FIRST FLOW RESULTS OF STAR FIXED-TARGET EXPERIMENT

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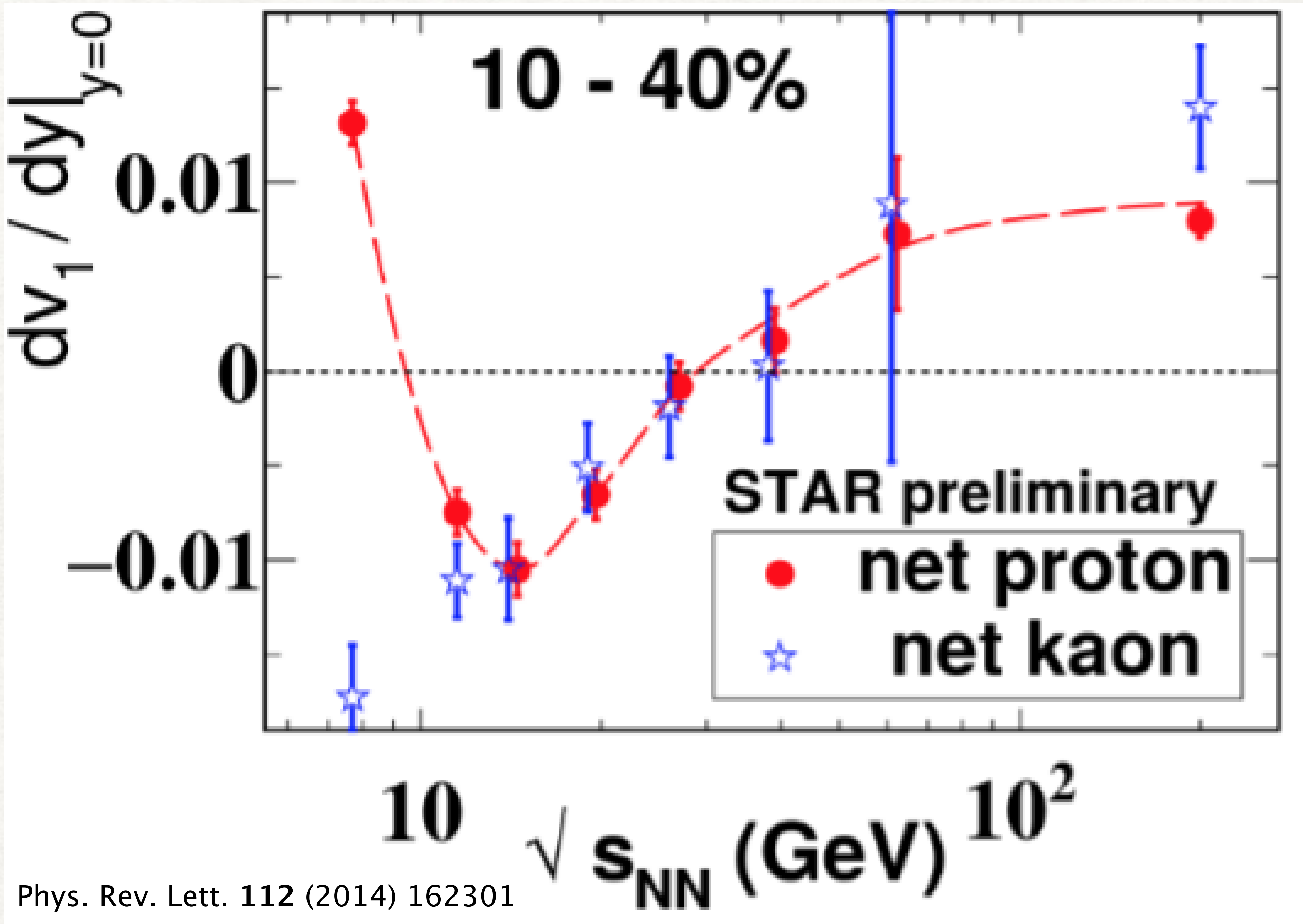
FOR THE STAR COLLABORATION

MOTIVATION

- STAR Beam Energy Scan (BES-I) results suggest a softening of the equation of state (EOS) which hints at critical fluctuations
- To help clarify these hints, STAR needs to access energies below 7.7 GeV where we expect no QGP formation
- At these lower energies the luminosity of RHIC is too low, making it impractical to take data in collider mode

P. Shanmuganathan for the STAR Collaboration, Quark Matter 2015



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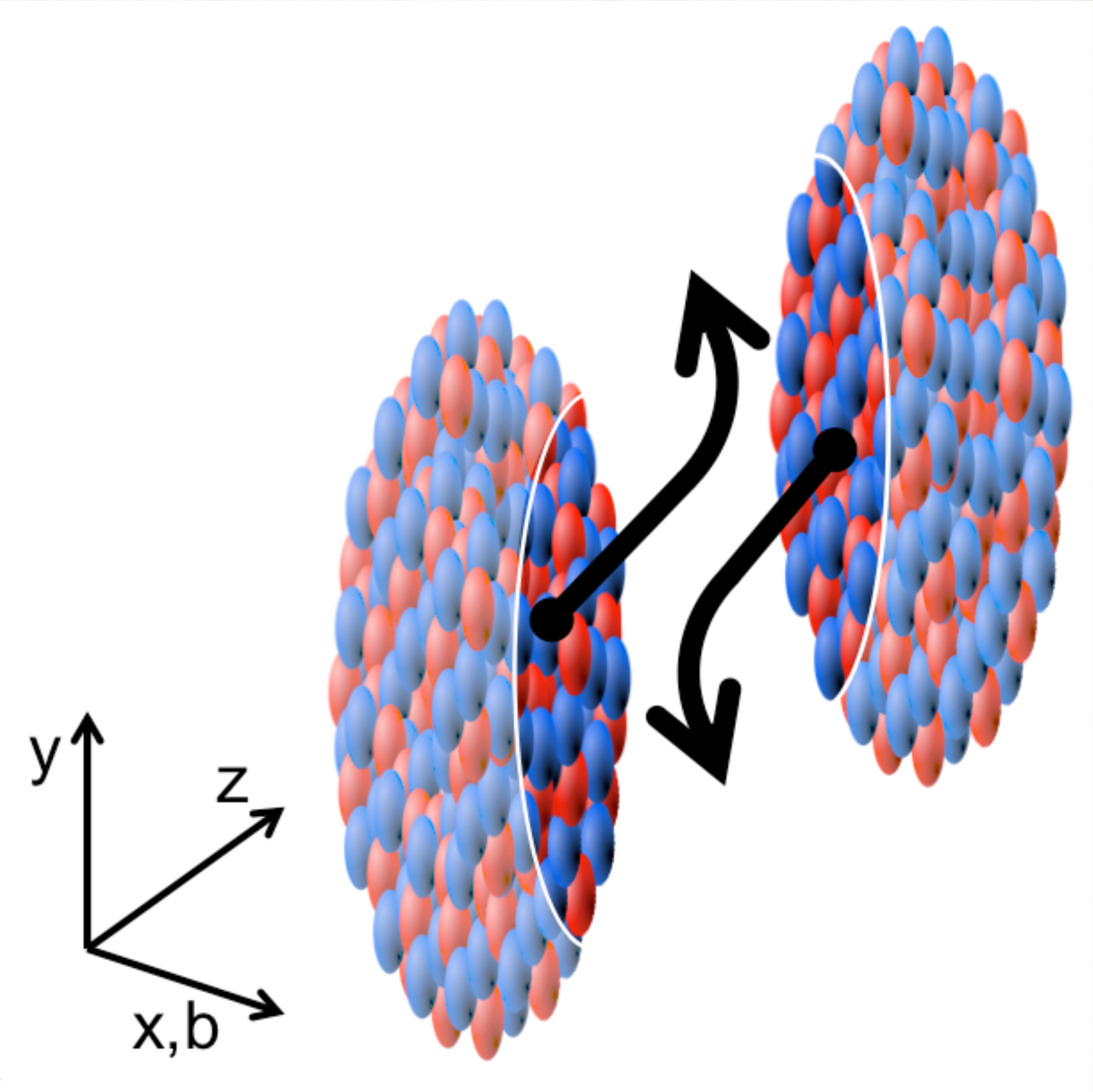
THE GOALS OF BEAM ENERGY SCAN (BES)-I:
1) OBSERVE THE DISAPPEARANCE OF QGP SIGNATURES
2) FIND EVIDENCE OF THE POSSIBLE FIRST-ORDER PHASE TRANSITION
3) FIND THE POSSIBLE CRITICAL POINT

DIRECTED FLOW

- Directed flow describes the sideward motion of the particles within the reaction plane

- Generated during the nuclear passage time ($2R/\gamma \approx 0.1$ fm/c)

- Therefore probes the very earliest stage of the collision dynamics



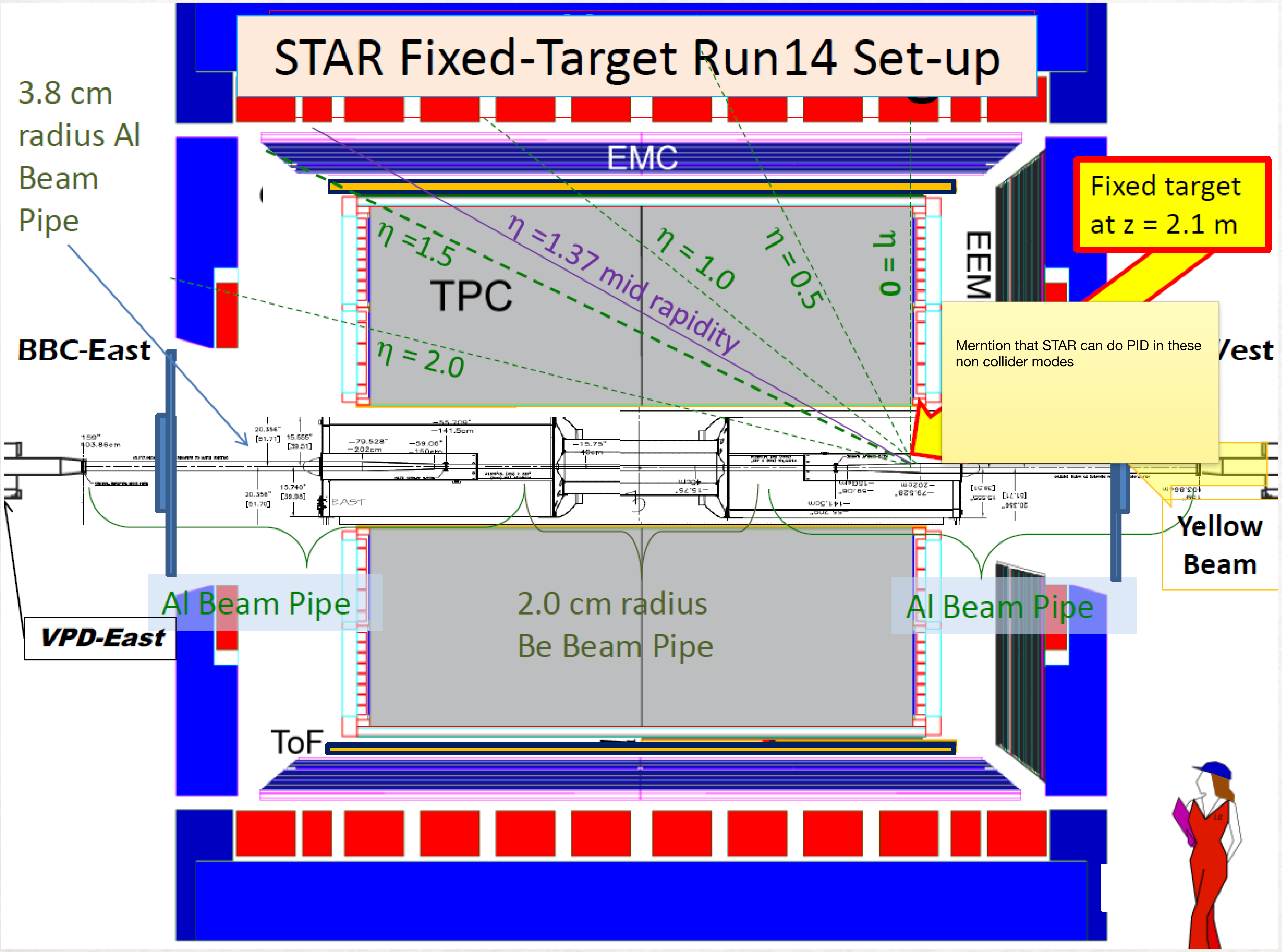
$$v_1 = \langle \cos(\phi - \Psi_{\mathrm{RP}}) \rangle$$

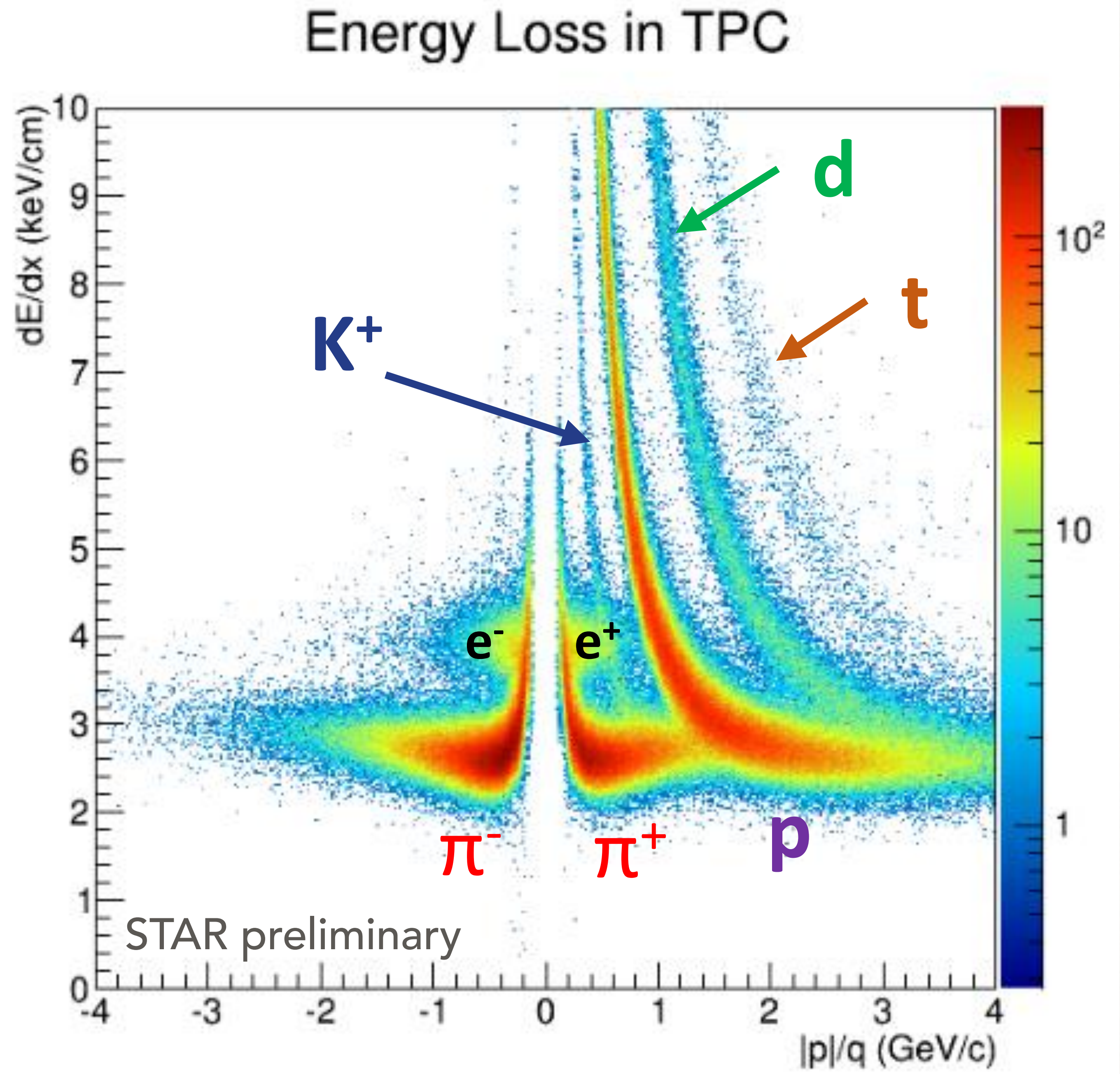
PREVIOUS RHIC RUNS BELOW NOMINAL INJECTION ENERGY

