How to Measure Drell-Yan TSSA Raw Asymmetry at 10^-3 Level with a polarized proton target?

- The challenges of precision TSSA measurements
  - Detector acceptance * efficiency varies >>1% level over a few hours of operation under a given "target polarization" configuration
  - Very difficult to measure the relative beam on target(NH3) luminosity at ~10^-3 level
    - Large beam x-y profile
    - small target size
    - Beam position/direction jitter (dX ~ 1-2mm),
      - see https://p25ext.lanl.gov/elog/Hardware/12
    - non-uniform DC responses to large beam intensity fluctuations (~O(10%))
    - NH3 packing factor variation >~1% from target to target
    - Target polarization known to ~O(3-4%) level through NMR
    - Other variations, including target changes etc, ~O(1%)
  - Frequent spin flip is hard/impossible
    - can't do what we are doing at RHIC and Jlab
    - Takes time to reach a stable polarization
    -
  - We must be able to measure raw TSSA at 10^-3 level for a given target polarization configuration
- A new approach needed

The Normal Approach in "collider-mode": RHIC, JLab etc.

Spin UP(1) and DOWN(2):

A = <pol>*physics asymmetry, ~O(1%)

$$dN_1(\phi) = N_1 \times (1 + A \times cos(\phi))$$

$$dN_2(\phi) = N_2 \times (1 - A \times cos(\phi))$$

$$R = N_1/N_2$$

Relative luminosity,
for E1039, this is the luminosity of beam on target, which is very hard to measure to <<(0.1%)!

$$A_{raw}(\phi) = (dN_1 - R \times dN_2)/(dN_1 + R \times dN_2) = A \times cos(\phi)$$

Need precision measurements of relative luminosity, better than ~O(0.1%)

$$\delta A_{raw} \sim (\delta R + X...)$$

Reality: Not So Perfect Detector and Beam Controls

- Not so perfect detectors (dt ~ minutes) without fast spin flip (dT << minutes)
  - Polarized target spin-flip period ~ several hours
- Acceptance varies within the time of a fixed "target spin config."
  - Time dependence
  - Dead and hot space points
  - Impossible to get to << O(0.1%)

$$dN_{Targte}(\phi) = N^0_{Target}(1 + P \times A \times cos(\phi)) \times \epsilon_{target}(\phi, t)$$

- If target is not a pure proton, for e.g. NH_3, another background fraction "f_B", including all other supporting materials,

$$dN_{Target} = [N_1 + N_2 \times (1 + p \times A \times cos(\phi))] \times \epsilon(\phi, t)$$

Background fraction:
Varies target to target

$$f_B = \frac{N_1}{N_1 + N2}$$

Target and time-dependent

$$dN_{Target}(\phi) = N^0_{Target}(f_B + (1 - f_B)(1 + P \times A \times cos(\phi))) \times \epsilon(\phi, t)$$

DY events produced in "Target"

Target variation

(space,time) variation

False Detector Asymmetry Study

- Run-2 data dimuons (Roadset 57)

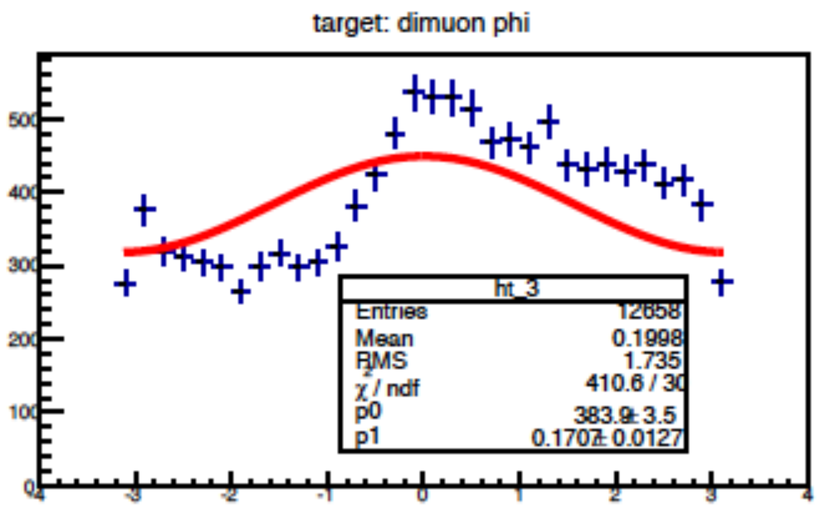
- Event selection:
  - 4< mass < 7
  - Target events: -250 < z0 < -50cm
  - Beam dump events: -50 < z0 < 200 cm
  - Track quality cuts

