Carnegie Mellon University

Belle II

Belle II Summer Workshop

Overview of $D^{*+} \rightarrow D^0 (\pi^+ \pi^- \pi^0) \pi^+_s$ Dalitz analysis

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August 2, 2022

Overview

- Introduction
  - A bit about me and my research
  - What is a Dalitz plot?
- Dataset and analysis
- Plots
- Summary

A bit about me…

Graduate student at Carnegie Mellon University in Pittsburgh, Pennsylvania, working with Prof. Roy Briere

Wean Hall, home of CMU's physics department
Photo:Ziplux (CC-BY/SA 3.0)

Member of *Belle II* since June 2018

Validation manager for Data production group, term ends October 2022

Did a lot of work on charm decays in the *Belle II* decay file in 2020 and 2021

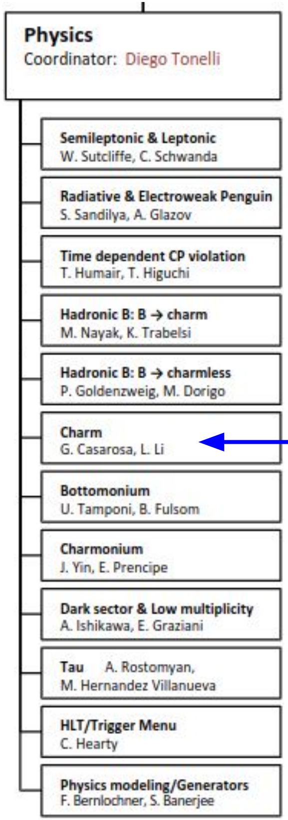
https://stash.desy.de/projects/B2/repos/basf2/browse/decfiles/dec/DECAY_BELLE2.DEC

… and my research

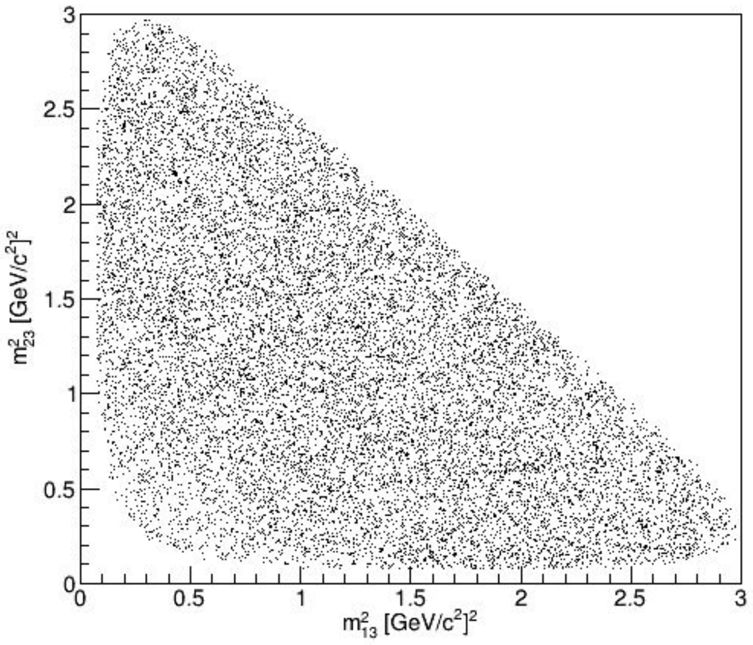
- Time-averaged analysis of $D^0 \to \pi^+ \pi^- \pi^0$ Dalitz plot using D*-tagged D^0 mesons to look for CP violation (CPV) in this decay
  - $D^{*+} \to D^0 \pi^+_s$, and charge conjugate
  - π^+_s = "slow pion"; charge of slow pion "tags" the flavor of the D meson
- Possible types of Dalitz analyses:
  - Energy test: statistical test on distribution, compare to expected value for non-CPV sample
  - Amplitude analysis: amplitude model fit, look for asymmetry between D^0 and anti-D^0 amplitudes
  - **Binned analysis**: look directly for asymmetries in bins of Dalitz plot and define a per bin asymmetry, $\mathcal{A}_{CP}$ = (difference between bins in D^0 and anti-D^0 plots)/(sum of bins)
- Cabibbo-suppressed mode $\Rightarrow$ need relatively large amount of data to get good result, BUT a good place to look for CPV from New Physics

Aside: recent results from Charm WG include Λ_c lifetime measurement being published in PRL and Ω_c lifetime measurement targeting PRD

From Belle II org. chart:



What is a Dalitz plot?



Why does this work?
If $M \rightarrow m_1\ m_2\ m_3$, then:
$M^2 + m_1^{\ 2} + m_2^{\ 2} + m_3^{\ 2} = m_{12}^{\ 2} + m_{13}^{\ 2} + m_{23}^{\ 2}$,
i.e., squares of invariant pair masses sum to a constant

What does this show?
Phase space is proportional to the area of the Dalitz plot.
Structure in the Dalitz plot reveals resonances and their angular dependence.
A flat Dalitz plot (such as this one) indicates no resonances in the decay.

MC15ri_b dataset

200 fb^{-1} of generic MC15, unskimmed

Produced with release-06-00-08

User analysis run on gbasf2 with light-2201-venus

Aside: if you have problems using gbasf2, send an email to comp-users-forum@belle2.org.
You can subscribe to this and other listservs via https://lists.belle2.org/.

$D^{*+} \to D^0 (\pi^+ \pi^- \pi^0 (\gamma\gamma)) \pi^+_s$

Item	Requirement
γ reconstruction	`isFromECL and E > 0.100 and clusterE9E21 > 0.9 and cluster E1E9 > 0.3 and thetaInCDCAcceptance;` at most one photon in an endcap
π^0 reconstruction	`0.105 < InvM < 0.150`
$\pi^\pm$ reconstruction	`dr < 0.5 and abs(dz) < 2.0 and thetaInCDCAcceptance and PID(π,K)_noSVD > 0.4`
π_s reconstruction	`dr < 0.5 and abs(dz) < 2.0 and thetaInCDCAcceptance`
D^0 reconstruction	`1.70 < M < 2.10;` flightSignificance > -0.4 (apply cut after vertex fits)
D* reconstruction	`massDifference(0) < 0.160 and useCMSFrame(p) > 2.5;`vertex fit decay tree w/mass fit on π^0, chiProb>0.001; vertex fit decay tree w/mass fit on π^0 and D^0, chiProb>0
Event cuts	`none`
Other cuts	Best candidate selection on χ-probability of second vertex fit; 492.5 MeV/c^2 < $m(\pi^+ \pi^-)$ < 500.0 MeV/c^2 (K_S^0 veto)
Corrections applied to data	Track momentum and photon energy bias corrections

Highlighted cuts have been changed in more recent versions of this analysis.

