Detector performance for Higgs physics measurements at muon collider

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Higgs Physics at Muon Collider

- A Muon Collider could be the ideal machine to study Higgs physics, since muons collisions can take place at **high energy and luminosity**
- It puts together the **advantages of lepton colliders** (all the beam energy available for collisions) and **hadron colliders** (negligible energy loss via beamsstrahlung and synchrotron radiation).

Parameter	Target Value		
Centre-of-mass energy [TeV]	3	10	14
Luminosity [10^{34} cm^{-2} s^{-1}]	1.8	20	40

- Challenge:

  the Beam Induced Background, produced by muons decay in circulating beams, may affect detector performance

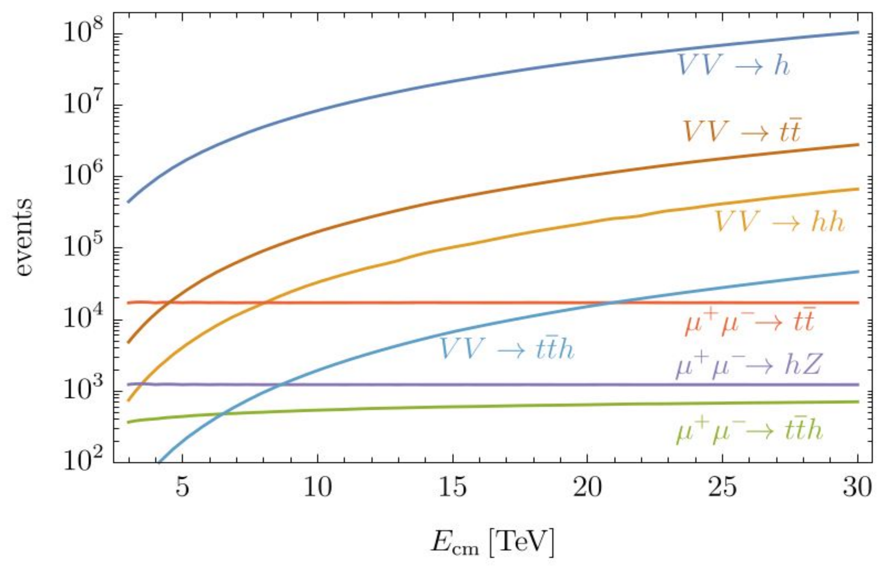


Figure: *Expected number of events for different processes as a function of E_{CM} [1]*

The Beam-Induced Background (BIB)

- O(10^8) BIB particles enter the detector at every bunch crossing (for a 750 GeV beam with ~$2\cdot10^{12}$ muons, $4\cdot10^5$ decays/m of lattice are expected)
- Although BIB levels in the detector can be mitigated with tungsten nozzles, **detailed simulation of detector and BIB** is crucial to determine **detector performance**
- BIB available for full simulation at 1.5 TeV, simulation at 3 TeV will be ready soon…

