Run 12 Sea Quark Polarization:
Data analysis by using $W \rightarrow \mu$

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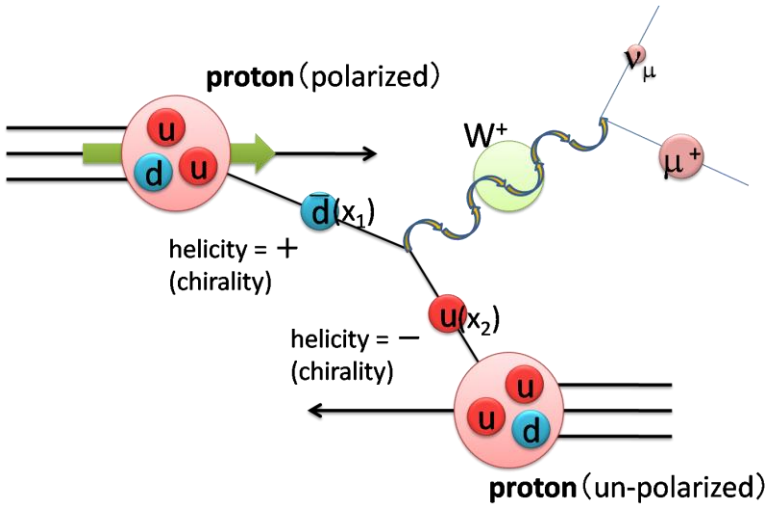
for the PHENIX collaboration

Japan-Korea PHENIX Collaboration Workshop 2013

Outline

1. **PHENIX Muon Arms**
   a. W physics
   b. Detectors and Recent Runs
2. **W → μ analysis**
   a. Preselection
   b. W likelihood
   c. Composing PDFs
   d. S/BG ratio estimation
   e. Single spin asymmetry (A_L)
3. **Summary and Perspectives**

1. PHENIX Muon Arms – a. *W* physics



* un-polarized: integrated for certain beam

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

$$\sim \frac{\Delta u(x_1)}{u(x_1)}(x_1 \gg x_2) \text{ or } \sim -\frac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)}(x_2 \gg x_1)$$

* Swap u and d for W^- case

in real experiment,

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

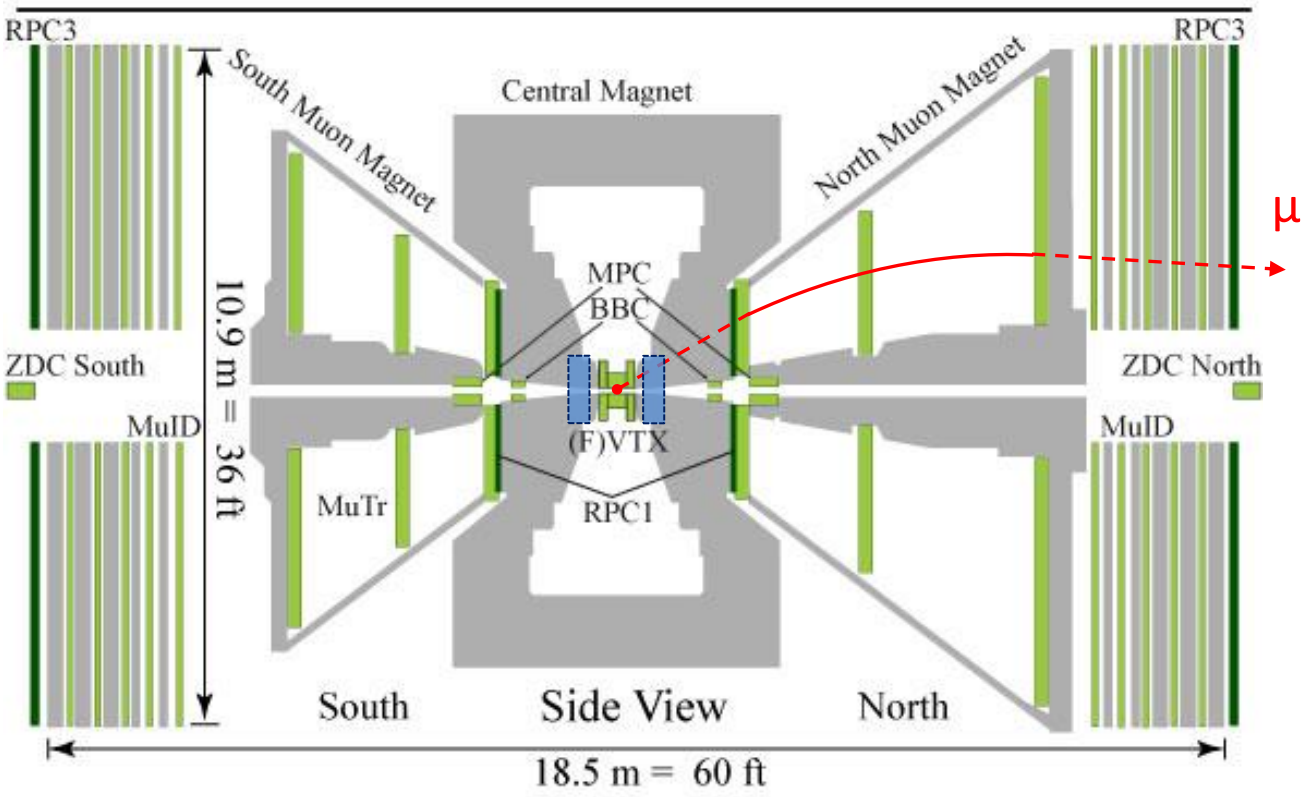
A_L^W : Single spin asymmetry

P : Beam polarization

$N_{-(+)}(W)$: # of events contains leptons decayed from W with corresponding helicity (negative/positive)

- ***W* physics in RHIC/PHENIX**
  - Target maximal parity-violating *W* bosons produced via polarized p – unpolarized p collision
  - Measure the Single spin asymmetry (A_L) of the quark, by using leptons directly decayed from *W* bosons
- **Advantages:**
  - Fixed flavor combination: full flavor separated measurements
  - No dependence on fragmentation functions: direct and clean signal

1. PHENIX Muon Arms – b. Detectors and Recent Runs



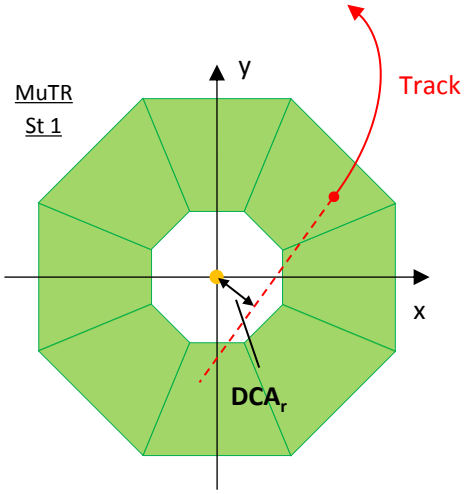
- **PHENIX Muon Arms (2013)**
  - **Acceptance:** $1.2 < |\eta| < 2.2$ (S) / 2.4 (N) and $\Delta\phi = 2\pi$
  - **Tracking:** FVTX, MuTR
  - **Triggering and PID:** MuID and RPCs
  - **Radial B field:** 0.72 (T·m) at $\theta = 15^{\circ}$

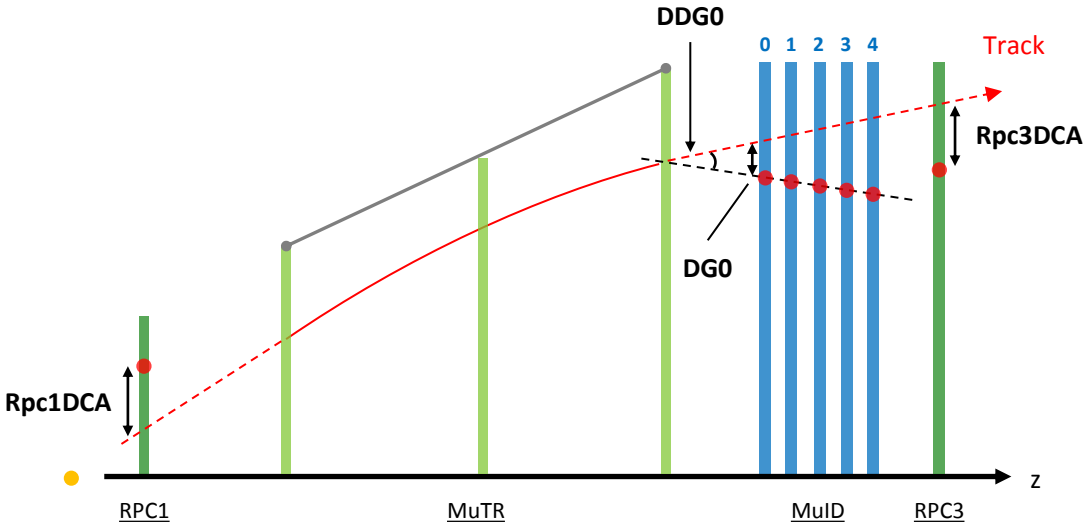
2. W → μ analysis – a. Preselection

- Preselection of μ candidates from data:

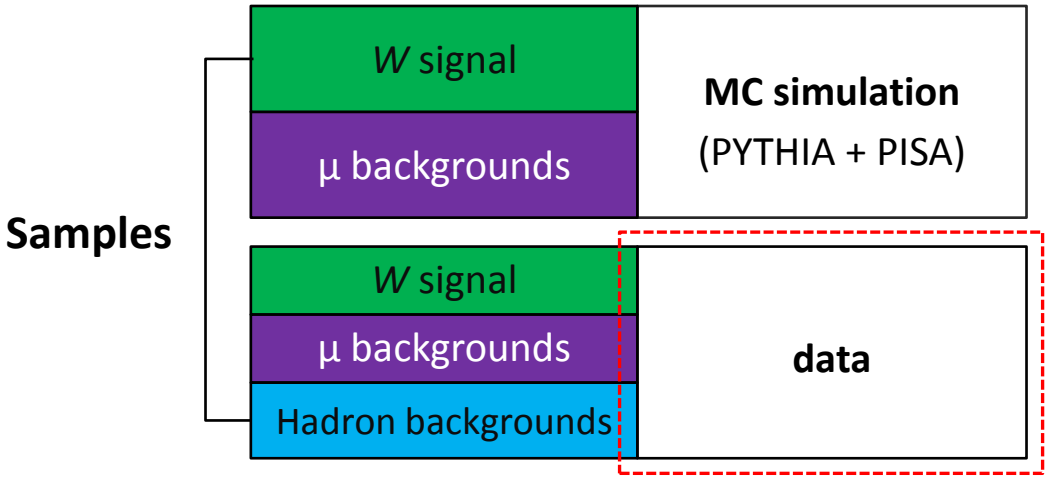
  by using **Basic cut** to several signal-sensitive **Kinematic variables**

