Optimising the search for *CP* violation in $D_s^+ \to K^+\pi^+\pi^-$ decays at LHCb

Using forward-backward asymmetry as a probe for CPV

Summer Project 2021
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Supervisors:
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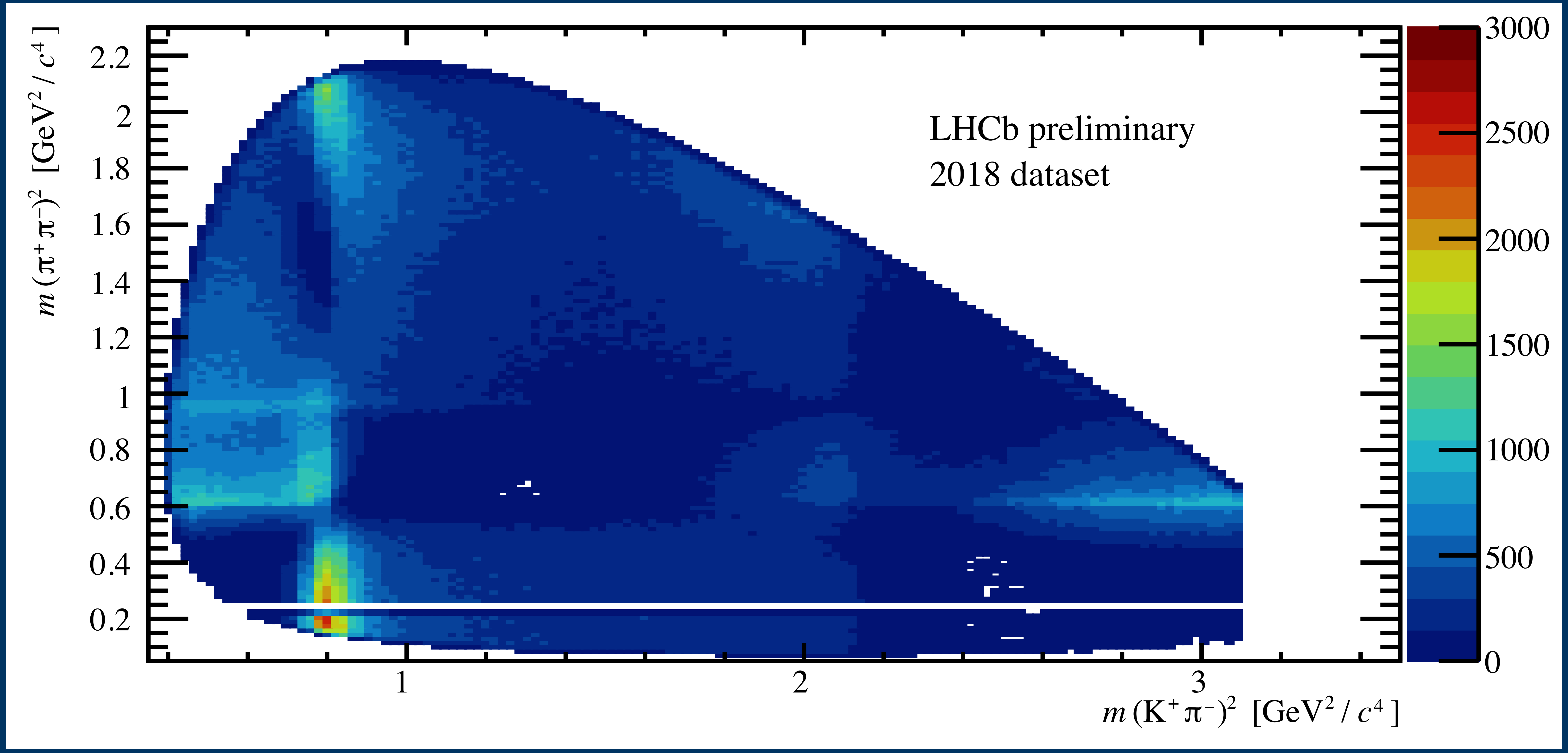
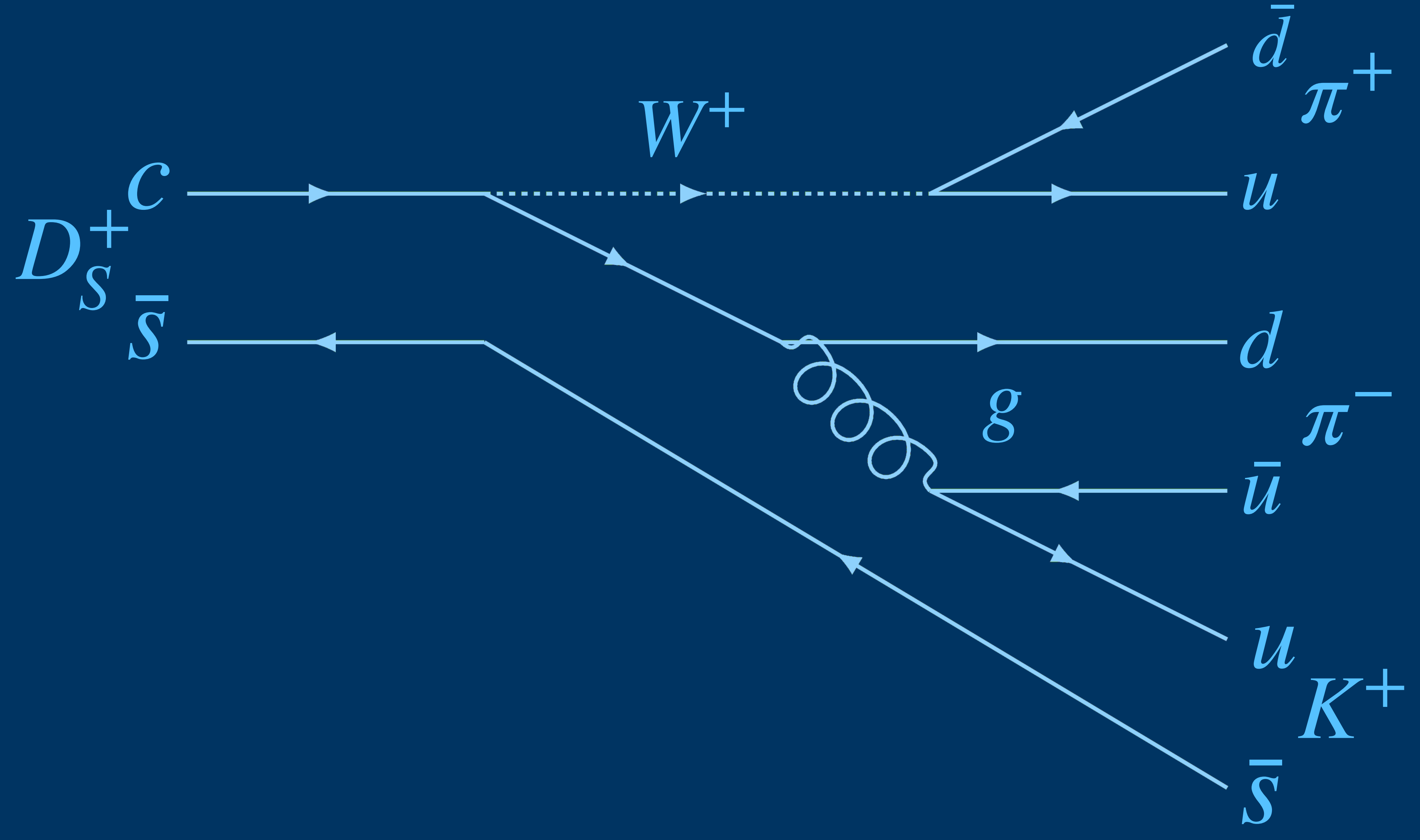
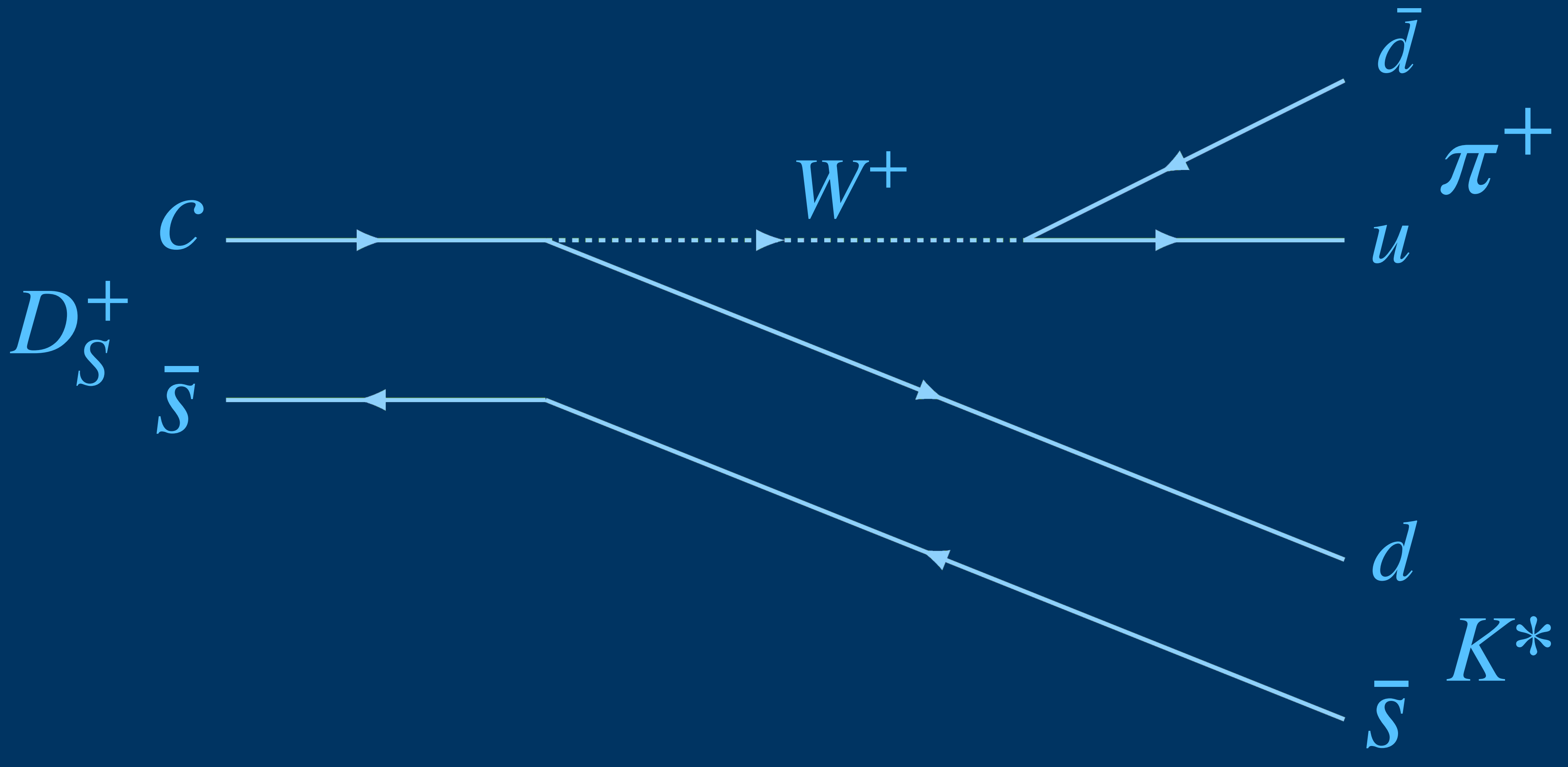
Dr. Laurent Dufour