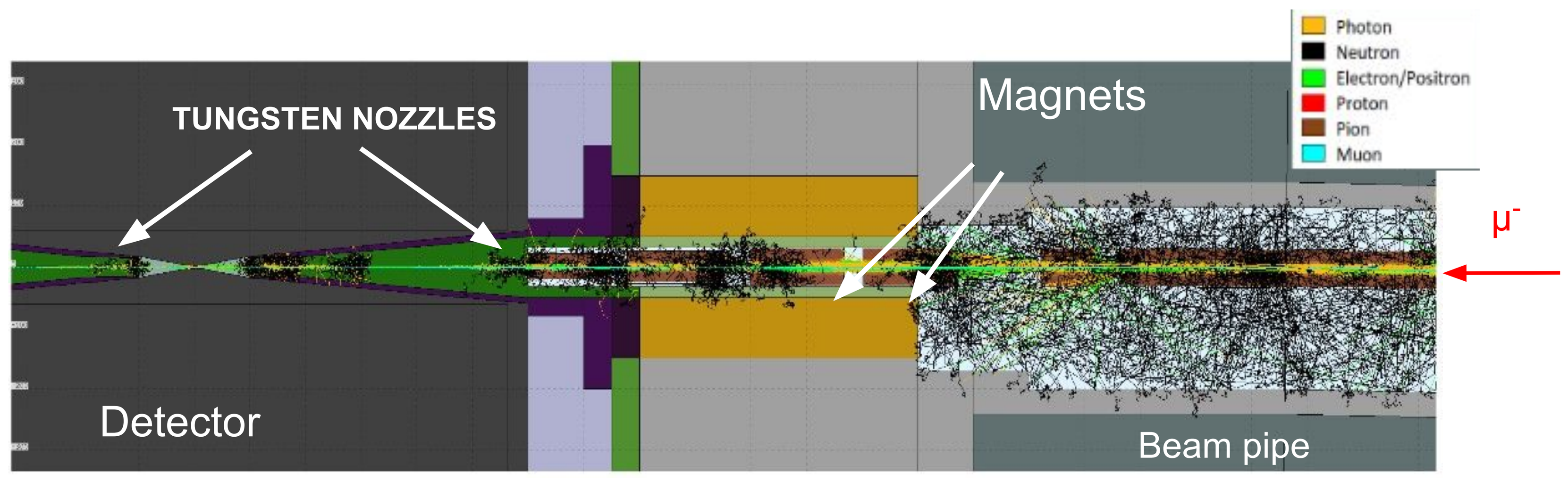


Figure: *Scheme of the detector and MDI with pictorial view of BIB particles tracks [2]*

BIB effects on Muon Collider Detector

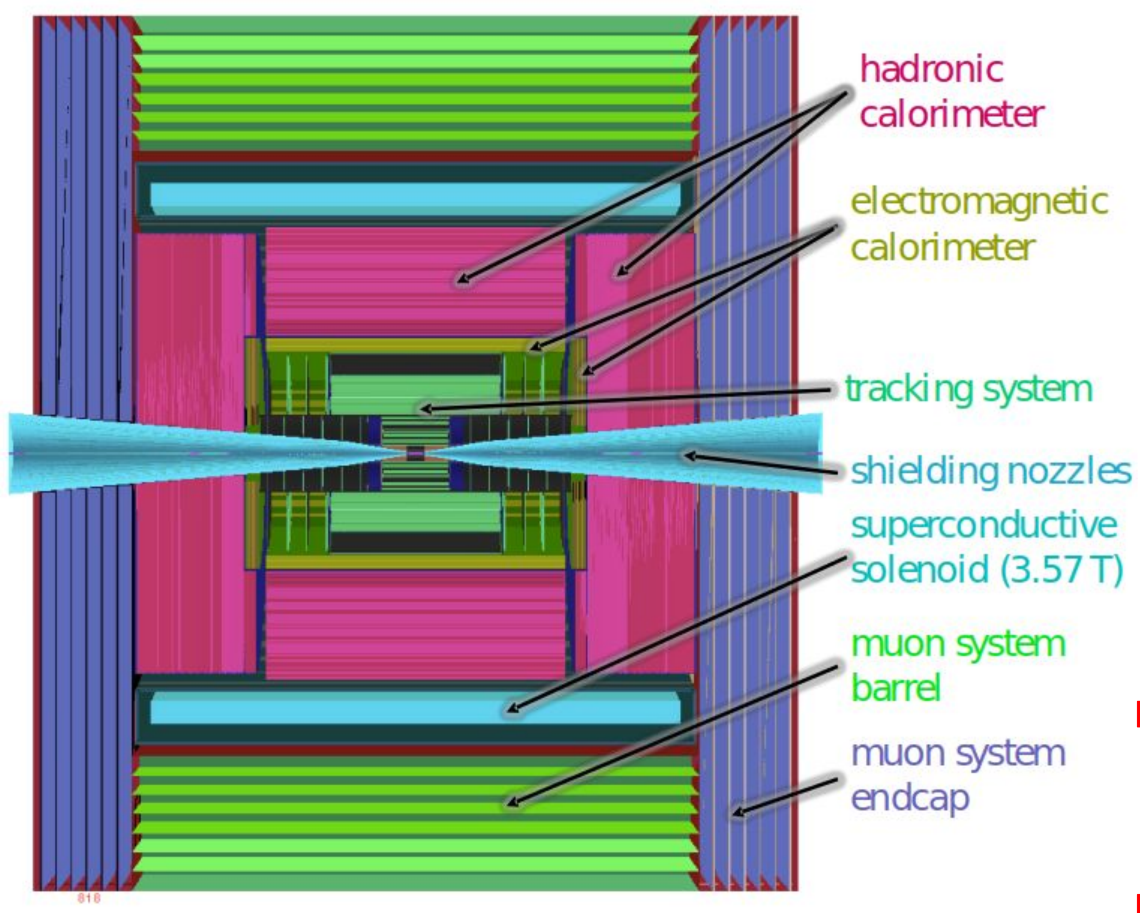


Figure: Scheme of the muon collider detector employed for the full simulation [3]

