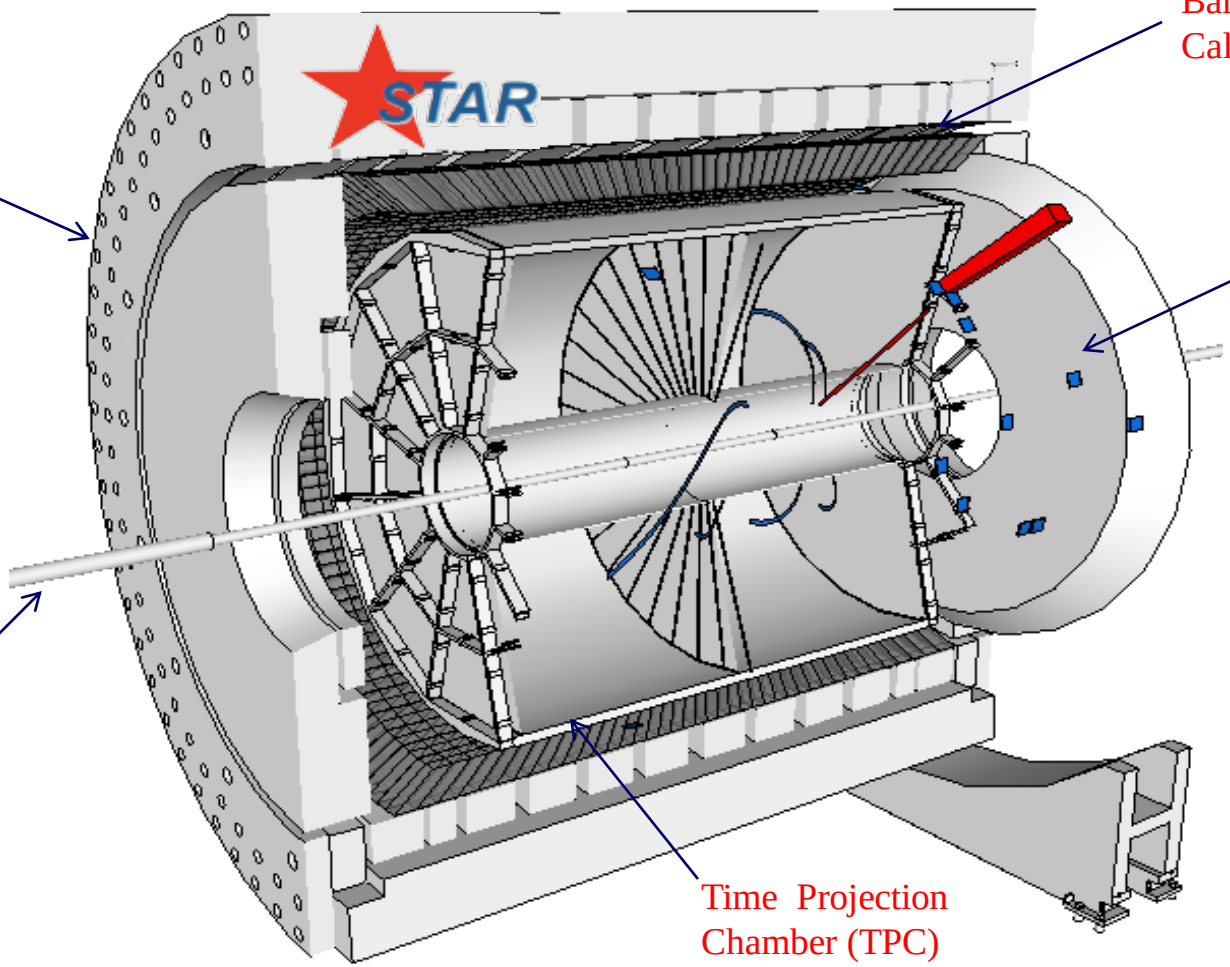
Measurement of the parity-violating longitudinal single-spin asymmetry for W boson production in polarized proton-proton collisions at $\sqrt{s} = 500 GeV$



DIFFRACTION 2010
September 10 -15
Otranto, Italy

George Igo
for STAR Collaboration

Introduction

- The over-all goal of the STAR Collaboration's spin program at RHIC is to understand the origin of the proton spin in terms of intrinsic quark and gluon spin and orbital angular momentum:

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

We note that inclusive polarized deep-inelastic scattering (DIS) experiments have shown that only approximately 30% of the spin of the proton is attributable to the polarization of the quarks and the anti-quarks.

We also point out that measurements in the medium x-range have shown that the contribution due to the polarization of the gluons, ΔG, is negligibly small. A lower x- region will be probed at STAR, run at 500 GeV in 2011, to widen the search for a contribution of ΔG to the proton's spin.

Introduction, contd

Inclusive measurements of $\Delta\Sigma$ do not discern between the various flavours of the quarks and their individual contributions to $\Delta\Sigma$.

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

Semi-inclusive DIS measurements can achieve separation of the quark and anti-quark spin contributions by flavour. However the extracted anti-quark polarized Parton Distribution Functions (PDFs) have sizeable uncertainties compared to the well-constrained (quark + anti-quark) sum.

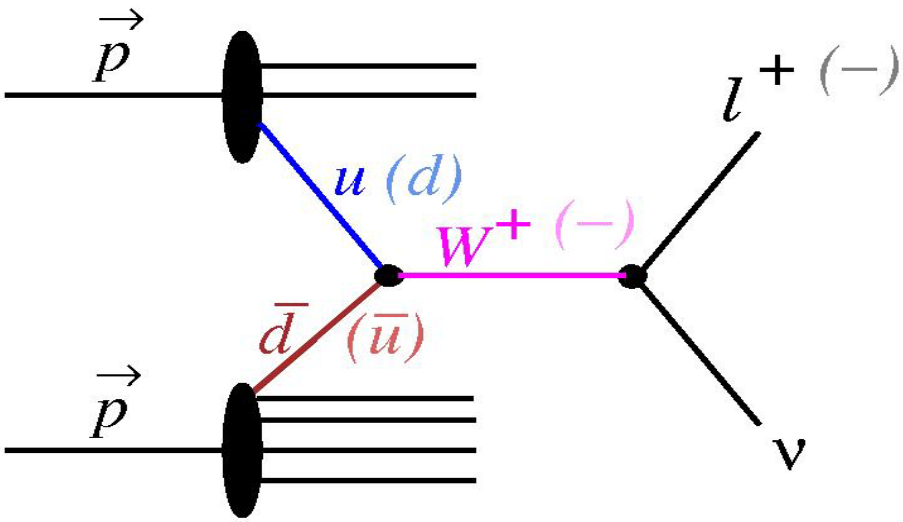
Introduction, contd

A study of W± decays will provide new information on the ubar & dbar quark contributions to the spin of the proton, as well as a check on the u and d quark contributions.

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

Measurements by the STAR collaboration at the RHIC collider during the year 2009 of W production in polarized proton collisions and their subsequent decay through electron/positron channels are the subject of this presentation. Much higher luminosity measurements planned for year 2011 will also be mentioned.

Introduction, contd



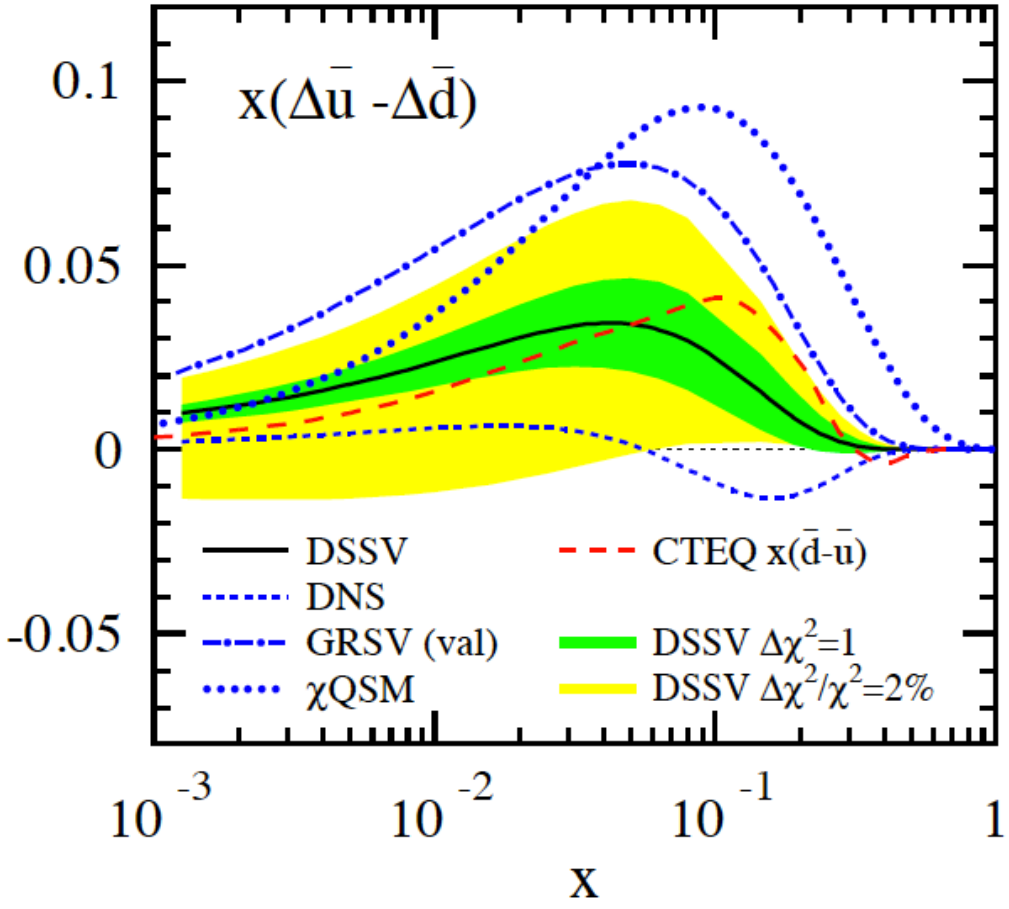
STAR measures $W^{\pm}$ through their $e^{\pm}$ decays:

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

- And measures their Parity-Violating Single Spin
- Helicity Asymmetries, $A_L = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-)$, where at LO:

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

What do we know from a global analysis about $x(\Delta\bar{u} - \Delta\bar{d})$?



