Measurement of $W^{\pm}$ Boson Production at Mid-rapidity in 510 GeV Polarized p + p Collisions at PHENIX

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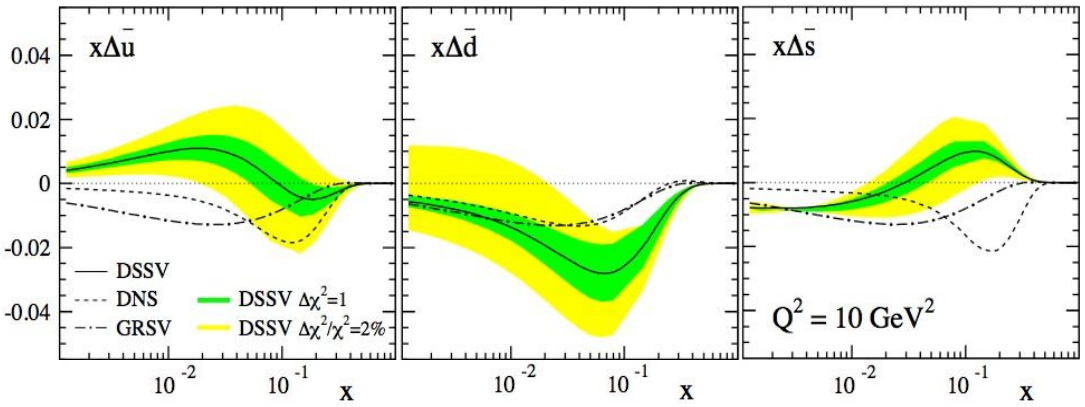
Motivation for Spin Physics with W bosons

Flavor-separated quark and anti-quark polarized PDF measurement

DSSV: PRL 101, 072001 (2008)

Polarized SIDIS measurements (SMC, HERMES, COMPASS) through fragmentation processes:



PHENIX exploits maximal-parity violation in W production in polarized p+p collisions:

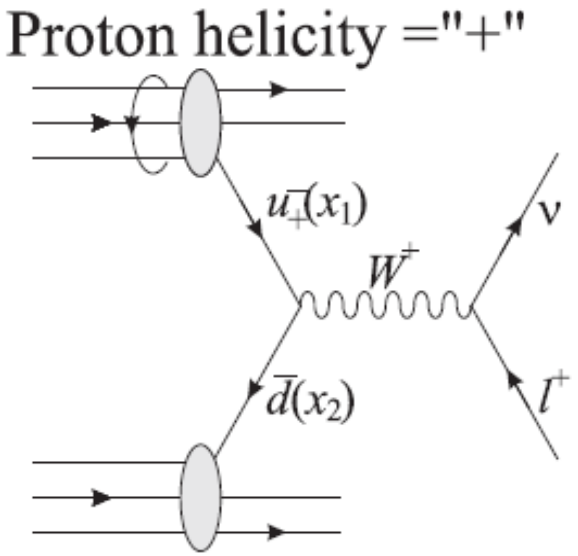
- no fragmentation involved
- high scale, Q^2 (set by W mass)
- extraction of $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$

$$p + p \rightarrow W^{\pm} \rightarrow e^{\pm} + \nu$$

(mid-rapidity)

$W^{\pm}$ Boson Production in Polarized Proton Collisions

W^+ production example at LO:



(Bunce et al., Ann. Rev. Nucl. Part. Sci. 50:525 (2000))

W couples to only one helicity:

