First W Production Results from STAR

Hal Spinka (ANL) for the
STAR Collaboration

Progress in High p_T Physics
at RHIC, RBRC Workshop
17 March 2010

Introduction

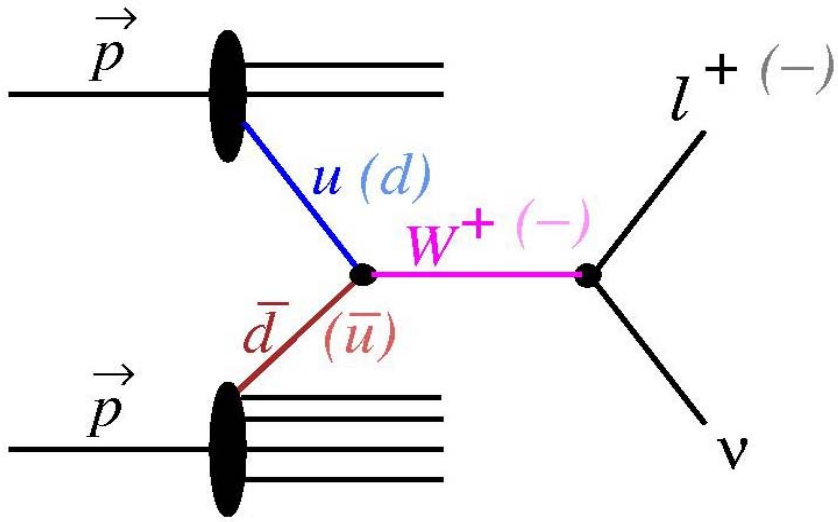
- The goal of the RHIC spin program is to understand the origin of the proton spin in terms of intrinsic quark and gluon spin and orbital angular momentum.

$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

- $\Delta\Sigma$ is well measured (~0.3), but its decomposition is not well understood – especially the sea quarks.
- Detection of $W^{\pm}$ decays will provide new information on the ubar and dbar contributions, as well as check the u and d quark contributions.

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

Introduction (cont.)



STAR measures $W^{\pm}$ through their $e^{\pm}$ decays:

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

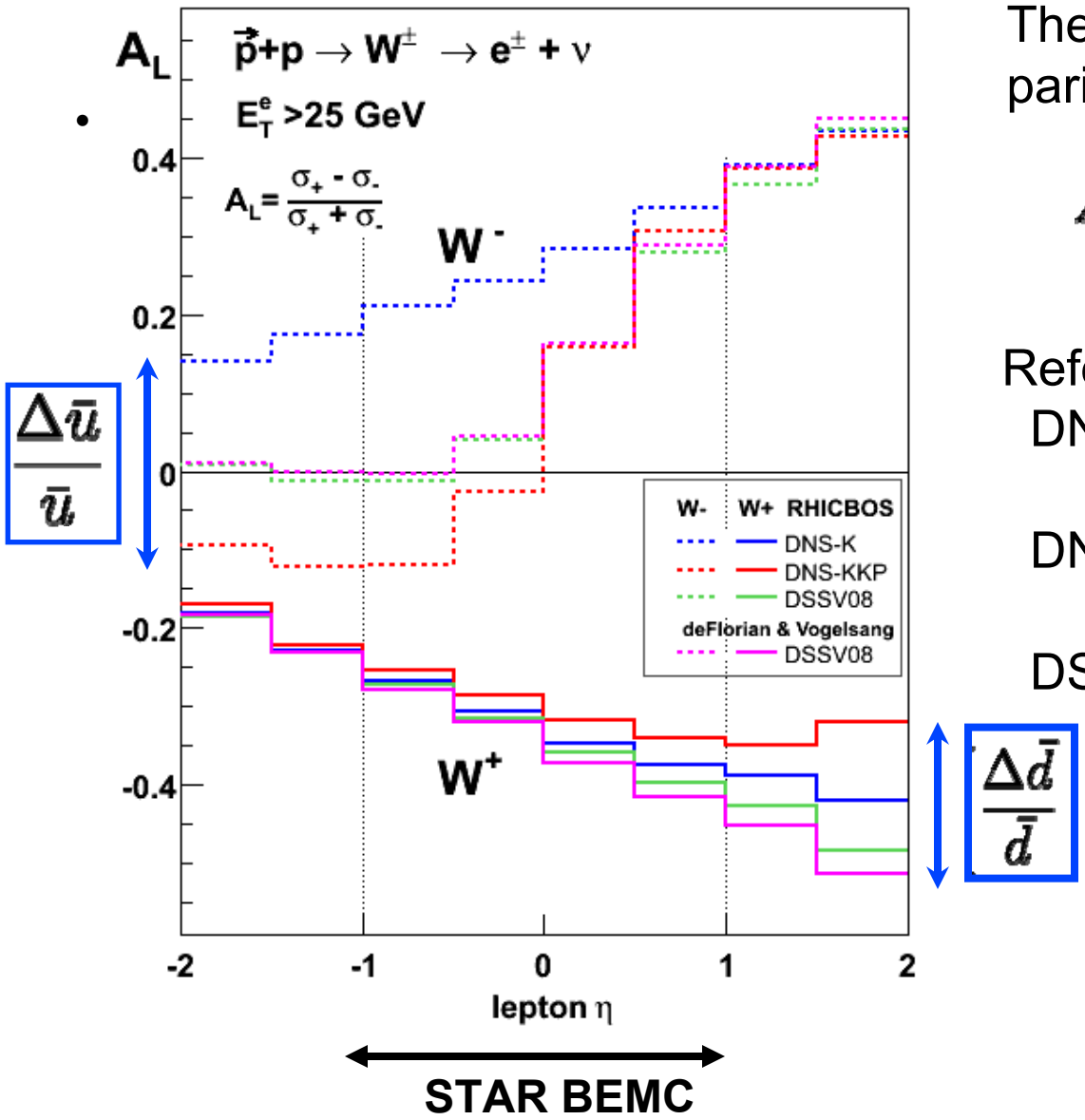
$$\bar{u} + d \rightarrow W^- \rightarrow e^- + \bar{\nu}$$

- Measure the parity-violating, single-spin helicity asymmetry $A_L = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-)$, where at LO:

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

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

Introduction (cont.)



Theoretical predictions for the parity-violating asymmetry

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

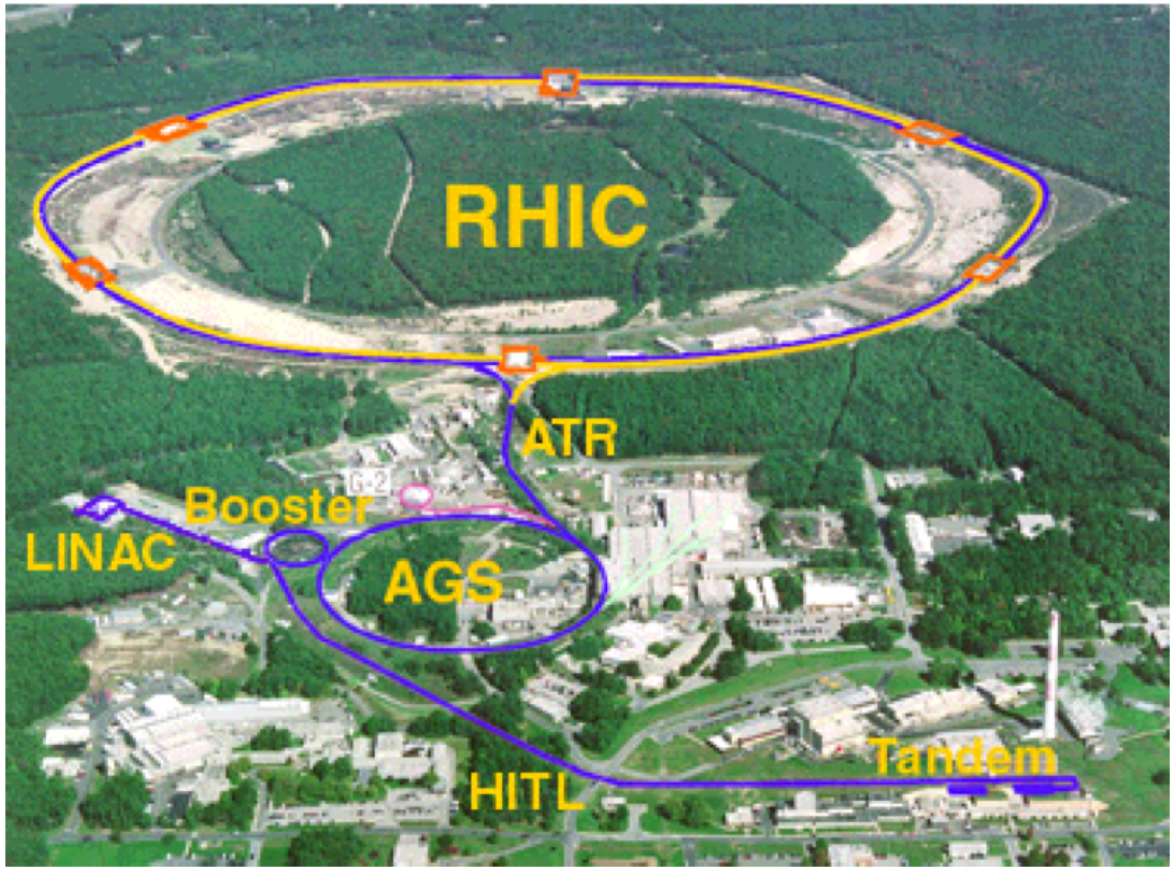
References:

DNS – K PR D71, 094018 (2005).
PR D62, 054001 (2000).

DNS – KKP PR D71, 094018 (2005).
NP B582, 514 (2000).

