γ analysis update in $B^{\pm} \to (K^+K^-\pi^+\pi^-)_D K^{\pm}$ decays

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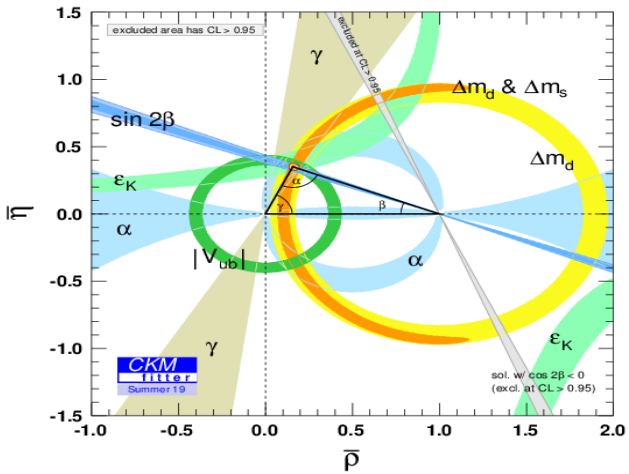


Outline

Summary of last time

- $B^{\pm} \to DK^{\pm}$, $D \to K^+K^-\pi^+\pi^-$, arXiv:hep-ph/0611272
- Model independent measurement with BESIII strong phase input
- Estimate 2000 B events from LHCb Run 1 and 2
  - Benchmark: $\sigma(\gamma) = 11^{\circ}$ from model dependent fit
  - LHCb amplitude model in AmpGen, arXiv:1811.08304
- Pull study to test and optimize binning scheme
  - Simulated 1000 experiments with 2000 events each
  - Strong phases from amplitude model using MC integration

Binning scheme

- Aim: Pick binning scheme to maximize $x_\pm$ and $y_\pm$ sensitivity

Event yield in bin i

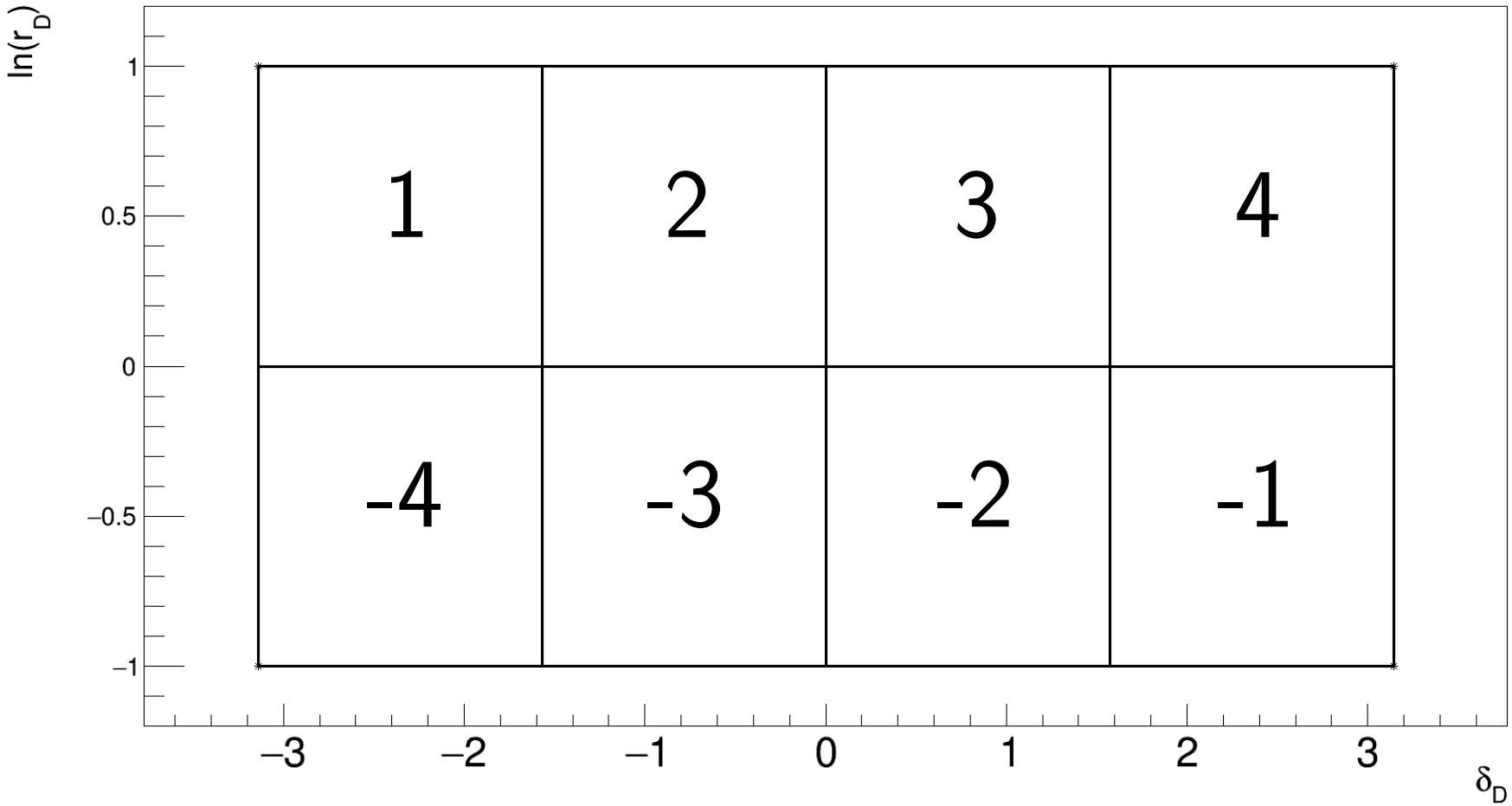
$$N_i^+ = h_{B^+}\left(\bar{K}_i + (x_+^2 + y_+^2)K_i + 2\sqrt{K_i\bar{K}_i}(x_+c_i - y_+s_i)\right)$$
$$N_{-i}^+ = h_{B^+}\left(K_i + (x_+^2 + y_+^2)\bar{K}_i + 2\sqrt{K_i\bar{K}_i}(x_+c_i + y_+s_i)\right)$$
$$x_\pm = r_B\cos(\delta_B \pm \gamma), \quad y_\pm = r_B\sin(\delta_B \pm \gamma)$$

- Previously: Rectangular parameterization of 5D phase space
- Better and simpler:
  - Generate C++ source code for amplitude model using AmpGen
  - Evaluate amplitude directly in analysis
  - Decide bin based on strong phase and amplitude ratio directly

Strong phase and amplitude ratio

$$\mathcal{A}(D^0)/\mathcal{A}(\bar{D}^0) = r_D\exp(i\delta_D)$$

Naive ampltiude binning scheme



Optimize bin widths

- Optimize $x_\pm$, $y_\pm$ sensitivity
- Vary bin edges, keep symmetric around $\delta_D = 0$

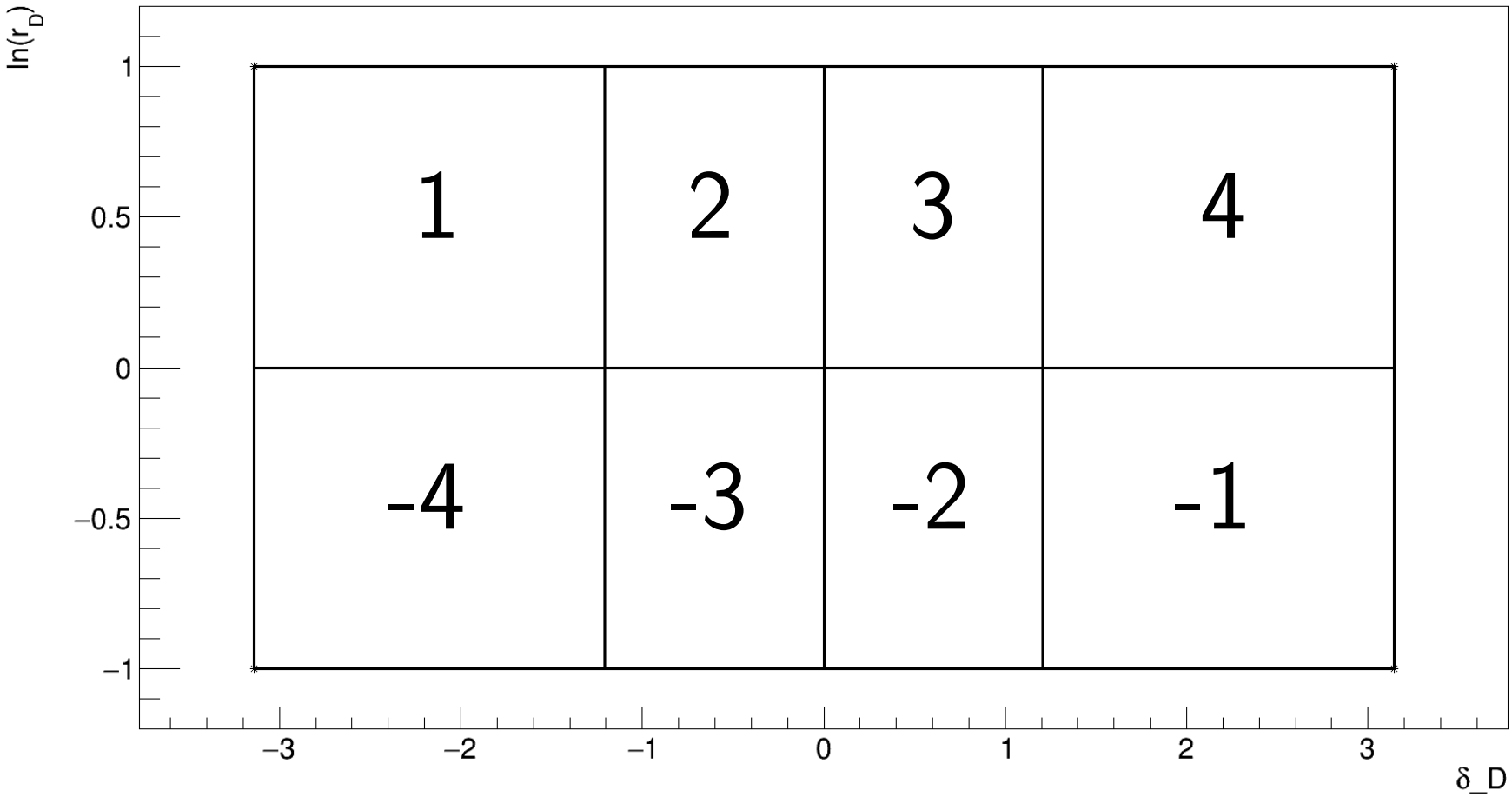
Binning Q value

$$Q^2 = 1 - \sum_i \frac{K_i \bar{K}_i (1 - c_i^2 - s_i^2)}{N_i} \Big/ \sum_i K_i$$

