

First look at $\phi(1020)$ meson flow *and other strange updates...*

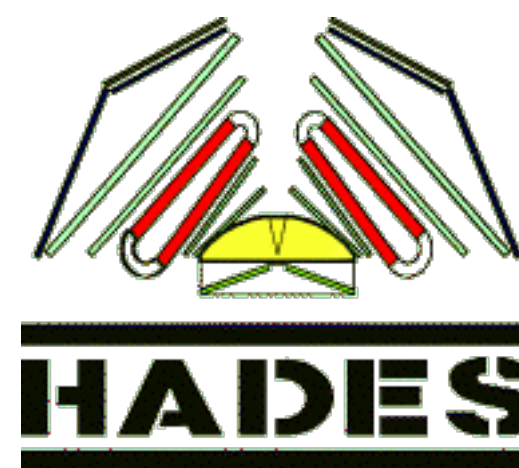
Jan Orlinski

VIII HADES Analysis Meeting
22-24 June 2026 · Darmstadt



NATIONAL SCIENCE CENTRE
POLAND

This work is part of a project co-financed by the N.S.C.
under reference number 2024/53/N/ST2/02107



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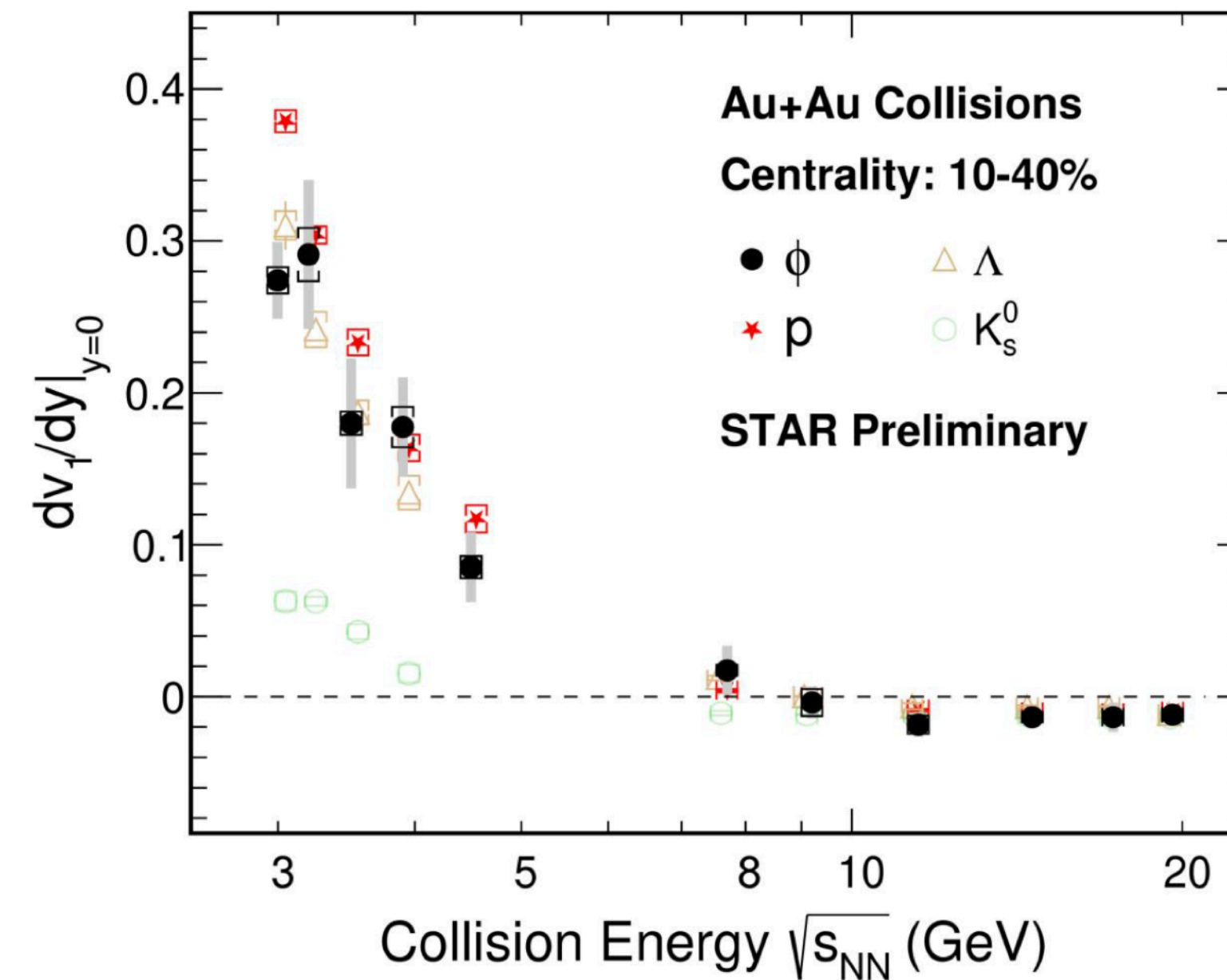
First look at ϕ flow

Introduction

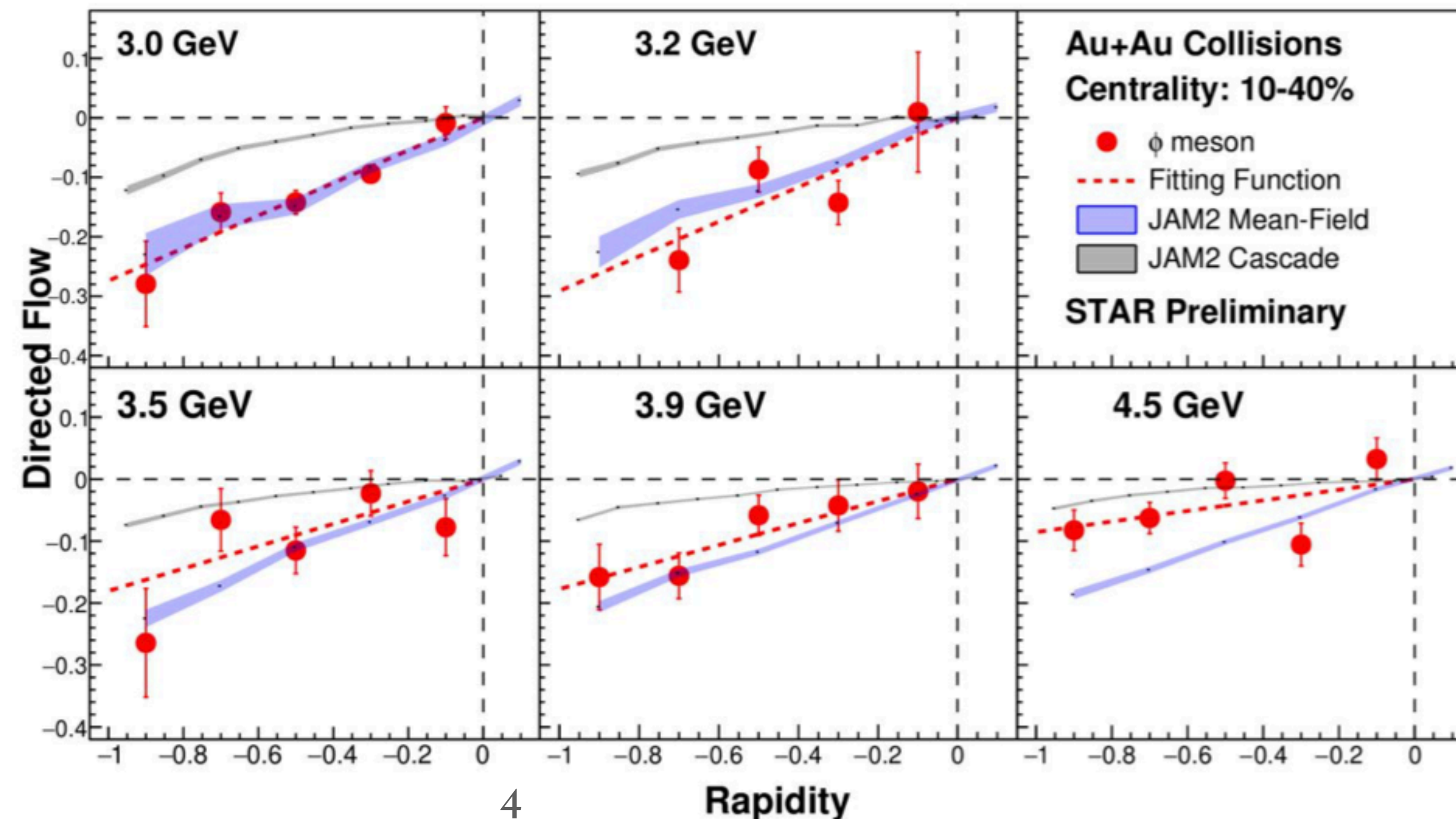
1. Re-analysis of ϕ meson anisotropic flow (previous attempt by Leon Skorpil)
2. No significant ϕ flow was found then (upper limit of $\sim |v_1| < 0.1$)
3. This is in contract with data from STAR's BES II, which suggests very strong (comparable to Λ and p) directed flow for the ϕ
4. Is this a rabbit worth chasing ... ?

Indications from STAR BES II

- ▶ The STAR Collaboration sees a strong directed flow of ϕ mesons
- ▶ Directed flow slope **increases** at low energies, indicating a strong effect for HADES
- ▶ Statistics of ϕ production (deep sub-threshold) are very much against us
- ▶ If we expect directed flow of about ± 0.2 , then the $\sim 10k$ sample of ϕ **should be enough!**



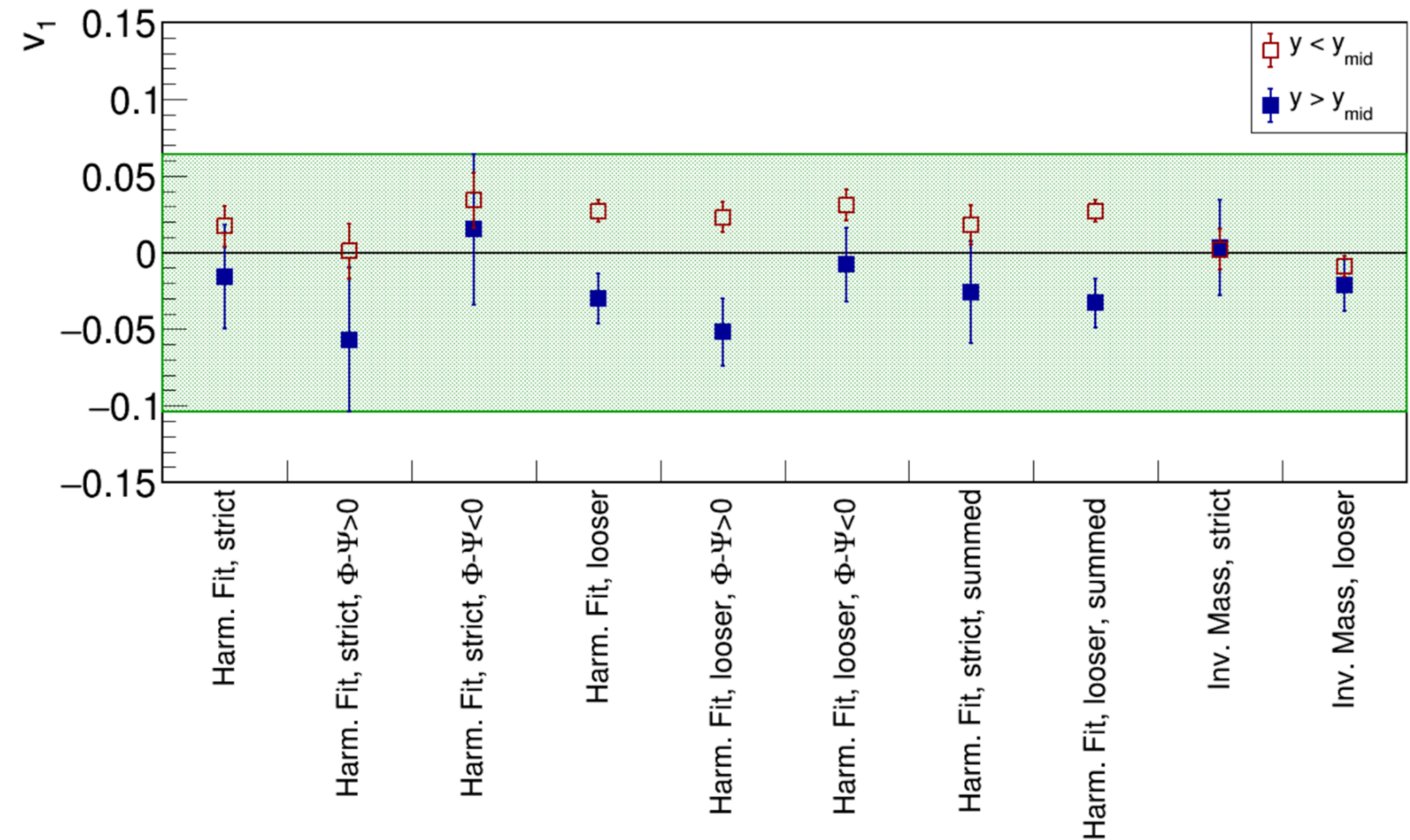
Guangyu Zheng (STAR), "Measurement of ϕ meson directed flow in $\sqrt{s}=3-19.6$ GeV Au+Au collisions from RHIC-STAR", Poster at QM 2025



- v_1 extraction range
 $0.6 < p_T < 1.8$ GeV/c for 3-4.5 GeV.
 $0.15 < p_T < 10$ GeV/c for 7.7-19.6 GeV.
- Fitting function for v_1 slope
Linear for 3- 4.5 GeV
 $v_1(y) = F * y$

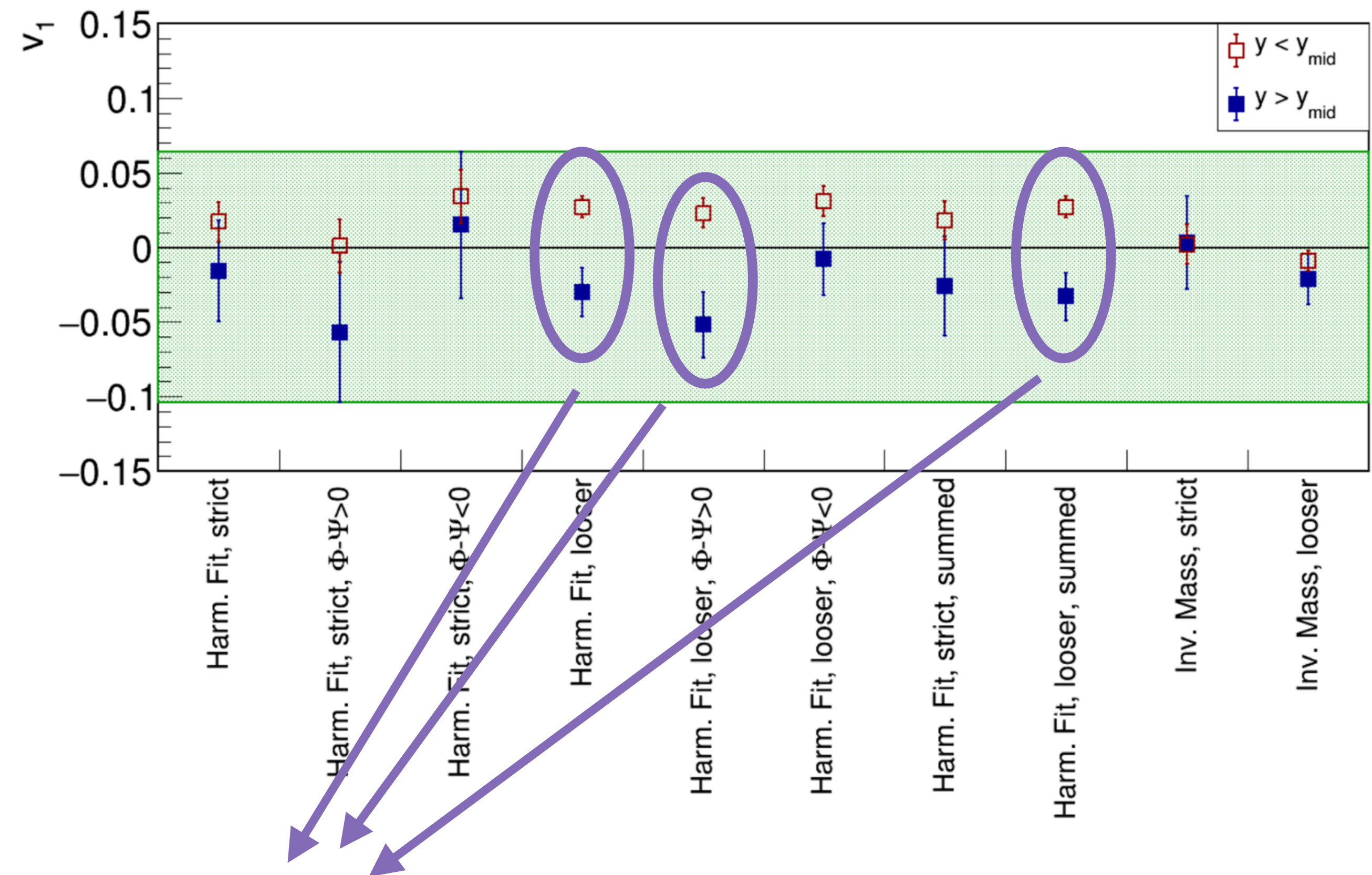
Status of analysis by Leon Skorpil (MSc thesis October 2024)

- ▶ Leon concluded that no significant anisotropic flow of ϕ meson is seen
- ▶ Instead, he estimated limits on v_1 and v_2 for this particle species
- ▶ In particular, it is found that $-0.10 \leq v_1 \leq 0.05$
- ▶ **This is in stark disagreement with observations from STAR at $\sqrt{s} = 3.0$ GeV!**



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Some methods indicate a non-zero, rapidity-symmetric directed flow!

ϕ signal reconstruction

Event & track selection

```
//----- Event selection -----
if(!evtInfo->isGoodEvent(Particle::kGoodTRIGGER) ) return kSkipEvent;
hEventCounter->Fill(cisTriggerPT3);
if(!evtInfo->isGoodEvent(Particle::kGoodSTART)) return kSkipEvent;
hEventCounter->Fill(cselectStart);
if(!evtInfo->isGoodEvent(Particle::kNoPileUpSTART)) return kSkipEvent;
hEventCounter->Fill(cselectStartPile);
if(!evtInfo->isGoodEvent(Particle::kGoodVertexClust)) return kSkipEvent;
hEventCounter->Fill(cisGoodClusterVertex);
if(!evtInfo->isGoodEvent(Particle::kGoodVertexCand)) return kSkipEvent;
hEventCounter->Fill(cisGoodVertexCand);
if(!evtInfo->isGoodEvent(Particle::kNoVETO)) return kSkipEvent;
hEventCounter->Fill(cisVeto);
if(!evtInfo->isGoodEvent(Particle::kGoodSTARTVETO)) return kSkipEvent;
hEventCounter->Fill(cisStartVeto);
if(!evtInfo->isGoodEvent(Particle::kGoodSTARTMETA)) return kSkipEvent;
hEventCounter->Fill(cisStartMeta);
```

