

# Measurement of the $\Lambda_c^+$ lifetime at Belle II

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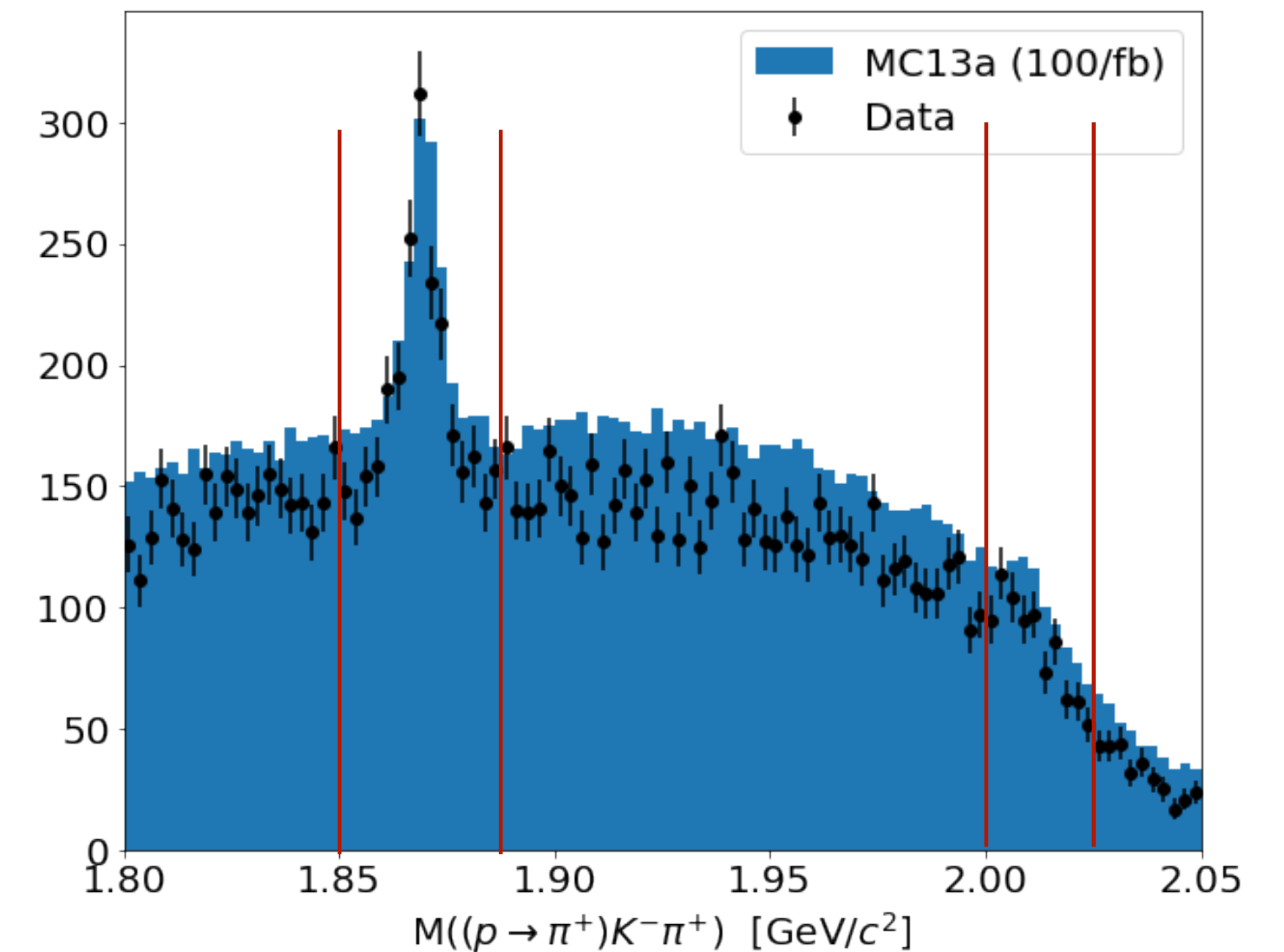
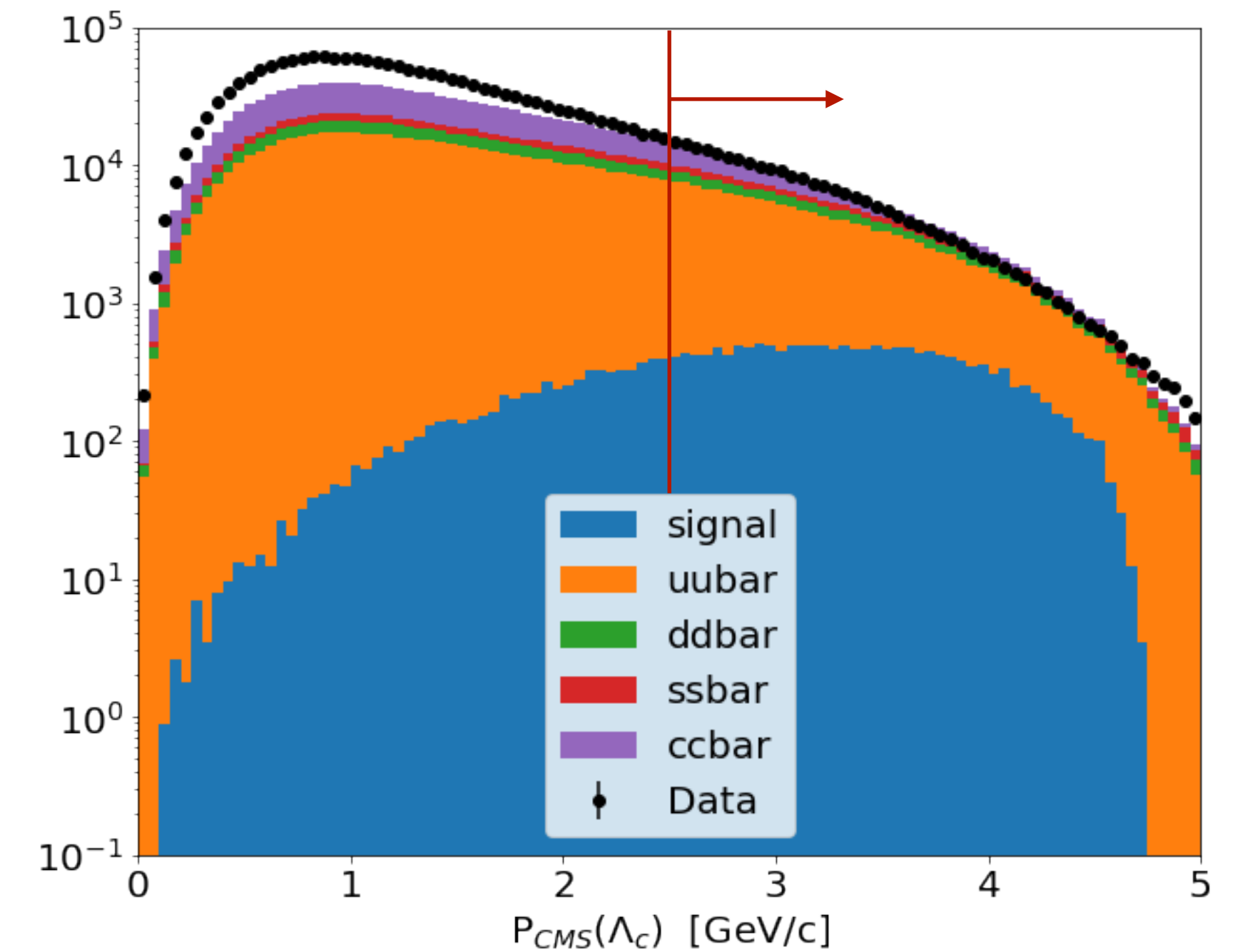


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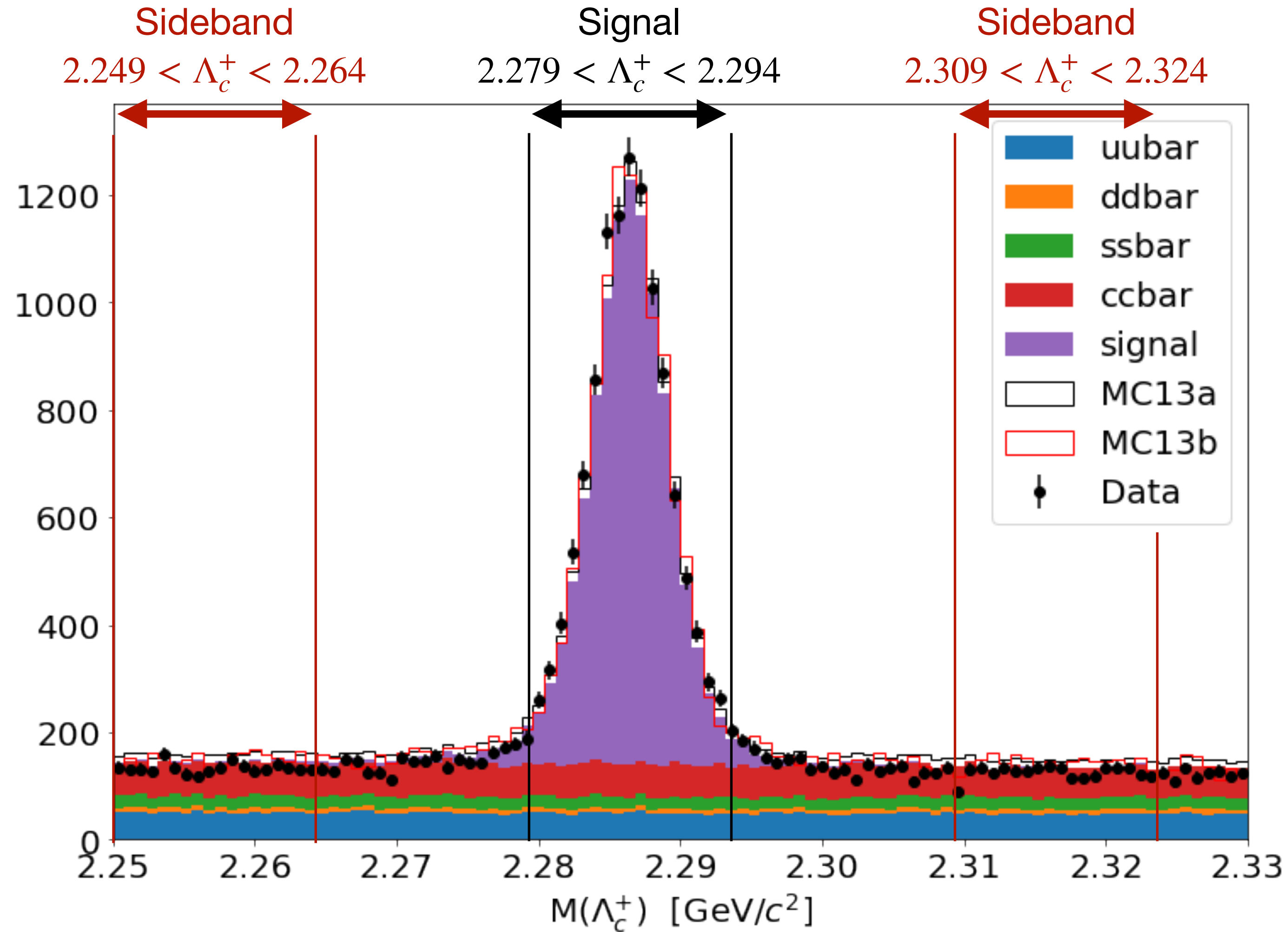


# Event selection

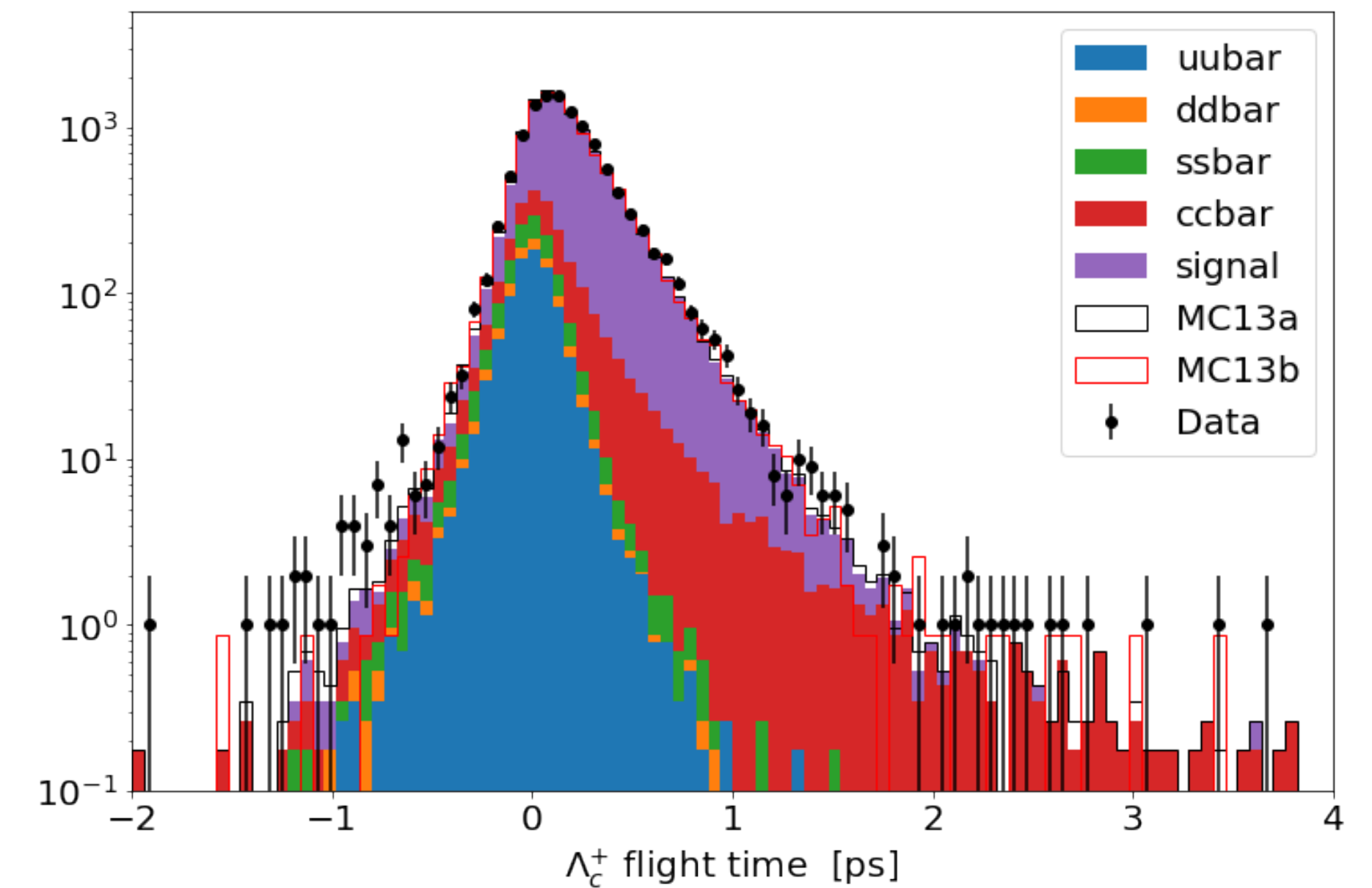
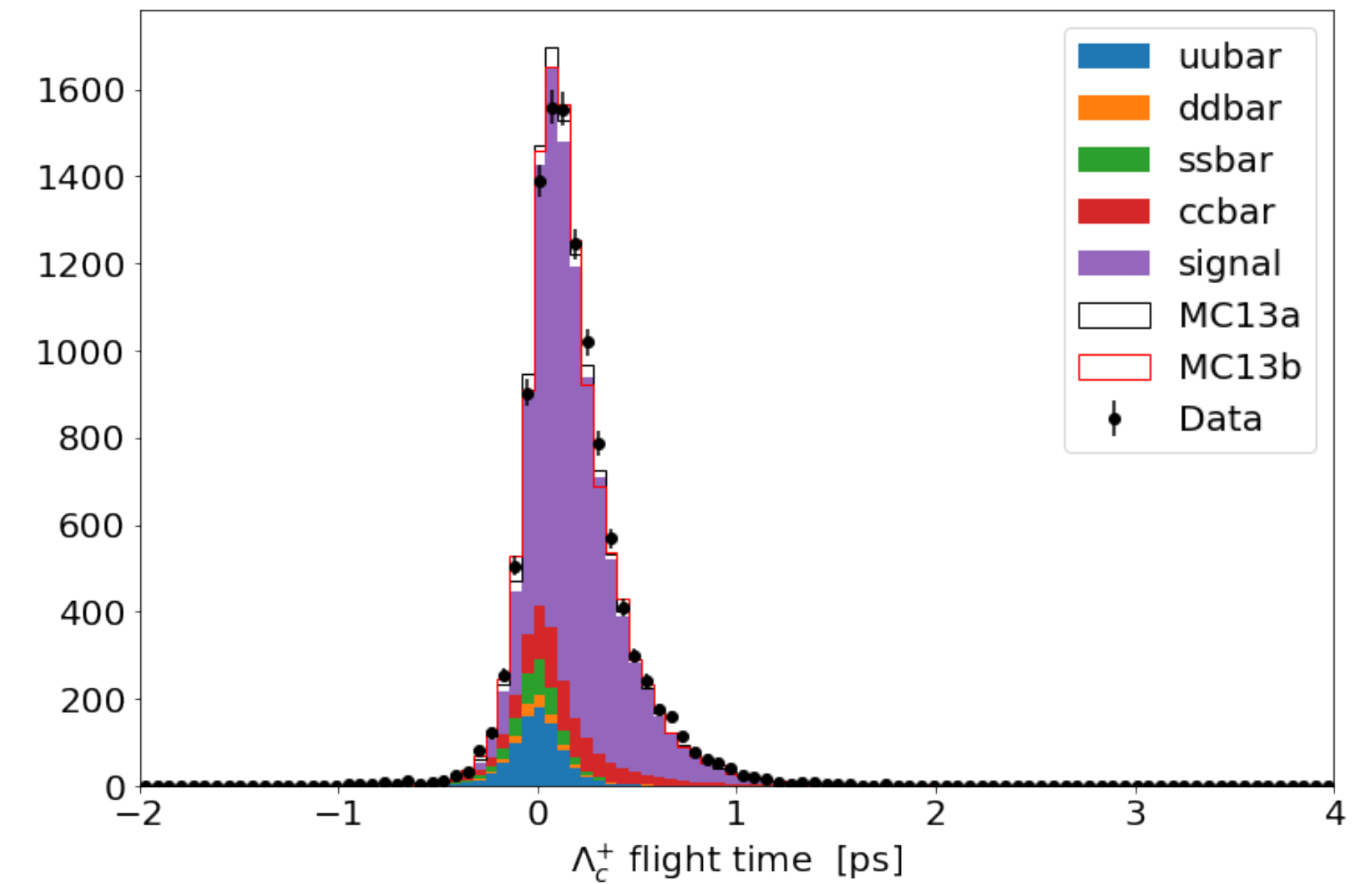
- Selection criteria:
  - Tracks must be in the CDC acceptance and have at least 20 CDC hits, at least one PXD hit, and the first SVD hit layer  $> 2$
  - $d_0 < 0.5$  cm,  $|z_0| < 2$  cm (standard track cuts)
  - Vertex fit (TreeFitter with IP constraint)  $\text{conf\_level} > 0.001$
  - $\Lambda_c$  CM momentum  $> 2.5$  GeV
  - Proton PID (trinary)  $> 0.8$
  - Kaon PID (global)  $> 0.5$
  - Remove charm backgrounds by cutting on  $M(pK\pi)$  with pion hypothesis for proton track
- Samples
  - Data: proc11 (8.764/fb), ~blinded
  - MC: MC13a (100/fb), MC13b\_proc11 (10/fb)



# Invariant mass after all cuts

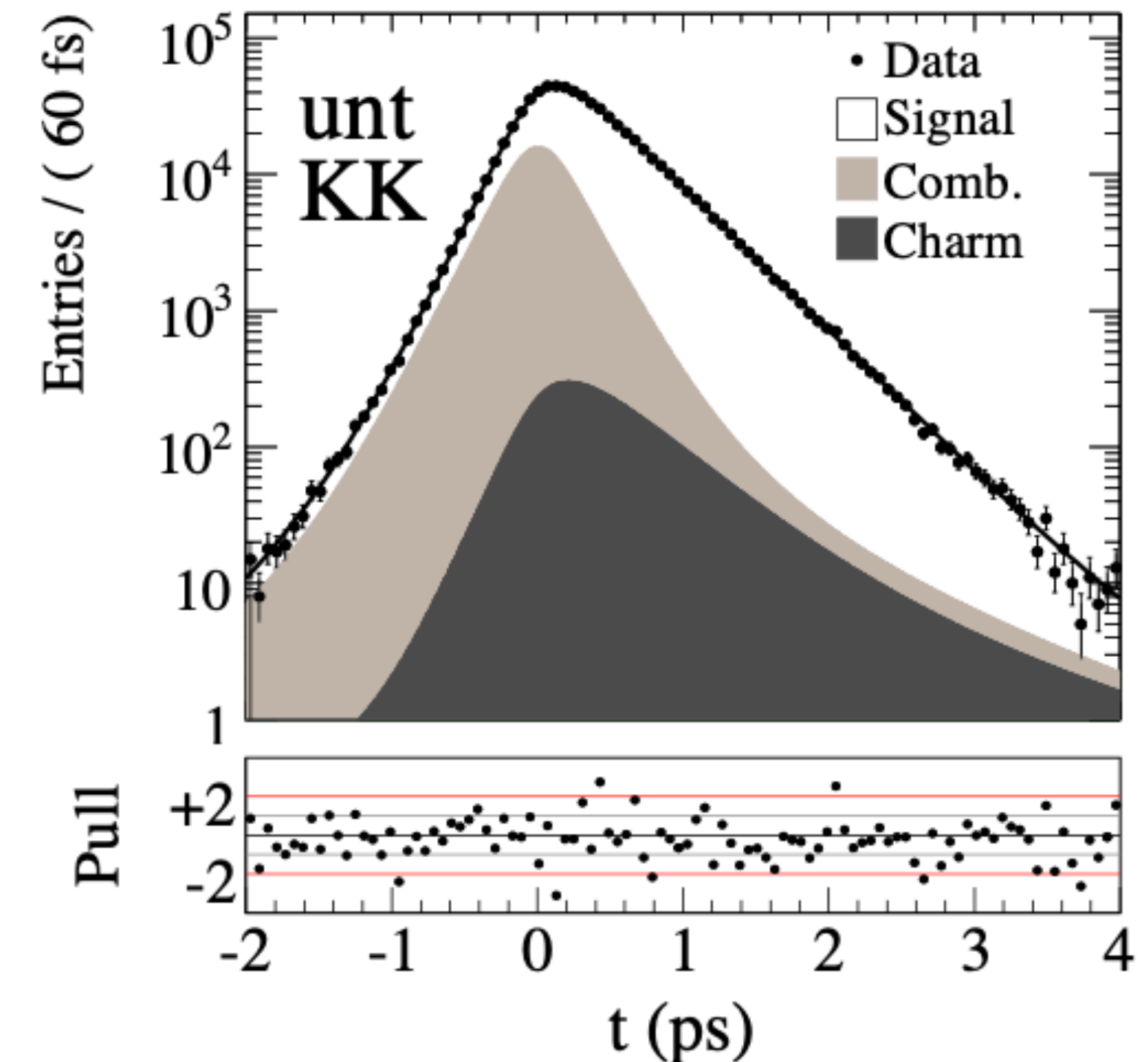
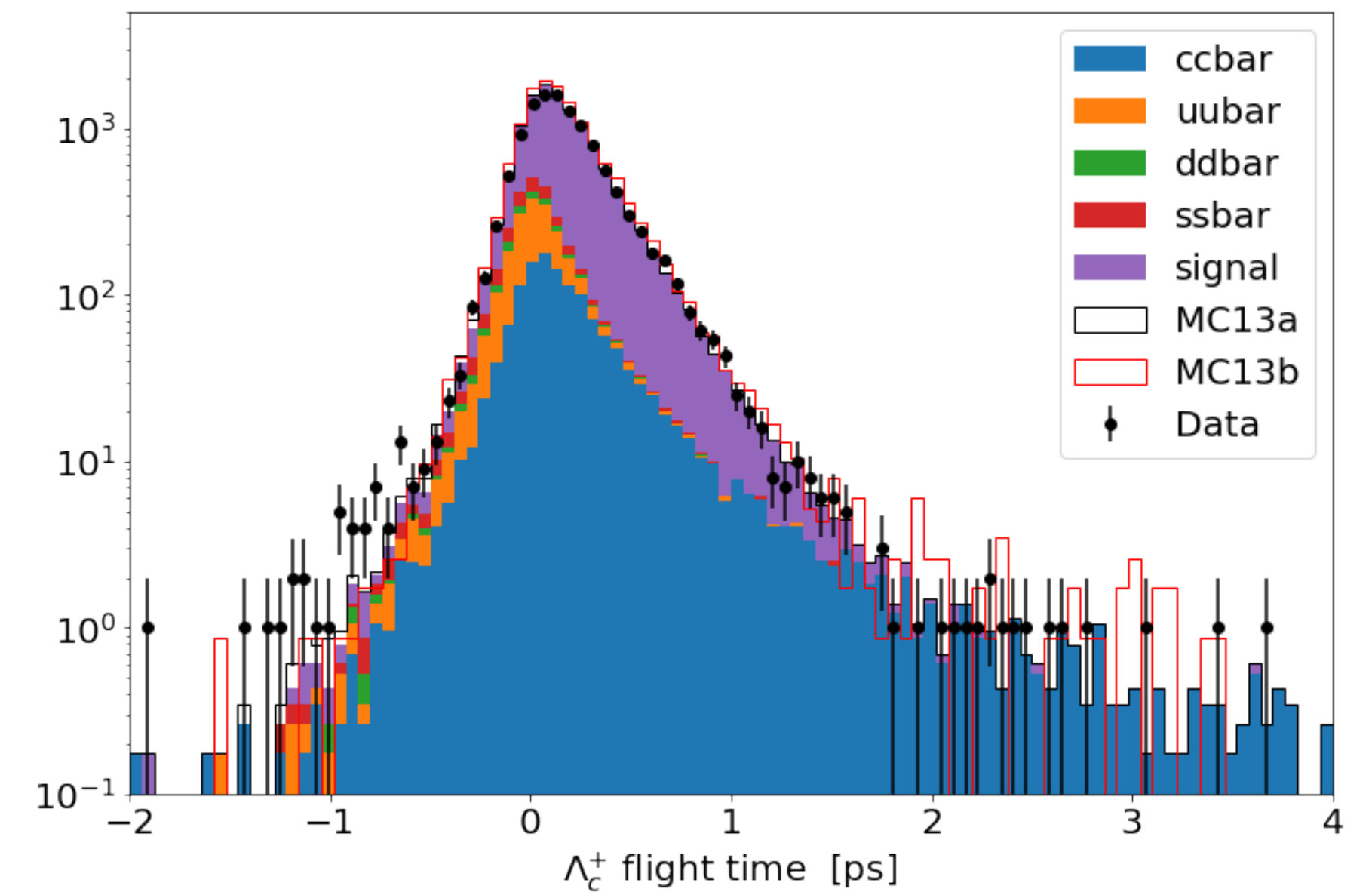


- Sizable remaining backgrounds from long-lived charm decays (complicated the lifetime fit)

