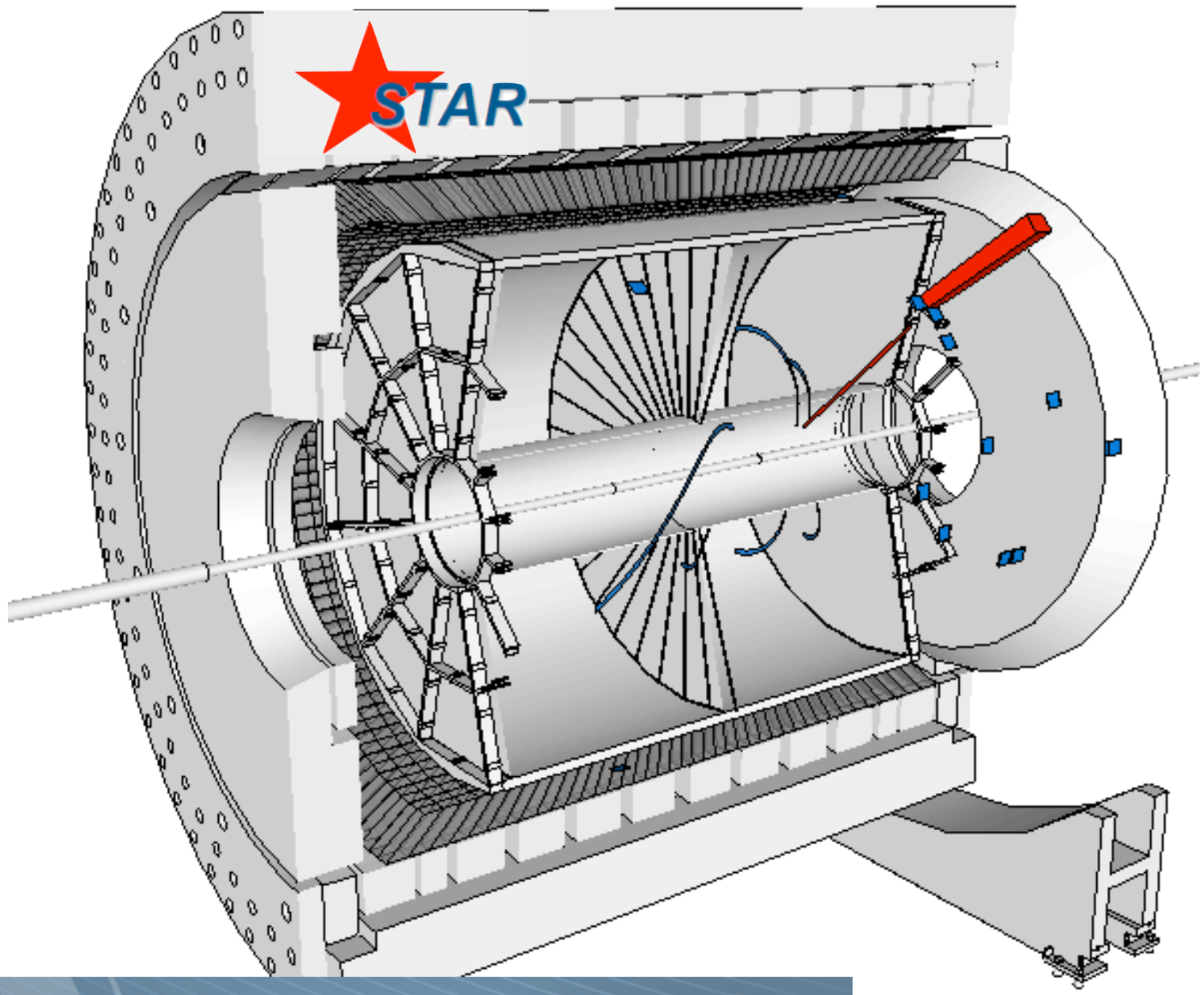
First Measurement of $W^{\pm}$ Boson Production at STAR in Polarized Protons Collisions at RHIC



The Physics of W and Z Bosons

RIKEN BNL Research Center Workshop
June 24-25, 2010 at Brookhaven National Laboratory

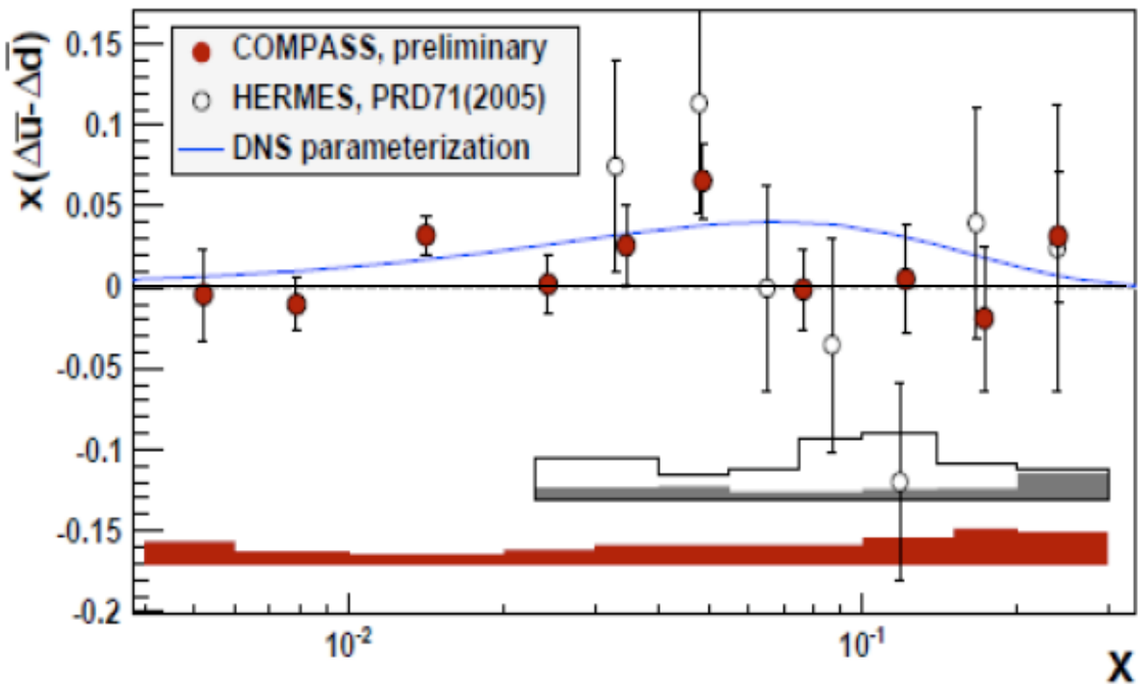
Jan Balewski
for STAR Collaboration

Asymmetry in the sea quarks: STAR W program

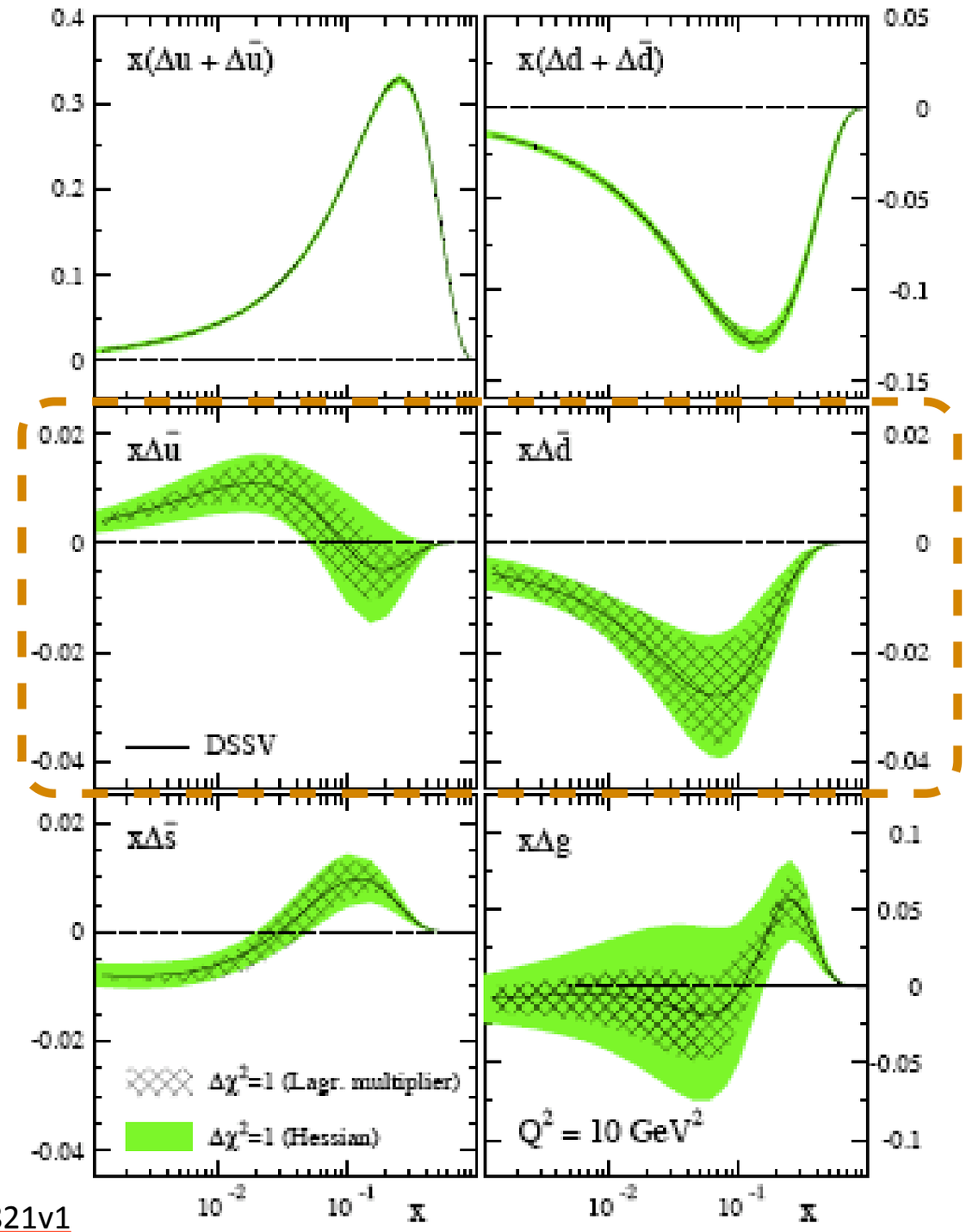
$$S_z = \tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_z^g + L_z^q \qquad (L = L_z^g + L_z^q)$$

$\Delta\Sigma$: u, d, s; $\bar{u}$, $\bar{d}$, $\bar{s}$ — ΔG: J_g

Global analysis predicts positive net helicity difference

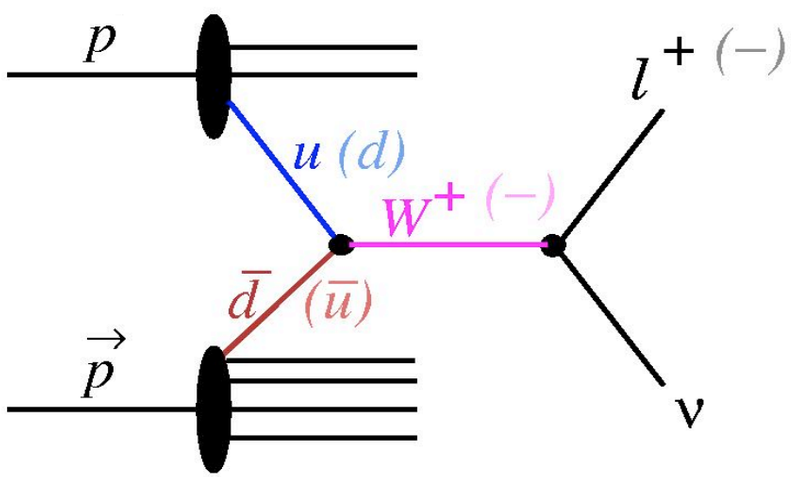


Recent global fit of polarized u,d anti-quarks distributions to DIS and SI-DIS measuremnt



de Florian: http://arxiv.org/pdf/0904.3821v1

Expectations for Ws Measured in Run 9

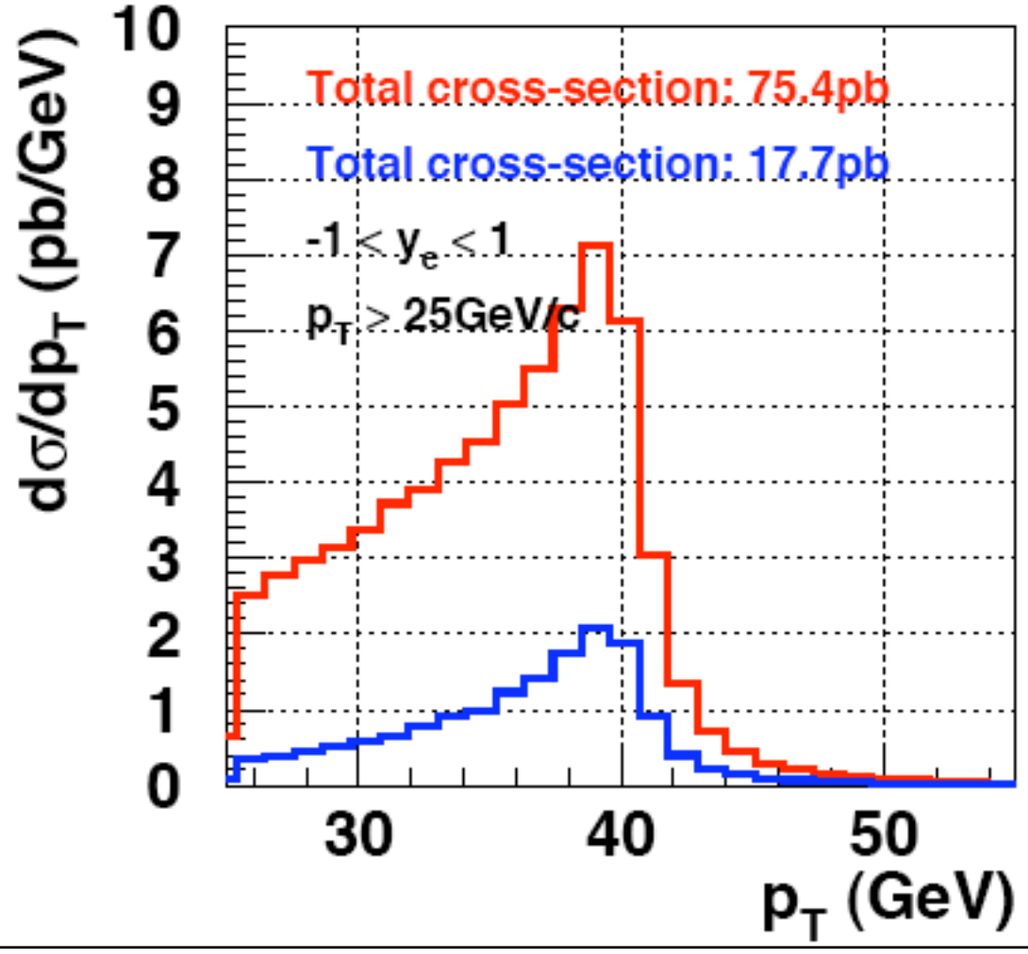


STAR measures $W^{\pm}$ through $e^{\pm}$ decays:

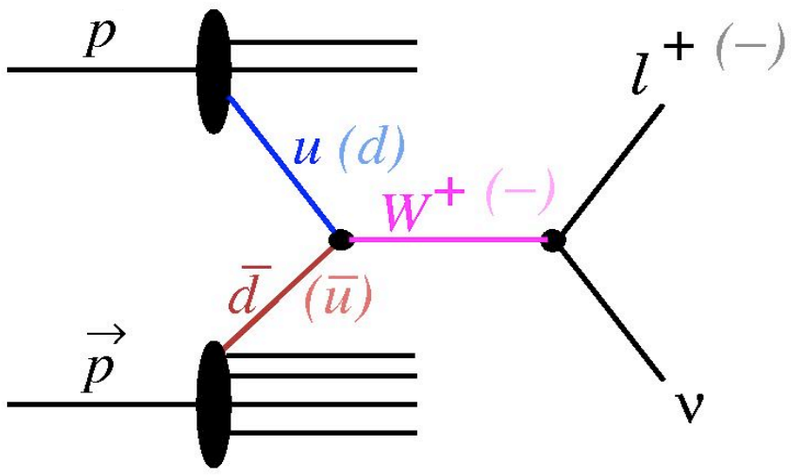
$$u + \bar{d} \rightarrow W^{+} \rightarrow e^{+} + \nu$$
$$\bar{u} + d \rightarrow W^{-} \rightarrow e + \bar{\nu}$$

deFlorian/Vogelsang

$$\int_{25} dE_T^e \int_{|\eta_e|<1.0} d\eta_e \frac{d^2\sigma^{W\pm}}{d\eta_e dE_T^e} \simeq \begin{pmatrix} 0.62 \\ 0.46 \end{pmatrix} \sigma_{tot}^{W\pm}$$



Expectations for Ws Measured in Run 9



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

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

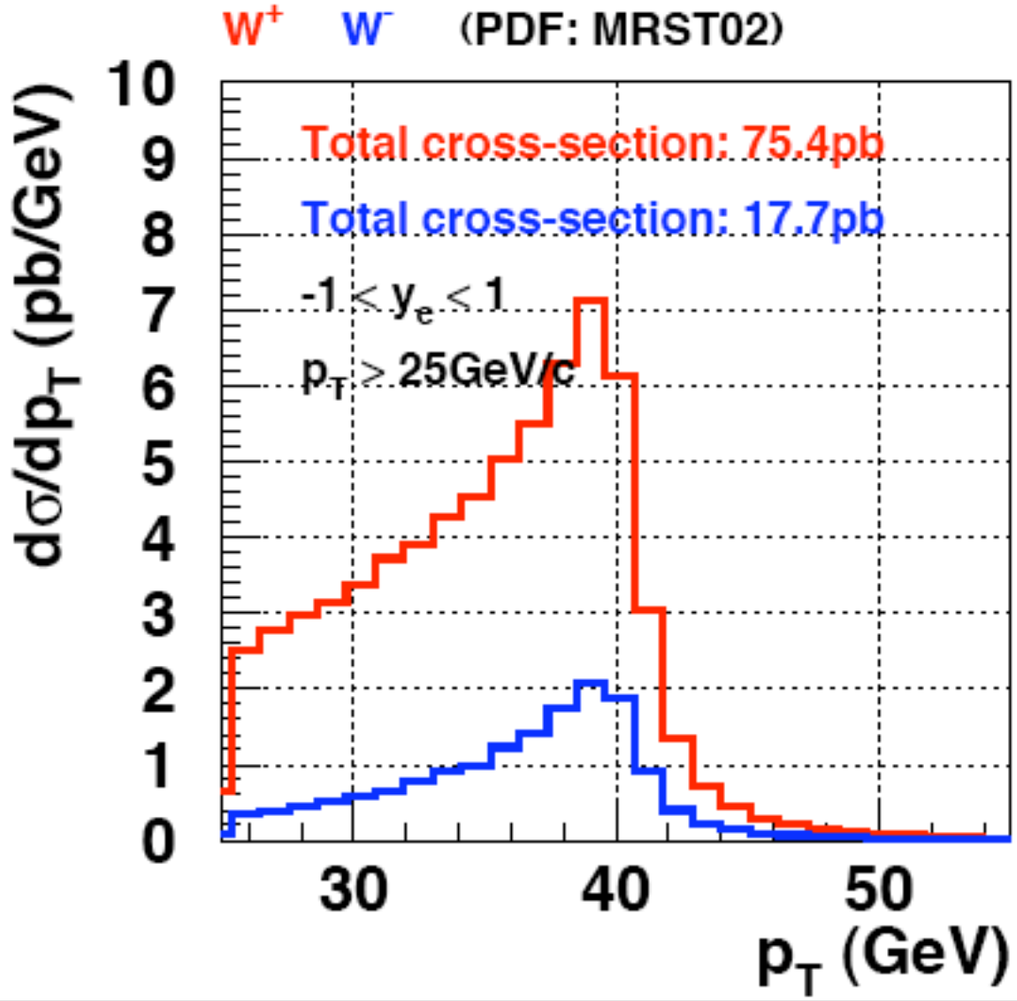
deFlorian/Vogelsang

Measure the parity-violating, single-spin helicity asymmetry

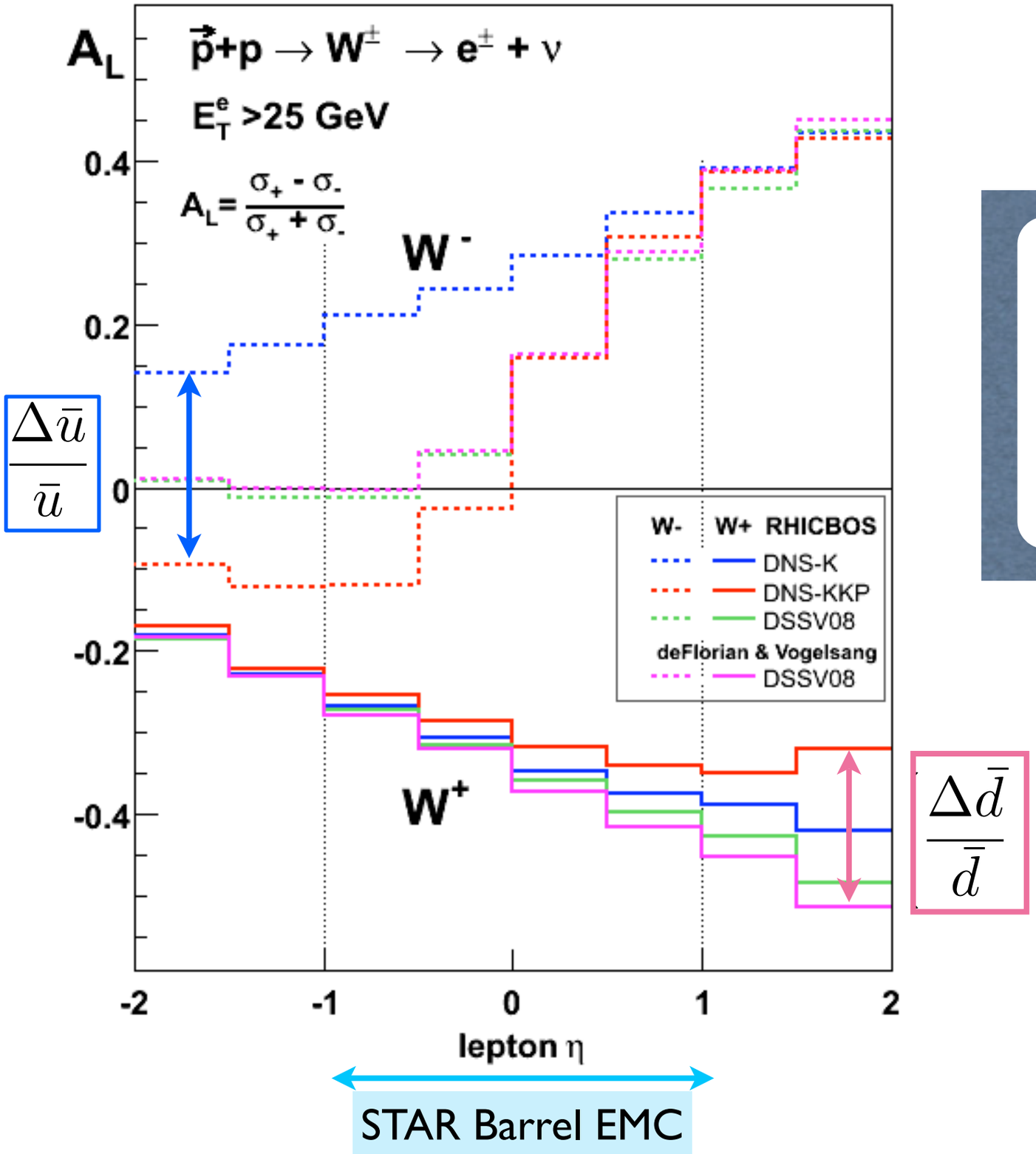
$$A_L = \frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\overrightarrow{\sigma} + \overleftarrow{\sigma}}$$

where at LO:

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



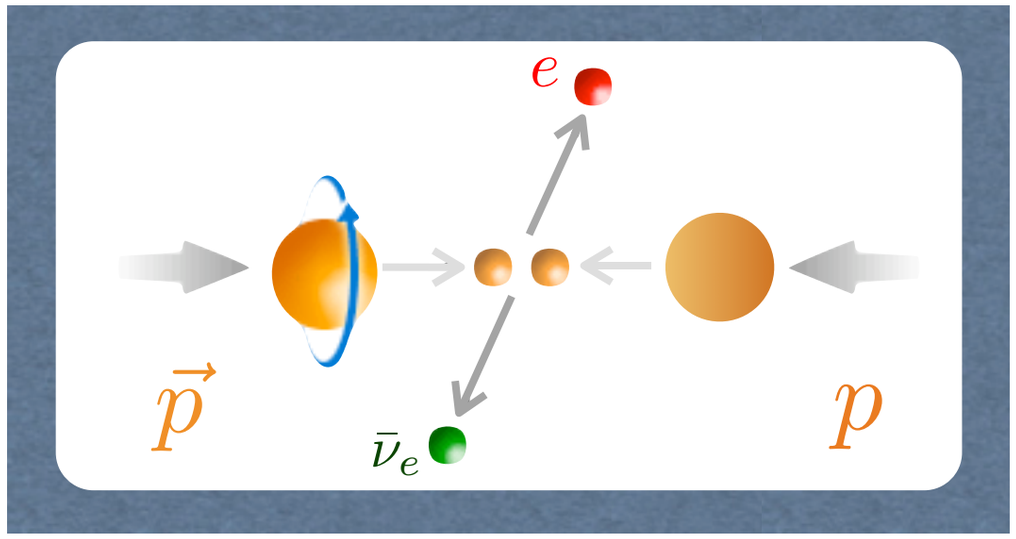
Predictions for A_L for p+p→W



$$\frac{\Delta\bar{u}}{\bar{u}}$$

$$\frac{\Delta\bar{d}}{\bar{d}}$$

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



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

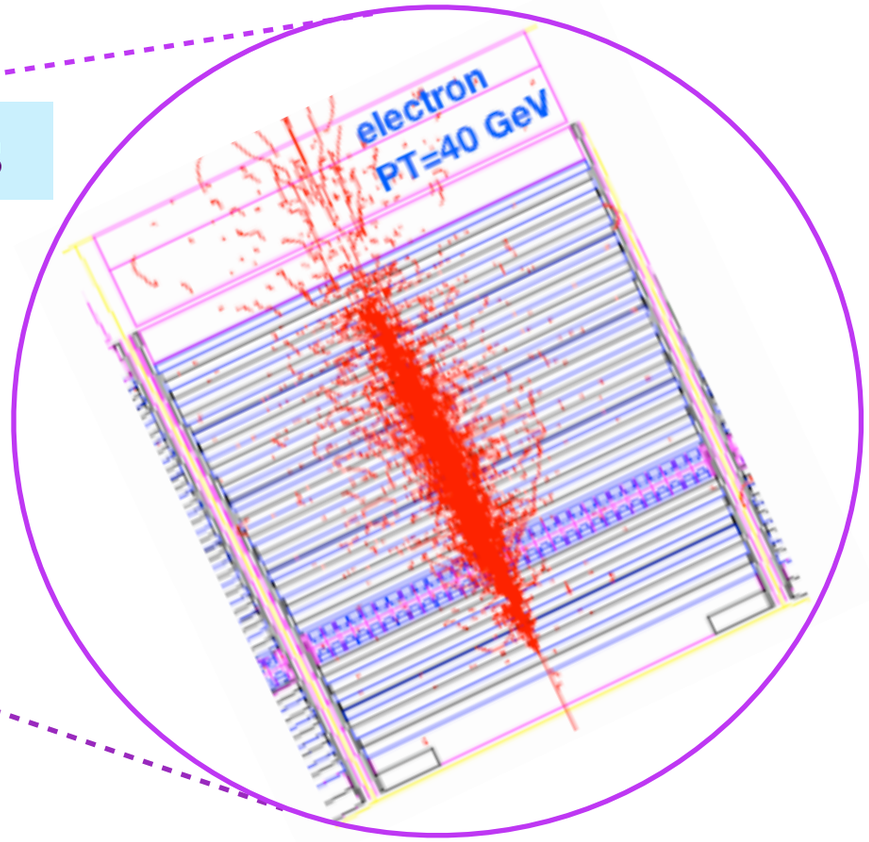
$$A_L^{W^+} = \frac{1}{2}\left(\frac{\Delta\bar{d}}{\bar{d}} - \frac{\Delta u}{u}\right)$$

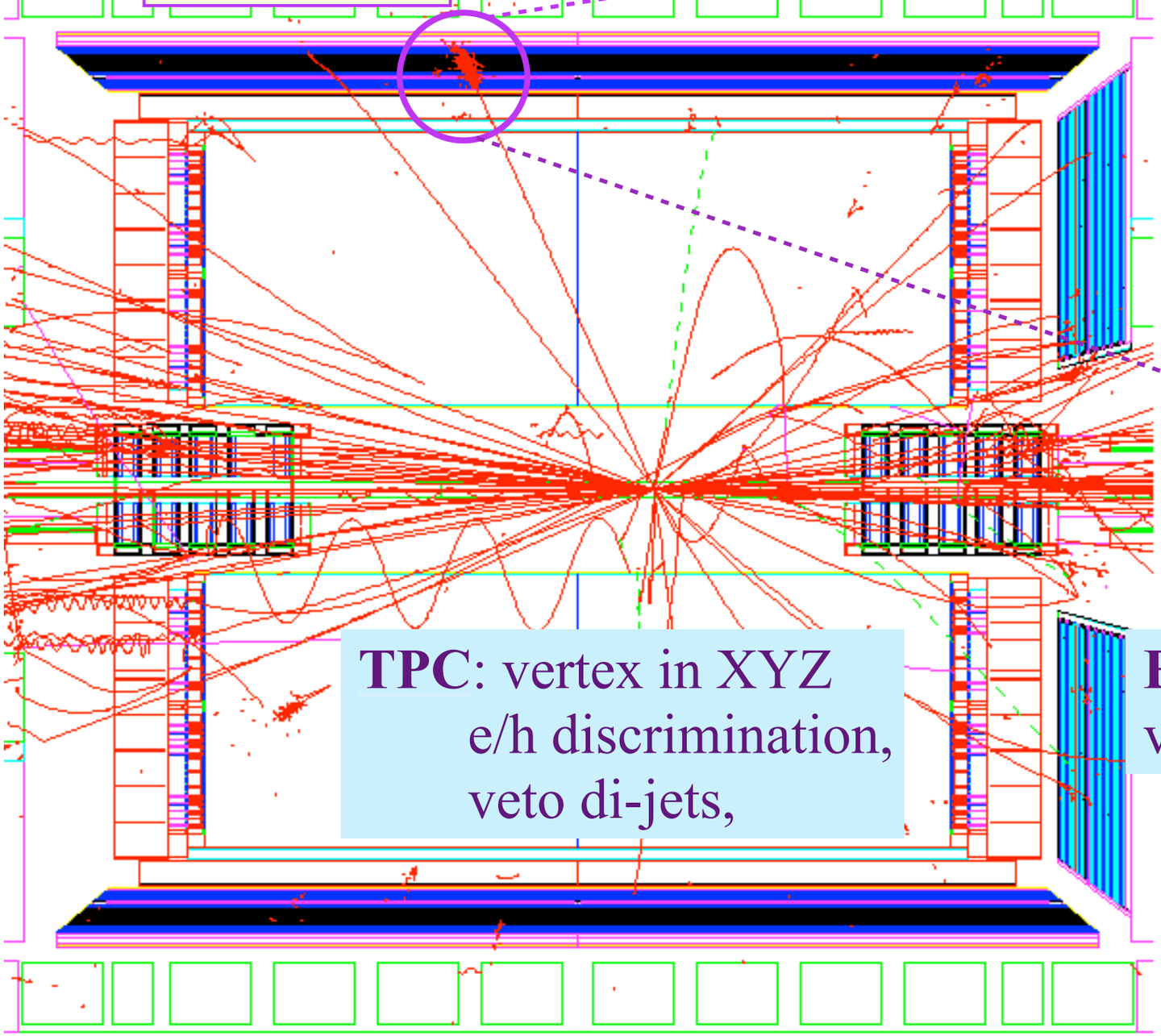
LO interpretation for x1=x2

Simulated W→e+ν event at STAR

EM shower from W --> e (L2-trigger)

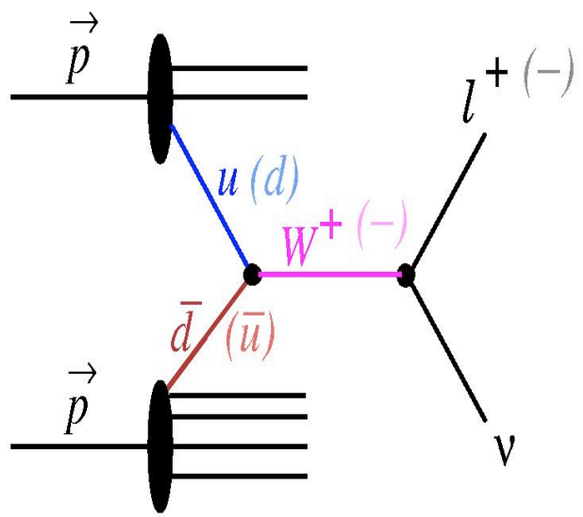
BEMC : lepton energy, veto jets



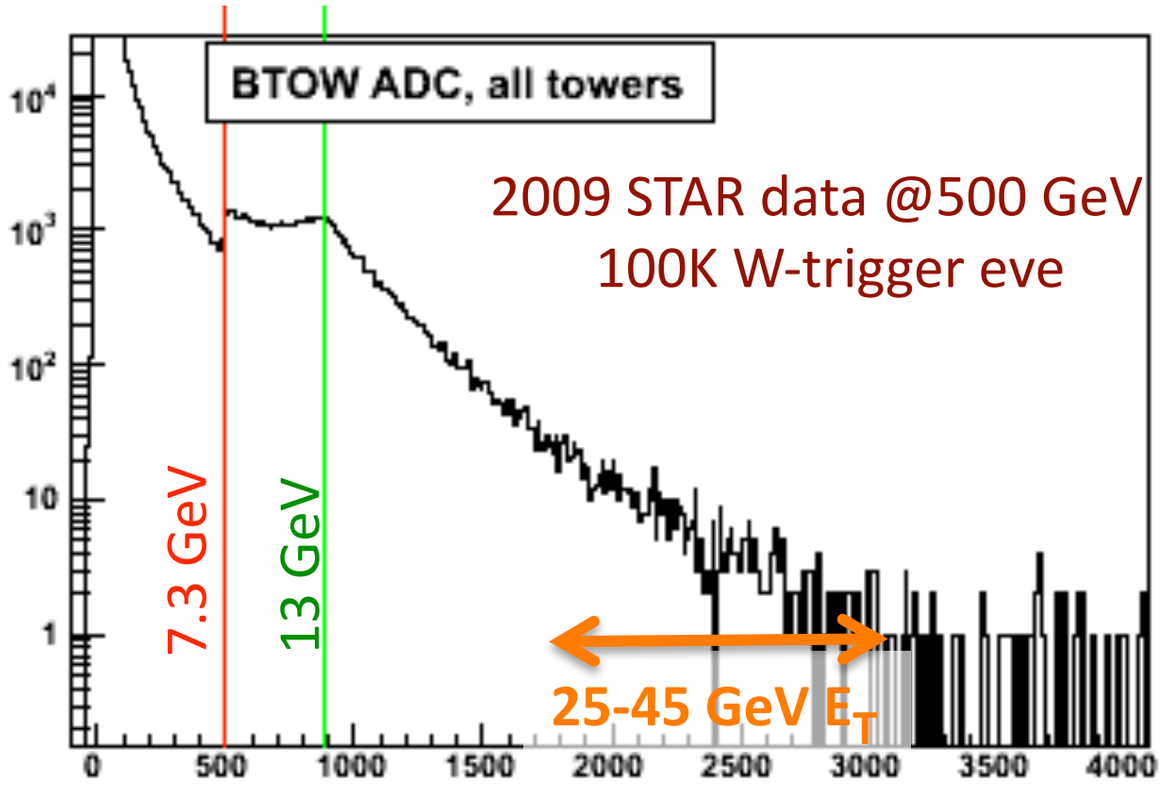


TPC: vertex in XYZ
e/h discrimination,
veto di-jets,

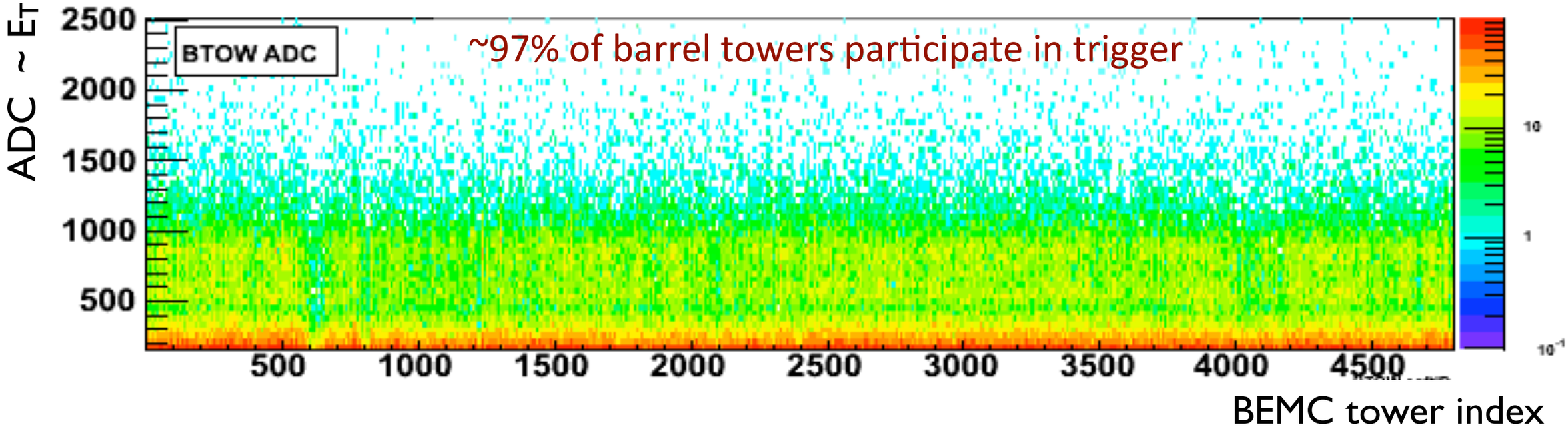
EEMC :
veto di-jets



EMC based W→e+ν trigger in Run 9

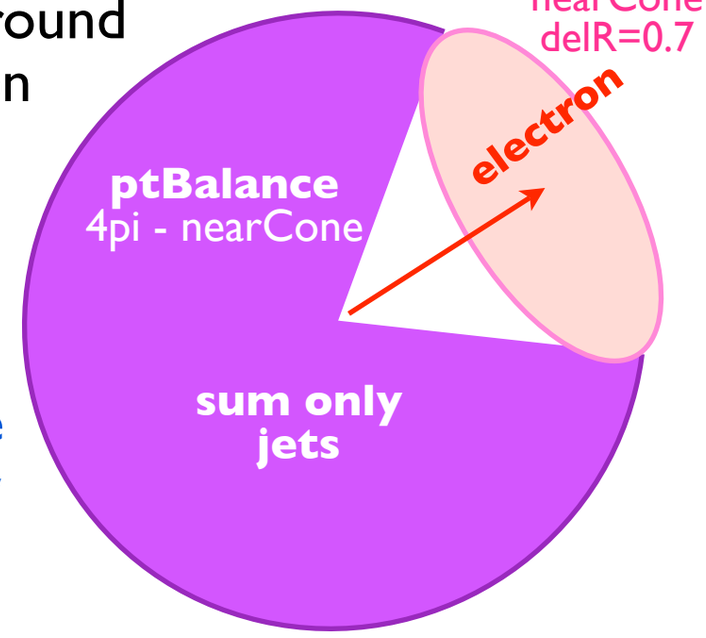


- **Trigger**
  - Level 0 trigger – BEMC single high tower threshold E_T > 7.3 GeV.
  - Level 2 trigger – BEMC 2 x 2 tower cluster threshold E_T > 13 GeV.
  - Use these recorded and triggered events to monitor the luminosity.



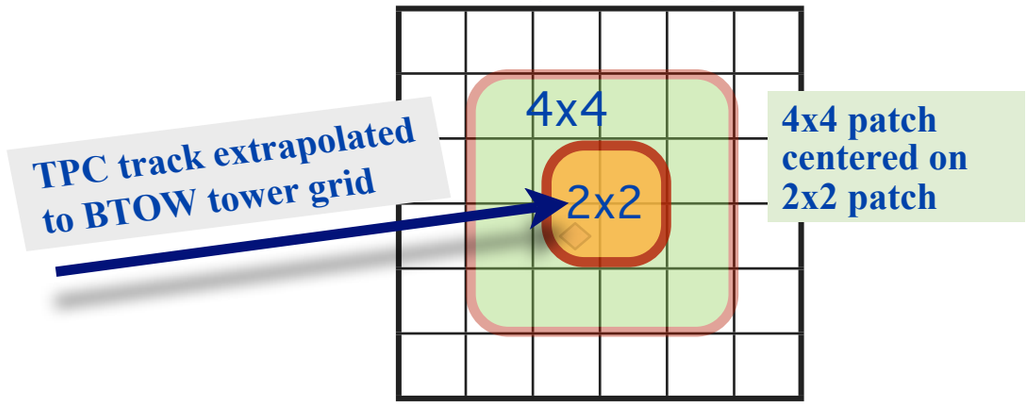
p+p→W→e+ν events selection

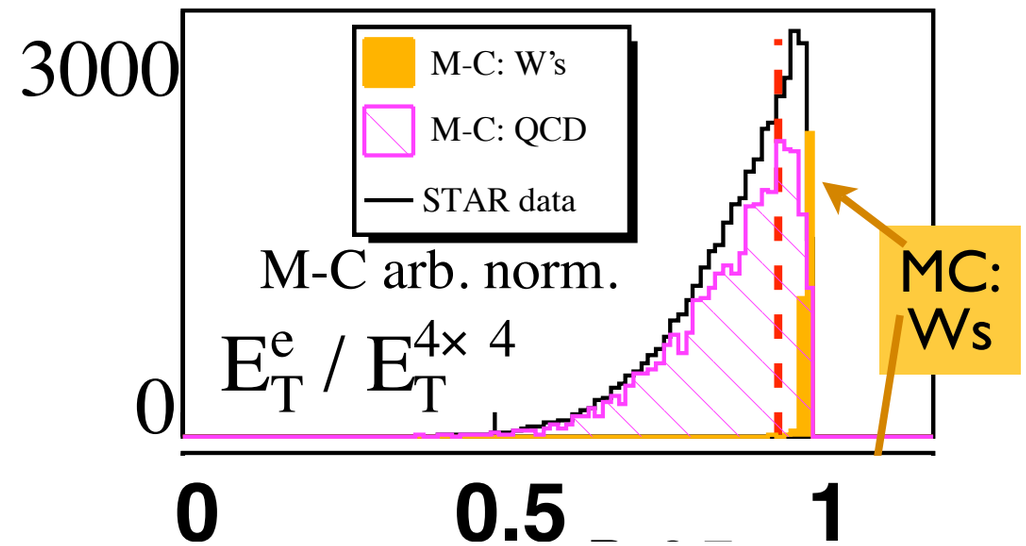
1. Find lepton in TPC (direction) and in EMC (energy)
   - TPC & EMC matching
2. Suppress QCD background
   - EMC cluster isolation
   - near jet veto
   - away ET veto



Transverse plane view

2x2 EM cluster with highest ET sum, must contain tower pointed by the track





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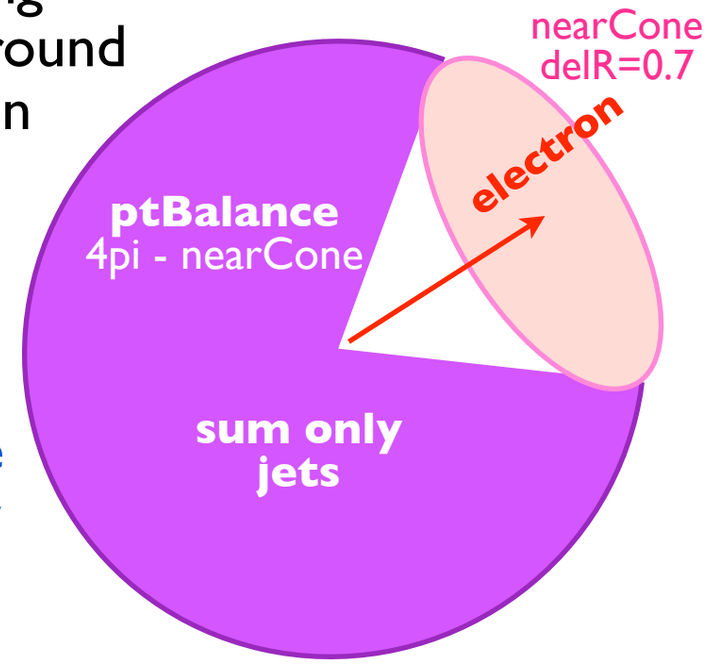

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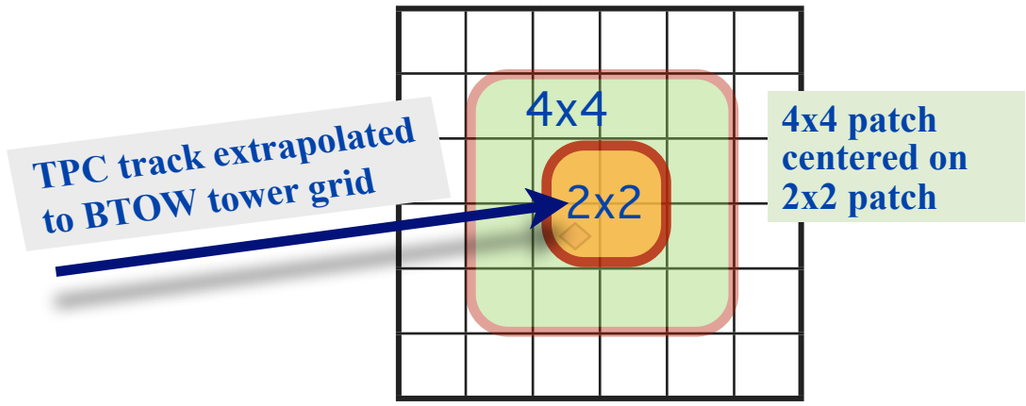