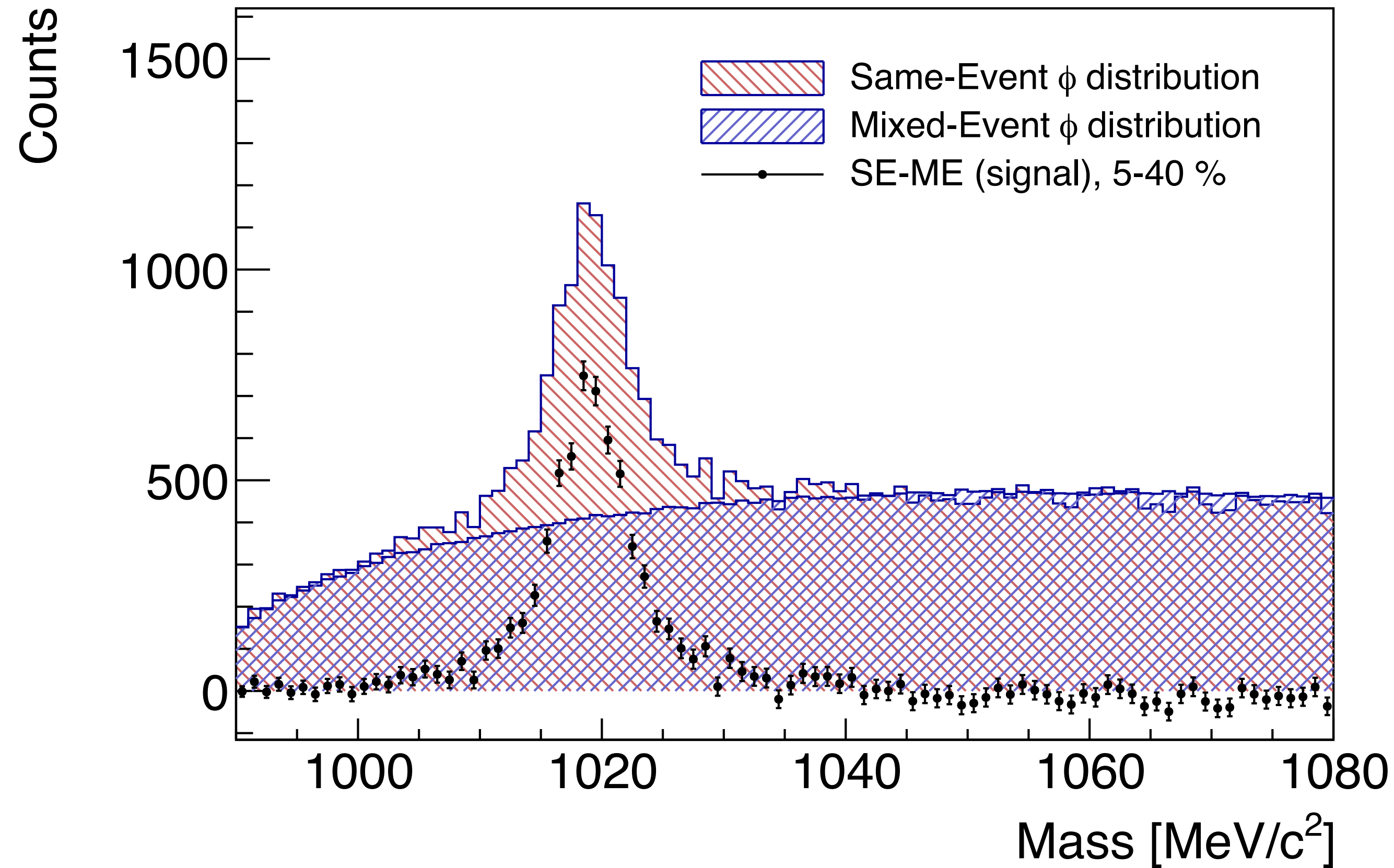
centrality 10 – 40 %

vertZ in [–64.0; – 10.0] mm

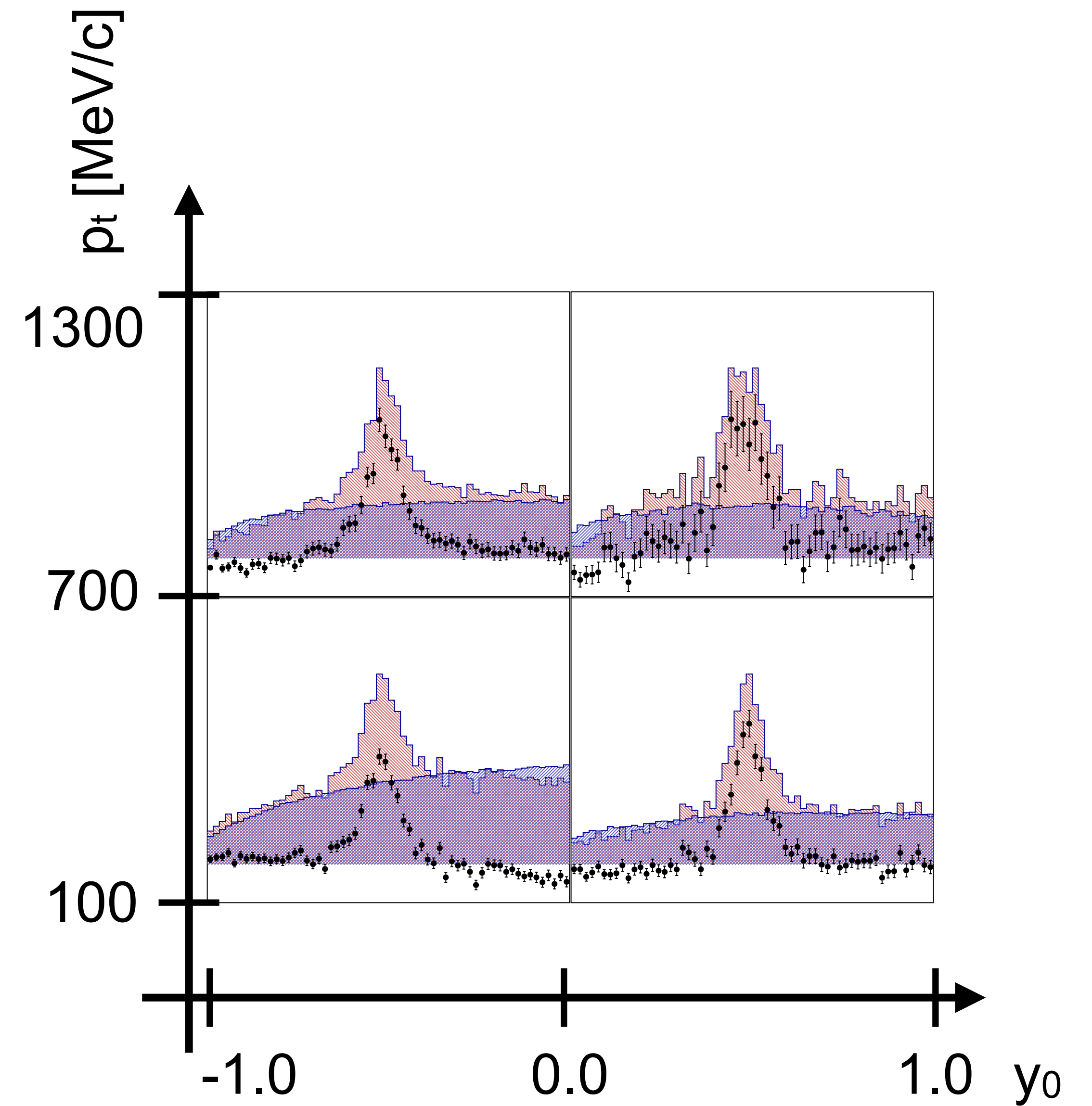
correct EP determination

	K plus	K minus	SE phi	ME phi	RA phi
<i>Charge</i>	+ 1	-1	-	-	-
<i>Mass</i>	460 - 540 [MeV/c ²]		-	-	-
<i>Momentum</i>	150-900 [MeV/c]		-	-	-
<i>Δ theta</i>	-	-	< 1.0 deg	< 1.0 deg	< 1.0 deg
<i>Δ phi</i>	-	-	< 3.0 deg	< 3.0 deg	< 3.0 deg
<i>distVpart1</i>	-	-	< 10	-	< 10
<i>distVpart2</i>	-	-	< 10	-	< 10
<i>distV-V</i>	-	-	< 10	-	< 10

5-40% signal



$6630 \pm 154 \phi$ mesons in this centrality class



Comparison to Marvin Kohls & Leon Skorpil

Criterion	K^+	K^-
Charge	+1	-1
Mass Window [MeV/c ²]	430 < M < 540	
Lower Momentum Cut [MeV/c]	150	
RPC Region Upper Momentum Cut [MeV/c]	800	
TOF Region Upper Momentum Cut [MeV/c]	1000	800
Sectors	1-6	
χ_{MM}^2	< 3	
χ_{RK}^2	< 200	
TOF dE/dx	yes	
MDC dE/dx	no	

	Parameter Set 1	Parameter Set 2
χ_{RK}^2	<130	<200
MetaQA	<2.5	<3
p_{K^-}	800 MeV	1000 MeV
p_{K^-RPC}	1000 MeV	1000 MeV
p_{K^+TOF}	800 MeV	1000 MeV
α	5-70°	5-85°
VerDist X	10 mm	20 mm
VerDist A,B	10 mm	15 mm
TOF dEdX Cut	Yes	No

Centrality 10-30%

Table 4.3.: Summary of the selection criteria applied onto the K^\pm daughter particle candidates.

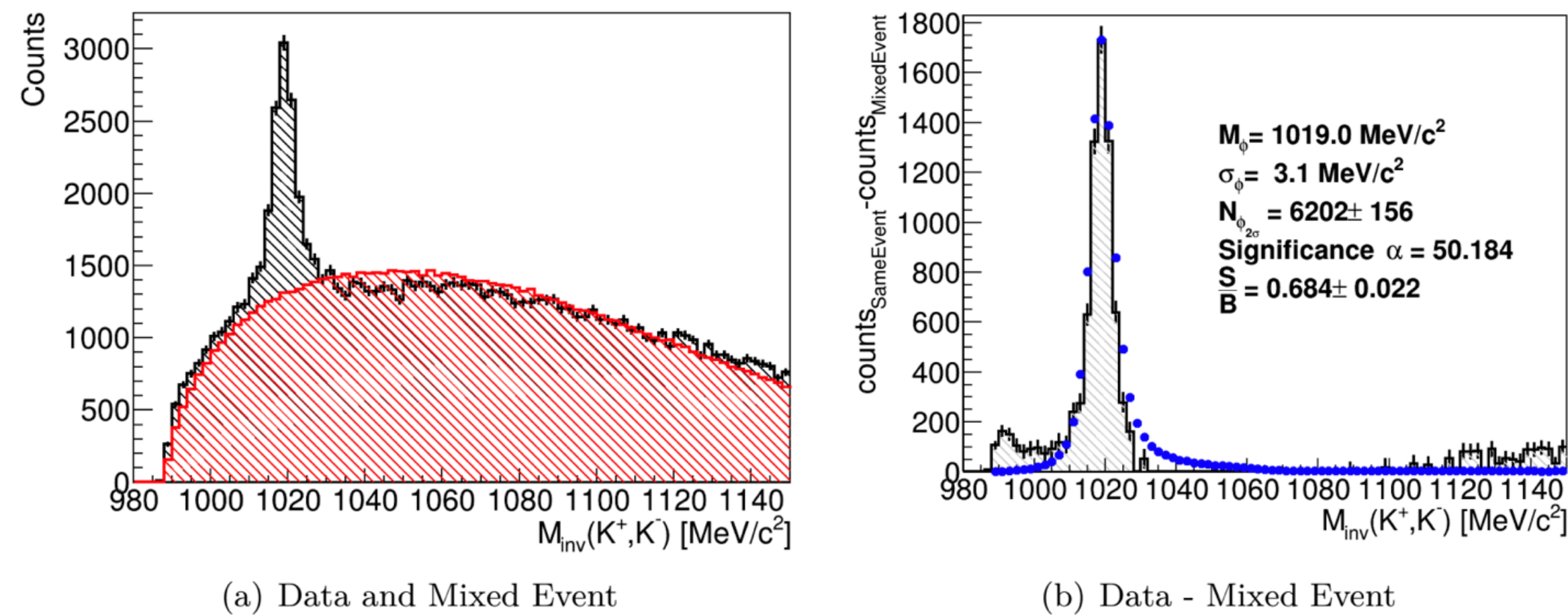
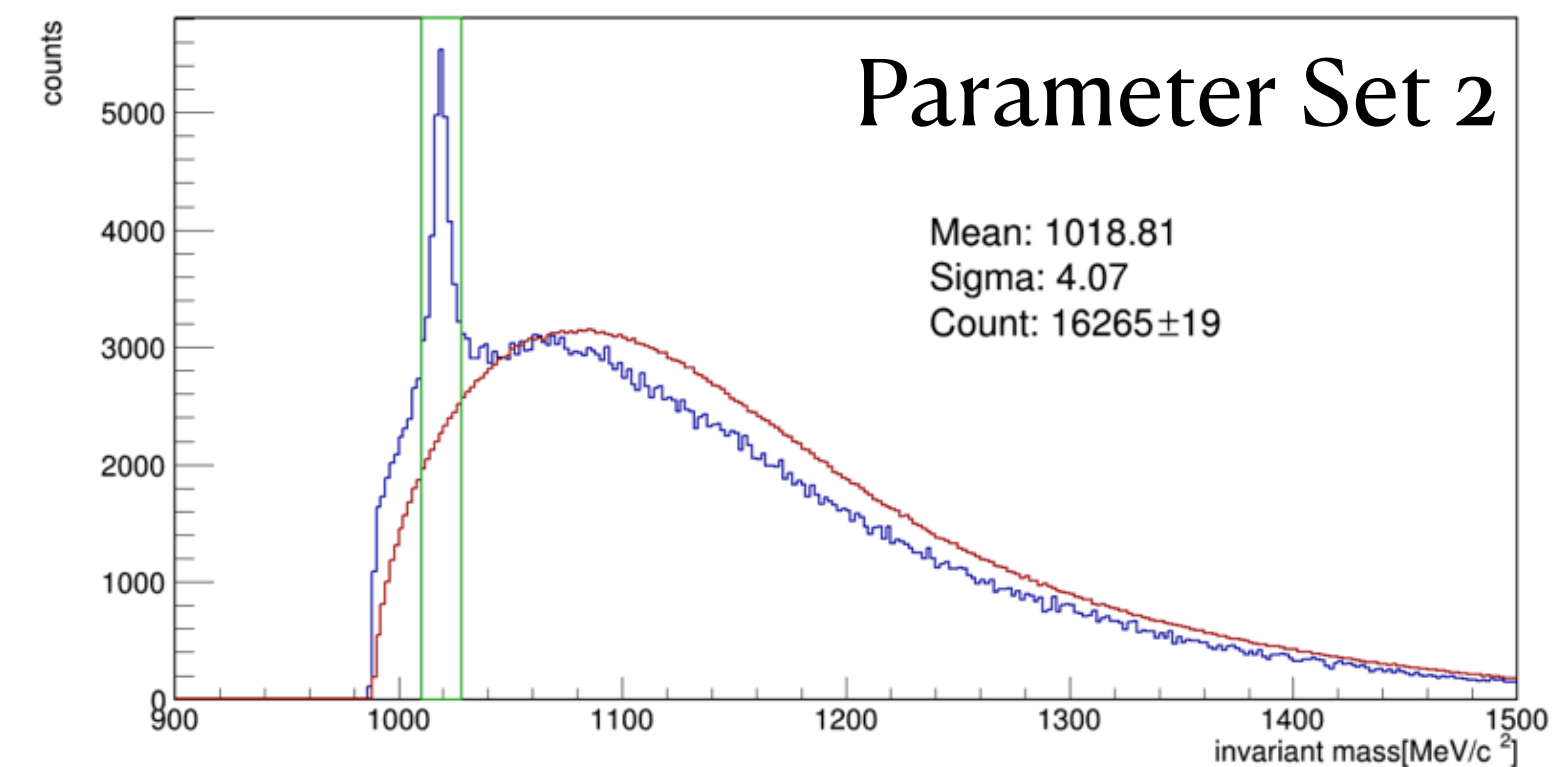
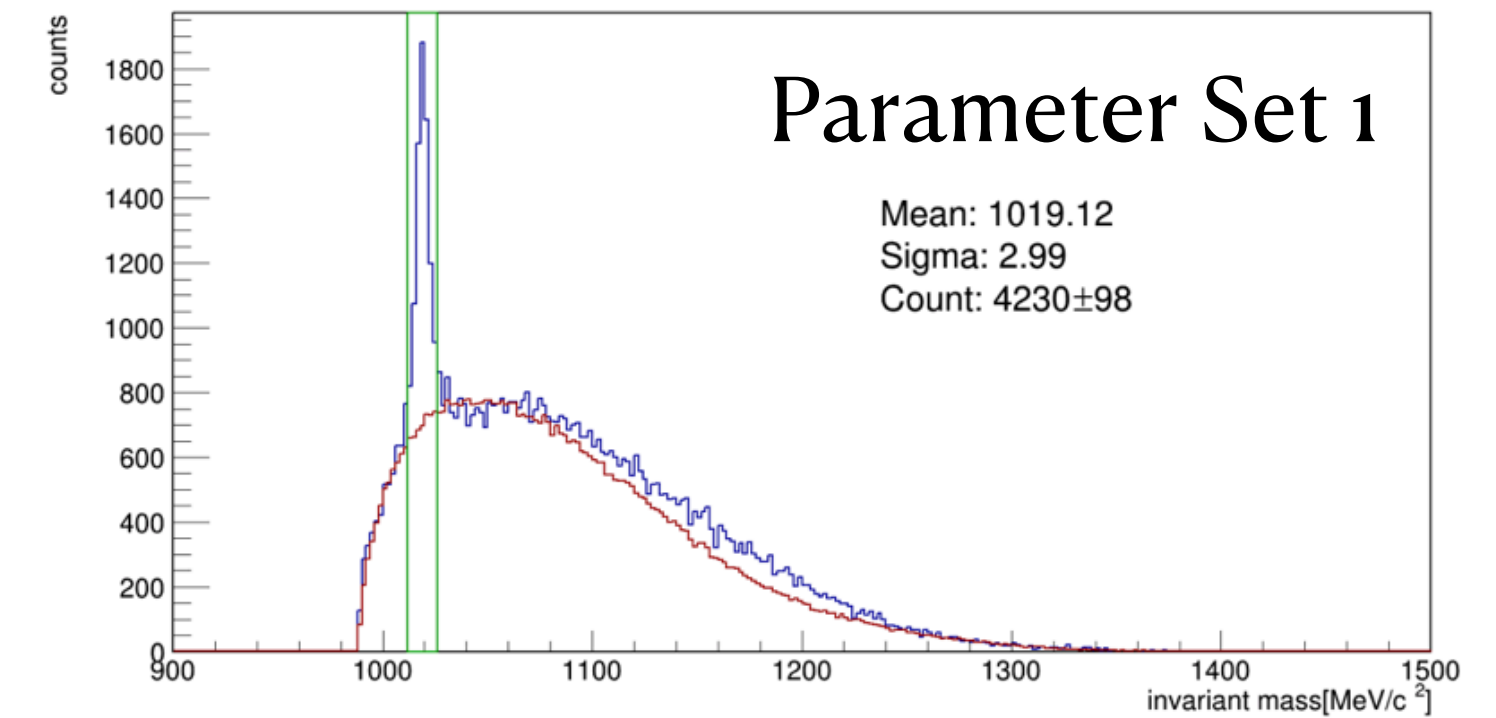


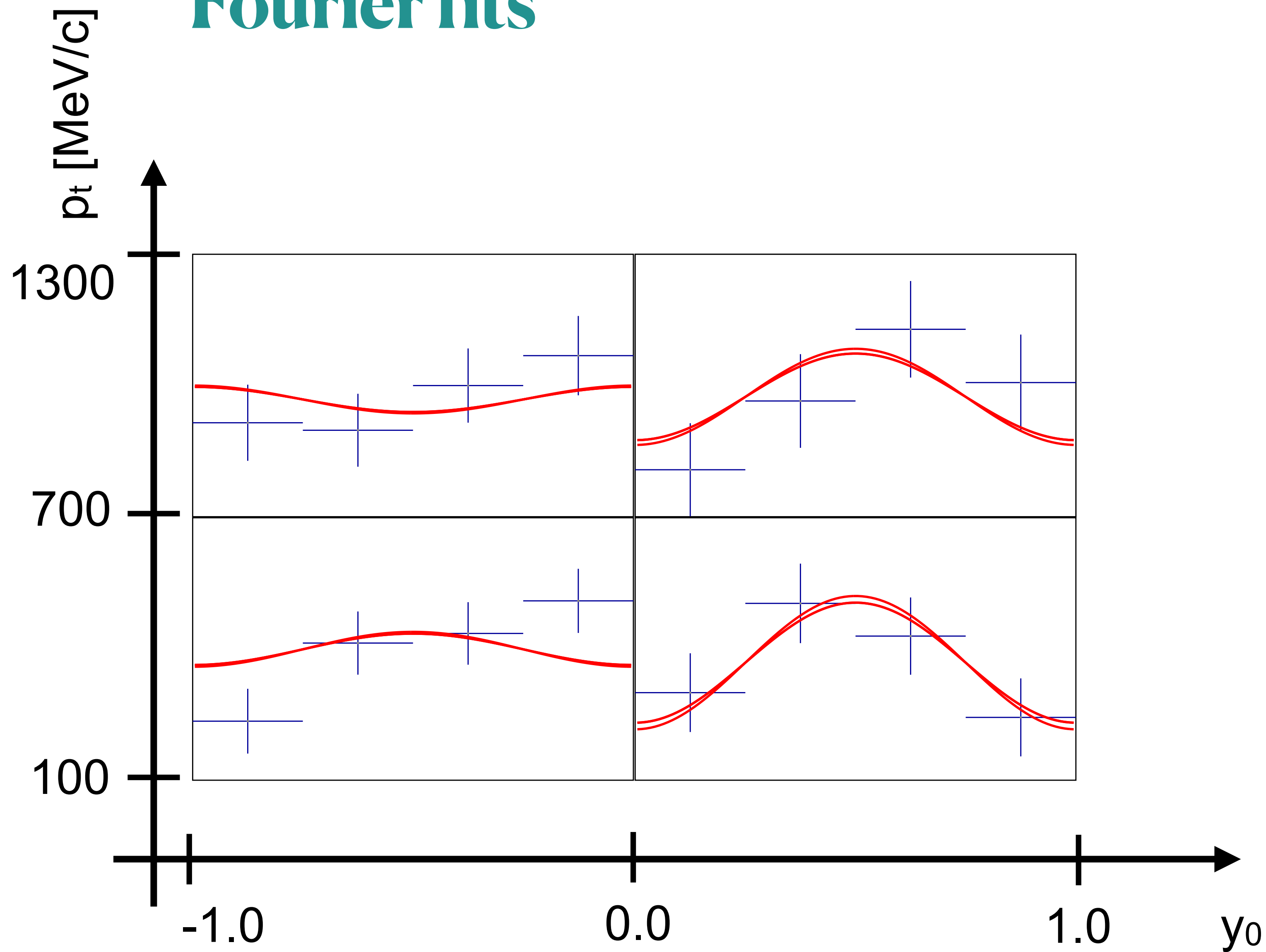
Figure 4.44.: Invariant mass distribution for all accepted $\phi \rightarrow K^+K^-$ candidates for 0 – 30% most central events plotted against the corresponding normalised mixed event distribution (a) as well as the final subtracted spectrum (b). The blue distribution in (b) corresponds to the signal obtained from the simulation.