✓ For W^+: Δu and $\Delta\bar{d}$ probed

• **parity violating longitudinal single-spin asymmetry:**

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

✓ For W^-: $\Delta\bar{u}$ and Δd probed

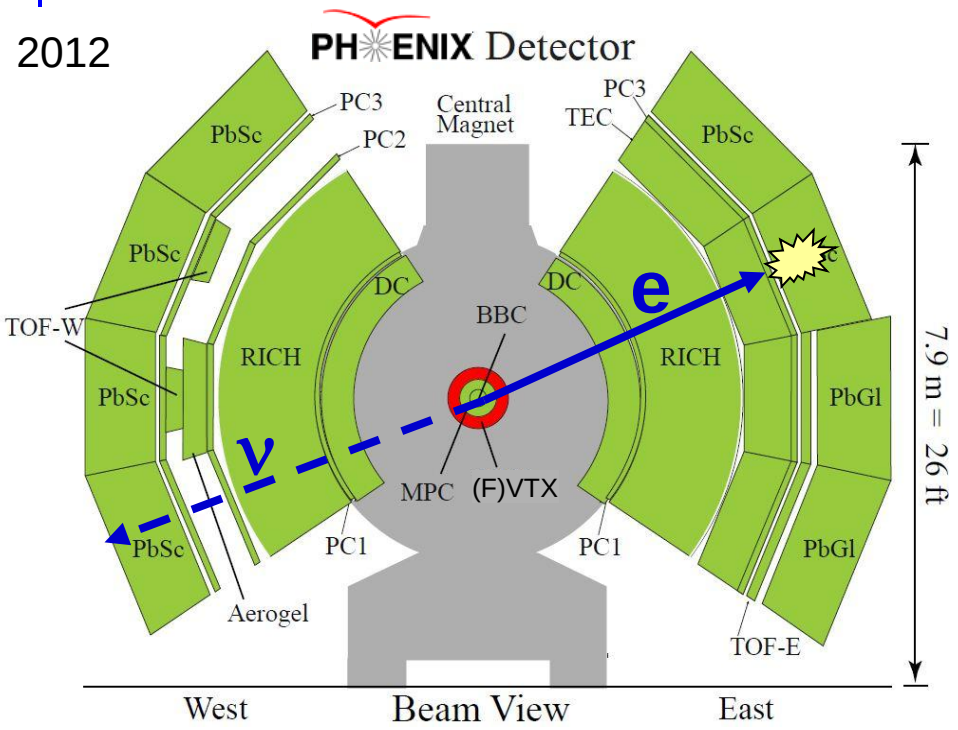
Denoting positive beam helicity by + and negative by −:

$$A_L^W = \frac{1}{P} \times \frac{N^+(W) - N^-(W)}{N^+(W) + N^-(W)}$$

N is the electron yield, normalized by luminosity; P is luminosity-weighted polarization

PHENIX Detector and Analysis Strategy

2012

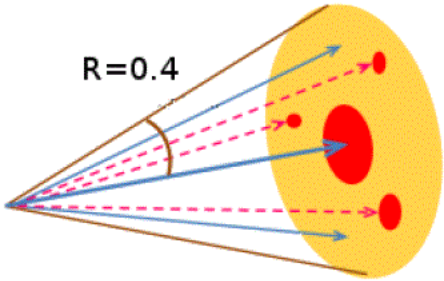


$$p + p \rightarrow W^{\pm} \rightarrow e^{\pm} + \nu$$

Detect high energy $e^{\pm}$ in the Central Arms:

- EMCal 4x4 Tower Sum Trigger (fully efficient at 10 GeV)
- High energy EMCal clusters matched to charged tracks in DC
- Isolation cut is the main background reducer:

$$\frac{\text{energy in a cone of } R = 0.4 \text{ excluding the candidate cluster energy}}{\text{energy of the } e^{\pm} \text{ candidate}} < 10\%$$



Central arm spectrometers:

- 2 arms: each $\Delta\phi = \pi/2$, $|\eta|<0.35$ in rapidity
- Electromagnetic Calorimeter (EMCal) with segmentation $\Delta\varphi x\Delta\eta \sim 0.01x0.01$
- Tracking: Charged tracks measured in Drift Chamber (DC) and Pad Chamber (PC)
- VTX detector

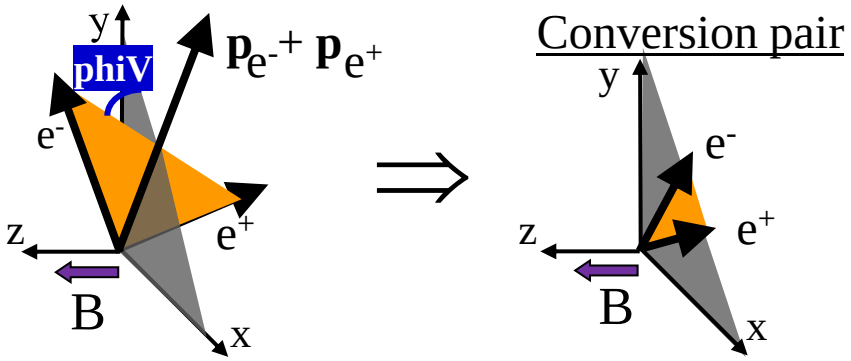
Background components

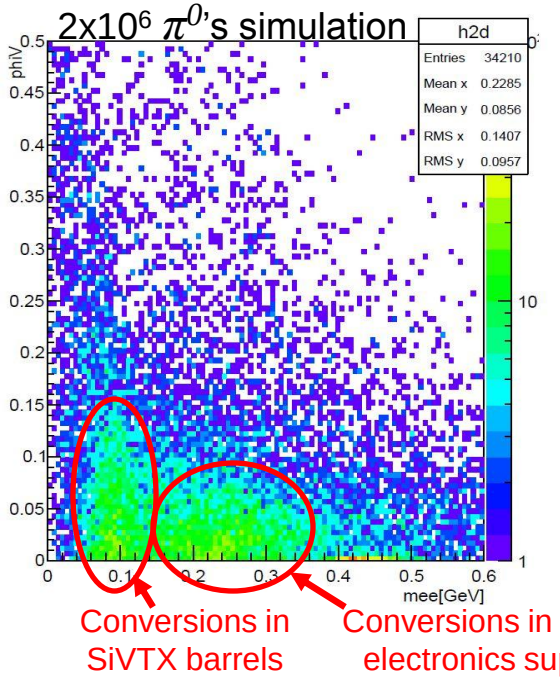
- ✓ Irreducible Backgrounds (pass cuts)
  - c/b decays to $e^{\pm} + X$ relatively small above 30 GeV
  - $W \to \tau \to e$ is also small
  - $Z \to e^{+} + e^{-}$ is part of the signal
- ✓ Reducible Backgrounds
  - QCD background
  - Photon conversions $\gamma \to e^{+}e^{-}$ (before the Drift Chamber):
    VTX Detector increases conversion background
    (radiation length =13.5%)

