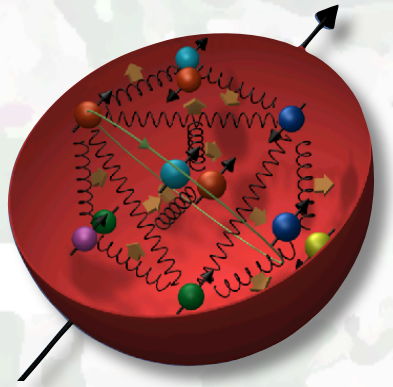
Recent results and future perspective of the high-energy spin physics program at RHIC at BNL

Bernd Surrow

Massachusetts Institute of Technology

(On behalf of the STAR Collaboration)



Outline

- Recent Jet and Hadron Production Results:

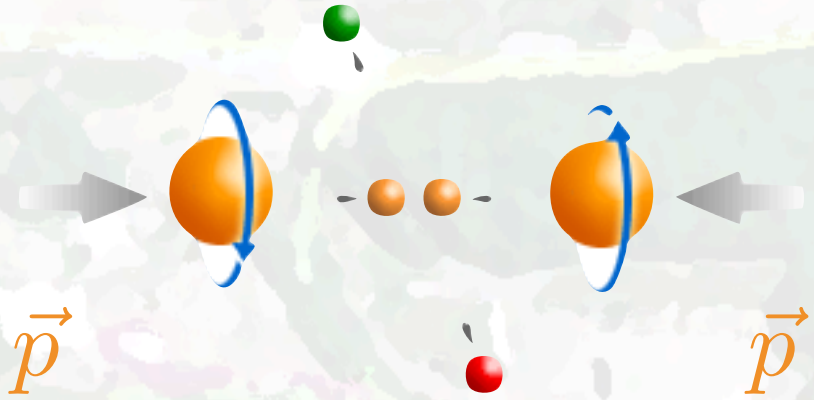
  ⇒ Gluon Polarization

- Recent W production results:

  ⇒ Quark / Anti-Quark Polarization

- Experimental aspects: RHIC / STAR

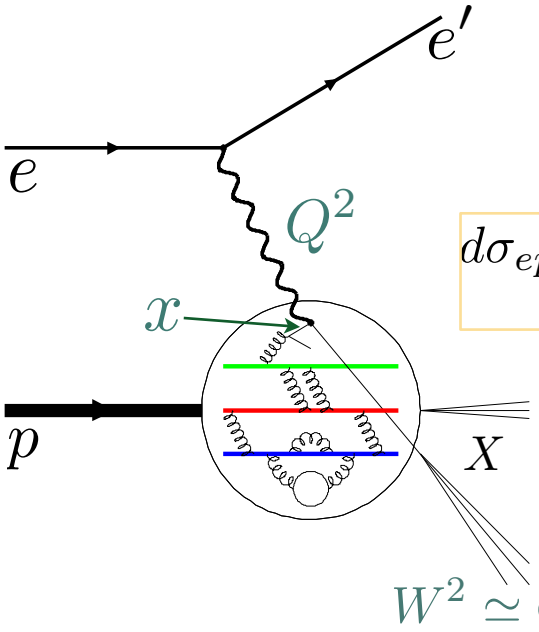
- Theoretical foundation



- Summary and Outlook

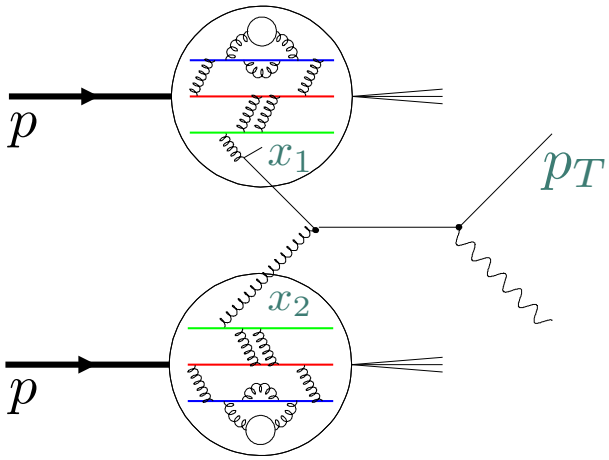
Theoretical foundation

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



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

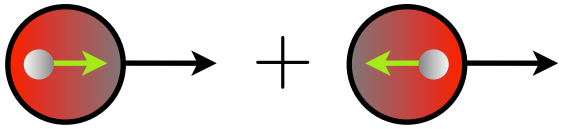
Universality



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

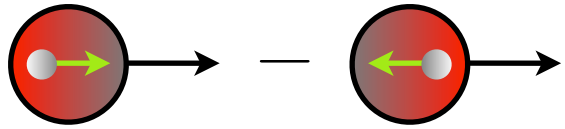
Momentum contribution

$$f(x) =$$



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

$$\Delta f(x) =$$



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

Spin contribution

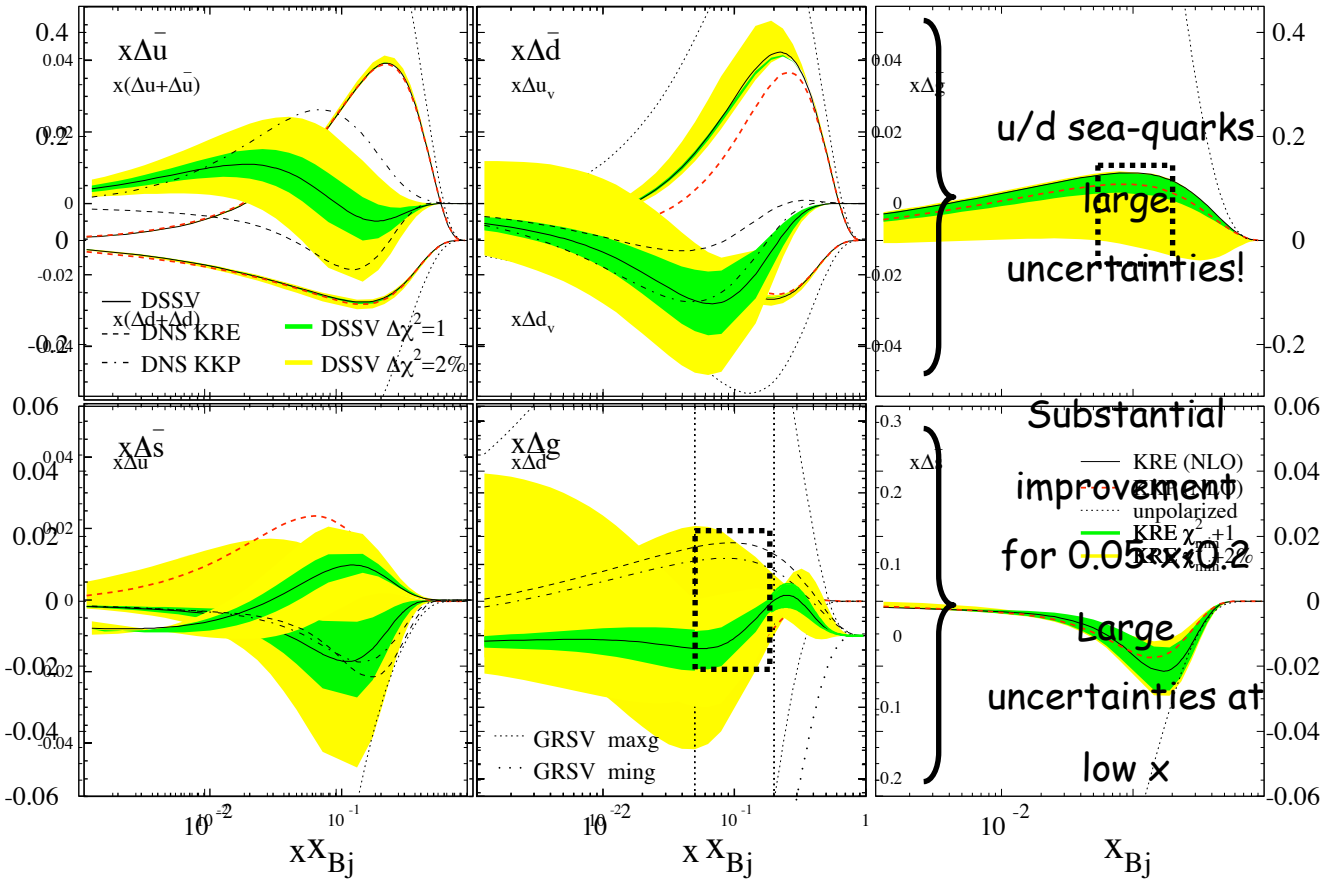
Theoretical foundation

- What do we know about the polarized quark and gluon distributions?
  - Spin carried by quarks is very small ($\Delta\Sigma \sim 0.3$)!

$$\underbrace{\frac{1}{2}\Delta\Sigma}$$

$$\frac{1}{2} = \langle S_q \rangle + \underbrace{\langle S_g \rangle + \langle L_q \rangle + \langle L_g \rangle}_{\Delta G}$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$



D. de Florian et al., Phys. Rev. D 71, 094018 (2005).

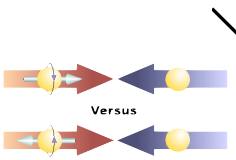
$$\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x, Q^2)dx$$

