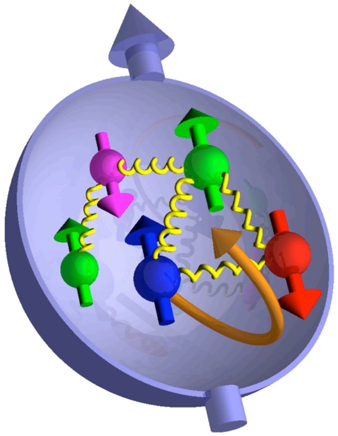
Recent STAR results and prospects of $W^{+/-}$ boson production in polarized p+p collisions at RHIC

Joe Seele (MIT) for the

STAR Collaboration

DIS 2011

The Spin Puzzle



The proton is viewed as being a "bag" of bound quarks and gluons interacting via QCD

Spins + orbital angular momentum need to give the observed spin 1/2 of proton

Being measured at RHIC

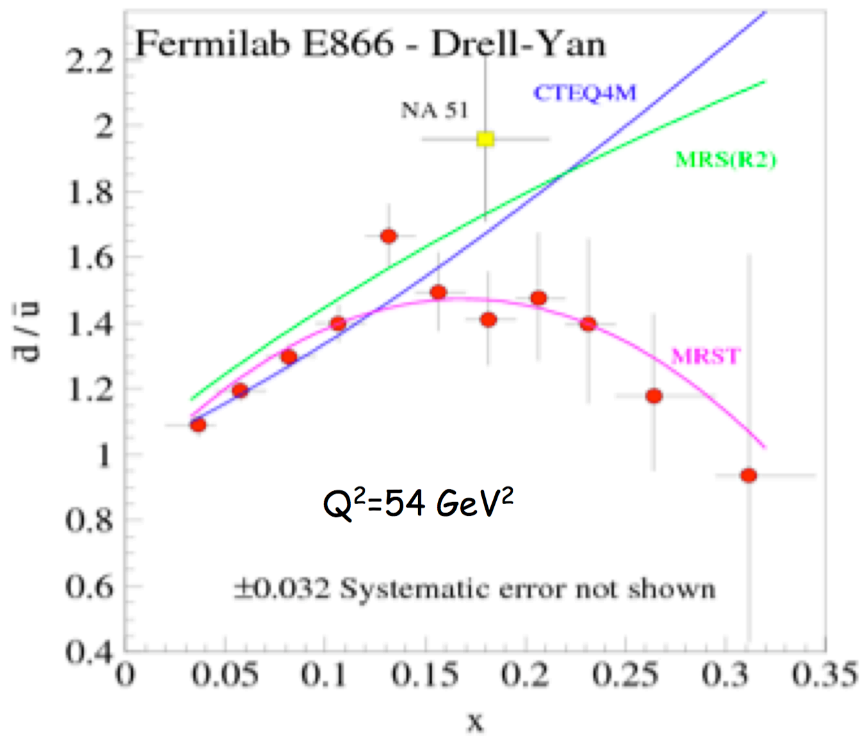
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q^z + \Delta G + L_g^z$$

Fairly well measured only ~30% of spin

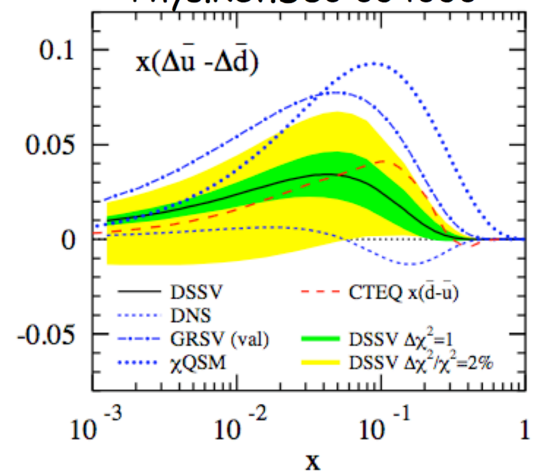
Its decomposition is not well understood, especially the sea… needs data

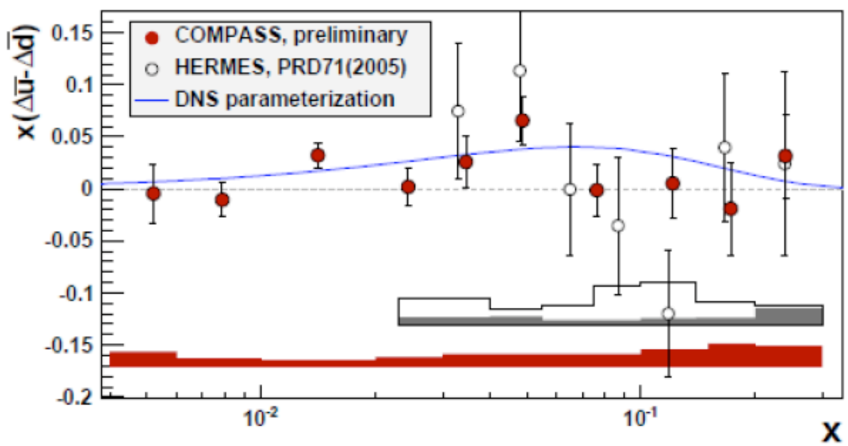
$$\Delta\Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s} + \cdots)dx$$

Flavor Asymmetry in the Sea



Phys.Rev.D80:034030

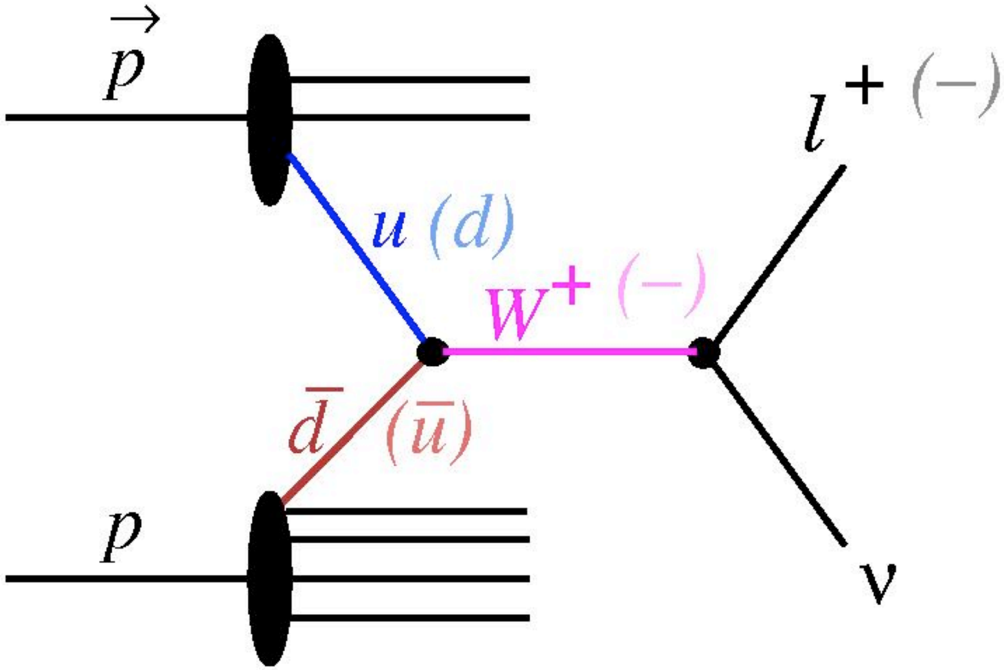




- E866 results are qualitatively consistent with pion cloud models, instanton models, chiral quark soliton models, etc.

- Pauli blocking should contribute to the observed signal, but how much is currently debated
- Non-perturbative processes may be needed in generating the sea

Probing the Sea through Ws



$$u + \bar{d} \rightarrow W^{+} \rightarrow e^{+} + \nu$$

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

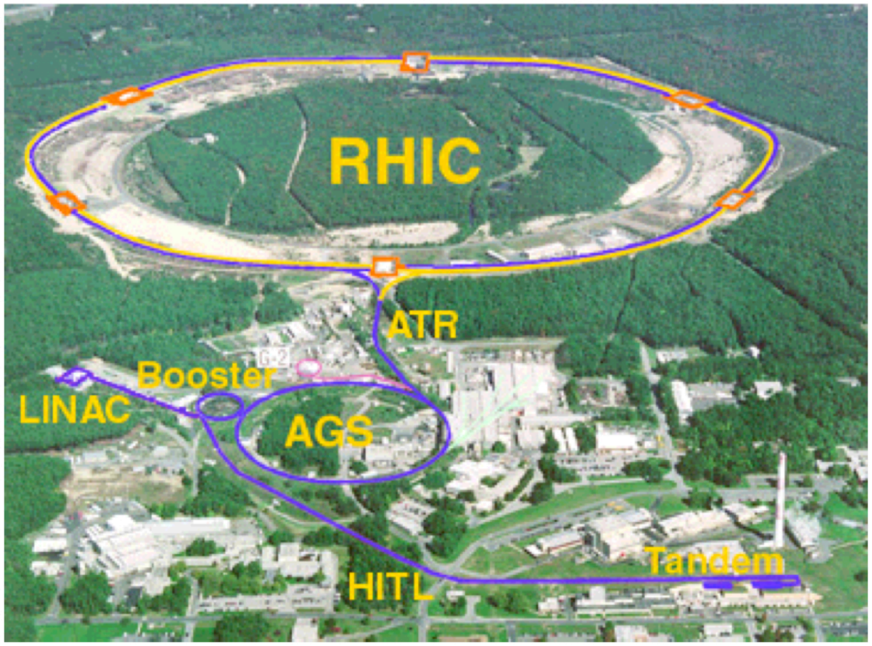
- Detect Ws through e^{+} and e^{-} decay channels
- V-A coupling leads to perfect spin separation
- Neutrino helicity gives preferred direction in decay

Measure parity violating single helicity asymmetry A_L

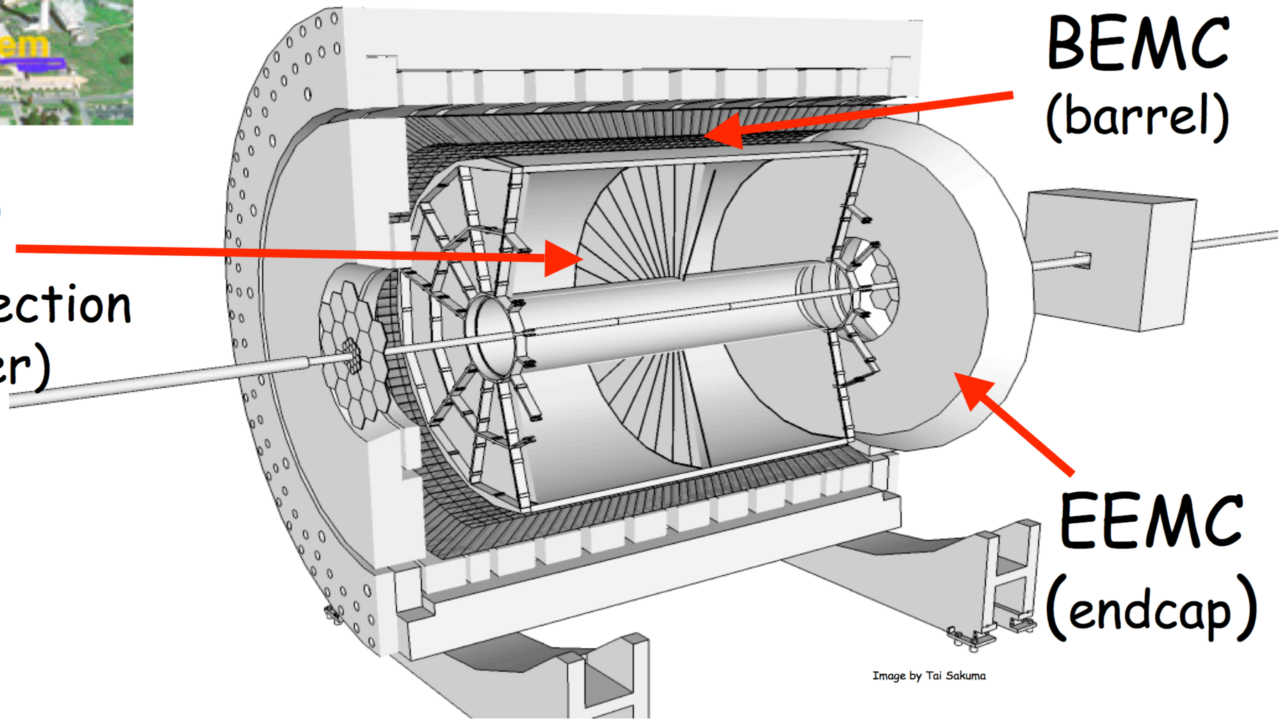
(Helicity flip in one beam while averaging over the other)

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

RHIC and STAR



A polarized proton-proton collider to study spin in QCD up to sqrt(s)=500 GeV



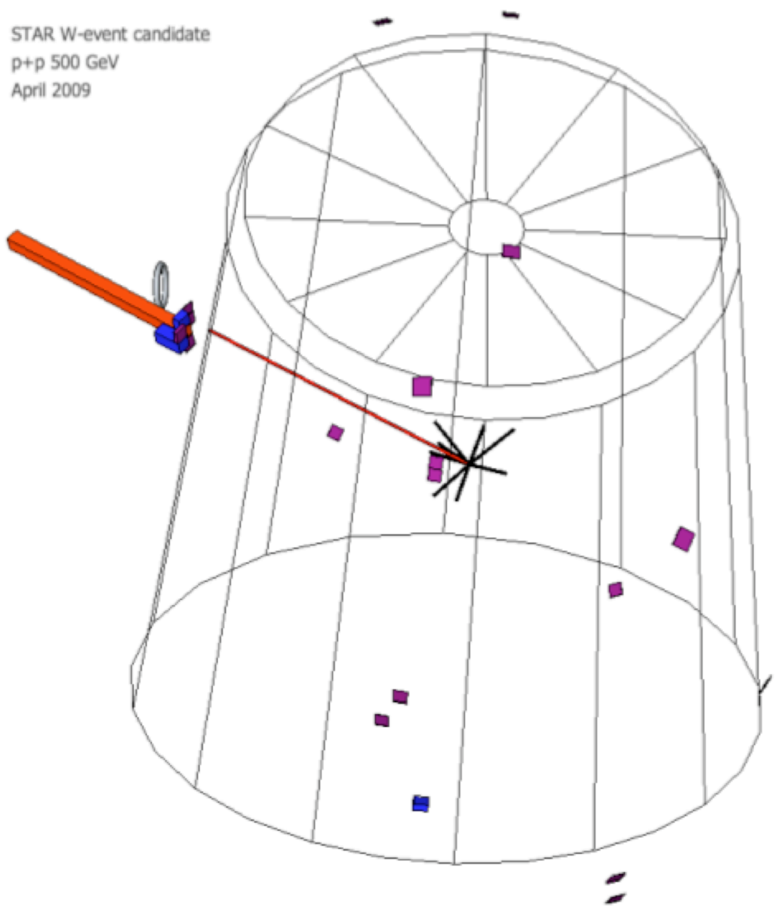
BEMC (barrel)

