Search for $\chi_{c1}(3872)$ in $B^+ \to p\overline{p}K^+$ and Pentaquark Searches in $\Lambda_b \to \Lambda_c\overline{D}^0 K$

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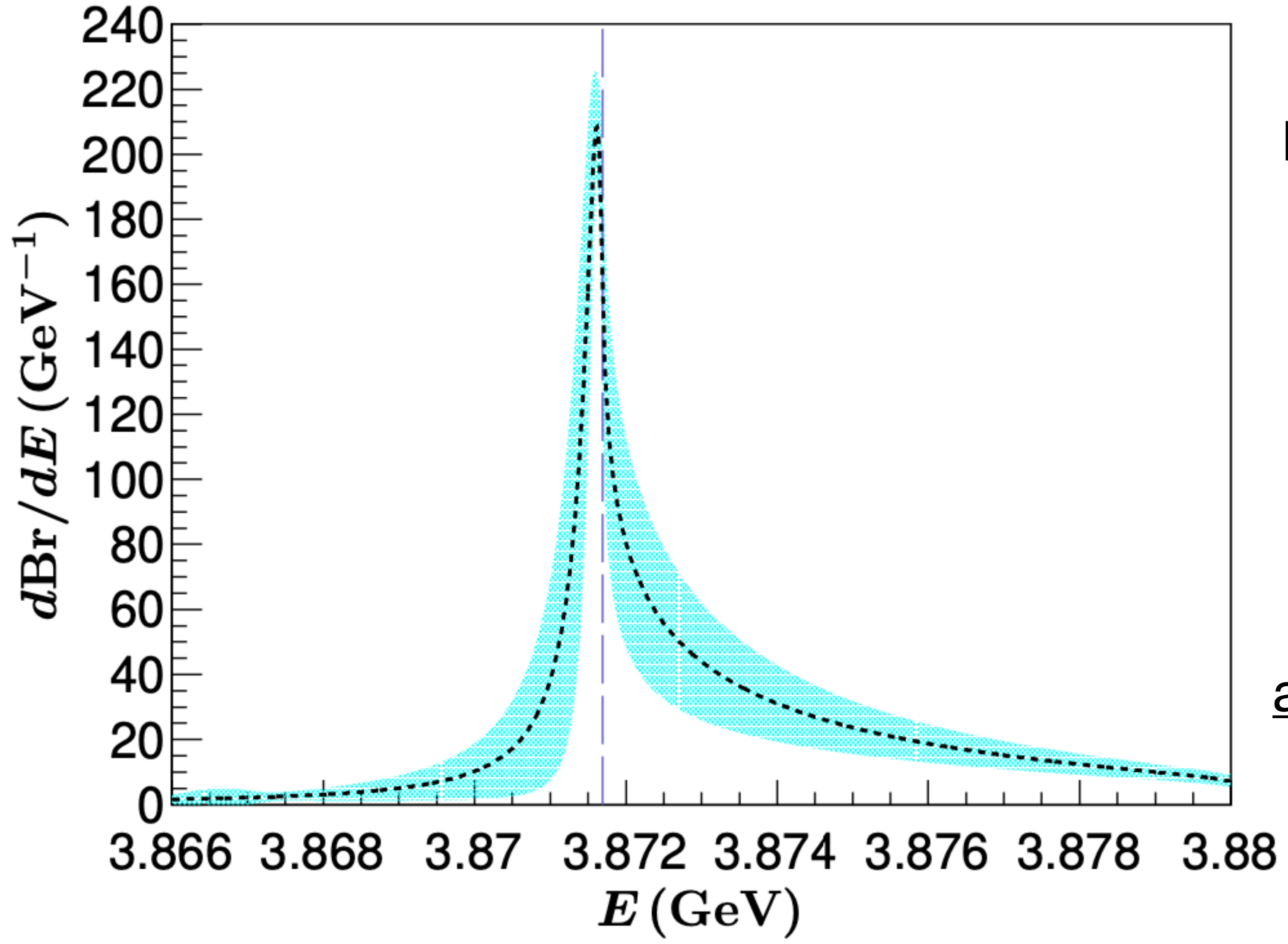
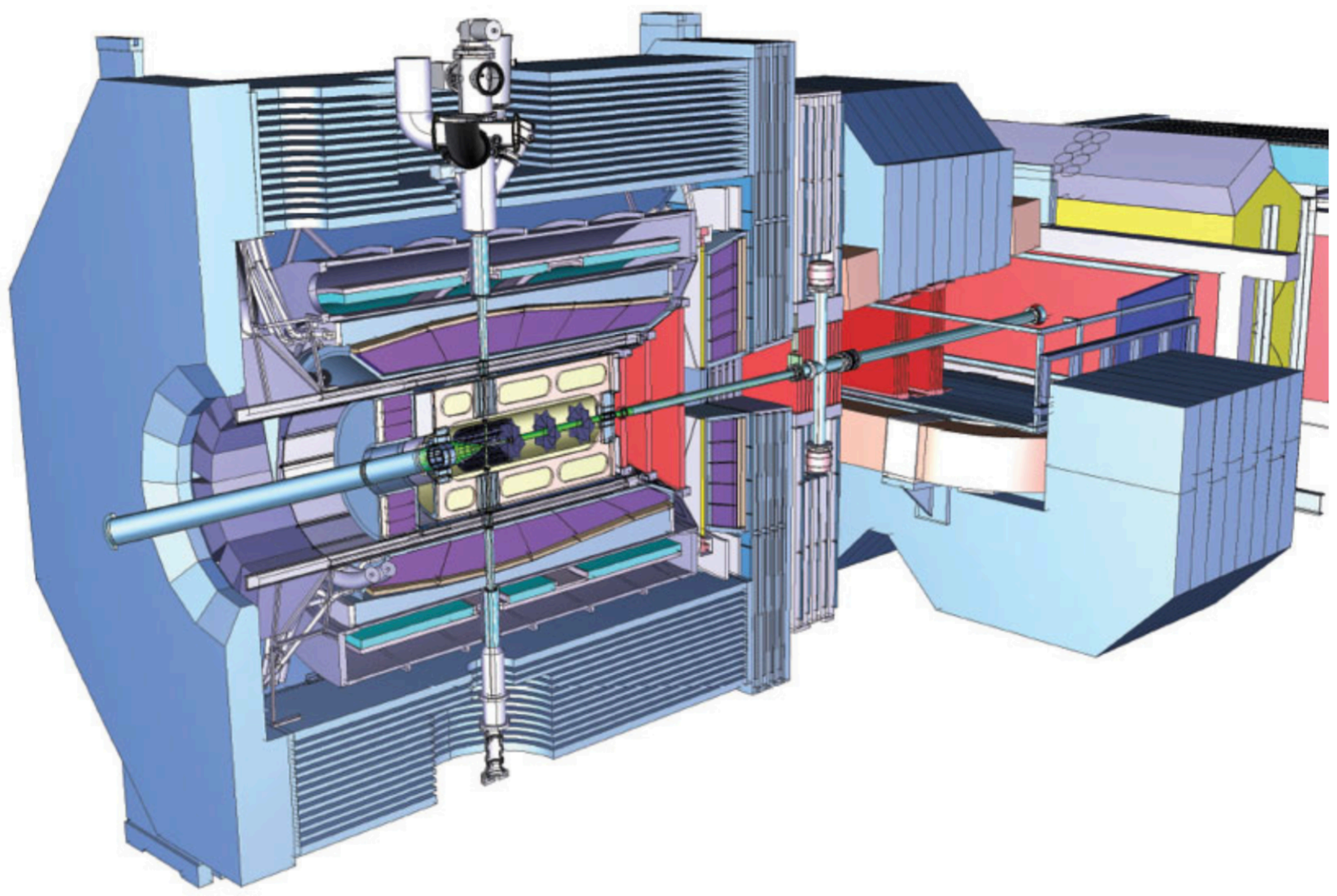
Search for $\chi_{c1}(3872) \rightarrow p\bar{p}$

- $\chi_{c1}(3872)$ found by Belle in 2003 is the first confirmed non $q\bar{q}$ state
- The exact nature of $\chi_{c1}(3872)$ is yet unknown
- Molecular models appear favorable due to the proximity to the $D^0\overline{D}^{*0}$ threshold
- The Form of the lineshape gives insight into the nature of the state



Lineshape of $\chi_{c1}(3872)$ from latest BESIII coupled channel analysis https://arxiv.org/abs/2309.01502

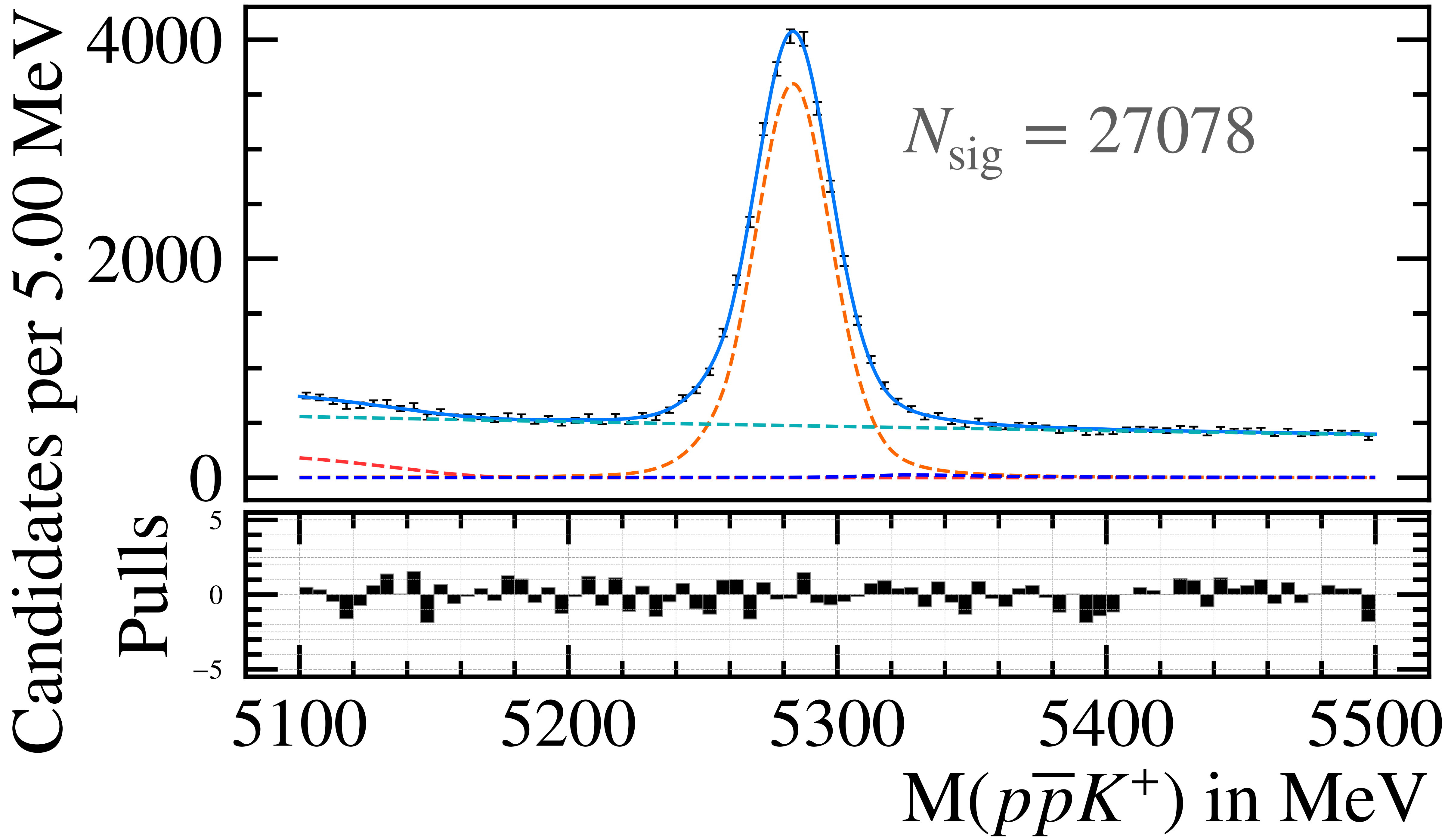


A sideview of the PANDA detector https://panda.gsi.de/article/panda-detector-overview