Aside: good time to plug B2 Questions https://questions.belle2.org/ and Sphinx documentation https://software.belle2.org/

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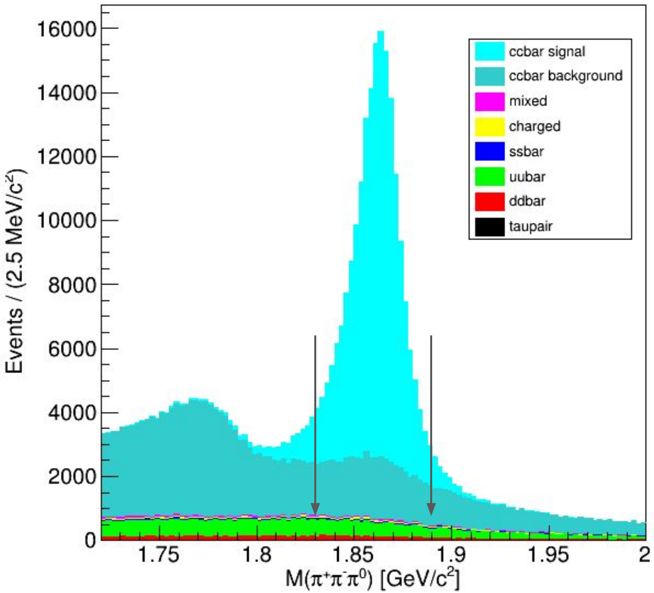
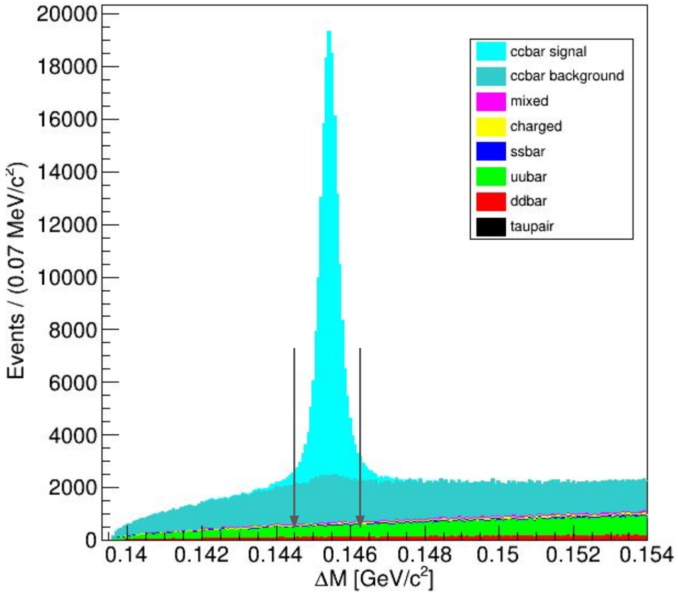
Signal-enhanced* mass plots

$\Delta M = M(D^*) - M(D^0)$, so-called "D*-trick"
ΔM resolution is sharper than resolution for either D^* or D^0 mass peak





Sometimes people will plot $Q = \Delta M - m(\pi_s)$ instead

*Each variable is cut on the other, i.e., for $M(3\pi)$ plot, 144.5 MeV/c^2 < ΔM < 146.2 MeV/c^2 and for ΔM plot, 1.83 GeV/c^2 < $M(3\pi)$ < 1.89 GeV/c^2.

