Run 15 pp J/ψ Multiplicity Analysis

PHENIX HI PWG Meeting

Zhaozhong Shi

Los Alamos National Laboratory

03/17/2022

Overview

Improvement since last meeting:

- Enhance dataset statistics for full 2015 pp dimuon data sample
- Refine fit strategies
  - ☐ Converge the fits
  - ☐ Improve the fitting performance
  - ☐ Reduce signal extraction systematics
- Estimate muon matching efficiency to the FVTX
  - ☐ Remove auto-correlation in the same FVTX arms
- Include J/ψ trigger systematic uncertainties as an additional source
- Improve double collision model estimation
- Refresh the final results and update the analysis notes
  - ☐ Ready for preliminary to present in QM 2022

PHENIX-AnaNote-2022-001
March 17, 2022

Run15 J/ψ Multiplicity Dependence Analysis

Yasser Corrales Morales[1], Cameron Dean[1], Zhaozhong Shi[1], Ajeeta Khatiwada[1], Sanghoon Lim[2], Haiwang Yu[3], and Ming Liu[1]

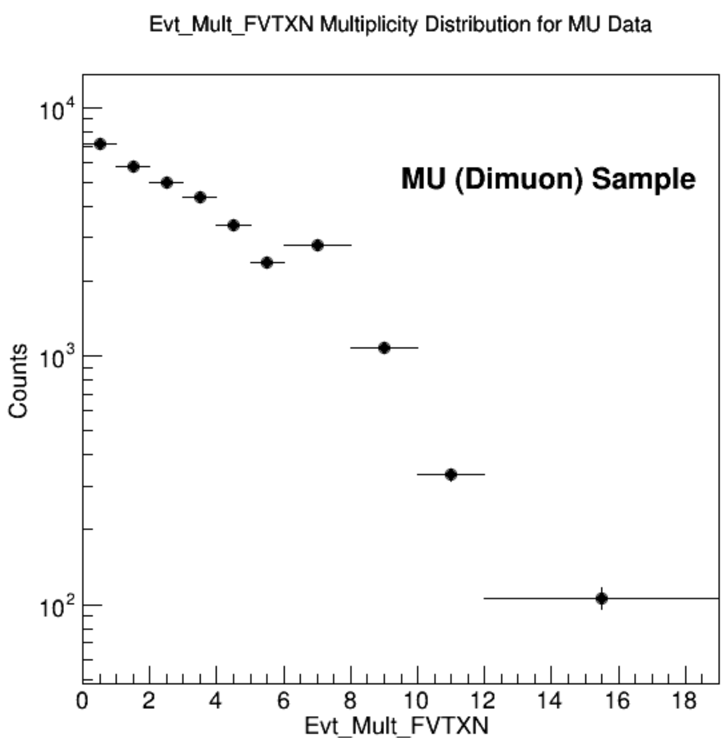
[1]Los Alamos National Laboratory
[2]Pusan National University
[3]Brookhaven National Laboraotry

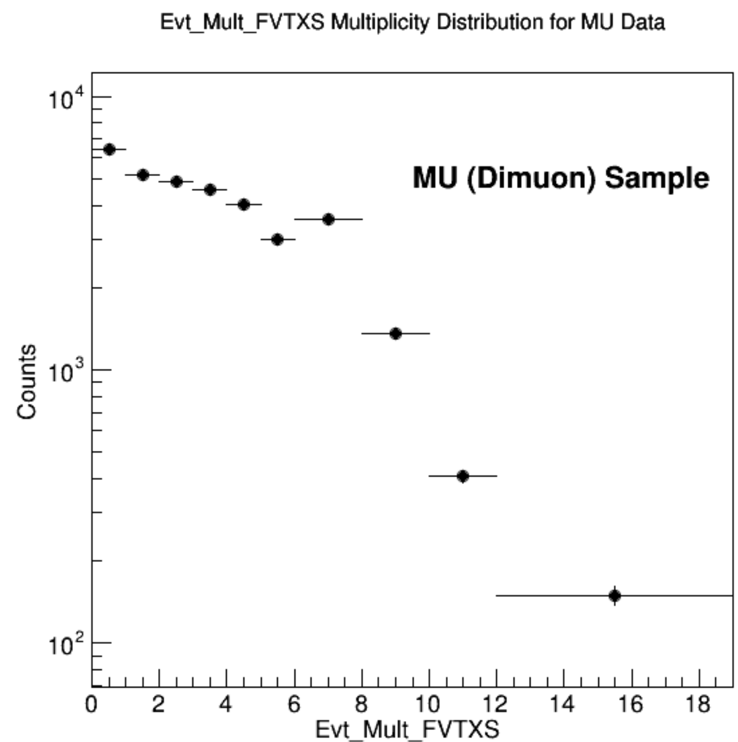
Abstract

This analysis note summarizes the technical details of the run15pp event multiplicity-dependent relative J/ψ yield analysis. The event multiplicity is determined by the PHENIX silicon detectors, the FVTX and SVX, which cover the pseudorapidity ranges $1.2 < |\eta| < 2.4$ and $|\eta| < 1.0$, respectively. The J/ψ candidates are measured by the two muon arms in the rapidity range of $1.2 < |y| < 2.2$. Our results show the relative yield of J/ψ mesons per $p+p$ collision increases with the event multiplicity, indicating possible multi-parton interactions in $p+p$ collisions. Interestingly, we find that such correlation also depends on the rapidity region used to classify the event multiplicity.

Enhancement of Statistics

- Previously we use the wrong dimuon triggered sample, which is not complete
- Current, we are using the correct sample, which corresponds to an 3× enhancement of the statistics
- Number of events: 16419 -> 49320
- We also fix the number of good runs, now the North has 524 good runs and South has 549 good runs



