W Physics in Polarized Proton-Proton Collisions at PHENIX

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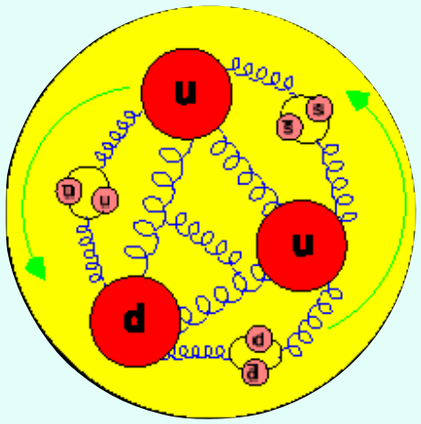
Physics Motivation



spin 1/2 quarks
spin 1/2 anti-quarks
spin 1 gluons

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

valence + sea quark spin — gluon spin — angular momentum

- Spin dependent quark distribution functions by the QCD analysis of (SI)DIS data

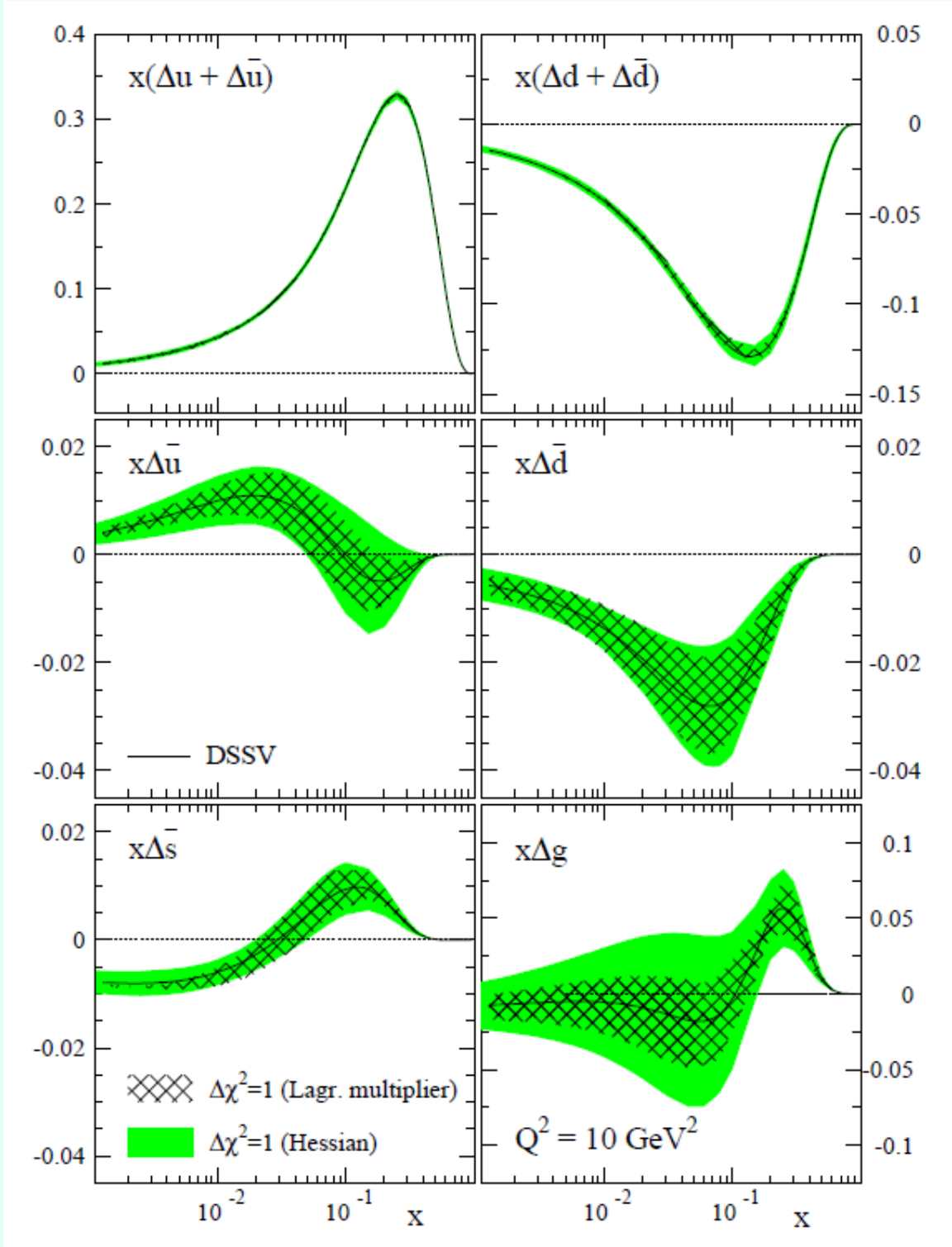
$\Delta q(x)$:well known

$\Delta\bar{q}(x)$:only known with large uncertainties

$\Delta\Sigma = 0.366 \pm 0.017$
for $Q^2 = 10$ and $0.001 \leqq x \leqq 1$

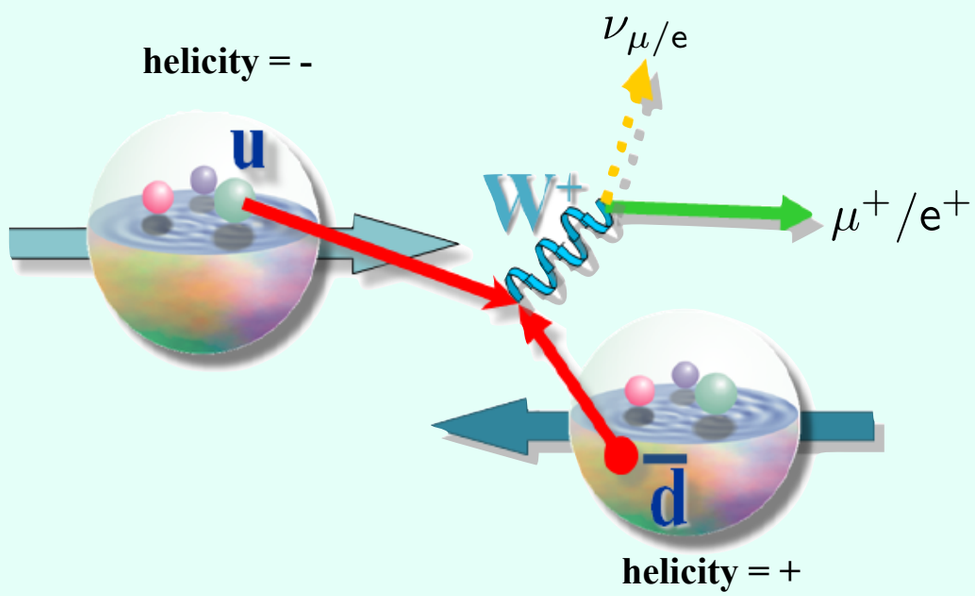
- Spin dependent gluon distribution function by the QCD analysis of (SI)DIS data

$\Delta g = 0.013 \pm 0.182$
for $Q^2 = 10$ and $0.001 \leqq x \leqq 1$
(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



Single spin asymmetry for W^+

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

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

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

- *W* boson production in $p + p$ collisions
  - ➡Parity violation of the weak interaction and u- & d-quark polarizations in proton
    - ▸control over helicity states of colliding partons
  - ➡Large scale (~ m_W) and independent of knowledge of fragmentation
    - ▸clean interpretation of the results in hard scattering QCD framework

- Asymmetry measurement of *W* boson production is ideal method
  - ➡Forward/backward muons
    - ▸flavor separation
  - ➡High luminosity and longitudinally polarized $p + p$ collisions at 500 GeV (Experimental goal to achieve: integrated $\mathscr{L}$ = 300 pb^{-1}, polarization = 60%)
  - ➡Experimental issues of $W \rightarrow$ lepton
    - ▸need good control of backgrounds at high P_T
      - -incorrectly reconstructed high P_T, cosmic rays, beam background

PHENIX Detector

Philosophy (initial design):

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

Central Arms:

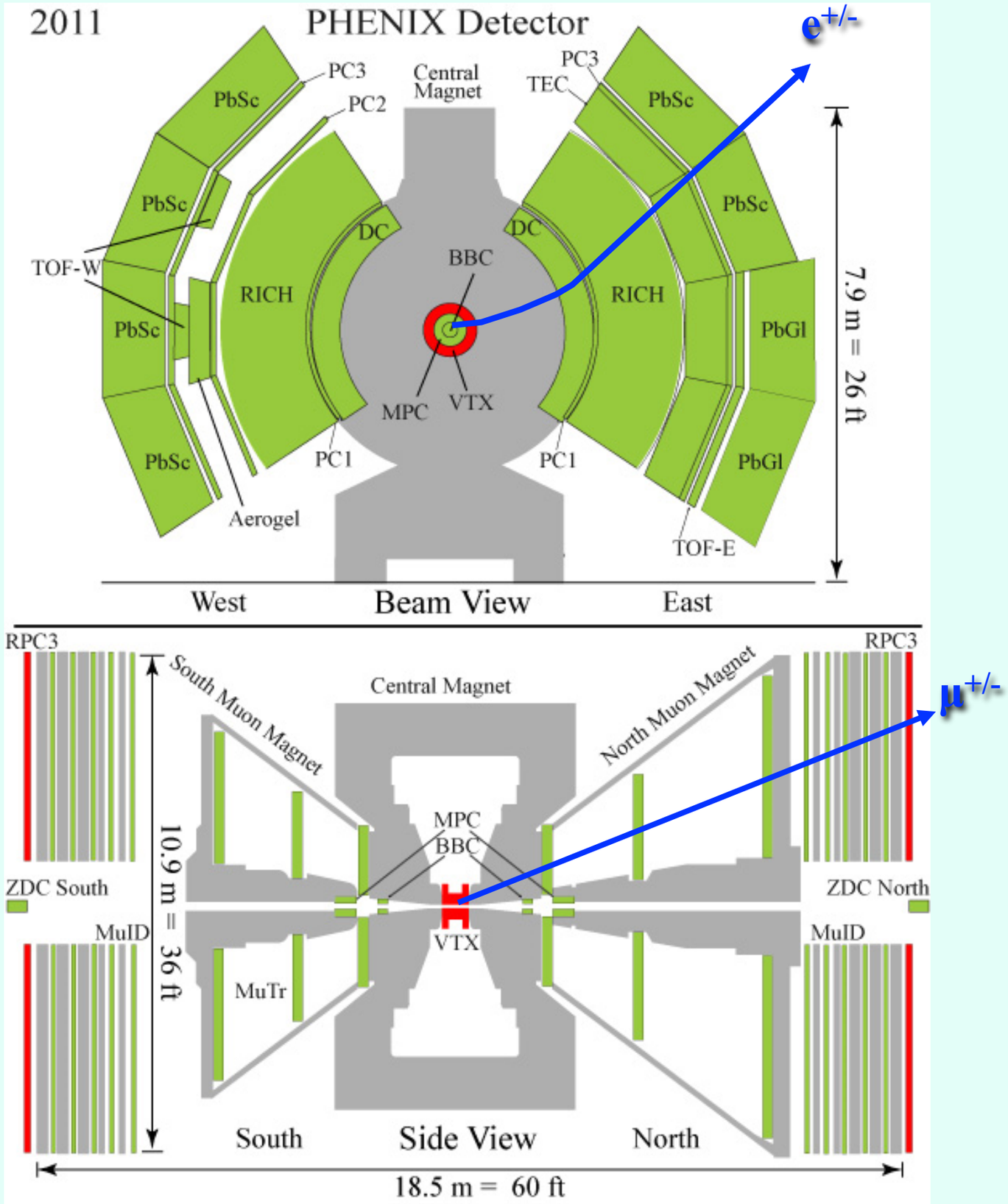
- hadrons, photons, electrons
- $|\eta| < 0.35$
- $\Delta\varphi = \pi$ (2 arms x $\pi/2$)
  - Drift Chamber, Pad Chamber
  - PbGl, PbSc
  - RICH, Aerogel, TOF E&W
  - VTX

Global Detectors:

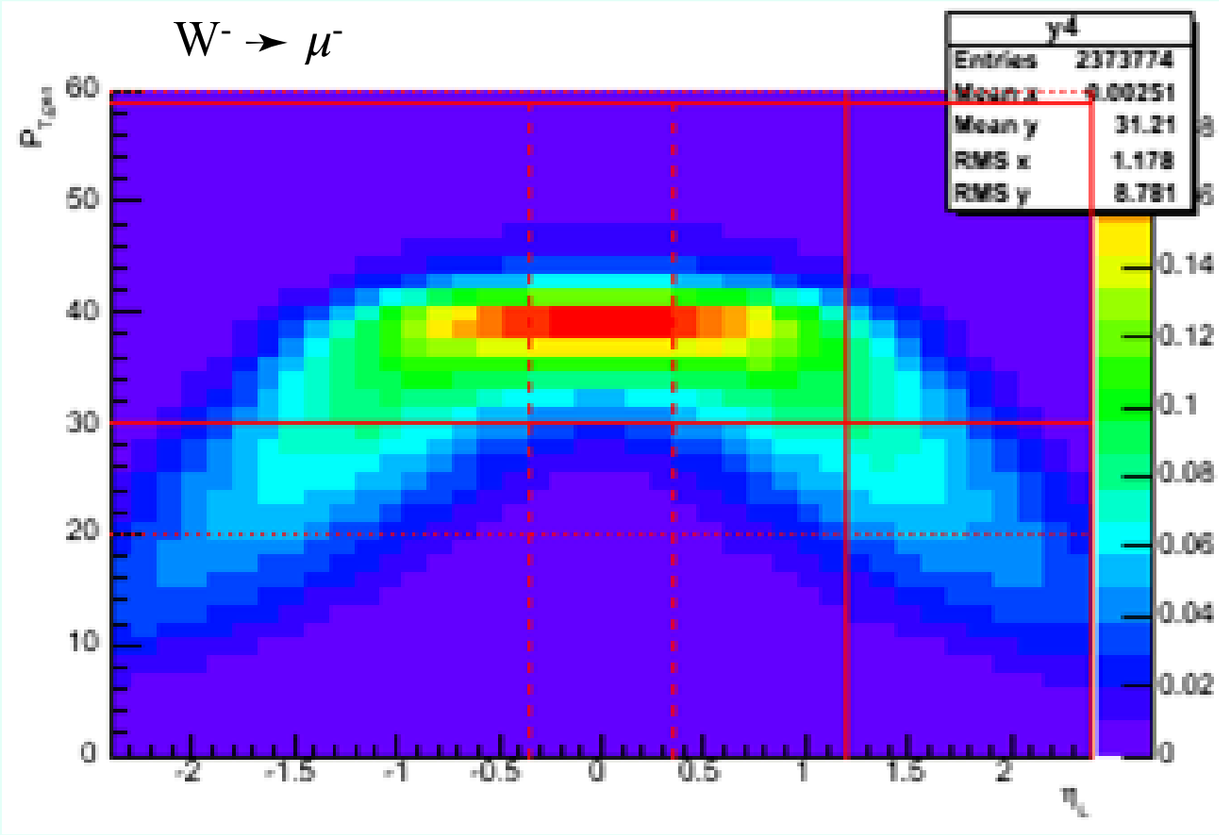
- Beam-Beam Counter (BBC)
- Zero Degree Calorimeter (ZDC)
- Muon Piston Calorimeter (MPC)

