Measurement of W single spin asymmetries at PHENIX

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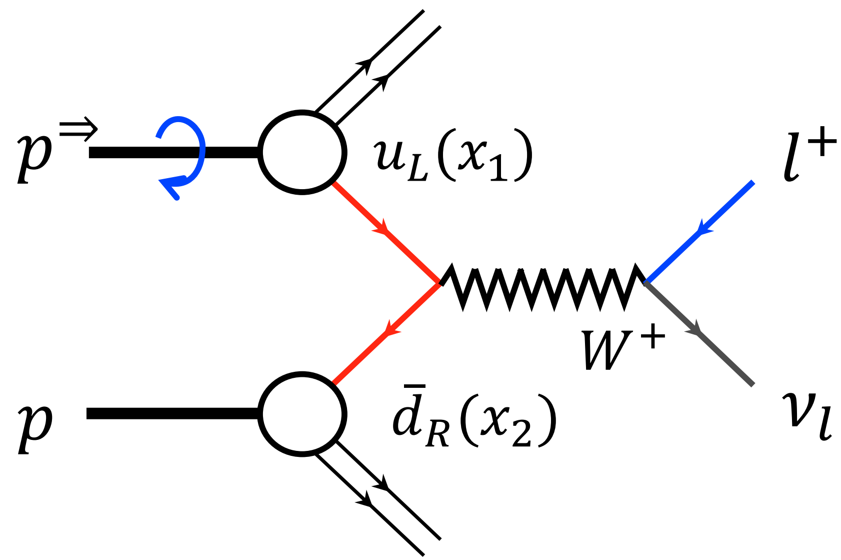
for the PHENIX Collaboration

W production: access to quark helicities

- Probing light quark sea via maximally parity violating W production and its lepton decay
- W couples only to left-handed quarks and right-handed anti-quarks
- W^+/W^- distinguishes between quarks and anti-quarks
- No fragmentation needed
- High Q^2 set by W mass

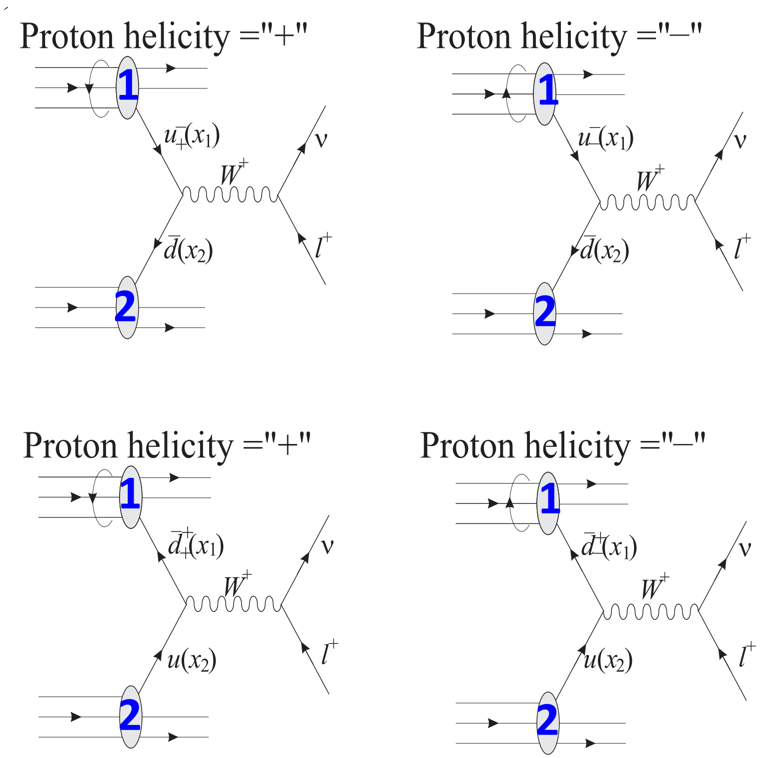


$$u_L \bar{d}_R \rightarrow W^+$$

$$d_L \bar{u}_R \rightarrow W^-$$

A_L^W Measurement

- Longitudinal single spin asymmetries directly access to quark helicity PDFs
- Combined with weak decay kinematics
  - quark flavor mixed at mid-rapidity
  - sensitive to anti-quark at forward and backward rapidity



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

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

A_L^W Measurement

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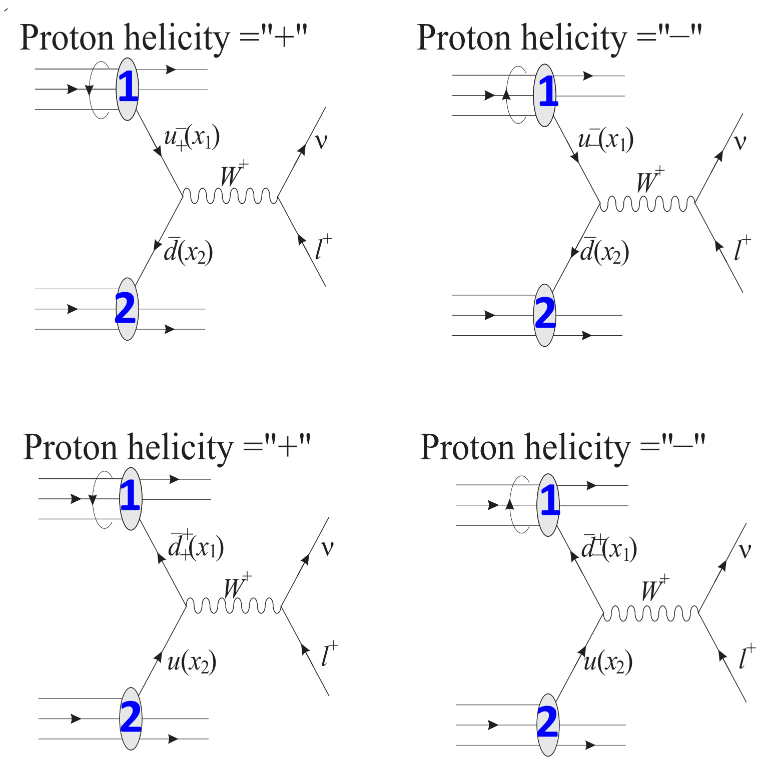
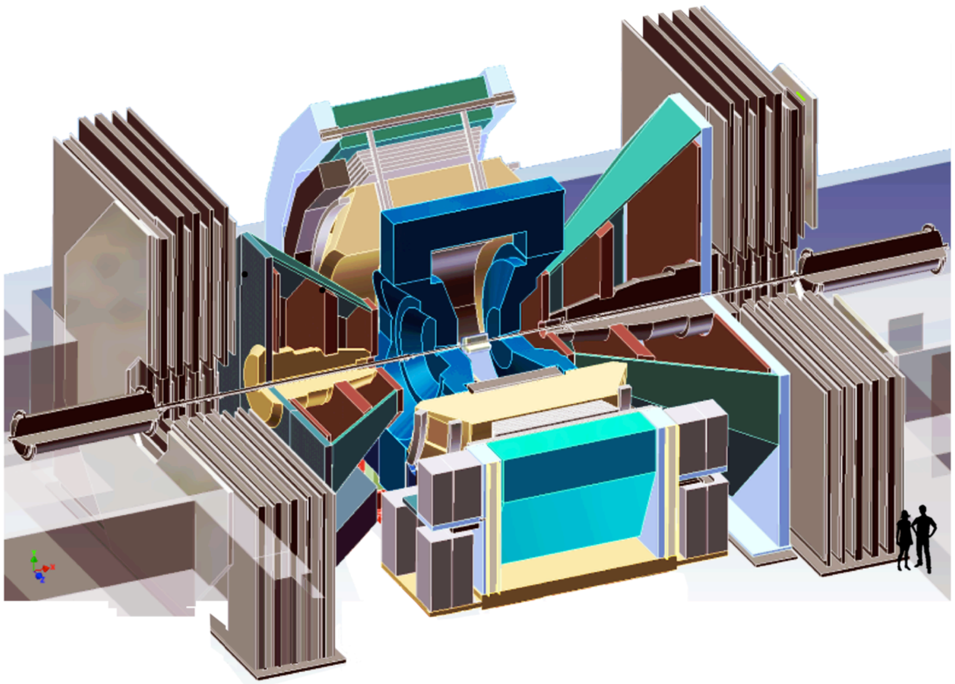


$$A_L^{W^+\to\ell^+} \approx \frac{\Delta\bar{d}(x_1)u(x_2)(1+\cos\theta)^2 - \Delta u(x_1)\bar{d}(x_2)(1-\cos\theta)^2}{\bar{d}(x_1)u(x_2)(1+\cos\theta)^2 + u(x_1)\bar{d}(x_2)(1-\cos\theta)^2}$$

$$A_L^{W^-\to\ell^-} \approx \frac{\Delta\bar{u}(x_1)d(x_2)(1-\cos\theta)^2 - \Delta d(x_1)\bar{u}(x_2)(1+\cos\theta)^2}{\bar{u}(x_1)d(x_2)(1-\cos\theta)^2 + d(x_1)\bar{u}(x_2)(1+\cos\theta)^2}$$

PHENIX

PHENIX W measurements



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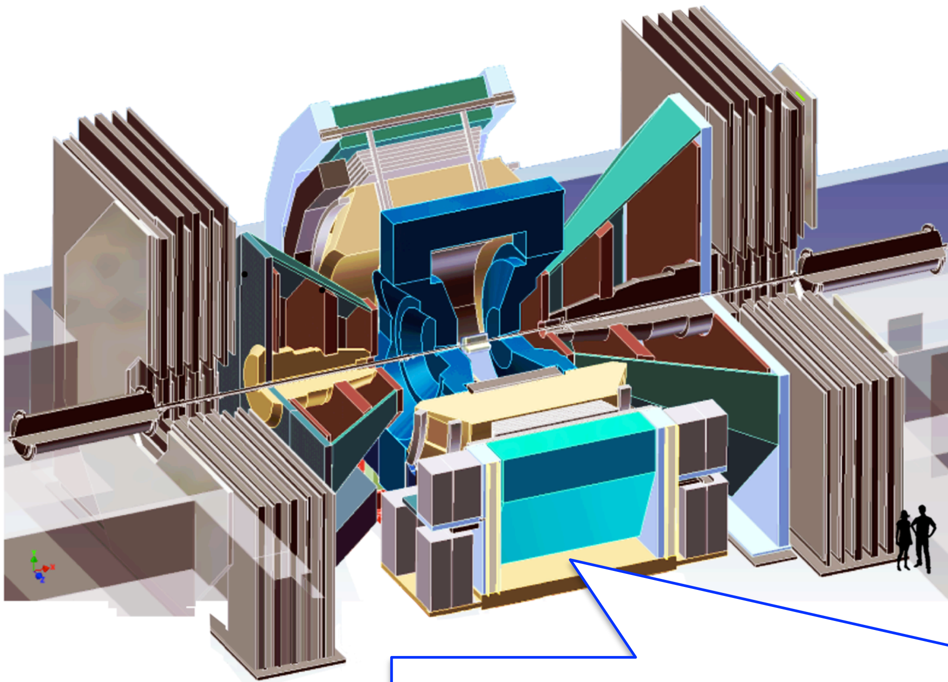
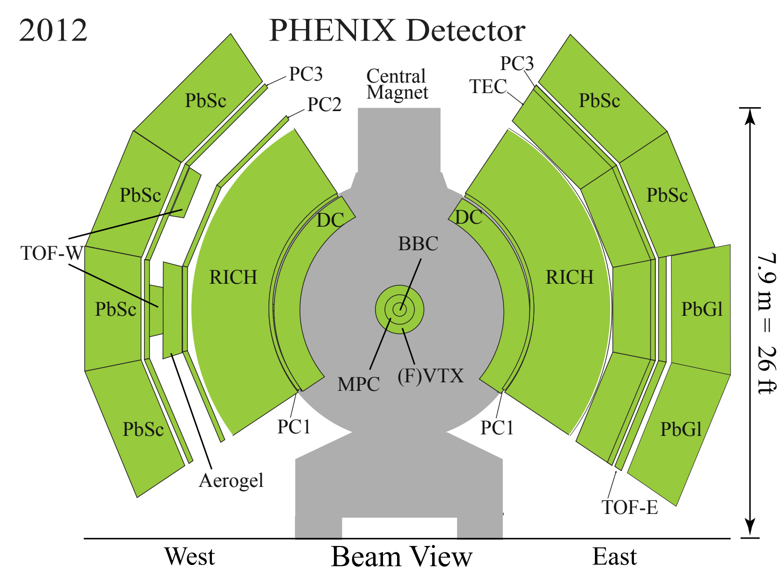
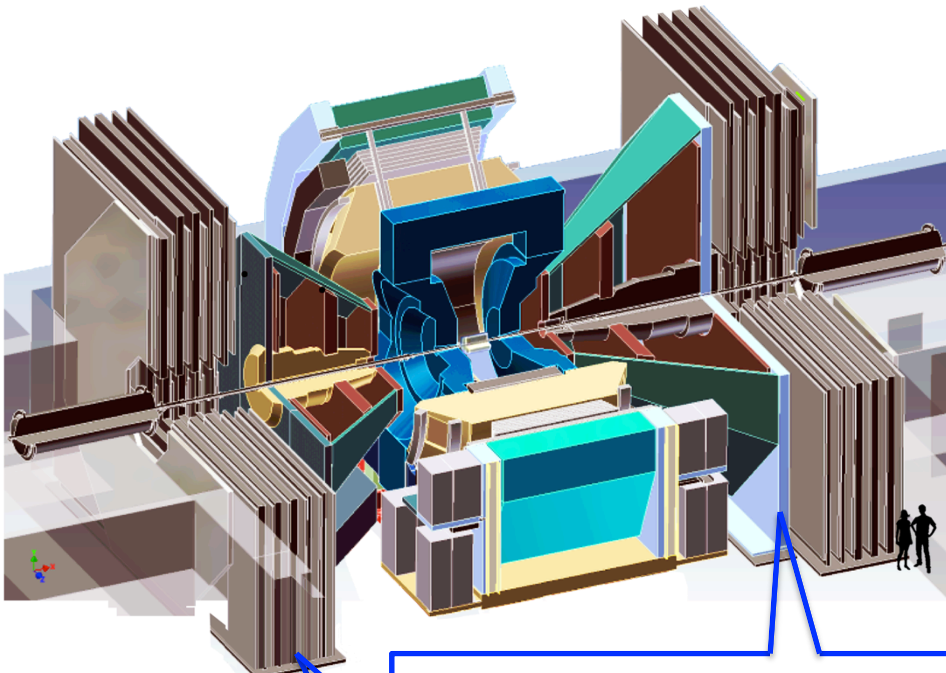


