W Results from PHENIX from Polarized pp Collisions at RHIC

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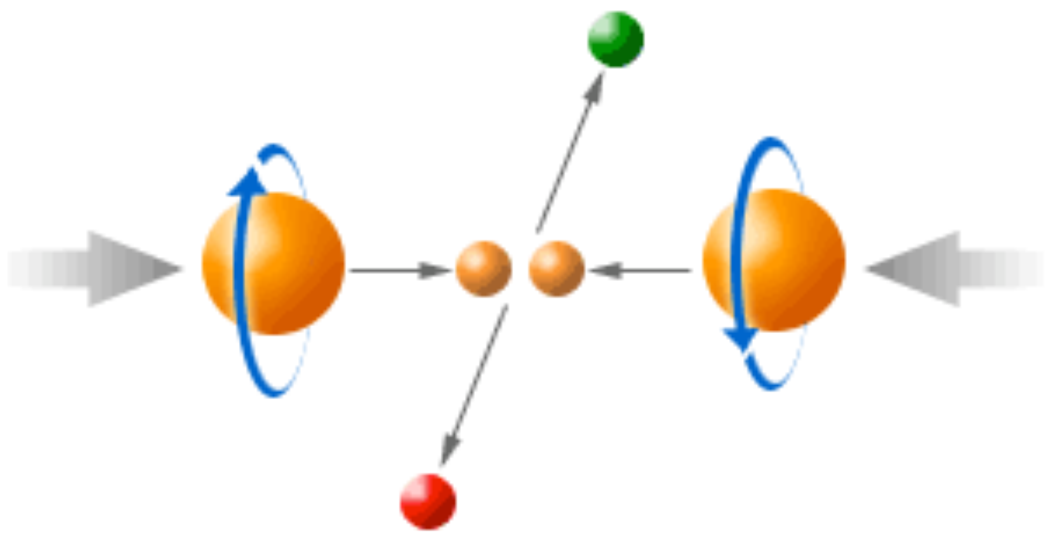
on behalf of the PHENIX Collaboration



Motivation for Spin Physics with Ws at RHIC

- Goal of this work : measurement of flavor separated, polarized PDFs $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$
- Recall $\Delta q(x,\mu^2) = q_+(x,\mu^2) - q_-(x,\mu^2)$, helicity-dependent PDFs
- Currently $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$ poorly known

- Why is this important?
  - NA51, E866 observed large differences in unpolarized sea quarks $\bar{u}(x) - \bar{d}(x) \neq 0$
  - Natural to ask whether $\Delta\bar{u}(x) - \Delta\bar{d}(x) \neq 0$?
  - Such differences related to fundamentals like Pauli principle : predicts $\Delta\bar{u} > 0,\ \Delta\bar{d} < 0$

- Measured in semi-inclusive polarized DIS experiments (SMC, HERMES, COMPASS) - detect scattered lepton and hadron h
- $\sigma \propto \displaystyle\sum_{q=u,d,s} \left[\Delta q(x) D_q^h(z) + \Delta\bar{q}(x) D_{\bar{q}}^h(z)\right]$
- Results limited by knowledge of fragmentation functions D_q^h
- Low scale $\Rightarrow$ active work on NLO, target fragmentation, higher twist corrections

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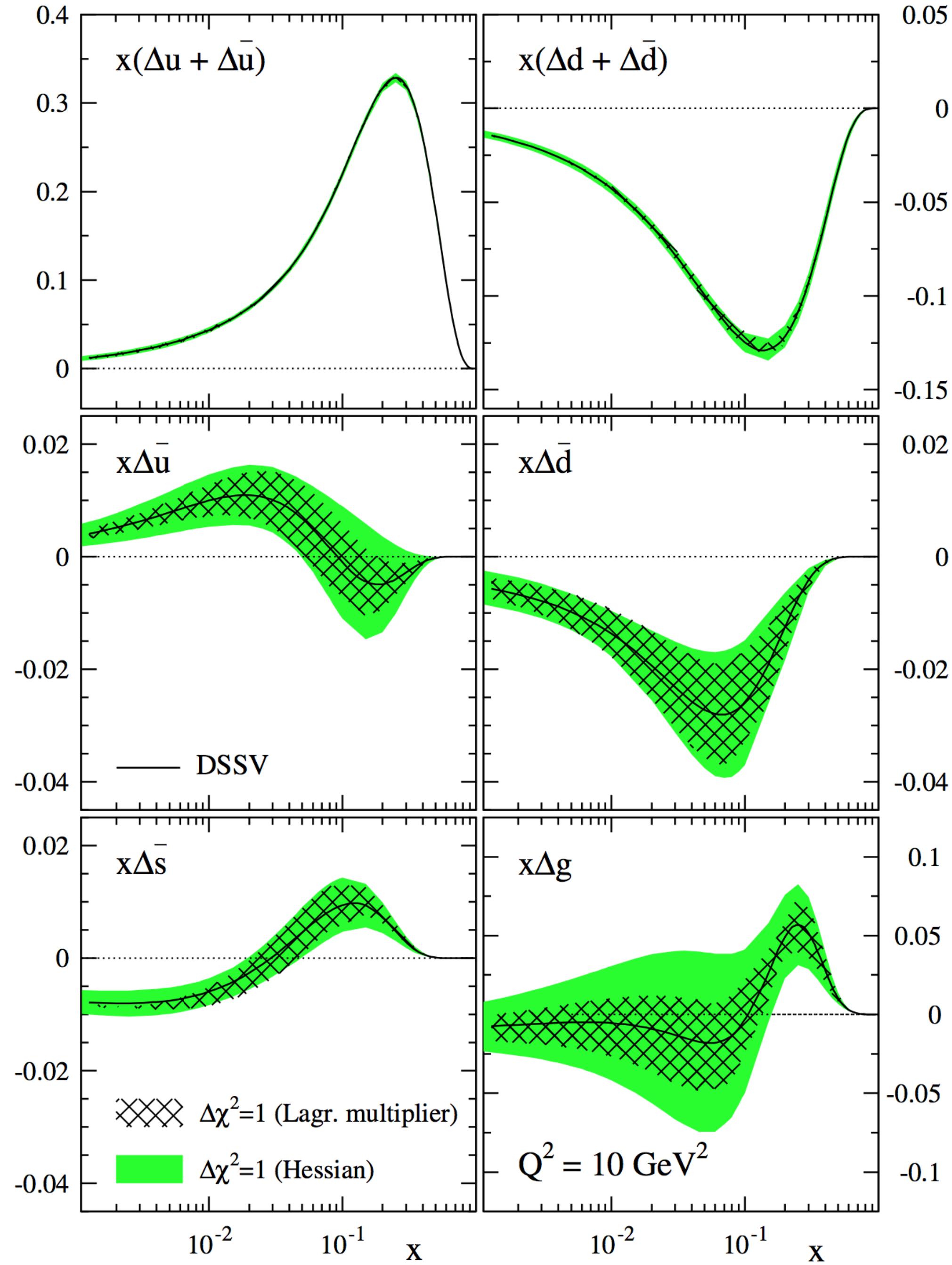

- Polarized PDF results from recent global analysis
- D. de Florian, R. Sassot, M. Stratmann, W. Vogelsang, Phys. Rev. D **80**, 034030 (2009)
- Fractional uncertainties large on $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$
- Q. How else can we reduce these uncertainties?
- A. STAR and PHENIX by exploiting maximal parity violation in W production in polarized pp collisions
  - No uncertainty from fragmentation (couplings of W well known)
  - Measurements made at high scale ($Q^2 \approx M_W^2 \approx 6400$ GeV^2)
  - NLO and resummation effectively handle QCD effects

