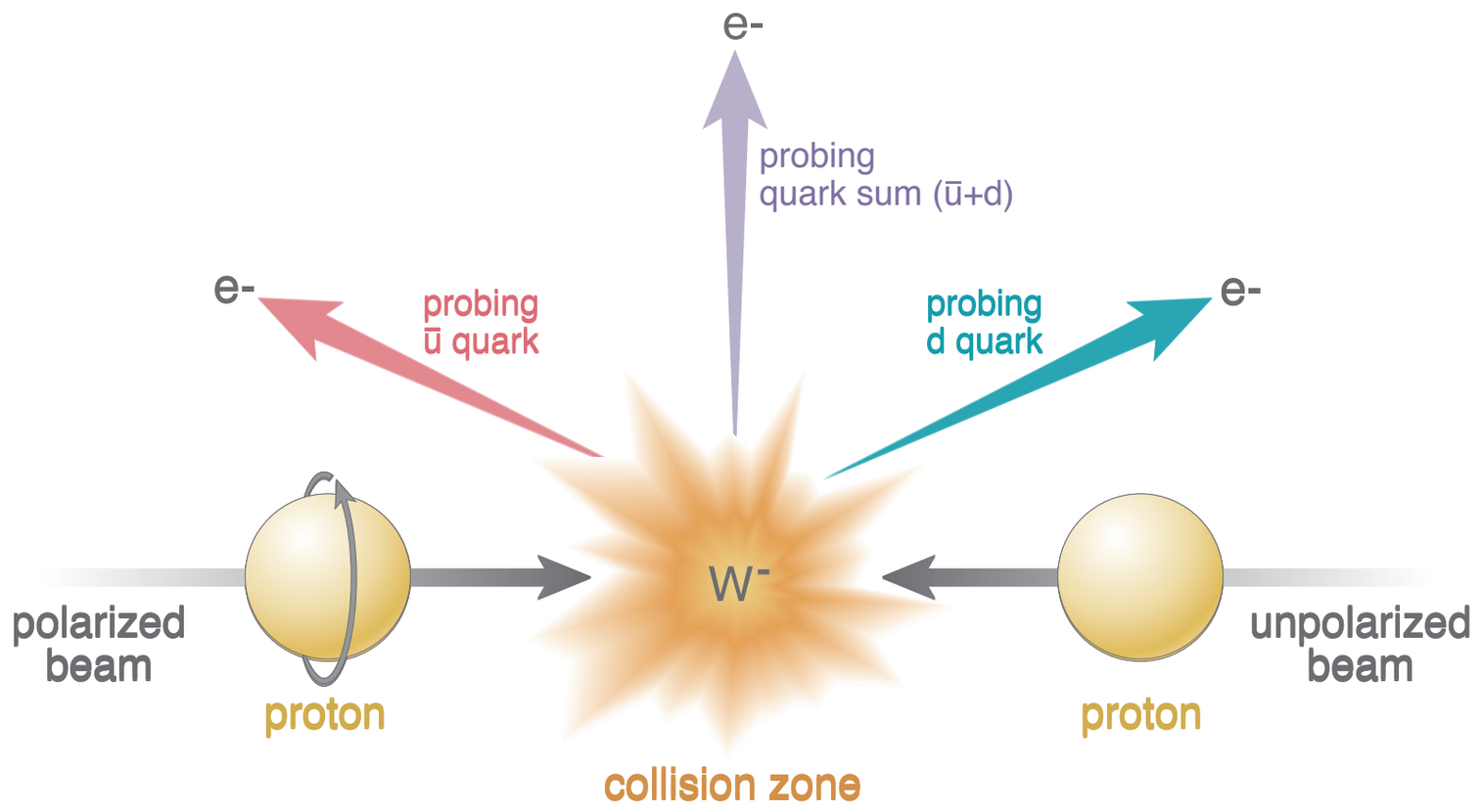
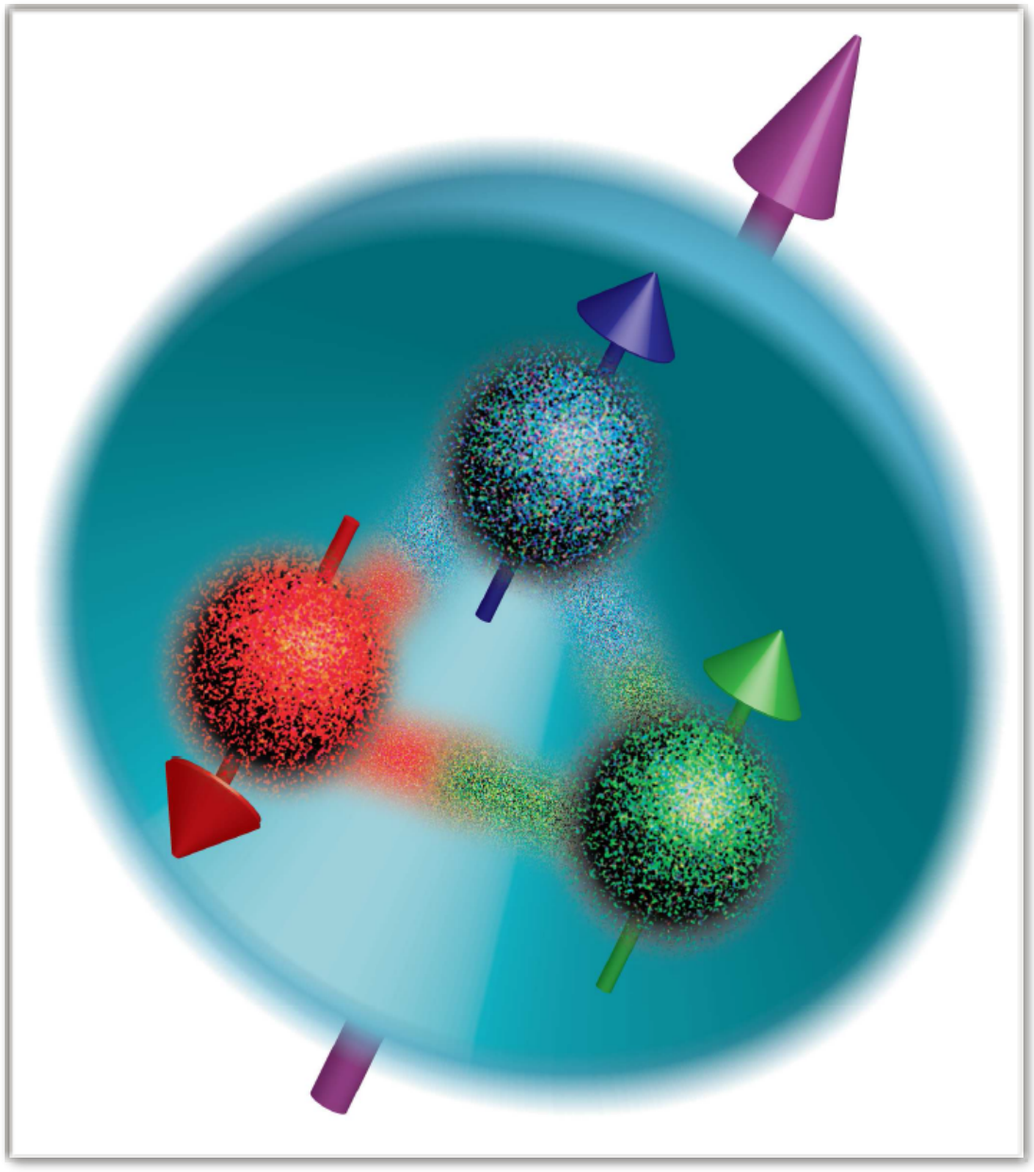
Measurement of longitudinal single-spin asymmetries for $W^{\pm}$ boson production in polarized p+p collision at √s=510 GeV at RHIC

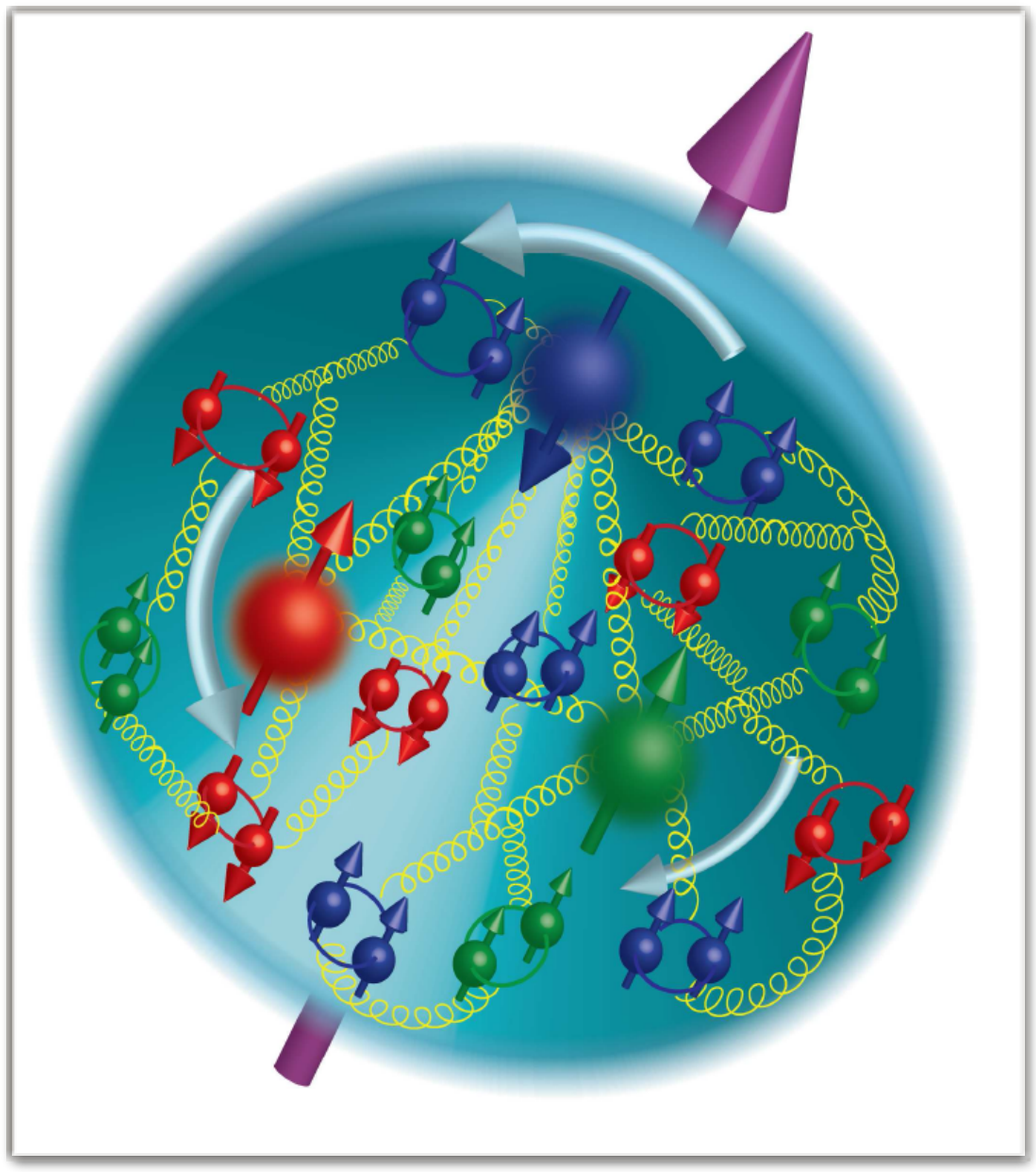


Devika Gunarathne
(for the STAR collaboration)
Temple University

Evolving Picture of Proton's Spin Structure



Valence Quarks



Sea Quarks and Gluons

Anti Quarks Polarization

Spin sum rule for longitudinally Polarized proton :

$$< S_p >= \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

Jeffe and Monahar, 1990

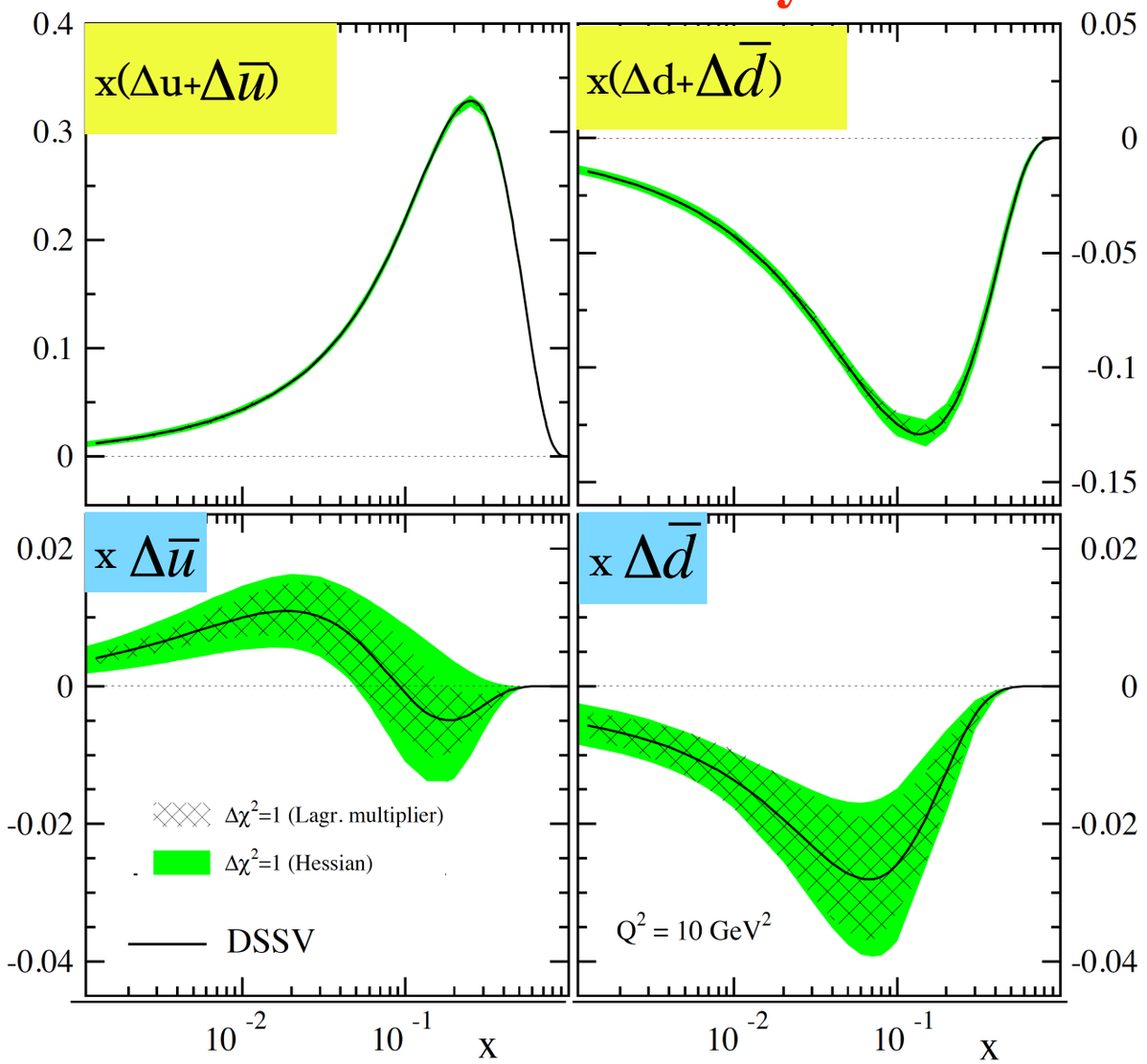
$$\Delta\Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s})dx$$

~30 % polarized inclusive DIS

Helicity PDF

$$\Delta f(x,Q^2) \equiv f^{+}(x,Q^2) - f^{-}(x,Q^2)$$

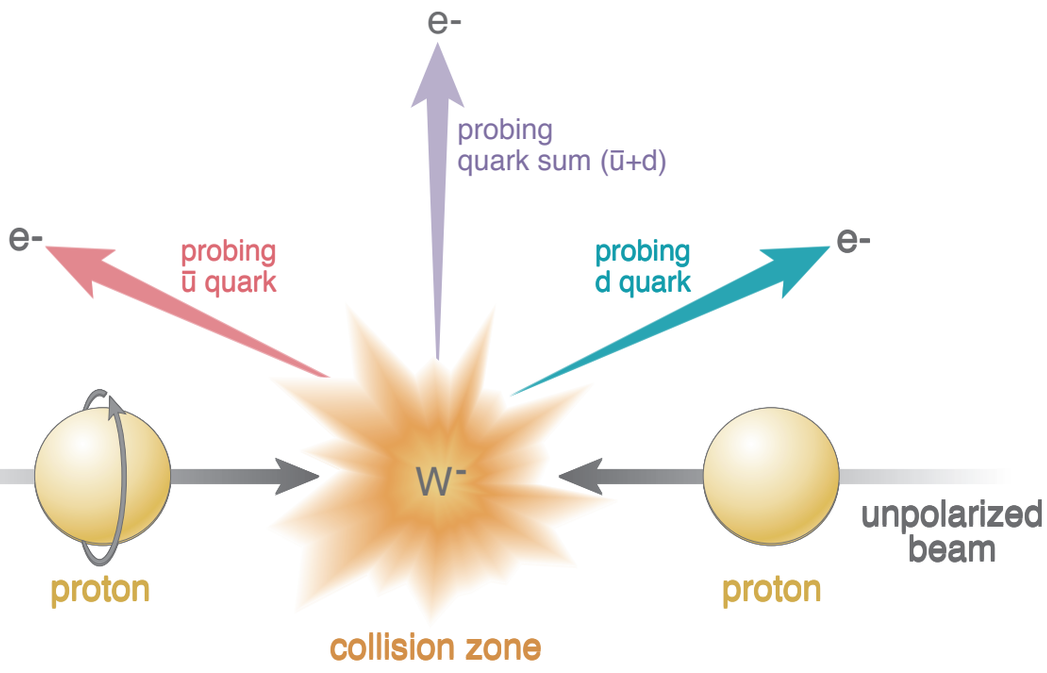
DSSV Global Analysis



PRD 80, 034030 (2009)

W-Boson Production

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



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

- Maximal **Violation of Parity** leads to perfect **spin separation.**
- **Direct coupling** to the quark and antiquark of interest.
- **High** resolution scale (Q^2) set by the **W mass.**
- **Easy detection** via the **leptonic decay** channels.