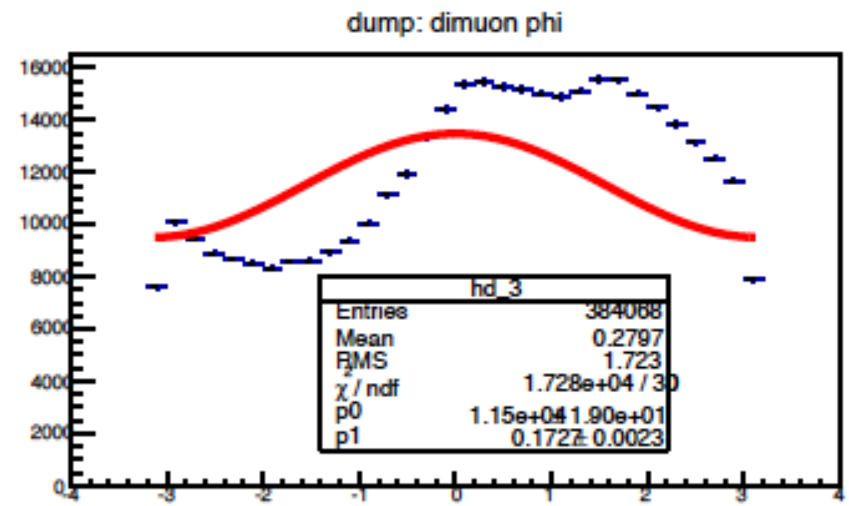
- Detector (relative) acceptance for DY events
  - Raw "spin" asymmetries
  - MC study need to correct target/beam dump acceptance difference
    - Trigger road bias
    - Detector acceptance corrections
  - Further reduce raw asymmetry via target spin-flip and Fmag/kMag field directions
    - Keep the same "target dipole field", only change RF frequency to flip the direction of target polarization
    - Change the FMag and kMag field directions
    - Impact of Relative beam on target beam luminosity