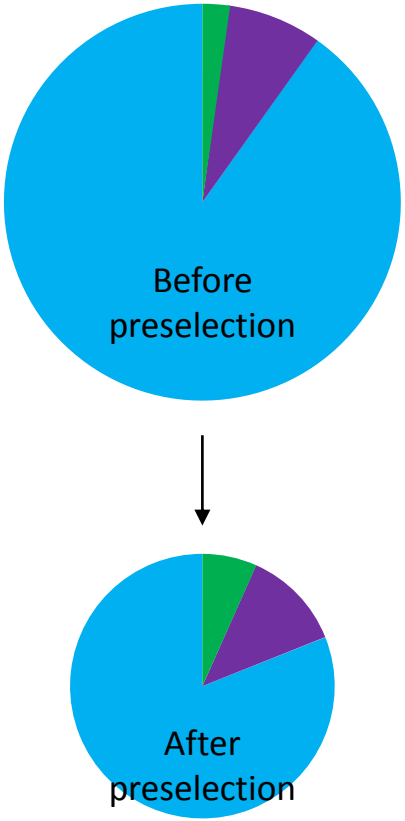
  - **Kinematic variables**: χ^2, DCA_r, Rpc1DCA, Rpc3DCA, DG0, DDG0
  - **Basic cut**: requirements for rough μ identification
    - Apply loose requirements to χ^2, DG0, and DDG0
    - **$16 < p_T < 60$** (GeV)
    - Last recorded hit in the MuID gap = 4 (5^{th} and last)





2. W → μ analysis – a. Preselection



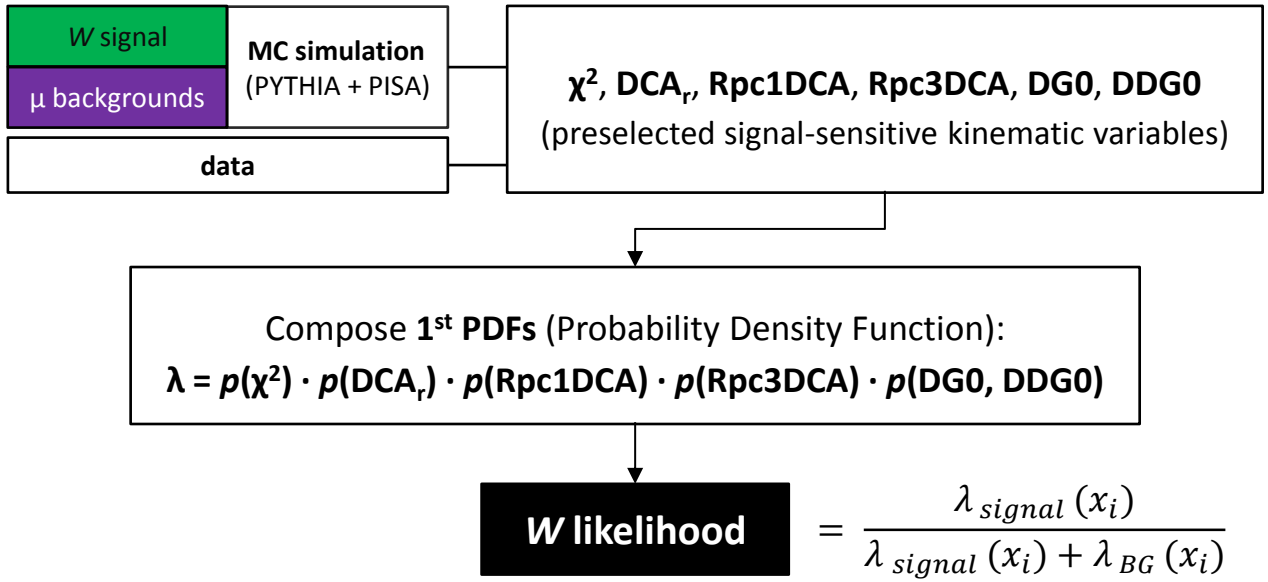


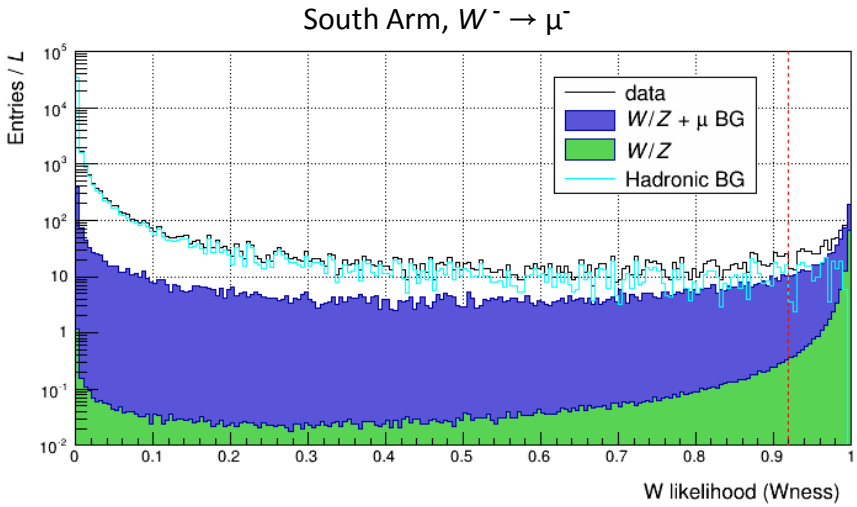
- **MC simulation (PYTHIA + PISA):**
  - Signal: $W \rightarrow \mu$ and $Z \rightarrow \mu$
  - μ backgrounds: Direct γ, Quarkonium, Opencharm, Openbottom, $W \rightarrow$ hadron/tau, and $Z \rightarrow$ hadron/tau
  - Hadronic BG MC is not available for now
- **data (pp510 Run 12):**
  - Sampled luminosity: 42 pb^{-1}
  - Still background dominant after preselection

Total data composition

- Size: surviving events
- Green: *W* events
- Violet: μ BG
- Cyan: Hadronic BG

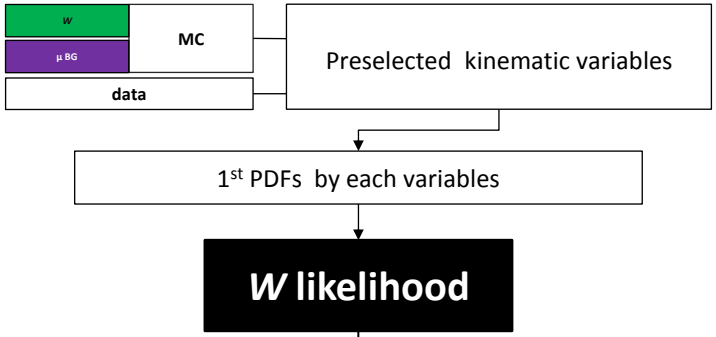
2. W → μ analysis – b. W likelihood



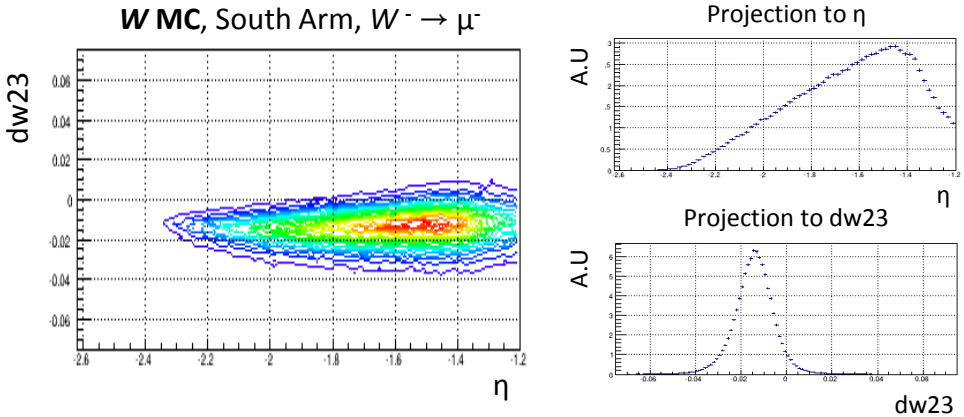


- **Data**
- **Signal** (PYTHIA + PISA)
- **Signal + μ backgrounds** (PYTHIA + PISA)
- **Hadronic backgrounds (fakes)**

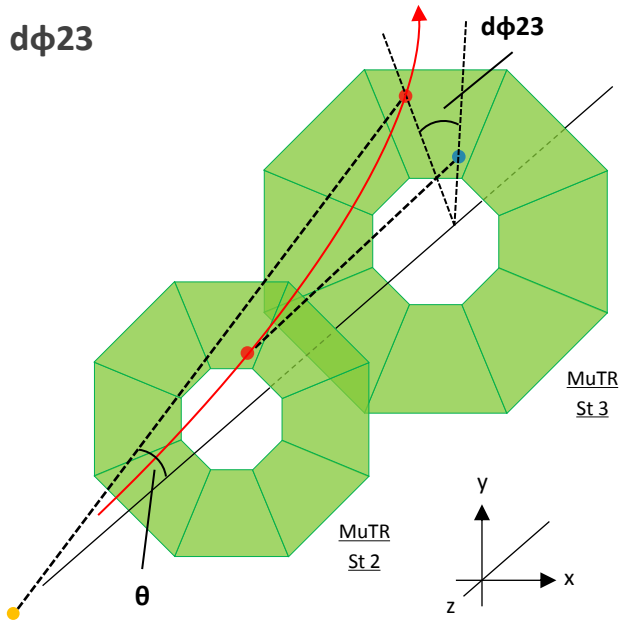
2. W → μ analysis – c. Composing PDFs



* **dw23** (reduced azimuthal bending) ≡ $\mathbf{p_T \times \sin\theta \times d\phi 23}$