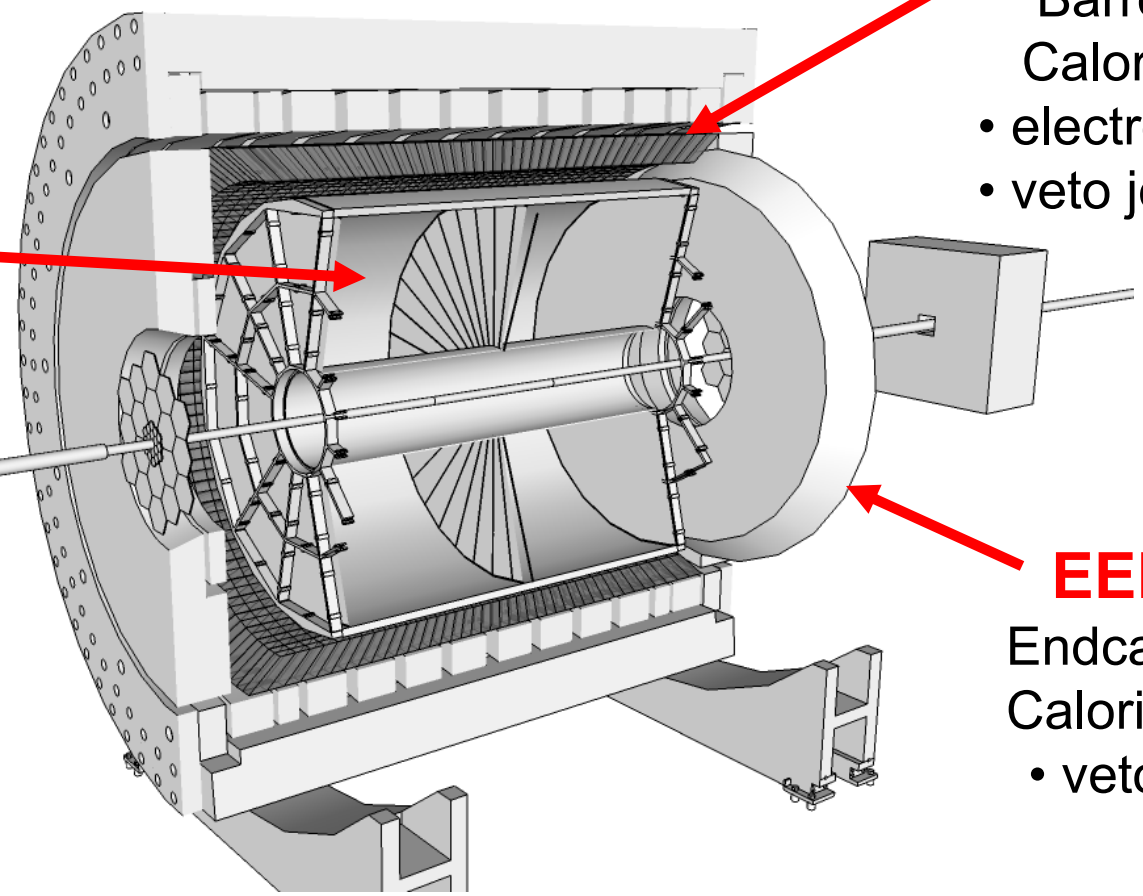
DSSV PRL 101, 072001 (2008).

RHIC – a Polarized p+p Collider to Study Spin in QCD



- First $\sqrt{s}$ = 500 GeV run for physics was March and April, 2009 for a couple weeks.
- Achieved beam polarizations of ~ 35 – 40%. Two additional RHIC polarimeters were also commissioned.

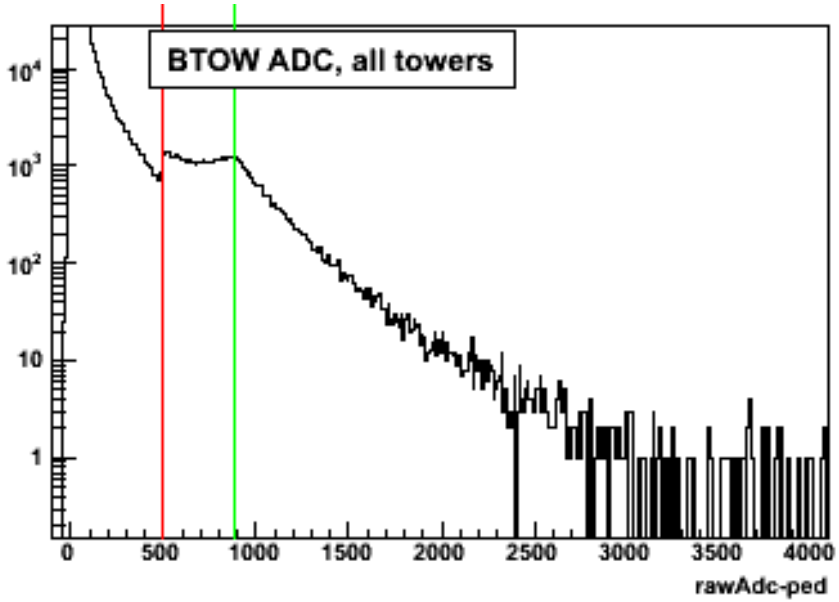
The STAR Detector

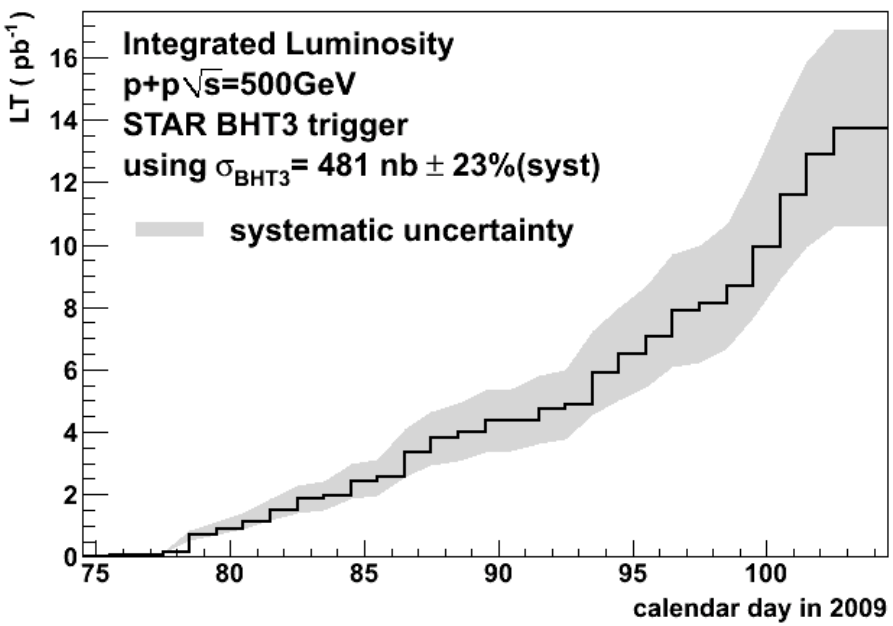


- Solenoidal magnetic field = 0.5 T for momentum and charge determination

Cross Section – The Data Set

- **Trigger**
  - Level 0 trigger – BEMC single high tower threshold $E_T > 7.3$ GeV.
  - Level 2 trigger – BEMC 2 x 2 tower cluster threshold $E_T > 13$ GeV.
  - Use these recorded and triggered events to monitor the luminosity.



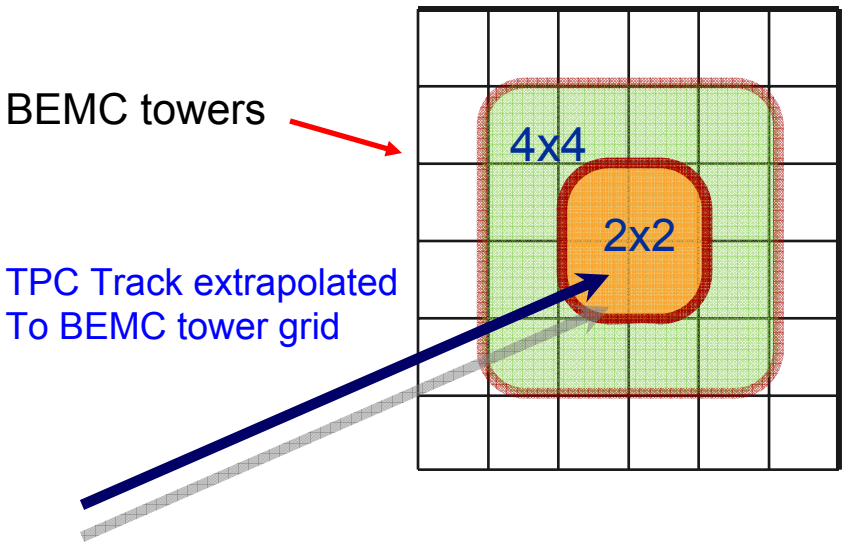


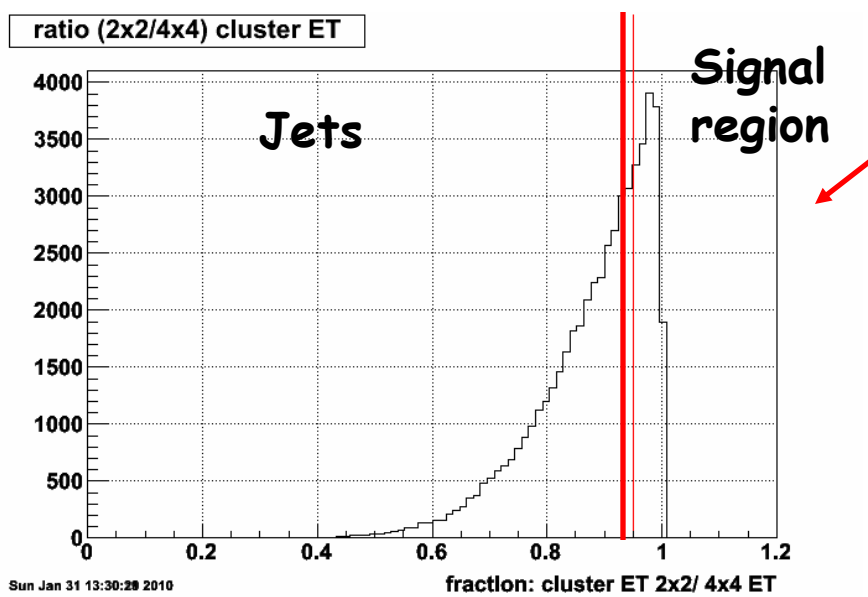
- **Integrated Luminosity**
  - Vernier scan method used to measure the cross section for the BHT3 trigger:

$$\sigma_{BHT3} = 481\text{nb} \pm 10(\text{stat.}) \pm 110(\text{syst.})$$

  - From the background subtracted triggers and the cross section, get the integrated luminosity of 13.7 pb^{-1}.

