PHENIX *W* Measurements

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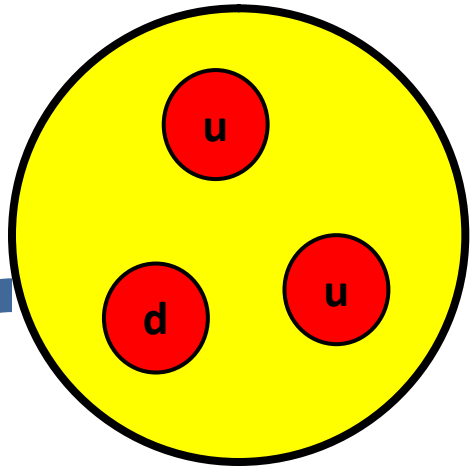
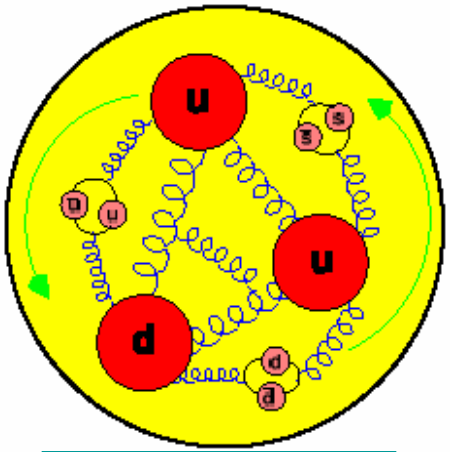
Proton Structure





Spin ½ quarks
Spin ½ anti-quarks
Spin 1 gluons

❖With three valence quarks:

- We understand
  - ➢Charge
- What about proton spin?
  - ➢Quark spin = ½

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma$$

quark spin

Spin Crisis: Quark Spin $\Delta\Sigma = 0.126 \pm 0.01 \pm 0.015$
only ~ 13% of proton spin carried by quarks!
EMC: Nucl. Phys. B 328, 1 (1989)

❖Proton = 3 valence quarks + sea quarks + gluons

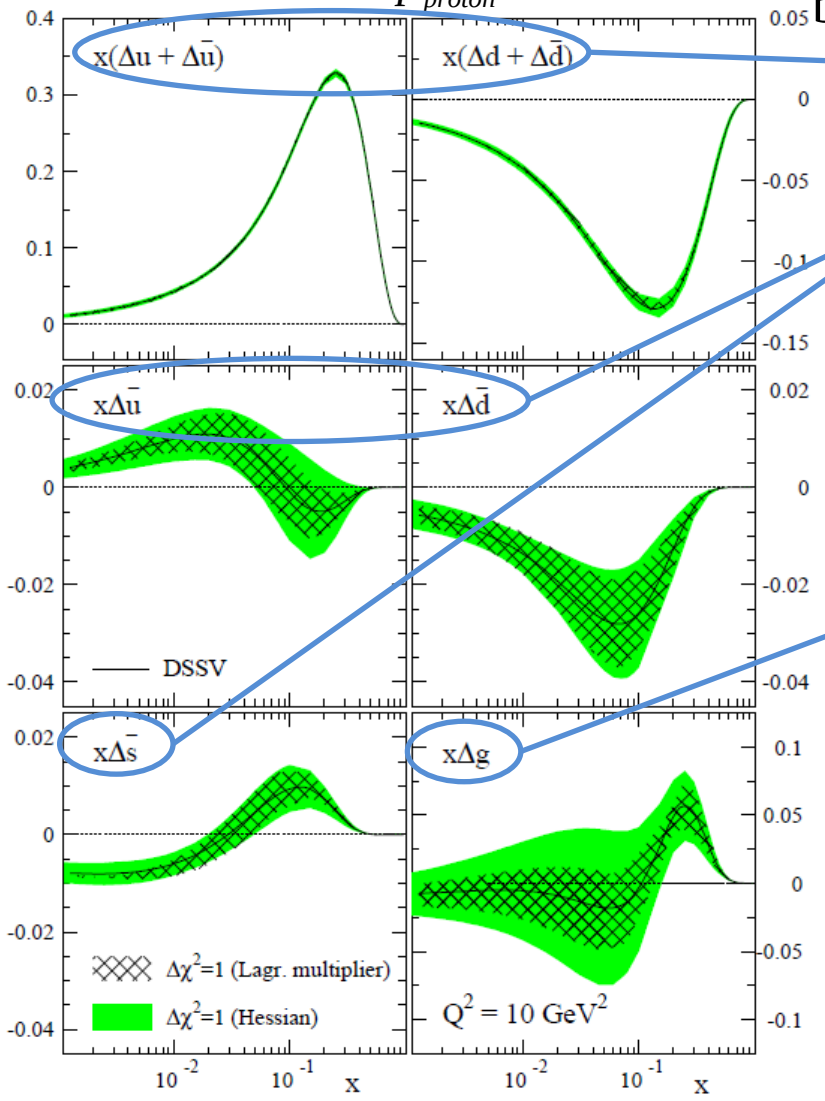
➢Momentum: carried by both quarks and gluons

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

valence + sea quark spin gluon spin orbital angular momentum

Quark and Gluon Distribution Functions

$$x = \frac{p_{quark}}{p_{proton}}$$



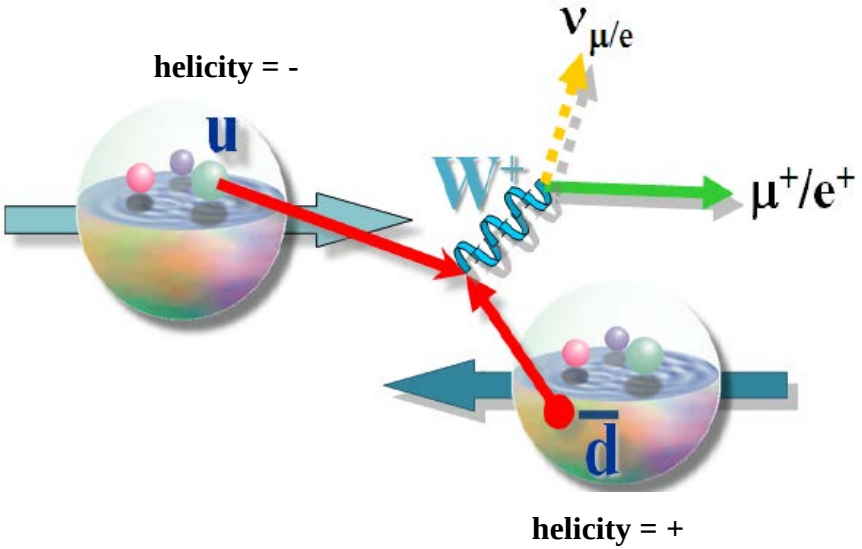
- Spin dependent quark distribution functions by the QCD analysis of (SI)DIS data
  - $\Delta q(x)$: well known
  - $\Delta \bar{q}(x)$: only known with large uncertainties
  - $\Delta\Sigma = 0.366 \pm 0.017$ for $Q^2 = 10$ and $0.001 \leq x \leq 1$
- Spin dependent gluon distribution function by the QCD analysis of (SI)DIS data
  - $\Delta g = 0.013 \pm 0.182$ for $Q^2 = 10$ and $0.001 \leq x \leq 1$ (possible large contributions at small x)

- The latest extraction of polarized parton distributions (DSSV):
  D. de Florian, R. Sassot, M. Stratmann, W. Vogelsang, Phys. Rev. D 80, 034030 (2009)

Parity Violating *W* Production

PHENIX

- *W* boson production in *p*+*p* collisions
  - **Large scale (~m_W) and independent of knowledge of fragmentation**
    - **clean interpretation of the results in hard scattering QCD framework**
  - **Parity violation of the weak interaction and u- and d-quark polarizations in proton**
    - **control over helicity states of colliding partons**
  - **Forward/backward muons**
    - **flavor separation**
  - **Experimental issues of $W \rightarrow$ lepton**
    - **need good control of backgrounds at high p_T**
      - **incorrectly reconstructed high p_T, cosmic rays, beam background**



Single spin asymmetry for W^+

$$A_L^{w^+} = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}$$

$$x_a >> x_b : A_L^{W^+} \approx \frac{-\Delta u}{u}\,(y^W >> 0)$$

$$x_b >> x_a : A_L^{W^+} \approx \frac{-\Delta\bar{d}}{\bar{d}}\,(y^W << 0)$$

- Asymmetry measurement of *W* boson production is ideal method
  - **High luminosity and longitudinally polarized *p*+*p* collisions at 500 GeV (integrated L = 300 pb^{-1}, polarization = 60%)**