Dalitz plot & Isobar model







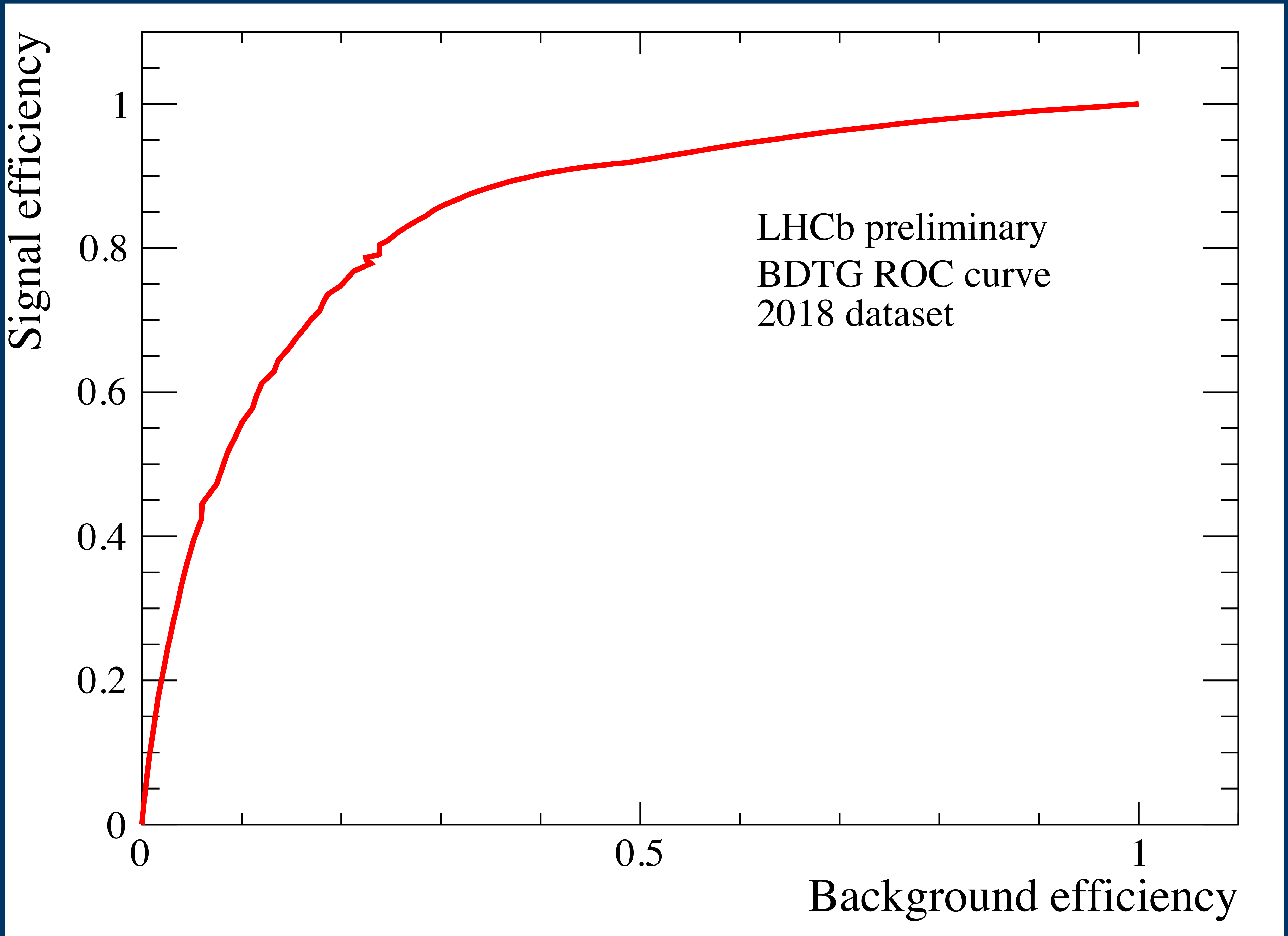
1) $D_S^+ \rightarrow K^+\pi^+\pi^-$

2) $D_S^+ \rightarrow K^+\alpha \rightarrow K^+\pi^+\pi^-$

3) $D_S^+ \rightarrow \pi^+\beta \rightarrow K^+\pi^+\pi^-$

Removing background: BDTG

- D_S^+ Impact parameter of primary vertex
- Secondary vertex χ^2
- D_S^+ Pseudorapidity
- D_S^+ transverse and total momentum
- D_S^+ decay length and lifetime
- D_S^+ flight distance to primary vertex
- Daughter track isolation variables



Cut a signal efficiency of 75%
→ Background rejection 82%

FOCUS collaboration

Based on 567 ± 31 events

Resonances:

$K^*(892)$

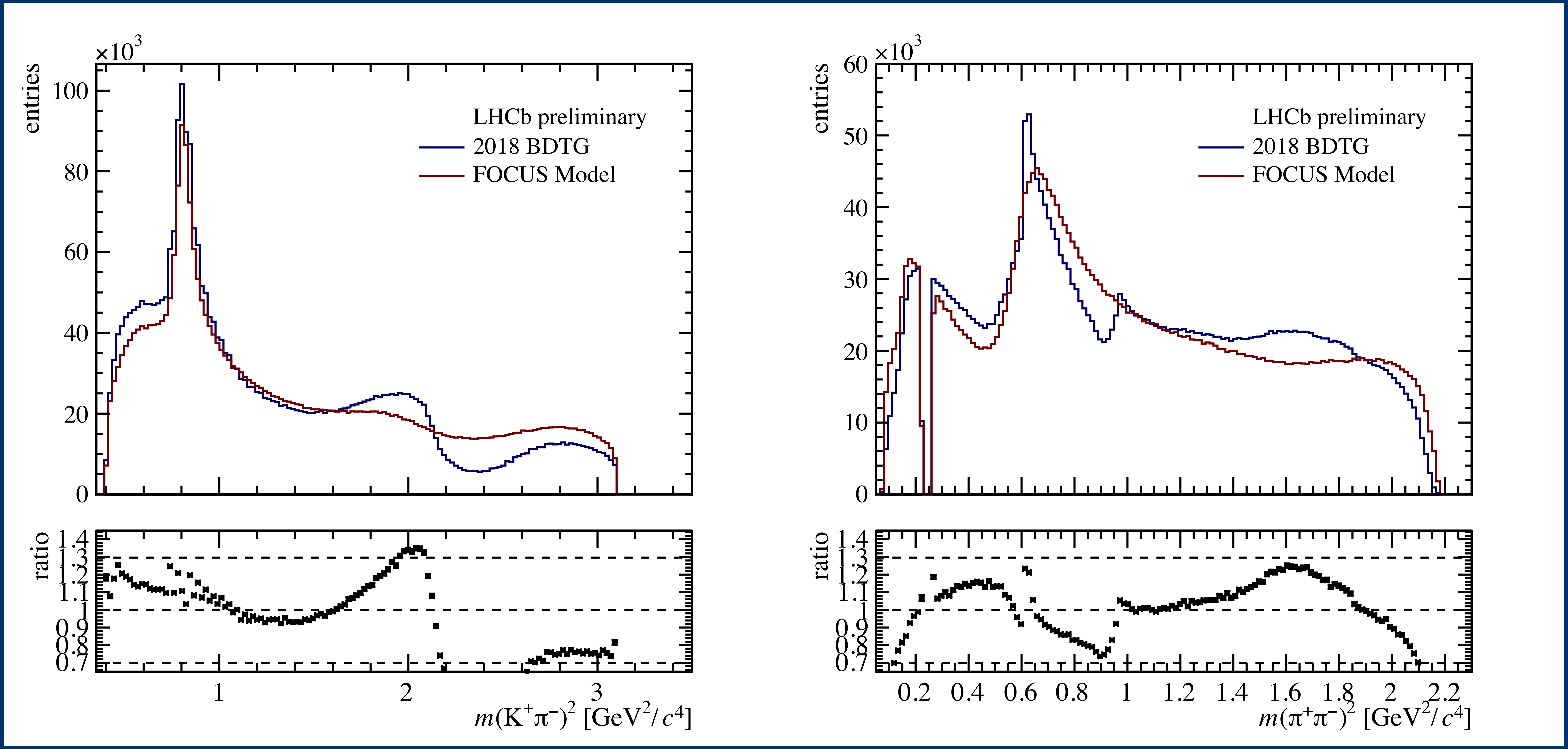
$\rho(770)$

NR

$K^*(1410)$

$K_0^*(1430)$

$\rho(1450)$



Incomplete model, missing structure both in $K^+\pi^-$ and $\pi^+\pi^-$ projection

