Recent STAR results on W/Z production of the high-energy polarized p+p program at RHIC at BNL

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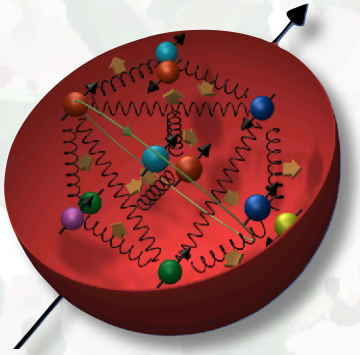
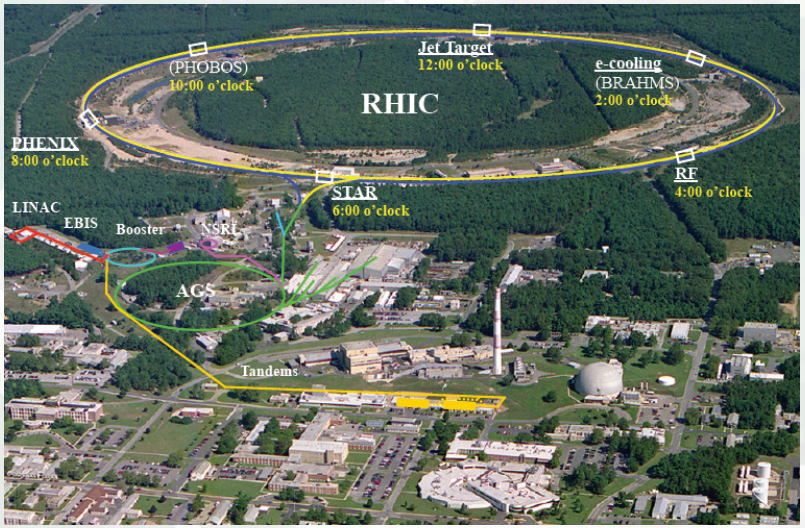
TEMPLE UNIVERSITY

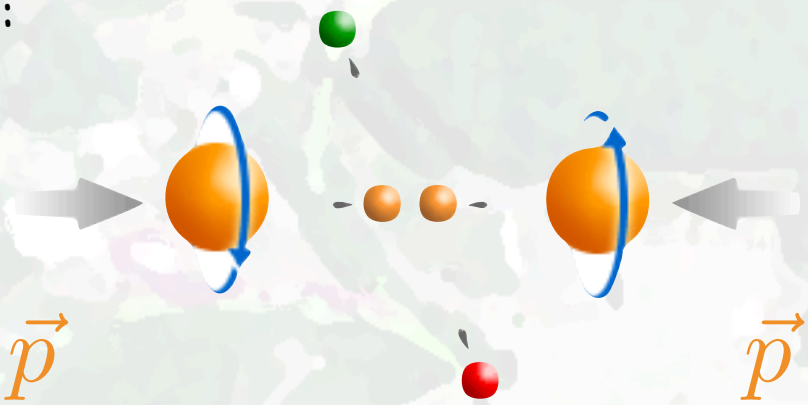
(On behalf on the STAR Collaboration)



Outline

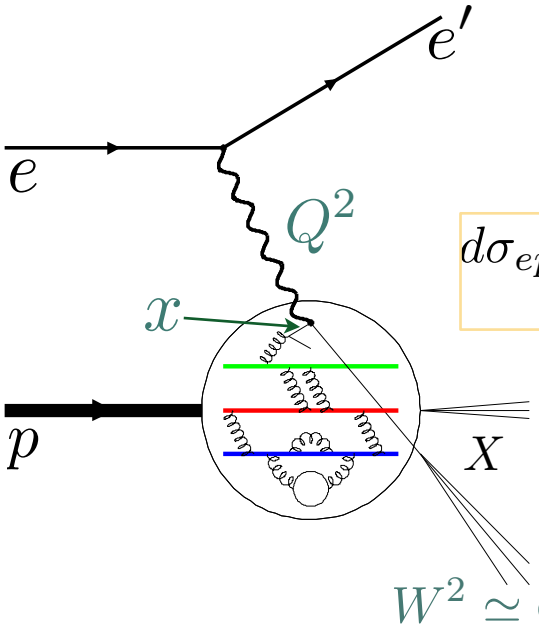


- Selected recent results and future prospects
  - W asymmetry results
  - Z asymmetry results
- Experimental aspects: RHIC / STAR
- Theoretical foundation
- Summary and Outlook



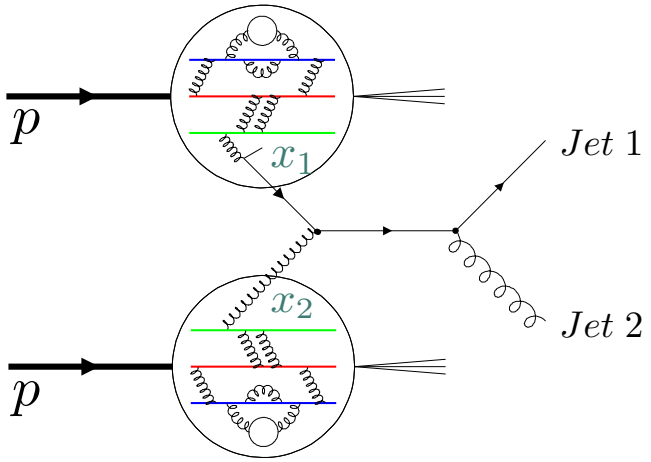
Theoretical foundation

- How do we probe the structure and dynamics of matter in ep vs. pp scattering?



$$d\sigma_{ep} \propto F_2 = \sum_q x e_q^2 f_q(x)$$

Universality

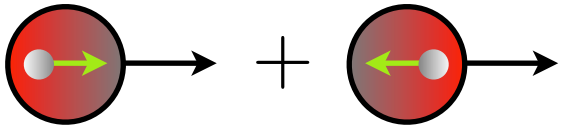


$$d\sigma_{pp} \propto f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h$$

Factorization

Momentum contribution

$$f(x) =$$



$$f^+(x) + f^-(x)$$

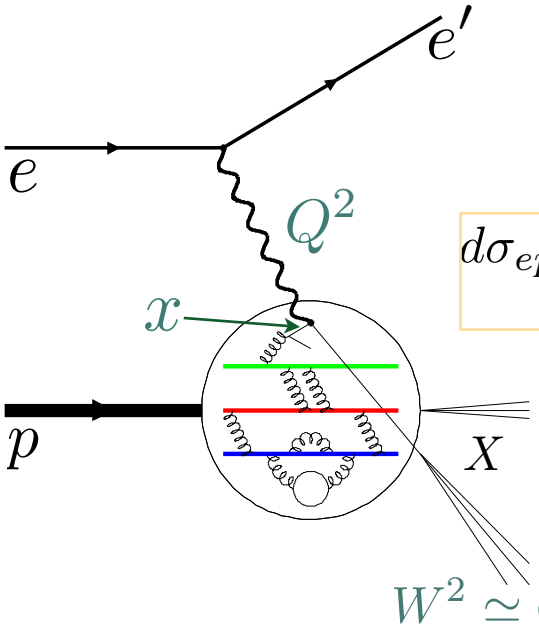
$$\Delta f(x) =$$

$$f^+(x) - f^-(x)$$

Spin contribution

Theoretical foundation

- How do we probe the structure and dynamics of matter in ep vs. pp scattering?



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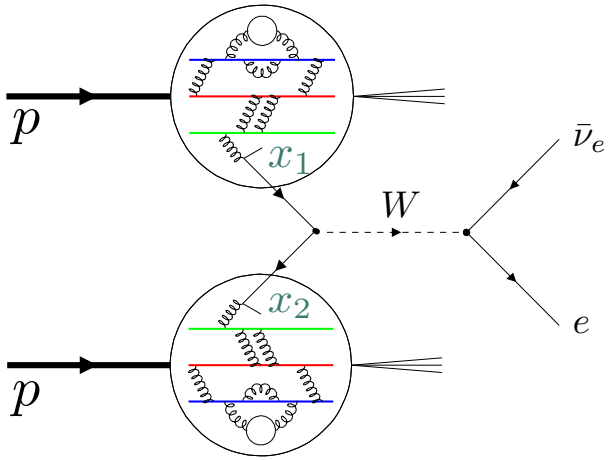

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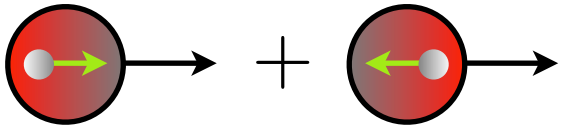


$$f^+(x) + f^-(x)$$

$$\Delta f(x) =$$

$$f^+(x) - f^-(x)$$

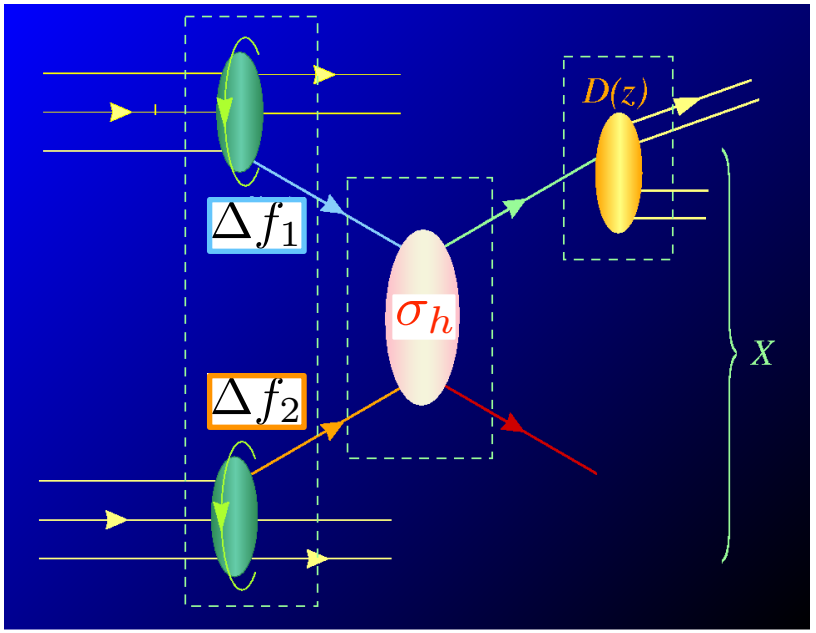
Spin contribution

Theoretical foundation

- Explore proton spin structure using high-energy polarized p+p collisions
  - Observable: Quark/Anti-quark polarization (W production)
    - Longitudinal single-spin asymmetry A_L

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

    - Parity (Spatial inversion) violating for W production!



  - Observable: Gluon polarization (Jet/Hadron production)
    - Double longitudinal single-spin asymmetry A_{LL}

long-range short-range long-range

Δf_1 Δf_2

$$a_{LL} = \frac{\Delta\sigma_h}{\sigma_h}$$

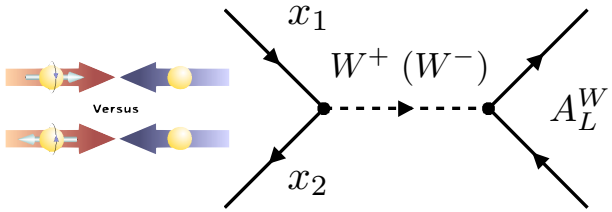
Input

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D_f^h}{f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h}$$

Theoretical foundation

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

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



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

$\nu_e\ (\bar{\nu}_e)$

$e^+\ (e^-)$

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

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

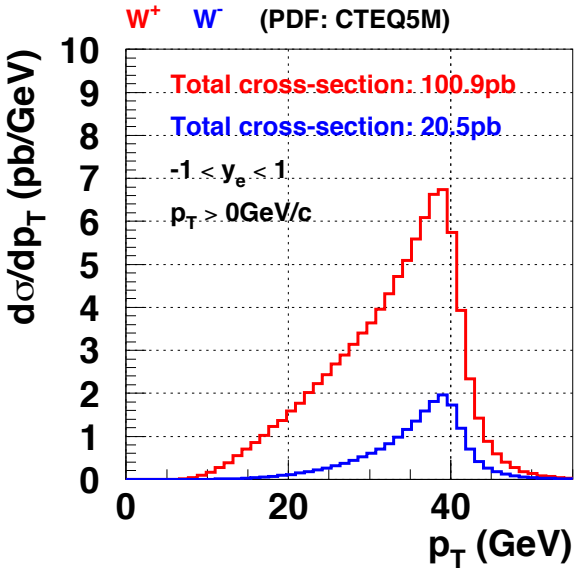
$$p_T = p_T^* = \frac{M_W}{2}\sin\theta^*$$

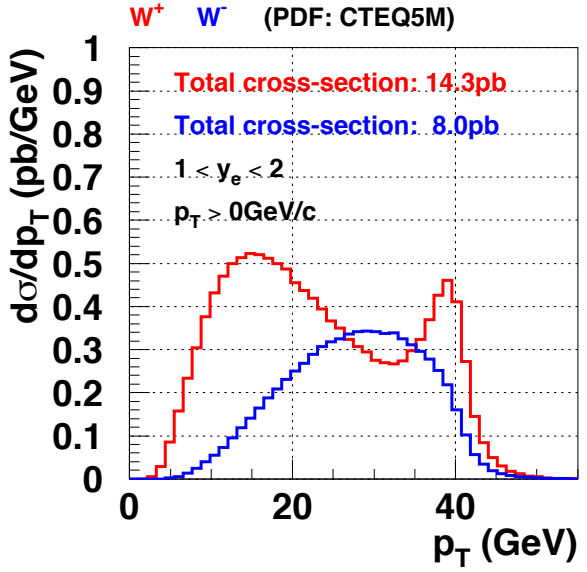
$$x_1 = \frac{M_W}{\sqrt{s}}e^{y_W}$$

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

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

- 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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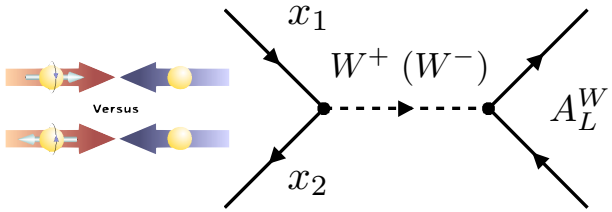
$u/\Delta u\ (d/\Delta d)$



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

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

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

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

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

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

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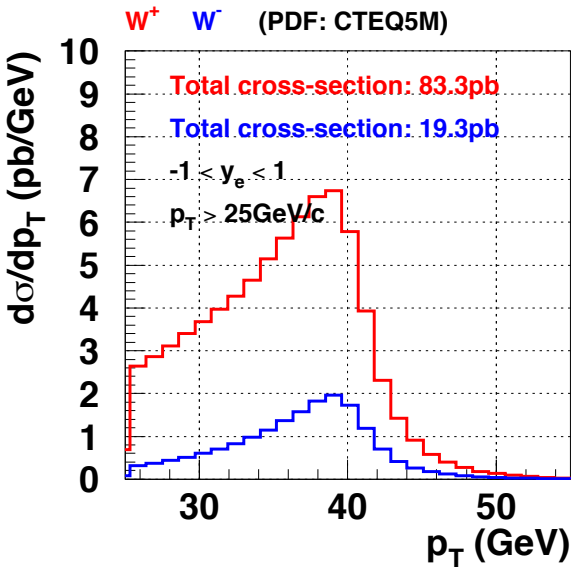