W likelihood > 0.92



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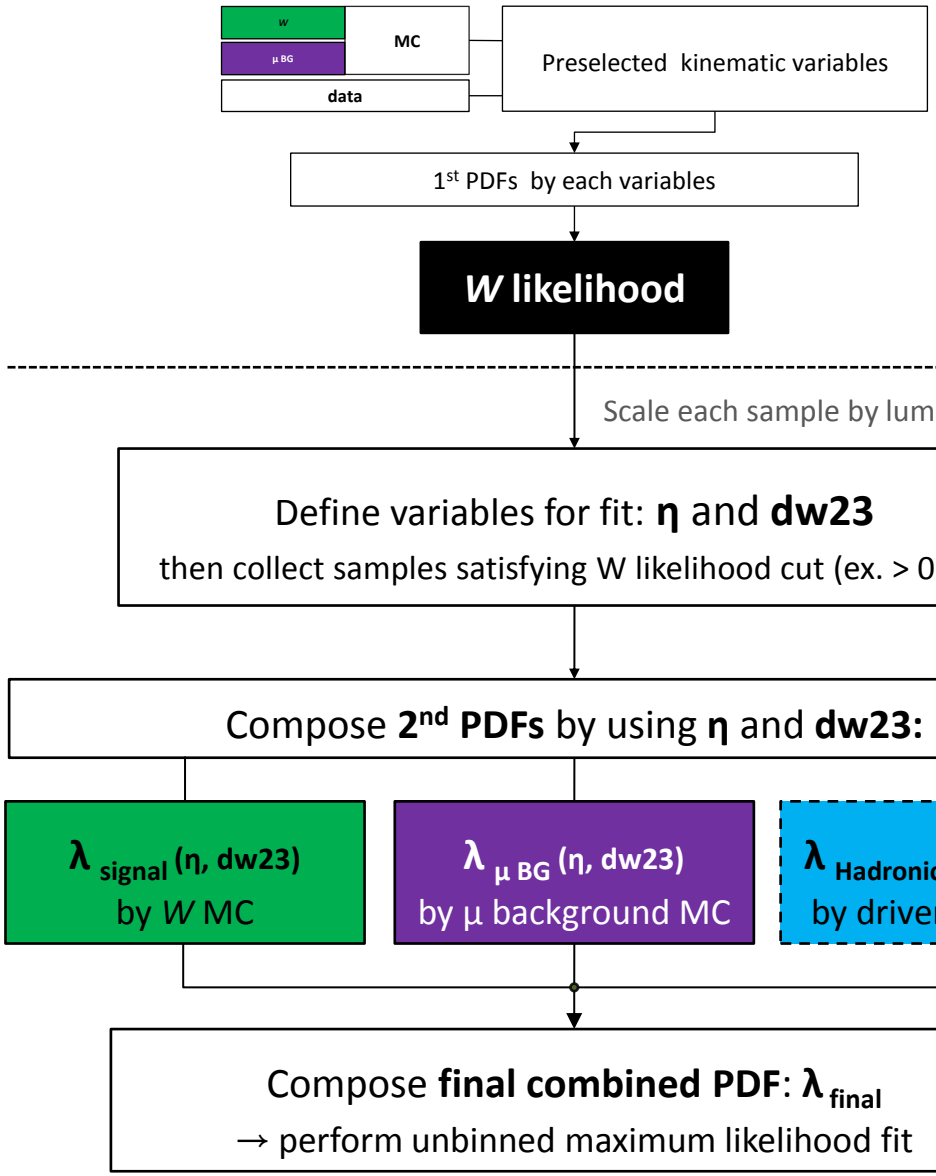

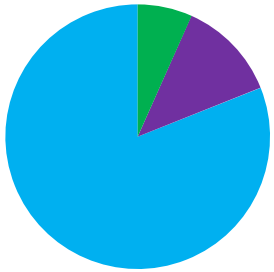

Total data composition

- Size: surviving events
- Green: *W* events
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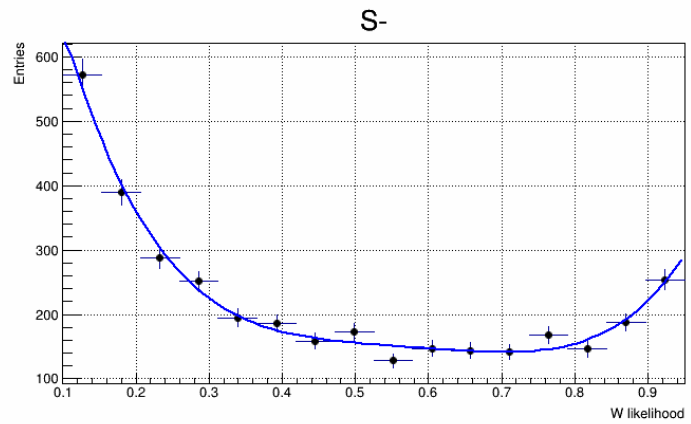
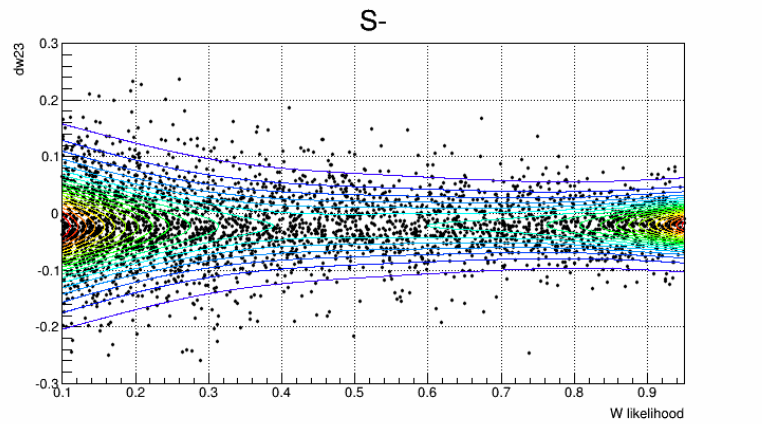
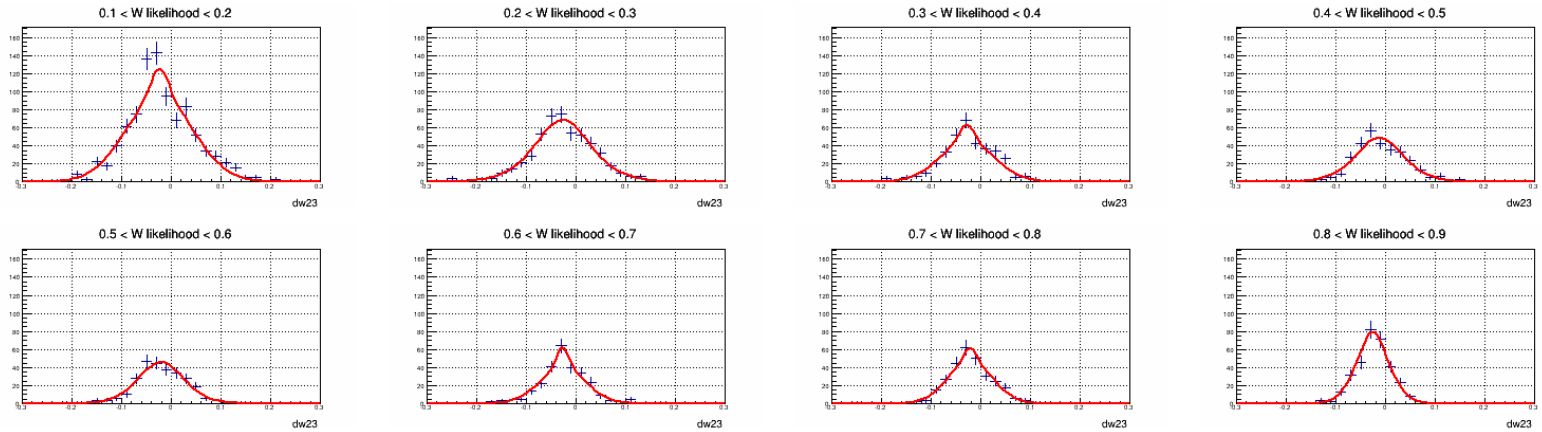
- Cyan: Hadronic BG

2. W → μ analysis – c. Composing PDFs

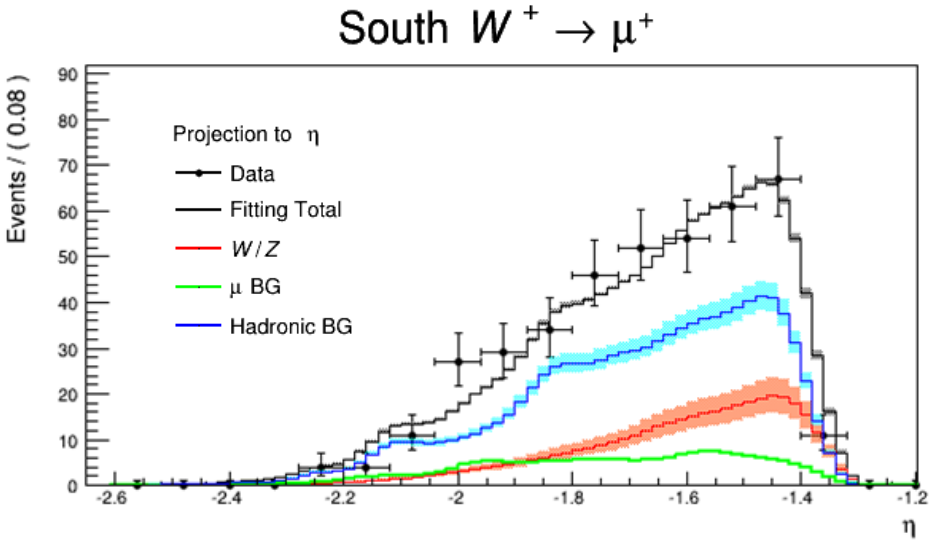


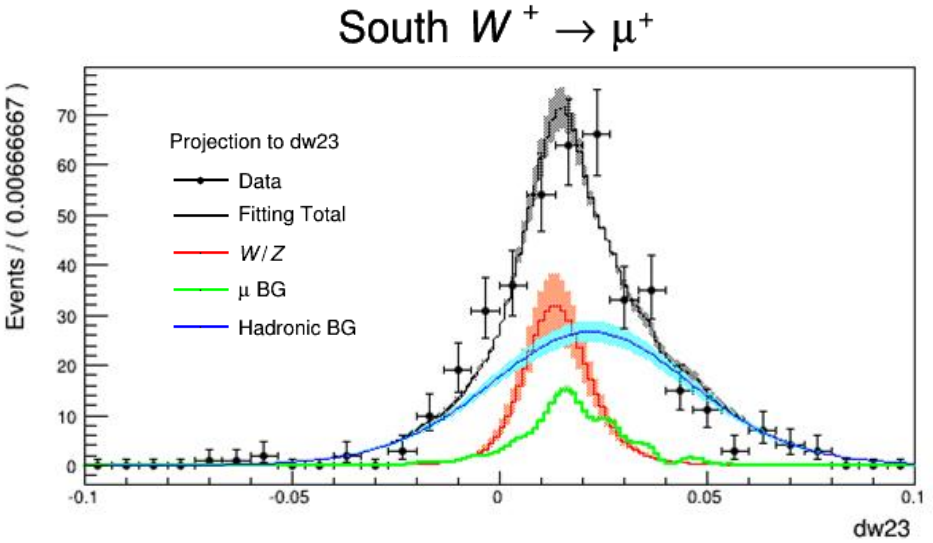




- **Data-driven Hadron backgrounds distribution in region of interest**
  - Unlike η, shape of dw23 sensitively varies by *W* likelihood
  - Extrapolate expected HBG distribution on ROI:
    perform 2D fit by using pol4 (*W* likelihood) and coaxial double Gaussian (dw23)

2. W → μ analysis – d. S/BG ratio estimation





2D unbinned max. likelihood fit:

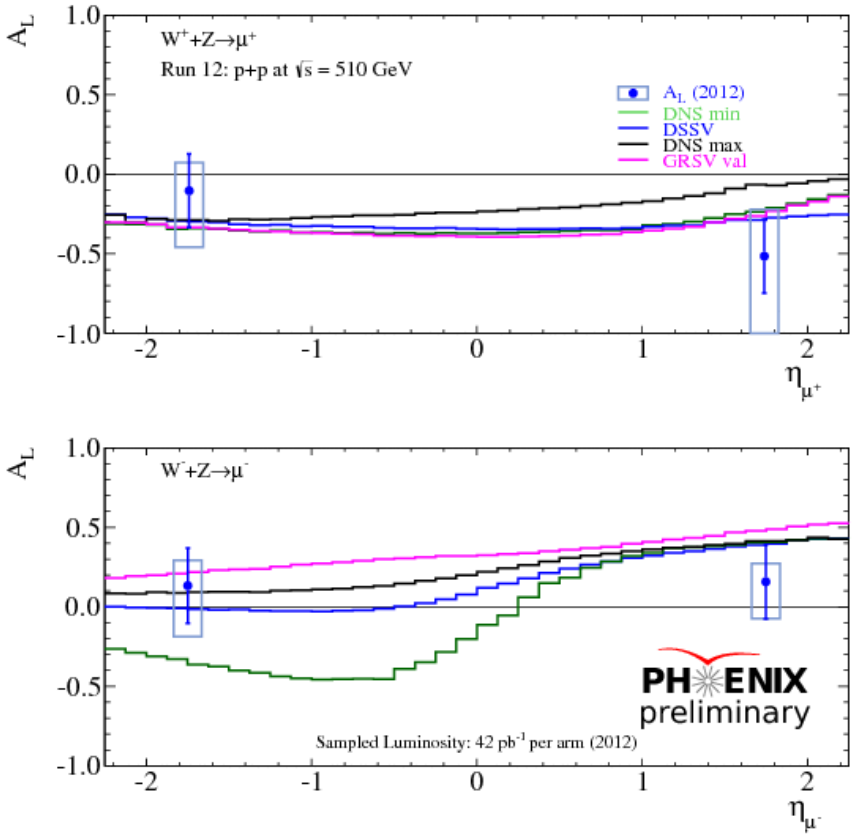
← 1D projections onto each variable

- **Signal (fit)**: $W \to \mu$ and $Z \to \mu$
- **μ backgrounds (fixed)**:
  sum of various channels of μ BG
  (*L* scaled & total efficiency corrected)
- **Hadronic backgrounds (fit)**

Estimated S/BG ratio (preliminary)

Channel	n_{sig}	n_{μ}	n_{had}	Sig/BG
South μ^-	$88.87^{+16.97}_{-16.28}$	44.42	$177.77^{+19.60}_{-18.60}$	0.40
South μ^+	$92.48^{+20.55}_{-19.91}$	44.88	$258.74^{+24.38}_{-23.31}$	0.30
North μ^-	$38.95^{+11.90}_{-11.15}$	42.71	$139.78^{+15.45}_{-14.56}$	0.21
North μ^+	$72.37^{+15.75}_{-15.04}$	38.67	$185.69^{+18.93}_{-17.98}$	0.32

2. W → μ analysis – e. Single spin asymmetry (A_L)



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

$$\sim \frac{\Delta u(x_1)}{u(x_1)}\,(x_1 \gg x_2) \text{ or } \sim -\frac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)}\,(x_2 \gg x_1)$$

* Swap u and d for W^- case

- Sampled Luminosity (pb^{-1}):
  - Run 12: 42
  - Run 13: 228

Run 12 preliminary

- Beam combined asymmetries for mid / forward rapidity WRT η_{mean}
- Shows optimistic agreement with theoretic expectation

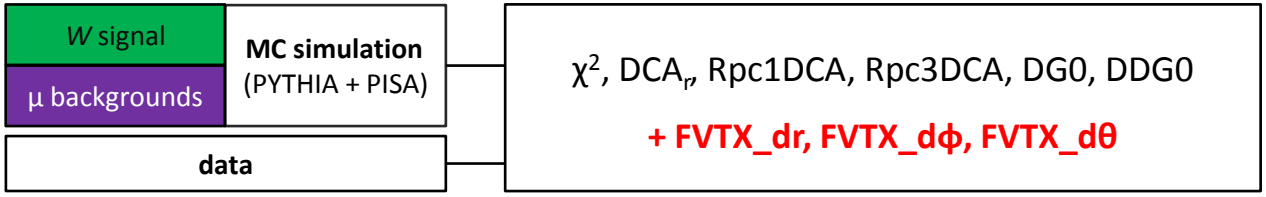
3. Summary and Perspectives

- **Summary**
  - ***W* physics in RHIC/PHENIX:**

    target better constraint on flavor-decomposed sea quark polarization
  - **Longitudinally polarized pp in PHENIX:**
    - Total achieved int. L: ~ 200 pb^{-1}
    - Avg. beam polarization: > 50 %
  - ***W* → μ in PHENIX Muon Arms:**
    - Main analysis method:
      - Backgrounds dominant in region of interest: estimation of direct S/BG ratio is impossible
      - Estimation of S/BG ratio by using unbinned maximum likelihood fit
    - Major challenge: separation of Hadronic backgrounds from in-flight decay
    - Estimated S/BG ratio: ~ 0.2 to ~ 0.4, varies by side and charge
    - Single spin asymmetry: shows optimistic agreement to the theoretic expectation

3. Summary and Perspectives

- **Perspectives**
  - **Refine current using factors:** efficiency tune, various cross checks…
  - **Inclusion of FVTX matching variables:**
    - 3 additional high-precision variables available
    - Looking forward enhanced statistics in region of interest as well as reduced error
    - Major update required for the proper integration: now ongoing



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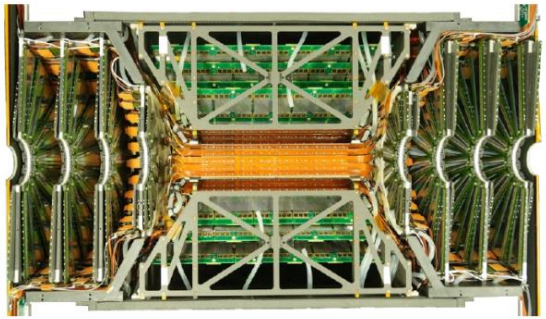
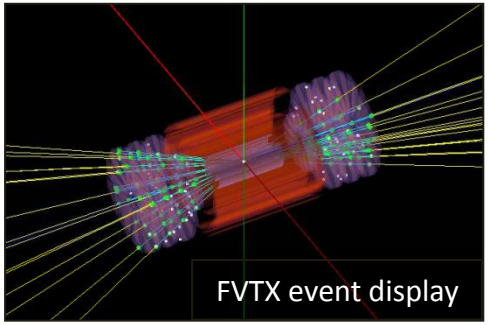
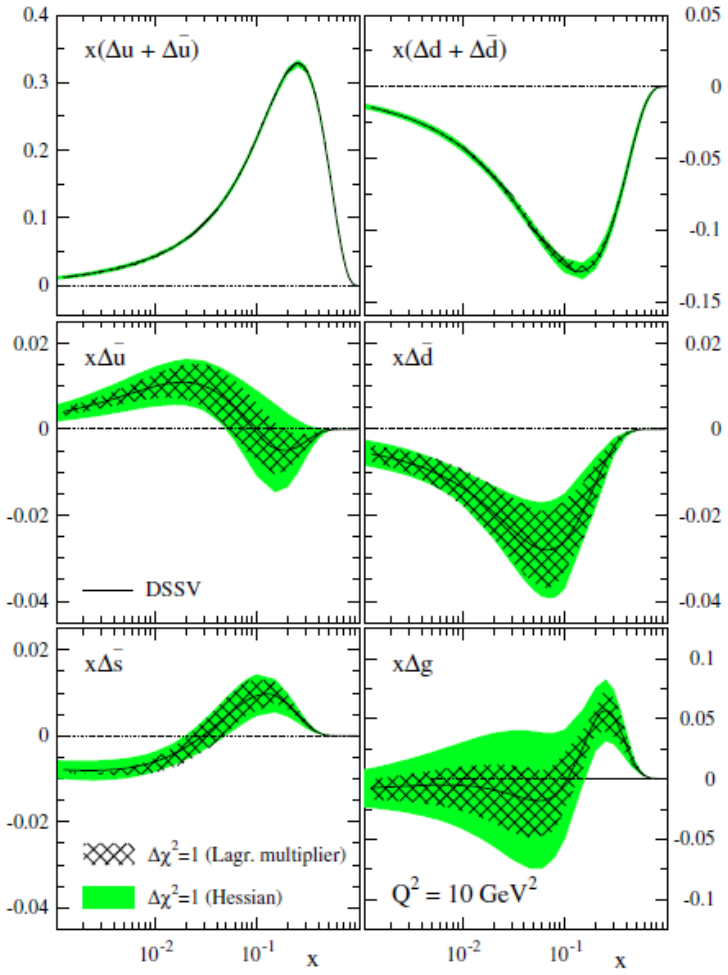




Backup



D. de Florian et al,
PRD 80. 034030 (2009)

- **Spin crisis:**

  proton spin is not a simple sum of its constituent quarks (quark spin contribution to the total: < 40 %)

- **Proton spin sum rule:**

  $\frac{1}{2} = \frac{1}{2}\,\underline{\mathbf{\Delta\Sigma}} + \Delta G + L_z$, where

  $\underline{\mathbf{\Delta\Sigma}}$ (quark spin contribution) = $(\Delta u + \underline{\Delta\bar{u}}) + (\Delta d + \underline{\Delta\bar{d}}) + (\Delta s + \Delta\underline{\bar{s}})$

  ΔG (gluon spin contribution) = $\int_0^1 \Delta g\,(x, Q^2)\,dx$

  L_z (orbital angular momenta) = $L_q + L_g$

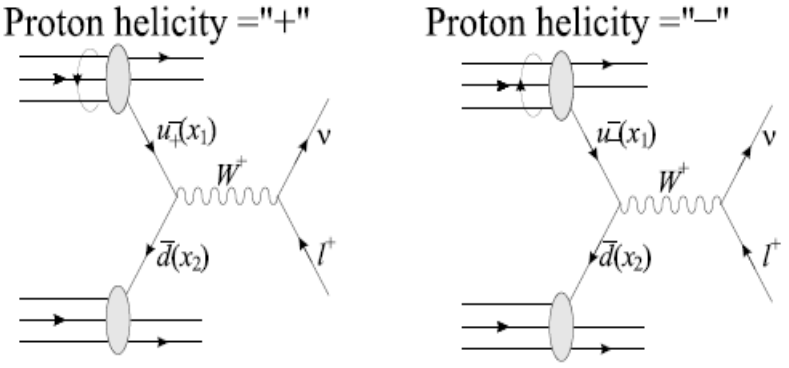
- **Polarized DIS/SIDIS:**

  Flavor-combined PDFs (ex. $\Delta u + \Delta\bar{u}$)) is well known, while their flavor-separated PDF is only known with large uncertainties

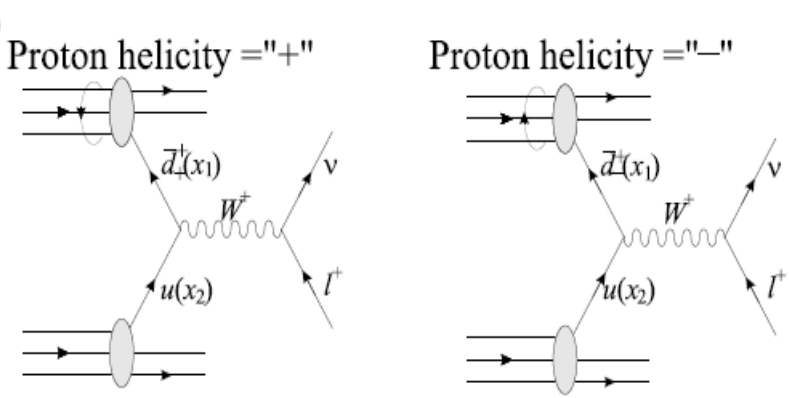
- **Still better constraint on sea quark polarization is required**

