Preliminary analysis of $D^{*+} \rightarrow D^0 (\pi^+ \pi^- \pi^0) \pi^+_s$ in early *Belle II* data

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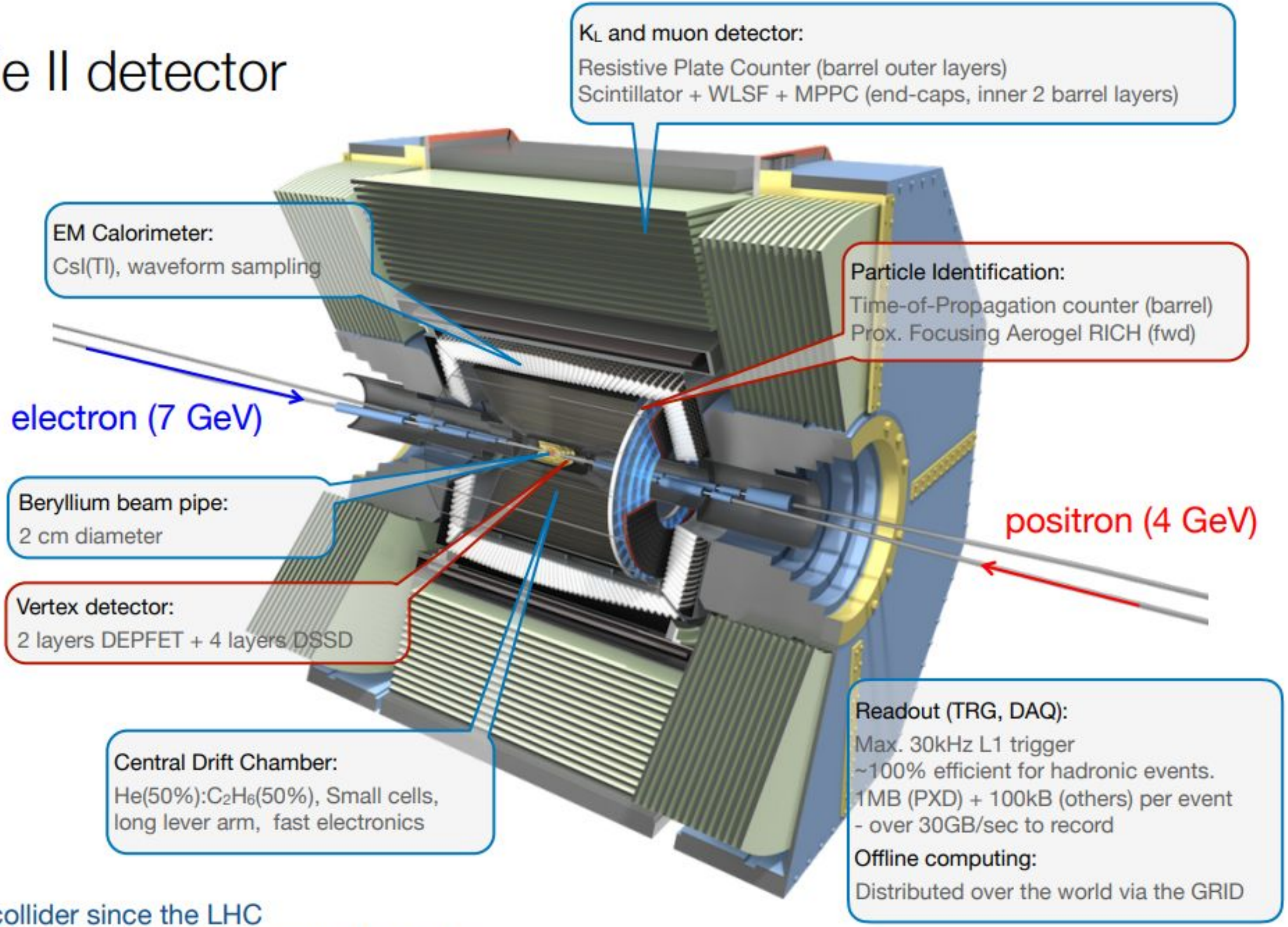
The *Belle II* Experiment