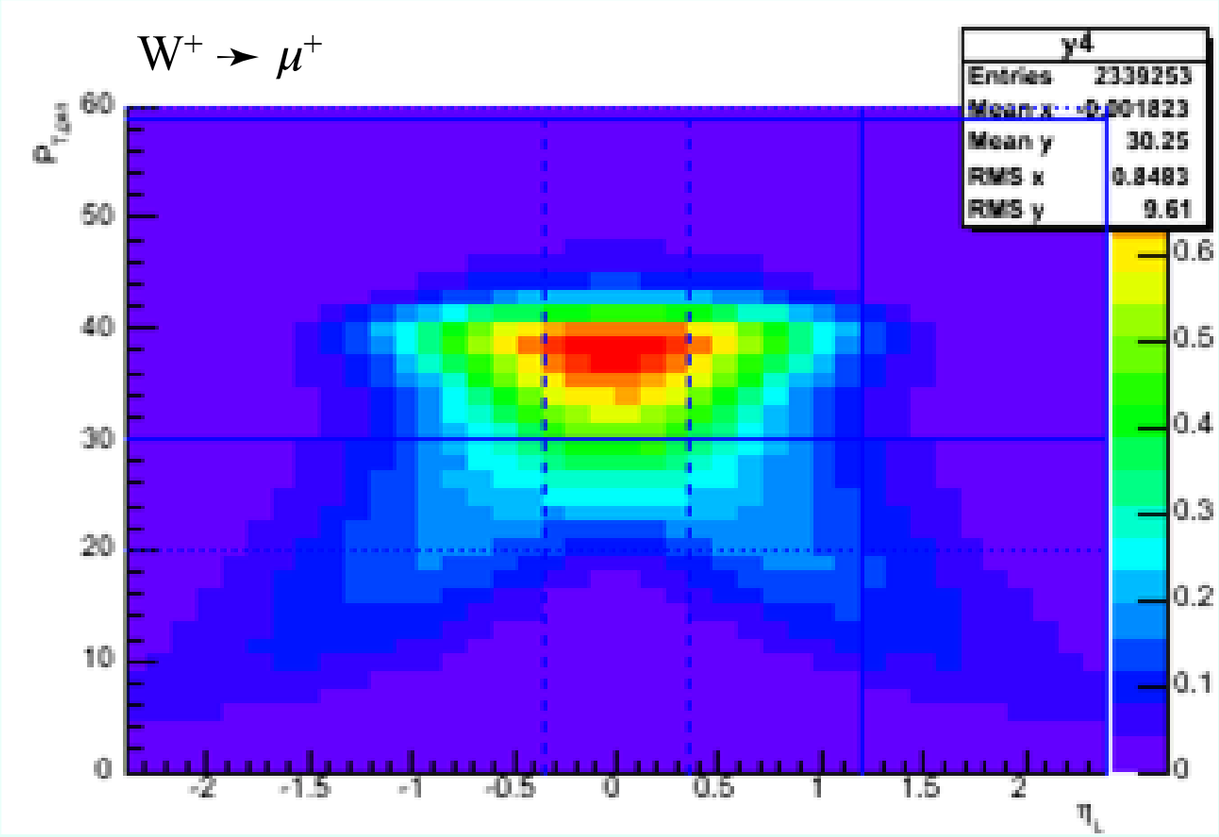
Muon Arms:

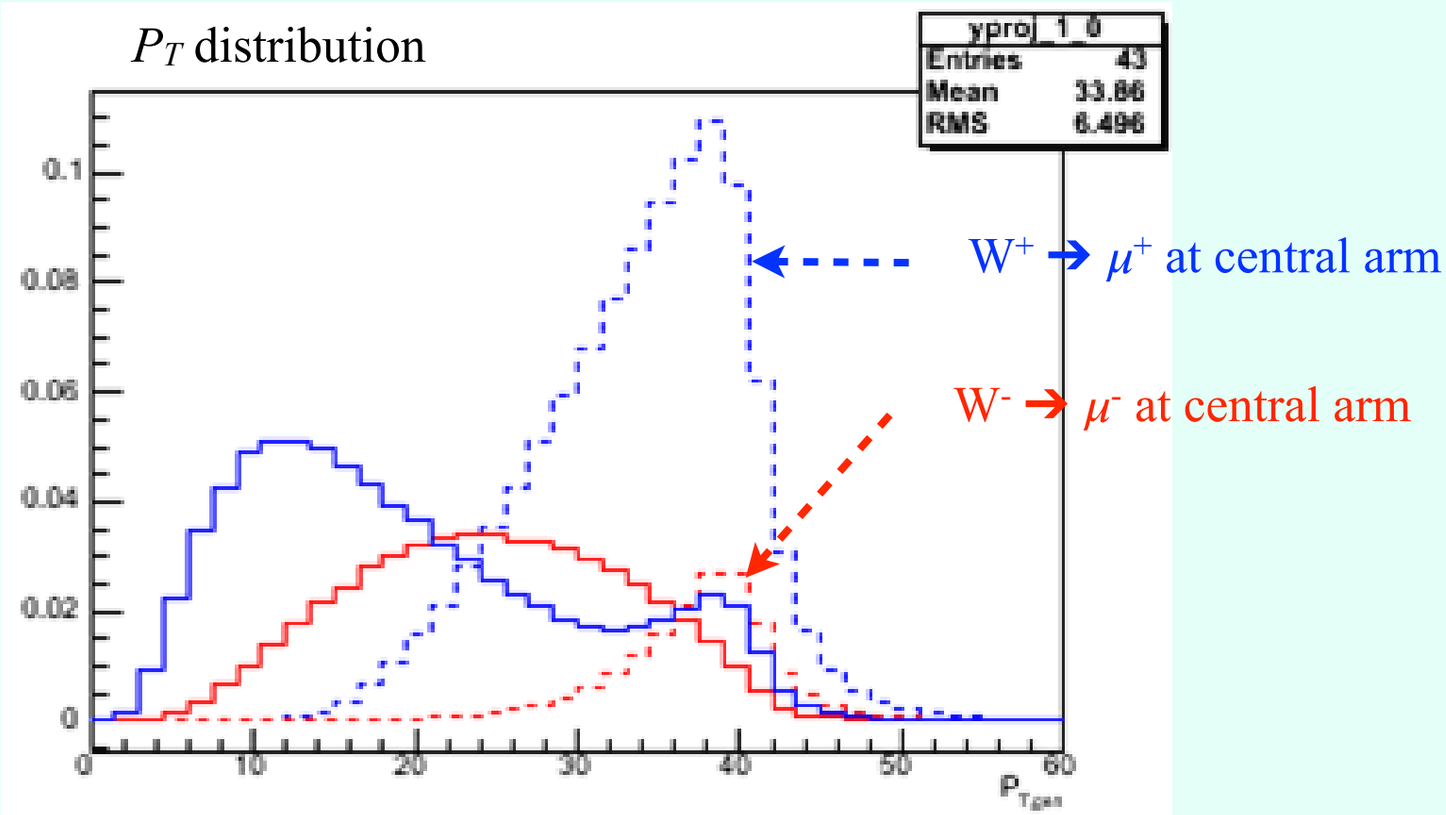
- muons
- $1.2 < |\eta| < 2.2$
- $\Delta\varphi = 2\pi$
  - Muon Tracker
  - Muon Identifier
  - Resistive Plate Chamber



First Look at *W* Measurement



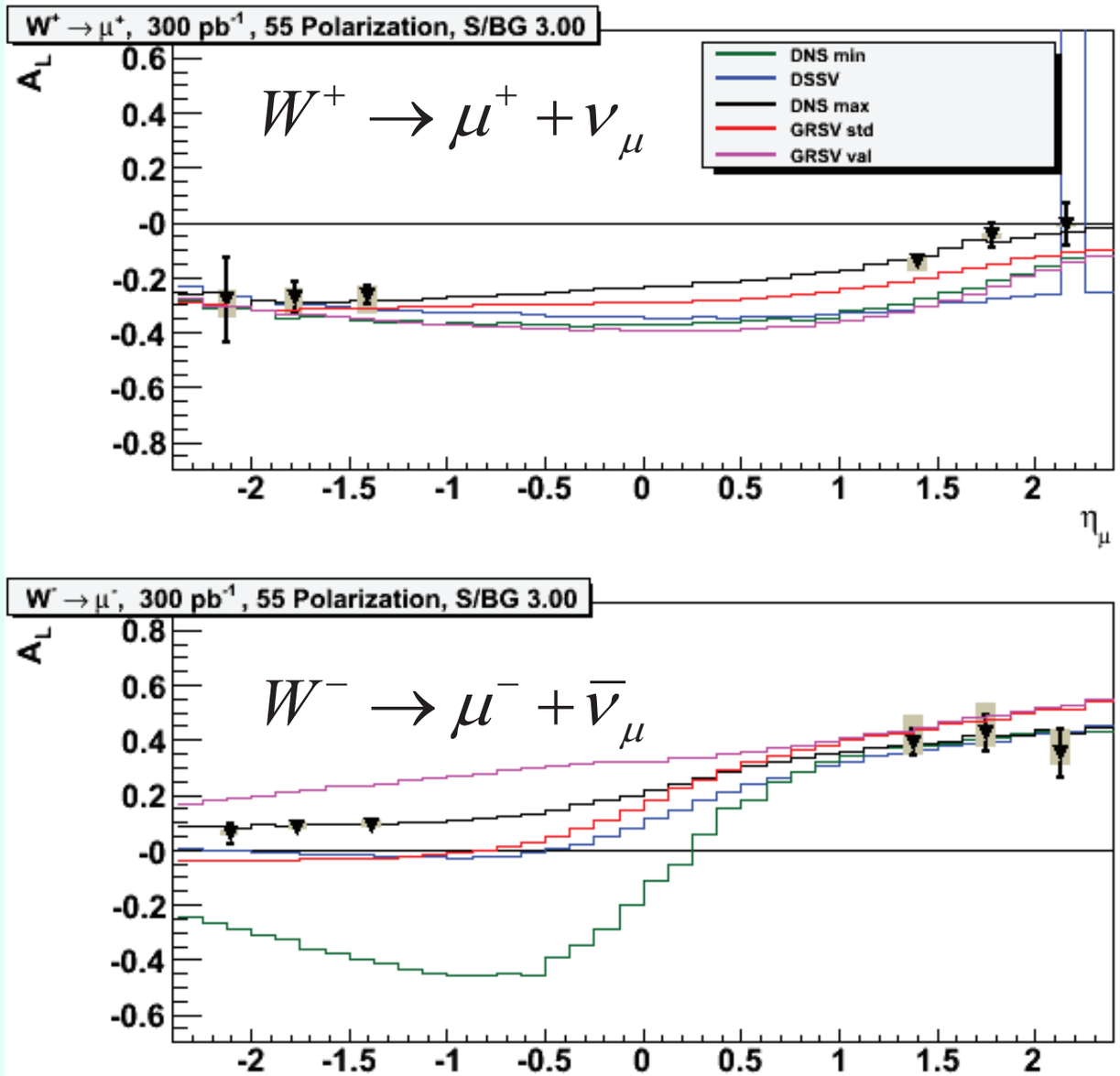




RHICBOS simulation

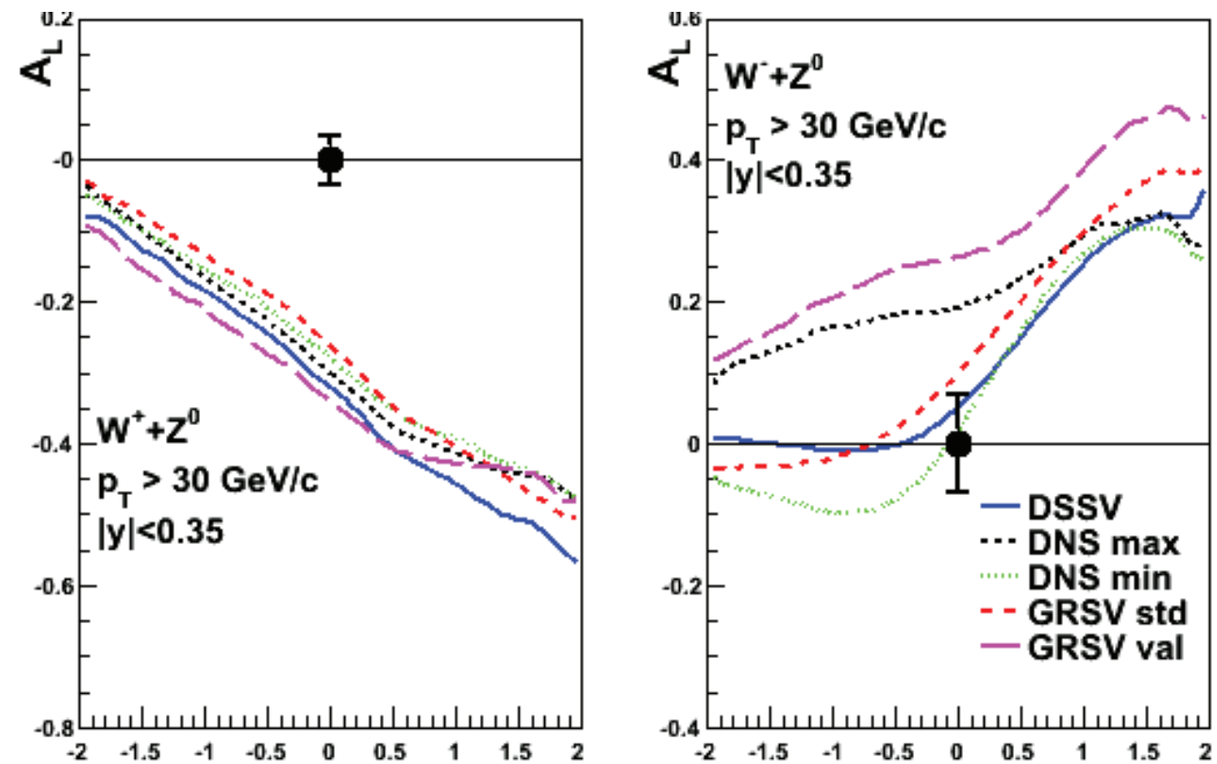
- Dashed lines for central arm
  - Clear Jacobian peaks
- Full lines for muon arm (x 10 for better visibility)
  - No Jacobian peak for W^-
  - Small bump for W^+

