$W^{\pm}$ Boson Production Measurement at Mid-rapidity in the PHENIX Experiment

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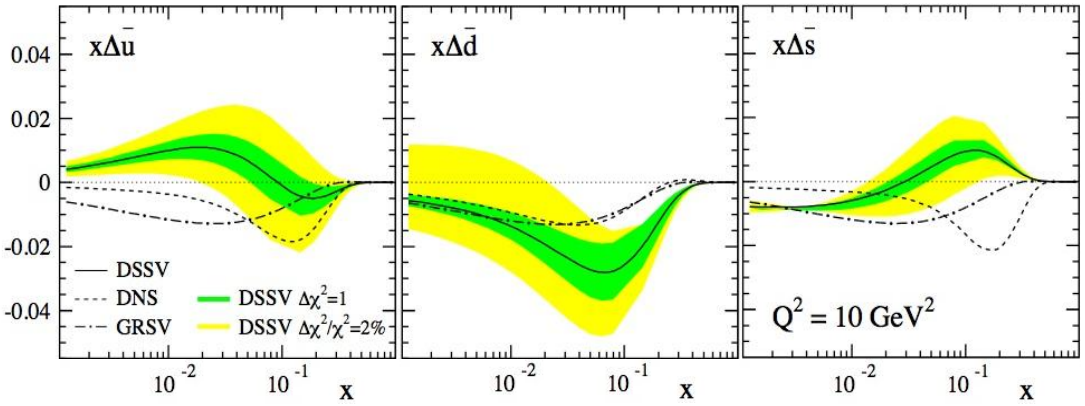
Motivation for Spin Physics with W bosons

Quark and anti-quark flavor separated 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:

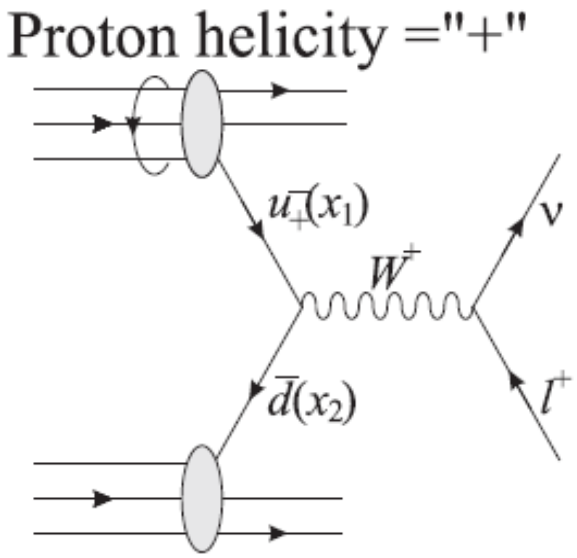
- no fragmentation involved
- high scale, Q^2 (set by W mass)
- extraction of $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$
- also possible to probe $\bar{u}(x)/\bar{d}(x)$ ratio

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

(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))

$$u\bar{d} \rightarrow W^+ \qquad \bar{u}d \rightarrow W^-$$

W couples to only one helicity:

- ✓ For W^+
  - u left-handed: Δu probed in polarized proton
  - $\bar{d}$ right-handed: $\Delta\bar{d}$ probed in polarized proton
  - **parity violating longitudinal single-spin asymmetry:**