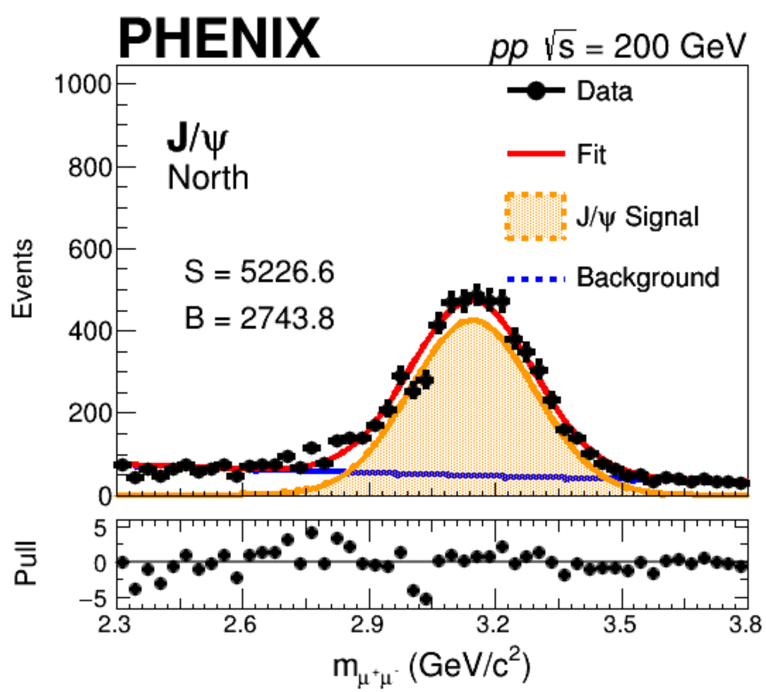


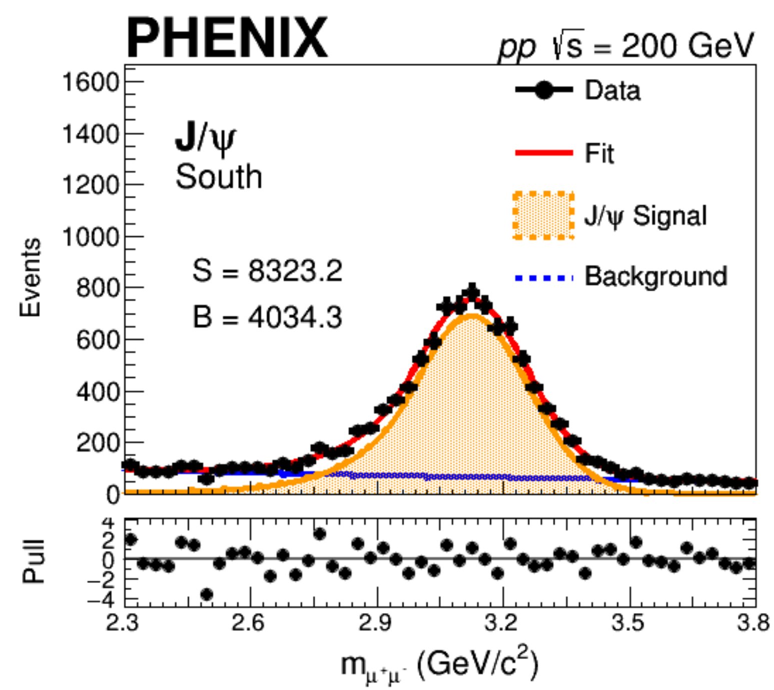
Fitting Improvement

Improvement of fitting

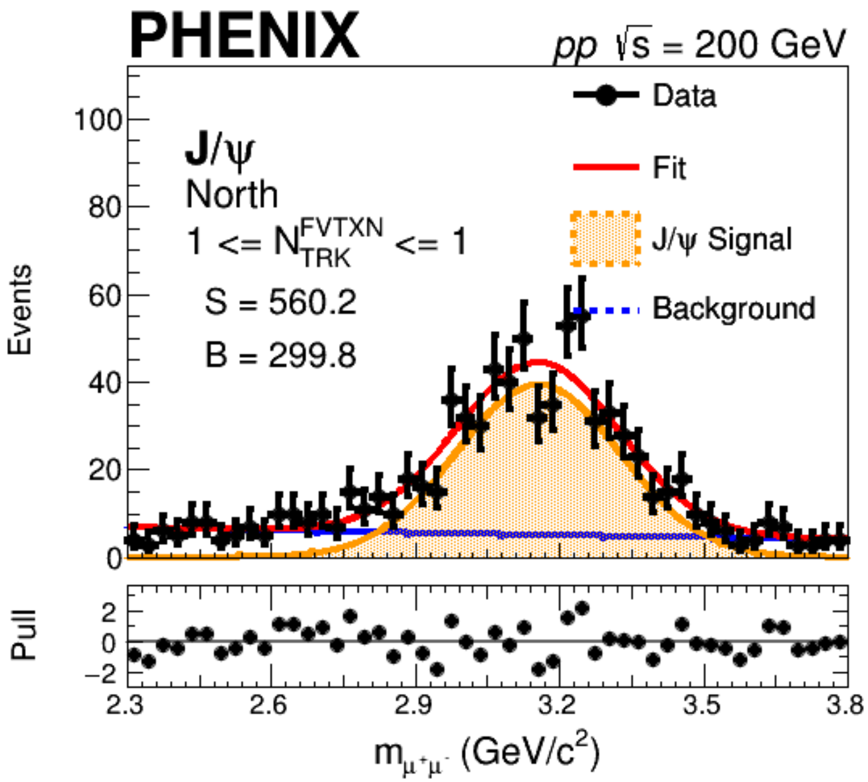
- Signal model: change double crystal ball -> single crystal ball
- Fit convergence and closure verified
- Refering to the published J/ψ analysis: improve the fit by first fitting the inclusive north and south FVTX J/ψ distributions and then fix α and n of the CB to fit the multiplicity bins

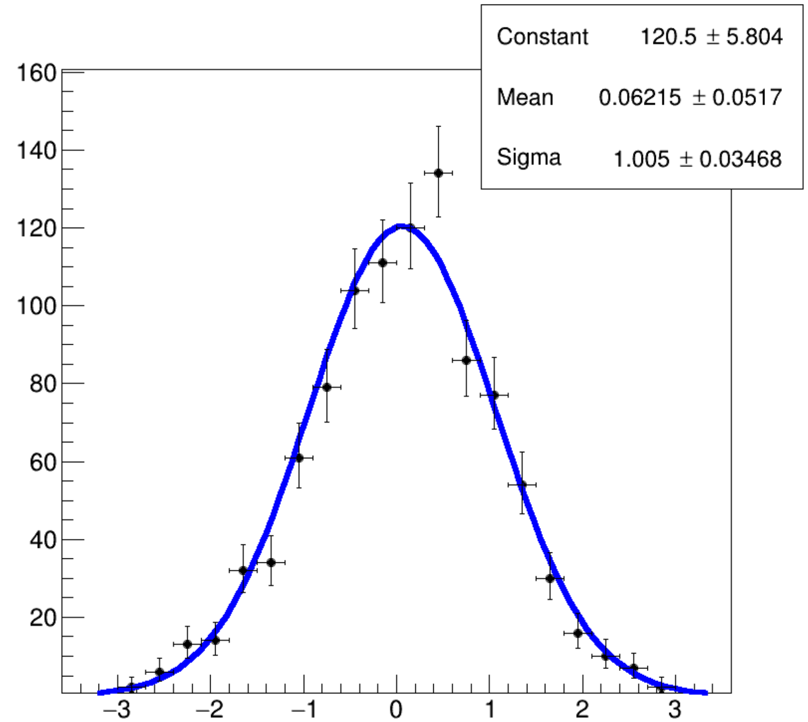
$$f(x;\alpha,n,\mu,\sigma) = \begin{cases} N\exp[-\frac{(x-\mu)^2}{2\sigma^2}], & \text{if } (\frac{x-\mu}{\sigma} > \alpha) \\ NA(B-\frac{x-\mu}{\sigma})^{-n} & \text{if } (\frac{x-\mu}{\sigma} \leq \alpha) \end{cases}$$





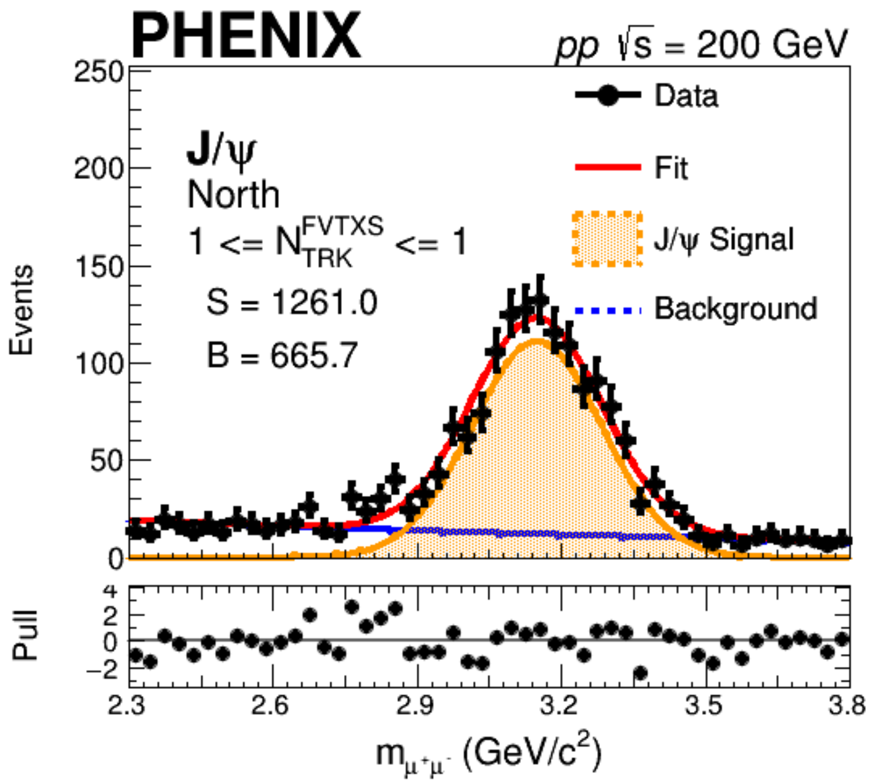
North J/ψ Fit Results for FVTXN N_{ch} = 1

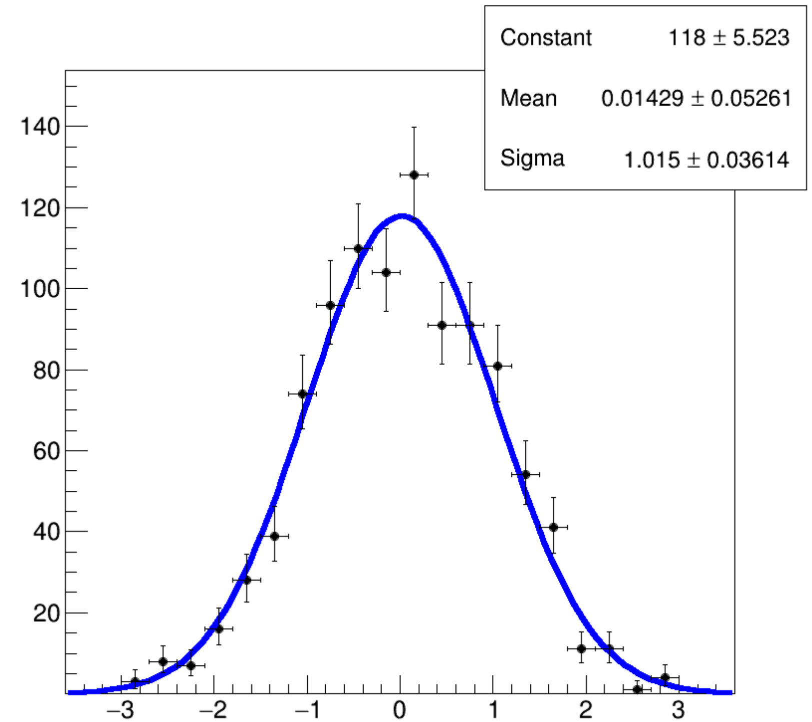




- The fit looks reasonable
- Unit pull is obtained
  - -> Closure test passed
  - -> Correct estimation of the signal raw yield mean and error from the unbinned fit

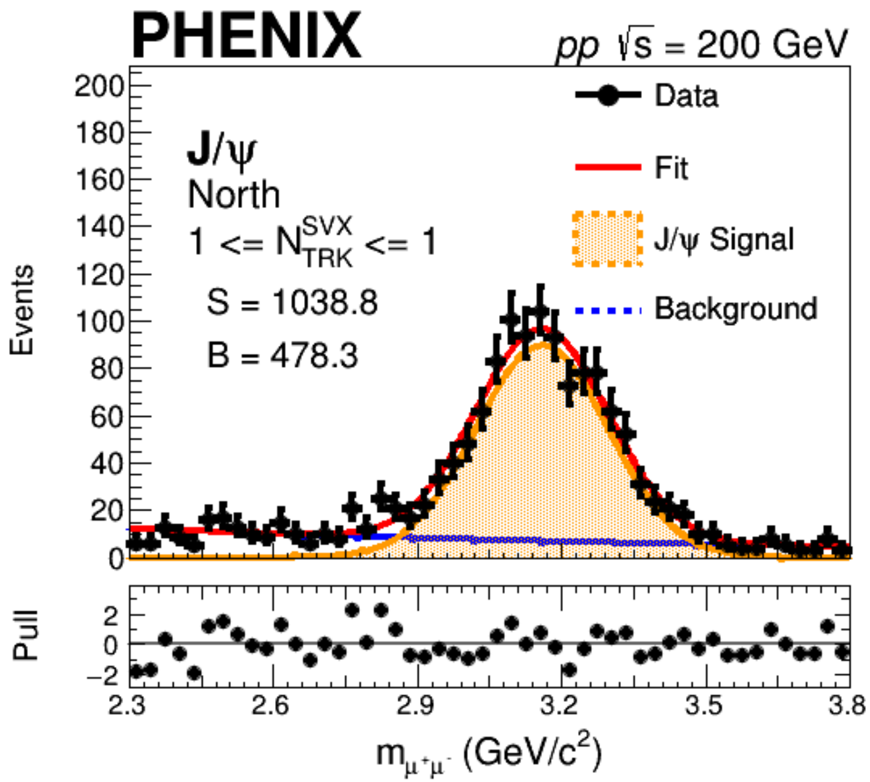
North J/ψ Fit Results for FVTXS N_{ch} = 1

