Muon Collider Activities

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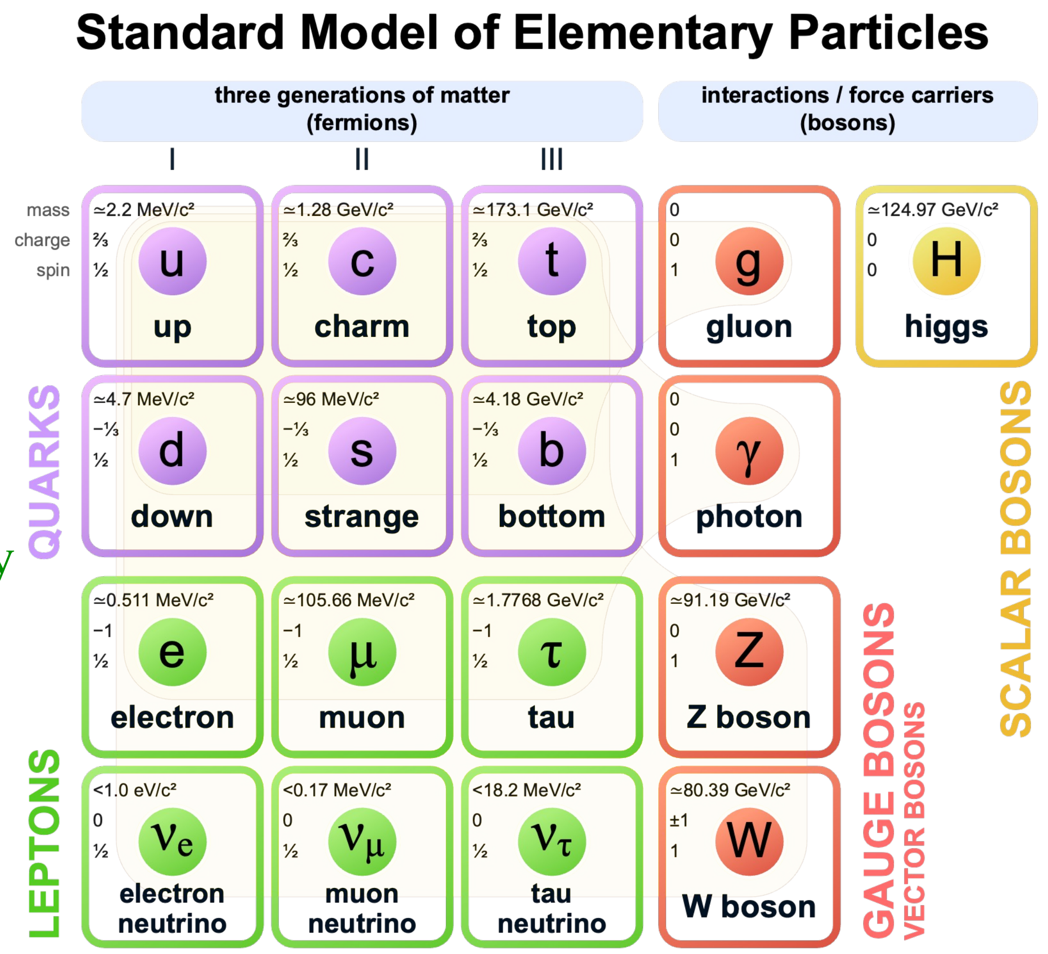
International MUON Collider Collaboration

The Standard Model, thanks to particle accelerators!

High-energy particle accelerators are marvelous tools for investigating short-distance, i.e., high-energy, interactions.

By means of accelerators, the experiments demonstrated that the theory, the so-called Standard Model, effectively describes the behavior of elementary particle interactions… up to a given energy.

None of the proposed models to extend the Standard Model to high energies have been experimentally confirmed.



Is there a future of high energy particle physics with accelerators?

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Experiments: study the Higgs boson to death!

Why a Muon Collider

Muons are fundamental point-like particles:
- ✯ well defined initial state and clean final states;
- ✯ collision energy fully available in the hard-scattering process.