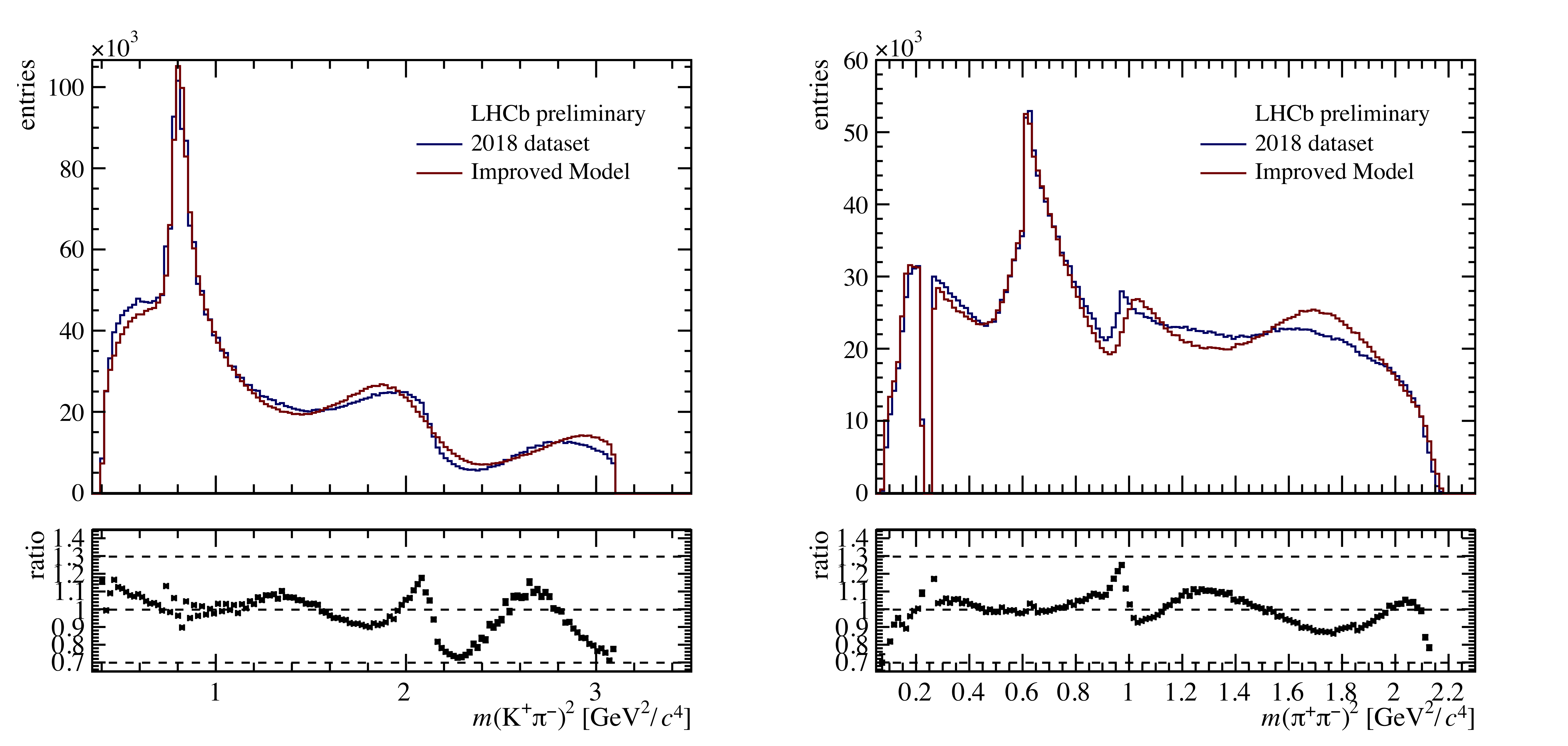
J.M. Link, et al. Phys. Lett. B, 610 (2004), p.10

Improved Model

Based on $3.5 \cdot 10^6$ events

Resonances:

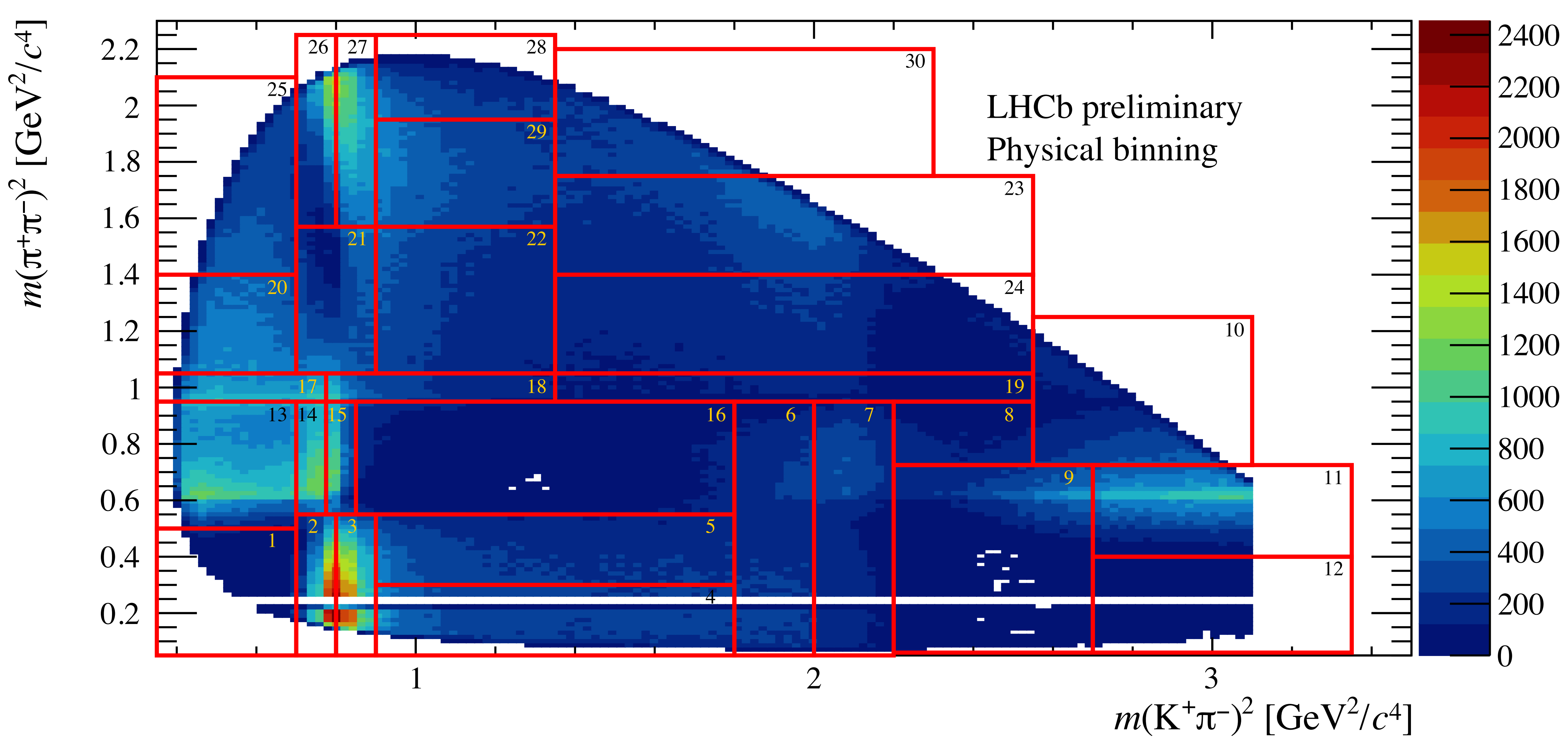
- $K^*(892)$
- $\rho(770)$
- NR
- $K^*(1410)$
- $K_0^*(1430)$
- $\rho(1450)$
- $f_0(980)$
- $f_0(1370)$
- $K_2^*(1430)$
- $\omega(782)$
- $f_2(1270)$



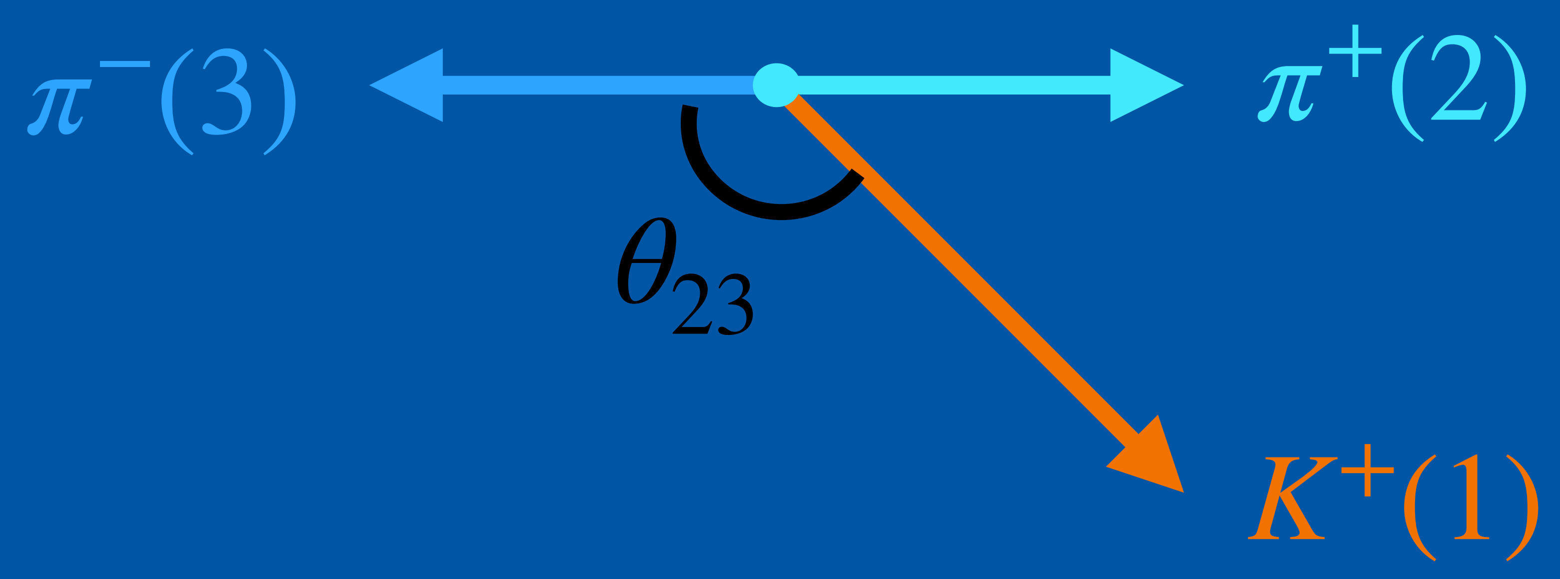
Improvement, yet still incomplete. Still useful for sensitivity study!

