W boson production and spin asymmetry measurements at PHENIX

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Kyoto Univ. / RIKEN

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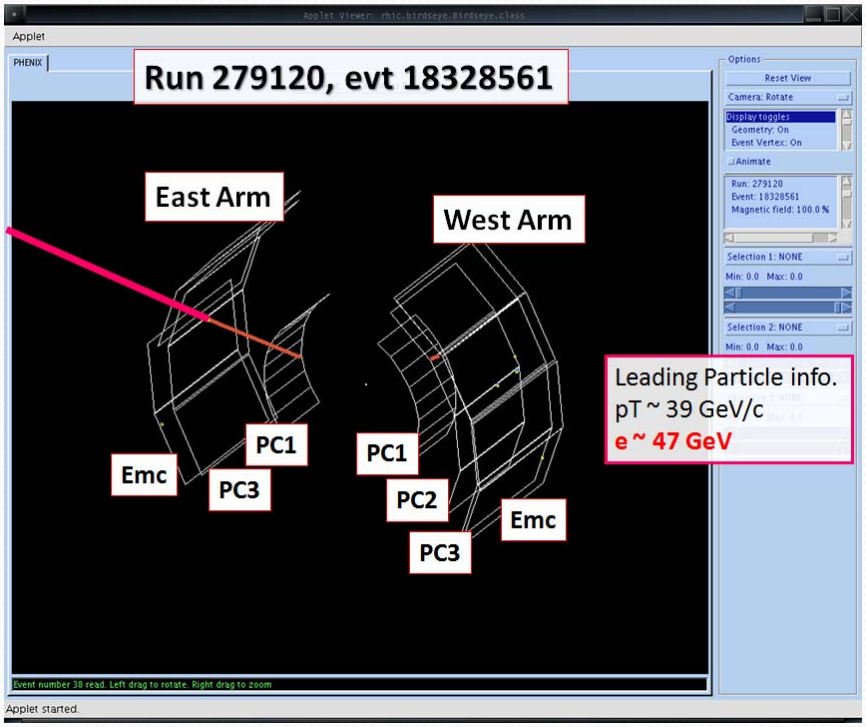
Contents

1. Probe Proton Spin with W boson
2. W detection @ PHENIX
   - PHENIX Muon Arms
   - PHENIX Central Arms
3. Summary & Outlook



1. Probe Proton Spin with W boson

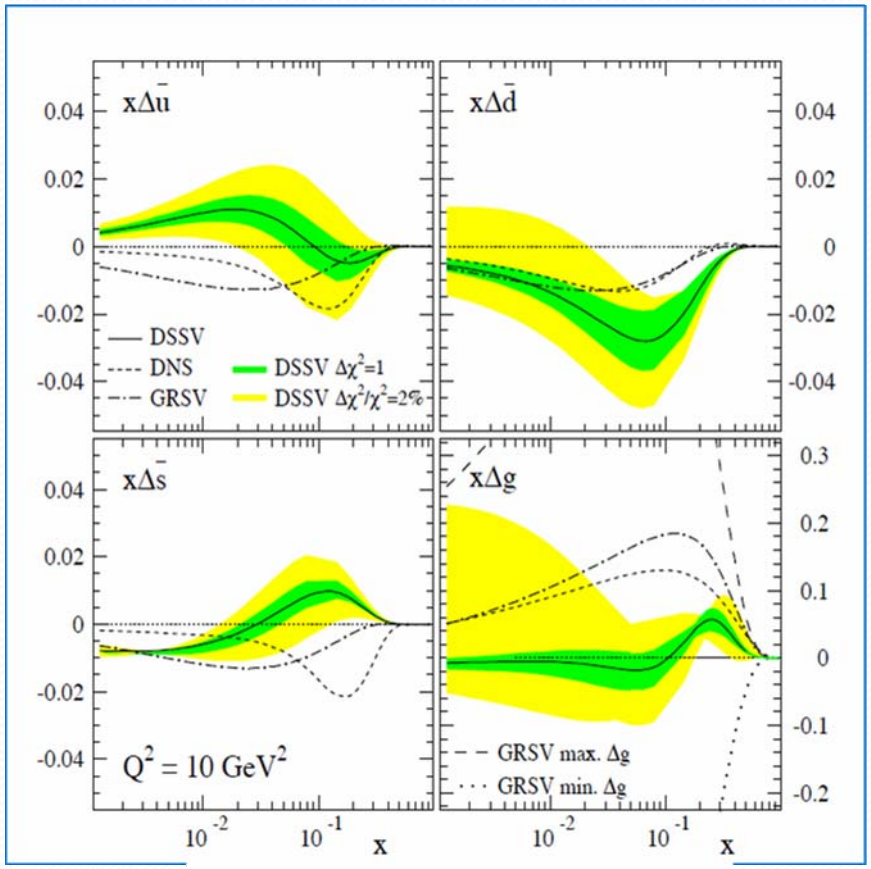
Parton Polarization Function

- Proton Spin : ½ = ½Δ∑ + ΔG + L

< about $\Delta\Sigma = \sum (\Delta q + \Delta \bar{q})$ >

- The polarization of valence quark (u, d) are well understood but, that of sea quark (anti-u, anti-d, anti-s) are not well constrained

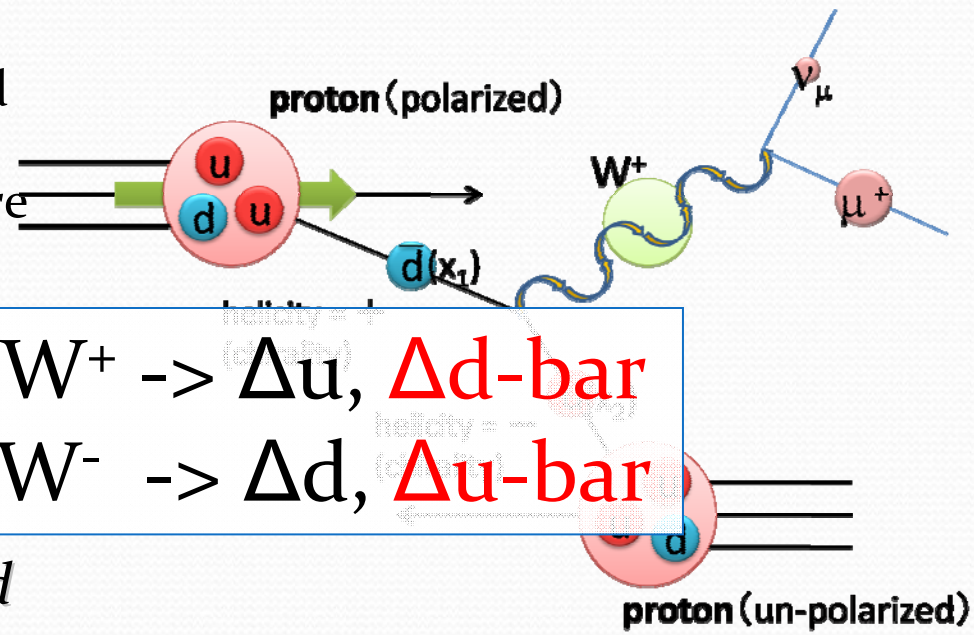
-> Single Spin Asymmetry of W boson is a good probe to measure the polarization of sea quark



DSSV Global Fit (2008)
(DIS+SIDIS+pp)

Measurement of spin structure with W boson

- W boson production in p-p collision
  - flavor combination is almost fixed
    - flavor separated measurement
  - helicities of interacting partons are fixed
    - spin measurement
  - W→ lepton decay in hadron fragmentation process
    - direct measurement
- *Asymmetry measurement of W boson production is ideal method*
- asymmetry A_L^W
  - In **forward** and **backward** region, quark polarization and anti-quark polarization can be extracted separately



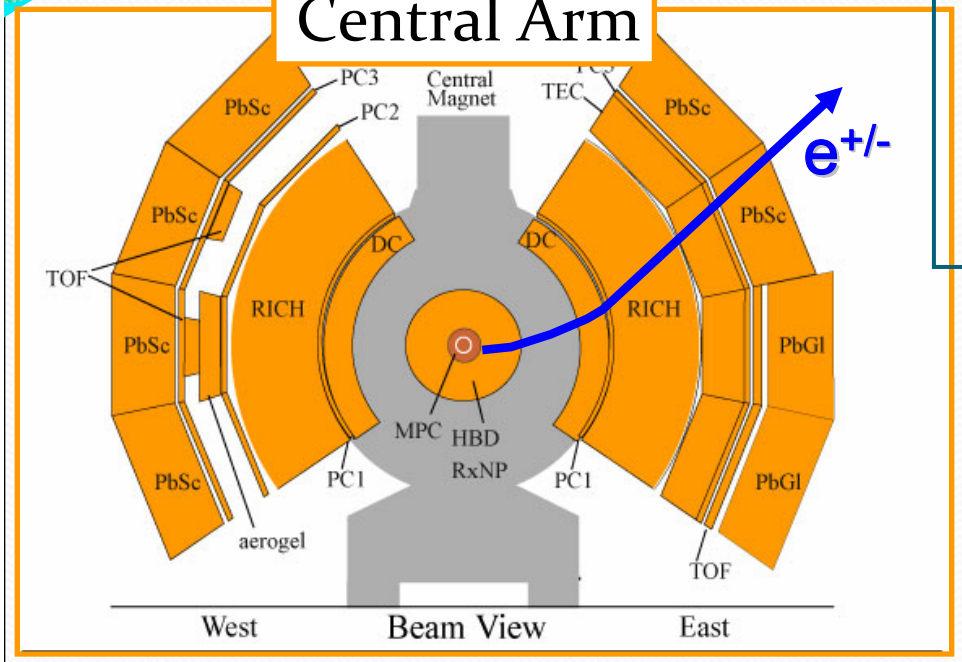
- Asymmetry of W^+ -> Δu, Δd-bar
- Asymmetry of W^- -> Δd, Δu-bar

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

2. W detection @ PHENIX

The PHENIX Experiment

Central Arm



Rapidity: $|\eta| < 0.35$
$\Delta\varphi = 2 * (\pi/2)$

Central Arm:
Drift Chamber (DC), Pad Chamber (PC),
Ring Imaging Cherenkov Counter (RICH),
Electromagnetic Calorimeter (Emc),
HBD, TOF, TEC

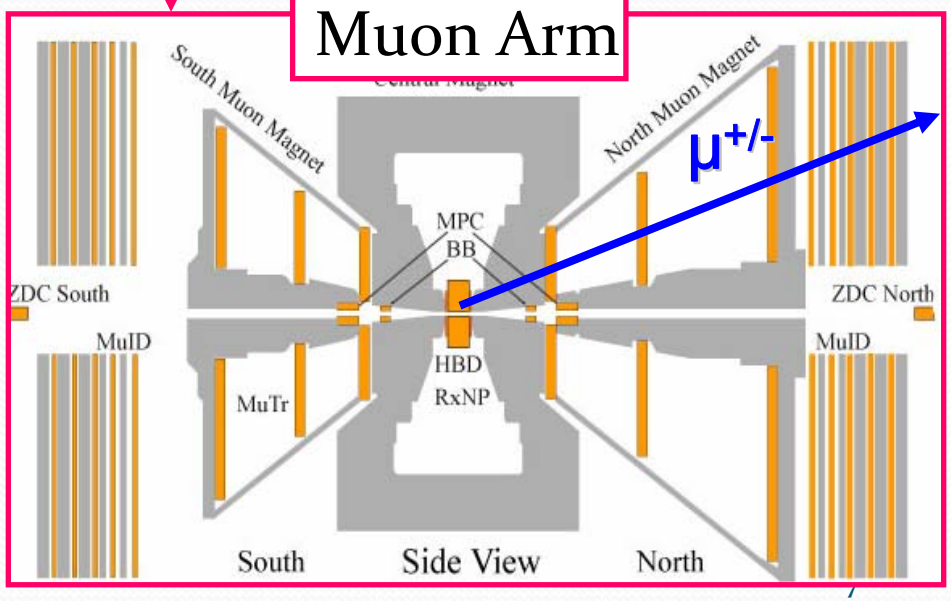
Philosophy (initial design):

- ✓ **High rate capability & granularity**
- ✓ **Good mass resolution & particle ID**
- ➢ **Sacrifice acceptance**

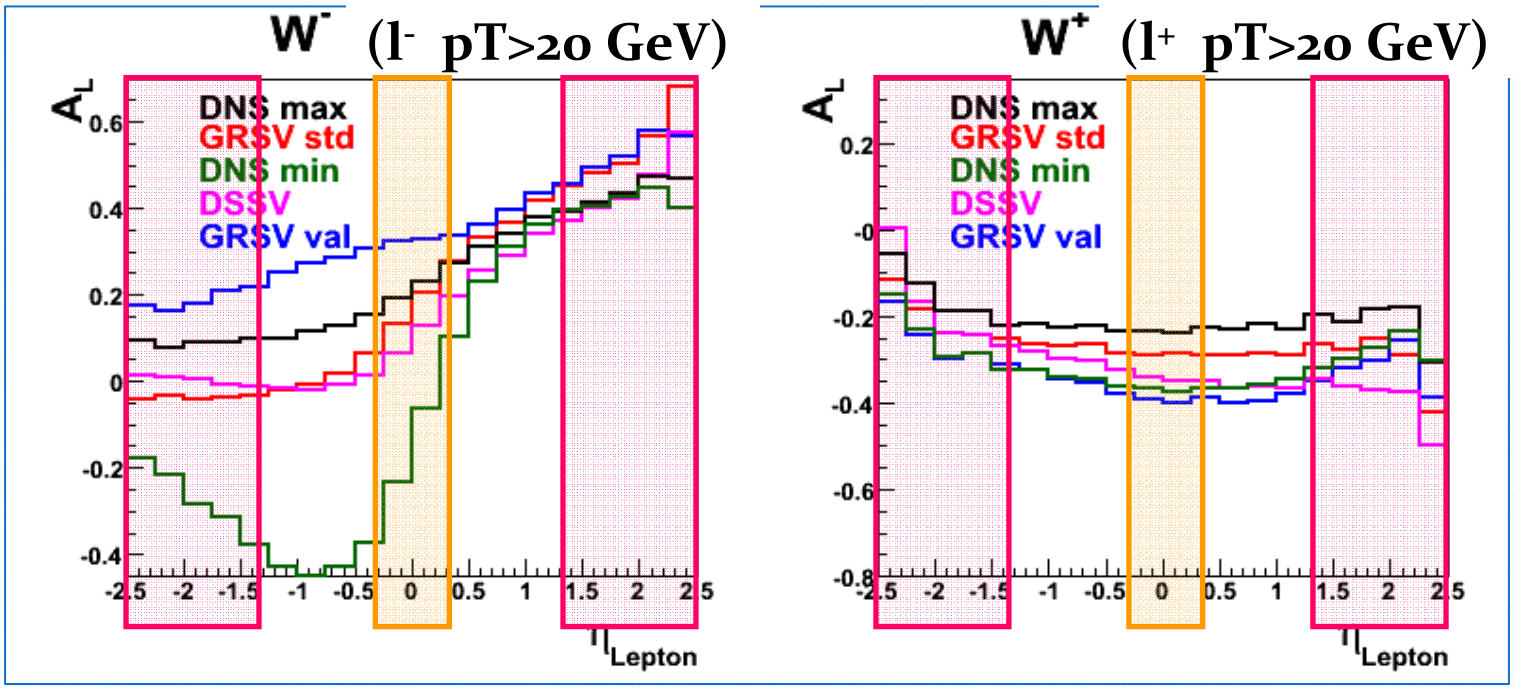
Muon Arm:
Muon Tracking Detector (MuTr),
Muon Identifier (MuID)

