RHIC Polarimetery: Results and Study of Systematic Uncertainties

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Preface

- Systematic uncertainty is always an estimate
  - Many assumptions must be made about correlations
  - Hard to avoid double counting
- Current goal $< 5\%$ uncertainty per measurement (?)
- Keep in mind the requirement on the EIC polarimetry $< 1 - 3\%$
  - Careful and honest analysis is required

Strategy Highlights

- What we have:
  - Several measurements $P^{(\mathrm{p})}_{\mathrm{crb}}$ by p-Carbon in a fill
  - Corresponding horizontal $R^{(\mathrm{p})}_{h}$ and vertical $R^{(\mathrm{p})}_{v}$ profiles
  - Fill average beam polarization P_{jet} by H-jet
- Note: I use p-Carbon sweep measurements as the nominal measurements
  - Benefit from high statistics

Strategy

- **Step 1:** Calculate the fill average from $P^{(\mathrm{p})}_{\mathrm{crb}}$, $R^{(\mathrm{p})}_{h}$, and $R^{(\mathrm{p})}_{v}$
- **Step 2:** On average correct each p-Carbon polarimeter (p) measurement to the H-jet one
  - Four independent measurements of beam polarization per fill
- **Step 2: Systematics**
- **Step 3:** Calculate beam polarization by combining the measurements from upstream and downstream polarimeters
- **Step 4:** Calculate beam polarization in collisions for the experiments
- **Step 5:** Provide a procedure for combining individual fills
- **Step 6:** Provide a procedure for combining two beams
  - Single spin asymmetry
  - Double spin asymmetry

Step 1

- For now I calculate the weighted average from all available measurements in a fill:

$$\overline{P^{(\mathsf{p})}_{\mathsf{crb}}}, \quad \overline{R^{(\mathsf{p})}_{v}}, \quad \overline{R^{(\mathsf{p})}_{h}}$$

- Might be better to include luminosity in the weight

Step 2

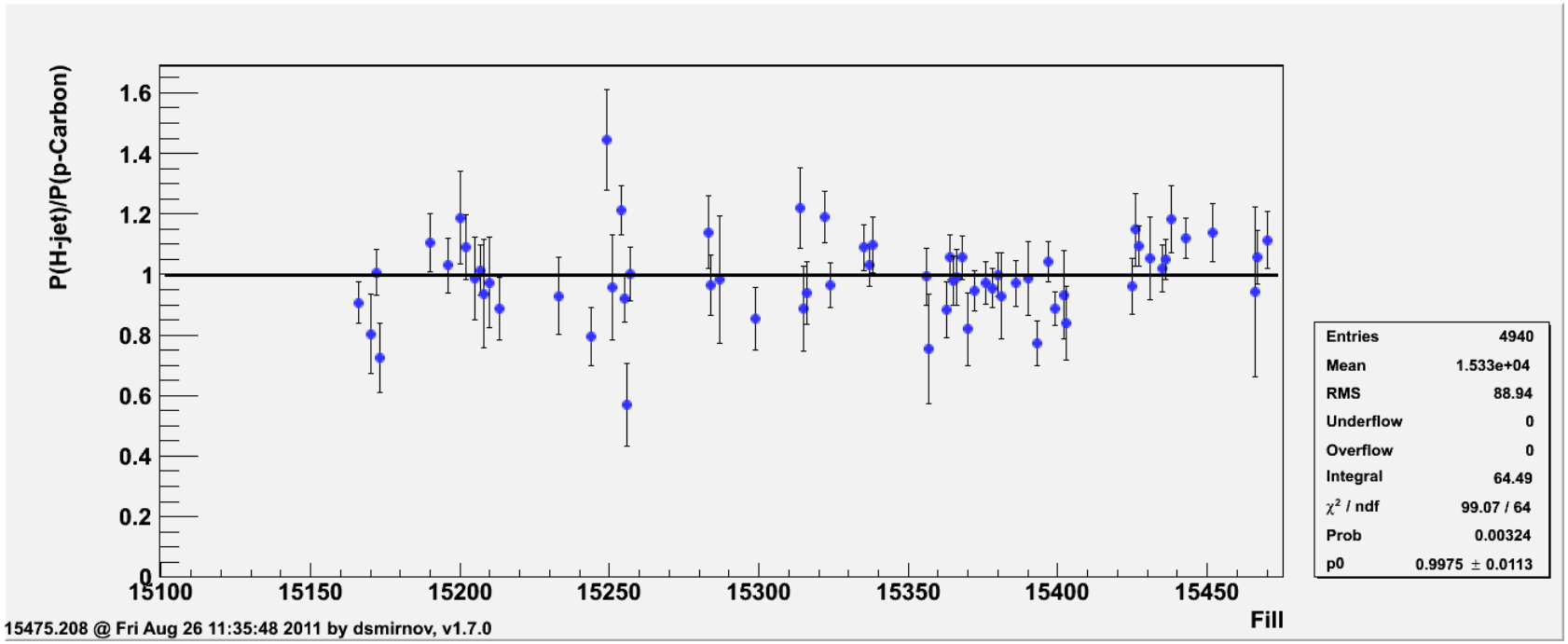
- Normalization to H-jet:

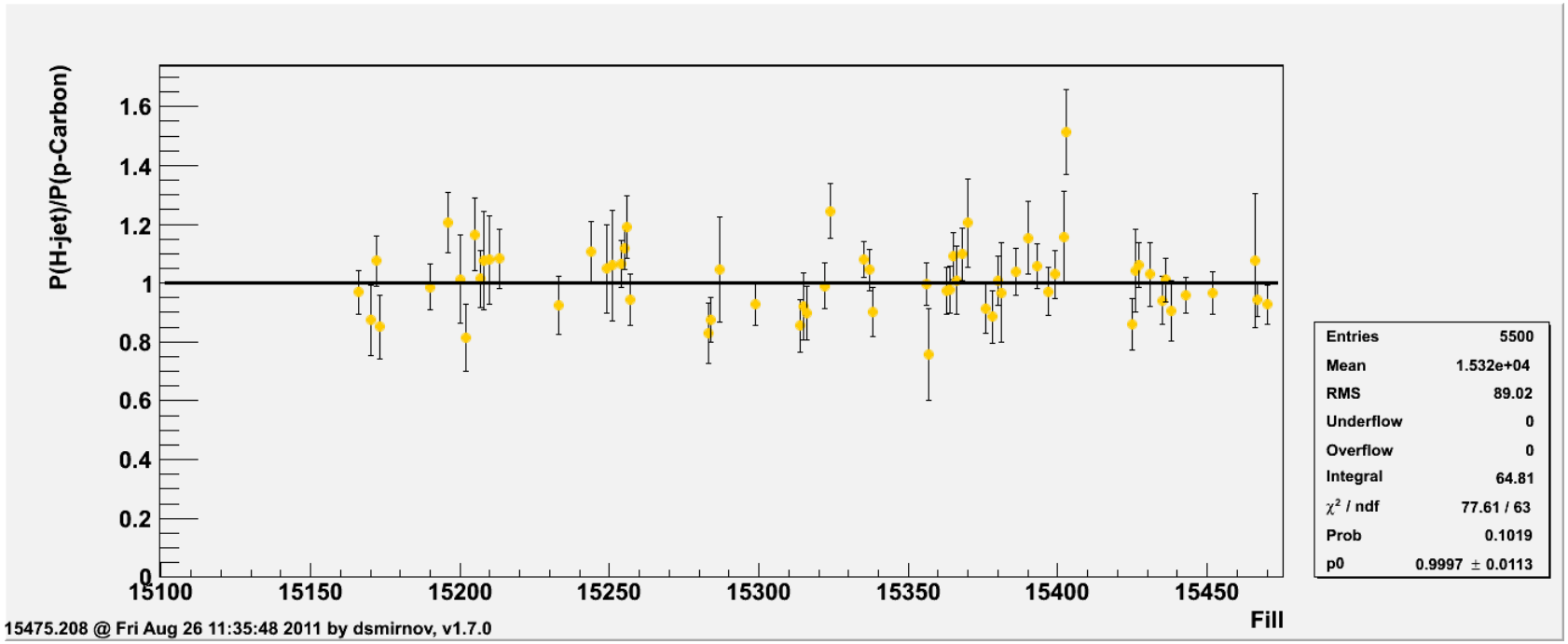
$$k^{(\mathsf{p})}_{\mathsf{jet/crb}} = \left\langle \frac{P_{\mathsf{jet}}}{\overline{P^{(\mathsf{p})}_{\mathsf{crb}}}} \right\rangle_{\mathsf{fills}}$$

$$\overline{P^{(\mathsf{p})}} \equiv \overline{P^{(\mathsf{p})}_{\mathsf{crb}}} \times k^{(\mathsf{p})}_{\mathsf{jet/crb}} \qquad \text{and} \qquad \underset{\mathsf{stat}}{\sigma}(\overline{P^{(\mathsf{p})}}) \equiv \underset{\mathsf{stat}}{\sigma}(\overline{P^{(\mathsf{p})}_{\mathsf{crb}}}) \times k^{(\mathsf{p})}_{\mathsf{jet/crb}}$$