Detailed simulation study is in progress to estimate carefully the QCD background and background from the VTX conversions – this will let us to proceed with the $W^{\pm}$ cross-section measurements for Run 2012 and will result in improved background estimation overall in the analysis (including asymmetry measurements)

VTX conversion background

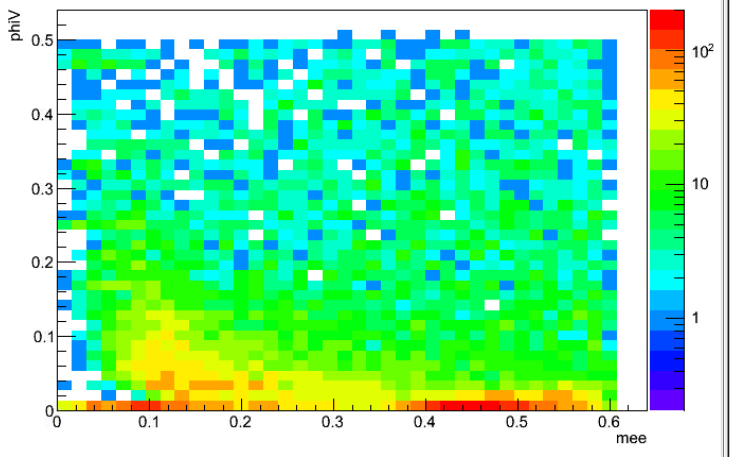
• orientation angle of the e^+e^- pair in the magnetic field (**phiV**) vs. apparent invariant mass $\mathbf{m_{ee}}$



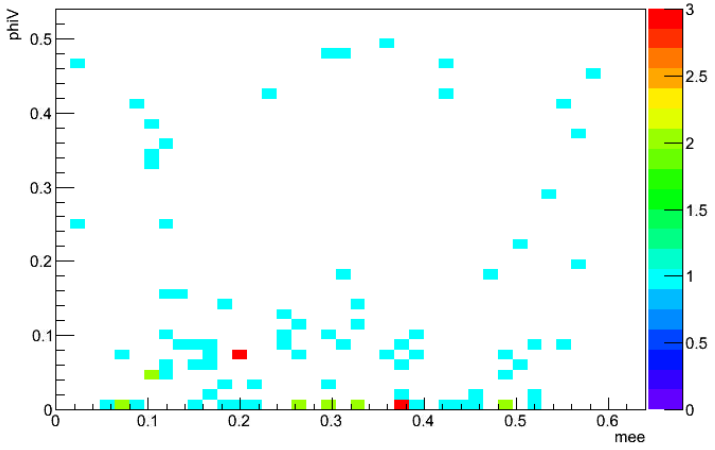


Isolation cut reduces effectively identified conversions:

Before Isolation Cut



After Isolation Cut



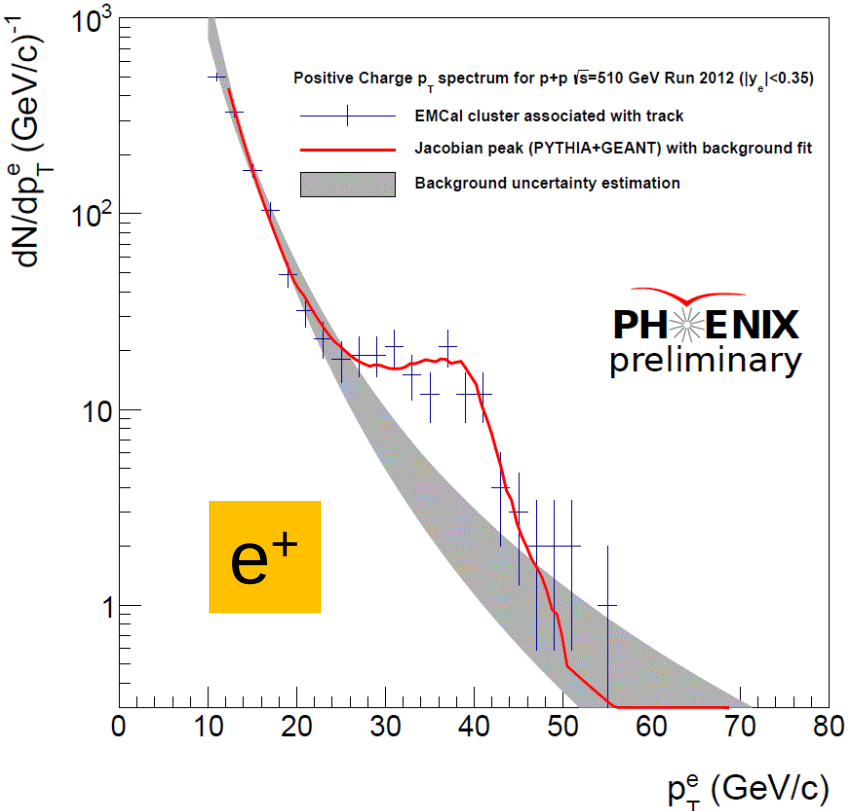
Run 2012 Measured W^+ and W^- Spectra

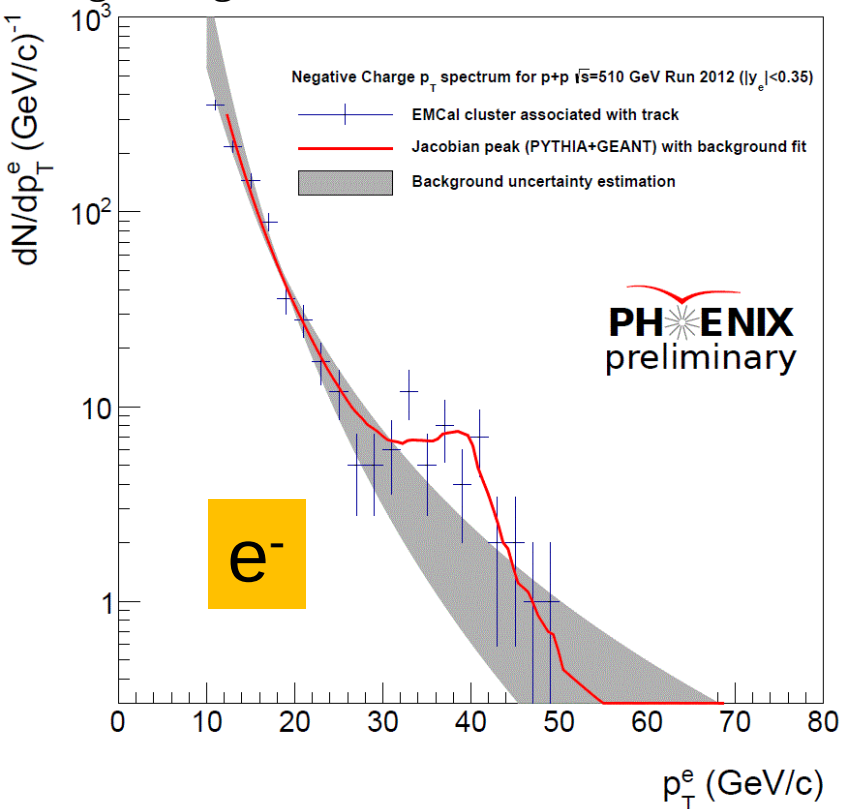
W^+ and W^- signal:

Jacobian peaks

$W^{\pm} \rightarrow e^{\pm}$ – rely on excess of events over background:

- Reduce background as much as possible
- 10-70 GeV/c – background estimation using power law fit
- 30-50 GeV/c – signal region