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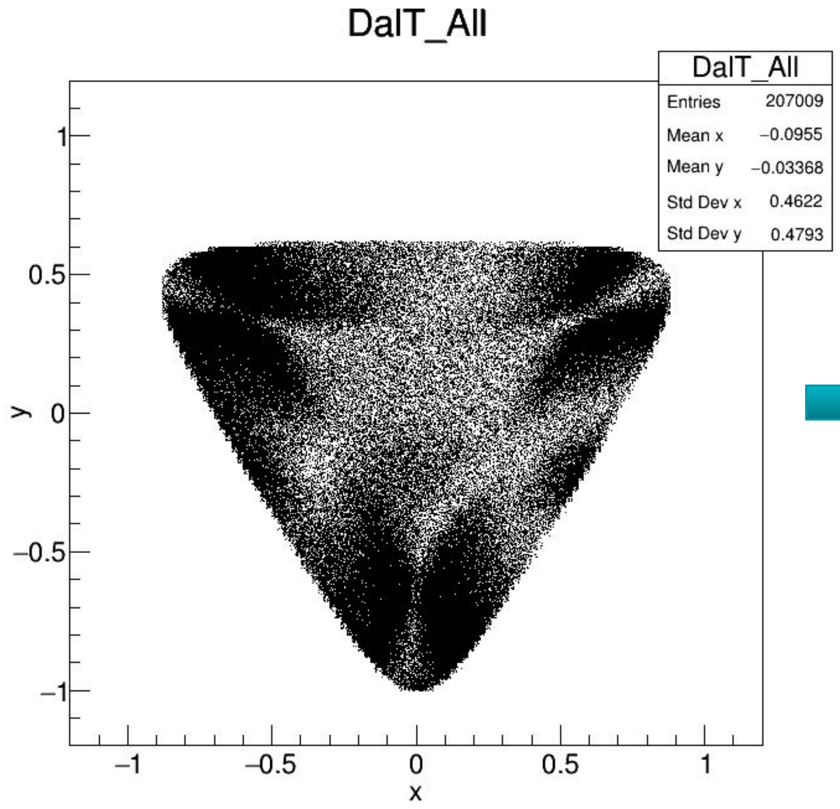
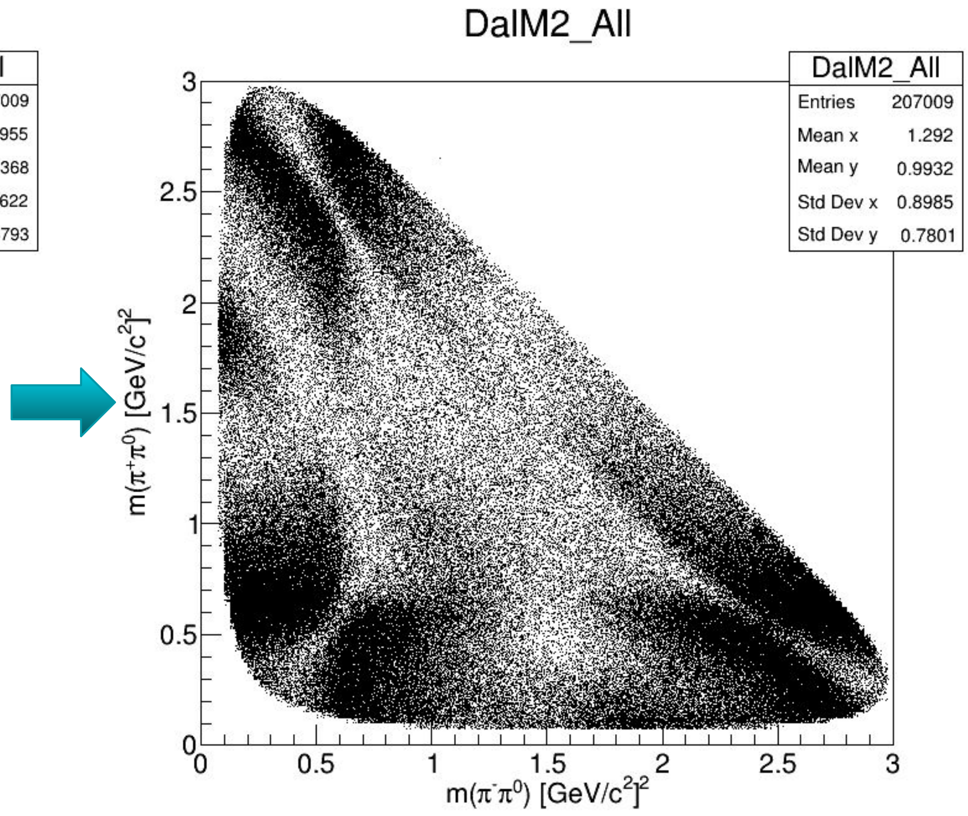
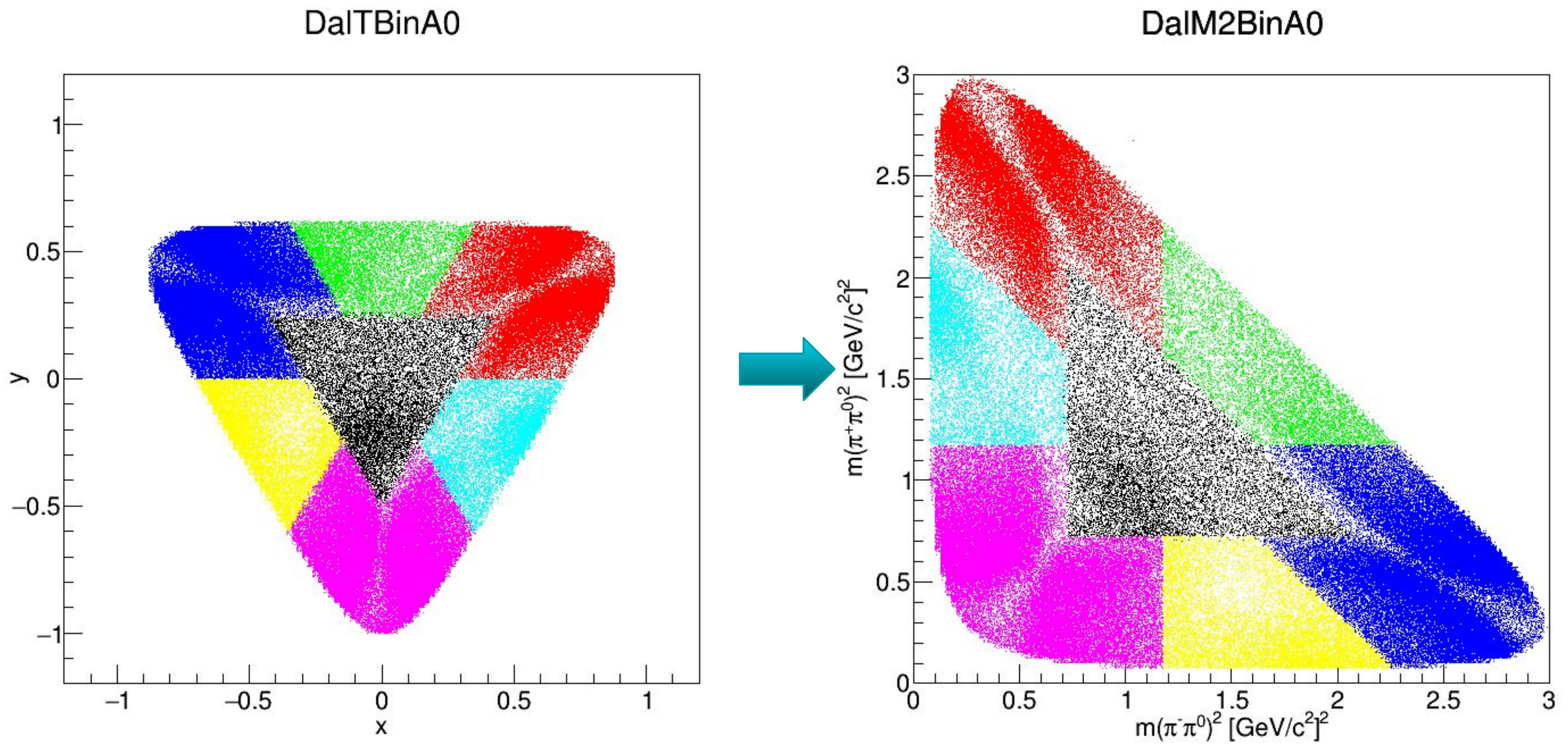
Dalitz plot, signal region





