Extending Long-lived Particle Measurements in LHCb

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LHCb Department

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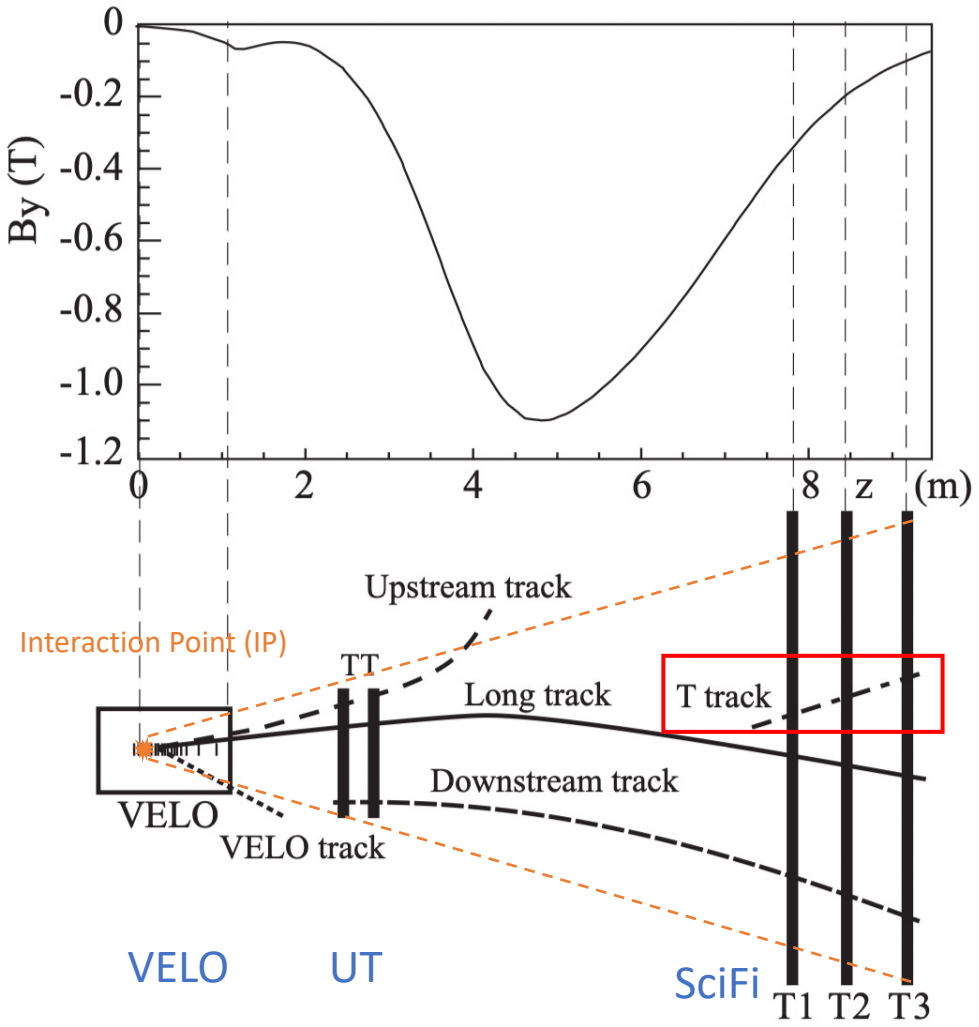
LHCb detector and tracks



- LHCb: Single-arm spectrometer covering forward-region
  - Precise IP vertex reconstruction (VELO)
  - PID information (RICH)
  - Track momentum measurement (UT & SciFi)
  - Calorimeter, Muon system
- Optimized to study decays of beauty and charm hadrons close to interaction point

- T-track: only hit the SciFi tracker
  - Include decay products of long-lived particles
- Long and Downstream track: decay length < 2m
  - All LHCb analysis so far have focused on these two

- T-track is essential for long-lived particle decay study
  - Λ EDM/MDM measurement → Tianze Rong's presentation tomorrow
  - Beyond the Standard Model (BSM) long-lived particle searches

Long-lived particles and BSM Higgs

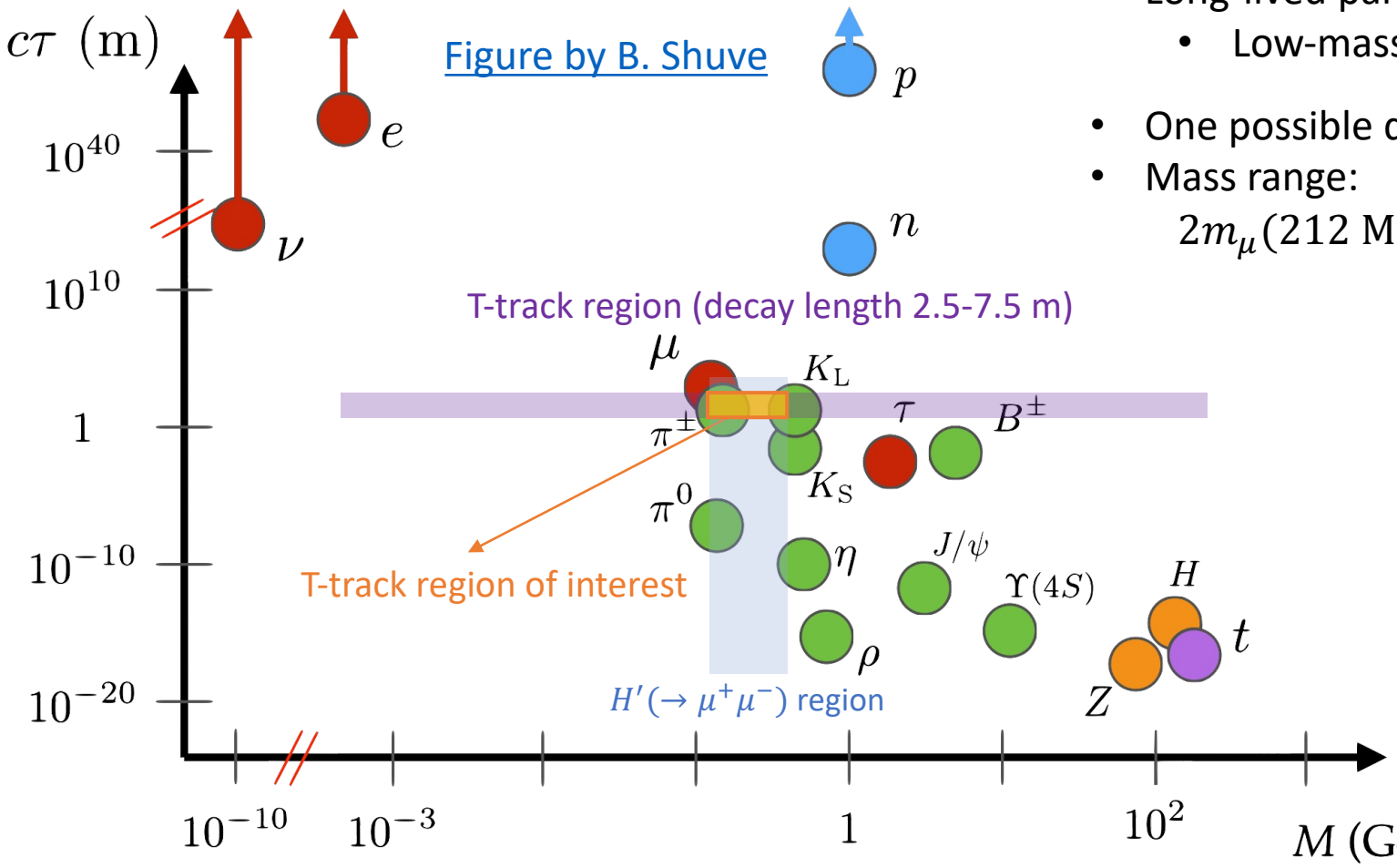


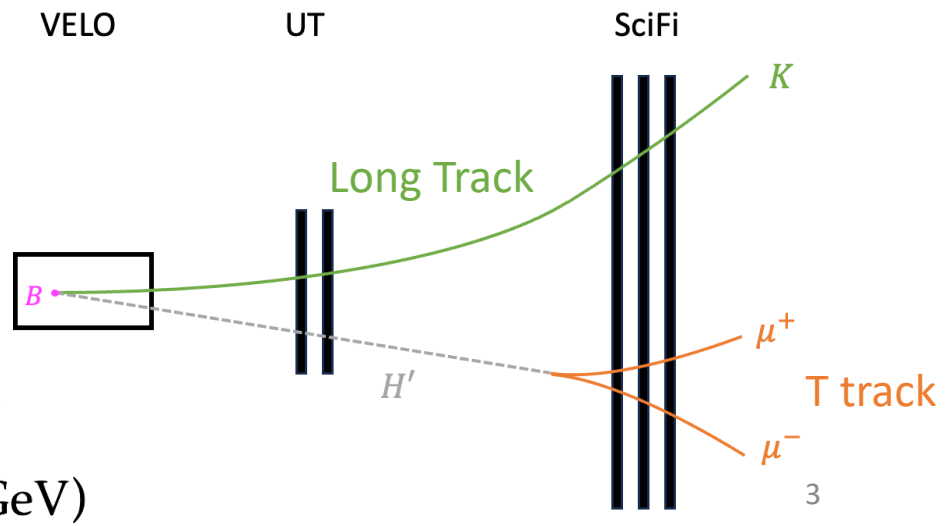
Figure by B. Shuve

T-track region (decay length 2.5-7.5 m)