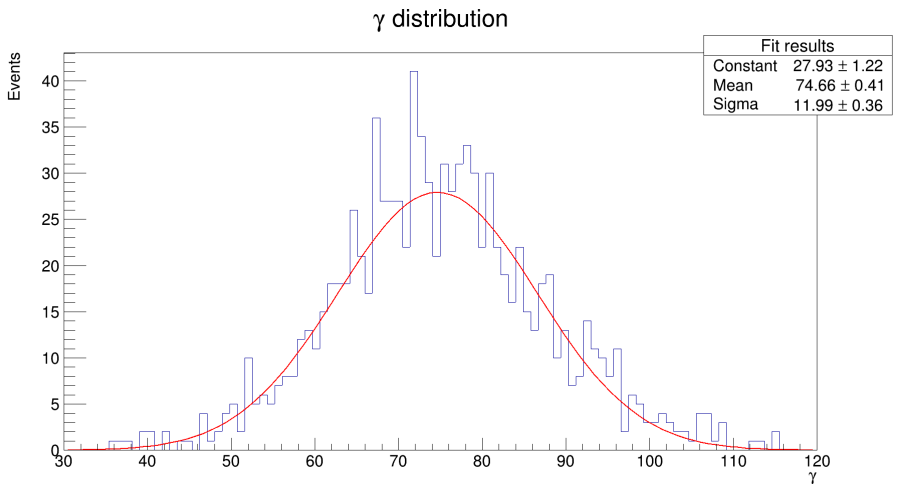
$$Q^2 \approx \sum_i N_i (c_i^2 + s_i^2) \Big/ \sum_i N_i$$

- Can achieve $Q \approx 0.90$ with 8 bins $\implies$ expect $\sigma(\gamma) = 12^\circ$

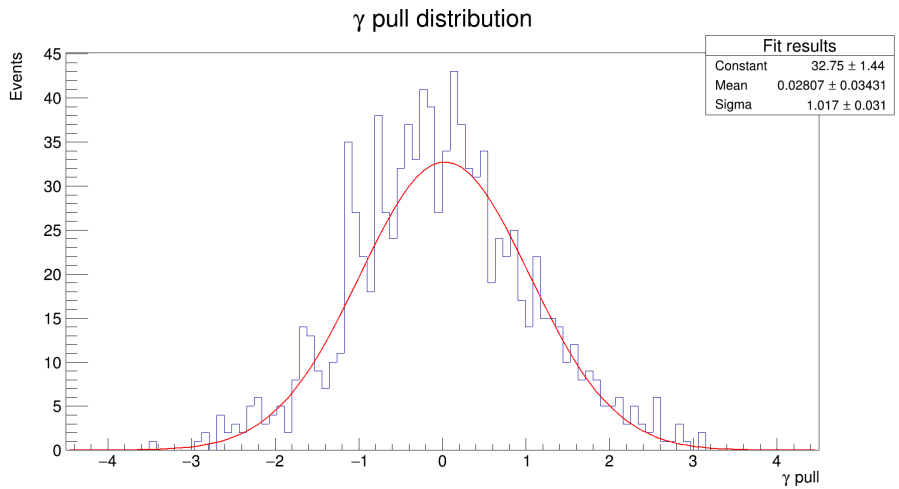
Variable widths binning scheme



Pull study with variable widths binning



(a) γ distribution

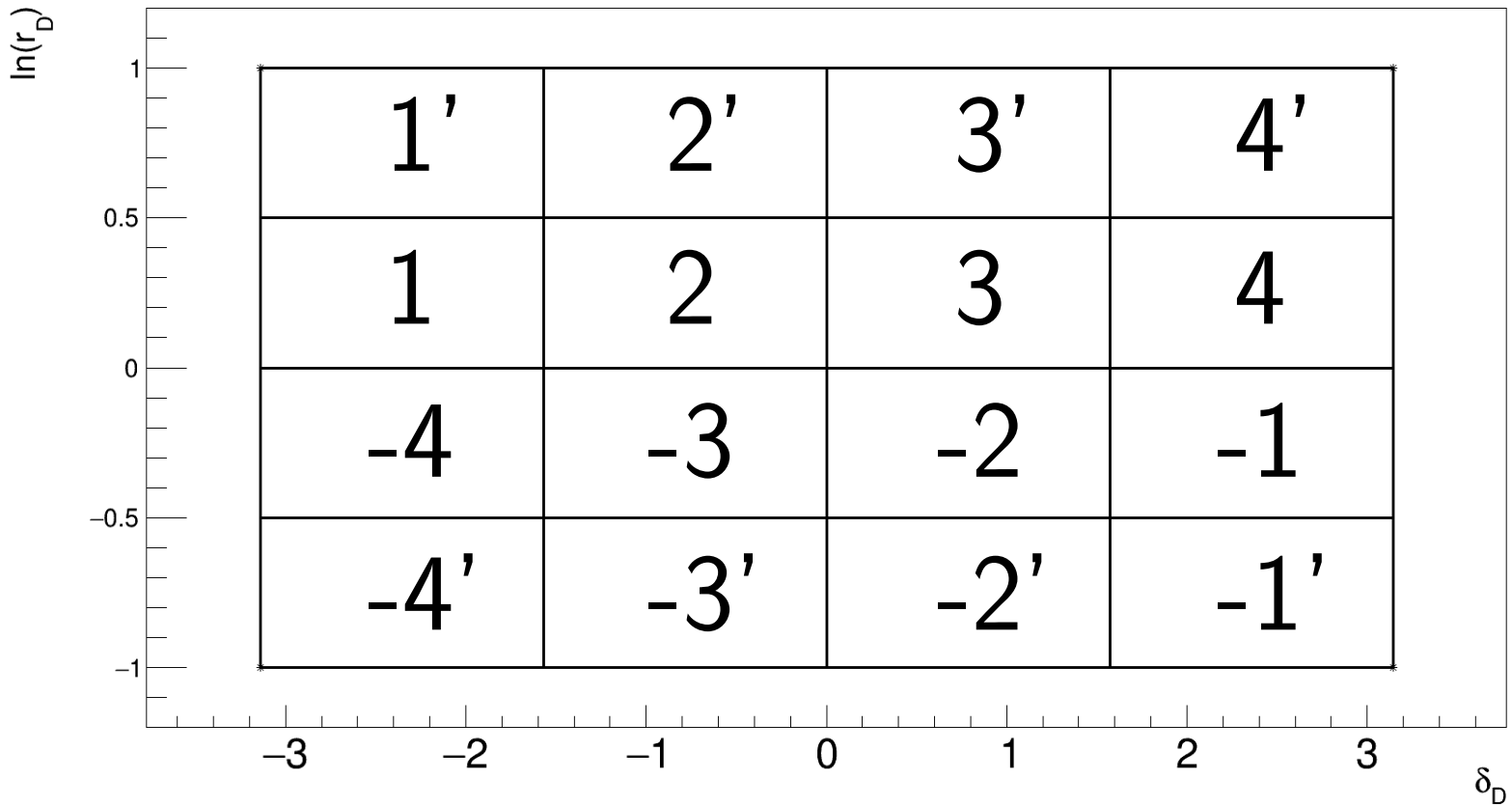


(b) γ pull

Achieved γ precision of $\sigma(\gamma) = 12^\circ$

Binning along r_D

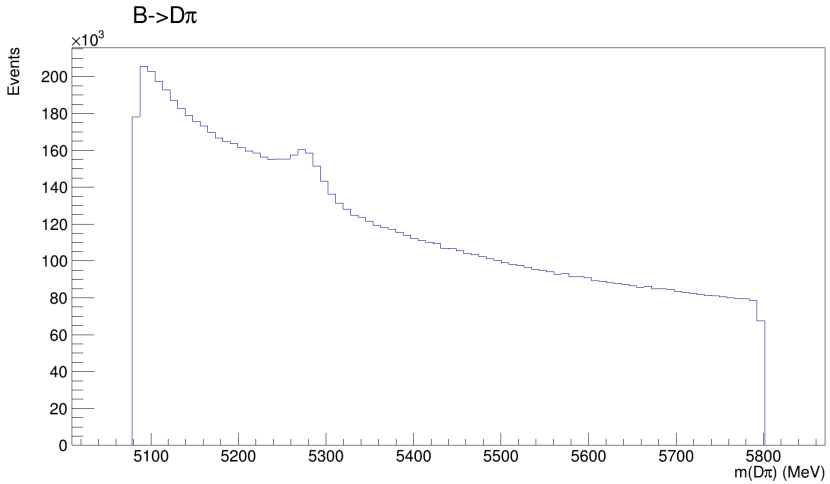
- Further optimization by binning along r_D
- Claim: Can use **same** c_i and s_i in bin i and i'
- Can push $\sigma(\gamma)$ down by 0.5°-1°