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx$$

Theoretical foundation

Quark / Anti-Quark Polarization - W production

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



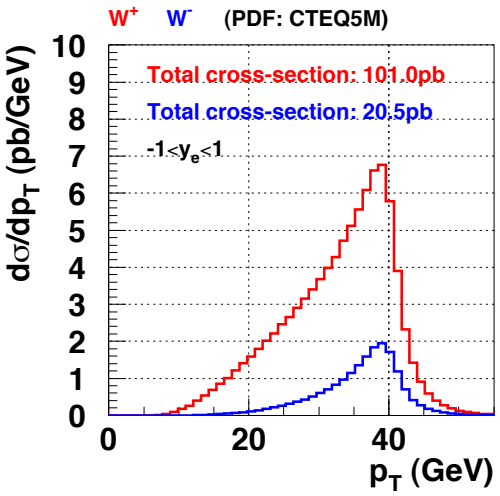
$$W^- \rightarrow e^- + \bar{\nu}_e$$

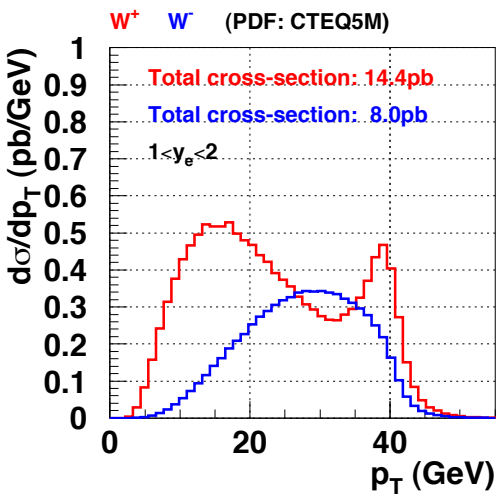
$$W^{\mp}$$

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

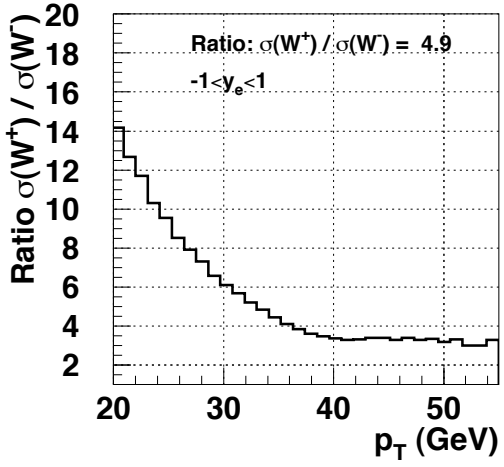
$$W^+ \rightarrow e^+ + \nu_e$$

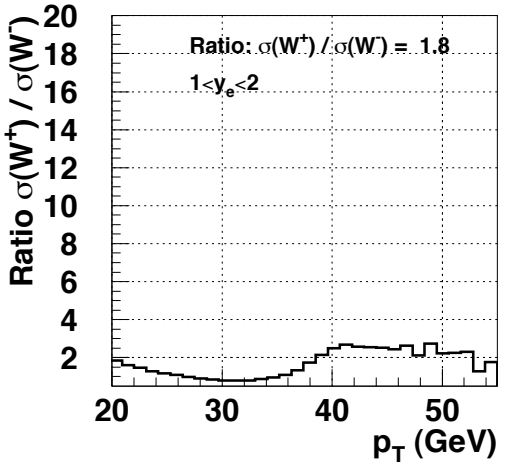
$$\Delta \bar{d} + u \rightarrow W^+$$
$$\Delta u + \bar{d} \rightarrow W^+$$





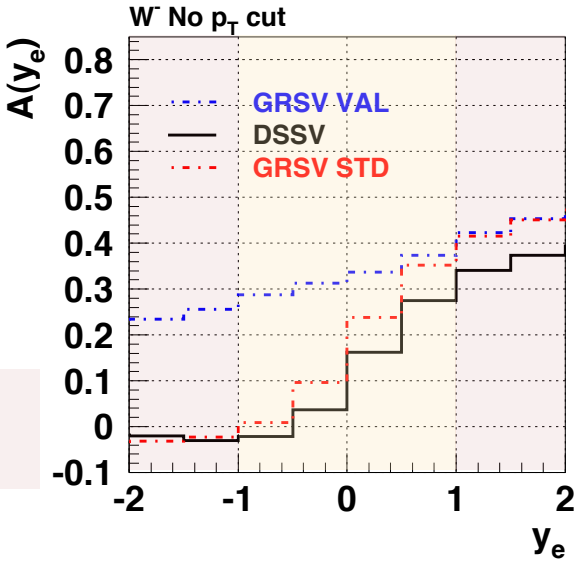
- Key signature: High p_T lepton (e^-/e^+ or μ^-/μ^+) (Max. $M_W/2$) - Selection of W^-/W^+ : Charge sign discrimination of high p_T lepton
- Required: Lepton/Hadron discrimination



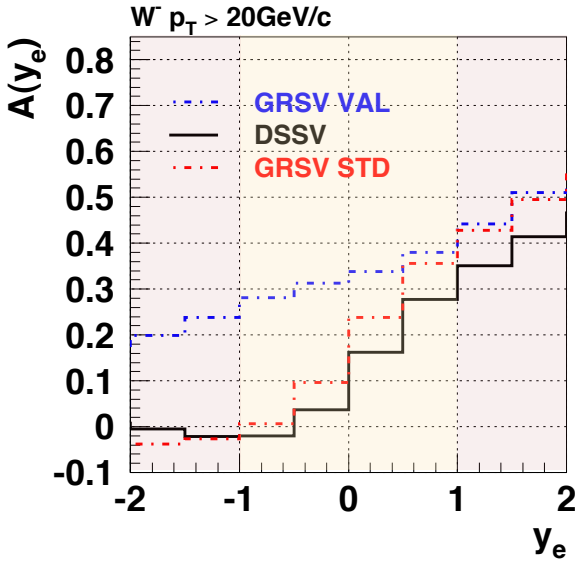


Theoretical foundation

- A_L: STAR mid-rapidity and forward rapidity (RHICBOS SImulations $\sqrt{s}$=500GeV)



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

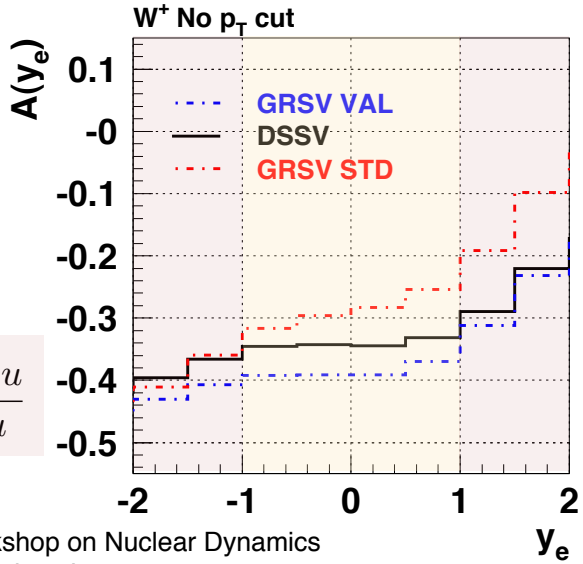


$$A_L^{W^-} = \frac{\Delta \bar{u}}{\bar{u}}$$

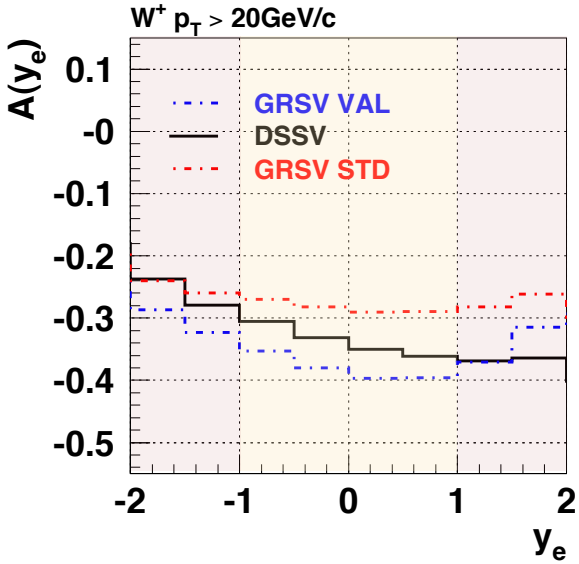
$$A_L^{W^-} = \frac{1}{2}\left(\frac{\Delta \bar{u}}{\bar{u}} - \frac{\Delta d}{d}\right)$$

$$x_1 = x_2$$

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



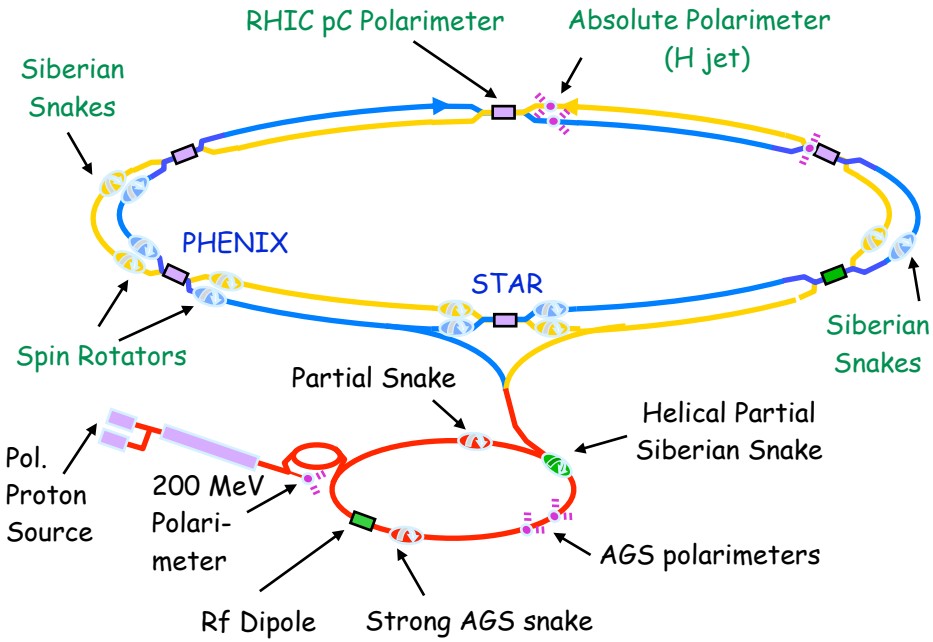
$$A_L^{W^+} = \frac{\Delta \bar{d}}{\bar{d}}$$



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

Collider: The First polarized p+p collider at BNL

Performance



RHIC RUN	s [GeV]	$L_{recorded}$ [pb^{-1}] (trans.)	$L_{recorded}$ [pb^{-1}] (long.)	Polarization [%]
RUN 2	200	0.15	0.3	15
RUN 3	200	0.25	0.3	30
RUN 4	200	0	0.4	40-45
RUN 5	200	0.4	3.1	45-50
RUN 6	200	3.4/6.8	8.5	60
RUN 8	200	7.8	-	45
RUN 9	200 / 500	-	25 / 10	55 / 35

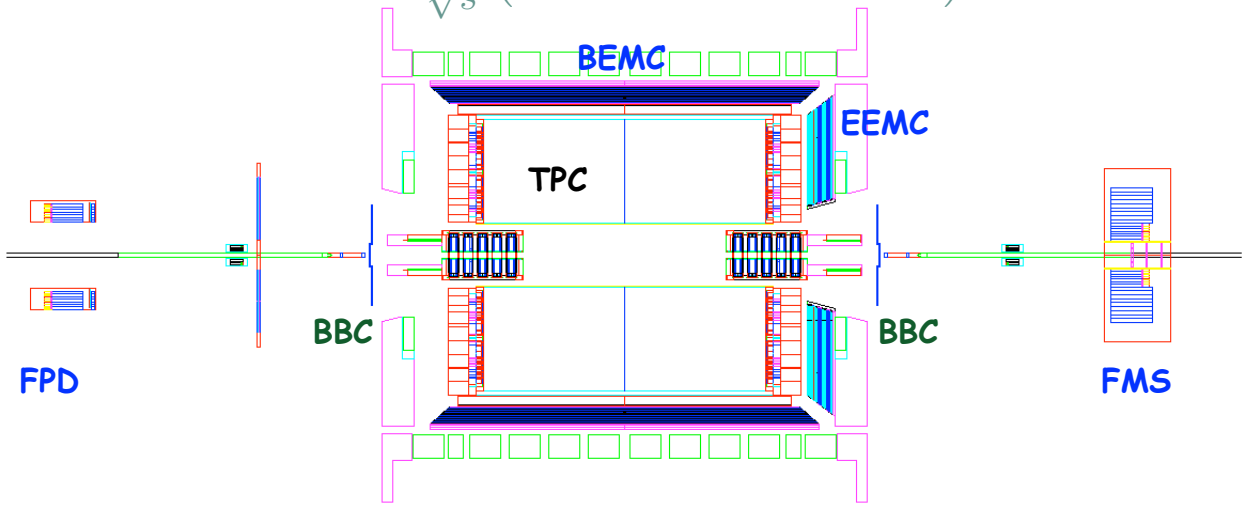
- Long 200GeV production runs at 200GeV (long. polarization): Run 6 / Run 9
- First collisions of polarized proton beams at 500GeV (long. polarization): Run 9