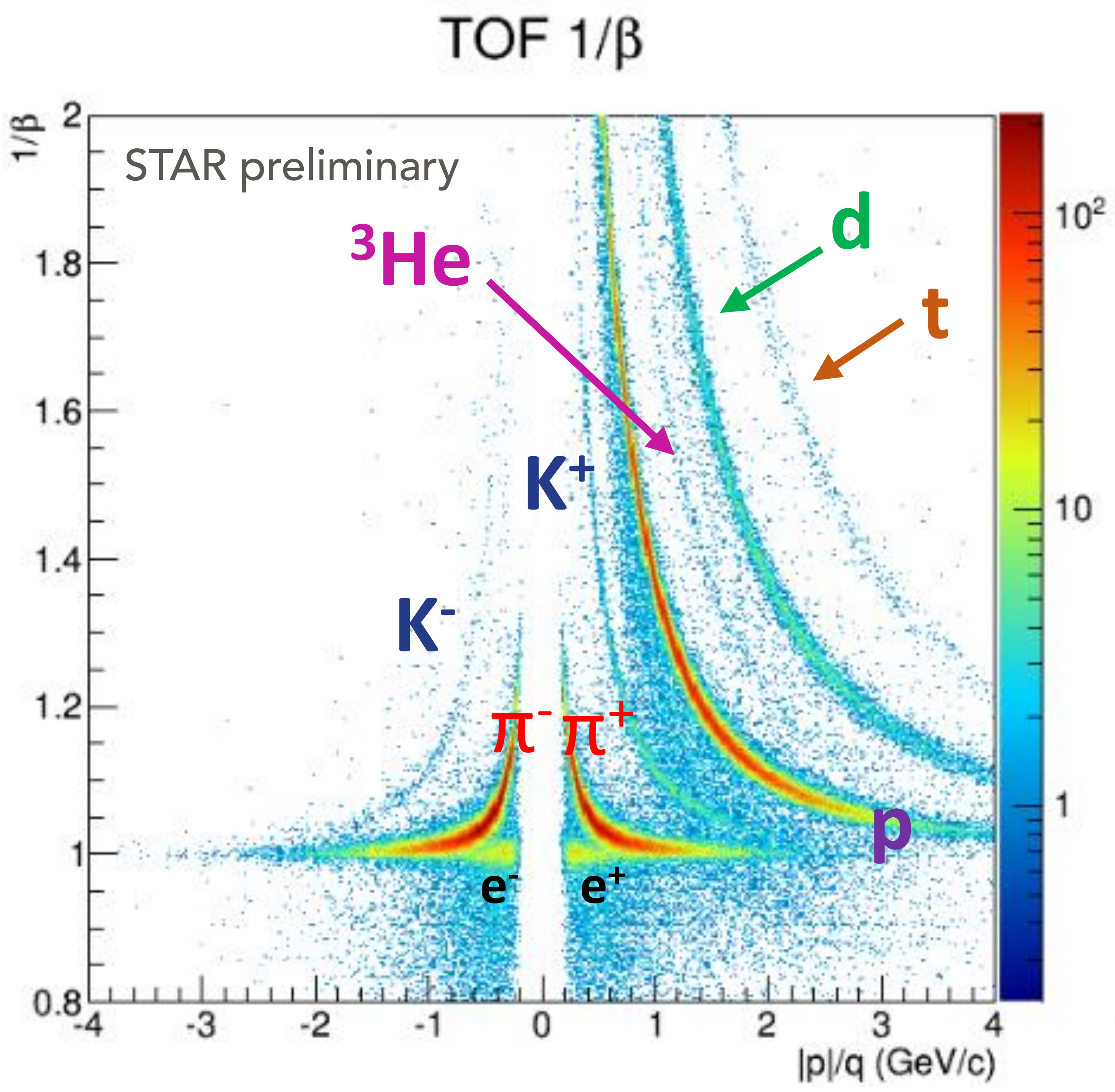
- 2001: Au+Au 19.6 GeV (Test Run) - 100k events
- 2005: Cu+Cu 22.4 GeV (Test Run) - 250k events
- 2008: Au+Au 9.2 GeV (Test Run) - 3k events
- 2010: Au+Au 7.7 GeV (Physics) - 5M events, Au+Au 11.5 GeV 2010 (Physics) - 8M events, Au+Au 5.5 GeV 2010 (Test Run) - 0 events
- 2011: Au+Au 19.6 GeV (Physics) - 36M events, Au+Au 27 GeV (Physics) - 70M events
- 2014: Au+Au 14.5 GeV (Physics) - 20M events, Fixed Target (FXT) 3.9 GeV (taken concurrently with Au+Au 14.5 GeV)
- 2015: Au+Au 4.5 GeV (Test Run)

$\sqrt{S_{NN}}$ = 3.9 GEV AU+AU TEST RUN

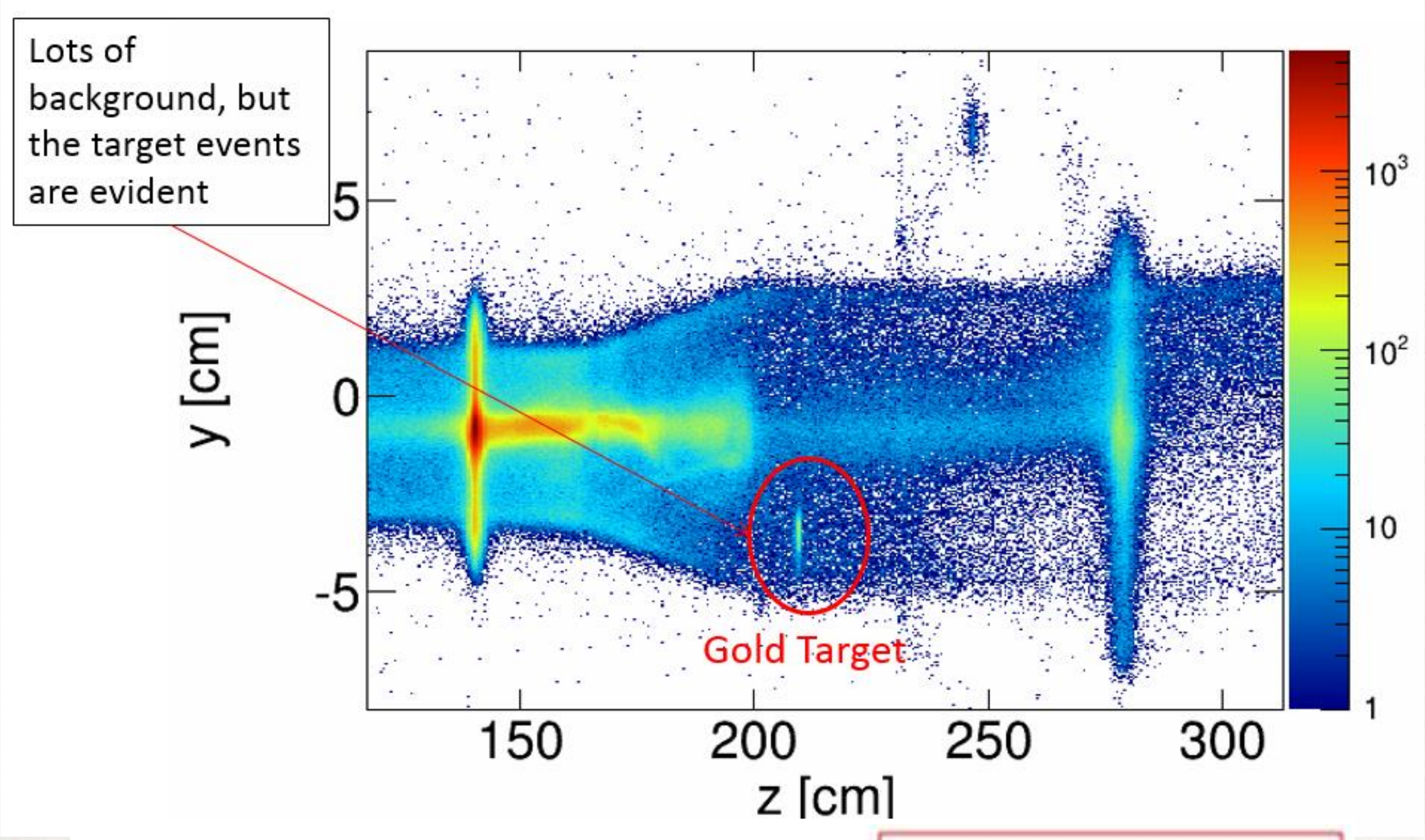
Particle Identification (PID) with STAR Time Projection Chamber (TPC) and Time of Flight (TOF) - outstanding for FXT