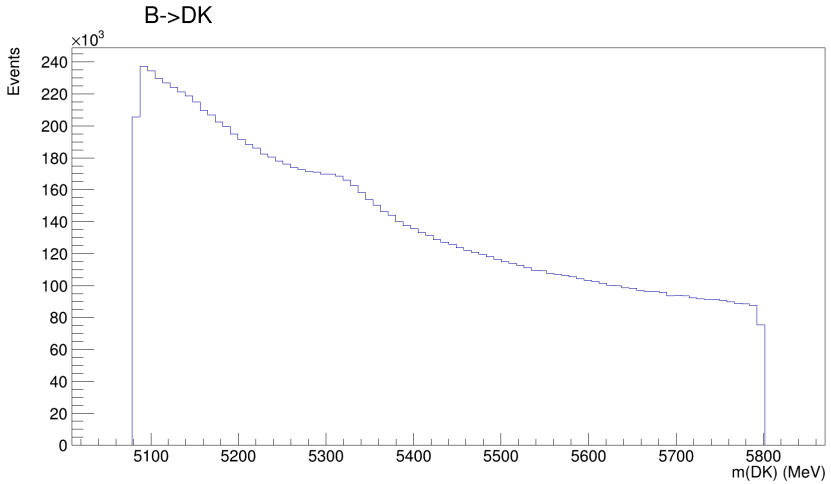
First look at LHCb data

- DaVinci scripts from $K_S\pi^+\pi^-$ analysis
- Have obtained full Run 2 data and MC
- DaVinci issues with Run 1, unable to run DecayTreeFitter
- Event selection:
  - Initial rectangular cuts
  - Gradient Boosted Decision Tree
  - Final cuts
  - Mass fit

First look at LHCb data



(a) $m(D\pi)$ distribution

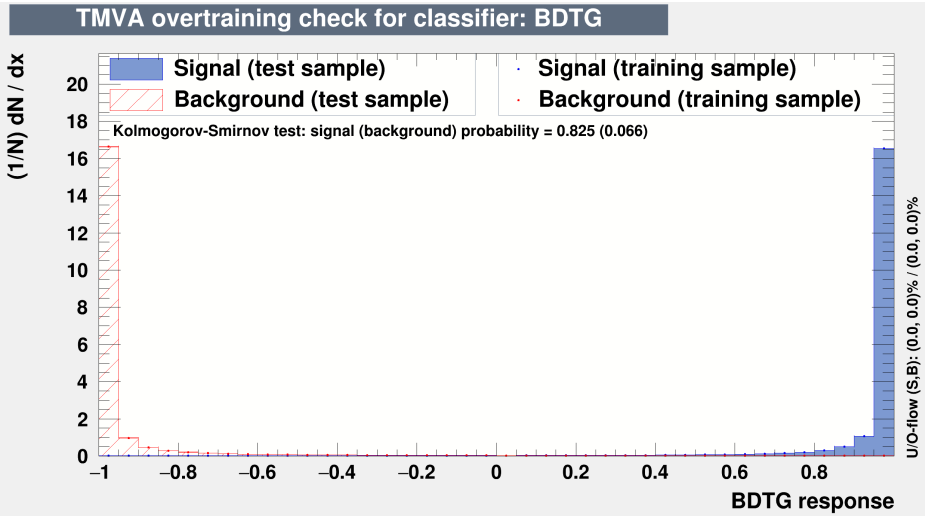


(b) $m(DK)$ distribution

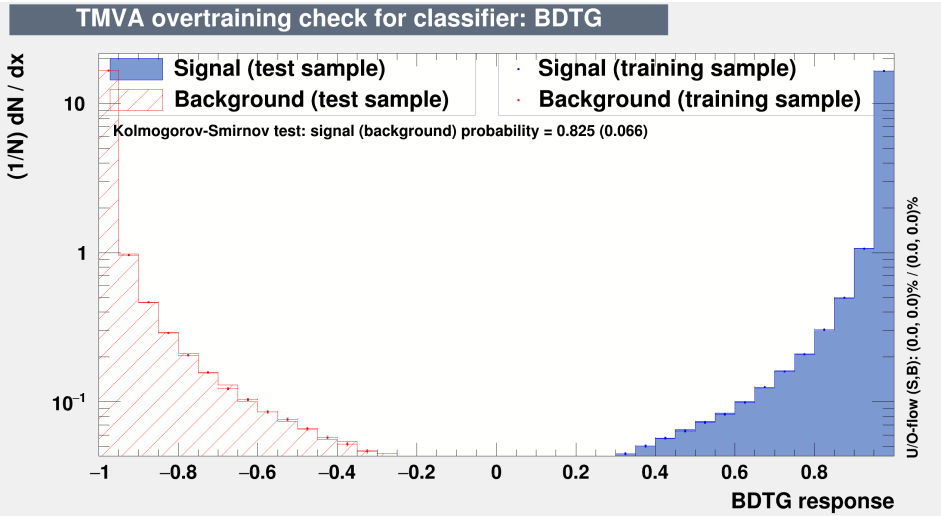
BDT sample preparation

- Signal training sample: $B \to D\pi$ MC samples
- Background training sample: High mass sideband in data
  - $5800\,\text{MeV} < m(Dh) < 7000\,\text{MeV}$
- Signal region: $5080\,\text{MeV} < m(Dh) < 5800\,\text{MeV}$
- Initial cuts:
  - Standard trigger requirements
  - Bachelor $P < 100\,\text{GeV}$ and has RICH
  - $K^{\pm}$ daughters $P < 100\,\text{GeV}$ and has RICH
  - DecayTreeFitter convergence
  - $|m(D) - m_{\text{PDG}}(D)| < 25\,\text{MeV}$

BDT training



(a) BDT output

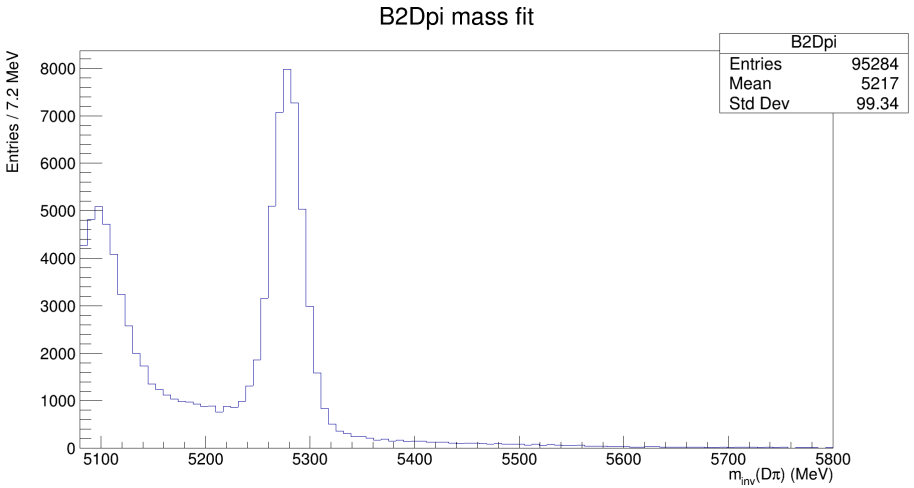


(b) BDT output on a logarithmic scale

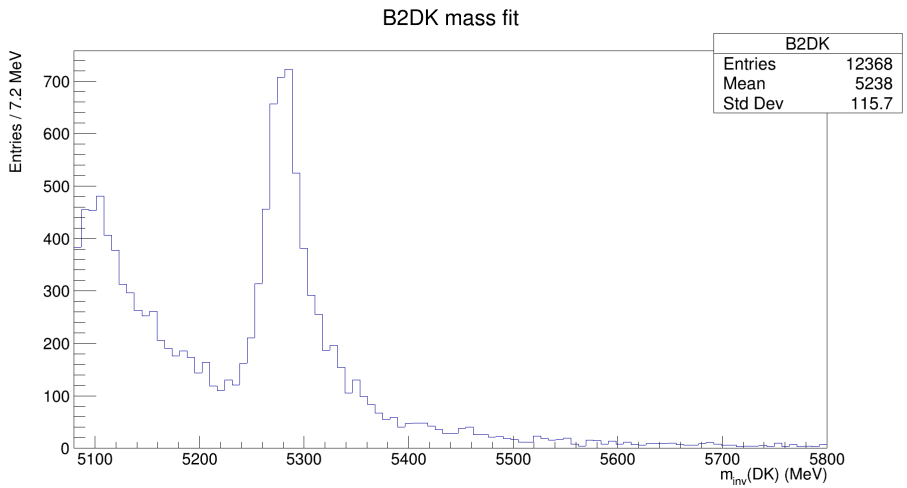
Final selection

- PID cut for bachelor at 4
  - Bach_PIDK > 4 for $B \to DK$
  - Bach_PIDK < 4 for $B \to D\pi$
- $K^{\pm}$ daughter PID cut at -5
- DecayTreeFitter $\ln(\chi^2) < 3$
- B-D flight significance at 0.5
- BDT working point at 0.75
- **Not** optimized yet