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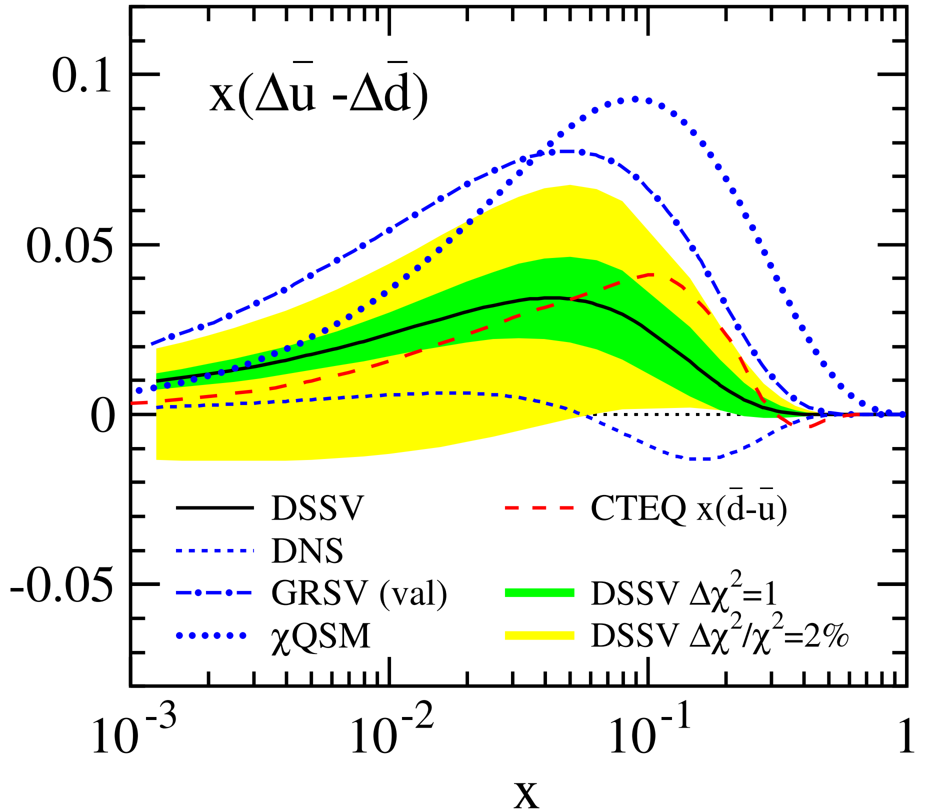
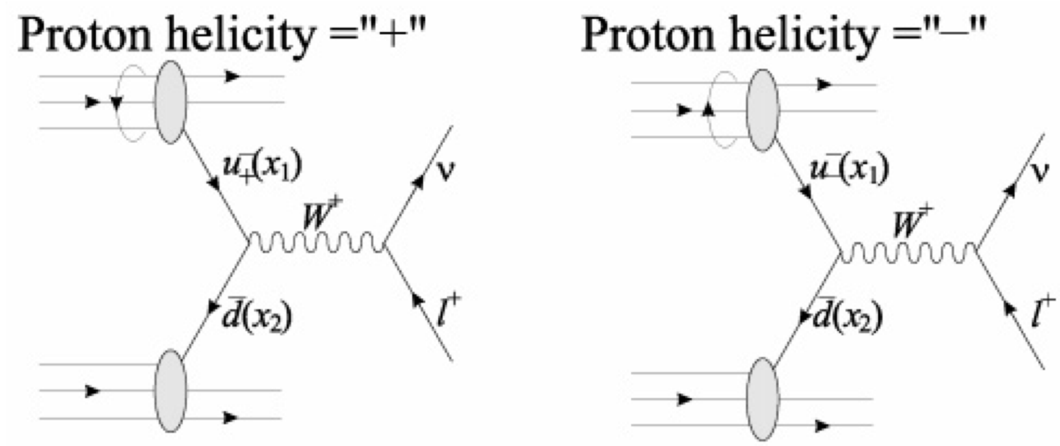


- Global analysis : D. de Florian, R. Sassot, M. Stratmann, W. Vogelsang, Phys. Rev. D **80**, 034030 (2009)
- Results determined primarily by semi-inclusive DIS
- Data already suggest symmetry breaking of polarized u and d sea quarks
- $\Delta\bar{u} > 0,\ \Delta\bar{d} < 0$, comparable to unpolarized case (red line)
- Many models : large-N$_c$, chiral quark solitons models, Pauli-blocking, ...

Measuring polarized sea quarks through $W^+ \to l^+ + \nu_l$ and $W^- \to l^- + \bar{\nu}_l$



- At leading order : $u_L \; + \; \bar{d}_R \; \to \; W^+ \;, \quad d_L \; + \; \bar{u}_R \; \to \; W^-$
- Construct parity-violating asymmetry :

$$A_L^{W^+} \; \equiv \; \frac{1}{P} \frac{N^+(W) - N^-(W)}{N^+(W) + N^-(W)} = \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

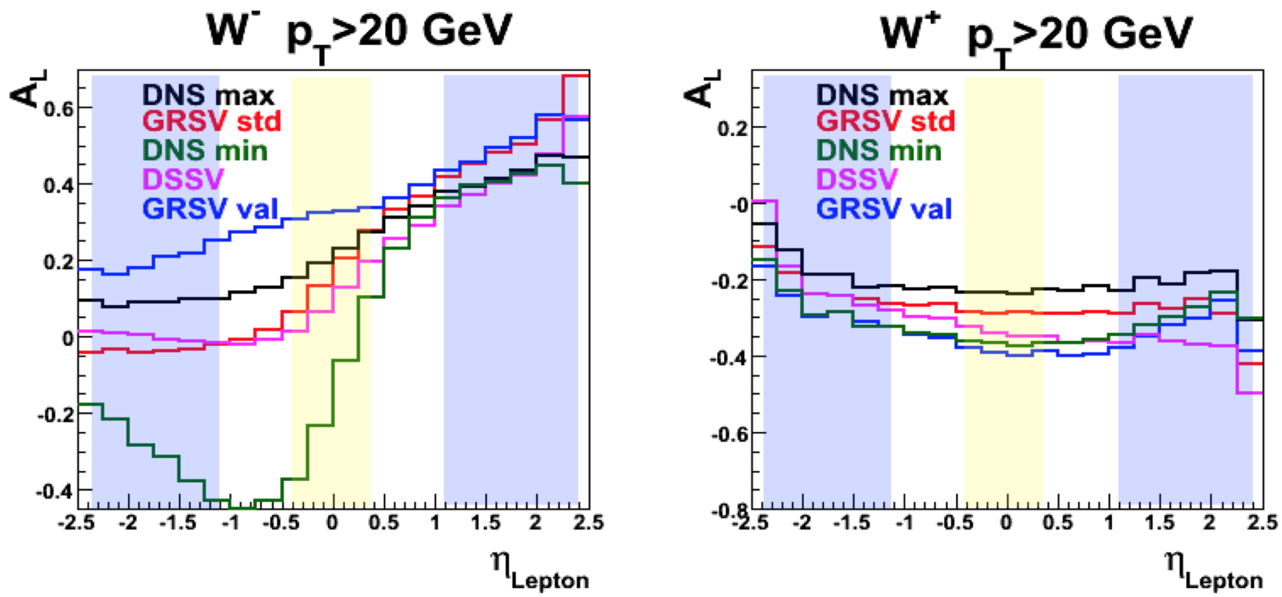
$\Rightarrow$ W^+ production sensitive to $\Delta u(x),\ \Delta\bar{d}(x)$; $\quad W^-$ sensitive to $\Delta d(x),\ \Delta\bar{u}(x)$;

- Can extract ratios [$\Delta d(x)/\Delta u(x)$] and [$d(x)/u(x)$]
- Central arm measurement $pp \; \to \; W^\pm \; \to \; e^\pm \; \nu$ probes PDFs at :

$$\langle x_{1,2} \rangle \; \approx \; \frac{M_w}{\sqrt{s}} \; \exp\left(\pm y_W\right) \; \approx \; 0.16$$