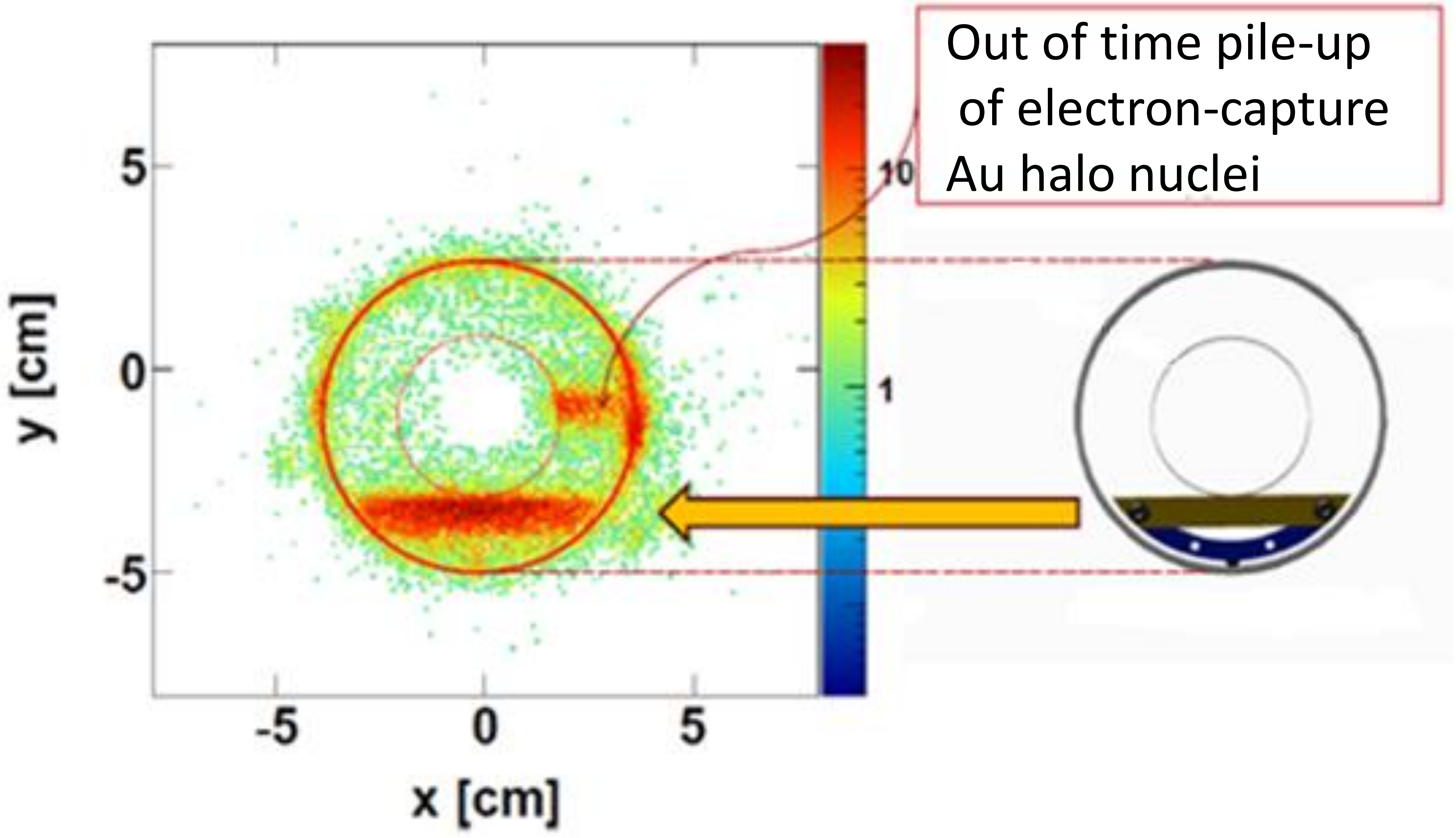




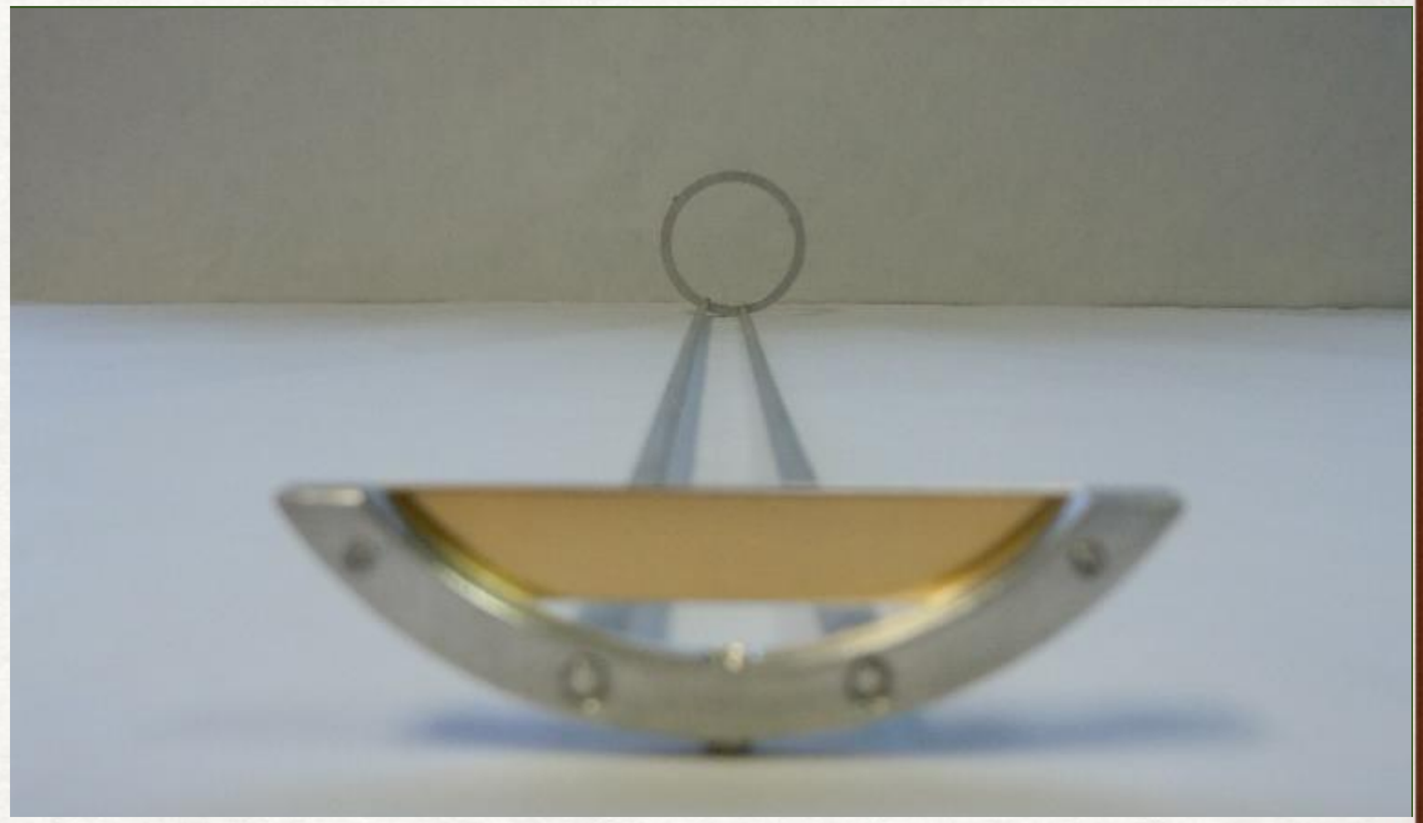


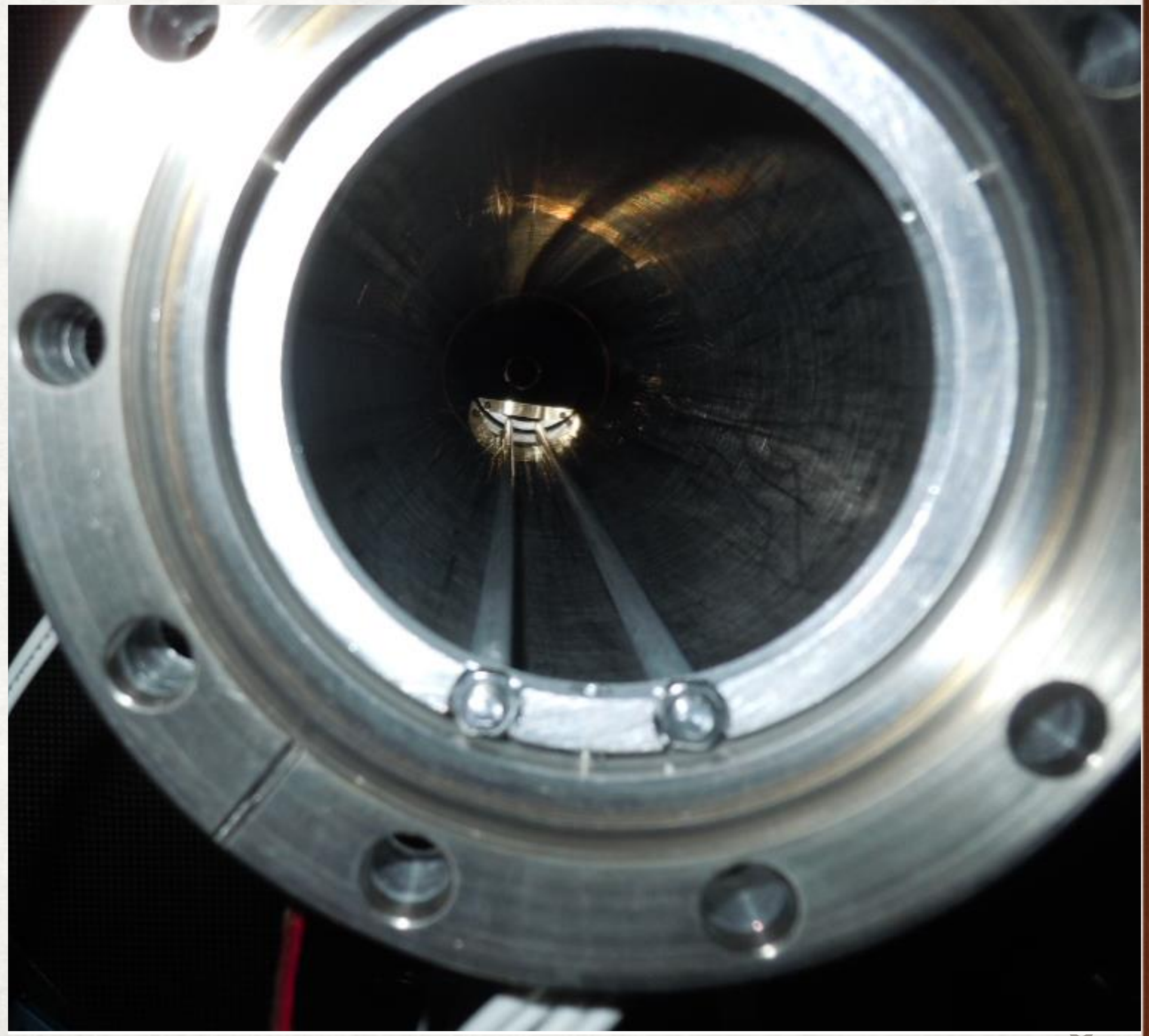
GOLD TARGET IN RUN 14





- The target foil was held 2 cm below of the beam axis
- The foil is 1 mm thick



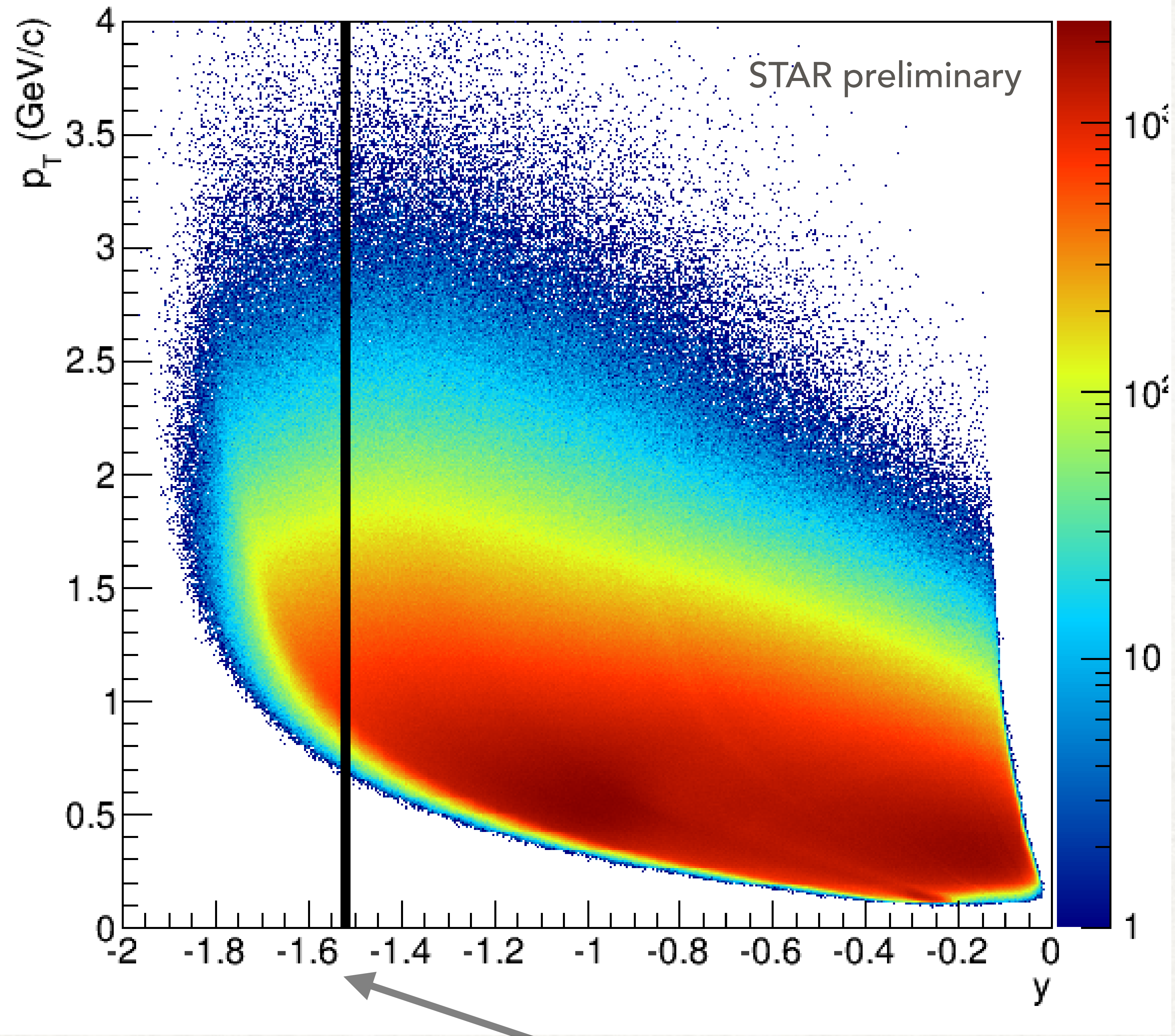


AU + AU $\sqrt{S_{NN}}$ =4.5 GEV 2015 TEST RUN PERFORMANCE

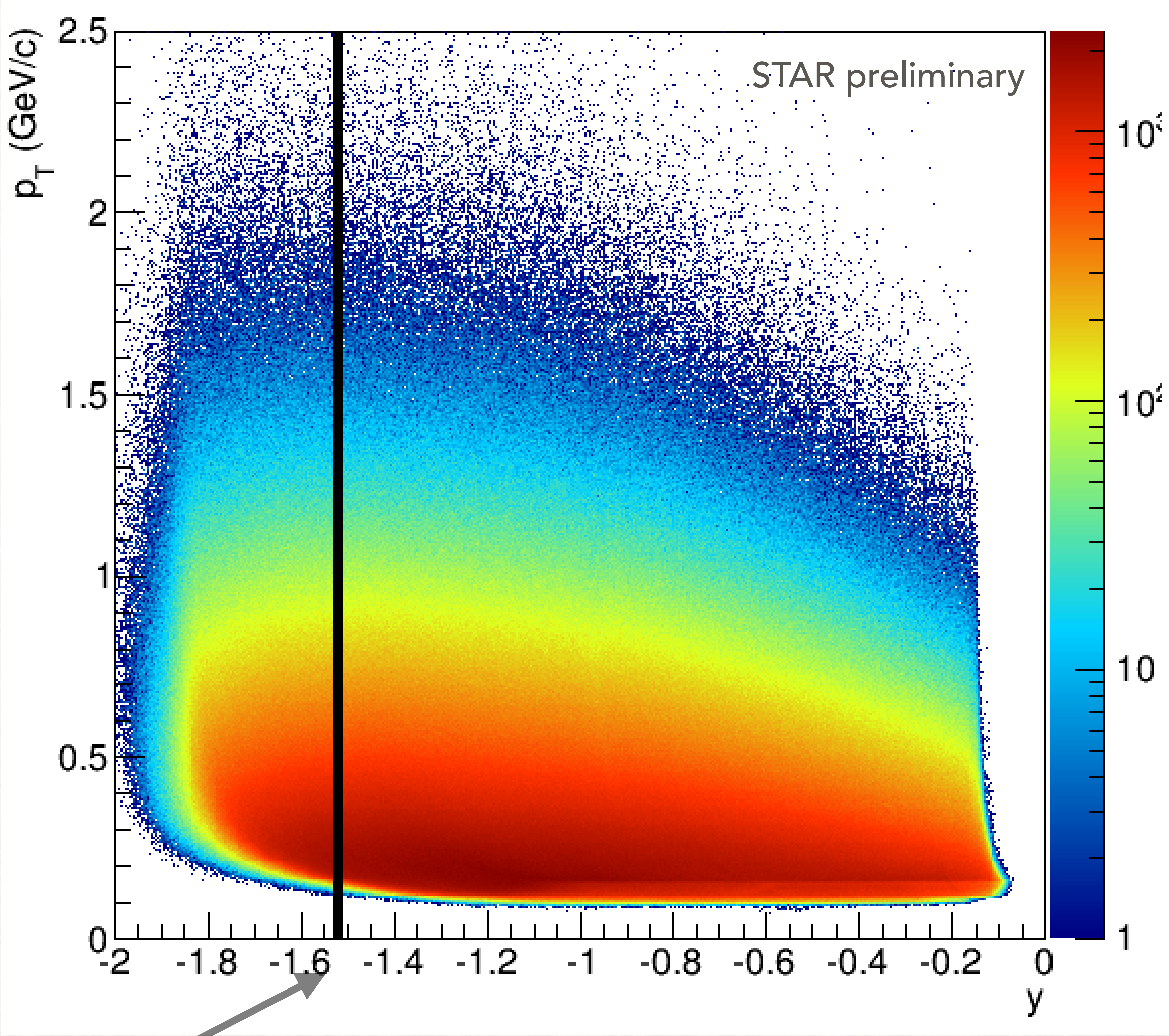
Beam energy: 9.8 GeV, ~8.9 AGeV

- May 20th, 2015, 4 hour test run (Au +Au)
- 6 bunches, 1.35M events collected in Au+Au (1M collected in last 30 minutes)
- beam lowered to graze the top edge of the target

Pion Acceptance



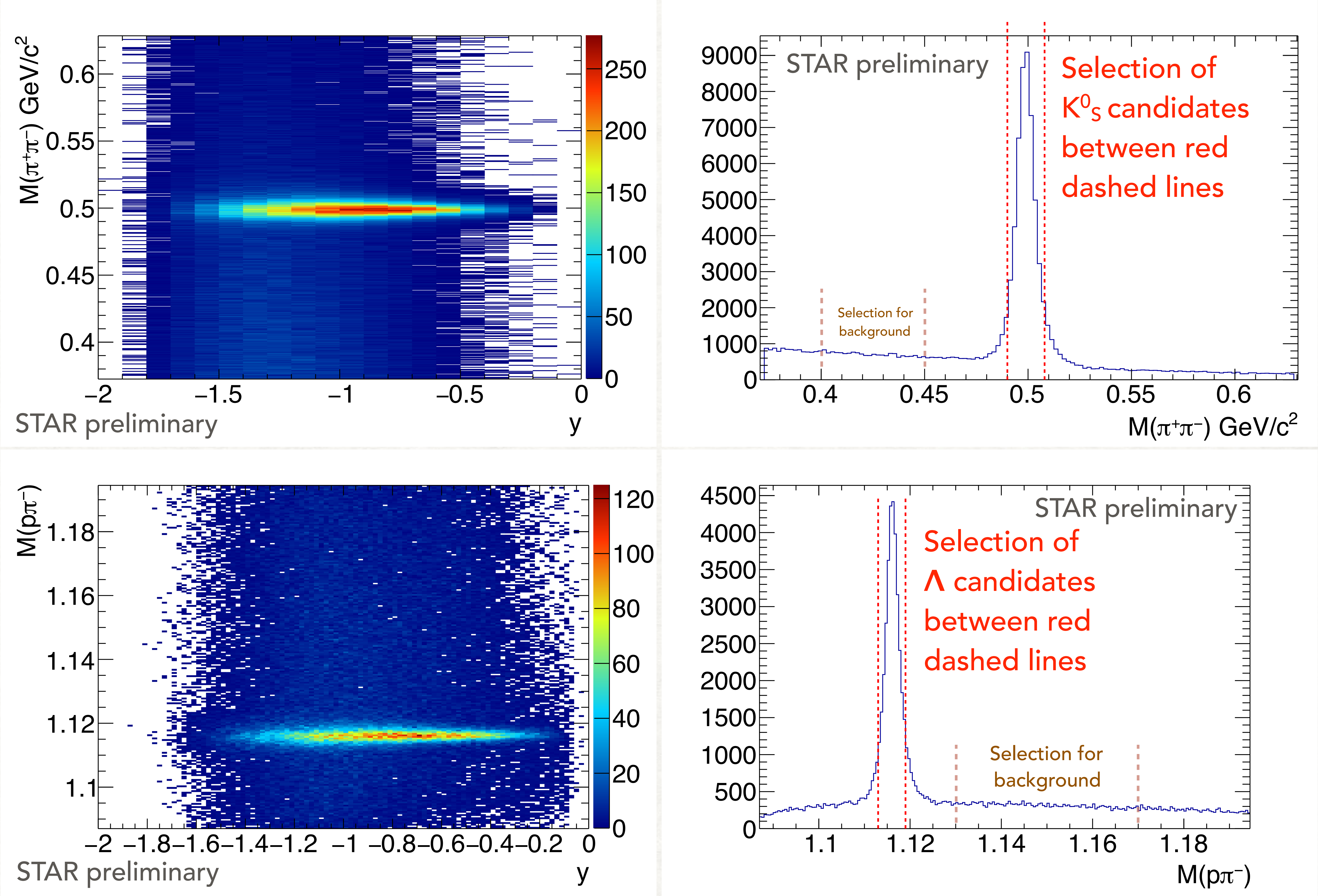
Proton Acceptance



Mid rapidity

LAMBDA AND K^0_S RECONSTRUCTION

- hadronic channels $K^0_S \longrightarrow \pi^+\pi^-$, $\Lambda \longrightarrow p\pi^-$
- pions and protons identified by their dE/dx in TPC
- secondary vertex determined from tracks reconstructed in TPC (magnetic field 0.5T)
  - path length for Λ = 7.8cm, K^0_S = 2.7cm, topological cuts used to reduce combinatorial background
- $-2 < \eta < -1.2$ - separation from the event plane