Rapidity: $1.2 < \eta < 2.2$ (2.4)
$\Delta\varphi = 2\pi$

Muon Arm



Expected Asymmetry of W production in the PHENIX Acceptance



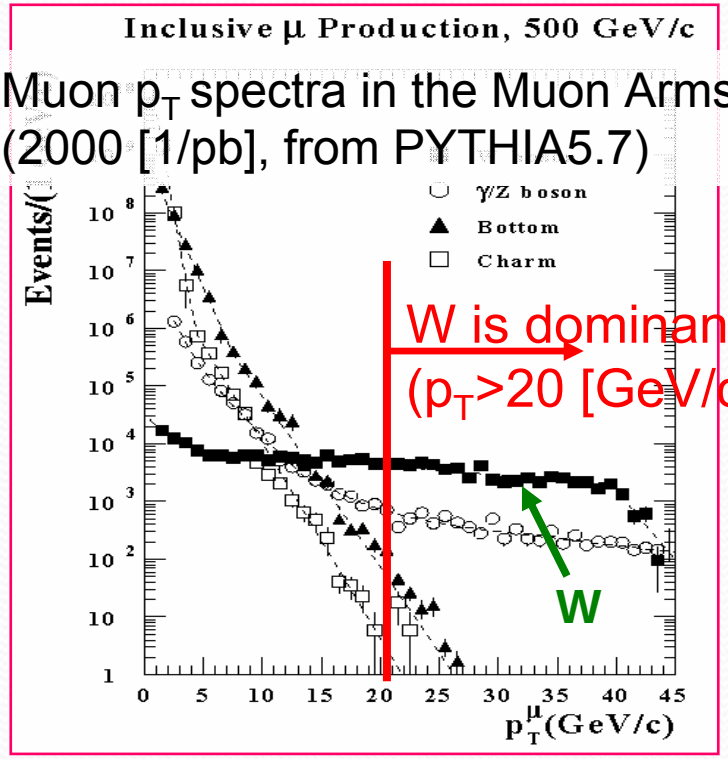
Muon Arms: trigger upgrade is ongoing

→ will be ready for next 500 GeV run

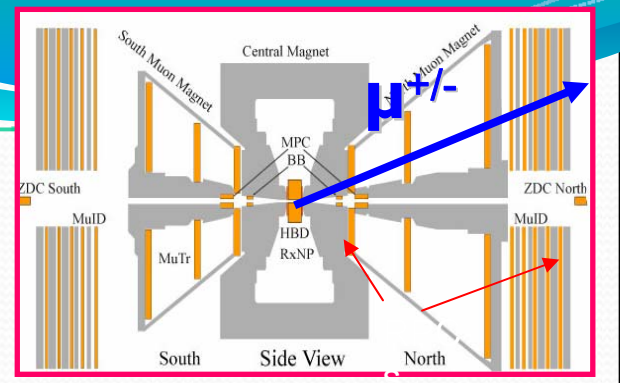
Central Arms: W measurement at 2009 run

W in the PHENIX Muon Arms

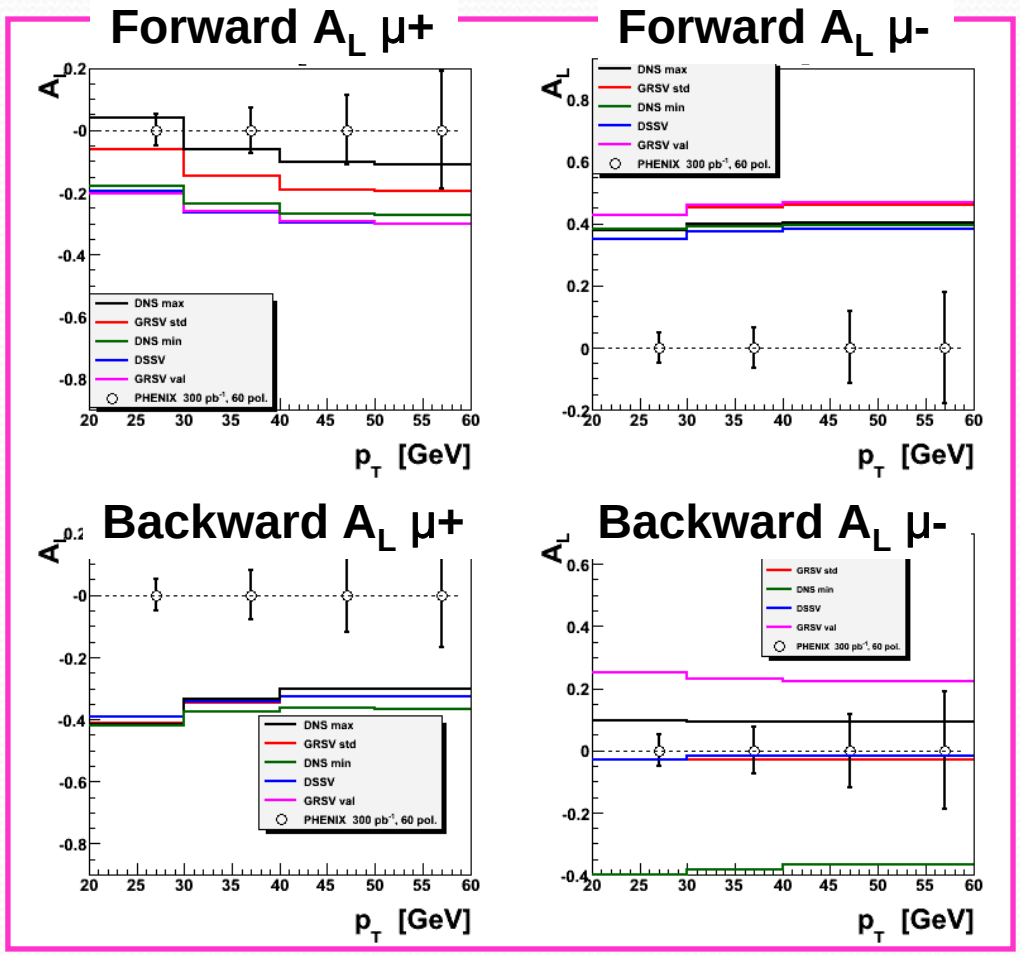
W in the PHENIX Muon Arms



Muon p_T spectra in the Muon Arms (2000 [1/pb], from PYTHIA5.7)



recorded luminosity
○ 300 [pb^{-1}]



Right plot:
expected asymmetry of W
(assuming 60 % polarization, backgrounds and detector resolution included)
from RHICBOS

W in the PHENIX Muon Arms

Design Luminosity

$\sqrt{s}$ = 500 GeV σ=60mb

L = $1.5 \times 10^{32}/cm^2/s$

Total interaction rate = 9MHz

DAQ LIMIT

= 2kHz (for Muon Arm)

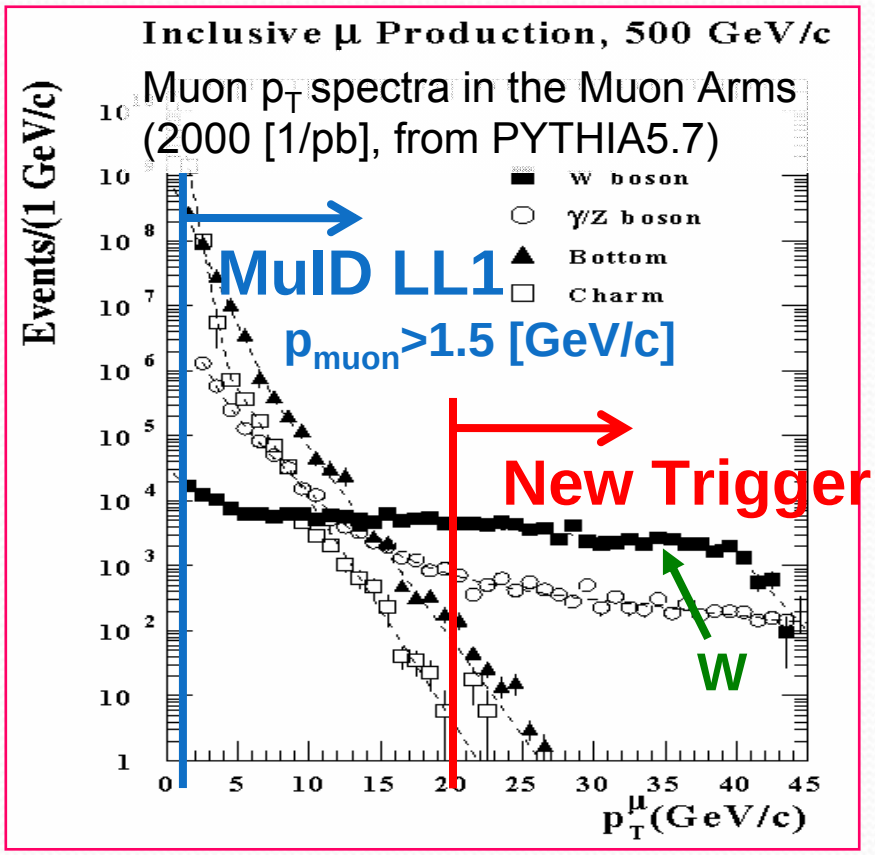
Required RF

4500

BUT

MuID LL1 (trigger)

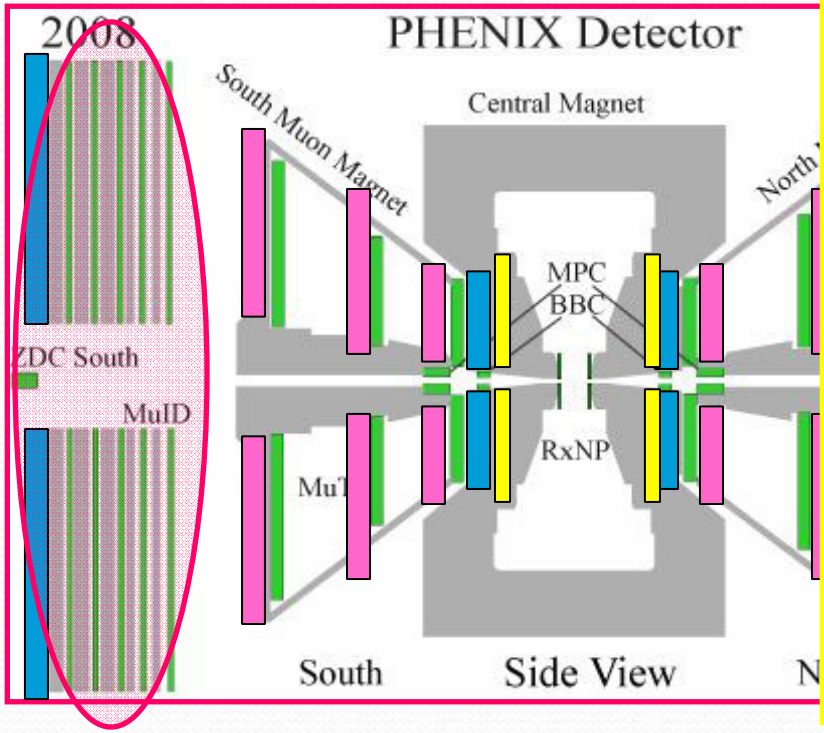
RF < 200

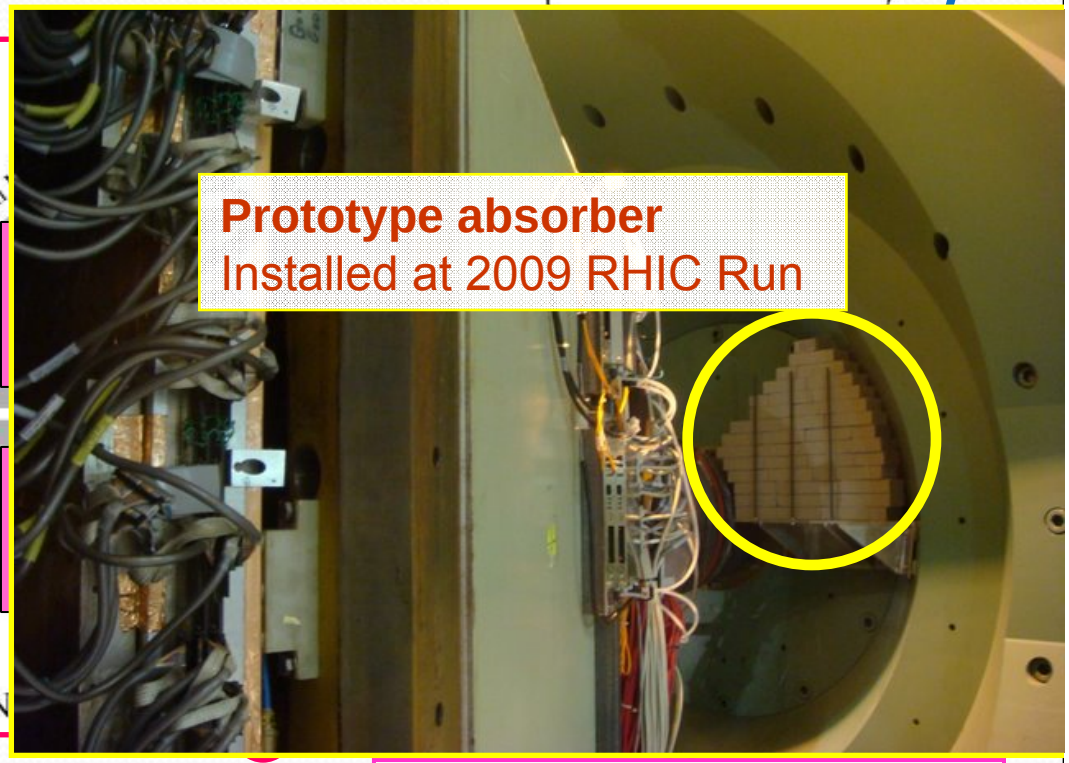


• Need Momentum Selectivity in the LVL-1 Trigger!

