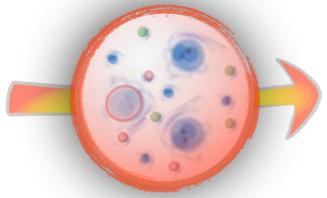


Proton Quark Helicity Structure via W-boson Production in pp Collision @ PHENIX

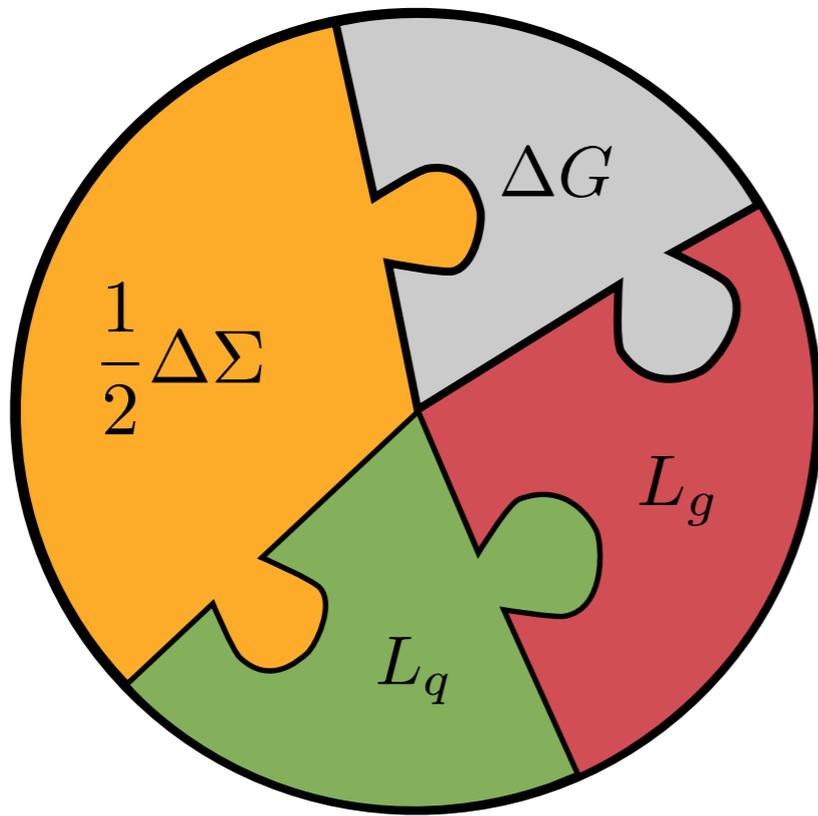
Francesca Giordano for the Phenix Collaboration
Spin 2014, Beijing, China, October 21st, 2014



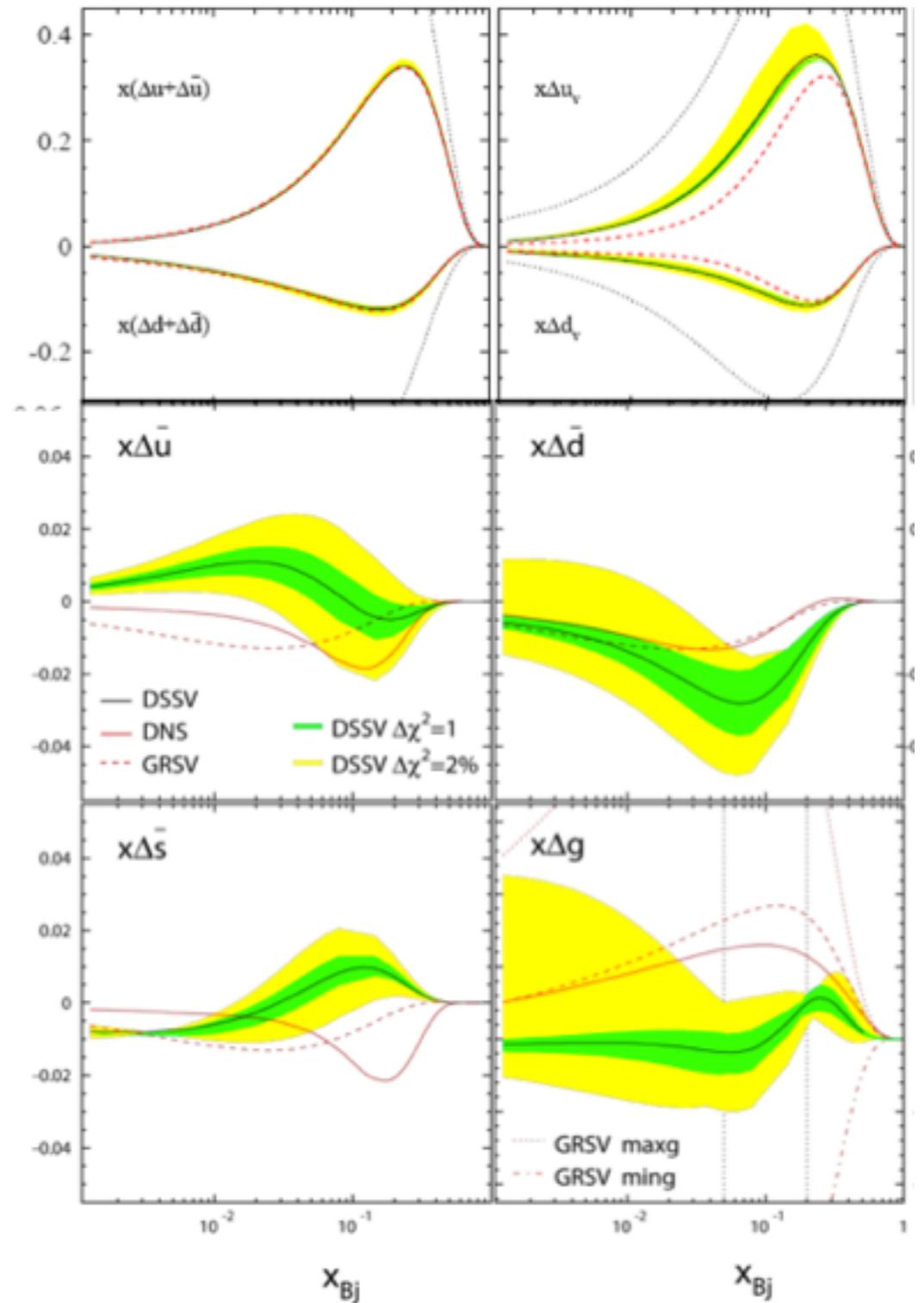


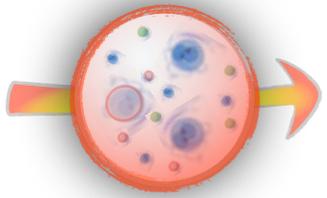
The proton spin puzzle

$$\frac{1}{2} = \frac{1}{2} \overset{\text{quark spins}}{\Delta\Sigma} + \overset{\text{gluon spins}}{\Delta G} + \overset{\text{quark\&gluon orbital motion}}{L_z}$$



D. De Florian et al., PRL101, 072001 (2008)



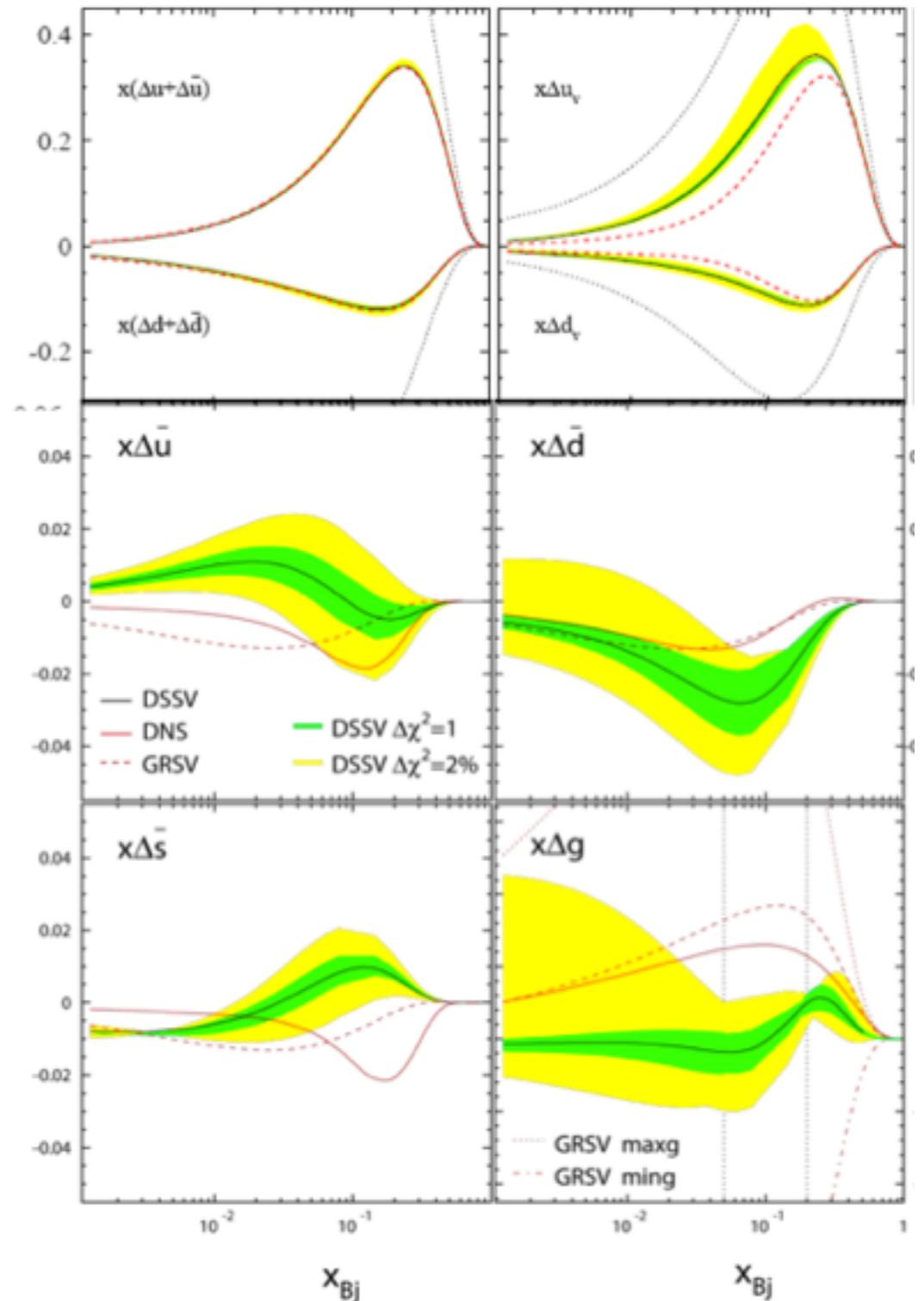


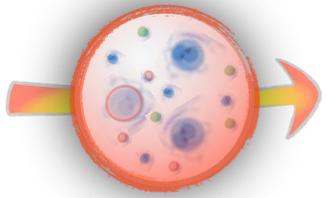
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$$\frac{1}{2} = \frac{1}{2} \overset{\text{quark spins}}{\Delta\Sigma} + \overset{\text{gluon spins}}{\Delta G} + \overset{\text{quark\&gluon orbital motion}}{L_z}$$

- precise (quark + antiquark) PDF's extracted mostly from Deep Inelastic Scattering experiments
- in DIS, flavor separation is bound to the knowledge of fragmentation functions
- leading to larger uncertainties

D. De Florian et al., PRL101, 072001 (2008)



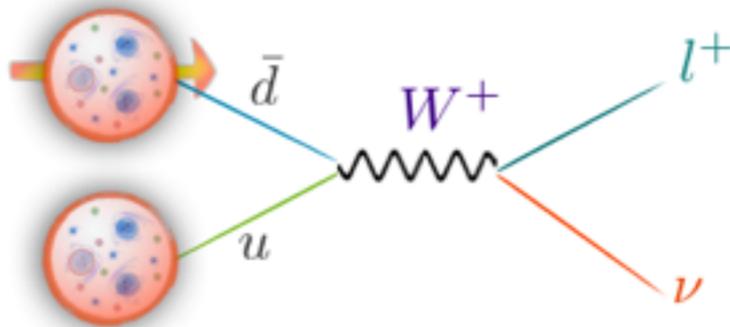


The proton spin puzzle

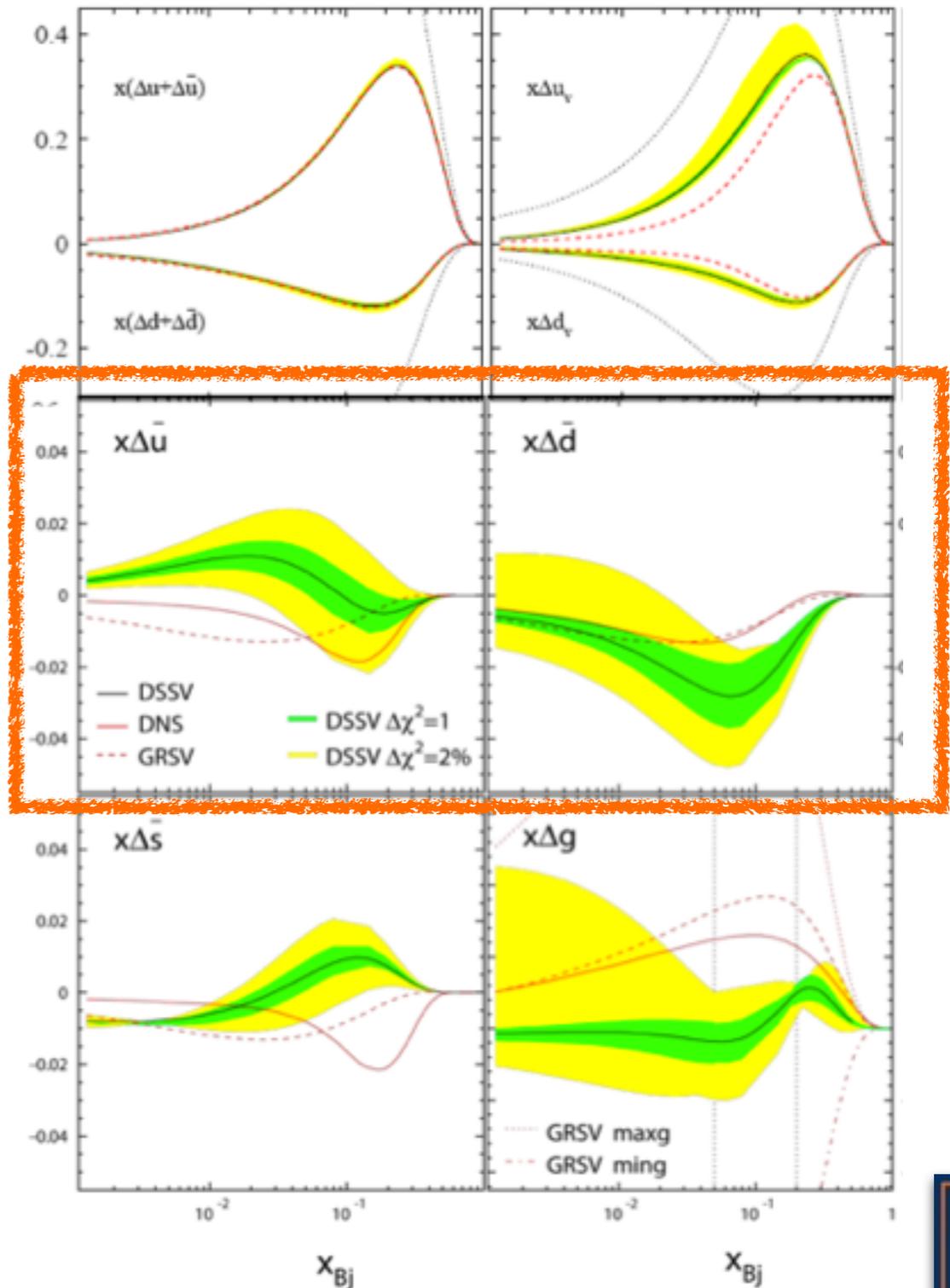
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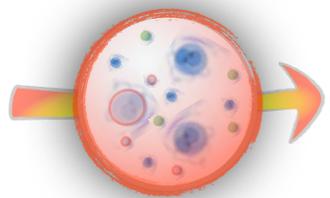
There is an alternative!

W production in proton-proton collision!



D. De Florian et al., PRL101, 072001 (2008)



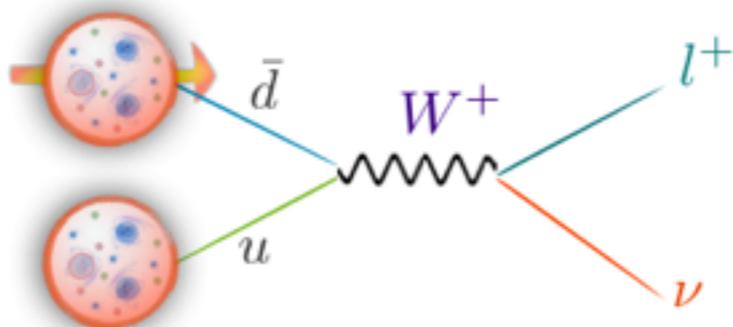


The proton spin puzzle

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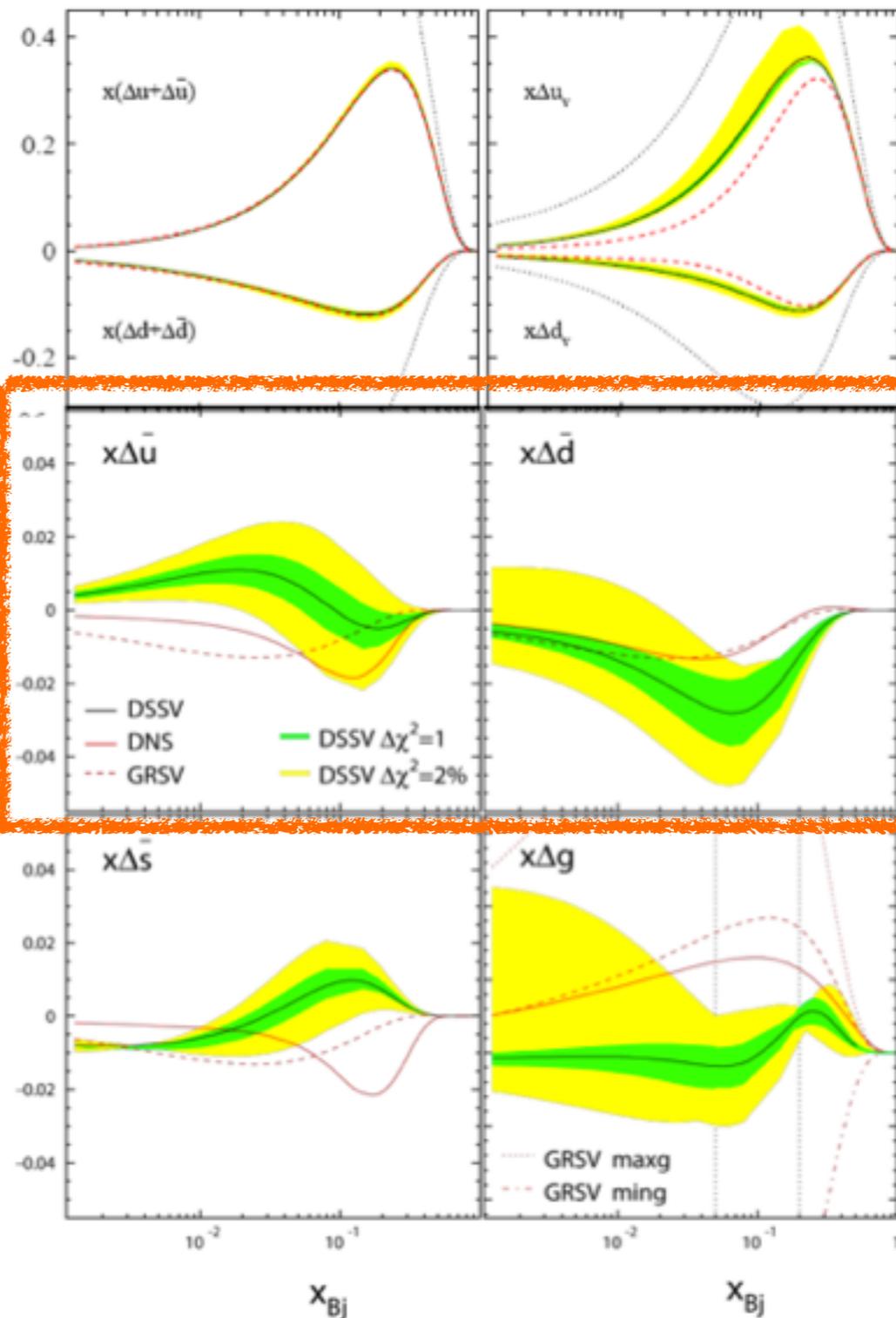


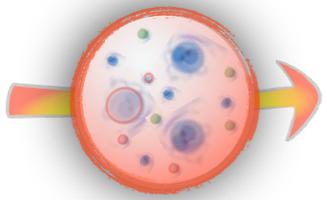
➔ Independent from Fragmentation Functions

➔ Maximally parity-violating!



D. De Florian et al., PRL101, 072001 (2008)



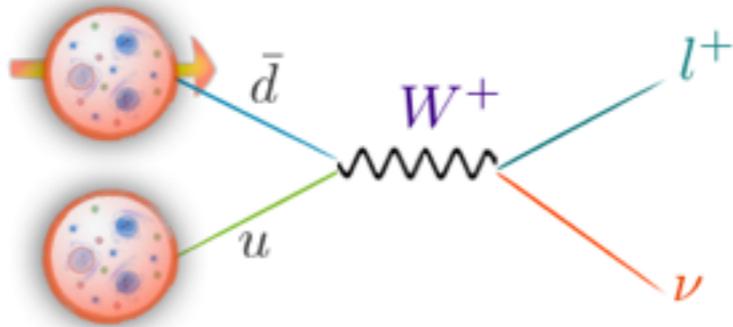


The proton spin puzzle

$$\frac{1}{2} = \frac{1}{2} \overset{\text{quark spins}}{\Delta\Sigma} + \overset{\text{gluon spins}}{\Delta G} + \overset{\text{quark\&gluon orbital motion}}{L_z}$$

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W production in proton-proton collision!