Muons can be accelerated to a multi-TeV energy:
- low synchrotron radiation losses ($m_{\mu}/m_e \sim 200$)

⇓

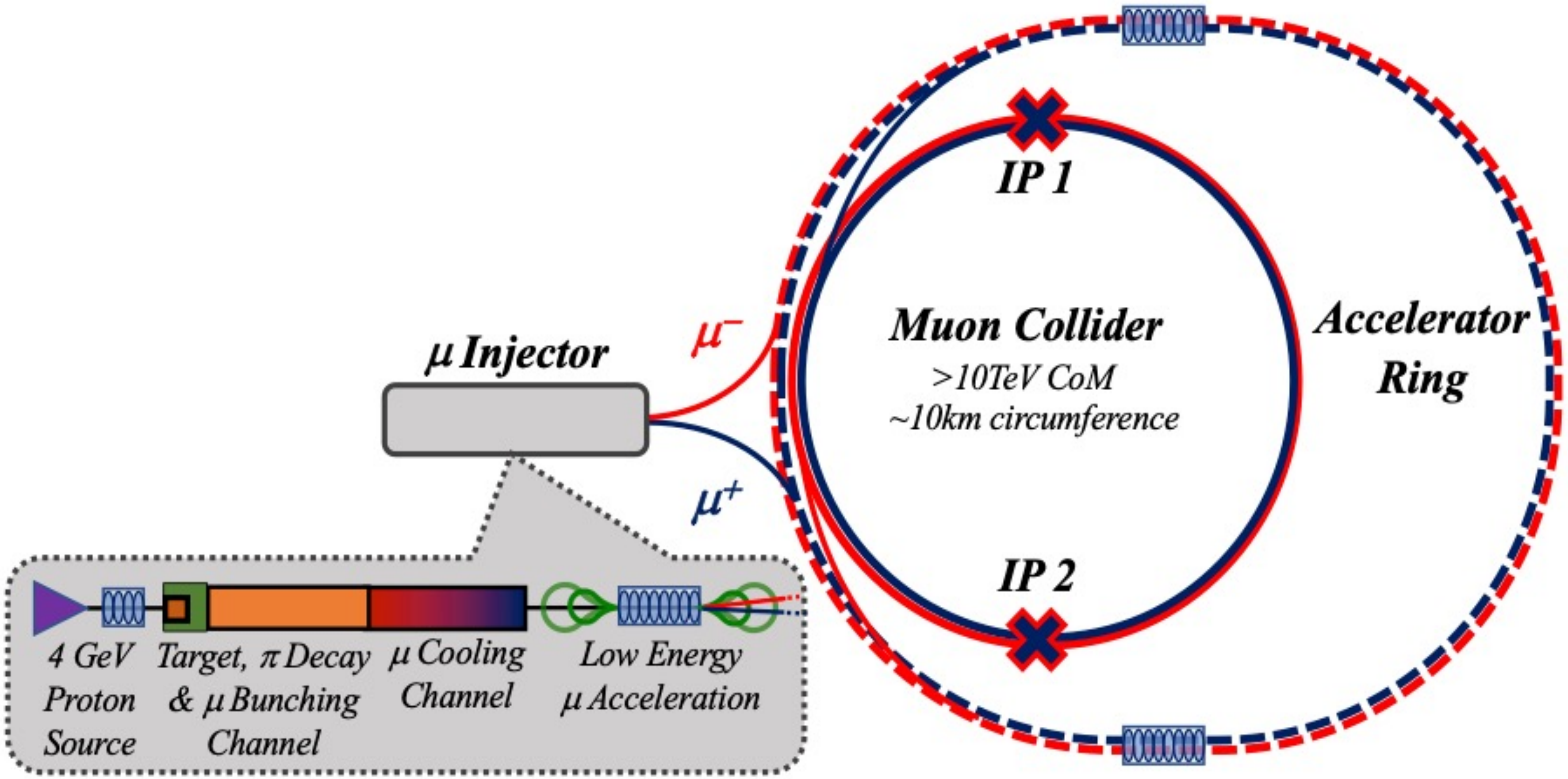
compact circular machine with a relatively small footprint
- no significant beam-strahlung
- high luminosity (a lot of events) in a short time