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

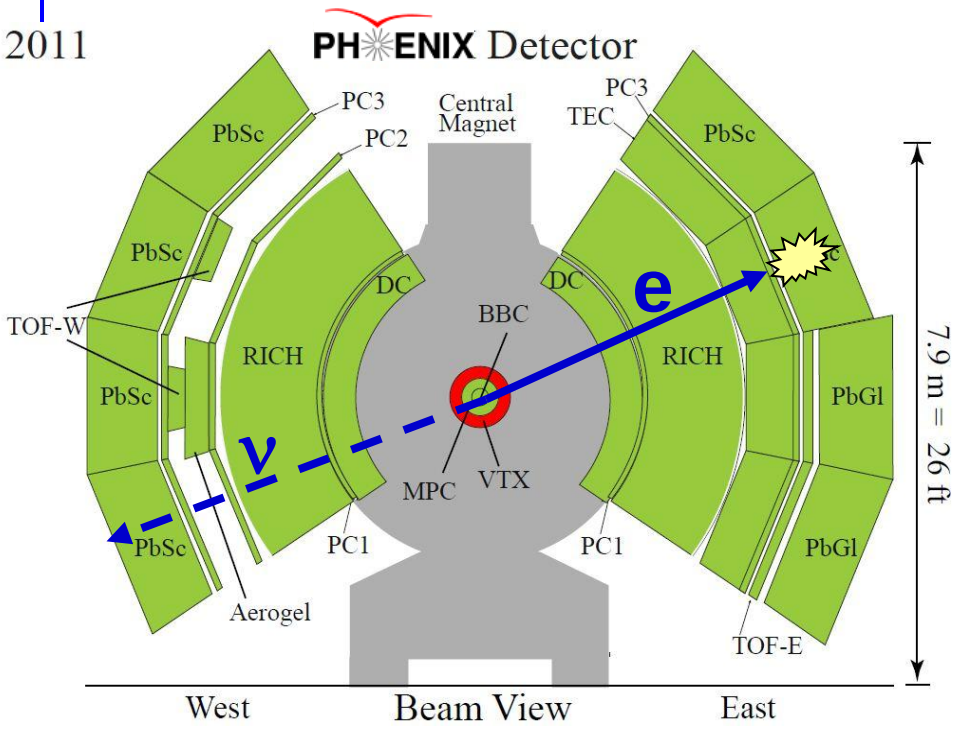
- ✓ For W^-: $\Delta\bar{u}$ and Δd probed

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

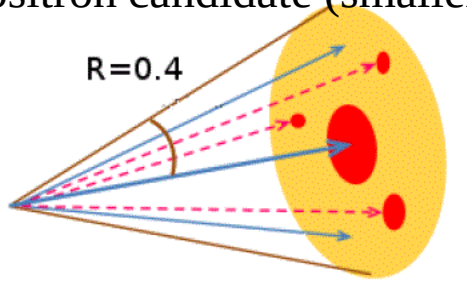
PHENIX Detector and Analysis Strategy



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

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

- EMCal 4x4 Tower Sum Trigger
- High energy EMCal clusters matched to charged tracks
- Timing cut to reduce cosmic ray bkg
- E/p cut to reduce hadron bkg
- Isolation cut is the main background reducer : energy in a cone of R = 0.4 excluding the candidate cluster energy divided by the energy of the electron/positron candidate (smaller than 10%)



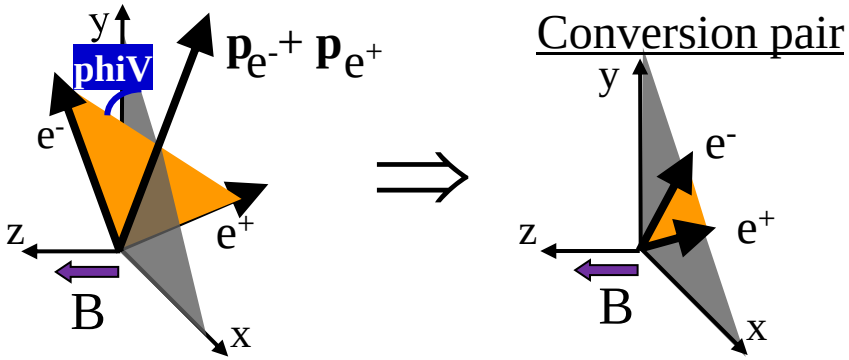
<u>Central arm spectrometers</u>:

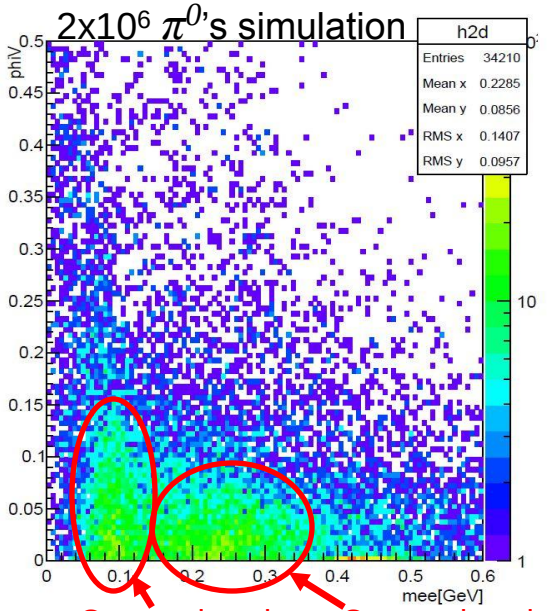
- 2 arms: each $\Delta\phi = \pi/2$, $|\eta|<0.35$ in rapidity
- Electromagnetic Calorimeter (EMCal) with segmentation $\Delta\varphi x\Delta\eta \sim 0.01x0.01$
- Tracking: Charged tracks measured in Drift Chamber (DC) and Pad Chamber (PC)
- SiVTX Detector (under commissioning during Run 2011)

