New Technologies & Ideas for Collider Detectors

Introduction

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MAX-PLANCK-INSTITUT FÜR PHYSIK

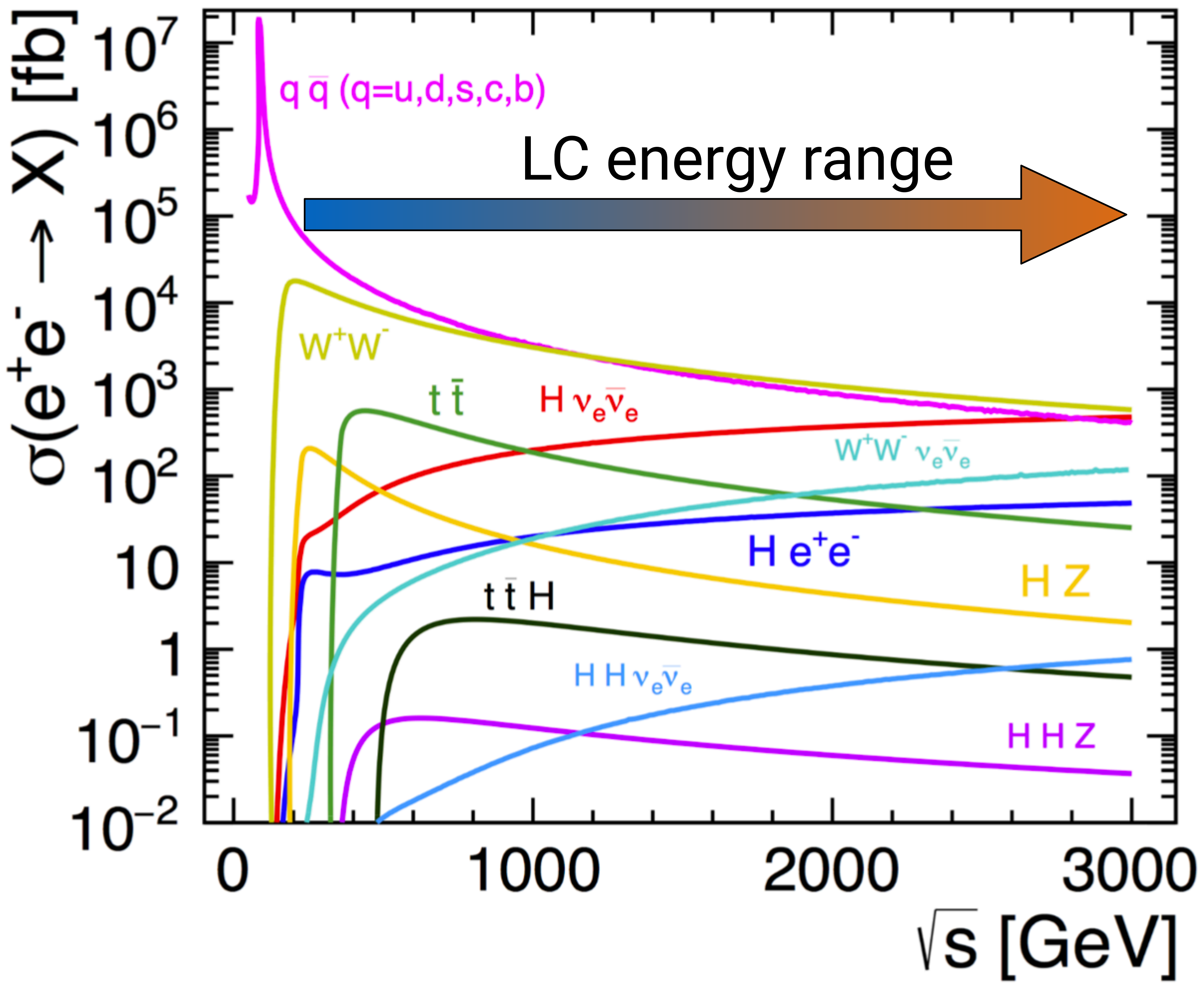
@ LCWS, March 2021

Overview

- Brief recap of LC Detector design “philosophy”
- Intro to the session today

Key Drivers for Detector Design

Physics & Experimental Conditions



Physics

- Collision energy:
  - ILC: 250 GeV - 500 GeV - 1+ TeV
  - CLIC: 380 GeV - 1.5 TeV - 3 TeV
  - ➩ Leptons, jets, from a few 10 to many 100 GeV, heavy bosons / complex final states
- Small cross-section: High luminosity required, Statistics is precious: Excellent reconstruction of all final states

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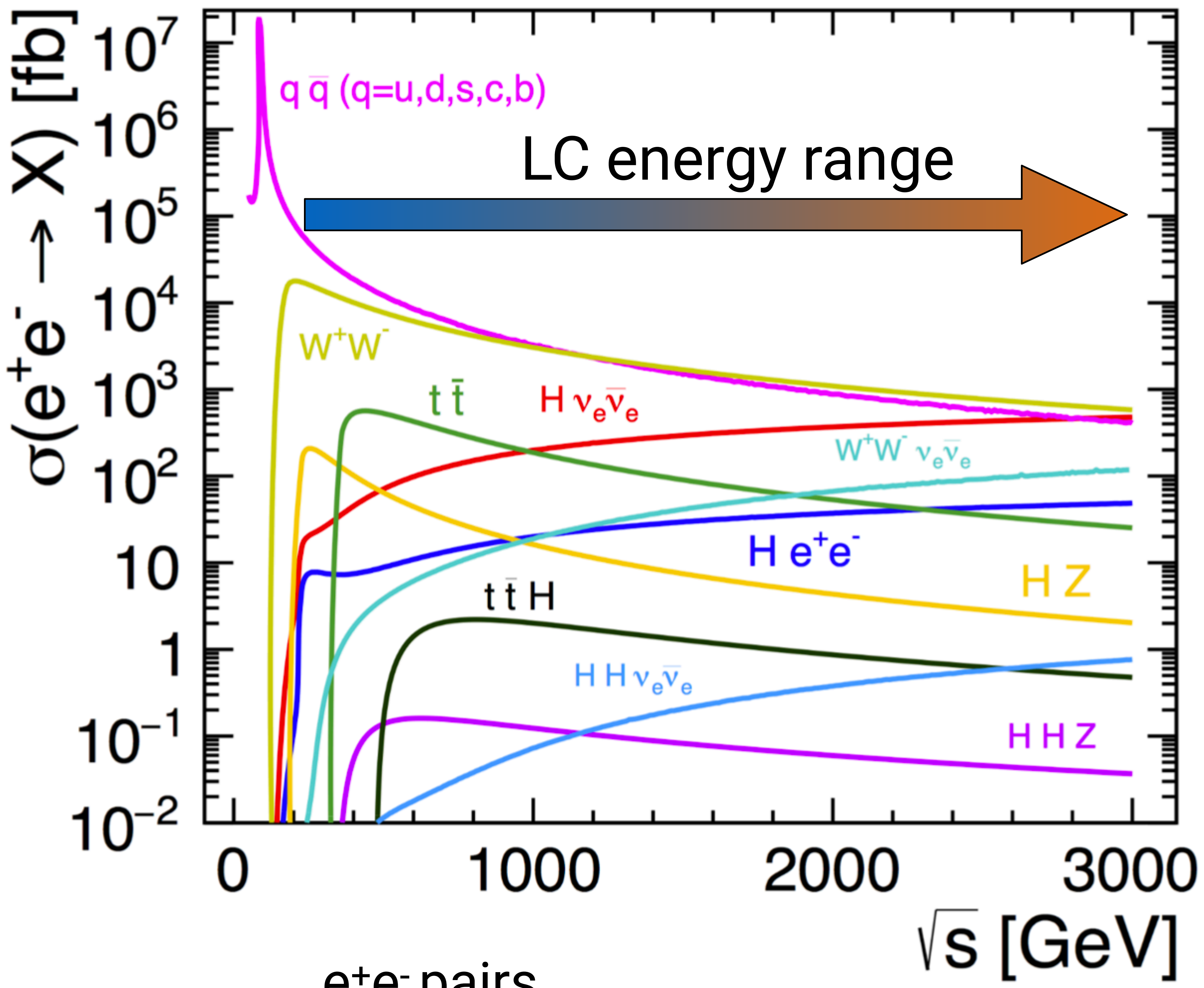

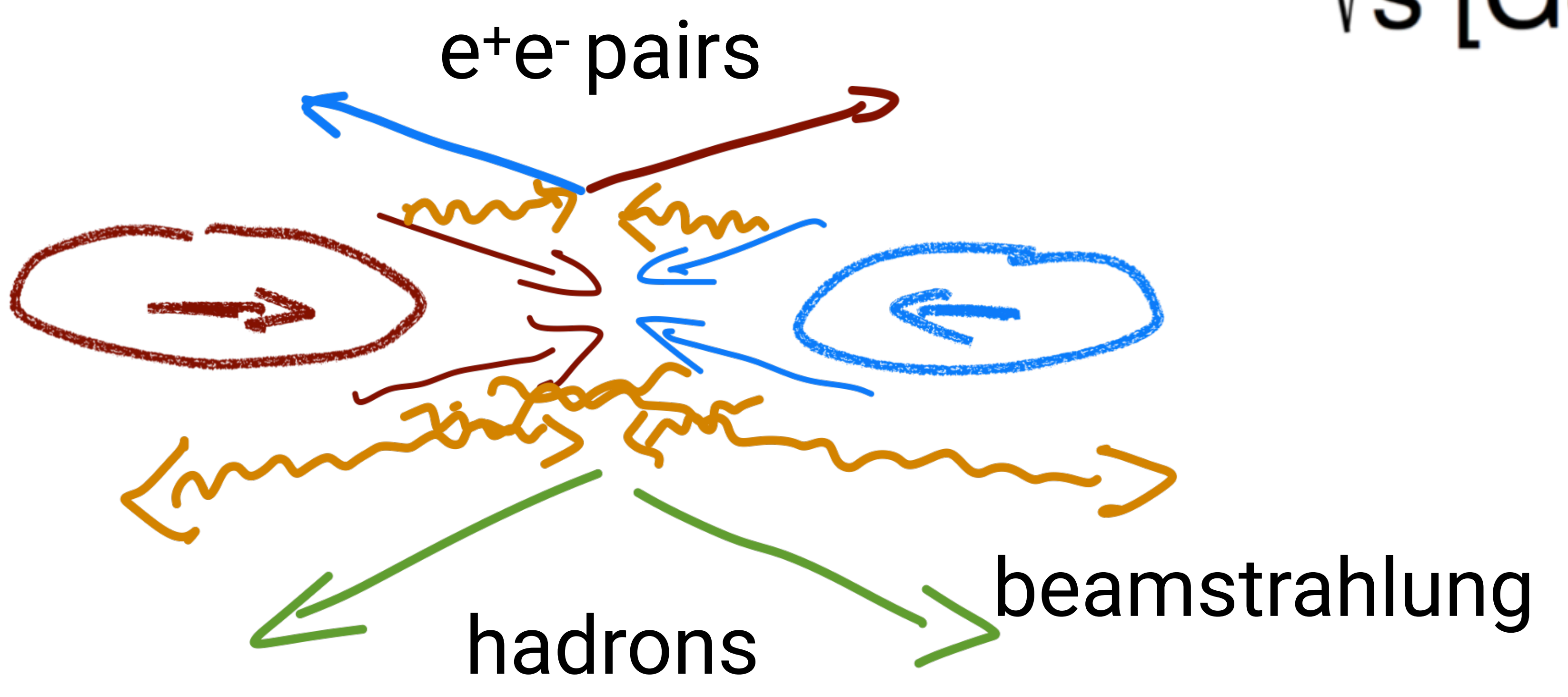

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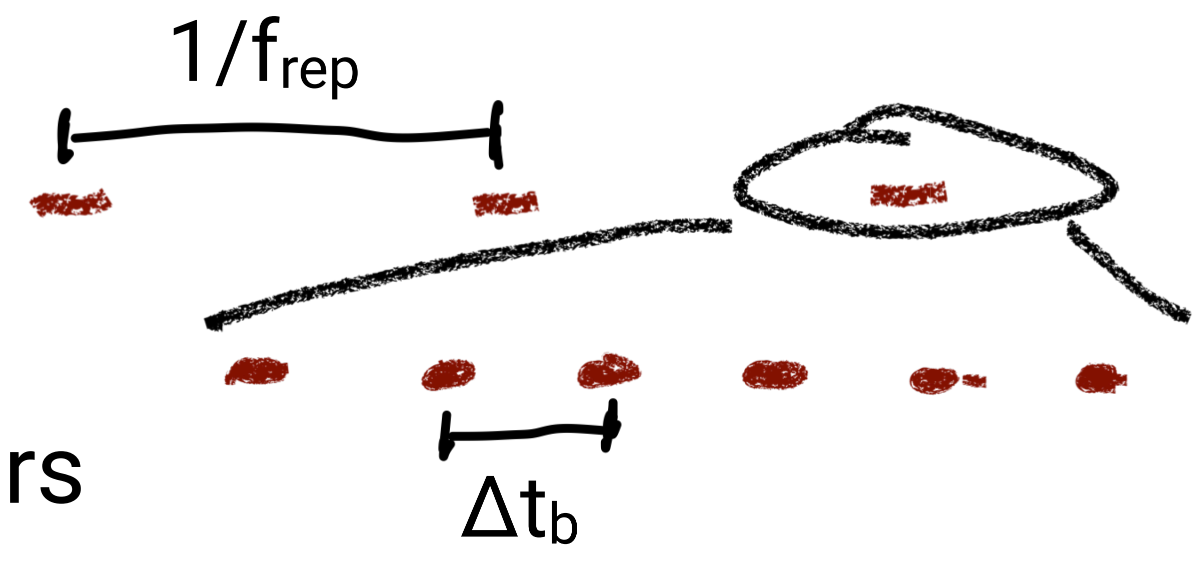
Experimental conditions