Expectation for *W* Measurement



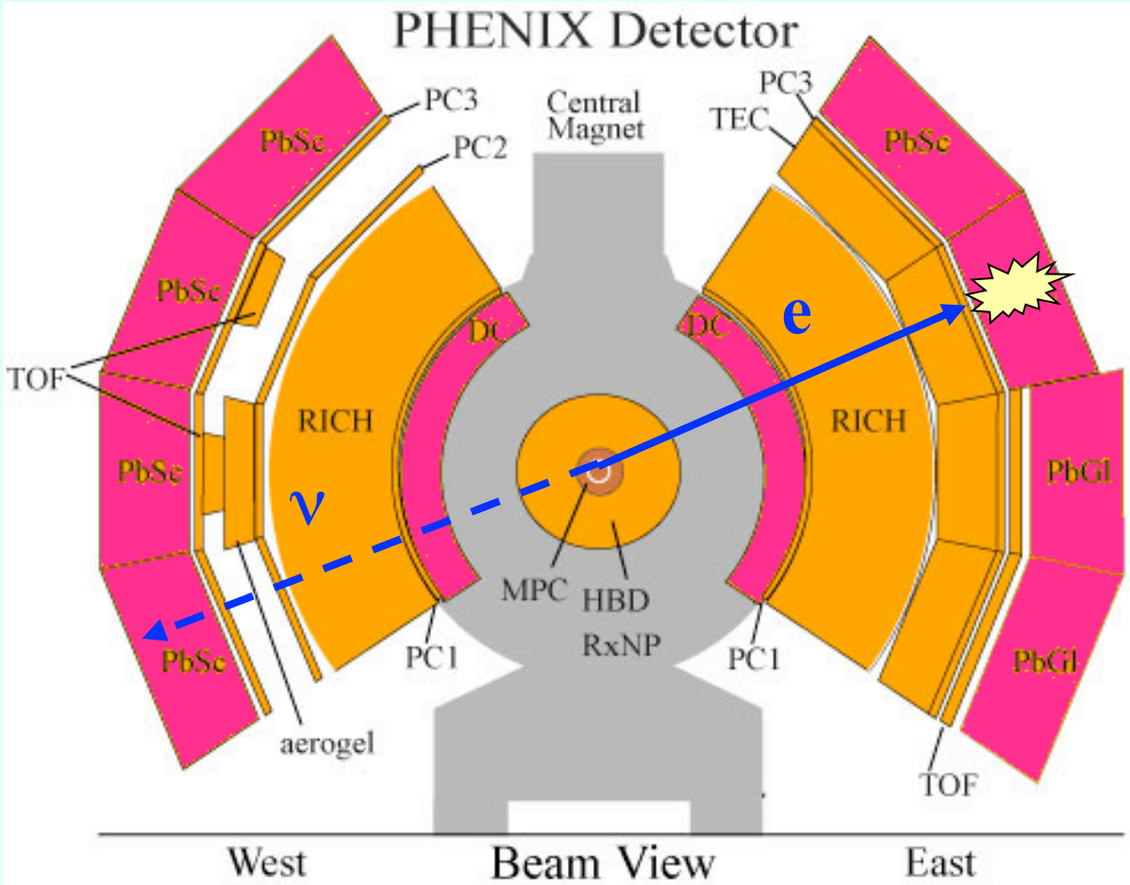
A_L for inclusive high p_T leptons for $\int Ldt = 300 pb^{-1}$, $P=0.55$

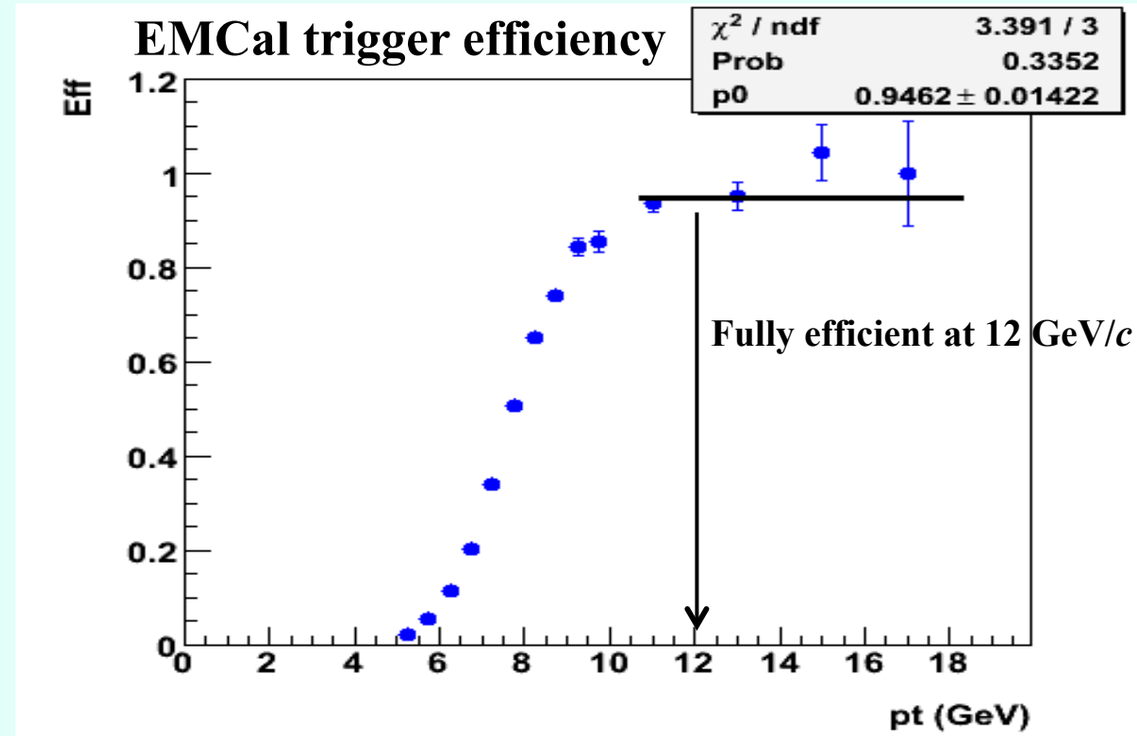
$W^+ \to e^+ + \nu_e$ $\qquad$ $W^- \to e^- + \bar{\nu}_e$



We want to collect statistics over next few years of RHIC runs

$W^{\pm} \rightarrow e^{\pm}$ Analysis at Central Arms (RHIC Run-9 data)





- EMCal ($\Delta\varphi x \Delta\eta \sim 0.01x0.01$) 4x4 tower sum trigger
- ±30 cm vertex cut

- Integrated luminosity (with vertex cut) = 8.6 pb^{-1}
- Polarization is <P> = 0.39±0.04

- High energy EMCal clusters matched to charged track
- Timing cut to reduce cosmic ray background
- *E/p* cut

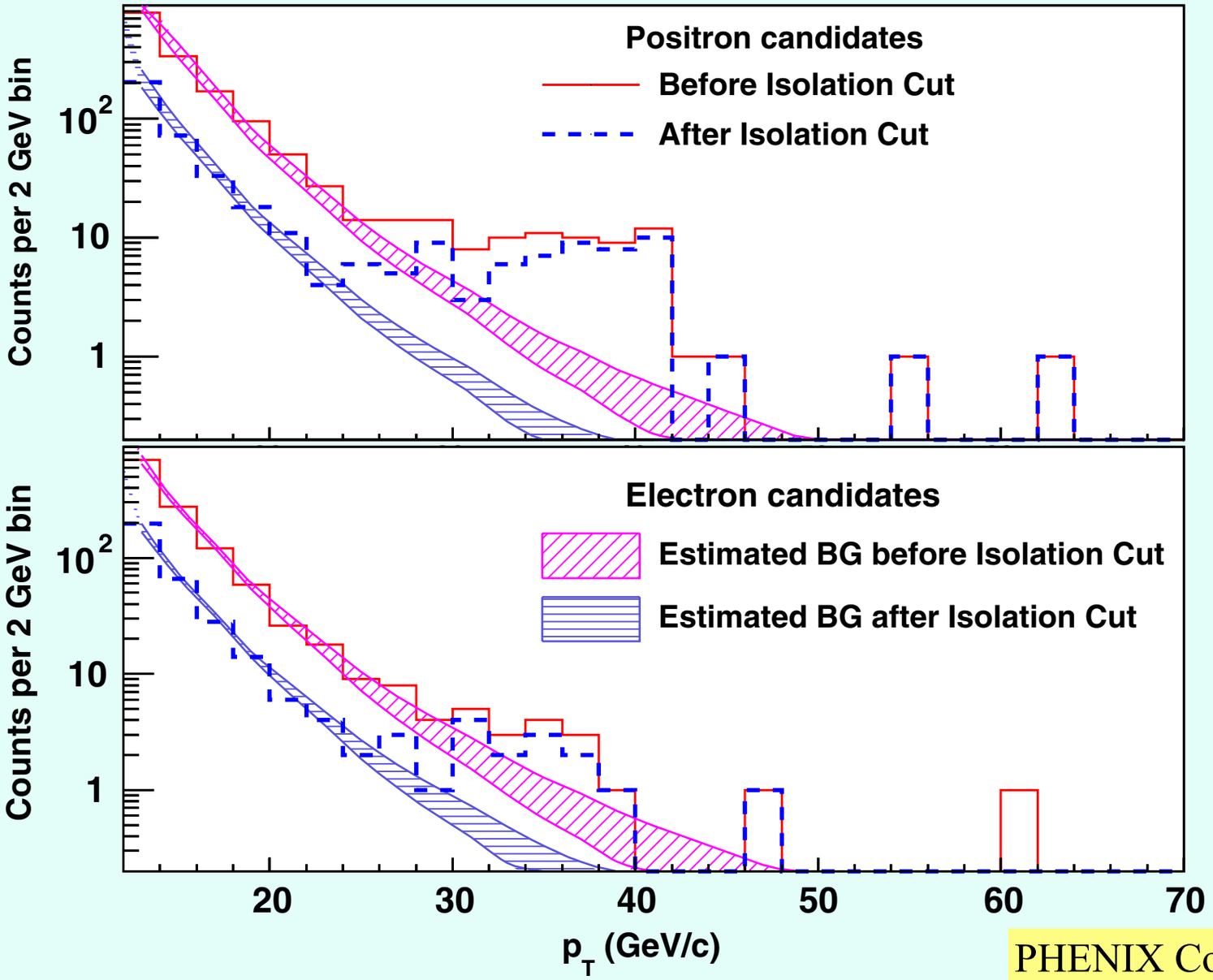
Comparison to Measured Spectra

Data and MC driven BG estimation:

EMCal cluster distribution after subtracting cosmic background × (Conversion + Accidental) × Tracking Acceptance

+

(NLO Hadrons thru GEANT + FONLL c/b) × Normalization from fit to 10-20 GeV

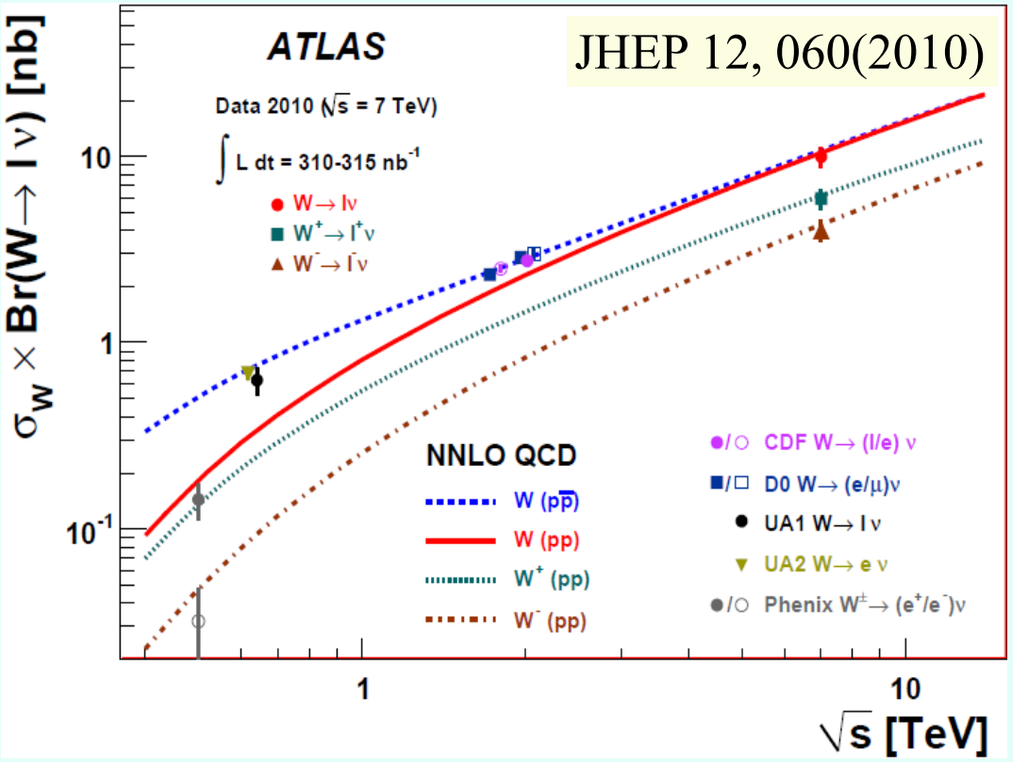


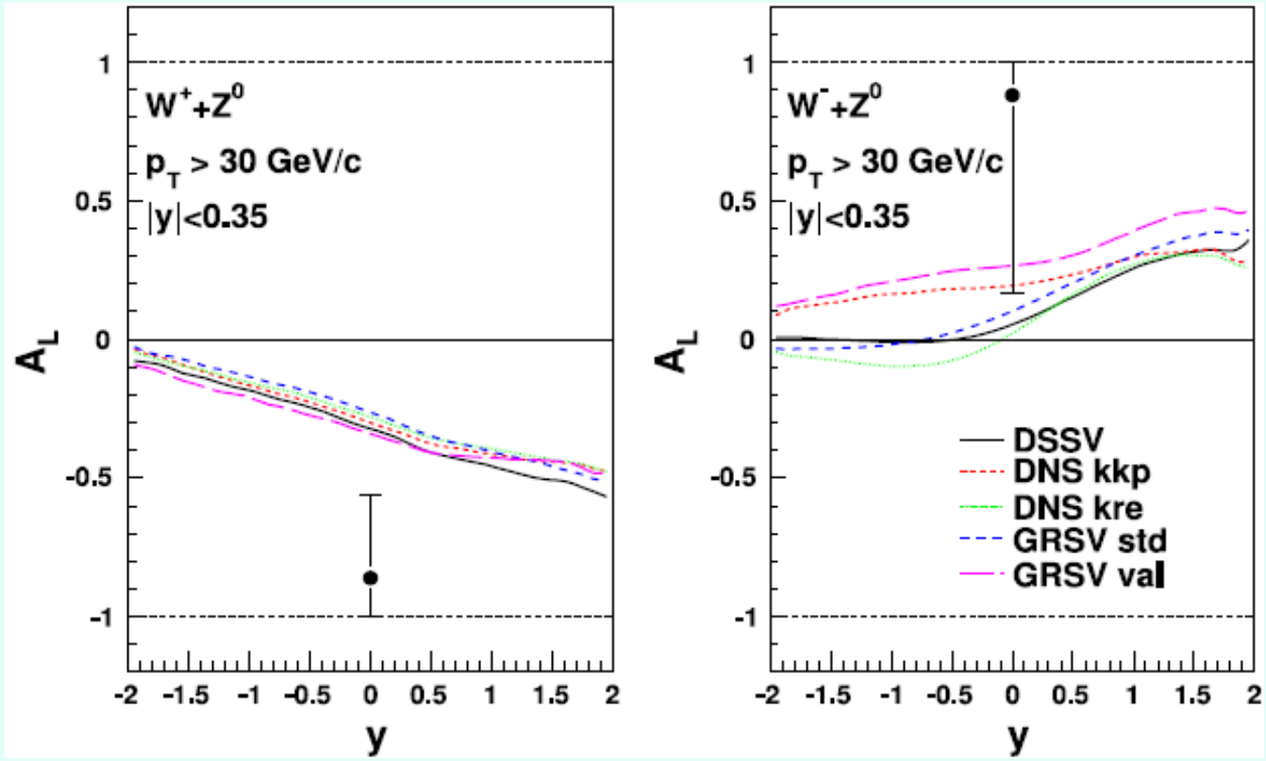
- The same scale factor for PYTHIA was used for W/Z shape
- $W^- \rightarrow e^-$ signal has fewer counts than $W^+ \rightarrow e^+$ signal as expected
- Isolation cut ($\Sigma E < 2$ GeV) applied