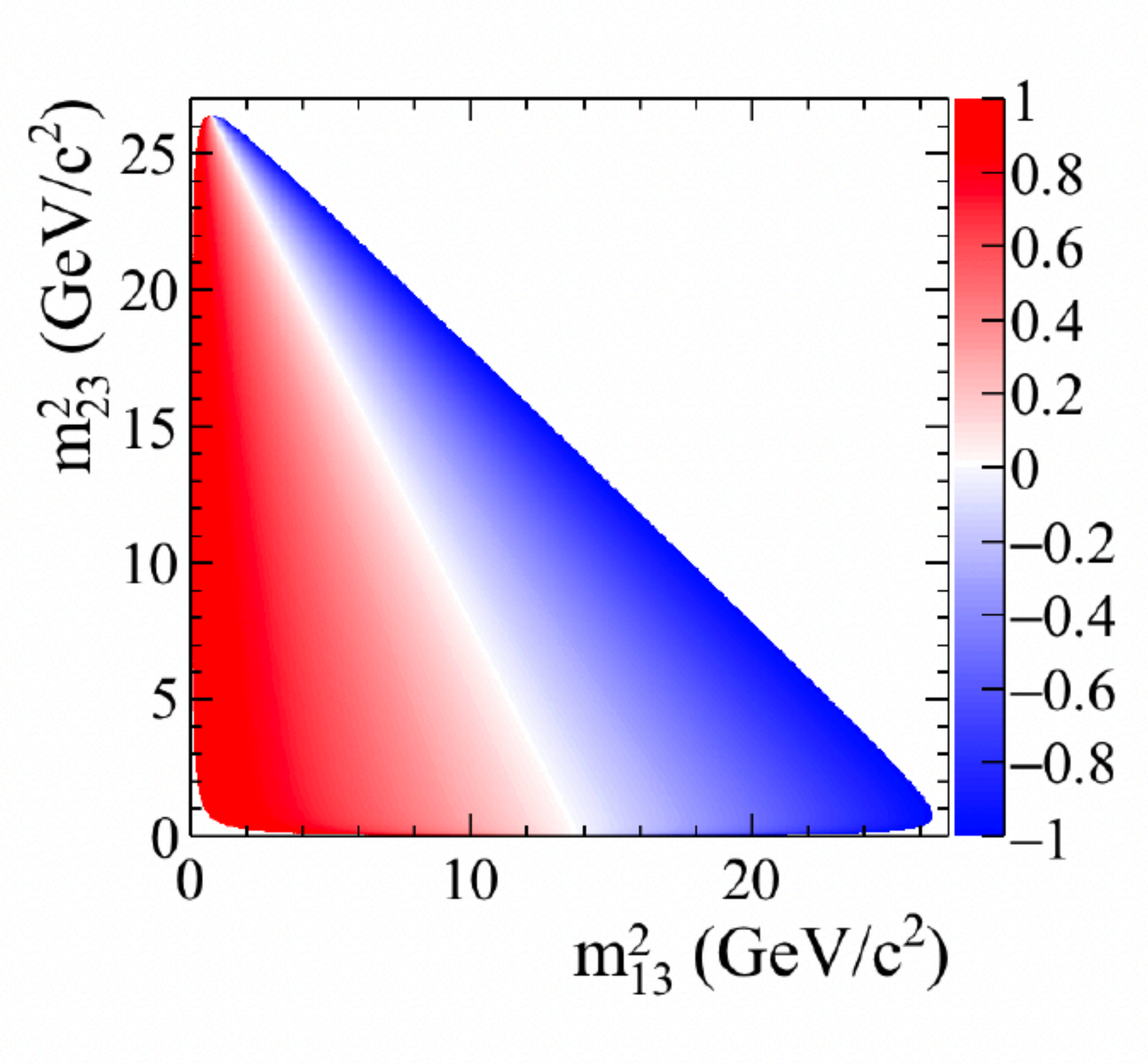
Regional charge asymmetry

$$A_{CP} = \frac{\#D_s^+ - \#D_s^-}{\#D_s^+ + \#D_s^-}$$



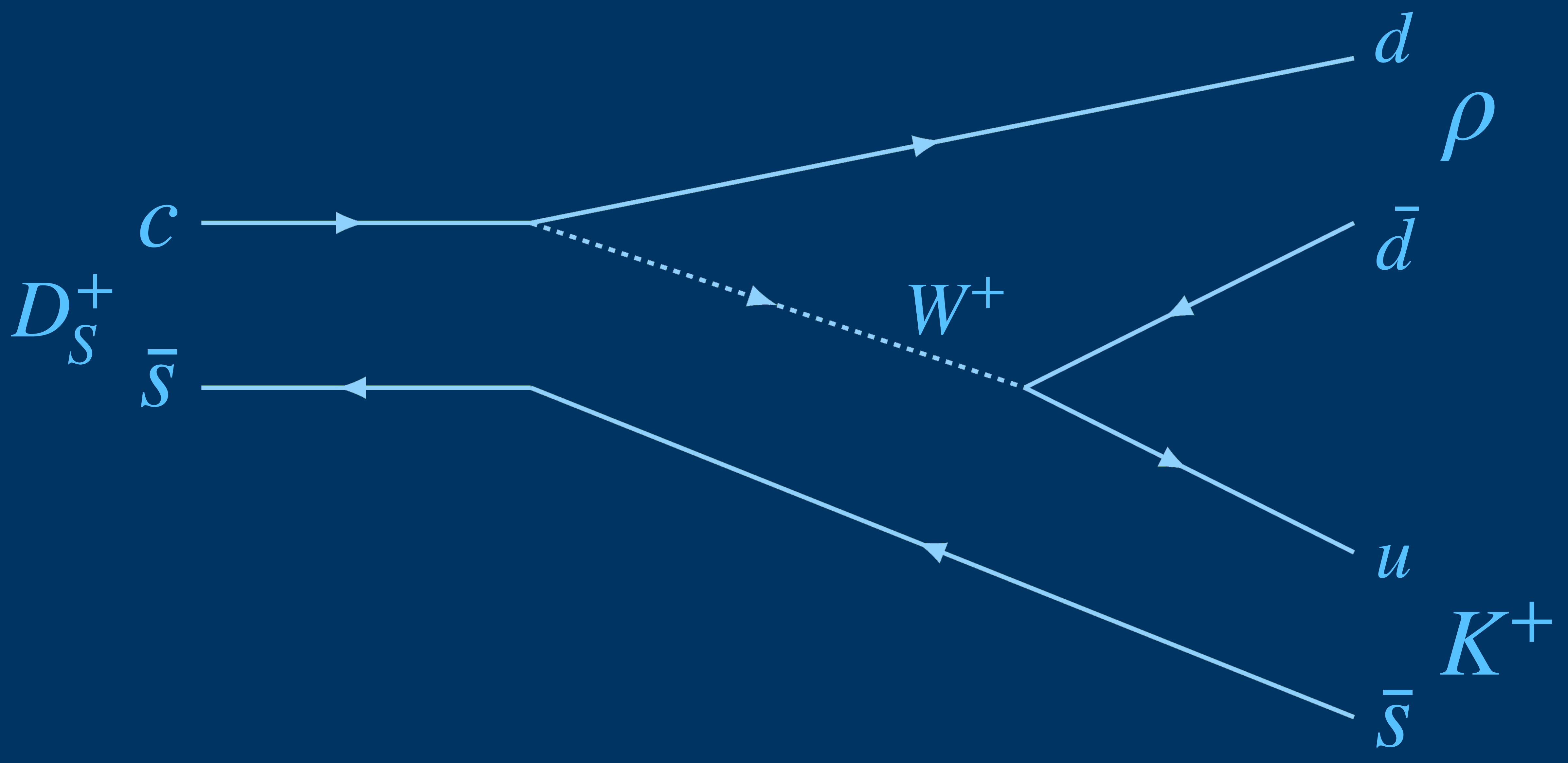
Forward-Backward charge asymmetry in helicity angle

