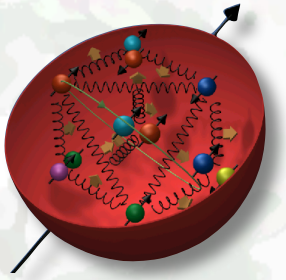
# Recent STAR W production results of the high-energy polarized p-p program at RHIC at BNL

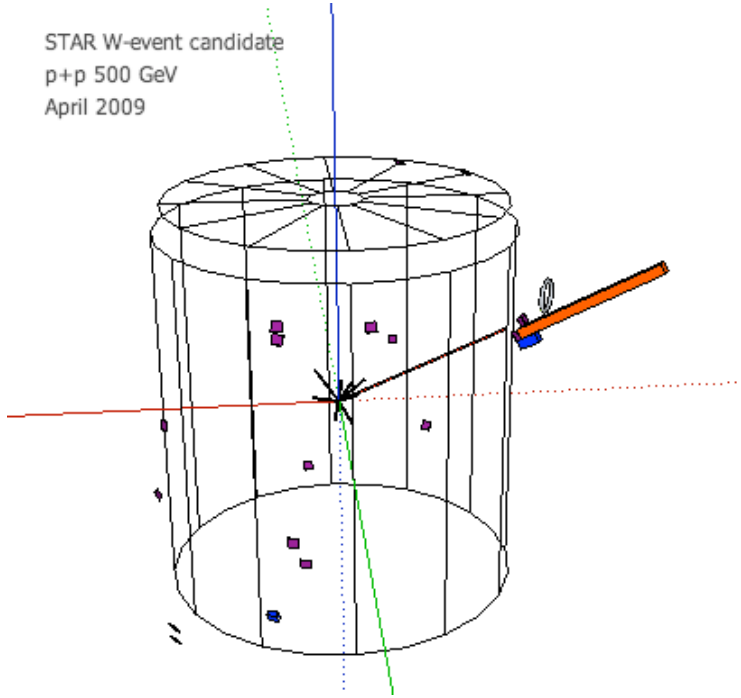
Bernd Surrow

Massachusetts Institute of Technology

(On behalf of the STAR Collaboration)



# Outline

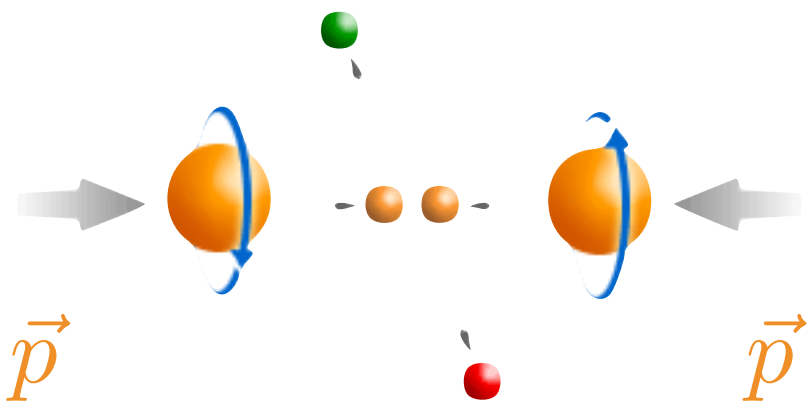



- W production - Recent Results

  First $W^+/W^-$ Cross-section and $A_L$ Measurement at STAR

- Experimental aspects: RHIC / STAR

- Theoretical foundation

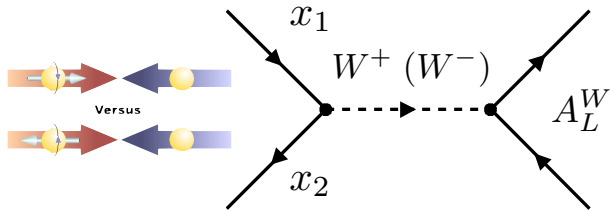



- Summary and Outlook

# Theoretical foundation

- STAR W program in e-decay mode at mid-rapidity and forward/backward rapidity

$u\,/\Delta u\;(d\,/\Delta d)$




$\Delta\bar{d}\,/\bar{d}\;(\Delta\bar{u}\,/\bar{u})$

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

$$y_l = y_W + \underbrace{\frac{1}{2}\ln\frac{1+\cos\theta^*}{1-\cos\theta^*}}_{y_l^*}$$

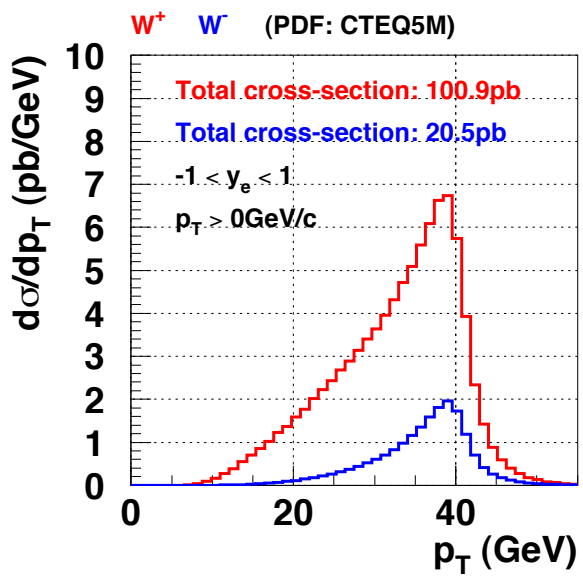
$$p_T = p_T^* = \frac{M_W}{2}\sin\theta^*$$

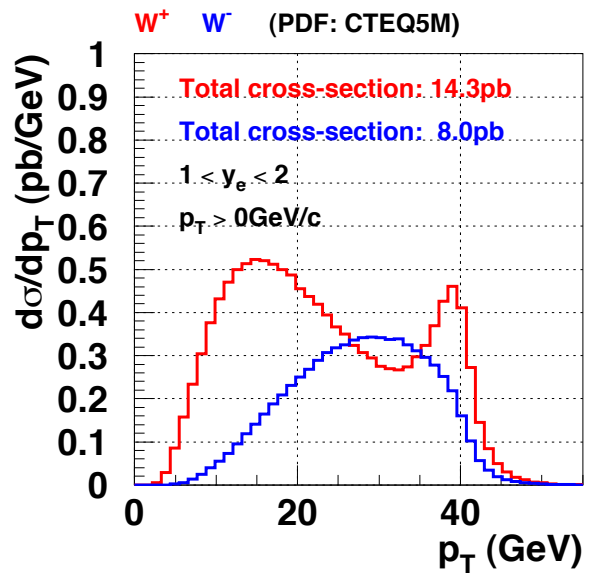
$$x_1 = \frac{M_W}{\sqrt{s}}e^{y_W}$$

$$x_2 = \frac{M_W}{\sqrt{s}}e^{-y_W}$$

$$\frac{M_W}{\sqrt{s}} = 0.16$$

- Key signature: High $p_T$ lepton ($e^-/e^+$)(Max. $M_W/2$) - Selection of $W^+/W^-$ : Charge sign discrimination of high $p_T$ lepton
- Required: Lepton/Hadron discrimination




Total ($\sqrt{s}$=500GeV) $\sigma(W^+)$=135pb and $\sigma(W^-)$=42pb

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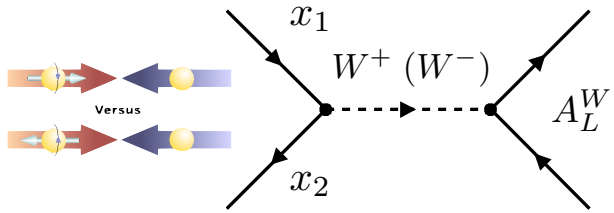


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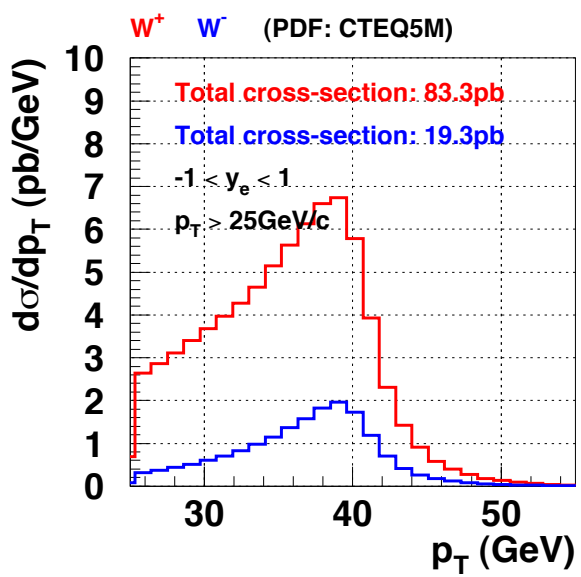


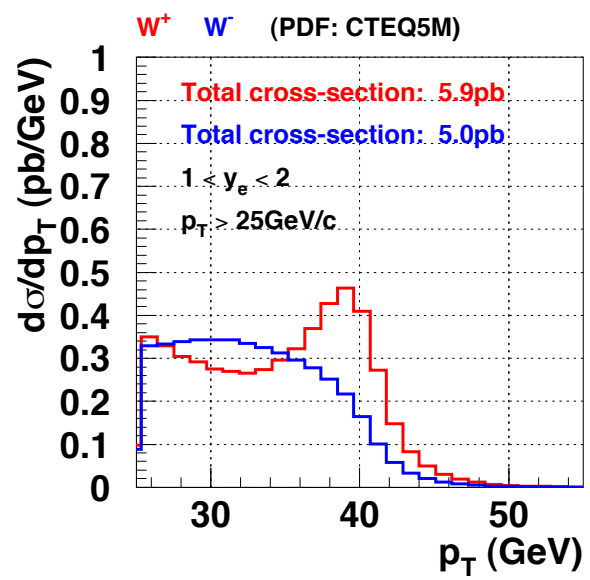


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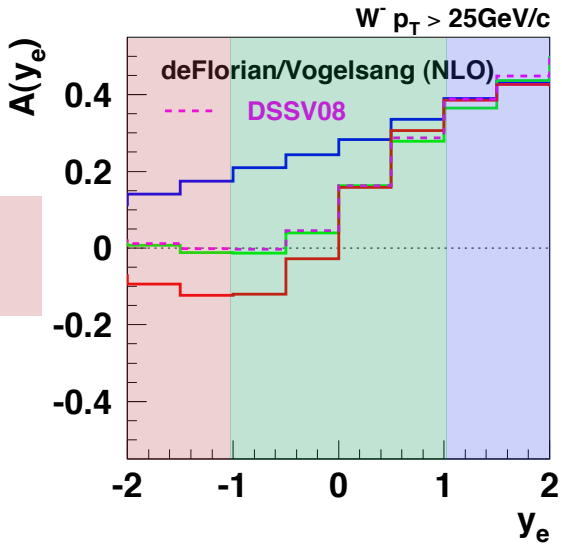
# Theoretical foundation

- $A_L$ behavior for STAR mid-rapidity and forward/backward rapidity region

$$A_L^{W^-} = \frac{\Delta\bar{u}}{\bar{u}}$$

$x_1 \ll x_2$




$$A_L^{W^-} = -\frac{\Delta d}{d}$$

$x_1 \gg x_2$

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

$x_1 = x_2$

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

$$A_L^{W^+} = -\frac{\Delta u}{u}$$

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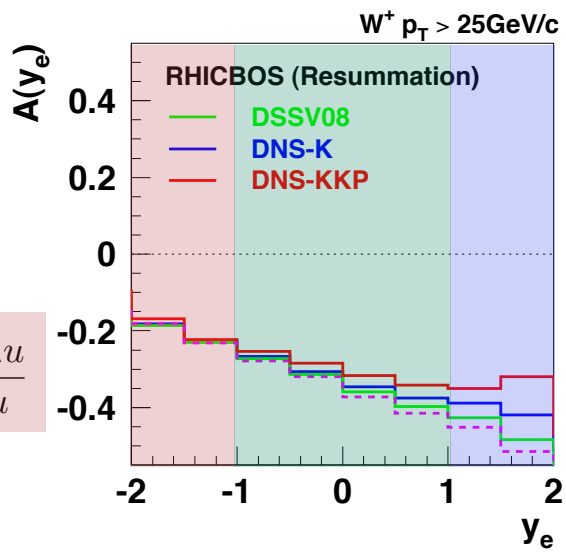


$$A_L^{W^+} = \frac{\Delta\bar{d}}{\bar{d}}$$

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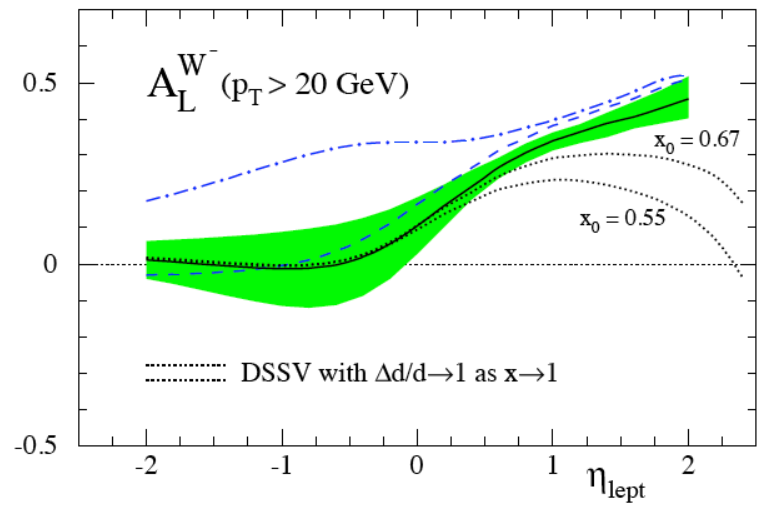
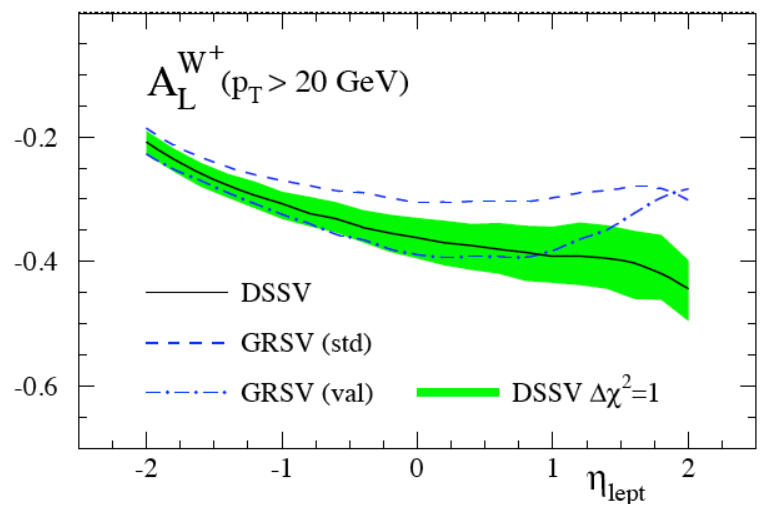



Calculations:

1) RHICBOS: P.M. Nadolsky and C.-P. Yuan, Nucl. Phys. B666 (2003) 31.

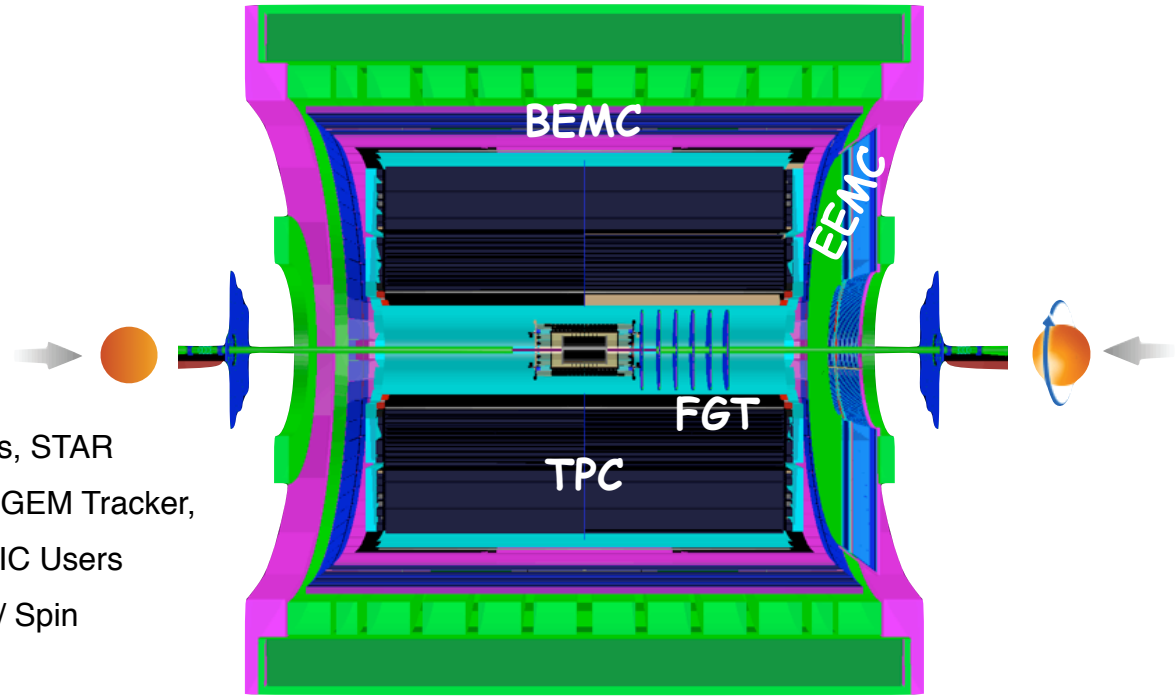
2) deFlorian / Vogelsang: D. deFlorian, private communications.