PHENIX mid-rapidity

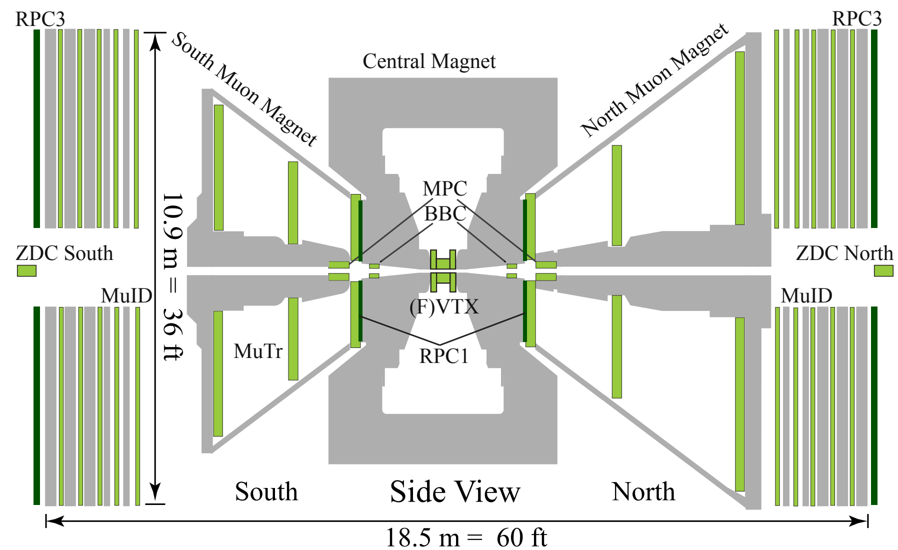


- $W^{\pm} \rightarrow e^{\pm} + \nu_e$ channel
- Two arm detector: $\Delta\phi = (\pi/2)\times 2$, $|\eta| < 0.35$
- High energy electron trigger by Electromagnetic Calorimeter
- Drift chamber (DC) and Pad chamber (PC) for tracking and charge separation

PHENIX W measurements

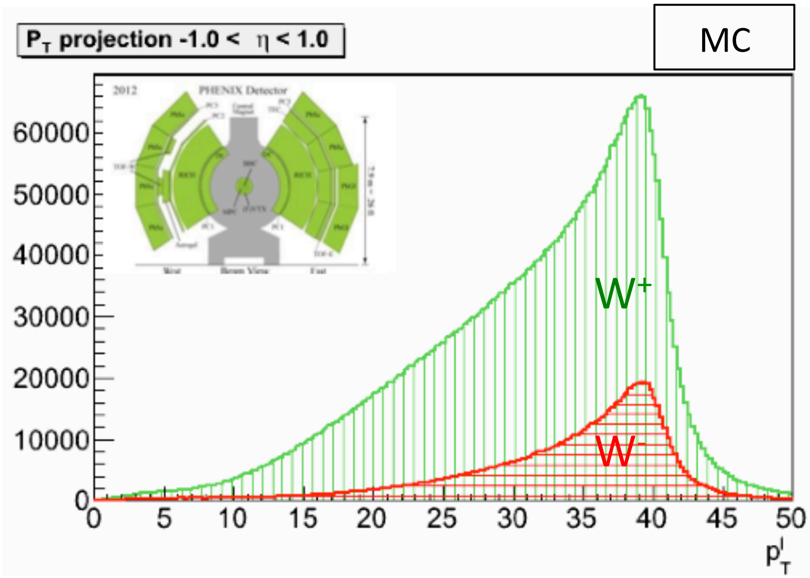


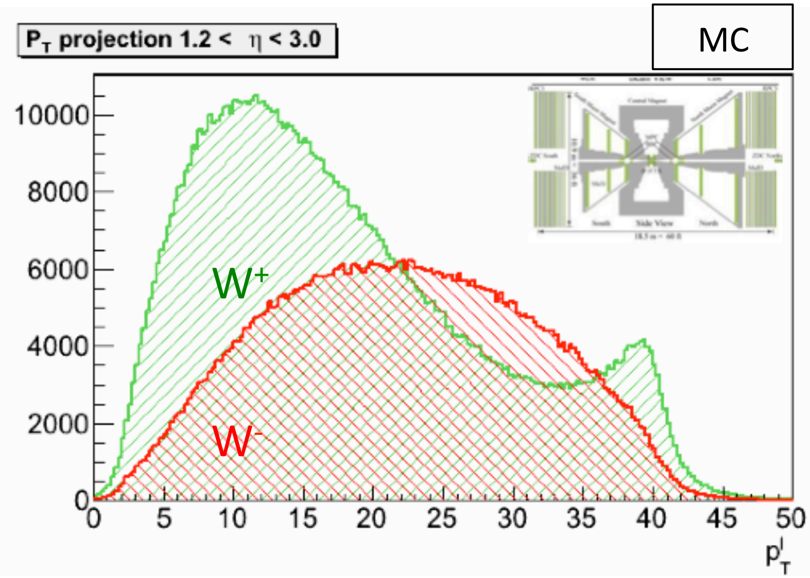
PHENIX forward rapidity



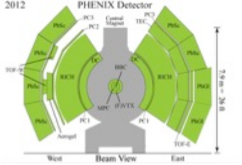
- $W^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}$ channel
- Two arm detector: $1.2 < |\eta| < 2.4$, Full azimuthal coverage
- Muon tracking chamber (MuTr)
- Muon Identifier (MuID) for PID
- Upgrade in 2012: high pT trigger, Resistive Plate Chambers (RPC), Forward Silicon Trackers (FVTX)

$W^{\pm} \rightarrow \ell^{\pm}$ Kinematics



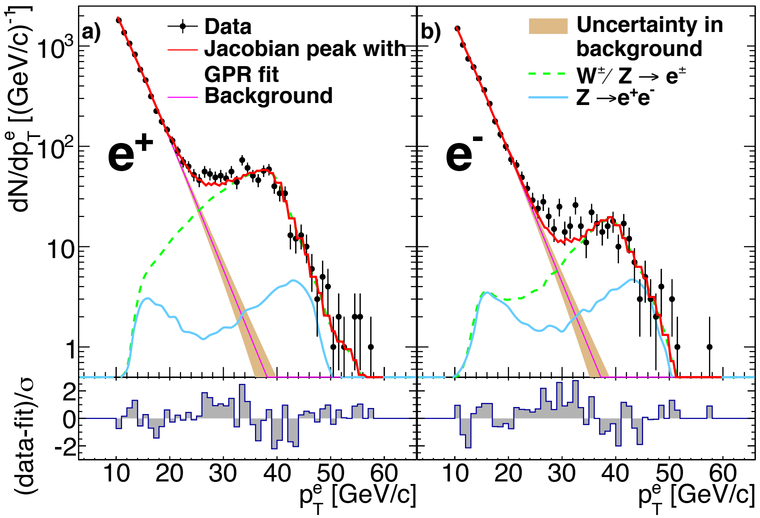


- Different kinematics at mid-rapidity and forward rapidity
- Jacobian peak at mid-rapidity
- Suppressed/no Jacobian peak at forward rapididity
- Access via two decay channels: electrons at mid-rapidity and muons at forward rapidity
- Different analyses to identify W signals in mid- and forward rapidities

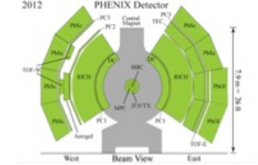


Mid-rapidity measurement

Phys. Rev. D 93, 051103(R)



- Clear electron signal via Jacobian peak
- 97% (94%) of signal remains for e^+ (e^-) in the signal region (30-50 GeV/c)



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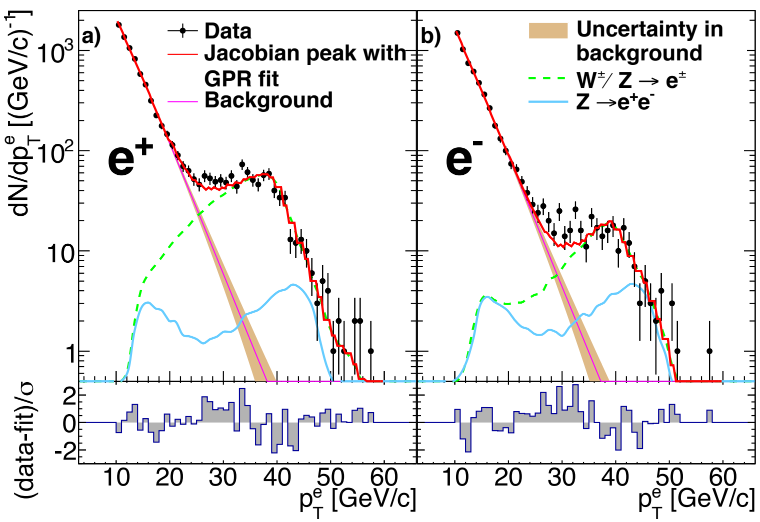