- Vertex Distance X < 10 mm
- Vertex Distance A/B < 10 mm

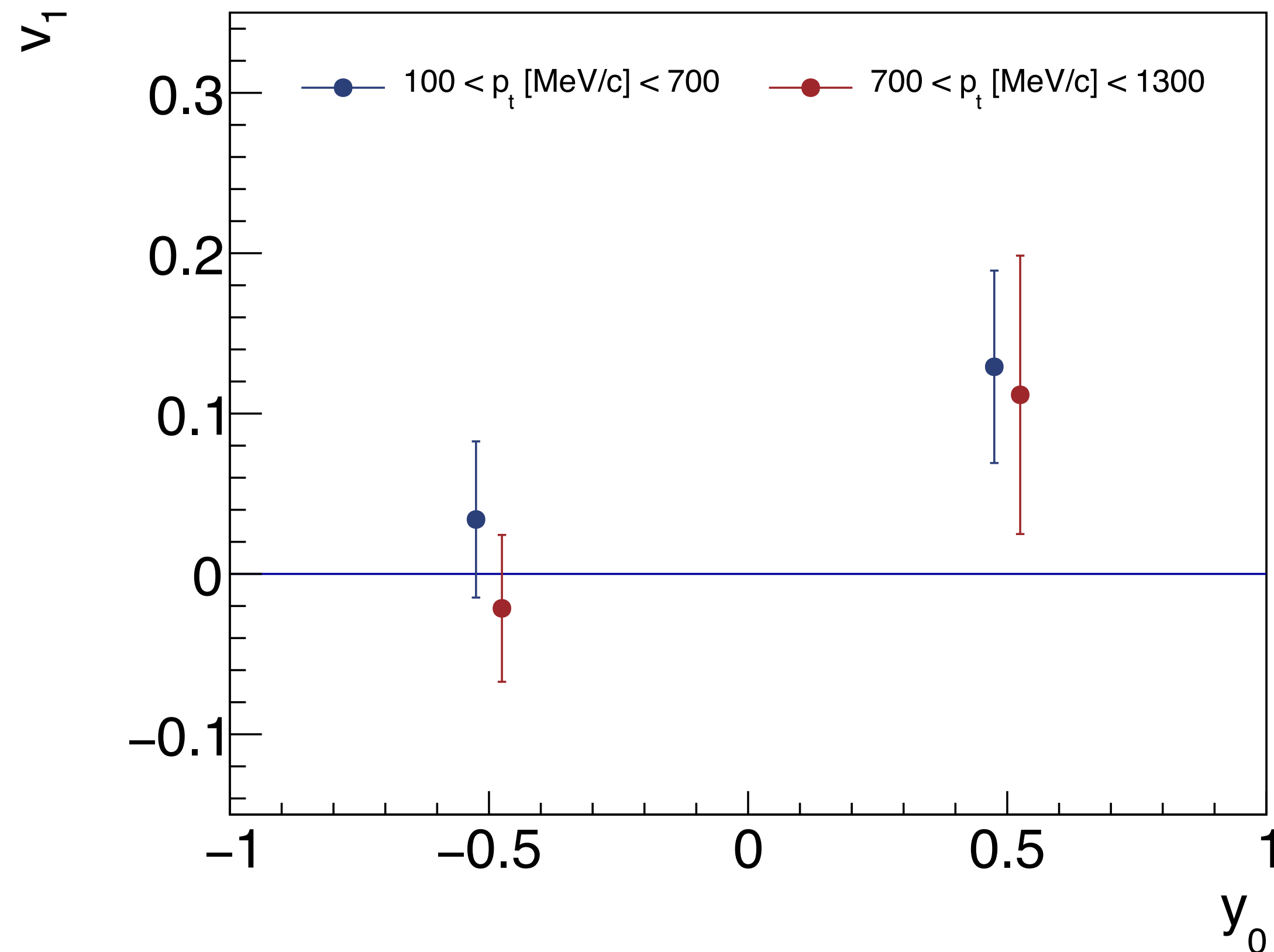
Fourier analysis

Fourier fits



- ▶ The statistics are very small, but allow some simple flow analysis
- ▶ Only 4 $\Delta\phi$ bins
- ▶ Only directed flow
- ▶ The $\Delta\phi$ histograms quality is heavily affected by background estimation
- ▶ To extract flow, the background subtraction needs to be tuned

"Differential" flow



- ▶ With enough care, a non-zero, statistically significant v_1 could be extracted for the ϕ meson
- ▶ Perhaps a value for $\frac{dv_1}{dy}$ could be estimated
- ▶ **Is it worth the effort?**

Update on the Λ flow analysis

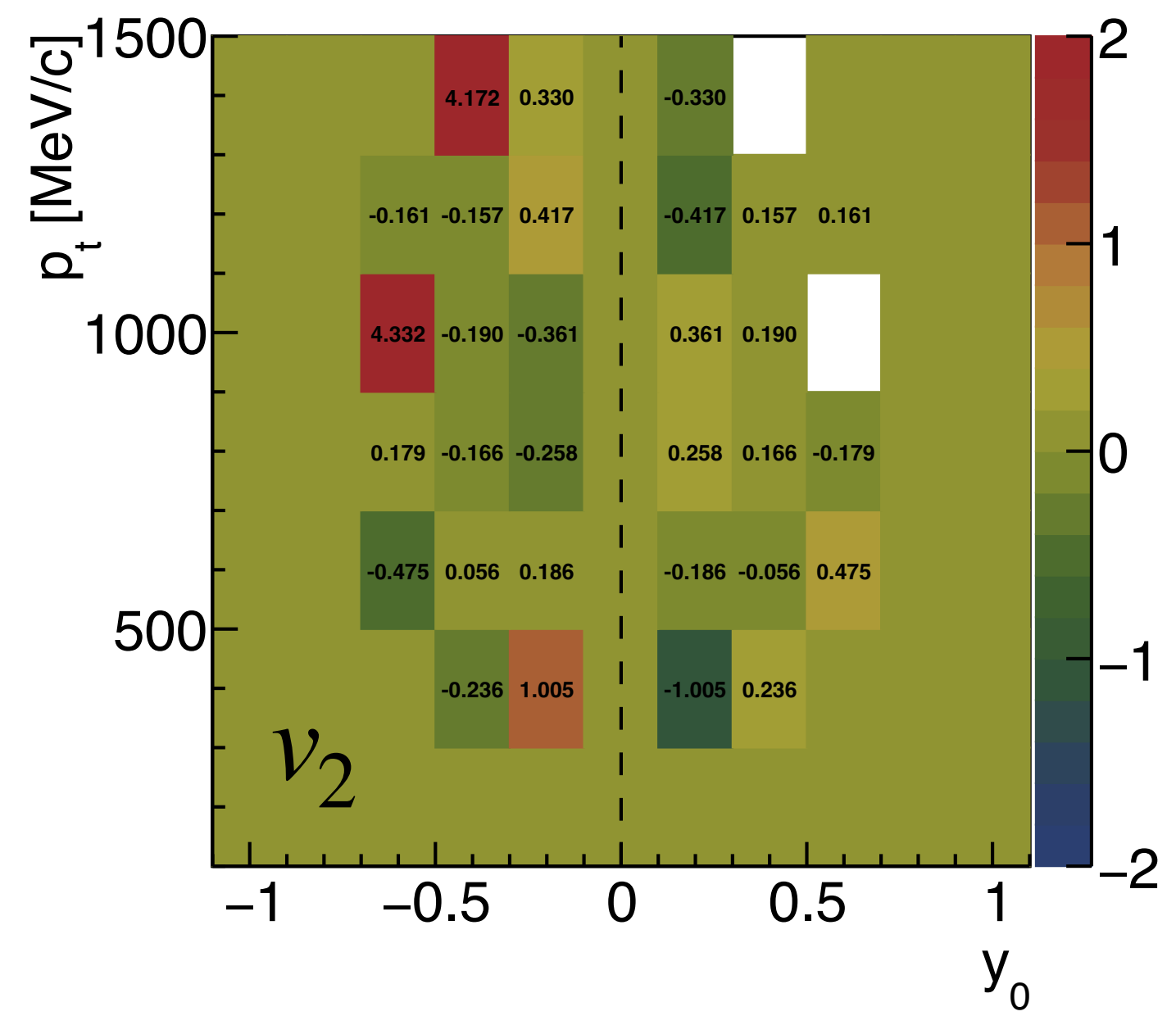
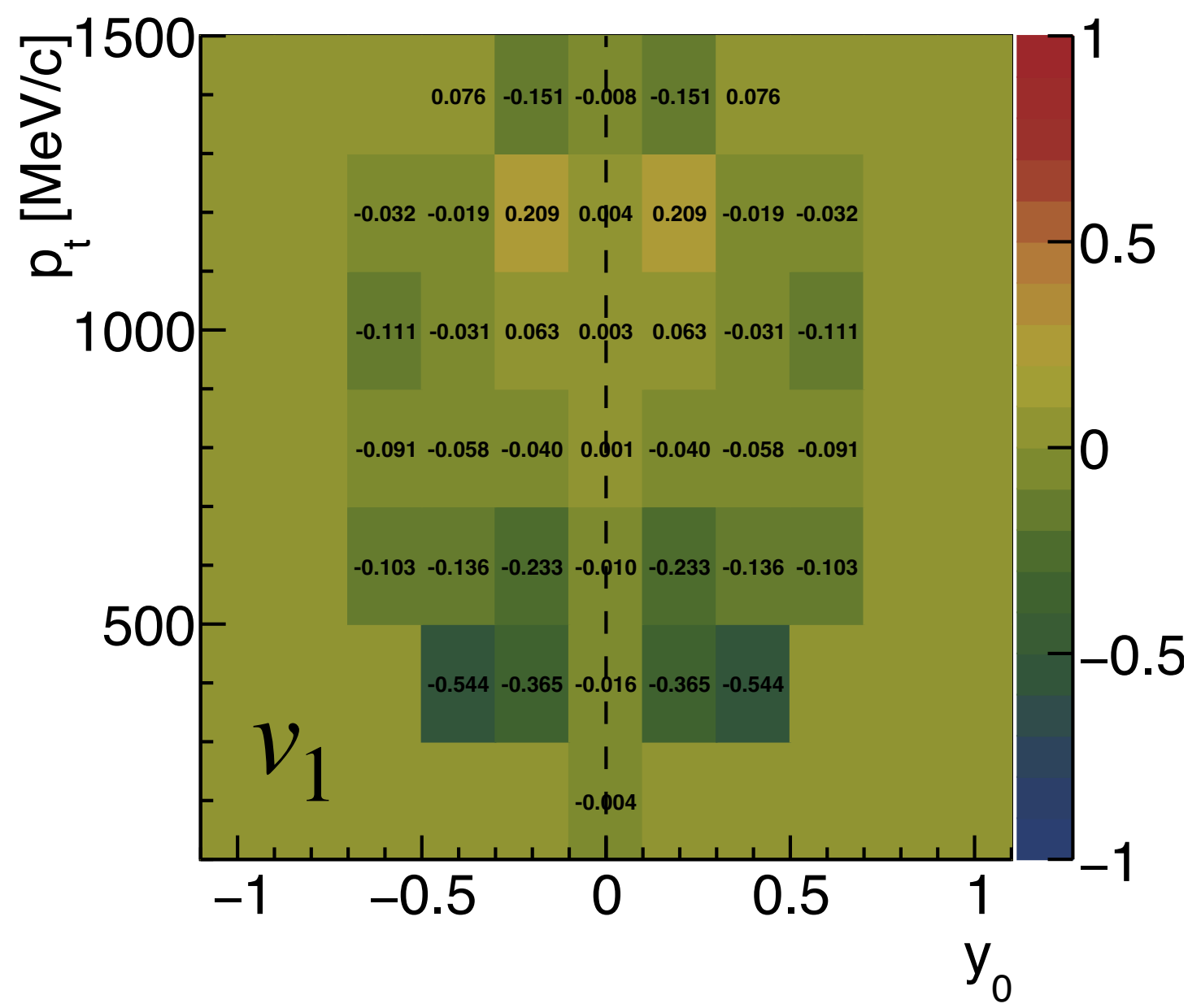
Systematic effects

Systematic effects

- ▶ First approach to evaluation of systematic uncertainties in Λ flow analysis
- ▶ Maps of v_n are compared for different scenarios of analysis (e.g. 12 $\Delta\phi$ bins vs. 18 $\Delta\phi$ bins)
- ▶ Relative deviation from average $\delta(x) = \frac{x_i - \bar{x}}{\bar{x}}$ useless for values ≈ 0 or with high errors
- ▶ Deviation in units of statistical uncertainty $\frac{\Delta_x}{\sigma_x} = \frac{x_1 - x_2}{\sqrt{\sigma_1^2 + \sigma_2^2}}$ is more informative

Should $\frac{\Delta_x}{\sigma_x} < 1$ be even considered a systematic uncertainty?

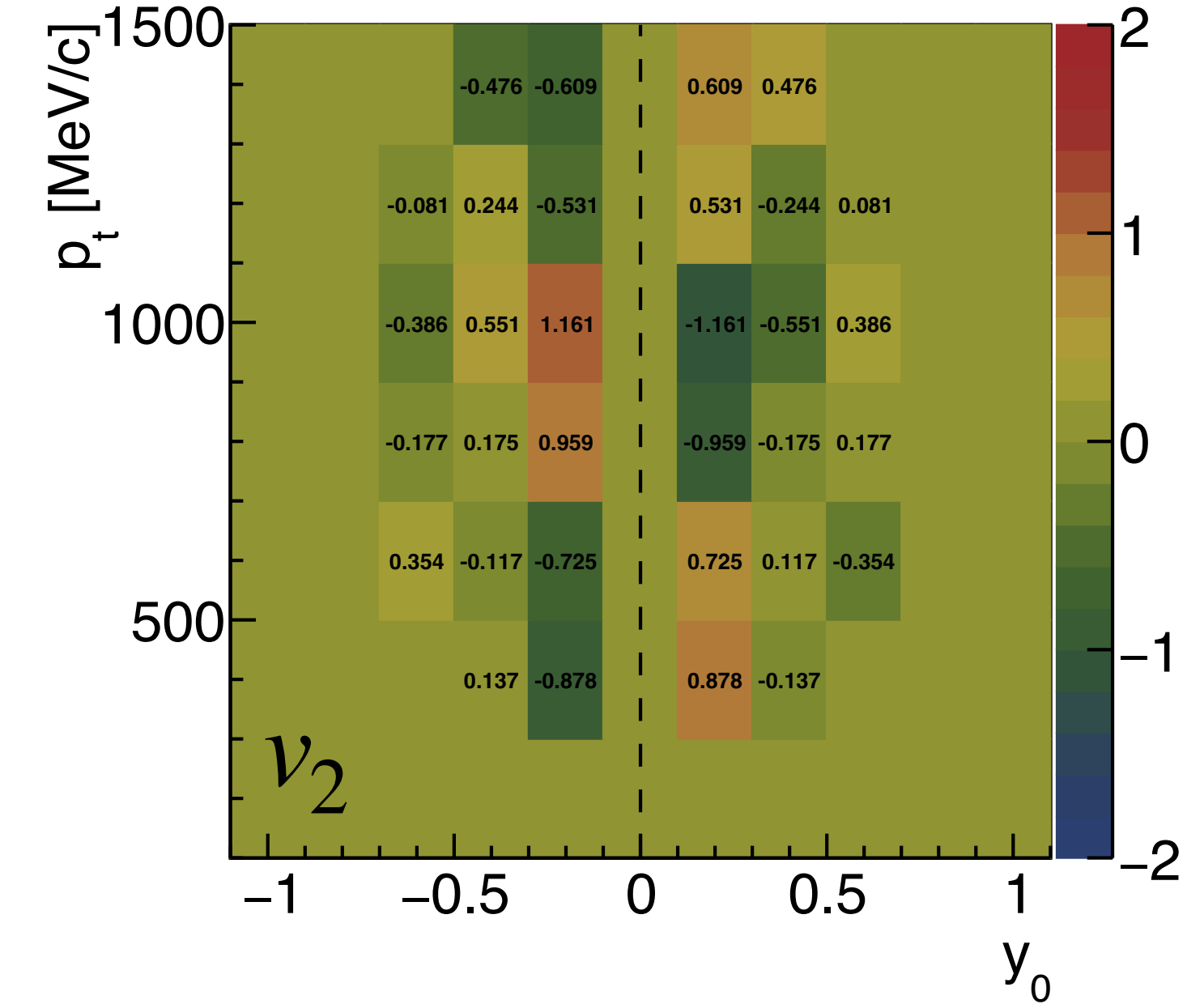
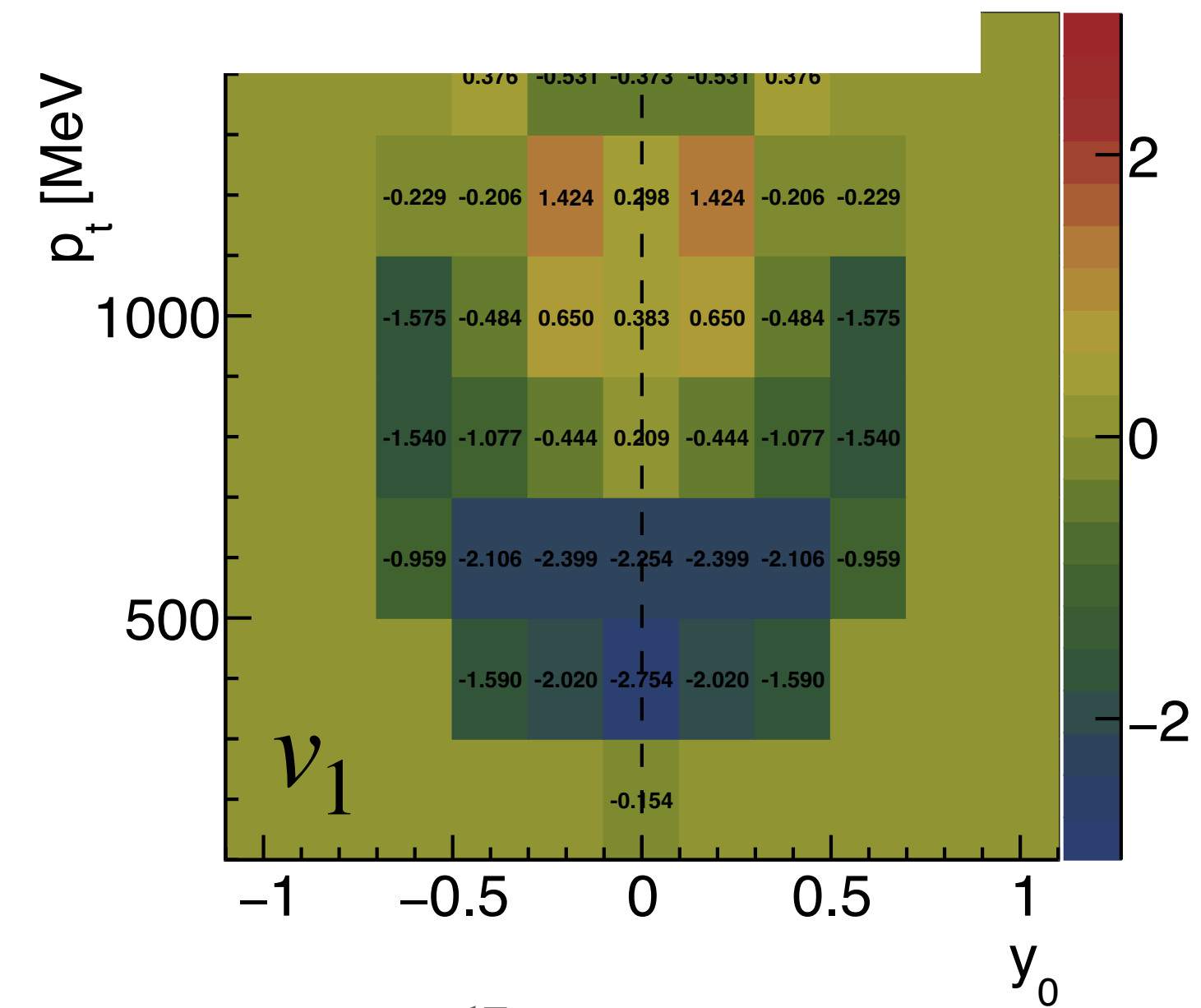
Rapidity-wise asymmetry



