# New Technologies & Ideas for Collider Detectors

## *Summary*


**Frank Simon**

MAX-PLANCK-INSTITUT FÜR PHYSIK


*@ LCWS, March 2021*

LCWS2021

INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS

# Overview

- Brief recap of LC Detector design “philosophy”
- Ideas beyond the baseline - based on discussions last night

# Key Drivers for Detector Design

*Physics & Experimental Conditions*

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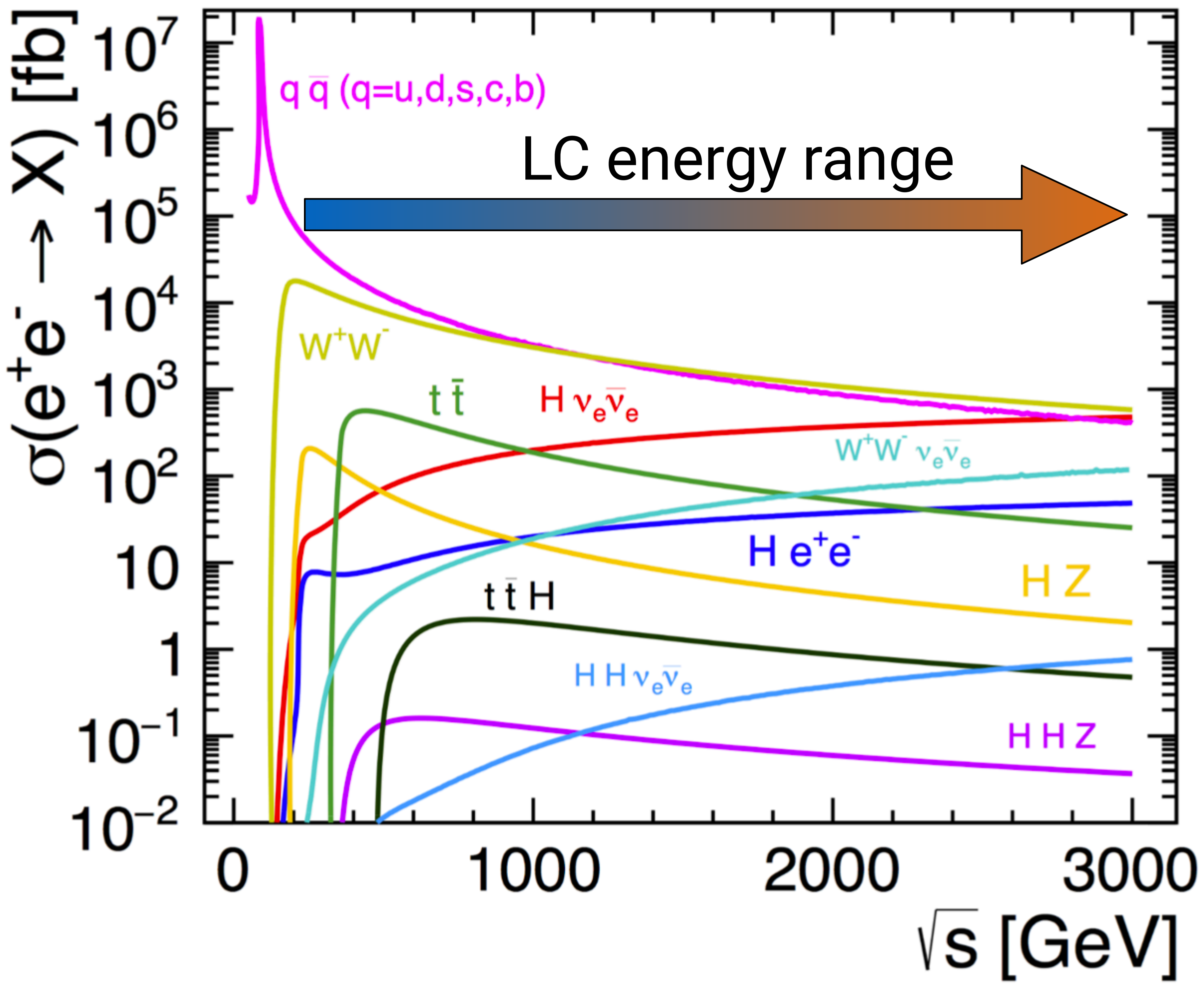


*Physics*

- 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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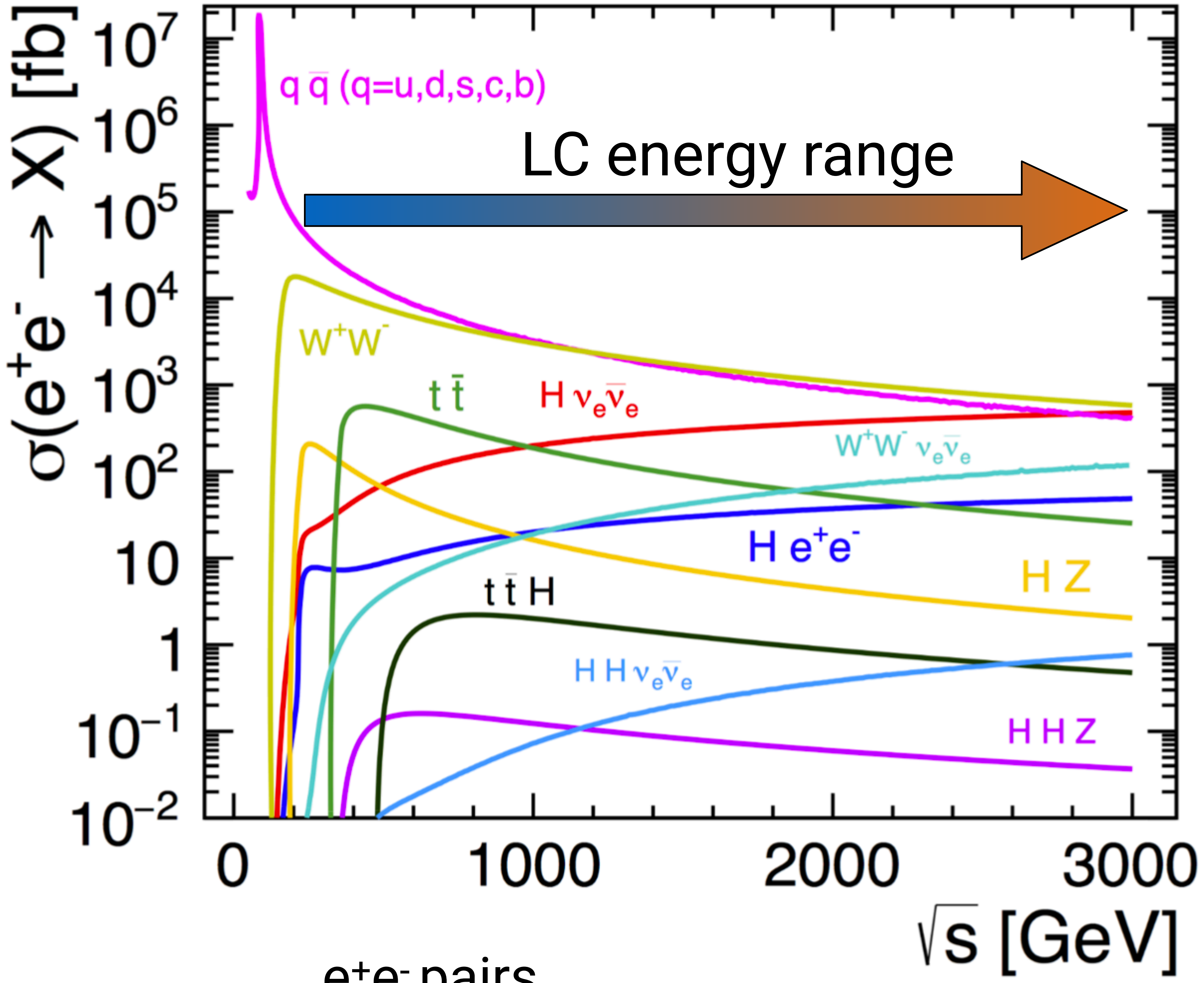


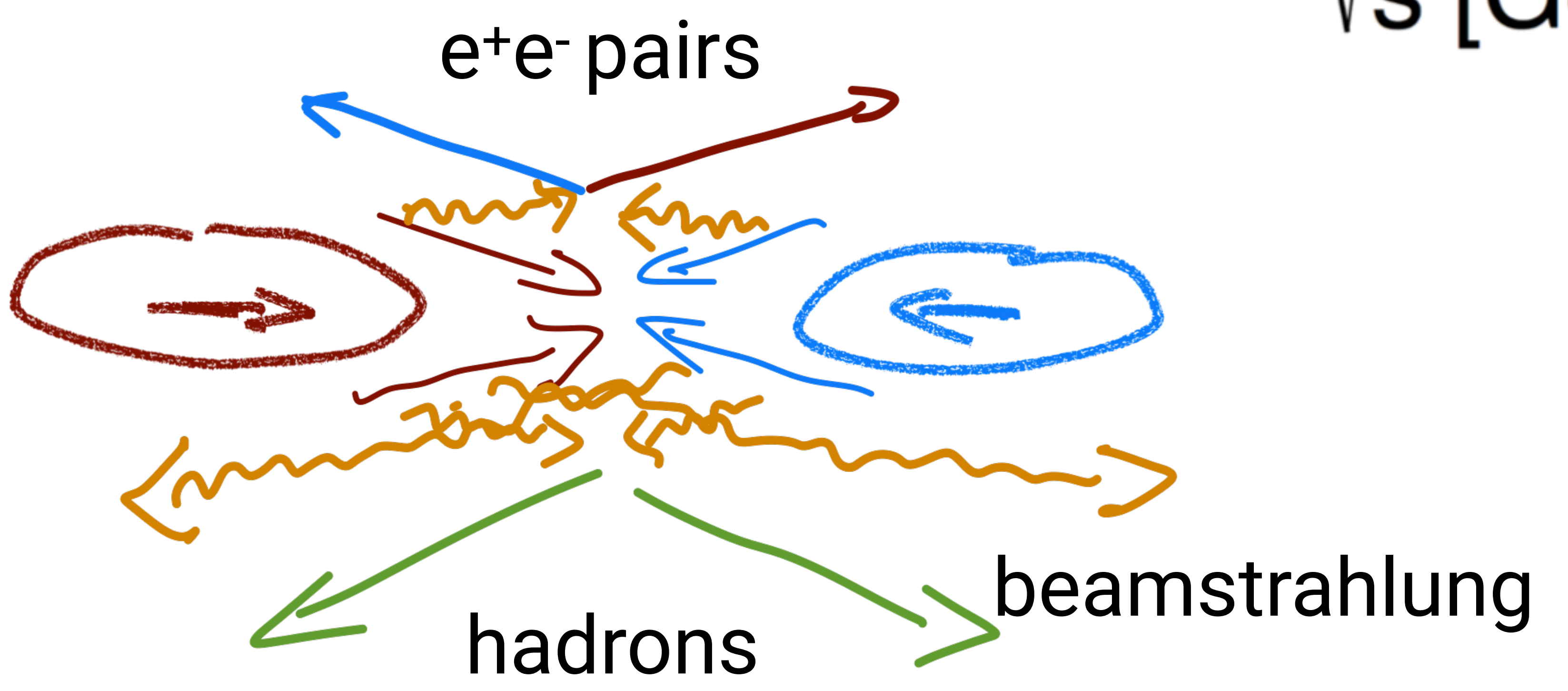


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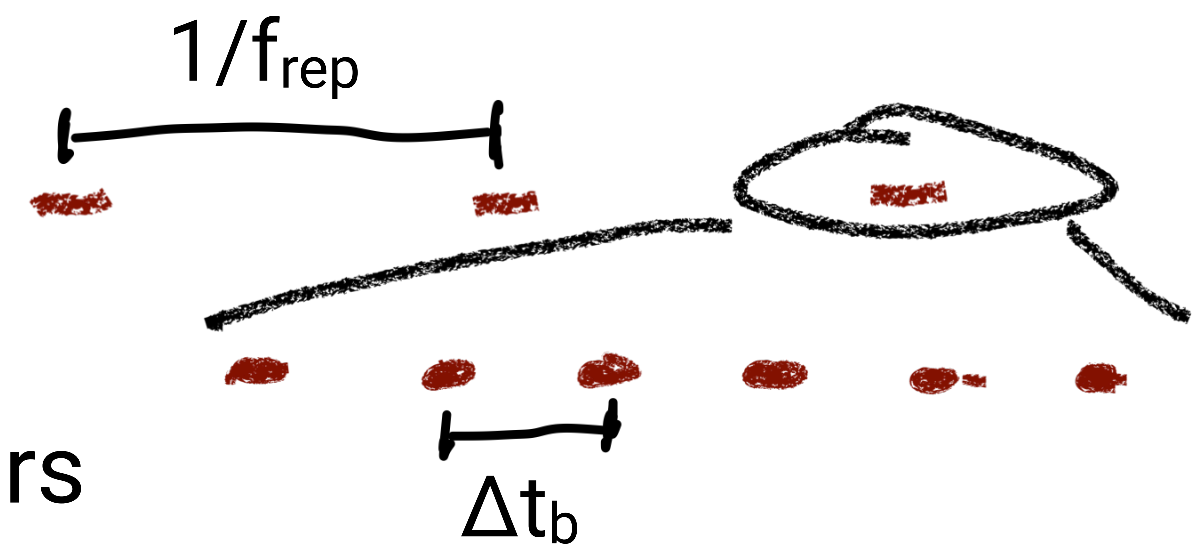
*Experimental conditions*

