Recent cross-section results on W/Z production of the high-energy polarized p+p program at STAR at RHIC
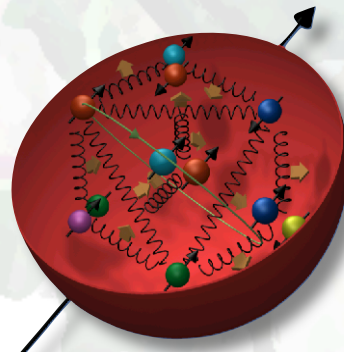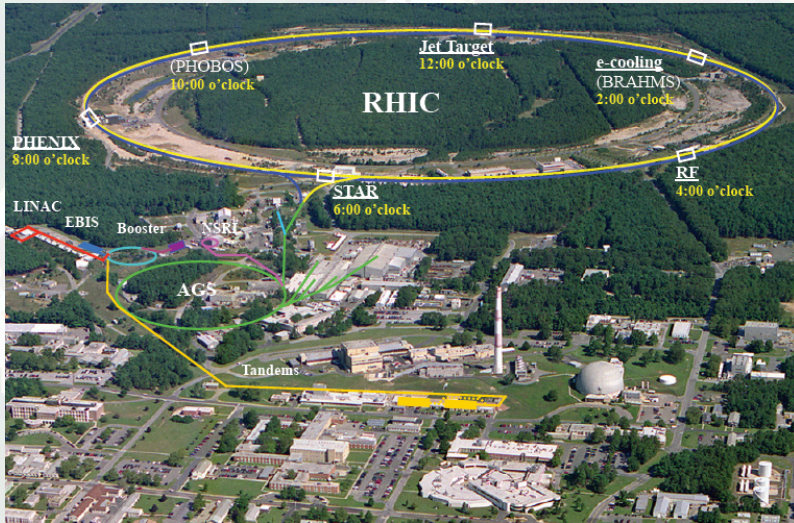
Bernd Surrow

TEMPLE UNIVERSITY®

XXI International Workshop on DIS and Related Subjects - DIS2013
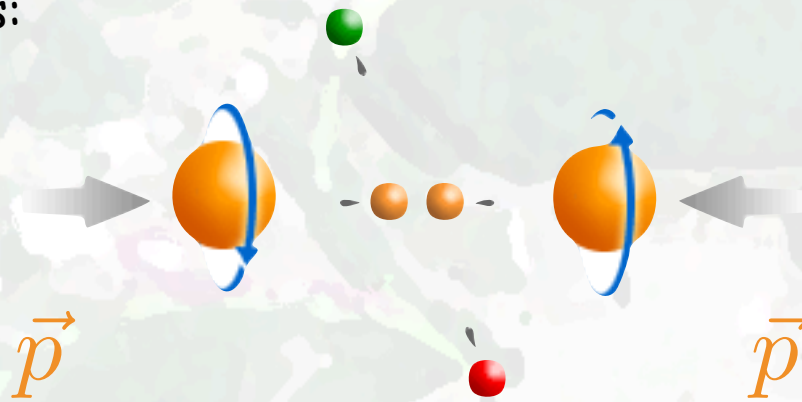Marseille, France, April 22-26, 2013

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Outline

□ Selected recent results and future prospects

    ○ W cross-section results

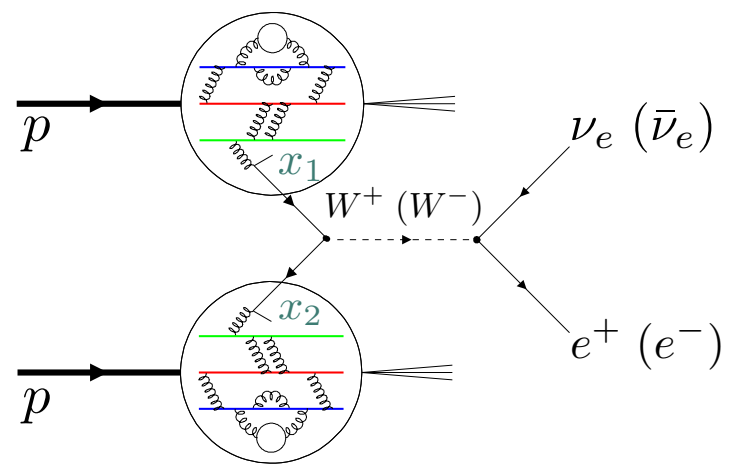   ○ Z cross-section results

□ Experimental aspects:
RHIC / STAR

□ Theoretical
foundation

$\vec{p}$

$\vec{p}$

□ Summary
and
Outlook

Theoretical foundation

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

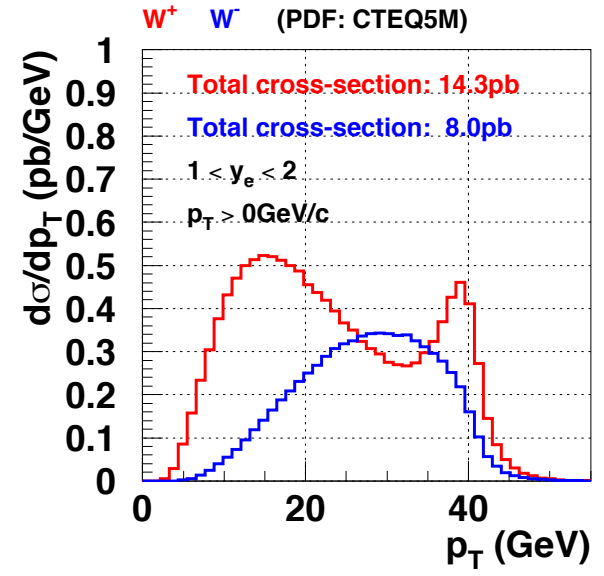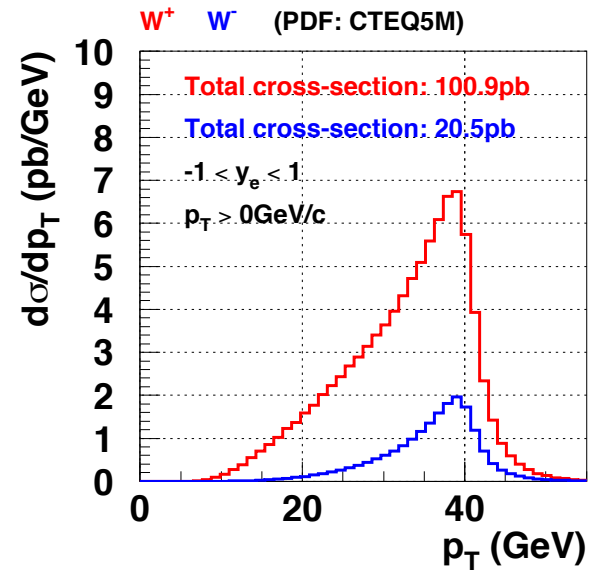$$y_l = y_W + \underbrace{\frac{1}{2} \ln \frac{1 + \cos\theta^*}{1 - \cos\theta^*}}_{y_l^*}$$

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

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

$$p_T = p_T^* = \frac{M_W}{2} \sin\theta^*$$
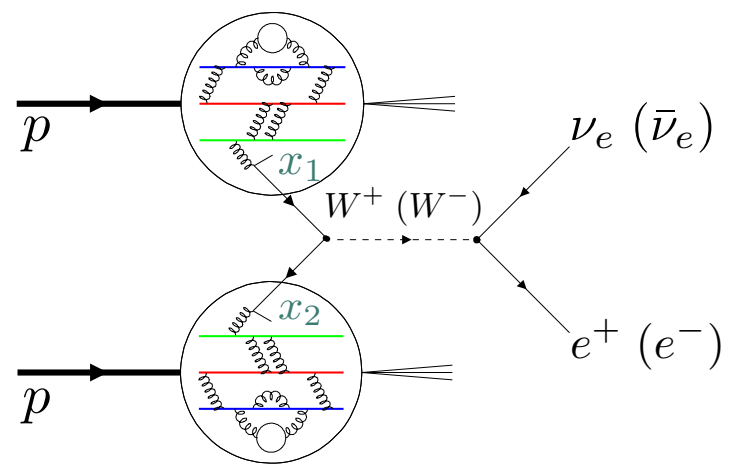
$$\frac{M_W}{\sqrt{s}} = 0.16$$

○ 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

W⁺ W⁻ (PDF: CTEQ5M)

Total cross-section: 100.9pb
Total cross-section: 20.5pb
-1 < y_e < 1
p_T > 0GeV/c

W⁺ W⁻ (PDF: CTEQ5M)

Total cross-section: 14.3pb
Total cross-section: 8.0pb
1 < y_e < 2
p_T > 0GeV/c

Total ($\sqrt{s}$=500GeV) σ(W⁺)=135pb and σ(W⁻)=42pb

Theoretical foundation

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

$$y_l = y_W + \underbrace{\frac{1}{2} \ln \frac{1 + \cos \theta^*}{1 - \cos \theta^*}}_{y_l^*}$$
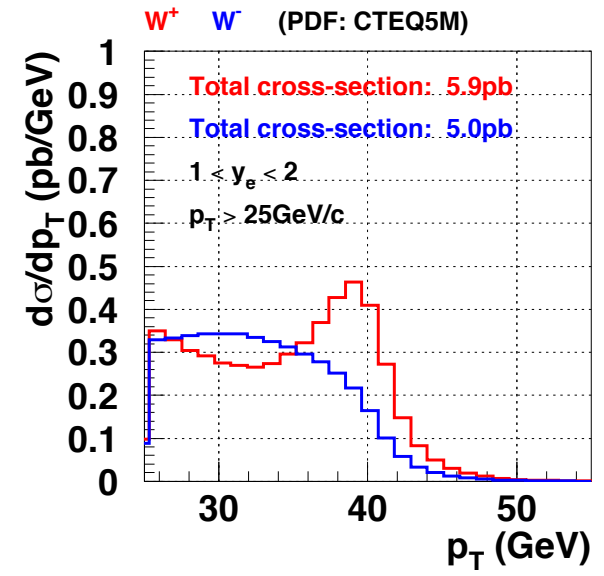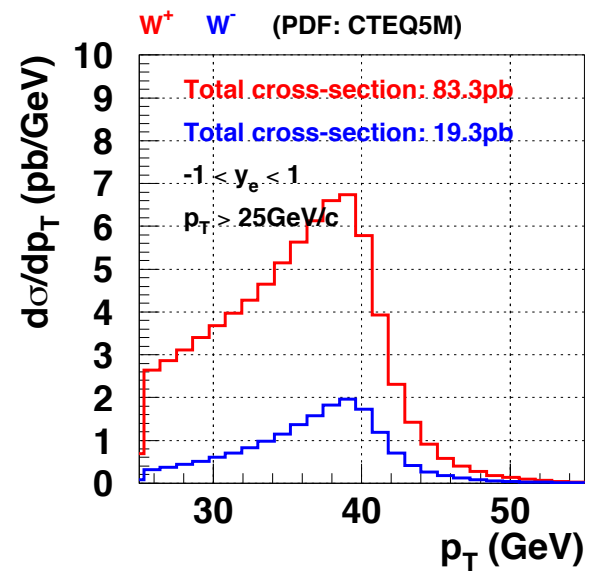
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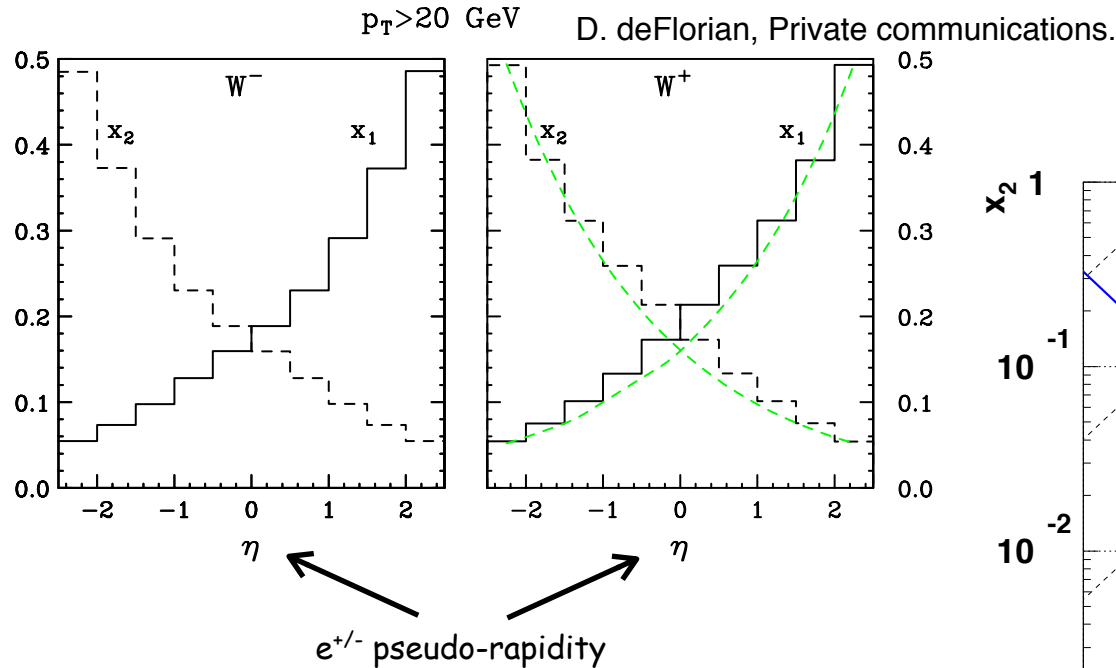
$$\frac{M_W}{\sqrt{s}} = 0.16$$