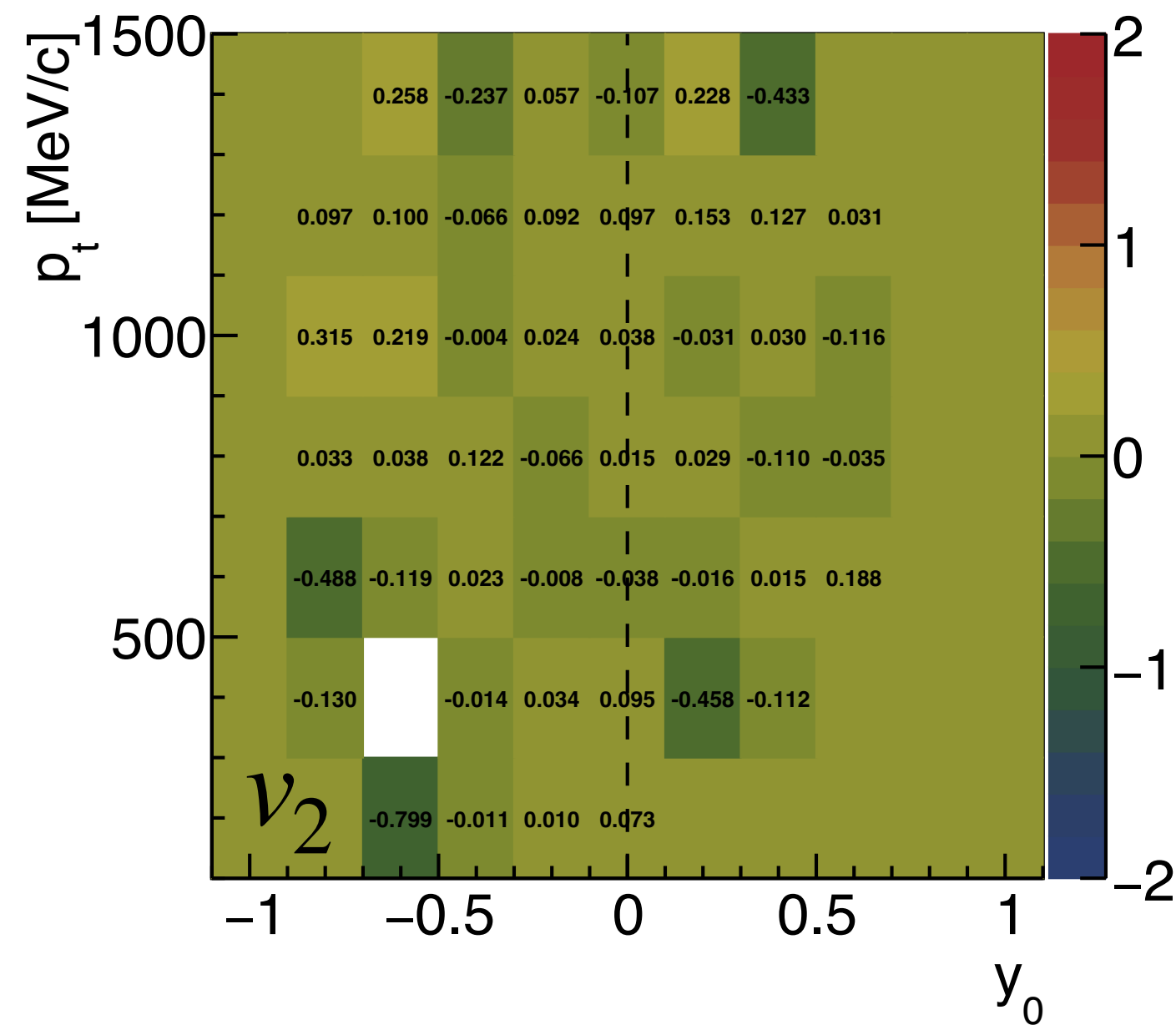
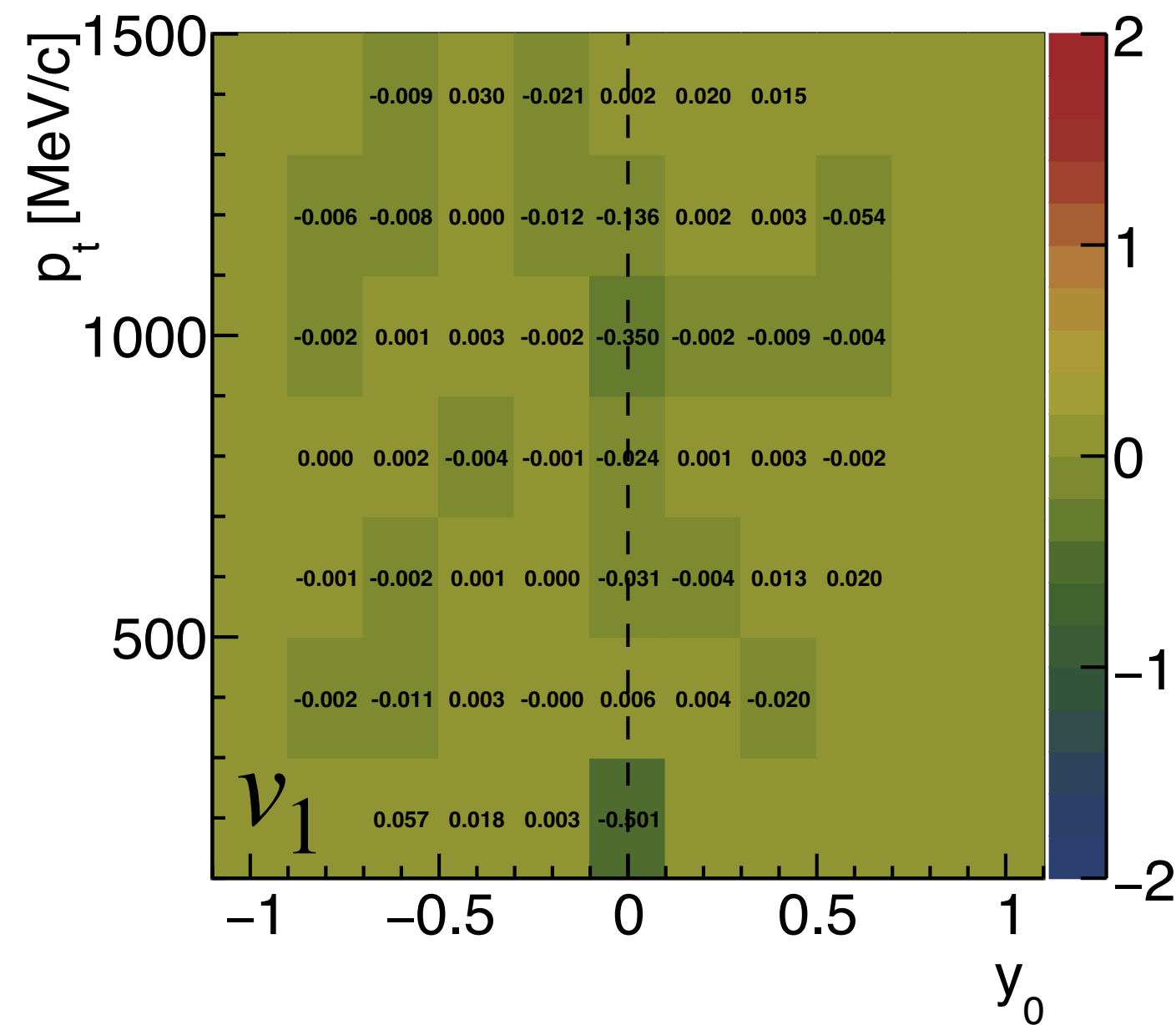
↑ $\delta(x) = \frac{x_i - \bar{x}}{\bar{x}}$

$\frac{\Delta_x}{\sigma_x} = \frac{x_1 - x_2}{\sqrt{\sigma_1^2 + \sigma_2^2}}$

→

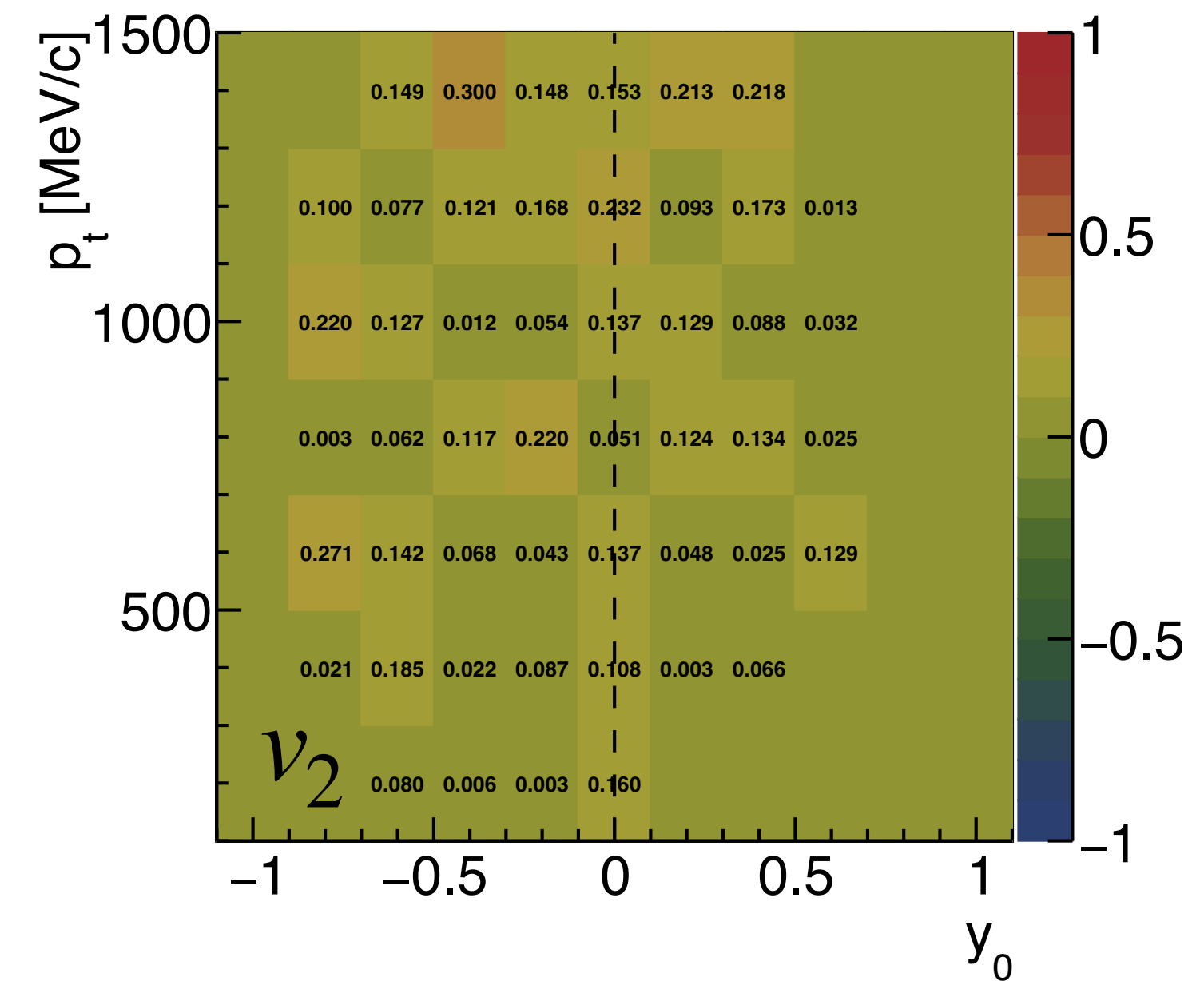
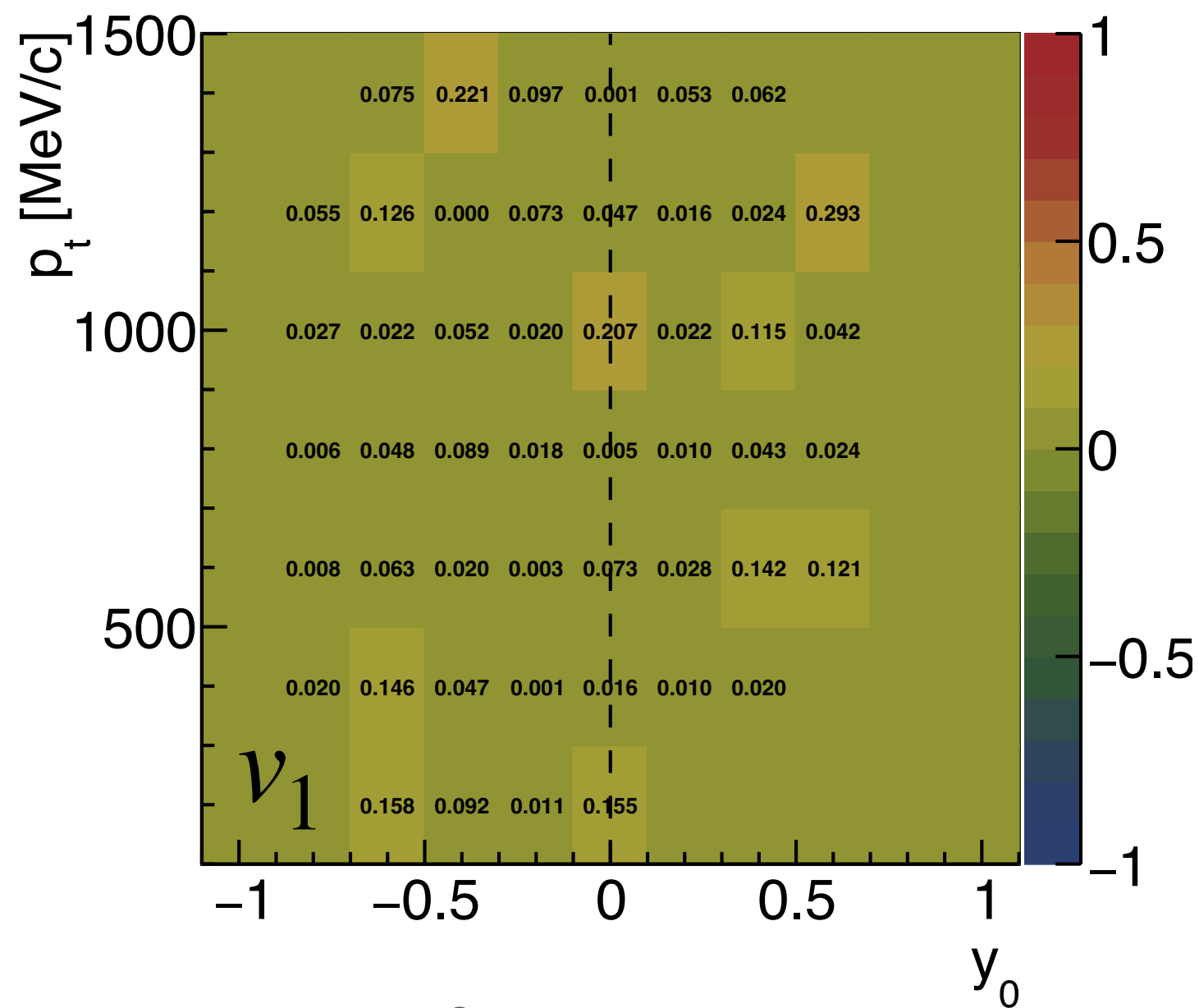


12 vs. 18 $\Delta\phi$ bins

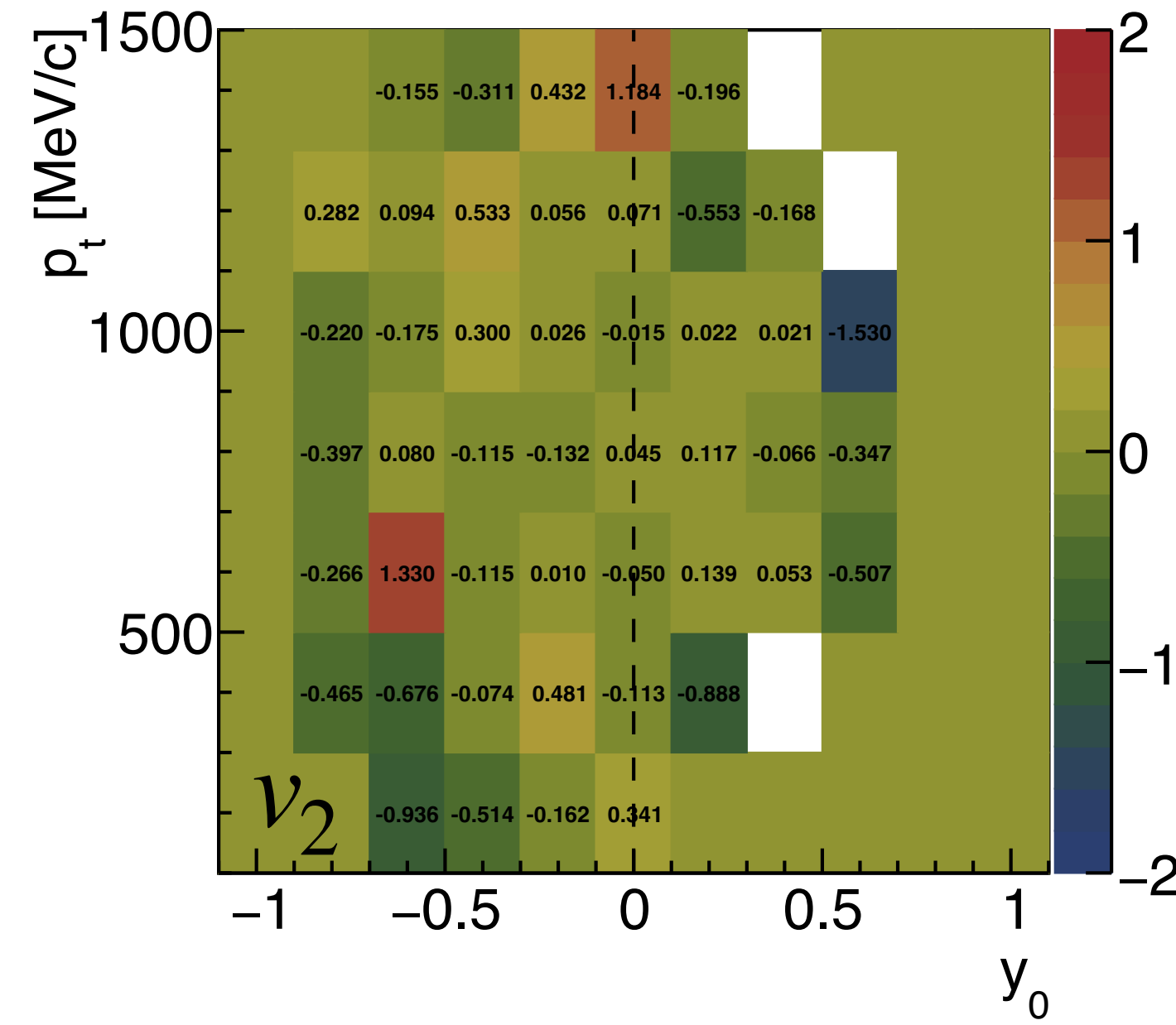
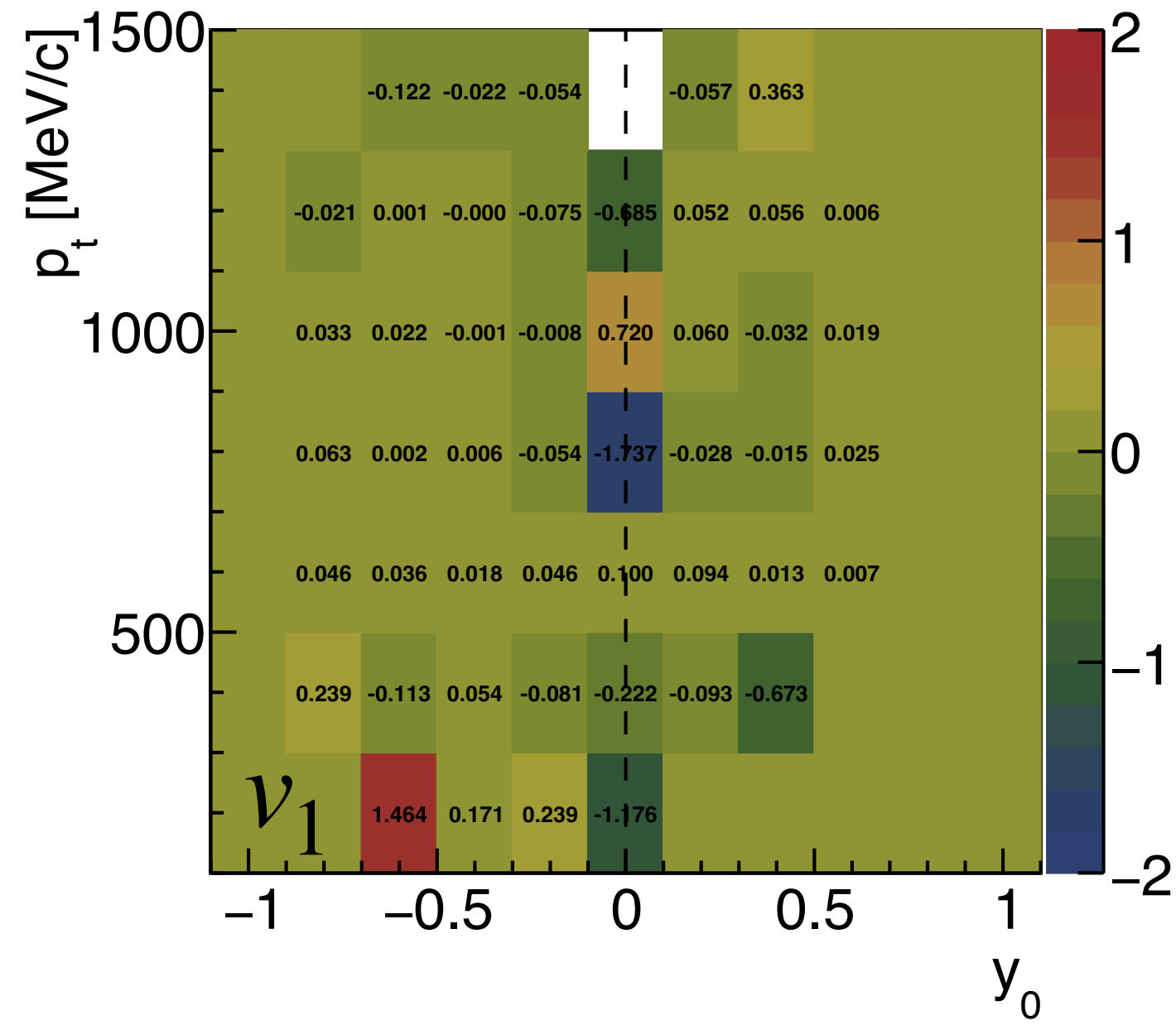