VTX conversion background

VTX increases $\gamma \rightarrow e^+e^-$ bkg (radiation length =13.5%)

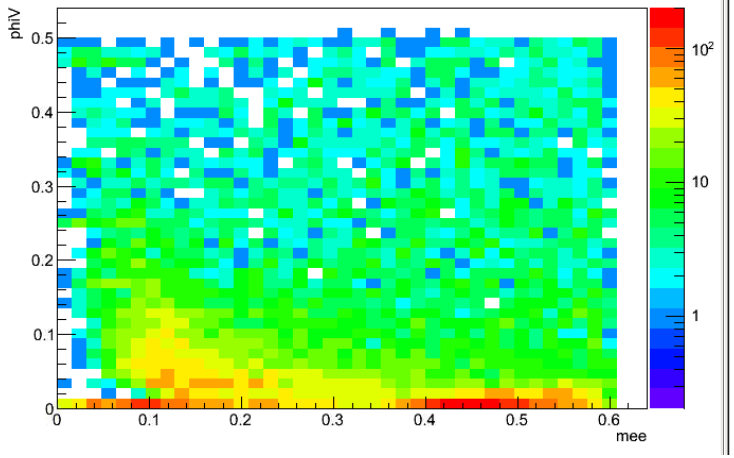
• orientation angle of the e^+e^- pair in the magnetic field (**phiV**) vs. apparent invariant mass $\mathbf{m_{ee}}$



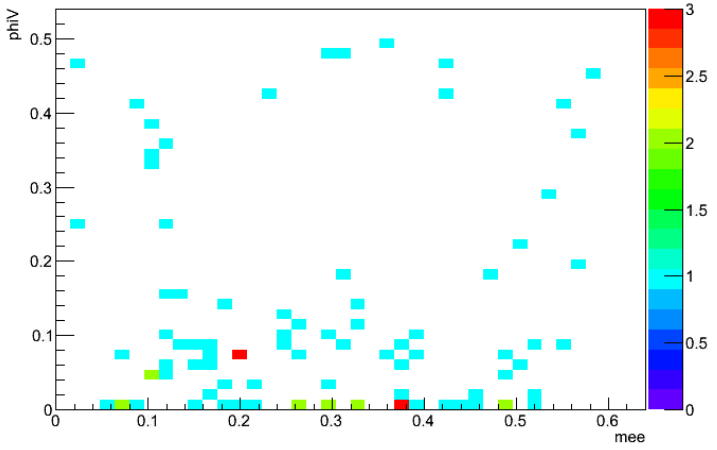


Isolation cut reduces identified conversions:

Before Isolation Cut



After Isolation Cut



PHENIX Run 2011 Dataset for Mid-rapidity $W^{\pm}$

- ✓ In Run 2009, PHENIX performed first W measurements in 500 GeV longitudinally polarized p+p collisions
- ✓ In Run 2011 500 GeV longitudinally polarized p+p collisions, PHENIX recorded larger data sample with improved polarization in comparison to Run 2009

Year	$\sqrt{s}$ (GeV)	$\int Ldt$ (pb^{-1})	Pol. (%)	P^2L (pb^{-1})
2009	500	8.6	39	1.3
2011	**500**	**16**	**48**	**3.7**