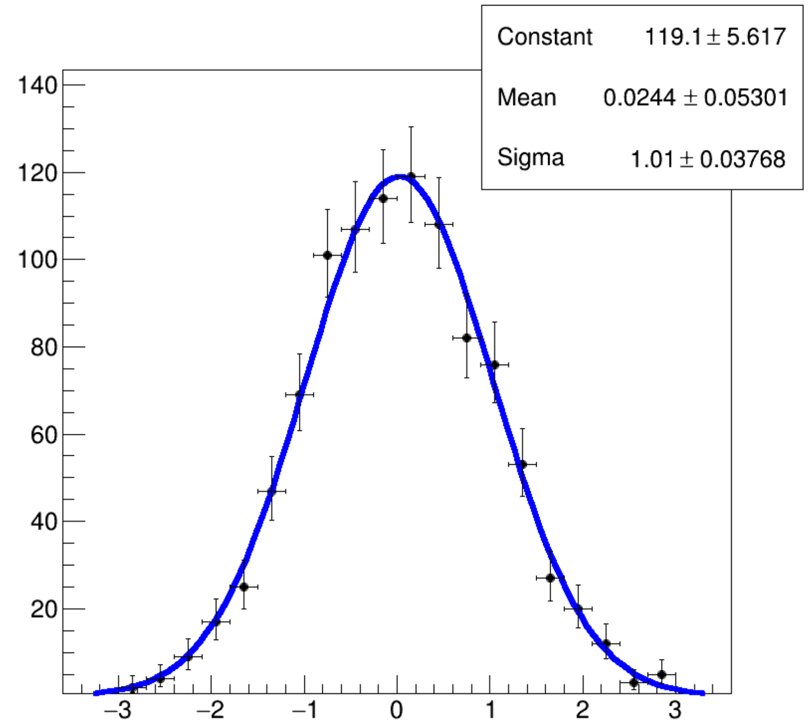




- Again, the fit looks reasonable
- Unit pull is obtained
  - -> Closure test passed
  - -> Correct estimation of the signal raw yield mean and error from the unbinned fit

North J/ψ Fit Results for SVX N_{ch} = 1





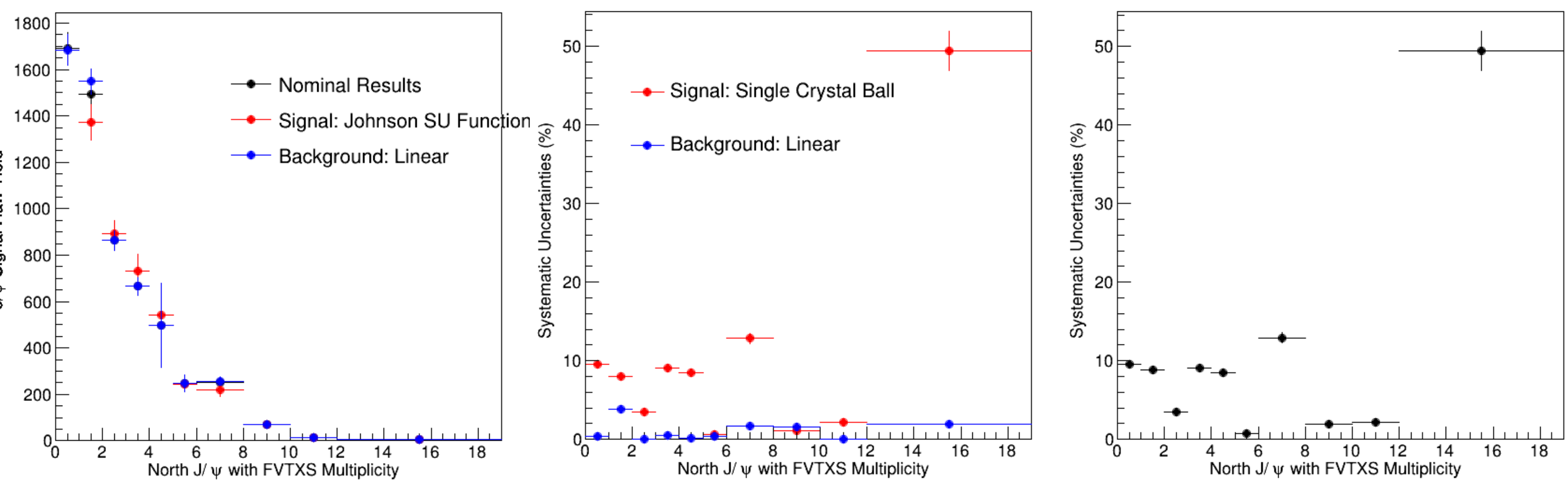
- Again, the fit looks reasonable
- Unit pull is obtained
  - -> Closure test passed
  - -> Correct estimation of the signal raw yield mean and error from the unbinned fit

Fit Systematic Uncertainties Revisit

- Change the variation of fits from single crystal ball to Johnson SU function

$$f(x;\mu,\gamma,\delta,\lambda) = \frac{\delta}{\gamma\sqrt{2\pi}}\frac{1}{\sqrt{1+\left(\frac{x-\mu}{\lambda}\right)^2}}\exp\left[-\frac{1}{2}\left(\gamma+\delta\sinh^{-1}\left(\frac{x-\mu}{\lambda}\right)\right)^2\right]$$

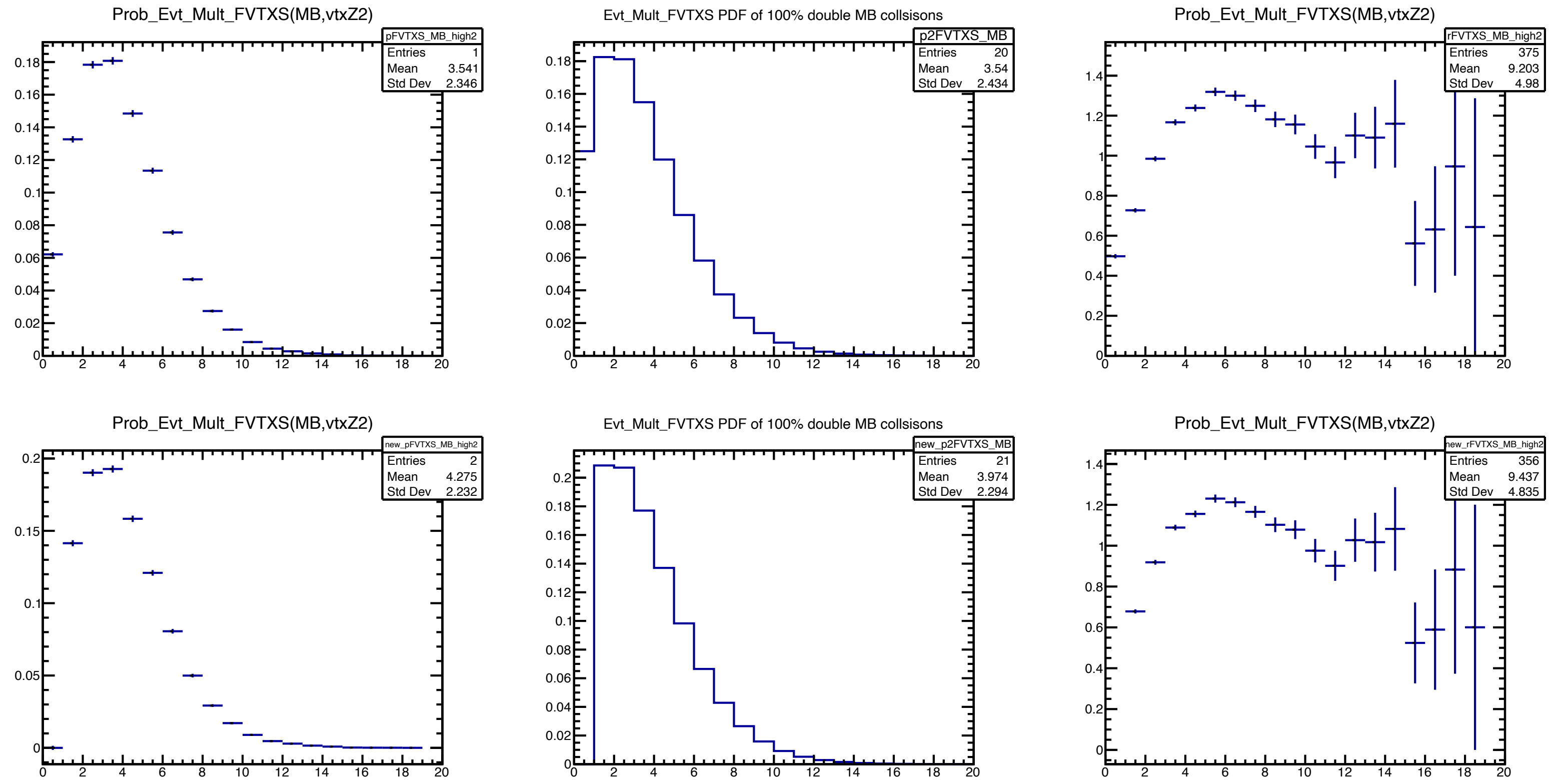
- Potentially can use single Gaussian as variation as well
- Significantly reduce fit systematic uncertainties



- Here, as preliminary results, we quote a 10% systematic uncertainties for the fits