$\delta(x) = \frac{x_i - \bar{x}}{\bar{x}}$

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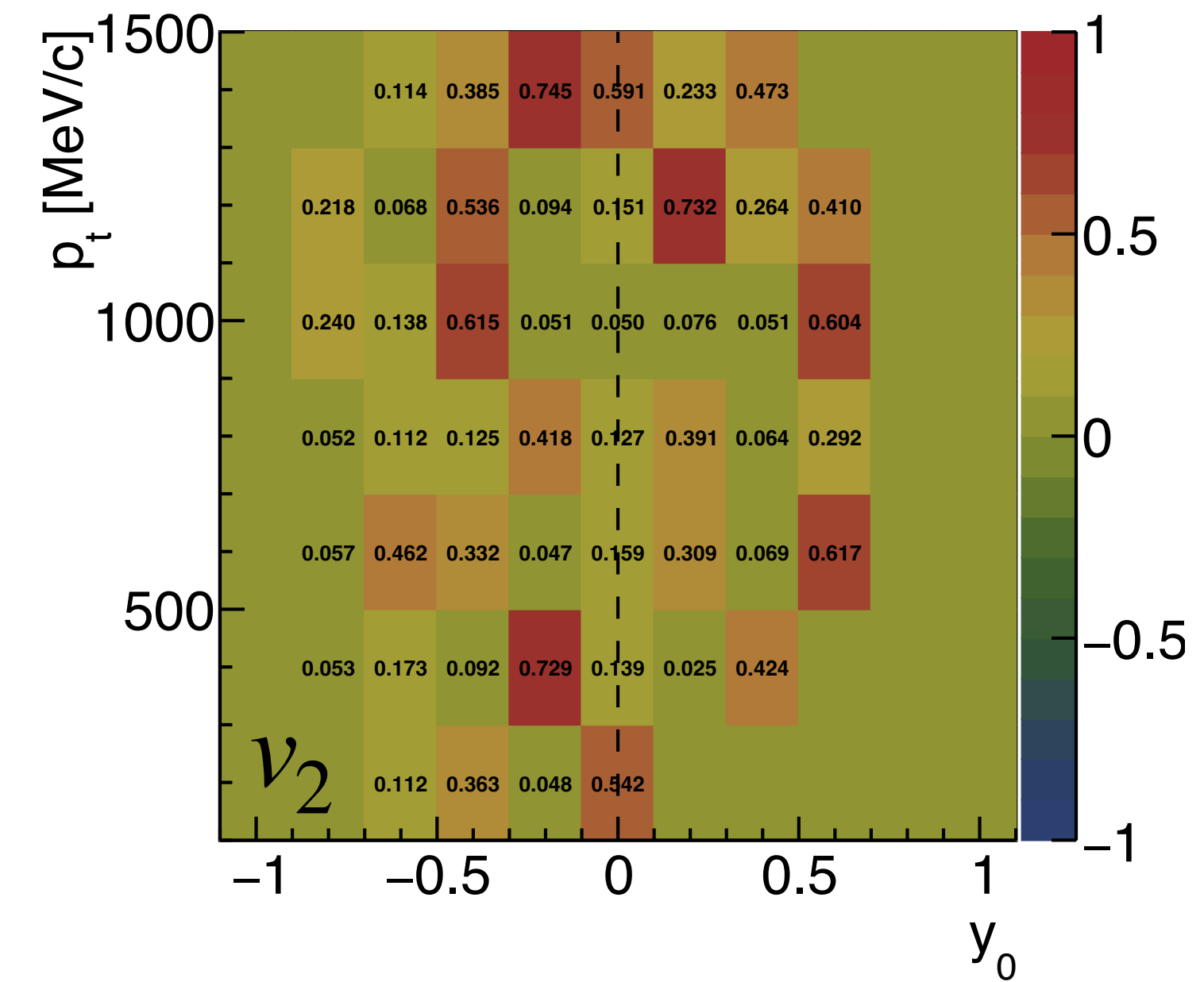
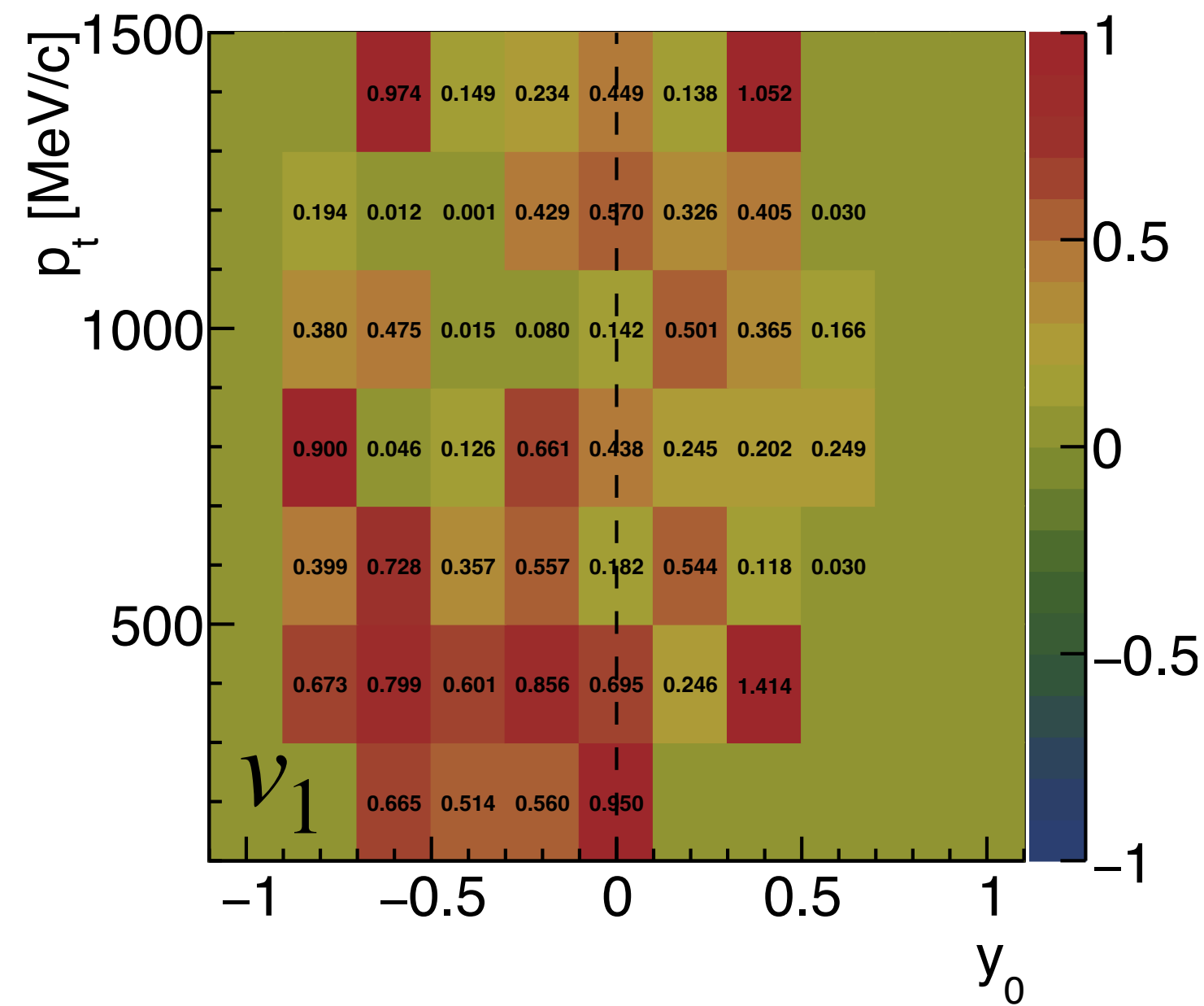
Hard cuts vs. TMVA



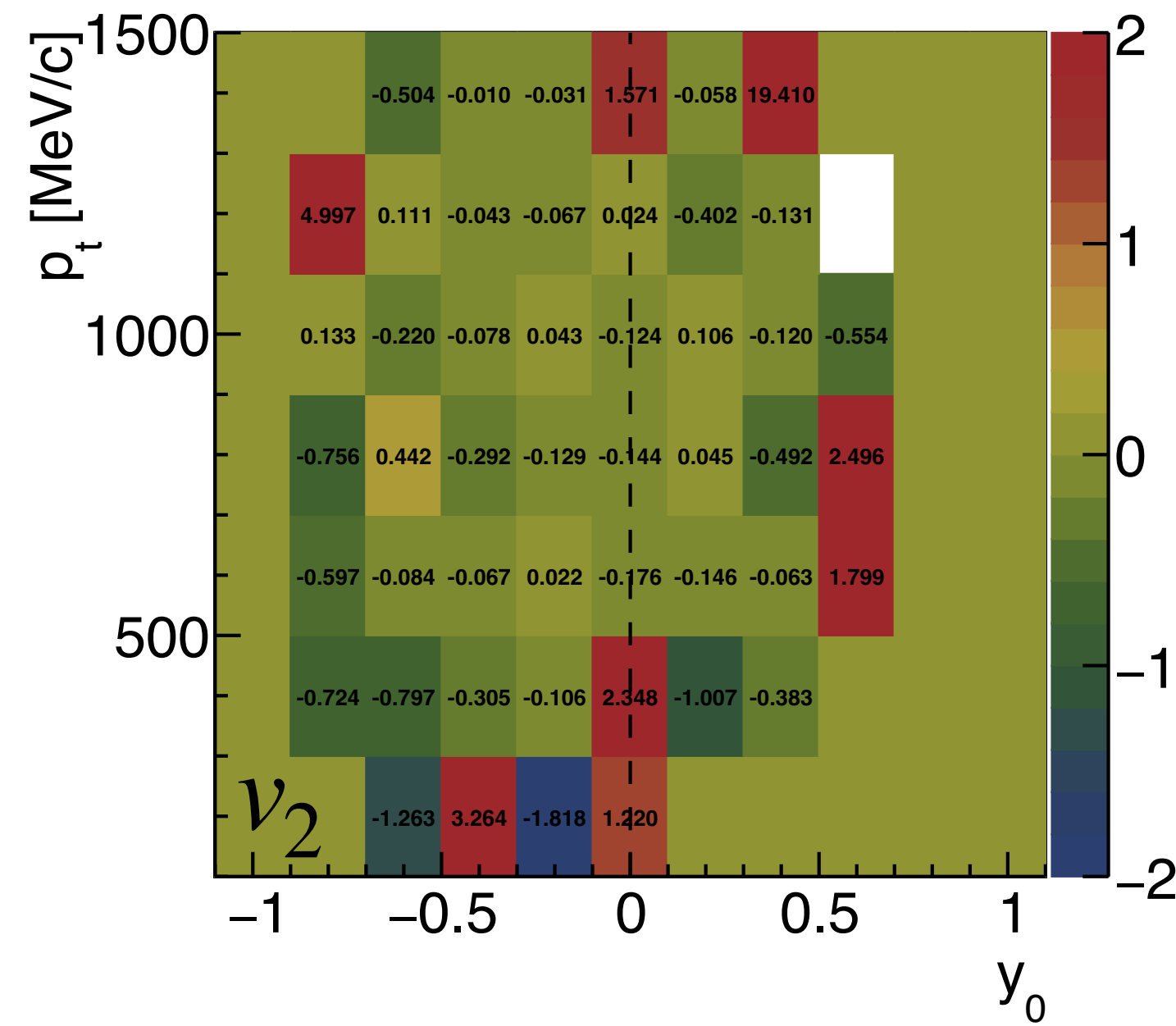
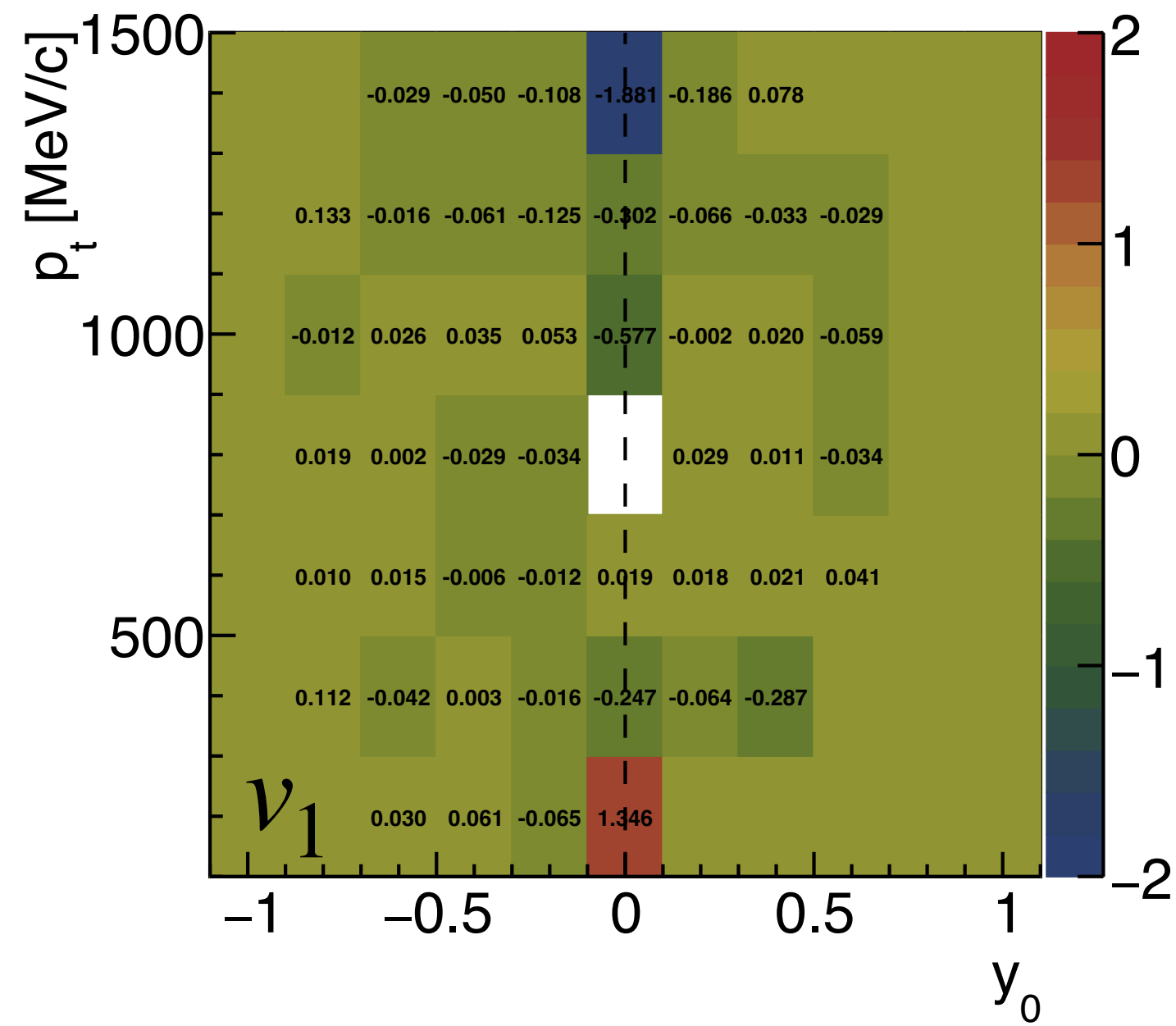
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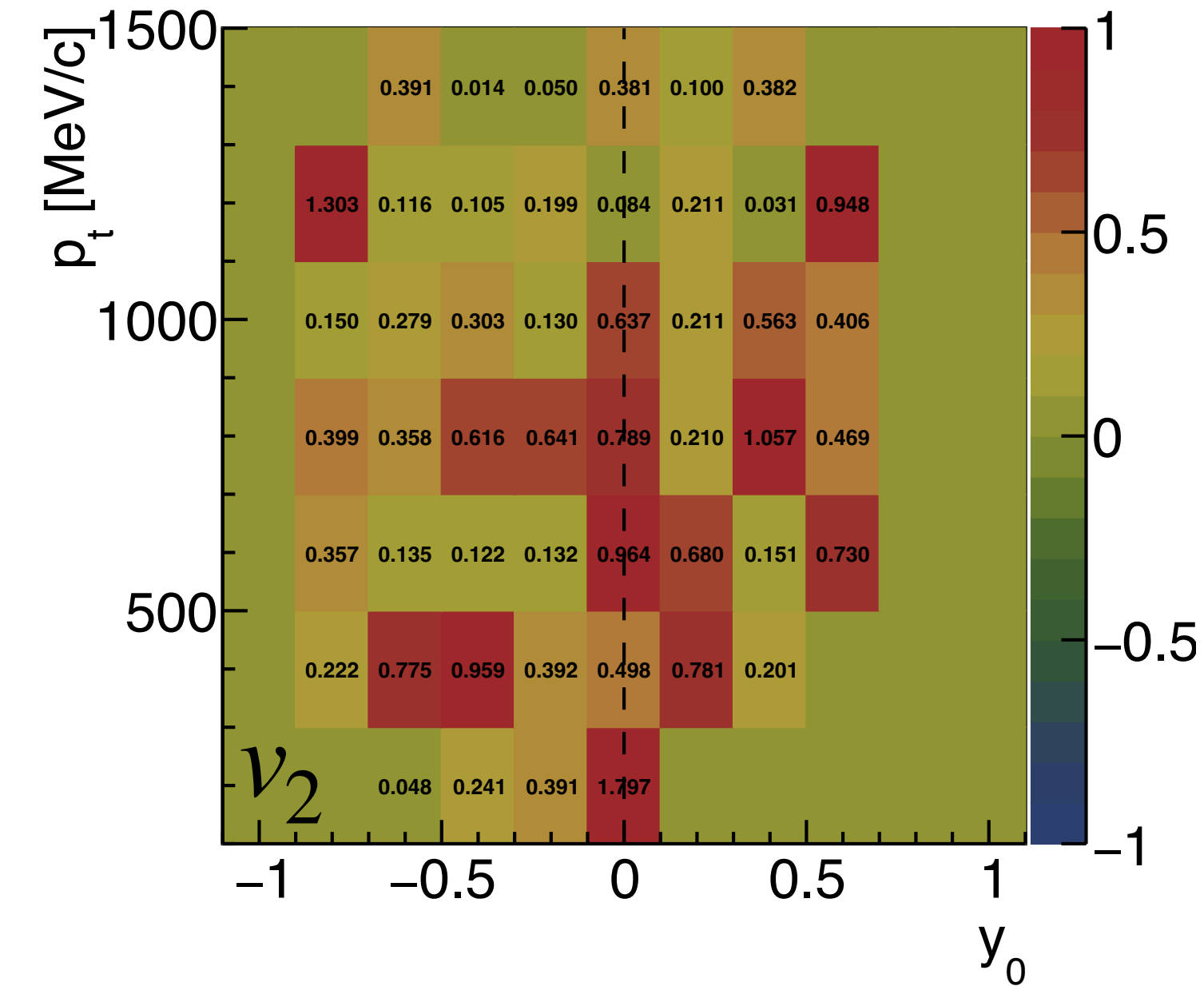
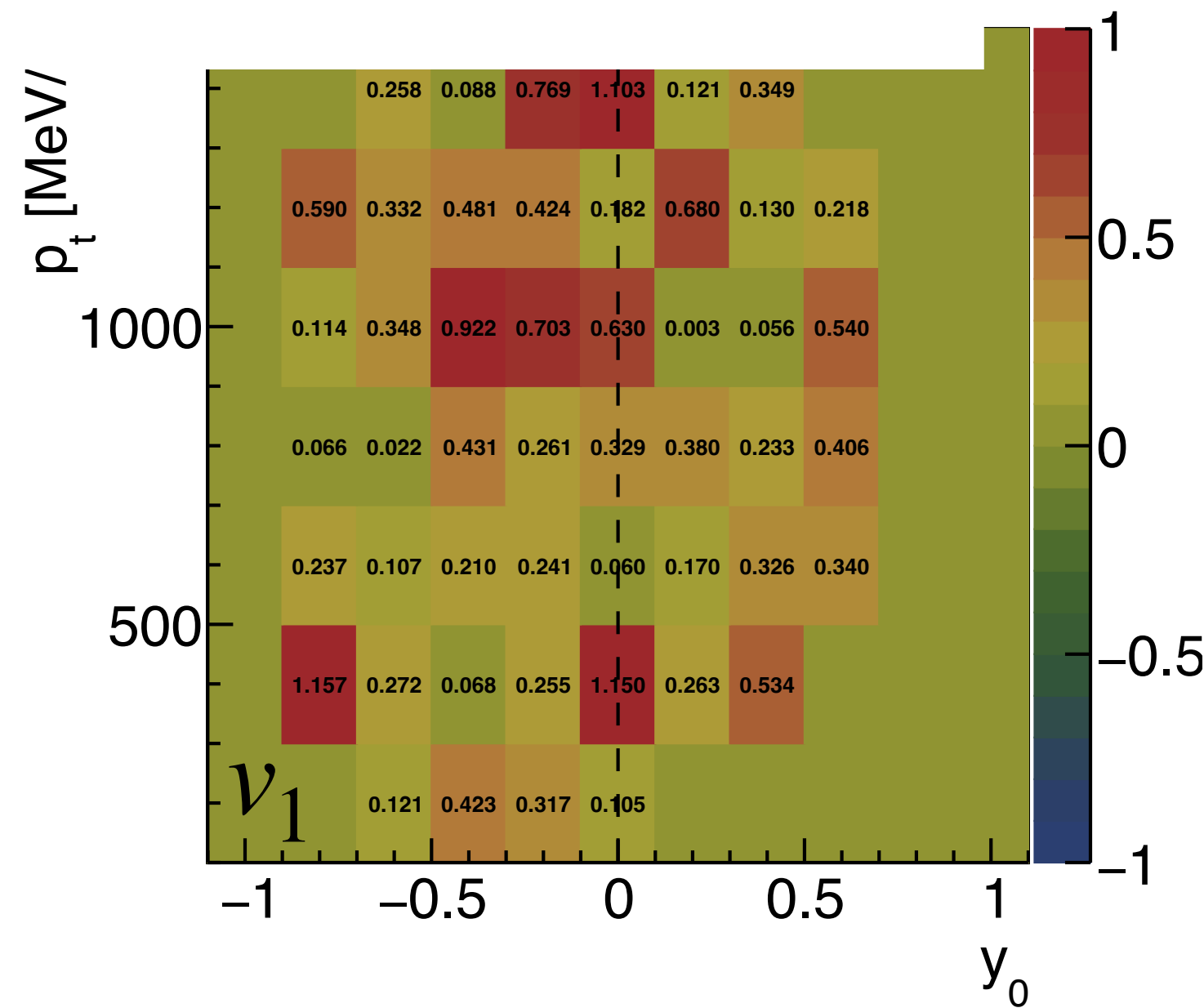
Fourier fit vs. TProfile