- N.B. We detect the decay lepton, not the W, interpretation more complicated

Motivation for Spin Physics with Ws at RHIC



Plots from RHIC Spin Plan 2008. For *lepton* asymmetry from W decay

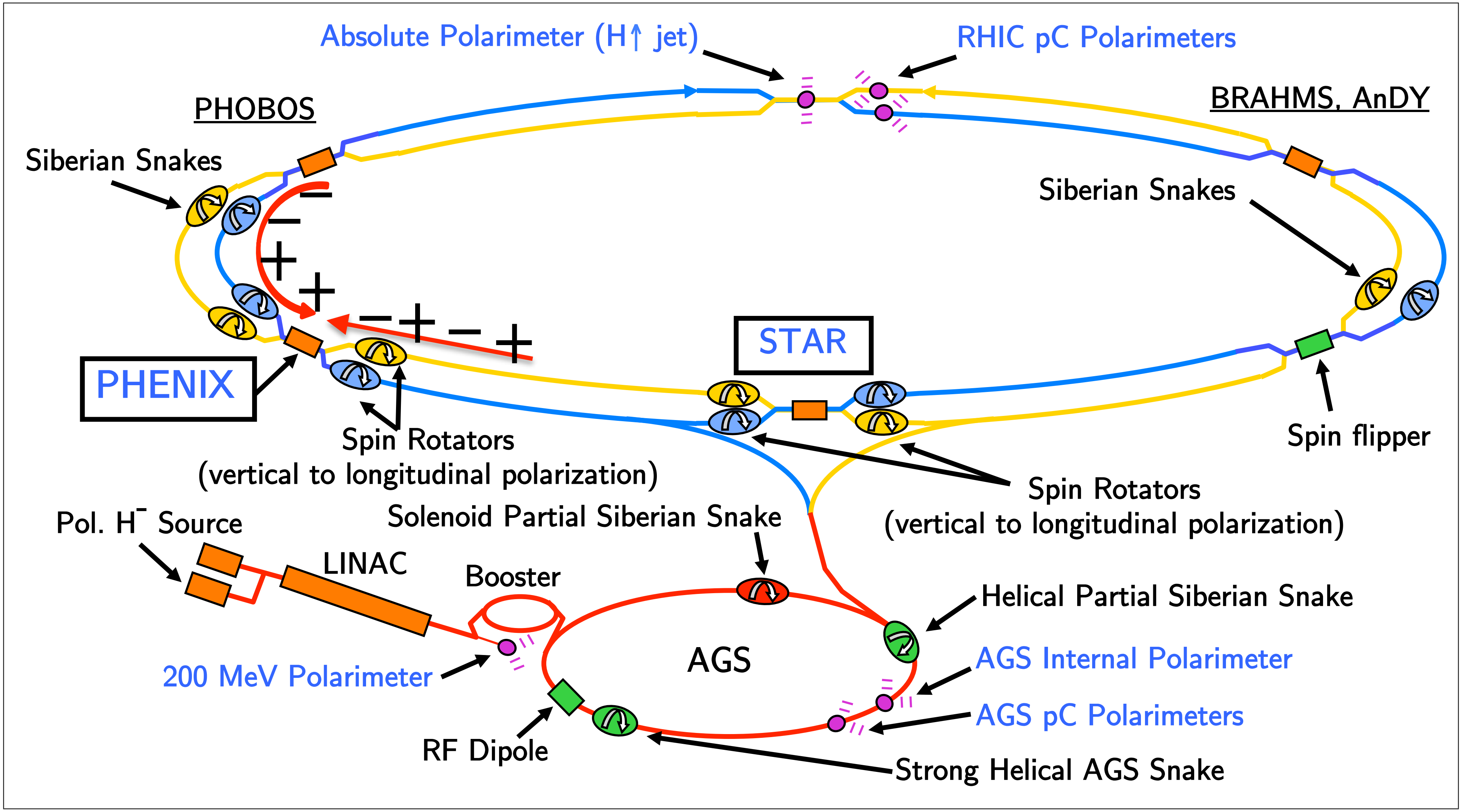
$$A_L(W^+) \propto -\Delta u(x_1)\bar{d}(x_2)(1-\cos\hat{\theta})^2 + \Delta\bar{d}(x_1)u(x_2)(1+\cos\hat{\theta})^2$$
$$A_L(W^-) \propto +\Delta\bar{u}(x_1)d(x_2)(1-\cos\hat{\theta})^2 - \Delta d(x_1)\bar{d}(x_2)(1+\cos\hat{\theta})^2$$

- At positive Y_{W+} ($x_1 >> x_2$) sensitive to $-\Delta u(x)/u(x)$, at negative Y_{W+} to $\Delta\bar{d}(x)/d(x)$
- y_W can not be determined unambiguously from y_e^{lab} at mid-rapidity :

$$y_e^{lab} = \hat{y}_e + y_W \ , \ \text{where } \hat{y}_e = \frac{1}{2}\ln\left[\frac{1+\cos\hat{\theta}}{1-\cos\hat{\theta}}\right] \ , \ p_T^e \approx \frac{M_W}{2}\sin\hat{\theta} = \frac{M_W}{2}\sin(\pi-\hat{\theta})$$

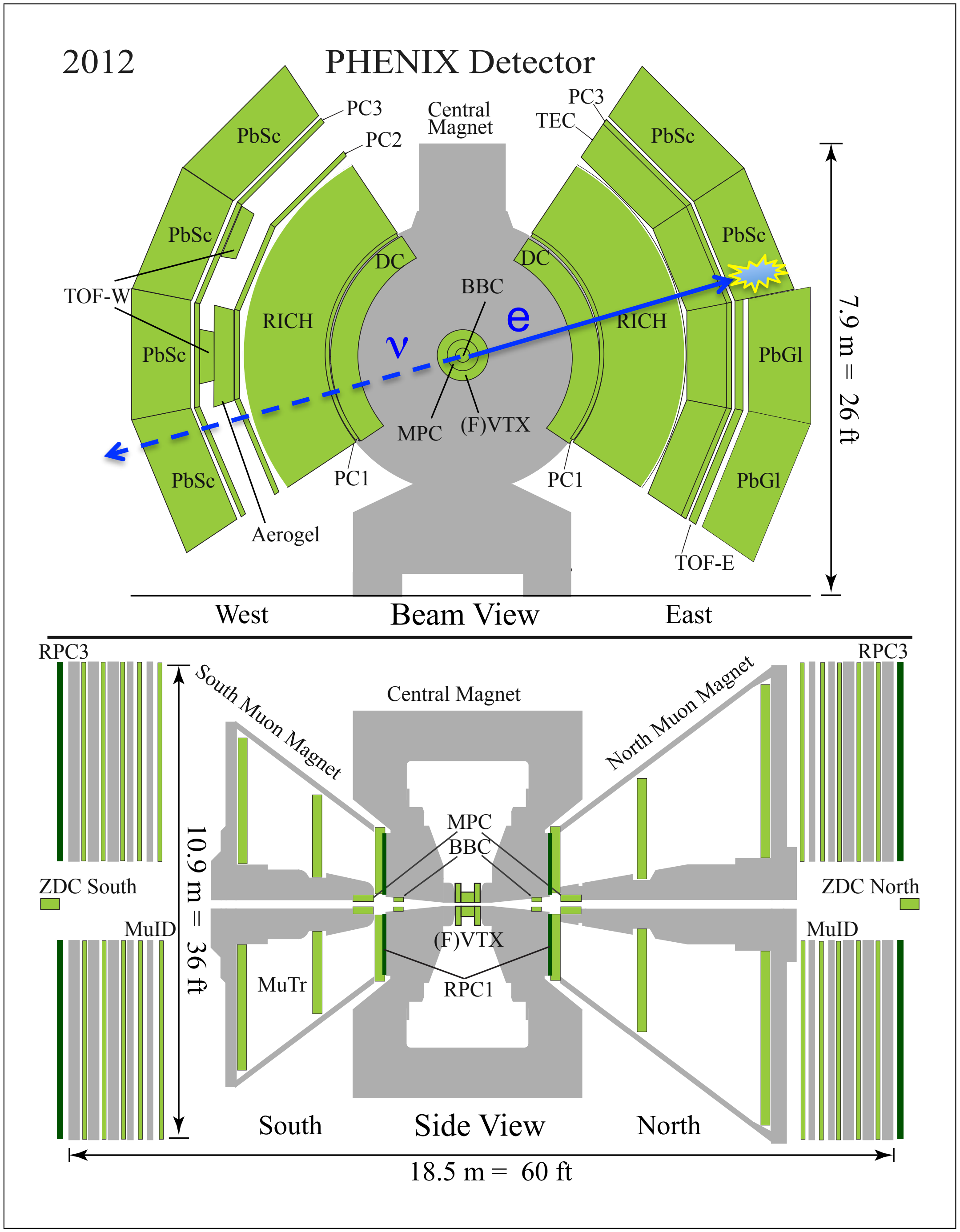
- Irreducible uncertainty in sign, $P_T^W \neq 0$ either, extraction of $\Delta\bar{u}(x)$, $\Delta\bar{d}(x)$ not trivial
- NLO+resummation description complete (Nadalosky, Yuan, Vogelsang, de Florian)