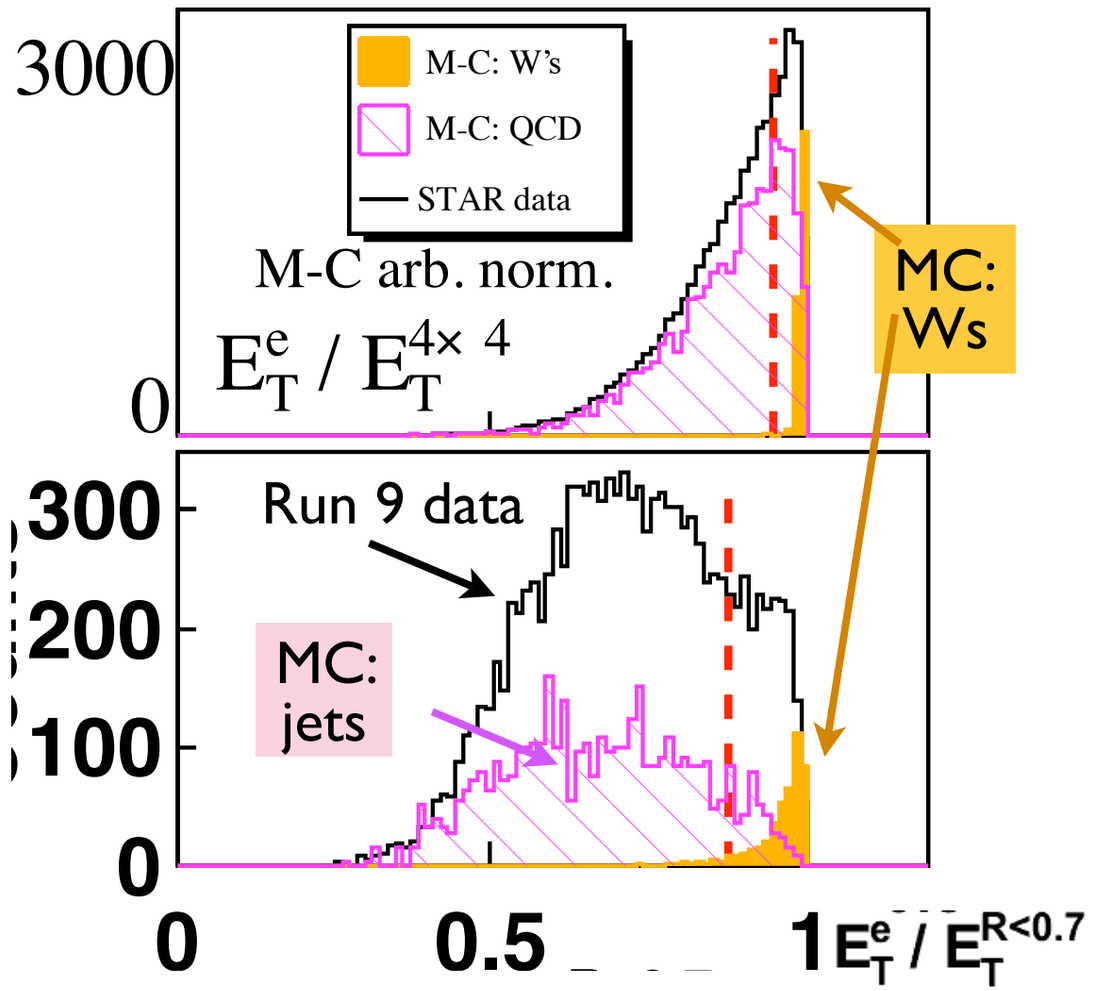

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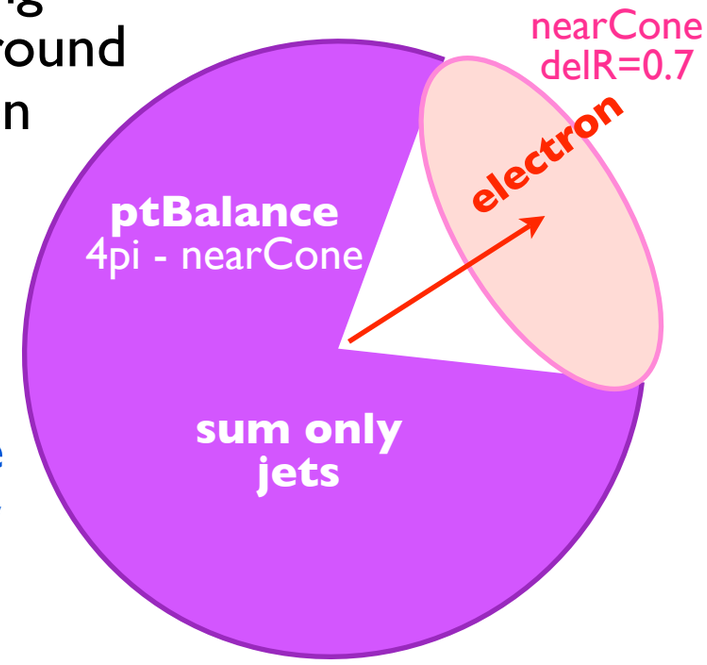

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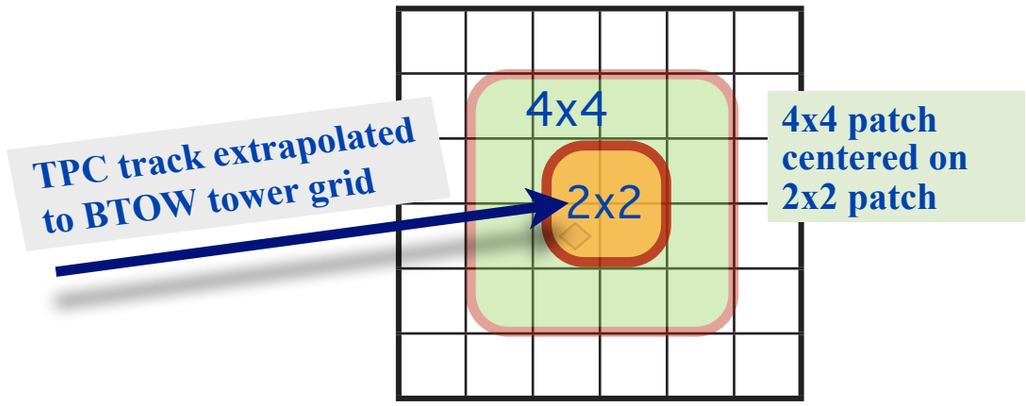
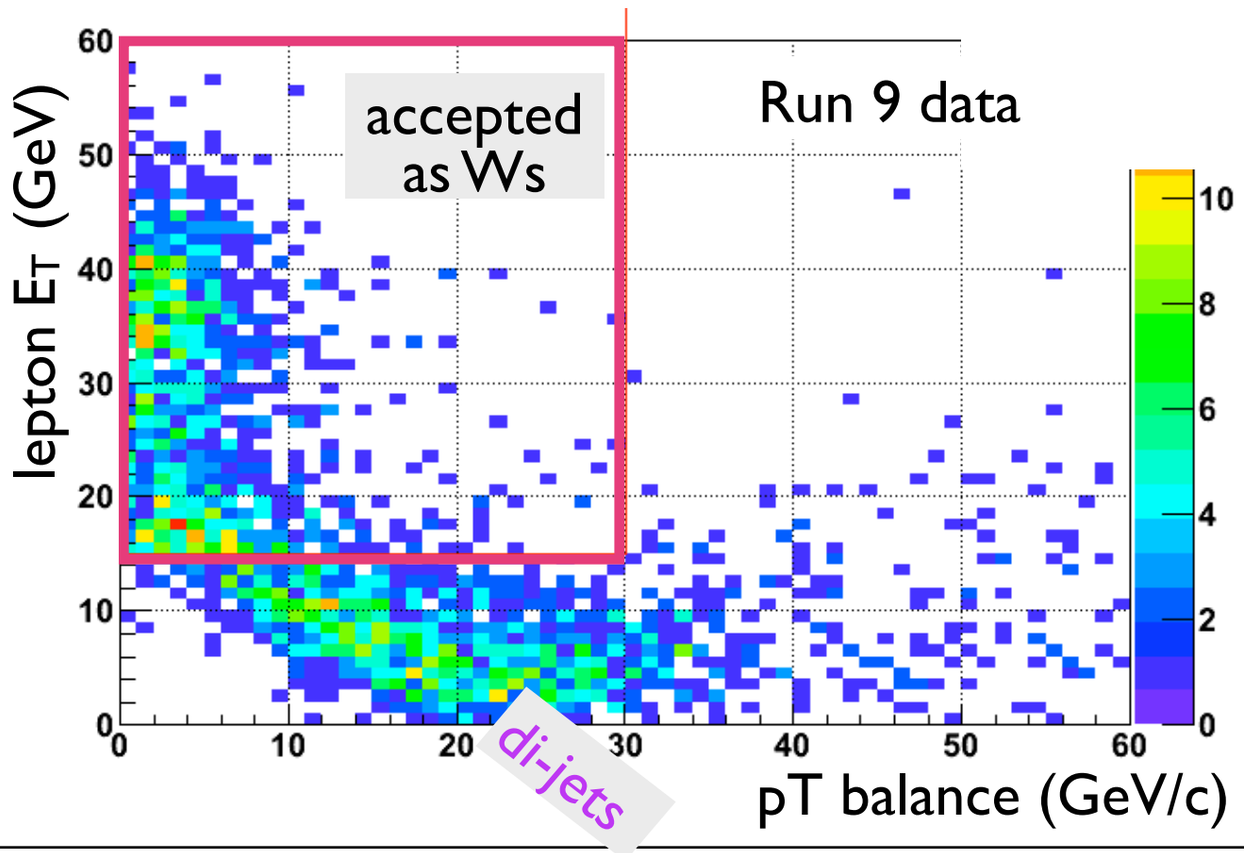
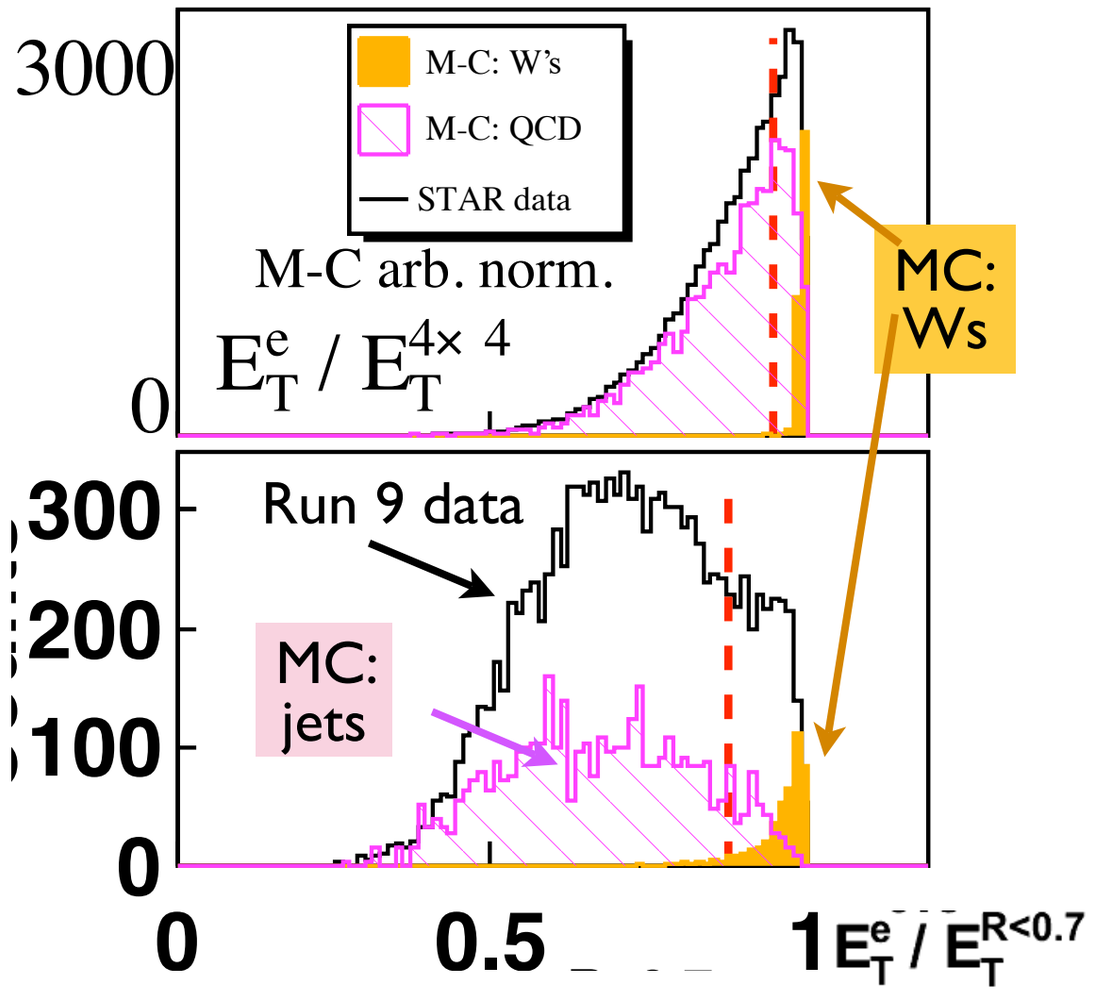


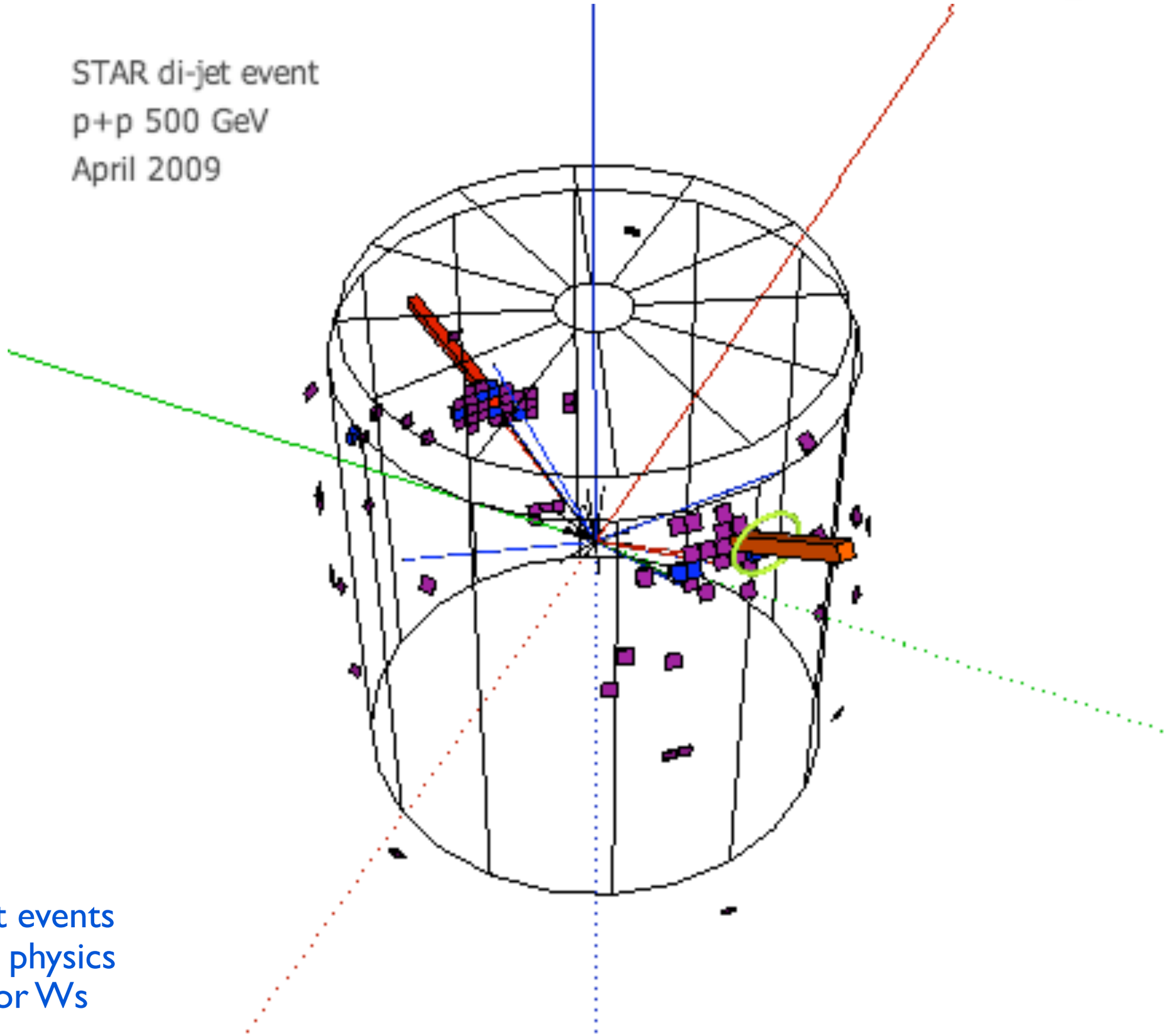




Reconstructed Di-jet Event (movie)

1,400,000 di-jet events were dominate physics background for Ws

Reconstructed Di-jet Event (movie)



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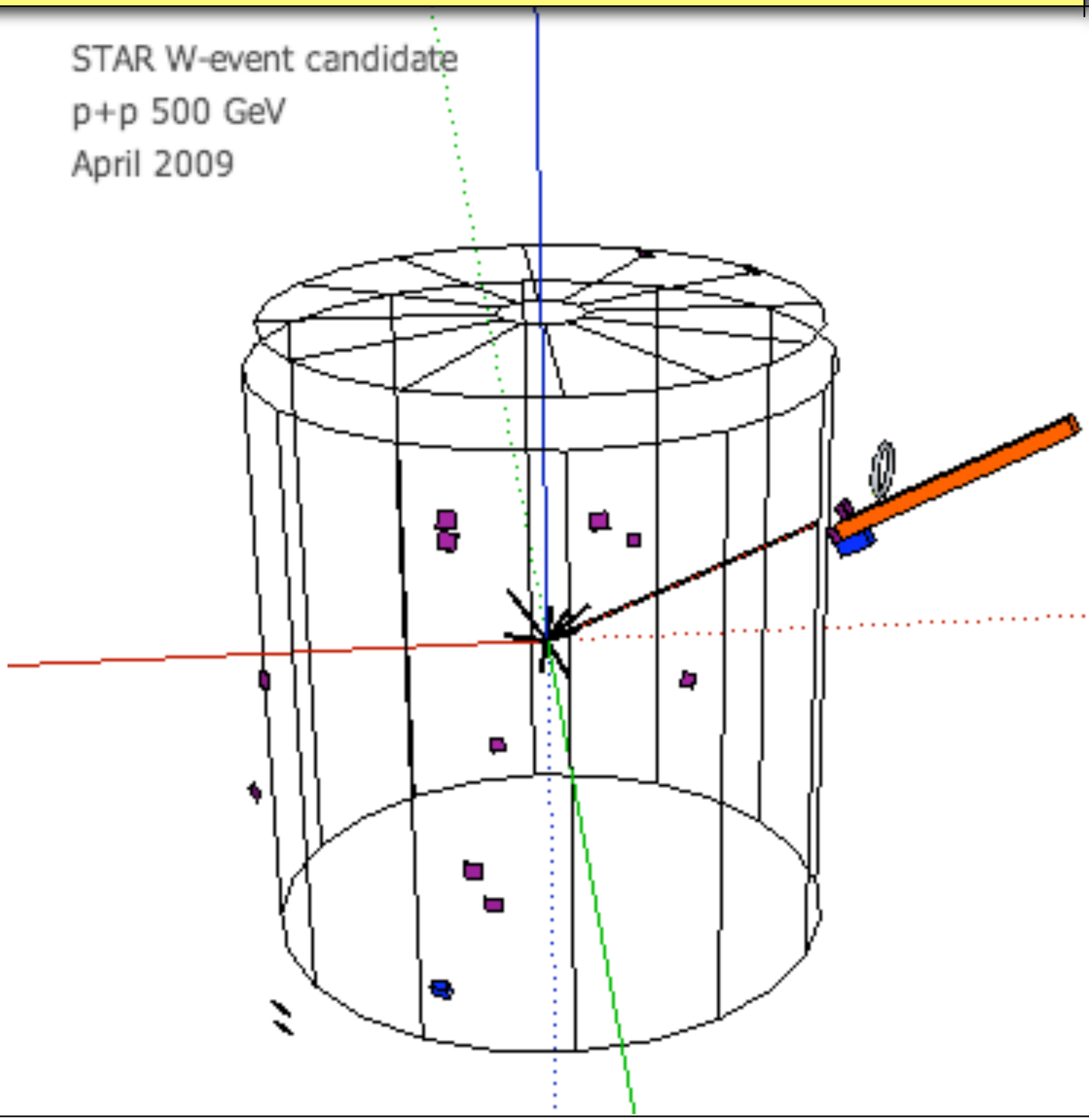
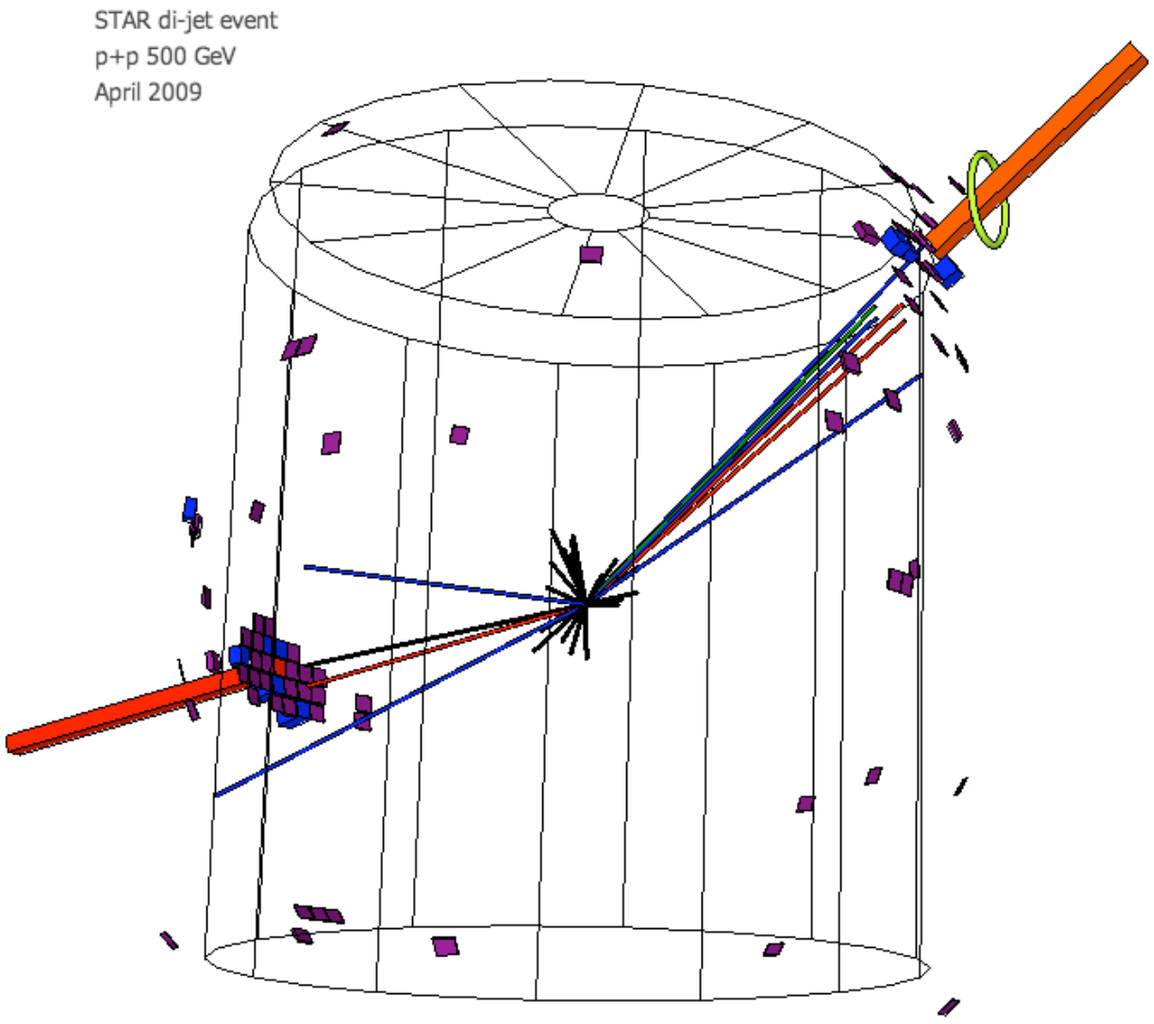
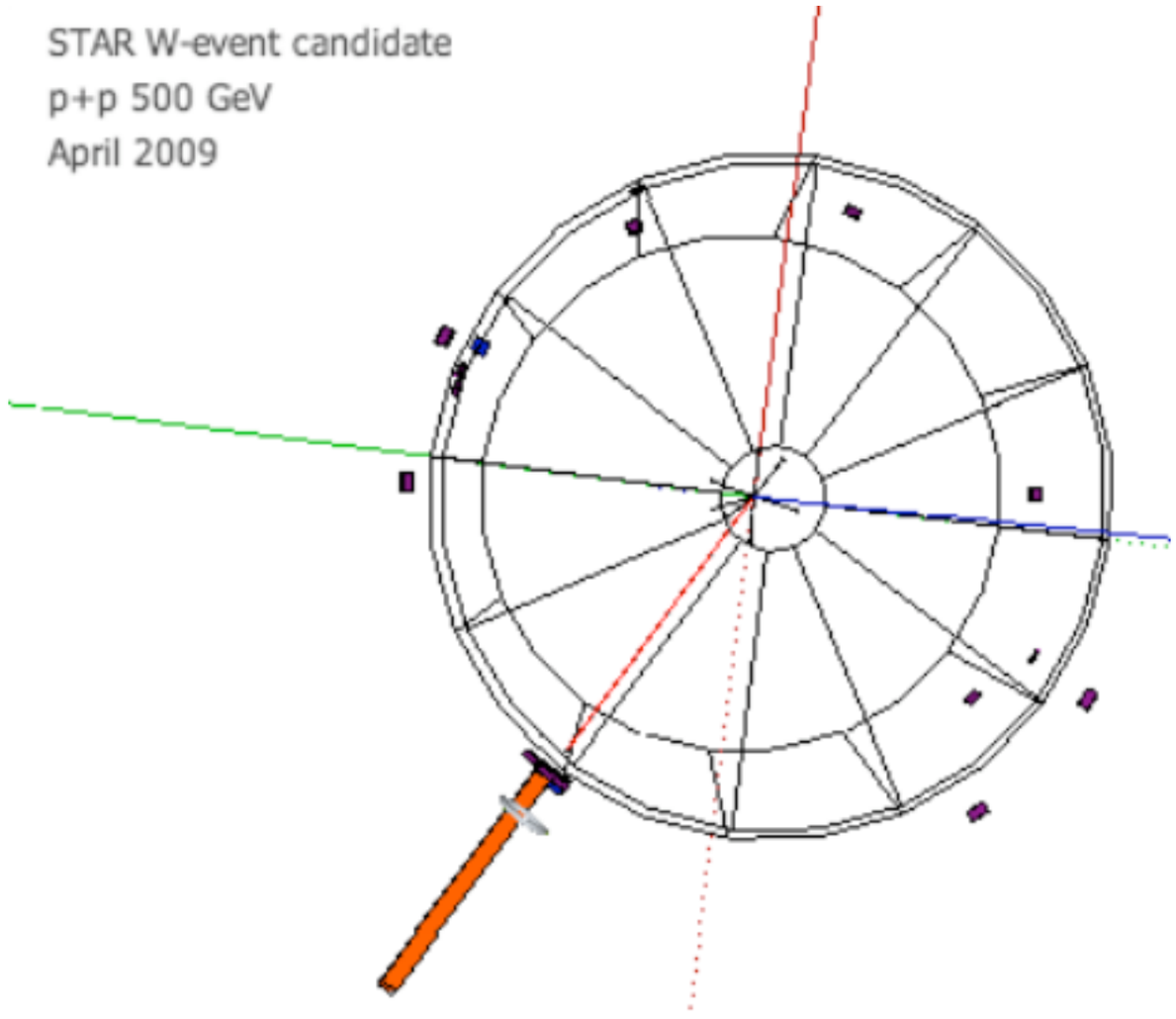
Reconstructed W→e+ν Event (movie)