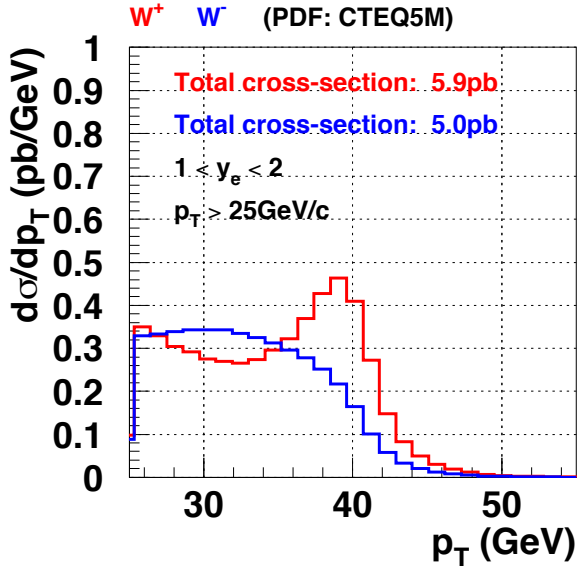

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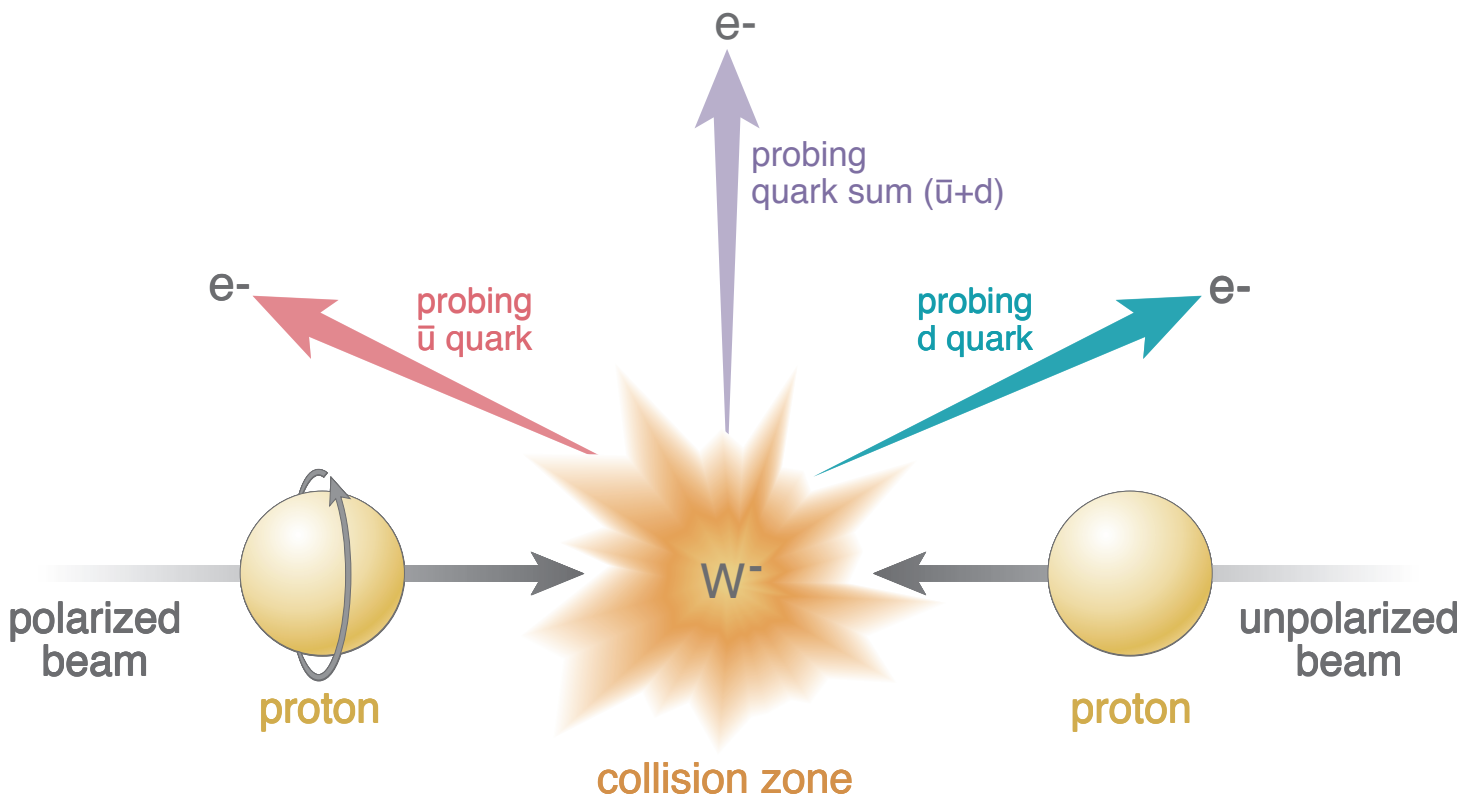
Theoretical foundation

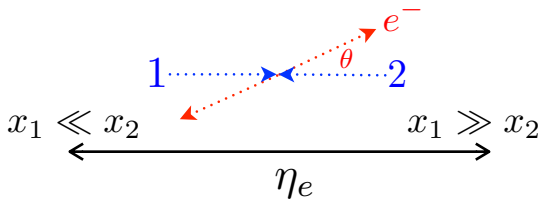
- Probing the quark flavor structure using W boson production: Unique new probe



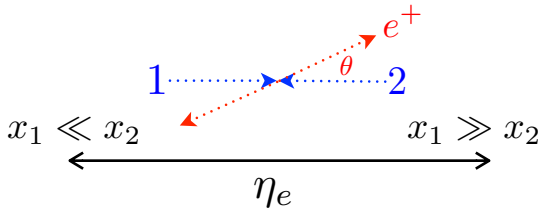
Theoretical foundation

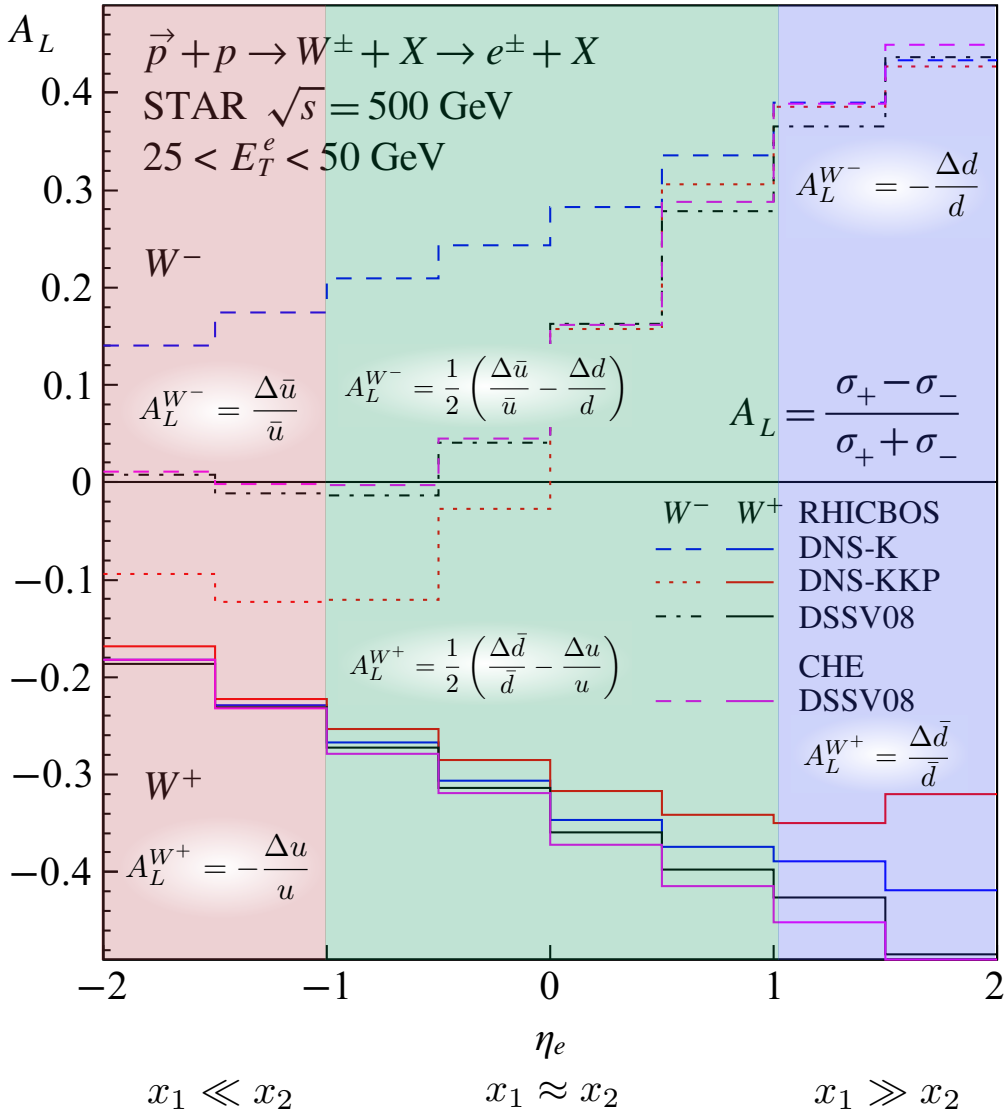
- Probing the quark flavor structure: W boson production

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



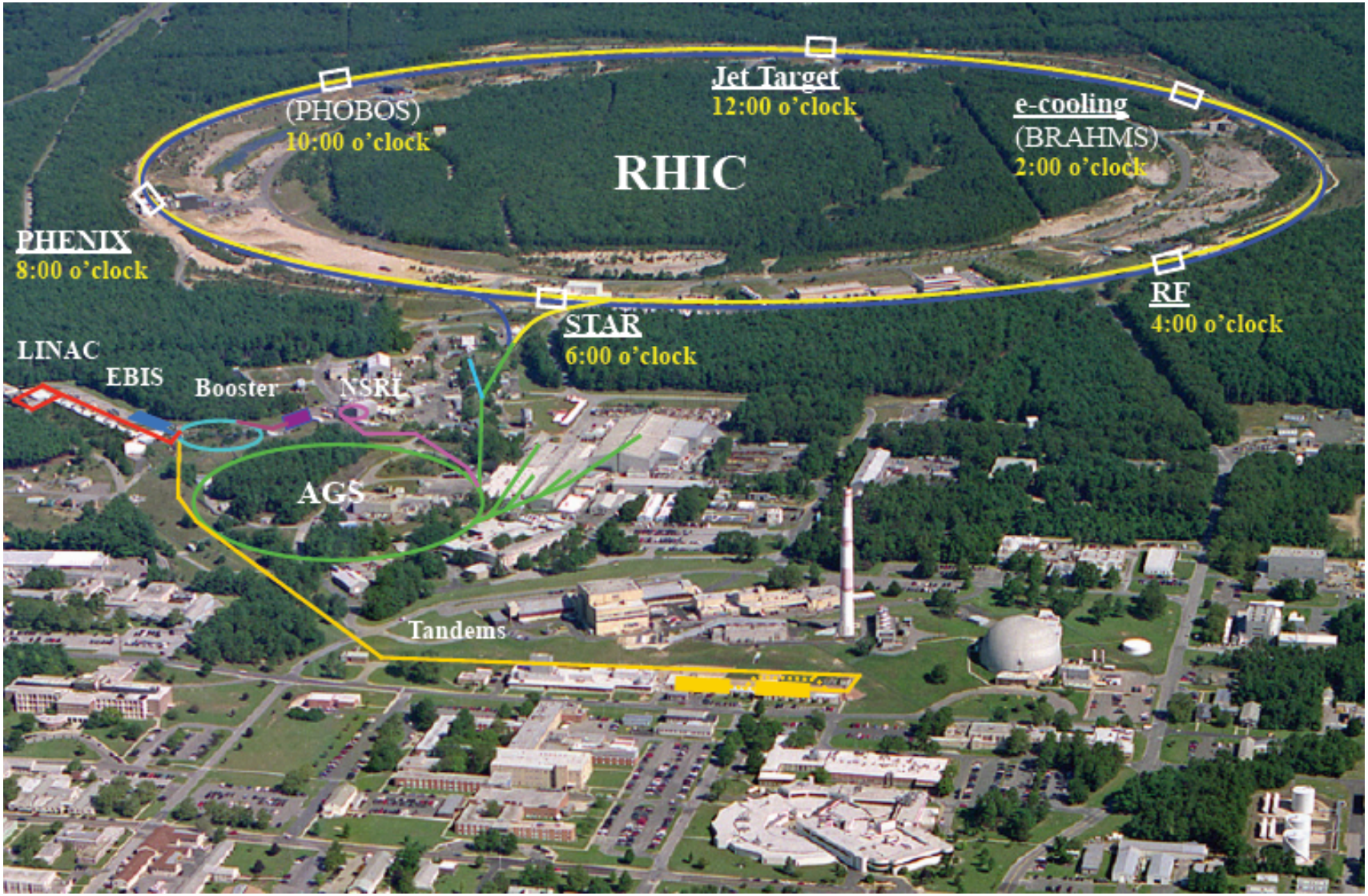
$$A_L^{e^+} \approx \frac{\int_{\otimes(x_1,x_2)} [\Delta\bar{d}(x_1)u(x_2)(1+\cos\theta)^2 - \Delta u(x_1)\bar{d}(x_2)(1-\cos\theta)^2]}{\int_{\otimes(x_1,x_2)} [\bar{d}(x_1)u(x_2)(1+\cos\theta)^2 + u(x_1)\bar{d}(x_2)(1-\cos\theta)^2]}$$





Experimental aspects - RHIC

- The world's first polarized proton-proton collider



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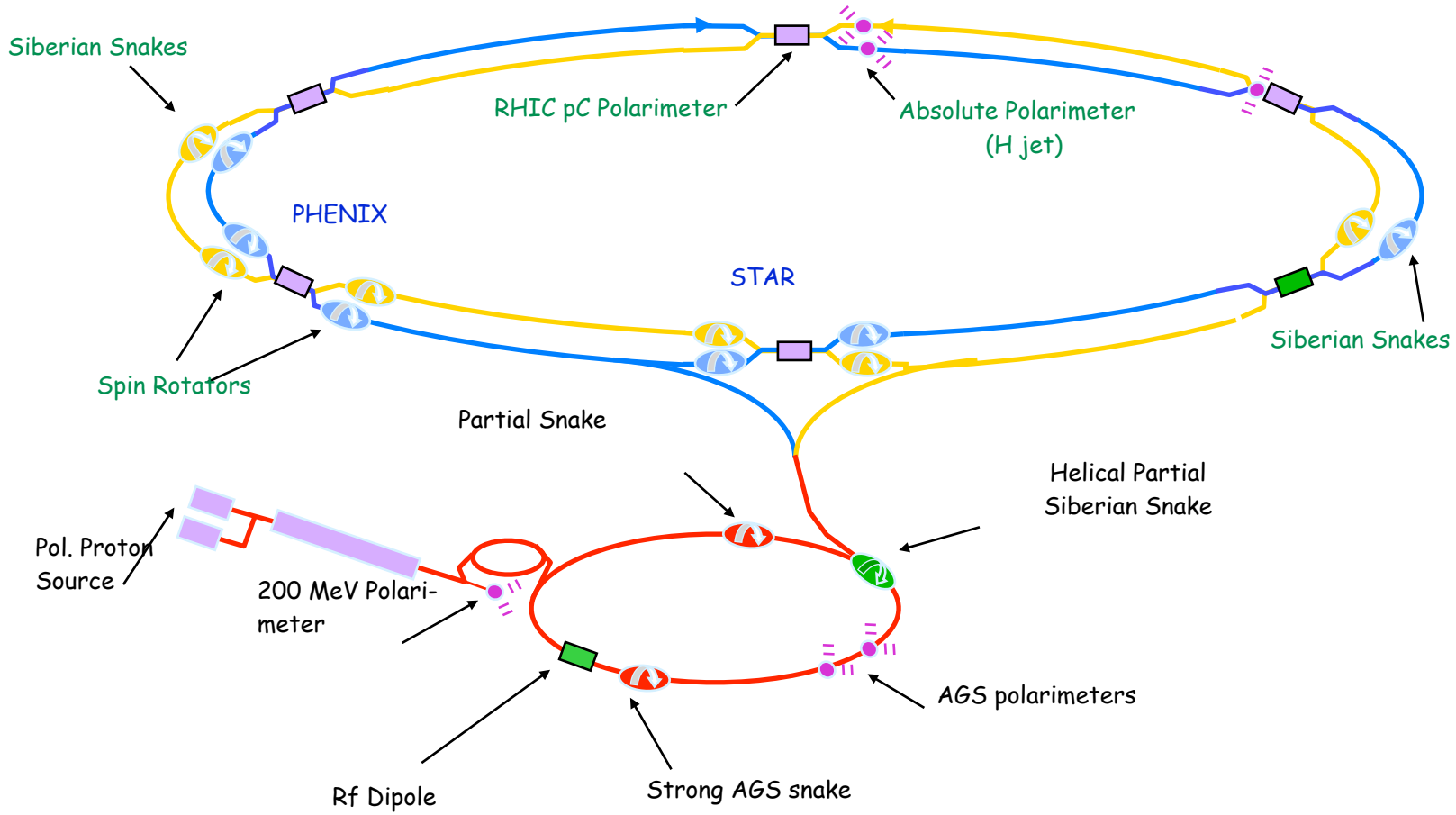