- SuperKEKB *B*-factory in Tsukuba, Japan
- Asymmetric e^+e^- collider (to allow for time-dependent *B* analyses)
- Run at $\Upsilon(4S)$ resonance to produce $B\bar{B}$ pairs at threshold
- Cross section for $e^+e^- \rightarrow c\bar{c}$ is comparable to $B\bar{B}$ cross section
- Investigation of charge-parity violation (CPV) is one of main goals

The Belle II detector



First new particle collider since the LHC
(intensity rather than energy frontier; e^+e^- rather than pp)

arXiv:1011.0352 [physics.ins-det]

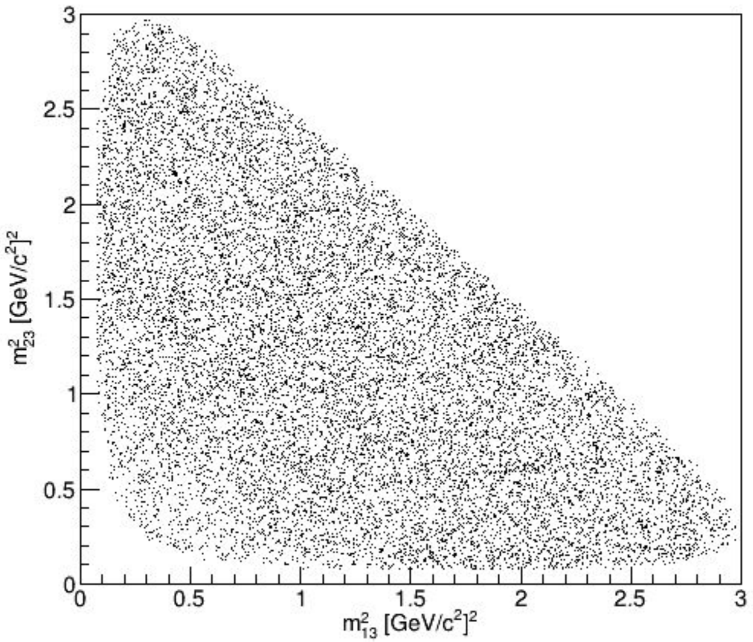
Planned analysis

- Ultimately, want to do a time-averaged analysis of $D^0 \to \pi^+ \pi^- \pi^0$ Dalitz plot using D*-tagged $D^0/\bar{D}^0$ mesons
  - $D^{*+} \to D^0 \pi^+_s$, and charge conjugate
  - π^+_s = “slow pion”; charge of slow pion “tags” the flavor of the D meson
- Possible types of Dalitz analyses:
  - Amplitude analysis: perform an amplitude model fit and look for asymmetries 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, A_{CP} = (difference between bins in D^0 and anti-D^0 plots)/(sum of bins)
  - Energy test: new method used to analyze this mode at LHCb
- Cabibbo-suppressed mode ⇒ need relatively large amount of data to get good result, BUT a good place to look for CPV from New Physics

Preliminary analysis

- Perform yield fit to $\Delta M = M(D^{*+}) - M(D^0)$
- Dalitz plot for signal region and sidebands
- No separation of D^0 and $\bar{D}^0$ candidates
- Currently studying 72 fb^{-1} of early *Belle II* data and 100 fb^{-1} equivalent of Monte Carlo (MC)
  - *Belle II* currently has 213 fb^{-1} of data

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.

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

- Charged tracks must originate from the IP
- 100 MeV/c^2 photon energy cut to reduce noise from beam background
- 105 $MeV/c^2 < m(\gamma\gamma) <$ 150 MeV/c^2
- 1.70 $GeV/c^2 < m(\pi^+\pi^-\pi^0) <$ 2.10 GeV/c^2
- $\Delta M <$ 160 MeV/c^2 (mass difference between D* and D^0 candidates)
- $p^*(D^{*+}) >$ 2.8 GeV/c^2 (to remove combinatorial background; this also effectively removes all D* candidates coming from $B\bar{B}$ decays)
- Vertex fit all tracks and constrain the D^0 mass to its nominal value (to enforce physical boundary of Dalitz plot)
- See backup slides for full list of cuts

Best Candidate Selection details

- Using the χ-probability of the vertex fit, select best candidate per event
- In MC, **19.2%** of all events have two or more candidates