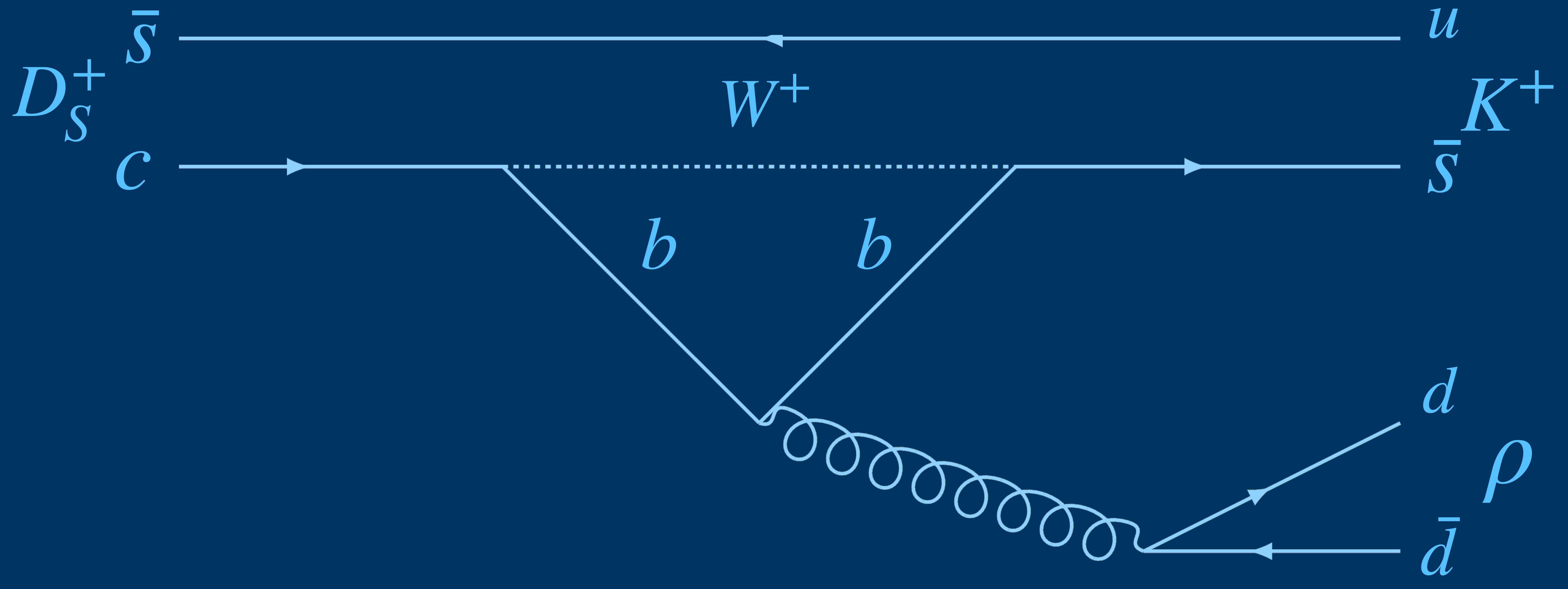




Z.-H. Zhang, Phys.Lett.B 820 (2021)
→ Twice as much statistics

Simulating CP violation





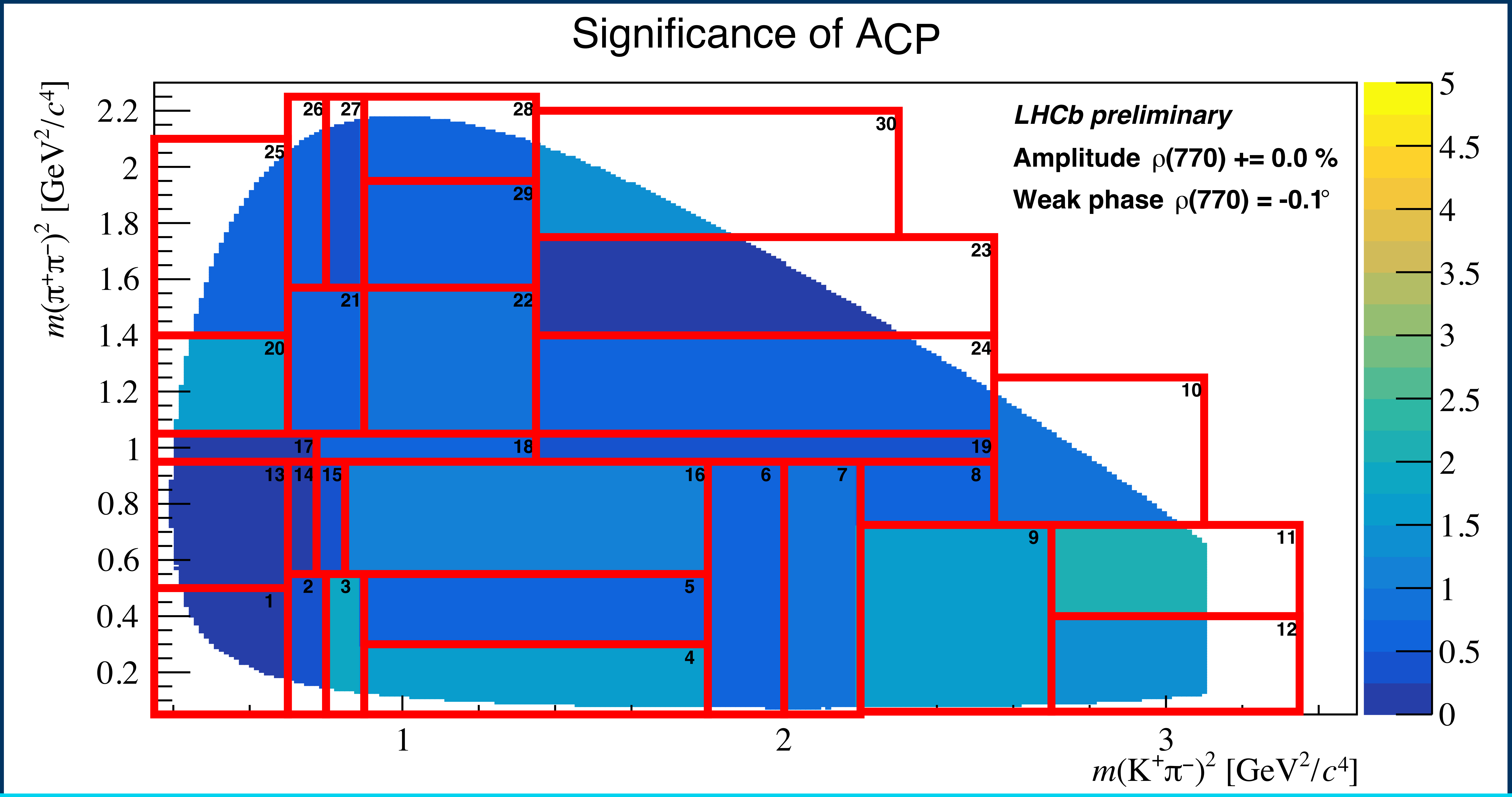
$$A_\rho = |A| e^{i\phi}$$

$$\rightarrow \Delta |A| \in \{-0.2\,\%, -0.1\,\%, 0\,\%, 0.1\,\%, 0.2\%\}$$

$$\rightarrow \Delta\phi \in \{-0.2^\circ, -0.1^\circ, 0^\circ, 0.1^\circ, 0.2^\circ\}$$

Sensitivity results (1 toy example)

$$1.5 \cdot 10^7\ D_S^+ \ \&\ 1.5 \cdot 10^7\ D_S^-$$



Sensitivity results (1 toy example)

ΔA	$\Delta\phi$	**Global** A_{CP-FB}	σ	**Angle**	**Best Bin**	A_{CP}	σ	**Best Bin**	A_{CP-FB}	σ	**Angle**
0.0 %	-0.1°	(-0.013 ± 0.018)%	0.7	θ_{13}	11	(0.158 ± 0.074)%	2.1	10	(-0.388 ± 0.136)%	2.9	θ_{12}
	+0.1°	(-0.018 ± 0.018)%	1.0	θ_{12}	12	(0.614 ± 0.268)%	2.3	12	(0.630 ± 0.268)%	2.4	θ_{13}
-0.1%	-0.1°	(0.030 ± 0.018)%	1.7	θ_{13}	21	(0.242 ± 0.109)%	2.2	21	(-0.253 ± 0.109)%	2.3	θ_{13}
	0.0 °	(-0.038 ± 0.018)%	2.1	θ_{12}	26	(-0.353 ± 0.119)%	3.0	26	(-0.353 ± 0.119)%	3.0	All three
	+0.1°	(-0.043 ± 0.018)%	2.4	θ_{23}	11	(-0.152 ± 0.074)%	2.0	11	(-0.152 ± 0.074)%	2.0	θ_{12} and θ_{23}
+0.1%	-0.1°	(0.028 ± 0.018)%	1.6	θ_{23}	9	(-0.288 ± 0.103)%	2.8	21	(-0.308 ± 0.109)%	2.8	θ_{13}
	0.0 °	(-0.026 ± 0.018)%	1.4	θ_{13}	9	(-0.215 ± 0.103)%	2.1	21	(-0.237 ± 0.109)%	2.2	θ_{13}
	+0.1°	(-0.045 ± 0.018)%	2.5	θ_{12}	13	(-0.190 ± 0.068)%	2.8	13	(-0.190 ± 0.068)%	2.8	θ_{12} and θ_{23}

Forward-backward charge asymmetry not twice as sensitive, but in some regions more sensitive than “regular” charge asymmetry