PHENIX Muon Trigger Upgrade

Rapidity: 1.2 < η <2.2 (2.4)





<Muon Trigger Upgrade>

- MuTr FEE Upgrade (MuTRG)
- Install RPC (Resistive Plate Chamber)
- Install additional Absorber

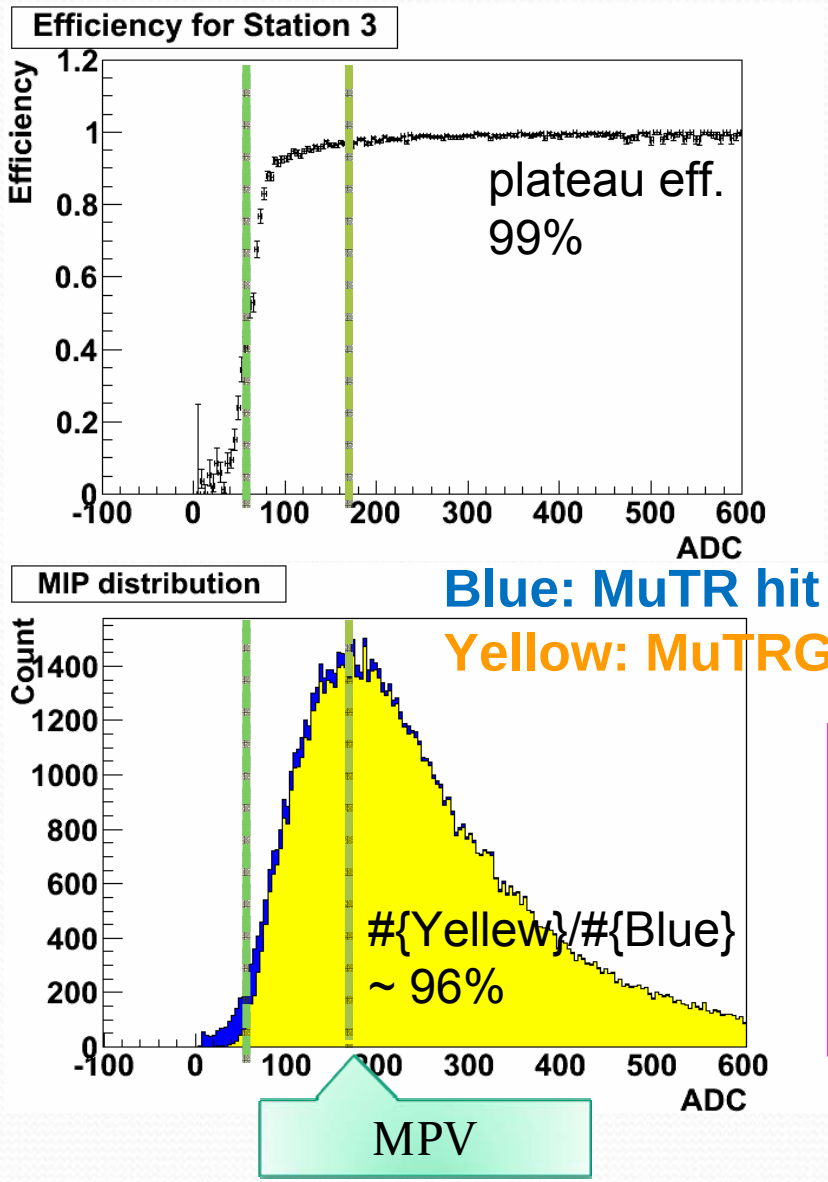
Absorber

- reject hadron background

- poor time resolution..
(> 1 beam crossing)

Performance study is on-going

Performance of New MuTr FEE (MuTRG)



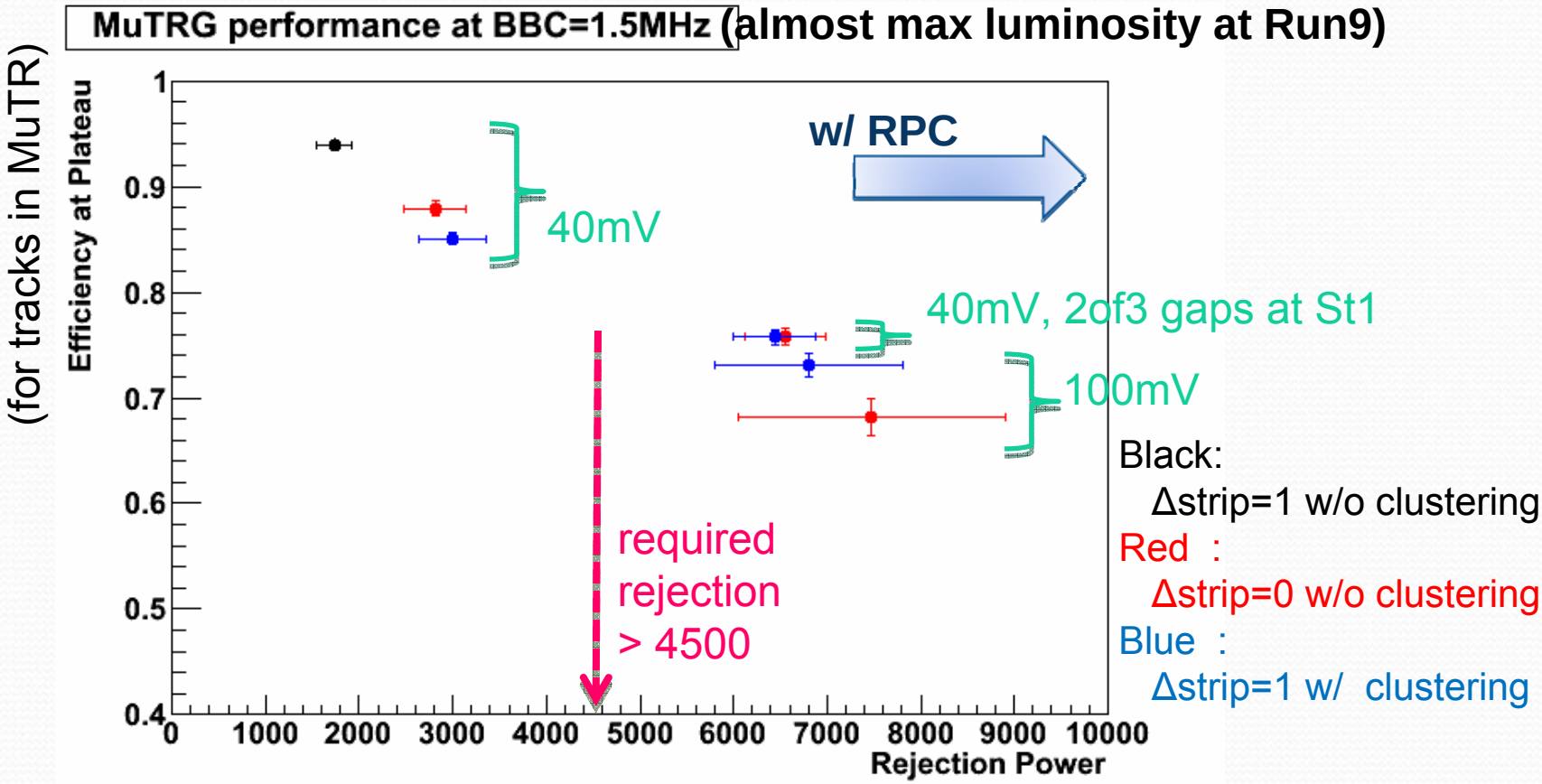
- ADTX Threshold 40mV
- 1 of 2 gap hit required
- timing gate: 3 bunch crossings

- Plateau Efficiency: 99%

MuTRG and MuTR matched properly.

Efficiency for MuTR track hit: 96%

MuTRG Rejection Power

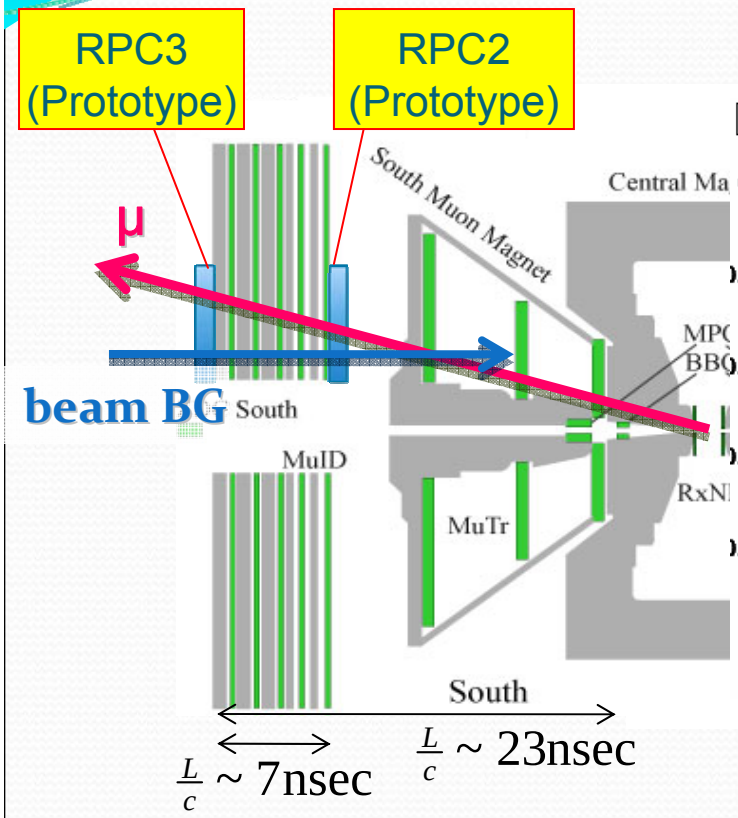


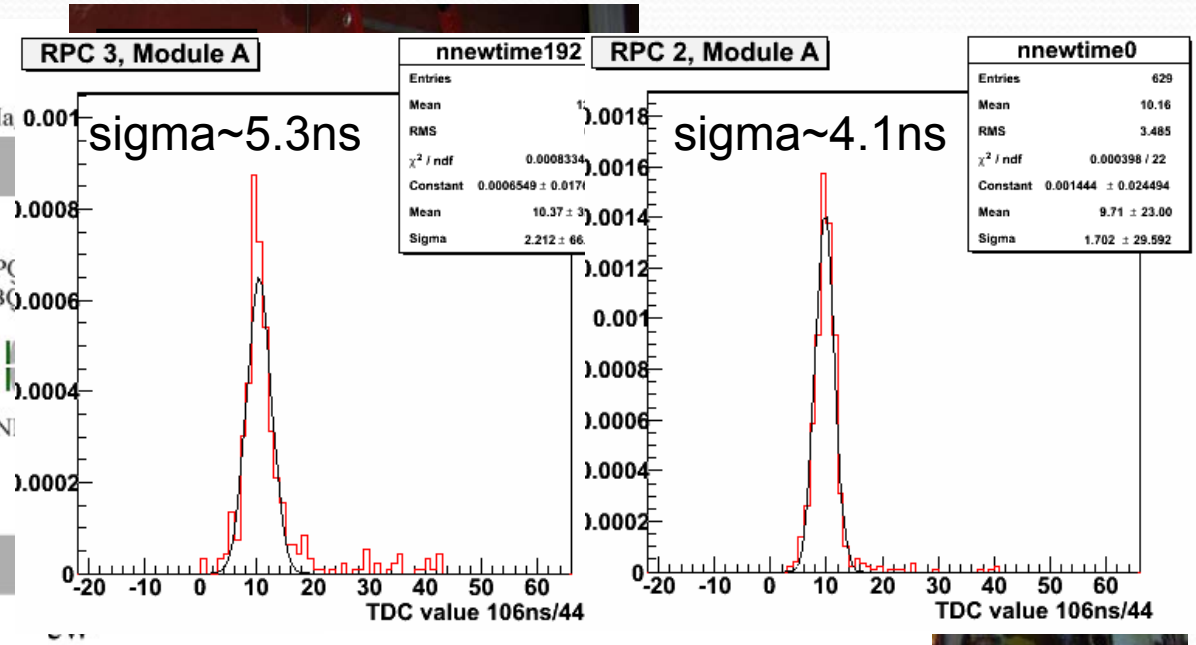
(assuming BBC rejection = 2)

σ_total ~ 60mb, σ_bbc ~ 30mb (500GeV)

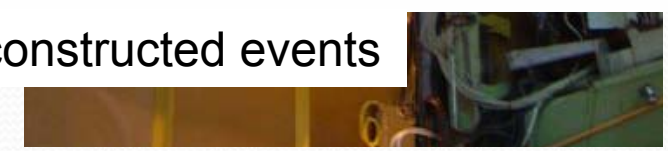
- Larger rejection power can be obtained by applying tight cuts
- More improvement is expected by RPC

Performance of RPC (Prototype)





track reconstructed events

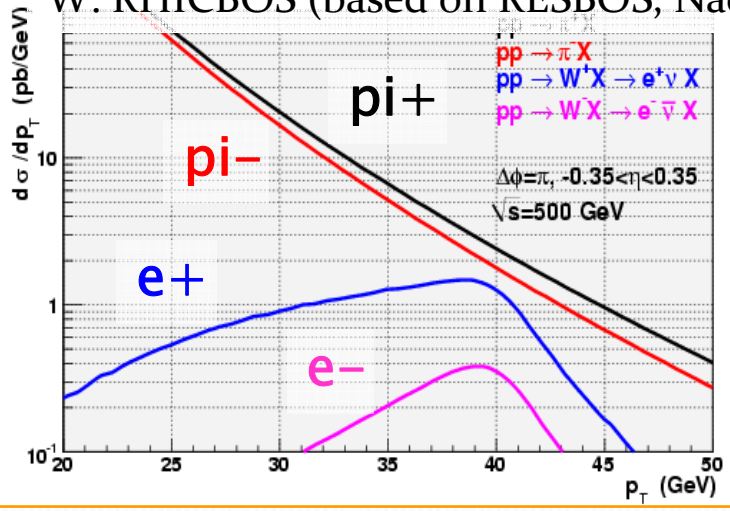


- 2 prototypes have been installed during 2009 run
- typical timing resolution 4 ~ 5 nsec
  - beam background can be separated
  - enough timing resolution

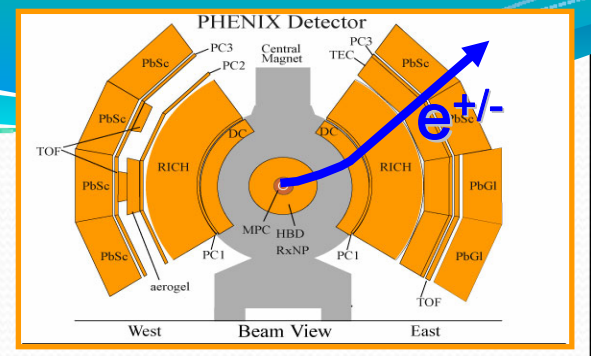
W in the PHENIX Central Arms

Expected W signal at Central Arms

pions: NLO pQCD calculation from W. Vogelsang
W: RHICBOS (based on RESBOS, Nadolsky, Yuan)