TPC (time projection chamber)

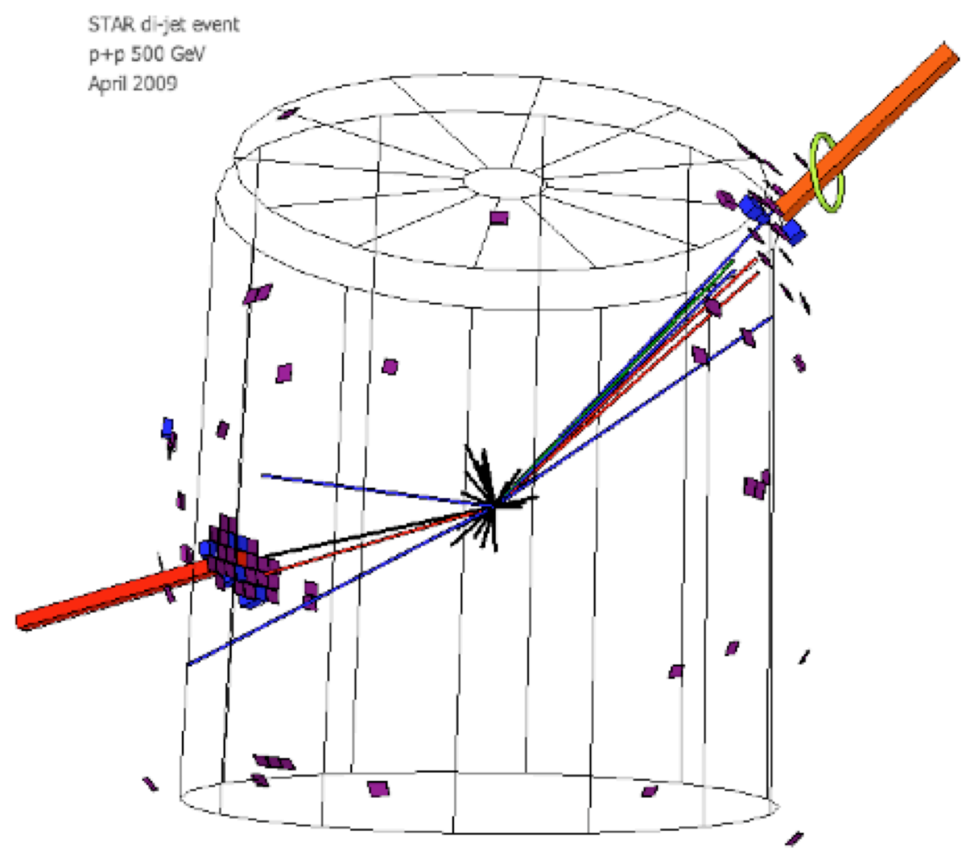
EEMC (endcap)

W Algo: Motivation

What we want to accept

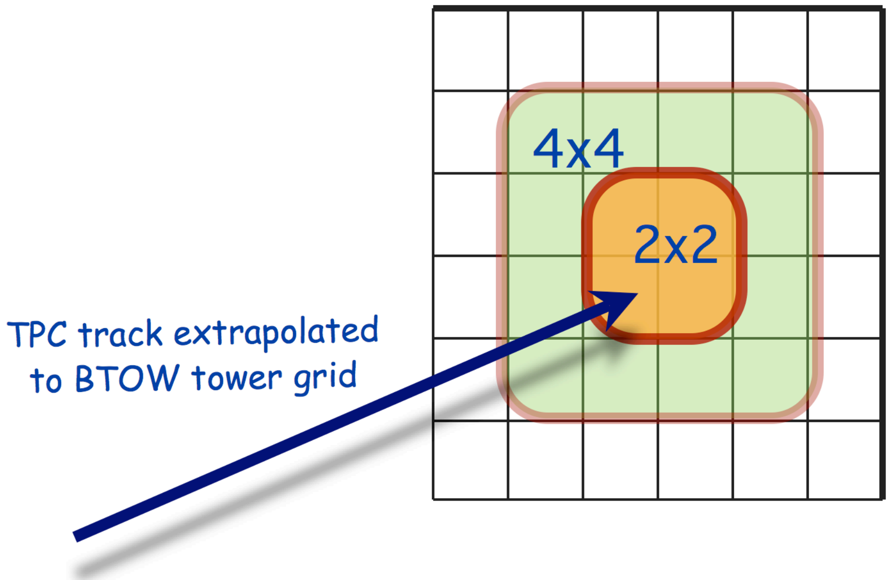


What we want to reject



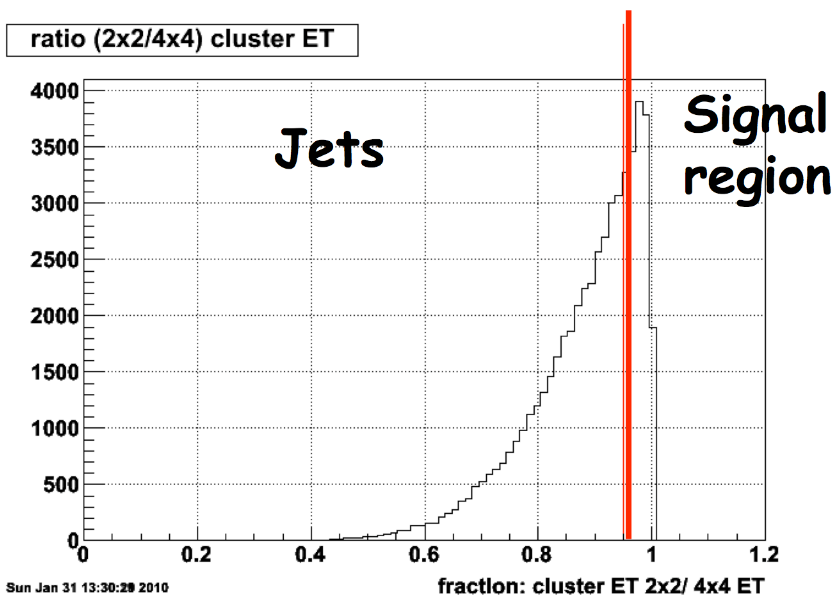
Look for the electron-type events with no energy/momentum on the away side

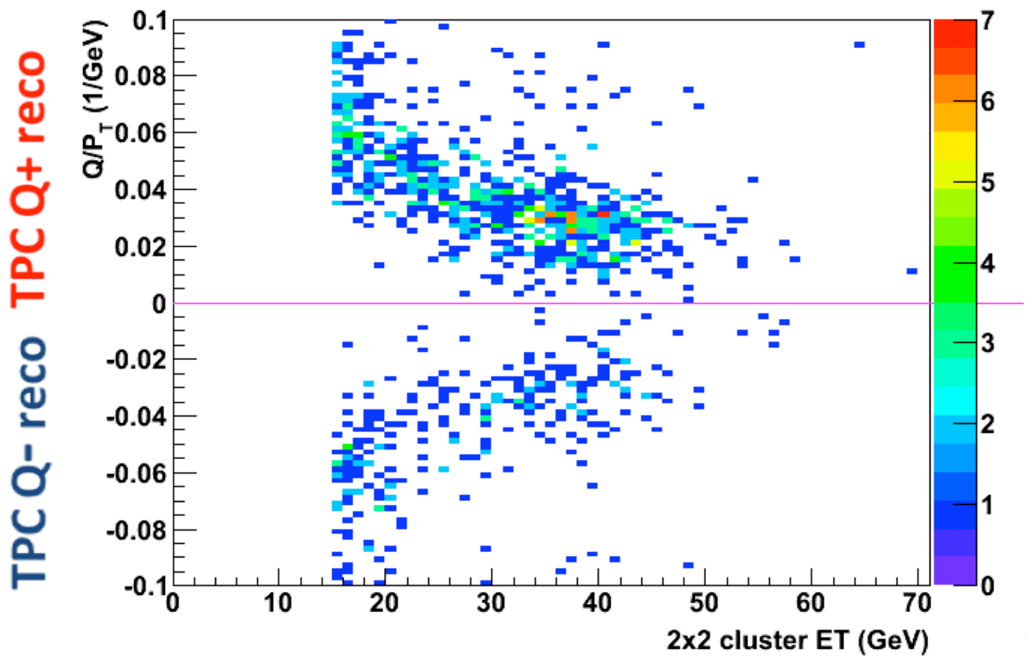
W Algo: Lepton Isolation



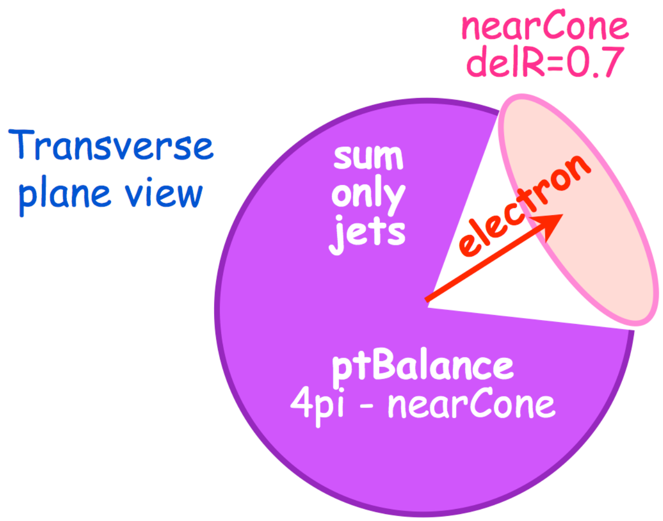
Lepton Isolation Cuts:

- Require TPC track with p_T > 10 GeV
- Extrapolate track to Barrel Calorimeter
- Require highest 2x2 cluster around pointed tower sum E_T > 15 GeV
- Require excess E_T in 4x4 cluster < 5%
- Match track to 2x2 cluster position
- Get charge sign of lepton



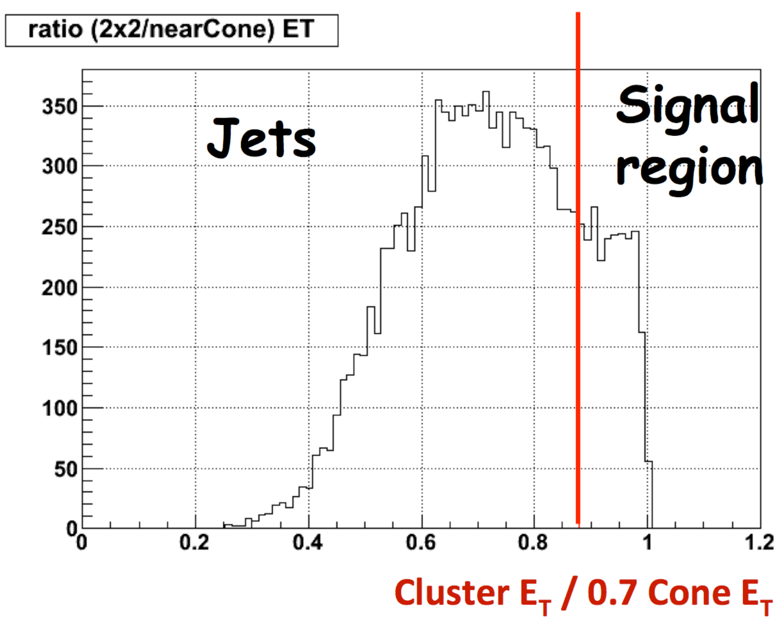


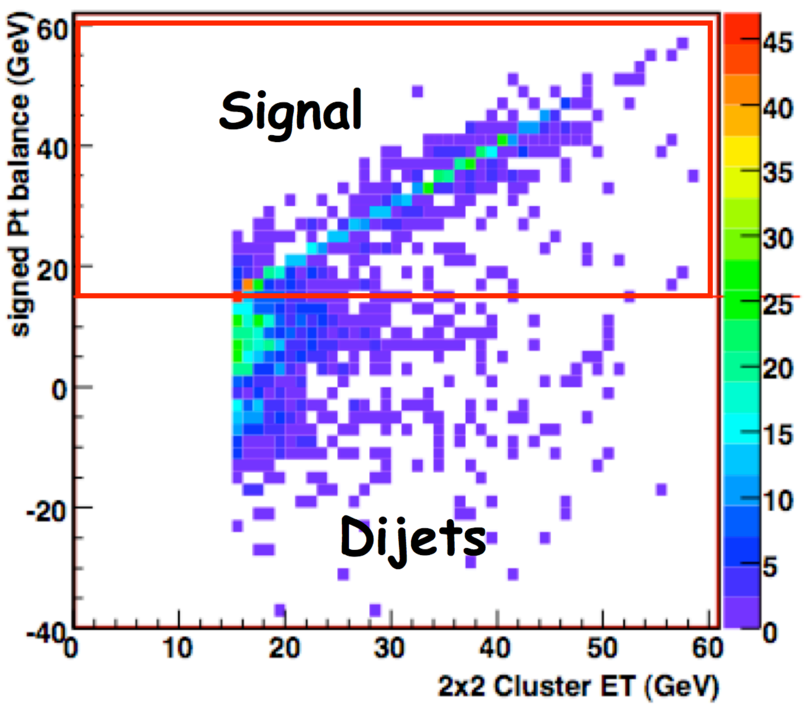
W Algo: Suppress QCD Background



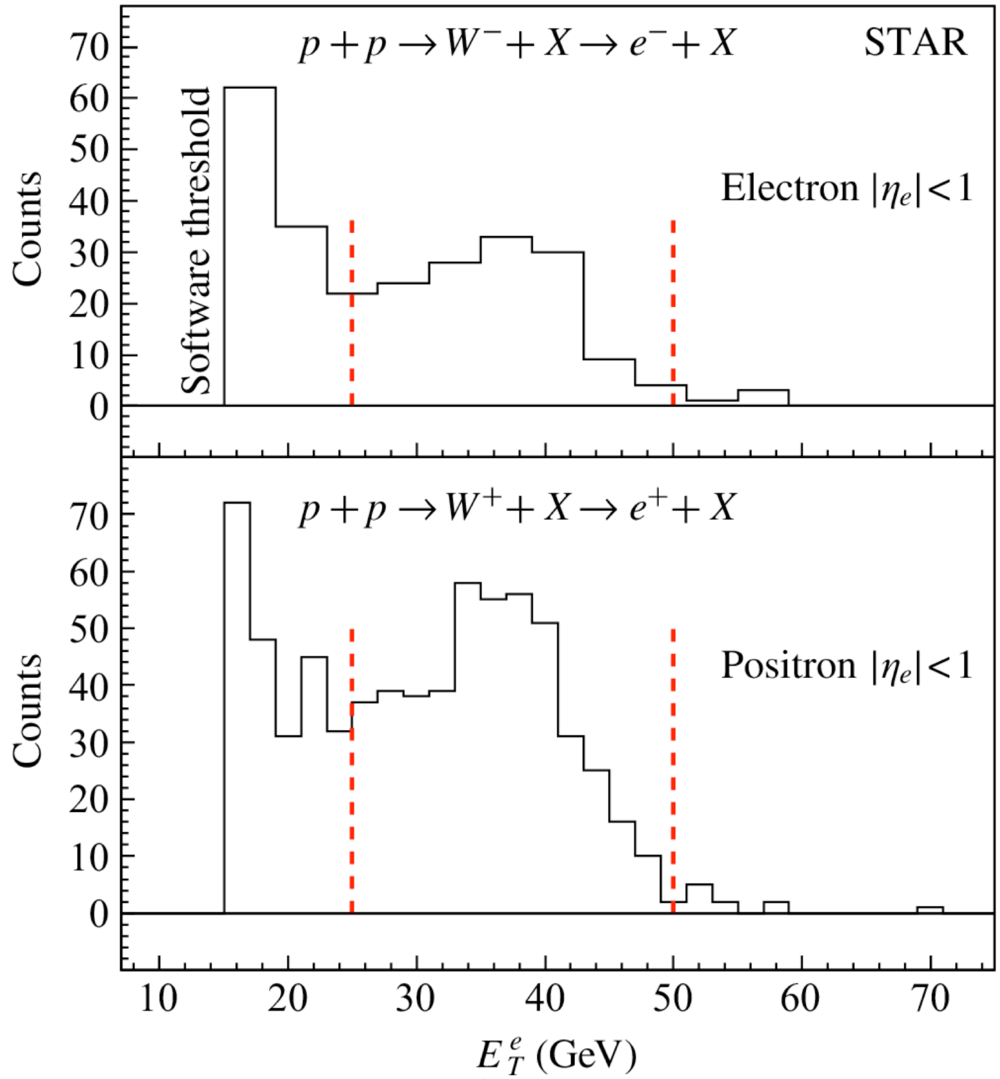
Suppress jets with leading hadron
- Near side jet-cone veto