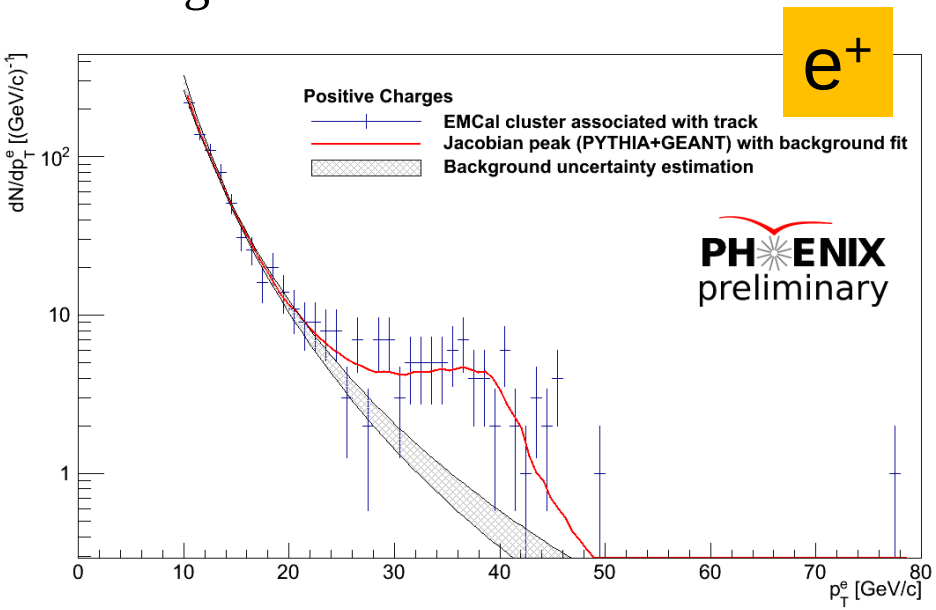
(Note: recorded luminosity within |z-vertex|<30 cm)

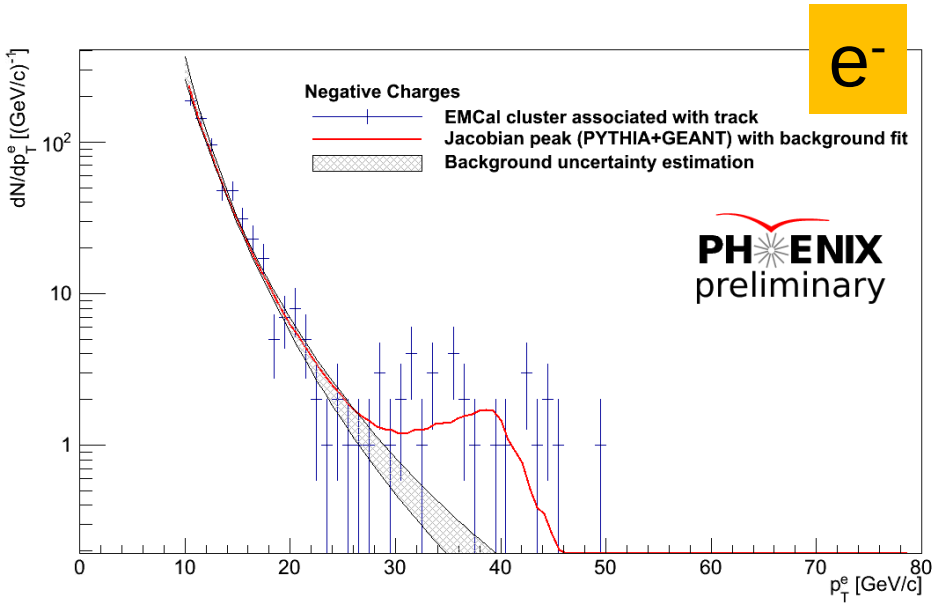
Run 2011 Measured W^+ and W^- Spectra

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

- Expected signal: Jacobian peaks for W^+ and W^-

- Reduce the background as much as possible and take the region between 30 and 50 GeV as the signal region, while using the 10 to 20 GeV region for background estimation