Double Collision Model

- Study the sensitivity of the 1st empty/no-hit bin in the reference low BBC rate Evt_Mult_FVTX/SVX
- Removed the 1st empty bin counts in the normalization, but still used it to calculate PDF2_model - overall scale change



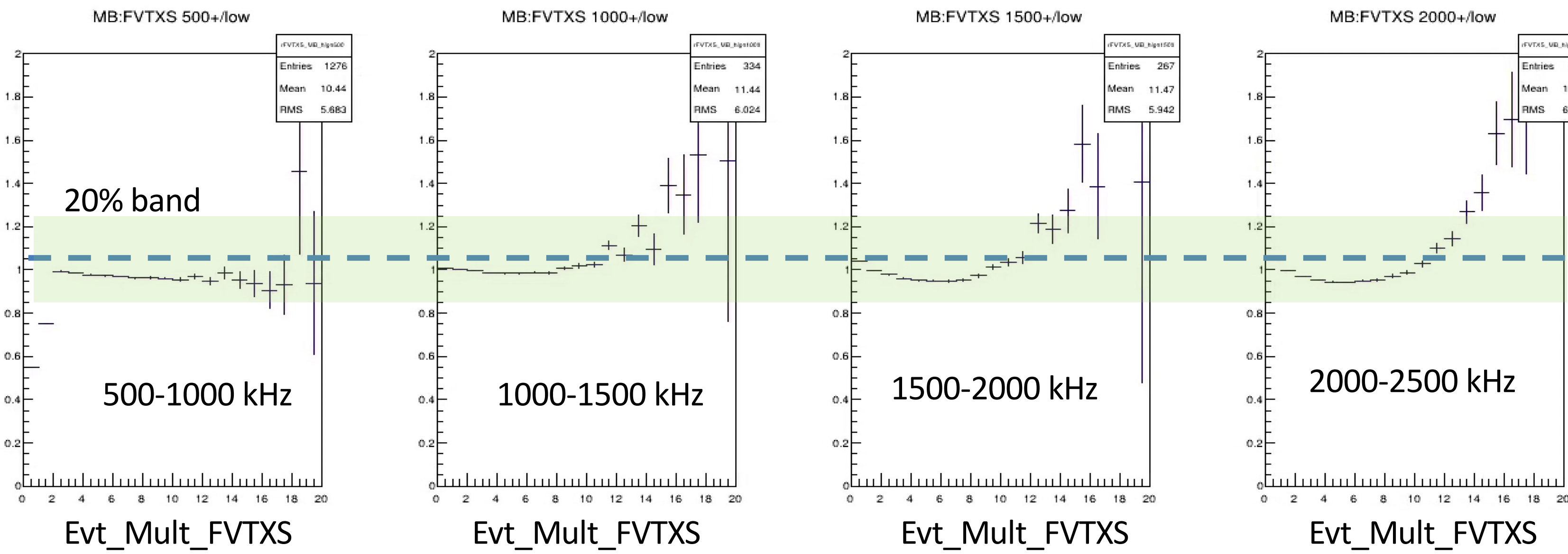
- Overall better agreement after removing the zero multiplicity bin

New Approach: BBC Rate Dependent Event Multiplicity Distributions

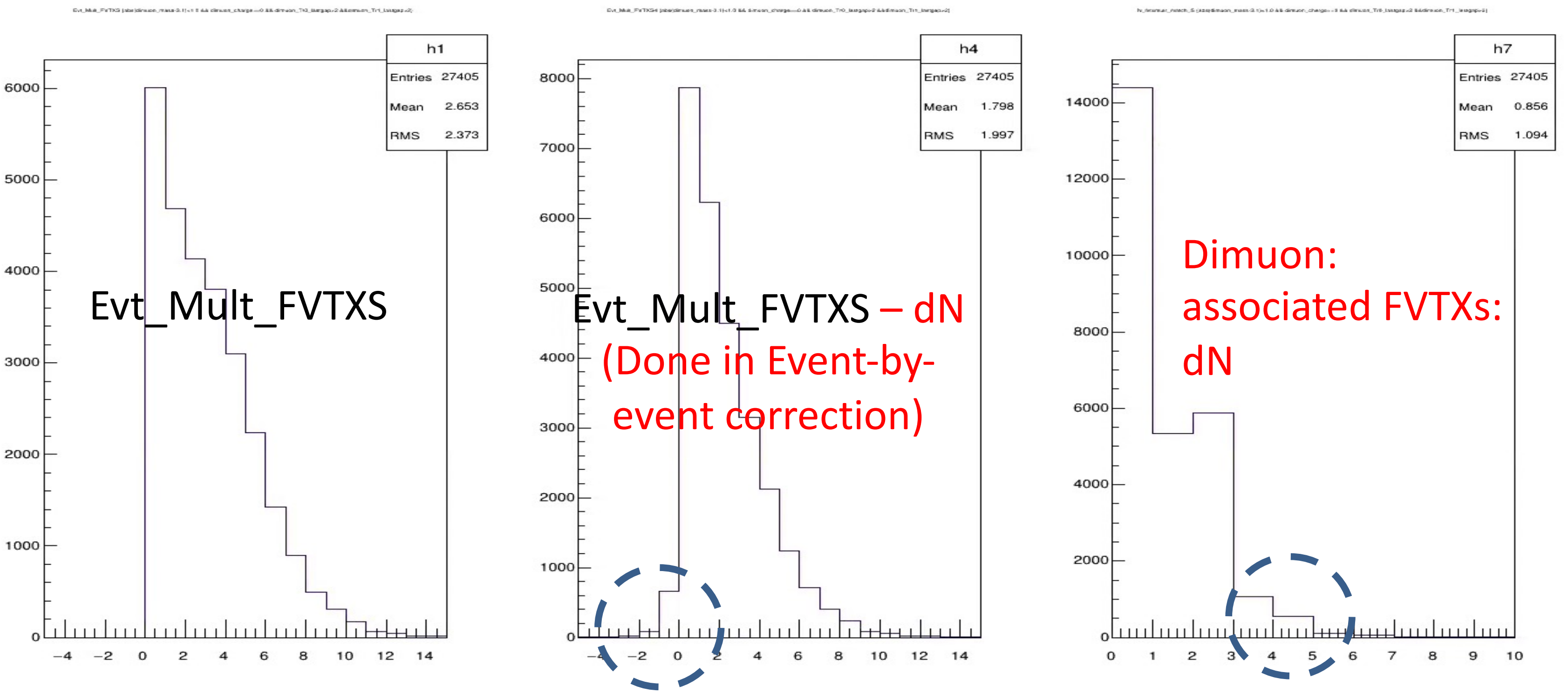
- Study the event normalized Evt_Mult_FVTX/SVX distributions relative to the reference one from low BBC Rate runs (<500kHz)
  - → New correction factor to be adopted for the final results and potentially reduce the systematic error
  - → Not used currently for preliminary results

$$R(N_{ch}, \mathrm{BBC\_Rate}) = \frac{\mathrm{d}N_{\mathrm{ch}}^{\mathrm{BBC\_Rate}}}{\mathrm{d}N_{\mathrm{ch}}^{\mathrm{BBC\_Rate<500kHz}}}$$

- BBC Rate: < 500 kHz, as the single collision reference
- BBC Rate: 500 < BBC_rate < 1000 kHz
- BBC Rate: 1000 < BBC_rate < 1500 kHz
- BBC Rate: 1500 < BBC_rate < 2000 kHz
- BBC Rate: 2000 < BBC_rate < 2500 kHz



Muon-FVTX Matching Correction on the Same Arm



- dimuon_mass > 2 GeV
- Tr0(1)_chi2_fvtxmutr < 3, good matching between MuTr track and FVTX tracklet
- Tr0(1)_nhits_fvtx >= 2, FVTX tracklet has at least 2 hits
- Tr0(1)_lastgap >= 3, must be a good muon candidate

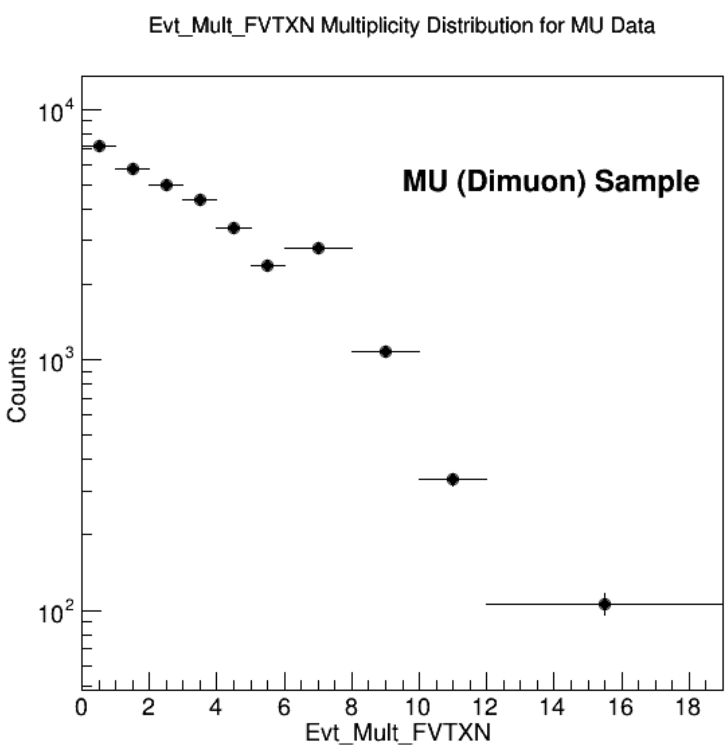
- Remove FVTX tracklets if from the muons in the Evt_Mult_FVTX counting
- Small fraction of over-subtraction - if more than 1 pair of dimuons ....