PHENIX Detector

PHENIX

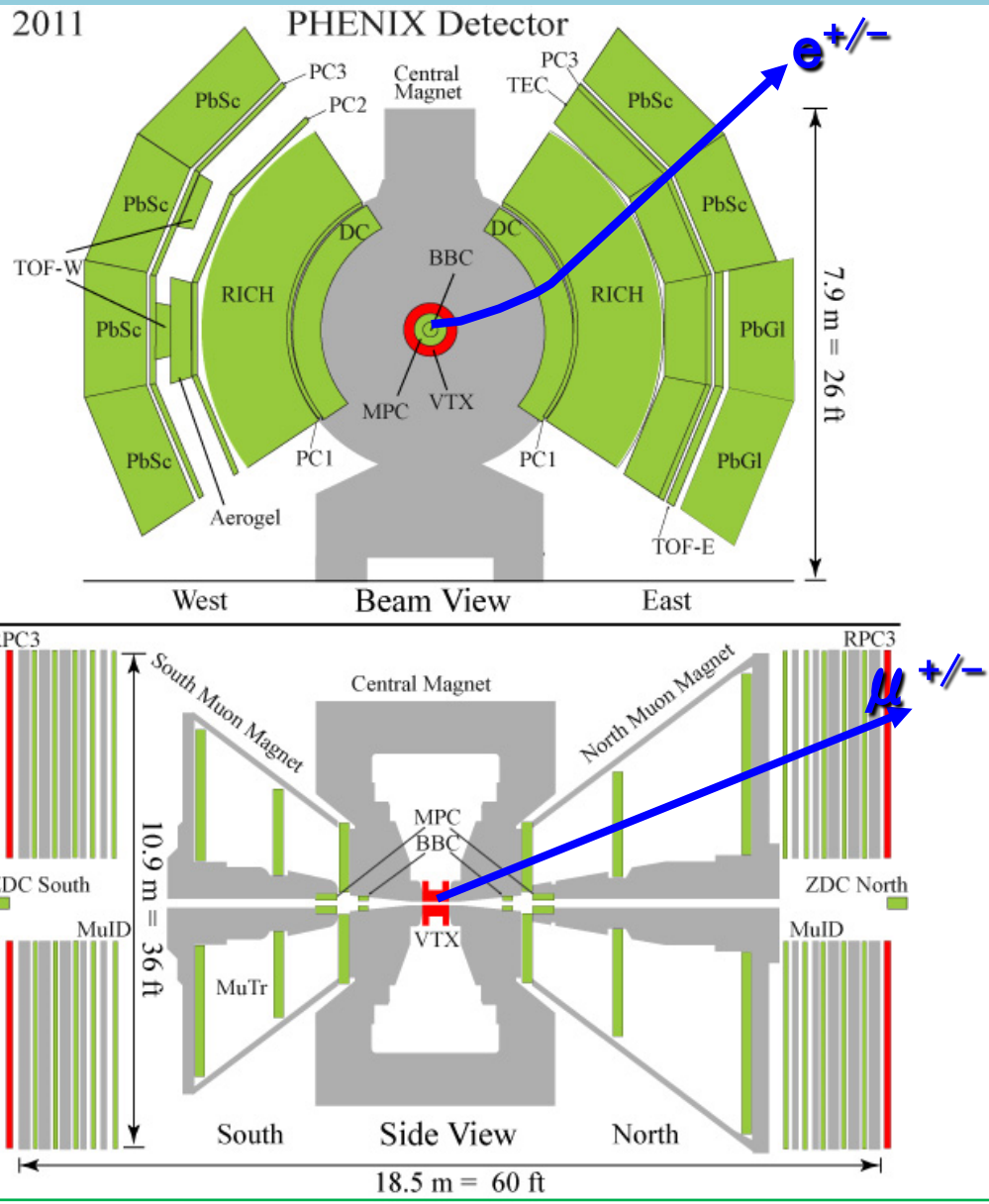
Philosophy (initial design):

- ✓ High rate capability & granularity
- ✓ Good mass resolution & particle ID
- ➢ Sacrifice acceptance

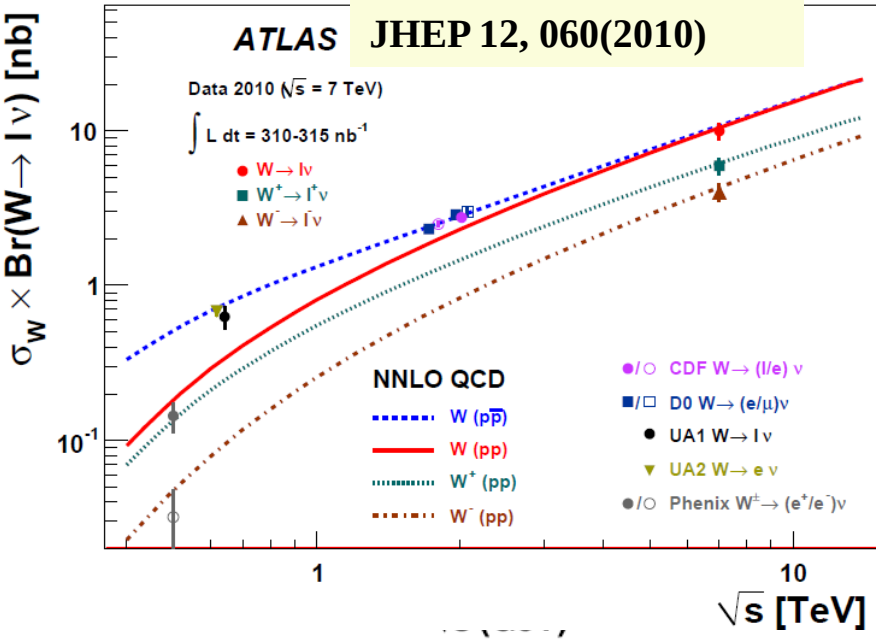
Central Arms:
- **hadrons, photons, electrons**
- **$|\eta| < 0.35$**
- **$\Delta\varphi = \pi$ (2 arms x $\pi/2$)**

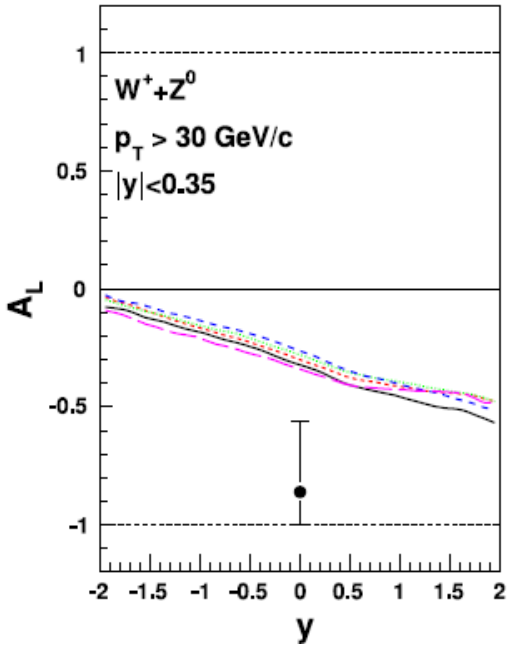
Global Detectors:
- **Beam-Beam Counter (BBC)**
- **Zero Degree Calorimeter (ZDC)**

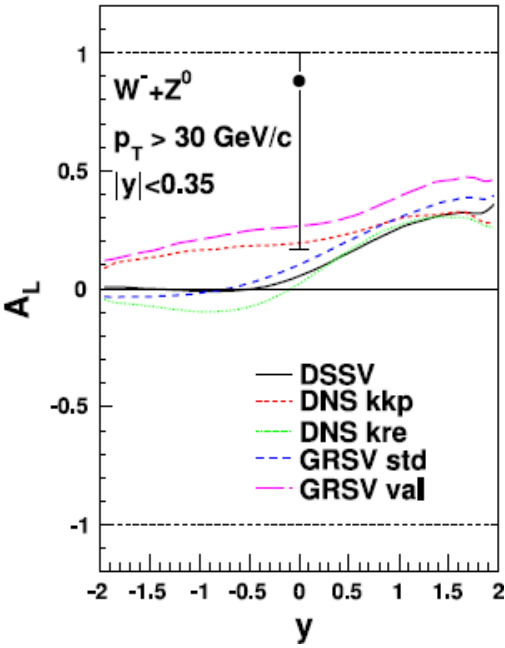
Muon Arms:
- **muons**
- **$1.2 < |\eta| < 2.2$**
- **$\Delta\varphi = 2\pi$**



Single Spin Asymmetry of *W* at RHIC Run-9







PHENIX Collaboration: Phys. Rev. Lett. 106, 062001(2011)

$$\sigma(pp \to W^+X) \times \mathrm{BR}(W^+ \to e^+\nu_e) = 144.1 \pm 21.2(\mathrm{stat})^{+3.4}_{-10.3}(\mathrm{syst}) \pm 21.6(\mathrm{norm})\ \mathrm{pb}$$