  -more than 90% of signal is kept and factor ~ 5 reduction in jet dominated region

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

RHIC Run-9 Result





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

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

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

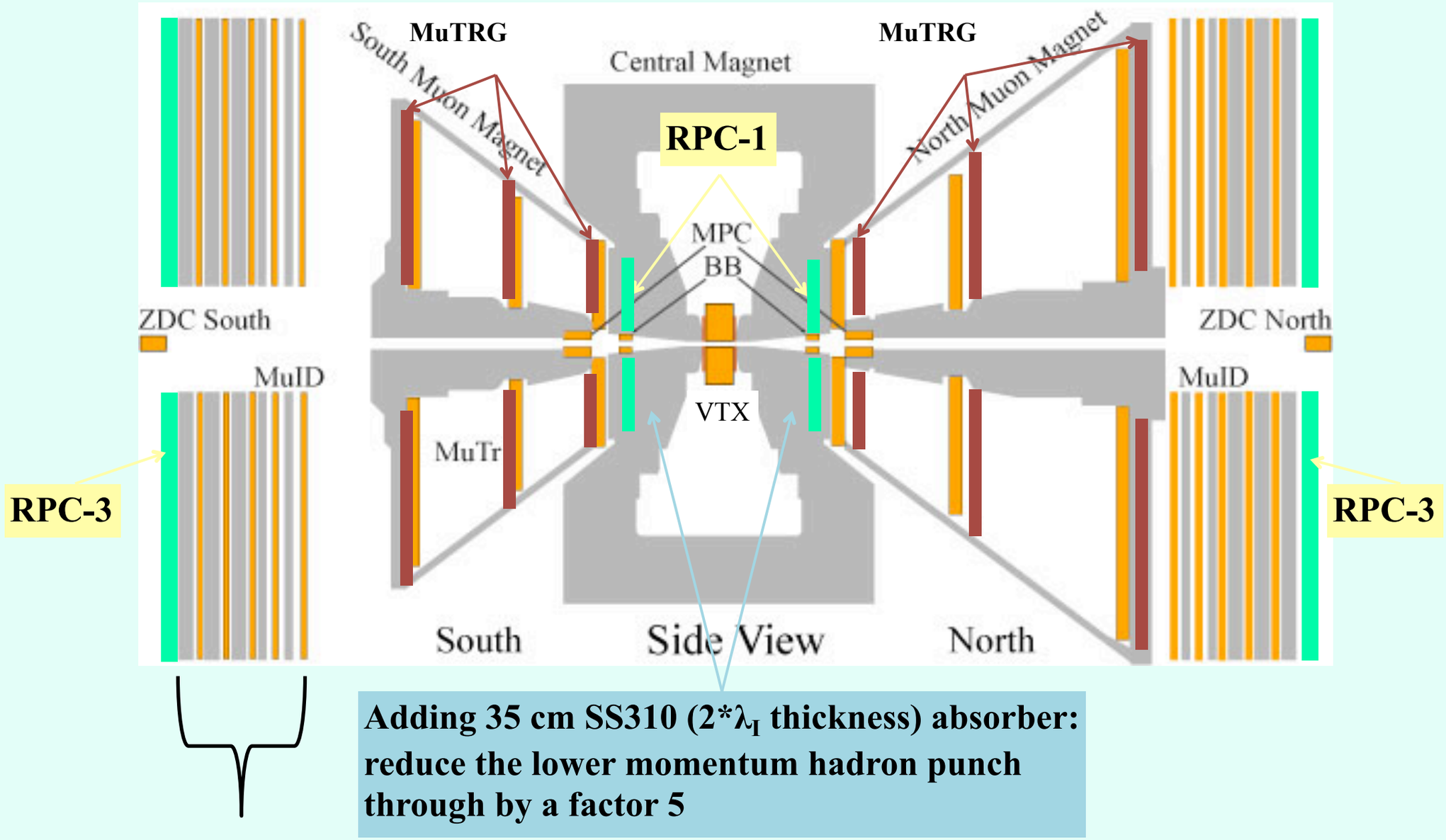
- First measurement of $W^{\pm}$ cross section in $p + p$ collisions
  - Good agreement between PHENIX and ATLAS data and NNLO pQCD calculations
- At 8.6 pb^{-1} with average polarization 0.39±0.04, we get

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

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

  - Asymmetry is corrected for dilution by QCD backgrounds

RHIC Run-11 Experimental Setup

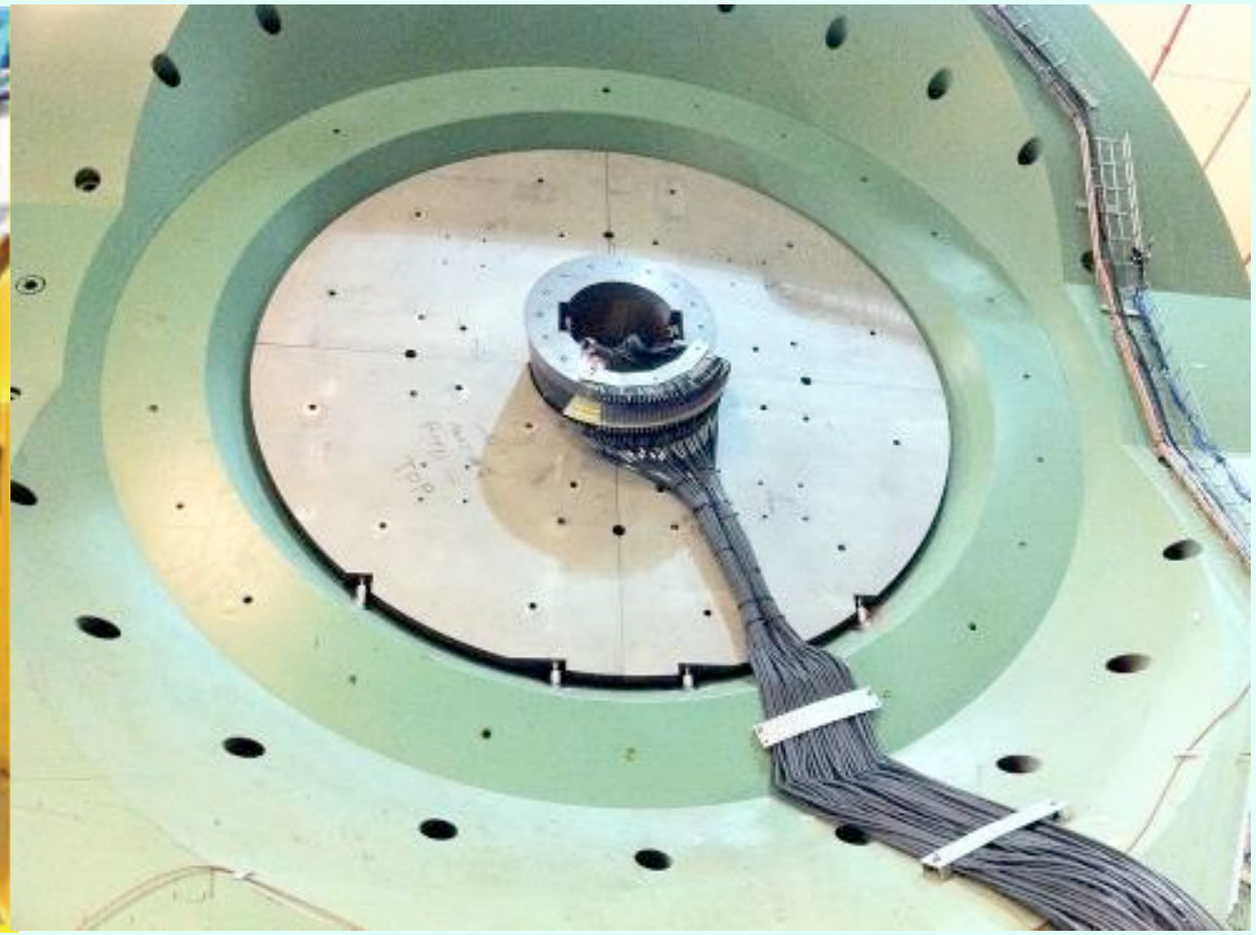


MuID Trigger:
Selecting momentum above 2 Gev/*c*

MuTRG (JSPS funded):
Fast selection of high momentum tracks

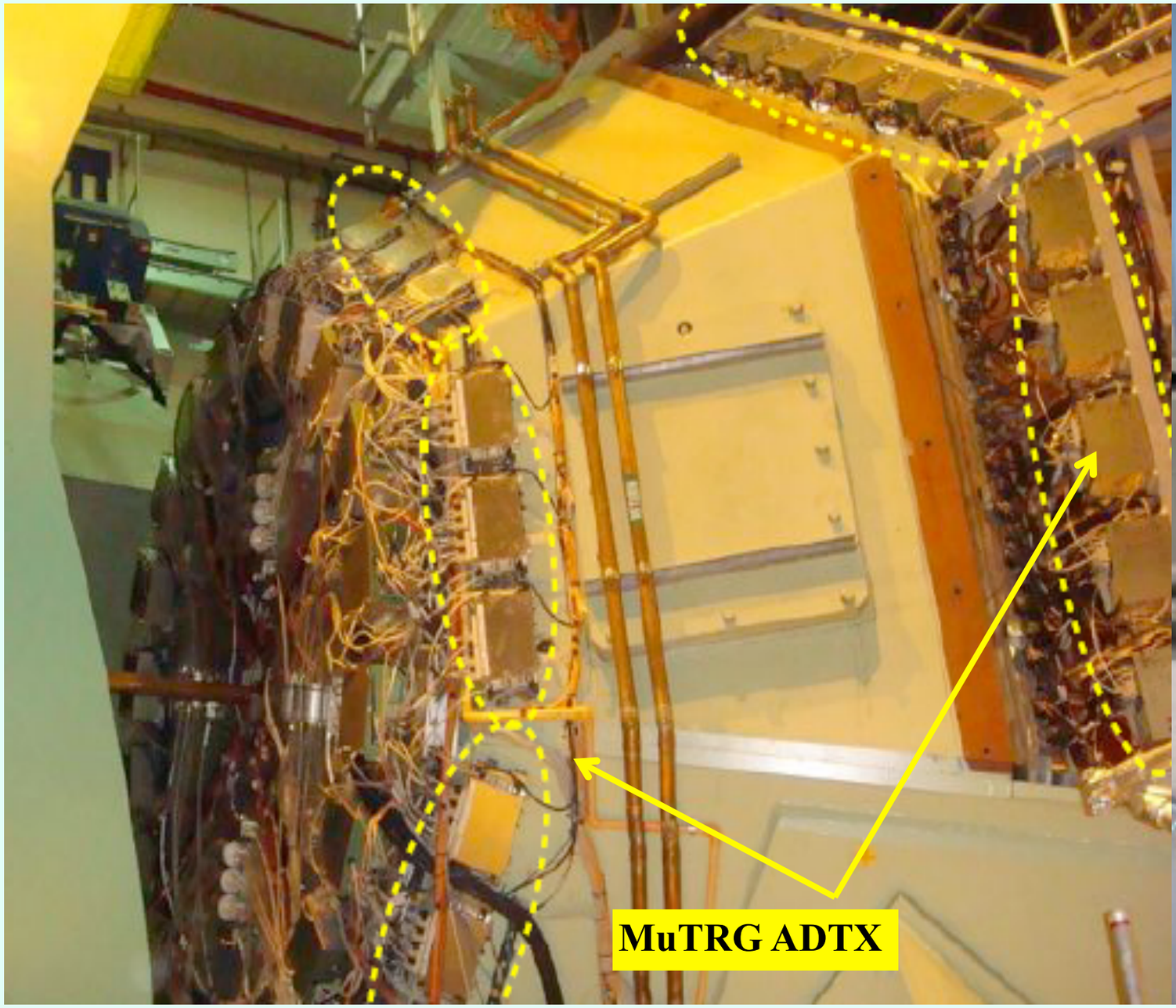
RPC (NSF funded, RPC-3 installed at RHIC Run-11 & RPC-1 installed at Run-12):
Provide timing information and rough position information

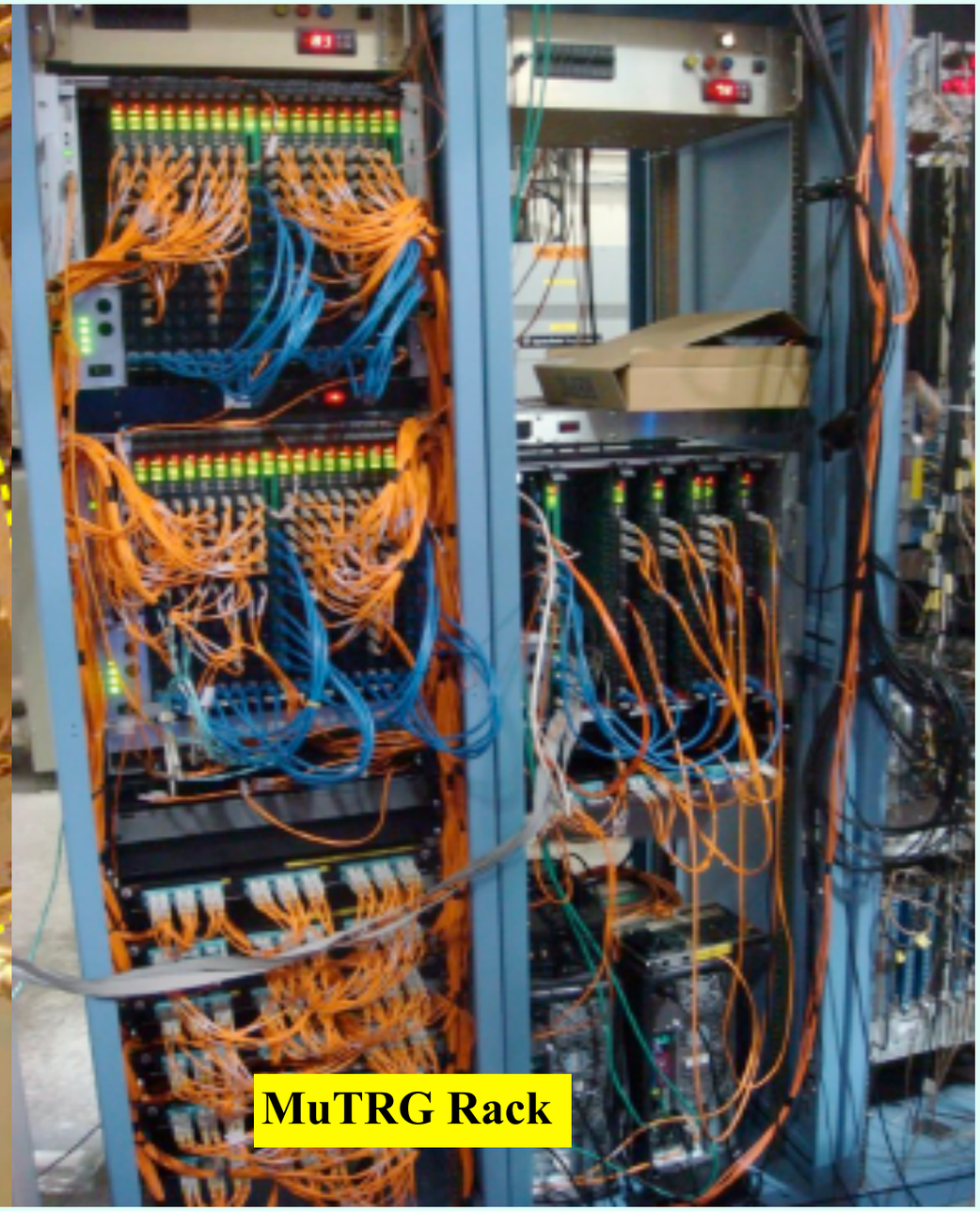
Hadron Absorber



35 cm SS310 ($2*\lambda_I$ thickness) absorber: reduce the lower momentum hadron punch through by a factor 5