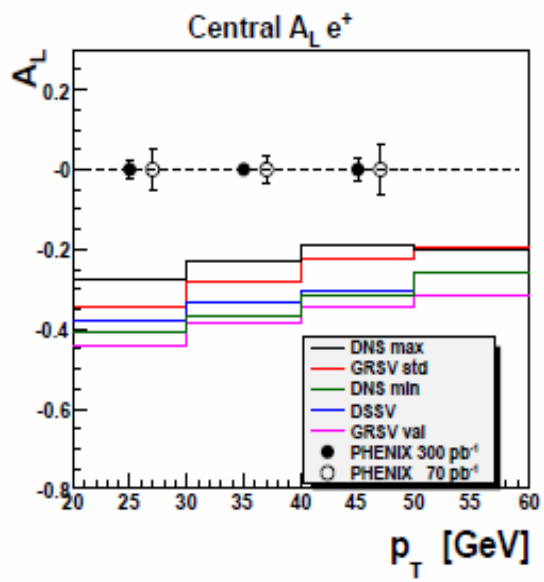


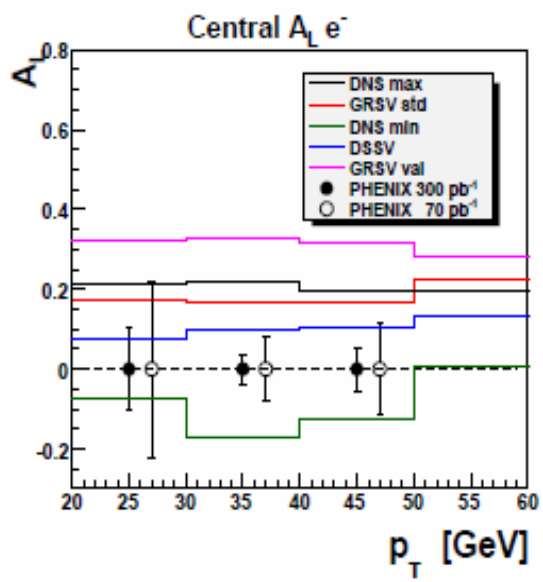
Upper plot:
cross section of e+/- from W & π+/- in the PHENIX acceptance



Rapidity: |η| < 0.35

<Charged hadron rejection>
EMCal intrinsic: 50-150
Shower profile: 2-4
Isolation cut: ~10
Total: 1000-6000

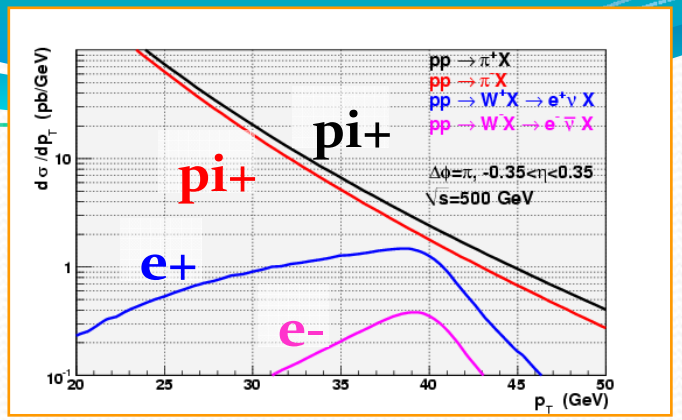




Lower plot:
expected asymmetry of W (assuming 70 % polarization, no background or detector resolution included)

recorded luminosity
- ● 300 [pb⁻¹]
- ○ 70 [pb⁻¹]

2009 RHIC Run Status - Central Arms



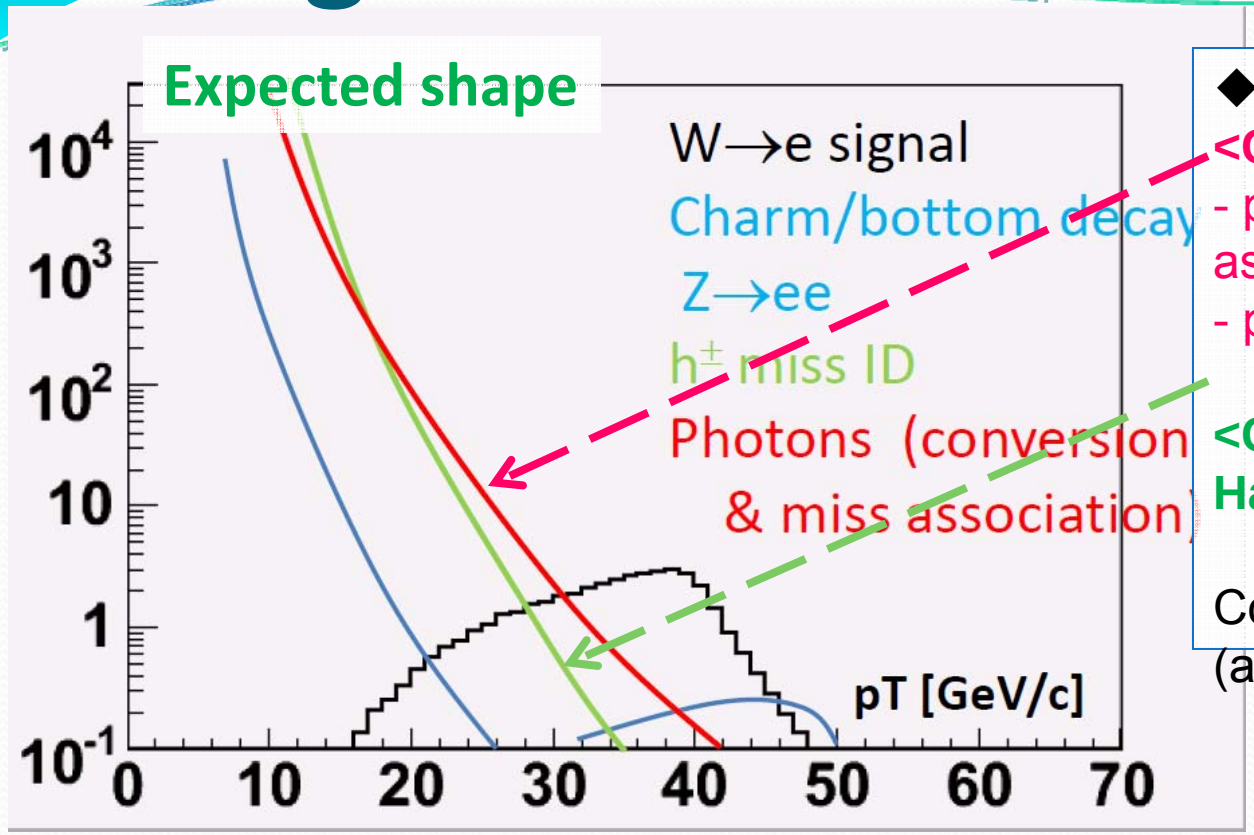
- 2009 RHIC Run (Run9)
- Polarization: <P> = 0.39±0.04 (from RHIC pol-group)
- recorded luminosity @ PHENIX: 9.28 [pb^{-1}] (with vertex cut)

- The aim of Run9 analysis

-> first measurement of W boson cross section @ RHIC! ($W^+ \rightarrow e^+$ & $W^- \rightarrow e^-$)

-> first measurement of non-zero A_L^W (the expectation value of the A_L^W of W^+ is 1 sigma from 0 assuming DSSV)

Background estimation



◆**Background**

<Component 1>: Photons

- pi0s in jet (mis association)
- pi0 decay + convversion

<Component 2>: Charged Hadrons

Cosmic contribution is small (after Tof cut)

<True Background>:

- charm/bottom decay (true electrons)
- Z bosons decay

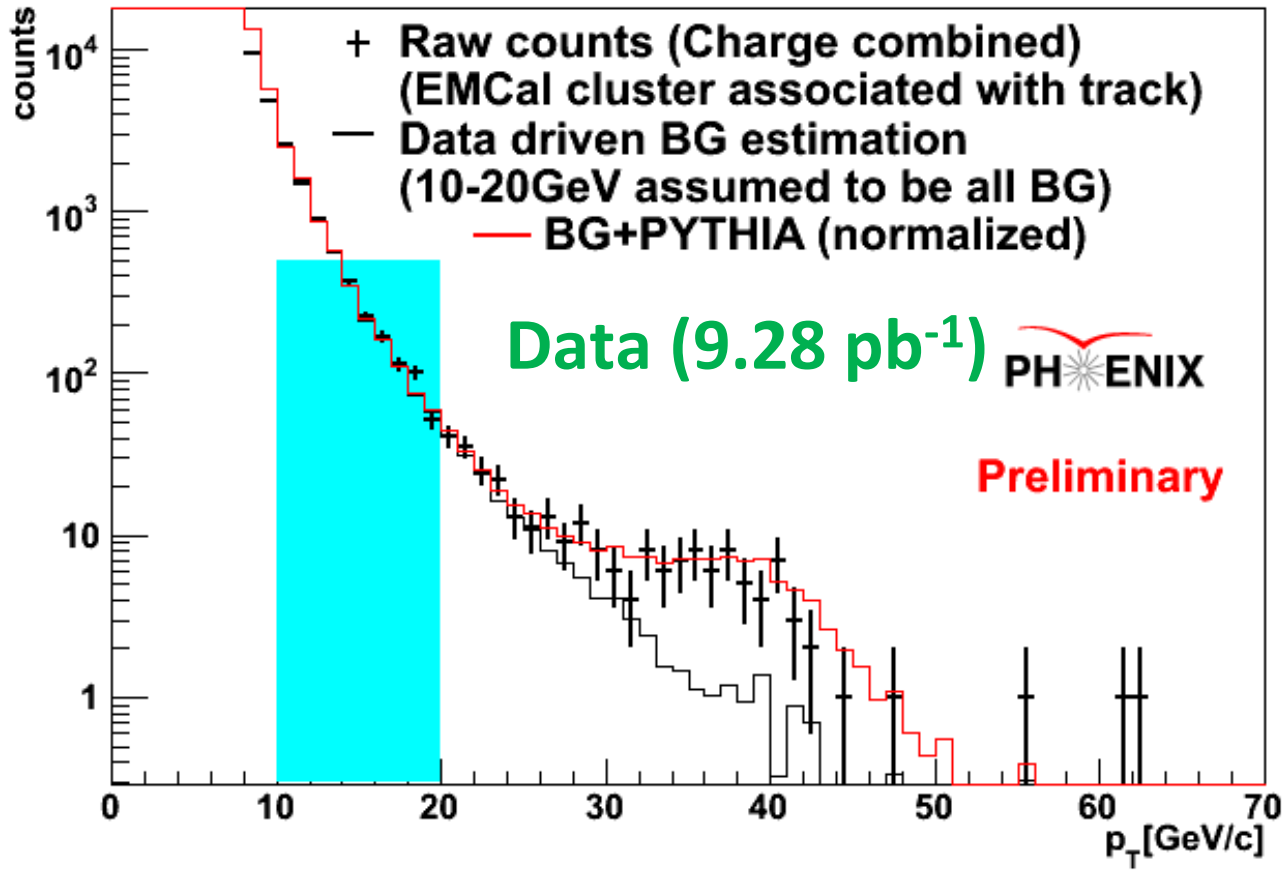
(Most likely PHENIX can't detect both leptons, W/Z~10, but for $W^- \rightarrow$electron, it's not negligible)

- W to tau, tau to electron (small contributions??)

Measured spectra

Data driven BG estimation:

- (EMCal cluster) x (conversion + mis association probability)
- The rest is explained by the $h^{\pm}$ shape (NLO pQCD+EMCal response, scaled so that the sum matches the 10-20 GeV region)

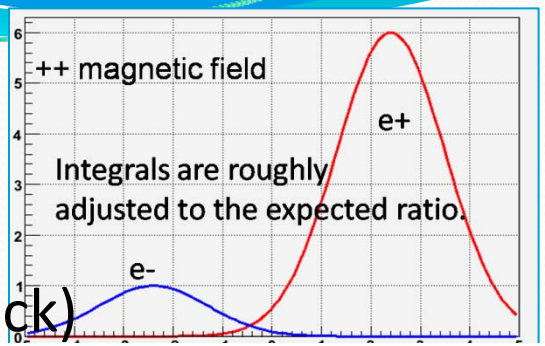


The bump is W+Z signal.

Signal shape looks reasonable

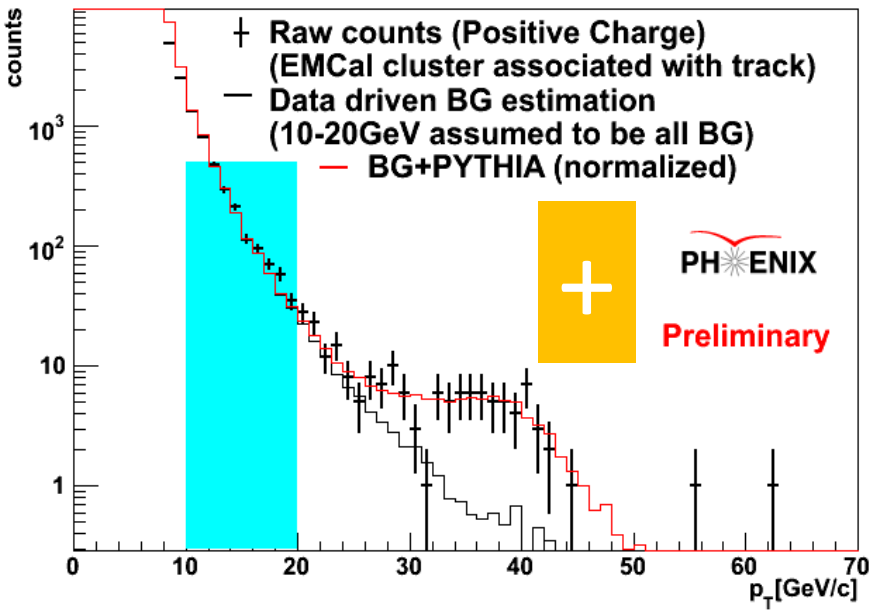
<u>Need to finalize (acc.)x(eff.) value to get cross section</u>

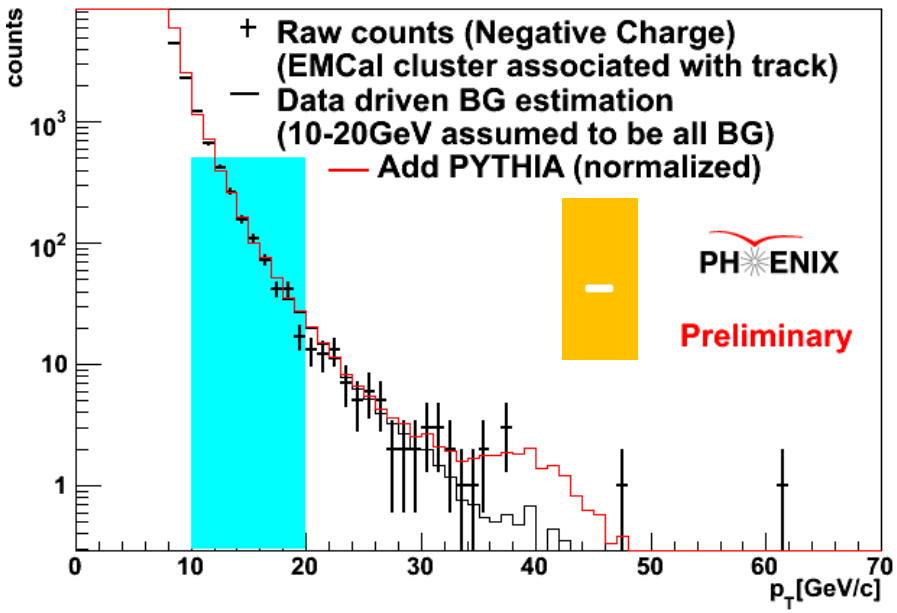
Charge separated spectra



Charge sign :

from DC angle (2.3σ separation for 40GeV/c track)