The STAR Experiment

Overview

- Wide rapidity coverage of **STAR calorimetry (Jets /Neutral Pions / Photons) system:**
  - FPD: -4.1 < η < 3.3
  - BEMC: -1.0 < η < 1.0
  - EEMC: 1.09 < η < 2.0
  - FMS: 2.5 < η < 4.0

$$x_{1\,(2)} = \frac{1}{\sqrt{s}}\left(p_{T_3}e^{\eta_3(-\eta_3)} + p_{T_4}e^{\eta_4(-\eta_4)}\right)$$

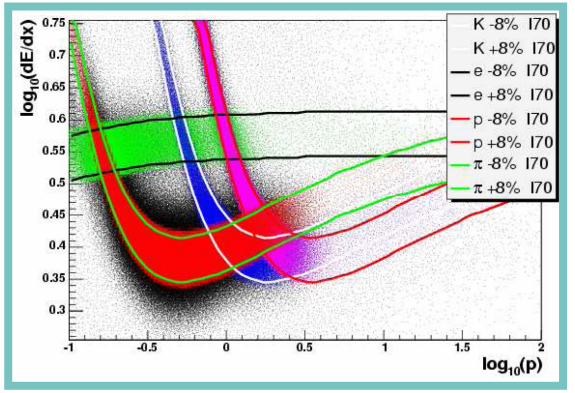


- **ZDC:** Relative luminosity
- **BBC:** Relative luminosity and Minimum bias trigger

Key elements for STAR Δg(x) program:

- Higher precision on Δg(x) : Luminosity / DAQ upgrade (DAQ 1000)
- Sensitivity to shape of Δg(x): Correlation measurements
- Low-x region of Δg(x): 500GeV program / Asymmetric collisions (Forward calorimetry)

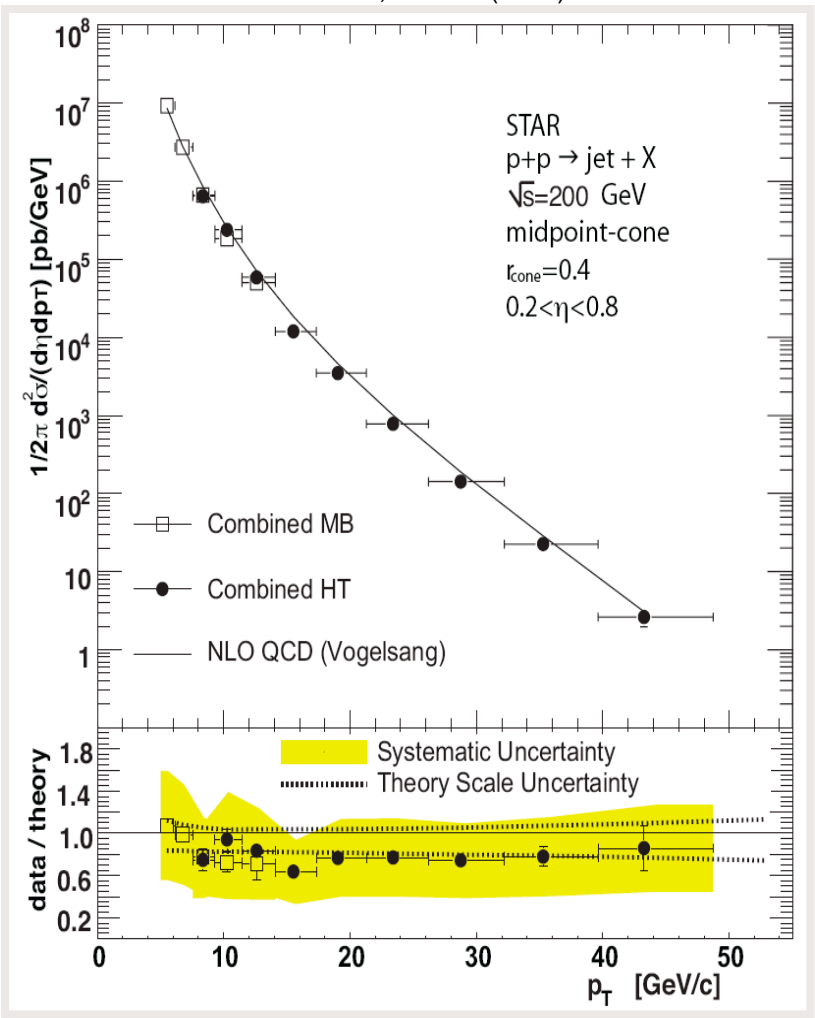
- **TPC:** Tracking and PID using dE/dx for |η| < 1.3 and p_T < 15 GeV/c



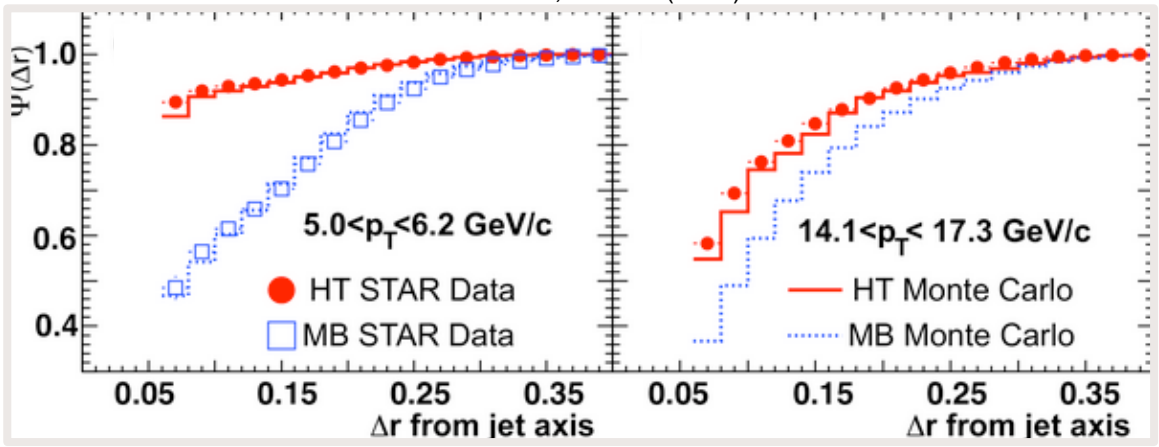
Recent results: Jet production

- STAR Run 3/4 Cross-section result: Mid-rapidity inclusive jet production

STAR Collaboration, PRL 99 (2007) 142003.



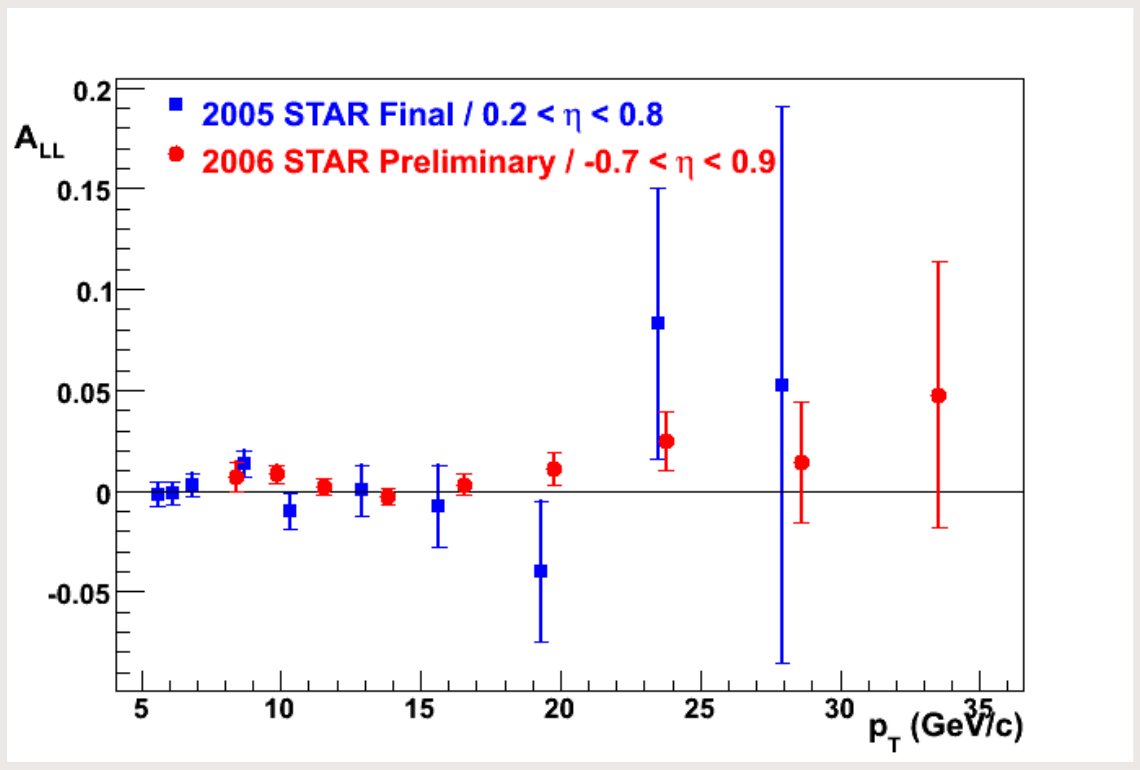
STAR Collaboration, PRL 99 (2007) 142003.