Example of Reconstructed Events (static)

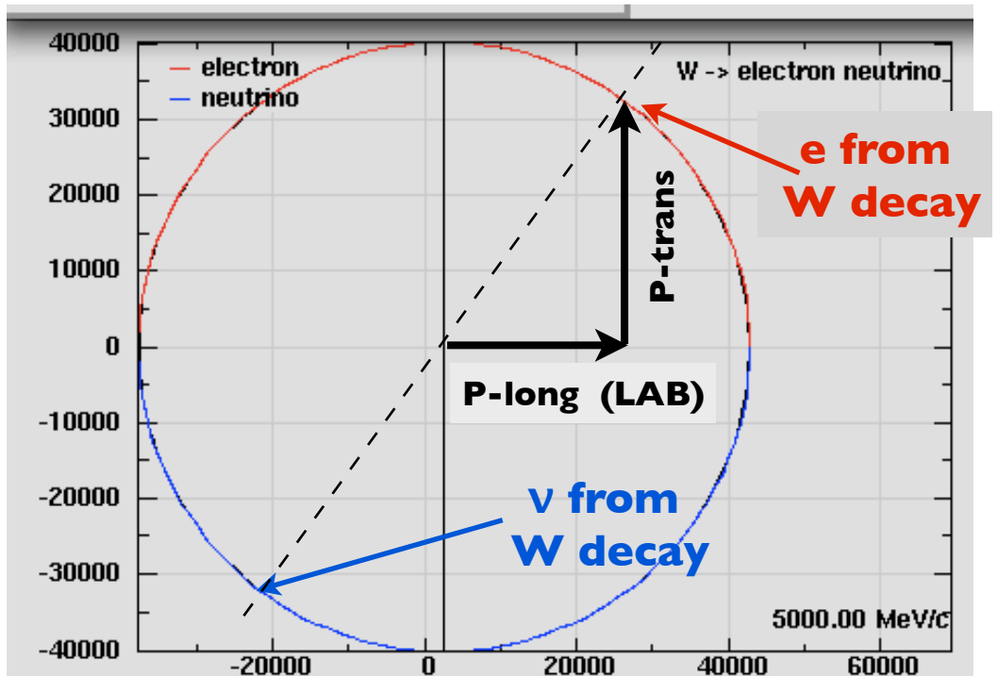
1,400,000 di-jet events were dominate physics background for Ws





Jacobian peak shape: 2 Body Decay & K_T-smearing

Isotropic decay $W \rightarrow e + \nu$
prob. density: $f_\Omega(\phi, \cos\theta) = const$,
electron $P_T = P_0 * \sin\theta$, where $P_0 = 40$ GeV/c.
Hence, prob. density: $f_{P_T}(P_T) = \frac{const}{\sqrt{1-(P_T/P_0)^2}}$
has singularity at $P_T = 40$ GeV/c



Assumed P-long of W of 5 GeV/c,
no K_T smearing

$$u + \bar{d} \quad \rightarrow \quad W^+$$

Jacobian peak shape: 2 Body Decay & K_T-smearing

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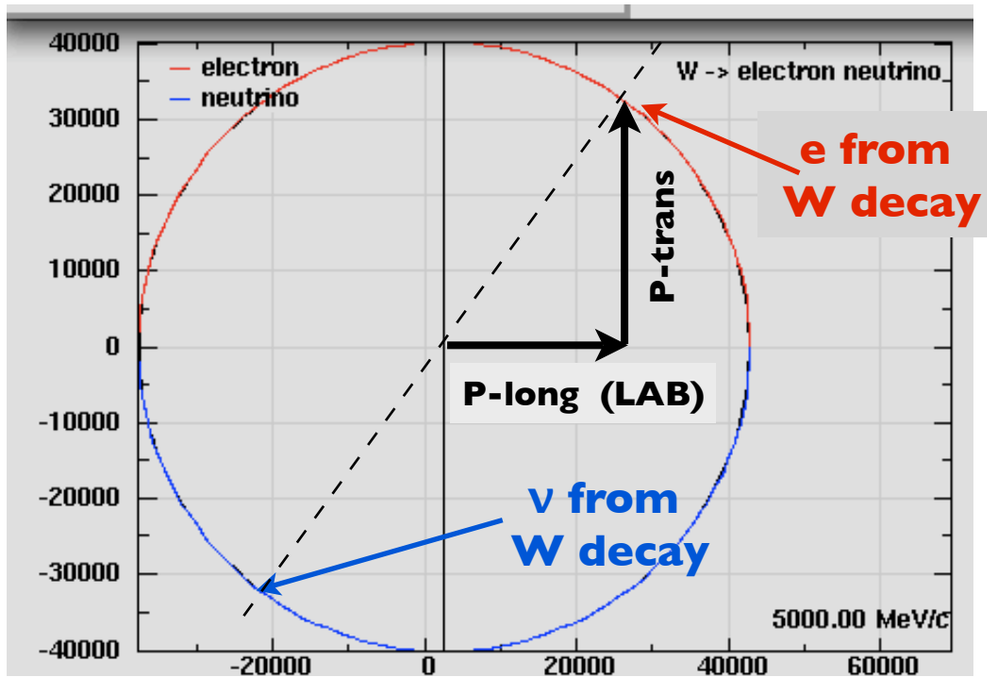

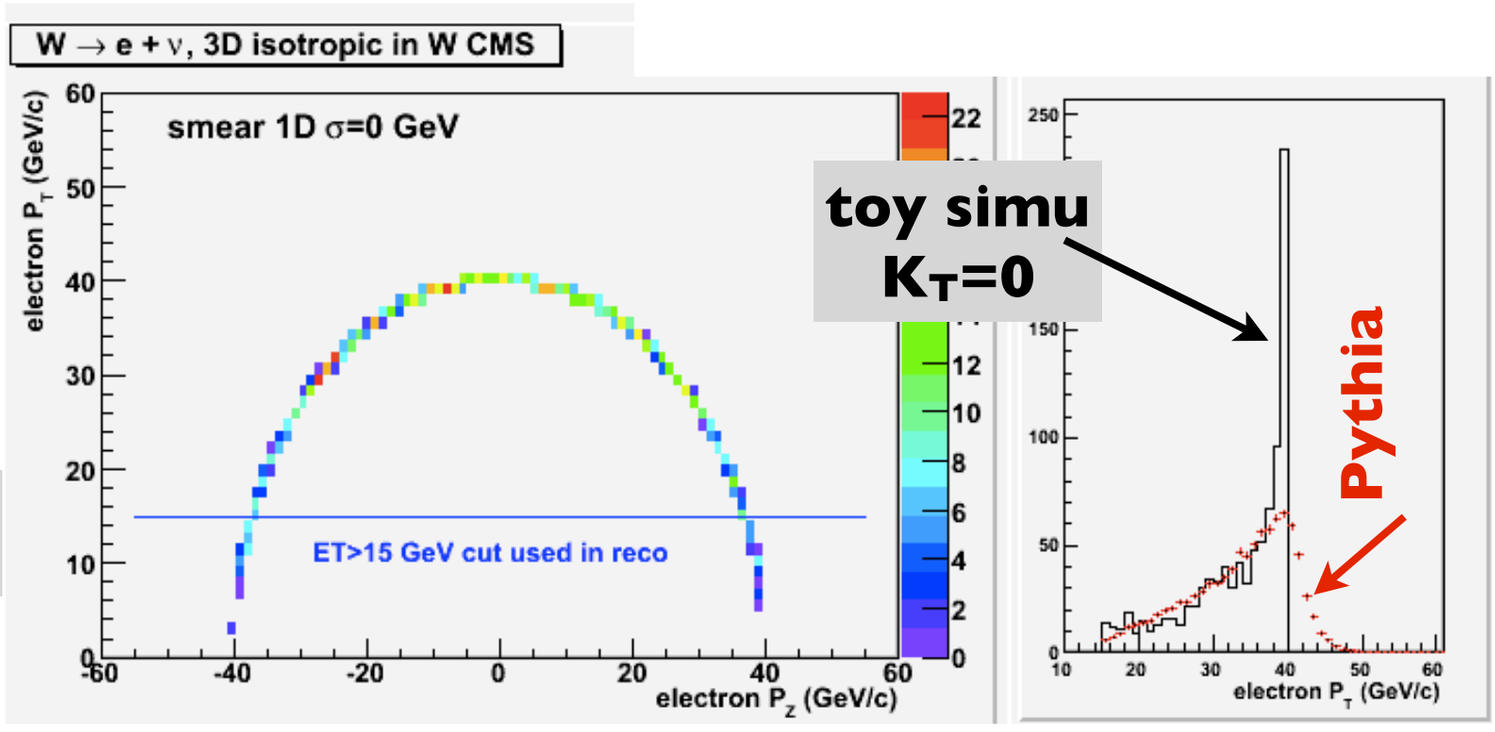

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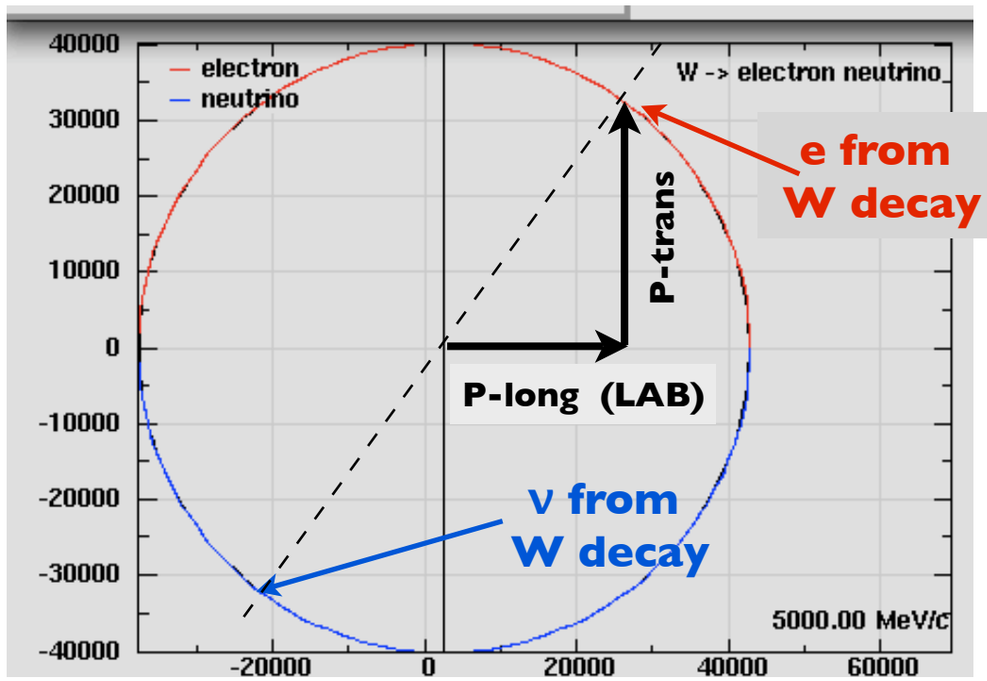

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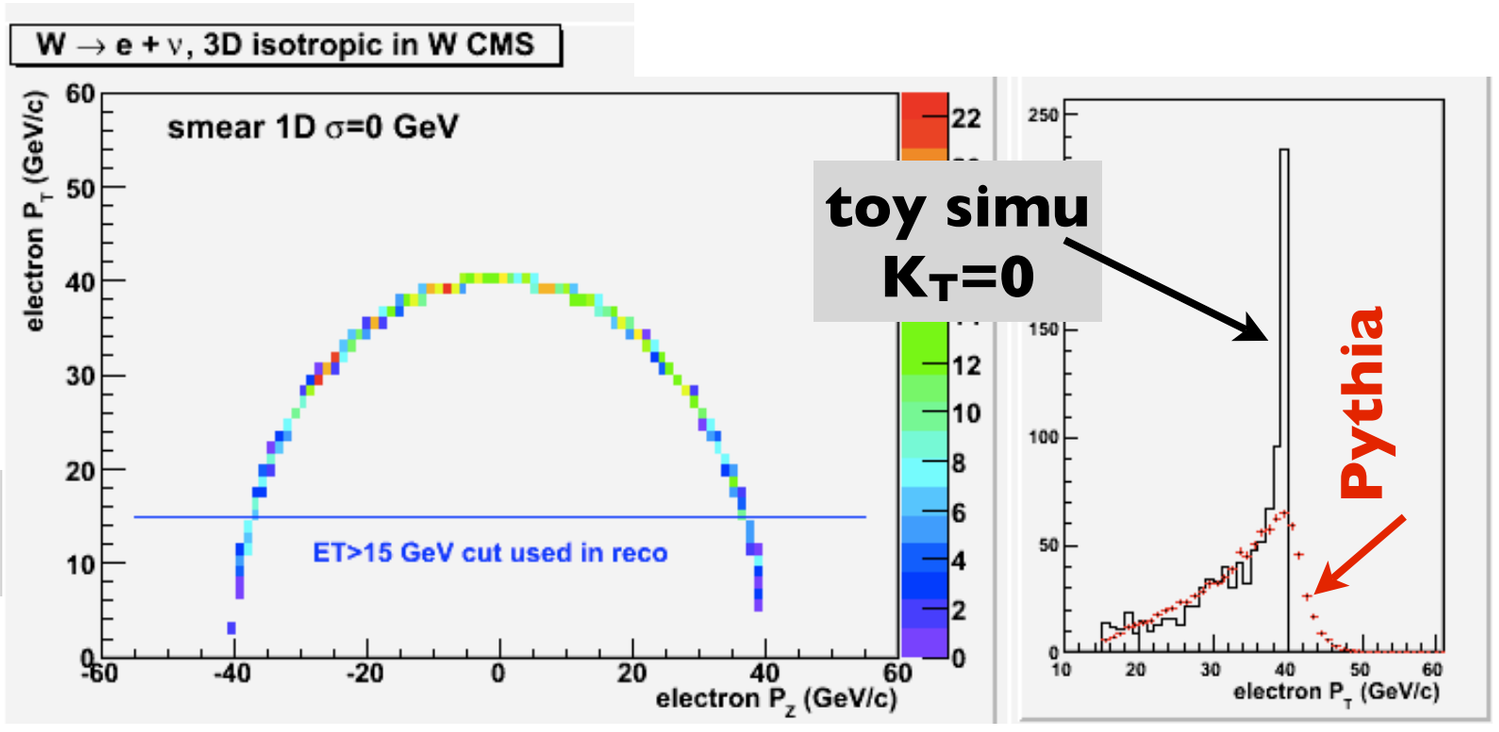
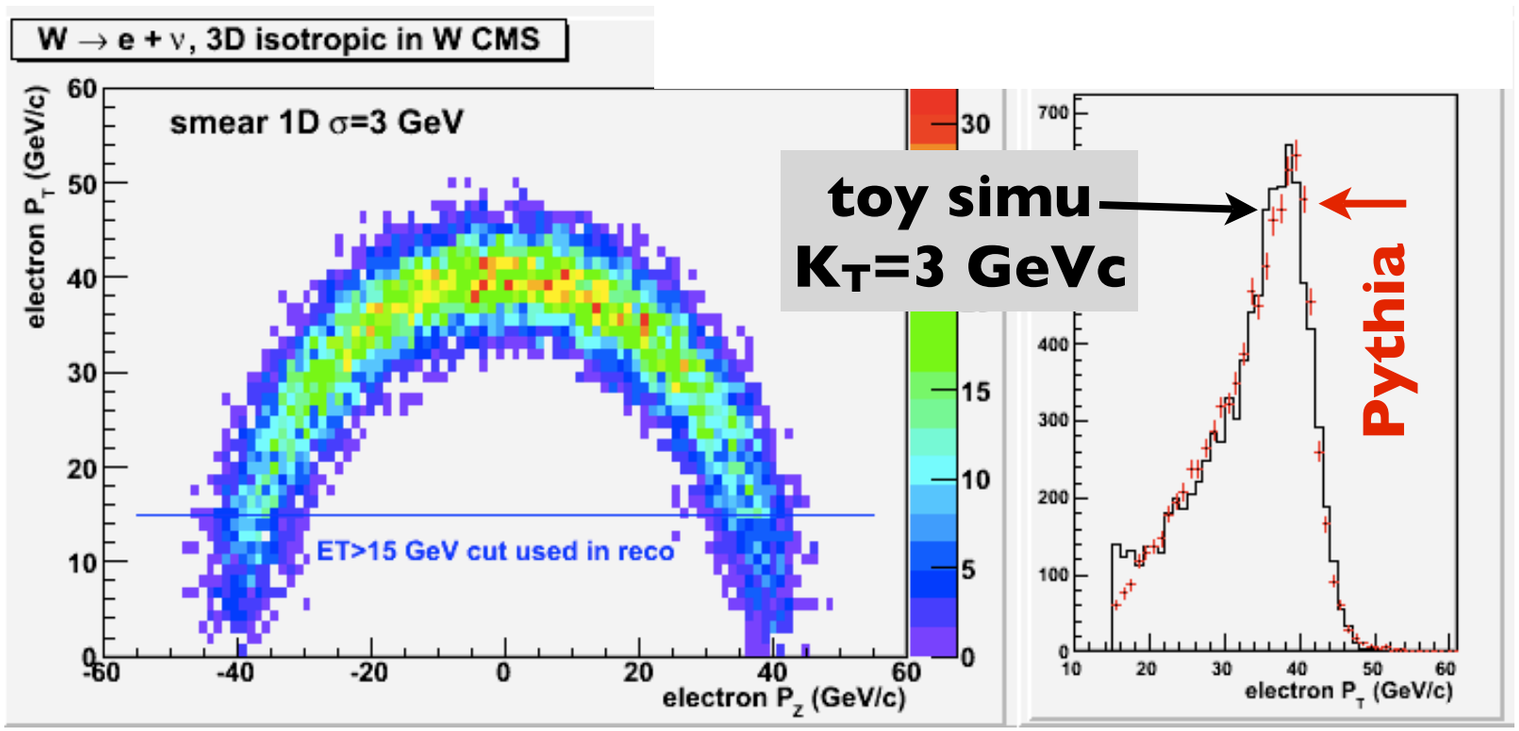
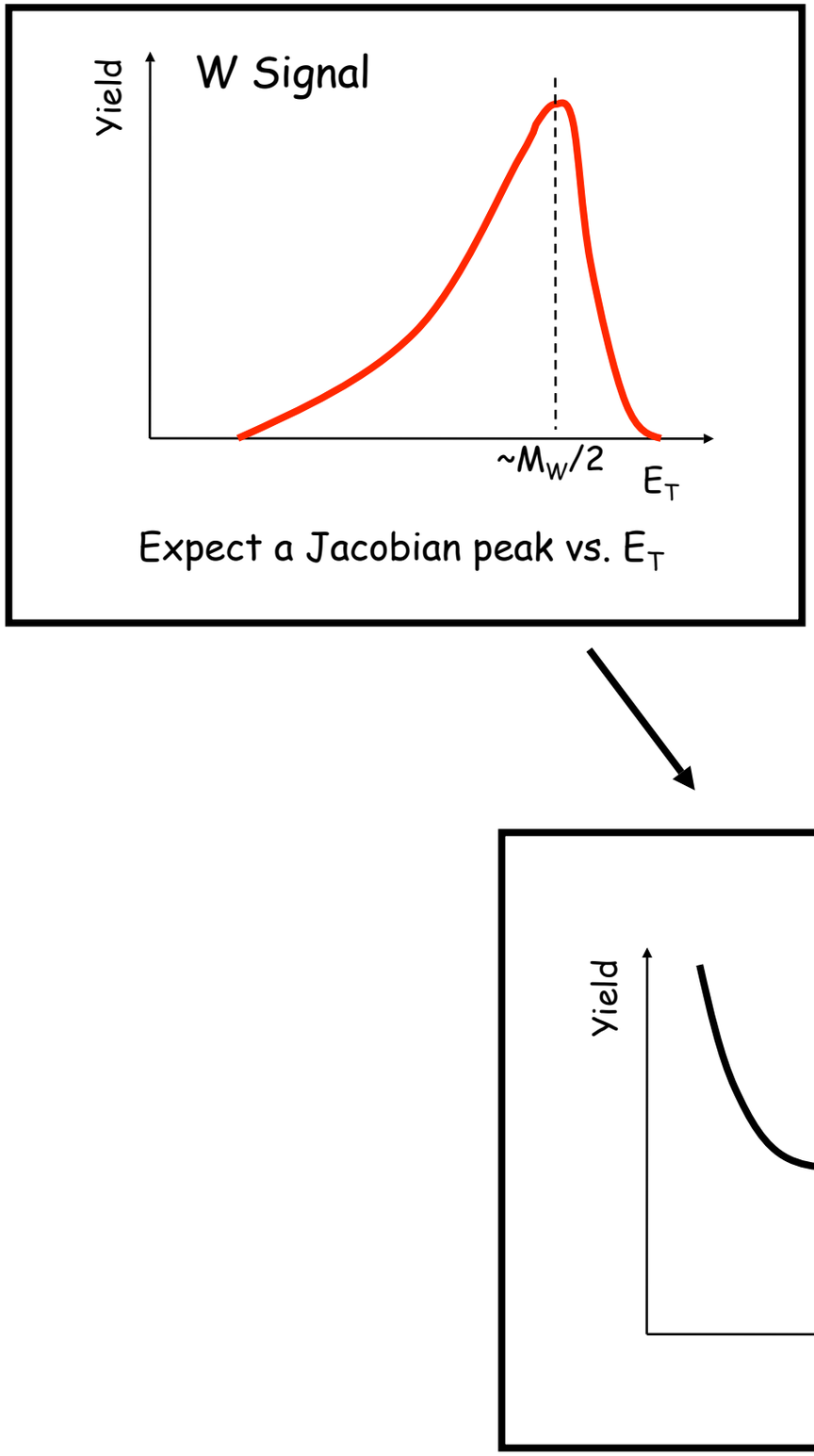
$$u + \bar{d} \quad \to \quad W^+$$