Earlier version of analysis:
Lower photon energy cut (50 MeV/c^2 in barrel)
Lower p*(D*) cut (2.5 GeV/c^2)
Modified ranking algorithm

https://docs.belle2.org/
BELLE2-NOTE-PL-2021-003

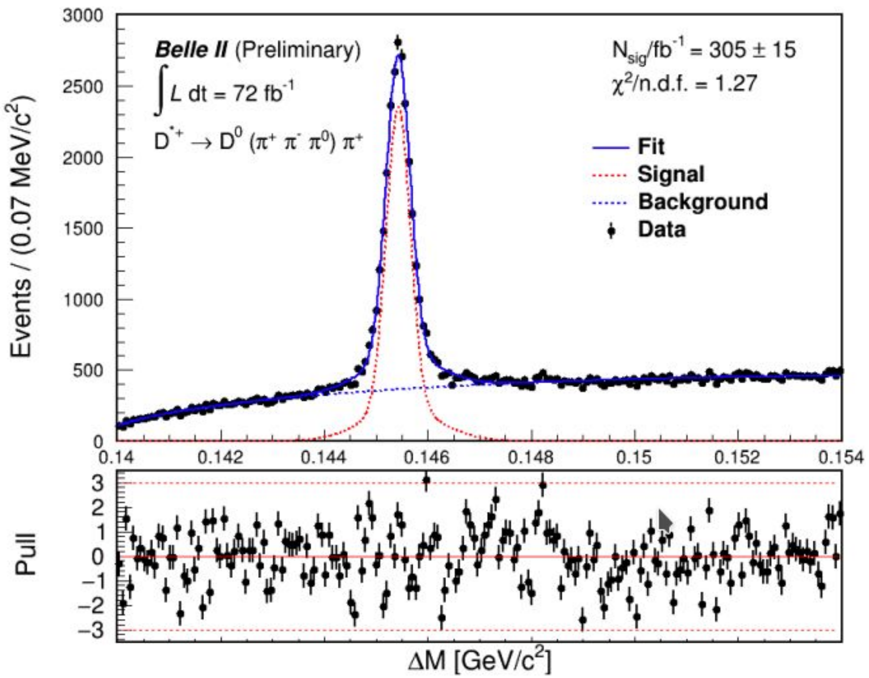
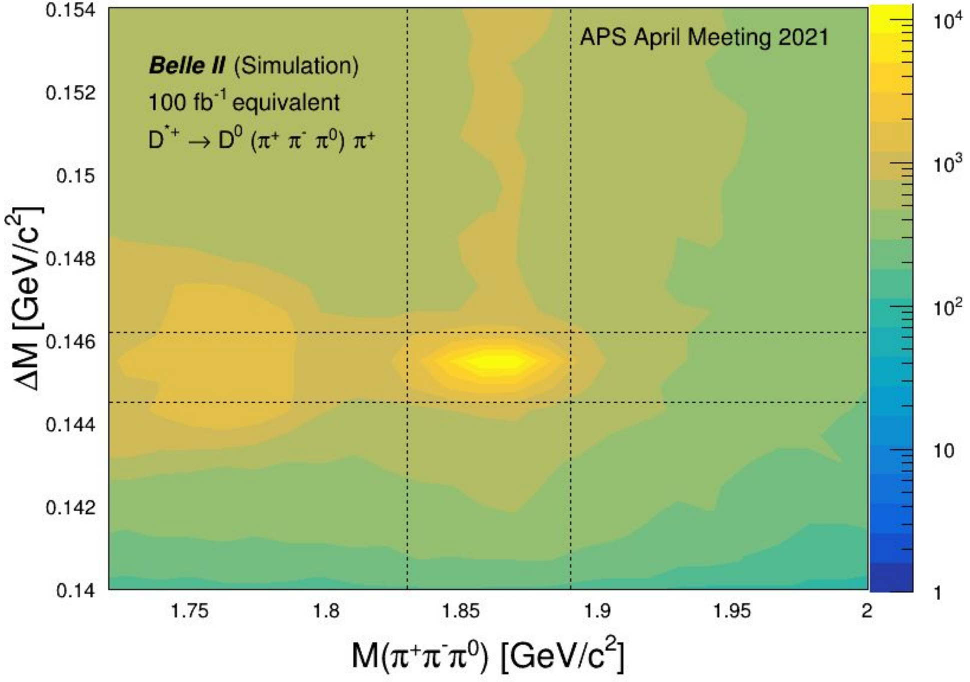
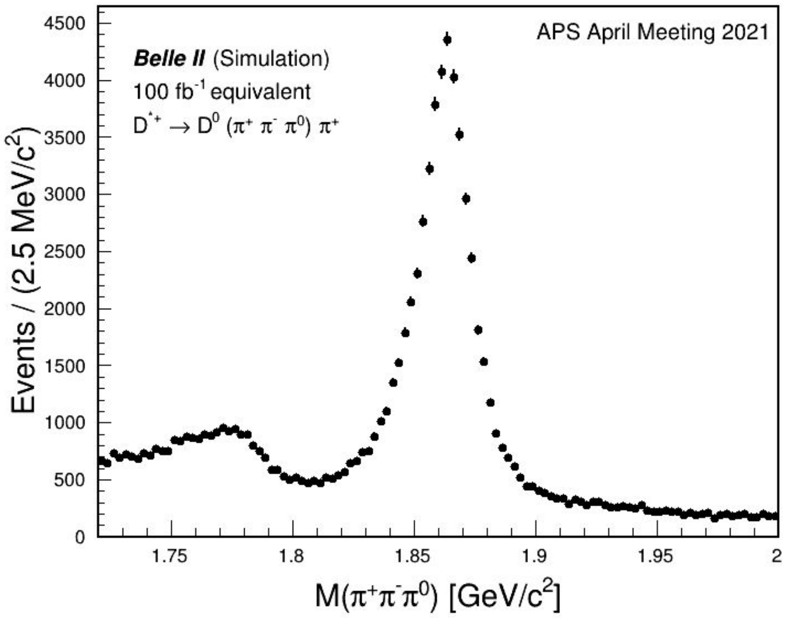