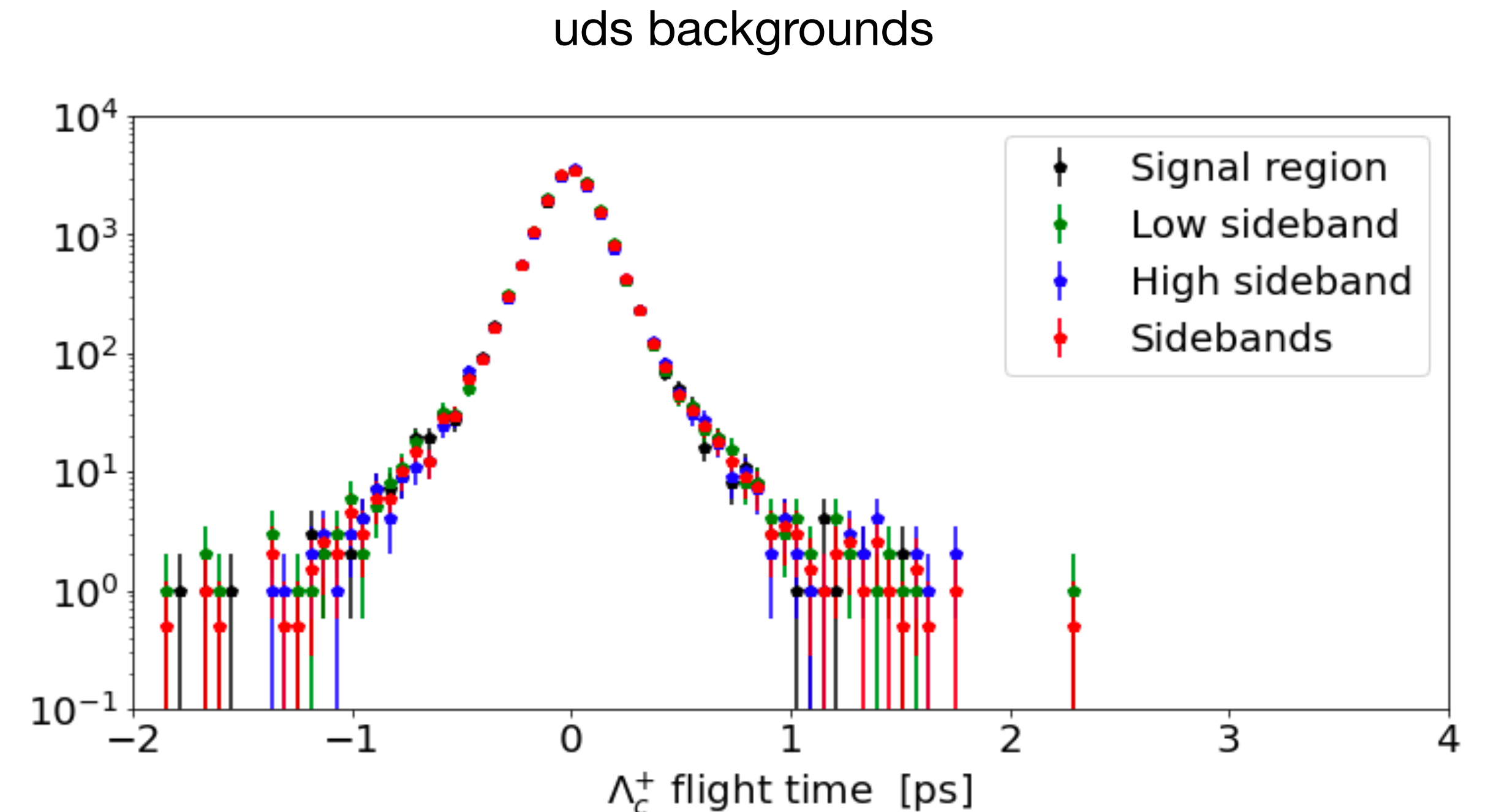
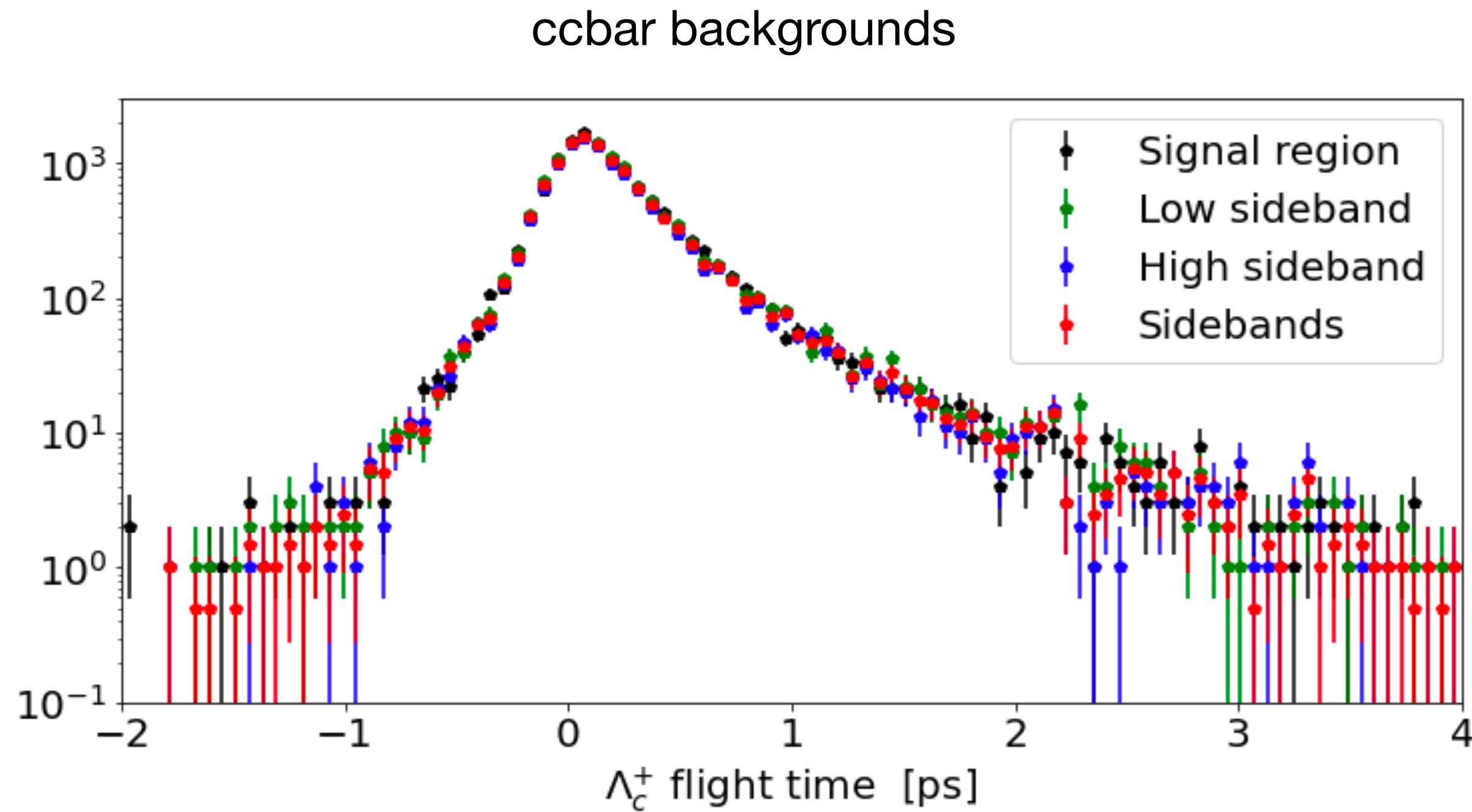


# Treating remaining background

- Significant remaining background contains long-lived contributions, which complicates the fit
- Lifetime extracted from background may be wrong due to correlations between mass and proper time
  - Study combinatorial background from uds MC samples and misreconstructed charm backgrounds from ccbar
  - Compare the proper time distributions from each with the signal region
- Fitting method
  - Fit ccbar backgrounds with signal PDF with all parameters floating
  - Extract weighted average of the 2D pdf from the data sidebands, fixing the misreconstructed charm component to that from MC



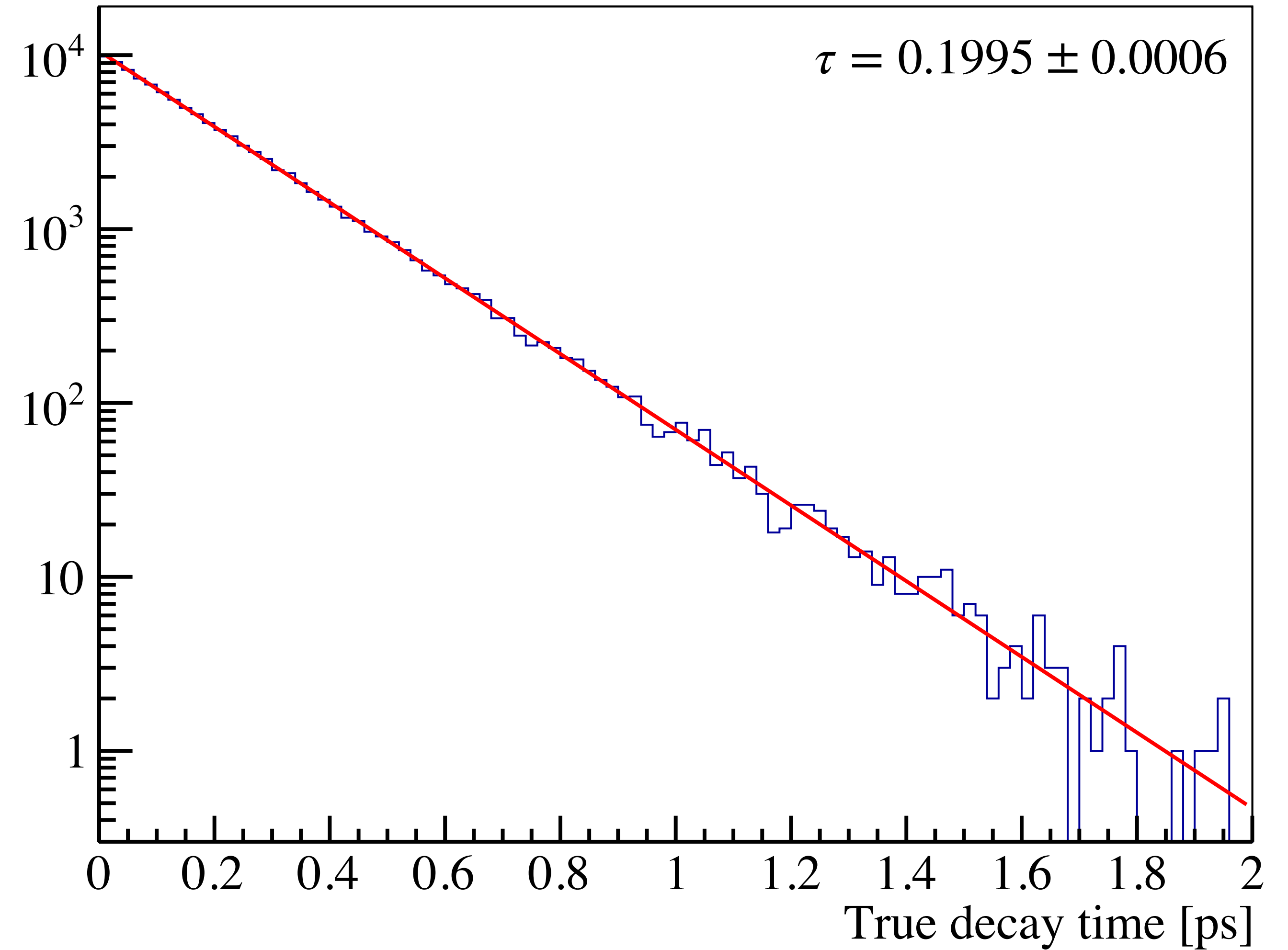
# Comparison of backgrounds in the sideband and signal regions



Black line - difference between signal region and sidebands, scaled by error on signal region  
Red line - difference between high and low sidebands, scaled by error on signal region

# Fit to true flight time

- Simple fit to an exponential function
  - Consistent with expected 200 fs



# Lifetime fit

- Unbinned maximum-likelihood fit to the 2D distribution of decay time ( $t$ ) and decay-time uncertainty ( $\sigma_t$ ):

$$pdf(t, \sigma_t | \tau, \mu, f, s, s_{wide}) \propto \int_0^{\text{inf}} e^{-t_{true}/\tau} R(t - t_{true} | \sigma_t, \mu, f, s, s_{wide}) dt_{true} pdf(\sigma_t)$$

$$R(t - t_{true} | \sigma_t, \mu, f, s, s_{wide}) = f G(t - t_{true} | \mu, s, \sigma_t) + (1 - f) G(t - t_{true} | \mu, s_{wide}, \sigma_t)$$

↙ Proper time scaling error ↘  
↙ Common bias ↘

- CLEO method:

$$L(\tau_{\Lambda_c^+}, f_{bg}, \tau_{bg}, S, f_{mis}, \sigma_{mis}, f_{wide}) = \prod_i \int_0^{\infty} dt' \left[ \underbrace{p_{sig,i} E(t' | \tau_{\Lambda_c^+})}_{\text{signal fraction}} + \underbrace{(1 - p_{sig,i}) [f_{bg} E(t' | \tau_{bg}) + (1 - f_{bg}) \delta(t')]}_{\text{background fraction}} \right]$$

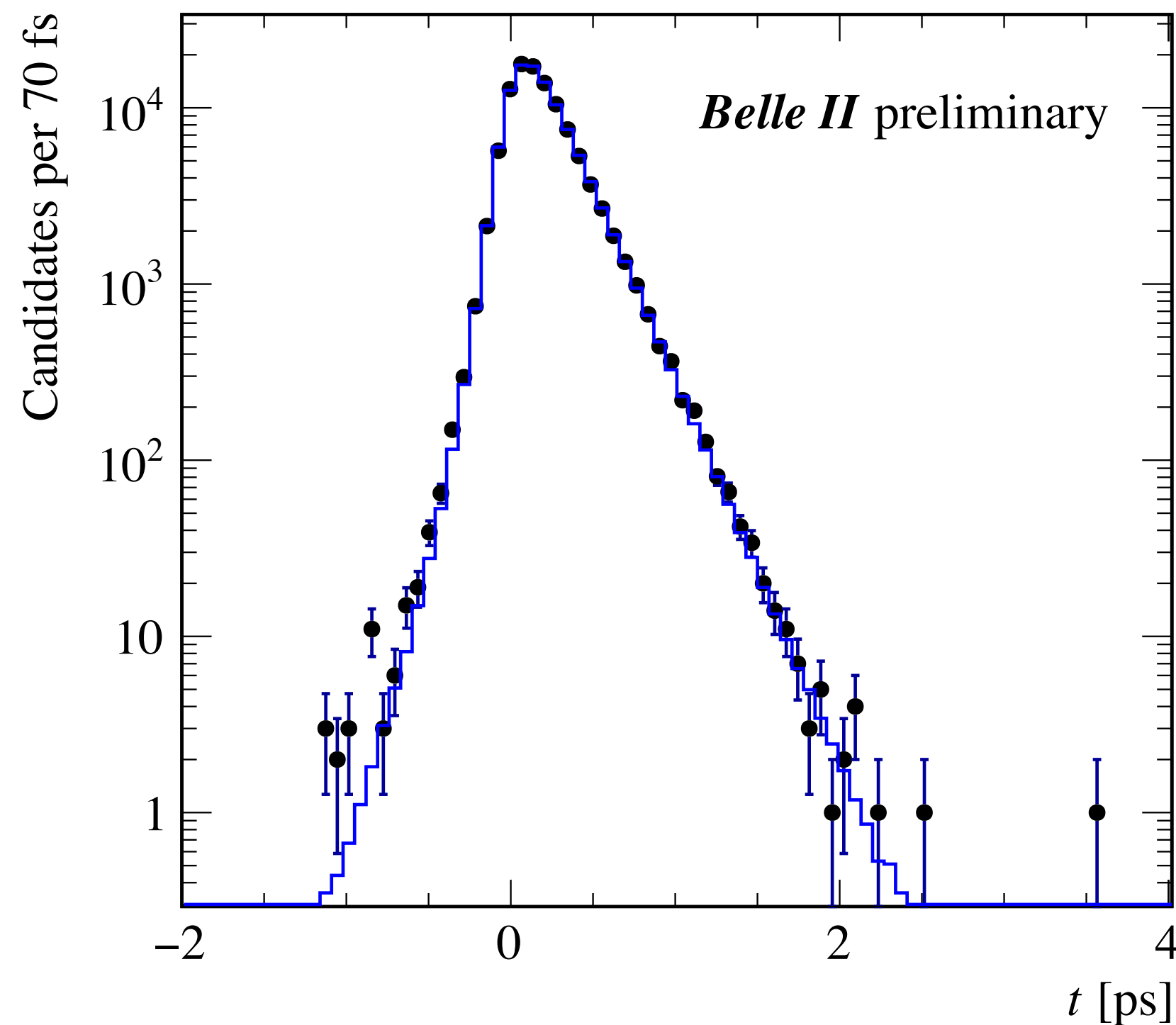
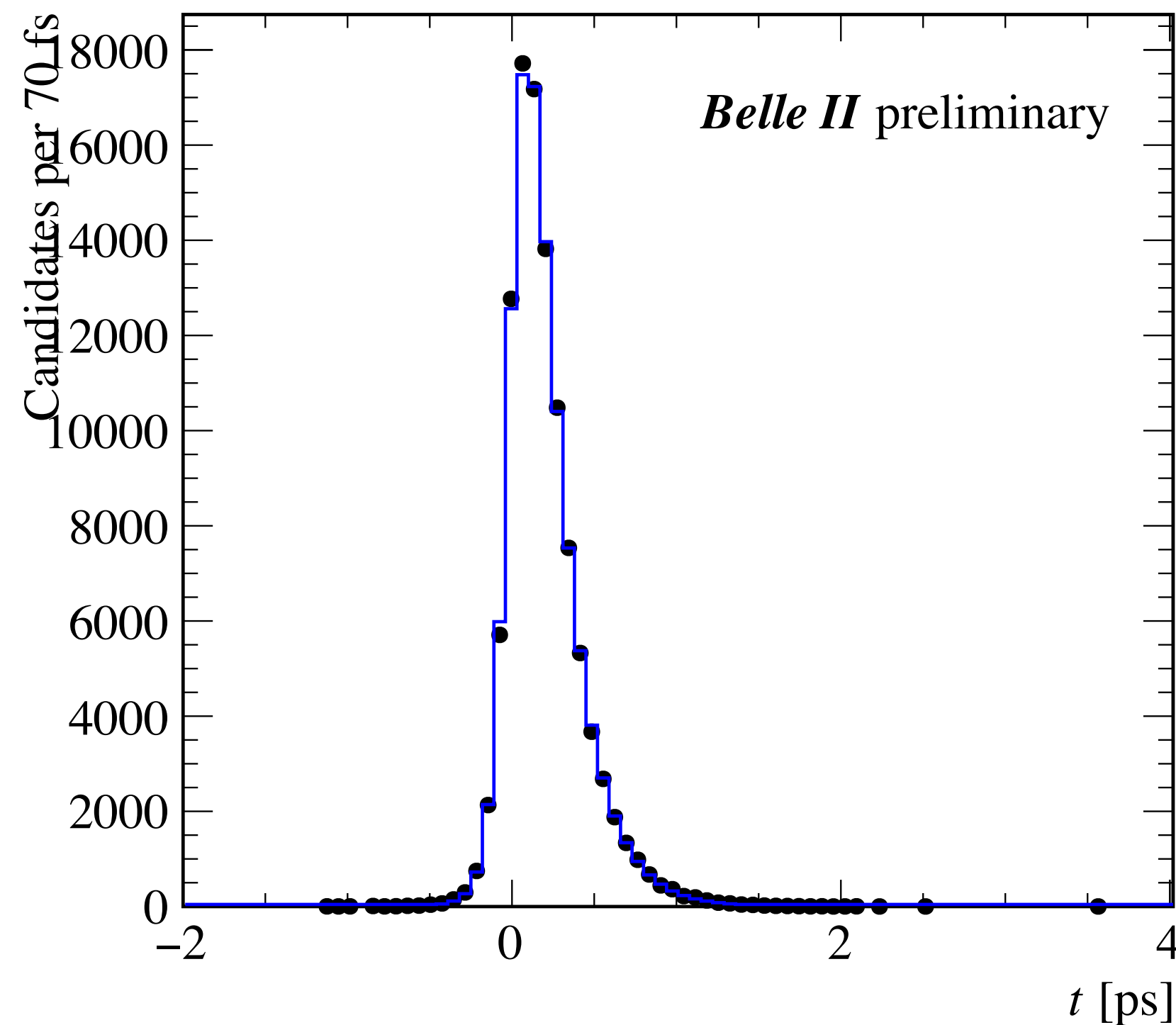
$$\times \left[ \underbrace{(1 - f_{mis} - f_{wide}) G(t_i - t' | S \sigma_{t,i})}_{\text{proper time resolution}} \right.$$

$$\left. + \underbrace{f_{mis} G(t_i - t' | \sigma_{mis}) + f_{wide} G(t_i - t' | \sigma_{wide})}_{\text{mismeasured fraction}} \right],$$

## Signal only fit

$$pdf(t, \sigma_t | \tau, \mu, f, s, s_{wide})$$

$$R(t - t_{true} | \sigma_t, \mu, f, s, s_{wide}) = f G(t - t_{true} | \mu, s, \sigma_t) + (1 - f)G(t - t_{true} | \mu, s_{wide}, \sigma_t)$$



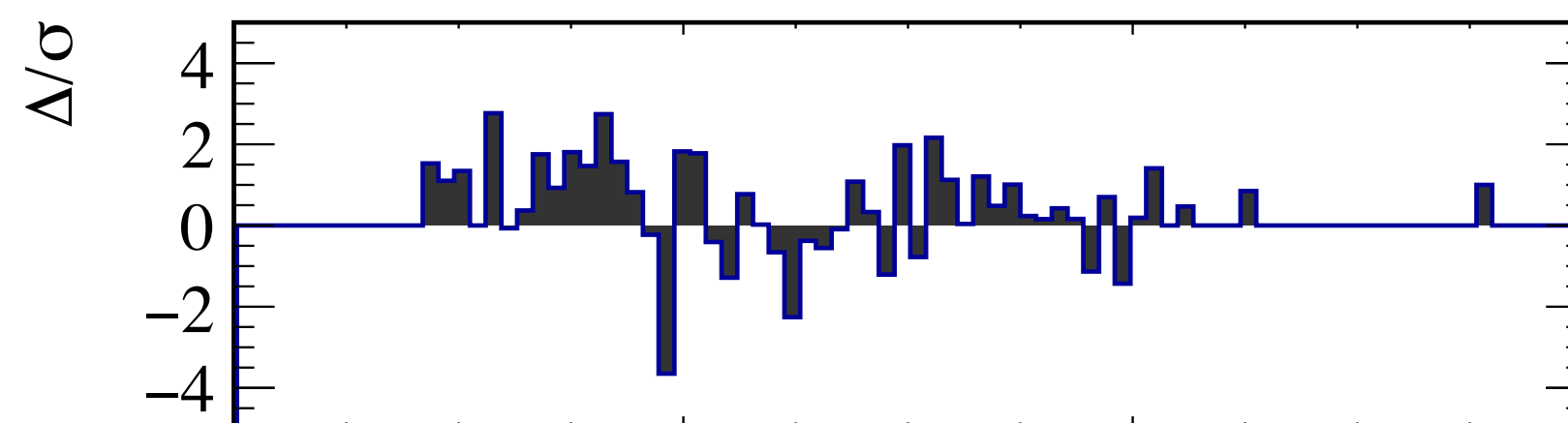
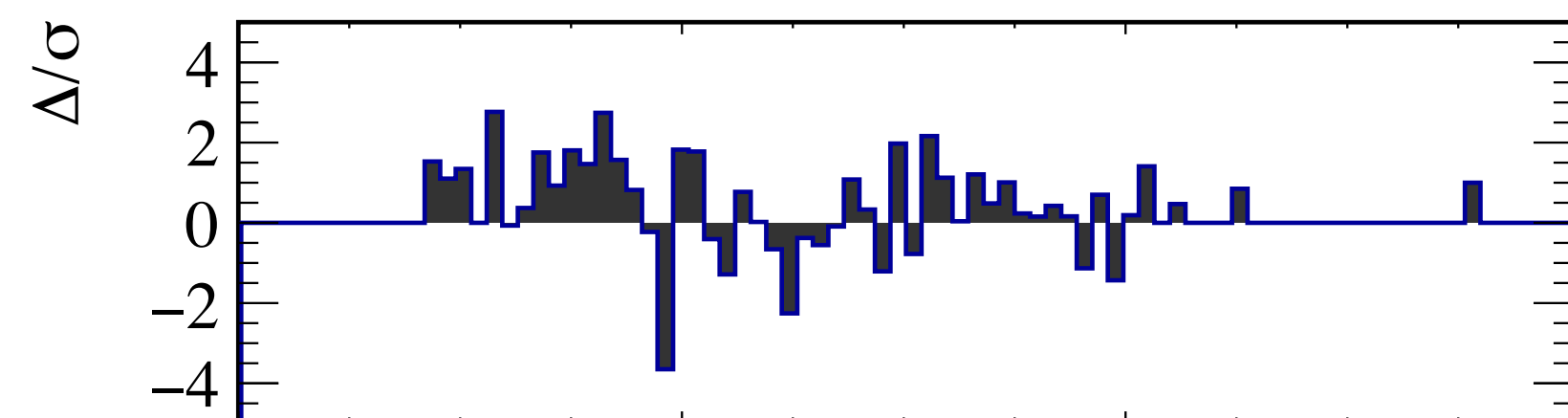
$$\tau = 0.2036 \pm 0.0009$$

$$\mu = 0.0013 \pm 0.0007$$

$$s = 0.979 \pm 0.022$$

$$s_{wide} = 2.467 \pm 0.791$$

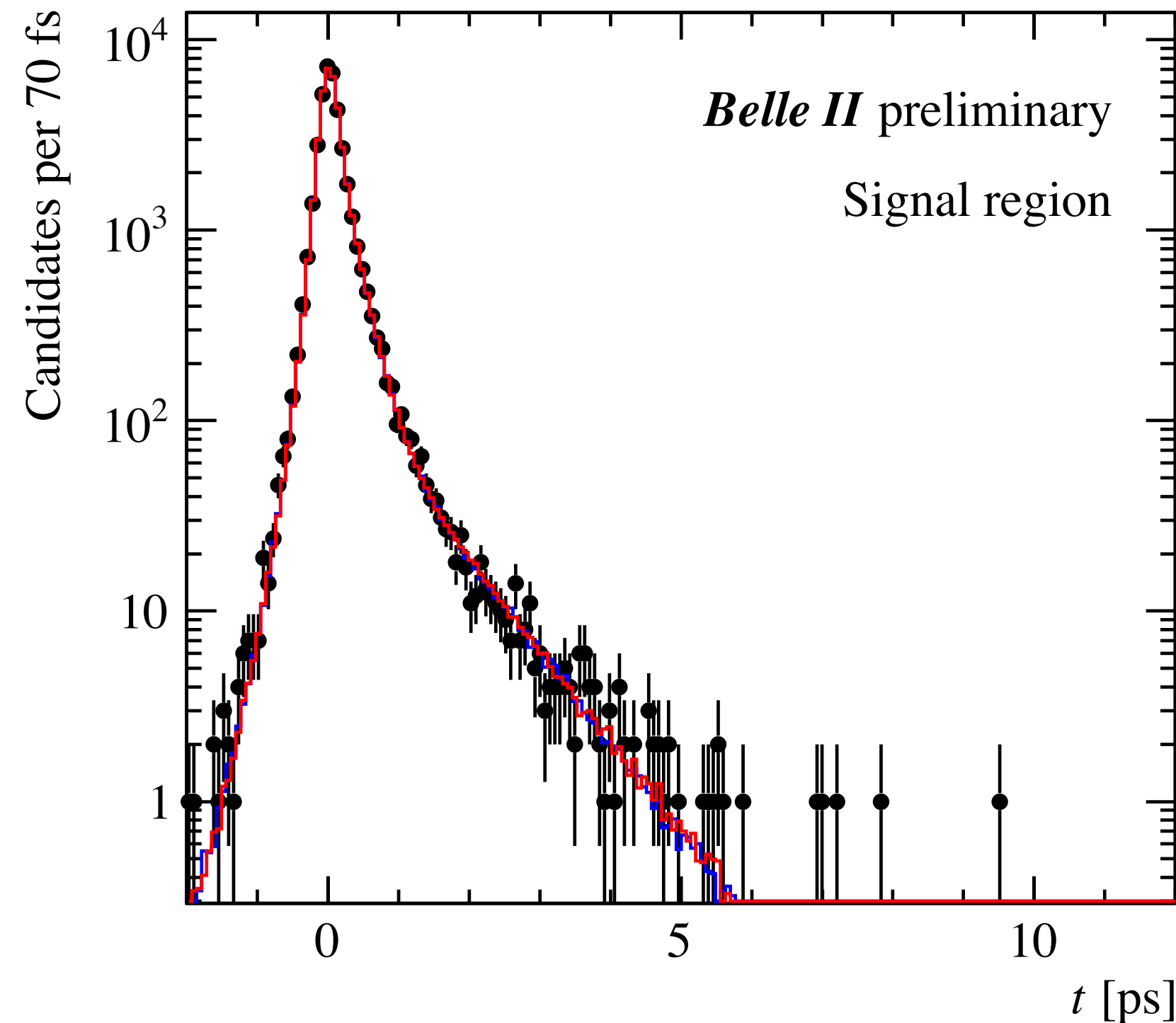
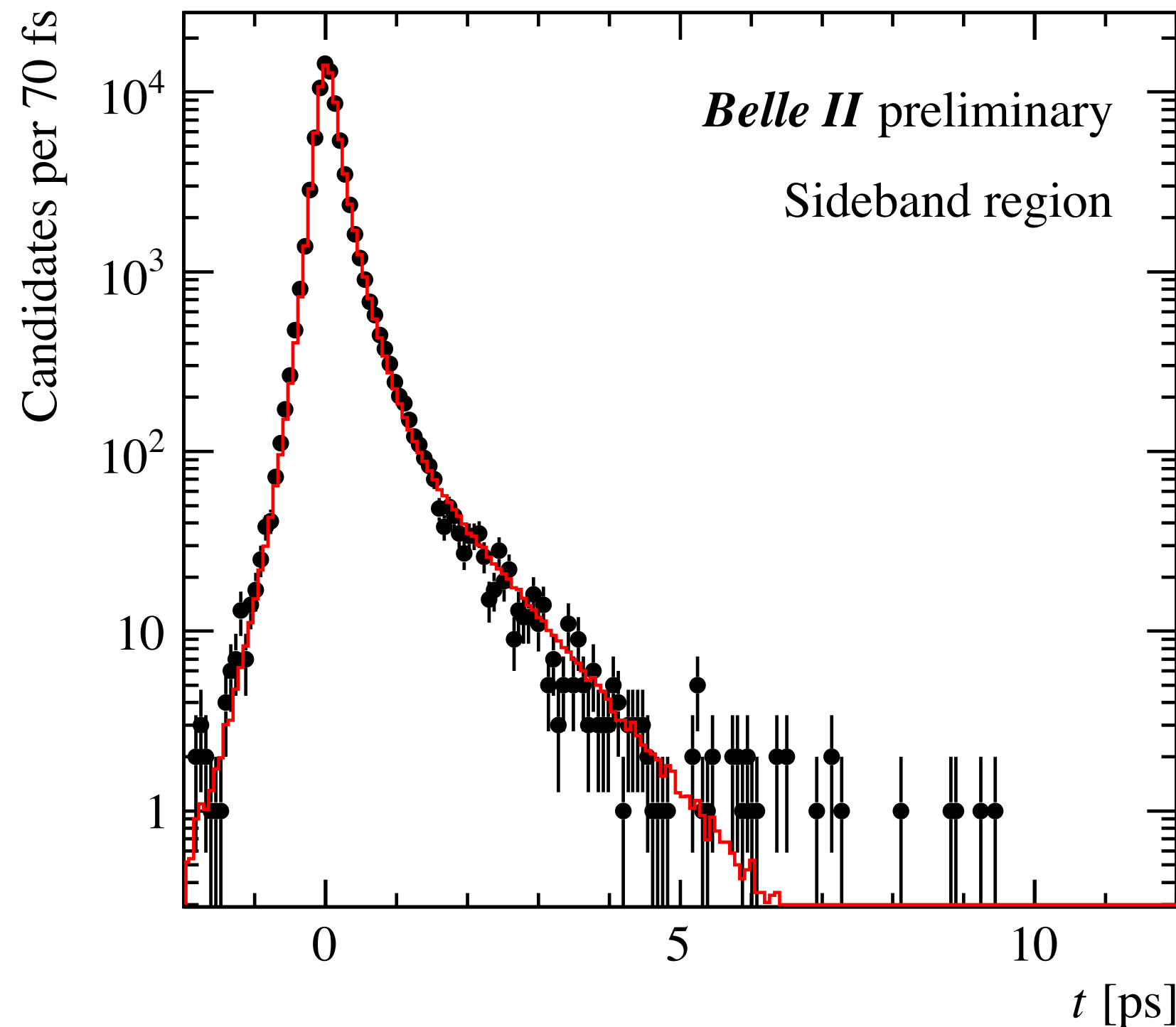
$$f = 0.989 \pm 0.015$$