T-track region of interest

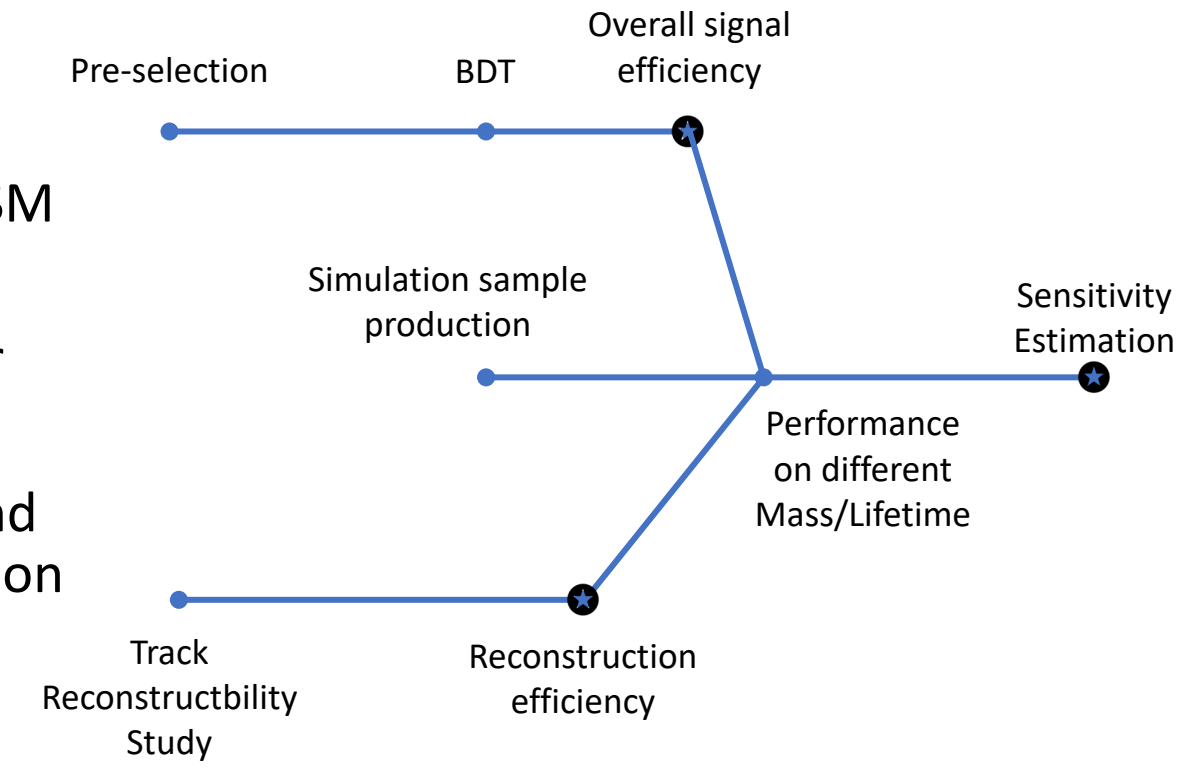
$H'(\rightarrow \mu^+\mu^-)$ region

- Long-lived particles are predicted in many BSM theories
  - Low-mass, long-lifetime Higgs H'
- One possible decay channel: $B \rightarrow H'(\rightarrow \mu^+\mu^-)K$
- Mass range:
  $2m_\mu(212\ \text{MeV}) \leq m_{H'} \leq m_B - m_K(4700\ \text{MeV})$



Sensitivity study: Roadmap and Milestones

- Characterize the performance of LHCb reconstruction with T-tracks for BSM LLPs
- Identify possible selections for dedicated BSM triggers and analyses
- Combine these into sensitivity estimates for different masses and lifetimes
- Estimate sensitivity as a function of mass and lifetime based on selection and reconstruction efficiency



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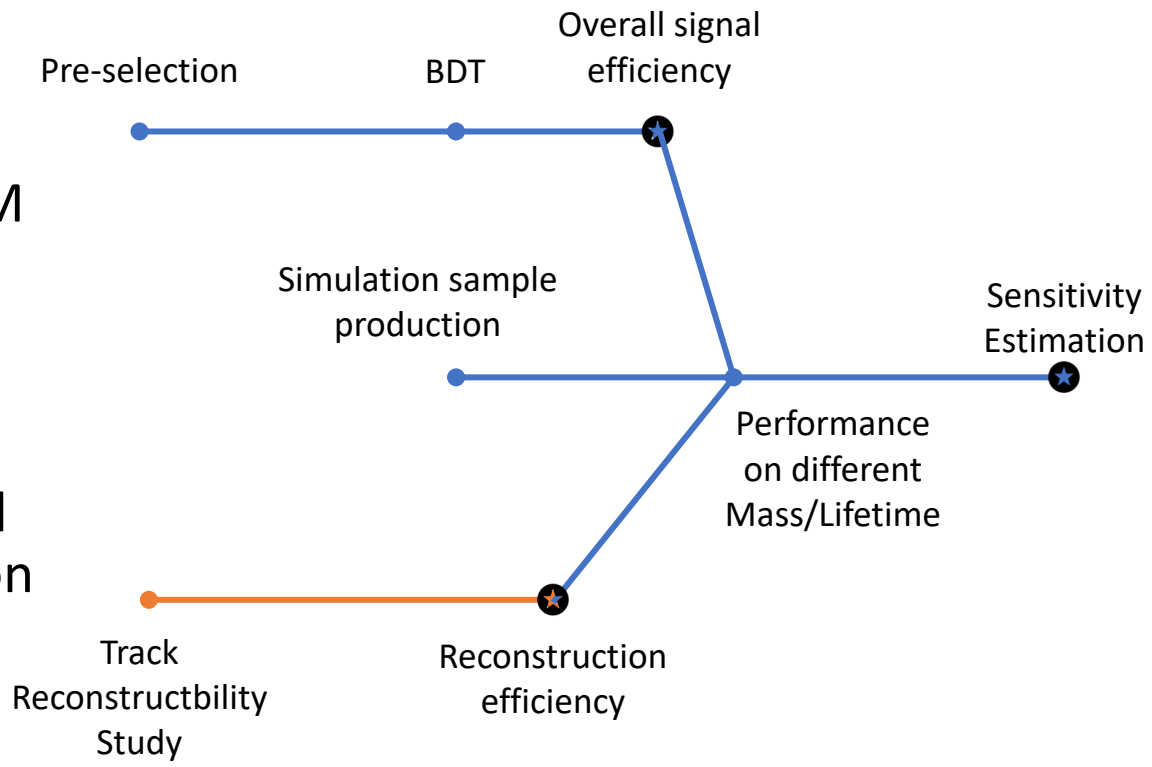

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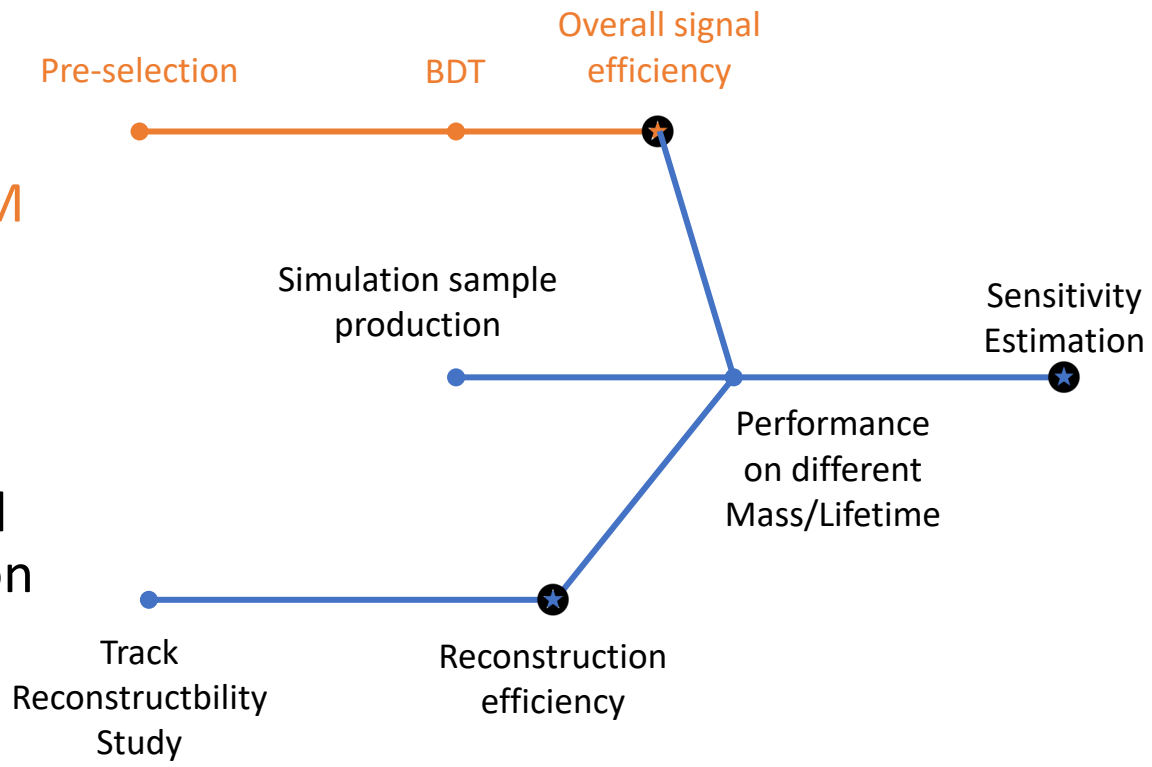

