Study of $B^+ \rightarrow K^+\tau^+\tau^-$ using hadronic tagging

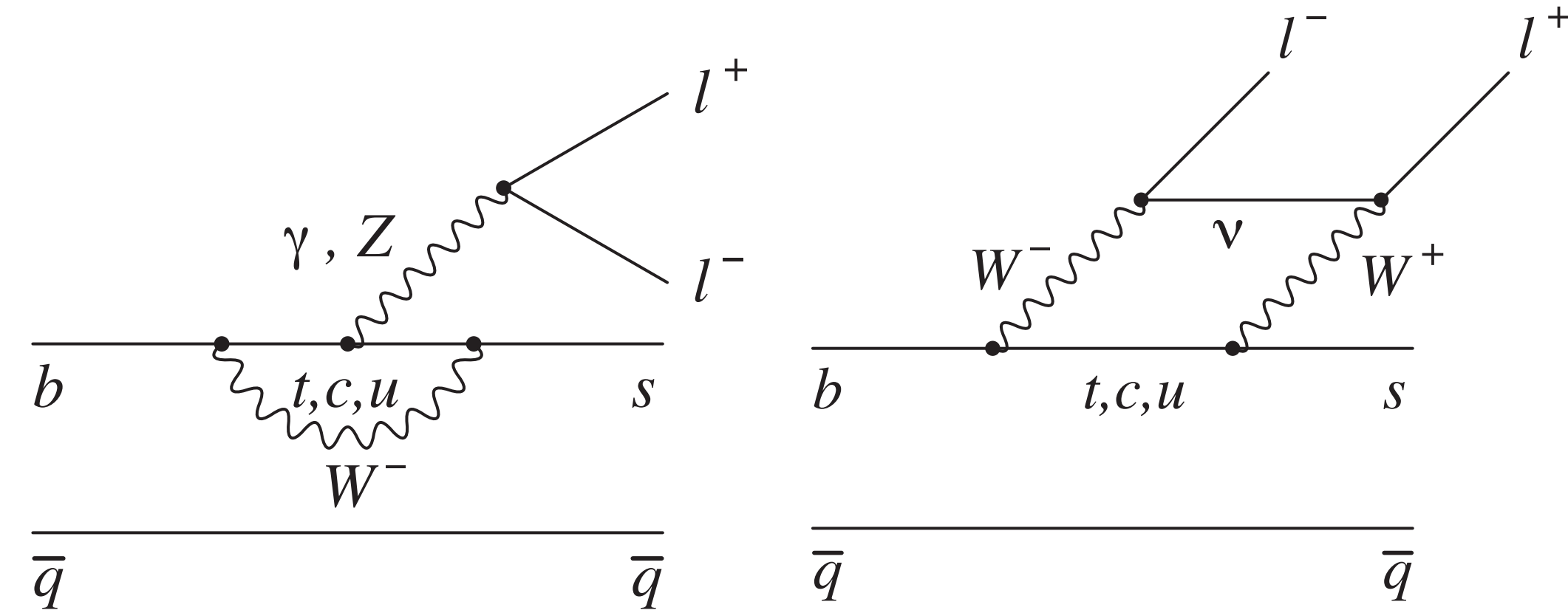Debjit Ghosh

August 12, 2022

Study of $B^+ \to K^+ \tau^+ \tau^-$

Motivation:

1. FCNC: highly suppressed in SM, $\mathcal{O}(10^{-7})$
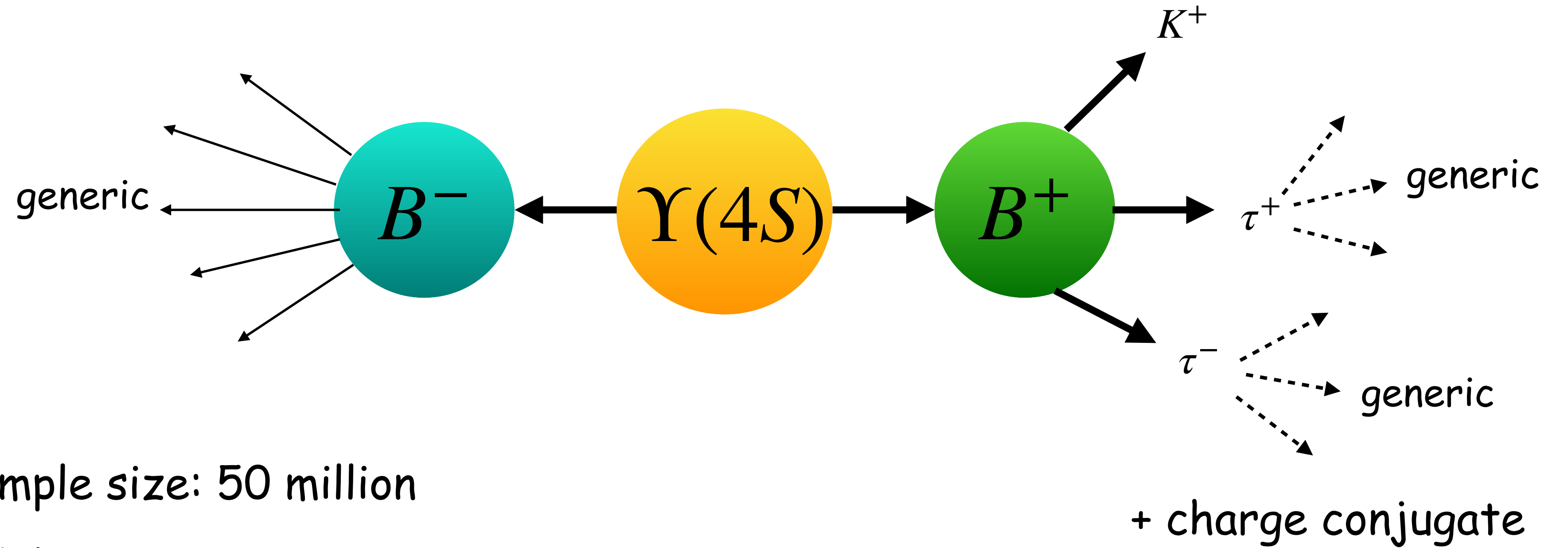2. 3rd generation strongly couples to NP

Earlier searches:

1. Attempt in Belle (by Simon Wehle, 2016): Belle Note- 1394
   upper limit at $90\,\%$ confidence level, $\mathcal{B}(B^+ \to K^+ \tau^+ \tau^-) < 3.17 \times 10^{-4}$

2. BaBar (2017): <u>arXiv:1605.09637</u>
   upper limit at $90\,\%$ confidence level, $\mathcal{B}(B^+ \to K^+ \tau^+ \tau^-) < 2.25 \times 10^{-3}$

Initial step: Perform similar to Simon's study in Belle II

modify Vidya's reconstruction script for Belle II

SignalMC generator

#simulated sample size: 50 million
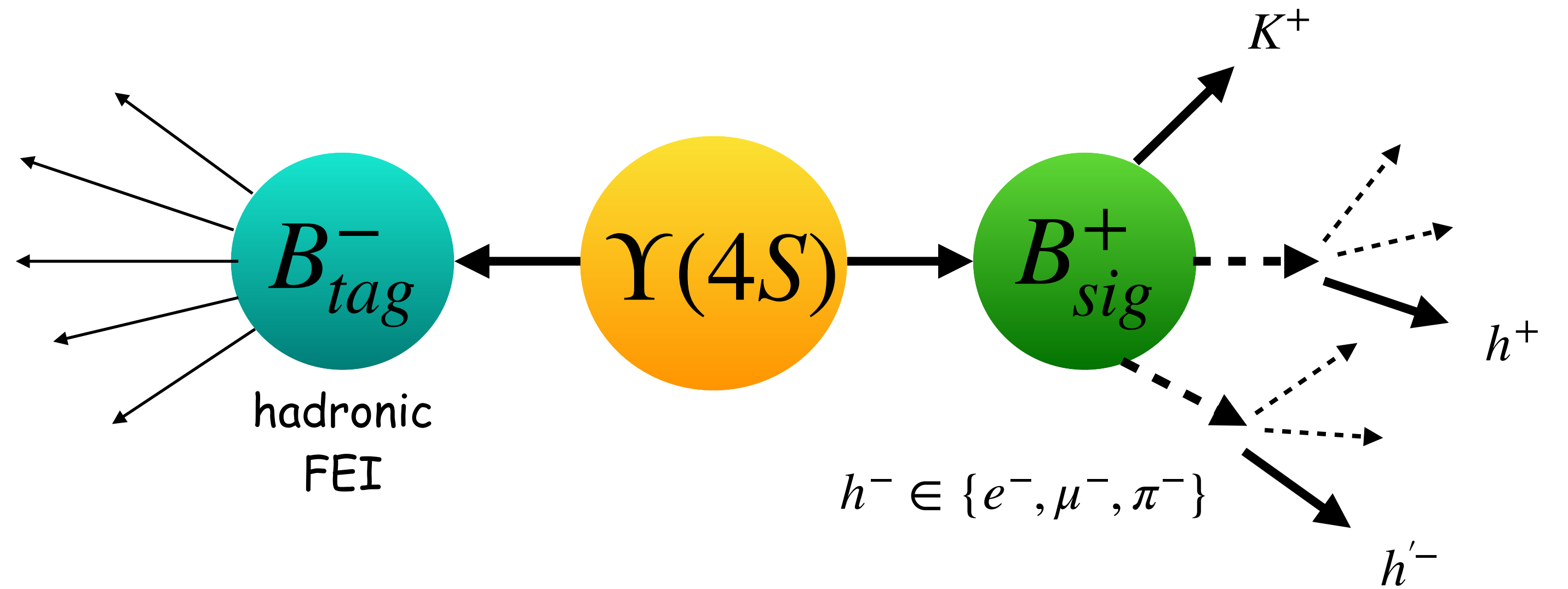
generator model: BTOSLLBALL

release-06-00-10

globalTag: mc_production_MC15ri_a

bkg: early phase III (release-06-00-05), BGx1

Reconstruction

B_{sig}^+ is composed of $K^+, h^+,$ and $h^{'-}$:

1. $K^+ e^+ e^-$
2. $K^+ e^+ \mu^-$
3. $K^+ e^- \mu^+$
4. $K^+ e^+ \pi^-$
5. $K^+ e^- \pi^+$
6. $K^+ \mu^+ \mu^-$
7. $K^+ \mu^+ \pi^-$
8. $K^+ \mu^- \pi^+$
9. $K^+ \pi^+ \pi^-$

B_{tag}^-

hadronic
FEI

$\Upsilon(4S)$

B_{sig}^+

K^+

h^+

$h^{'-}$

$h^- \in \{e^-, \mu^-, \pi^-\}$

Selection

Charged tracks (e, μ, K, π) cuts:

- transverse distance from IP, $dr < 0.5$
- distance in beam direction from IP, $|dz| < 2$
- polar angle is with in CDC acceptance (thetaInCDCAcceptance)

PID cuts:

- e: $\mathscr{L}(\text{electronID}) > 0.9$
- μ: $\mathscr{L}(\text{muonID}) > 0.9$
- K: $\mathscr{L}(\text{kaonID}) > 0.6$
- π: $\mathscr{L}(\text{pionID}) > 0.6$

photon: use all photons (gamma:all)

Selection

Reconstruct FEI hadronic B_{tag}:

- weight file prefix - 'FEIv4_2021_MC14_release_05_01_12'
- two most probable B_{tag} candidates are accepted
- $M_{bc} > 5.27$
- $|\Delta E| < 0.1$
- FEI signal probability > 0.001
- ROE of B_{tag} has 3 charged tracks

Continuum suppression:

- event sphericity > 0.2
- cosTBTO < 0.9

ROE mask:

- $dr < 0.5, |dz| < 2$, thetaInCDCAcceptance
- $E > 0.06$ and $|$cluster time$| < 20$

Analysis globalTag: 'analysis_tools_light-2203-zeus'

Reconstruction

- Reconstruct B_{sig}^+ with $K^+ h^+ h^{'-}$ combinations

- Reconstruct $\Upsilon(4S) \to B_{sig}^+ B_{tag}^-$

- Build ROE with mask and reconstruct ROE π^0

ROE mask:

- $dr < 0.5, |dz| < 2,$ thetaInCDCAcceptance
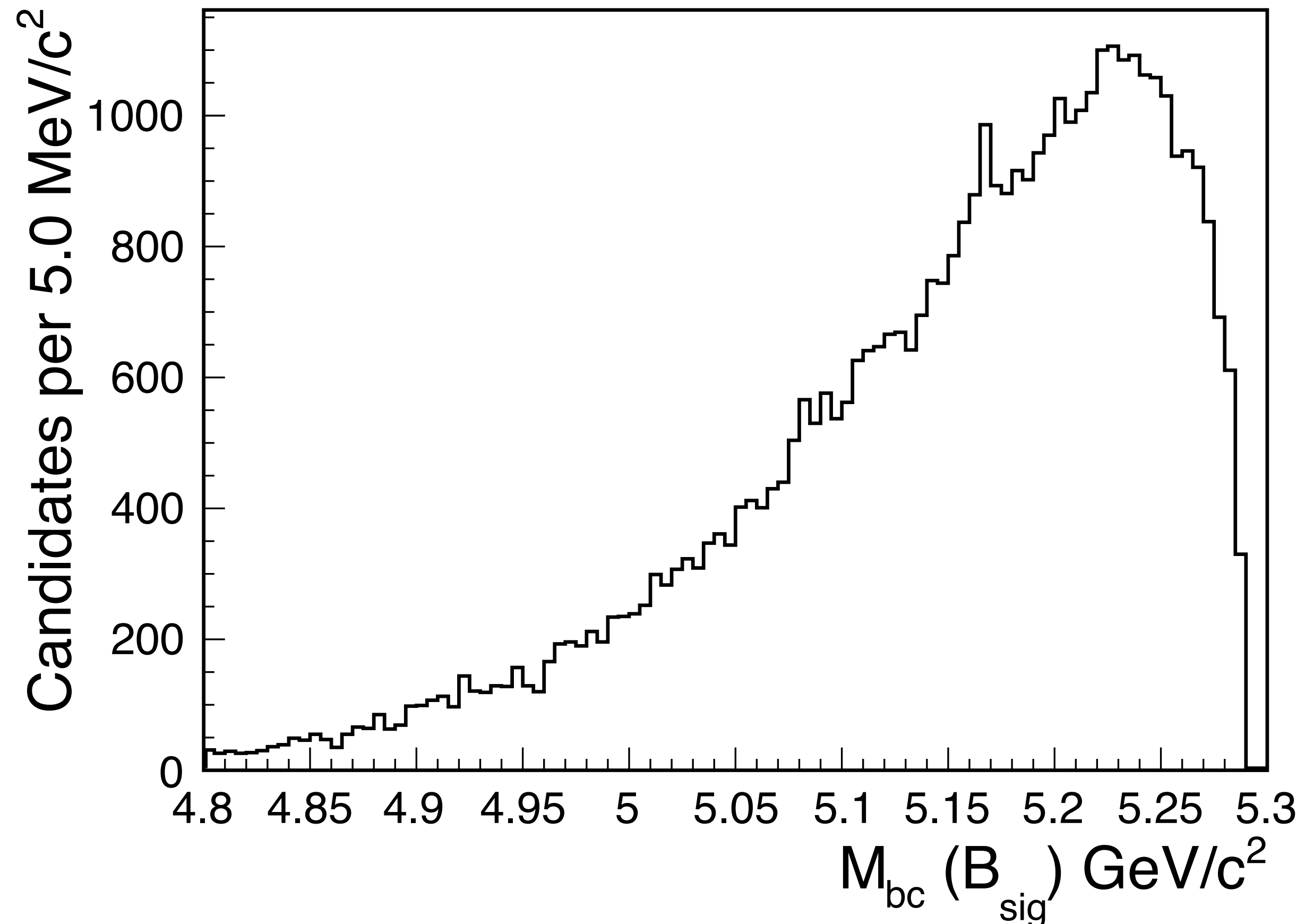
- $E > 0.06$ and $|$cluster time$| < 20$

ROE π^0:

- daughter photons are in ROE and passes ROE mask
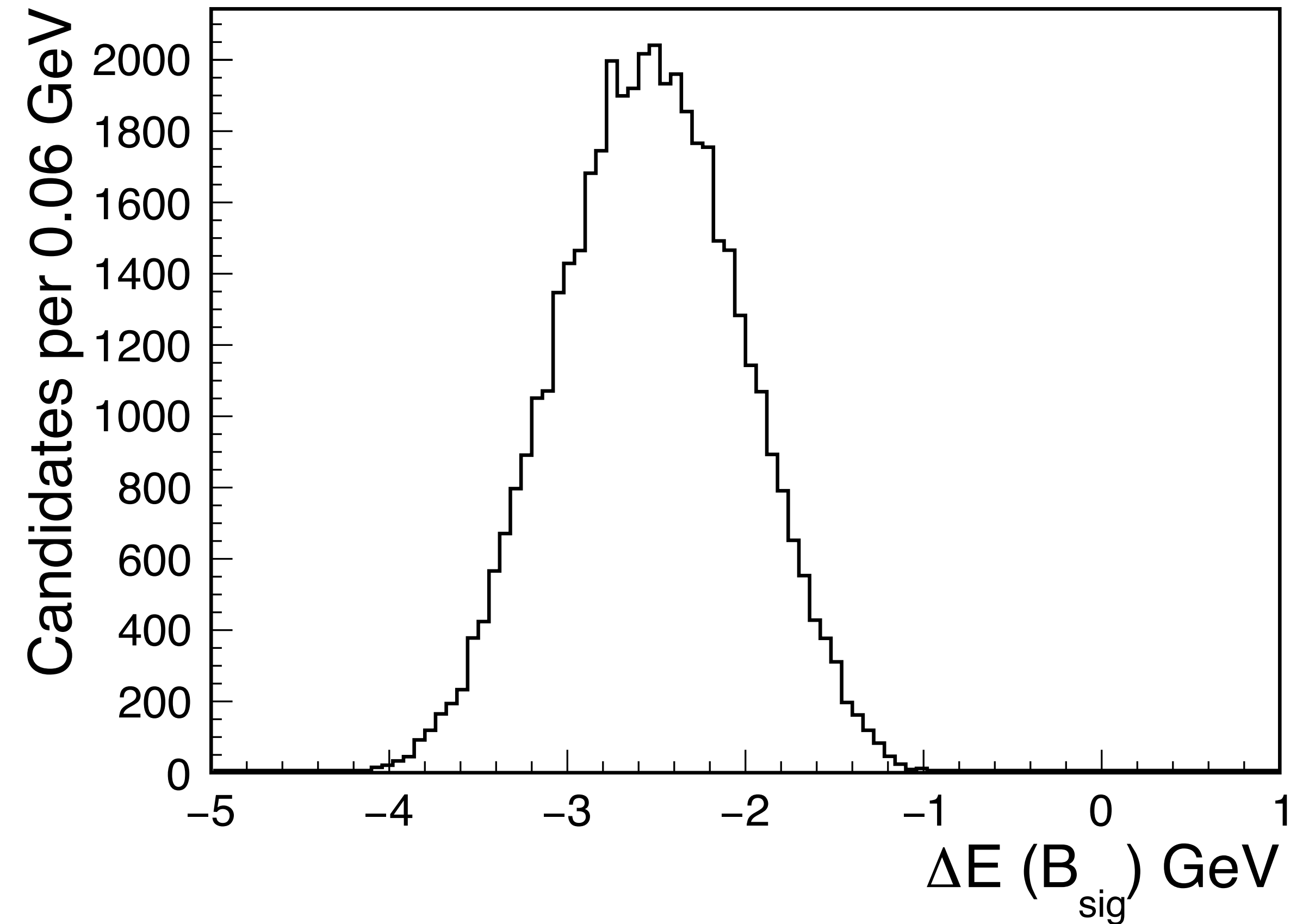- select π^0 with least difference between M and InvM
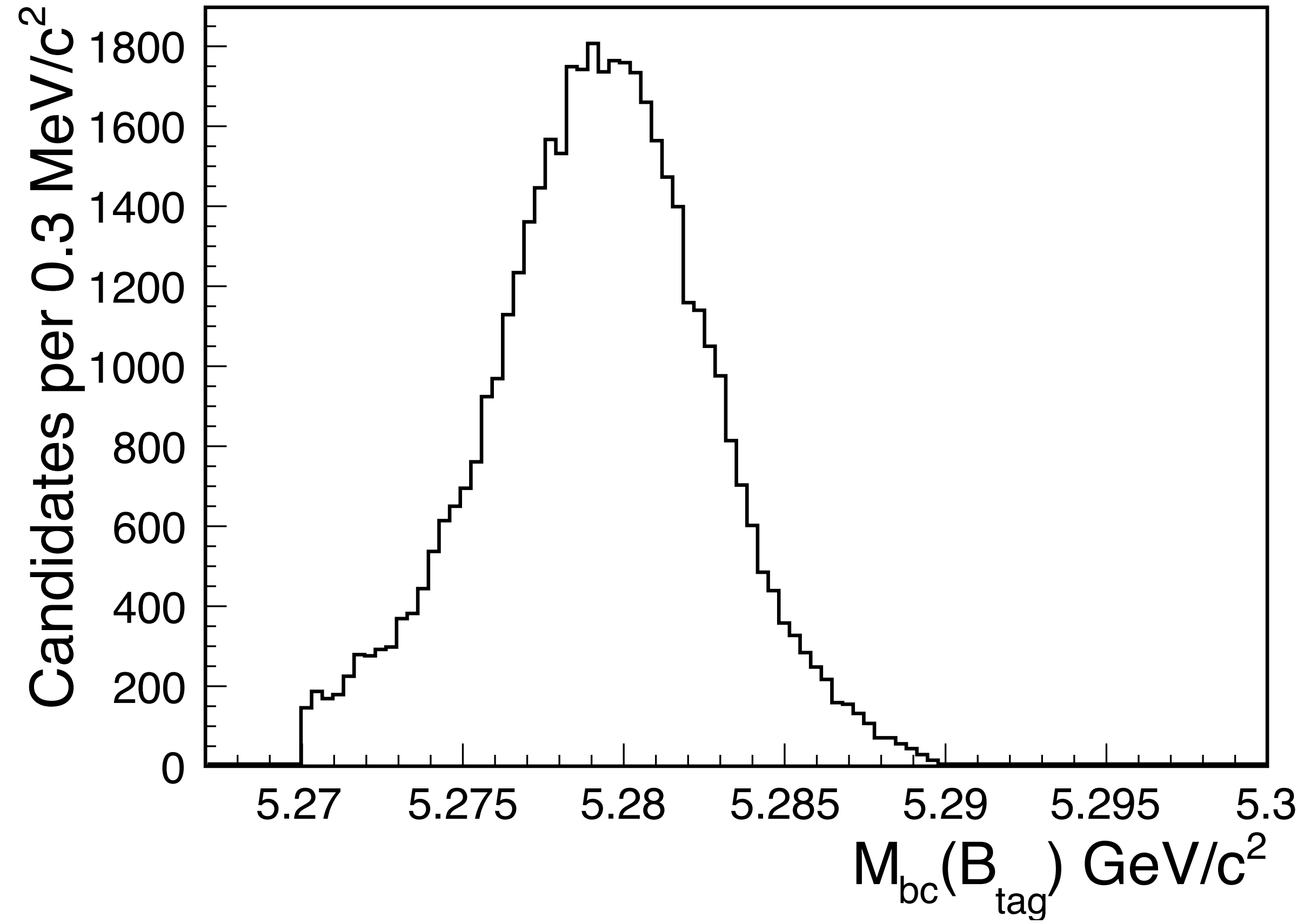
..let's look at few distributions