Suppress di-jets and multi-jet events
- Away side p_T sum veto
- Require an imbalance in p_T of the lepton cluster and any jets reconstructed outside the near side jet cone





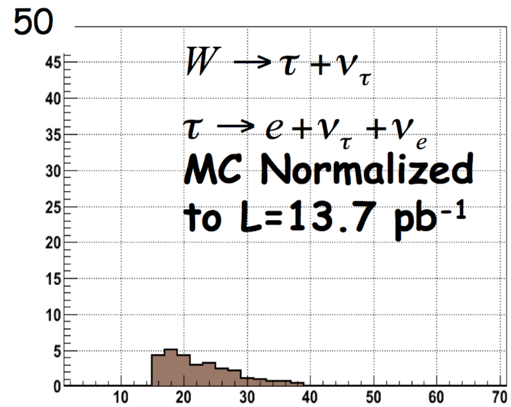
The Raw Signal



STAR recorded 13.7pb^{-1} in the run9 500 GeV running period

Extracting the W Signal

PYTHIA+GEANT MC →



Extracting the W Signal

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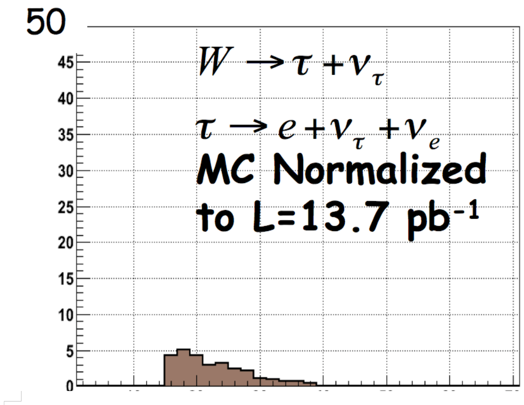
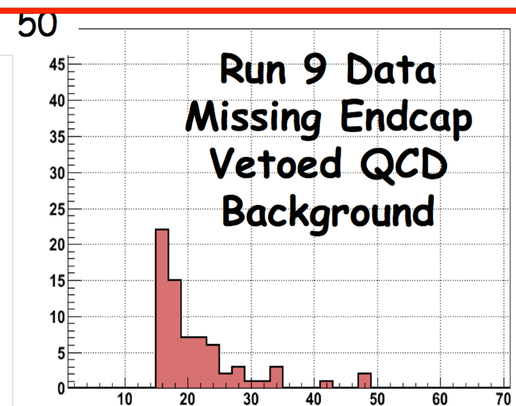


1. Run analysis with EEMC in veto cuts
2. Run analysis without EEMC in veto cuts
3. Subtract two raw signals



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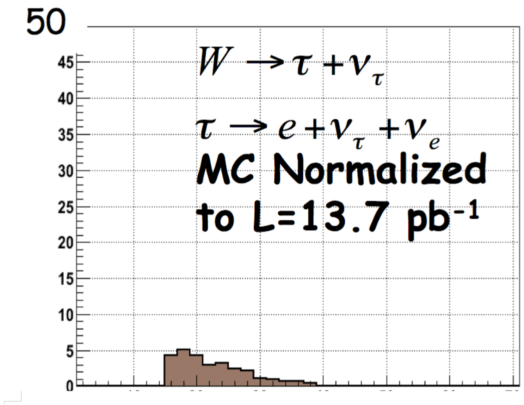

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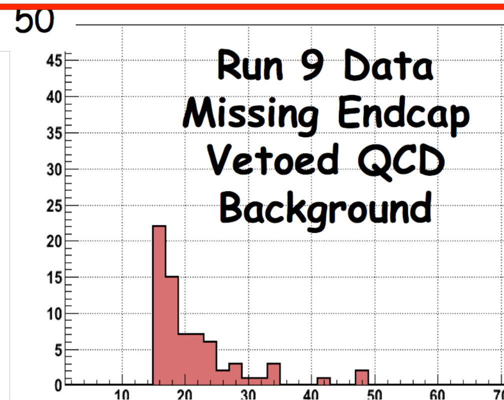
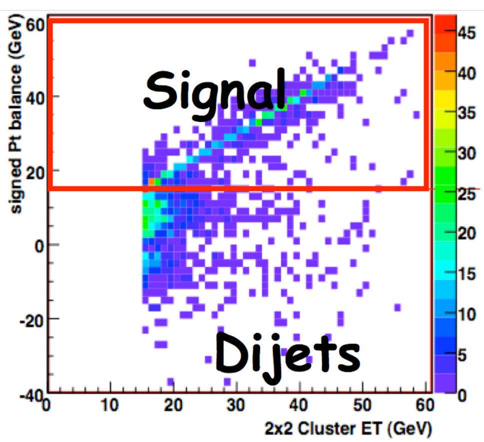
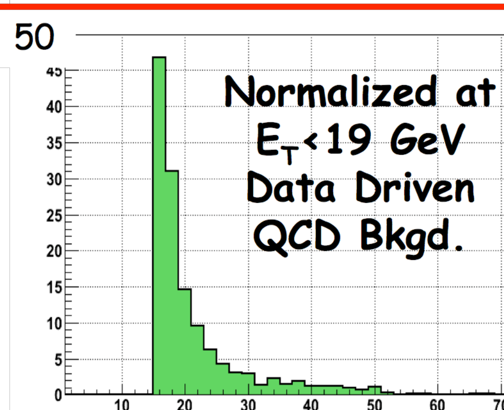




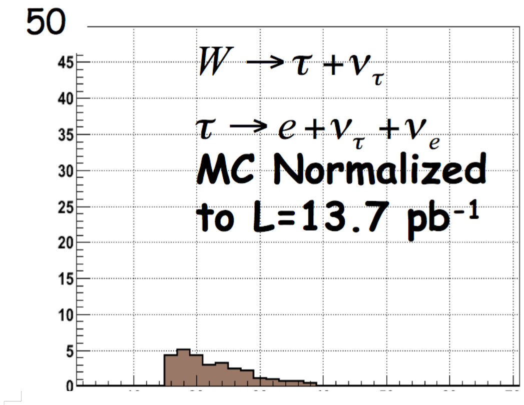
→



EMC Cluster E_T (GeV)

Extracting the W Signal

PYTHIA+GEANT MC →



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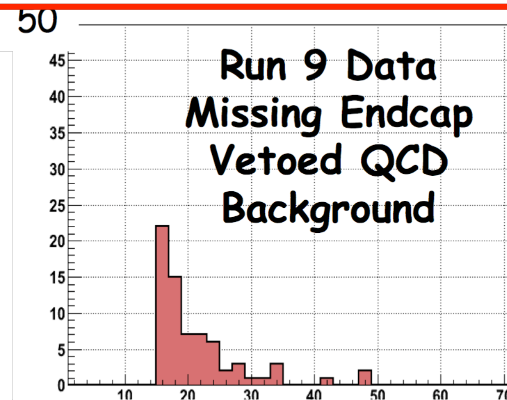
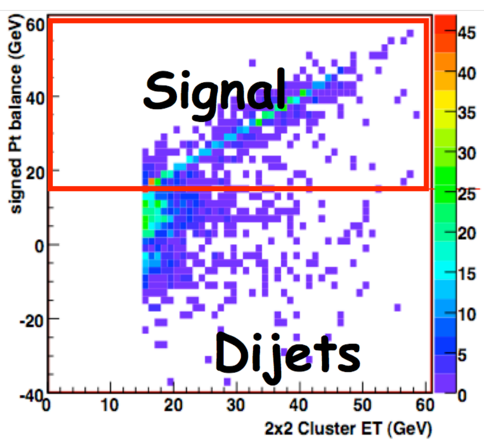
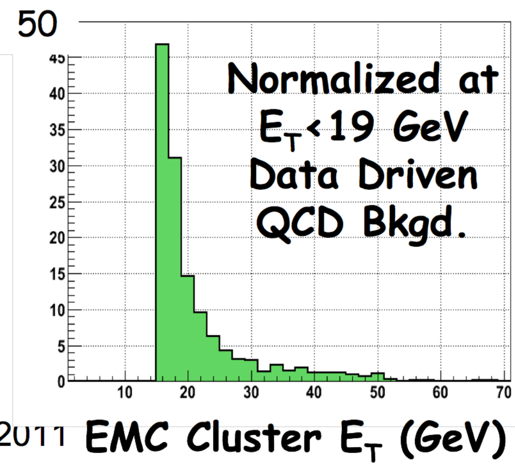
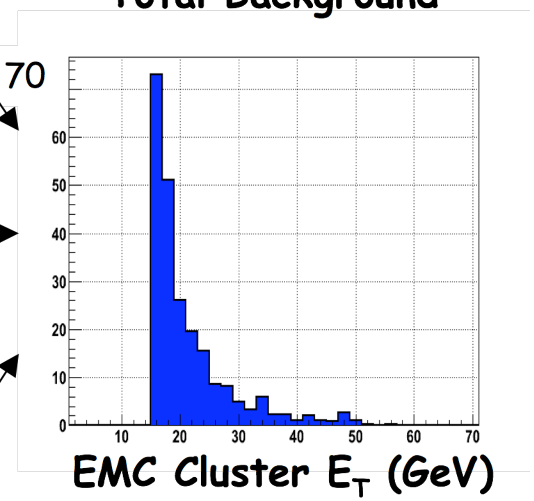