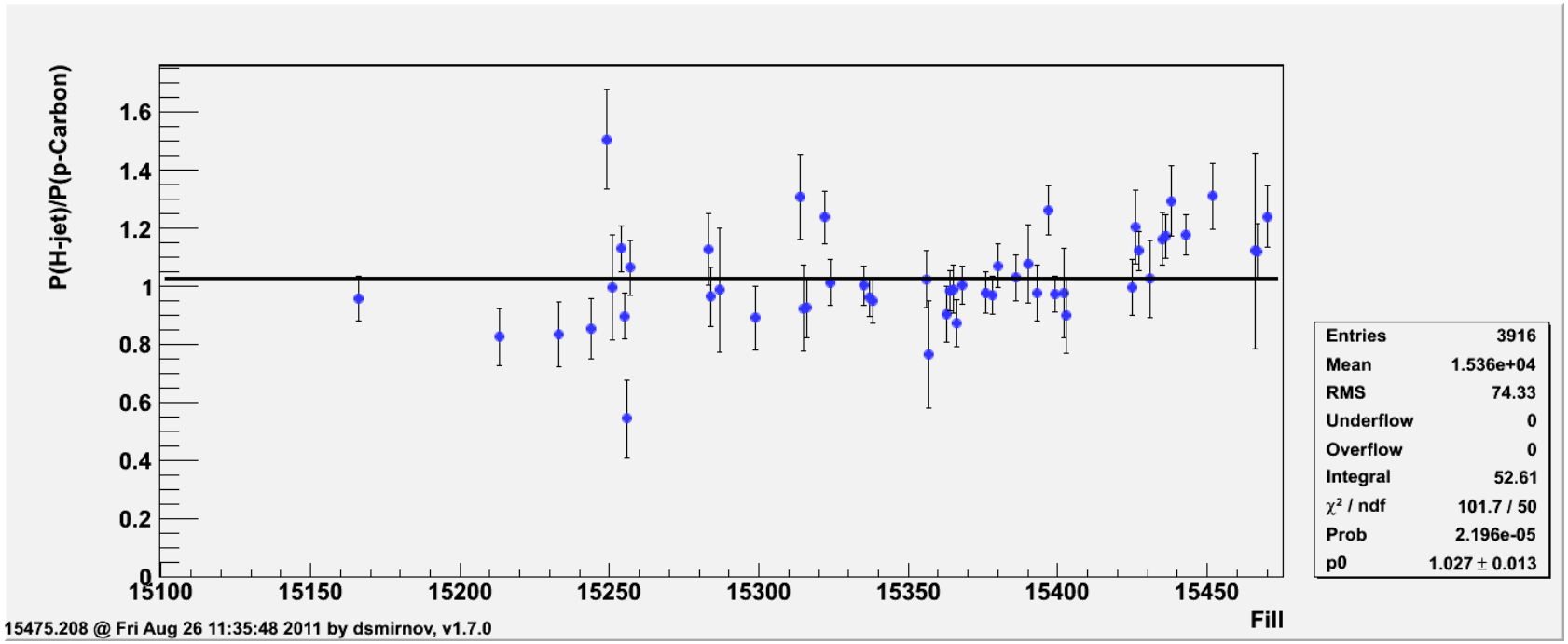
- End up with $\overline{P^{(\mathsf{B1U})}}, \quad \overline{P^{(\mathsf{Y2U})}}, \quad \overline{P^{(\mathsf{B2D})}}, \quad \overline{P^{(\mathsf{Y1D})}}$
- Need to estimate the total $\Delta\overline{P^{(\mathsf{p})}}$