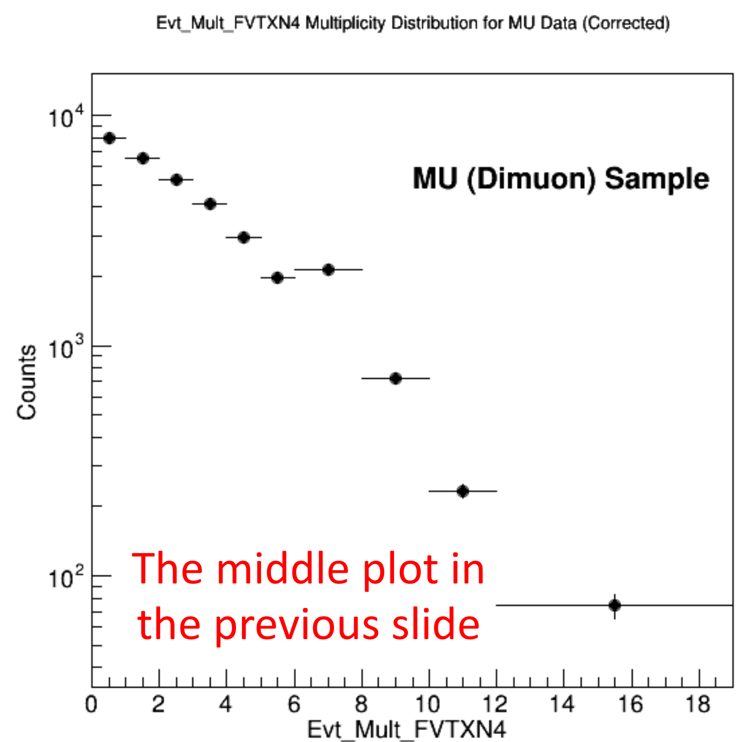
Modification on the FVTX Tracklet Multiplicity

- There is an about p = 70% of probability that a muon matched to an FVTX tracklet
- For the same arm, the average contribution of two muons from the J/ψ is given by the binominal distribution:

  $\langle \Delta N \rangle = Np = 2 \times 0.7 = 1.4$

- We need to apply this correction to dimuon sample of North J/ψ on FVTXN and South J/ψ on FVTXS by recalculation the multiplicity (FVTXN/S -> FVTXN/S4)





Addition of J/ψ Trigger Systematics

- Aside from MB trigger bias systematic, we also estimated the J/ψ trigger systematics due to the variation from multiplicity dependence
- We believe the J/ψ trigger will be around 85% $\pm$ 10%
- Quote a systematic uncertainties of 10% for J/ψ trigger efficiency bias uncertainties

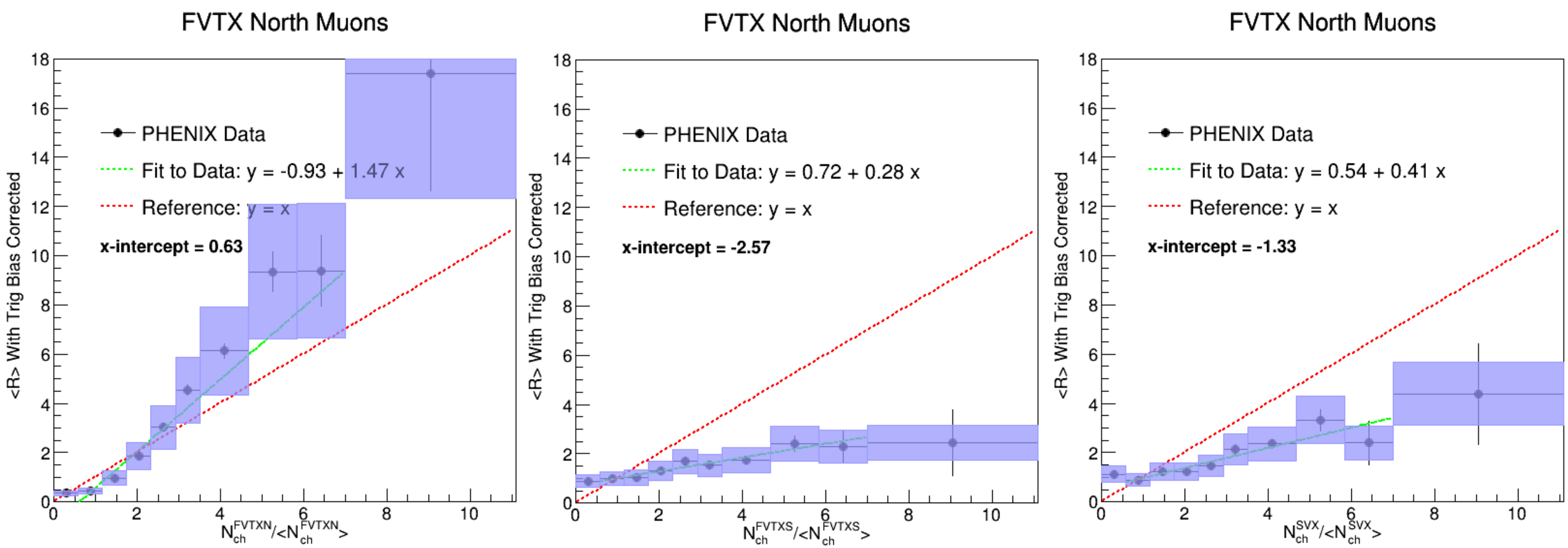
Summary of Systematic Uncertainties

Sources of Systematic Errors	Systematic Uncertainties
J/ψ Signal Extraction	10%
MB Trigger Bias	5%
J/ψ Trigger Bias	10%
Multiple Collision Modeling	20%
J/ψ Reconstruction Efficiency	15%
Total	29.2%

- Quote a systematic uncertainties of **29.2%** all the data points in our final results

Preliminary Figures

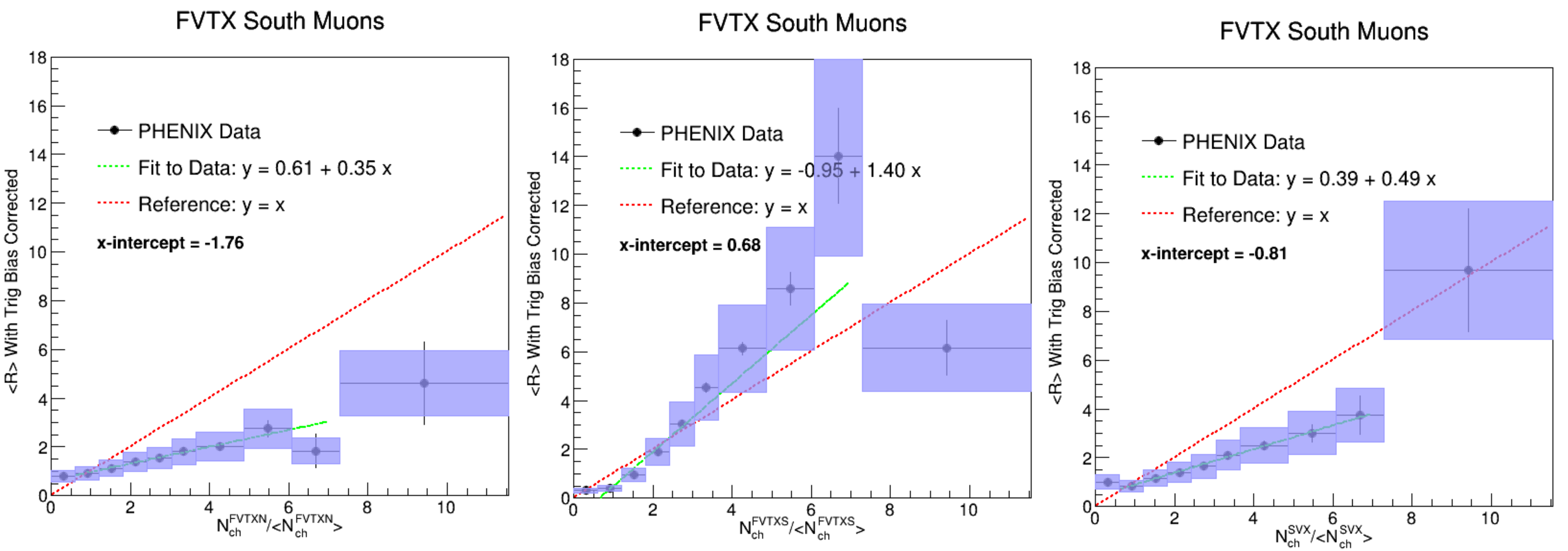
Preliminary Results – North J/ψ



Analysis Note Figure 75

- Common scale for all plots in Y-axis: 0 – 18
- Improve nominal values from better fit performance
- Improved statistical due to more statistics
- Better systematic uncertainties thanks to the improvement of the data analysis

