Search for a long-lived scalar S in $b \to s$ transitions at Belle II.

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Long-lived particles at Belle II — FSP workshop
11.12.2020

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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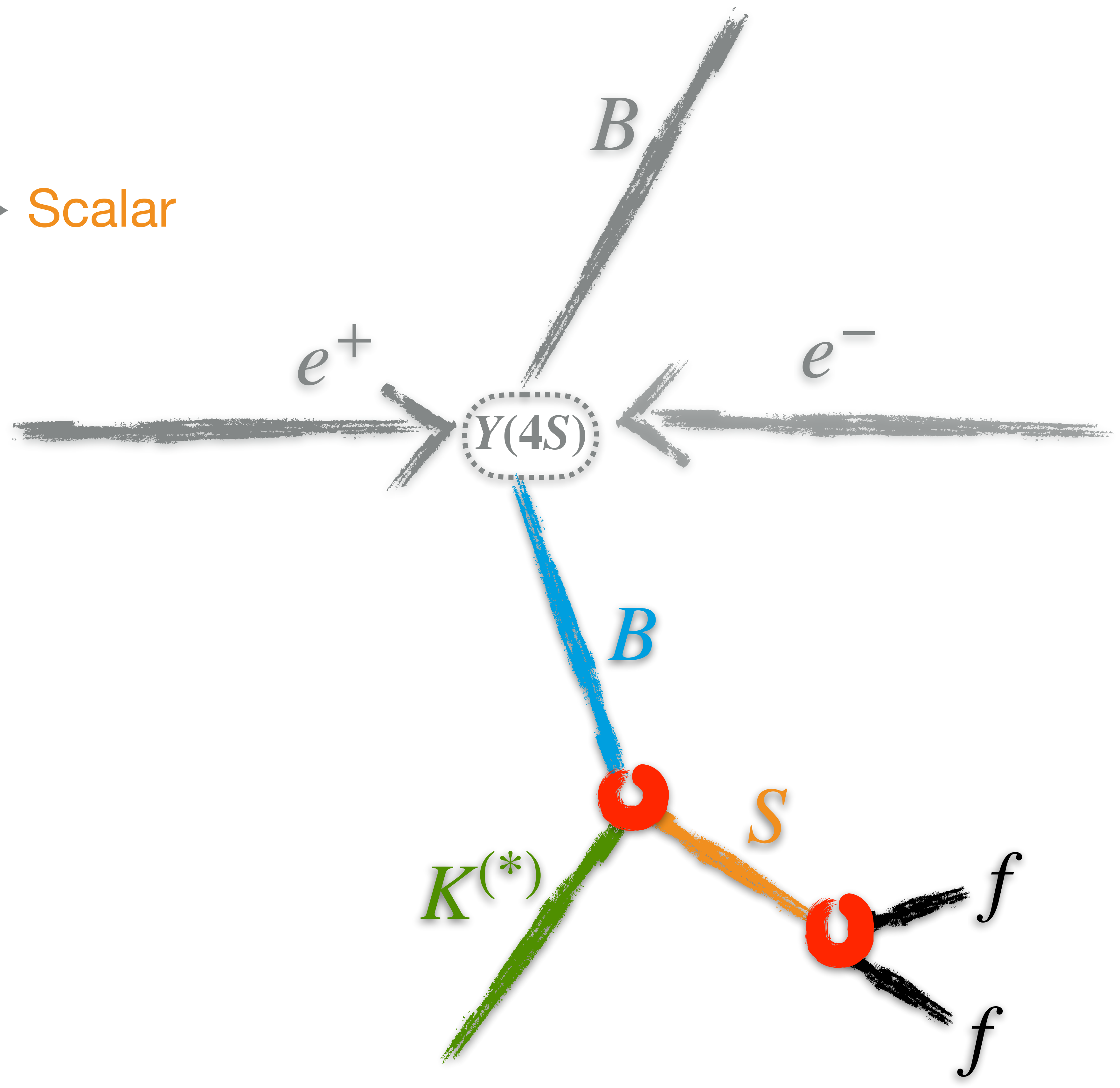
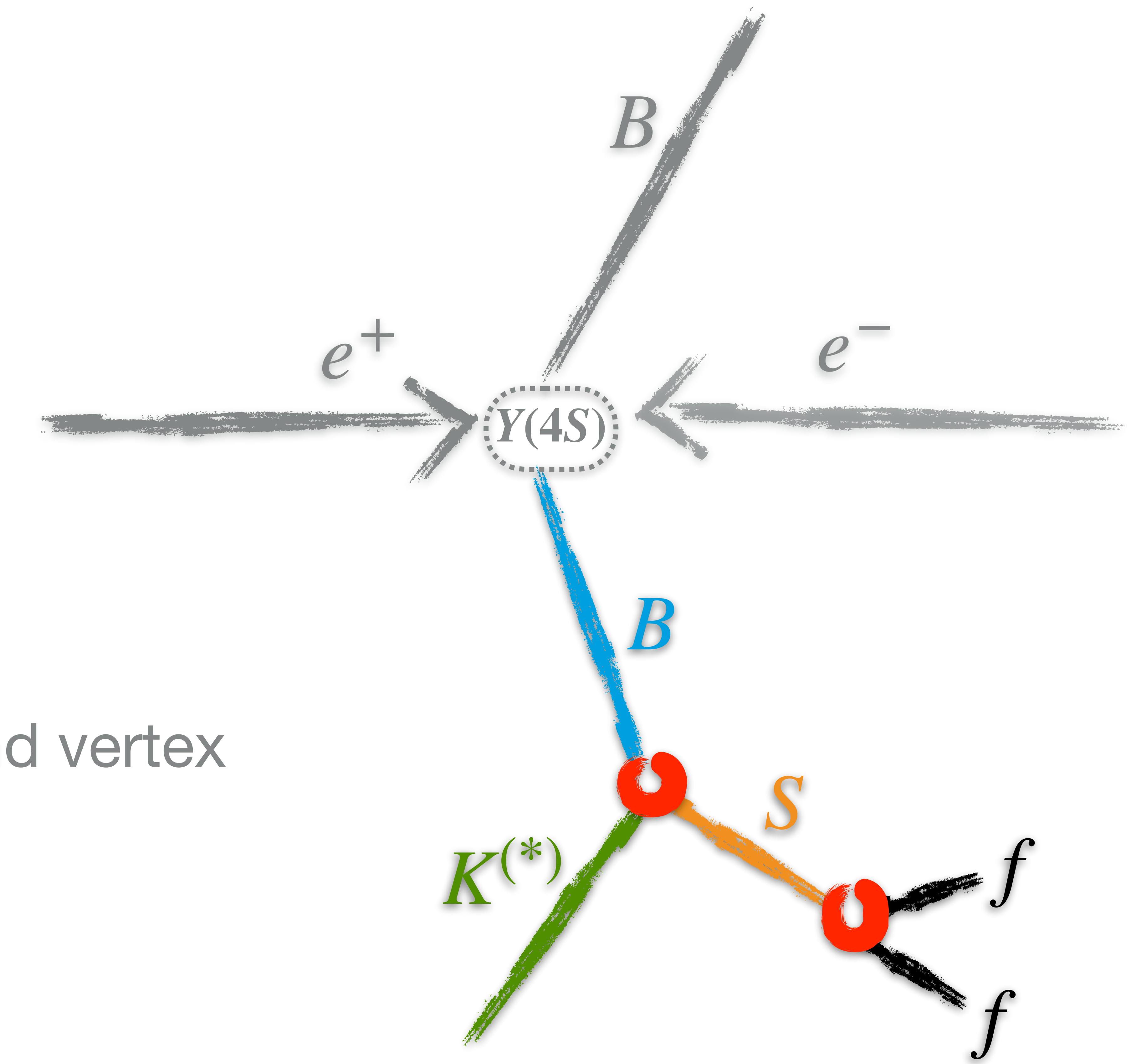
The search.