RHIC : The World's only Polarized Proton Collider



- Peak luminosity $\approx 2 \times 10^{32}$ cm^{-2}s^{-1} at $\sqrt{s} = 500$ GeV$/c$, P $\approx$ 50 %, longitudinal or transverse
- Up to 120 bunches in each ring, crossing every 106 ns, helicity of pairs ++, +-, -+, - - alternates rapidly
- Rapid reversals reduce most systematics; $\exists$ crossing-by-crossing differences in $\mathcal{L}$ and vertex distribution

PHENIX Central Arm Spectrometers



$\Rightarrow$ For $W^{\pm} \to e^{\pm} + \nu_e$ at $|\eta| < 0.35$

- Each arm $\Delta\phi = \pi/2,\ |\eta| < 0.35$ $(70^\circ < \theta < 110^\circ)$
- $\int \vec{B} \cdot d\vec{l} \approx 0.8$ T·m
- Vertex cut : $|z| < 30$ cm

- EM calorimeter finely segmented : $\Delta\phi \times \Delta\eta \approx 0.01 \times 0.01$
- Tracking : Drift Chamber (DC) and Pad Chamber (PC1)
- Charge sign determination in DC
- SiVTX commissioned in 2011
- FVTX commissioned in 2012
- DAQ : Handles trigger rates 7-9 kHz

Backgrounds : Reducible and Irreducible

- Look for $e^{\pm}$, limited acceptance means can't see missing E_T from ν, can't identify $W \Rightarrow e + \nu_e$ definitively on event-by-event basis : rely on excess of events over background

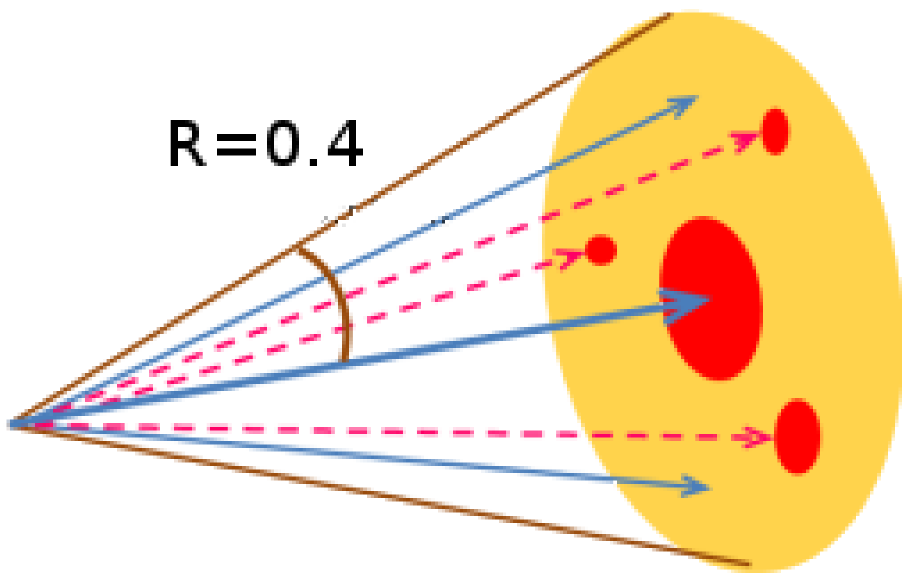
- Reducible Backgrounds : Collision-independent
  - Cosmic rays
  - Beam related backgrounds (fragments, halo, scattering upstream)
  - Timing cuts reduce by more than factor of 5

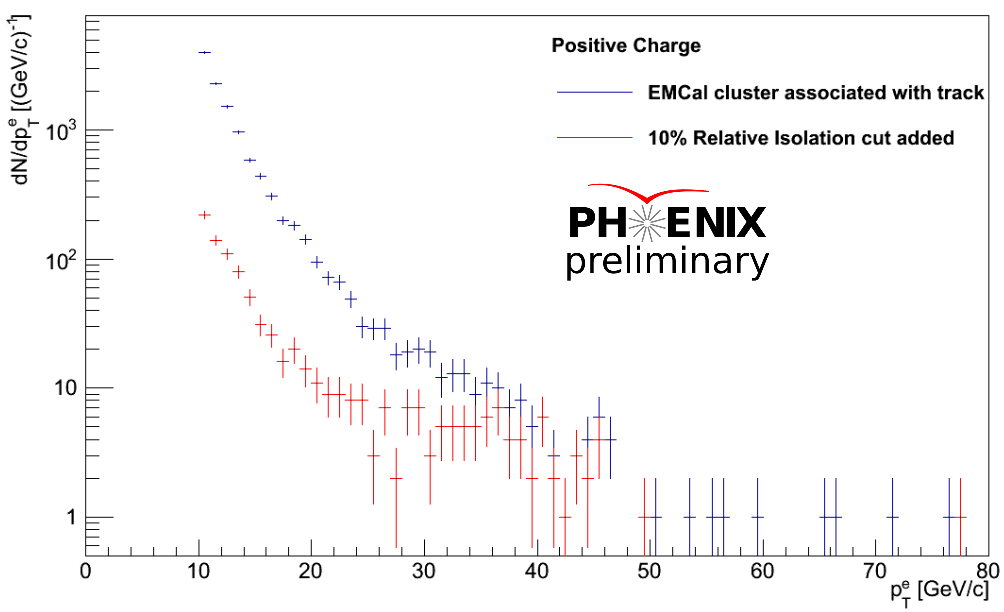
- Backgrounds : Collision-dependent
  - π^0, $\eta \Rightarrow \gamma\gamma$, or direct-$\gamma$: conversion $\gamma \to e^+e^-$ yields cluster + matching track
  - $h^{\pm}$+hadronic shower in EMCal : cluster + matching track
  - π^0 or direct-γ with accidentally matching track from other fragments

- Irreducible Backgrounds
  - Irreducible in the sense they pass our cuts (high energy cluster+matching track)
  - Leptonic charm, bottom decay : $\Rightarrow e^{\pm}$+anything
  - Other W decays : $W \Rightarrow \tau + \nu_\tau \Rightarrow e\nu_e\nu_\tau\bar{\nu}_\tau$, detect e
  - $Z/\gamma^* \Rightarrow e^+ + e^-$, detect one e, other outside acceptance
  - $Z \Rightarrow e^+ + e^-$ rate significant compared to $W^- \Rightarrow e^- + \bar{\nu}_e$
  - Z production comes with a small parity-violating asymmetry