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○ Required: Lepton/Hadron discrimination

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

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Theoretical foundation

□ Kinematic range of W production at RHIC

$p_T > 20$ GeV   D. deFlorian, Private communications.

$e^{+/-}$ pseudo-rapidity

○ Approximate kinematic range at RHIC:

0.06 < x < 0.4 for -2 < η < 2

○ Measurement at LHC in **high-x range** would require very forward measurements

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

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

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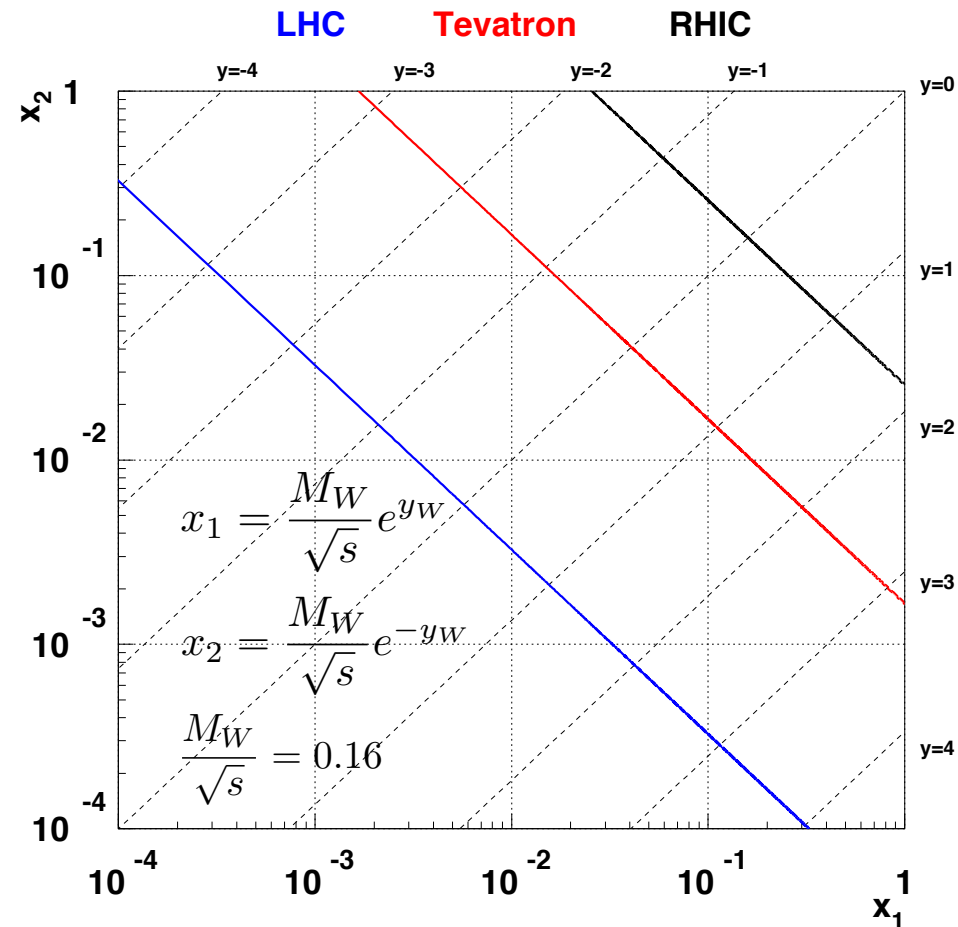
Theoretical foundation

Large-x uncertainties of unpolarized distribution functions

- Important constrain from lepton asymmetry on d/u at high-x

- **Puzzle**: NLO calculations based on recent PDFs fail to describe most precise charged-lepton asymmetry $A_e(y_e)$ measurements

- Potential input from RHIC focusing on high-x and high-Q^2 measurements

Agreement of PQCD with D0 $A_e(y_e)$	Order of α_s	χ^2/npt	Source
CTEQ6.6	NLO	191/36=5.5	*Our study*
CT10W	NLO	78/36=2.2	
ABKM'09	NNLO	540/24=22.5	*Catani, Ferrera, Grazzini,*
MSTW'08	NNLO	205/24=8.6	*JHEP 05, 006 (2010)*
JR09VF	NNLO	113/24=4.7	

