Sea Quark Polarization Measurement via W to Muon Decay at RHIC-PHENIX Experiment

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Self Introduction

- Ph.D. Candidates in Seoul National University
  - 4^{th} year, Kiyoshi Tanida's Lab.
- RIKEN IPA (International Program Associate) Student (2012~)

- Joined PHENIX experiment since 2011
  - MuTr, MuTrig, ZDC, Local Polarimeter subsytem expert
  - Ph.D. thesis topic: Measurement of longitudinal single spin asymmetry of W boson production at forward/backward rapidities in polarized p+p collisions at $\sqrt{s}$=510 GeV at RHIC-PHENIX (tentative title)

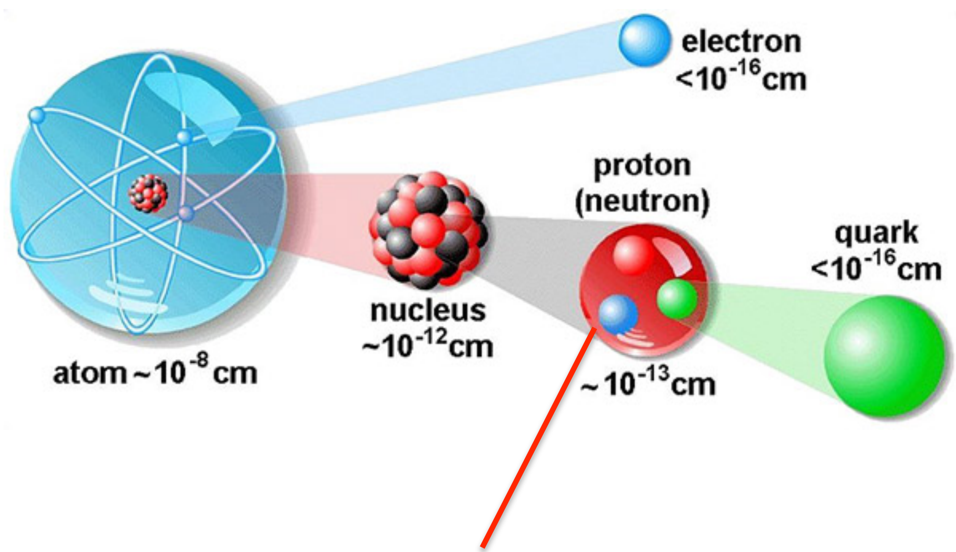
Outline

- Introduction of Spin Physics
- RHIC-PHENIX experiment
- PHENIX W Measurement
- Forward Muon Arm Analysis (single spin asymmetry of W production)
  - Experiment overview
  - Detector setup, upgrade history
  - Analysis overview
  - Detector performance
  - Data analysis, preliminary
  - Future analysis prospect

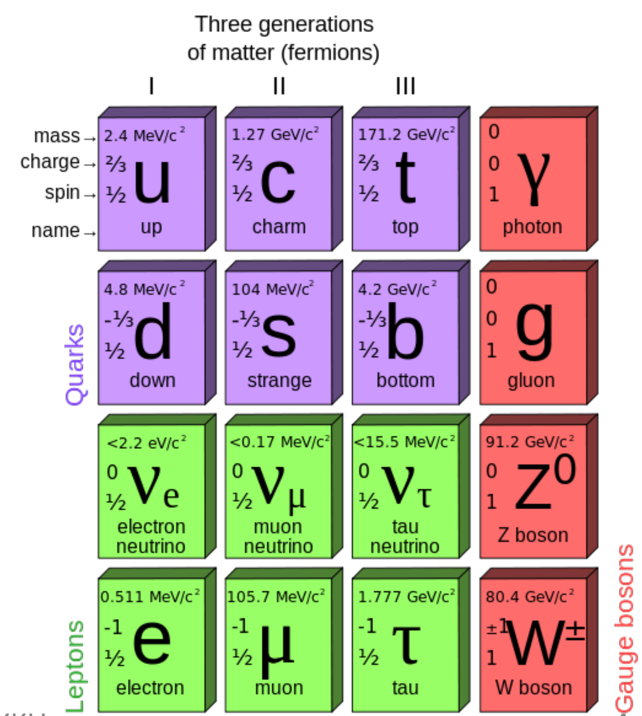
Following talk by Chong Kim (Korea Univ.)

Spin?

- Intrinsic angular momentum
- Spin quantum number s = 1/2, 1, ...
- Subatomic particles:



Standard Model



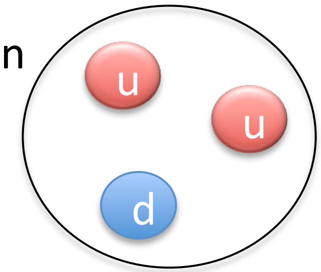
Proton = (uud) composite particle.

Spin ½ fermion

Proton Spin Structure

- "Where does proton spin come from?"

→ Simple thought:



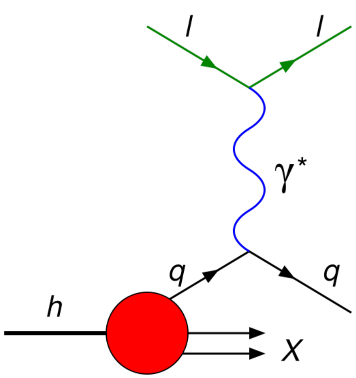
- **Quark Model**:

Simply thinking..

Proton consists of three valence quark = (uud)

$$\boxed{\frac{1}{2} = \frac{1}{2} + \frac{1}{2} - \frac{1}{2}}$$ ← OK?

→ DIS (Deep Inelastic Scattering)



$$\Delta\Sigma = \Delta U + \Delta D + \Delta S$$

$$\Delta\Sigma = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s})$$

Measured by DIS experiment:

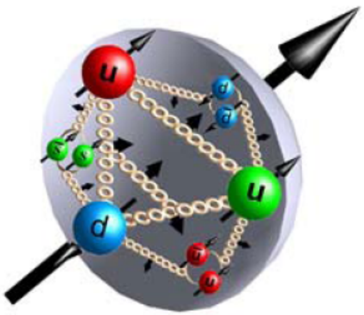
Combined quark contribution to the proton spin: ~30%

Proton spin crisis

Proton Spin Structure

- "Where does proton spin come from?"

→ Parton Model:



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

Quark — Gluon — Orbital angular momentum (q,g)

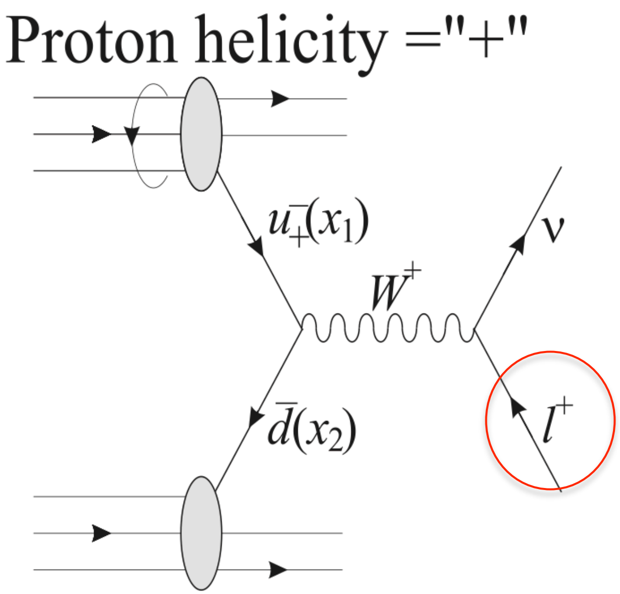
$$\Delta\Sigma = (\Delta u + \underline{\Delta \bar{u}}) + (\Delta d + \underline{\Delta \bar{d}}) + (\Delta s + \underline{\Delta \bar{s}})$$

Large uncertainty

- Well known combined quark PDFs by polarized DIS experiment.
  - Small contribution to proton spin (~30%)
  - DIS, global QCD analysis: negative polarized sea quarks

- Semi-Inclusive DIS (SIDIS) constrains separated PDFs. Limited by large uncertainties of fragmentation functions

W Physics in Polarized PP Collisions



- W production in polarized pp collision
- Large Q^2
- Independent of the knowledge of fragmentation functions:

  - maximum parity violation;
  left handed quark + right handed anti-quark
  → flavor is almost fixed:

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

- Single Spin Asymmetry:

$$A_L^{W^+} \equiv \frac{\sigma_- - \sigma_+}{\sigma_- + \sigma_+}$$

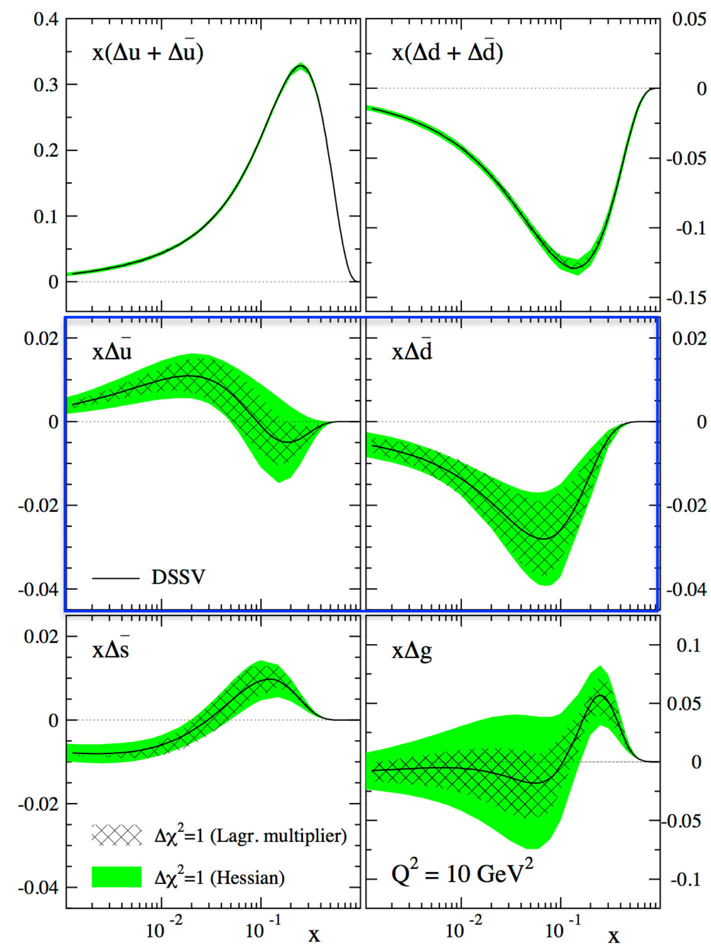
$$= -\frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

Relative rapidity of W to the proton, y_W

At $y_W >> 0$, $A_L^{W+} \approx -\Delta u/u$
At $y_W << 0$, $A_L^{W+} \approx \Delta\bar{d}/\bar{d}$

RHIC-PHENIX Longitudinal Spin Program

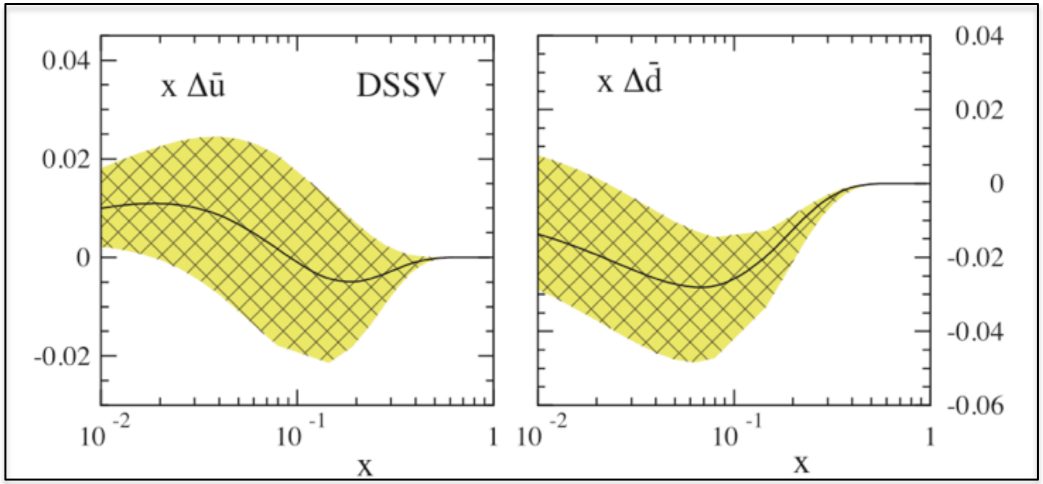
- Well known combined quark PDFs
- Sea Quark Distribution Measurement
  - large uncertainty for sea quark
  - → W measurement
- Gluon Distribution Measurement
  - Need more constraint
  - → Double helicity asymmetry
  - → talk by Inseok Yoon.