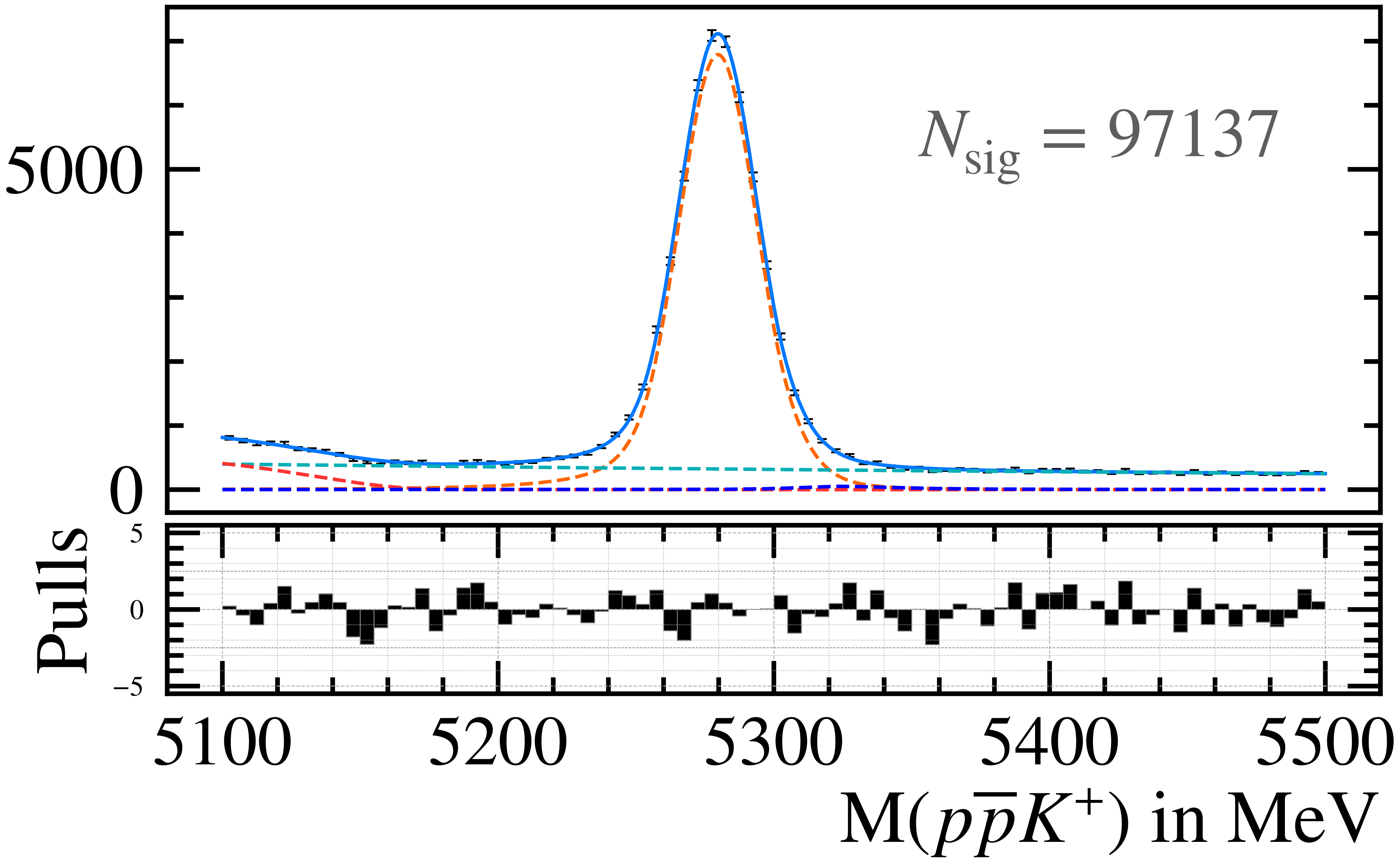
- $\chi_{c1}(3872)$ decaying to $p\bar{p}$ shows the possibility of production in $p\bar{p}$ collisions
- With input from LHCb the possibility of a precise scan of the $\chi_{c1}(3872)$ line shape from $p\bar{p}$ experiments such as PANDA can be explored
- Search for $\chi_{c1}(3872) \rightarrow p\bar{p}$ at LHCb

Mass Fit

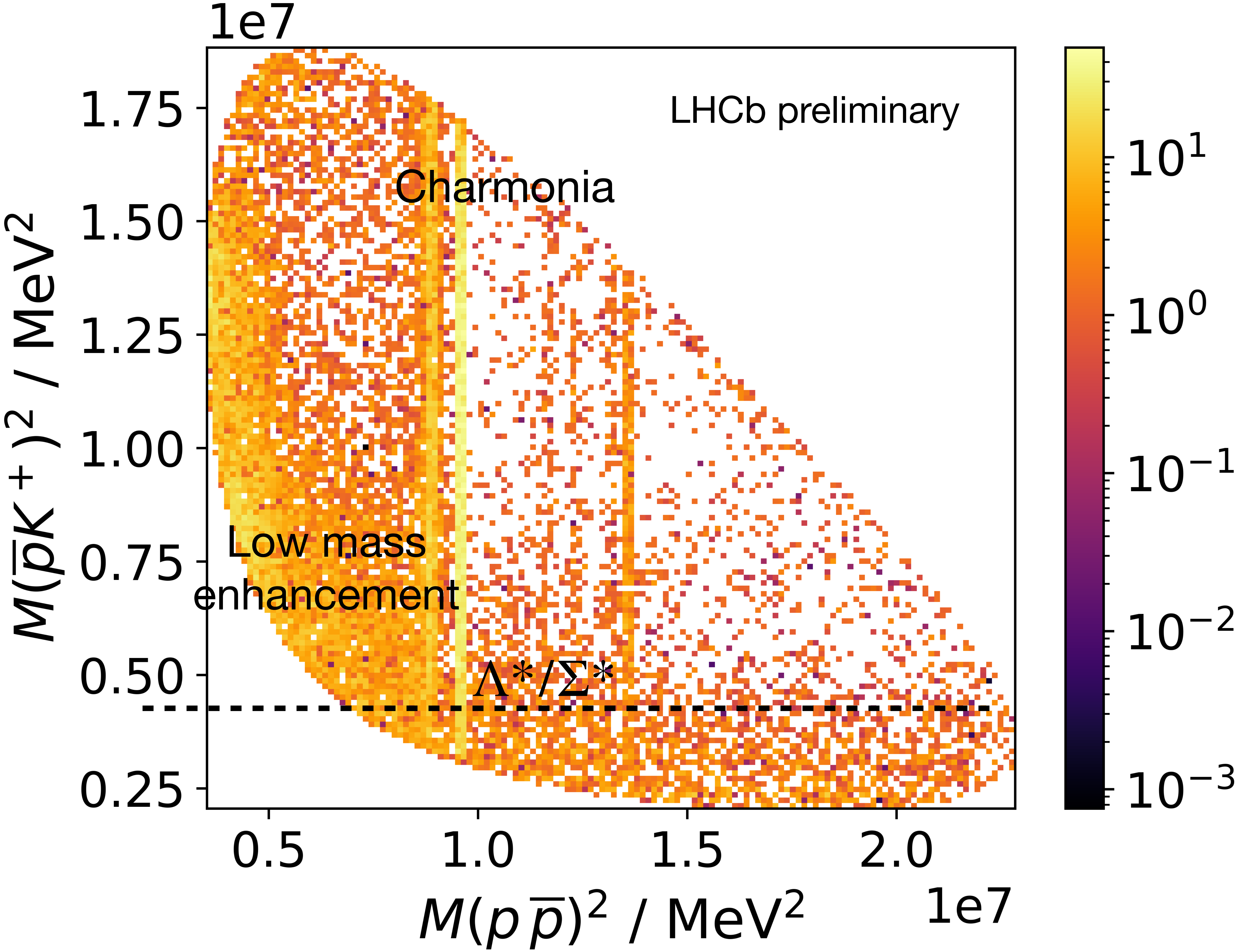
Run 1



Run 2

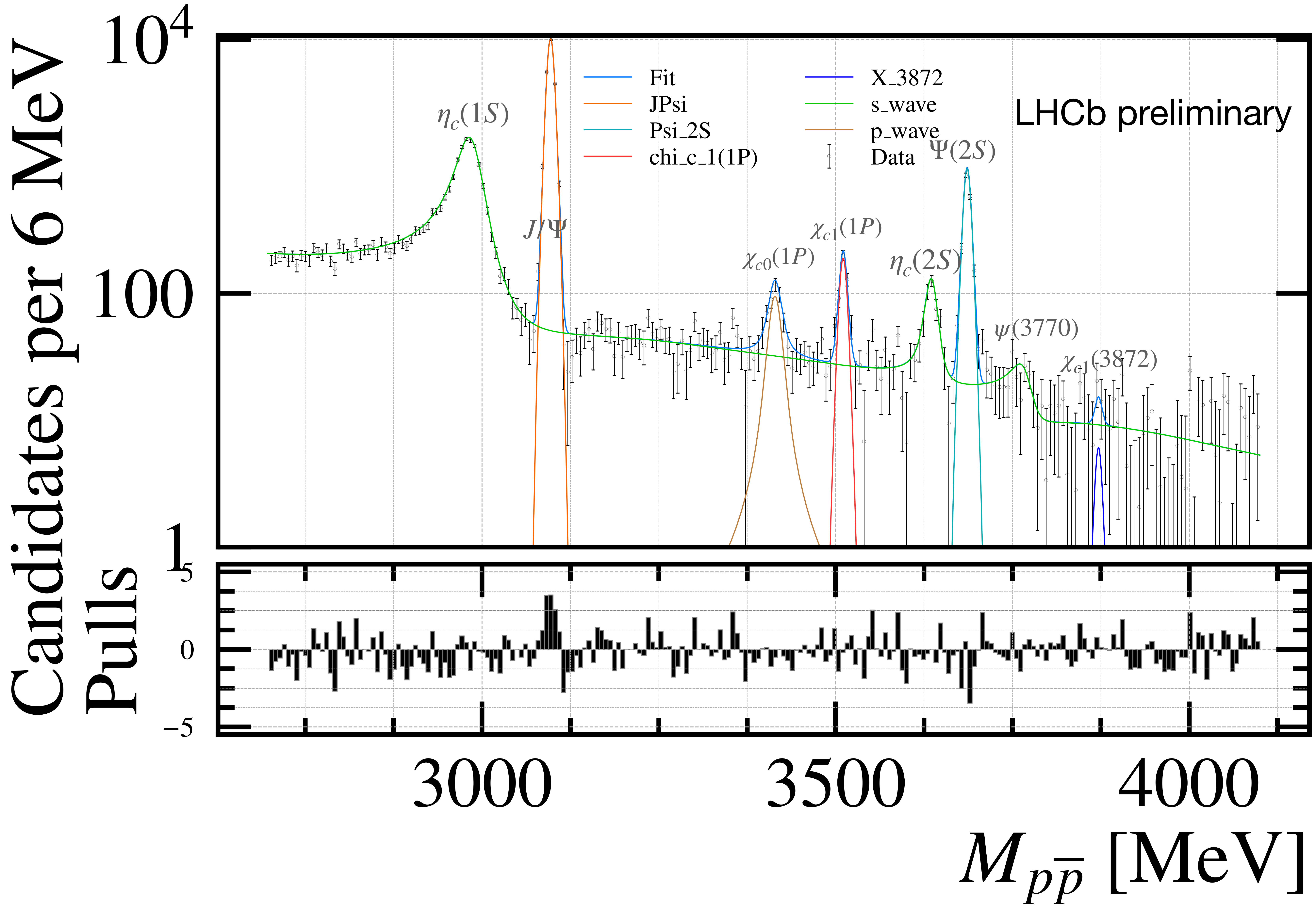


Dalitz Plot



- Possible interference from low mass Λ^*/Σ^* states $\rightarrow$ amplitude analysis might be necessary for higher statistics
- Otherwise rejection cut
- Low mass $p\bar{p}$ enhancements can be cut away

Fit to $p\bar{p}$ Spectrum



- Good description with only charmonia states included
- One dimensional Fit
- No PWA

Further Analysis Strategy

Lineshape Parameters

- Of interest: $\eta_c(1S)$ and $\eta_c(2S)$
- Parameters from lineshape fit
- Systematic and statistical uncertainties from Likelihood Scan