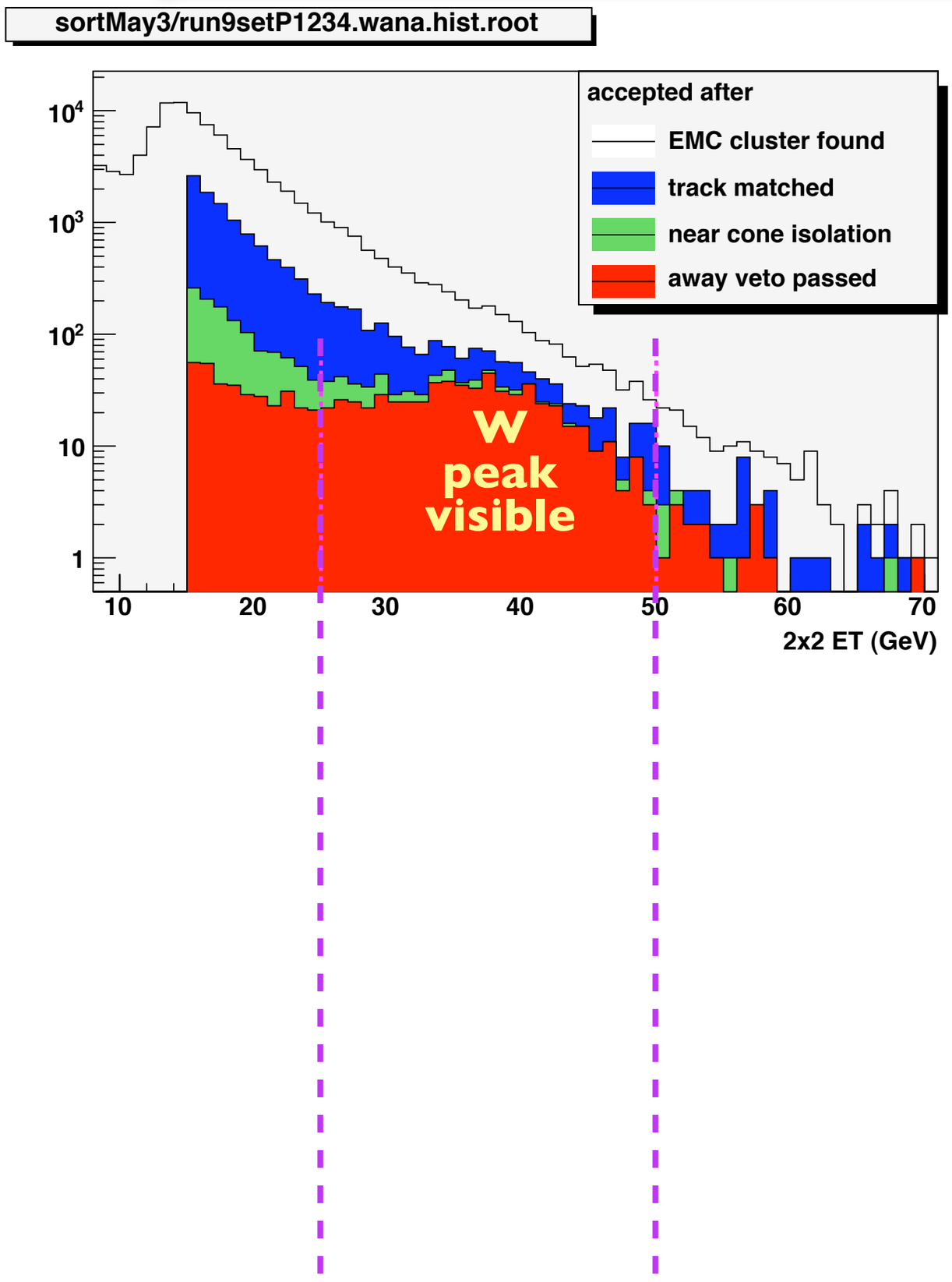


Expected Reconstructed W→e+ν spectrum



We expect to see a peak in the E_T spectrum at $M_W/2$

Emerging of W peak over background

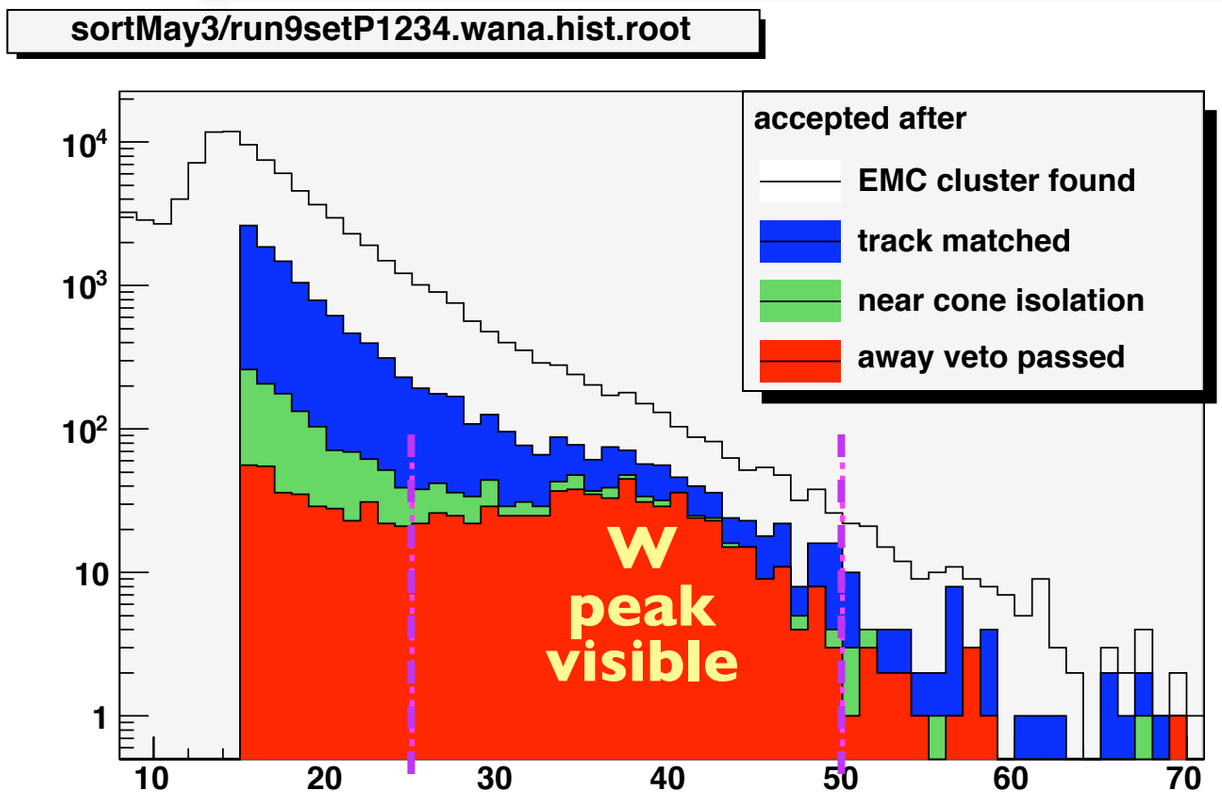


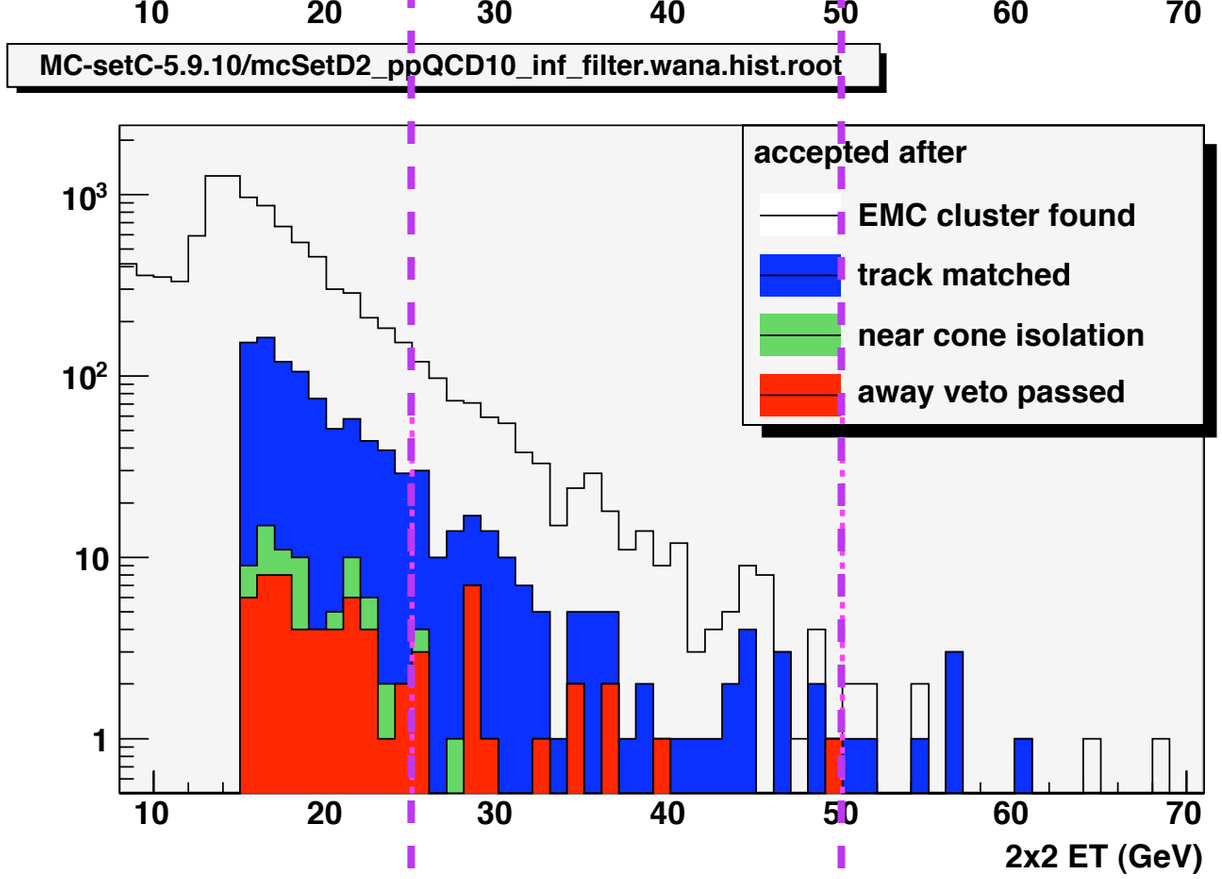
STAR Run 9 pp500 data

W-reco applied

LT~12 pb^{-1}

Emerging of W peak over background





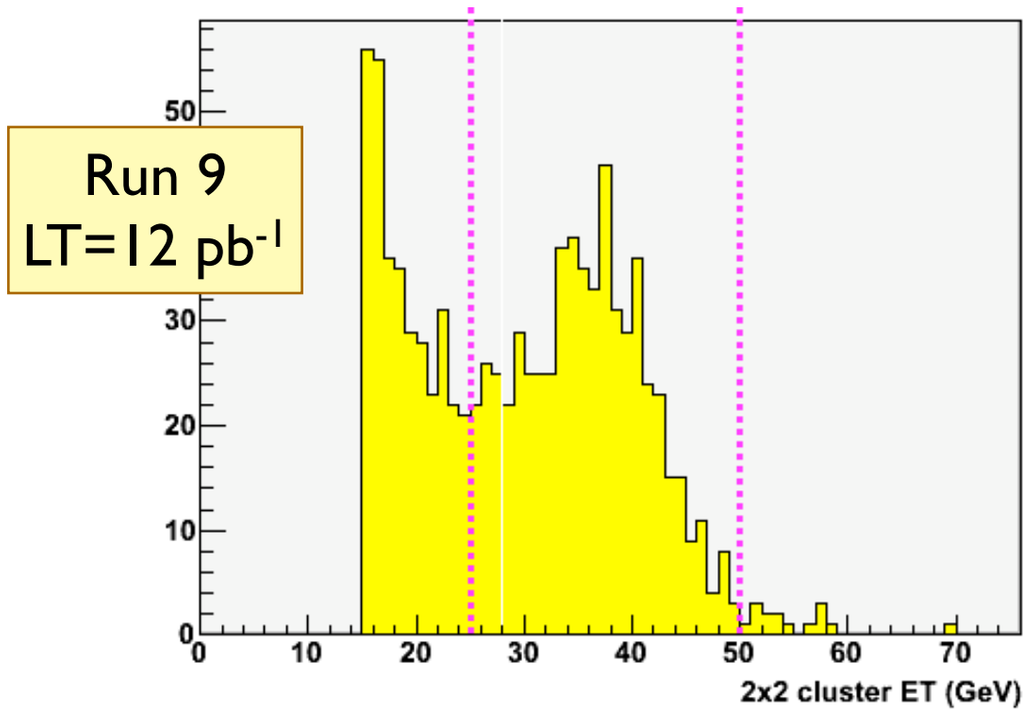
STAR Run 9 pp500 data
W-reco applied
LT~12 pb^{-1}

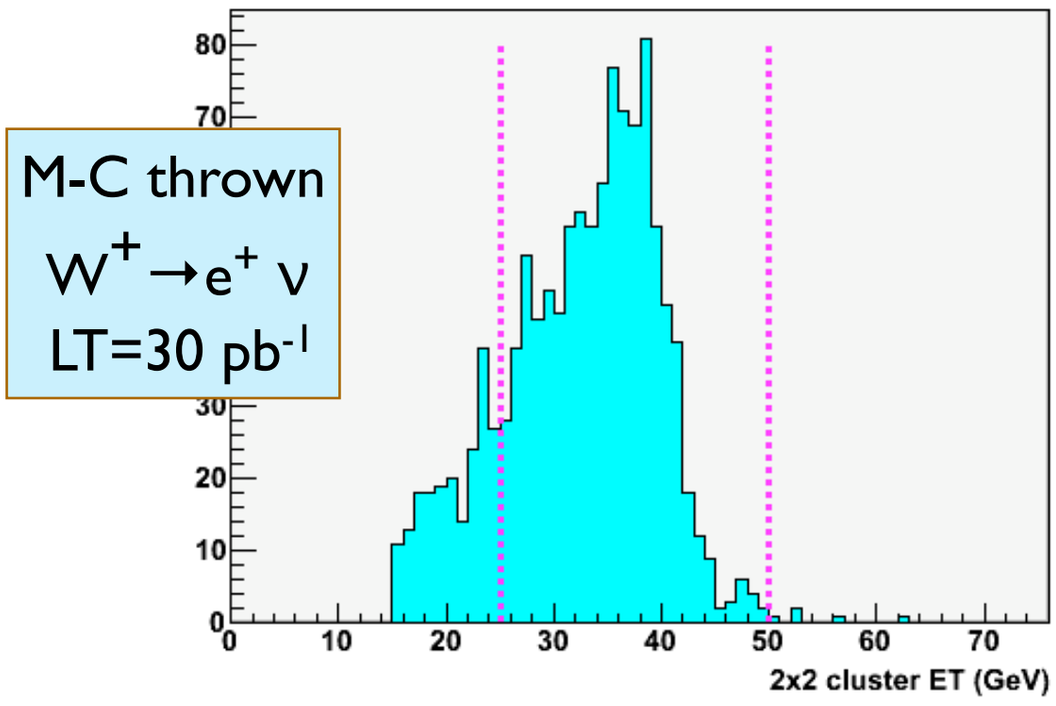
- Pythia: p+p→jet+jet
- STAR Geant model
- W-reco algo applied

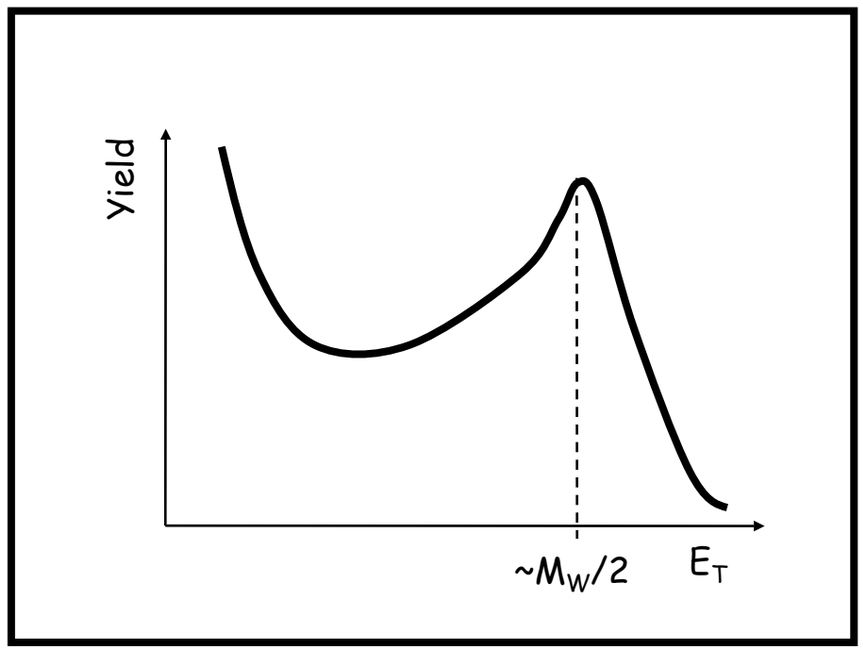
LT~6 pb^{-1}

Data/MC Comparison

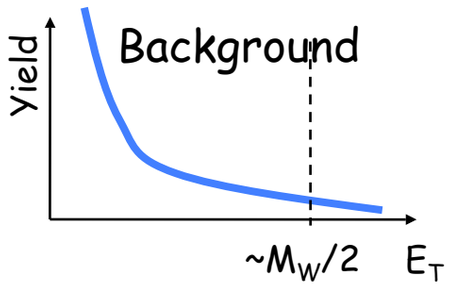
reco $p+p \rightarrow W^{\pm} \rightarrow e^{\pm} \nu$ ($\pm$ added)



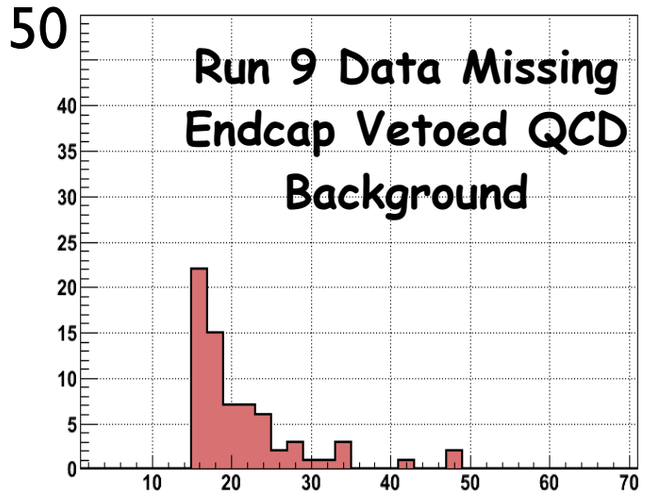




Modeling Experimental Background



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

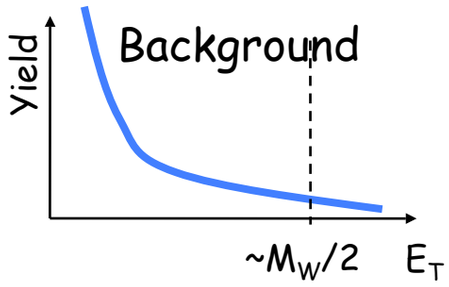


→

→

EMC Cluster E_T (GeV)

Modeling Experimental Background



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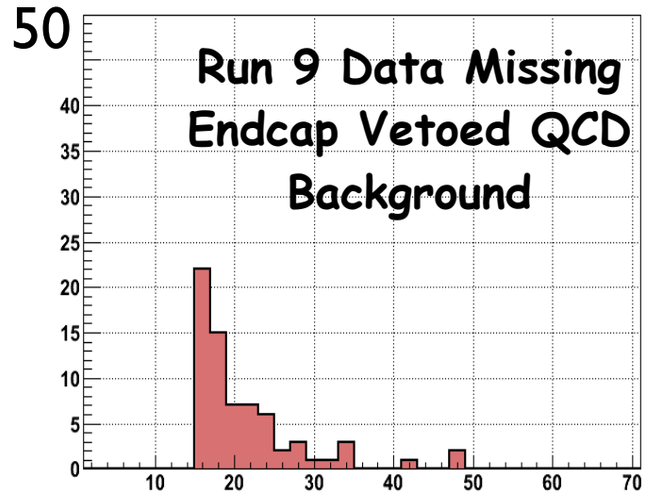
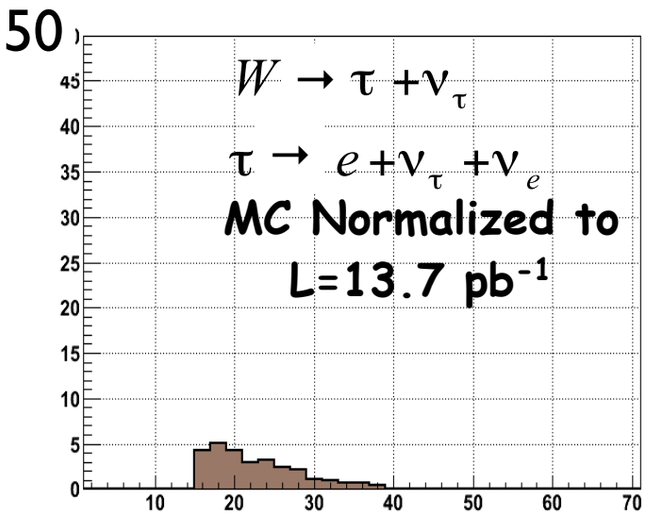
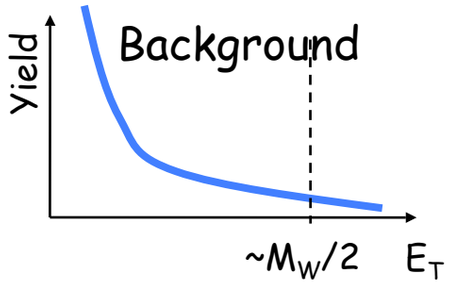
PYTHIA+GEANT MC →