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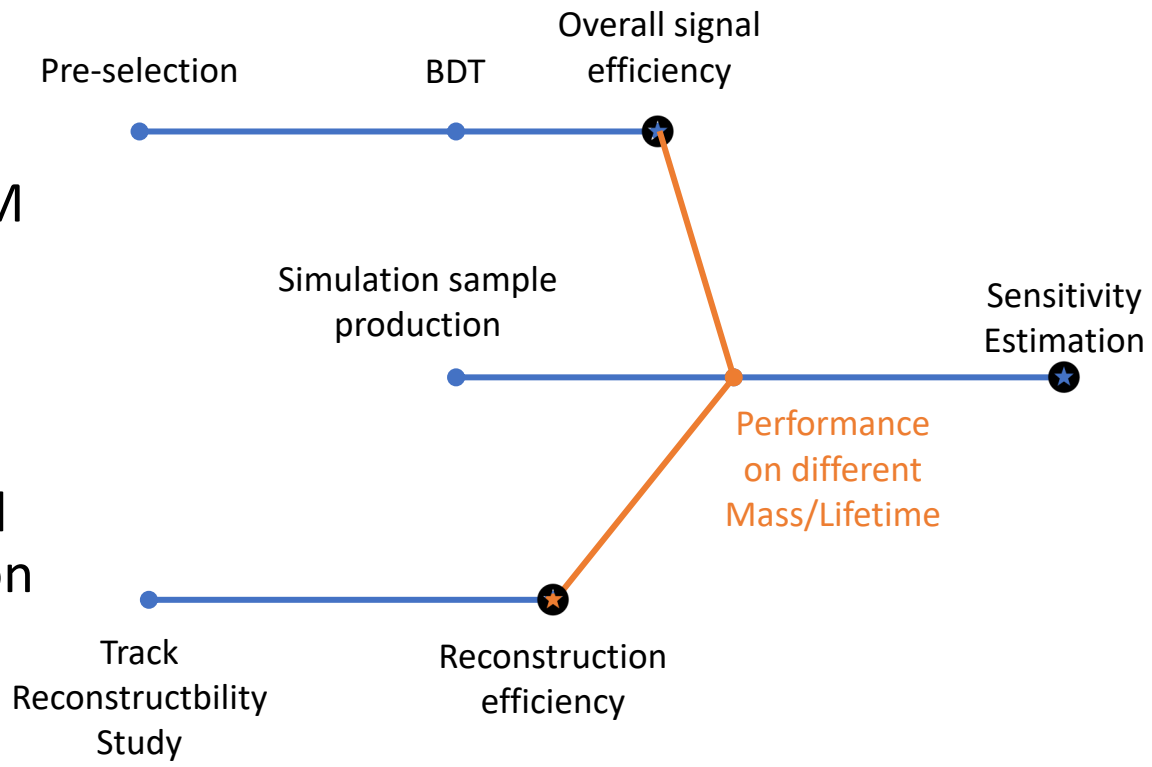

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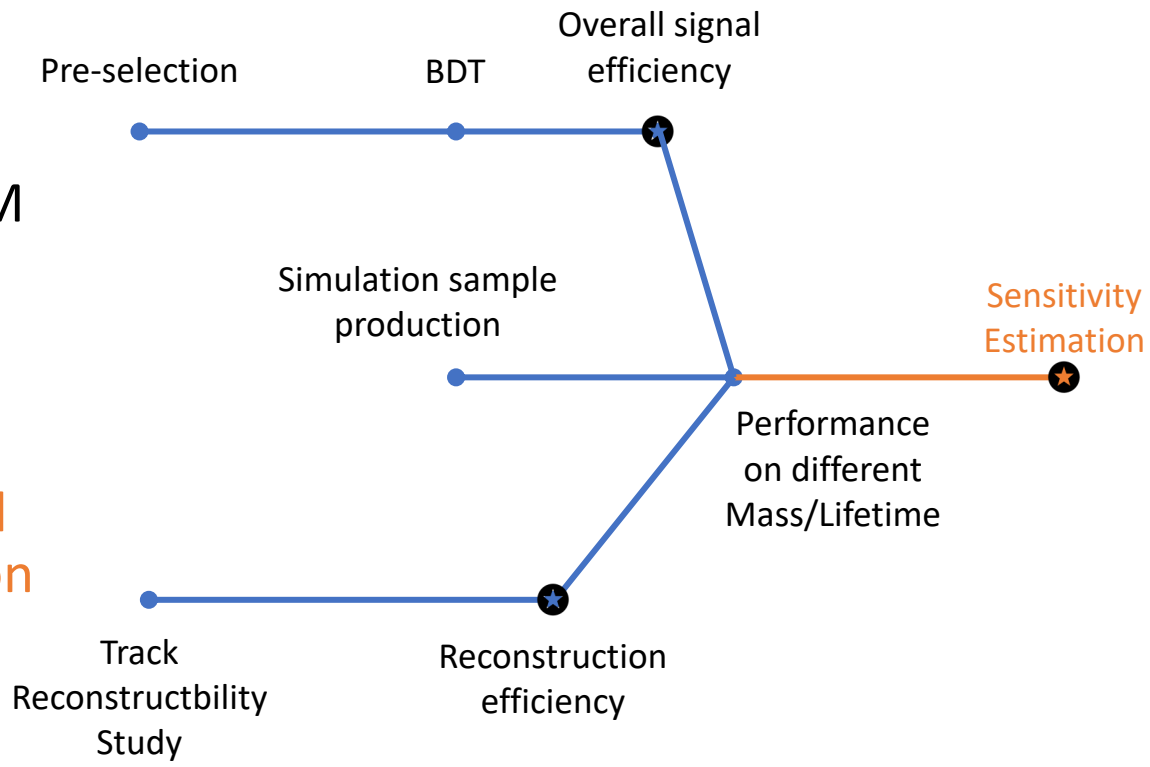
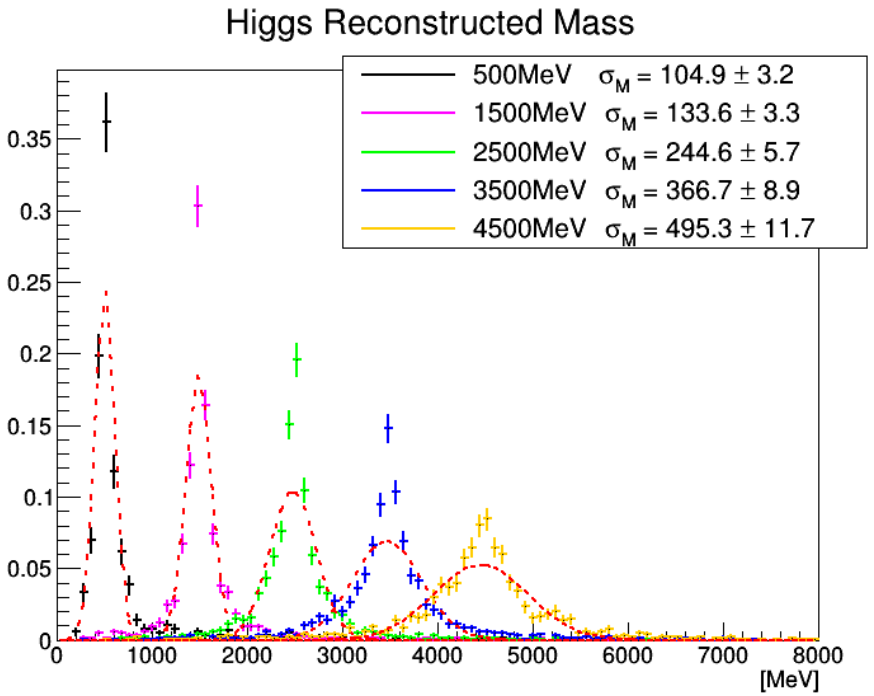
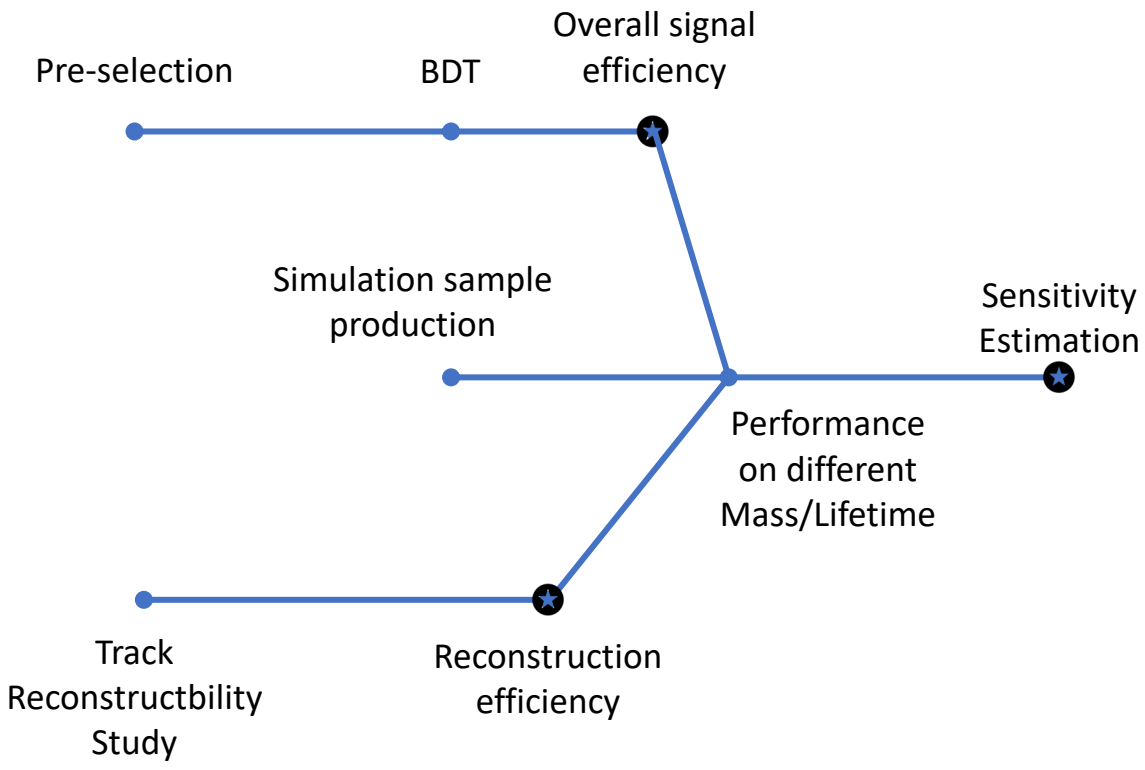