Branching fractions

- $\chi_{c1}(3872) \to p\bar{p}$ and $\psi(3770) \to p\bar{p}$
- Limit setting or significance taken from Likelihood Scan

Likelihood Scan

- Relatively simple approach to estimate uncertainties/confidence intervals
- Idea: shape and value of Likelihood can be translated to confidence intervals
- Issue: Altering parameter of interest (POI) neglects correlations
- Solution:
  - Alter POI and re-optimize
  - Report likelihood value
  - Determine confidence intervals based on resulting Likelihood Parabola
  - Handle systematic uncertainties via combination of parabolas for different Models like different descriptions of resolution

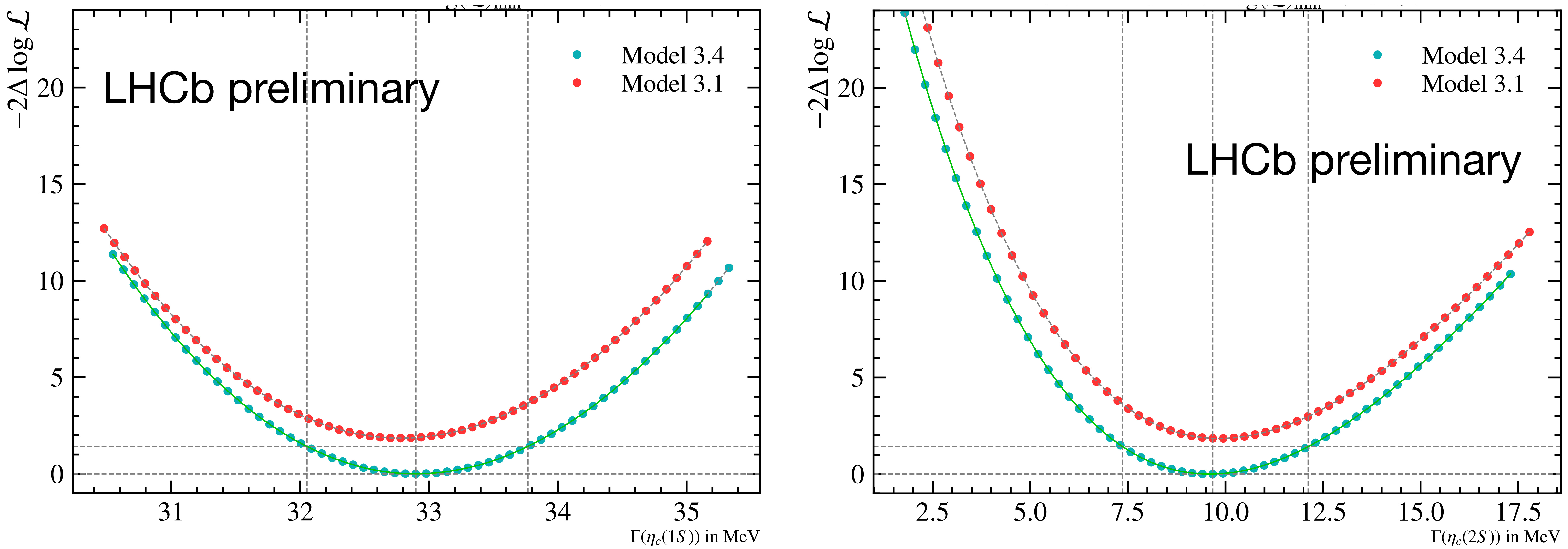
Measurement of η_c states

Uncertainty

- Use likelihood scan to compare the resolution models
- More sophisticated model is better

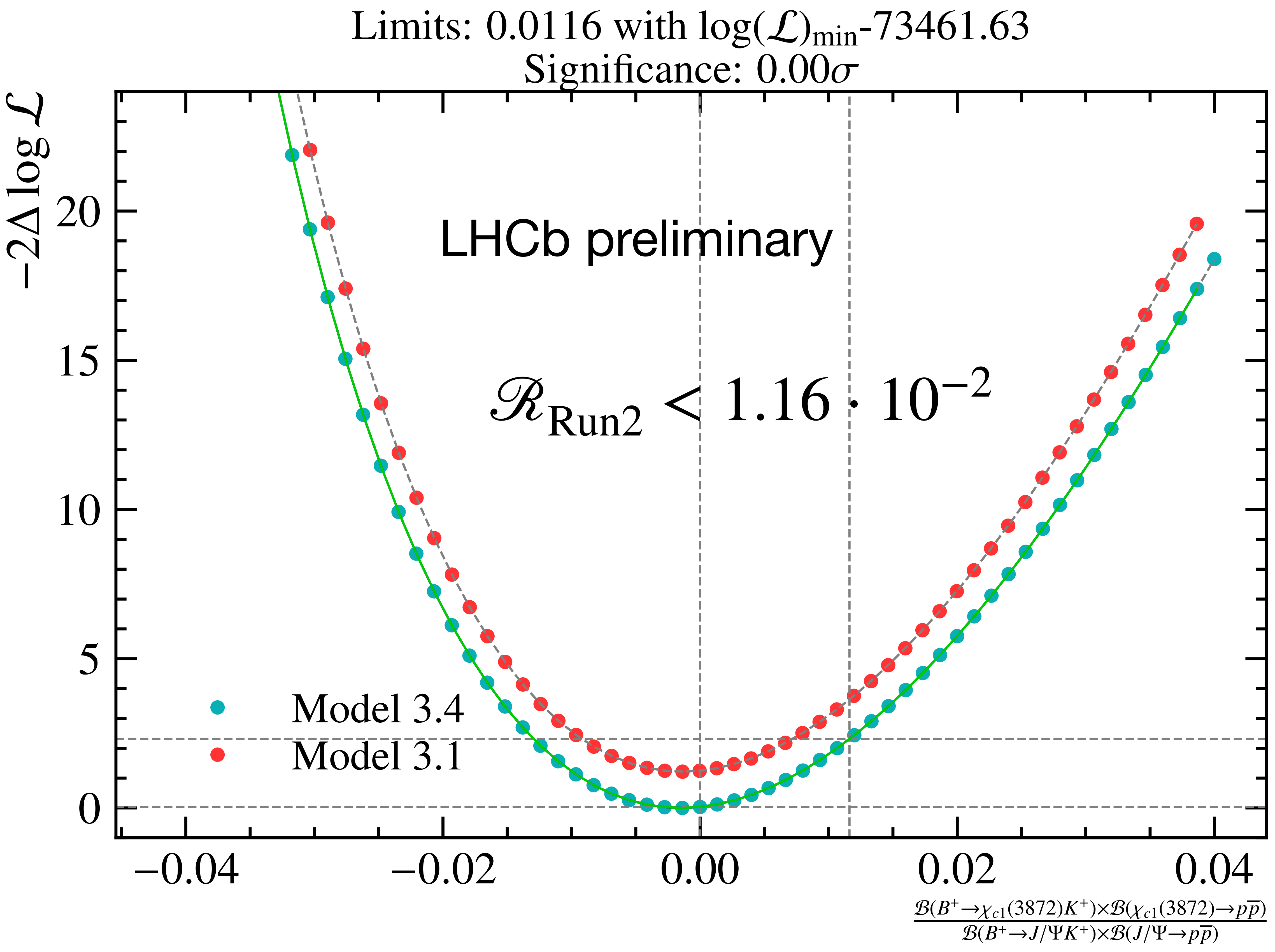
→ No systematic uncertainty from resolution model

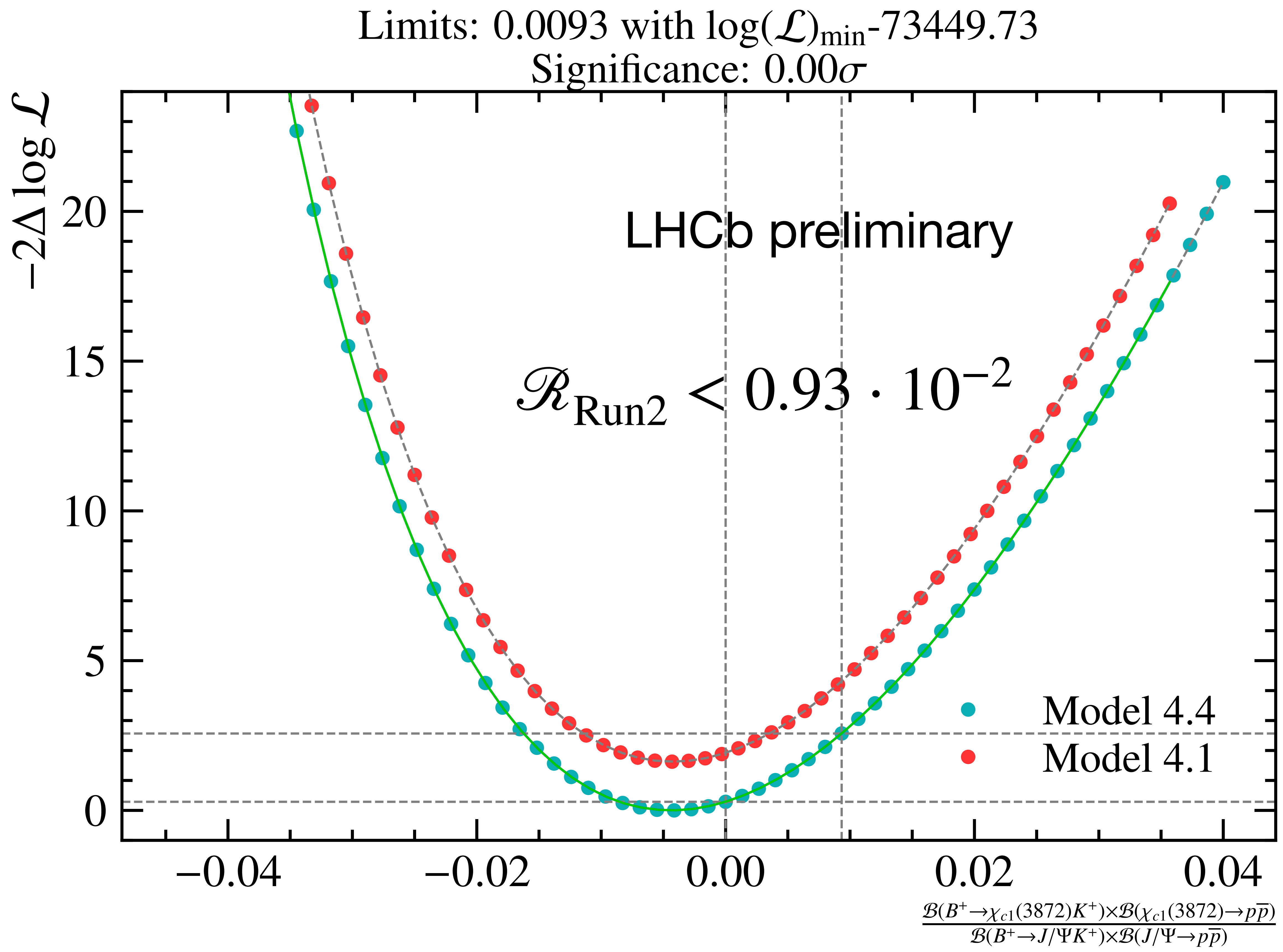
→ Bootstrap errors are used



$$M_{\eta_c(1S)} = 2984.6^{+0.3}_{-0.4}(\mathrm{stat})\,\mathrm{MeV}$$
$$\Gamma_{\eta_c(1S)} = 32.9^{+0.7}_{-0.7}(\mathrm{stat})\,\mathrm{MeV}$$
$$M_{\eta_c(2S)} = 3635.7^{+2.0}_{-1.7}(\mathrm{stat})\,\mathrm{MeV}$$
$$\Gamma_{\eta_c(2S)} = 9.7^{+2.5}_{-2.6}(\mathrm{stat})\,\mathrm{MeV}$$