MuTRG





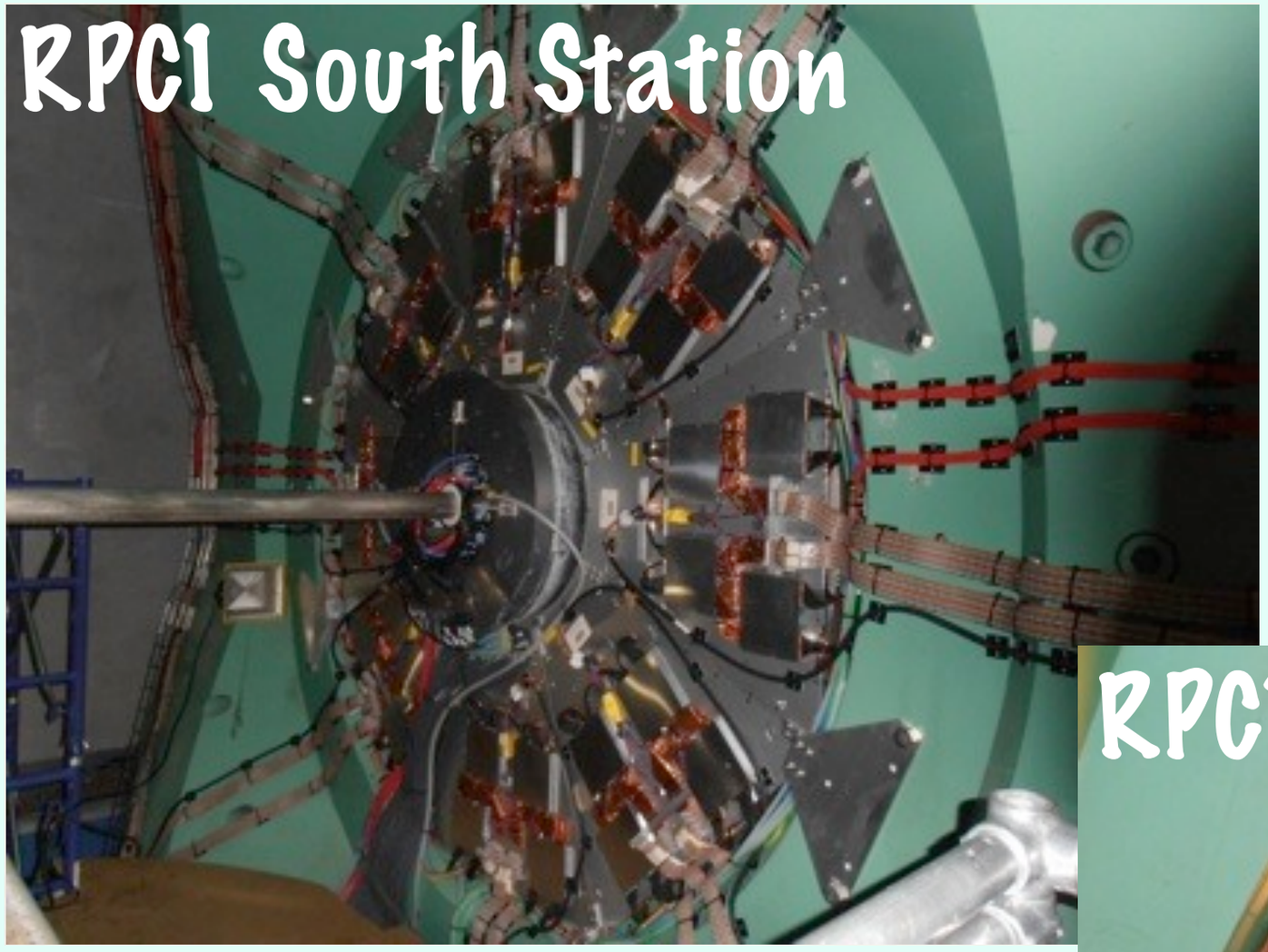
Installed at 2009

RPC-3

Installed:
November 2009
Integrated:
June 2010

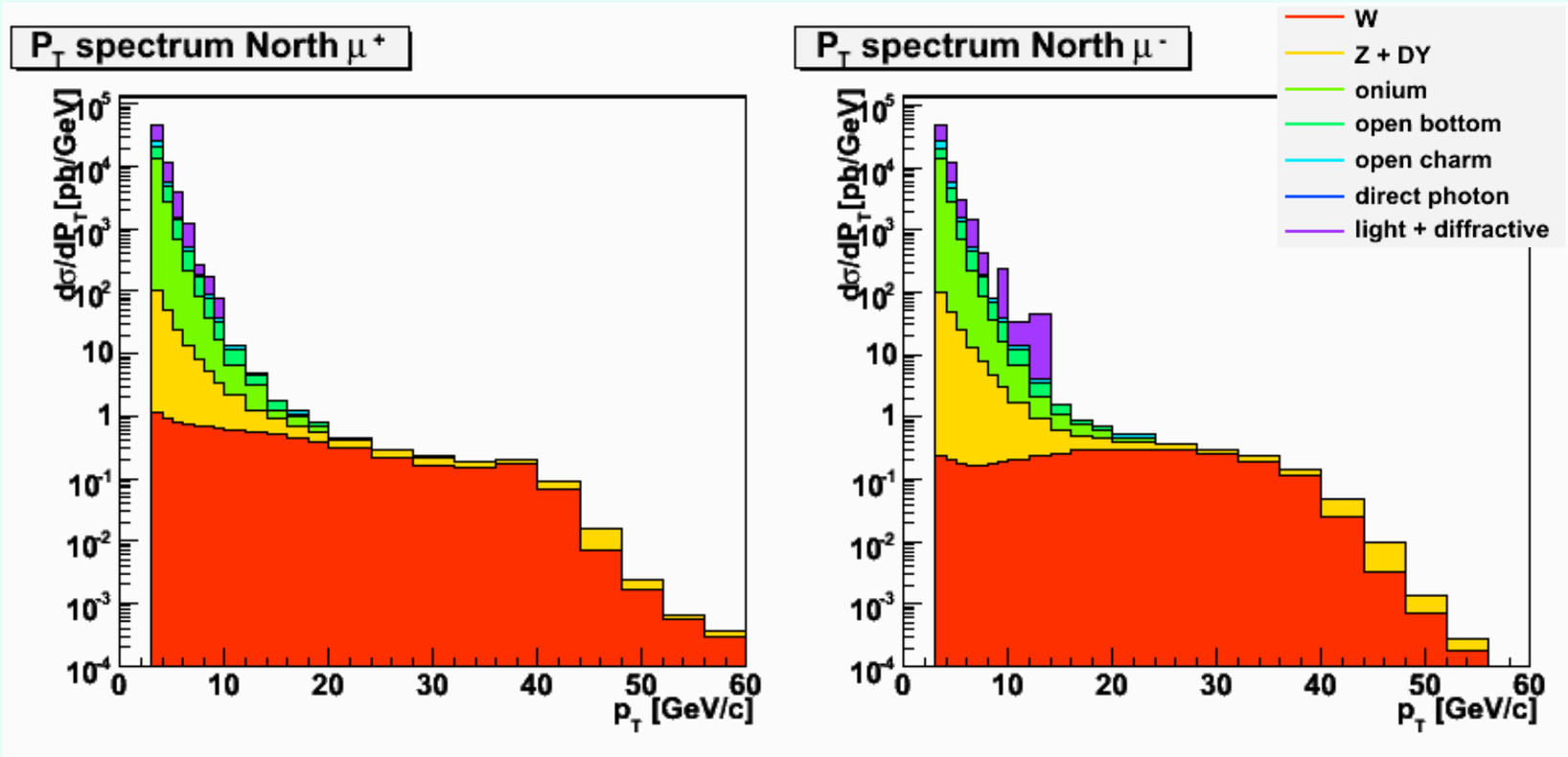
Installed:
September 2010
Integrated:
December 2010

RPC-1



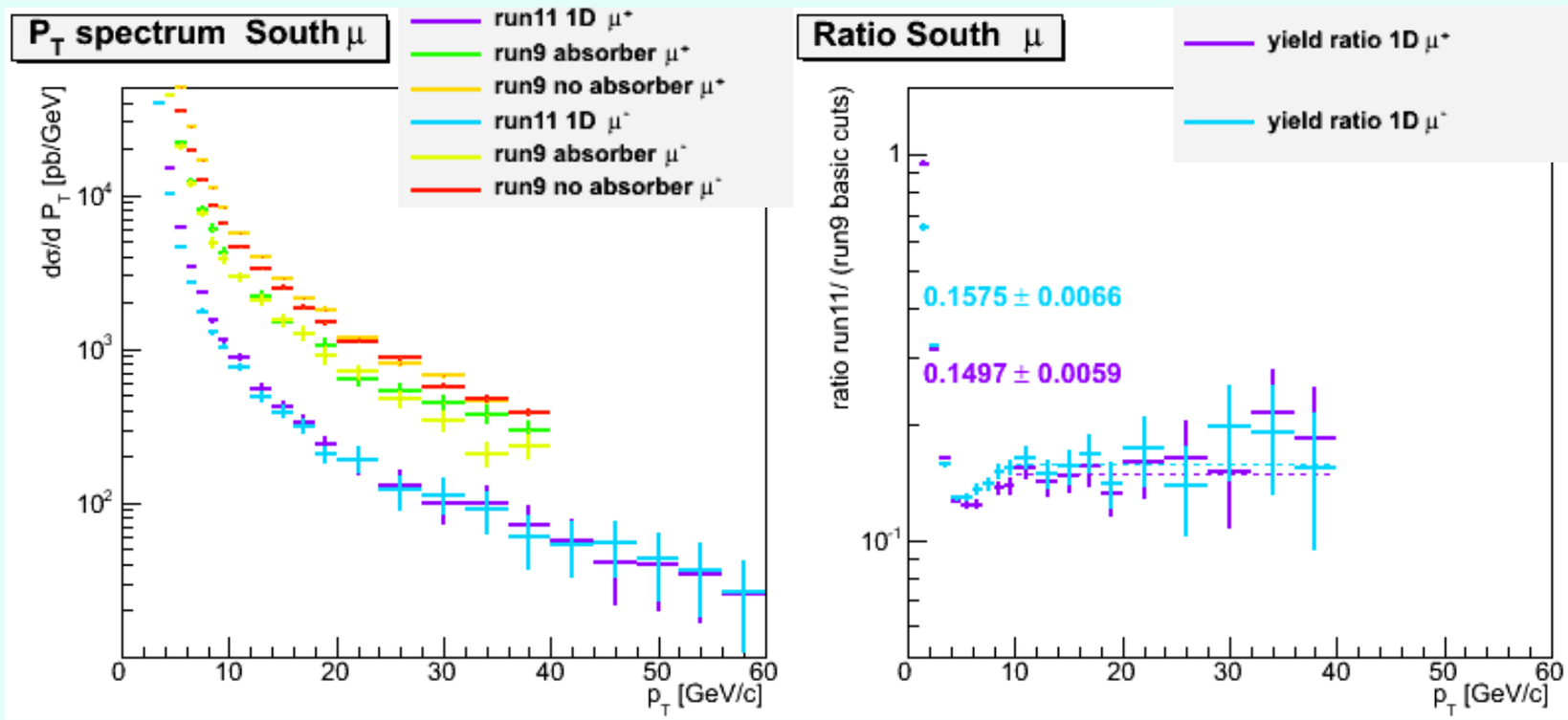
Installed at 2011

$W^{\pm} \rightarrow \mu^{\pm}$ Analysis at Muon Arms (RHIC Run-11)



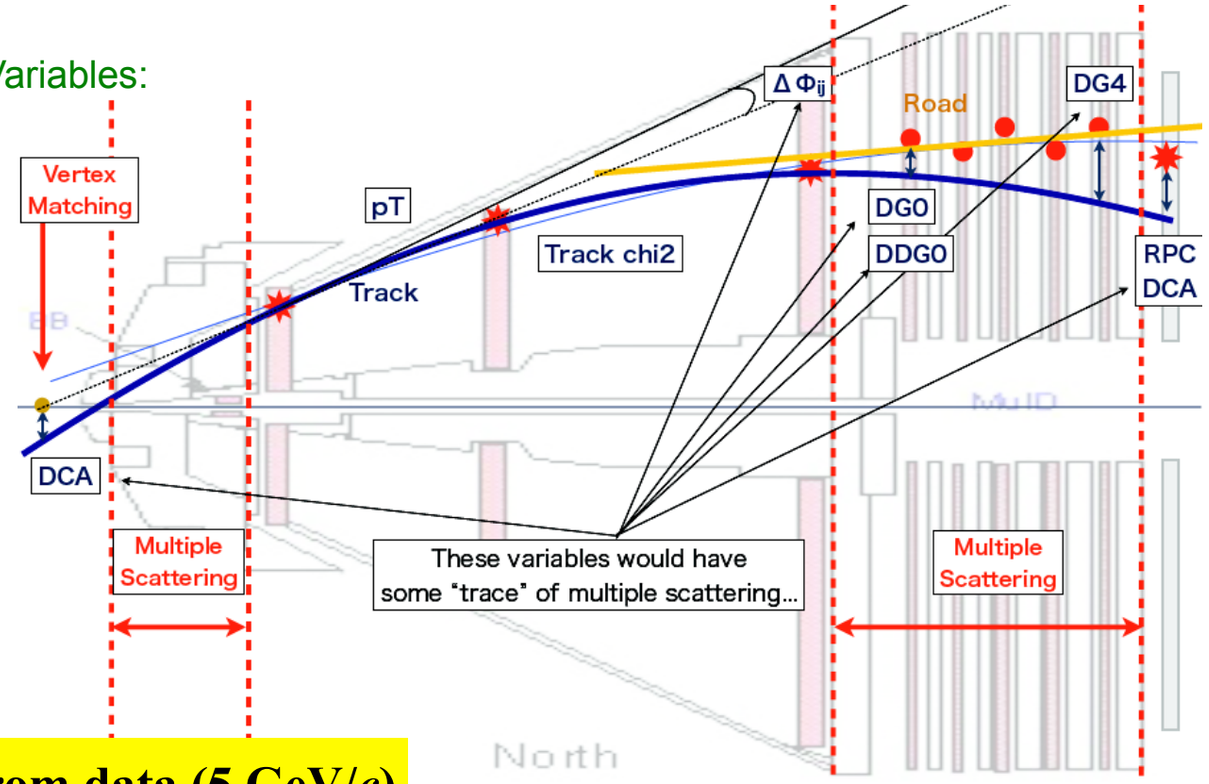
- Monte Carlo simulation
  - no Jacobian peak
    - ➡experimentally more difficult