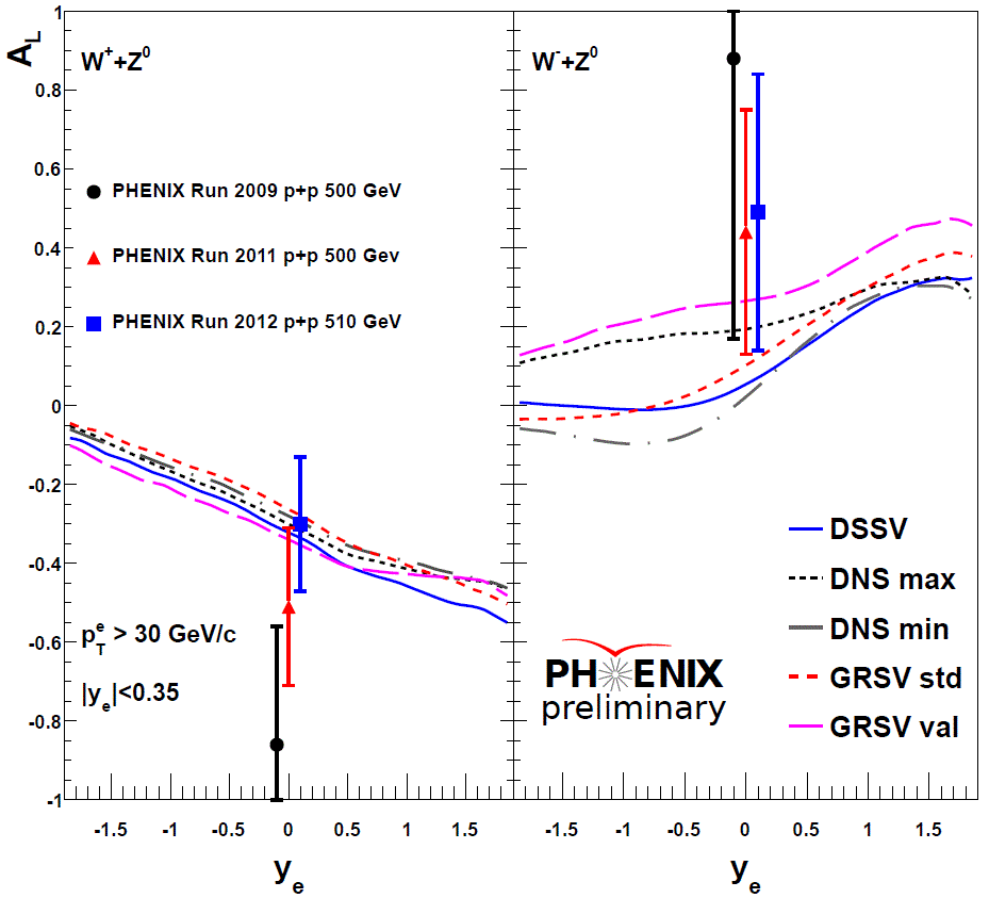


- After all cuts, we have 25% background in the signal region for W^+
- After all cuts, we have 42% background in the signal region for W^-
- As expected $W^- \rightarrow e^-$ signal has fewer counts than $W^+ \rightarrow e^+$ signal

Run 2012 $W^{\pm}$ Single-Spin Asymmetry A_L

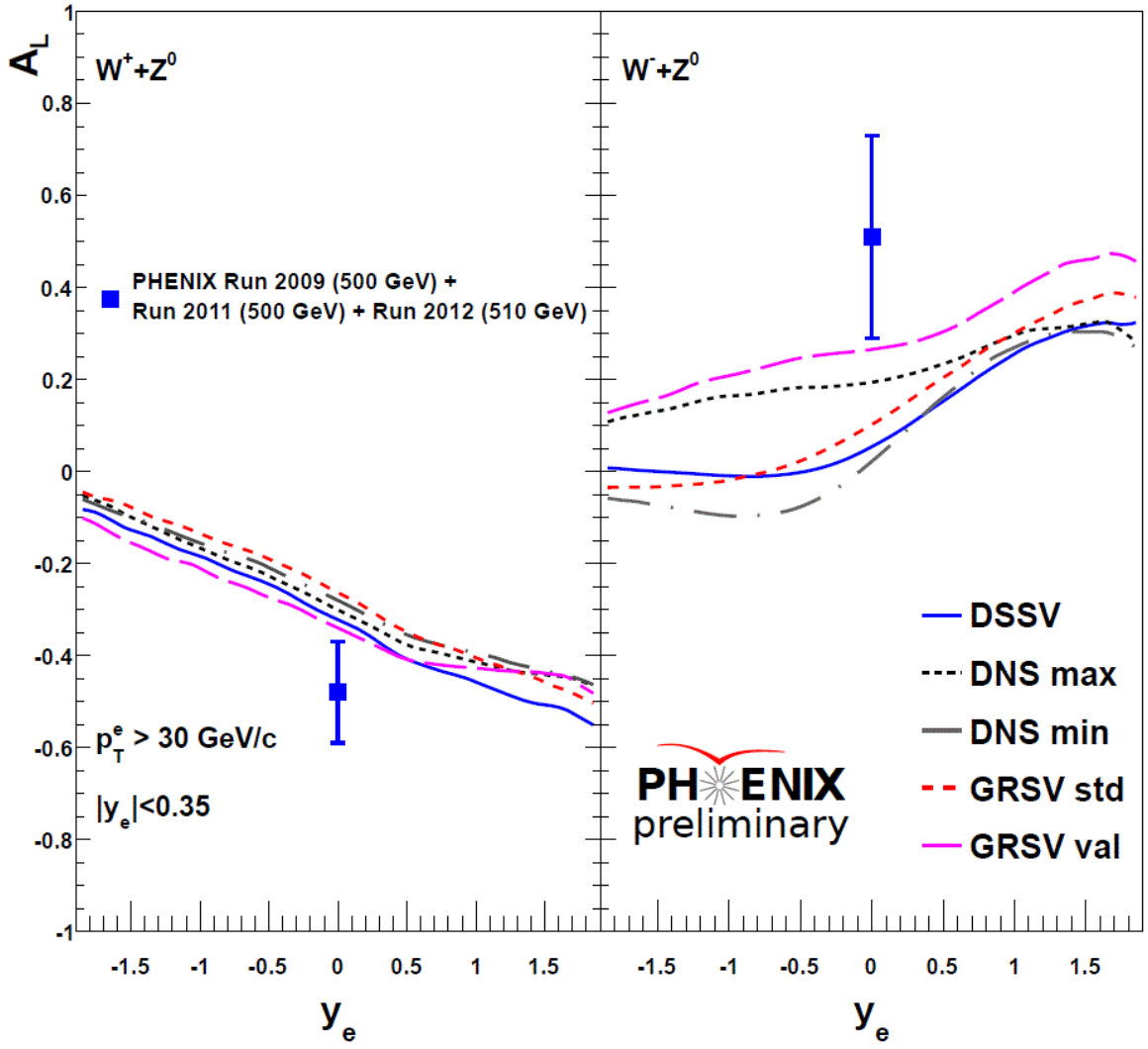
Year	√s (GeV)	∫Ldt (pb^{-1})	Pol. (%)	P^2L (pb^{-1})
2009	500	8.6	39	1.3
2011	500	16	48	3.7
2012	**510**	**23.7**	**55**	**7.2**