- $e^+e^- \to \Upsilon(4S) \to \boldsymbol{B}\ (\to \boldsymbol{K}^{(*)}\ [\ \boldsymbol{S}\to f\bar{f}\ ]\ )\ B$
- Reconstruct the signal B meson:
  - Two oppositely charged tracks forming a displaced vertex $\to$ Scalar
  - Additional track(s) from interaction region$\to$ Kaon
- Study the combined two track final states:
  - Set limits in scalar mass + lifetime ($\to$ mixing angle) plane
  - Exclusive final states:
    - $S \to \mu\mu, \pi\pi, KK$
- Consider production with:
  - K^+ (focus here), $K^0_S \to \pi^+\pi^-$,
  - $K^{*0}_{(892)} \to K^+\pi^-$, $K^{*+}_{(1270)} \to K^+\pi^+\pi^-$



The search.

- Backgrounds
  - standard model long lived particles
  - random track combinations from prompt decays
  - cosmics
- Reconstruction challenges
  - tracking algorithms not optimised for LLPs
  - need to understand reconstruction efficiencies, mass and vertex resolutions & particle identification
- Systematics
  - tracking + data/mc agreements for displaced tracks
  - particle identification, luminosity, MC statistics, (fit model)

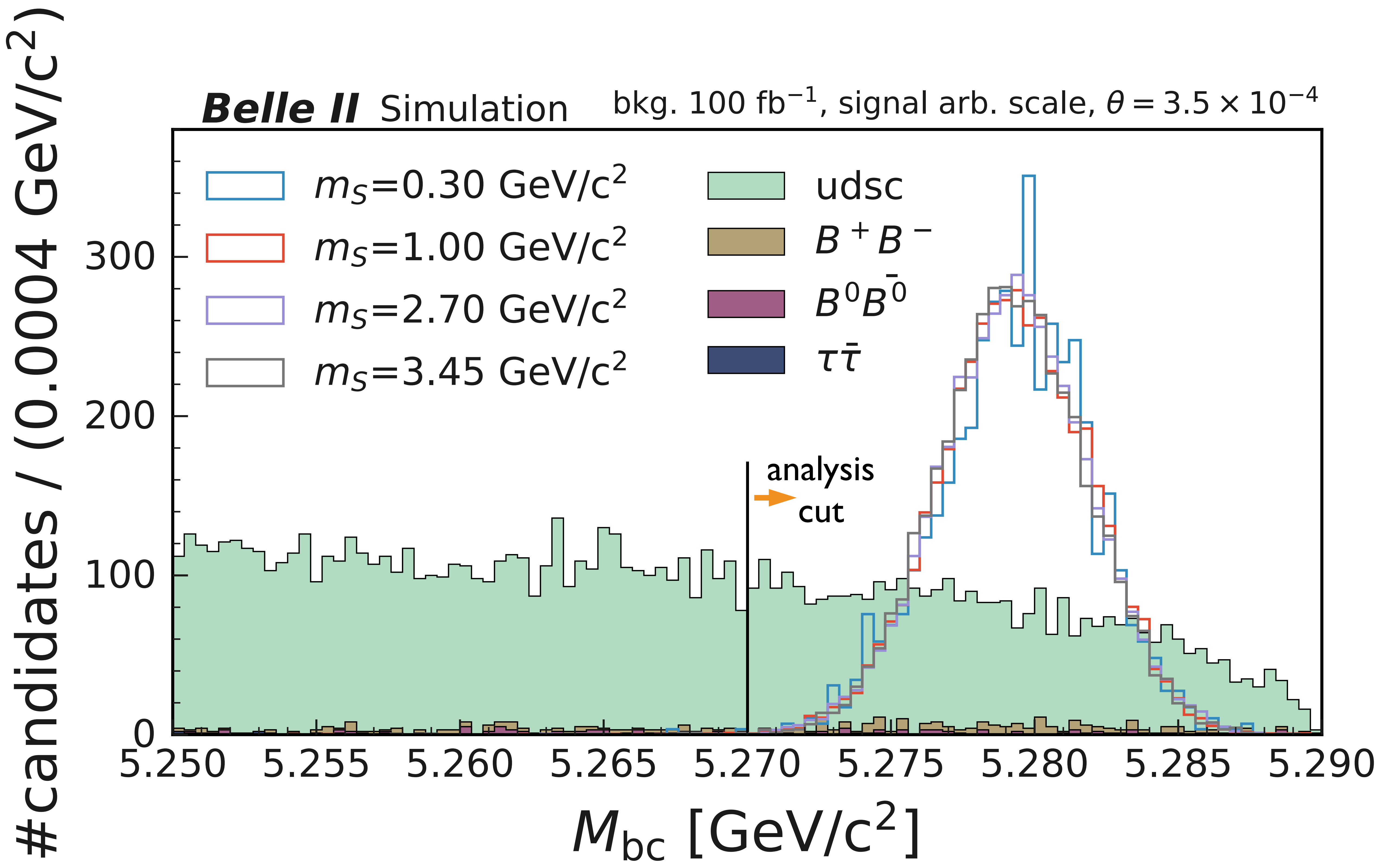


Reconstructing the event.