- 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

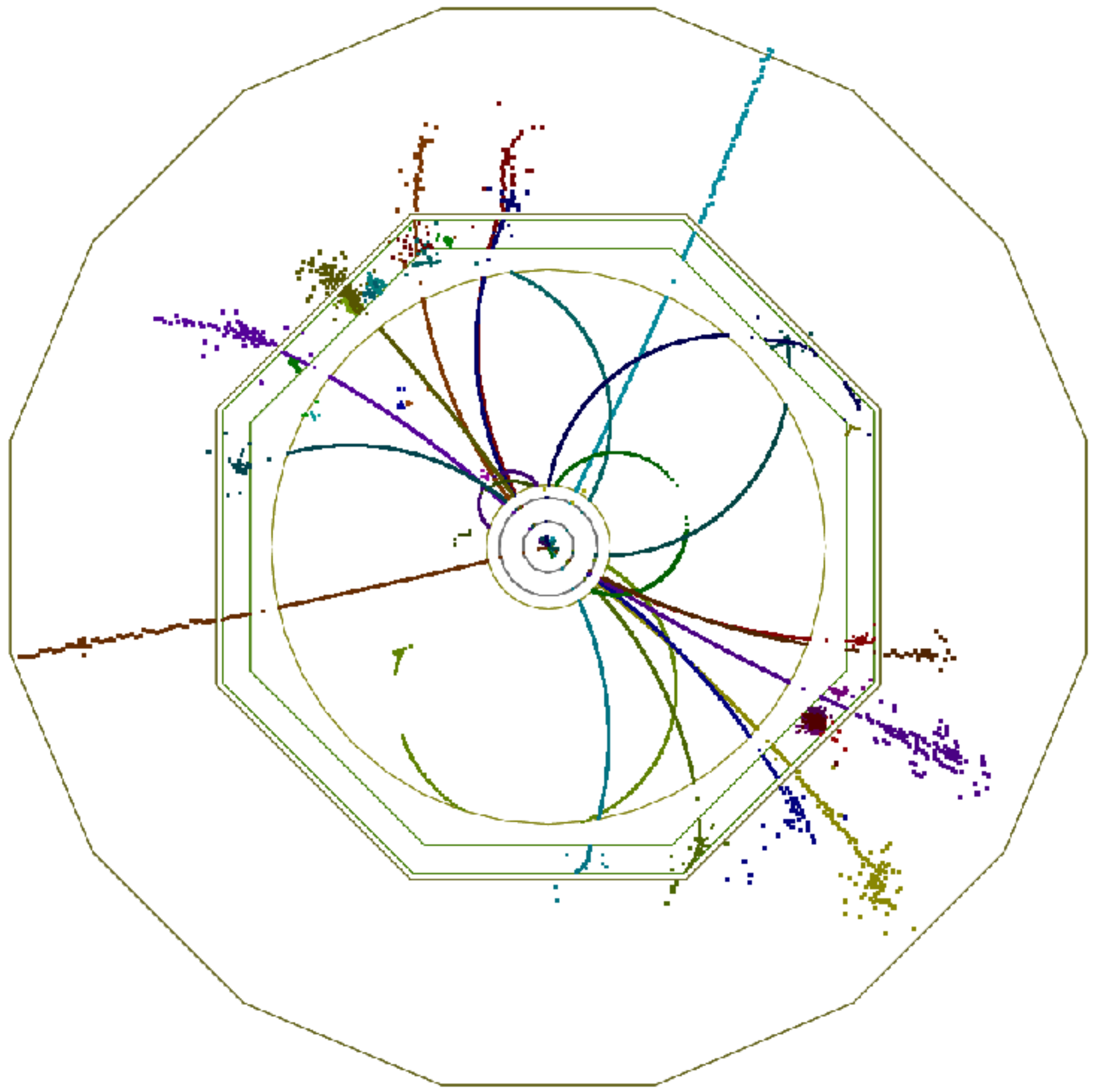
*Motivated by key physics signatures*

- ***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

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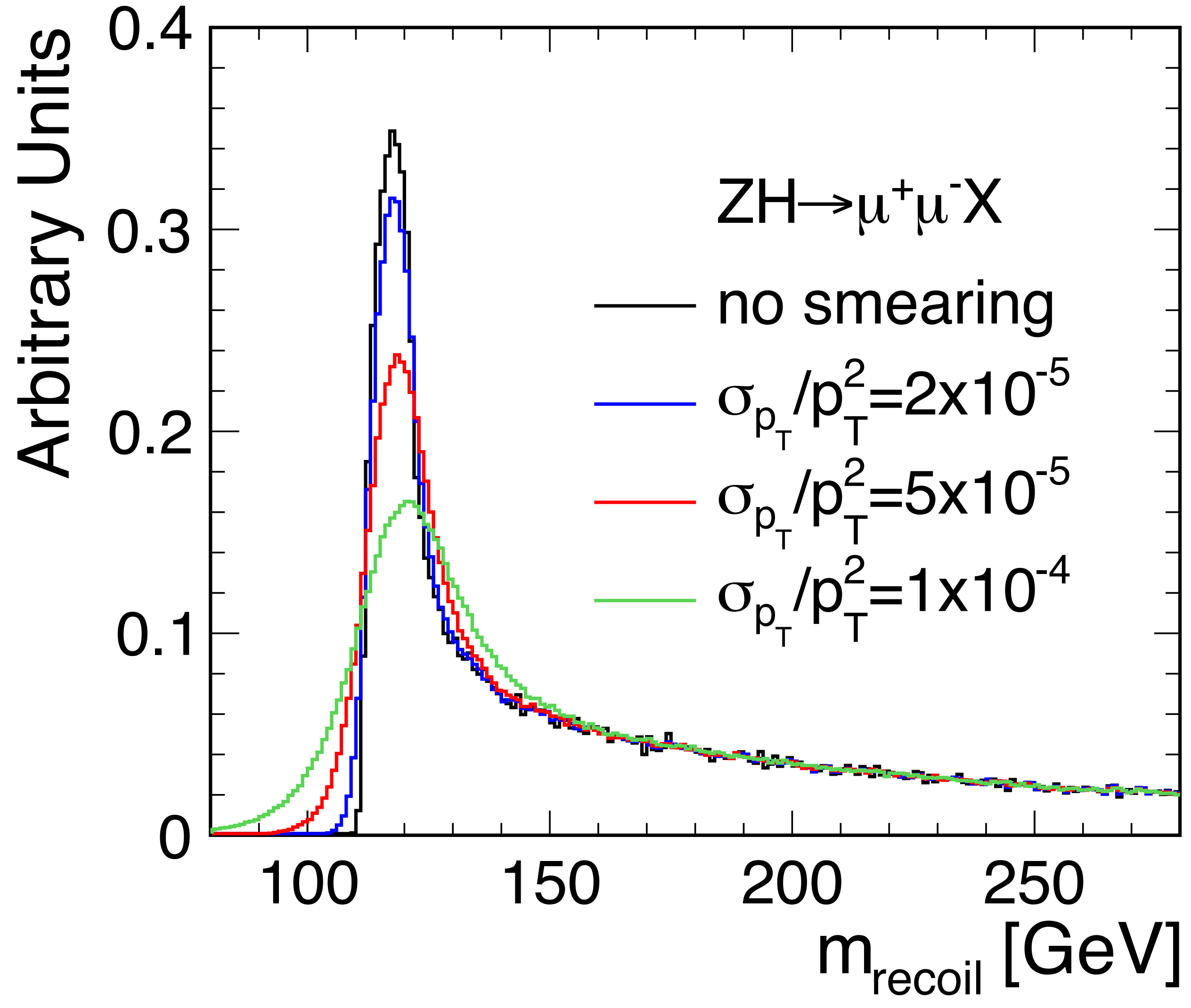


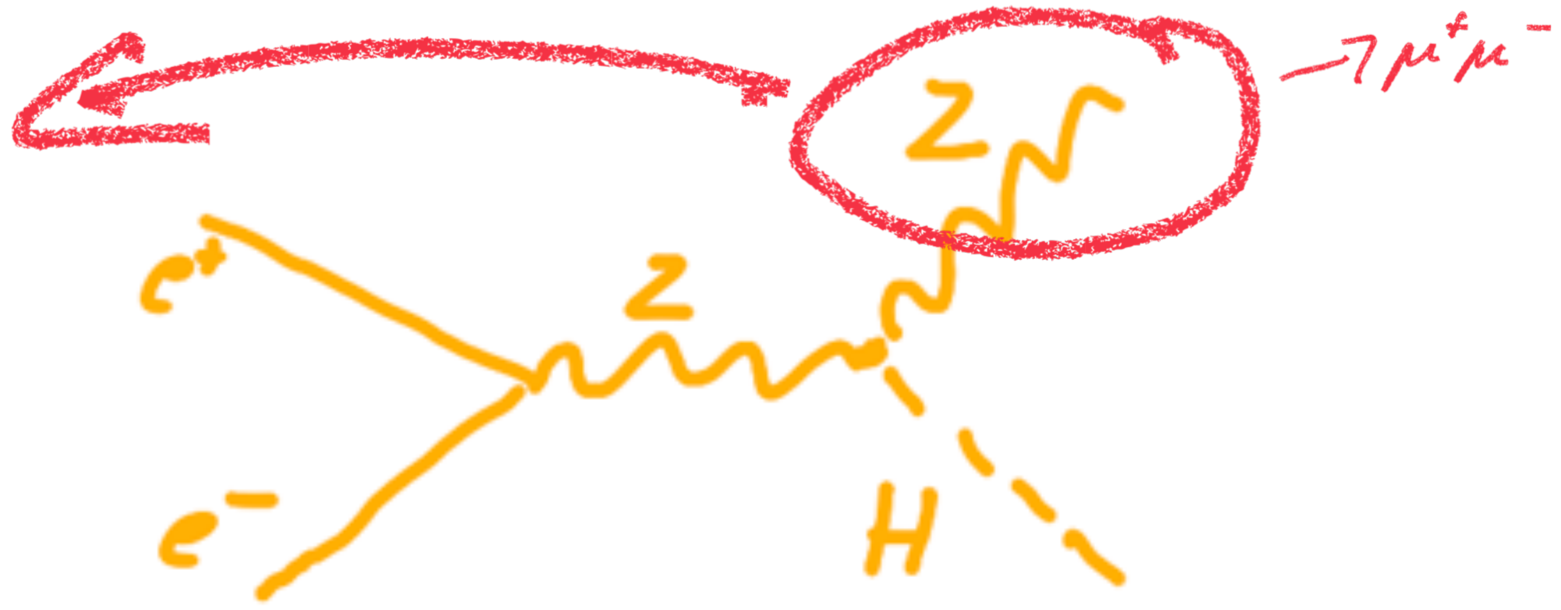


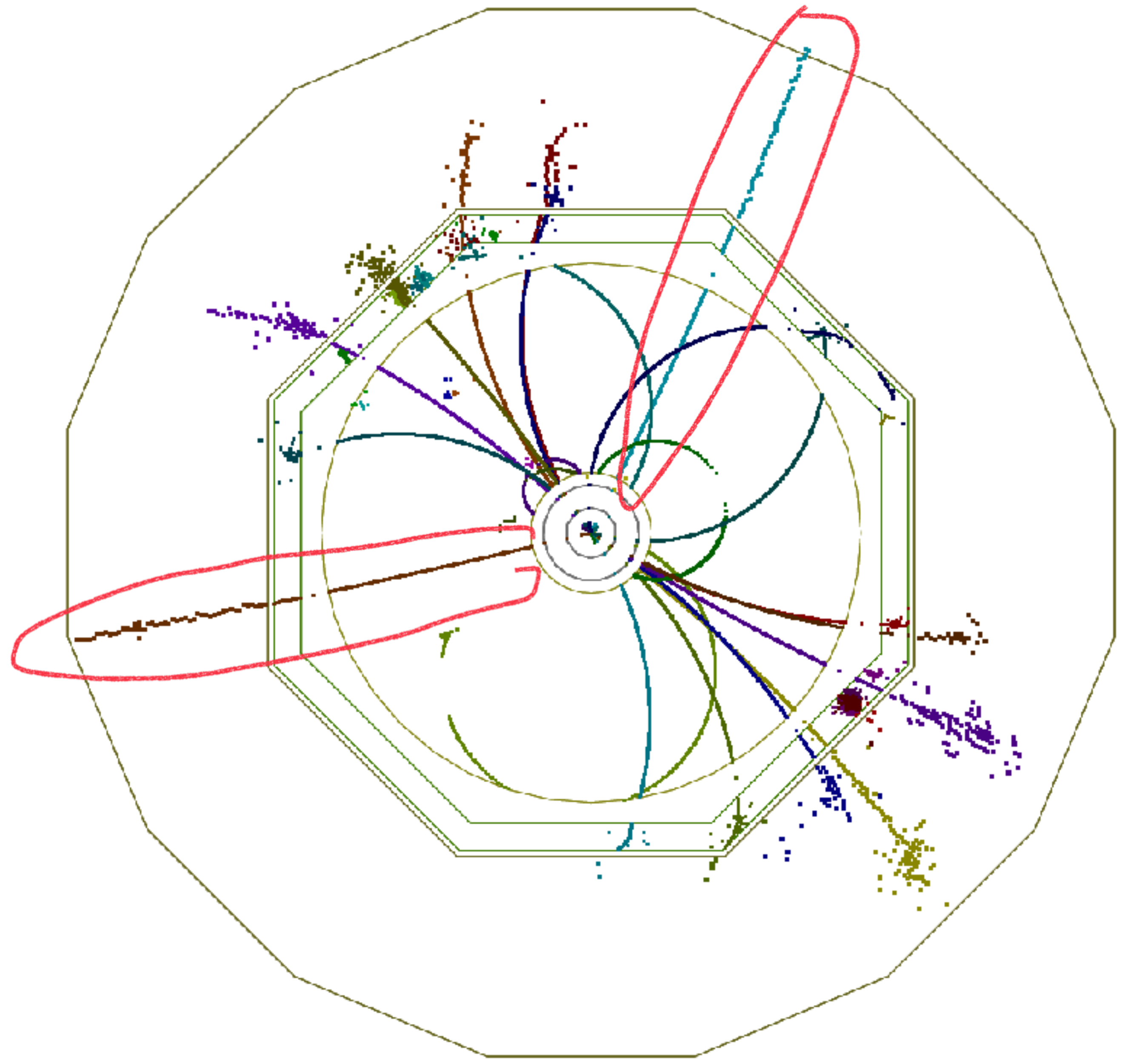

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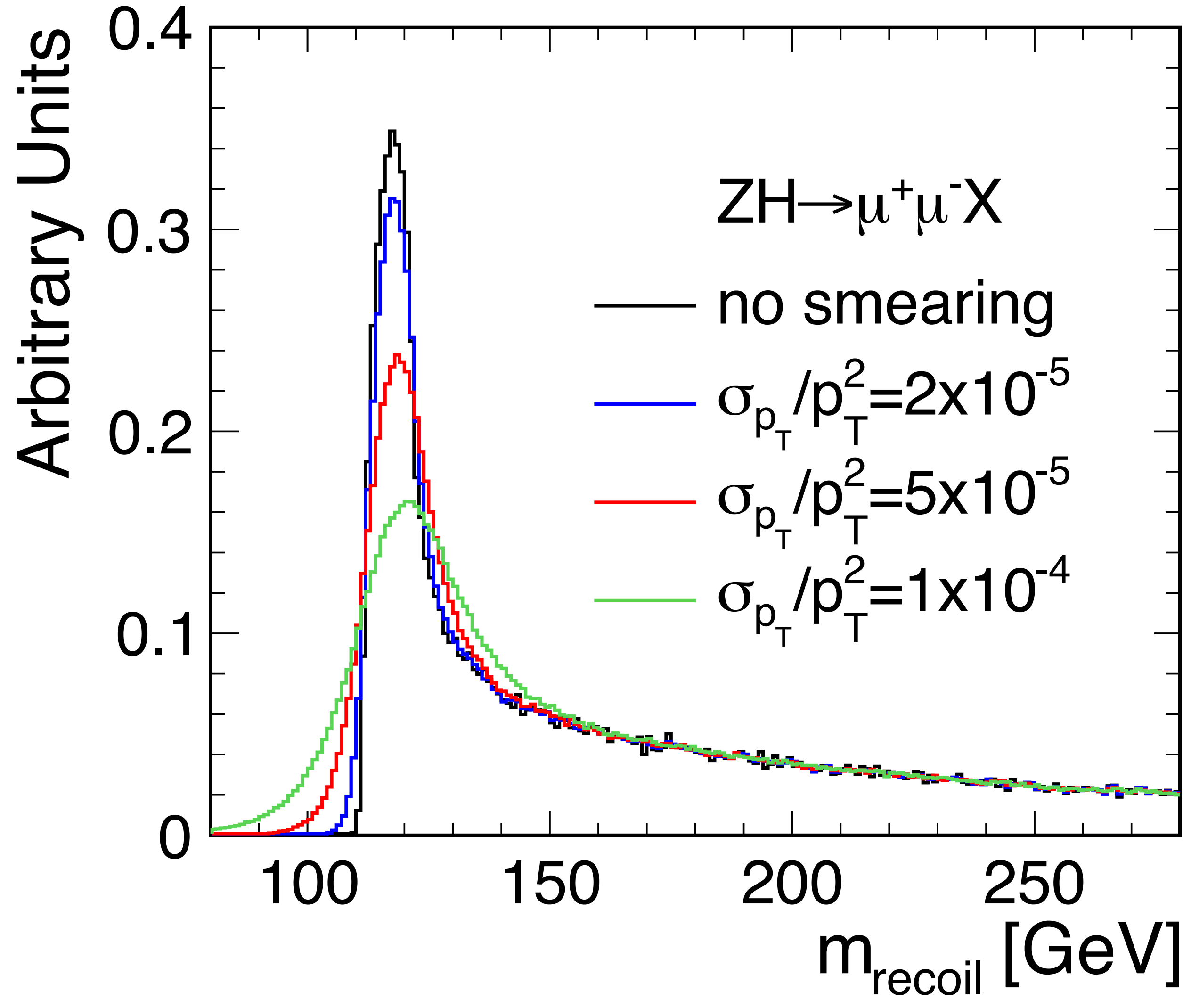
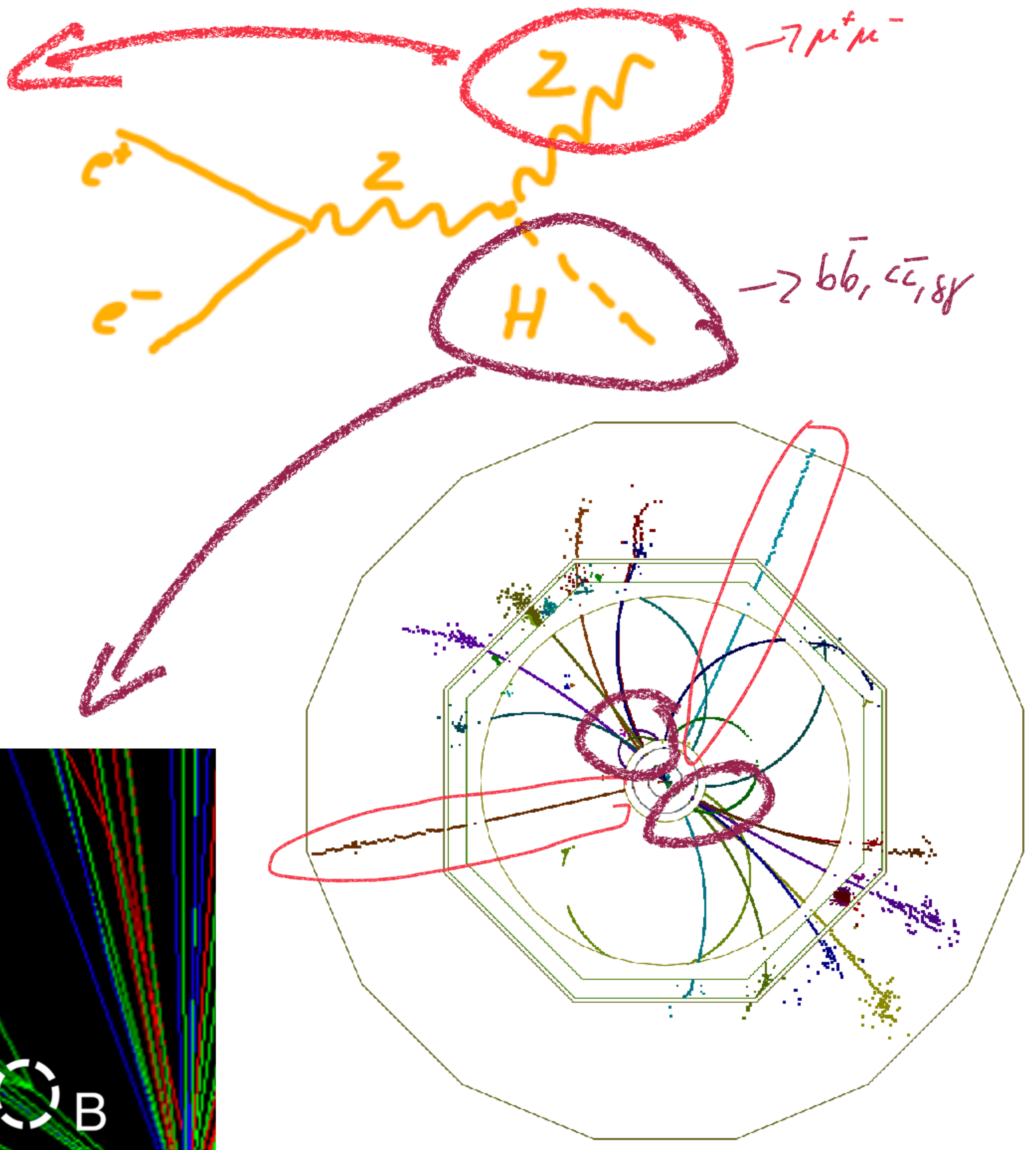
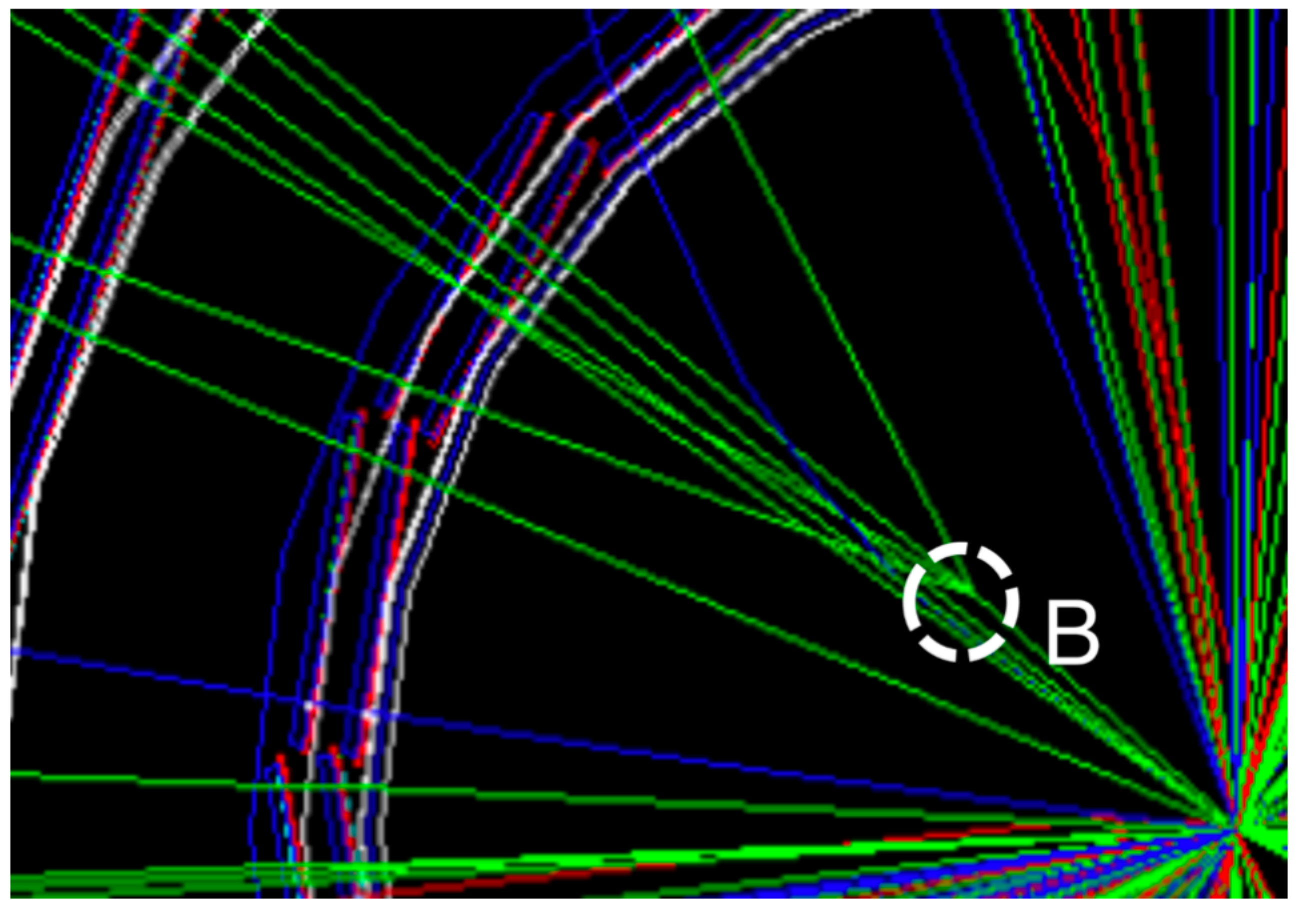