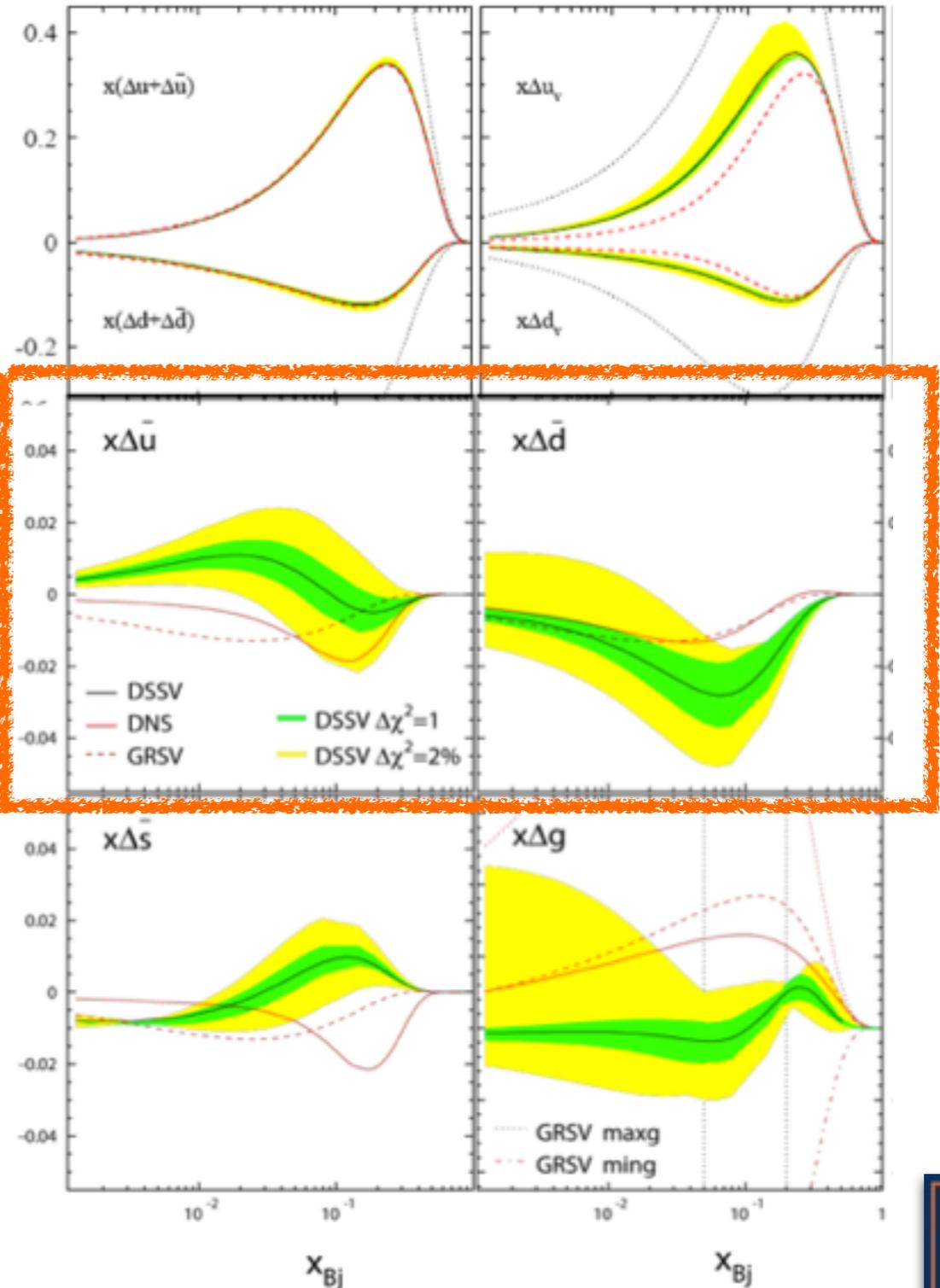


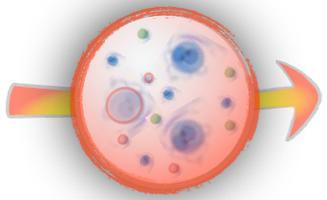
$$A_L = \frac{1}{P} \frac{N^+ - N^-}{N^+ + N^-}$$

$$\begin{matrix} d_L \\ \bar{u}_R \end{matrix} \rightarrow W^-$$

$$\begin{matrix} u_L \\ \bar{d}_R \end{matrix} \rightarrow W^+$$

D. De Florian et al., PRL101, 072001 (2008)



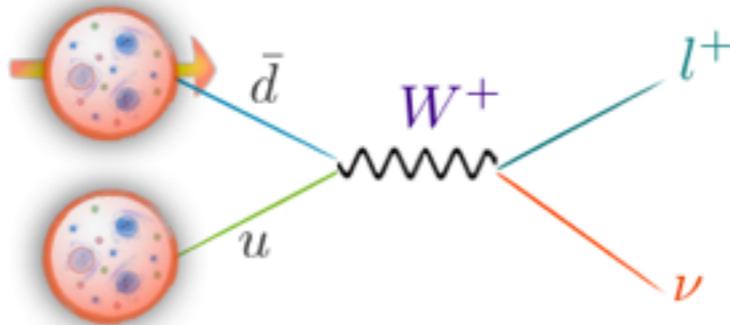


The proton spin puzzle

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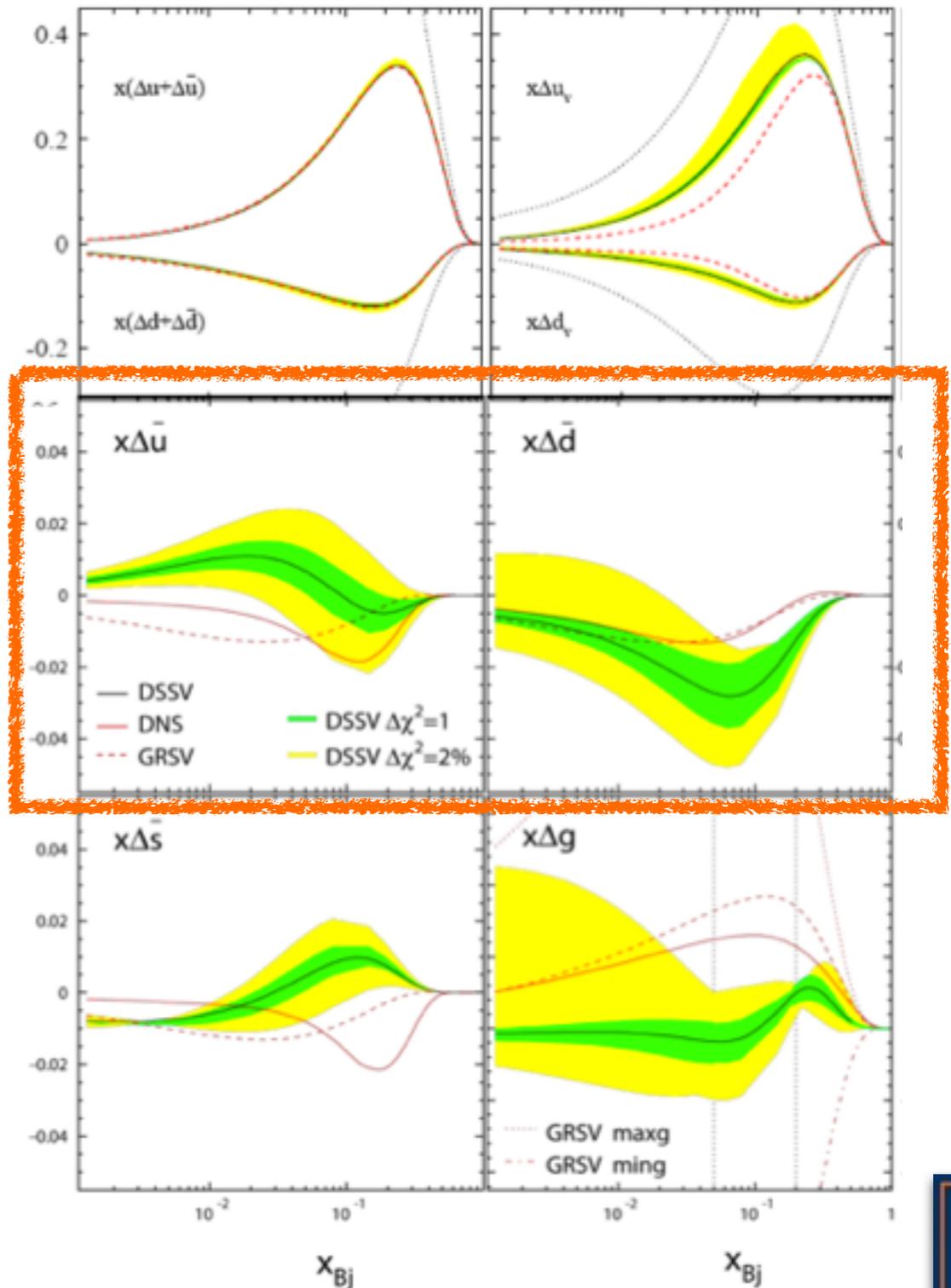
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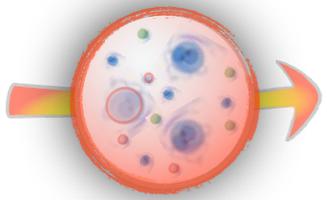


$$A_L^{W^+} = \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

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

D. De Florian et al., PRL101, 072001 (2008)



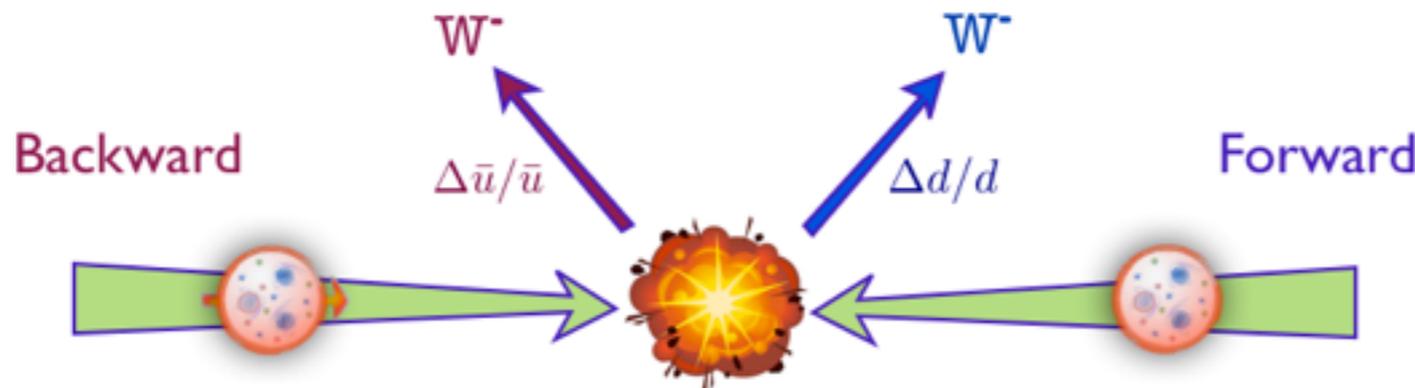
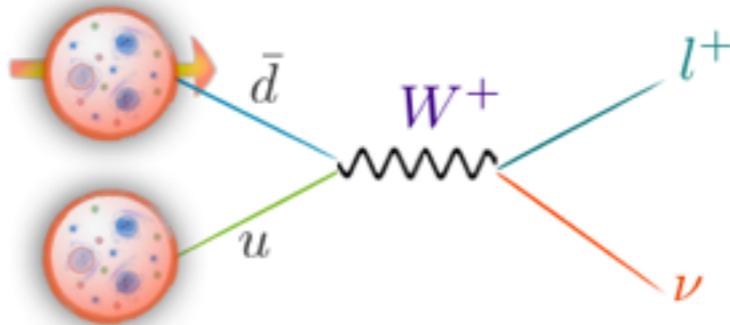


The proton spin puzzle

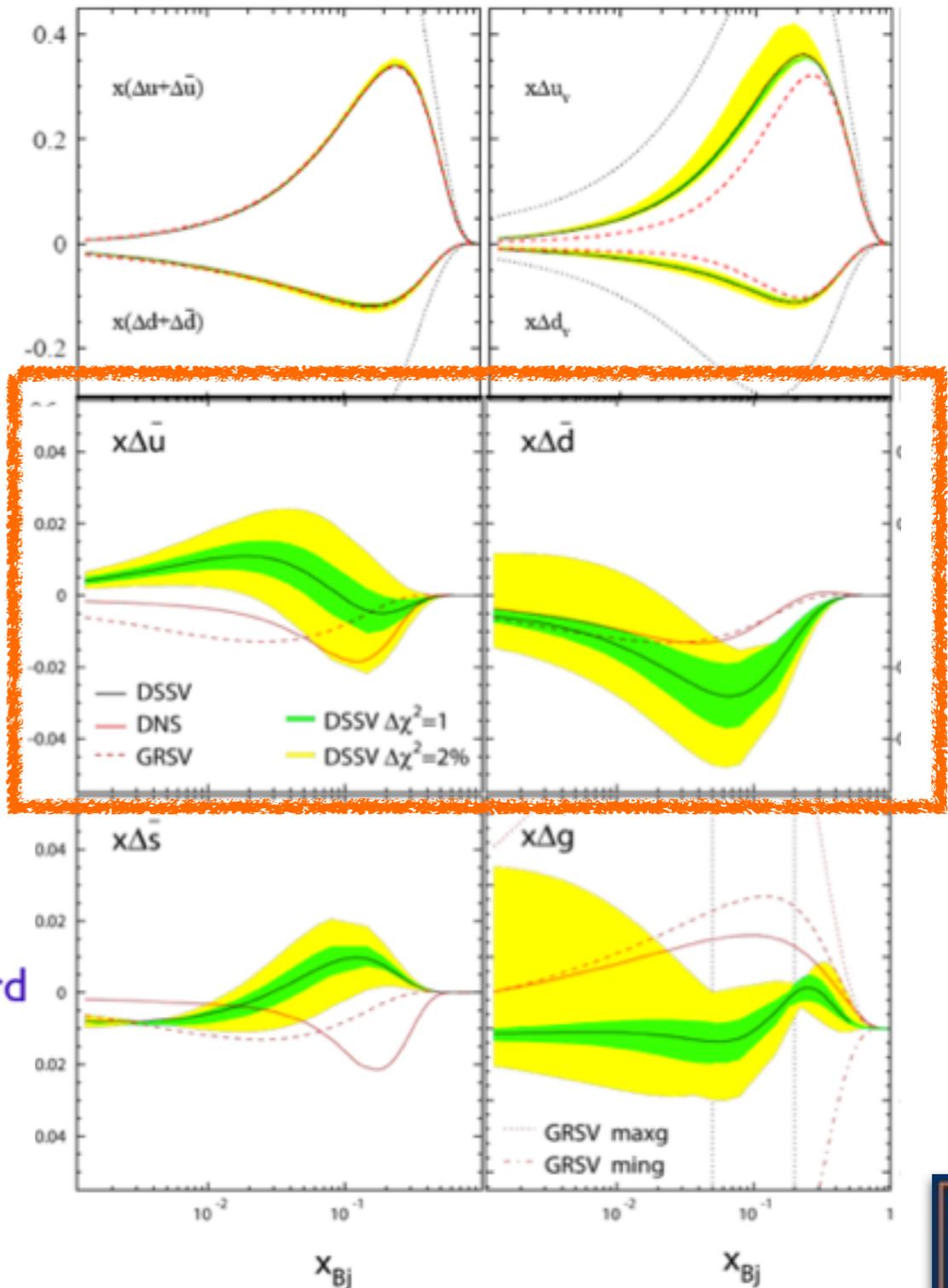
$$\frac{1}{2} = \frac{1}{2} \overset{\text{quark spins}}{\Delta\Sigma} + \overset{\text{gluon spins}}{\Delta G} + \overset{\text{quark\&gluon orbital motion}}{L_z}$$

There is an alternative!

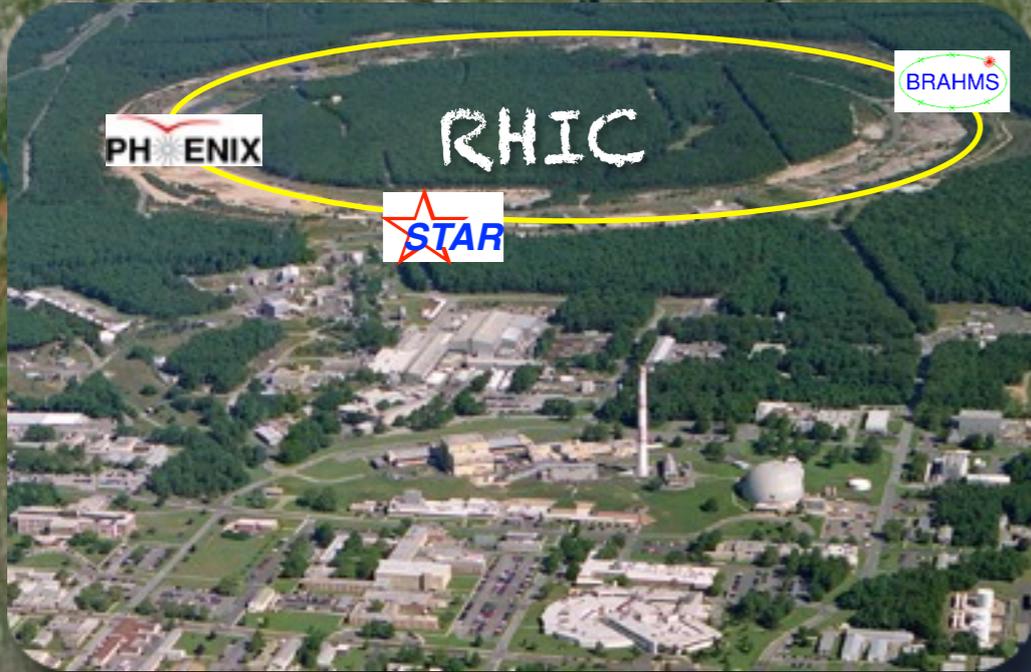
W production in proton-proton collision!



D. De Florian et al., PRL101, 072001 (2008)



PHENIX @ RHIC

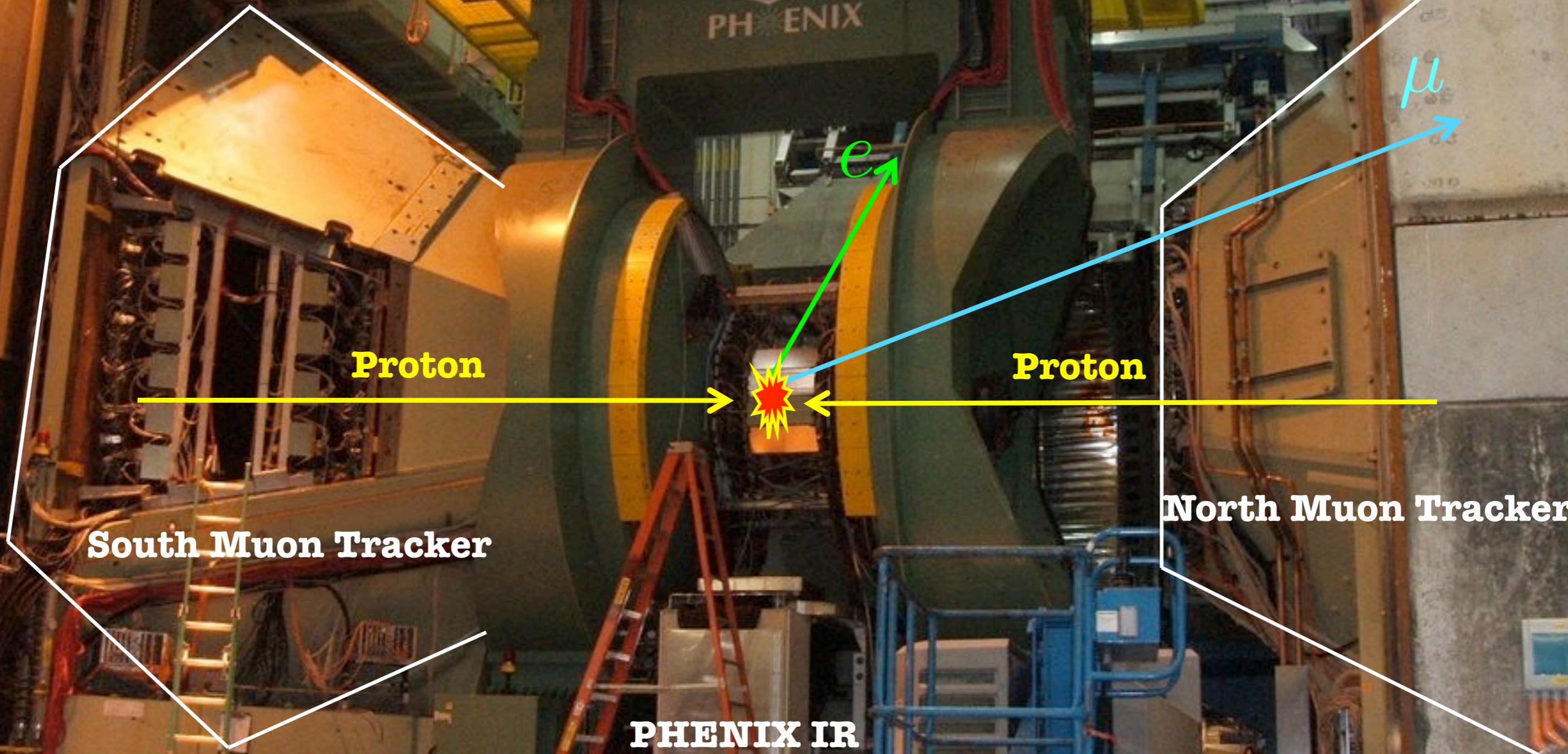


BROOKHAVEN
NATIONAL LABORATORY

Hadron-Hadron collider
 \sqrt{s} of 62 GeV, 200 GeV, 500 GeV



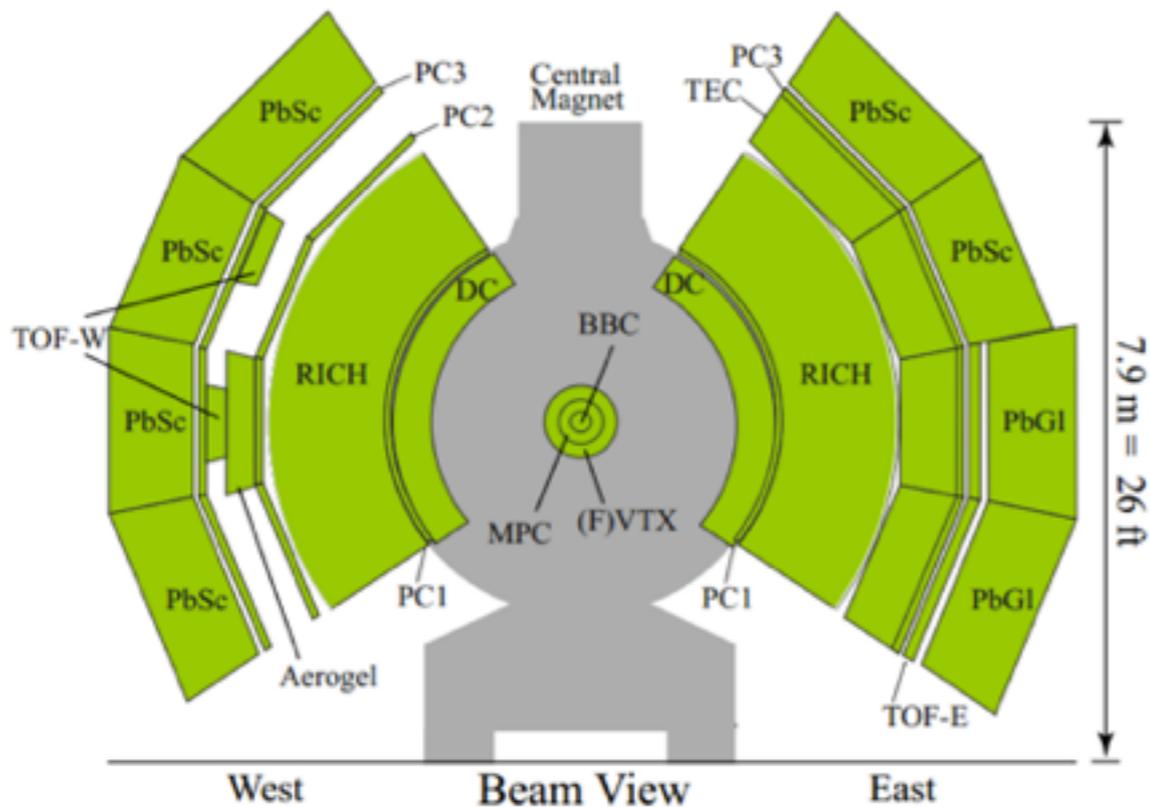
PHENIX



PHENIX

Central Arms

$$|\eta| < 0.35$$

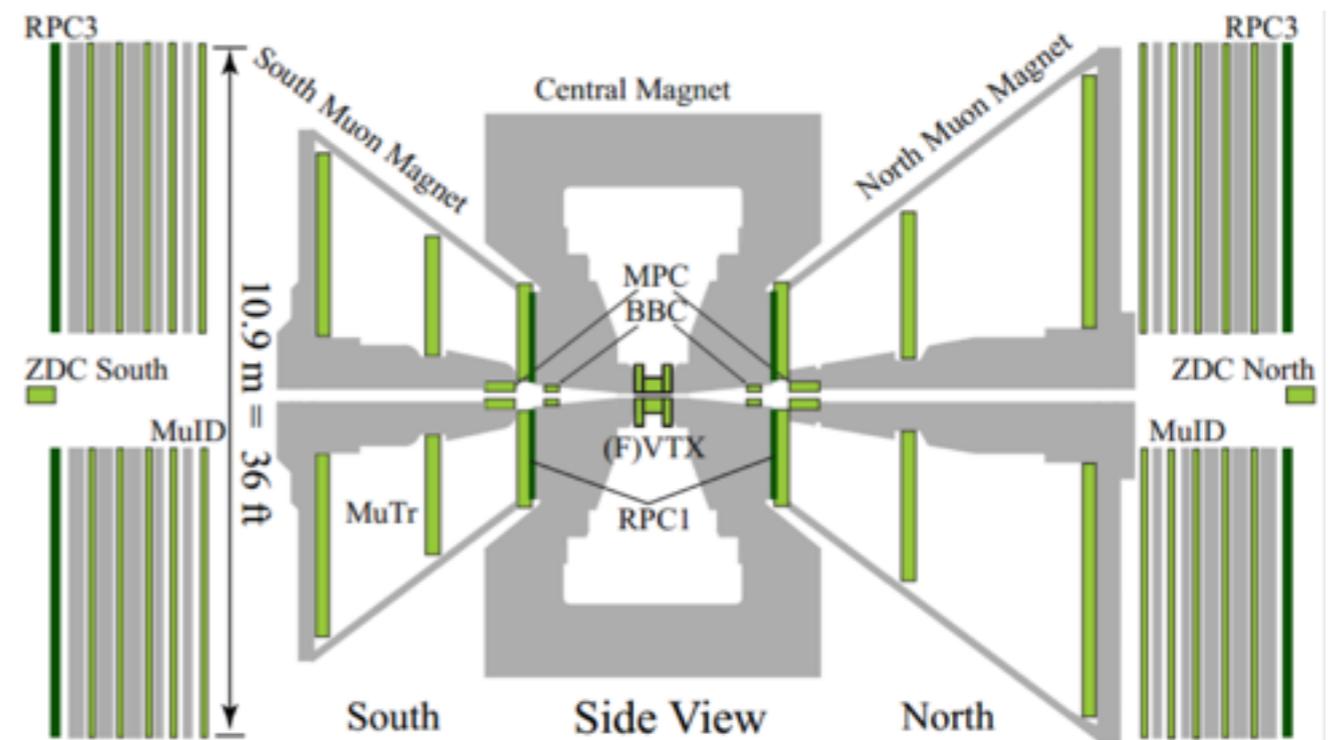


$$\vec{p}p \rightarrow W^\pm \rightarrow e^\pm \nu$$

Tracking, Momentum and PID for e^\pm

Forward Arms

$$1.2 < |\eta| < 2.4$$



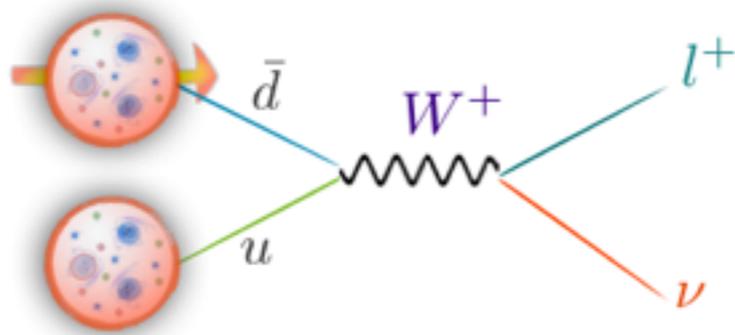
$$\vec{p}p \rightarrow W^\pm \rightarrow \mu^\pm \nu$$