- **Large hits multiplicity** in the tracking system due to BIB particles
- **Diffuse BIB background** in the calorimeter: at the ECAL barrel surface the flux: 300 part/cm^2 , mostly photons with <E>=1.7 MeV

In the **reconstruction** of physics processes involving heavy flavour jets in the final state (such as H→bb), this implies:

- Large number of **fake tracks**
  - Large number of **fake secondary vertices** (SV)
- Large number of **fake jets**

→ **Most of BIB particles are asynchronous with respect to the bunch crossing: timing is crucial to remove tracker and calorimeter hits due to BIB**

→ **Energy threshold of 2 MeV is applied to calorimeter hits selection to reject BIB calorimeter clusters**

Track reconstruction performance

- Reconstruction of single muons events from IP [4]

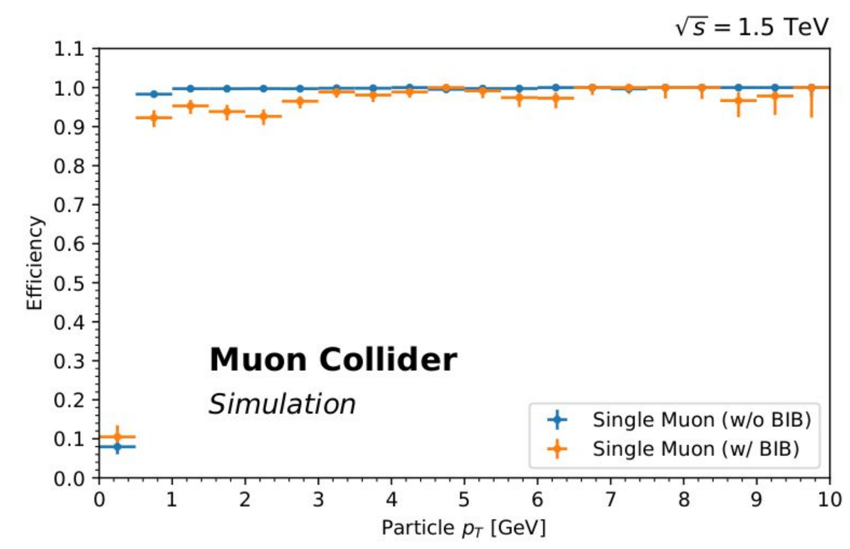


Figure (up): *track reconstruction efficiency as a function of the true muon transverse momentum*

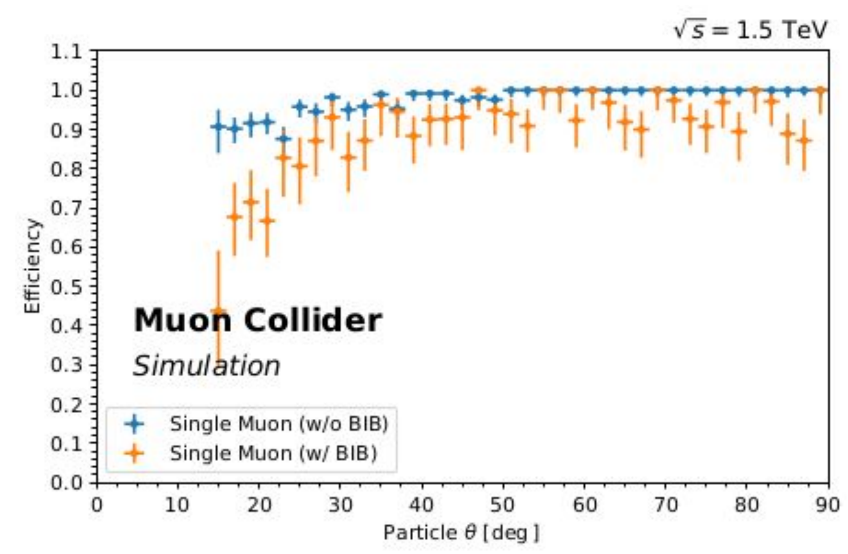


Figure (down): *track reconstruction efficiency as a function of the true muon polar angle*

→ **Combinatorial fake tracks due to BIB have low p_T (<2 GeV) and number of hits in the tracking system**

Heavy flavor jets identification

- Selection requirements on p_T, number of hits in the tracking system and tracks impact parameter to reduce fake tracks
- Primary Vertex (PV) reconstruction
- SV reconstruction: use tracks not compatible with PV [4]