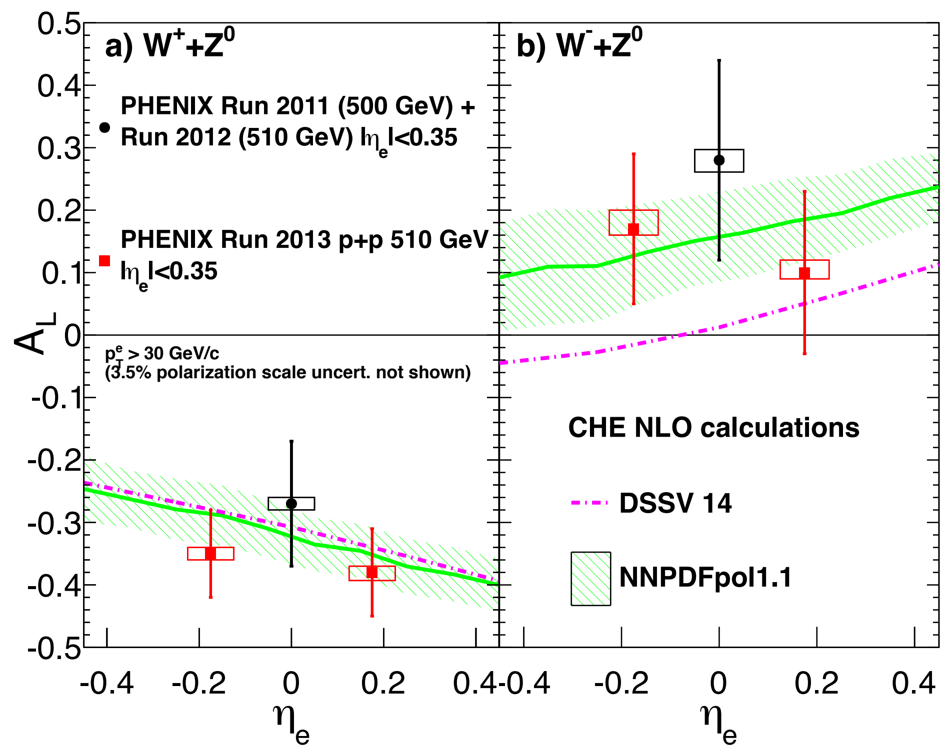

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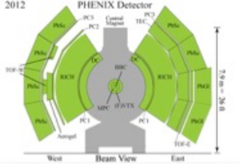
- Large asymmetries
- Data above latest global fit (DSSV14) for e-
- Consistent with the STAR data



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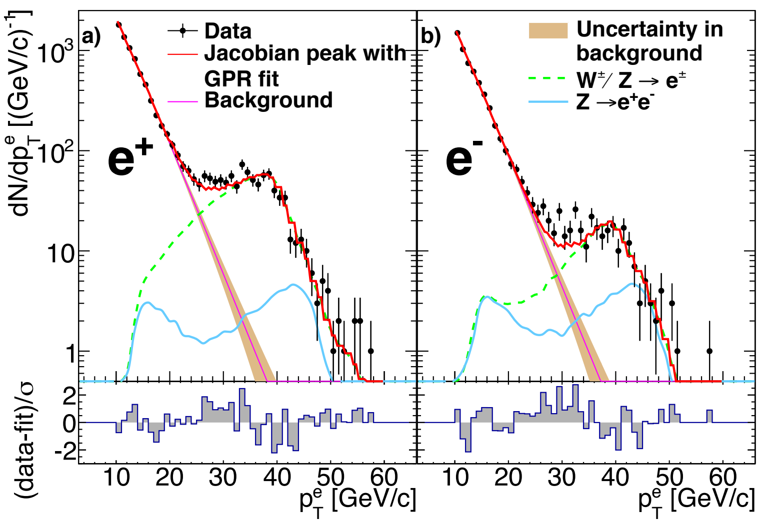

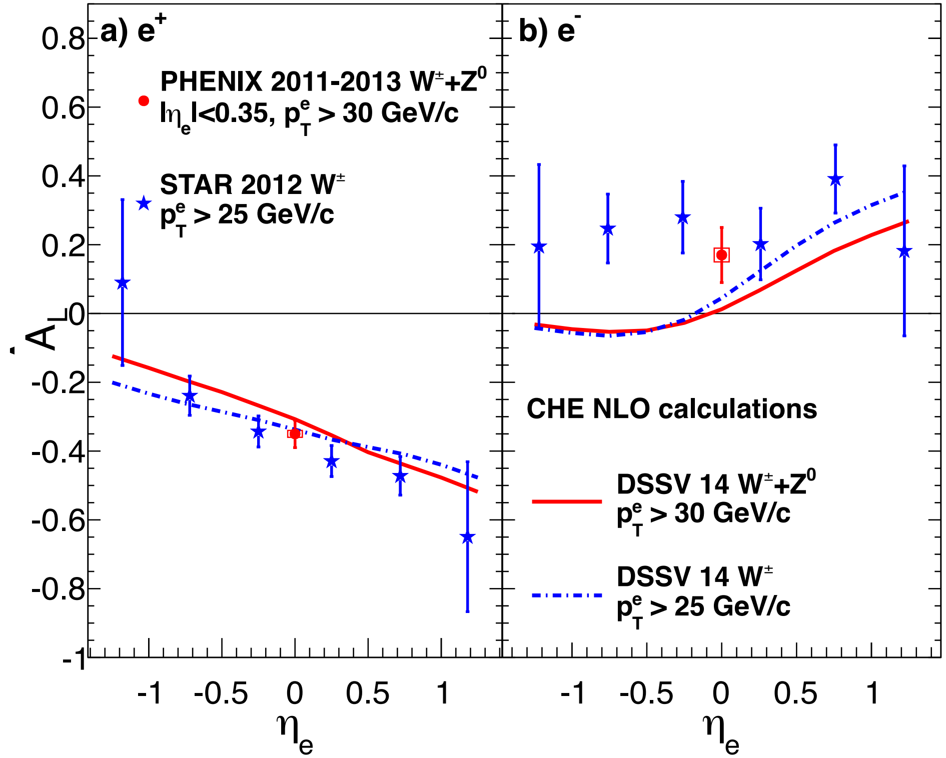

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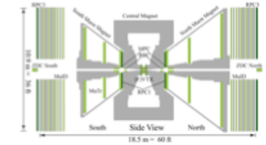
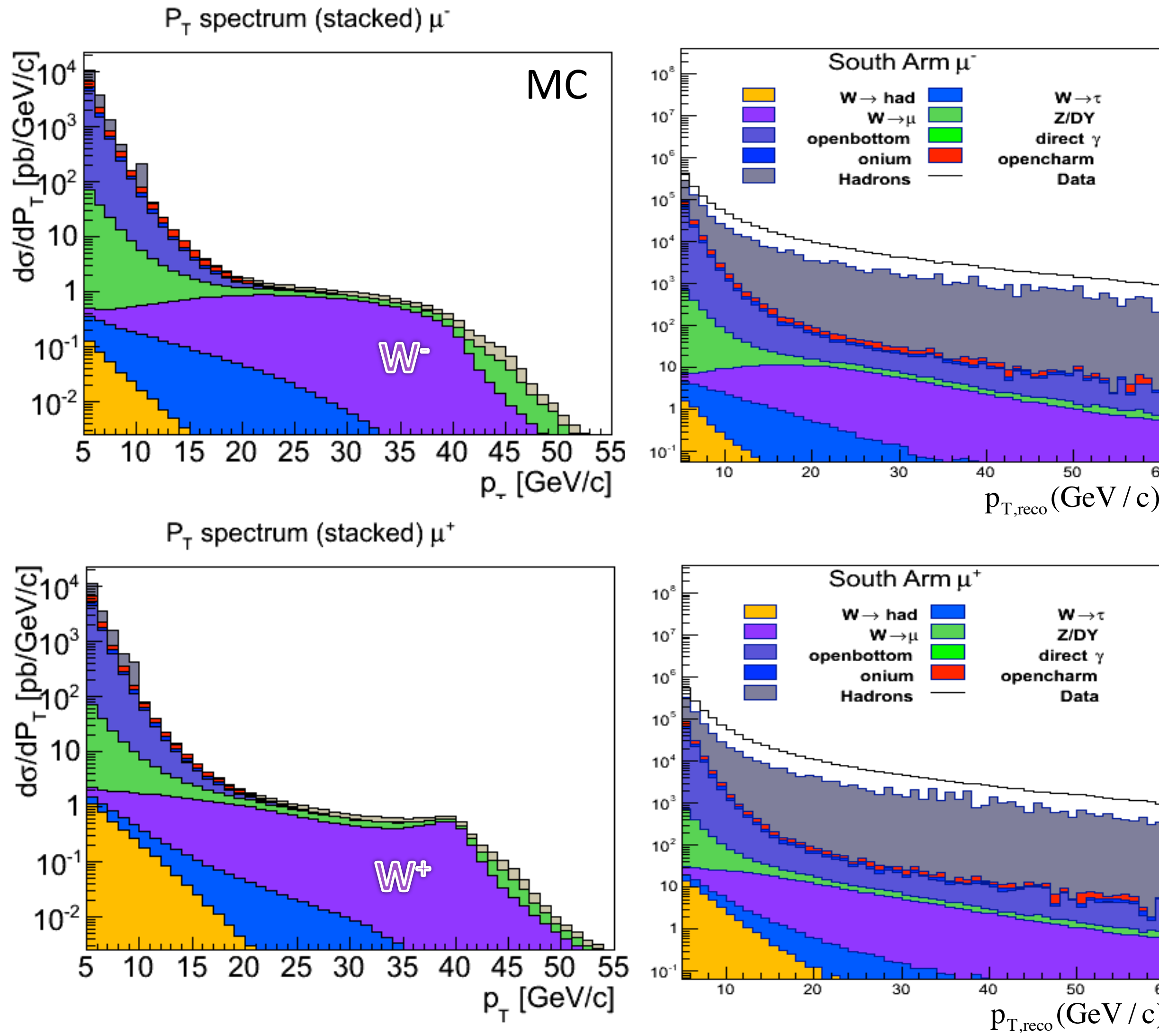
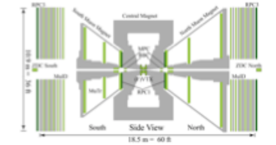


Forward measurement

- Suppressed/no Jacobian peak
- Real muon decays from Heavy flavour and Drell-Yan get smeared into high pT region.
- Large hadron BG contamination (low pT charged kaons, pions) → fake high pT muons
- Looking for W at pT > 16 GeV/c
- Signal/background separation is challenging

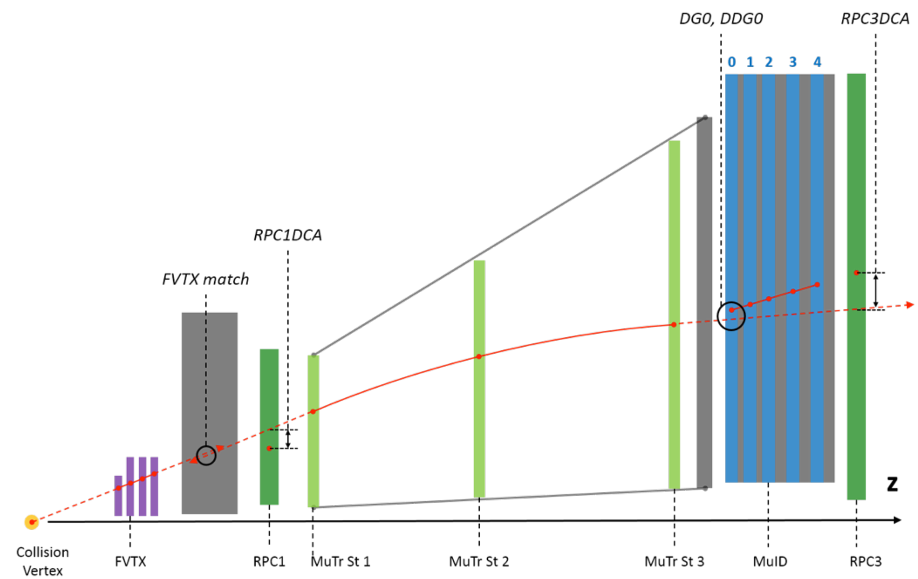


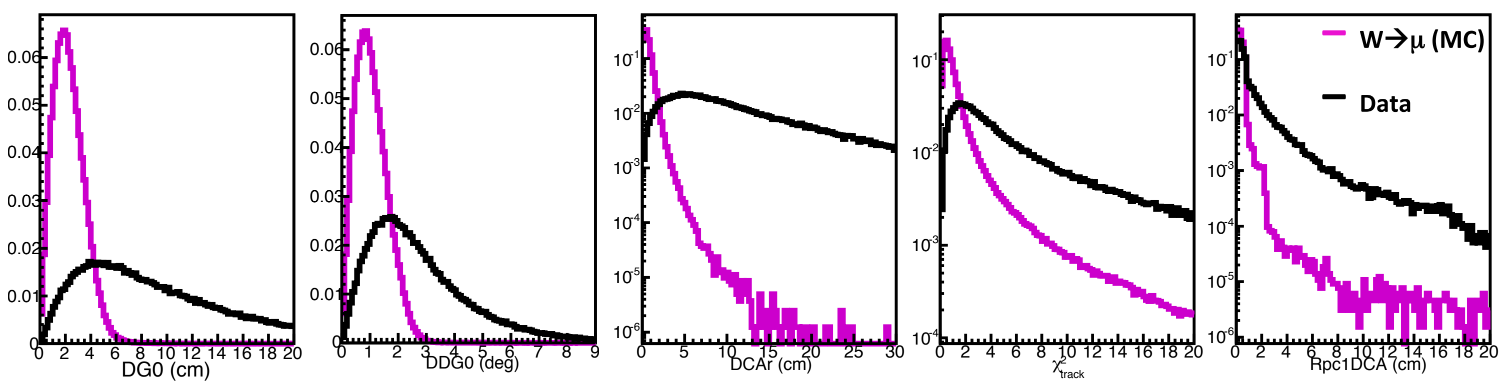


Forward measurement

courtesy of C. Kim

- Reducing BG by likelihood based pre-selection
- Multivariate analysis: 5-9 signal/BG sensitive kinematic variables
- Define likelihood ratio (Wness) based on signal (MC) and BG shapes (data)