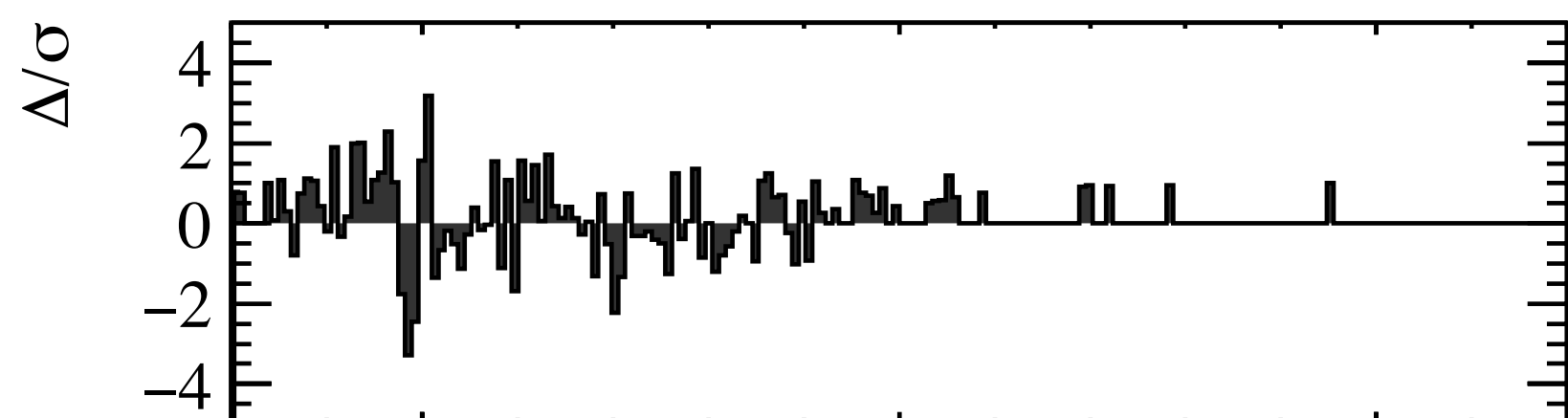
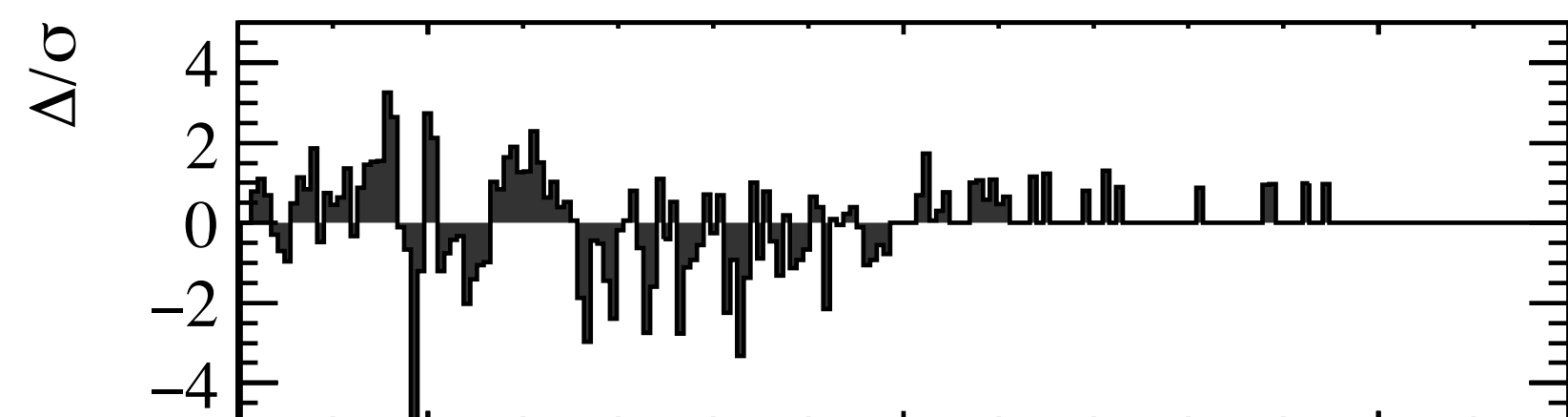


# Lifetime fit to charm backgrounds (signal and sideband regions)

$$pdf(bkg) = (1 - f_b)[f_{\tau_1}pdf(t, \sigma_t | \tau_{bkg1}, \mu_{bkg}, f, s, s_{wide}) - (1 - f_{\tau_1})pdf(t, \sigma_t | \tau_{bkg2}, \mu_{bkg}, f, s, s_{wide})] + f_b R(\sigma, \mu_{bkg}, f, s, s_{wide})pdf(\sigma_t)$$



$$\begin{aligned} \tau_{bkg1} &= 0.217 \pm 0.002 \\ \tau_{bkg2} &= 0.924 \pm 0.002 \\ \mu_{bkg} &= -0.013 \pm 0.001 \\ s &= 1.015 \pm 0.003 \\ s_{wide} &= 2.601 \pm 0.033 \\ f &= 0.930 \pm 0.002 \\ f_b &= 0.308 \pm 0.002 \\ f_{\tau_1} &= 0.832 \pm 0.004 \end{aligned}$$



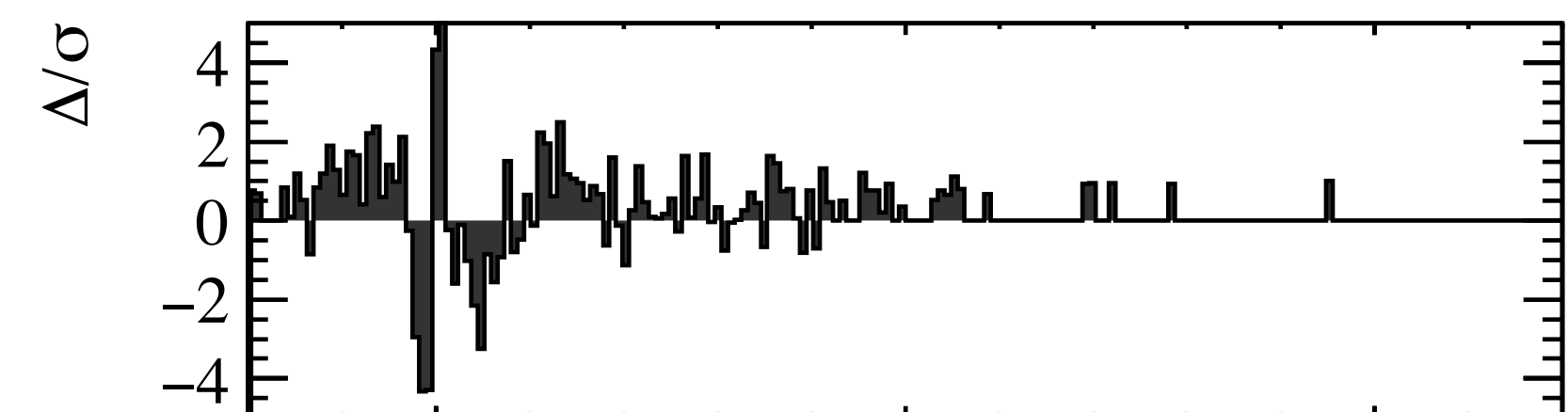
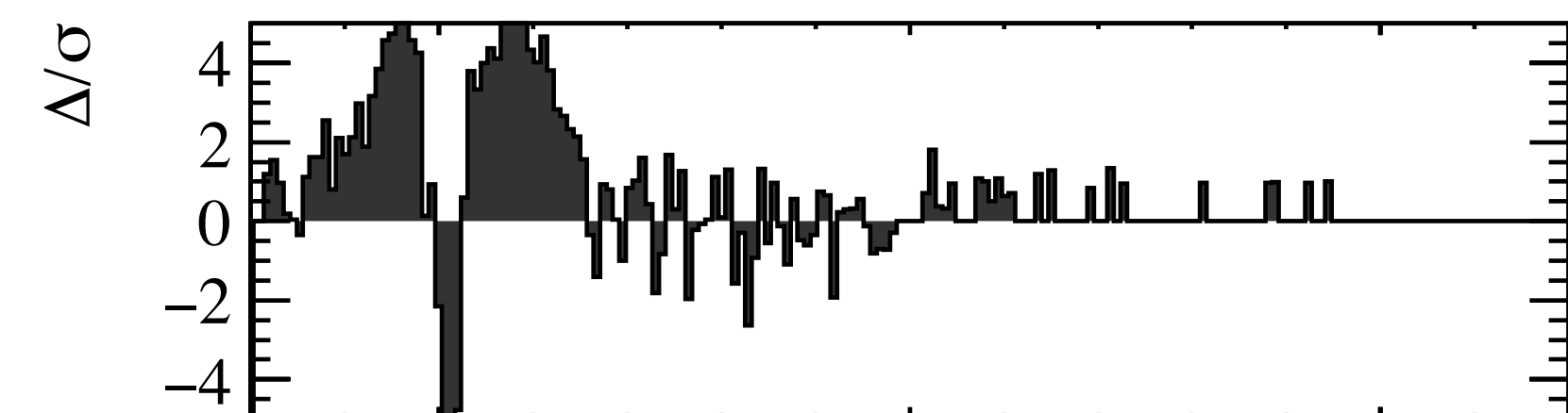
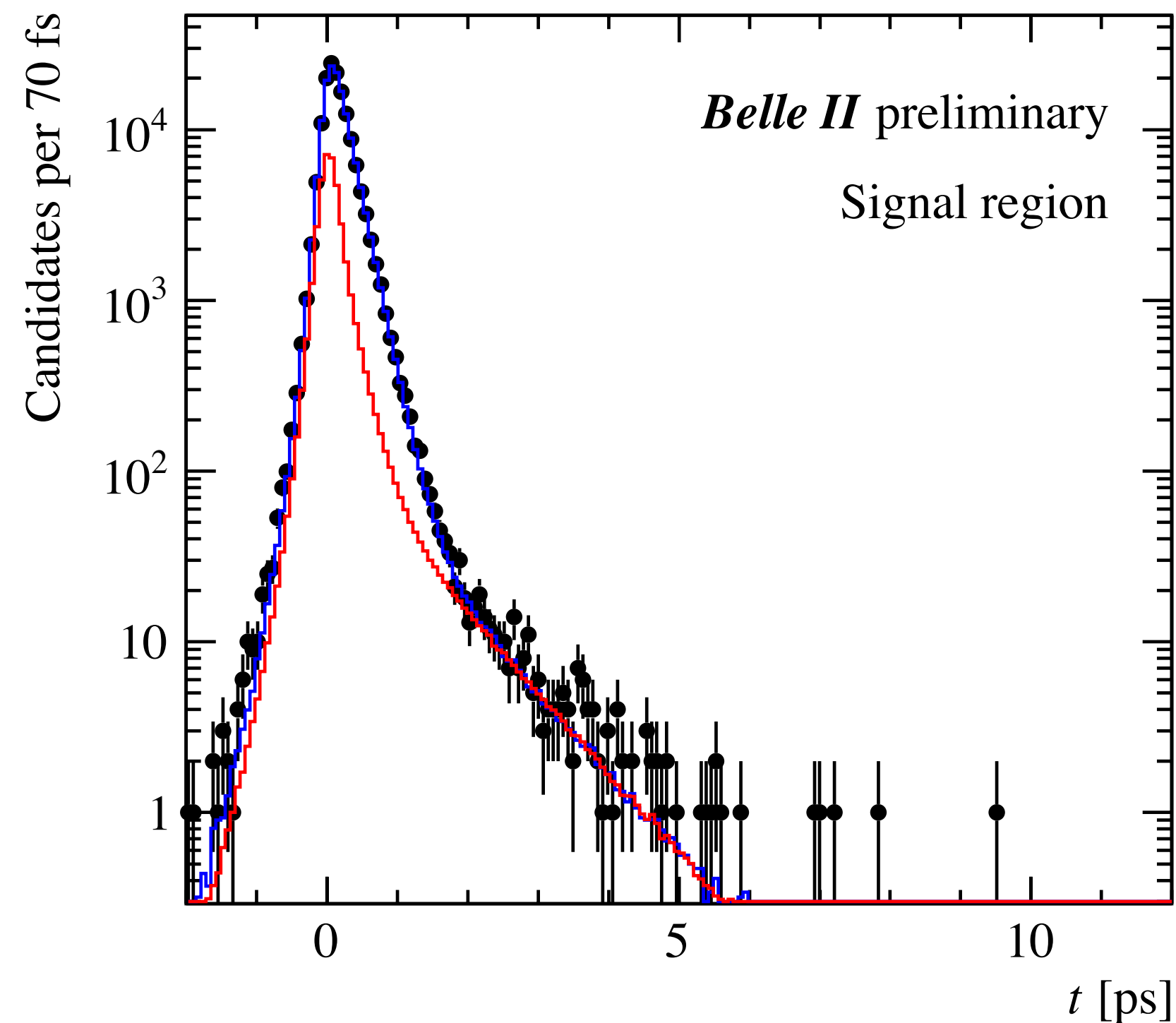
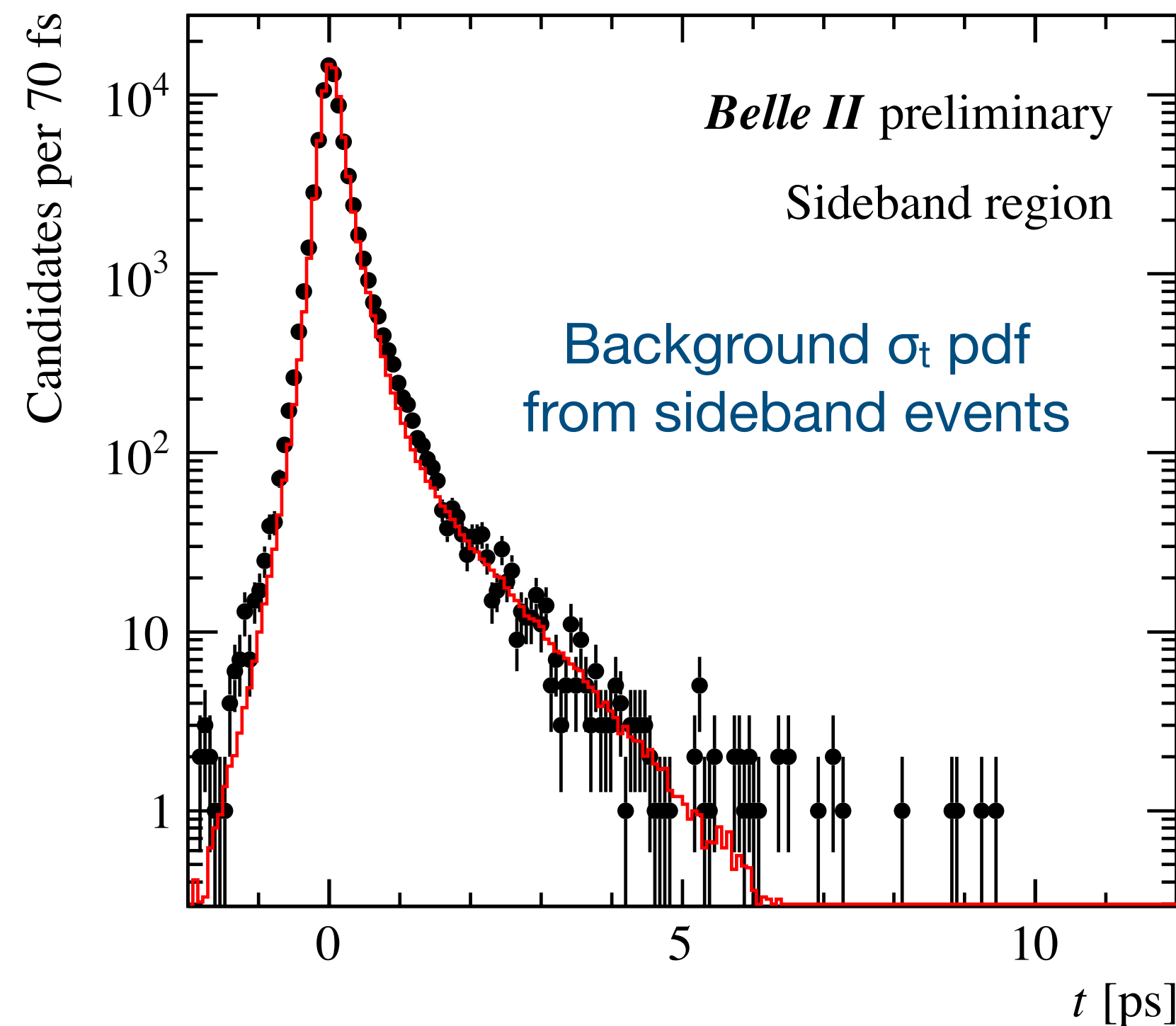
## Lifetime fit

$$\tau_{bkg1} = 0.217 \pm 0.002 \quad \tau_{bkg2} = 0.924 \pm 0.002 \quad f_{\tau_1} = 0.832 \pm 0.004$$

Background lifetimes and relative fraction fixed from fit to sidebands

$$(1 - f_{bkg}) \times pdf(t, \sigma_t | \tau, \mu, f, s, s_{wide}) + f_{bkg} \times pdf(bkg)$$