→ **Further cuts are applied to reduce mistag and fake SV**

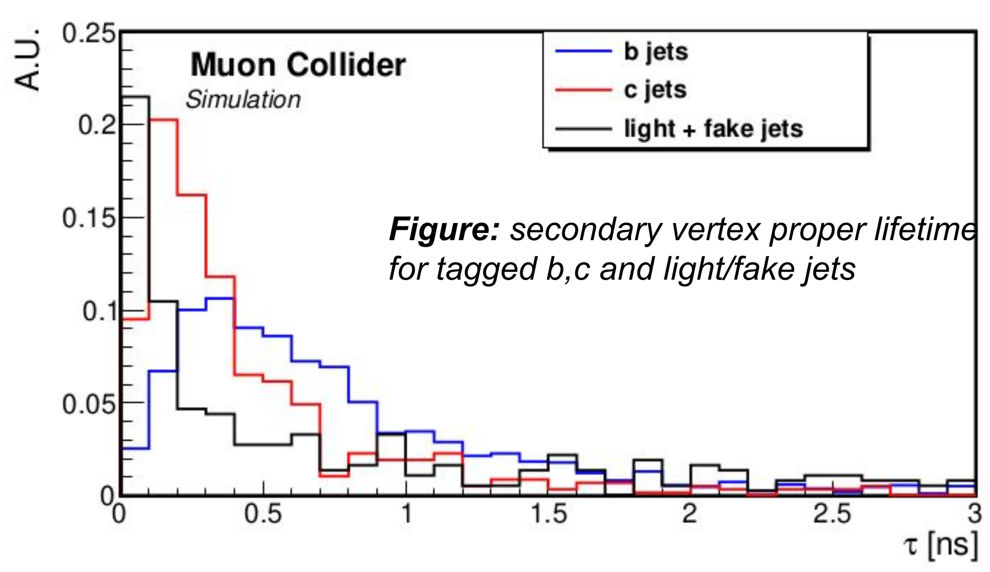


Figure: *secondary vertex proper lifetime for tagged b,c and light/fake jets*

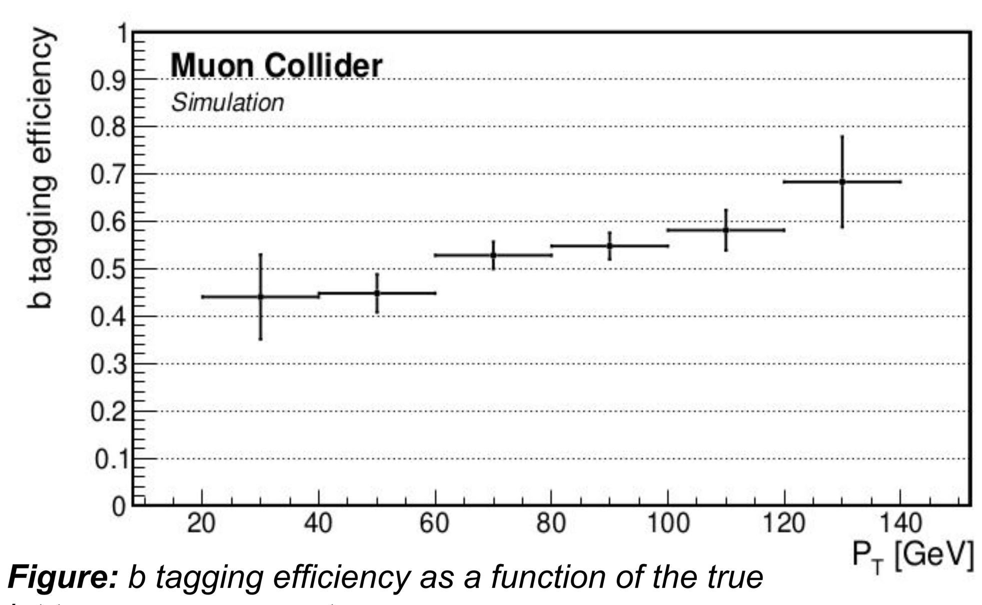


Figure: *b tagging efficiency as a function of the true jet transverse momentum*

★ **b jet tagging efficiency ~55%**
★ **Mistag on c jet ~20 %**
★ **Mistag on light and fake jets ~5%**

Jet reconstruction performance

- Combine tracks and calorimeter information to reconstruct particles, jet clustering with k_T algorithm [4]