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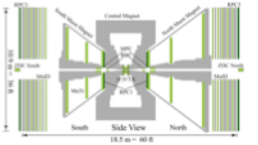

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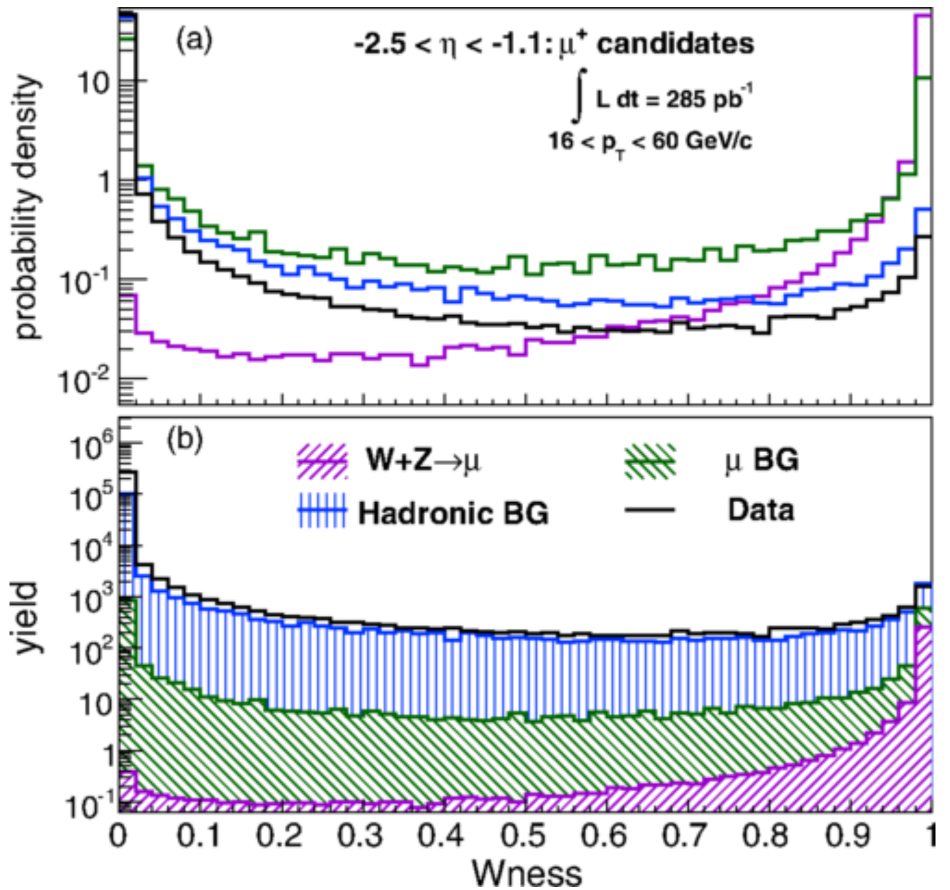
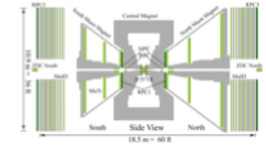


$$\mathrm{Wness} \equiv \frac{\lambda_{\mathrm{sig}}(\mathrm{x})}{\lambda_{\mathrm{sig}}(\mathrm{x}) + \lambda_{\mathrm{BGs}}(\mathrm{x})}$$

Wness
- Wness → 1: signal-like event
- Wness → 0: background-like event



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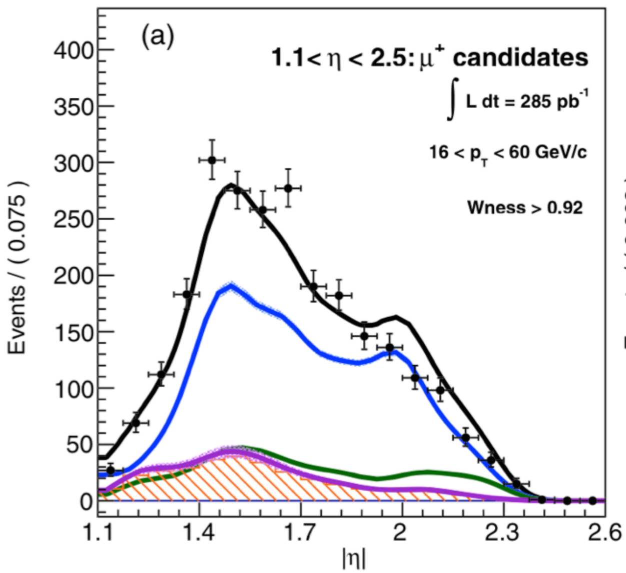
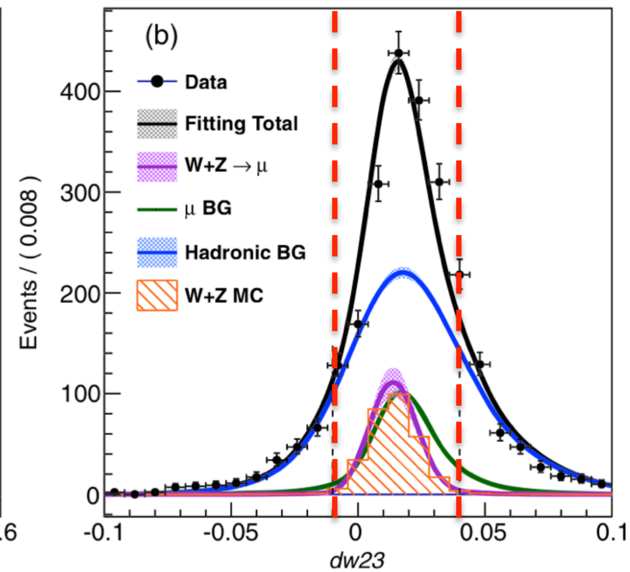
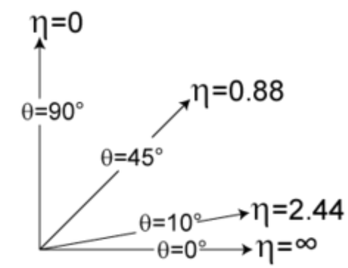
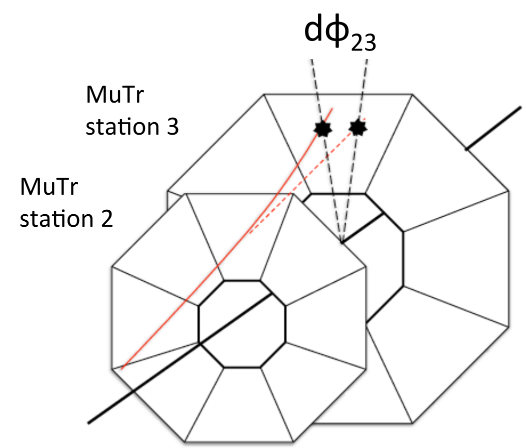




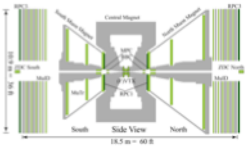
$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$





$$dw23 = p_T \times sin(\theta) \times d\phi_{23}$$

- Performed 2D unbinned maximum likelihood fit to estimate Signal-to-Background ratio
- Two independent variables: rapidity(η), azimuthal bending angle (dw23)



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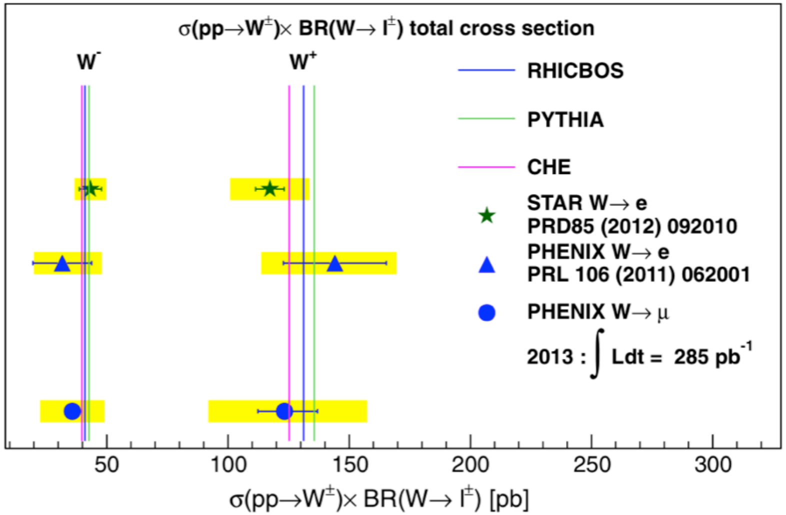
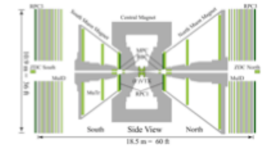
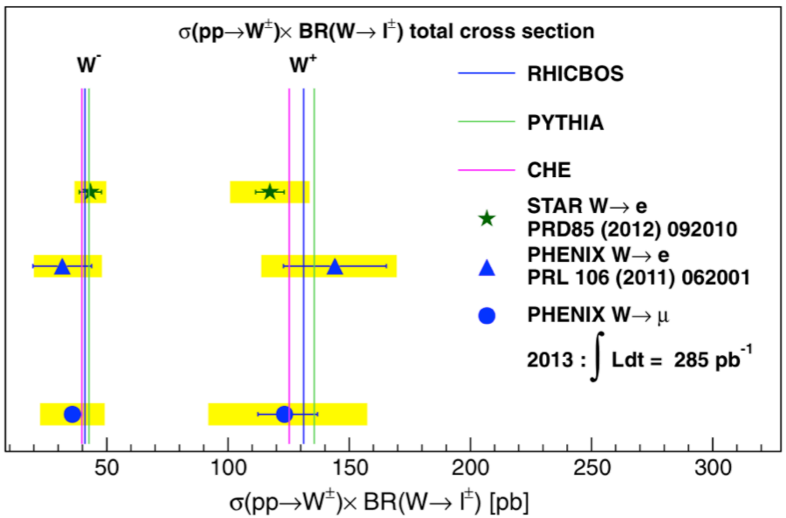