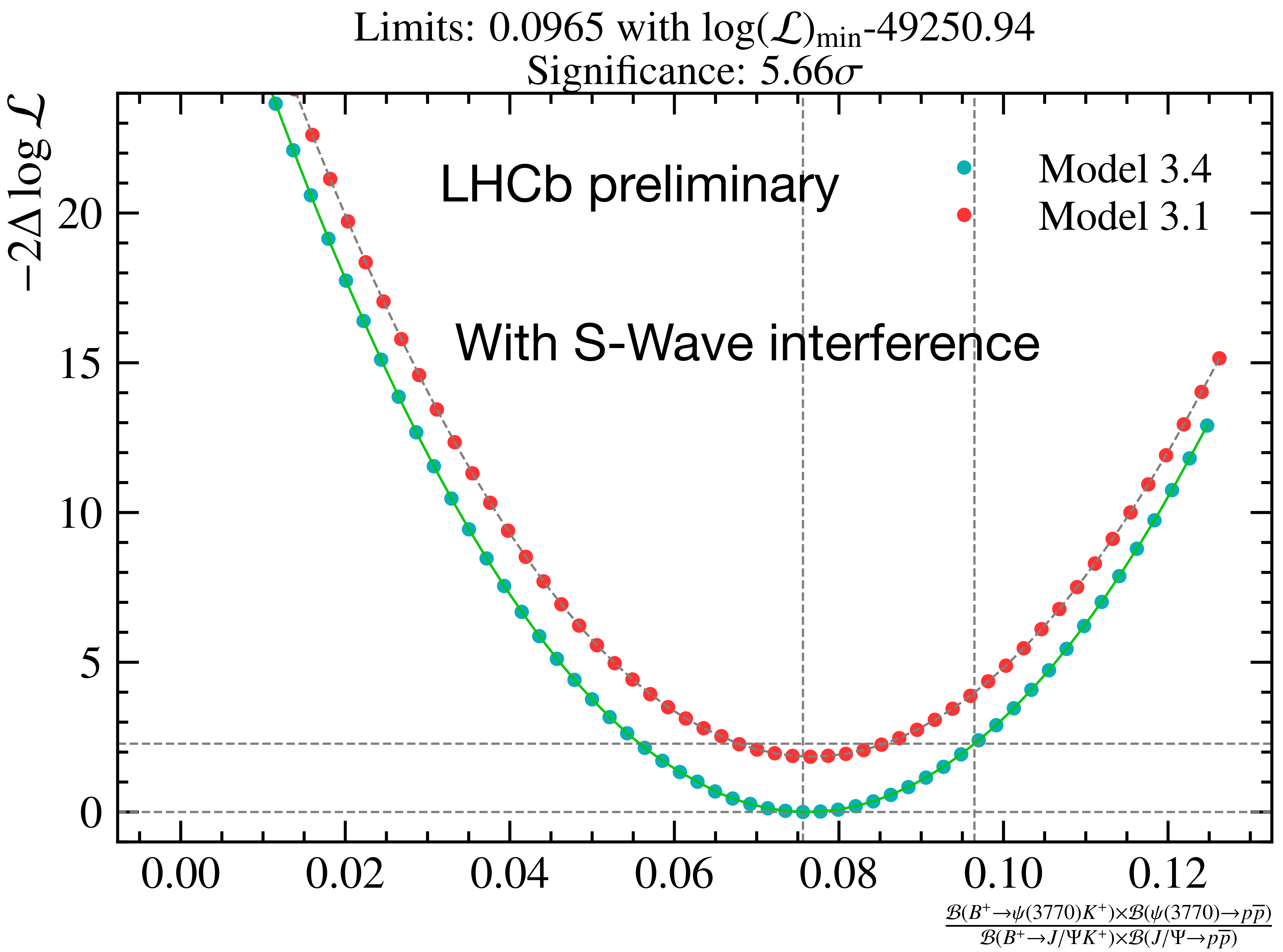
Limit Setting on the $\chi_{c1}(3872)$

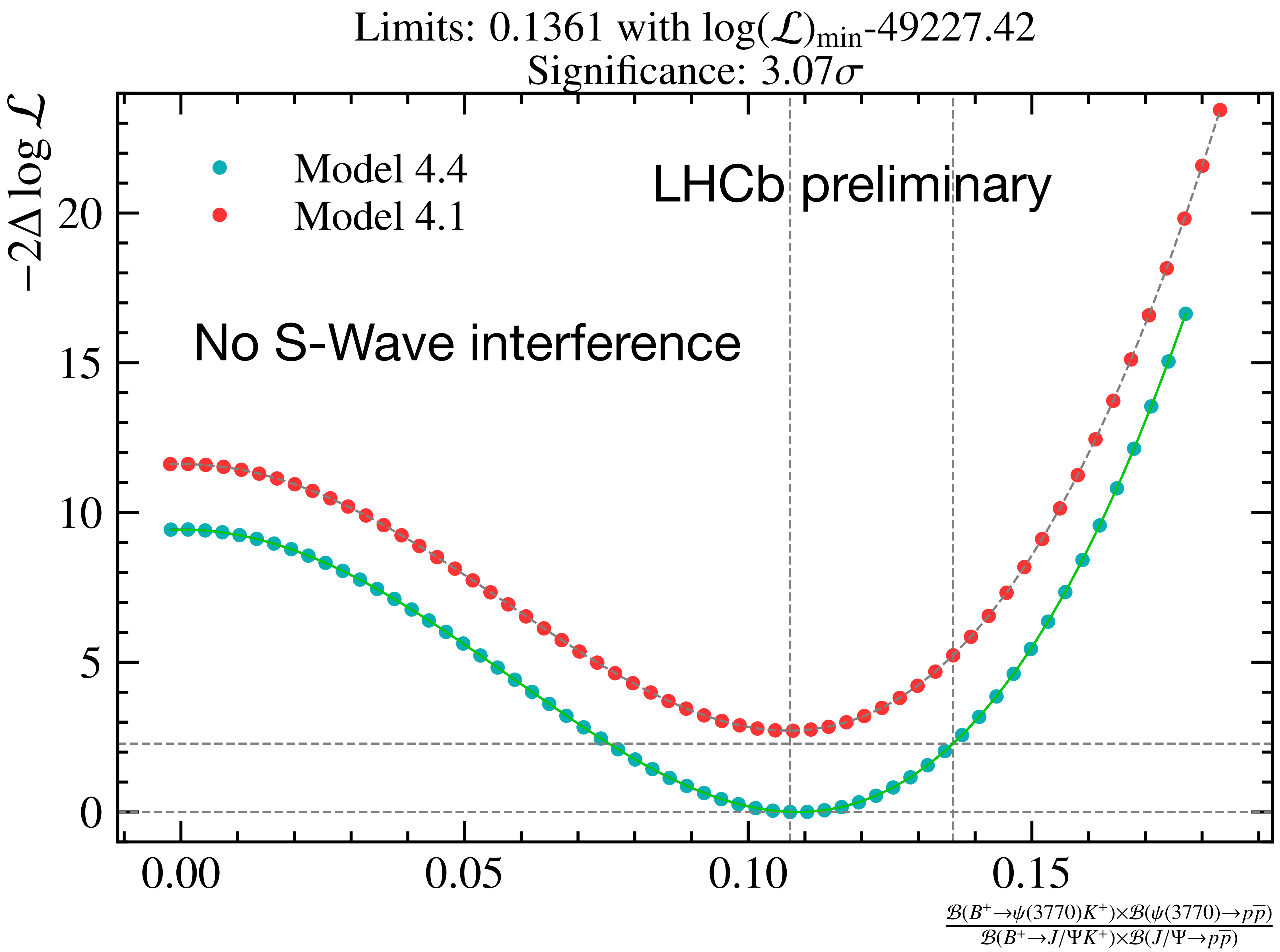




$$\mathcal{R}_{\text{Run2}} > \mathcal{R}_{\text{Run1}} = 0.25 \times 10^{-2}$$

Search for the $\psi(3770)$



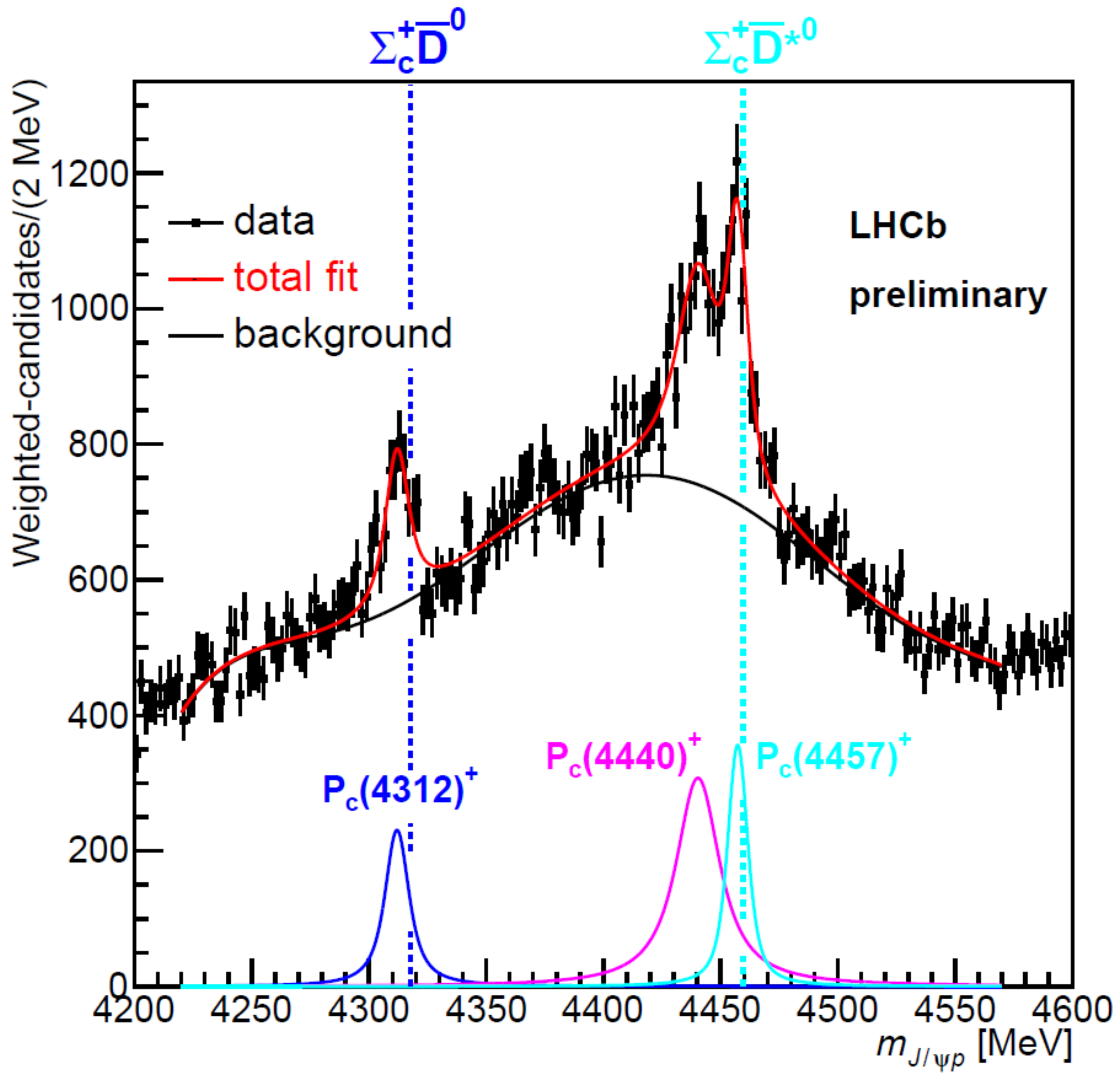


Significant contribution from $\psi(3770)$ when interference with S-Wave is taken into account