Target Integrated Luminosity in 5 years one experiment

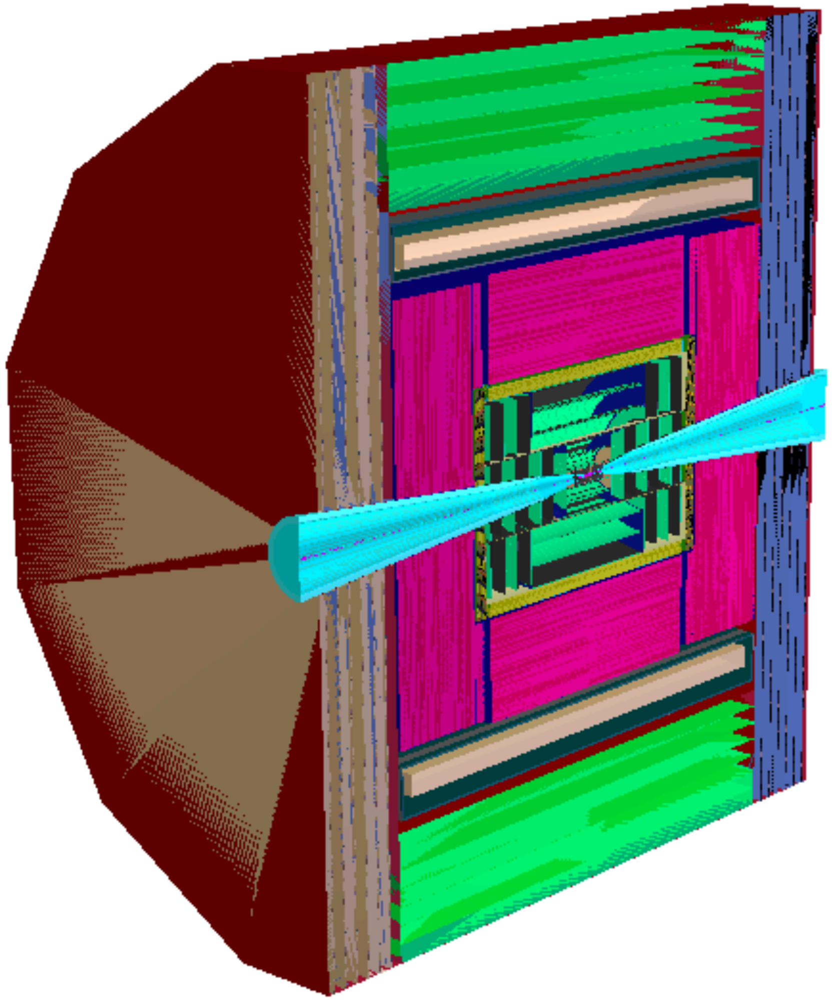
$\sqrt{s}$	$\int \mathcal{L}dt$
3 TeV	1 ab^{-1}
10 TeV	10 ab^{-1}
14 TeV	20 ab^{-1}

Therefore, muon collider is most power-efficient machine at high energies

Muon Collider Facility



Muon collider experiment detector at center-of-mass energy 3 TeV



hadronic calorimeter

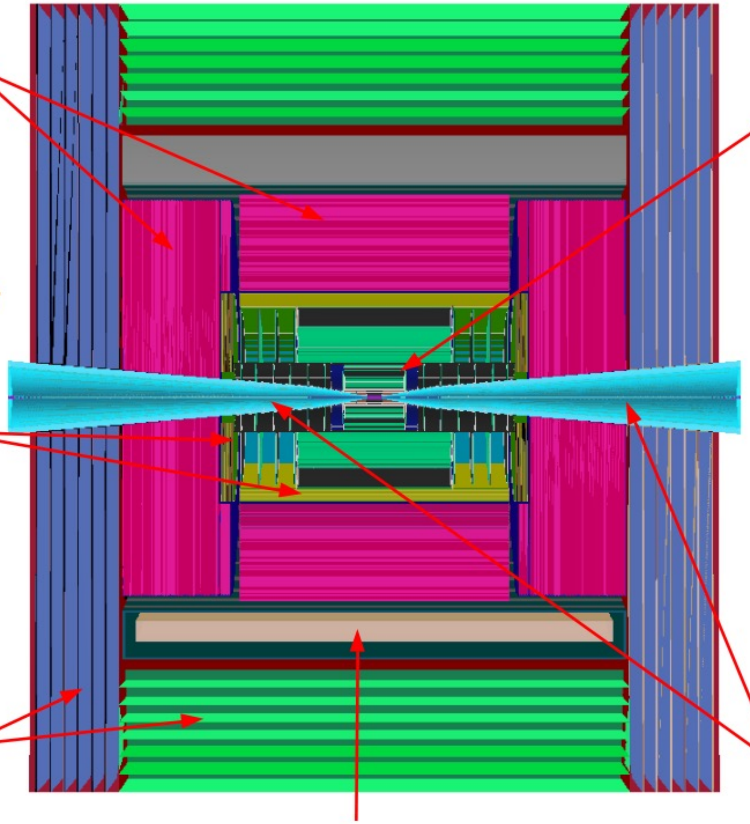
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm^2 cell granularity;
- 22 X_0 + 1 λ_I.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm^2 cell size.