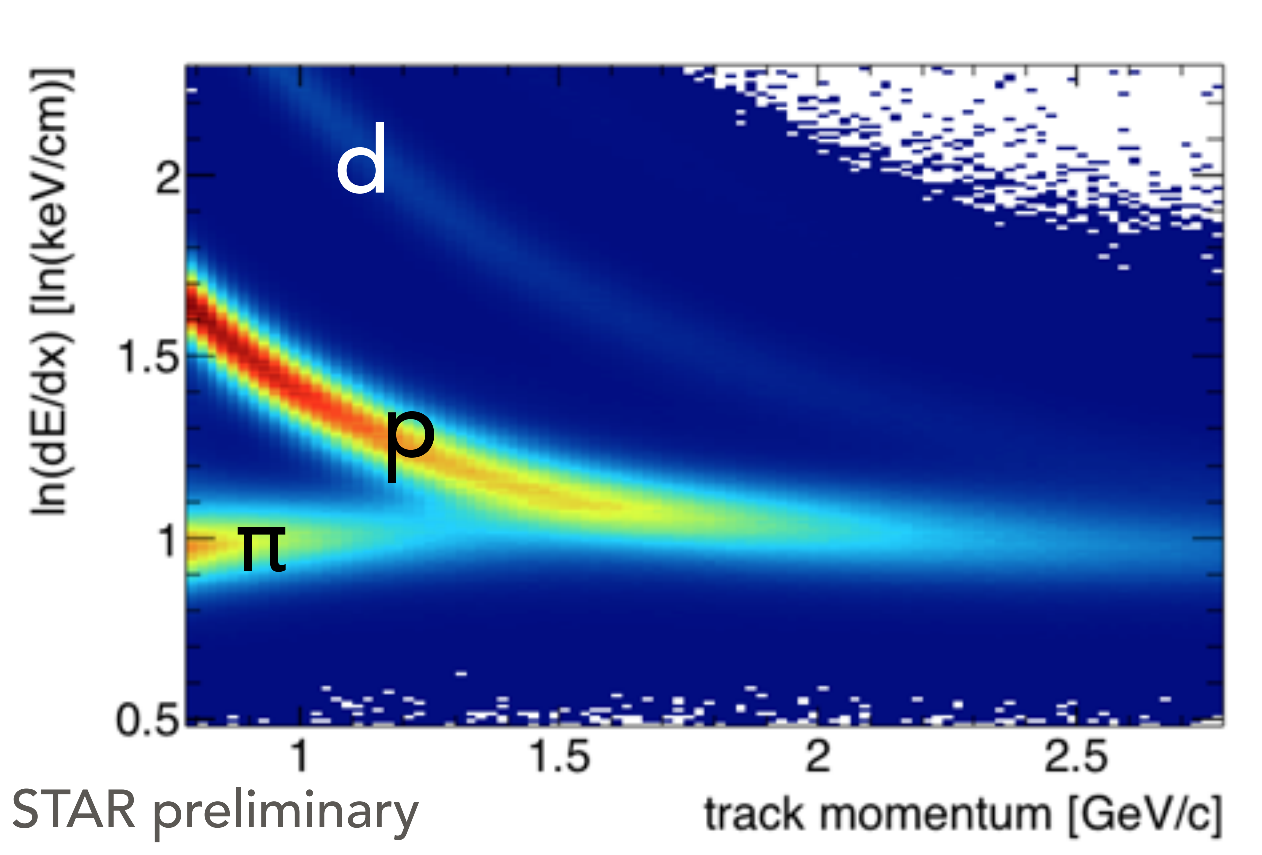


Excellent suppression of combinatorial background
Mass resolution of peaks consistent with collider data

EVENT PLANE RECONSTRUCTION

IN THE FIRST HARMONIC

- Using TPC identified protons and deuterons coming from the primary vertex with $-0.7 < \eta < 0$
- protons dominate the yield at higher p_T



Event Flow Vectors:

$$Q_x = \sum_i (y_{\text{lab}} - y_{\text{c.m.}}) p_T^{(i)} \cos\phi^{(i)}$$

$$Q_y = \sum_i (y_{\text{lab}} - y_{\text{c.m.}}) p_T^{(i)} \sin\phi^{(i)}$$

Centering of Event Flow Vectors:

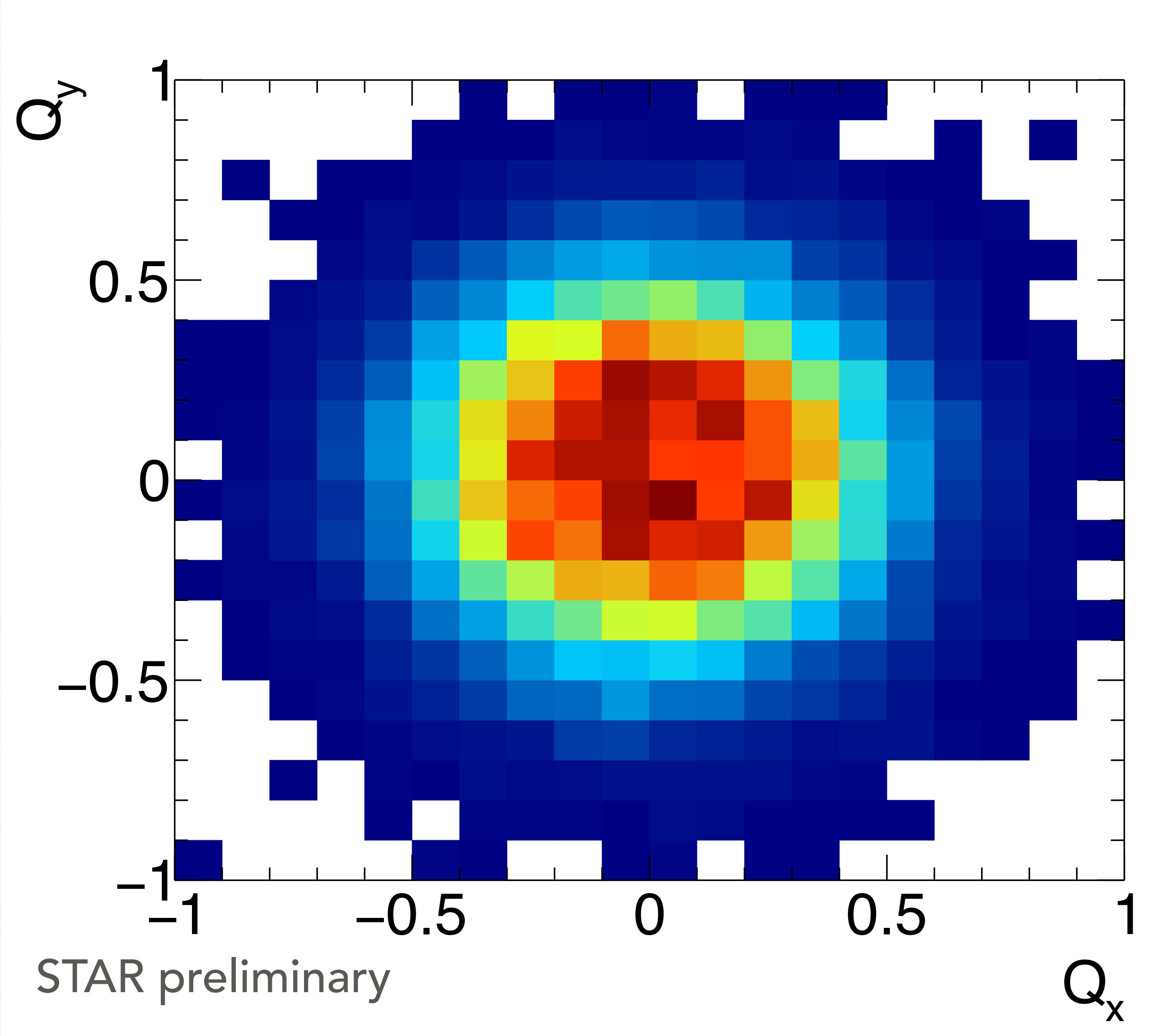
$$Q_x^{\text{centered}} = Q_x - \left\langle \frac{Q_x}{N_{\text{trk}}} \right\rangle N_{\text{trk}}$$

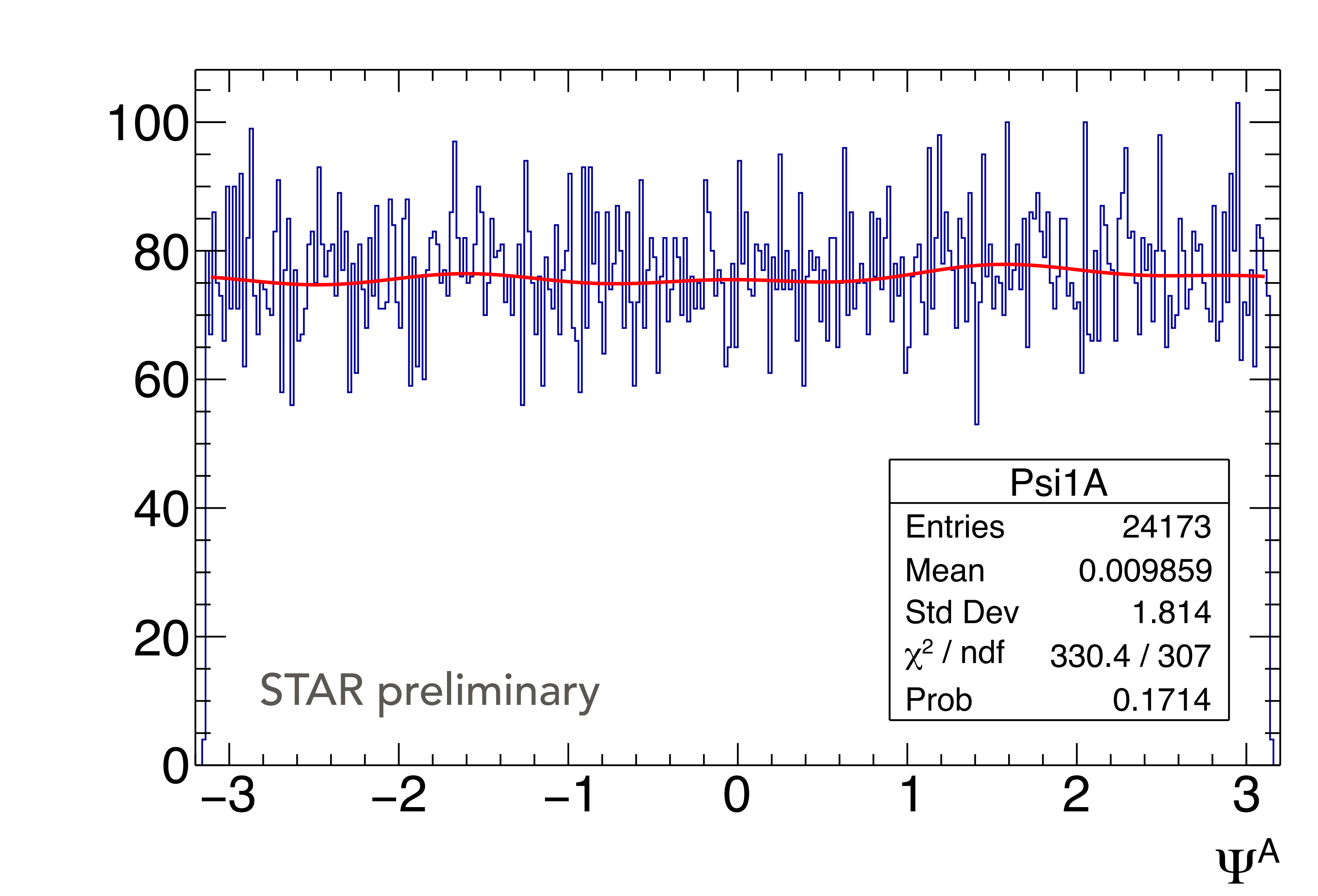
$$Q_y^{\text{centered}} = Q_y - \left\langle \frac{Q_y}{N_{\text{trk}}} \right\rangle N_{\text{trk}}$$

$$N_{\text{trk}} \geq 5$$

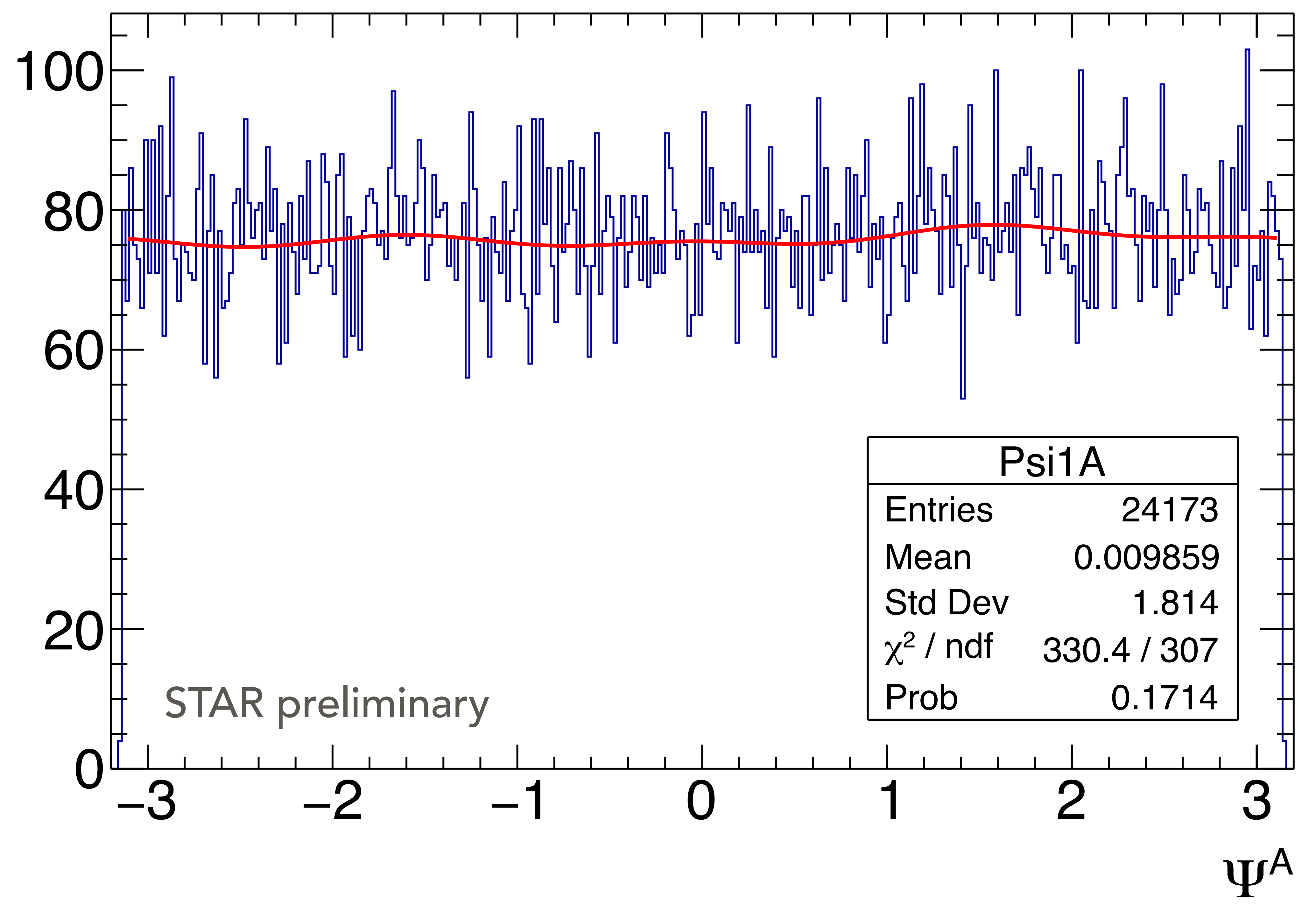
Event Plane Angle Calculation:

$$\Psi = \tan^{-1}\left(\frac{Q_y^{\text{centered}}}{Q_x^{\text{centered}}}\right)$$