Fit only to events in the signal region



$$\tau_{true} = 0.200$$

$$\tau = 0.198 \pm 0.001$$

$$\mu = 0.003 \pm 0.001$$

$$s = 1.026 \pm 0.007$$

$$s_{wide} = 2.695 \pm 0.101$$

$$f = 0.968 \pm 0.004$$

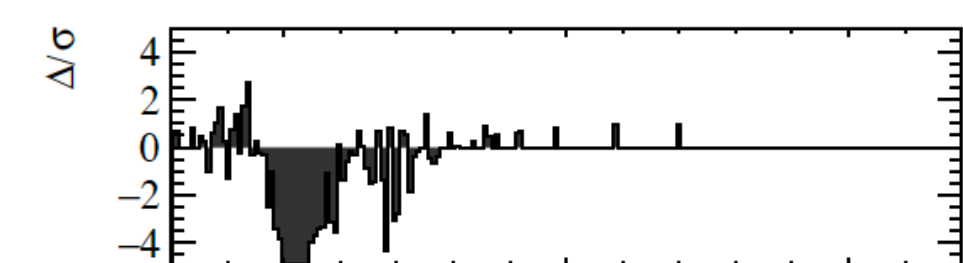
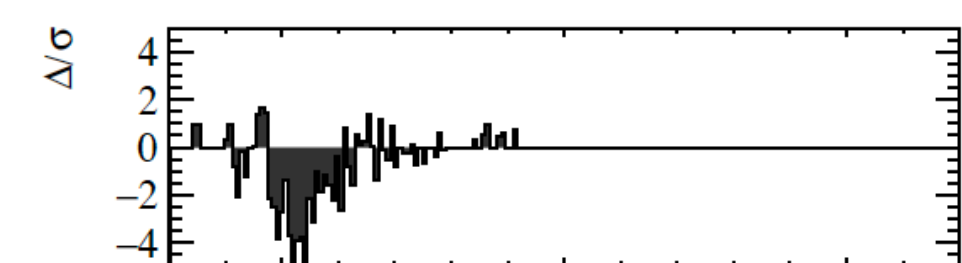
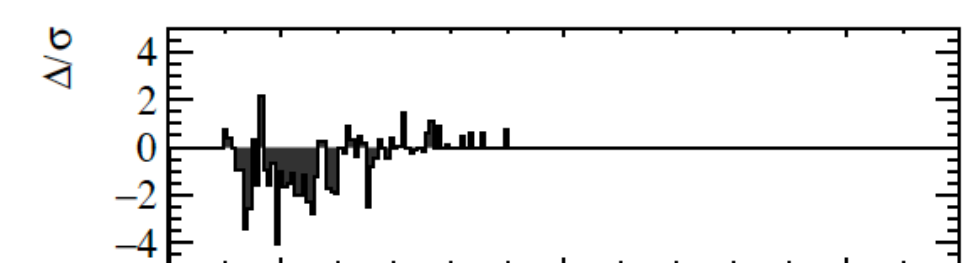
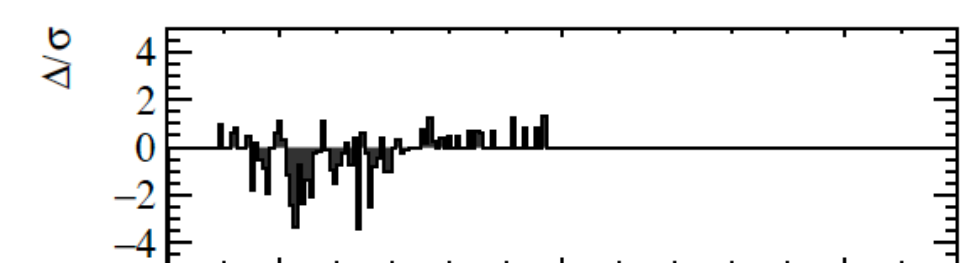
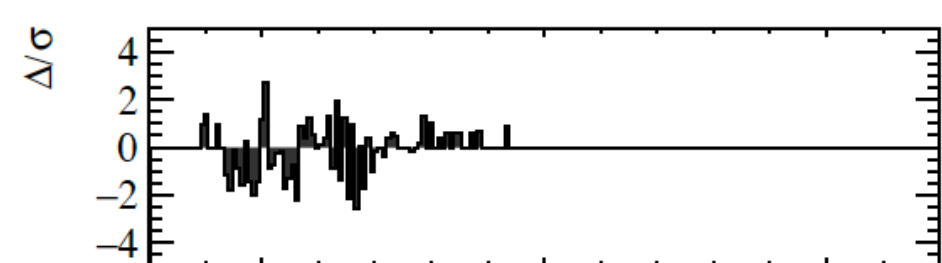
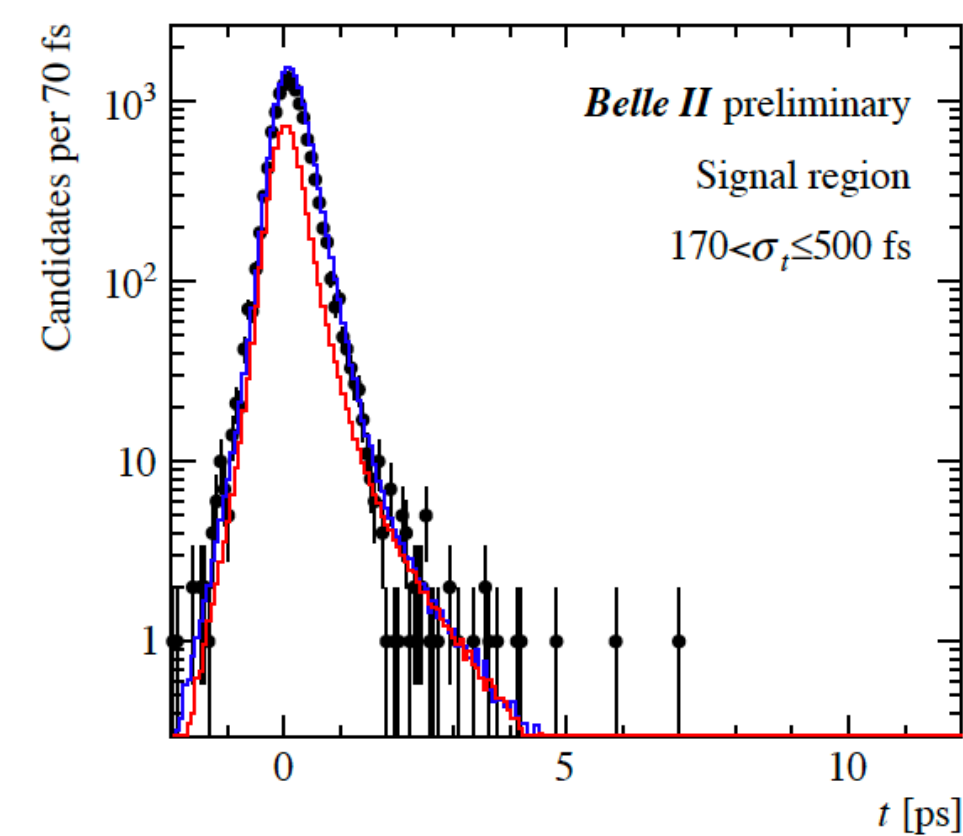
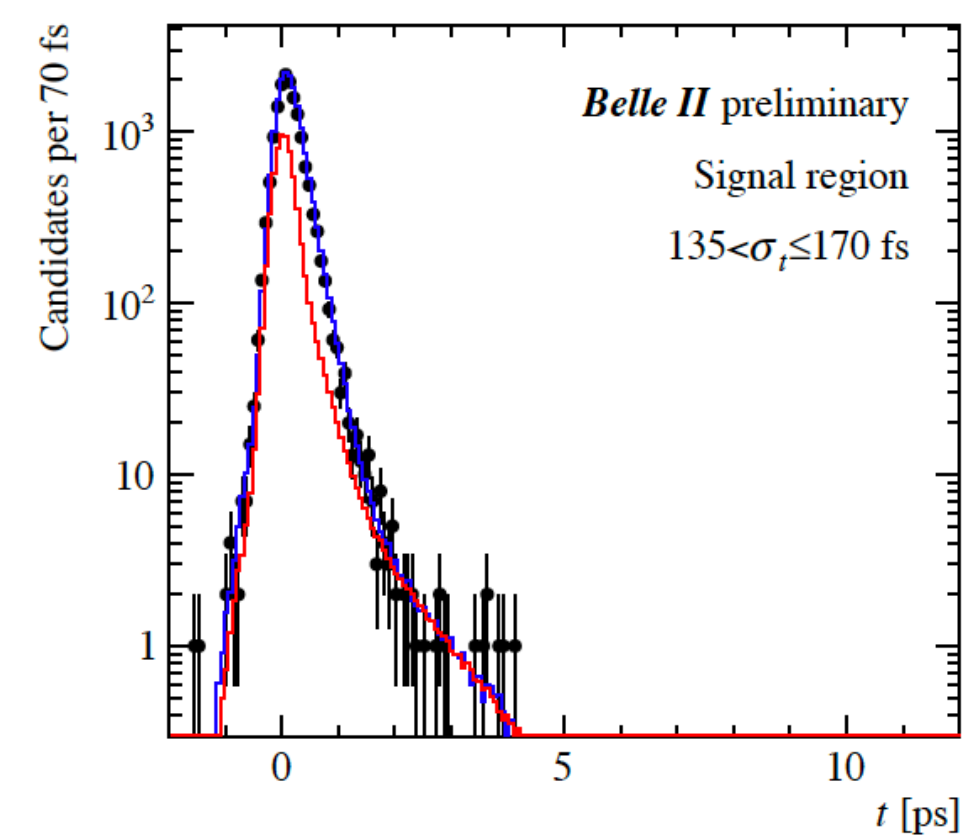
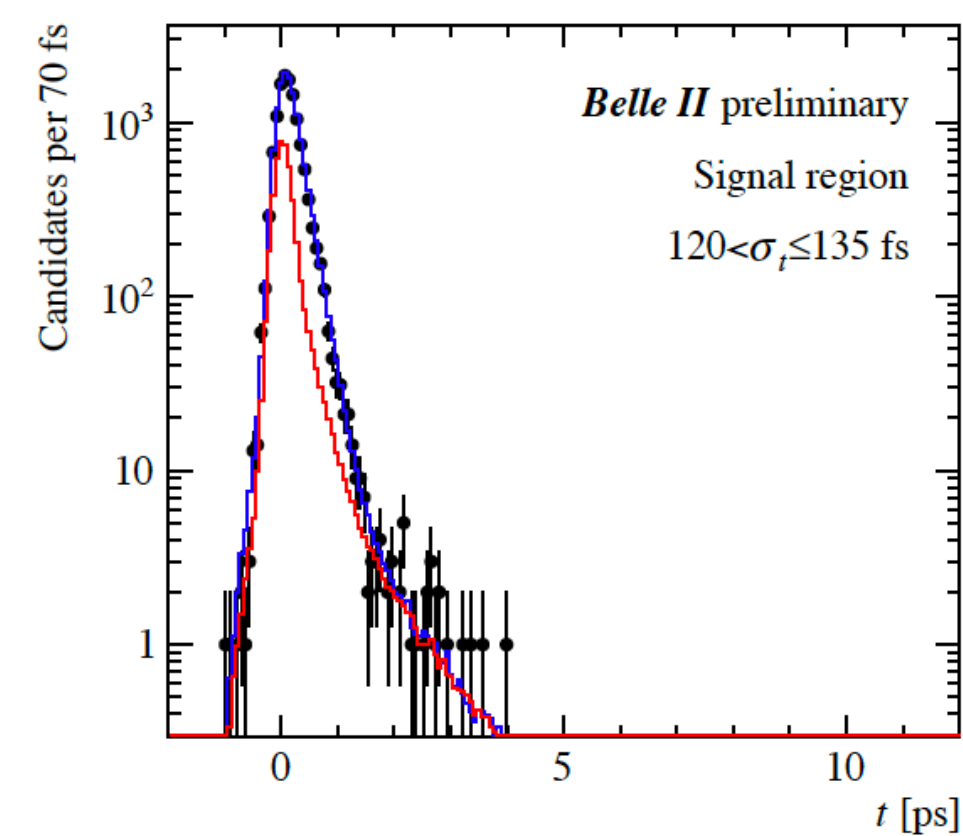
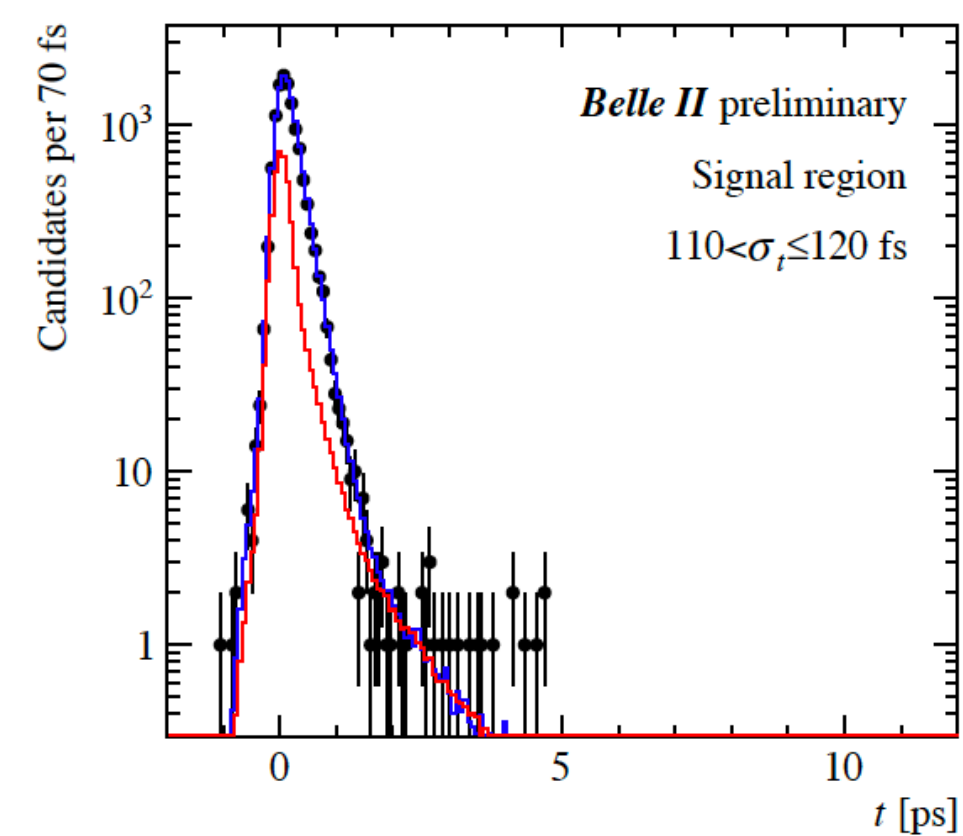
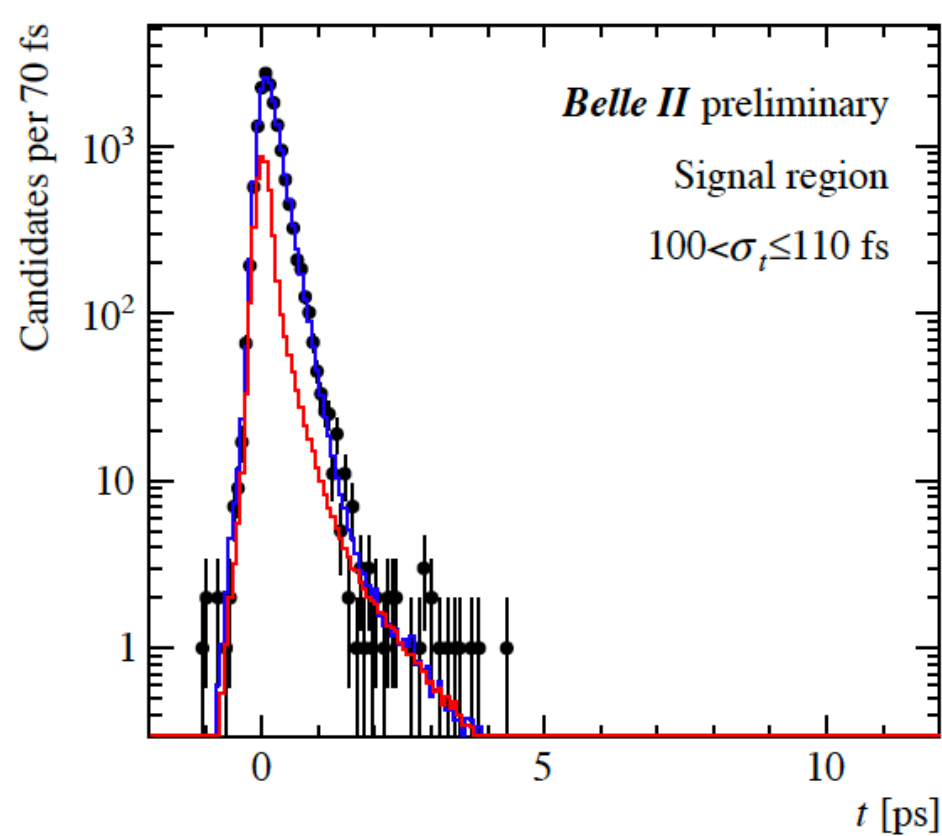
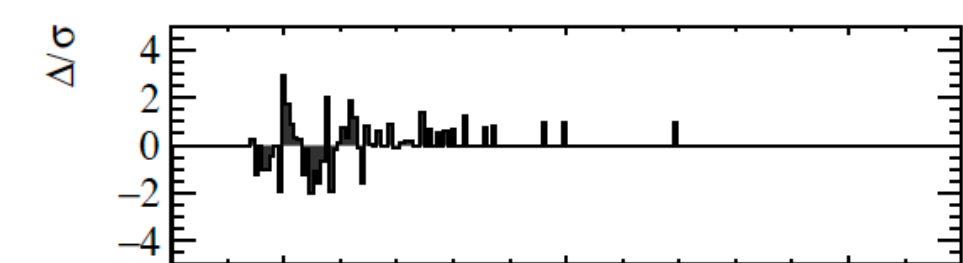
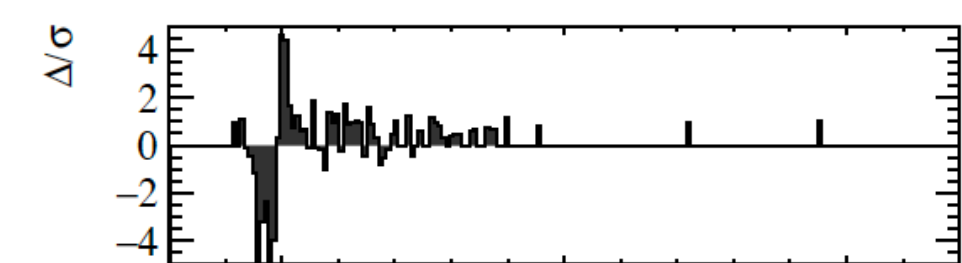
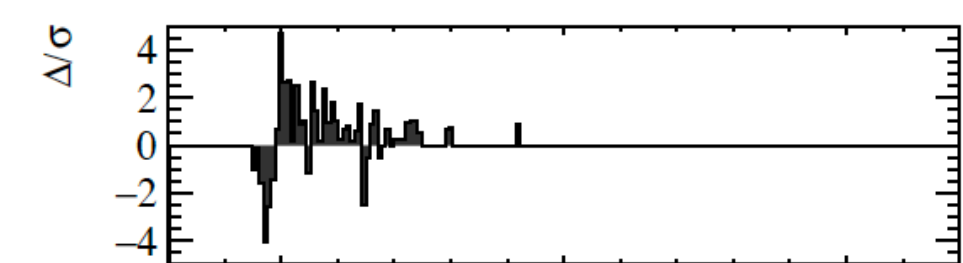
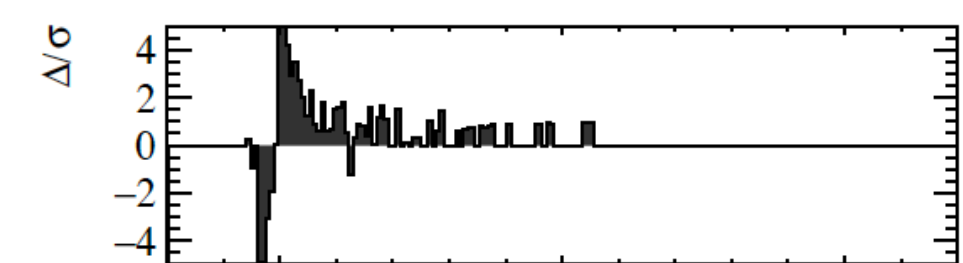
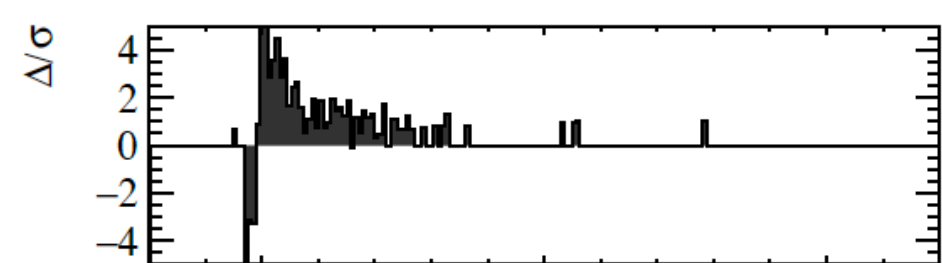
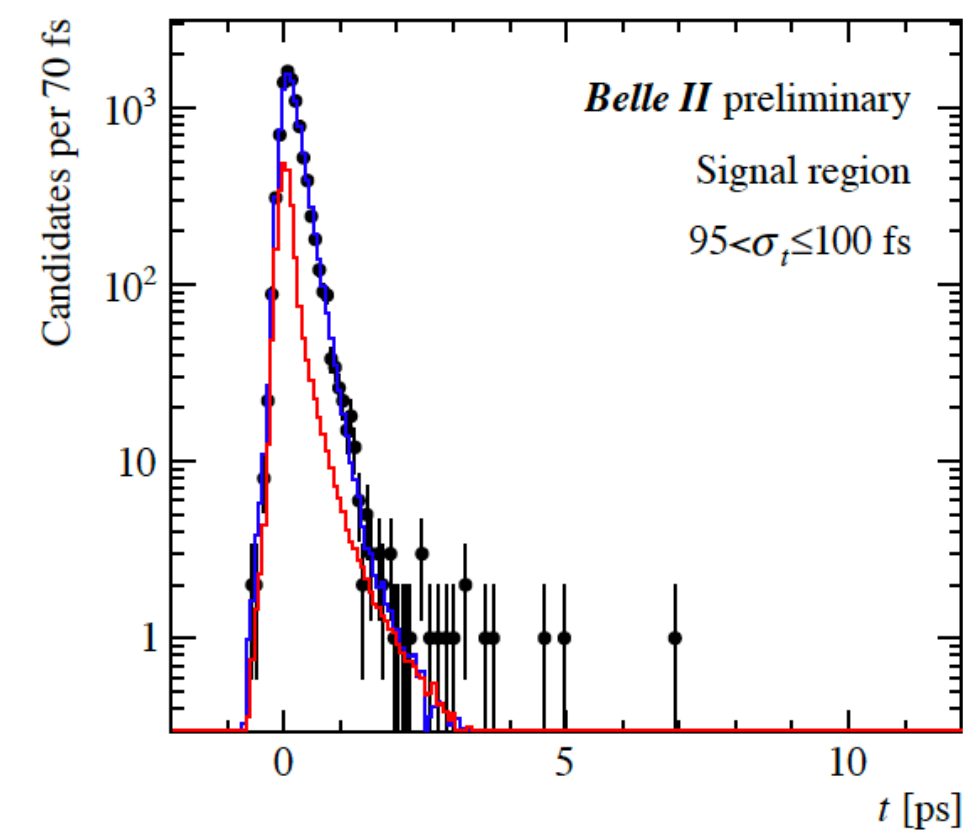
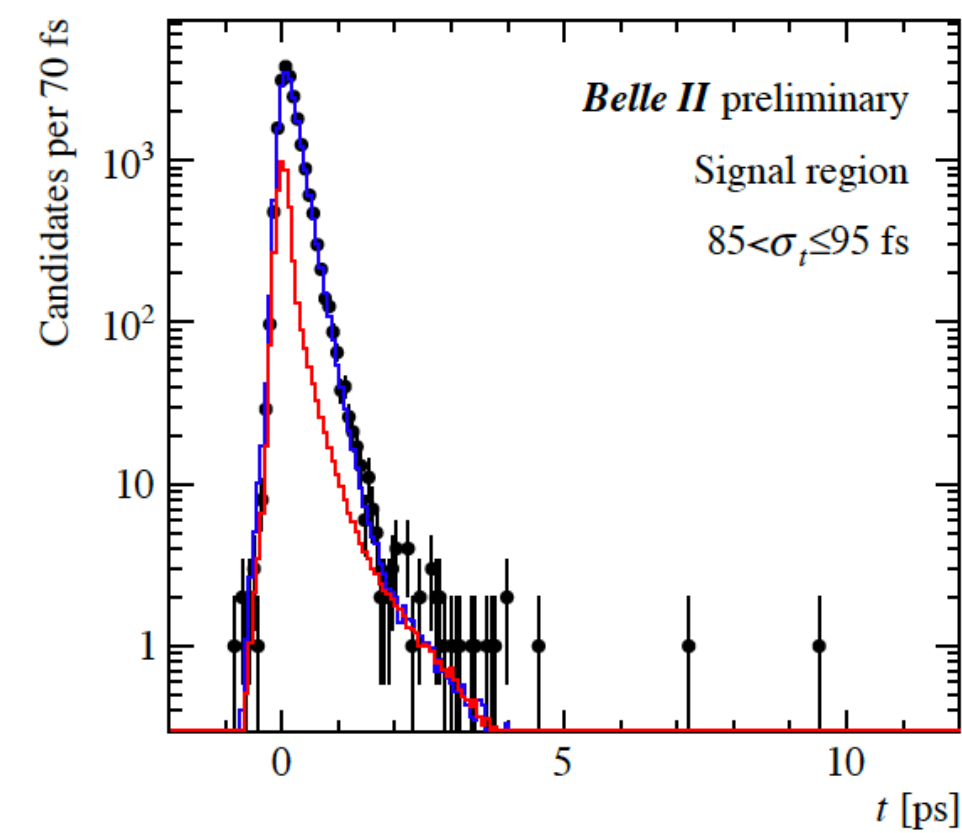
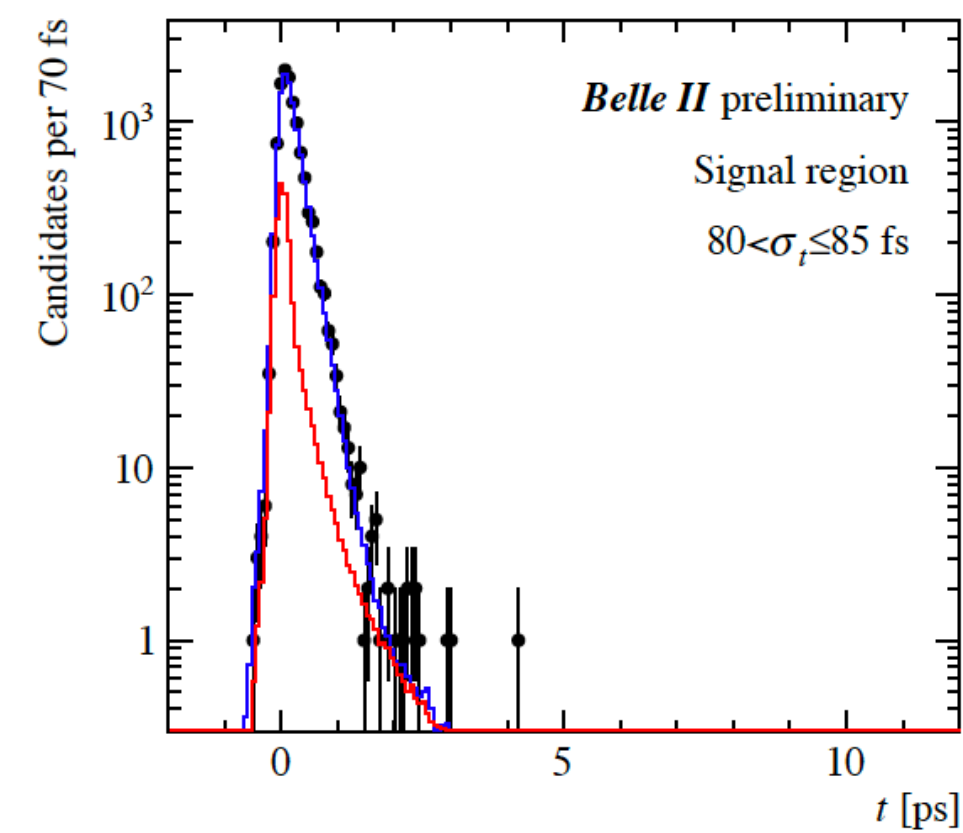
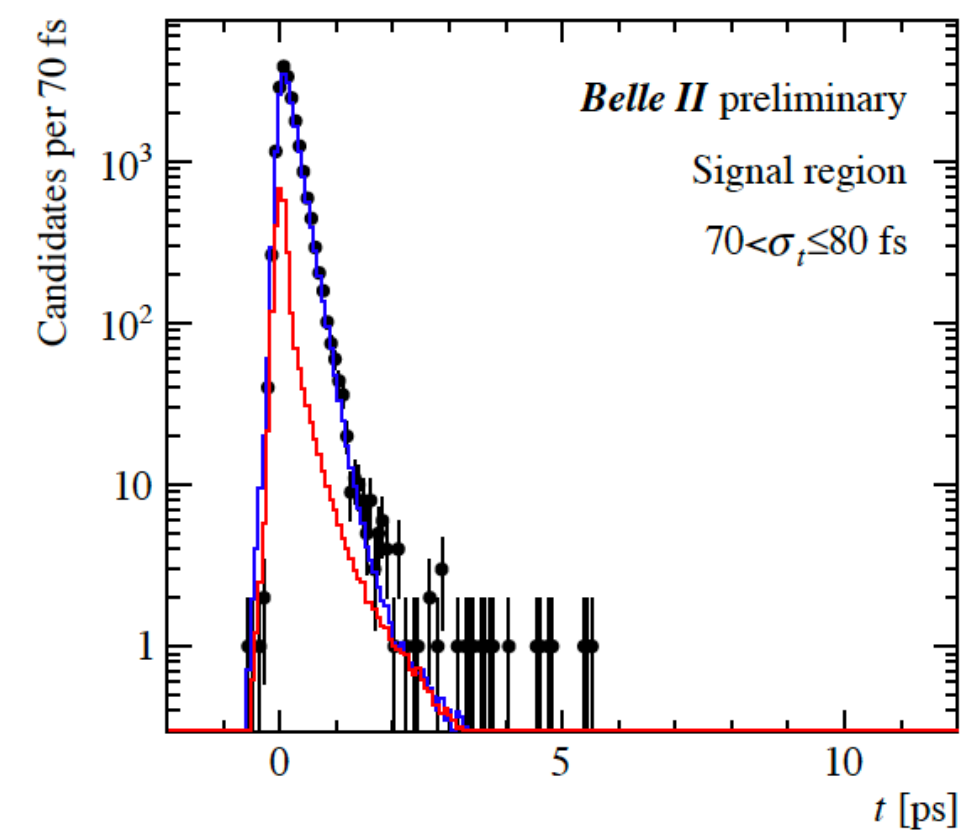
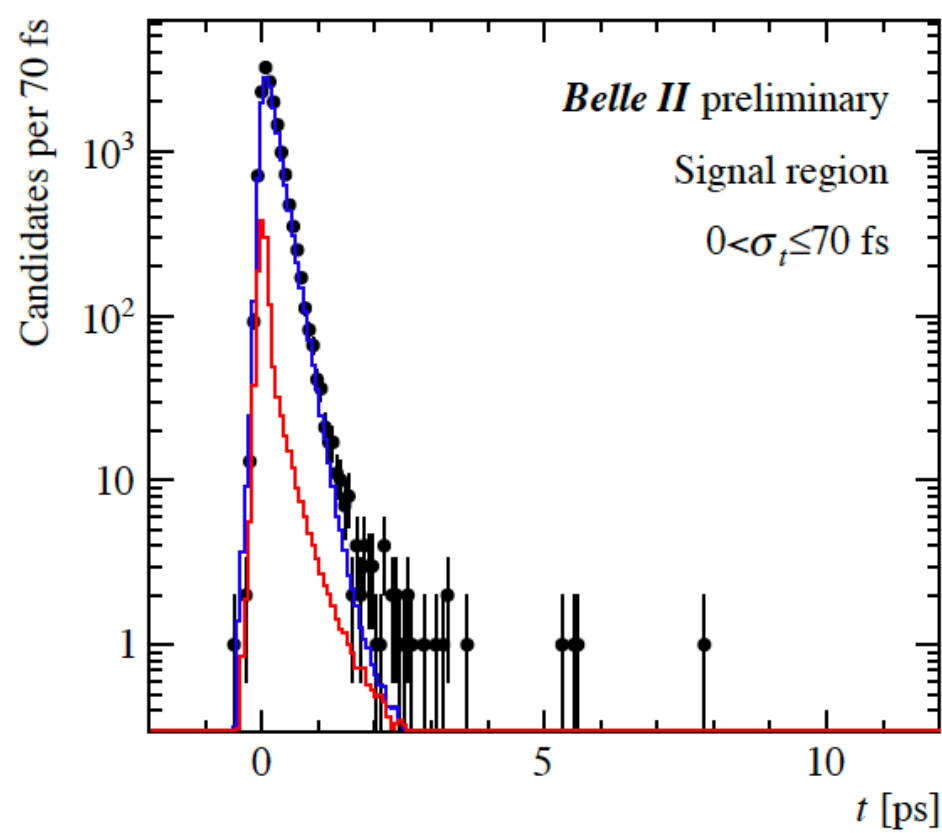
$$f_{bkg} = 0.2580 \pm 0.0001$$