# The STAR Experiment at RHIC

- Overview

First collisions of polarized proton beams at STAR at $\sqrt{s}$ = 500GeV: Run 9 (P~40% / L~12pb$^{-1}$)

- Calorimetry system with 2π coverage: BEMC (-1<η<1) and EEMC (1<η<2)
- TPC: Tracking and particle ID
- ZDC: Relative luminosity and local polarimetry
- BBC: Relative luminosity and Minimum bias trigger

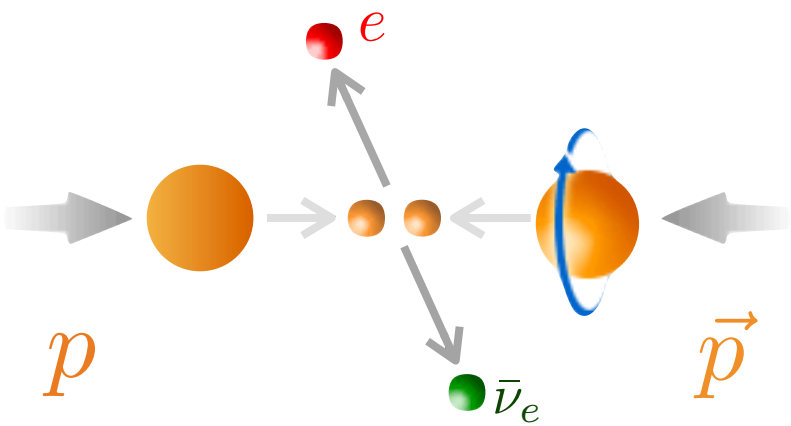


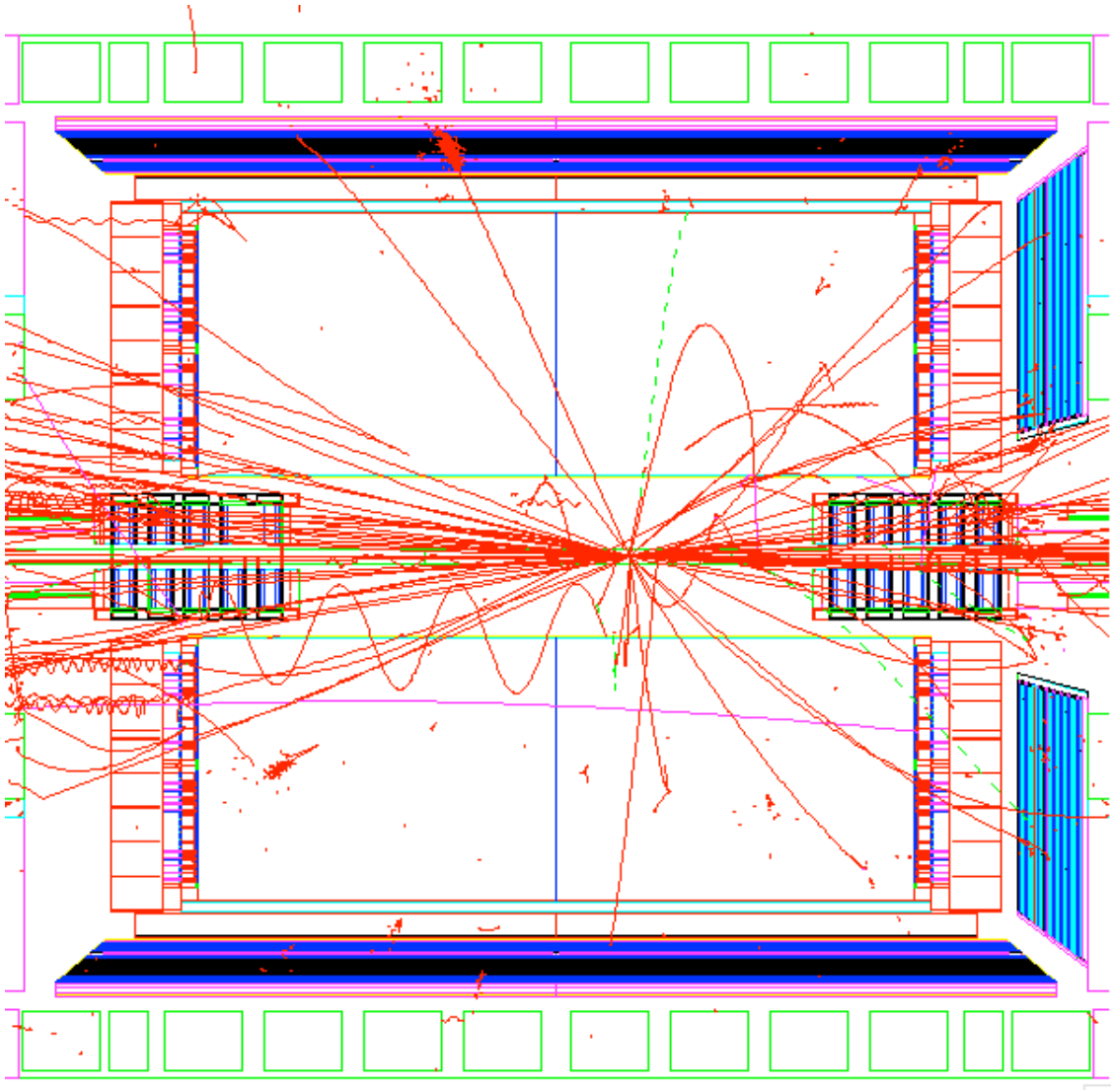

R. Corliss, STAR Forward GEM Tracker, AGS-RHIC Users Meeting / Spin Session

- STAR Mid-rapidity W program (-1<η<1): BEMC and TPC
- STAR Forward/Backward W program (1<η<2): EEMC and TPC / FGT (Installation in summer 2011)

# W production results: Algorithm

- W reconstruction - Algorithm : Idea



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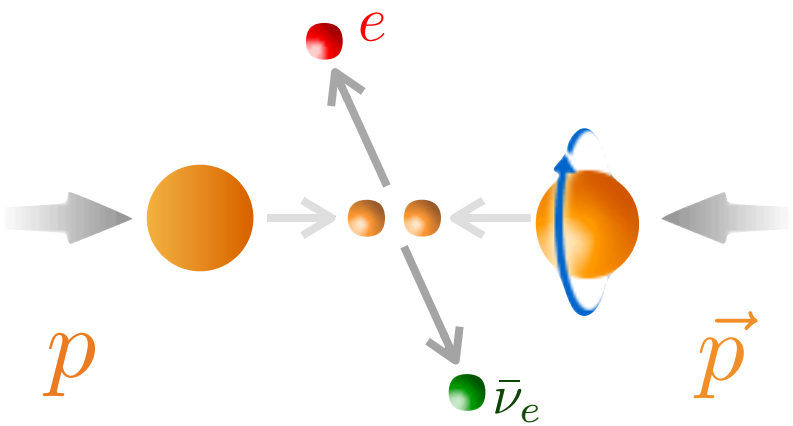


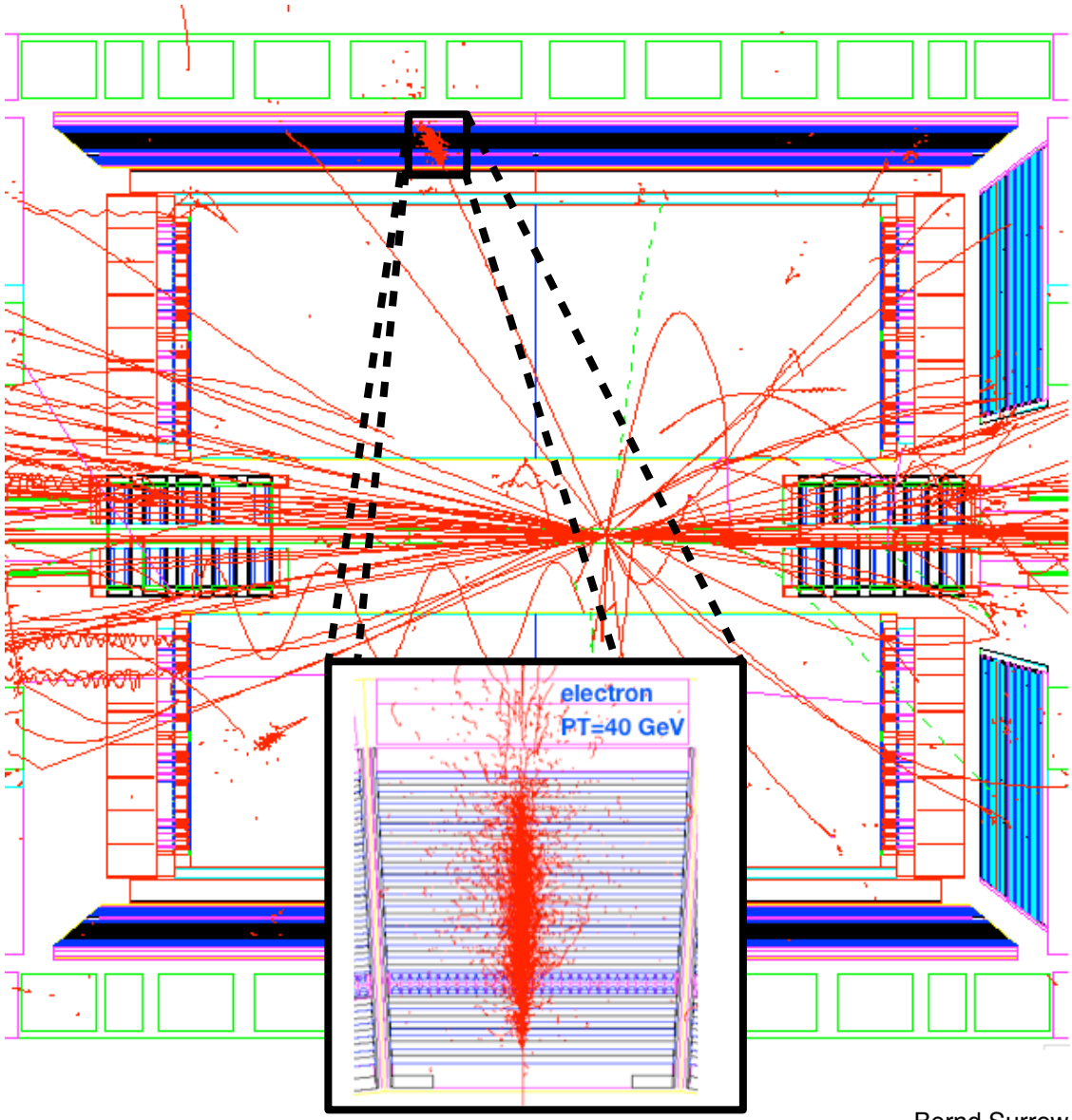

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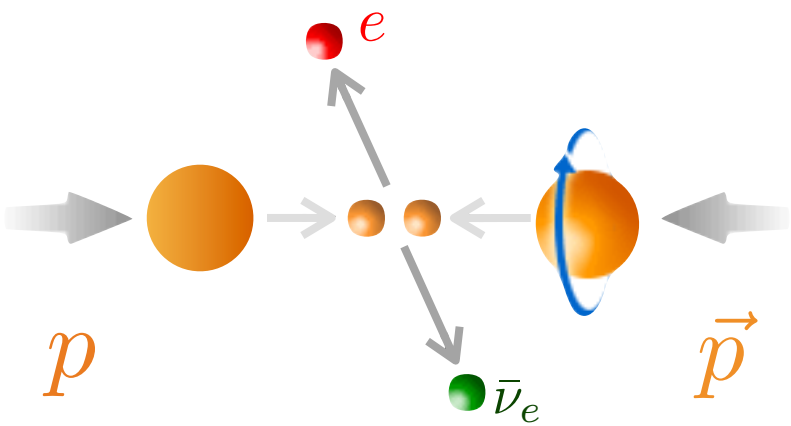
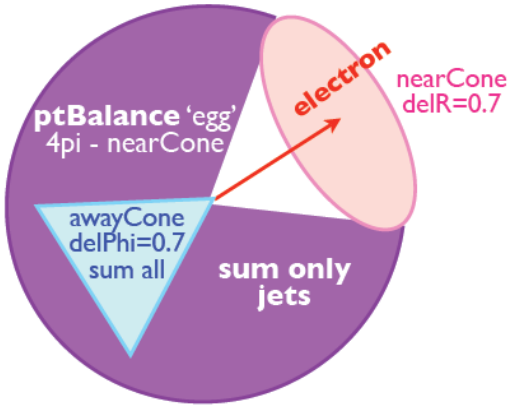
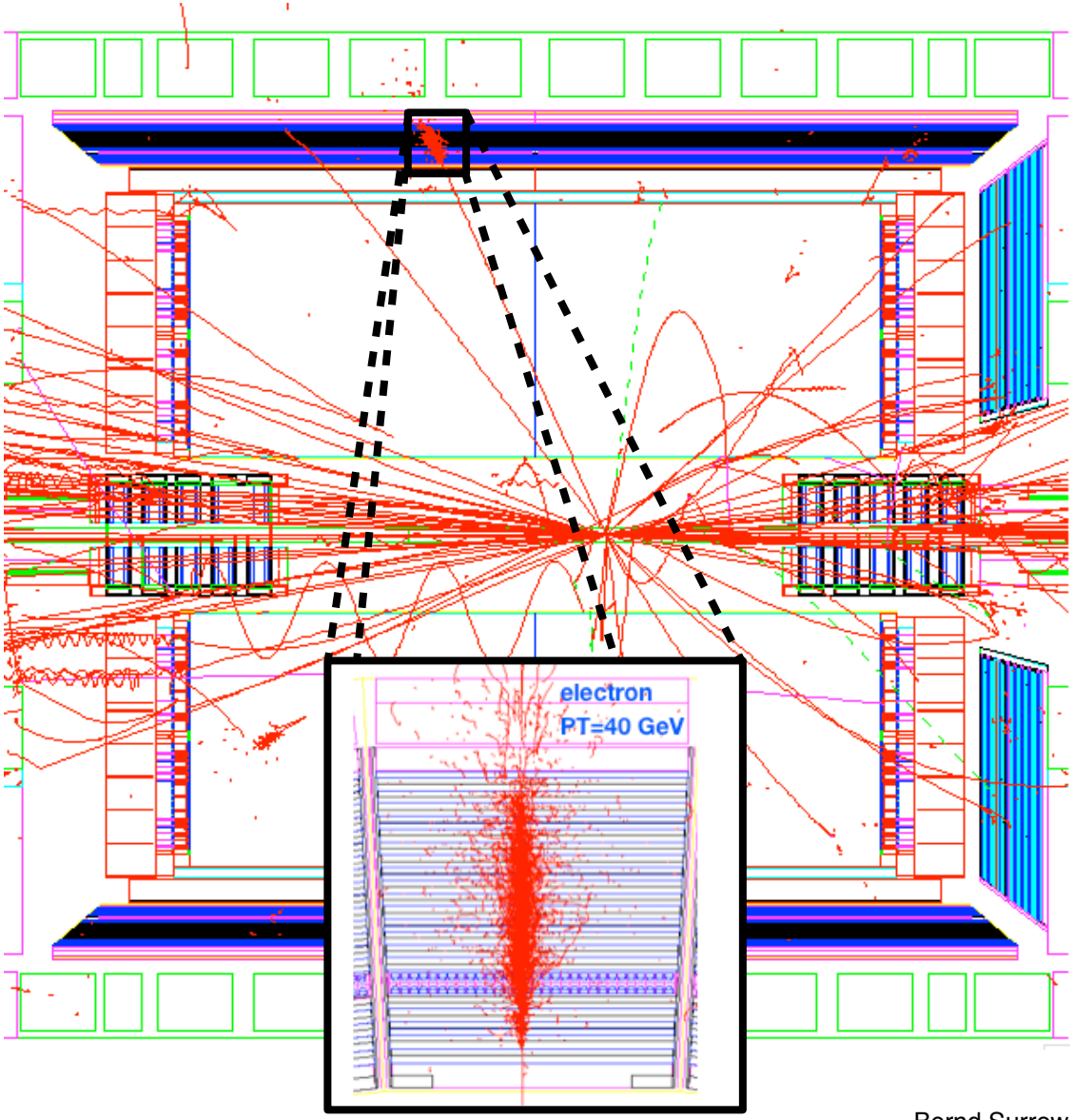



Transverse plane view



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- Event display (W event candidate) and detector signature

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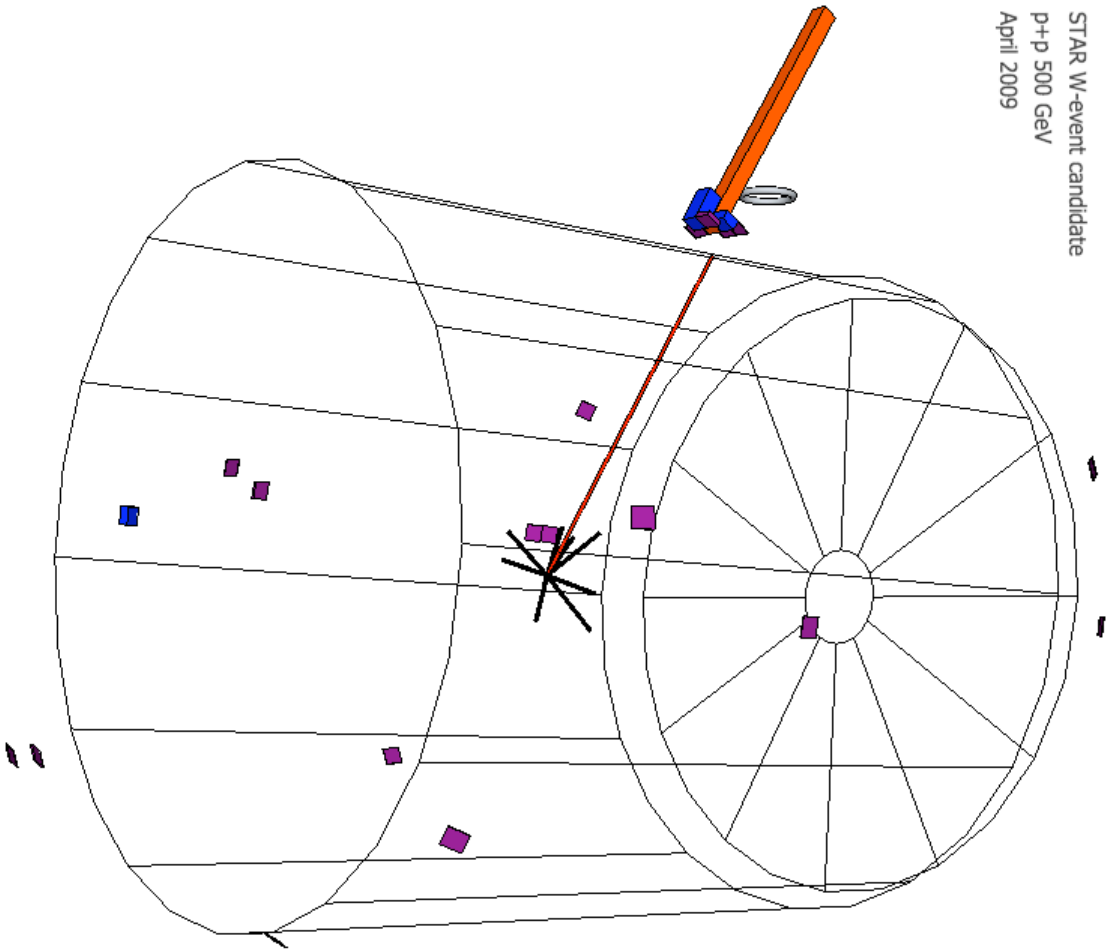

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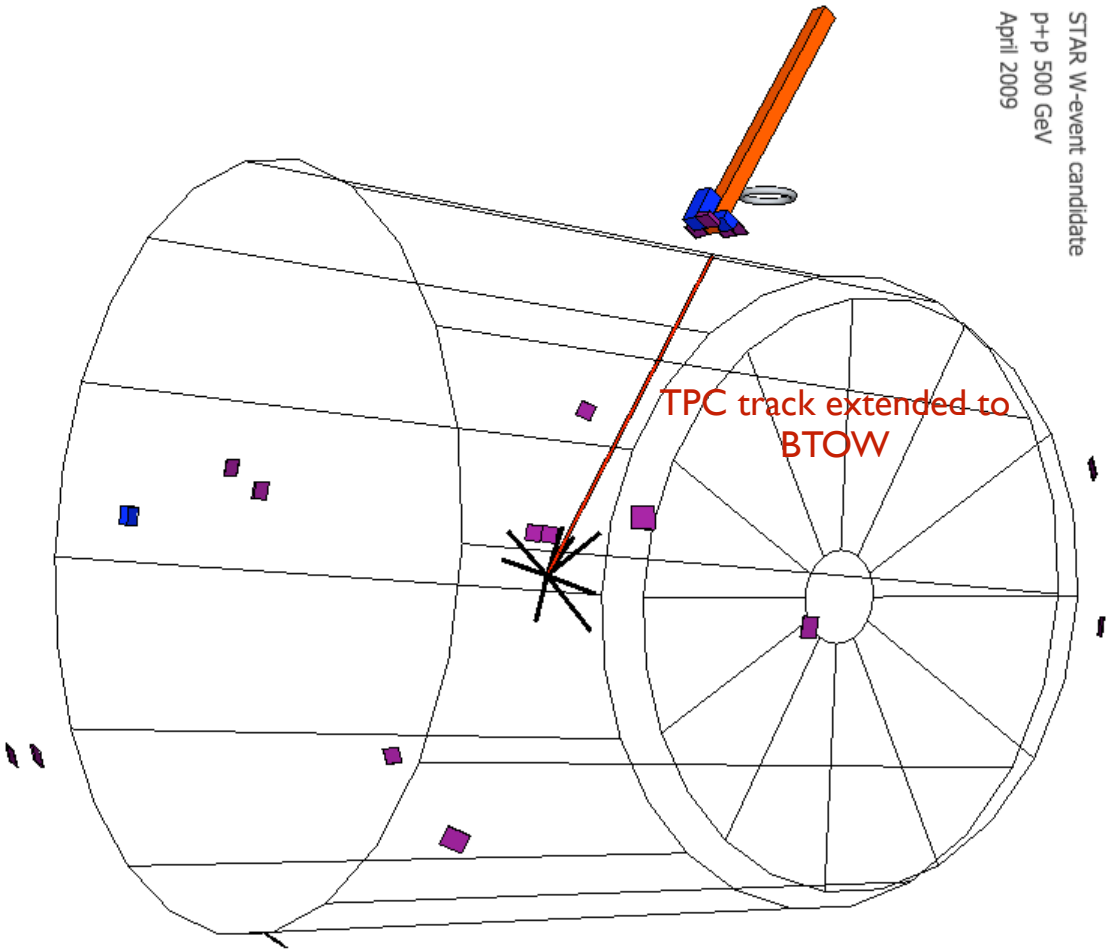

