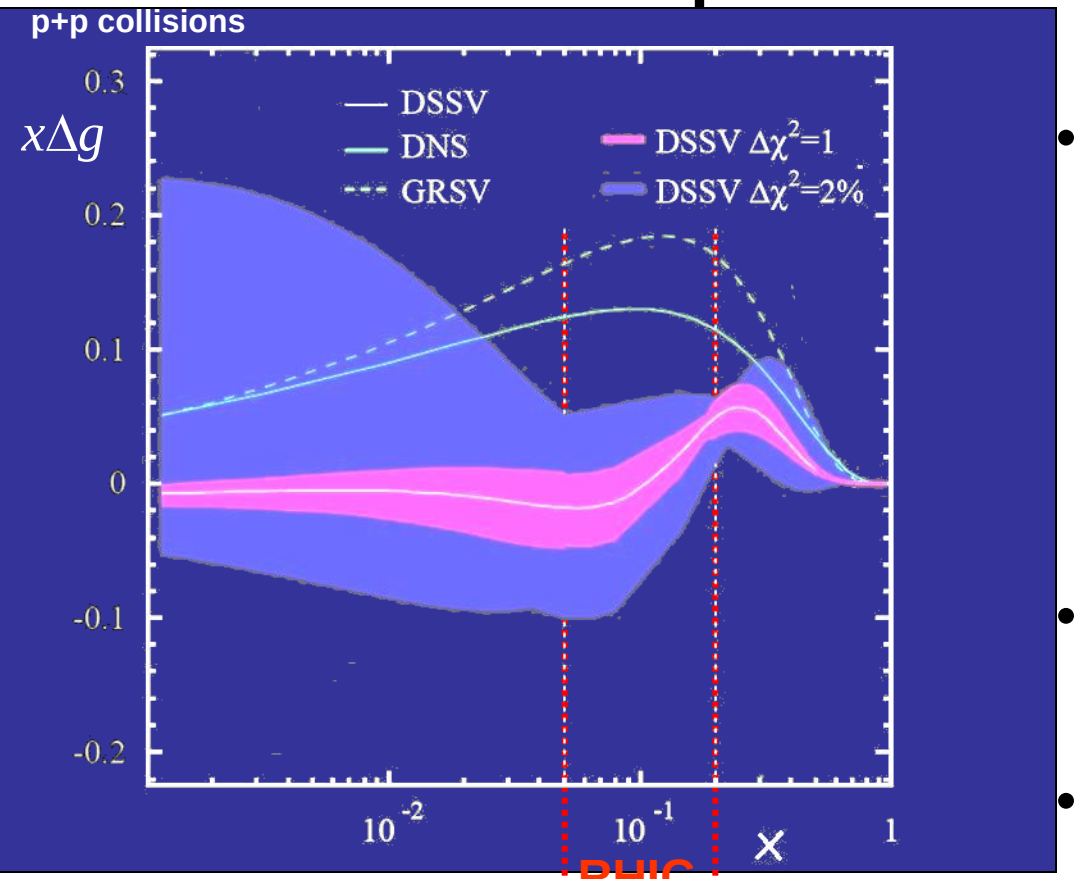
- In the near future the PHENIX experiment at Brookhaven National Laboratory will install several upgrades to enable an extended physics program in the next decade. Centerpieces of this effort will be new vertex detectors, forward calometry and a muon trigger upgrade.
  This talk will focus on the later two.
  The planned forward calorimeter FoCal will bridge the gap in the acceptance of currently installed electromagnetic calometry in PHENIX in the pseudorapidity range 1 to 3. Using silicon tungsten technology it will enable the measurement of direct photons and neutral mesons as well as
  jets in a kinematic domain that will allow the access to low x values in heavy ion and polarized proton collisions. .
  This is especially true in sqrt(s)=500GeV proton-proton collisions.
  At these energies a milestone in the RHIC spin program is the measurement of the sea quark polarization of protons via W production.
  Using the parity violating nature of the weak interaction single spin asymmetries can be used to access this quantity at high momentum transfers and independent
  of quark fragmentation models.
  In order to detect muons from W decays an upgrade of the PHENIX muon trigger is currently underway.
  It consists of new detector stations using RPC technology and new FEE for the existing muon tracker stations.