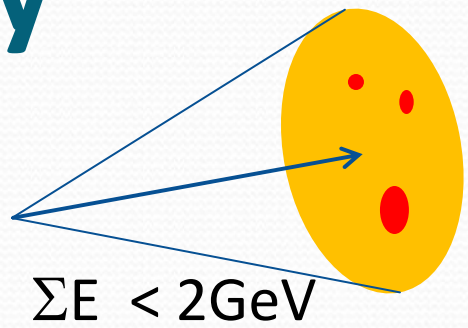
The same factor for PYTHIA was used for signal shape

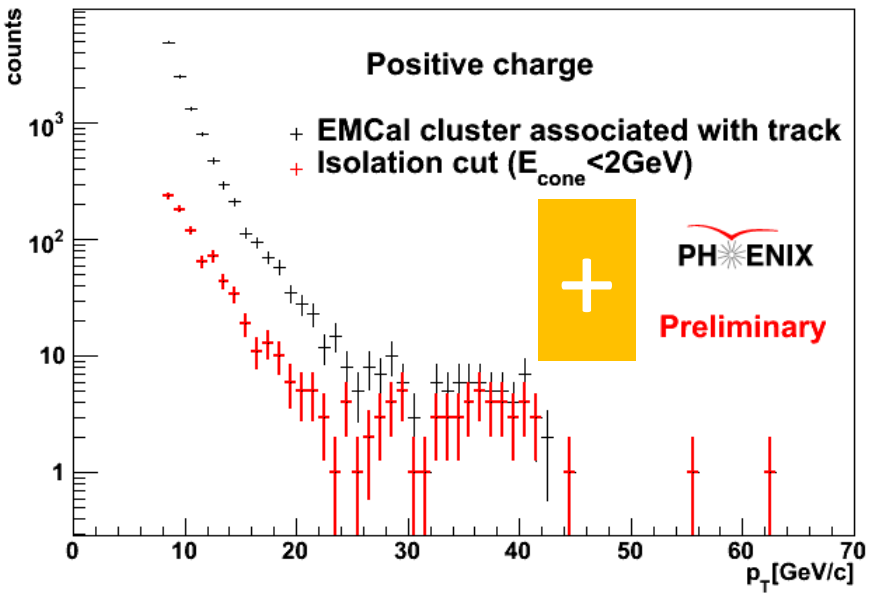
$W^- \rightarrow e^-$ signal has less acceptance than $W^+ \rightarrow e^+$ signal

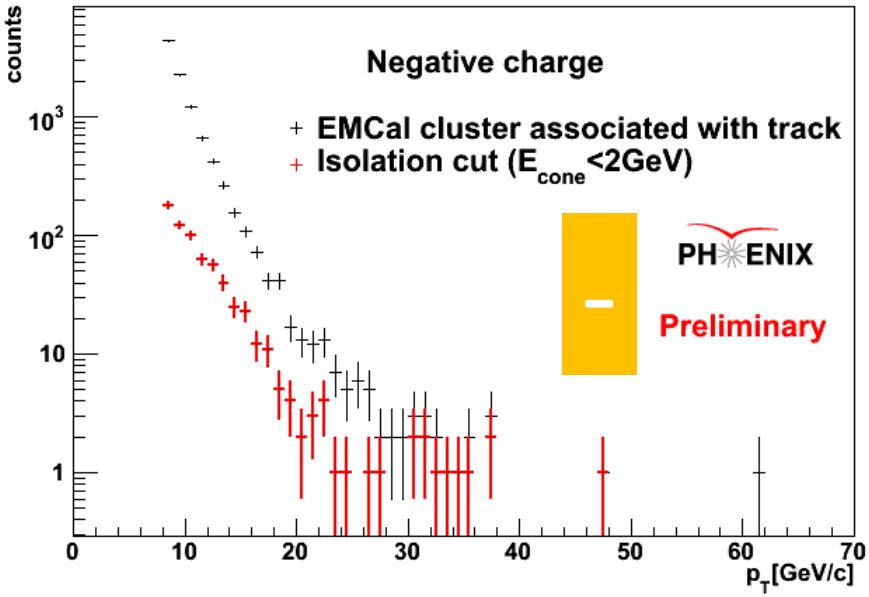
Single Spin Asymmetry

When extracting spin asymmetry, any cut can be applied to improve S/N ratio, if it's spin independent

-> Isolation Cut

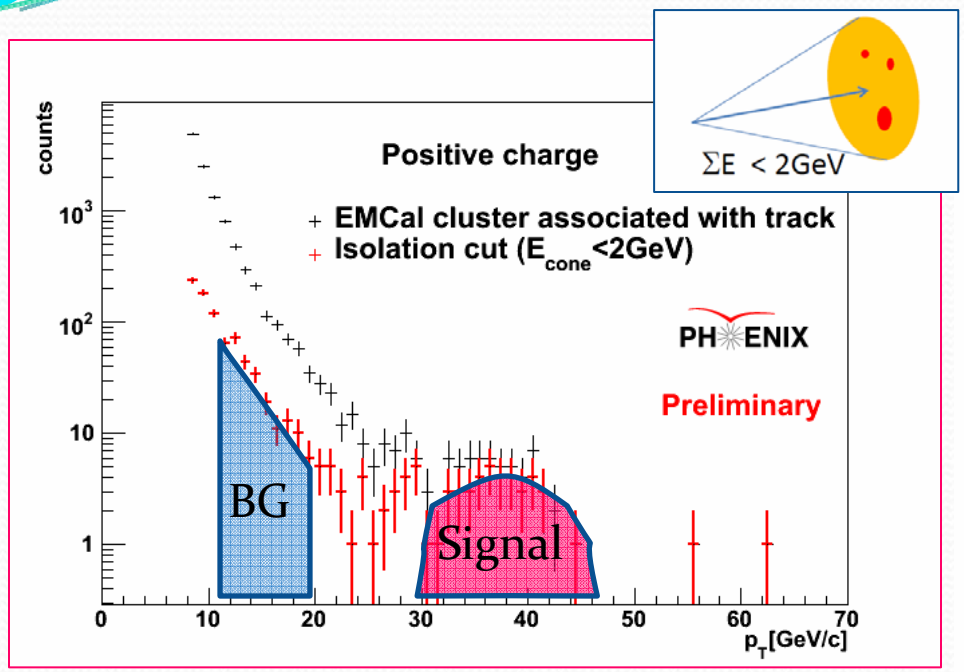






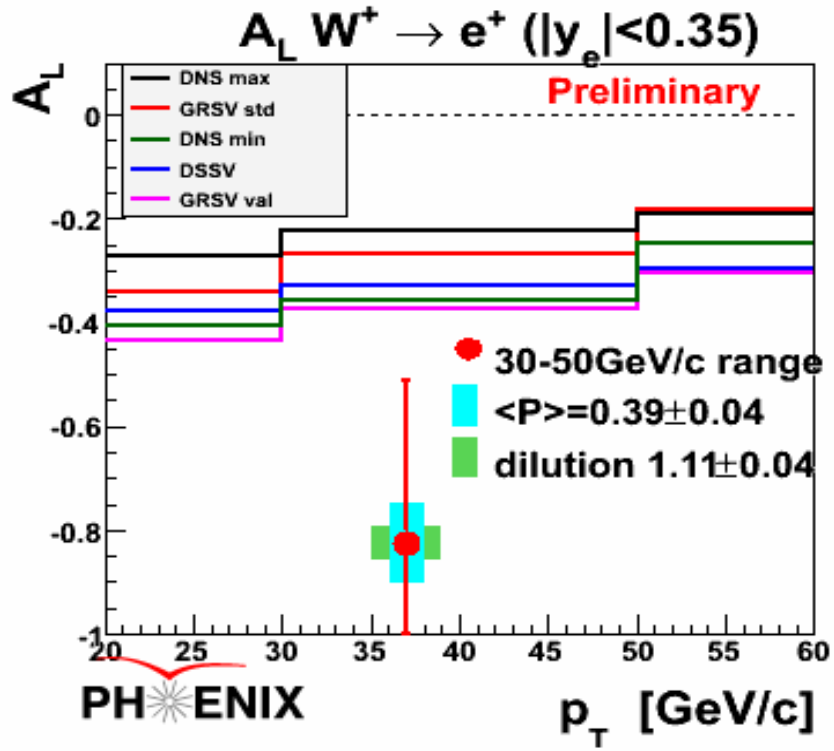
90+% of signal is kept (red histograms)

Single Spin Asymmetry (positive charge)



	pT range	Raw Asymmetry
BG	12-20	0.035±0.047
Signal	30-50	-0.29±0.11

non-zero asymmetry @ signal region



Physics Asymmetry

- *1/<P> to raw asymmetry
- *(Dilution factor): BG from Z, hadron
- consistent with projections

A_L = -0.83±0.3 1

3. Summary & Outlook

- W bosons provide possibilities for flavor separated measurements -> sensitive to the polarization of sea quark
- Upgrades are ongoing to measure W boson in the PHENIX Muon Arms. They have been partially installed & tested at 2009 & 2010 RHIC Run

-> Ready for the next 500 GeV run!

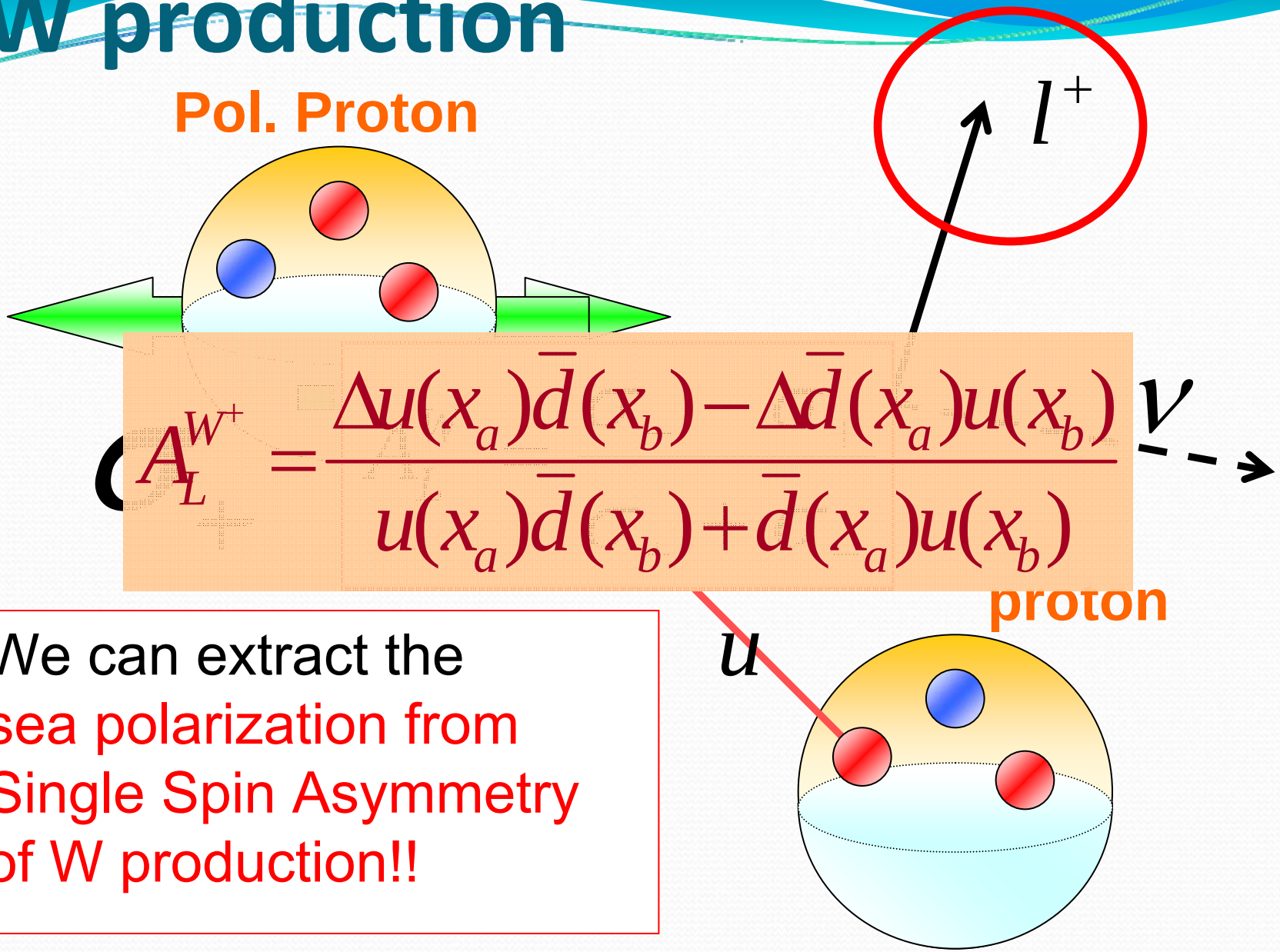
- PHENIX observed W→ e decay in the mid-rapidity region

  - Preliminary result for single spin asymmetry

-> Experience from analysis enables us to obtain greater result from the next 500 GeV run!