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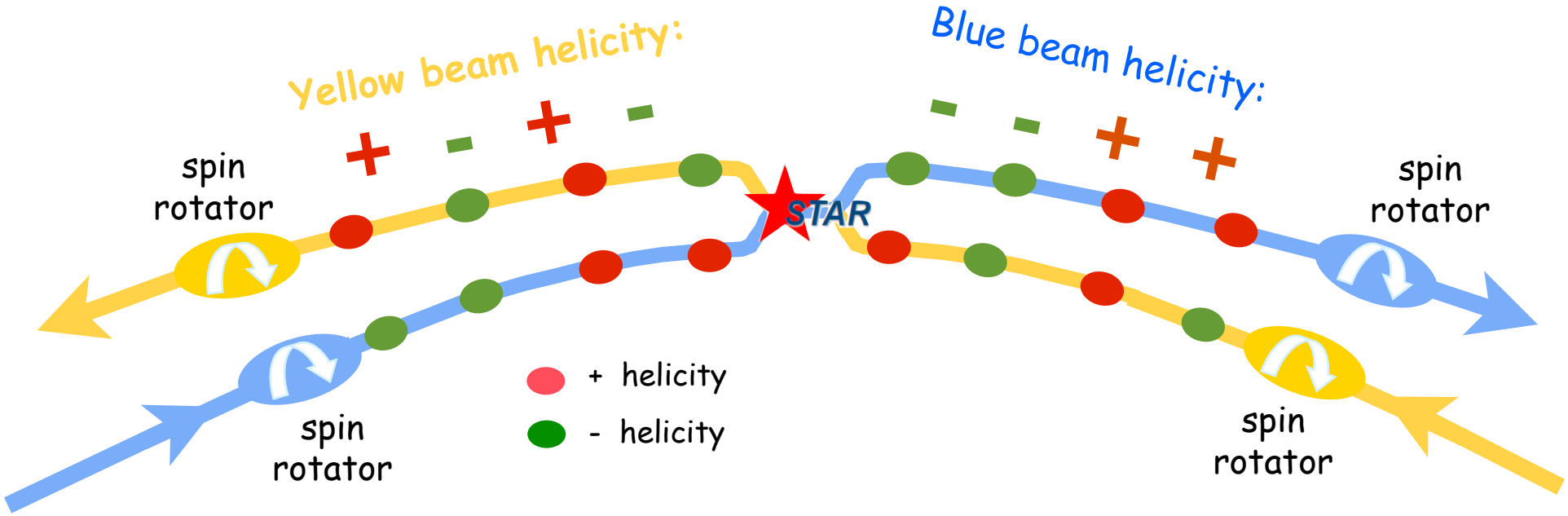
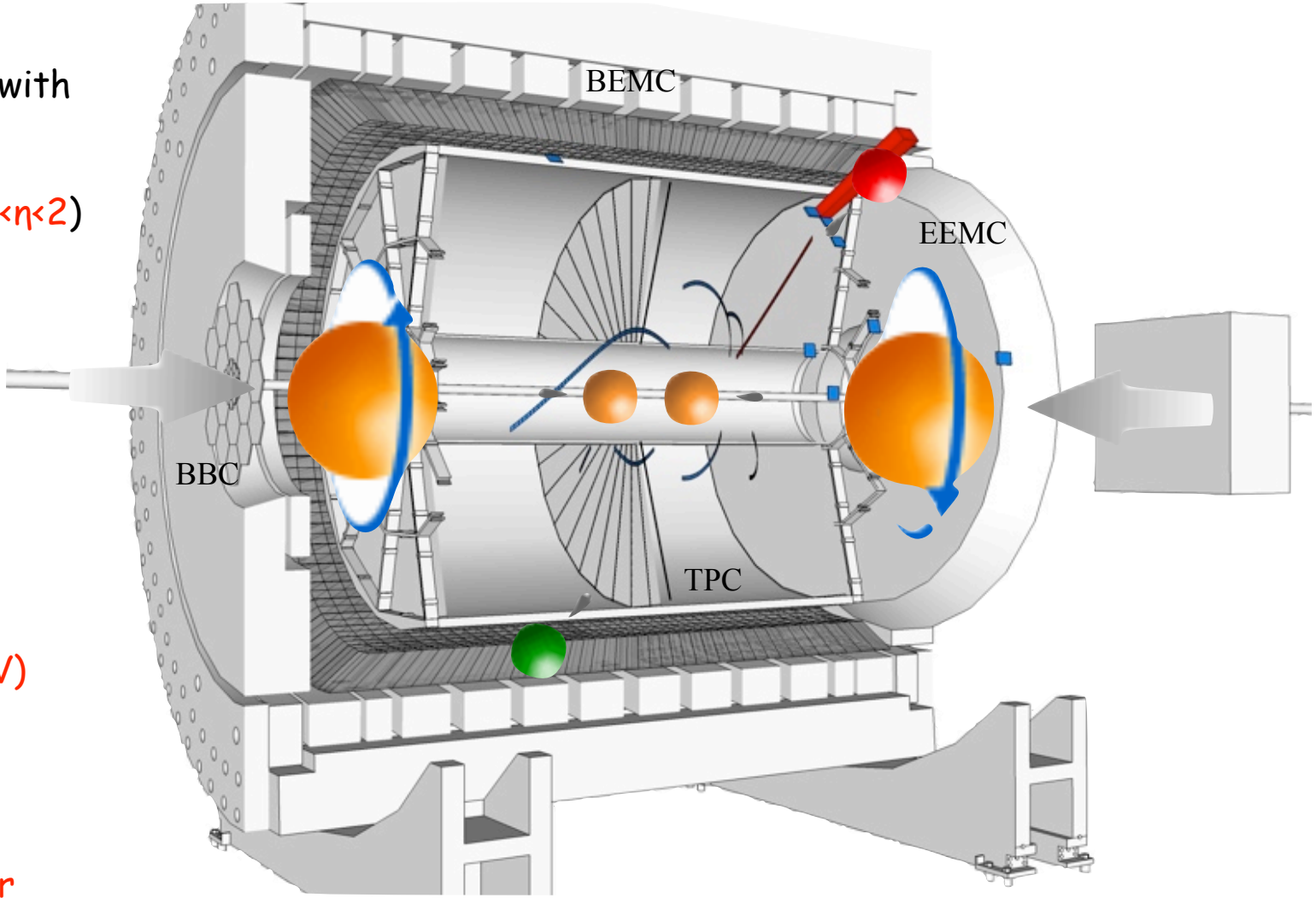


Experimental aspects - STAR

Overview

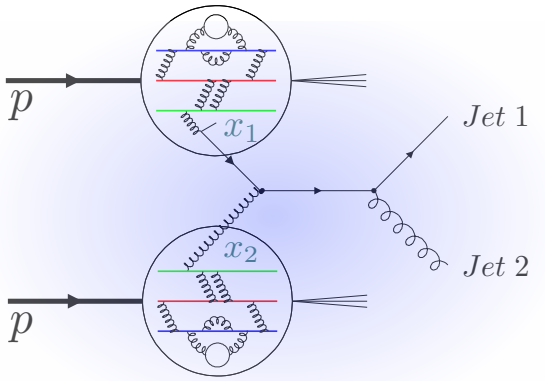
- Calorimetry system with 2π coverage: BEMC ($-1<\eta<1$) and EEMC ($1<\eta<2$)
- TPC: Tracking and particle ID
- ZDC: Relative luminosity and local polarimetry (500GeV)
- BBC: Relative luminosity and Minimum bias trigger



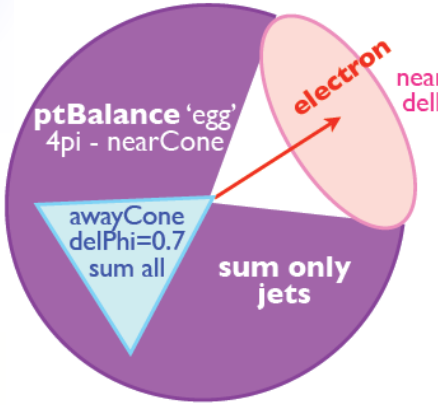
$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

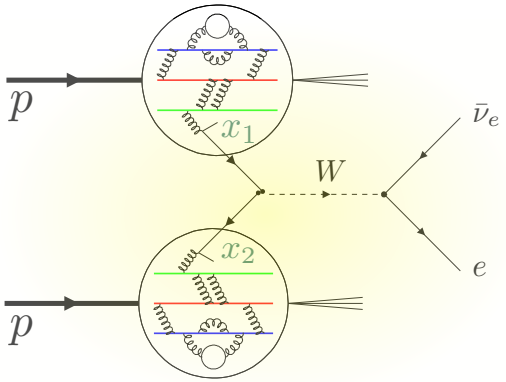
Recent results - W production

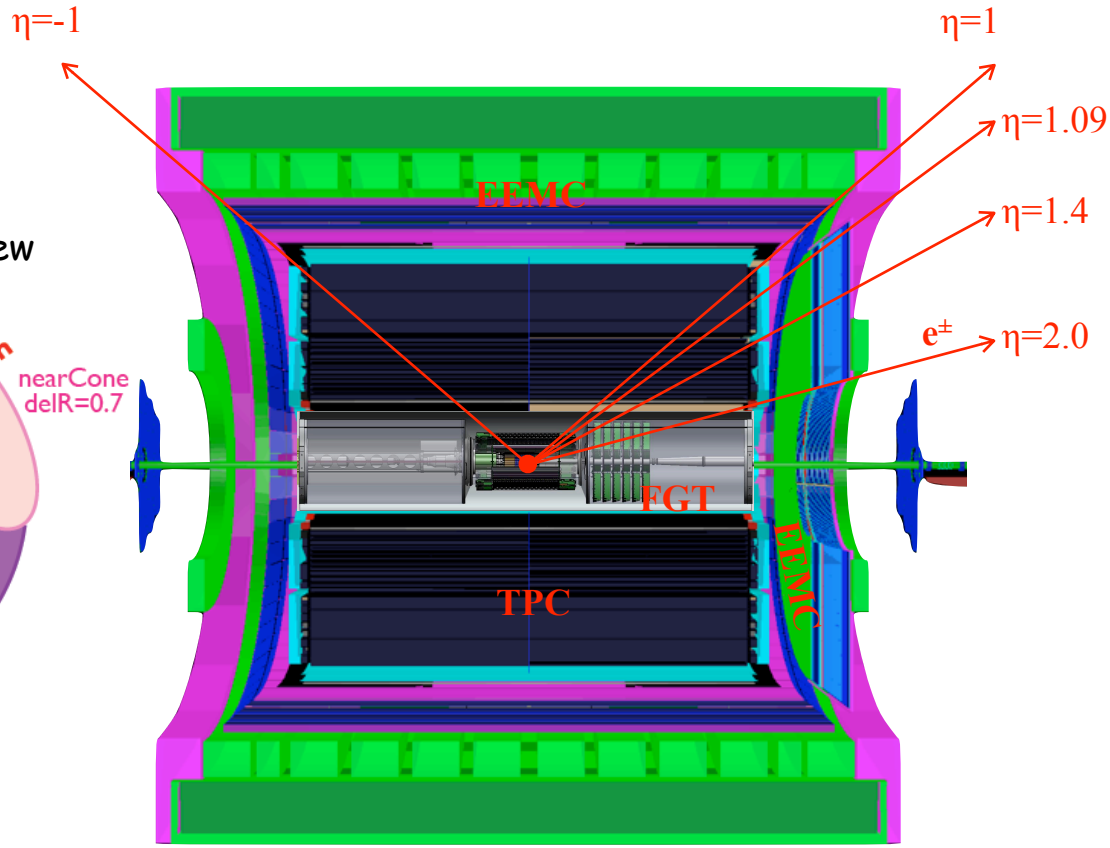
- W boson reconstruction at STAR vs. pseudo-rapidity η



Transverse plane view







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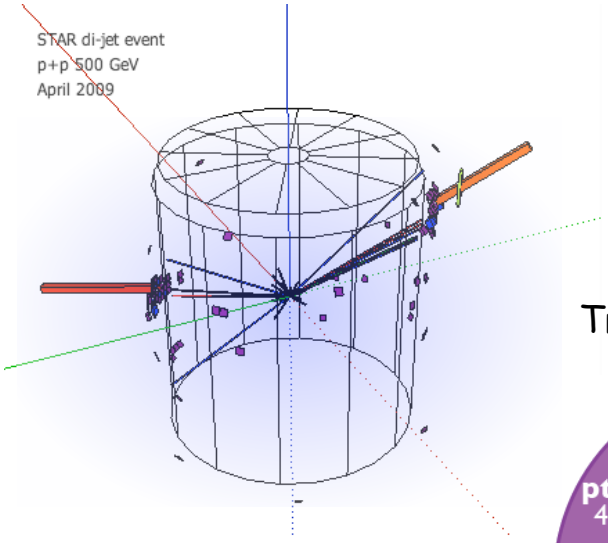

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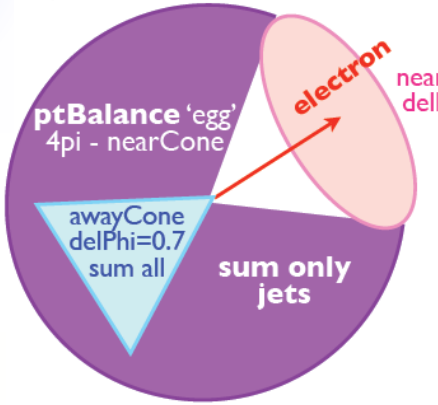

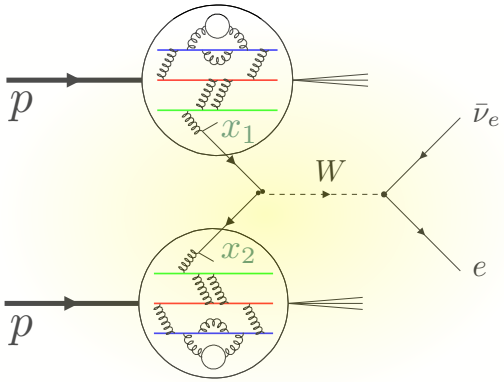

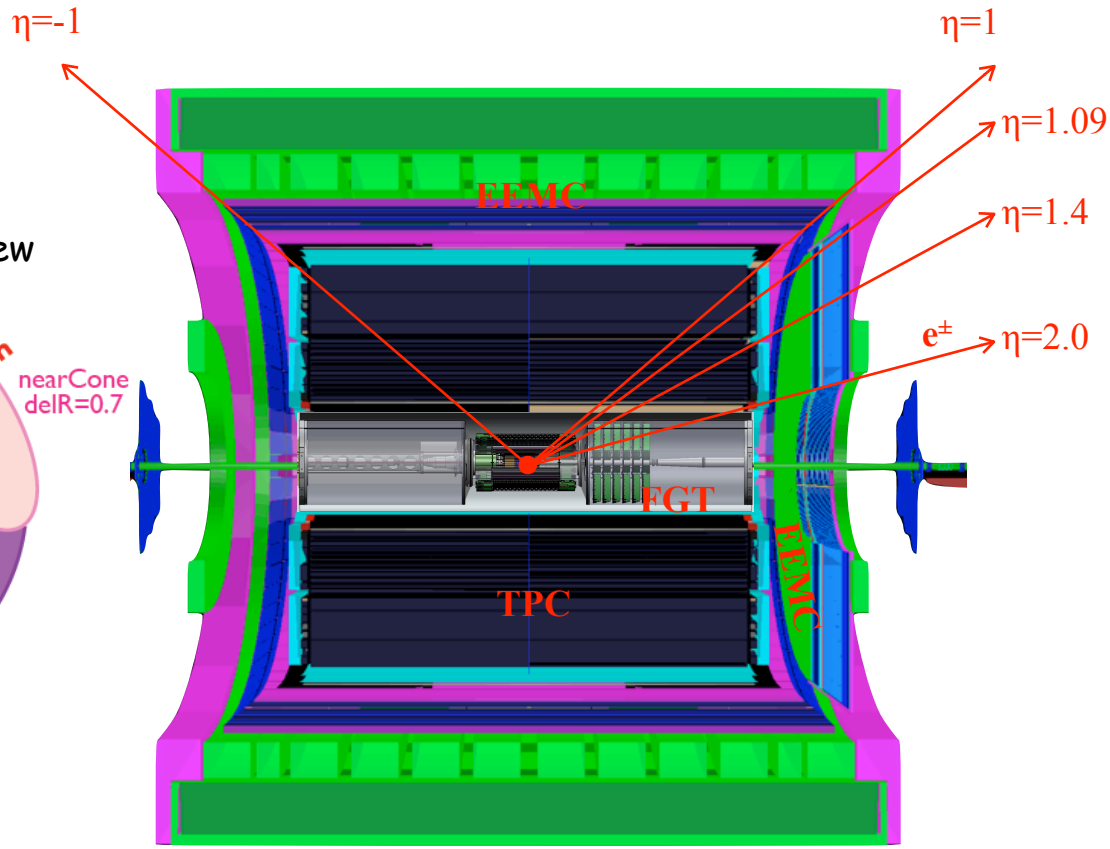

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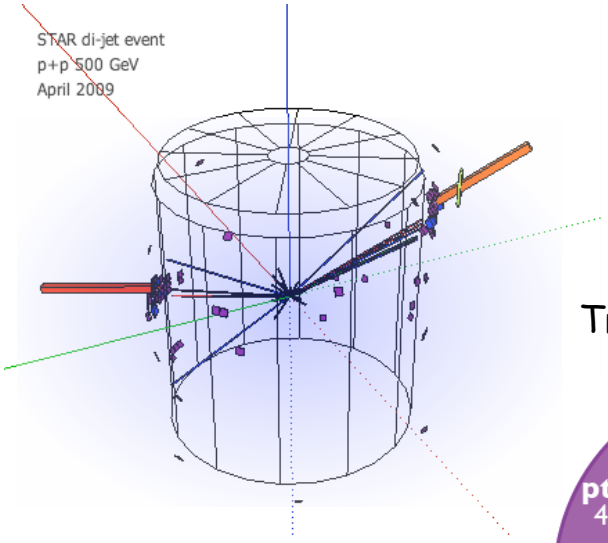