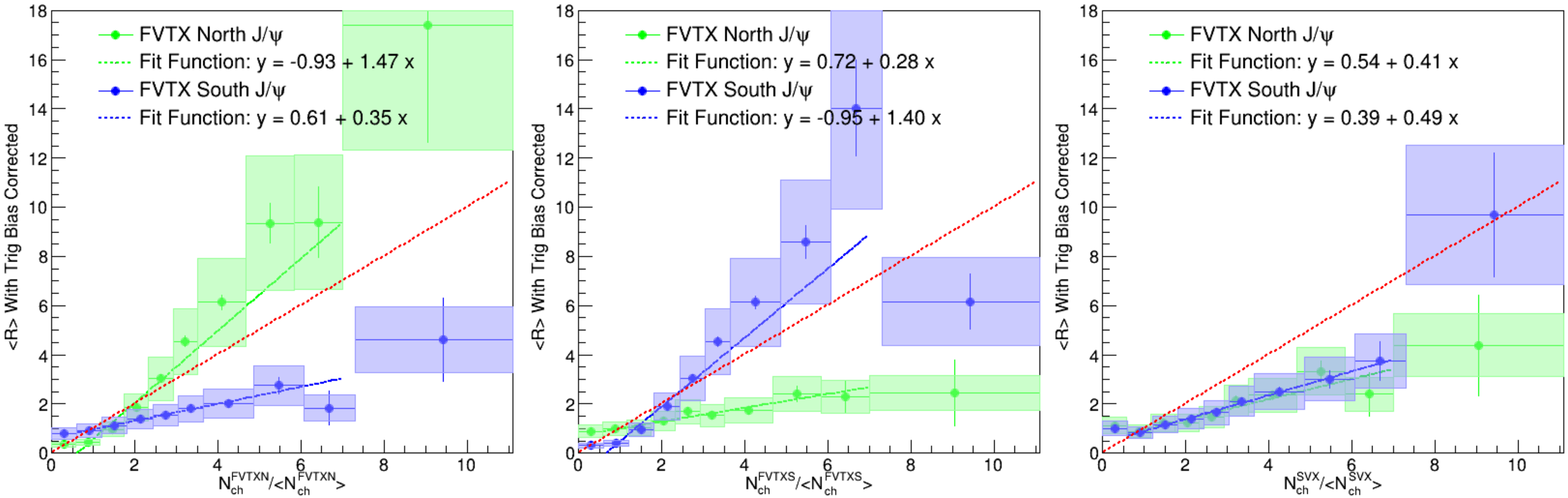
Preliminary Results – South J/ψ



Analysis Note Figure 76

- Similar results to the North J/ψ
- Improve nominal values from better fit performance
- Improved statistical due to more statistics
- Better systematic uncertainties thanks to the improvement of the data analysis

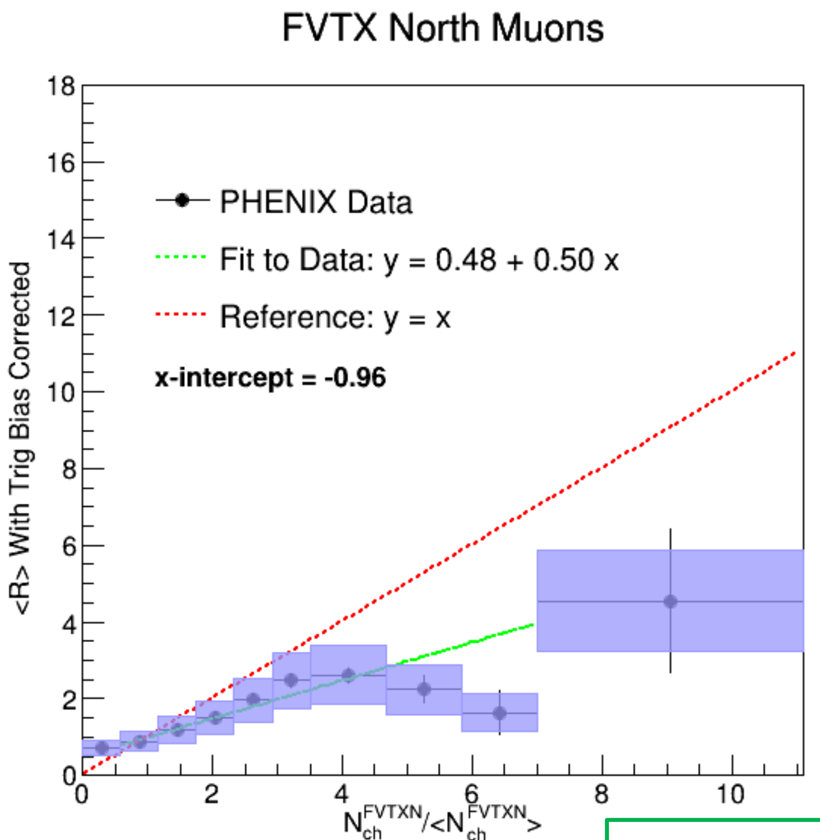
Preliminary Results – Plot Together

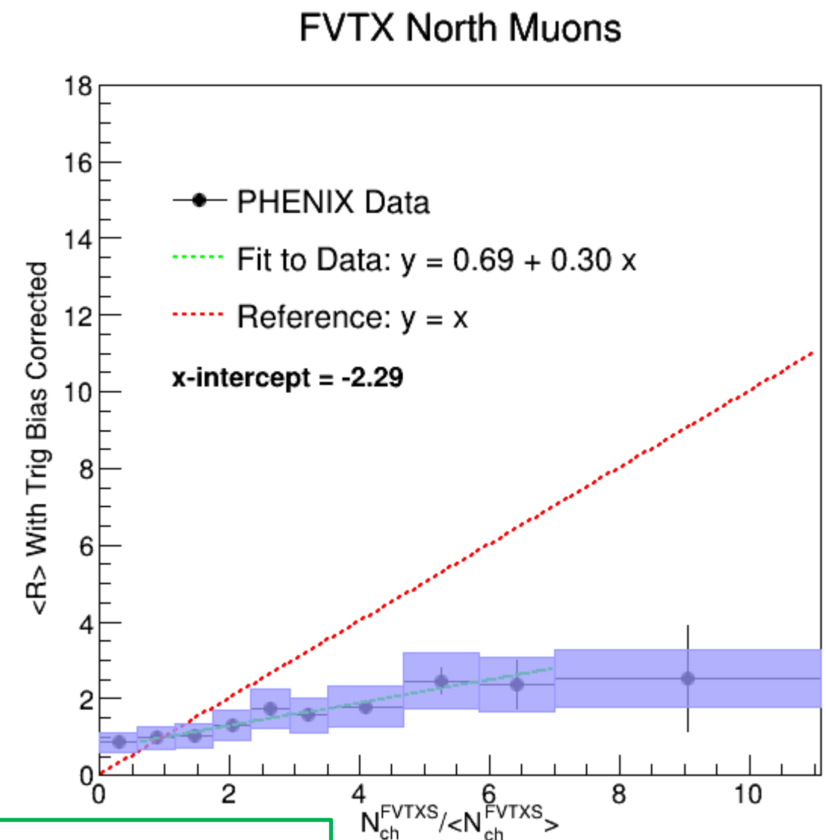


Analysis Note Figure 77

- Overall good agreement for SVX in both north and south FVTX arms J/ψ
- Different behavior for the same arm to opposite arm before corrections
- Similar trends for North and South, which makes sense due to parity symmetry

Preliminary Results – Dimuon Subtracted North J/ψ

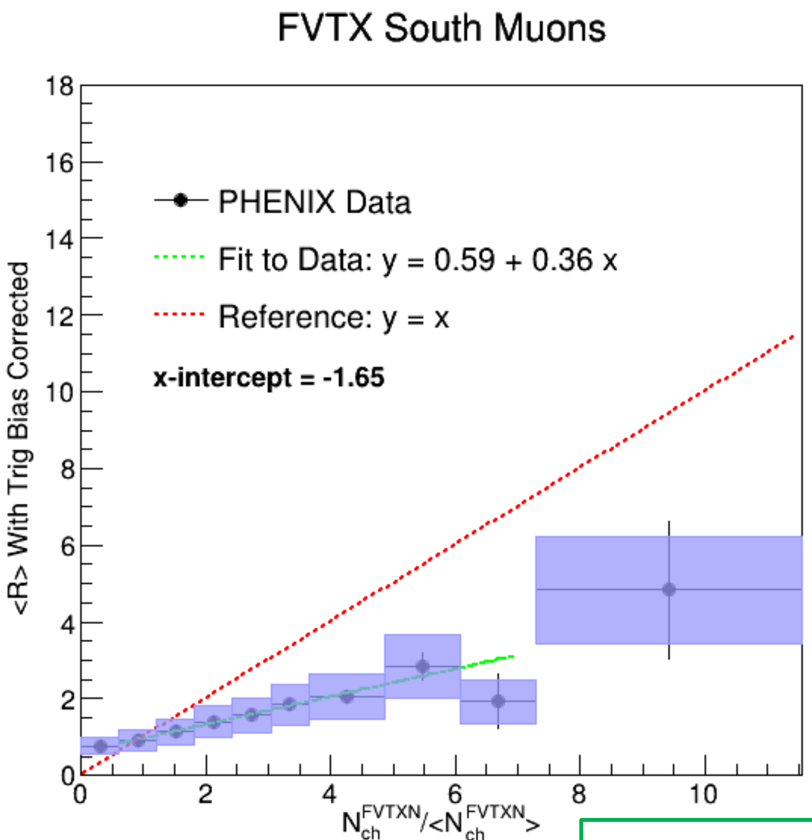


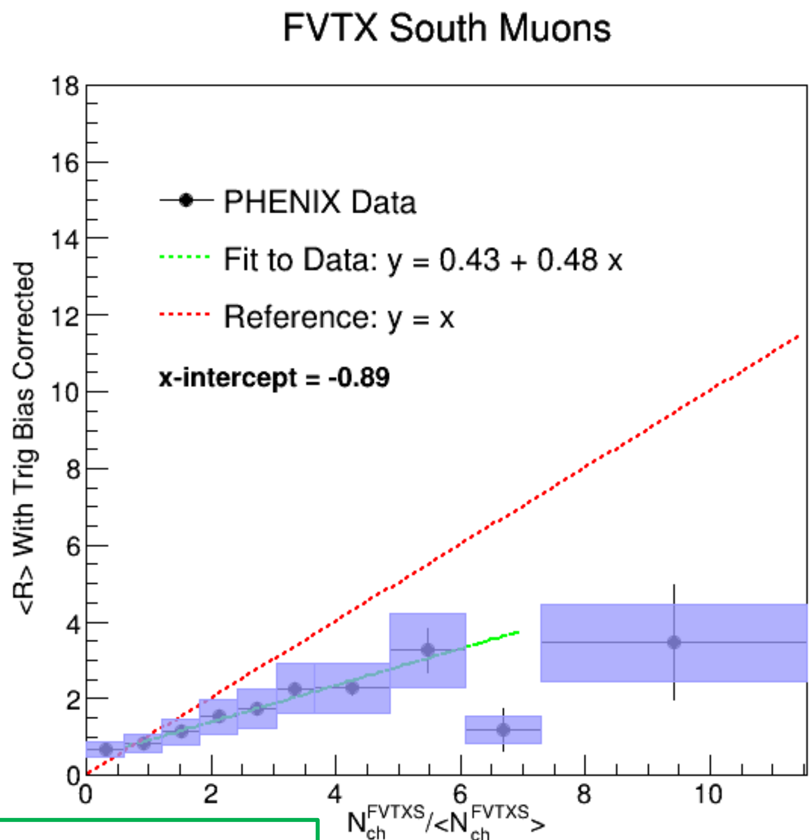


Analysis Note Figure 80

- Improve nominal values from better fit performance
- Improved statistical due to more statistics
- Better systematic uncertainties thanks to the improvement of the data analysis
- Significantly better agreement between same and opposite arms after correction