Parity violating longitudinal single spin asymmetry

$$A_L = \frac{\sigma^{+} - \sigma^{-}}{\sigma^{+} + \sigma^{-}}$$

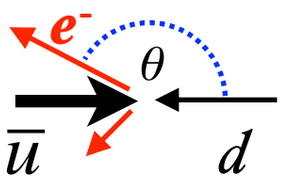
W A_L :Theoretical Aspects

W A_L, highly sensitive to individual polarizations at forward and backward decay lepton pseudo rapidity (η_e)

$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right) \qquad < x_{1,2} > \sim \frac{M_W}{\sqrt{s}} e^{\pm \eta_e/2}$$

$\eta <<< 0 \rightarrow x_1 << x_2, \theta \rightarrow \pi$

$$A_L^{e^-} \approx \frac{\int_{\otimes(x_1,x_2)} [\Delta\bar{u}(x_1)d(x_2)(1-\cos\theta)^2 - \Delta d(x_1)\bar{u}(x_2)(1+\cos\theta)^2]}{\int_{\otimes(x_1,x_2)} [\bar{u}(x_1)d(x_2)(1-\cos\theta)^2 + d(x_1)\bar{u}(x_2)(1+\cos\theta)^2]}$$



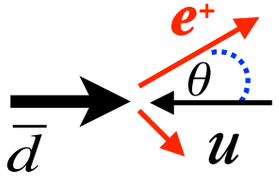
backward e⁻

parallel to W⁻

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

$\eta >>> 0 \rightarrow x_1 >> x_2, \theta \rightarrow 0$

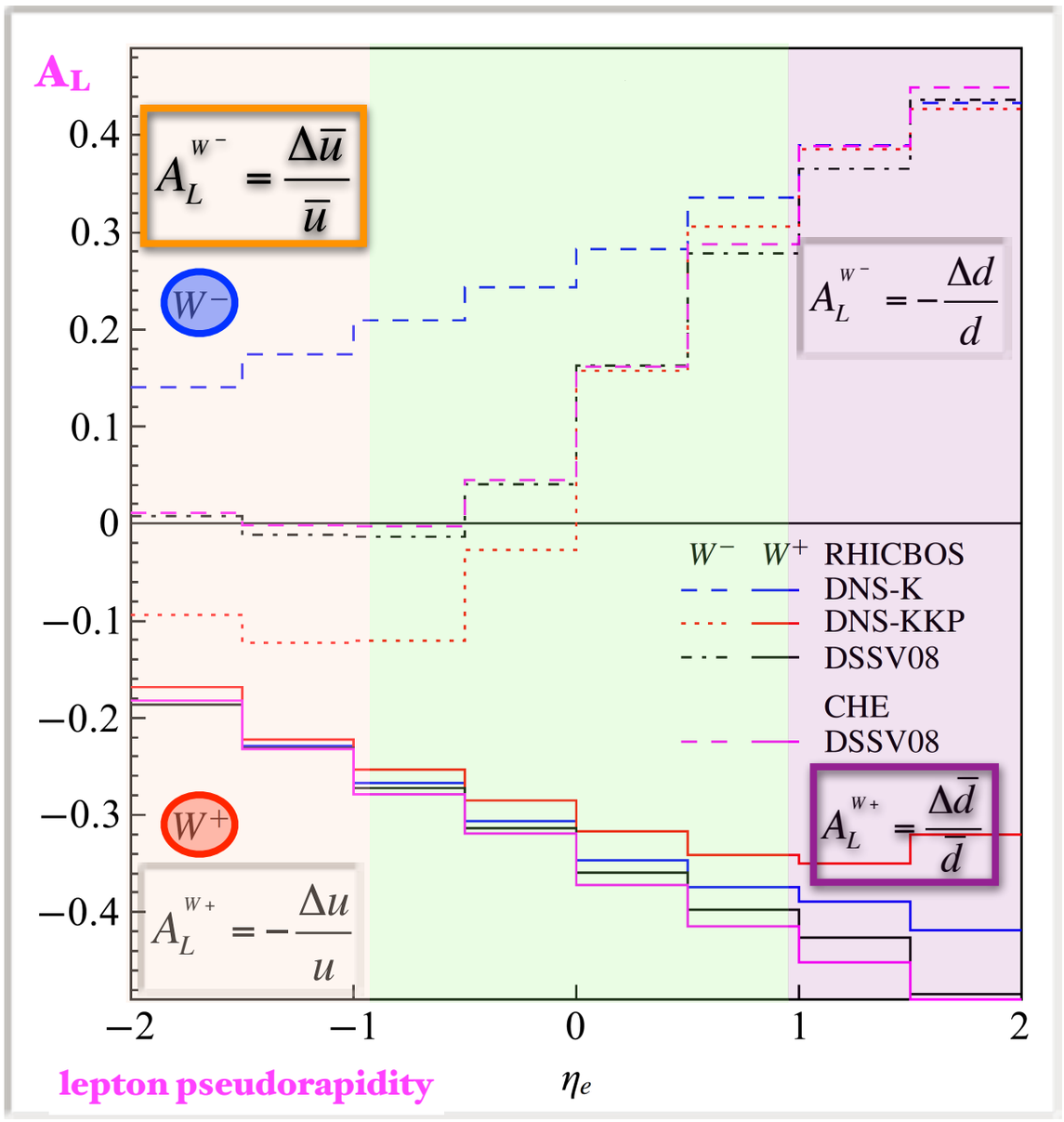
$$A_L^{e^+} \approx \frac{\int_{\otimes(x_1,x_2)} [\Delta\bar{d}(x_1)u(x_2)(1+\cos\theta)^2 - \Delta u(x_1)\bar{d}(x_2)(1-\cos\theta)^2]}{\int_{\otimes(x_1,x_2)} [\bar{d}(x_1)u(x_2)(1+\cos\theta)^2 + u(x_1)\bar{d}(x_2)(1-\cos\theta)^2]}$$



forward e⁺

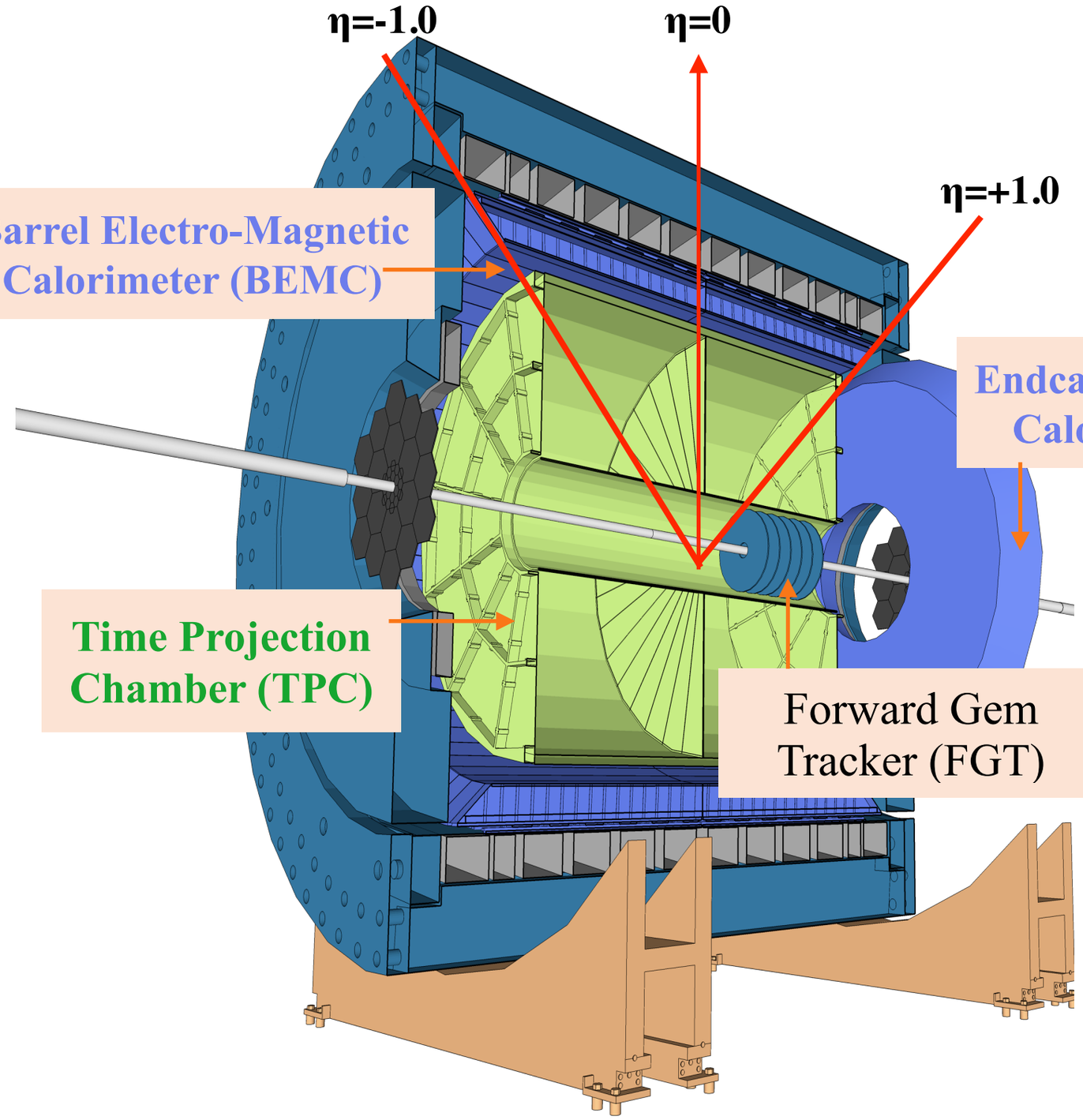
anti parallel to W⁺

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



STAR Detector Overview

$$\eta = -\ln(\tan(\theta/2))$$



TPC: Charge particle tracking

BEMC, EEMC: EM calorimetry

TPC : $-1.3 < \eta < +1.3$

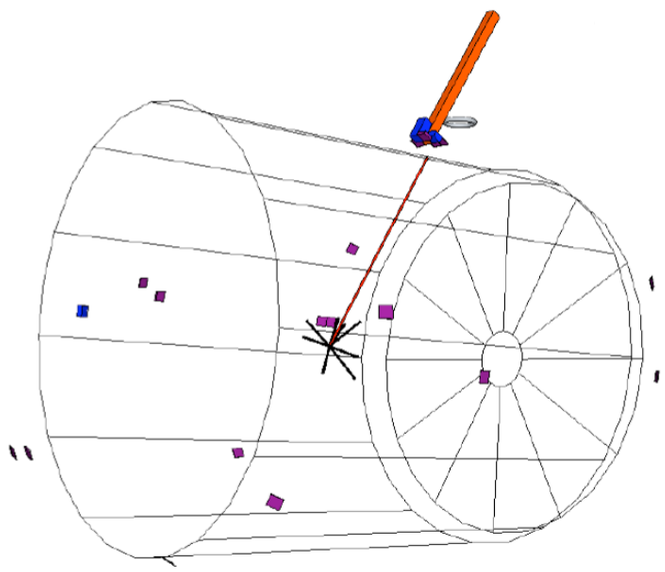
BEMC : $-1.0 < \eta < +1.0$

EEMC : $+1.1 < \eta < +2.0$

FGT : $+1.0 < \eta < +2.0$

Mid-rapidity ($|\eta_e| < 1$) W Selection

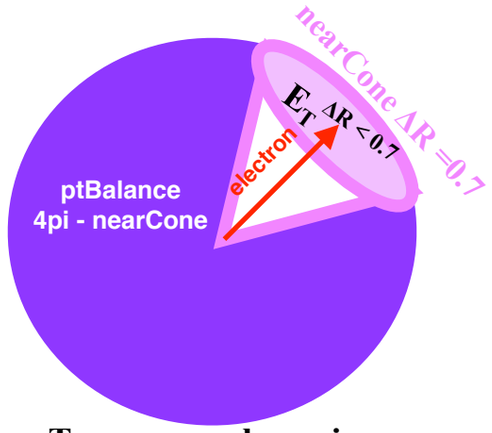
W-> e+ν candidate



Isolated tracks -> isolated EMC cluster

Large opposite missing "energy"

P_T > 10 GeV

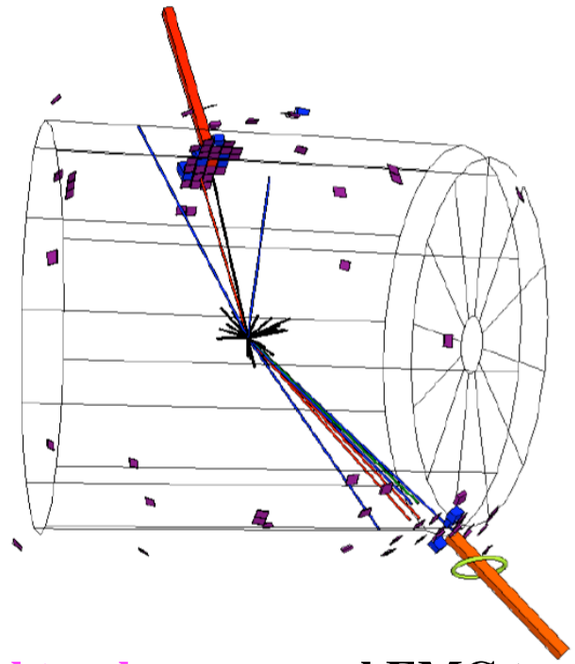


Transverse plane views

$$\vec{p}_T^{\,balance} = \vec{p}_T^{\,e} + \sum_{\Delta R>0.7} \vec{p}_T^{\,jets}$$

$$signed\ P_T - balance = \frac{(\vec{p}_T^{\,e} \cdot \vec{p}_T^{\,balance})}{|\vec{p}^{\,e}|}$$

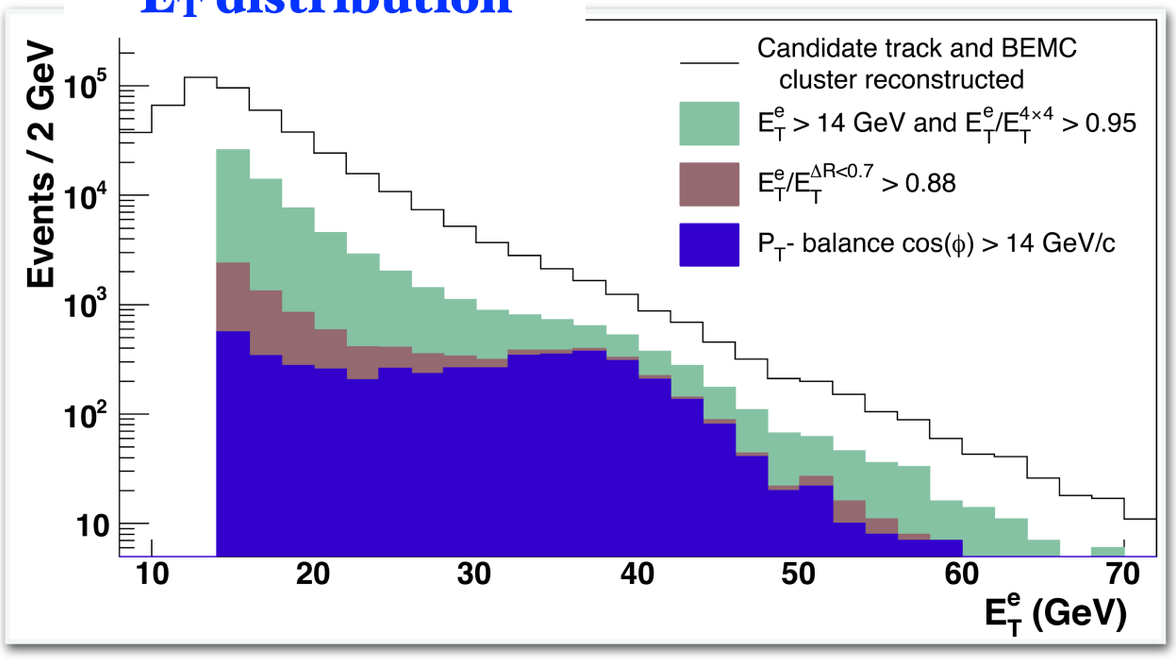
QCD background candidate



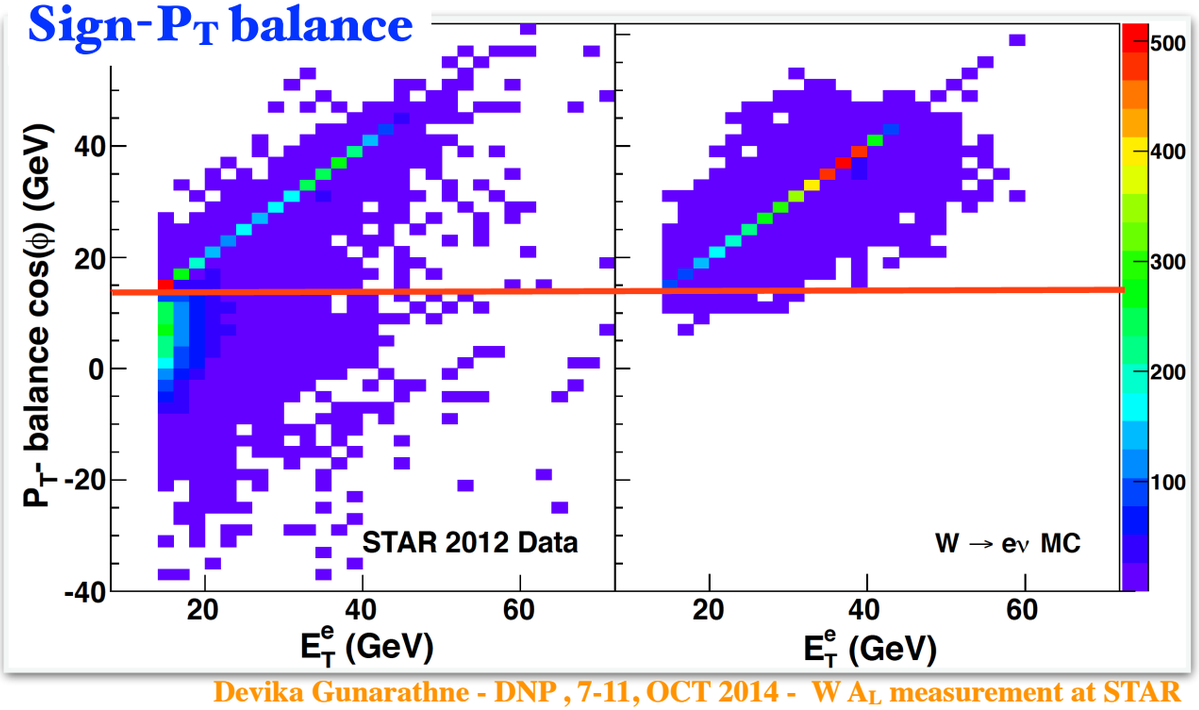
Several tracks -> several EMC towers

No large missing "energy"