- ***Impact parameter resolution****, vertex charge*
  Flavour tagging: b/c/light tagging in Higgs decays, top physics, …

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



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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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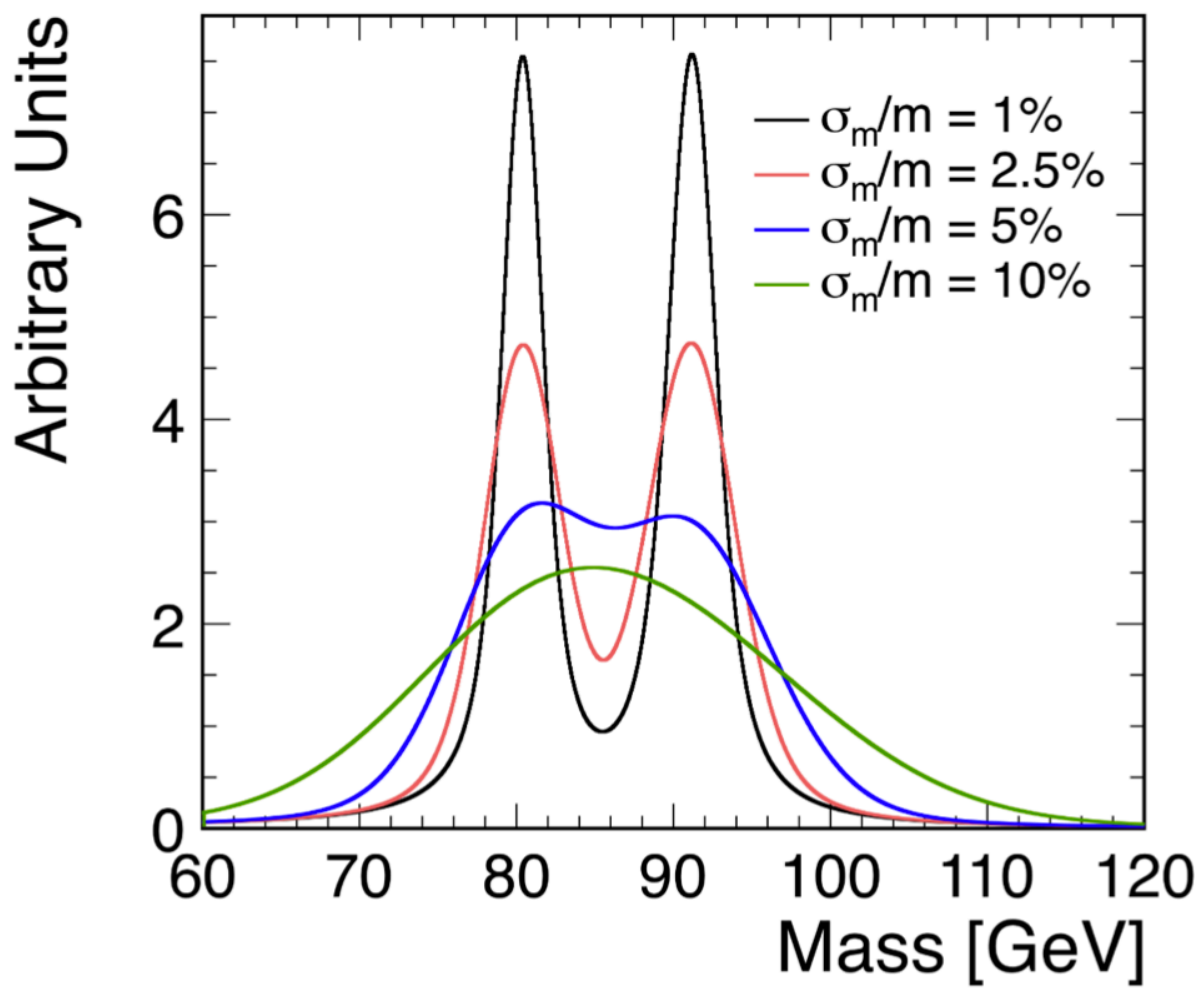
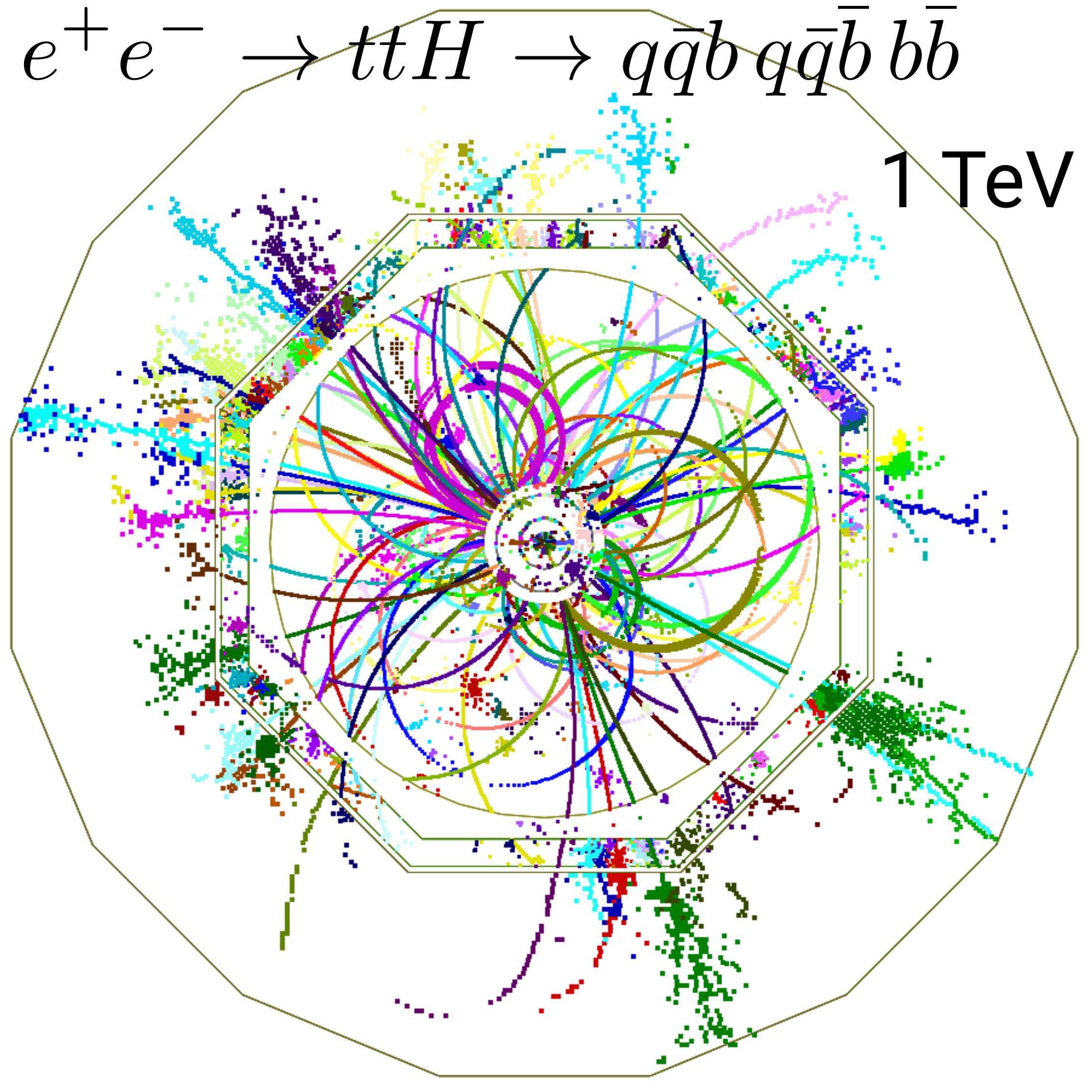
  Resolution not in the focus: ~ 15 - 20%/√E
  Worth another look ?
  Coverage to 100s of GeV important



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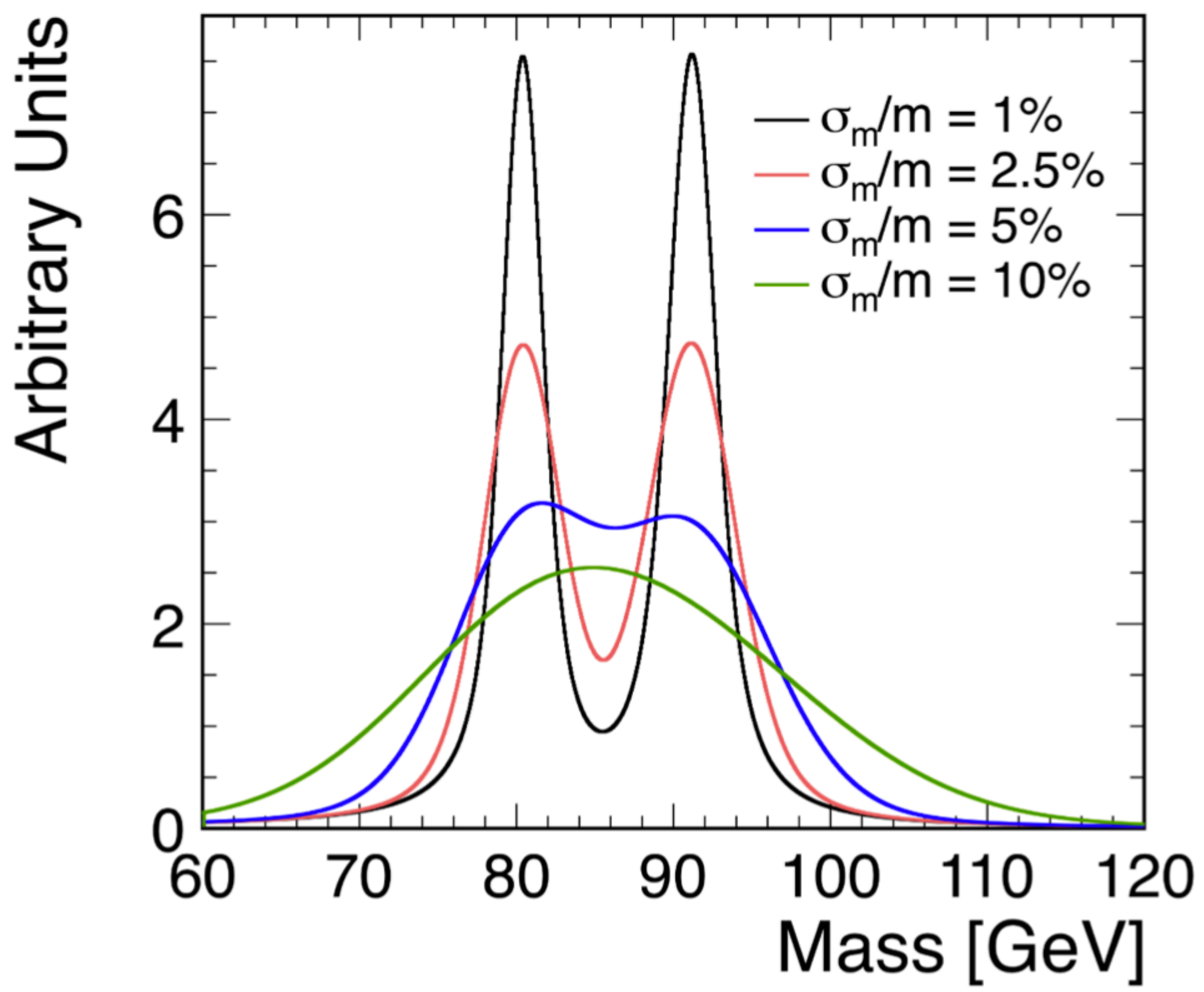
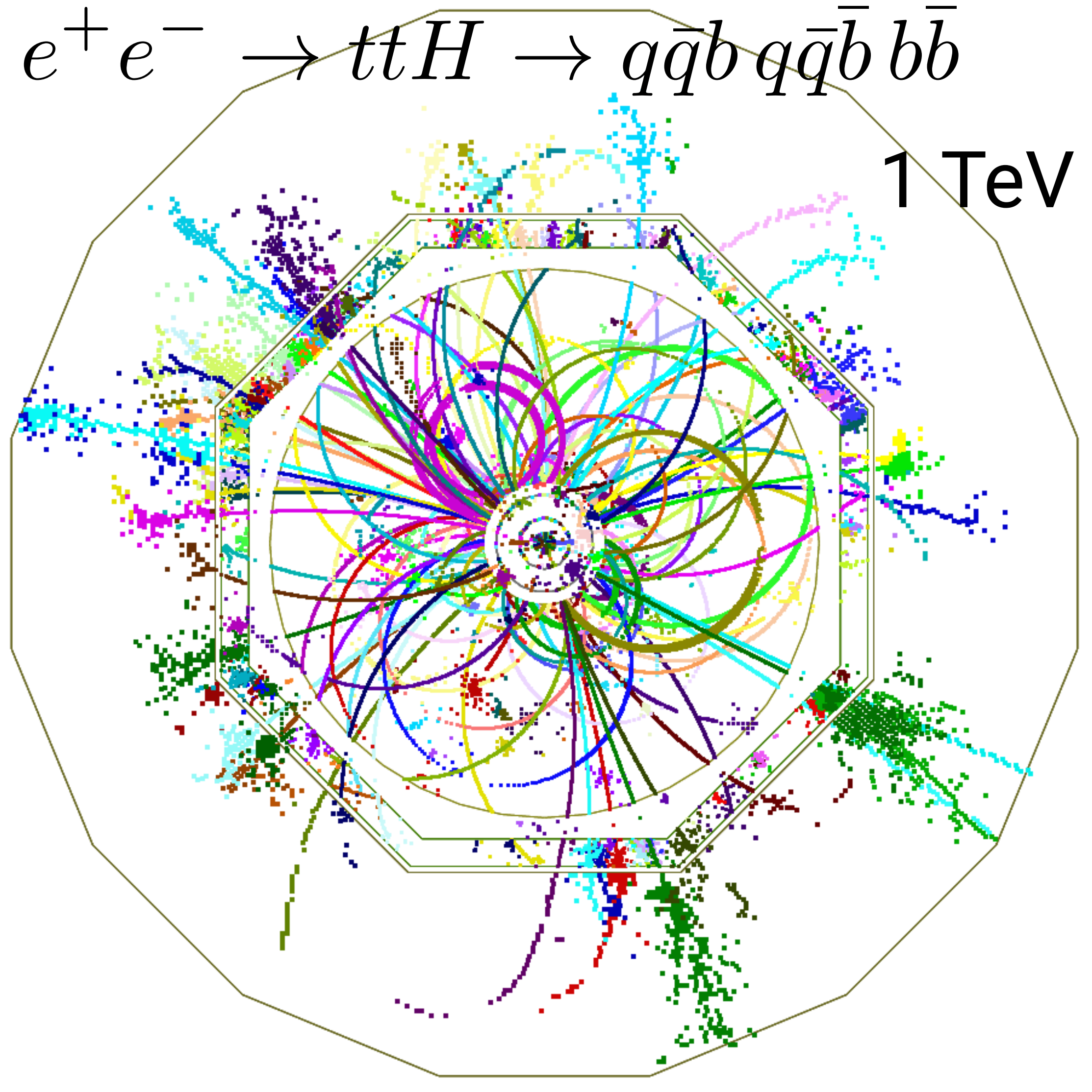
  Moderate capabilities, not overly emphasised in original design (with the exception of e, μ)