- Extreme focussing: Beamstrahlung - tails in the luminosity spectrum, background from two-photon processes
- Pulsed operation in “bunch trains”: O(10 Hz) bunch train rate 0.5 /~550 ns bx separation
  - ➩ Enables power pulsing of detectors



Detector Performance Goals - Tracking

Motivated by key physics signatures

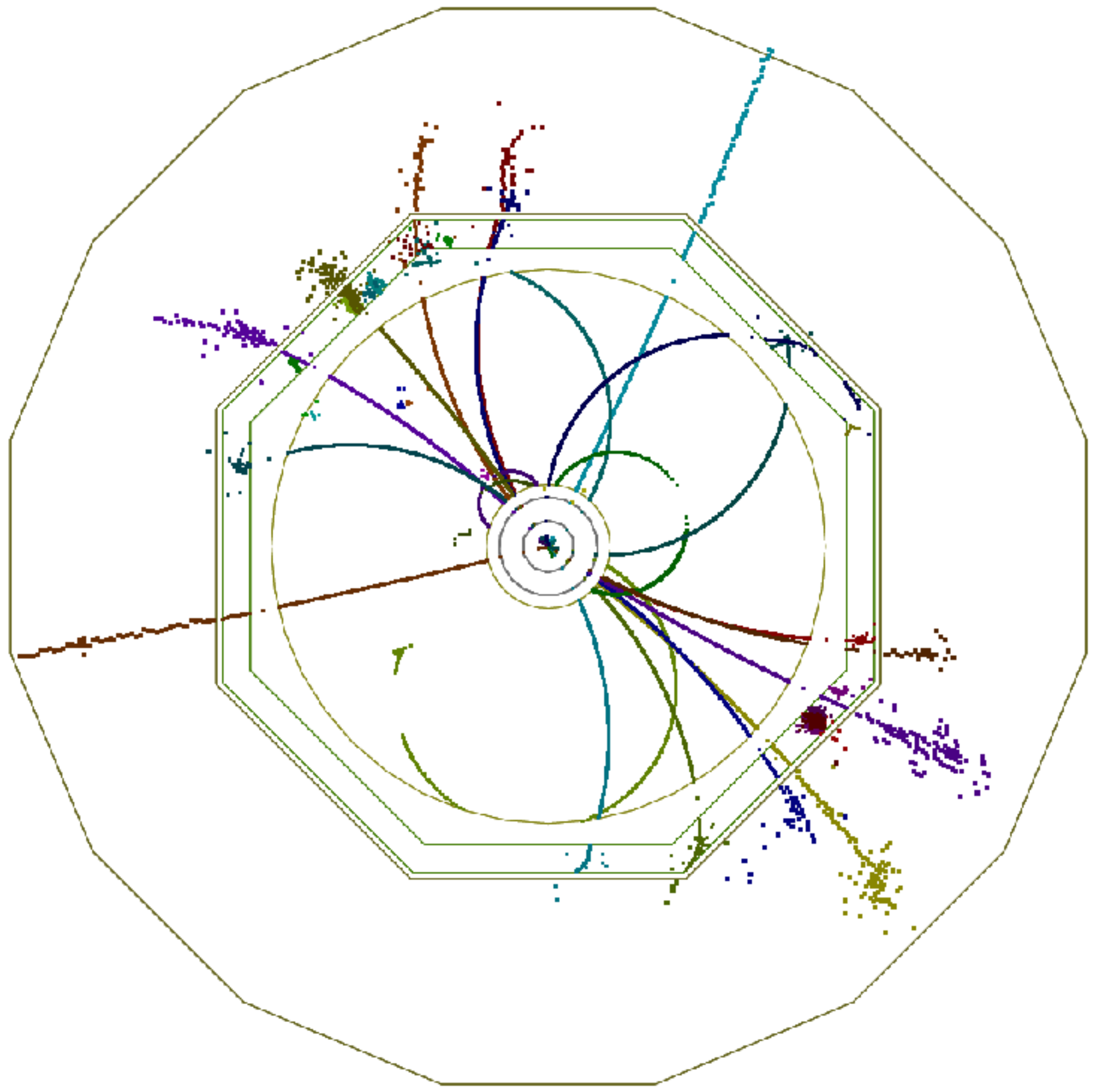
- ***Momentum resolution***

  Higgs recoil measurement, H -> μμ,
  BSM decays with leptons

  $\sigma(p_T) / p_T^2 \sim 2 \times 10^{-5}$ / GeV

  precise and highly efficient tracking,
  extending to 100+ GeV

low mass, good resolution:
for Si tracker ~ 1-2% X_0 per layer, 7 μm point resolution



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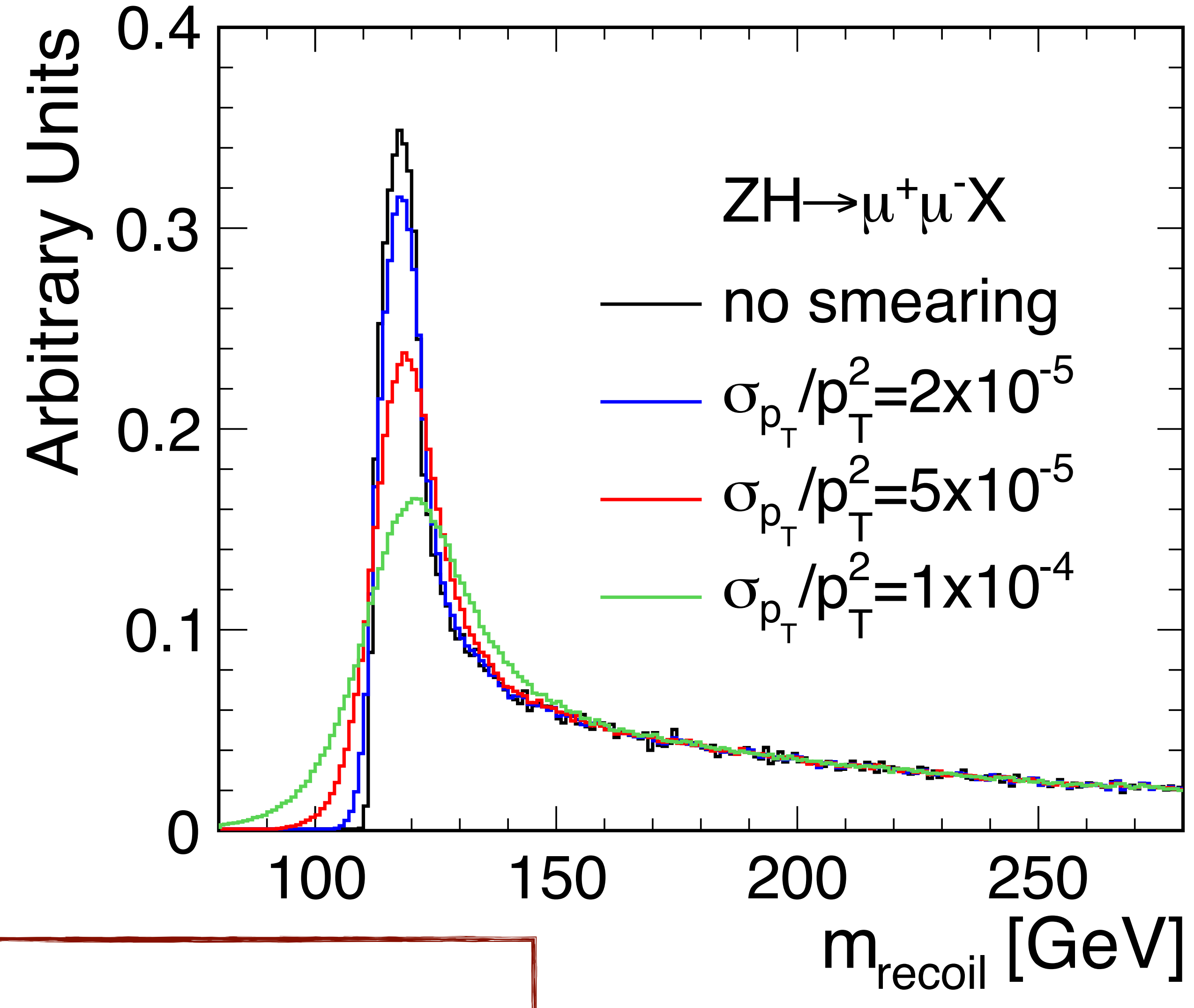