P. Nadolsky, Private Communications.
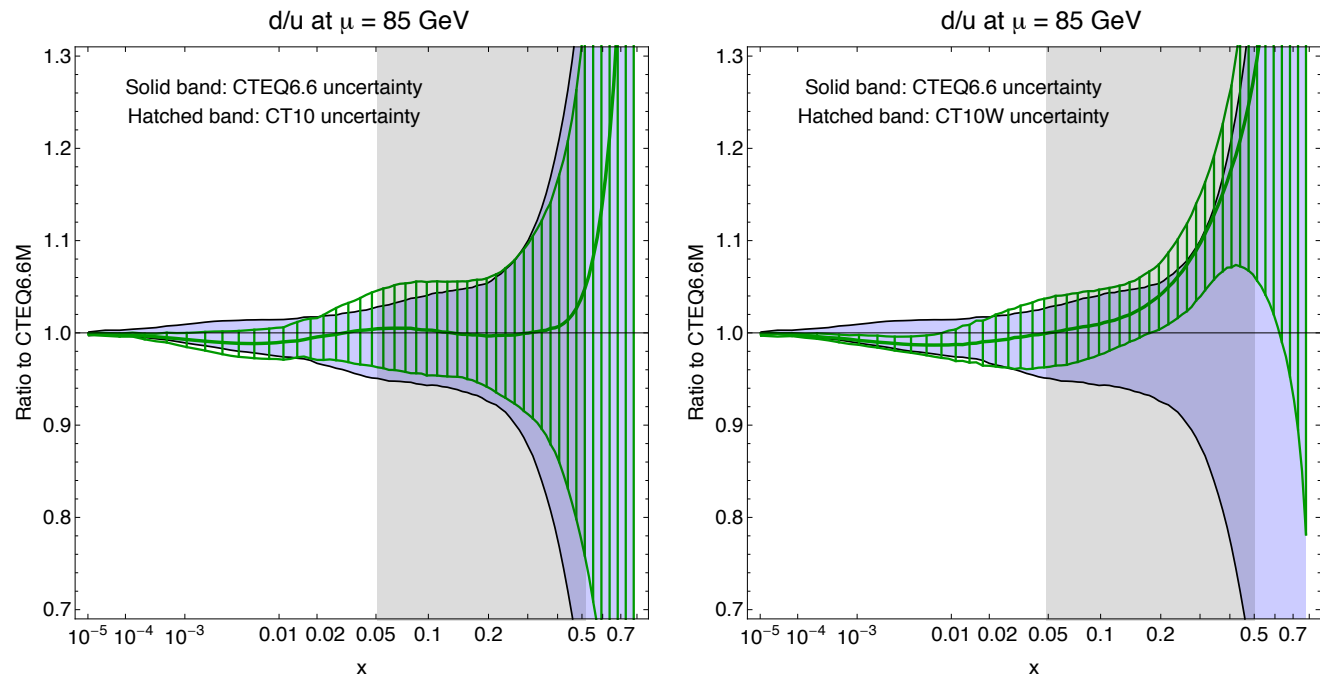
P. Nadolsky, Private Communications.

Theoretical foundation

Cross-section ratio R_W

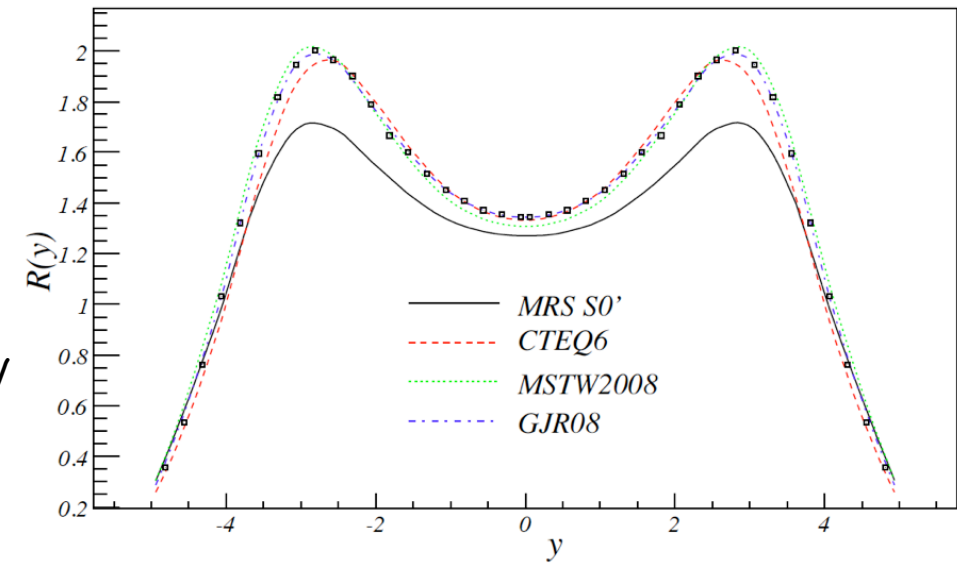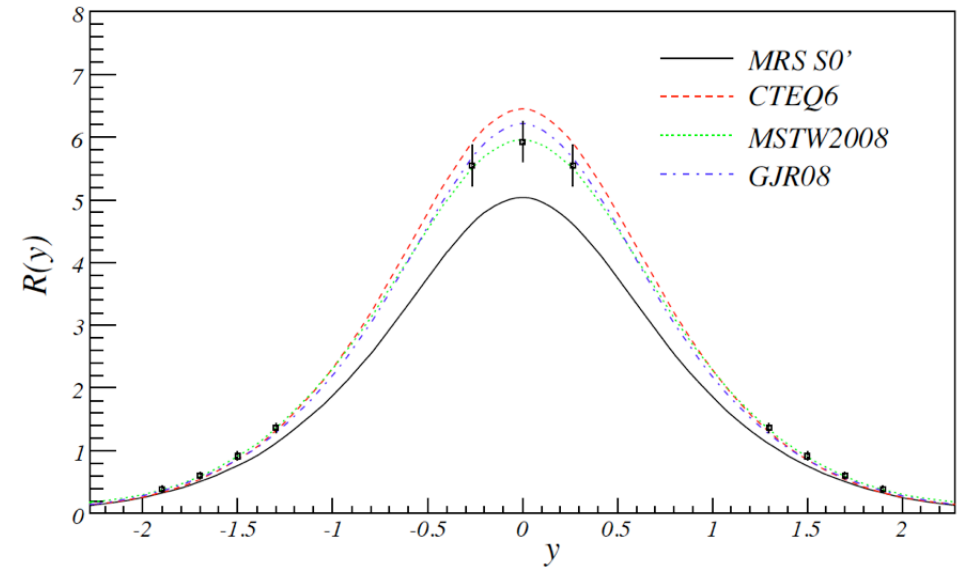R. Yang et al., Phys Lett. B680 (2009) 231.

○ **RHIC** provides **solid sensitivity** to unpolarized

distribution functions, in particular at mid-rapidity

constraining **dbar / ubar at high-x and high-Q²**

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

LO decomposition

of

cross-section ratio R(x_F)

○ **RHIC projections** (PHENIX): 300pb⁻¹ at √s=500GeV

○ **LHC projections**: 10fb⁻¹ at √s=14000GeV
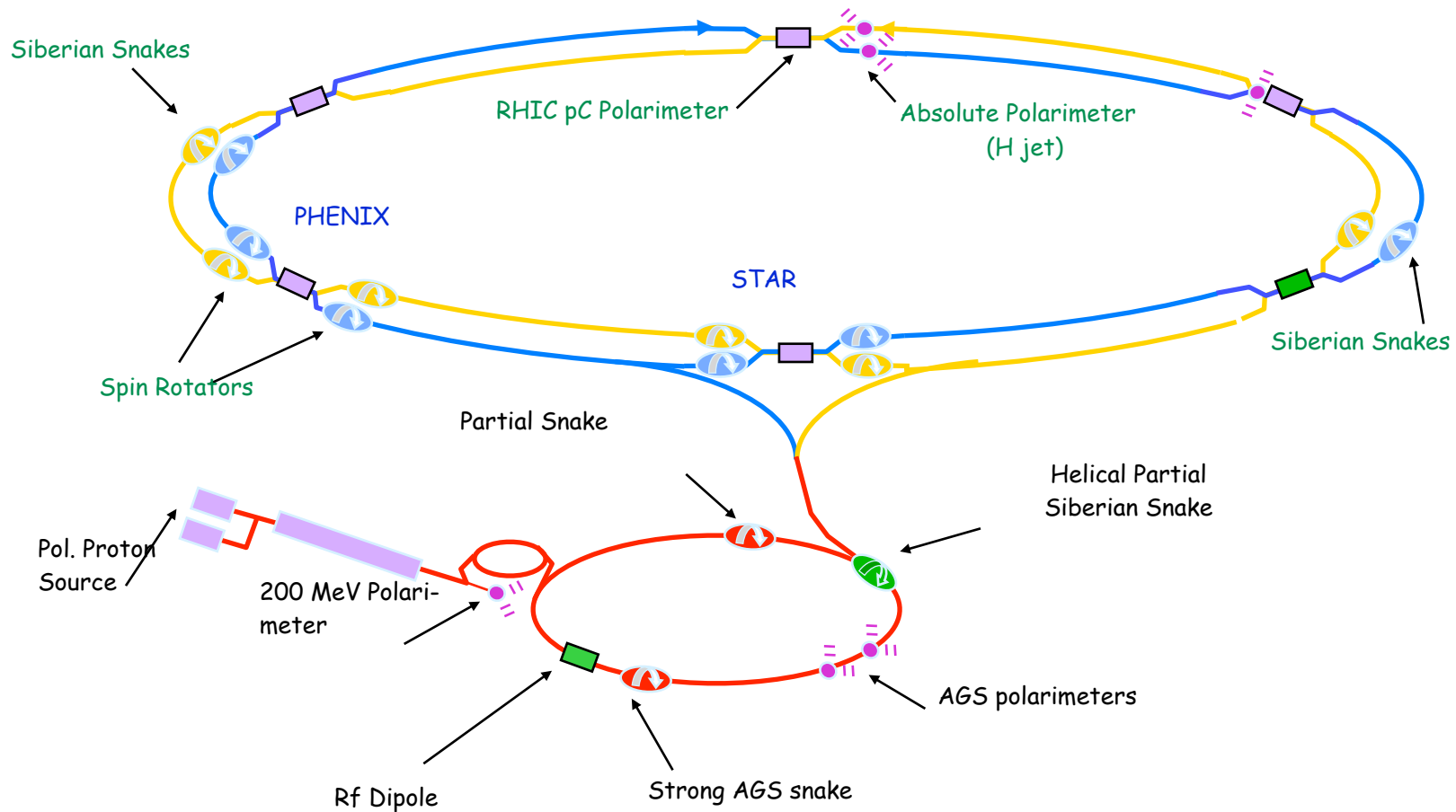
Experimental aspects - RHIC

- The world's first polarized proton-proton collider
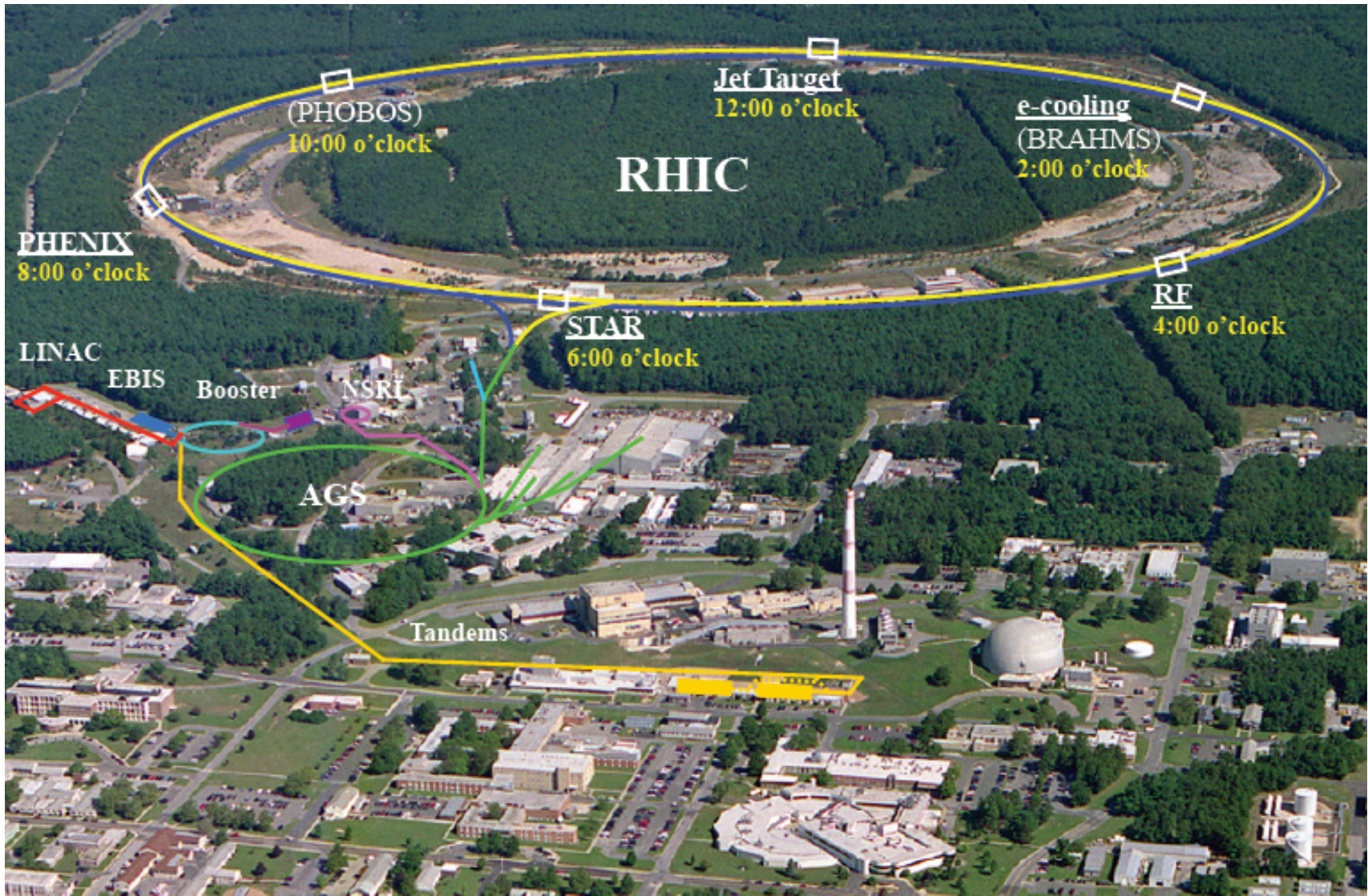
Experimental aspects - RHIC