Backup – *W* measurement in PHENIX

(a)



(b)



- If W pdoruction processed only through (a),

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

- If processed only through (b),

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

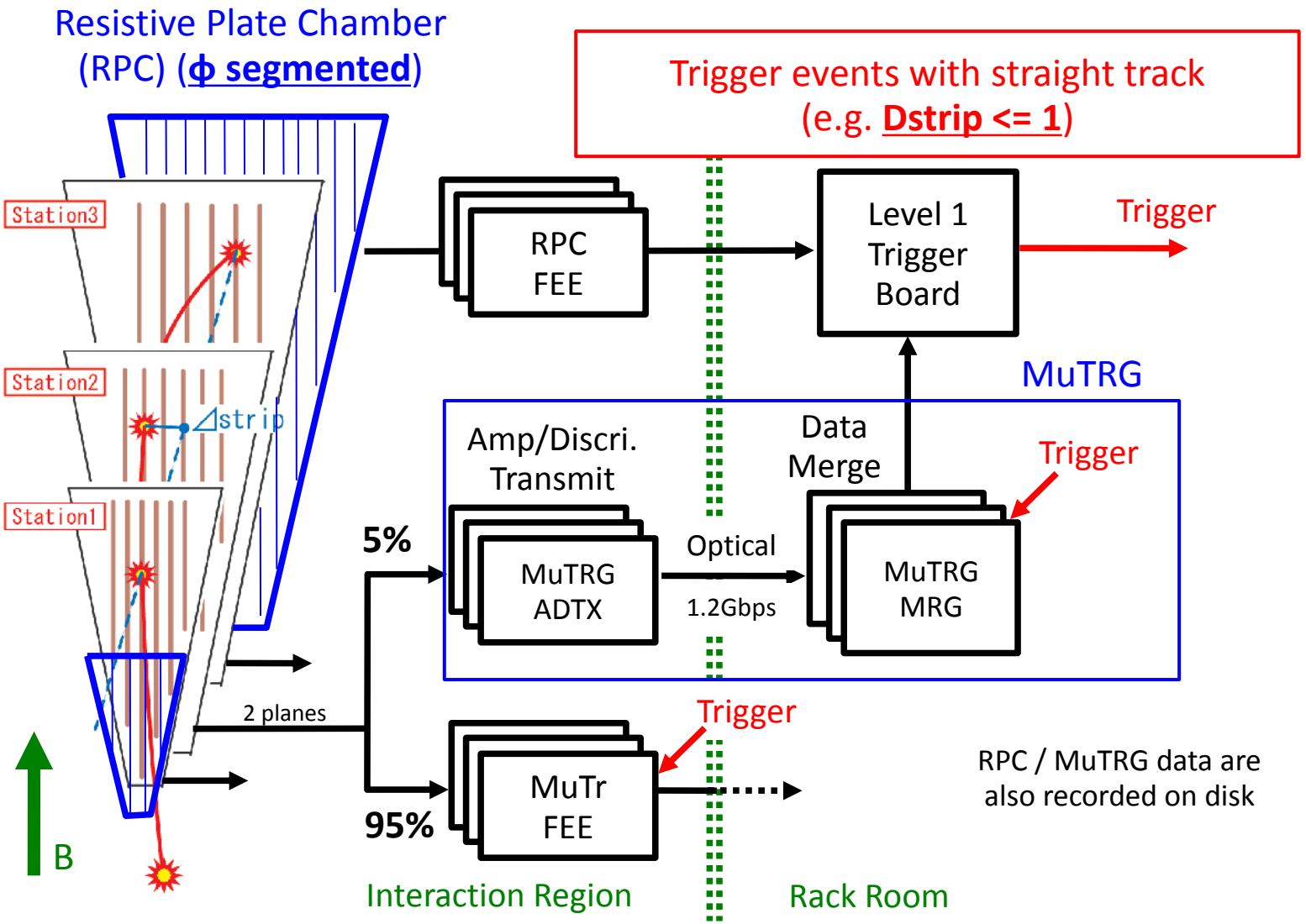
- In general, the asymmetry is a superposition of two cases:

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

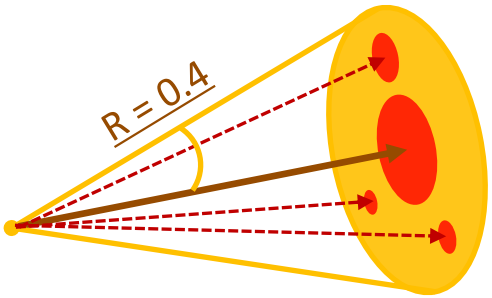
* To obtain the asymmetry for W^-, swap u and d

$$A_L^W = \frac{1}{P} \times \frac{N_-(W) - N_+(W)}{N_-(W) + N_+(W)} \quad \longleftrightarrow \quad A_L = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\sigma_{polarized}}{\sigma_{unpolarized}} \quad \begin{pmatrix} \sigma^+ = \sigma_{unpolarized} + \sigma_{polarized} \\ \sigma^- = \sigma_{unpolarized} - \sigma_{polarized} \end{pmatrix}$$

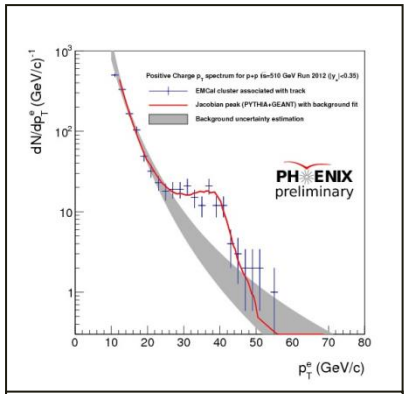
Backup – Forward μ trigger upgrade

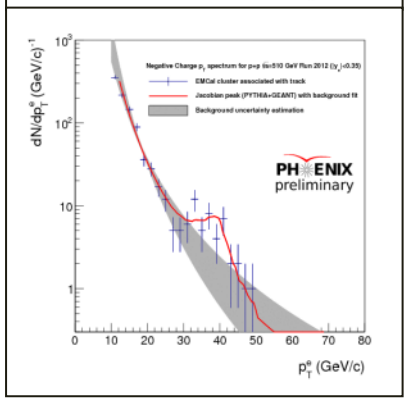


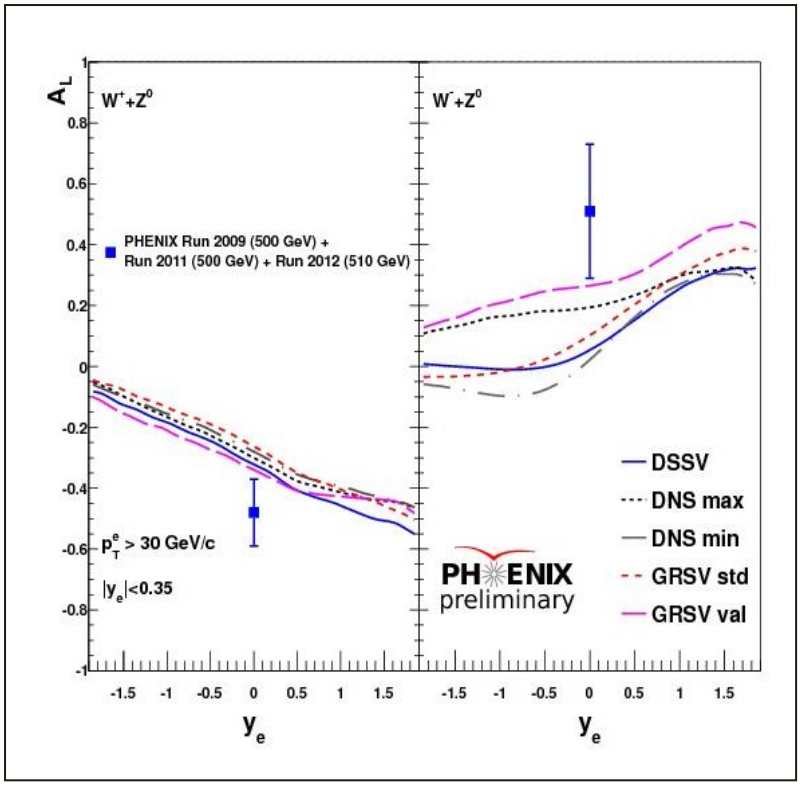
Backup – Central Arm *W* analysis



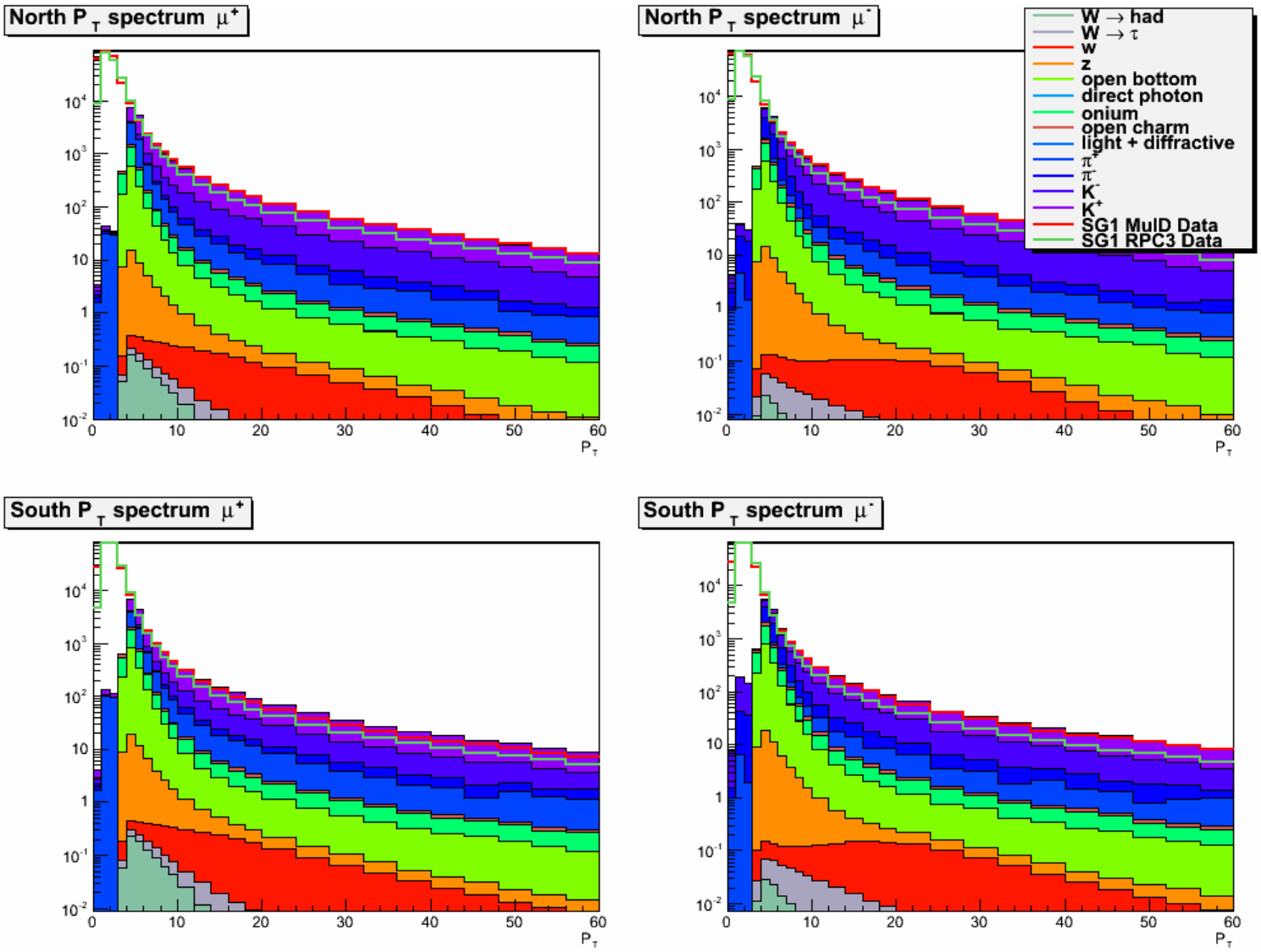
$$\frac{E_{cone} - E_{candiate}}{E_{candiate}} < 10\ (\%)$$