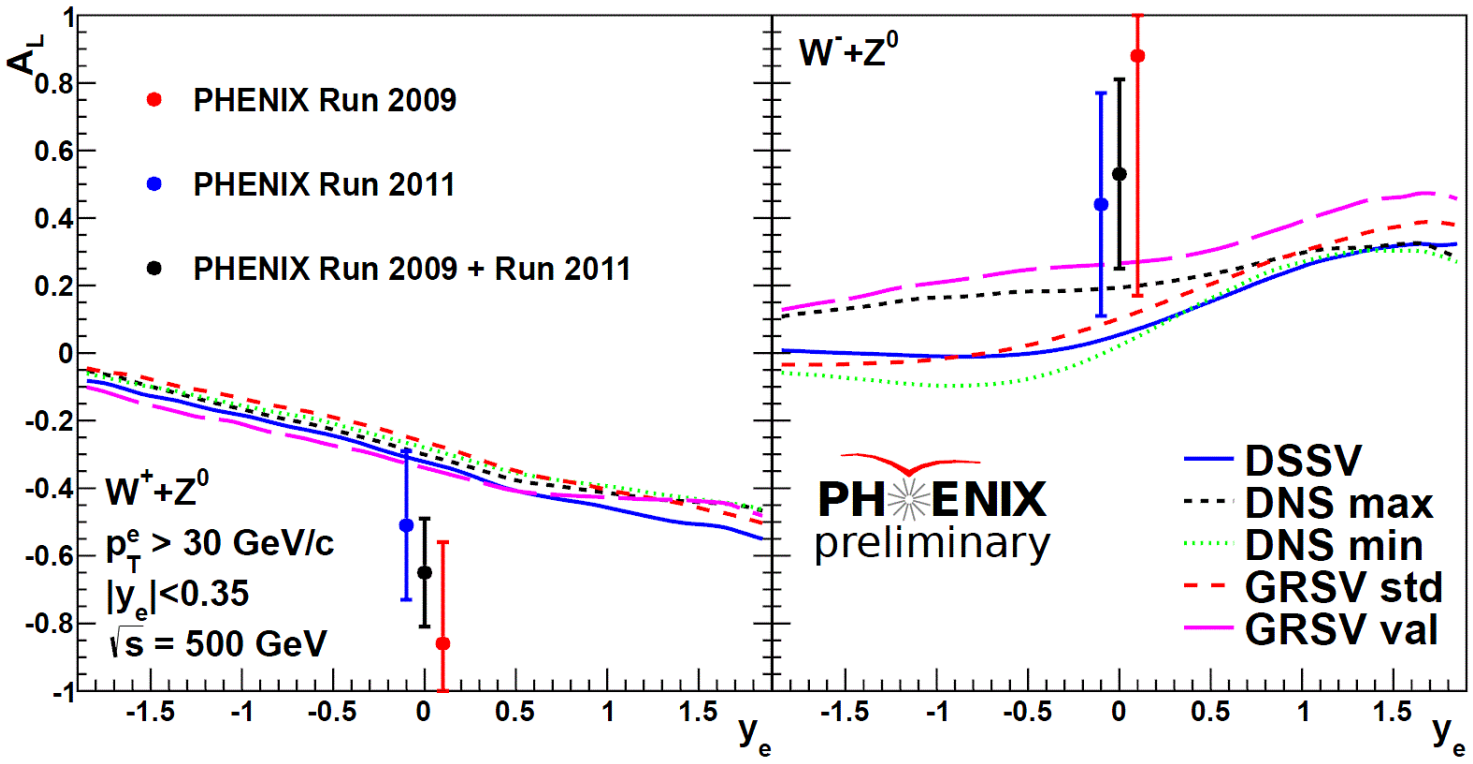


- After all cuts we have 18% background in the signal region (30 to 50 GeV)

- After all cuts we have 15% background in the signal region (30 to 50 GeV)

- $W^- \rightarrow e^-$ signal has fewer counts than $W^+ \rightarrow e^+$ signal as expected