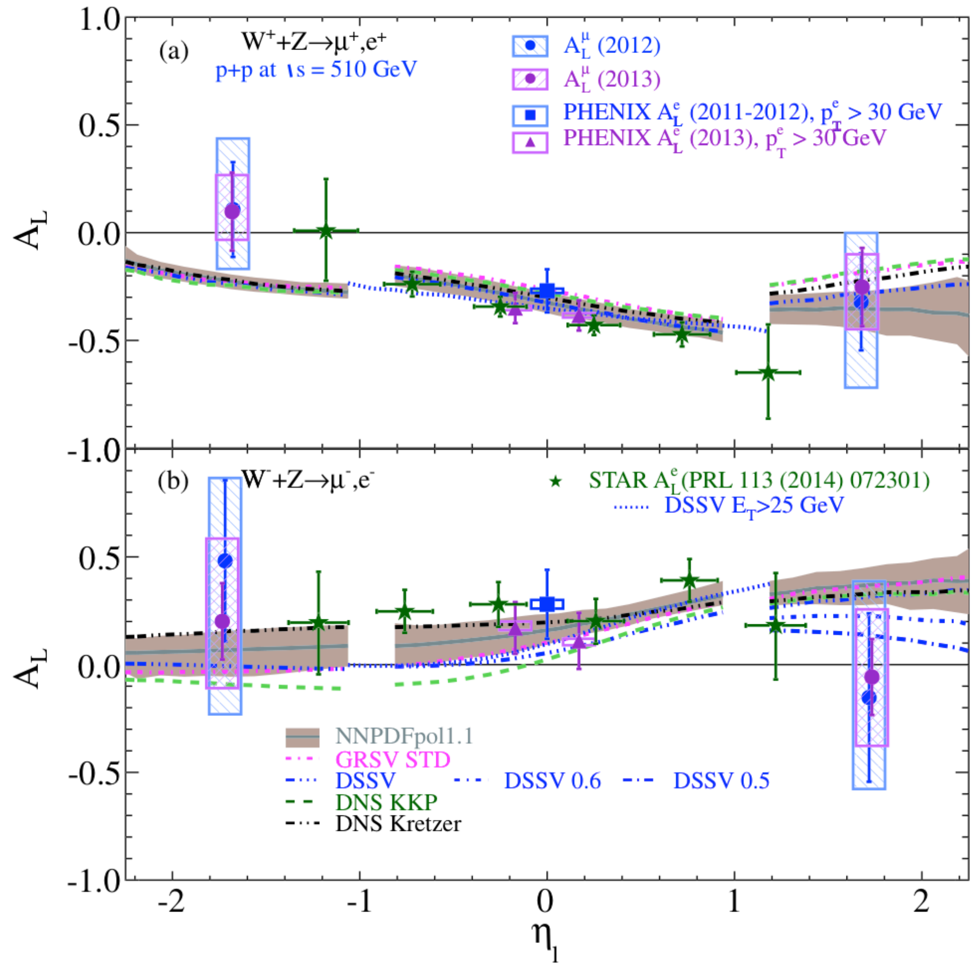
- First results from muon decay channel published
- Cross sections consistent with previous measurements and theoretical calculations within uncertainties

Phys. Rev. D 98, 032007 (2018)

Forward measurement







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Phys. Rev. D 98, 032007 (2018)

Summary

- W measurement provides clean access to light sea quark helicity PDFs
- PHENIX W results with dedicated RHIC longitudinal data (2011-2013) have been published:

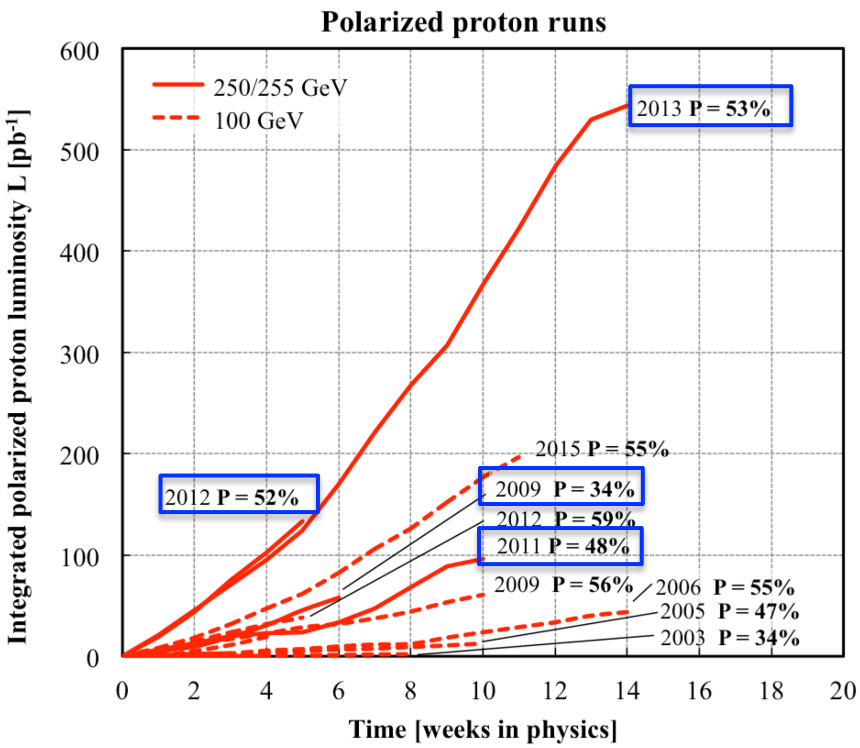
  Phys. Rev. D 93, 051103(R) (mid-rapidity),

  Phys. Rev. D 98, 032007 (forward rapidity)
- PHENIX results will be an important constraint on the extraction of light sea quark helicity PDFs.

Backup

Polarized Proton Data

- First mid-rapidity A_L measurement at 500 GeV in 2009
- Followed by over 300 pb^{-1} data taken with higher beam polarization (2011-2013)
- Average beam polarization of ~57% in 2012 and 55% in 2013



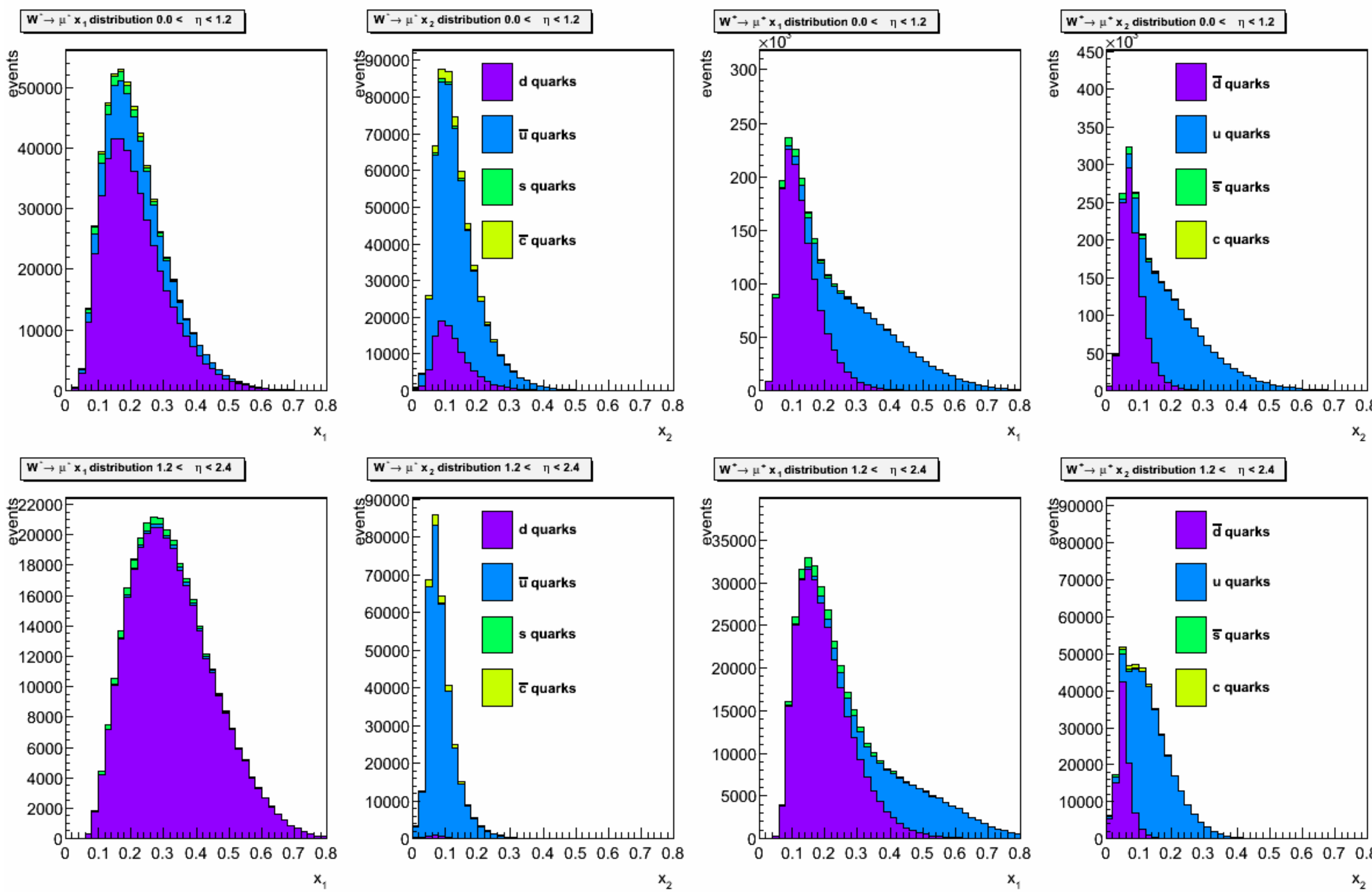
x1, x2

PYTHIA

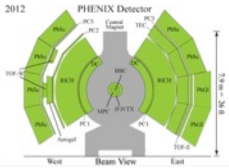
W⁻ W⁺

Central

Forward



Mid-rapidity Measurement



- Jacobian peak at pT ~ $M_W/2$
- Backgrounds (BG):

  Reducible:

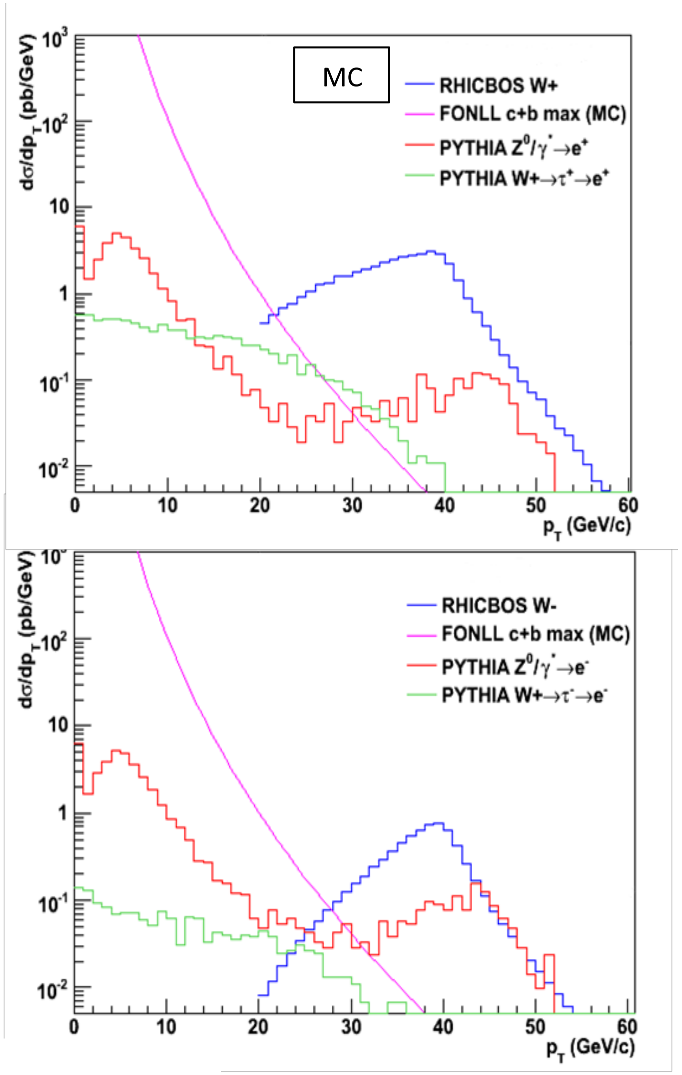
  - Photons from neutral pion/eta decays followed by $e^{\pm}$ pair production