- Inclusive Jet production - Well understood in comparison to Full PYHTIA-based MC simulations
- Good agreement between data and NLO pQCD calculations at mid-rapidity

Recent results: Jet production

- STAR Run 5 / 6 A_{LL} result: Mid-rapidity inclusive jet production



A_{LL} systematics	(x 10^{-3})
Reconstruction + Trigger Bias	[-1,+3] (p_T dep)
Non-longitudinal Polarization	~ 0.03 (p_T dep)
Relative Luminosity	0.94
Backgrounds	1^{st} bin ~ 0.5 else ~ 0.1

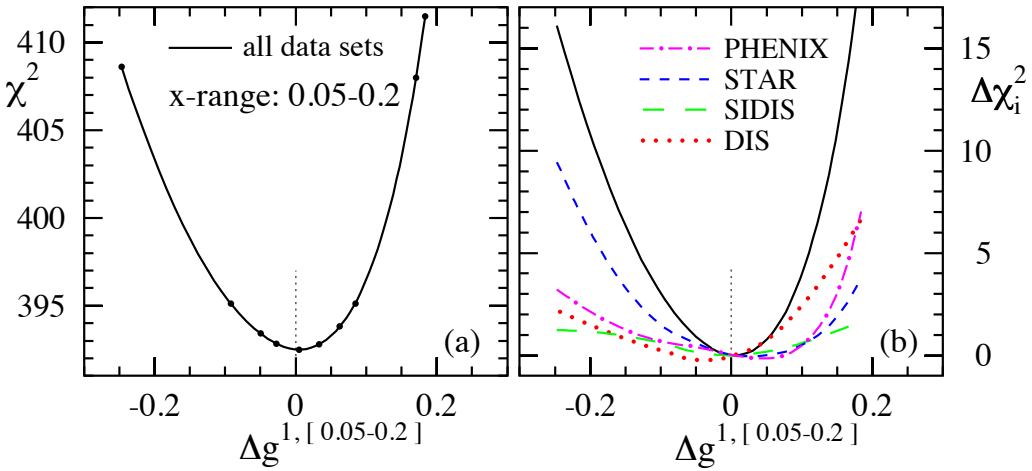
p_T systematic	± 6.7%

STAR Collaboration, PRL 100 (2008) 232003.

- RUN 6 results: GRSV-MAX / GRSV-MIN ruled out - A_{LL} result favor a gluon polarization in the measured x-region which falls in-between GRSV-STD and GRSV-ZERO
- Consistent with RUN 5 result (Factor 3-4 improved statistical precision for p_T>13GeV/c)

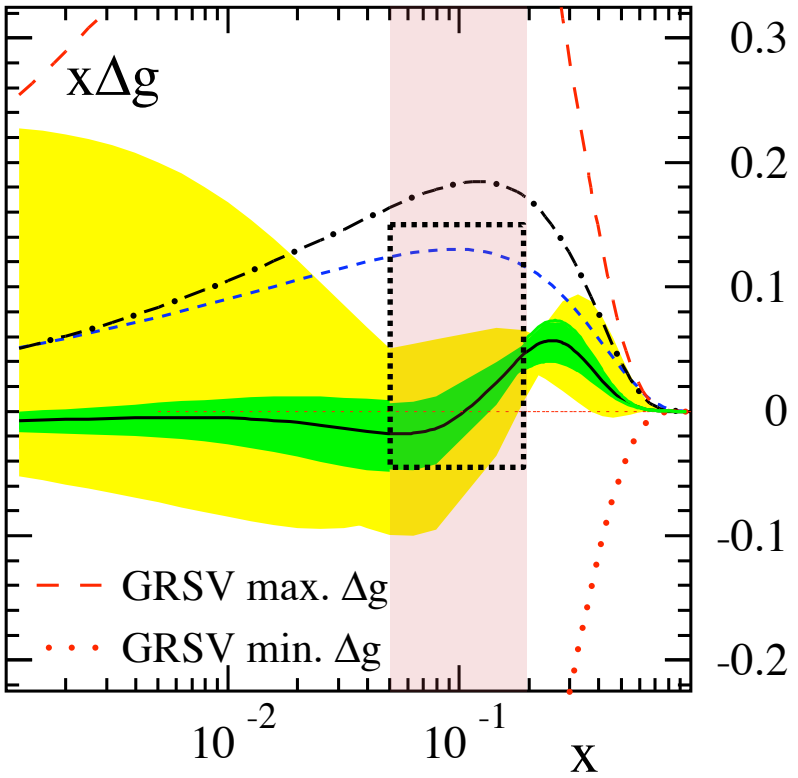
Recent results: Global analysis

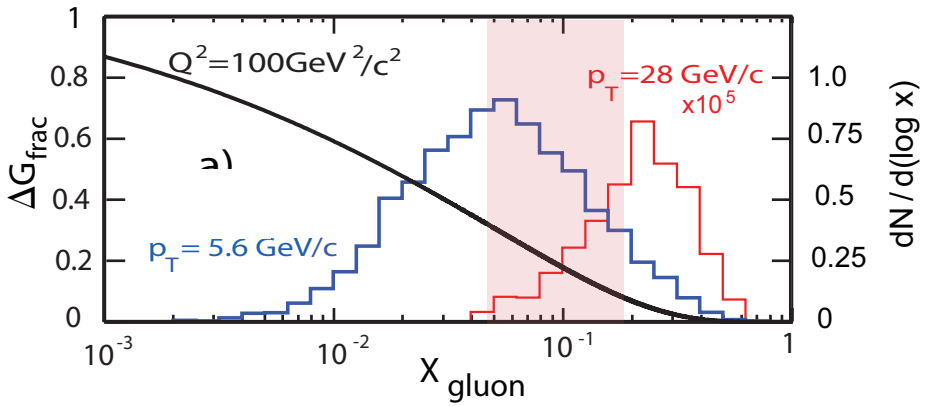
- Global analysis incl. RHIC pp data



- Strong constraint on the size of Δg from RHIC data for 0.05<x<0.2
- Evidence for a small gluon polarization over a limited region of momentum fraction
- Important: Mapping of x-dependence and extension of x-coverage needed!

D. de Florian et al. PRL 101 (2008) 072001.

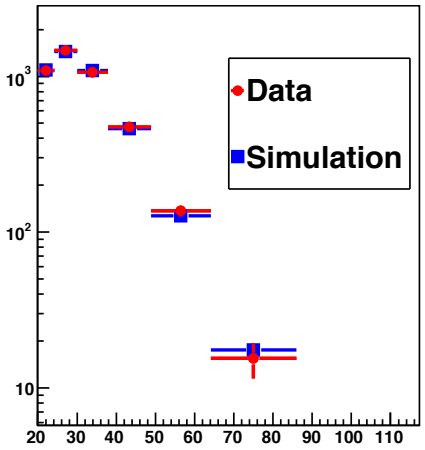


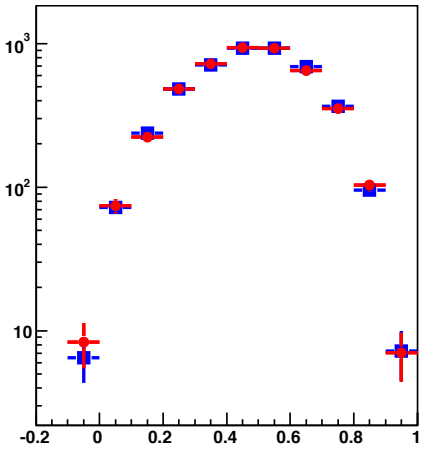


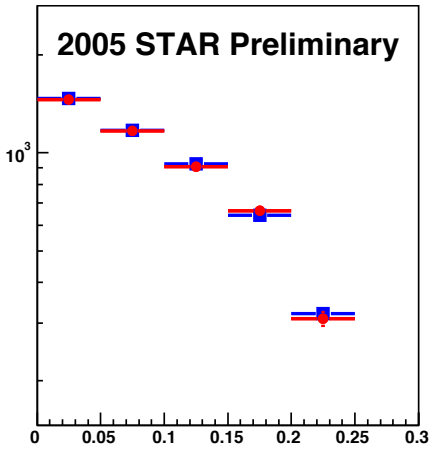
STAR Collaboration, PRL 100 (2008) 232003.

Results: Di-Jet measurements

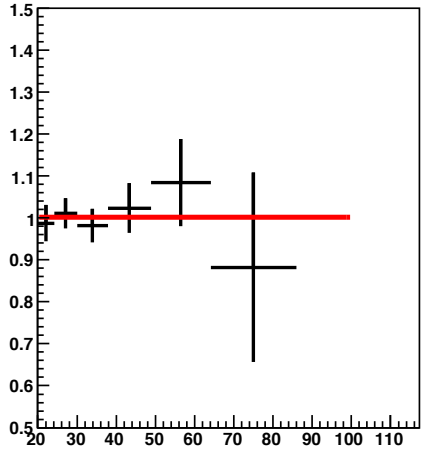
Correlation measurements: Di-Jet production - Data Understanding - Run 5

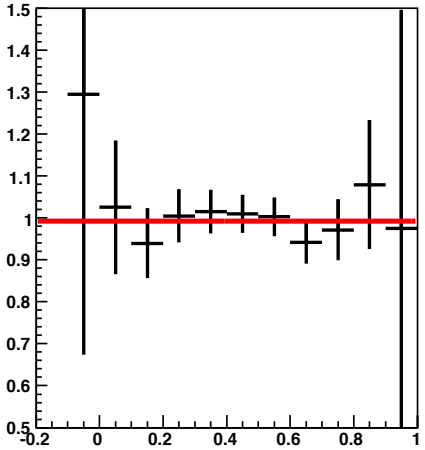


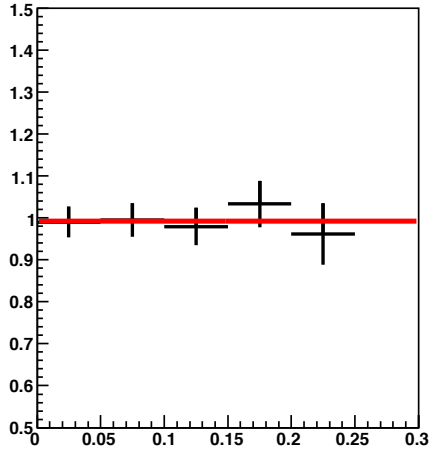




$\sqrt{s} = 200$ GeV $\quad \min(p_T) \geq 7.0$ GeV/c, $\max(p_T) \geq 10.0$ GeV/c $\quad -0.05 \leq \eta \leq 0.95 \quad |\Delta\eta| < 0.5 \quad |\Delta\varphi| > 2$