Preliminary Results – Dimuon Subtracted South J/ψ

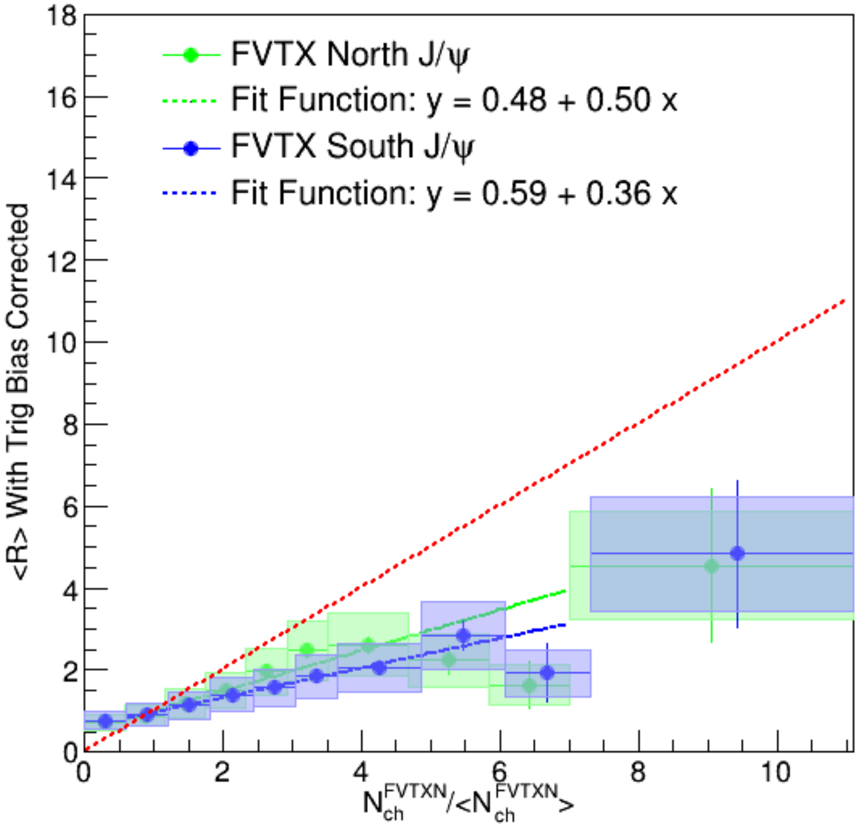


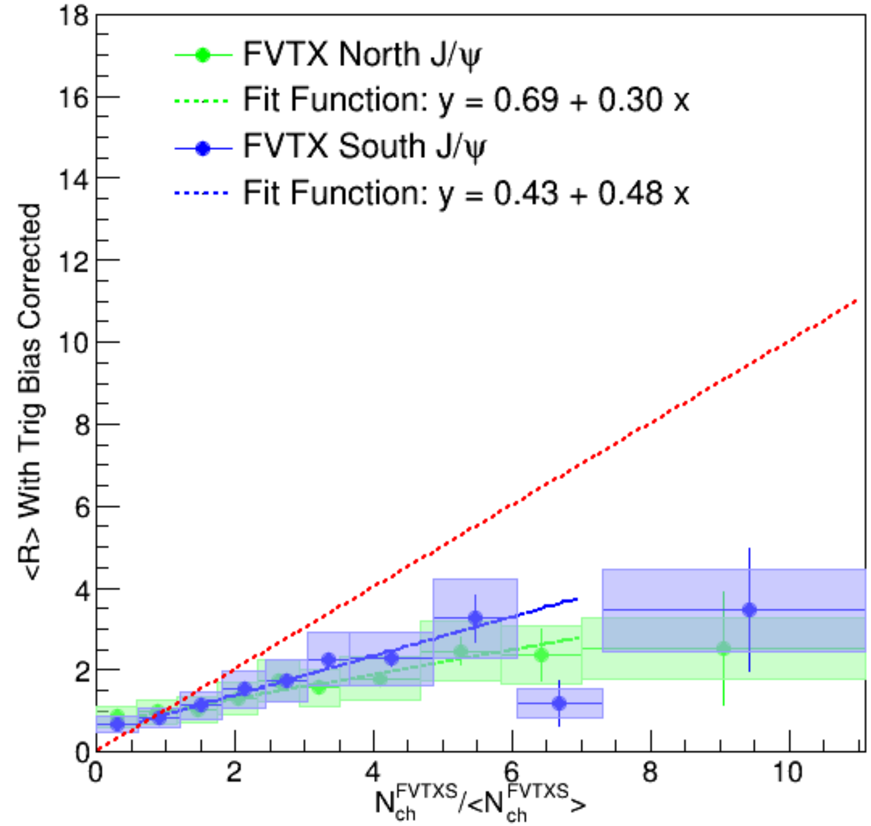


Analysis Note Figure 81

- Improve nominal values from better fit performance
- Improved statistical due to more statistics
- Better systematic uncertainties thanks to the improvement of the data analysis
- Significantly better agreement between same and opposite arms after correction

Preliminary Results – Dimuon Subtracted Plot Together



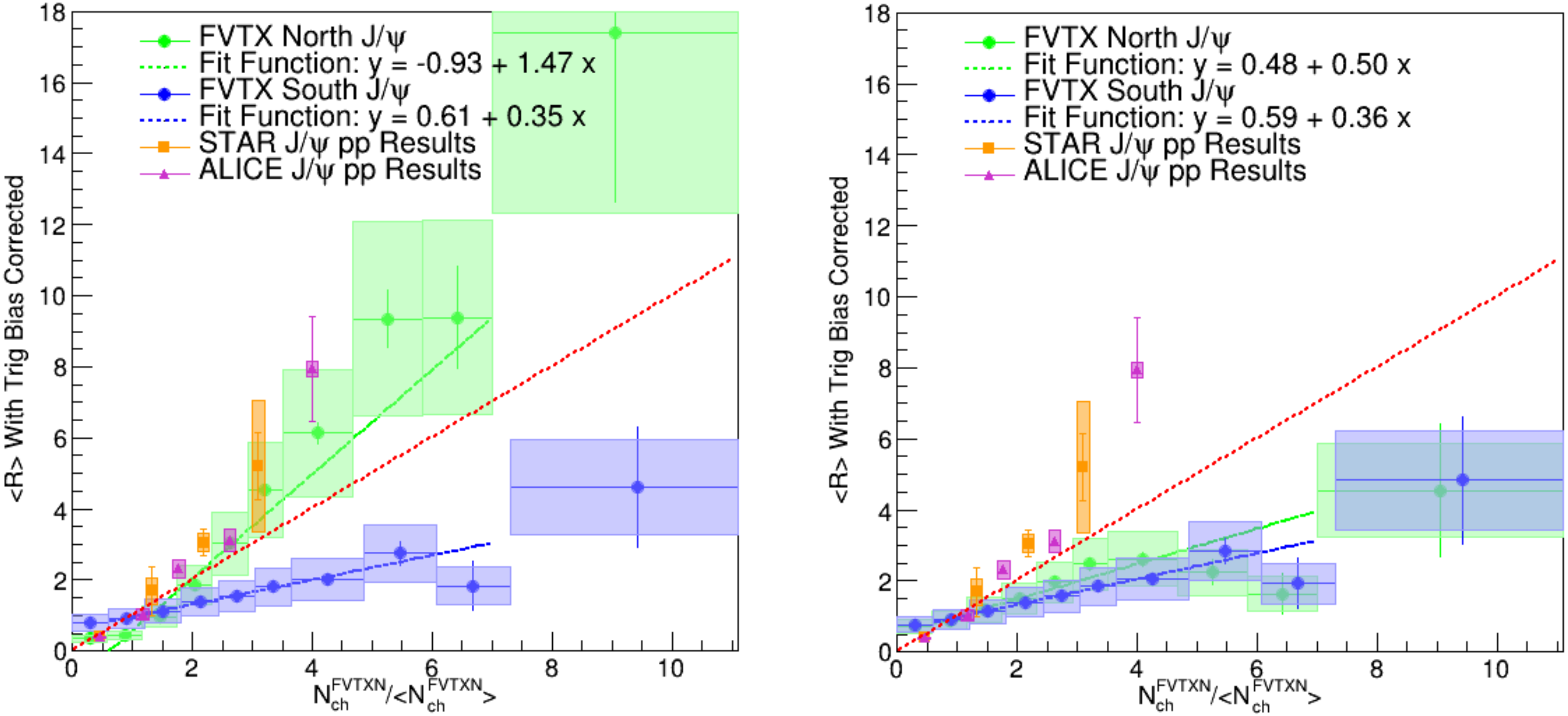


Analysis Note Figure 82

- Excellent agreement of the results between the same arm and opposite arm after applying the correction