Backup – μ backgrounds

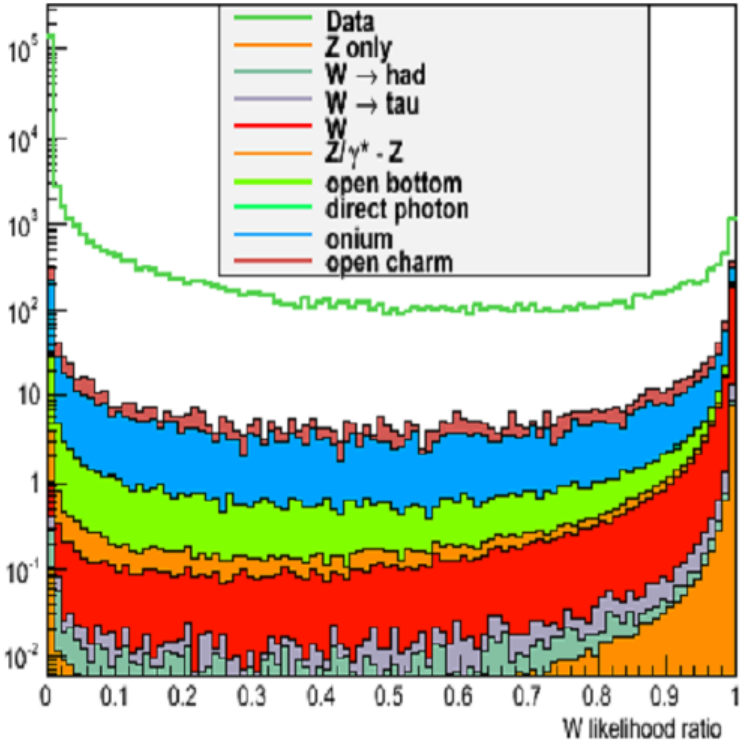


Backup – μ backgrounds

Before we can utilize the muon backgrounds simulation, we must weight each simulation appropriately

Process	Generated k events * 10 ^3	$\sigma\ (mb)$	$L = \#\frac{Events}{\sigma}\sigma$ (pb-1)	Scale Factor
Direct γ	6400	5.32×10^{2}	120.30	0.771367
onium	55470	0.14	410.89	0.209710
Z Only	106.5	$(-)1.33 \times 10^{-7}$	-800751.88	-0.000083
Open bottom	4003	7.3×10^{-3}	548.36	0.093074
Open charm	134220	0.571000	235.06	0.960310
W had	81	1.66×10^{-6}	48795.18	0.001358
W tau	82	1.66×10^{-6}	49397.59	0.001342
Z	245.2	1.59×10^{-5}	15421.38	0.009456

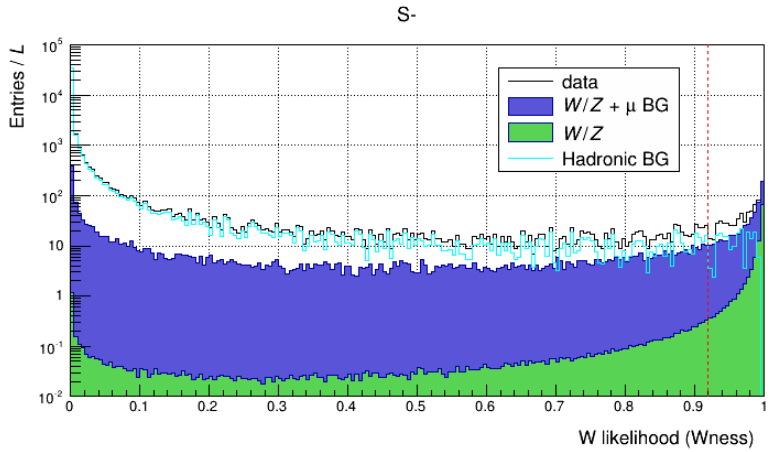
W simulation and **Data** are shown below relative to muon backgrounds, stacked and weighted, Wness distriubiton used for comparison, for S, μ^{+}

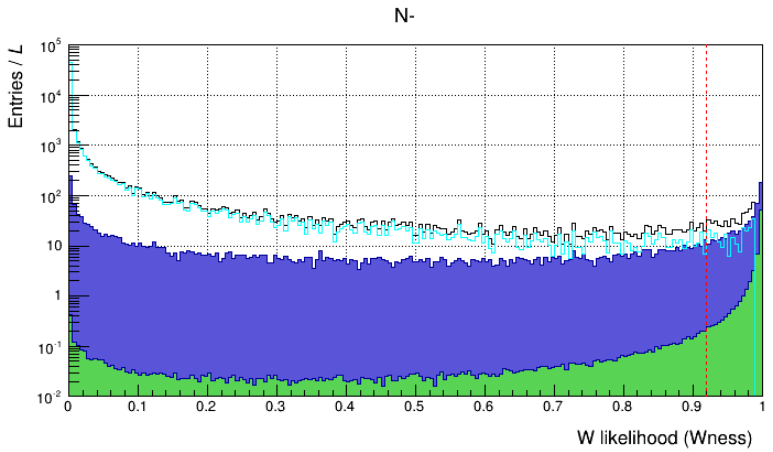


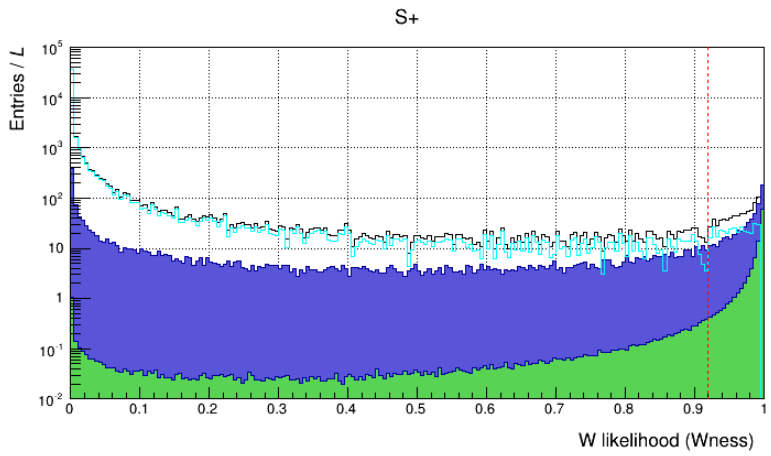
$$Scale\ Factor = \frac{228}{L(pb-1)} \times k\_factor \times detector\_eff$$

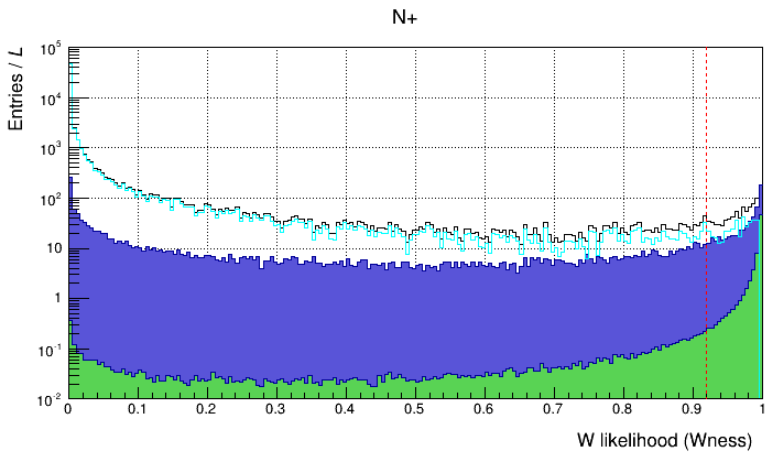
Detector_eff = 0.407

Backup – *W* likelihood distribution









Backup – MC Production statistics and Luminosity

Ref. 368630 (low)

pytune100	k factor	# of gen events (M)	x-section (mb)	luminosity (pb-1)
data (common)	1.5	N/A	N/A	43
dy (direct photon)	1.5	11600	5.32E-002	218.0
light	1.5	311.1	5.94E+001	0.0
onium	1.5	32910	1.35E-001	243.8
openbottom	1.5	1552	7.30E-003	212.6
opencharm	1.5	145940	5.71E-001	255.6
w	1.5	65.1	1.66E-006	39216.9
whad	1.5	120	1.66E-006	72289.2
wjet	1.5	11.9	1.20E-006	9916.7
wtau	1.5	118	1.66E-006	71084.3
z	1.5	81.5	1.59E-005	5125.8
zjet	1.5	11.9	1.02E-006	11666.7
zonly	1.5	0.000001	1.33E-007	0.0

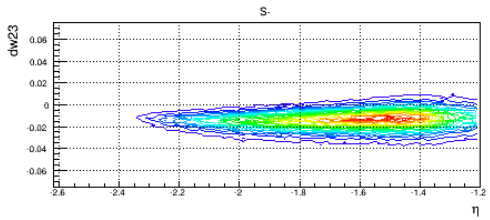
Ref. 367466 (mid)

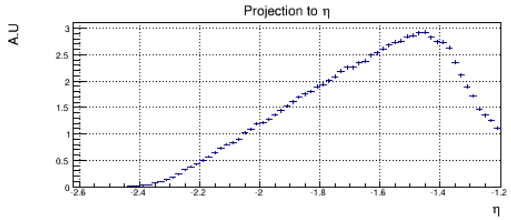
pytune100		# of gen events (M)	x-section (mb)	luminosity (pb-1)
data (common)	1.5	N/A	N/A	43
dy (direct photon)	1.5	48510	5.32E-002	911.8
light	1.5	152	5.94E+001	0.003
onium	1.5	69790	1.35E-001	517.0
openbottom	1.5	4489	7.30E-003	614.9
opencharm	1.5	250830	5.71E-001	439.3
w	1.5	451.2	1.66E-006	271807.2
whad	1.5	335	1.66E-006	201807.2
wjet	1.5	13.3	1.20E-006	11083.3
wtau	1.5	346	1.66E-006	208433.7
z	1.5	253.7	1.59E-005	15956.0
zjet	1.5	13.2	1.02E-006	12941.2
zonly	1.5	136.8	1.33E-007	1028571.4