Back up

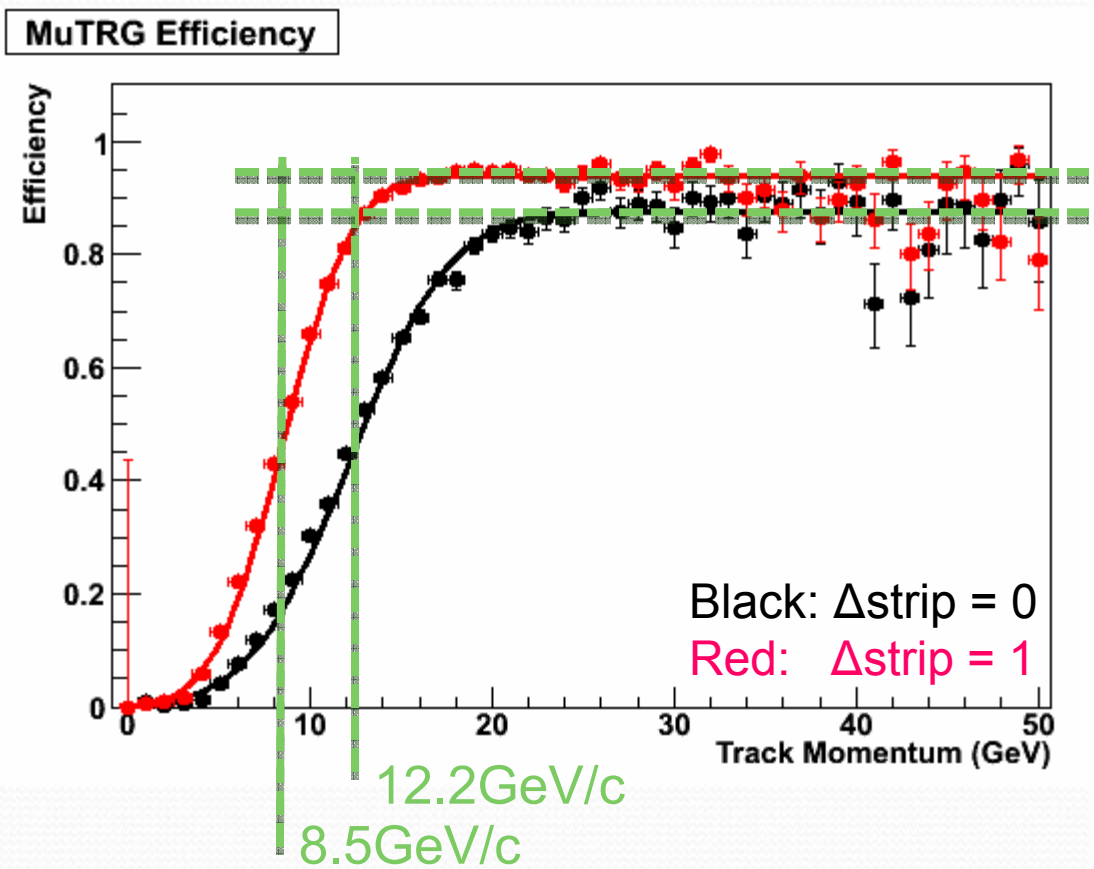
W production

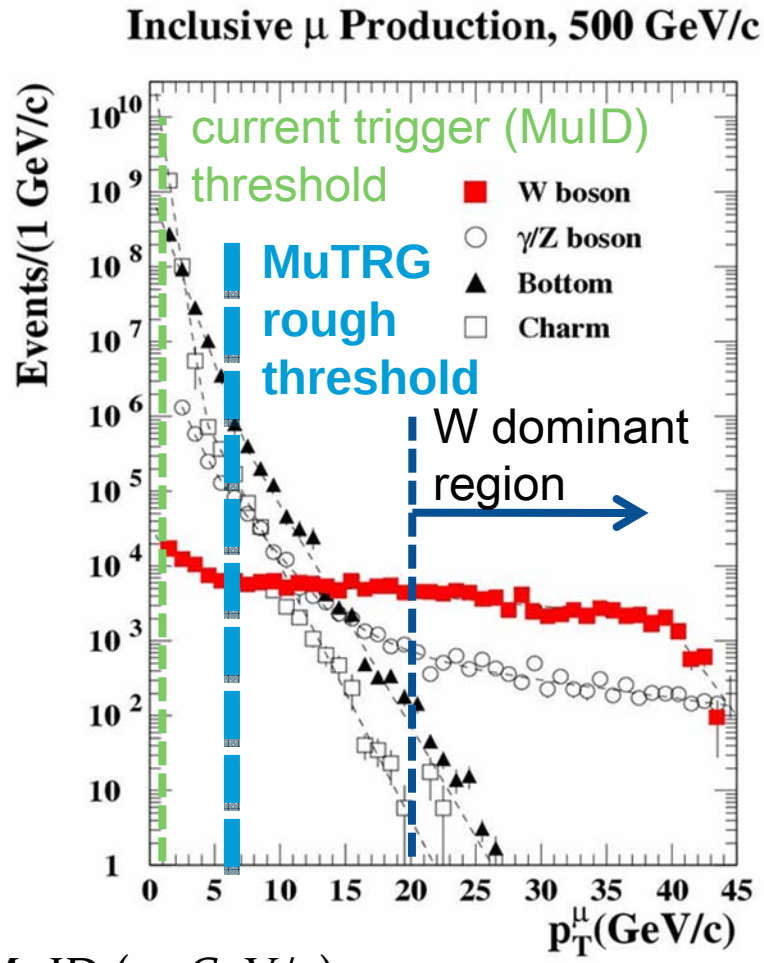


$$A_L^{W^+} = \frac{\Delta u(x_a)\bar{d}(x_b) - \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}$$

- We can extract the sea polarization from Single Spin Asymmetry of W production!!

MuTRG momentum selection performance

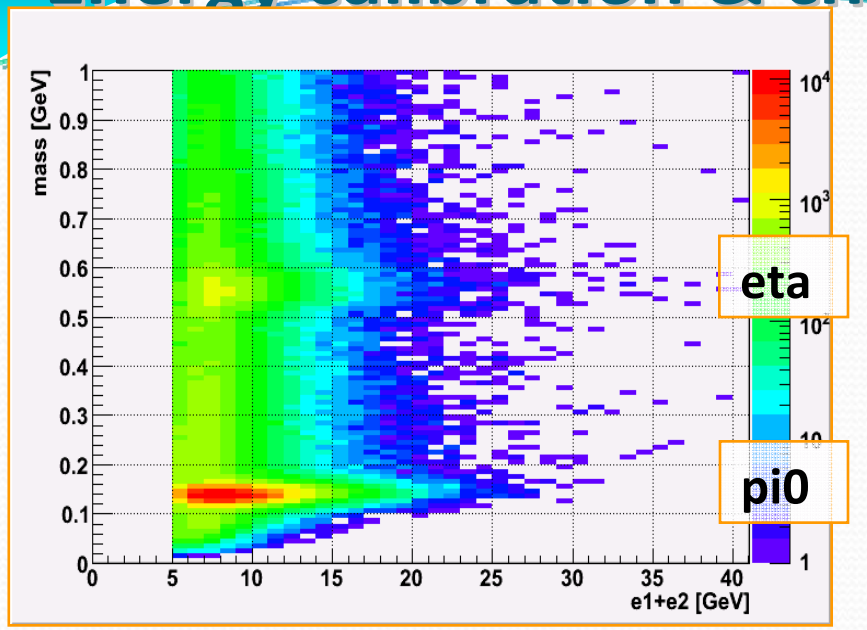




- perfect efficiency can be achieved with MuTRG
- turn on momentum point is enough larger than MuID (2.5GeV/c)
  - **p = 12.2GeV/c ... pT ~ 6GeV/c**

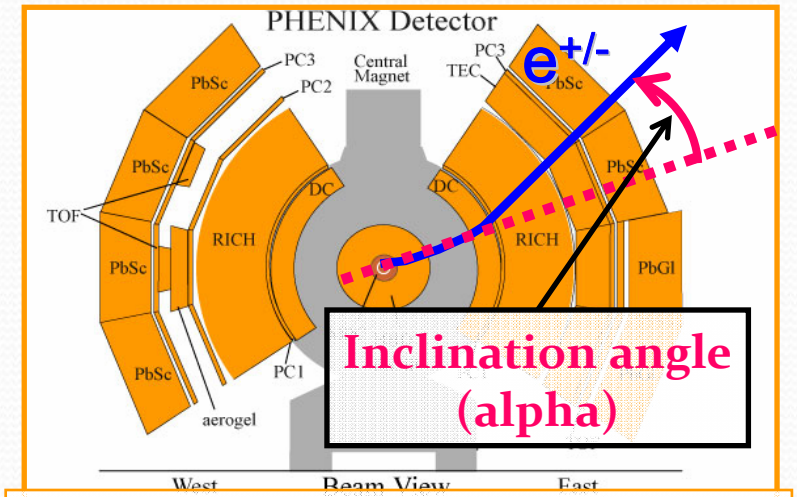
simulated muons into Muon Arm
(2000pb−1, with PYTHIA5.7)

Energy calibration & charge separation



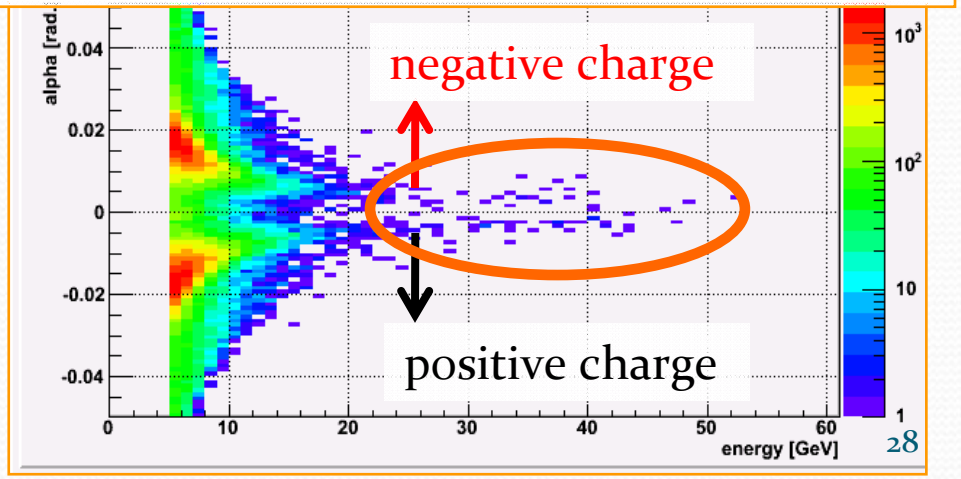
< Emc Energy calibration >
Left: Inv. mass v.s. total energy of 2 photons

pio and eta are well reconstructed even in high energy region

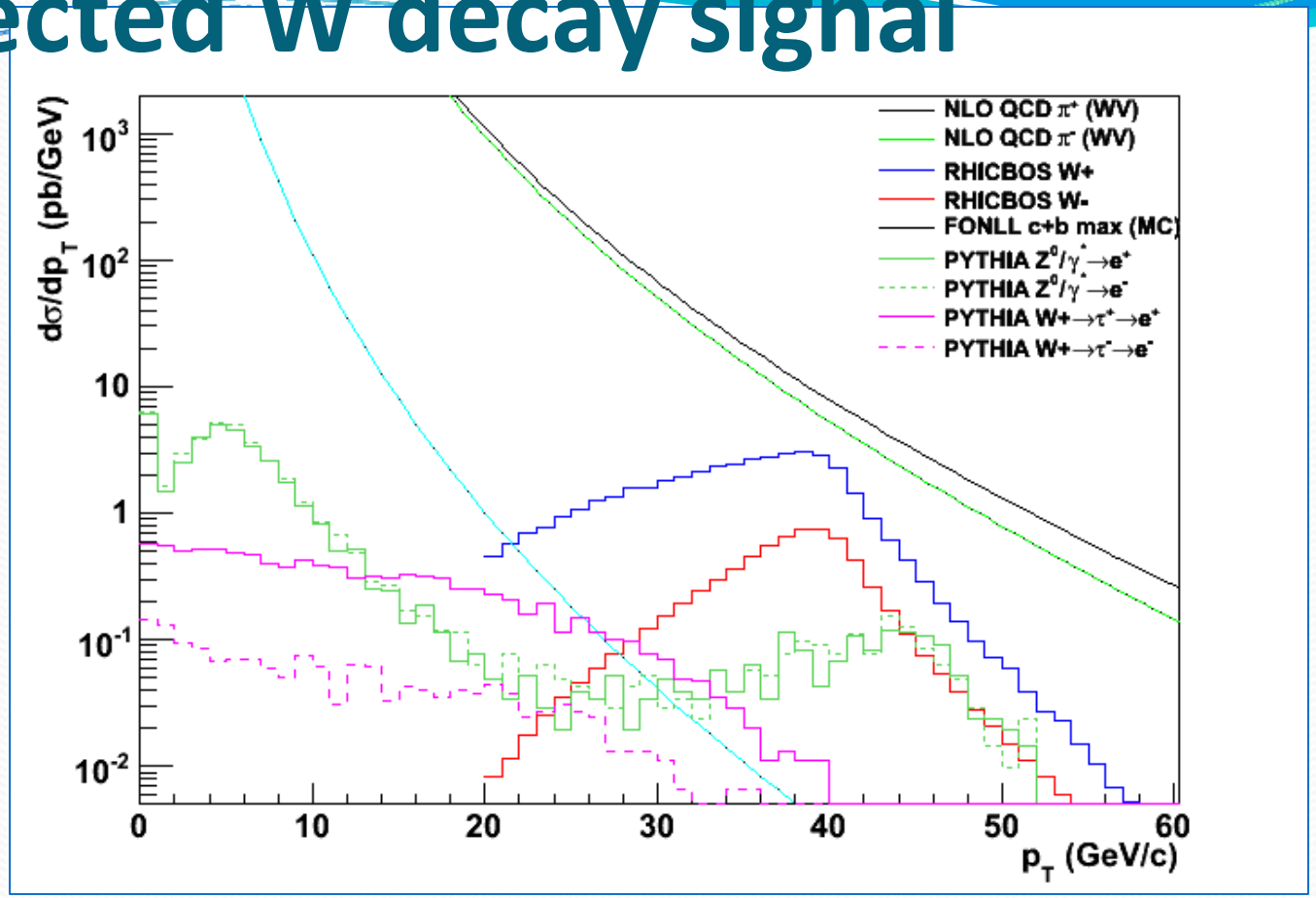


alpha [rad.] ~ 0.1/ mom [GeV/c]

Energy v.s. alpha (charge separation)
"energy / mom < 2" cut applied



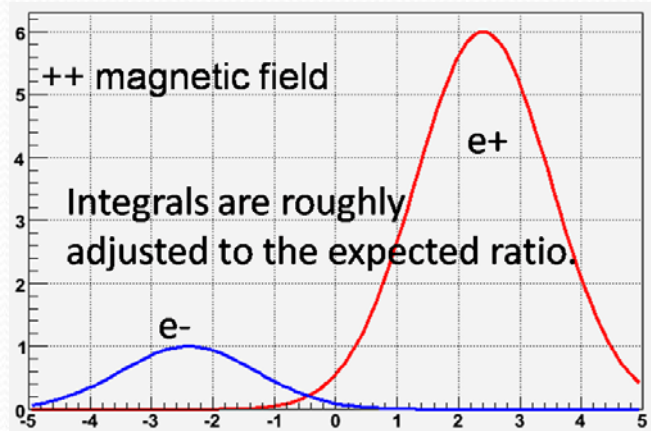
Expected W decay signal



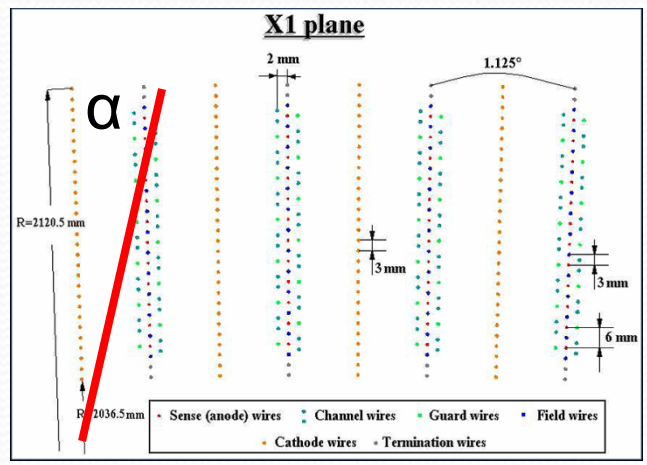
- QCD provides the most obvious background (W. Vogelsang)
- Not shown here
  - Cosmics and photons (from meson decays and direct), which can have accidental matches to tracks or conversions
- c/b relatively small above 30 GeV, calculated at FONLL (Matteo Carciari)
- Z/γ* background is estimated from PYTHIA (~1 count is expected in Run09).
- W→τ→e is also small