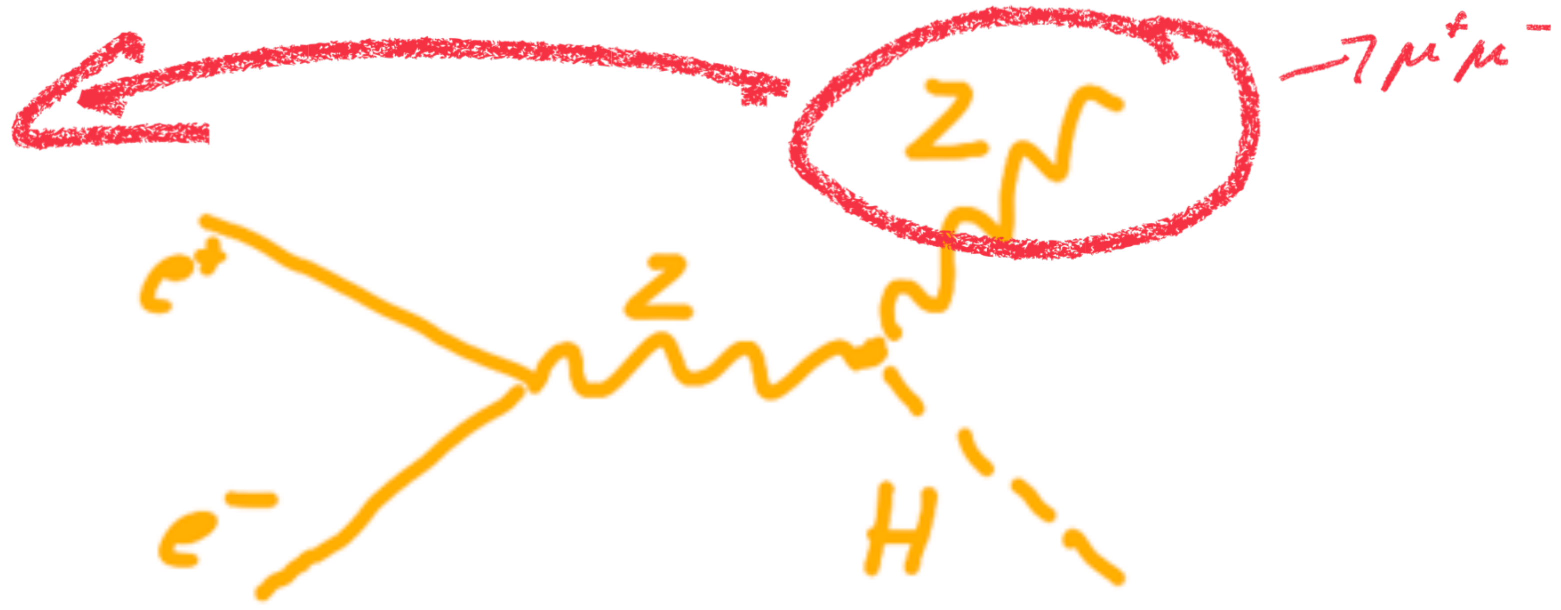

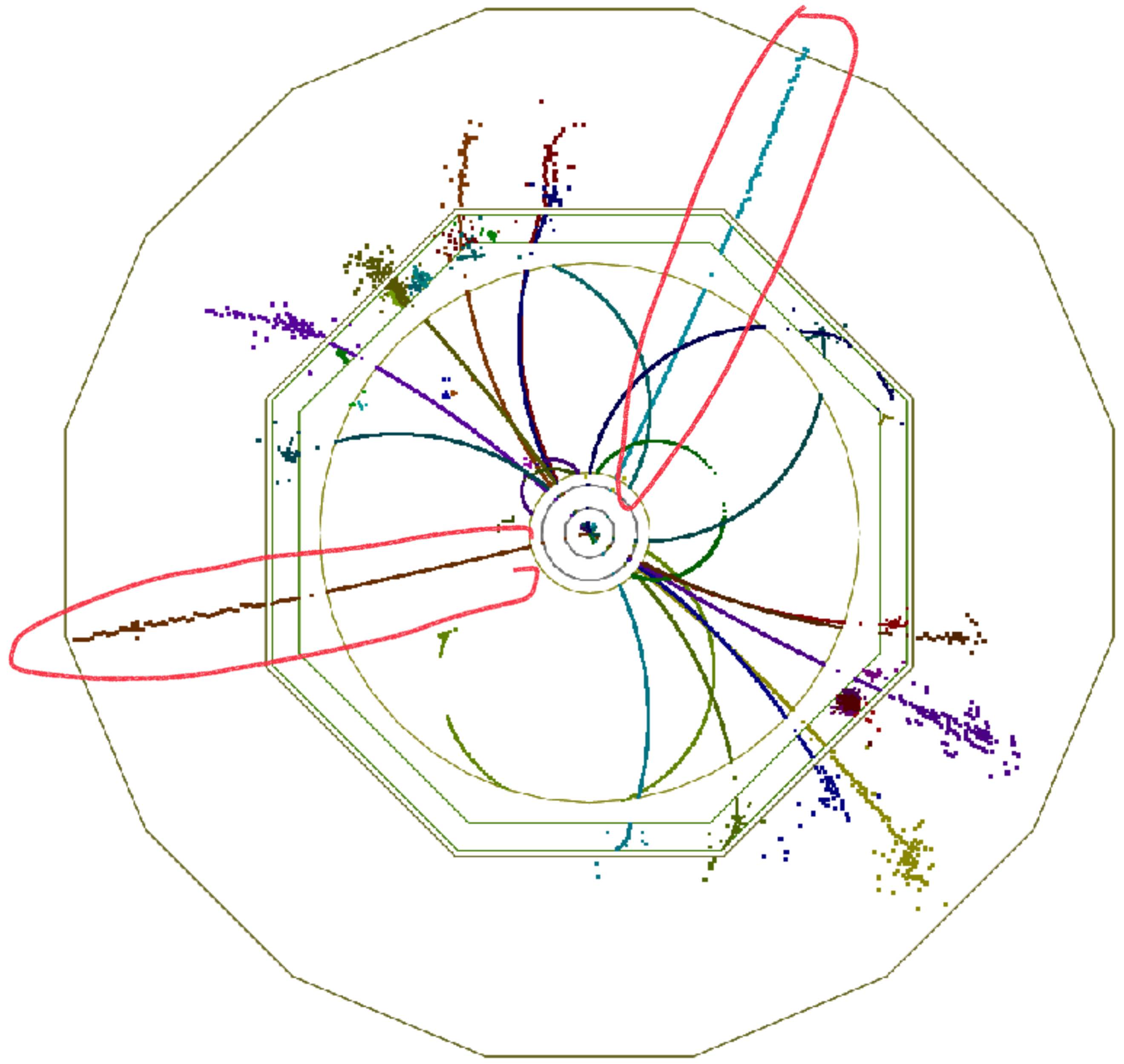

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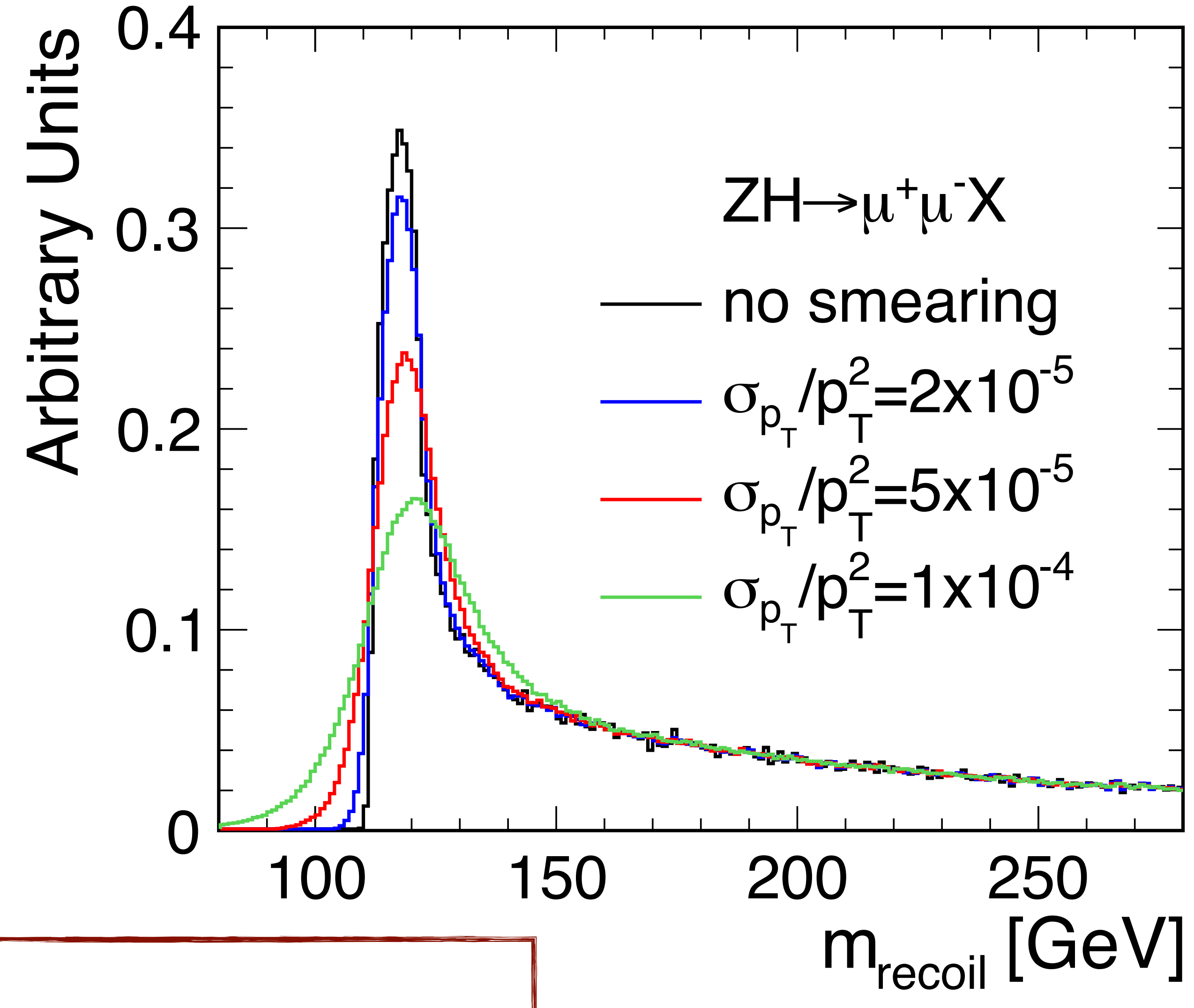

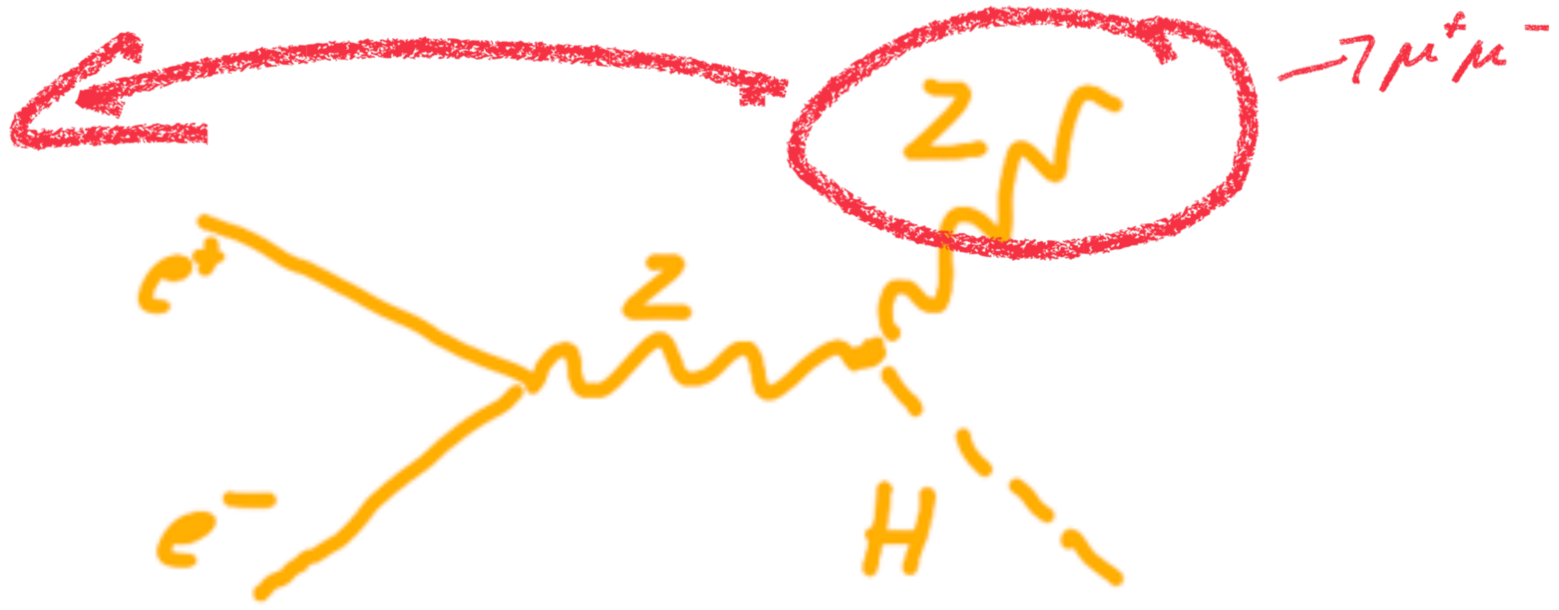

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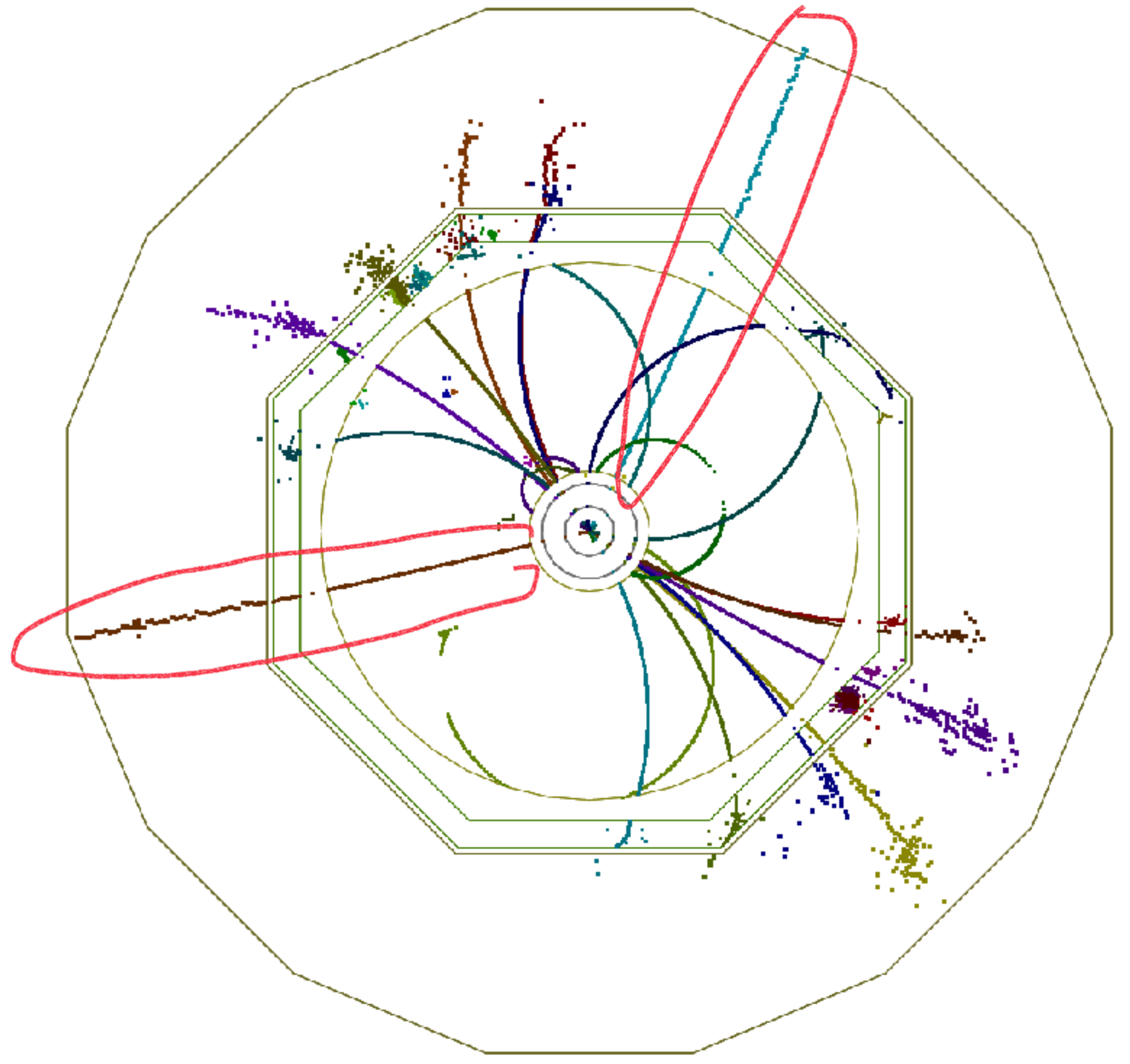
- ***Impact parameter resolution,*** *vertex charge*