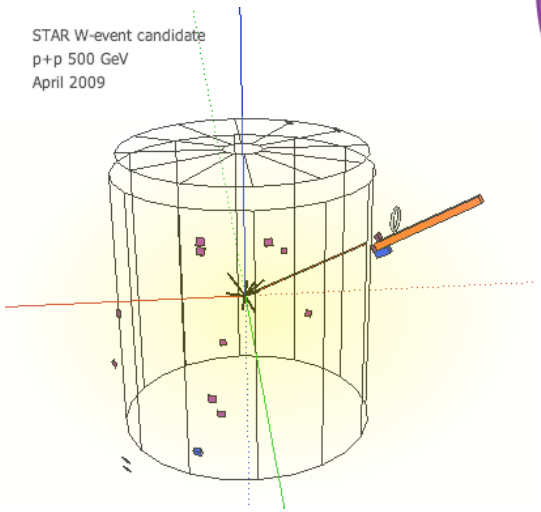

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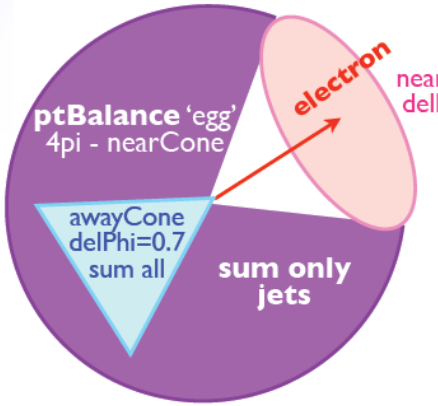

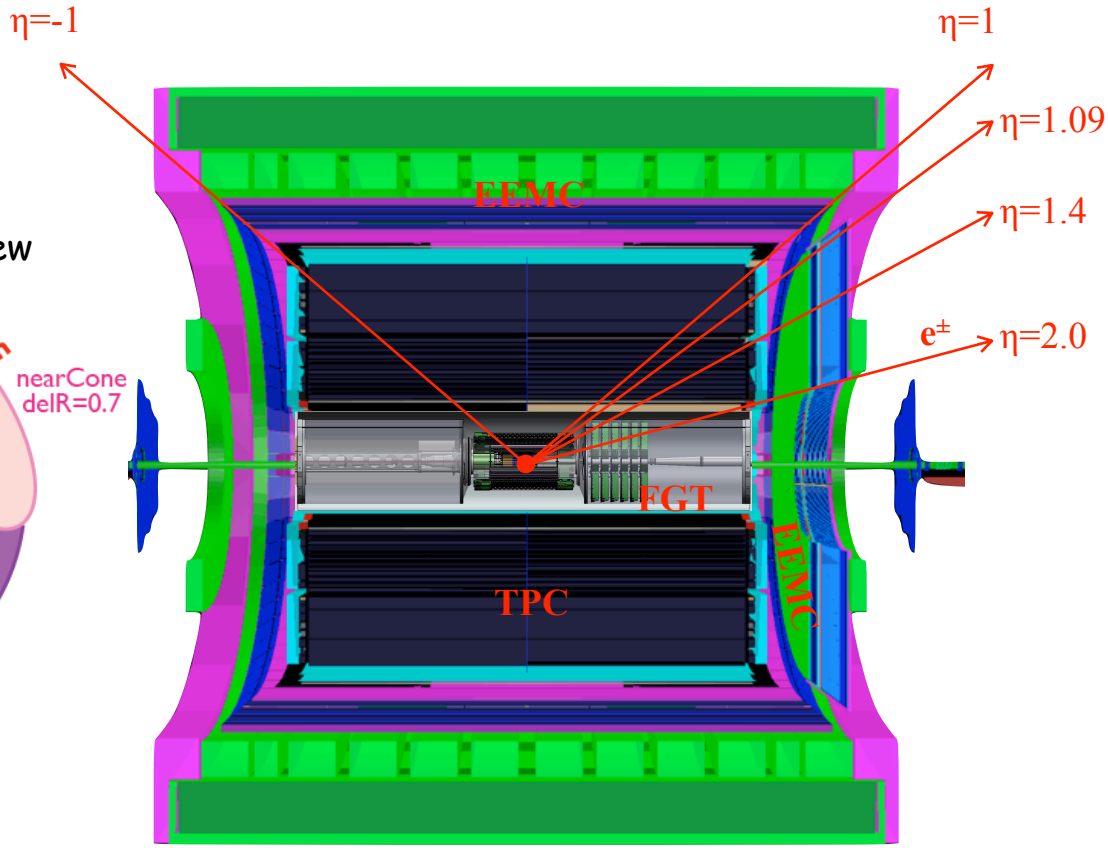

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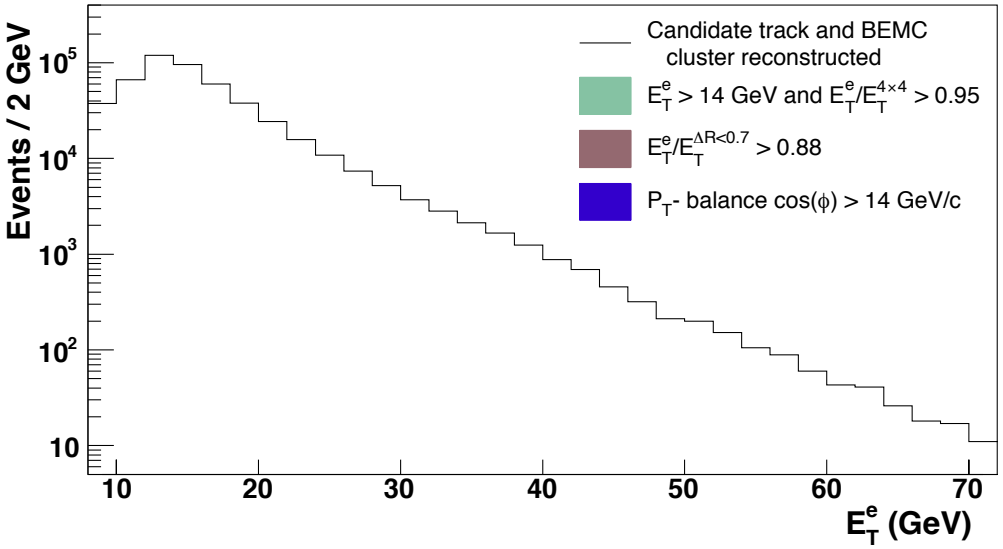
Recent results - W production

- Mid-rapidity STAR selection criteria
  - Match p_T > 10 GeV track to BEMC cluster
  - Isolation ratios
  - p_T-balance cut

$$\vec{p_T}^{\,bal} = \vec{p_T}^{\,e} + \sum_{\Delta R>0.7} \vec{p_T}^{\,jets}$$

$$P_T\text{-balance}\cos(\phi) = \frac{\vec{p_T}^{\,e} \cdot \vec{p_T}^{\,bal}}{|\vec{p_T}^{\,e}|}$$



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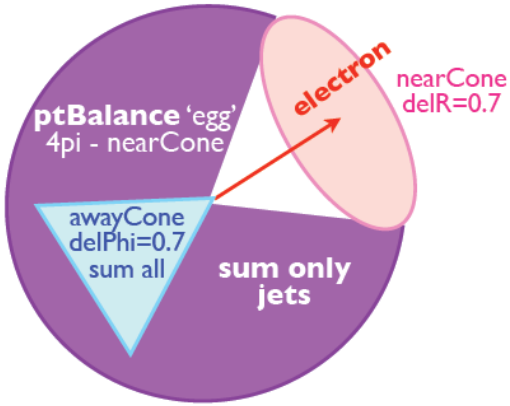

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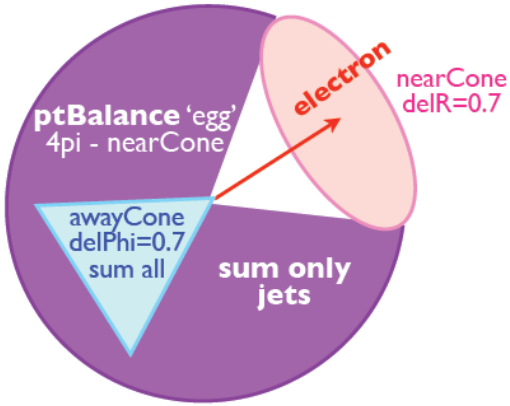

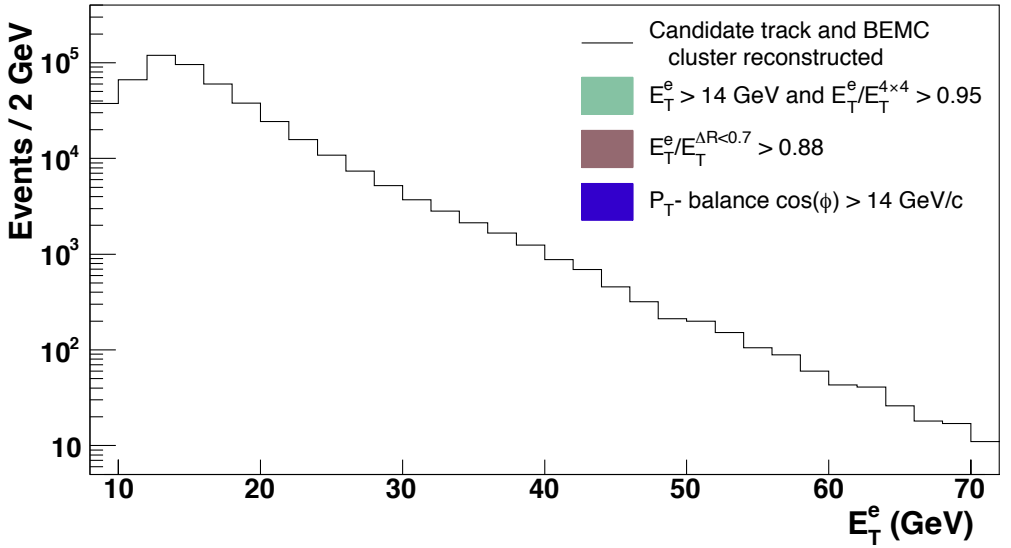

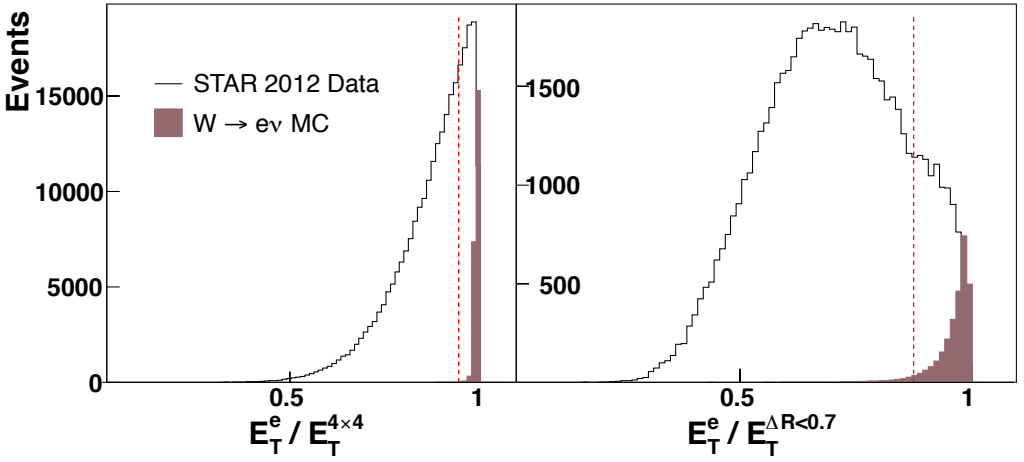

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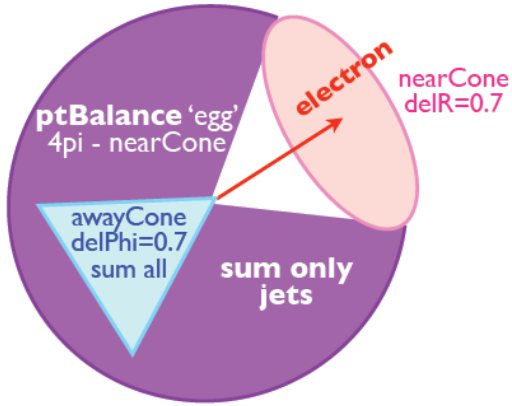