Tracking and Momentum for μ^\pm



Phenix 500 GeV Runs

W production in proton-proton collision at 500 (510) GeV



High Longitudinal Polarization (up to 56%)

Total luminosity: $\sim 300 \text{ pb}^{-1}$

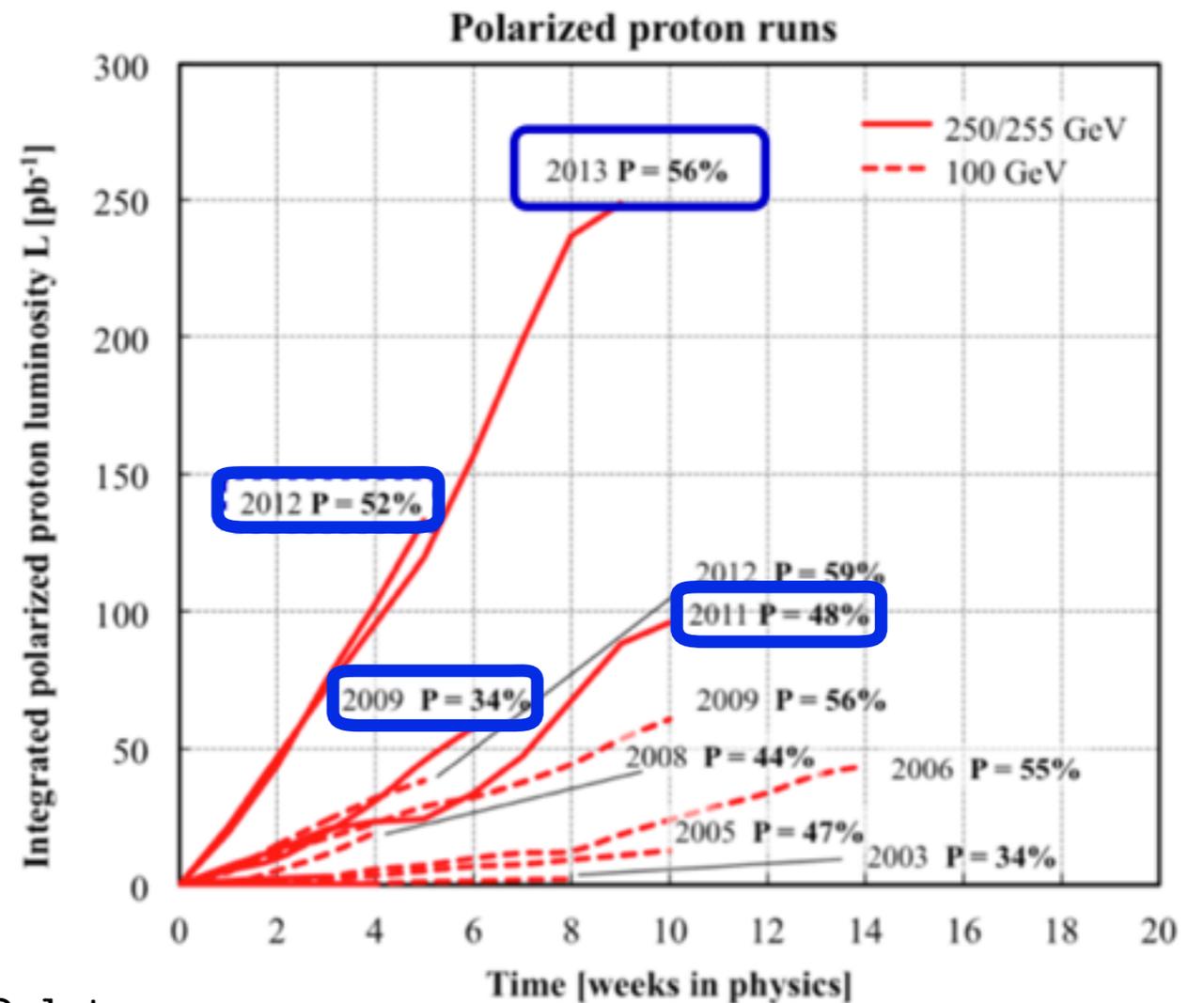
→ Central arms:

- Results being finalized

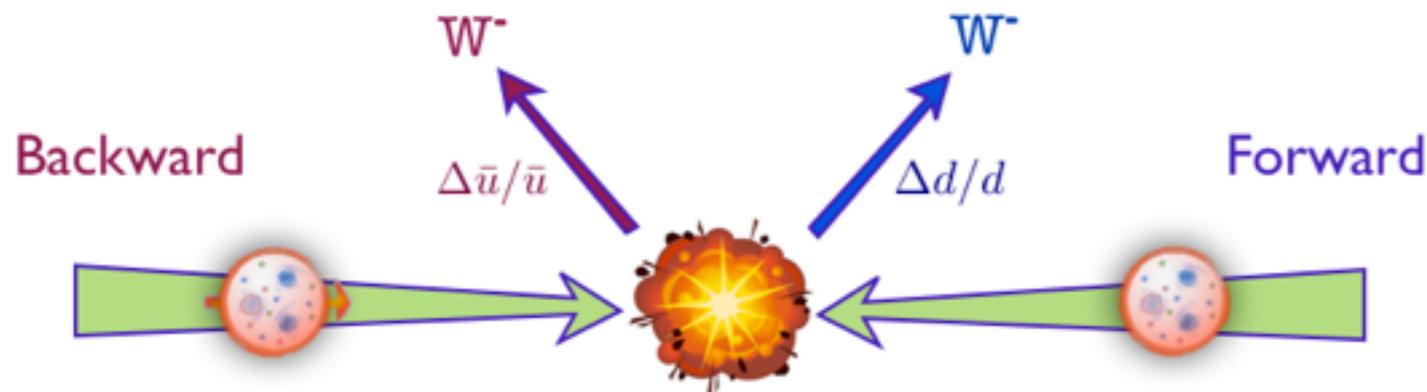
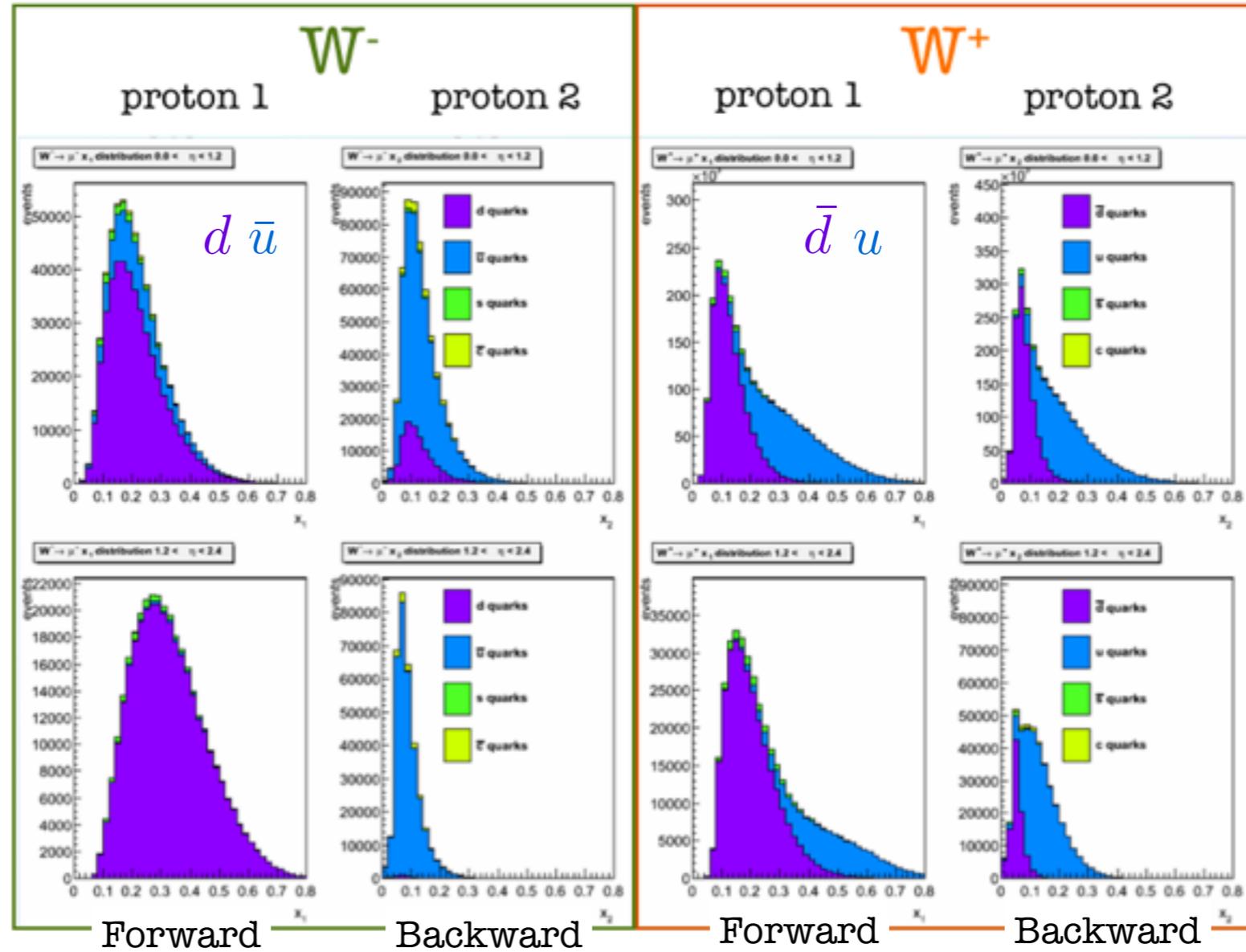
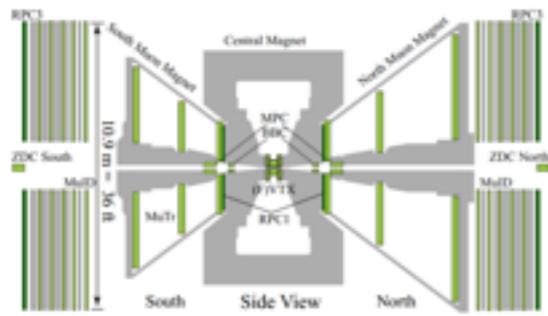
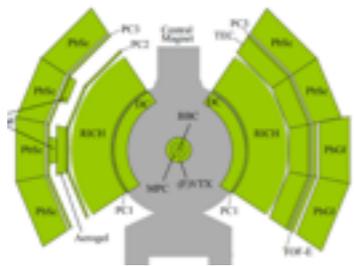
→ Forward Arms:

- Preliminary results on 2011 and 2012 data

- 2013 data preliminary **New!**



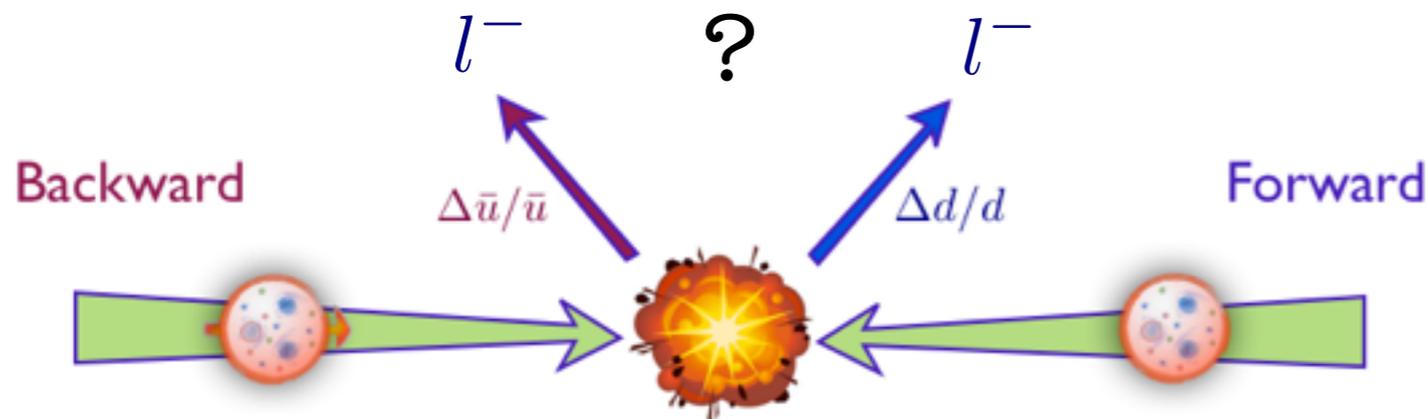
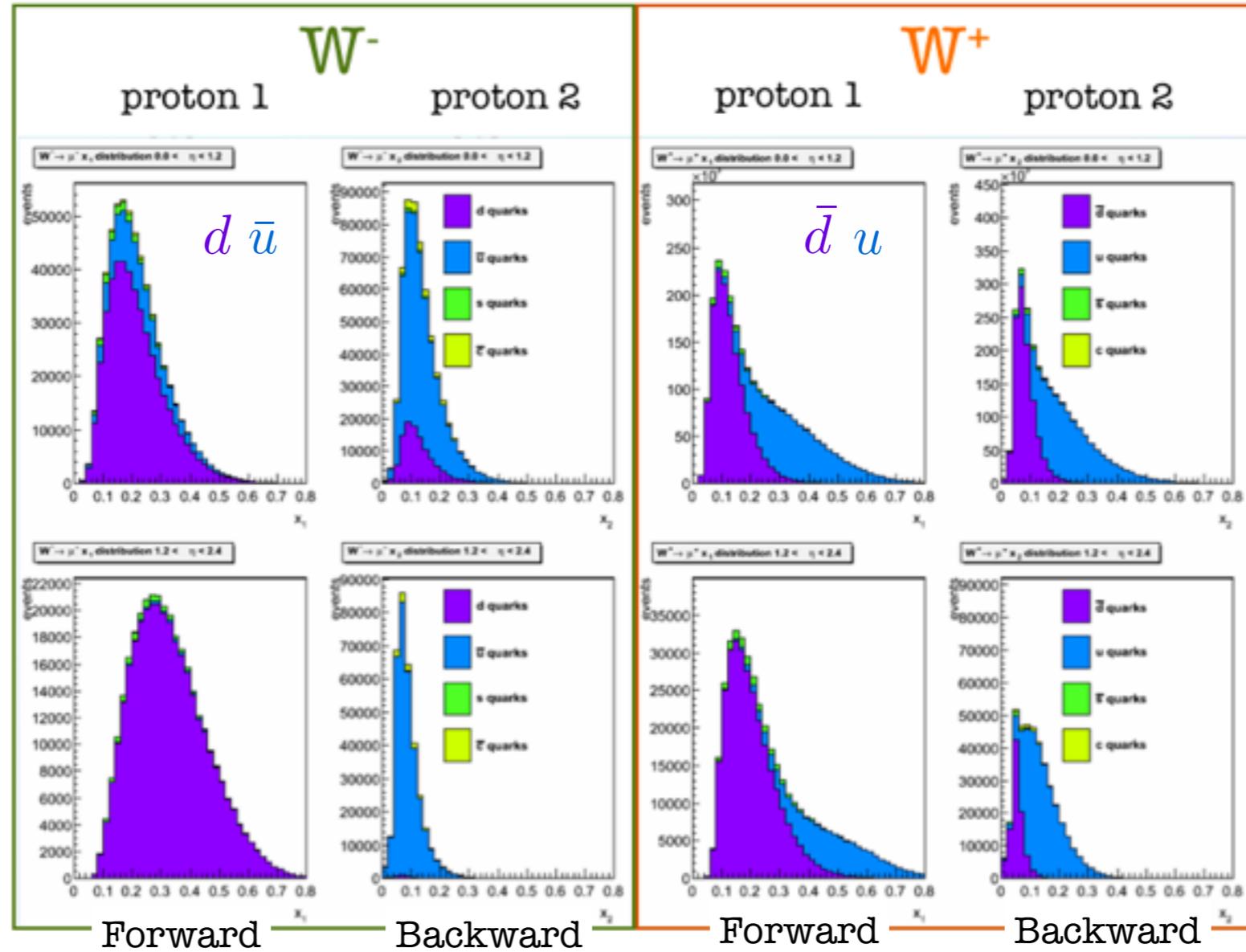
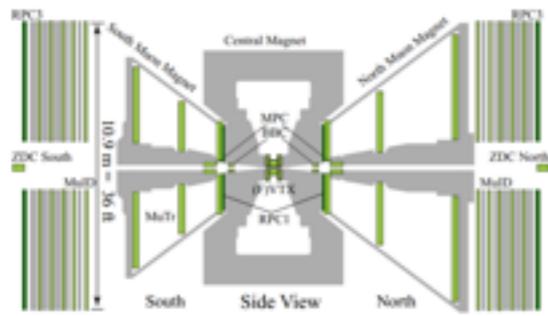
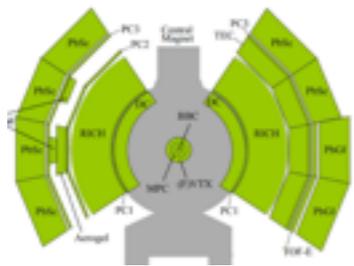
Decay lepton kinematics



Pythia



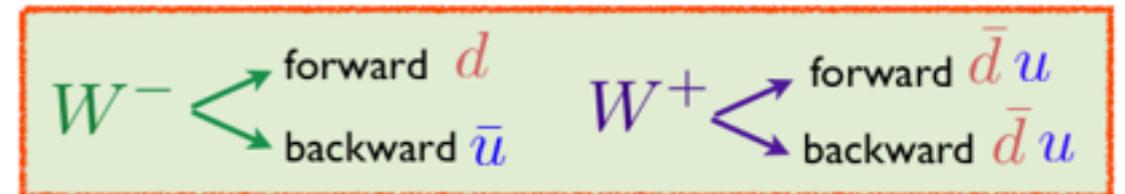
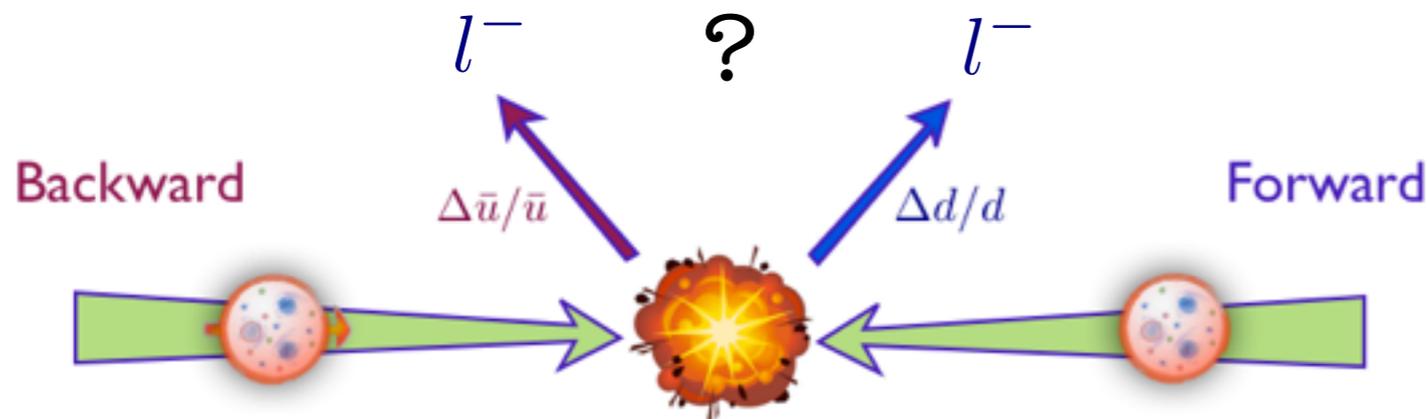
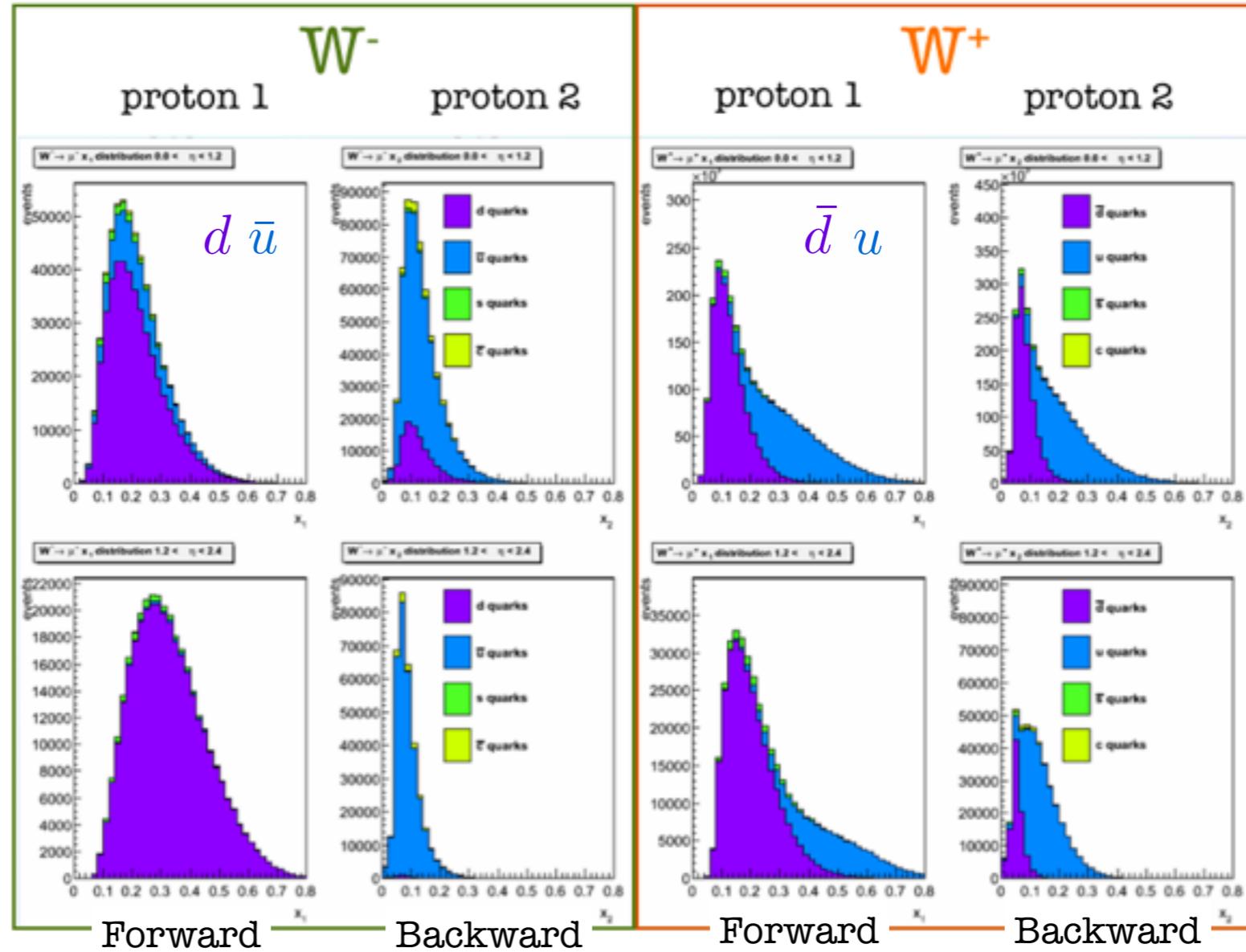
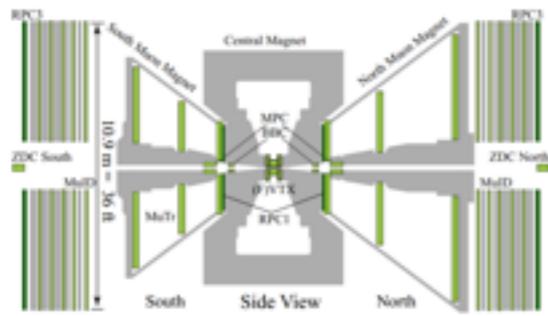
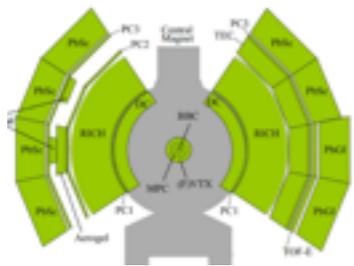
Decay lepton kinematics



Pythia



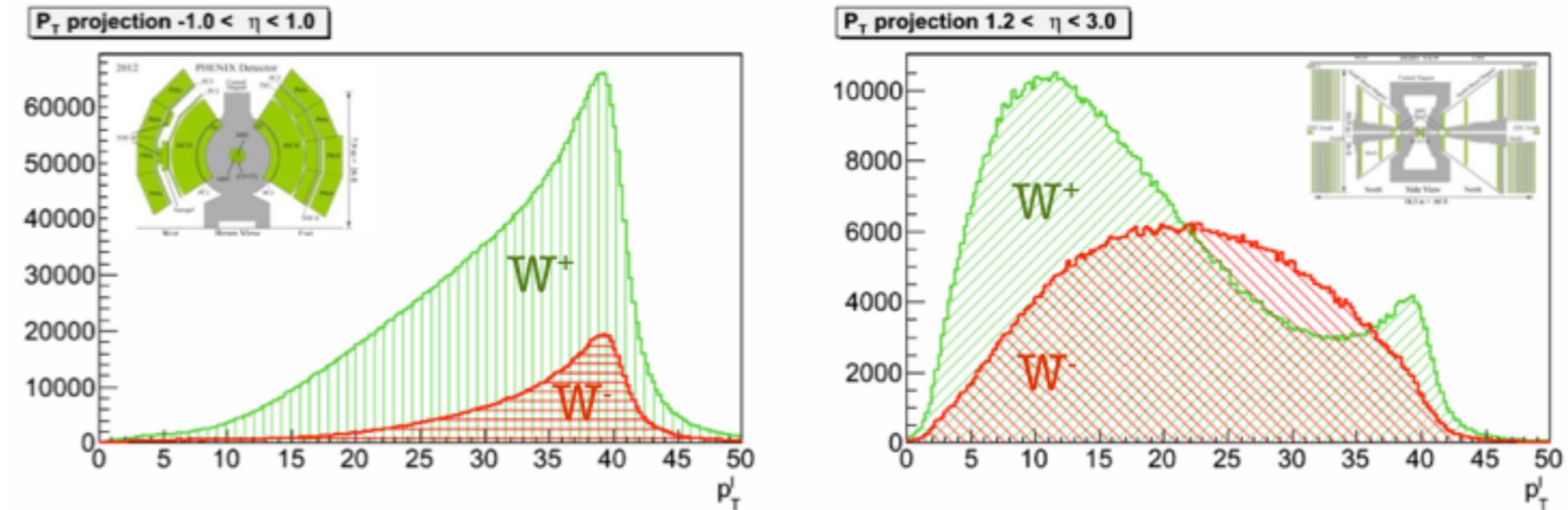
Decay lepton kinematics



Pythia



Decay lepton kinematics



Jacobian peaks at central rapidities!