- Experimental data
  - Large improvement in raw muon candidates
    - ➡2009: ~ 0.8 pb^{-1}
    - ➡2011: ~ 1.6 pb^{-1} with MuID trigger
    - ➡2011: ~ 25 pb^{-1} with new muon trigger electronics (MuTRG) + RPC

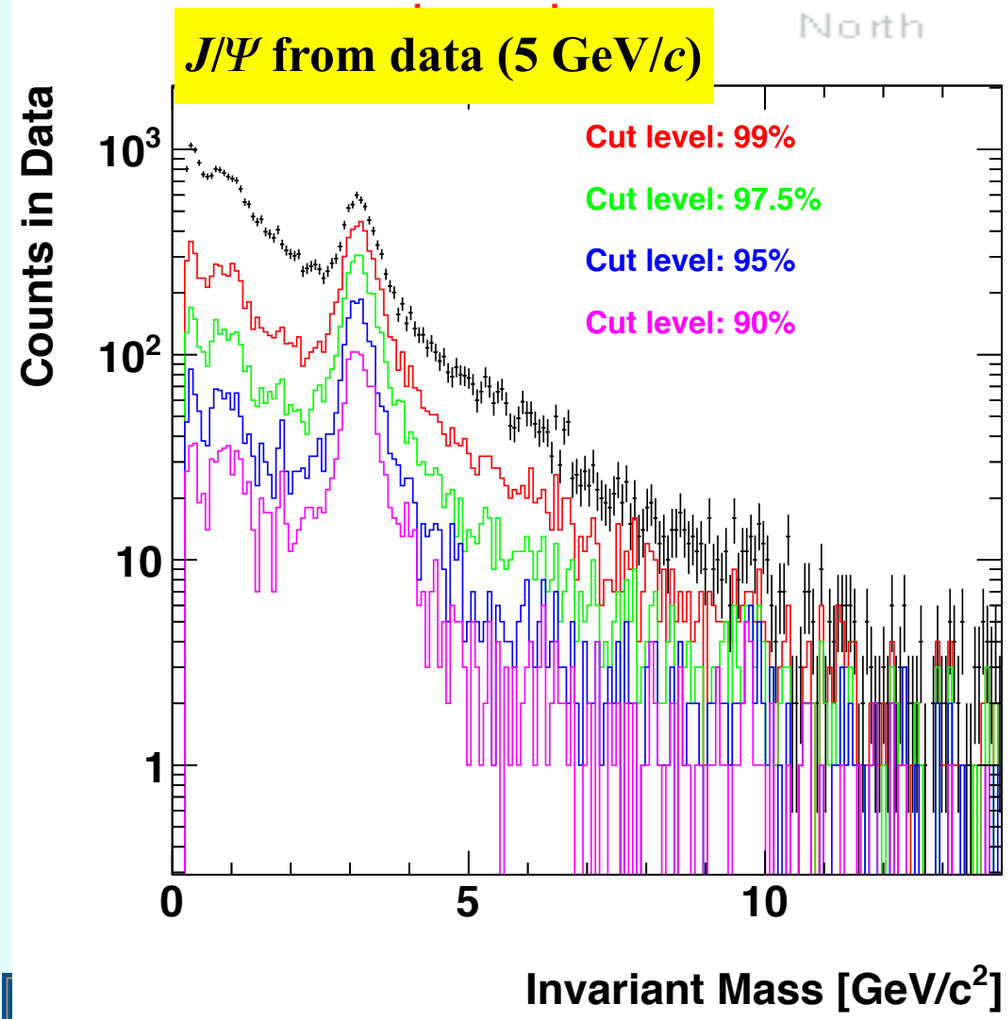


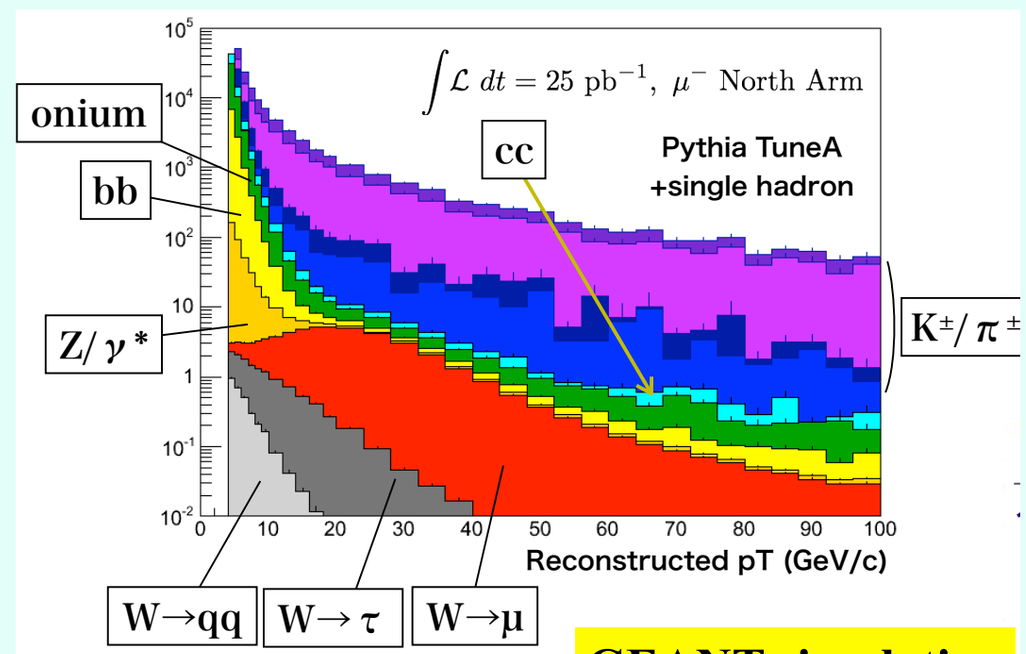
PHENIX Muon Arm Analysis

Main Selection Variables:
Track χ^2
DG0
DDG0
DG4
DCA(z,r)
$\Delta\Phi_{1,2}$ & $\Delta\Phi_{2,3}$
RpcDCA,time
multiplicity



Variable	99.5%	97 %	95%	90 %
dg0	6	4.8	4.4	4
ddg0	1.1	0.9	0.8	0.7
dg4	6	4.8	4.5	3.9
chi	12.98	7.92	6.38	4.4
dcar	3.85	2.75	2.2	1.65
dcaz	12.6	6.6	5.4	4.2
dphi12	0.018	0.012	0.0108	0.0084
dphi23	0.0132	0.0108	0.0096	0.0096
RpcDCA	11.5	9	8	7
mult	4	3	2	1
RpcTime	4	3	3	3

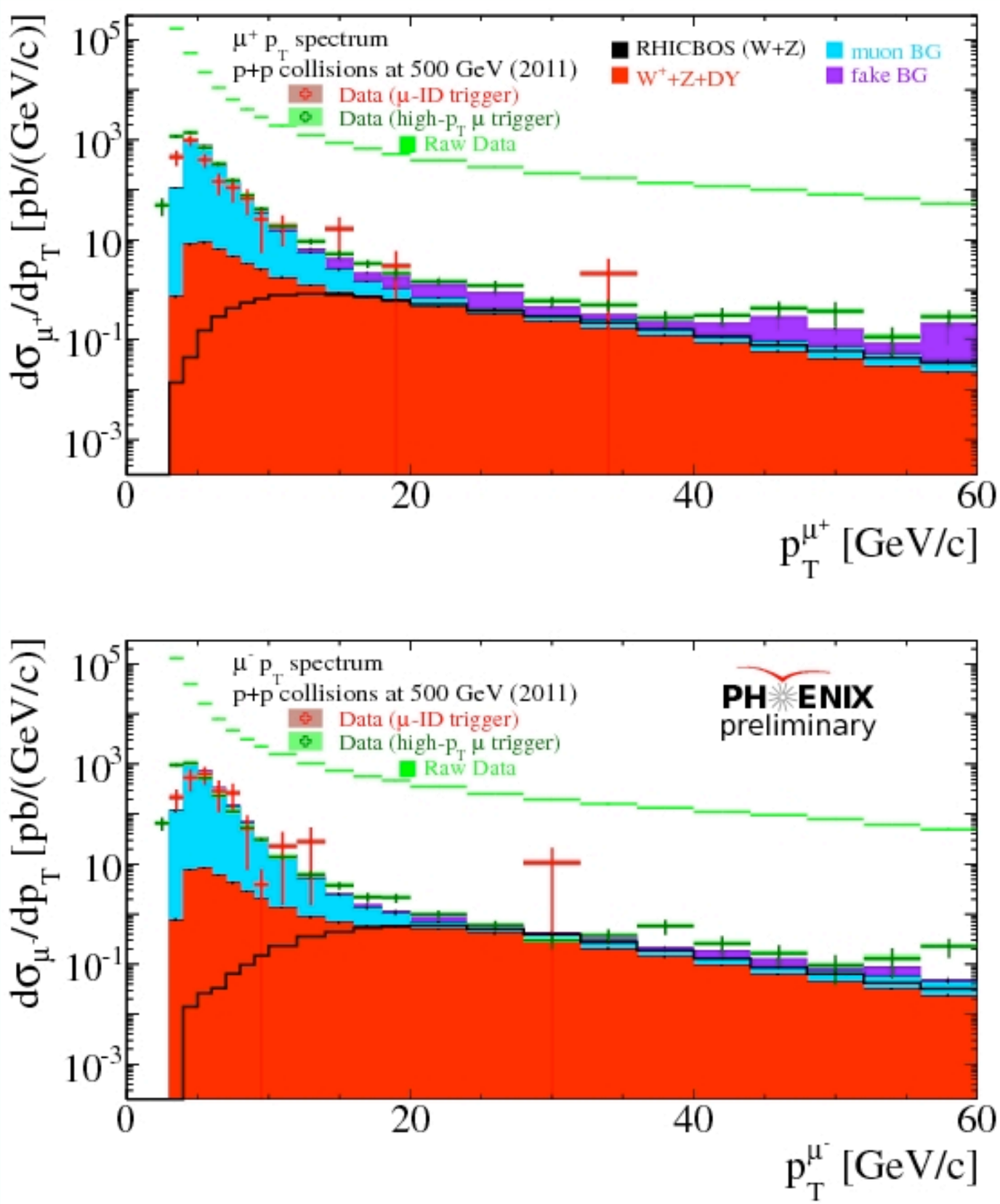




GEANT simulation

We used
- Simulation of signal and background
- Crosscheck with real muons from cosmic and real data

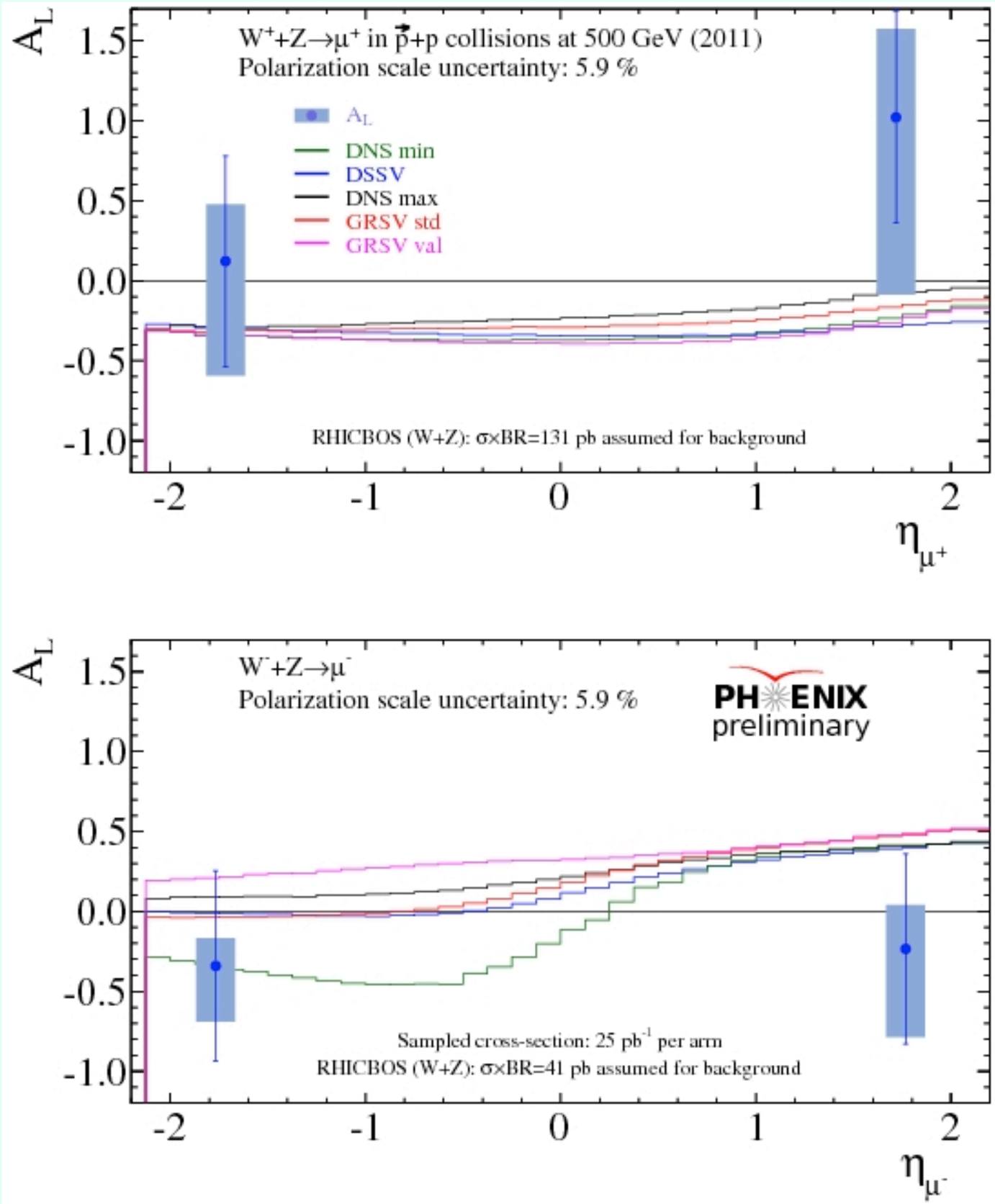
$W^{\pm} \rightarrow \mu^{\pm}$ P_T Spectra at Muon Arms



+ MuID trigger data
+ New MuTRG + RPC data
Systematic error due trigger efficiency (10 % absolute variation)

others from GEANT
- Shape of simulation is well described of data

$W^{\pm} \rightarrow \mu^{\pm}$ Single Spin Asymmetry at Muon Arms



First measured single spin asymmetries at forward $W^{\pm} \rightarrow \mu^{\pm}$

Beam averaged experimental results

In order to reduce statistical & systematic errors, improve detector & trigger performances and plan to collect 500 GeV $p + p$ collision data over 2016 at least

Different lines are expectation from RHICBOS calculation

Summary and Outlook

PHENIX

- RHIC Run-9 with PHENIX Central Arms

-First $W^{\pm}$ cross section results at 500 GeV $p + p$ collisions
-Results on single spin asymmetry of $W^{\pm}$