  Flavour tagging: b/c/light tagging in Higgs decays, top physics, …

$$\sigma(d_0) \sim [5 \oplus (10 - 15)/p\sin^{3/2}\theta]\ \mu m$$

single point resolution in vertex detector ~3 μm
< 0.2 X_0 per layer



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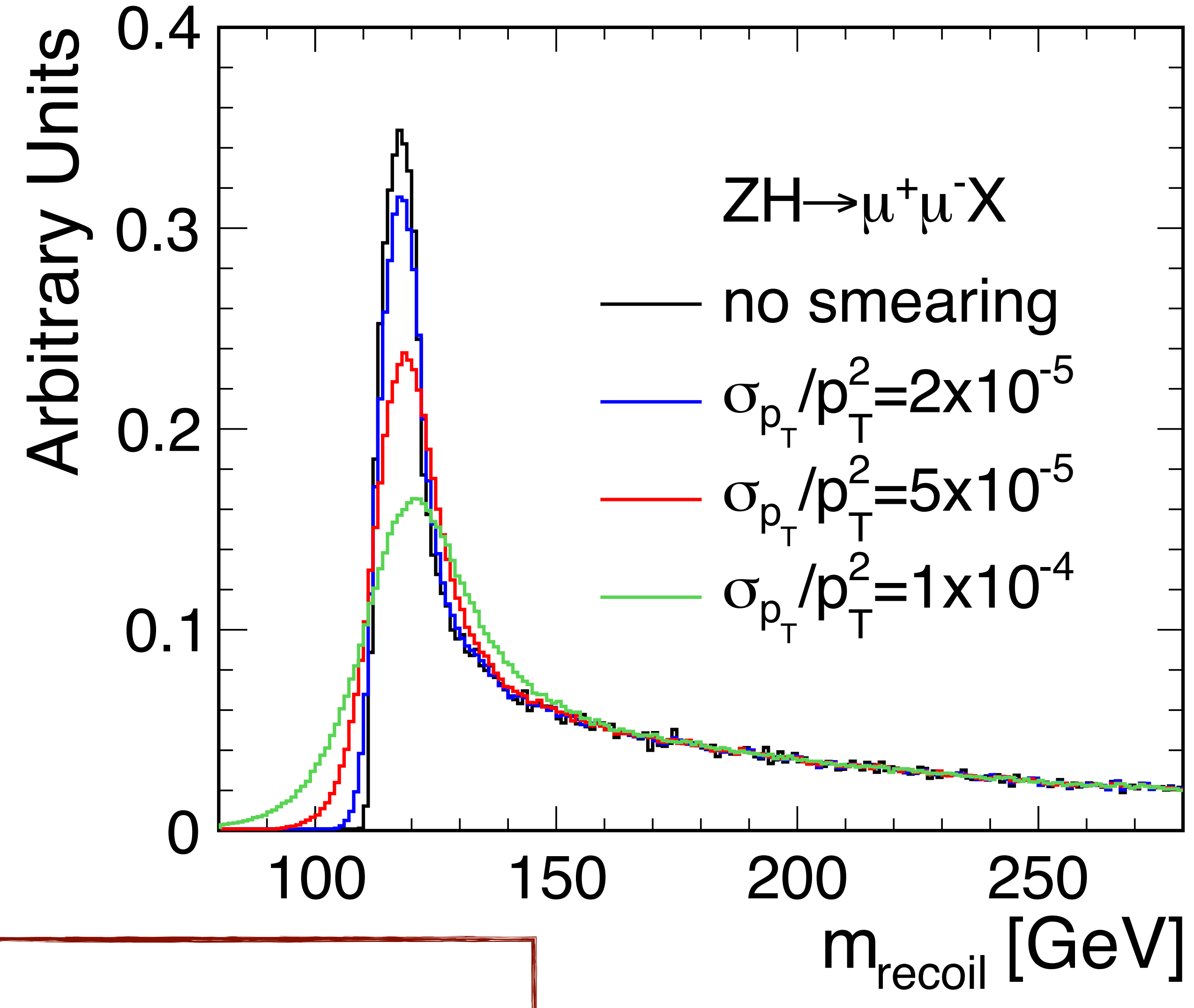

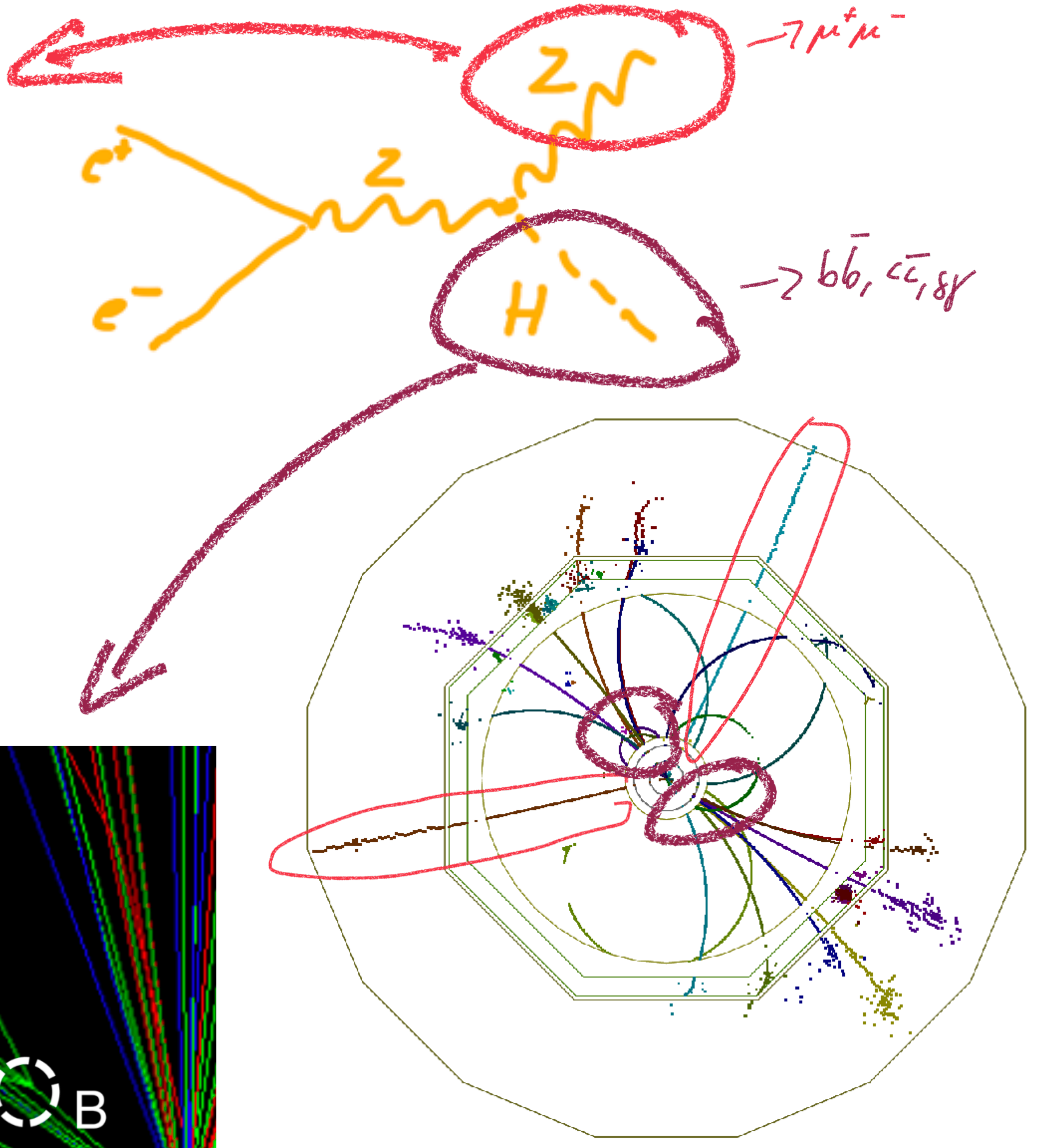

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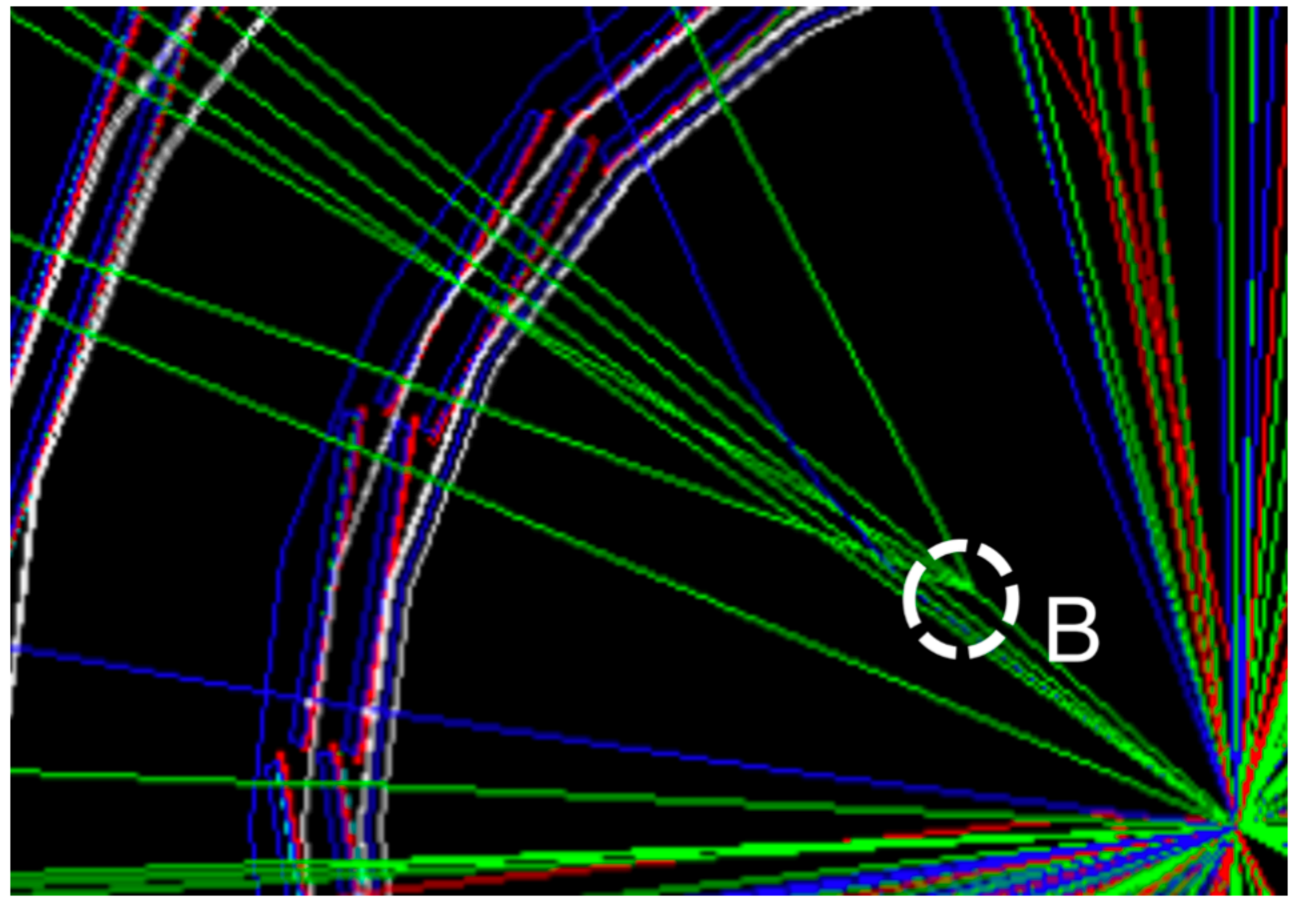