Suppressed/no Jacobian peaks
at forward rapidities!

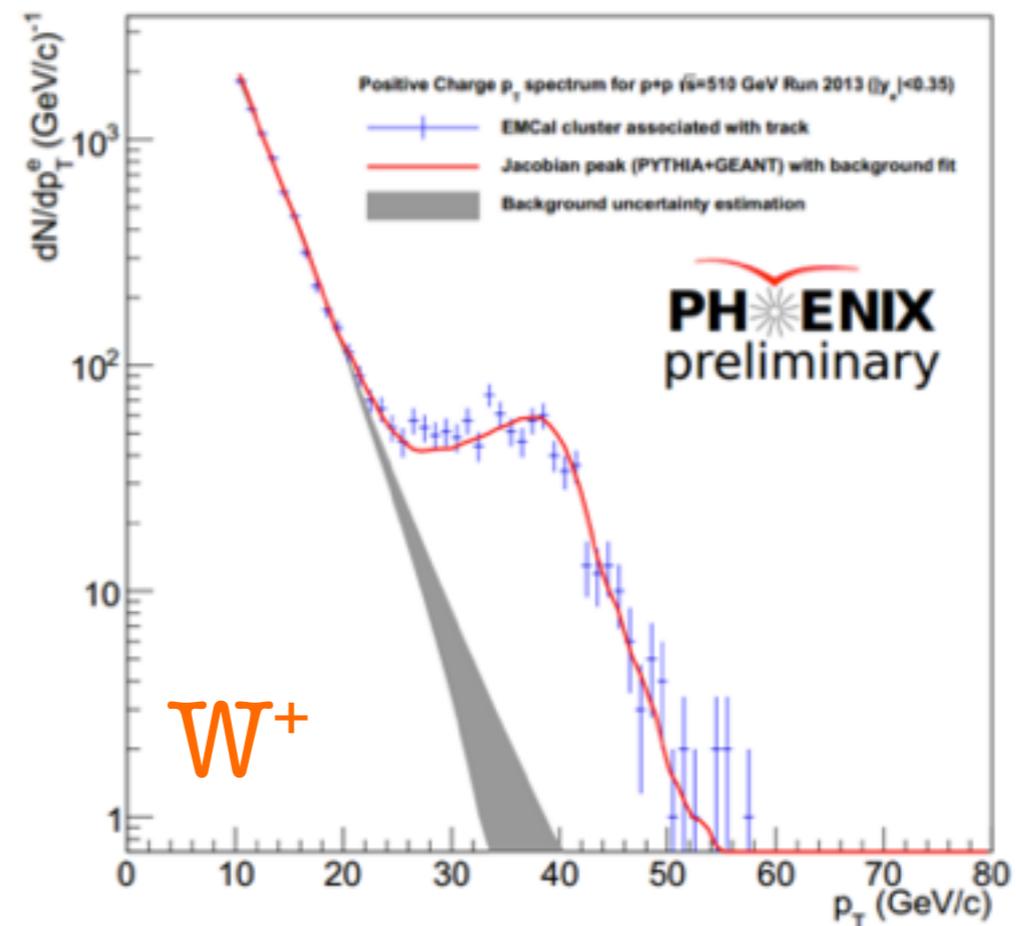
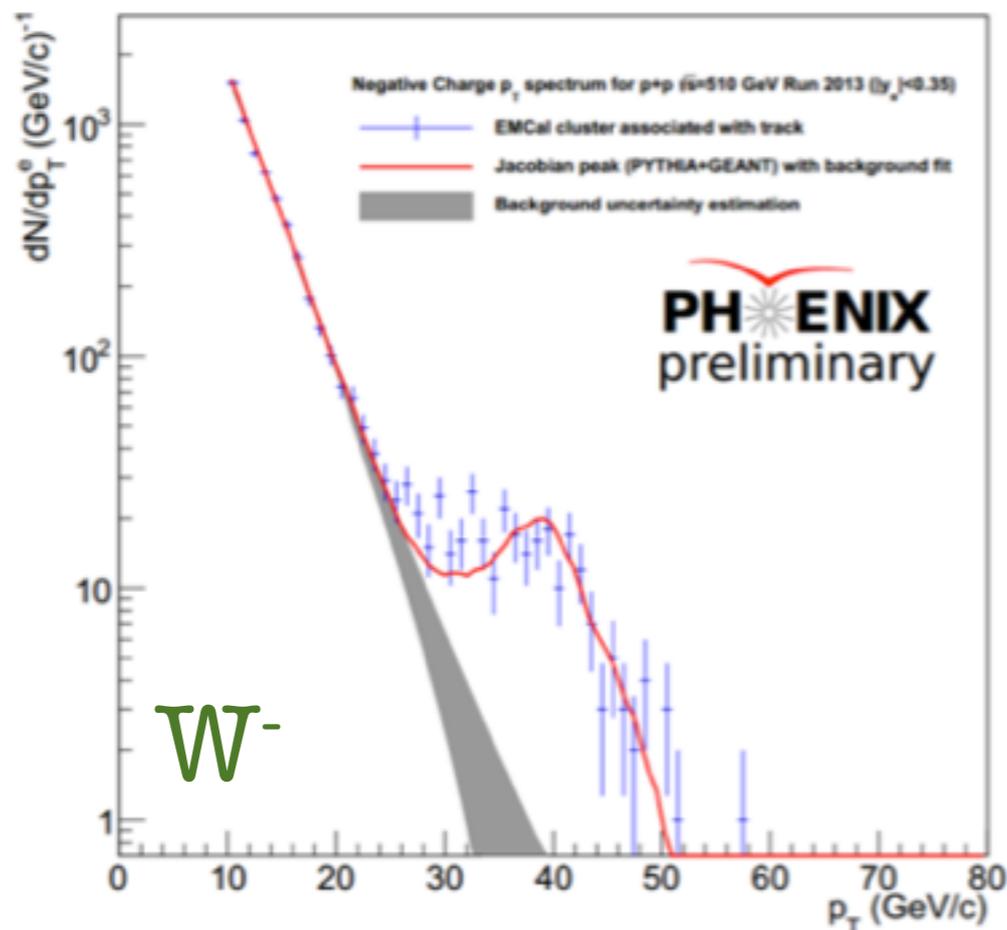


W decay at central rapidities

Jacobian peaks visible!

Analysis strategy:

1. Reduce background as much as possible
2. Extract the Bg shape then fit the whole spectrum together with a signal shape
3. Evaluate asymmetries



W decay at central rapidities

Jacobian peaks visible!

Analysis strategy:

1. Reduce background as much as possible

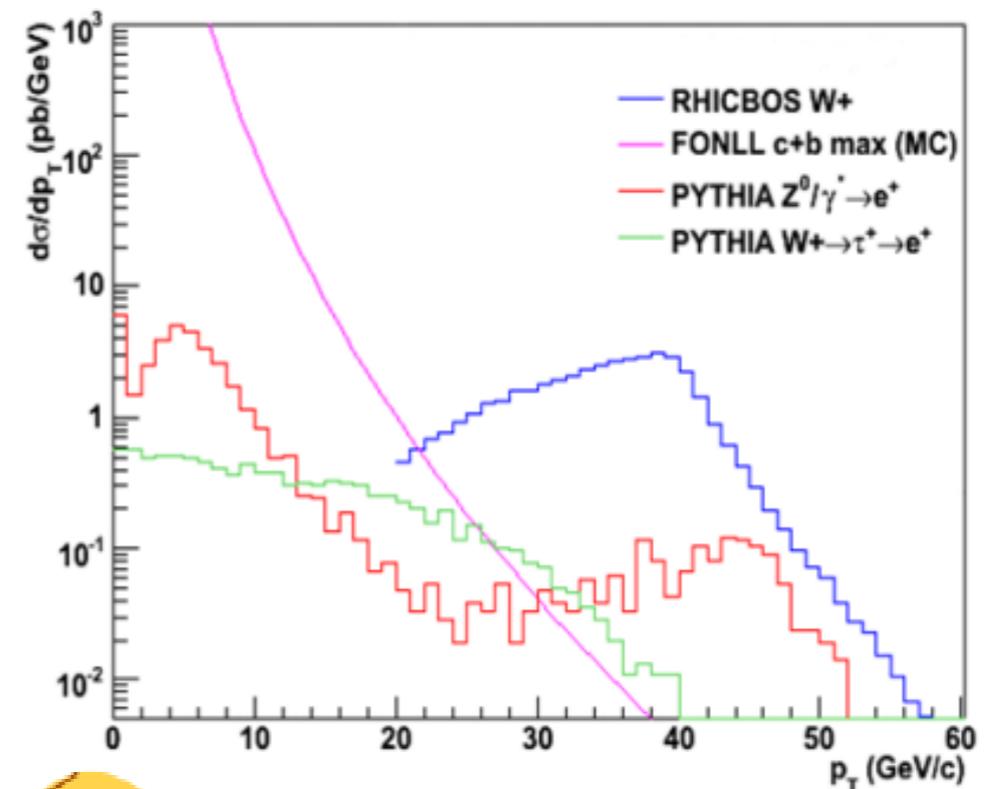
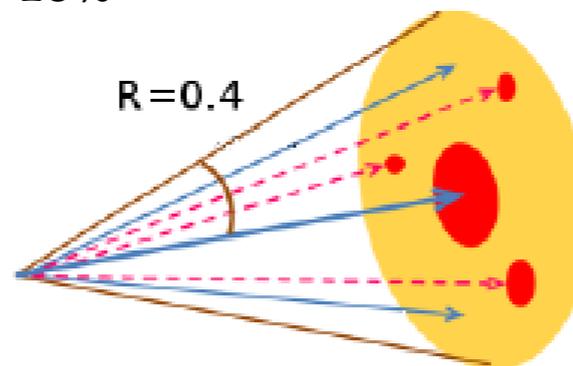
Background sources:

1. e^\pm -pair production by π^0/η decay photons
2. cosmic rays
3. background from beams
4. Z/charm-bottom decays/other W decays

Main background discriminator:

Relative isolation cut: energy in a cone ($R=0.4$ rad)
not from the candidate electron $< 10\%$

→ background reduced
by a factor 10!



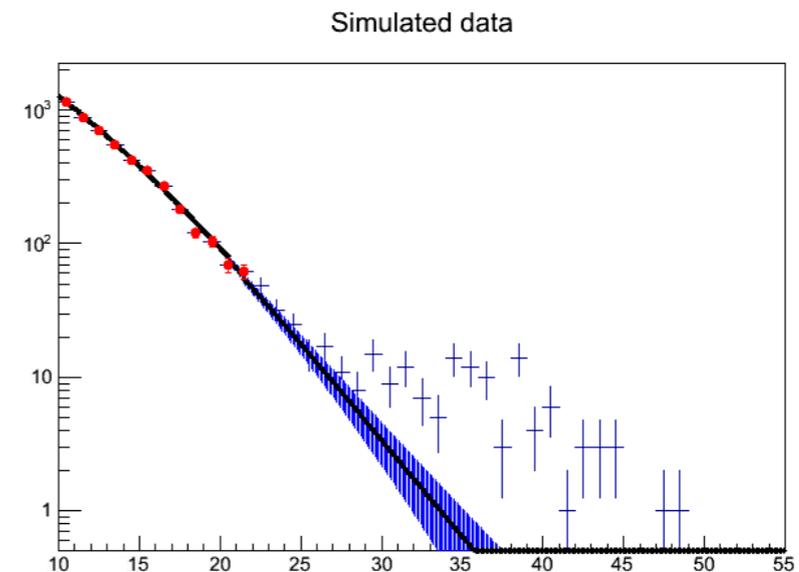
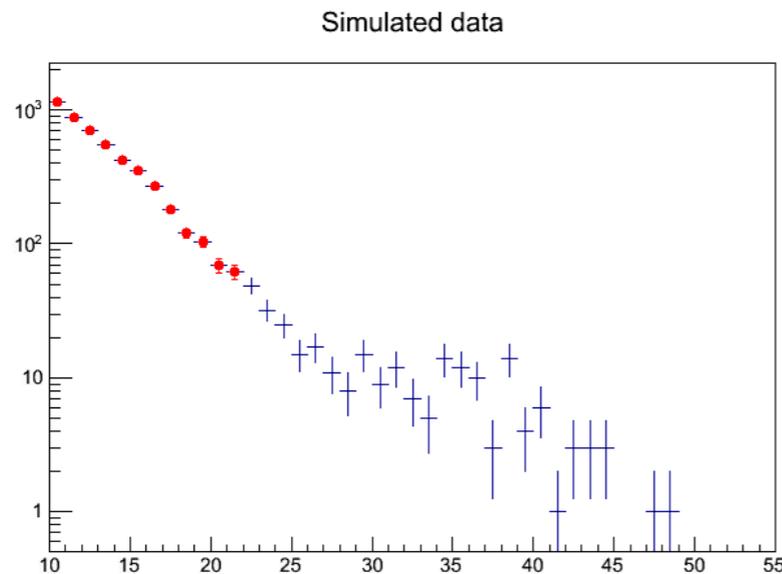
W decay at central rapidities

Jacobian peaks visible!

Analysis strategy:

1. Reduce background as much as possible
2. Extract the Bg shape then fit the whole spectrum together with a signal shape

Gaussian process regression



→ uses the low p_T (background dominated) spectra used to define the shape of the background

→ extrapolate the expected bg shape and uncertainty in the higher p_T region

→ Assumption 1: background shape does not change at higher p_T

→ Assumption 2: smooth curve to describe background

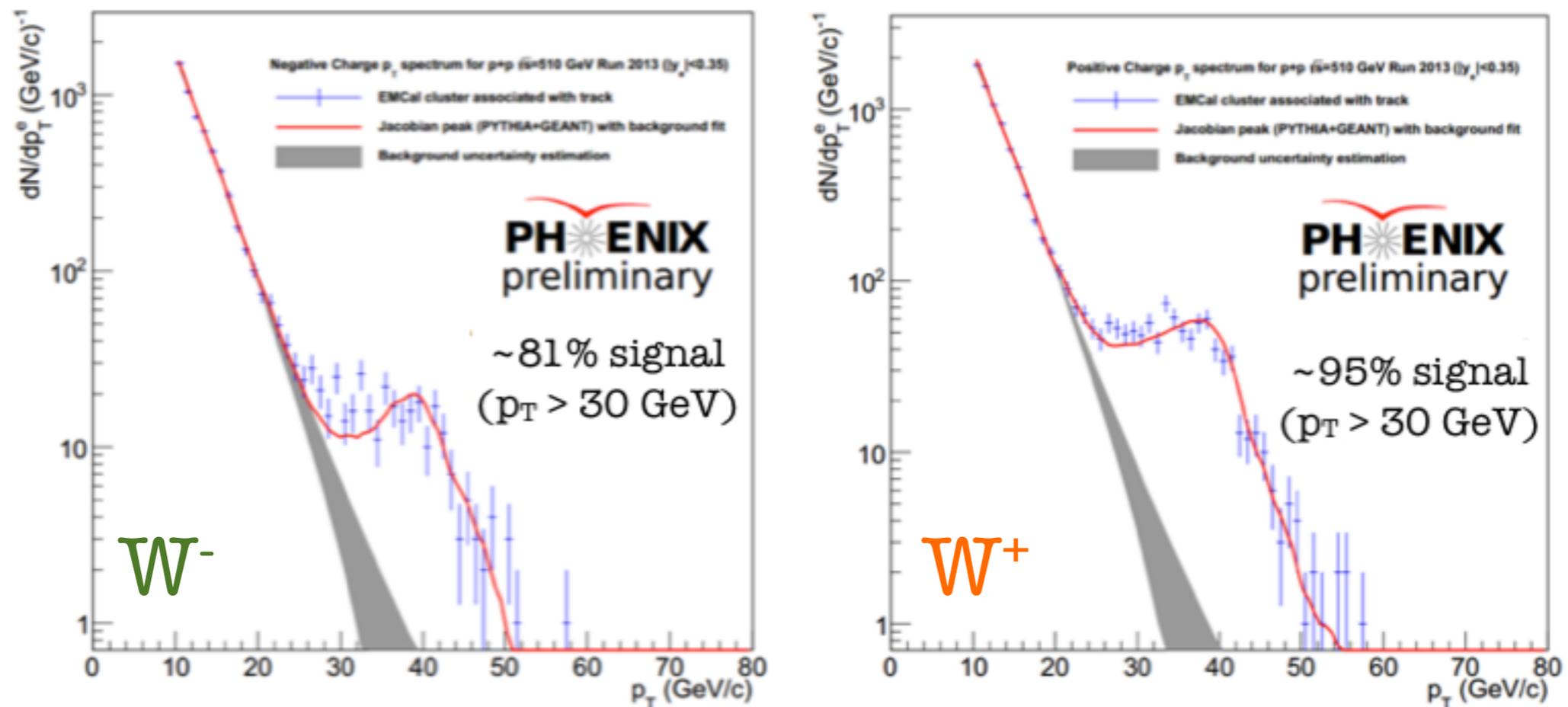


W decay at central rapidities

Jacobian peaks visible!

Analysis strategy:

1. Reduce background as much as possible
2. Extract the Bg shape then fit the whole spectrum together with a signal shape



➔ Fit the extracted bg shape + signal



W decay at central rapidities

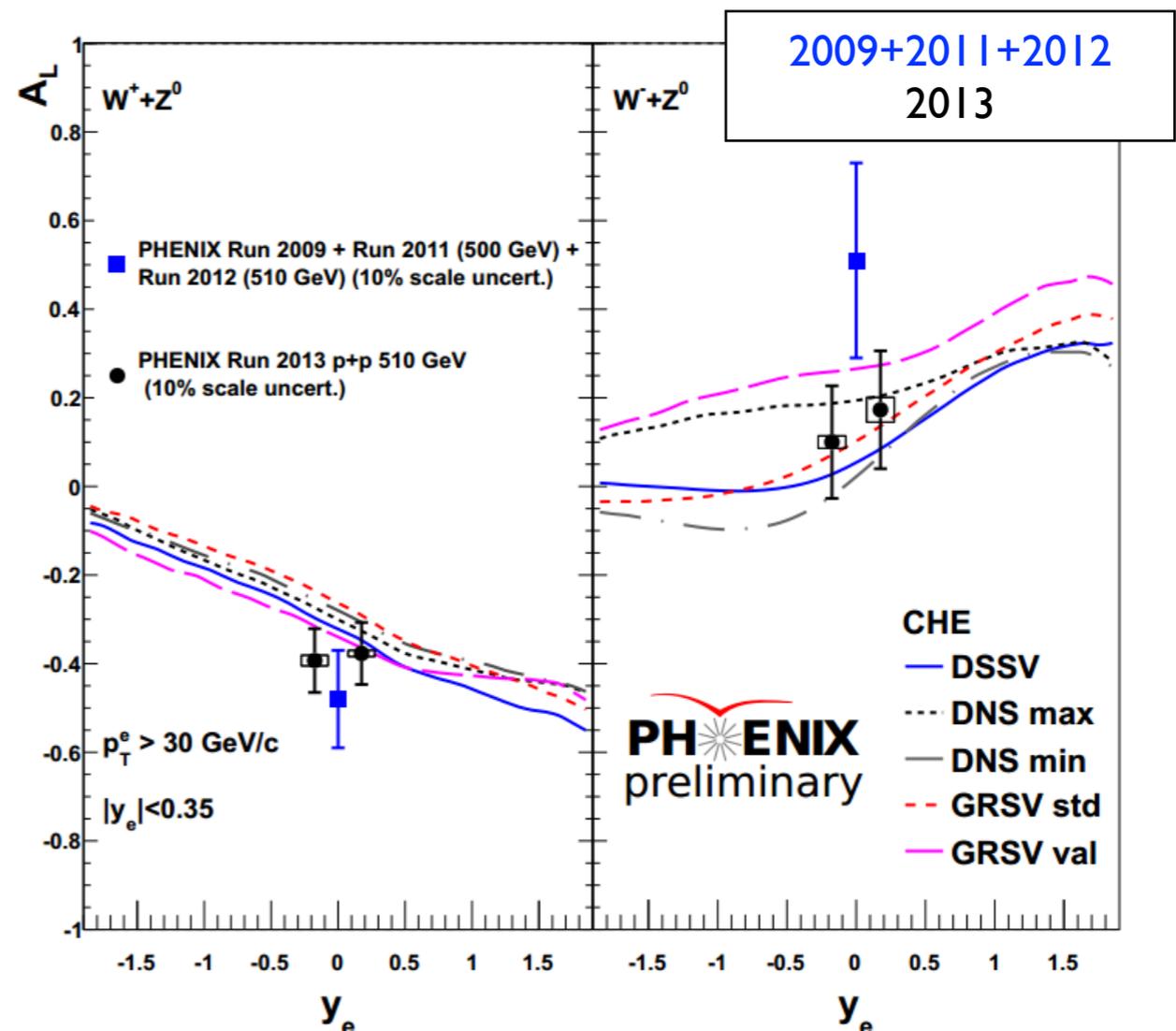
Jacobian peaks visible!