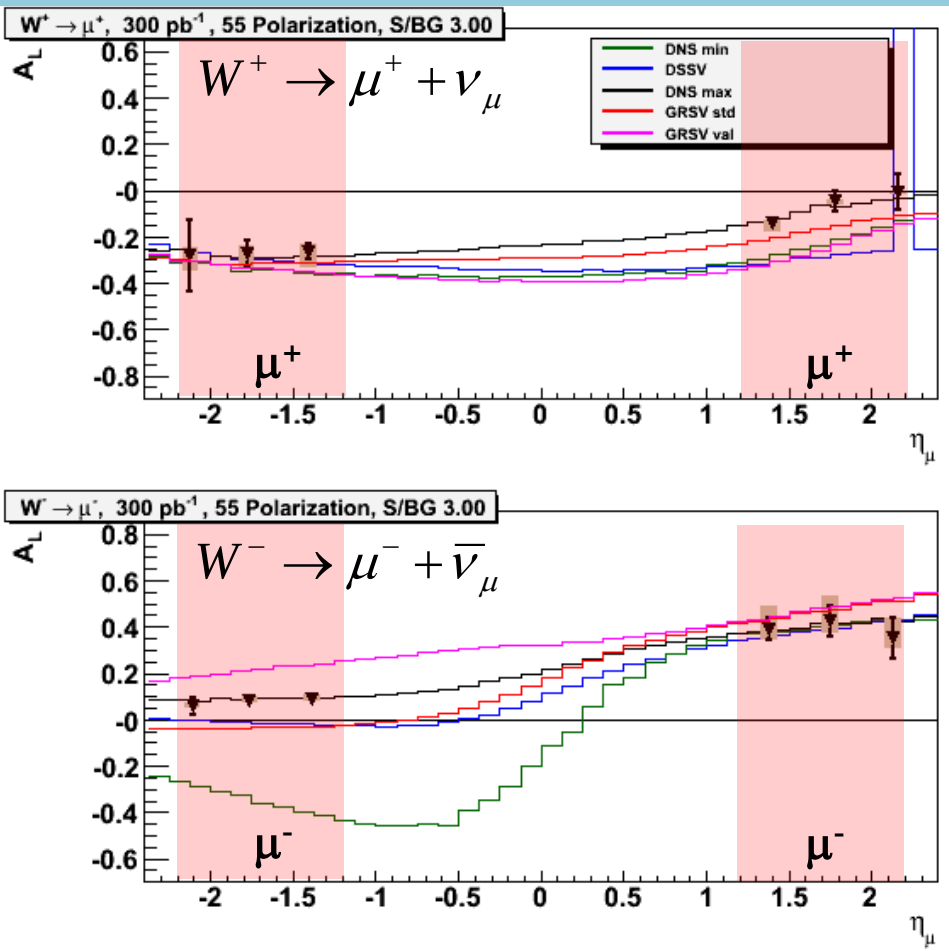
$$\sigma(pp \to W^-X) \times \mathrm{BR}(W^- \to e^-\bar{\nu}_e) = 31.7 \pm 12.1(\mathrm{stat})^{+10.1}_{-8.2}(\mathrm{syst}) \pm 4.8(\mathrm{norm})\ \mathrm{pb}$$

- Good agreement between PHENIX and ATLAS data and NNLO pQCD calculations
- At 8.6 pb^{-1} with average polarization 0.39±0.04, we get

$$A_L^{e^+} = -0.86^{+0.30}_{-0.14}$$
$$A_L^{e^-} = 0.88^{+0.12}_{-0.71}$$

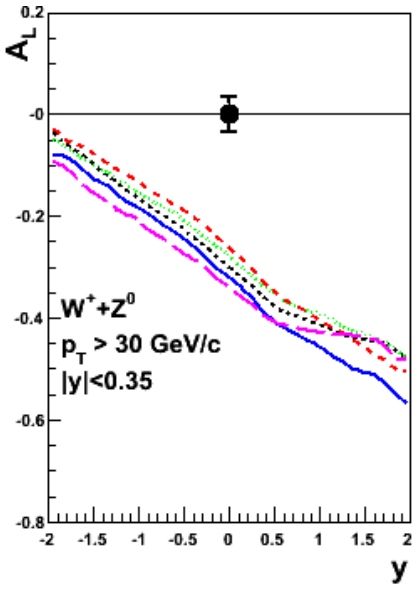
- Asymmetry is corrected for dilution by QCD backgrounds

Expected Single Spin Asymmetry of *W* in the PHENIX Acceptance

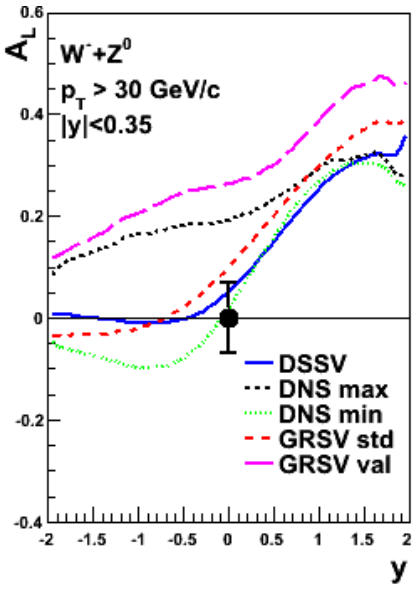


A_L for inclusive high p_T leptons for $\int Ldt = 300 pb^{-1}$, $P = 0.55$

$W^+ \rightarrow e^+ + \nu_e$



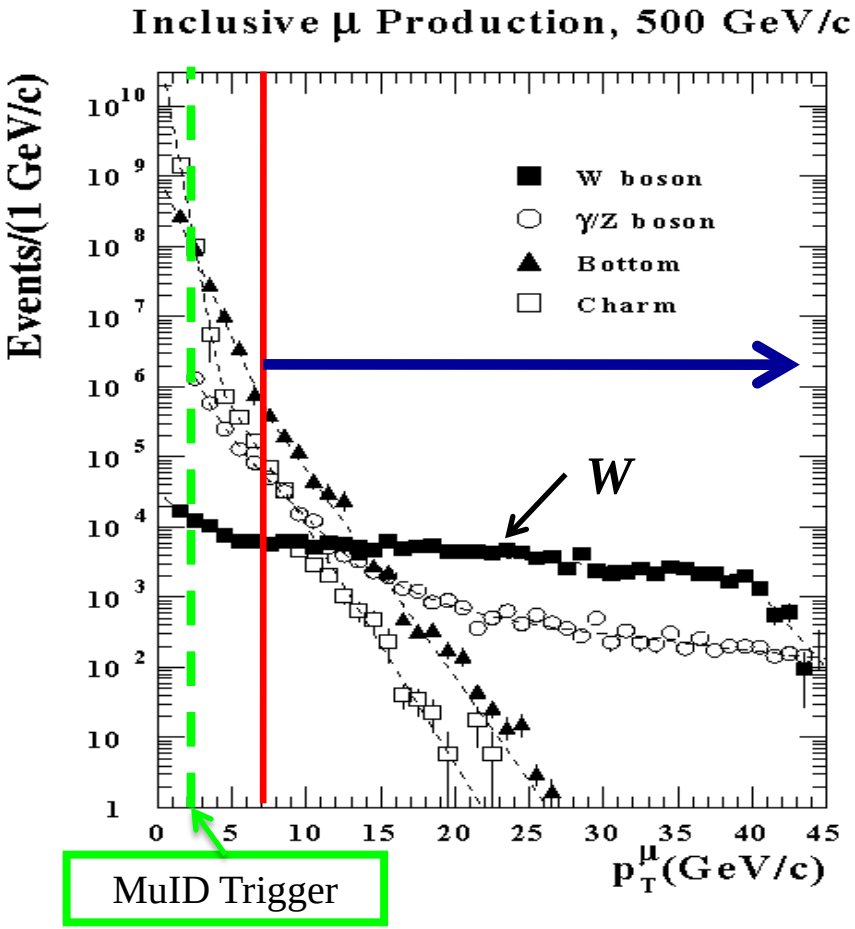
$W^- \rightarrow e^- + \bar{\nu}_e$



- Central Arms: *W* measurement at RHIC Run-9
- Muon Arms: Forward muon trigger upgrade is ongoing and ready for RHIC Run-11

W Measurements at PHENIX Muon Arms

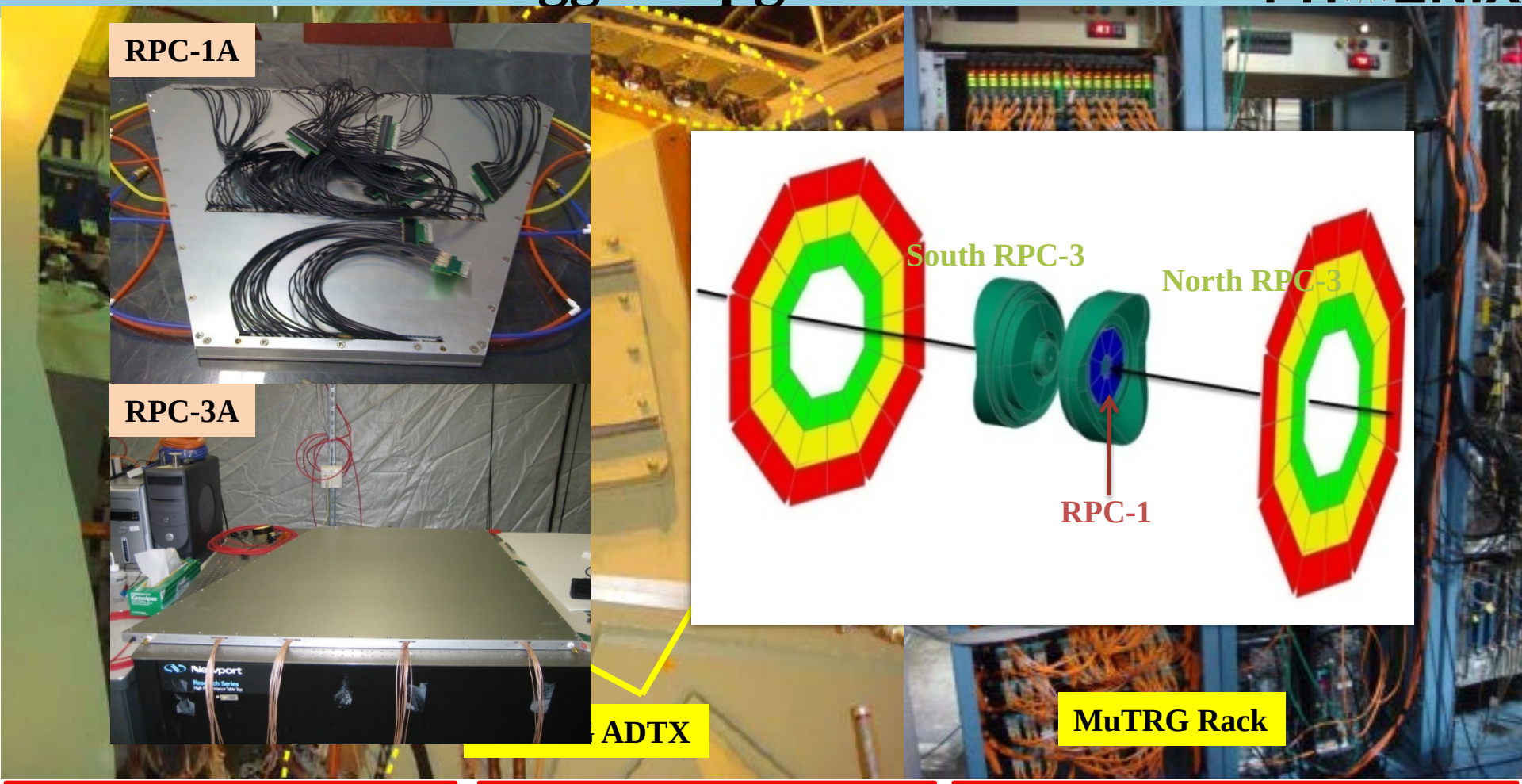
simulated muons into Muon Arms (2000 pb^{-1}, with PYTHIA 5.7)