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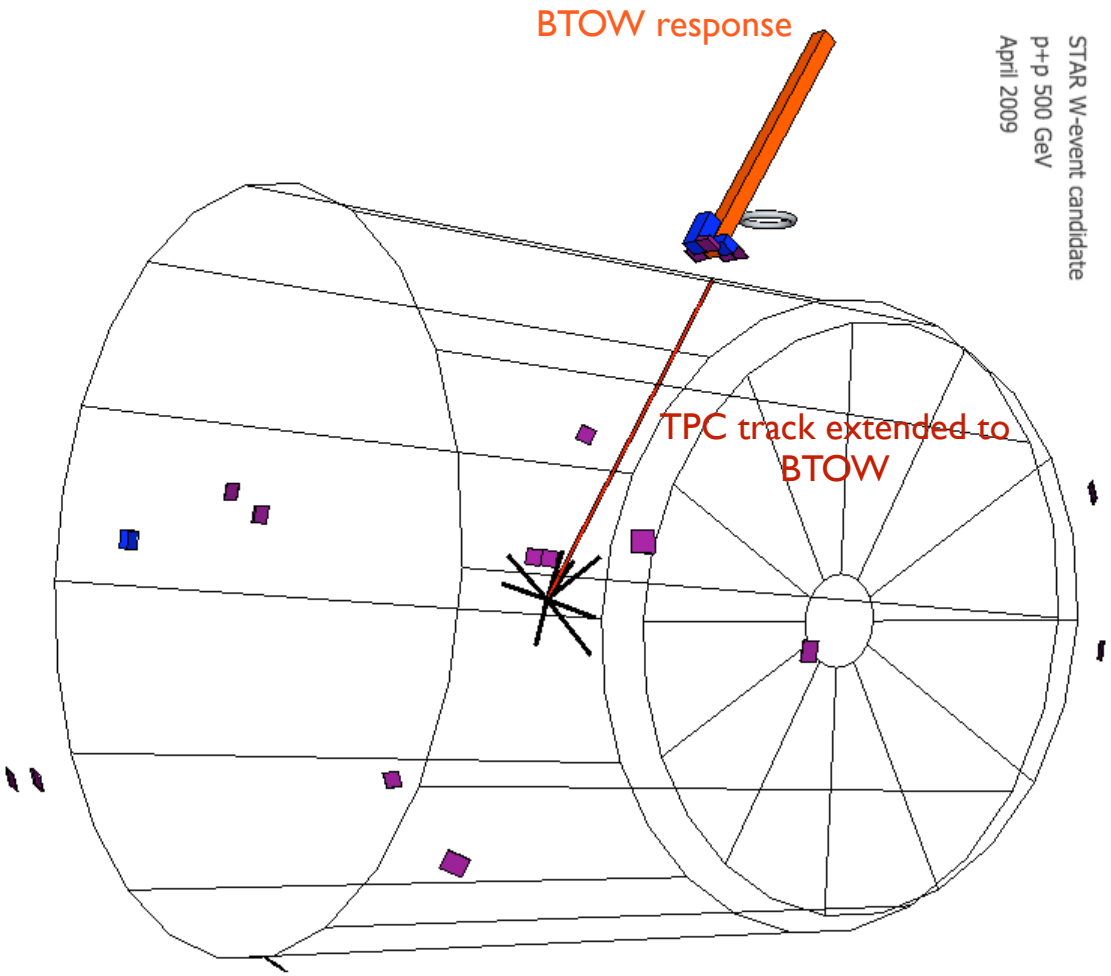

# W production results: QCD Background event

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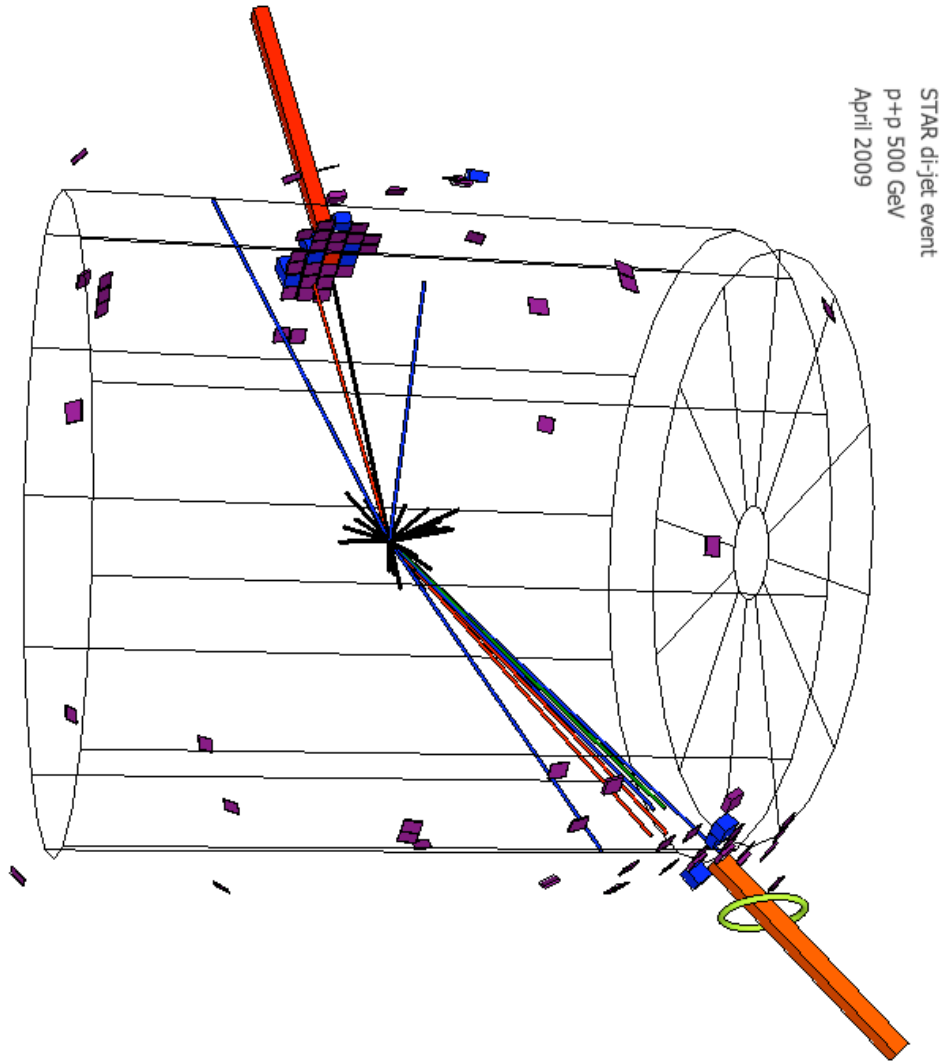

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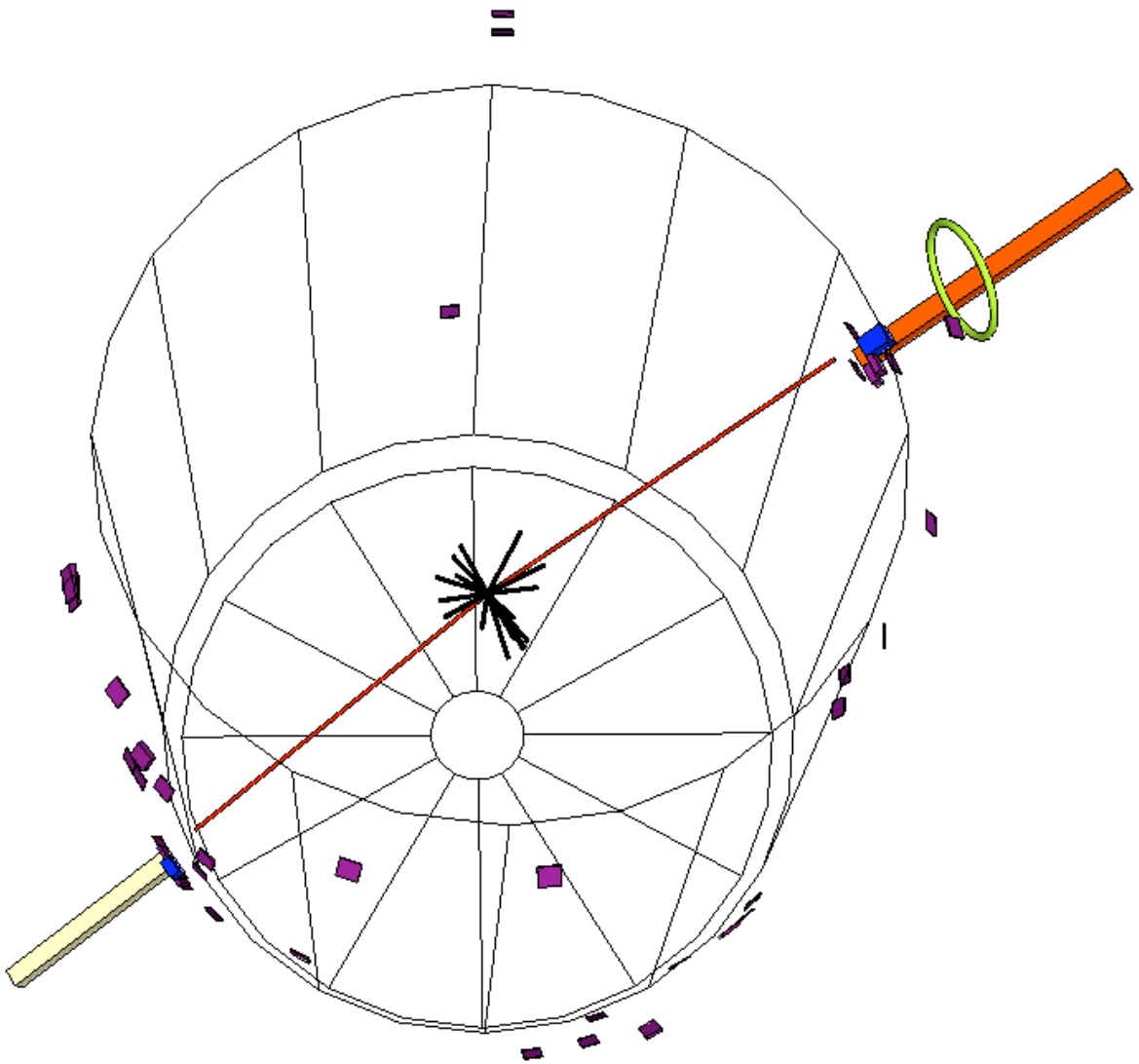

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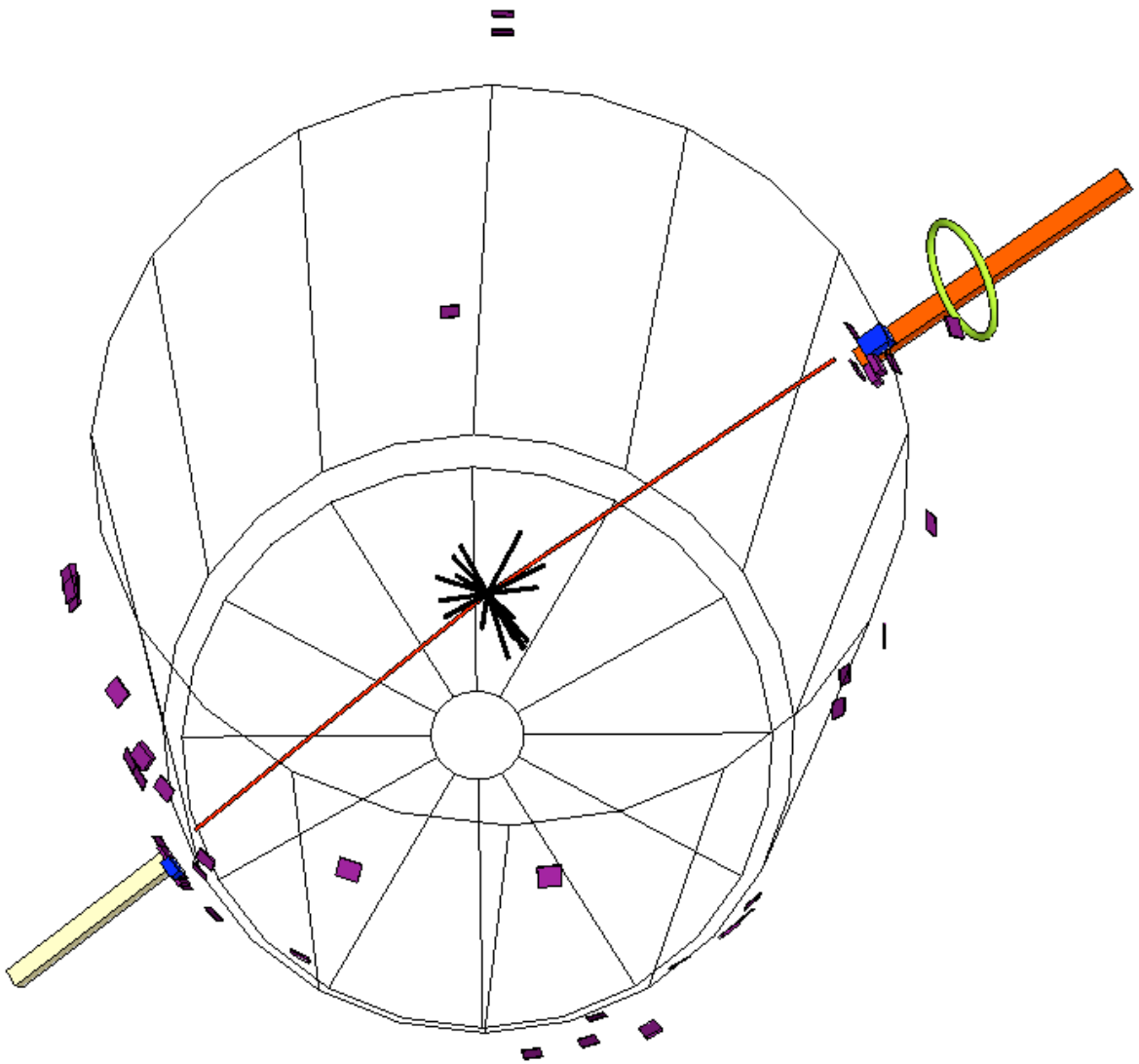
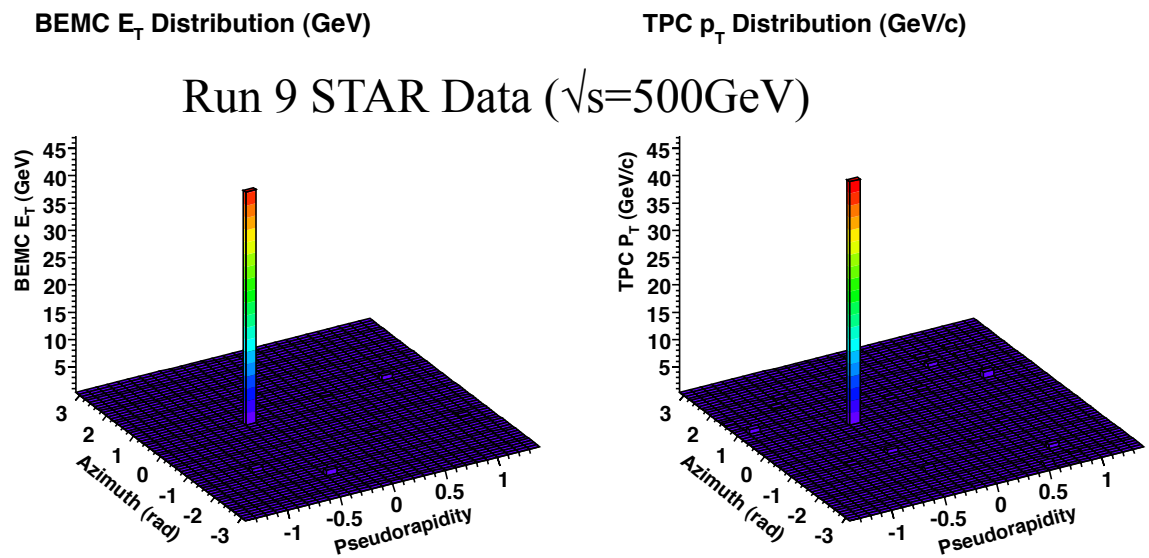


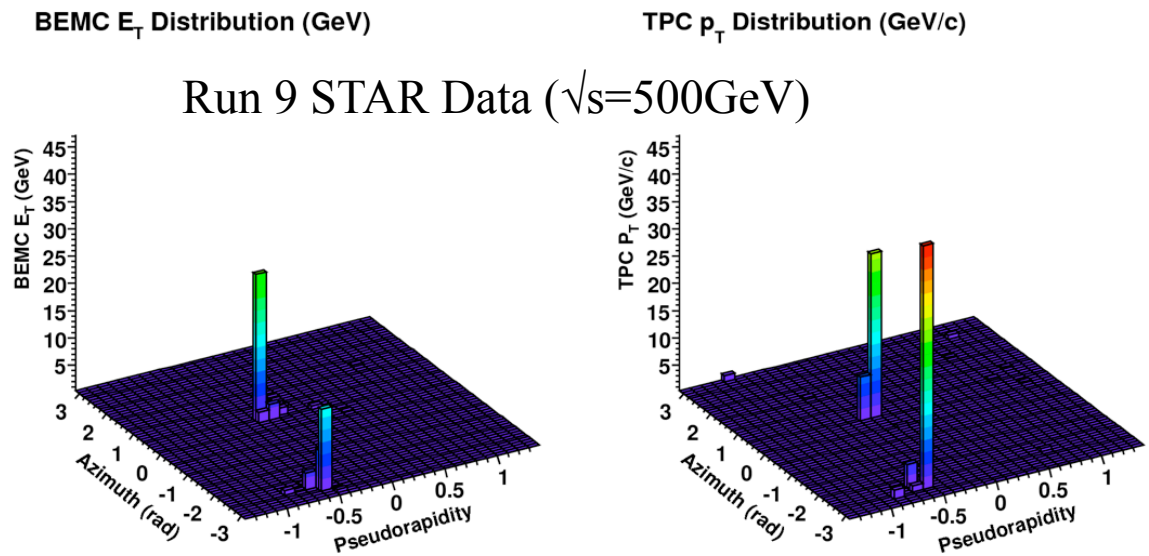
# W production results: Lego plots

- Lego plots - STAR BEMC/TPC

W event



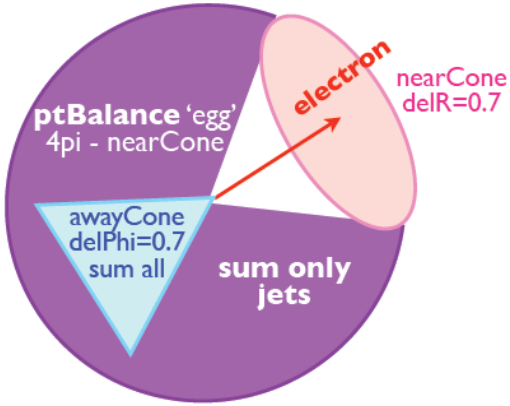

Di-Jet event

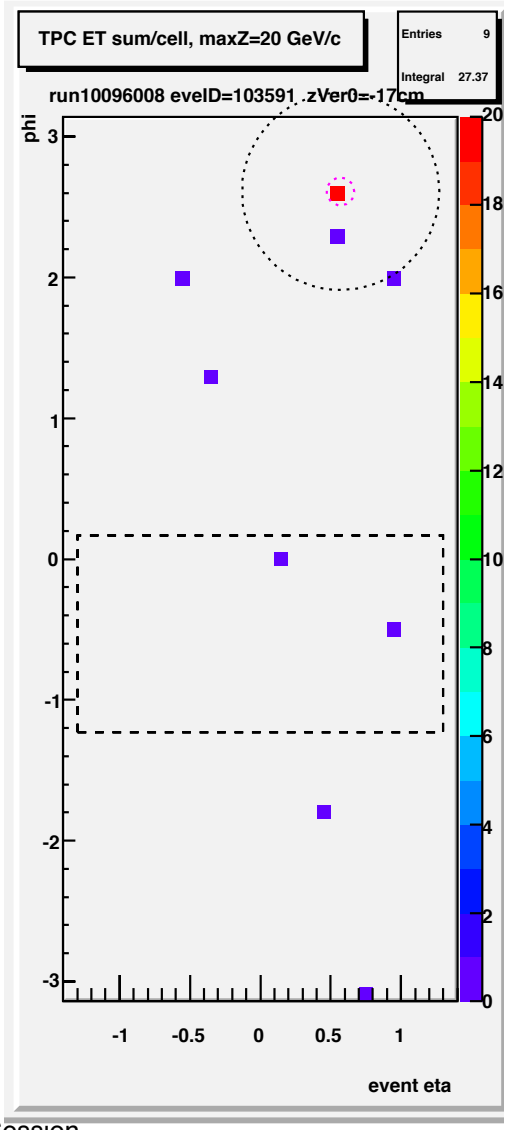


# W production results: Algorithm Details

- W reconstruction - Algorithm : Details

Transverse plane view



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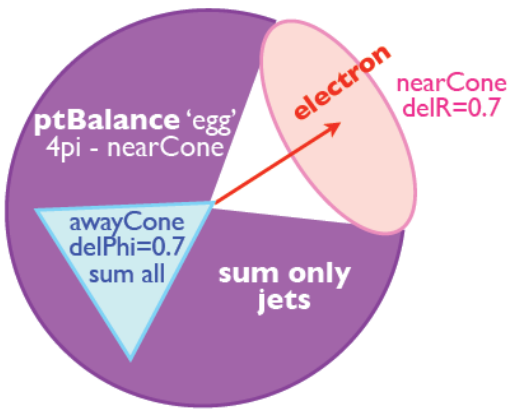