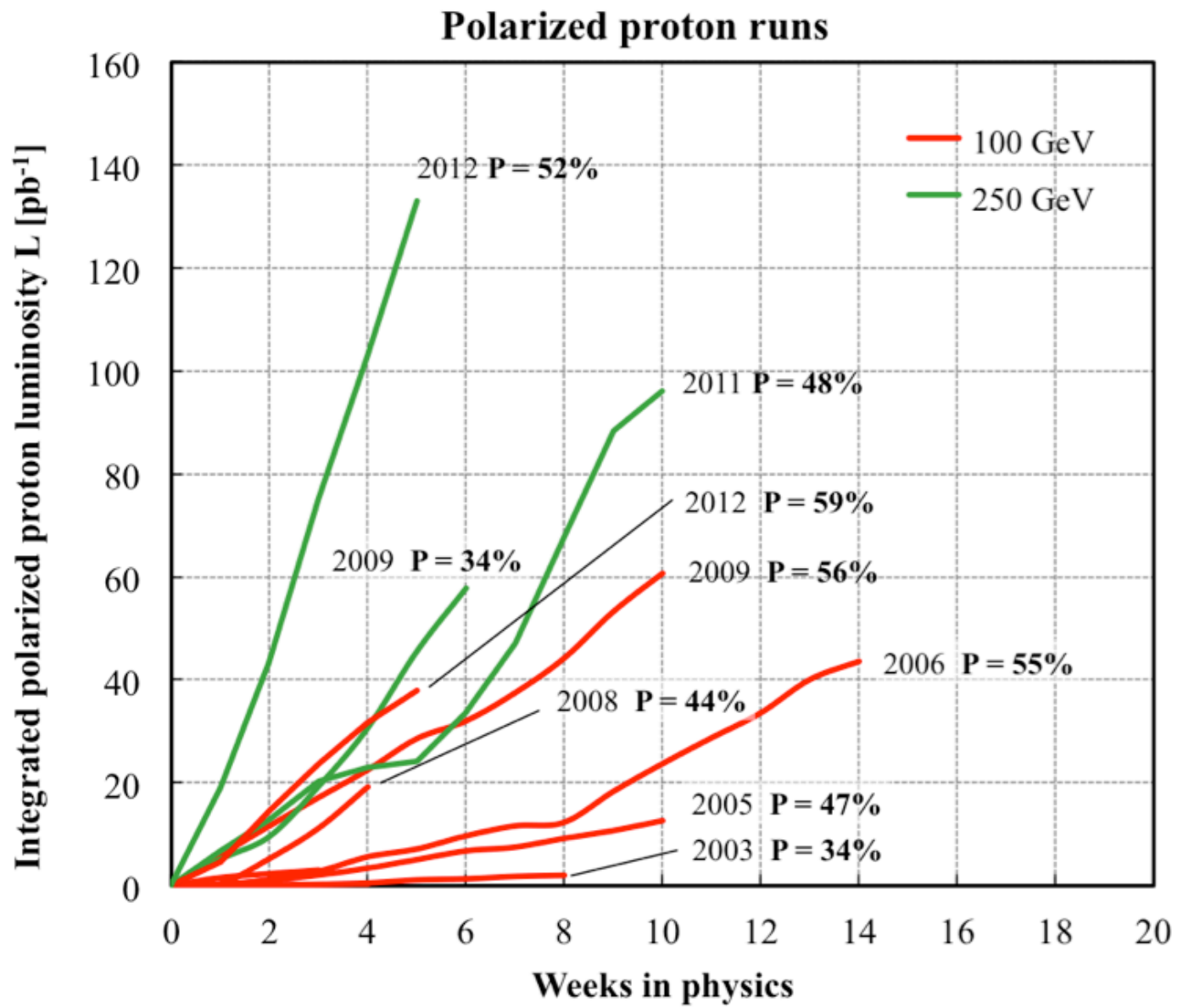- The world's first polarized proton-proton collider

Experimental aspects - RHIC

☐ The world's first polarized proton-proton collider

Experimental aspects - RHIC
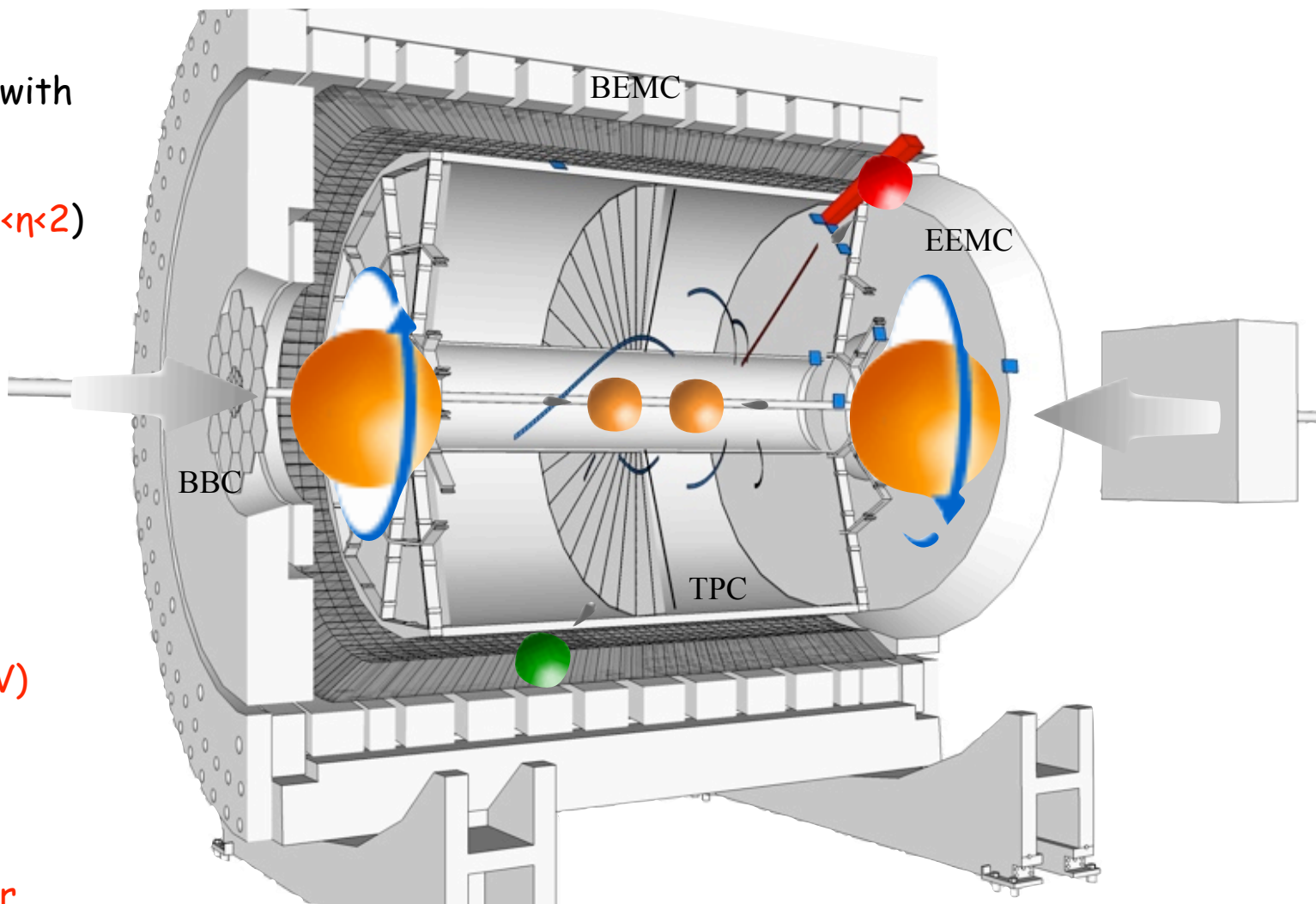
Polarized p-p collisions

- Long production runs at √s=200GeV (long. polarization) in 2005, 2006, 2009 and 2012: Jet and Hadron production (Gluon polarization)

- First collisions of polarized proton beams at √s=500GeV (long. polarization) in 2009 and 2012: W production (Quark polarization)

Polarized proton runs

- 100 GeV
- 250 GeV

2012 P = 52%
2011 P = 48%
2012 P = 59%
2009 P = 34%
2009 P = 56%
2006 P = 55%
2008 P = 44%
2005 P = 47%
2003 P = 34%

Integrated polarized proton luminosity L [pb⁻¹]

Weeks in physics

Experimental aspects - STAR

☐ **Overview**

○ 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 (500GeV)

○ BBC: Relative luminosity and Minimum bias trigger

BEMC

EEMC

BBC

TPC

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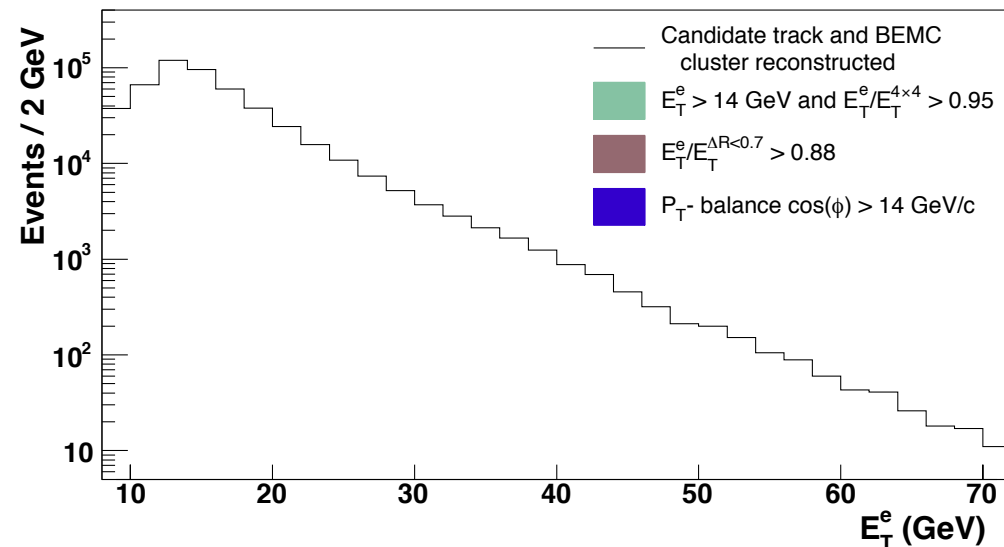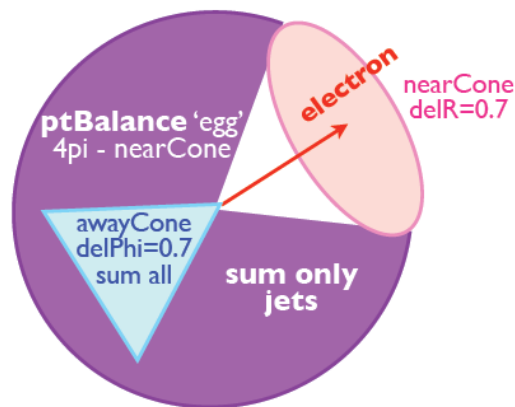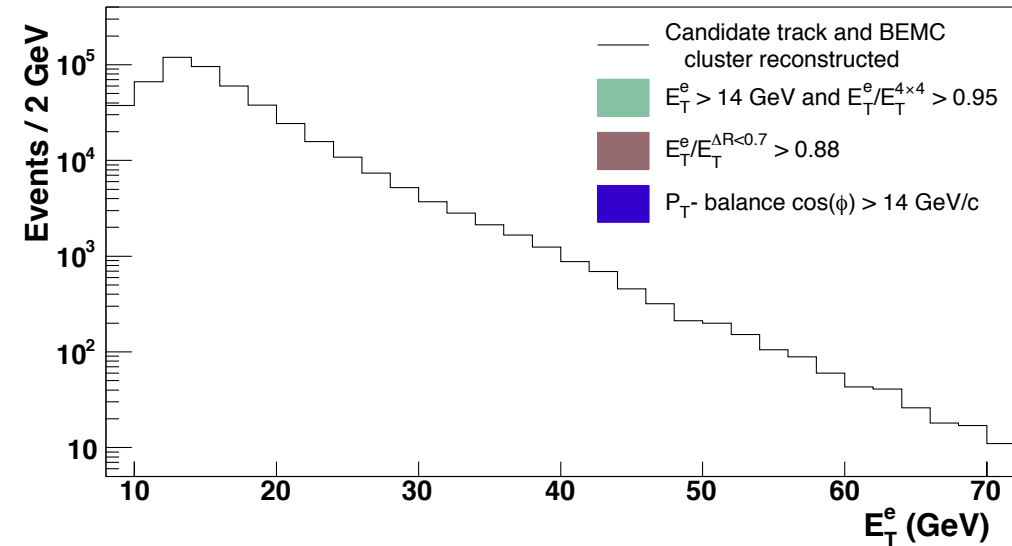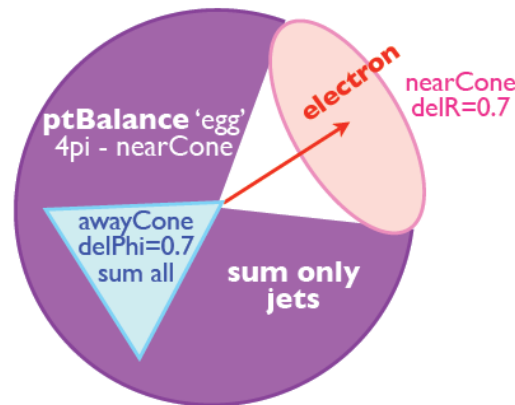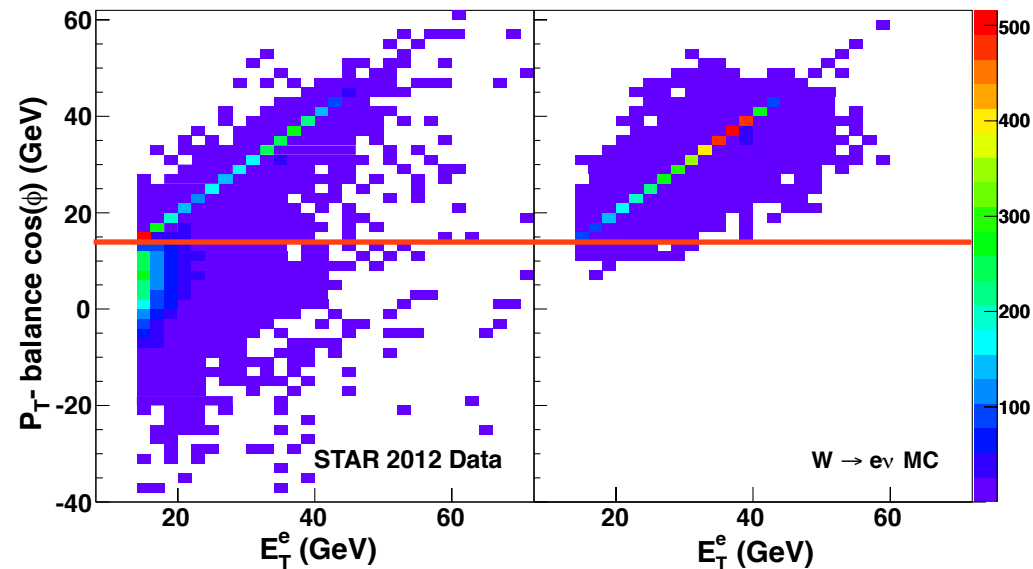
Recent results - W production