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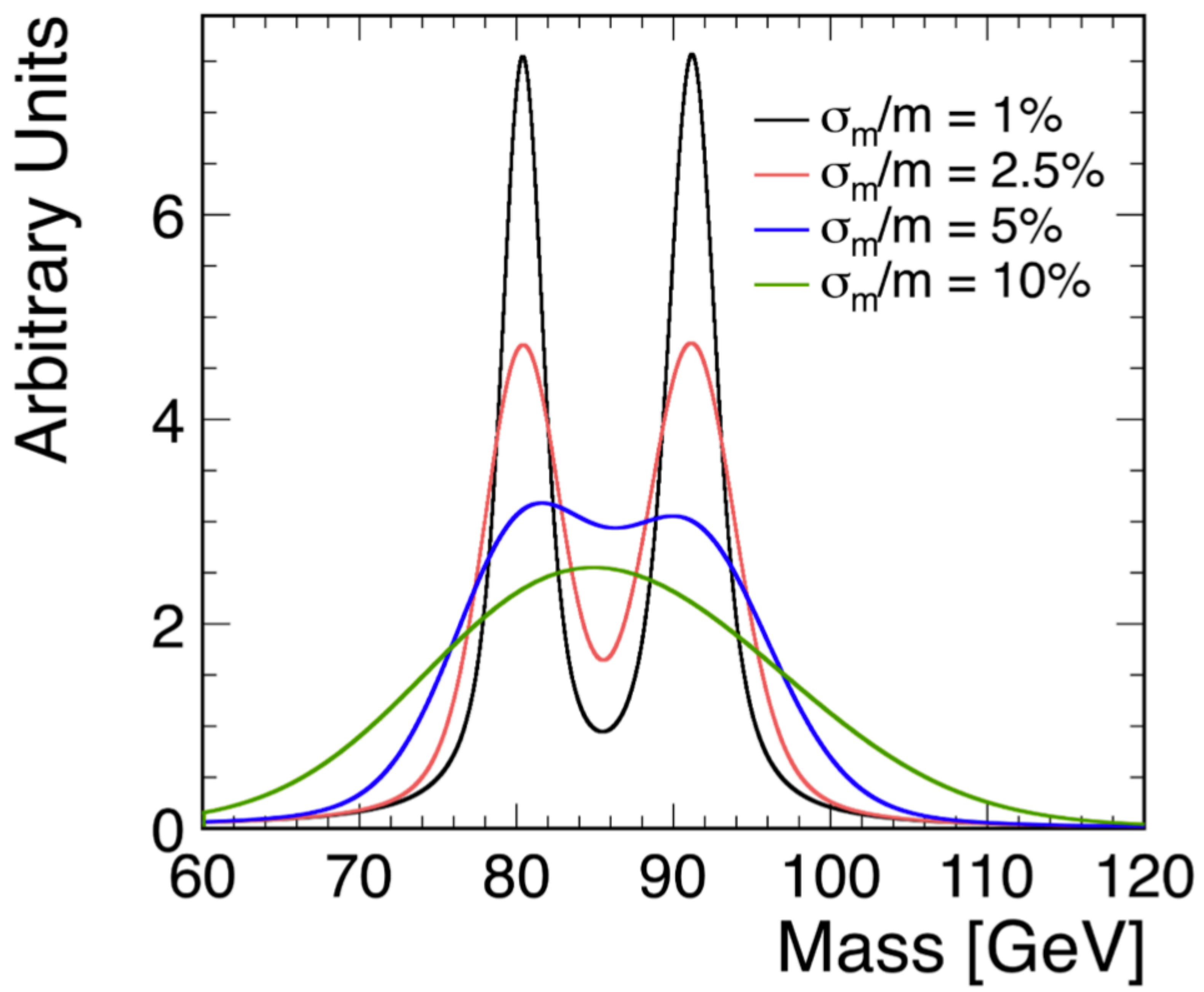
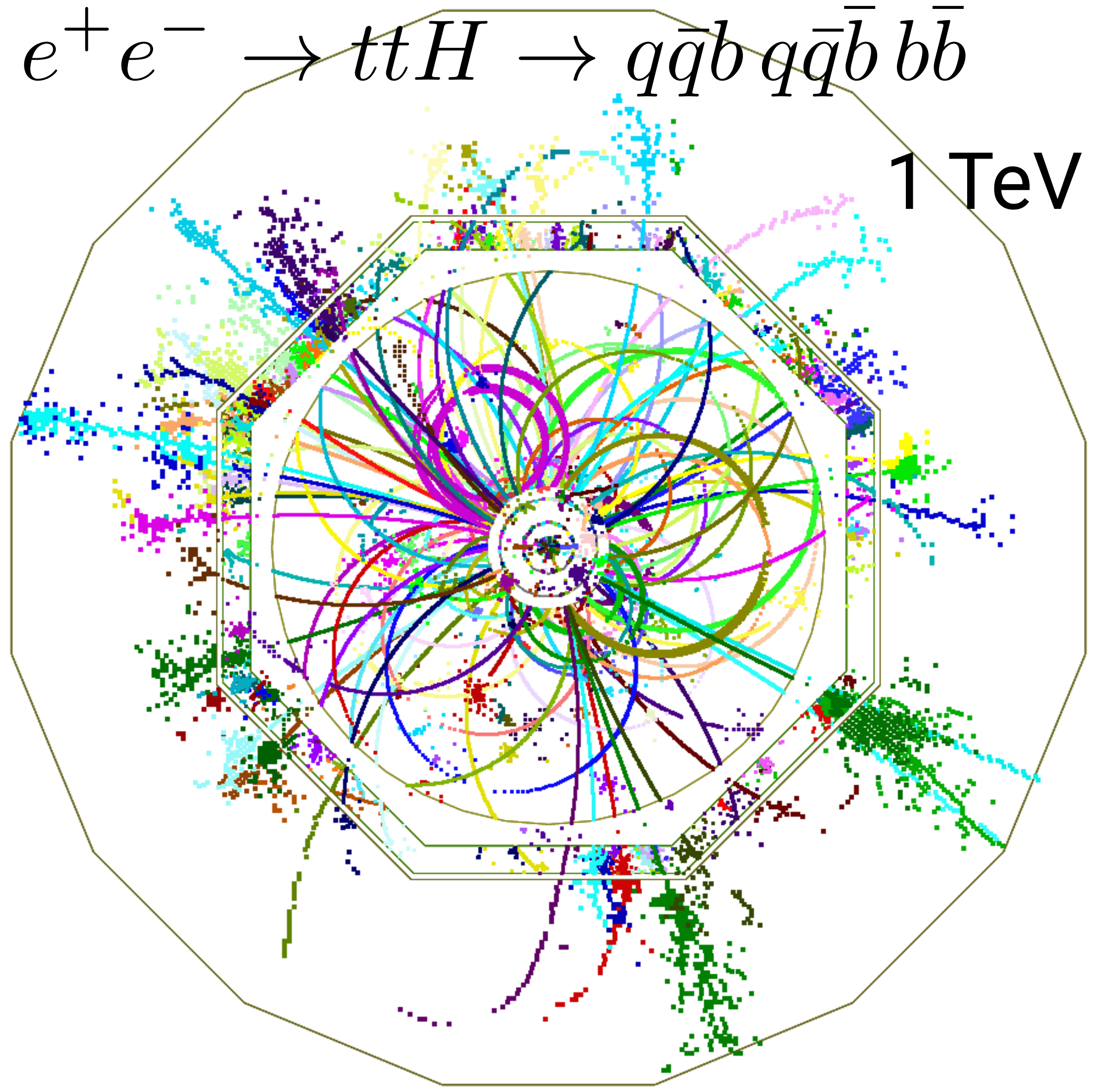
  Recoil measurements with hadronic Z decays, separation of W, Z, H bosons, …

  $\sigma(E_{jet}) / E_{jet}$ ~ 3% - 5% **for E_{jet} > 45 GeV**

  reconstruction of complex multi-jet final states.





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  Coverage to 100s of GeV important

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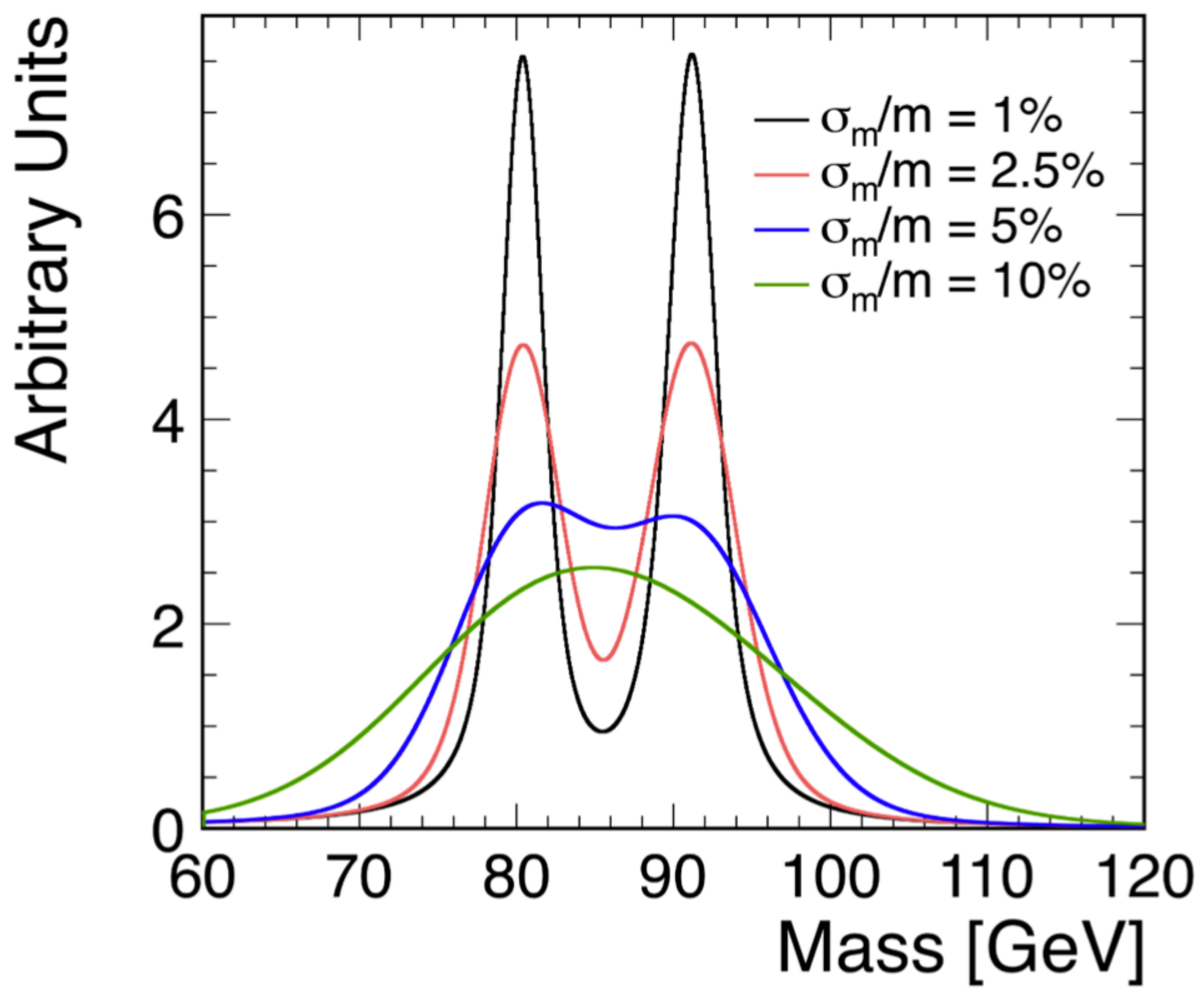
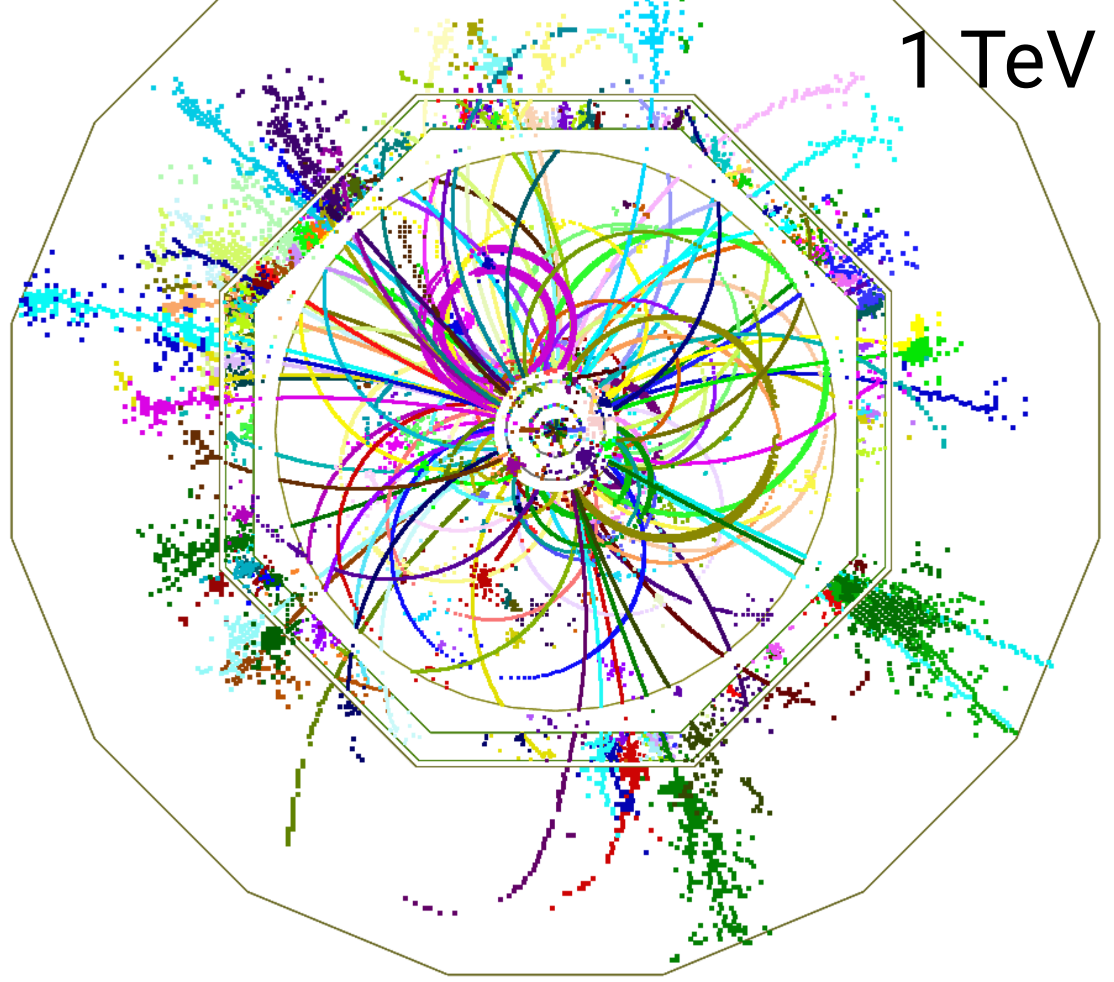
- PID of hadrons to improve tagging, jets,…