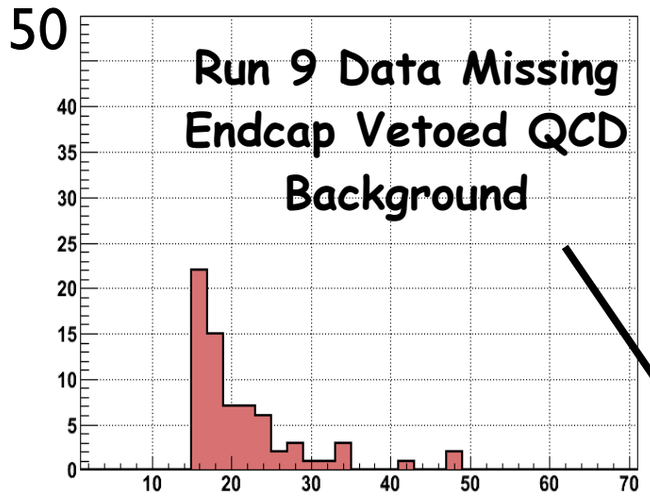
EMC Cluster E_T (GeV)

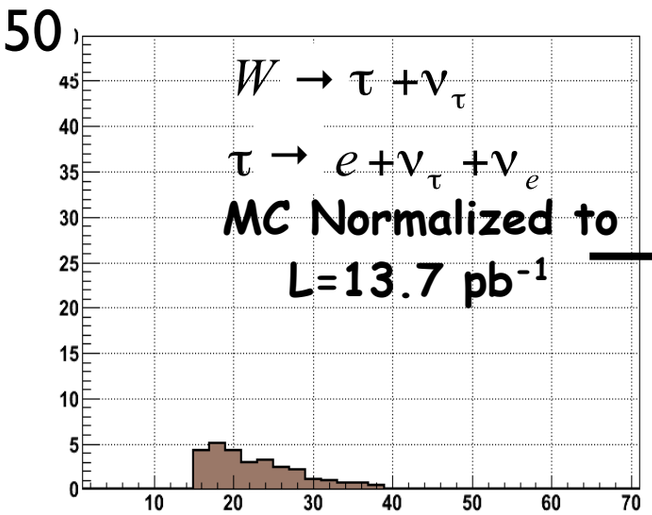
Modeling Experimental Background



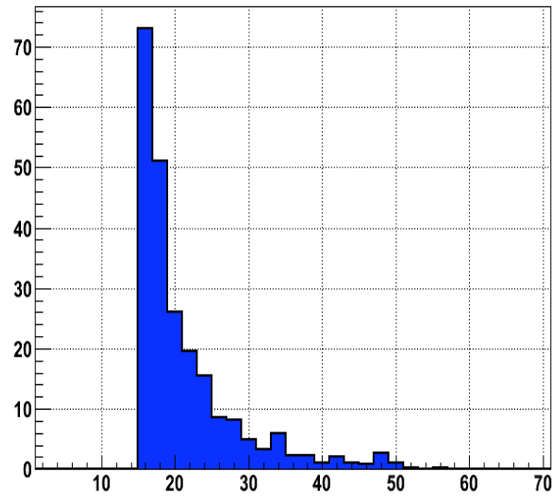
1. Run analysis with EEMC in veto cuts
2. Run analysis without EEMC in veto cuts
3. Subtract two raw signals

PYTHIA+GEANT MC

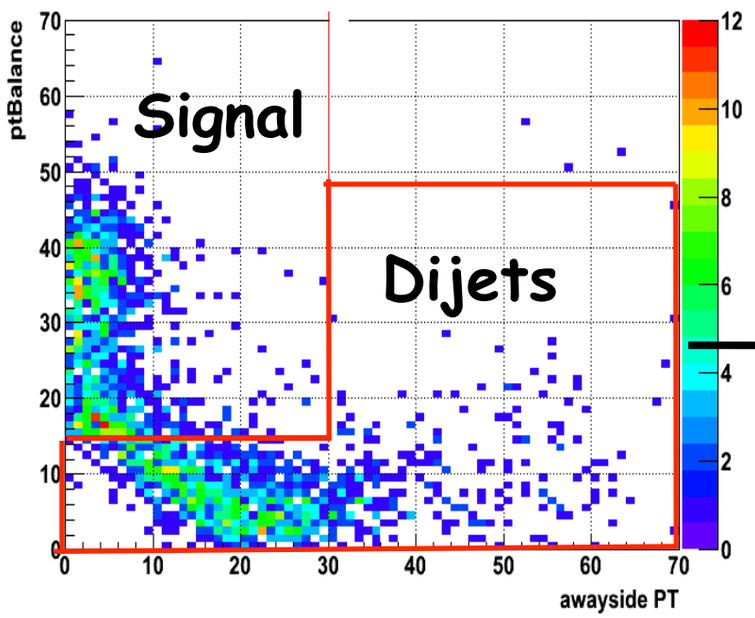


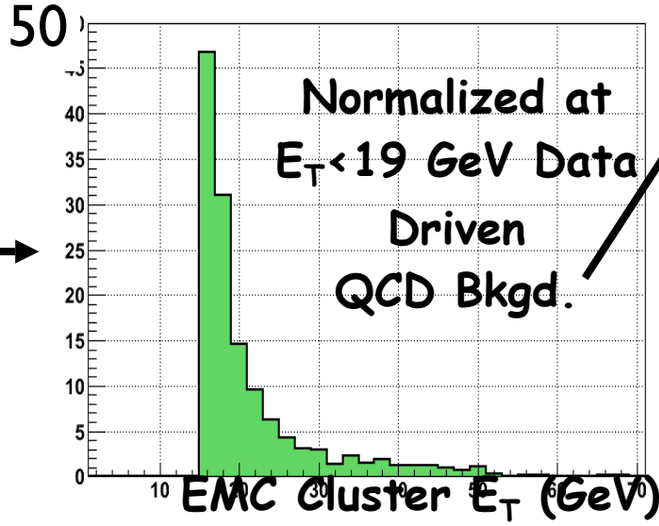


Total Background



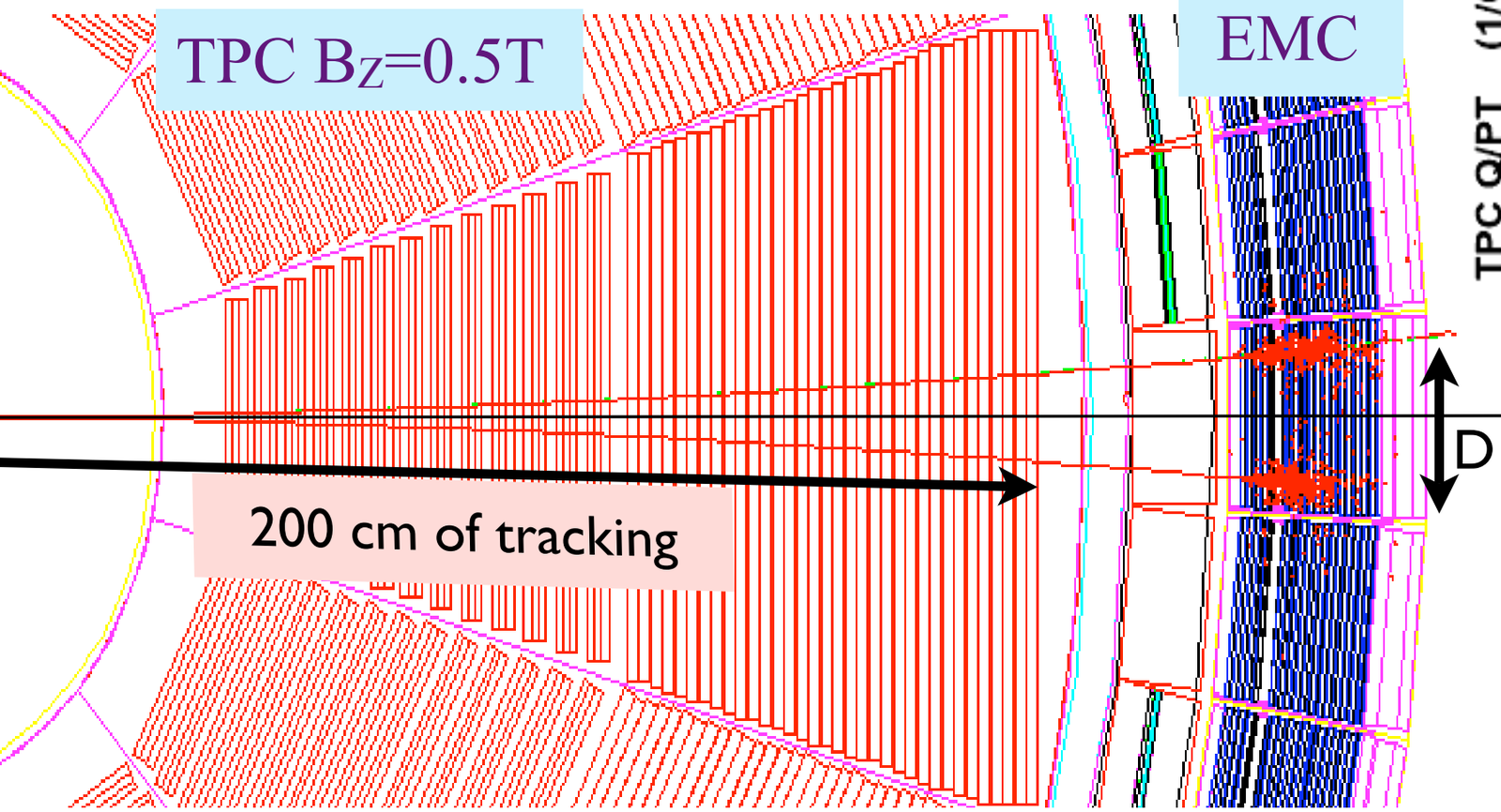
Data Driven QCD Bkgd.