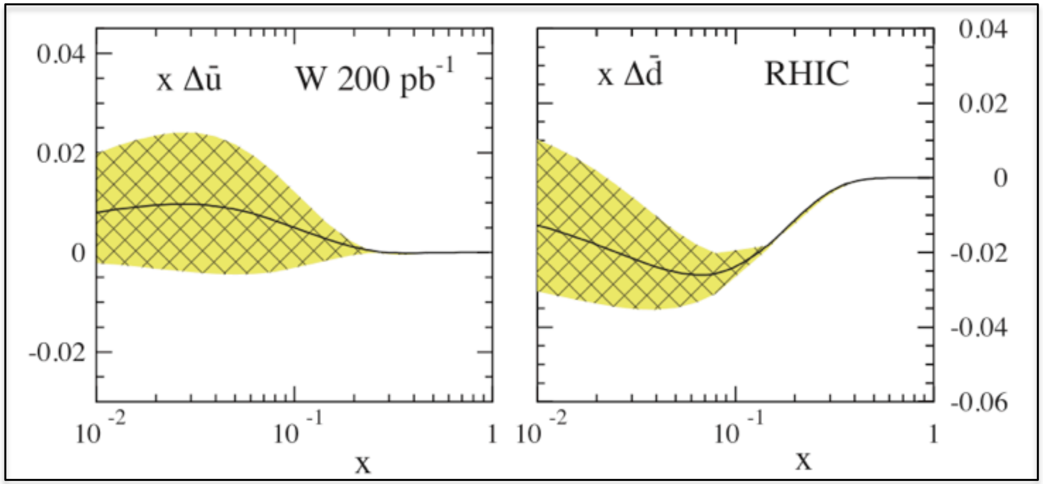
D. de Florian, R. Sassot, M. Stratmann, W. Vogelsang, Phys. Rev. D 80, 034030 (2009)

Physics Impact of A_L

- Global analysis DSSV (top) and Pseudo-experiment data of 200 pb^{-1} (bottom)
- Significant impact for reducing uncertainties



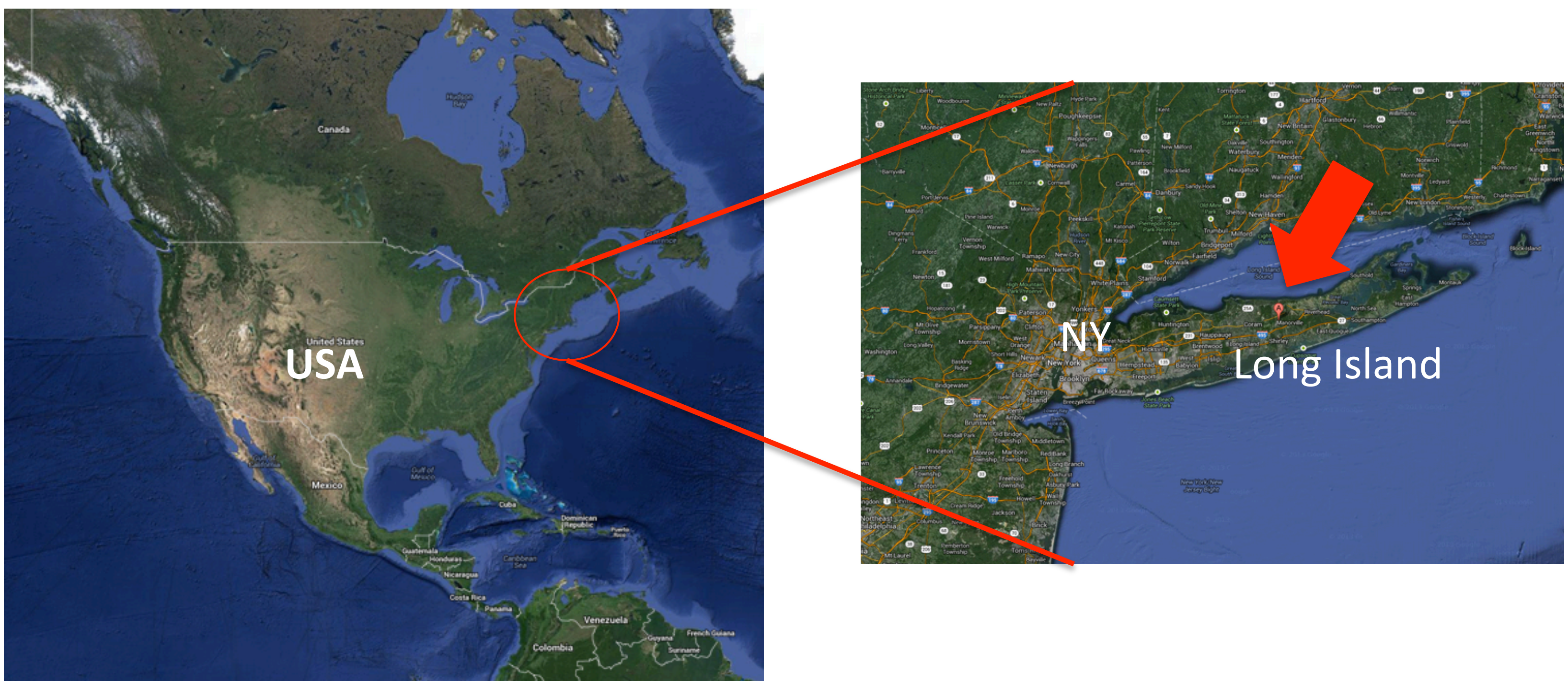
Global analysis DSSV



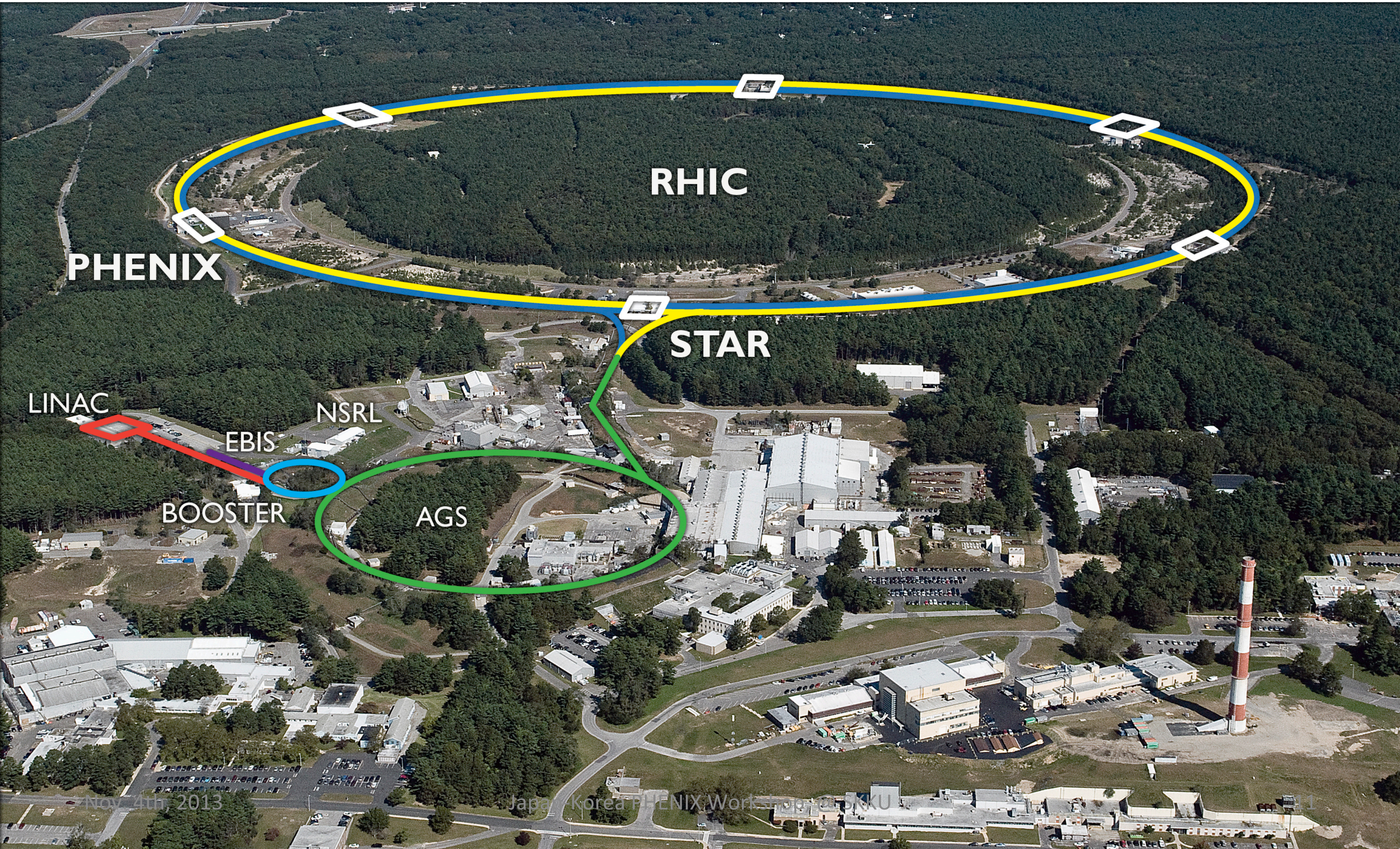
DSSV + Pseudo-RHIC data of 200 pb^{-1}

RHIC-PHENIX Experiment

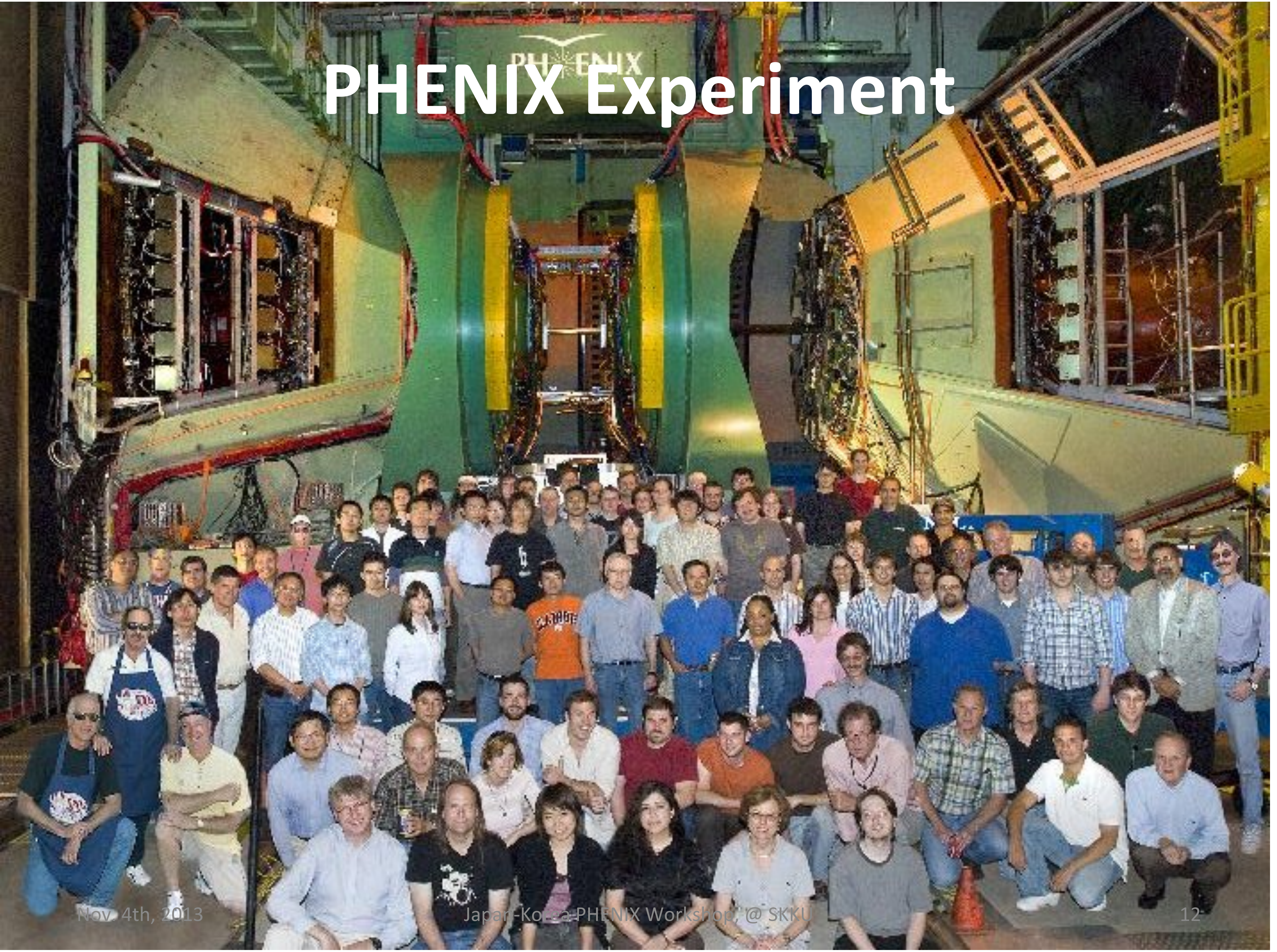
- RHIC (Relativistic Heavy Ion Collider)
  - Brookhaven National Lab., NY, US.
  - Two independent collider ring (3.83km)
  - Capable of spin-polarized proton collision



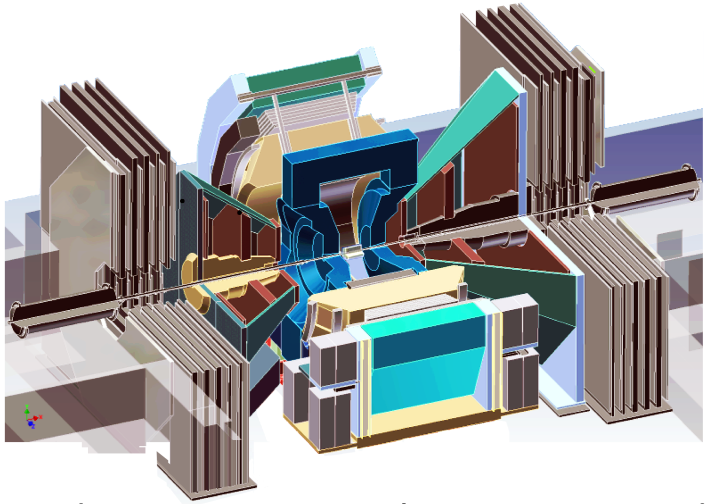
RHIC-PHENIX Experiment



PHENIX Experiment



PHENIX Detector



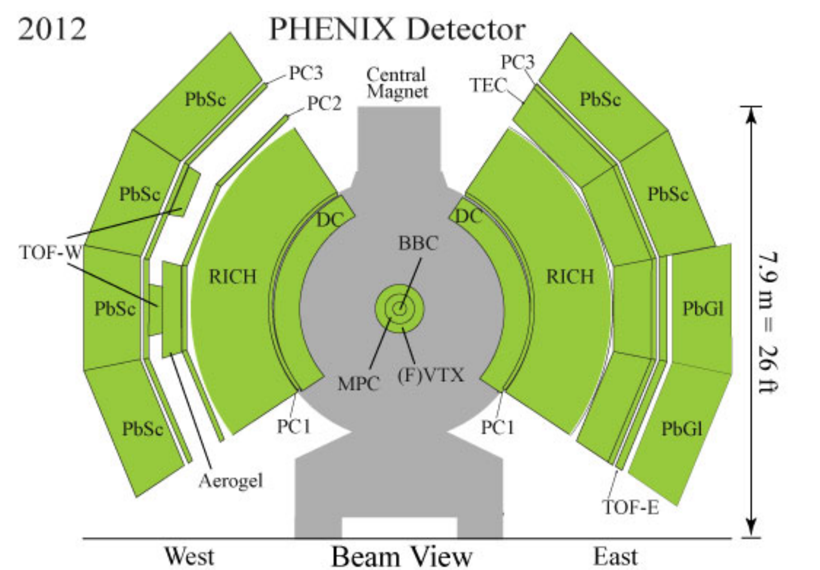
Forward Arm Central Arm Forward Arm

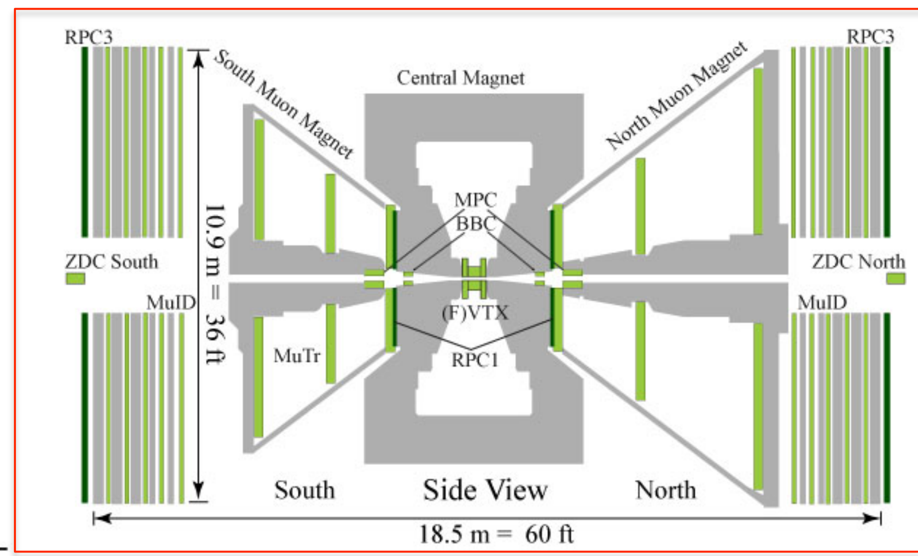
Central Arm (W→e):