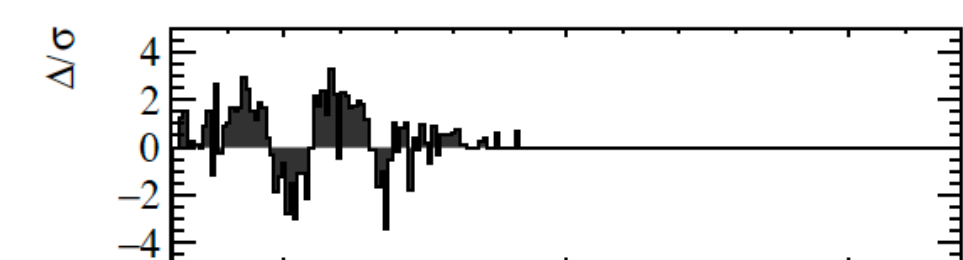
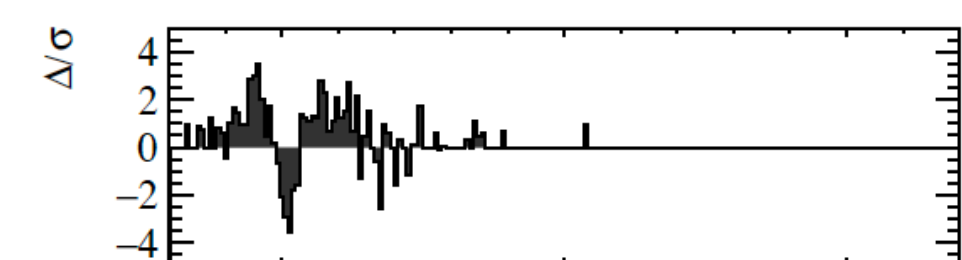
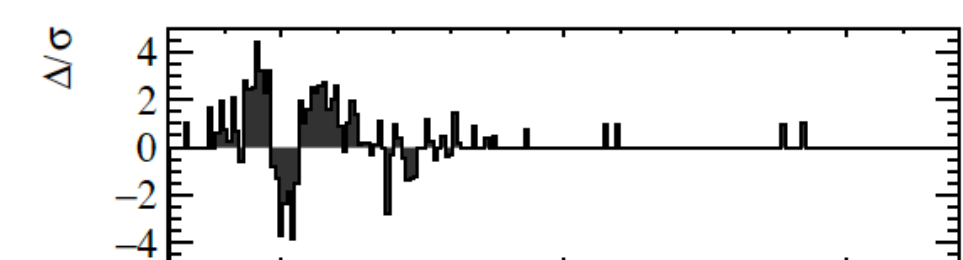
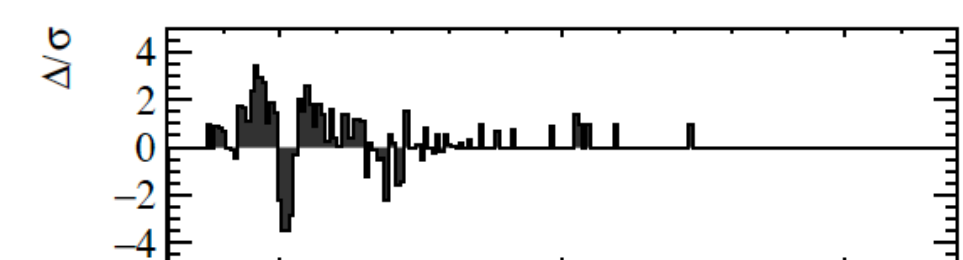
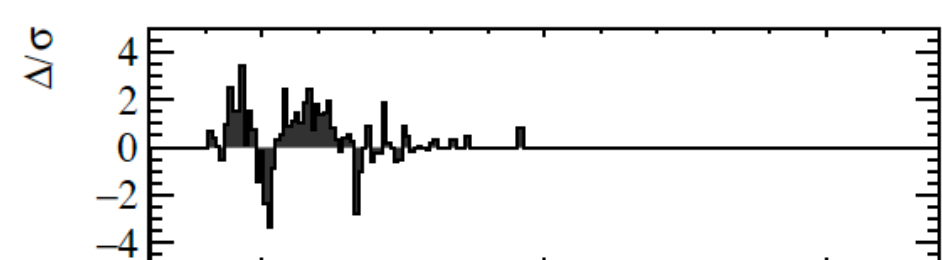
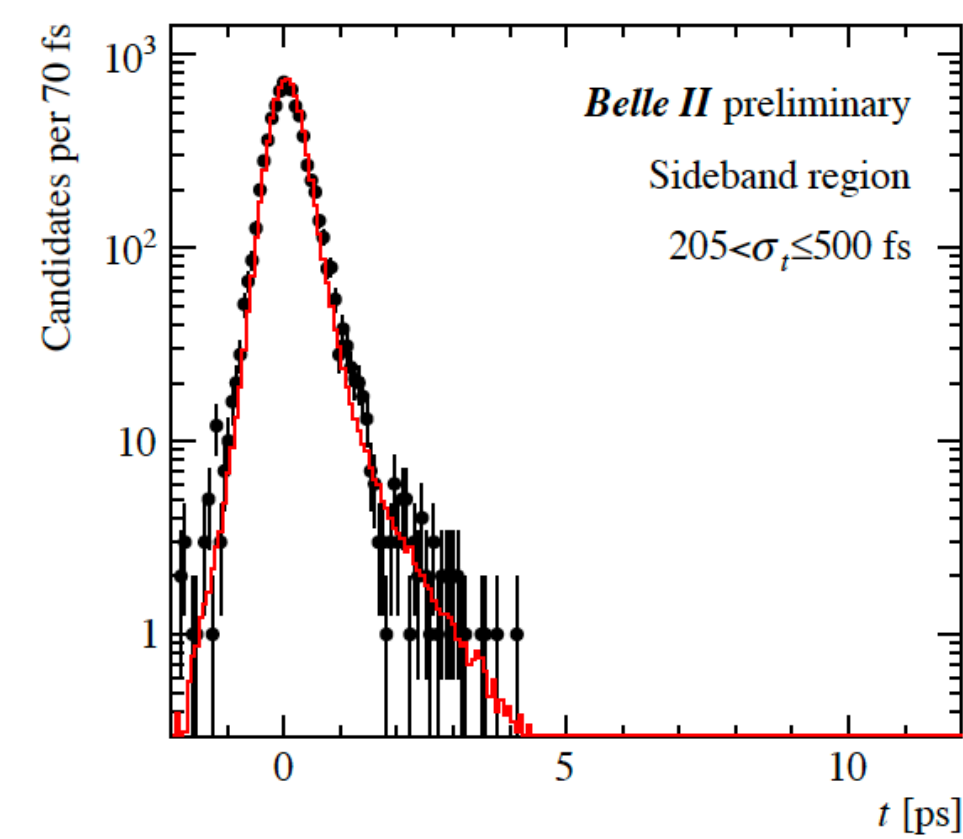
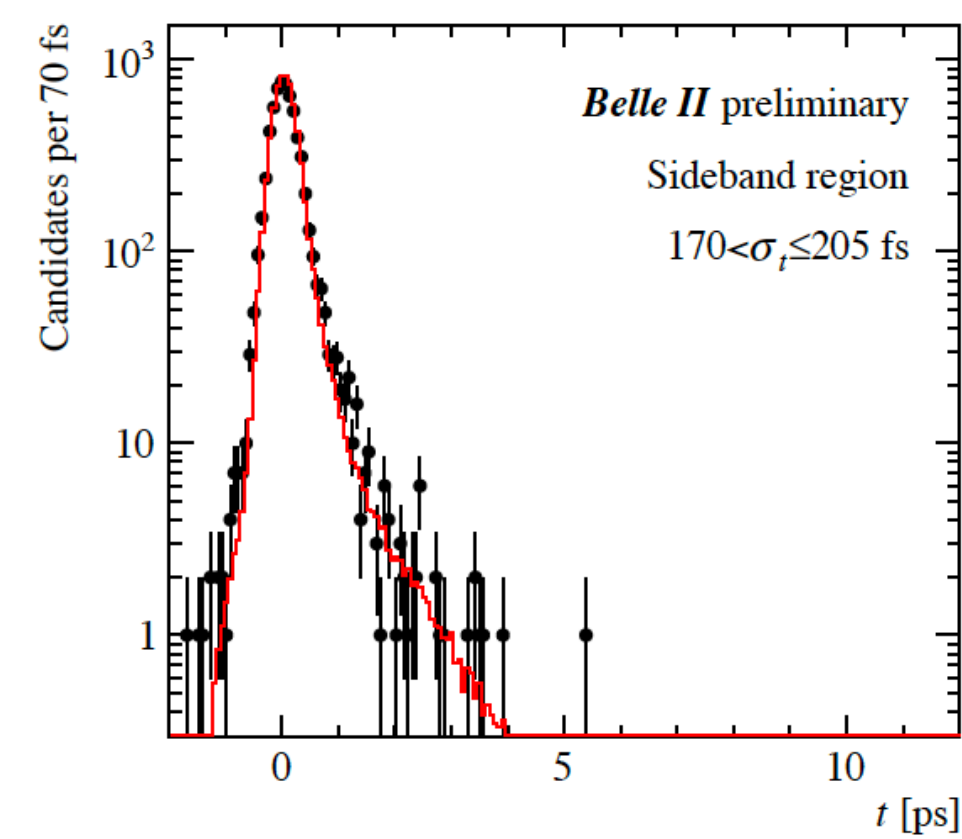
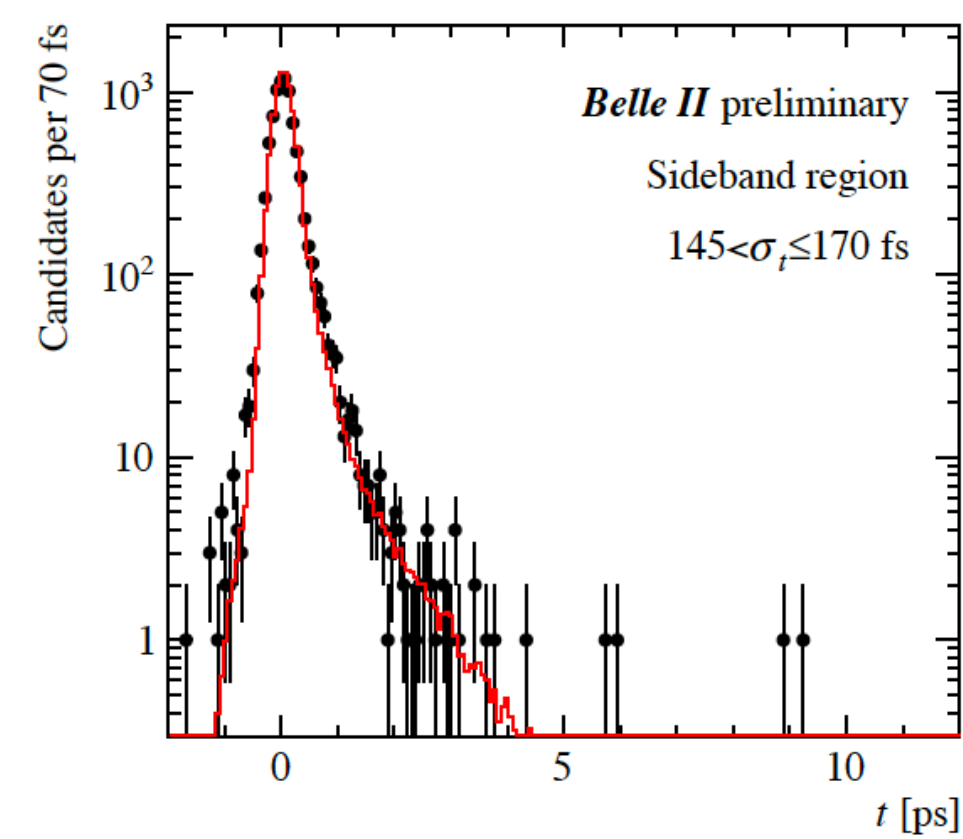
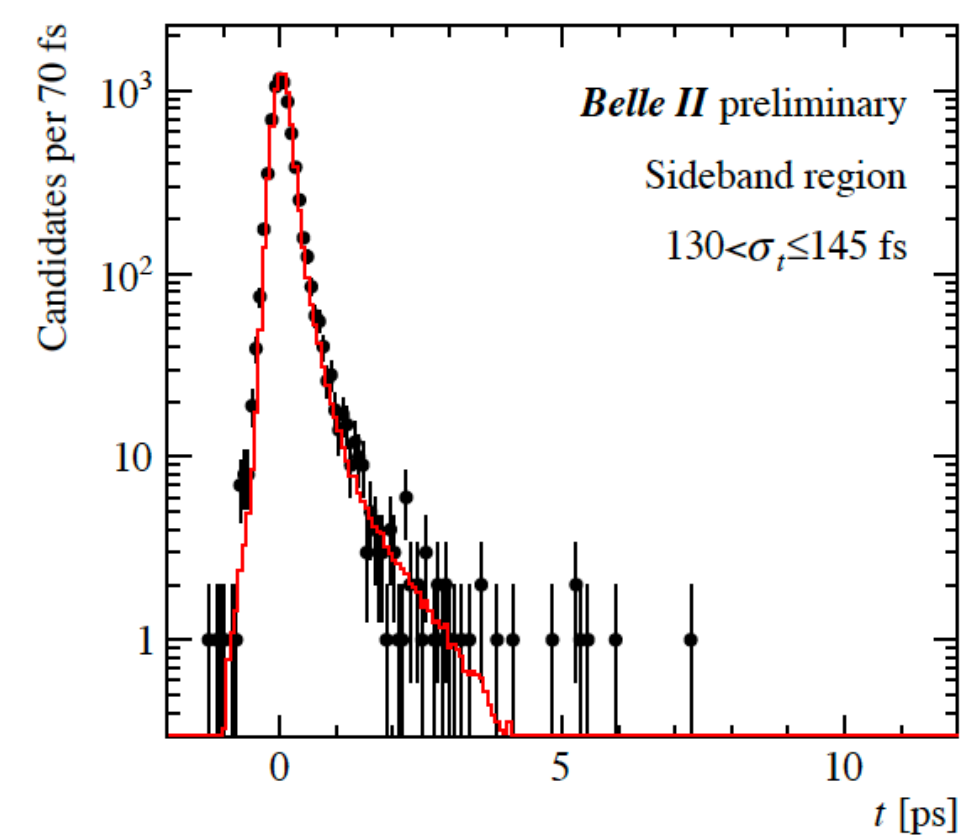
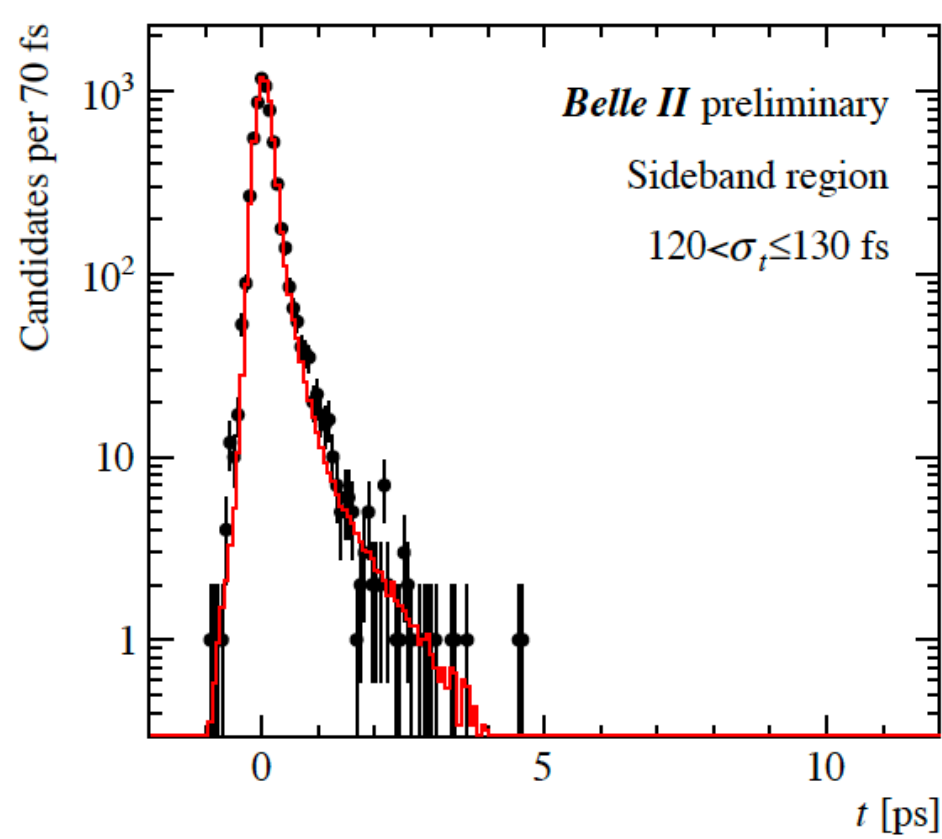
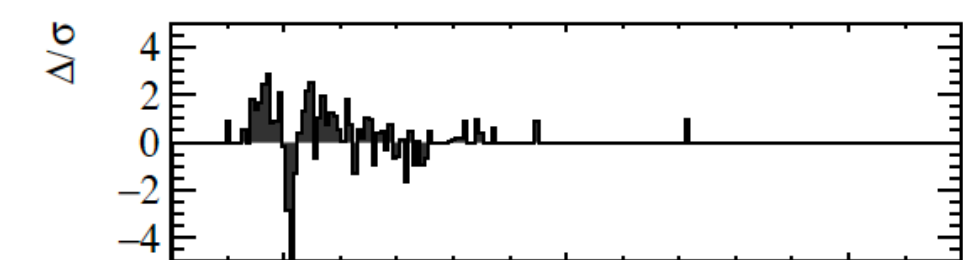
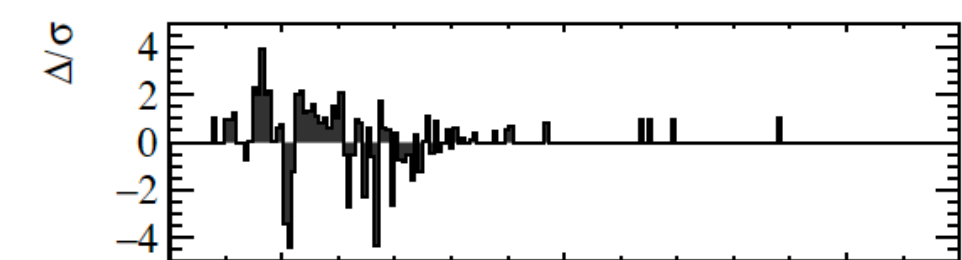
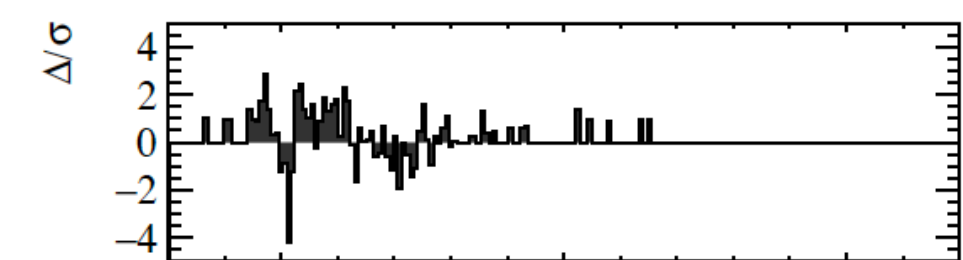
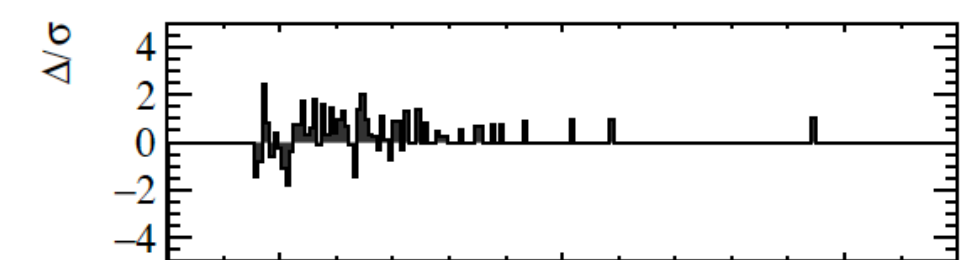
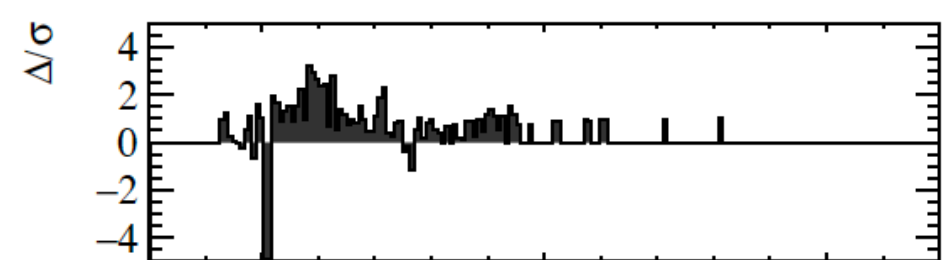
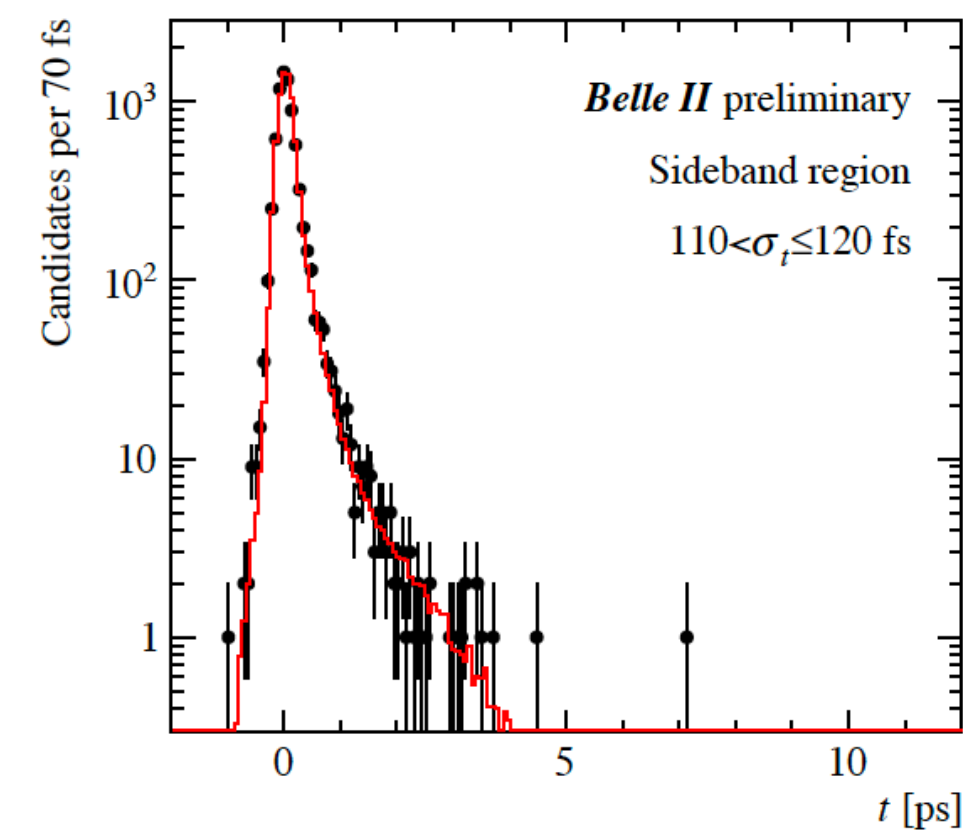
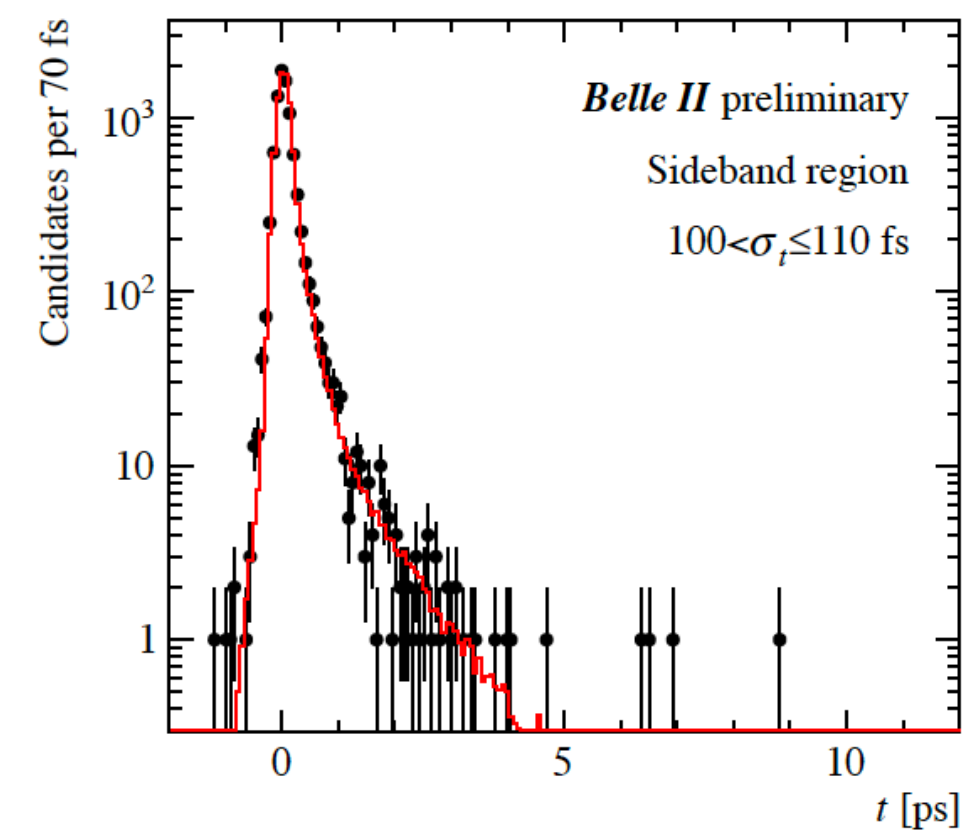
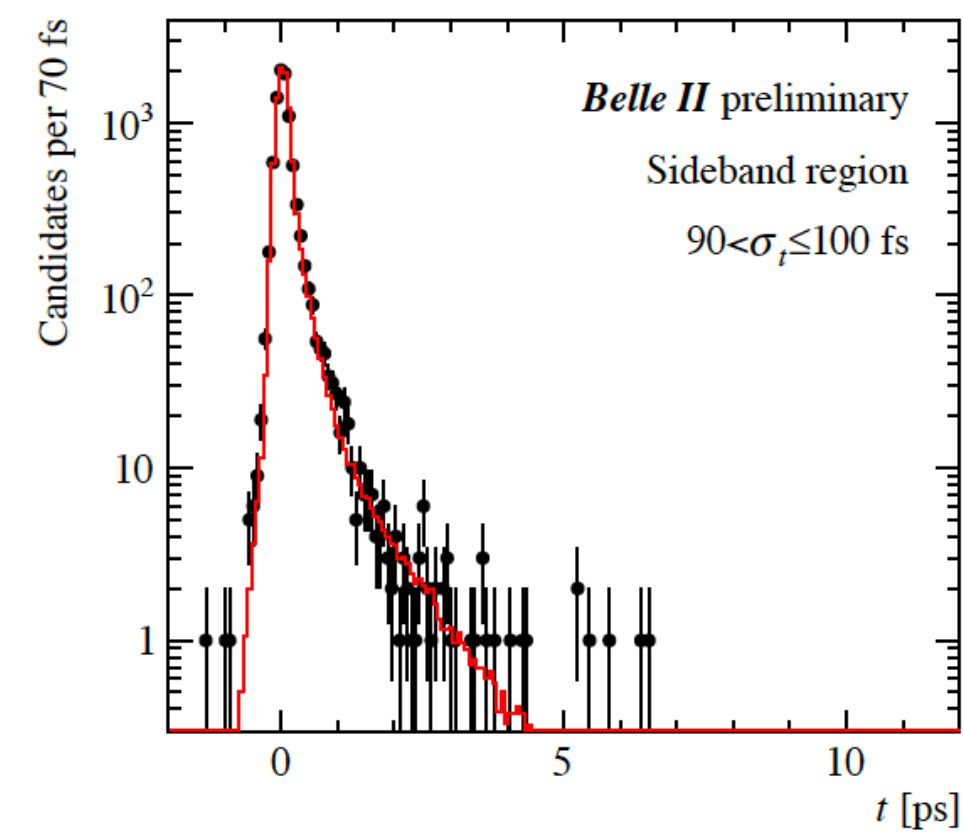
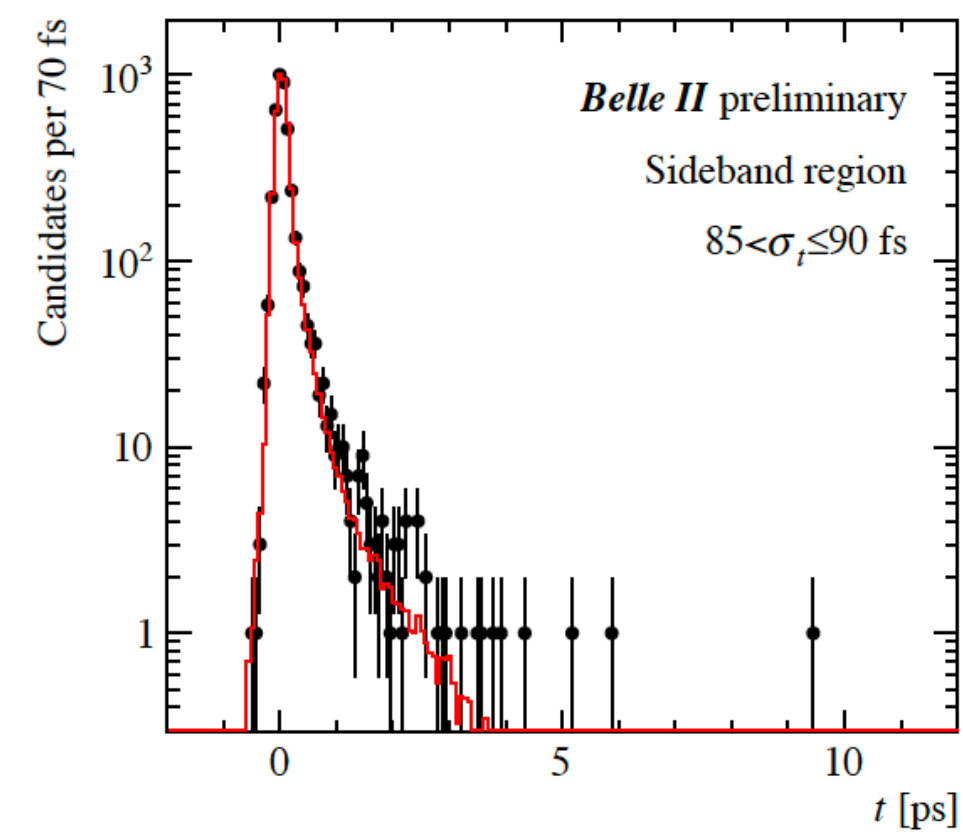
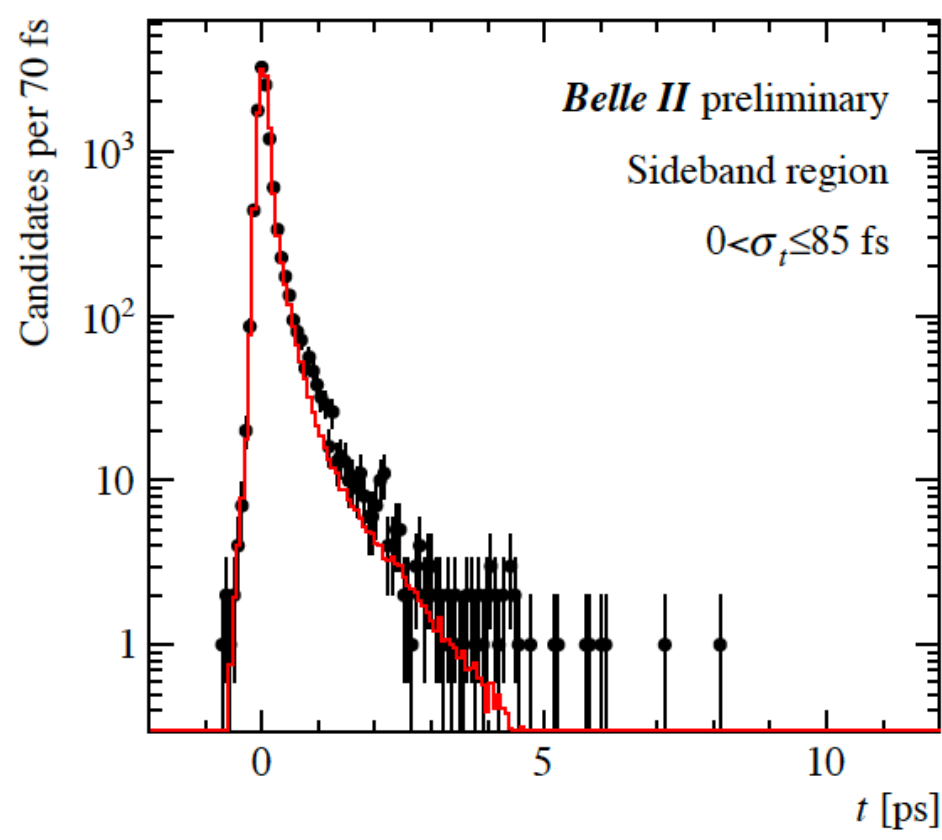
$$f_{\tau} = 0.249 \pm 0.012$$