$$M = \sqrt{x_1 x_2 s}$$

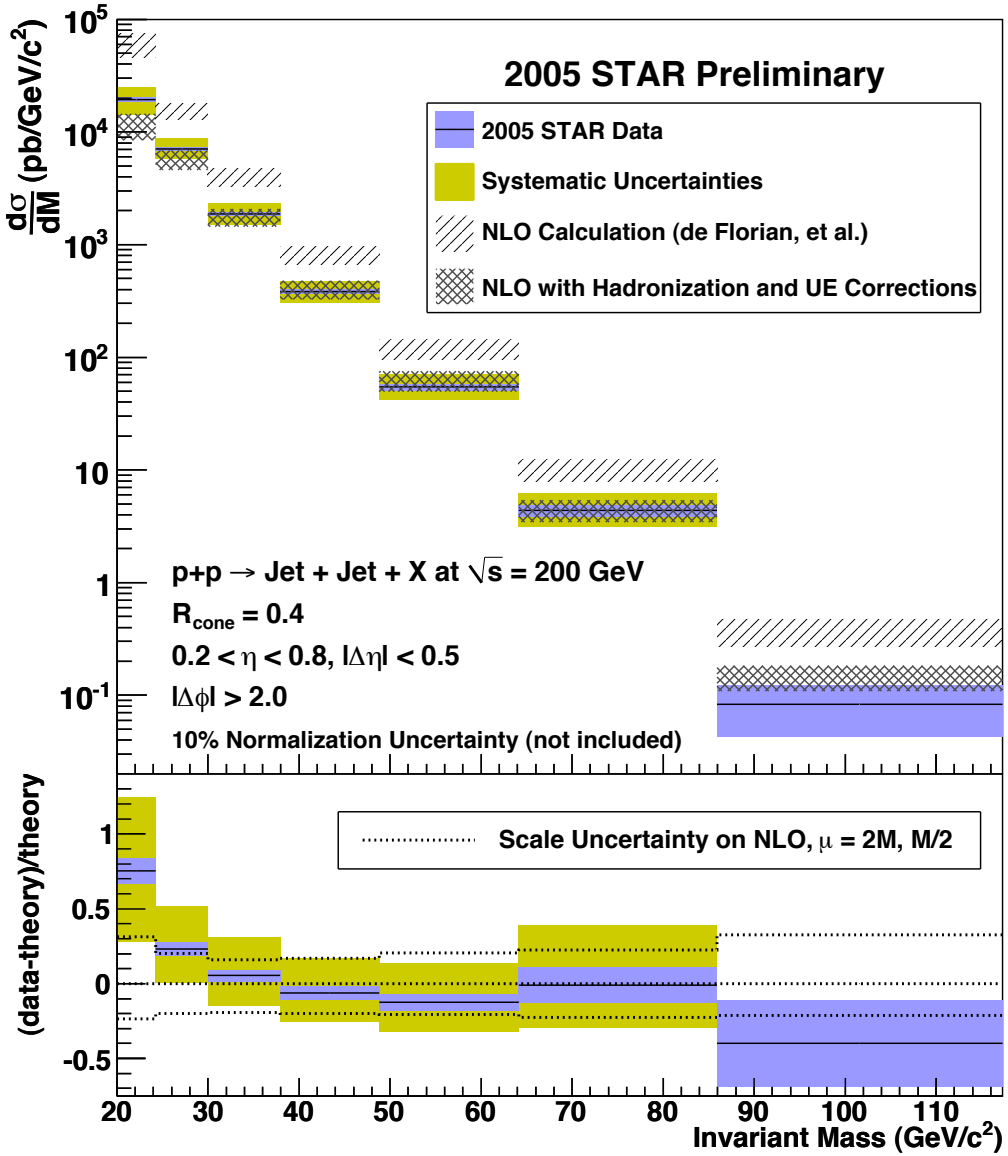
$$\eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

$$\cos\theta^* = \tanh\left(\frac{\eta_3 - \eta_4}{2}\right)$$

- Di-Jet distributions with asymmetric p_T cuts more appropriate for NLO comparison
- Very good agreement between data and PYTHIA MC simulations incl. detector effects

Results: Di-Jet measurements

- First di-jet cross-section measurements
  - Unpolarized differential cross-section vs. invariant mass M above 20GeV/c2
  - NLO theory predictions by D. deFlorian et al. using MRST2004 pdf-set with (▨) and without (▨) Hadronization / UE Corrections over data inv. mass bins
  - Statistical uncertainties are shown in blue (▬)
  - Energy scale uncertainty is shown in yellow (▬)
  - Comparison to theory together with theory scale uncertainties



Future prospects: Di-Jet measurements

- Run 9 STAR Beam-Use Request (BUR): Di-Jet projections

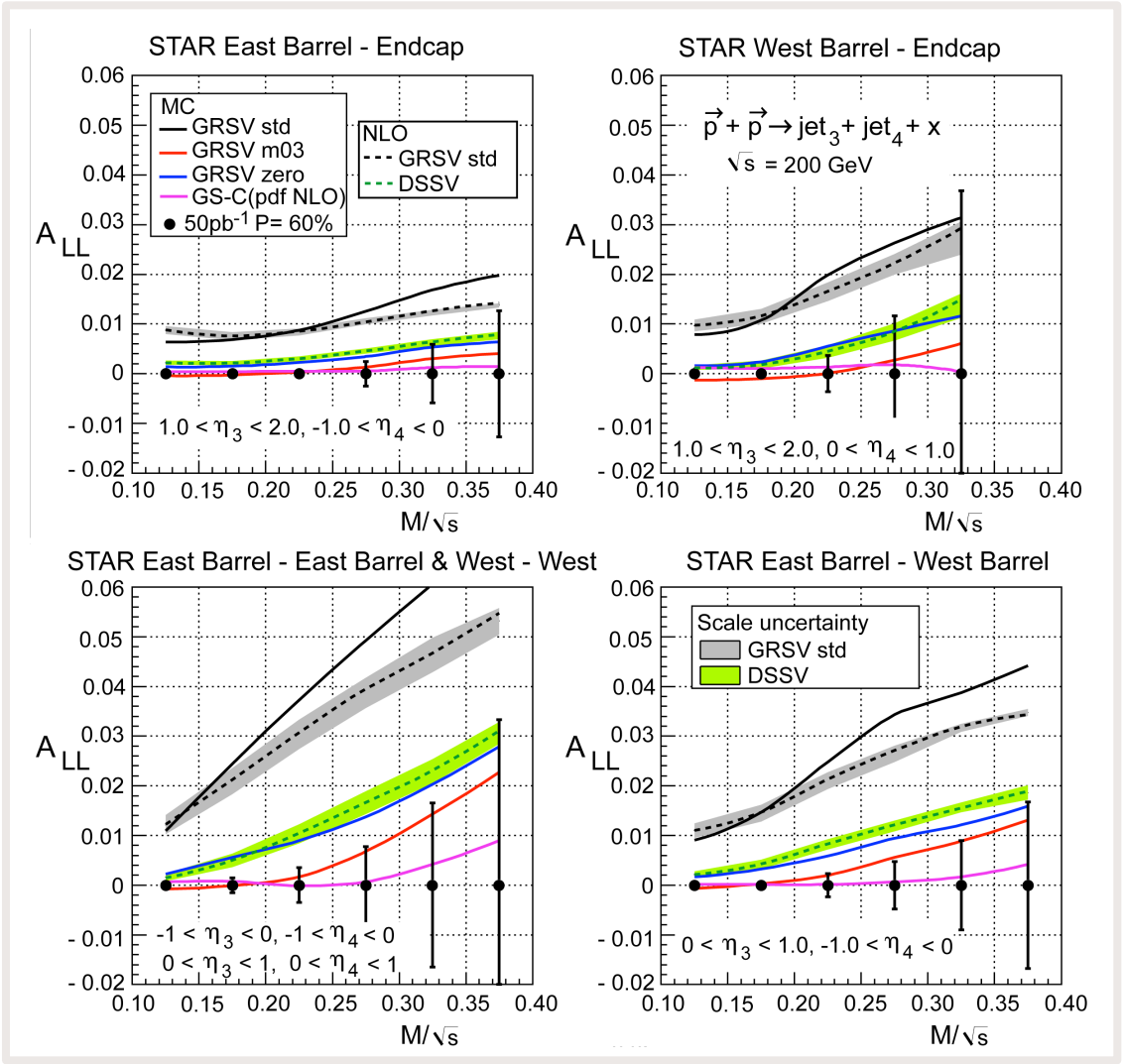
  - Substantial improvement in Run 9 from Di-Jet production: 200GeV

    Run just started: April 21, 2009 - June 28, 2009 (Recorded: 1/3 of Run 9 FOM = $P^4L \sim 6.5 pb^{-1}$)

  - Good agreement between LO MC evaluation and full NLO calculations

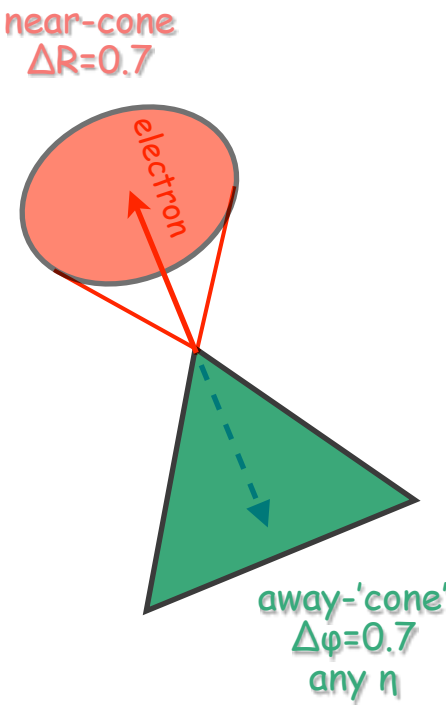
$$M = \sqrt{x_1 x_2 s} \qquad \eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$

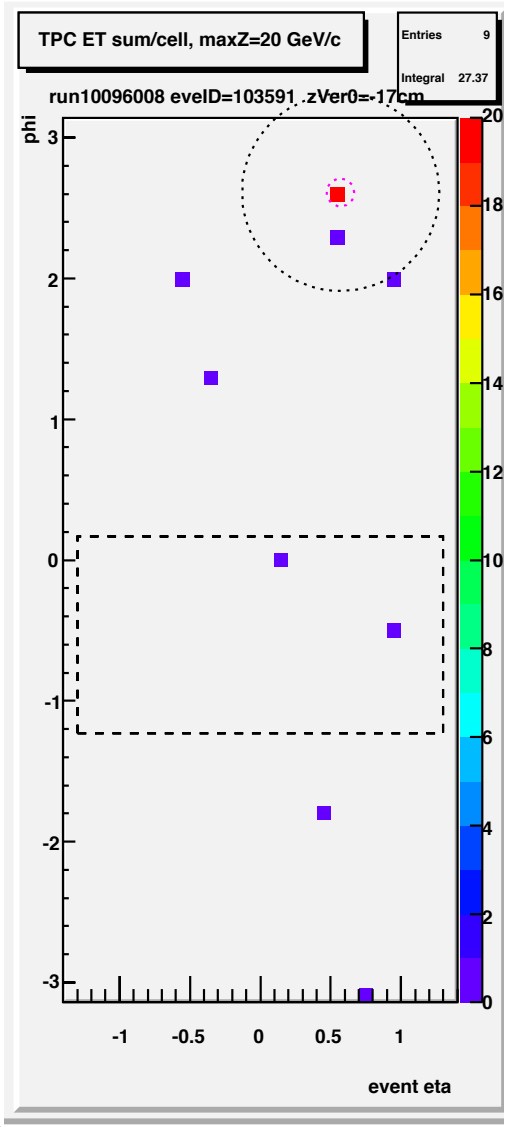
$$x_{1\,(2)} = \frac{1}{\sqrt{s}} \left(p_{T_3} e^{\eta_3(-\eta_3)} + p_{T_4} e^{\eta_4(-\eta_4)} \right)$$