Run-2: Close Look of DY Phi Distributions

We need to get the false asymmetry << 0.1% ~ expected raw spin asymmetry

$$y(\phi) = N \times (1 + A \times cos(\phi))$$



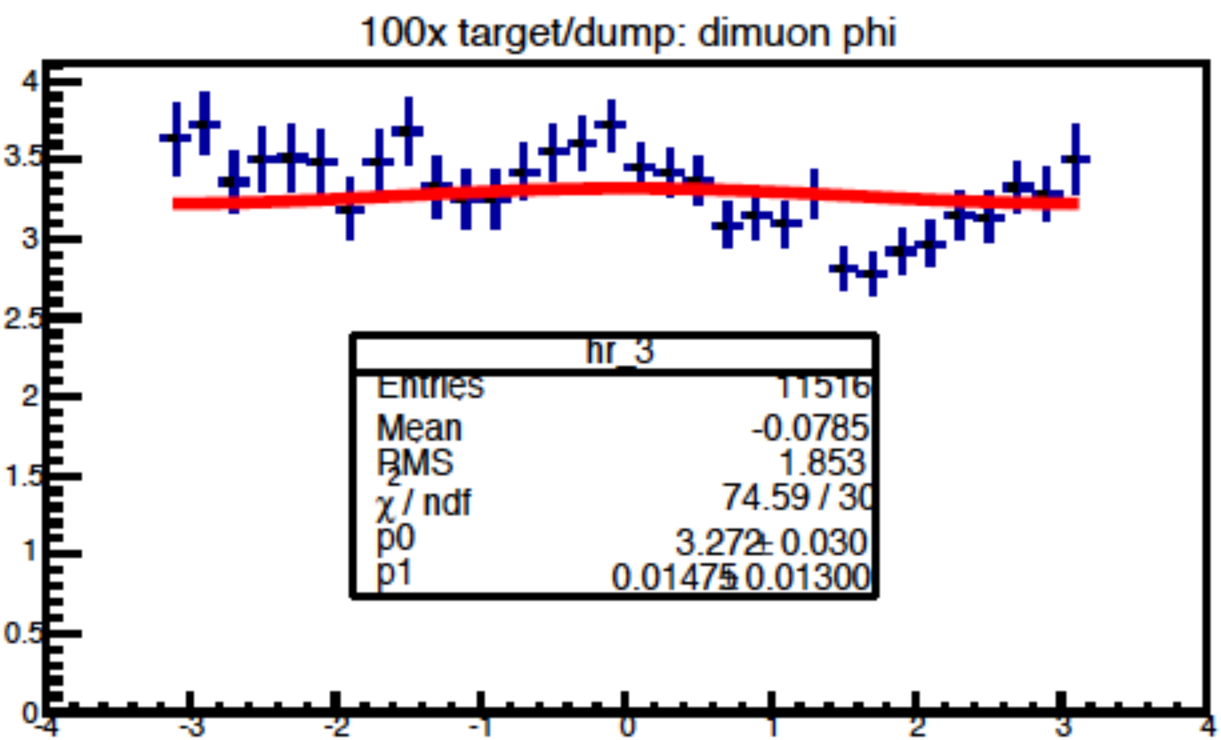


A = 0.171 +/- 0.013 --→ 100x too large!

Huge false asymmetry: >> X10 sigma

A New Approach

- Using the same DY events from beam dump to normalize the detector acceptance effects
  - Beam dump events, 100x statistics, similar muon acceptance
    - the stat_err from reference << signal stat_err
  - the beam dump asymmetry = 0
    - Known physics
  - normalize the beam intensity
    - Can achieve O(1%) on relative luminosity of beam on target, with dedicated telescopes
  - Identical timing and spatial variation of detector acceptance and efficiency for signal and background
    - Can achieve O(0.1%) on raw asymmetry



False asymmetry after normalization:

~ 1 sigma, good!

Need to run ~100x more MC or data to prove we can reach 0.001 level!

$$A = 0.015 \pm 0.013$$

How it works?

$$dN_{Target}(\phi) = N_1 + N_2(1 + P \cdot A \cdot \cos(\phi))$$
$$= N^0_{Target}(f_B + (1 - f_B)(1 + P \cdot A \cdot \cos(\phi))) \times \varepsilon(\phi, t)$$

$$dN_{Dump}(\phi) = N^0_{Dump} \times \varepsilon(\phi, t)$$

$$f_B \equiv \frac{N_1}{N_1 + N_2}$$

If we use the same DY dimuon events (mass, pT,xF etc) from Target and Dump:

- the time-dependent detector acceptance variations are mostly canceled out
- The small difference can be corrected with MC and data by using the muons measured in the same phase space
- Much reduced requirements on relative lumi, background fraction, target polarization measurements
  - sufficient at O(1%) level.

$$\Delta R(\phi) = dN_{Target}(\phi)/dN_{Dump}(\phi)$$

$$\Delta R(\phi) = \frac{N^0_{Target}}{N^0_{Dump}}(f_B + (1 - f_B)(1 + P \times A \times cos(\phi))) \times (\epsilon_{target}(\phi, t)/\epsilon_{dump}(\phi, t))$$

$$\Delta R(\phi) = \frac{N^0_{Target}}{N^0_{Dump}}(f_B + (1 - f_B)(1 + P \times A \times cos(\phi)))$$