Calculations:

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

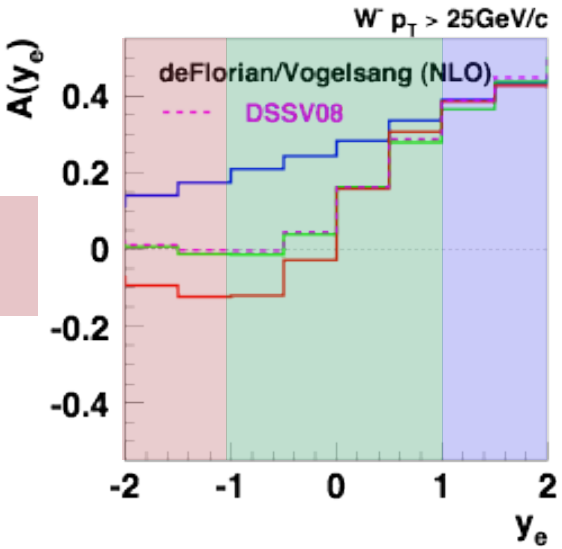
Global Analysis : deFlorian/Vogelsang Private Communication, Uncertainties: green & yellow bands

Theoretical foundation

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

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

$x_1 \ll x_2$



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

$x_1 \gg x_2$

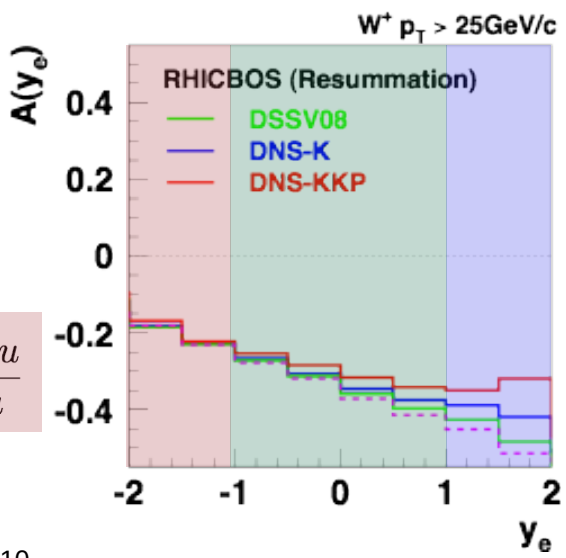
$$A_L^{W^-} = \frac{1}{2}\left(\frac{\Delta\bar{u}}{\bar{u}} - \frac{\Delta d}{d}\right)$$

$x_1 = x_2$

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

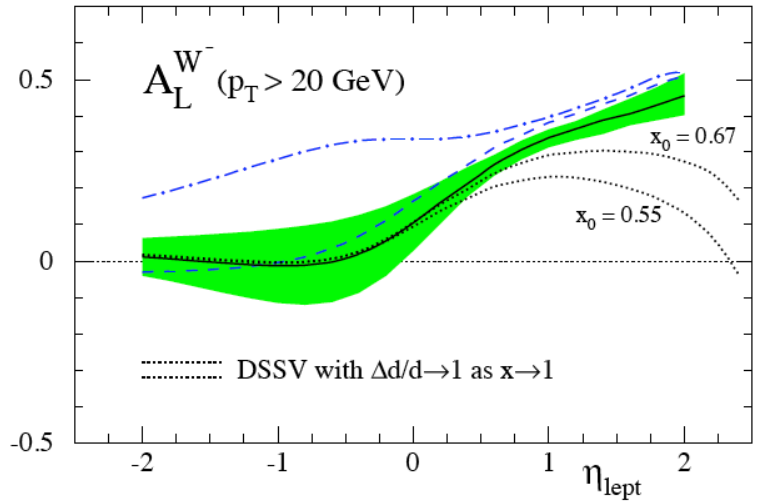
$$A_L^{W^+} = -\frac{\Delta u}{u}$$

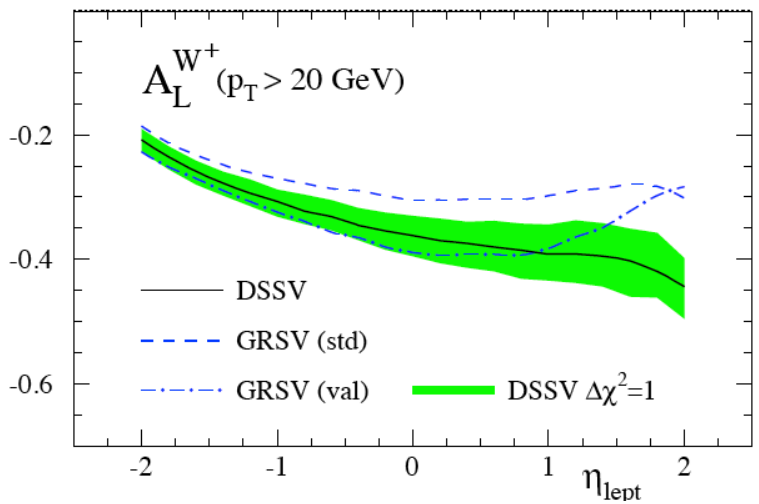
$x_1 \ll x_2$



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

$x_1 \gg x_2$





Calculations:

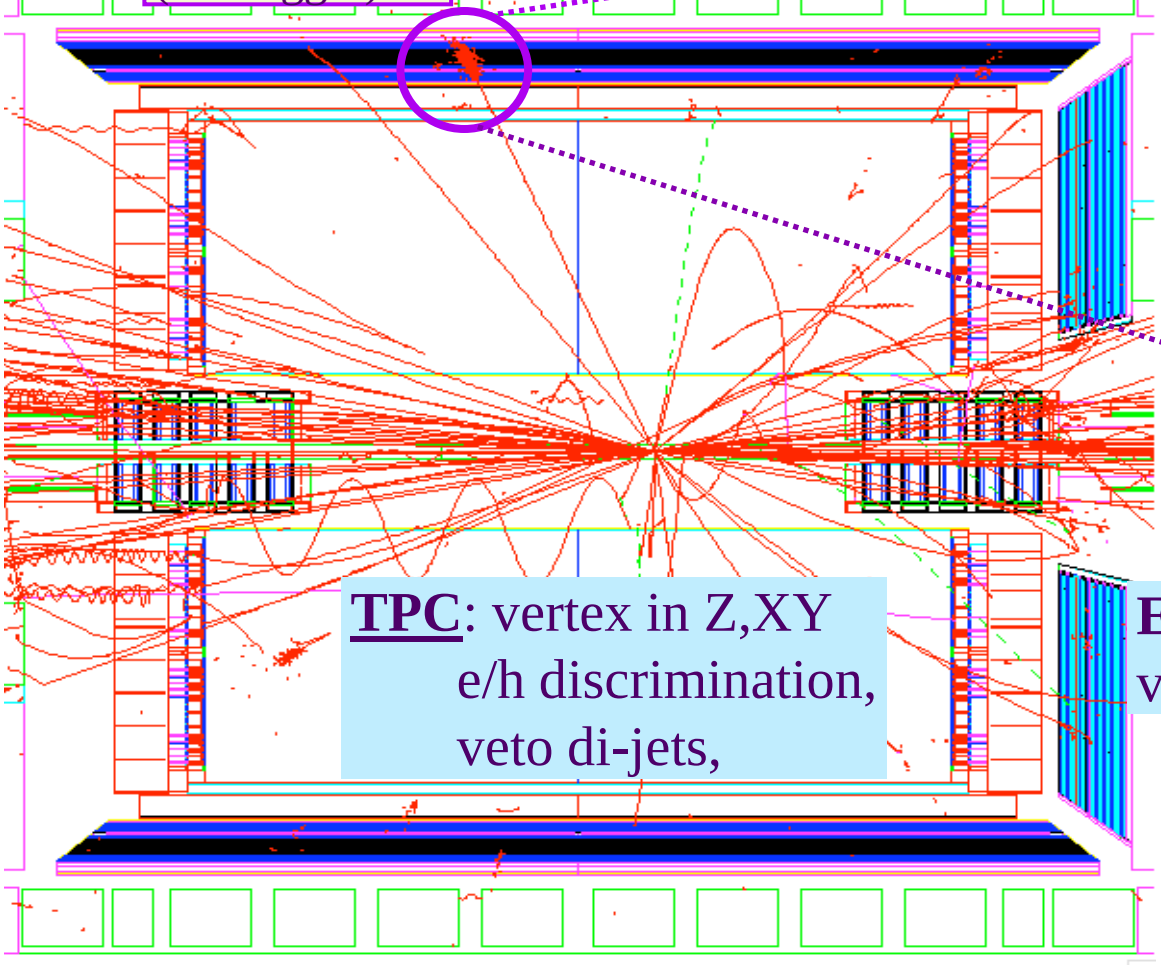
1) RHICBOS: P.M. Nadolsky and C.-P. Yuan, Nucl. Phys. B666 (2003) 31.

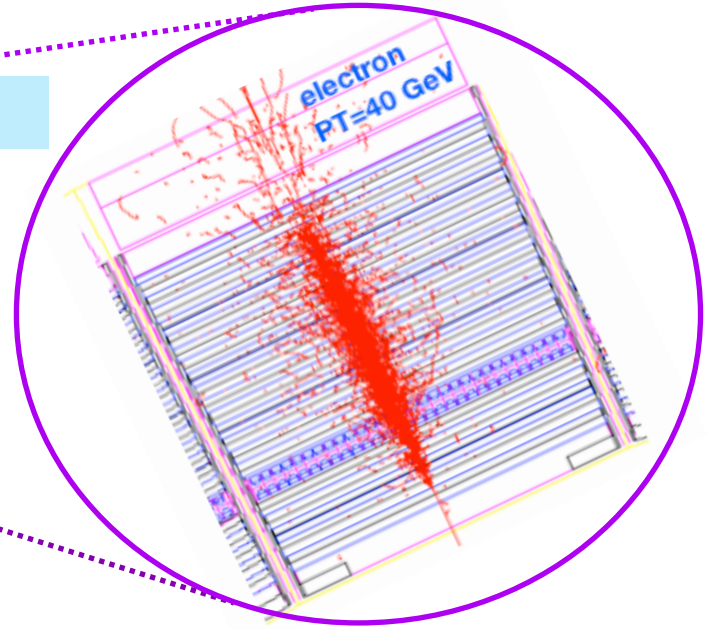
2) deFlorian / Vogelsang: D. deFlorian, global analysis.