Pentaquark Searches in $\Lambda_c \overline{D}^0$

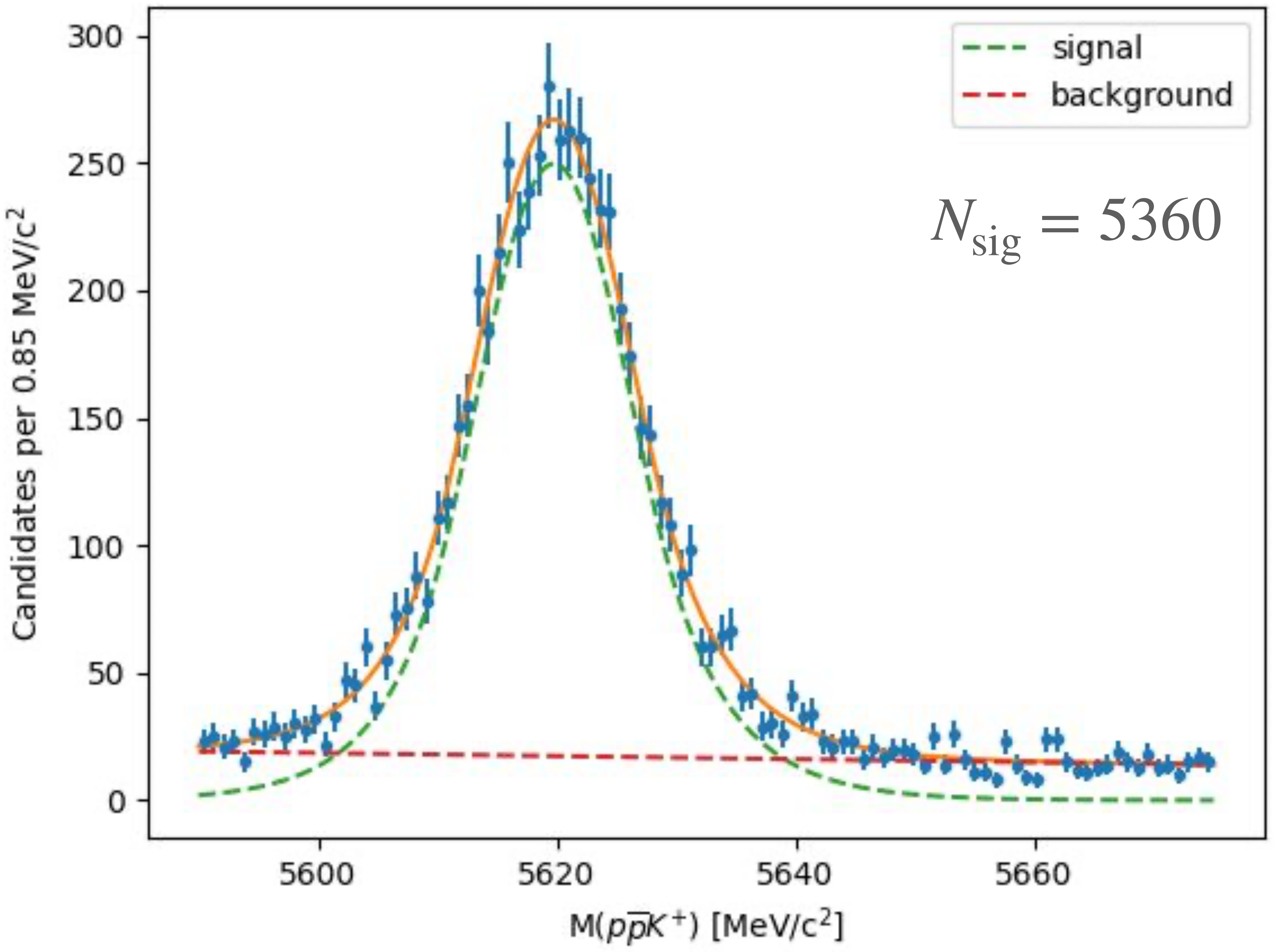
- First pentaquark observations from LHCb in 2015
- More precise Run2 study finds 3 states
  - $P_c(4312)$, $P_c(4440)$ and $P_c(4457)$
- All states appear close to meson-baryon thresholds

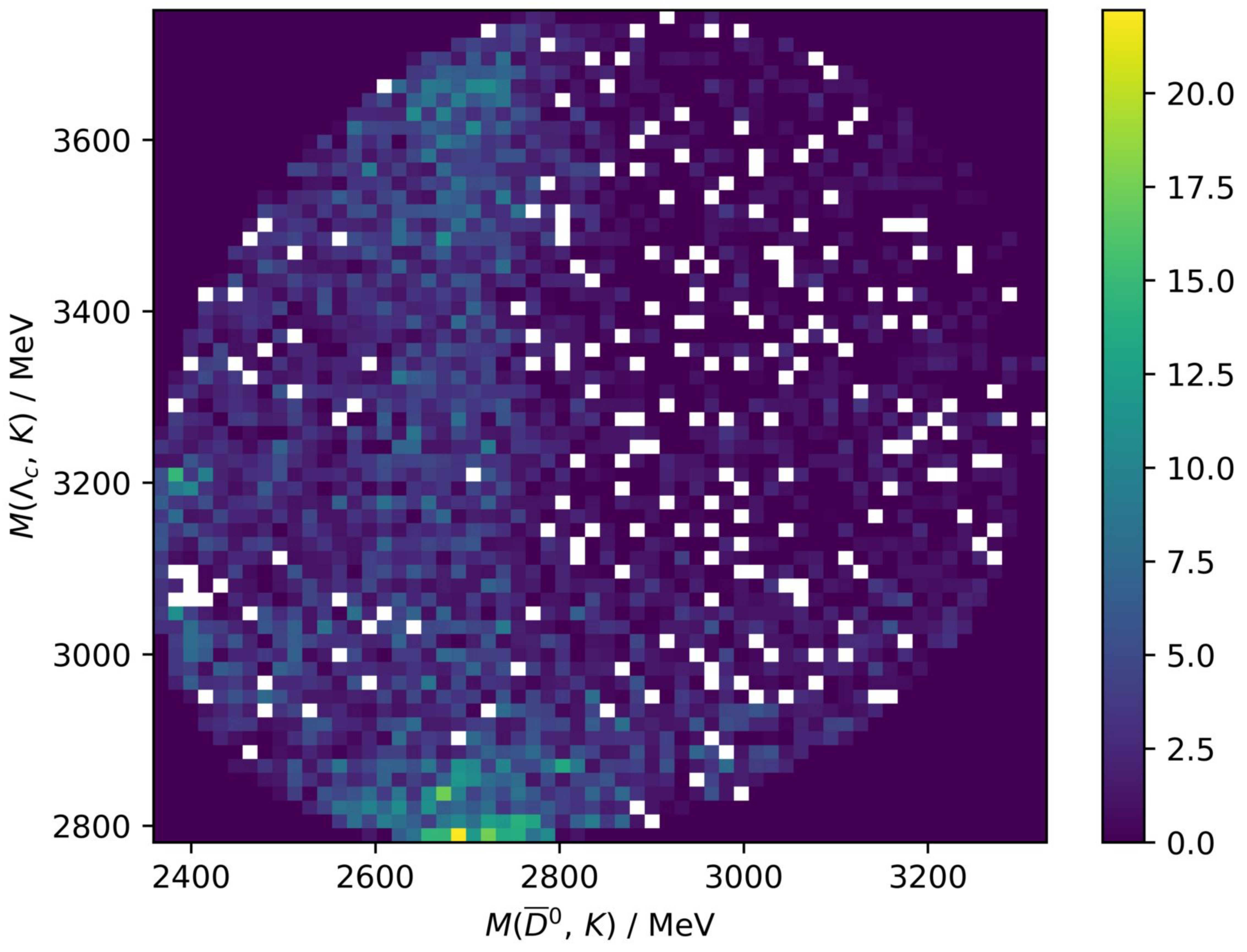
  $\rightarrow$ Molecular states?
- Models predict coupling to other channels such as $P_c \rightarrow \Lambda_c \overline{D}^{0(*)}$
- Measurement of $\mathscr{B}\left(P_c \rightarrow \Lambda_c \overline{D}^{0(*)}\right)$ helpful



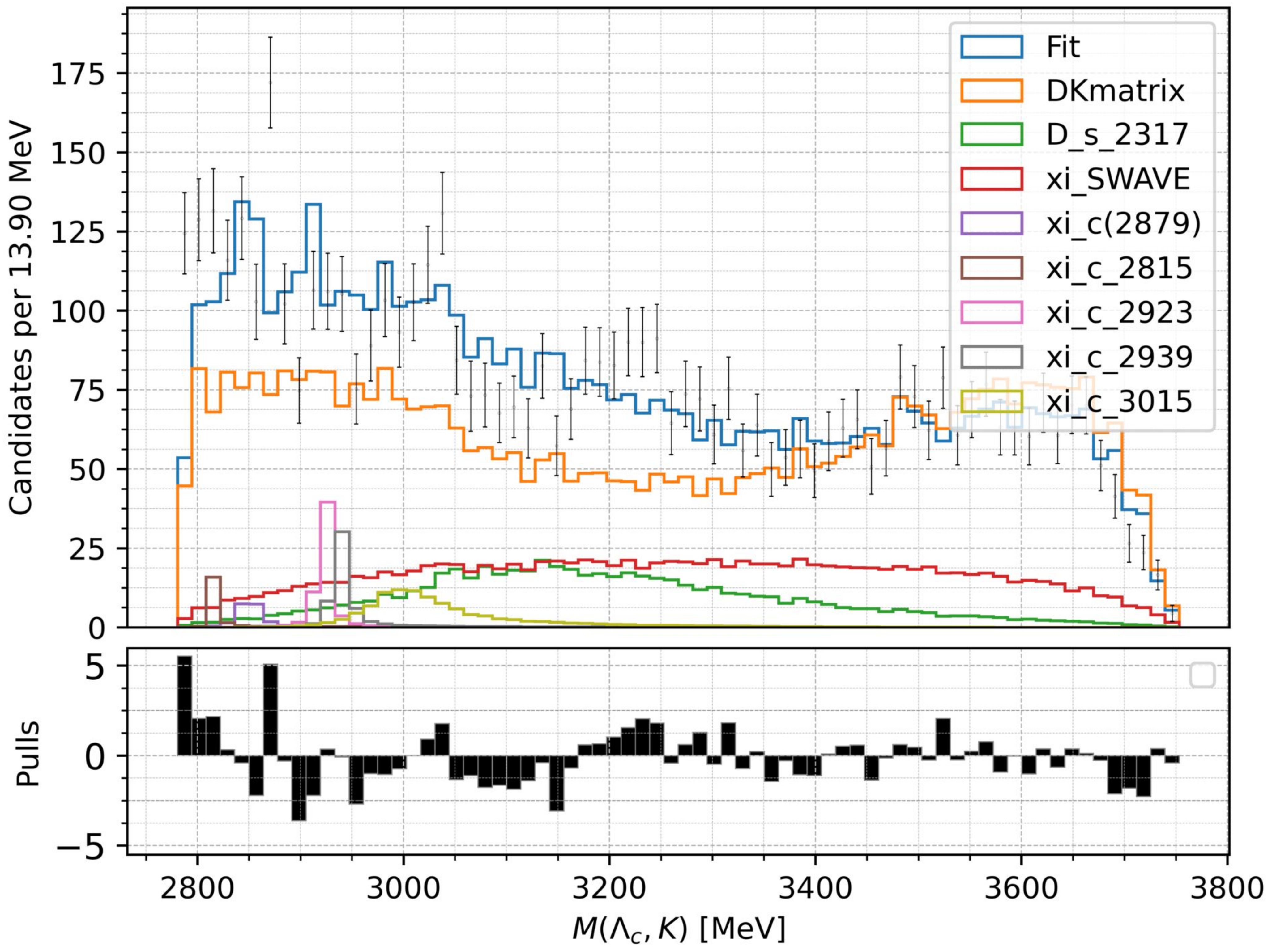
Fit to the $J\psi\, p$ mass spectrum finding three pentaquark candidates
https://lhcb-outreach.web.cern.ch/2019/03/26/observation-of-new-pentaquarks/