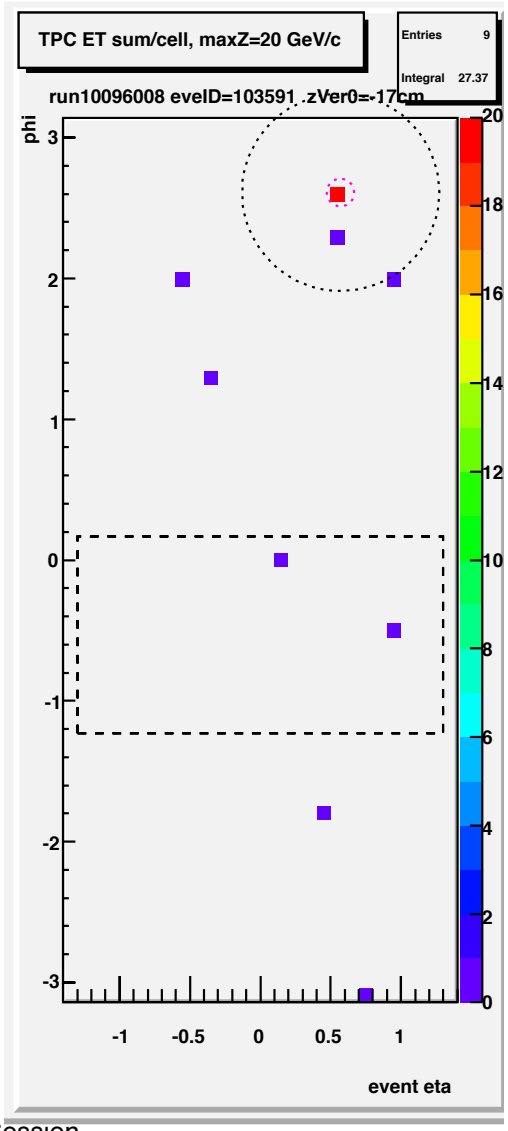


General:

- Select L2W-$E_T$ triggered events
- Select vertices with |Z|<100 cm

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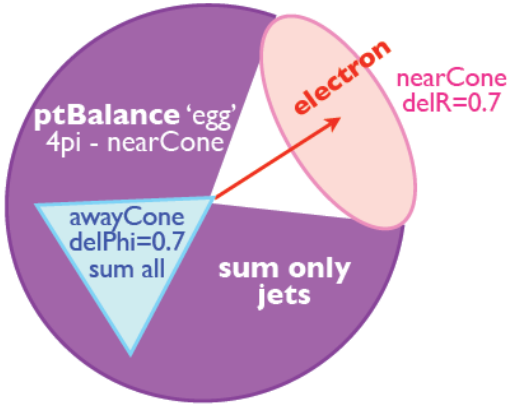


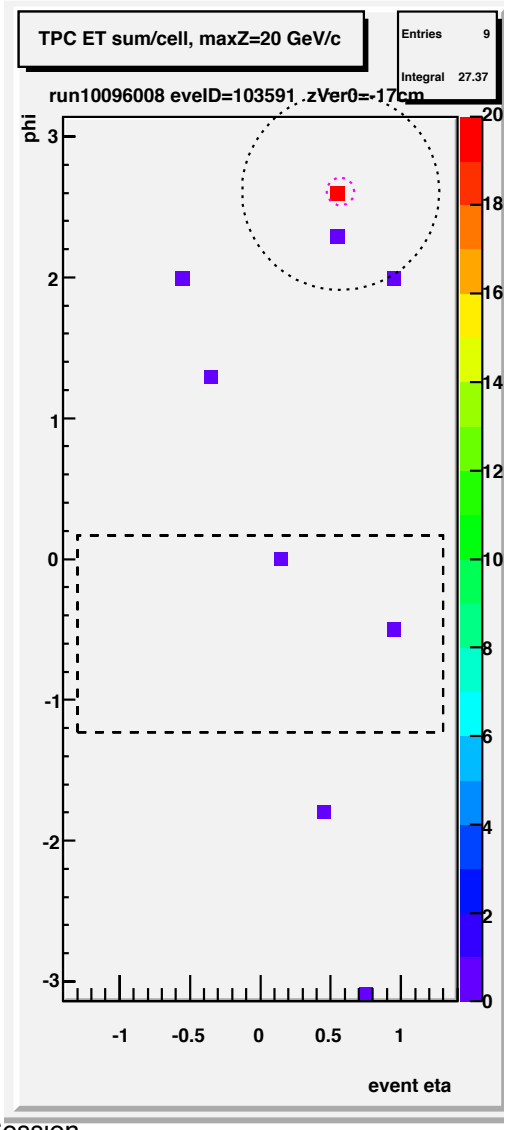


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Electron isolation cuts:

- Electron candidate is any primary TPC track with global $P_T$ >10 GeV/c
- Extrapolate TPC track to BTOW tower
- Compute 2x2 tower cluster $E_T$, require $E_T$ sum > 15 GeV
- Require the excess $E_T$ in 4x4 tower patch over 2x2 patch to be below 5%
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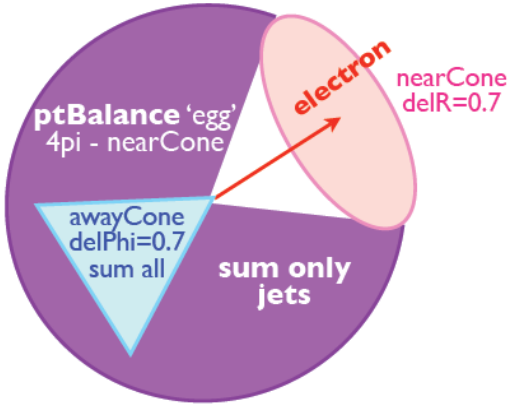


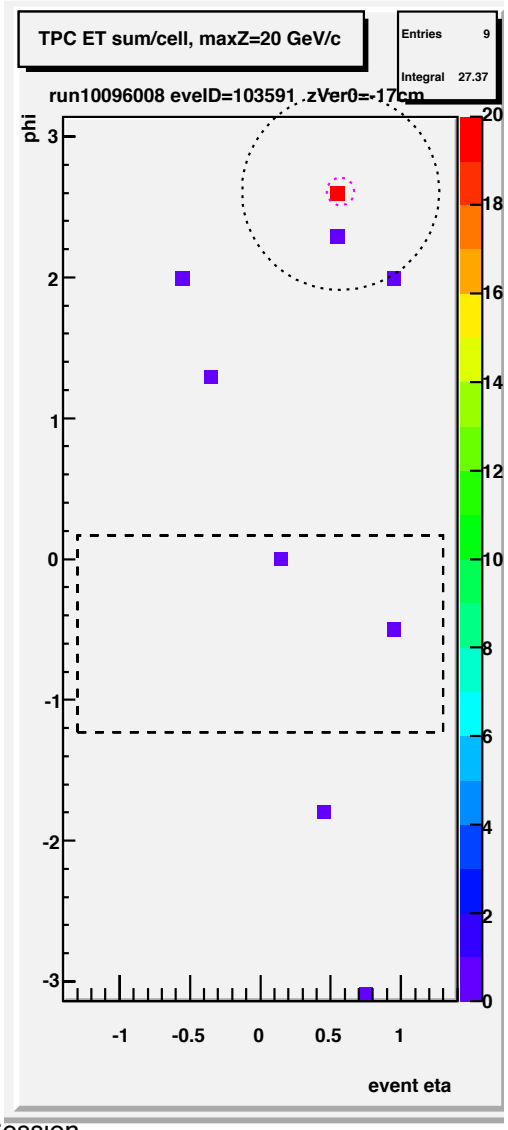


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Near-cone veto:

- Compute near-cone $E_T$ sum of BEMC+TPC over $\Delta R$=0.7 in eta-phi space
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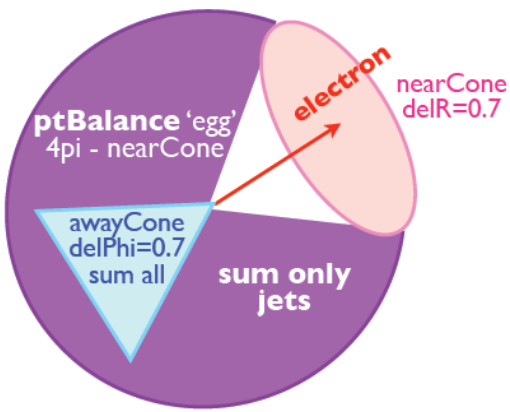
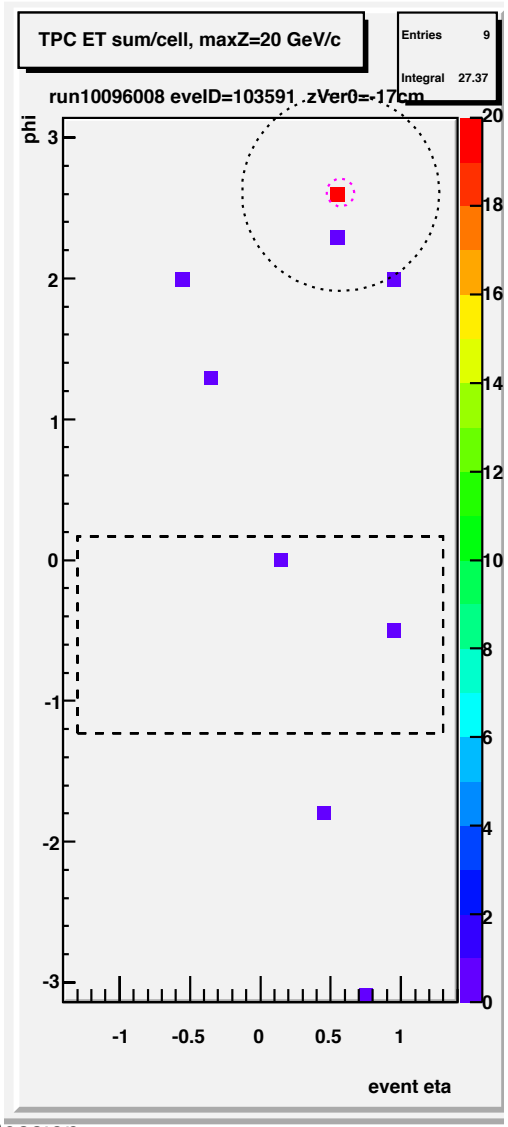
## W reconstruction - Algorithm : Details

Transverse plane view

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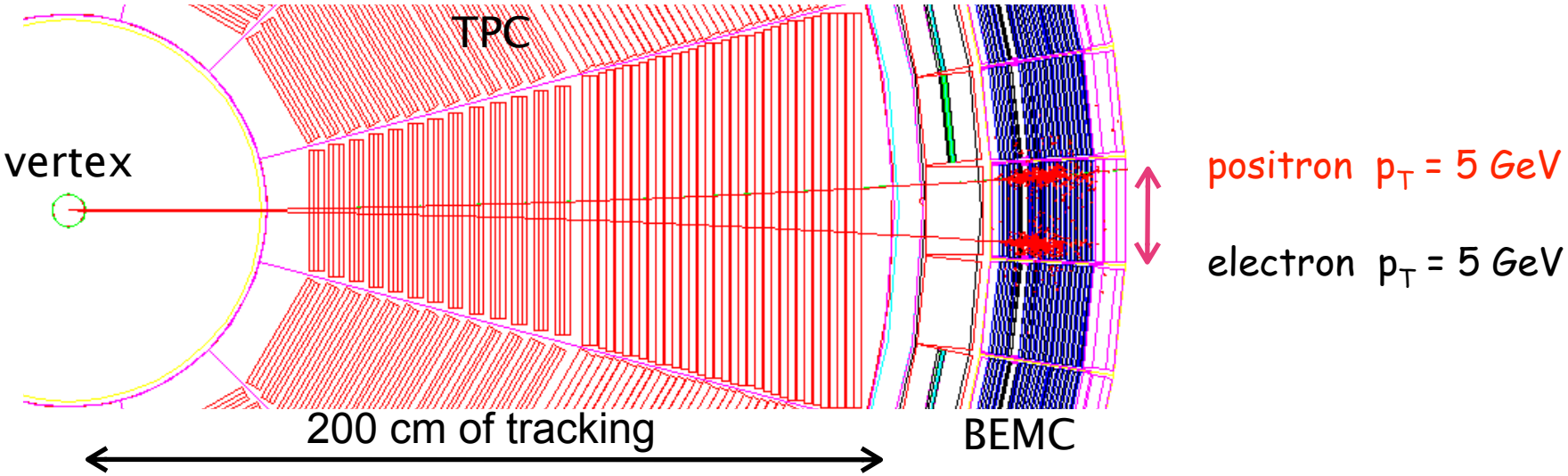
Away-'cone' cuts: $p_T$ balance requirement

- Vector sum > 15GeV/c of: 2X2 tower cluster $p_T$ and $p_T$ of any number of jets outside near-cone
- $E_T$ of jet > 3.5GeV

# W production results: Charge separation

- Mid-rapidity high $p_T$ $e^{\pm}$ charge separation



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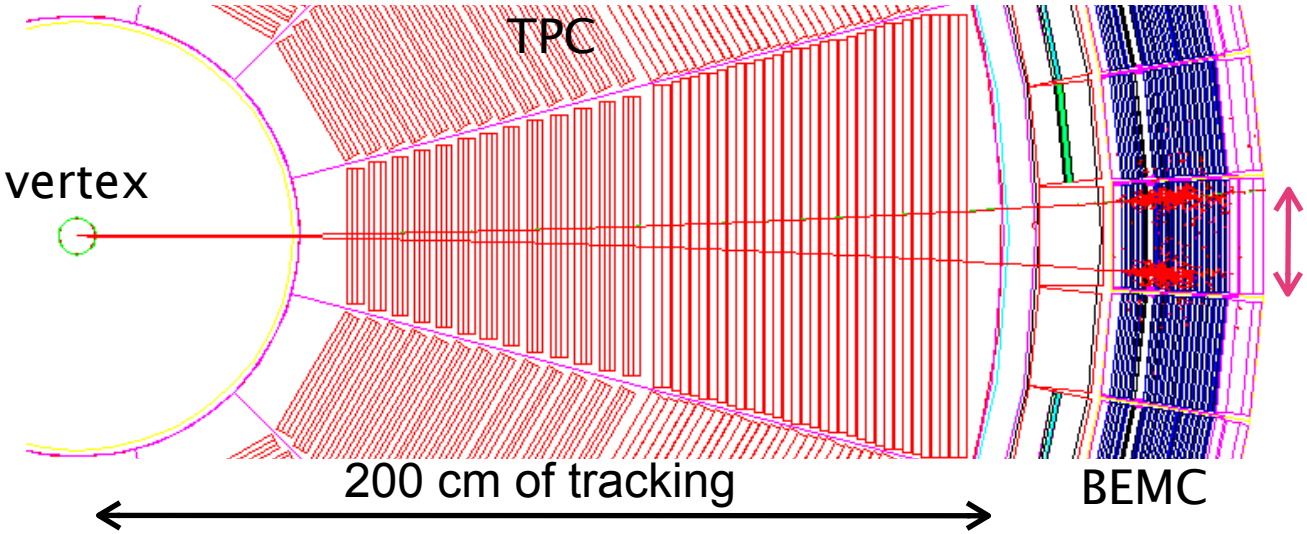


positron $p_T$ = 5 GeV

electron $p_T$ = 5 GeV

+/- distance D: ~$1/P_T$

$p_T$ = 5 GeV : D ~15 cm

$p_T$ = 40 GeV : D ~2 cm

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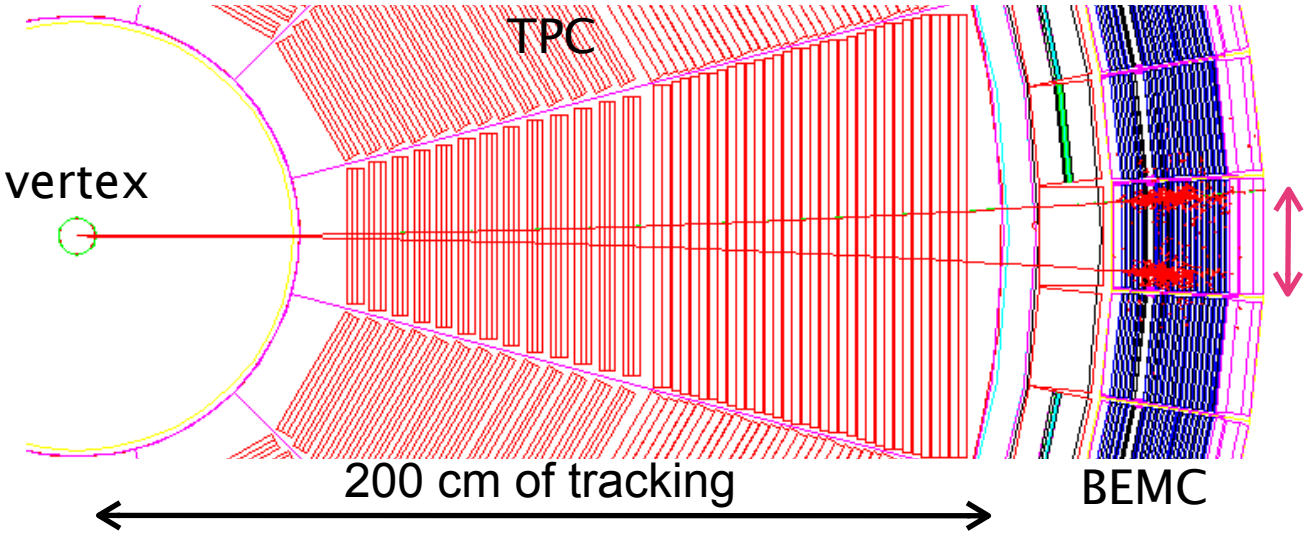


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$p_T$ = 40 GeV : D ~2 cm

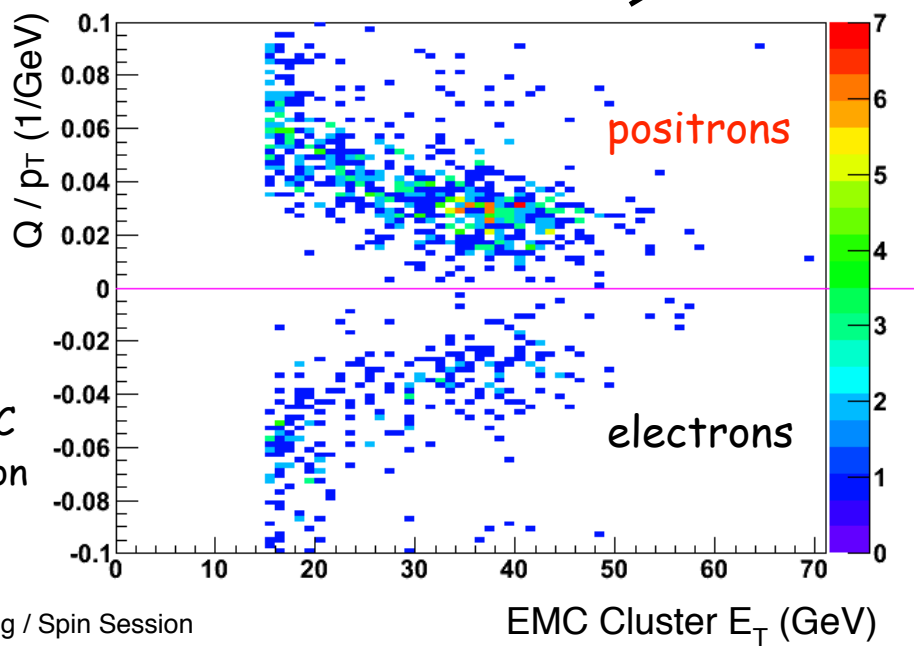
Assign:

$Q/p_T > 0$ positrons

$Q/p_T < 0$ to be electrons

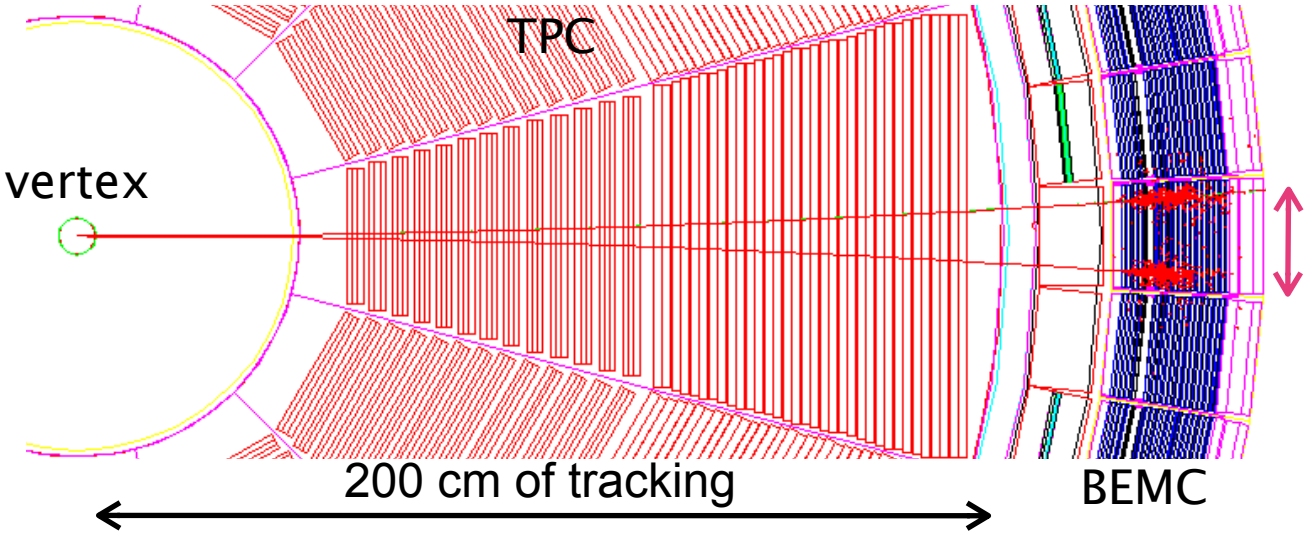
Q: Charge-sign of reconstructed track

Final TPC calibration



# W production results: Charge separation

- Mid-rapidity high $p_T$ $e^{\pm}$ charge separation




positron $p_T$ = 5 GeV

electron $p_T$ = 5 GeV

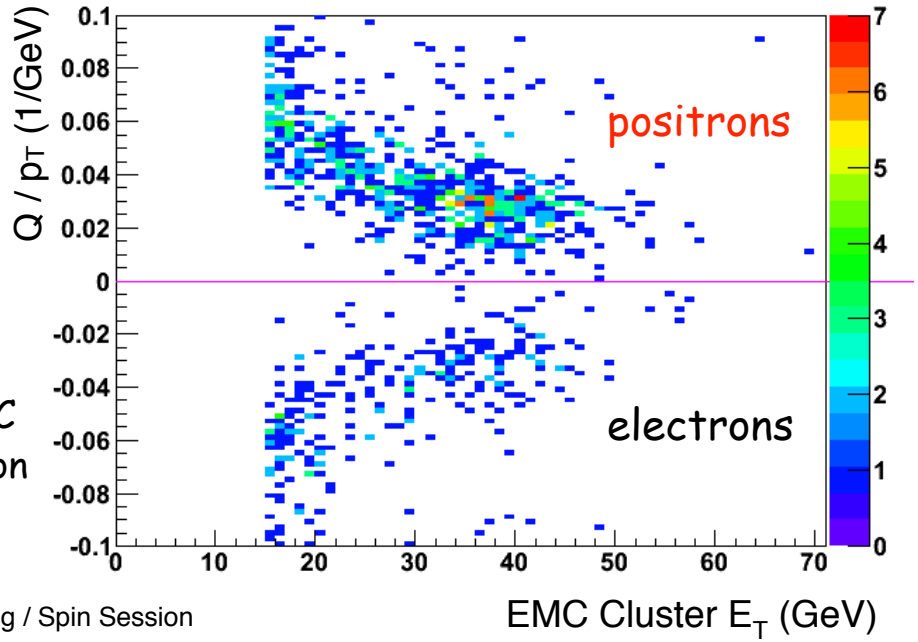
+/- distance D: ~$1/P_T$

$p_T$ = 5 GeV : D ~15 cm

$p_T$ = 40 GeV : D ~2 cm

Q: Charge-sign of reconstructed track

Final TPC calibration




Assign:

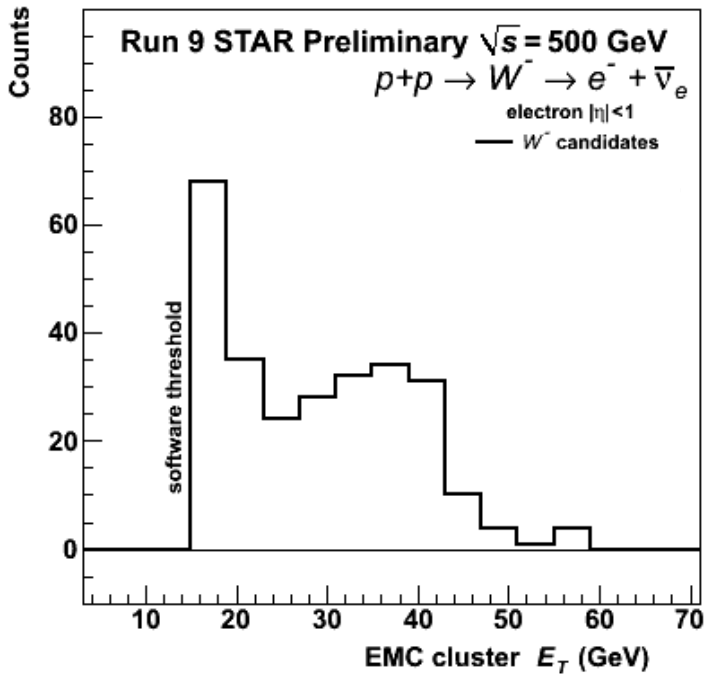
$Q/p_T > 0$ positrons

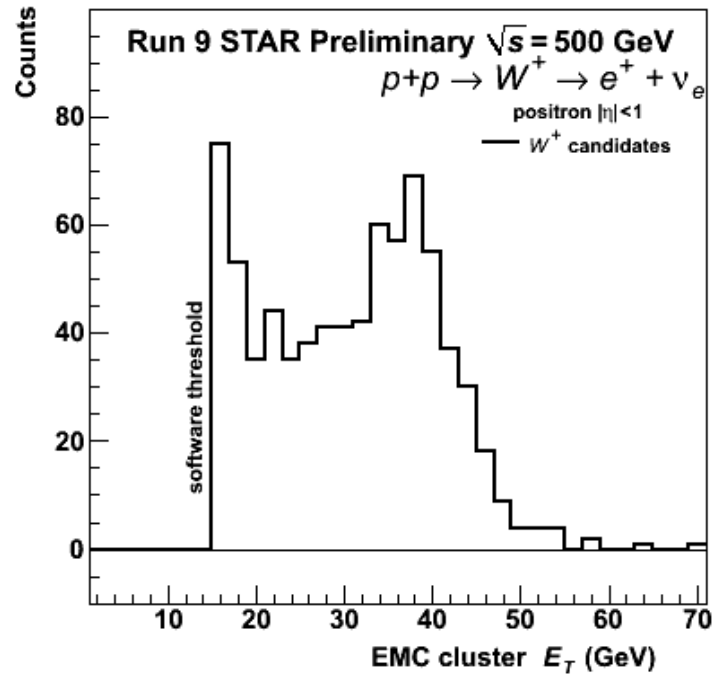
$Q/p_T < 0$ to be electrons

Successful separation of different charge states!

# W production results: Charged-separated Yields

- Charge separated raw Signal / Jacobian Peak Distributions




- Charged separated $W^+/W^-$ candidate distributions of the BEMC cluster transverse energy $E_T$ (GeV)
- Cuts: All previously discussed cuts!

# W production results: Background

- Background treatment

# W production results: Background

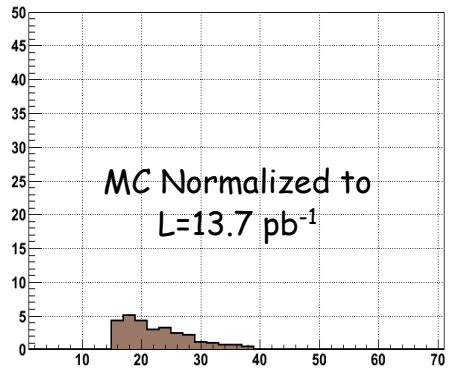
- Background treatment

PYTHIA+GEANT MC ⟶

$W \rightarrow \tau + \nu_\tau$

$\tau \rightarrow e + \nu_e + \nu_\tau$

$W^+$ distributions



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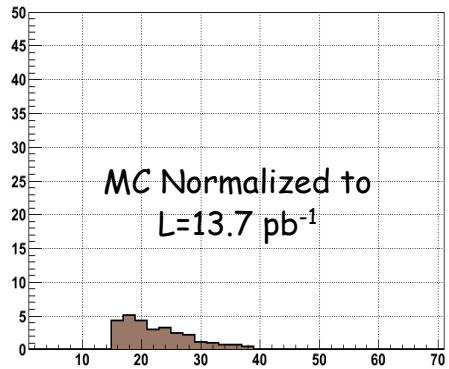


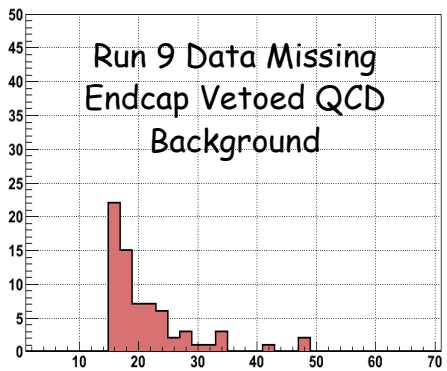


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3. Subtract two raw signals

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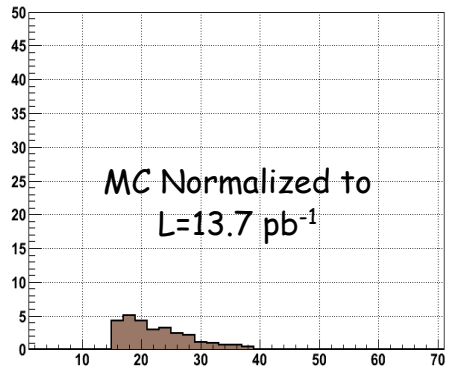


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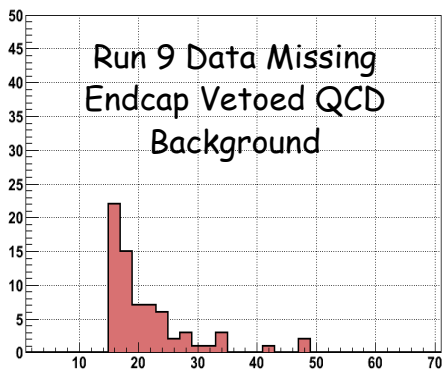


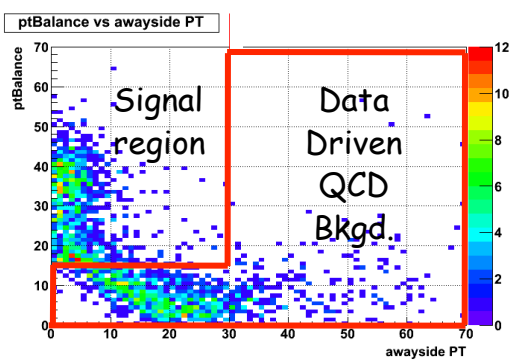


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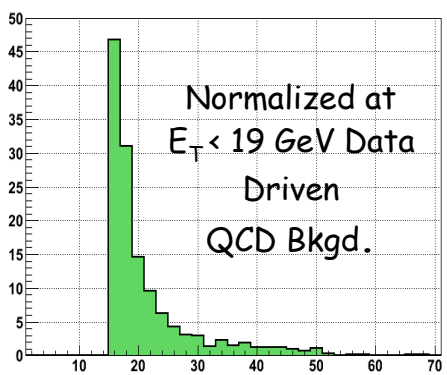

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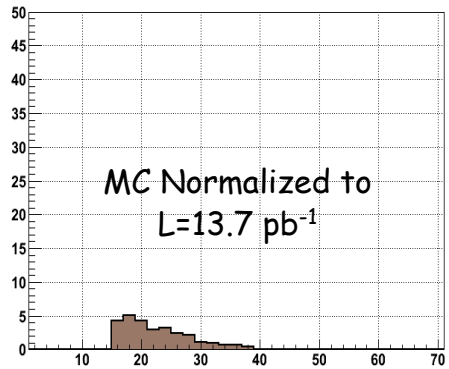


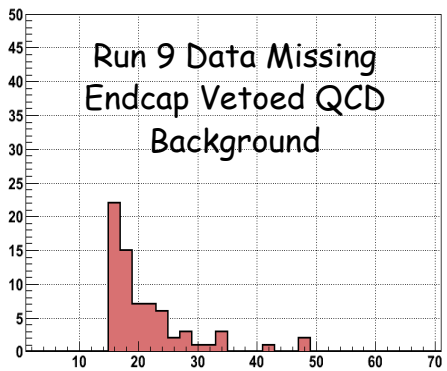


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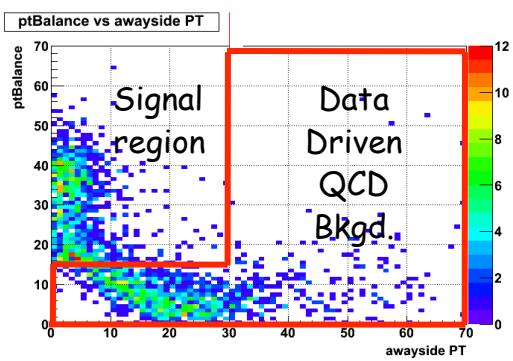


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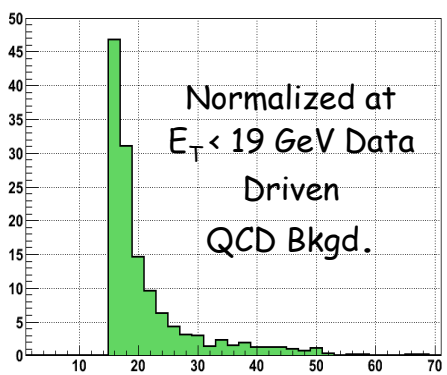

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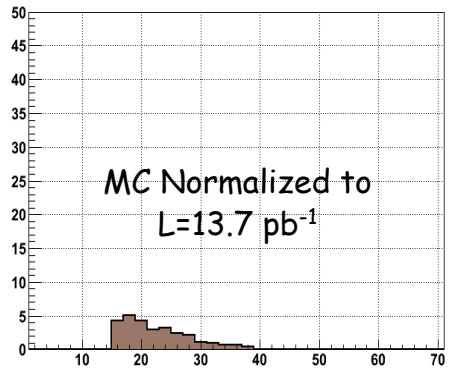


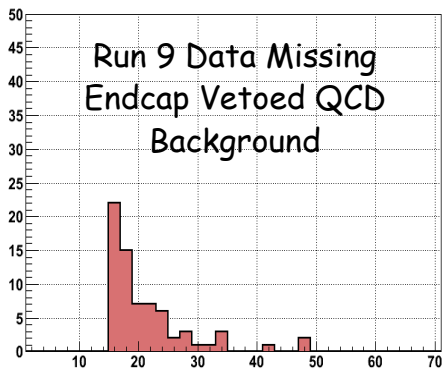


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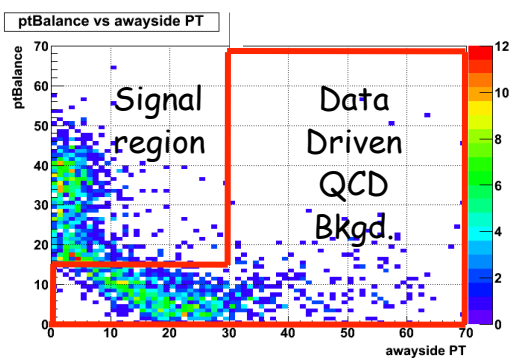


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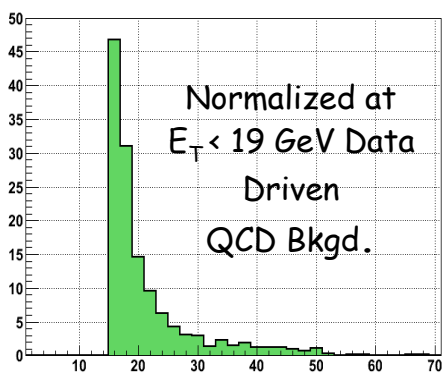

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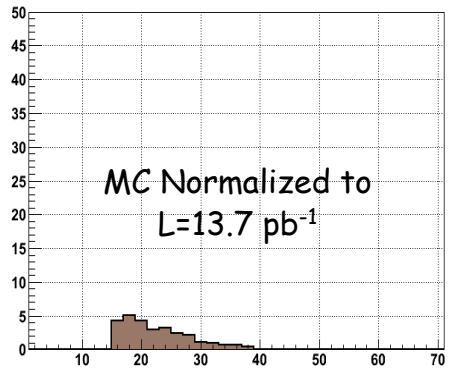


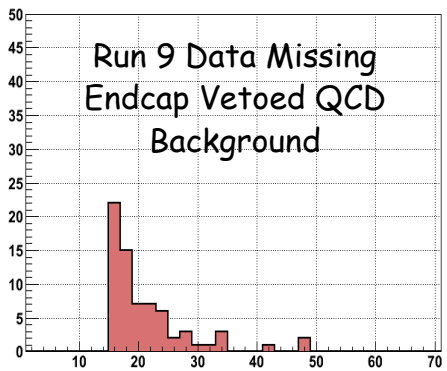


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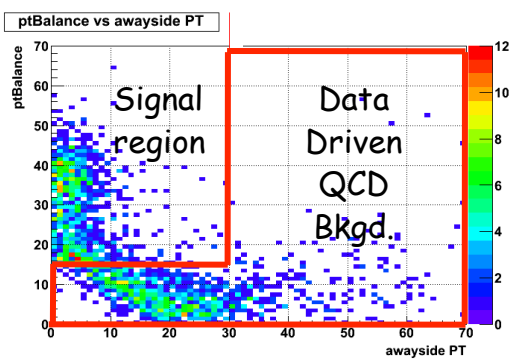


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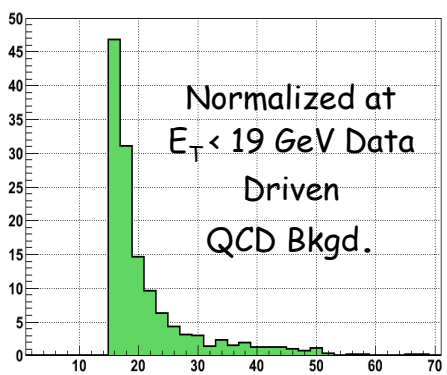

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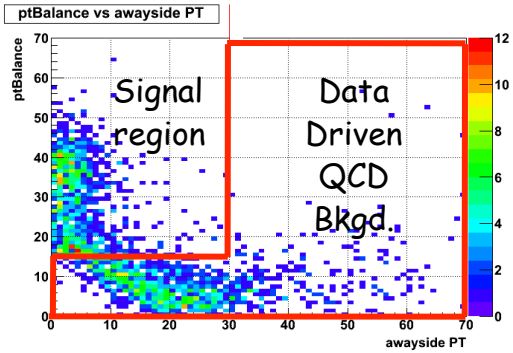
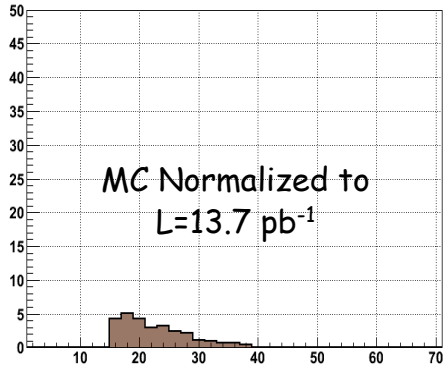
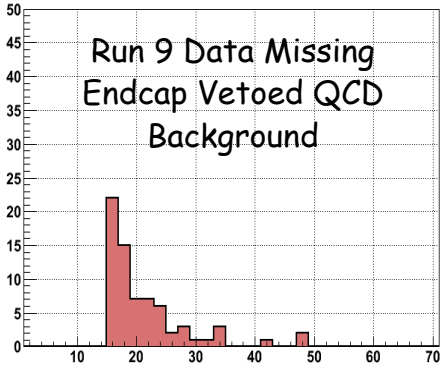
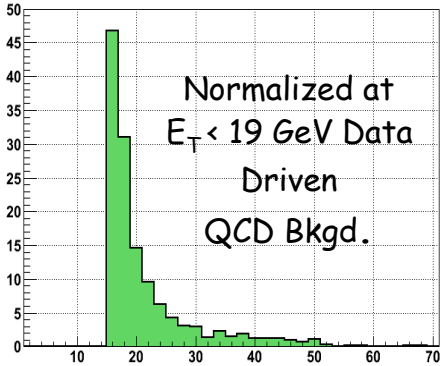