Mass plots after final selection



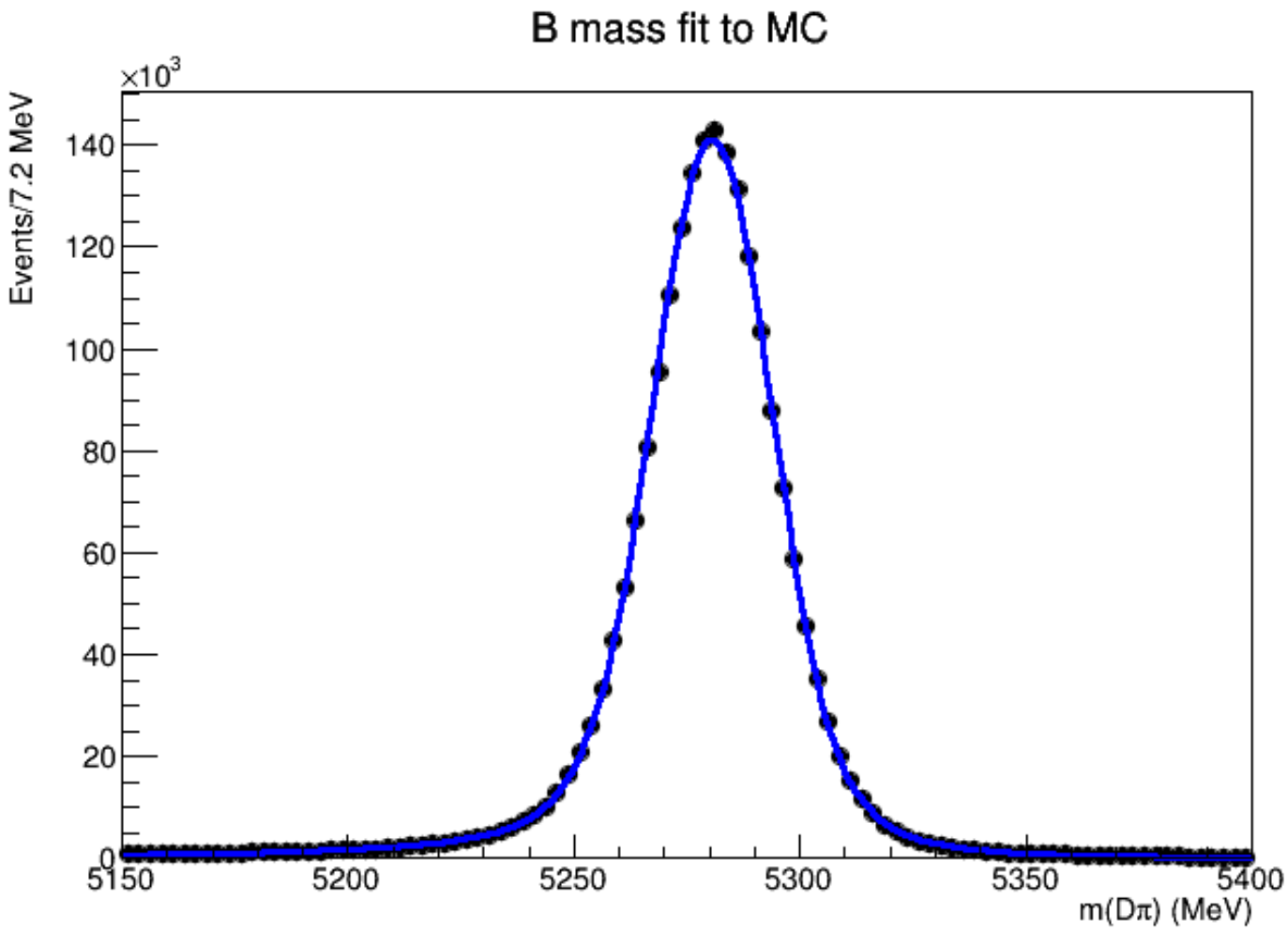
(a) $m(D\pi)$ distribution



(b) $m(DK)$ distribution

Mass fit

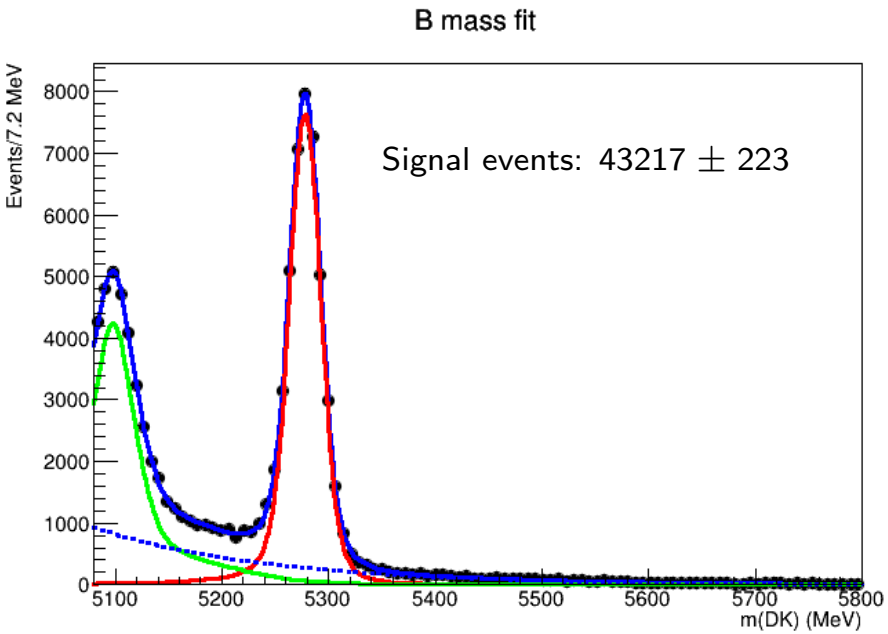
- Signal shape: Double Crystal Ball
  - Tail parameters taken from fit to MC $B \to D\pi$
  - Width and mean is floated



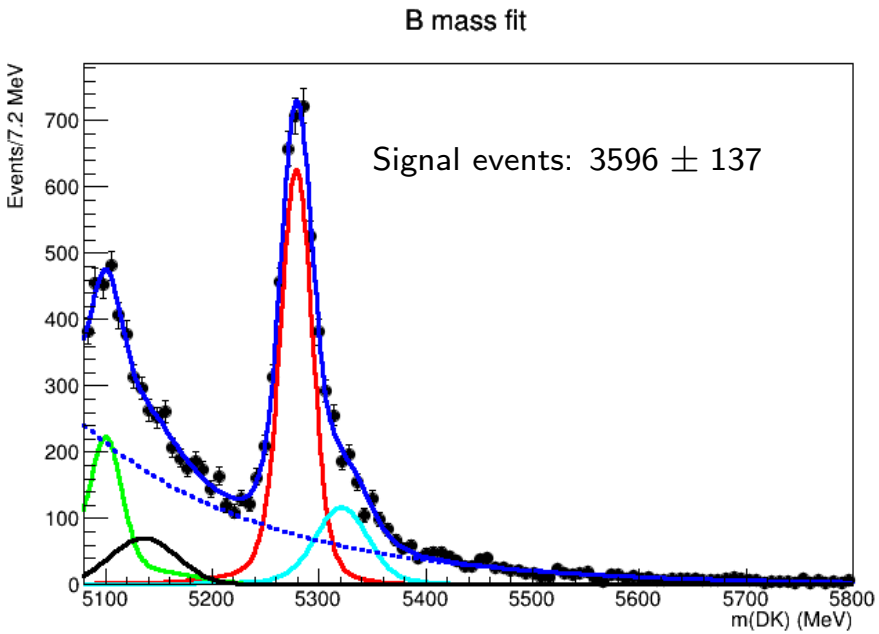
Mass fit

- Combinatorial background: Exponential curve
- Partially reconstructed background:
  - Shape parameters taken from LHCb-ANA-2017-057.1
  - $B^{\pm} \to (D^{*0} \to D^0[\pi^0])\pi^{\pm}$: HORNSdini
  - $B^0 \to (D^{*\pm} \to D^0[\pi^{\mp}])\pi^{\pm}$: HORNSdini
  - $B^{\pm} \to D^0 \to (\rho^{\pm} \to \pi^{\pm}[\pi^0])\pi^{\pm}$: HORNSdini
  - $B^{\pm} \to (D^{*0} \to D^0[\gamma])\pi^{\pm}$: HILLdini
- Further complication for $B \to DK$ mode:
  - Cross-feed from $B \to D\pi$: Double Crystal Ball with same tail parameters as signal for now
  - Mis-ID of partially reconstructed background: Haven't considered yet, absorb into a Gaussian for now

Mass fit plots



(a) $m(D\pi)$ mass fit

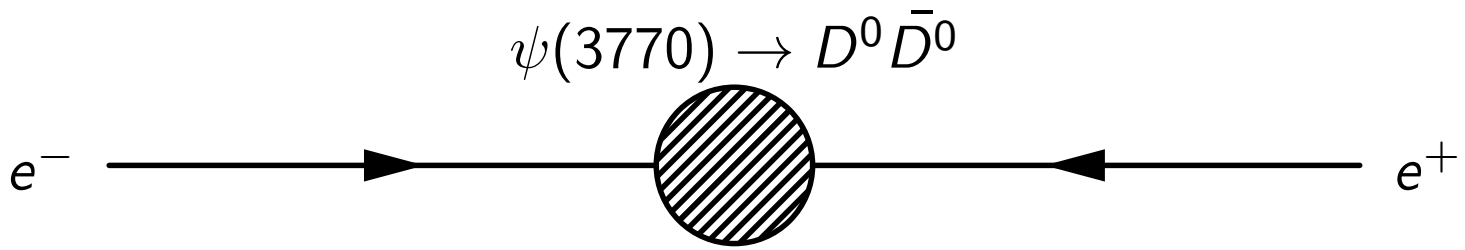


(b) $m(DK)$ mass fit

- Signal
- Partially reconstructed background
- Combinatorial background (dashed)
- Cross feed
- Mis-ID of partially reconstructed background

