Performance studies on benchmarking physics channels for LHCb ECAL Upgrade II

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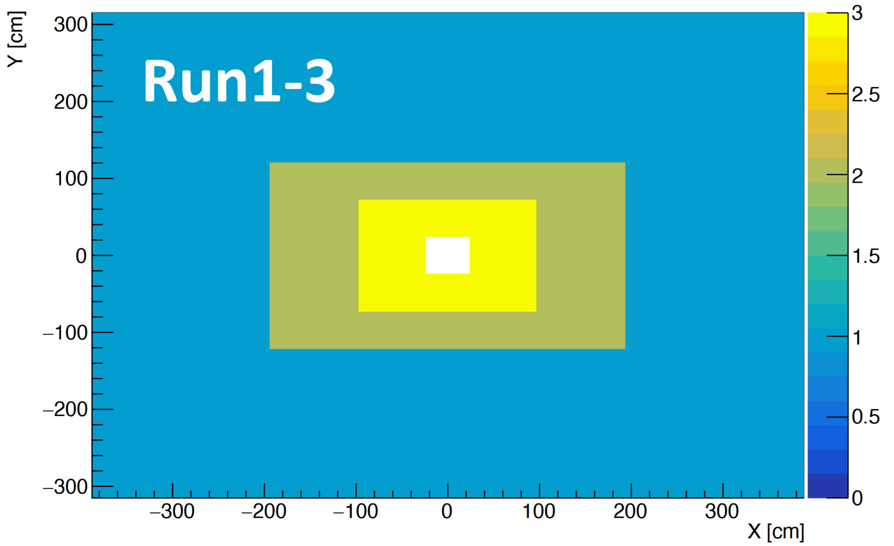
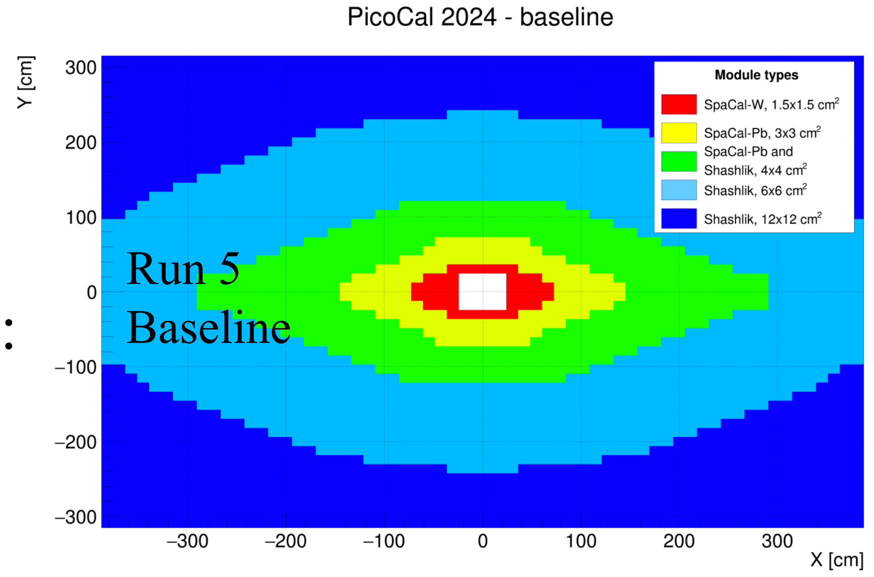
ECAL Upgrade II scenarios

- Run1-3: 4×4/6×6/12×12 cm^2 Shashlik
- Run 5 Baseline of Upgrade II:
  - Innermost: 1.5×1.5 cm^2 SpaCal-W + GAGG fibers
  - Second inner: 3×3 cm^2 SpaCal-Pb + Poly fibers
  - Outer: 4×4/6×6/12×12 cm^2 Shashlik
  - With longitudinal segmentation: front and back sections
  - SpaCal modules rotated
- Run 5 Downscoped of Upgrade II:
  - Derived from the Baseline with single-side readout except for SpaCal regions
- Upgrade II luminosity configurations (lumi1.0, lumi1.5):
  - $\mathcal{L}_{\mathrm{peak}} = 1.0\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}, 1.5\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Simulation based on Hybrid-MC framework
  - Pile-up included