Cross Section – Electron Isolation Cuts

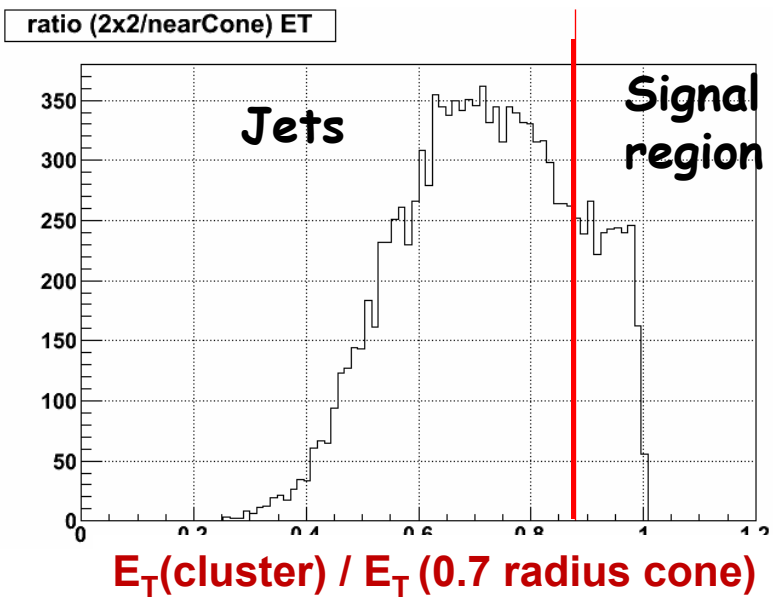


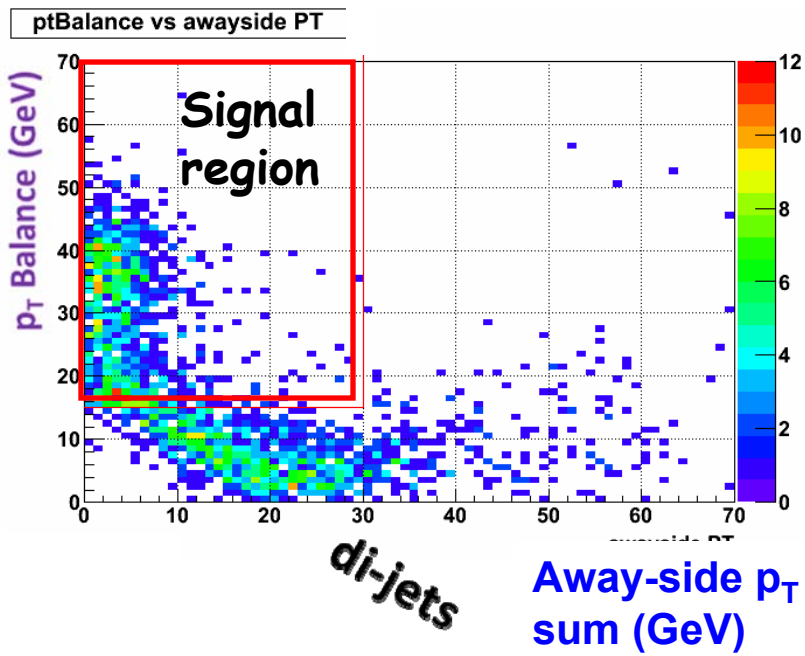


- **Electron Isolation Cuts**
  - Require a TPC track with p_T > 10 GeV/c.
  - Extrapolate the track to the BEMC towers.
  - Require ΣE_T > 15 GeV for the 2 x 2 tower cluster to which the TPC track pointed.
  - Require the excess E_T in the 4 x 4 tower cluster to be < 5%.
  - Perform a tighter cut on the matching of the extrapolated TPC track to the 2 x 2 cluster energy-weighted position.

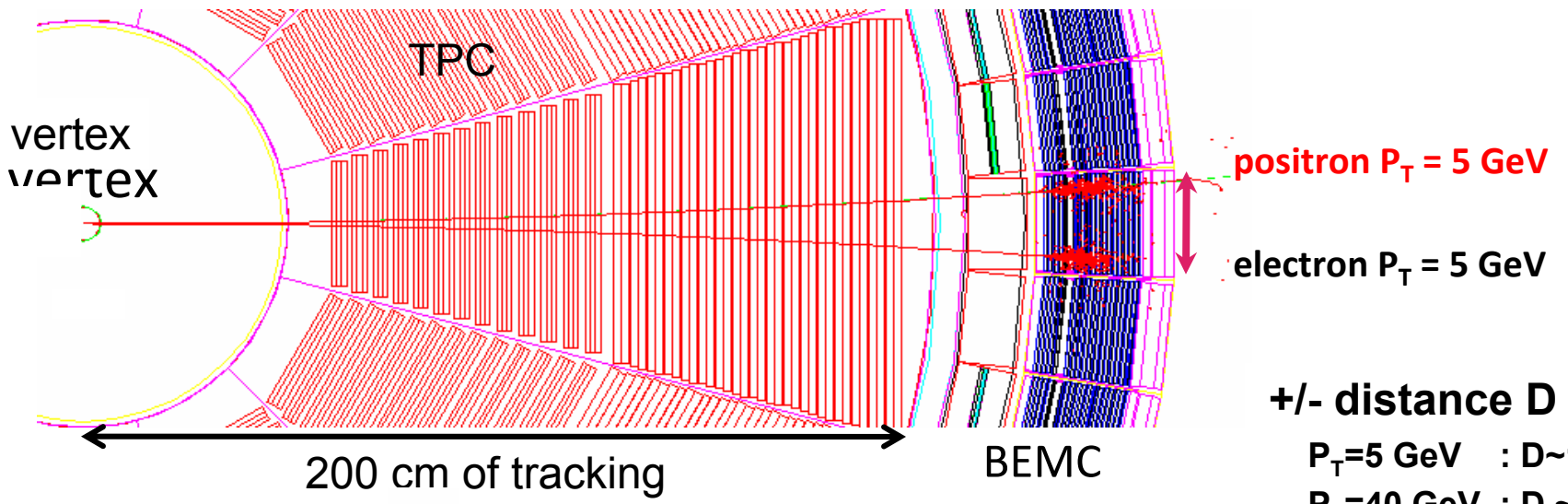
Cross Section – QCD Background Cuts

- Suppress jets with a leading hadron
  - "Near-side" jet cone veto [E_T (2 x 2 cluster) / E_T (0.7 radius cone)]
- Suppress di-jet and multi-jet events
  - Away-side (180° away from the electron candidate TPC track) p_T sum veto (see below).
  - Require an imbalance in the p_T of the 2 x 2 cluster and any jets reconstructed outside the near-side jet cone.





Cross Section – Charge Separation

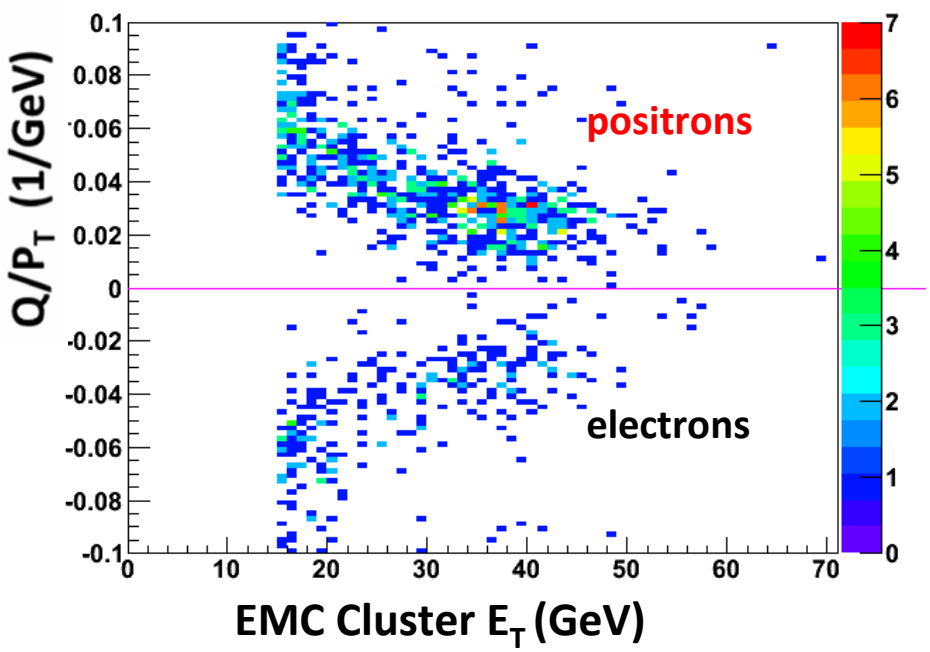


+/- distance D ~ $1/P_T$

P_T=5 GeV : D~15 cm

P_T=40 GeV : D ~2 cm

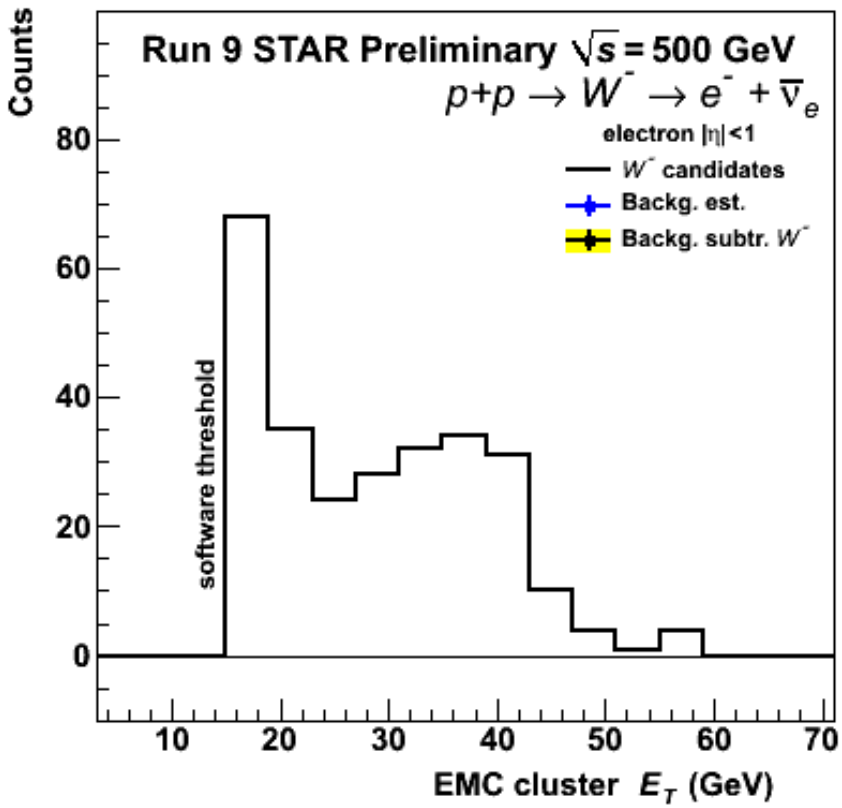
Q is the charge sign of the track in STAR's magnetic field.