- In order to measure *W* at 500 GeV, we need a first level trigger rejection of a factor 10000
- The current MuID trigger accepts muons above 2 GeV/*c* and current DAQ cannot take full rate at 500 GeV

  - **We need a momentum sensitive muon trigger and fast readout electronics for muon tracker**
    - ✓**NSF funded trigger RPC stations**
    - ✓**JSPS funded MuTr front end electronics**
  - **Additional RPC and MuTr information in the trigger makes it possible to measure the sagitta of charged particles online**
  - **The upgraded first level trigger will select events with muons of high transverse momentum $p_T \geq 7$ GeV/*c* from *W* boson decay**

PHENIX Muon Trigger Upgrade



MuID Trigger (existing): Selecting momentum above 2 Gev/*c*

MuTRG (fully installed): Fast selection of high momentum tracks

RPC (being installed): Provide timing information and rough position information

PHENIX Muon Trigger Upgrade

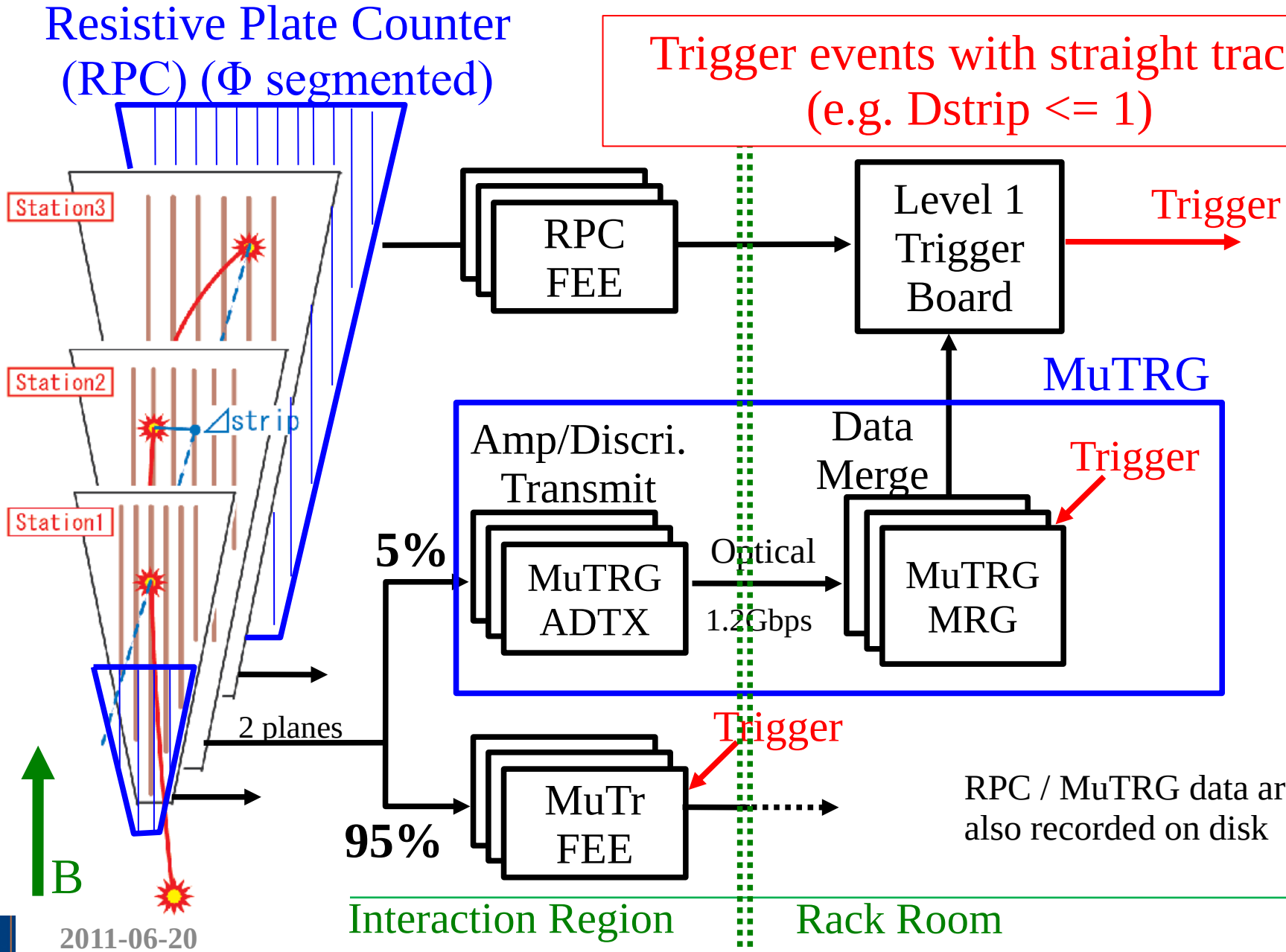
Installed:
November 2009
Integrated:
June 2010

North

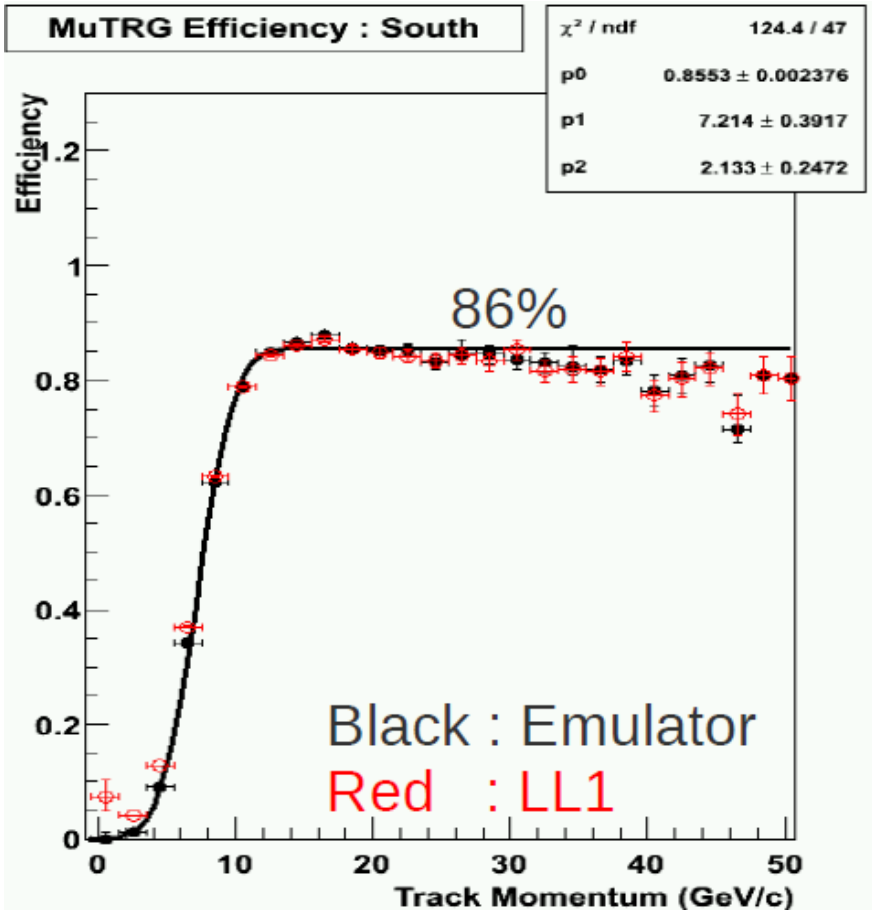
Installed:
September 2010
Integrated:
December 2010