$e^+e^- \to t\bar{t}H \to q\bar{q}b\,q\bar{q}\bar{b}\,b\bar{b}$



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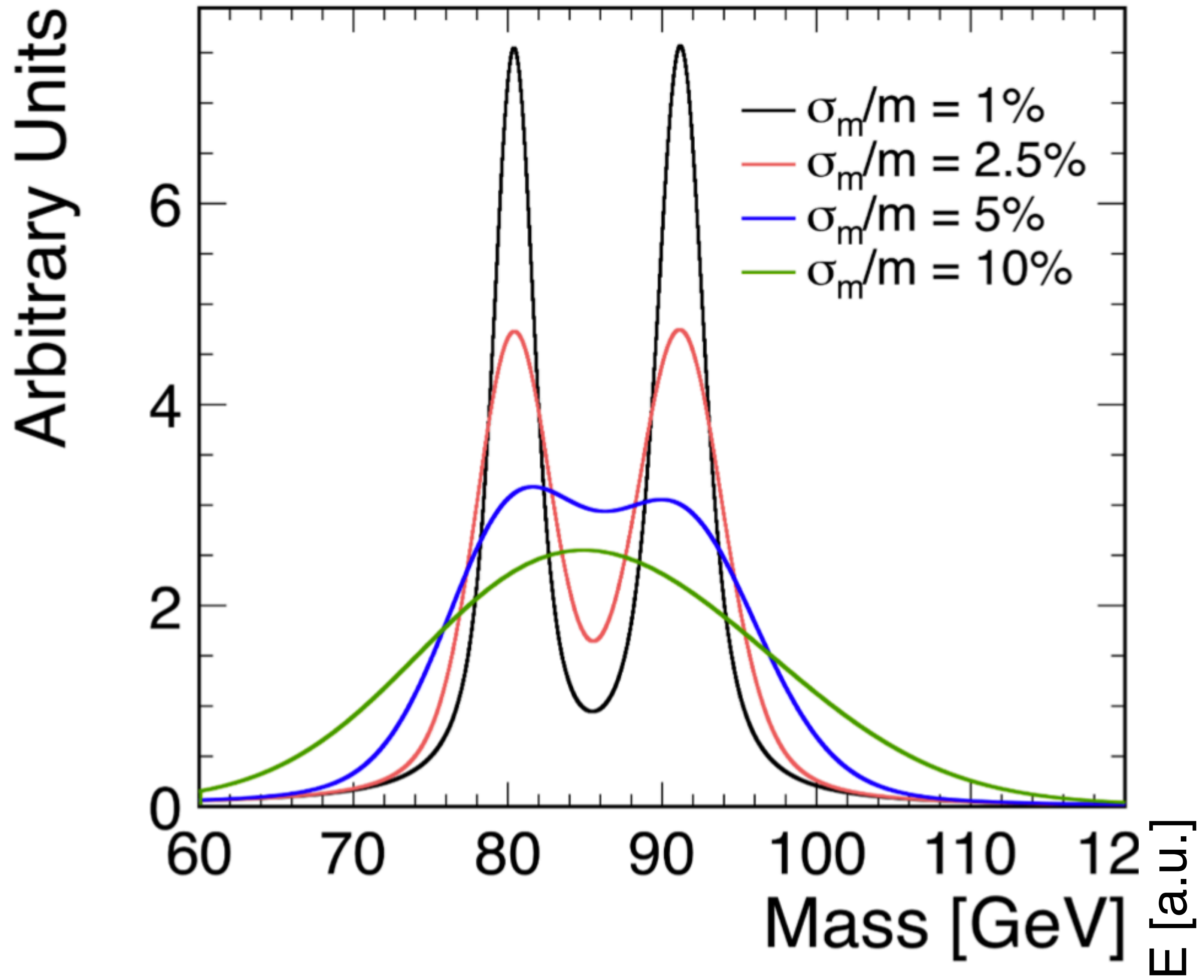
- ***Hermetic coverage***

  Dark matter searches in mono-photon events, …

  N.B.: Achievable limits do not depend strongly on $\sigma(E_\gamma)$



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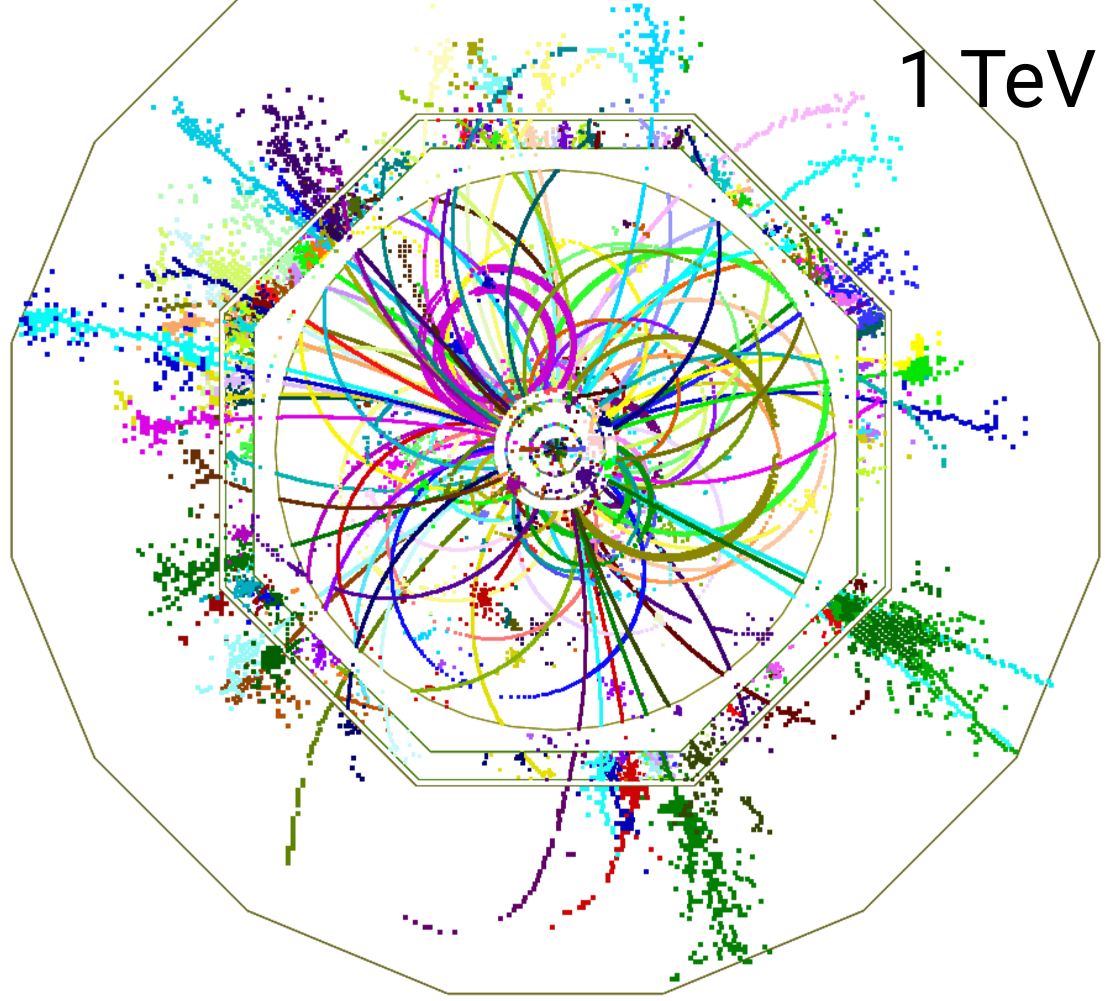
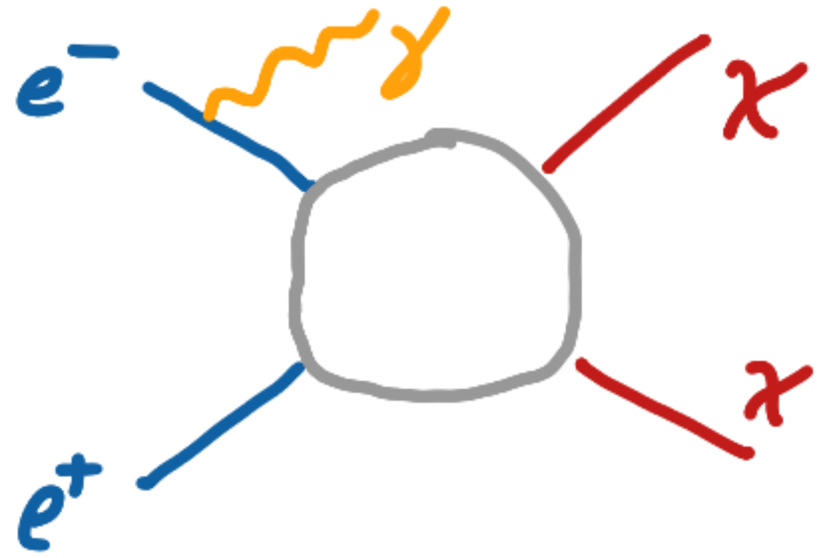
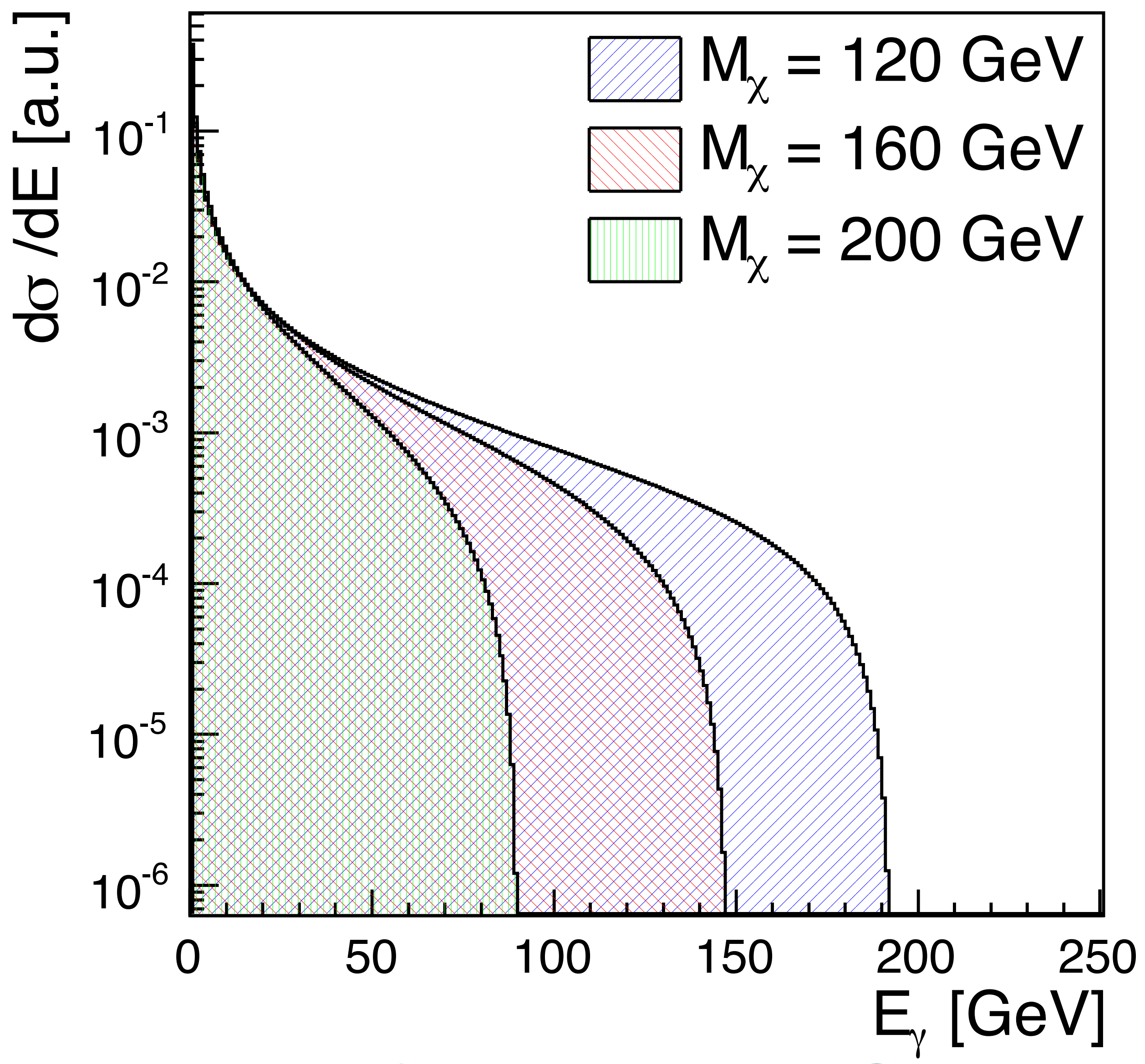
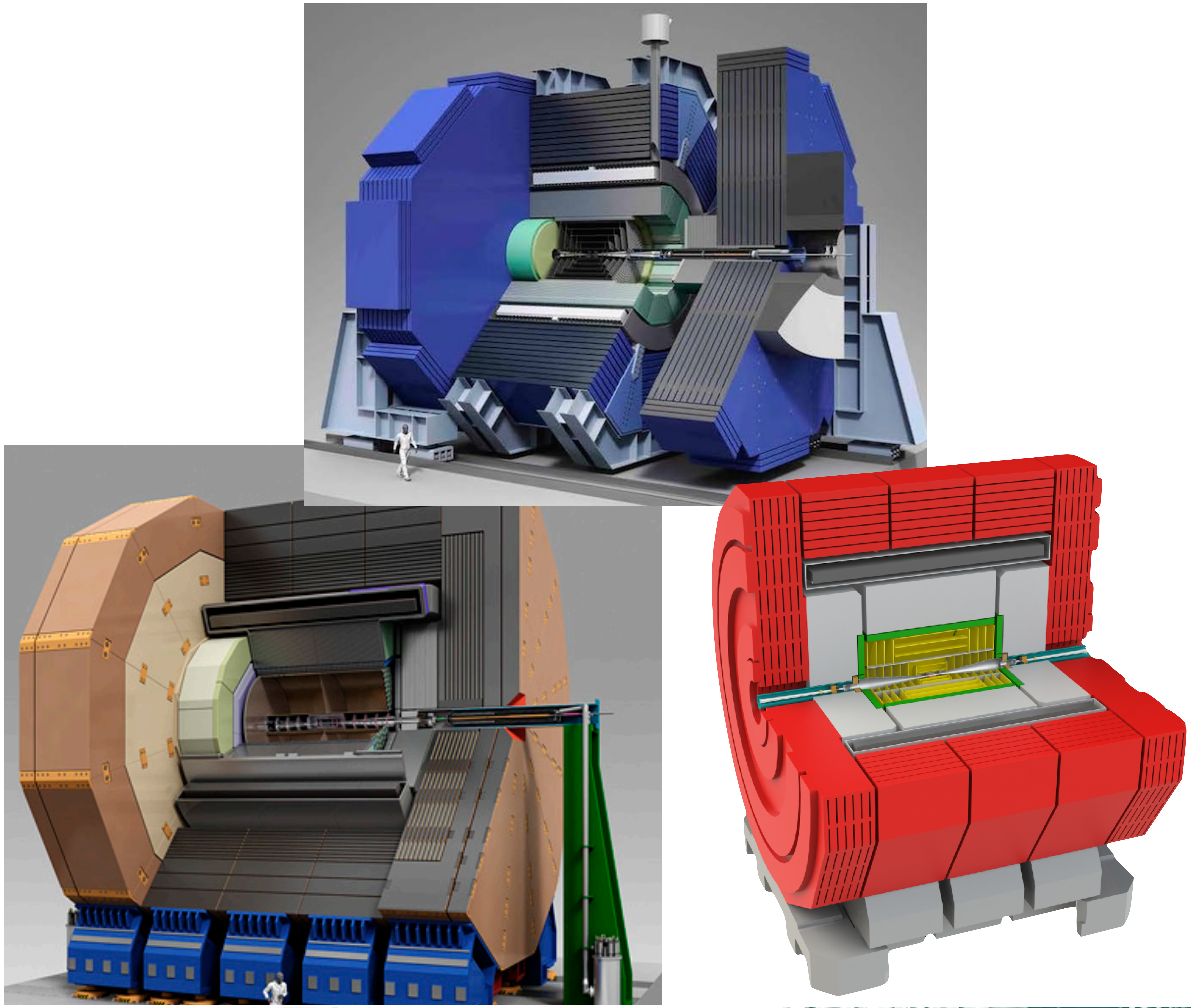