Sensitivity study: Roadmap and Milestones

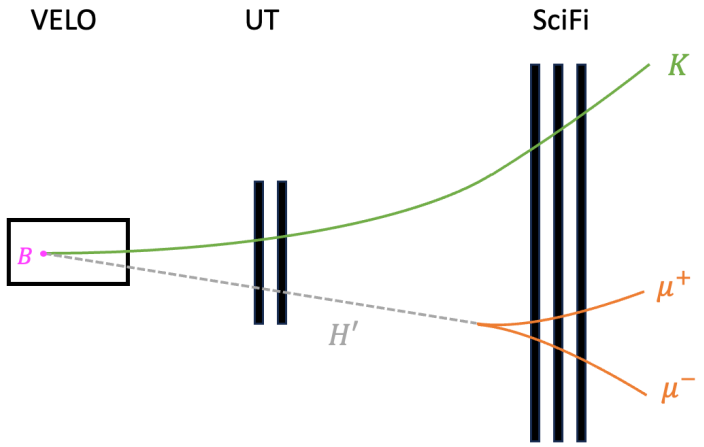
H' mass reconstruction from pure signal



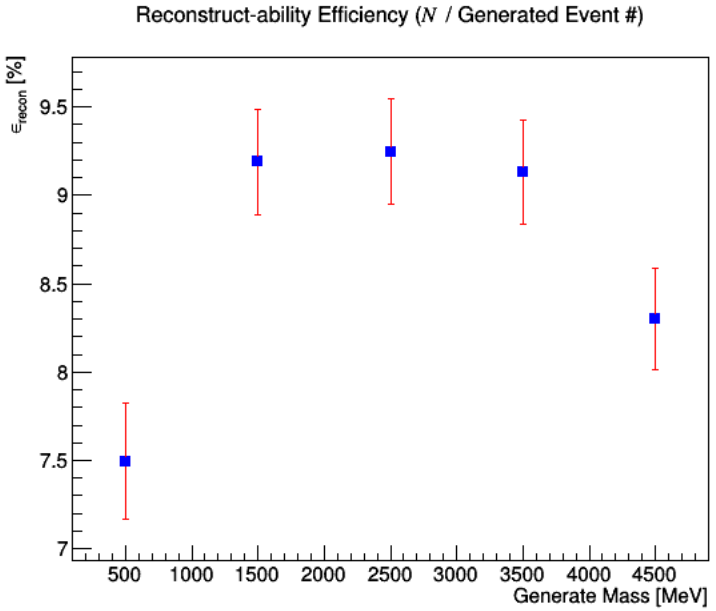
The mass resolution of a ‘perfect’ selection
The upper limit we can reach



Reconstruction performance study

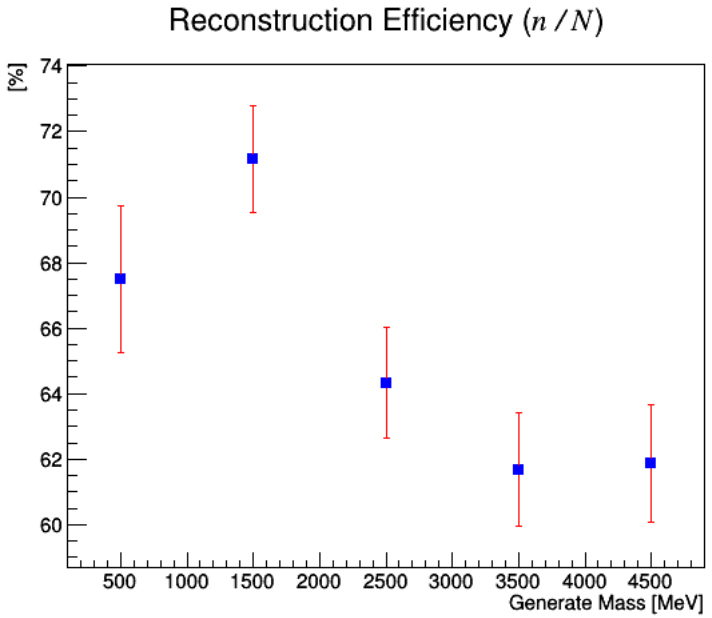


- Event of interest: n
  - K reconstructed as Long-track && $\mu^+\mu^-$ reconstructed as T-track (3-track reconstruction process)
- "Reconstruct-able" events: N
  - Kaon leaves hit on UT, SciFi && Muon pair leaves hit on SciFi (in principle they should be reconstructed)



Less than 10% of all generated events can be reconstructed. Low-mass H' has lower efficiency

Around 70% of 3-track "reconstruct-able" events can eventually be reconstructed

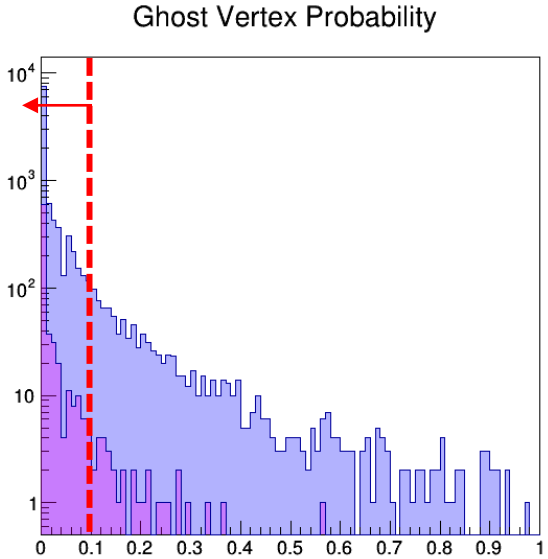


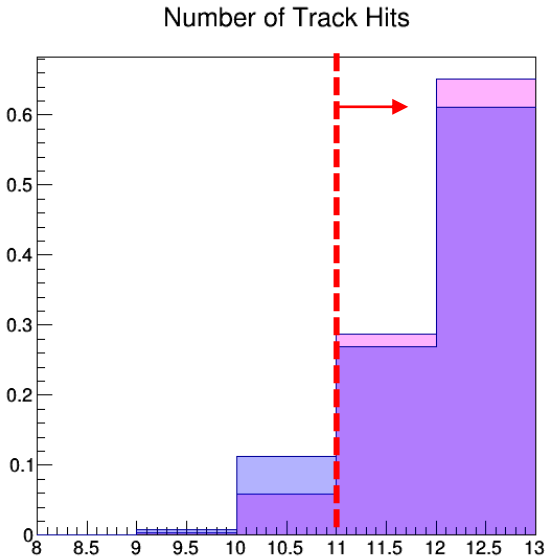
* No muon ID from Muon System for now
* With H' decay vertex z > 2500 mm