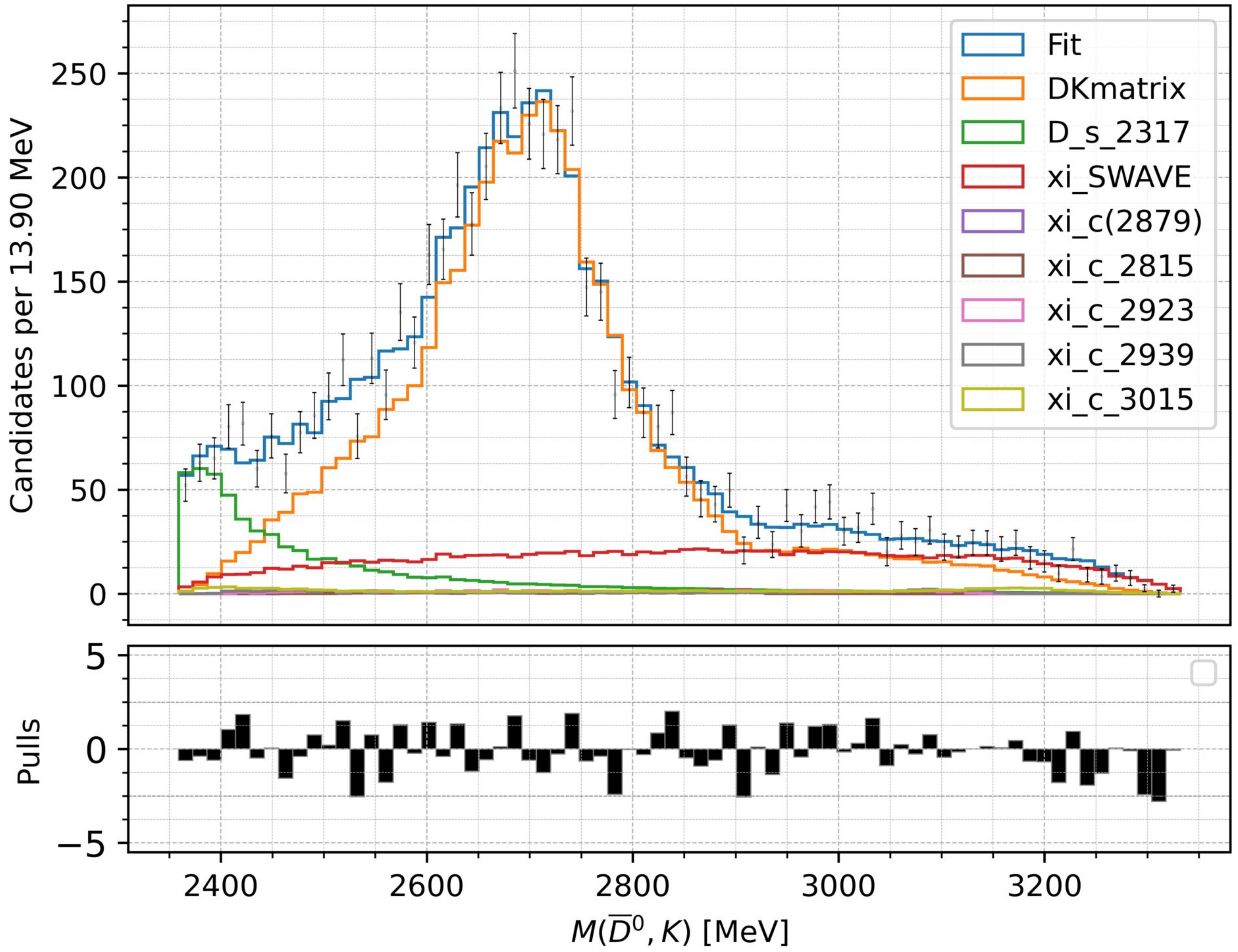
Mass Fit and Dalitz Plot





Understanding the non-exotic spectra

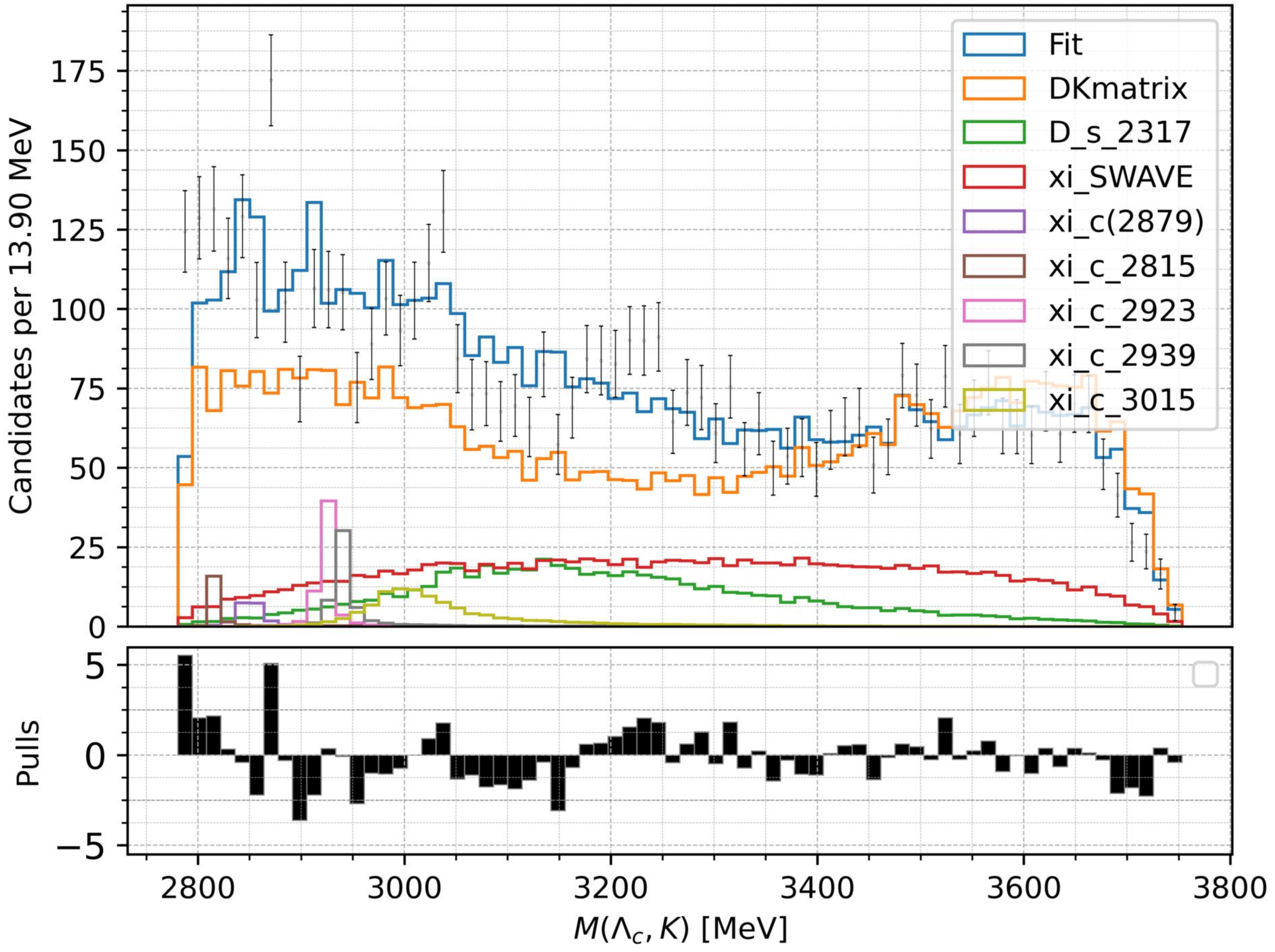


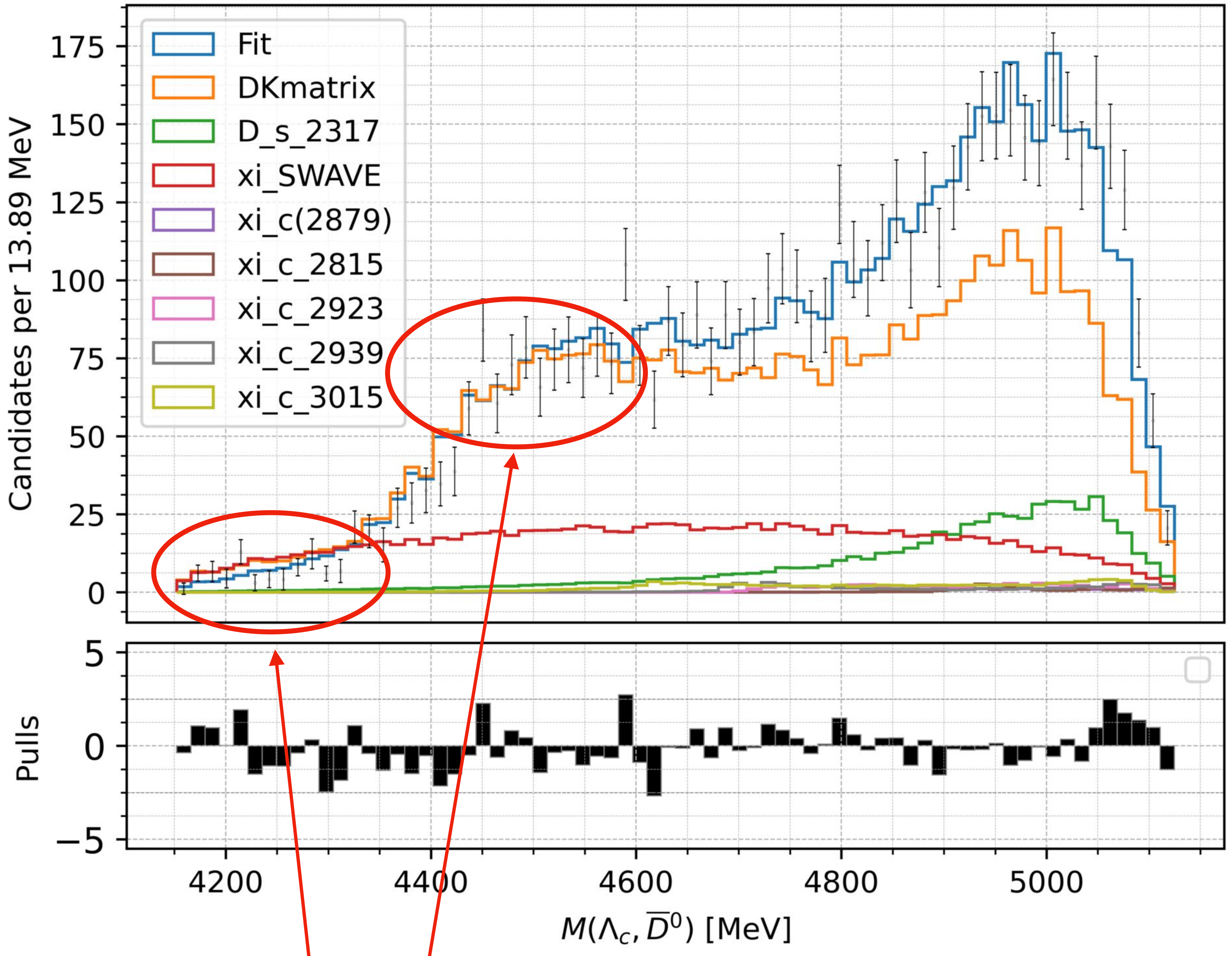


- $\Lambda_c K$ spectrum not well understood
- Many Ξ_c states may couple

- Good description of $\overline{D}^0 K$ mass spectrum with K-Matrix of $D_s^*(2700)$ and $D_s^*(2860)$

Understanding the non-exotic Spectra





- $\Lambda_c K$ spectrum not well understood
- Many Ξ_c states may couple

- Ξ_c can contribute significantly to the Region of Interest
- **Good description is necessary!**

Overview

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Analysis of $B^+ \to p\bar{p}K^+$