→ **Requirement of at least one track into jets to remove fake jets**

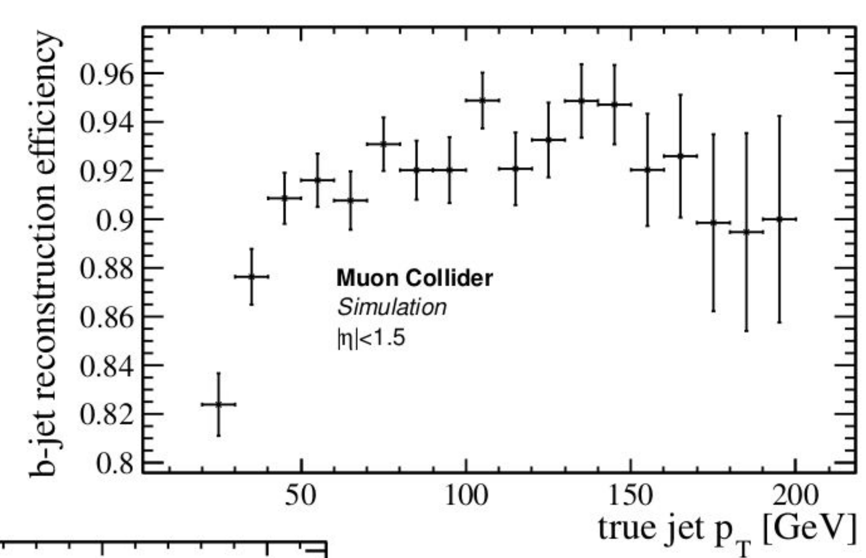
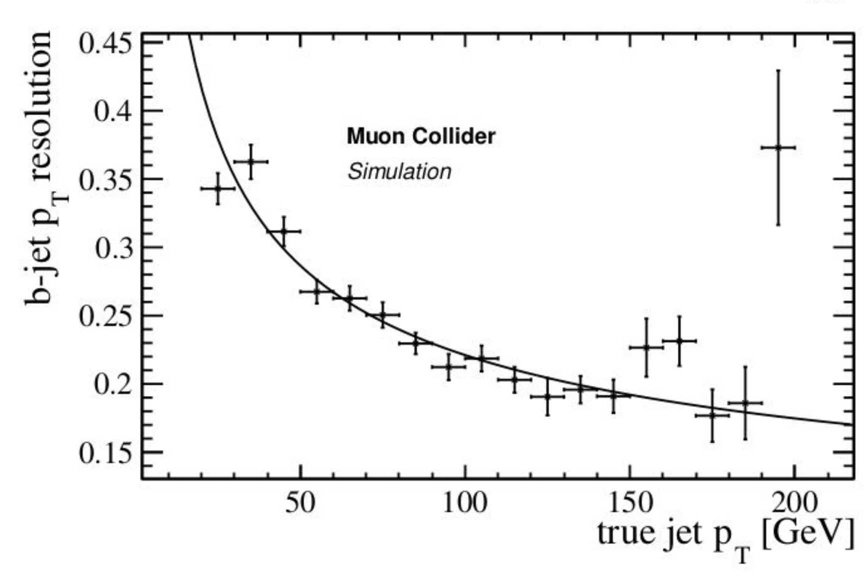


Figure (up): *jet reconstruction efficiency as a function of the true jet transverse momentum*



Figure(down): *jet transverse resolution as a function of the true jet transverse momentum*

Determination of the uncertainty on H→bb cross section

	Process	σ [fb] (3 TeV)	Events with $\mathcal{L}$=1 ab^{-1} (5 y data taking)
Signal:	$\mu^+\mu^- \to H\,\nu\bar{\nu} \to b\,\bar{b}\,\nu\bar{\nu}$	324.0	59500
Background:	$\mu^+\mu^- \to b\,\bar{b} + X$ and $\mu^+\mu^- \to c\,\bar{c} + X$	610.7	65400