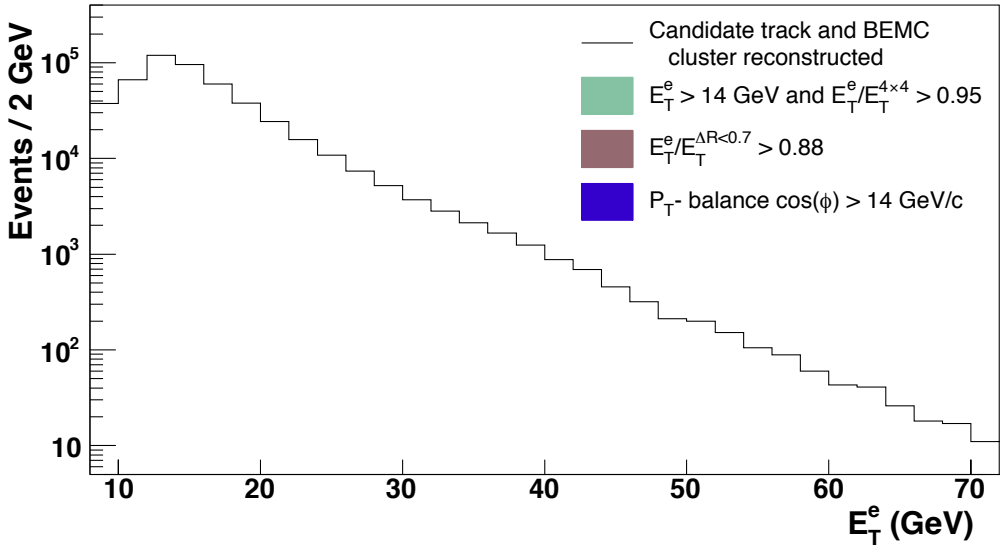

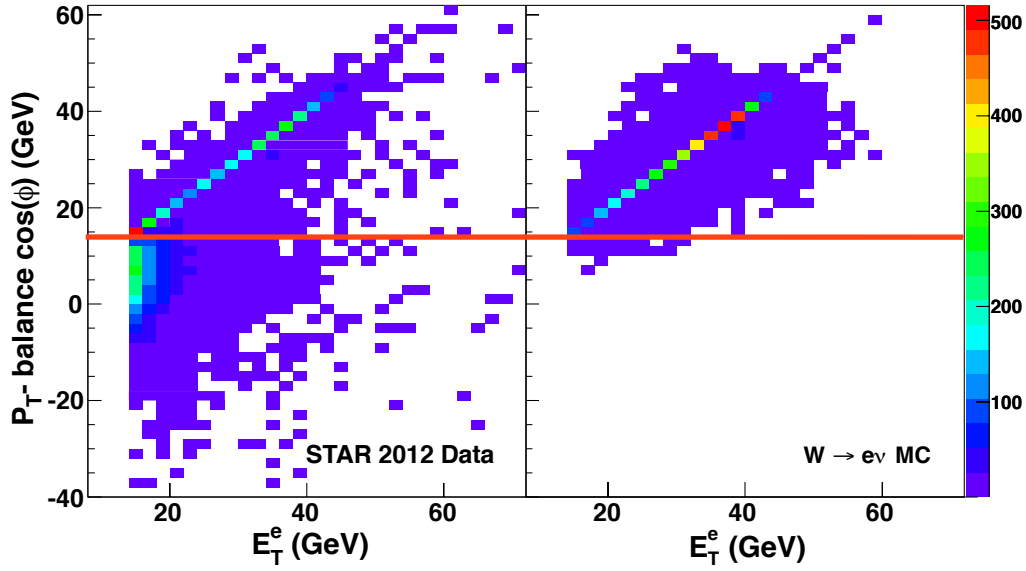

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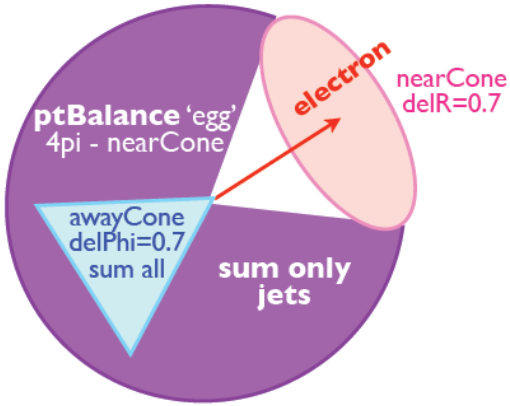
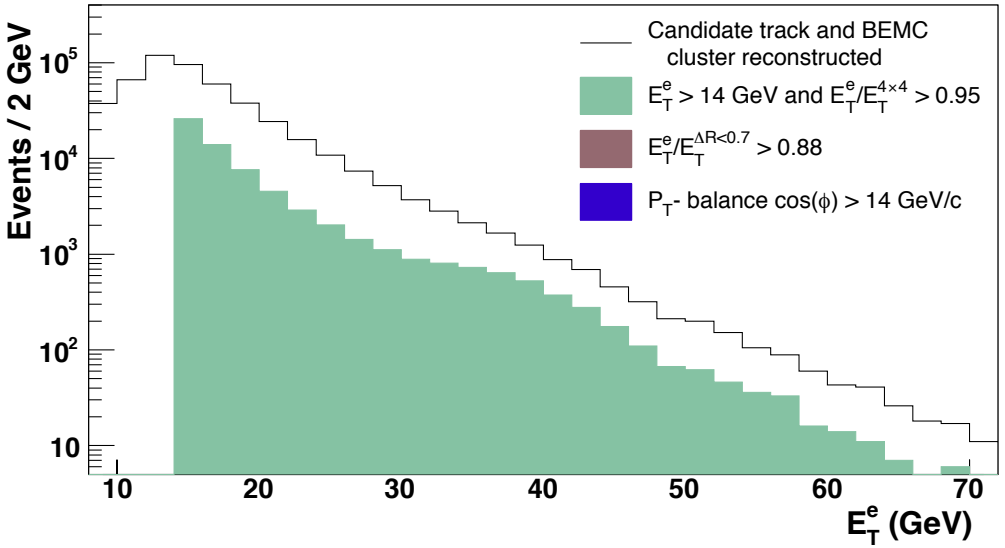
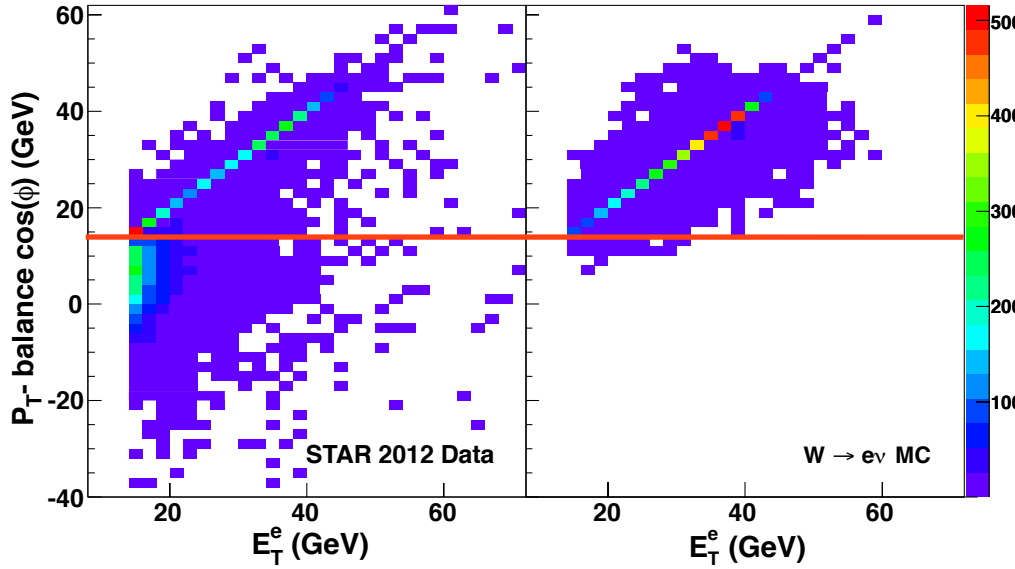
$$\vec{p_T}^{\,bal} = \vec{p_T}^{\,e} + \sum_{\Delta R>0.7} \vec{p_T}^{\,jets}$$

$$P_T\text{-balance}\cos(\phi) = \frac{\vec{p_T}^{\,e} \cdot \vec{p_T}^{\,bal}}{|\vec{p_T}^{\,e}|}$$

Transverse plane view







Recent results - W production

- Mid-rapidity STAR selection criteria
  - Match p_T > 10 GeV track to BEMC cluster
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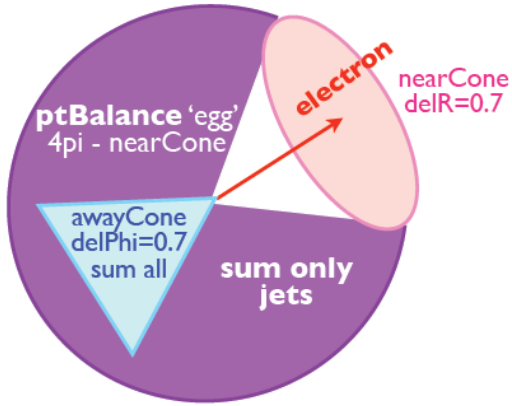

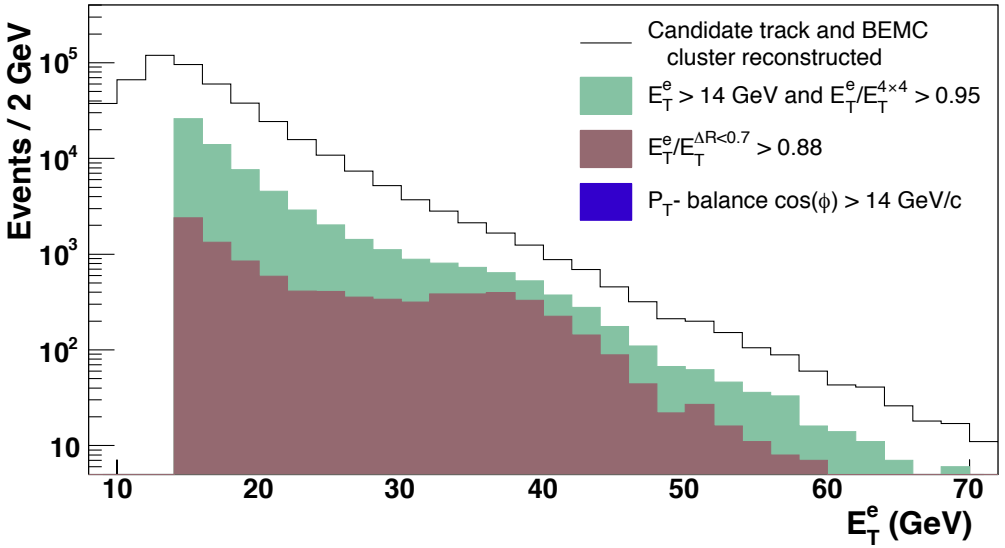

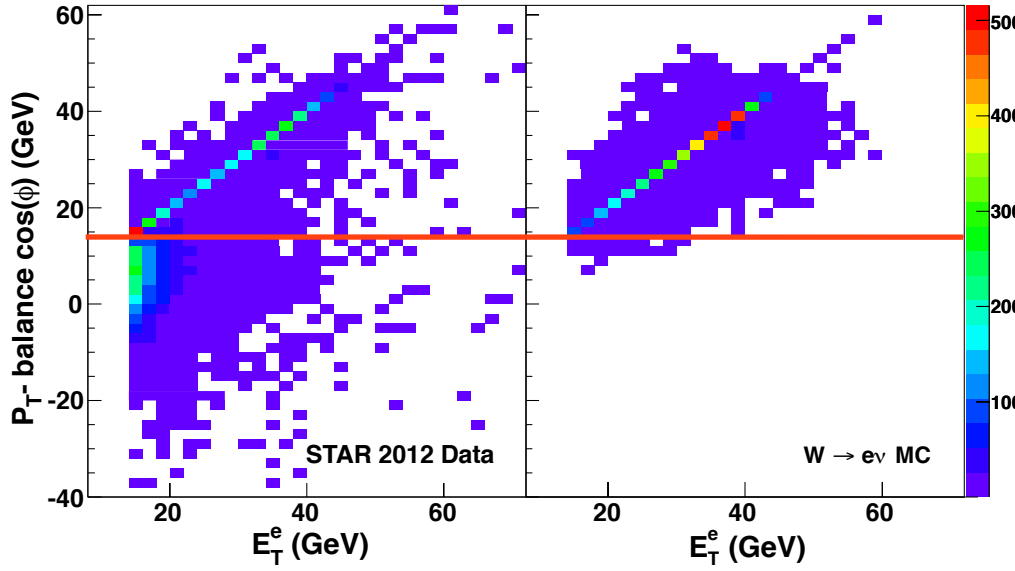

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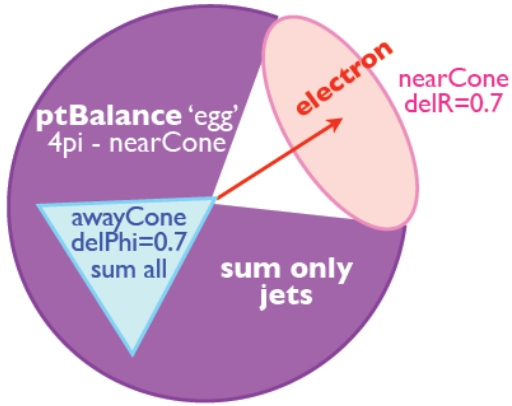
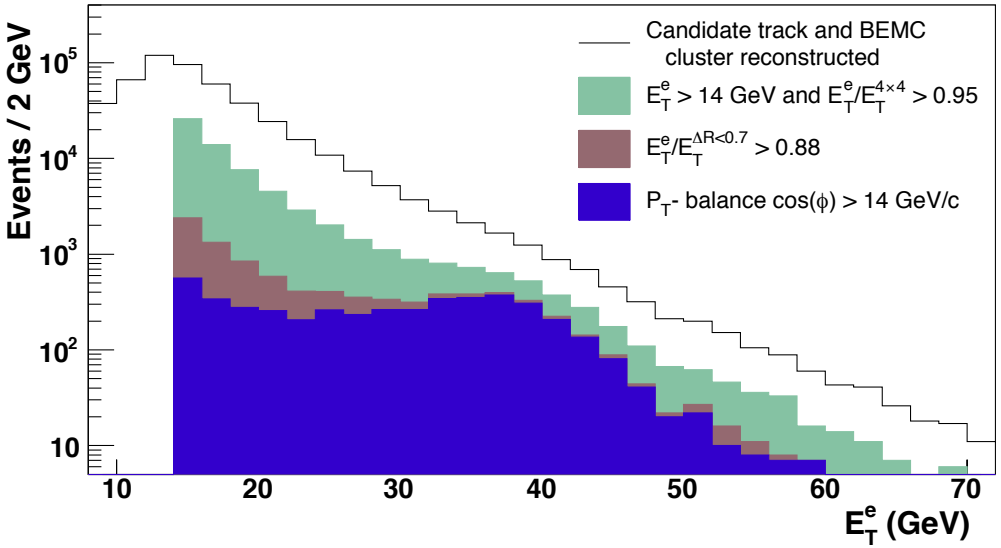
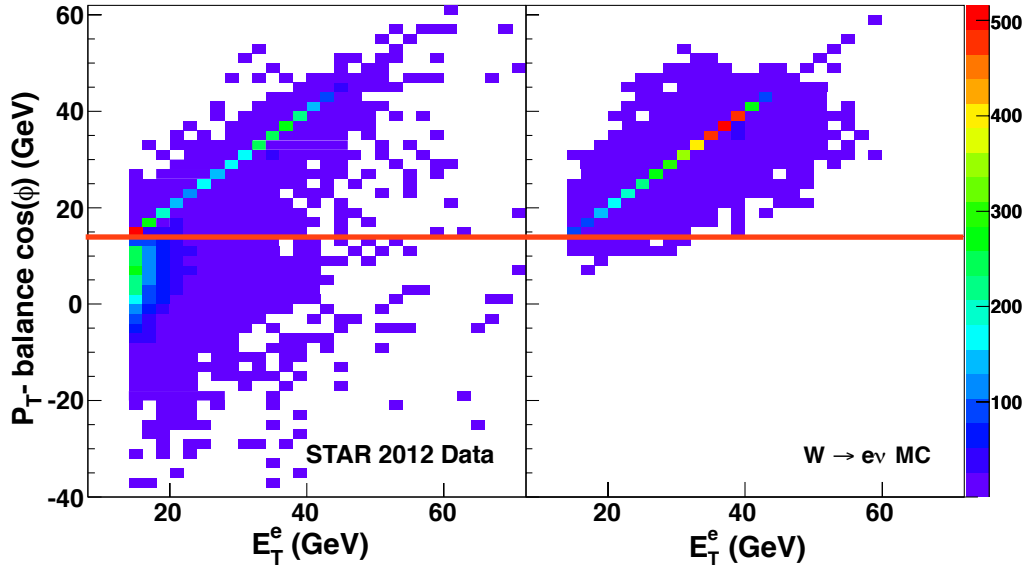
Transverse plane view

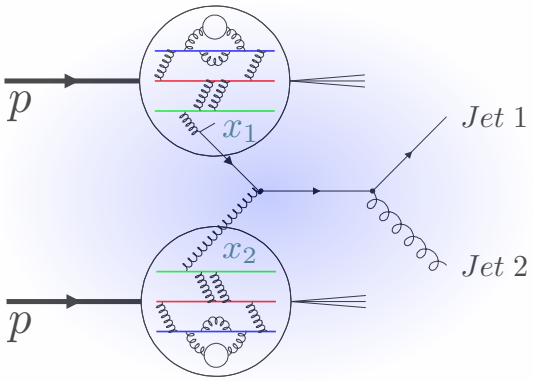


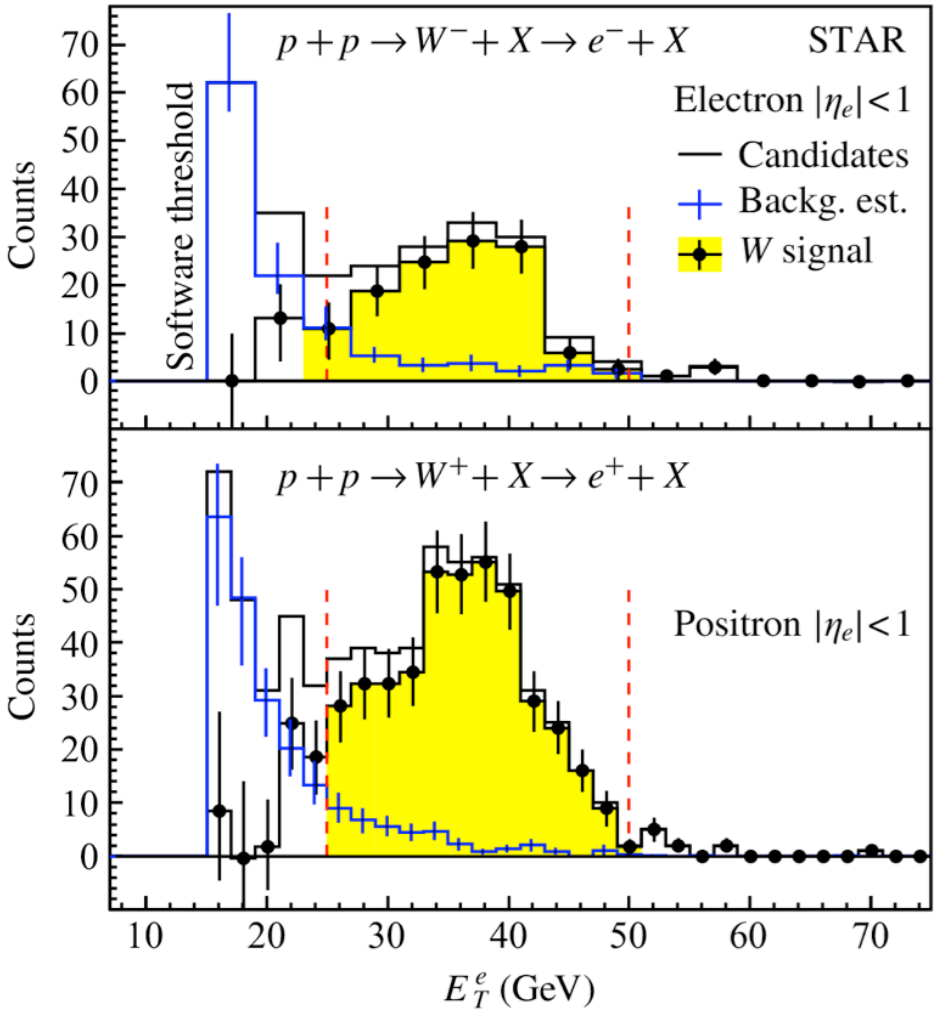


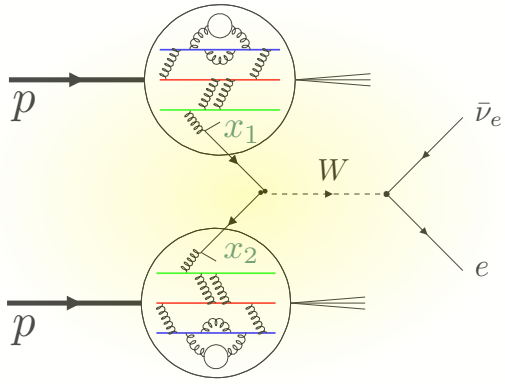


Recent results - W production

- Mid-rapidity: STAR Background treatment / Signal distribution (Run 9)







- Background dominated by QCD background (Data driven estimate) with smaller fractions from W boson induced τ decays and Z^0 boson events (MC estimate)

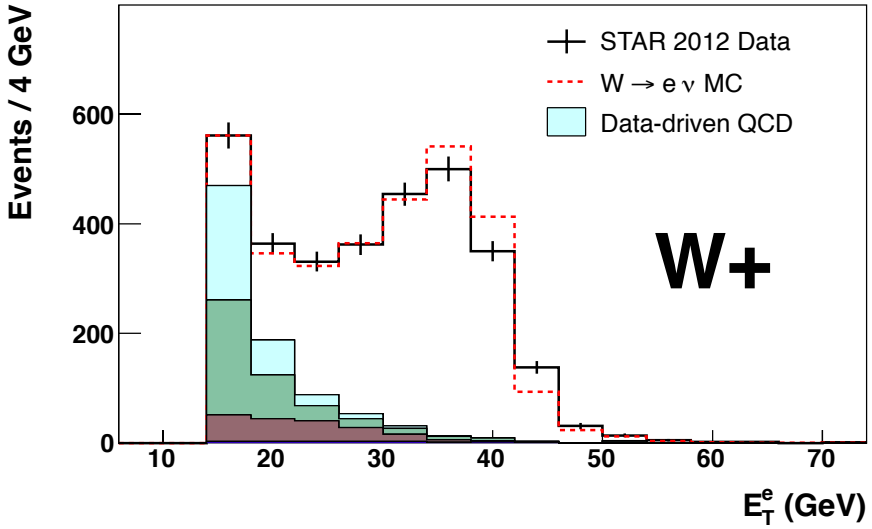
- Total background (B):
  - e^+: 39 ± 9
  - e^-: 23 ± 6