1. Reconstruct scalar candidate from two oppositely charged tracks with all three hypotheses: $S \to \mu\mu, \pi\pi, KK$
2. Particle identification requirements on one of the daughter tracks
3. Vertex fit both tracks and cut away small vertex distances
   - Cut out a window around the K_S^0 mass in the $S \to \pi\pi$ channel
4. Third track from interaction region: Kaon with particle identification
5. Form B meson candidate and impose kinematic constraints + other selection variables
6. If there are multiple candidates in the event: apply a best candidate selection

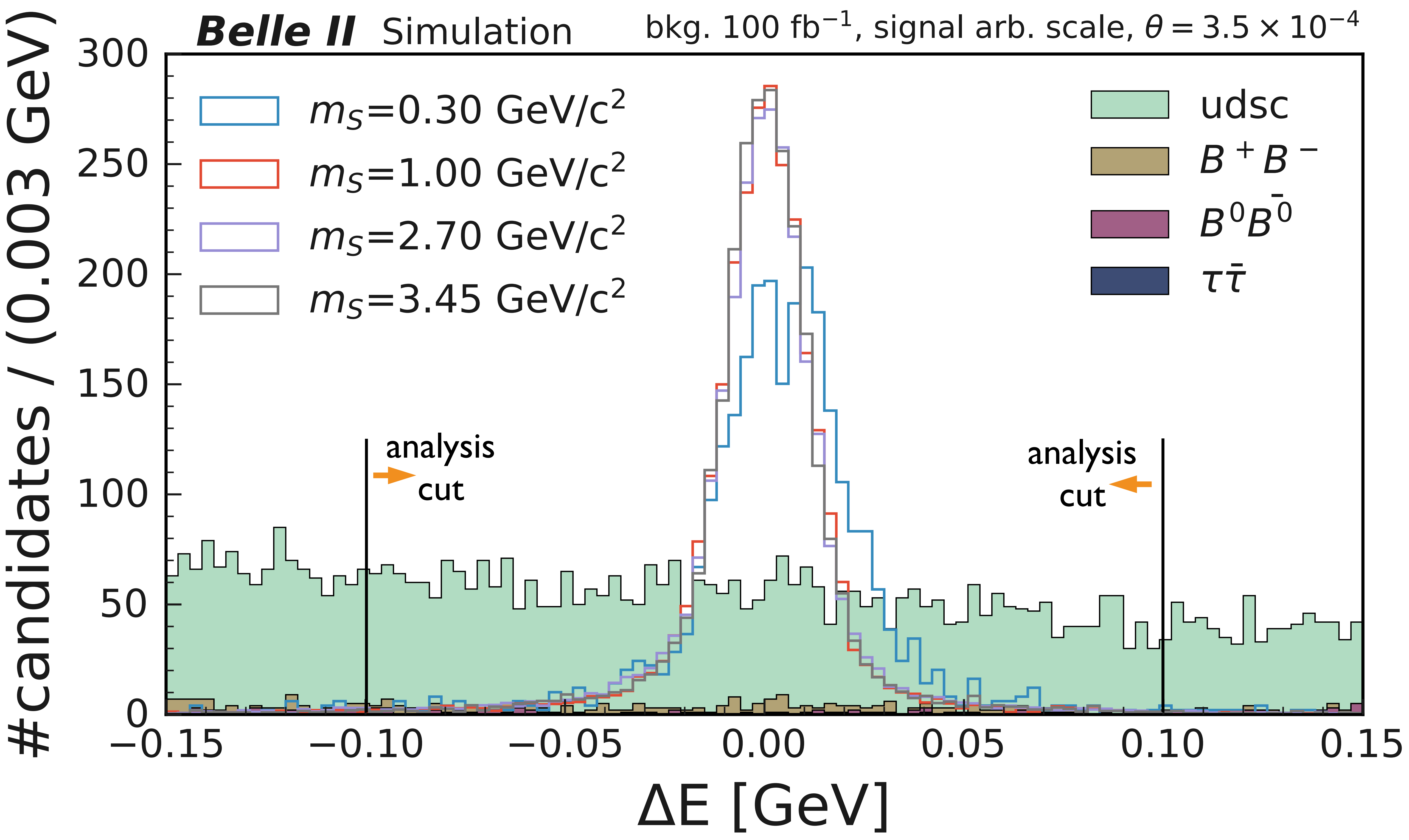
Selection: beam constraint mass M_{bc}.

- $M_{\text{bc}} = \sqrt{E^{*2}_{\text{beam}} - p^{*2}_{B}}$
- Beam energy and measured particle momenta
  - close to the B mass for true B events
  - slightly affected by long lifetimes (small mass sample has a larger lifetime at the same mixing angle)
- 'standard' technique at B-factories



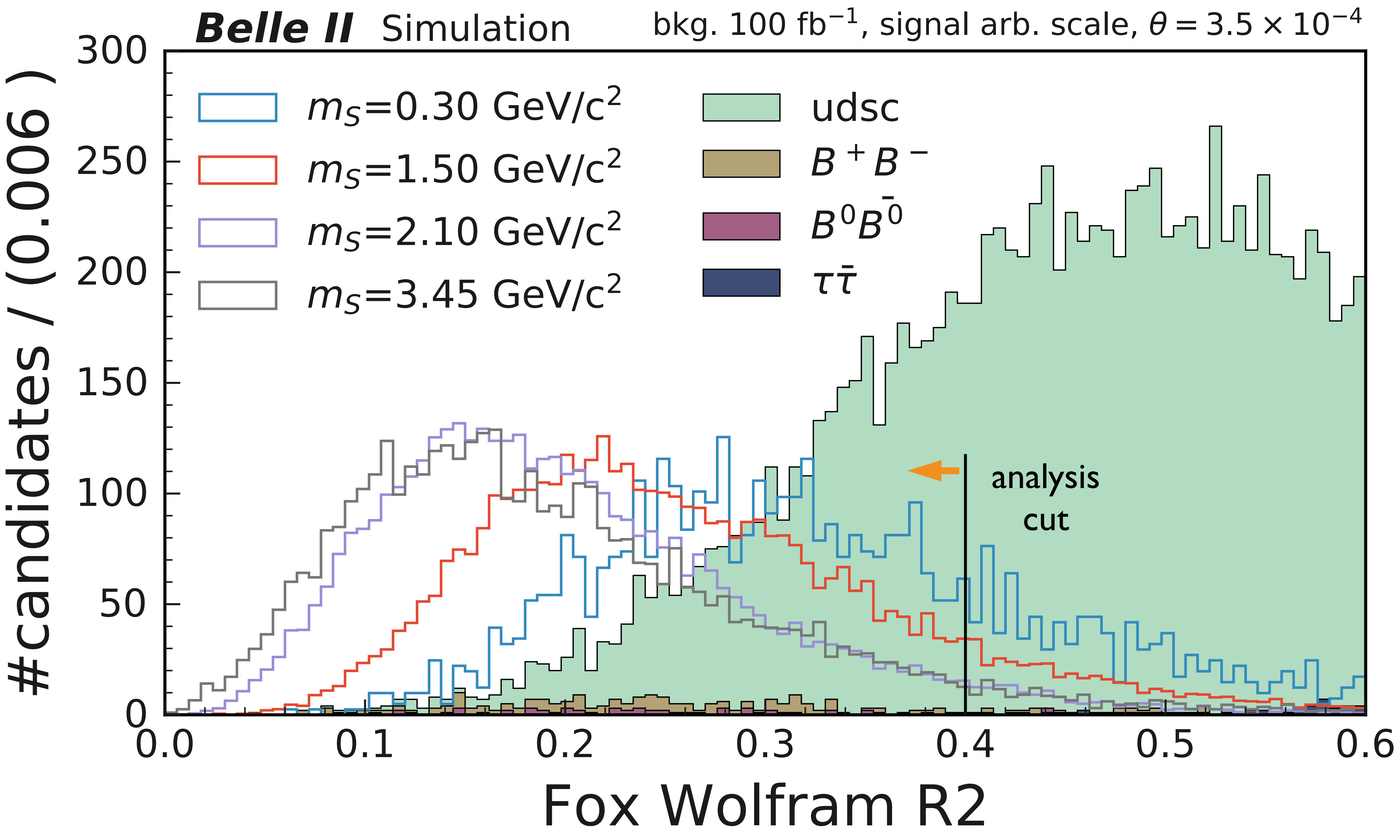
Selection: ΔE.