Onset of Gluon Saturation



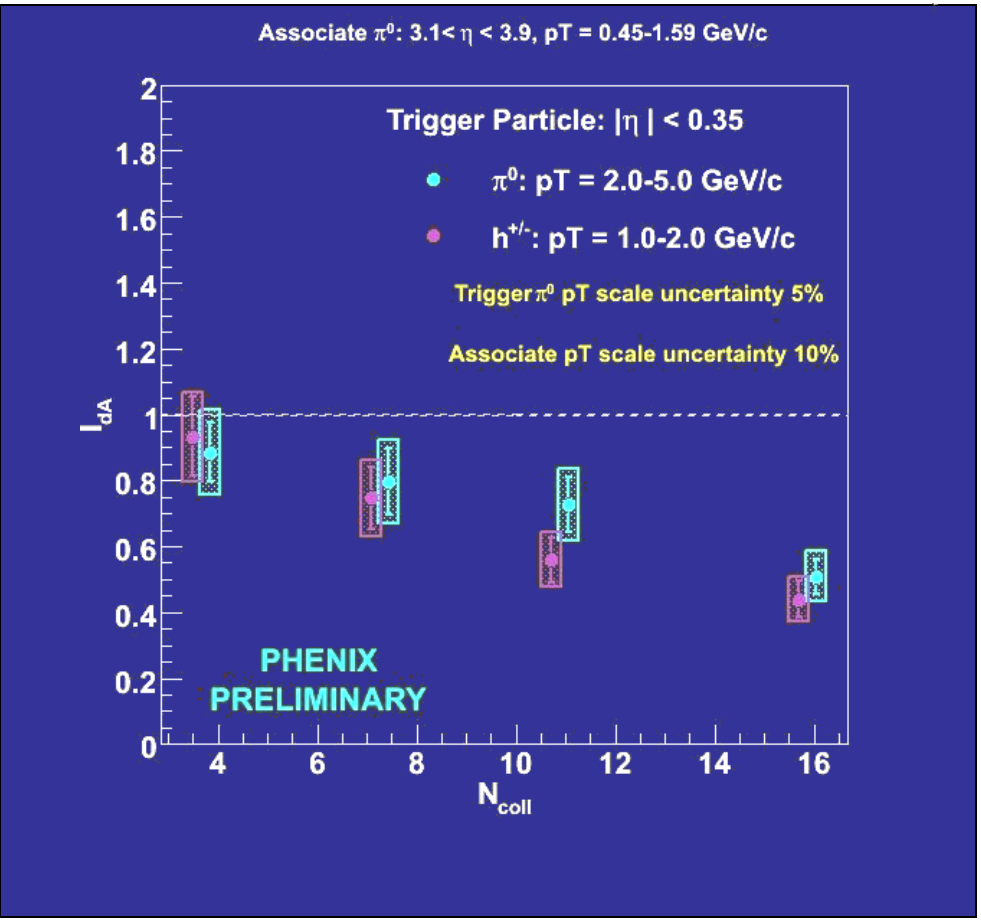
- Nuclear modification factor:
  - Increasing suppression with η
- Consistent with the onset of gluon saturation at small-x in the Au nucleus.
- Need to study this in more detail by
  - identifying particles
  - expanding forward coverage