(Note: recorded luminosity within |z-vertex|<30 cm)



In Run 2012 510 GeV longitudinally polarized p+p collisions, PHENIX recorded larger data sample with improved polarization in comparison to Run 2011 and Run 2009

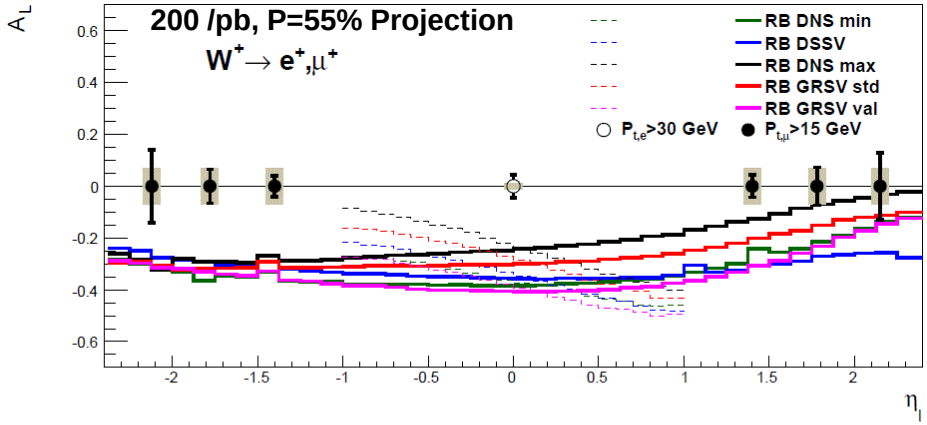
$W^{\pm}$ Single-Spin Asymmetry A_L combined over Run 2012, Run 2011 and Run2009



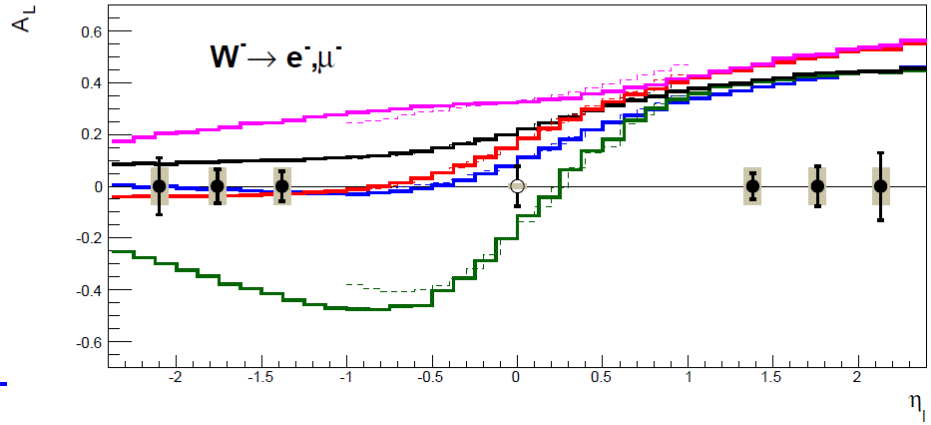
PHENIX in Run 2013

Year	√s (GeV)	∫Ldt (pb^{-1})	Pol. (%)	P^{2}L (pb^{-1})
2009	500	8.6	39	1.3
2011	500	16	48	3.7
2012	**510**	**23.7**	**55**	**7.2**
2013 (expected)	**510**	**~200**	**55**	**60.5**