superconducting solenoid (3.57T)

tracking system

- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 μm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 μm x 10 mm micro-strip Si sensors.

shielding nozzles

- Tungsten cones + borated polyethylene cladding.

Muon decay… the beam-induced background issue

Example:

$N_\mu \sim 2 \cdot 10^{12}$ per bunch, E_{beam}= 1.5 TeV ($\sqrt{s} = 3$ TeV)

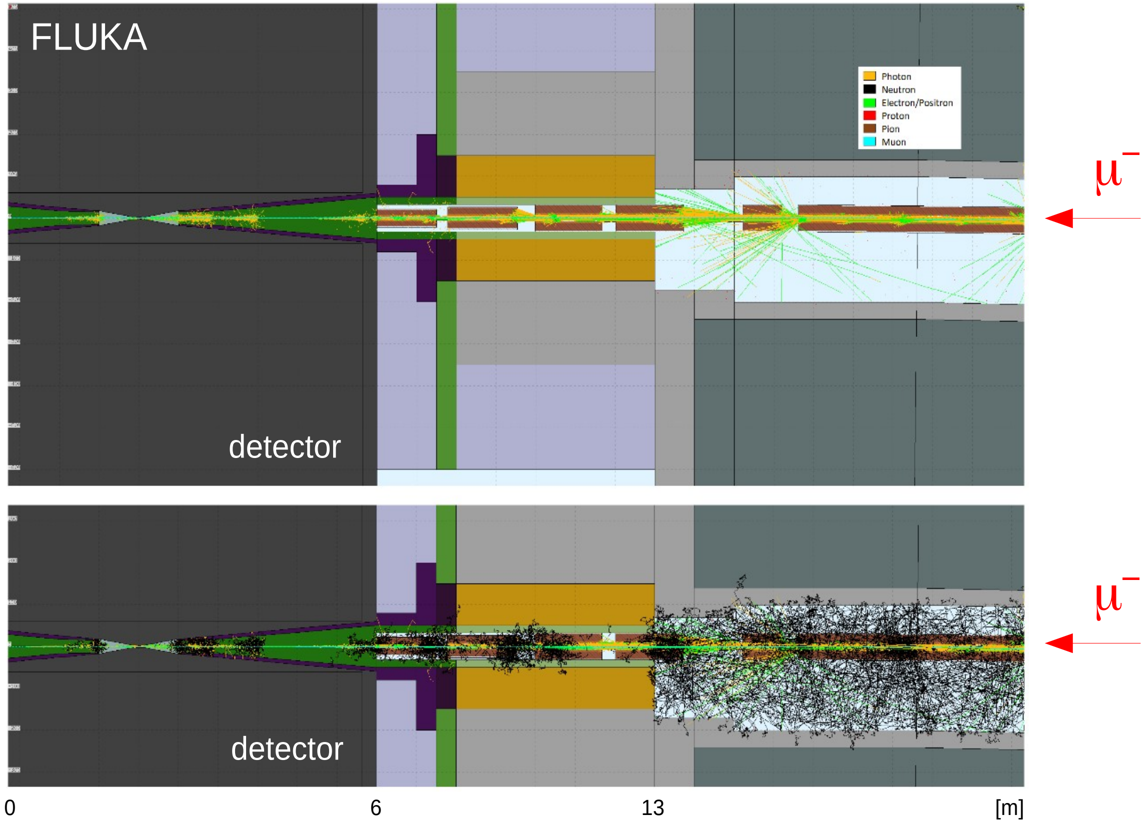
$\Rightarrow$ $2{\times}10^5$decays/meter of lattice

Current solution to protect detector:

the nozzles, two conical tungsten shielding structures cladded with borated polyethylene:

- reduce background particle flux into detector by 2-3 orders of magnitude;
- high flux of low momentum electrons/positrons, photons, neutrons, charged hadrons and muons still on detector;
- reduce detector acceptance.