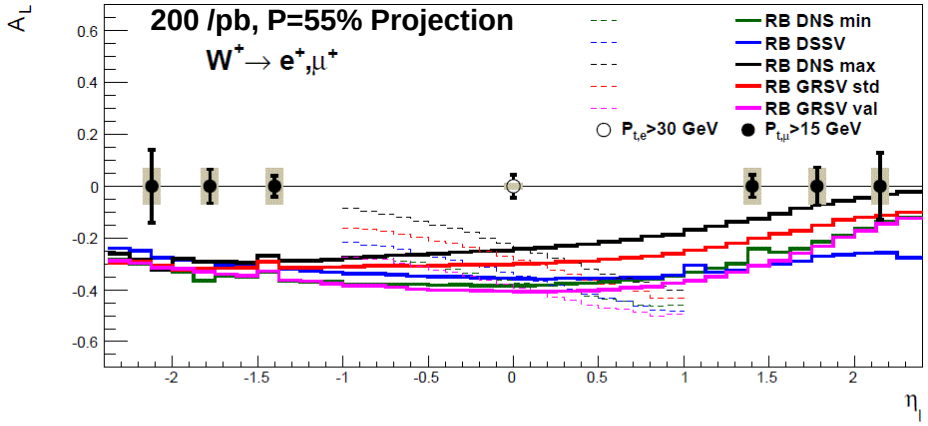
Run 2011 Single-Spin Asymmetry A_L

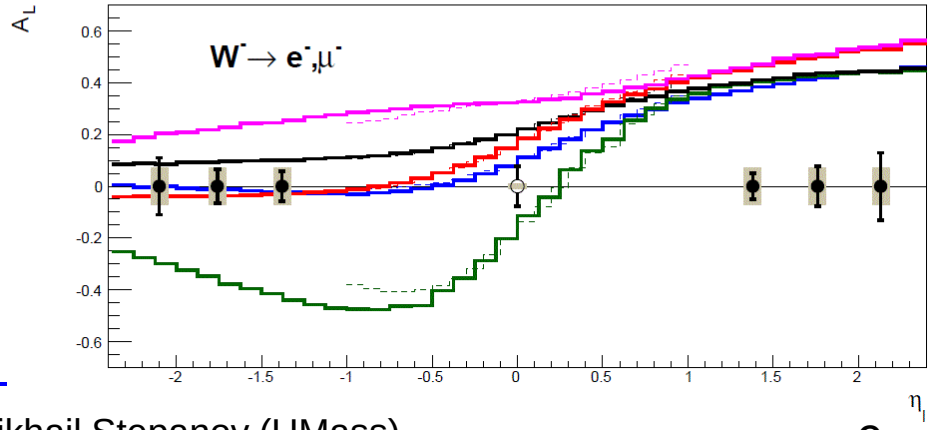


PHENIX in Run 2012 and 2013

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**	**~30**	**52**	**8.1**
2013 (expected)	**510**	**~200**	**55**	**60.5**

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





✓ In Run 2012, PHENIX recorded more than half of our currently recorded data; SiVTX detector is fully operational and will be used in the central arm W analysis

✓ 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

Summary

- ✓ Run 2011:
  - PHENIX recorded larger data sample with improved polarization in comparison to Run 2009
  - Measured $W^{\pm}$ spectra and A_L in 500 GeV p+p collisions
  - Within errors, A_L measurements are consistent with the theoretical predictions
- ✓ Run 2012:
  - PHENIX recorded more than half of the currently recorded data (Run 2009 + Run 2011 + Run 2012)
  - Data is ready to be analyzed
  - SiVTX is fully operational, will be used in the analysis
- ✓ Run 2013:
  - Run 2013 is expected to bring us enough data to finalize our W measurements

Backup slides:

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

(Anti-)quark flavor separation:

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

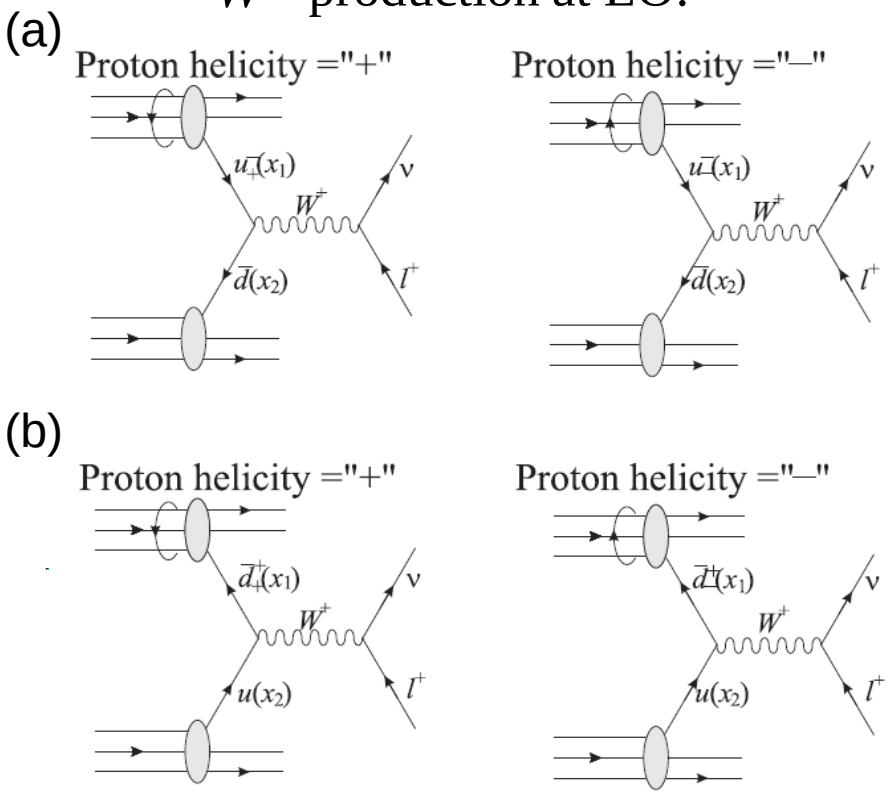
(a) u is left-handed:
Δu probed in polarized proton