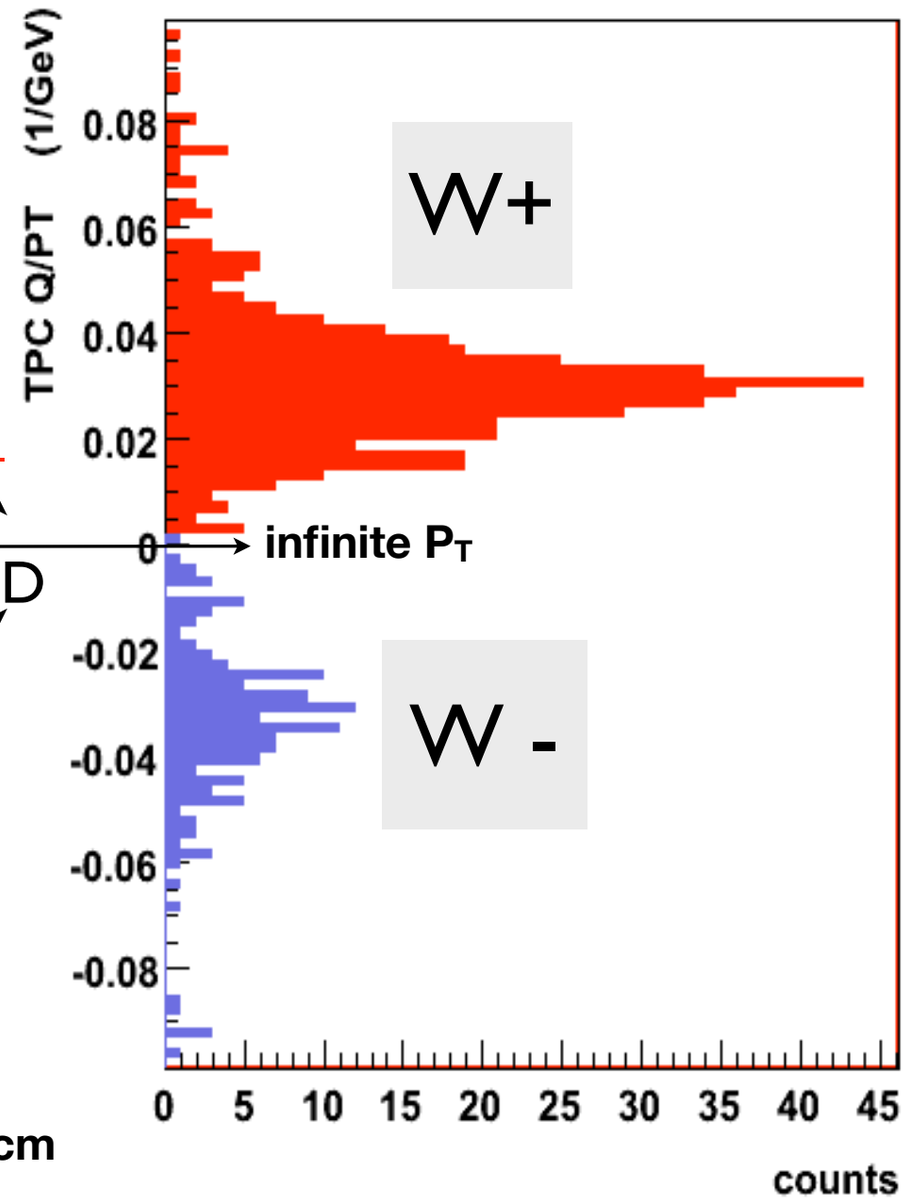


W+/ W- charge separation in STAR TPC

shown here
electron & positron
P_T= 5 GeV/c



STAR Run 9 data
E_T>25 GeV



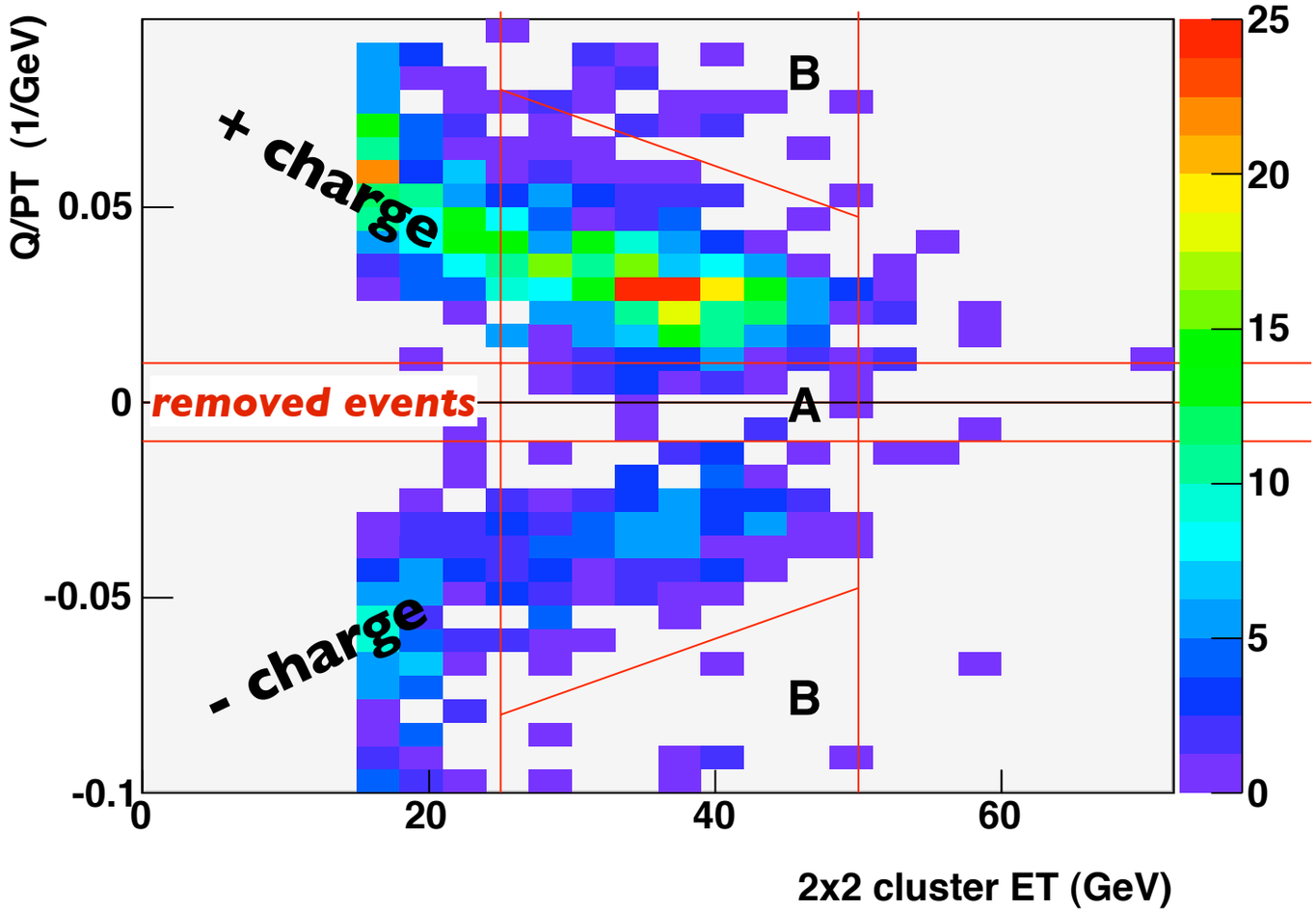
distance D ~ 1/P_T

P_T=5 GeV/c ➪ D~15 cm

P_T=40 GeV/c ➪D ~2 cm

Ambiguous reco charge removed for A_L

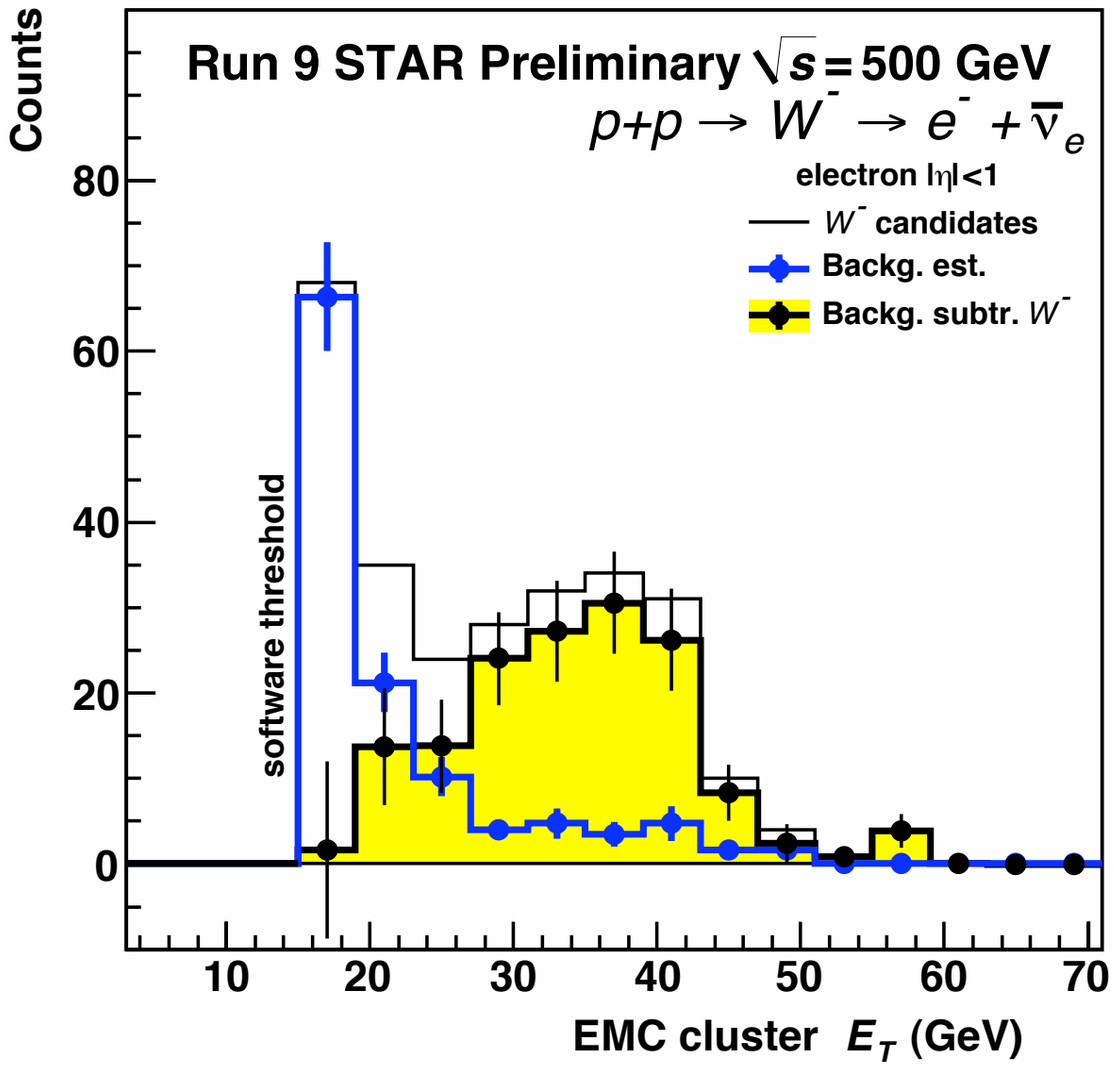
Run 9
LT=12 pb^{-1}

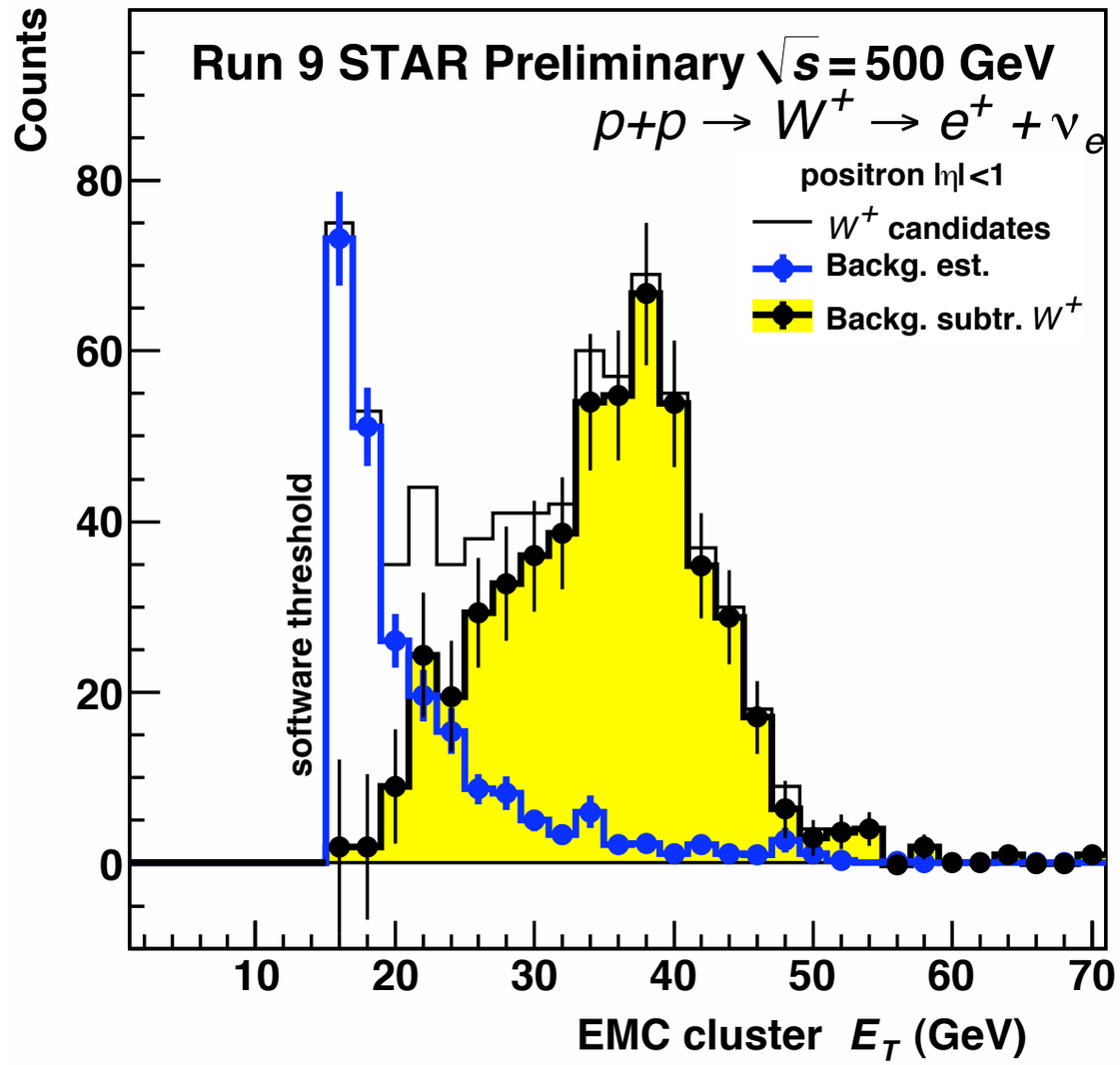


± charges do NOT mix for E_T<50 GeV

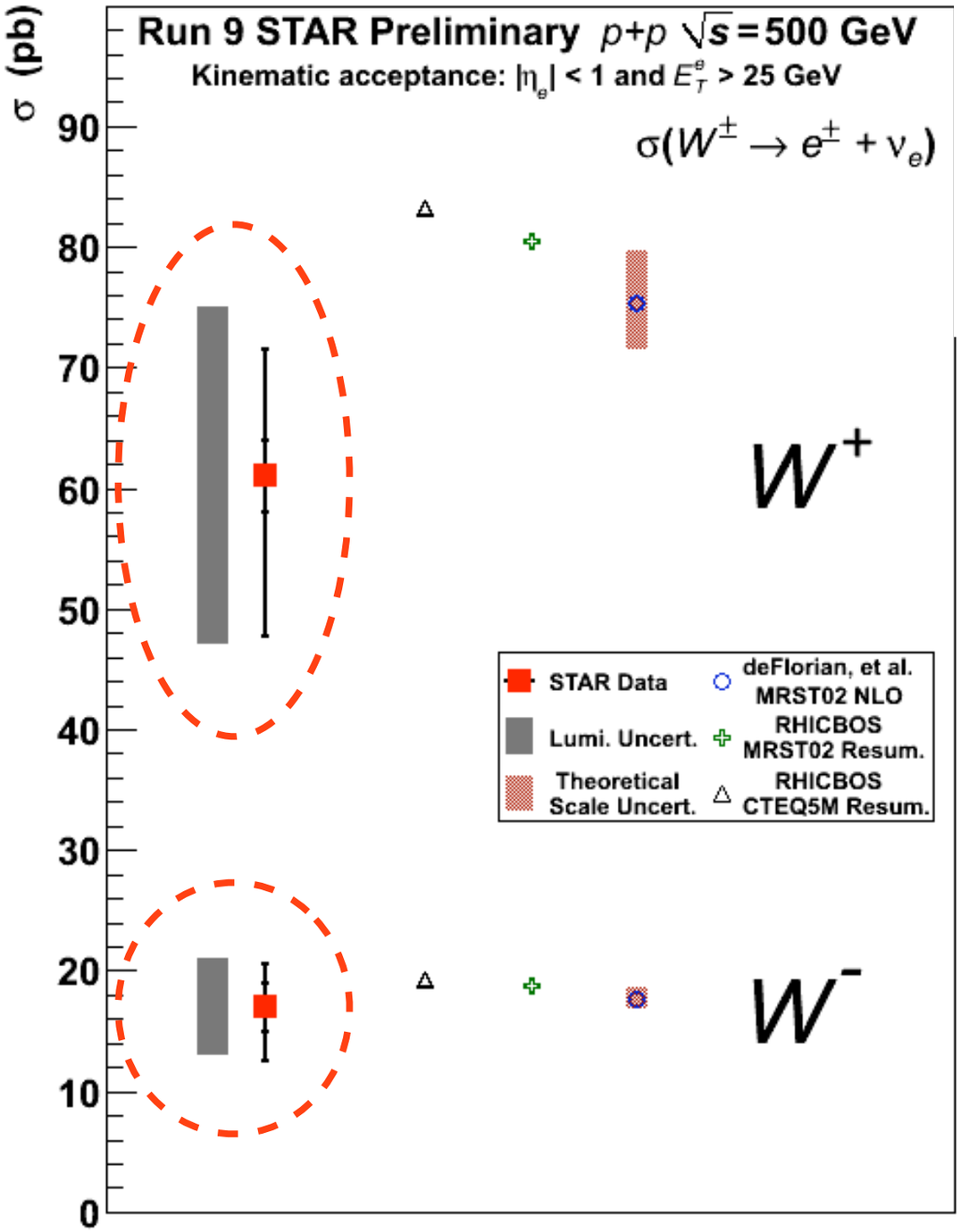
➡ **A_L(W+) , A_L(W-) independent**

Reconstructed Jacobian Peak for W+, W-





W 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

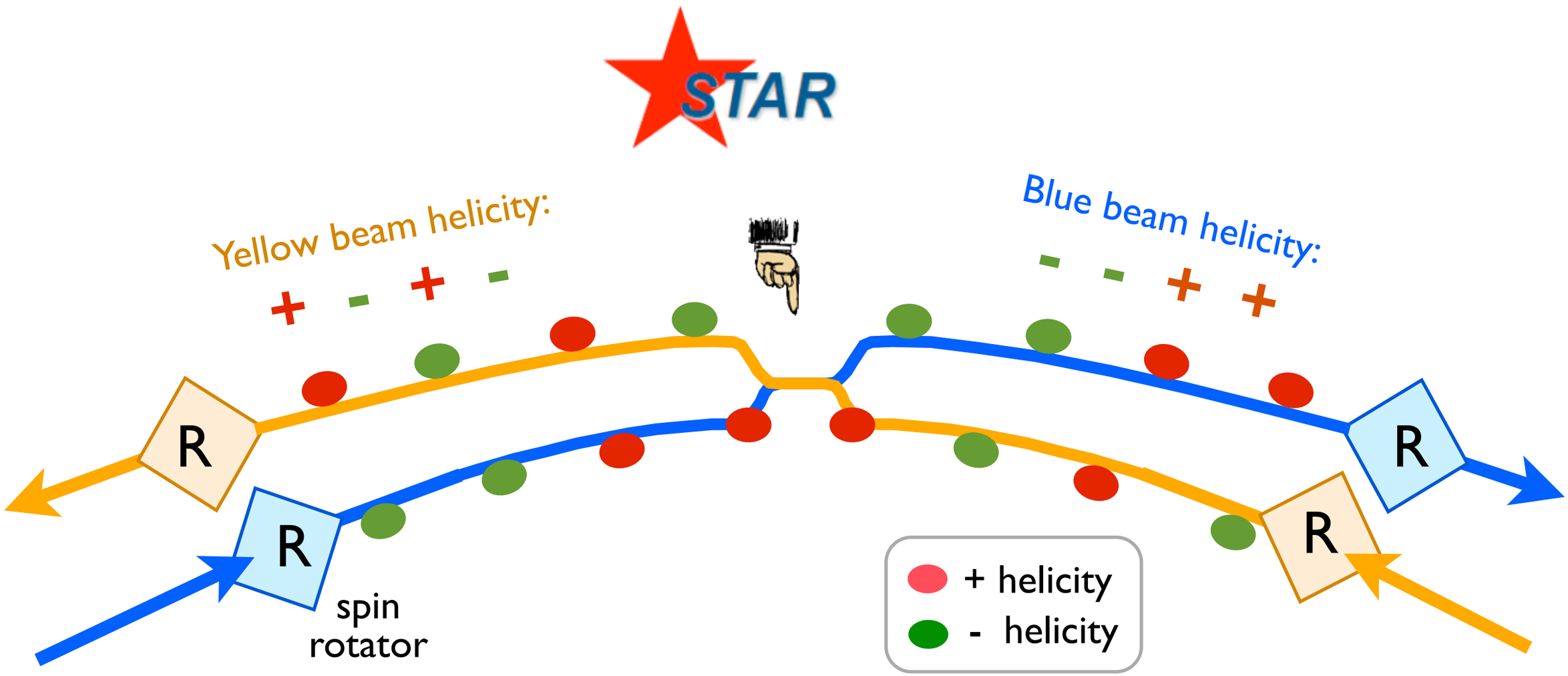
Run 9 STAR Preliminary (p+p 500 GeV)

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

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

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

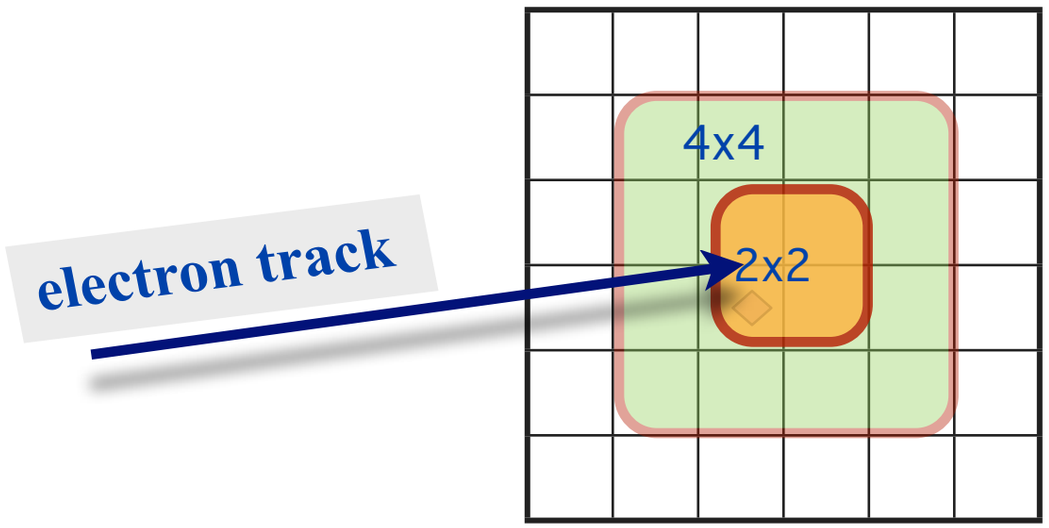
Helicity of beams colliding at STAR

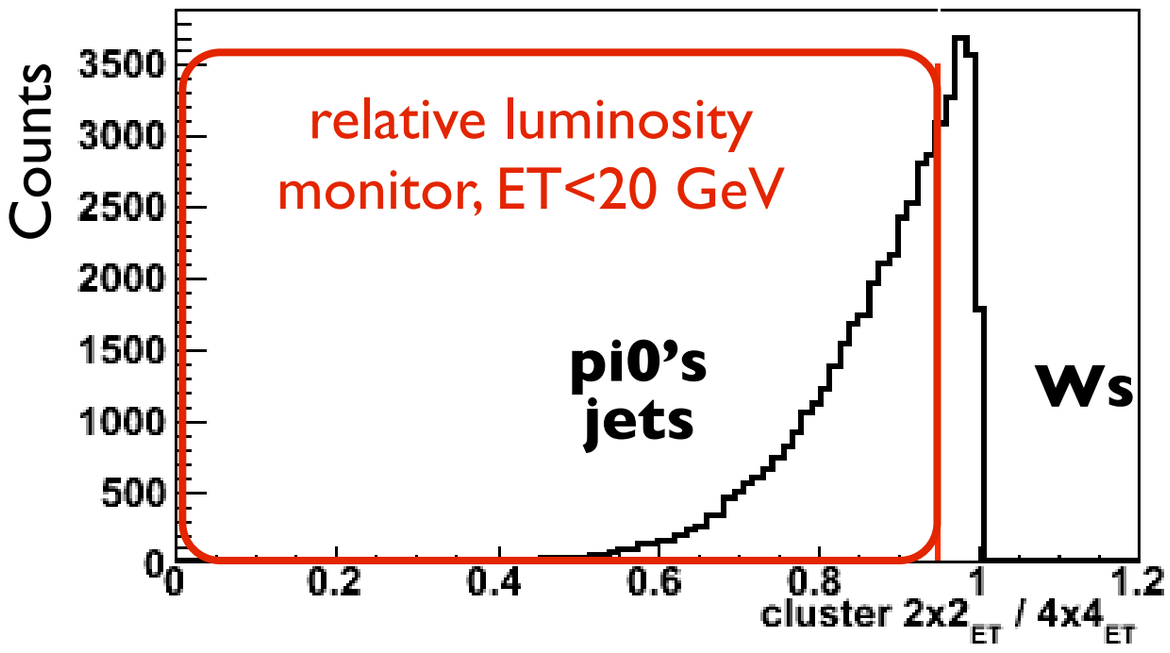


STAR sees 4 helicity configurations
STAR runs 4 parallel measurements

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

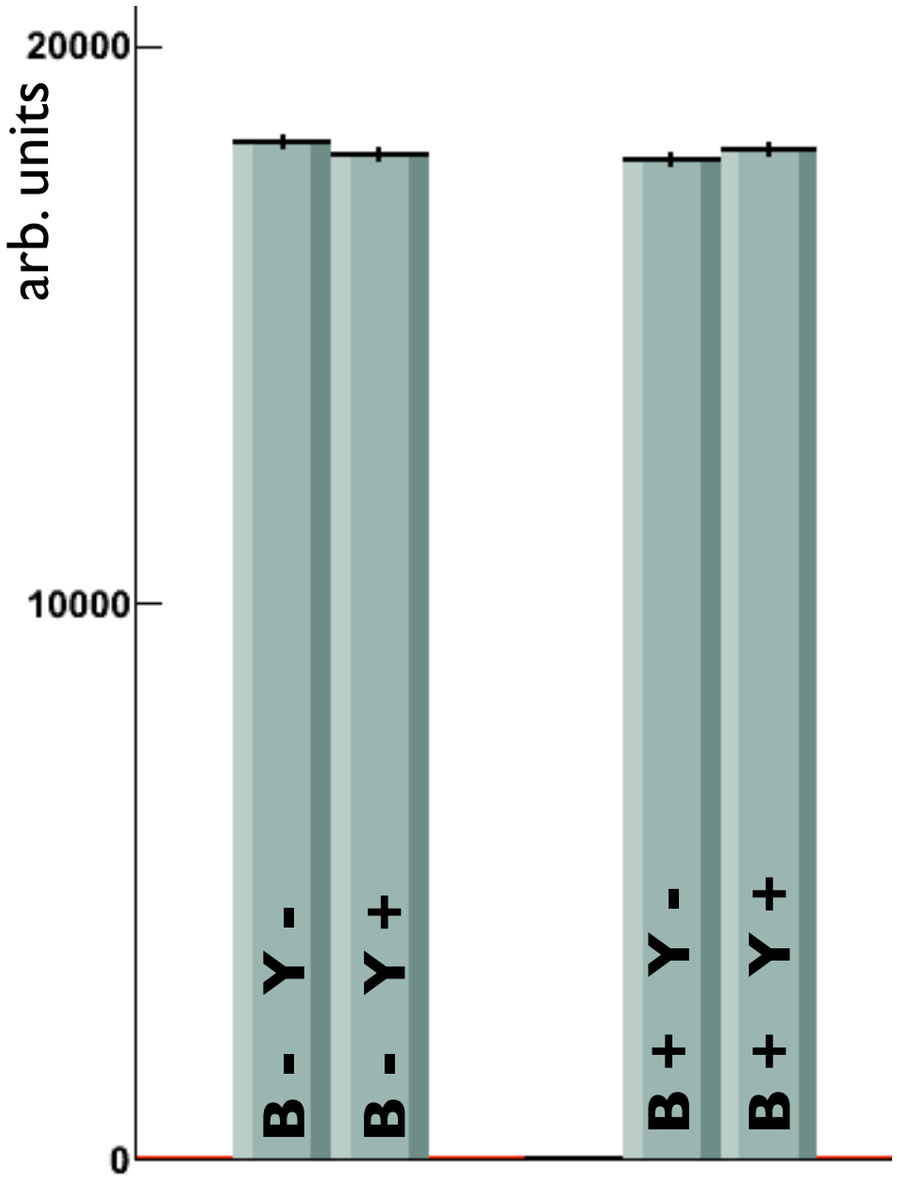
Spin dependent luminosity monitoring





QCD processes conserve parity → A_L=0
→ no spin dependent lumi bias

spin dependent luminosity of
4 states monitored to ~1%



helicities of
beams colliding at STAR

Spin dependent x-section for longitudinal polarization

yields integrated over |eta|<1

P-V A_L (the goal)

A_{LL}

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

$$A_L = \frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\overrightarrow{\sigma} + \overleftarrow{\sigma}}$$

$$A_N = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow - \sigma\downarrow}$$

$$A_{LL} = \frac{\sigma_{\rightarrow\rightarrow} - \sigma_{\rightarrow\leftarrow}}{\sigma_{\rightarrow\rightarrow} + \sigma_{\rightarrow\leftarrow}}$$

Spin dependent x-section for longitudinal polarization

yields integrated over |eta|<1

P-V A_L (the goal)

A_N x residual transverse pol Q

A_{LL}

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

$$A_N = \frac{\sigma\uparrow - \sigma\downarrow}{\sigma\uparrow - \sigma\downarrow}$$

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 x-section for longitudinal polarization

yields integrated over |eta|<1

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

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

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

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

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

neglected because STAR is phi-symmetric

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

Longitudinal 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 (average)	$(\sigma_{++} - \sigma_{--}) \;/\; sum4$	$A_L \dfrac{P_1 + P_2}{2}$
A_{LL}	$(\sigma_{++} + \sigma_{--} - \sigma_{-+} - \sigma_{+-}) \;/\; sum4$	$A_{LL} P_1 P_2$
Null test $A_L(P_1 - P_2)$	$(\sigma_{+-} - \sigma_{-+}) \;/\; (\sigma_{-+} + \sigma_{+-})$	$\dfrac{A_L(P_1 - P_2)}{1 - A_{LL} P_1 P_2}$

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

Longitudinal 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

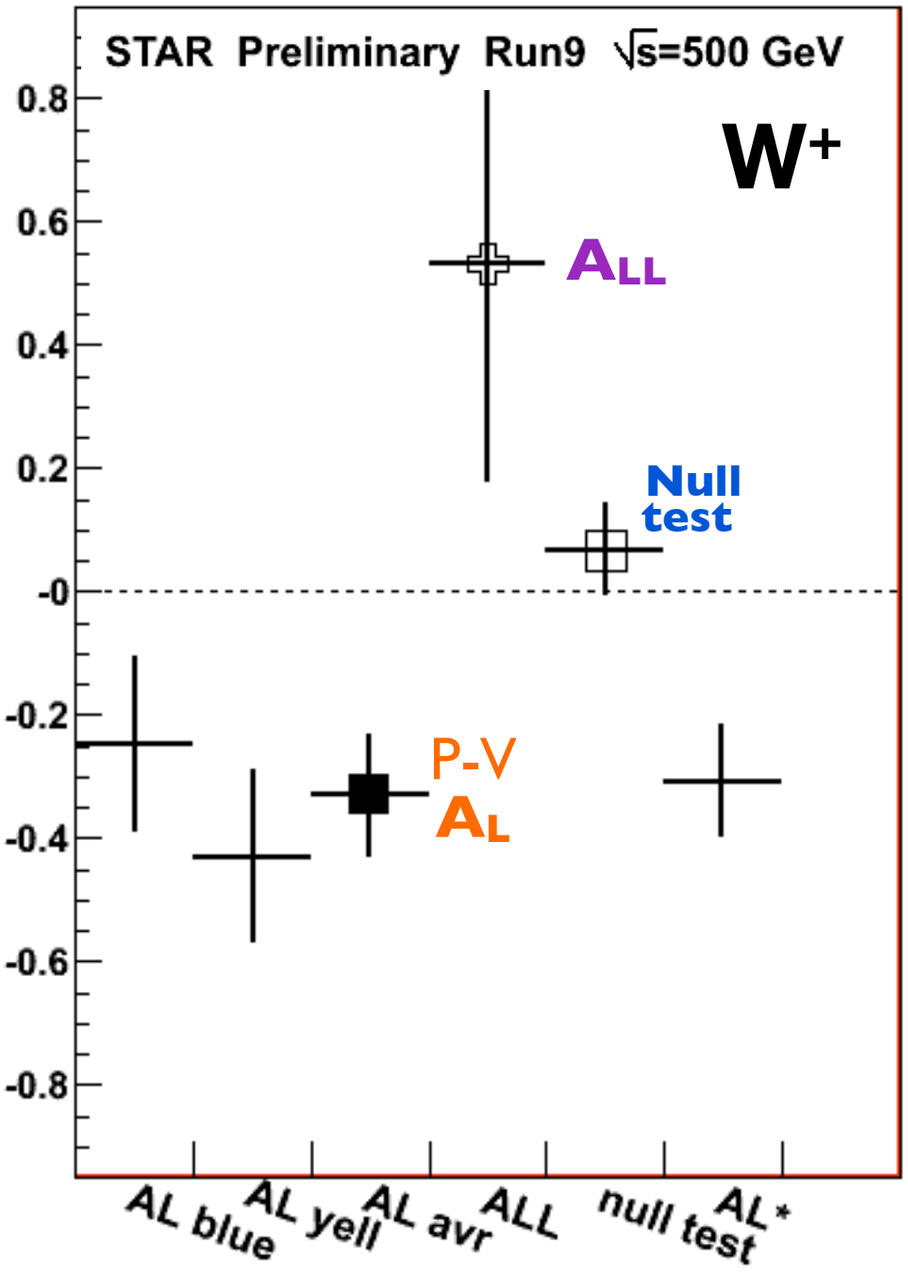
Leading physics asymmetry	cross section dependence	raw asymmetry
A_L (blue)	$(\sigma_{++} + \sigma_{+-} - \sigma_{--} - \sigma_{-+})/sum4$	$A_L P_1$
A_L (yellow)	$(\sigma_{++} + \sigma_{-+} - \sigma_{--} - \sigma_{+-})/sum4$	$A_L P_2$
A_L (average)	$(\sigma_{++} - \sigma_{--}) \;/\; sum4$	$A_L \dfrac{P_1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