EVENT PLANE RECONSTRUCTION



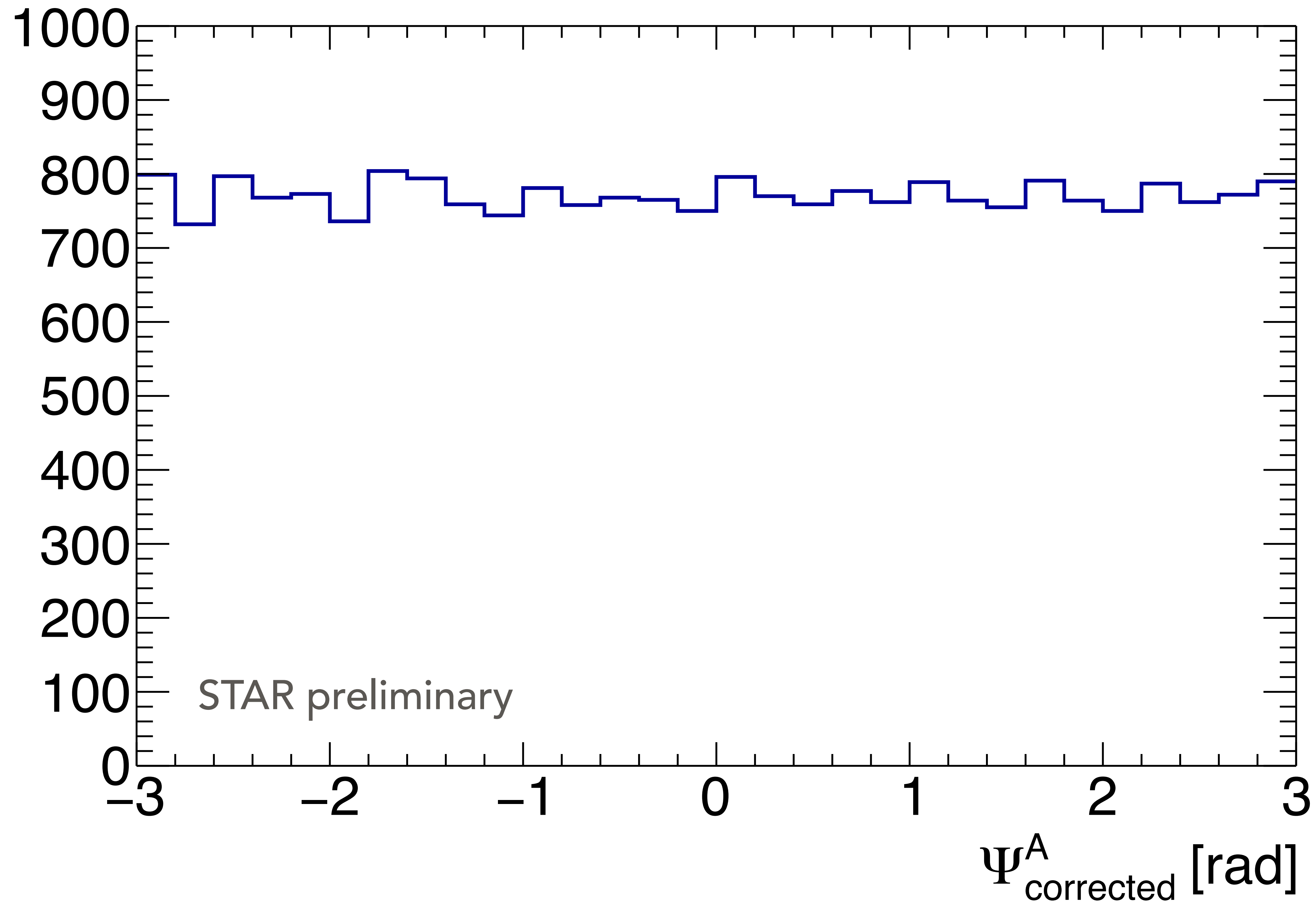
where Fourier coefficients $\nu_1, \ldots, \nu_2$ were obtained by fiting

$$f(\Psi) = A[1 + 2\nu_1 \cos(\Psi) + 2\nu_2 \sin(\Psi) + 2\nu_3 \cos(2\Psi) + 2\nu_4 \cos(2\Psi) + 2\nu_5 \cos(4\Psi) + 2\nu_6 \sin(4\Psi)]$$

to Ψ distribution

Event Plane Angle Correction:

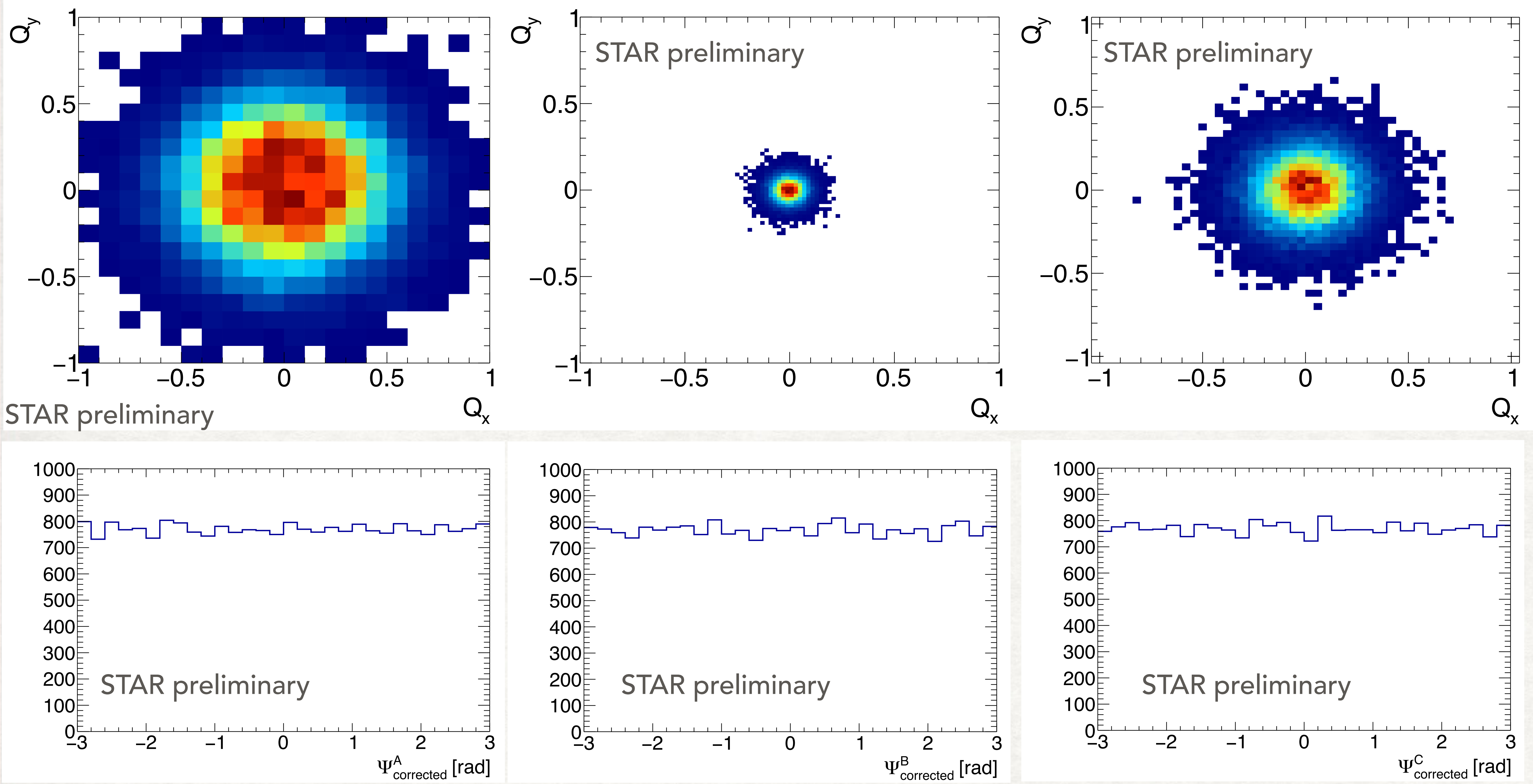
$$\Psi^{\text{corrected}} = \Psi + 2\nu_1 \sin(\Psi) - 2\nu_2 \cos(\Psi) + \nu_3 \sin(2\Psi) - \nu_4 \cos(2\Psi) + \frac{1}{2}\nu_5 \sin(4\Psi) - \frac{1}{2}\nu_6 \cos(4\Psi)$$