- **Acceptance:**
  - $|\eta| < 0.35$
  - $\Delta\phi = 2 \times \pi/2$

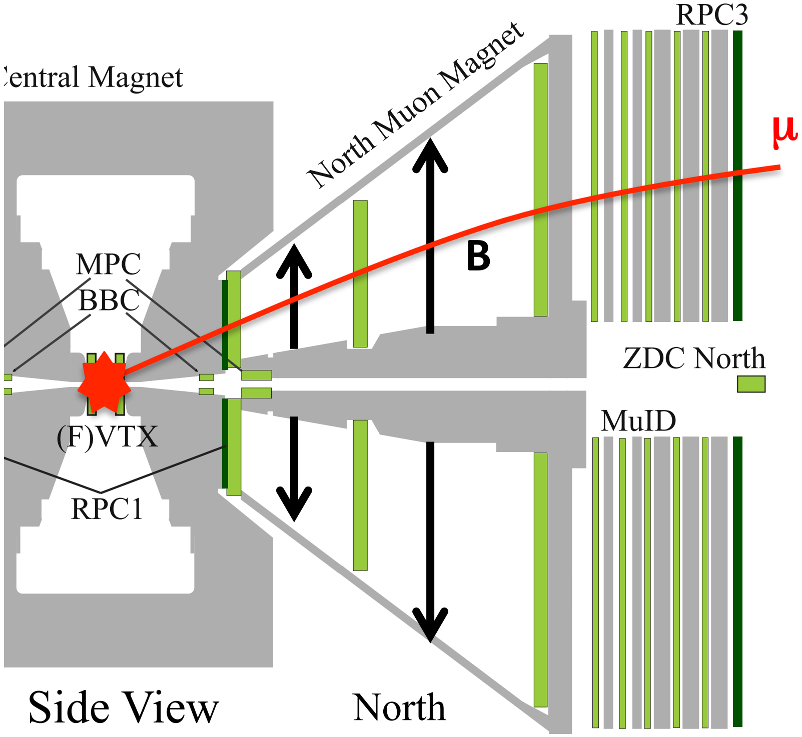
Muon Arm (W→μ):

- **Acceptance:**
  - $1.2 < |\eta| < 2.4$, North
  - $1.2 < |\eta| < 2.2$, South
  - $\Delta\Phi = 2\pi$





Forward Muon Arm



PHENIX Forward Muon Arm Subsystems:

- Fully Upgraded in 2012
- Subsystems:
  - **Beam Beam Counter (BBC)**: Minimum Bias, Collision timing
  - **Muon Tracking Chamber (MuTr)**: Tracking, triggering
  - **Muon Identifier (MuID)**: Particle ID, triggering
  - **Resistive Plate Chamber (RPC)**: particle ID, triggering
  - **Forward Silicon Vertex (FVTX)**: Particle ID

Muon Arm Acceptance:

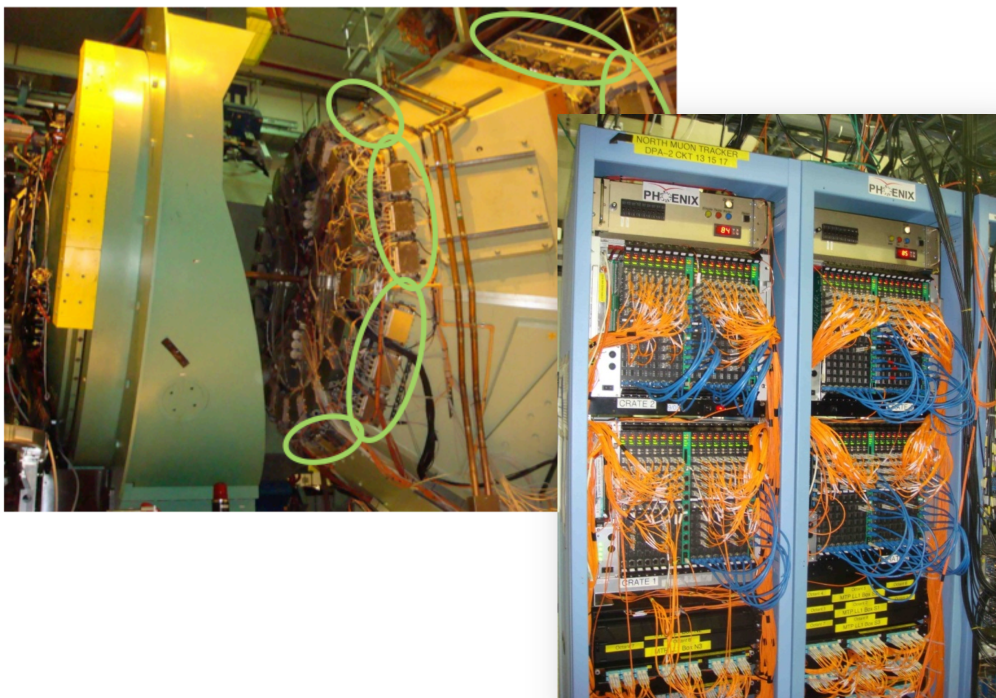
- $1.2 < |\eta| < 2.4$, North
  $1.2 < |\eta| < 2.2$, South
  $\Delta\Phi = 2\pi$

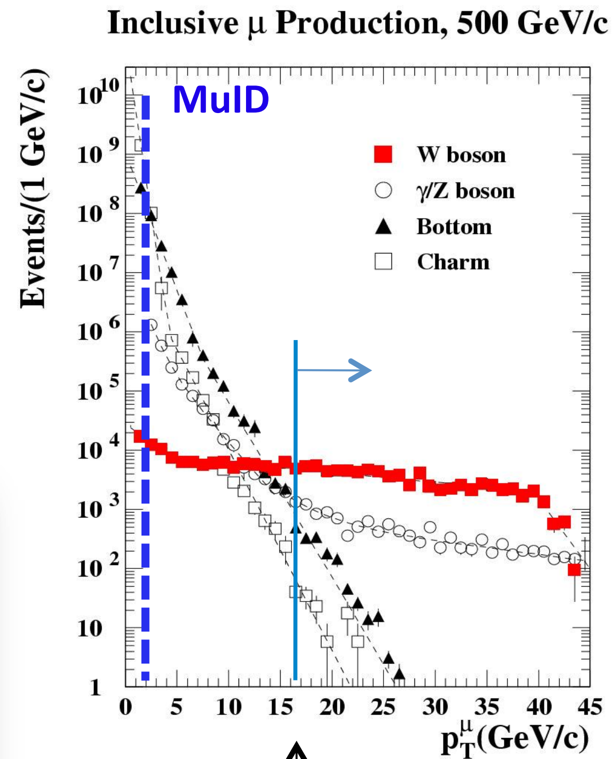
PHENIX Muon Arm Upgrade

- MuTRG-FEE (Front-End-Electronics)
  - Momentum sensitive trigger & fast readout electronics
- Resistive Plate Chambers (RPC1, RPC3)
  - Good timing resolution. Particle ID, triggering
- Hadron Absorber
  - Reject hadron(K, π) to muon decay
- Forward Silicon Vertex Detector (FVTX)
  - Improve background rejection in offline analysis
- Muon Tracking Chamber Recapacitation
  - Quench cross talk effect, improve position resolution and performance

MuTRG-FEE Upgrade

- Low momentum threshold of the existing trigger (MuID) in the past; ~2GeV
- Need to improve trigger RP.
- Fast online tracking of high pT muons