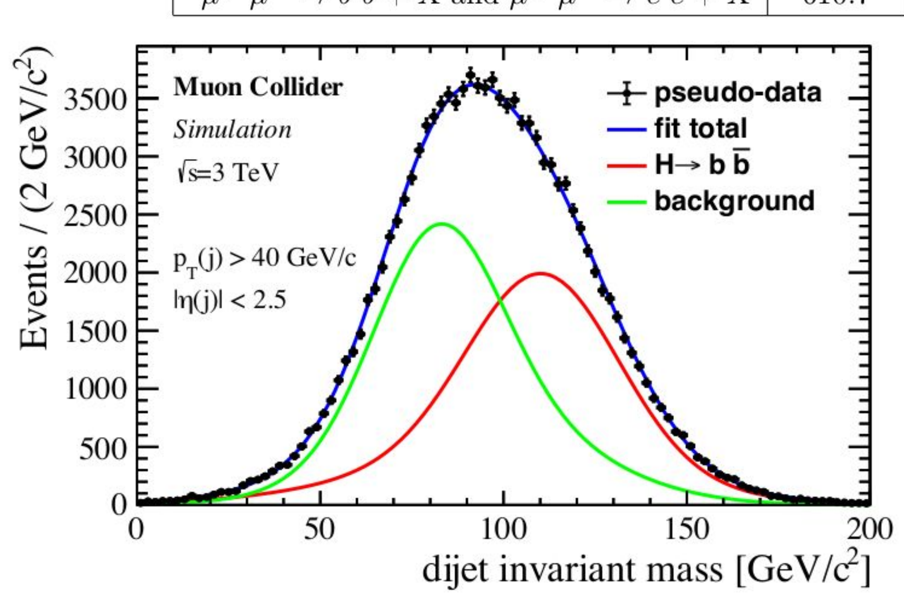
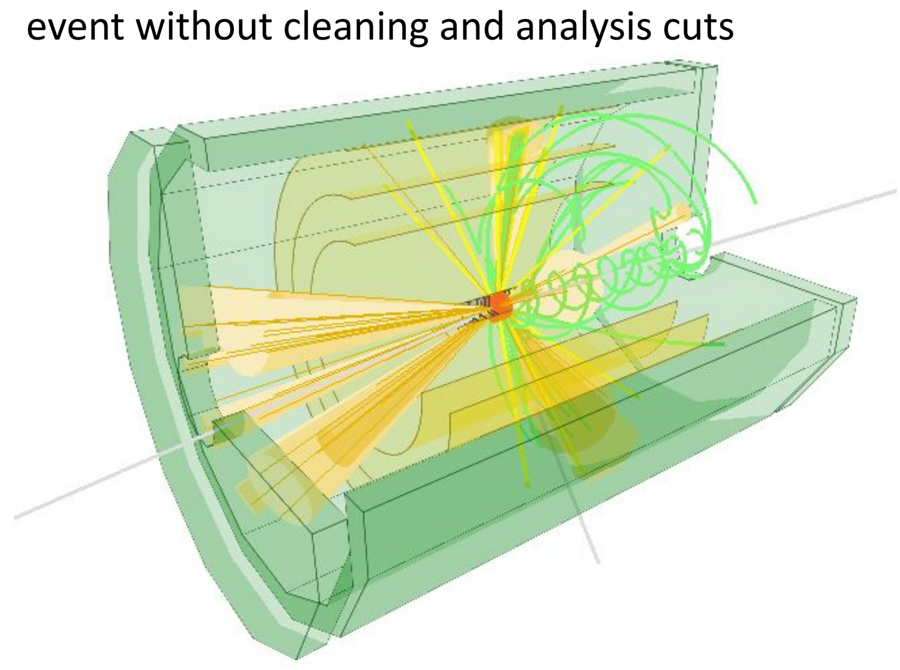


Figure: $\mu^+\mu^- \to H(\to b\bar{b})$+X reconstructed event without cleaning and analysis cuts



- Events selection:
  - Two tagged jets
  - M_{jj} <300 GeV
  - $|\eta^{jet}|$<2.5
  - p_T^{jet} > 40 GeV
- Fit of the invariant mass gives an expected statistical uncertainty on **σ($\mu^+\mu^- \to$H)•BR(H→b$\bar{b}$) of 0.75% at 3 TeV and 1.0 ab^{-1}**
- Results comparable with CLIC (0.3% with 2.0 ab^{-1}) [5]

REFERENCES:

[1] J. De Blas et al. In: 2022 **Snowmass Summer Study.** Mar. 2022. arXiv: 2203.07261

[2] F. Collamati *et al* 2021 *JINST* **16** P11009

[3] ILCSoft repository. url: https://github.com/iLCSoft.

[4] N, Bartosik et al. In: 2022 **Snowmass Summer Study.** Mar. 2022. arXiv: 2203.07964

[5] Abramowicz, H., Abusleme, A., Afanaciev, K. *et al. Eur. Phys. J. C* **77,** 475 (2017).

Conclusions:

- Very good detector performance even though detector configuration and reconstruction algorithms are not optimized