- $\Delta E = E_B^* - E_{\text{beam}}^*$
- Beam energy, measured particle momenta and mass
  - close to zero for true B events
  - sensitive to wrongly assigned particle hypotheses
- Is affected more by large-lifetime effects for small scalar masses
- 'standard' technique at B-factories
- Best candidate selection: smallest $|\Delta E|$

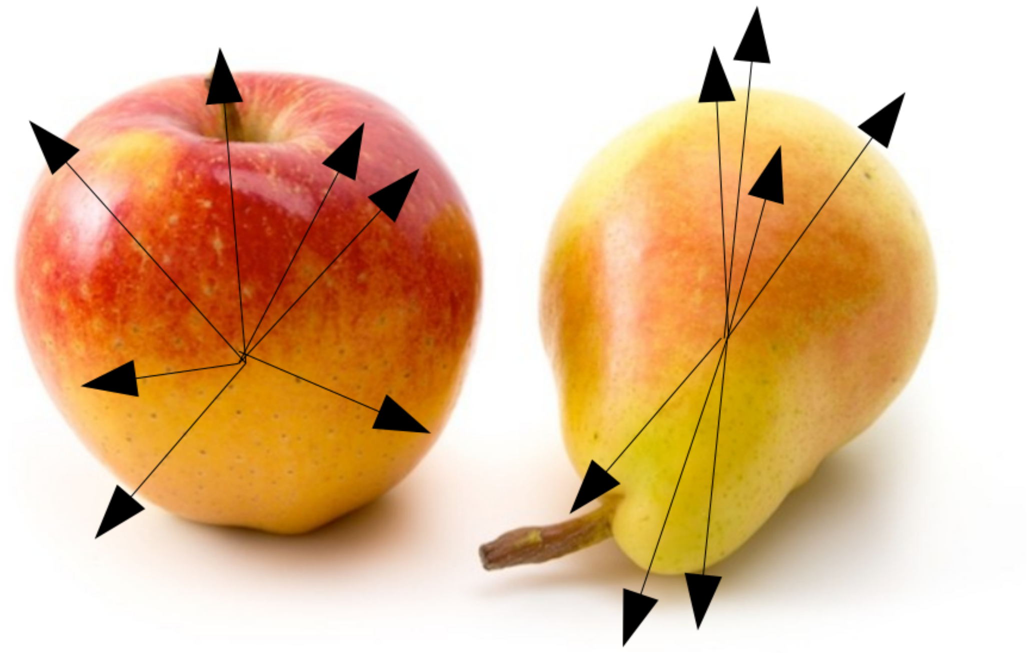


Selection: Fox Wolfram R2.

- Checks geometrical distribution of measured momenta
  - Large → momenta more strongly aligned (continuum)
  - Small → momenta more spherically distributed ($B\bar{B}$ events)
- Lower boost at large scalar masses → more spherical