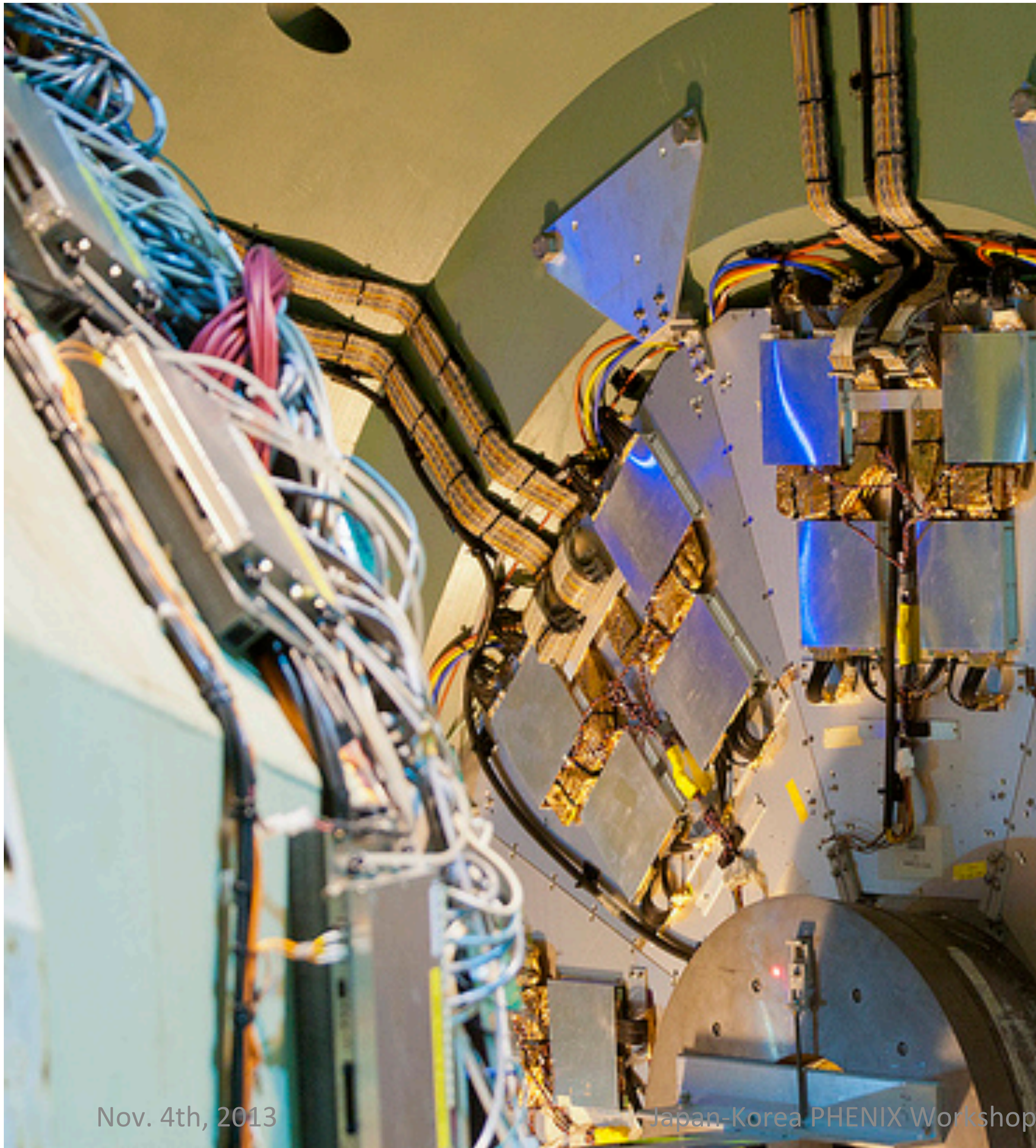


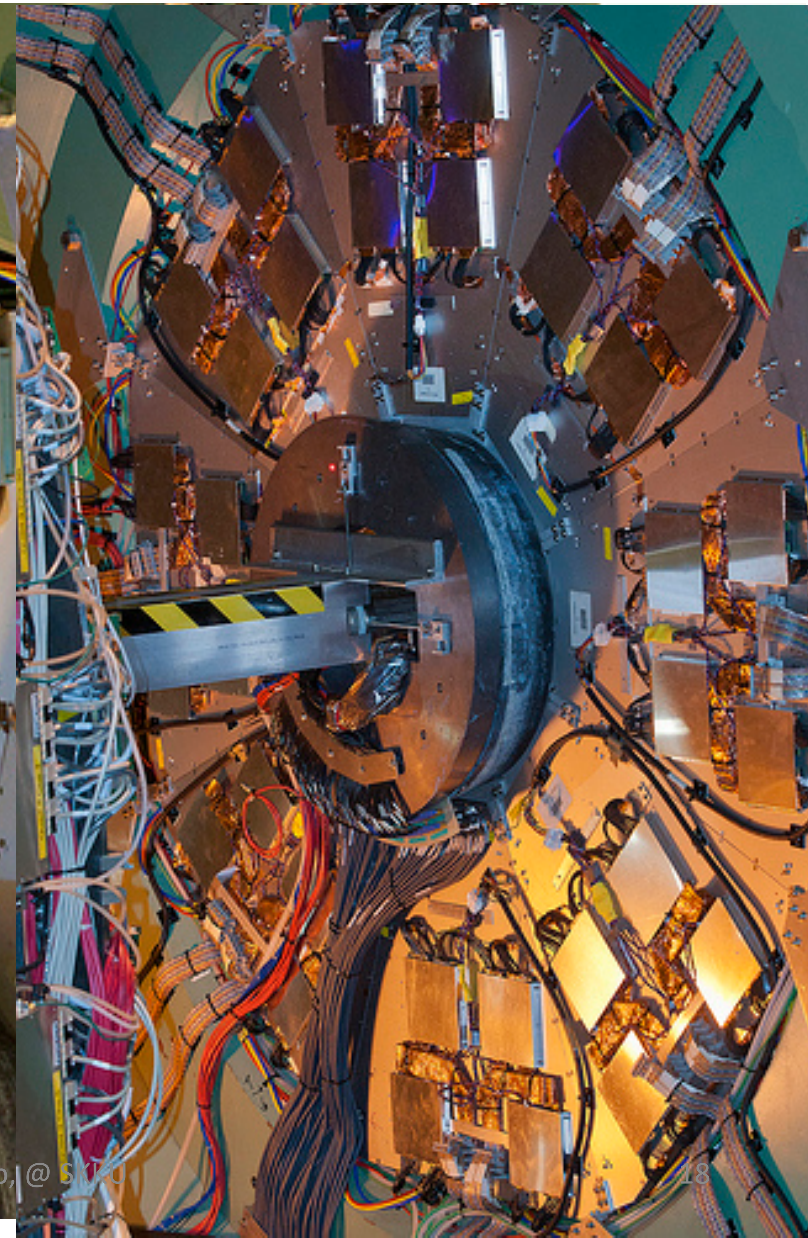


W dominant region

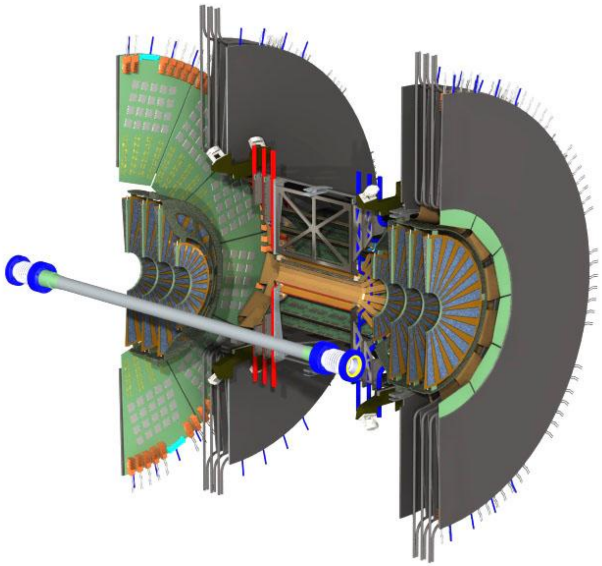
RPC3

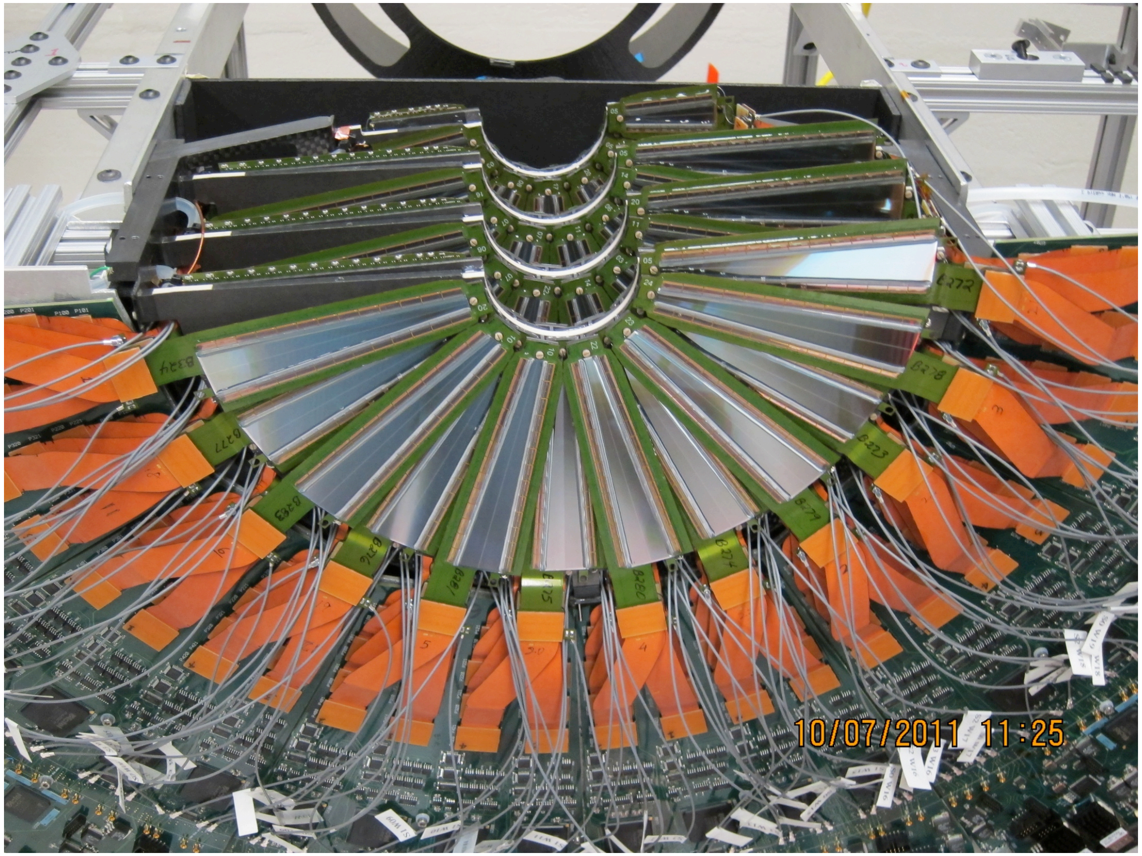
RPC1





FVTX





PHENIX W Measurement Data Set

	2011	2012	2013
Beam energy	√s = 500 GeV	√s = 510 GeV	√s = 510 GeV
Integrated luminosity	25 pb^{-1}	50 pb^{-1}	228 pb^{-1}
Beam Polarization (blue / yellow)	0.52 / 0.53	0.55 / 0.57	0.56 / 0.57
FOM ($L*P^2$)	6.9	15.7	74.1

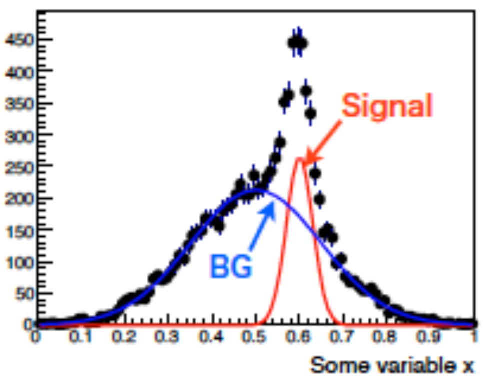
- 2012: First data taking for W->muon analysis
- 2012:
  - RPC3 is used for W trigger
  - RPC1 installed
  - FVTX installed
- 2013:
  - Significant amount of data
  - RPC1 is also used for W trigger

2012 W→μ Analysis

- **Data is dominated by backgrounds**
  - Backgrounds: hadron BG, muon BG
- **Signal, background separation is important and challenging.**

→ Likelihood-based signal selection

- Pre-selection: multivariate cut using likelihood ratio



Probability distribution function for given x
→ Signal λ(x), background λ(x)

$$f \equiv \frac{\lambda_{\mathrm{sig}}}{\lambda_{\mathrm{sig}} + \lambda_{\mathrm{BGs}}}$$

f → 1: signal-like
F → 0: background-like

- S/B ratio extraction: unbinned maximum likelihood fitting

$$\mathcal{L}(\theta|X) \equiv \frac{n^N e^{-n}}{N!} \prod_{x_i \in X}^{N} \left[\sum_c \frac{n_c}{n} p_c(x_i) \right], \quad n = \sum_c n_c$$

2012 W→μ Analysis

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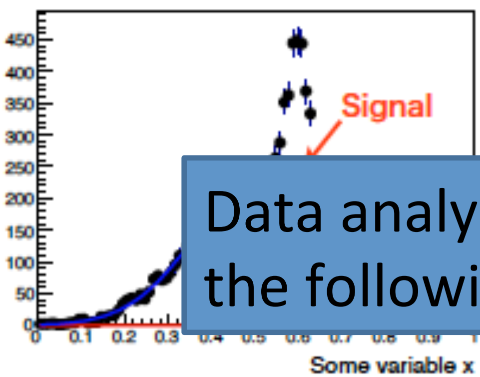


Probability distribution function for given x
→ Signal λ(x), background λ(x)

Data analysis detail will be given by Chong Kim in the following talk

- S/B ratio extraction: unbinned maximum likelihood fitting

$$\mathcal{L}(\theta|X) \equiv \frac{n^N e^{-n}}{N!} \prod_{x_i \in X}^{N} \left[\sum_c \frac{n_c}{n} p_c(x_i) \right], \quad n = \sum_c n_c$$

Simulation Tune

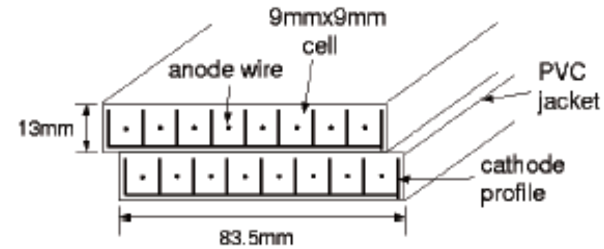
- Composition of Probability distribution functions

	W→μ signal	Hadron BG	Muon BG
Probability dist. funcs	MC simulation	Data	MC simulaton

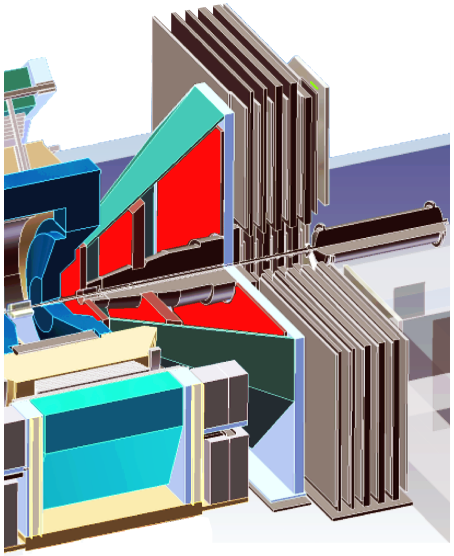
- The probability distribution functions for signal and muon BG are extracted from the MC simulation
- PYTHIA event generator + GEANT4 simulation
- Rate dependence of detector response is introduced.

Rate Dependence of Detector Response

1. MuID Hit Efficiency:
- data driven tube efficiency.
- Clear degradation as a function of BBC(noVtx) rate in 2012 as well as 2011 analysis.



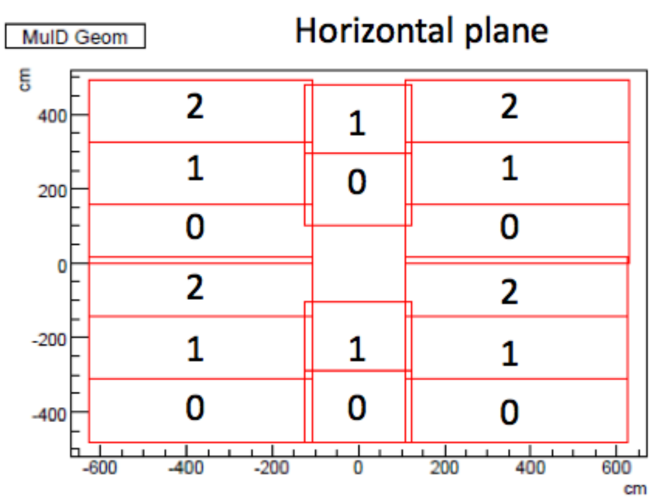
2. MuTr Hit Efficiency:
- Gap, plane efficiencies extracted from data
- additional adjustment for tuning the simulation due to the charge discrepancy between two cathode planes.
- tune parameters: base efficiency, asymmetry width as a function of multiple collision parameter μ