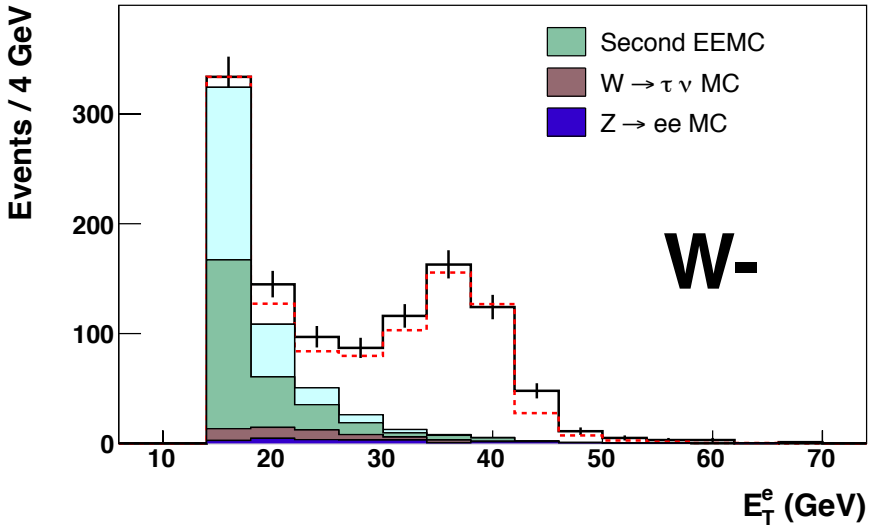
- Total e^+/e^- cand. events (S+B):
  - e^+: 462
  - e^-: 139

STAR Collaboration, PRL 106, 062002 (2011)

Recent results - W production

- Mid-rapidity: STAR Background treatment / Signal distribution (Run 12)

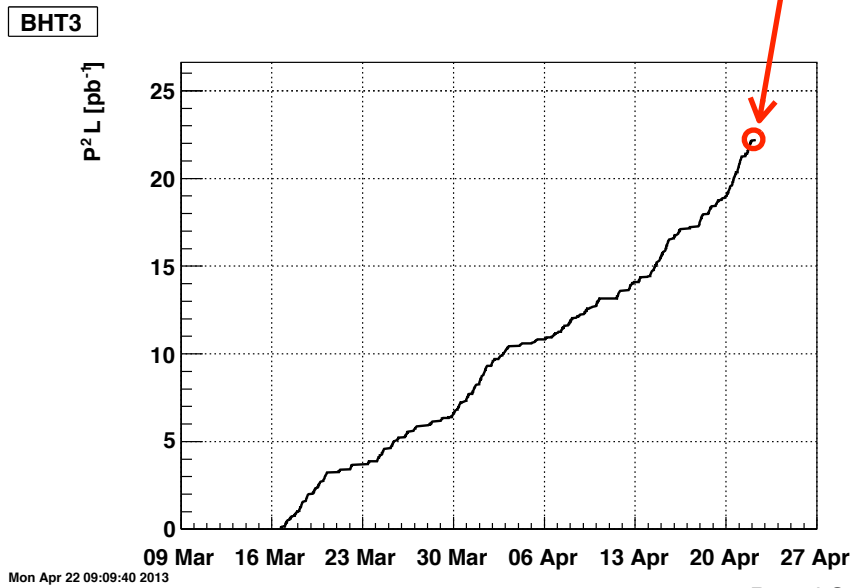




	L (pb^{-1})	P	P^2L (pb^{-1})
Run 9	12	0.40	1.9
Run 12	72	0.56	22.6

Current FOM Run 13 (Mid-rapidity W trigger BHT3): ~ $22pb^{-1}$

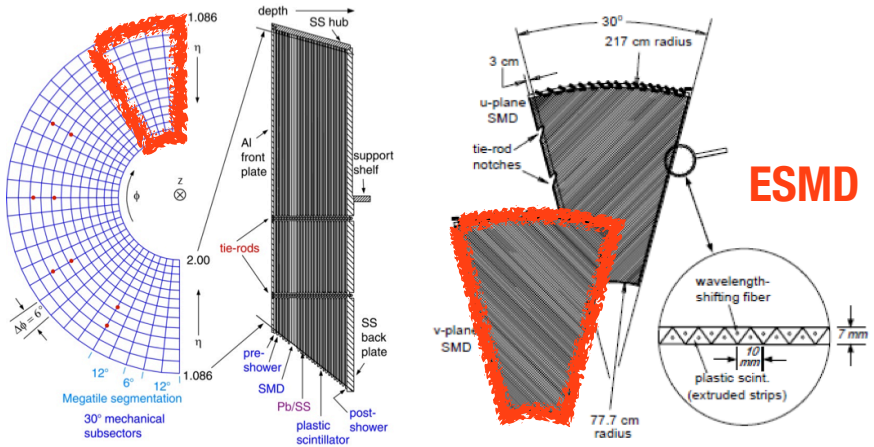
Goal for Run 13: ~$50pb^{-1}$



Recent results - W production

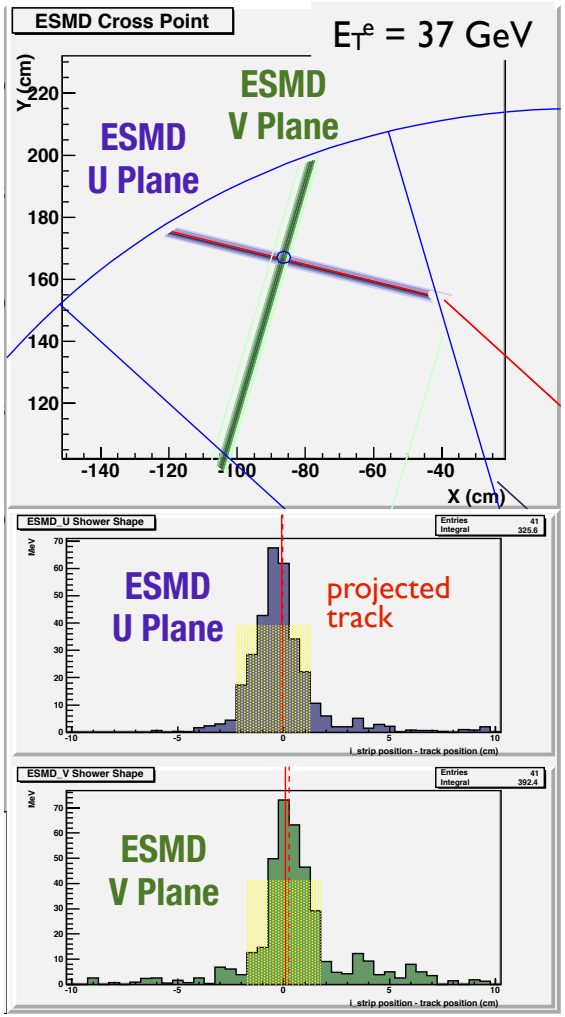
- Forward-rapidity selection criteria
  - Similar concept as at mid-rapidity
    - Utilize TPC up to $\eta = 1.4$
    - Use isolation ratios and vector p_T imbalance to reduce QCD background
  - Improve background rejection by using STAR Endcap Shower Maximum (ESMD) Detector

Endcap EM Calorimeter (EEMC)

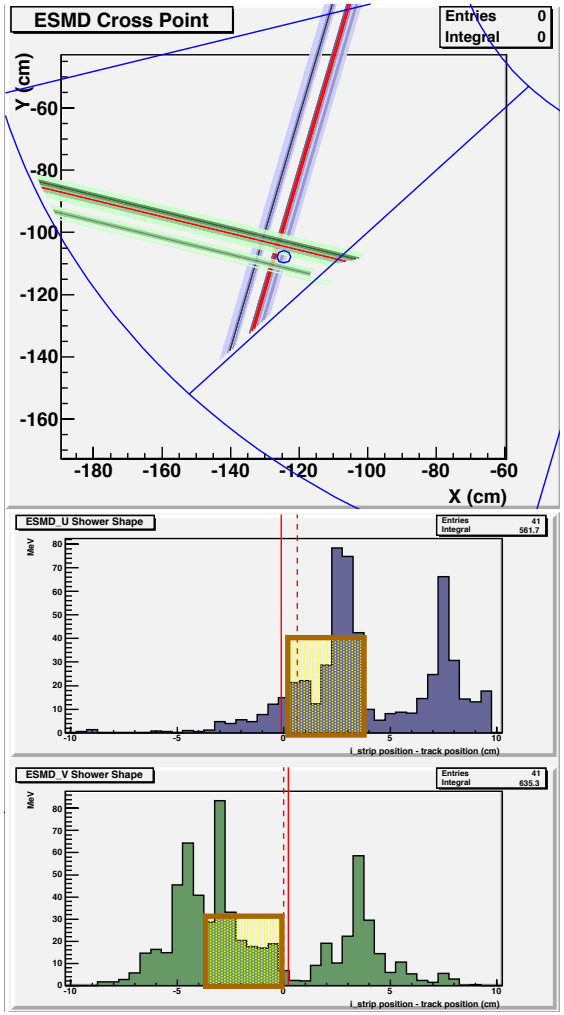


2012 data events which satisfy all previous cuts

Signal Example

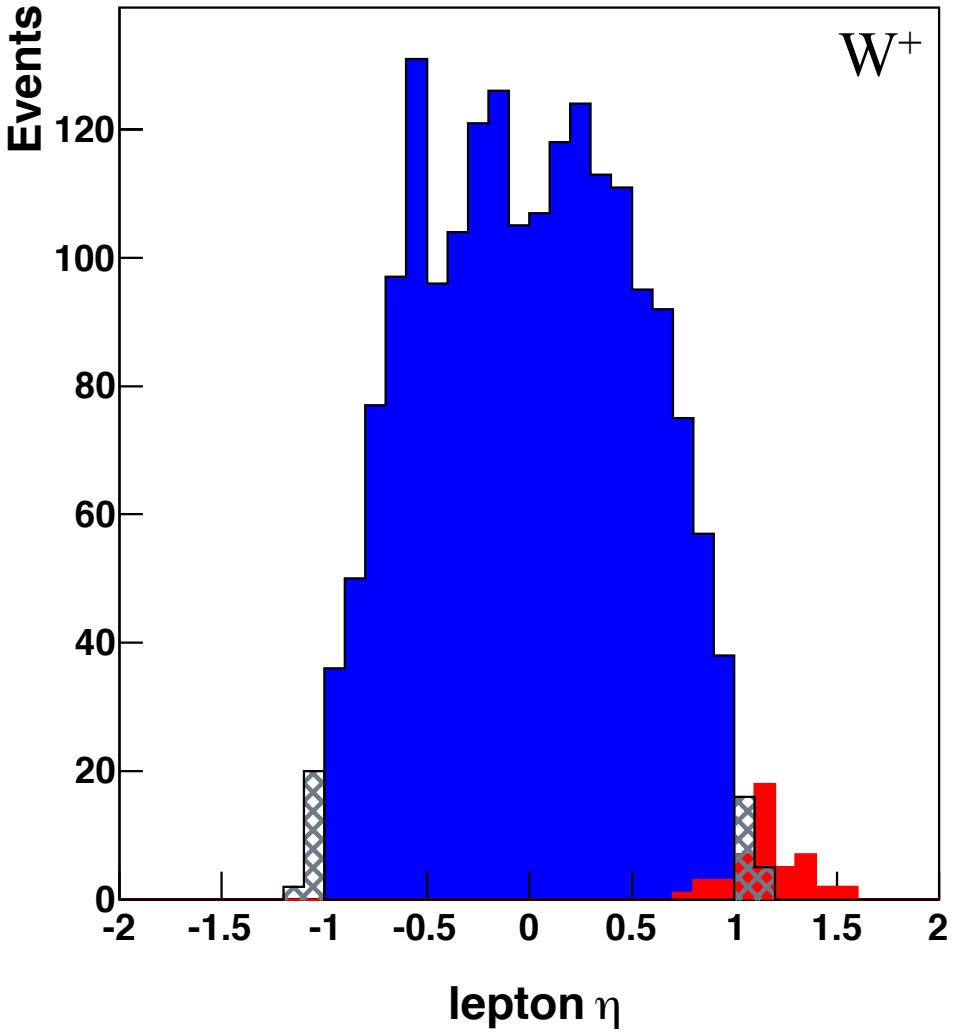


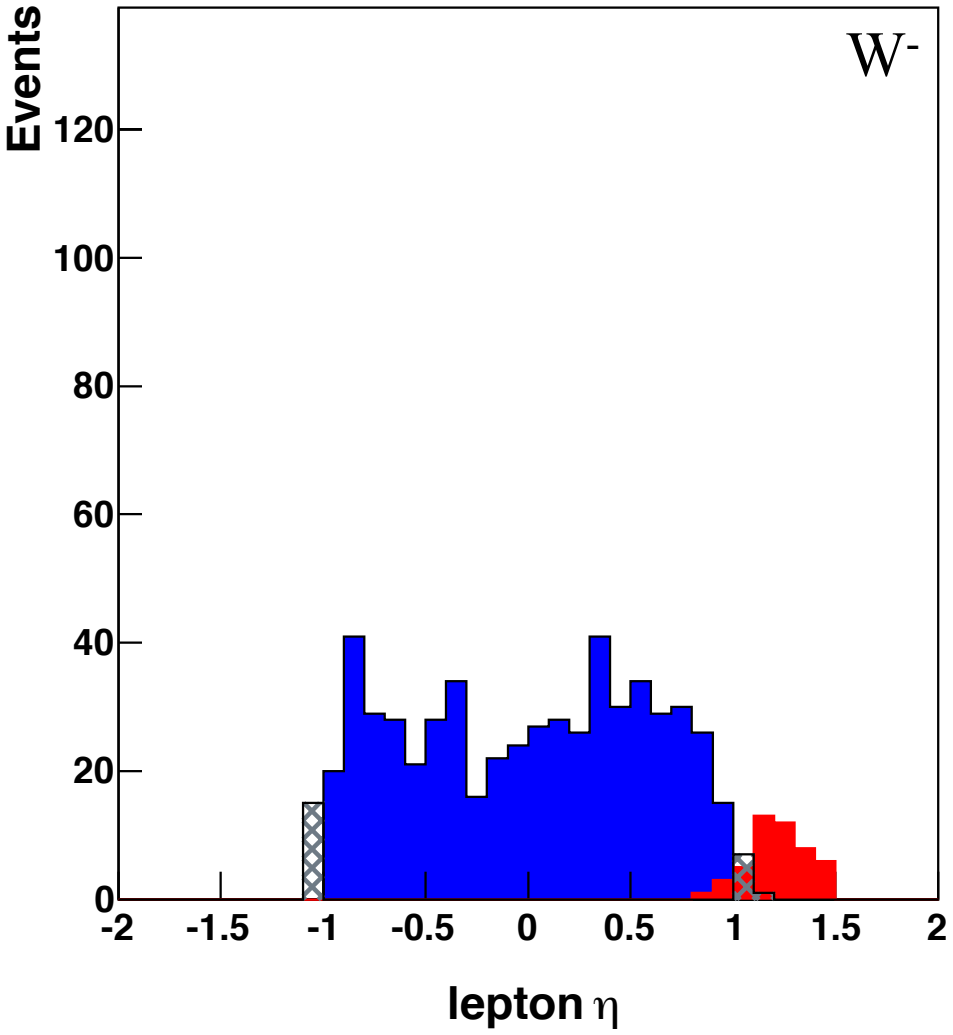
Background Example



Recent results - W production

- Mid rapidity / Forward rapidity: W candidate distributions (Run 12)