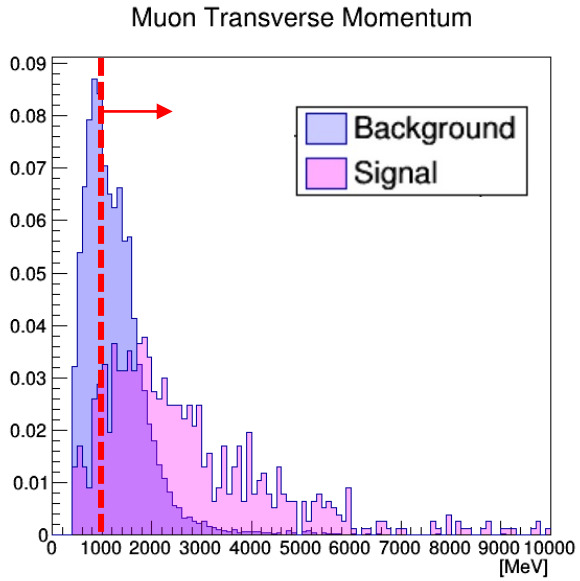
Preselection cuts

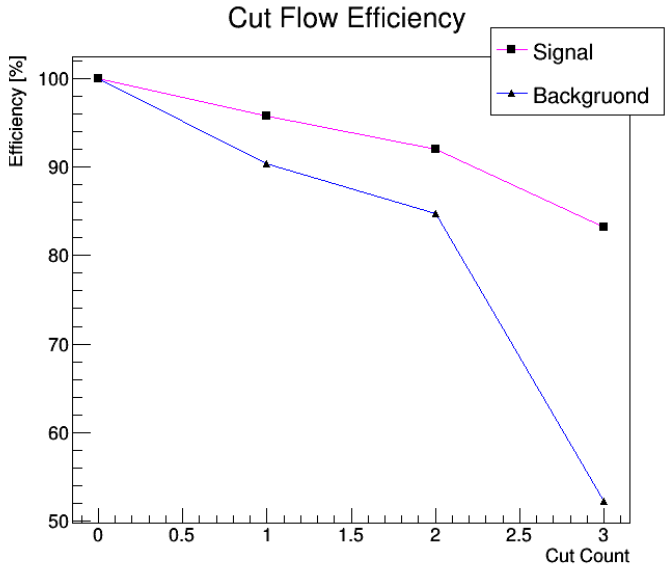
- Signal: Particle is Muon (Particle ID == ±13) && Decay from H' (Mother Particle ID == 25)

Cuts	Single **in** % (Saparate)	Background **in** % (Saparate)	Signal **in** % (Cut Flow)	Background **in** % (Cut Flow)
mu_plus_GHOSTPROB < 0.1	95.6975	90.2918	95.6975	90.2918
mu_plus_NHITS>10	93.7419	88.0284	92.0469	84.7105
mu_plus_PT > 1000	89.309	59.7128	83.1812	52.2134





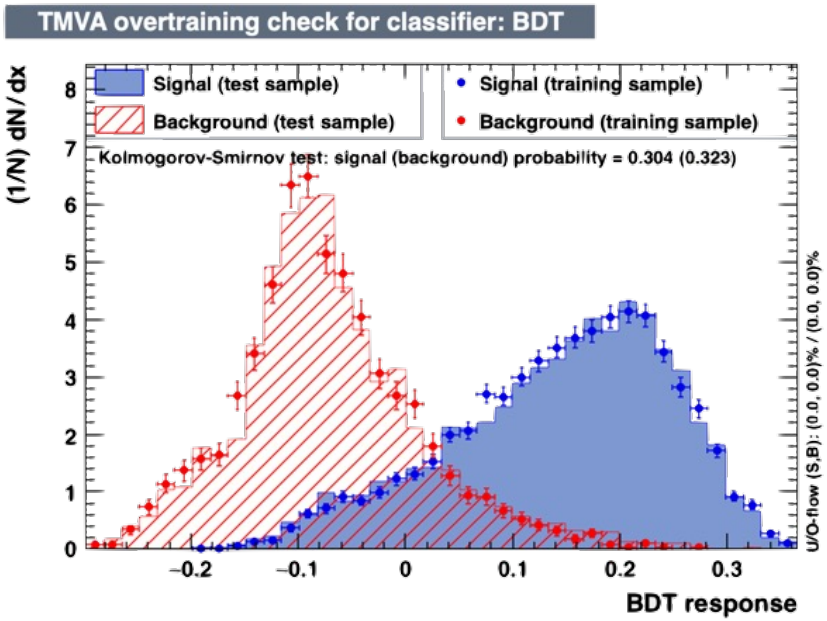


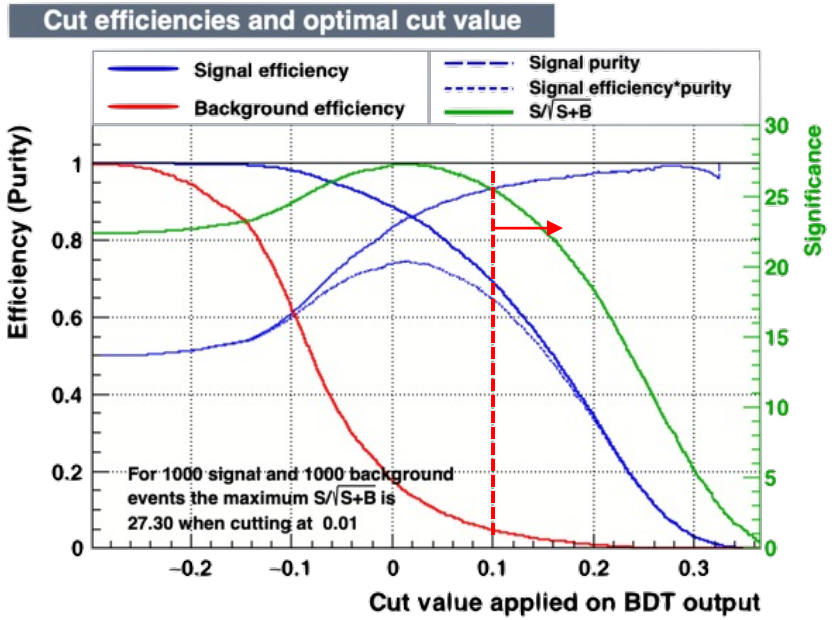


* No muon ID from Muon System for now

* With H' decay vertex z > 2500 mm

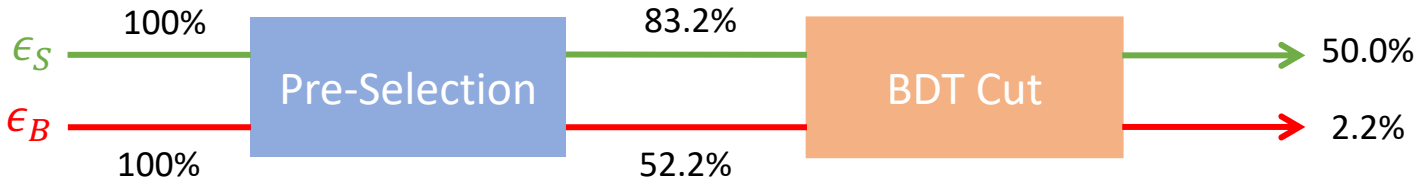
Boosted Decision Tree (BDT)





- No sign of overtraining
- Discriminating threshold: 0.1
- Signal efficiency: 56%
- Background efficiency: 15%

- Variables used in BDT:
  see backup slides



- Overall signal efficiency: 50.0%
- Overall background efficiency: 2.2%
- Adjustment according to subsequent combined selection analysis:
  - $\mu^+ + \mu^- \rightarrow H'$
  - $H' + K \rightarrow B$

* No muon ID from Muon System for now
* With H' decay vertex z > 2500 mm

Conclusion & Future Prospects

- T-track, which has hardly been utilized before, can be an excellent probe for long-lived particle research
- Some BSM predicts a Higgs with light mass and a long lifetime, being suitable to search using T-track information
- The reconstruction study shows less than 10% of all events can be reconstructed, and among these 60-70% are eventually reconstructed, both of which vary with mass
- A pre-selection and BDT cut have been performed on a single mass sample (2 GeV), with an overall signal and background efficiency of 50.0% and 2.2% respectively

- Based on muon selection, develop the selection for H' and B
- Verify selections work across different masses and lifetimes, adjust/separate selections if necessary
- Review theoretical predictions, current experimental limits, reconstruction and selection efficiencies to estimate sensitivity

Thanks!