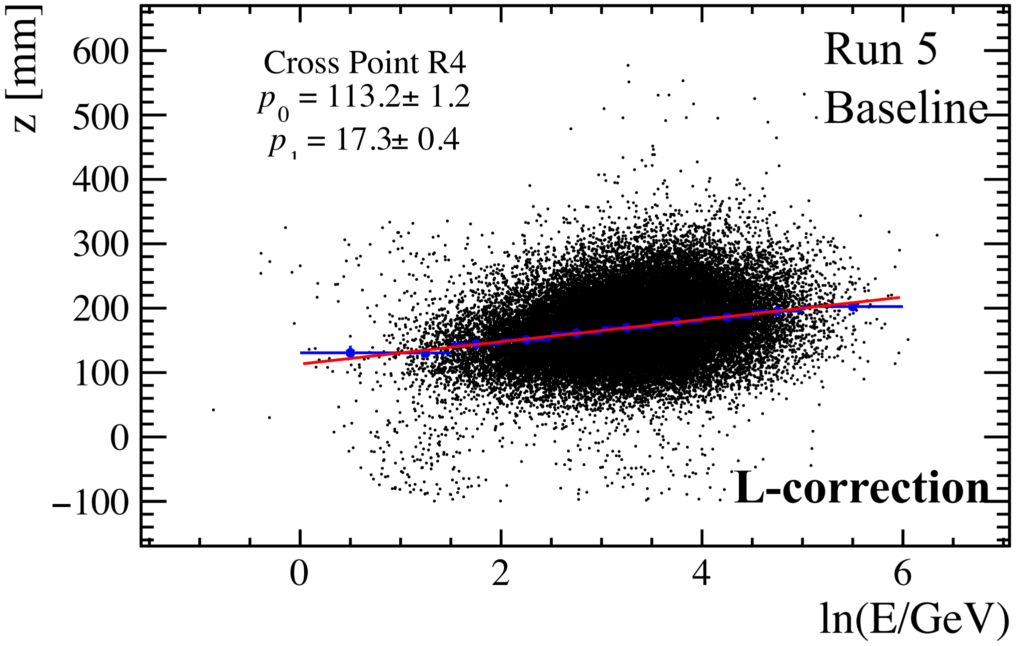
Benchmarking physics modes

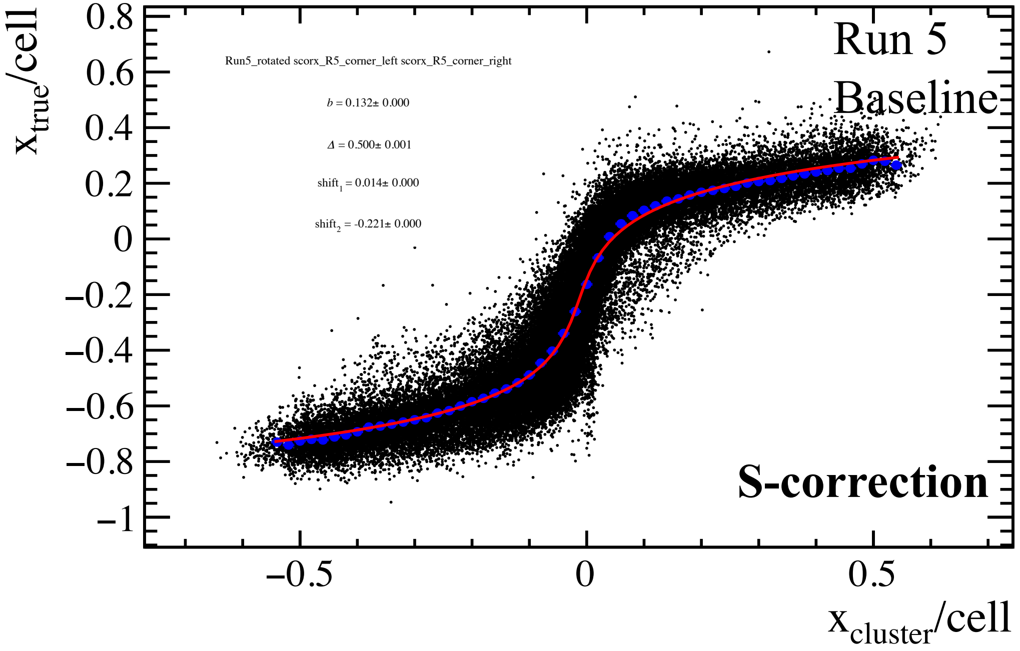
- To cover physics modes involving photons and π^0 and with different energy coverage, background level…
  - Single photons
  - Photons from $B^0 \rightarrow K^{*0}\gamma$ decays
  - Neutral π^0 from $D^{*+} \rightarrow D^0(\rightarrow \pi^+\pi^-\pi^0)\pi^+$ decays

Reconstruction algorithm

- The 2×2 clustering method with longitudinal segmentation information is used against pile-up

- L-correction: to correct the longitudinal barycenter position *z* in reconstruction, taken to be ECAL surface z-coordinate
  - $z = z_0 + \text{slope} \times \ln(E) + \text{offset}$
- S-correction: to correct the transverse cluster positions $(x_{cluster}, y_{cluster})$