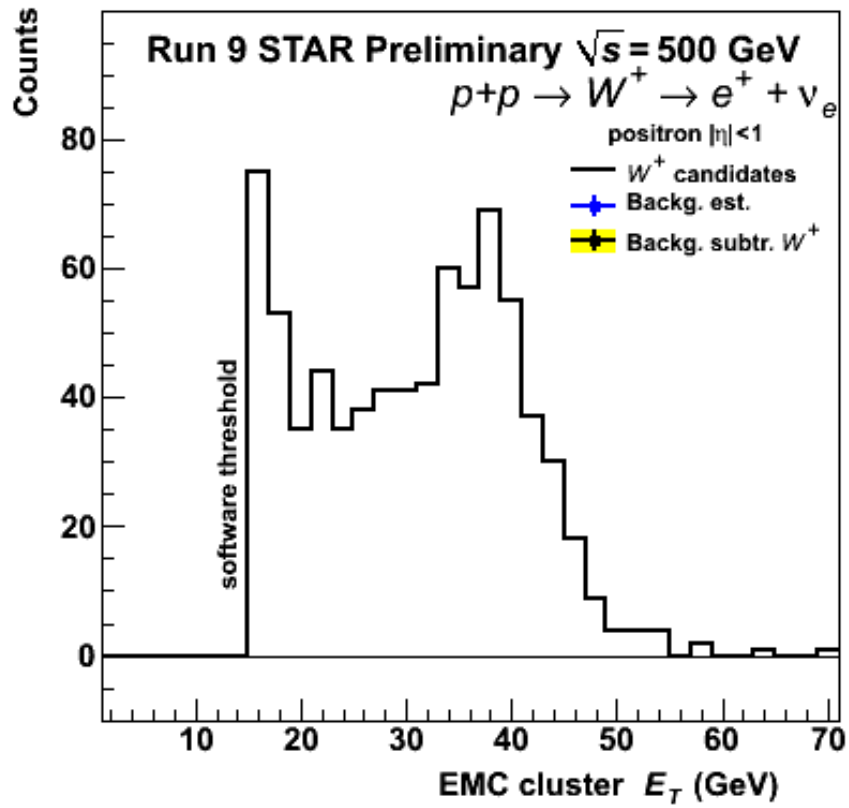


Easy to separate different charge states!

Assign $Q/p_T > 0$ to be positrons and $Q/p_T < 0$ to be electrons.

Cross Section – The Raw Signal

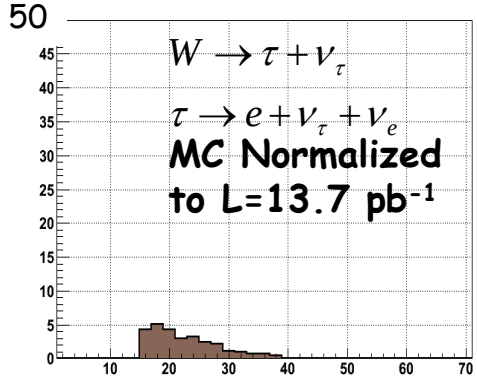




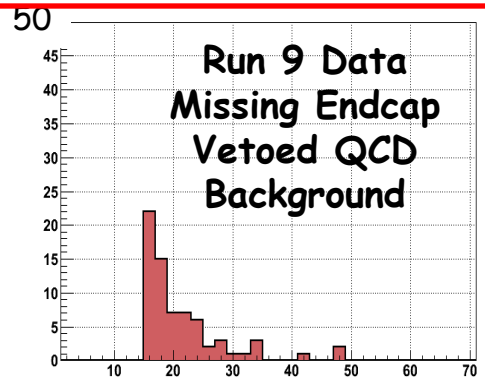
- The raw signals after the cuts described earlier are shown above (~ 13.7 pb^{-1}), from the 2009 run at 500 GeV.

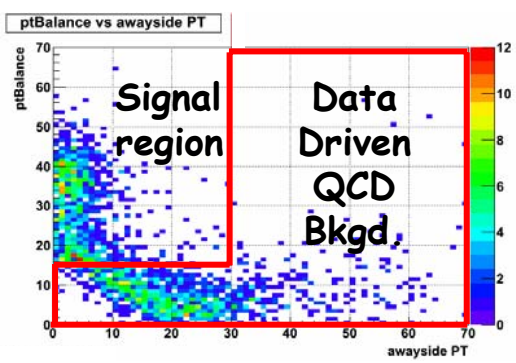
Cross Section – Remaining Background

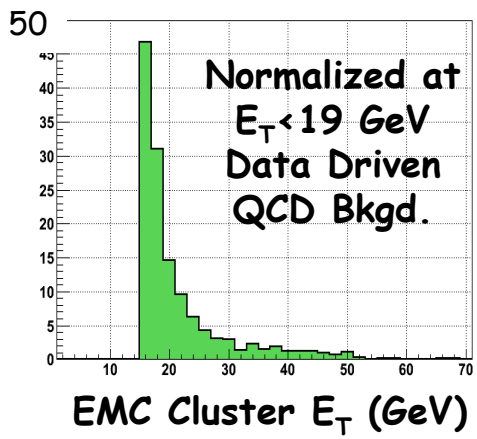
PYTHIA+GEANT MC →



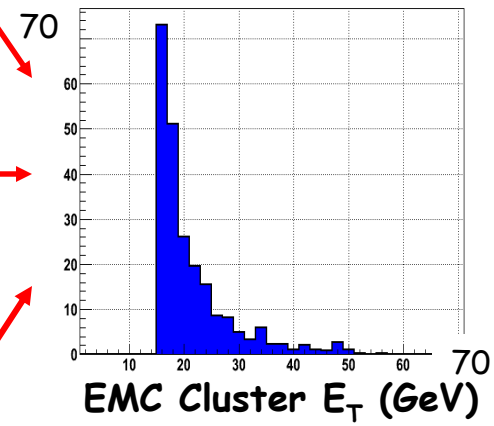
1. Run analysis with EEMC in veto cuts
2. Run analysis without EEMC in veto cuts
3. Subtract two raw signals





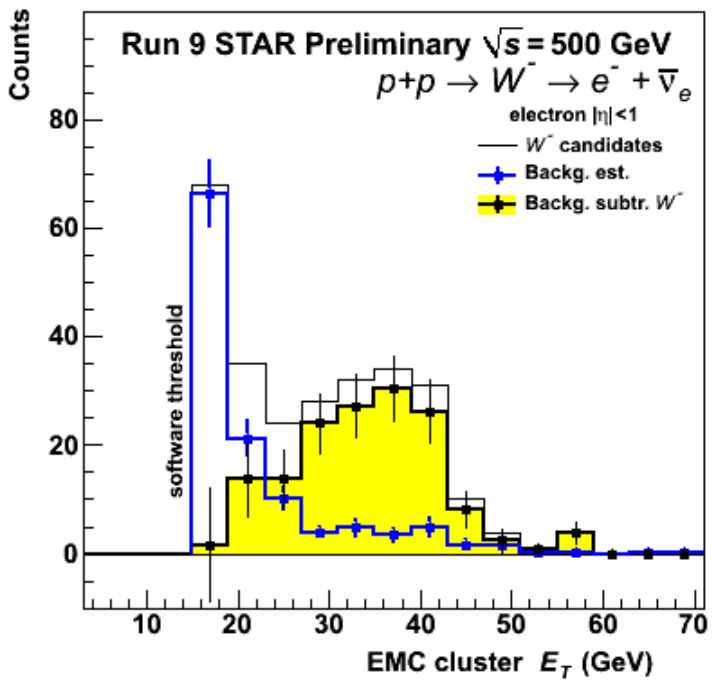


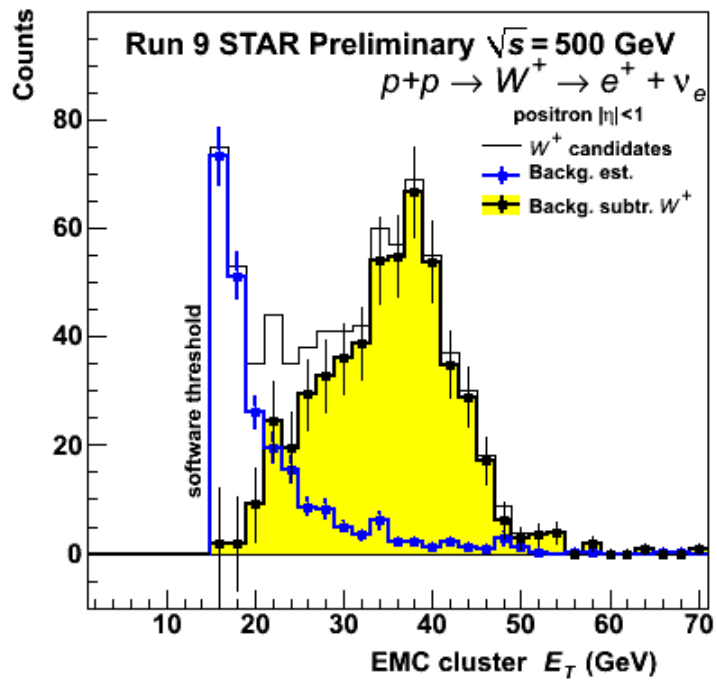
Total Background



Vary the cuts and normalization regions (E_T < 17 – 21 GeV). The max difference gives systematic error estimate.

Cross Section – Bkg. Subtraction

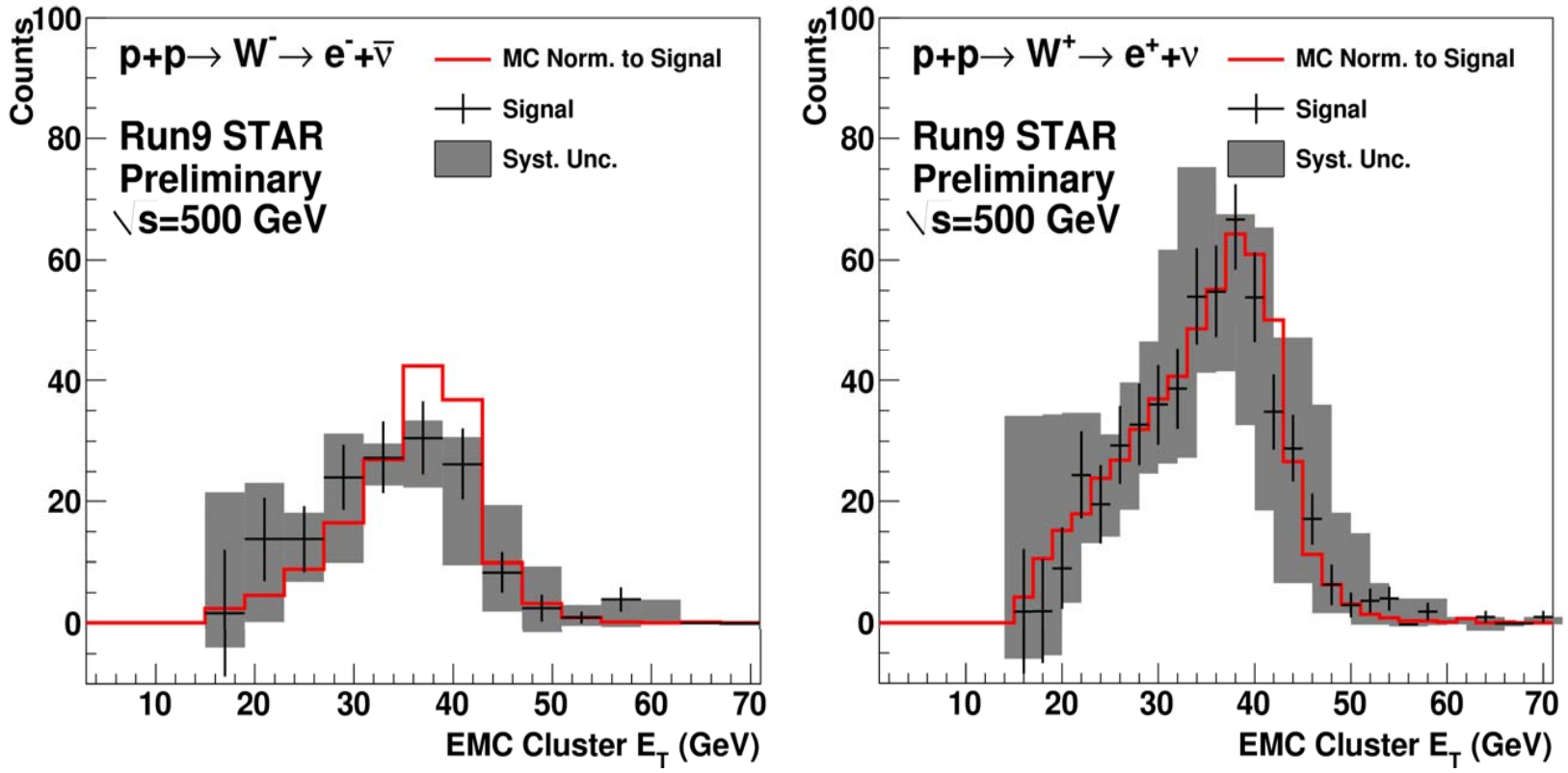




The background-subtracted signals are shown in yellow and the backgrounds in blue.