- **Mid-rapidity selection criteria**

  - ○ Match $p_T > 10$ GeV track to BEMC cluster

  - ○ Isolation ratios

  - ○ p_T-balance cut

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

$$P_T\text{-balance}\cos(\phi) = \frac{\vec{p}_T^{\,e} \cdot \vec{p}_T^{\,bal}}{|\vec{p}_T^{\,e}|}$$
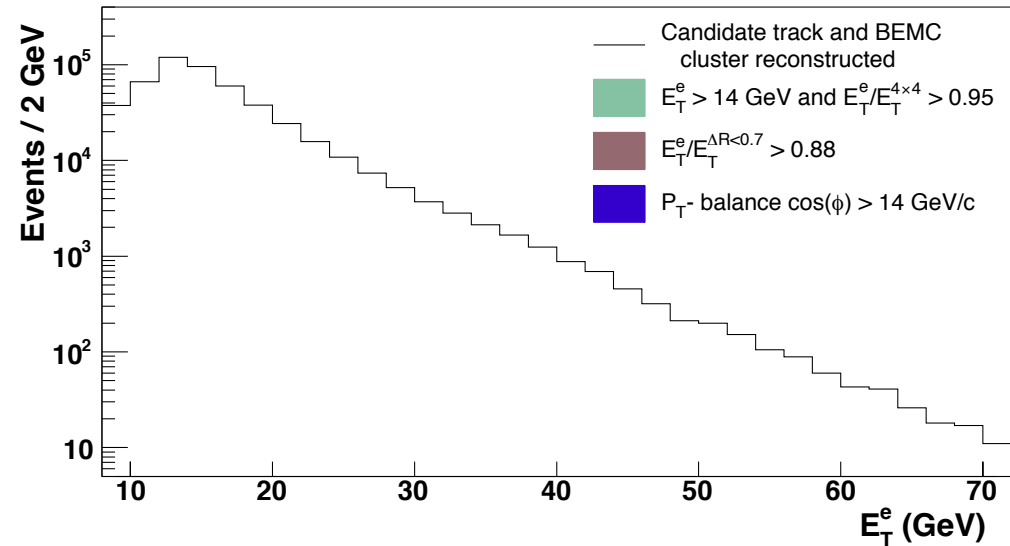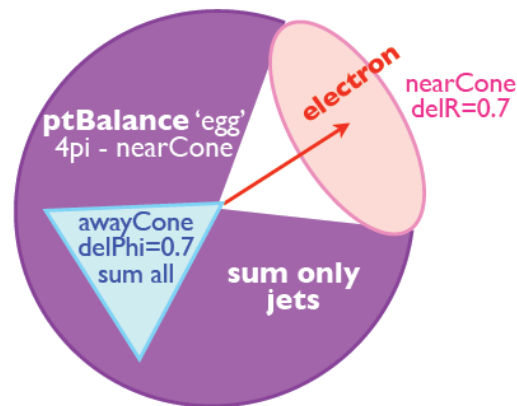
Transverse plane view

Recent results - W production

Mid-rapidity selection criteria

- Match $p_T > 10$ GeV track to BEMC cluster

- Isolation ratios

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

Transverse plane view

Candidate track and BEMC cluster reconstructed

$E_T^e > 14$ GeV and $E_T^e/E_T^{4\times4} > 0.95$

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

P_T- balance $\cos(\phi) > 14$ GeV/c
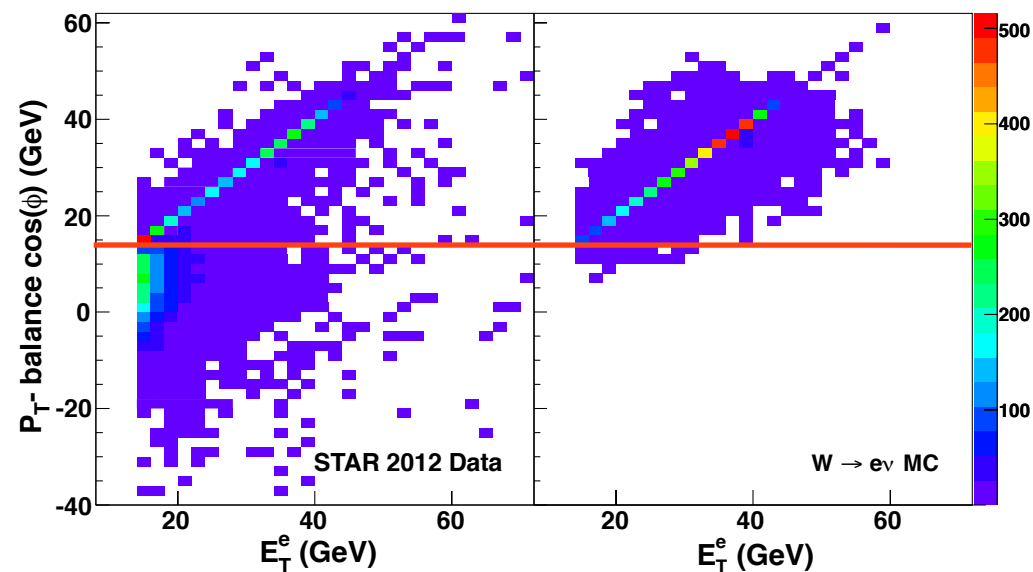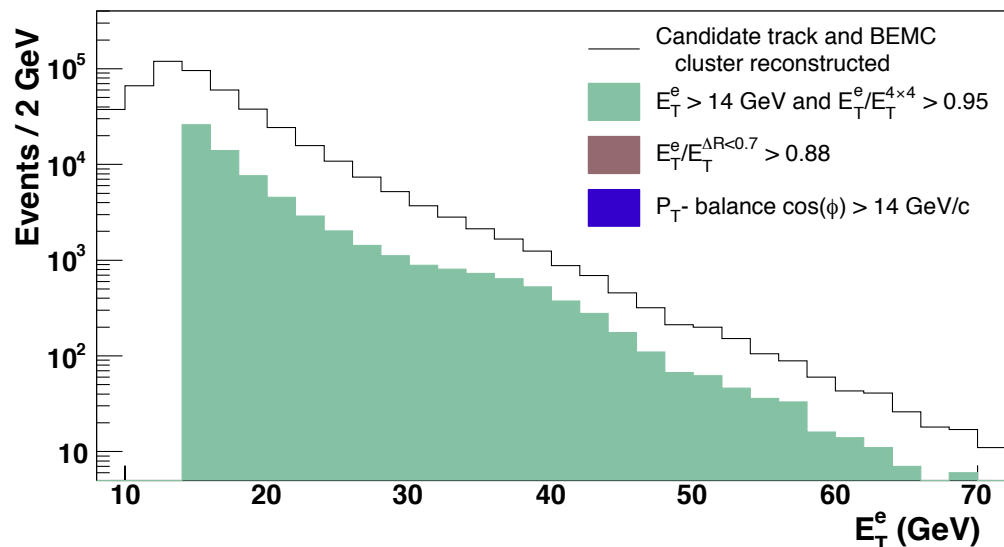
STAR 2012 Data