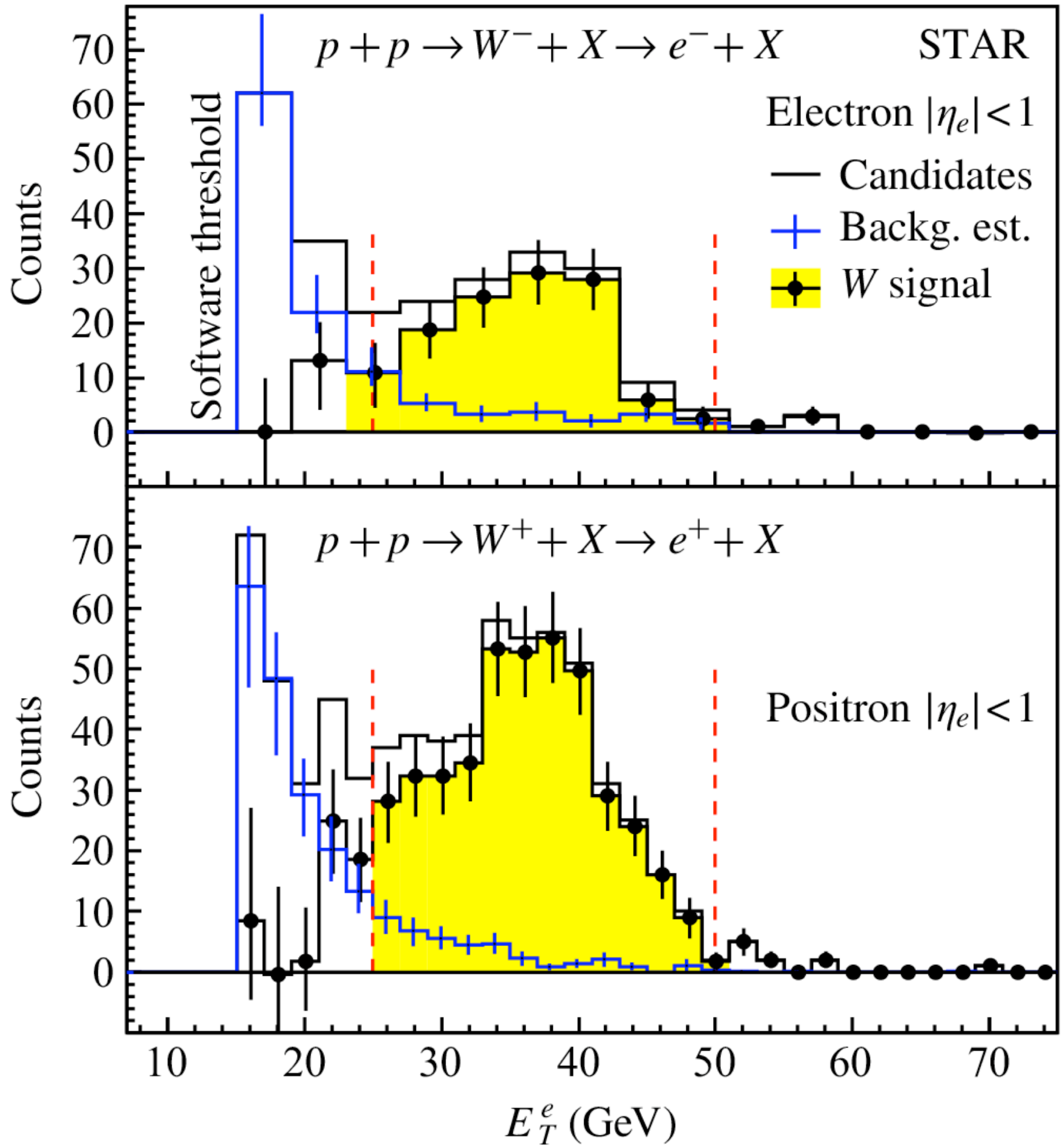




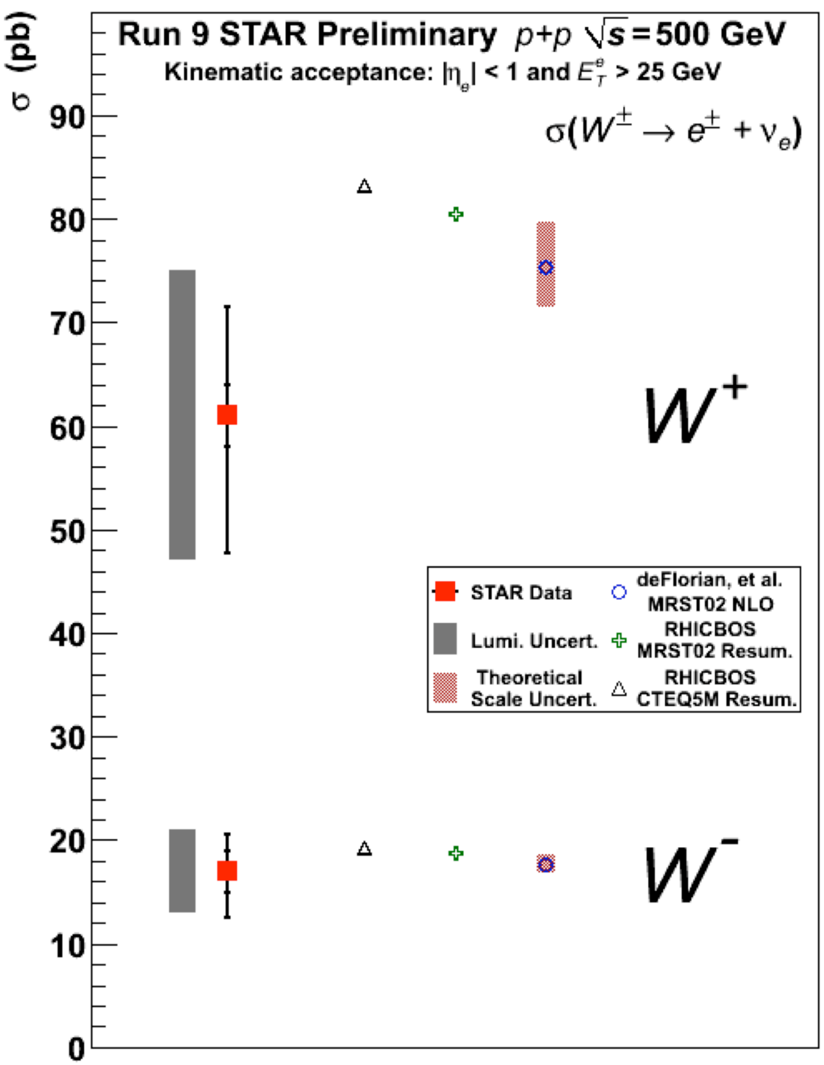
Total Background



STAR W Signals



First STAR W Cross Section



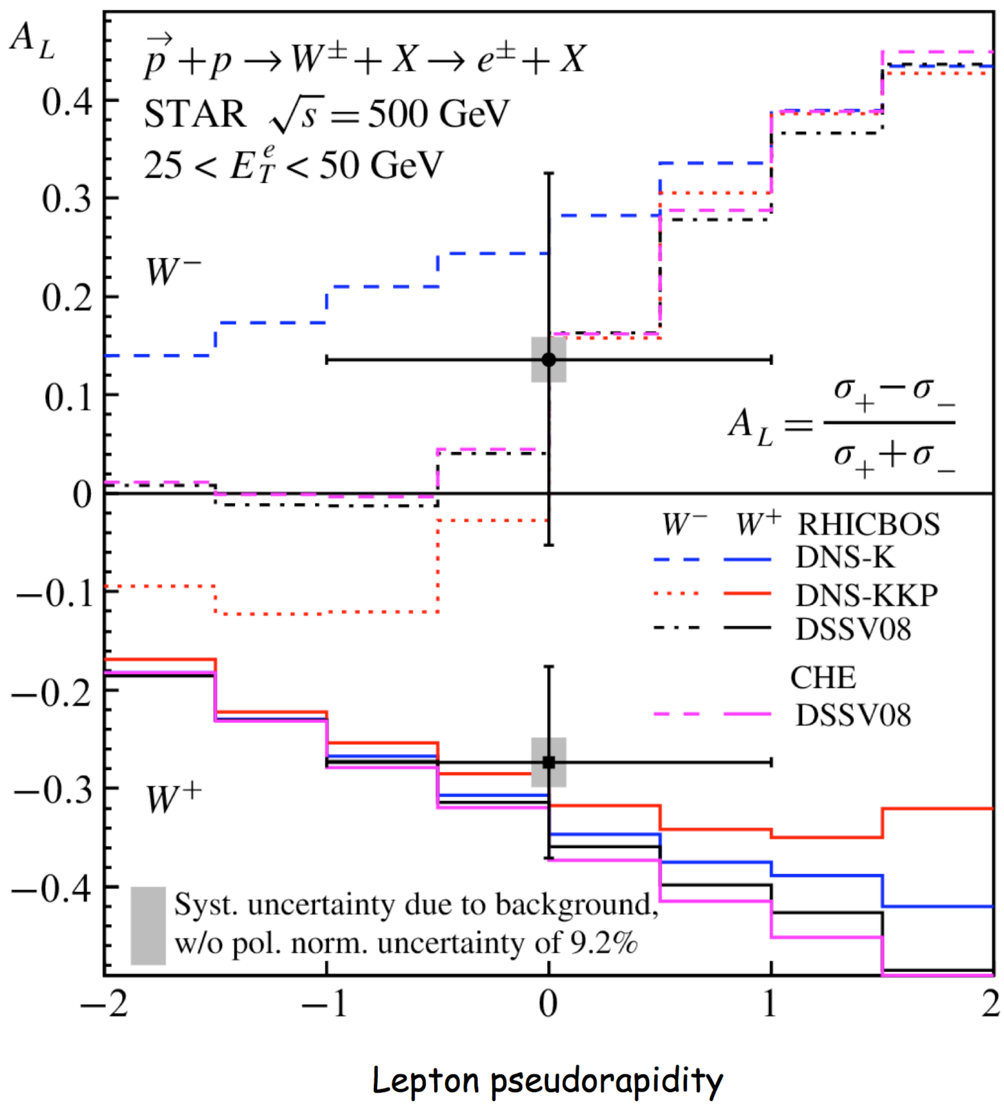
	$W^- \rightarrow e^- + \bar{\nu}_e$	$W^+ \rightarrow e^+ + \nu_e$
N_W^{obs}	156	513
N_{back}	$25\ ^{+21}_{-7}$	$46\ ^{+36}_{-11}$
ϵ_{total}	$0.56\ ^{+0.11}_{-0.09}$	$0.56\ ^{+0.12}_{-0.09}$
$\int Ldt\ (\mathrm{pb}^{-1})$	13.7 ± 3.2	13.7 ± 3.2

Run 9 STAR Preliminary (p+p 500 GeV)

$$\sigma_{W^+ \rightarrow e^+ + \nu} = 61 \pm 3\,(\mathrm{stat.})\ ^{+10}_{-13}\,(\mathrm{syst.}) \pm 14\,(\mathrm{lumi.})\ \mathrm{pb}$$

$$\sigma_{W^- \rightarrow e^- + \bar{\nu}} = 17 \pm 2\,(\mathrm{stat.})\ ^{+3}_{-4}\,(\mathrm{syst.}) \pm 4\,(\mathrm{lumi.})\ \mathrm{pb}$$

First STAR W A_L



Then spin sorting, we calculate the A_L

$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

STAR Run 9 Result

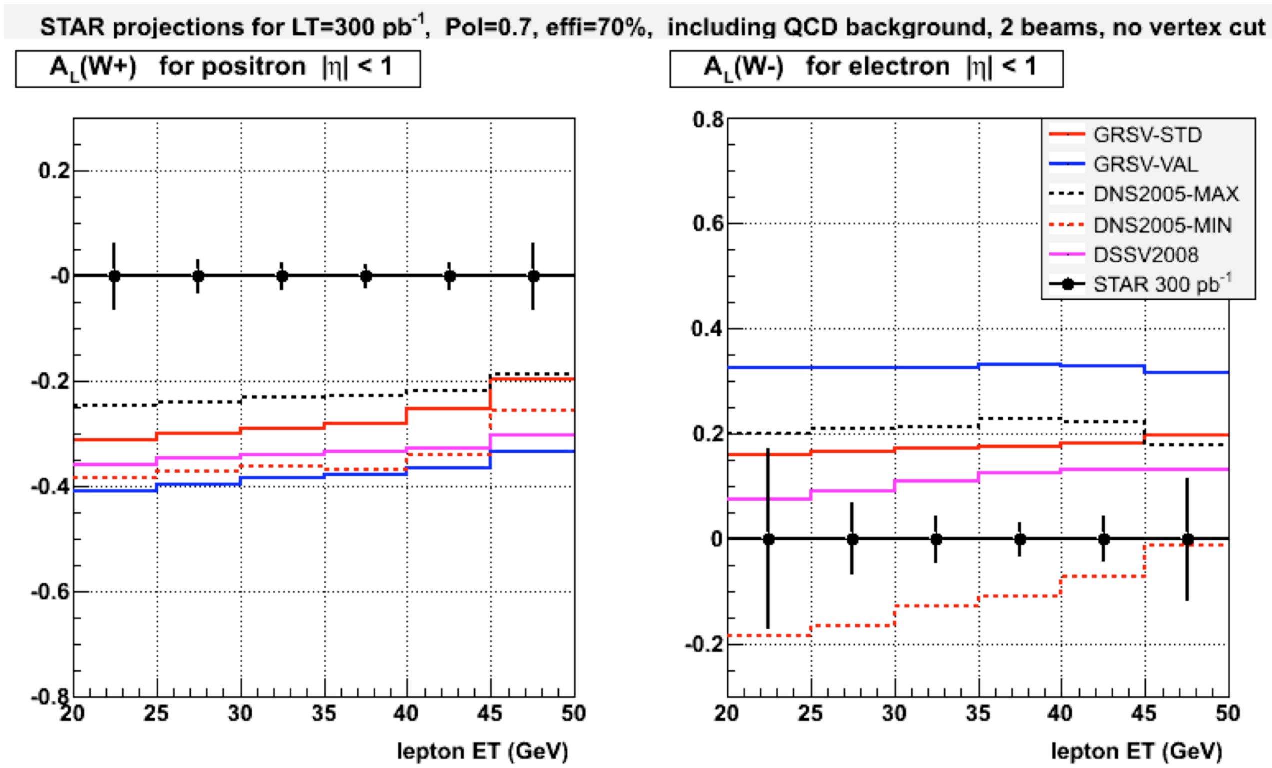
$A_L(W^+) = -0.27 \pm 0.10(stat) \pm 0.02(syst)$

$A_L(W^-) = 0.14 \pm 0.19(stat) \pm 0.02(syst)$

arXiv:1009.0326

Future W A_L Measurements

Future Ws at mid-rapidity



STAR has shown the capability to detect the W at mid-rapidity.

With the expected 300pb^{-1} for the 500 GeV program STAR will provide strong constraints on the polarized sea pdfs using the mid-rapidity data

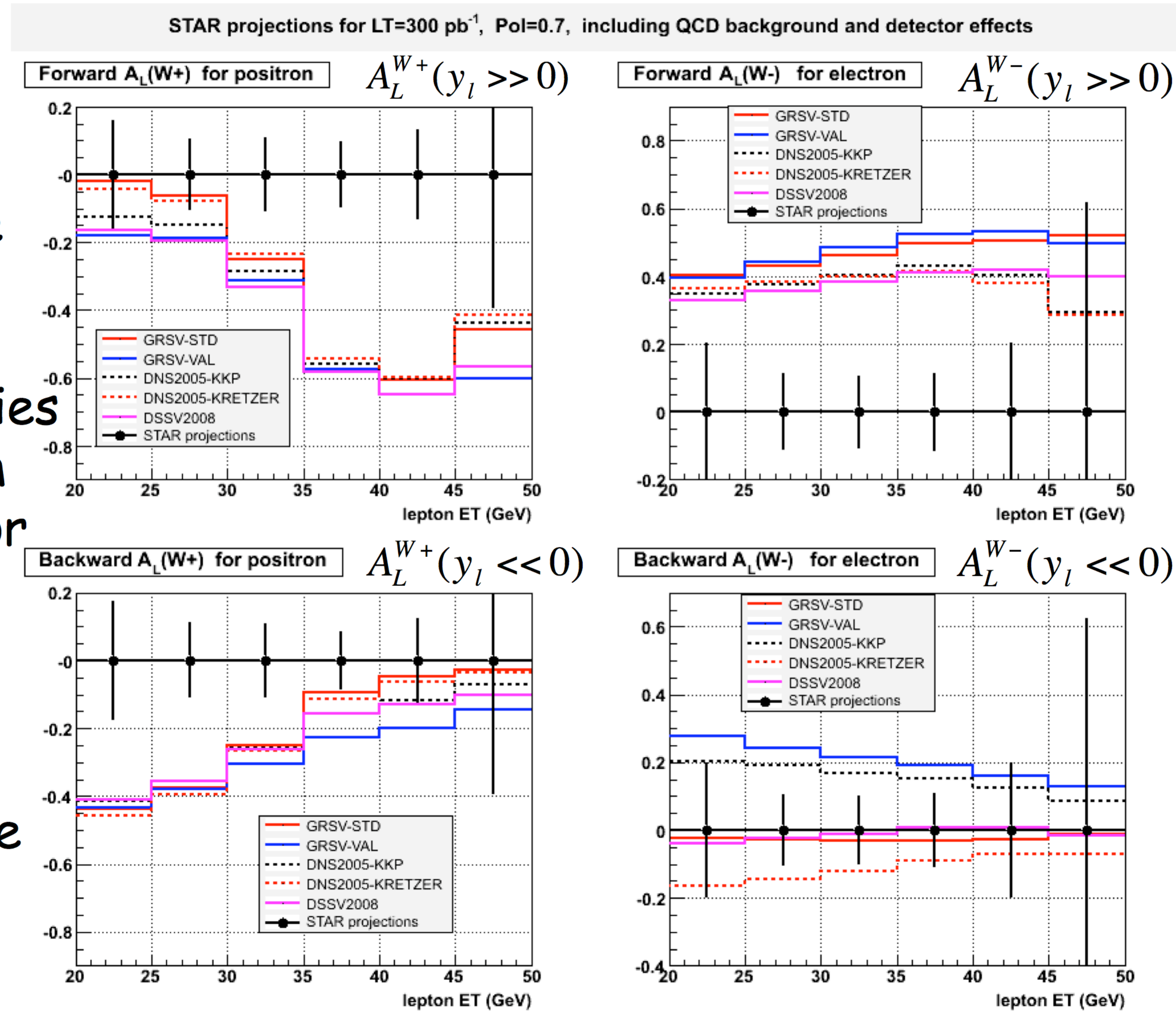
Future Ws at forward rapidity

At forward/backward rapidity the A_Ls become more sensitive to a single quark flavor