Find the Ws : Analysis Strategy

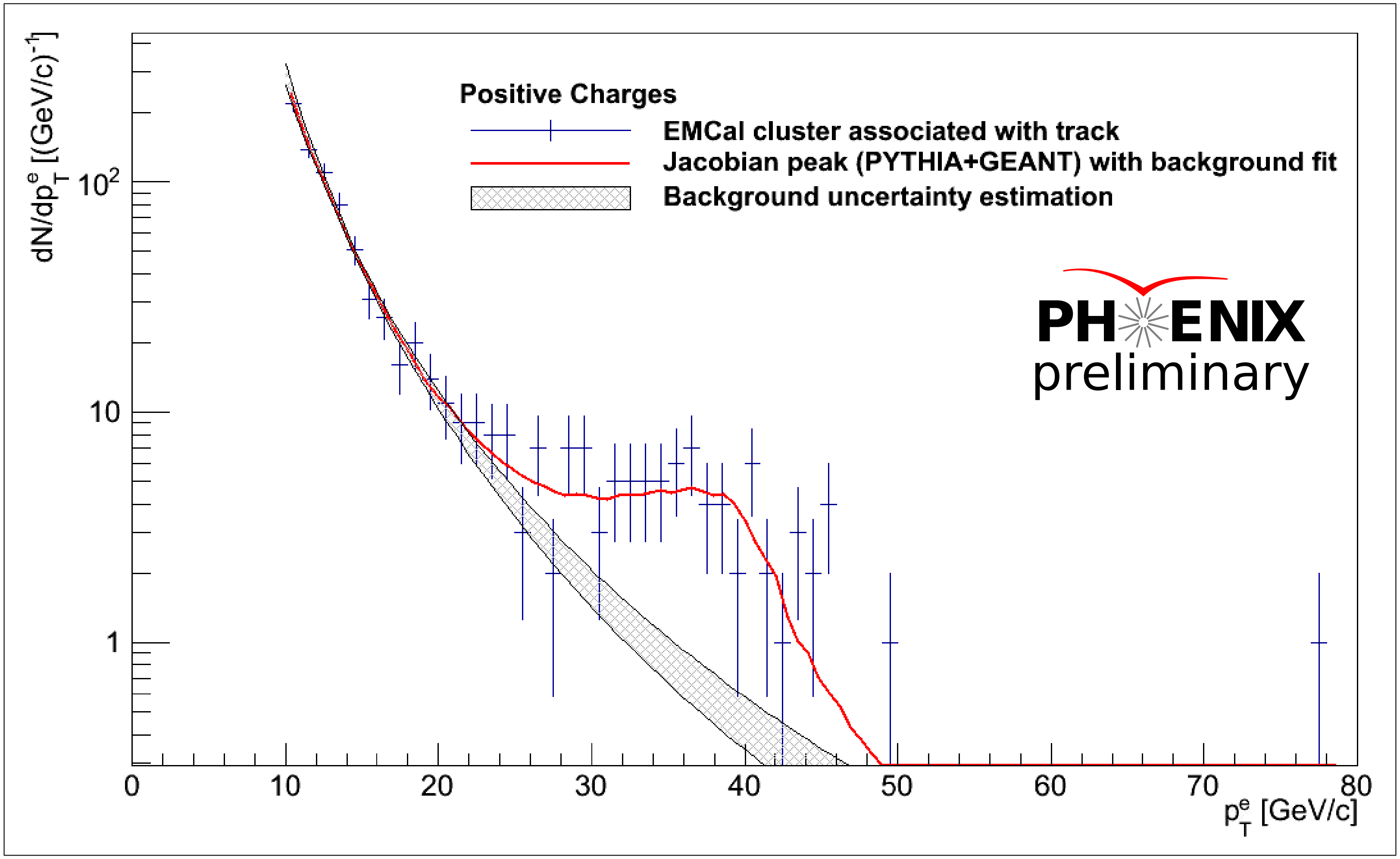
- Trigger on high E cluster in EMCal, threshold 10 GeV, timing cut reduces cosmics
- Match cluster with track in DC and PC1,
- Determine momentum from bend angle in DC, E/p cut reduces hadronic background and mismatches; fiducial cuts on DC reduce ghost tracks
- Determine charge sign from bend angle in DC, 40 GeV track ≈ 2.3 mrad
- Resolution ≈ 1.5 mrad, remove region $|\alpha| < 1$mrad, charge mid-ID few %
- Relative isolation cut : Energy in $R = \sqrt{\Delta\phi^2 + \Delta\eta^2} \leq 0.4$ less than 10% of candidate cluster energy
    - Signal region 30-50 GeV unchanged
    - Background region 10-20 GeV reduced factor 10





Preliminary $W^+ + Z$ Spectra from 2011 Data

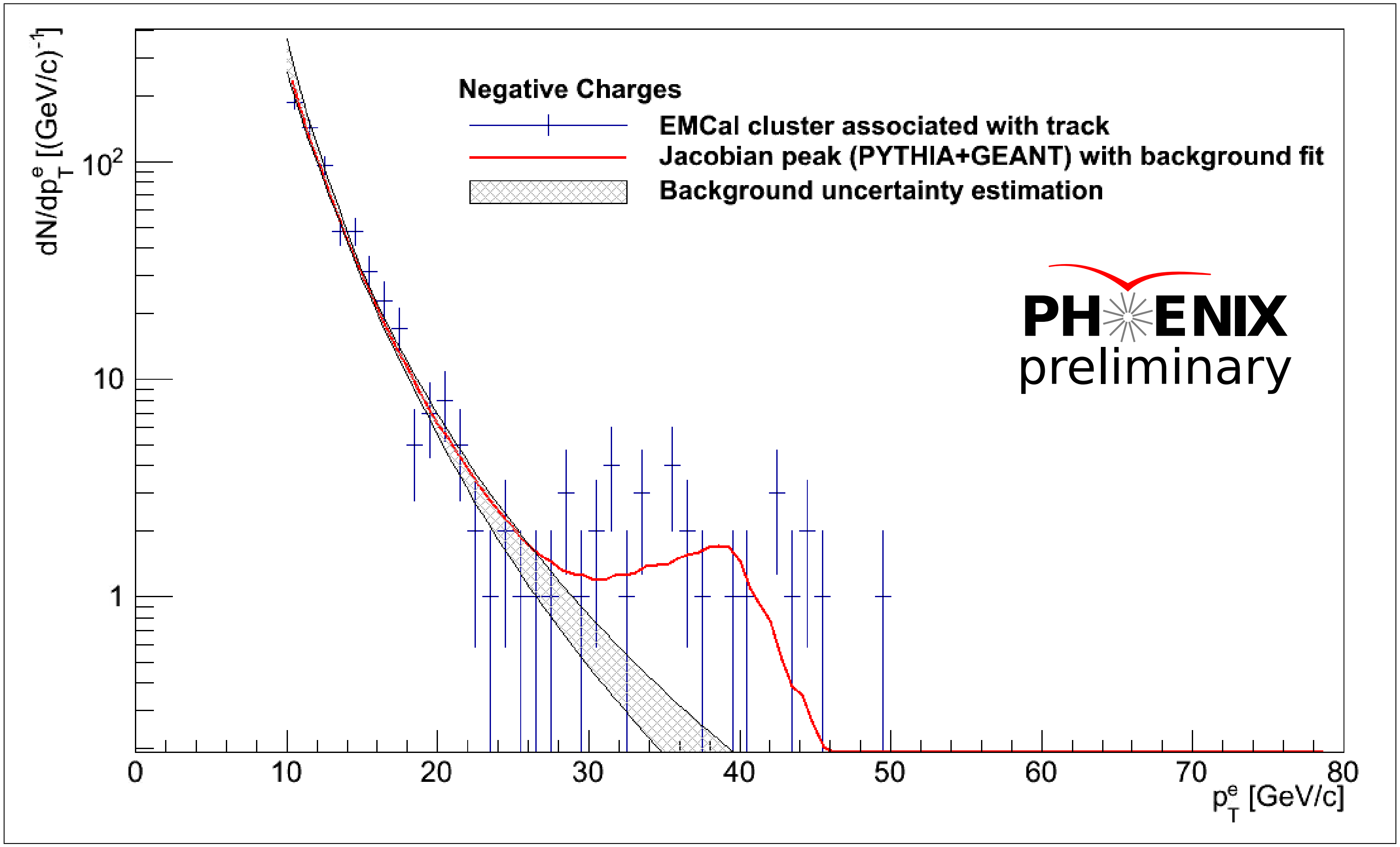
- Identify $W^+ \to e^+ + \nu_e$ from Jacobian peak of signal events over falling background