Analysis strategy:

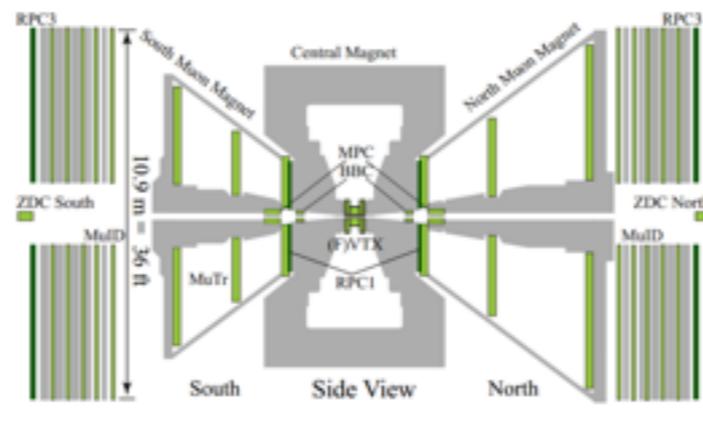
1. Reduce background as much as possible
2. Extract the Bg shape then fit the whole spectrum together with a signal shape
3. Evaluate asymmetries

Good agreement with prediction

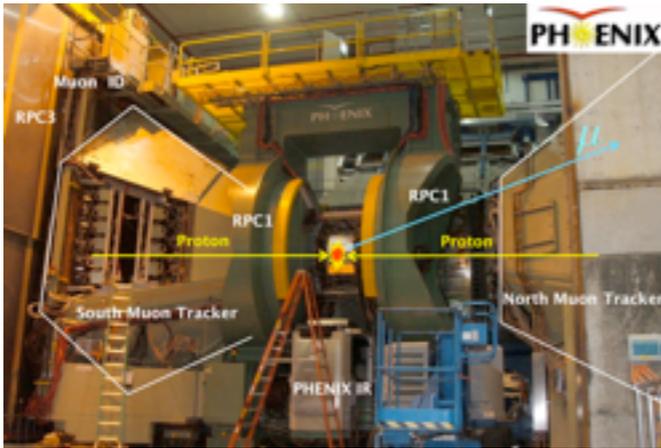
Final results will be submitted soon



W asymmetries in forward rapidities



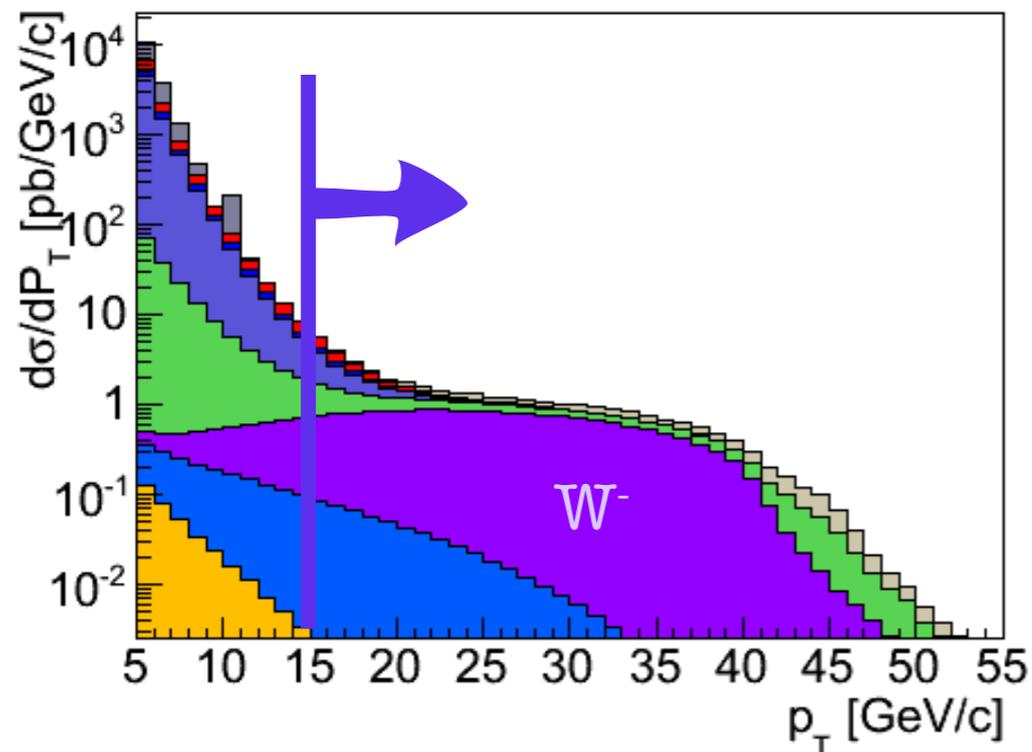
W decay at forward rapidities



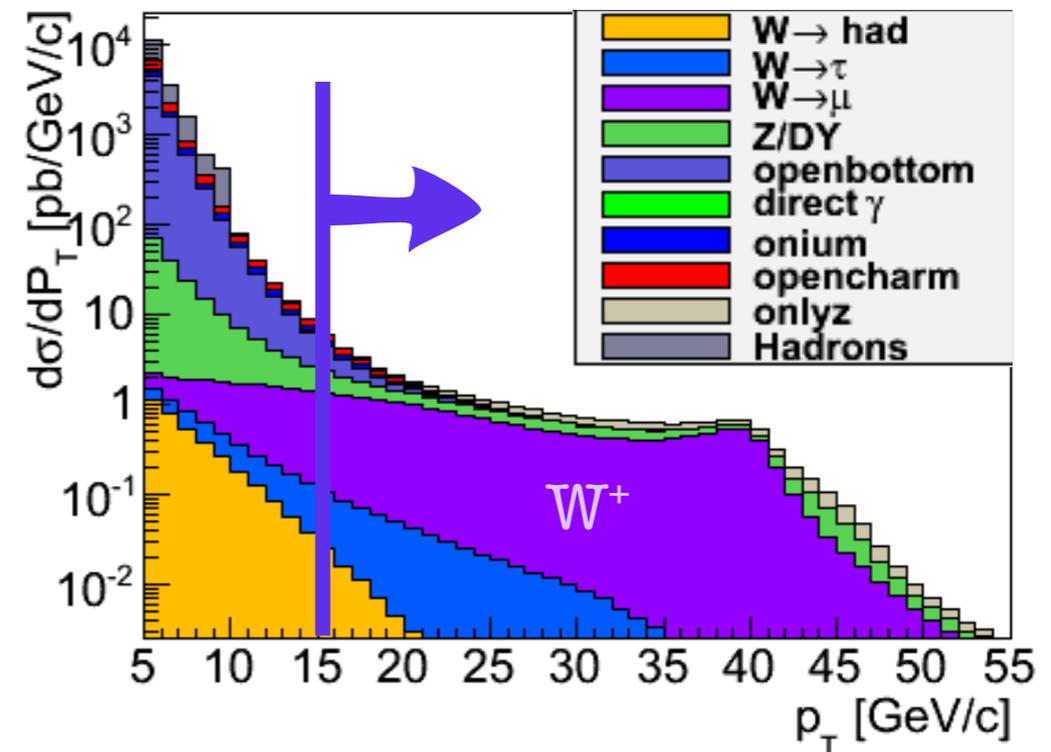
Large Background !

Muon cross-section dominated by W only at high p_T !

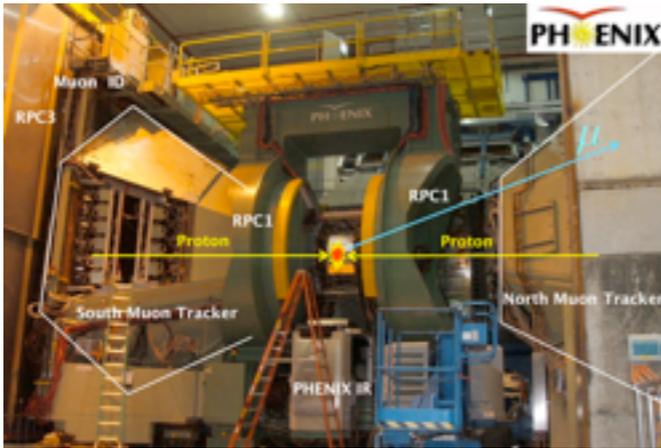
P_T spectrum (stacked) μ^-



P_T spectrum (stacked) μ^+



W decay at forward rapidities

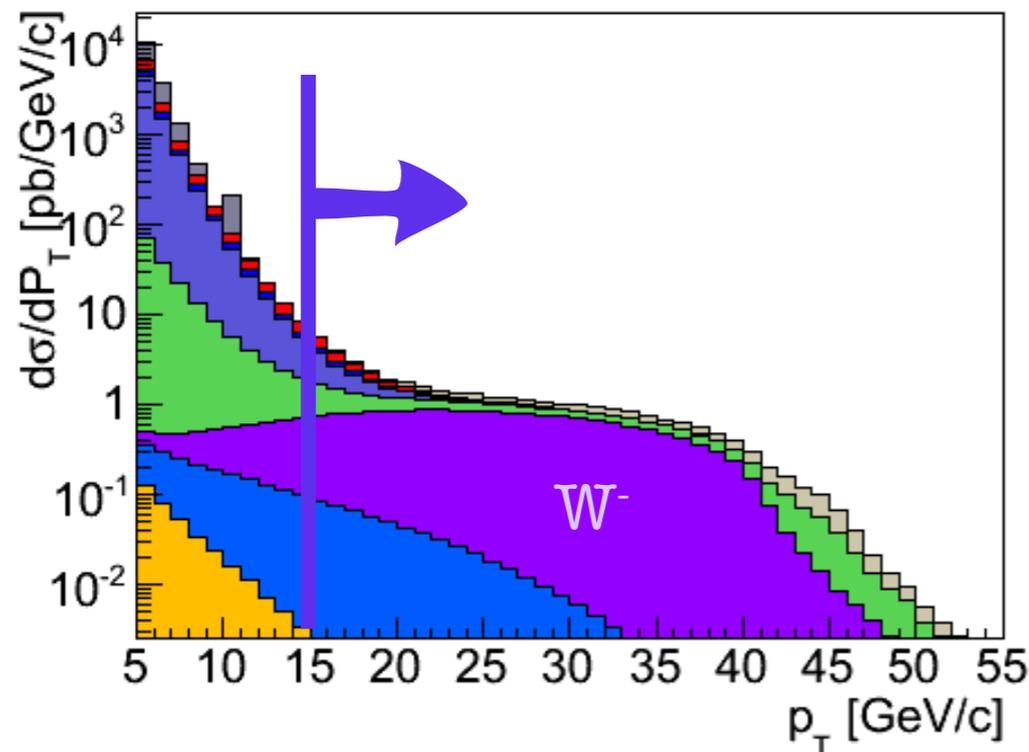


Background from other than W muon sources
only part of the story!

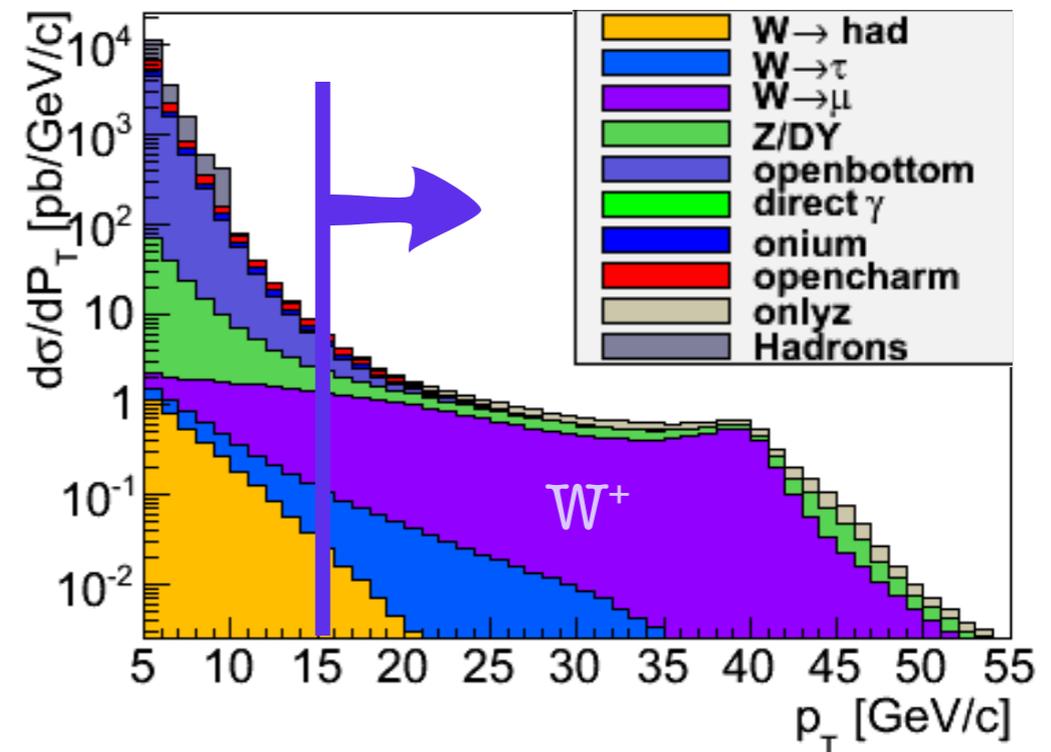
3 types of Backgrounds:

1. Muon background: open-heavy flavor decay, quarkonia, Drell-Yan

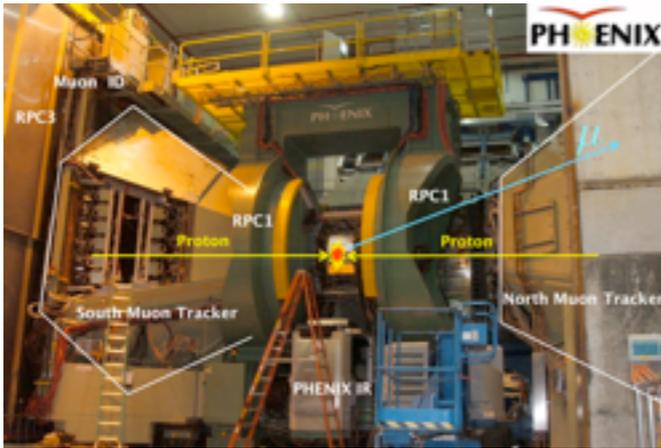
P_T spectrum (stacked) μ^-



P_T spectrum (stacked) μ^+



W decay at forward rapidities

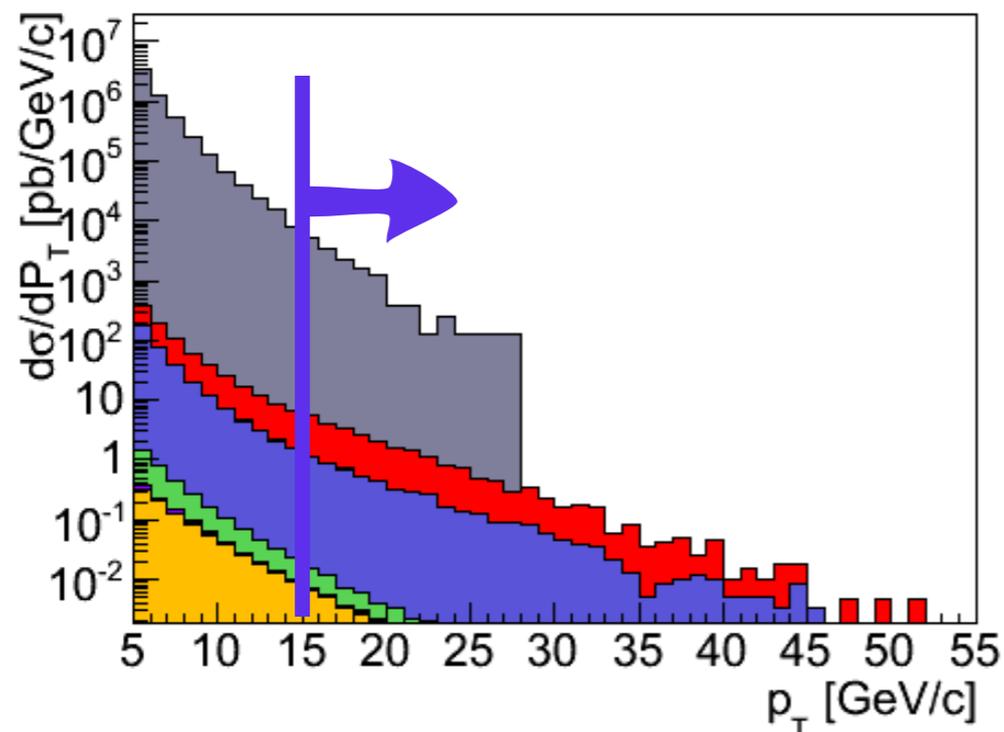


Background from other than W muon sources
only part of the story!

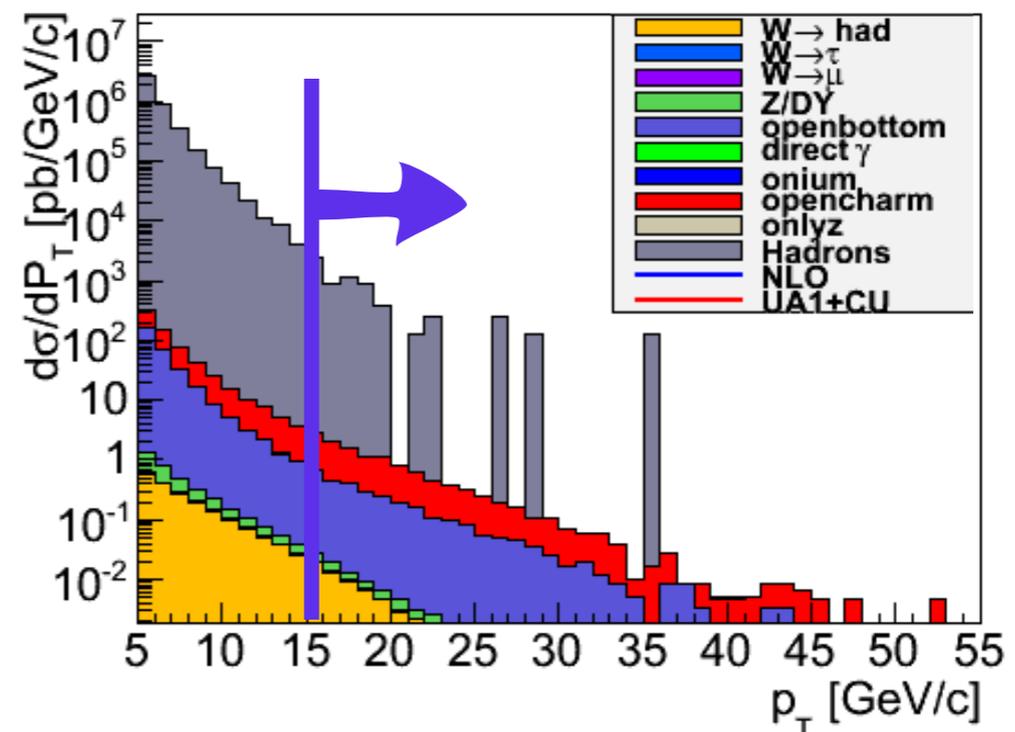
3 types of Backgrounds:

1. Muon background: open-heavy flavor decay, quarkonia, Drell-Yan
2. Punch-through Hadrons: from W and other sources
- in principle at low p_T , but muon arms have large momentum smearing !

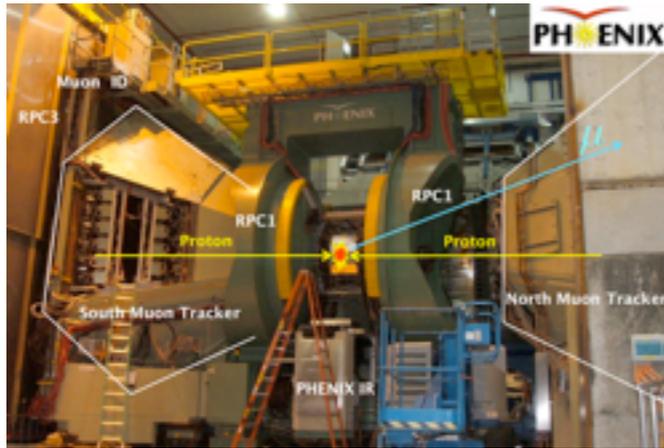
P_T spectrum (stacked) h^-



P_T spectrum (stacked) h^+



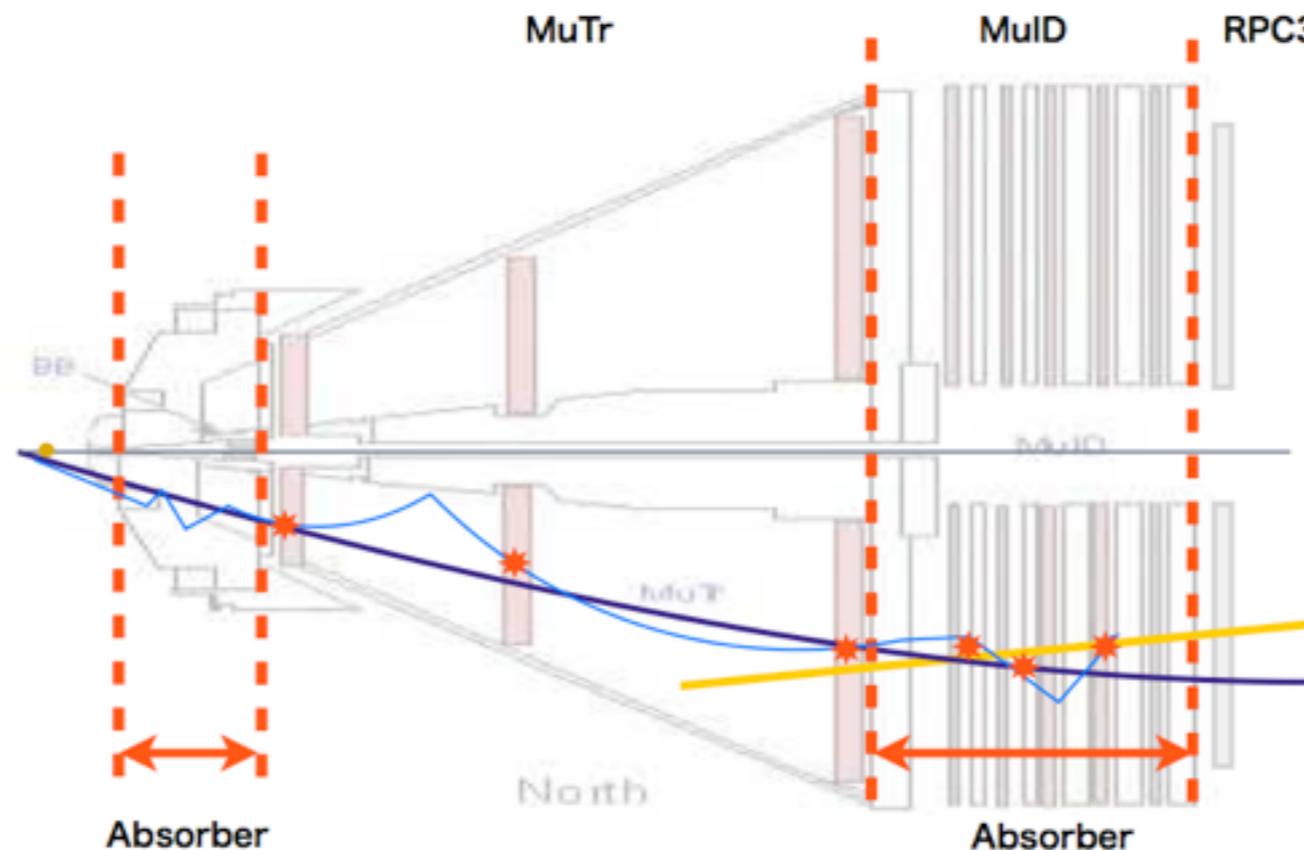
W decay at forward rapidities



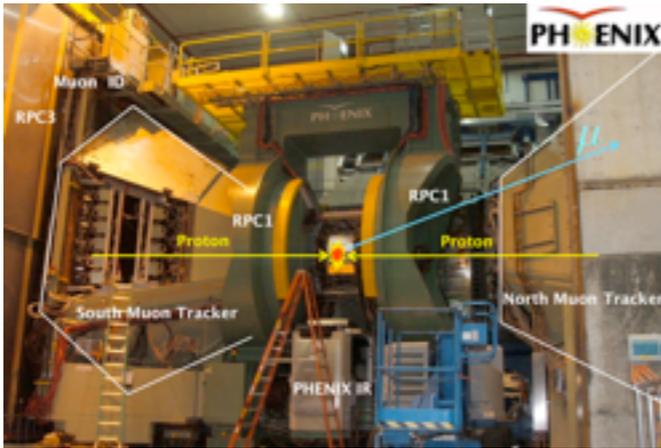
Background from other than W muon sources
only part of the story!