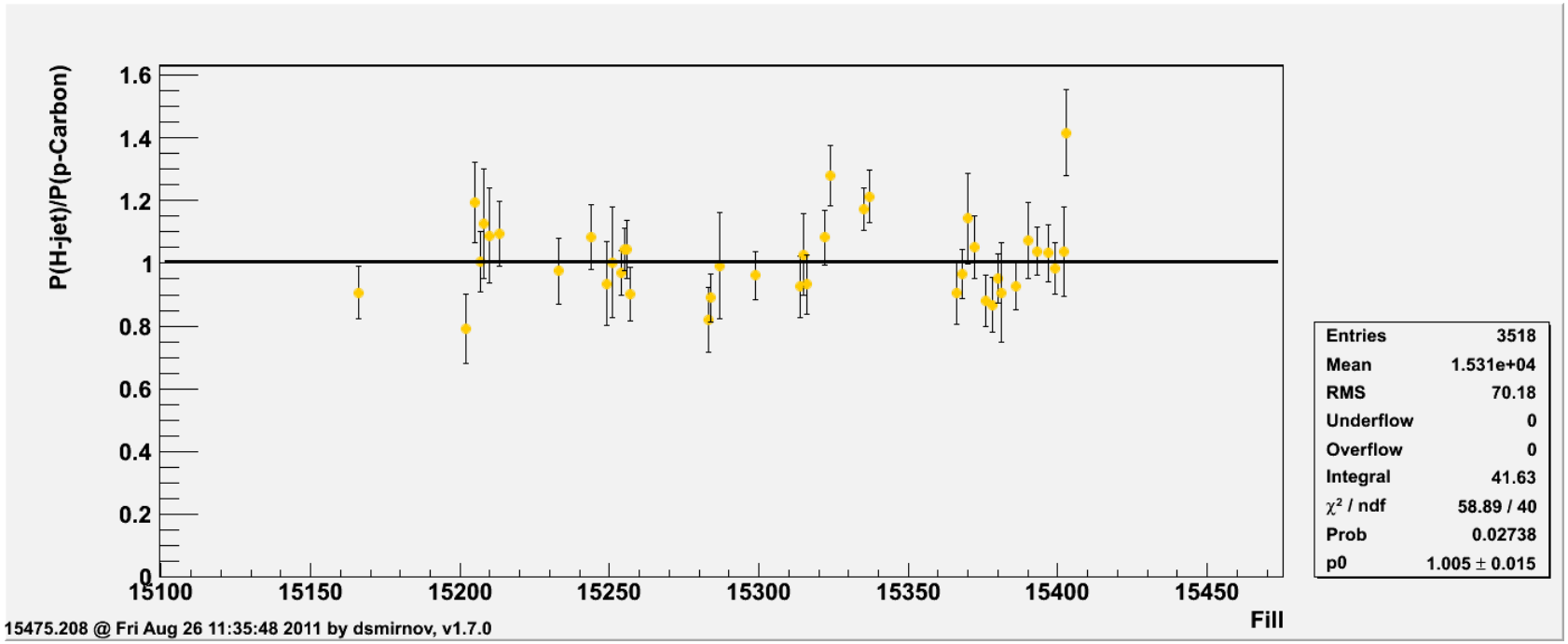
Step 2: Systematics, B1U, Y2U





Step 2: Systematics, B2D, Y1D





Step 2: Systematics

- Normalization to H-jet $K \equiv P_{\text{jet}}/\overline{P^{(\text{p})}_{\text{crb}}}$

$$\frac{1}{N}\sum_{i=\text{fills}} \frac{(K_i - k^{(\text{p})}_{\text{jet/crb}})^2}{(\sigma^2_{K_i} + (\sigma^{\text{norm}})^2)} = 1$$

- H-jet molecular background: $\Delta^{\text{mol}}_{\text{jet}} = 2\%$ (2006)
- Total background: $\Delta^{\text{bkg}}_{\text{jet}} = 3\%$ (2009)

	B1U	**Y2U**	**B2D**	**Y1D**
Δ^{norm}	6.6	6.7	5.8	9.1
σ^{norm}	7.0	5.4	10.1	6.3
$\Delta k^{(\text{p})}_{\text{jet/crb}}/k^{(\text{p})}_{\text{jet/crb}}$	1.1	1.1	1.2	1.5
$\Delta^{\text{mol}}_{\text{jet}}$	2.0	2.0	2.0	2.0
$\Delta^{\text{bkg}}_{\text{jet}}$	3.0	3.0	3.0	3.0

Step 2: Systematics

- The total uncertainty $\Delta\overline{P^{(\mathsf{p})}}$ on $\overline{P^{(\mathsf{p})}}$ is:

$$\frac{\Delta\overline{P^{(\mathsf{p})}}}{\overline{P^{(\mathsf{p})}}} = \sigma^{\mathsf{stat}} \oplus \frac{\Delta k^{(\mathsf{p})}_{\mathsf{jet/crb}}}{k^{(\mathsf{p})}_{\mathsf{jet/crb}}} \oplus \sigma^{\mathsf{norm}} \oplus \Delta^{\mathsf{mol}}_{\mathsf{jet}} \oplus \Delta^{\mathsf{bkg}}_{\mathsf{jet}}. \qquad (1)$$

Step 2: Systematics (cross checks)