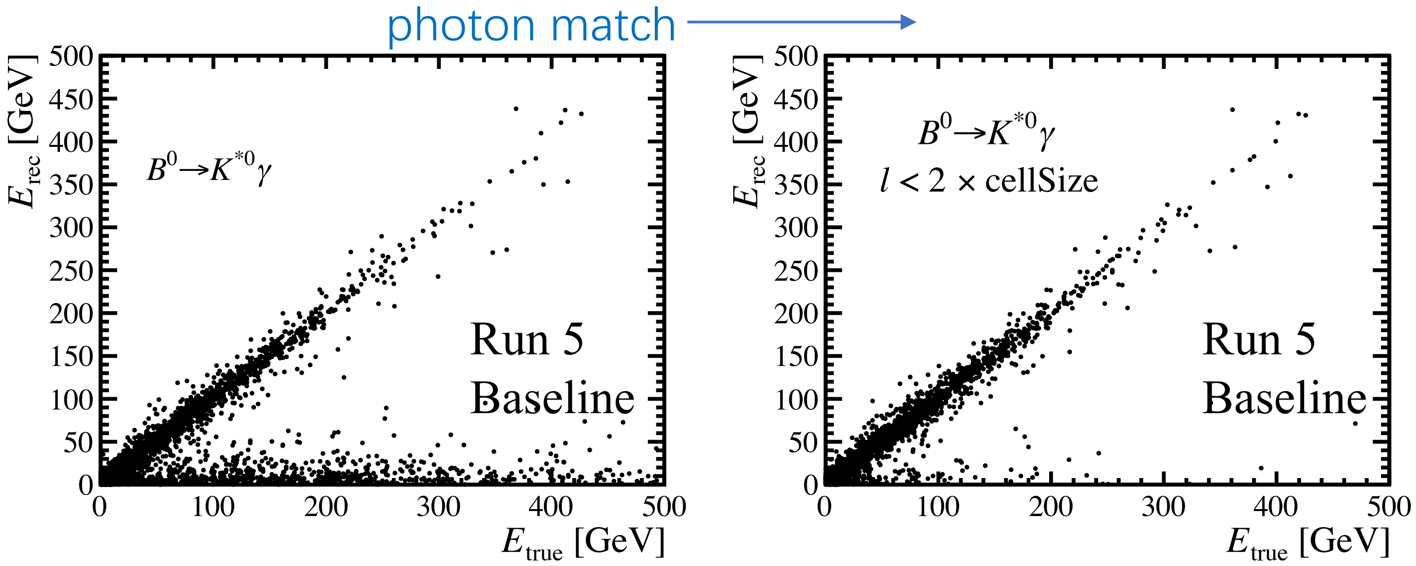


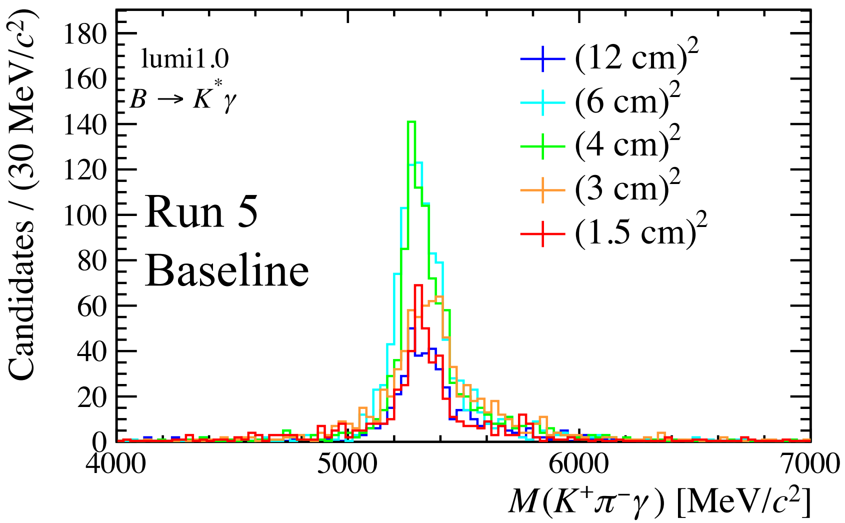


- E-correction: to correct the energy leakage
  - depends on E, distance to seed cell center
- Using single photons for calibration purposes

$B^0 \to K^{*0}\gamma$ photon truth match

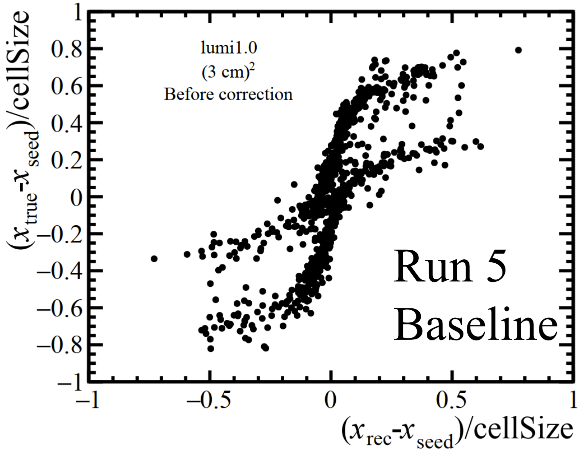
- Truth-matched photons are used to study energy and timing resolution
  - photon match works well
  - signal mass peaks well reproduced without background

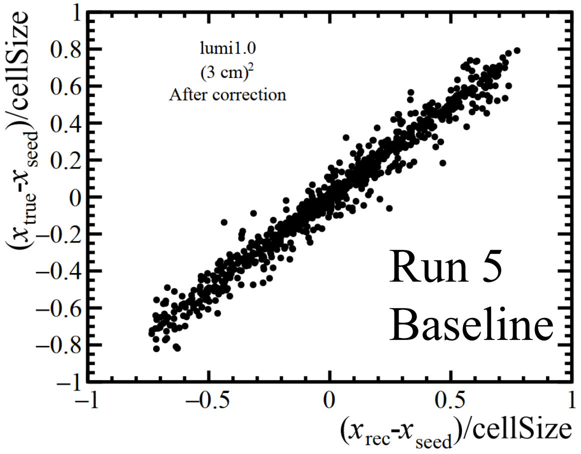


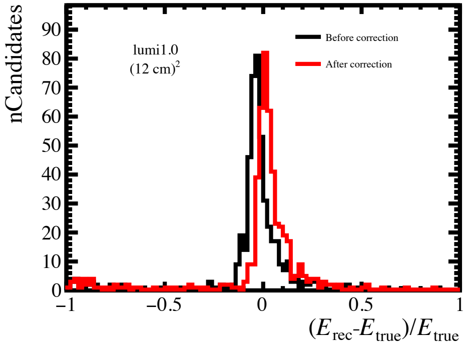


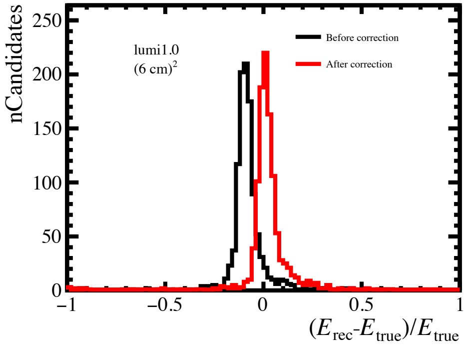
$B^0 \to K^{*0}\gamma$ corrected position and energy

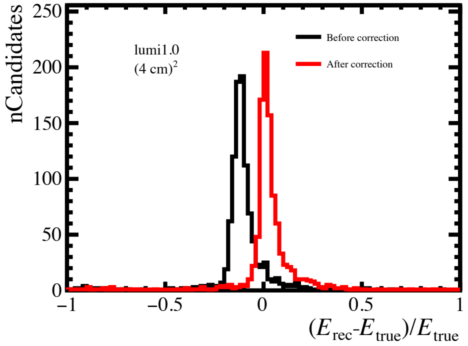
- Both reconstructed position and energy after L, S and E-corrections are closer to the true values