Simulated W event at STAR

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

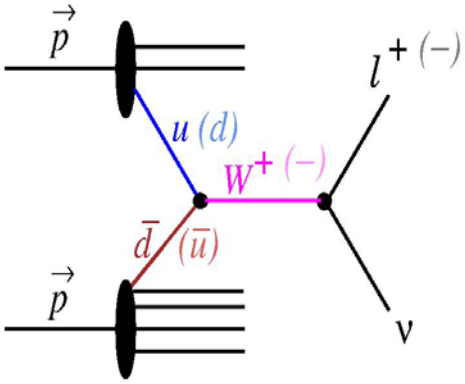
BEMC : lepton energy, veto jets





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

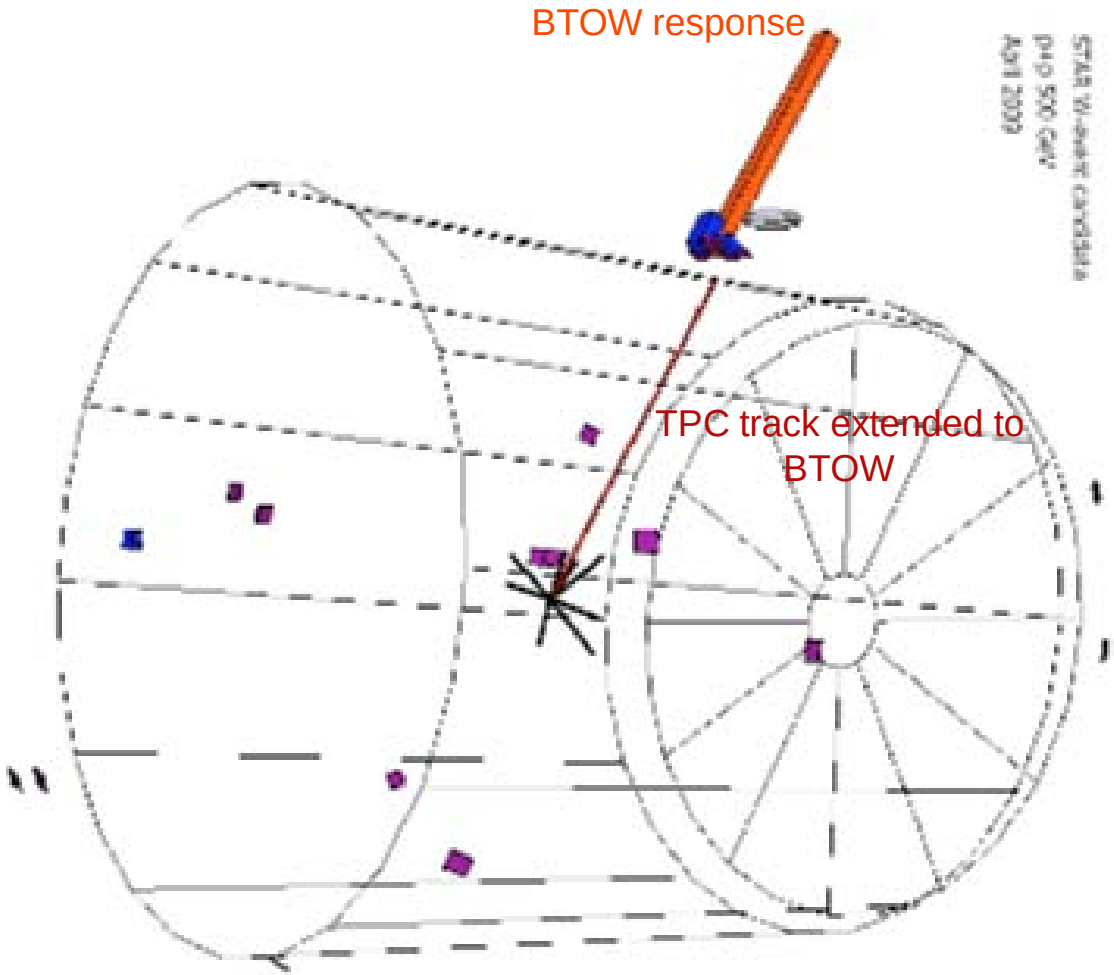
EEMC :
veto di-jets



W production results: W event

- Event display (W event candidate) and detector signature

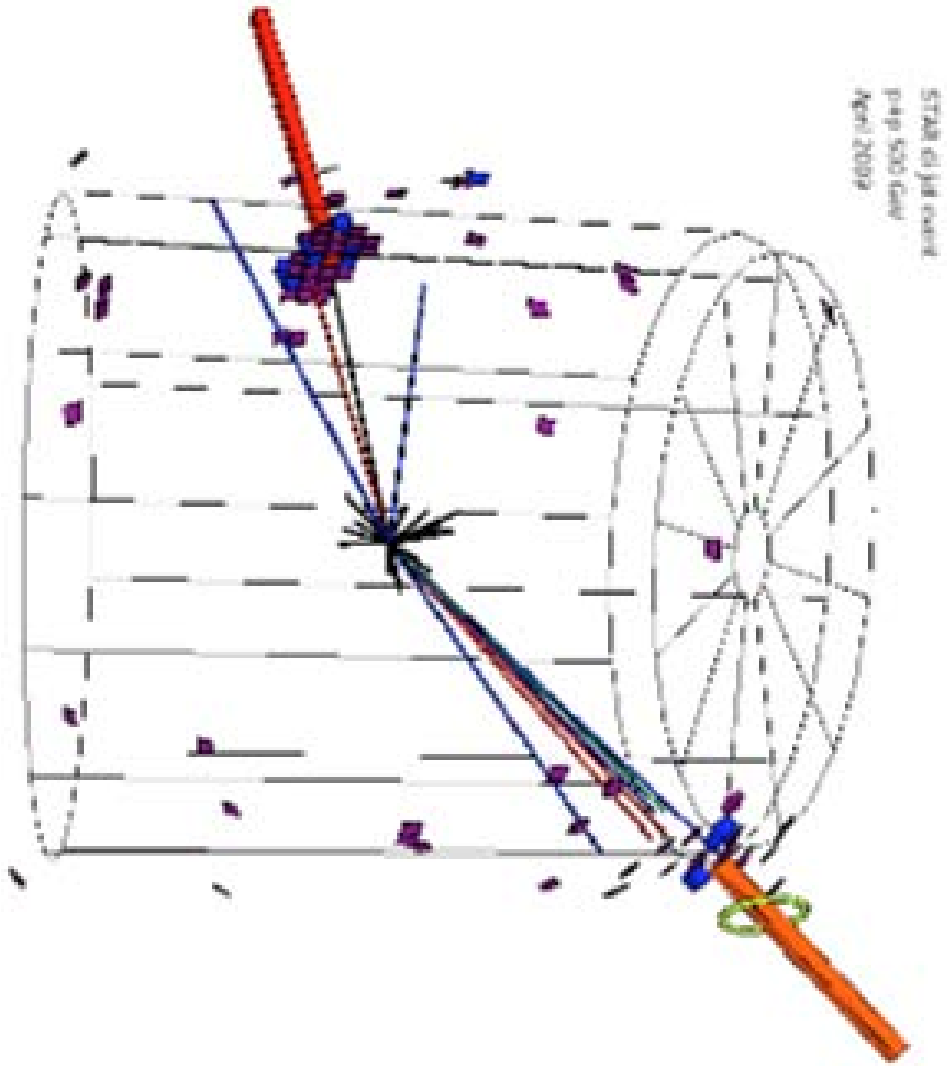
We found ~600 of those kinds of events!



W production results: QCD Background event

- Event display (Di-Jet event candidate) and detector signature

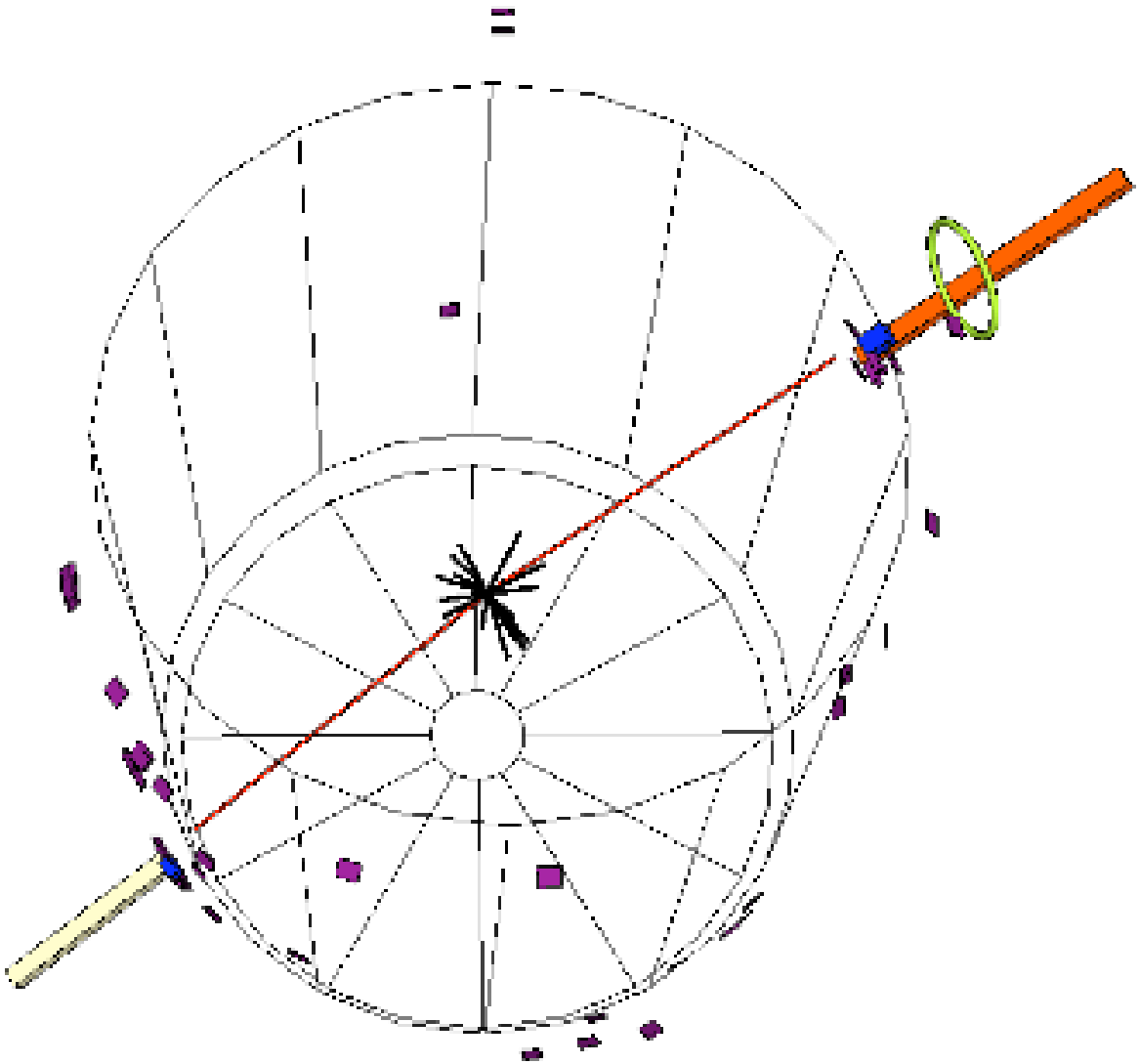
We recorded and rejected ~1.5M of those kinds of events!



W production results: Z^0 event

- Event display (Z event candidate) and detector signature

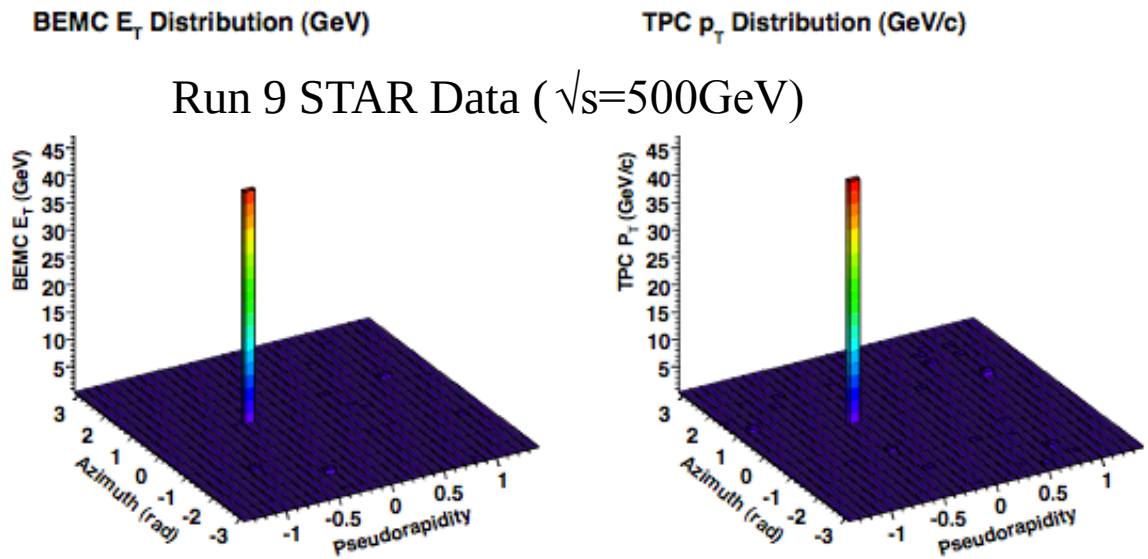
We found a handful of those kinds of events!