$$\mu_{bkg} = 0.014 \pm 0.002$$

LHCB,  $\tau = 203.5 \pm 1.0 \pm 1.3 \pm 1.4$  fs

CLEO,  $\tau = 179.6 \pm 6.9 \pm 4.4$  fs

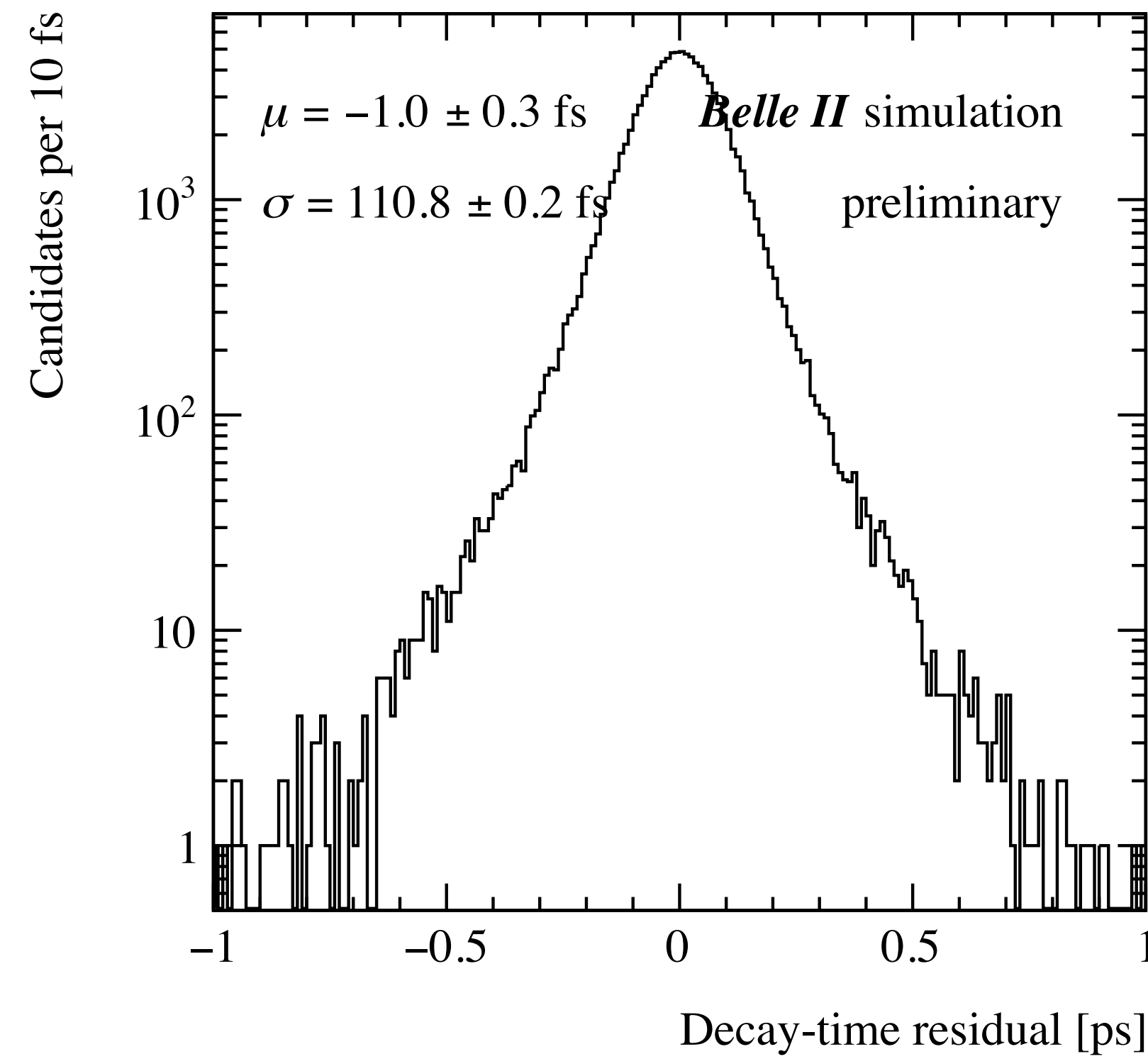
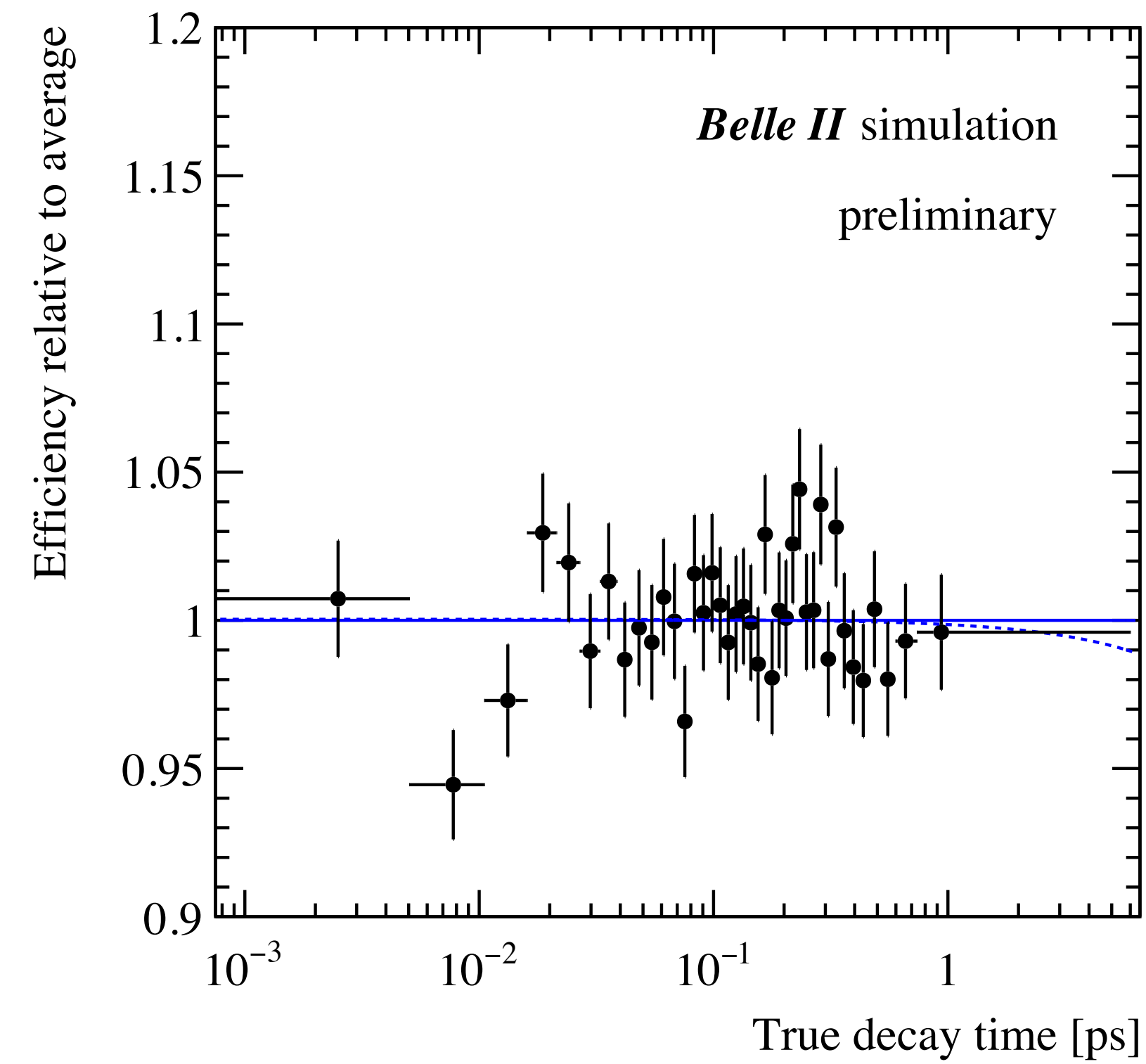




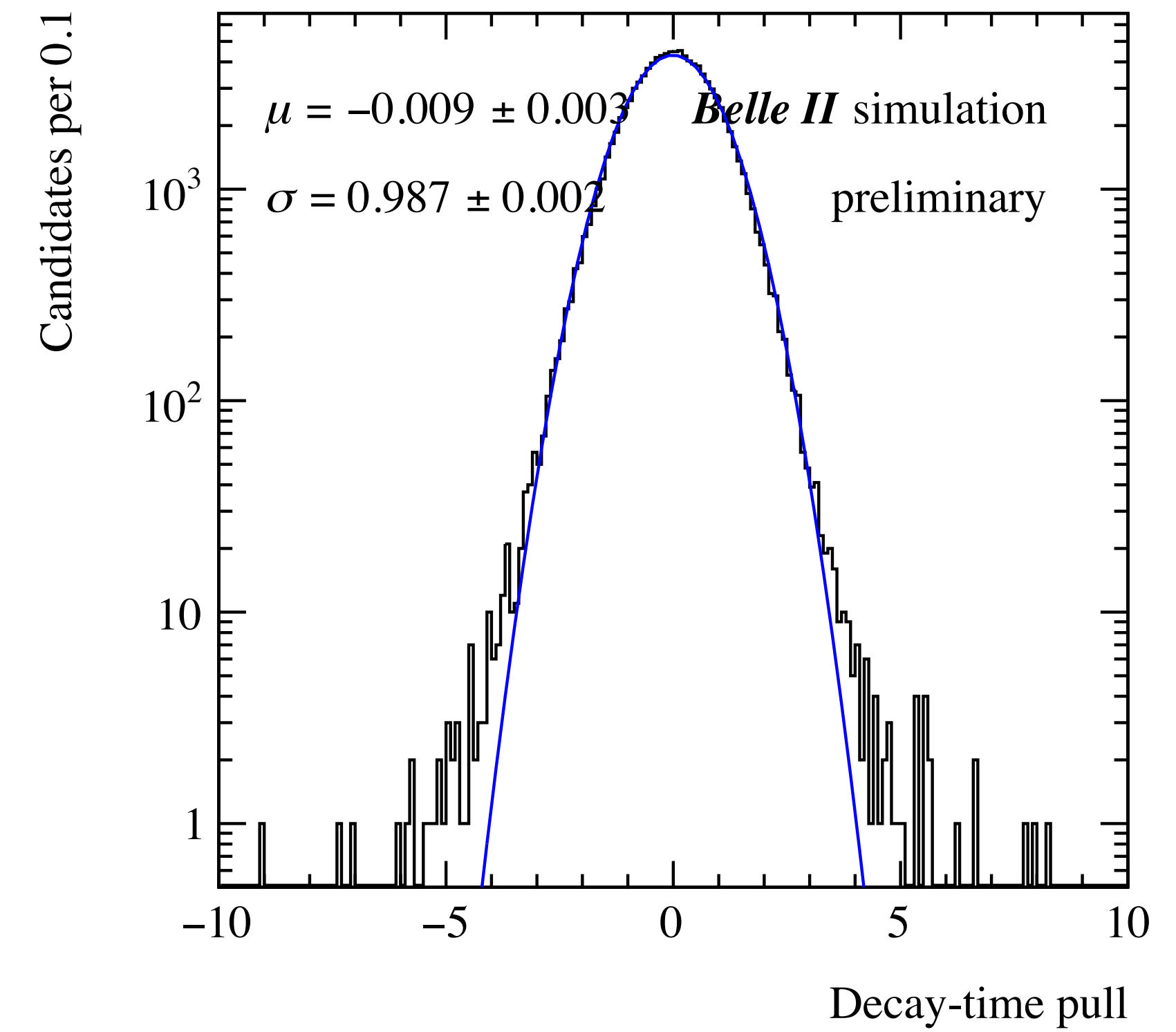


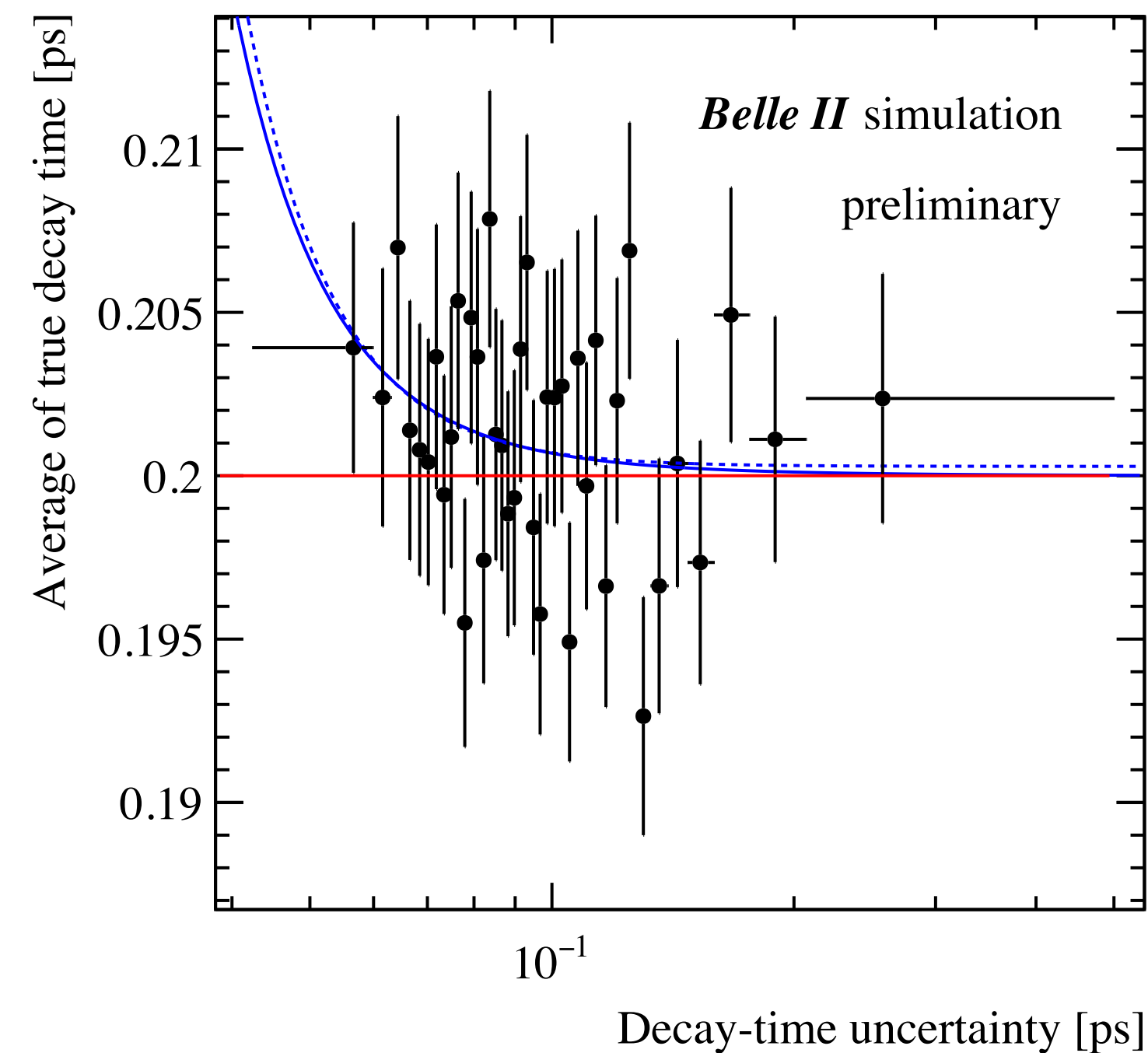
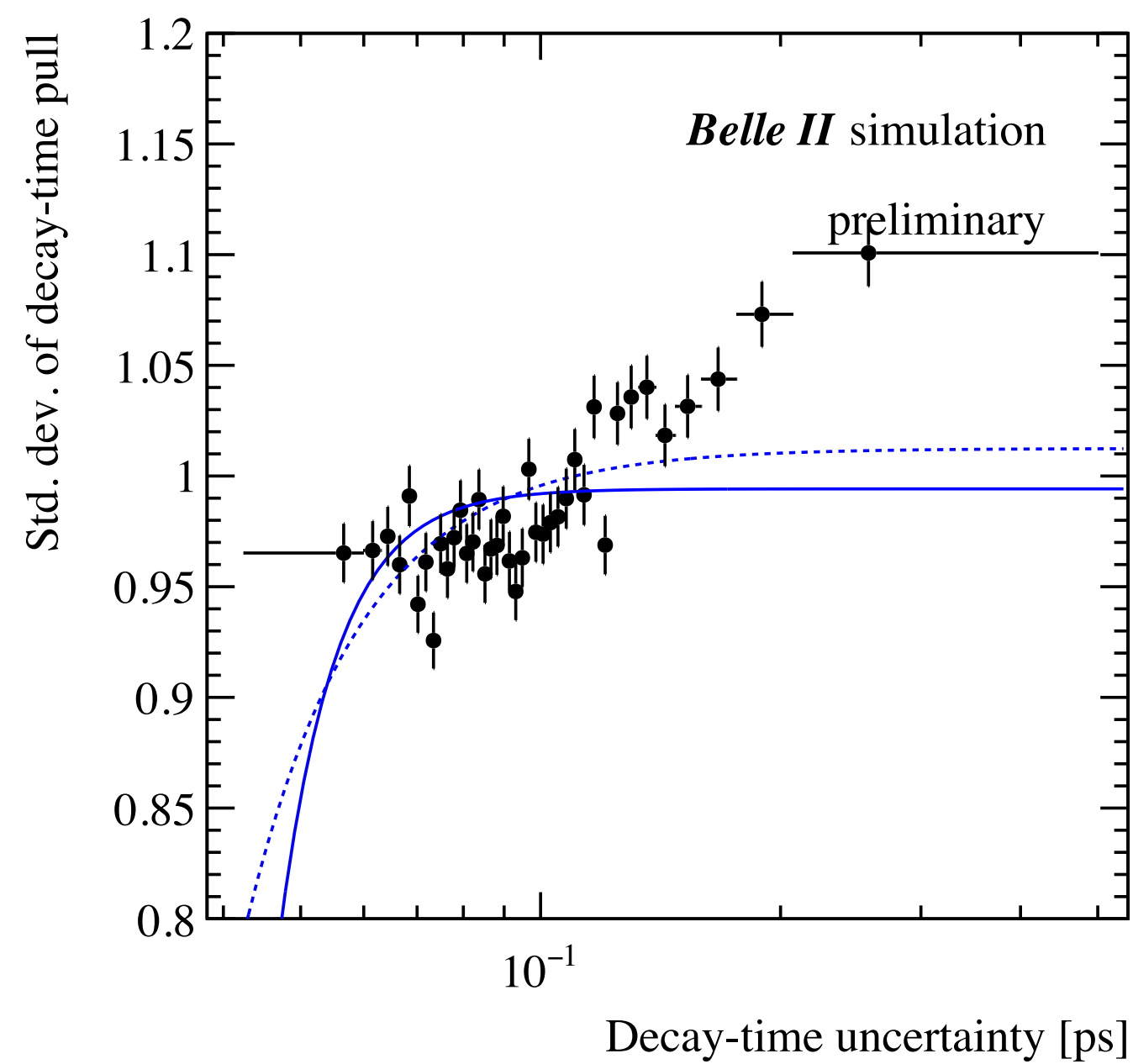
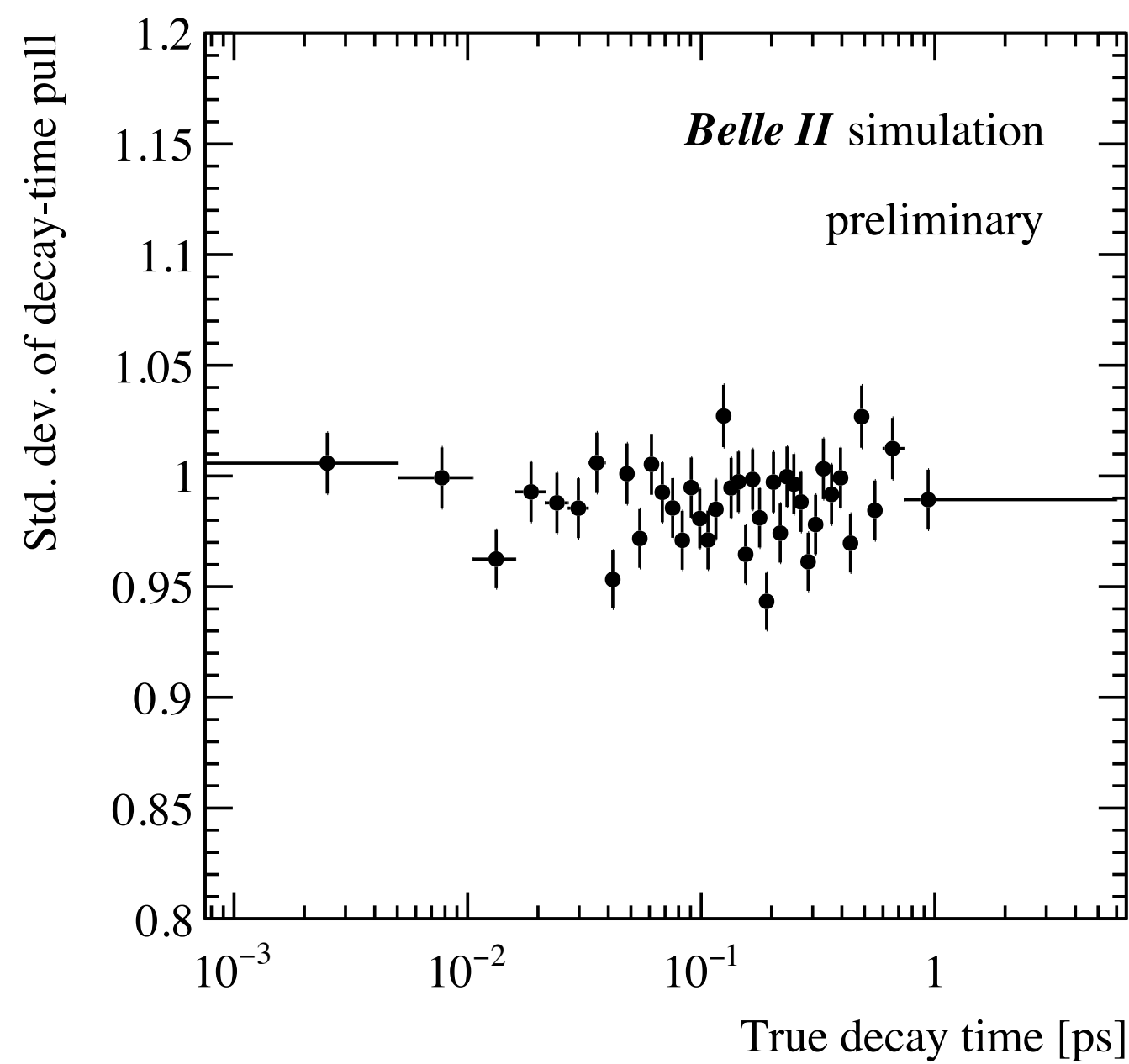
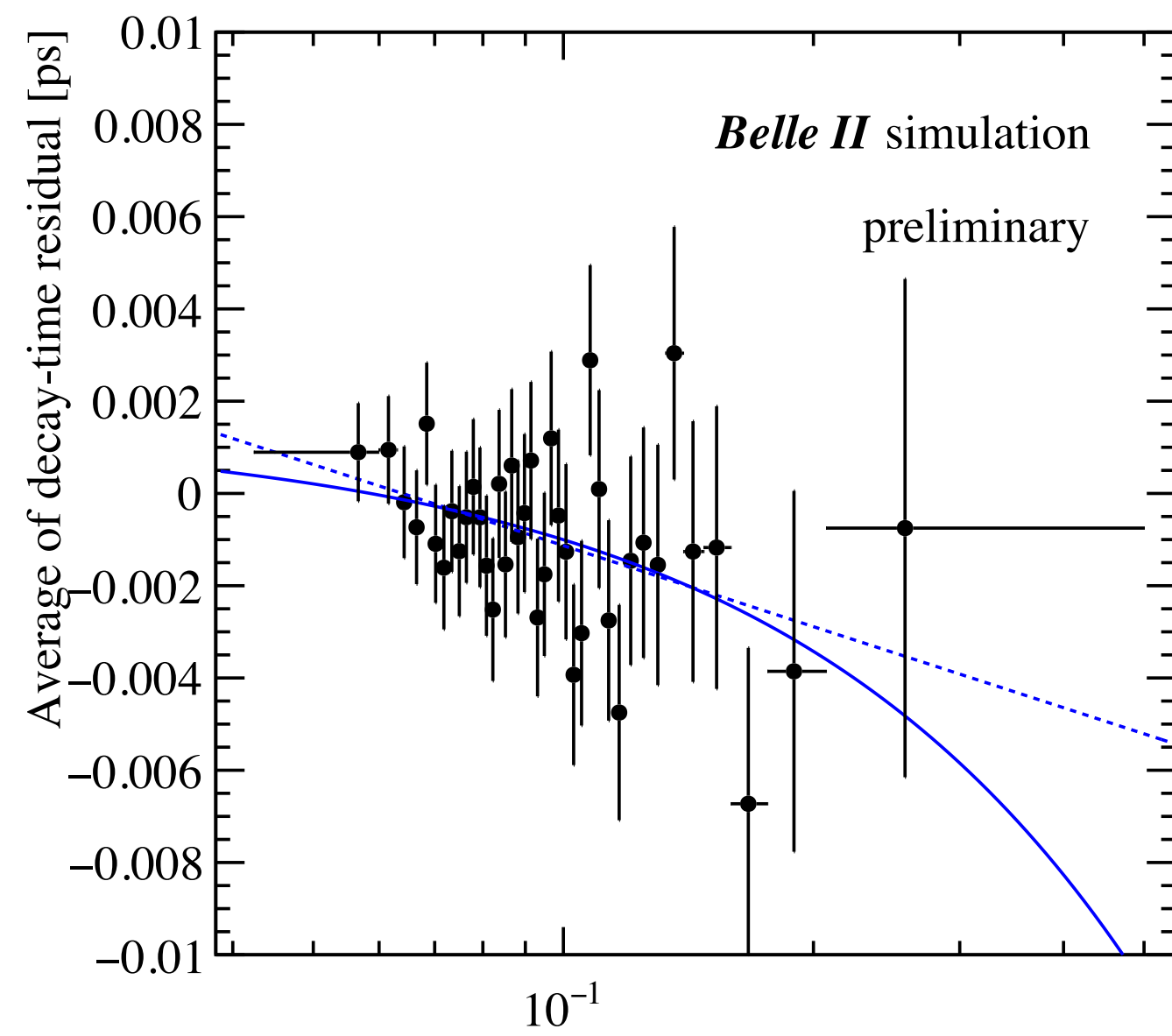
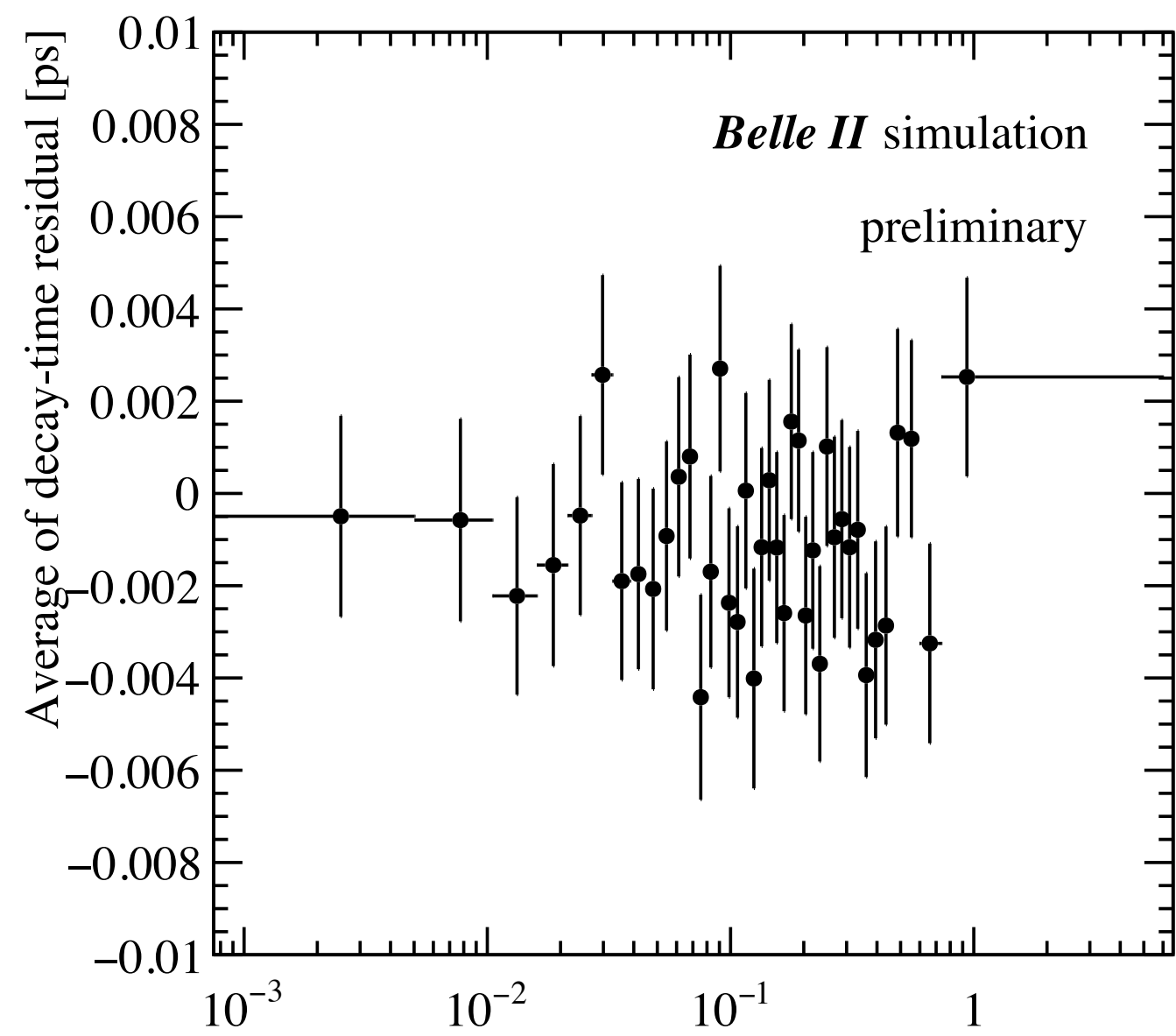
# Reconstruction effects