FIG. 1: ΔM peak for the decay $D^{*+} \to D^0\ (\pi^+\pi^-\pi^0)\ \pi_s^+$ in 72 fb^{-1} of early *Belle II* data. The yield fit and its signal (double Gaussian) and background (threshold function) components are overlaid. χ^2/d.o.f. $= 1.27$, and the raw yield estimate is $N_{\text{sig},fit}/\,\text{fb}^{-1} = 326.5 \pm 4.2$. Estimating the effect from the peaking background using MC, the final yield is estimated to be $N_{\text{sig}}/\,\text{fb}^{-1} = 305 \pm 15$.

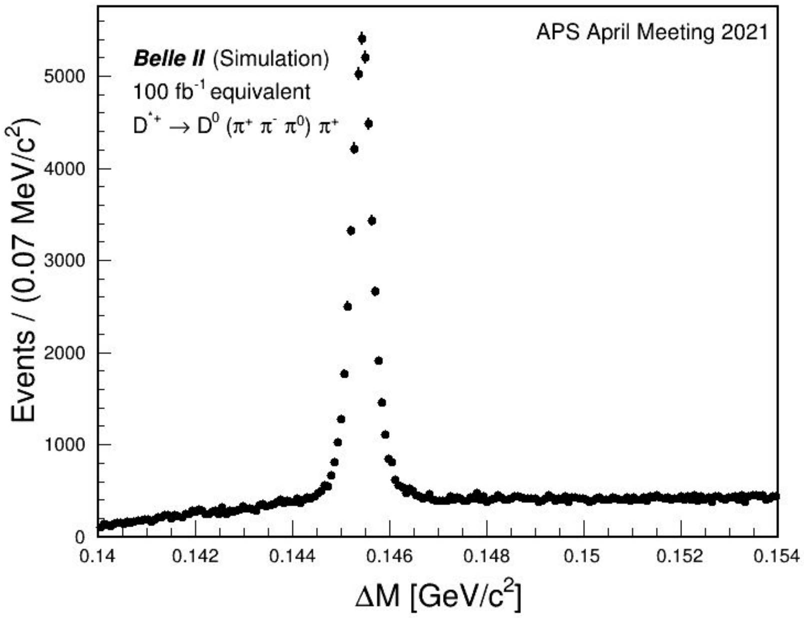
ΔM vs. M(D^0) plot for top-ranked candidates