Dalitz binning, signal region



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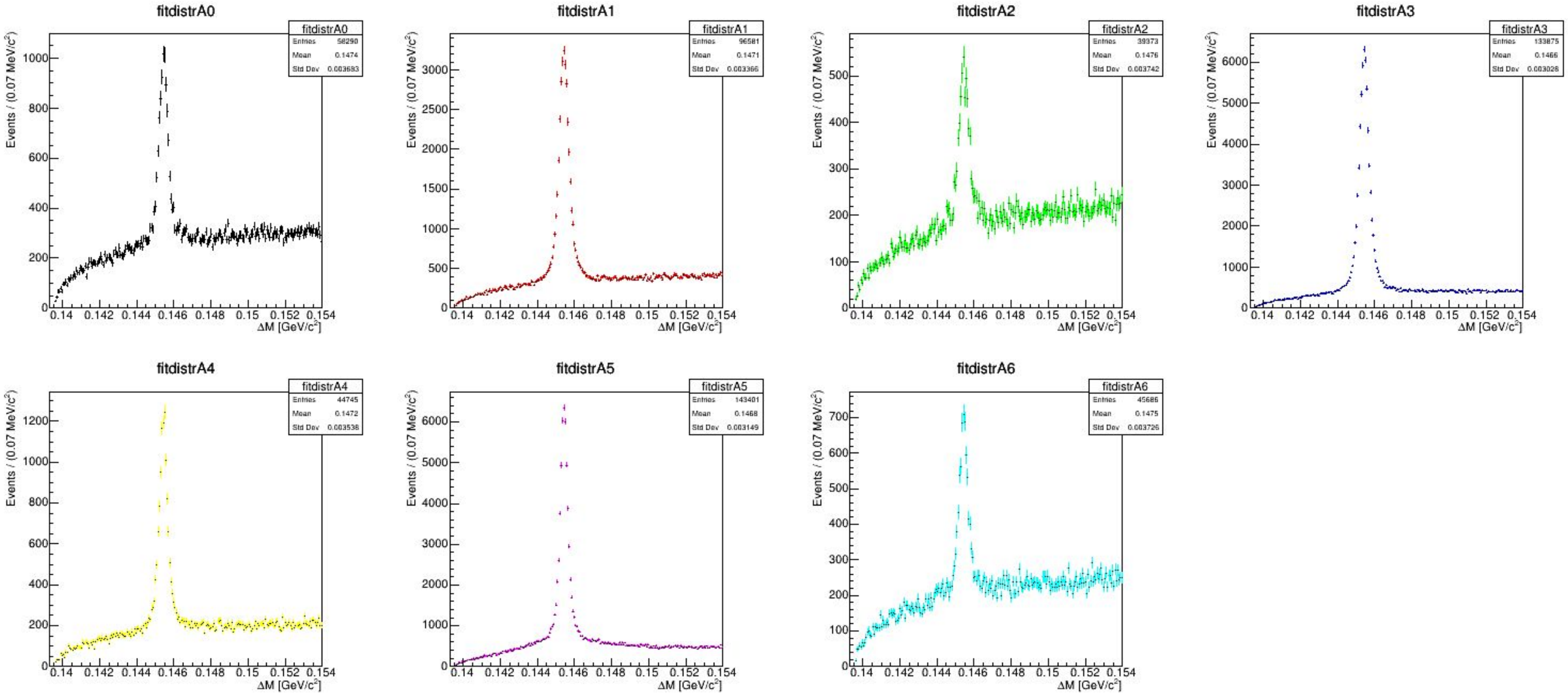
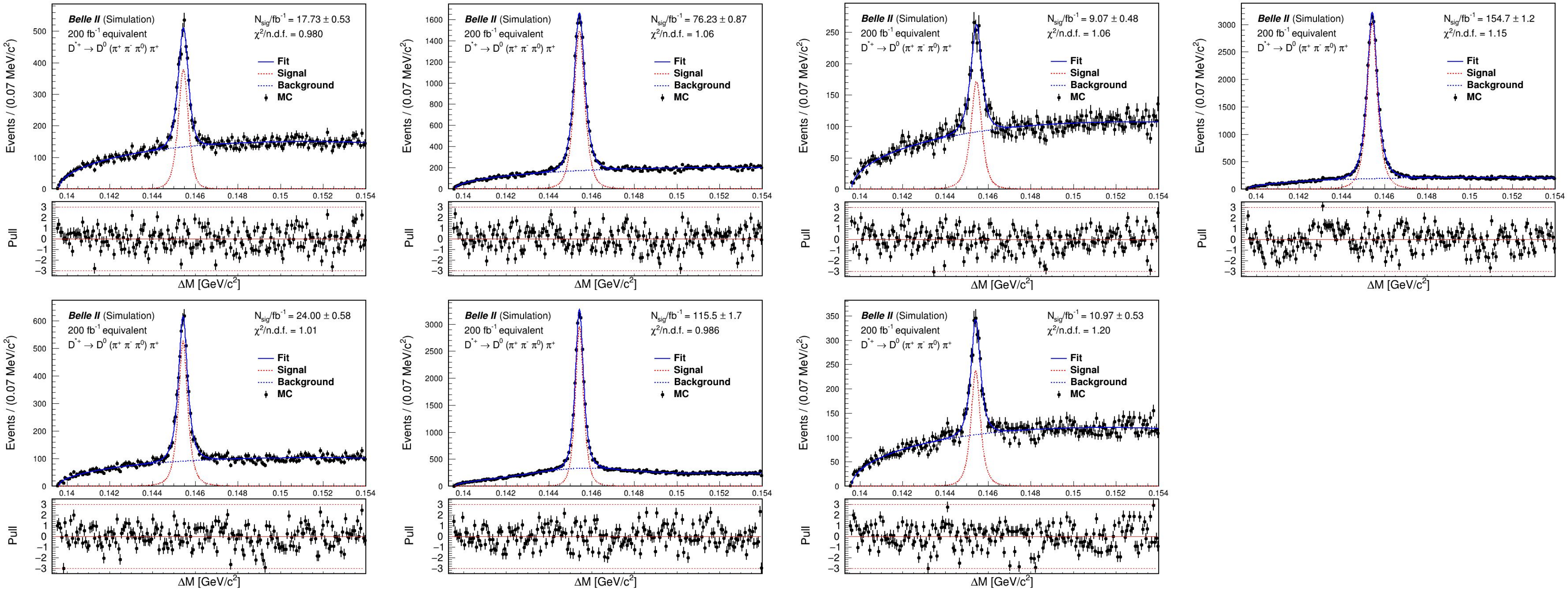
ΔM plots in Dalitz bins, M(D^0) signal region