Outlook

With an increased number of MC events

→Improve BDTG

→Improve detector efficiency map

In general

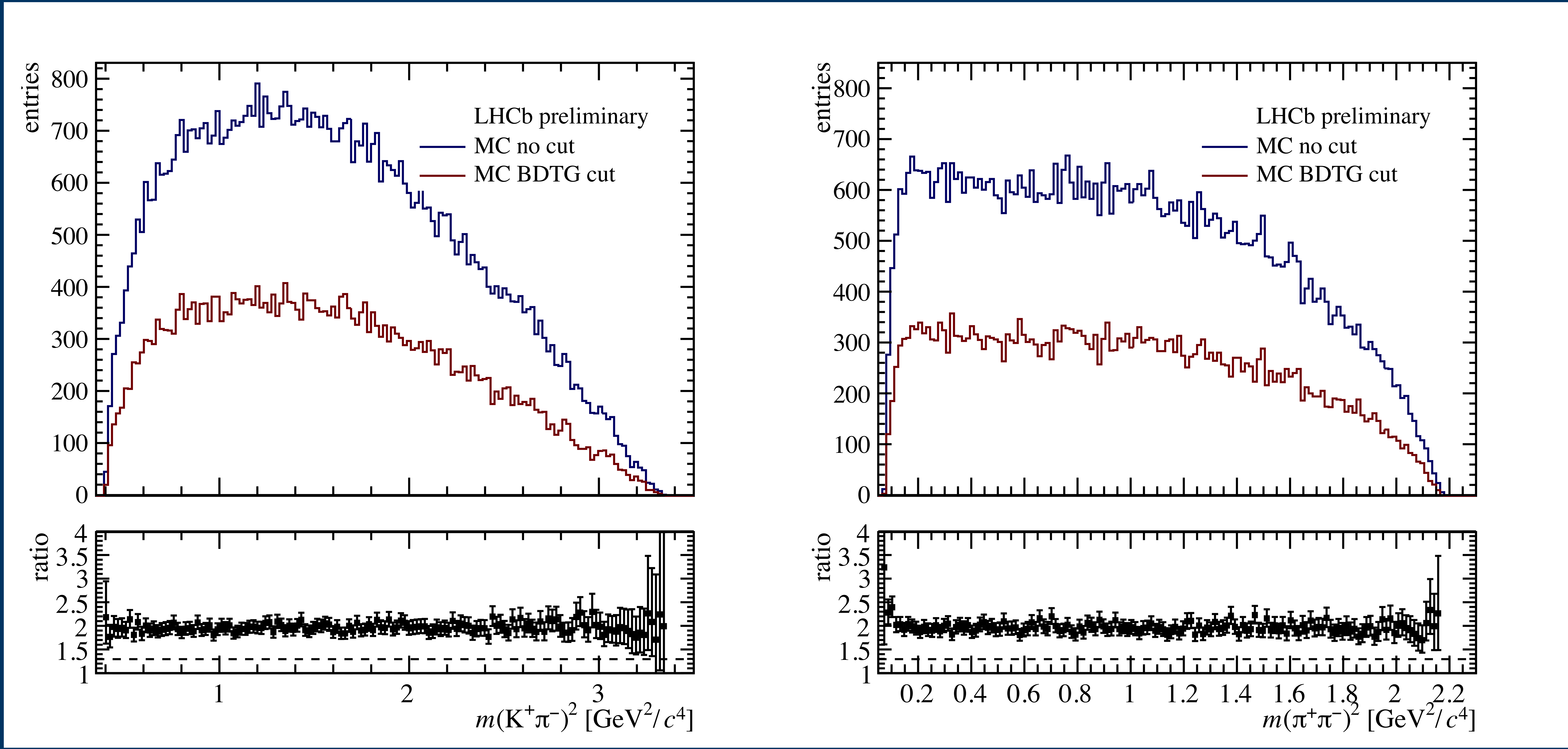
→Introduce CPV in multiple resonances

→Use K-matrix formalism

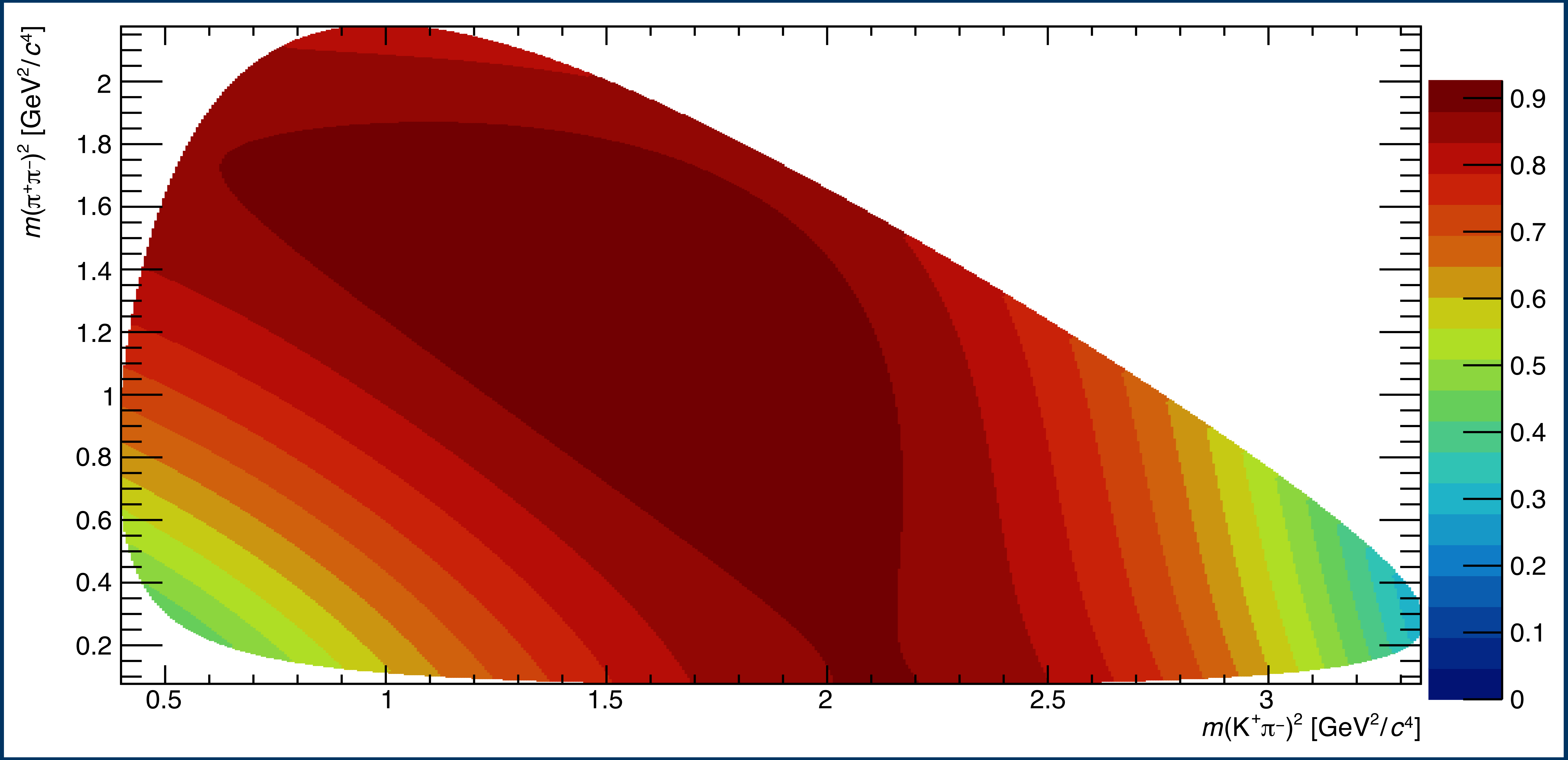