Supplementary Figure

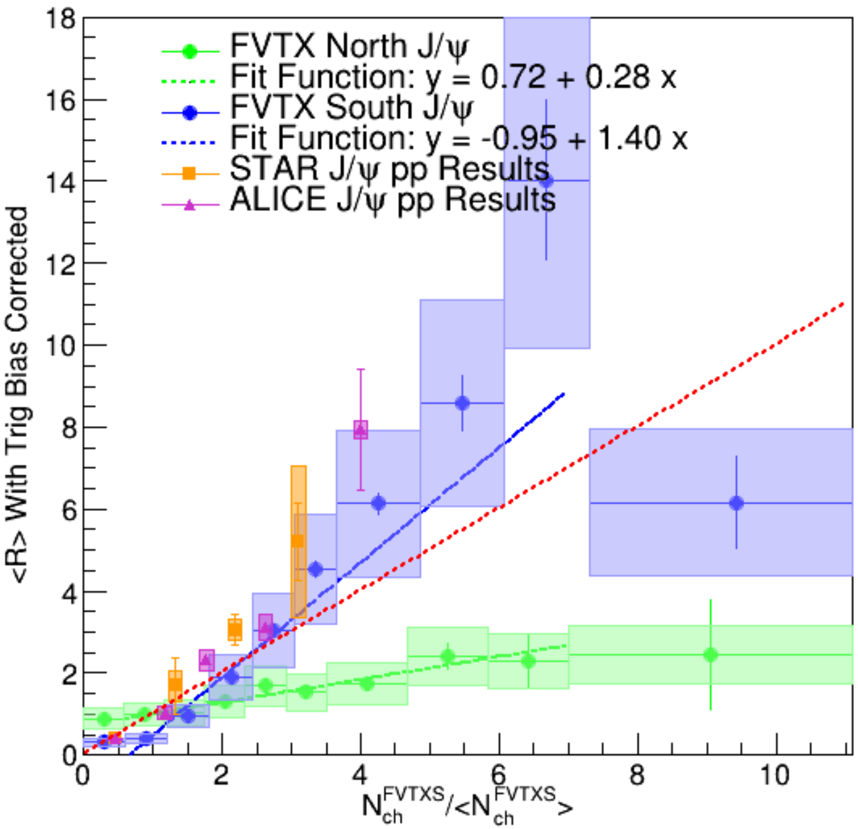
Comparison with Other Results – FVTXN

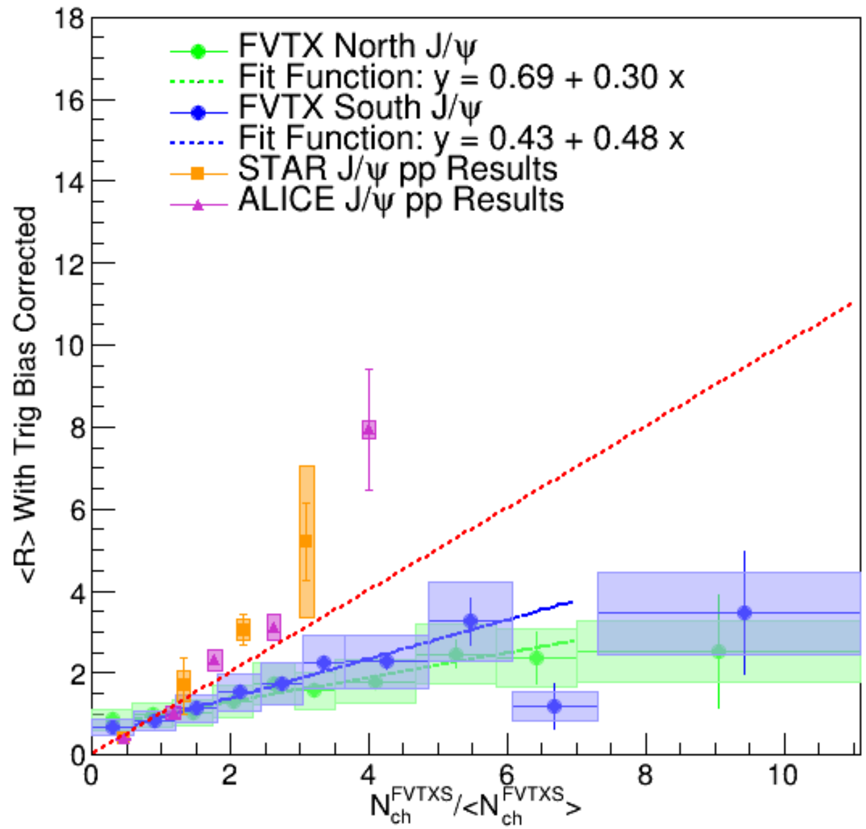


STAR Reference: PLB 786 (2018)

- Overall very good agreement with STAR published results
- Include theoretical calculations as well?

Comparison with Other Results – FVTXS

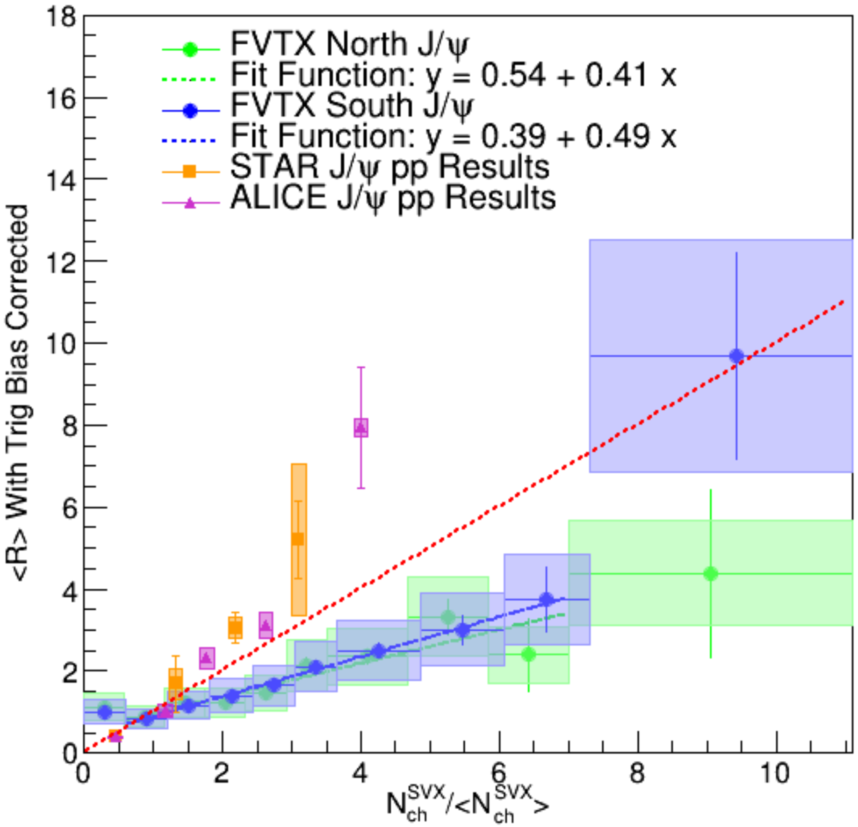


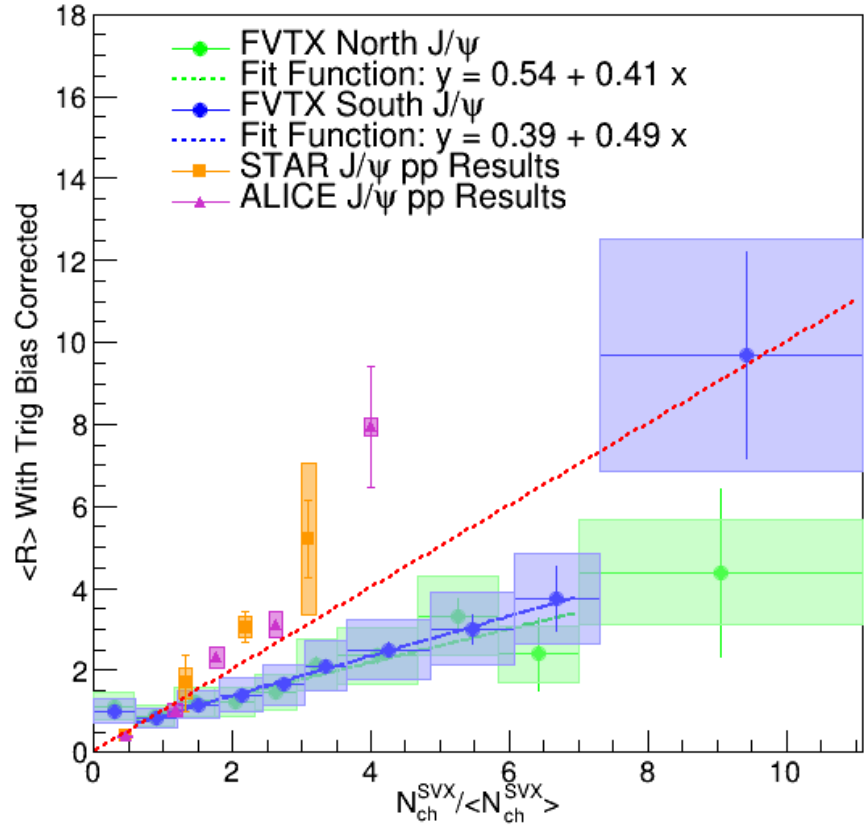


STAR Reference: PLB 786 (2018)

- Overall very good agreement with STAR published results
- Include theoretical calculations as well?

Comparison with Other Results – SVX





STAR Reference: PLB 786 (2018)

- Overall very good agreement with STAR published results
- Include theoretical calculations as well?

PHENIX

Los Alamos NATIONAL LABORATORY

Summary

- A lot of improvements have occurred over the last week
  - ☐ Increase the data sample statistics by a factor of 3
  - ☐ Improve of unbinned fits performance
  - ☐ Revisit the double collision model and better understand the systematics
  - ☐ Including J/ψ trigger efficiency bias systematic uncertainties
  - ☐ Apply corrections to remove J/ψ decay muons contributing to the same arm

- Improve the nominal results as well as the statistical and systematic uncertainties

- Obtain consistent results of same and opposite arms after the subtraction of dimuon tracklets on muon-FVTX matching to remove auto-correlation

- Update the analysis notes to make it more readable

- **Request preliminary for Quark Matter 2022**