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



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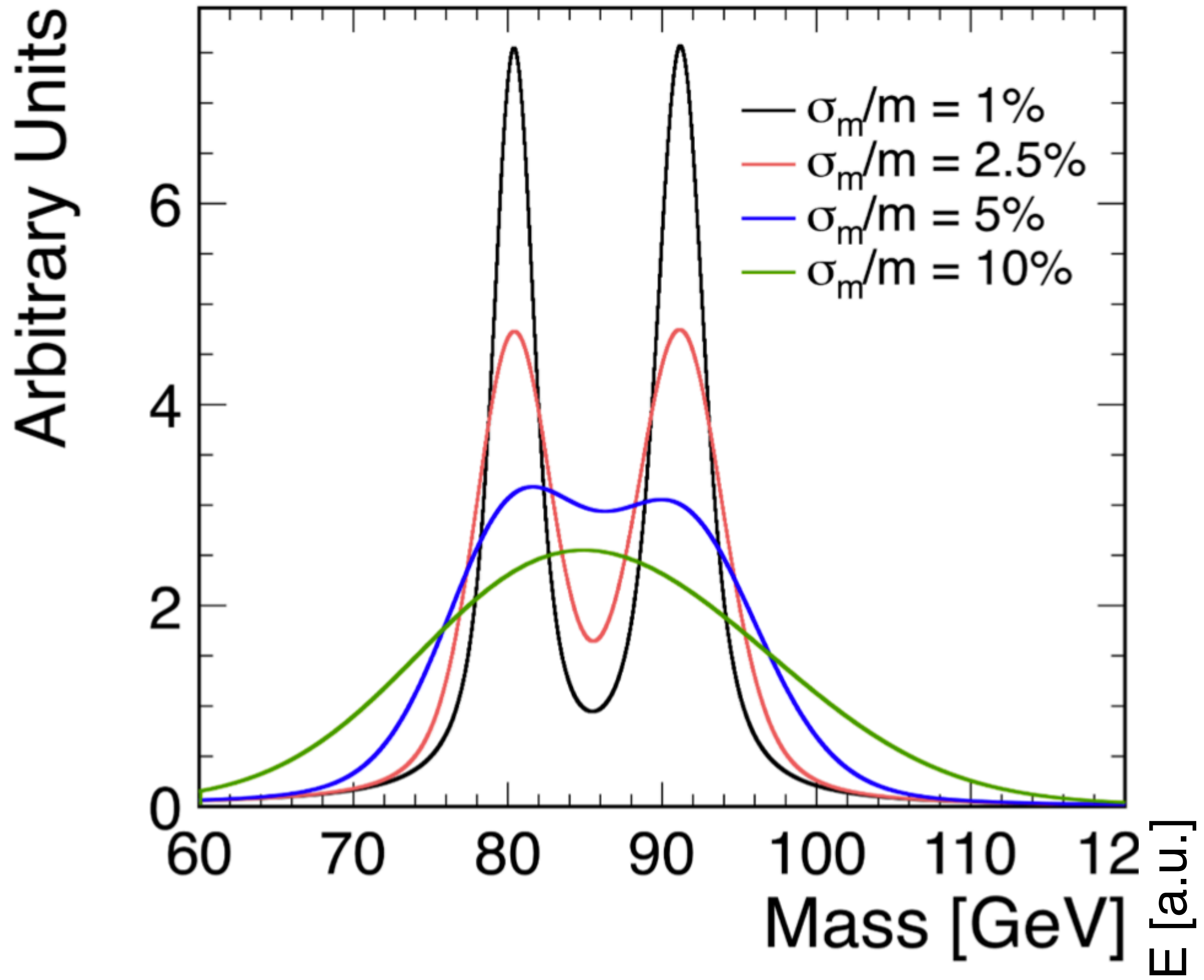
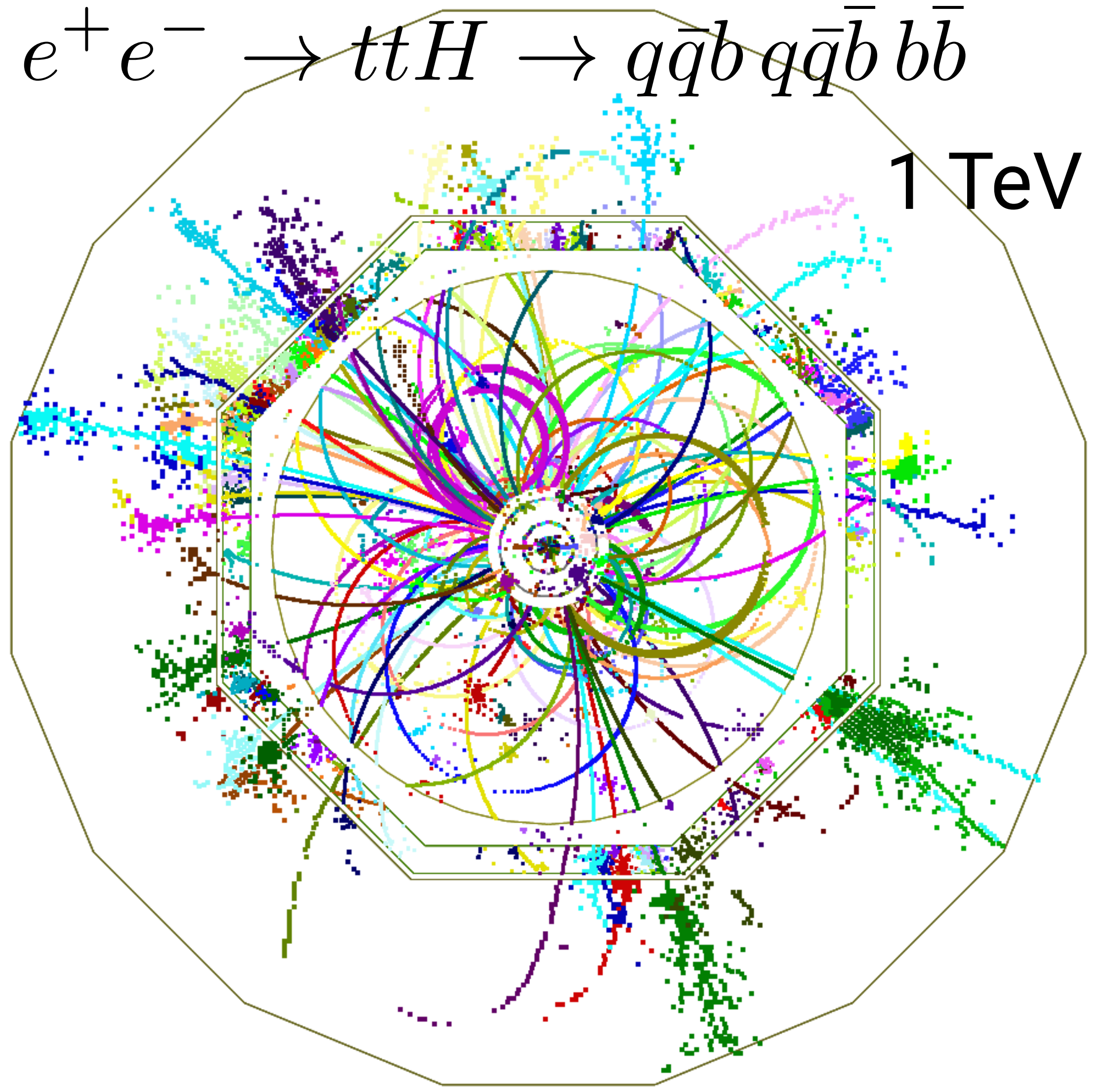
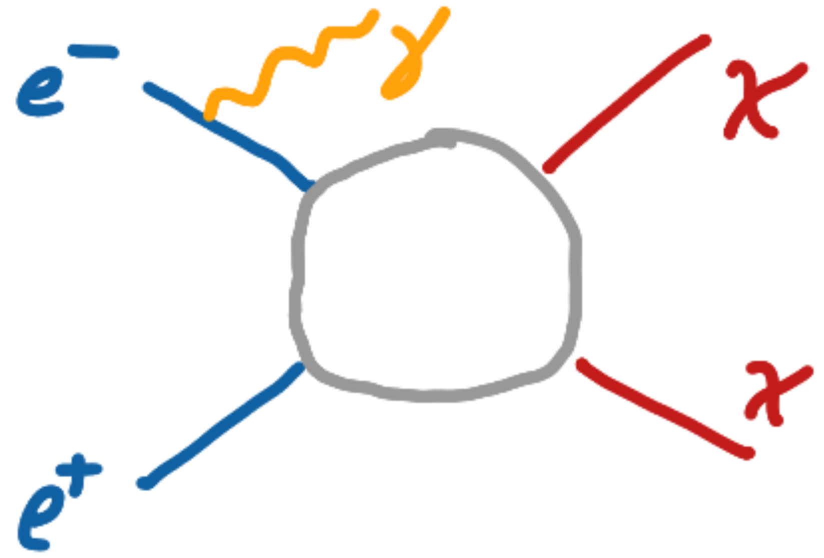
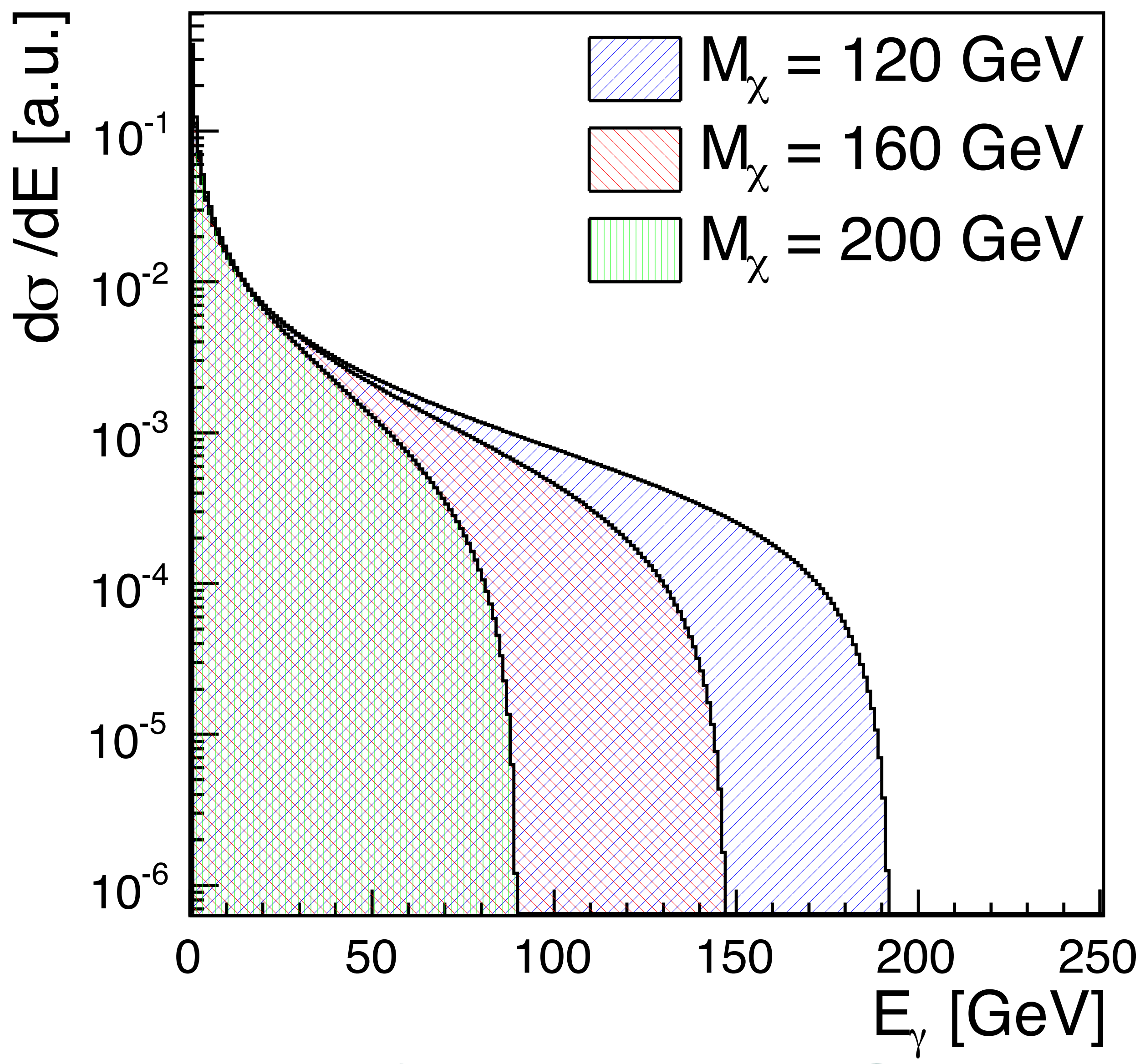
- ***Hermetic coverage***
  Dark matter searches in mono-photon events, …
  N.B.: Achievable limits do not depend strongly on $\sigma(E_\gamma)$



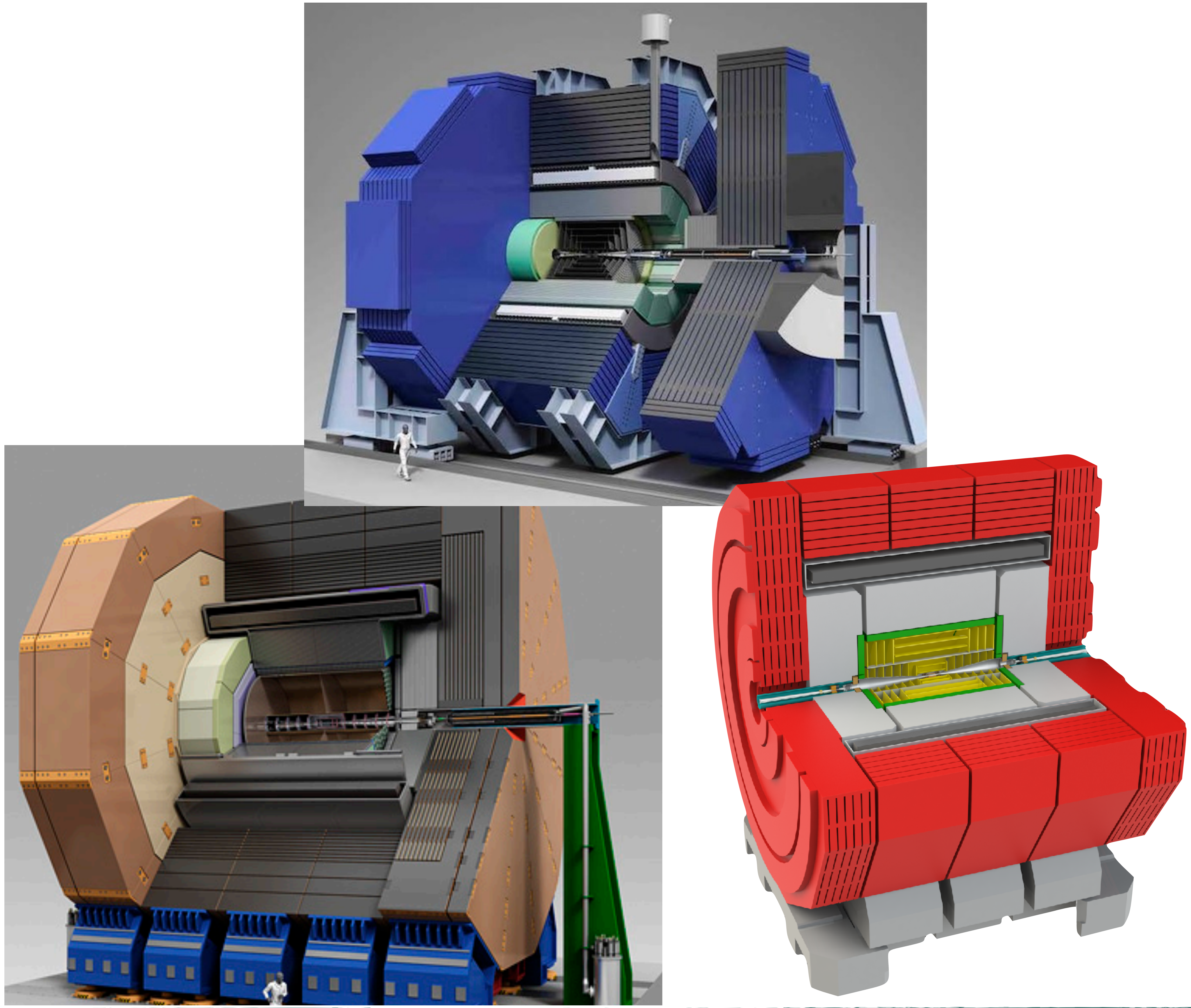



# The Linear Collider Detector Design - Main Features

*Variations in terms of size, field and tracker / calorimeter details*





- 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

# Ideas Beyond The Baseline

*Just first thoughts and discussion starters*

- *Evolution of the current designs*:
  Technological advances, reduction in cost, …
- *Additional Capabilities*:
  Particle ID, additional dimensions in reconstruction, …
- *Revolutionising the current designs*:
  Different approaches to key elements