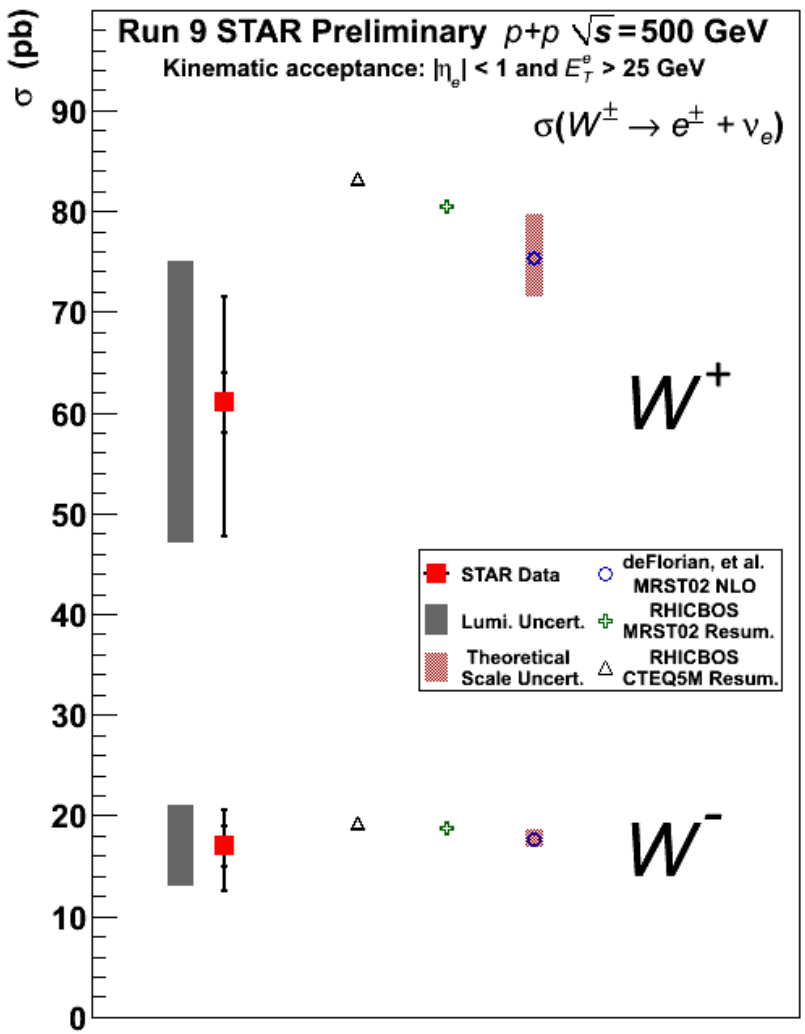
Background Events ($E_T > 25$ GeV)	$W^- \rightarrow e^- + \bar{\nu}_e$	$W^+ \rightarrow e^+ + \nu_e$
$W \rightarrow \tau + \nu_\tau$	2.7 ± 0.7	8.4 ± 2.2
Missing Endcap	14 ± 4	13 ± 4
Normalized QCD	$8.0\ ^{+20}_{-4}$	$25\ ^{+36}_{-9}$
Total	$25\ ^{+21}_{-7}$	$46\ ^{+36}_{-11}$

Cross Section – Shape



- A comparison is shown of full PYTHIA + GEANT simulations of STAR W → e ν events at 500 GeV.
  - The systematic uncertainties were estimated by varying cuts and normalization regions for the QCD background and by varying the BEMC energy scale uncertainty (± 7.5%).

Cross Section – Results



	$W^- \to e^- + \bar{\nu}_e$	$W^+ \to e^+ + \nu_e$
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)

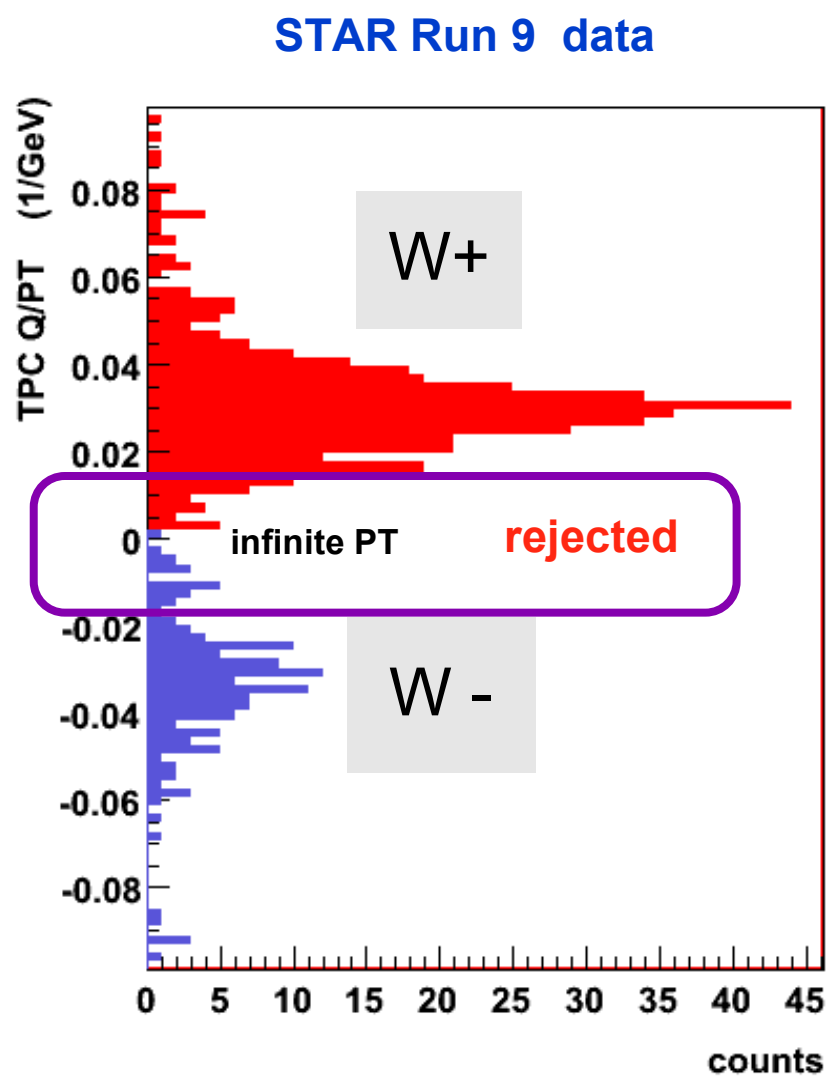
$$\sigma_{W^+ \to e^+ + \nu} = 61 \pm 3\ (\text{stat.})\ ^{+10}_{-13}\ (\text{syst.}) \pm 14\ (\text{lumi.})\ \text{pb}$$

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

There is reasonable agreement between the measured and expected cross sections.

A_L Determination - Cuts

- All cuts for the cross section were also applied for A_L with the exception of the charge separation condition.
  - A tighter constraint was applied to avoid possible cross contamination of the two W samples, with their different A_L values.



A_L Determination – Yield Equations

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

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

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

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

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

N = # events and
L = luminosity for
each spin state

neglected because
STAR is phi-symmetric

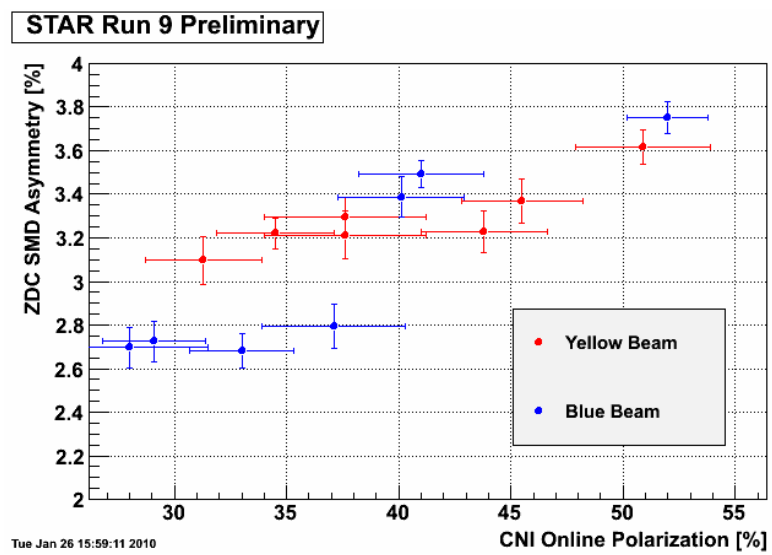
$$\delta \simeq \int_{2\pi} d\phi_e \; \mathrm{Effi}(\phi_e) sin(\phi_e) \simeq 0.02$$

Yields integrated over |η| < 1

$N_{++} / L_{++} = \sigma_{++}$, etc.

A_L Determination – Yield Equations

- A new local polarimeter (ZDC) was commissioned at STAR for the 500 GeV run in 2009 to monitor the transverse spin components of the beam polarization.
  - These were found to have magnitudes $|Q_i| < 0.1$.
- The equations on the previous page ignore some other negligible terms:
  - Parity-conserving A_{SL} or A_{LS} and parity-violating A_{NL}, since transverse component is small and STAR is quite cylindrically symmetric (same argument as for A_N).
  - Parity-conserving A_{NN}, etc., as this would involve two small transverse spin components plus ~ cylindrical symmetry.



ZDC asymmetry (%) vs CNI online Pol (%)
Calibrated during transverse pol. runs.

A_L Determination – Yield Equations

- Four independent yields were measured. Six asymmetries were computed, of which three are independent, and one of these is a null test.