Projections

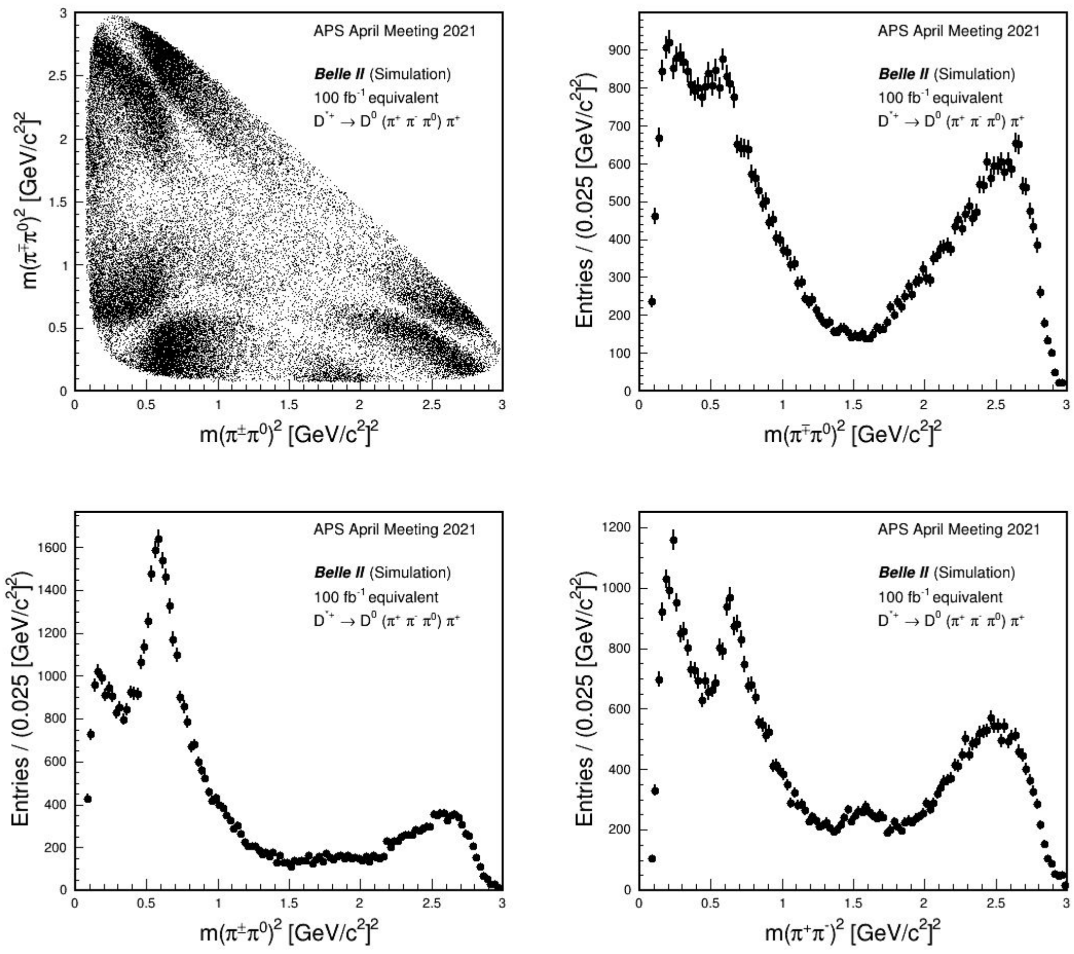


$0.1445\ GeV/c^2 < \Delta M < 0.1462\ GeV/c^2$



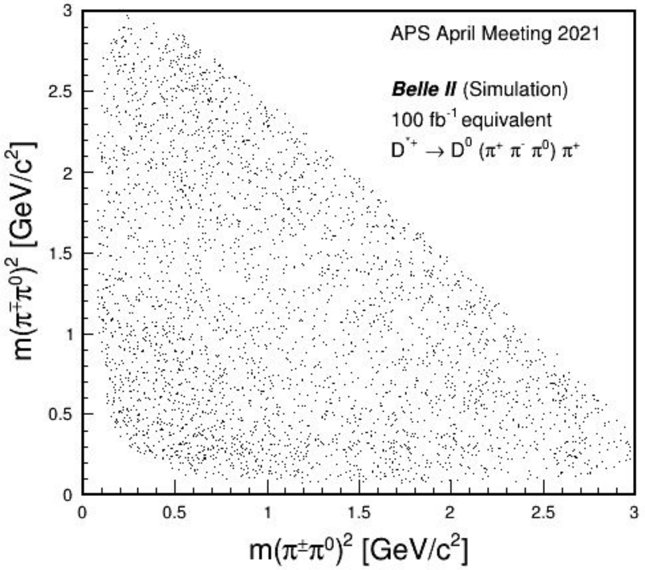
$1.83\ GeV/c^2 < M(\pi^+\pi^-\pi^0) < 1.89\ GeV/c^2$