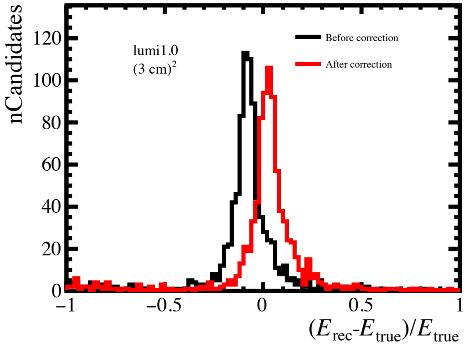


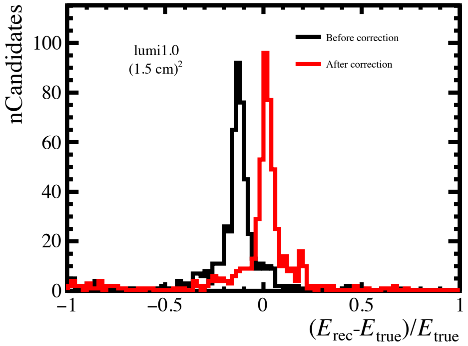












Run 5
Baseline

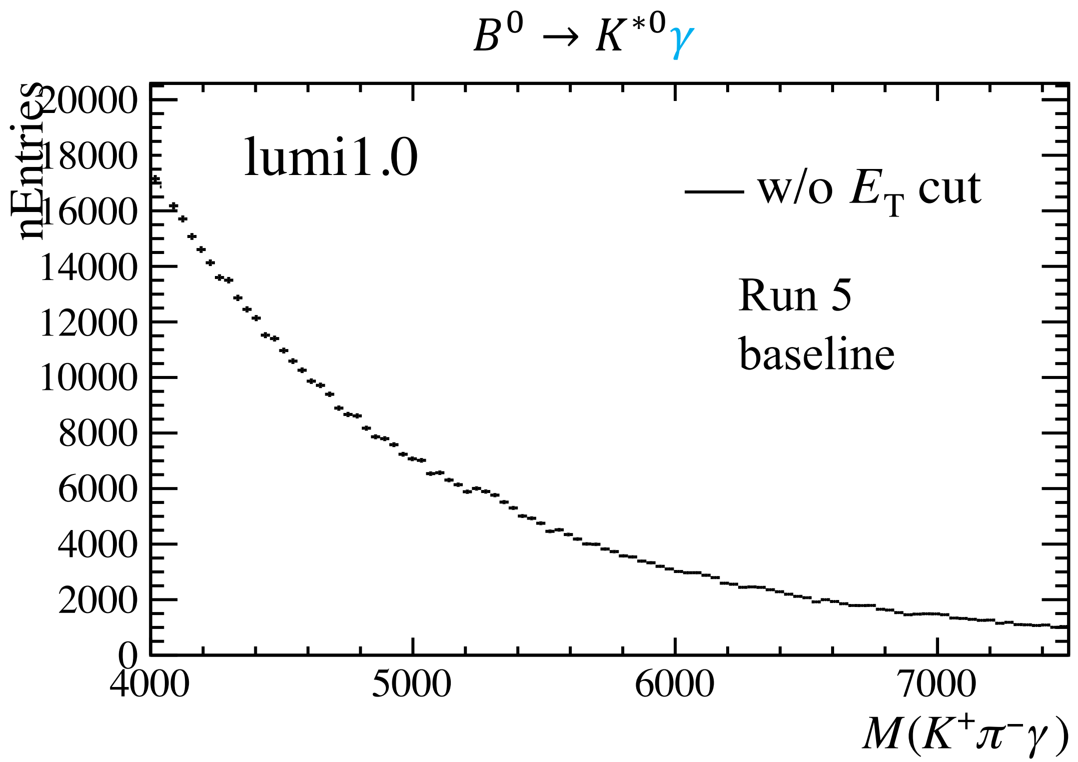
$B^0 \to K^{*0}\gamma$ performance study

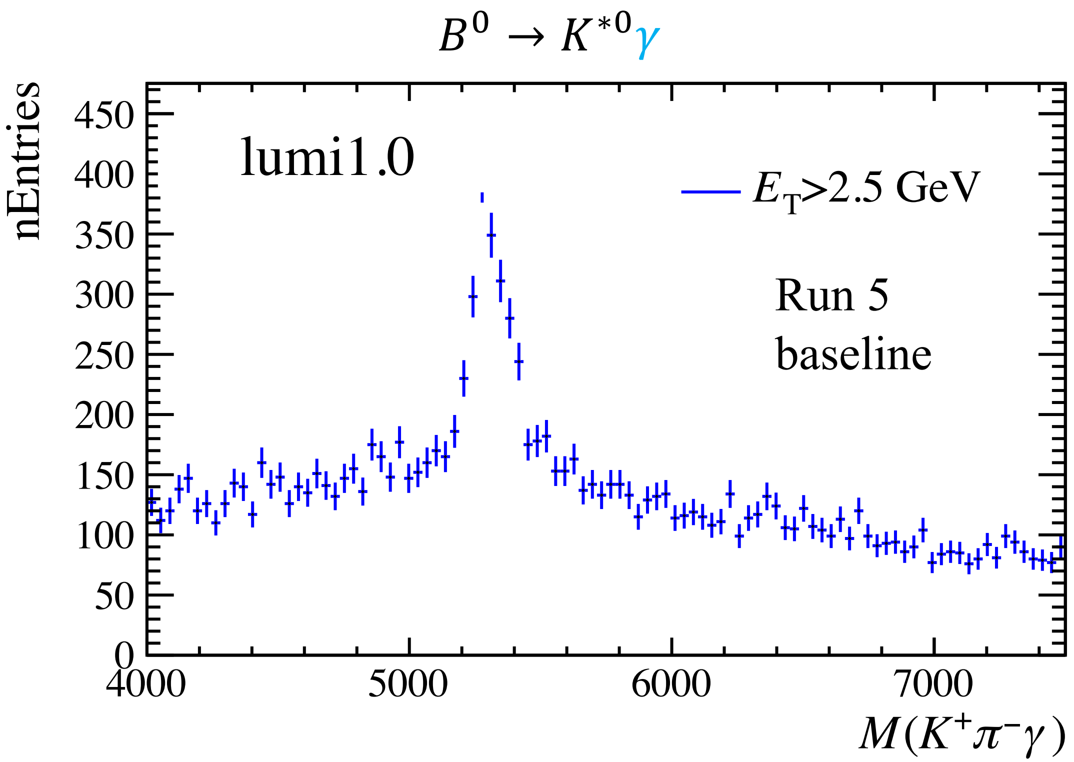
- To study the overall performance, additional $K^+\pi^-$ backgrounds are added
  - $K^+\pi^-$ background fraction is fixed according to Run 2 data assuming the same tracking performance
  - $792 < M(K^+\pi^-) < 992\ \mathrm{MeV}/c^2$
  - kaons and pions have p_T>500 MeV and momentum smeared as $\frac{\delta p_{x,y,z}}{p_{x,y,z}} = 1\%$