F. Collamati *et al.*, 2021 JINST 15 P11009

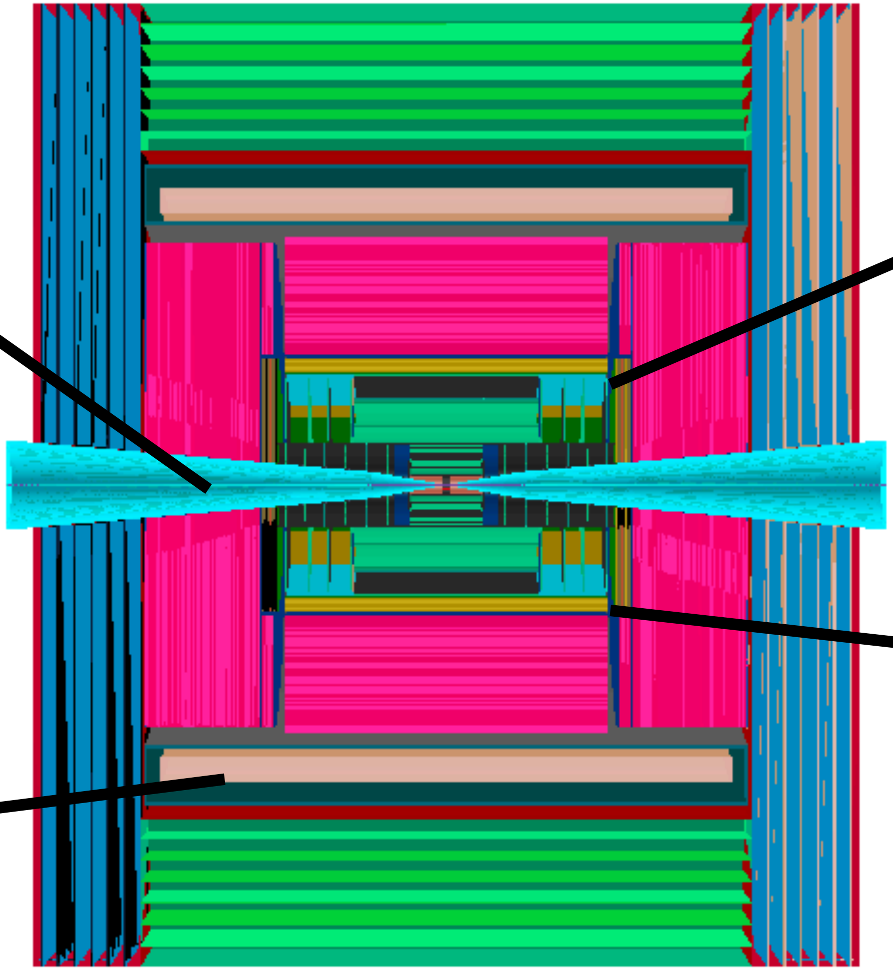


Possible thesis on accelerator physics and beam-induced background studies in collaboration with CERN and Fermilab

Design a detector for center-of-mass energy of 10 TeV

Never done before!