$W \to e\nu$ MC

Recent results - W production

- ☐ Mid-rapidity selection criteria

  - ○ Match p_T > 10 GeV track to BEMC cluster

  - ○ Isolation ratios

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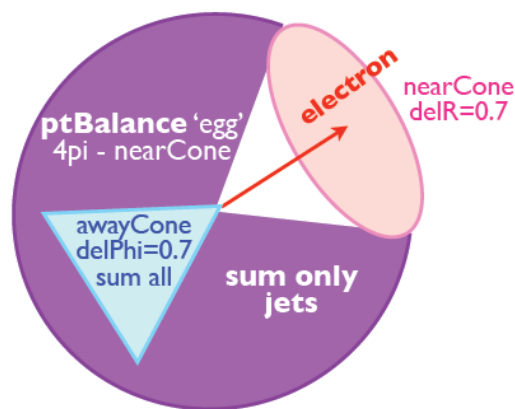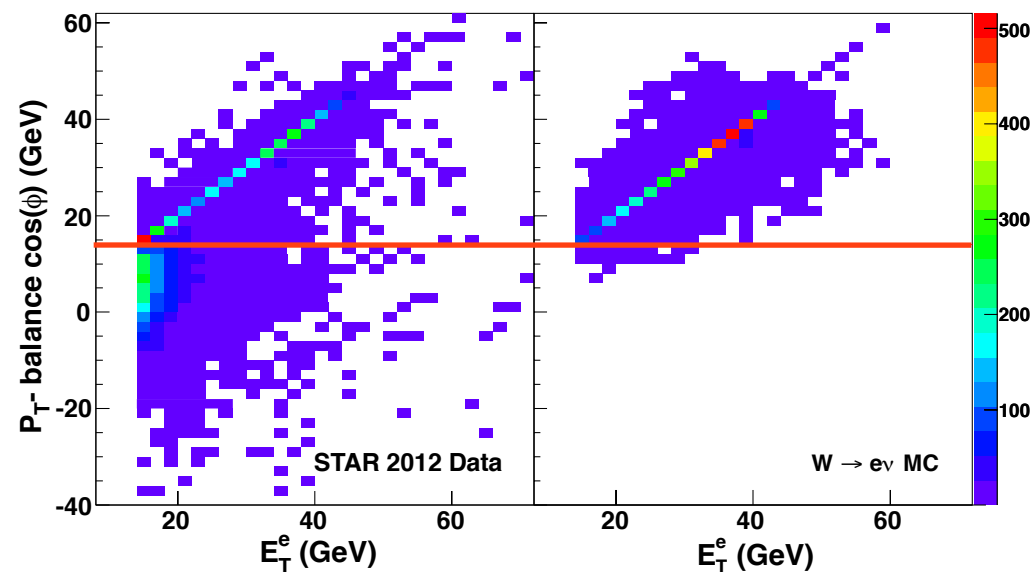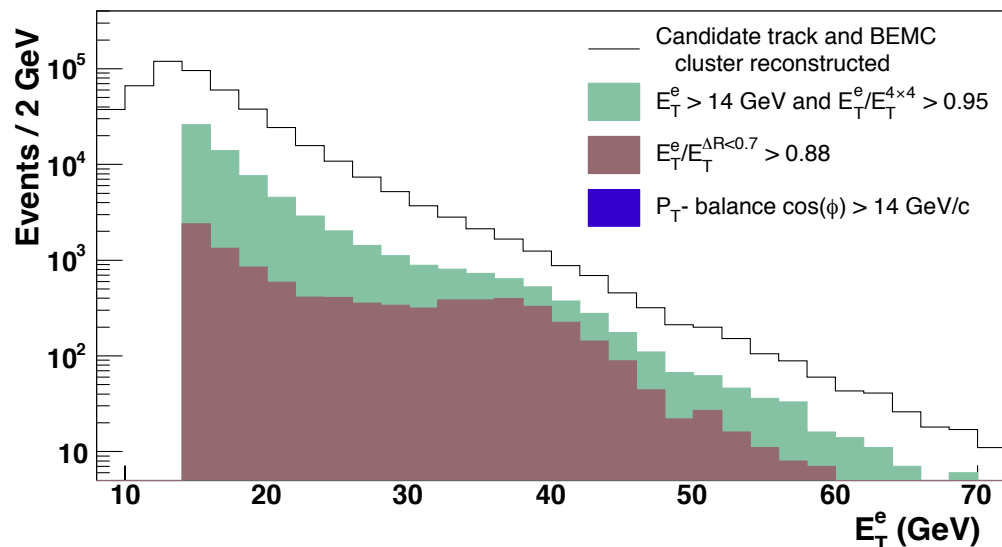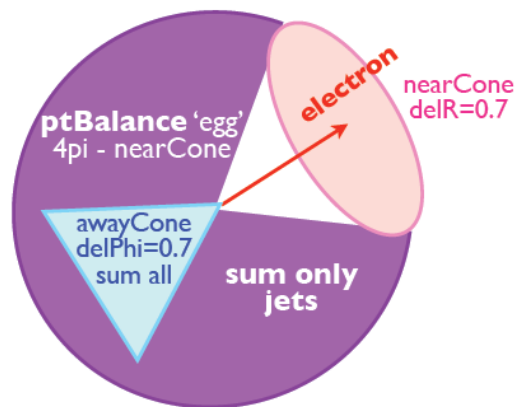
Transverse plane view

Recent results - W production

Mid-rapidity selection criteria

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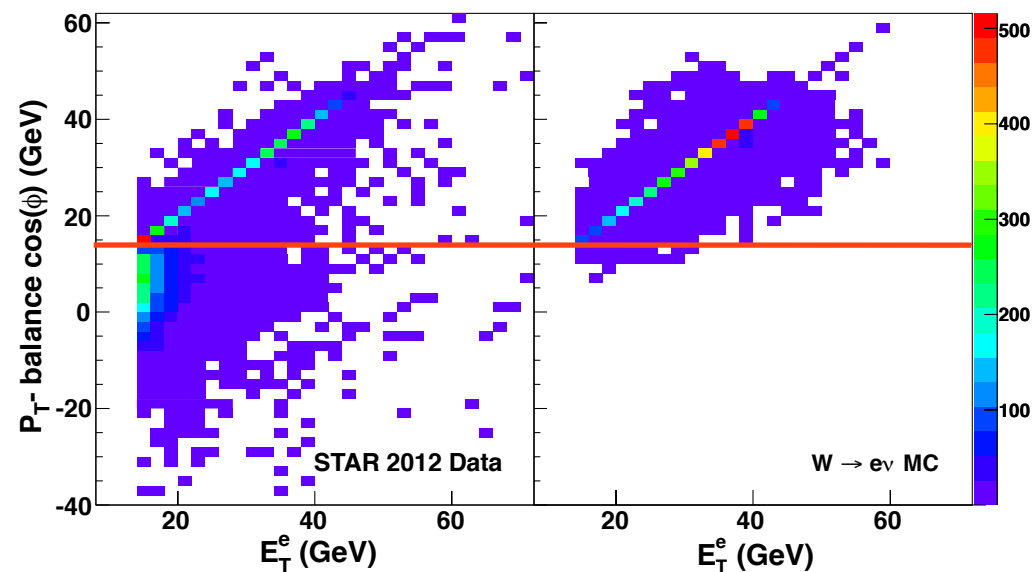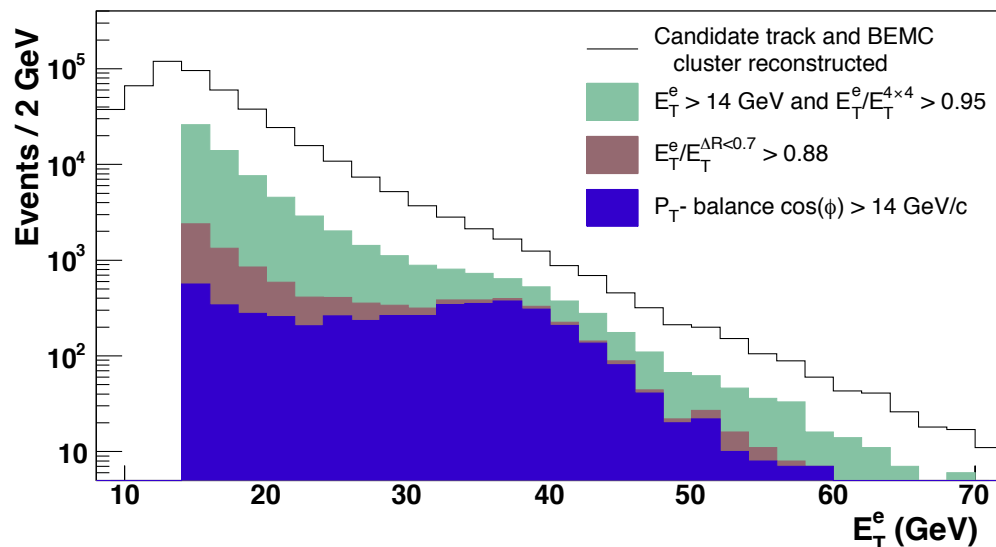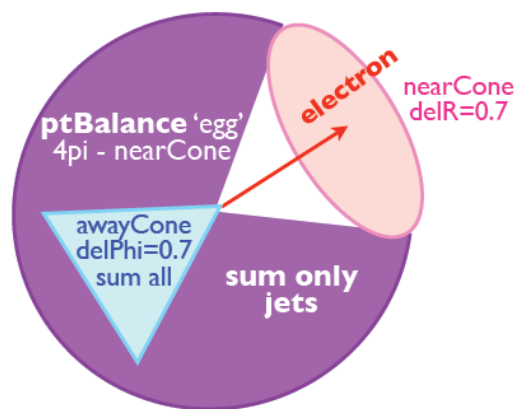
Transverse plane view

Recent results - W production

Mid-rapidity selection criteria

- Match p_T > 10 GeV track to BEMC cluster

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$$\vec{p_T}^{bal} = \vec{p_T}^{e} + \sum_{\Delta R > 0.7} \vec{p_T}^{jets}$$
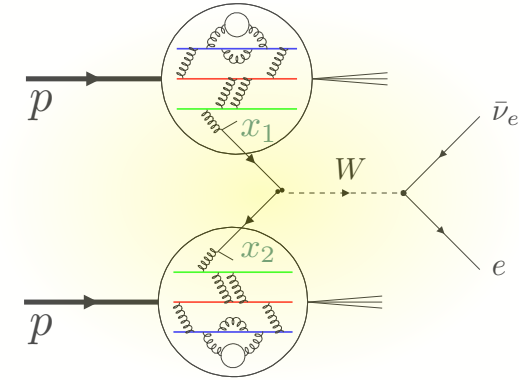
$$P_T\text{-balance} \cos(\phi) = \frac{\vec{p_T}^{e} \cdot \vec{p_T}^{bal}}{|\vec{p_T}^{e}|}$$

Transverse plane view

Recent results - W production

Mid-rapidity selection criteria

- Match p_T > 10 GeV track to BEMC cluster

- Isolation ratios

- p_T-balance cut

$$\vec{p_T}^{\,bal} = \vec{p_T}^{\,e} + \sum_{\Delta R > 0.7} \vec{p_T}^{\,jets}$$
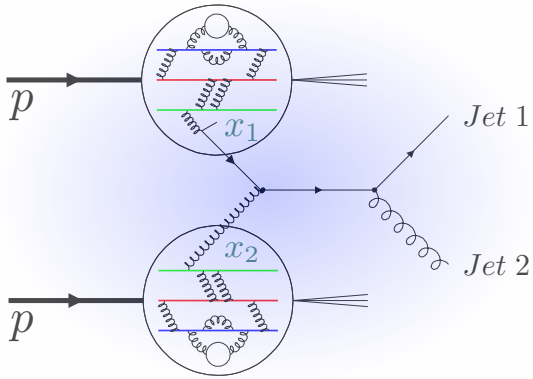
$$P_T\text{-balance}\cos(\phi) = \frac{\vec{p}_T^{\,e} \cdot \vec{p}_T^{\,bal}}{|\vec{p}_T^{\,e}|}$$