- RHIC Run-11

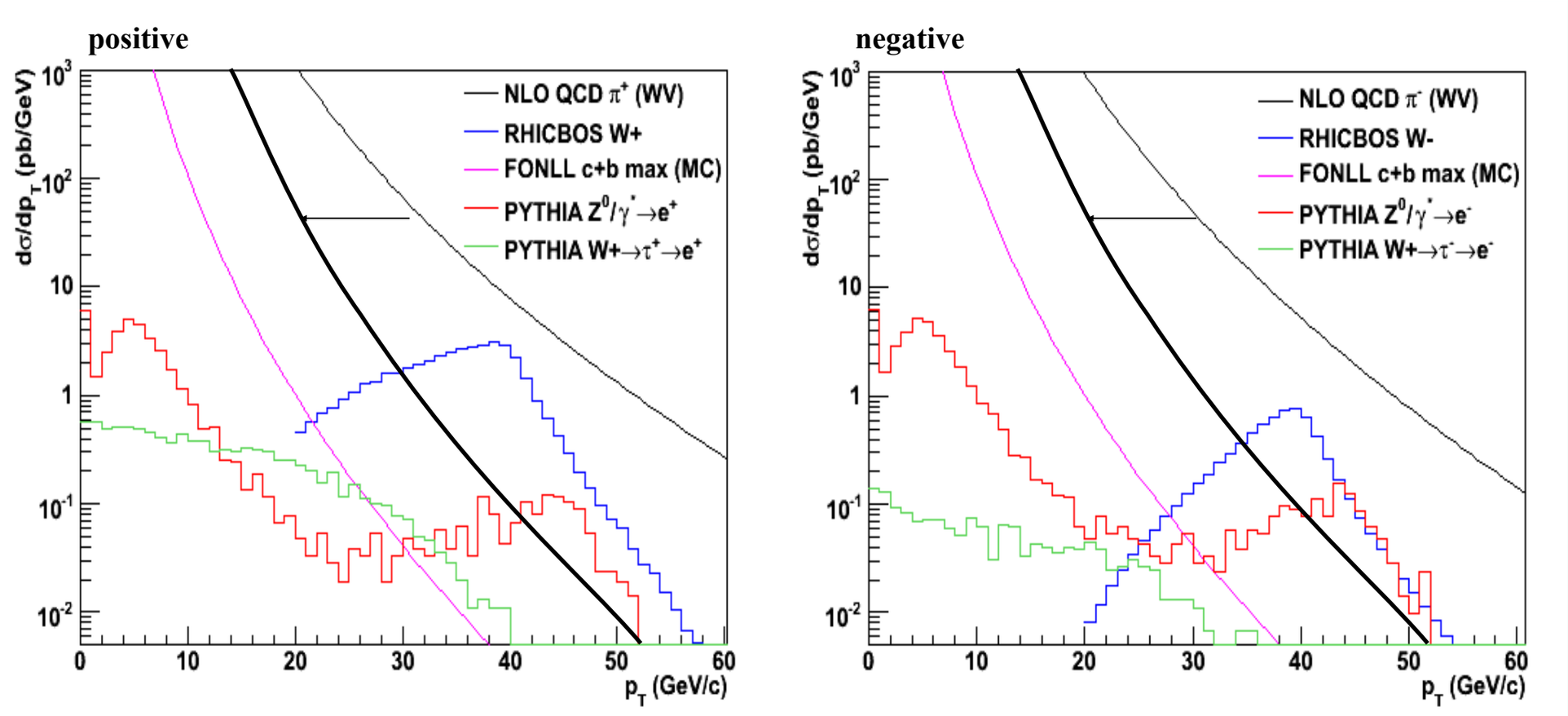
-New muon trigger electronics (MuTRG) + RPC detector system delivered largely improved data
-First results at forward rapidity on
  $W^{\pm}$ measured transverse momentum spectra
  $W^{\pm}$ single spin asymmetry
-Central arm analysis is in progress

- RHIC Run-12

-PHENIX forward upgrade for W measurement is completed
-Integrated RPC detector into LL1 trigger and data taking ongoing

Backup Slides

Expected $W^{\pm} \rightarrow e^{\pm}$ Decay Signal



RHICBOS: Nadolsky and Yuan, Nucl. Phys. B 666:31-55,2003

- QCD provides the most obvious background (W. Vogelsang)
- Not shown here but very important
  - Cosmics and photons (from meson decays and direct), which can have accidental matches to tracks or conversions
- c/b relatively small above 30 GeV, calculated at FONLL (Matteo Carciari)
- Z/γ^* background is estimated from PYTHIA (~1 count is expected in RHIC Run-9)
- $W \rightarrow \tau \rightarrow e$ is also small

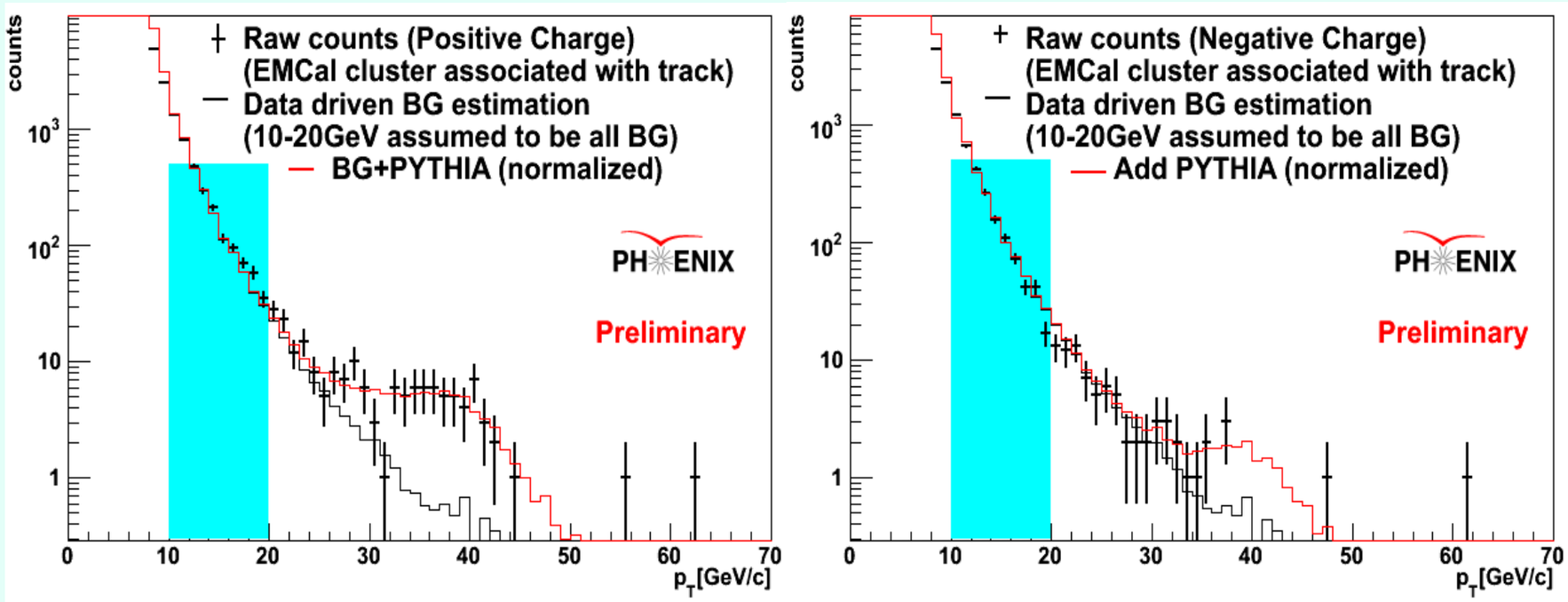
Comparison to Measured Spectra

Data and MC driven BG estimation:

EMCal cluster distribution after subtracting cosmic background × (Conversion + Accidental) × Tracking Acceptance

+

(NLO Hadrons thru GEANT + FONLL c/b) × Normalization from fit to 10-20 GeV



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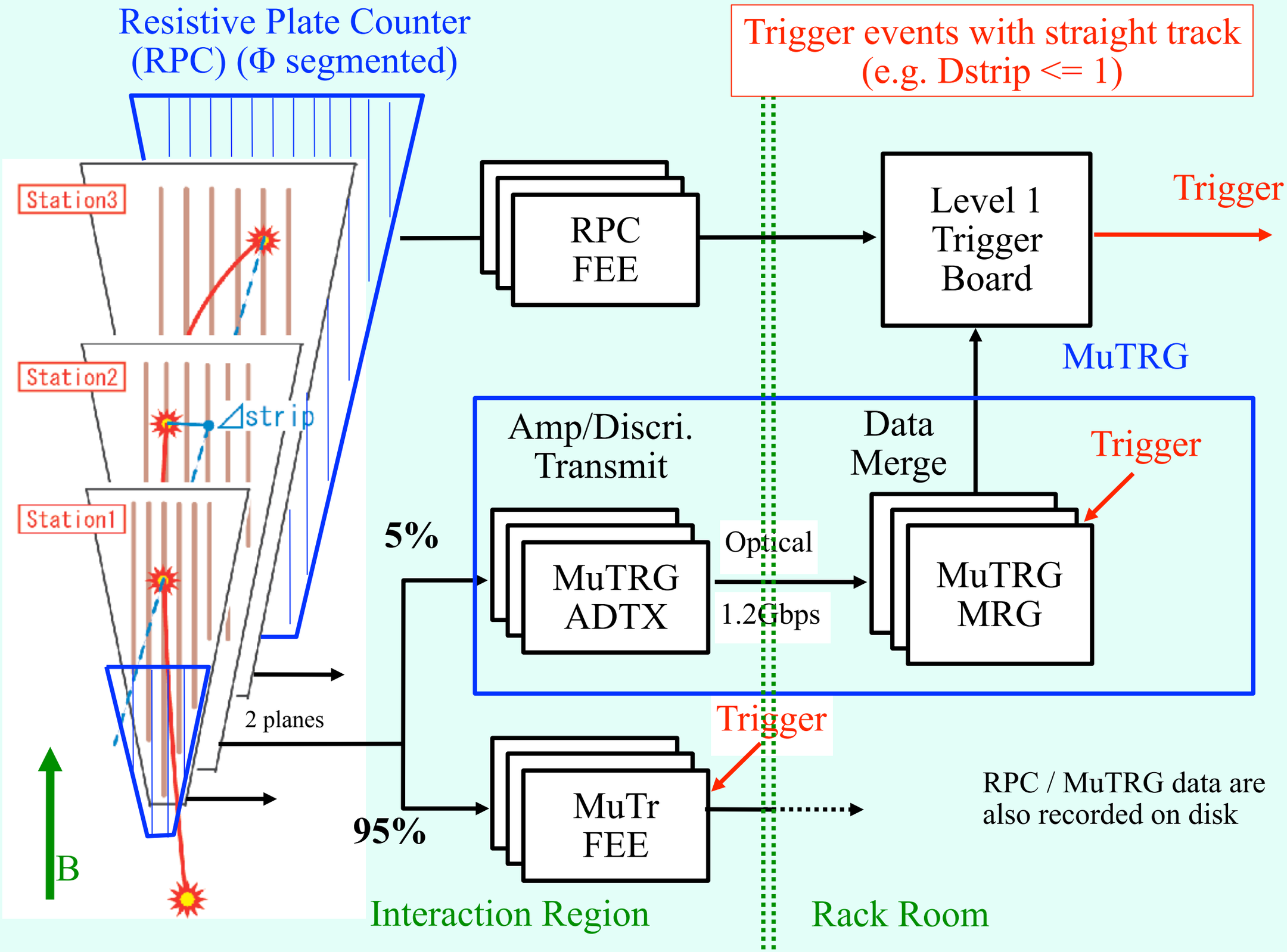
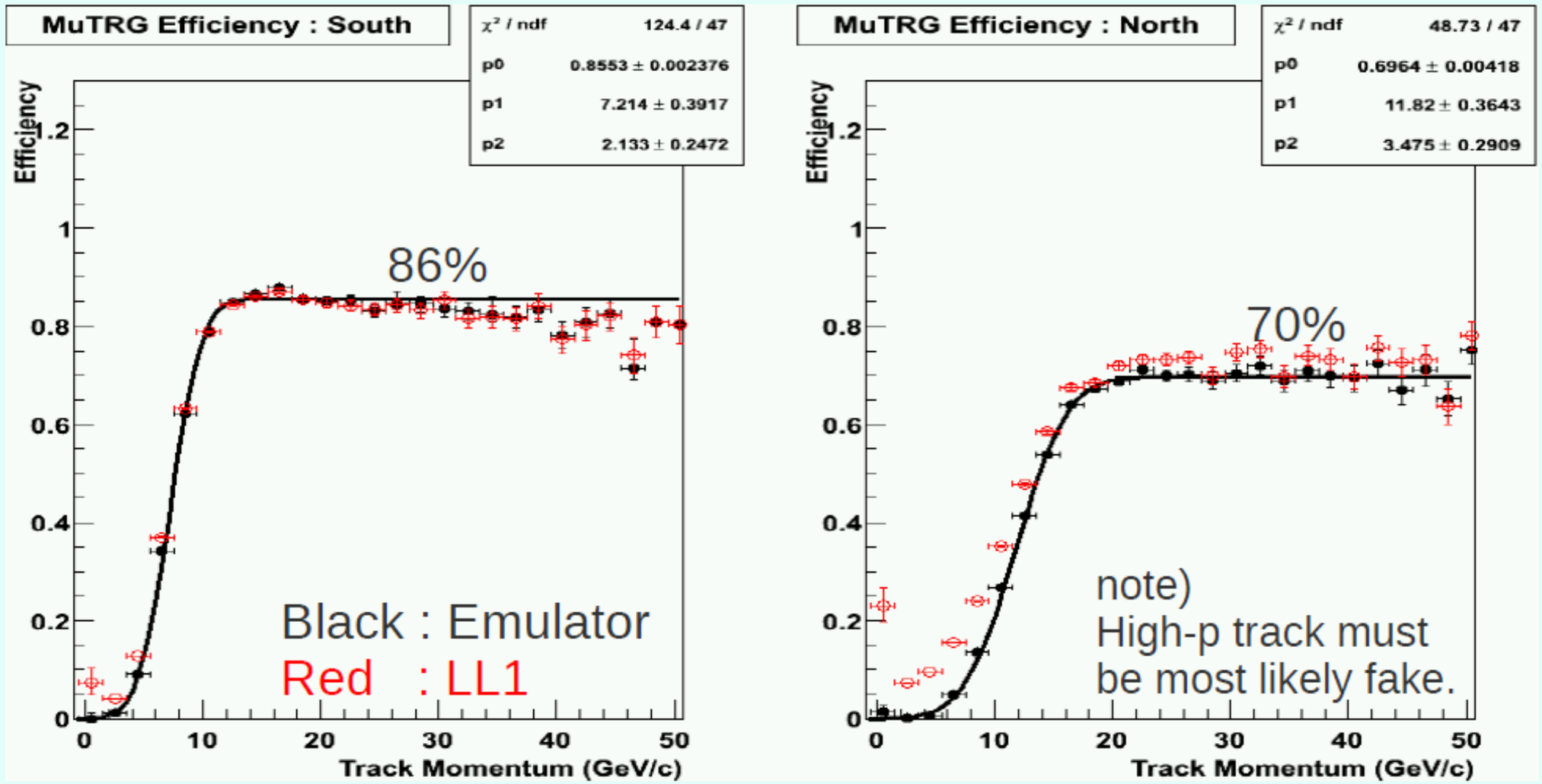
  - -90+% of signal is kept and factor ~ 5 reduction in jet dominated region