The expected uncertainties for the 500 GeV program are shown to the right for the endcap acceptance

$$1 < \eta < 2$$

Measurements rely on the planned Forward GEM Tracker upgrade

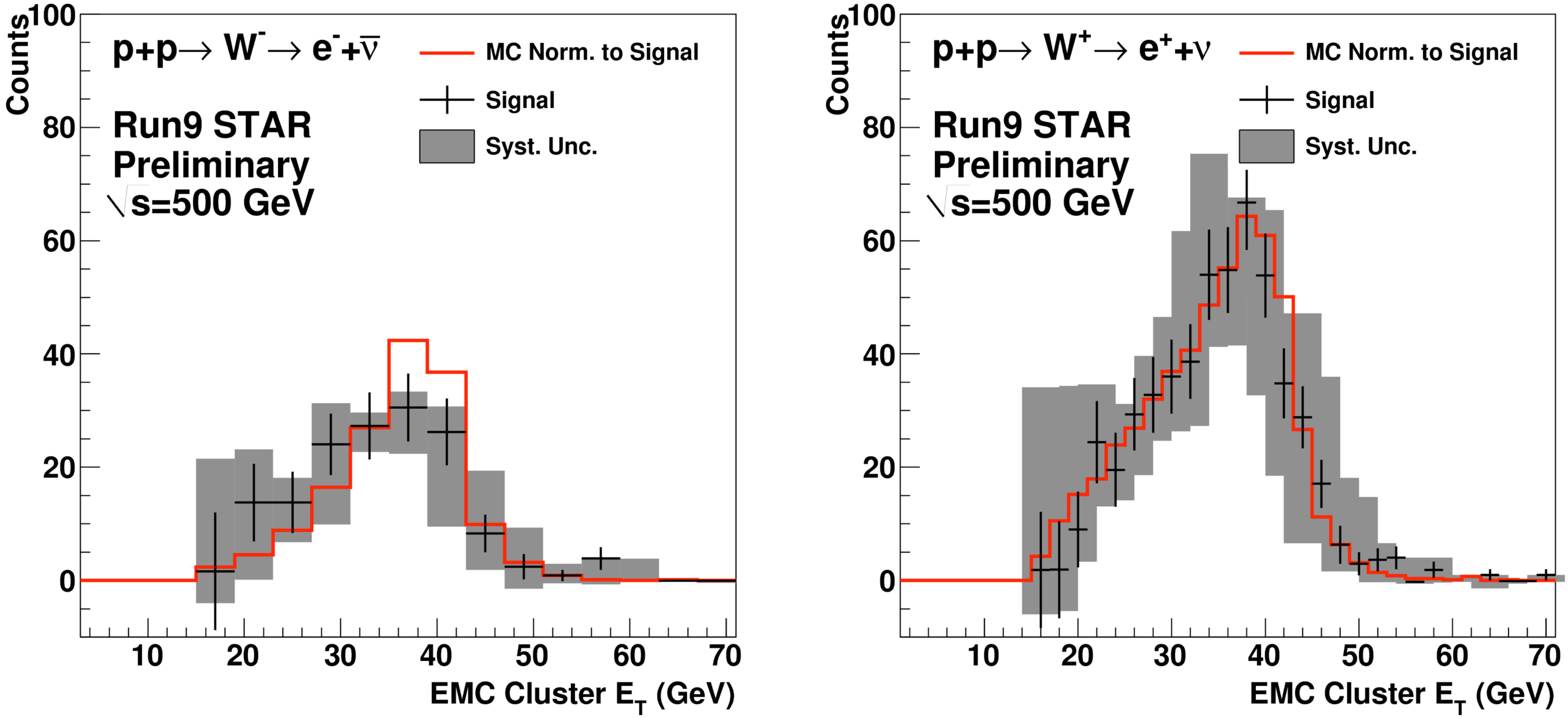


Conclusions

- Measurements of the W in polarized p+p collisions provide needed information about the polarized sea in the proton.
- STAR has shown a first measurement of the cross section and single helicity asymmetry of the W signal in polarized p+p collisions at sqrt(s)=500 GeV which agree with expectations.
- Planned STAR measurements will provide strong constraints on the polarized sea of the proton.

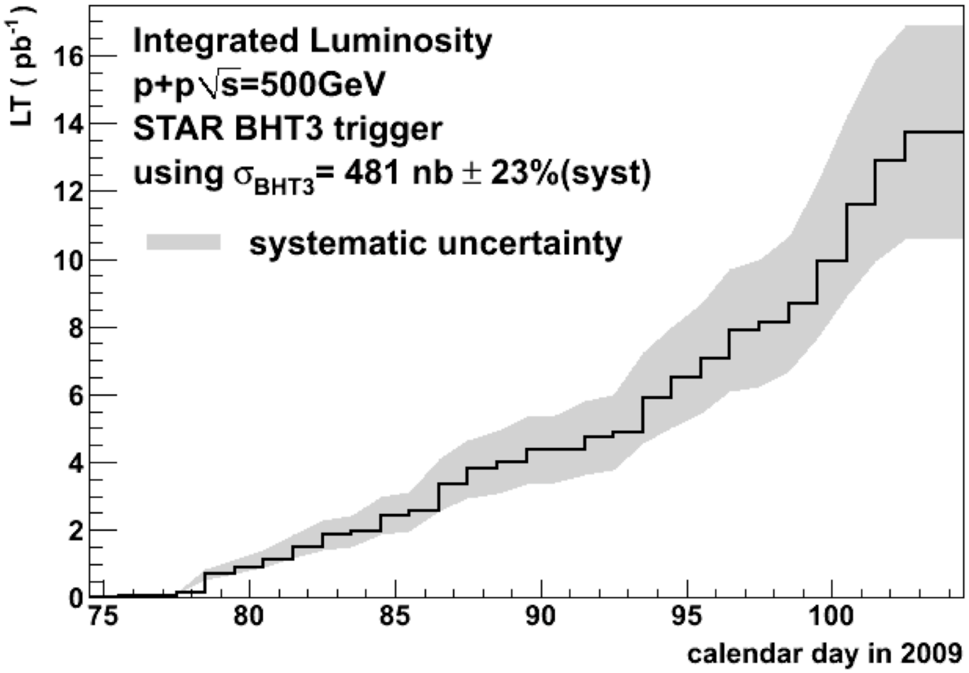
Backup Slides

Data/MC Shape Comparison



Monte-Carlo is full PYTHIA+GEANT simulation of W→e+ ν events at 500 GeV

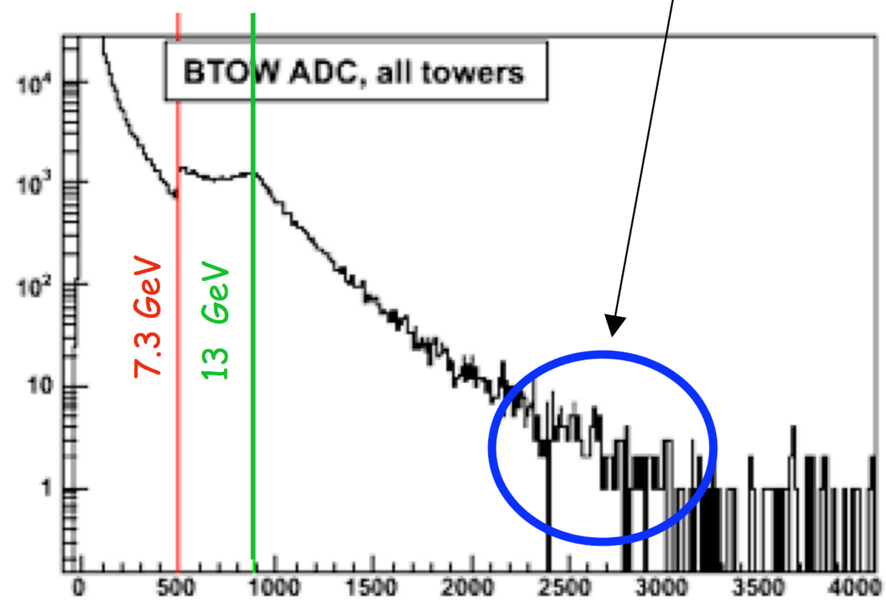
2009 500 GeV Data Set



STAR recorded 13.7pb^{-1} in the 500 GeV running period

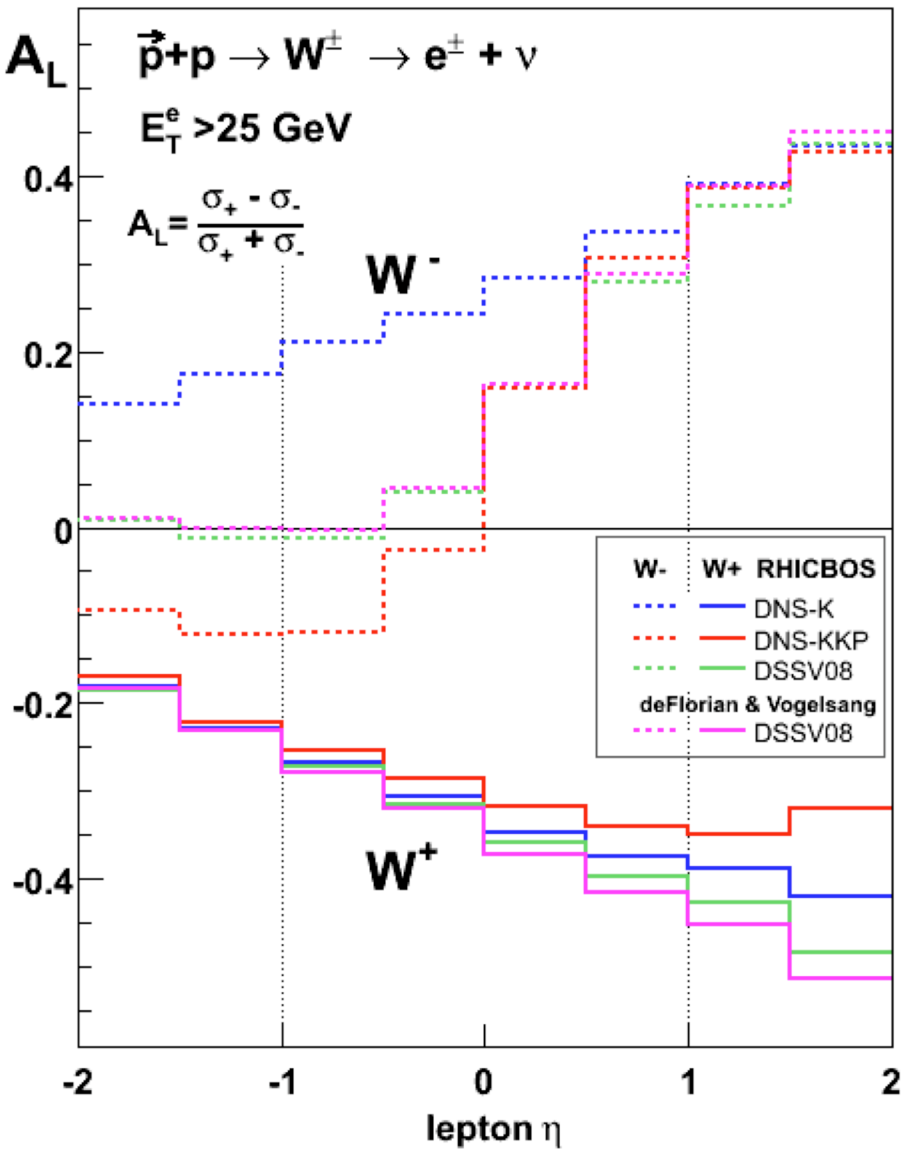
Required a high tower trigger (E_T > 7.3 GeV) and a high E_T 2x2 clusters (E_T > 13 GeV)