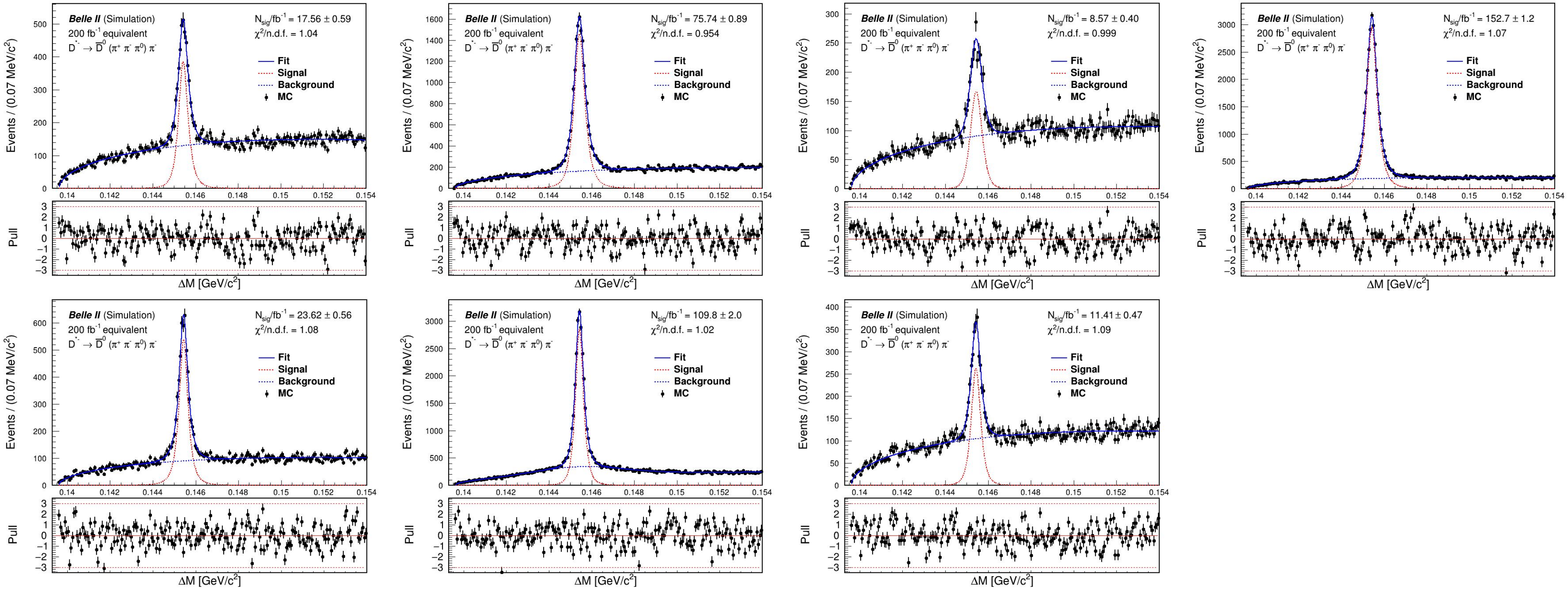


Fits per bin, D*+



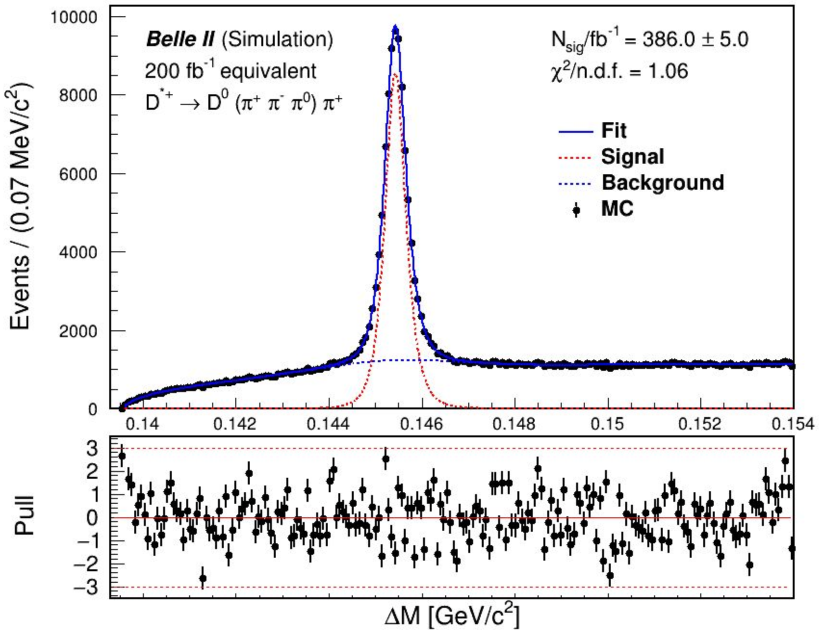
Aside: guidelines for public plots can be found at https://stash.desy.de/projects/B2D/repos/belle2style/browse