Signal side

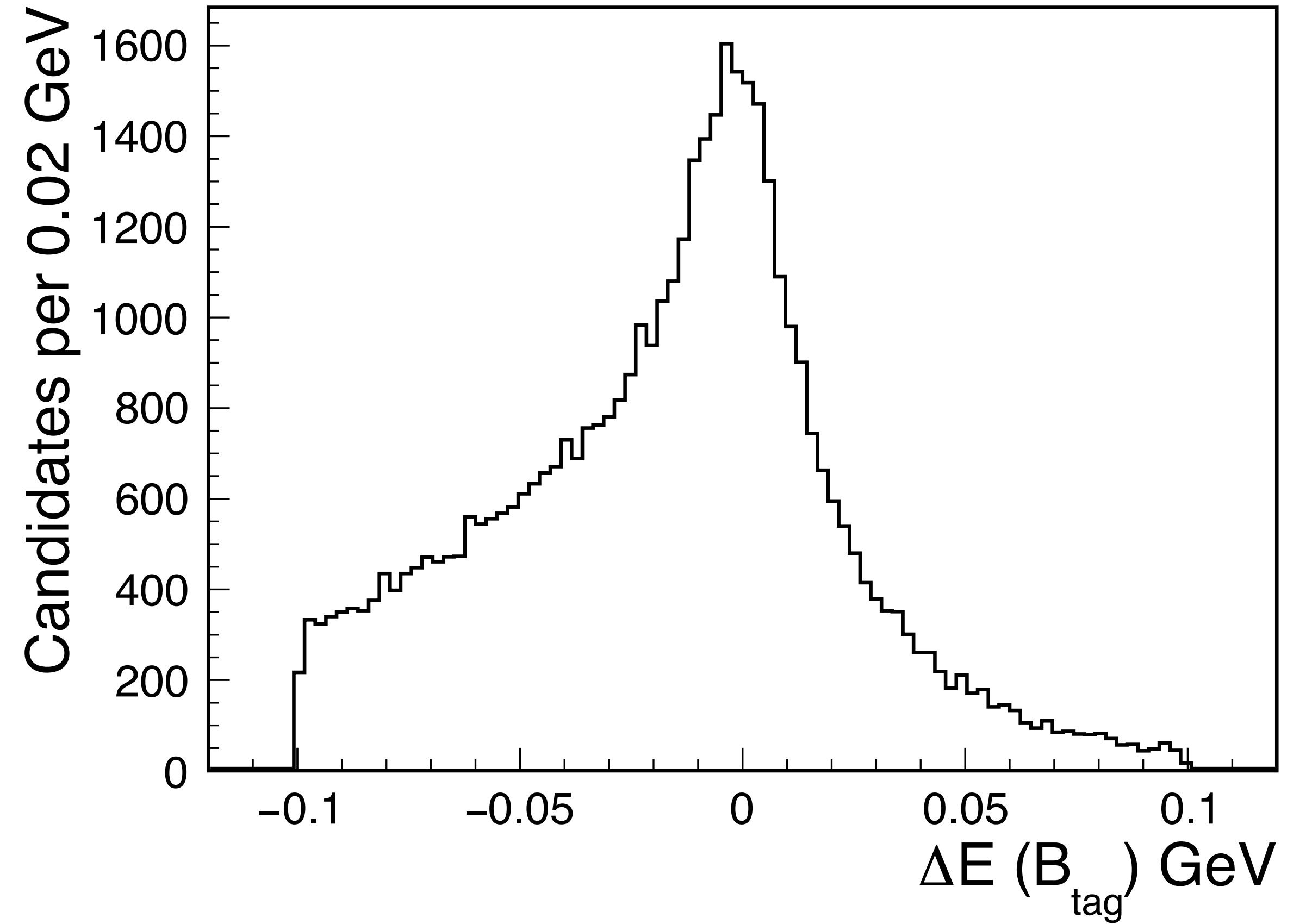"signal" is selected by "isSignalAcceptMissingNeutrino"
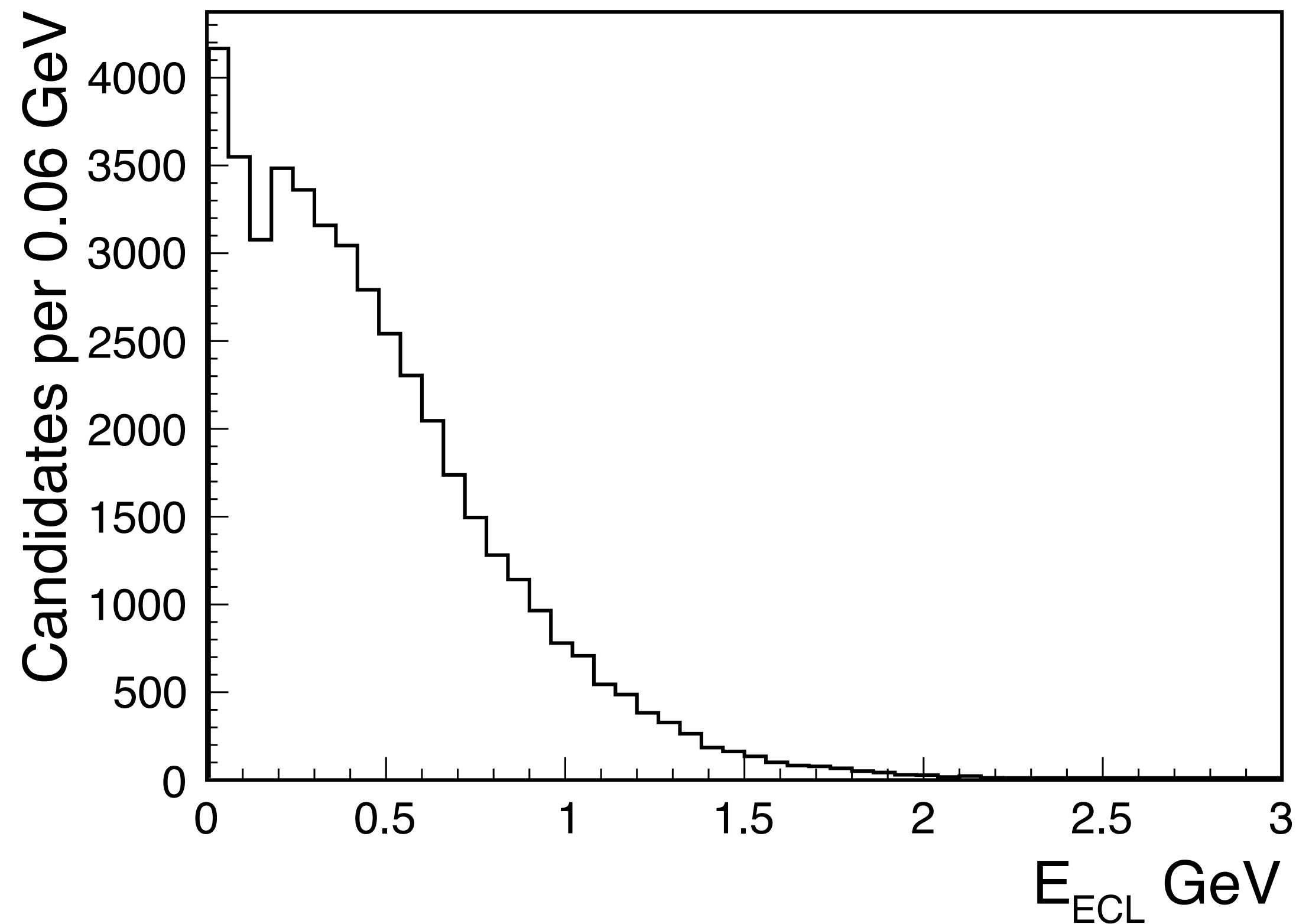
Tag side
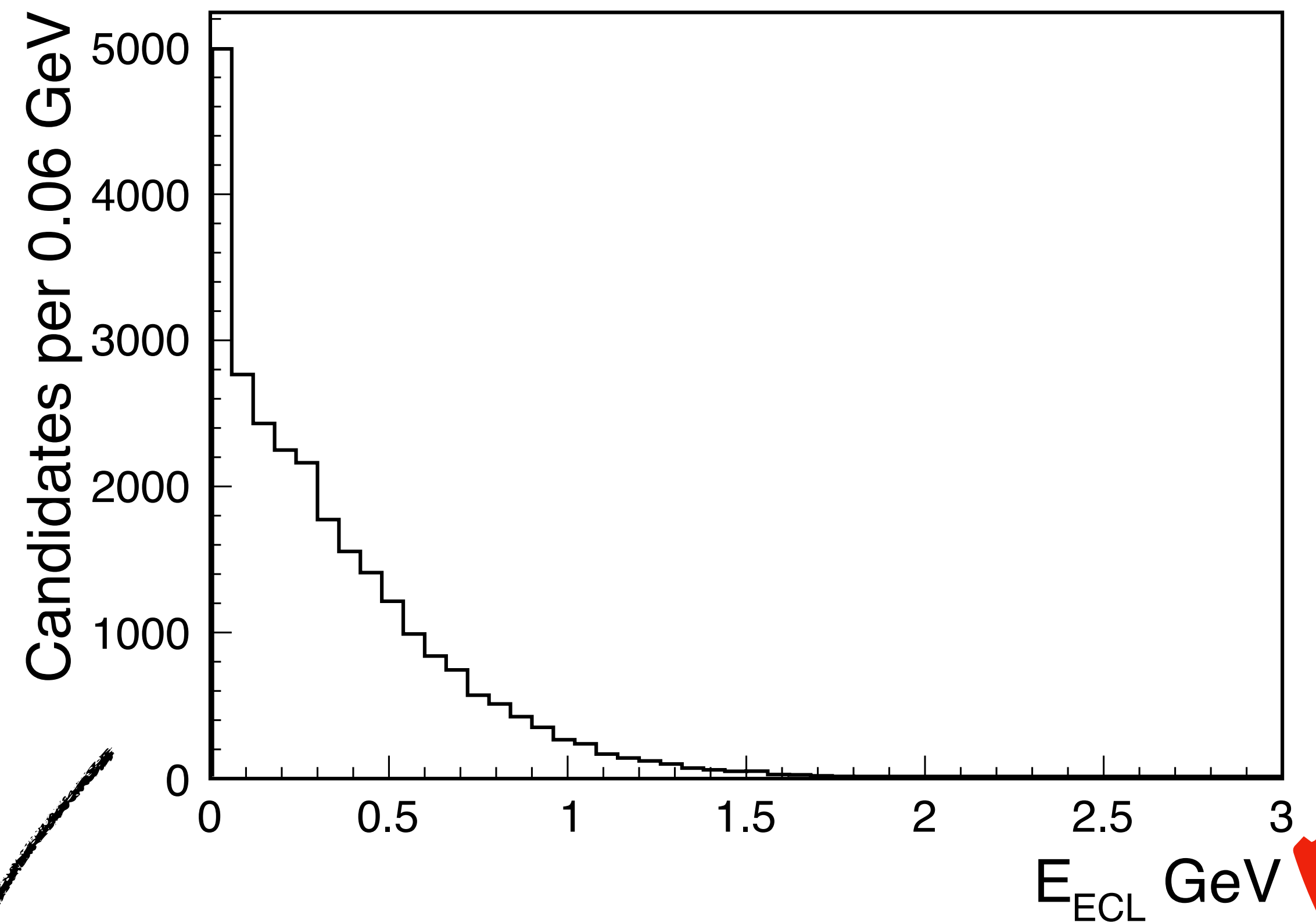
M_{bc}