  - Cosmic rays

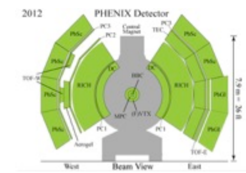
  - Beam related backgrounds

  Irreducible:

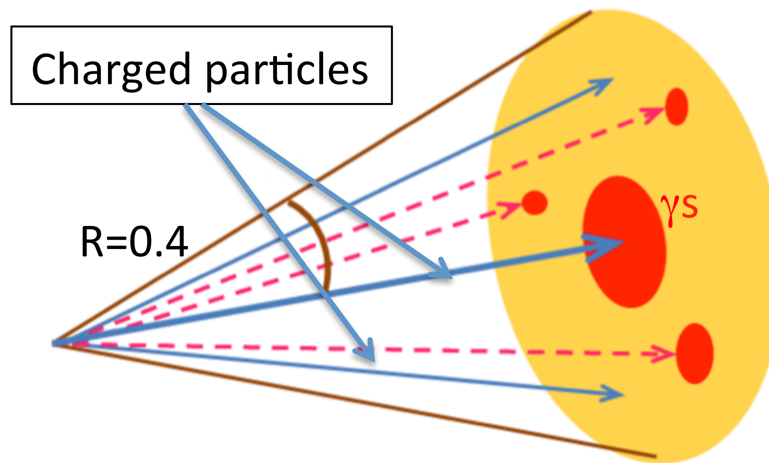
  - Z, charm and bottom, other W decay



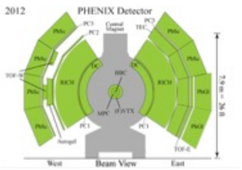
Mid-rapidity Measurement

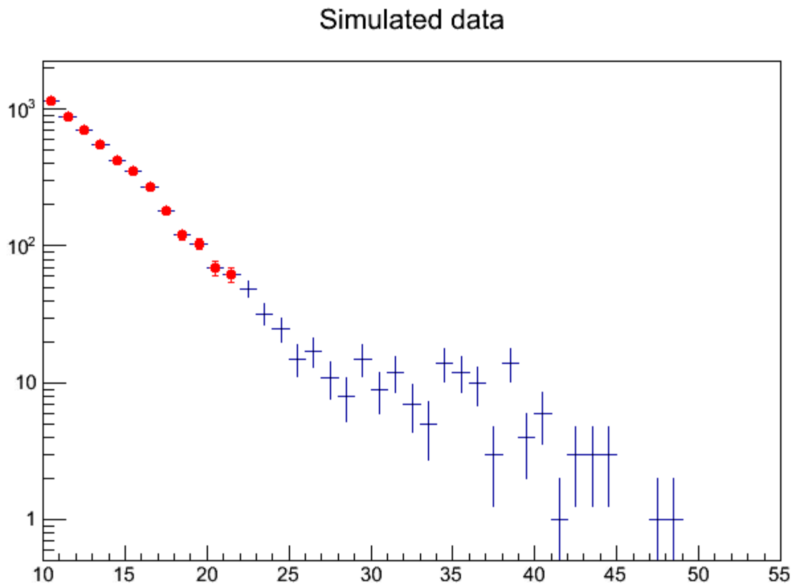


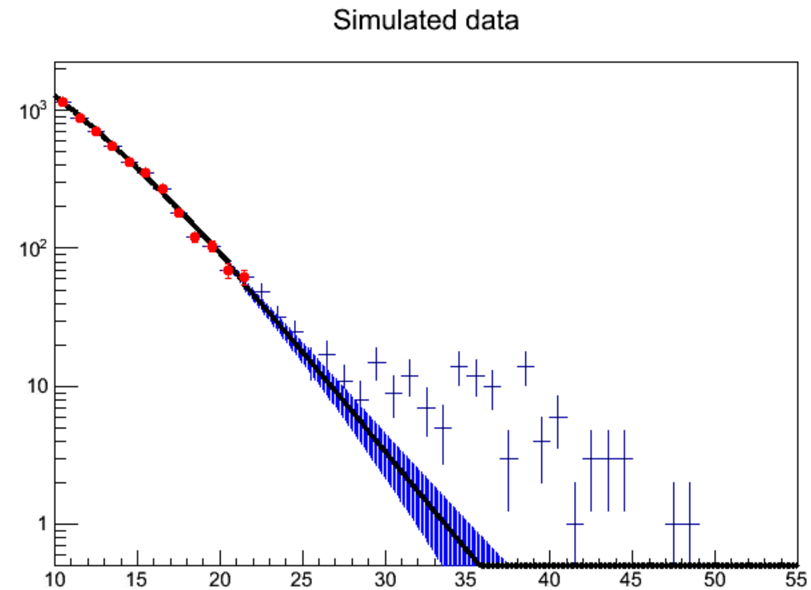
- Measure high pT electrons using EMCal
- DC-EMCal matching (Δϕ<0.01 rad)
- Relative isolation cut - Main BG discriminator
  – Energy in a cone of R=0.4 devided by energy of the candidate
  – Reduces background by a factor of 10



Gaussian Process Regression







- Use background control region to extrapolate a shape in the signal region (30 to 50 GeV/c)
- The GPR gives a background contribution and uncertainty
- Cross check with a classical functional form (modified power law) showed good agreement

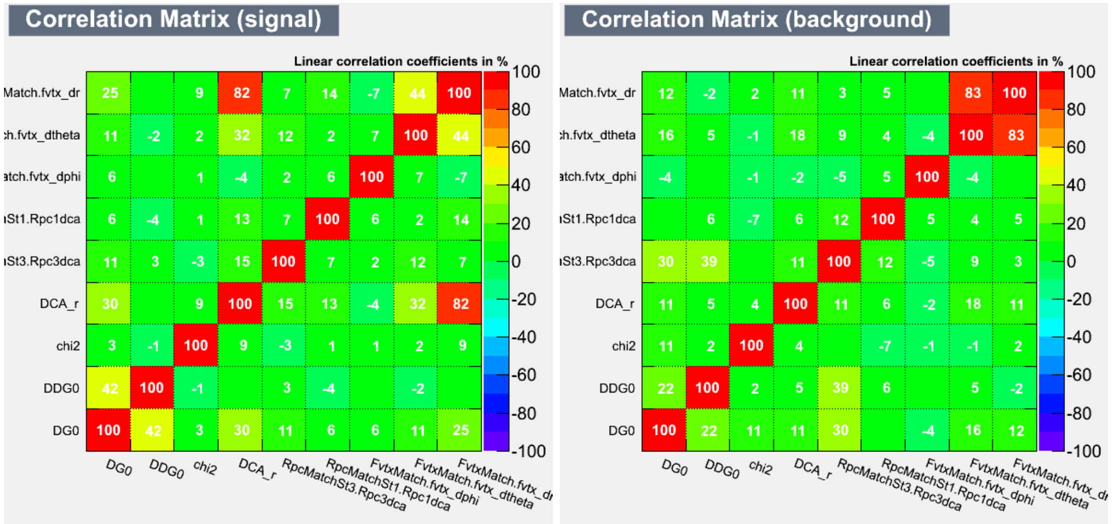
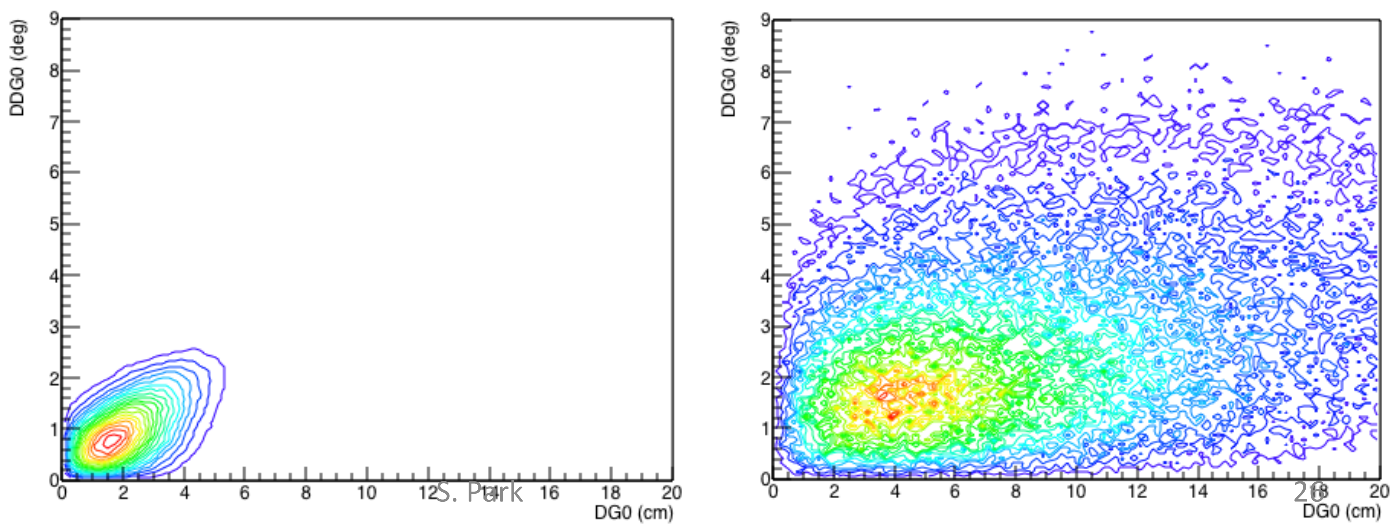
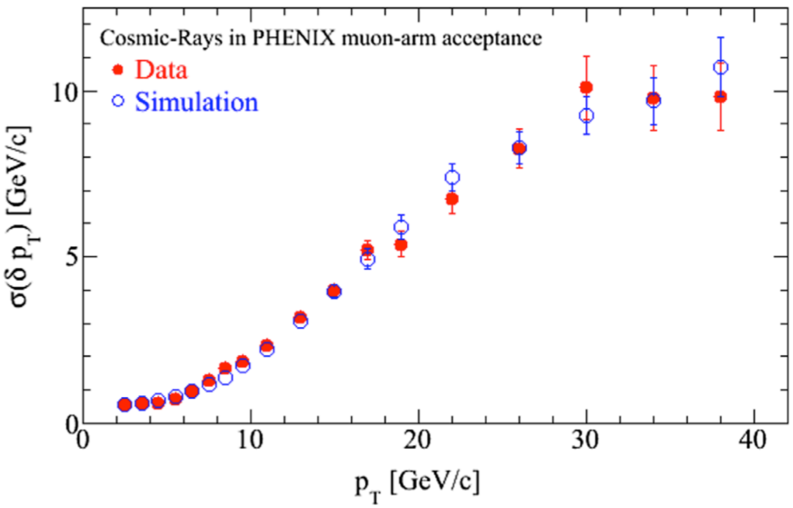
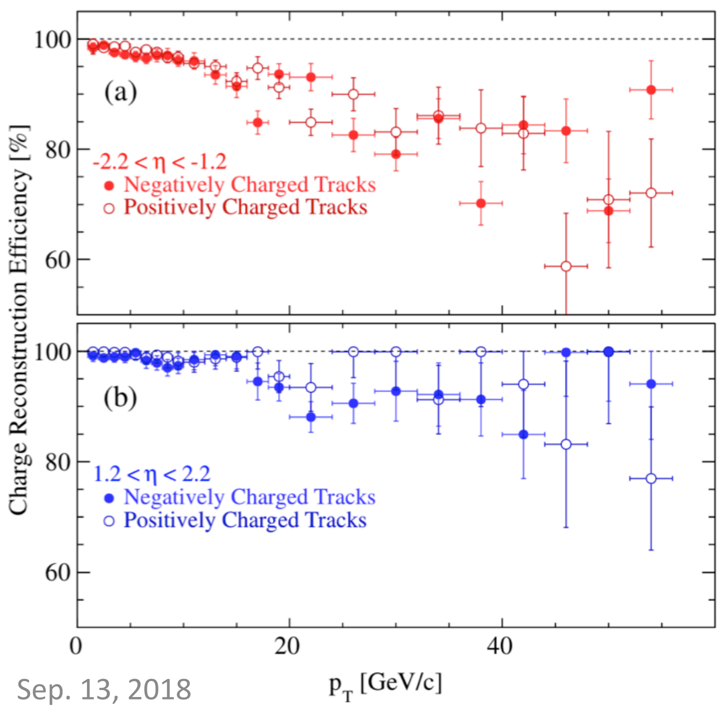
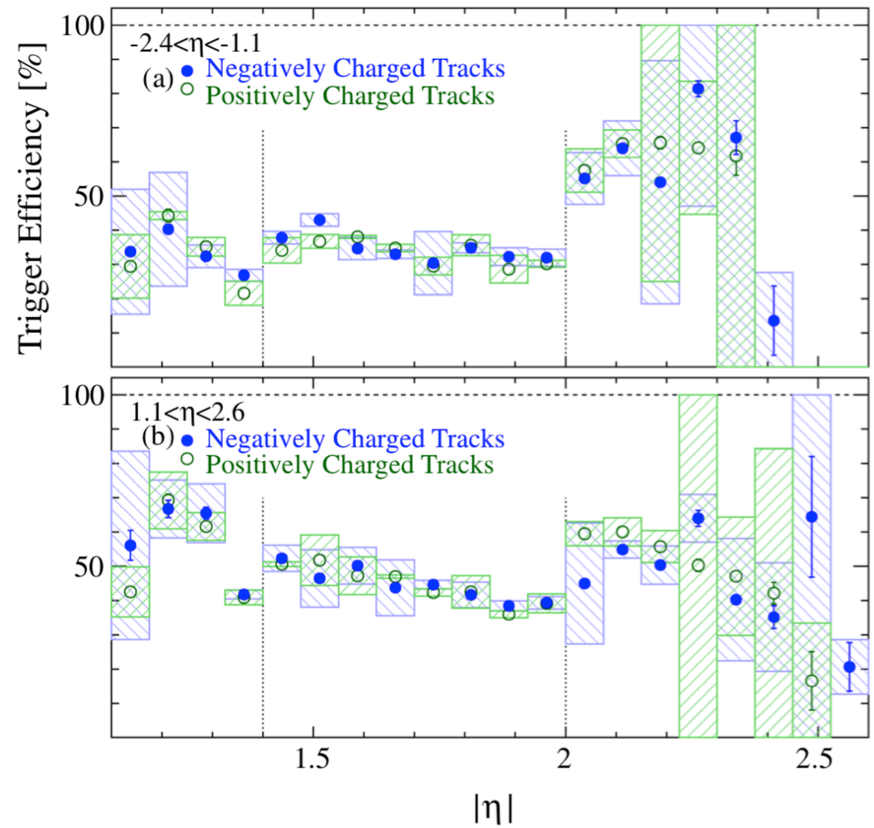