- Polarization profile, sweep vs. P vs I fit
- Upstream vs downstream

	B1U	Y2U	B2D	Y1D
Δ^{norm}	6.6	6.7	5.8	9.1
σ^{norm}	7.0	5.4	10.1	6.3
$\Delta k^{(\text{p})}_{\text{jet/crb}}/k^{(\text{p})}_{\text{jet/crb}}$	1.1	1.1	1.2	1.5
$\Delta^{\text{mol}}_{\text{jet}}$	2.0	2.0	2.0	2.0
$\Delta^{\text{bkg}}_{\text{jet}}$	3.0	3.0	3.0	3.0
Δ^{prfl}	2.6	2.4	1.4	1.4
σ^{prfl}	2.9	2.2	1.9	3.5
$\Delta k^{(\text{p})}_{\text{prfl/swp}}/k^{(\text{p})}_{\text{prfl/swp}}$	0.2	0.1	0.2	0.1
$\sigma^{\text{U vs D}}$	4.5 ($\approx \frac{8.9}{2}$)	5.8 ($\approx \frac{11.7}{2}$)	4.5 ($\approx \frac{8.9}{2}$)	5.8 ($\approx \frac{11.7}{2}$)

Step 3: Combine upstream and downstream

- Weighted average:

$$\overline{P} = \frac{\sum\limits_{\mathsf{p=U,D}} \overline{P^{(\mathsf{p})}} w^{(\mathsf{p})}}{\sum\limits_{\mathsf{p=U,D}} w^{(\mathsf{p})}}, \qquad w^{(\mathsf{p})} = \frac{\sum\limits_{\mathsf{p1=U,D}} (V^{-1})_{(\mathsf{p1p})}}{\sum\limits_{\mathsf{p1,p2=U,D}} (V^{-1})_{(\mathsf{p1p2})}}$$

- Uncertainty on the weighted average:

$$\frac{\Delta\overline{P}}{\overline{P}} = w_U \times \frac{\Delta\overline{P^{(\mathsf{U})}}}{\overline{P^{(\mathsf{U})}}} \oplus w_D \times \frac{\Delta\overline{P^{(\mathsf{D})}}}{\overline{P^{(\mathsf{D})}}}$$

Step 4: Beam polarization in collisions

- Assume gaussian polarization and intensity profiles:

$$\overline{P}_{\text{coll}} = \overline{P} \times k_{\text{coll}} \qquad \text{with} \qquad k_{\text{coll}} = \frac{\sqrt{1+\overline{R_h}}\sqrt{1+\overline{R_v}}}{\sqrt{1+\frac{1}{2}\overline{R_h}}\sqrt{1+\frac{1}{2}\overline{R_v}}}.$$

- Uncertainty $\Delta\overline{P}_{\text{coll}}$

$$\frac{\Delta\overline{P}_{\text{coll}}}{\overline{P}_{\text{coll}}} = \frac{\Delta\overline{P}}{\overline{P}} \oplus \Delta^{\text{R}} \tag{2}$$

- Δ^{R} is defined by propagation of statistical $\Delta\overline{R_h}$ and $\Delta\overline{R_v}$

Step 5: Average for a set of fills

- Similar to the calculation of the weighted average for U and D
- Correlation between the different components has to be properly taken into account

Step 6: Single and Double Spin Asymmetries

- We provide normalization factors for SSA and DSA
- SSA: $\frac{\langle P^{(\mathrm{B})}\rangle + \langle P^{(\mathrm{Y})}\rangle}{2}$
- DSA: $\langle P^{(\mathrm{B})}\rangle \times \langle P^{(\mathrm{Y})}\rangle$
- Correlation between the different components has to be properly taken into account

$$\Delta = \frac{1}{2} \times (\Delta^{\mathrm{norm}})^{(\mathrm{B})} \oplus (\Delta^{\mathrm{norm}})^{(\mathrm{Y})} \oplus \left((\Delta^{\mathrm{mol}}_{\mathrm{jet}})^{(\mathrm{B})} + (\Delta^{\mathrm{mol}}_{\mathrm{jet}})^{(\mathrm{Y})} \right) \oplus \left((\Delta^{\mathrm{bkg}}_{\mathrm{jet}})^{(\mathrm{B})} + (\Delta^{\mathrm{bkg}}_{\mathrm{jet}})^{(\mathrm{Y})} \right)$$

Summary

- The overall procedure for calculation of final results and total uncertainties is established
- Suggestions/Comments are encouraged
- More details in the analysis note (on the wiki):

  Analysis note v0.4

- Final result appear at

  `http://www.phy.bnl.gov/cnipol/fills/`