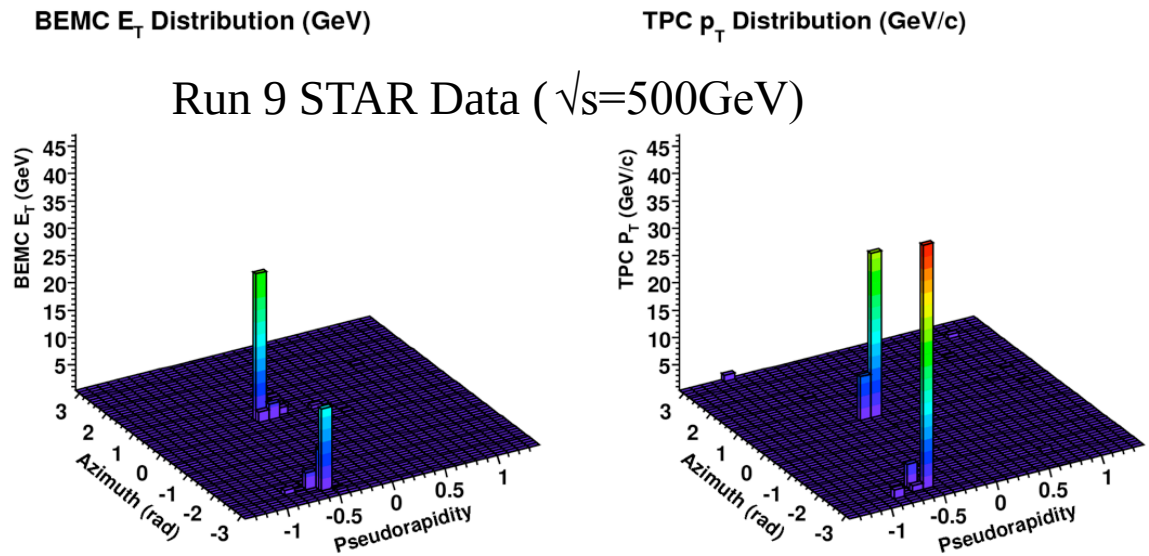
W production results: Lego plots

- Lego plots - STAR BEMC/TPC

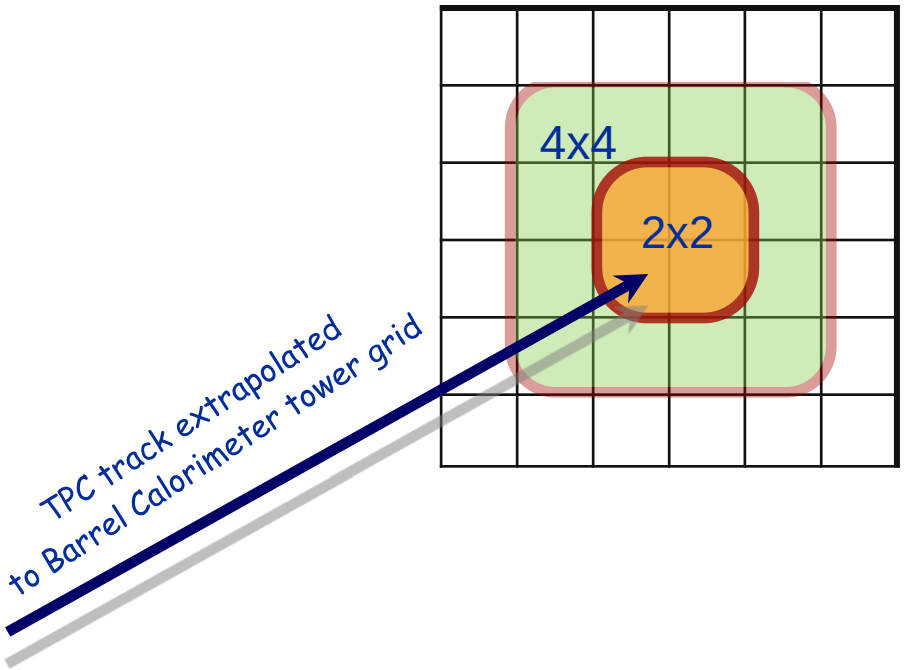
W event



Di-Jet event

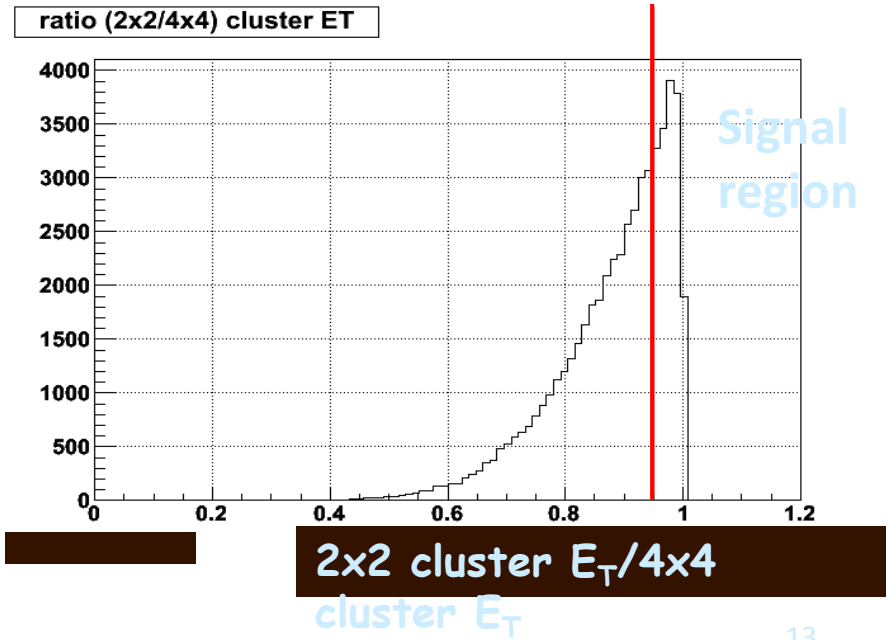


W Algorithm: Lepton Isolation



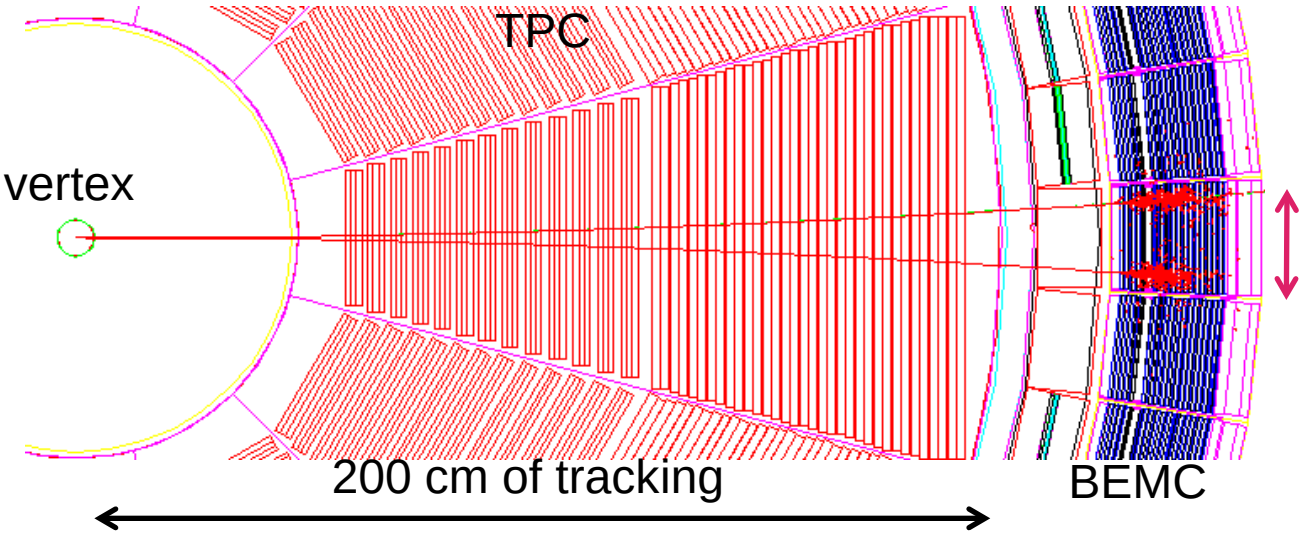
Lepton Isolation Cuts:

- Require TPC track with p_T > 10 GeV, $W \rightarrow e\nu$, nothing on the away side.
- 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



W production results: Charge separation

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



positron p_T = 5 GeV

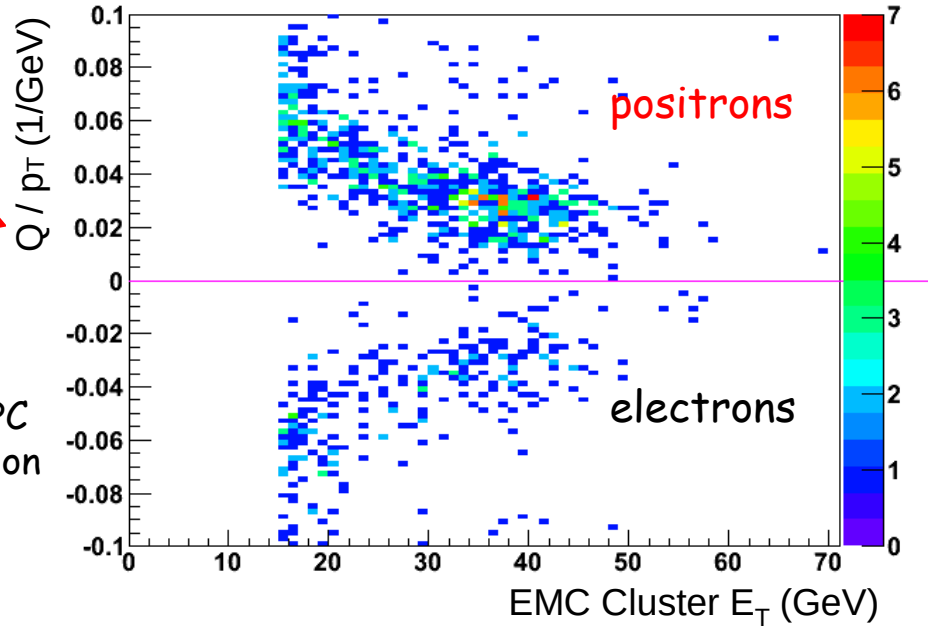
electron p_T = 5 GeV

+/- 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



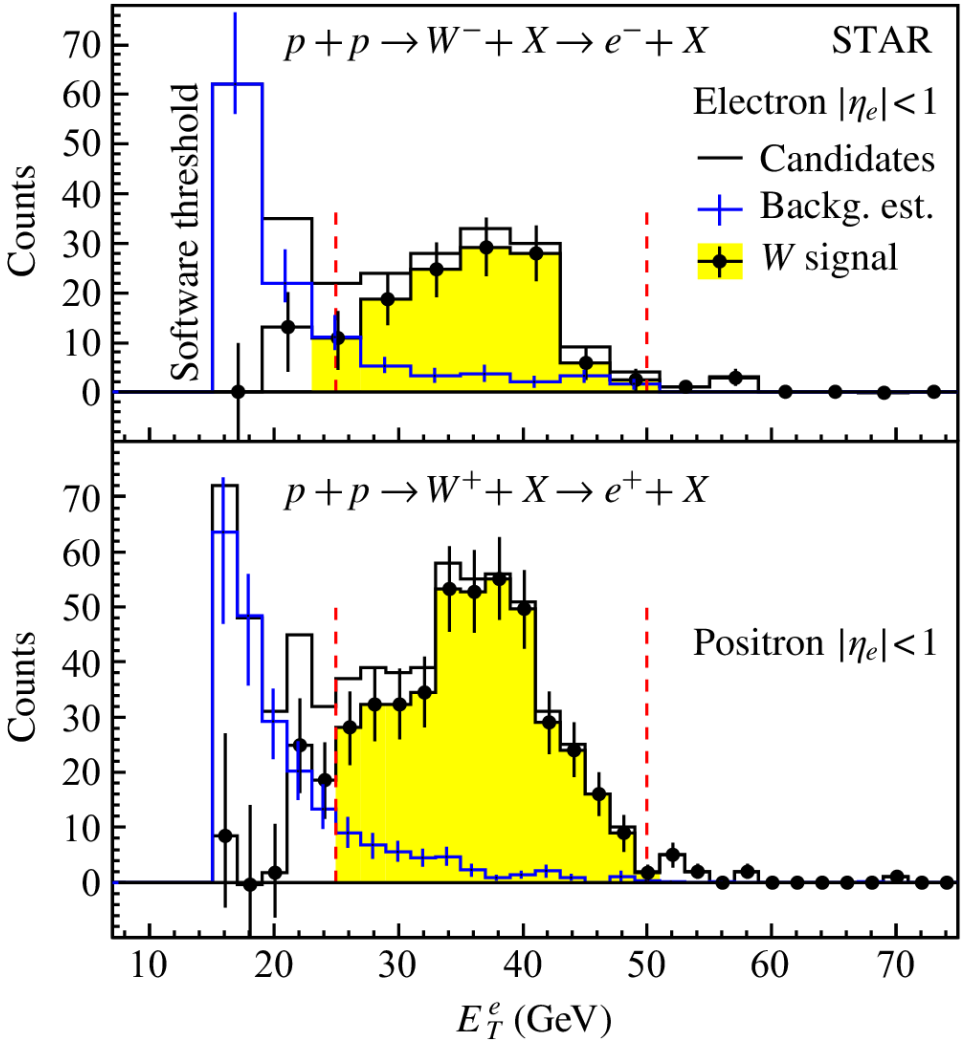
Final TPC calibration

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

Successful separation of different charge states!