- No evidence of reconstruction effects that would bias the decay time



- Approximately Gaussian decay-time pull from truth-matched events

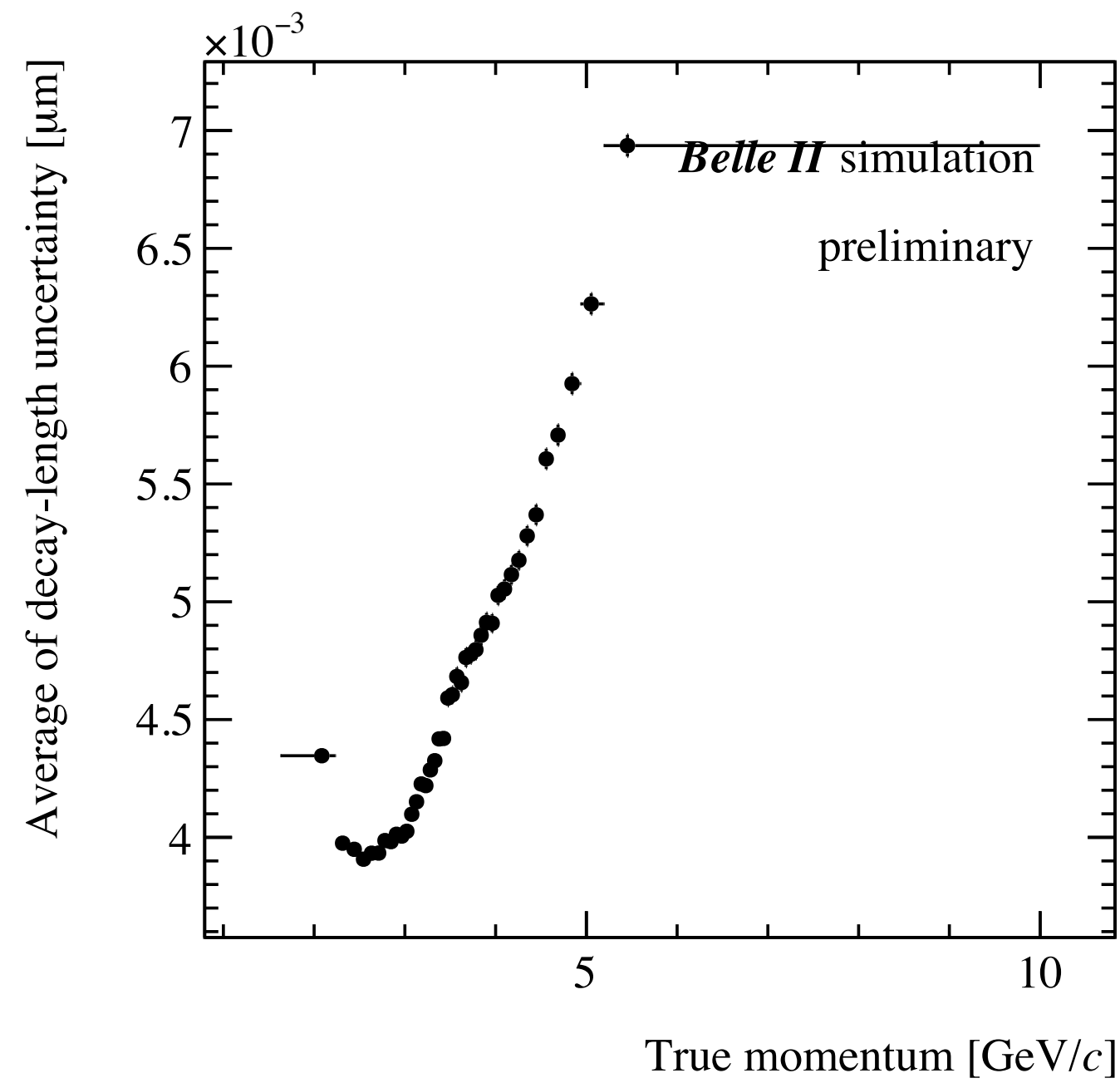
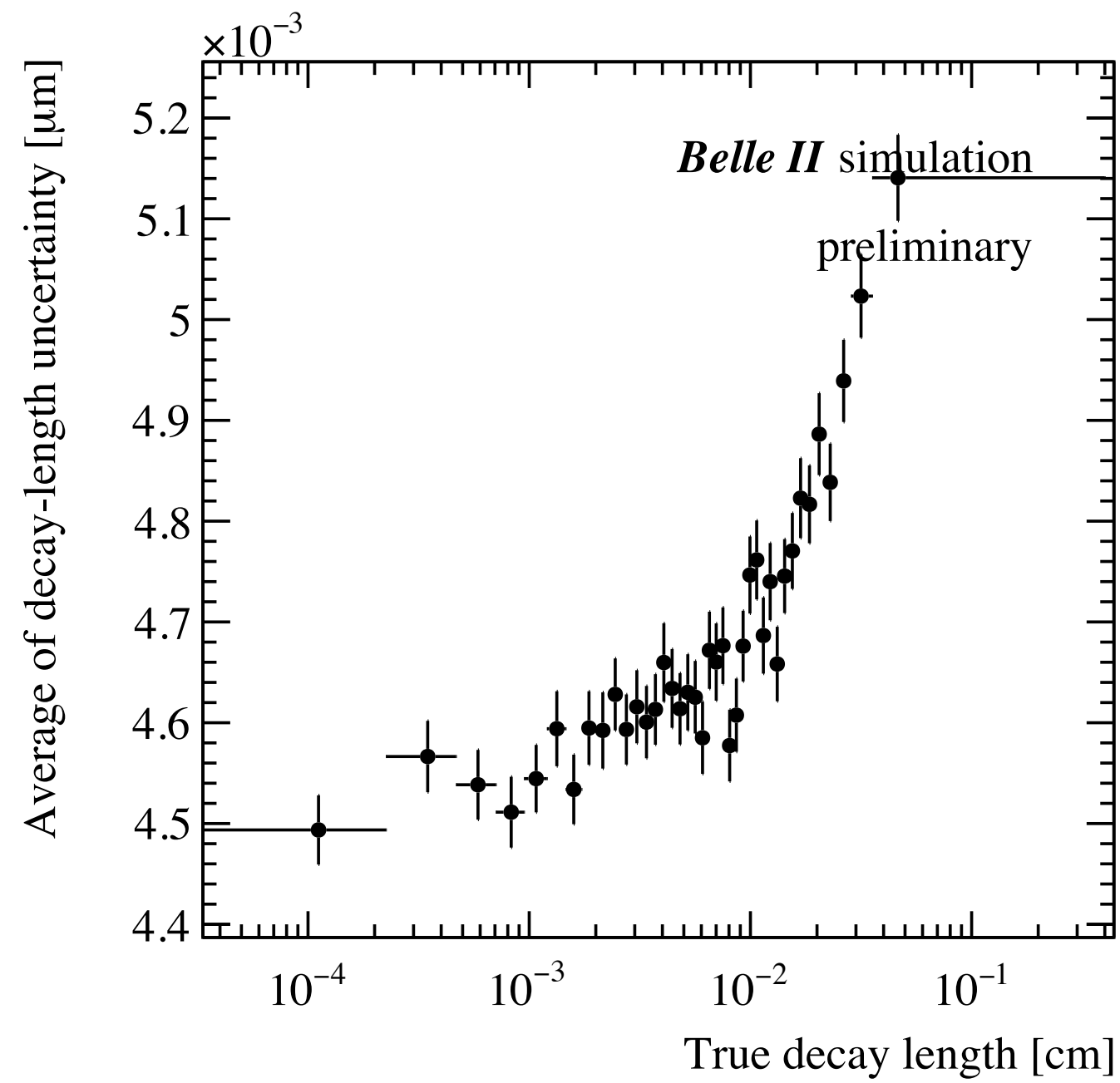




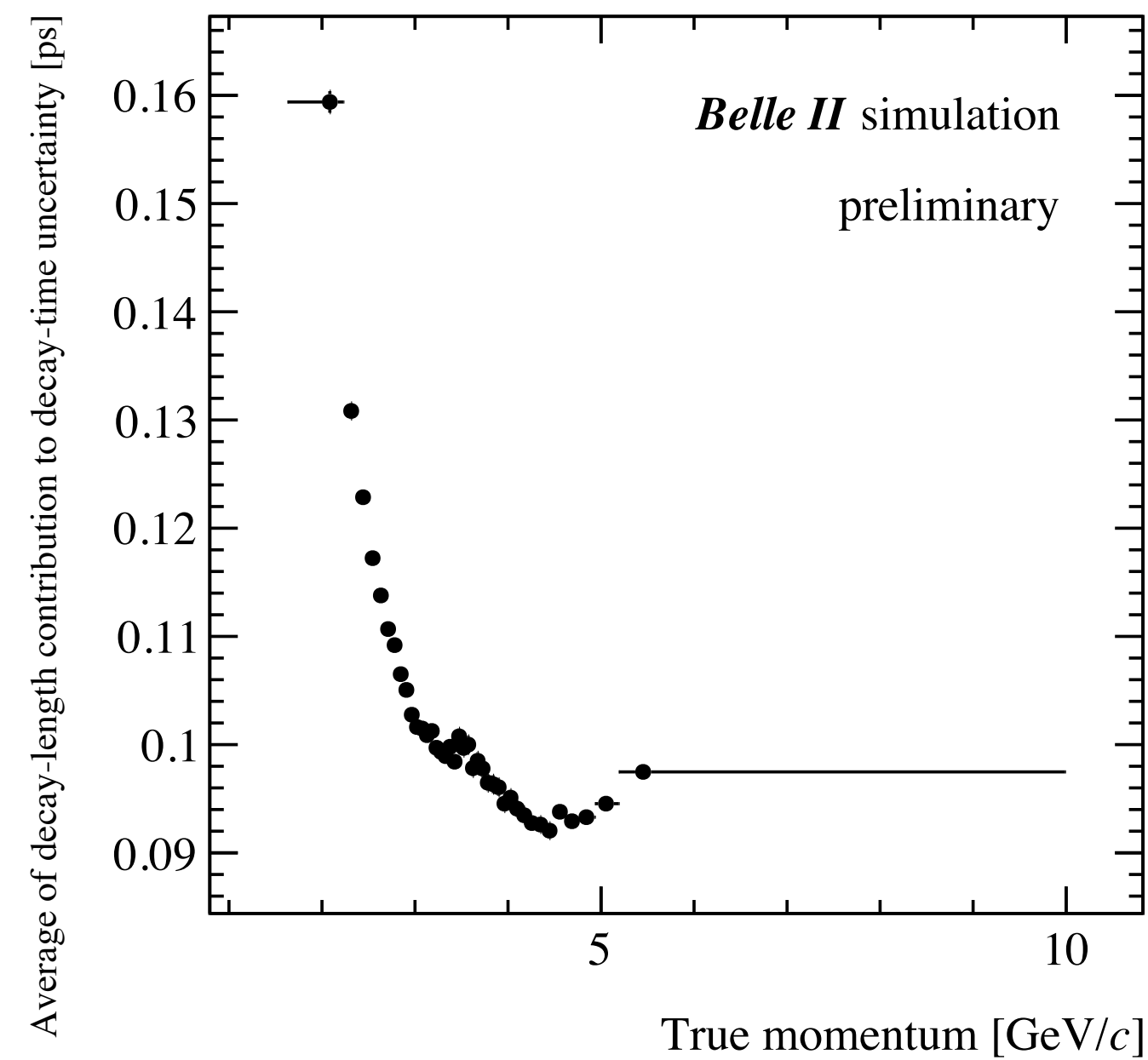
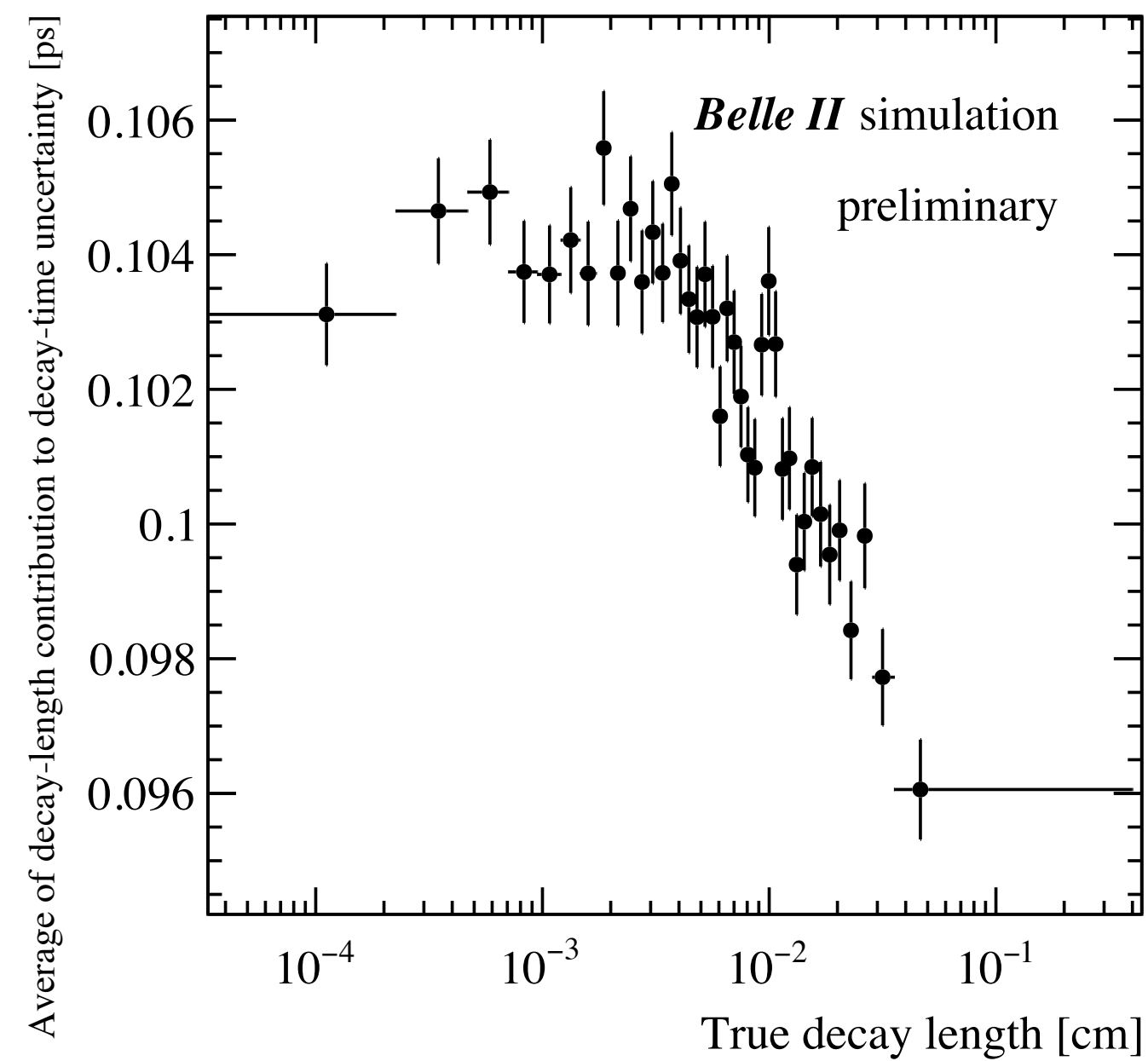
- No dependence of the decay-time residual/pull on true decay time

- Some dependence on decay-time resolution

- No significant variation of true decay-time vs uncertainty



- Expected dependencies on decay-length uncertainty on the true decay time and momentum
  - Neglected in the lifetime fit

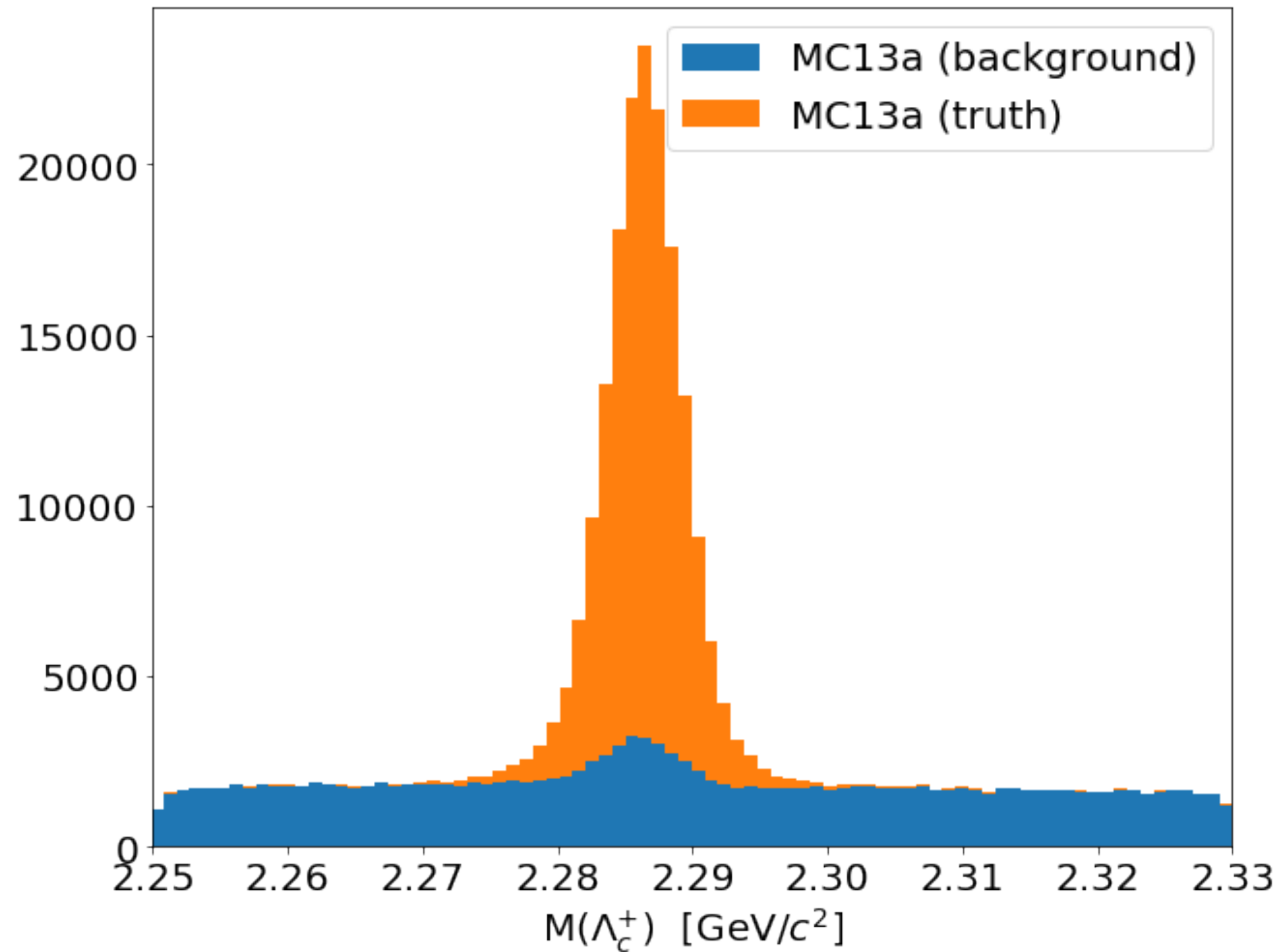




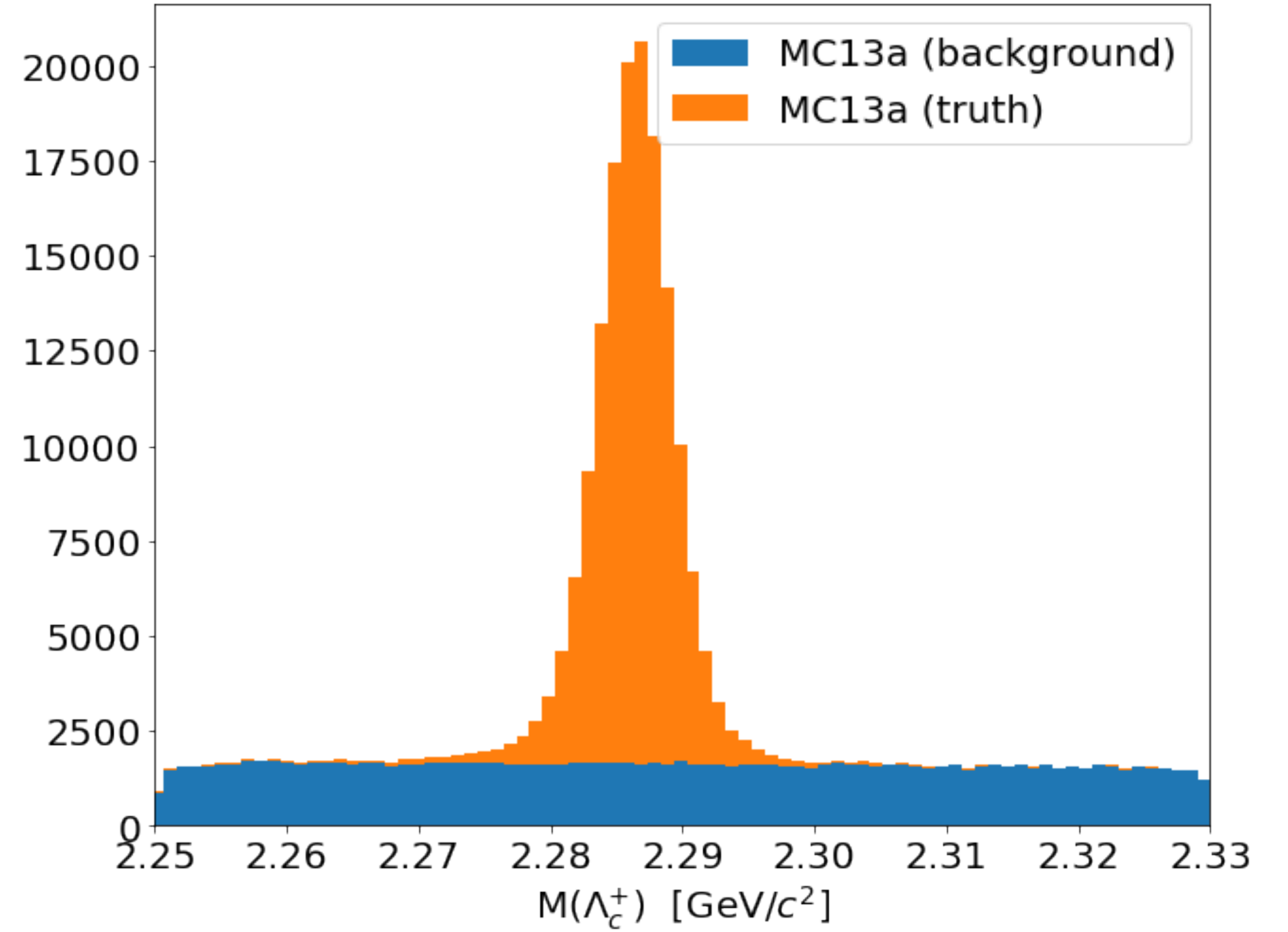
# MC truth matching

- Use mcErrors to allow: missing FSR, missing intermediate resonance, decay in flight, missing neutrino, missing photon, missing final state particle, missing KLID
- Background includes (among others) misidentification, invalid matches, etc.