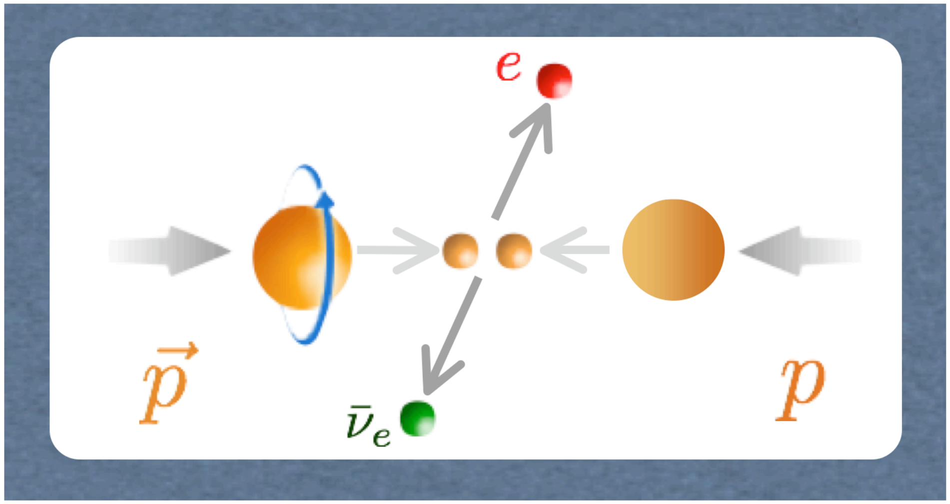
leptons from Ws should appear here



EMC tower ADC

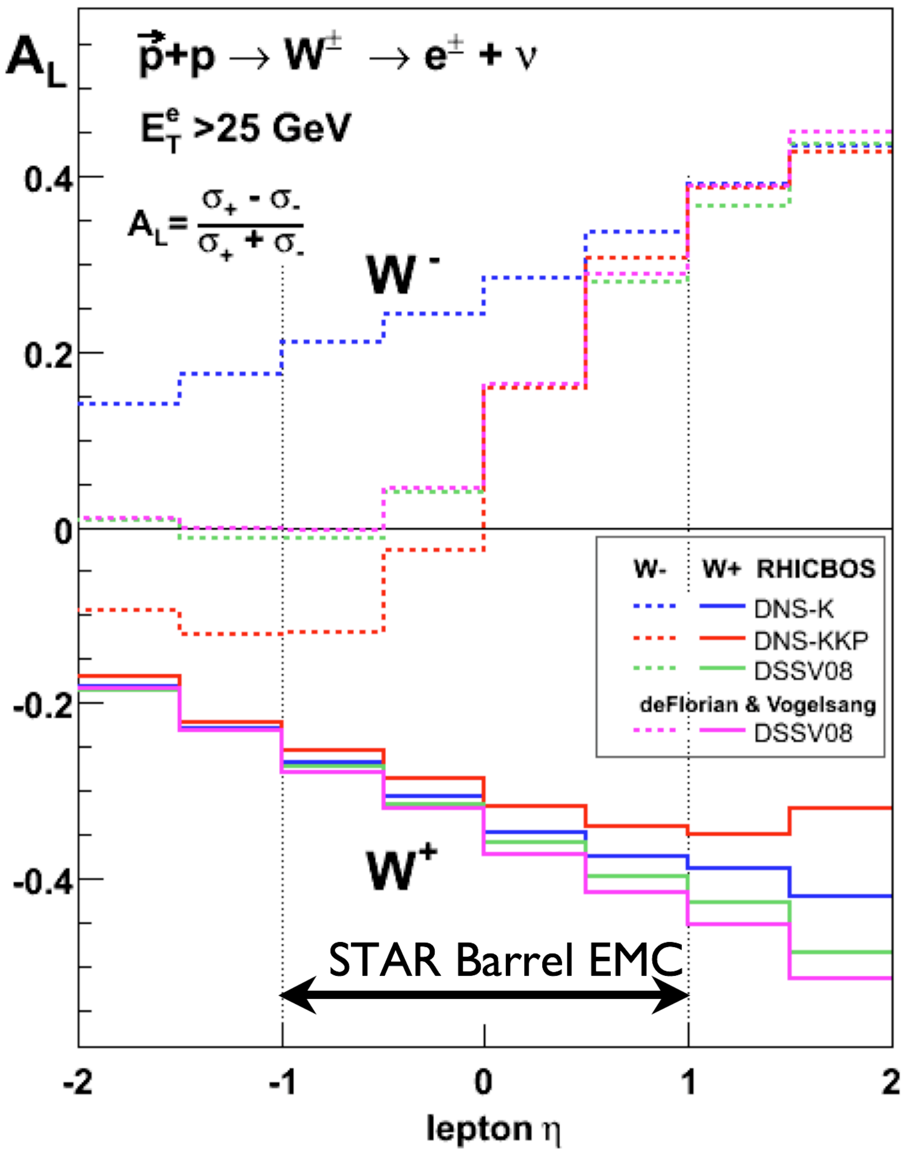
Predictions for A_L

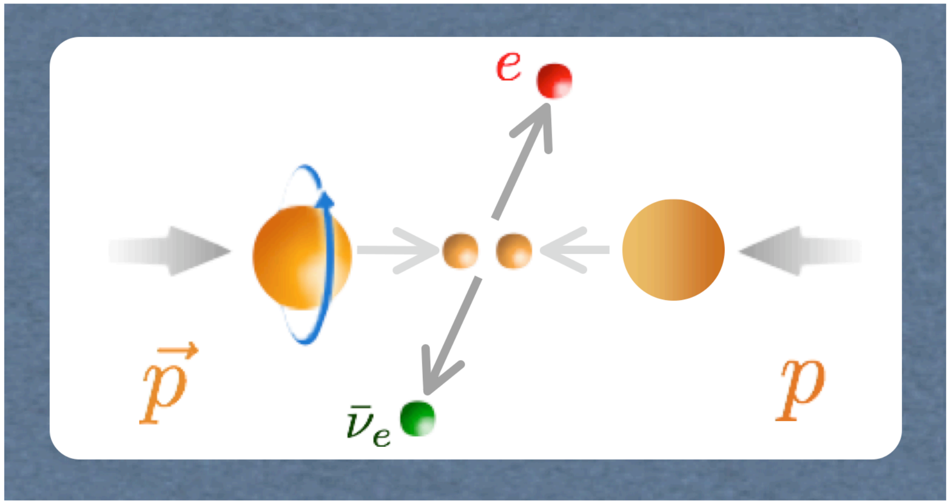




LO interpretation for x1=x2

Predictions for A_L





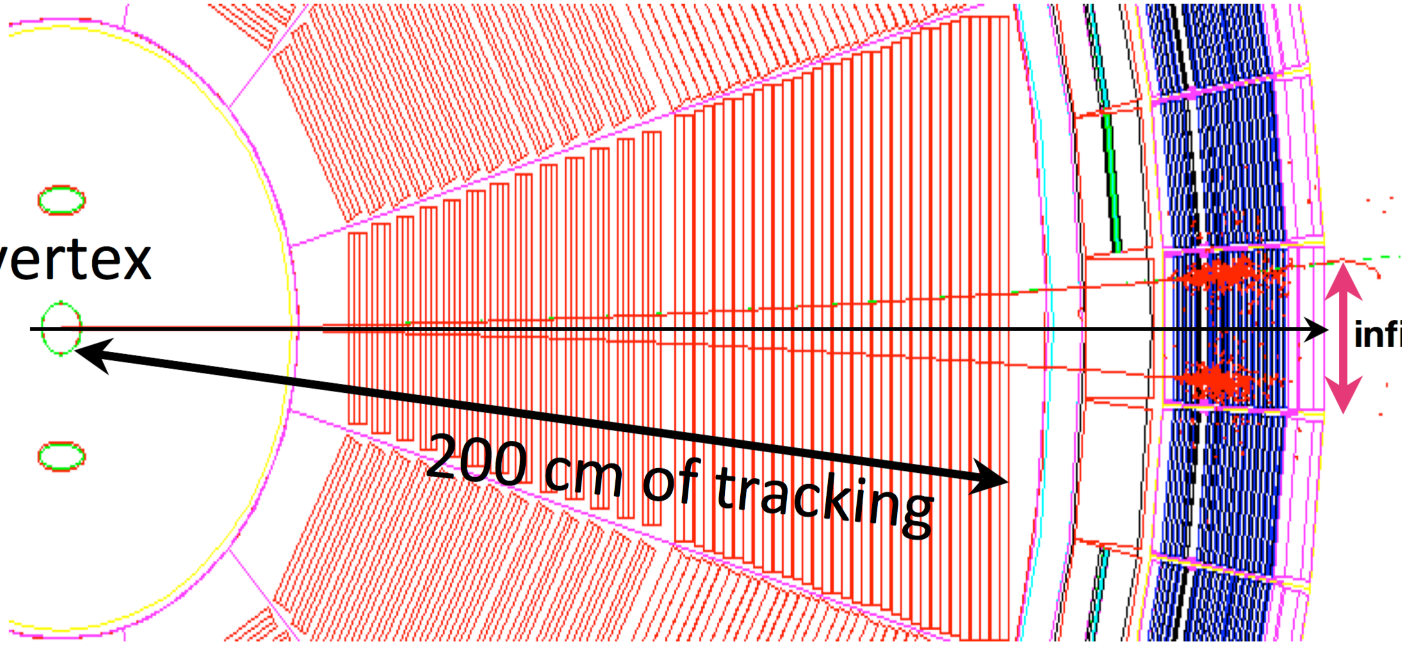
$$\int_{25} dE_T^e \int_{|\eta_e|<1.0} d\eta_e \frac{d^2\sigma^{W\pm}}{d\eta_e dE_T^e} \simeq \begin{pmatrix} 0.75 \\ 0.50 \end{pmatrix} \sigma_{tot}^{W\pm}$$

$$A_L^{W^-} = \frac{1}{2}\left(\frac{\Delta\bar{u}}{\bar{u}} - \frac{\Delta d}{d}\right)$$

$$A_L^{W^+} = \frac{1}{2}\left(\frac{\Delta\bar{d}}{\bar{d}} - \frac{\Delta u}{u}\right)$$