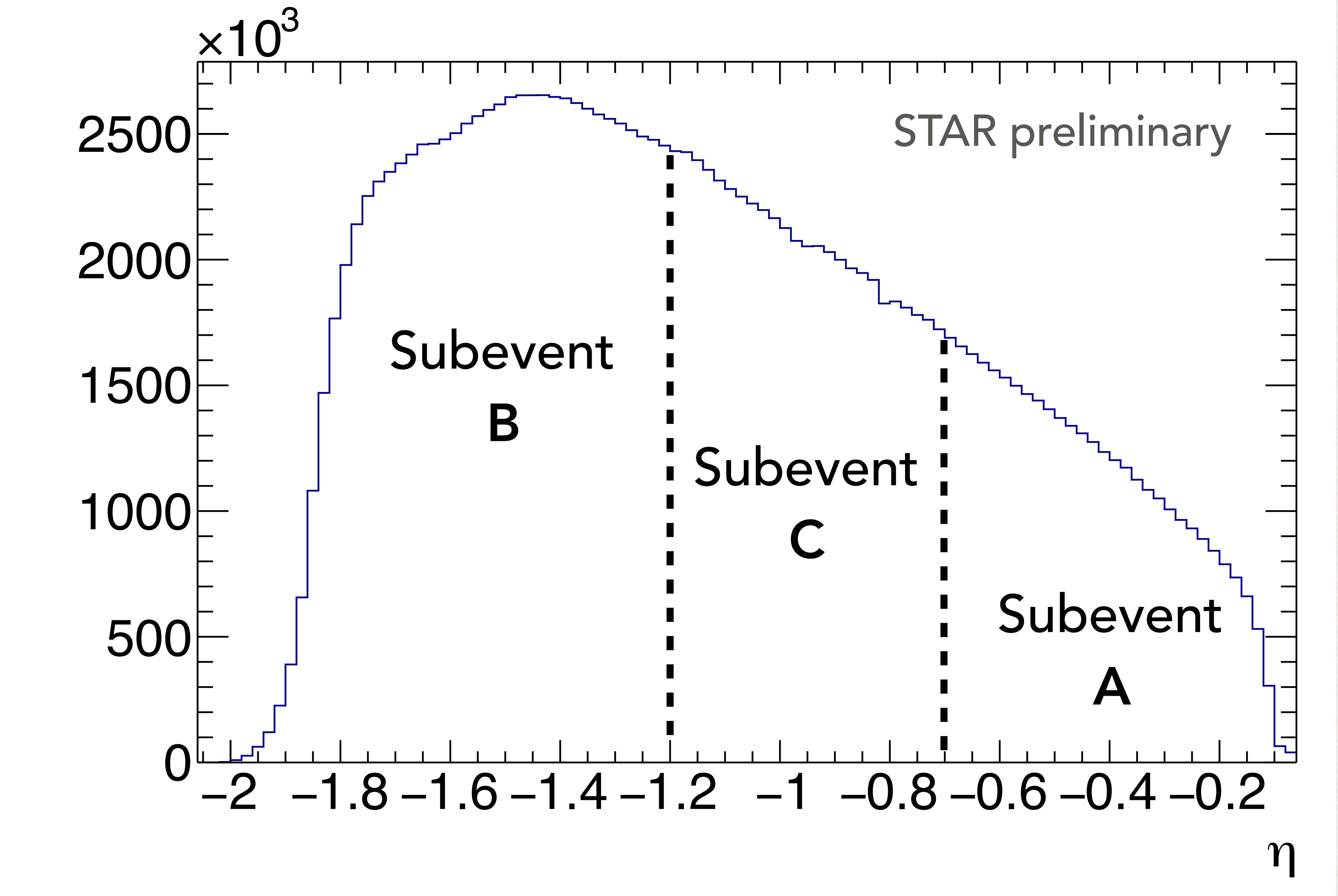


EVENT PLANE RESOLUTION

Minimum number of tracks for each subevent was 5

A **B** **C**





mid rapidity = −1.52

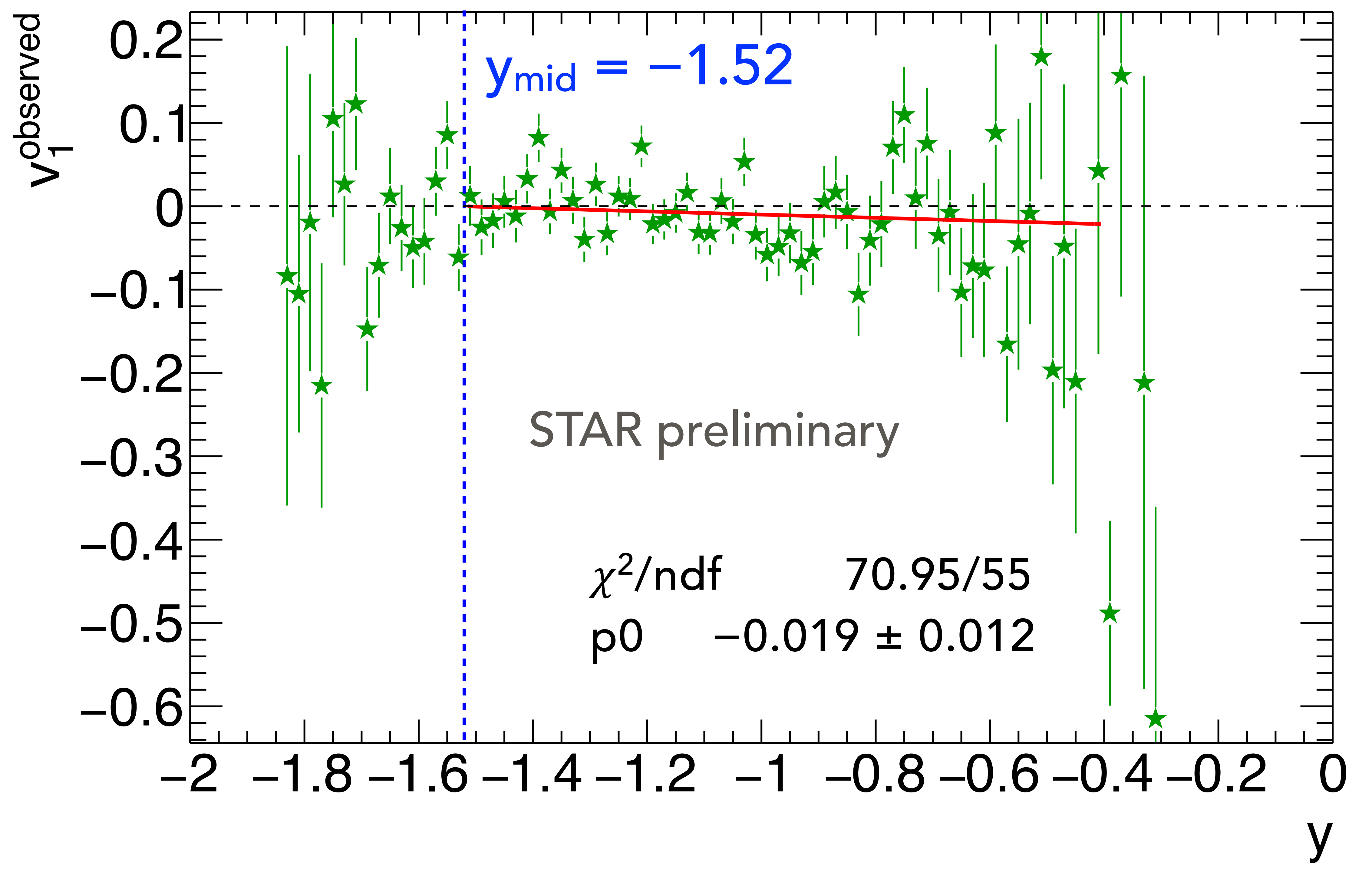
$$\langle\cos(\Psi^A - \Psi^R)\rangle = \sqrt{\frac{\langle\cos(\Psi^A - \Psi^B)\rangle\langle\cos(\Psi^A - \Psi^C)\rangle}{\langle\cos(\Psi^B - \Psi^C)\rangle}}$$

K^0_S(10-25%) Λ(0-30%) Λ(10-30%)

= 0.85 ± 0.03, 0.79 ± 0.02, 0.81 ± 0.03

K^0_S DIRECTED FLOW (10-25%)

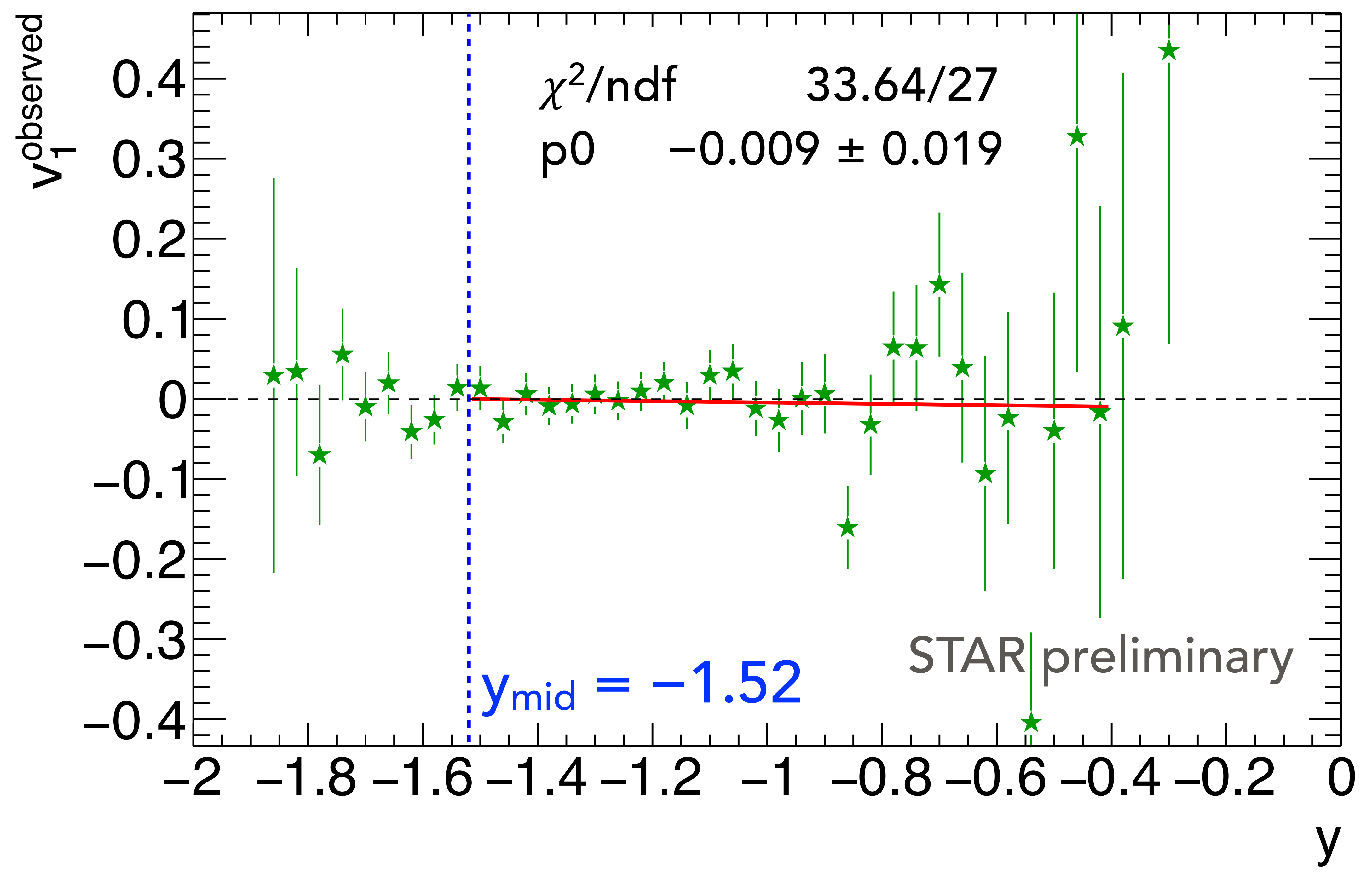
$v_1^{observed} = \langle \cos(\phi - \Psi^A_{corrected}) \rangle$ parametrization: $f(y) = p0(y + 1.52)$ - v_1 always 0 at y_{mid}



The result corrected on the event plane resolution:

−0.023 ± 0.018

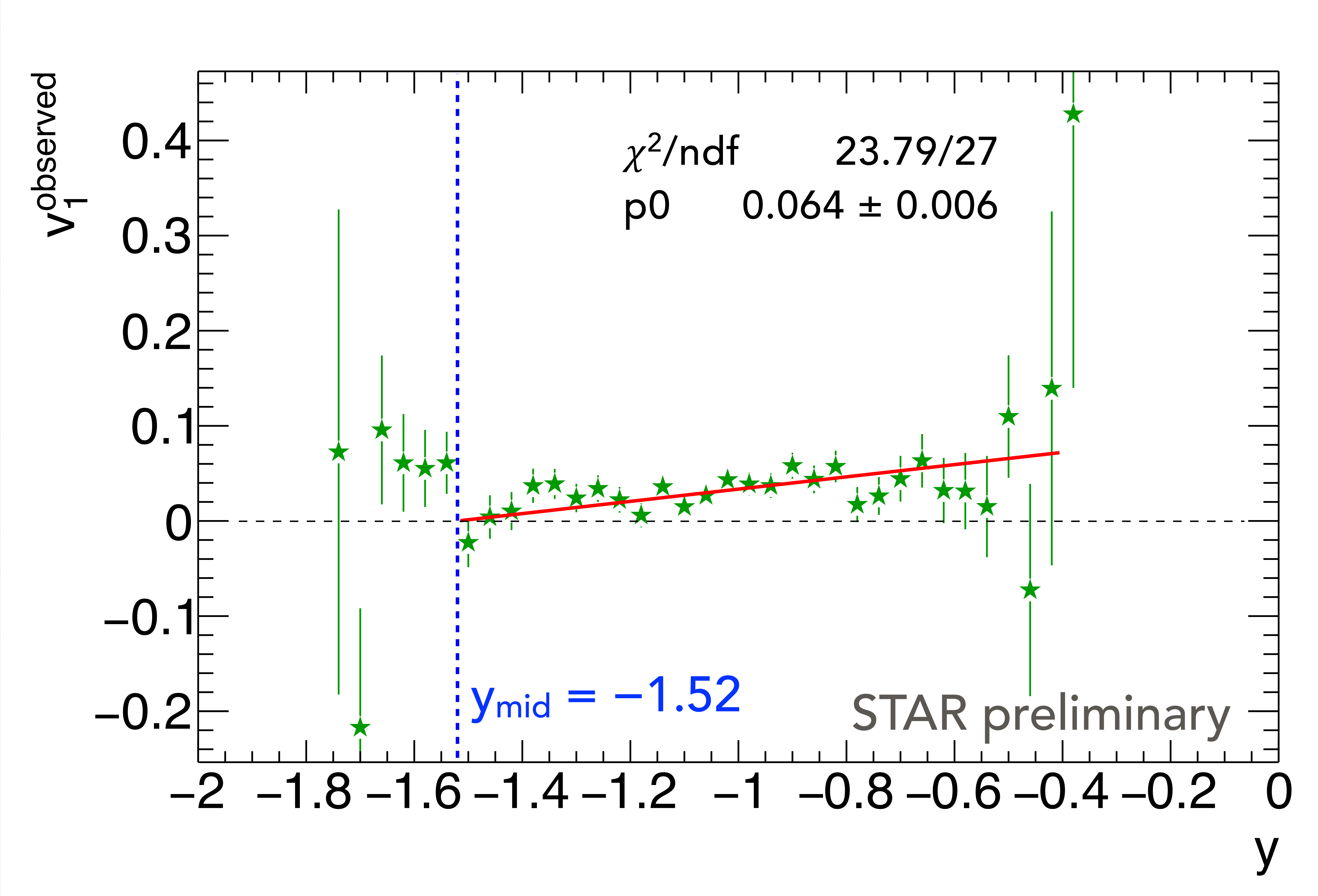
Flow of $\pi^+\pi^-$ pairs outside the K^0_S peak (side band)



- Suggests negative value, as expected
- Result of the fitting to side band is consistent to zero (−0.01±0.03 - corrected on EP resolution).

Λ DIRECTED FLOW (0-30%)

$v_1^{observed} = \langle \cos(\phi - \Psi^A_{corrected}) \rangle$ parametrization: $f(y) = p0(y + 1.52)$ - v_1 always 0 at y_{mid}



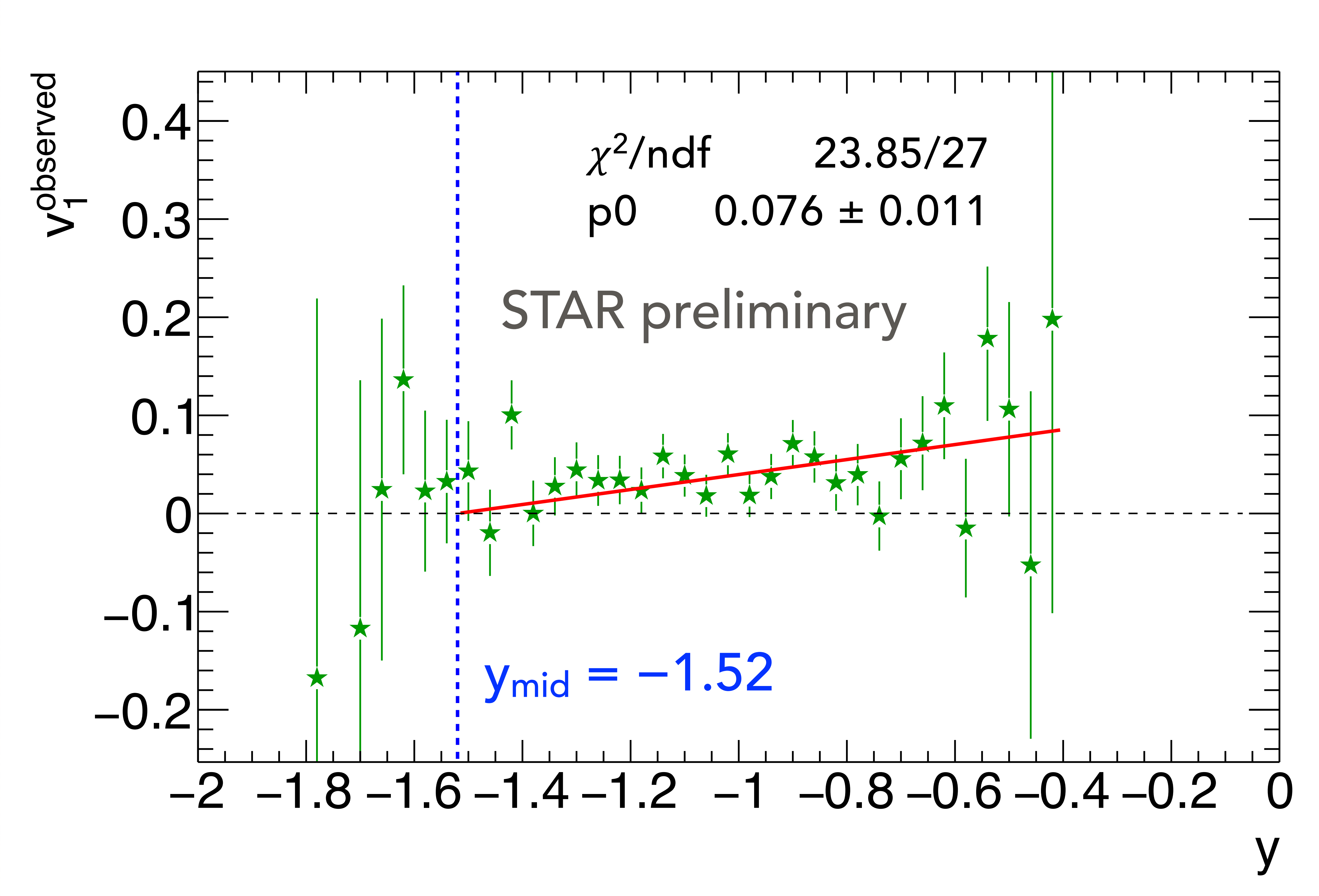
The result corrected on the event plane resolution:

0.082 ± 0.009

- Substantial positive flow

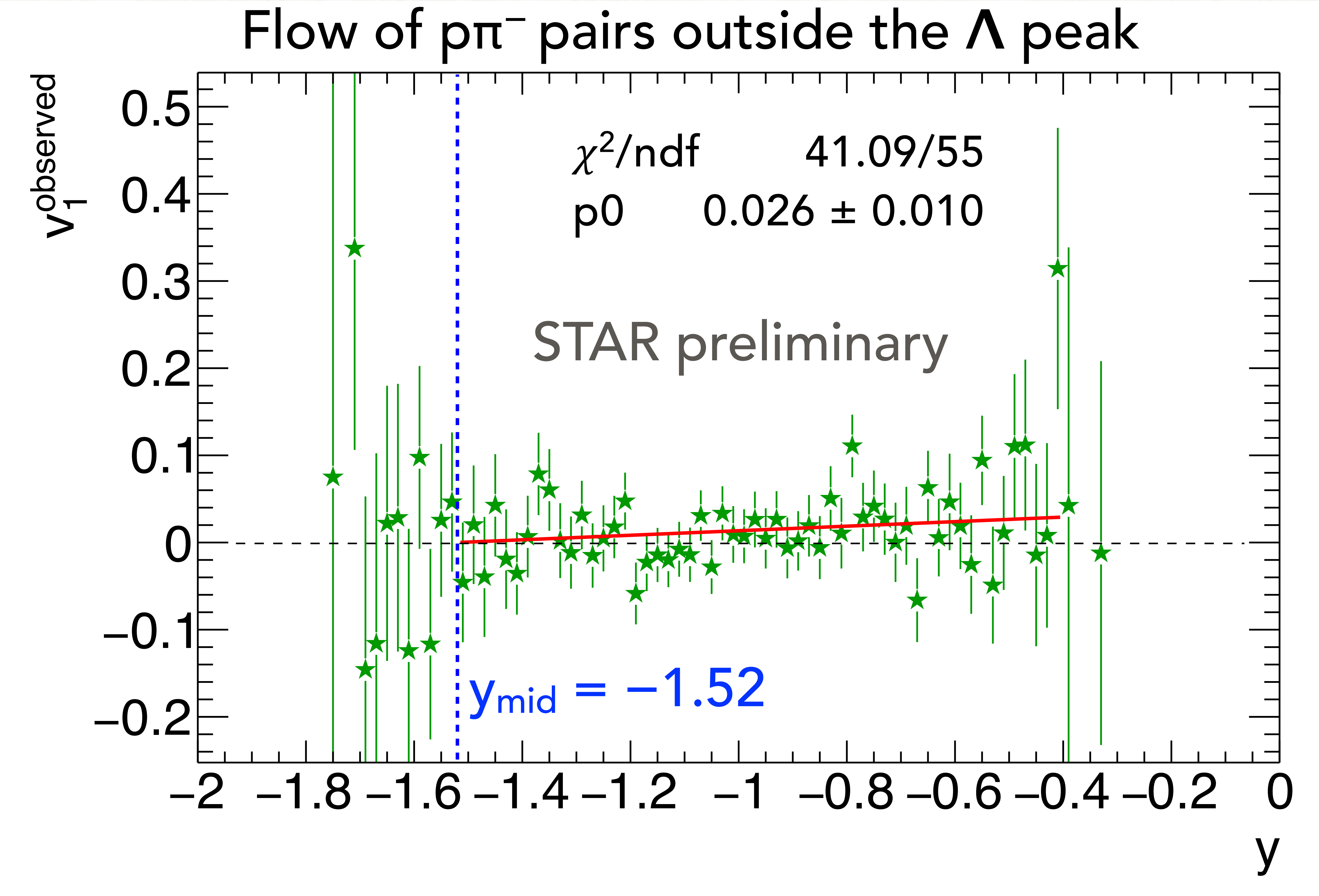
Λ DIRECTED FLOW(10-30%)

$v_1^{\text{observed}} = \langle \cos(\phi - \Psi^A_{\text{corrected}}) \rangle$ parametrization: f(y) = p0(y + 1.52) - v_1 always 0 at y_{mid}



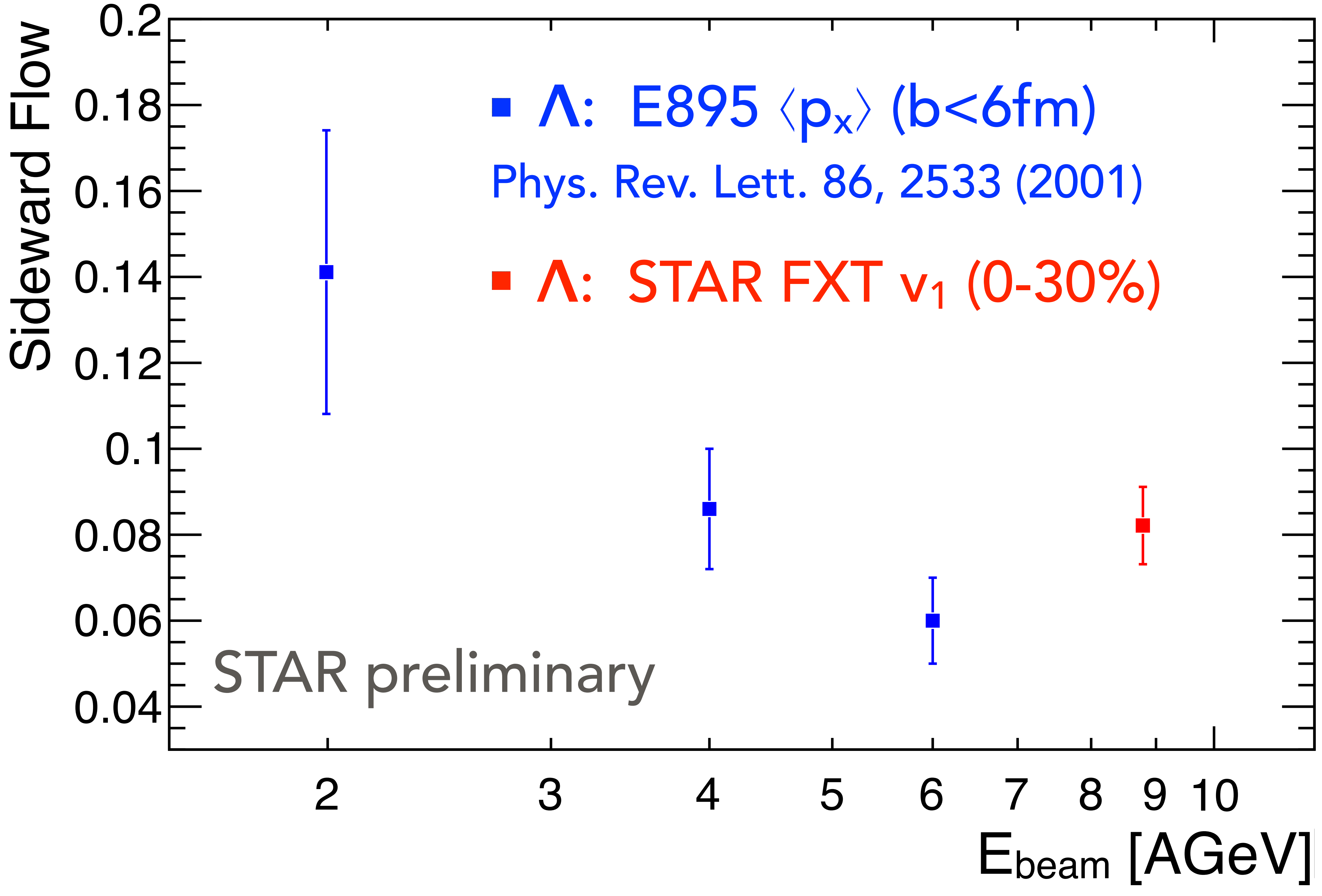
The result corrected on the event plane resolution:

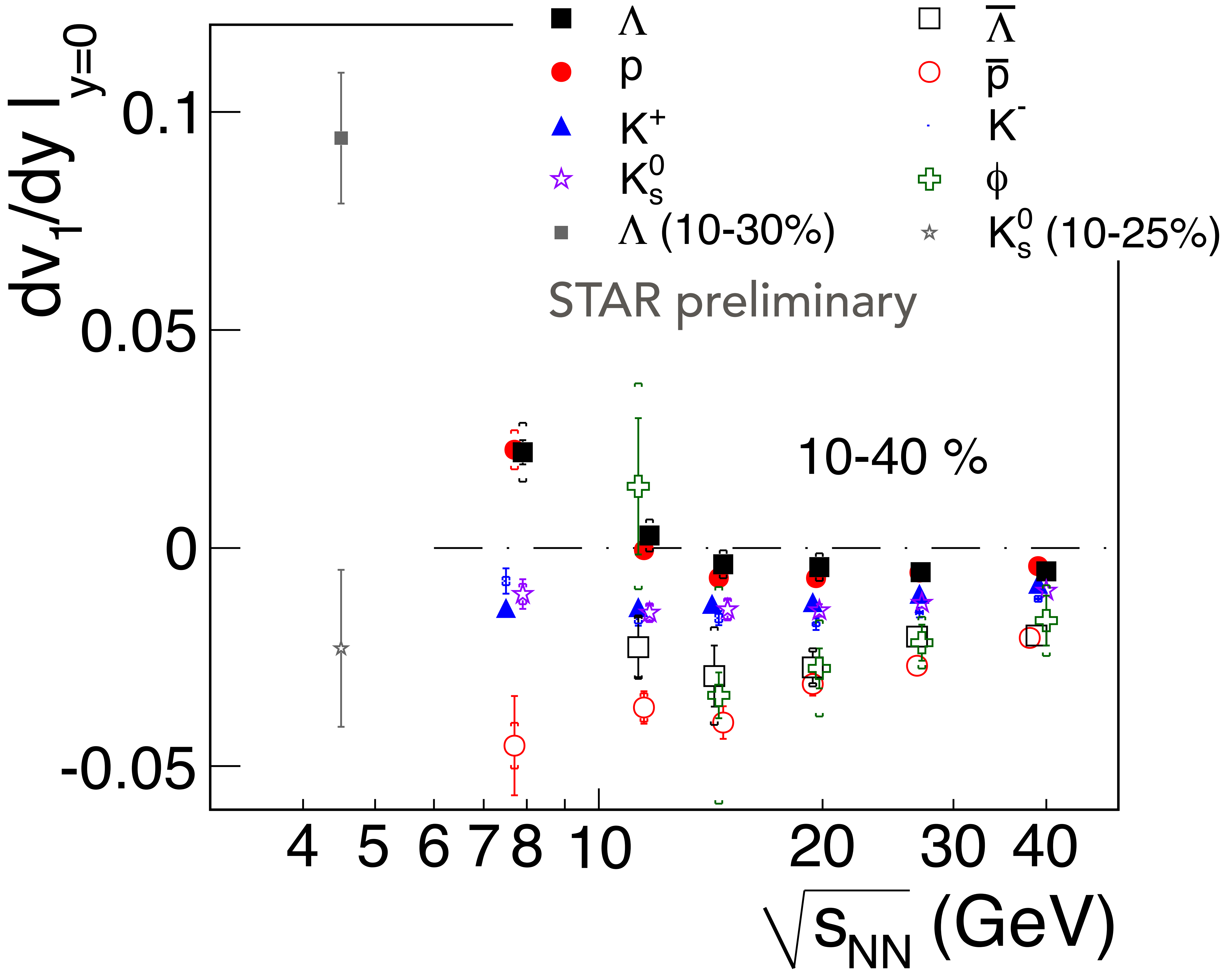
0.094 ± 0.015



- Results stable within statistical uncertainties
- Substantial positive flow
- Non-zero flow of $p\pi^-$ pairs outside the Λ peak

COMPARISON WITH E895 AND STAR BES-I

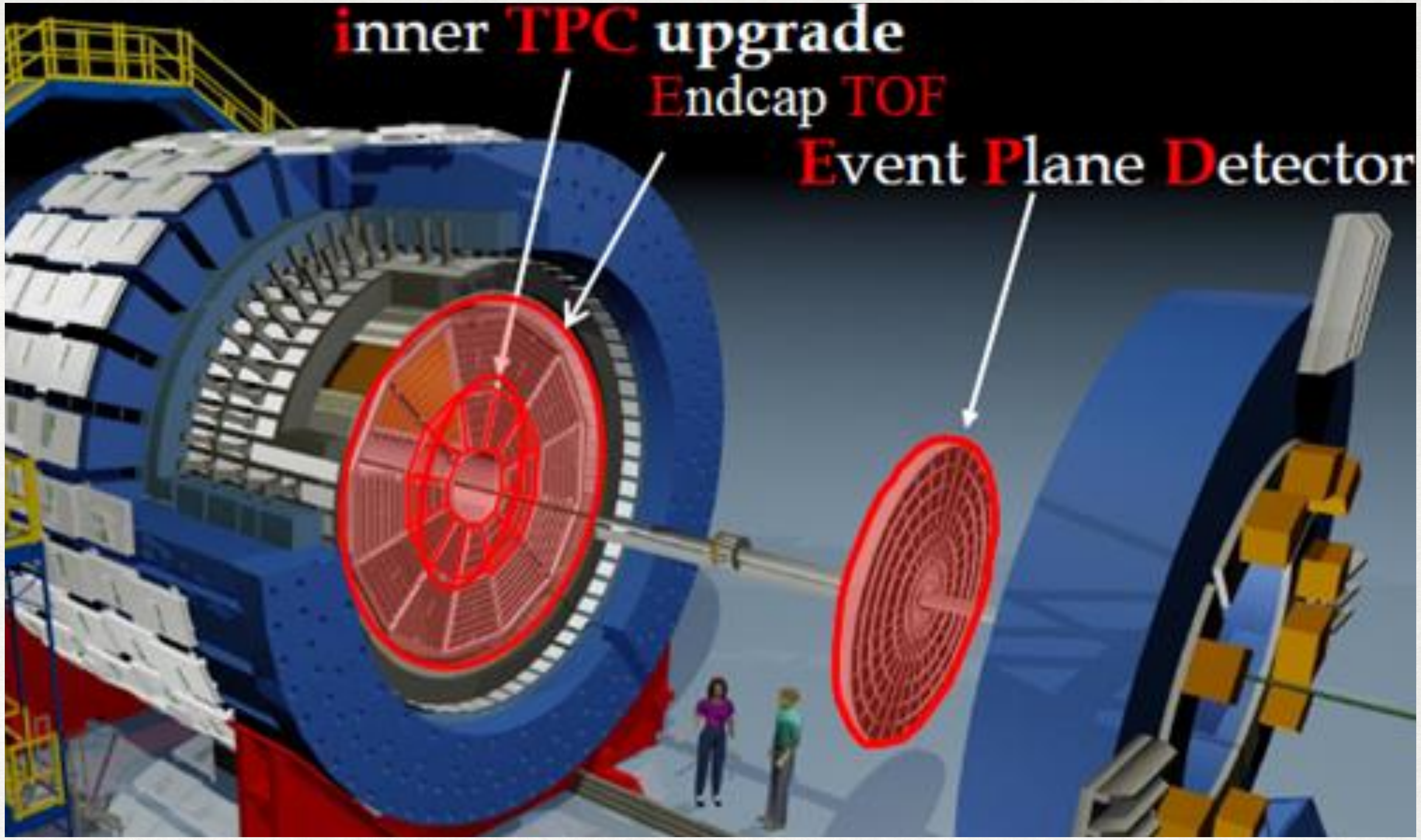




- v_1 of Both K^0_S and Λ follow the trend from the STAR Beam Energy Scan.
- v_1 of Λ does not follow the E895 trend, but the acceptance for the E895 data points are different from the STAR data and E895 shows ⟨p_x⟩ instead of v_1