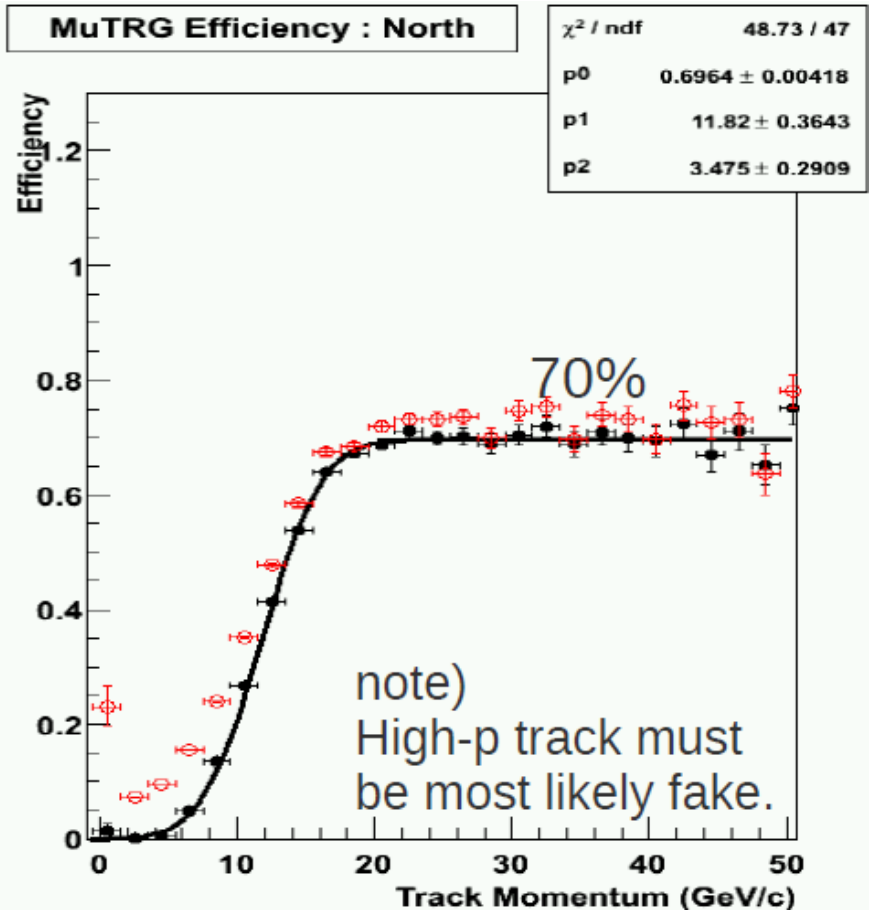
South

PHENIX Muon Trigger Upgrade



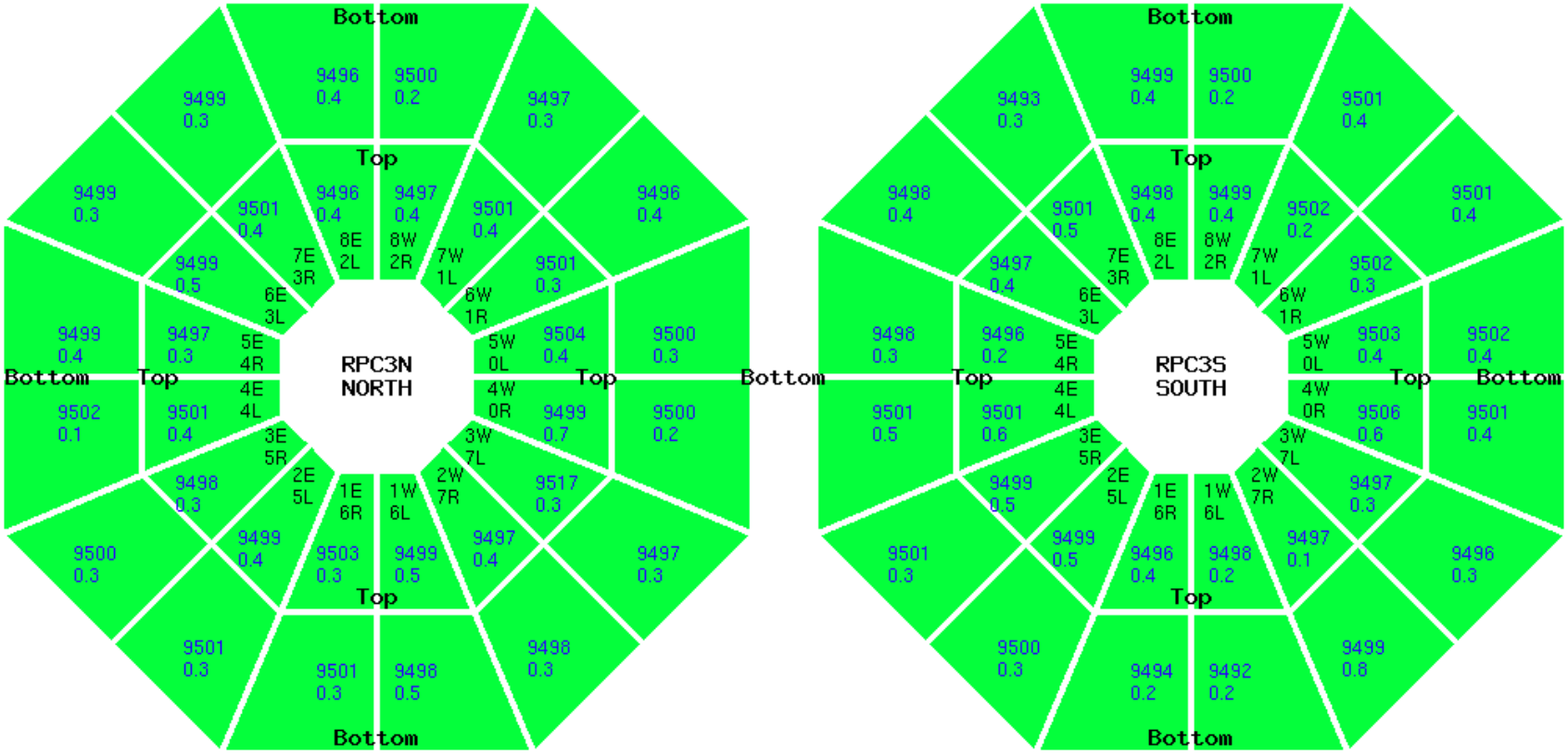
MuTrg Efficiency





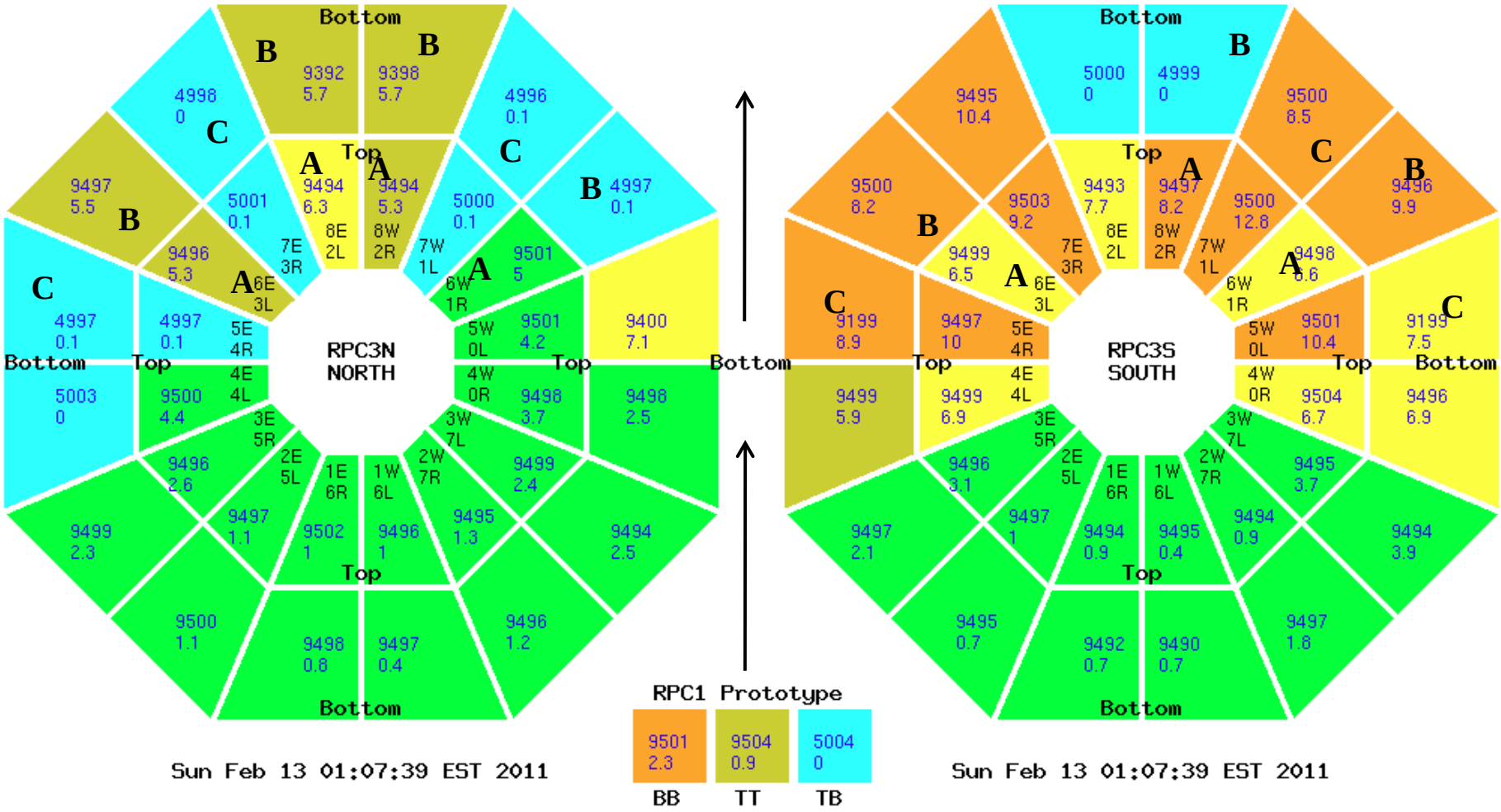
- Clustering : Inefficiency ~ 5%
- Need to understand North/South difference
- Need (LL1 efficiency) && (Track-by-track matching in emulator)
- Possible inefficiency due to fake track must be evaluated