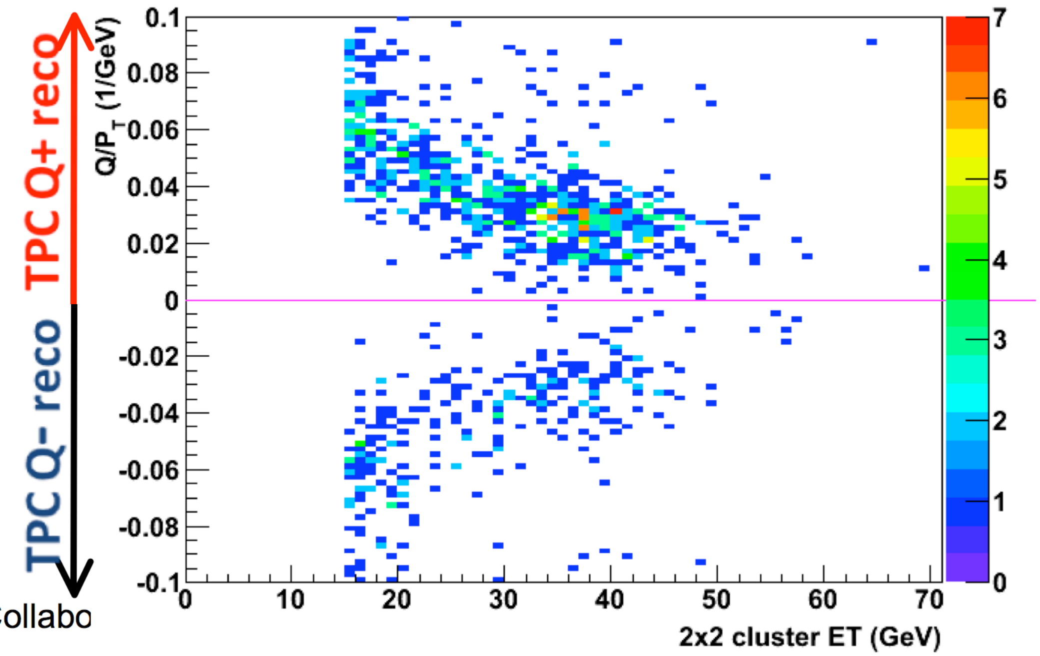
LO interpretation for $x1=x2$

Charge Separation at High p_T



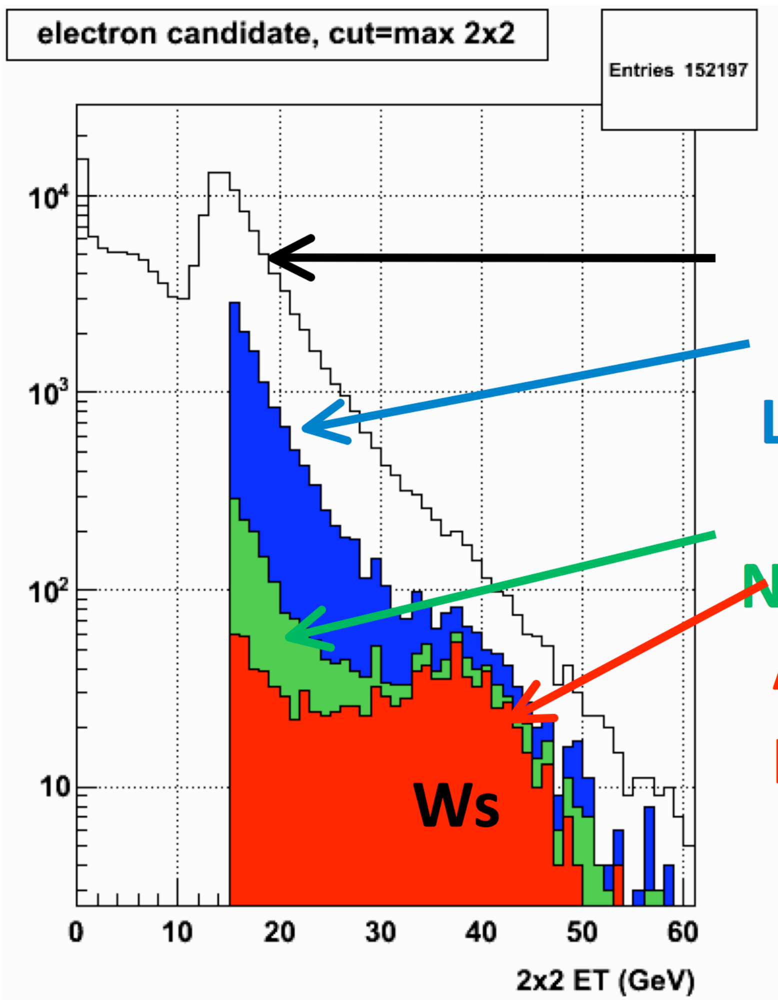
shown
electron &
positron
PT= 5 GeV/c

+/- distance D ~ 1/PT
PT=5 GeV/c : D~15 cm
PT=40 GeV/c : D ~2 cm



Event Rejection

Run 9 Data



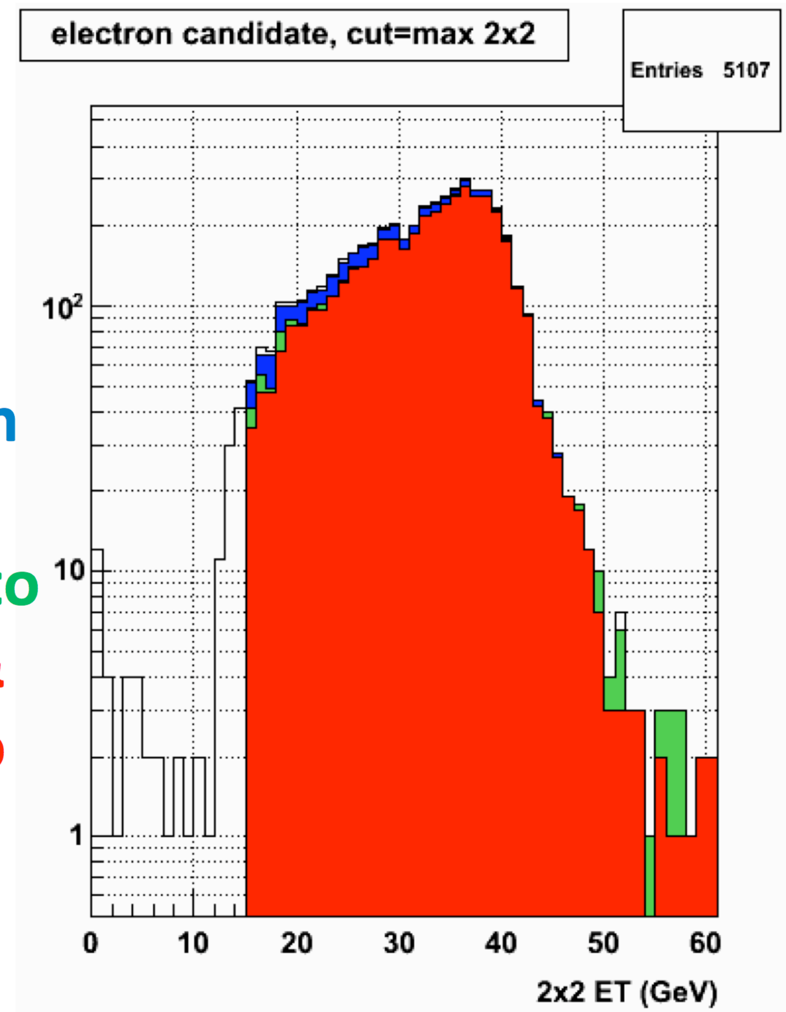
Track pT > 10 GeV

Lepton Isolation Cut

Near Side p_T Veto

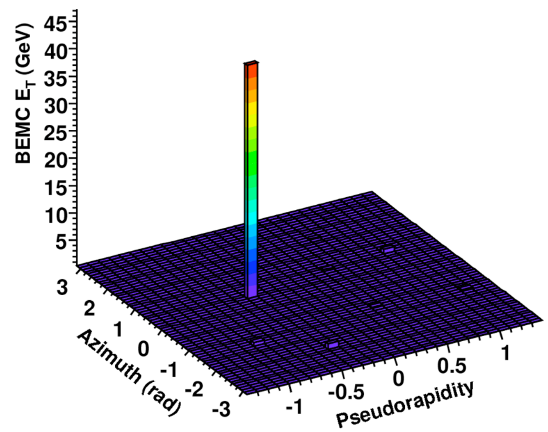
Away Side p_T & ptBalance Veto

Pythia+Geant W^+ MC

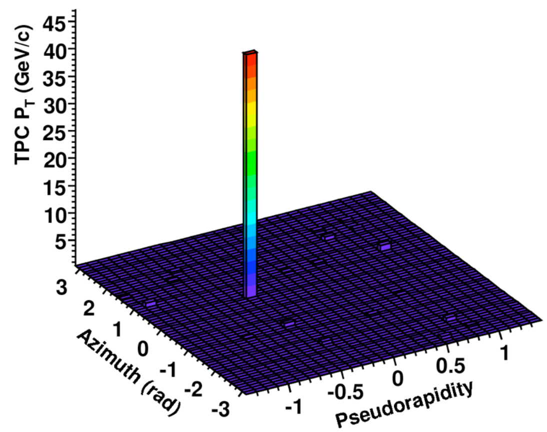


Example Lego Plots

BEMC E_T Distribution (GeV)



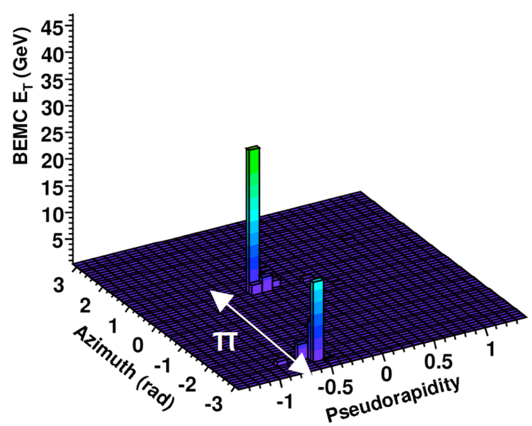
TPC p_T Distribution (GeV/c)



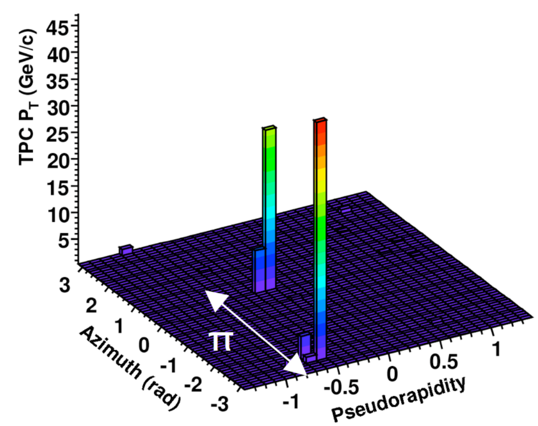
← W event

Dijet event →

BEMC E_T Distribution (GeV)



TPC p_T Distribution (GeV/c)



Cross Section Formula

$$\sigma_W = \int dE_T^e \int d\eta^e \frac{d^2\sigma_{W\to e\nu}}{d\eta^e dE_T^e} = \frac{1}{L}\frac{1}{\varepsilon_{trig}}\frac{1}{\varepsilon_{vertex}}\frac{1}{\varepsilon_{reco}}\left(N_W^{obs} - N_{back}\right)$$

Kinematic Acceptance : $|\eta_e| < 1$ and $E_T^e > 25\,\text{GeV}$

Efficiencies Calculated from full PYTHIA + GEANT simulations

Efficiency Component	$W^- \to e^- + \bar{\nu}_e$	$W^+ \to e^+ + \nu_e$
Trigger: ϵ_{trig}	0.86 ± 0.04	0.88 ± 0.04
Vertex: ϵ_{vertex}	0.91 ± 0.03	0.91 ± 0.03
Reconstruction: ϵ_{reco}	$0.72\ ^{+0.13}_{-0.11}$	$0.71\ ^{+0.14}_{-0.11}$
Total: ϵ_{total}	$0.56\ ^{+0.11}_{-0.09}$	$0.56\ ^{+0.12}_{-0.09}$

Cross Section Uncertainties

- W Reconstruction Systematic
  - Track Reconstruction: 15-20%
  - Vertex Reconstruction: 4%
  - Energy Scale: < 1%
- Normalization/Luminosity Systematic
  - Vernier scan absolute cross section: 23%
- Background Systematic
  - Vary data driven QCD background shape and normalization region

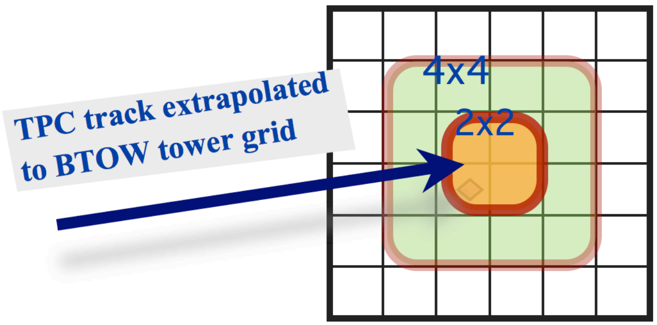
Helicity of beams at STAR

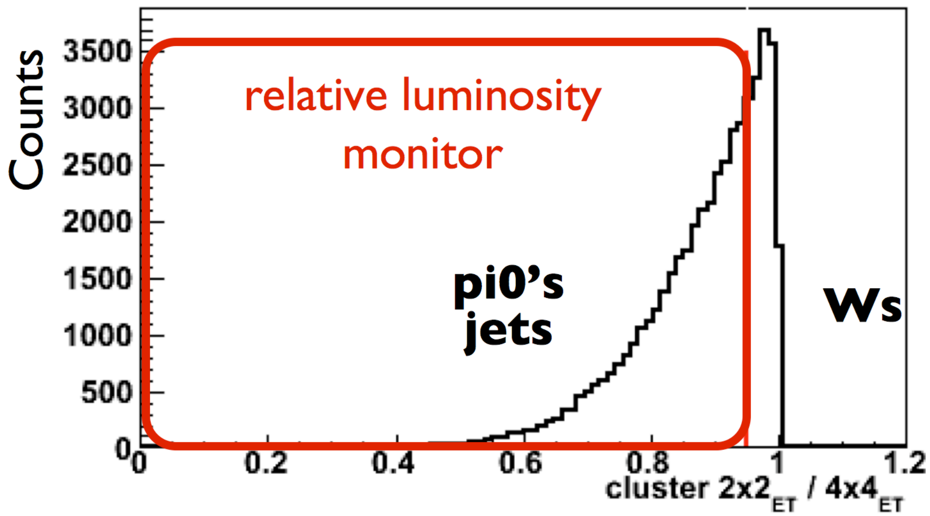
RHIC measured polarization
Run 9 @ 2x250 GeV
Pol yellow 0.40
Pol blue 0.38
syst. pol (blue+yellow)=9.2%

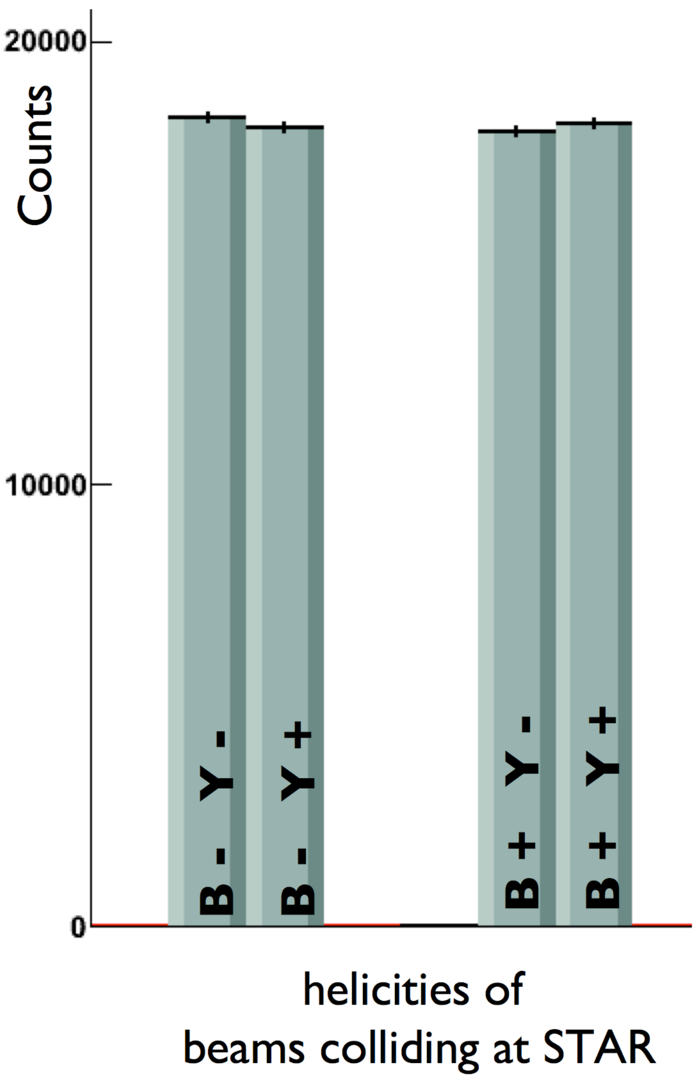
STAR sees 4 helicity states
STAR runs 4 parallel measurements

Monitor spin dependent luminosity

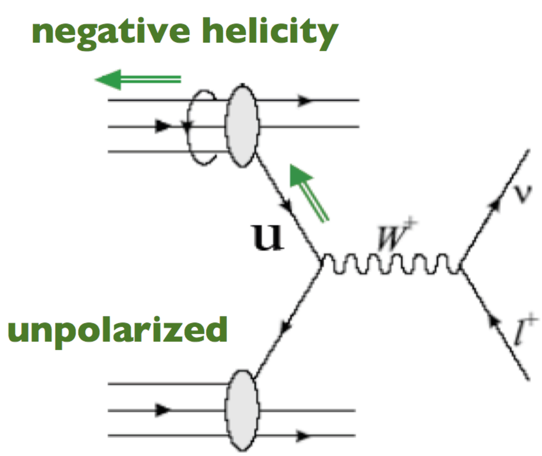
relative luminosities of 4 states monitored to ~1%







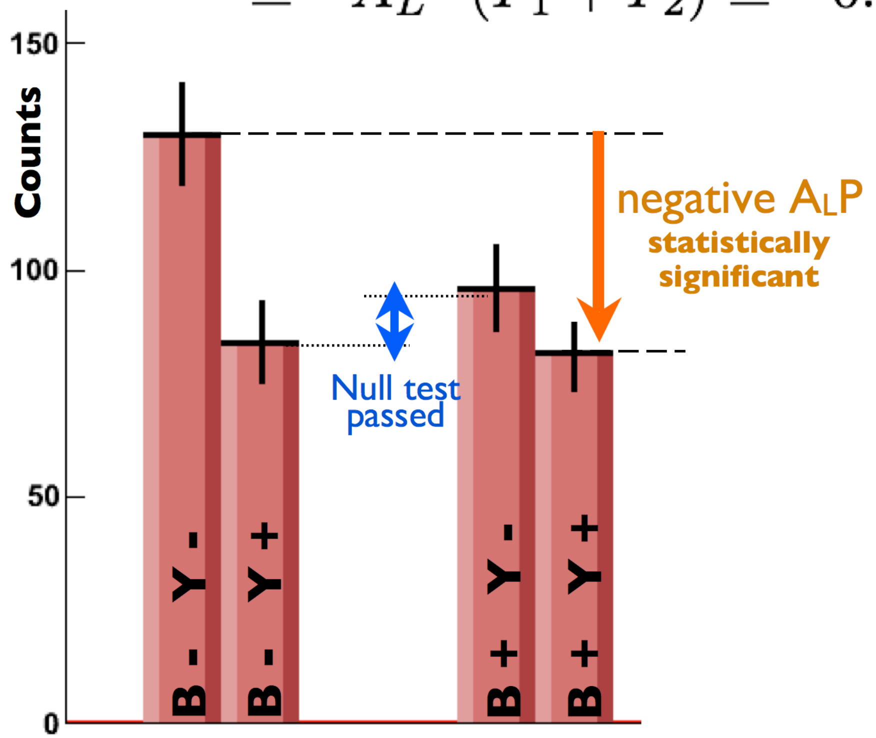
Up quark pol. seen by "naked eye"



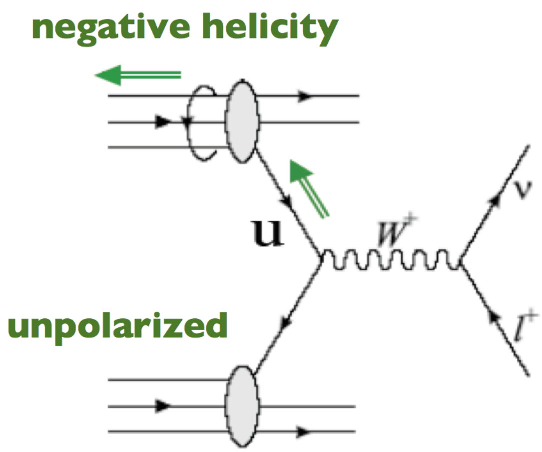
$$A_L^{W^+} = \frac{1}{2}\left(\frac{\Delta\bar{d}}{\bar{d}} - \frac{\Delta u}{u}\right)$$

W+ yield integrated over |eta|<1

$$\begin{aligned}
\mathcal{N}_{++} &\simeq \sigma_0\, \mathcal{L}_{++}\, [\,1 + A_L P_1 + A_L P_2\,] \\
\mathcal{N}_{--} &\simeq \sigma_0\, \mathcal{L}_{--}\, [\,1 - A_L P_1 - A_L P_2\,] \\
\text{eps} &= \frac{\mathcal{N}_{++} - \mathcal{N}_{--}}{\mathcal{N}_{++} + \mathcal{N}_{--}} \\
&\simeq A_L \cdot (P_1 + P_2) \simeq -0.3 \cdot 0.8 = -0.24
\end{aligned}$$