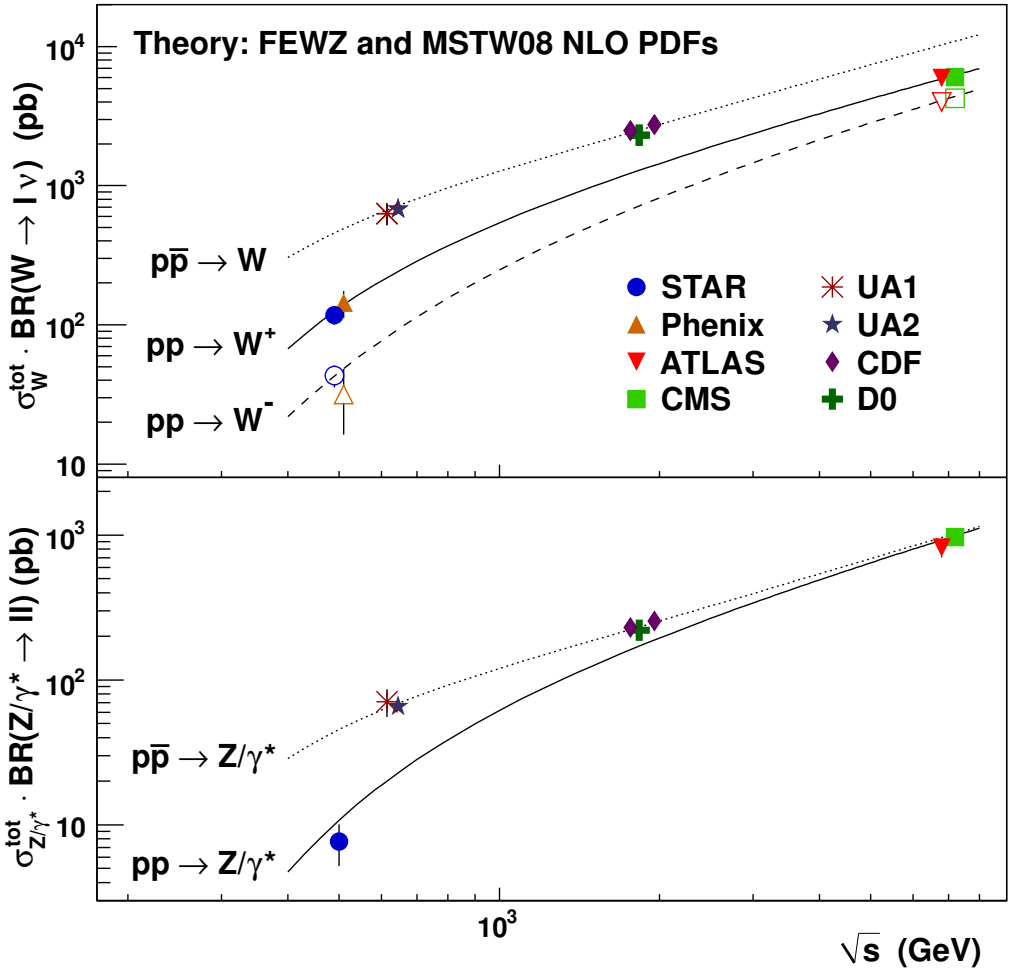


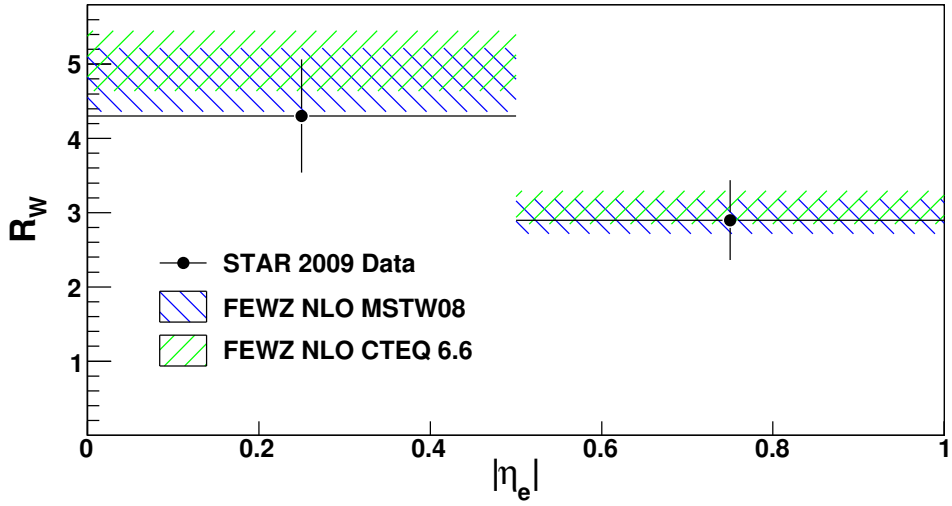


Recent results - W/Z production

- STAR Z / γ* cross-section results

STAR Collaboration, PRL 106, 062002 (2011)



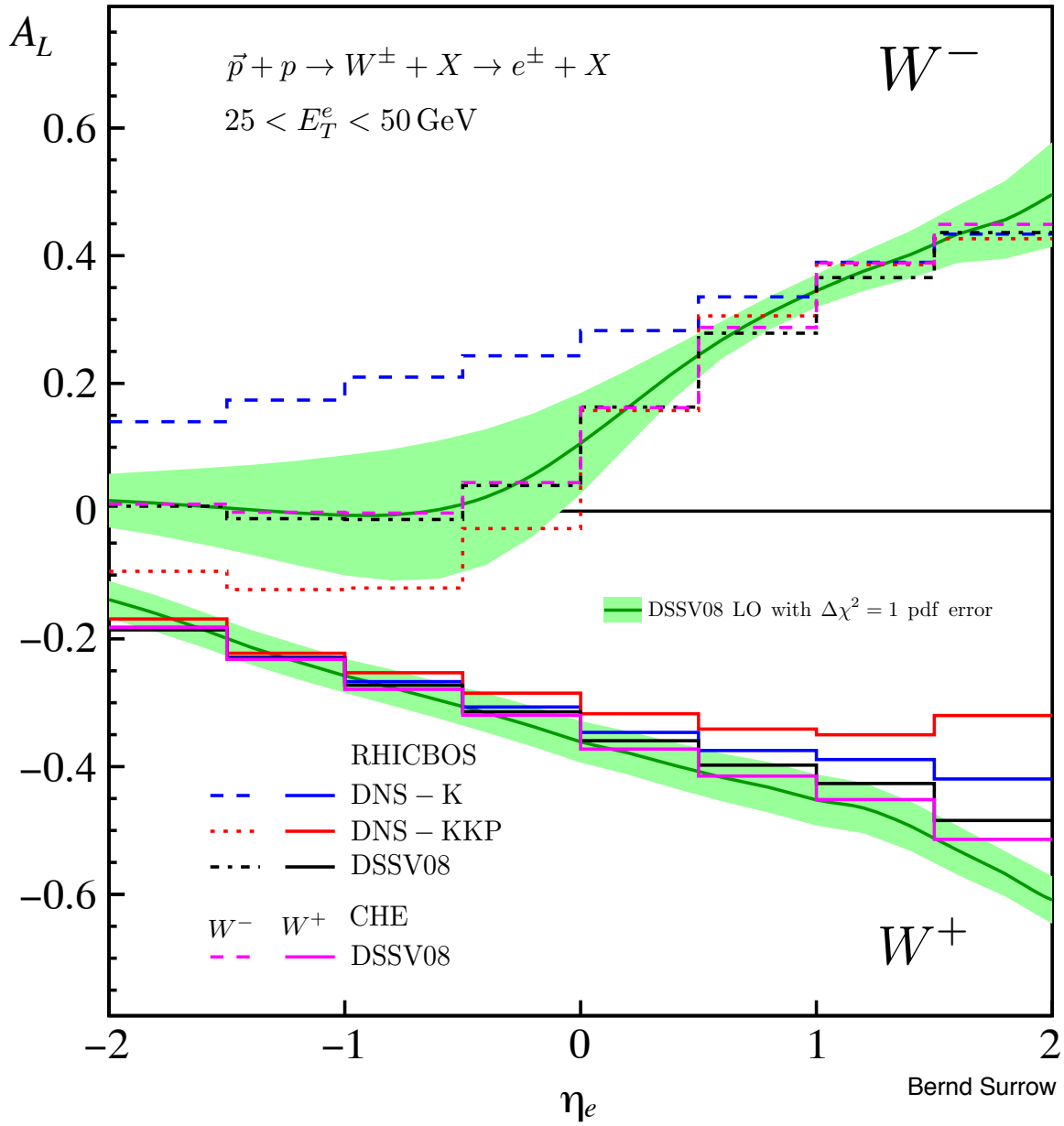


$$R(x_F) \equiv \frac{\sigma_{W^+}}{\sigma_{W^-}} = \frac{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2)}$$

LO decomposition of cross-section ratio $R(x_F)$

Recent results - W production

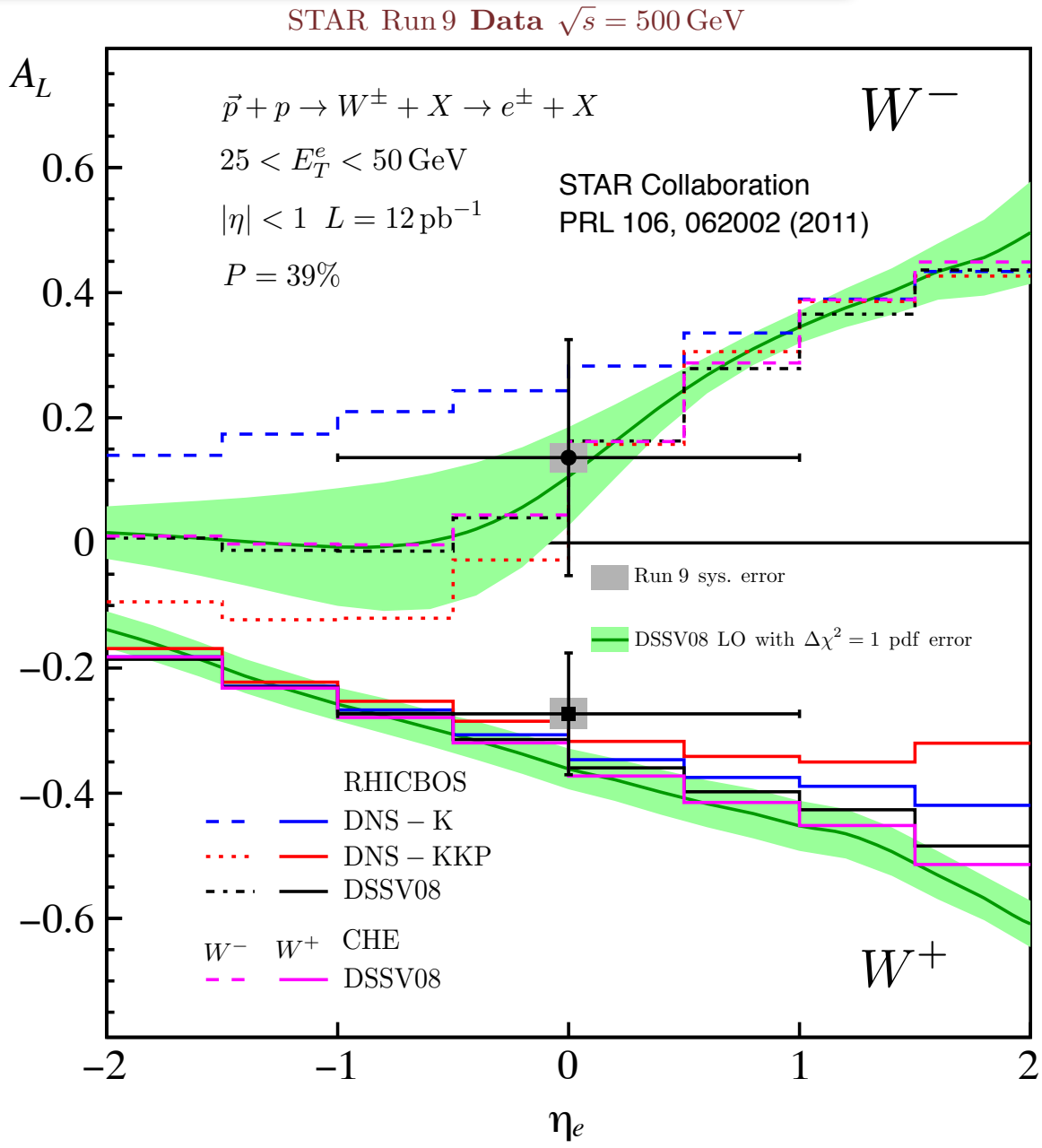
- STAR W A_L results / projections



Recent results - W production

- STAR W A_L results / projections
  - Measured asymmetries (Run 9) are in agreement with theory evaluations using polarized pdf's (DSSV) constrained by polarized DIS data

    ⇒ Universality of helicity distr. functions!



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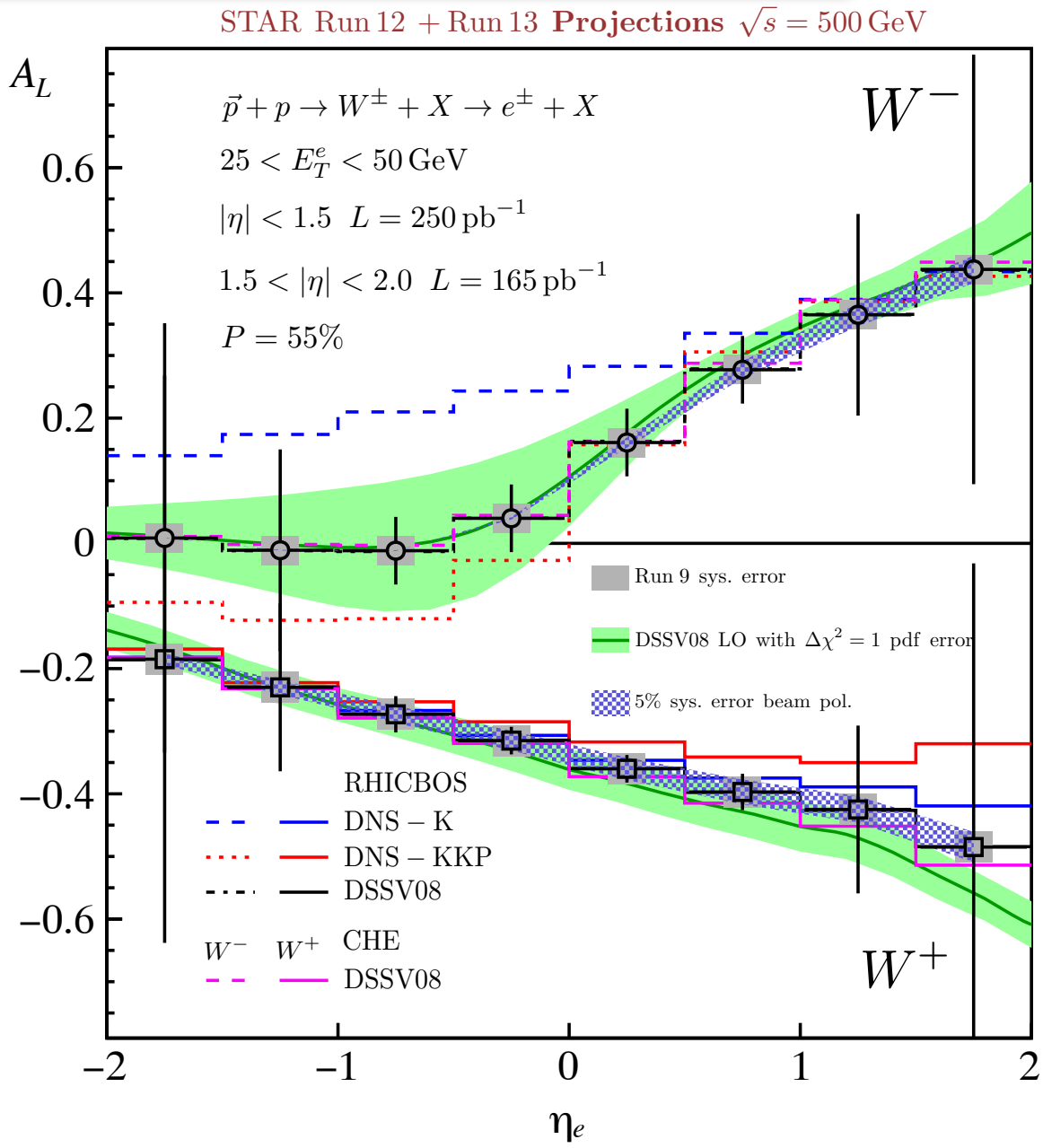
  - Critical: Measurement of W^+ and W^- asymmet as a function η_e



Recent results - W production

STAR W A_L results / projections

- Measured asymmetries (Run 9) are in agreement with theory evaluations using polarized pdf's (DSSV) constrained by polarized DIS data

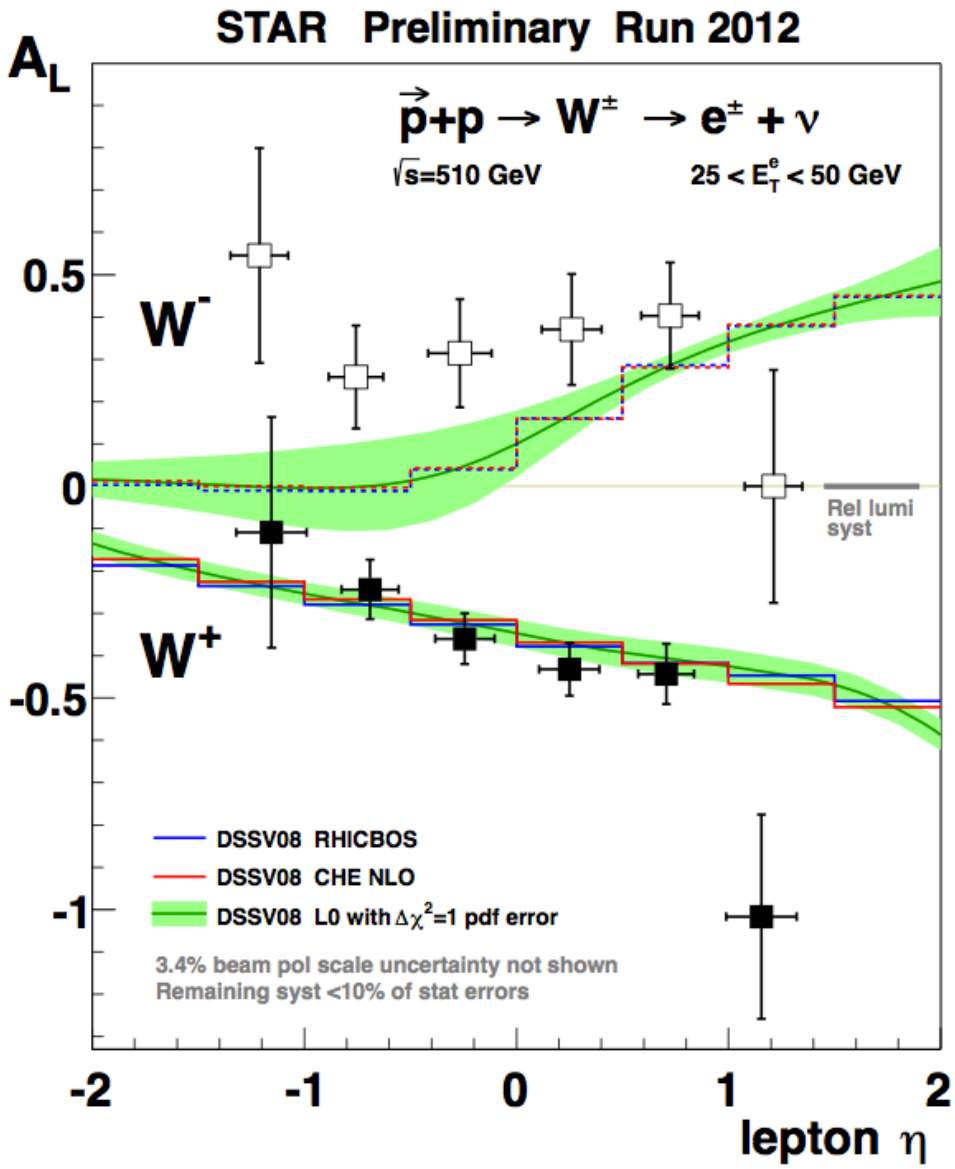
  ⇒ Universality of helicity distr. functions!