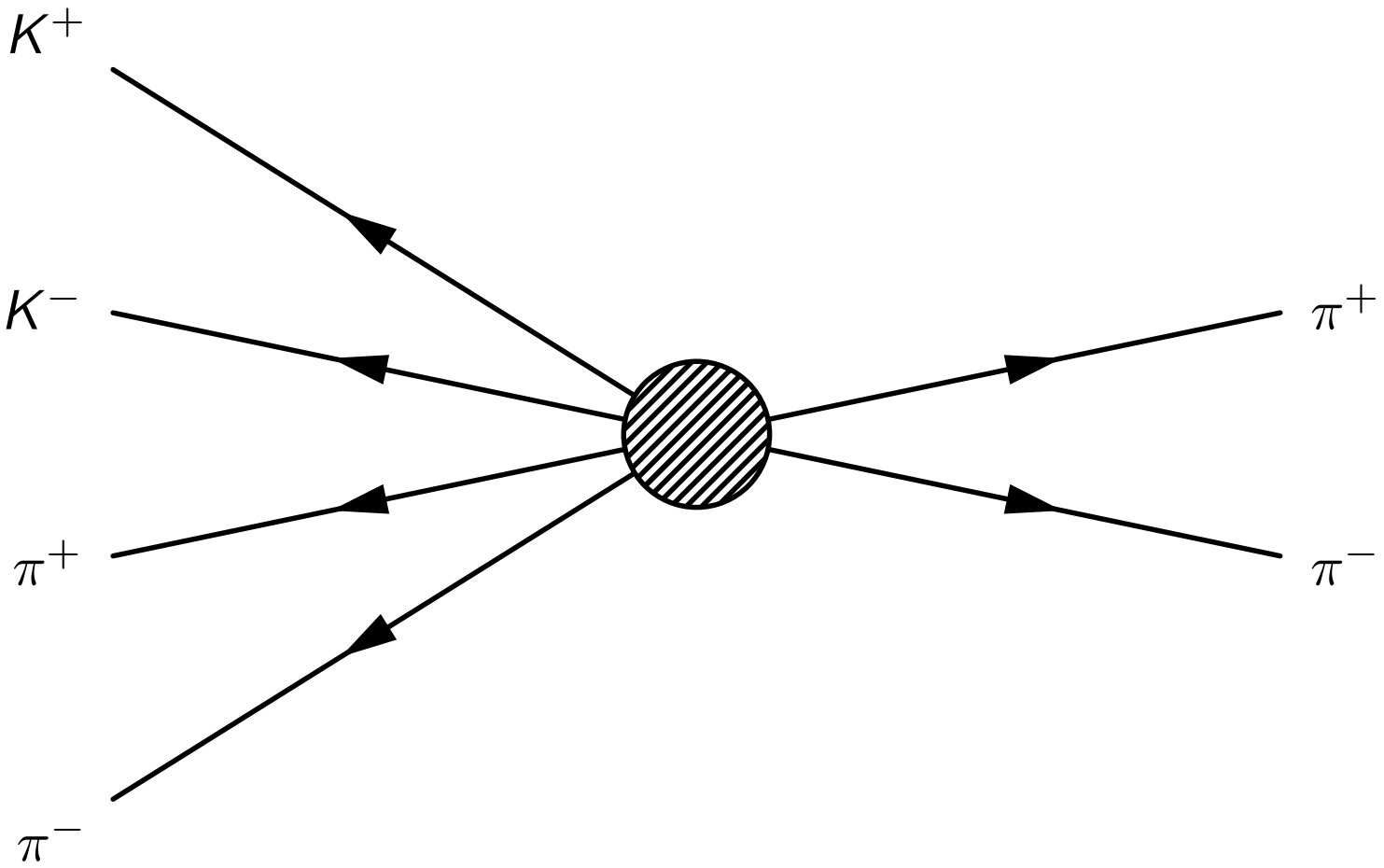
BESIII double tag analysis

Produce D mesons through $e^+e^- \to \psi(3770) \to D^0\bar{D}^0$:



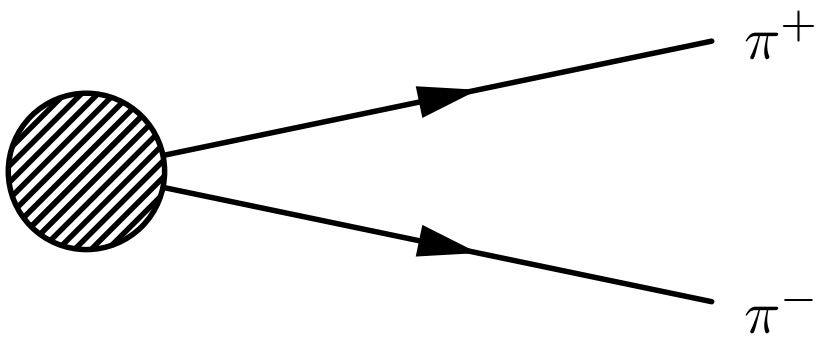
BESIII double tag analysis

Double tagged signal ($K^+K^-\pi^+\pi^-$) with known CP tag ($\pi^+\pi^-$)



BESIII double tag analysis

Single tagged $(\pi^+\pi^-)$



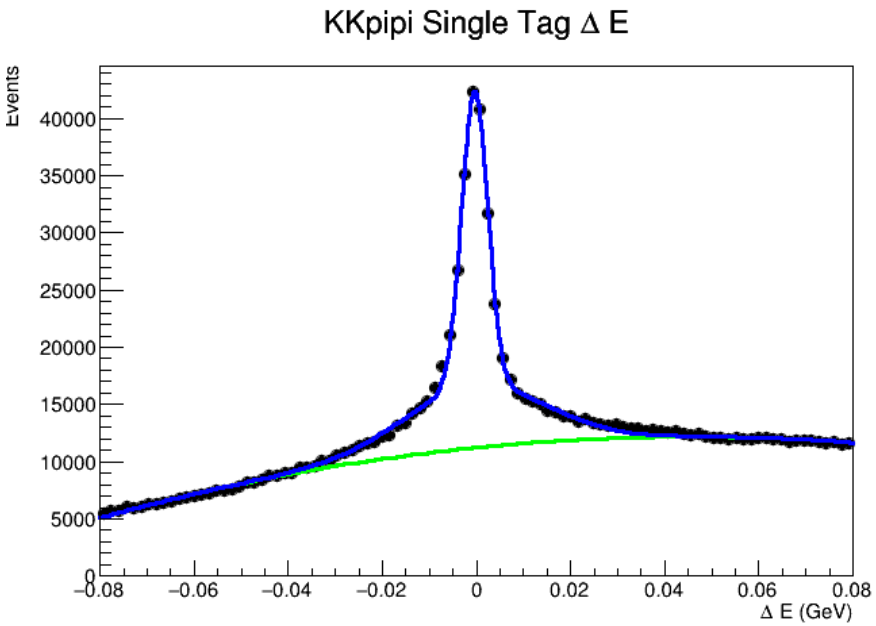
Double tag method

- $M_i = h(K_i \mp 2c_i\sqrt{K_i\bar{K}_i} + \bar{K}_i)$
- $M_{ij} = h(K_i\bar{K}_j + \bar{K}_iK_j - 2\sqrt{K_i\bar{K}_iK_j\bar{K}_j}(c_ic_j + s_is_j))$
- Normalization constant h depends on single tagged yields

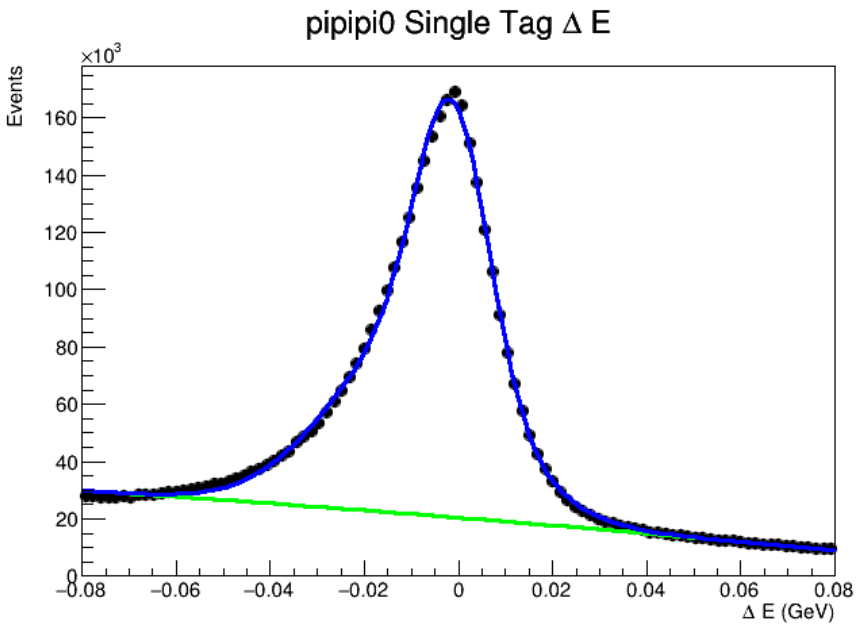
Double tag progress

- Implemented 14 tag modes so far, with another 5 to come (full list in backup slides)
- Run over the full 2010+2011 MC $D^0\bar{D}^0$ dataset
- Single tagged yield:
  - Fit $m_{BC} = \sqrt{E^2_{\text{beam}} - \mathbf{p}^2_D}$
  - Double Crystal Ball for signal
  - Argus PDF for background
- Double tagged yield
  - $\Delta E = E_D - E_{\text{beam}}$ cut
  - Fit double Gaussian and 2nd order polynomial to ΔE
  - Cut at $[-3\sigma, 3\sigma]$ ($[-4\sigma, 3\sigma]$ for π^0 modes)
  - Subtract flat background from sidebands