RPC-3 HV Stability (Without Beam)



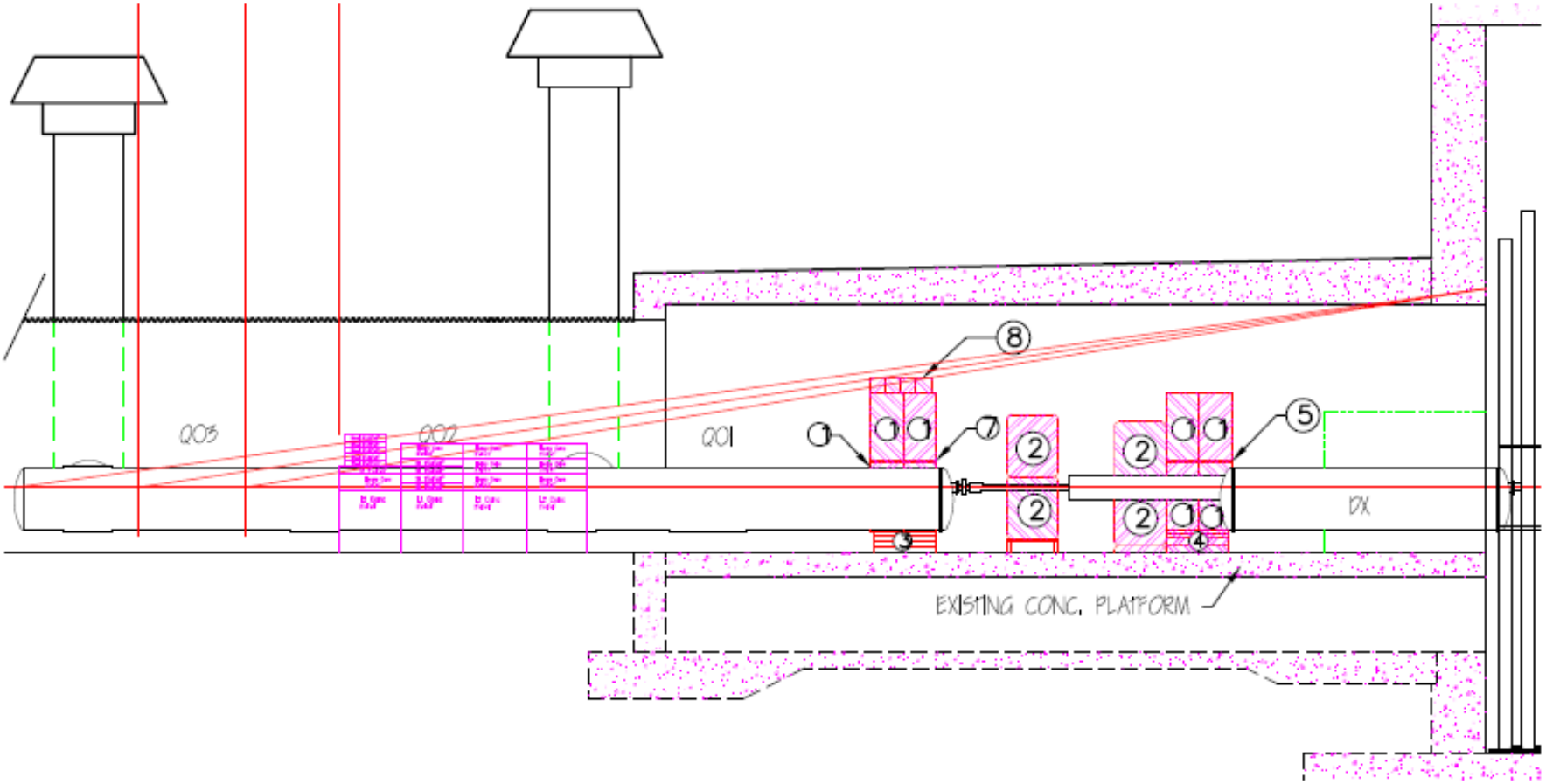
- RPC gas started to flow from the end of Dec. 2010
- All RPC-3 (192 gas gaps) has been operated without problem
  - RPC-3 South since February 17th
  - RPC-3 North since March 2nd

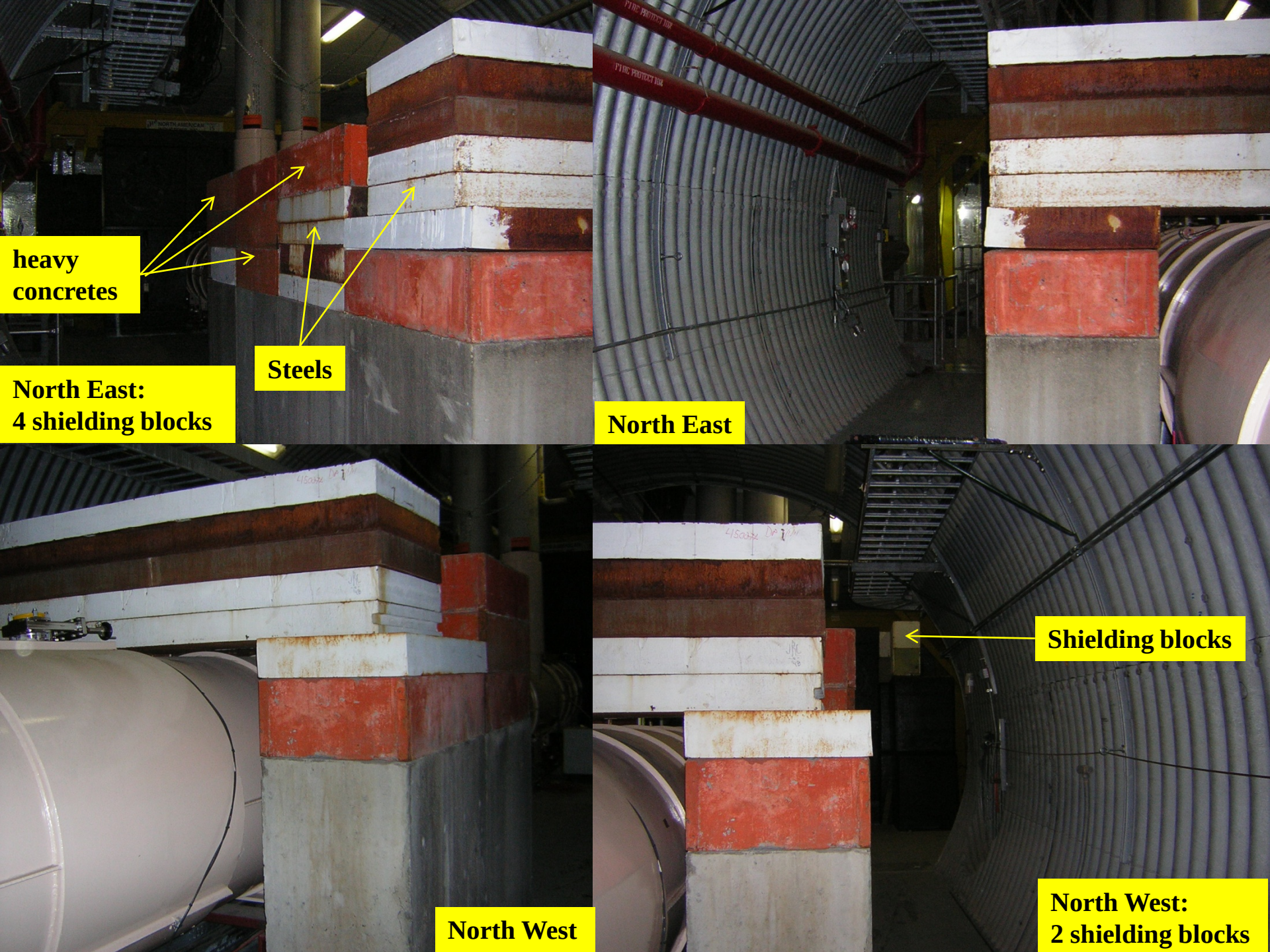
RPC-3 HV Stability (Under Beam)