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

yields integrated over $|\eta| < 1$

A_L Determination – Yield Equations

- For a detector centered at η, the equations become
  - "A_L (blue)" $\rightarrow A_L (+\eta)$
  - "A_L (yellow)" $\rightarrow A_L (-\eta)$
  - "A_L (average)" $\rightarrow [A_L (+\eta) + A_L (-\eta)] / 2$
  - "$A_L (P_1 - P_2)$" $\rightarrow A_L (+\eta) - A_L (-\eta)$ ignoring A_{LL}
  - "A_L^*" $\rightarrow A_L (+\eta) + A_L (-\eta)$ ignoring A_{LL}

- Then averaging over the STAR BEMC detector acceptance, which is symmetric about $\eta = 0$, it is clear why the fifth asymmetry is expected to be zero (null test)
  - See also C. Bourrely and J. Soffer, Phys. Lett. **B314**, 132 (1993).

A_L Determination – Unpol. Background

- The QCD background was estimated as described for the cross section determination. This background is assumed to be unpolarized. However, it can impact the extraction of the physics asymmetry, A_L.

$$\mathcal{N}_\pm = \sigma_0\ \mathcal{L}_0\ \varepsilon_0\ [1\beta\ \pm A\ P]$$

$$\beta = \frac{signal + backg}{signal}$$

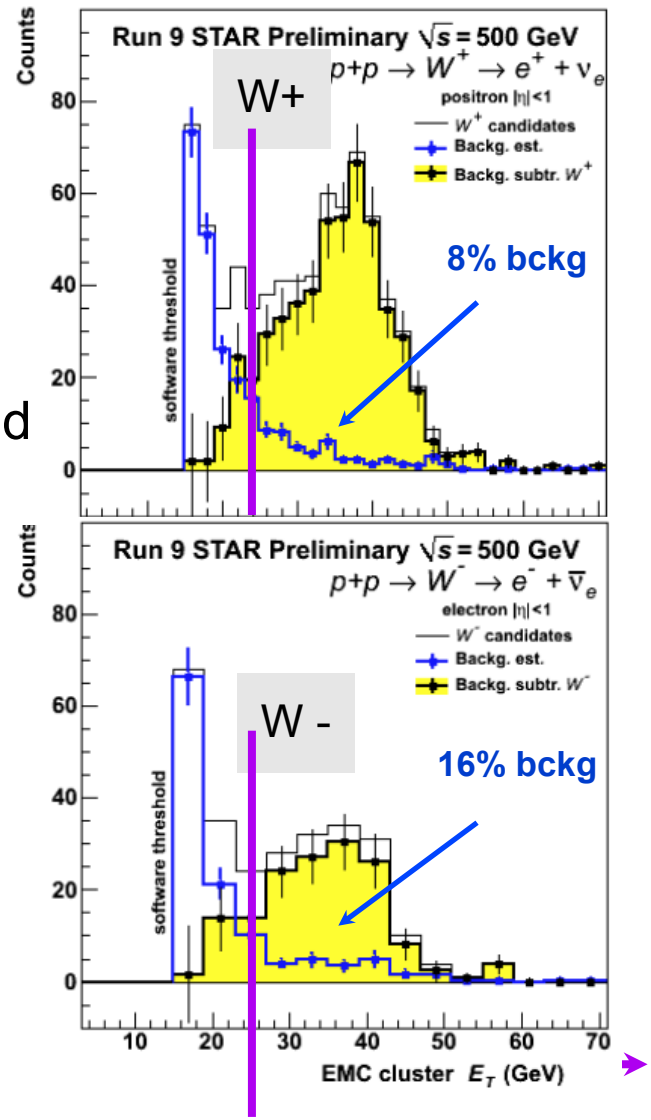
β is the background contamination

$$\text{eps} = \frac{N_+ - N_-}{N_+ + N_-}$$

$$A = \frac{\beta\ \text{eps}}{P}$$

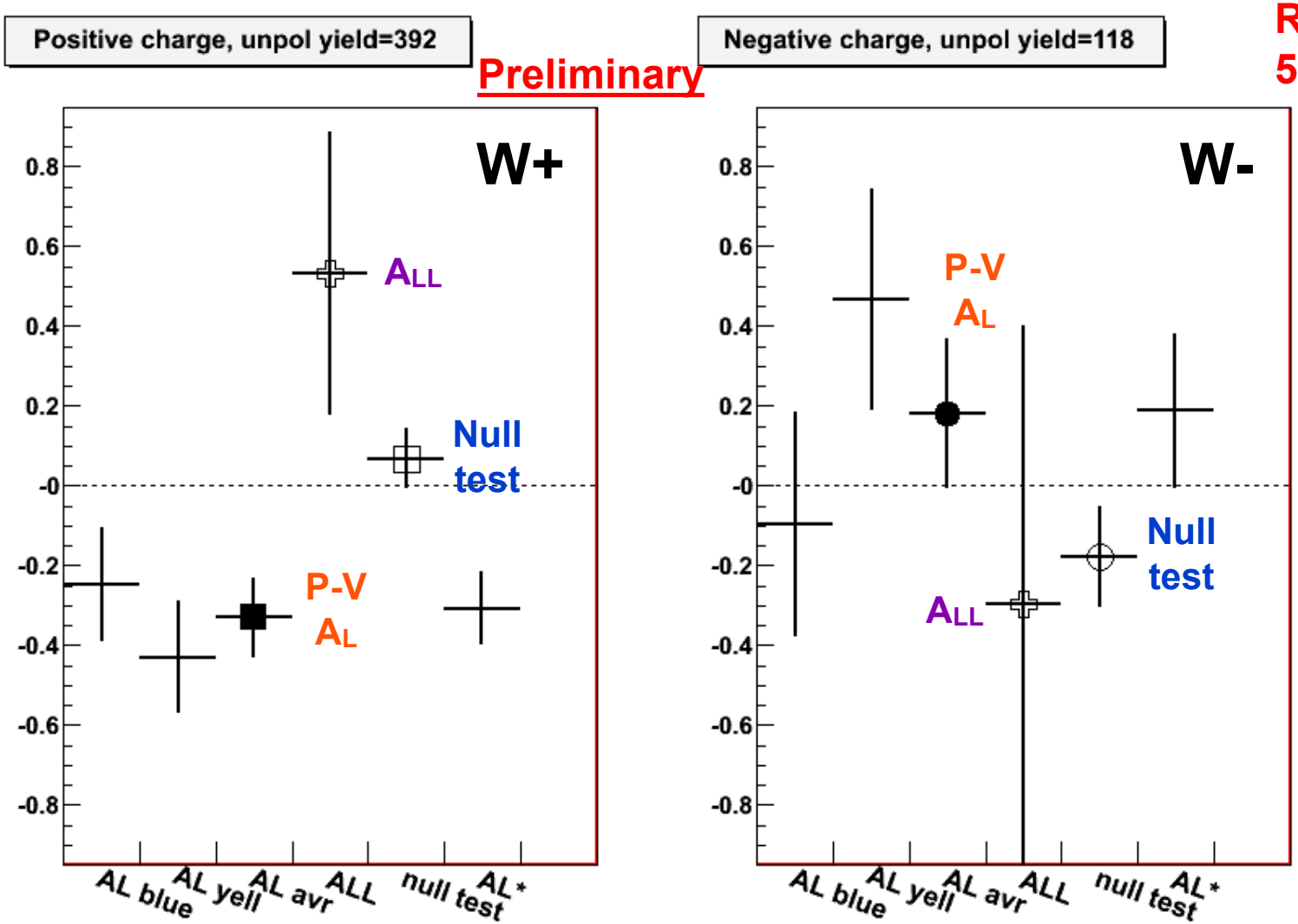
physics asy corrrected for background

- Uncorrected event by event background is equivalent to beam depolarization.
- High/low limits on the background translate to an A_L scale uncertainty.



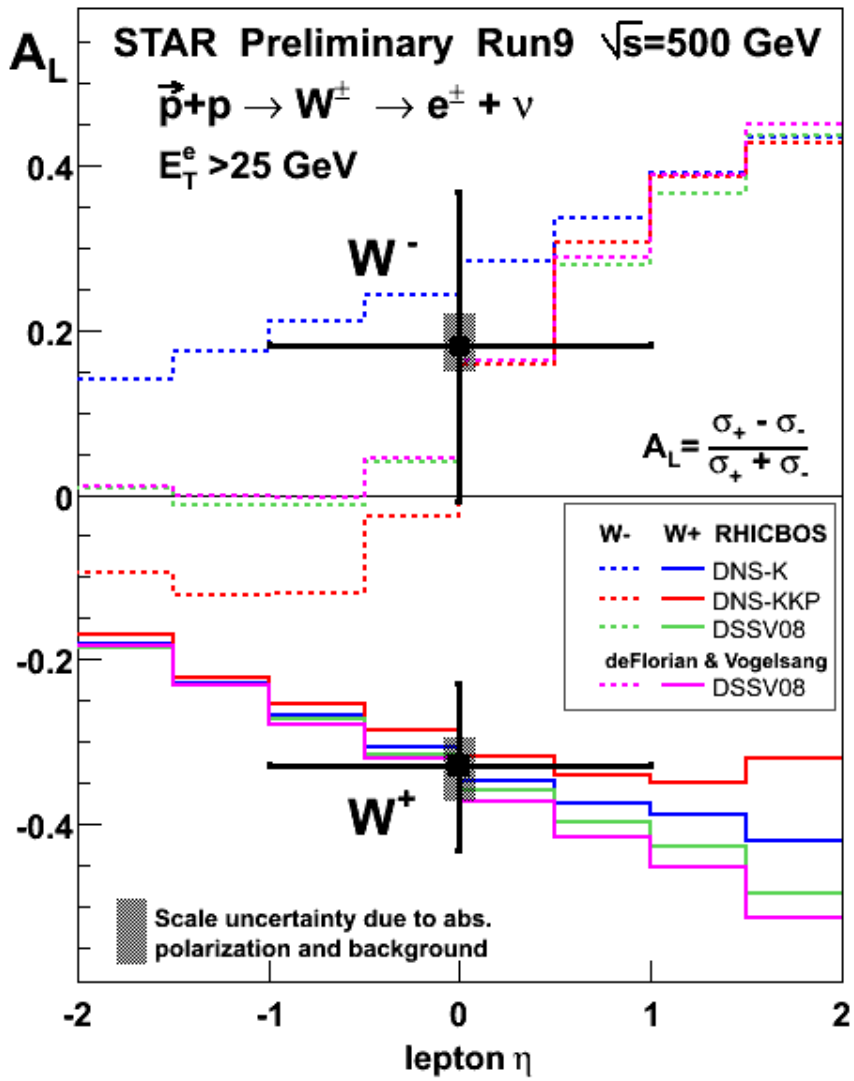
A_L Determination – Results

Run 9 (pp)
500 GeV



Physics asymmetries (A_L, A_{LL}) are corrected for unpolarized background.