Figure 1.1: Correlation coefficients between various kinematic variables used in the analysis. The left panel shows the MC simulated signal while the other panel show the data.

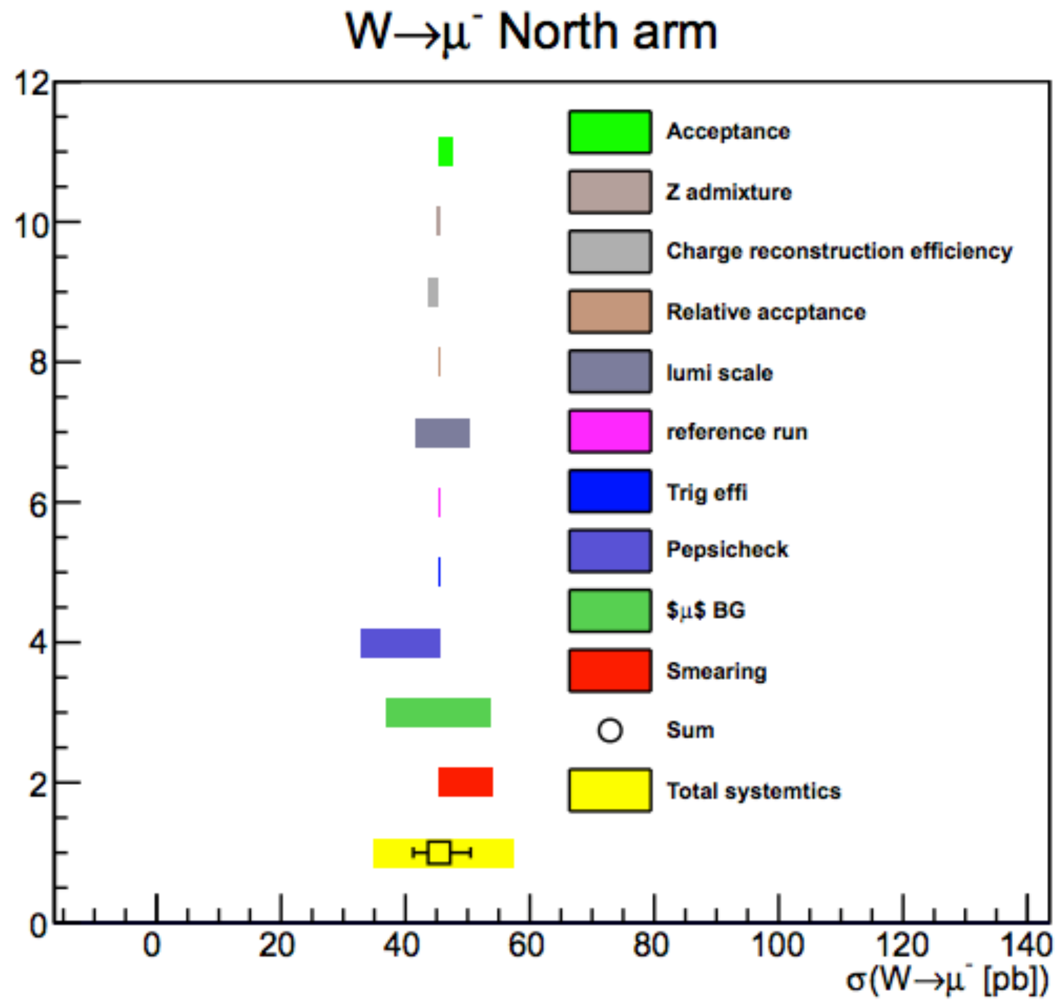



Cosmic-Rays in PHENIX muon-arm acceptance
Data
Simulation
σ(δ p_T) [GeV/c]
p_T [GeV/c]

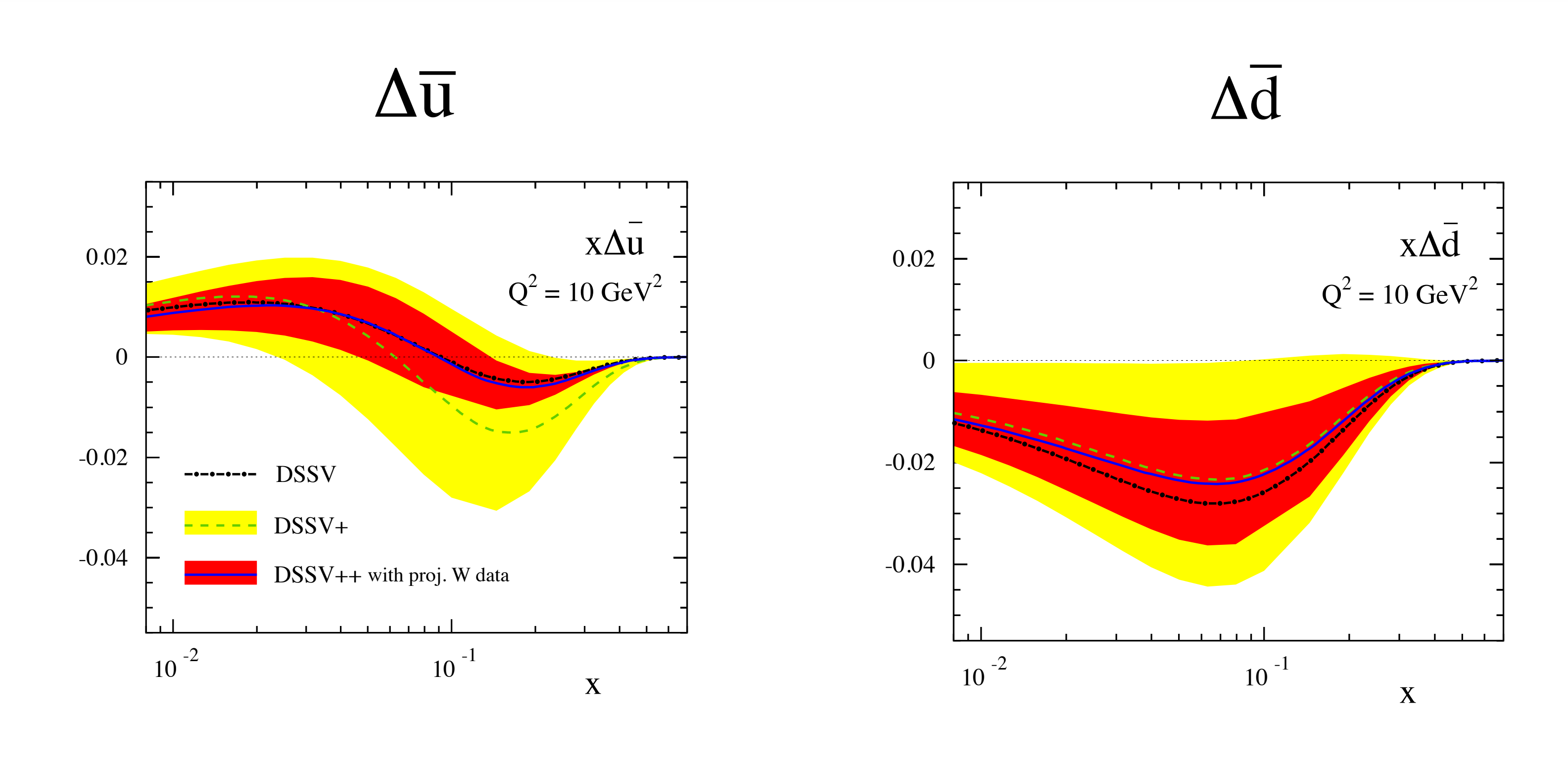

(a)
-2.2 < η < -1.2
Negatively Charged Tracks
Positively Charged Tracks
(b)
1.2 < η < 2.2
Negatively Charged Tracks
Positively Charged Tracks
Charge Reconstruction Efficiency [%]
p_T [GeV/c]


-2.4<η<-1.1
(a)
Negatively Charged Tracks
Positively Charged Tracks
1.1<η<2.6
(b)
Negatively Charged Tracks
Positively Charged Tracks
Trigger Efficiency [%]
|η|