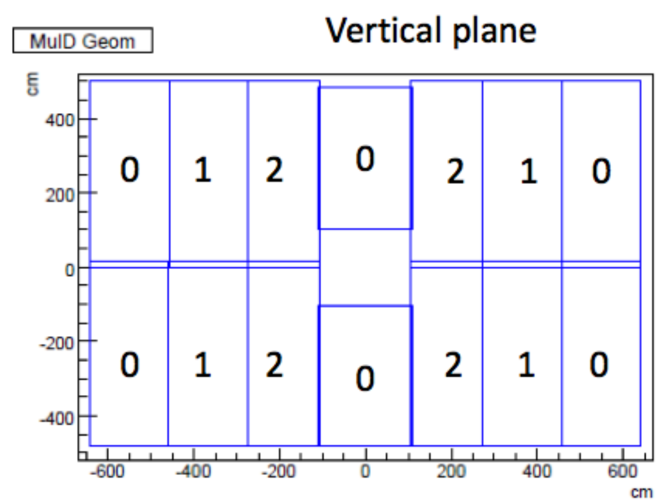


MuID Hit Efficiency

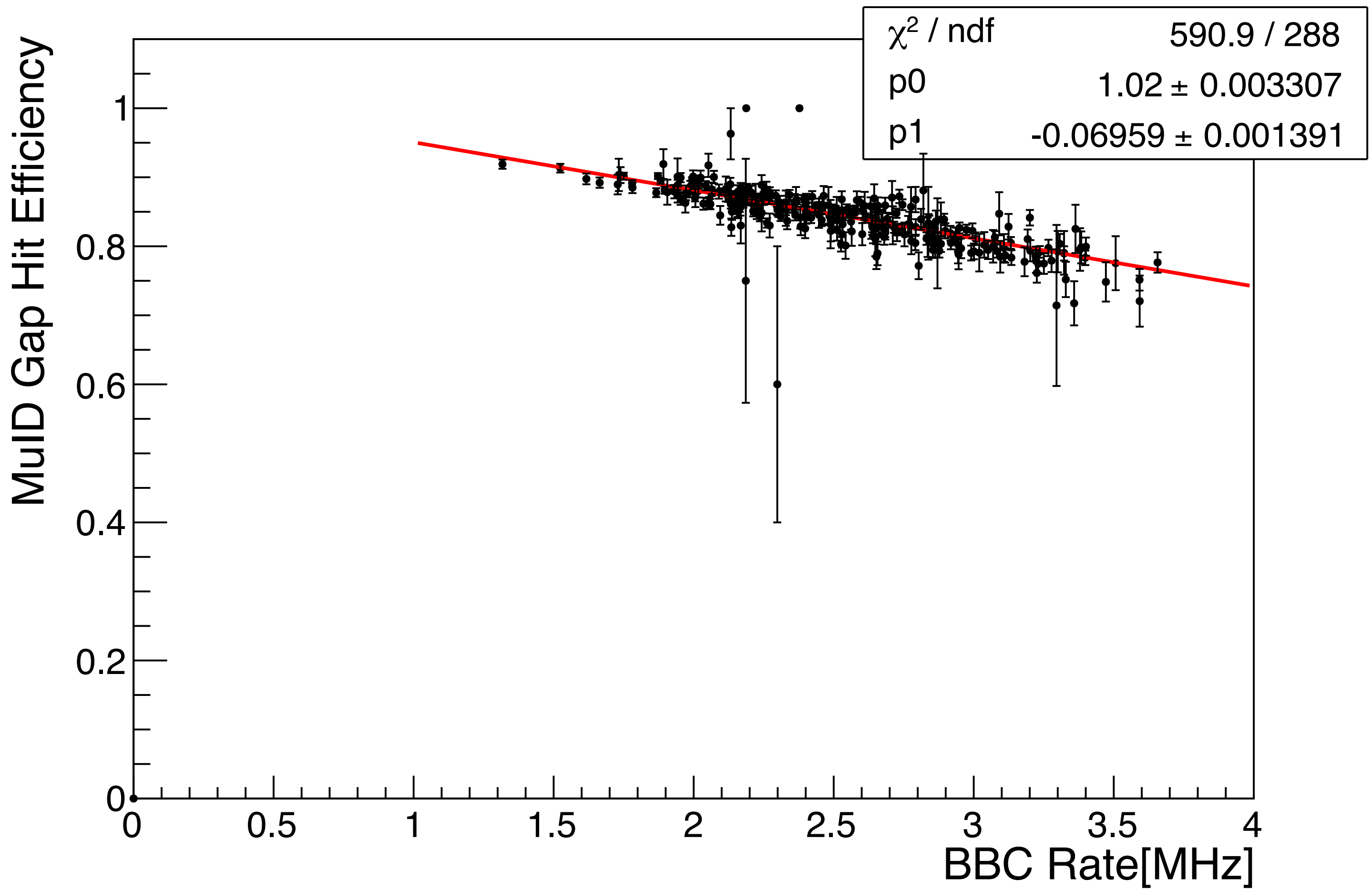
- Based on HV group (see the below for HV group structure)
- Assume the uniform tube efficiency due to the limitation of statistics
- Sampled by all triggers + some quality cuts

$$\text{Efficiency[iplane]} = \frac{\text{hit in ith plane}}{\text{MuTr tracks} \cap \text{MuID road finder} \cap \text{trigger emulator}}$$





MuID Hit Efficiency



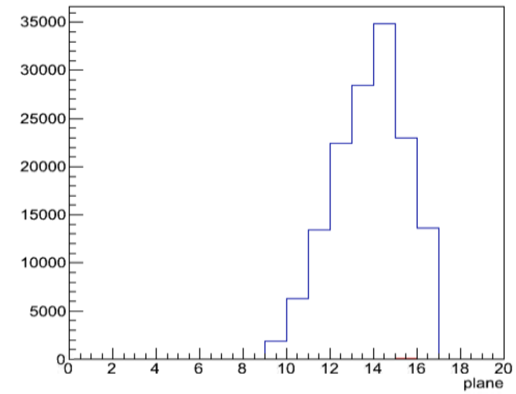
- Clear degradation as a function of collision rate.

MuTr Hit Efficiency

- Assume the unitor detector response, and symmetry between two planes in the same gap
- Deifine two probabilities P1, P2:
  - p1: probability to have OR hit in a gap
  - p2: probability that one plane in the same gap doesn't have a hit when the gap has OR hit
- Gap(OR) efficiency, plane efficiency can be defined as:

$$P_k = {}_nC_k P_1^k (1-P_1)^{n-k}, (0 \le k \le n)$$

$$P_i = \sum_{\frac{i}{2} \le k \le i} {}_nC_k P_1^k (1-P_1)^{n-k} {}_kC_{2k-i} (1-P_2)^{i-k} P_2^{2k-i}, (k = integer, k \le n)$$



- Perform binomial fitting to get p1, p2
- Interpretation of Gap(AND) efficiency, plane efficiency using p1, p2

$$\epsilon_{Gap} \equiv p_1(1-p_2)$$

$$\epsilon_{Plane} \equiv p_1(1-\frac{p_2}{2})$$

MuTr Hit Efficiency

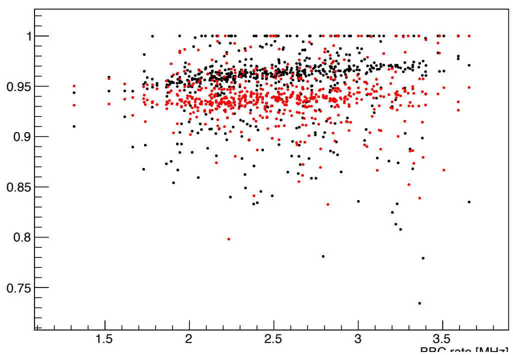
- Weak correlation between gap and plane efficiencies as the luminosity increases
- Tuning parameter for simulation

  - Base efficiency: total hit efficiency

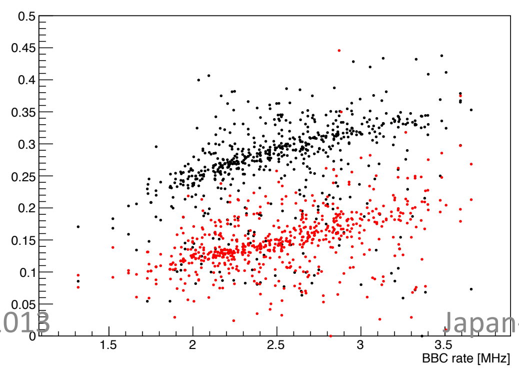
  - Asymmetry width: charge discrepancy between two cathode planes

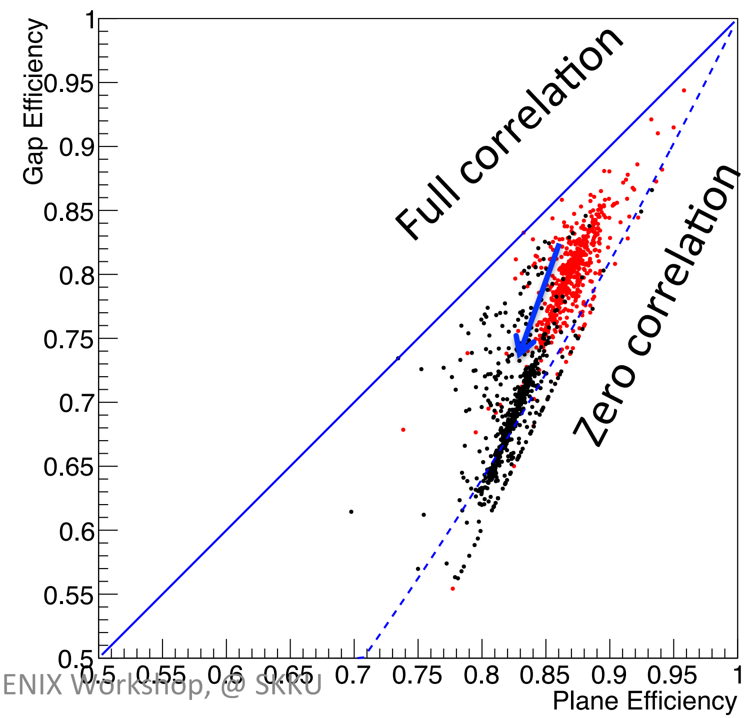
  → fine the map between gap, plane efficiency and base efficiency, asym width for given multiple collision parameter

P1



P2



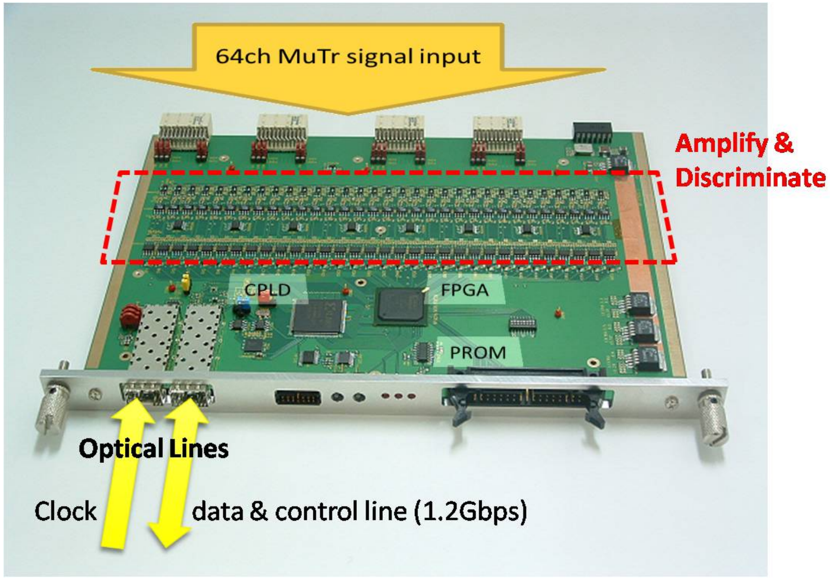


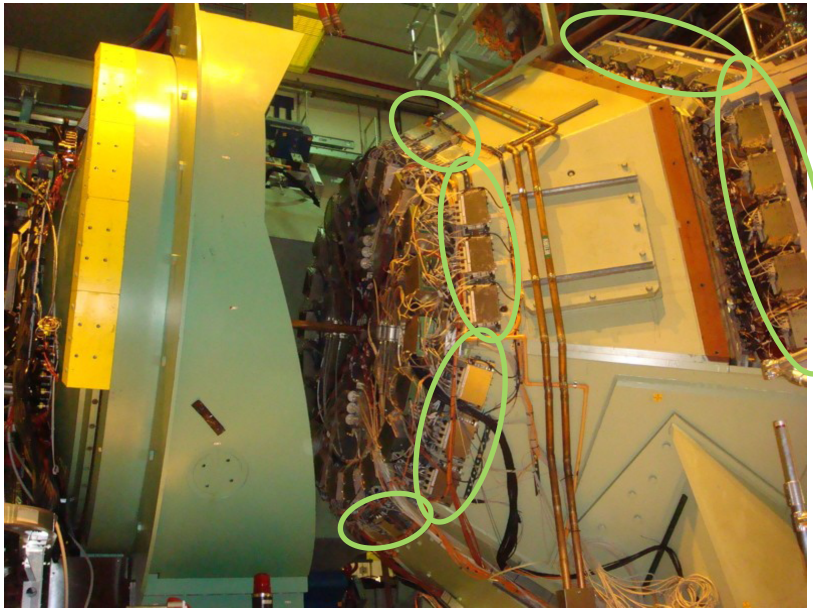
Summary

- PHENIX has collected data for W measurement to study sea quark contribution to proton spin.
- Forward muon arm upgrade is completed.
- FVTX is installed and operated.
- 2012 data analysis is ongoing.
  - Rate dependence of detector performance has been studied.
  - Detail of data analysis and preliminary result will be shown in the next presentation.

Backup

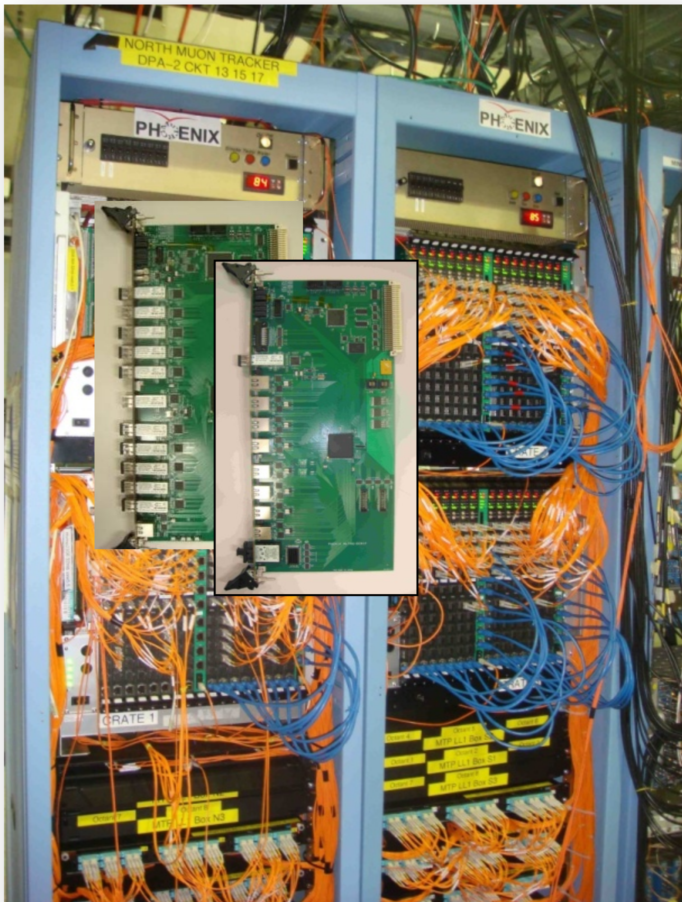
MuTRG-ADTX





Functions	Charge splitting into two paths	
	Amplifying and discriminating raw signals	
	Transmit digitized signals to MRG boards	
Discriminator mode	CFD	LED