ΔE fits



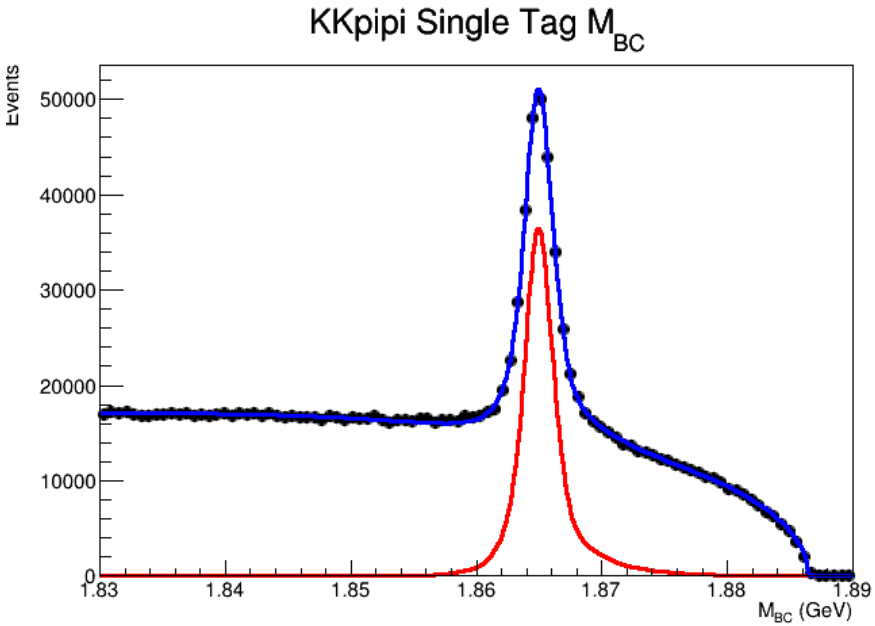
(a) $KK\pi\pi$ tag



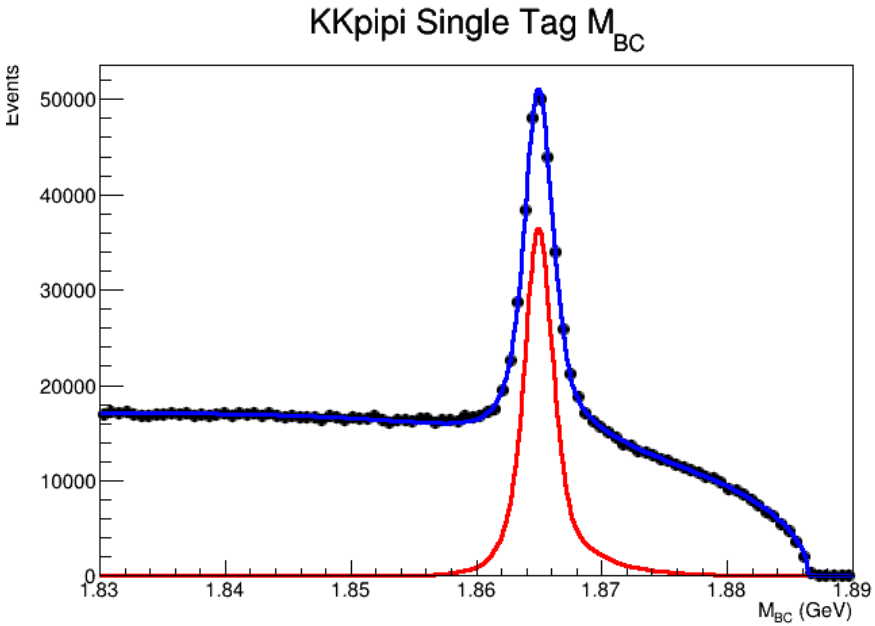
(b) $\pi\pi\pi^0$ tag

See backup for other tag modes

M_{BC} fits



(a) $KK\pi\pi$ beam constrained mass



(b) $\pi\pi\pi^0$ beam constrained mass

Summary

Summary:

- Binning scheme is satisfactory
- Started mass fits with LHCb data
- Most tag modes in BESIII analysis are ready

Next steps:

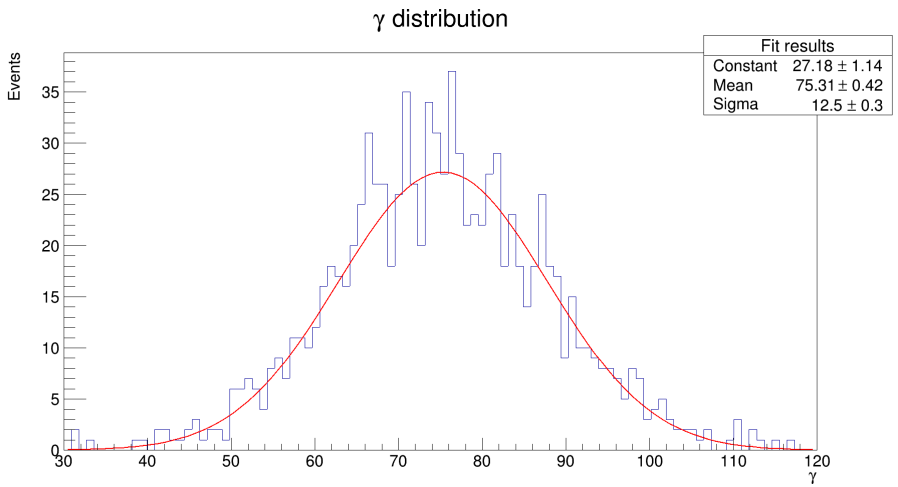
- Understand partially reconstructed backgrounds in LHCb data
- Finish implementing all tag modes in BESIII analysis, analyse peaking backgrounds

Backup slides: DaVinci error

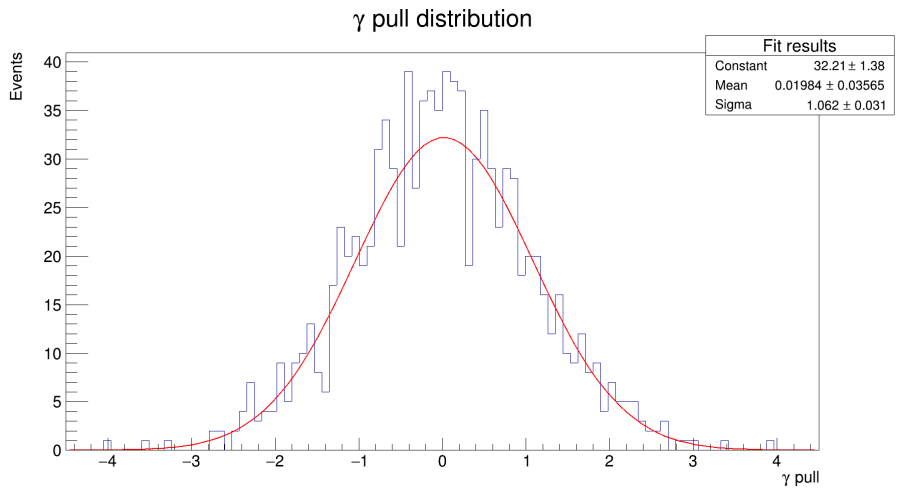
DaVinci error message:

```
B2DPi_D2KKPiPi....    INFO TupleToolDecayTreeFitter:: The INFO message is suppressed : 'Renaming duplicate to Bu_constD0PV_D0_piplus_0'
B2DPi_D2KKPiPi....    INFO TupleToolDecayTreeFitter:: The INFO message is suppressed : 'Renaming duplicate to Bu_constD0PV_D0_Kplus_1'
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_Kplus_0_ID != Bu_constD0PV_D0_Kplus_1_ID StatusCode=FAILURE
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_Kplus_0_PE != Bu_constD0PV_D0_Kplus_1_PE StatusCode=FAILURE
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_Kplus_0_PX != Bu_constD0PV_D0_Kplus_1_PX StatusCode=FAILURE
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_Kplus_0_PY != Bu_constD0PV_D0_Kplus_1_PY StatusCode=FAILURE
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_Kplus_0_PZ != Bu_constD0PV_D0_Kplus_1_PZ StatusCode=FAILURE
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_piplus_1_ID != Bu_constD0PV_D0_piplus_0_ID StatusCode=FAILURE
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_piplus_1_PE != Bu_constD0PV_D0_piplus_0_PE StatusCode=FAILURE
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_piplus_1_PX != Bu_constD0PV_D0_piplus_0_PX StatusCode=FAILURE
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_piplus_1_PY != Bu_constD0PV_D0_piplus_0_PY StatusCode=FAILURE
B2DPi_D2KKPiPi....   ERROR TupleToolDecayTreeFitter:: Tuple entry error : Bu_constD0PV_D0_piplus_1_PZ != Bu_constD0PV_D0_piplus_0_PZ StatusCode=FAILURE
B2DPi_D2KKPiPi       FATAL Tool 'TupleToolDecayTreeFitter' acting on particle 'Bu' returned a failure status.
```

Backup slides: Pull study naive amplitude binning



(a) γ distribution



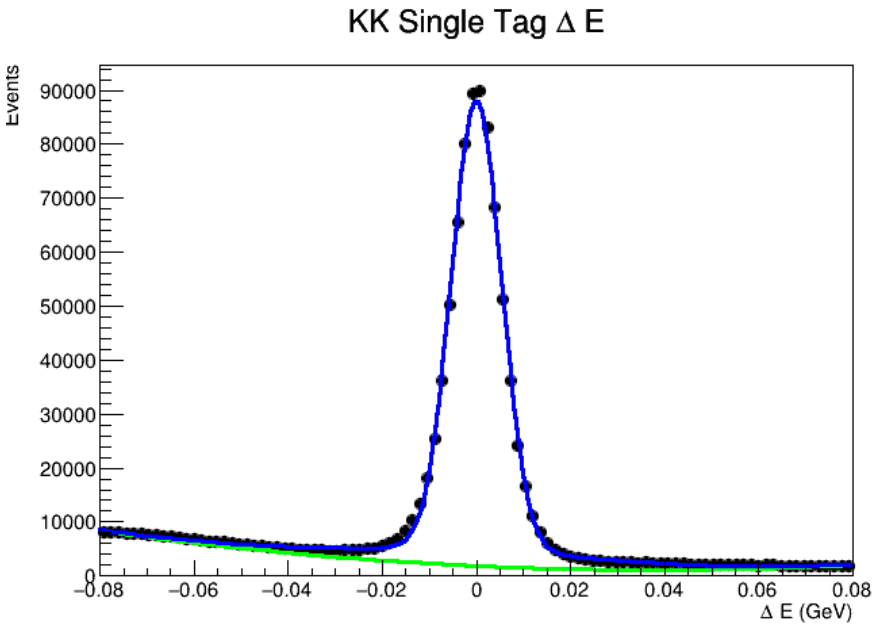
(b) γ pull

Achieved γ precision of $\sigma(\gamma) = 13^\circ$

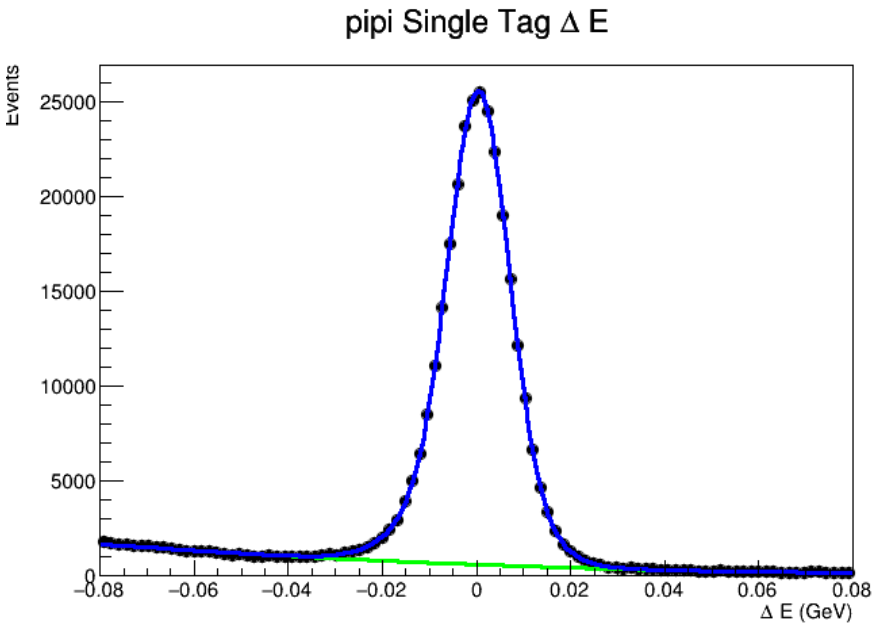
Backup slides: List of tag modes

- Flavour tags:
  - $K\pi$, $K\pi\pi^0$
- CP tags:
  - KK, $\pi\pi$, $\pi\pi\pi^0$
  - $K_S\pi^0$, $K_S\pi^0\pi^0$, $K^0_S\eta$, $K^0_S\eta'(\pi\pi\eta)$, $K^0_S\eta'(\rho\gamma)$
  - $K^0_S\omega(\pi\pi\pi^0)$, $K^0_S\eta(\pi\pi\pi^0)$, $K^0_S\phi$
  - $K^0_S\pi^+\pi^-$
  - $K^+K^-\pi^+\pi^-$
- Will also include:
  - $K\pi\pi\pi$, $Ke\nu_e$
  - $K_L\pi^0$, $K_L\pi^0\pi^0$, $K_L\omega$