↑ $\delta(x) = \frac{x_i - \bar{x}}{\bar{x}}$

$\frac{\Delta_x}{\sigma_x} = \frac{x_1 - x_2}{\sqrt{\sigma_1^2 + \sigma_2^2}}$

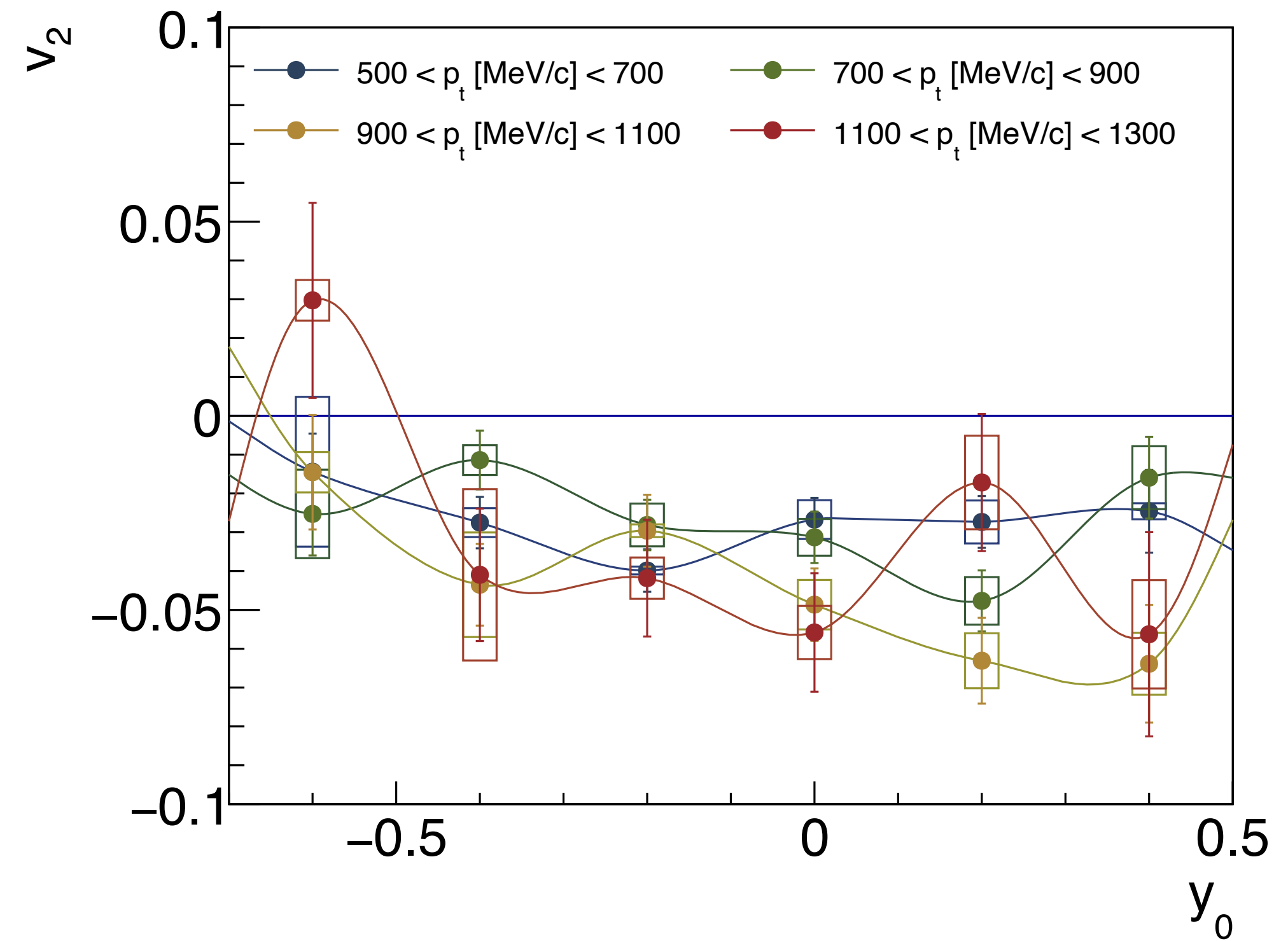
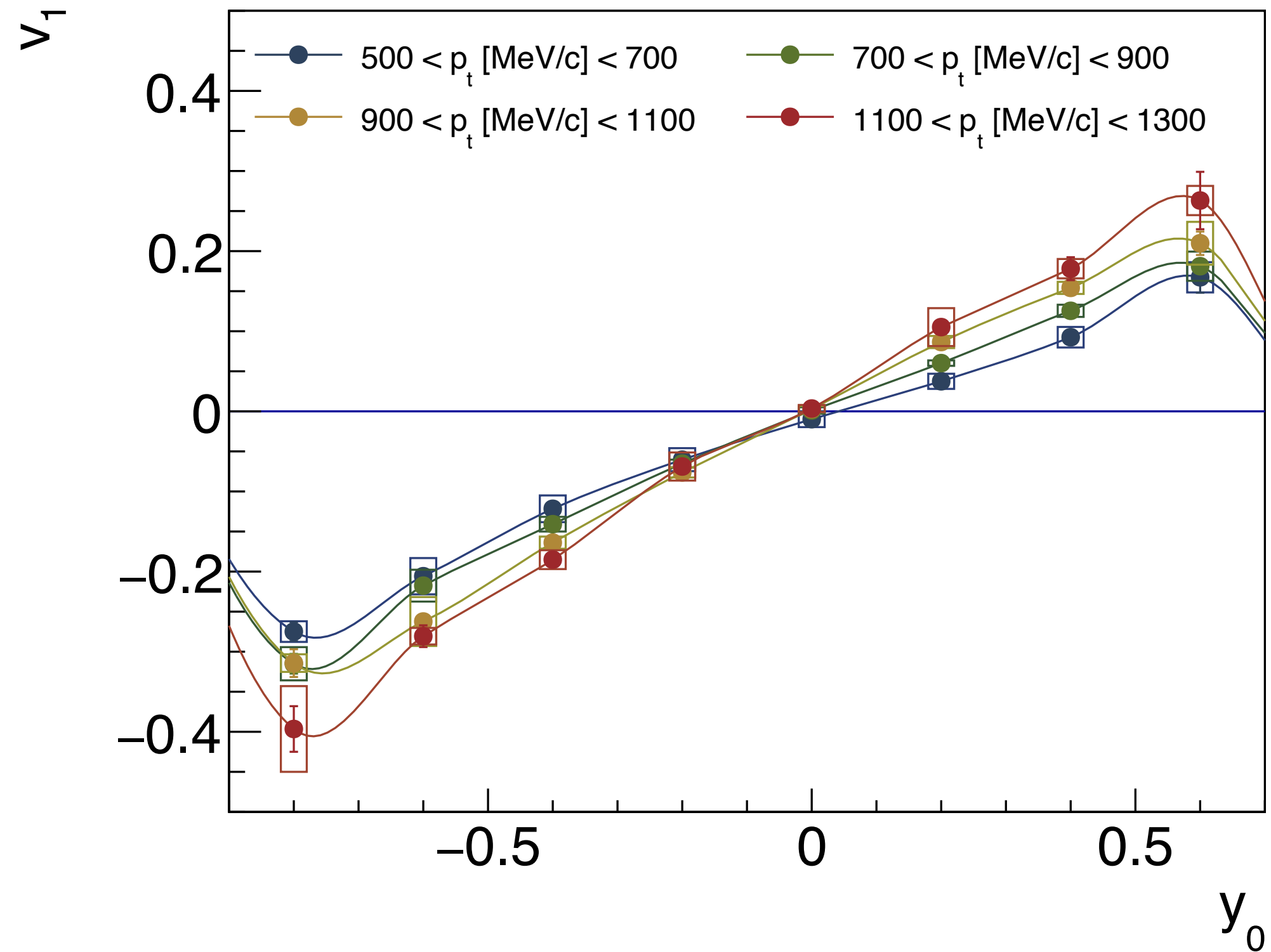
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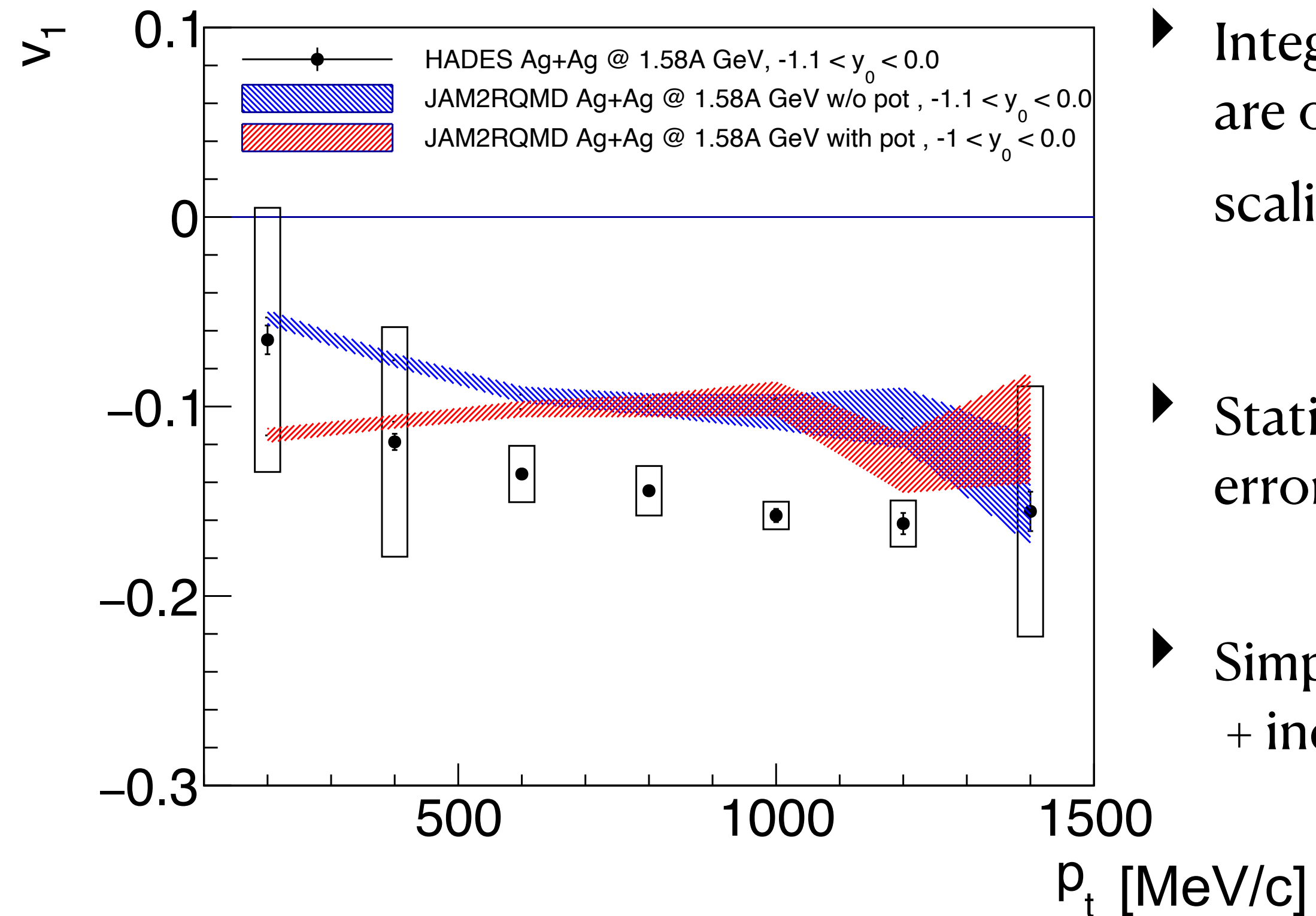
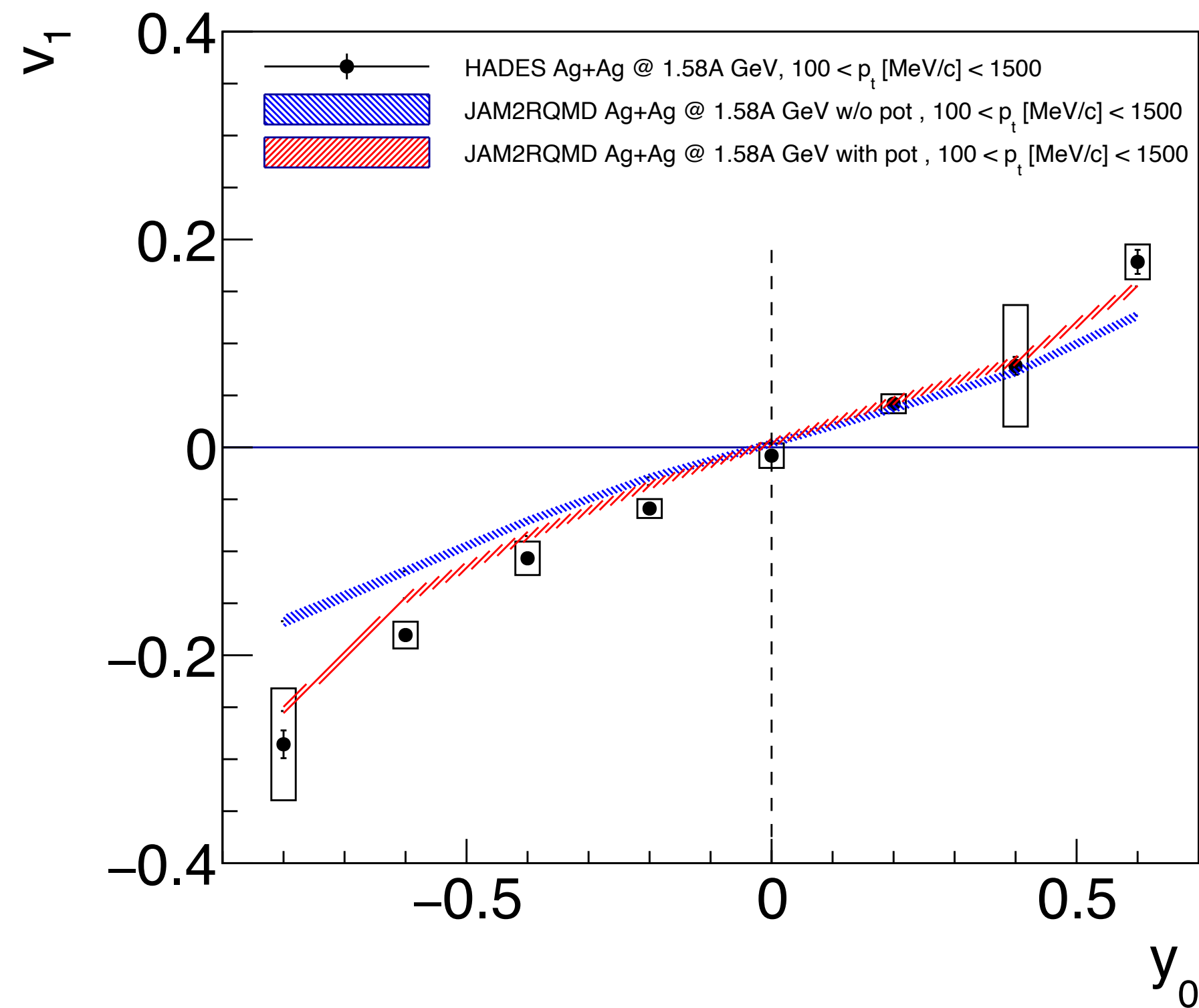
What's left to be checked

- ▶ Some systematic checks are still planned:
 - different days of the beamtime
 - pt:y binning
 - occupancy correction
- ▶ The systematic check is also an opportunity to check if chosen methods are optimal
- ▶ Hard cuts appear to have slightly better rapidity symmetry than TMVA cuts (?)
- ▶ 18 $\Delta\phi$ bins is more accurate for v_2 measurement

Final plots including systematic uncertainties



Comparison to JAM2 RQMDv (with/without potential)