The Linear Collider Detector Design - Main Features

Focusing on general aspects



- A **large-volume solenoid** 3.5 - 5 T, enclosing calorimeters and tracking
- **Highly granular calorimeter systems**, optimised for particle flow reconstruction, best jet energy resolution *[Si, Scint + SiPMs, RPCs]*
- **Low-mass main tracker**, for excellent momentum resolution at high energies *[Si, TPC + Si]*
- **Forward calorimeters**, for low-angle electron measurements, luminosity *[Si, GaAs]*
- **Vertex detector**, lowest possible mass, smallest possible radius *[MAPS, thinned hybrid detectors]*
- **Triggerless readout** of main detector systems

The Linear Collider Detector Design

Variations of the main design

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- Two detector concepts for ILC: SiD, ILD - with somewhat different optimisation, one for CLIC (CLICdet)

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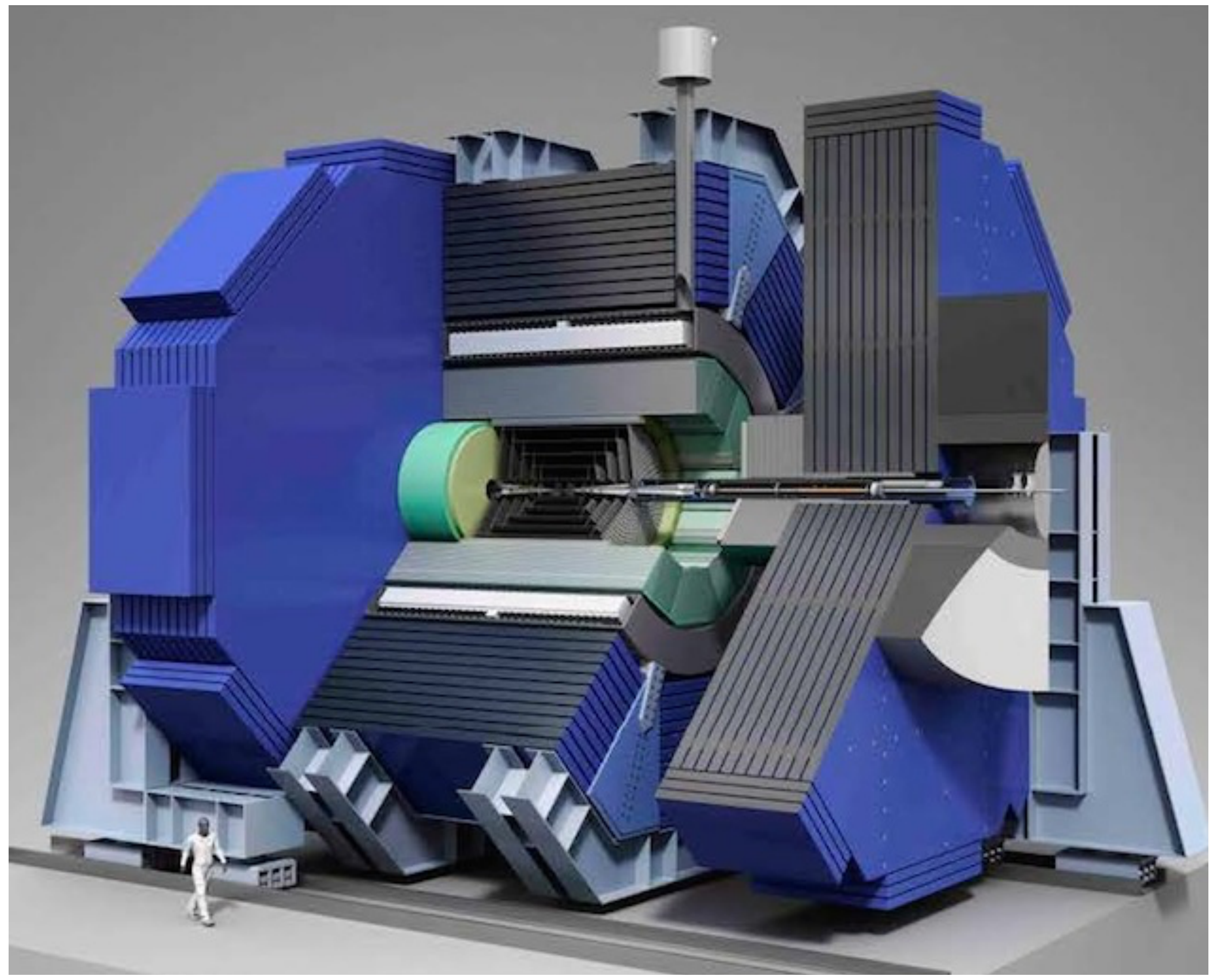

SiD

- 5T field
- all-Si tracker with outer radius of 1.2 m
- VTX inner radius 14 mm
- 4.5 λ_I HCAL

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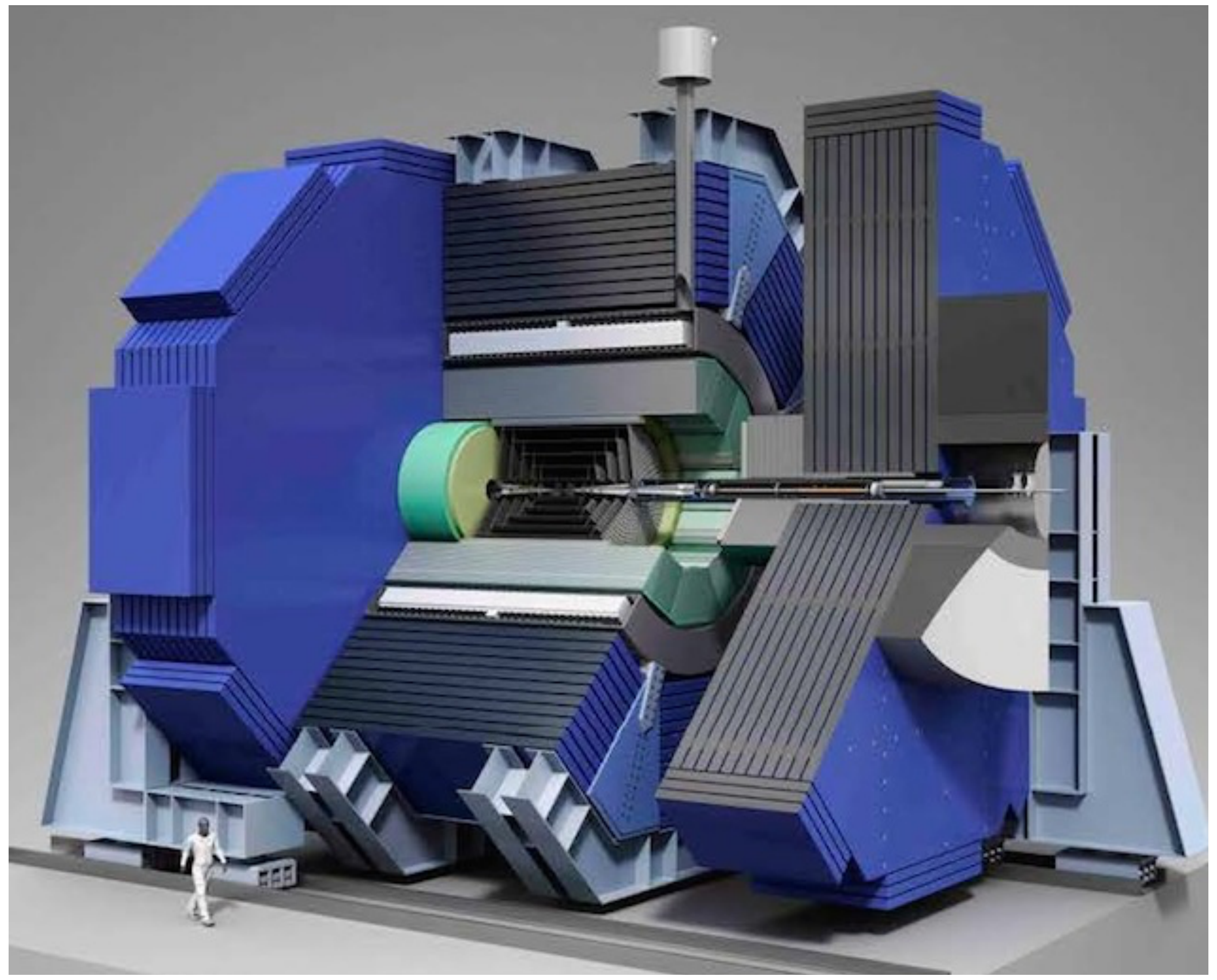

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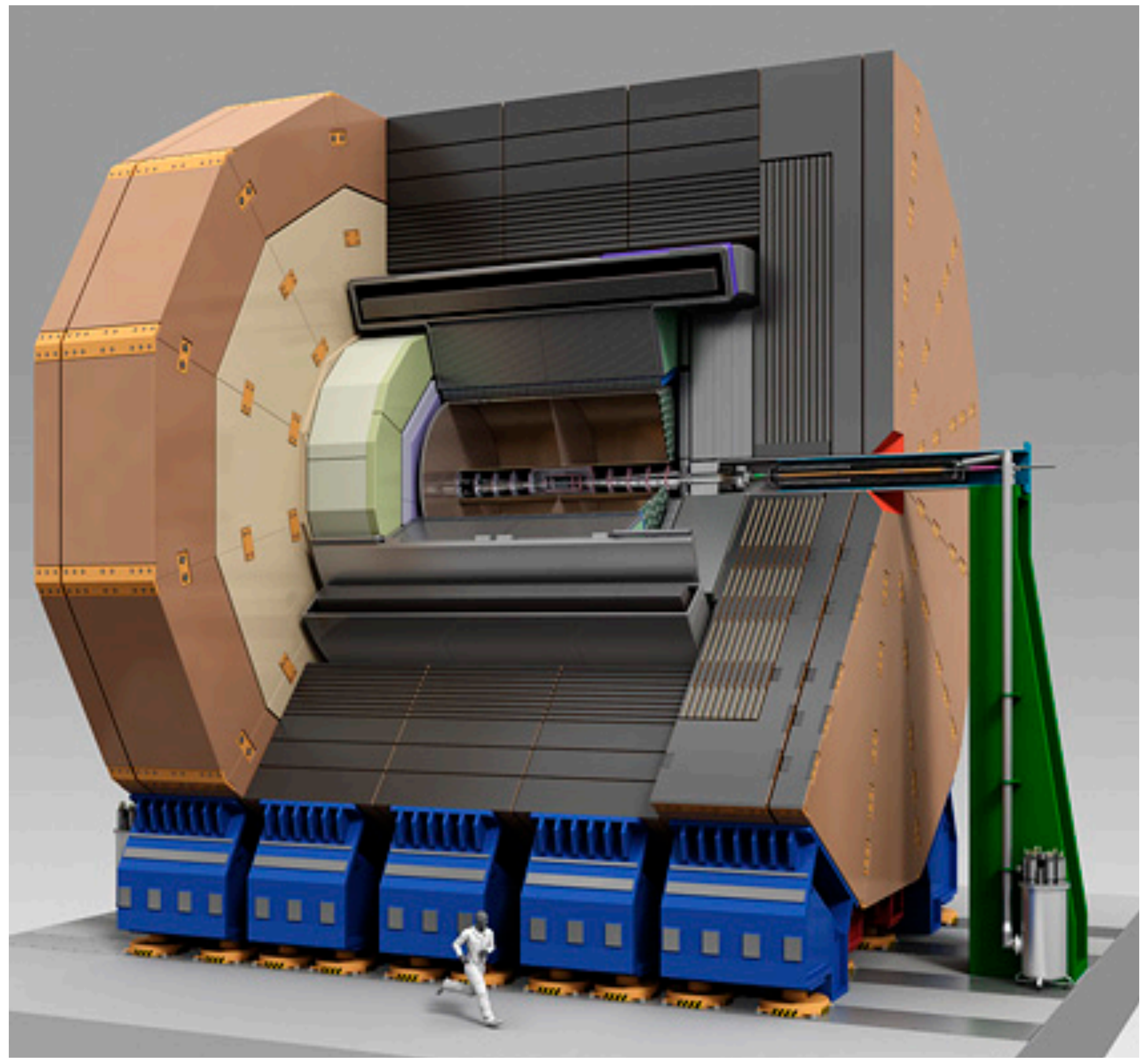