Backup slides: ΔE fits

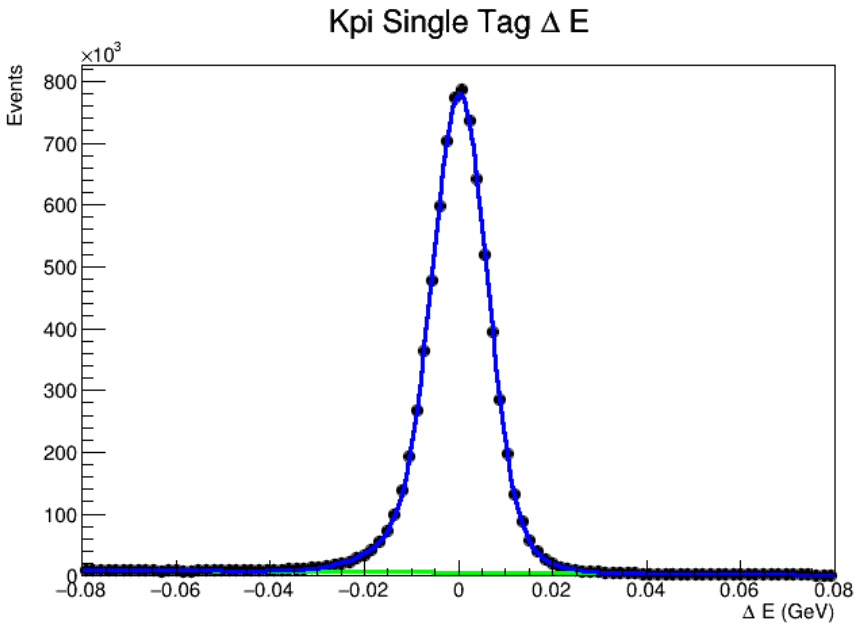


(a) KK tag

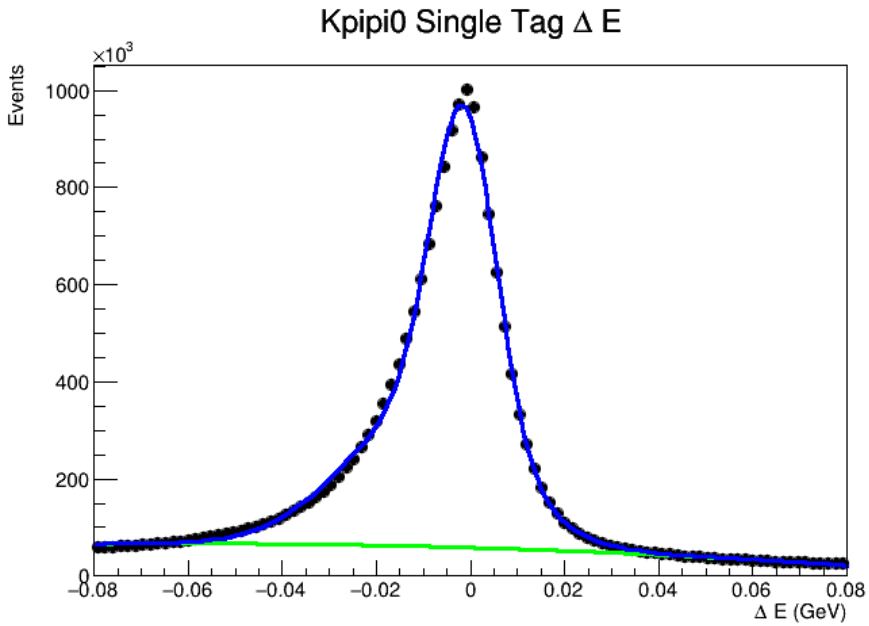


(b) $\pi\pi$ tag

Backup slides: ΔE fits

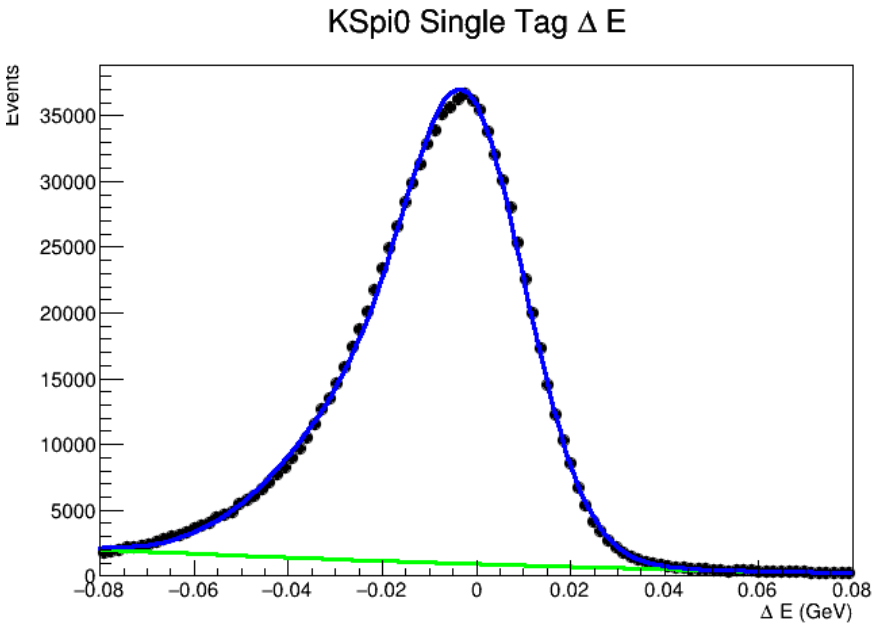


(a) $K\pi$ tag

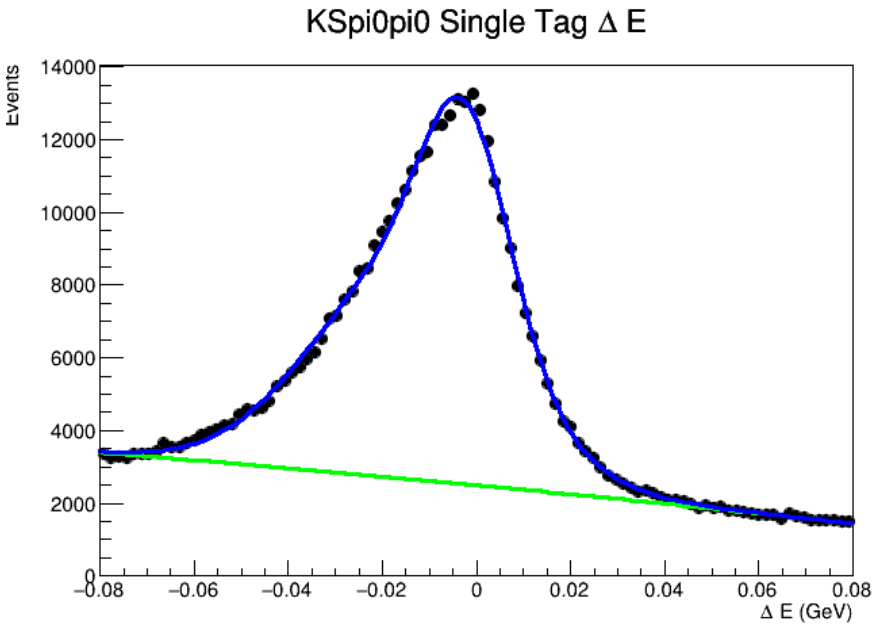


(b) $K\pi\pi^0$ tag

Backup slides: ΔE fits

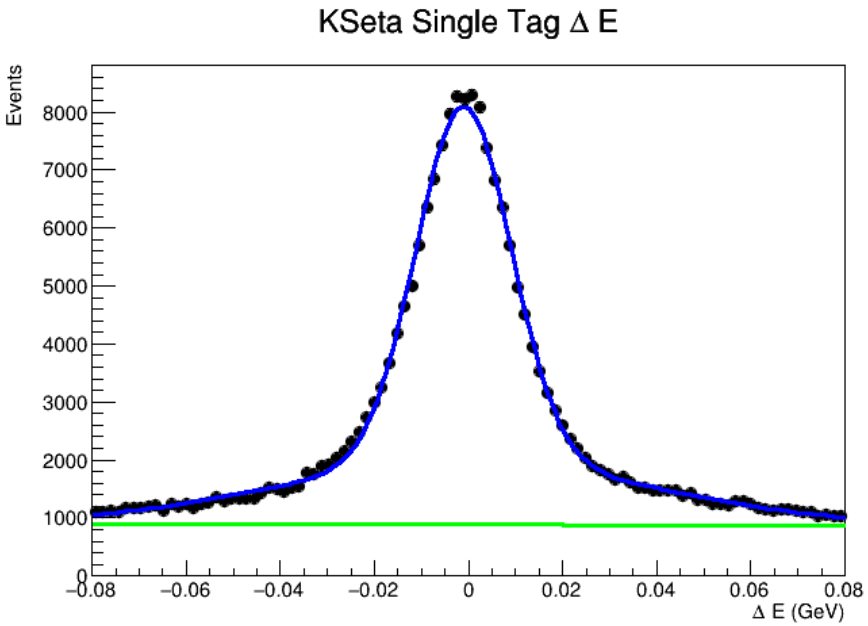


(a) $K_S\pi^0$ tag

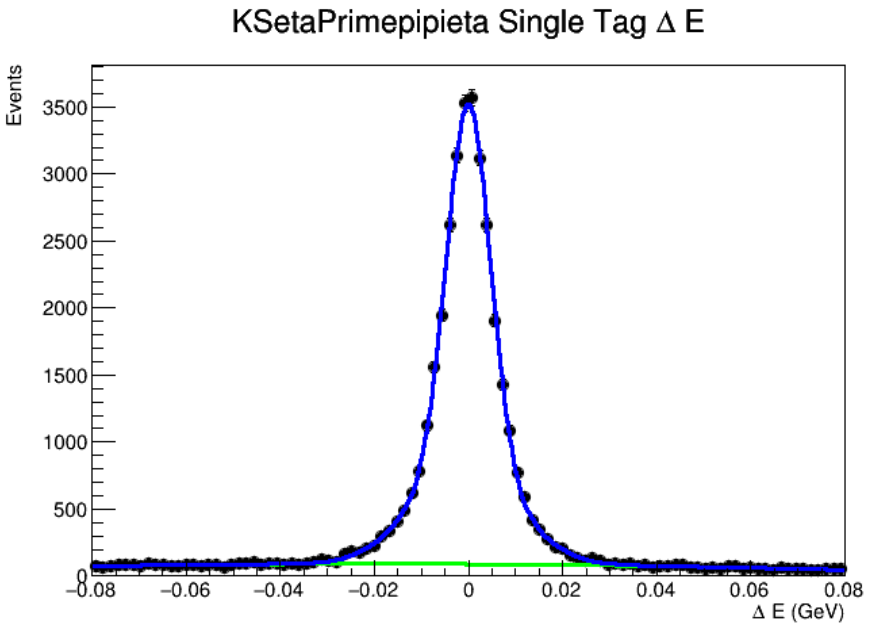