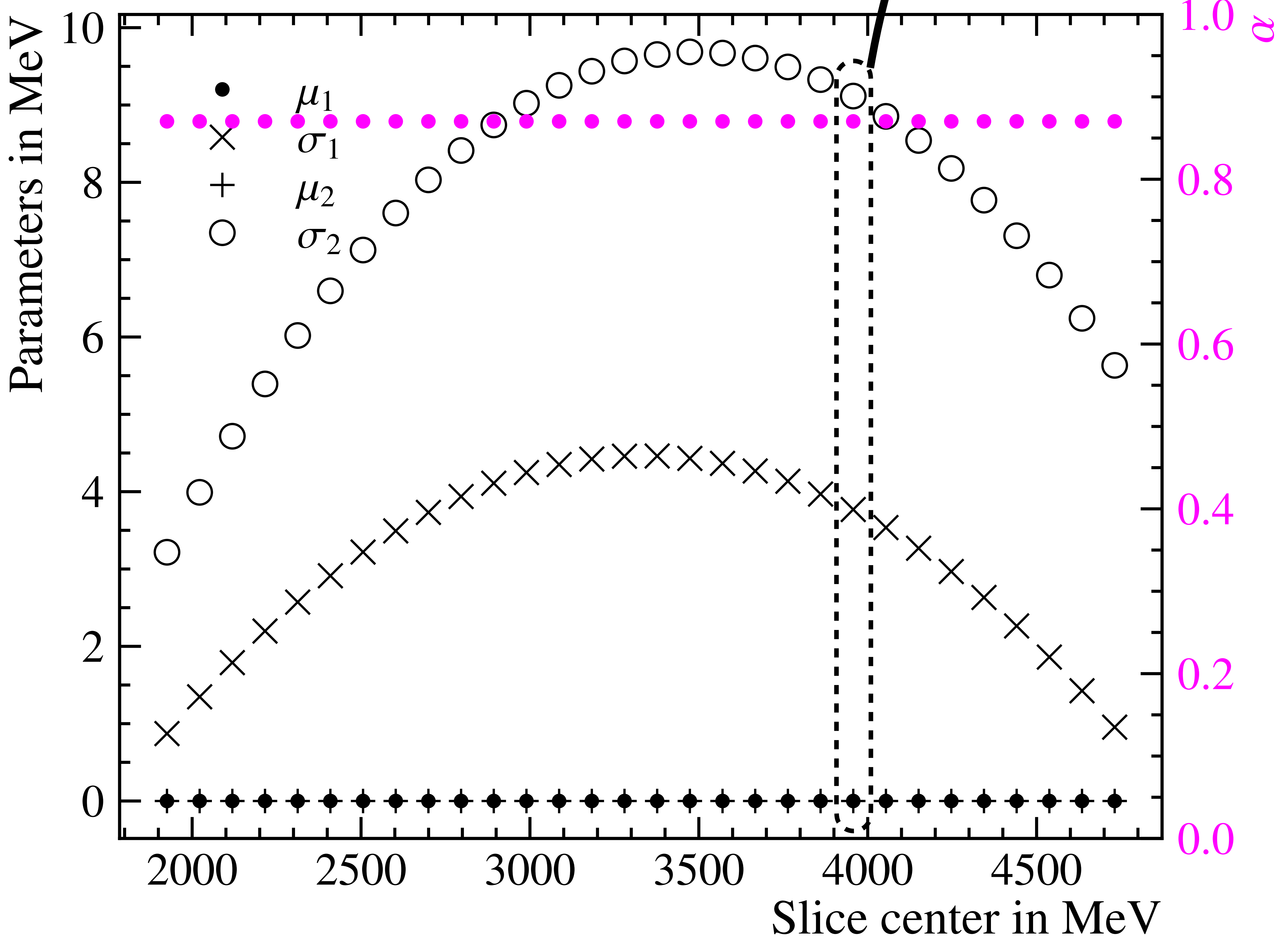
- 97000 events in Run 2 (27000 in Run 1)
- Fit model able to describe Charmonium Spectrum
- First results for Lineshape parameters of $\eta_c(1S)$ and $\eta_c(2S)$
- Measurement of the branching ration for $\psi(3770) \to p\bar{p}$
- Updated limit on the branching fraction $\chi_{c1}(3872) \to p\bar{p}$

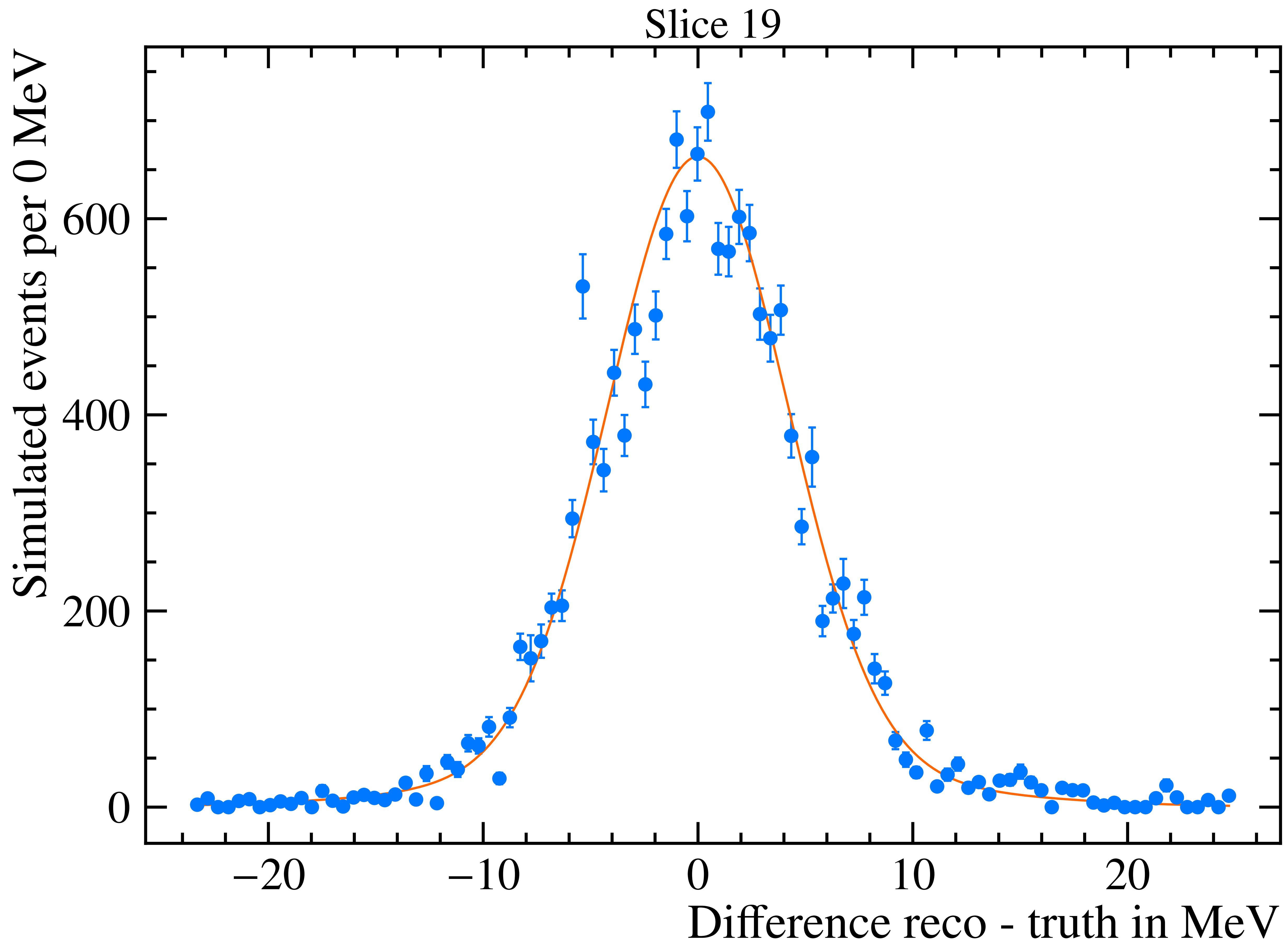
Analysis of $\Lambda_b \to \Lambda_c \overline{D}^0 K$

- 5300 events in Run 2
- Full amplitude analysis necessary
- Good description of $\overline{D}^0 K$ mass spectrum
- $\Lambda_c K$ still not fully understood
  - Run 3 data may help here
- Once $\Lambda_c K$ is well described limit setting on the branching fractions of $P_c \to \Lambda_c \overline{D}^0$ is possible

Backup

Resolution





Modelled as $\alpha \cdot G(\mu_1, \sigma_1) + (1 - \alpha) \cdot G(\mu_2, \sigma_2)$

With $G(\mu, \sigma)$ a Gaussian, $\sigma_{1/2} = a_{1/2} + b_{1/2} \cdot m^2_{p\bar{p}}$, $\mu_{1/2} = 0$ and $\alpha,\ a_{1/2},\ b_{1/2}$ floating

Construction of the Likelihood

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$$-\mathscr{L}(\omega) = -\frac{\sum_k w_k^s}{\sum_l (w_l^s)^2} \sum_i \log\left(\frac{|A|^2(x_i, \omega)}{N_\omega}\right) \cdot w_i^s \times \log(P_{\mathrm{Poisson}}(N, N_\omega))$$

Effective Sample Size based on the sWeights

Standard Log Likelihood

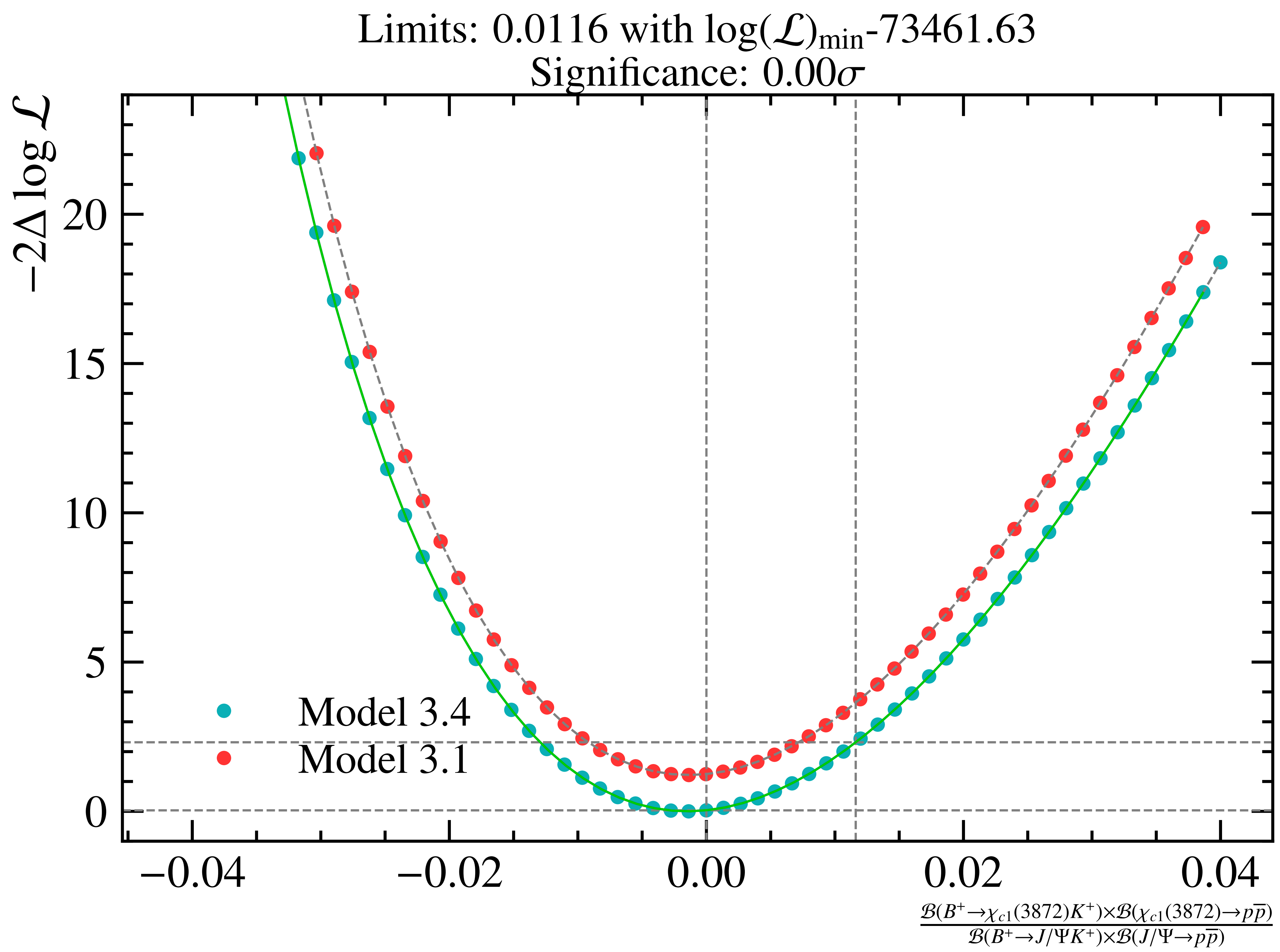
Extension with Poisson distribution

$$N_\omega = \sum_j |A|^2(\xi_i, \omega) \cdot w_j^{\mathrm{MC}}$$

Monte Carlo integral using phase space simulation

$$\mathscr{L}(\omega) = \frac{\sum_k w_k^s}{\sum_l (w_l^s)^2} \left(N_\omega - \sum_i (1 - w_i^s) \cdot \log(N_\omega) - \sum_j w_j^s |A|^2(x_j, \omega) \right)$$