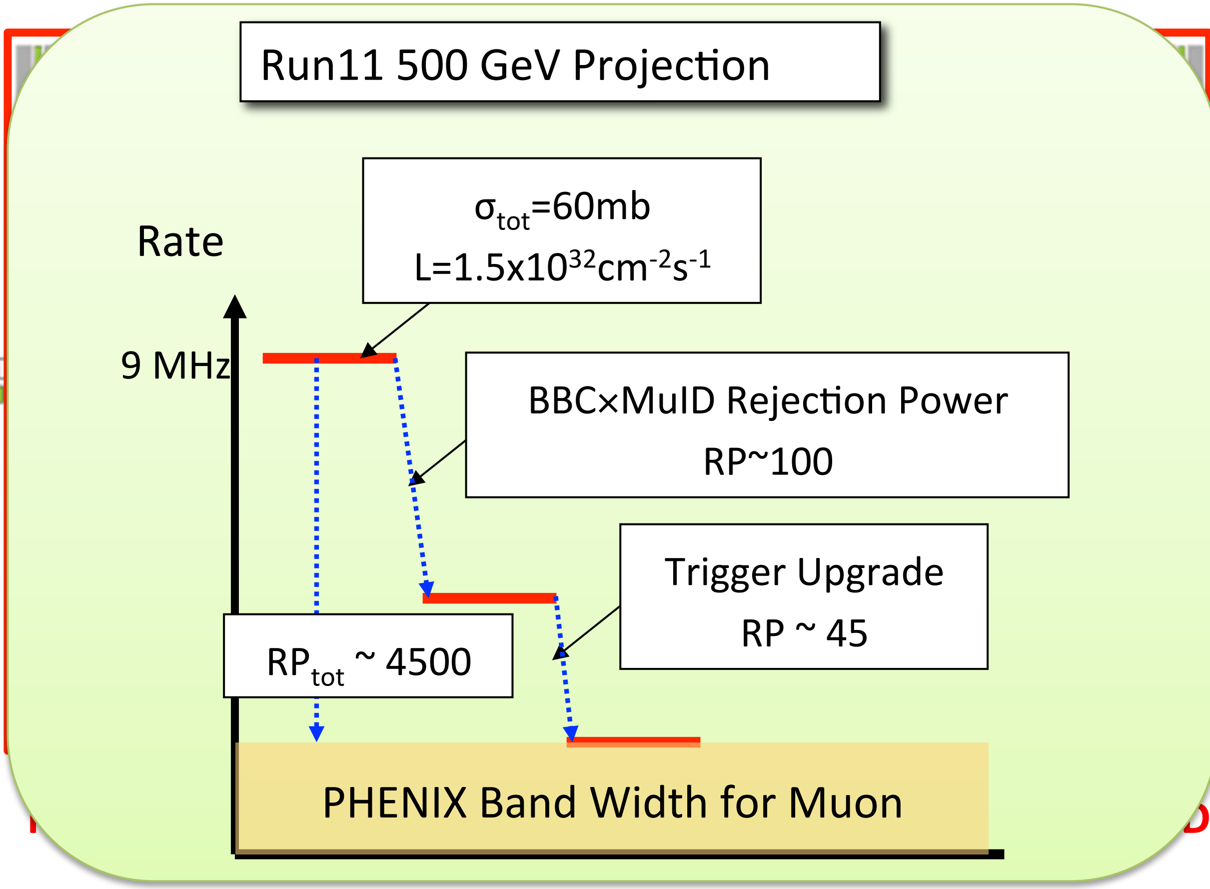
Systematic uncertainty sources

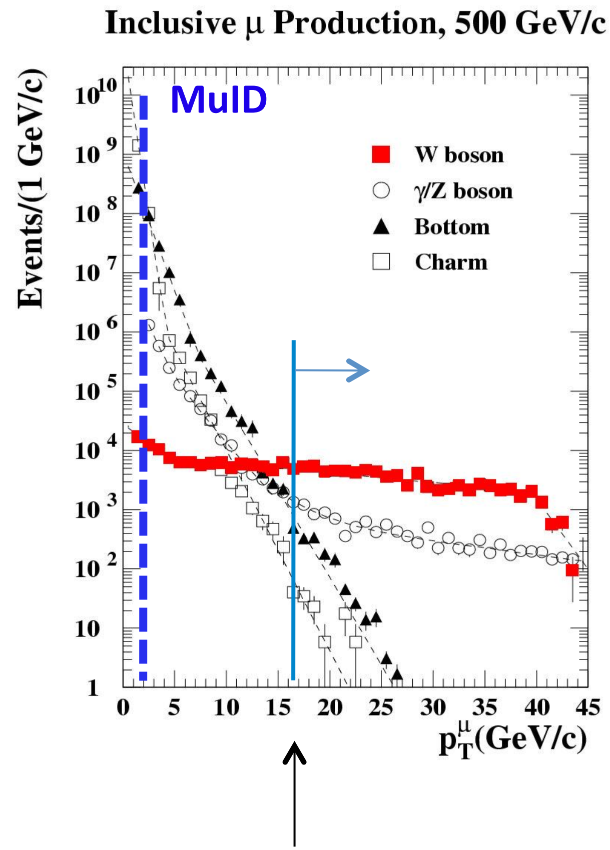


Impact of the RHIC data



PHENIX Detector System (in the past)





W dominant region

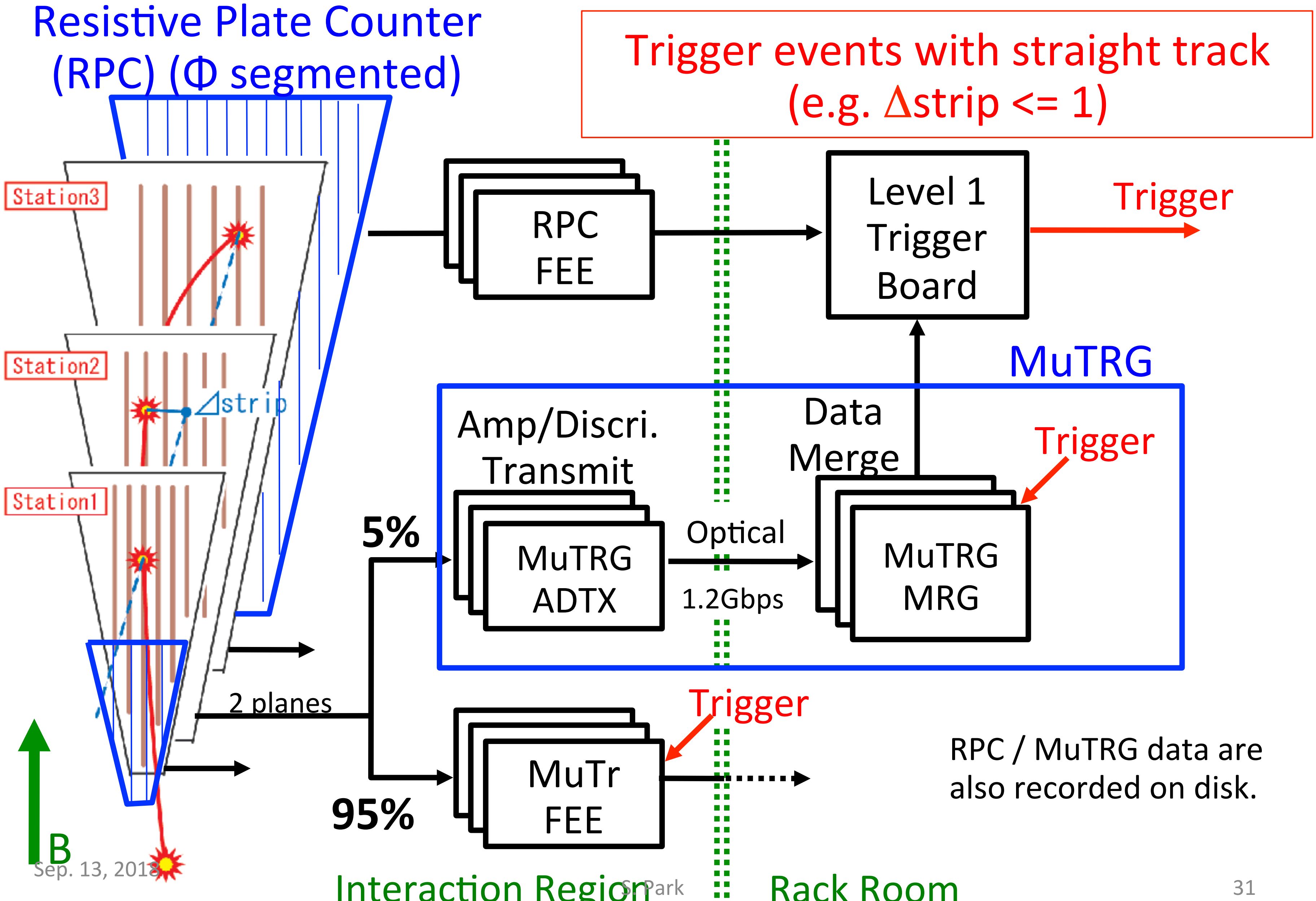
- **Data acquisition system limit (< 2 KHz)**
- **Low momentum threshold of MuID (~2 GeV)**

  - MuID rejection power ~100

  - Collision rate ~9 MHz at designed luminosity

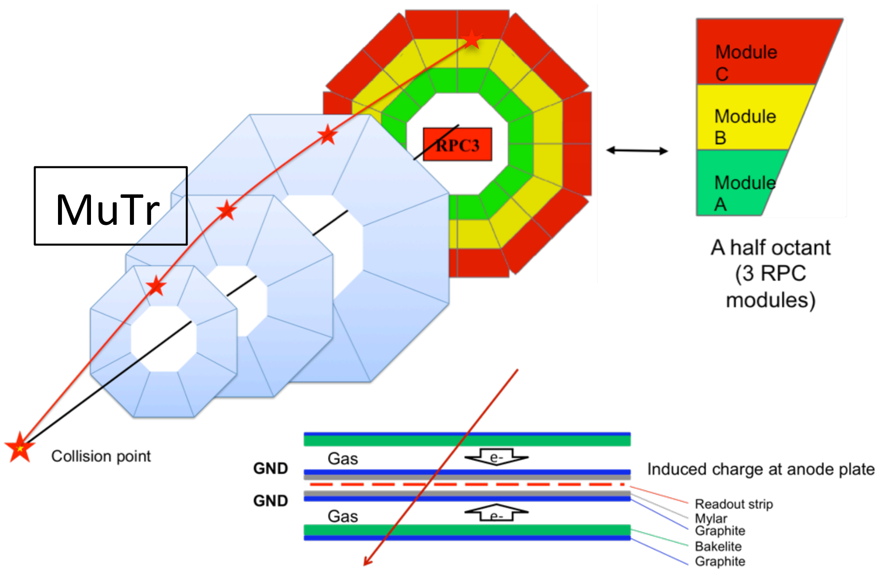
  - Required rejection power ~ 4500

W Trigger System



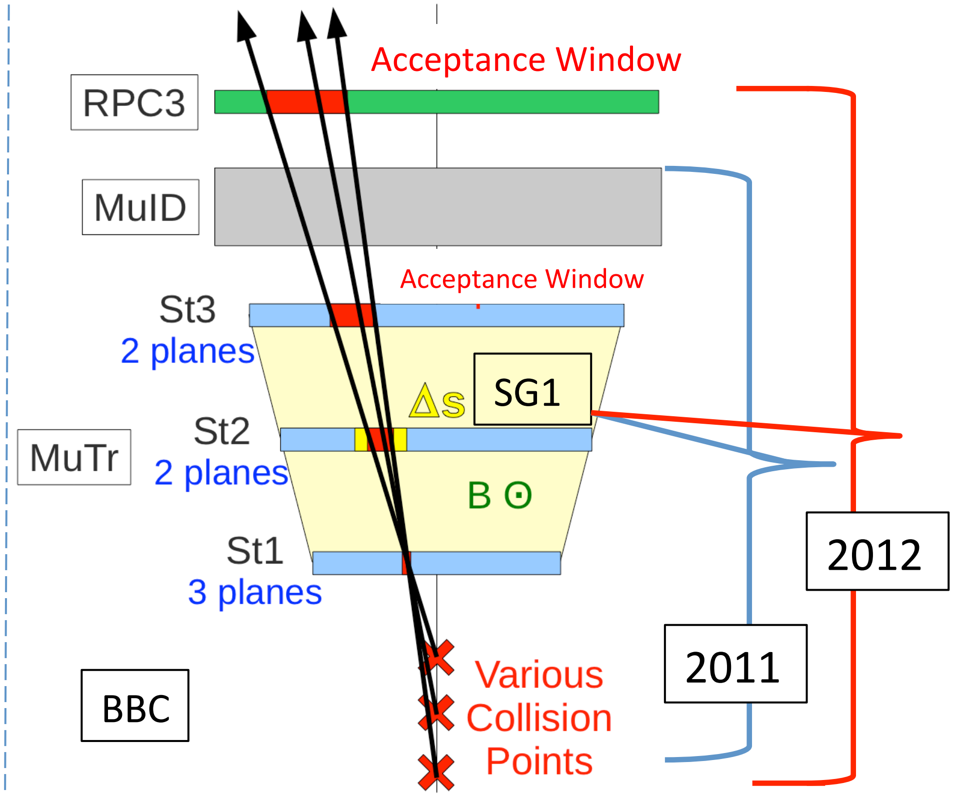
Introduction of New W Trigger in 2012

- **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)