(Note: recorded luminosity within |z-vertex|<30 cm)



✓ The ongoing Run 2013 is expected to bring us ~200 pb^{-1} of data at 55% polarization giving us opportunity to finalize our W measurements



Summary

- ✓ Run 2012:
  - PHENIX recorded approximately half of the currently analyzed data (Run 2009 + Run 2011 + Run 2012) with improved polarization in comparison to Run 2011 and Run 2009
  - Measured $W^{\pm}$ spectra and A_L in 510 GeV p+p collisions
  - Within errors, A_L measurements are consistent with the theoretical predictions
- ✓ Run 2013:
  - Run 2013 is ongoing
  - Run 2013 is expected to bring us enough data giving us opportunity to finalize our W measurements which will result in improved extraction of the flavor separated quark and anti-quark polarized PDFs

Backup slides:

$W^{\pm}$ Boson Production in Polarized Proton Collisions

(Anti-)quark flavor separation:

Through $u\bar{d} \to W^+$ and $\bar{u}d \to W^-$

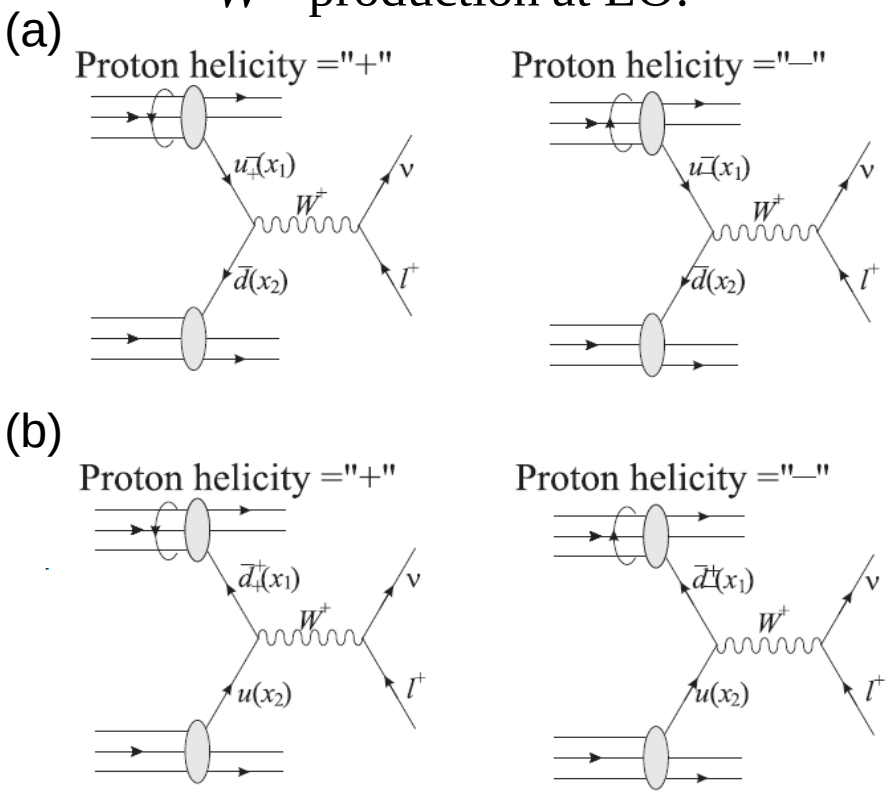
(a) u is left-handed:
Δu probed in polarized proton

(b) $\bar{d}$ is right-handed:
$\Delta \bar{d}$ probed in polarized proton

In general, asymmetry is
a superposition of (a) and (b):

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

W^+ production at LO:



(Bunce et al., Ann. Rev. Nucl. Part. Sci. 50:525 (2000))

✓ For W^-, $\Delta\bar{u}$ and Δd probed

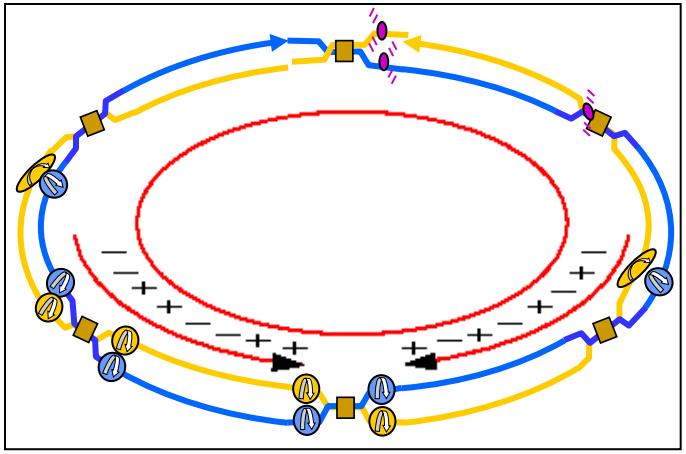
Parity Violating Single Spin Asymmetry

Denoting positive beam helicity by + and negative by −, parity violating longitudinal spin asymmetry can be used to access polarized PDF's by measuring:

$$A_L^W = \frac{1}{P} \times \frac{N^+(W) - N^-(W)}{N^+(W) + N^-(W)}$$

N is the electron yield, normalized by luminosity; P is luminosity-weighted polarization