Fits per bin, D*⁻

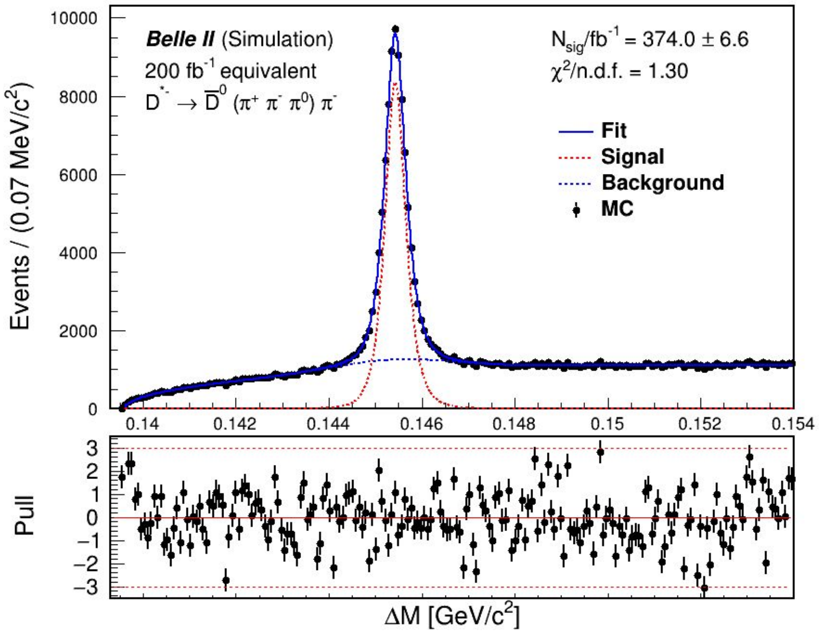


Global fit plots

D^{*+}



D^{*-}



Johnson's S_U signal + Gaussian and threshold function to 3/2 power background

Summary of fit results, signal

Bin	Signal function	Background function	χ^2/ndf (D^{*+} / D^{*-})	Yield/fb^{-1} (D^{*+} / D^{*-})	Asymmetry
center	Johnson's S_U	3/2 power threshold	0.980 / 1.04	17.73 ± 0.53 / 17.56 ± 0.59	(0.5 ± 2.2)%
A1	Johnson's S_U	3/2 power threshold	1.06 / 0.954	76.23 ± 0.87 / 75.74 ± 0.89	(0.032 ± 0.82)%
A2	Johnson's S_U	3/2 power threshold	1.06 / 0.999	9.07 ± 0.48 / 8.57 ± 0.40	(2.8 ± 3.5)%
A3	Johnson's S_U	3/2 power threshold	1.15 / 1.07	154.7 ± 1.2 / 152.7 ± 1.2	(0.65 ± 0.55)%
A4	Johnson's S_U	3/2 power threshold	1.01 / 1.08	24.00 ± 0.58 / 23.62 ± 0.56	(0.7 ± 1.7)%
A5	Johnson's S_U	Gaussian + 3/2 power threshold	0.986 / 1.02	115.5 ± 1.7 / 109.8 ± 2.0	(2.5 ± 1.2)%
A6	Johnson's S_U	3/2 power threshold	1.20 / 1.09	10.97 ± 0.53 / 11.41 ± 0.47	(-2.0 ± 3.2)%
Global fit	Johnson's S_U	Gaussian + 3/2 power threshold	1.06 / 1.30	386.0 ± 5.0 / 374.0 ± 6.6	(1.6 ± 1.1)%

All of these values are consistent with 0 (i.e., no asymmetry), BUT the fact that out of seven bins only one calculated asymmetry has a negative central value points to some systematic asymmetries affecting our measurements.

Sources of asymmetry

- $\mathcal{A}_{\text{tot}} = \mathcal{A}_{\text{CP}} + \mathcal{A}_{\text{other}} \Rightarrow \mathcal{A}_{\text{CP}} = \mathcal{A}_{\text{tot}} - \mathcal{A}_{\pi\text{s}} - \mathcal{A}_{\text{FB}}$
- $\mathcal{A}_{\text{tot}}$ is what we find from the ΔM fits, but what we actually want is $\mathcal{A}_{\text{CP}}$
- $\mathcal{A}_{\pi\text{s}}$ is the slow pion reconstruction asymmetry; $\mathcal{A}_{\text{FB}}$ is the forward-backward production asymmetry
- We can find $\mathcal{A}_{\pi\text{s}}$ by looking at a Cabibbo-favored (CF) mode. Assuming it is the same across all Dalitz plot bins (see backup slides for why we can assume this), we can subtract it from $\mathcal{A}_{\text{tot}}$.
- $\mathcal{A}_{\text{FB}}$ is generally found by adding bins of opposite cosθ in the center-of-mass (CM) frame.
- This is separate from accounting for sources of systematic error, which we also have to do.

Summary

- This is just one type of physics analysis you can do with *Belle II* data and software - there are many more!
- Even something that seems like a straightforward question can become quite complex, especially in systematic error analysis
- Plots shown here are a couple months out of date - I've continued to work on this analysis and plan to graduate, with this as my PhD thesis, next year

Backup

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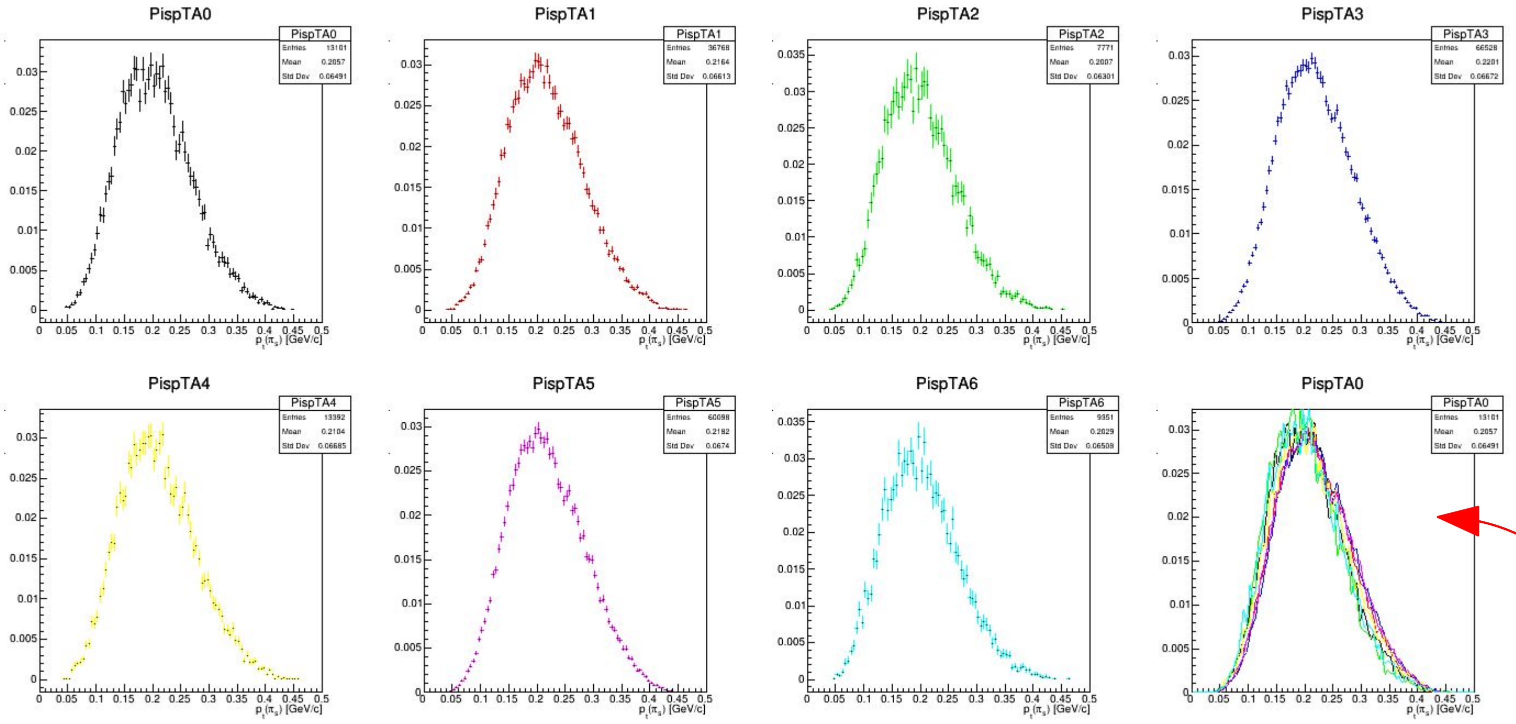
Slow pion p_T plots