- Several background components are considered
  - signal K^{*0} + background photon
  - background K^{*0}or combinatorial $K^+\pi^-$ + signal/background photon

Mass distributions with backgrounds

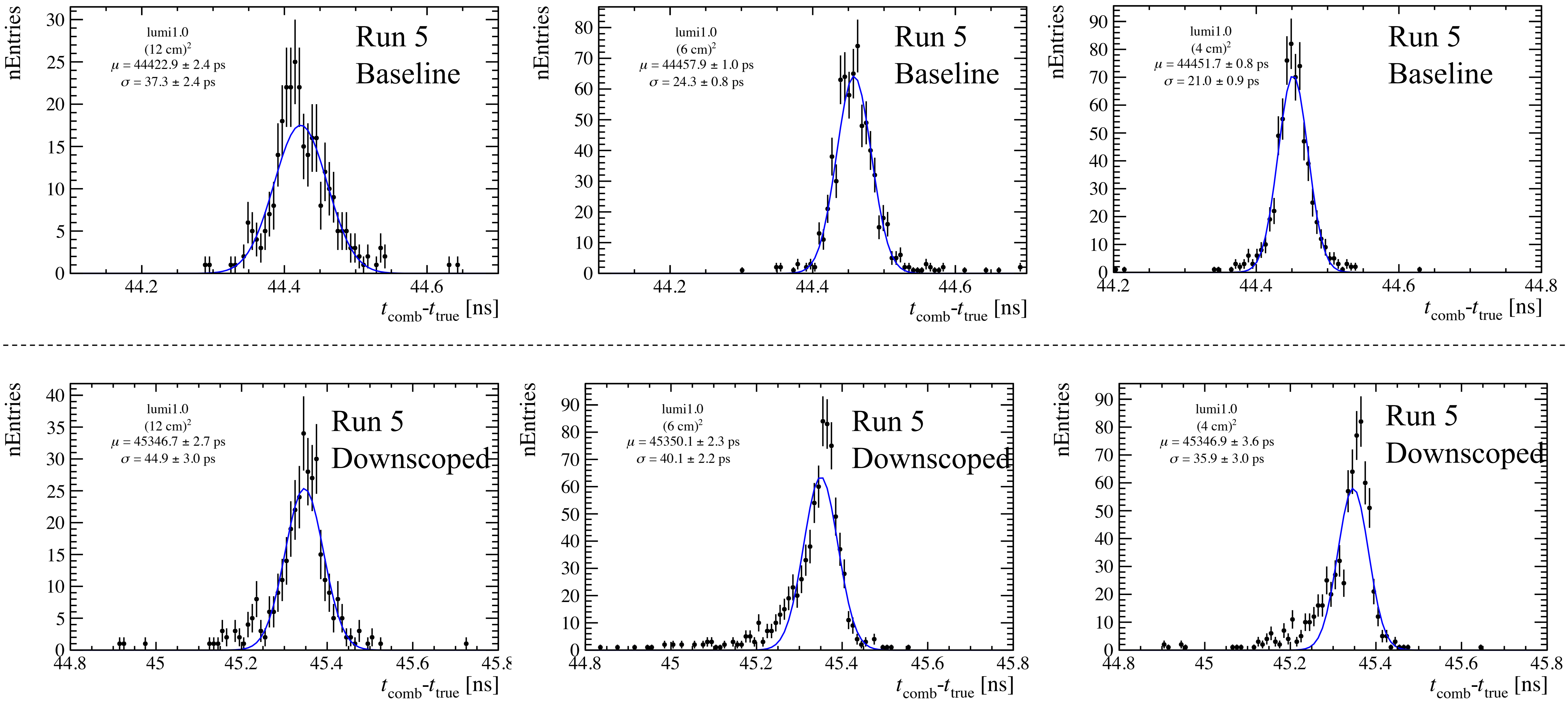
- The background level increases significantly after adding $K^+\pi^-$ backgrounds
- With the application of the photon E_T cut, the signal peak can be effectively seen