ΔE

Extra ECL energy (E_{ECL})

Energy left in ECL cluster after removing B_{tag} and B_{sig} related deposition
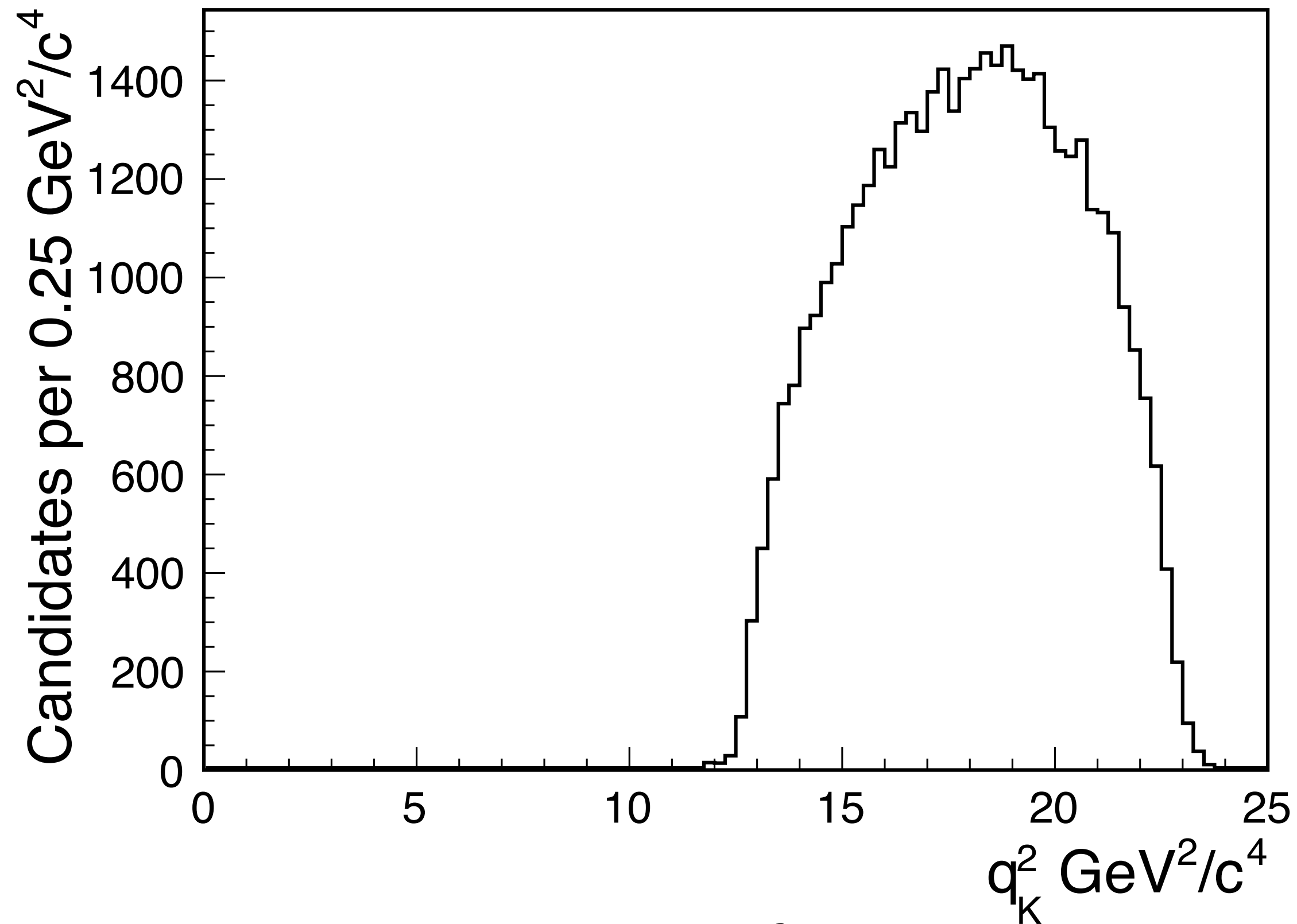

Ideally it should peak at zero

subtract energy of ROE π^0 from E_{ECL}

bug in ROE π^0 reconstruction: multiple π^0 got selected instead of one
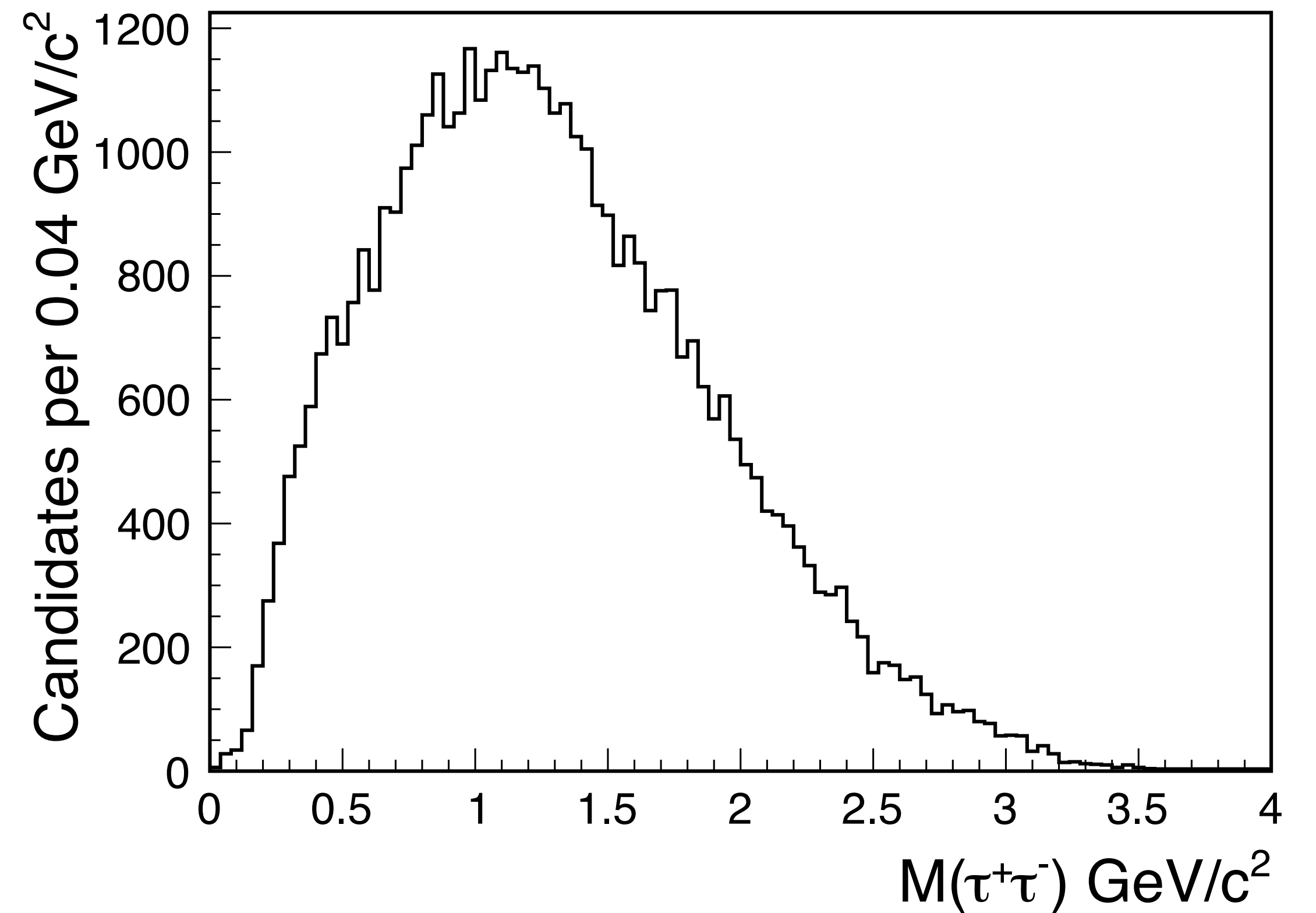
q_K^2 and $M(\tau^+\tau^-)$