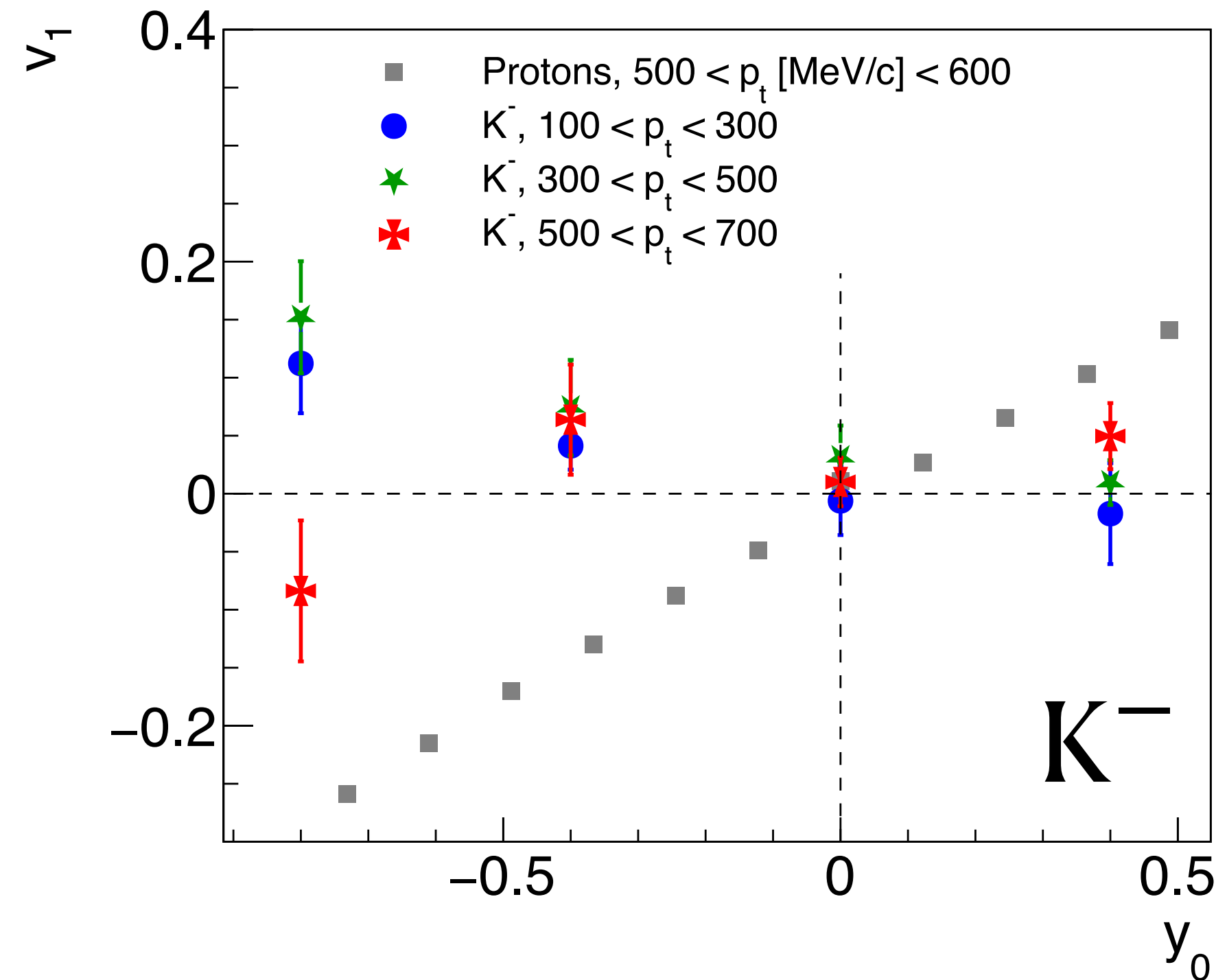
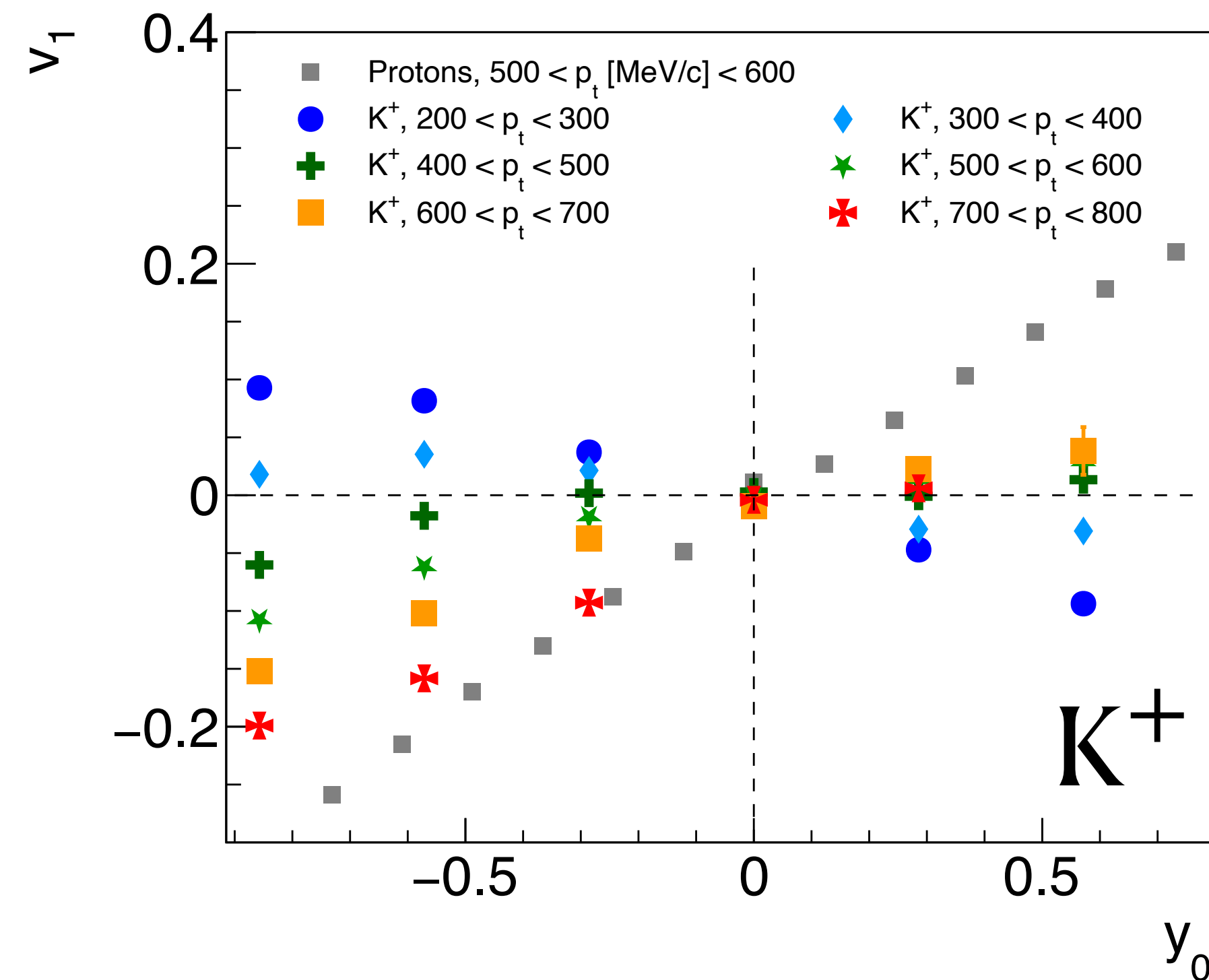
- ▶ Integrated flow distributions are obtained by scaling by $\frac{1}{\epsilon \cdot \alpha(y_0, p_t)}$
- ▶ Statistical and systematic errors alike
- ▶ Simplifies comparison + increases statistics

- ▶ GiBUU, UrQMD 4.0 and SMASH(?) calculations are planned

(Disappointing) Update on the K^\pm

Rework of K^\pm is ongoing

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- ▶ Adjusting old style of analysis ("inherited" from Lukaš) to new macros (developed for Λ)
- ▶ Takes longer than expected
- ▶ The framework is ready
- ▶ Once all data-based issues are fixed, there will be a lot of new results

Instead of a summary...

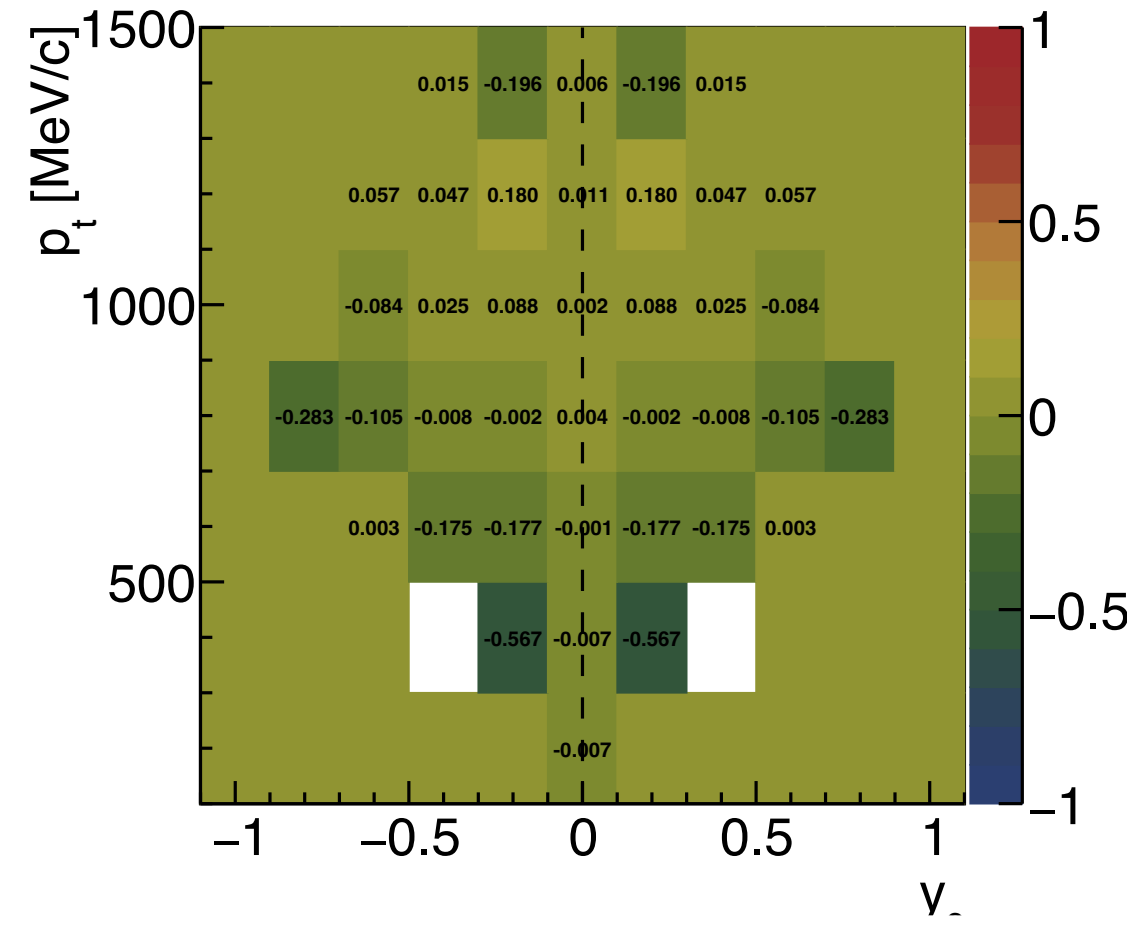
	Signal extraction	Total flow analysis	Pretty plots	Efficiency	Systematic uncert.	Comparison to models	Occupancy correction
Lambda	Done (Fits, ME)	Done (Fourier & TProfile)	Done	Done	Ongoing (some contribs pending)	Ongoing (JAM2, other models pending)	Pending (framework ready)
K+/-	Done (optimized fits)	Ongoing (Fourier, TProfile pending)	Pending (framework ready)	Pending (framework ready)	Pending (framework ready)	Pending	Pending (framework ready)
Phi feasibility check	Done (ME works, RA tested not used)	Done (Fourier, TProfile, pQ)	Done	-	-	-	-

Thank you!

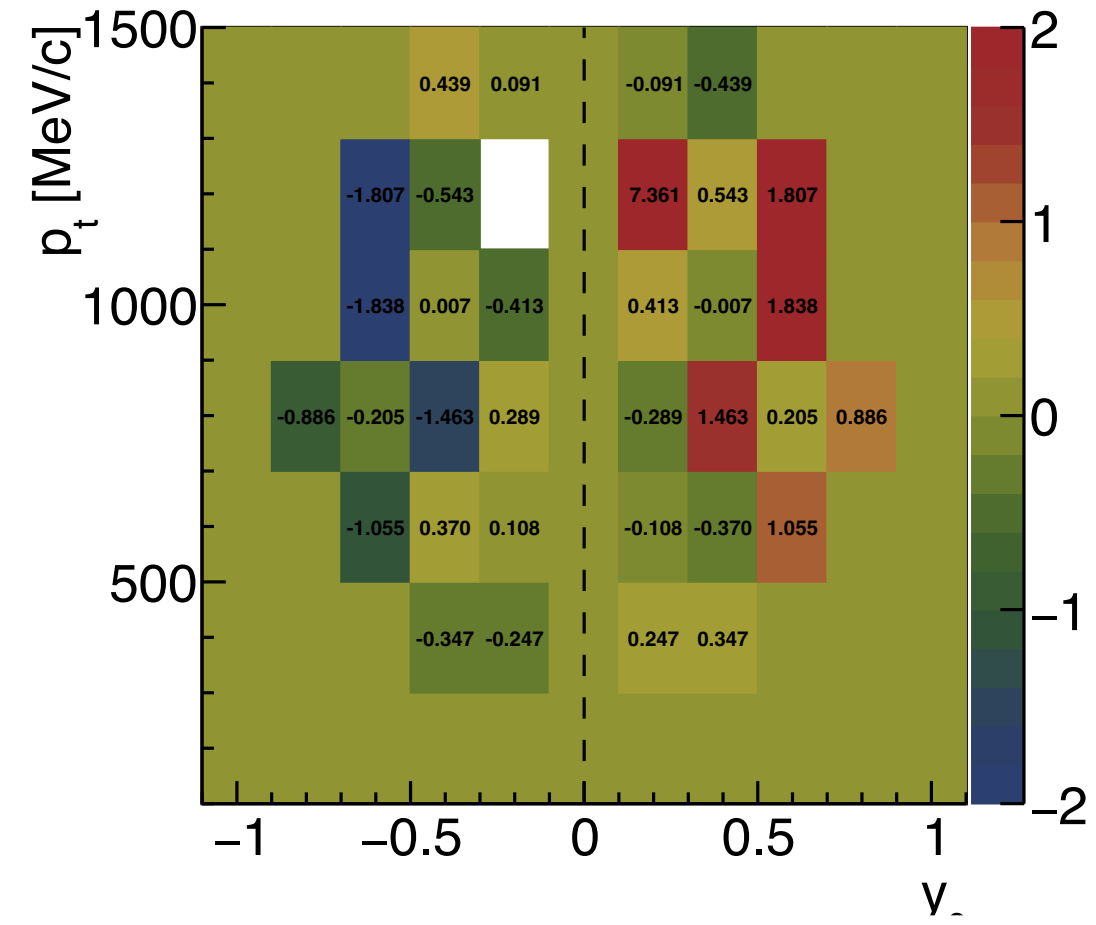
backup slides:

Symmetry TMVA vs hard cuts

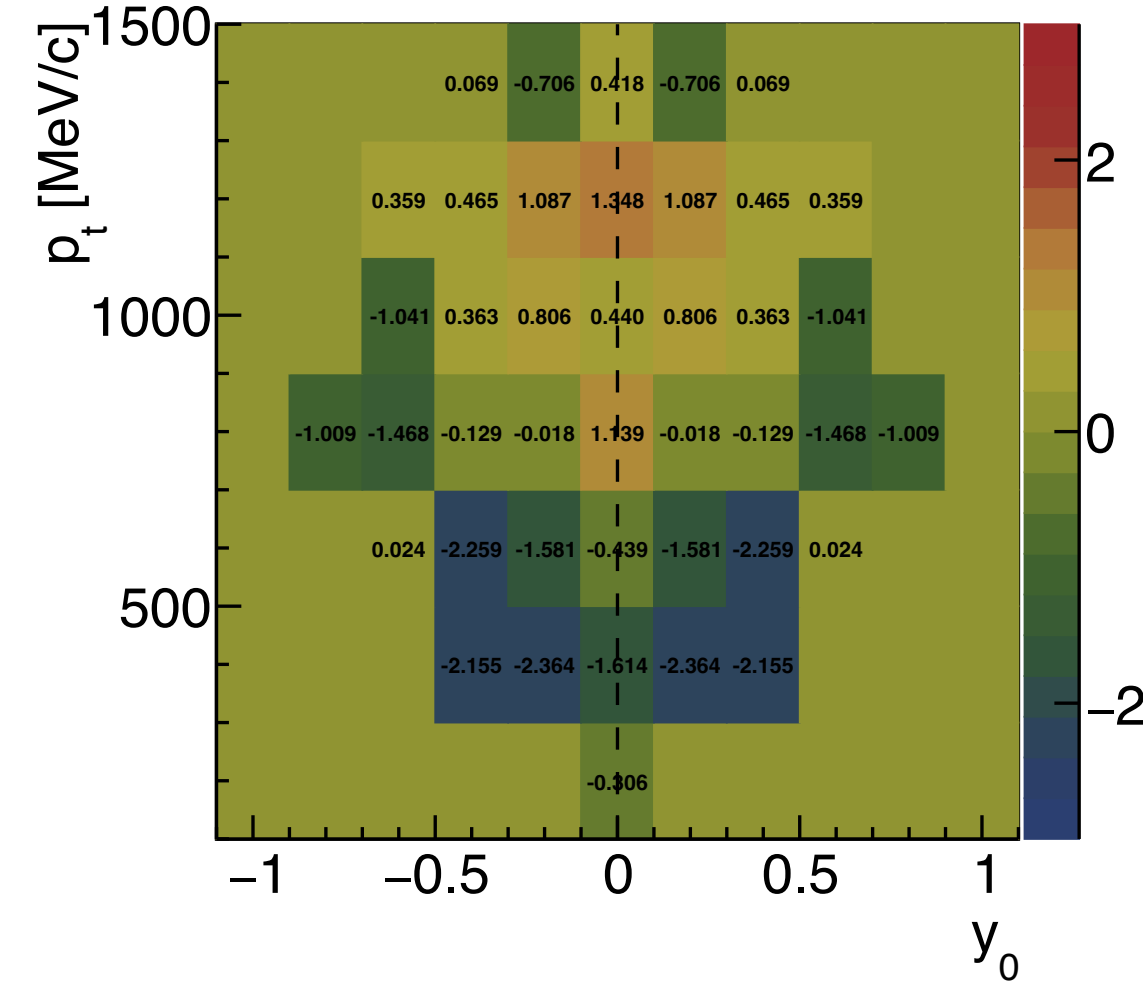
12 $\Delta\phi$ bins, MVAscore > 0.950 (relative dev. from symmetry)



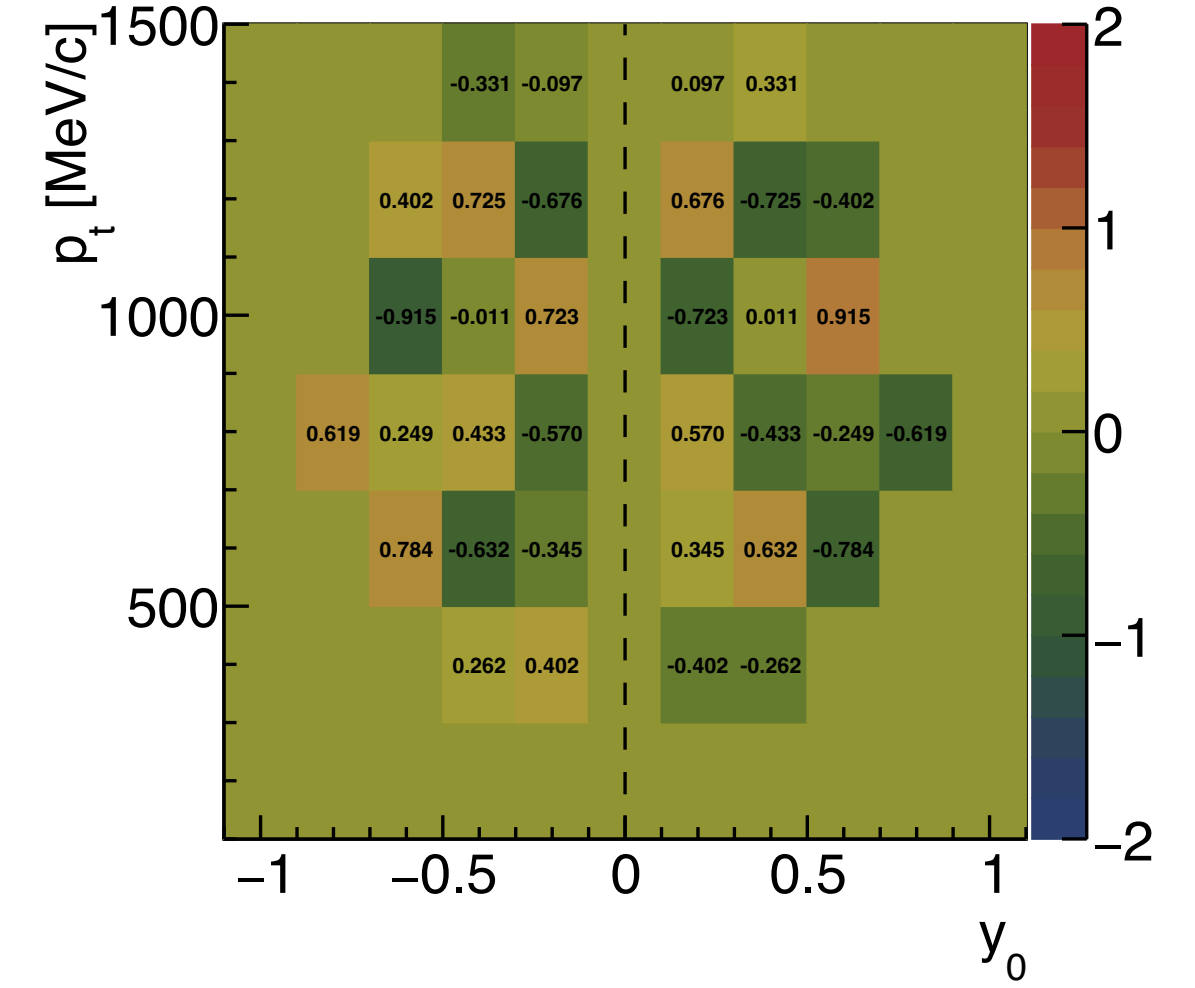
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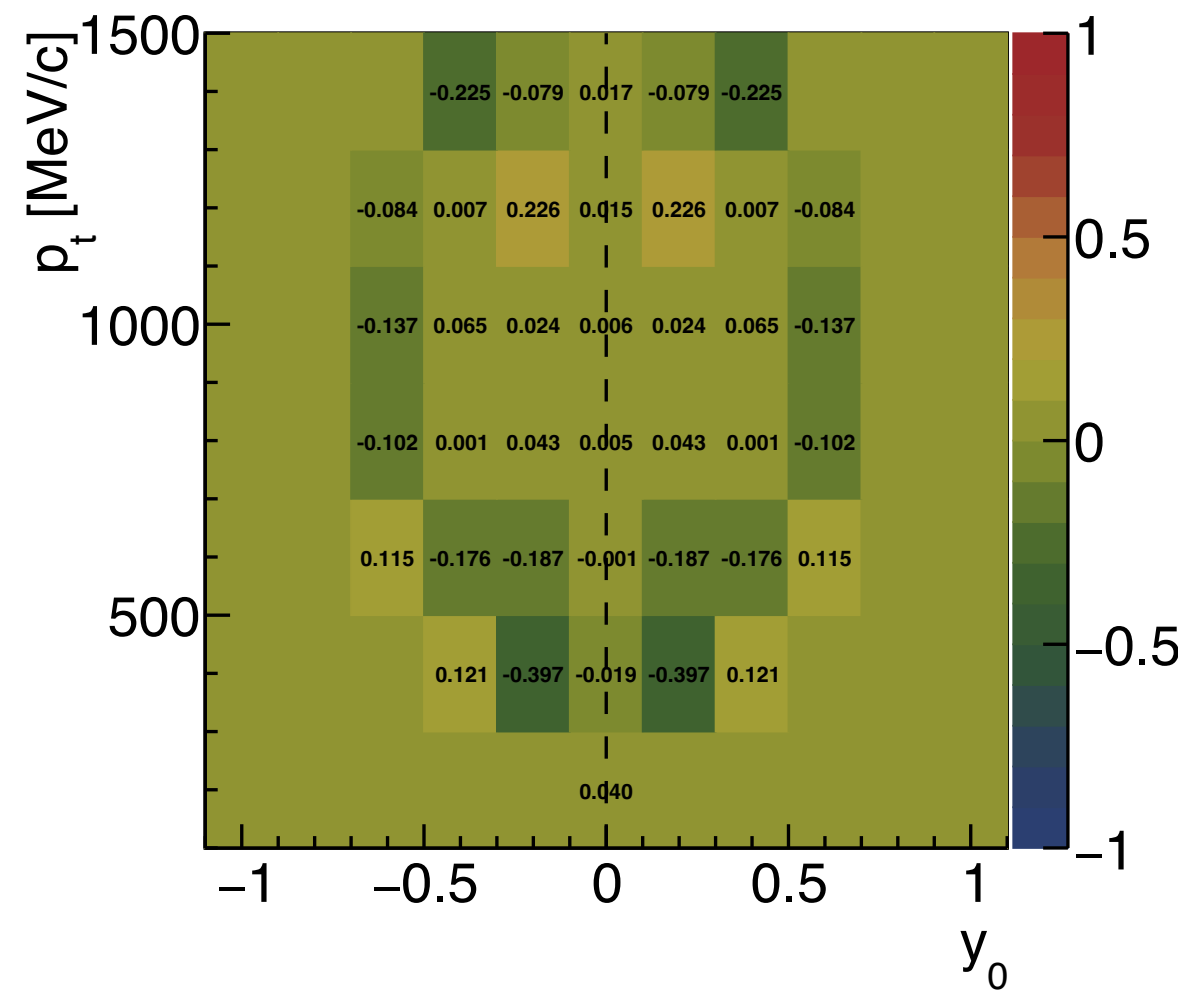
12 $\Delta\phi$ bins, MVAscore > 0.950 ($n\sigma$ from symmetry)