Transverse plane view

Recent results - W production

☐ Measurement: STAR Background treatment / Signal distribution (Run 9)
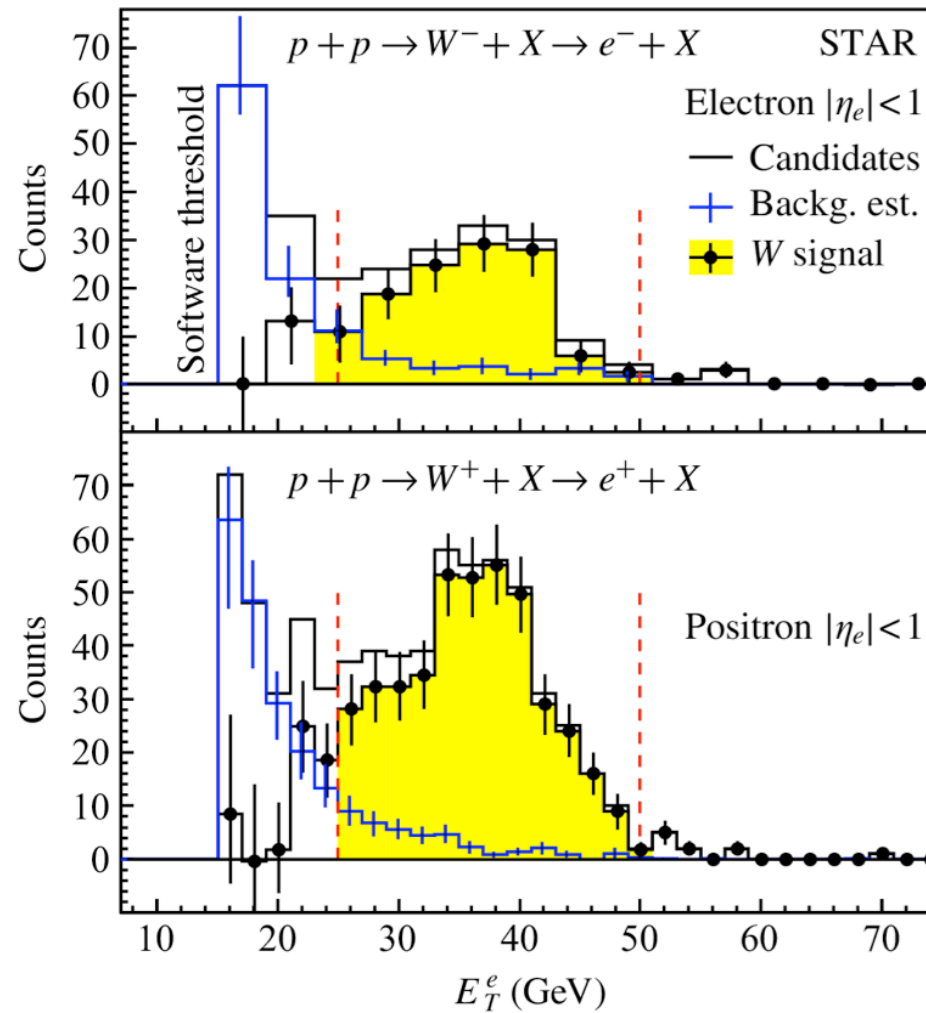

○ **Background dominated by QCD background** (Data driven estimate) with smaller fractions from W boson induced τ decays and Z^0 boson events (MC estimate)
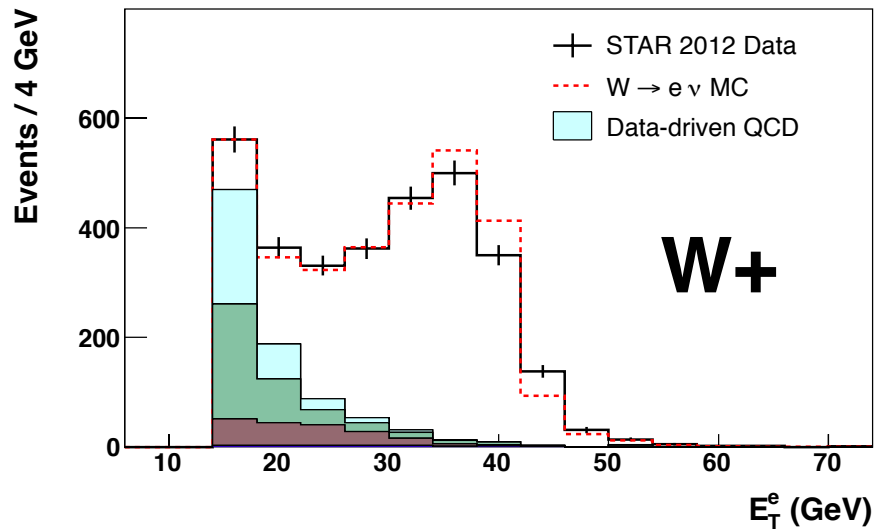
○ Total background (B):
  ☐ e^+: 39 ± 9
  ☐ e^-: 23 ± 6

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

Recent results - W production

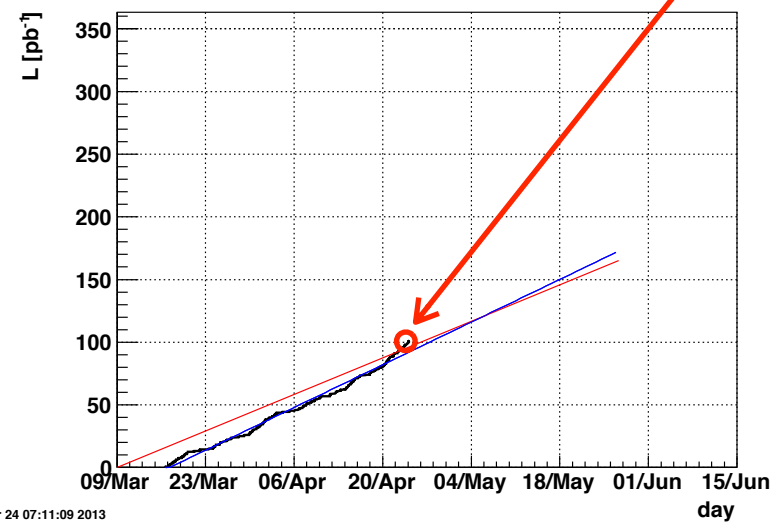☐ Mid-rapidity: STAR Background treatment / Signal distribution (Run 12)

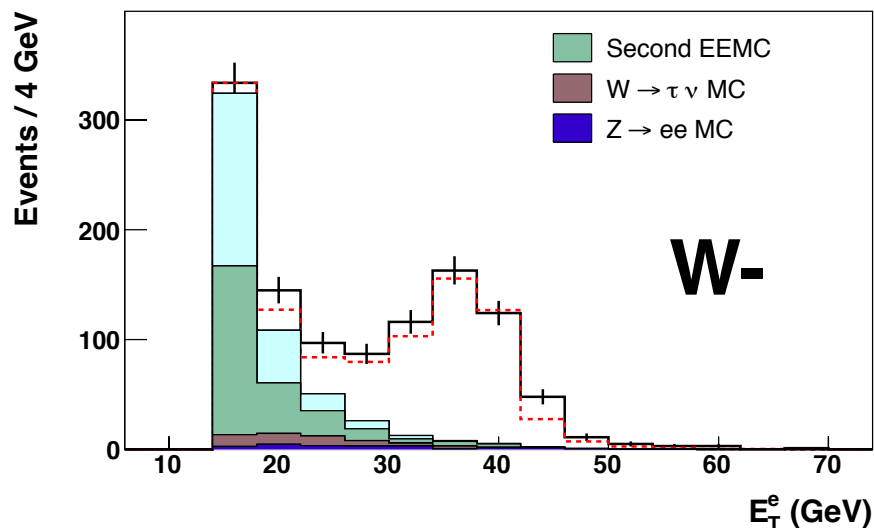|	L (pb⁻¹)
Run 9	13
Run 12	72

Current L Run 13 (Mid-rapidity W trigger BHT3): ~ 100pb⁻¹

Goal for Run 13: ~165pb⁻¹

Recent results - Z/γ* production

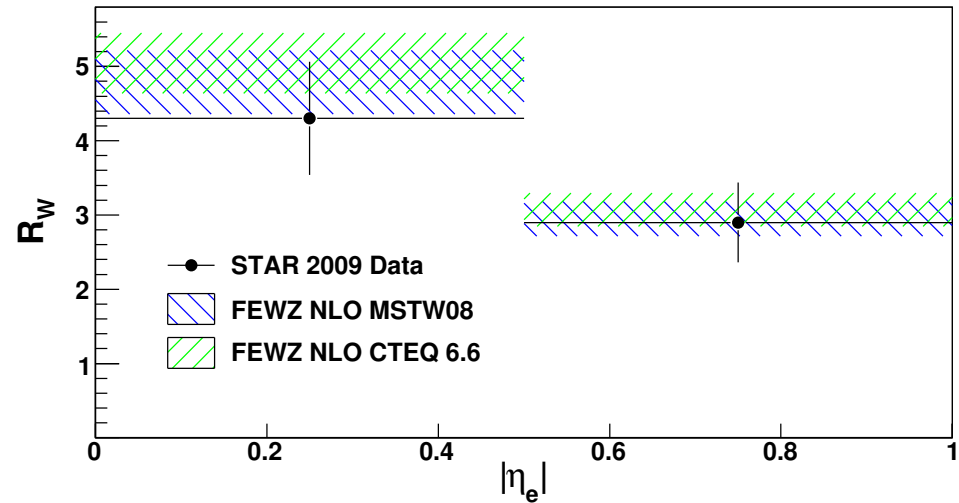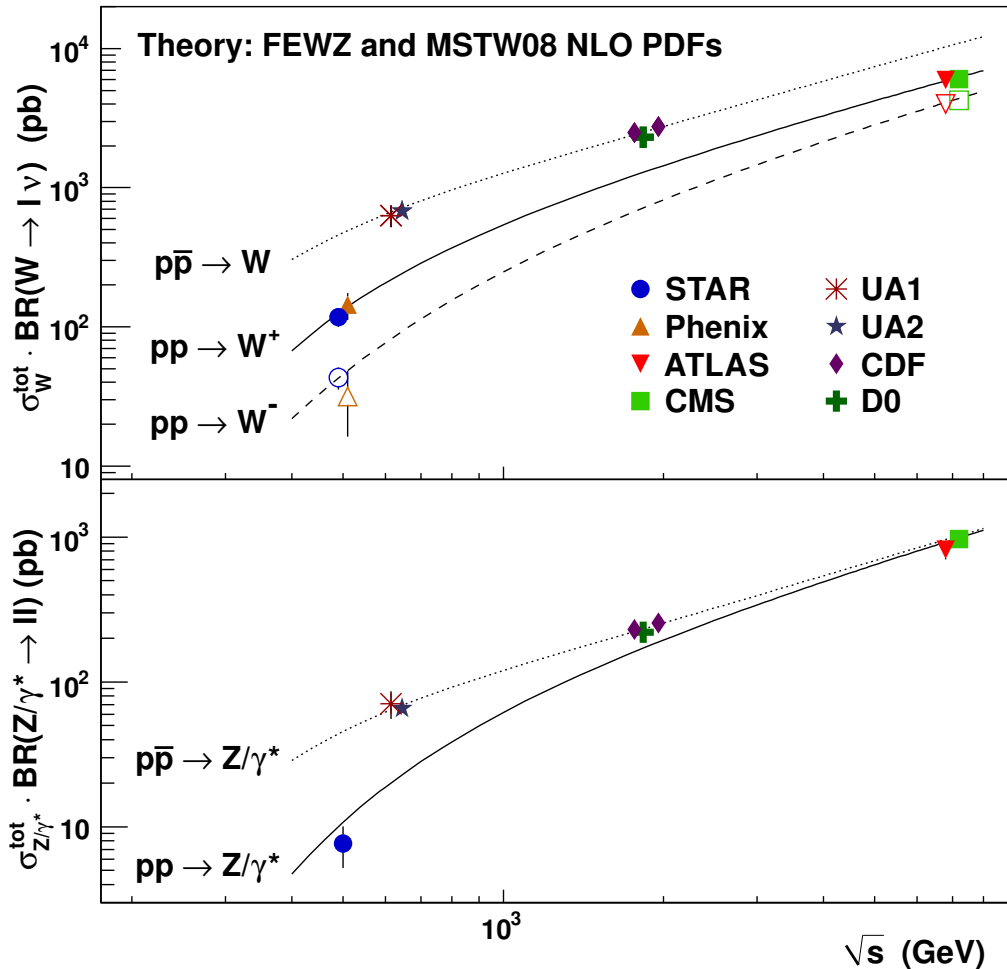- STAR Z / γ* results