MuTRG-MRG, MuTRG-DCMIF

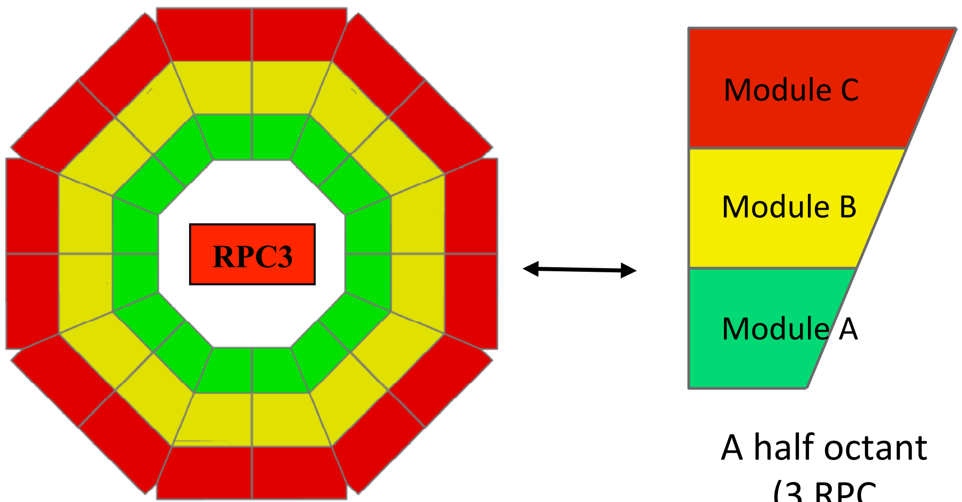


In PHENIX Rack room

MuTRG-MRG
Receive data from ADTX
Merging and reformatting data
Transmit data to LL1 for trigger decision and MuTRG-DCMIF

MuTRG-DCMIF
Receive data from MRG boards and combine them
Send data to DCM

RPC(Resistive Plate Chamber)

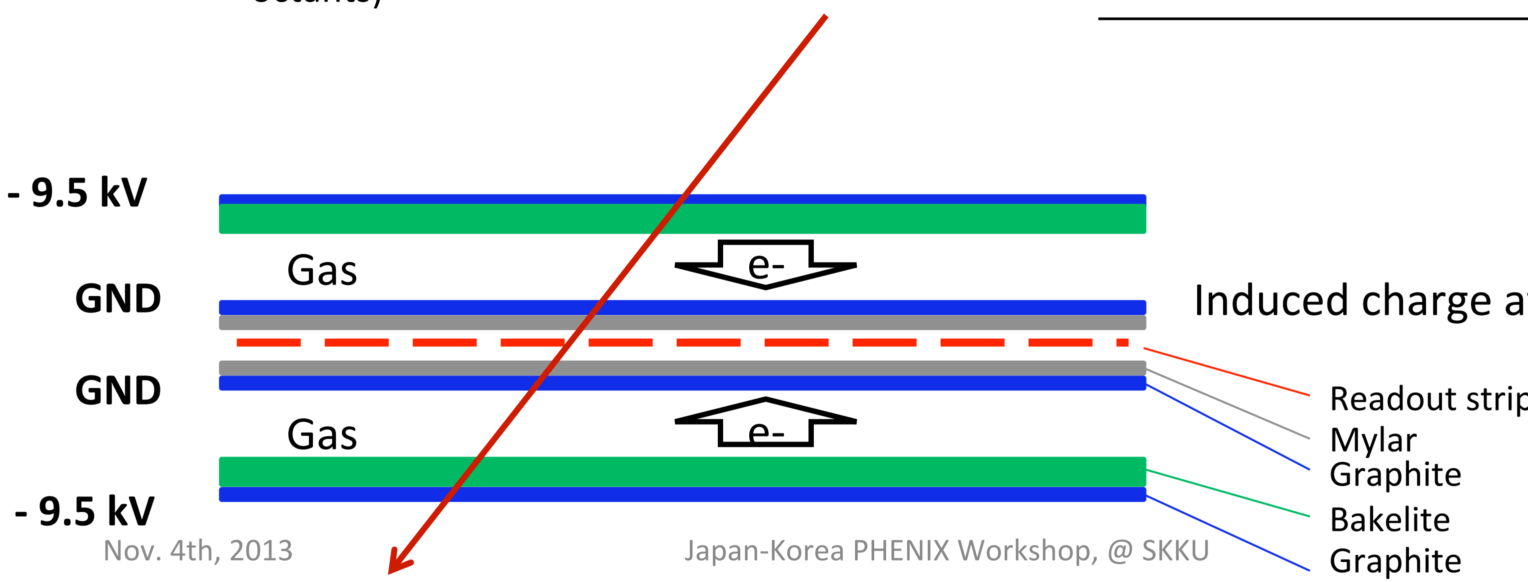


Station 3 (16 half octants)

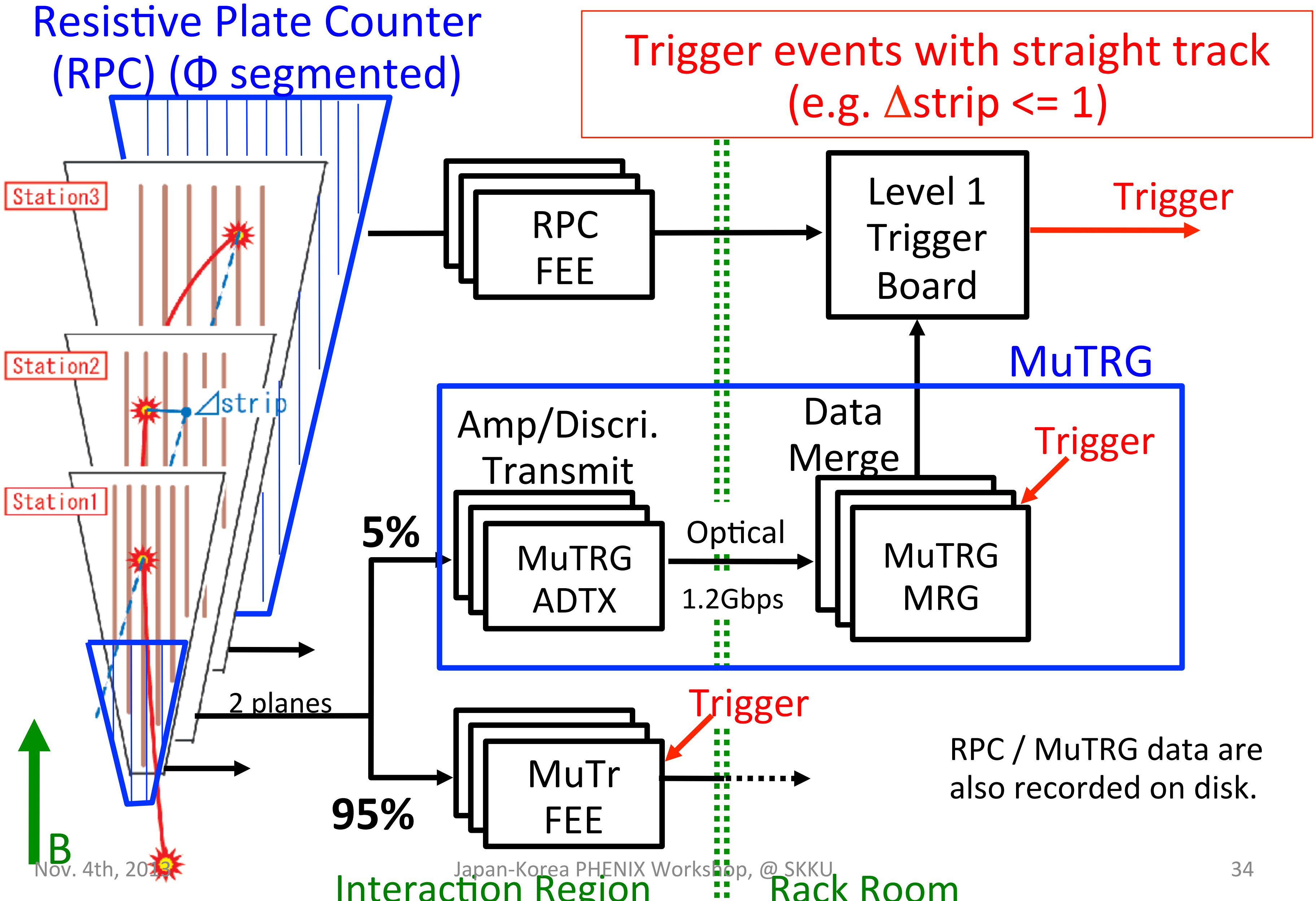
A half octant (3 RPC modules)

PHENIX RPC requirements

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

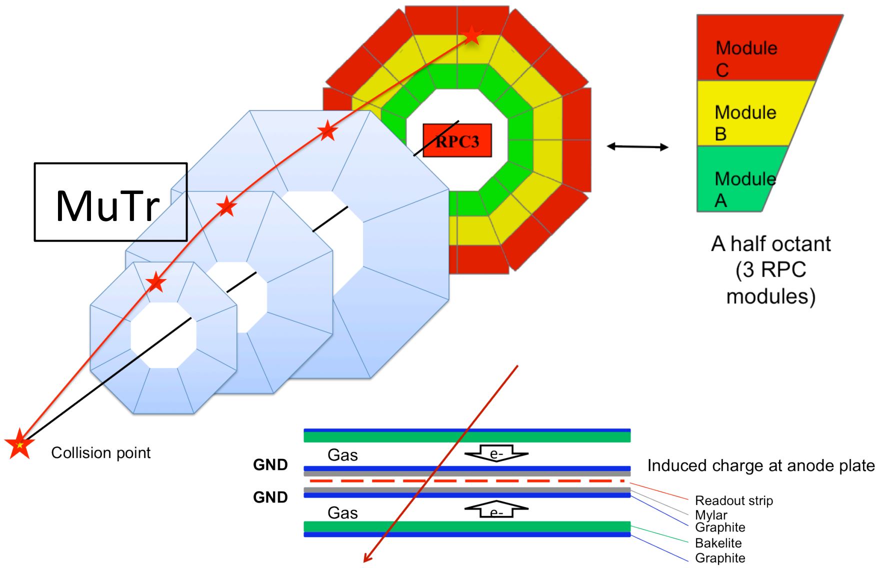


W Trigger System



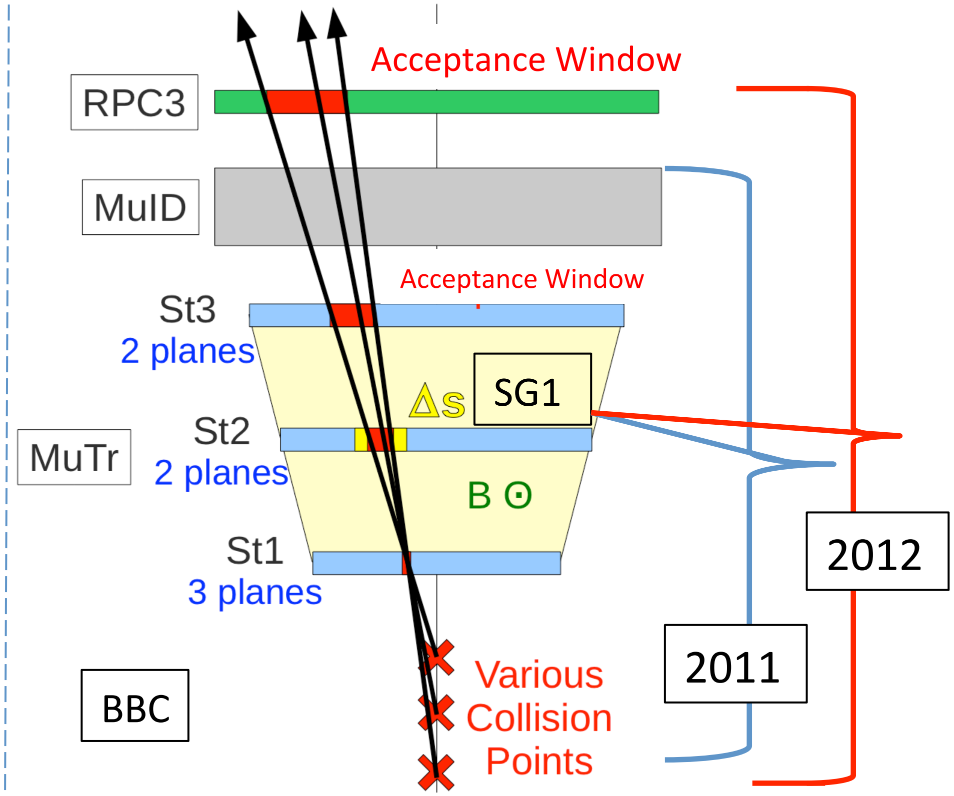
Introduction of New W Trigger in 2012

- **RPC (Resistive Plate Chamber)**



- RPC has good timing resolution (< 3ns).
  → align events with correct beam crossing.
- Better online tracking than MuID
- Provides additional hit information.
- Background rejection in offline analysis

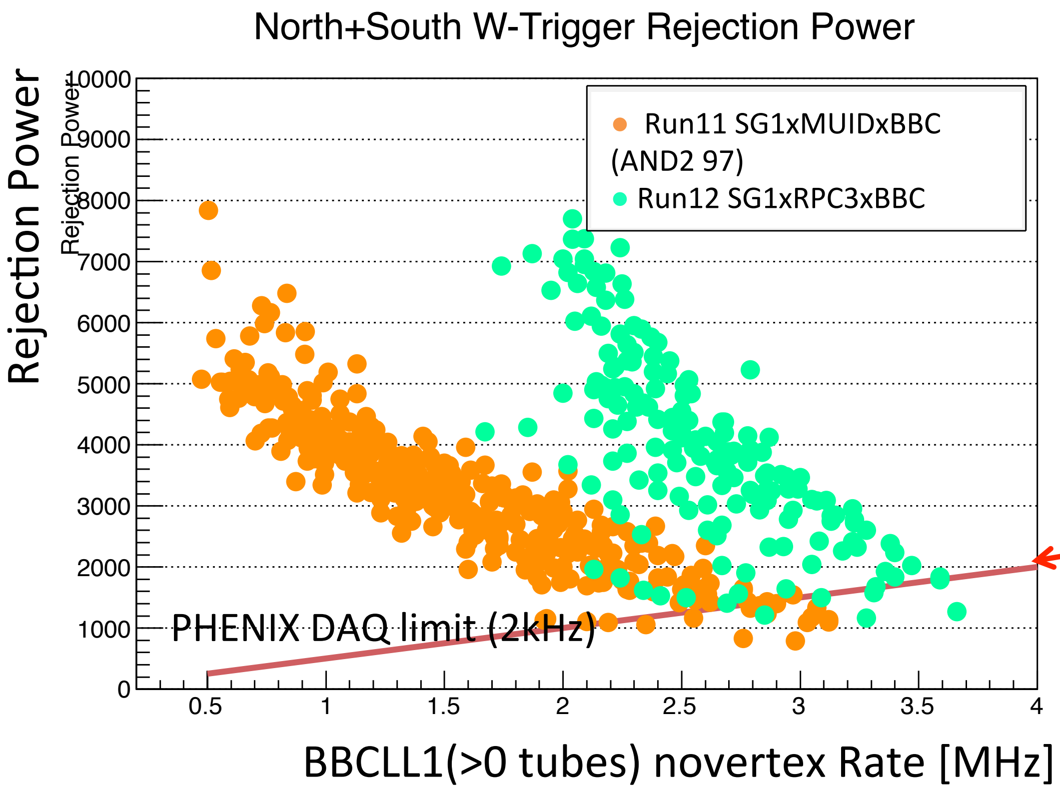
→ **New W Trigger gives higher rejection power**