Two distinct shapes are coming from the different signal-to-background ratios in some bins, not from different behavior within the signal.

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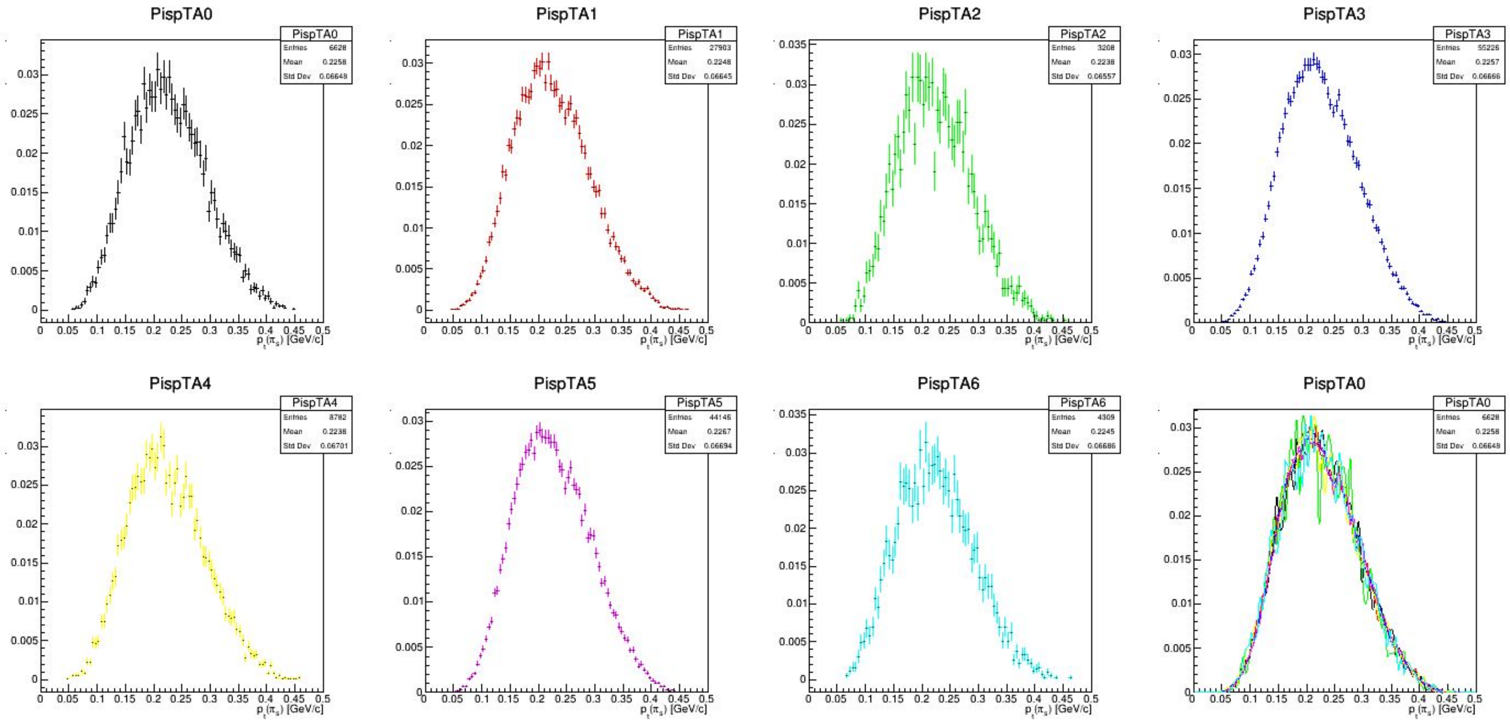
Slow pion p_T plots, signal only