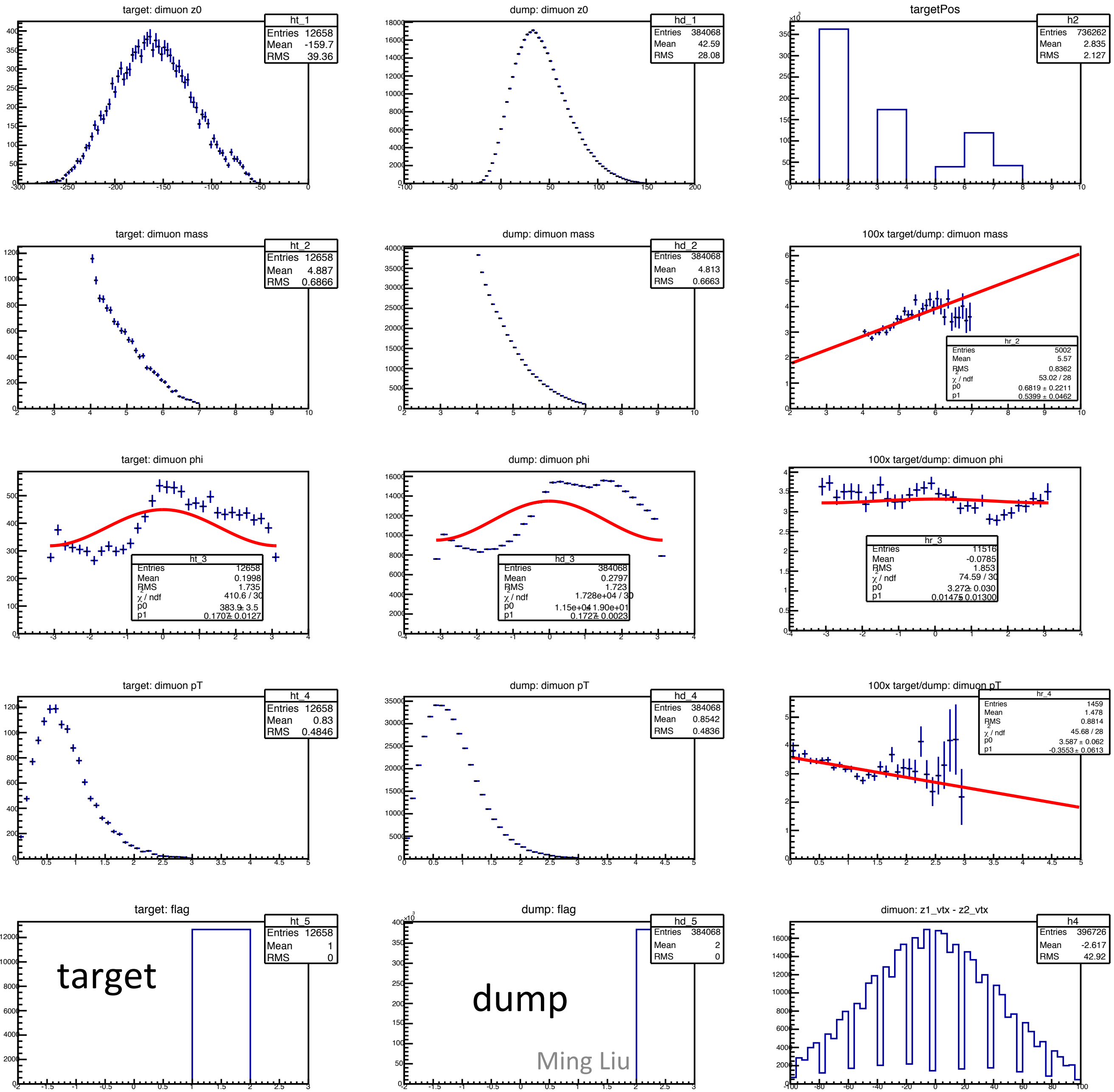
Run-2 DY Dimuon (Roadset 57): all targets