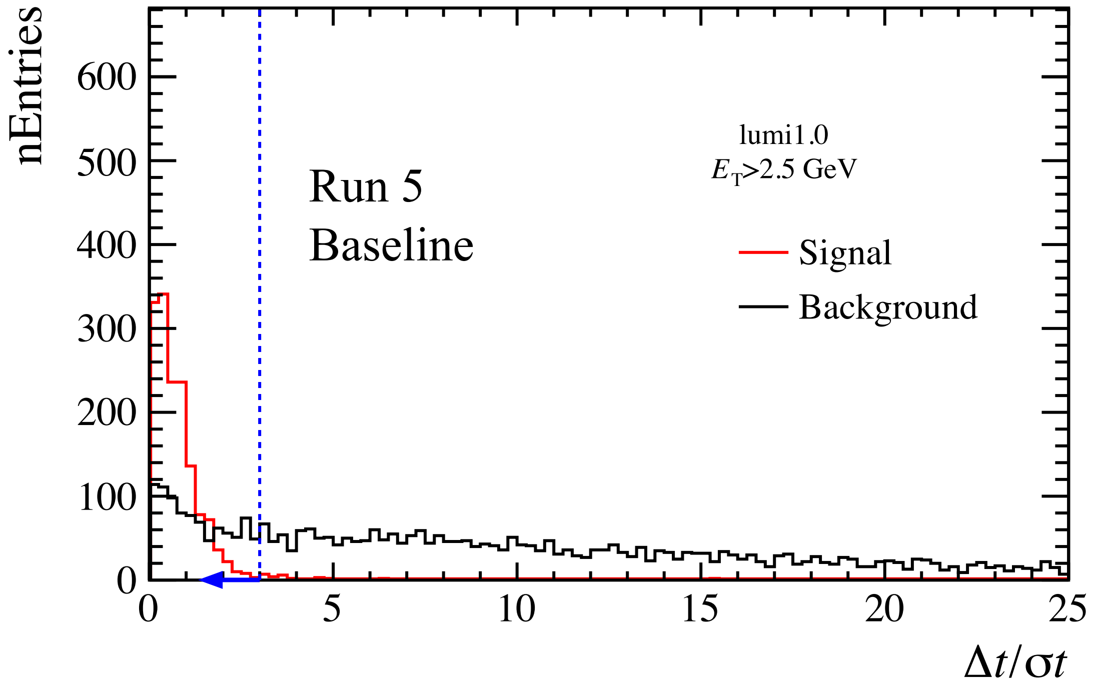
$B^0 \rightarrow K^{*0}\gamma$ timing resolution

- Timing resolution obtained as weighted average of front & back section time for Baseline
- Timing resolution degrades notably in Downscoped single-sided readout regions