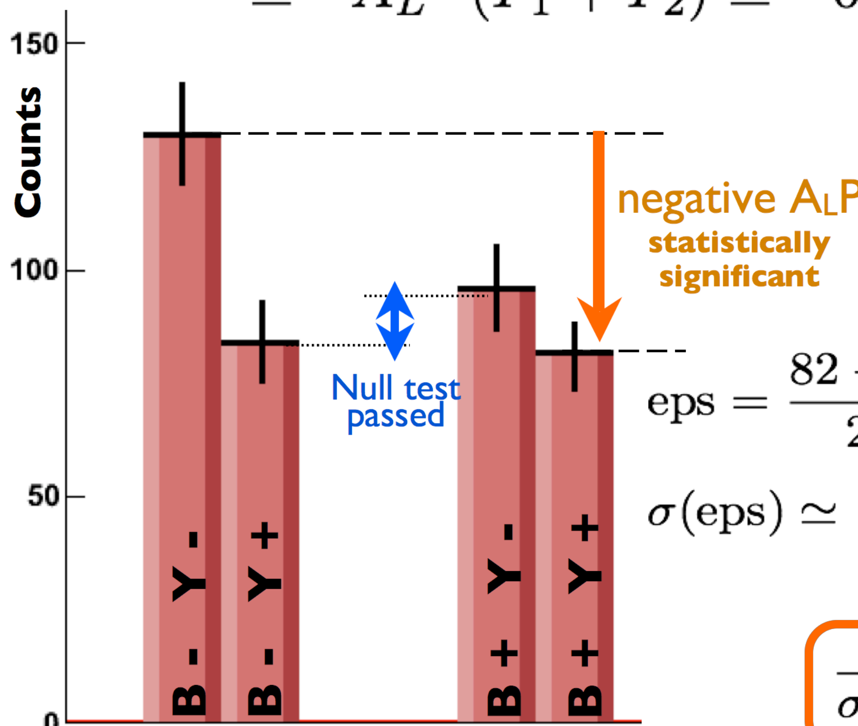
Up quark pol. seen by “naked eye“



$$A_L^{W^+} = \frac{1}{2}\left(\frac{\Delta\bar{d}}{\bar{d}} - \frac{\Delta u}{u}\right)$$

W+ yield integrated over |eta|<1

$$\mathcal{N}_{++} \simeq \sigma_0\, \mathcal{L}_{++}\, [\, 1 + A_L P_1 + A_L P_2 \,]$$
$$\mathcal{N}_{--} \simeq \sigma_0\, \mathcal{L}_{--}\, [\, 1 - A_L P_1 - A_L P_2 \,]$$
$$\text{eps} = \frac{\mathcal{N}_{++} - \mathcal{N}_{--}}{\mathcal{N}_{++} + \mathcal{N}_{--}}$$
$$\simeq A_L \cdot (P_1 + P_2) \simeq -0.3 \cdot 0.8 = -0.24$$



$$\text{eps} = \frac{82 - 130}{212} = -0.23$$
$$\sigma(\text{eps}) \simeq \frac{1}{\sqrt{212}} = 0.07$$
$$\frac{\text{eps}}{\sigma(\text{eps})} = 3.3$$

Spin dependent xsec for long. Pol.

yields integrated over |eta|<1

P-V A_L
(the goal)

$$\frac{\mathcal{N}_{++}}{L_{++}} = \sigma_0 \left[1 + \underline{A_L(P_1 + P_2)} + \underline{A_N(Q_1 - Q_2)\delta} + \underline{A_{LL}P_1P_2} \right]$$

$$\frac{\mathcal{N}_{+-}}{L_{+-}} = \sigma_0 \left[1 + A_L(P_1 - P_2) + A_N(Q_1 + Q_2)\delta - A_{LL}P_1P_2 \right]$$

$$\frac{\mathcal{N}_{-+}}{L_{-+}} = \sigma_0 \left[1 - A_L(P_1 - P_2) - A_N(Q_1 + Q_2)\delta - A_{LL}P_1P_2 \right]$$

$$\frac{\mathcal{N}_{--}}{L_{--}} = \sigma_0 \left[1 - A_L(P_1 + P_2) - A_N(Q_1 - Q_2)\delta + A_{LL}P_1P_2 \right]$$

Spin dependent xsec for long. Pol.

yields integrated over |eta|<1

P-V A_L (the goal)

A_N x residual transverse pol Q

$$\frac{\mathcal{N}_{++}}{L_{++}} = \sigma_0 \left[1 + \underline{A_L(P_1 + P_2)} + \underline{A_N(Q_1 - Q_2)\delta} + \underline{A_{LL}P_1P_2} \right]$$

$$\frac{\mathcal{N}_{+-}}{L_{+-}} = \sigma_0 \left[1 + A_L(P_1 - P_2) + A_N(Q_1 + Q_2)\delta - A_{LL}P_1P_2 \right]$$

$$\frac{\mathcal{N}_{-+}}{L_{-+}} = \sigma_0 \left[1 - A_L(P_1 - P_2) - A_N(Q_1 + Q_2)\delta - A_{LL}P_1P_2 \right]$$

$$\frac{\mathcal{N}_{--}}{L_{--}} = \sigma_0 \left[1 - A_L(P_1 + P_2) - A_N(Q_1 - Q_2)\delta + A_{LL}P_1P_2 \right]$$

neglected because STAR is phi-symmetric

$$\delta \simeq \int_{2\pi} d\phi_e \, \mathrm{Effi}(\phi_e) sin(\phi_e) \simeq 0.02$$

Spin dependent xsec for long. Pol.

yields integrated over |eta|<1

P-V A_L (the goal) | **A_N x residual transverse pol Q** | **A_{LL}**

$$\frac{\mathcal{N}_{++}}{L_{++}} = \sigma_0 \, [\, 1 + A_L(P_1 + P_2) + A_N(Q_1 - Q_2)\delta + A_{LL}P_1P_2 \,]$$

$$\frac{\mathcal{N}_{+-}}{L_{+-}} = \sigma_0 \, [\, 1 + A_L(P_1 - P_2) + A_N(Q_1 + Q_2)\delta - A_{LL}P_1P_2 \,]$$

$$\frac{\mathcal{N}_{-+}}{L_{-+}} = \sigma_0 \, [\, 1 - A_L(P_1 - P_2) - A_N(Q_1 + Q_2)\delta - A_{LL}P_1P_2 \,]$$

$$\frac{\mathcal{N}_{--}}{L_{--}} = \sigma_0 \, [\, 1 - A_L(P_1 + P_2) - A_N(Q_1 - Q_2)\delta + A_{LL}P_1P_2 \,]$$

neglected because STAR is phi-symmetric

$$\delta \simeq \int_{2\pi} d\phi_e \ \mathrm{Effi}(\phi_e) sin(\phi_e) \simeq 0.02$$

Long. spin asymmetries for Ws

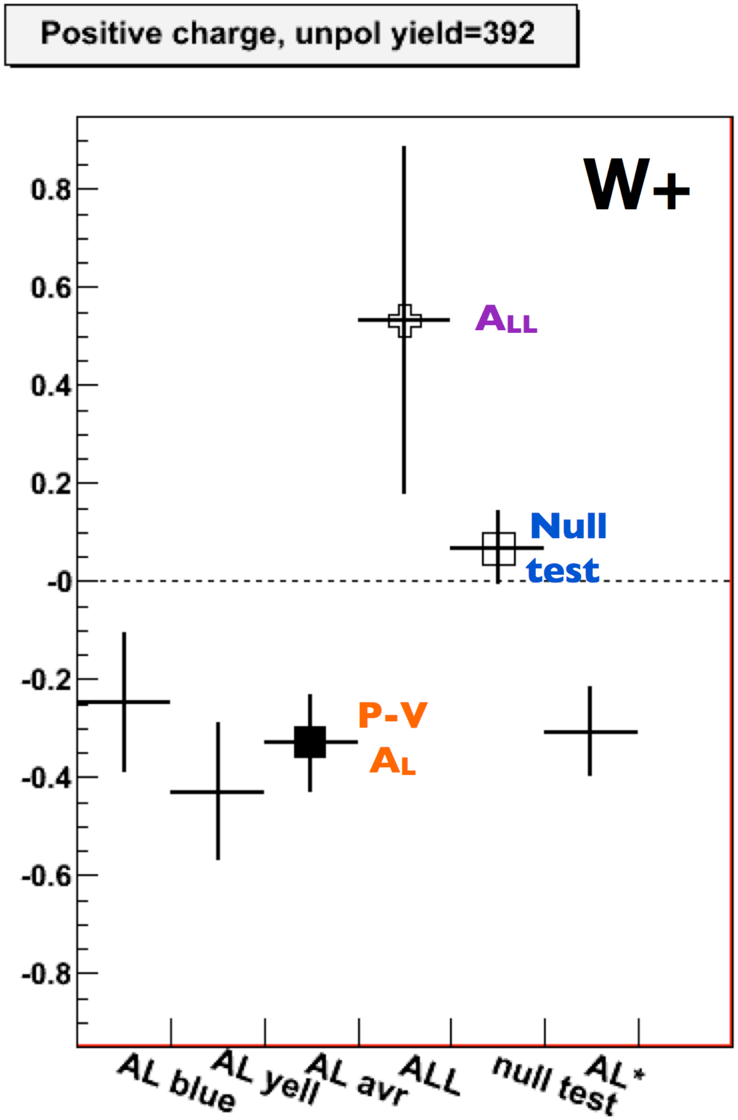
STAR has measured 4 independent yields for the physics process
selected 3 asymmetries are independent (6 were investigated)

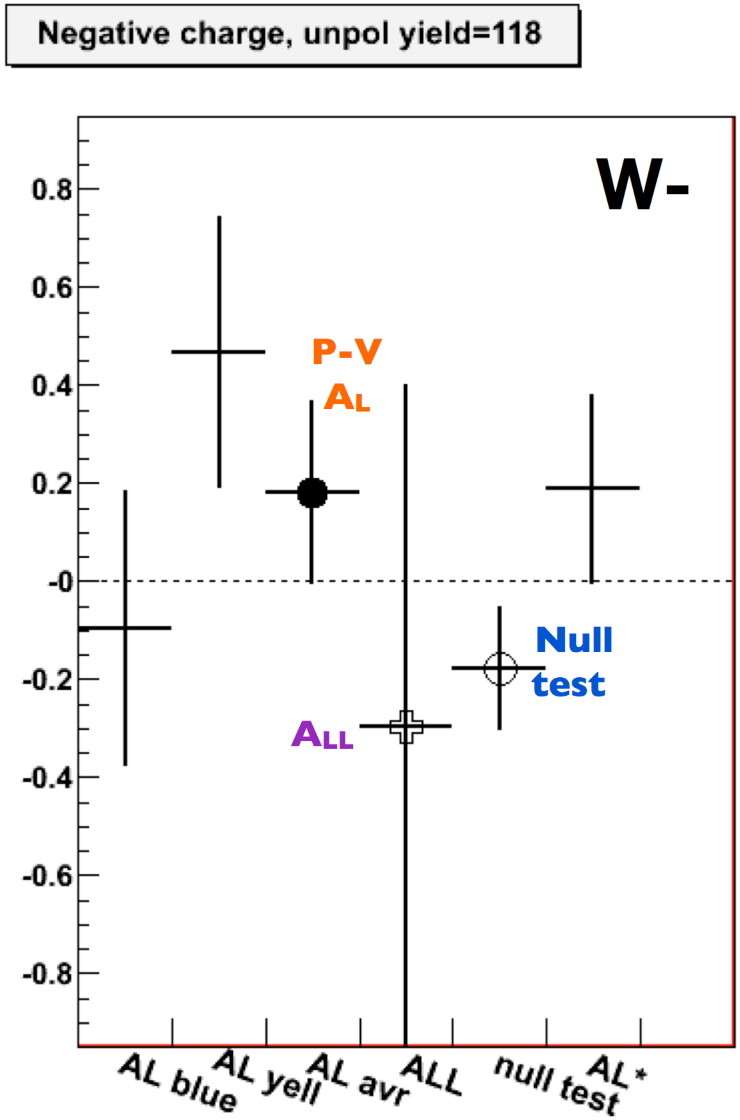
yields integrated over |eta|<1

	Leading physics asymmetry	cross section dependence	raw asymmetry
	A_L (blue)	$(\sigma_{++} + \sigma_{+-} - \sigma_{--} - \sigma_{-+})/sum4$	$A_L P_1$
	A_L (yellow)	$(\sigma_{++} + \sigma_{-+} - \sigma_{--} - \sigma_{+-})/sum4$	$A_L P_2$
	A_L (average)	$(\sigma_{++} - \sigma_{--}) / sum4$	$A_L \frac{P_1 + P_2}{2}$
	A_{LL}	$(\sigma_{++} + \sigma_{--} - \sigma_{-+} - \sigma_{+-}) / sum4$	$A_{LL} P_1 P_2$
Null test	$A_L(P_1 - P_2)$	$(\sigma_{+-} - \sigma_{-+}) / (\sigma_{-+} + \sigma_{+-})$	$\frac{A_L(P_1 - P_2)}{1 - A_{LL} P_1 P_2}$
	$A_L^* \simeq A_L$	$(\sigma_{++} - \sigma_{--}) / (\sigma_{++} + \sigma_{--})$	$\frac{A_L(P_1 + P_2)}{1 + A_{LL} P_1 P_2}$

where $sum4 = \sigma_{++} + \sigma_{+-} + \sigma_{-+} + \sigma_{--}$

6 measured spin asymmetries for Ws





Physics asymmetries corrected for unpolarized background

Systematic errors for AL

Full list of accounted systematic errors in Run 9

Following effects were considered and their contribution **set to zero**

* dilution of A_L due to swap of W+/W- charge - the Q/PT cut prevents it

* $A_{LL}P_1P_2$ term cancells out

* $A_N\ \delta(P_1^T - P_2^T)\ < 1/1000$ since: $\delta \simeq \int_{2\pi} d\phi_e\ \mathrm{Effi}(\phi_e) sin(\phi_e) \simeq 0.02$ and $P_1^T \sim P_2^T < 0.1$

W+ high	W+ low	W - high	W - low	
0.092	0.092	0.092	0.092	CNI average polarization of both beams (P1+P2)
0.070	0.020	0.130	0.030	QCD unpolarized background
0.065	0.065	0.135	0.135	QCD pol. bckg. ~0: use 1/2 stat error of this test
0.004	0.000	0.004	0.000	decay of pol. within fill
0.13	**0.11**	**0.21**	**0.17**	total syst. in fraction of measured AL