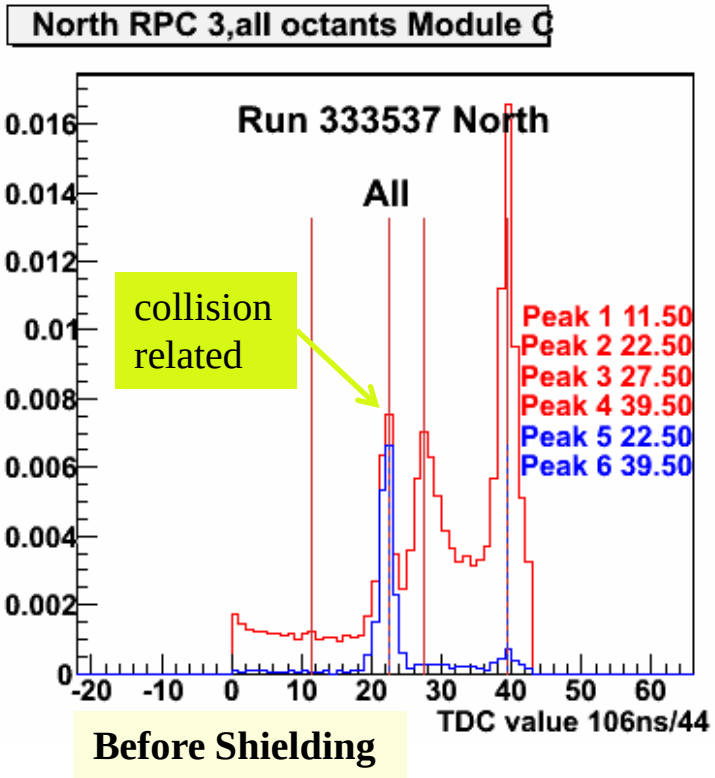
- When beam background above 1E+6 counts/sec., RPC tripped during ramping up HV
- At beam background ~ 5E+5 counts/sec., RPC drove high current but still be able to operate
- RPC suffers large beam background

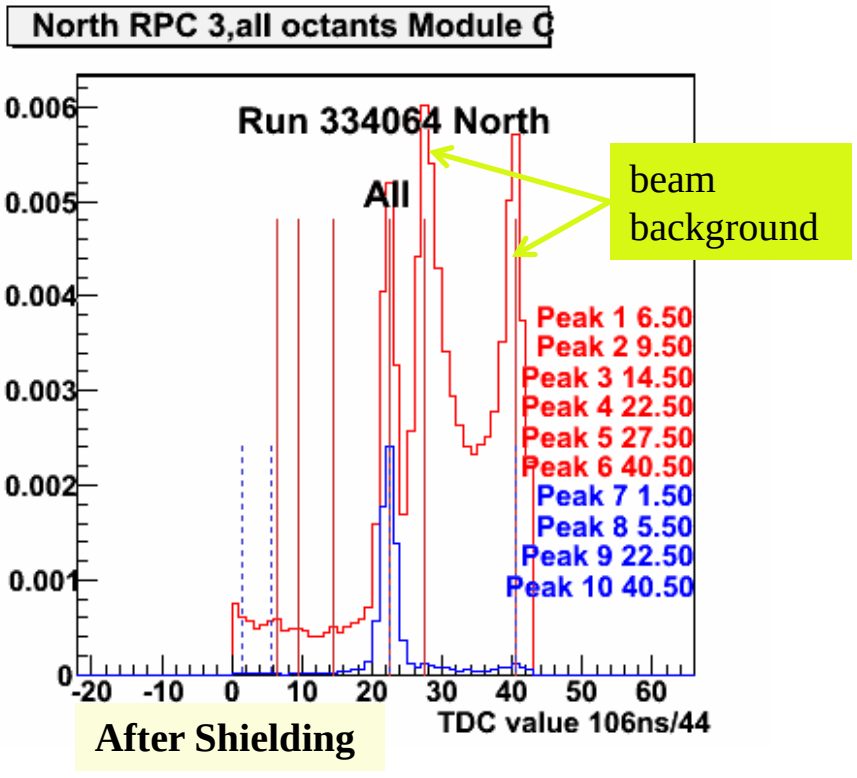
Adding More Shielding




heavy concretes
Steels
North East: 4 shielding blocks
North East
North West
Shielding blocks
North West: 2 shielding blocks

Effect of Additional Shielding

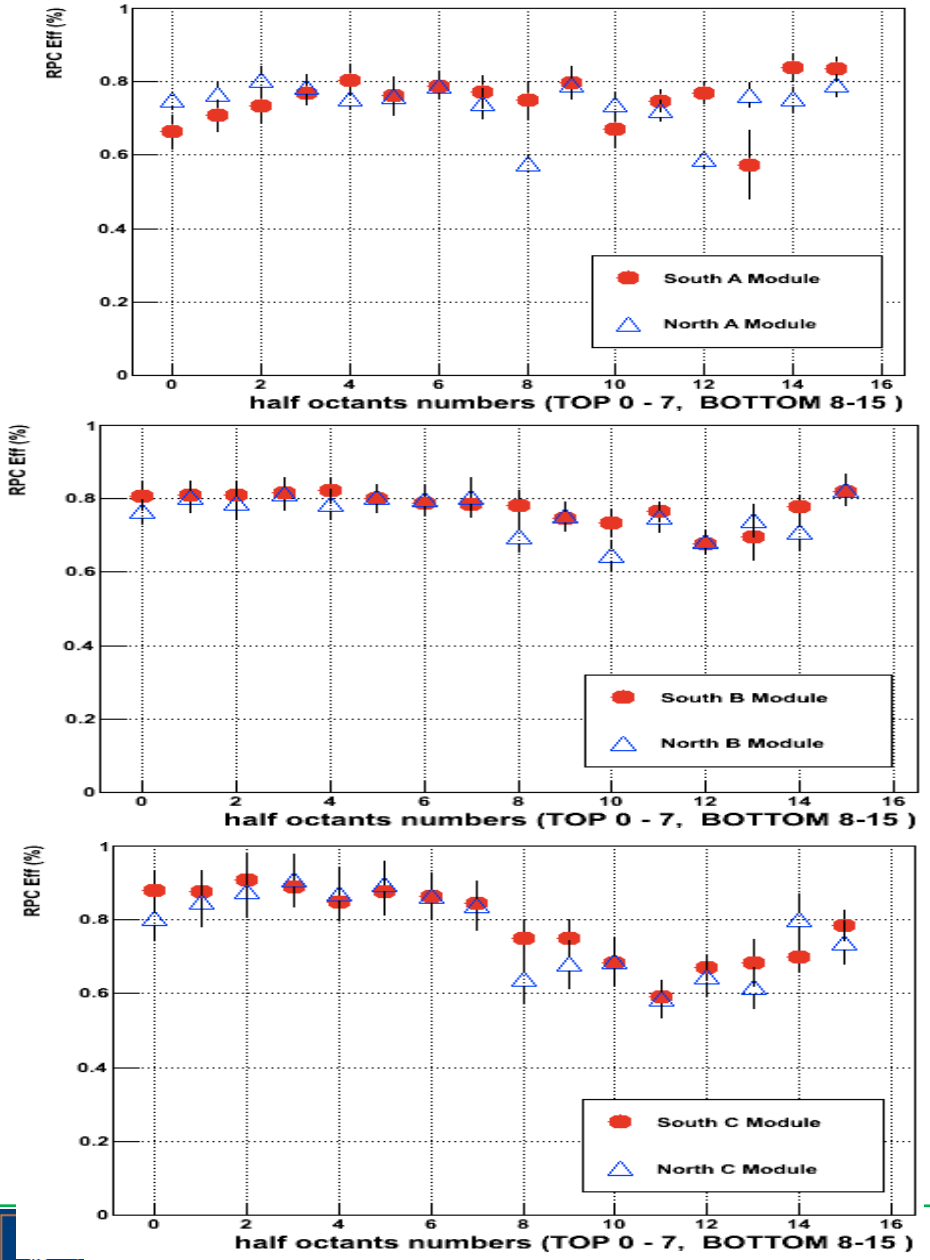




- **Plots are scaled with total amount of muons**
- **All RPC hits from all of most outer radial detectors in one arm**
- **RPC hits associated with MuTr tracks**

- **Able to switch on earlier**
- **Significant improvement of MuID rates → rejections up**
- **Still sizeable background remaining → update shielding during upcoming shutdown**