W production results: Jacobian peak distributions

- Charged separated Jacobian peak distributions

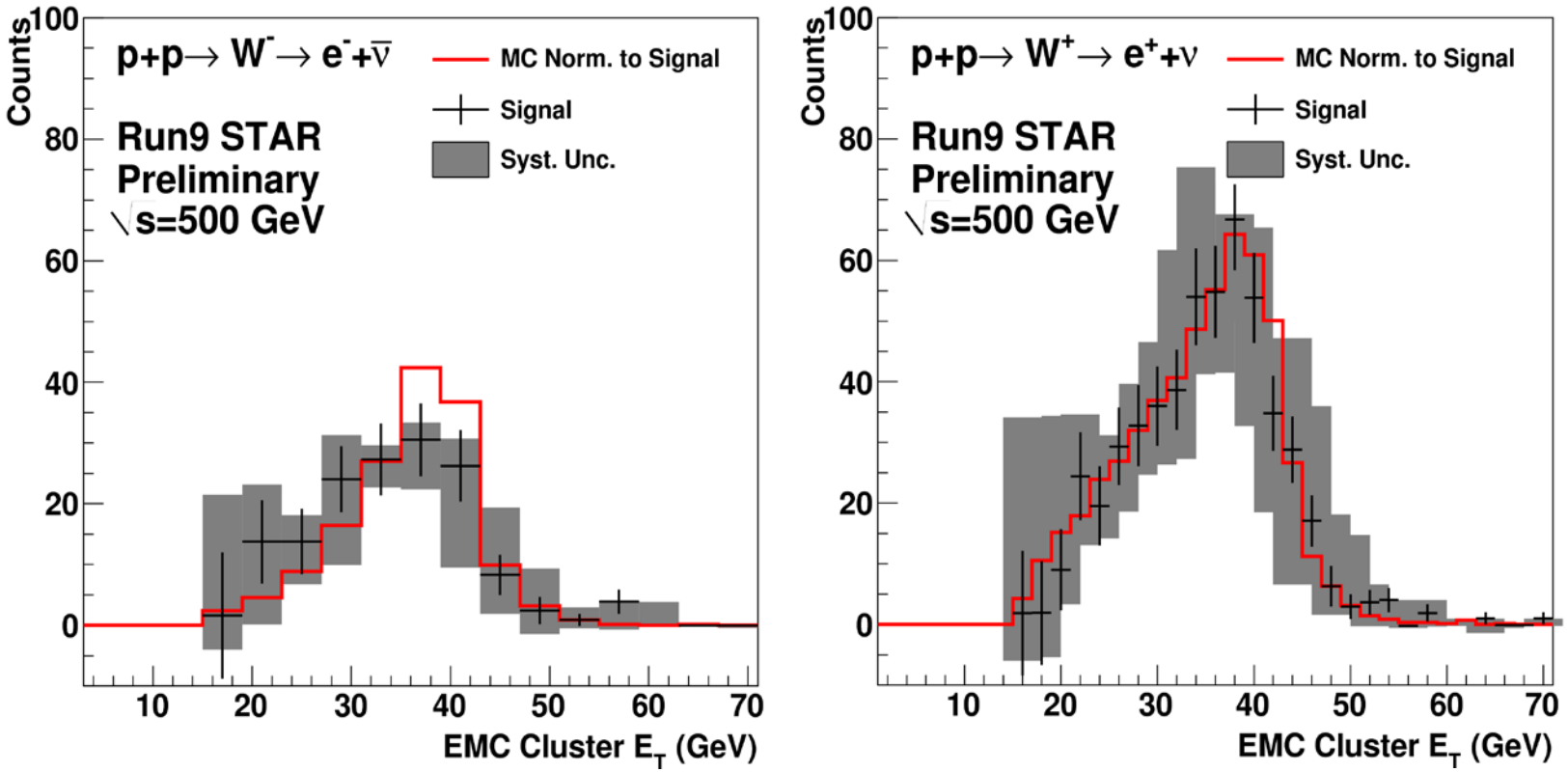


- Background distribution and background-subtracted signal distribution
- B/(S+B) (E_T > 25GeV) W^-:16%
- B/(S+B) (E_T > 25GeV) W^+: 8%

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

W production results: Data/MC comparison

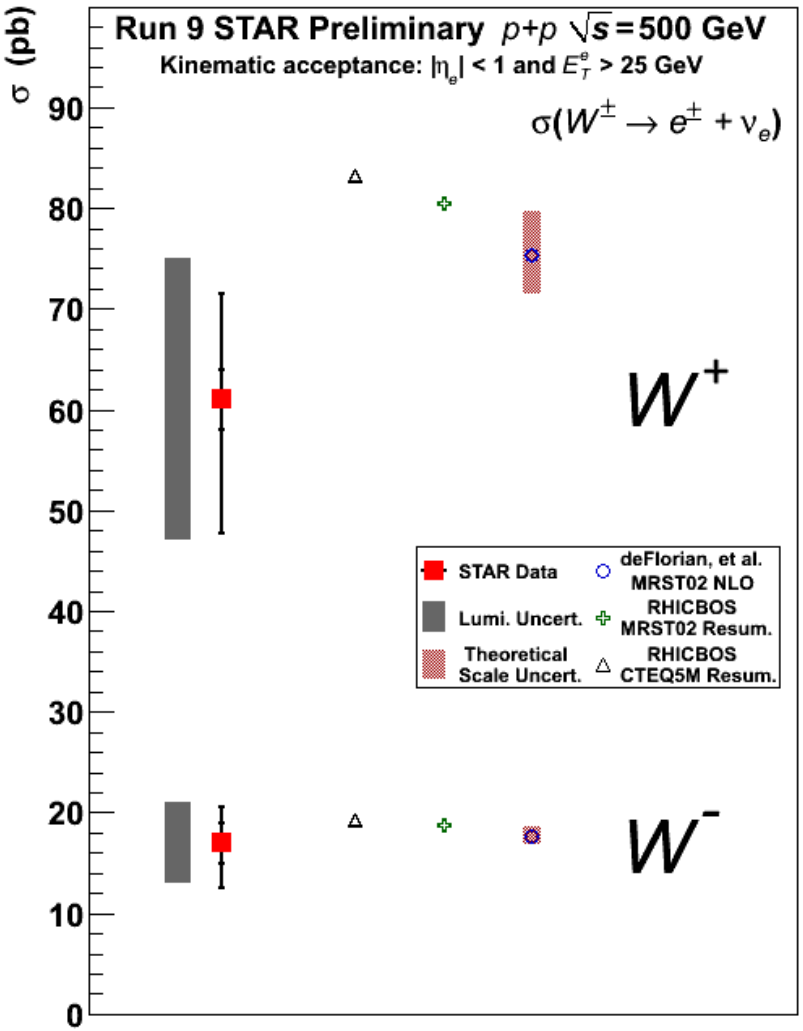
- Data/MC Comparison of charge-separated Jacobian peak distributions



- 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



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

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

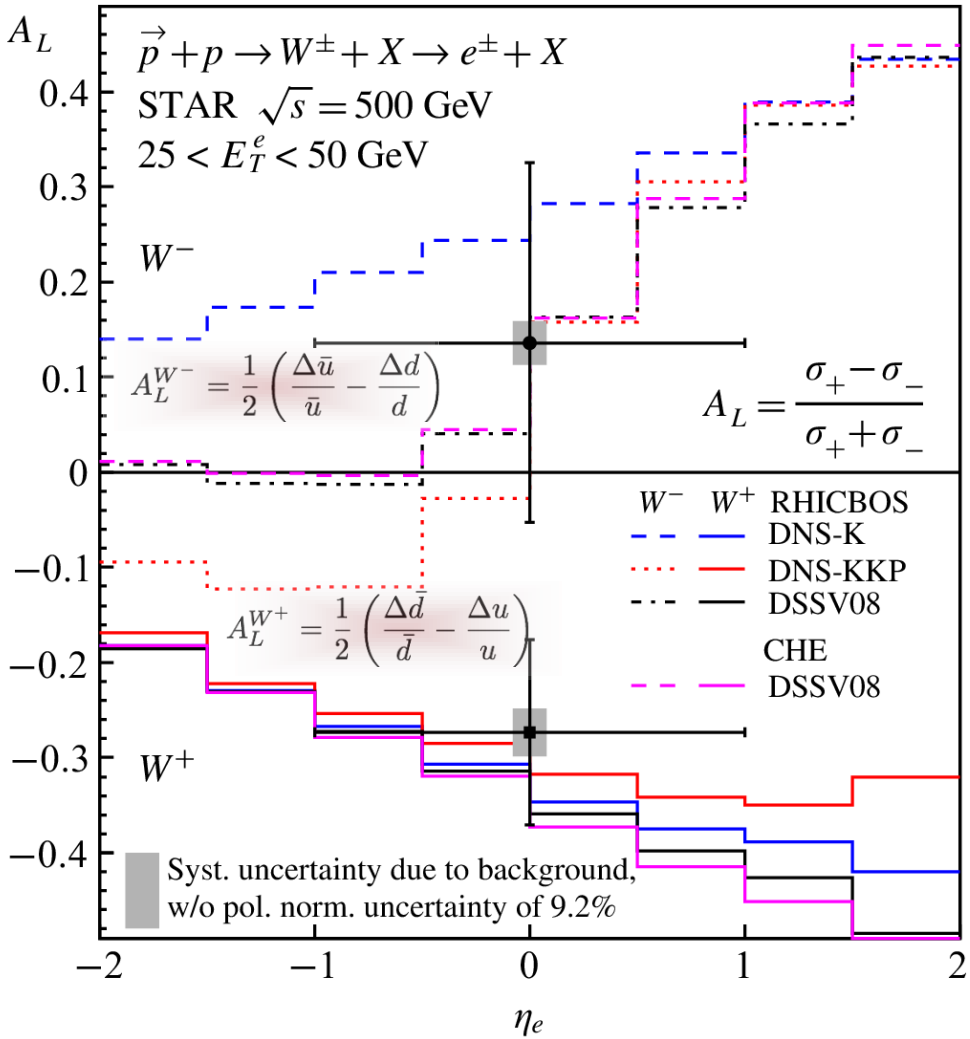
$$\sigma_{W^+ \to e^+ + \nu} = 61 \pm 3\ (\mathrm{stat.})\ ^{+10}_{-13}\ (\mathrm{syst.}) \pm 14\ (\mathrm{lumi.})\ \mathrm{pb}$$