→Performing the CPV analysis on data

Back Up

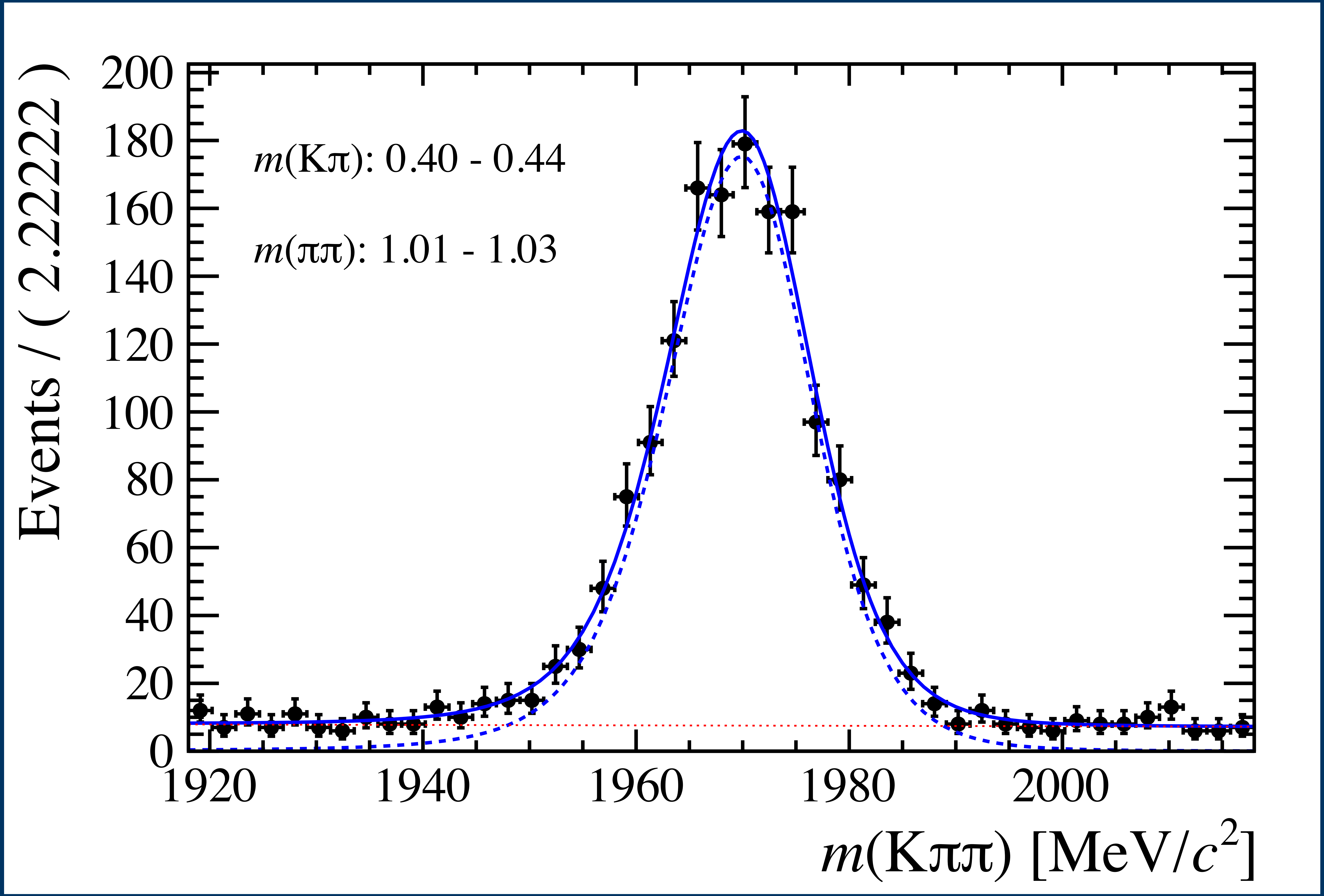
MC Efficiency for BDTG cut at 0.4



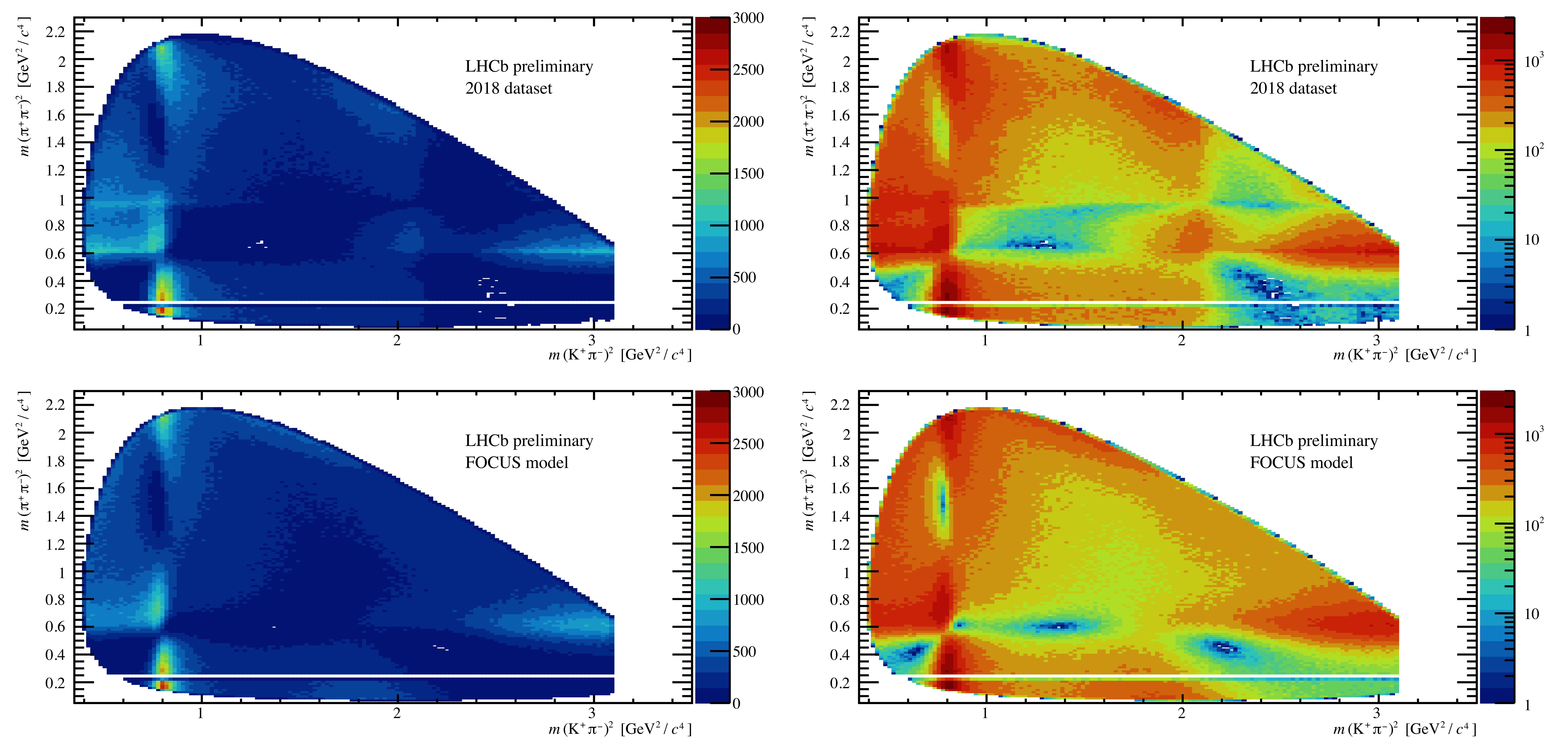
Detector efficiency estimation



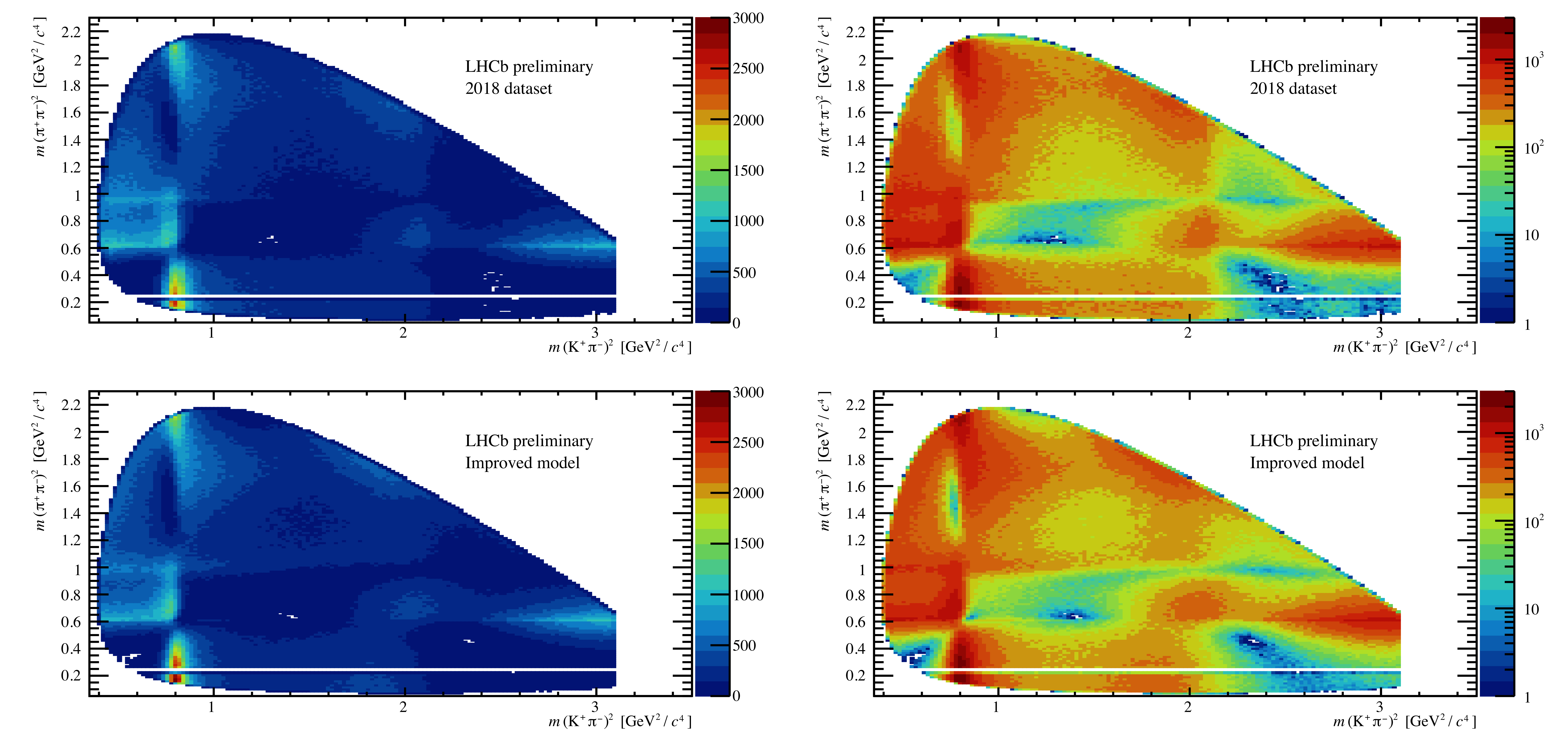
Example of residual background subtraction