vtxZ

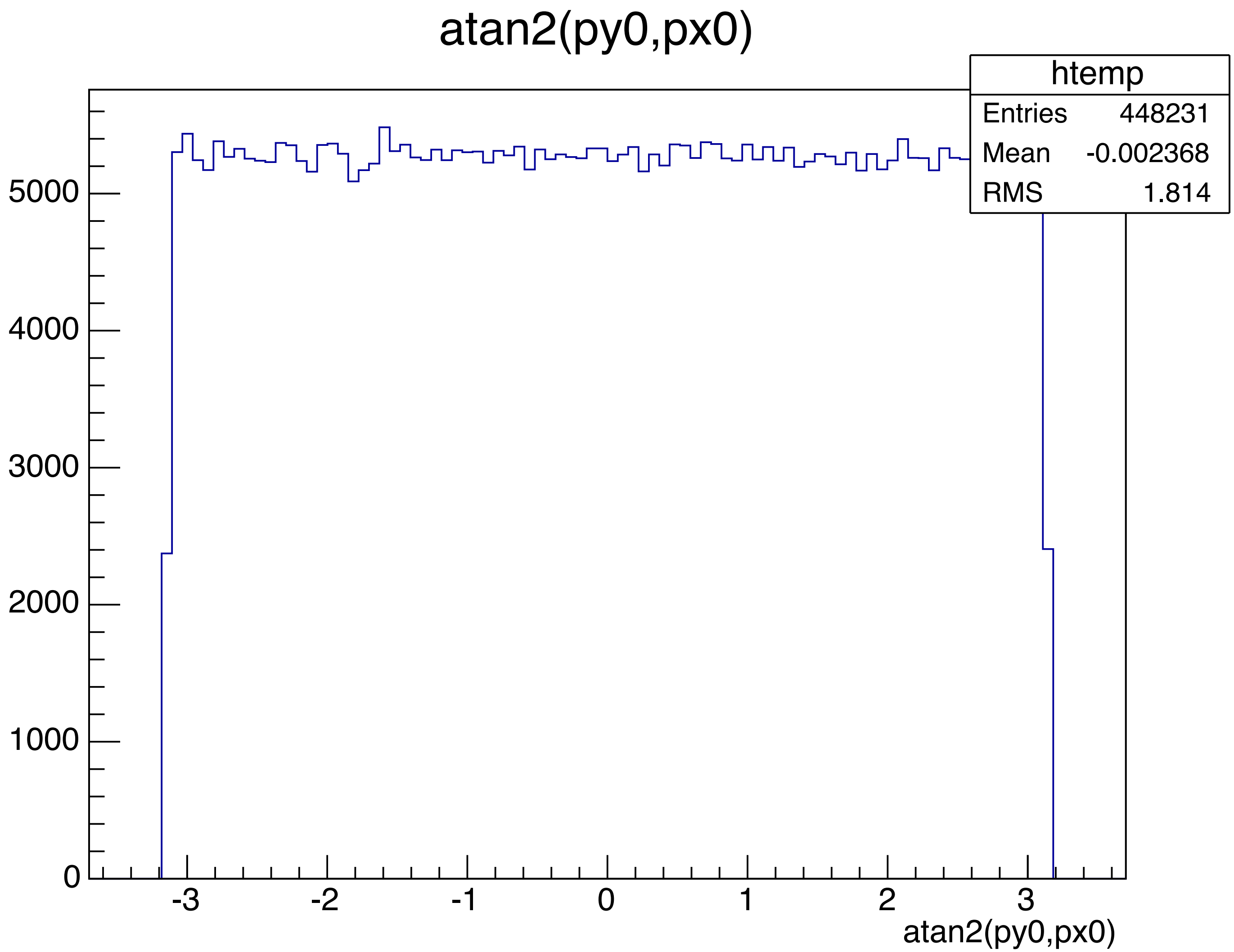
4 < m <7

phi

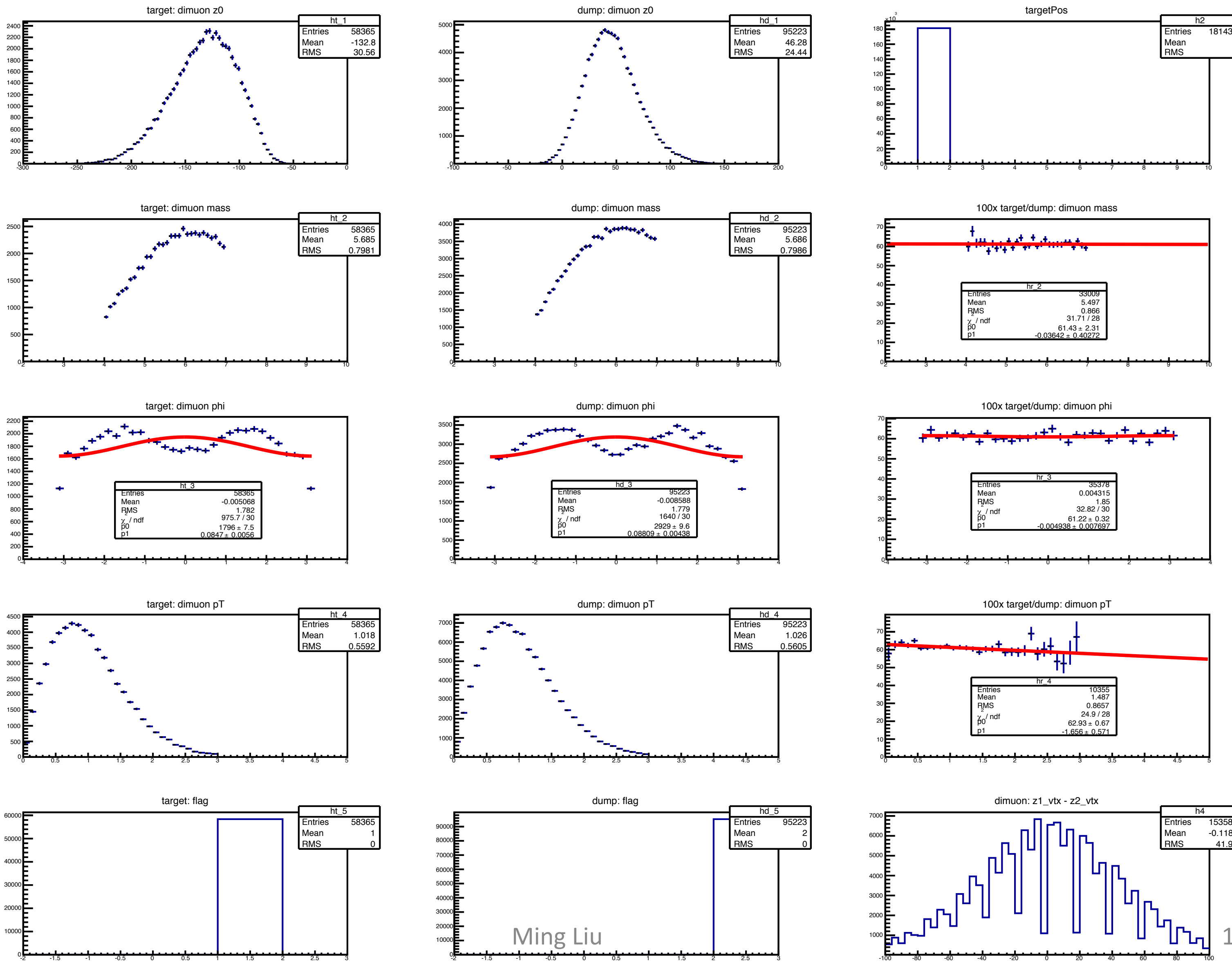
pT



J/Psi MC at Production: Phi



Drell-Yan MC: H and Dump symmetric distributions



Future Work for improvements

- Detailed MC simulation with the new polarized target position
  - Prove the systematic error can be controlled to O(0.1%)
  - Target/Dump DY acceptance correction study
  - 100x more MC events to reach O(0.1%) level precision
- Run2 and Run3 data analysis to understand and correct the large asymmetry
  - Beam axis, directions
  - Detector response to instant beam fluctuations
  - Systematic reduction of the false asymmetry
- New beam position/direction monitoring instruments?
  - Summer shutdown work 2015?
- Beam on target luminosity telescope
  - Summer shutdown work 2015?