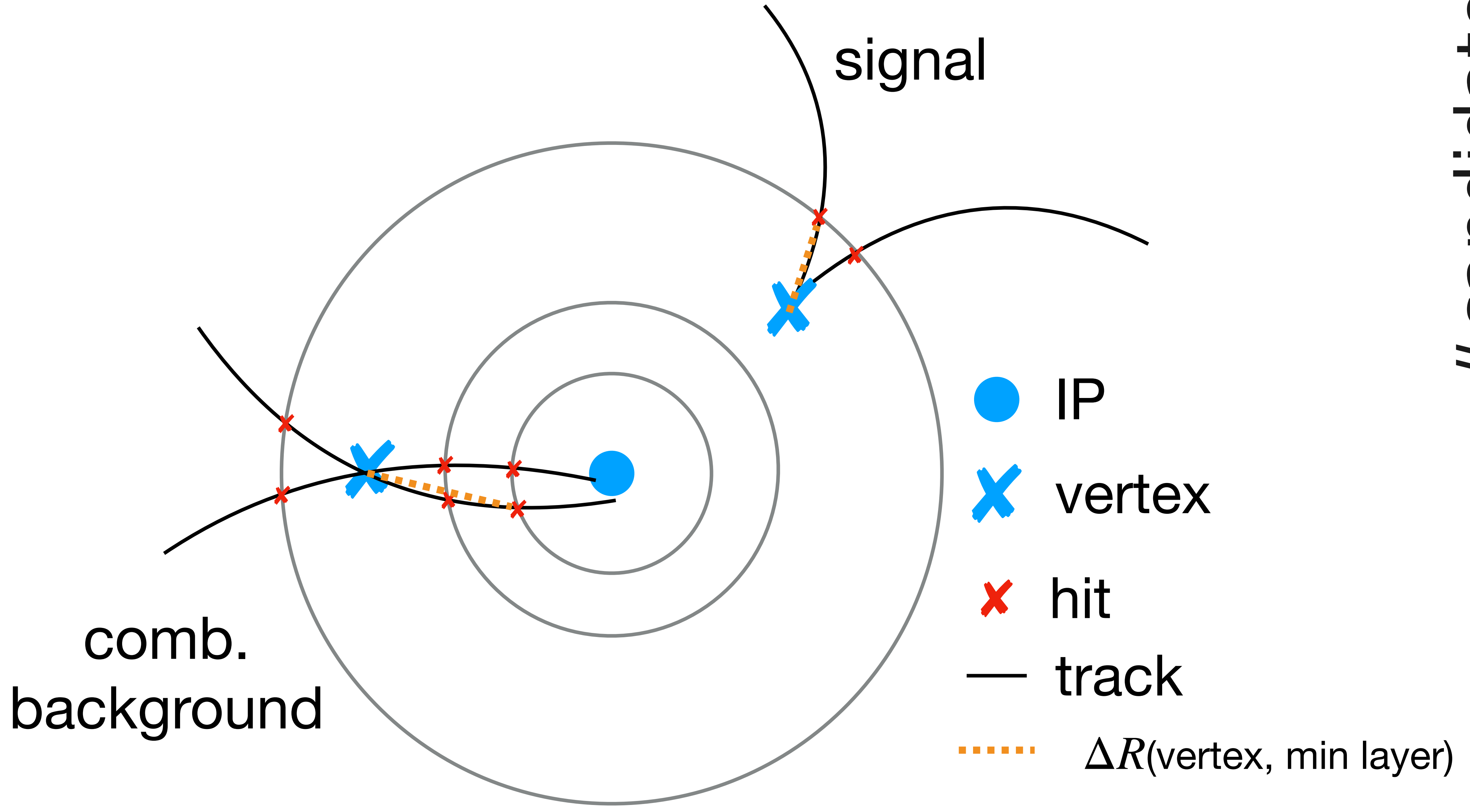


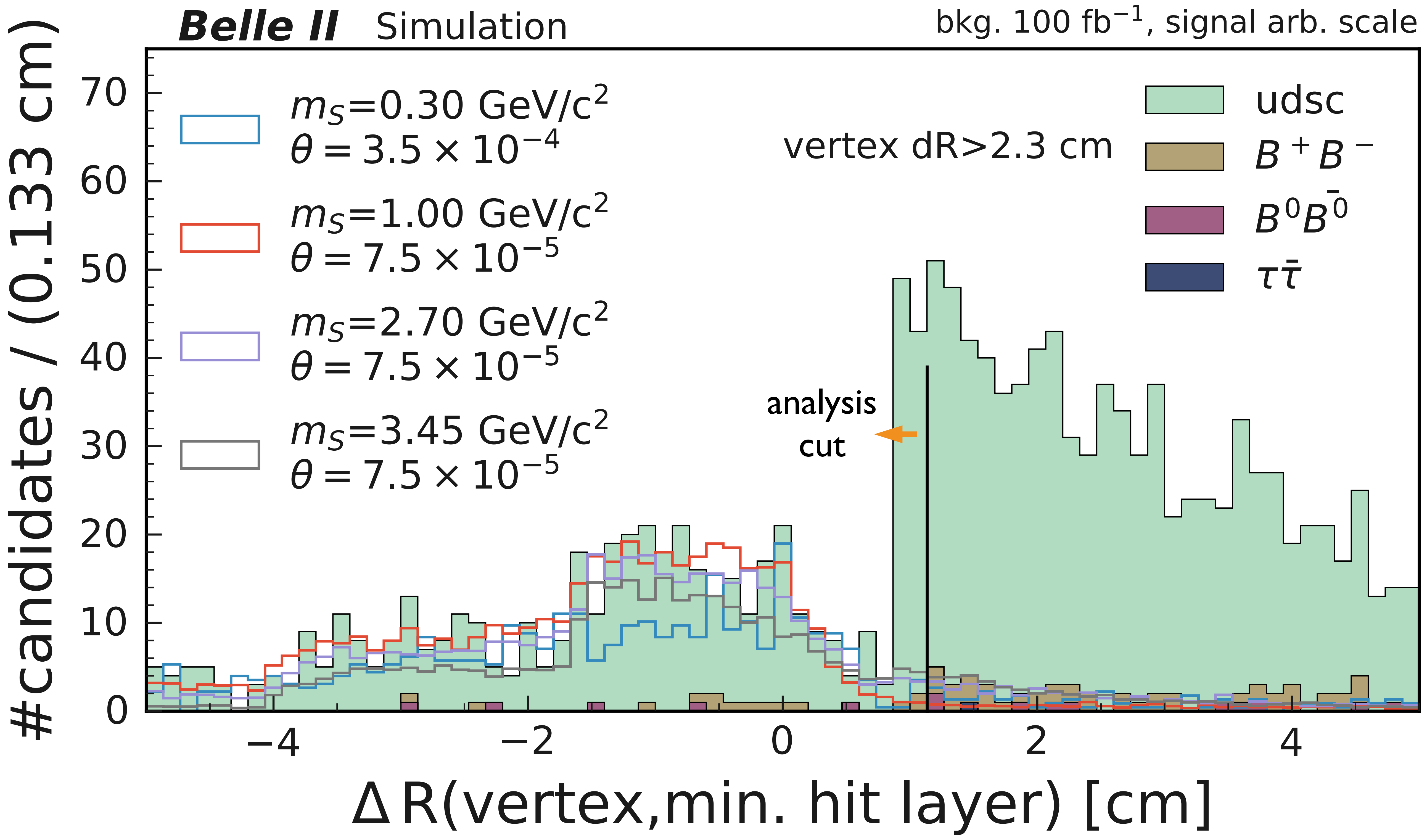
$$R_2 = \frac{H_2}{H_0} \sim \frac{\text{jetty}}{\text{spherical}}$$



Selection: distance between first hit and vertex.