2011: SG1xMUIDxBBC trigger
2012: SG1xRPC3xBBC trigger (main)
SG1xMUIDxBBC trigger (backup)

Performance of W Trigger (I)

- **Rejection Power**



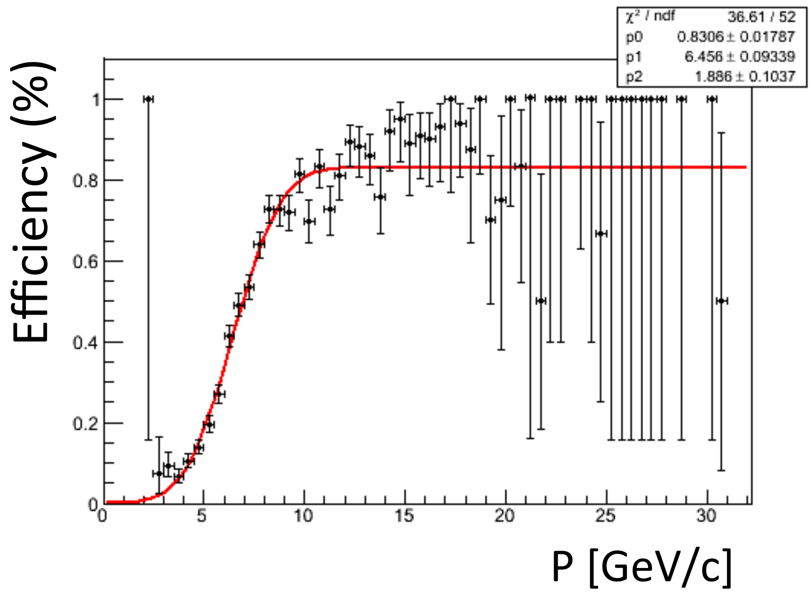
It is important to keep RP higher than this PHENIX DAQ limit line for successful data taking.

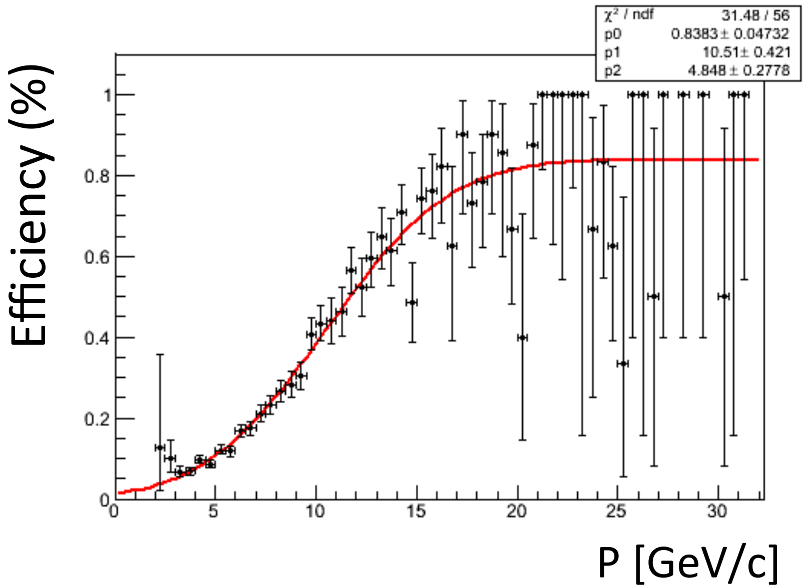
- Run12 SG1xRPC3xBBC gives us higher rejection power.
- RPC1 installation was done but not included as physic trigger in 2012
→ expected higher RP by using RPC1 in 2013.

Performance of W Trigger (II)

- **SG1 Trigger efficiency for tracks (preliminary)**

$$\text{Efficiency(Trigger)} = \frac{\#\text{Tracks by (Trigger)} \cap \#\text{Tracks by MuTr}}{\#\text{Tracks by Muon Tracker}}$$





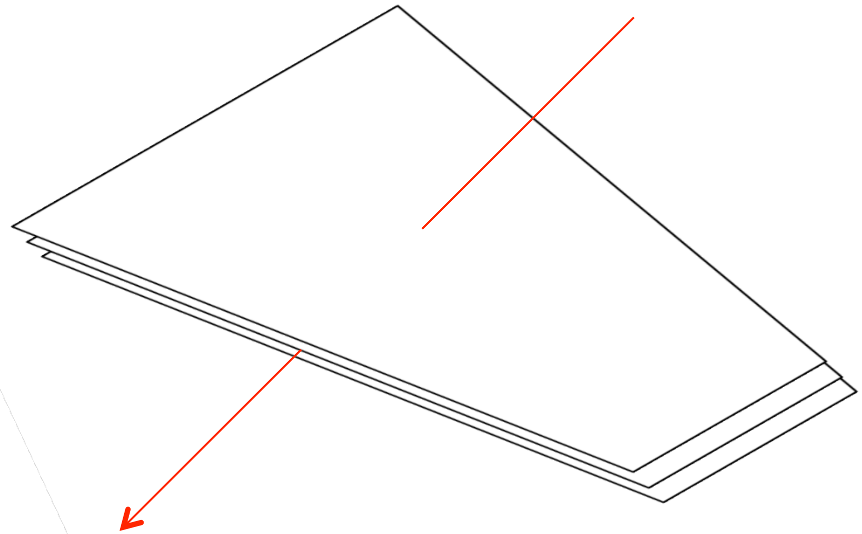
Arm	Efficiency at Plateau [%]	Turn-on Point [GeV/c]
South	83.1	6.5
North	83.8	10.5

Cathode readout strips

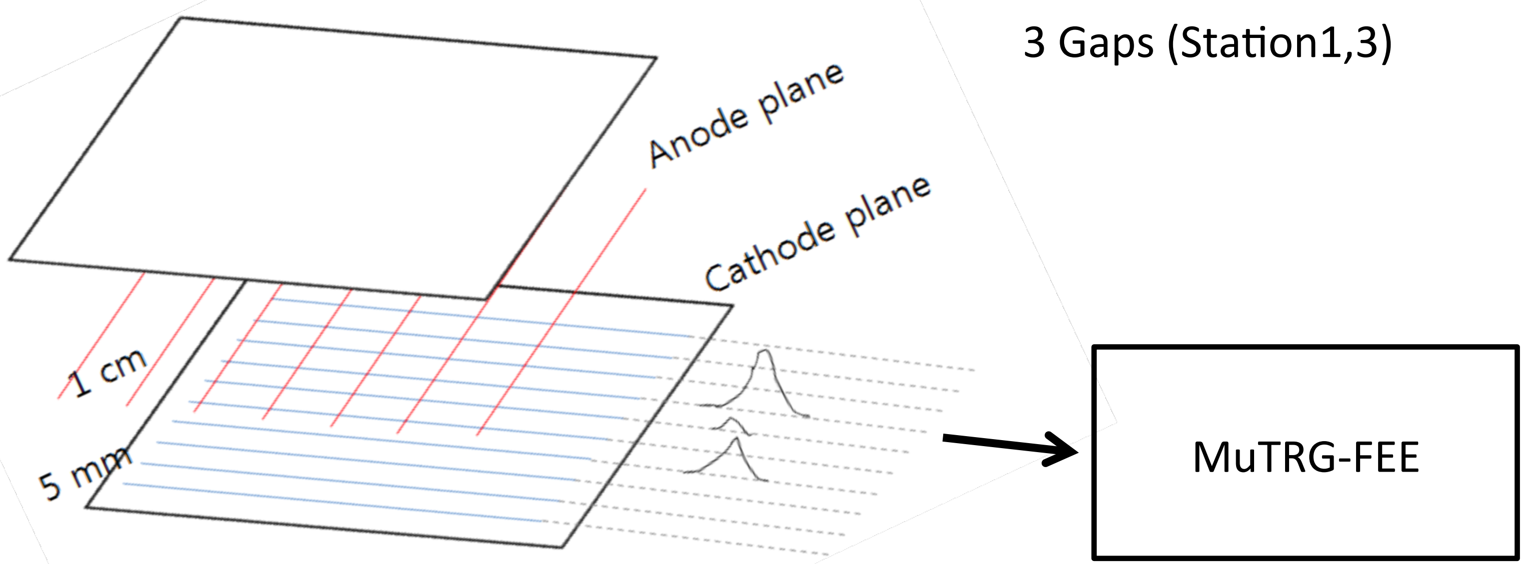
Cathode strip plane (non-stereo type)

Anode wire plane

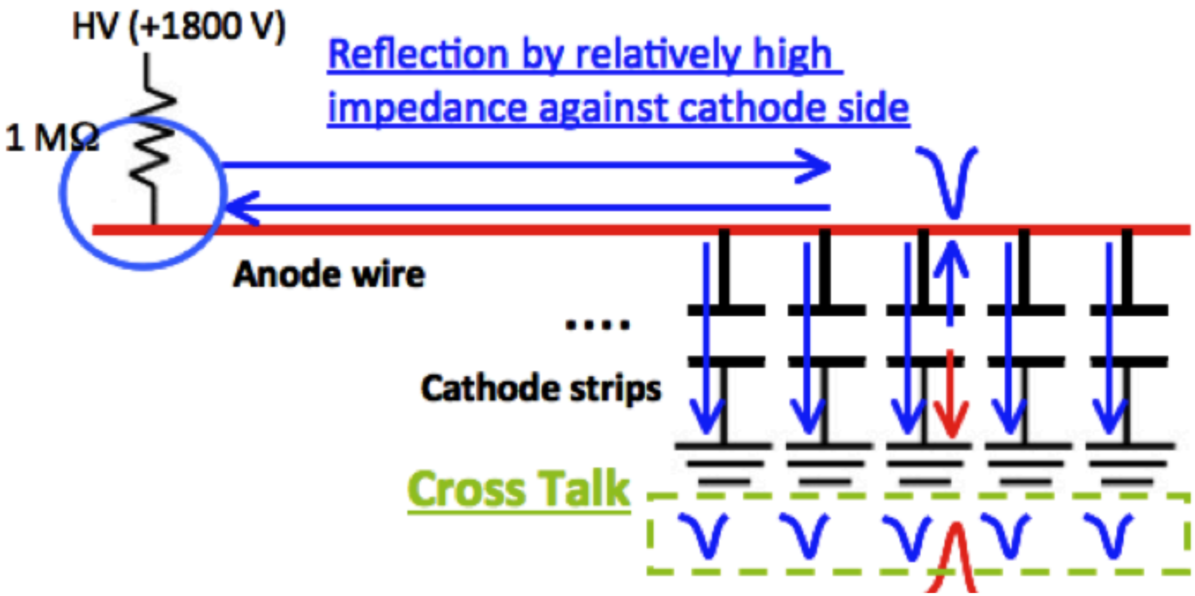
Cathode strip plane(stereo type)

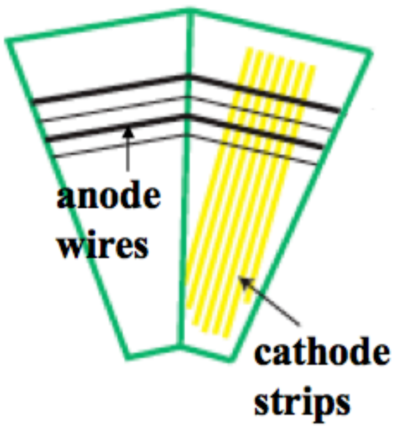


3 Gaps (Station1,3)

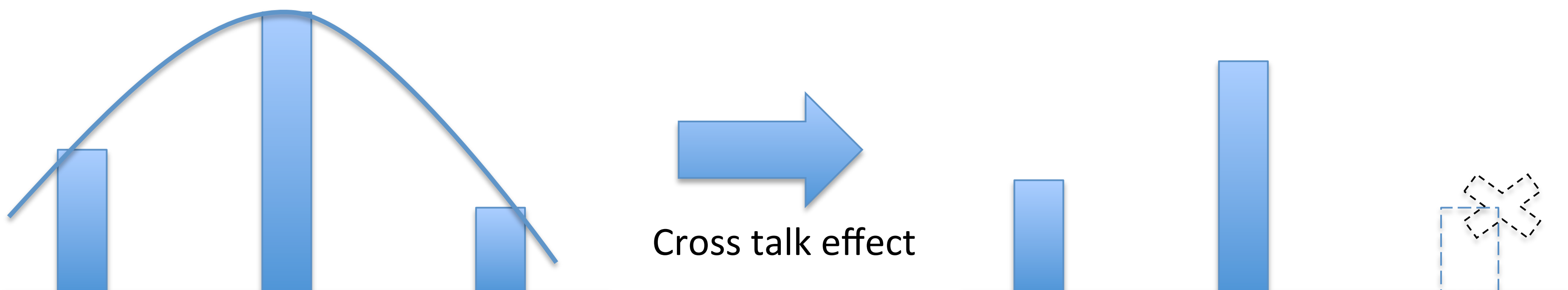


Cross Talk Effect





(Pic. by: Yoshi Imazu)