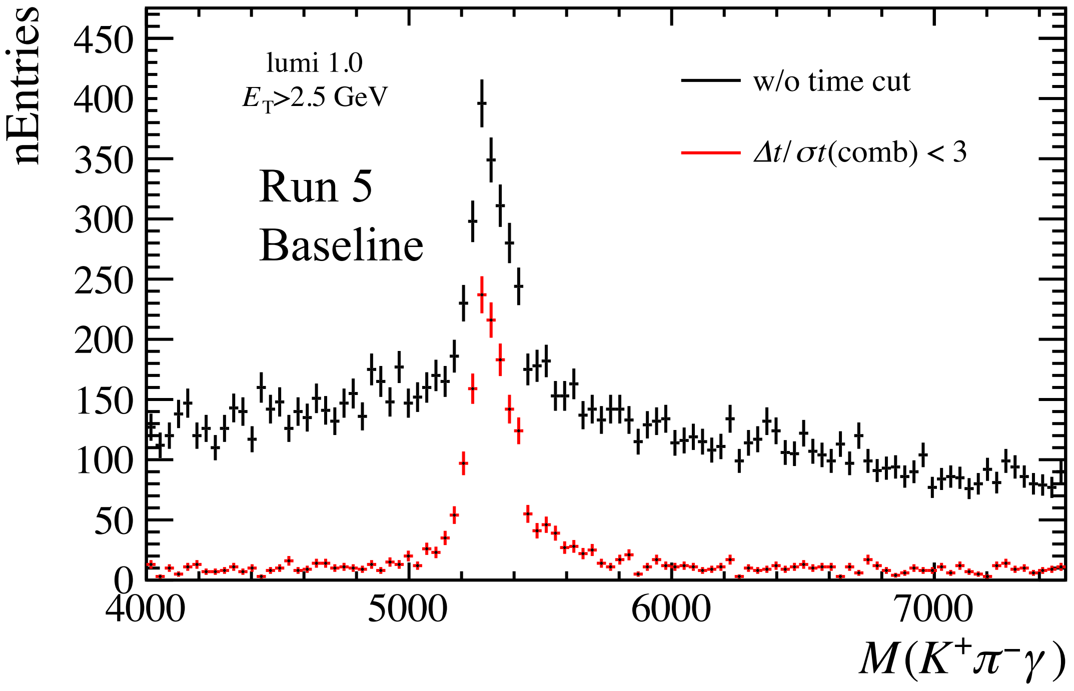


$B^0 \to K^{*0}\gamma$ timing cut

- A cut on the arrival time of the photon is effective to reduce the background

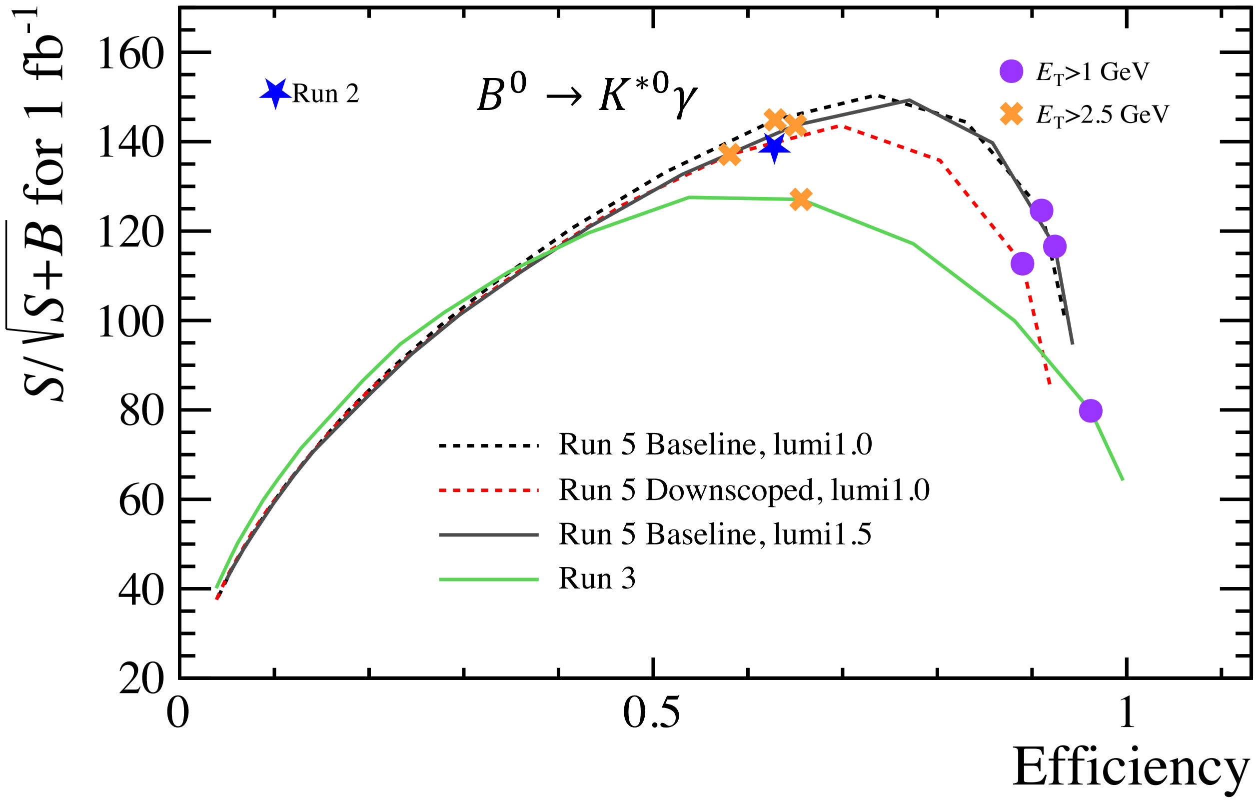


$$\Delta t = t_{rec} - (t_{prod} + t_{flight})$$



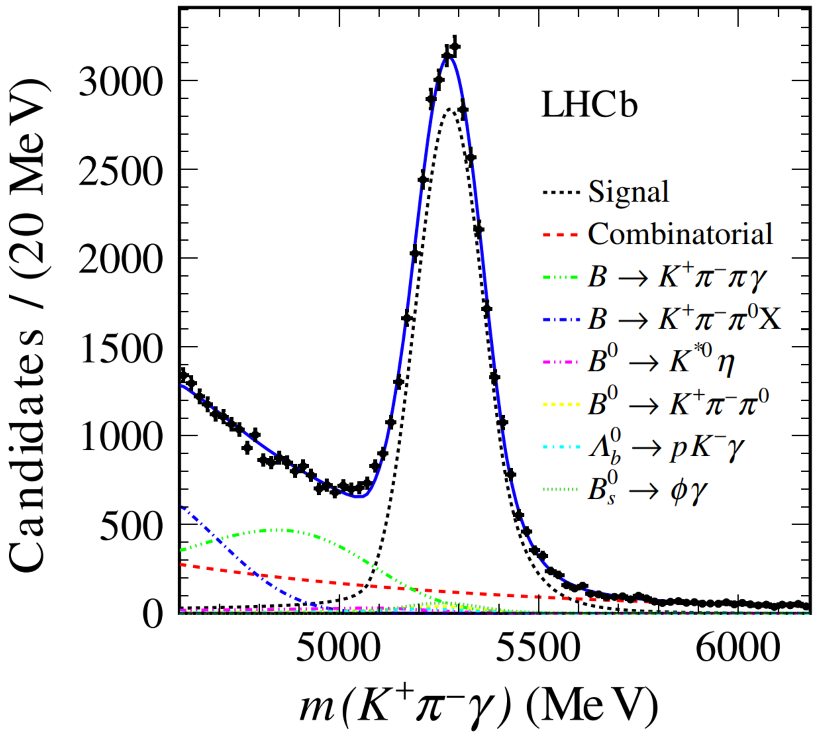
Performance of $B^0 \to K^{*0}\gamma$

- The performance of $B^0 \to K^{*0}\gamma$ is compared between different PicoCal scenarios
  - significance $= S/\sqrt{S+B}$
- Higher peak luminosity in the Run 5 Baseline slightly reduces significance
- Downscoped configuration's poorer time resolution leads to decreased performance compared to the Baseline
- Run 5 scenarios, with timing cut, generally perform better than Run 3 without it.
- It is promising to achieve the target performance of Run 2 with Upgrade II.



$B^0 \to K^{*0}\gamma$ mass fit

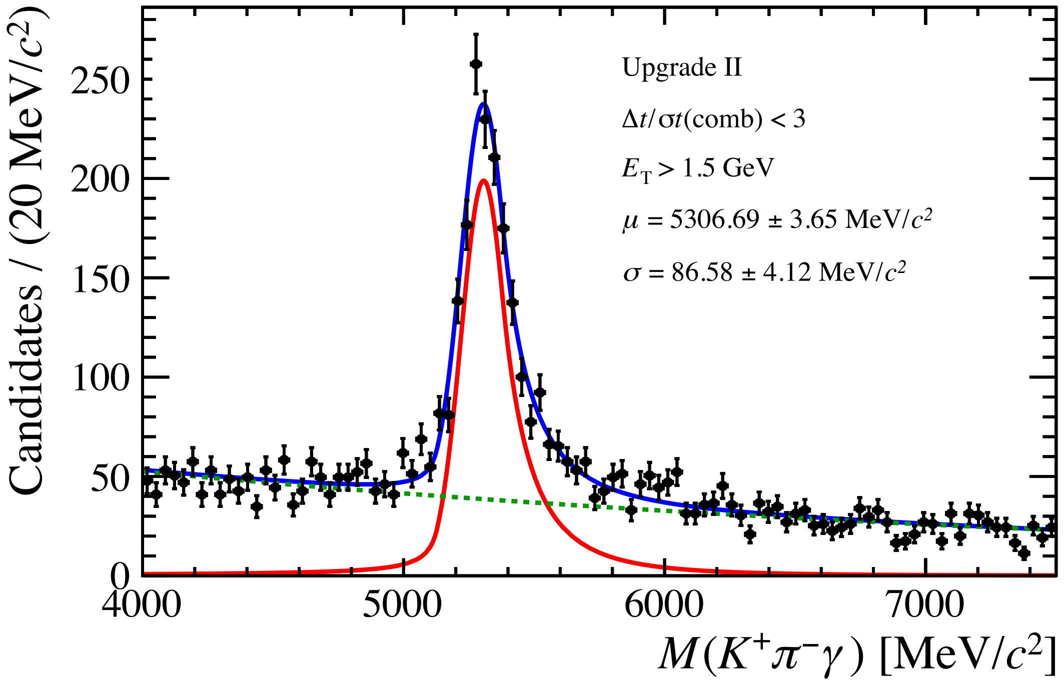
- Run 2 [Phys. Rev. Lett. 123 (2019) 031801]