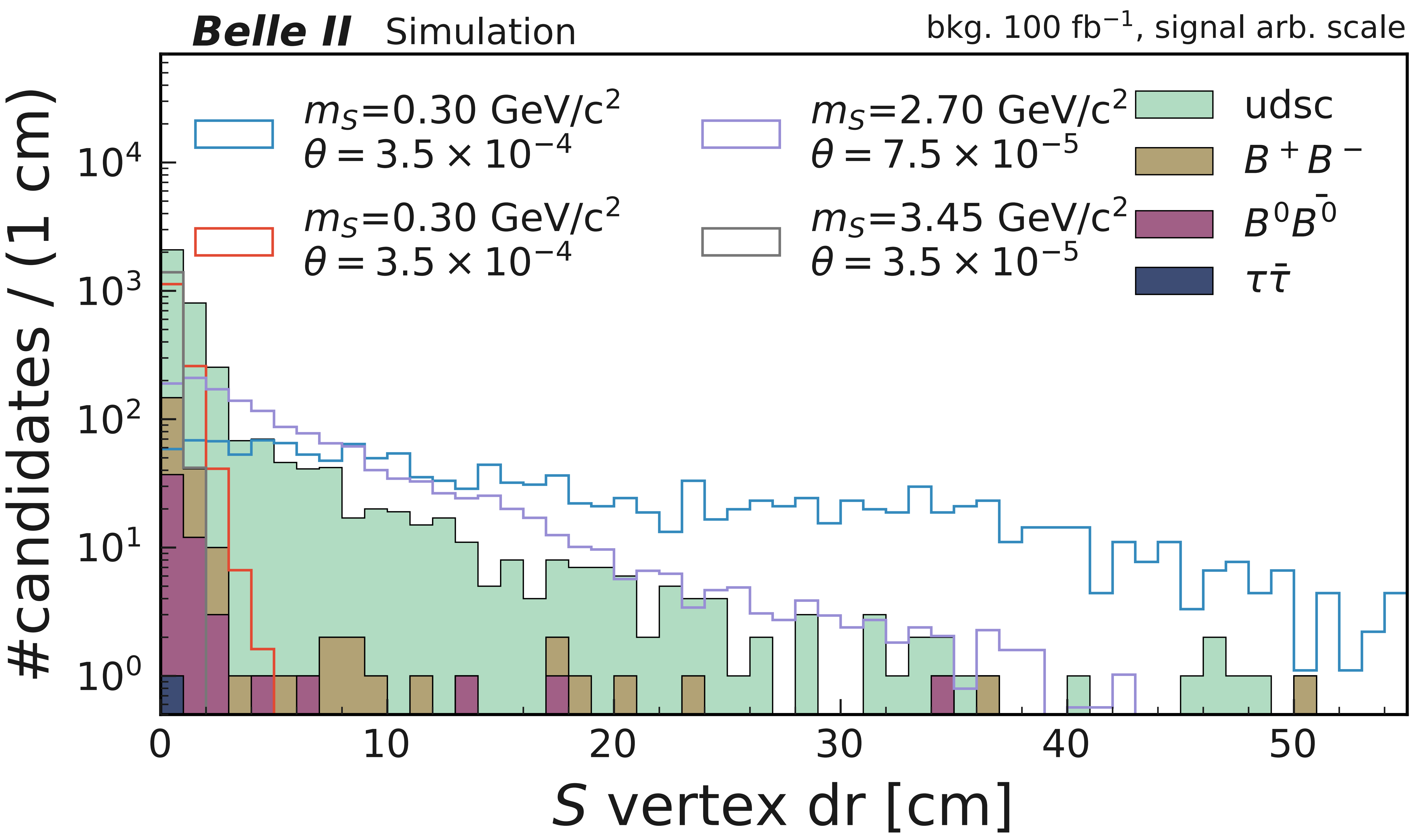
- LLP tracks should not have detector hits closer to the interaction point than the vertex (production point)
- Check hit nearest to the interaction point for both tracks
- Compare the minimum of both to the vertex displacement
  - > 0: there are hits ‘in front’ of the vertex
  - < 0: only hits further away than the vertex





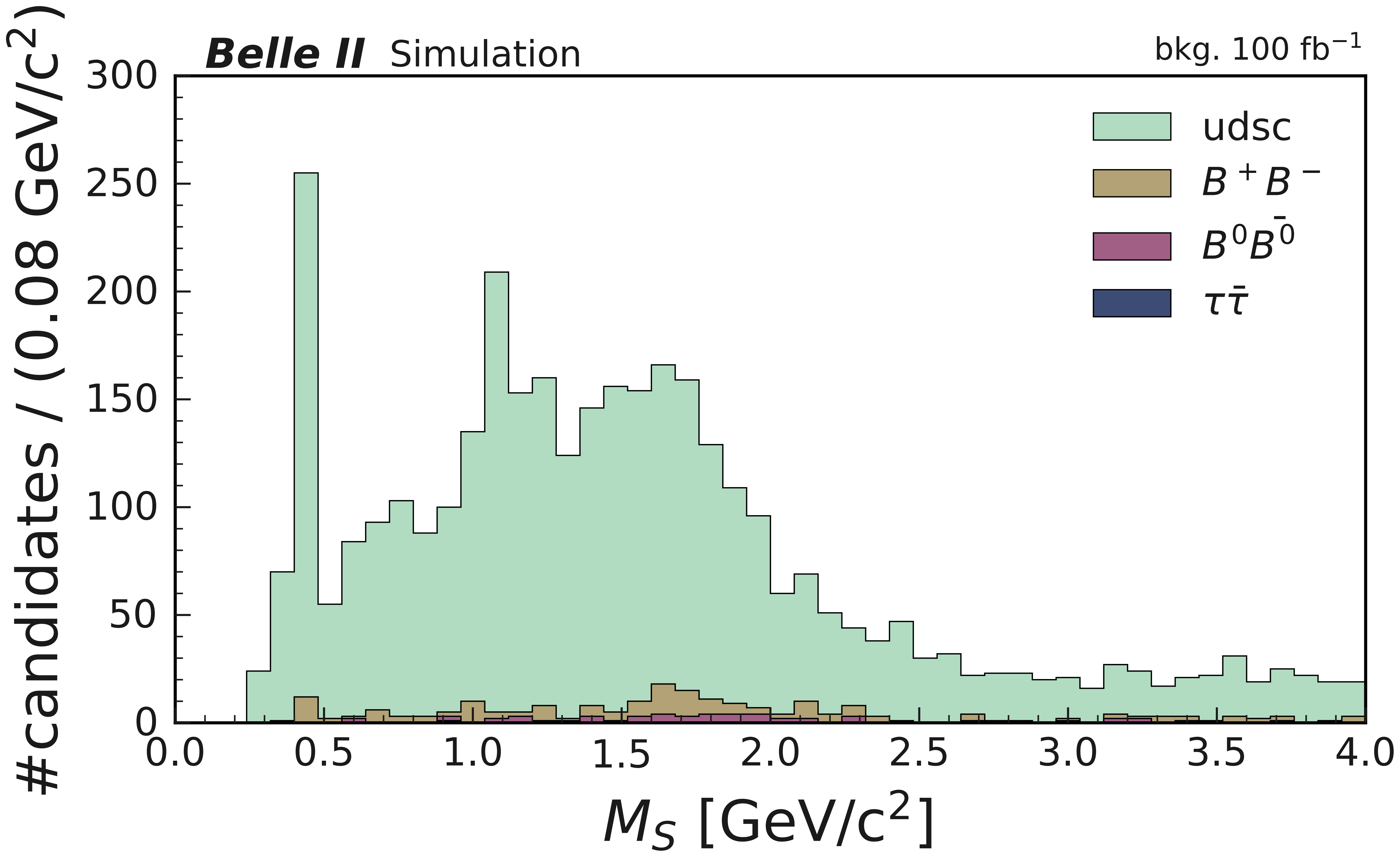
Remaining background — vertex displacement.