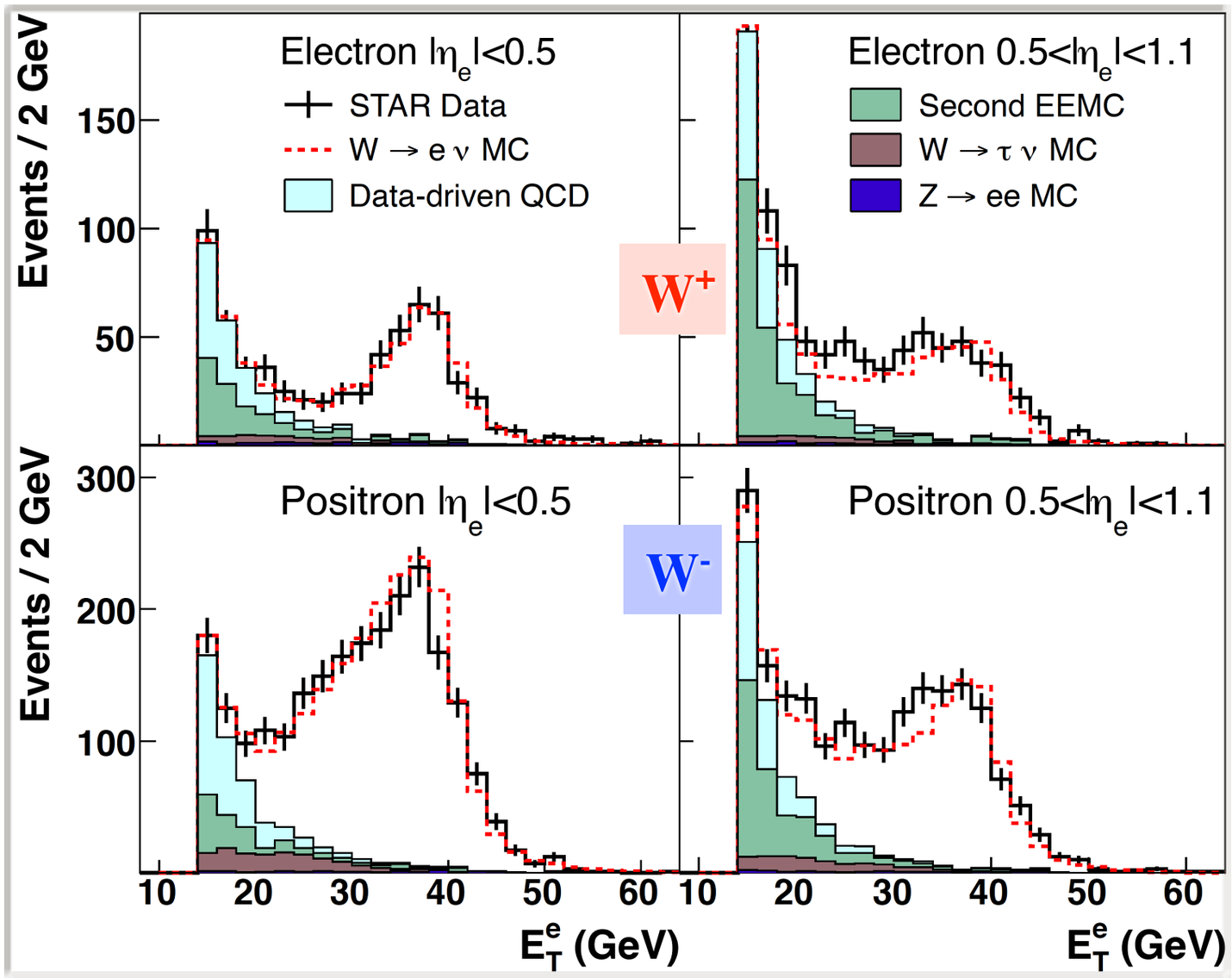
E_T distribution



Sign-P_T balance



Mid-rapidity Background Estimation



PRL 113,72301 (2014)

Primary Background

QCD processes which a jet fragments satisfy candidate $e^{+/-}$ isolation cuts while all other jets escape detection outside the acceptance.

- **Second Endcap** $-2 < \eta < -1.09$
- **Data driven QCD** $|\eta| < 2$

Electroweak BG

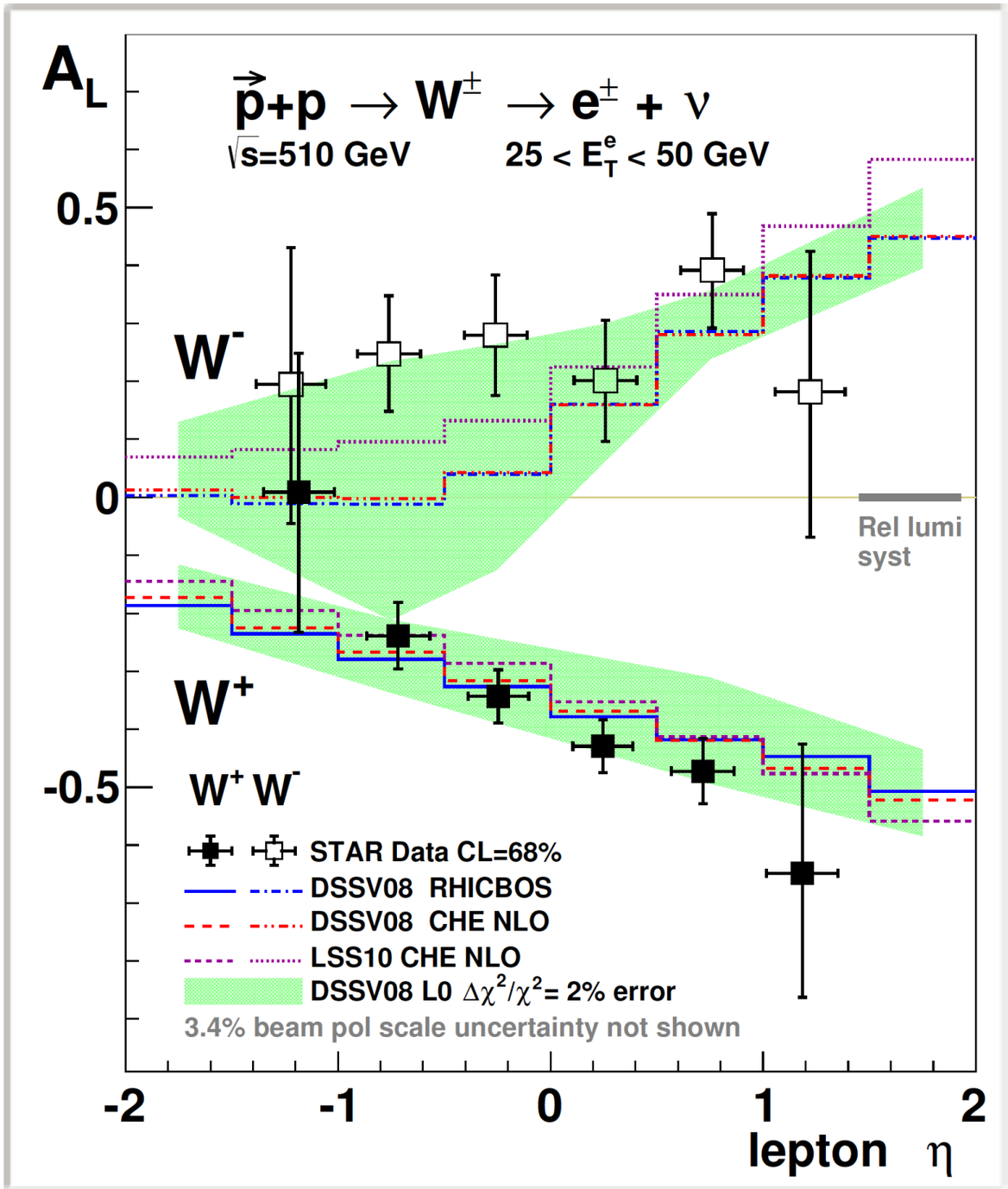
- $W \dashrightarrow \tau\nu$
- $Z \dashrightarrow e^+ + e^-$

MC Embedded in Zero-bias events

Forward rapidity ($1<\eta_e<1.4$) W selection use similar technique as mid rapidity and Background Estimation improve using additional Endcap Shower Maximum Detector (ESMD)

Results

W A_L (η_e) 2012+2011



PRL 113,72301 (2014)

✤**Profile Likelihood method used to extract Asymmetries from combination of 2012 and 2011 data.**

✤**$A_L(W^-)$ is larger than the DSSV Predictions.**

- ✦**The enhancement at $\eta_e < 0$, in particular is sensitive to the $\Delta\bar{u}$, polarized antiquark distribution.**

✤**A_L (W^+) is consistent with theoretical predictions using the DSSV polarized PDFs.**

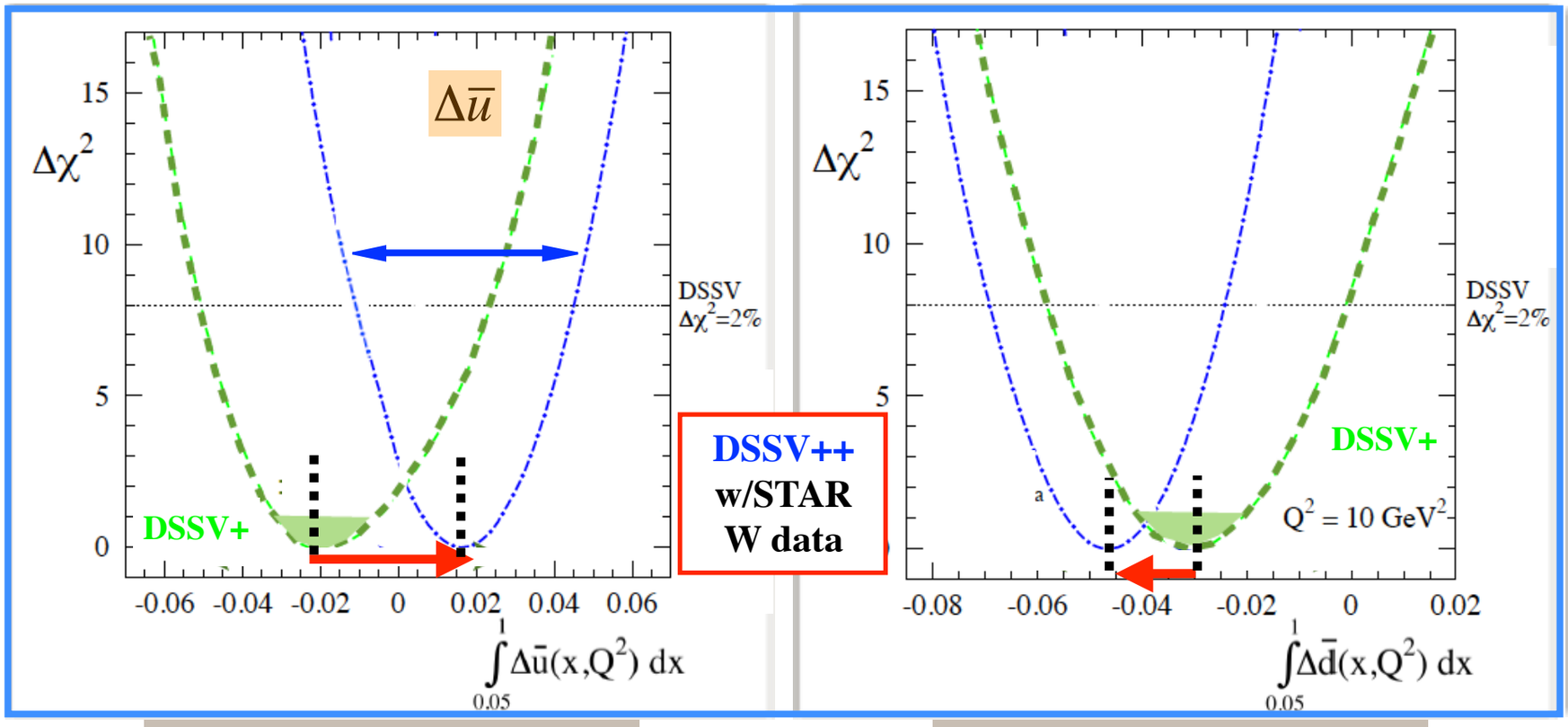
✤**The Systematic uncertainties for A_L are well under control for $|\eta_e| < 1.4$.**

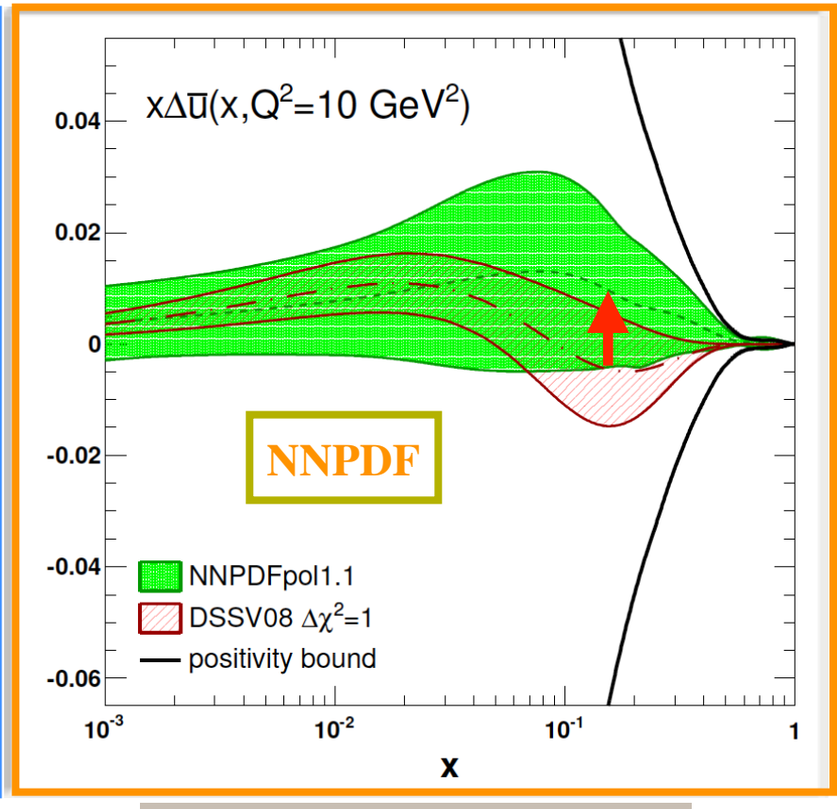
Impact on Recent Global Analysis

- **Preliminary Global analysis (DSSV++) from DSSV group and recent NNPDF includes preliminary STAR 2012 W A_L data.**

- **Shift in central value for $\Delta\bar{u}$ (negative -> positive) and $\Delta\bar{d}$ due to A_L W from STAR .**

- **STAR 2012 W results provide significant constraints on anti u and anti d quark polarization.**