RPC-3 Efficiency during RHIC Run-11

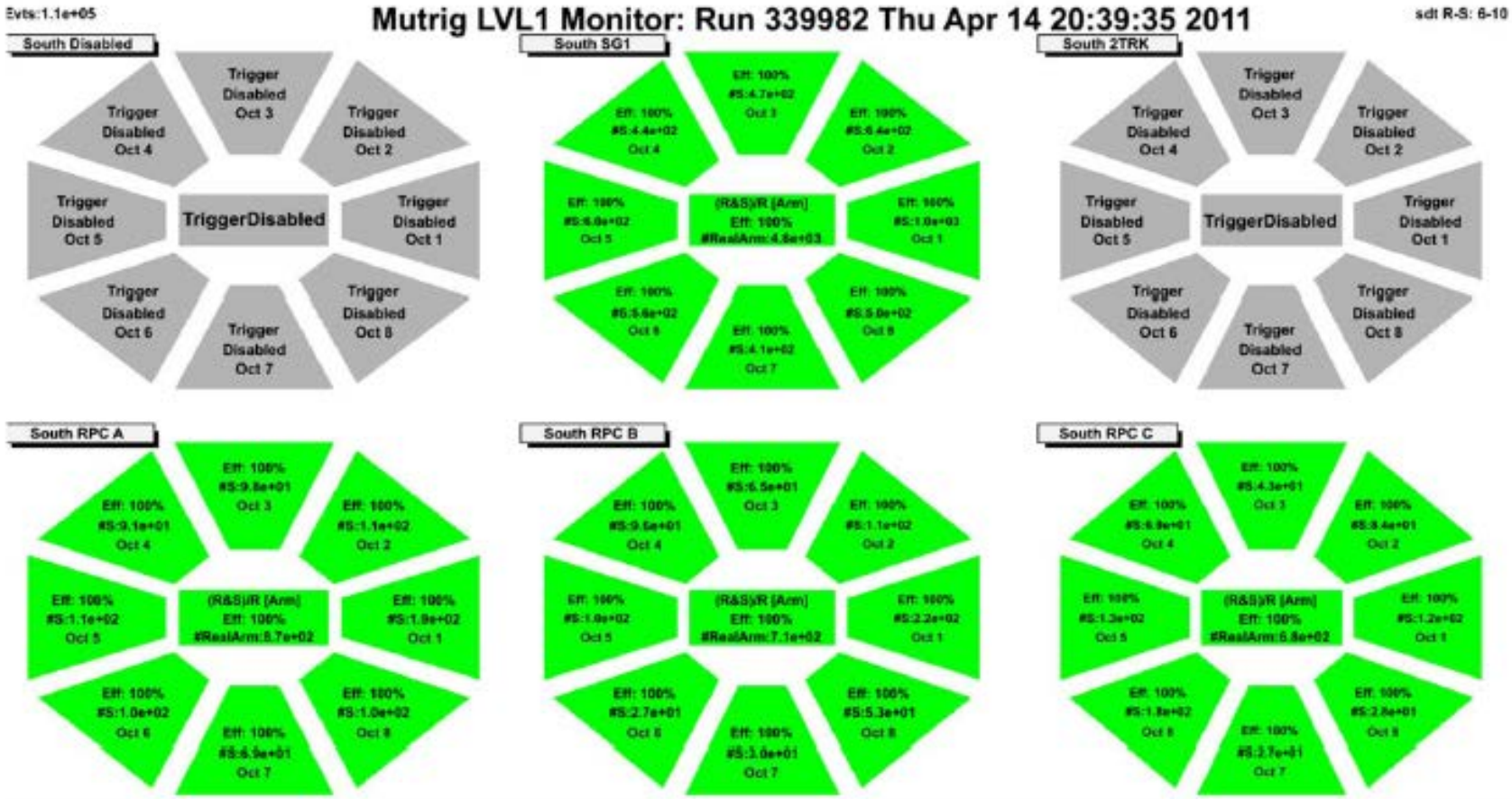


- Before March 21st , there were initial issues with the gas composition/mixing system
- New gas analysis result after gas tuning
  - R134a/Isobutane/SF6 = 94.8517%/4.6167%/0.5316%
    - Very close to real RPC gas mixture what we need (95%/4.5%/0.5%)

- Data after March 21st can be used for *W* analysis
  - Total: 30 pb^{-1} without vertex cut
  - 25 pb^{-1} with MuTrg & RPCs

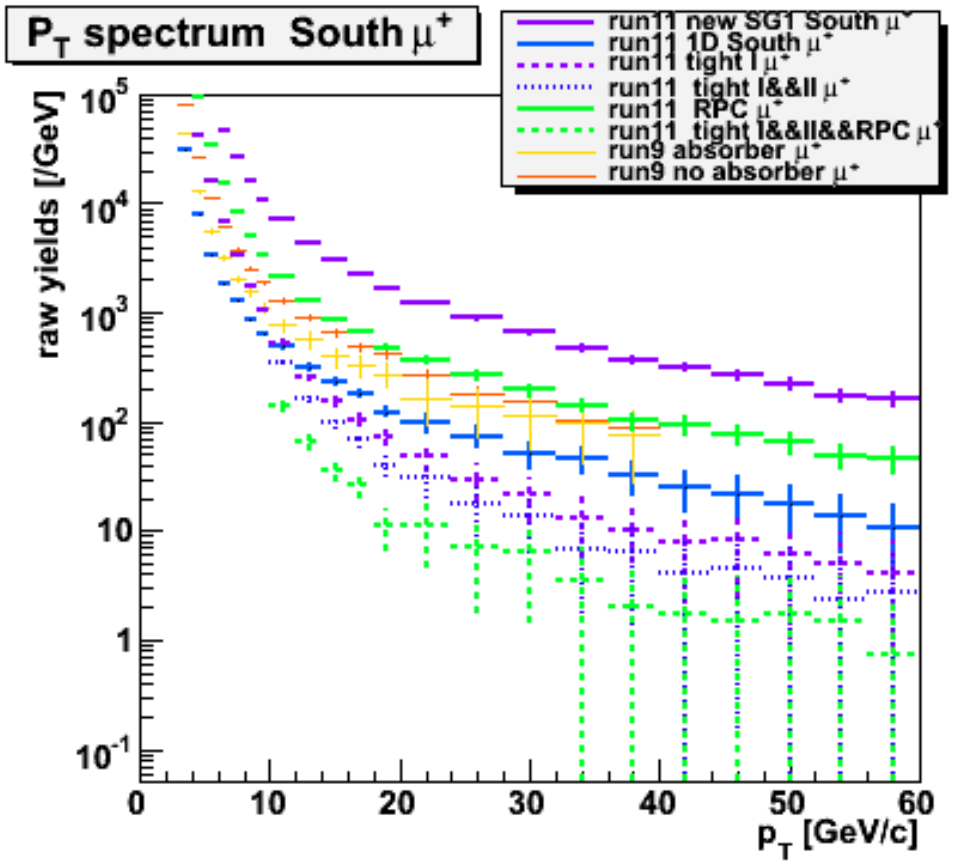
- Need to recalibrate power supply at control unit
- Need to redistribute gas panels and lines

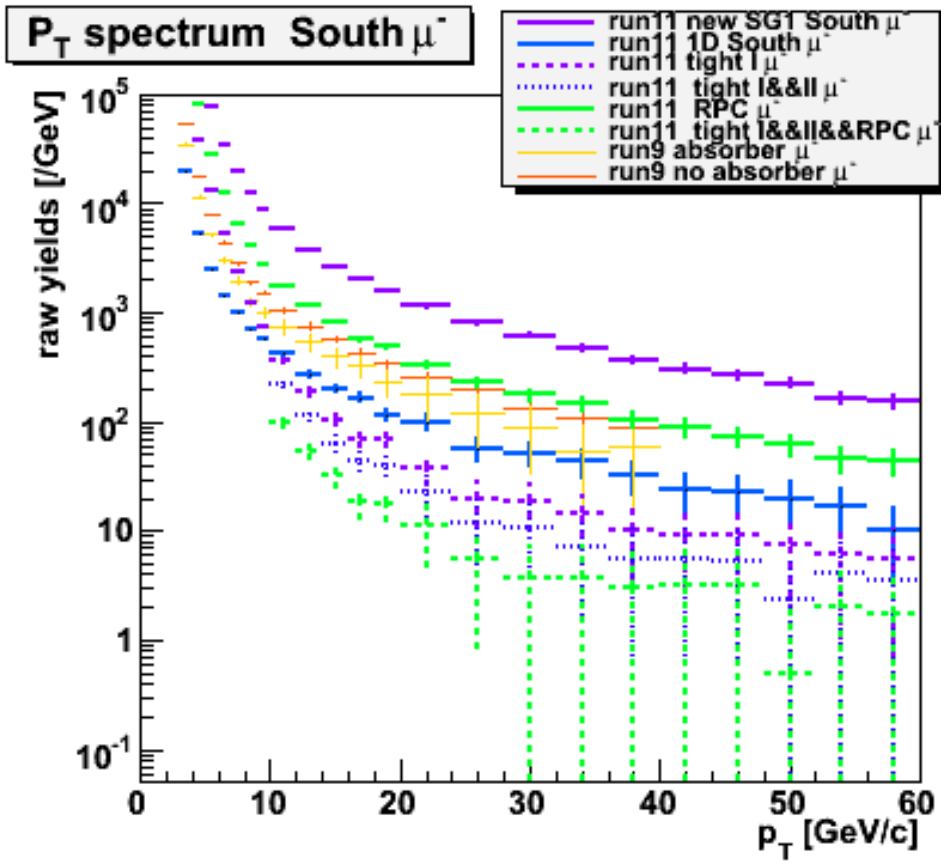
Muon Trigger Peformance



- Muon Trigger with RPCs working nicely
- Timing shift from RPCs happens from time to time
  - Try to find out where is the origin of the problem → could be LV system or one of trigger electronics
  - We use large timing window for collision related muon caused limit of rejection

Single Muon Analysis





- Raw Yields for different triggers
- Applied different level of cuts

- More raw yields in SG1 triggers (magenta) than 1D triggers (blue)
- Absorber effect already visible in raw distributions

Summary

PHENIX

- Flavor decomposed proton quark polarization can be probed using the single spin asymmetry of W^+ and W^- in longitudinally polarized $p+p$ collisions

- During RHIC Run-11, PHENIX MuTrg & RPC are commissioned

- 500 GeV $p+p$ collision data taking is finished and W analysis is ongoing

- Future improvement
  - RPC-3 efficiency can be increased by modification of gas system
  - Narrow RPC-3 timing window and better shielding will bring more rejection power
  - RPC-1 station will be installed during upcoming shutdown
  - RPC-1 will give us more timing and hit information
    - provide further rejection