- After cuts, background in $W^+ \to e^+$ signal region 30-50 GeV $\approx$ 18%

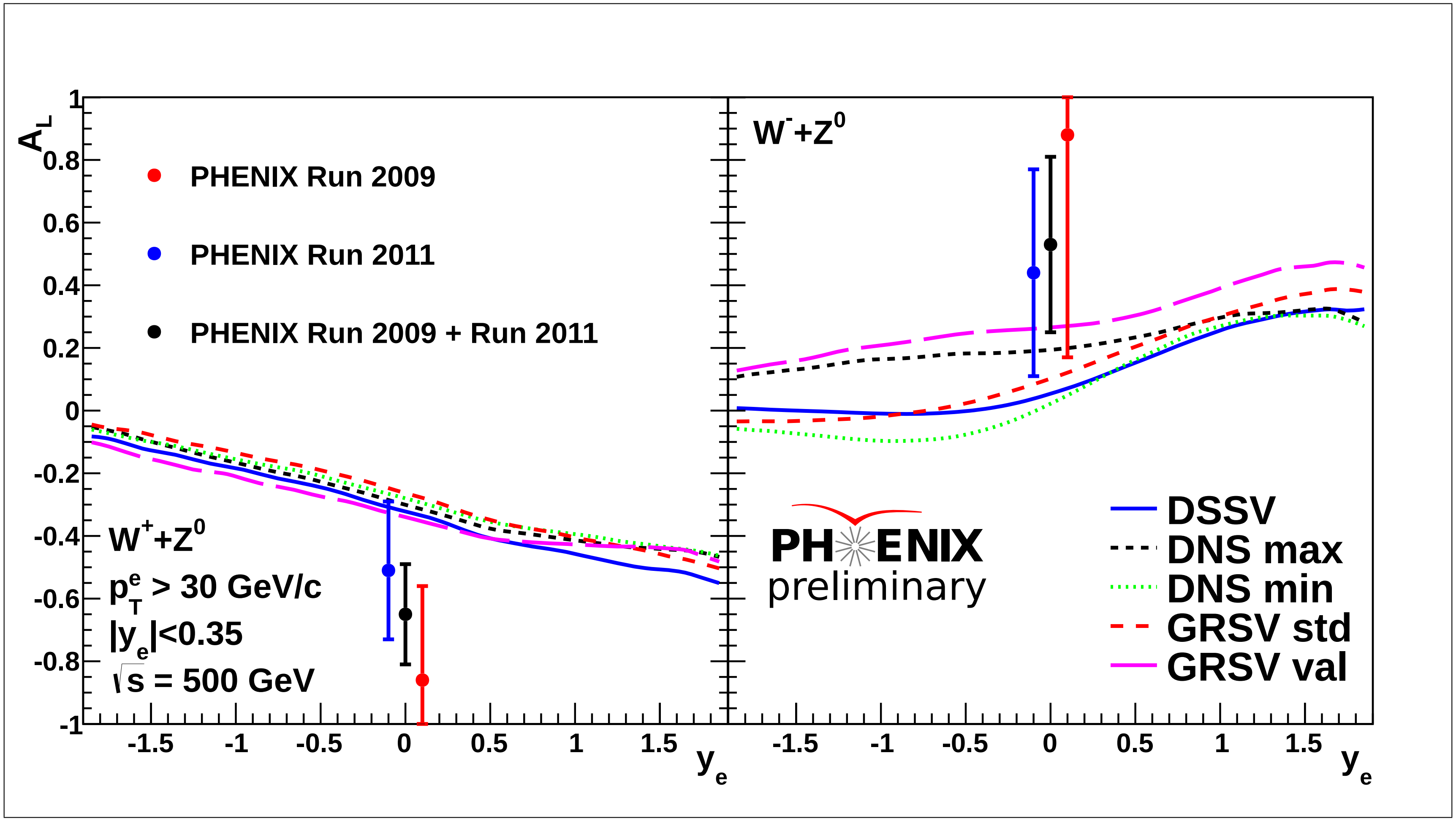
Preliminary $W^- + Z$ Spectra from 2011 Data

- Identify $W^- \to e^- + \bar{\nu}_e$ from Jacobian peak of signal events over falling background



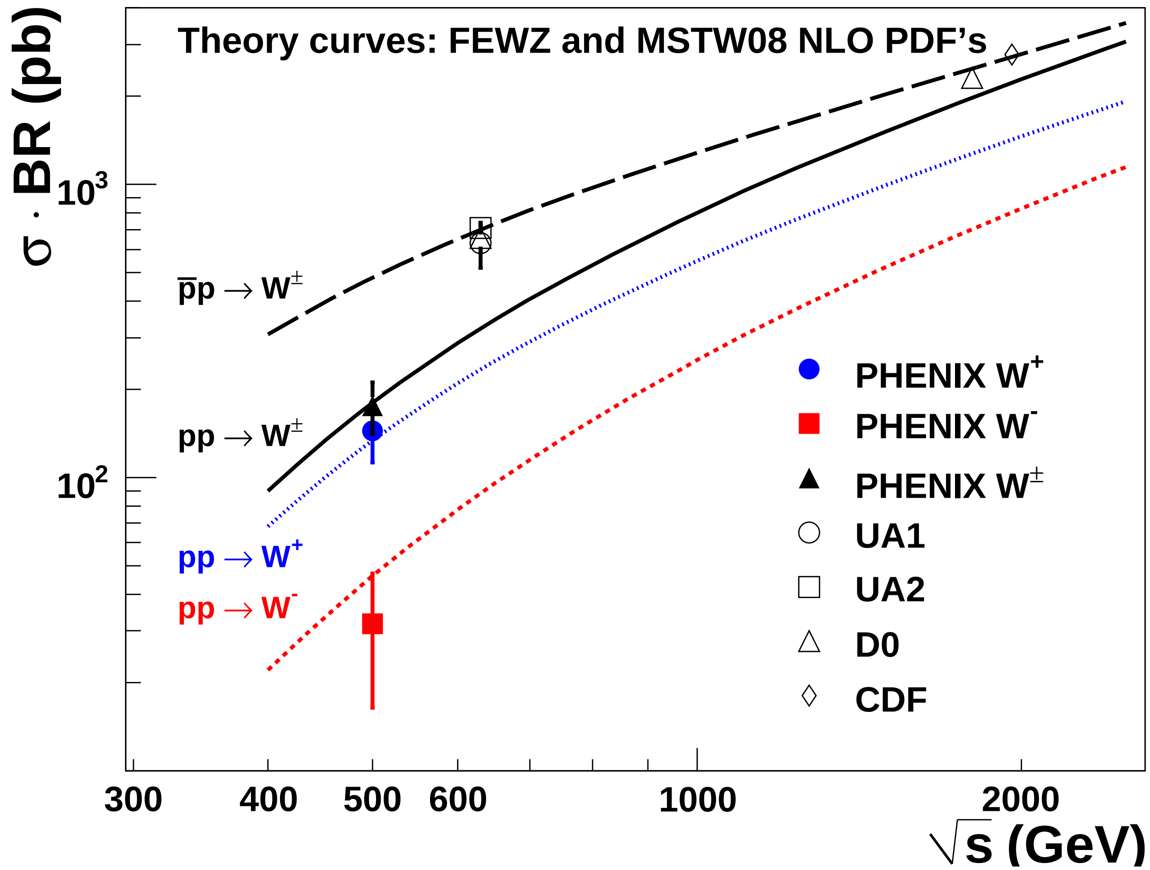
- After cuts, background in $W^- \to e^-$ signal region 30-50 GeV $\approx\ 14\%$
- χ^2 for combined results $\approx$ 50 for 35 DoF

Single Spin Parity-Violating Asymmetry Results A_L from 2011 Data



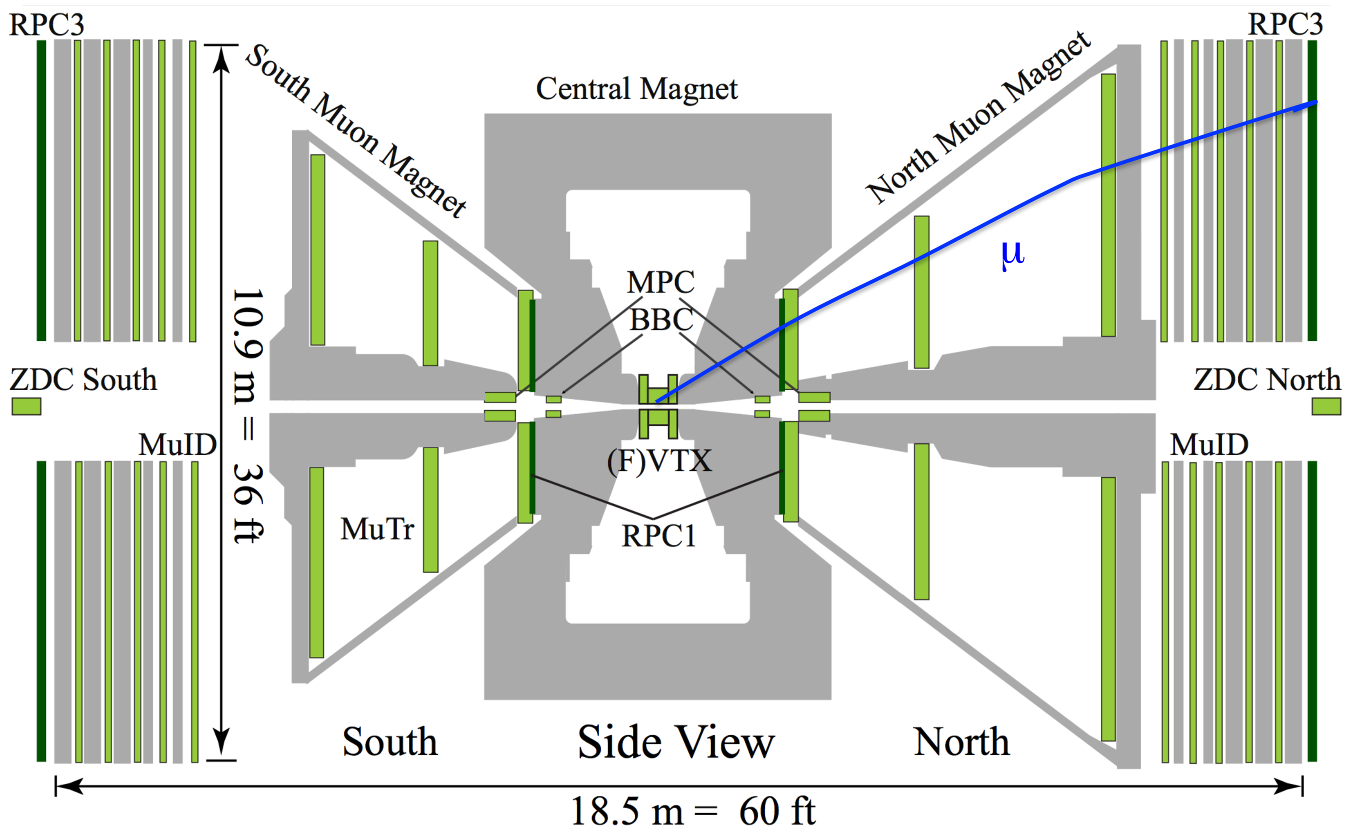
- Need more events to discriminate between different models of polarized PDFs