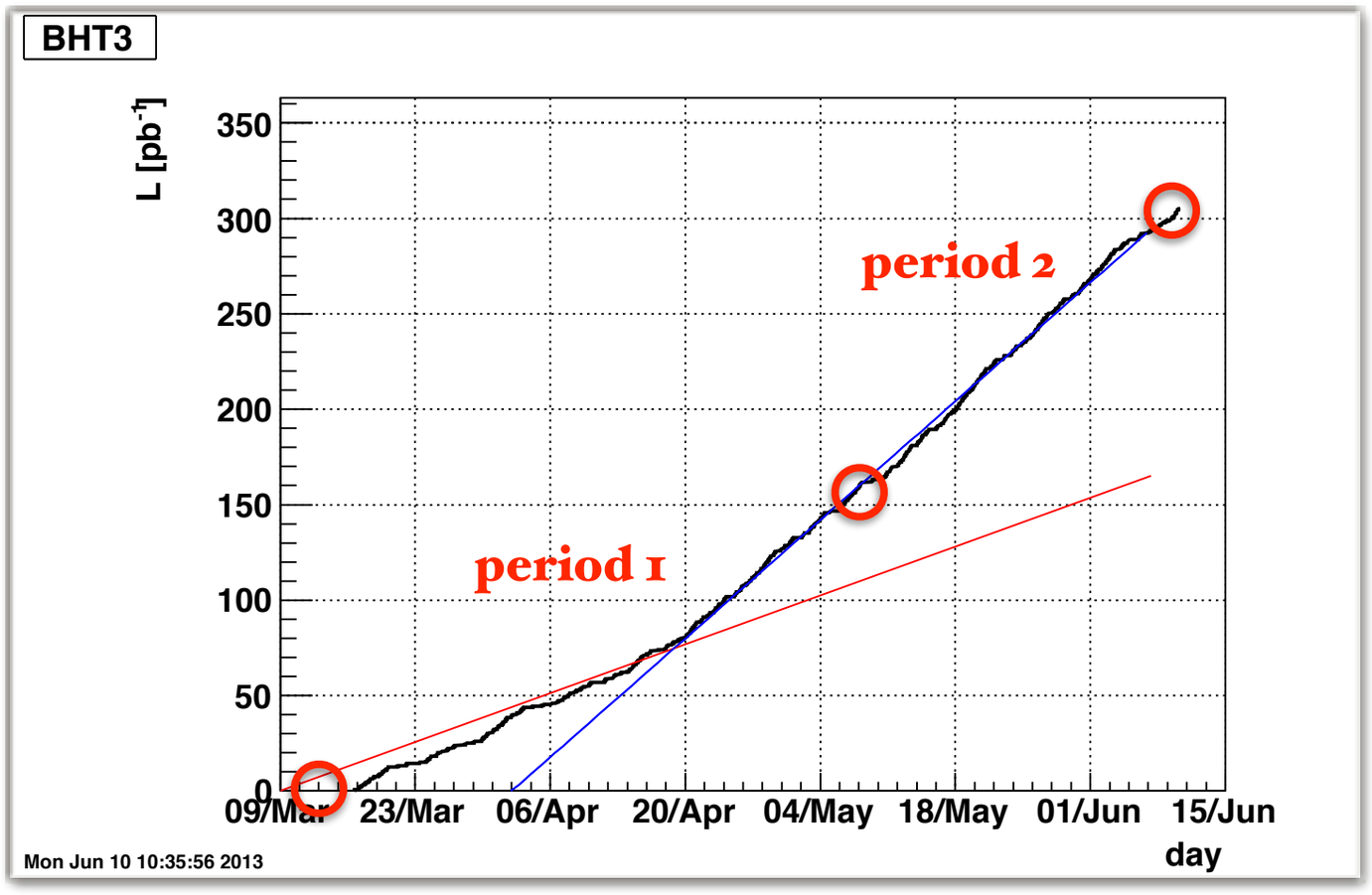


arXiv: 1304.0079 | **arXiv: 1304.0079** | **arXiv: 1403.0440**

STAR 2013 W Analysis Status

2013 Data Sample

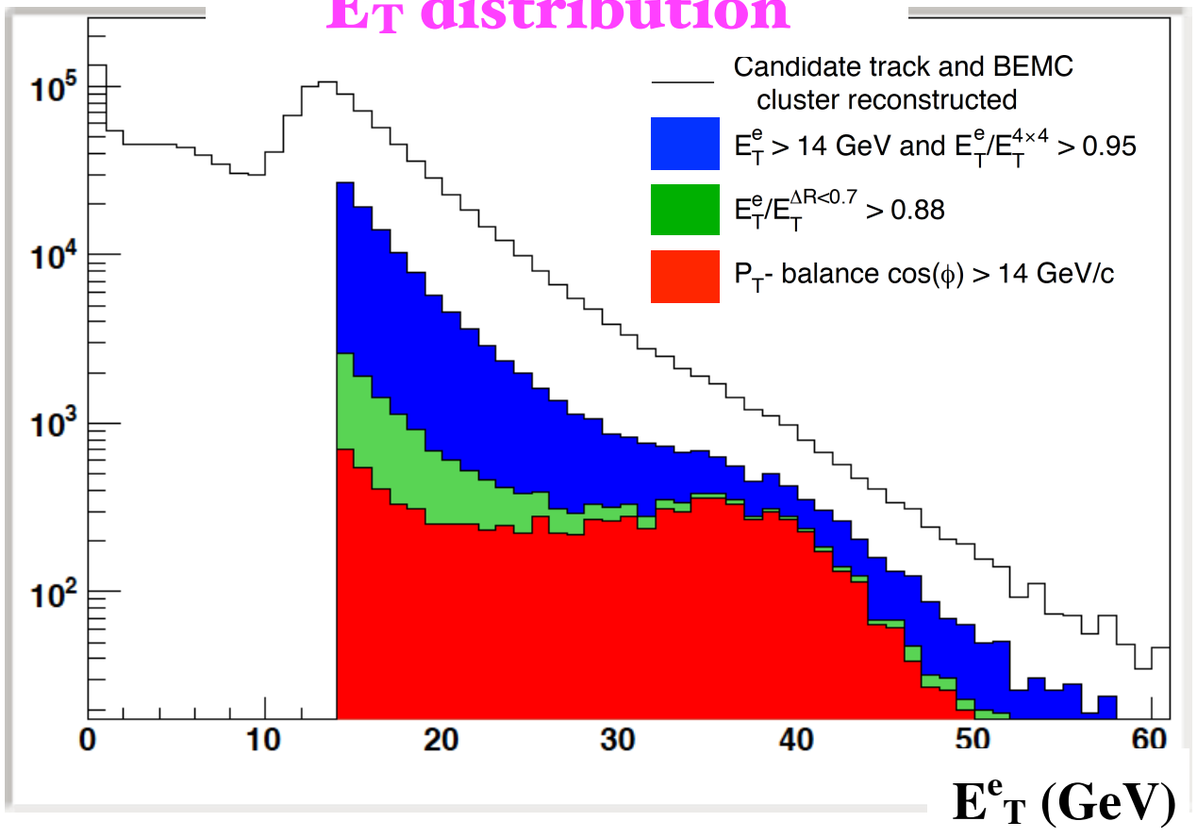
Barrel EMC triggered Integrated Luminosity



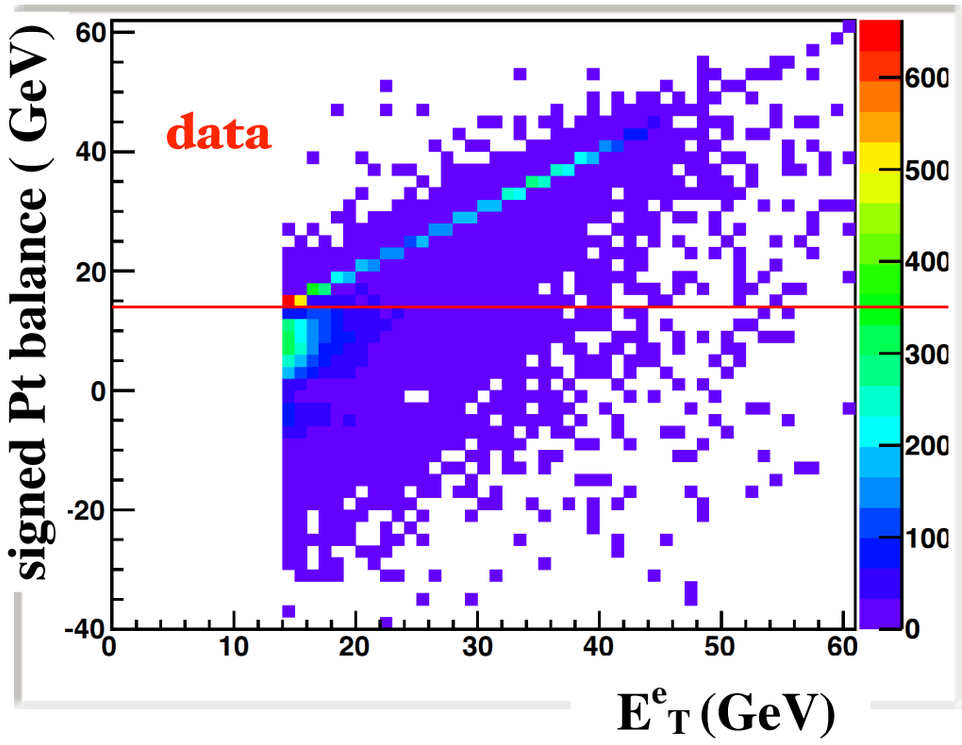
	L (pb^{-1})	P	P^2L (pb^{-1})
Run 9	12	0.38	1.7
Run 11	9.4	0.49	2.3
Run 12	72	0.56	24
Run 13	~300	0.54	~87

Mid-rapidity Analysis Status : W selection

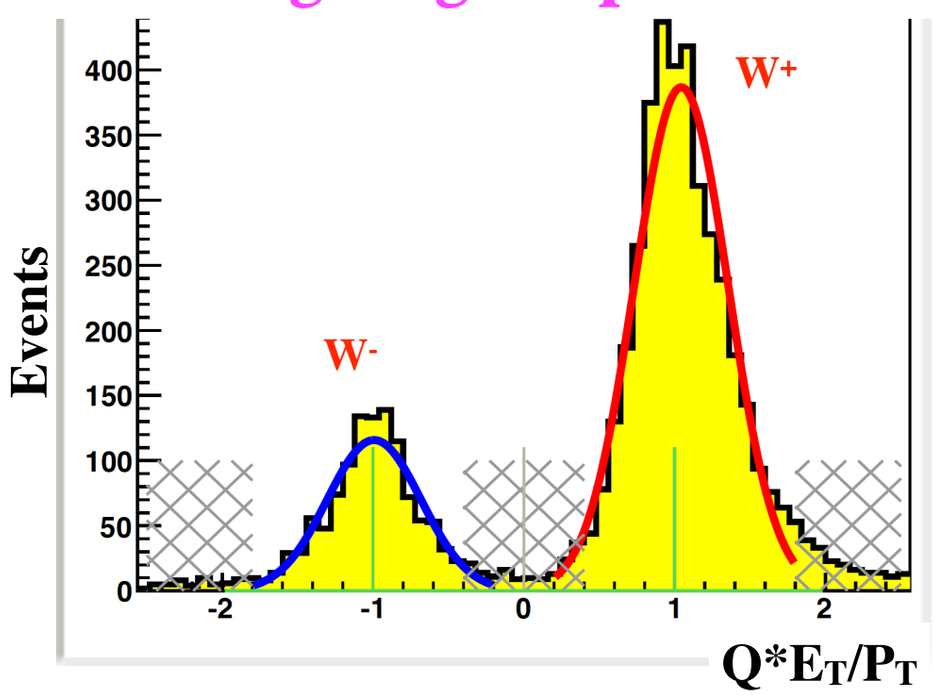
E_T distribution

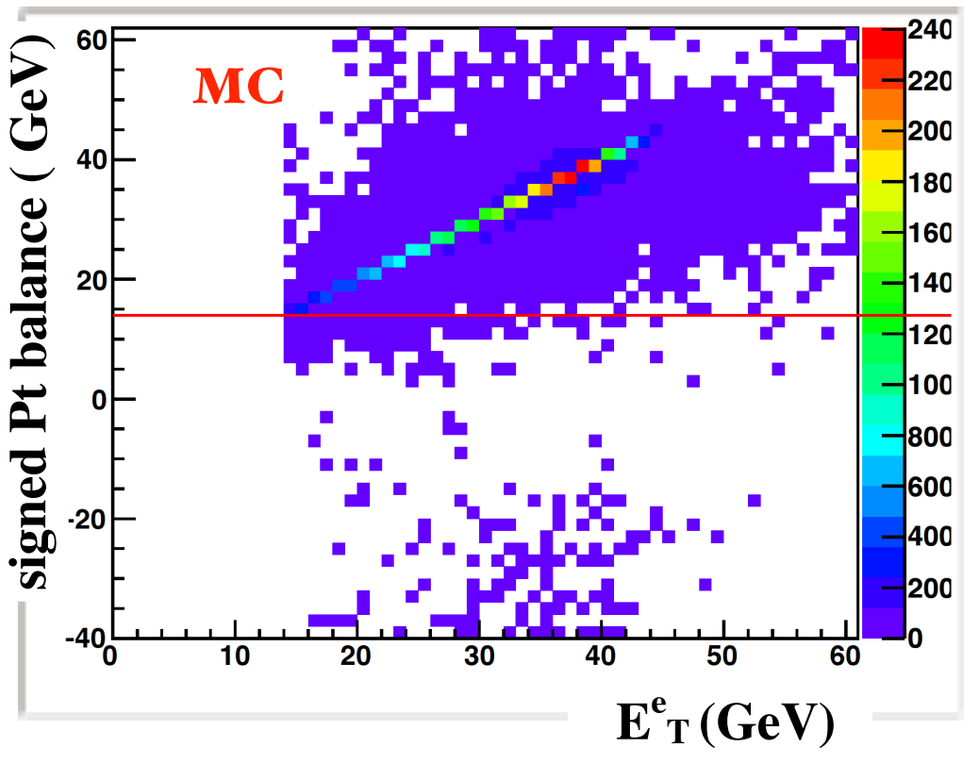


Sign-P_T balance



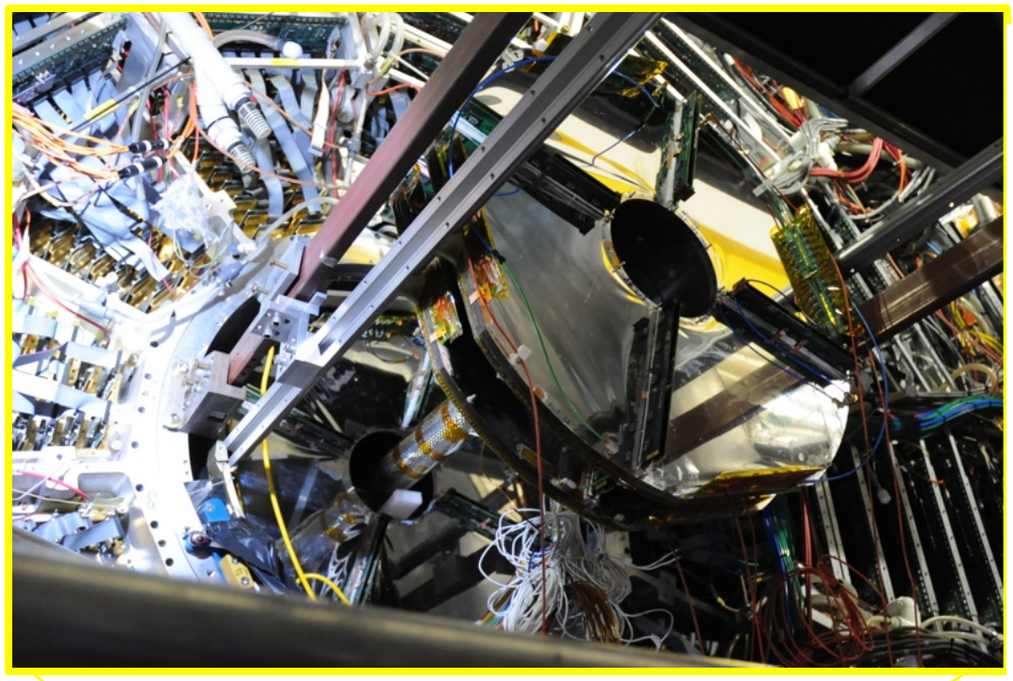
Charge-sign Separation

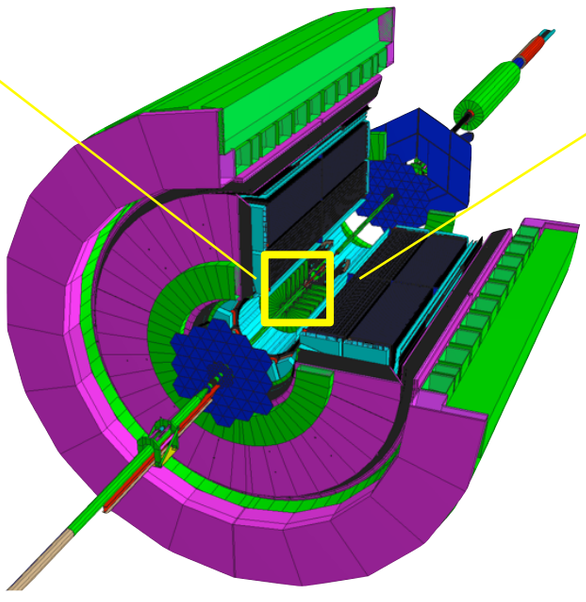




Forward-rapidity Analysis Status :

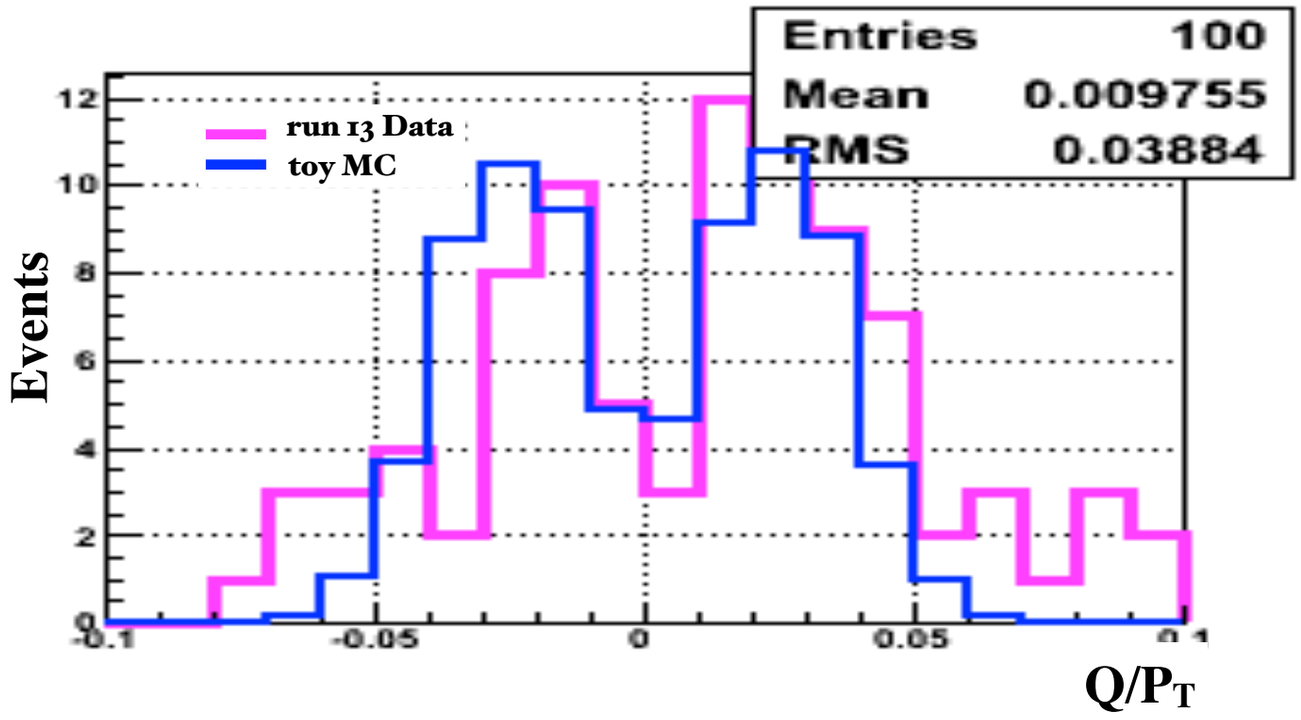
FGT (Forward Gem Tracker)