→

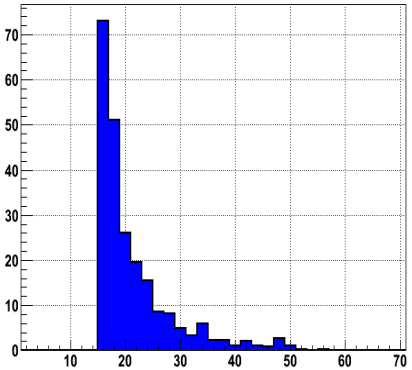
W⁺ distributions




Total Background



EMC Cluster $E_T$ (GeV)

# W production results: Background

## Background treatment

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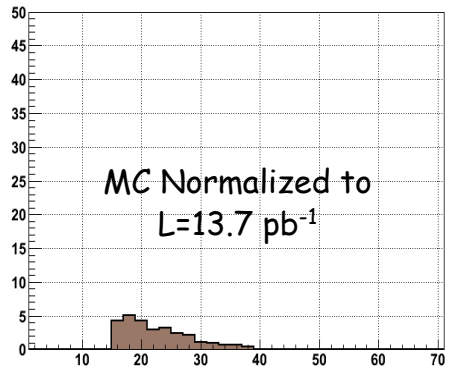
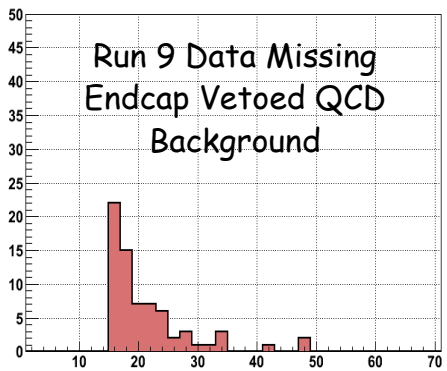
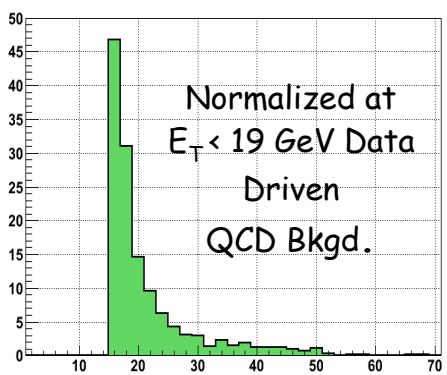
$W^+$ distributions

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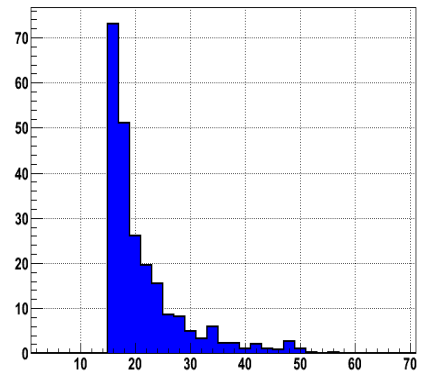

EMC Cluster $E_T$ (GeV)

1. Run analysis with EEMC in veto cuts
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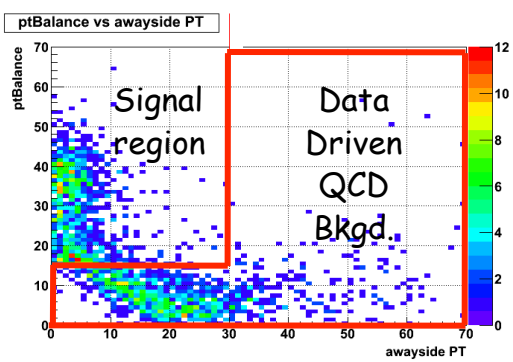
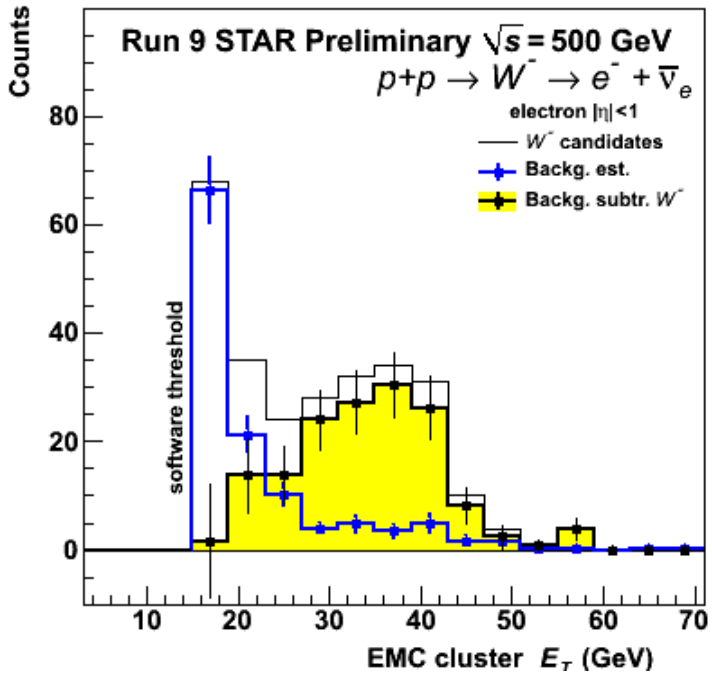


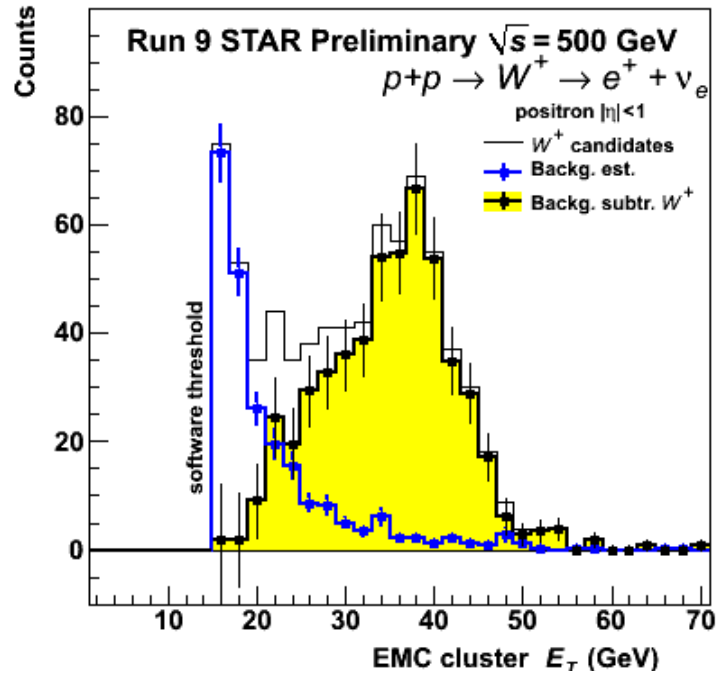

Background systematics:

- Calculate different data driven QCD background shapes by varying $p_T$ balance and away-side $p_T$ cuts
- Vary normalization region ($E_T$ < 17 – 21 GeV)
- The largest deviation in each bin used for sys. error estimate

# W production results: Background

- Background subtraction

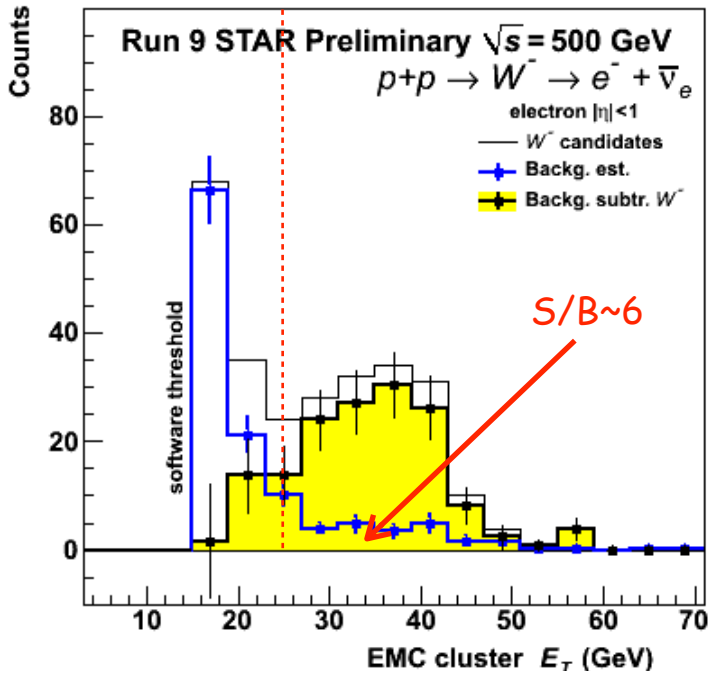


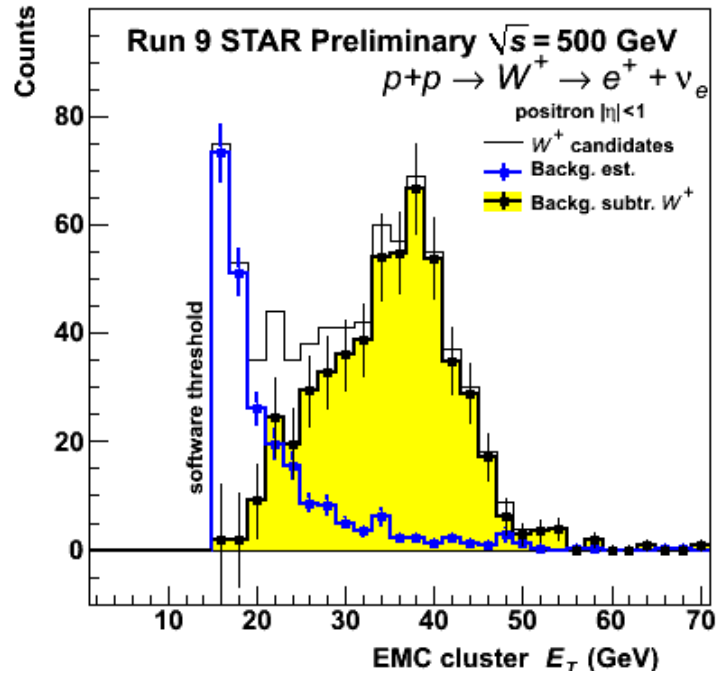




- Background distribution and background-subtracted signal distribution
- B/(S+B) ($E_T$ > 25GeV) $W^-$: 16%
- B/(S+B) ($E_T$ > 25GeV) $W^+$: 8%

# W production results: Background

- Background subtraction

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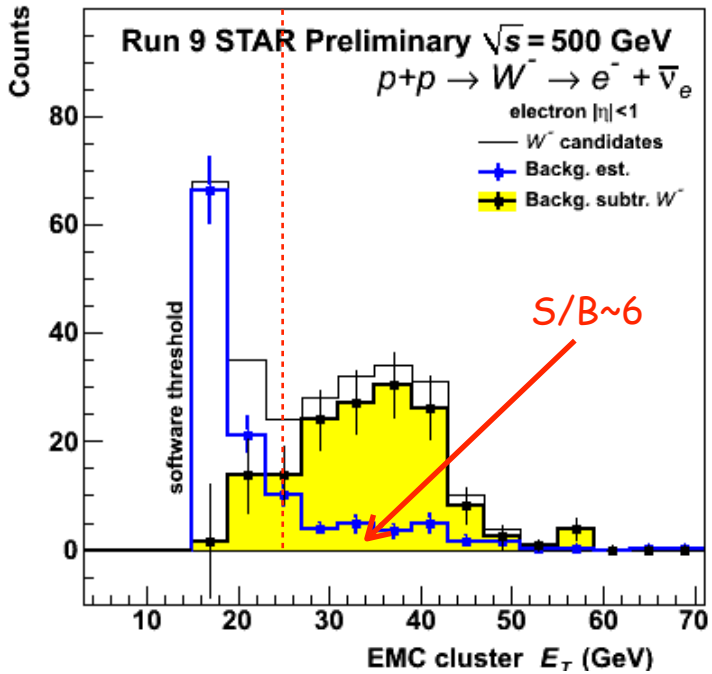


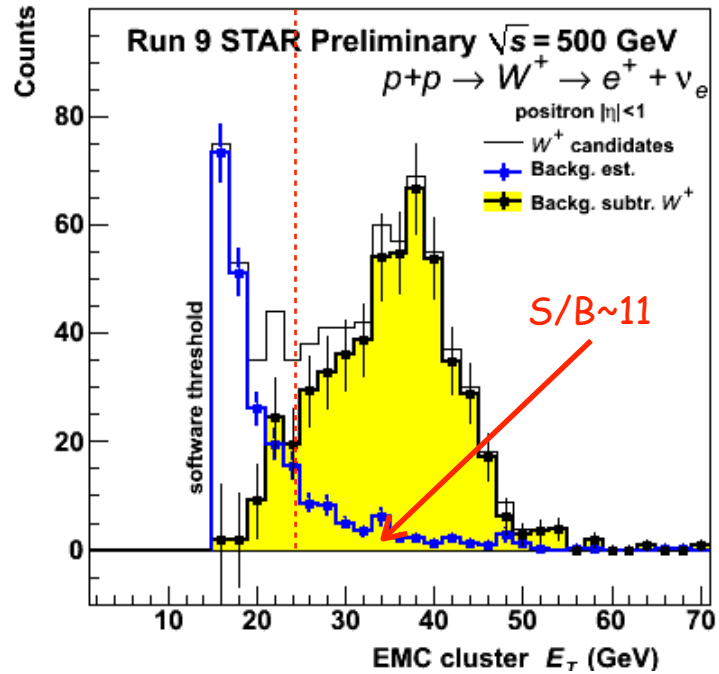


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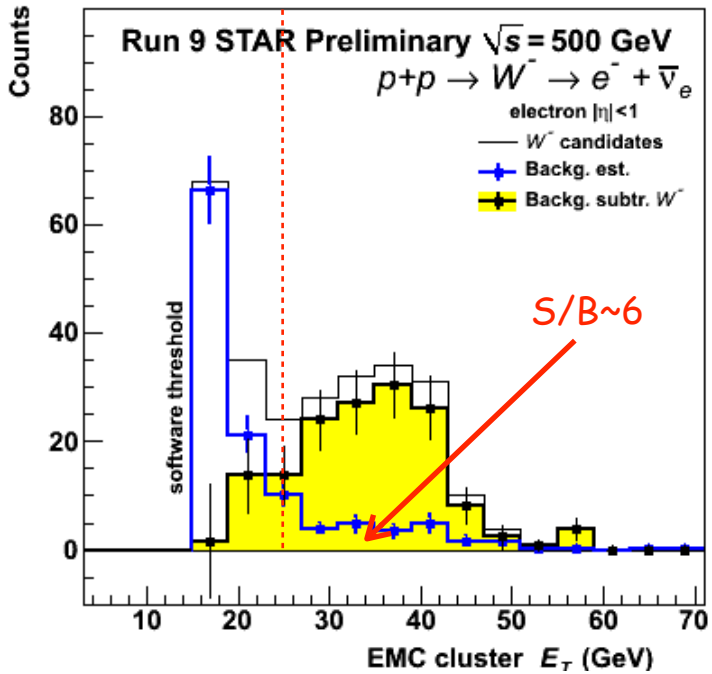


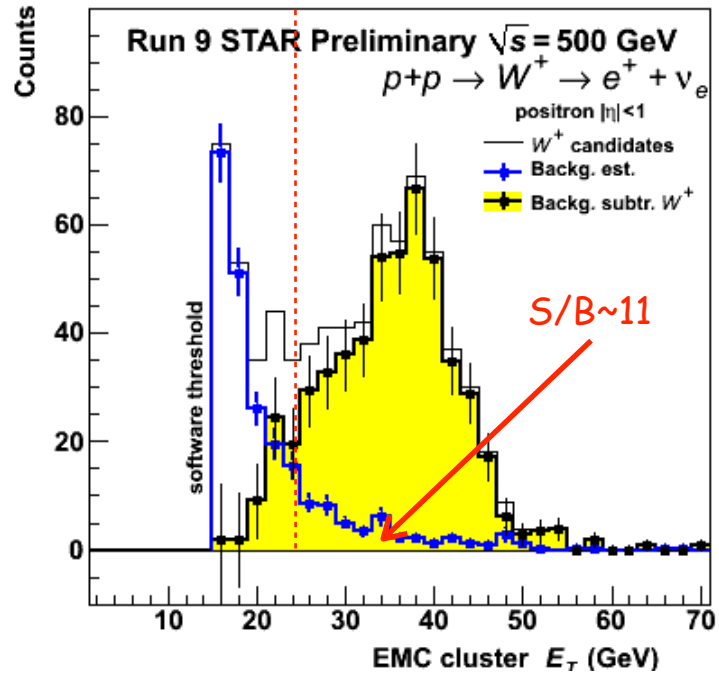


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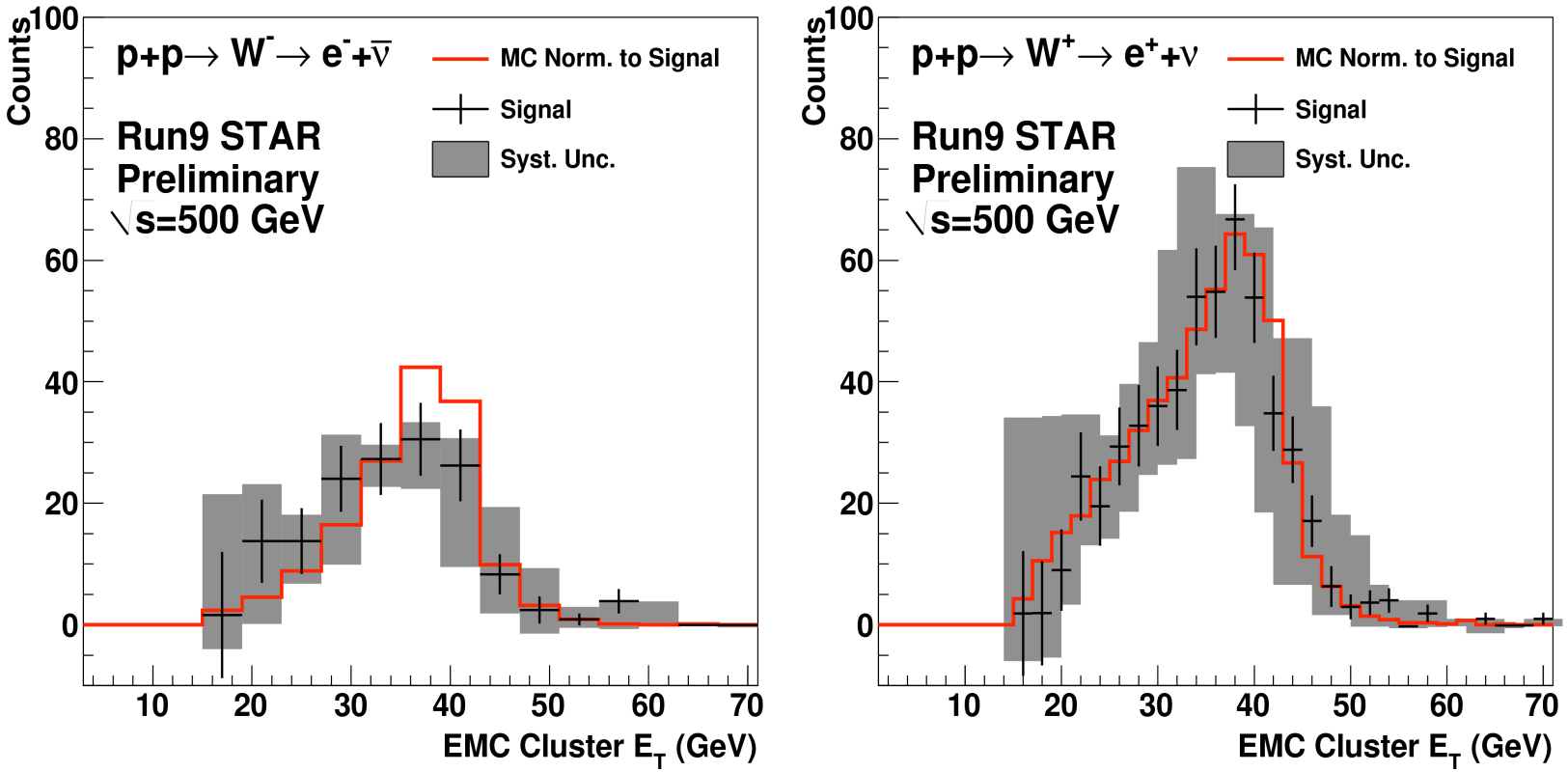
| Background Events ($E_T > 25$ GeV) | $W^- \rightarrow e^- + \bar{\nu}_e$ | $W^+ \rightarrow e^+ + \nu_e$ |
|---|---|---|
| $W \rightarrow \tau + \nu_\tau$ | $2.7 \pm 0.7$ | $8.4 \pm 2.2$ |
| Missing Endcap | $14 \pm 4$ | $13 \pm 4$ |
| Normalized QCD | $8.0\ ^{+20}_{-4}$ | $25\ ^{+36}_{-9}$ |
| Total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