- Critical: Measurement of W^+ and W^- asymmet as a function η_e

- Major step forward in Run 12: Large A_L (W^-) asymmetry above DSSV suggests large anti-u quark polarization

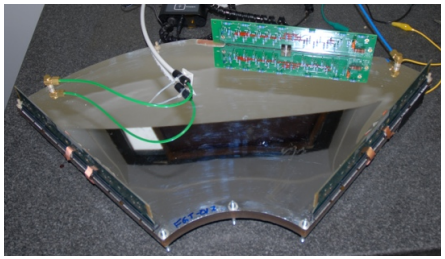
- Extension of backward / forward η_e acceptanc enhances sensitivity to anti-u / anti-d quark polarization

  ⇒ STAR Forward GEM Tracker ($1<|\eta_e|<2$)

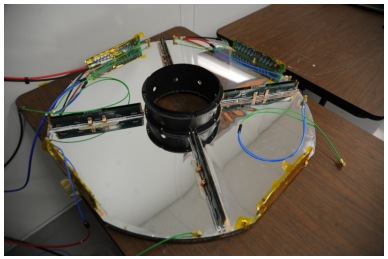


Future prospects - W production / STAR

- STAR Forward GEM Tracker - Layout

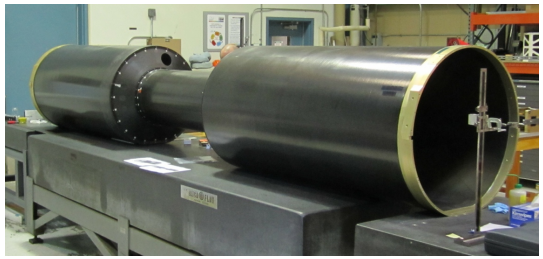


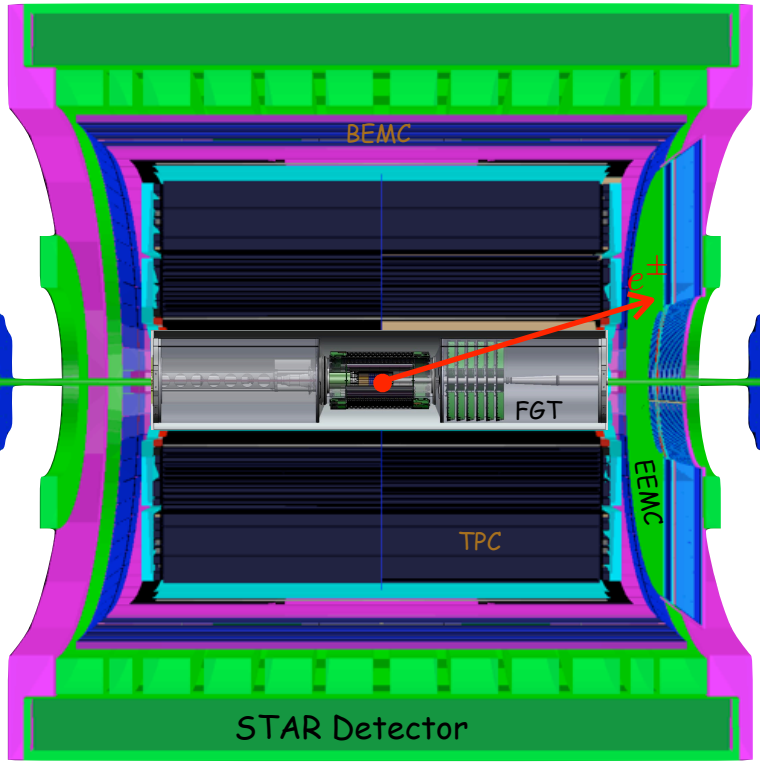
Quarter section



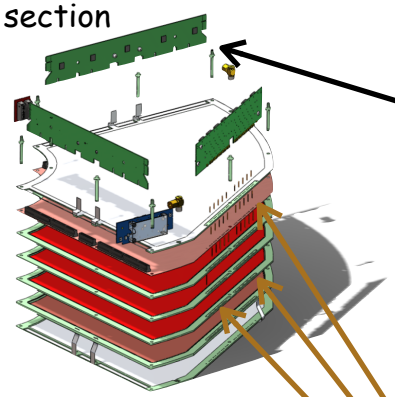
Disk

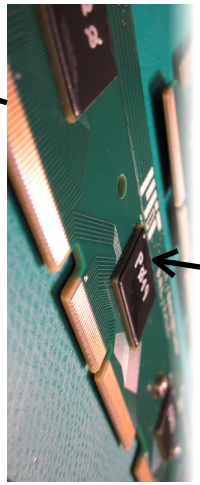
Quarter section





Installation completed prior to Run 13!





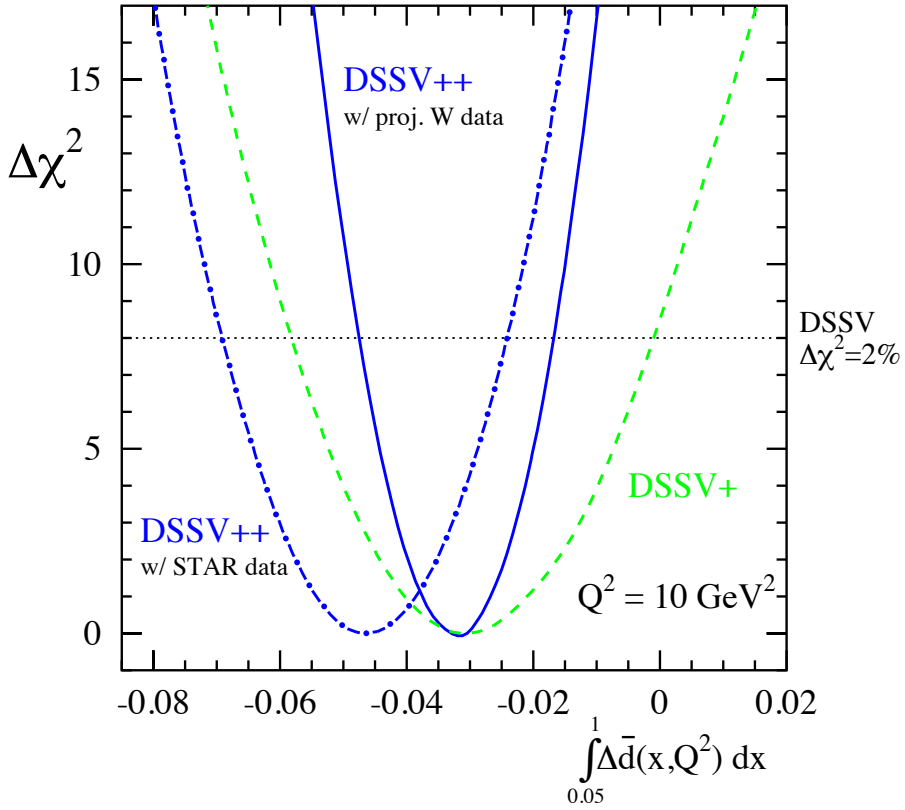
APV module

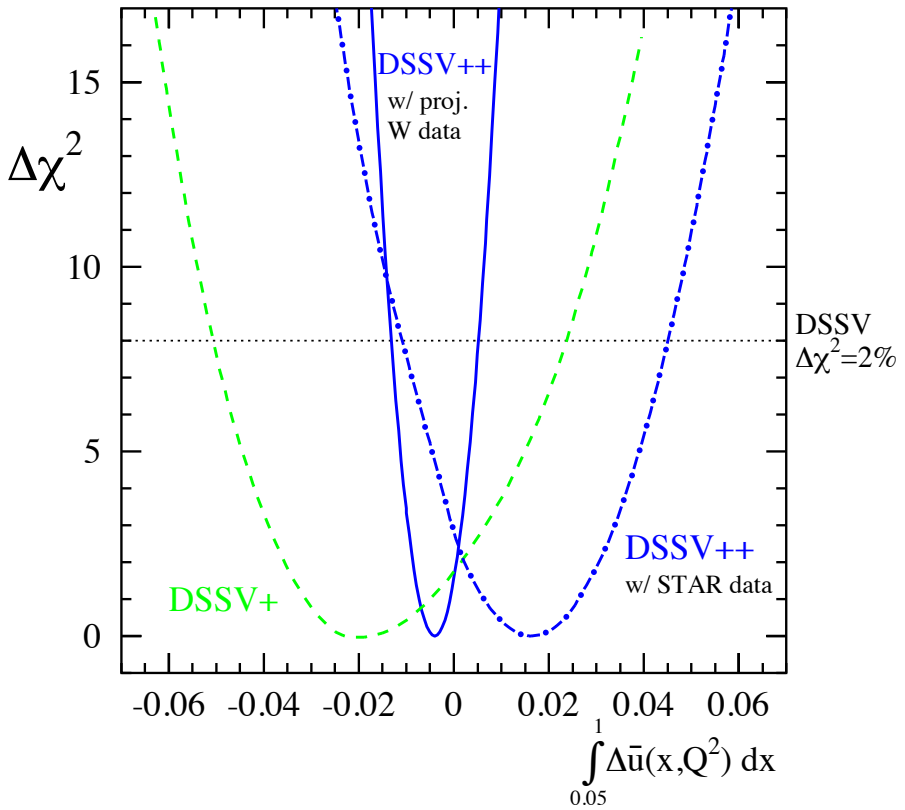
Packaged APV chip

FGT GEM foil

Recent results - W production

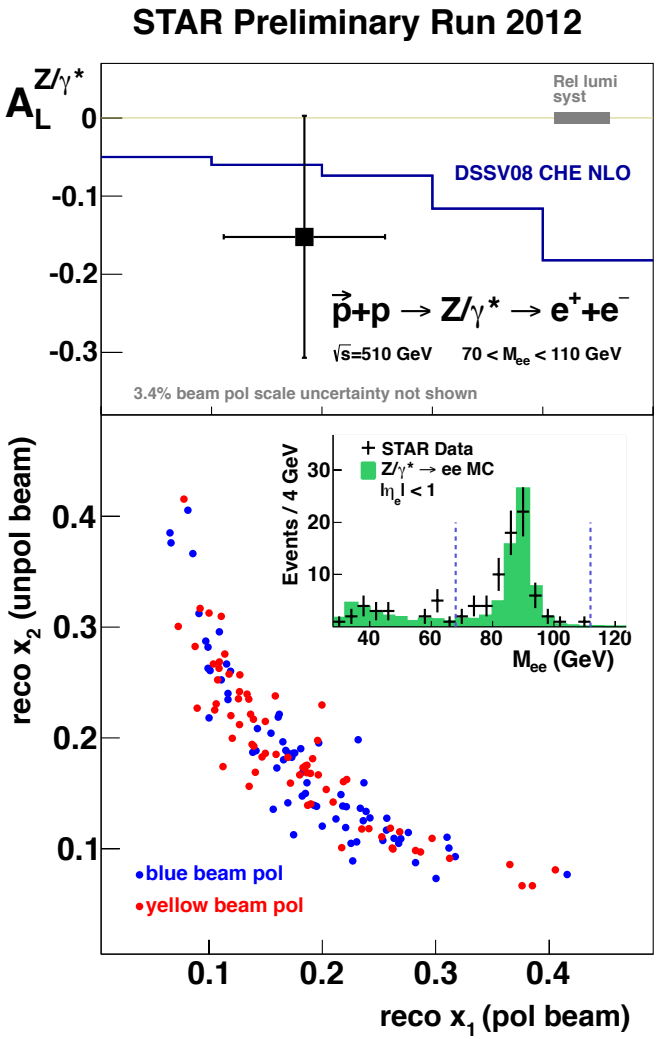
- Impact of new DSSV global fit result
  - DSSV++ (w/ STAR data) includes 2009 A_L data and preliminary 2012 A_L data
  - Significant shift in anti-u quark polarization from W^- Run 12 data

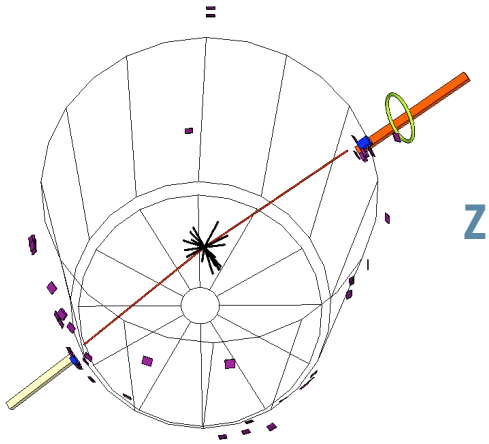




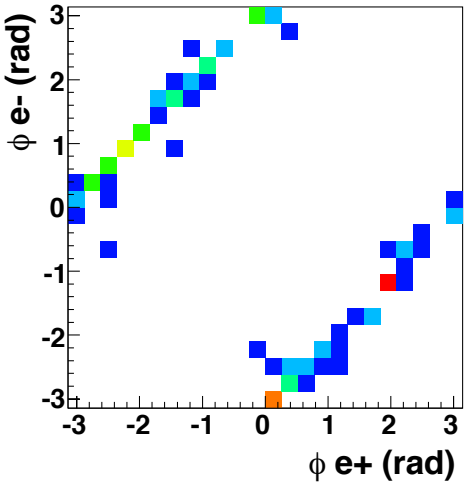
Recent results - Z / γ* production

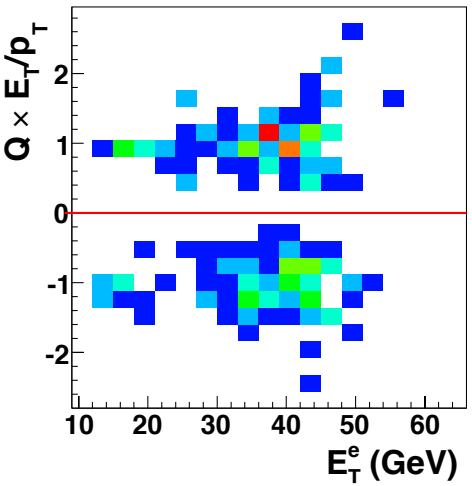
- STAR Z / γ* A_L results





Z → e⁺e⁻ Candidate





Reconstruct initial state kinematics at leading order:

$$x_{1(2)} = \frac{M_{ee}}{\sqrt{s}} e^{\pm y_Z}$$

Summary / Outlook

- W boson program
  - Mid-rapidity: New W^- results suggest large anti-u quark polarization
  - Critical: Measurement of W^+ and W^- asymmetries as a function η_e
  - Backward/Forward rapidity: Upgrade of STAR Forward Tracking system: Forward GEM Tracker (FGT)
- Run 12/13 and future
  - Run 12 / Run 13: Long. 510GeV (~85pb^{-1} rec.) runs in Run 12 and ongoing Run 13
  - Future: Expect and need several long 500GeV production runs beyond Run 13