- Current event selection (previous variables, particle identification, vertex fit χ^2)
- Remaining backgrounds
  - mostly at small displacements
  - dominated by continuum samples
  - mostly random combinations left
- Vertex displacement cut will be made dependent on tested scalar lifetime



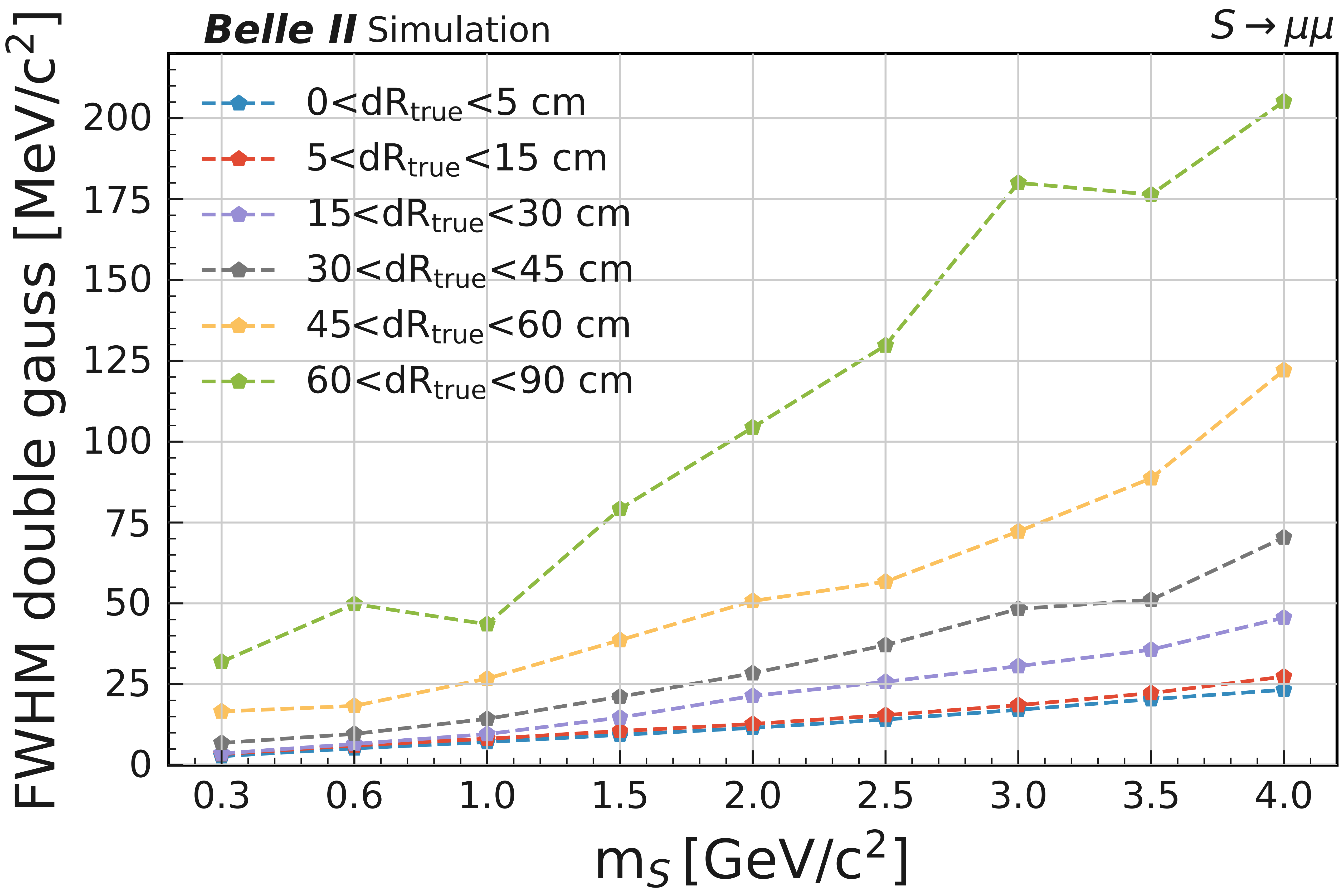
Remaining background — scalar mass distribution.

- Current event selection
- Mass resolution < bin size here (see next slide)
- Two spikes from remaining K_S^0 reconstructed as $\mu\mu$ around 0.4 GeV/c^2 and as KK around 1 GeV/c^2
  - will be tackled by re-computing scalar mass with pion hypothesis and cutting the same mass window



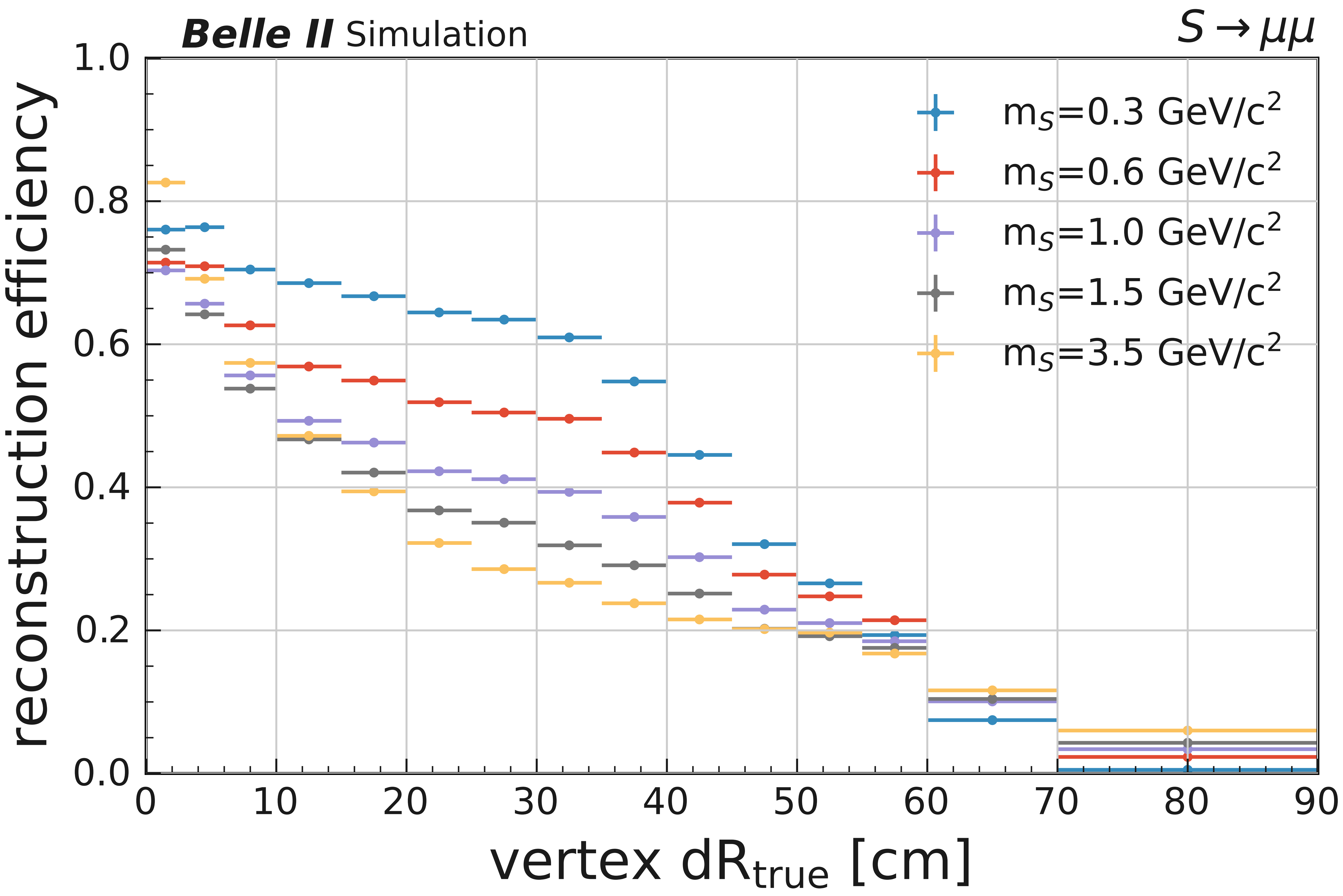
Performance — mass resolution.