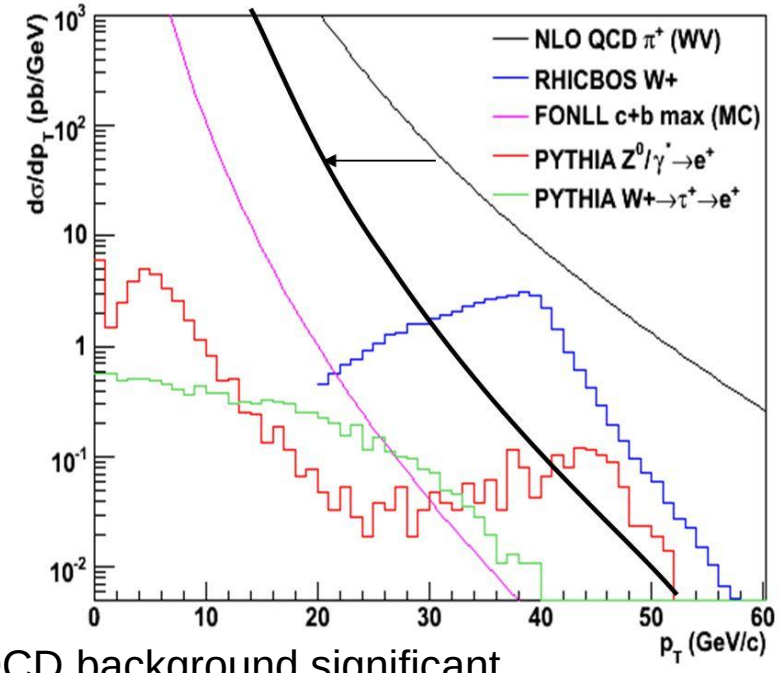
- ✓ At RHIC, up to 120 bunches in each ring, crossing every 106 ns, helicity of pairs ++,+−,−+,−− alternates rapidly
- ✓ Get one measurement treating "blue" beam as polarized, averaging over "yellow" beam
- ✓ Get second measurement treating yellow beam as polarized, averaging over blue beam

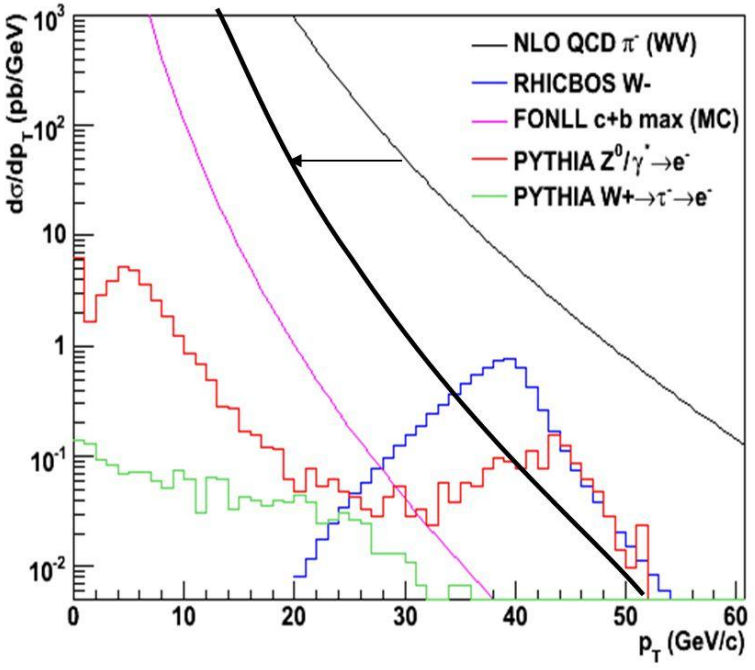


Signal and Background components

Identify $W^{\pm} \rightarrow e^{\pm}$: rely on excess of events over background

✓ Signal: Jacobian peaks for W^+ and W^-





✓ QCD background significant
✓ c/b relatively small above 30 GeV
✓ $W \rightarrow \tau \rightarrow e$ is also small
✓ Z->e is part of the signal
✓ Not shown here but very important:

- Hadronic shower in EMCal – hadronic response simulation and data study is in progress
- Photon conversions $\gamma \rightarrow e^+e^-$ (before the Drift Chamber) - simulation study is in progress

PHENIX in Run 2013 (expected)

✓ The upcoming Run 2013 is expected to bring us ~200 pb^{-1} of data at 55% polarization giving us enough data to finalize our W measurements