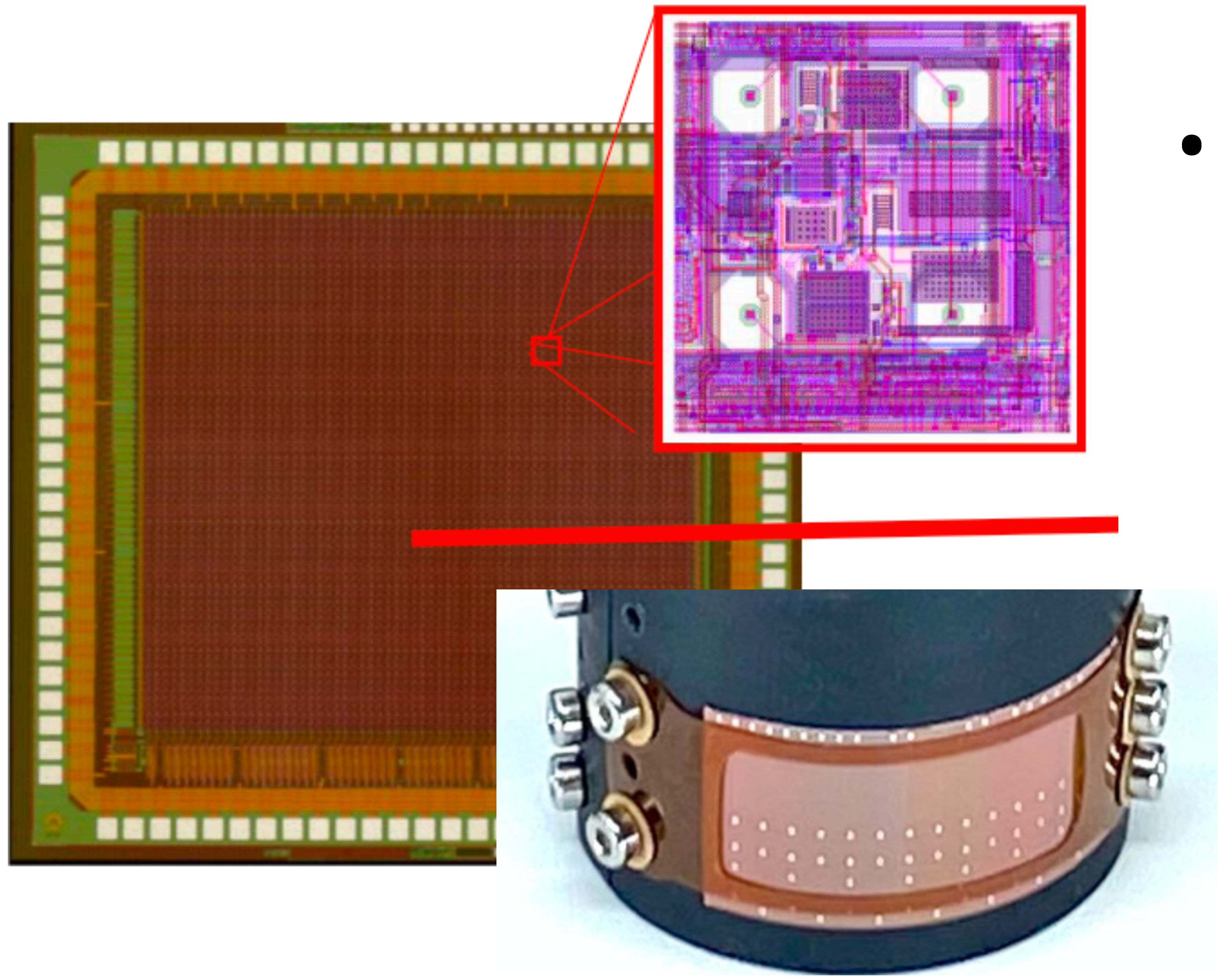
Based on “flash talks” in session N2*, and open discussion - thanks to all who participated!

*session organizers: Sarah Eno, Philipp Roloff, FS

# Evolution of the current design

*Technology evolution, cost, scalability*

- A central theme: semiconductor technology evolution



- CMOS sensors for vertex, tracker, em calorimetry
  - industrial process with high throughput: scalable, cost advantage wrt high-resistivity Si
  - integration of “intelligence” - reduced complexity

Towards a common technology for all Si systems?

An important element: power consumption

Eliminating the need for power pulsing in some detector regions may have significant benefits for stability, system design

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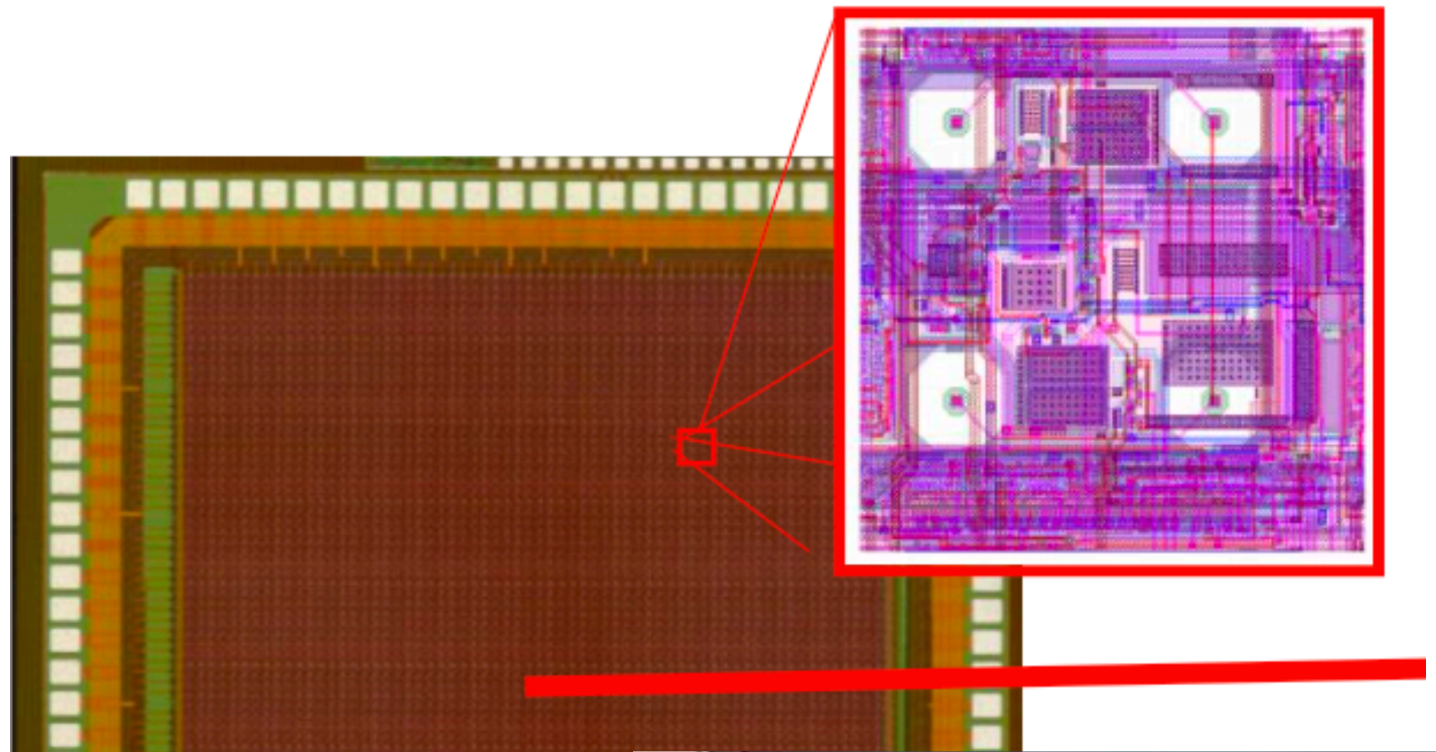

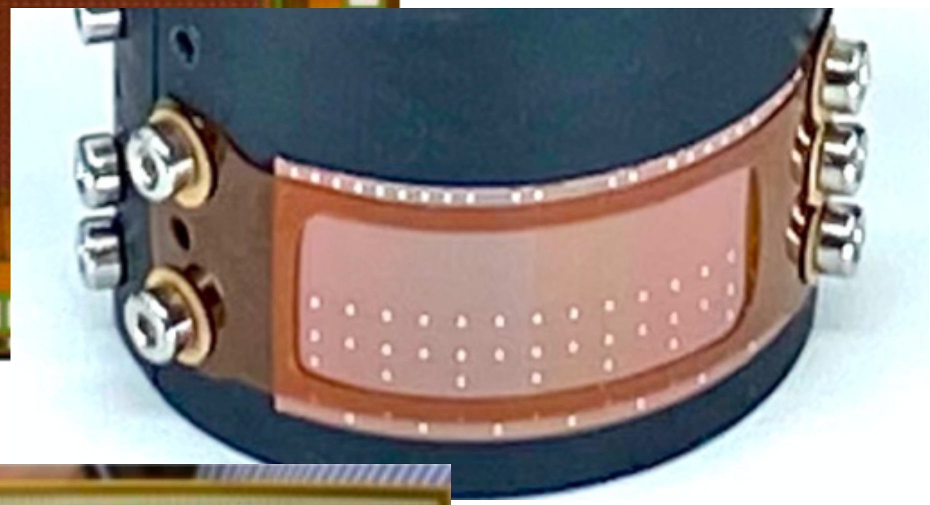

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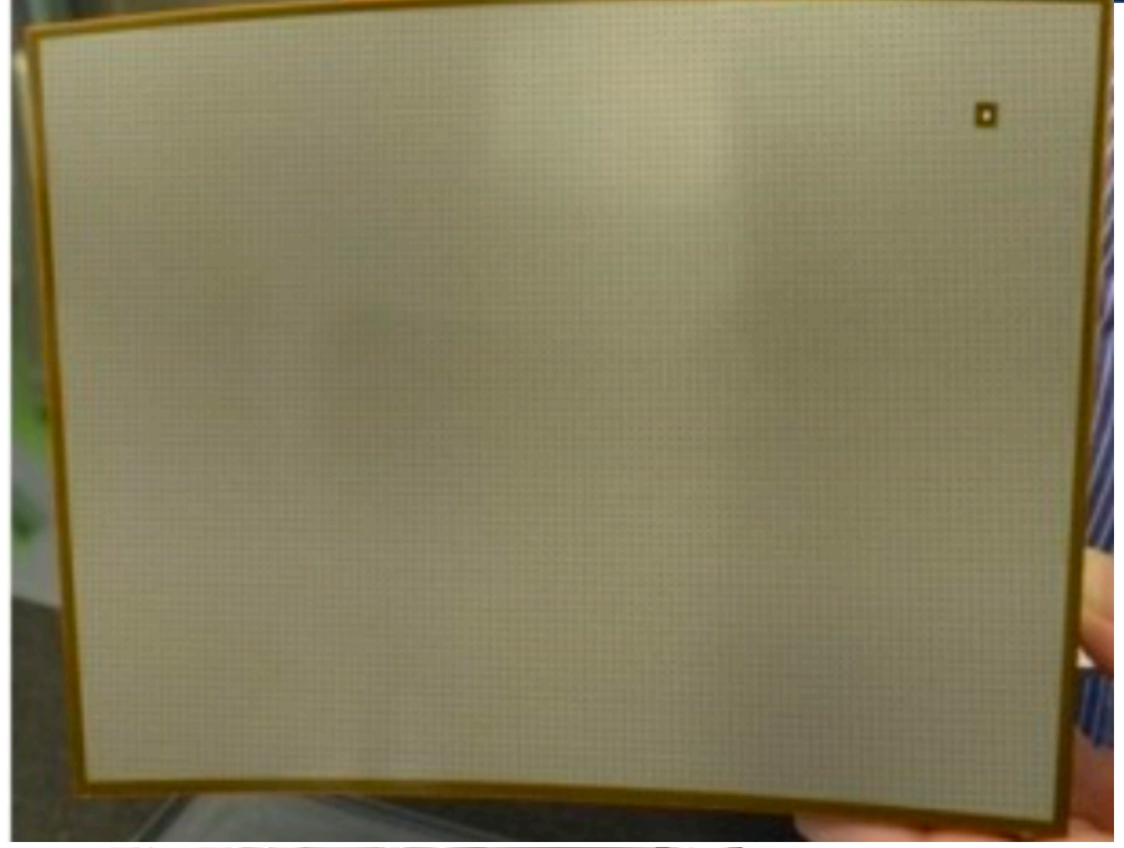

- Pixelated readout planes for TPC endplates: highest possible granularity for gaseous detectors

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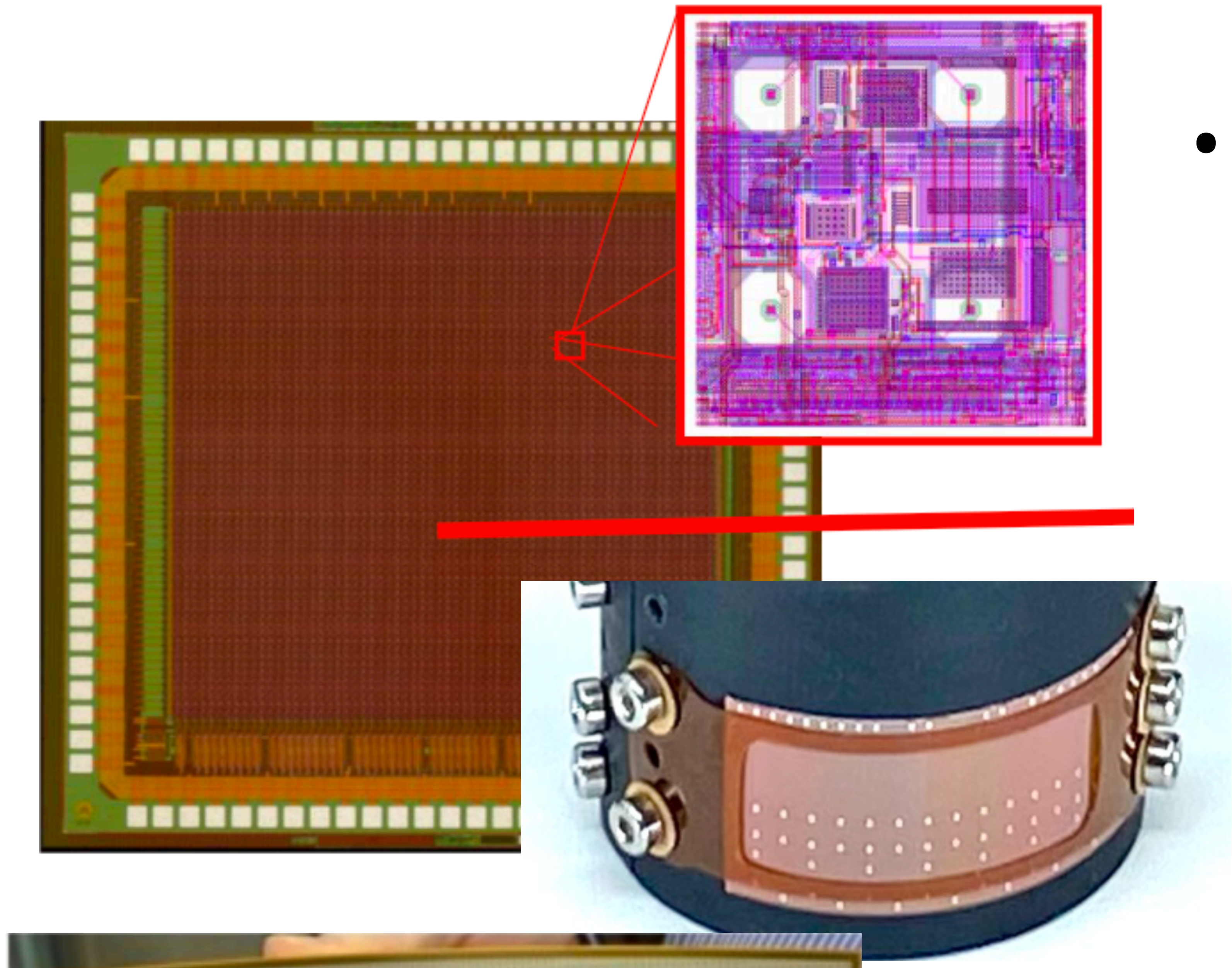