PHENIX Muon Trigger Upgrade

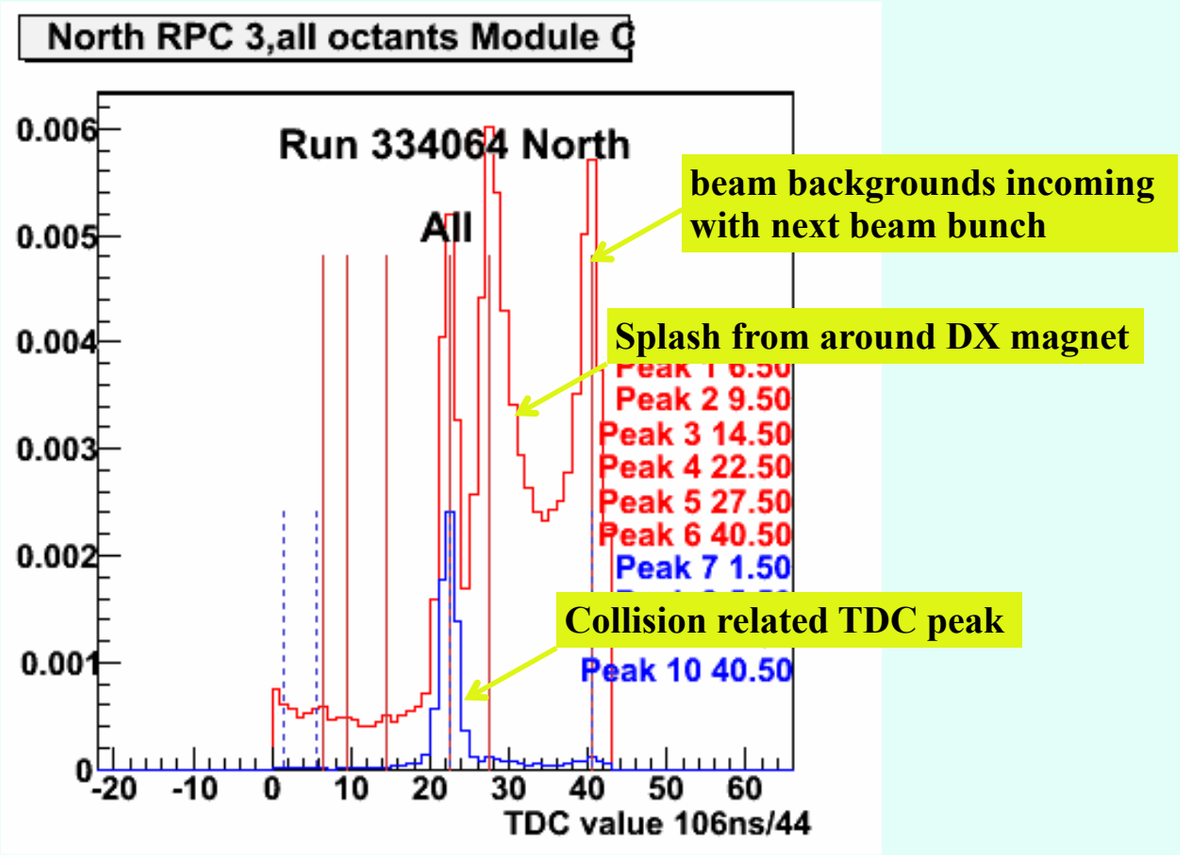


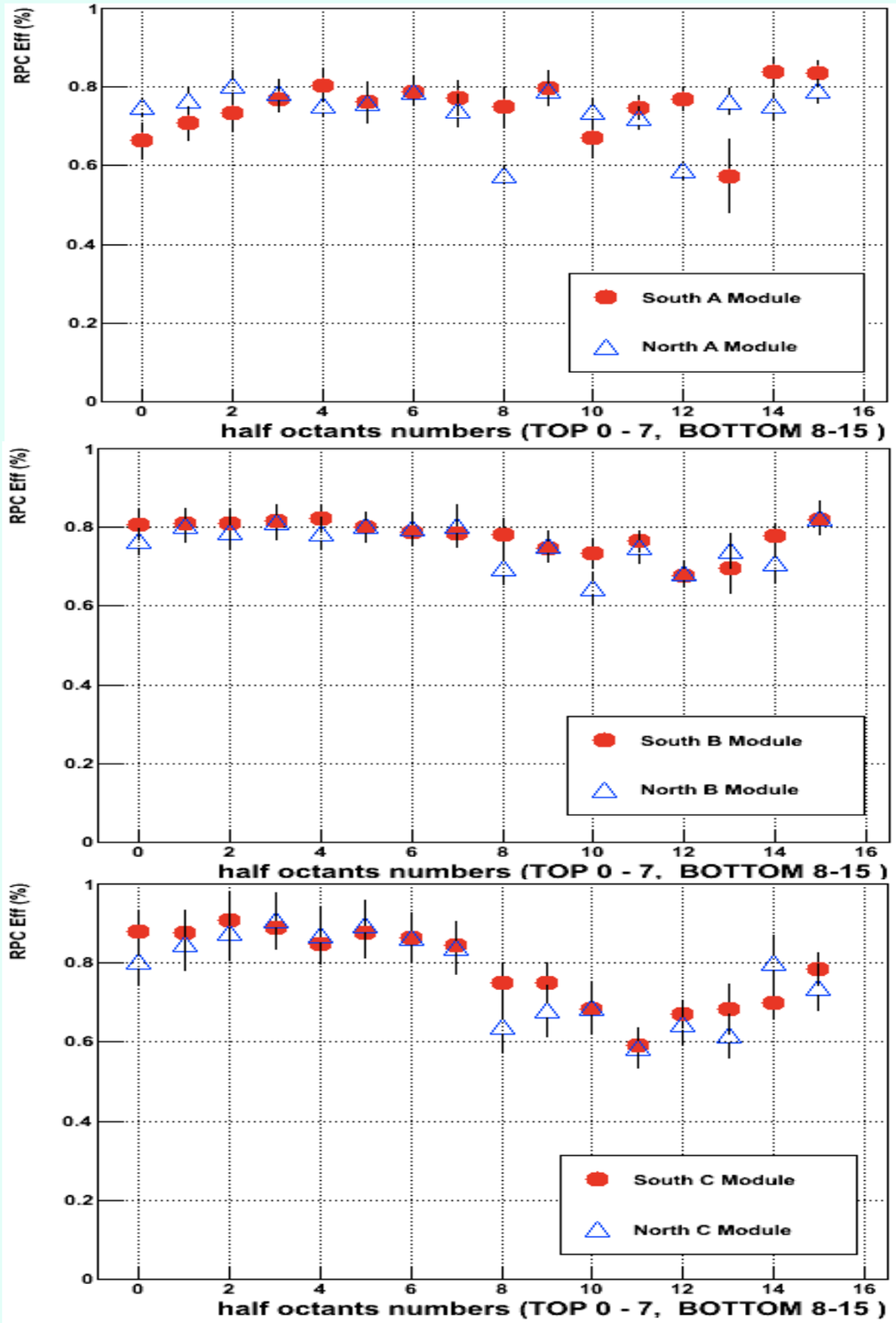
MuTRG Performance



- 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

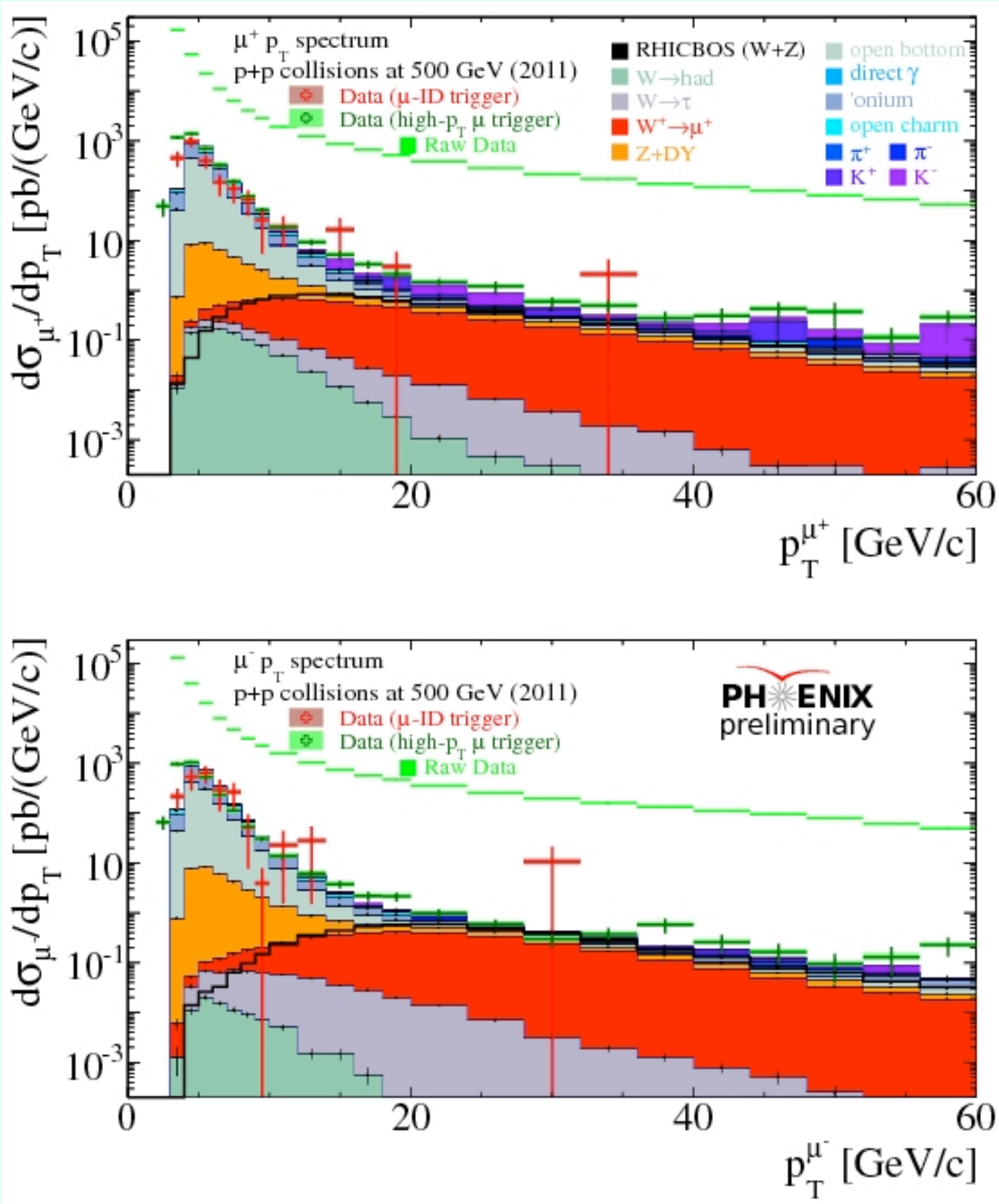
RPC-3 Performance





- RPC-3 TDC spectra identify background sources
  - ➡Additional shielding is being installed during this shutdown
- RPC-3 efficiency can be improved by using correct gas mixture and redistributing gas lines

$W^{\pm} \rightarrow \mu^{\pm}$ P_T Spectra at Muon Arms



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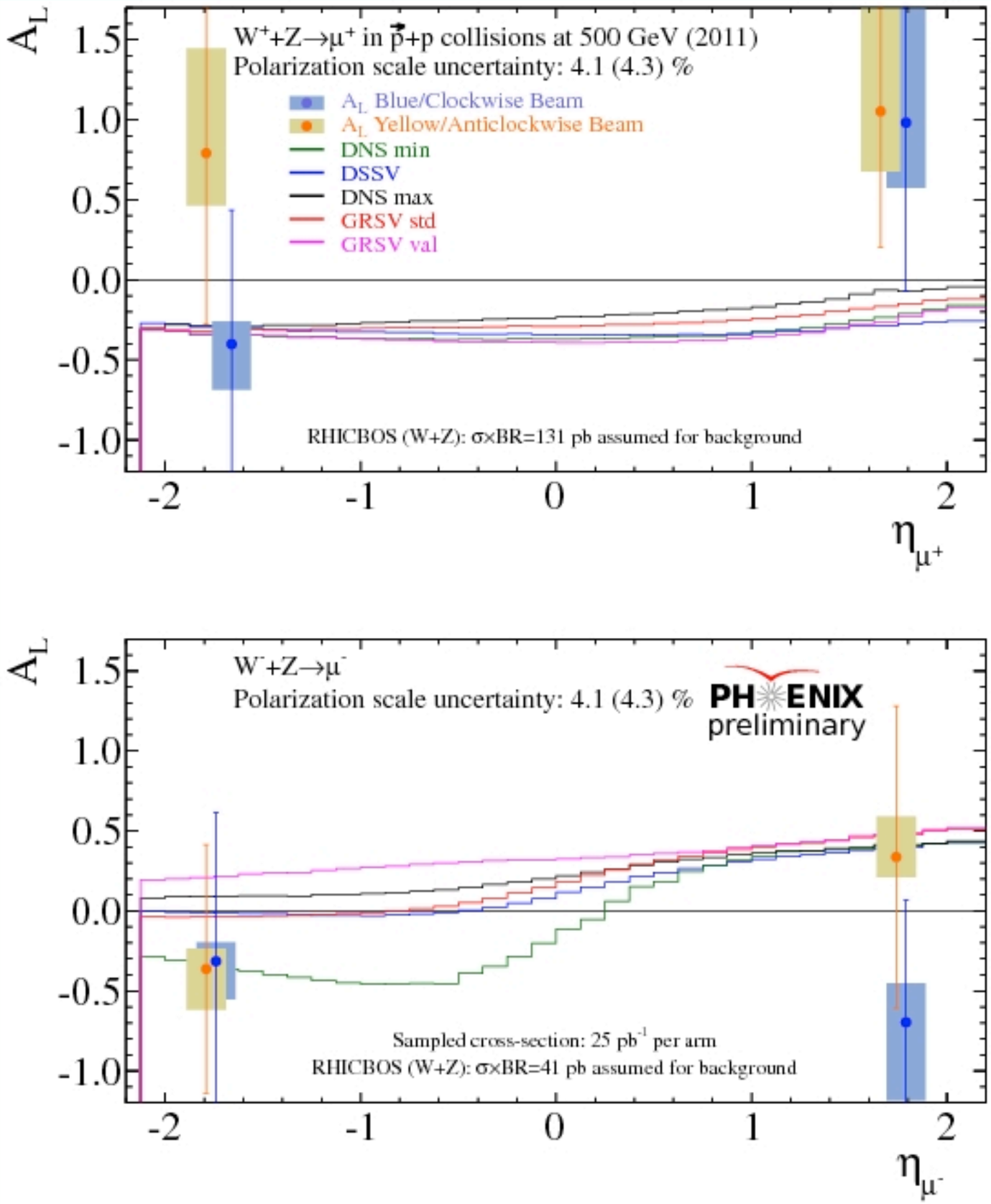

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