W Charge-sign Separation using FGT

FGT(2≥hits)+Vertex+EEMC+Prompt



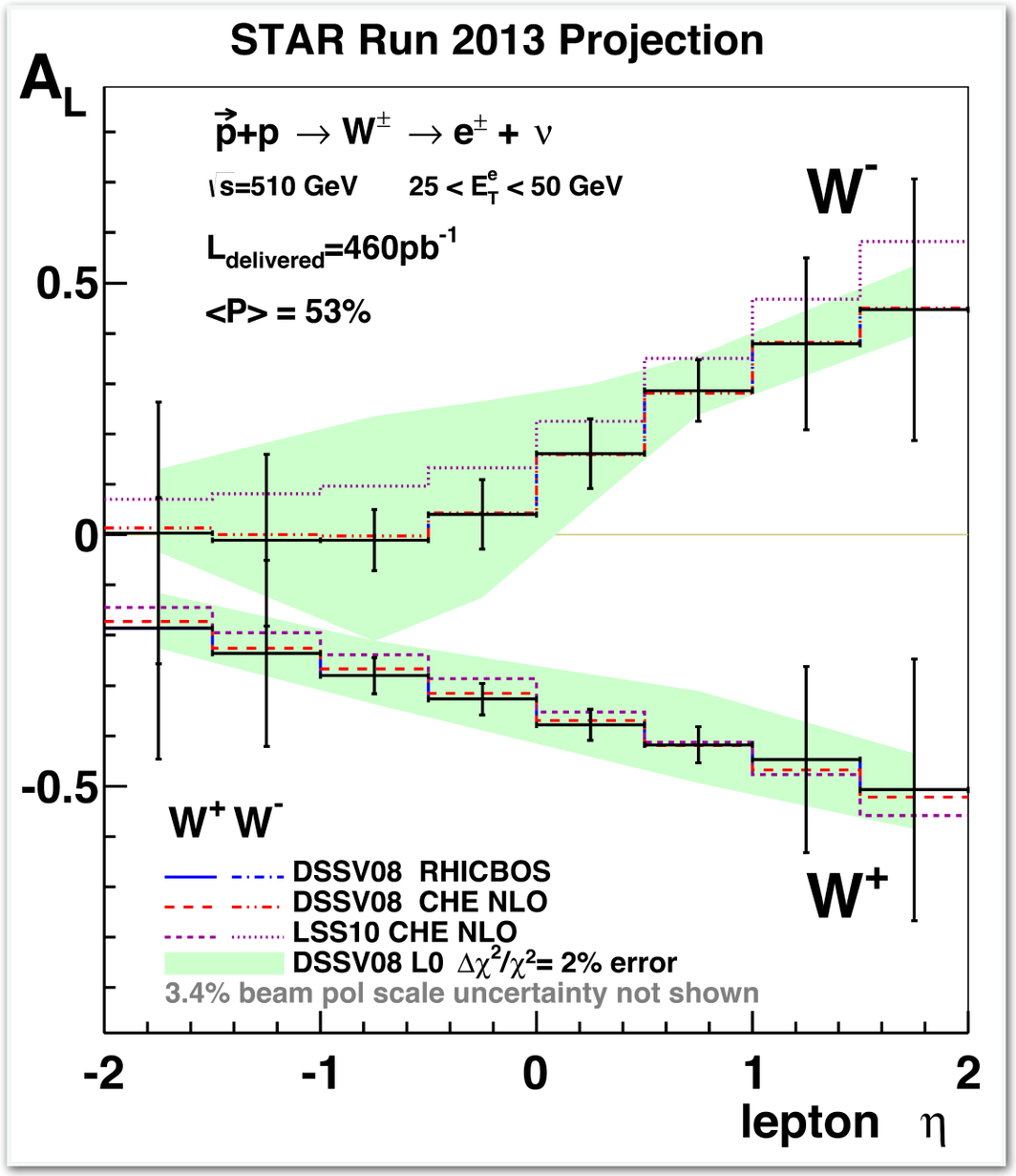
Prompt = actual measurement using TPC internal Multi-Wire proportional chamber

FGT res=0.02cm , VTX-XY res=0.02cm, VTX-Z res=1cm, TPC prompt res=0.1cm, EEMC res=0.3cm

~2.5 sigma separation with FGT+VTX+EEMC +PROMPT (~1/3 events)

STAR 2013 W A_L Projections

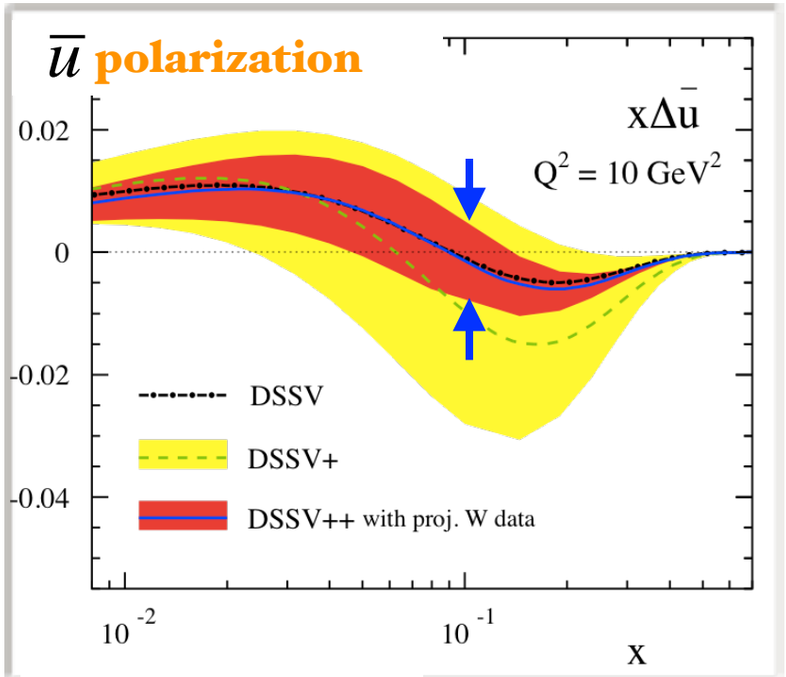
STAR W A_L Projections

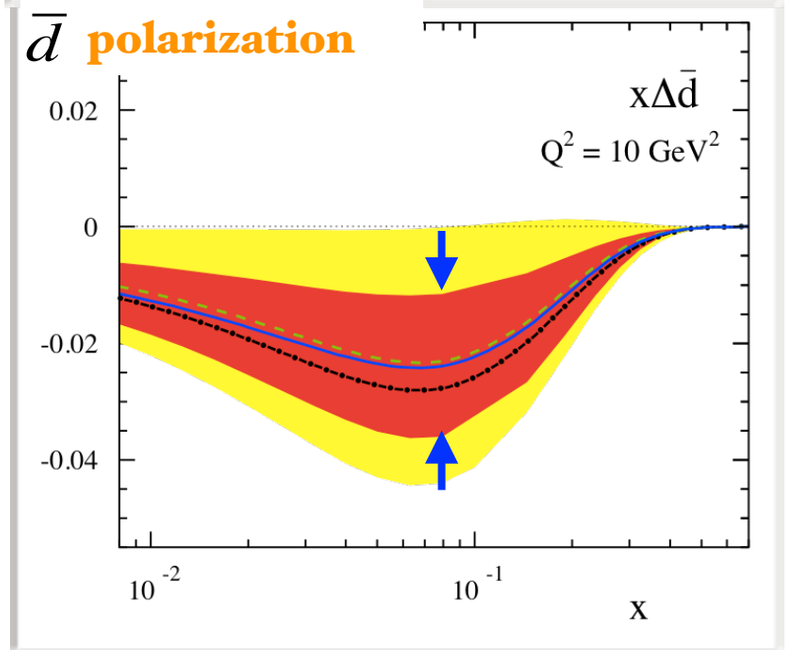


Higher precision results is expected from much larger statistics

Extension of forward and backward acceptance enhance sensitivity to $\bar{u}$ and $\bar{d}$ quark polarization

Impact on antiquark polarization





arXiv: 1304.0079

Summary / Outlook

- **The Production of W Bosons in polarized p+p collisions provides a new means to study the spin and flavor asymmetries of the proton sea quark distributions**

- **STAR has measured the parity violating single-spin asymmetry A_L for $|\eta_e| < 1.4$ from 2012 and 2011 data, providing the first detailed look at the asymmetry's η_e dependance.**

- **STAR 2012 W A_L results provide significant constraints on anti u and anti d quark polarization.**

- **The first half of the data from the high statistics 2013 run is in the final state of analysis and the analysis of the second half is under way.**

- **Higher precision result from 2013 will improve the constraints on the sea quark polarization.**

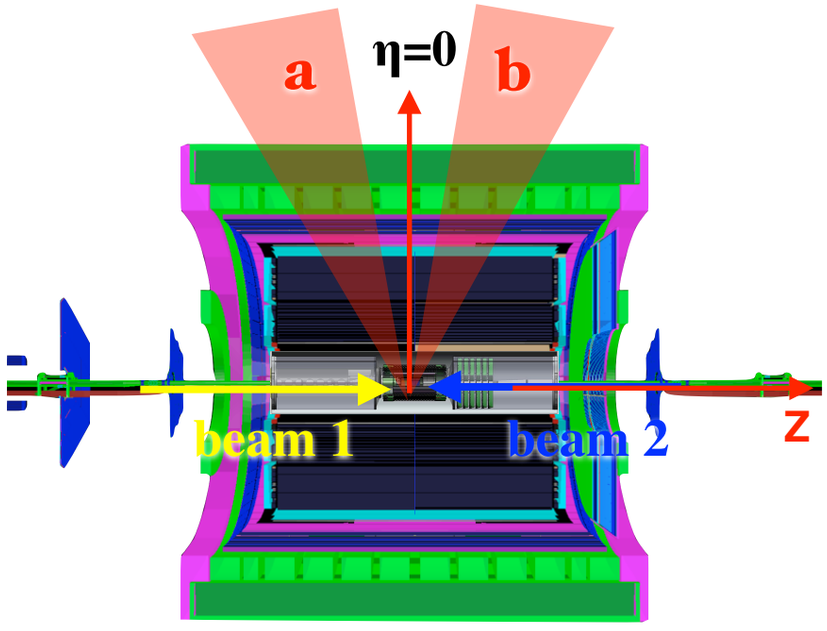
Backup

Extracting Asymmetries using Profile Likelihood Method

- **Profile Likelihood method used in extracting Asymmetries from combination of run 2012 and run 2011 data [simple gaussian uncertainties breakdown particularly for small 2011 data sample]**

- **Define likelihood function for 8 spin-dependent yields from pair of symmetric η region of STAR**

$$L = \Pi_i^4 p(M_i^a \mid \mu_i^a) p(M_i^b \mid \mu_i^b) g(\beta^a) g(\beta^b)$$



$p(M_i \mid \mu_i)$ **- Poisson probability, for measured spin sorted yield M_i in the expected value μ_i given by:**

$$\mu_{++}^a = I_{++} N(1 + P_1 \beta A_L^{+\eta_e} + P_2 \beta A_L^{-\eta_e} + P_1 P_2 \beta A_{LL})$$

$$\mu_{+-}^a = I_{+-} N(1 + P_1 \beta A_L^{+\eta_e} - P_2 \beta A_L^{-\eta_e} - P_1 P_2 \beta A_{LL})$$

$$\mu_{-+}^a = I_{-+} N(1 - P_1 \beta A_L^{+\eta_e} + P_2 \beta A_L^{-\eta_e} - P_1 P_2 \beta A_{LL})$$

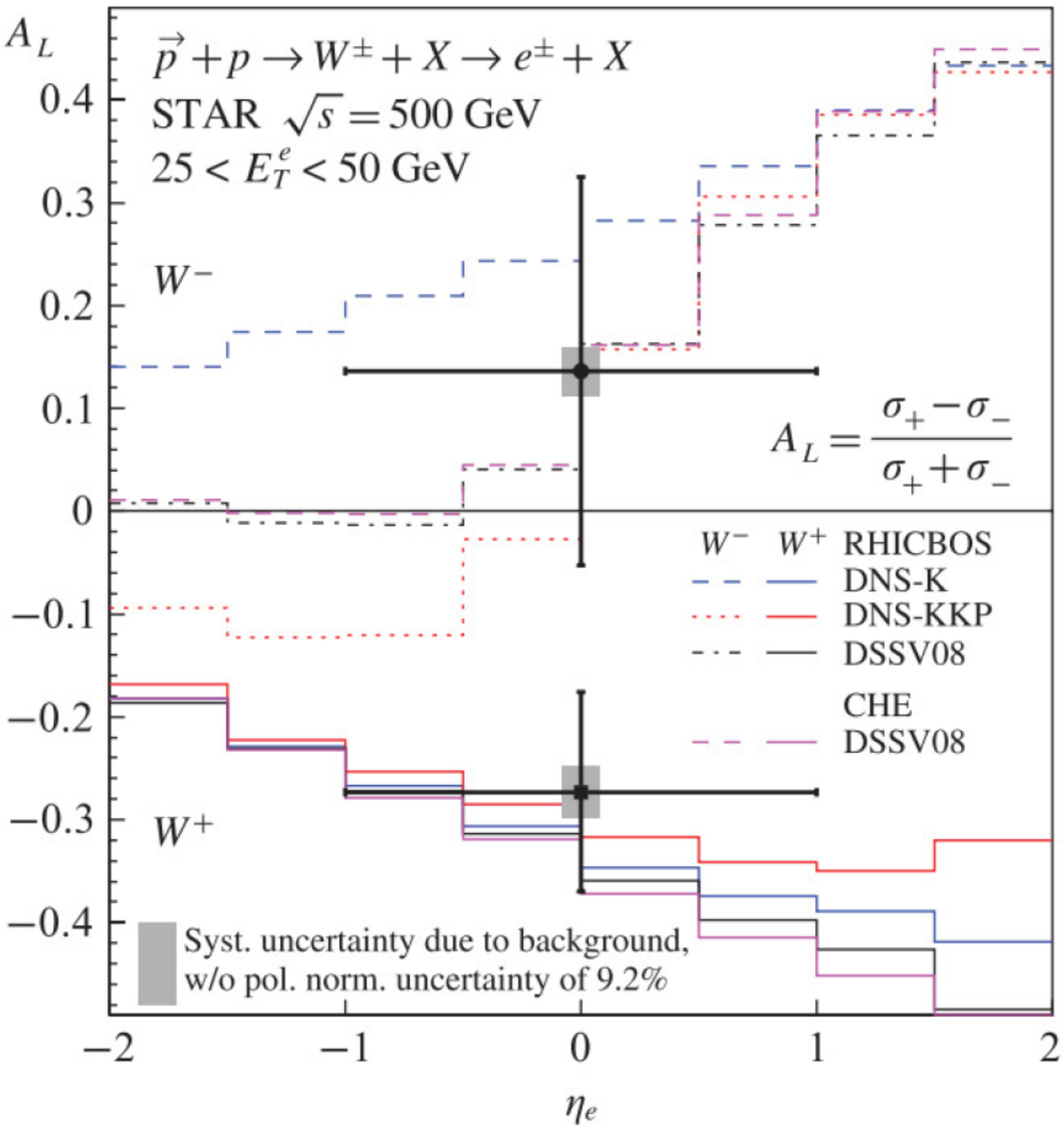
$$\mu_{--}^a = I_{--} N(1 - P_1 \beta A_L^{+\eta_e} - P_2 \beta A_L^{-\eta_e} + P_1 P_2 \beta A_{LL})$$

P_1, P_2 - beam polarization $A_L^{+\eta_e}(A_L^{-\eta_e})$ **- single spin asymmetry**