Constraint invariant mass of τ pair:

$$q_K^2 \equiv (p_{\Upsilon(4S)} - p_{B_{tag}} - p_K)^2$$

where $p_{\Upsilon(4S)}$ is the four momentum of beam

reconstructed invariant mass of τ pair

$$M(\tau\tau) \equiv \sqrt{(p_h + p_{h'})^2}$$

Generic MC

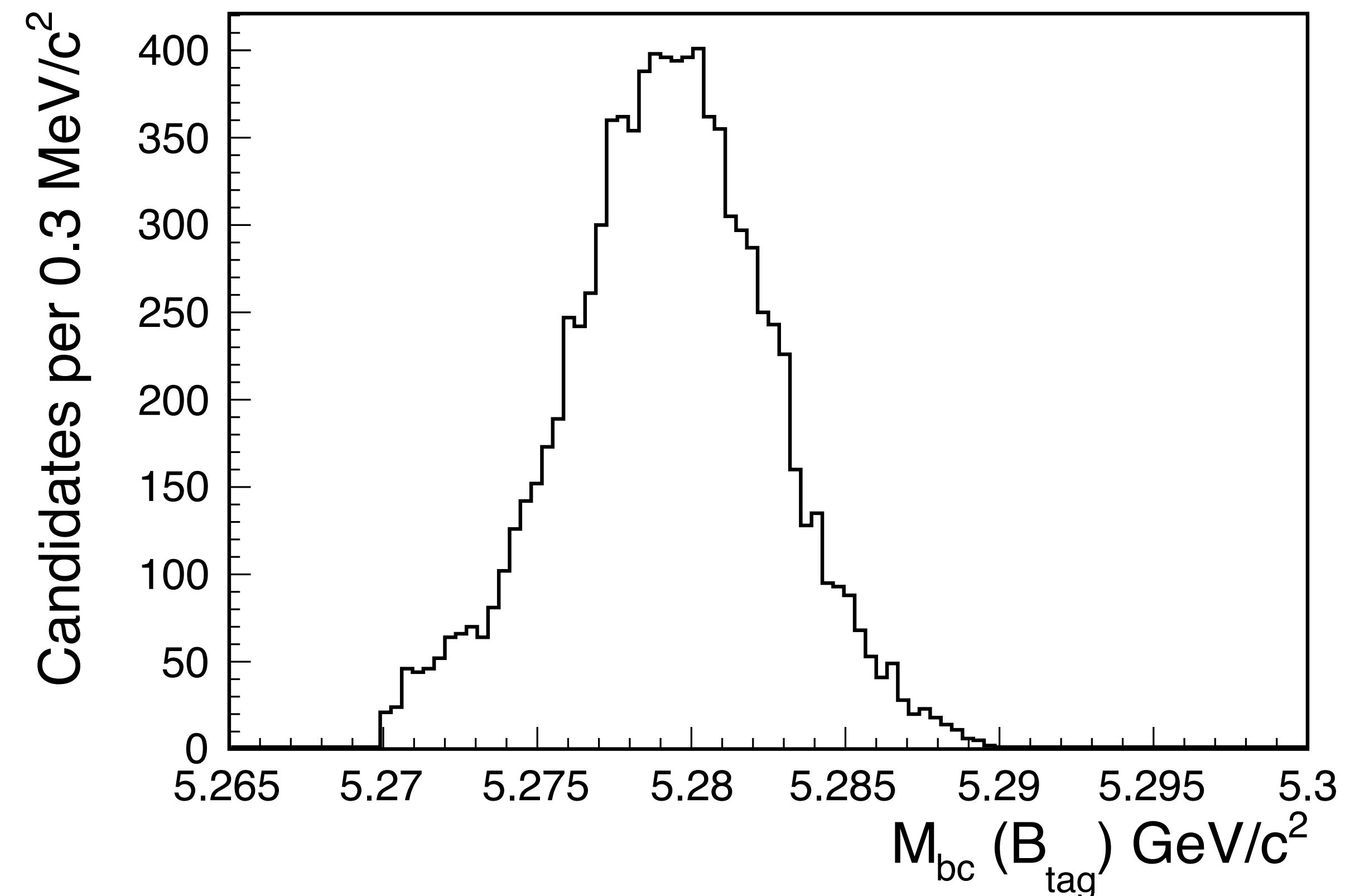MC14ri_a ($\sim 300\,fb^{-1}$)

[12 files failed to run before shutdown]
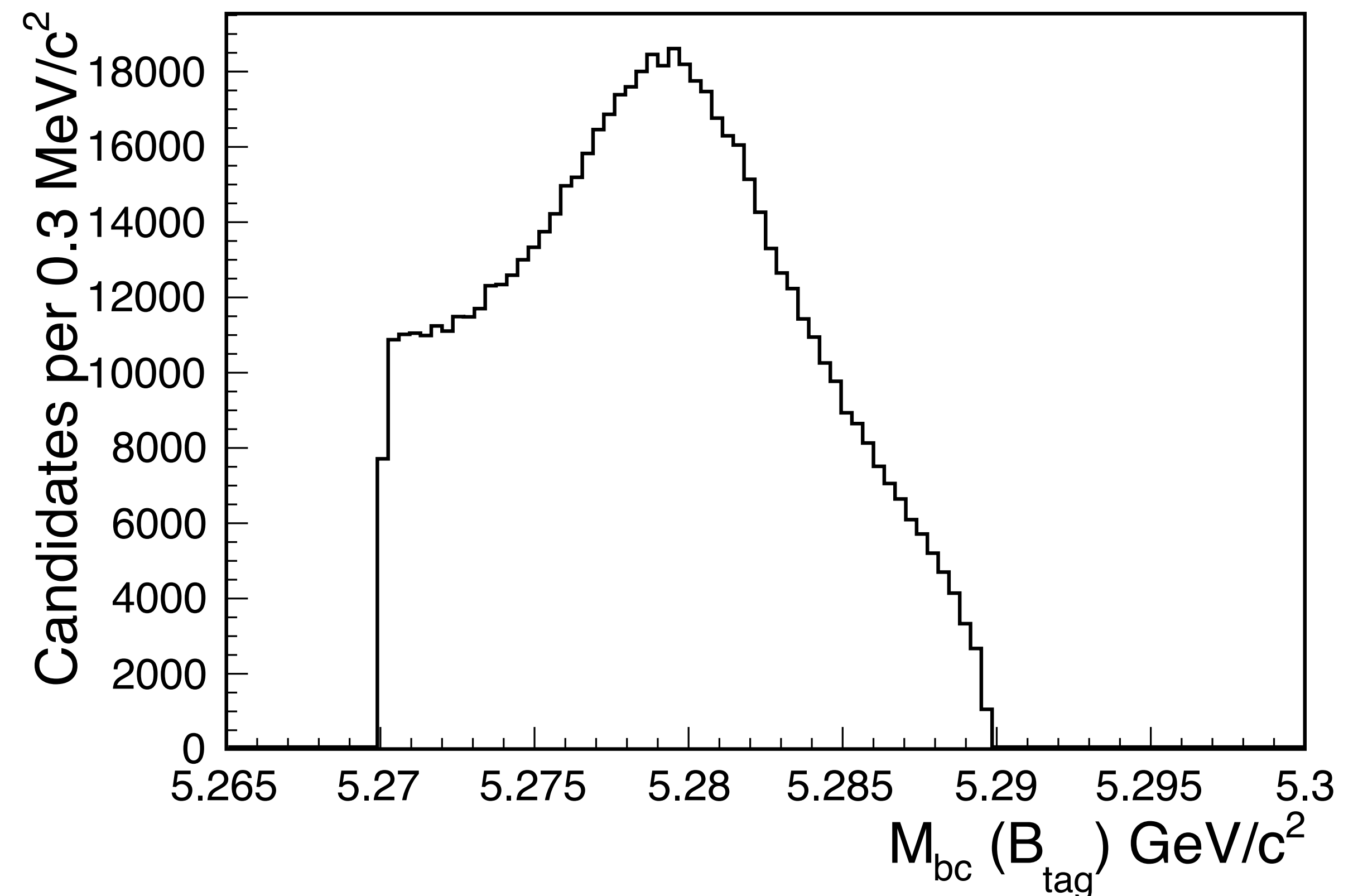#signal= 9323; #background= 680116