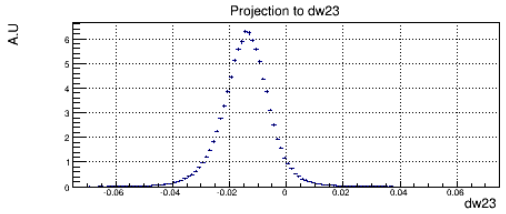
Ref. 367593 (high)

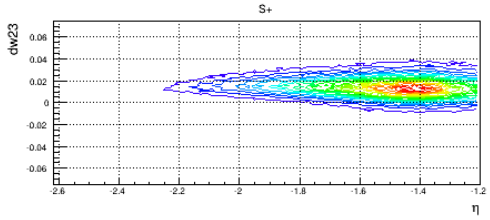
pytune100		# of gen events (M)	x-section (mb)	luminosity (pb-1)
data (common)	1.5	N/A	N/A	43
dy (direct photon)	1.5	6400	5.32E-002	120.3
light	1.5	193.6	5.94E+001	0.003
onium	1.5	55470	1.35E-001	410.9
openbottom	1.5	4003	7.30E-003	548.4
opencharm	1.5	134220	5.71E-001	235.1
w	1.5	173.4	1.66E-006	104457.8
whad	1.5	81	1.66E-006	48795.2
wjet	1.5	8.2	1.20E-006	6833.3
wtau	1.5	82	1.66E-006	49397.6
z	1.5	245.2	1.59E-005	15421.4
zjet	1.5	8.2	1.02E-006	8039.2
zonly	1.5	106.5	1.33E-007	800751.9

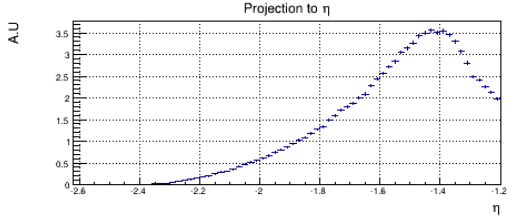
Backup – η vs. dw23, by *W* MC

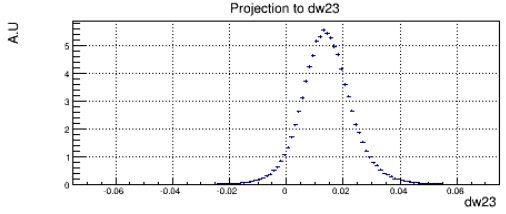


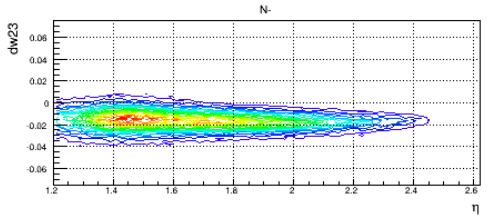


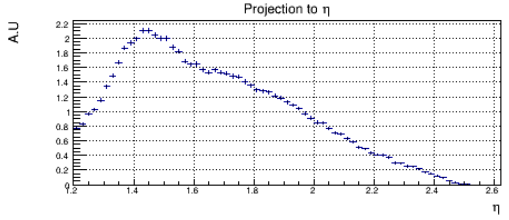


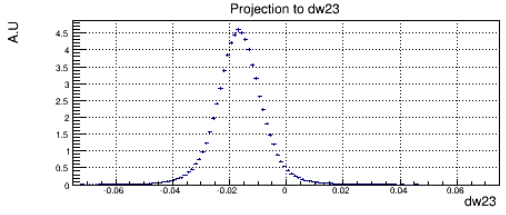


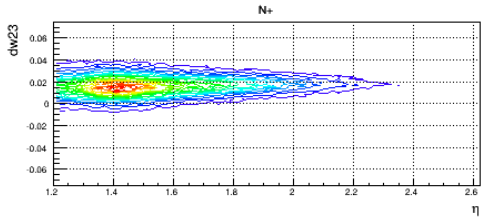


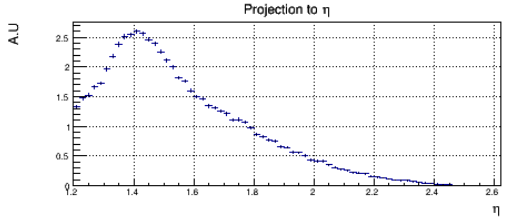


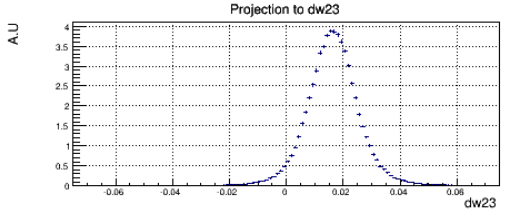




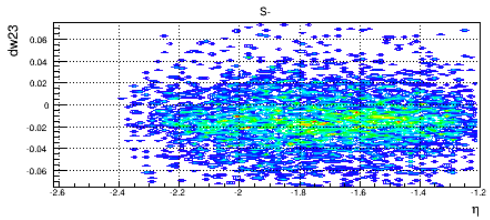


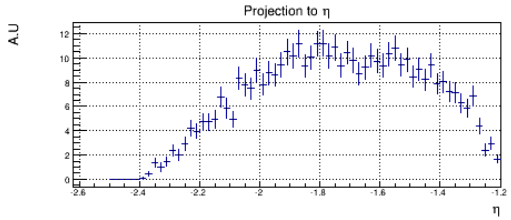


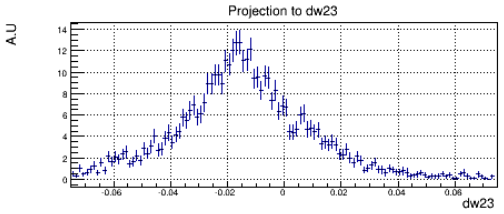


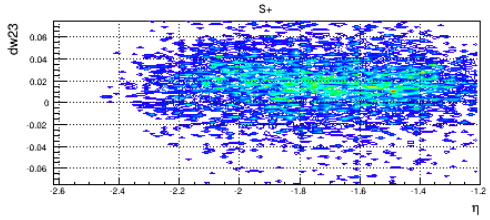


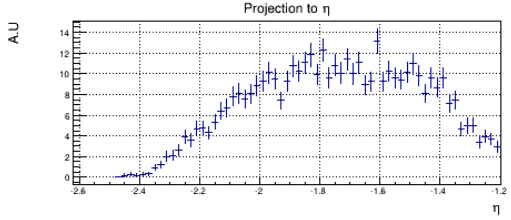
Backup – η vs. dw23, by μ BG MC

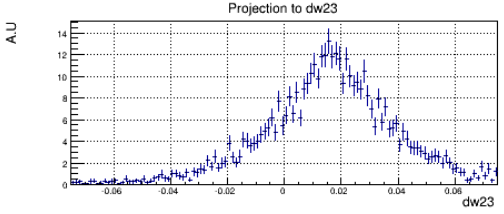


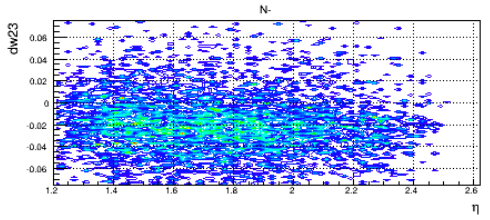


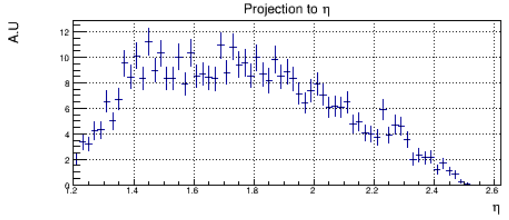


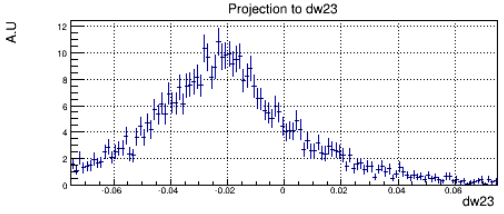


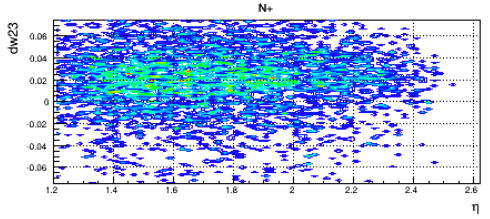


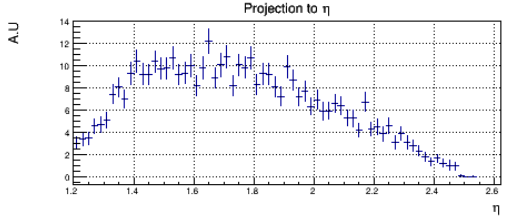


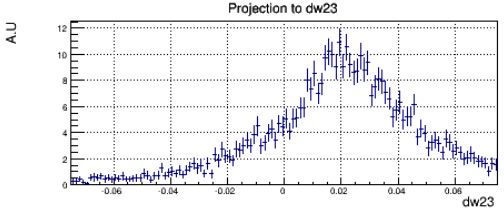




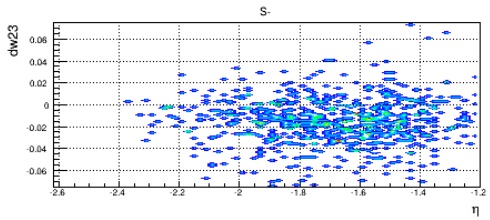


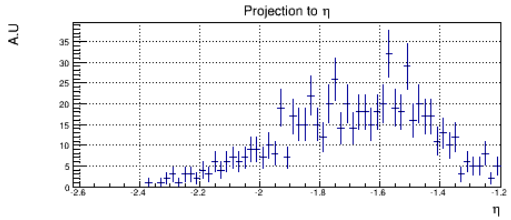


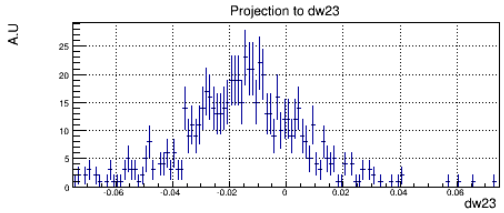


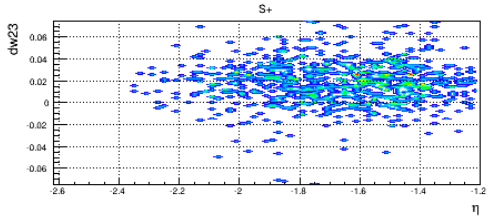


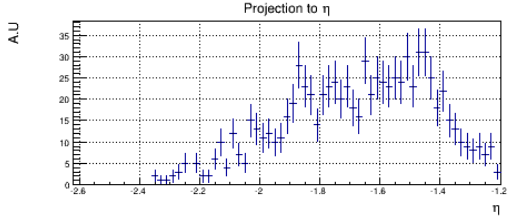
Backup – η vs. dw23, by data (≒ μ BG + Hadronic BG)