For ILD: 2 versions (large / small) under study

ILD

- 3.5T / 4T field
- TPC as main tracker, supplemented by outer Si envelope radius 1.77 m / 1.43 m
- VTX inner radius 16 mm
- 6 λ_I HCAL

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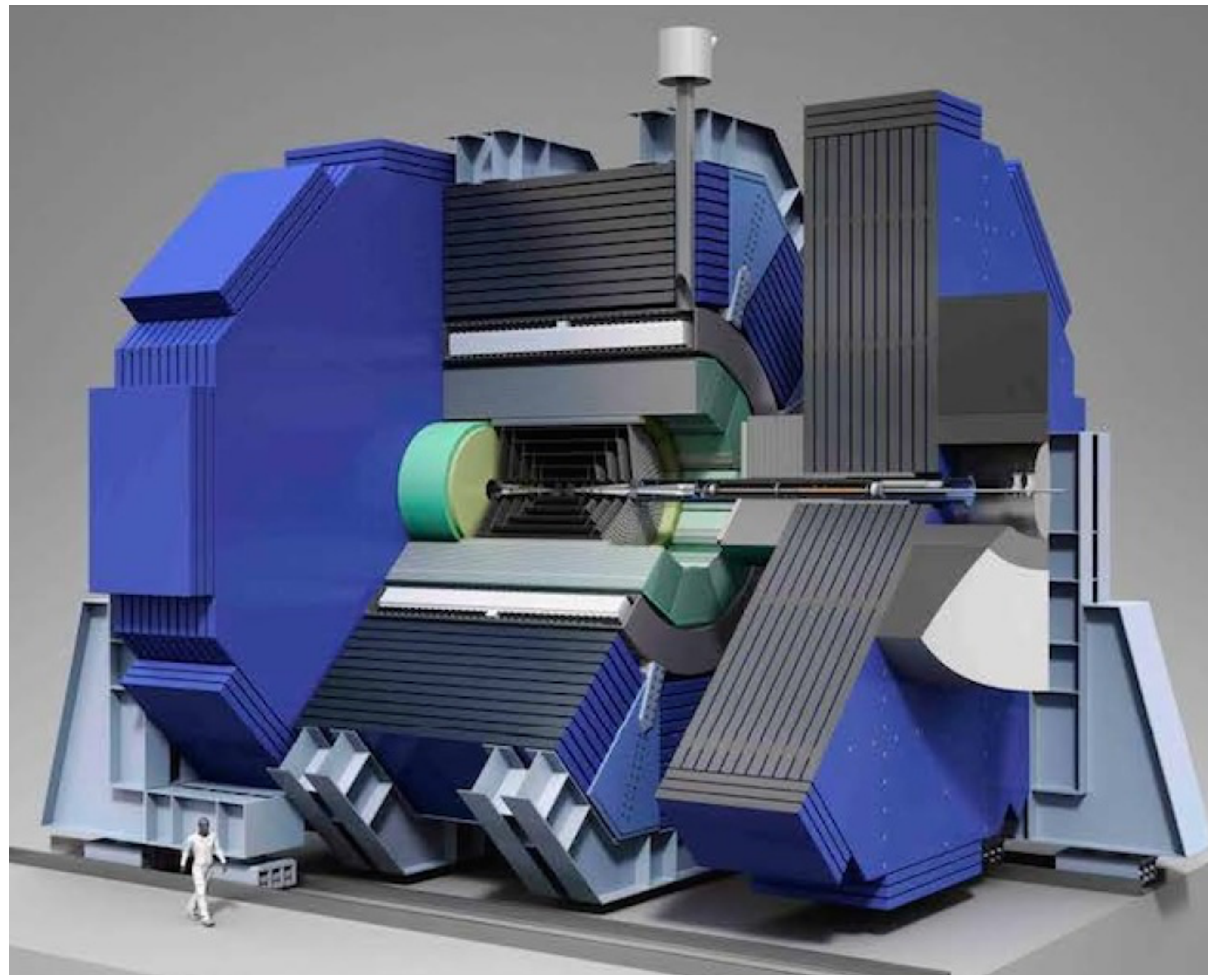
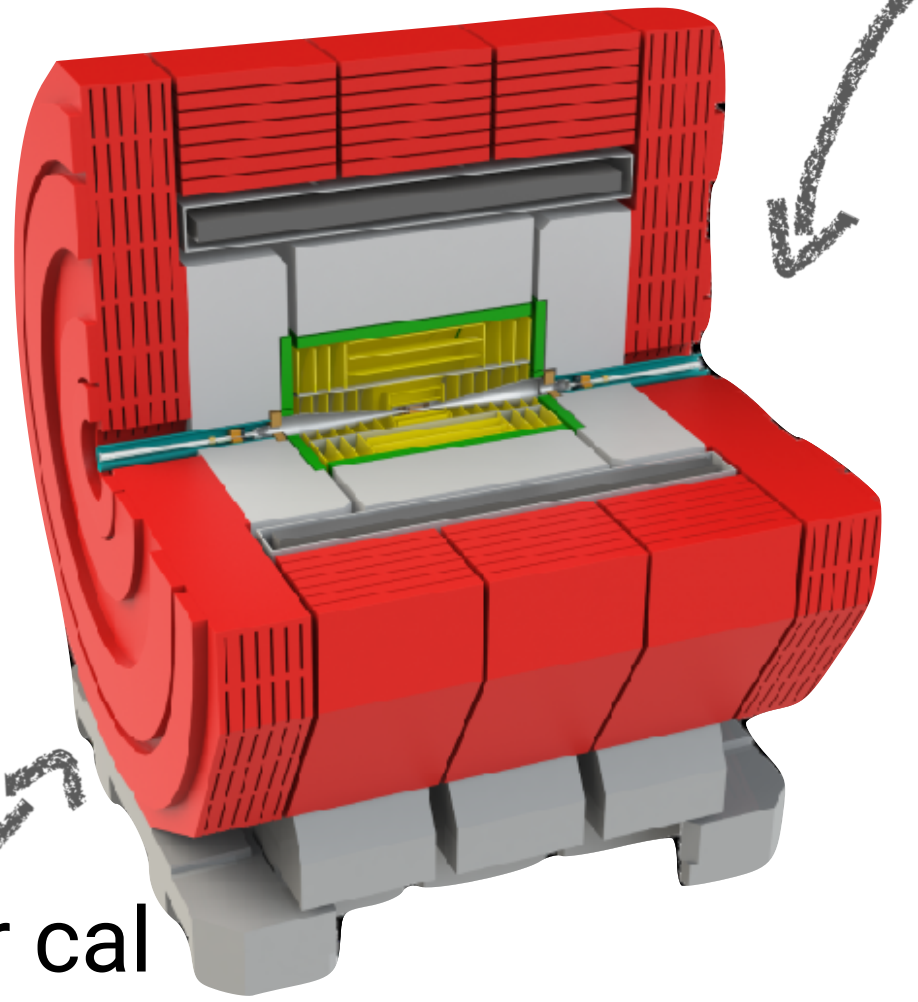


SiD

- 5T field
- all-Si tracker with outer radius of 1.2 m
- VTX inner radius 14 mm
- 4.5 λ_I HCAL

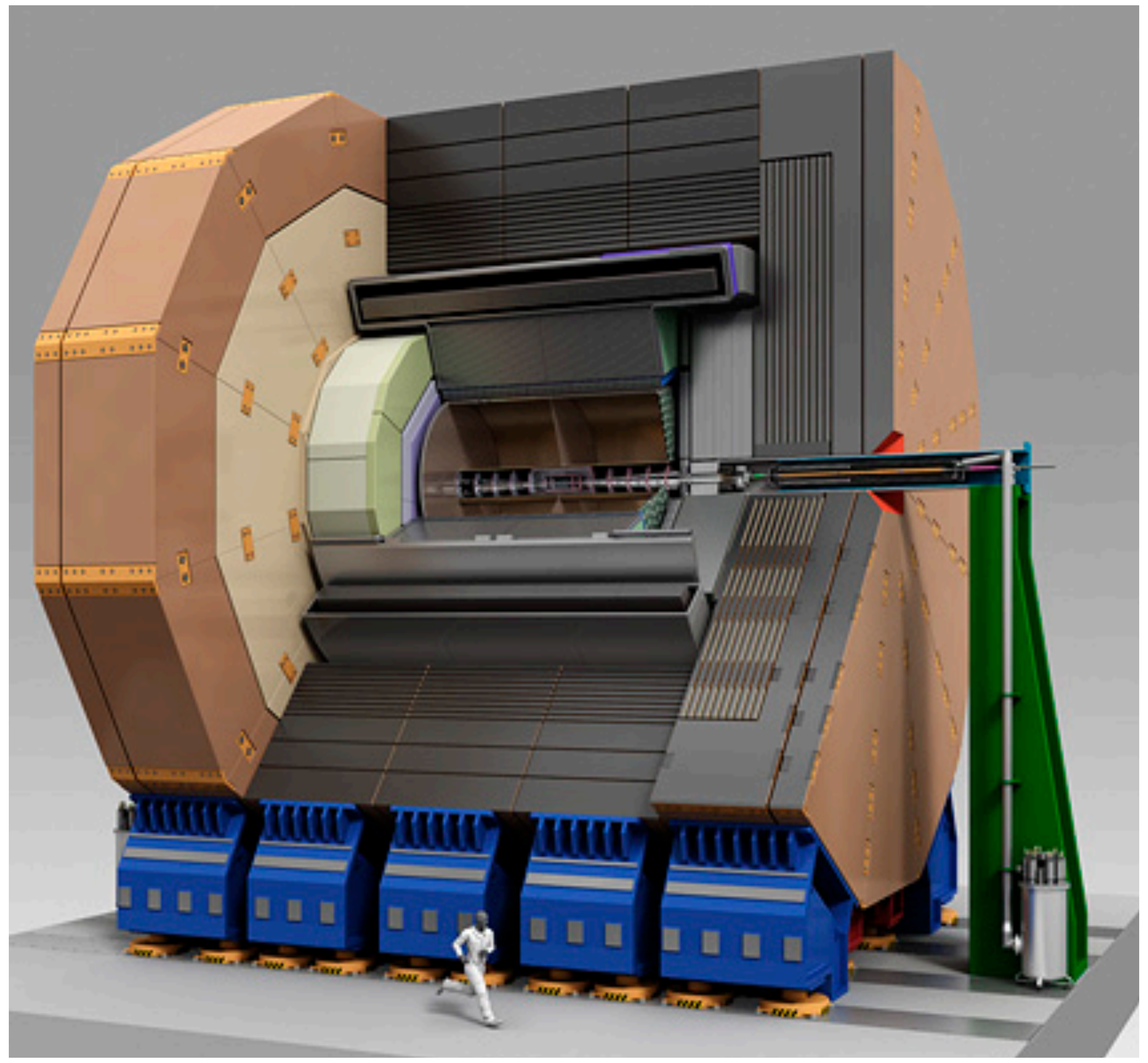
larger volume, deeper cal

more compact,
higher backgrounds



CLICdet

- 4T field
- all-Si tracker, outer radius 1.5 m
- VTX inner radius 31 mm
- 7.5 λ_I HCAL



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The Session Today

Preparing for Discussions

- ***This is an experiment***:
  The goal is to get discussion and speculation on how we can evolve (or possibly revolutionise) the LC detector concepts, incorporating new technologies or new ideas
  - Improved performance
  - Additional physics reach
  - Reduced cost
  - …

- Started of with a few (short!) presentations, covering
  - Plans of existing ILC concepts
  - Alternative approaches to (some) key LC performance goals
  - New / evolving detector technologies

- Finally: Open discussion - as the beginning of a process that should extend to the phase of EOIs for ILC detectors and beyond

Discussion

Discussion Points

… to provide some structure

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- ***Evolution of current design***
  - Increasing performance
  - Evolving technology
  - Reducing cost

- ***Adding Capabilities***
  - New features of the detector
  - Additional physics coverage
    - In this context: More emphasis on Z pole running and associated detector capabilities?

- ***Revolutionizing the current design***
  - Could we do it completely different? Pros, Cons?

The Time Line for ILC Detectors

To provide some background

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Timeline for the ILC experiments

2021 IDT calls for EoI

Necessary R&D for EoI

2022 ---------- Assumed start of Pre-lab ----------

2022 EoI presentation

Necessary R&D for LoI

2023 LoI submission and presentation

Continuation of R&D
Selection process by the ILCC

2024 ILCC recommendation on the first set of the projects to proceed toward TP

Necessary R&D for TP

2025 TP submission and presentation of the first set of experiments

Continuation of R&D
Selection process by the ILCC

2026 ---------- Assumed start of ILC-lab ----------

2026-27 ILCC recommendation for the first set of experiments to proceed toward TDRs

2027 ILC-lab approval of the first set of experiments and request to proceed toward TDRs

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- Funding agencies will not provide dedicated ILC detector R&D funds before the Pre-lab being established.
- For some EoIs, R&D would be needed to make LoIs.
  → driving the timing for the LoI submission
- Selection process starts with the LoIs.
  → driving the timing for the LoI decision
- Experiments are formally approved based on TPs.
- The ILC-lab is needed for approvals.
- Availability of resources is part of the approval criteria.
  → driving the timing for the TP decision
- These considerations are for the initial set of experiments. There could be more experiments proposed at later time.

IDT: International Development Team
EoI: Expression of Interest
LoI: Letter of Interest
TP: Technical Proposal
TDR: Technical Design Report
ILCC: ILC Committee

IDT-EB 21/12/2020

From Hitoshi, earlier today

Bottom line (my interpretation):

- ***2023***: Detector concepts
- ***2025***: Technical layout with options
- ***2027***: Proceed to TDRs, final technology choices