Tag side M_{bc}

cut: $(M_{bc})_{tag} > 5.27$
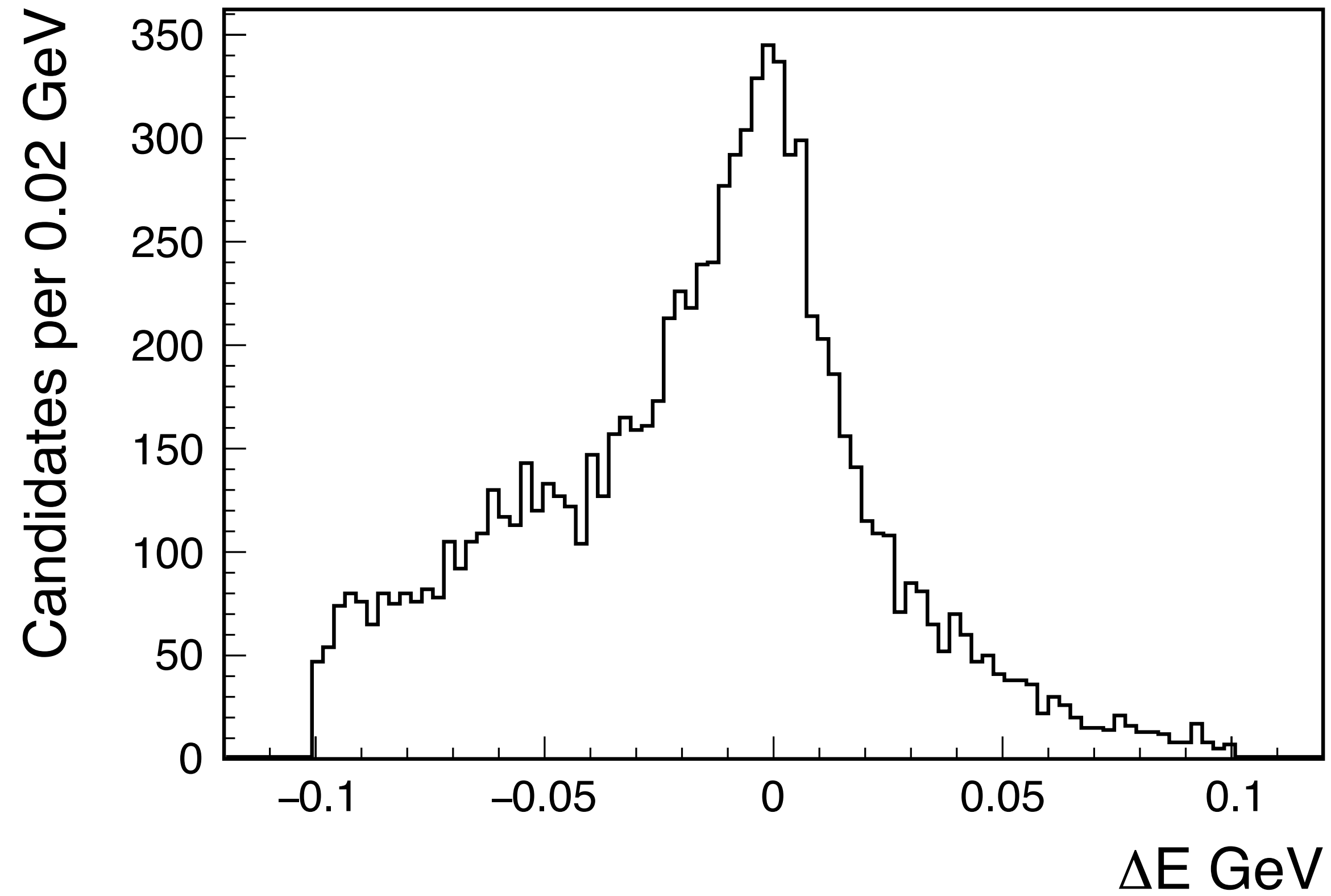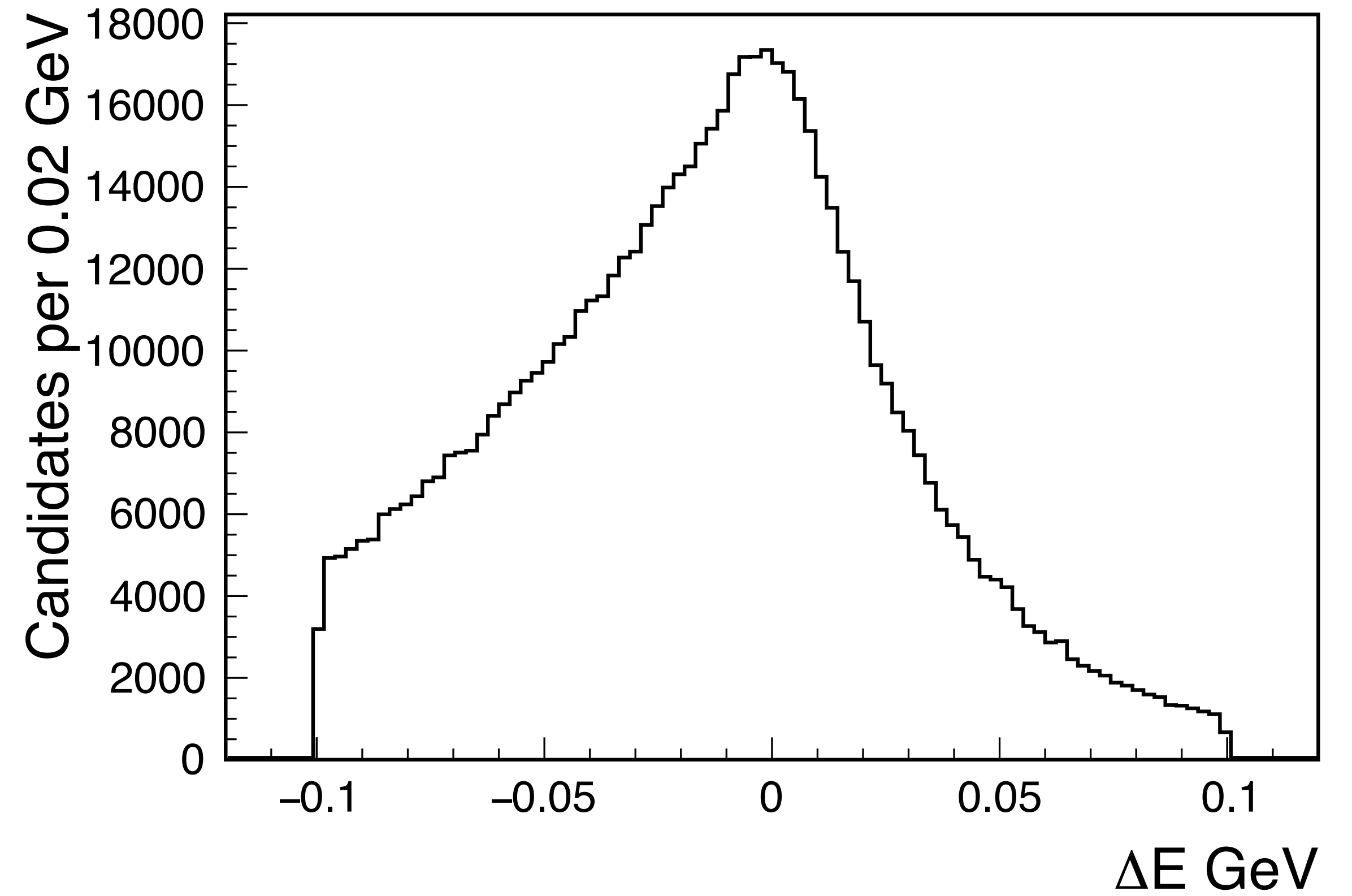
signal

background
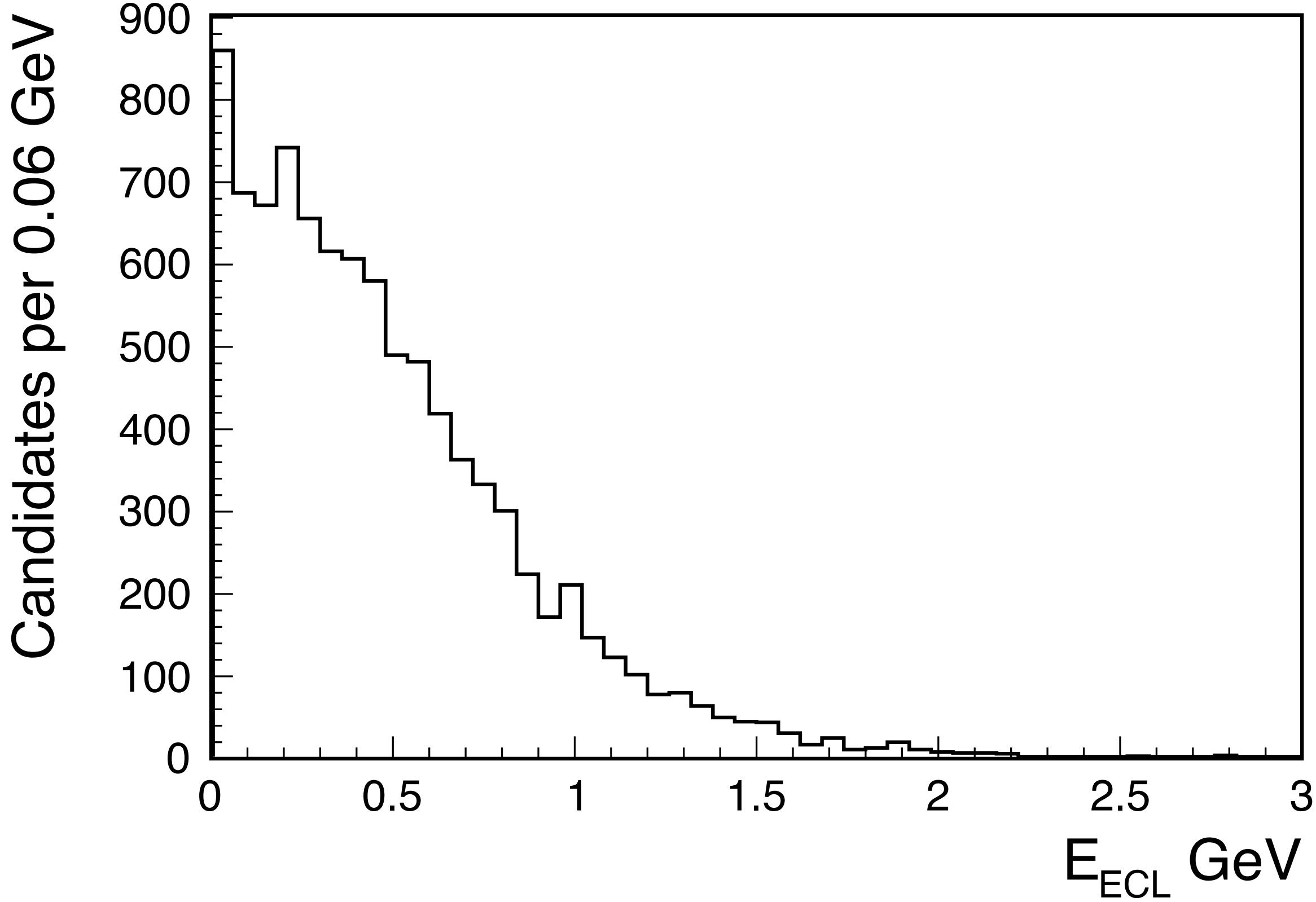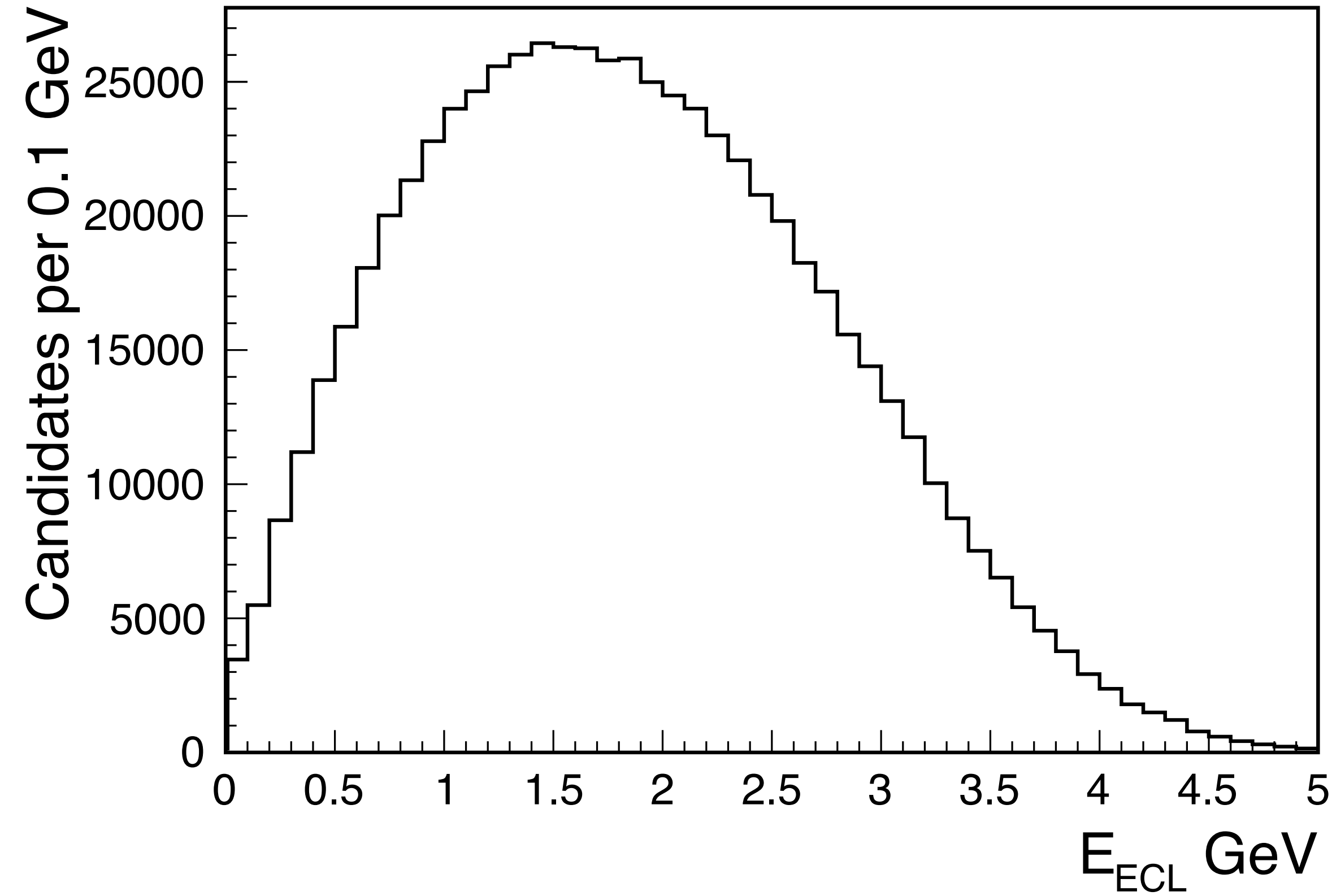
Tag side ΔE

signal

background

Extra ECL energy (E_{ECL})