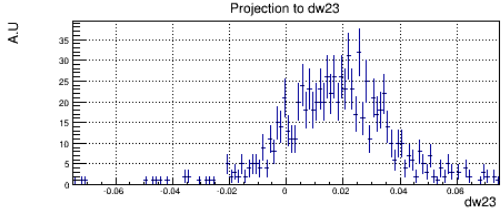


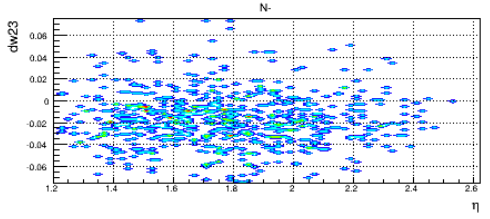


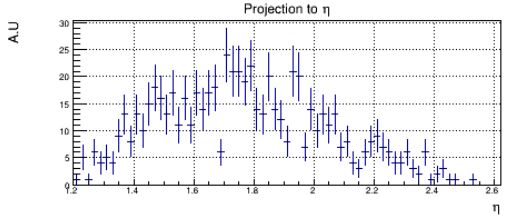


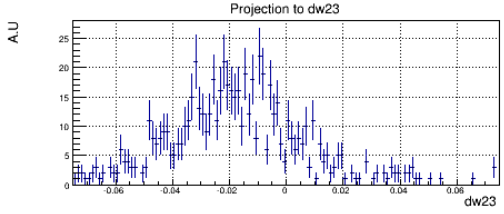


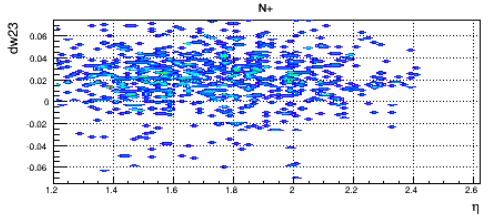


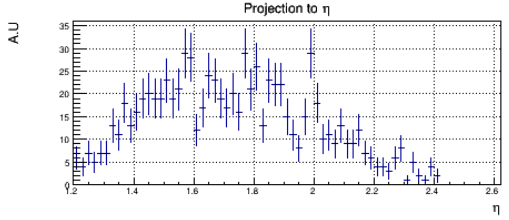


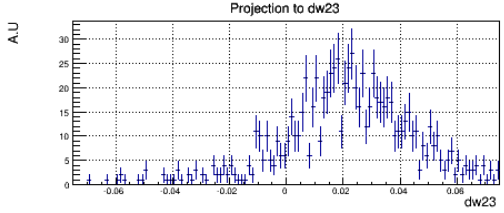




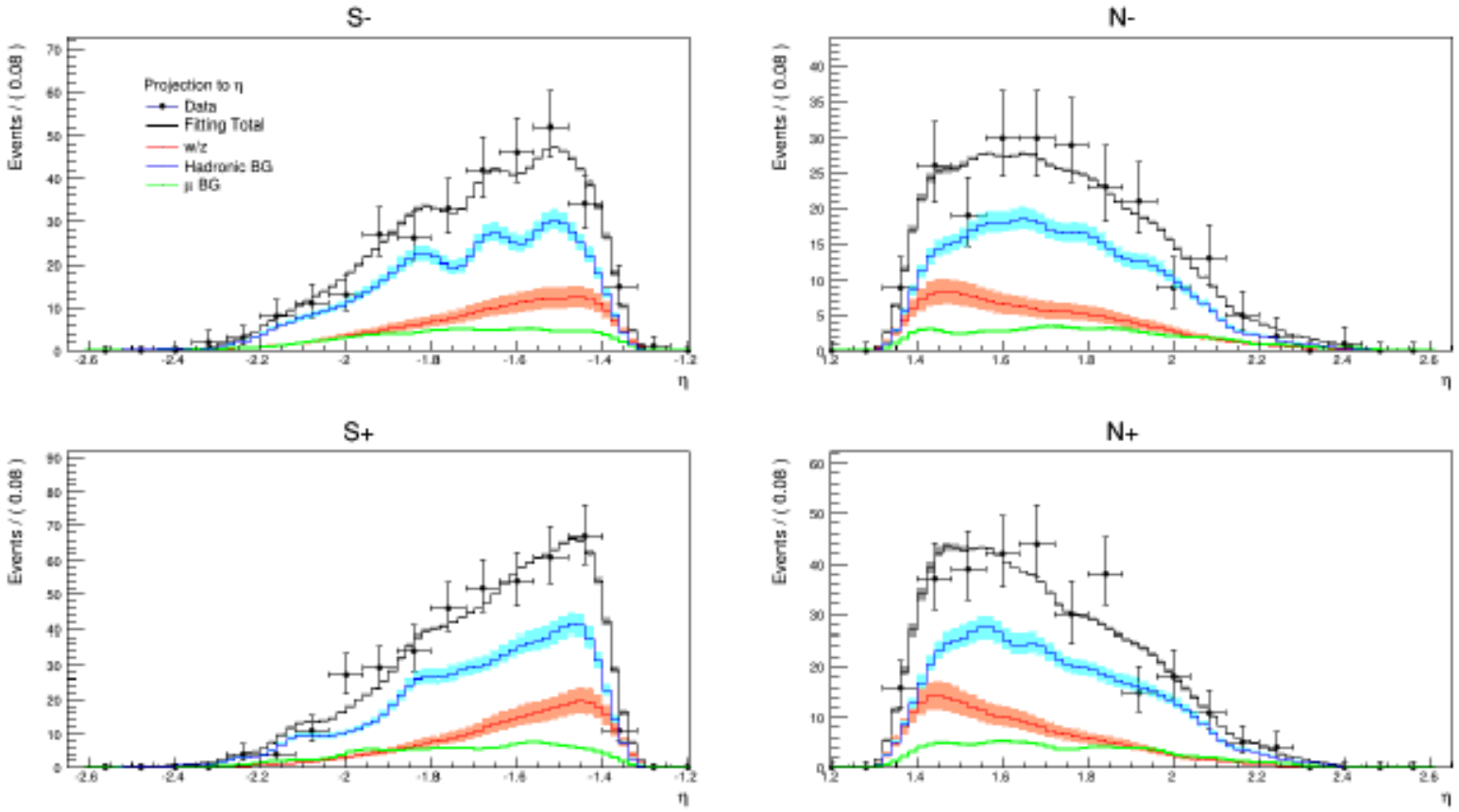




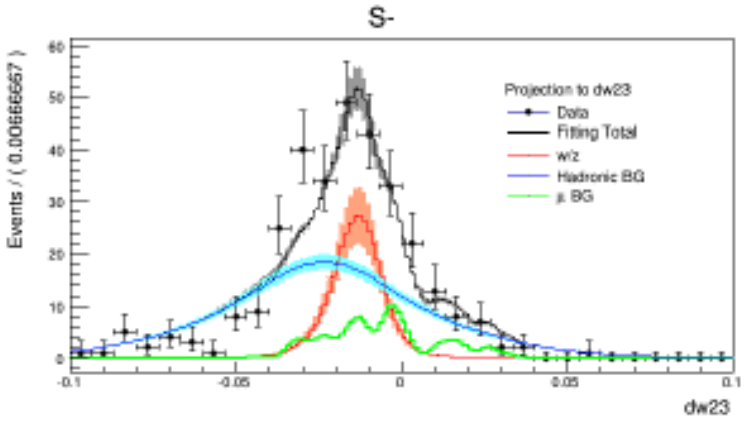


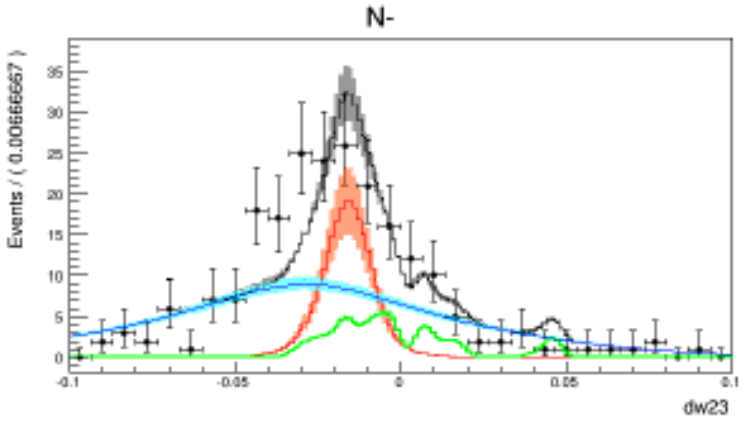


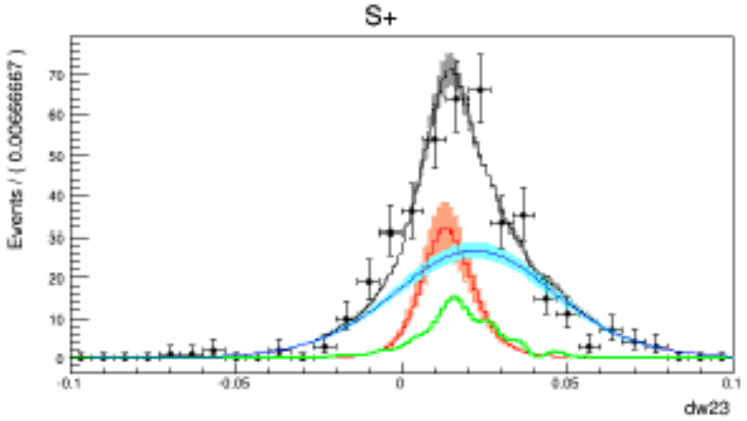
Backup – Fit results (preliminary)

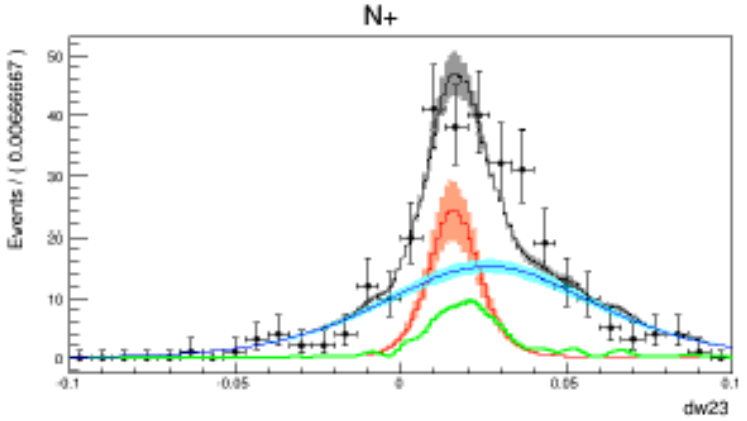


Backup – Fit results (preliminary)









Backup – Beam separated/Run11 and 12 A_L