3 types of Backgrounds:

1. Muon background: open-heavy flavor decay, quarkonia, Drell-Yan
2. Punch-through Hadrons: from W and other sources
- in principle at low p_T , but muon arms have large momentum smearing !
3. Fake high- p_T muons



W decay at forward rapidities

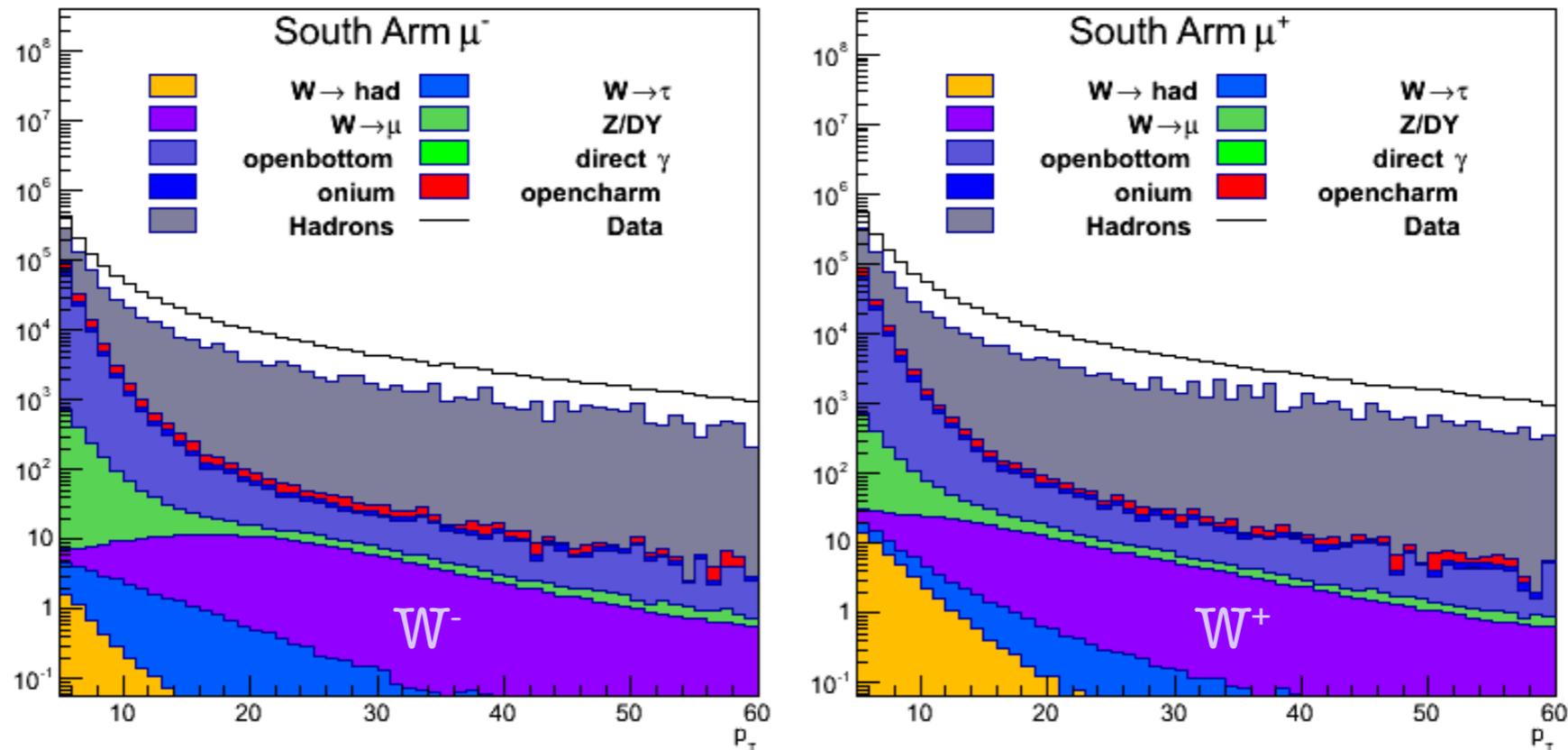


Background from other than W muon sources
only part of the story!

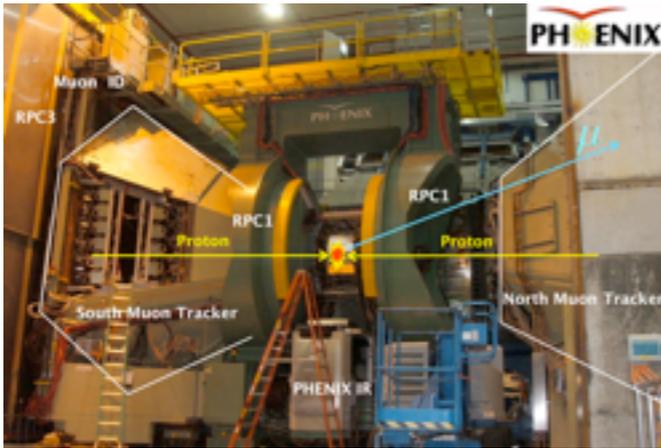
3 types of Backgrounds:

1. Muon background: open-heavy flavor decay, quarkonia, Drell-Yan
2. Punch-through Hadrons: from W and other sources
- in principle at low p_T , but muon arms have large momentum smearing !
3. Fake high- p_T muons

Total background, accounting for all sources and smearing:



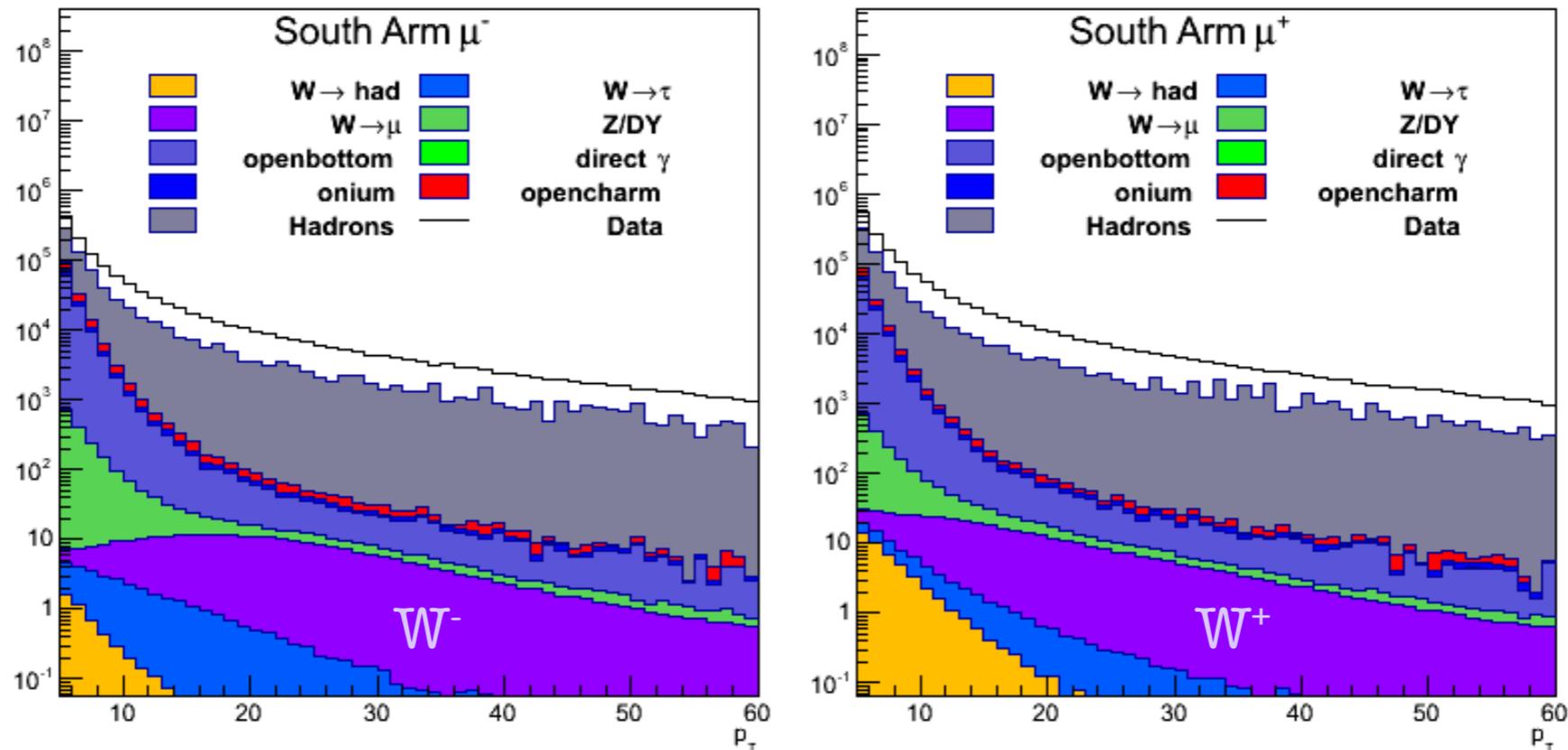
W decay at forward rapidities



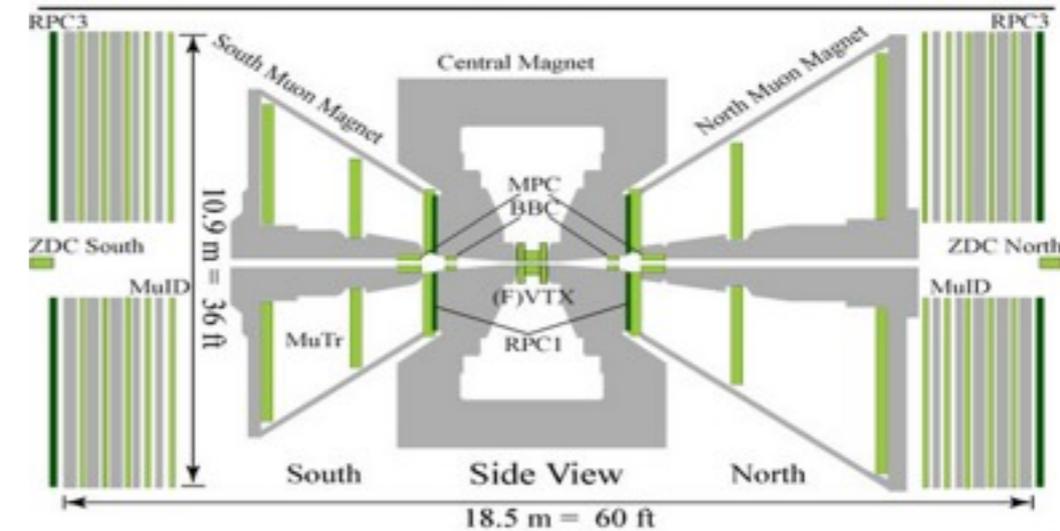
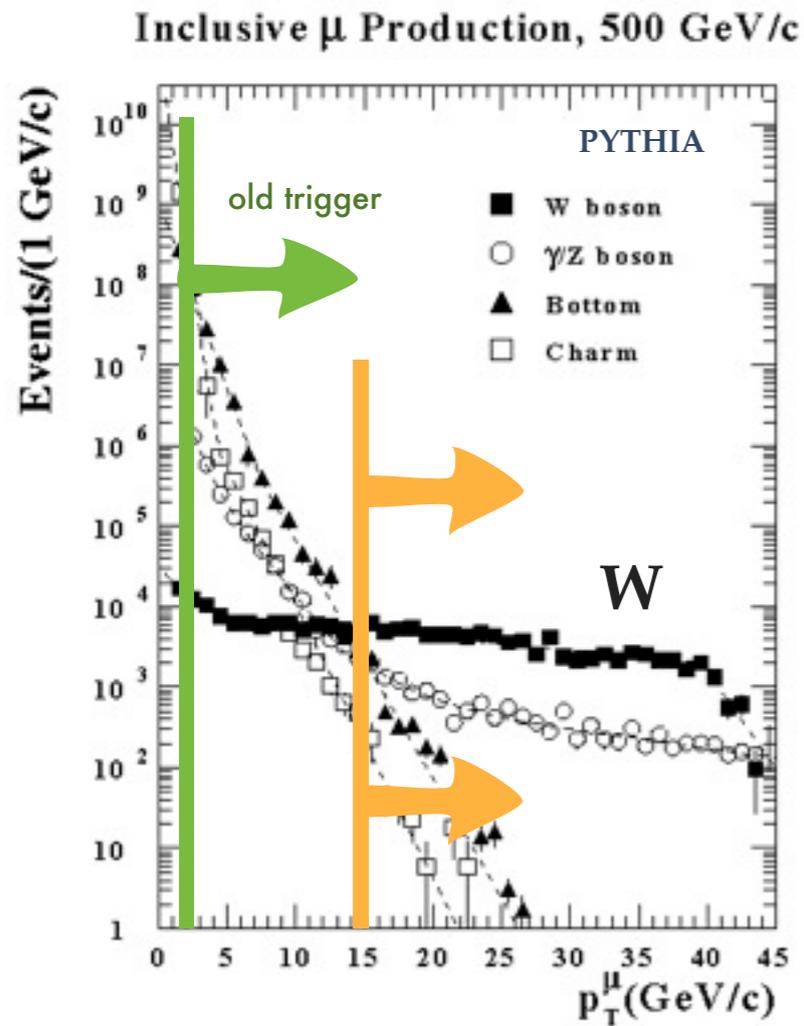
Analysis strategy:

1. Muon Trigger upgrade
2. Reduce background as much as possible
3. Estimate signal-to-background ratio
4. Evaluate asymmetries

Total background, accounting for all sources and smearing:



Phenix Forward Upgrade



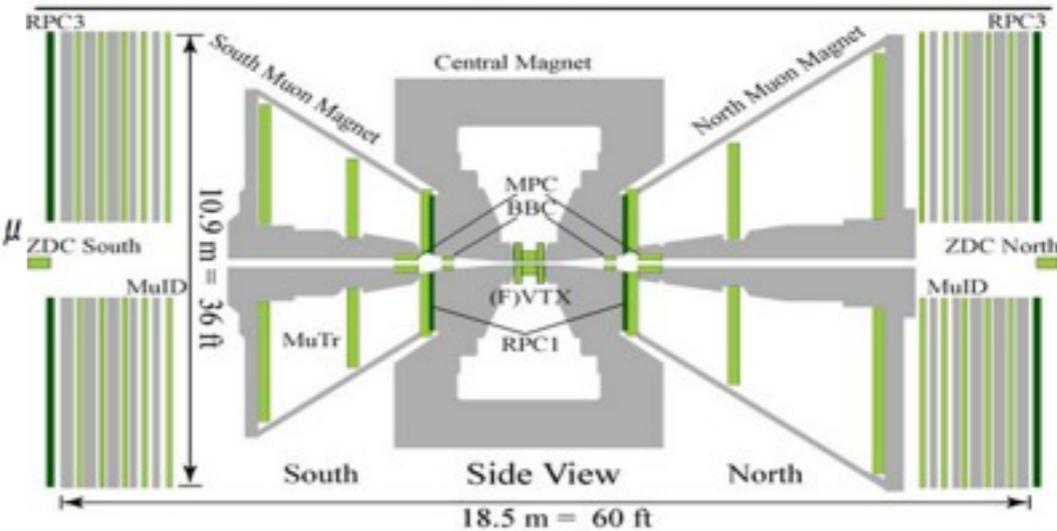
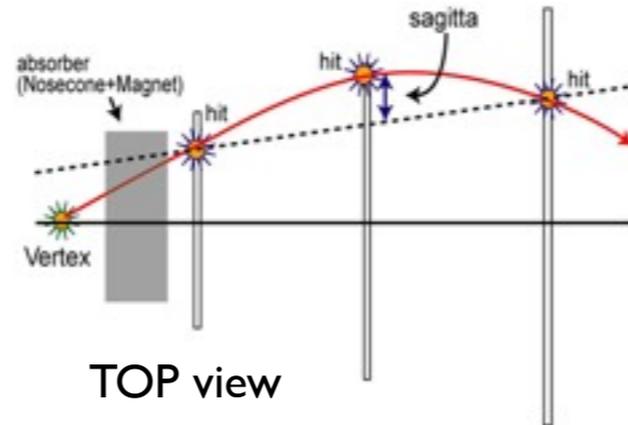
Phenix upgraded the existing muon arms for a dedicated muon-from-W trigger!



Phenix Forward Upgrade

1. Add momentum info in the trigger

MuTracker FEE upgrades



Phenix upgraded the existing muon arms for a dedicated muon-from-W trigger!

➔ Reject muons with momentum < 15 GeV

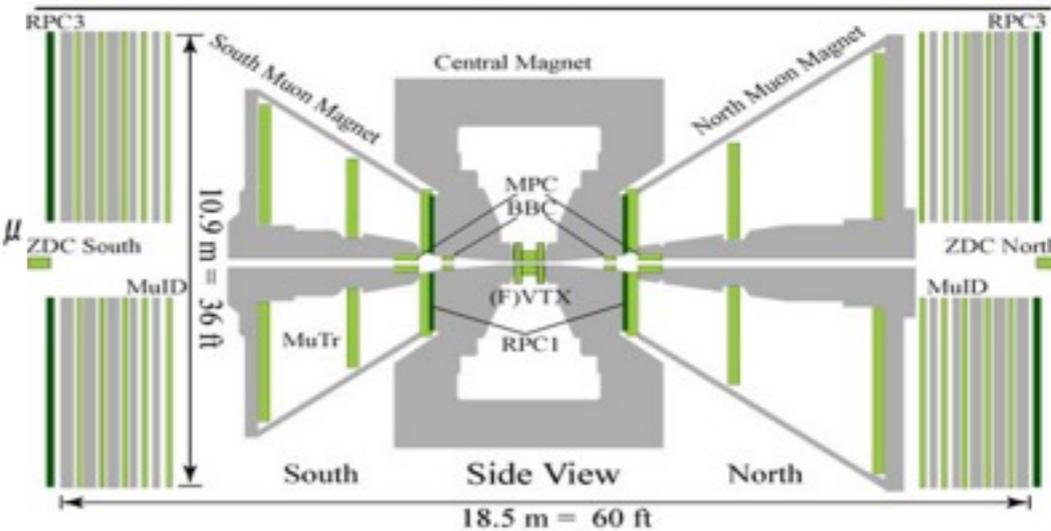
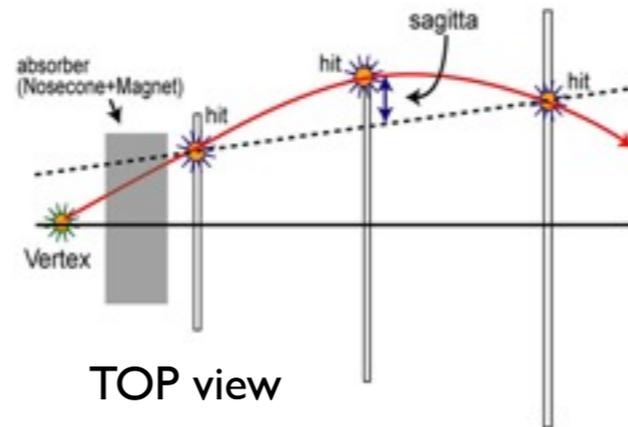


Phenix Forward Upgrade

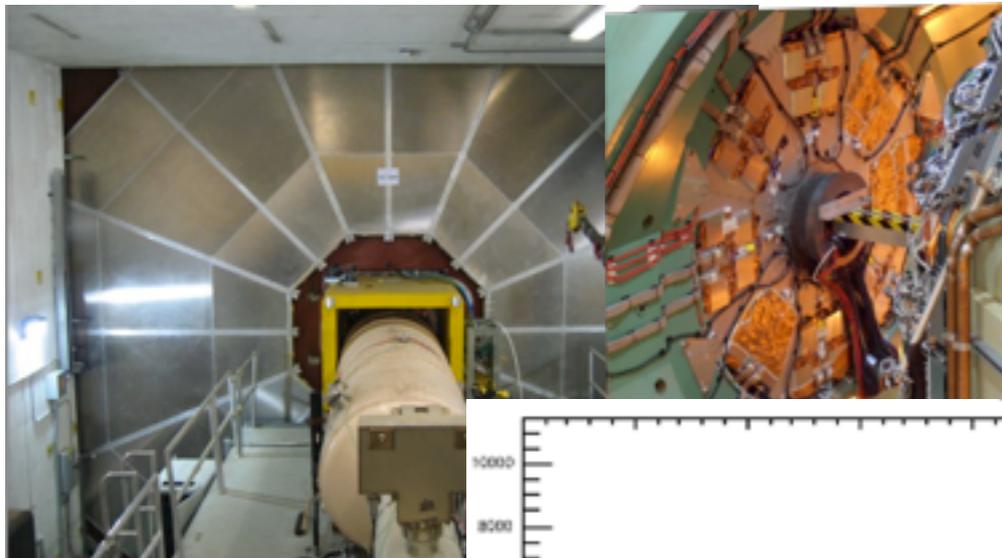
1. Add momentum info in the trigger



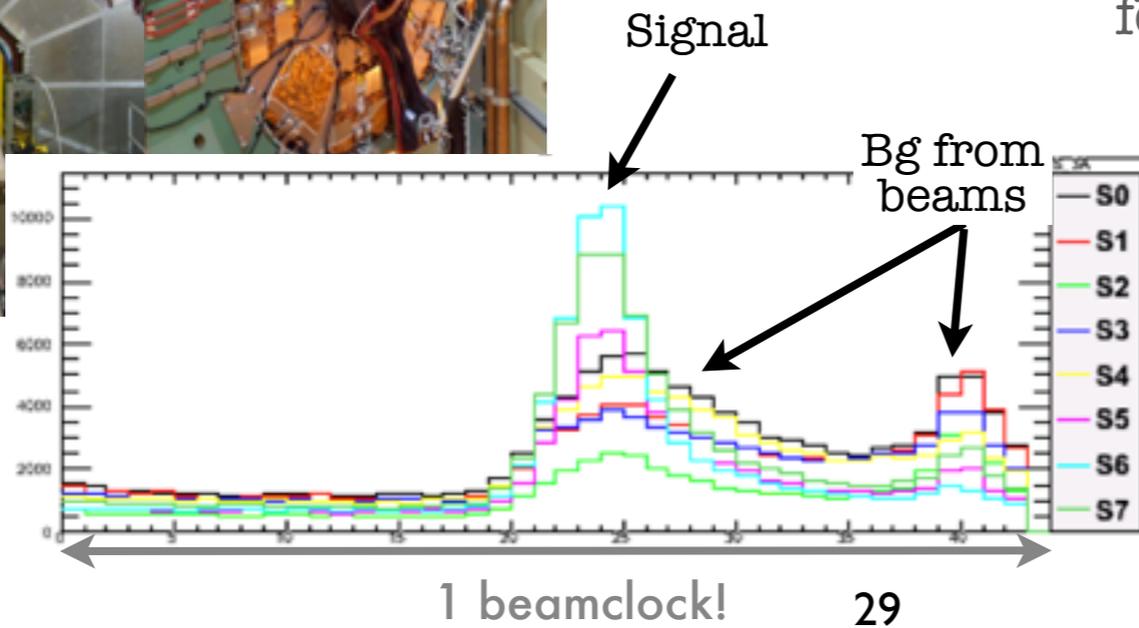
MuTracker FEE upgrades



2. Addition of 4 new RPC stations



Phenix upgraded the existing muon arms for a dedicated muon-from-W trigger!