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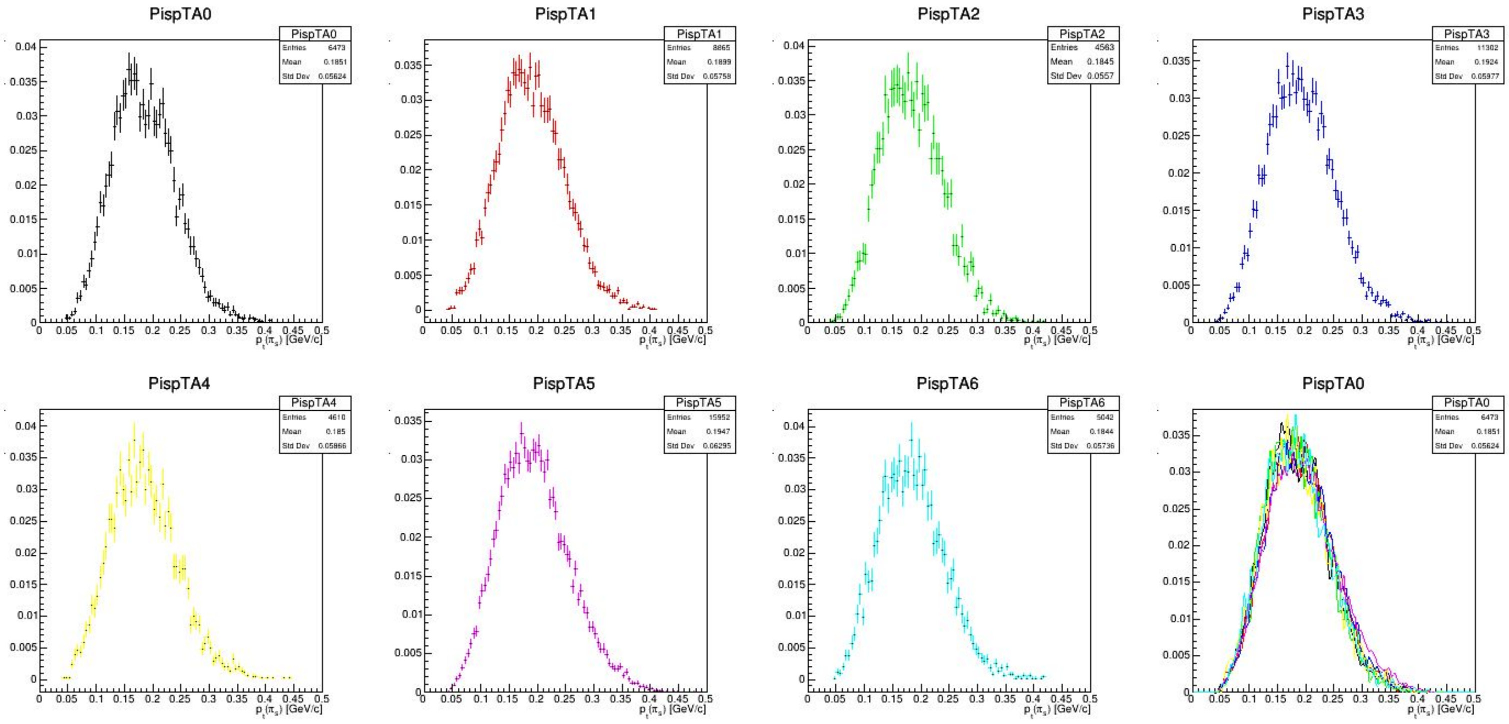
Slow pion p_T plots, background only



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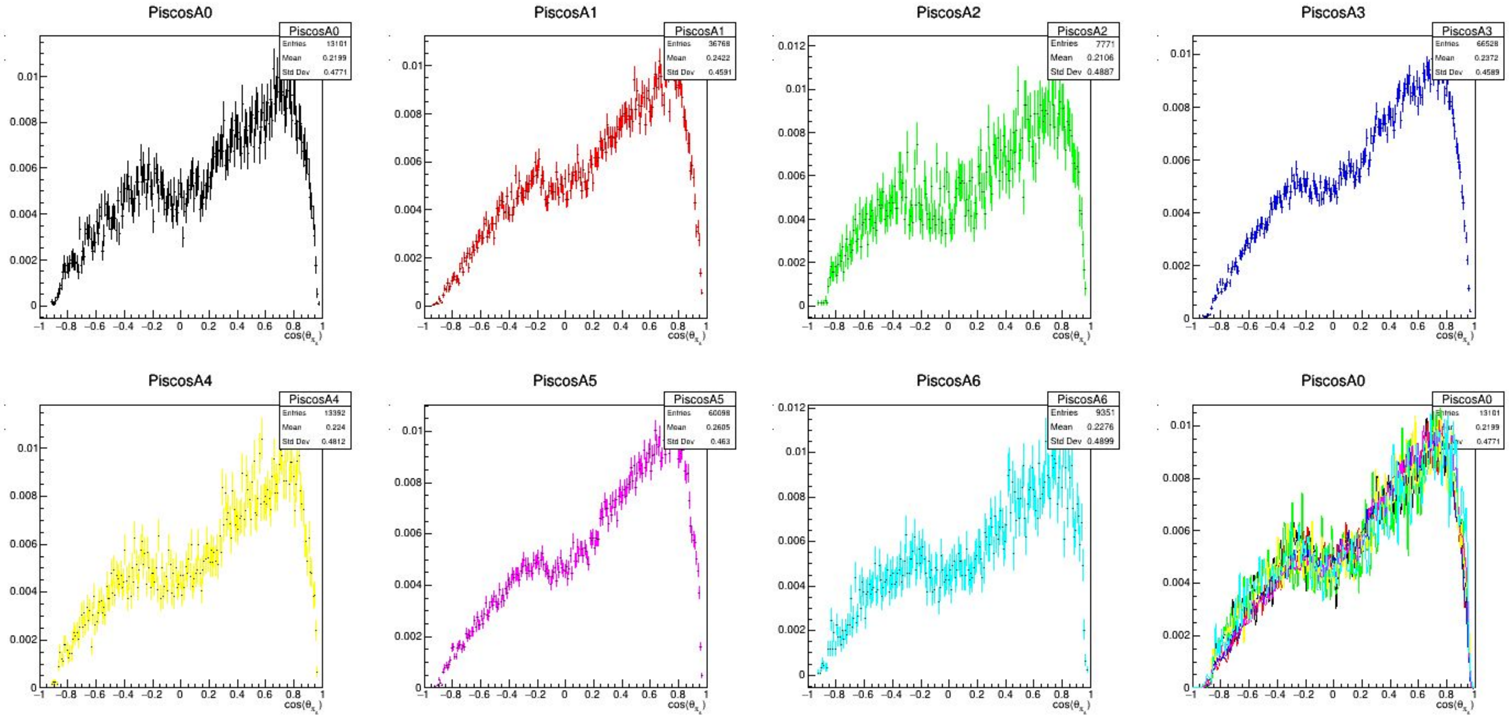
Slow pion cos(θ) plots



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Slow pion p_T vs. $\cos(\theta)$ plots