Event selection

- ±30 cm vertex cut
- High energy EM Calorimeter clusters matched to charged track
- Loose timing cut eliminates cosmic rays
- Poor momentum resolution allows only loose E/p cut

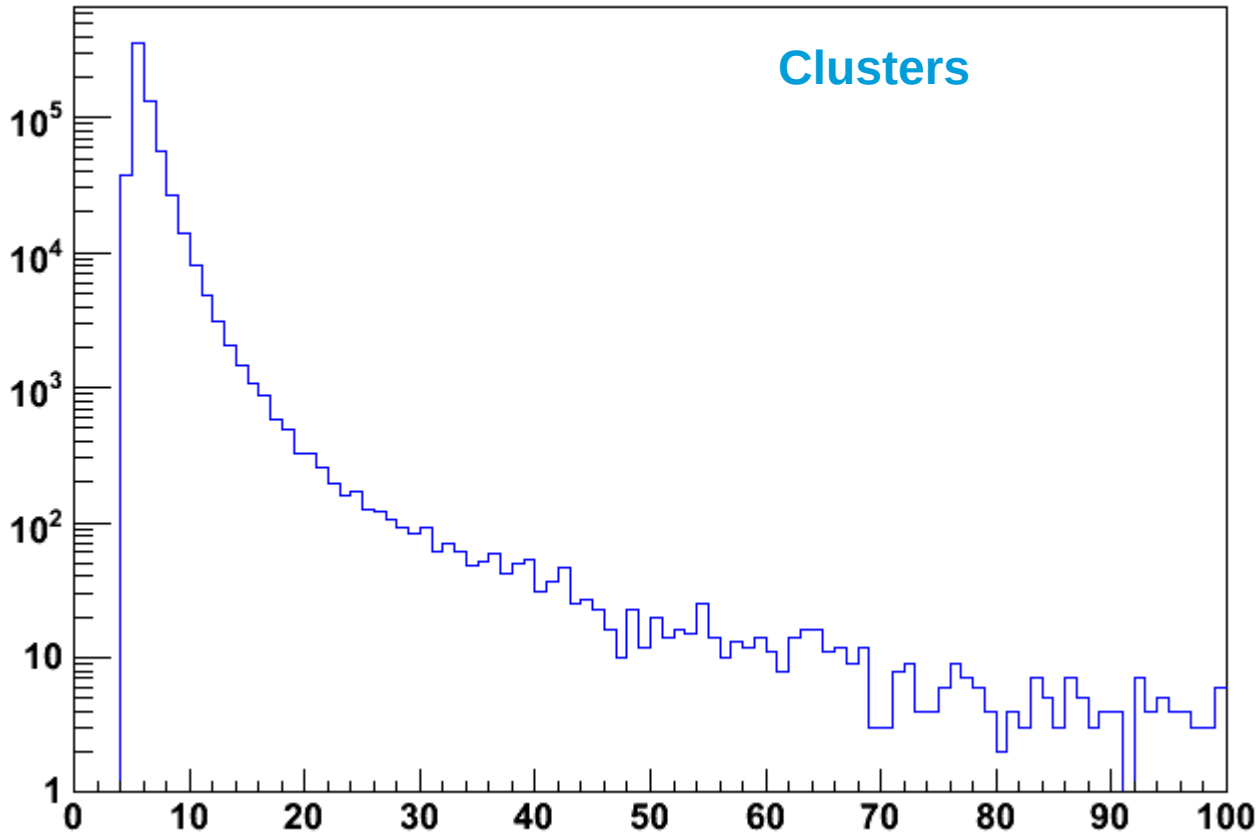


α = bend angle



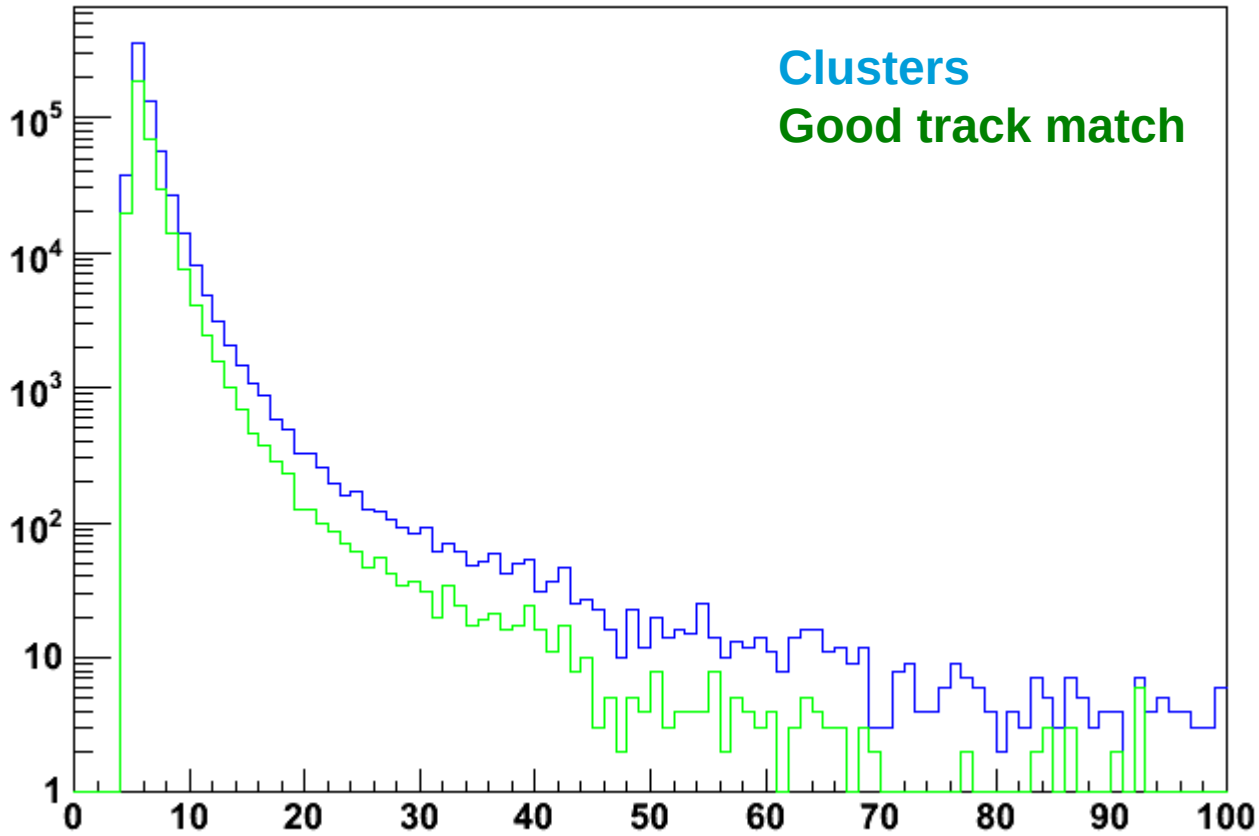
Drift Chamber cell

Effect of Cuts



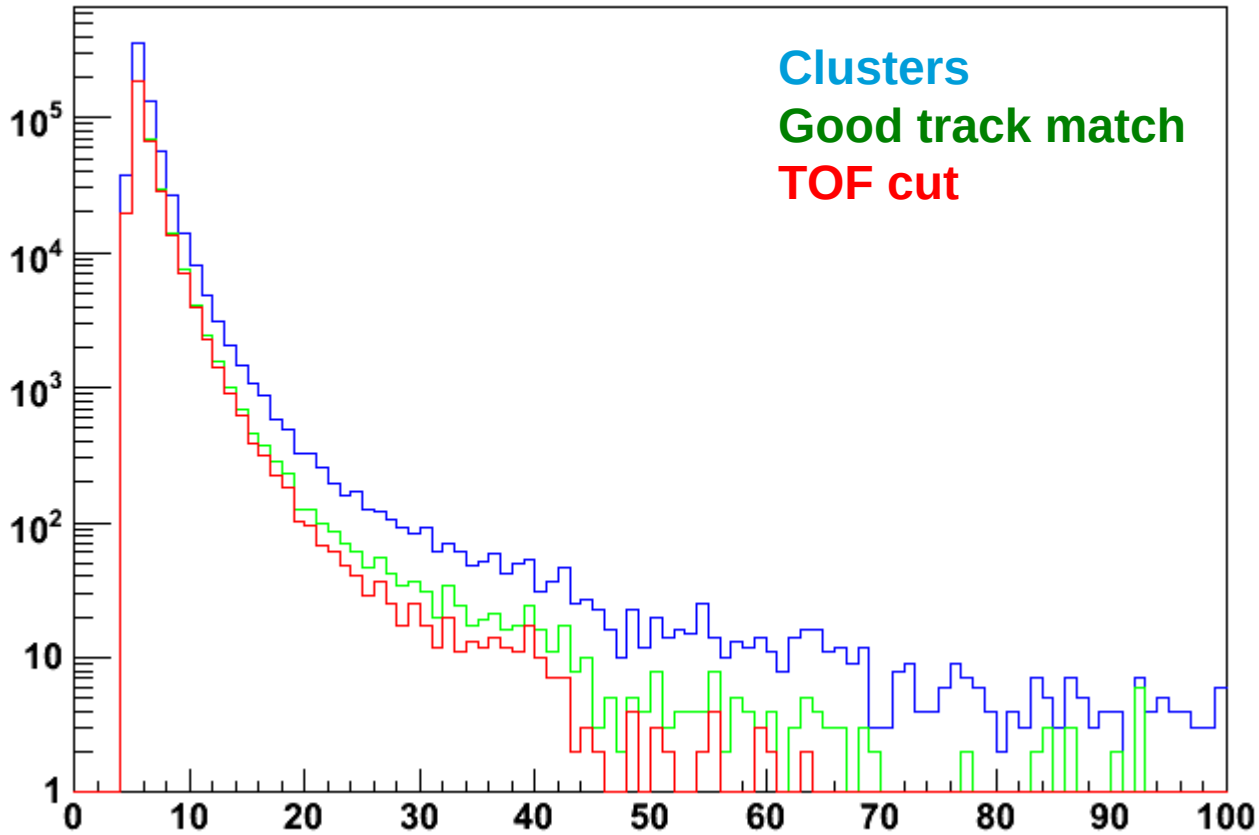
•Get smooth spectrum after removing bad towers

Effect of Cuts



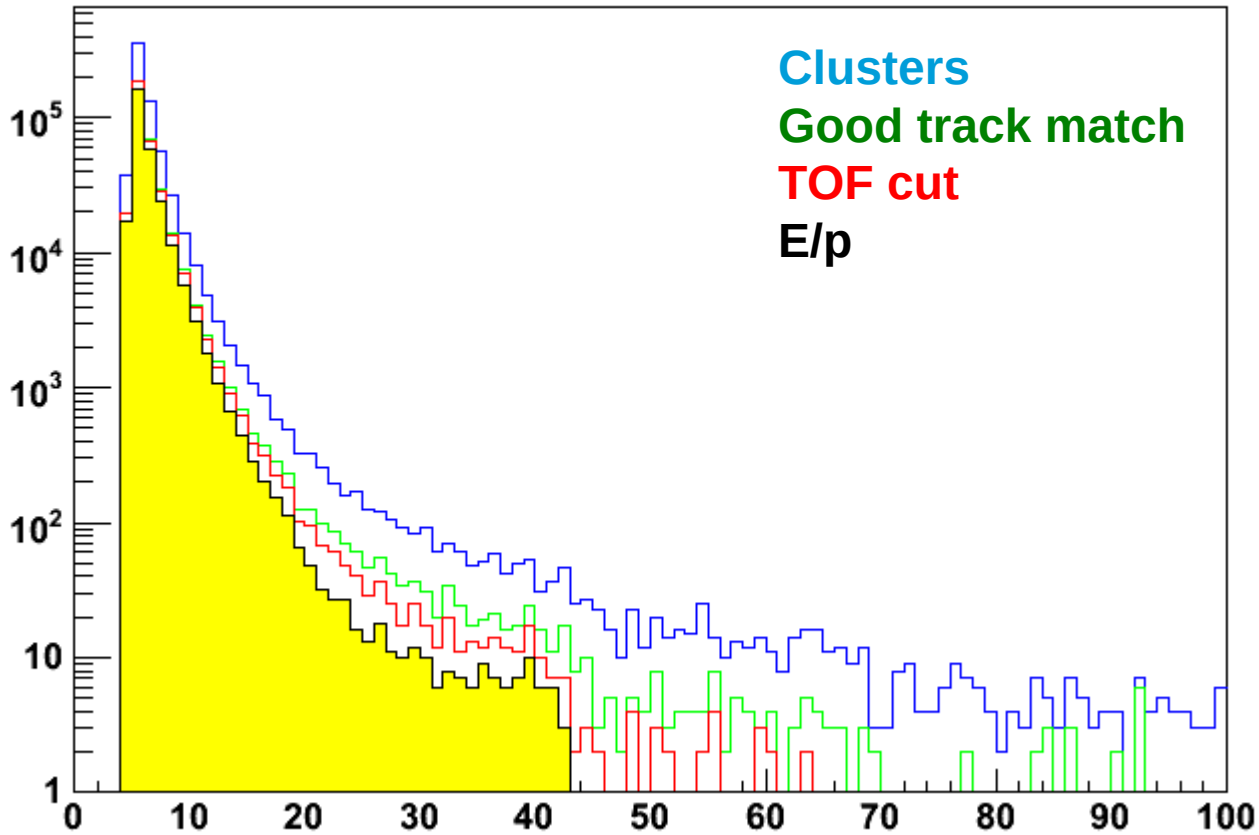
- Number of wires >4 in DC X1 and X2 with PC1 and EMC association
  - Have a good track pointing to a cluster