Dalitz plot - signal region

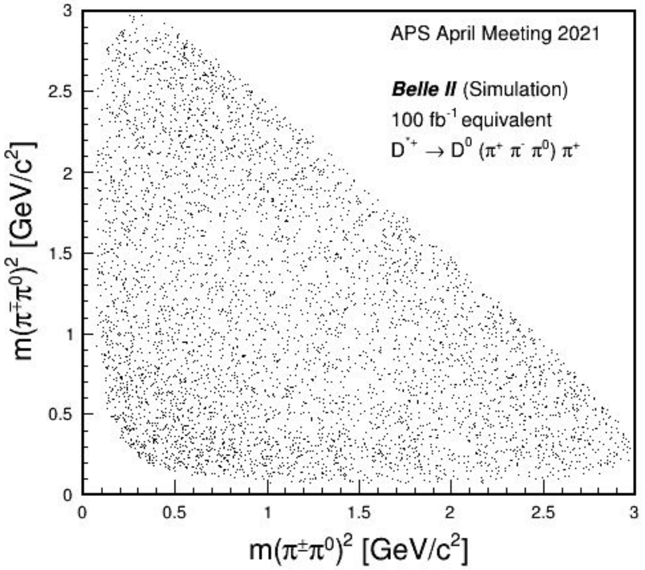


Dalitz model in EvtGen is from BaBar data, Phys.Rev.Lett. 99 251801 (2007)

Dalitz plot - sidebands



0.14215 GeV/c^2 < ΔM < 0.14300 GeV/c^2



0.14770 GeV/c^2 < ΔM < 0.14855 GeV/c^2

Summary and next steps

- Preliminary analysis with yield fit to ΔM
- Updated analysis with lower background ready to be applied to data
- Next steps: study background using MC
  - Mis-identified kaon background, K_S^0 π^0 contamination, π^0 background from low-energy photons
- Stay tuned!

Backup

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

γ reconstruction: E > 100 MeV; E9 to E21 ratio > 0.9; at most one photon found in endcap

π^0 reconstruction: 105 MeV < m(γγ) < 150 MeV

$\pi^\pm$ reconstruction: dr < 0.5 cm and |dz| < 2.0 cm (impact params.); in CDC acceptance range with at least 20 hits; χ-probability of the track > 0.001; global pion ID > 0.1; pion pair ID > 0.3 (i.e., pion vs. kaon ID)

π_s reconstruction: dr < 0.5 cm and |dz| < 2.0 cm (impact params.); in CDC acceptance range with at least 20 hits; χ-probability of the track > 0.001

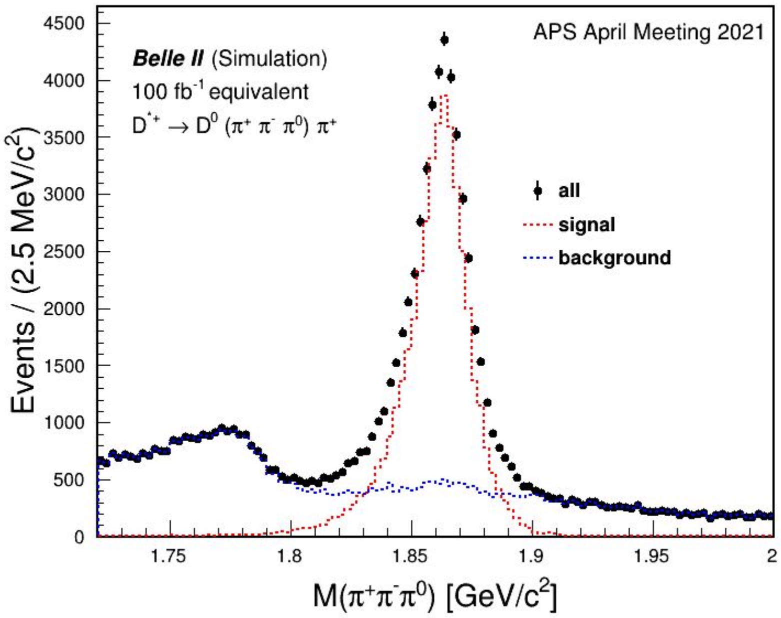
D^0 reconstruction: 1.70 GeV < $m(\pi^+\pi^-\pi^0)$ < 2.10 GeV