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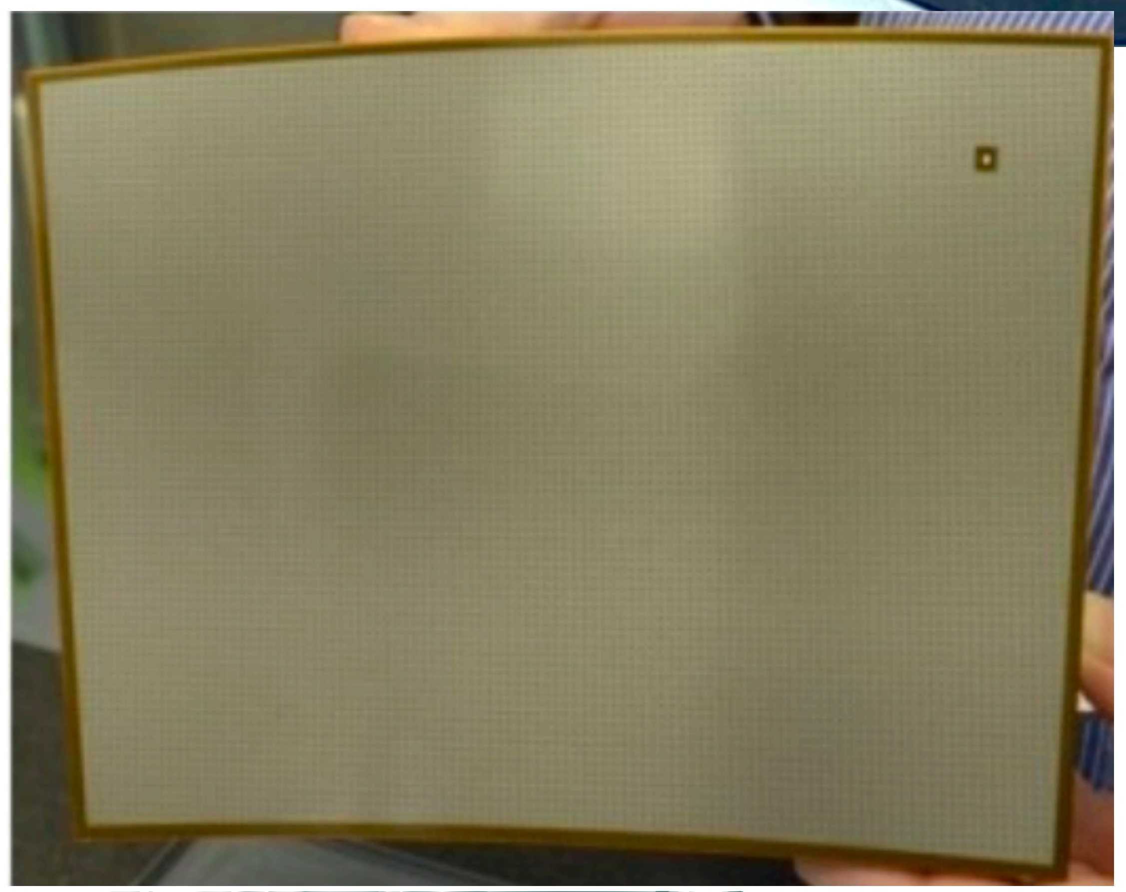

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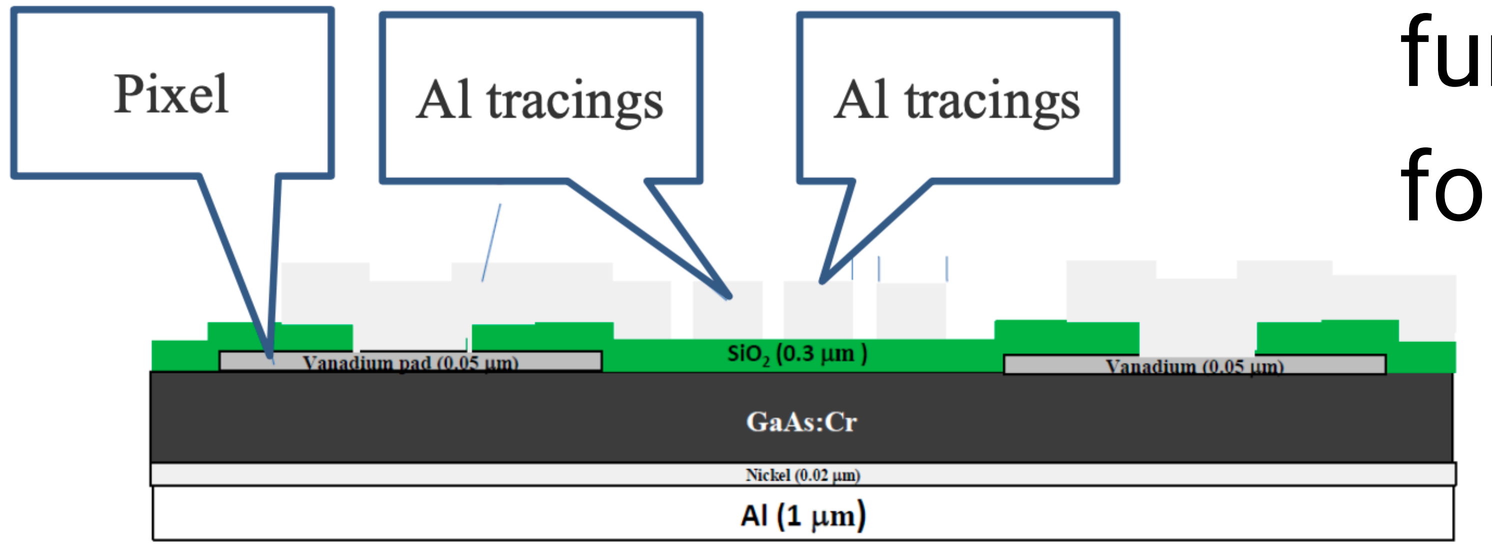


- GaAs sensors with traces: reduced complexity, further compactness for forward calorimeters

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*Its not only sensors*

- Mechanical systems: Ultra-light materials, additive manufacturing - reducing material, increasing stability, reducing cost?

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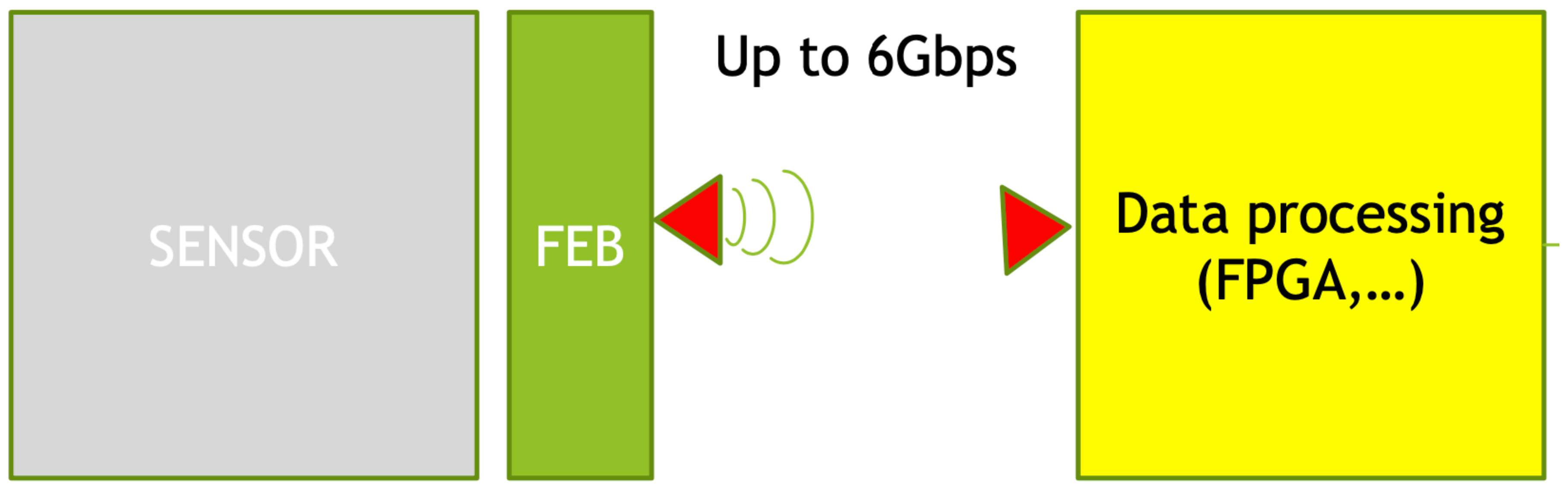

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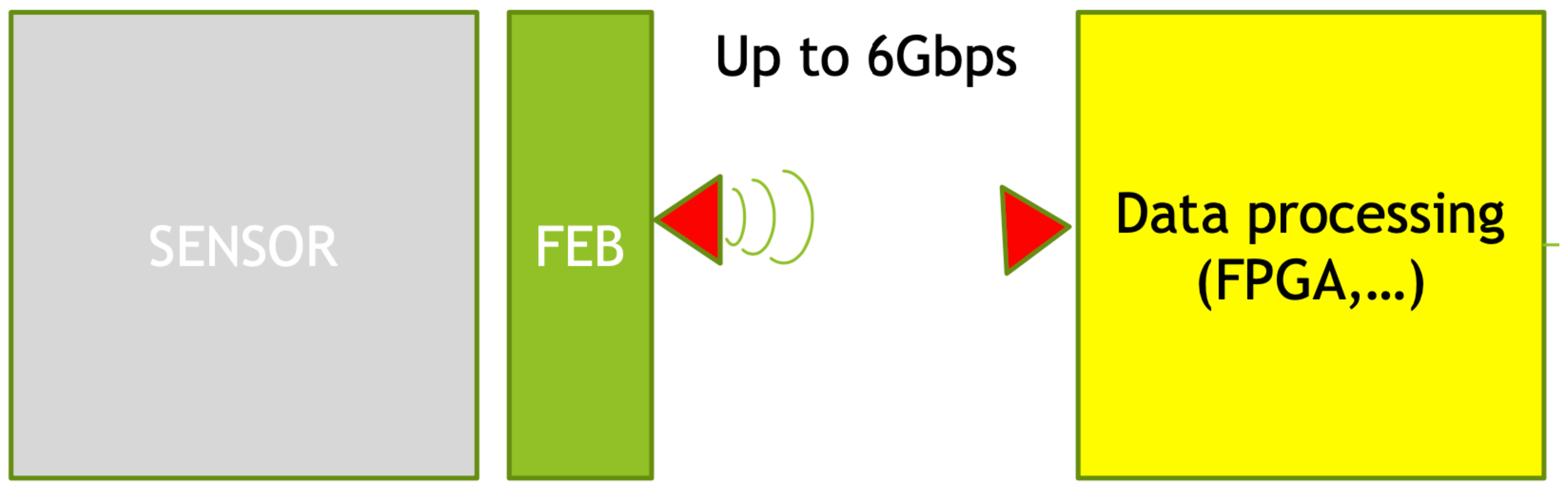
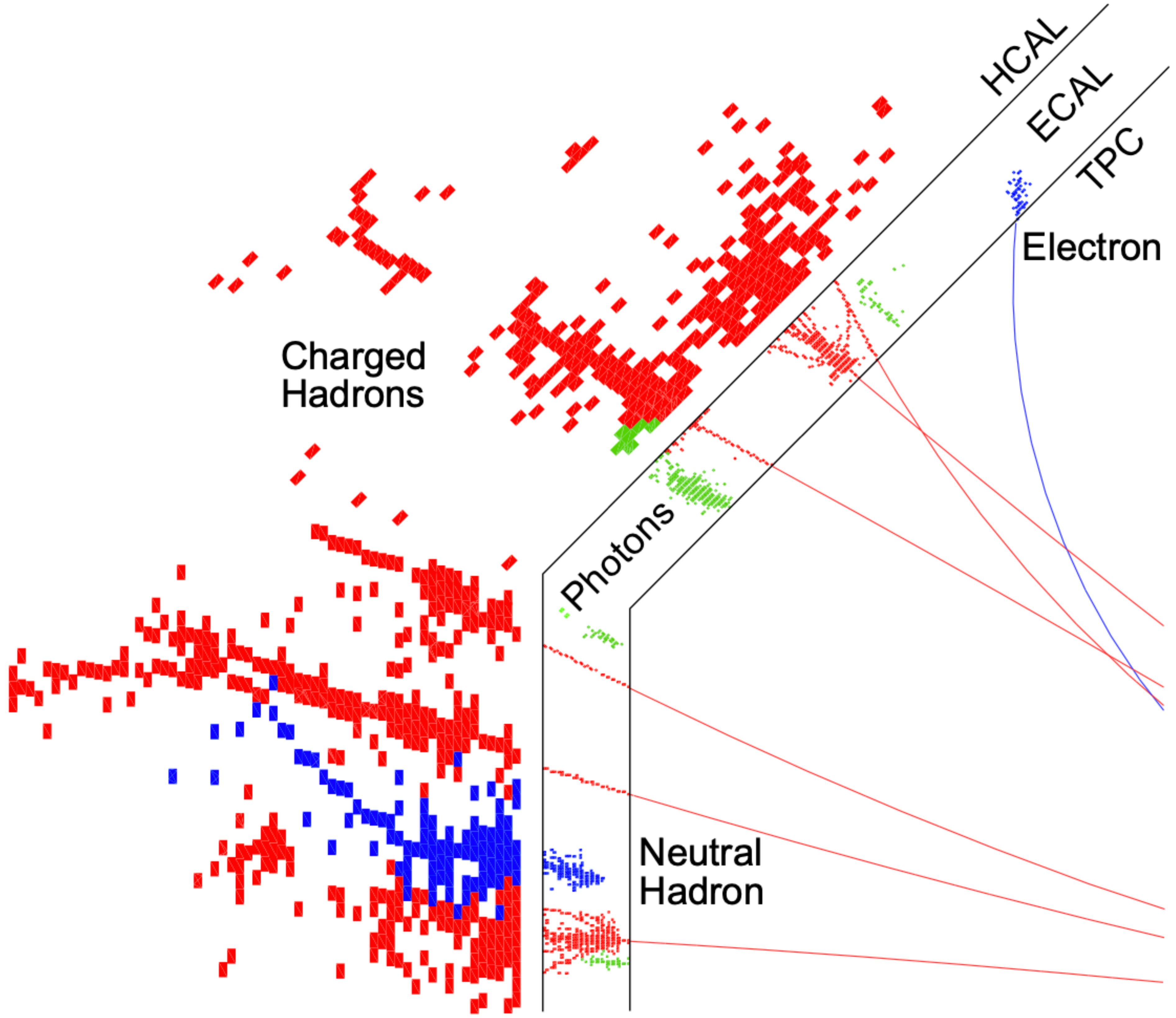
- Detector design and reconstruction tools form a symbiosis - Particle Flow paradigm a great example
  *For best results:*
  - Careful integration and optimisation of all components together (hard- and software)
  - ➯ Design for "understanding": a uniform and understood response may ultimately be a more important figure of merit for many measurements than the ultimate resolution



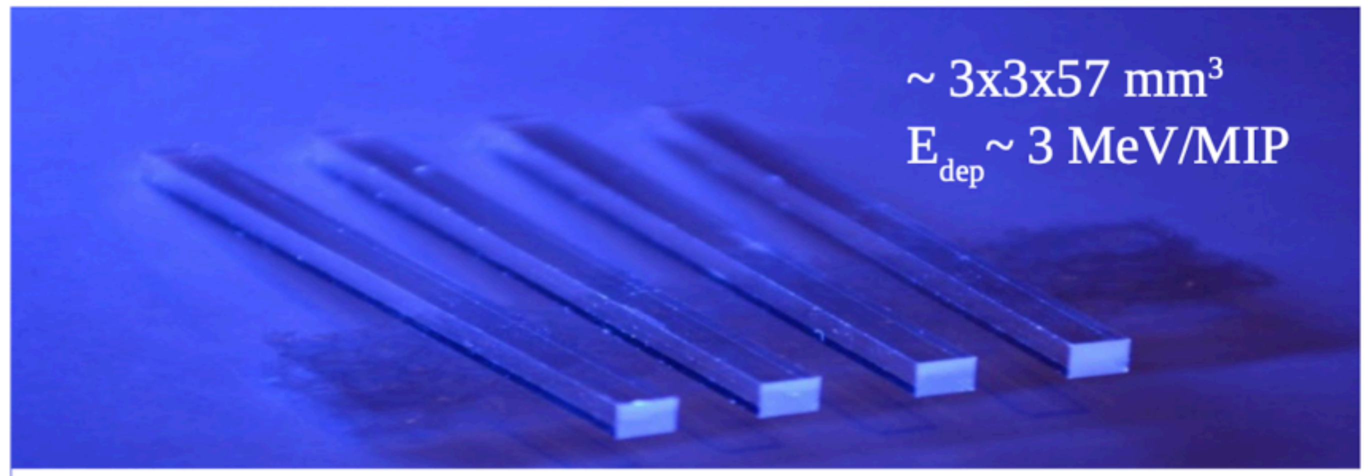
# Adding Capabilities

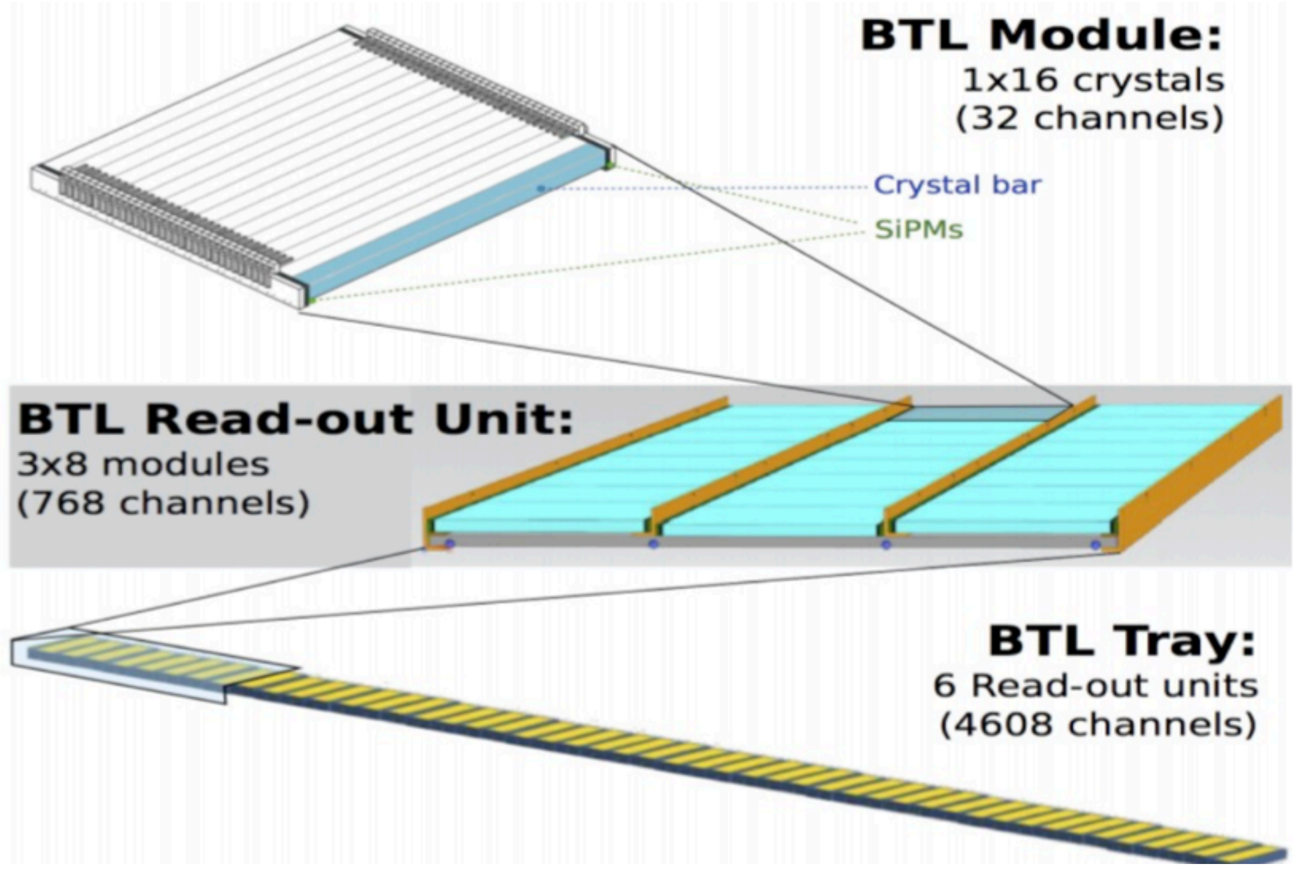
*The main trend: Timing*

- Timing detectors with few 10 ps resolution now feasible - pioneered for HL-LHC upgrades