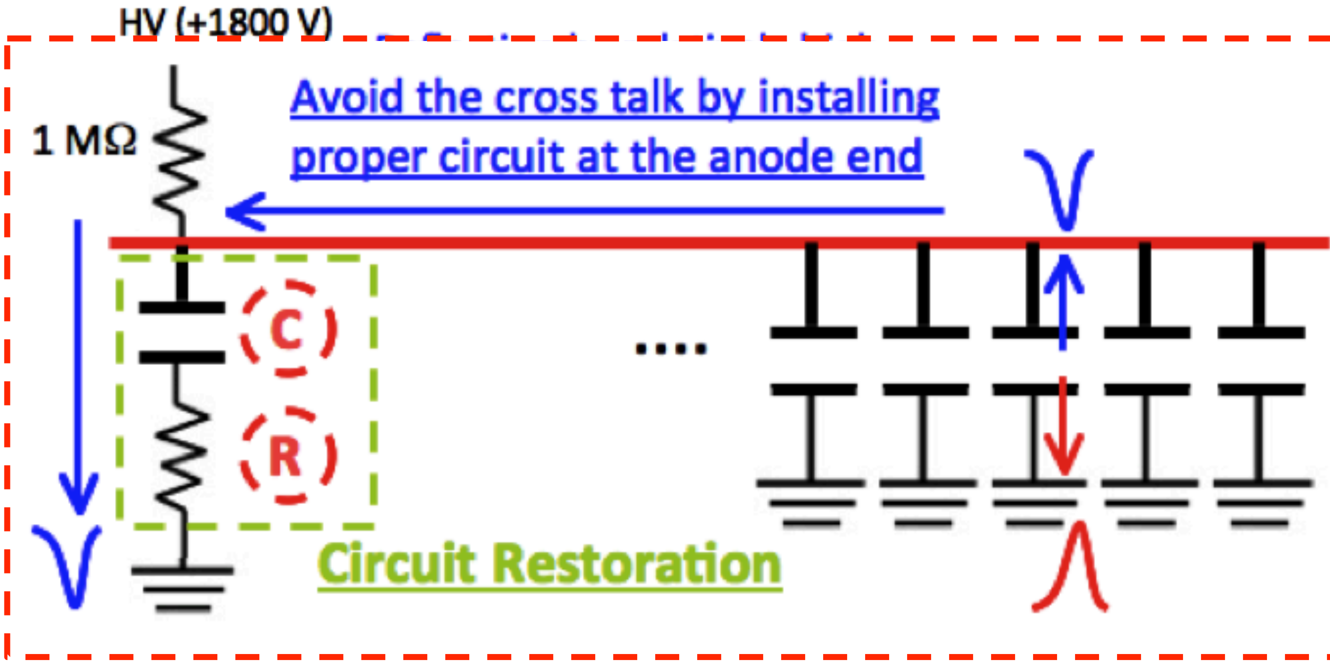


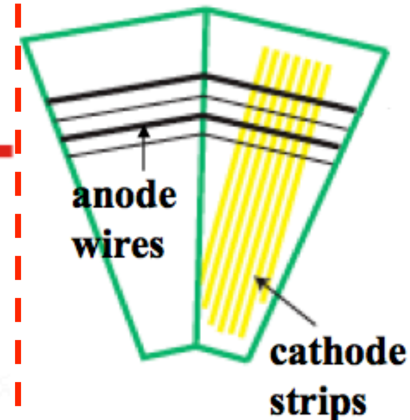
Three neighbor strips

Cross talk effect

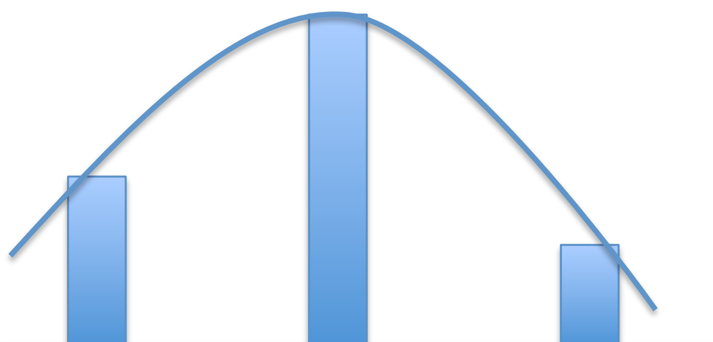
If we loose signal by negative signal..
→ can't know the exact position of particle (position resolution ↓)

Solution



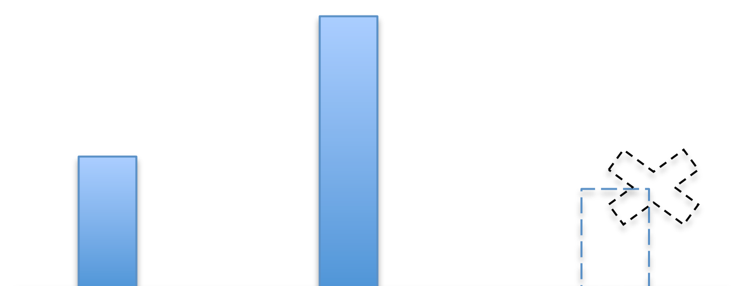


(Pic. by: Yoshi Imazu)



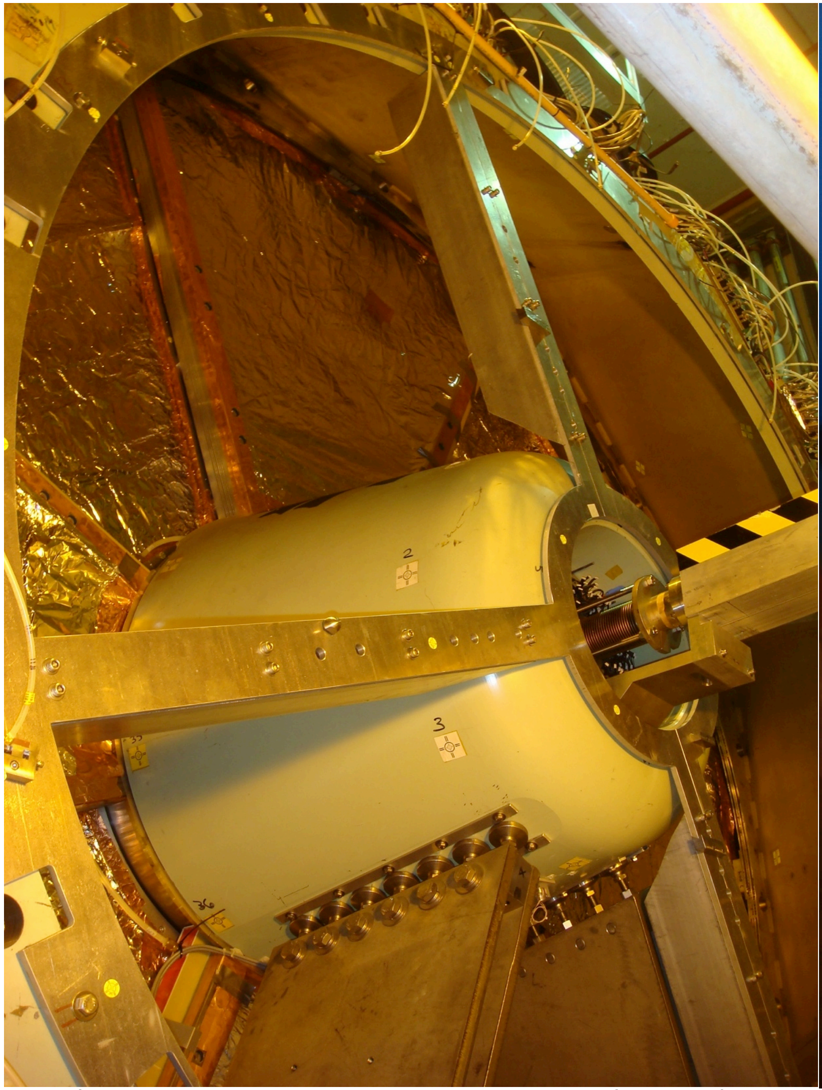
Three neighbor strips

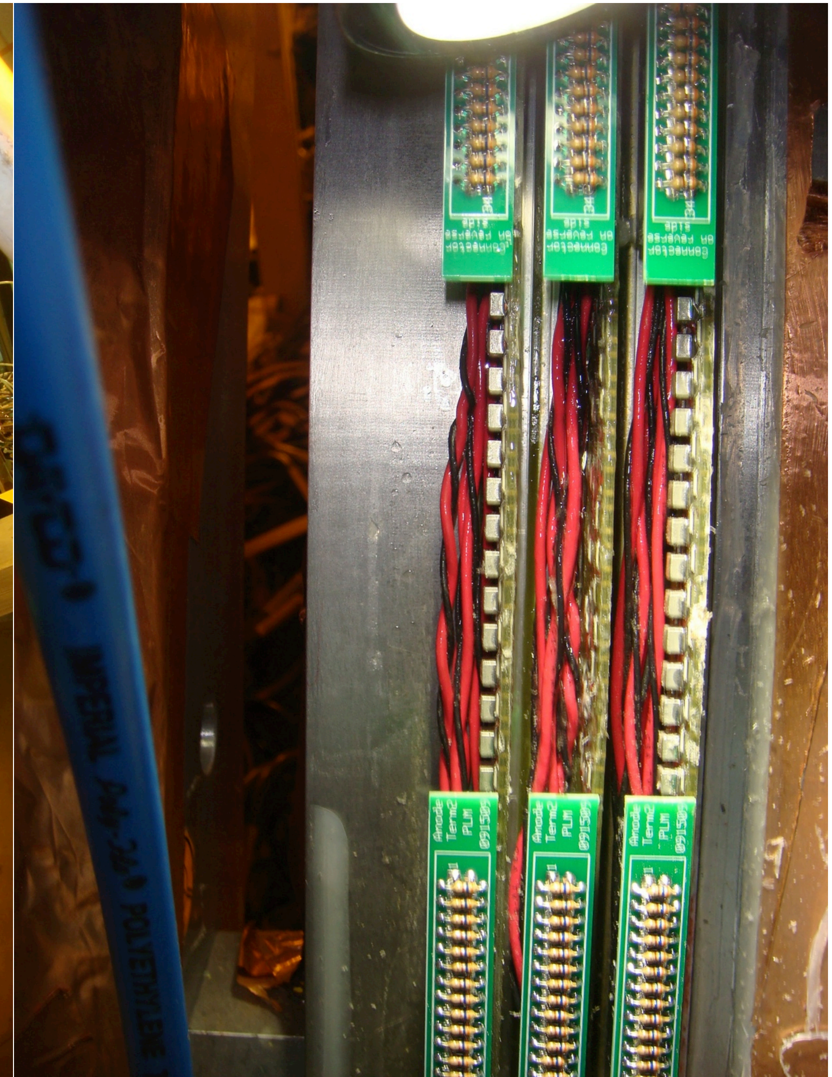
Cross talk effect



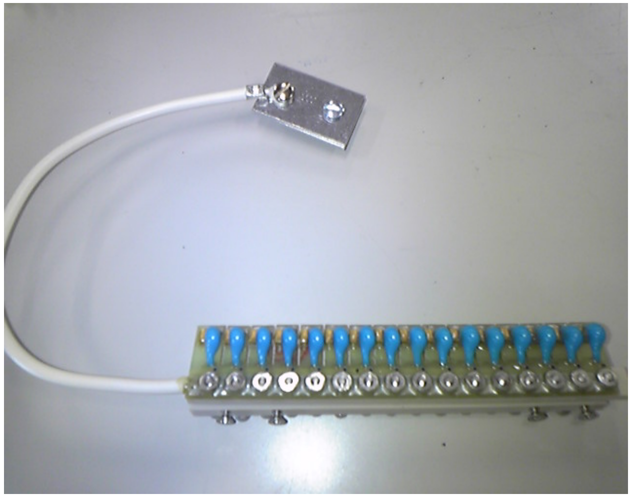
If we loose signal by negative signal..
→ can't know the exact position of particle (position resolution ↓)

South Station2 Recap.

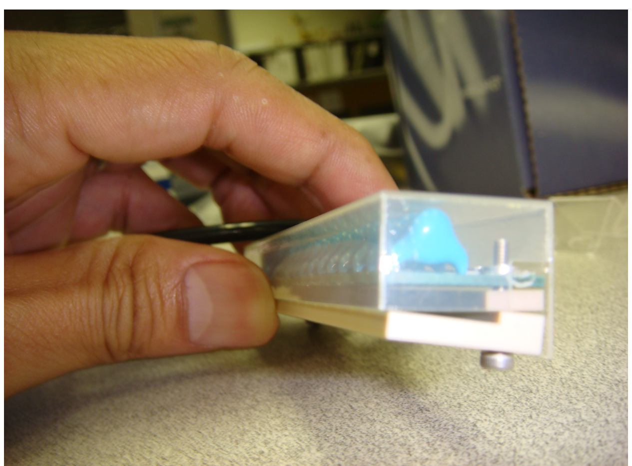




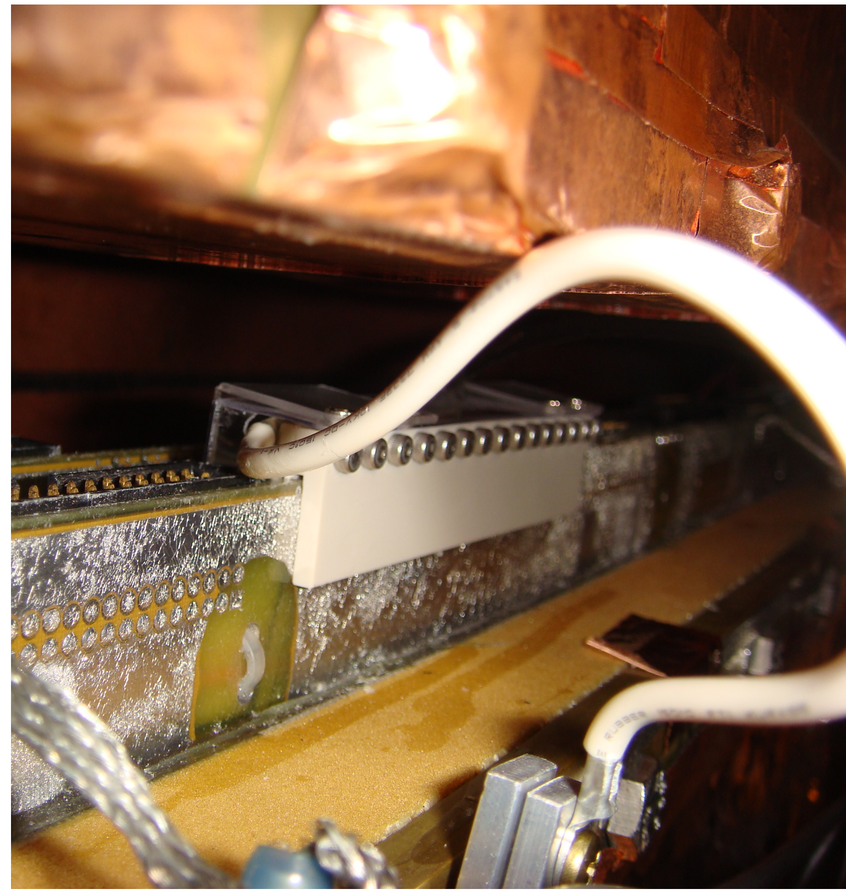
Station3 Recapacitation – Clamp Structure



clamp



Clamp w/ dry air cover



Installation to the anode card