A_{LL} **- double spin asymmetry** **N - spin averaged yield** $I_{\pm\pm}$ **- relative luminosity**

g(β) - Gaussian probability for estimated dilution background β

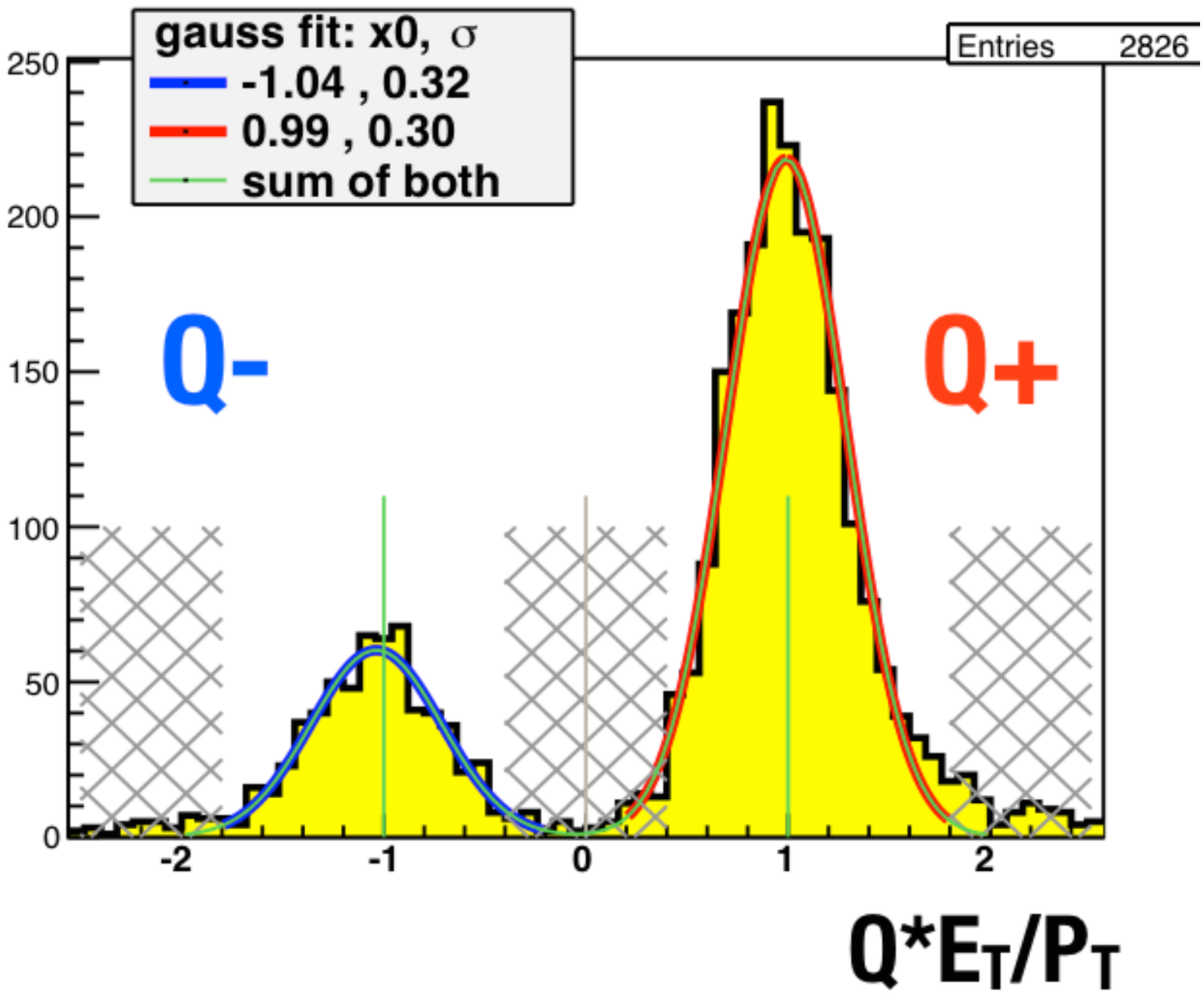
STAR 2009 W Results



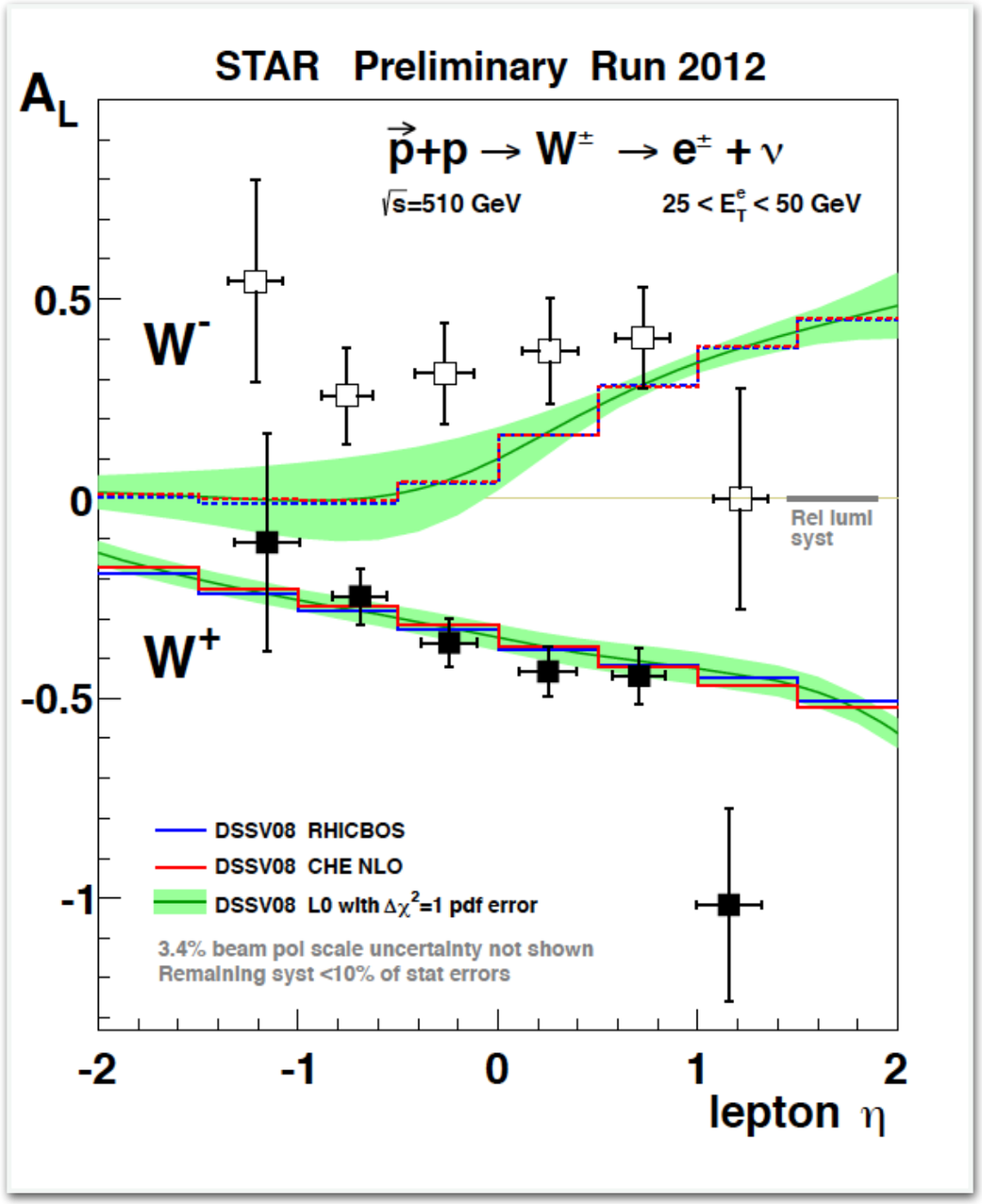
PRL 106, 062002 (2011)

STAR pp500 Longitudinal		
Run	L (pb^{-1})	$W^+(W^-)$ raw yield
2009	12	462 (192)
2011	9	342 (103)
2012	77	2417 (734)

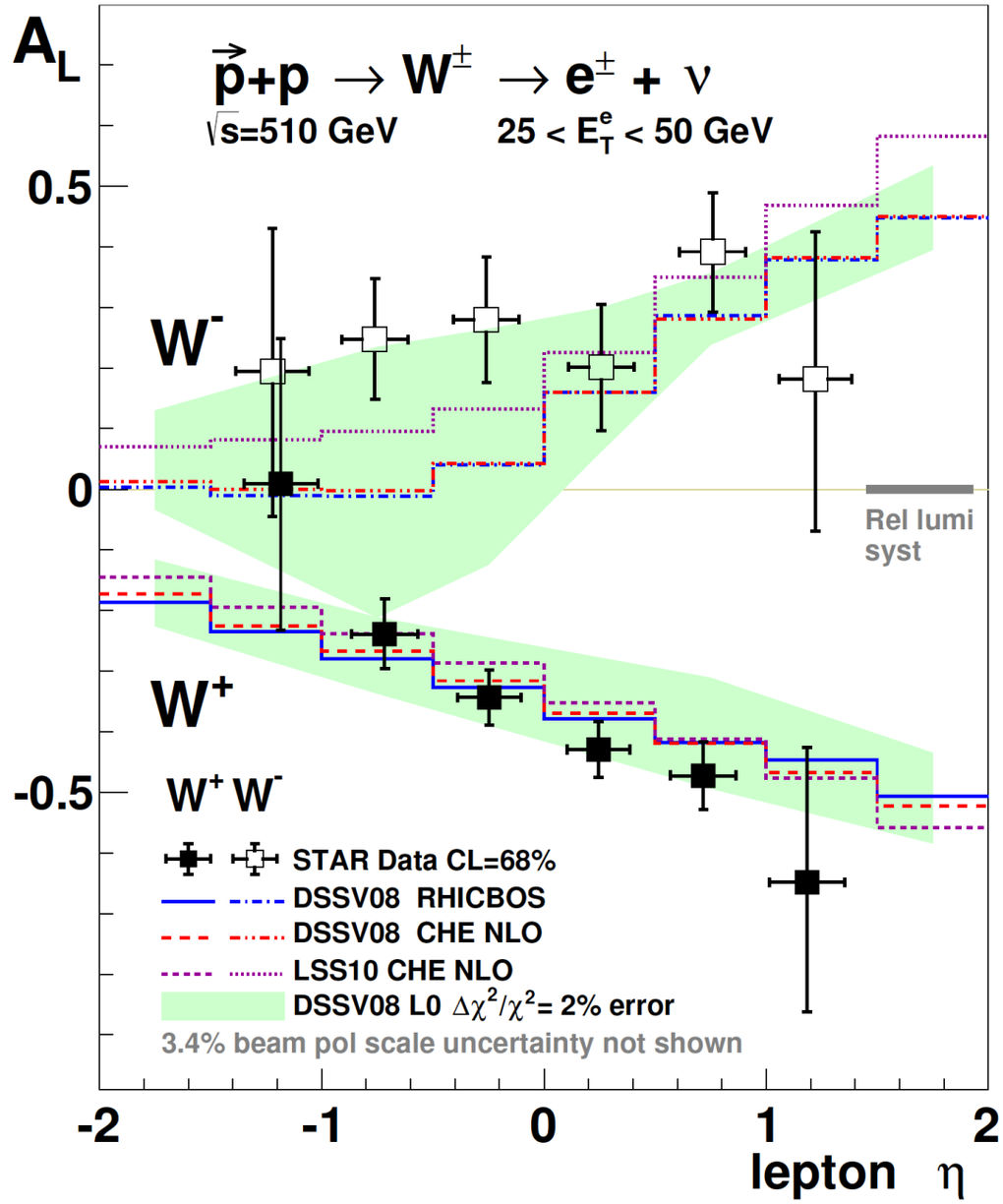
Mid-Rapidity charge sign separation



Run 12 Preliminary results compare to Final

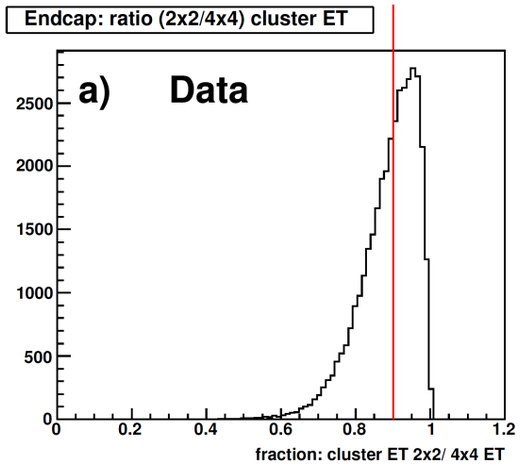


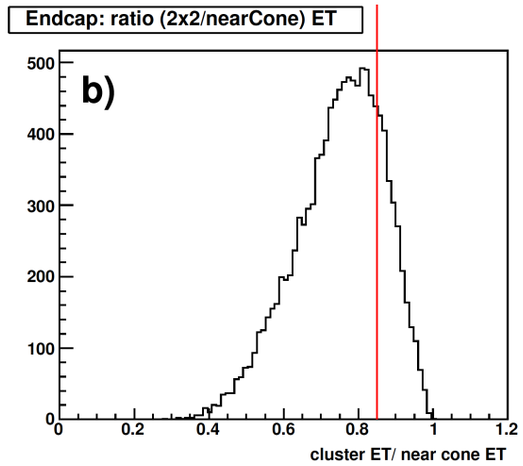
STAR FINAL Run 2012+2011

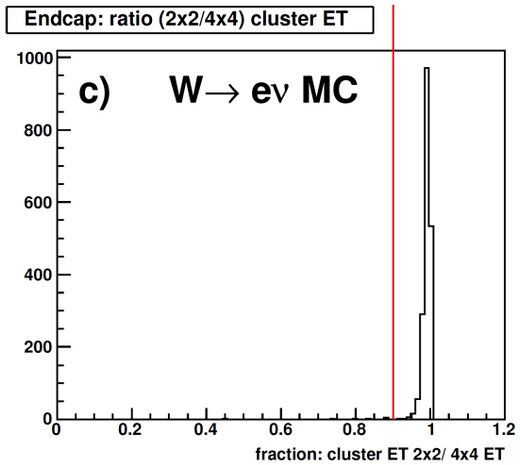


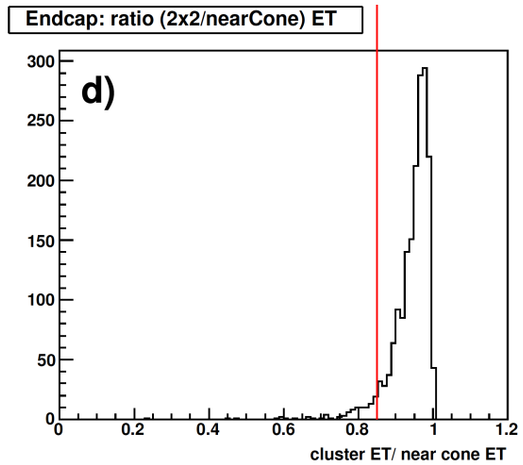
PRL 113,72301 (2014)