Results: First observation of W production

W reconstruction - Algorithm : Details





General:

- Use BTOW ideal gains and actual peds, status tables
- 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 ΔR=0.7 in eta-phi space
- Require near-cone excess E_T below 12%

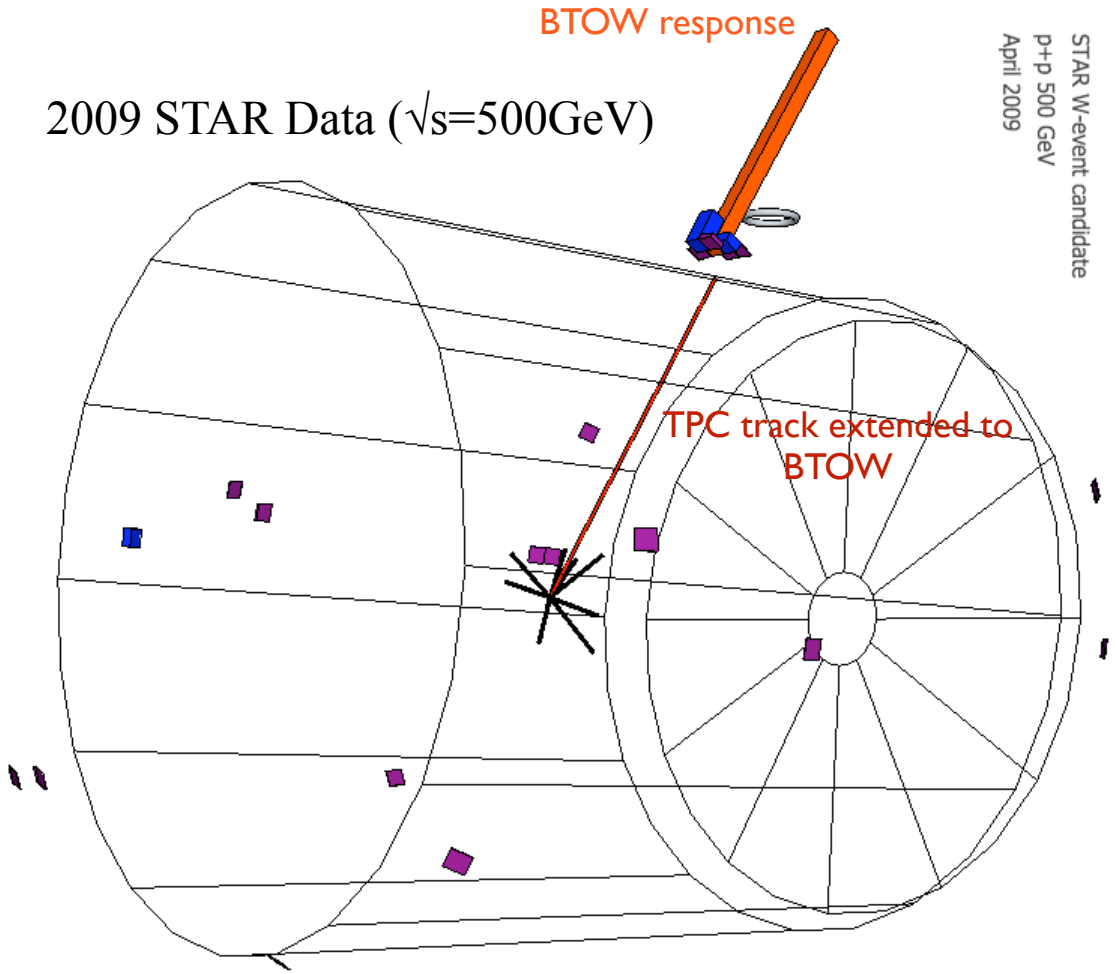
Away-'cone' veto:

- Compute away-'cone' E_T sum of BEMC+TPC over Δphi=0.7 and any eta (it is a rectangle)
- Require away-cone E_T below 8 GeV

Results: First observation of W production

- Event display (W event candidate) and detector signature

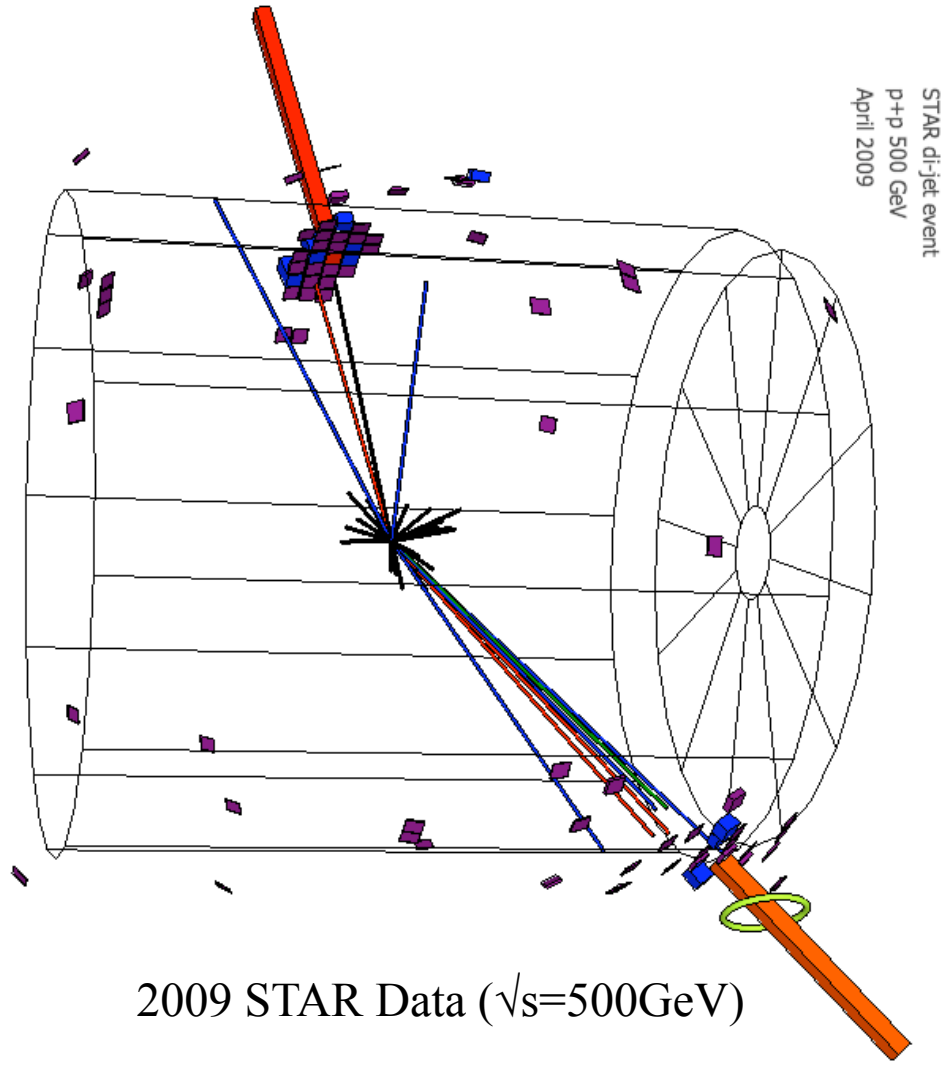
We found ~400 W candidate events!



Results: First observation of W production

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

We recorded and rejected ~1.5M QCD background events!