Any questions are welcome!

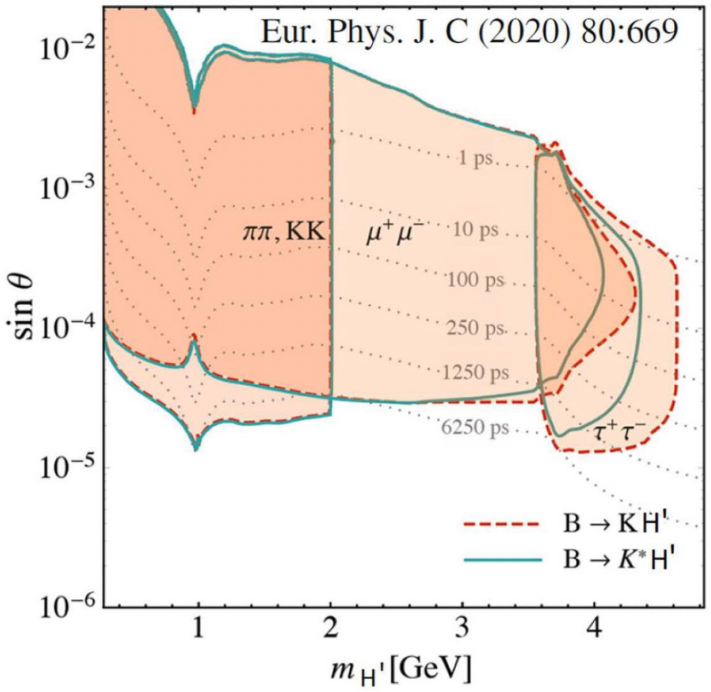
Backup

Backup - BSM Higgs

$B \to H'(\to \mu^+\mu^-)K$

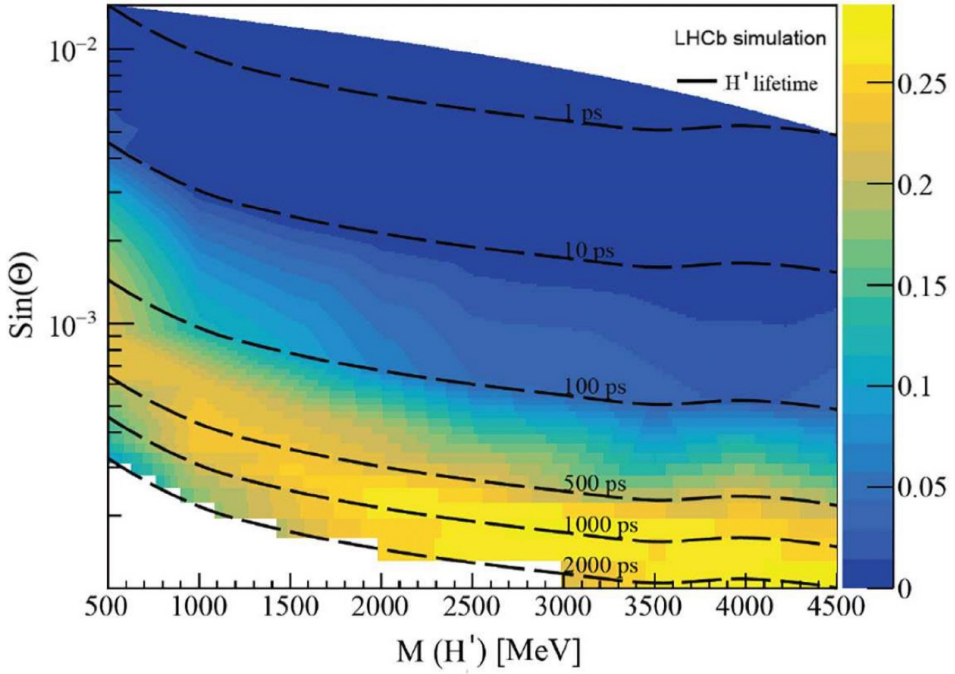
- A mixed state of low-mass Higgs H' and SM Higgs H: portal to the dark sector

$$h = H\cos\theta \; - H'\sin\theta$$



H' mass, mixing angle and lifetime

https://doi.org/10.1140/epjc/s10052-020-8240-z

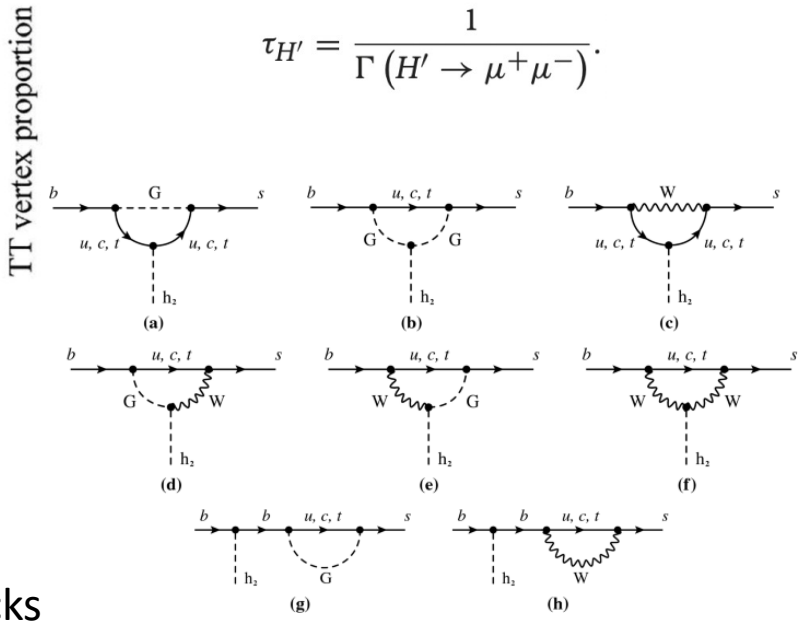


Reconstructibility of $H' \to \mu^+\mu^-$ with 2 T-tracks

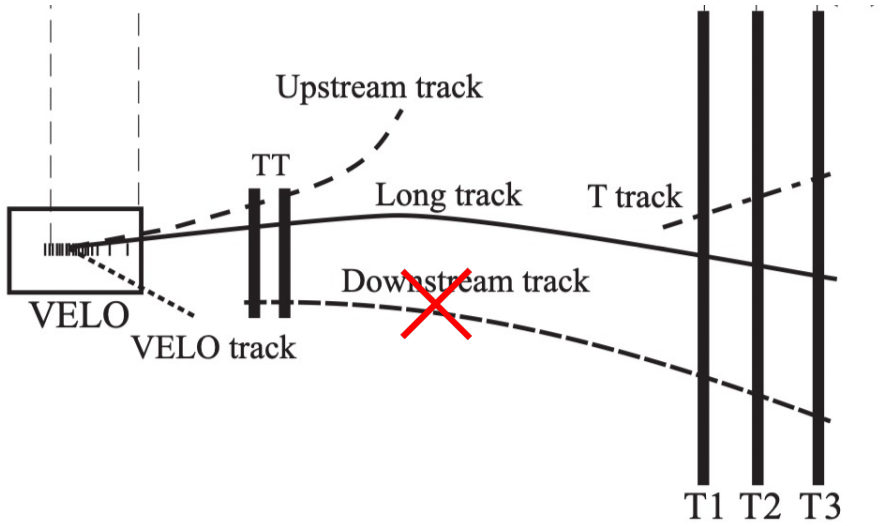
https://doi.org/10.3389/fdata.2022.1008737

$$\Gamma\left(H' \to \ell\ell\right) = \sin^2\theta \frac{G_F m_{H'} m_\ell^2}{4\sqrt{2}\pi}\left(1 - \frac{4m_\ell^2}{m_{H'}^2}\right)^{3/2}$$