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

6 measured spin asymmetries for W+

STAR Run 9 data integrated over |eta|<1

Positive charge, unpol yield=392

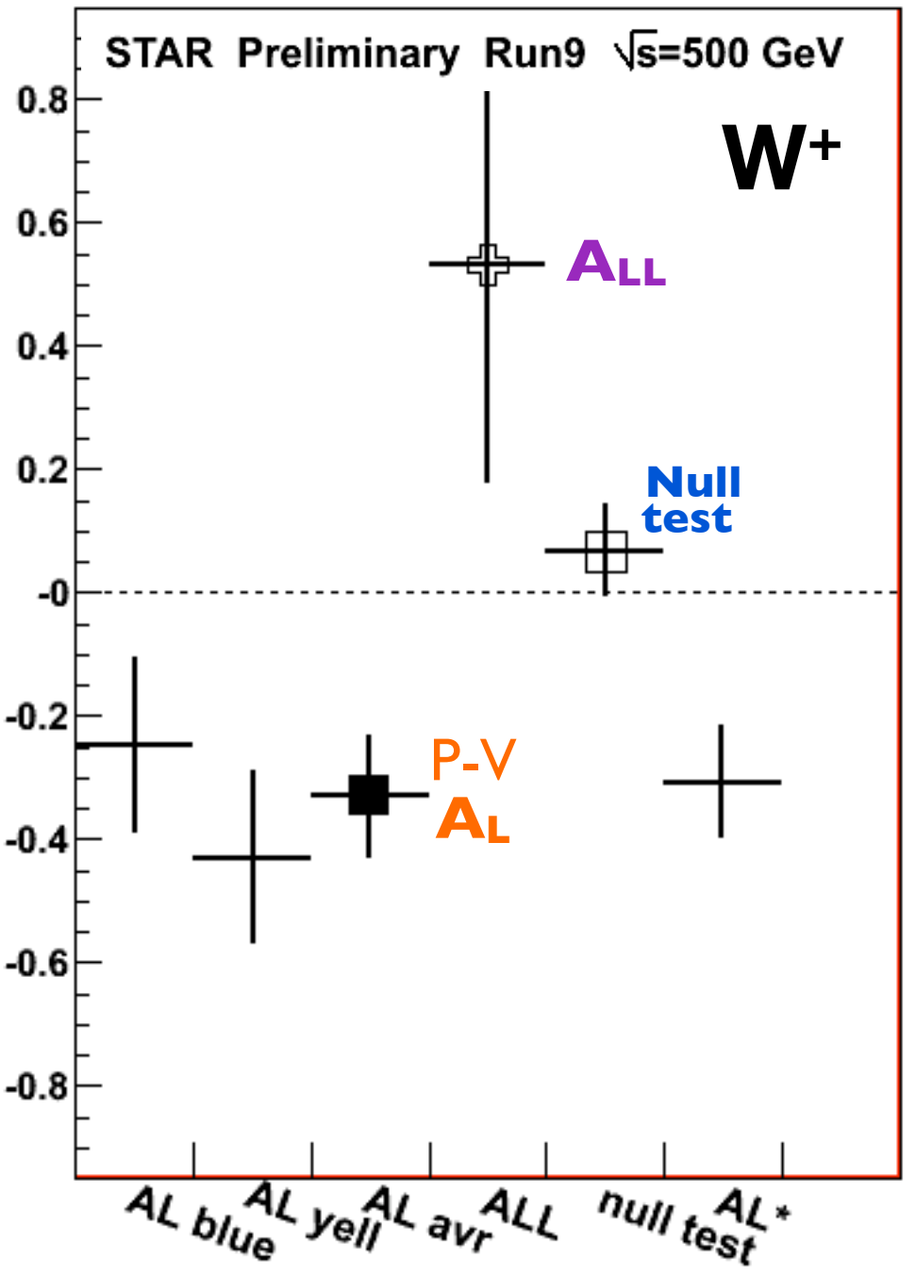


Physics asymmetries corrected for unpolarized background

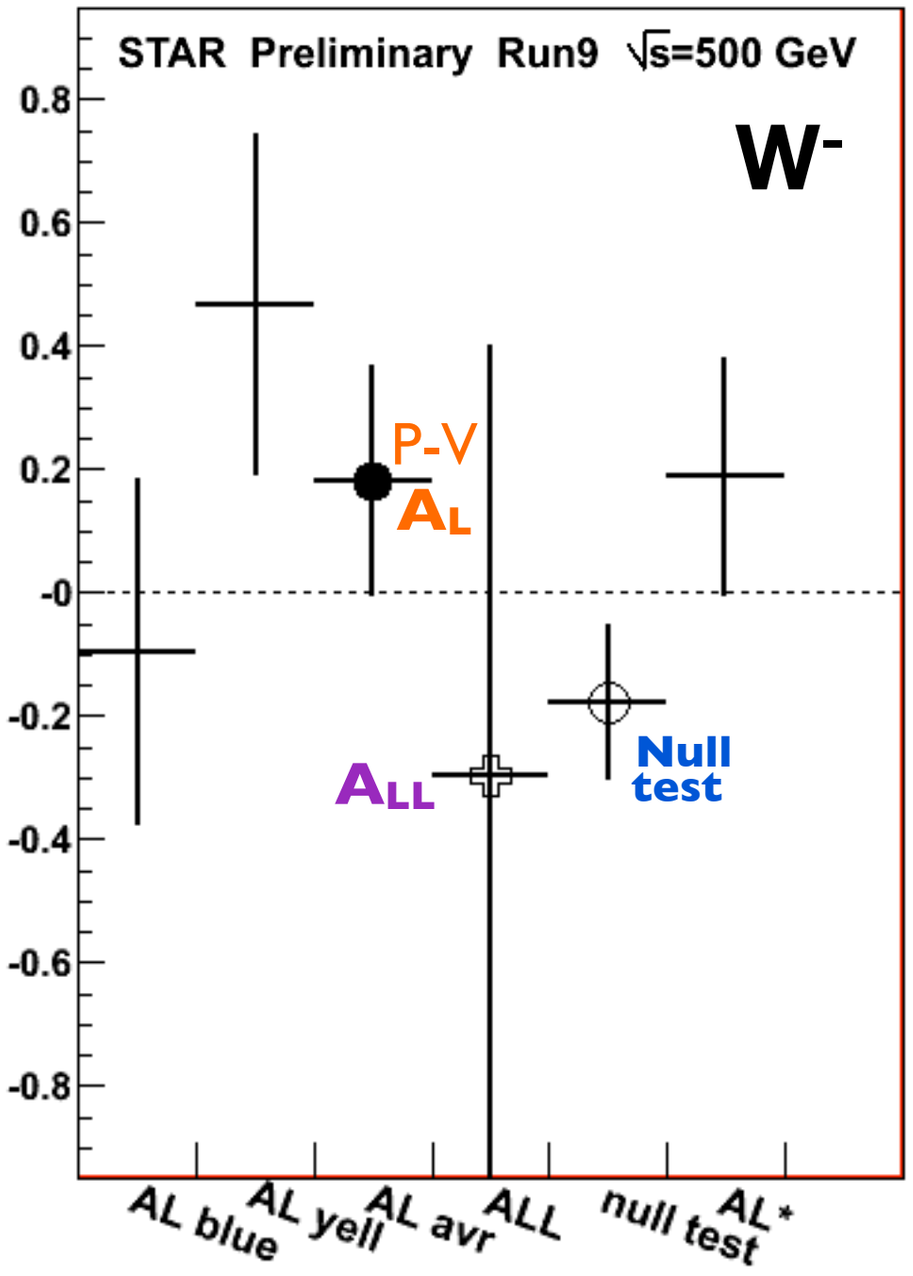
6 measured spin asymmetries for W+ and W-

STAR Run 9 data integrated over |eta|<1

Positive charge, unpol yield=392

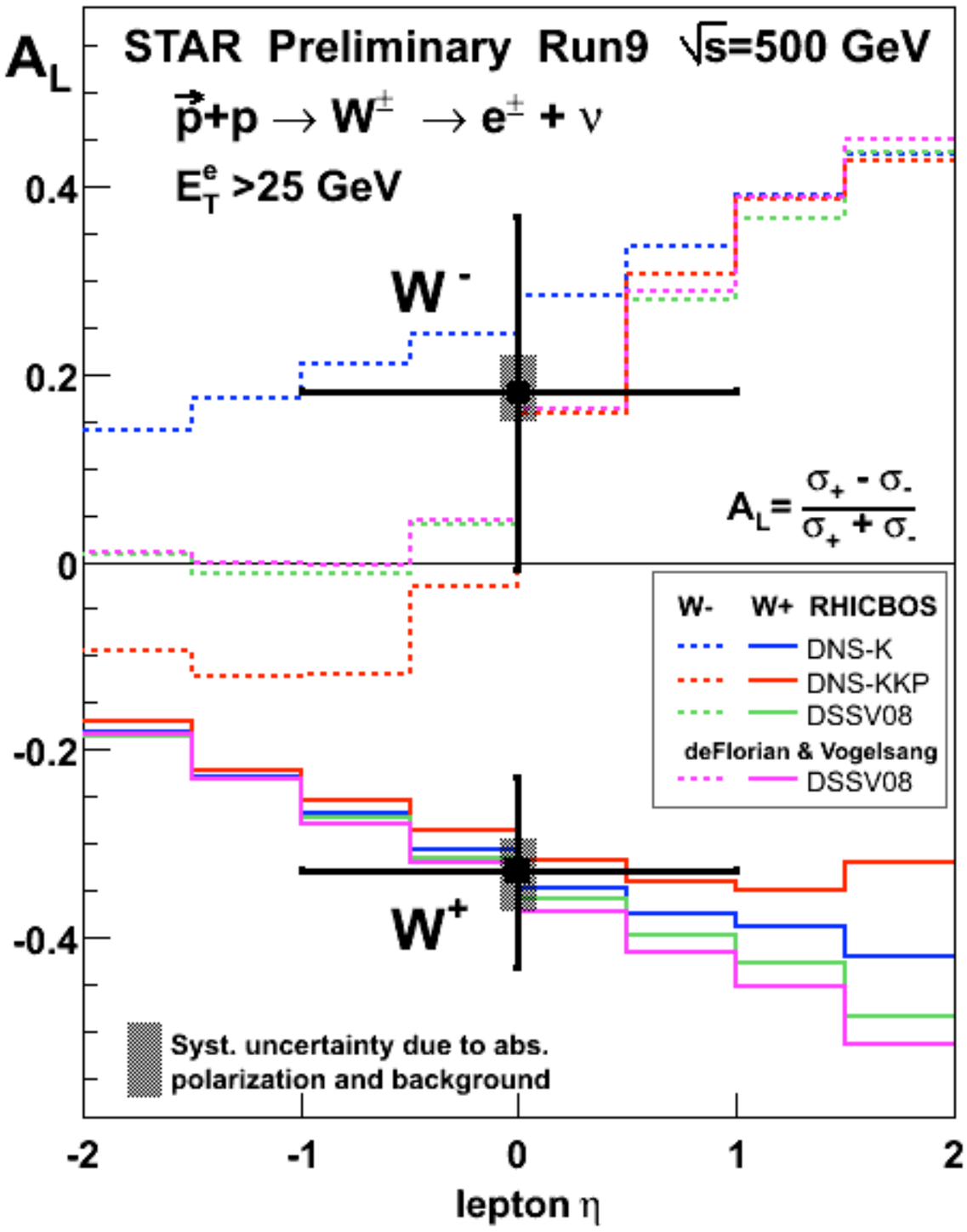


Negative charge, unpol yield=118



Physics asymmetries corrected for unpolarized background

A_L for Ws measured in Run 9



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

STAR Preliminary Run 9

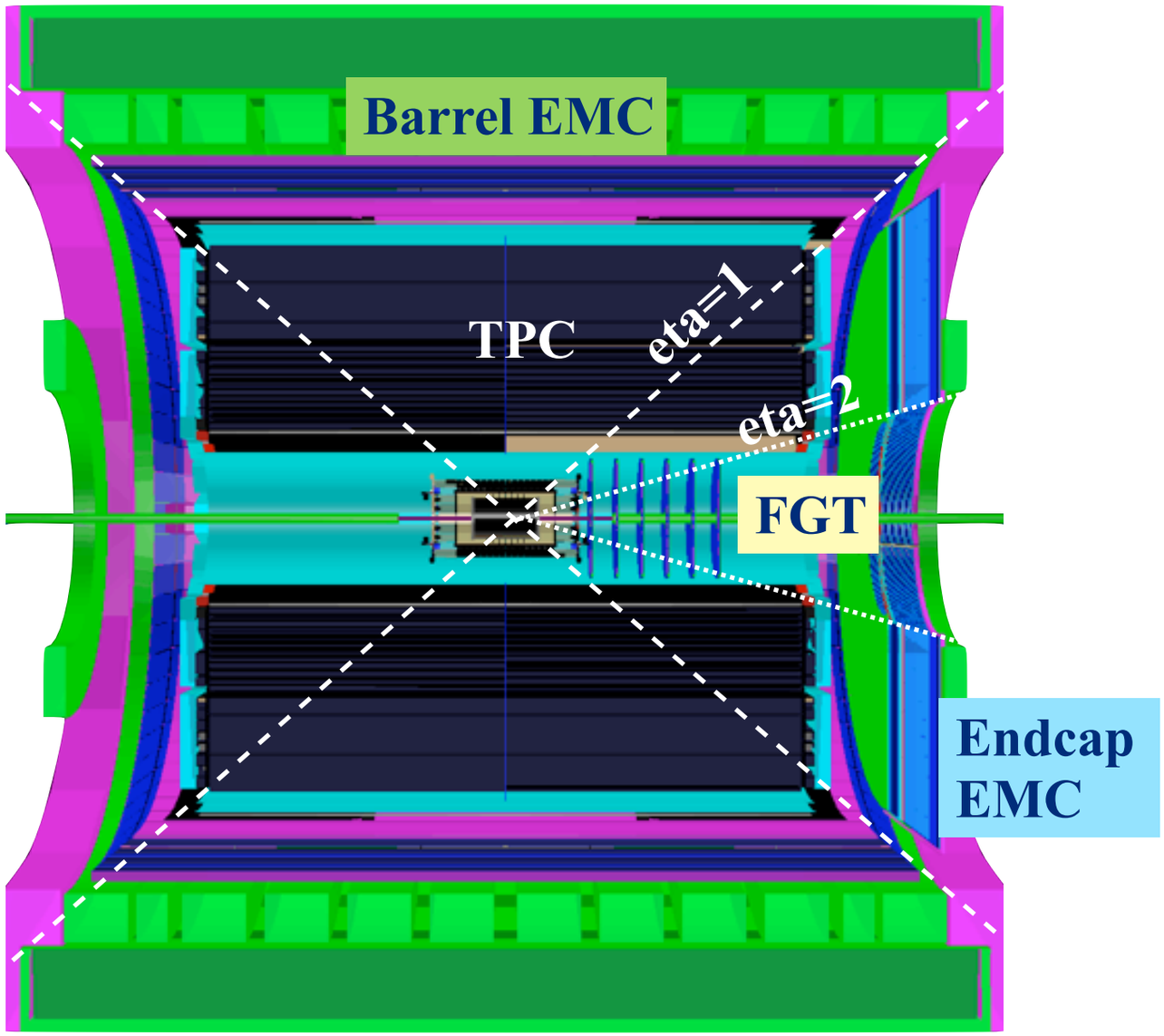
$$A_L(W^+) = -0.33 \pm 0.10(\text{stat.}) \pm 0.04(\text{syst.})$$

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

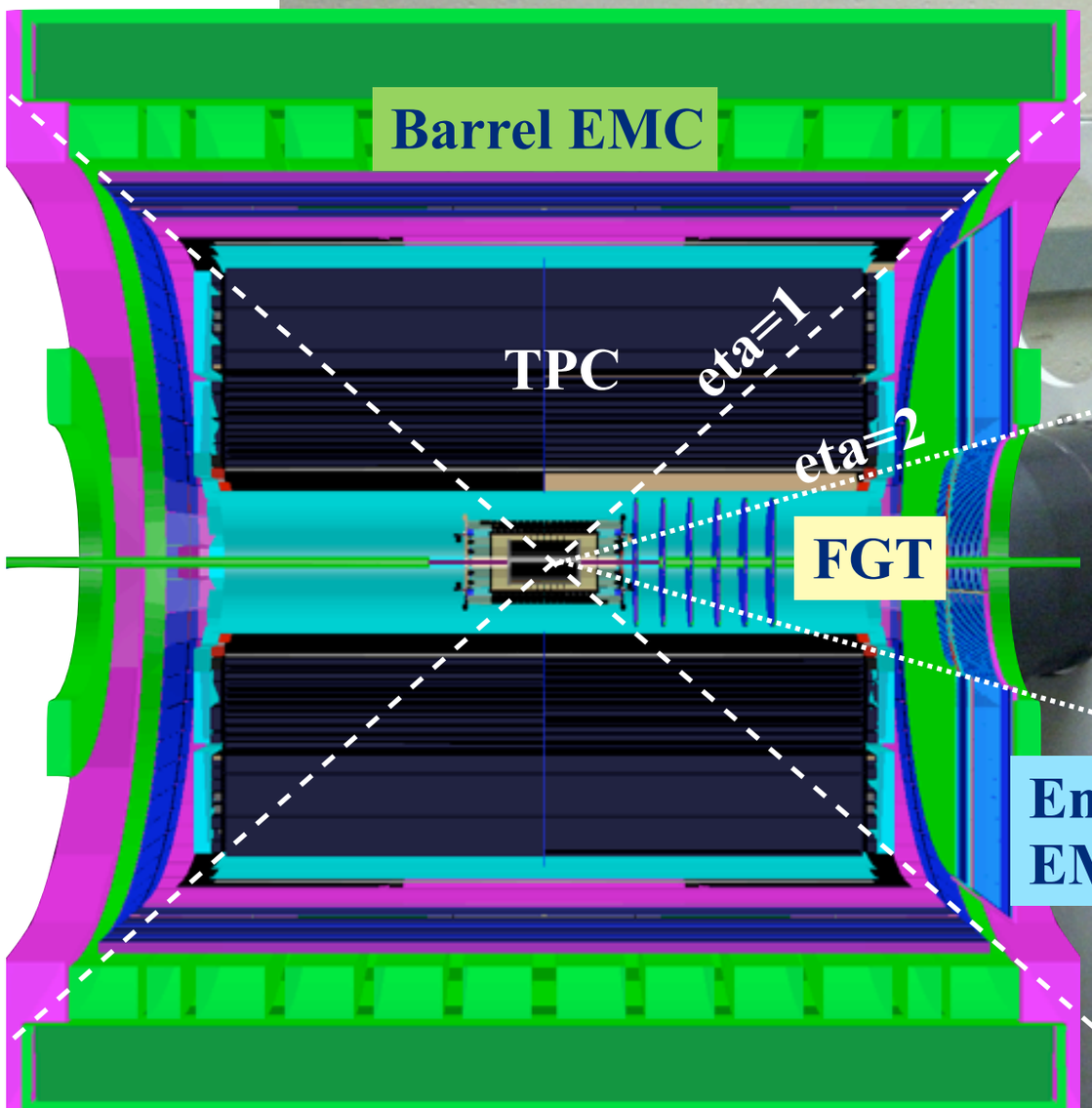
Summary
(for mid rapidity leptons)

- $A_L(W^+)$ negative, as predicted, **~3 sigma <0**
- $A_L(W^-)$ central value positive, as expected
- systematic errors of A_L under control
- TPC charge separation works up to ET~50 GeV

Future W Measurements at STAR



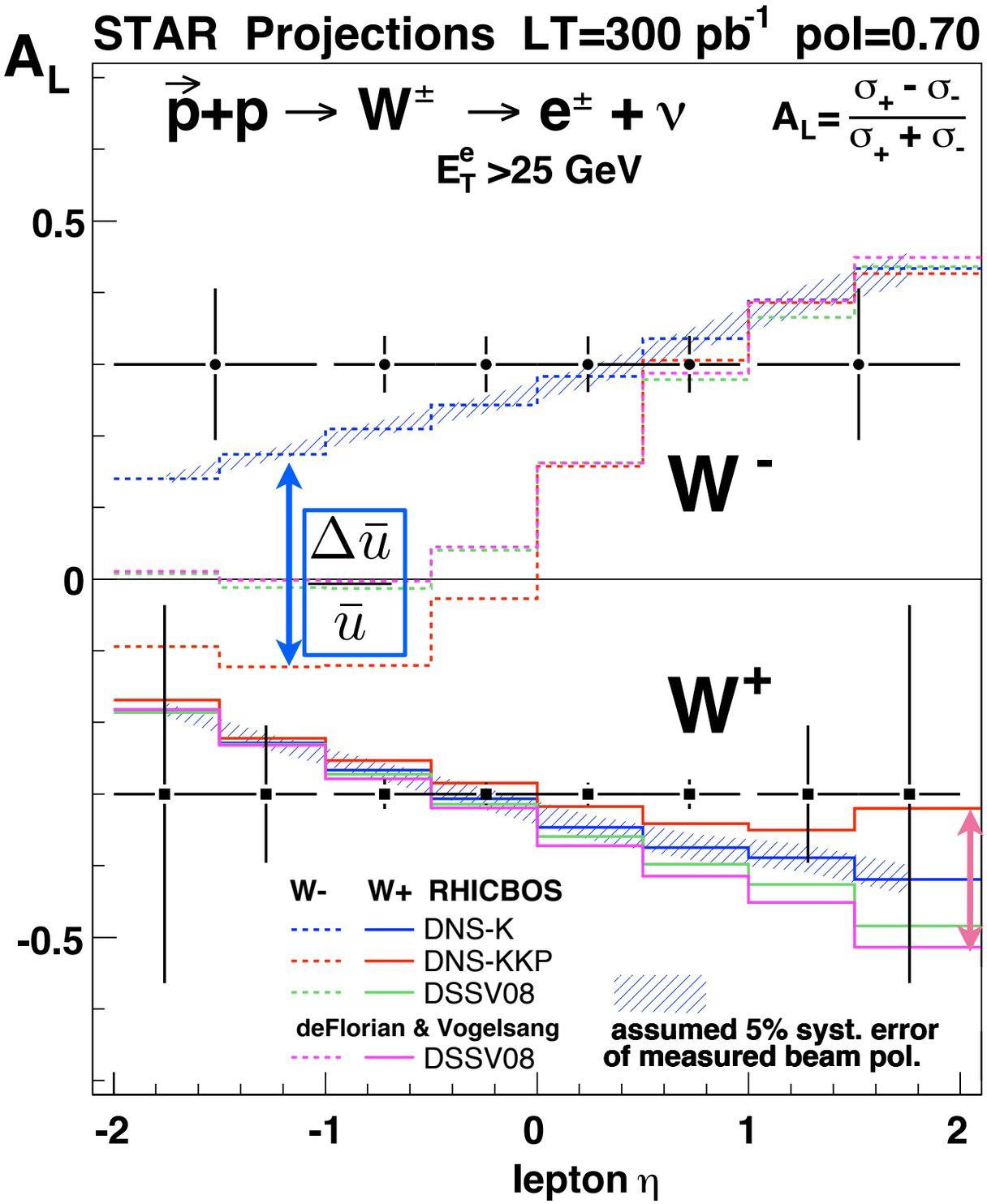
Future W Measurements at STAR

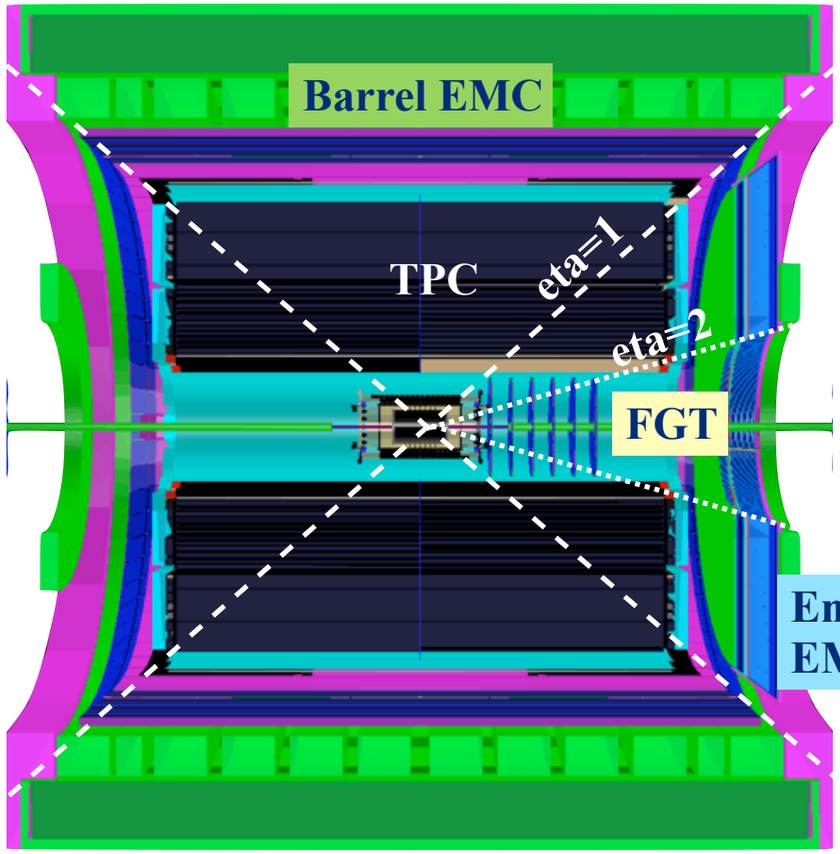


FGT thermo-model
1:1 prototype

Future W Measurements at STAR

lepton $|\eta|<1$: 2 beams, eff=0.65 w/ 9MHz RF, Run9 QCD bckg, rhicbos $\sigma W^+, W^- = 82, 19$ pb
lepton $|\eta| \in [1,2]$: 1 beam, eff=0.60 w/ 9MHz RF, M-C QCD bckg, rhicbos $\sigma W^+, W^- = 5.3, 4.7$ pb





$\frac{\Delta \bar{d}}{\bar{d}}$

Expected installation of FGT in Summer of 2011

Summary

- Run 9: First observation of W production at STAR
  First collision of polarized proton beams at $\sqrt{s}$ = 500GeV (P~40% / L~14pb-1)
  W± Cross-section and Parity violating single-spin asymmetry measurement

- Critical analysis aspects:
  Charge-sign discrimination at high pT
  Rejection and treatment of QCD background

- W A_L & cross section papers in preparation

- Forward tracking upgrade, large luminosity & polarization
  allow STAR to access helicity of the sea quarks