Optimize nozzle geometry



Tracker to be optimized

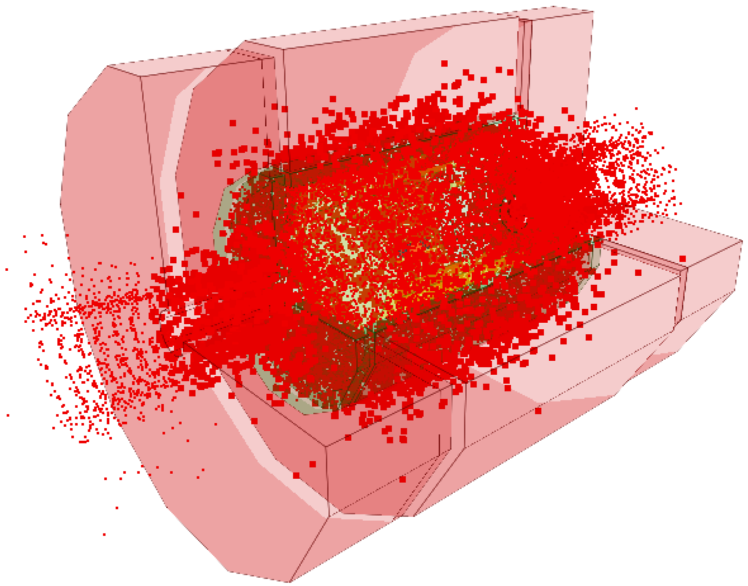
Thicker calorimeters

Might move to semi-homogenous ECAL (Crilin)

Magnet position:
- Before calorimeters
- Between calorimeter
- After calorimeters

Possible thesis on detector configurations, advanced machine learning reconstruction algorithms

A new calorimeter!



Beam-induced background in EM calorimeter

Crilin (Crystal calorimeter with longitudinal information)
EM Calorimeter: **semi-homogeneous calorimeter** based on Lead-Fluorite (PbF2) crystals, read out by Silicon Photomultipliers.

- Excellent timing resolution.
- Fine granularity.
- Longitudinal segmentation.
- Radiation hardness.

Prototype tested at CERN last summer

Possible thesis on calorimeter performance with simulations, electrons, photons and jets identification algorithms with advanced machine learning and test beam participation and data analysis