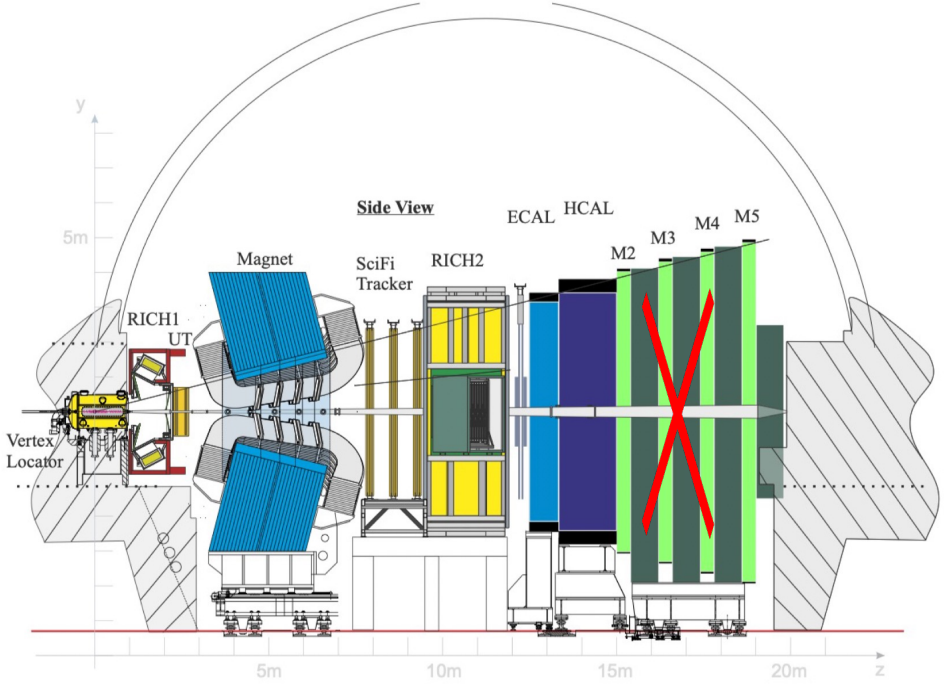
$$\tau_{H'} = \frac{1}{\Gamma\left(H' \to \mu^+\mu^-\right)}.$$



Backup - Technique issues



Malfunction of UT -> Downstream-track also reconstructed as T-track
Currently need manually select decay vertex z > 2500 mm



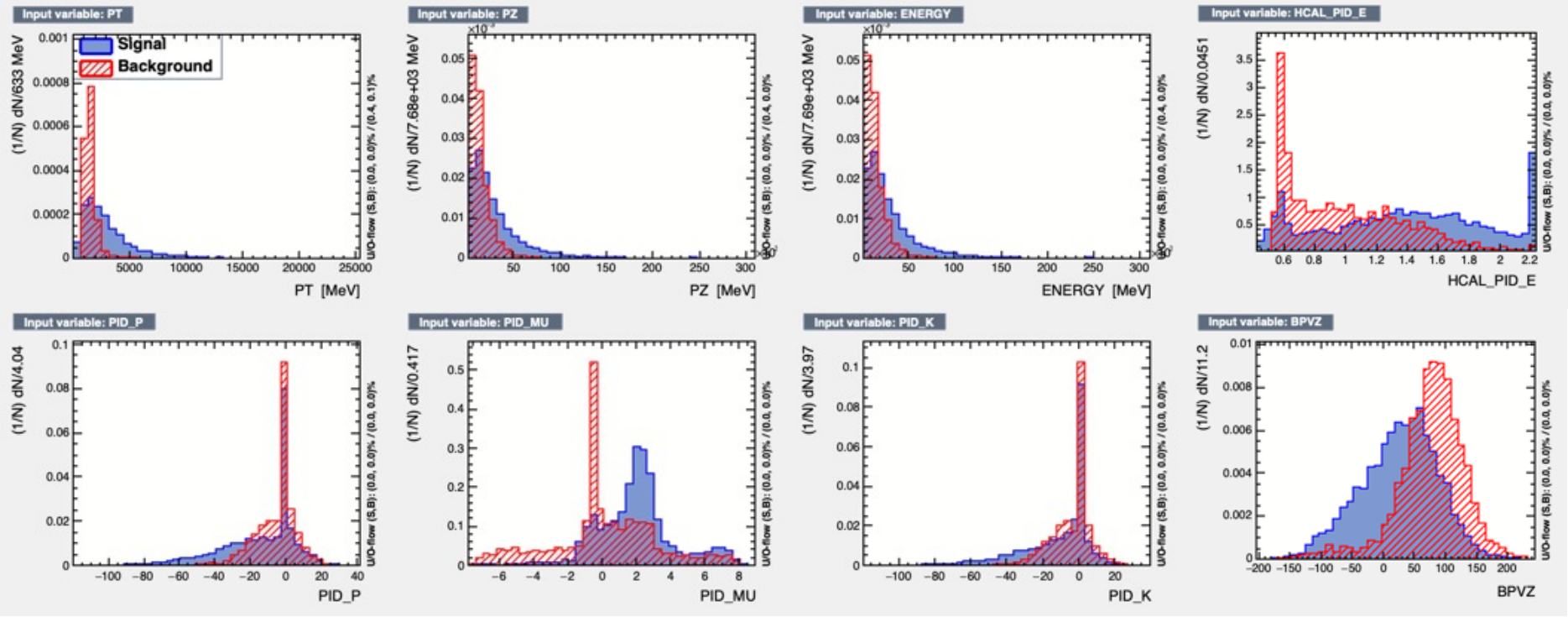
Muon system information is currently unavailable
For now, we only use PID Mu from RICH

Backup – BDT variables

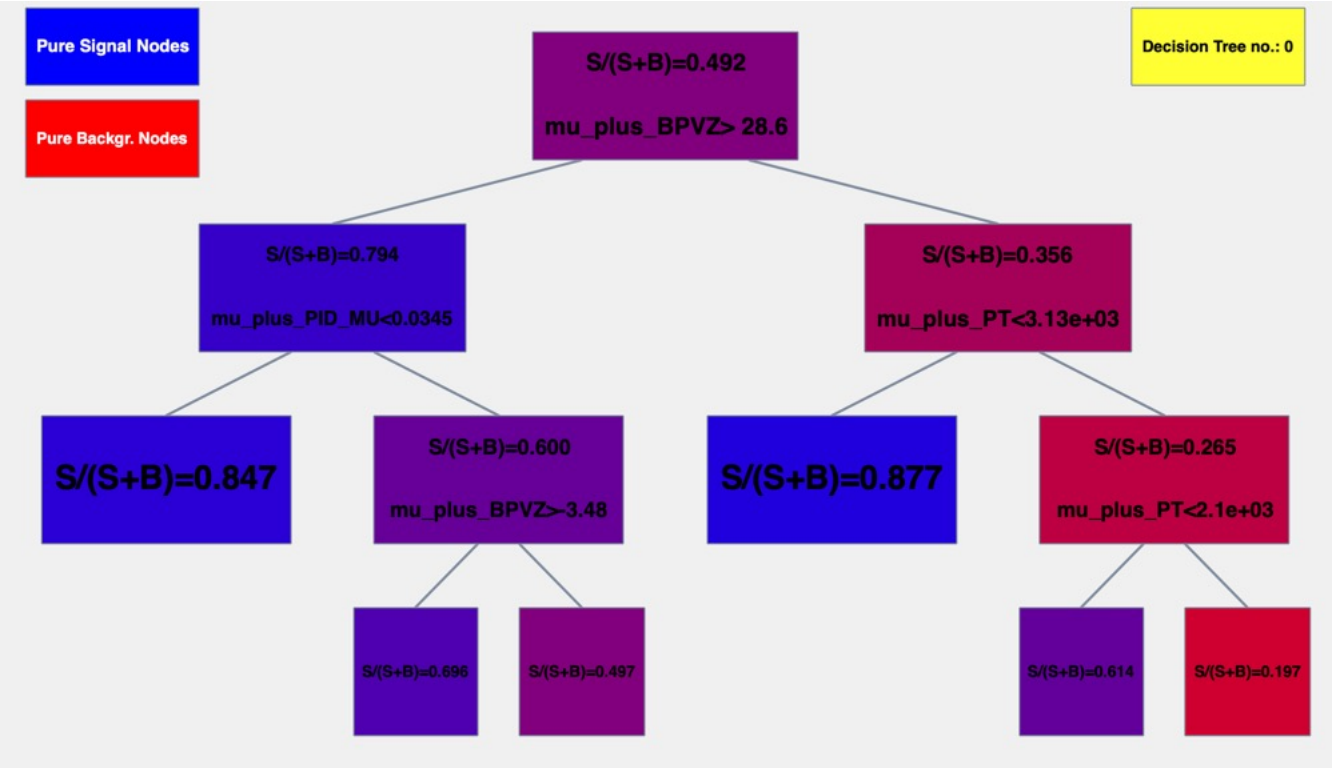
- Input Muon variables:

  Transverse momentum, Z momentum, Energy, PID e/μ/K, HCAL PID e, Best Primary Vertex Z