FUTURE UPGRADES

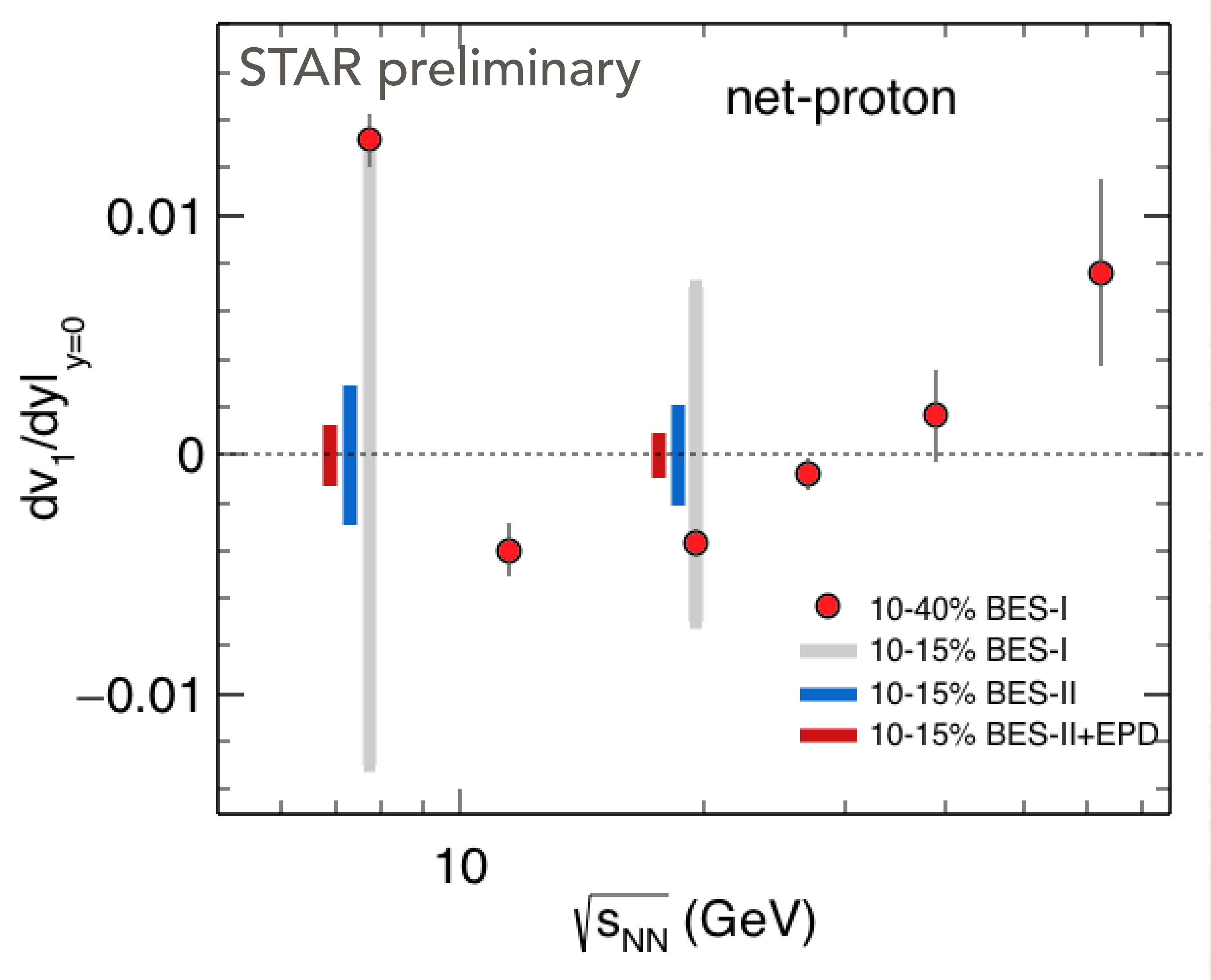
- Inner TPC (ITPC) upgrade
- Event Plane detector (EPD)
- Endcap TOF (ETOF)

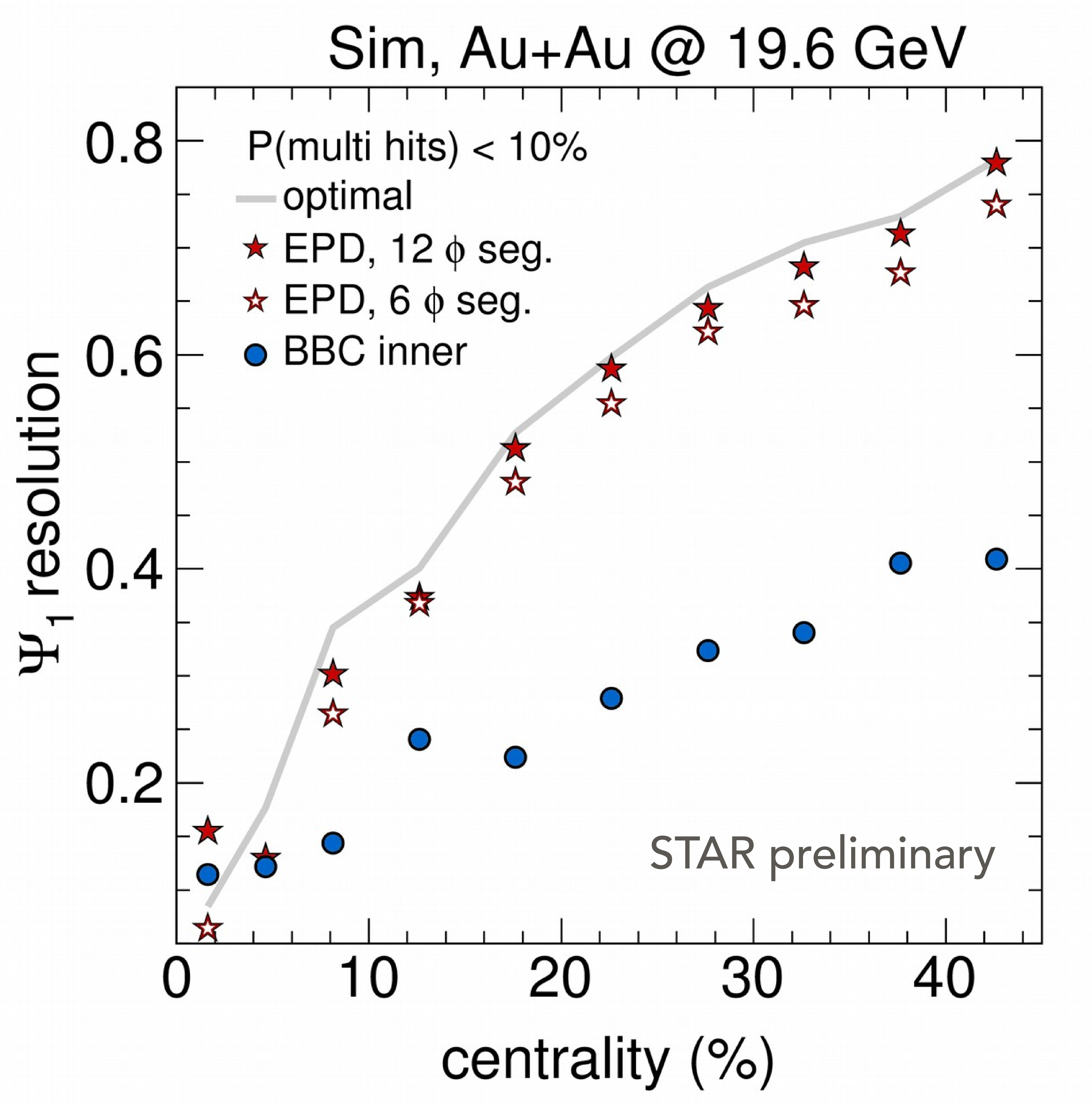


- Physics goals include looking for a 1st order phase transition (e.g. dv_1/dy...) and clarifying possible evidence for a critical point (eg. kurtosis...)
- Need 1-2 days of dedicated fixed target running at each energy to collect sufficient statistics (FXT program is capable to collect ~50M events per day)

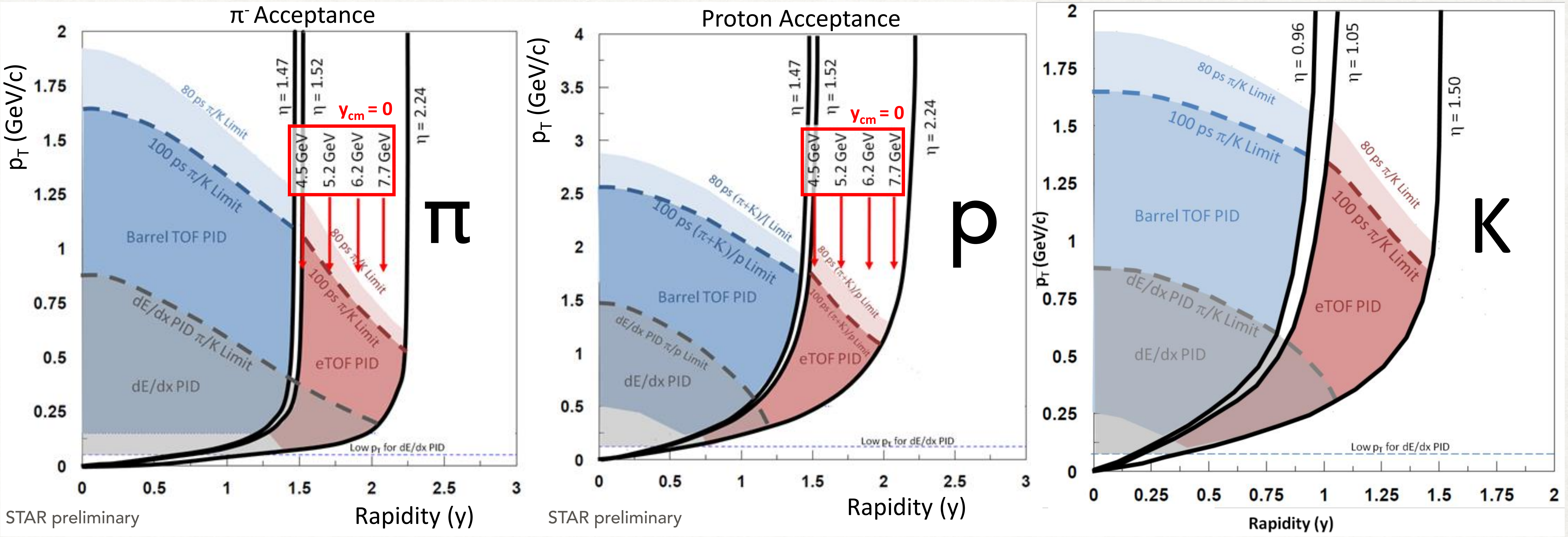
EVENT PLANE DETECTOR

- Large forward eta coverage 2.1<|η|< 5.1 compared to TPC (|η|<1.0),
- independent measurement of a reaction plane with great resolution
- improve centrality determination and flow harmonic measurements





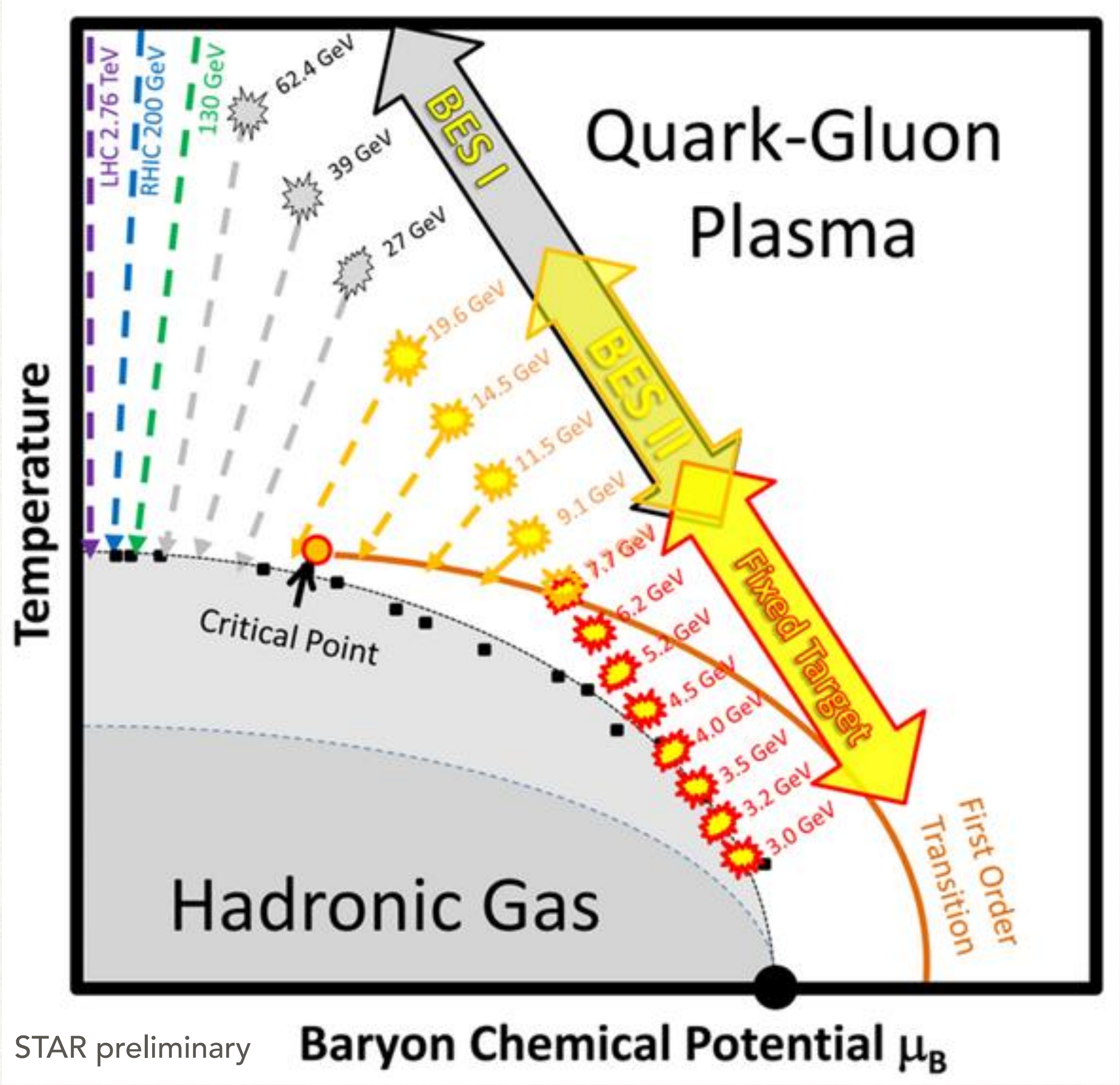
ETOF + ITPC IN FIXED TARGET



- Increased acceptance for tracking and PID allows the FXT program to extend its energy range to 7.7 GeV allowing comparisons with collider analyses.

SUMMARY

- STAR is a typical collider experiment but it can take data in the fixed target mode
- First directed flow v_1 results of 2015 STAR Fixed target test run were presented. v_1 of Both K^0_S and Λ follow the trend from the STAR Beam Energy Scan.
- The detector upgrades will allow to run in both collider and fixed target modes at $\sqrt{s_{NN}}$ = 7.7 GeV making a comparison with collider mode analyses at the same energy possible.
- The FXT program extends BES-II down to $\sqrt{s_{NN}}$ = 3.0 GeV
- The STAR Fixed Target will make significant contribution to the STAR Beam Energy Scan II program in 2019 and 2020
- Many more FXT results coming - see Kathryn Meehan's talk at Quark Matter 2017 (Wednesday, 2:20pm)



THANK YOU

BACKUP SLIDES

FIT PARAMETERS FROM VARIOUS FIT RANGES

K^0S (10-25%)

Fit region	parameter	Value	Error
−1.52 - −1.0	p0	0.001	0.017
−1.52 - −0.8	p0	−0.025	0.013
−1.52 - −0.6	p0	−0.018	0.012
−1.52 - −0.4	p0	−0.019	0.011

Λ (0-30%)

Fit region	parameter	Value	Error
−1.52 - −1.0	p0	0.073	0.011
−1.52 - −0.8	p0	0.074	0.008
−1.52 - −0.6	p0	0.066	0.007
−1.52 - −0.4	p0	0.064	0.006

Λ (10-30%)

Fit region	parameter	Value	Error
−1.52 - −1.0	p0	0.104	0.021
−1.52 - −0.8	p0	0.085	0.014
−1.52 - −0.6	p0	0.077	0.012
−1.52 - −0.4	p0	0.076	0.011