Must apply π^0 veto. Due to the bug it is not applied.

signal

background

Simon put a cut $E_{ECL} < 1.5$ to separate signal from background

q_K^2

signal

background

large difference w.r.t signalMC
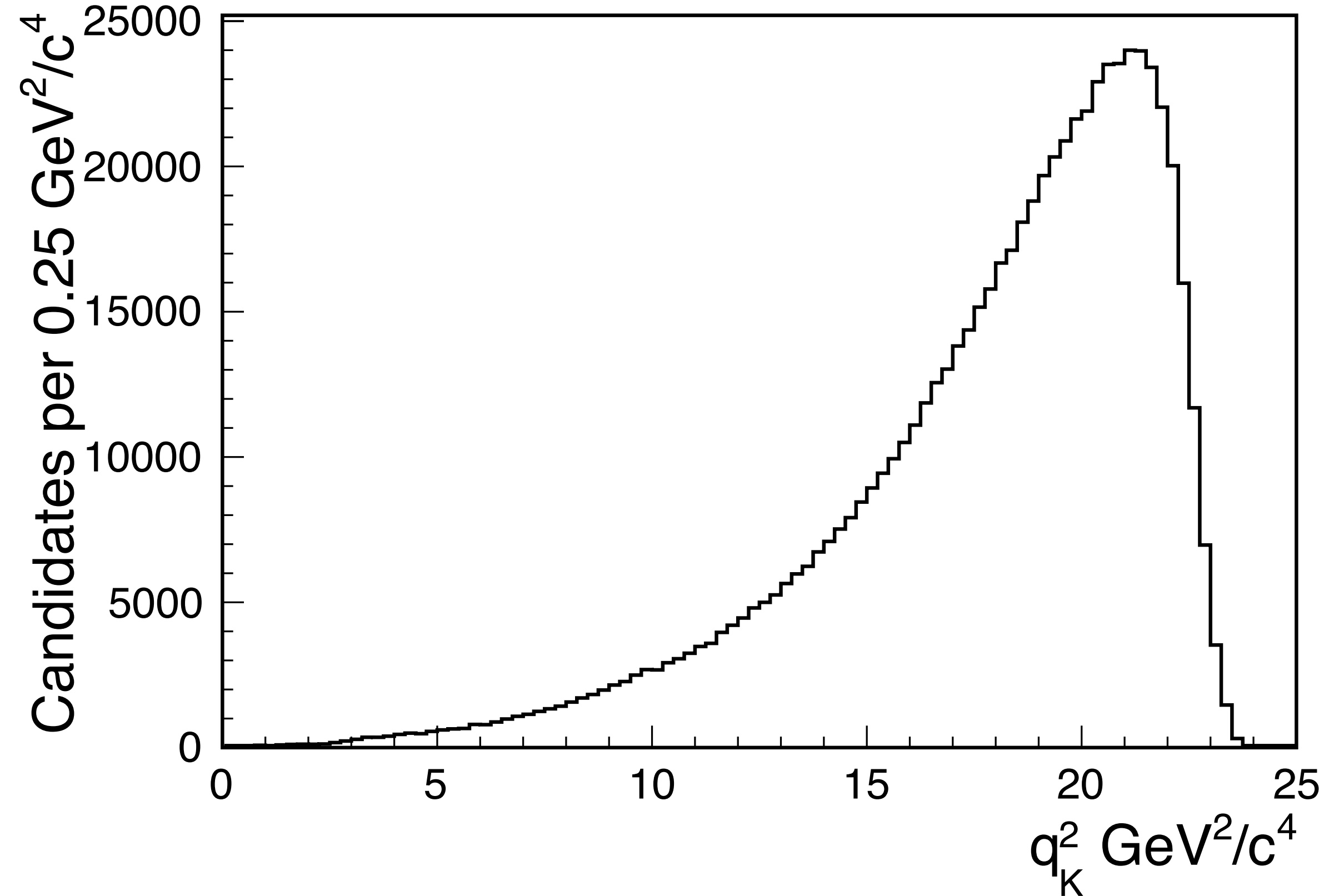
Simon put a cut $q_K^2 > 12$ to separate signal from background

M($\tau^+\tau^-$)

signal

background

Comments from last meetings..
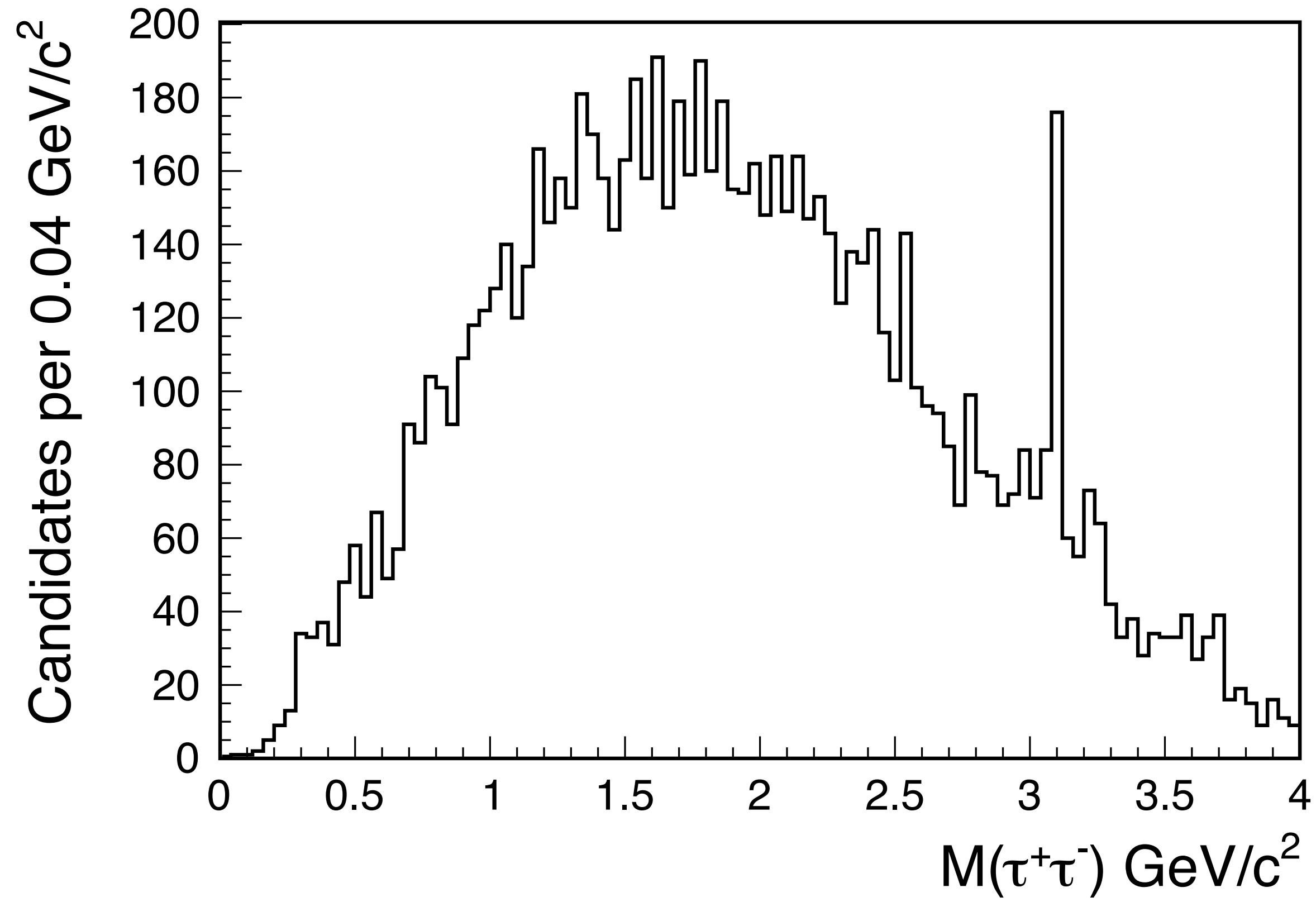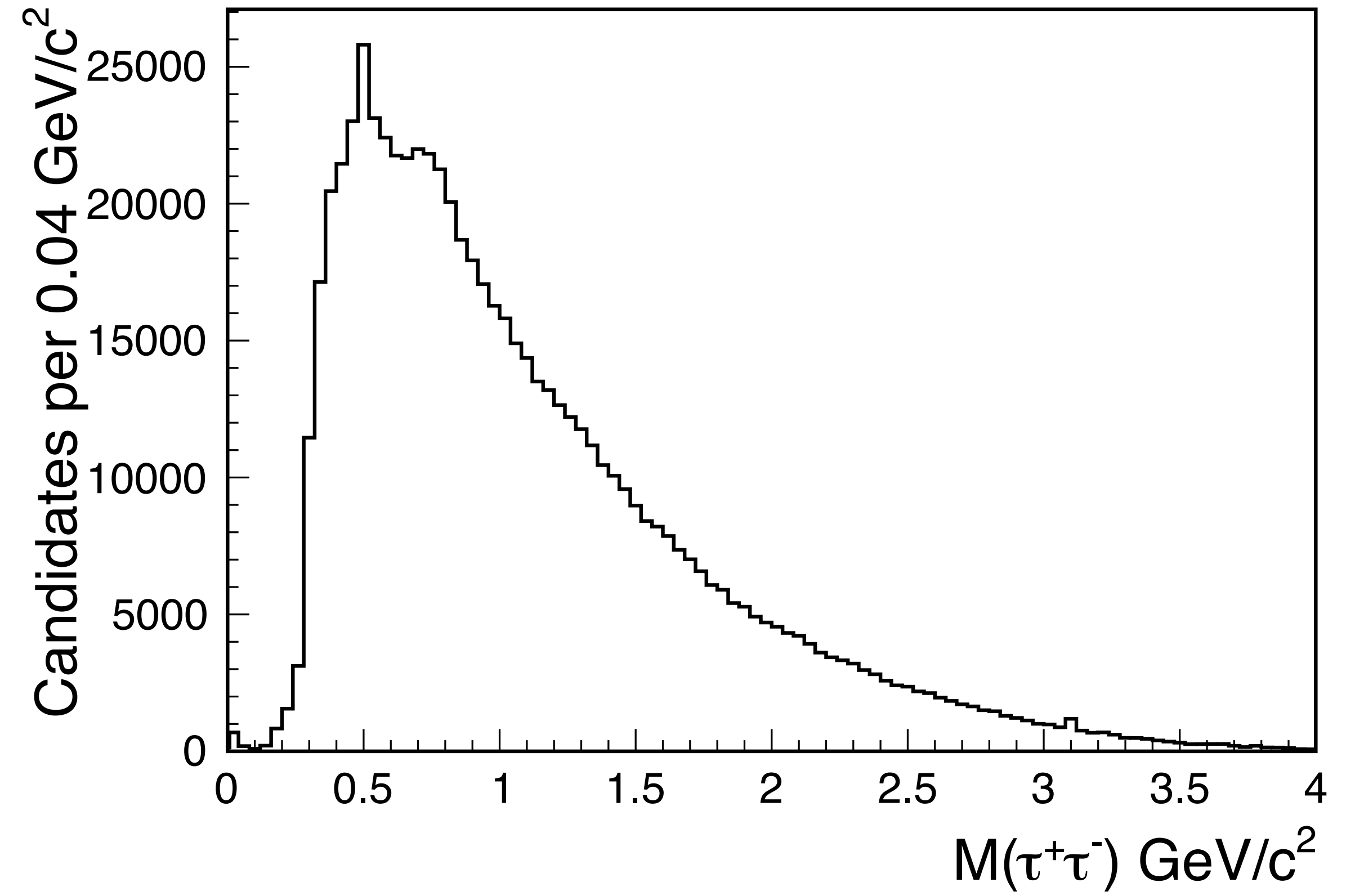
- "isSignalAcceptMissingNeutrino" is not perfect to select signal as it also accept

  other intermediate resonances like $B \to J/\psi(\to ee, \mu\mu)K$.