(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

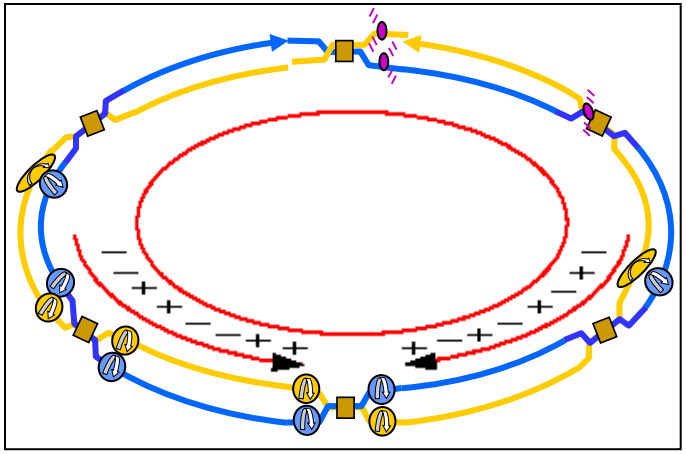
Parity Violating Single Spin Asymmetry

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

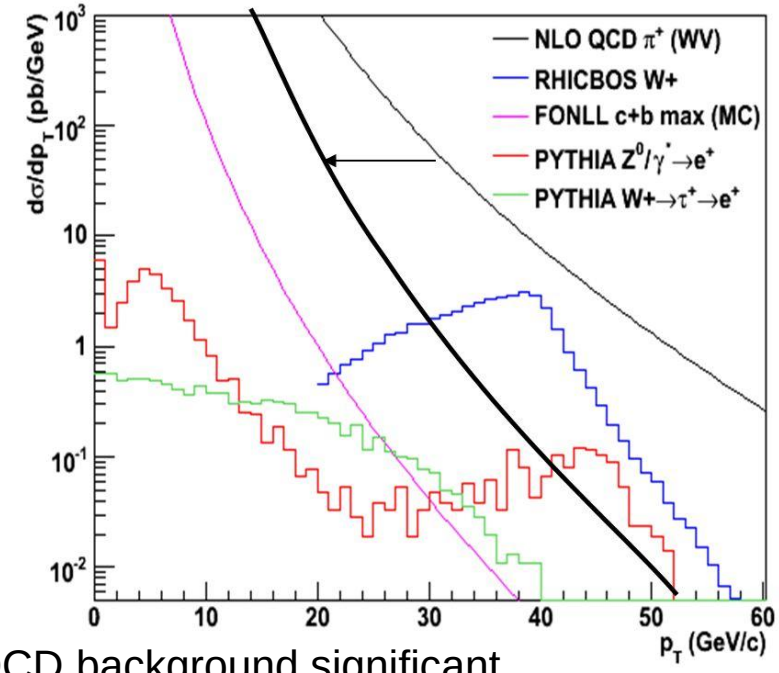
- ✓ At RHIC, up to 120 bunches in each ring, crossing every 106 ns, helicity of pairs ++,+−,−+,−− alternates rapidly
- ✓ Get one measurement treating "blue" beam as polarized, averaging over "yellow" beam
- ✓ Get second measurement treating yellow beam as polarized, averaging over blue beam