*Optical*:

Fast scintillators, SiPMs



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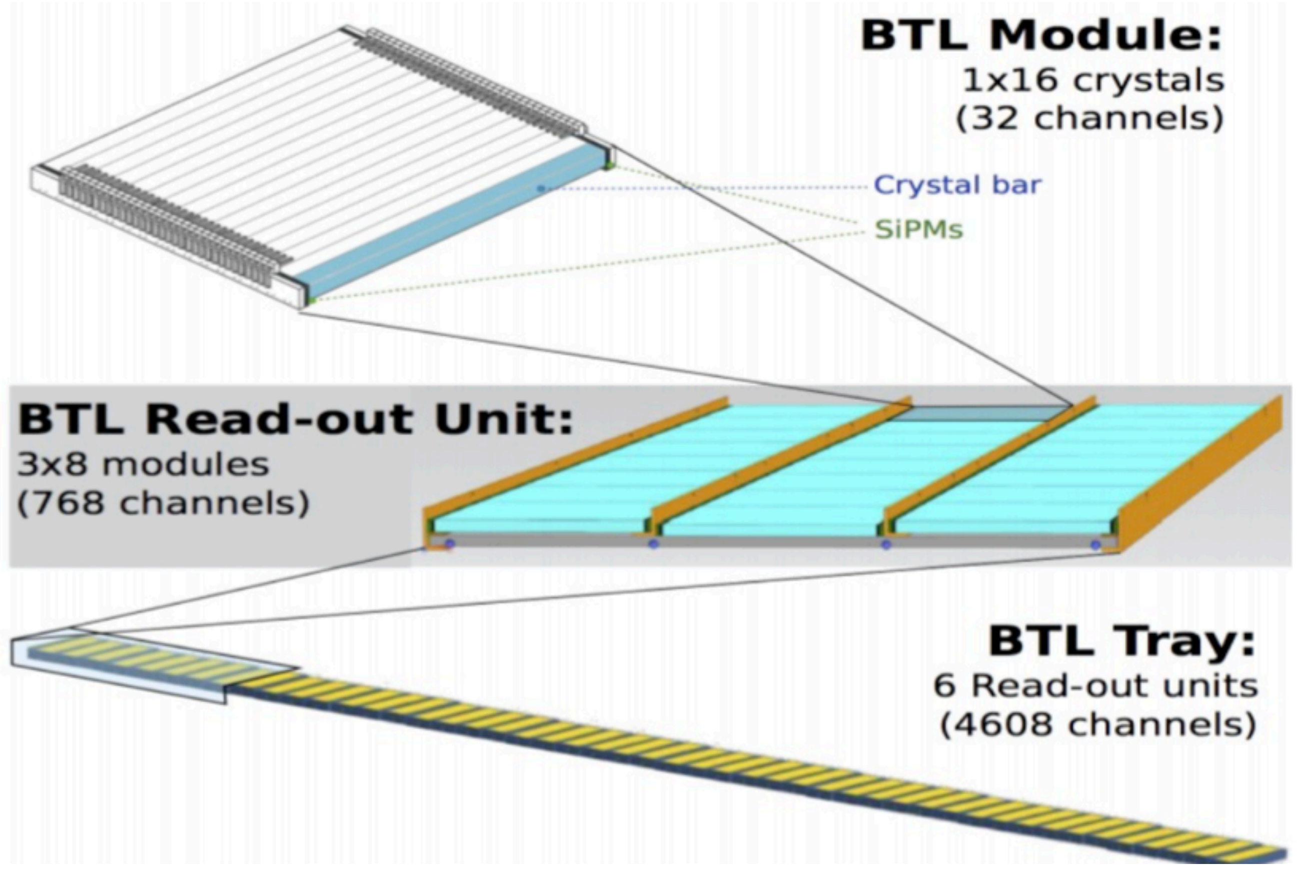
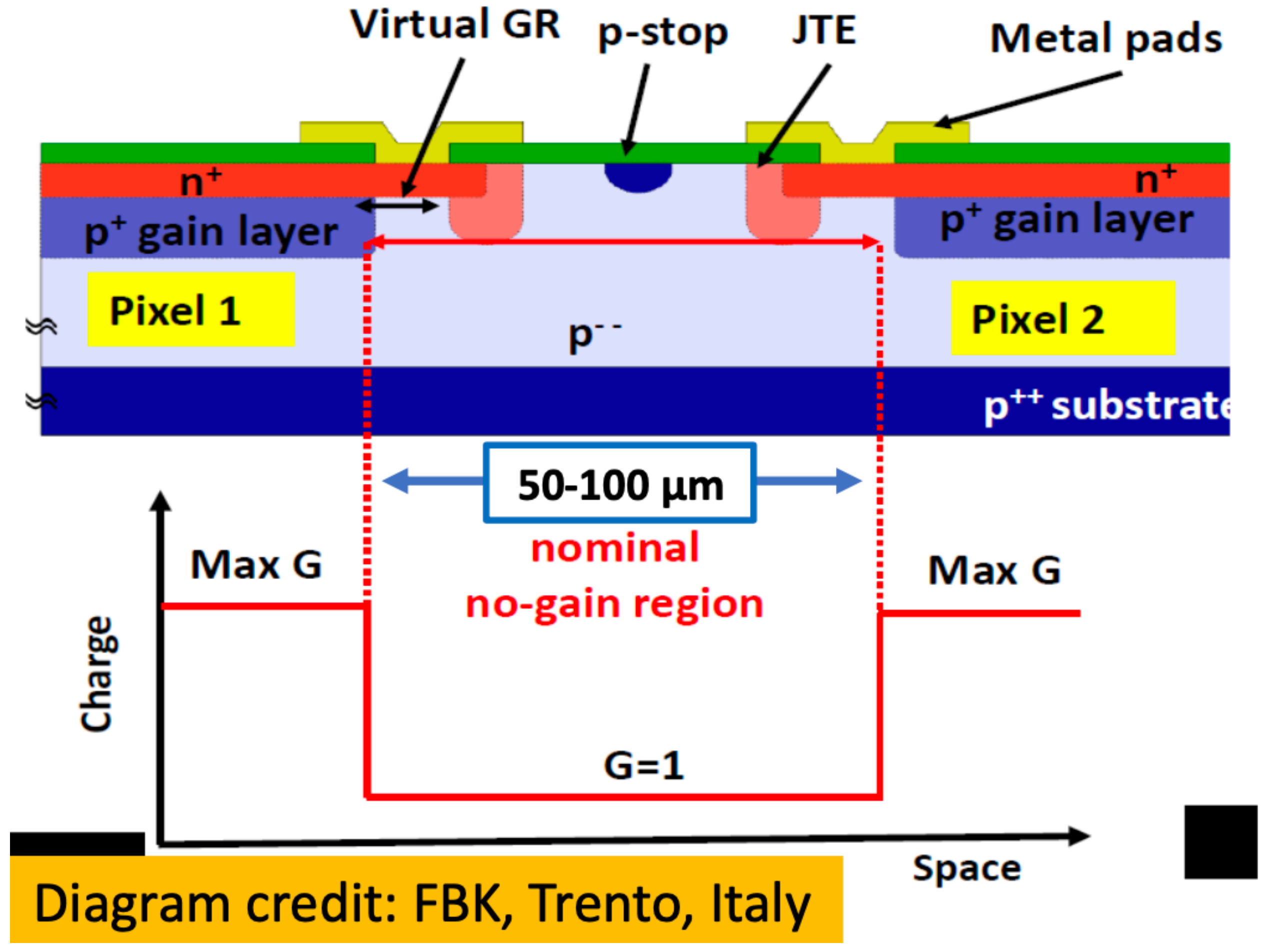
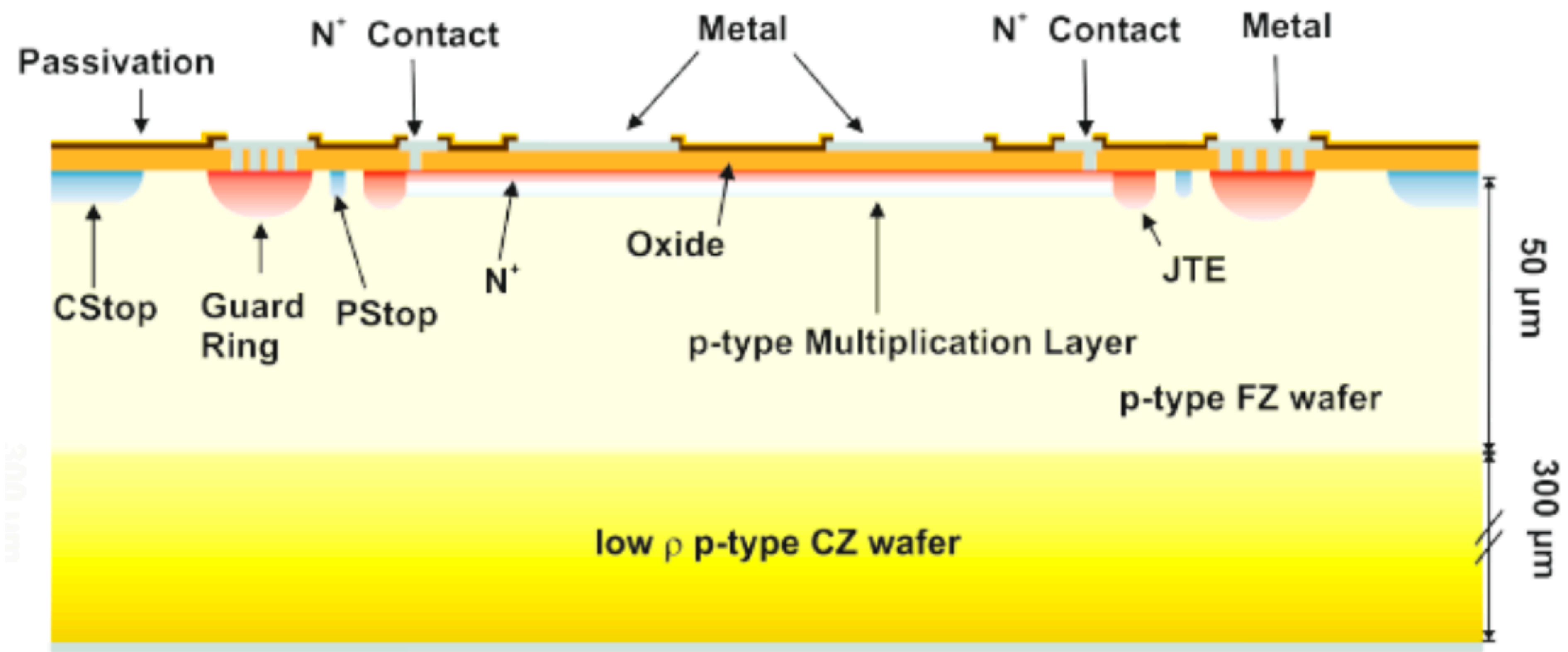



*Silicon*:

LGADs and variants




Newer ideas: AC-coupled LGADs, deep-junction, trenches, …

Potential for fine pixilation

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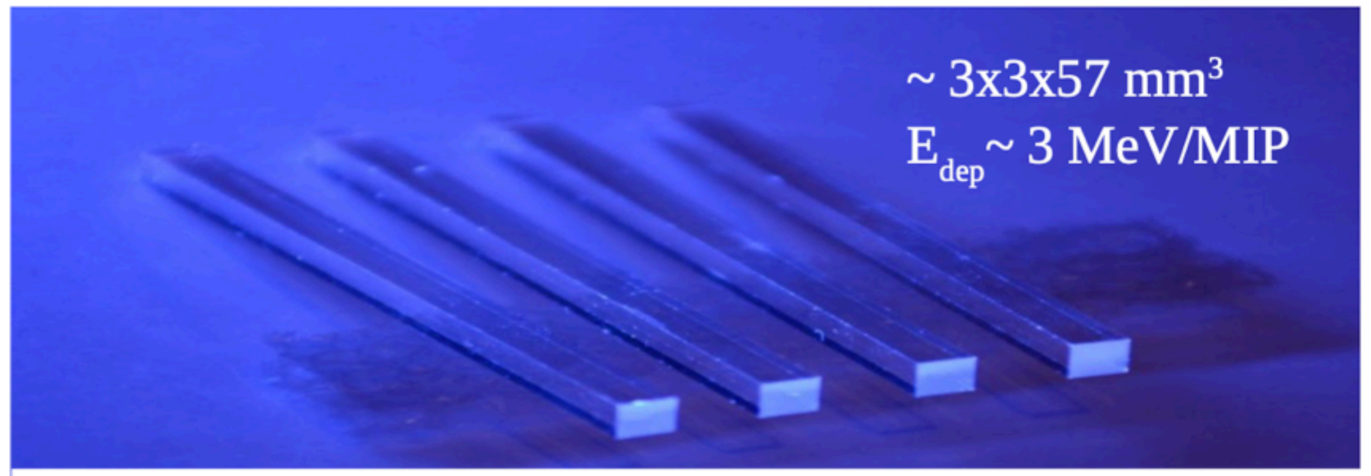