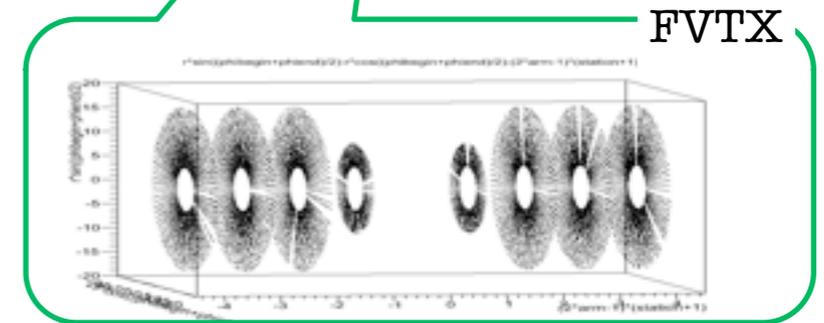
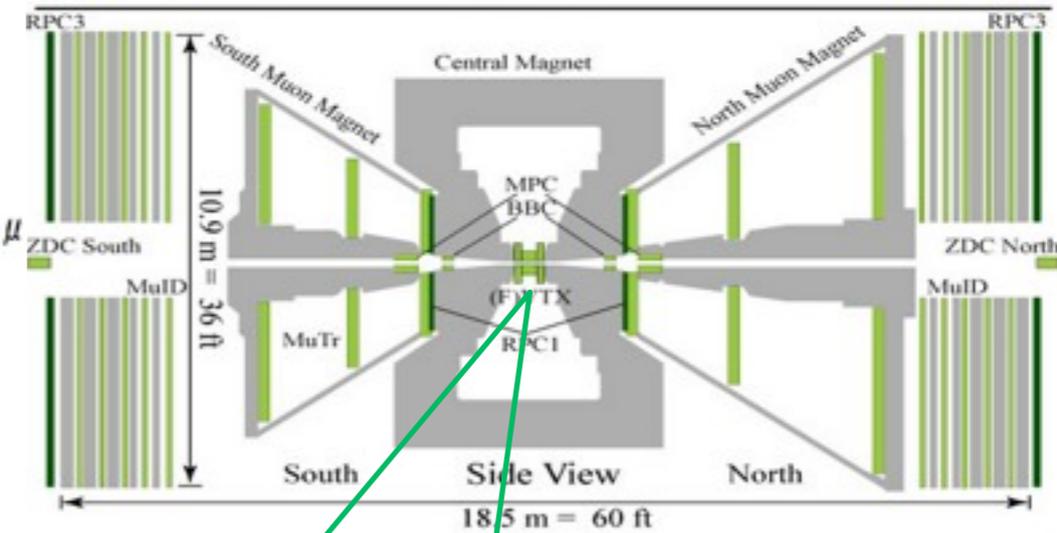
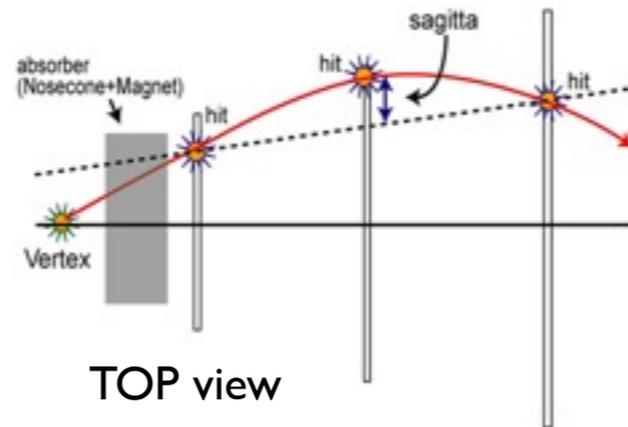
- ➔ Reject muons with momentum < 15 GeV
- ➔ Add precise timing information
 1. to reject out of time background
 2. to correlate events with beam polarization



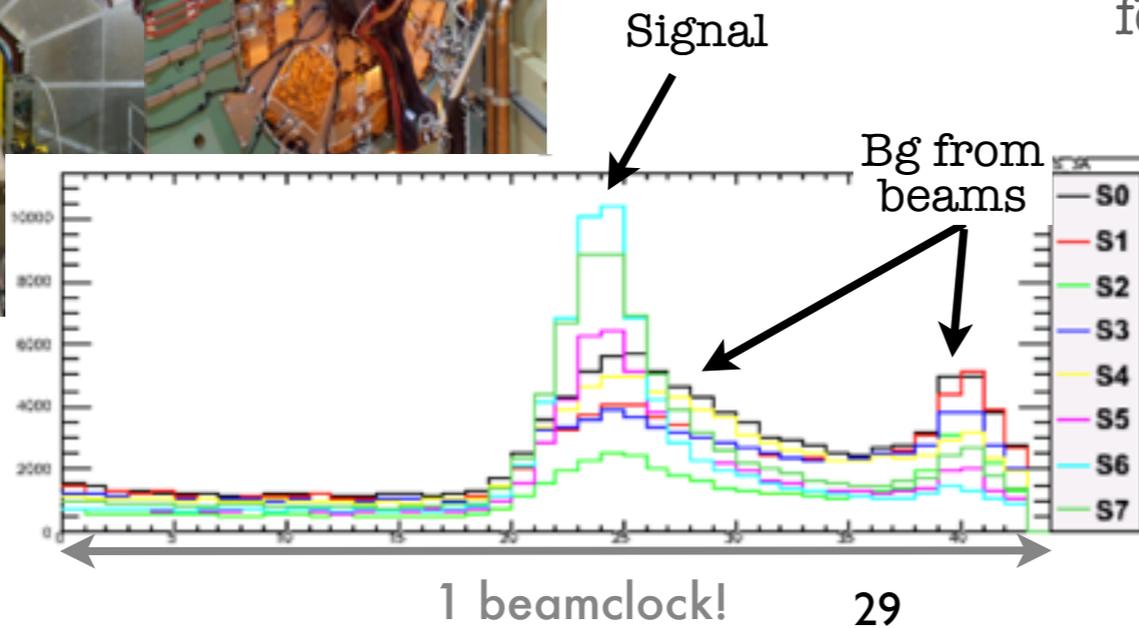
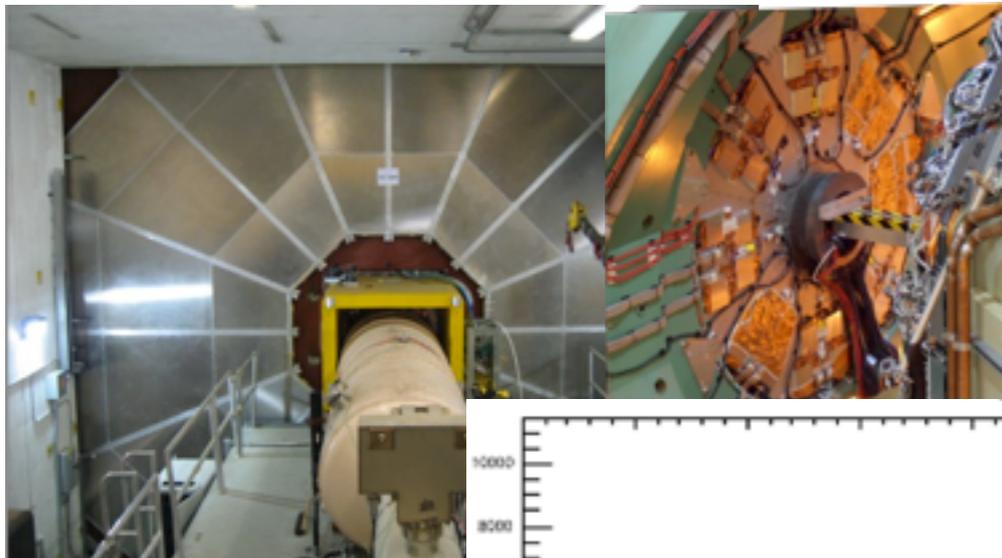
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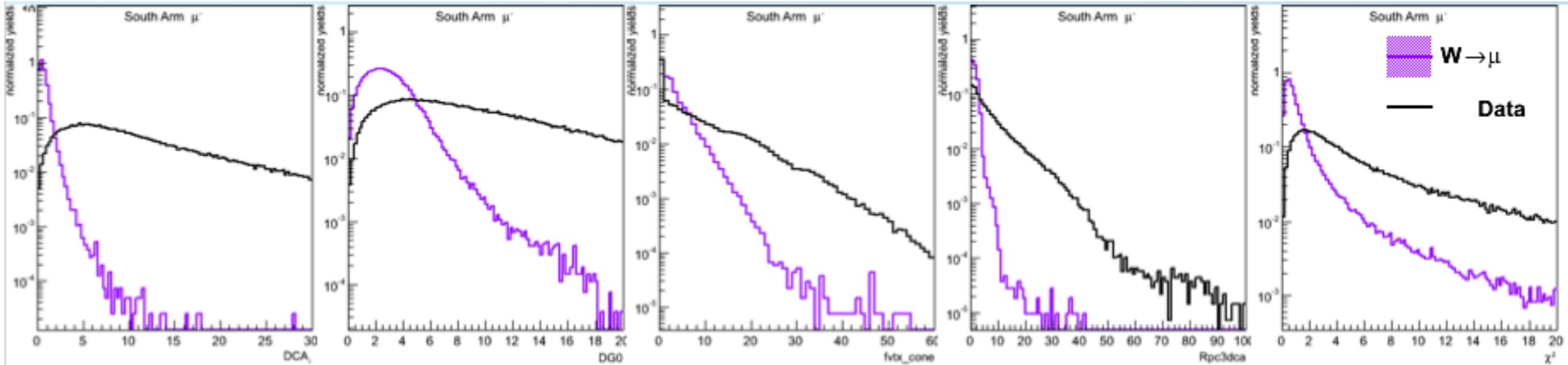


Phenix upgraded the existing muon arms for a dedicated muon-from-W trigger!

- ➔ Reject muons with momentum < 15 GeV
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 1. to reject out of time background
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Definining the W-ness of an event

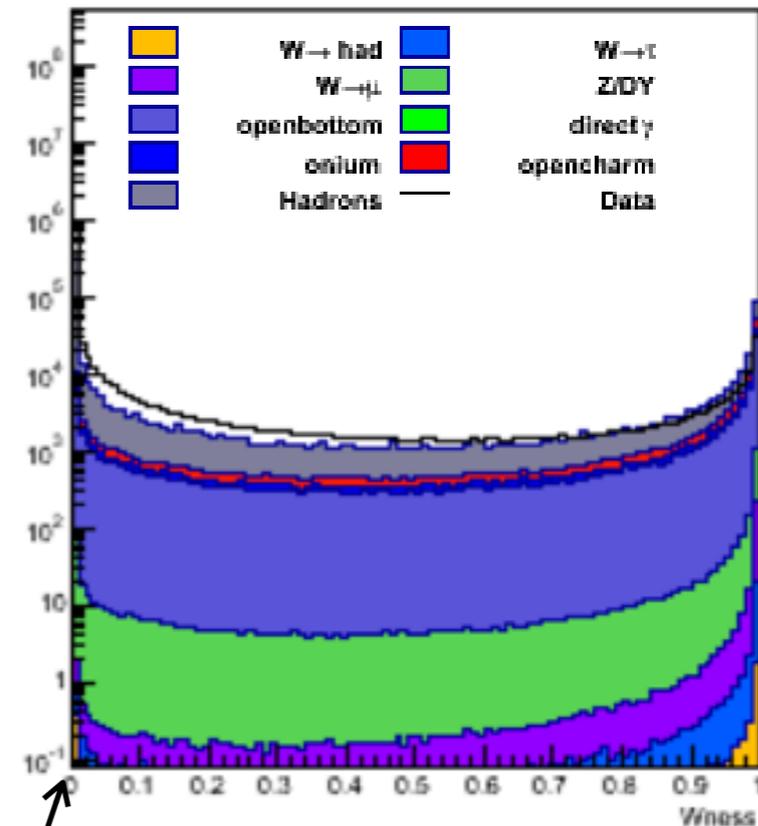


$$Wness = \frac{\lambda_{signal}}{\lambda_{signal} + \lambda_{bg}}$$

$$\lambda = [p(DG0, DDG0), p(DCA), p(\chi^2), p(RPC_DCA), p(FVTX_match), p(FTVX_cone)]$$

Signal likelihood based on probability density functions from simulated W events

Background likelihood based on pdfs from bg-dominated data (signal < 1%)

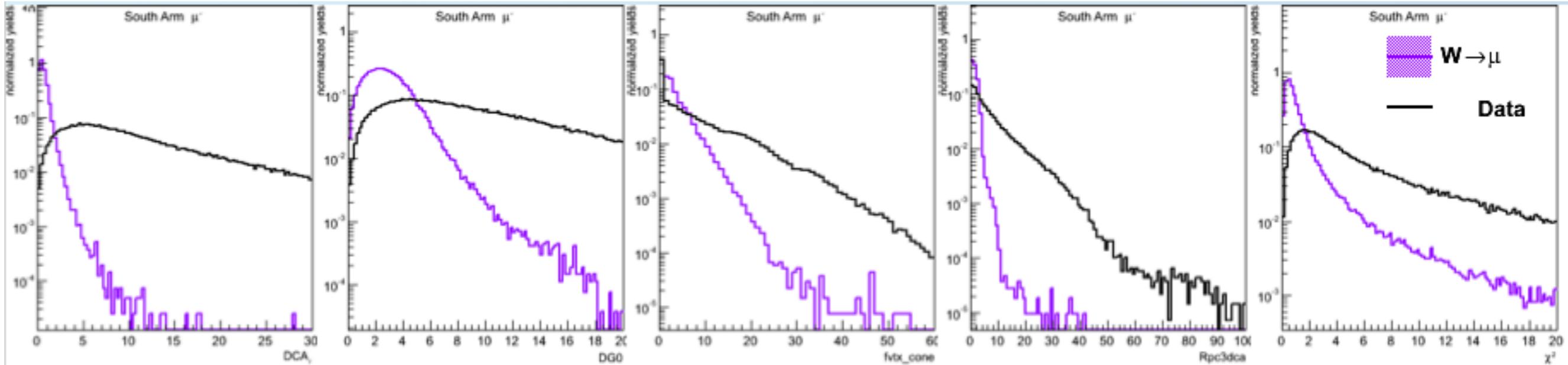


Unlikely a W-event

Very likely a W-event



Definining the W-ness of an event

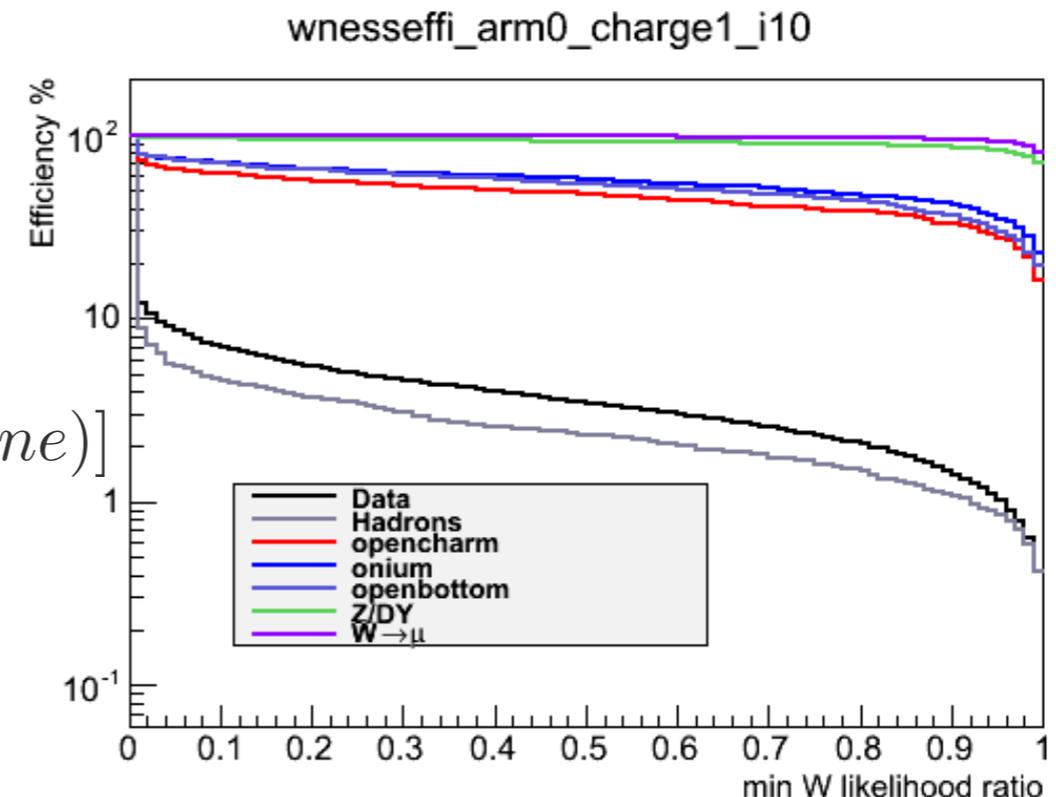


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Signal likelihood based on probability density functions from simulated W events

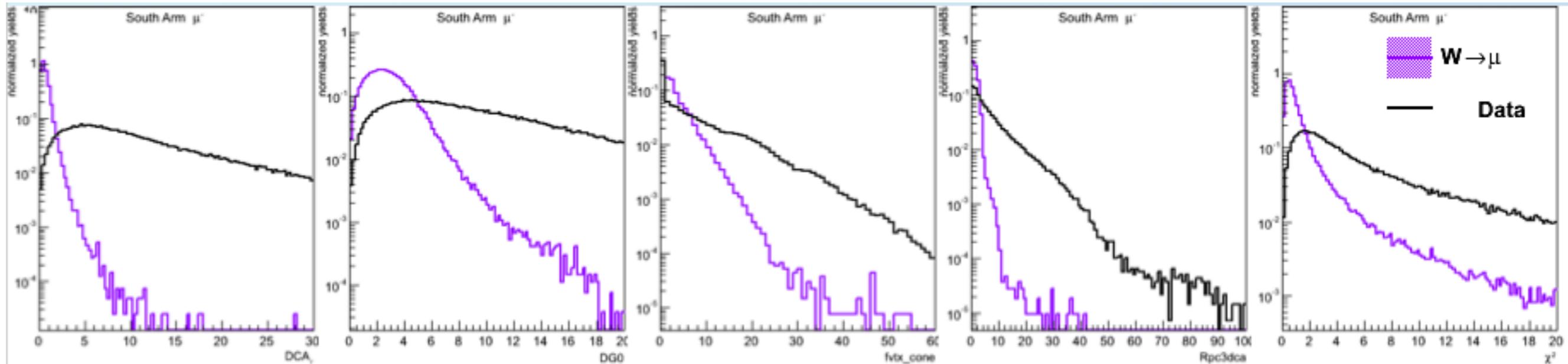
Background likelihood based on pdfs from bg-dominated data (signal < 1%)



High-efficiency cut parameter!



Definining the W-ness of an event



$$Wness = \frac{\lambda_{signal}}{\lambda_{signal} + \lambda_{bg}}$$

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Signal likelihood based on probability density functions from simulated W events

Background likelihood based on pdfs from bg-dominated data (signal < 1%)

Cut chosen:

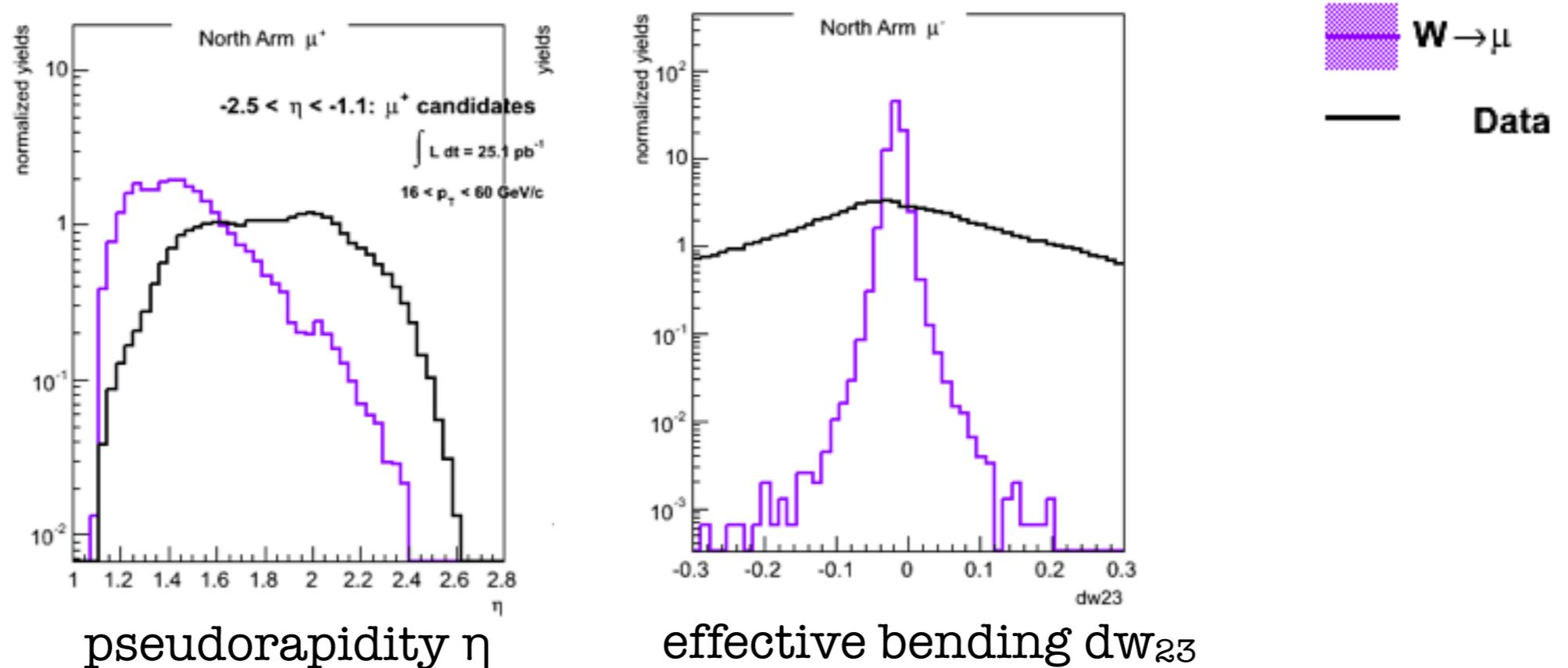
$$Wness > 0.99$$

fixed looking at the FOM of uncertainties (stat+sys) for the final asymmetries



Extraction of the Sig/Bg ratio

via an Extended Unbinned, 2-D, Maximum-Likelihood fit
(2D EUMLF)



(Independent from the variables
used in the wness estimation)



Extraction of the Sig/Bg ratio

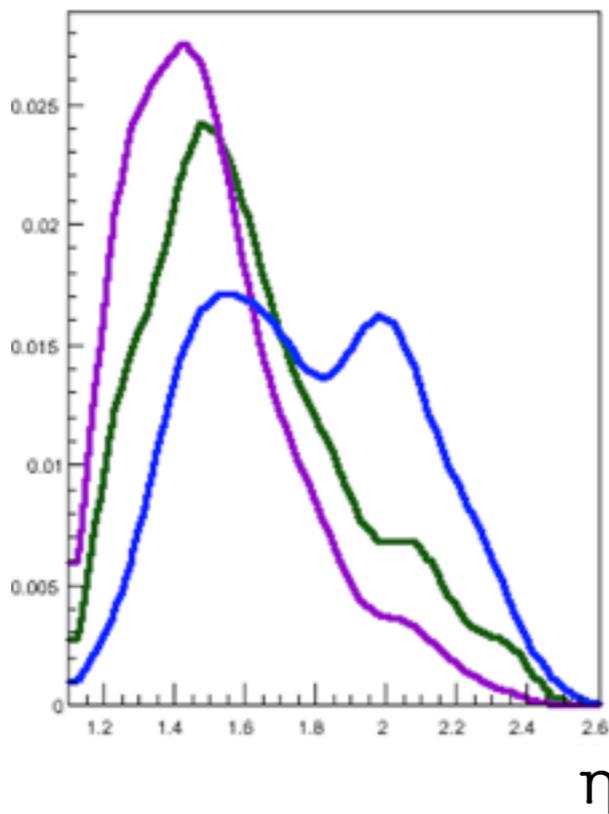
via an Extended Unbinned, 2-D, Maximum-Likelihood fit
(2D EUMLF)

$$\mathcal{L}(\theta|X) \equiv \frac{n^N e^{-n}}{N!} \prod_{x_i \in X} \sum_c \frac{n_c}{n} p_c(x_i)$$