# W production results: Data/MC comparison

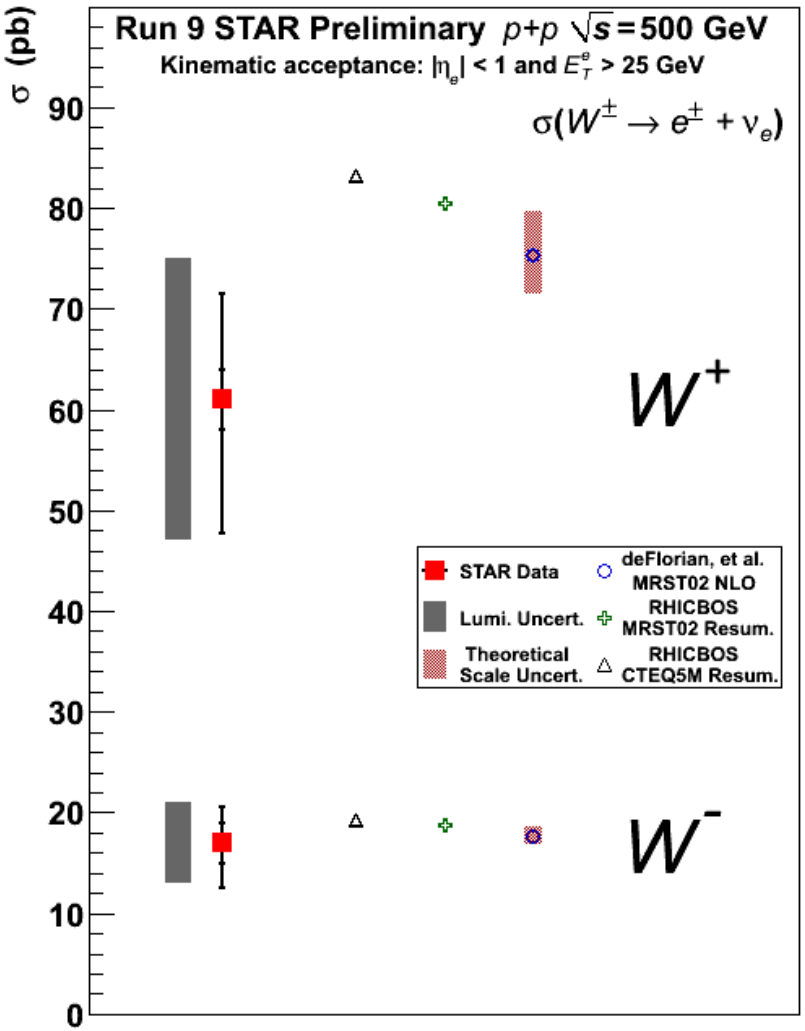
- Data/MC Comparison of charge-separated Jacobian peak distributions




- Comparison of data and PYTHIA+GEANT simulations for W signal events at $\sqrt{s}$=500GeV
- Systematic uncertainties were estimated by varying cuts and normalization regions for QCD background and by varying BEMC energy scale uncertainty (±7.5%)

# W production results: Cross-Section

- Total $W^+/W^-$ Cross-section results




STAR Preliminary Run 9 (p+p √s=500 GeV)

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

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

# W production results: Cross-Section

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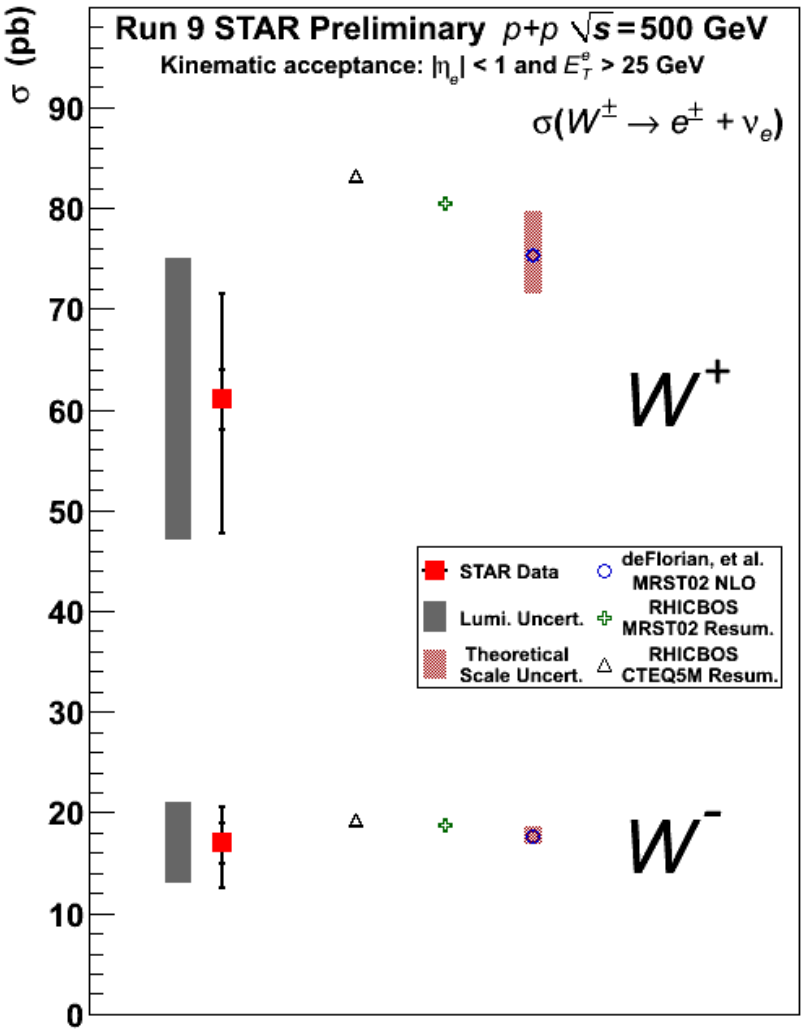


| | $W^- \to e^- + \bar{\nu}_e$ | $W^+ \to e^+ + \nu_e$ |
|---|---|---|
| $N_W^{obs}$ | 156 | 513 |
| $N_{back}$ | $25\ ^{+21}_{-7}$ | $46\ ^{+36}_{-11}$ |
| $\epsilon_{total}$ | $0.56\ ^{+0.11}_{-0.09}$ | $0.56\ ^{+0.12}_{-0.09}$ |
| $\int Ldt\ (\mathrm{pb}^{-1})$ | $13.7 \pm 3.2$ | $13.7 \pm 3.2$ |

STAR Preliminary Run 9 (p+p √s=500 GeV)

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

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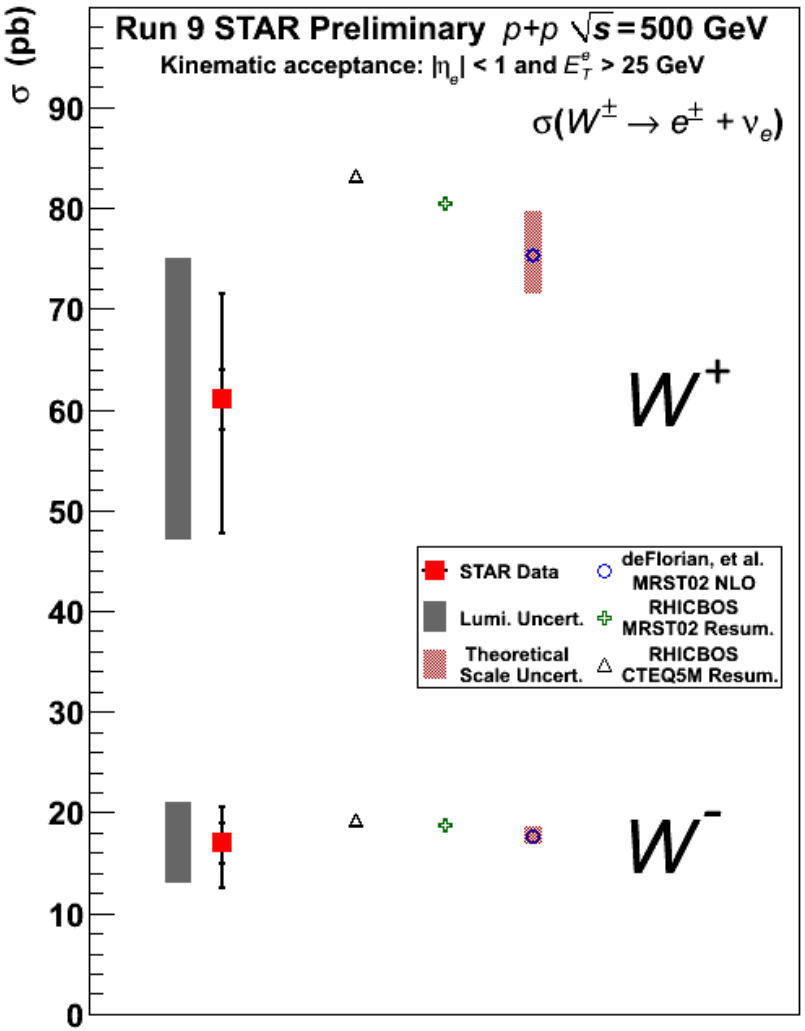


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| $N_W^{obs}$ | 156 | 513 |
| $N_{back}$ | $25\ ^{+21}_{-7}$ | $46\ ^{+36}_{-11}$ |
| $\epsilon_{total}$ | $0.56\ ^{+0.11}_{-0.09}$ | $0.56\ ^{+0.12}_{-0.09}$ |
| $\int Ldt\ (\mathrm{pb}^{-1})$ | $13.7 \pm 3.2$ | $13.7 \pm 3.2$ |

STAR Preliminary Run 9 (p+p √s=500 GeV)

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

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

- Reasonable agreement between measured and theory evaluated cross-sections within uncertainties!

# W production results: Asymmetry result

- Parity-violating single-spin asymmetry $W^+/W^-$ $A_L$ results

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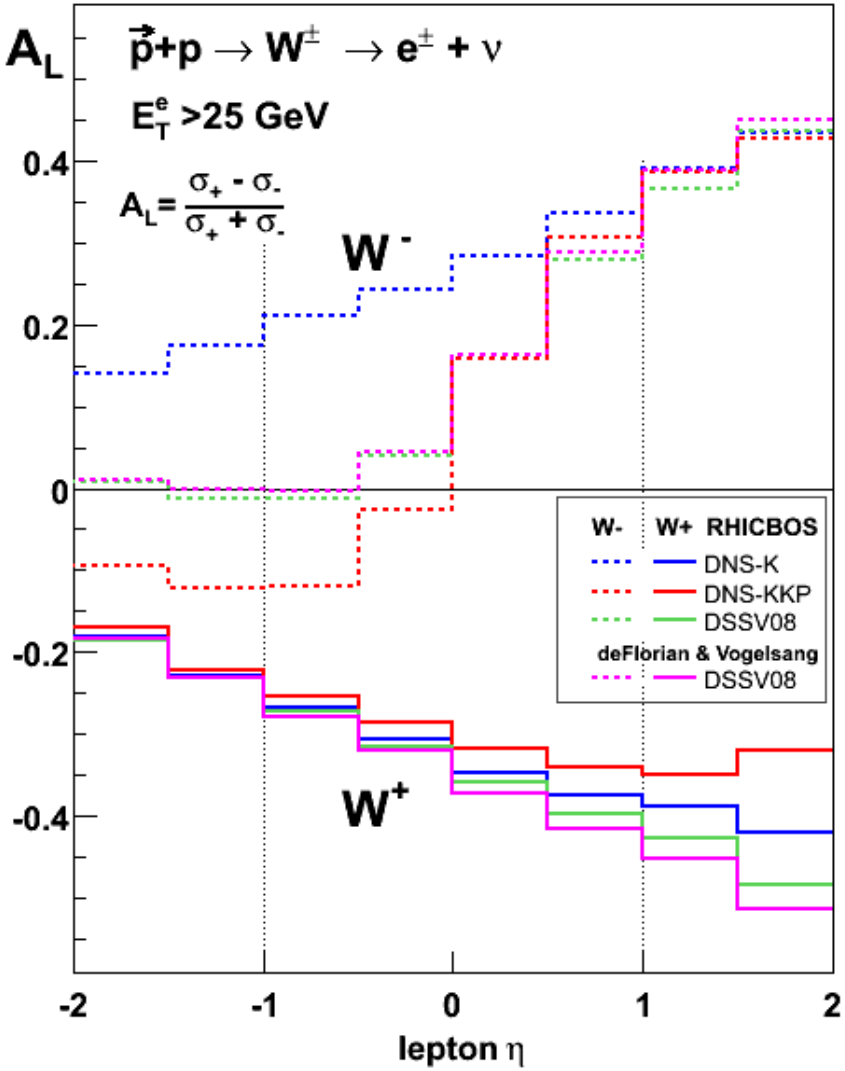

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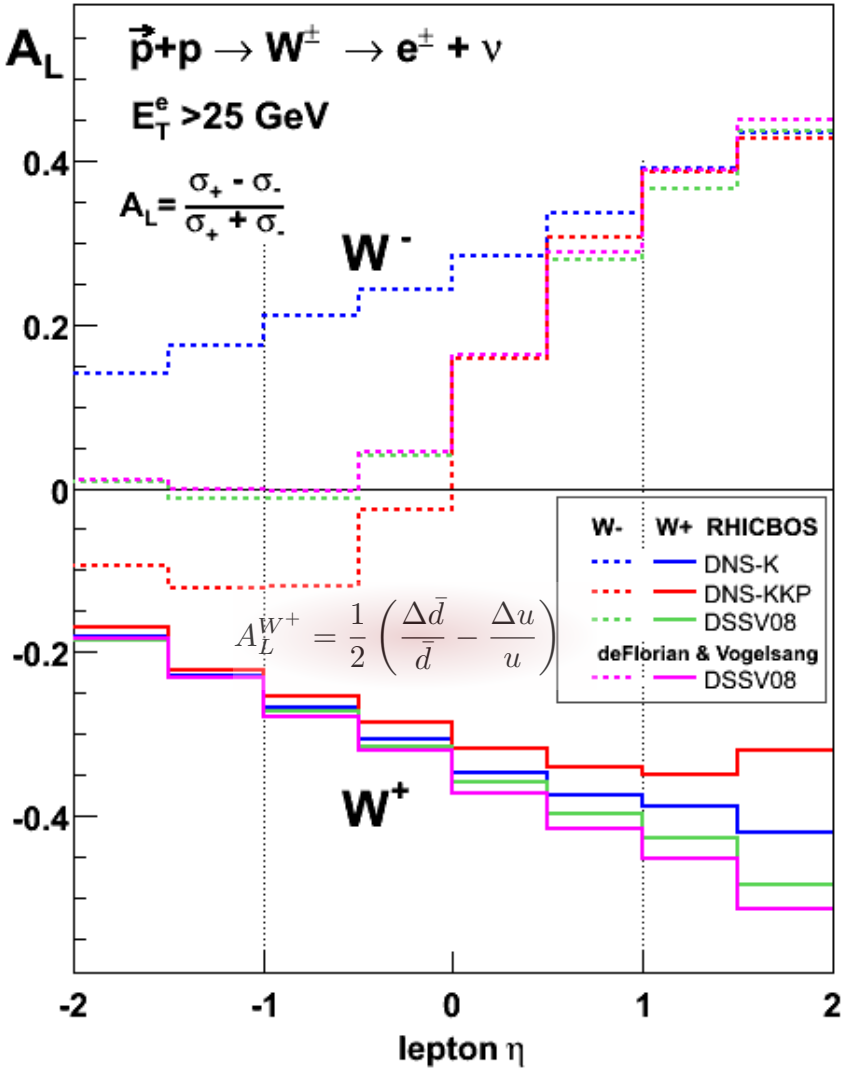

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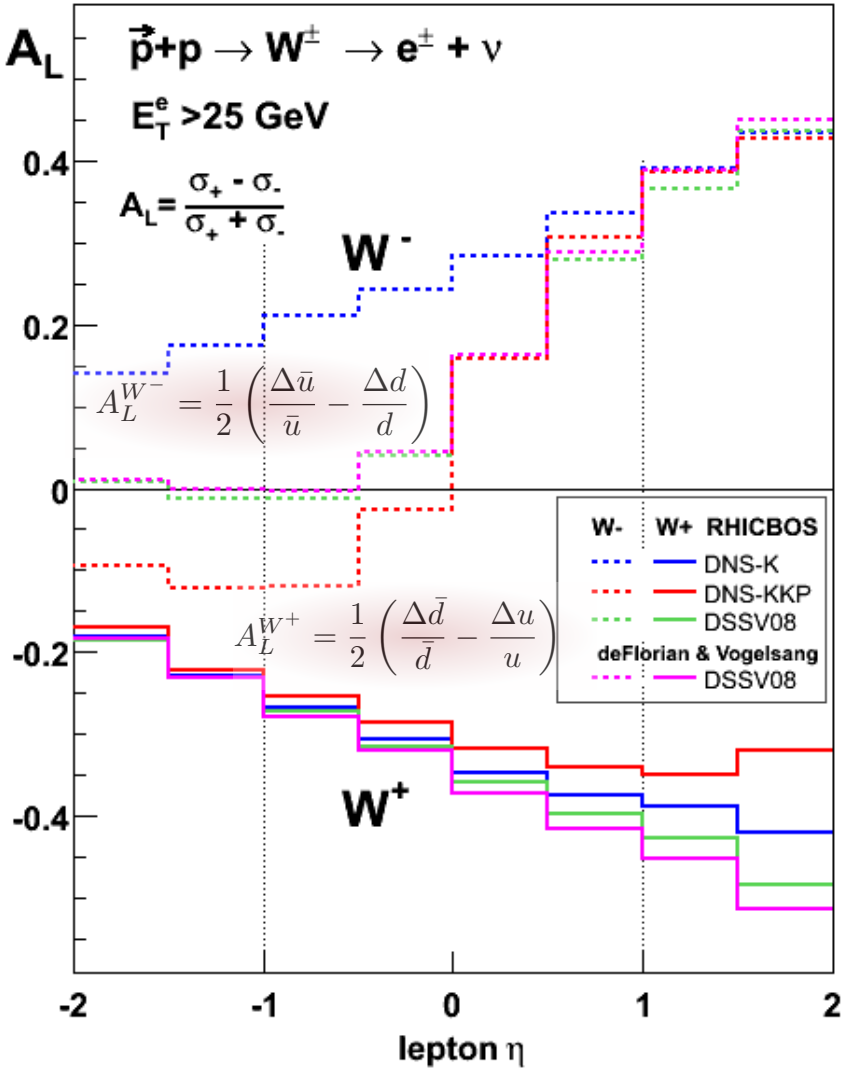