Proton spin contribution from gluon polarization



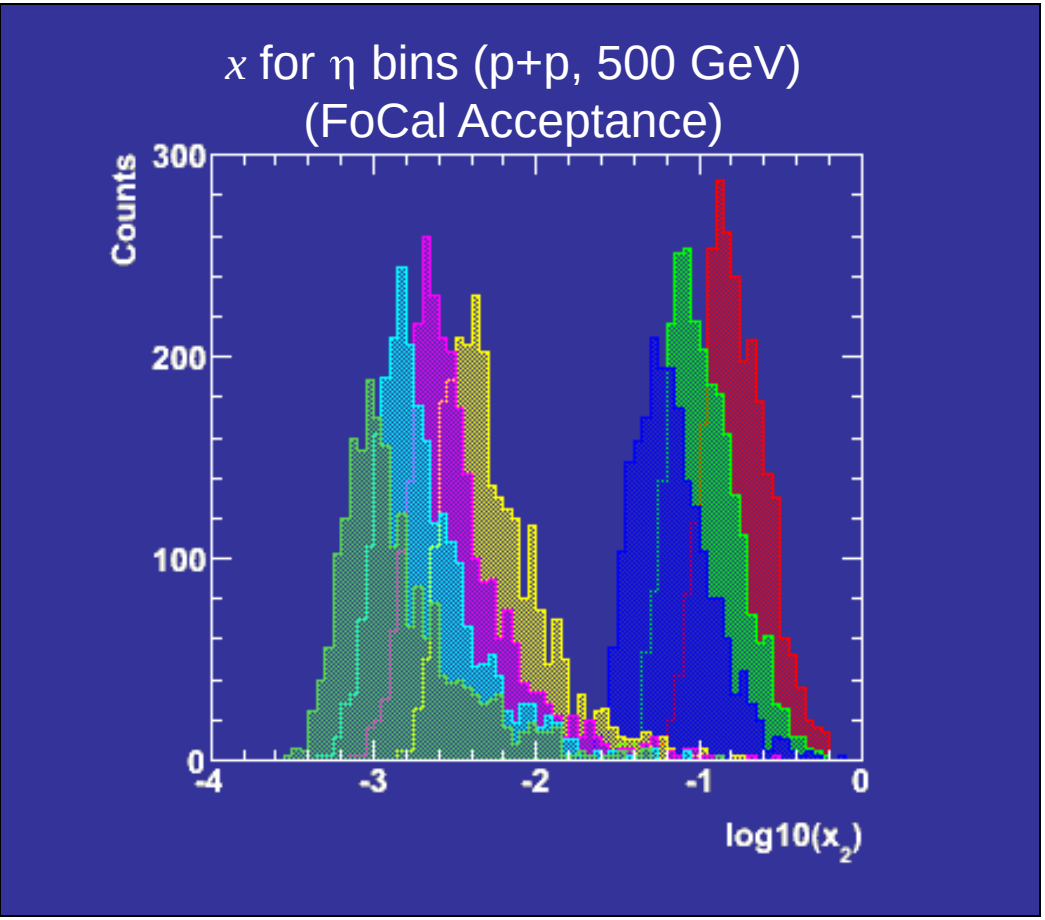
RHIC range
$0.05 < x < 0.2$

- Spin contribution from gluon polarization
  - derived from measured A_{LL}
  - currently over a narrow region of x
- Large uncertainty at low-x
- Need to measure A_{LL} over a broader region of x
  - forward η
  - measure direct photons



- Correlation of central arm π^0 and $h^{\pm}$ with MPC π^0
- Measured associate yields relative to ***pp***
- Systematic suppression with centrality
  - No appreciable trigger dependence
- Probe low-x ($0.006<x<0.1$)