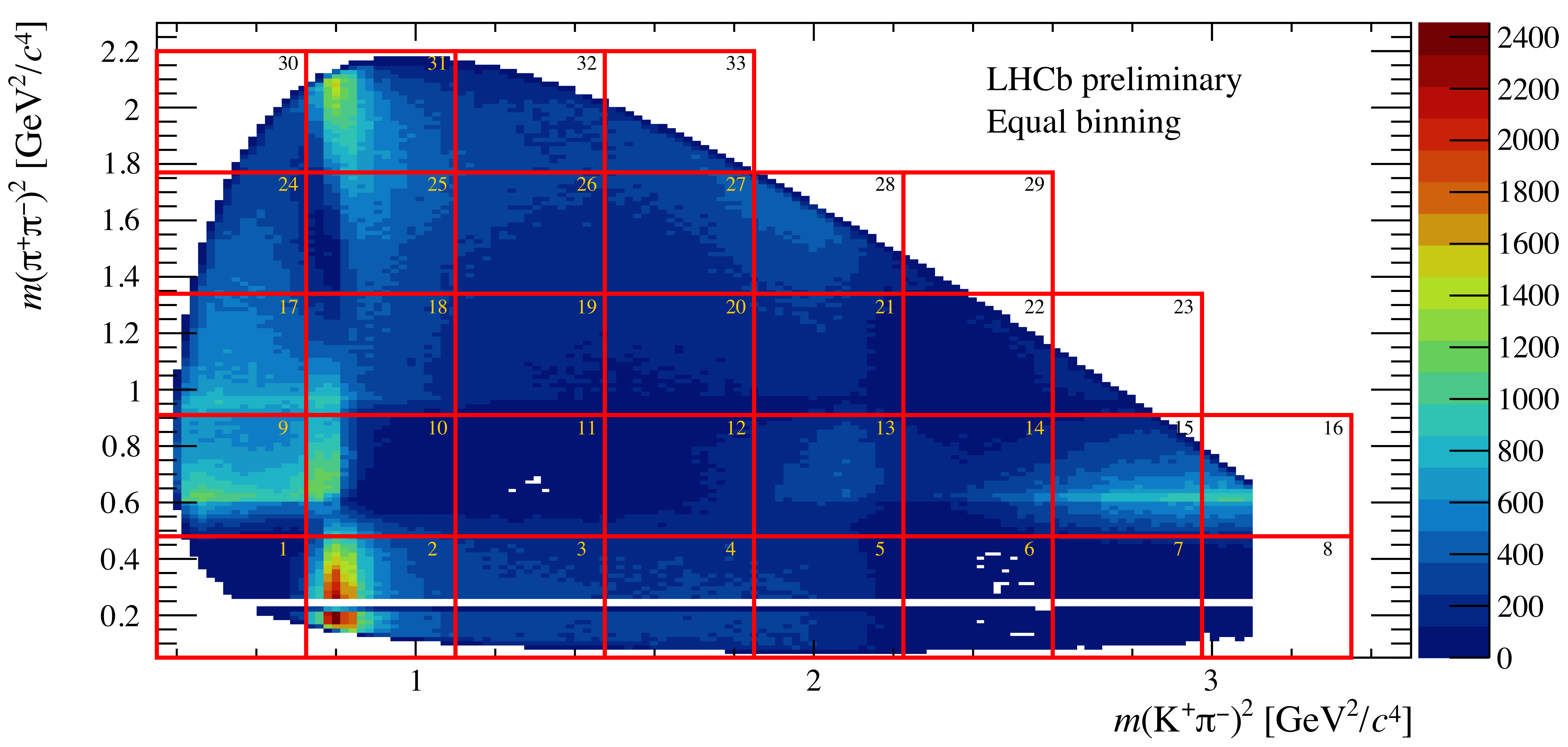
Dalitz plot of model by FOCUS Collaboration



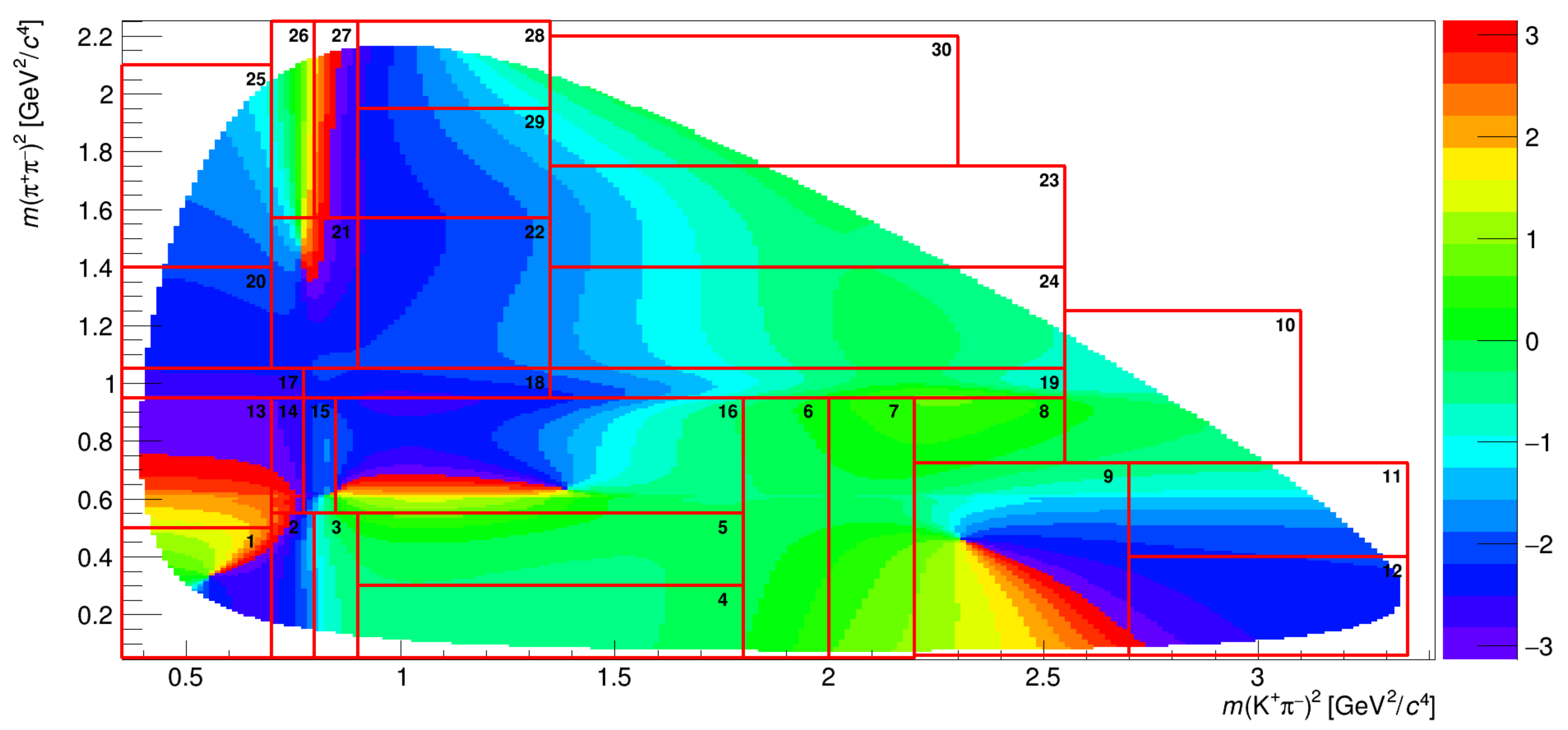
Dalitz plot of Improved model



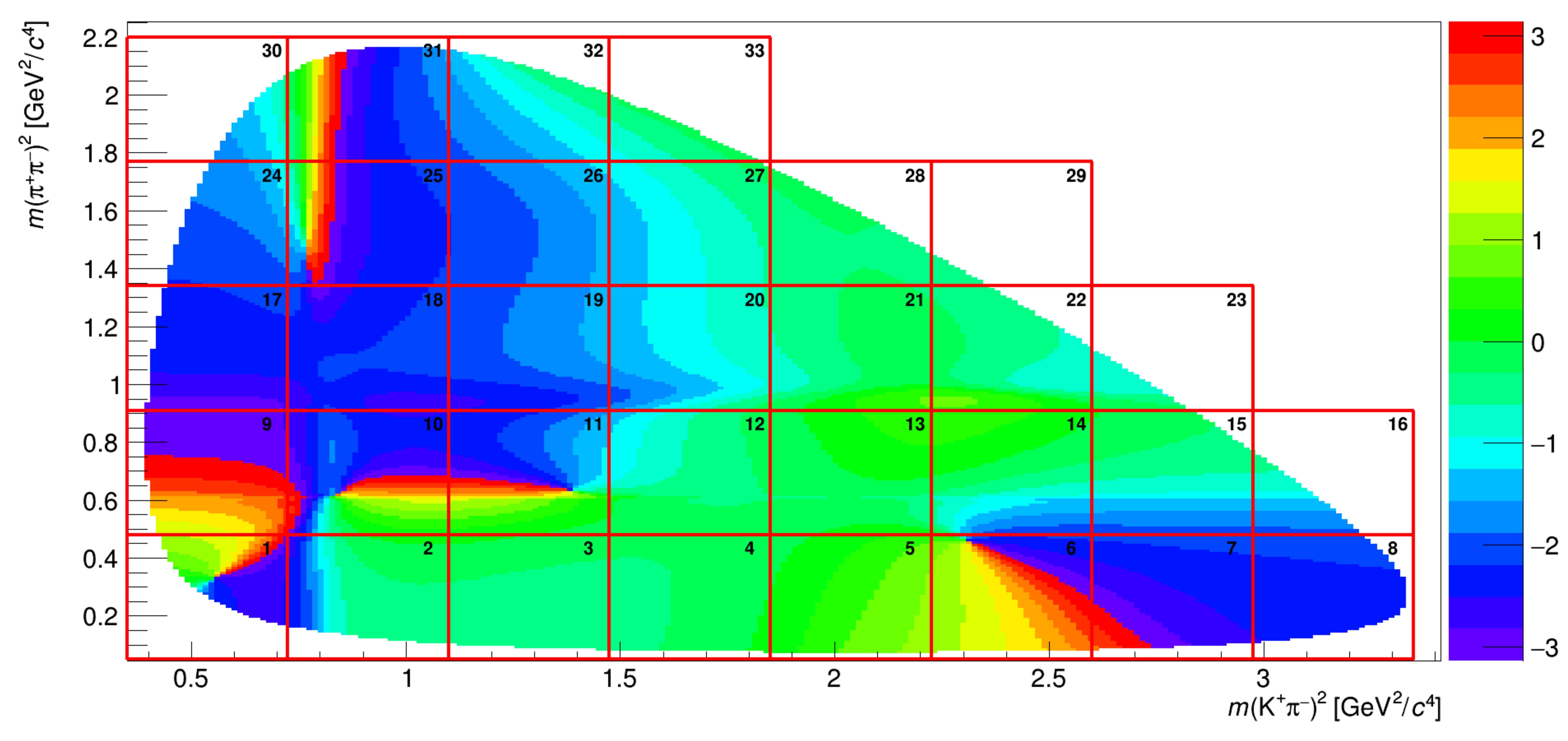
Uniform binning of DP



Phase over DP: Physical Binning



Phase over DP: Uniform binning



Uniform Binning results

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