- Reconstructed scalar mass distribution in $S \rightarrow \mu\mu$ fit with the sum of two gaussians
- Full width at half maximum computed as resolution
- Good resolution in most of the detector regions except for very large displacements
- No errors shown



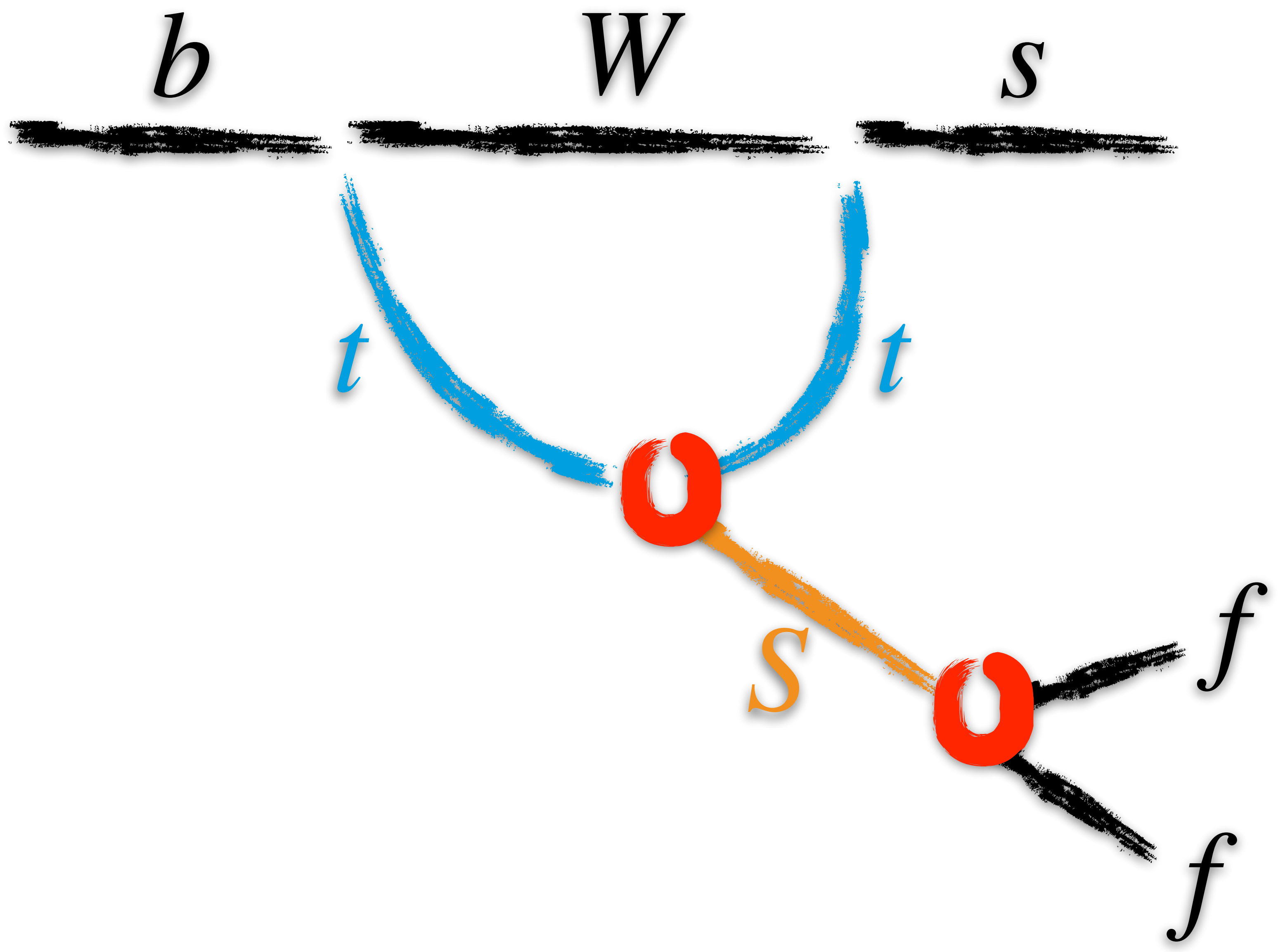
Performance — reconstruction efficiency.

- Reconstruction efficiency for $S \to \mu\mu$
- As a function of true vertex displacement
  - good reconstruction efficiency at low displacement
  - dropping after a few centimetres
  - current tracking algorithms optimised for tracks far from the interaction point
- Lower efficiency for larger masses
  - One of the tracks often lies outside the detector acceptance
  - One track is pointing towards the interaction region, the second track does not due to the large angle between them



Summary.

- Reconstruction of LLPs at Belle II is possible but does pose challenges.
- Presented distributions based on simulated data, to give you a flavour of how to perform such an analysis.
- Probably will not reach "zero background" conditions, efficiency is small for LLPs far into the detector.
- **We expect results based on existing data and data to be collected in the coming year.**



Backup.