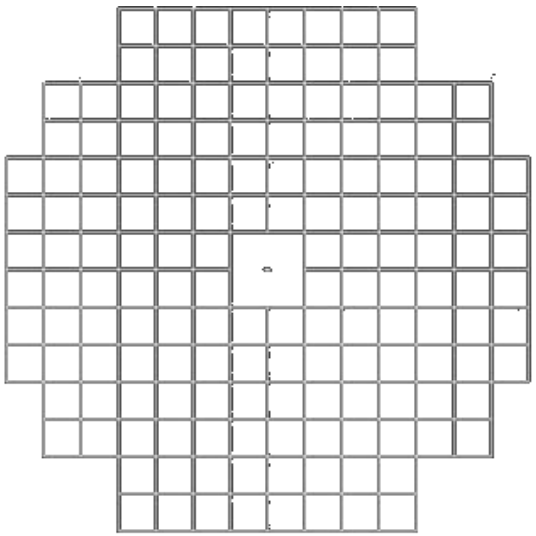
FoCal x Coverage

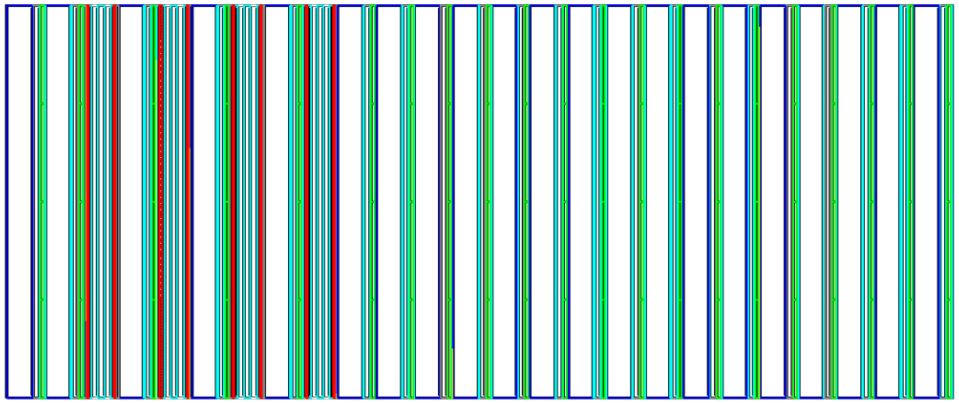


- x coverage:
  - Weak p_T dependence
  - Strong η dependence
  - FoCal complementary to MPC
- Selecting η region probes a specific x range

FoCal

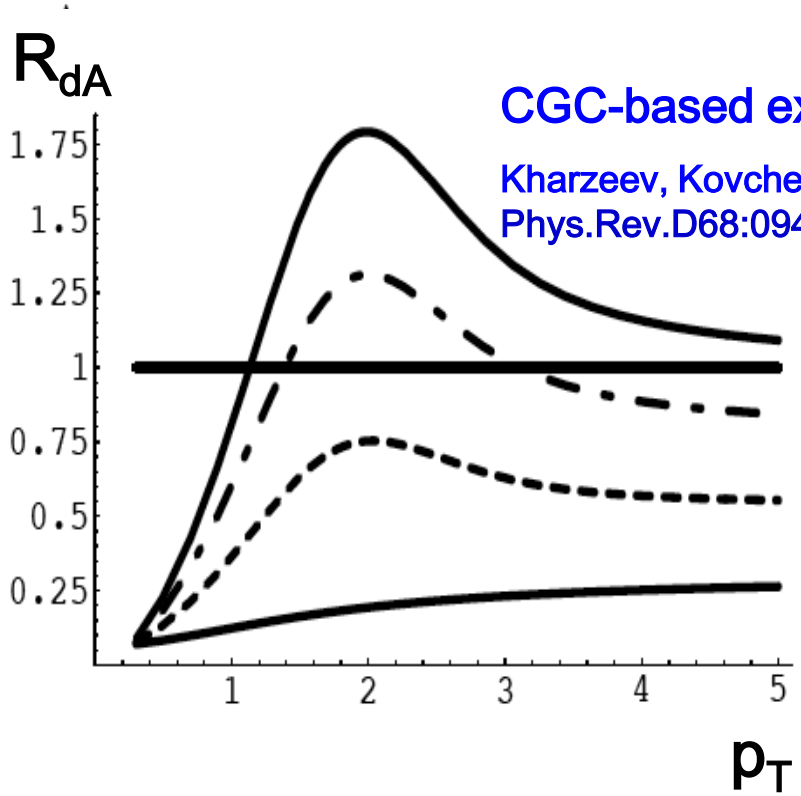
- Silicon-Tungsten sampling calorimeter
  - 21 layers ~21X_0
- Each Arm: $1<|\eta|<3$
- Expect good resolution in E and η/ϕ
  - Active readout ~1.5x1.5cm
- Distinct 2-shower π^0 up to p_T~3 GeV/*c* (η~1)





Nuclear Modification Factor:

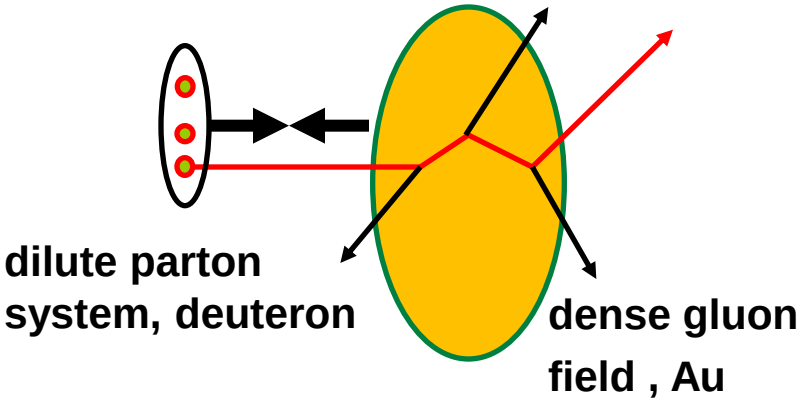
$$R_{dAu} \equiv \frac{1}{\langle N_{coll} \rangle} \frac{d^2 N^{d+Au}/dp_T d\eta}{d^2 N^{p+p}_{inel}/dp_T d\eta}$$