D* reconstruction: ΔM < 160 MeV; p*(D*) > 2.8 GeV

Vertex fits: 1) vertex fit on entire decay chain, fit tracks to IP and constraint π^0 mass (for yield fit); 2) repeat vertex fit with same constraints plus additional D^0 mass constraint (to enforce physical boundary of Dalitz plot)

Event cuts: at least 3 tracks that are consistent with originating from the IP and have at least 20 CDC hits

Projections with tagged signal and background



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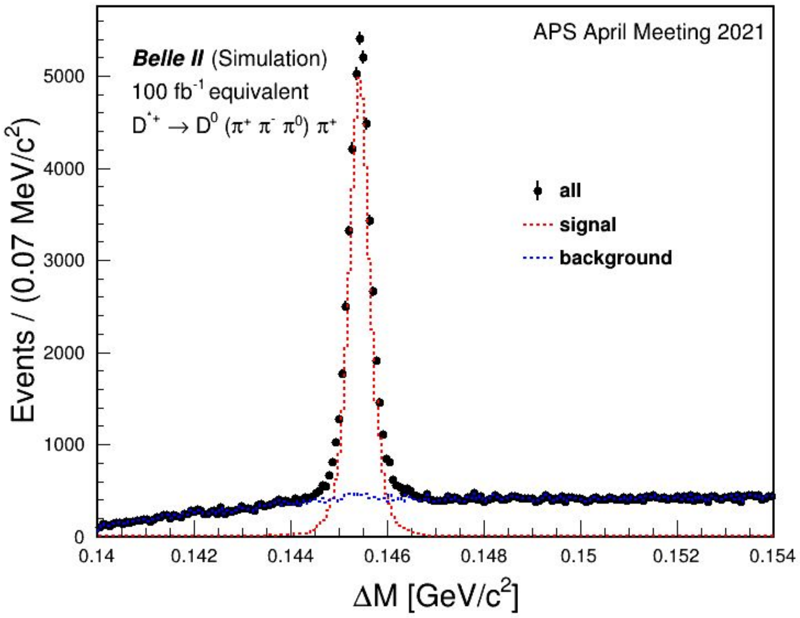
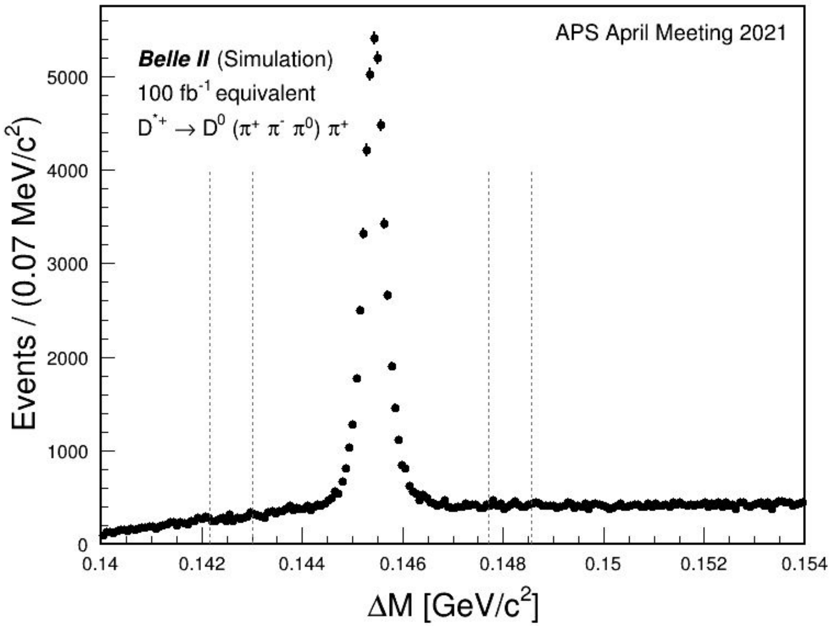


1.83 GeV/c^2 < $M(\pi^+\pi^-\pi^0)$ < 1.89 GeV/c^2

ΔM projection - lines indicate sideband regions



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