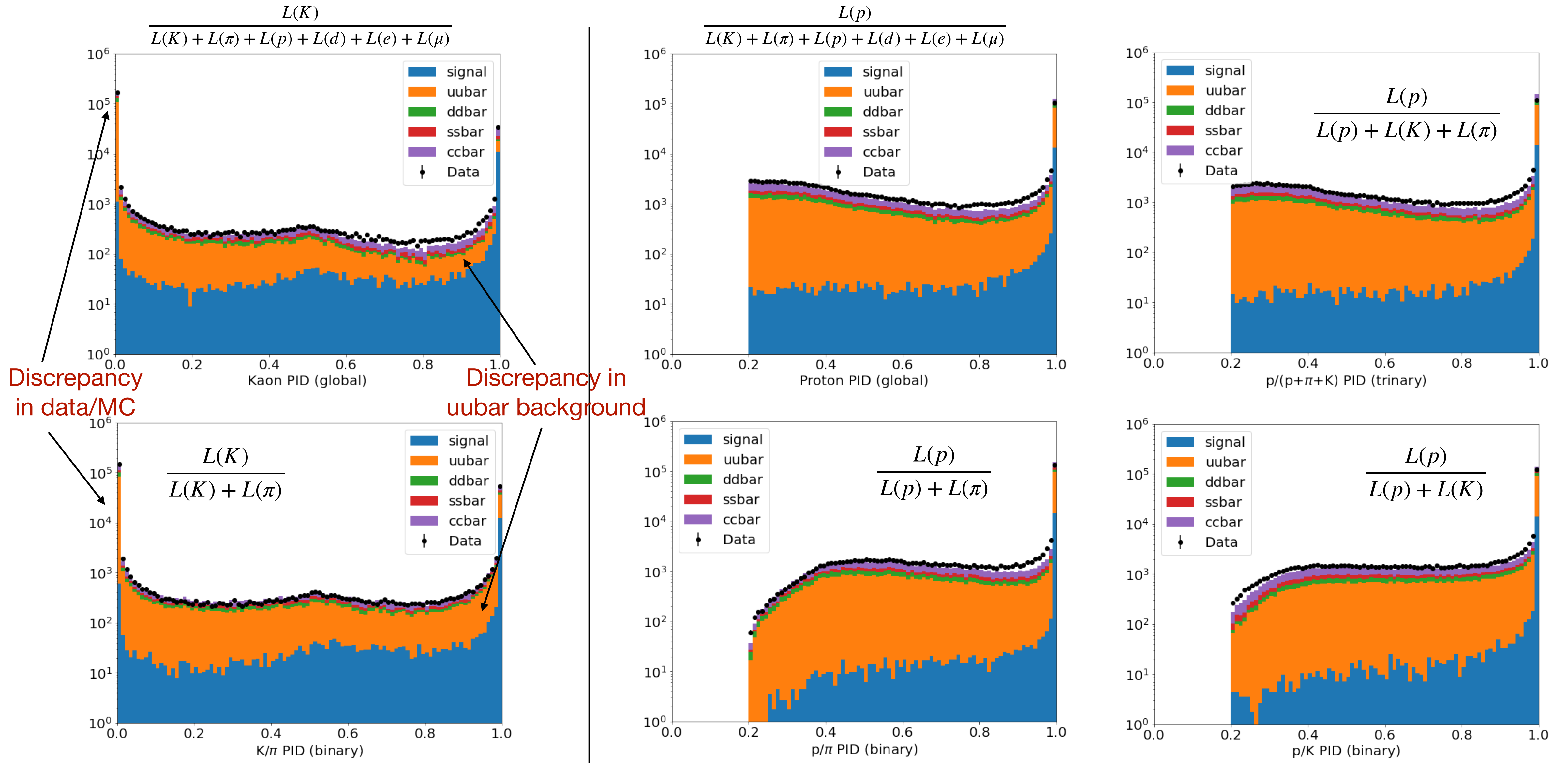
isSignal==1



isSignal==1 or mcErrors < 128



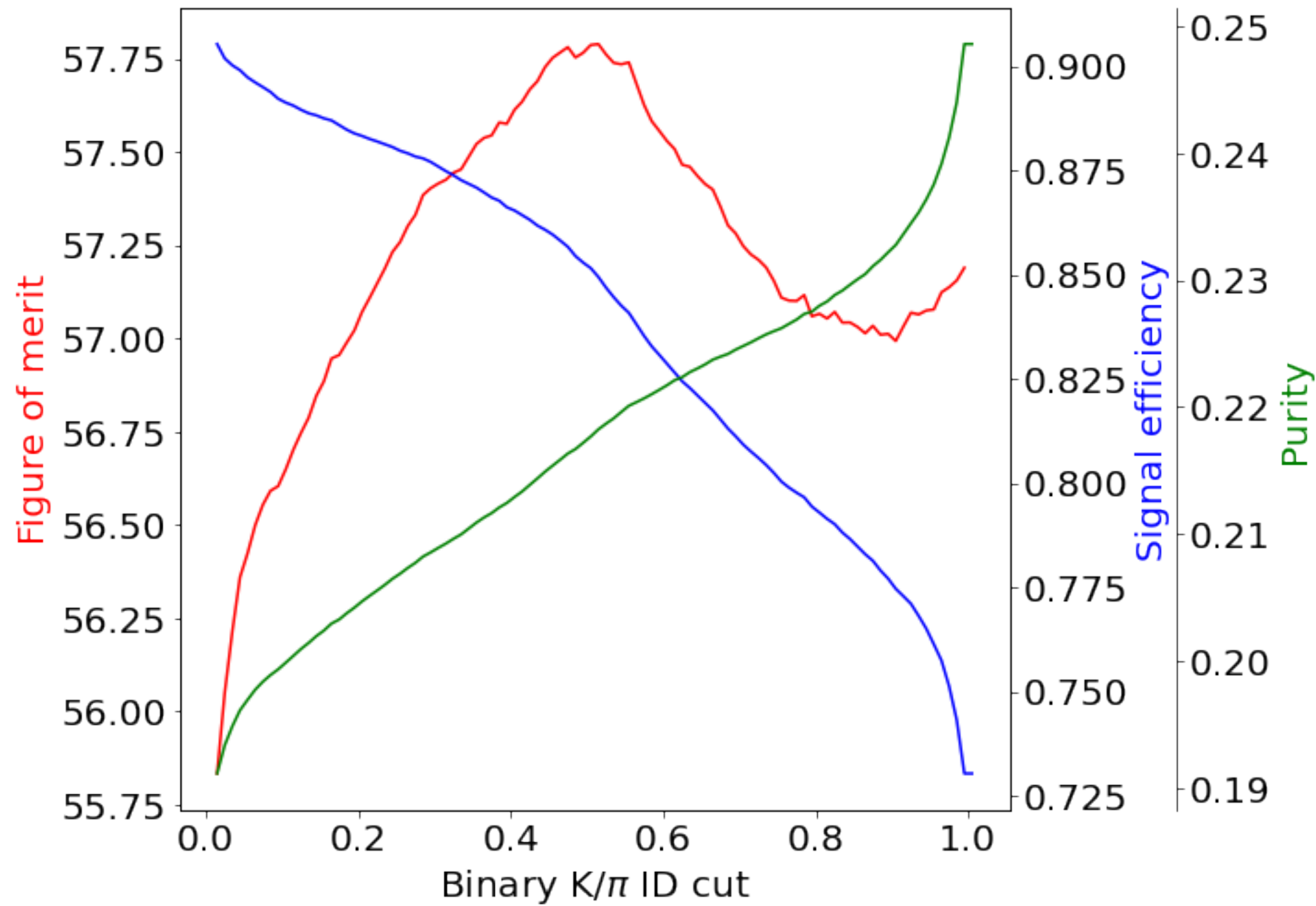
# PID (global versus trinary/binary)



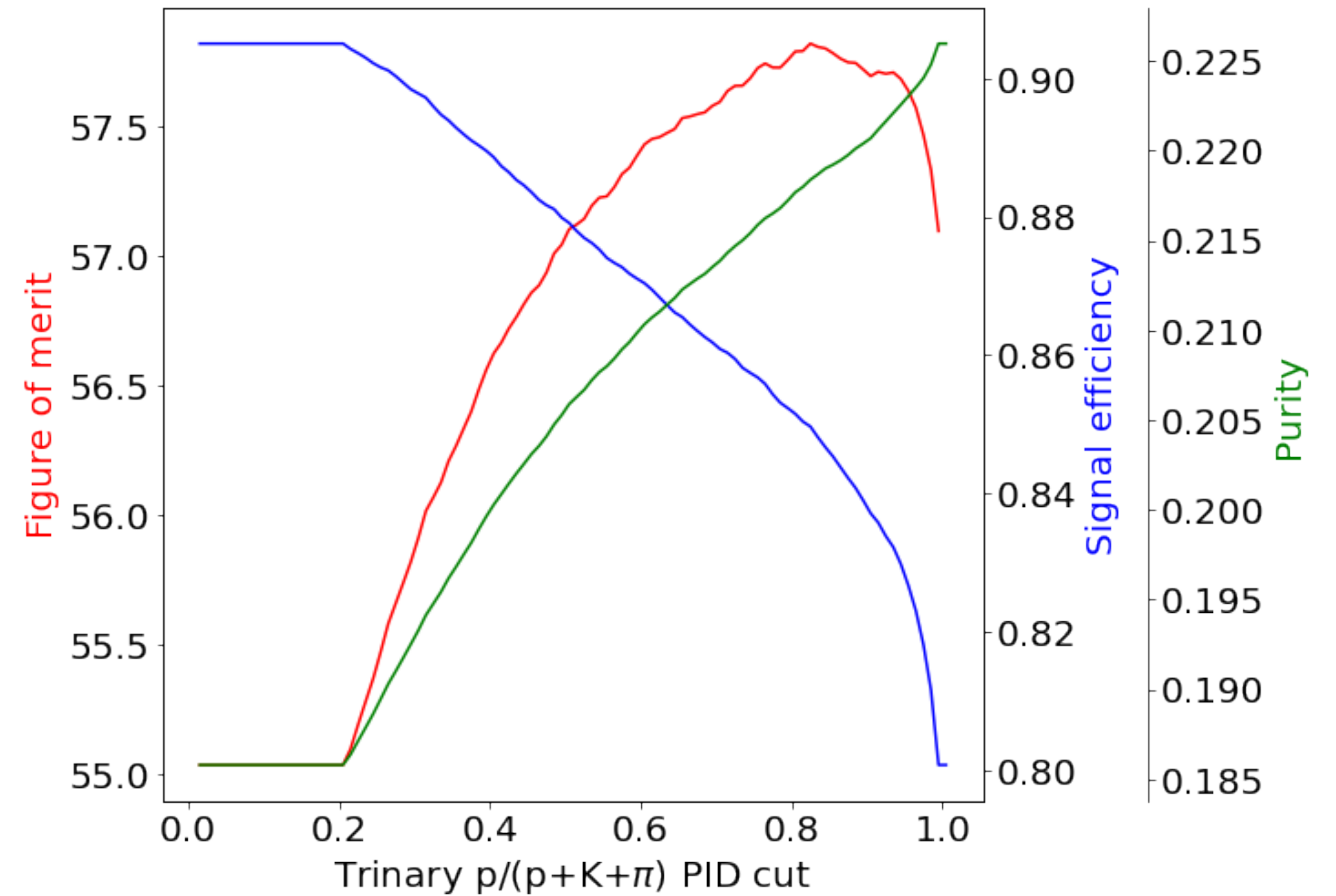
# PID optimization

$$FOM = \frac{S}{\sqrt{S+B}}$$

K/ $\pi$  ID with proton trinary PID > 0.8



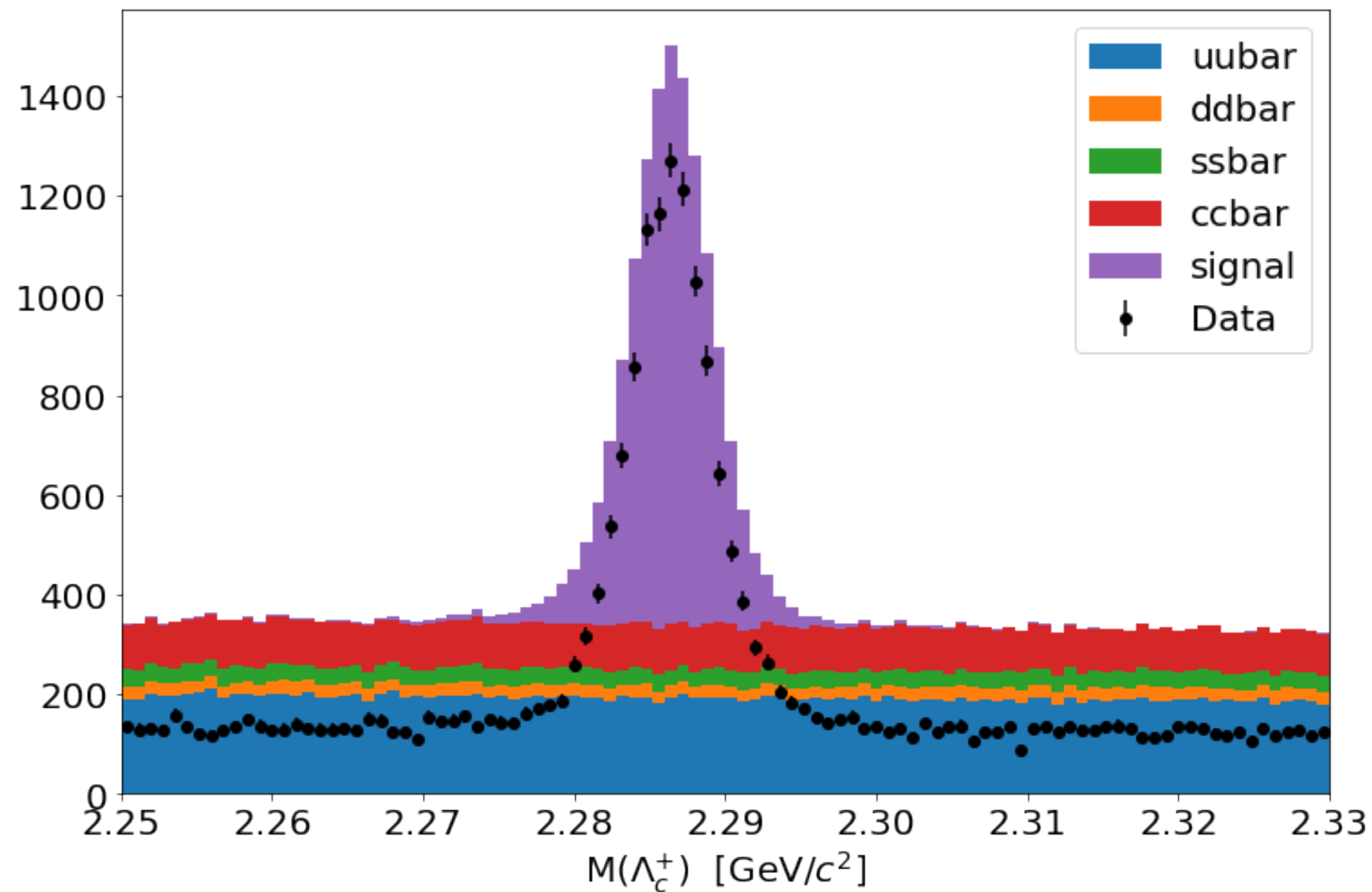
Proton ID with K/ $\pi$  binary PID > 0.5



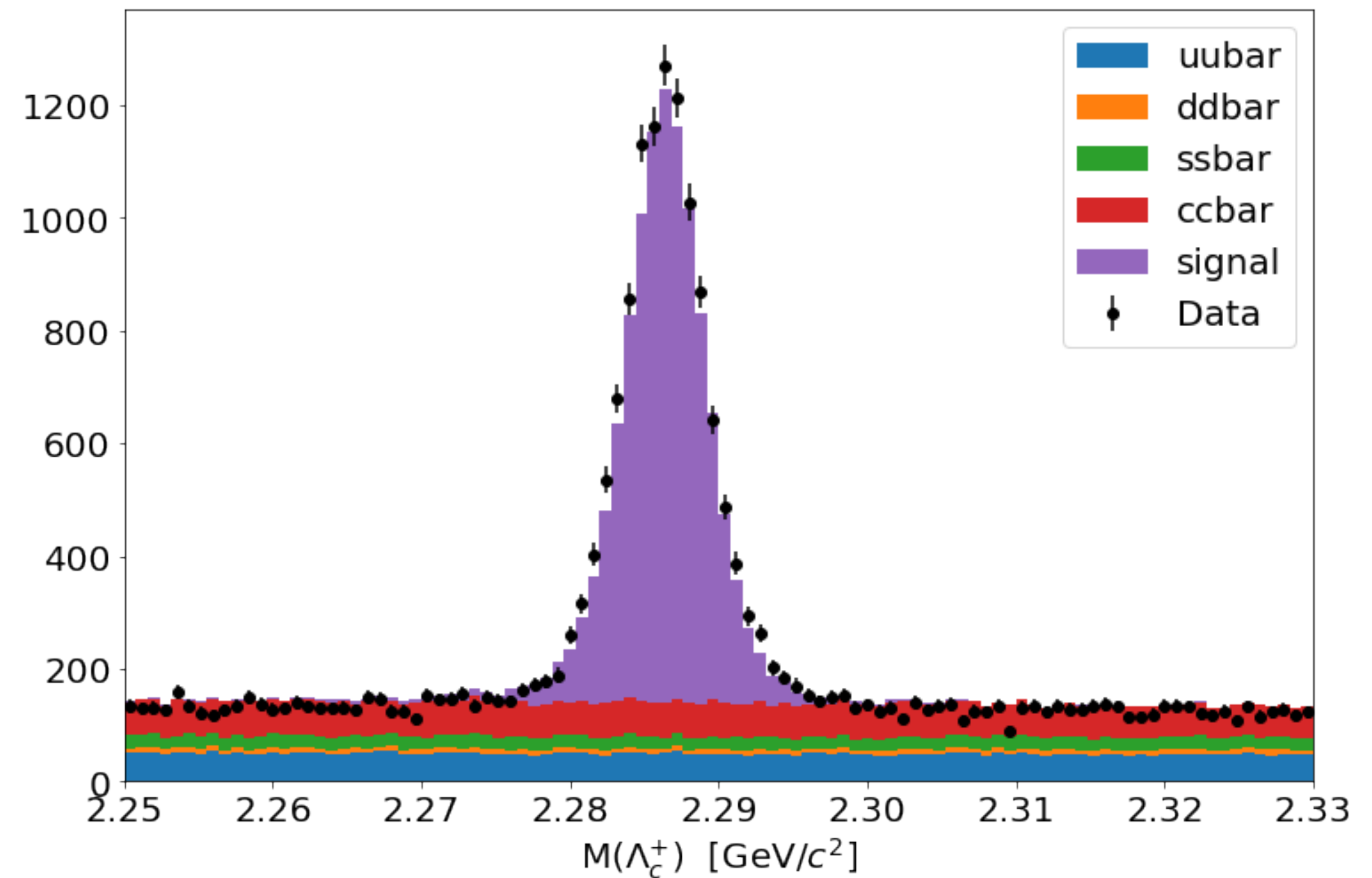
\*Similar distributions/maxima for global PID variables

# Binary/trinary versus global PID

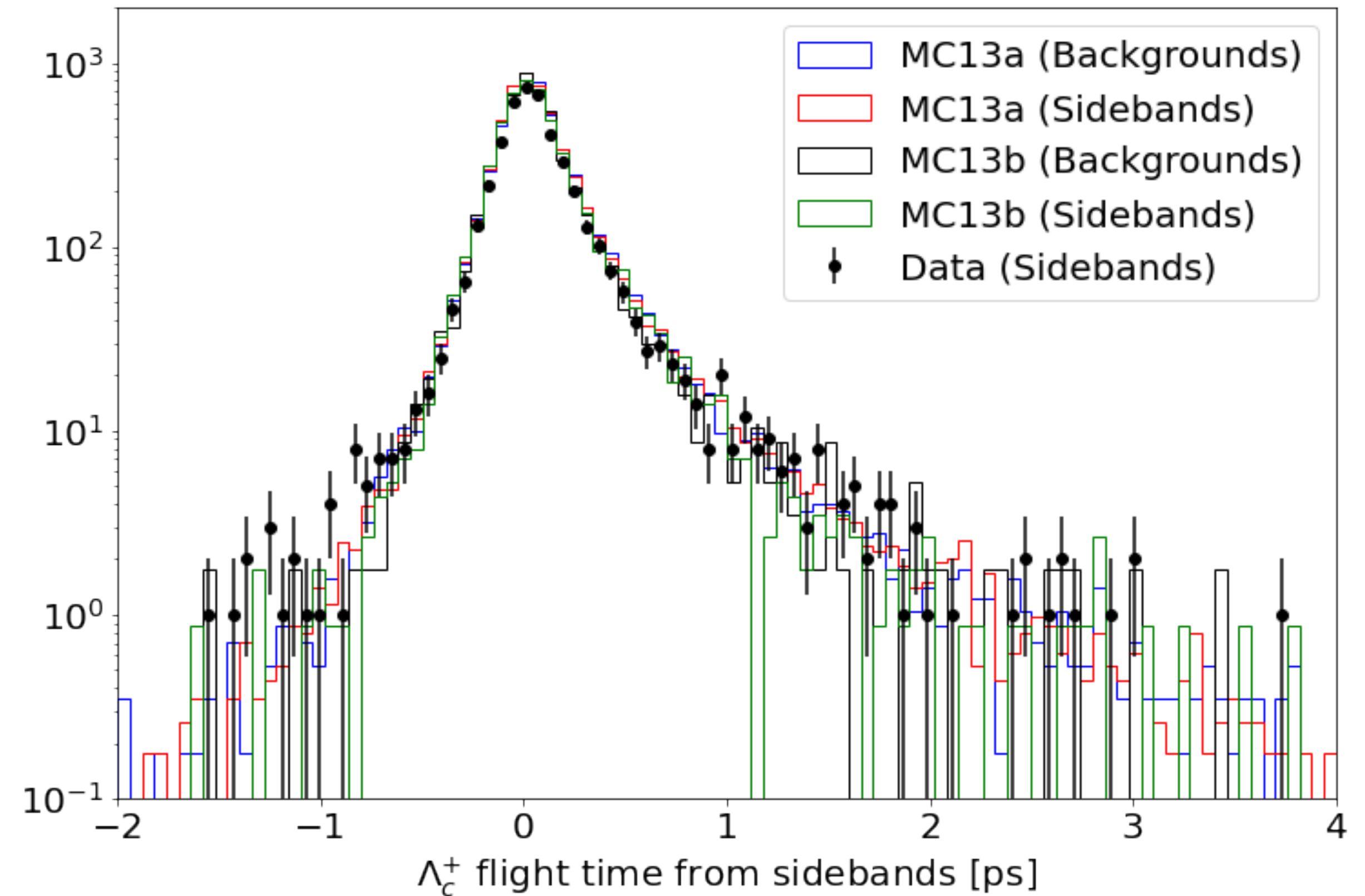
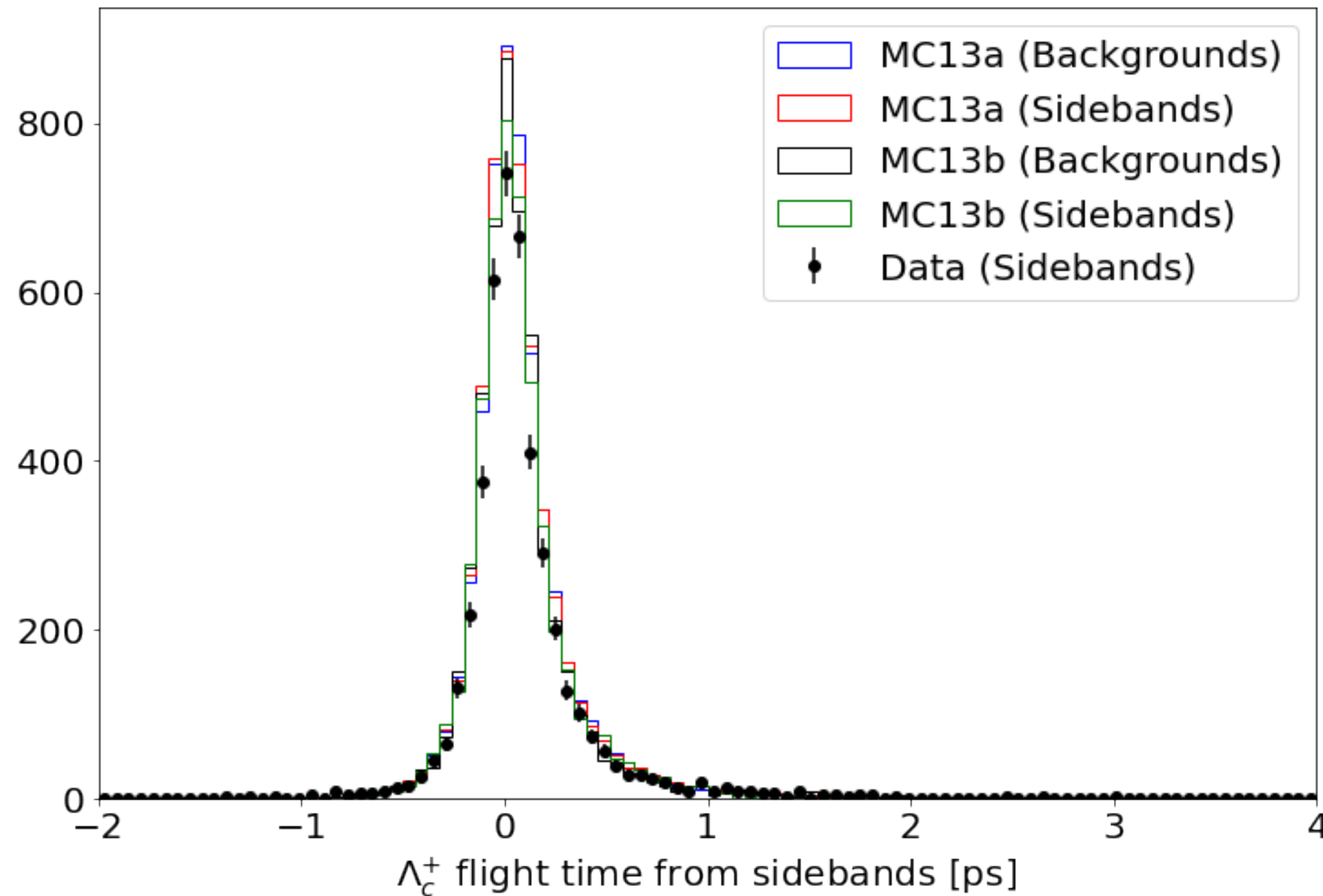
Proton trinary PID  $> 0.8$   
K/ $\pi$  binary PID  $> 0.5$



Proton trinary PID  $> 0.8$   
Kaon global PID  $> 0.5$

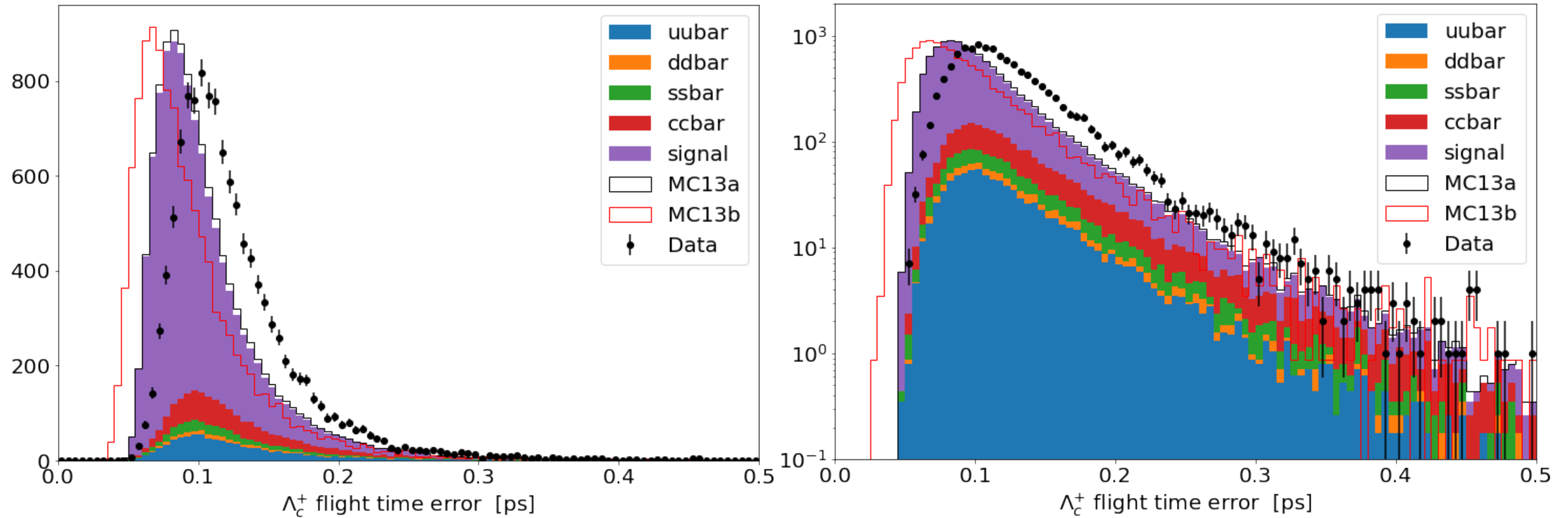


# Compare truth-matching to sidebands



- Good data/MC agreement for both MC13a (run-independent) and MC13b (run-dependent)
- Still a significant background from long-lived particles

# Decay time uncertainty



- Discrepancies between data and MC for flight time uncertainty (even between MC13a and MC13b)

# Efficiency dependence on flight time uncertainty

- No apparent efficiency dependence on  $t$ ,  $\sigma_t$
- Outside region of apparent shift in  $D$  analyses