  Built my own flag to select signal where, in addition to

  "isSignalAcceptMissingNeutrino", it also matches PDG code of mother, grand M, ...
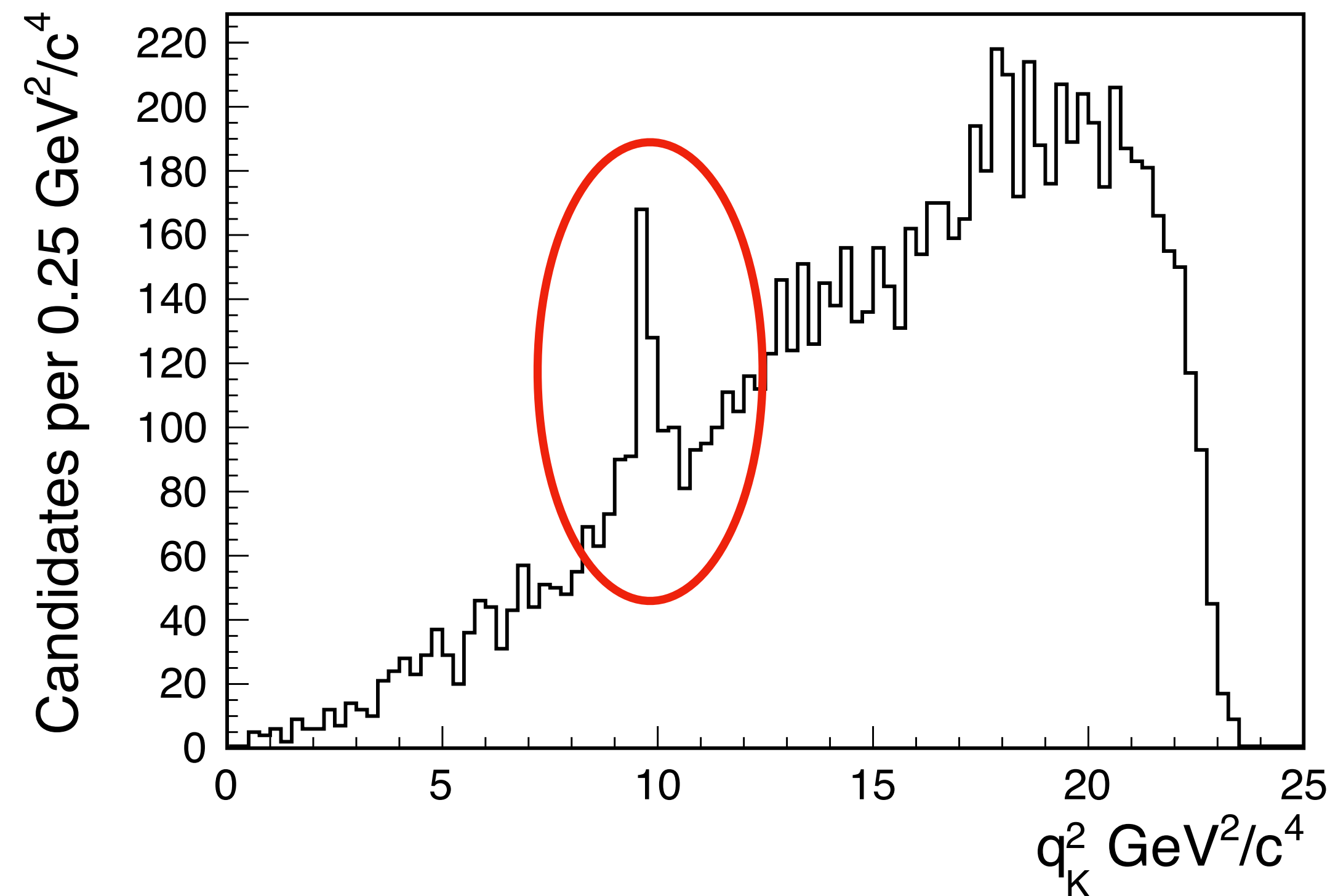
Comments from last meetings..

- Remove all PID cuts: left for offline selection.

Charged tracks (e, μ, K, π) cuts:

- transverse distance from IP, $dr < 0.5$
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- polar angle is with in CDC acceptance (thetaInCDCAcceptance)

PID cuts:
- e: $\mathscr{L}(\text{electronID}) > 0.9$
- μ: $\mathscr{L}(\text{muonID}) > 0.9$
- K: $\mathscr{L}(\text{kaonID}) > 0.6$
- π: $\mathscr{L}(\text{pionID}) > 0.6$

photon: use all photons (gamma:all)

- Best candidate selection: One B_{tag} is selected with highest FEI signal probability.
- π^0 reconstruction in ROE is fixed: best π^0 candidate is selected which has least difference between its invariant mass and PDG mass.

Signal efficiency

$$\text{Signal eff.}(\epsilon) = \frac{\#\,\text{signal events}}{\#\,\text{generated events}}$$

$$\#\,\text{generated events} = 50 \times 10^6$$

$$N = \epsilon \times \sigma(e^+e^- \to \Upsilon(4S) \to B^+B^-) \times \mathcal{L}_{\Upsilon(4S)} \times \mathcal{B}(B^+ \to K^+\tau^+\tau^-) \times \mathcal{B}(\tau \to e\nu_e\nu_\tau, \mu\nu_\mu\nu_\tau, \pi\nu_\tau)$$

$$\mathcal{B}(B^+ \to K^+\tau^+\tau^-) = 2.25 \times 10^{-3} \quad \text{(BaBar)}$$

$$\sigma(e^+e^- \to \Upsilon(4S) \to B^+B^-) = 0.57\,\text{nb}$$

$$\mathcal{L}_{\Upsilon(4S)} = 400\,\text{fb}^{-1}$$

$$\mathcal{B}(\tau \to e\nu_e\nu_\tau) = 0.18$$
$$\mathcal{B}(\tau \to \mu\nu_\mu\nu_\tau) = 0.17$$
$$\mathcal{B}(\tau \to \pi\nu_\tau) = 0.11$$

$$\mathcal{B}(\tau \to e\nu_e\nu_\tau, \mu\nu_\mu\nu_\tau, \pi\nu_\tau) = 0.46$$

Signal efficiency

$$\text{Signal eff.}(\epsilon) = \frac{\#\text{ signal events}}{\#\text{ generated events}}$$

$$= 1.38 \times 10^{-3}$$

$\#\text{ signal events} = 68935$

$\#\text{ generated events} = 50 \times 10^{6}$

$$N = \epsilon \times \sigma(e^{+}e^{-} \to \Upsilon(4S) \to B^{+}B^{-}) \times \mathscr{L}_{\Upsilon(4S)} \times \mathscr{B}(B^{+} \to K^{+}\tau^{+}\tau^{-}) \times \mathscr{B}(\tau \to e\nu_{e}\nu_{\tau}, \mu\nu_{\mu}\nu_{\tau}, \pi\nu_{\tau})$$

$\mathscr{B}(B^{+} \to K^{+}\tau^{+}\tau^{-}) = 2.25 \times 10^{-3}$ (BaBar)

$\sigma(e^{+}e^{-} \to \Upsilon(4S) \to B^{+}B^{-}) = 0.57\,\text{nb}$

$\mathscr{L}_{\Upsilon(4S)} = 400\,\text{fb}^{-1}$

$$\mathscr{B}(\tau \to e\nu_{e}\nu_{\tau}) = 0.18$$
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$$\mathscr{B}(\tau \to \pi\nu_{\tau}) = 0.11$$

$$\mathscr{B}(\tau \to e\nu_{e}\nu_{\tau}, \mu\nu_{\mu}\nu_{\tau}, \pi\nu_{\tau}) = 0.46$$

$N = 322$

with Simon's additional pre-cuts

- K PID cut: $\mathscr{R}_K \equiv \dfrac{\mathscr{L}_K}{\mathscr{L}_K + \mathscr{L}_\pi} > 0.6$

- Beam constraint invariant mass of τ pair ($q_K^2 > 12$)

- Extra ECL cluster energy, $E_{ECL} < 1.5$

- K has opposite charge to B_{tag}

- Other two charge tracks have opposite charge

- No π^0 in the ROE of B_{tag} (this cut is not applied)

$$\mathscr{L}_{\Upsilon(4S)} = 400\,\text{fb}^{-1}$$

Signal eff.$(\epsilon) = 1.25 \times 10^{-3}$

$$N = 292$$

this number will reduce with future cuts and background suppression

comparing with Simon's data

Signal eff.$(\epsilon) = 2.71 \times 10^{-4}$

$$N = \epsilon \times \sigma(e^+e^- \to \Upsilon(4S) \to B^+B^-) \times \mathscr{L}_{\Upsilon(4S)} \times \mathscr{B}(B^+ \to K^+\tau^+\tau^-) \times \mathscr{B}(\tau \to e\nu_e\nu_\tau, \mu\nu_\mu\nu_\tau, \pi\nu_\tau)$$

$\mathscr{B}(B^+ \to K^+\tau^+\tau^-) = 3.17 \times 10^{-4}$ (Simon)

$\sigma(e^+e^- \to \Upsilon(4S) \to B^+B^-) = 0.57\,\mathrm{nb}$

$\mathscr{B}(\tau \to e\nu_e\nu_\tau) = 0.18$

$\mathscr{L}_{\Upsilon(4S)} = 711\,\mathrm{fb}^{-1}$

$\mathscr{B}(\tau \to \mu\nu_\mu\nu_\tau) = 0.17$

$\mathscr{B}(\tau \to \pi\nu_\tau) = 0.11$

$\rule{9cm}{0.4pt}$

$\mathscr{B}(\tau \to e\nu_e\nu_\tau, \mu\nu_\mu\nu_\tau, \pi\nu_\tau) = 0.46$

$N = 2$