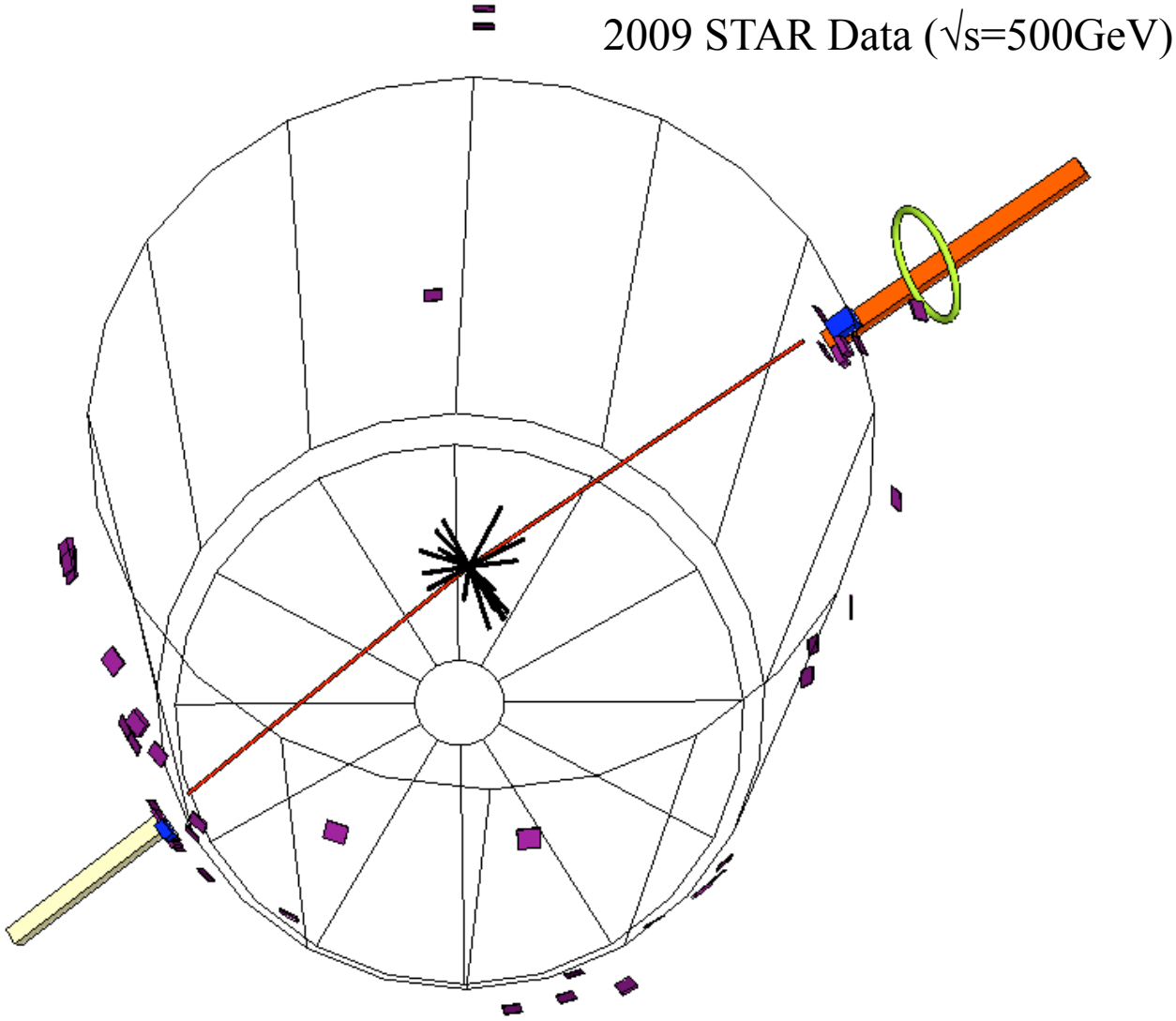


2009 STAR Data ($\sqrt{s}$=500GeV)

Results: First observation of W production

- Event display (Z^0 candidate event) and detector signature

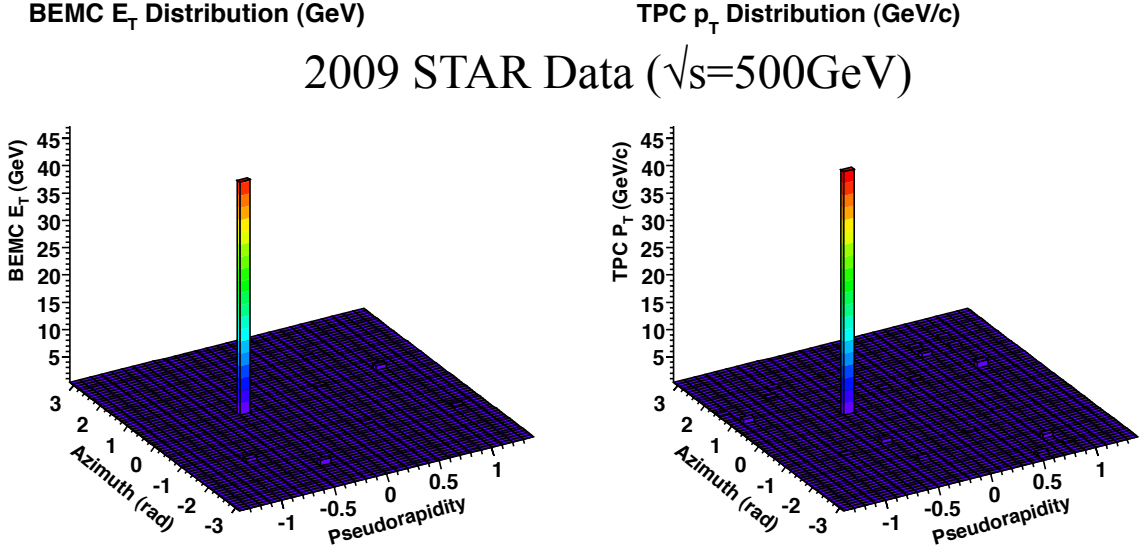
We found a handful of Z^0 candidate events!



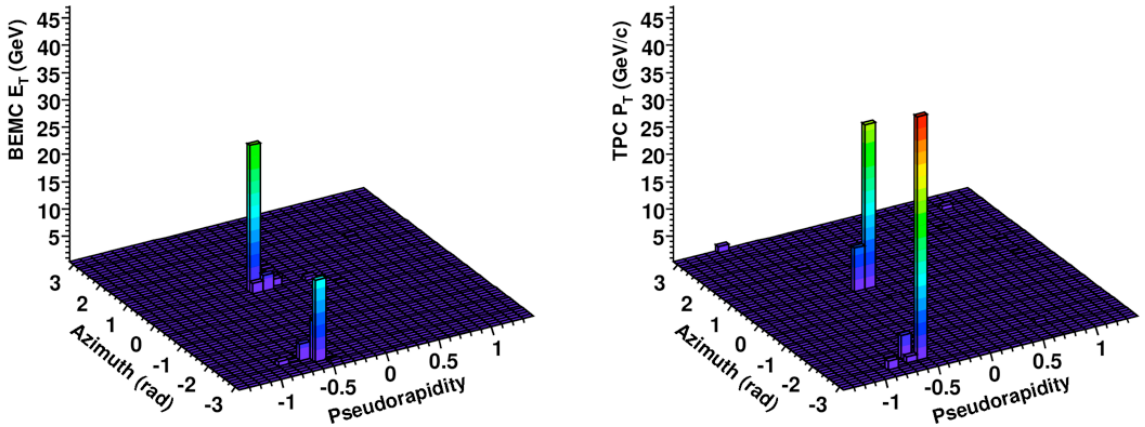
Results: First observation of W production

- Lego plots - BEMC/TPC

W event

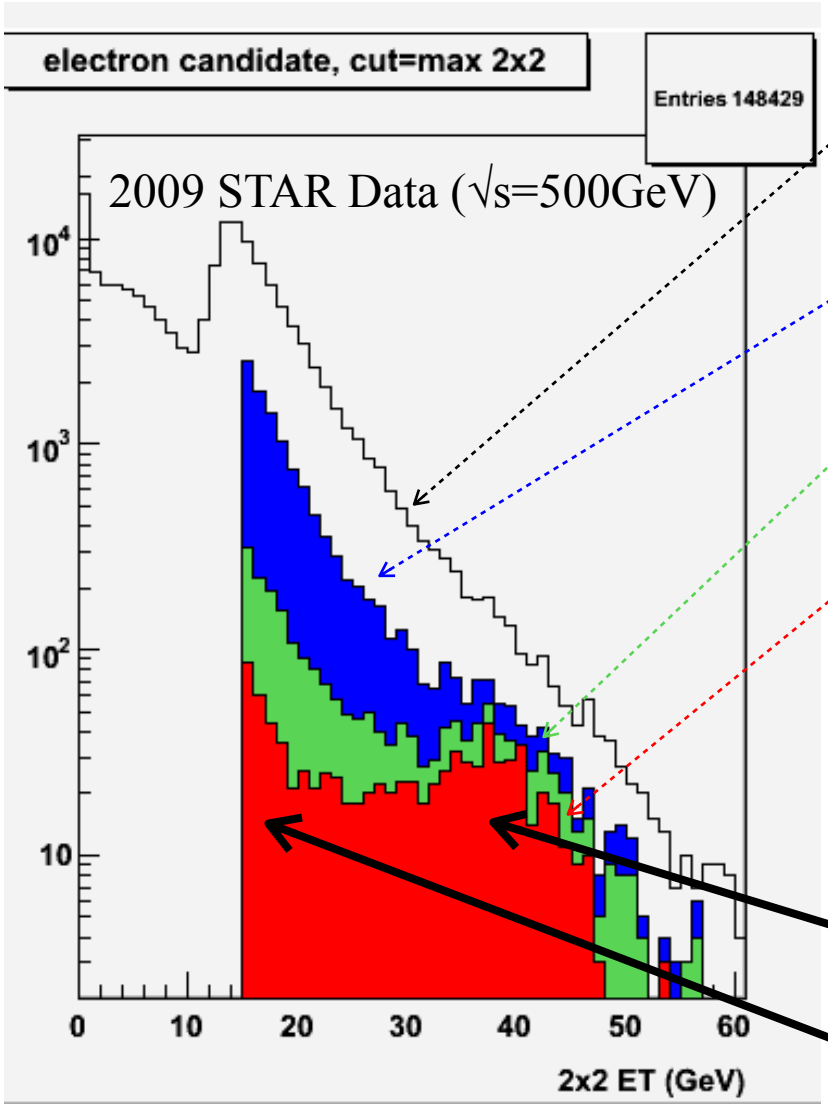


Di-Jet event



Results: First observation of W production

- Evolution of E_T distribution vs. cut ID



Starting raw distribution

Track-cluster match

No near cone E_T

No away cone E_T

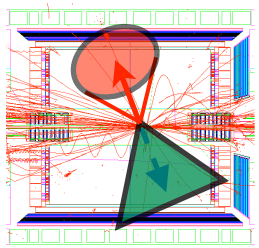
Using the algorithm a clear Jacobian peak can be seen characteristic for W production in contrast to QCD background!

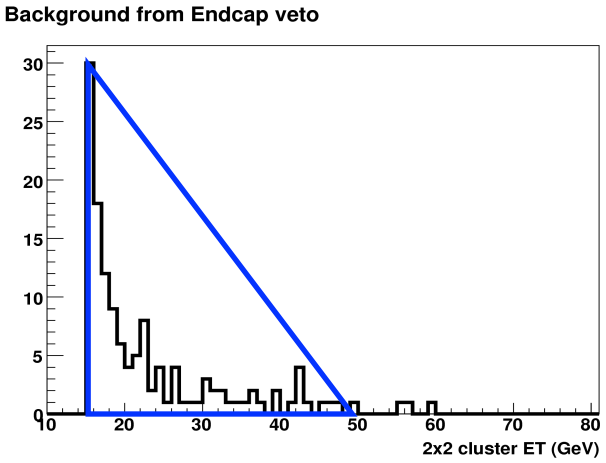
Results: First observation of W production

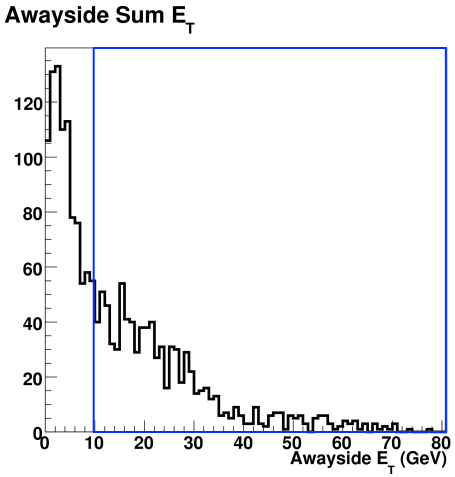
QCD background treatment

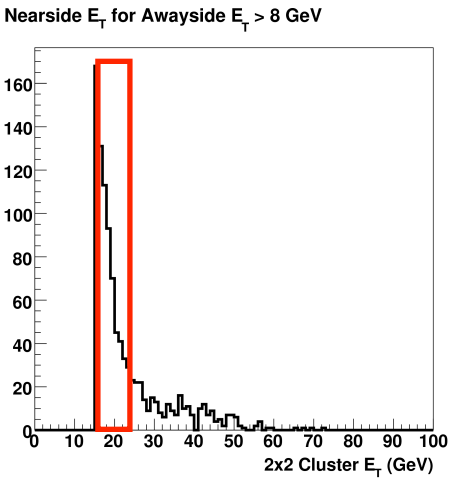
Estimate QCD background in a fully data-driven manner