(b) $K_S\pi^0\pi^0$ tag

Backup slides: ΔE fits

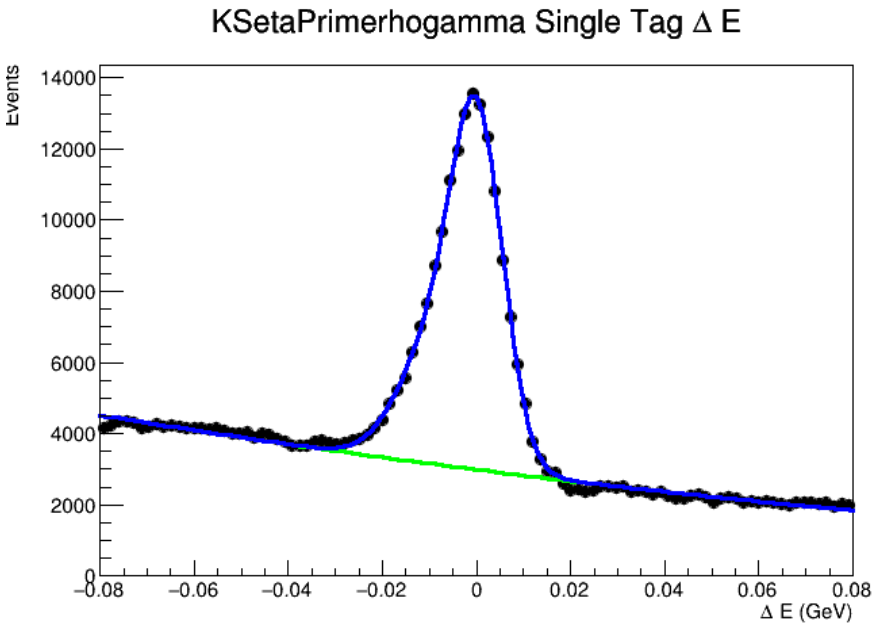


(a) $K_S\eta$ tag

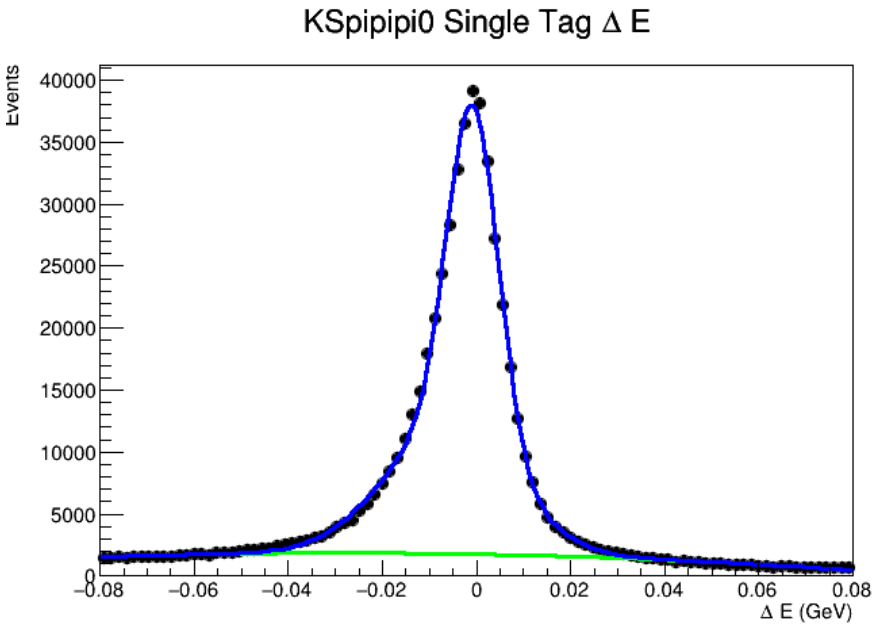


(b) $K_S\eta'(\pi\pi\eta)$ tag

Backup slides: ΔE fits

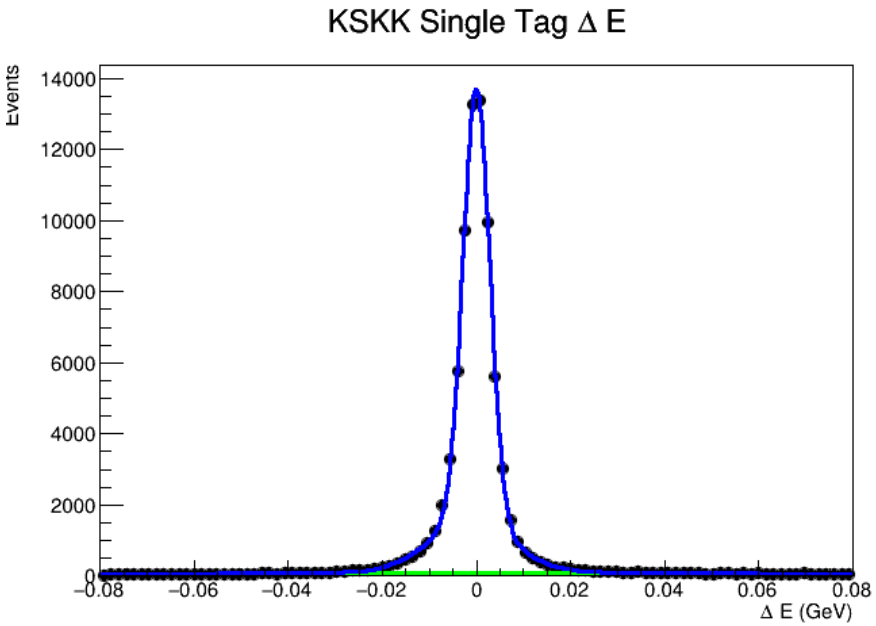


(a) $K_S\eta'(\pi\pi\gamma)$ tag

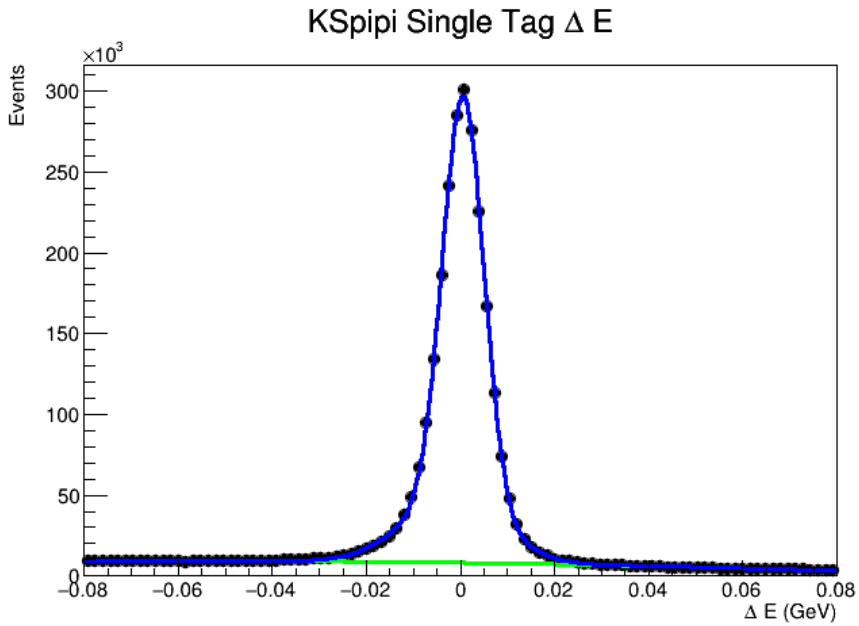


(b) $K_S(\eta,\omega)(\pi\pi\pi^0)$ tag

Backup slides: ΔE fits



(a) $K_S KK$ tag



(b) $K_S \pi\pi$ tag