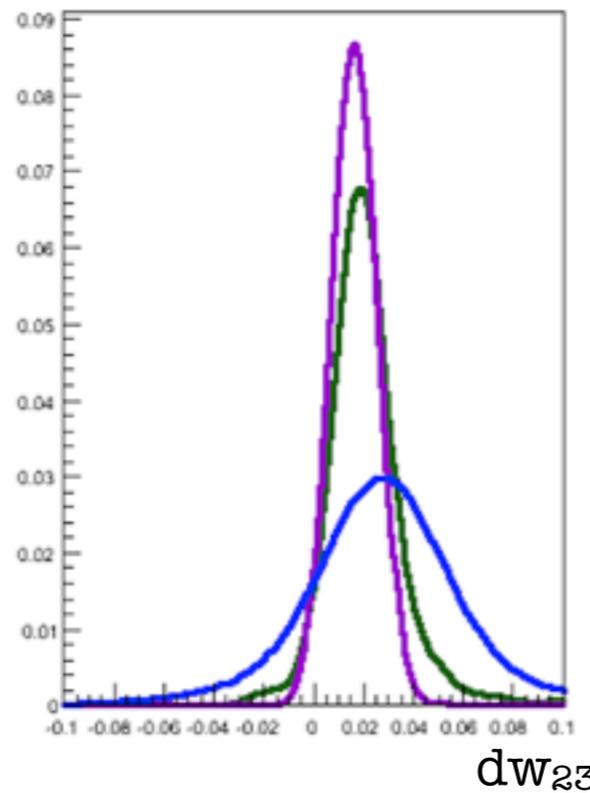
$\theta = (n_{sig}, n_{\mu}, n_{had})$

fixed \rightarrow n_{μ}

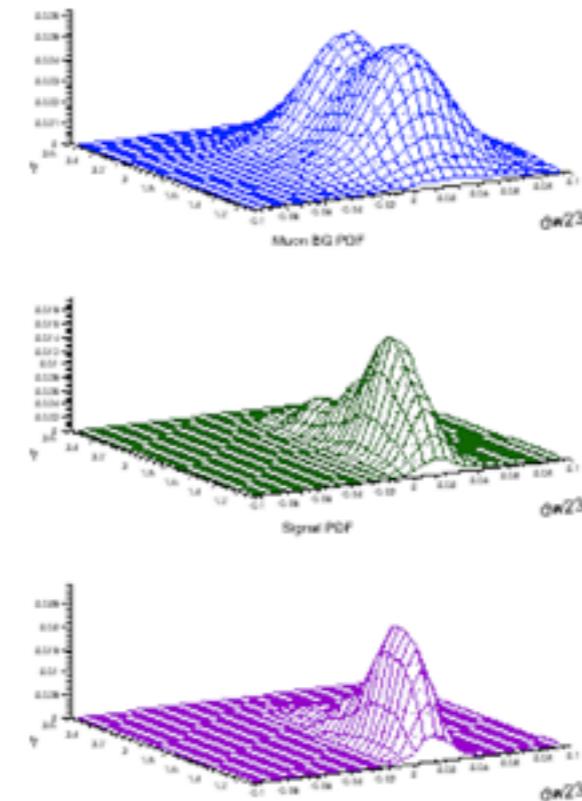
parameters \rightarrow n_{sig}, n_{had}



for W
from Simulation



for Muon bg
from Simulation



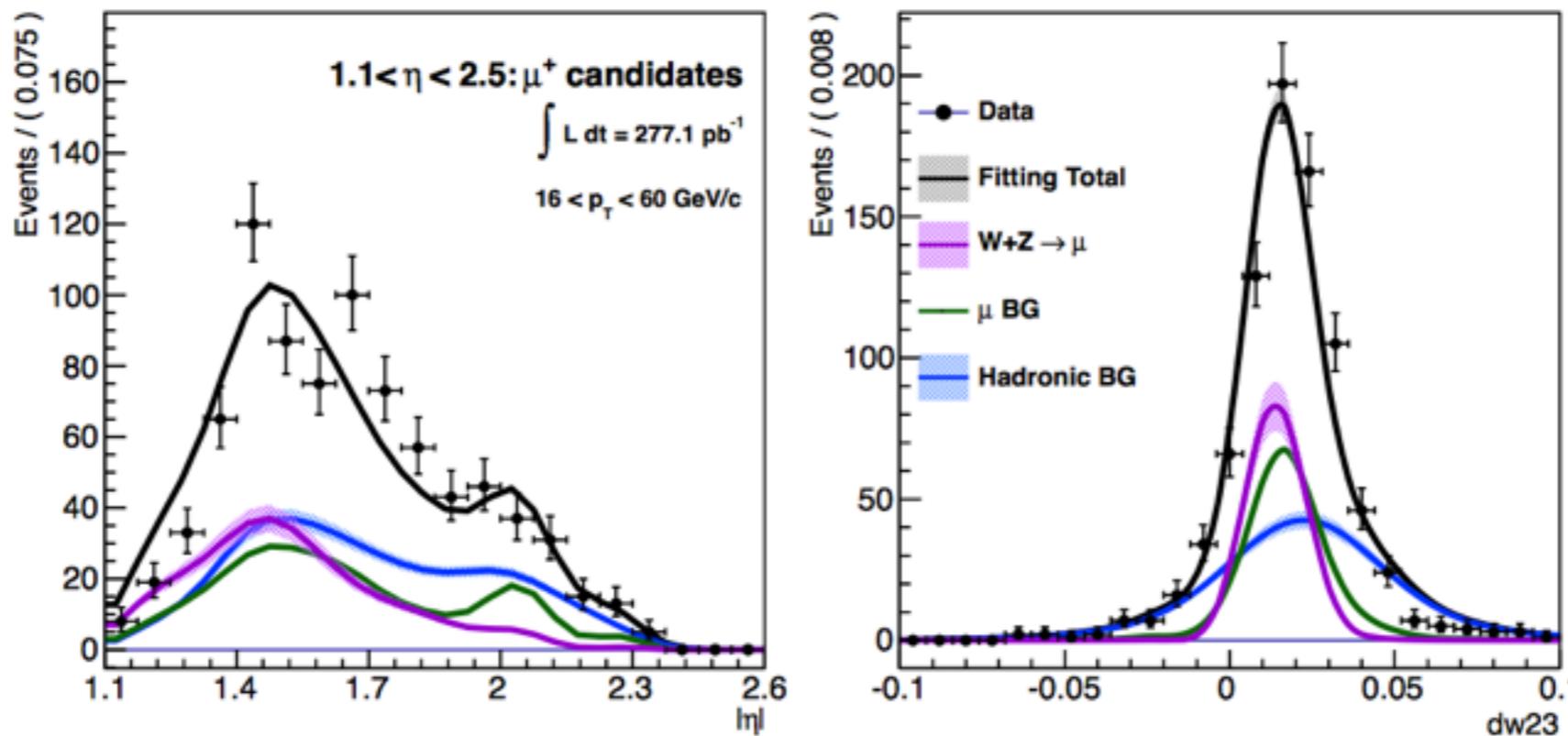
for Hadron bg
& Fake muons extrapolated from
bg-dominated data (low-wness)



Extraction of the Sig/Bg ratio

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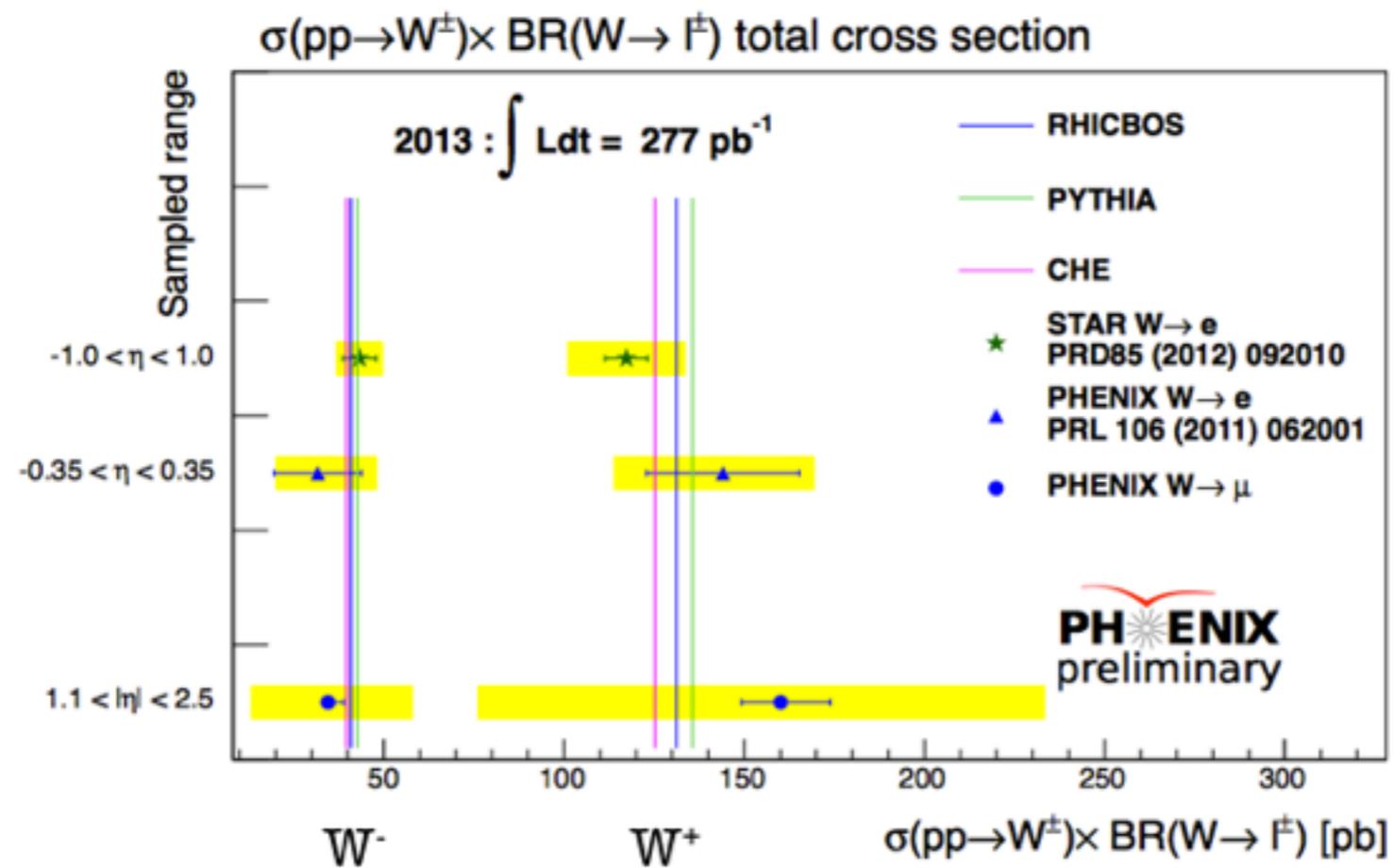
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Sig/Bg ratio from 30% to 50%, depending on
Phenix arm/muon charge/eta region



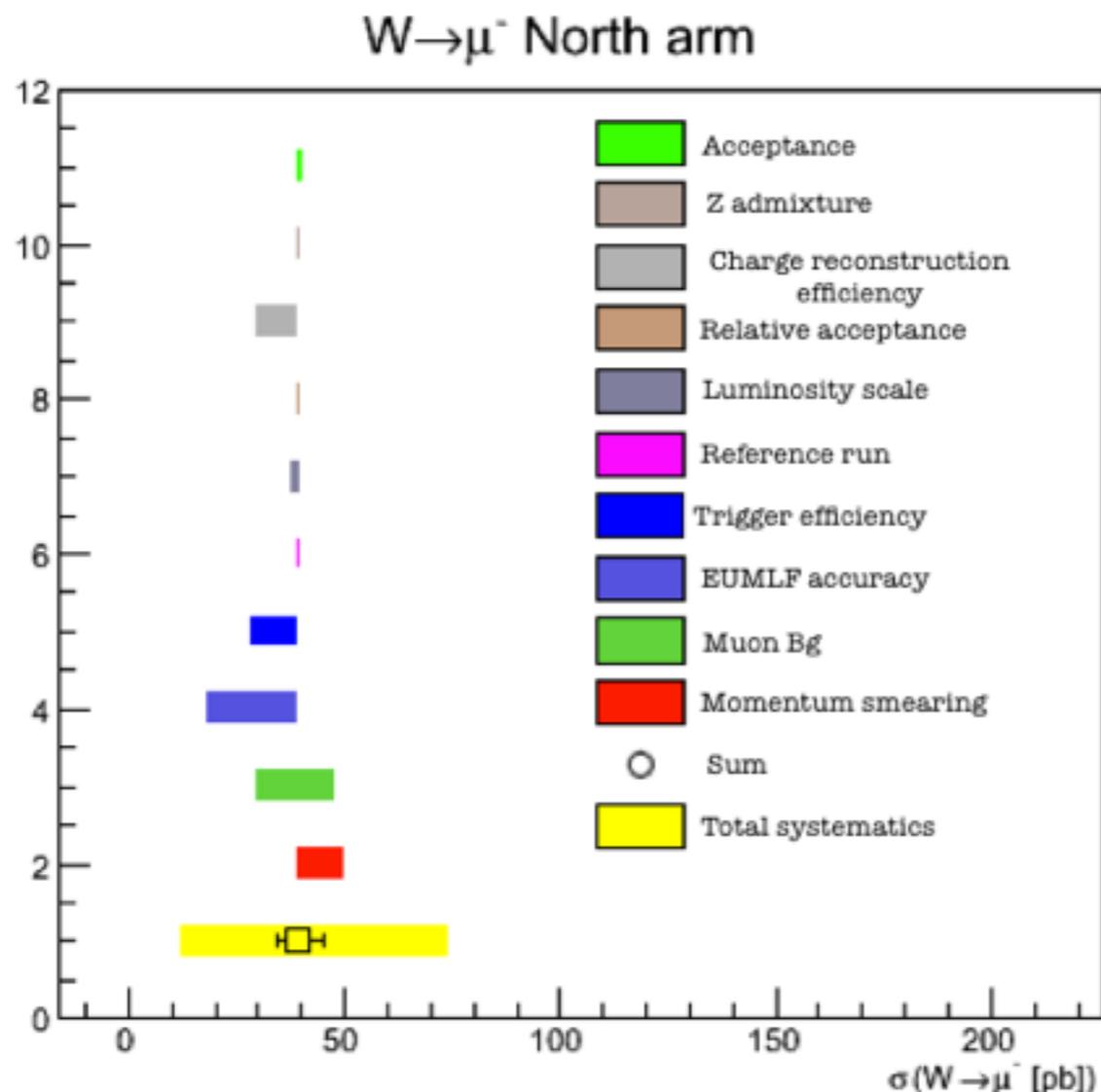
W cross-section



Consistent with prediction within
the large uncertainties



W cross-section: systematics



Major contributions:

→ Momentum smearing

→ Muon bg estimate

→ 2D-EUMLF accuracy
(tested with MC inputs)

→ Trigger efficiency

→ About 20% charge
misidentification

All uncertainties propagated to the asymmetries via sig/bg fit uncertainty

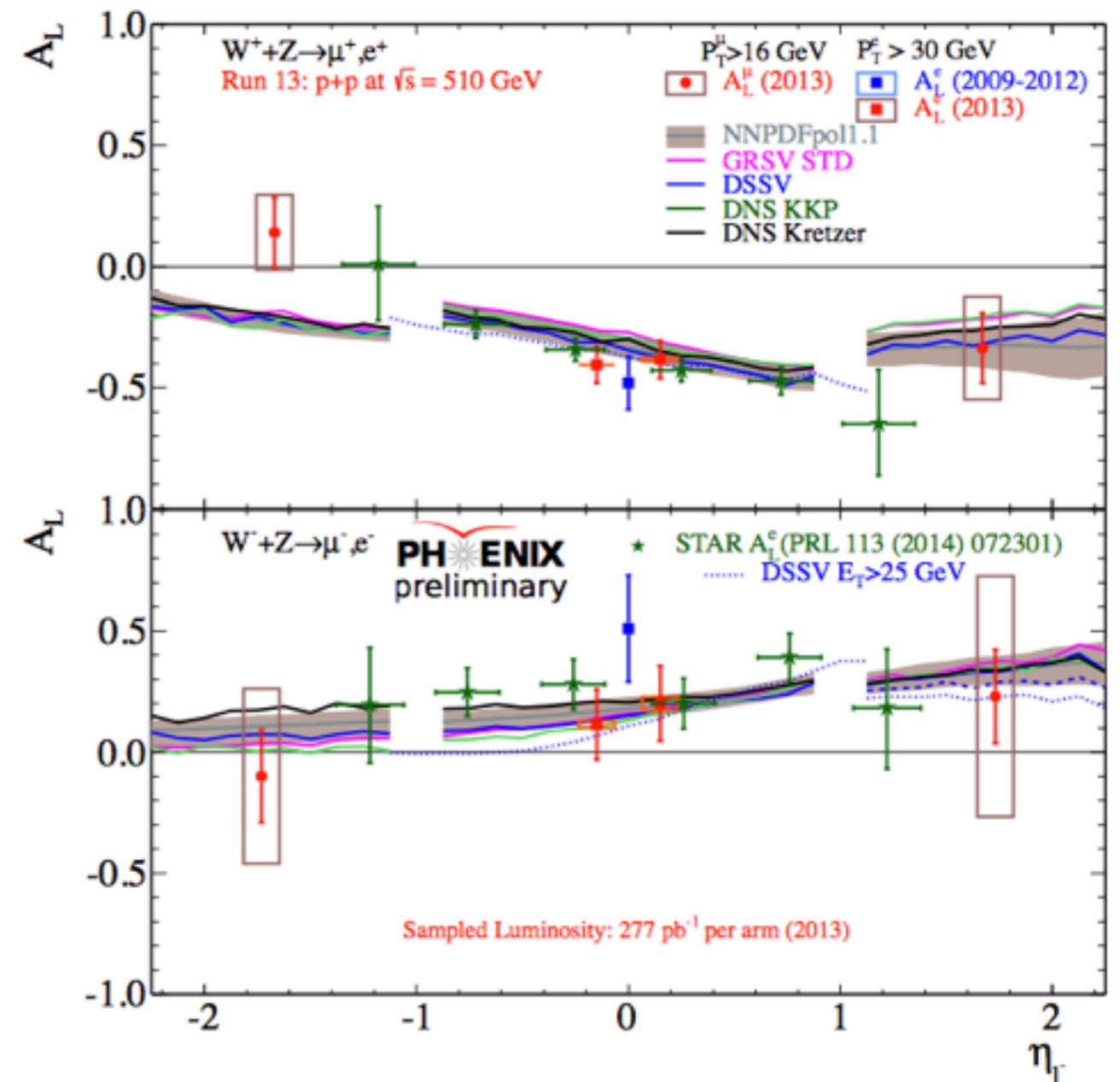


Single Spin Asymmetries

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

Background A_L
consistent with 0

Background treated as a
dilution in the measured A_L



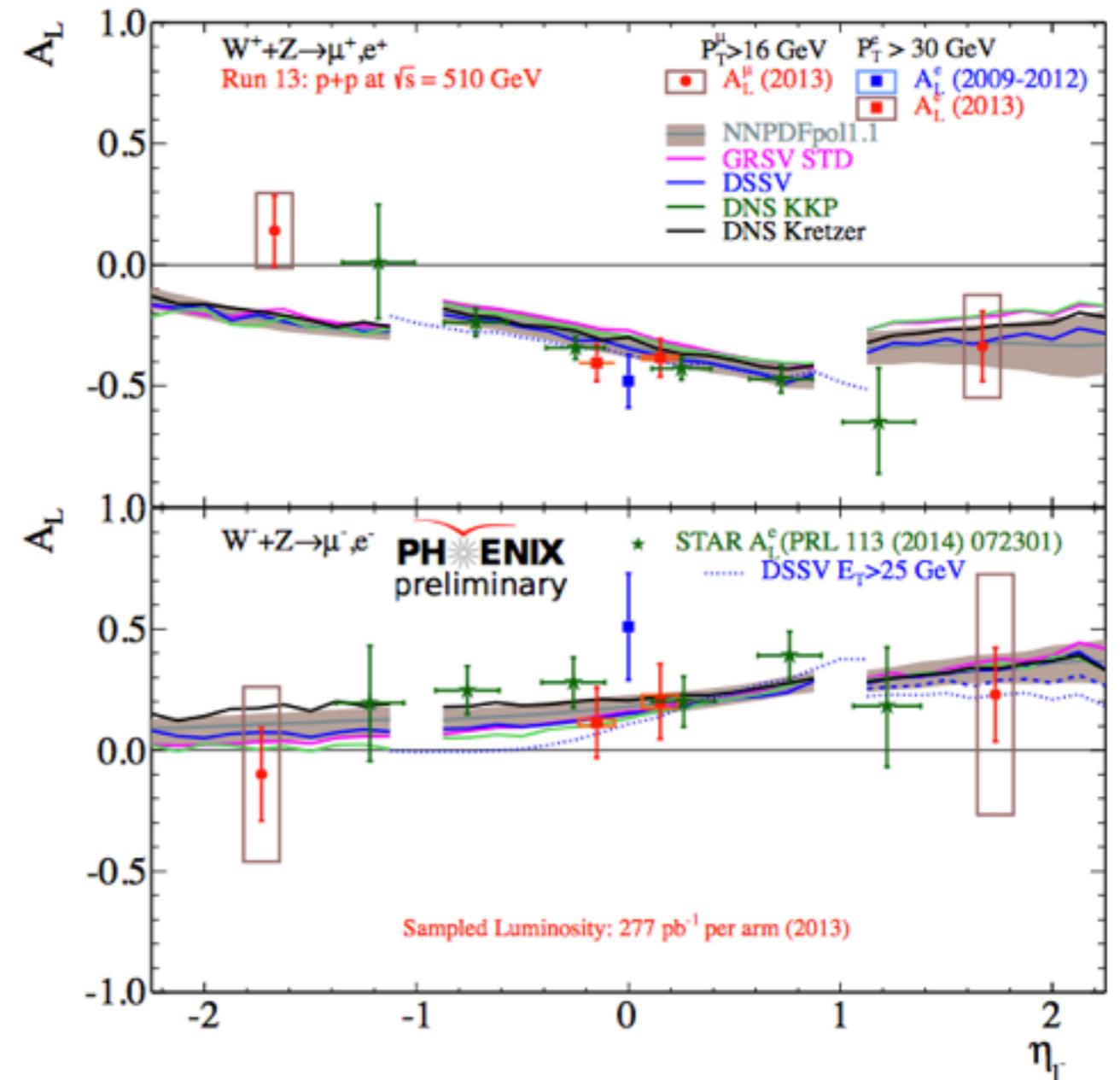
Single Spin Asymmetries

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

Phenix A_L for W^+ decay leptons appear to be consistent with prediction at center and forward rapidities

At backward rapidities A_L seems to be positive/consistent with zero (similarly to the A_L observed from STAR for positive electrons A_L)

Phenix A_L for W^- decay leptons are qualitatively consistent with predictions



Summary

About 300 pb^{-1} at 500 GeV collected at Phenix for $W \rightarrow l\nu$

All data analyzed

→ $W \rightarrow e^{+-}$ in central rapidities:

final results and paper in advance stage, will be submitted soon

→ $W \rightarrow \mu^{+-}$ in forward rapidities:

preliminary results for run 2013 presented here for the first time

Work in progress to reduce systematics:

- improve signal to background extraction
- new data production to correct for known momentum smearing and improve the charge reconstruction



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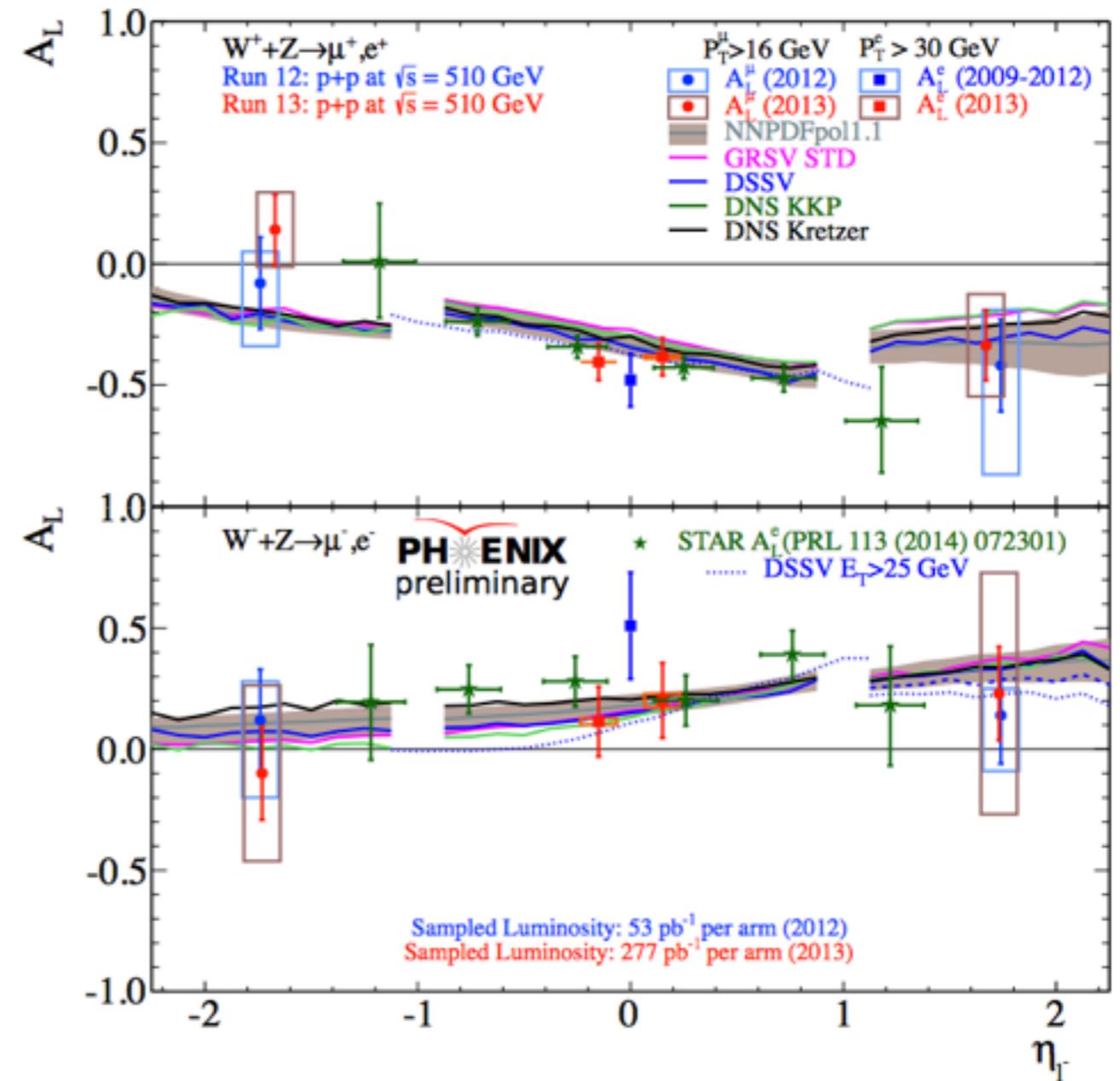
Thank you!



Single Spin Asymmetries

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

Results from 2013 data compatible with previous results (2012 data)



Single Spin Asymmetries

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

η dependence:

Large uncertainties, similar conclusions

Phenix A_L for W^+ decay leptons appear to be consistent with prediction at center and forward rapidities

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