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

- 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



STAR Preliminary Run 9 (p+p $\sqrt{s}$=500 GeV)

$$A_L(W^+) = -0.28 \pm 0.10\,(\text{stat.}) \pm 0.02\,(\text{syst.})$$

$$A_L(W^-) = 0.14 \pm 0.19\,(\text{stat.}) \pm 0.02\,(\text{syst.})$$

- $A_L(W^+)$ negative with a significance of 3.3σ
- $A_L(W^-)$ central value positive
- Systematic errors of A_L under control
- TPC charge separation works up to p_T ~ 50GeV

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

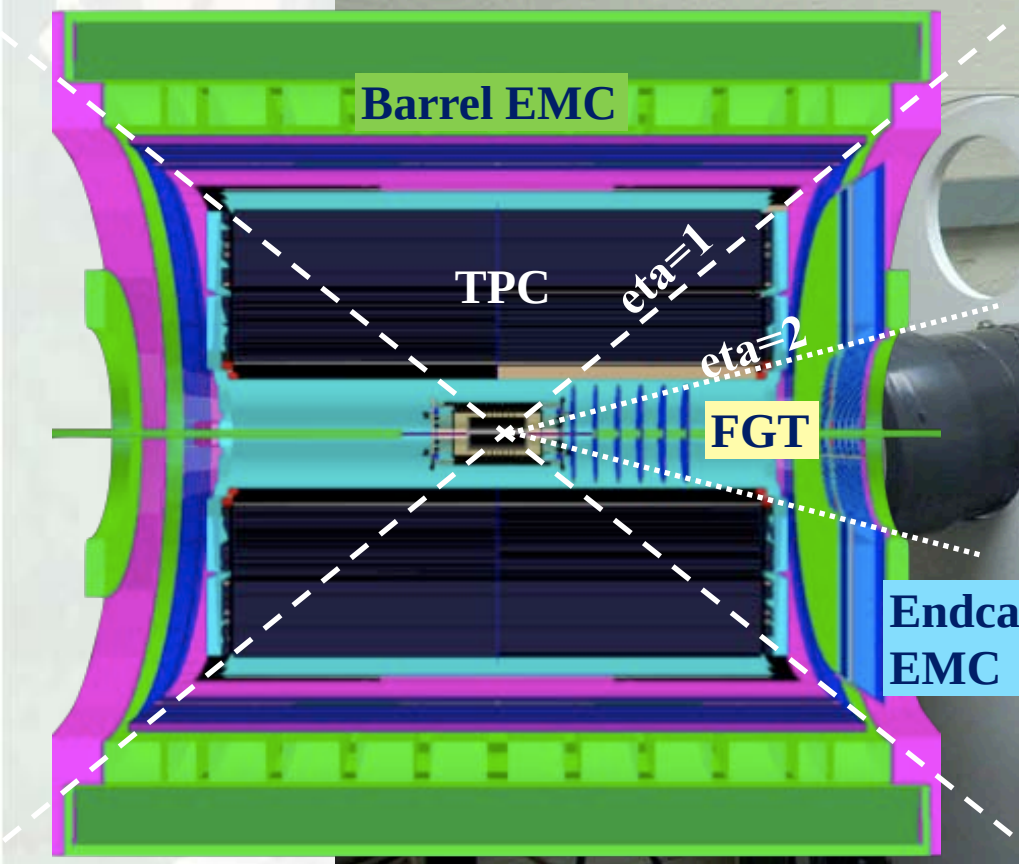
Universality of helicity distribution functions!

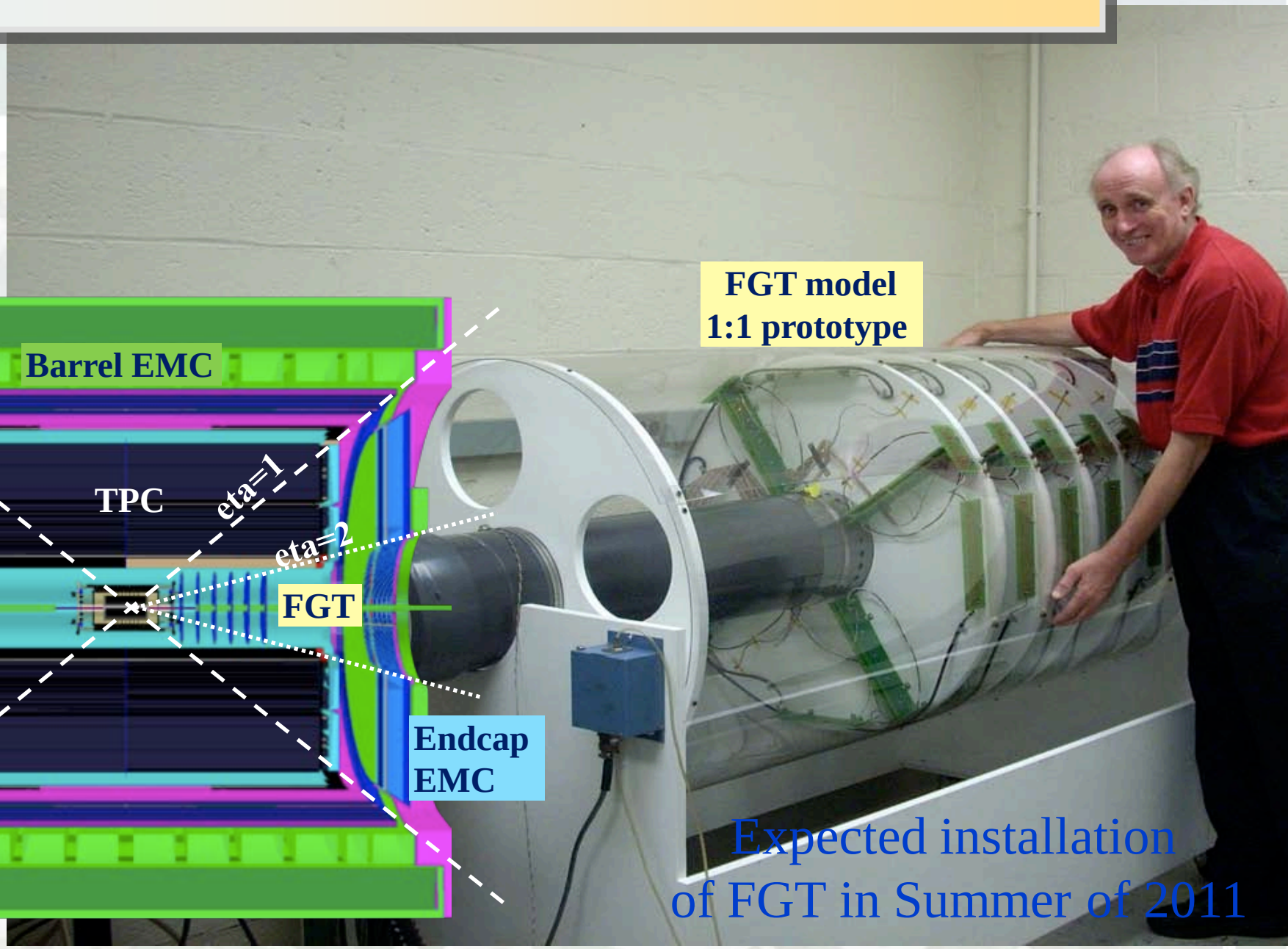
Summary and Outlook

- 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

Future W Measurements at STAR: Forward Gem Tracker

FGT provides tracking coverage of Endcap (region of higher AL)





Expected installation of FGT in Summer of 2011

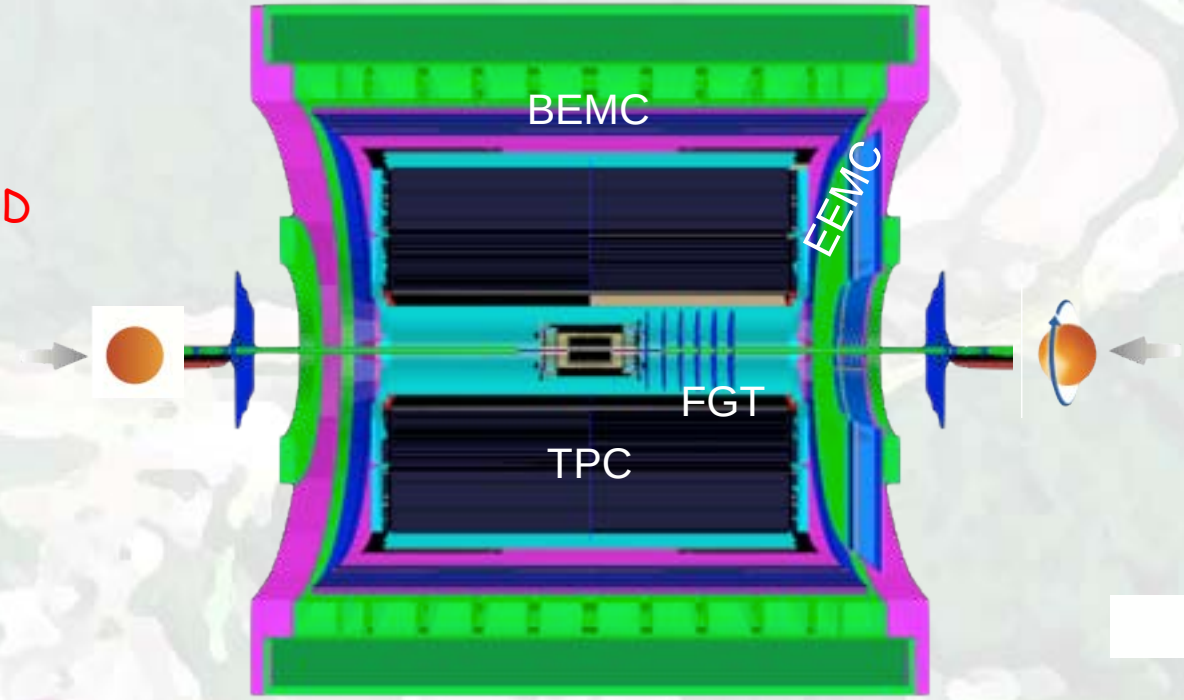
Backup

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})