$Z \to e^+e^-$ Candidate
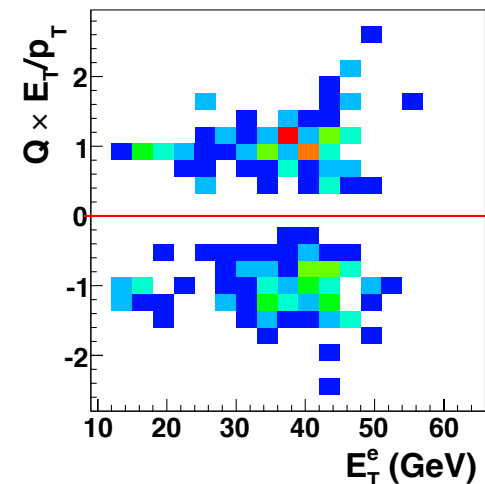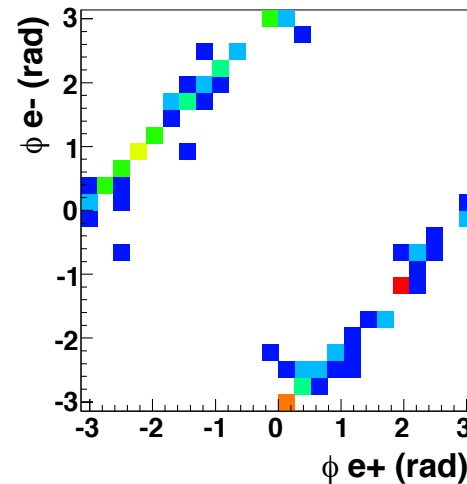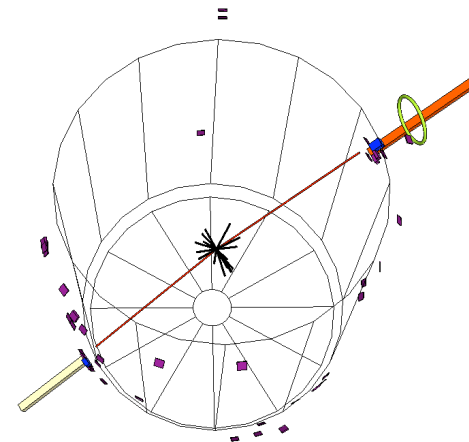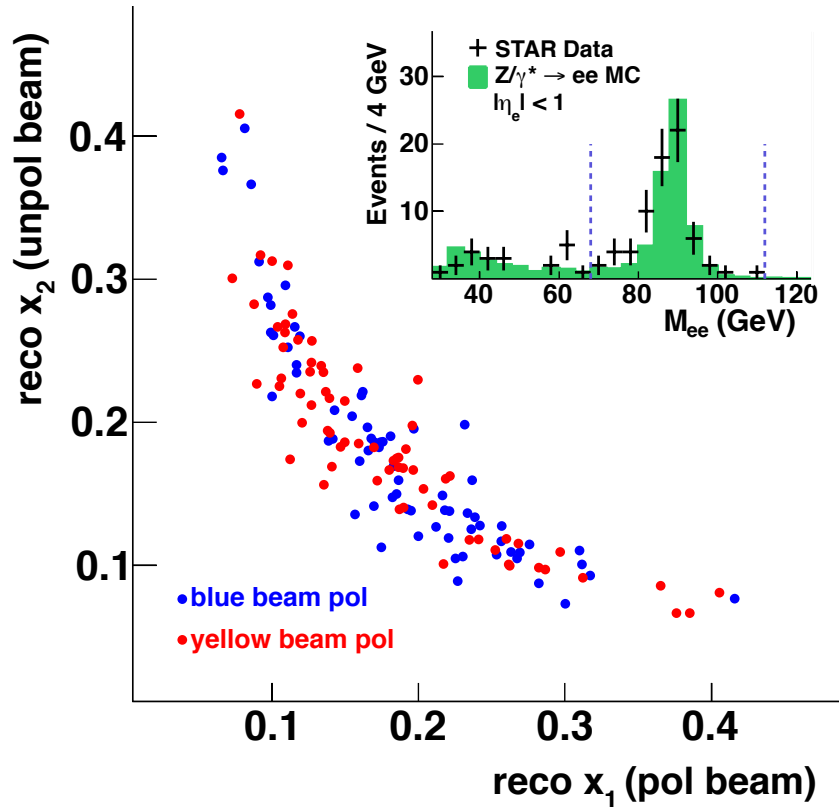
Reconstruct initial state kinematics at leading order:

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

Recent results - W/Z production

□ STAR W$^{+/-}$ and Z / γ* cross-section results

Theory: FEWZ and MSTW08 NLO PDFs

$\sigma_W^{tot} \cdot BR(W \to l\nu)$ (pb)

$p\bar{p} \to W$

$pp \to W^+$

$pp \to W^-$

STAR   UA1
Phenix   UA2
ATLAS   CDF
CMS   D0

$\sigma_{Z/\gamma^*}^{tot} \cdot BR(Z/\gamma^* \to ll)$ (pb)

$p\bar{p} \to Z/\gamma^*$

$pp \to Z/\gamma^*$

$\sqrt{s}$ (GeV)

R_W

STAR 2009 Data
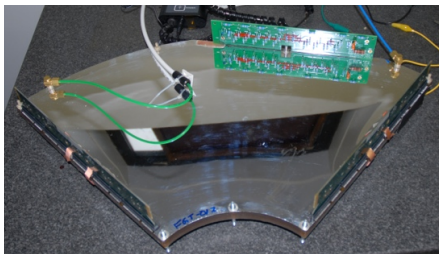FEWZ NLO MSTW08
FEWZ NLO CTEQ 6.6

$|\eta_e|$

$$R(x_F) \equiv \frac{\sigma_{W^+}}{\sigma_{W^-}} = \frac{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}{\bar{u}(x_1)d(x_2) + d(x_1)\bar{u}(x_2)}$$
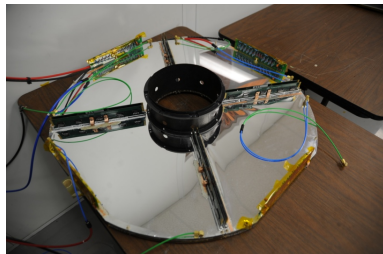
LO decomposition
of
cross-section ratio R(x$_F$)

Future prospects - W production / STAR
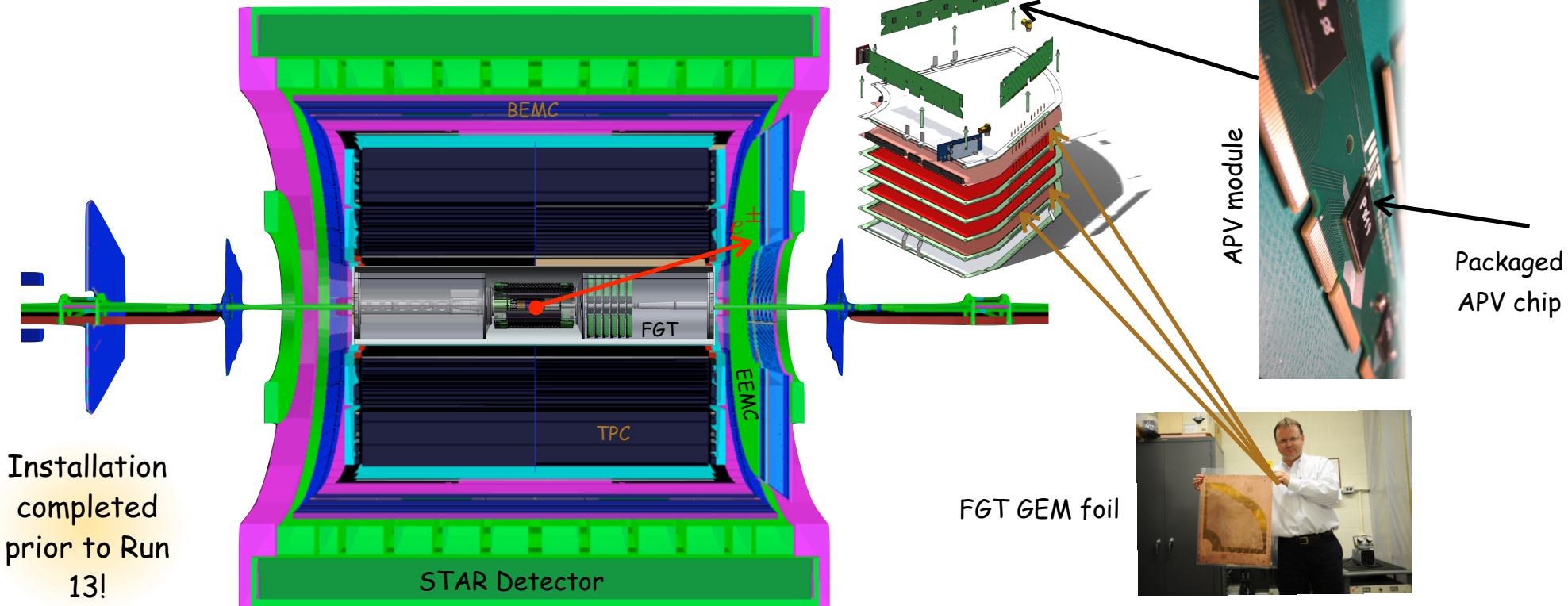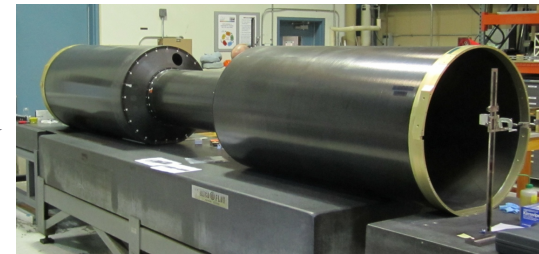
- STAR Forward GEM Tracker - Layout

Quarter section

Disk

Quarter section

BEMC

EEMC

FGT

TPC

STAR Detector

Installation completed prior to Run 13!

APV module

Packaged APV chip

FGT GEM foil

Summary / Outlook

☐ W boson program

- ○ Mid-rapidity: First proof-of-principle measurement of R_W in Run 9

- ○ Critical: Measurement of W^+ and W^- R_W and charge asynnetry as a function η_e

- ○ Backward/Forward rapidity: Upgrade of STAR FGT (Forward GEM Tracker)

- ○ Potential to provide additional constrain from RHIC program for unpolarized quark distributions for $0.05 < x < 0.5$

☐ 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