A_L Determination – Results



STAR Preliminary Run 9

$$A_L(W^+) = -0.33 \pm 0.10(\text{stat.}) \pm 0.04(\text{syst.})$$

$$A_L(W^-) = 0.18 \pm 0.19(\text{stat.}) \; ^{+0.04}_{-0.03}(\text{syst.})$$

- For mid-rapidity, W decay electrons / positrons
  - A_L (W^+) is negative, as predicted, by 3.3 σ.
  - A_L (W^-) is consistent with being positive, as expected.

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

A_L Determination – Uncertainties

- The table below lists the systematic uncertainties for A_L.
  - No contribution assumed from wrong sign W contamination, due to Q/p_T cut.
  - No other spin observables assumed to contribute.

W+		W -		
high	low	high	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

Summary

- There was a successful polarized $\sqrt{s}$ = 500 GeV p+p run at RHIC last year. First data were collected at this energy.
- STAR observed W decay electrons and positrons at mid-rapidity ($|\eta| < 1$).
  - The measured cross sections for both W^+ and W^- are in reasonable agreement with theoretical expectations.
  - The parity-violating asymmetries, A_L, were also obtained and the results agree with theoretical predictions. In particular, A_L (W^+) was found to be 3.3 σ away from zero (negative).
  - Future results will work towards flavor separation of the different quark and anti-quark contributions to the proton spin.
- We look forward to additional $\sqrt{s}$ = 500 GeV data in the future (see the upcoming talk by B. Surrow).

Backup

Cross Section – Efficiencies

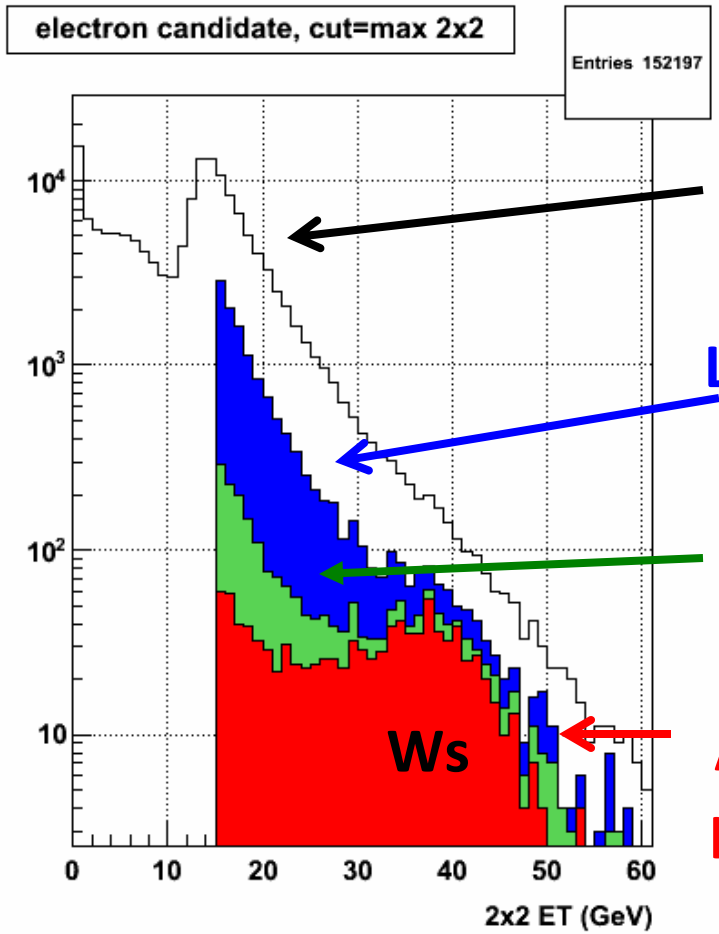
Efficiencies were calculated from full PYTHIA + GEANT simulations of the STAR geometry within the kinematical acceptance $|\eta| < 1$ and $E_T > 25$ GeV for the electron.

Efficiency Component	$W^- \rightarrow e^- + \bar{\nu}_e$	$W^+ \rightarrow e^+ + \nu_e$
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}	$0.56\ ^{+0.11}_{-0.09}$	$0.56\ ^{+0.12}_{-0.09}$

Note: PYTHIA 6.41 and CTEQ5L PDFs were used.

Cross Section – Event Rejection

Run 9 Data



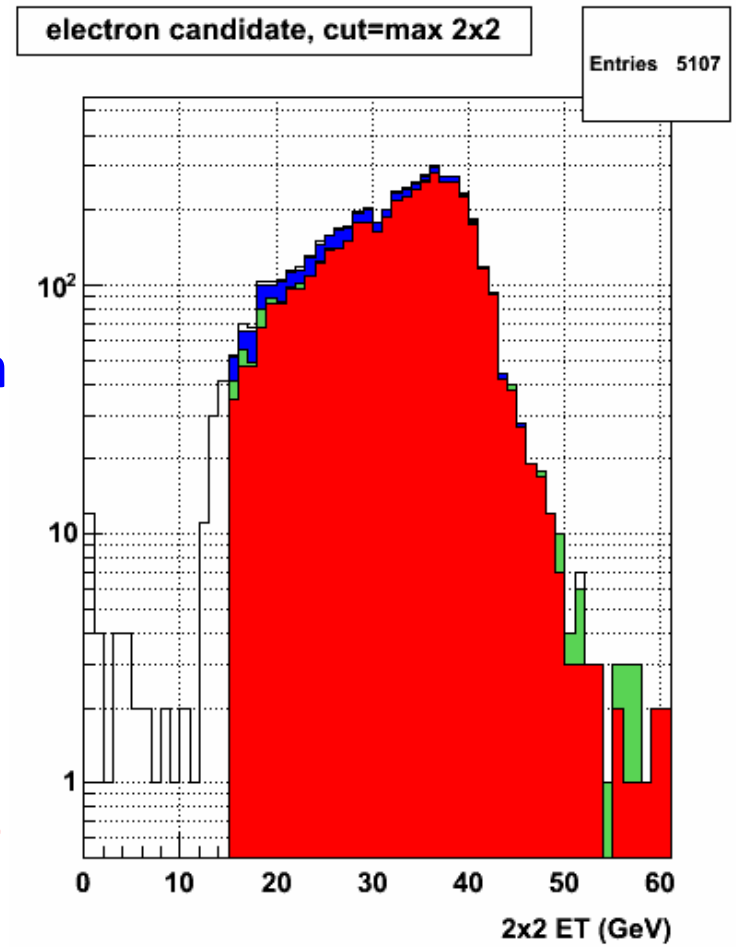
Track $p_T > 10$ GeV

Lepton Isolation Cut

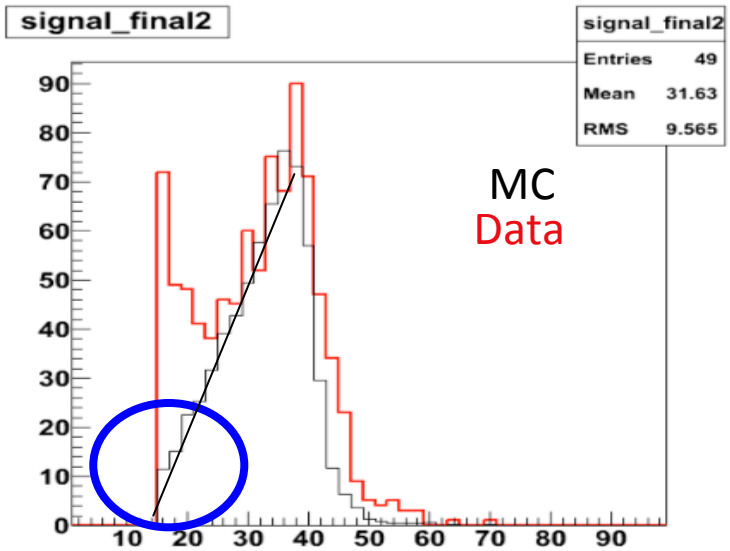
Near-Side p_T Veto

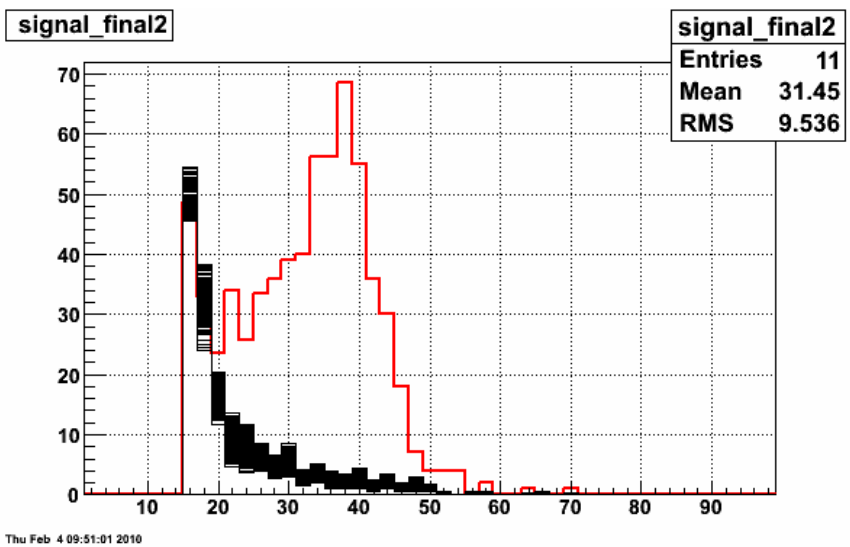
Away-Side p_T & p_T Balance Veto

Pythia+Geant W^+ MC



Data Driven Background Estimation





Iterative Normalization

- Small W signal is expected in the normalization region (E_T <19 GeV).
- Use linear fit to low E_T side of the Jacobian peak to estimate signal in the normalization region.

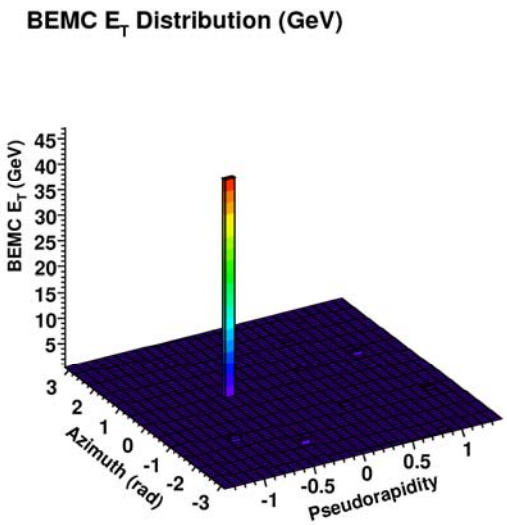
Systematic Uncertainty

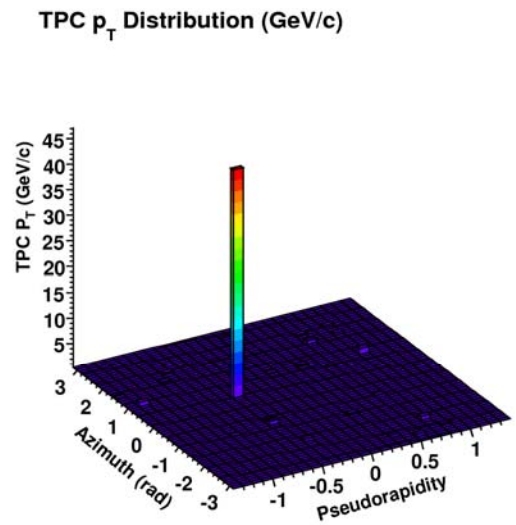
- Calculate 1200 different QCD background shapes by varying away-side p_T cut, p_T balance cut, and normalization region.
- Take maximum extent for each bin as the uncertainty.