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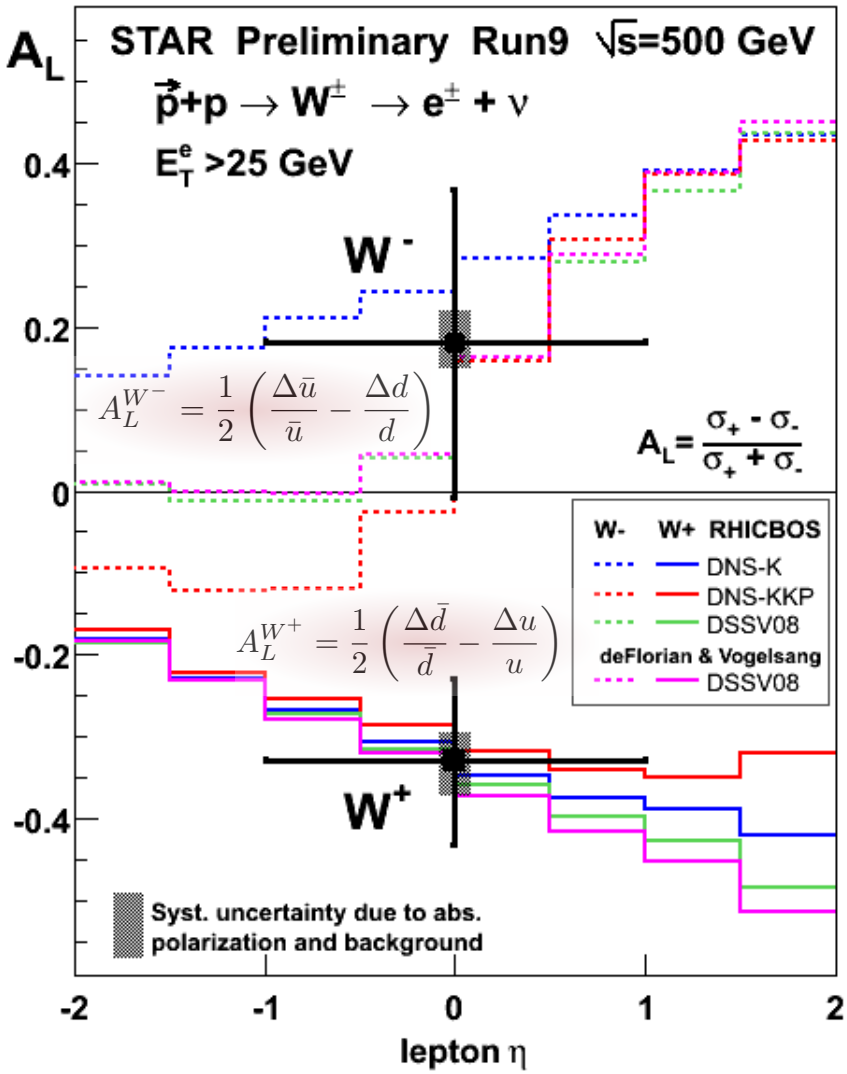

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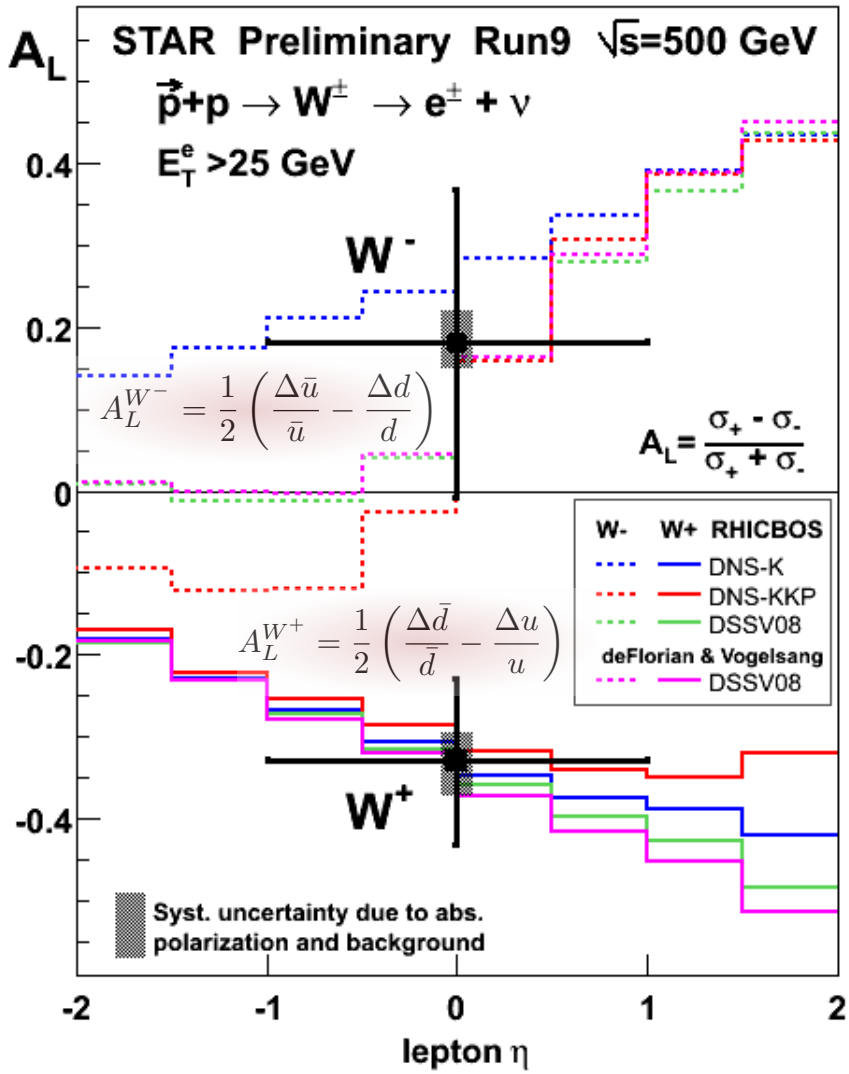


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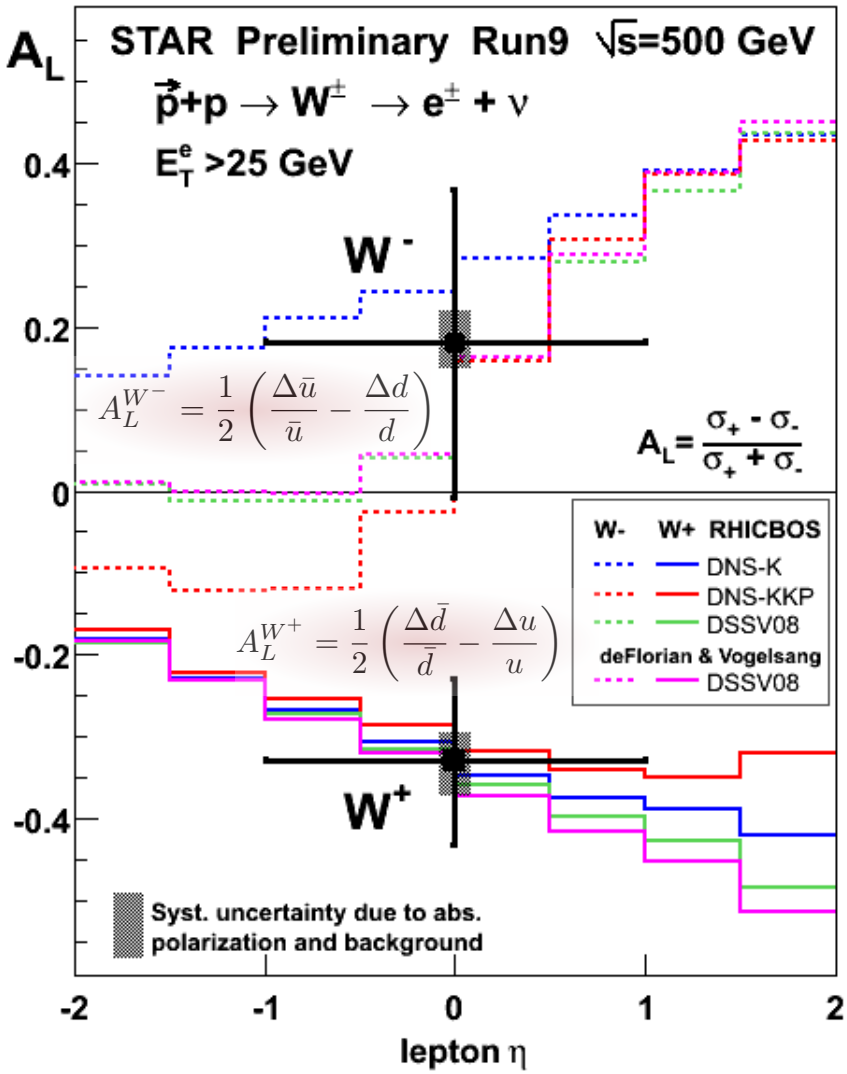


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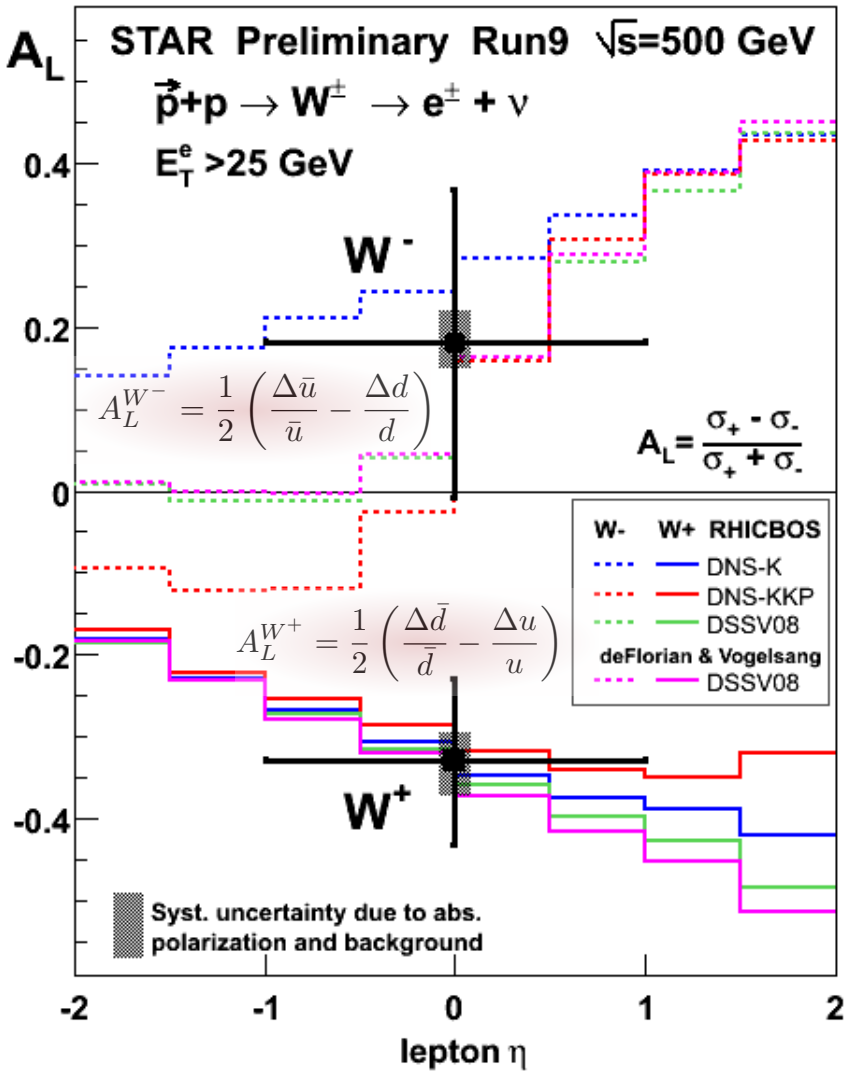


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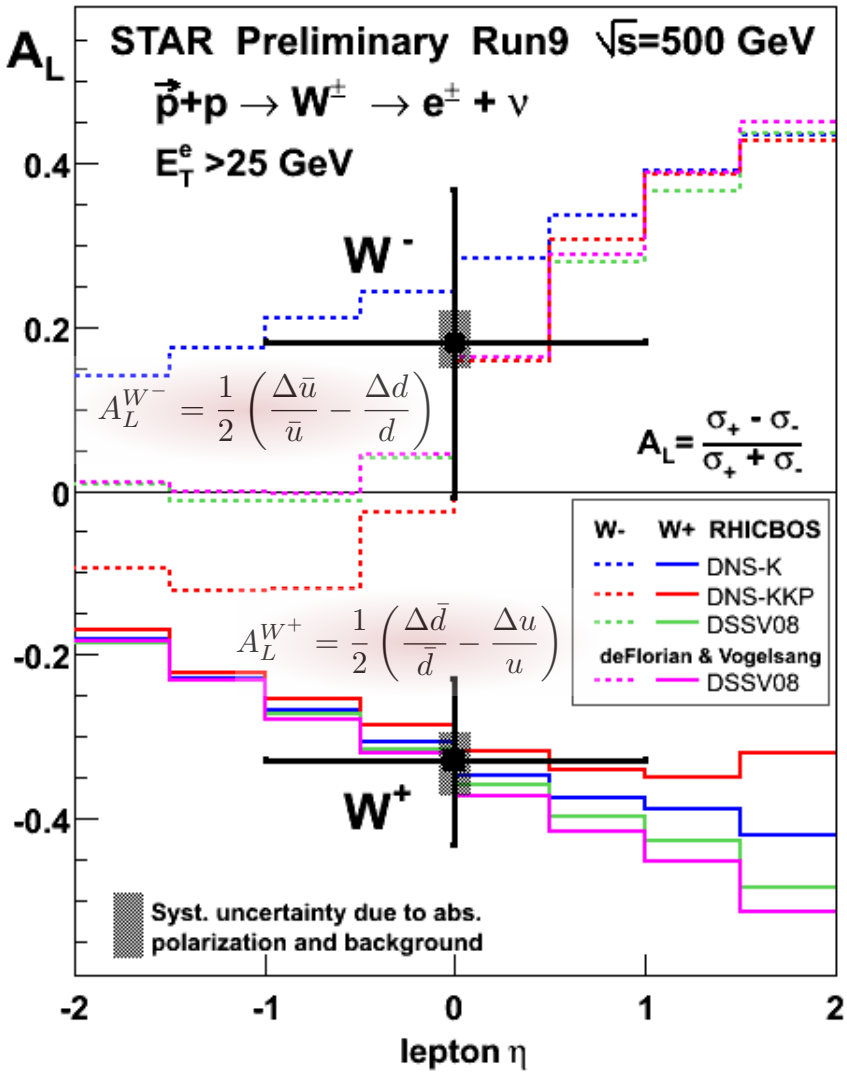


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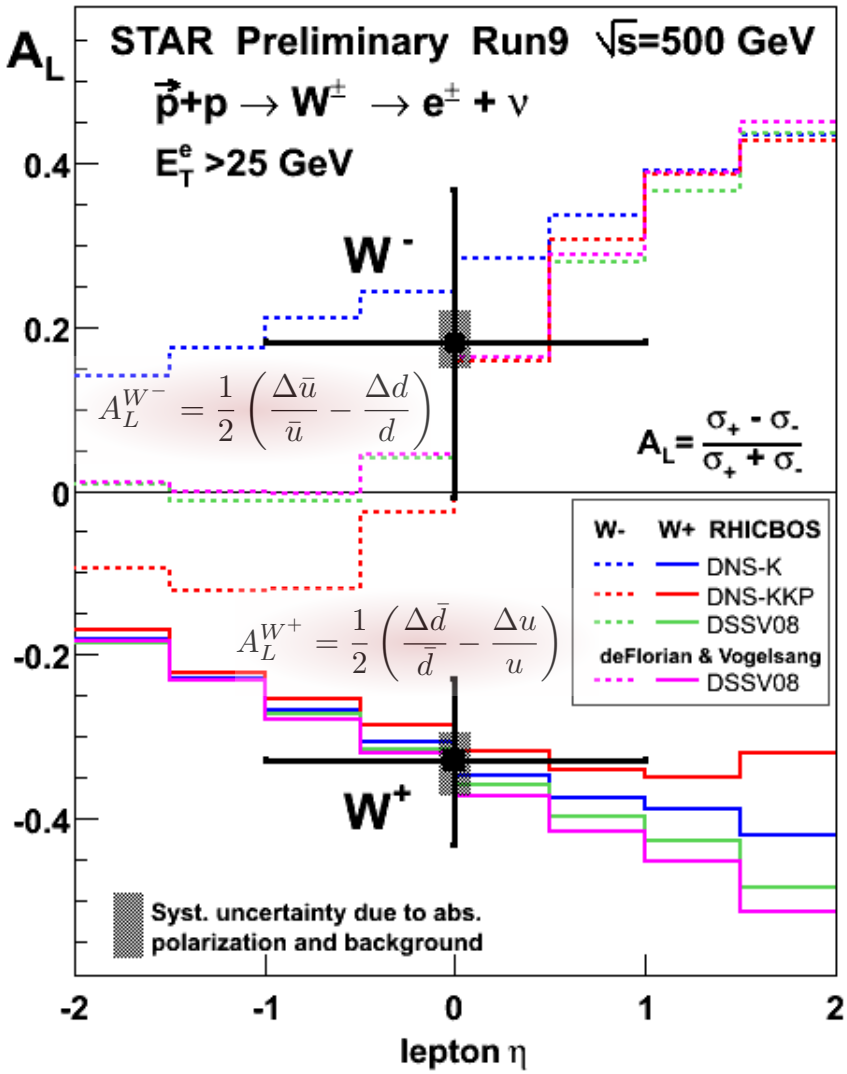


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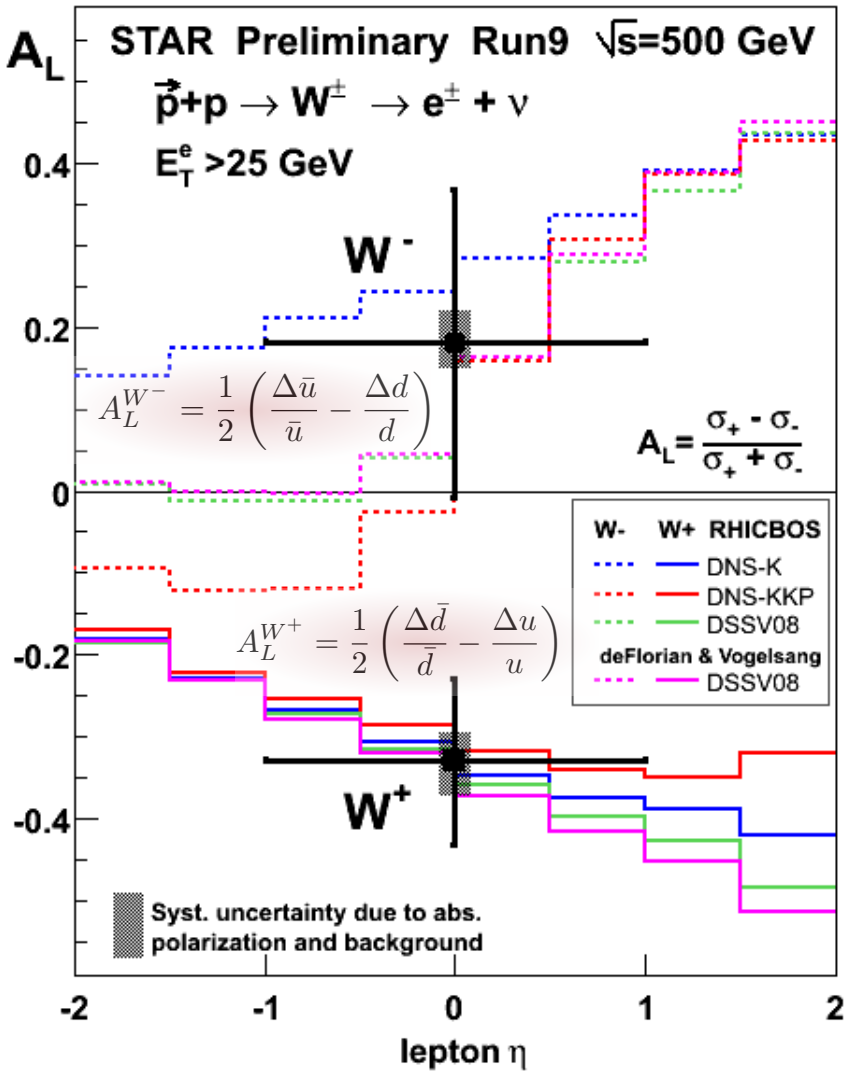


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- Measured asymmetries are in agreement with theory evaluations using polarized pdf's (DSSV) constrained by polarized DIS data

  ⇒ Universality of helicity distribution functions!

# Summary and Outlook

- Run 9: First observation of W production at STAR
  - First collision of polarized proton beams at $\sqrt{s}$ = 500GeV (P~40% / L~12pb$^{-1}$)
  - $W^{\pm}$ Cross-section and Parity violating single-spin asymmetry measurement
- Critical analysis aspects:
  - Charge-sign discrimination at high $p_T$
  - Rejection and treatment of background
- STAR W program at forward/backward rapidity:
  - Installation of STAR Forward GEM Tracker ($1<\eta<2$) (FGT): Summer 2011