Muon collider experiment is the perfect place to study the Higgs boson

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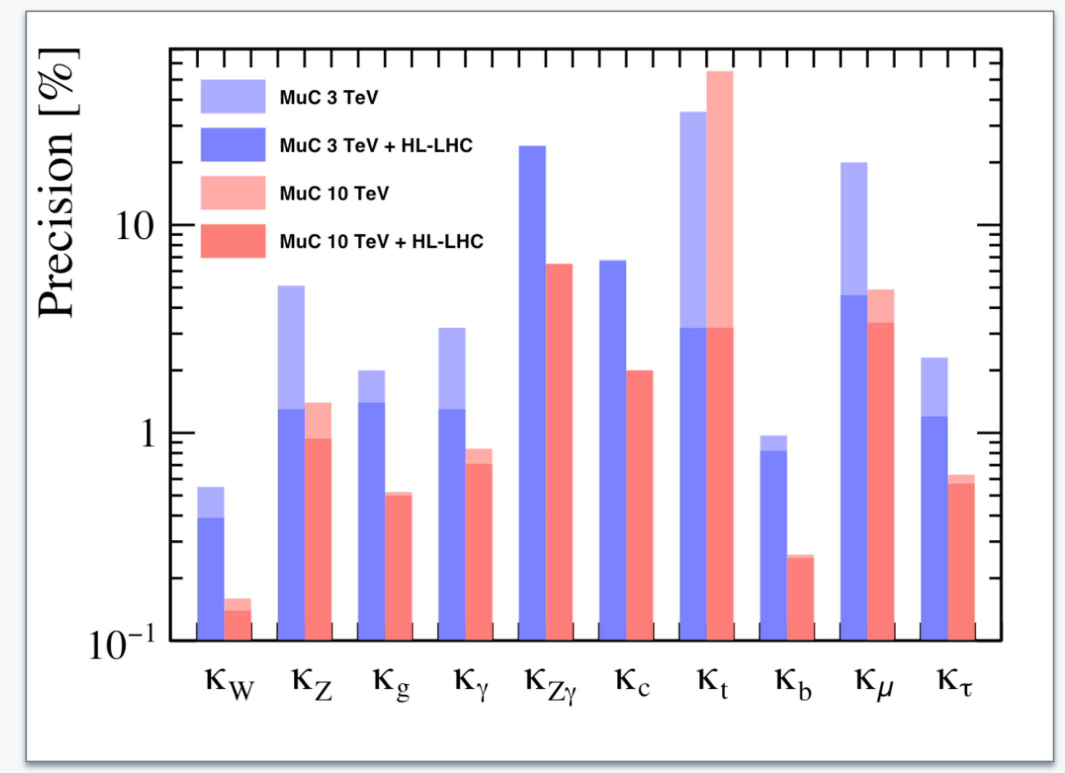
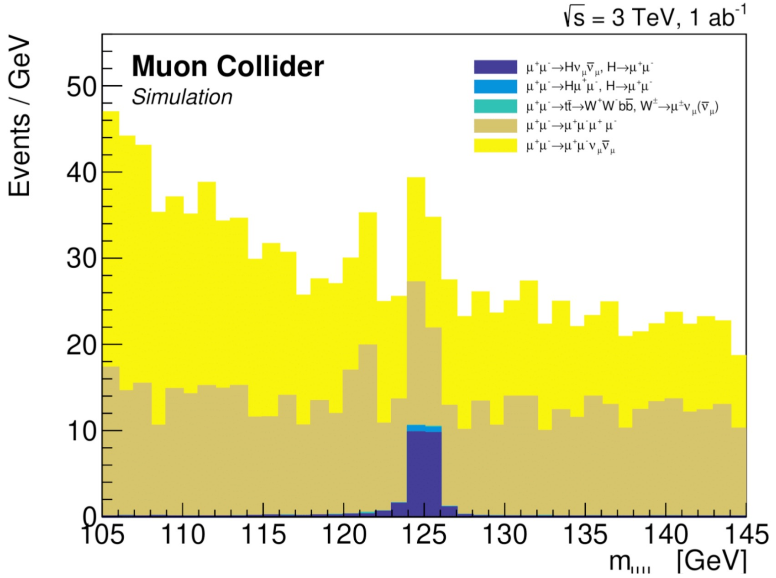
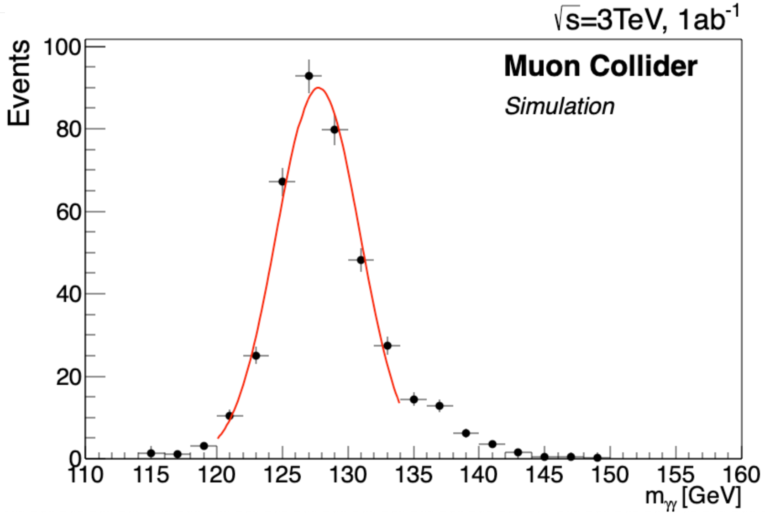
Higgs coupling precision at $\sqrt{s}$ =3 TeV







Test the Higg theory as described in the Standard Model

Higgs boson potential determination

In SM, Higgs potential expanded around the minimum

$$V(H) = \frac{1}{2} m_H^2 H^2 + \lambda_3 v H^3 + \frac{\lambda_4}{4} H^4$$

Single H study | Double H study | Triple H study

λ_3: 20% with 1 ab^{-1} $\sqrt{s}$ =3 TeV

λ_3: 5.6% with 10 ab^{-1} $\sqrt{s}$ = 10 TeV

λ_4 : tens of percent with 20 ab^{-1}
only phenomenological studies up to now

Unique to muon collider

The performance of a muon collider experiment on many other New Physics possible processes can be studied: supersymmentry models, long lived particles, disappearing tracks, di-bosons scattering…

In each case the detector requirements need to be investigated and determined.

Possible thesis on physics reaches on Higgs physics, in general on any Standard Model process, New Physics model process, new proposed models.

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