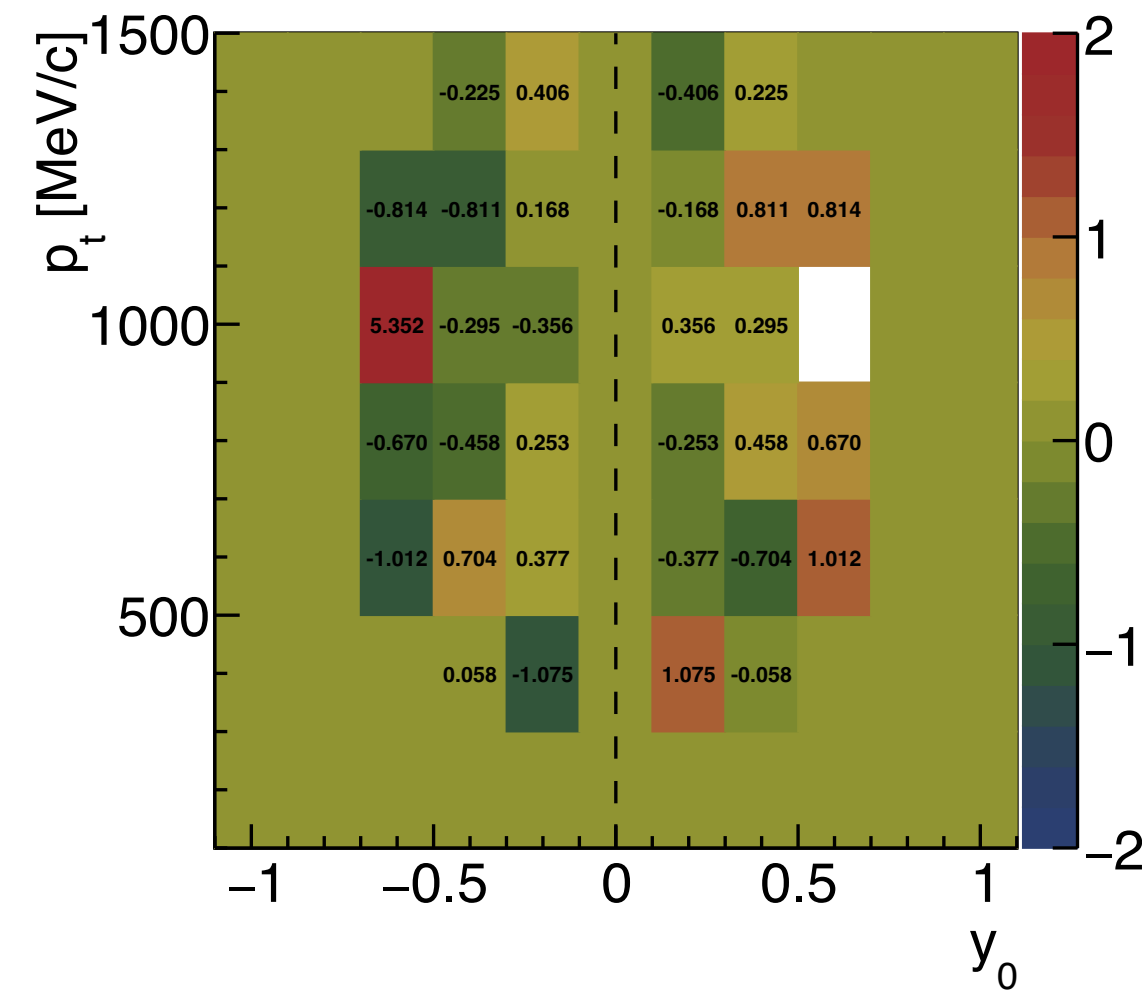
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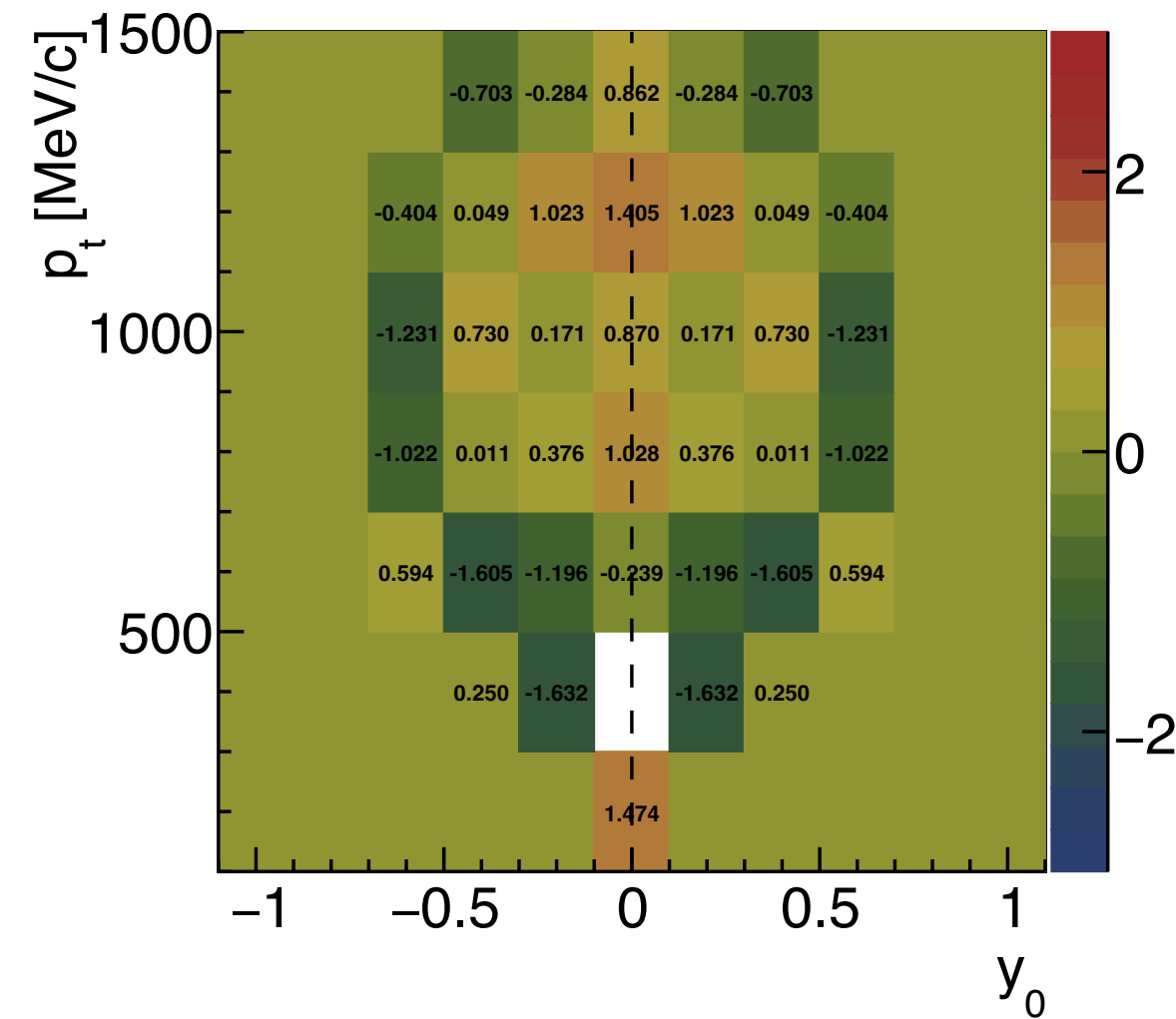
12 $\Delta\phi$ bins, strict topology cuts (relative dev. from symmetry)



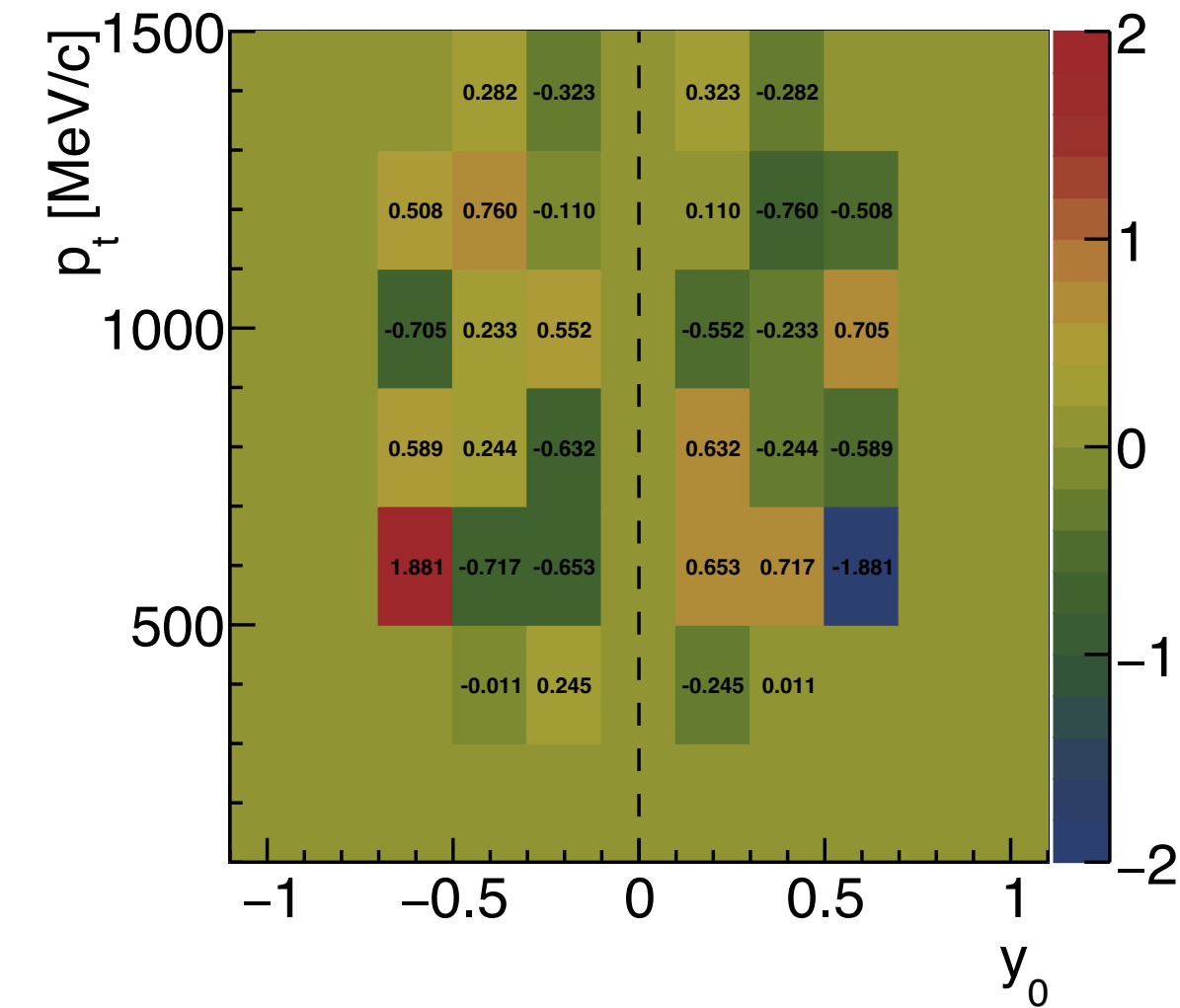
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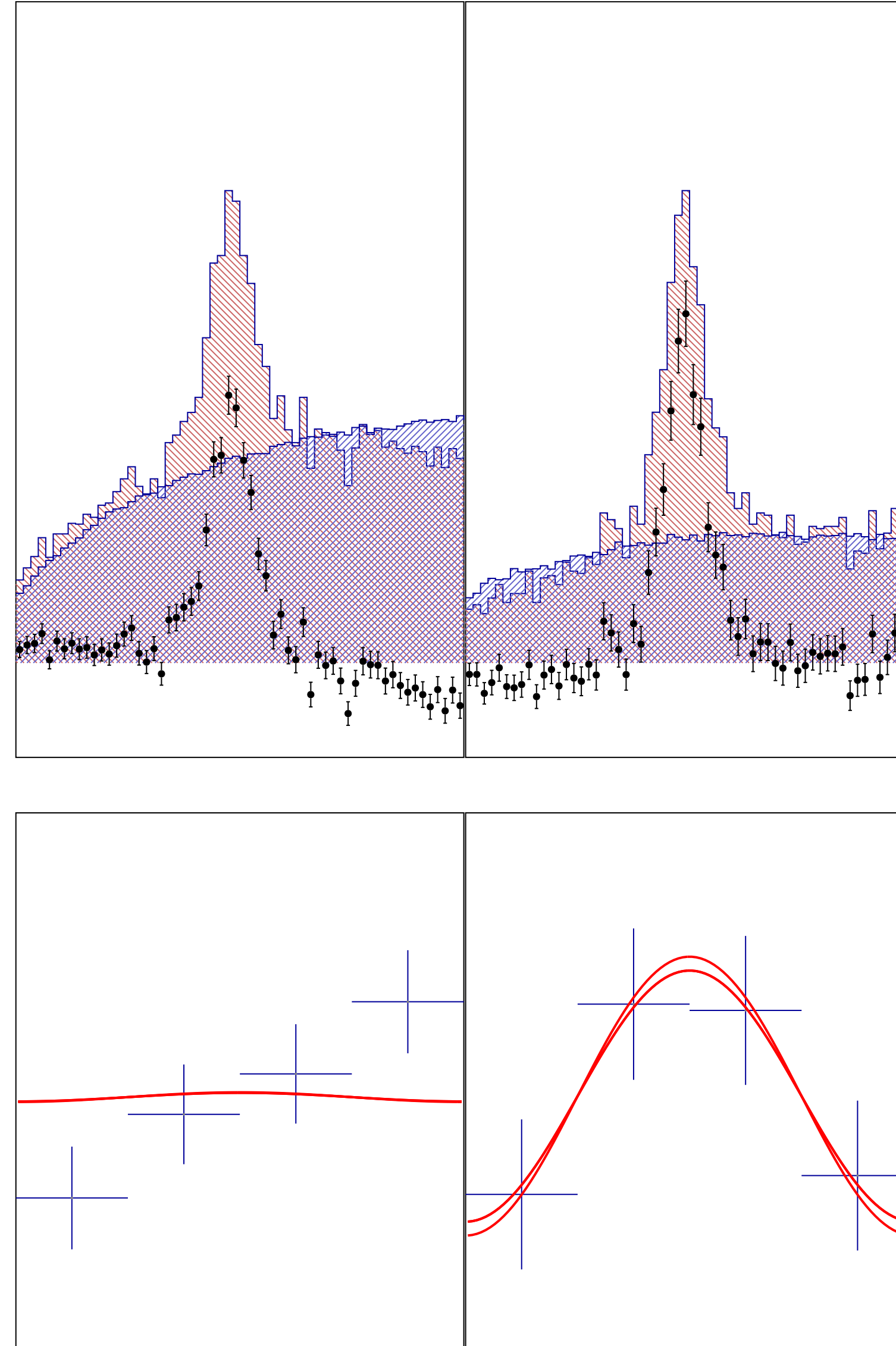
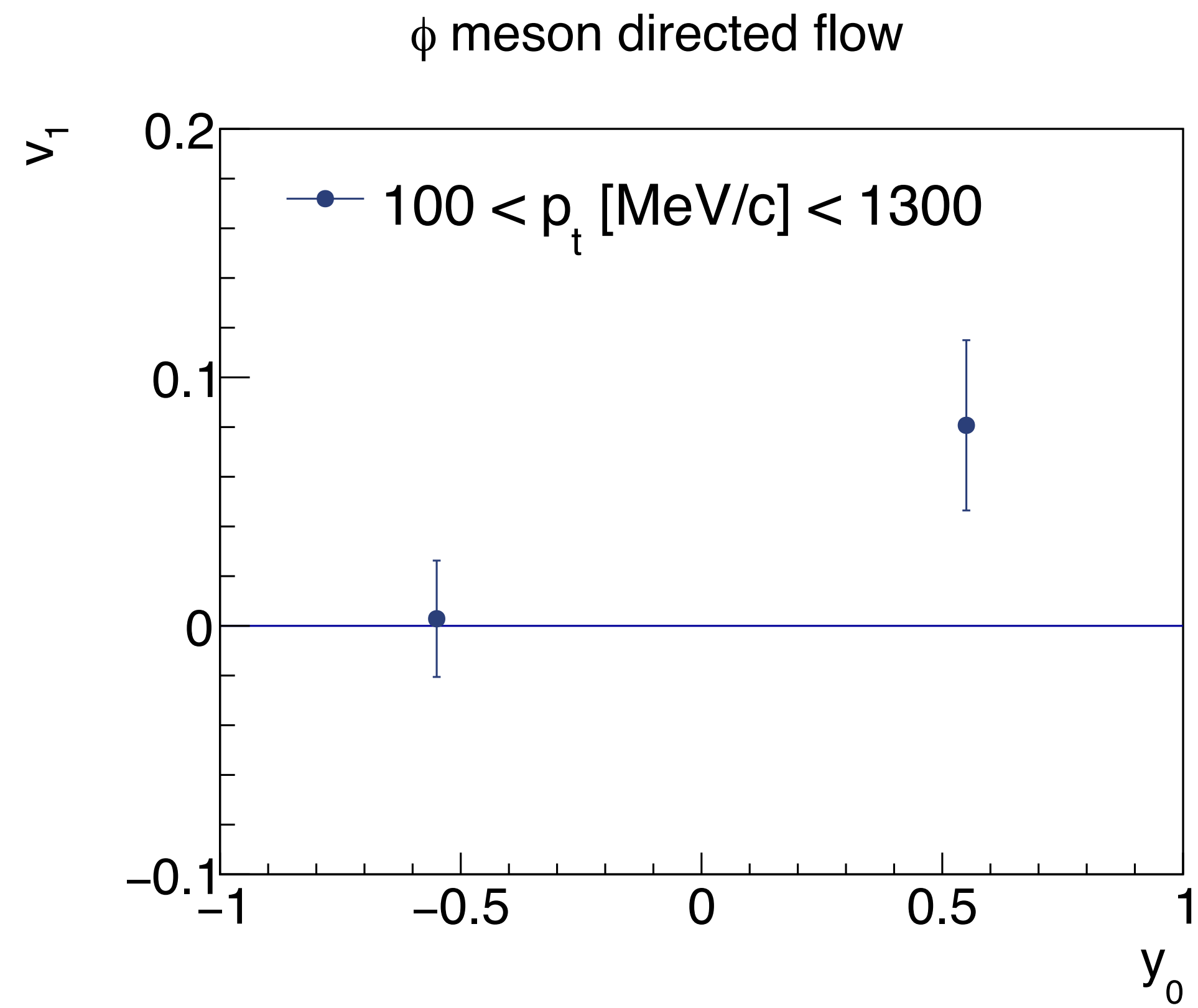
12 $\Delta\phi$ bins, strict topology cuts ($n\sigma$ from symmetry)



12 $\Delta\phi$ bins, strict topology cuts ($n\sigma$ from symmetry)



1 pt bin



1 pt bin + 10 $\Delta\phi_{Lab}$ bins