Data Driven Background Estimation

- "Near-side" jet cone is a region of radius 0.7 in η and φ.
- "Away-side" E_T sum veto – sum together all E_T from the TPC, BEMC, and EEMC in a region 180° $\pm$ 0.7 rad. from the TPC track in φ and any η. Require the sum to be < 30 GeV.
- "p_T balance cut" – find all jets outside the near-side jet cone using the TPC, BEMC, and EEMC. Form the vector sum of the p_T from the electron candidate in the near side jet cone and the other jets. Take the magnitude of this vector sum, and require it to be > 15 GeV.

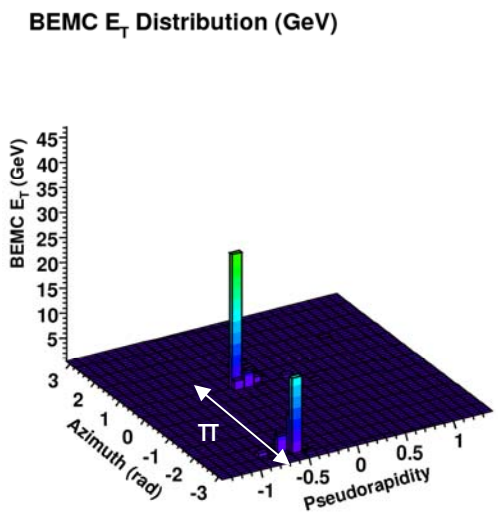
Sample Events (Lego Plots)

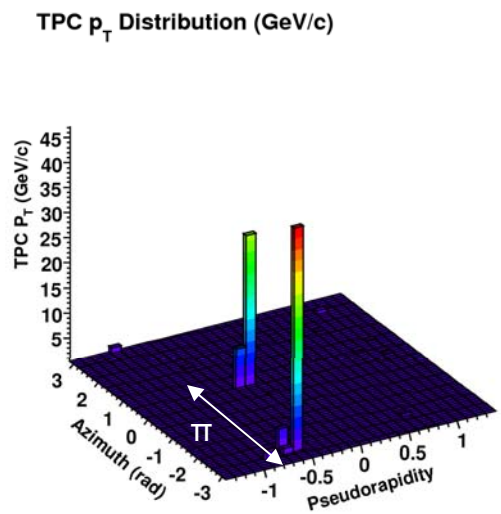




W event

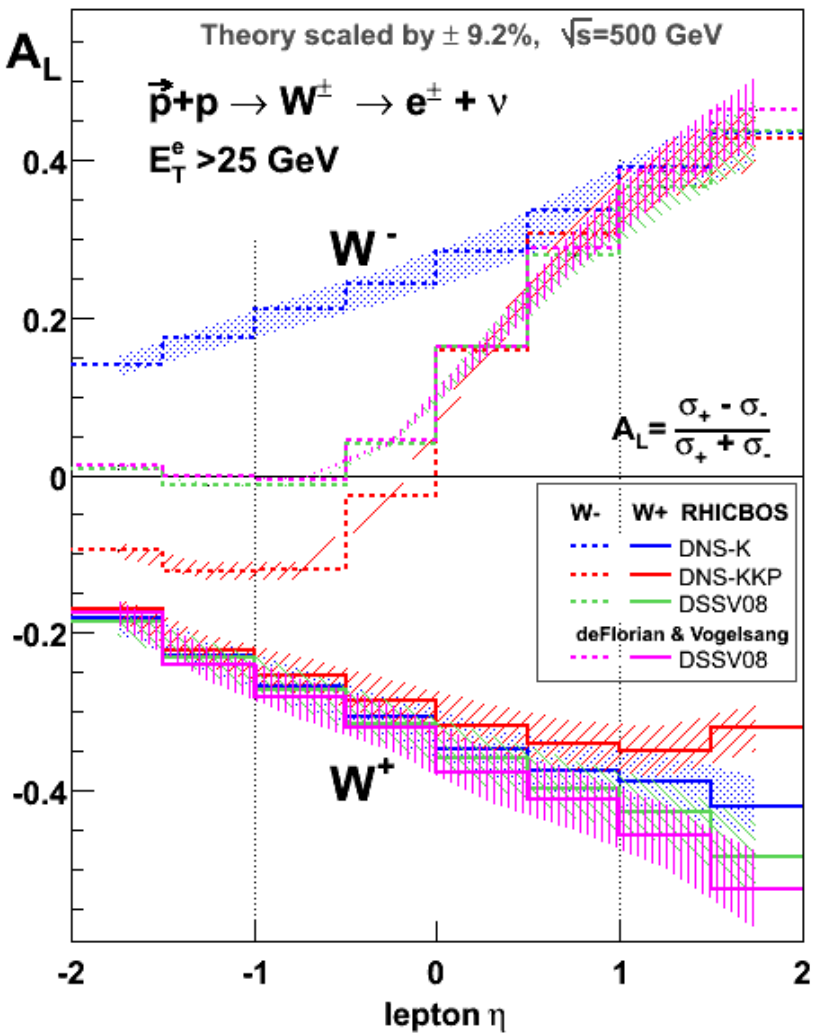
Dijet event



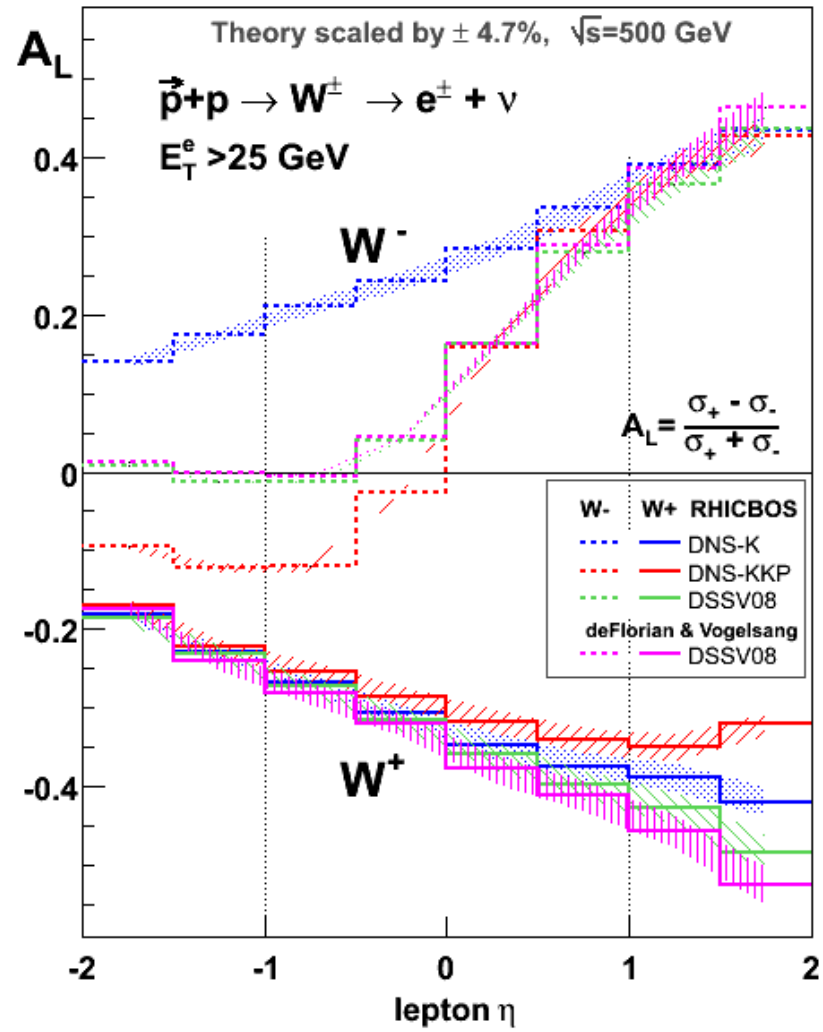


Impact of Beam Polarization Systematic Uncertainty on A_L

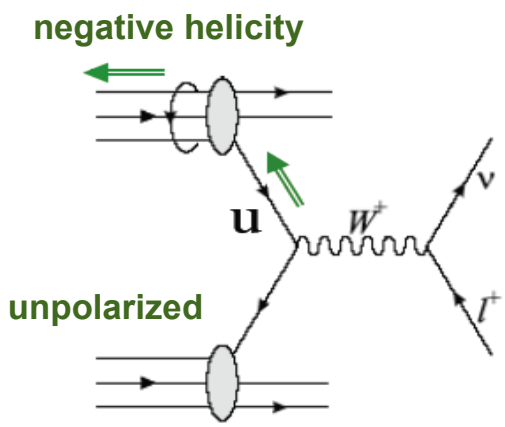
scale varied by +/- 9.2%



scale varied by +/- 4.7%



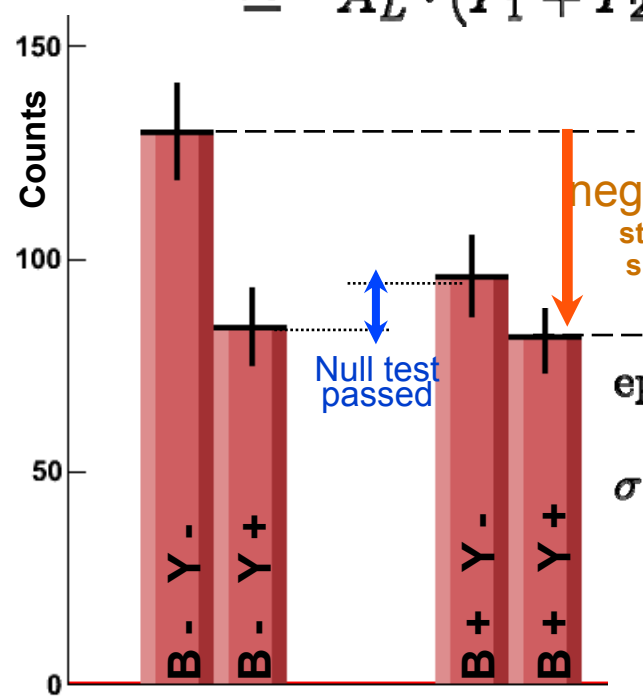
Directly Observed Up Quark Pol. Effects



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

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

W^+ yield integrated over $|\eta|<1$



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

Counts detected in 4 spin states