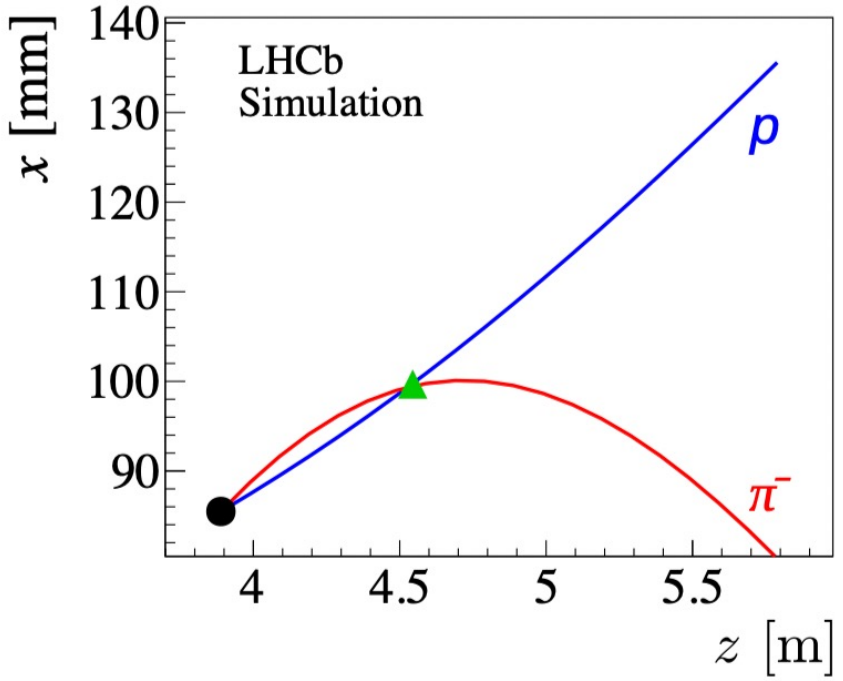
- Signal: 500 – 4500 MeV, Background: 2000 GeV (larger sample is producing)

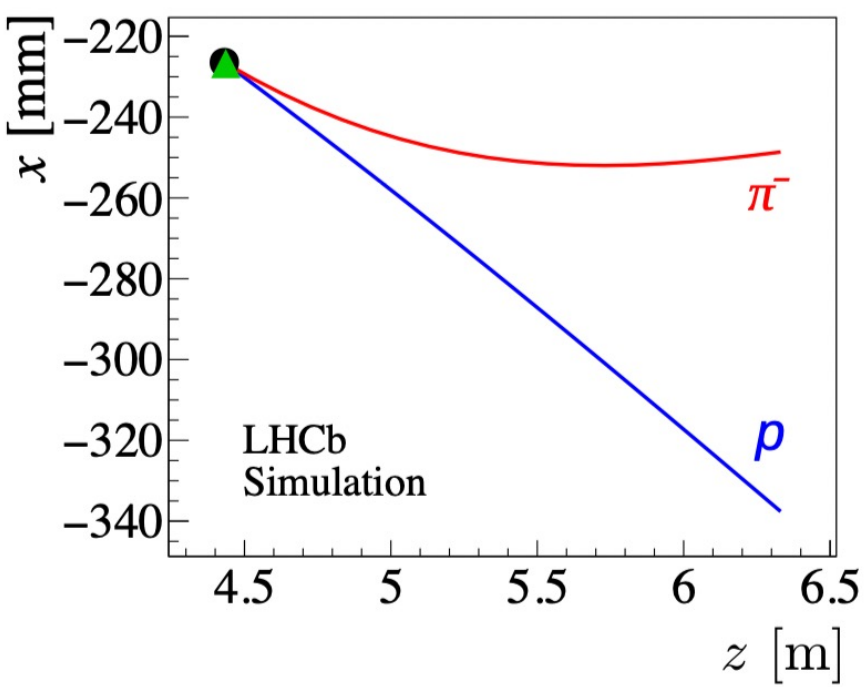


Backup – BDT decision tree



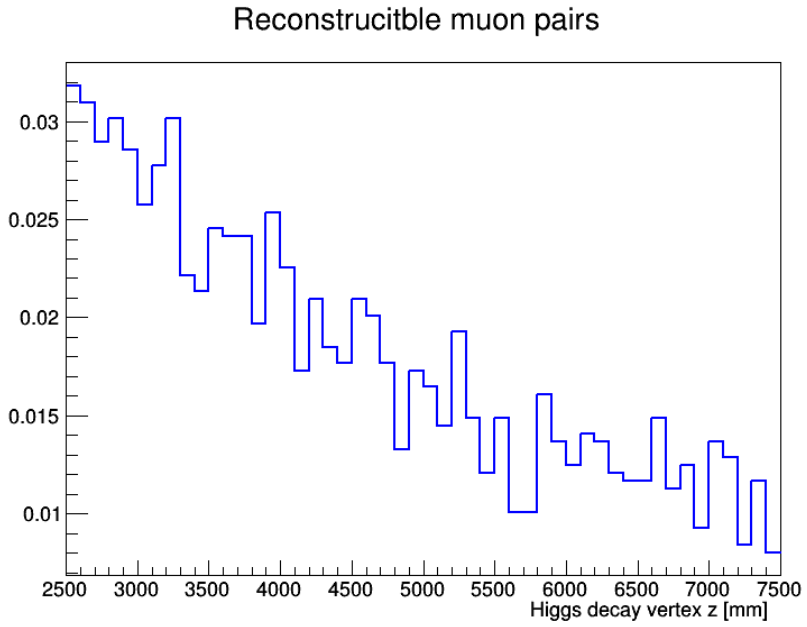
Backup - Ghost Vertex



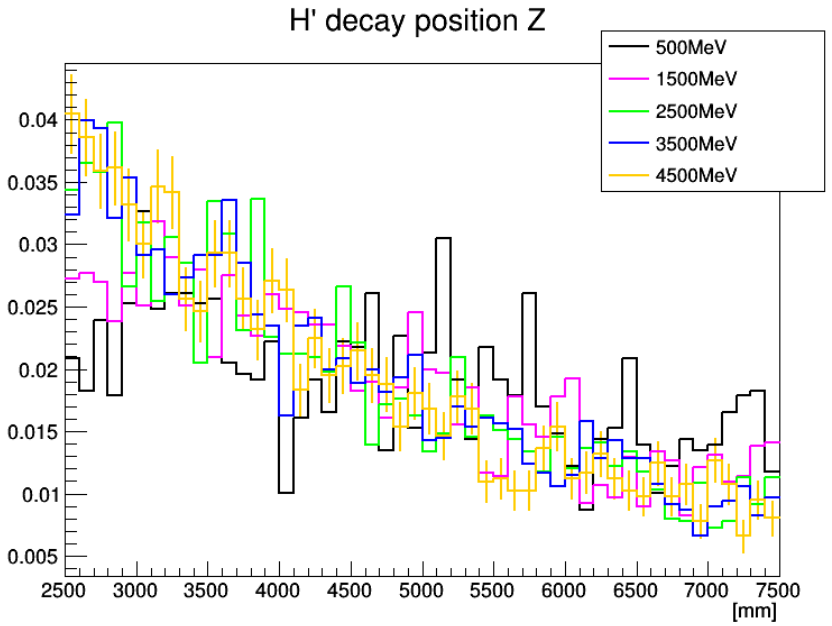


Green triangle: reconstructed vertex
Black dot: true vertex

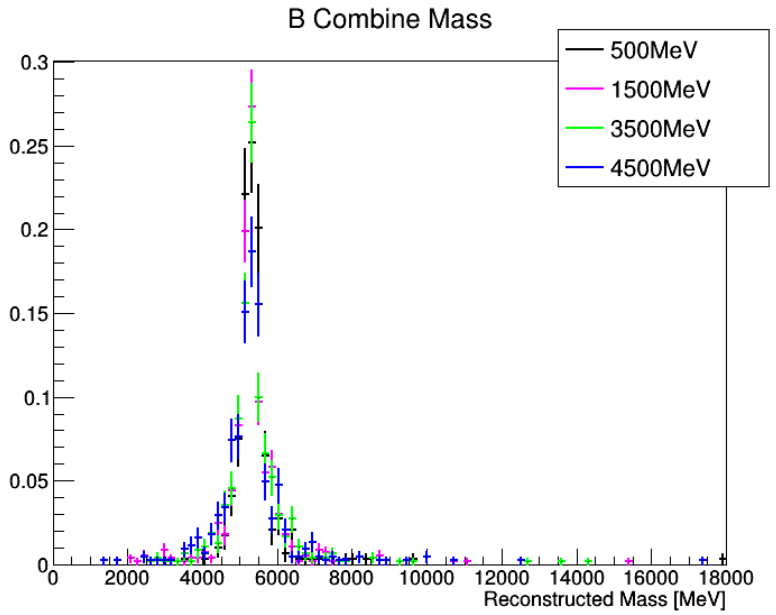
Backup – Other Plots



Reconstructibility – vertex position



Decay vertex position – H' mass



Reconstructed B mass