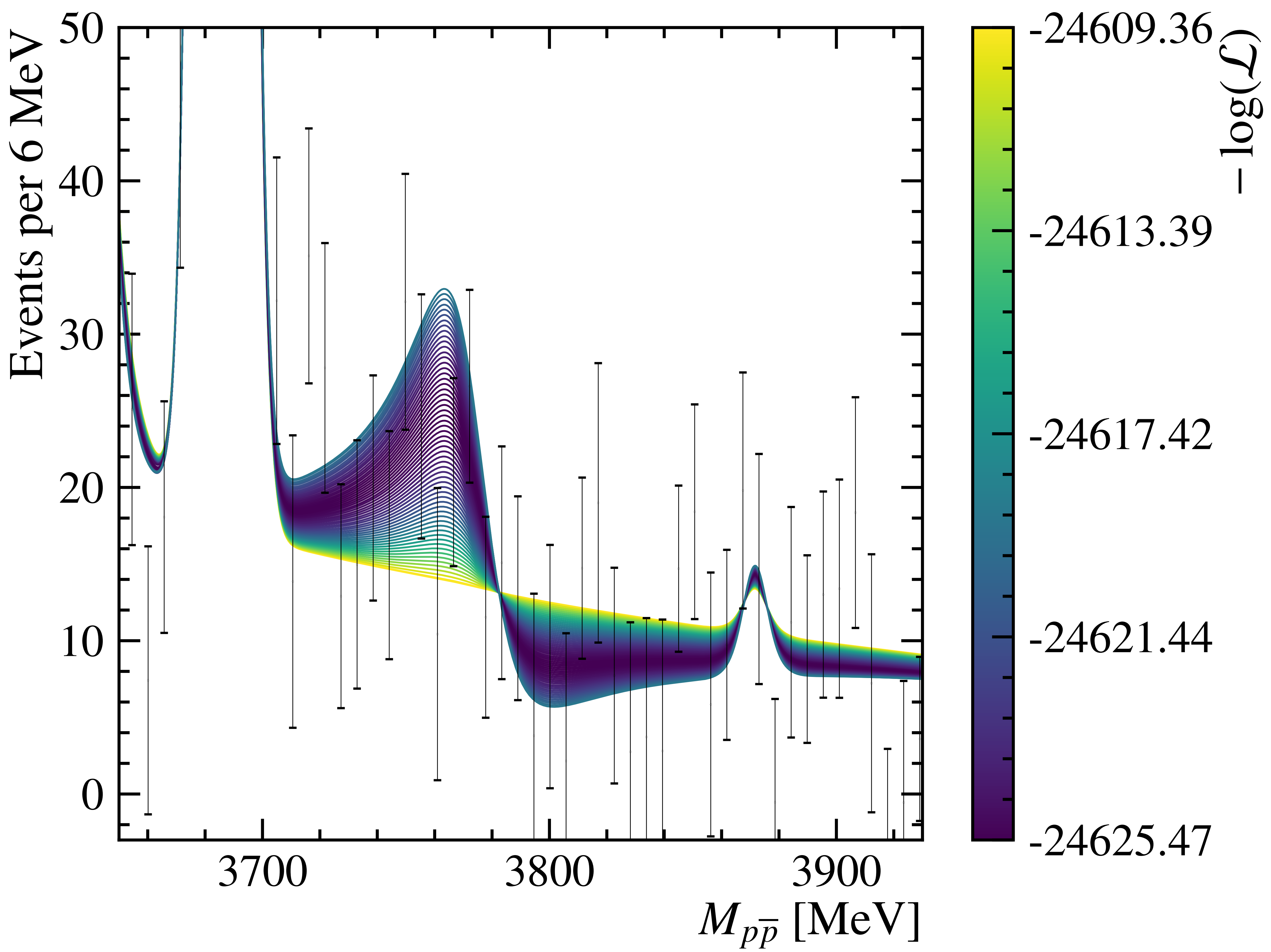
Limit Setting on $\chi_{c1}(3872)$



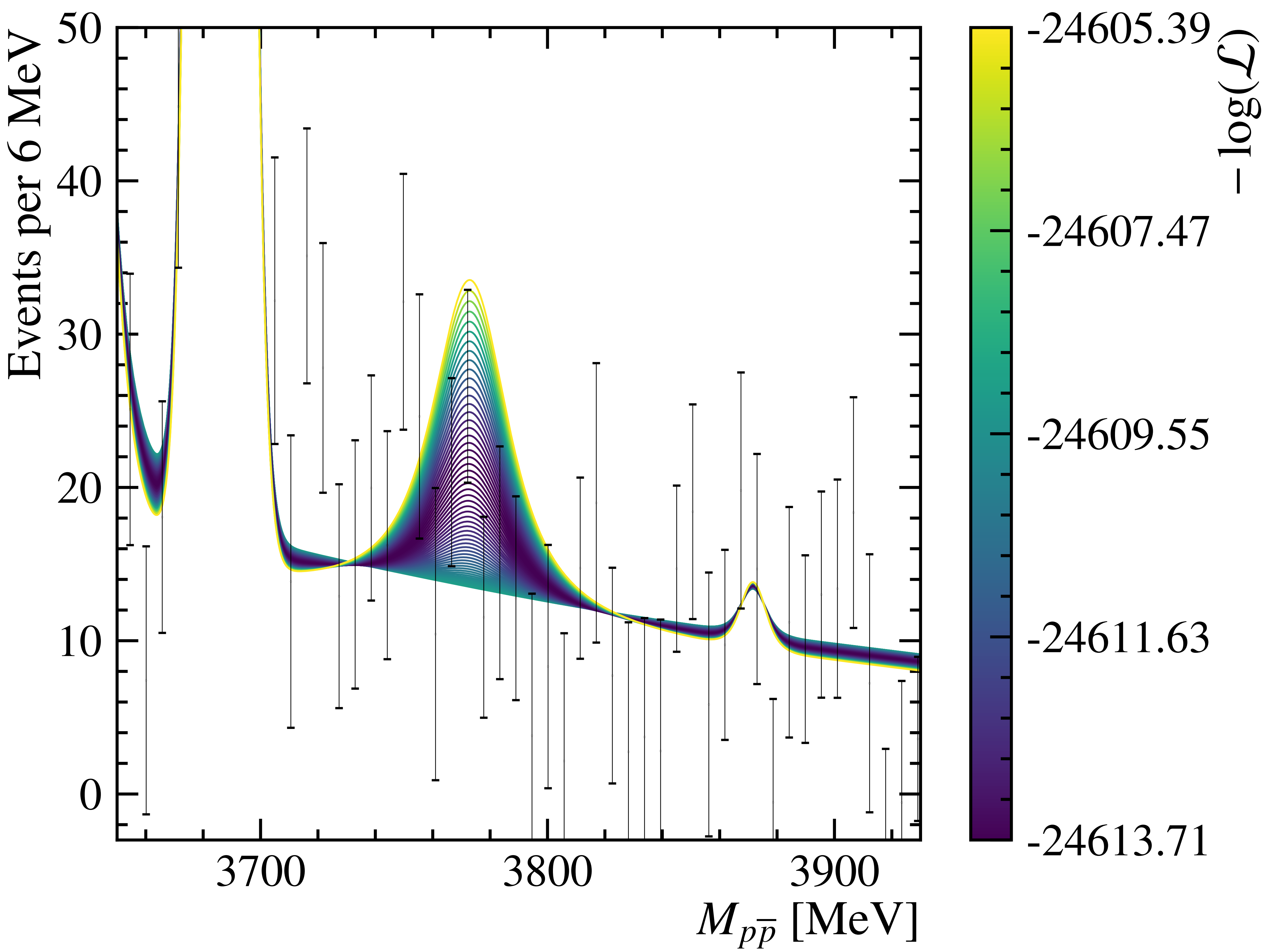
Likelihood Profile

- Fix parameter of interest $\mathscr{F}(\chi_{c1}(3872))$ to multiple values and re-optimize
- Interpolate between points of $(\mathscr{F}(\chi_{c1}(3872)), \Delta \log(\mathscr{L}))$
- Assumption: Posterior is gaussian distribution
- Get 95% Confidence from gaussian intervals (1.65σ)

Limit Setting → Profile Likelihood (Run2)

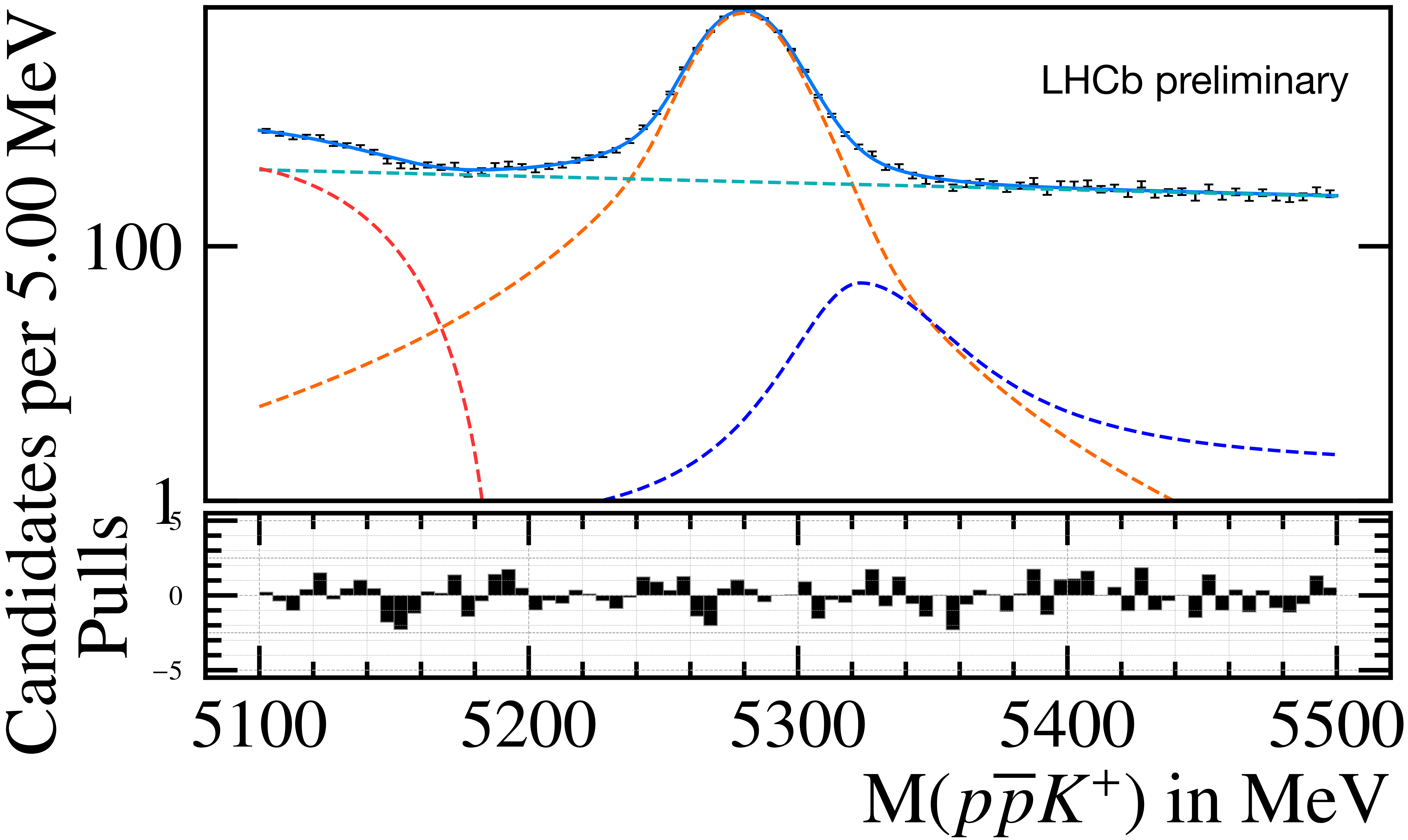


$\mathscr{R}_{\text{Run2}} < 1.16 \cdot 10^{-2}$



$\mathscr{R}_{\text{Run2}} < 0.93 \cdot 10^{-2}$

Mass Fit (Run2)



- Partially reconstructed background
- Signal
- Misidentified background
- Combinatorial background