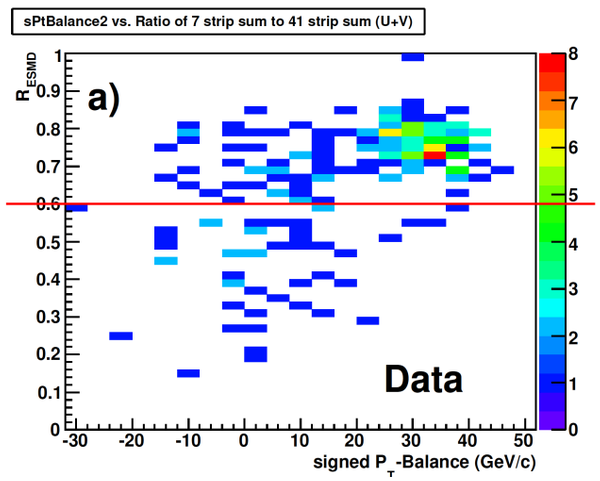
Endcap W Selection

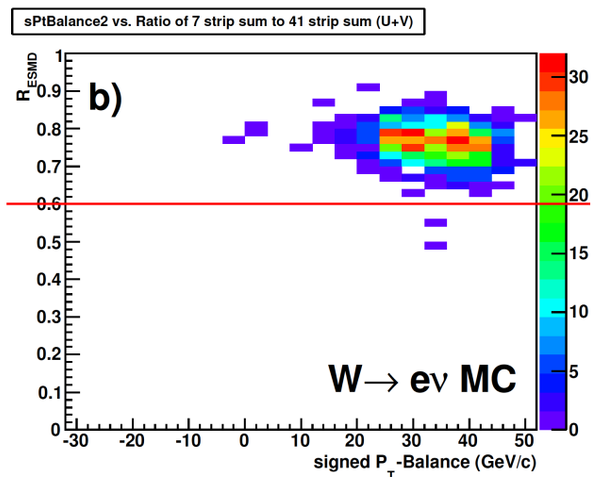




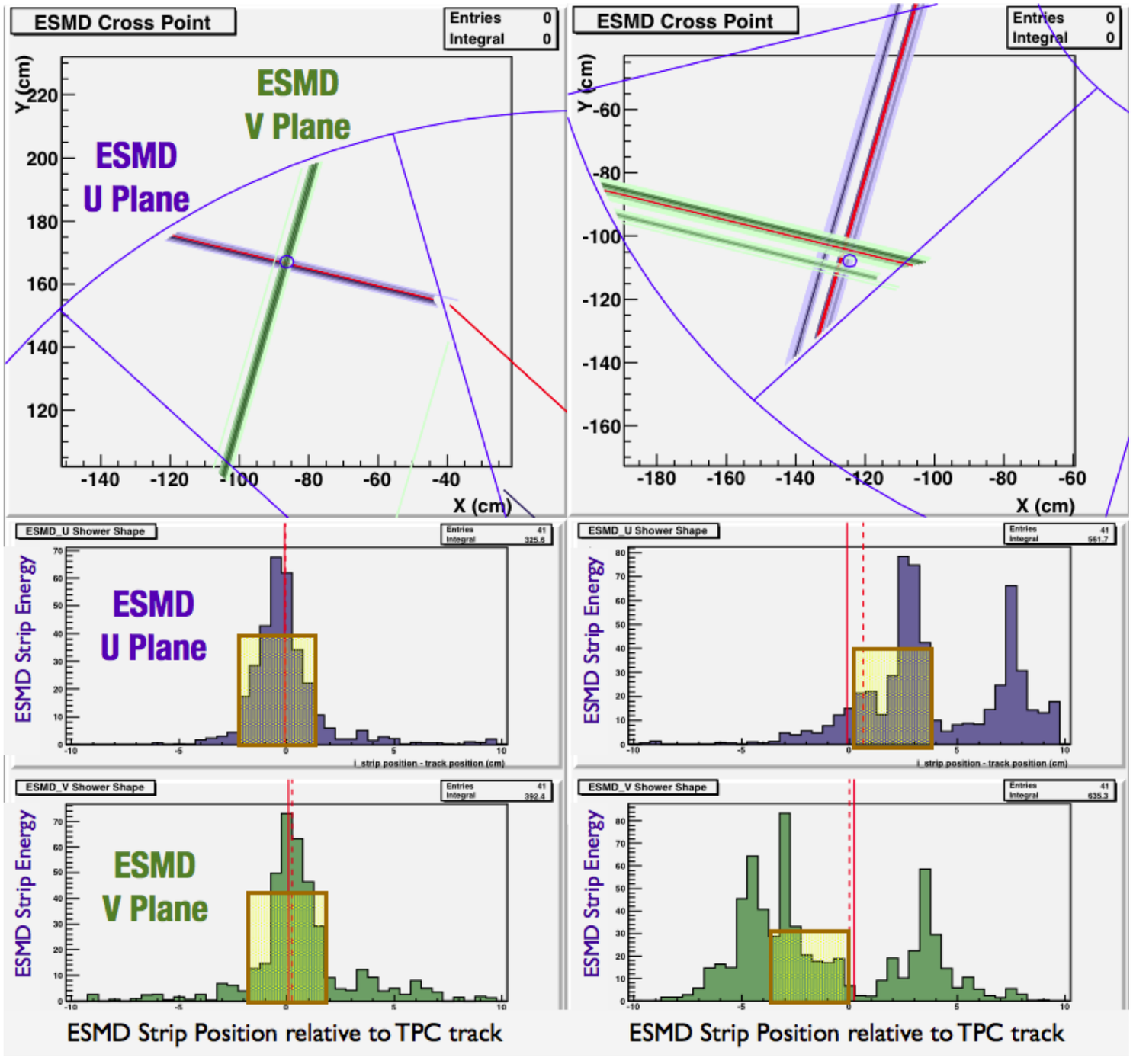


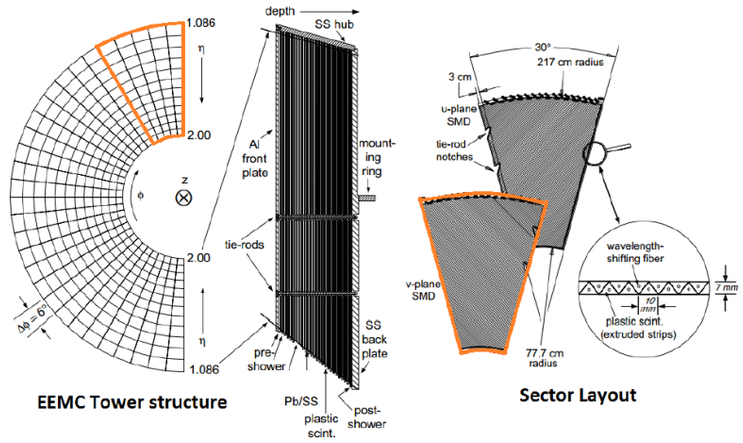






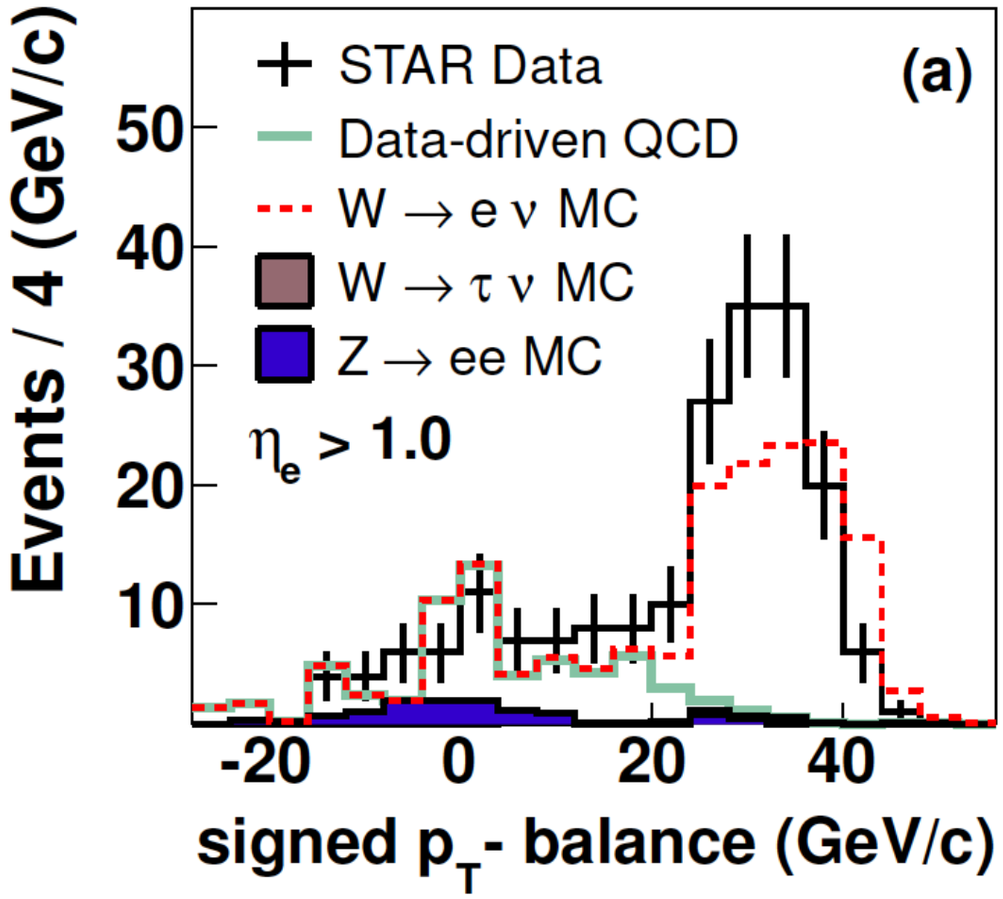
ESMD CUTS

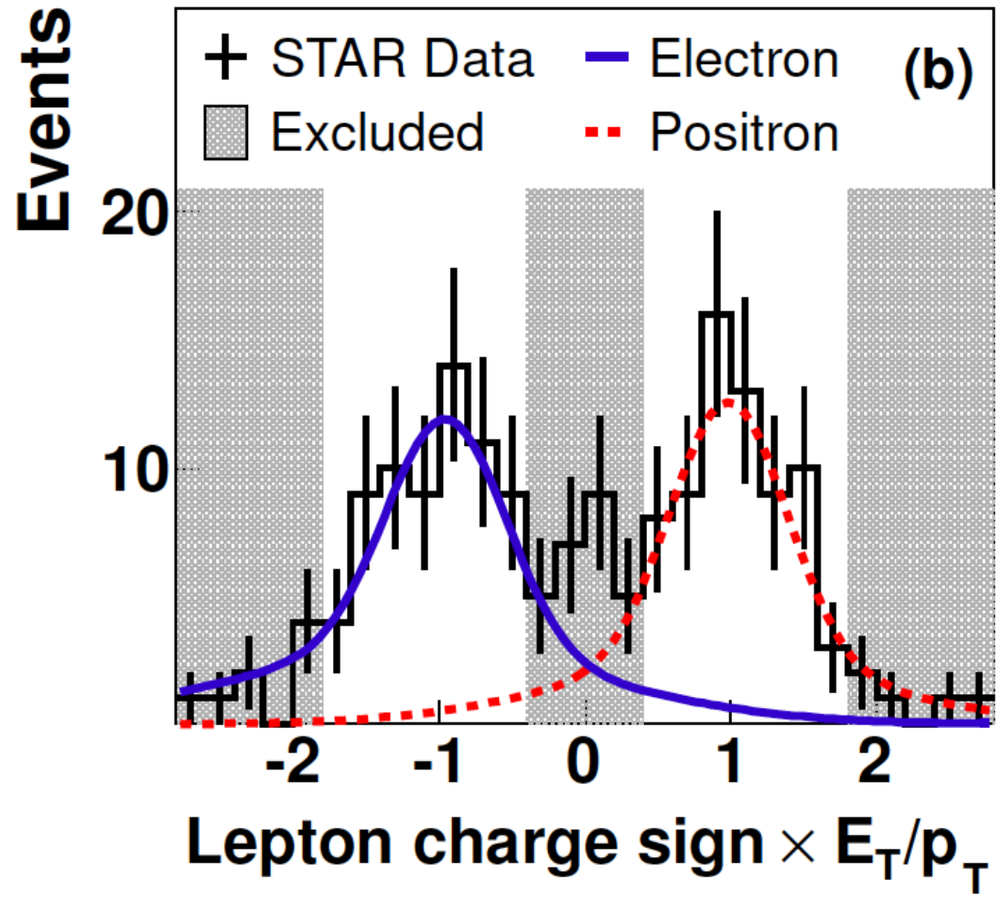




$$R_{ESMD} = \frac{\sum_{i=-3}^{+3} E_i^U + E_i^V}{\sum_{i=-20}^{+20} E_i^U + E_i^V}$$

Forward Rapidity Background Estimation and charge sign separation

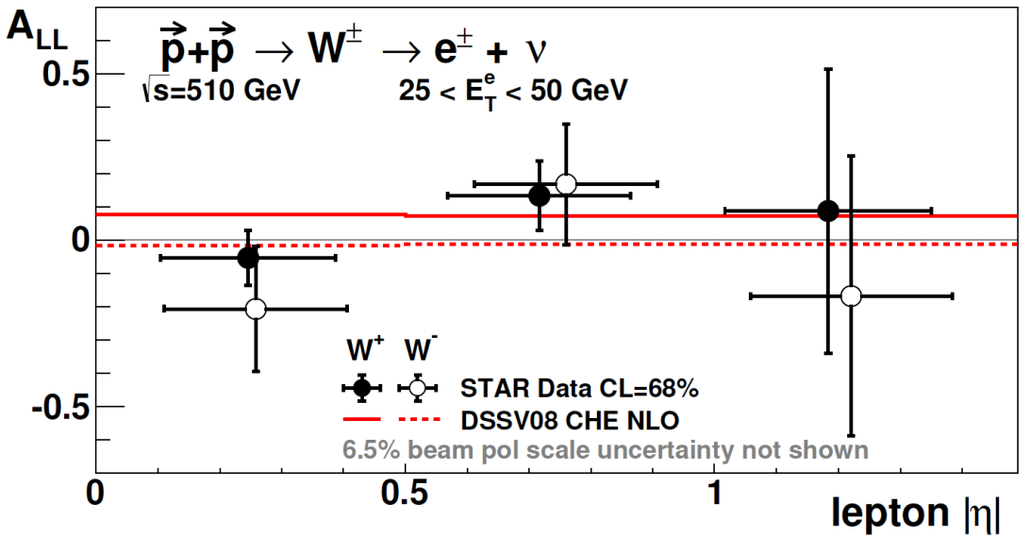




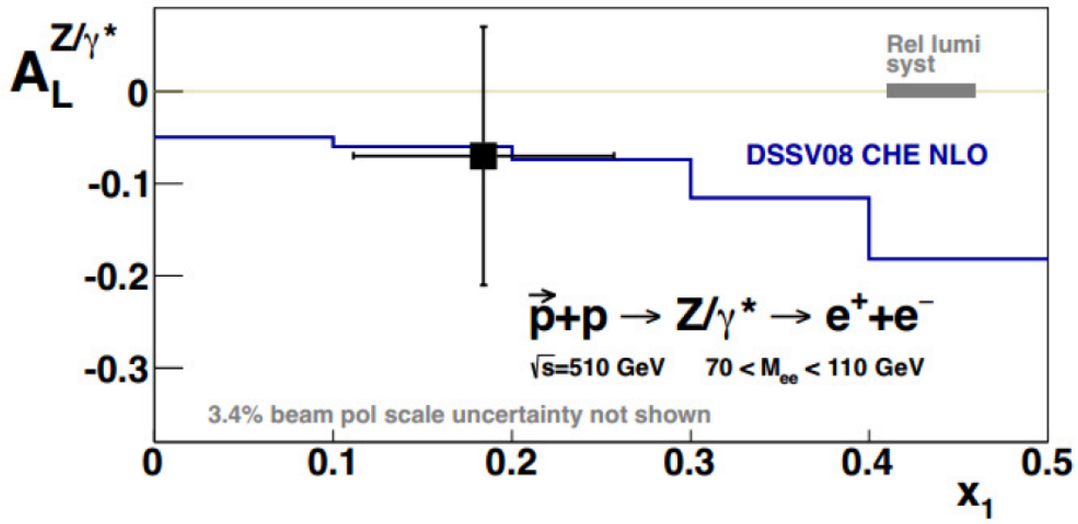
PRL 113,72301 (2014)

Run 12 ALL and Z AL results

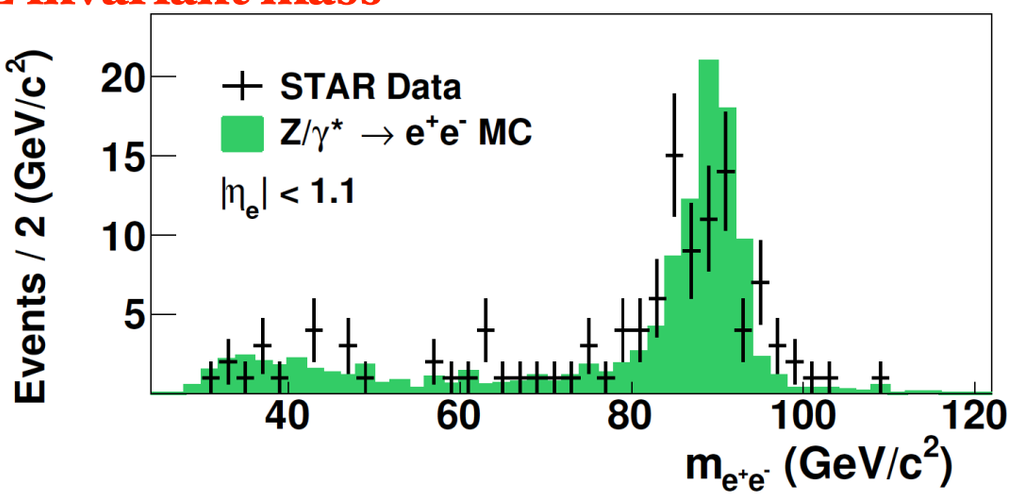
$$A_{LL} = \frac{(\sigma^{++}+\sigma^{--})-(\sigma^{+-}+\sigma^{-+})}{(\sigma^{++}+\sigma^{--})+(\sigma^{+-}+\sigma^{-+})}$$



PRL 113,72301 (2014)



Z invariant mass



PRL 113,72301 (2014)

W production: more details

Helicity structure can see in the differential cross section of W

$$\frac{d\sigma_{W^+}}{d\cos\theta} \propto \bar{d}(x_1)u(x_2)(1+\cos\theta)^2 + u(x_1)\bar{d}(x_2)(1-\cos\theta)^2$$
$$\frac{d\sigma_{W^-}}{d\cos\theta} \propto \bar{u}(x_1)d(x_2)(1-\cos\theta)^2 + d(x_1)\bar{u}(x_2)(1+\cos\theta)^2,$$

W tends to boost direction of the valance quark traveling

Helicity structure of the interaction causes lepton to emit parallel (antiparallel) to W-(W+)

higher (lower) x parton in the collision is most likely quark (antiquark) . And quark is very likely to come from valance region

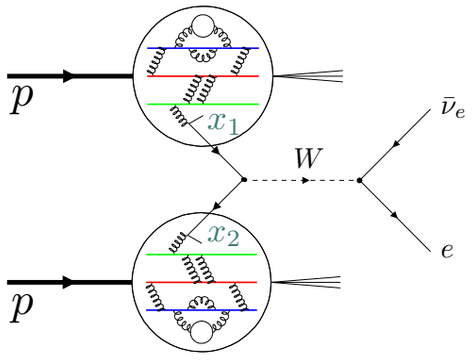
W longitudinal momentum

$$p_{L,W} = \frac{\sqrt{s}}{2}(x_1 - x_2)$$

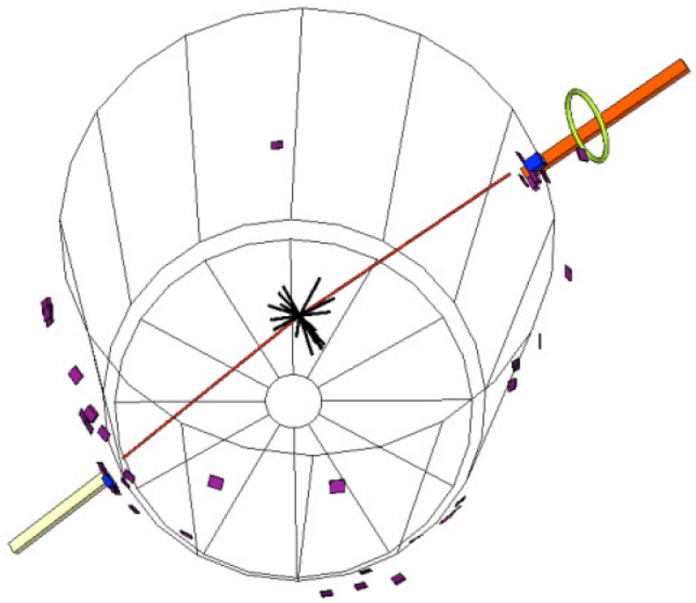
e decay kinametics in lab frame related to W boost direction

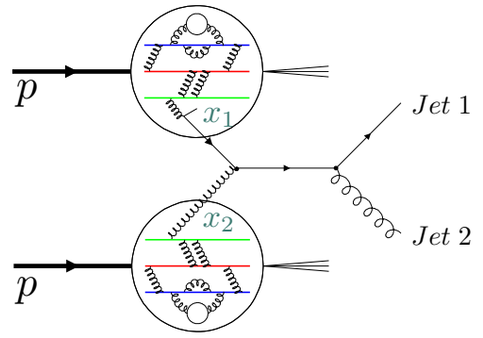
$$p_{L,e}^{lab} = \frac{1}{\gamma}p_{L,e}^{*} + \beta E_e^{lab}, \quad p_{L,e}^{*} = \cos\theta \cdot M_W/2 \quad (p_T^e = \sin\theta \cdot M_W/2).$$