W production cross section measurement from 2009



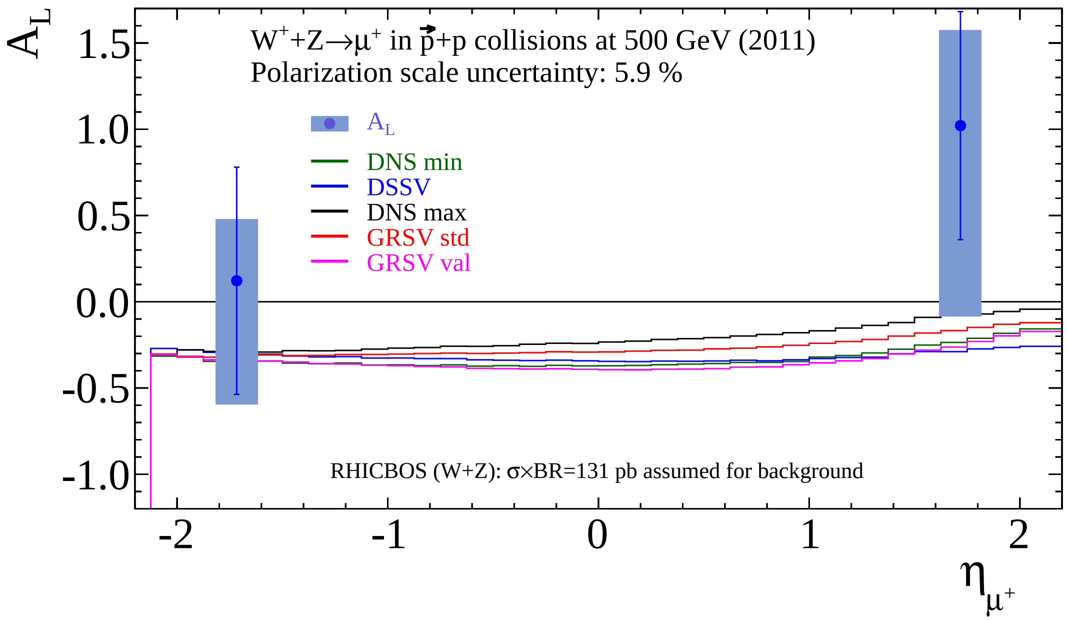
- $\sigma(pp \rightarrow W^+X) \times \mathrm{BR}(W^+ \rightarrow e^+\nu_e) \;=\; 144.1 \;\pm\; 21.2(\mathrm{stat})^{+3.4}_{-10.3}(\mathrm{syst}) \pm 21.5(\mathrm{norm})$ pb
- $\sigma(pp \rightarrow W^-X) \times \mathrm{BR}(W^- \rightarrow e^-n\bar{u}_e) \;=\; 31.7 \;\pm\; 12.1(\mathrm{stat})^{+10.1}_{-8.2}(\mathrm{syst}) \pm 4.8(\mathrm{norm})$ pb
- Theory curves from FEWZ; K. Melnikov and F. Petriello, Phys. Rev. D **70**, 114017 (2006).

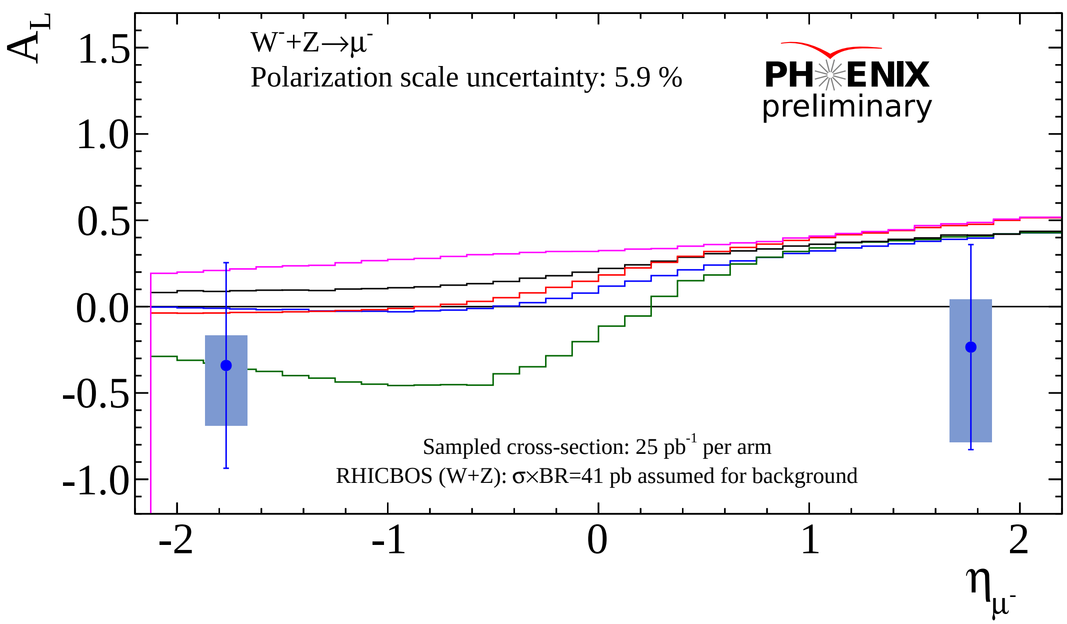
Measuring Sea Quark Polarizations with the Muon Arms : $W^{\pm} \to \mu^{\pm}$



- South Muon Arm $-2.2 < \eta < -1.2$; North Muon Arm $1.2 < \eta < 2.4$, $\Delta\phi = 2\pi$
- Signal is isolated high p$_T$ muon, detected with MuTr, MuID, RPC
- Trigger on small sagitta in magnetic field + muon ID + timing cut from BBC,RPC
- Reduced collision rate of several MHz to trigger rate of few kHz dedicated to muon arms
- Absorber between vertex and MuTr, and interspersed in MuID, reduces low energy and decay background

Measuring Sea Quark Polarizations with the Muon Arms : Preliminary Results





- Preliminary results from 2011 data set
- $\sqrt{s}$ = 500 GeV, Pol.≈ 50%, $\int \mathcal{L}dt \approx 25$ pb^{-1}
- First results in this channel
- Anticipated for many years