Ming's T&E on Pol. DY LDRD

- T&E @20% level (for budget purpose)
  - Joint effort of (Kun + Ming)
- Focused efforts
  - Integration and transition from E906 to E1039
  - Simulations and optimization
  - Polarized target related work
- Progress
  - 2015 summer shutdown work plan
    - New relative luminosity telescopes etc.
    - Possible electrical and mechanical work in target area
  - Identify and develop experimental approach to do high precision spin asymmetry measurements
    - Simulations with optimal target positions
    - Using E906 data and MC to test and confirm new approaches
- Future work
  - Target test and installation
    - Pump and cryo
    - NMR
    - Calibration
  - Design and build the target actuator
  - Development of the target control and monitoring software
  - Trigger/DAQ optimization

Xiaodong's talk at LDRD meeting 3/12/2015

The Measured Asymmetry:

$$A_{\mathrm{meas}} = \underbrace{f \cdot P_{\mathrm{T}}}_{\sim 0.1} \cdot A_{\mathrm{phy}}$$

P_T=0.8 target polarization

for pure NH_3 dilution factor: $f = \frac{\text{polarized protons}}{^{14}\mathrm{NH}_3} = \frac{3}{17} = 0.176$

In reality, need count all unpolarized material in beam's path, f=0.12~0.14.
In JLab Hall B, deep-inelastic scattering data, **f=0.14** (eg1-dvcs).

$$\text{dilution factor } f = \frac{\text{polarized protons}}{\mathrm{Al.}+\mathrm{Kapton}+{}^{4}\mathrm{He}+{}^{14}\mathrm{NH}_3+\mathrm{NMR\ Coil}+\ldots}$$

➔ Need to control systematic uncertainty on measured asymmetry to $\delta(A)_{meas} \approx 0.1\%$

Extremely Challenging !!!

Over two years of data collection, need to carefully monitor the changes of:

- Beam pulse intensity, duty factor, charge profile, halo…
- Target contents, Helium level, polarization…
- Trigger Eff. detector responses, DAQ dead time…
- Background. Track reconstruction Eff. …

$$A_{meas} = \frac{\frac{N^{\uparrow}}{\mathcal{L}^{\uparrow}} - \frac{N^{\downarrow}}{\mathcal{L}^{\downarrow}}}{\frac{N^{\uparrow}}{\mathcal{L}^{\uparrow}} + \frac{N^{\downarrow}}{\mathcal{L}^{\downarrow}}} = \frac{N^{\uparrow} - N^{\downarrow} \cdot \frac{\mathcal{L}^{\uparrow}}{\mathcal{L}^{\downarrow}}}{N^{\uparrow} + N^{\downarrow} \cdot \frac{\mathcal{L}^{\uparrow}}{\mathcal{L}^{\downarrow}}}$$

➔ Control raw false asymmetry: $\delta(\mathbf{A})_{\mathbf{raw}} \approx \mathbf{0.1\%}$

Note from Andi and Pat

- Dilution factor
- Packing fraction
- Empty target (what is it)
- Study of background with distributed vs single target in E906
- Study e906 empty vs hole target (david task)
-
- background contributions
- relative luminosity
- beam monitoring (90 degree monitor) luminosity measurement (measure intensity * target mass)
- synchronize beam spill with NMR measurements (random or regular)
  - help us determine depol during spill
- beam asymmetry on target determined by spectrometer:
  - However: assumes symmetric response. Need to measure this.
  - E906 data analyzed. (david kleinjan)
- beam profile during spill
- time sync between DAQ and pol target (fast control vs Slow control)
- What do we need to record on spill by spill from target system.
- Design Labview for target system.
- Design interface between labview and DAQ; responsible for recording history
- influence of changing beam profile; as an example go from symmetric profile to asymmetric. What would be the limits we could see. Also matters for non homogeneous polarization.
- Rate dependence in spectrometer efficiency as a function of geometry. Does not cancel in 2nd order
- polarization and intensity connected. Over time pol decreases so need to find a way to have same intensity * p product.
- beam angle:
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