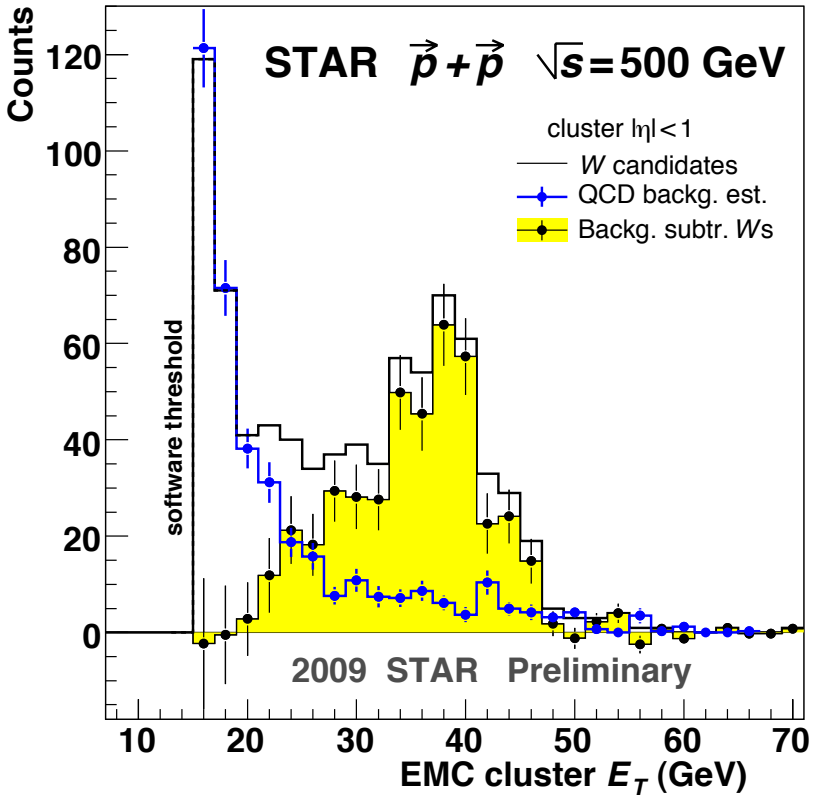
Background from "missing" endcap





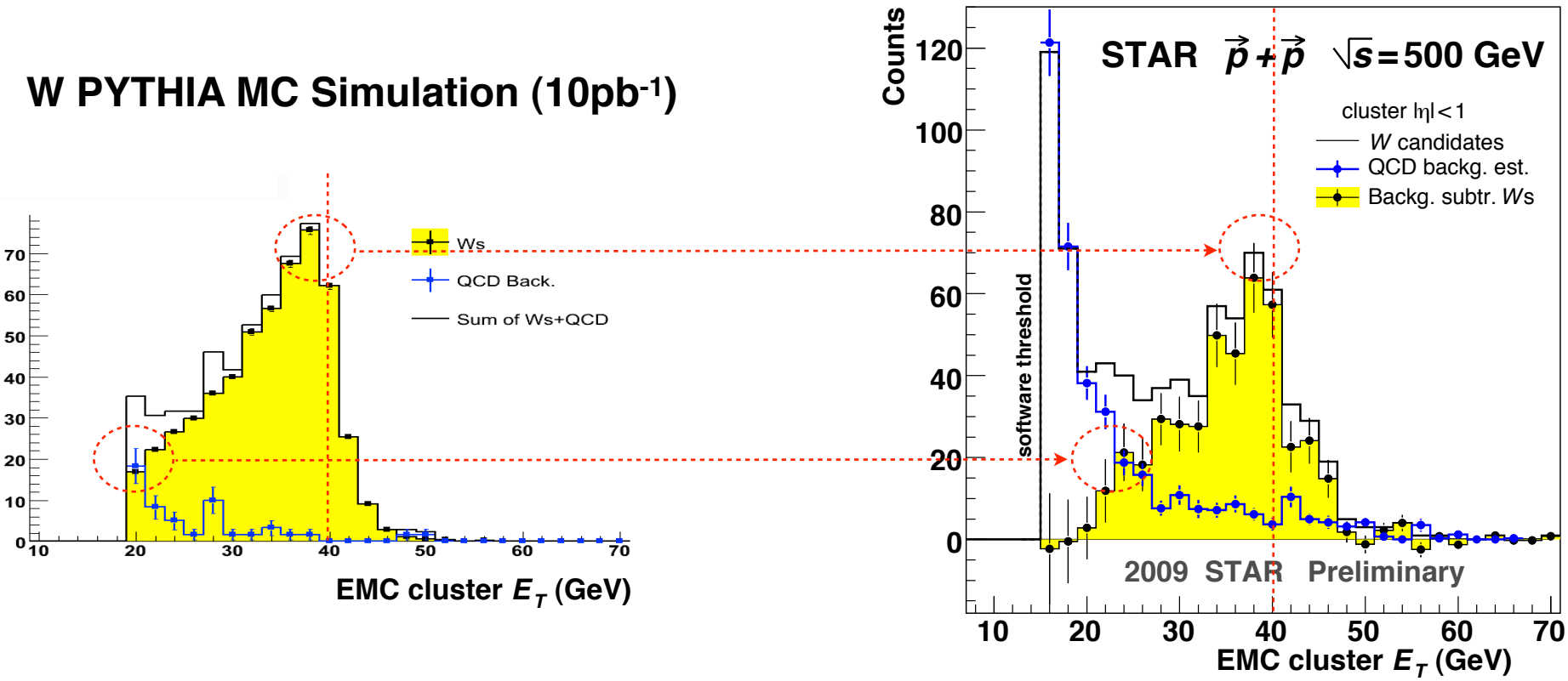






Results: First observation of W production

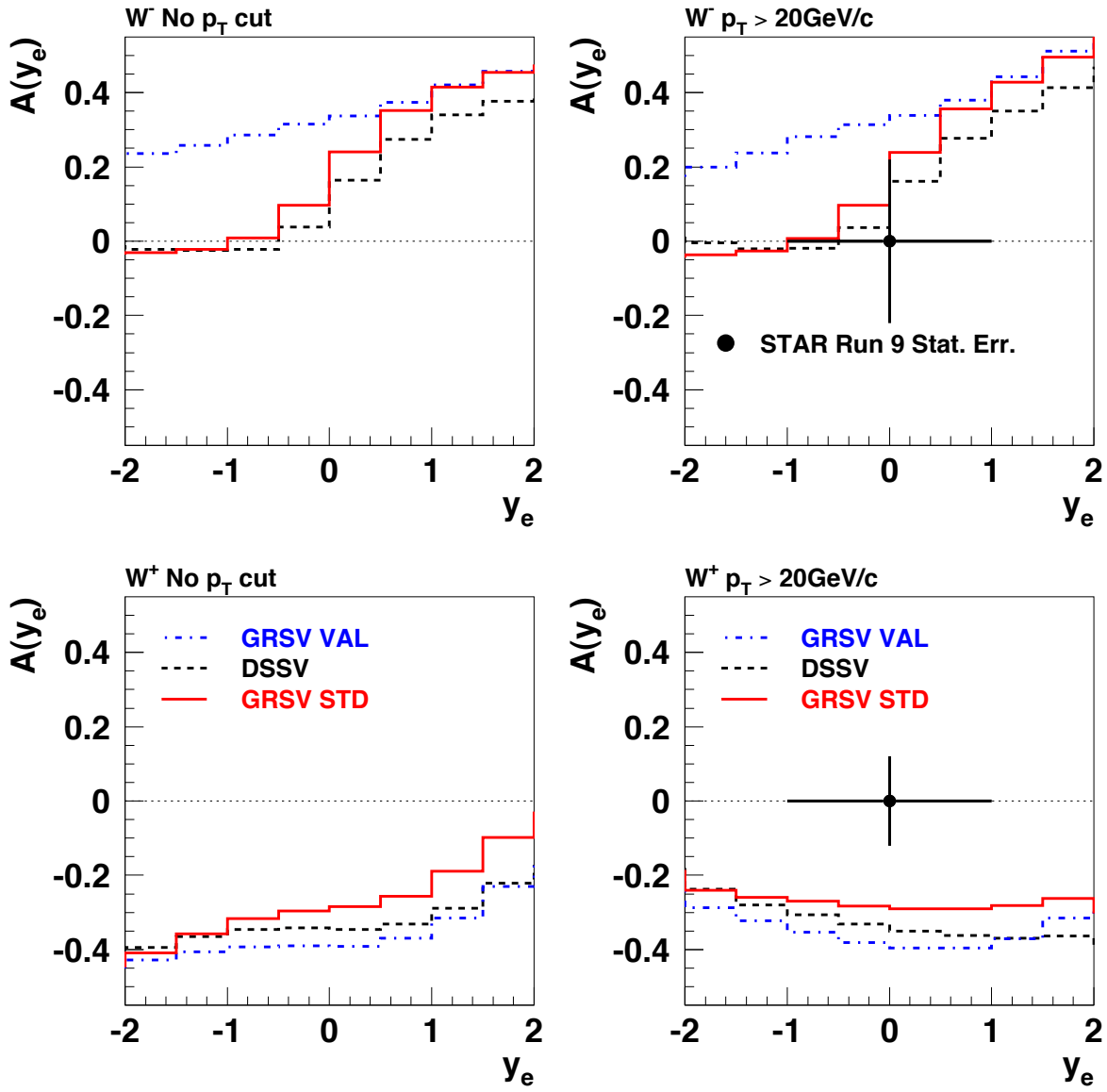
- Final result and overall yield: First Observation of W boson production at STAR



⇒ Comparable shape/yield of W PYTHIA MC Simulation and Data Run 9

Results: First observation of W production

- Statistical precision in A_L from Run 9
  - Projected statistical uncertainties of A_L for W^- and W^+ from Run 9 (E_T > 30GeV) in comparison to RHICBOS predictions
    - Assumed mean polarization: P = 35%
    - No background contribution



Summary and Outlook

- pQCD: Critical role to interpret measured asymmetries at high-energy polarized pp collisions
- 2006 results: Improved precision at mid-rapidity (hadron and jet A_{LL}) / Improve π^+ analyzing power at high z
- First global analysis incl. RHIC SPIN data ⇒ Evidence for small gluon polarization for $0.05<x<0.2$ where $\Delta g(x)$ is expected to be largest!
- Correlation measurements (Di-Jets / γ-Jets) will allow to provide needed constraint on the partonic kinematics
- 500GeV program together with wide rapidity coverage in STAR ($-1<\eta<4$) will allow to extend the currently measured kinematic region at small-x ($x \sim 10^{-3}$) to constrain the gluon polarization
- Run 9: First W production in 500GeV run and large 200GeV data!
- Installation of STAR Forward GEM Tracker (FGT) - Tracking for $1 < \eta < 2$: Summer 2011