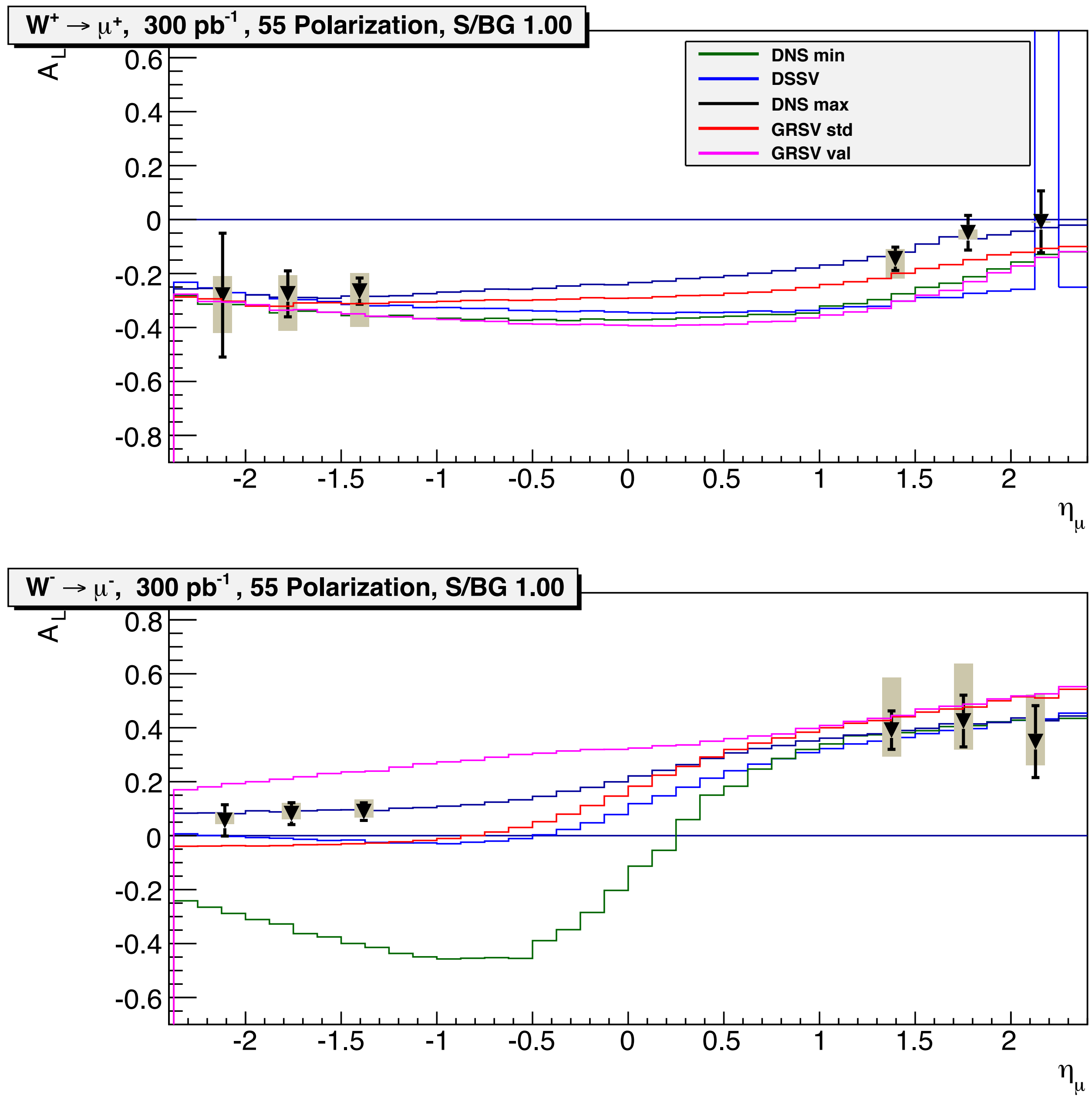
⇒ Cover different x than central arms

Further Improvements : Data from 2012 and 2013

Year	$\sqrt{s}$ (GeV)	$\int \mathcal{L} dt$ (pb^{-1})	Pol. (%)	P^{2}L (pb^{-1})
2009	500	8.6	39	1.3
2011	500	16	48	3.7
2012	510	$\approx$ 30	52	8.1
2013 (TBD)	510	$\approx$ 200	55	60

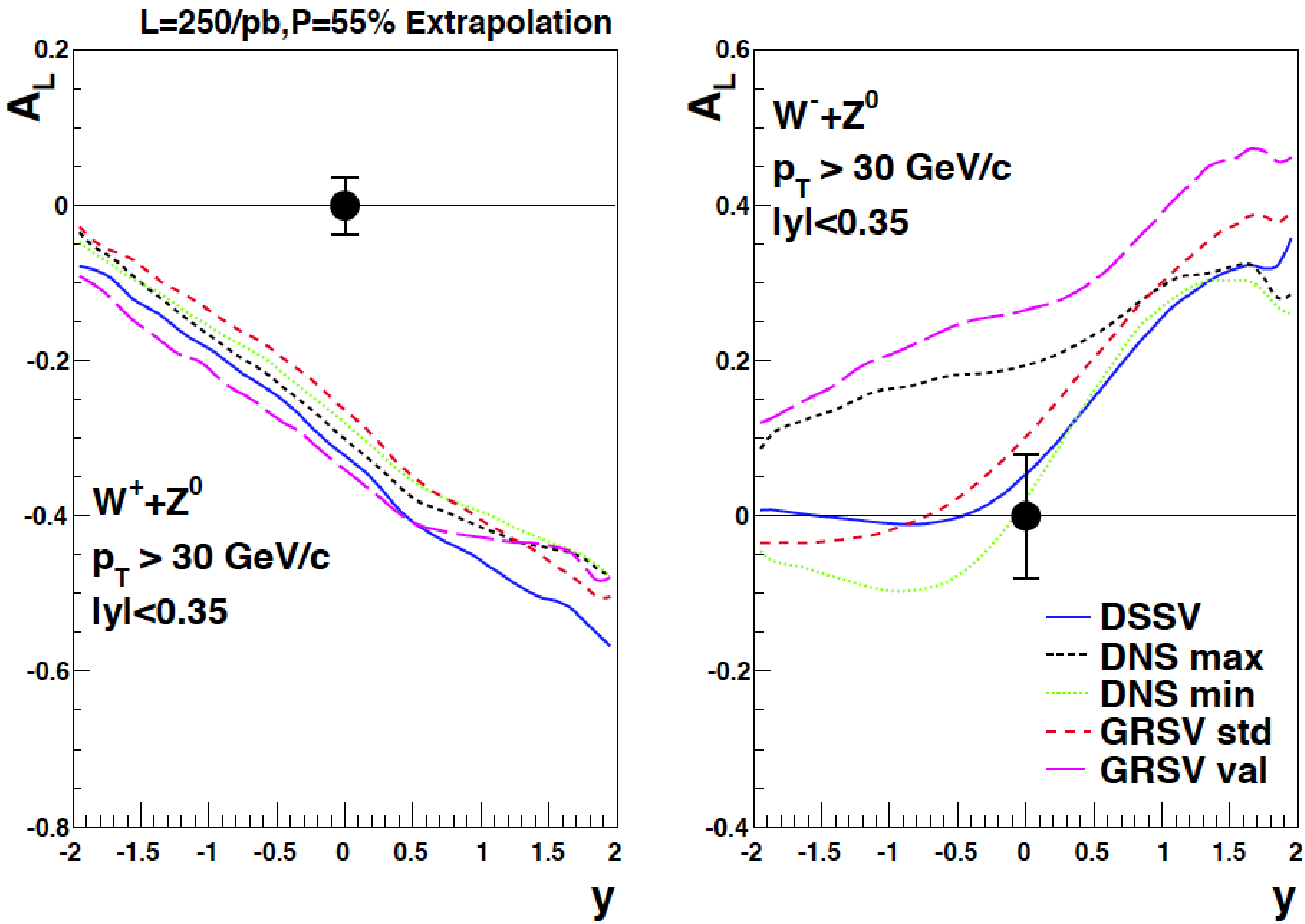
- $\int \mathcal{L} dt$ recorded luminosity within vertex cut $|z| < 30$ cm (more for μ analysis)
- Analysis of 2011 data sets being finalized
- Data from 2012 being analyzed : substantial compared to 2009 and 2011
- For μ analysis 2012 includes improved trigger, VTX/FVTX detectors to reduce background
- For e analysis, commissioning of VTX detector might improve isolation cut
- Very large data set anticipated in 2013

Projections for Muon Arms : 300 pb^{-1} and P=55%



- Anticipated $W^{\pm}$ results in central and muon arms should discriminate between some models

Projections for Central Arms : 250 pb^{-1} and P=55%



- Anticipated $W^{\pm}$ results in central and muon arms should discrimate between some models

Summary

- RHIC spin program to measure polarized sea quark distributions well underway
- Published results for central arms available :
  A. Adare *et al.*, Phys. Rev. Lett. **106**, 062001 (2011).
- Substantial data sets under analysis (2011 at $\sqrt{s} = 500$ GeV, 2012 at $\sqrt{s} = 510$)
- More than 200 pb^{-1} anticipated in 2013 - combined results should discriminate between some models
- Data should allow a measurement of $\Delta\bar{d}(x)$ / $\Delta\bar{u}(x)$ between $0.08 \lesssim x \lesssim 0.4$