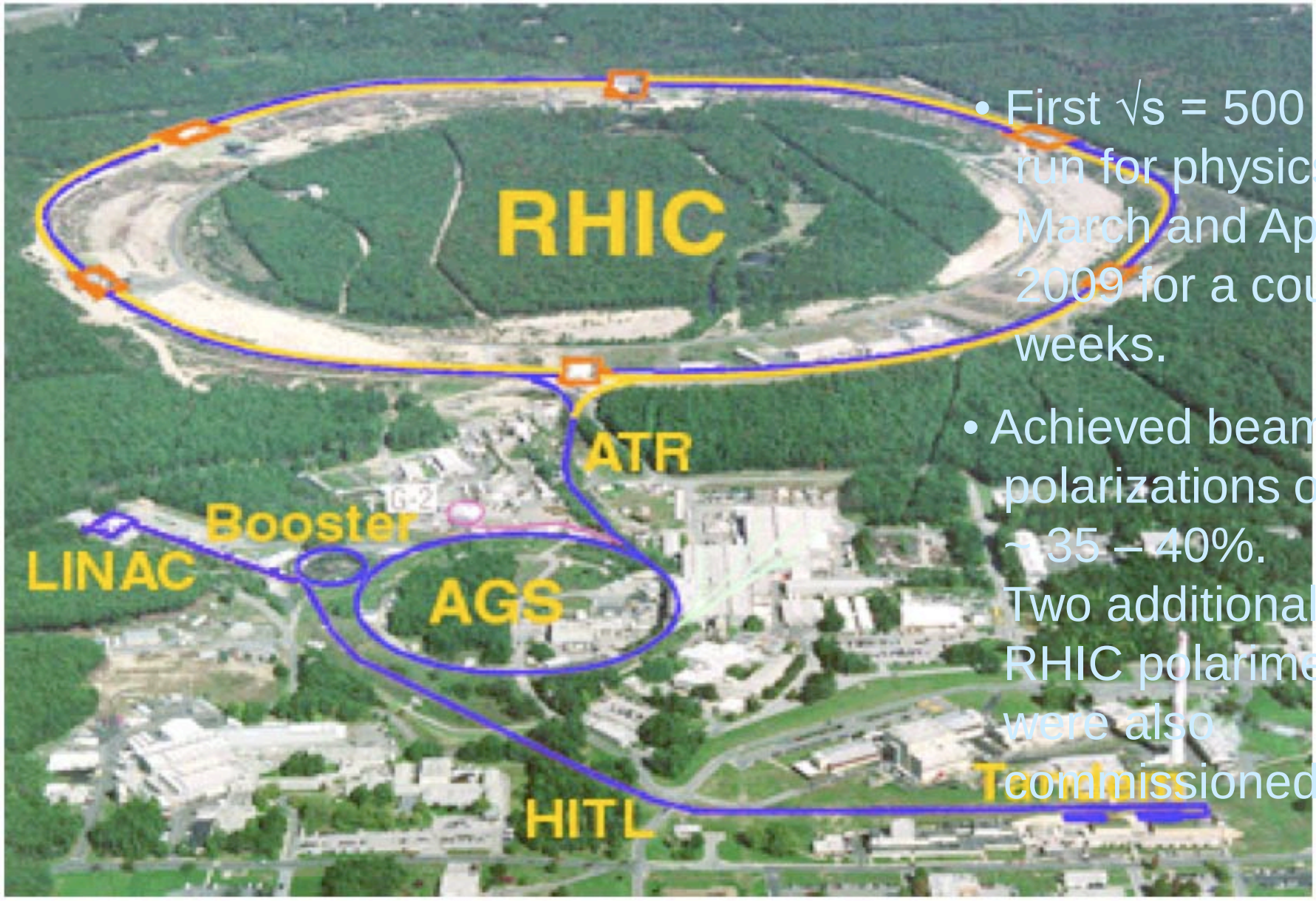
- Calorimetry system with 2π coverage: BEMC (-1<η<1) and EEMC (1<η<2)
- TPC: Tracking and particle ID



- ZDC: Relative luminosity and local polarimetry
- BBC: Relative luminosity and Minimum bias trigger

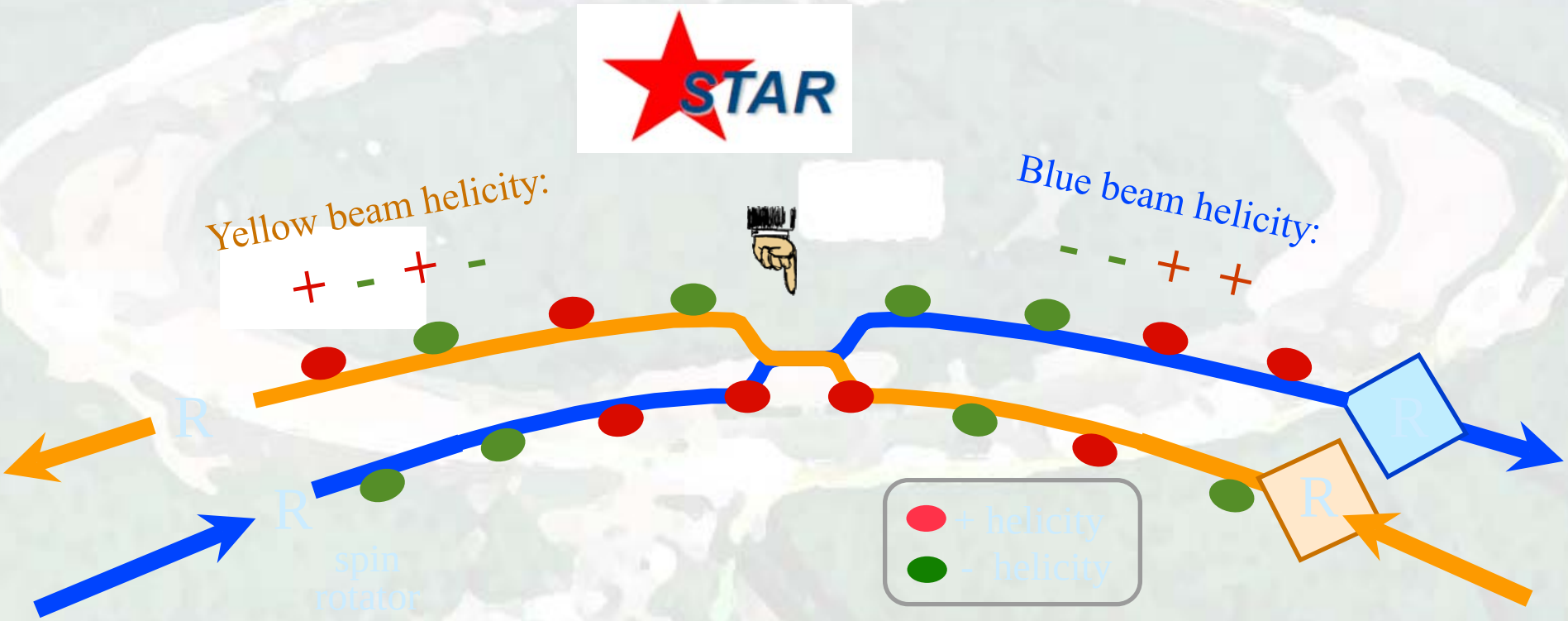
- STAR Mid-rapidity W program (-1<η<1): BEMC and TPC
- STAR Forward/Backward W program (1<η<2): EEMC and TPC / FGT (Installation in summer 2011)

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.

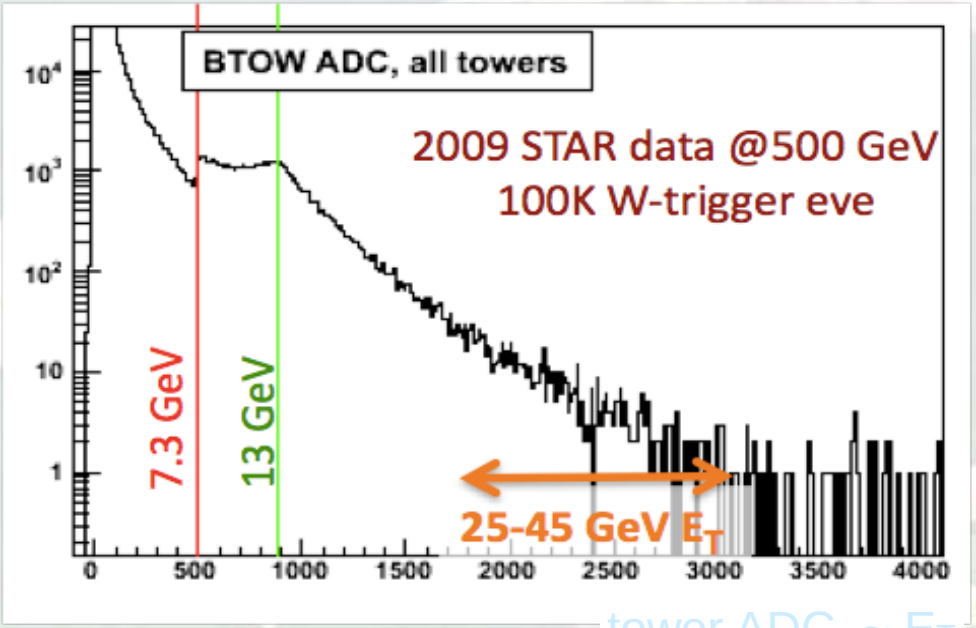
Helicity of beams colliding at STAR



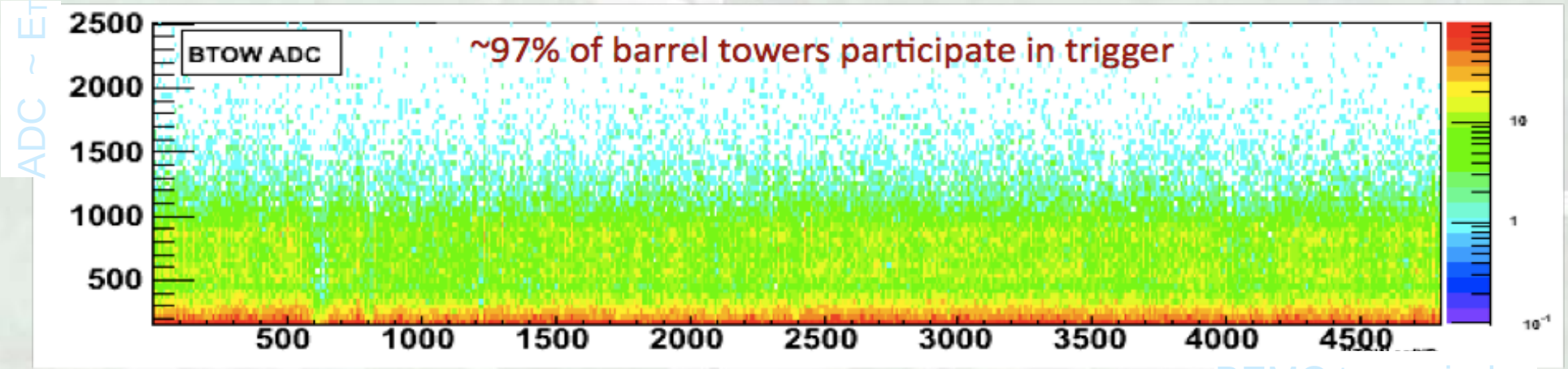
STAR sees 4 helicity configurations
STAR runs 4 parallel measurements

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

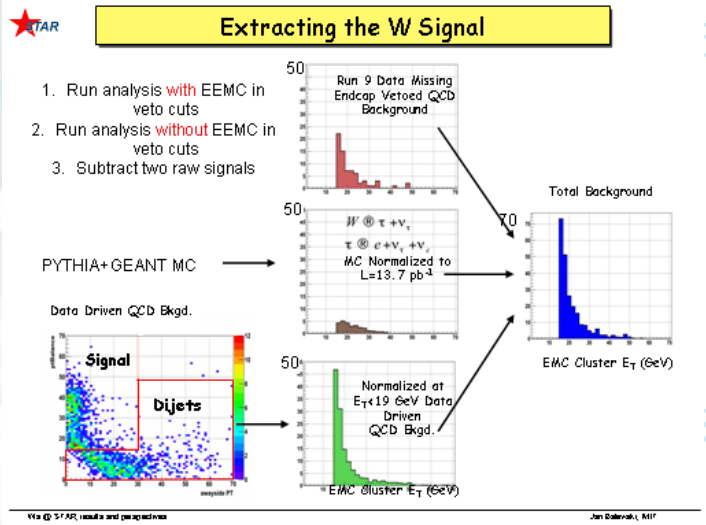
W trigger in Run 9

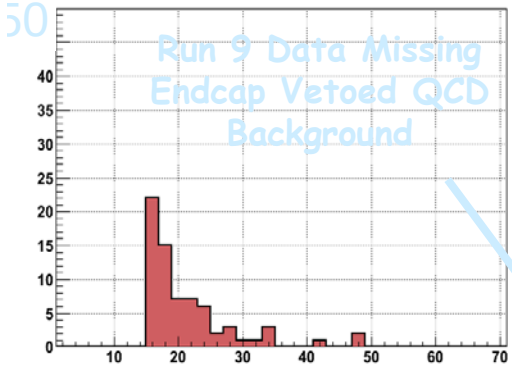


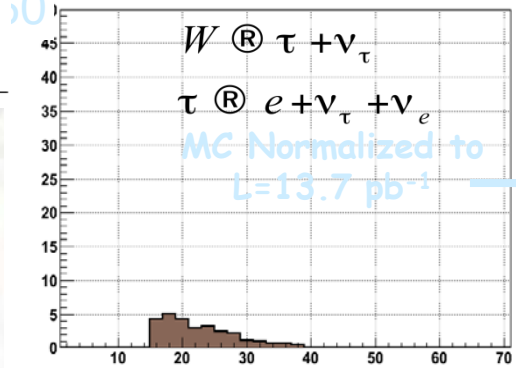
- Trigger
  - Level 0 trigger – BEMC single high tower threshold E_T > 7.3 GeV.
  - Level 2 trigger – BEMC 2 x 2 tower cluster threshold E_T > 13 GeV.
  - Use these recorded and triggered events to monitor the luminosity.