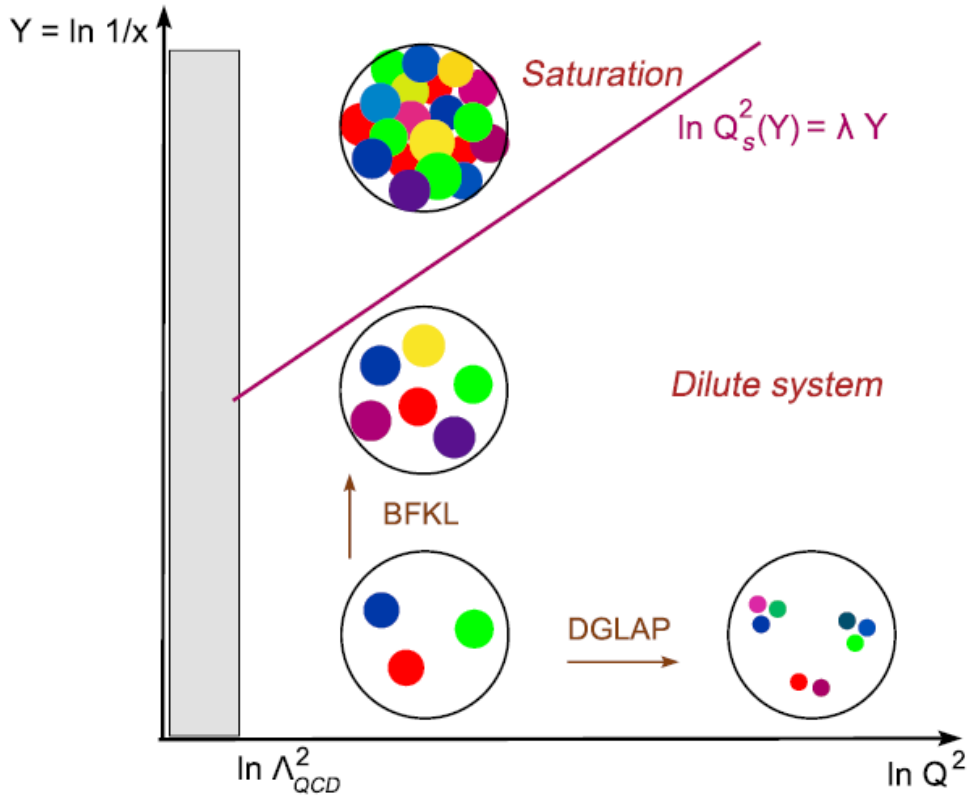


CGC-based expectations

Kharzeev, Kovchegov, and Tuchin, Phys.Rev.D68:094013,2003

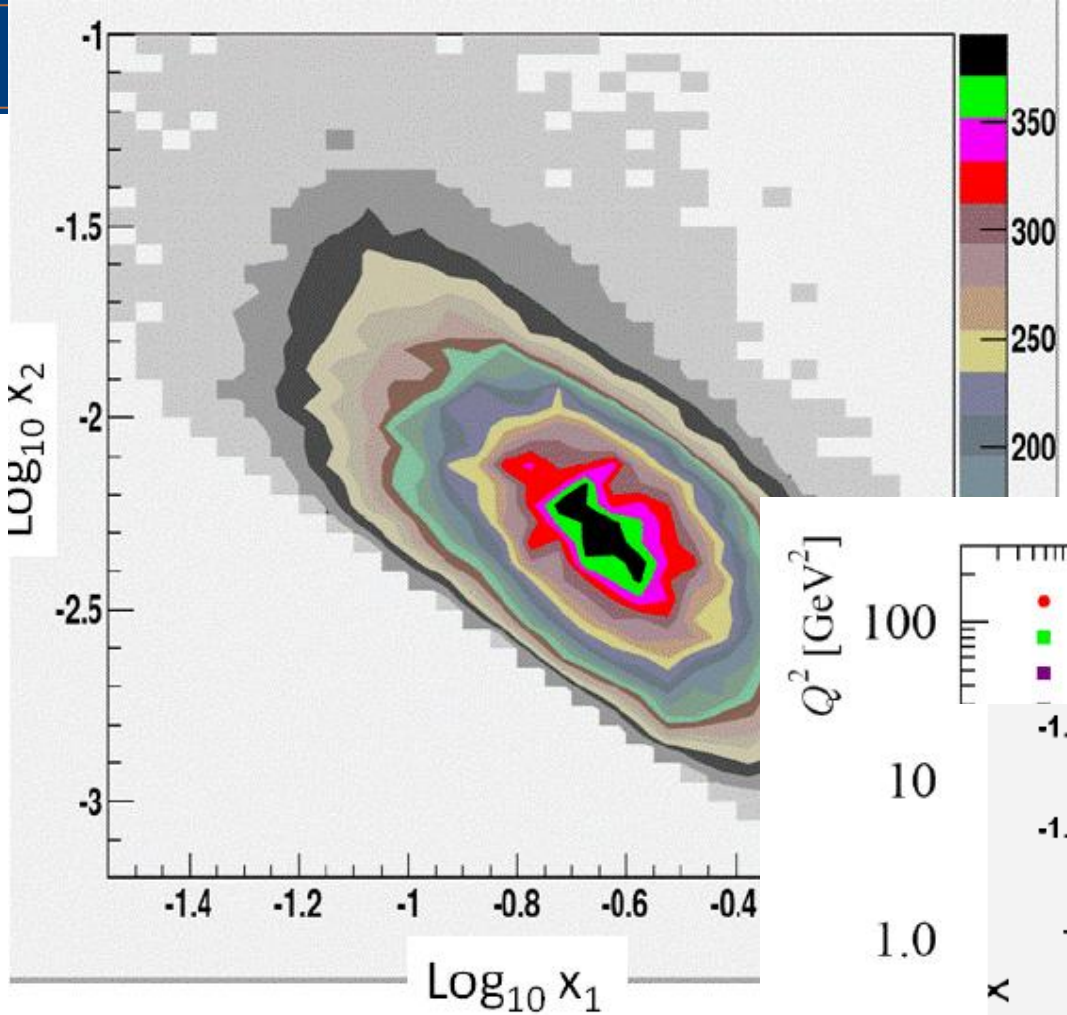
rapidity, y

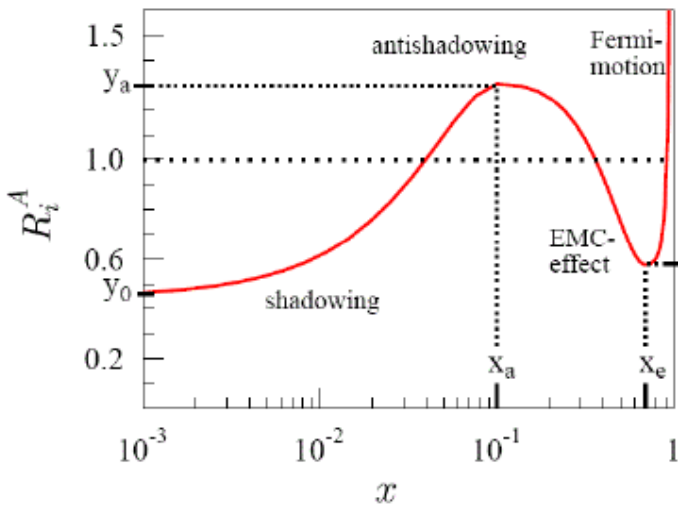


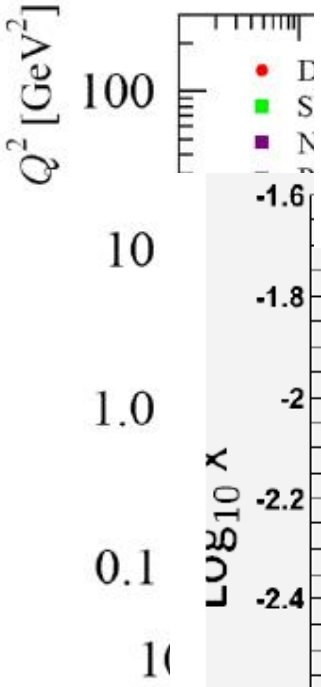


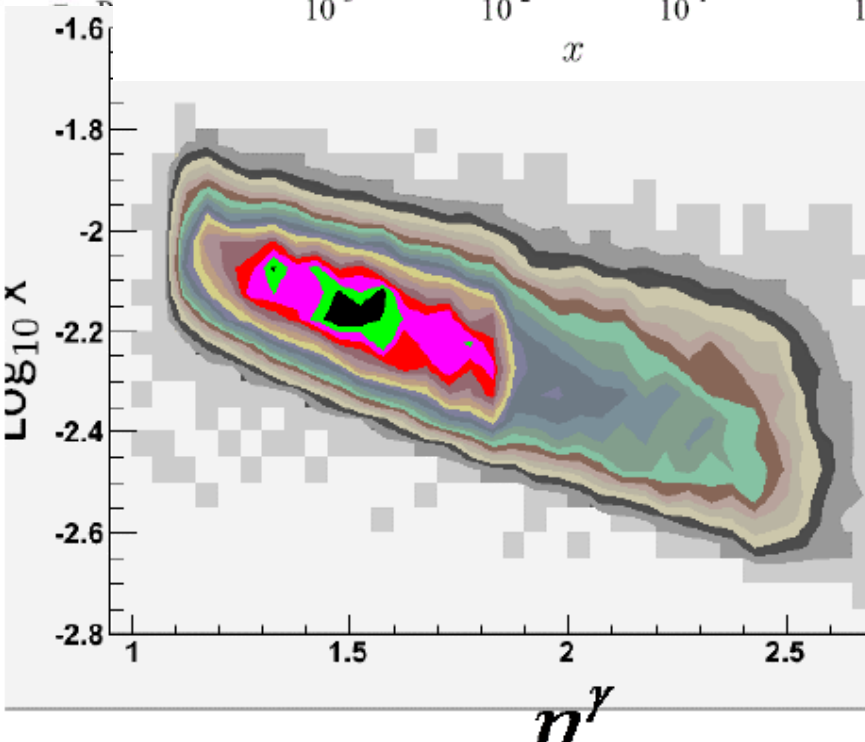
Idea:

Presence of dense gluon field ir the Au nucleus leads to multiple scattering and parton can distribute its energy to many scattering centers ➔ "Mono-jet signature". D. Kharzeev, E. Levin, L. McLerran, Nucl.Phys.A748:627-640,2005


-1
-1.5
-2
-2.5
-3
-1.4
-1.2
-1
-0.8
-0.6
-0.4
350
300
250
200
Log10 x2
Log10 x1


1.5
ya
1.0
0.6
y0
0.2
antishadowing
Fermi-
motion
EMC-
effect
shadowing
xa
xe
10-3
10-2
10-1
x


Q2 [GeV2]
100
10
1.0
0.1


-1.6
-1.8
-2
-2.2
-2.4
-2.6
-2.8
1
1.5
2
2.5
Log10 x
ηγ

Measuring Gluon Densities