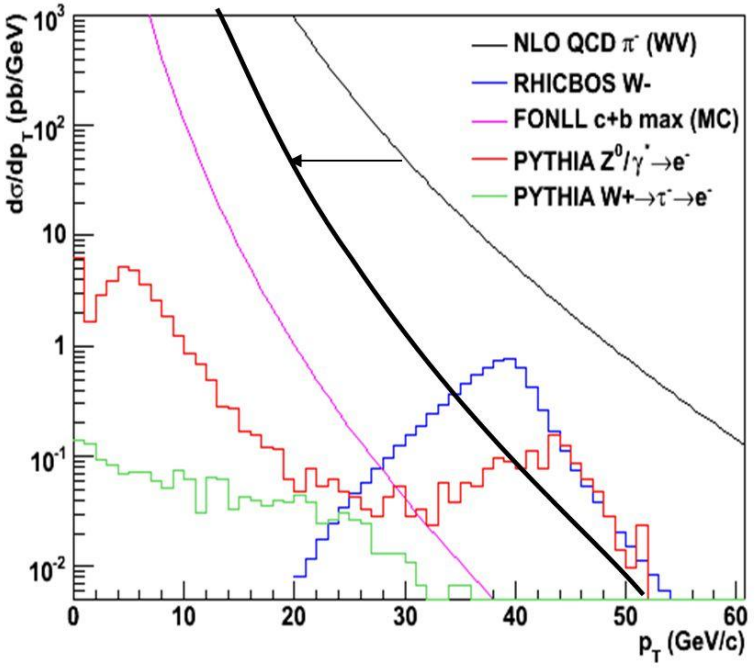


Signal and Background components

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

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

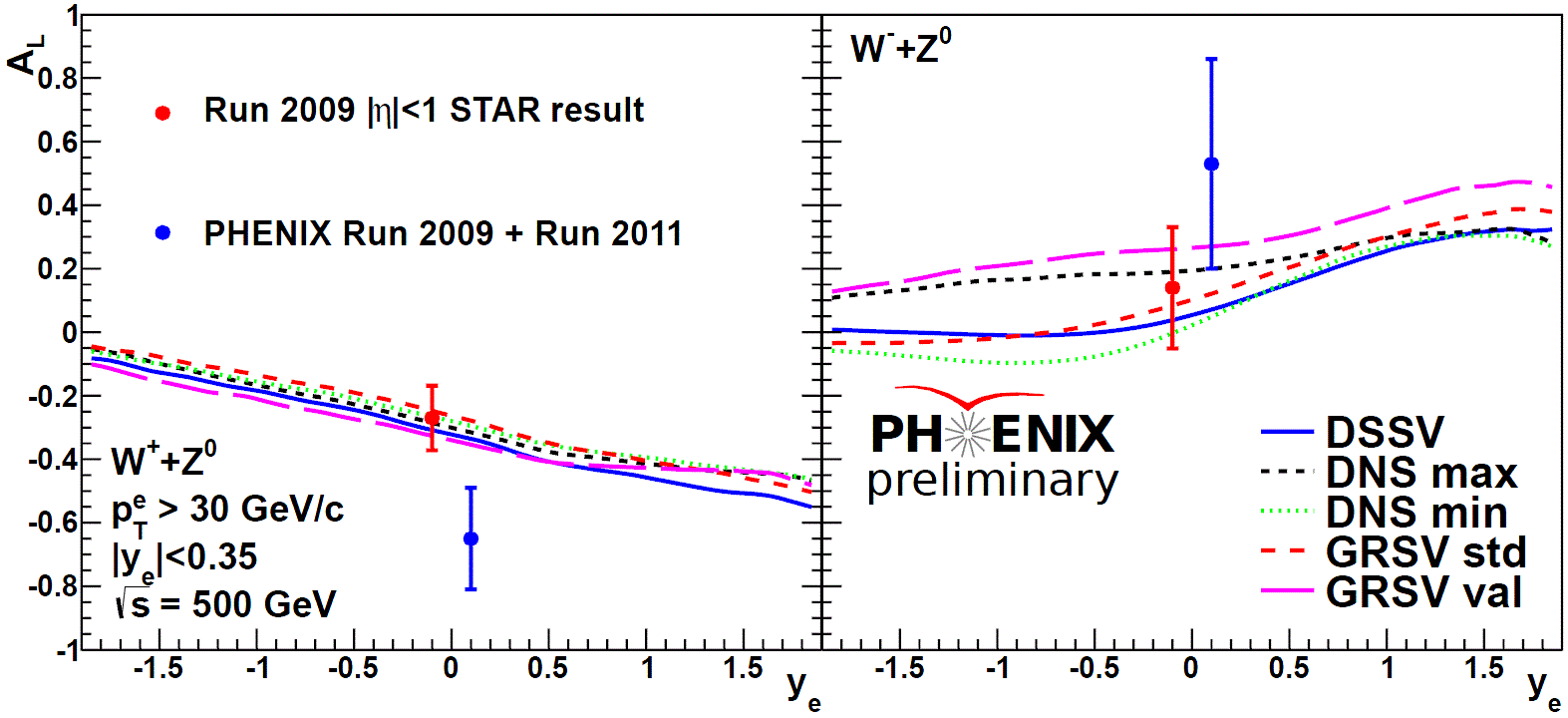




✓ QCD background significant
✓ c/b relatively small above 30 GeV
✓ $W \rightarrow \tau \rightarrow e$ is also small
✓ Z->e is part of the signal
✓ Not shown here but very important:

- 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 A_L compared to Run 2009 STAR A_L



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