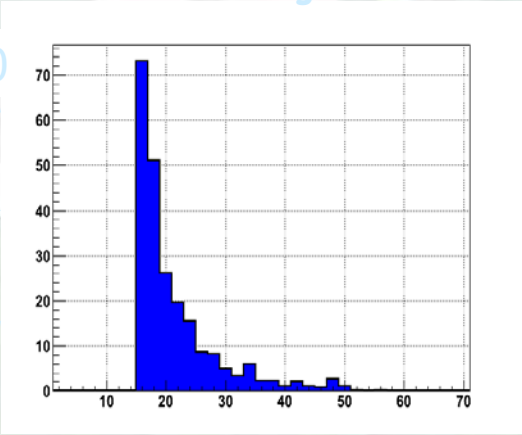


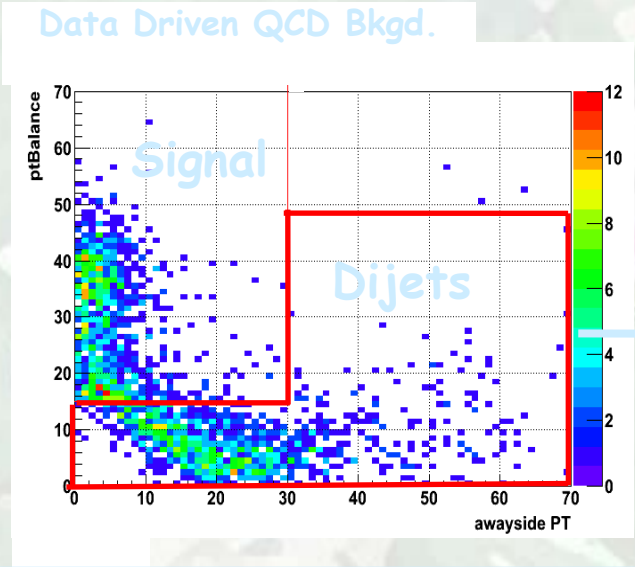
Extracting the W Signal

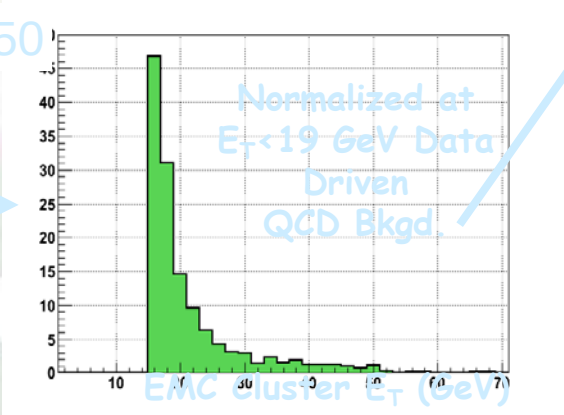




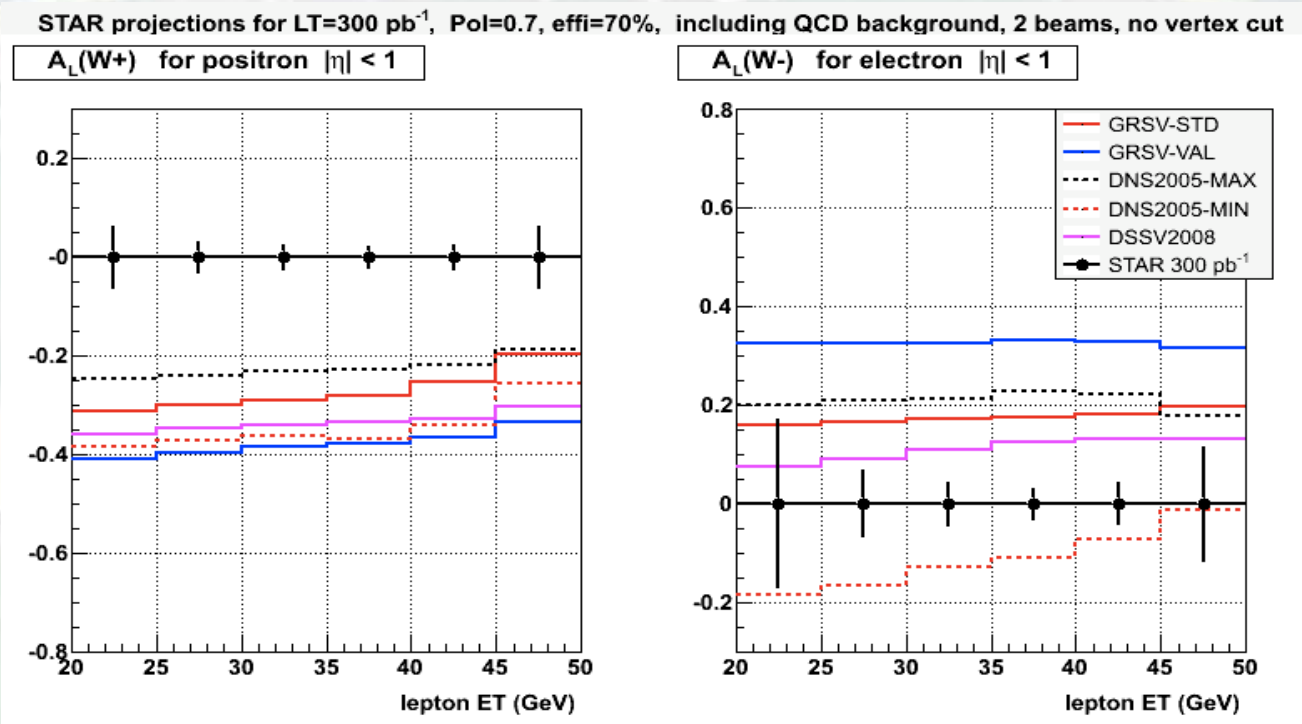








Future Ws at mid-rapidity



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

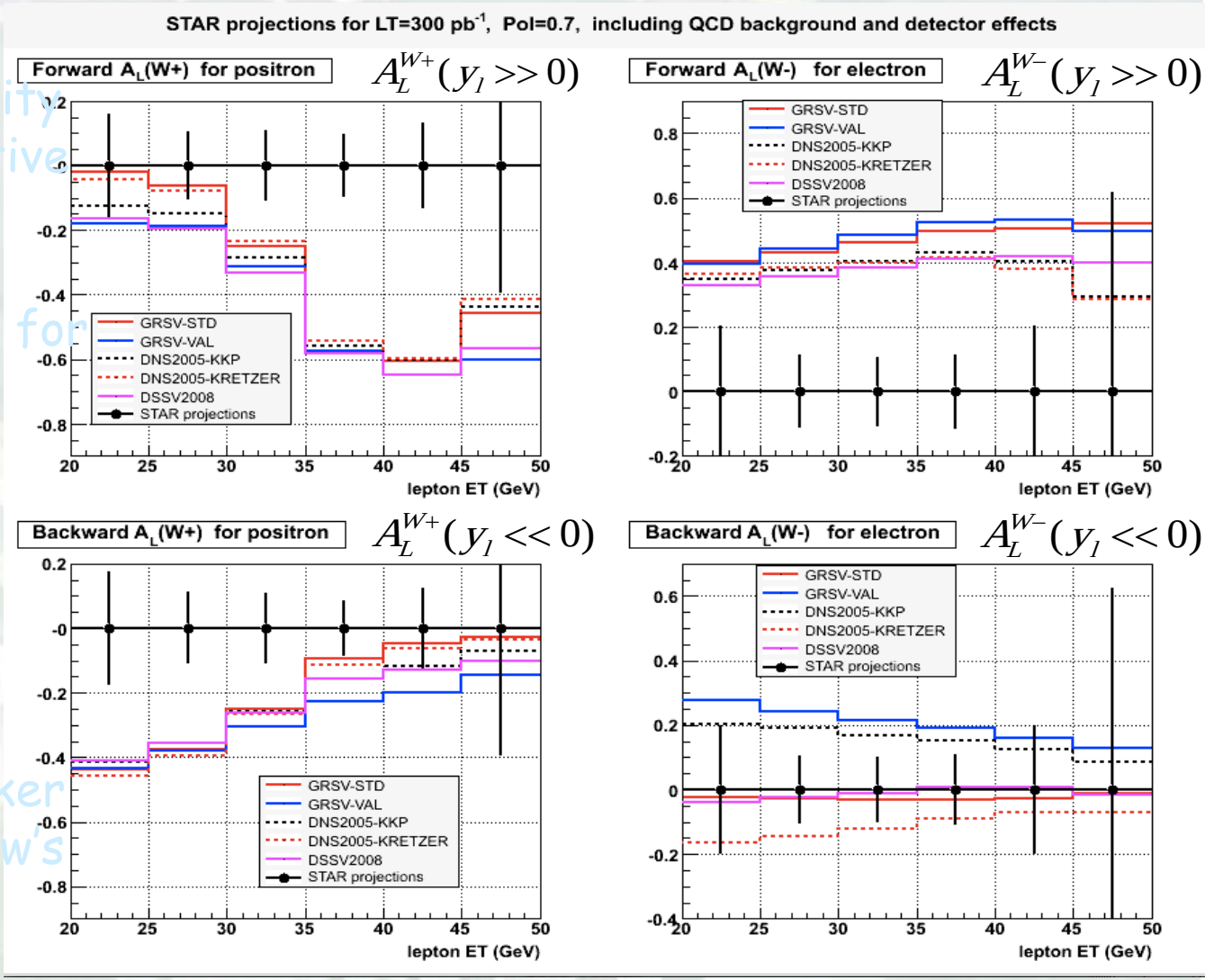
Future Ws at forward rapidity

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

$$1 < \eta < 2$$

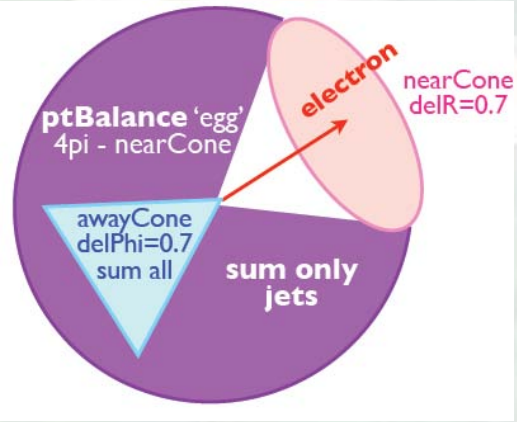
Measurements rely on the planned Forward GEM Tracker upgrade (see B. Surrow's talk on Sat.)



W production results: Algorithm Details

- W reconstruction - Algorithm : Details

Transverse plane view



General:

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

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%
- Require distance of 2x2 cluster vs. TPC track below 7 cm

Near-cone veto:

- Compute near-cone E_T sum of BEMC+TPC over $\Delta R=0.7$ in eta-phi space
- Require near-cone excess E_T below 12%

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