Effect of Cuts



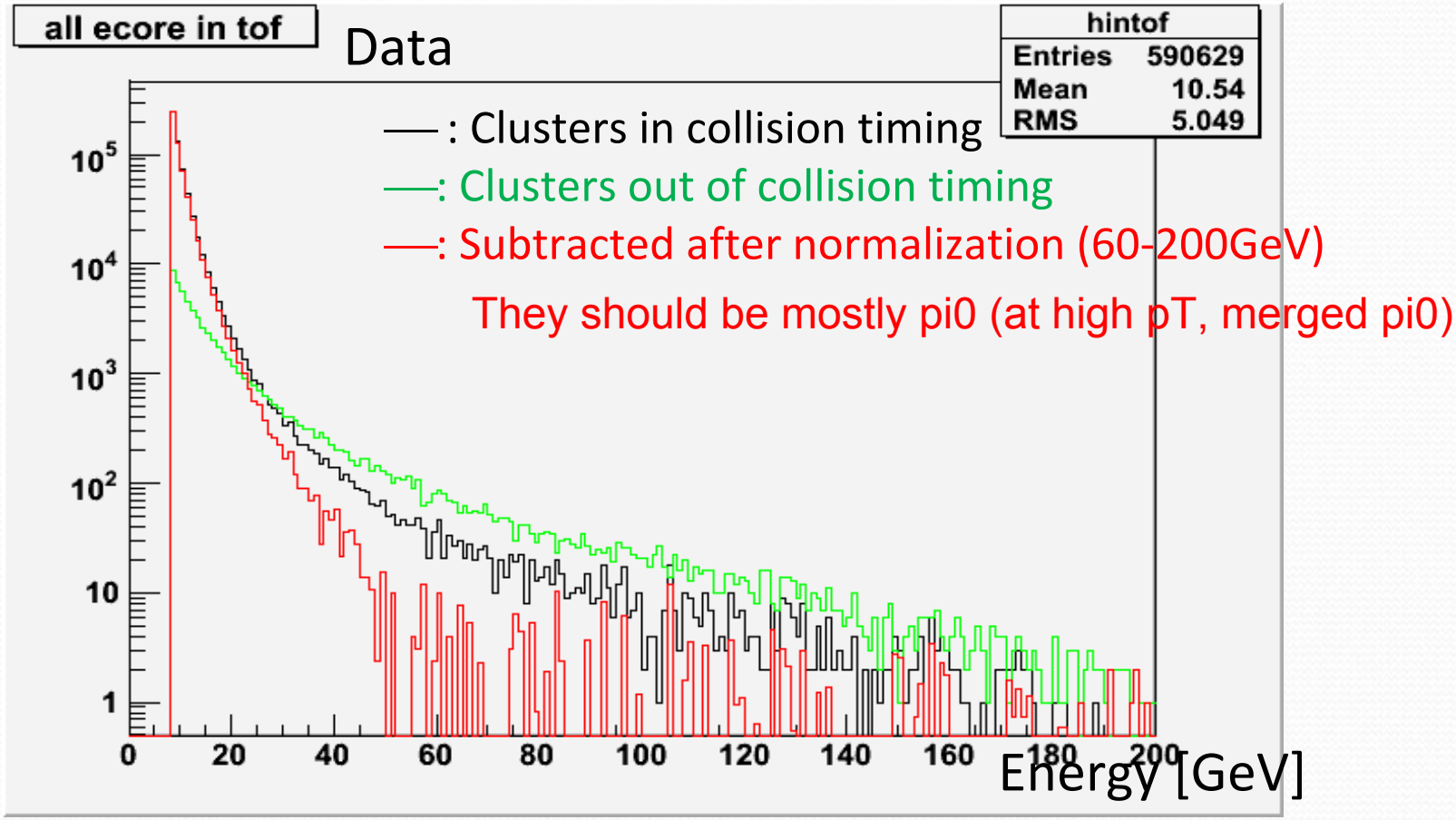
- TOF consistent with start time of collision
  - Reduces cosmic background by ~80%

Effect of Cuts



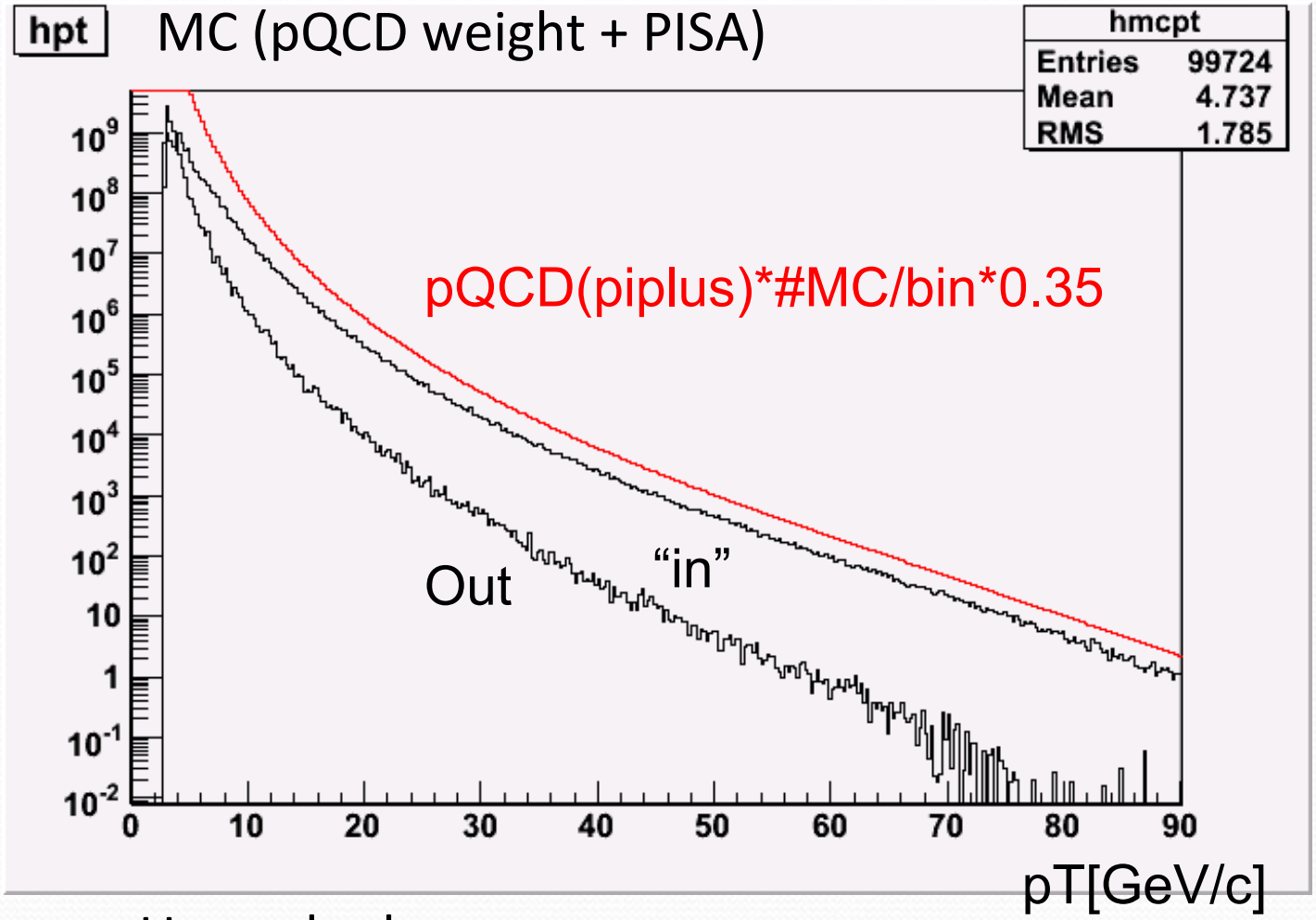
- EMC energy ~ DC momentum
  - Selects electrons
  - Some conversion background remains, or possibly W+jets

Component 1:
Raw EMCal hit distribution



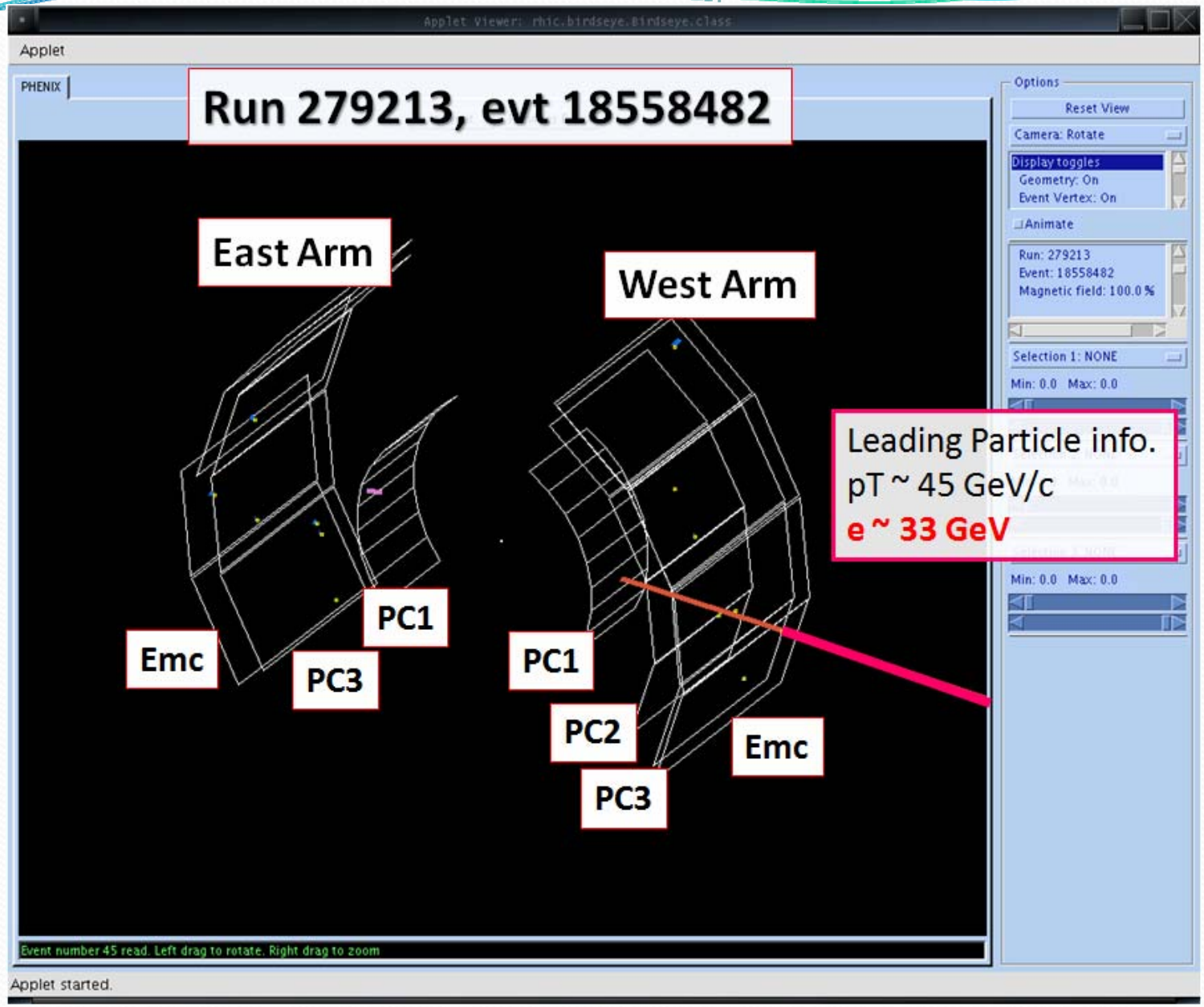
* Since cosmic rays hit EMCal from any direction, it is not necessarily the true energy deposit.
* Shower shape cut also reduces another factor 10.

Component 2: Hadronic clusters

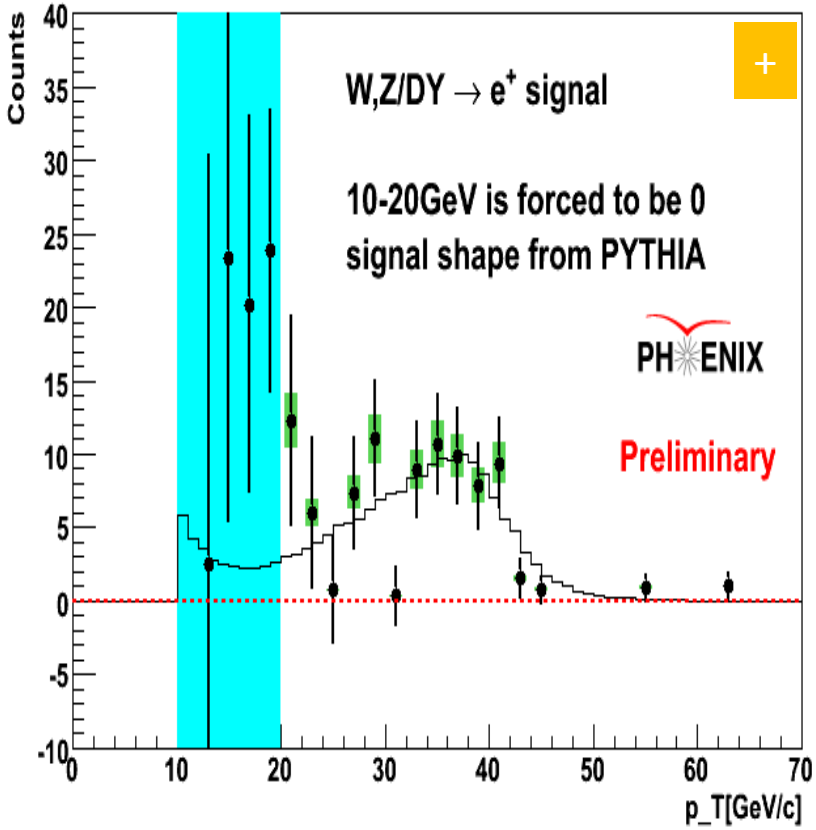


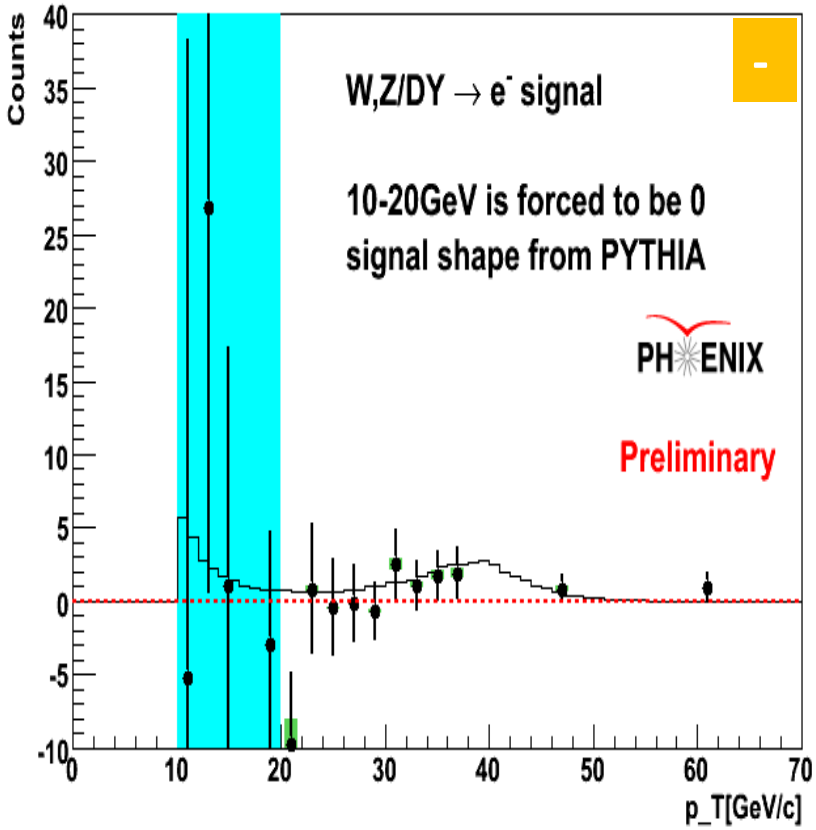
Use only shape.

Some event displays of High energy events



Background Subtracted Spectra





Event sample $30<p_T<50$ GeV/c

From 9.28 pb^{-1} of data

Sample	Raw counts	Background counts	Background subtracted	Isolation cut counts
Positive	60	11.1	48.9	39
Negative	16	10.6	5.4	11
Total	76	21.7	54.3	50