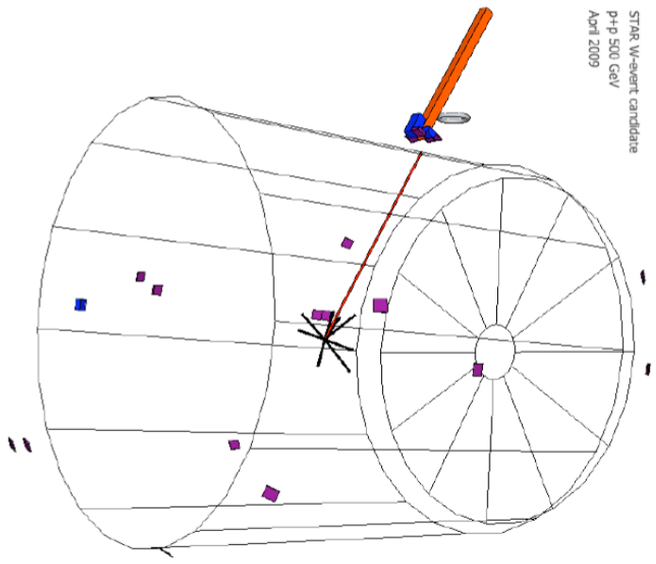
W , di-Jet and Z type events



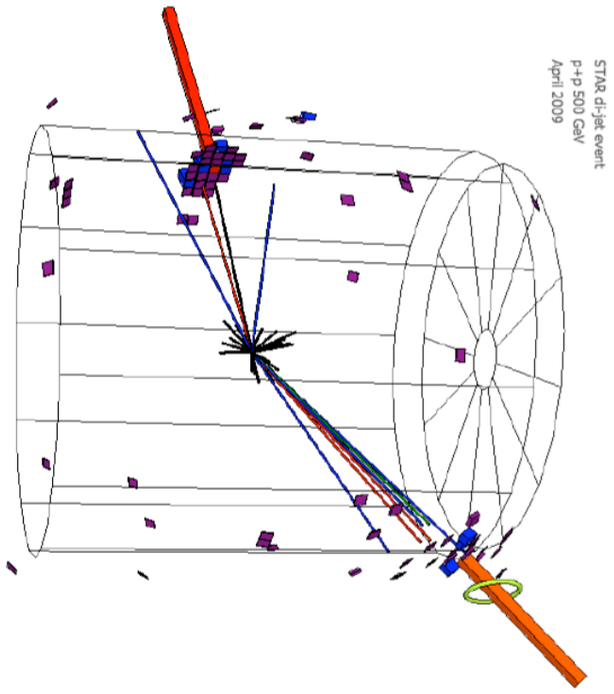
simulated Z-ee event







simulated W->e event

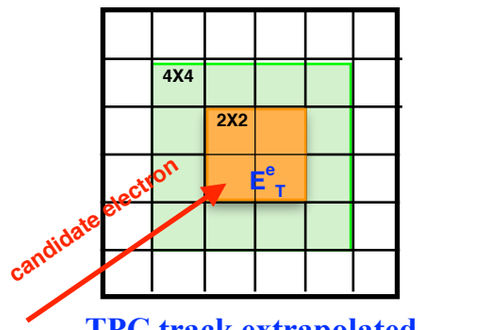


simulated di-jet event

Mid-rapidity ($|\eta_e| < 1$) W Selection

✤ Match P_T > 10 GeV TPC tracks to EMC cluster

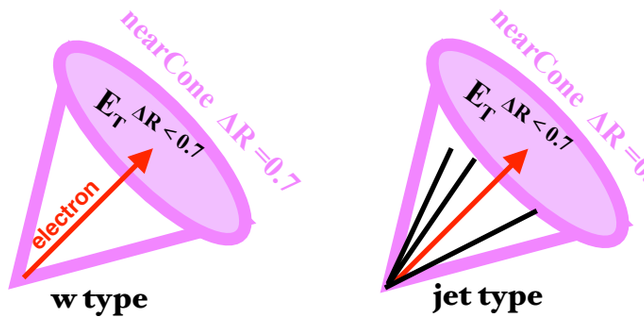
$$E^e_T / E_T^{4X4} > 0.95$$



TPC track extrapolated to Barrel colorimeter tower grid

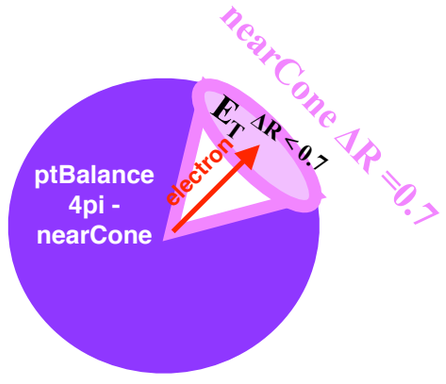
✤ Isolate from QCD di-jet type event

$$E^e_T / E_T^{\Delta R < 0.7} > 0.88$$



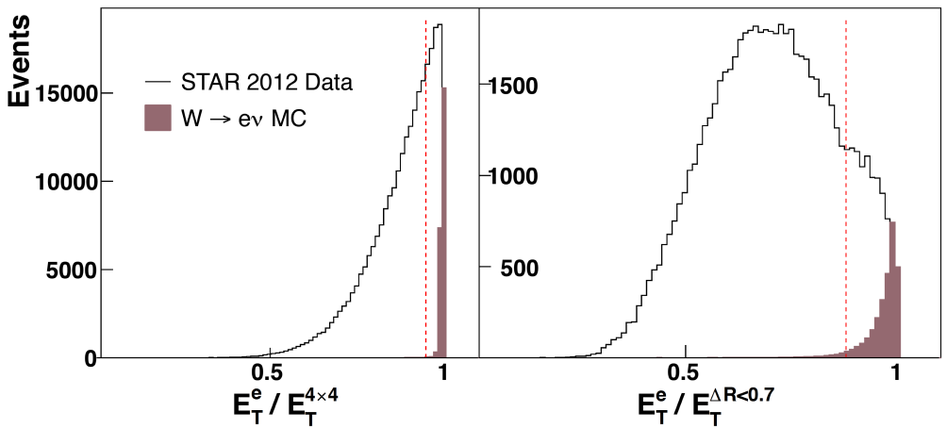
✤ Use Larger imbalance of transverse momentum

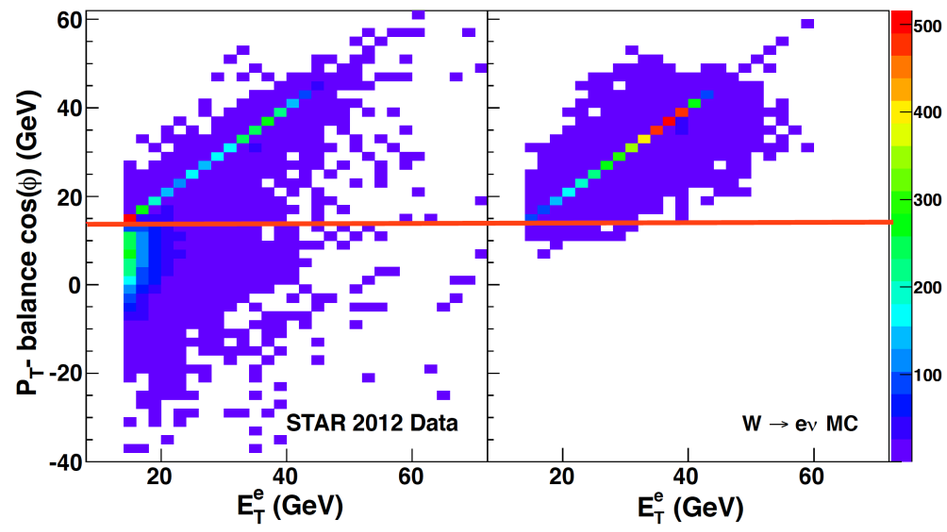
$$\vec{p}_T^{\,balance} = \vec{p}_T^{\,e} + \sum_{\Delta R>0.7} \vec{p}_T^{\,jets}$$

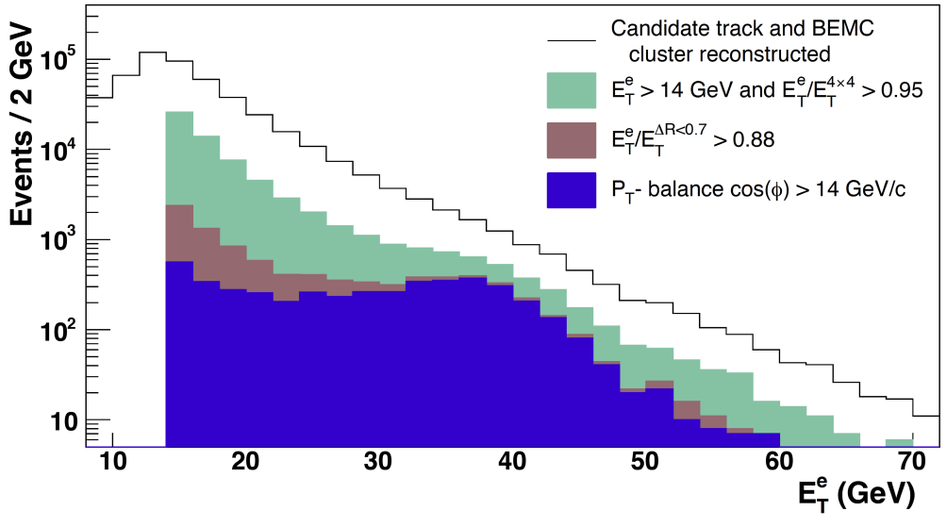


Transverse plane views

✤ e^+ and e^- Charge sign Separation

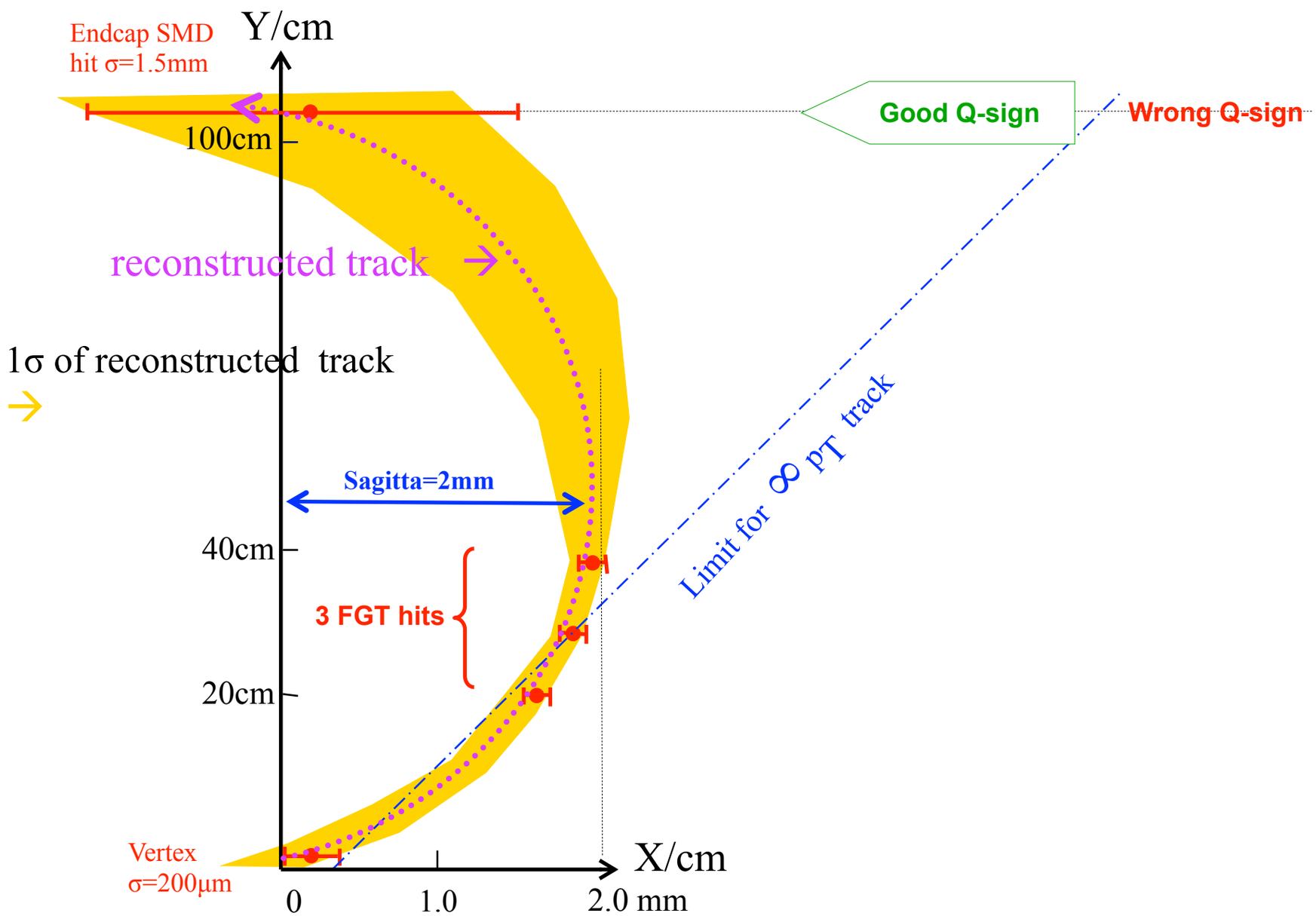






FGT

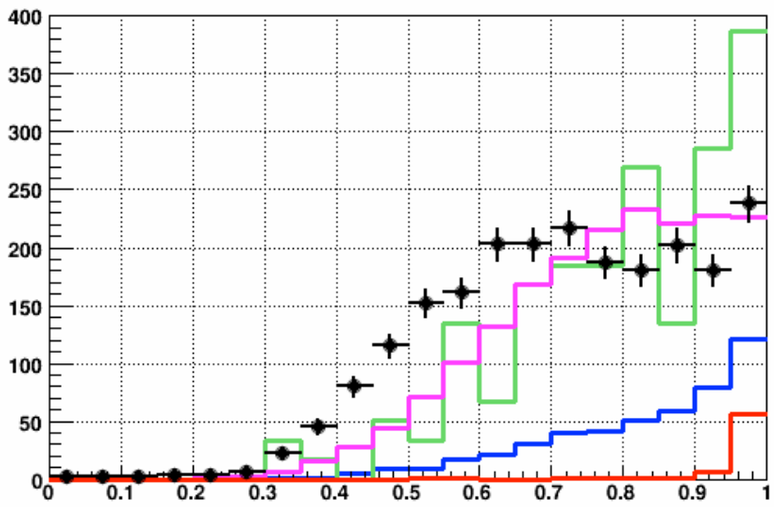
Illustration of charge-sign discrimination



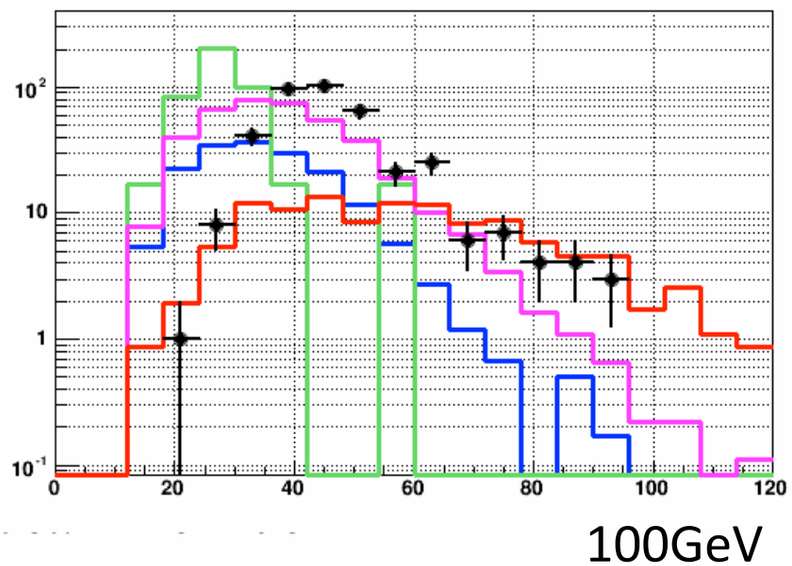
FGT track reconstruction

- Comparison of data / fast MC: Track reconstruction

$R^{ISOLATION}$

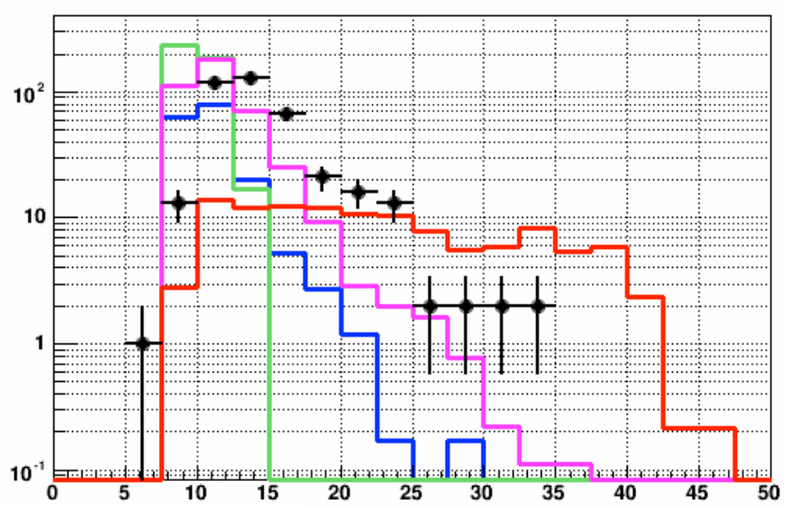


E [GeV]



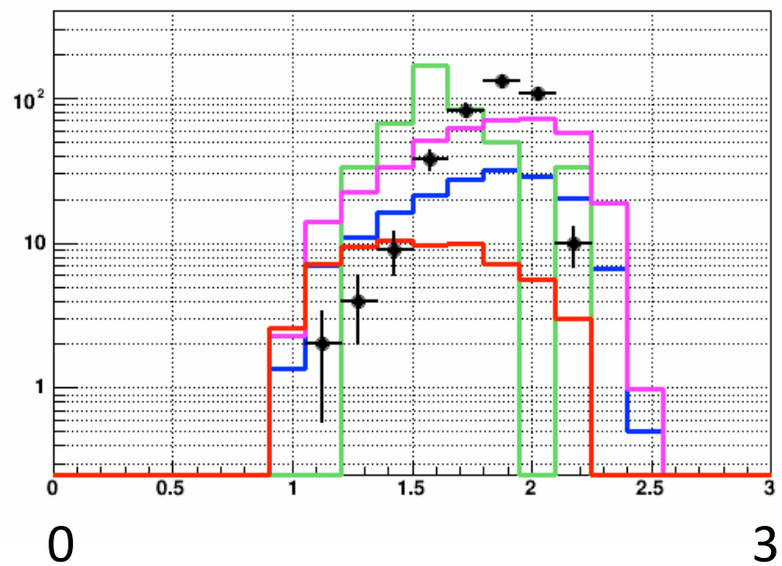
100GeV

pT[GeV/c]



PseudoRapidity

50GeV/c



0

3

Run13 Data (FGT+VTX +EEMC, no prompt)

PYTHIA QCD charged hadrons

PYTHIA W

PYTHIA QCD electrons

PYTHIA QCD photons

Unpolarized BG β and systematic uncertainties

[simple gaussian uncertainties breakdown particularly for small 2011 data sample]