$M = 5277.49 \pm 0.65$ MeV

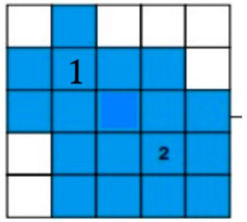
$\sigma = 85.99 \pm 0.72$ MeV

- Run 5 Baseline, lumi1.0



- Mass resolution close to the Run 2 result
- Mass peak shifted upwards due to pile-up

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



Two clusters

- Neutral pion could be reconstructed from ECAL, here only consider **resolved** $\pi^0(\to \gamma\gamma)$
- Same simulation & reconstruction with L, S and E-corrections from single photons
- Combine two clusters → $m_{\gamma\gamma}$ spectrum

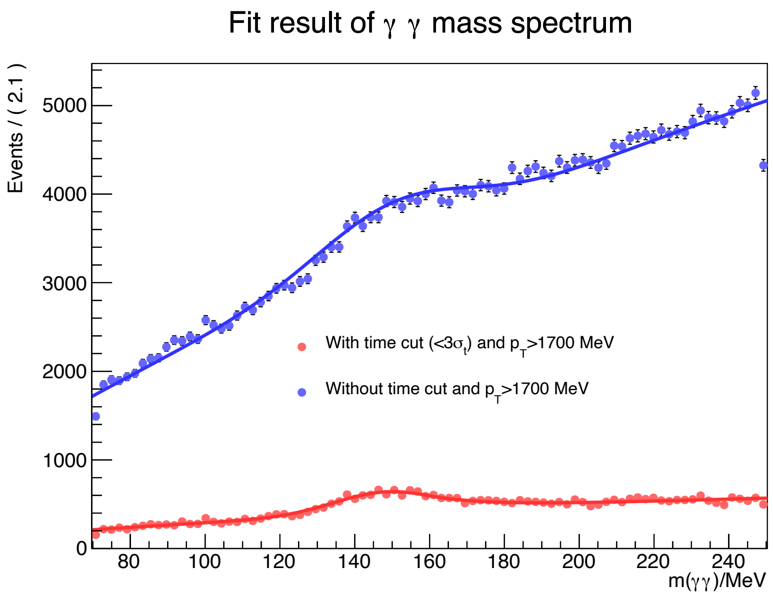


Fig: $m(\gamma\gamma)$ with and without time cut (Run 5 Baseline)

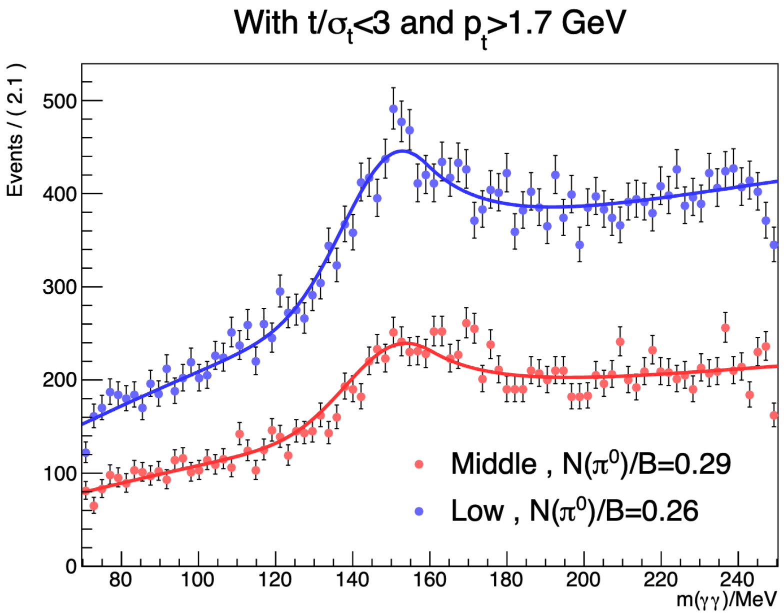


Fig: Comparison between middle (Run 5 Baseline) and low scenario (Run 5 Downscoped)

Summary and Prospects

- The $B^0 \to K^{*0}\gamma$ and $D^{*+} \to D^0(\to \pi^+\pi^-\pi^0)\pi^+$ decays are studied based on hybrid-MC framework
  - L, S and E-corrections for Upgrade II scenarios are calculated and applied
  - Good timing resolution is achieved and proven effective in reducing backgrounds
  - Performance studies outlined in the scoping document indicate the PicoCal design holds promise for achieving good performance

- Prospects
  - Clustering should fully harness the potential of longitudinal segmentation and timing information
  - The impact of timing resolution from the tracking system is being investigated through joint VELO-ECAL simulation

Thank you!