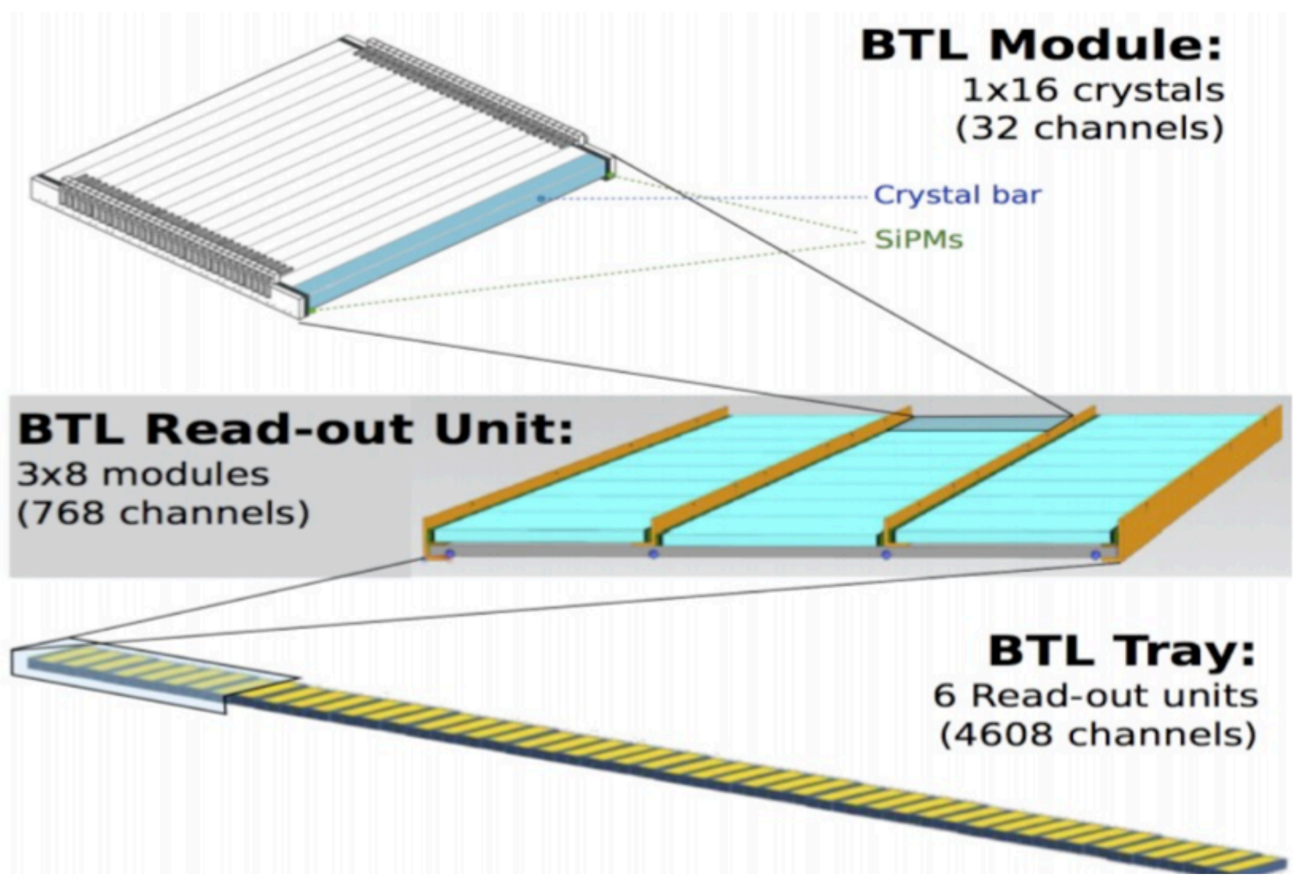


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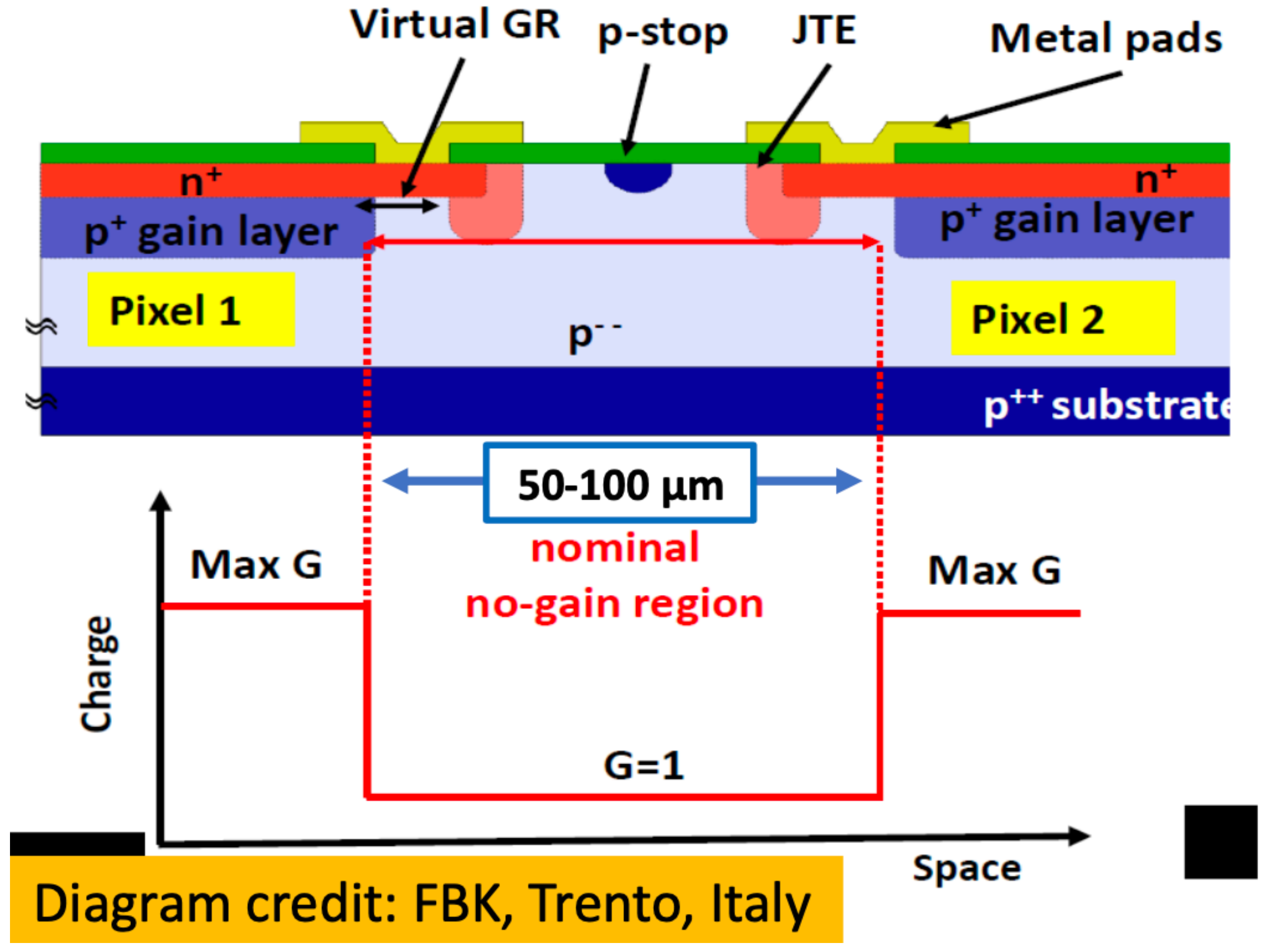


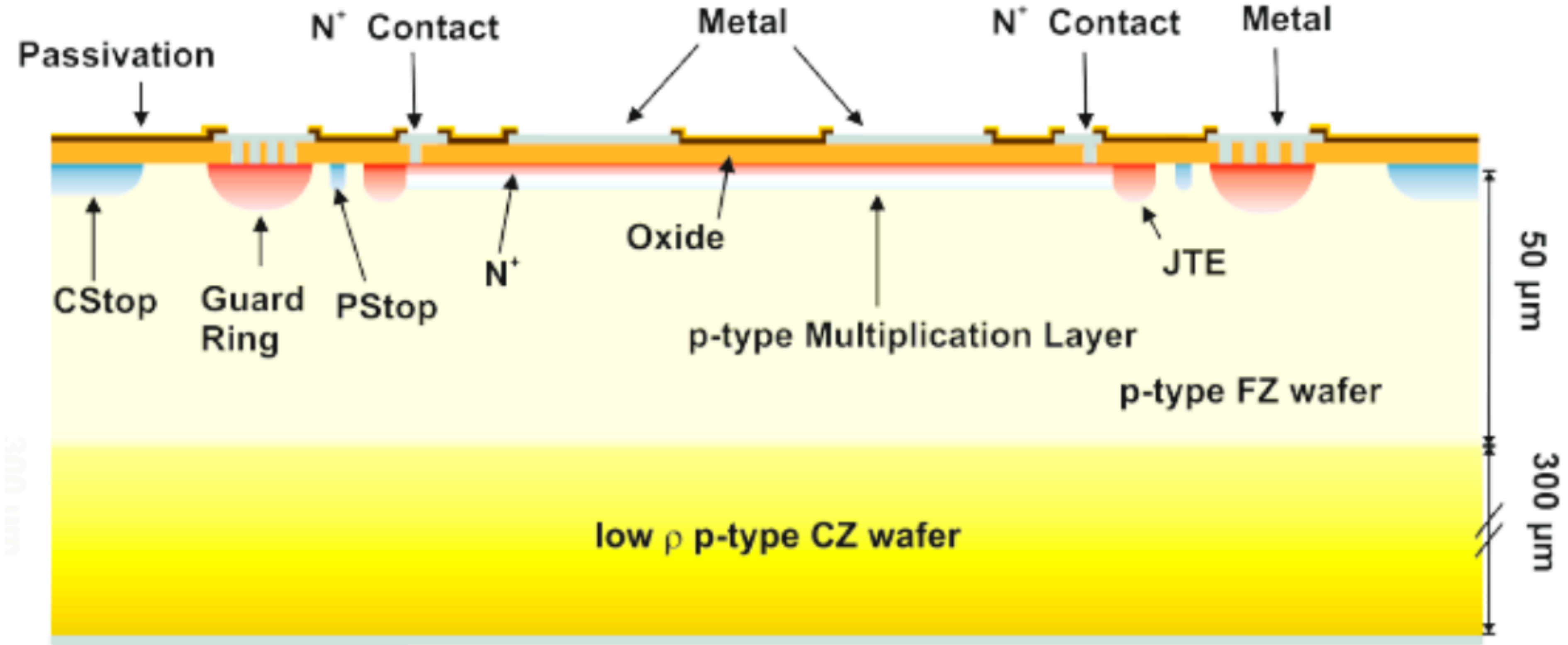


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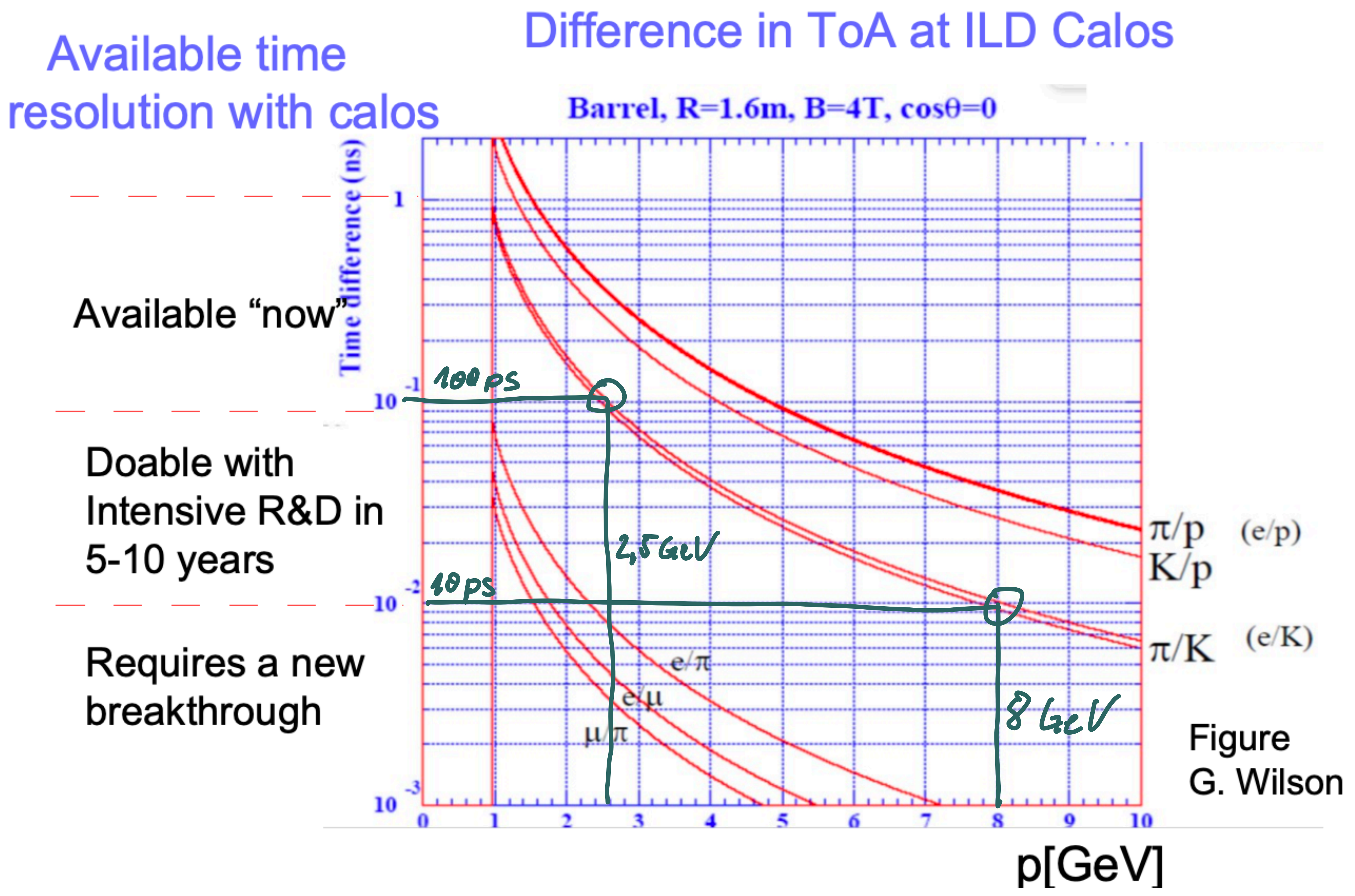
➡ Dedicated timing systems, but also potential in trackers, calorimeters, …

Also here: interesting optimisation questions: A balance between time resolution, spatial resolution, data rate and power consumption

# Adding Capabilities

*Additional Dimensions: Timing and others*

- Timing: What would we need?
  (note: Bgd rejection at LCs needs ~ns - level only)
  - A clear use case: PID via time-of-flight.
    In the focus: π/K separation - important for example for flavour tagging.
    - Typical momenta in the ~ 5 GeV region - depending on collision energy
- Resolutions today: < 10 ps with multiple layers - but system challenges to scale this up are formidable



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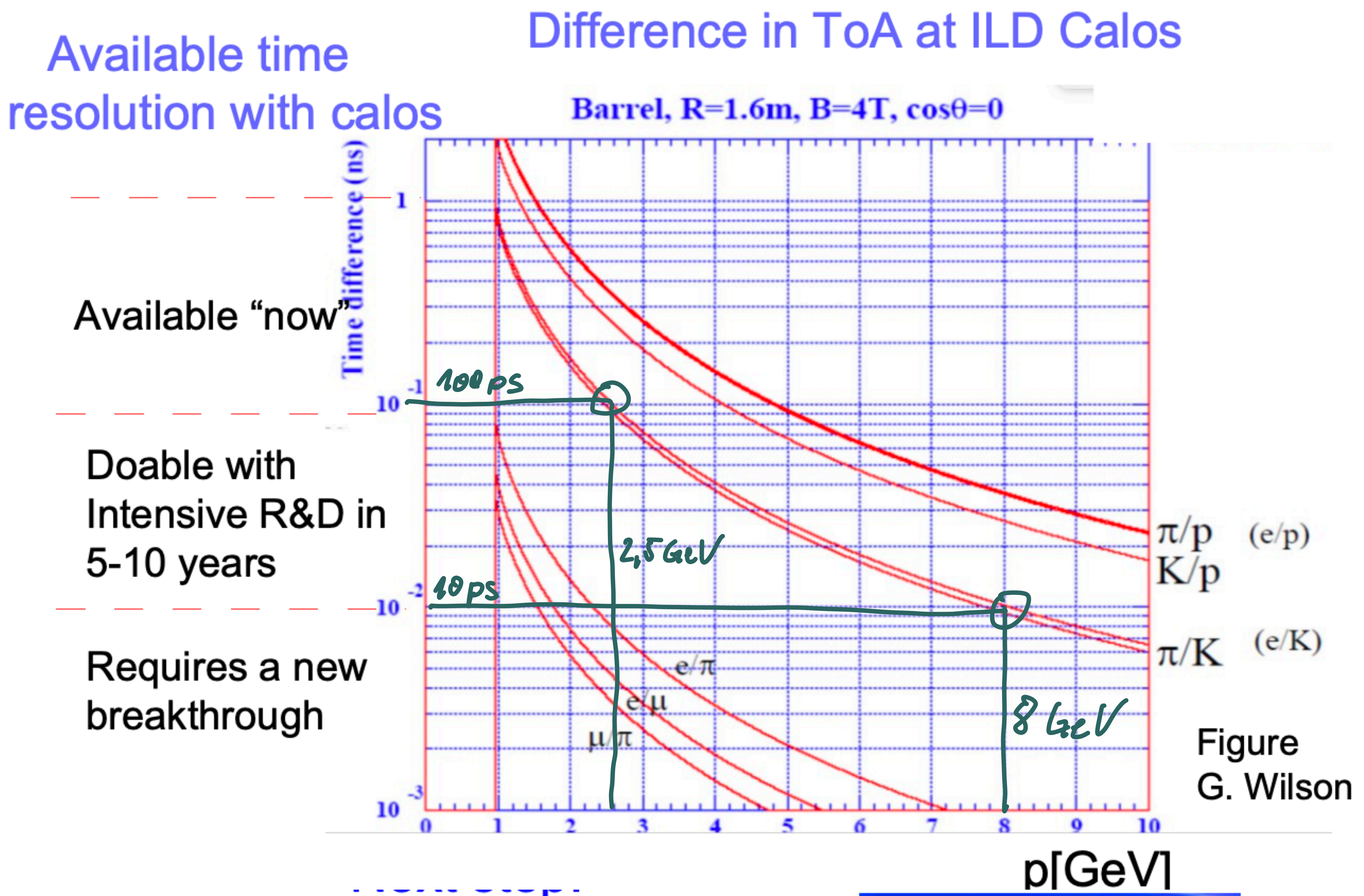
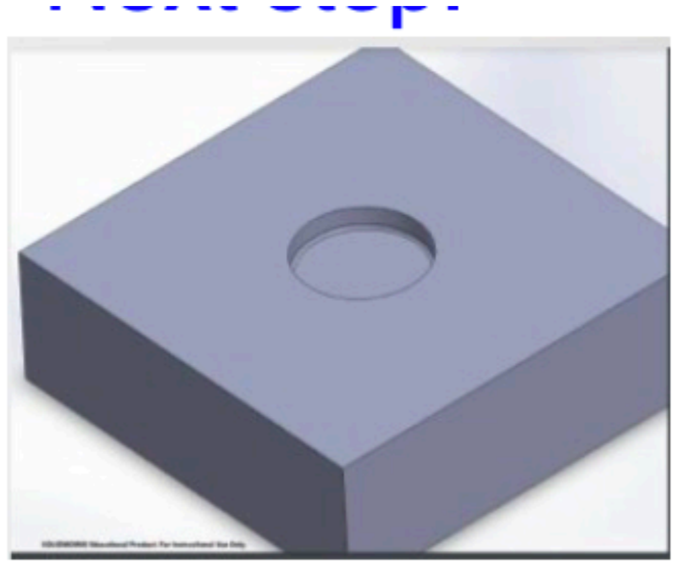
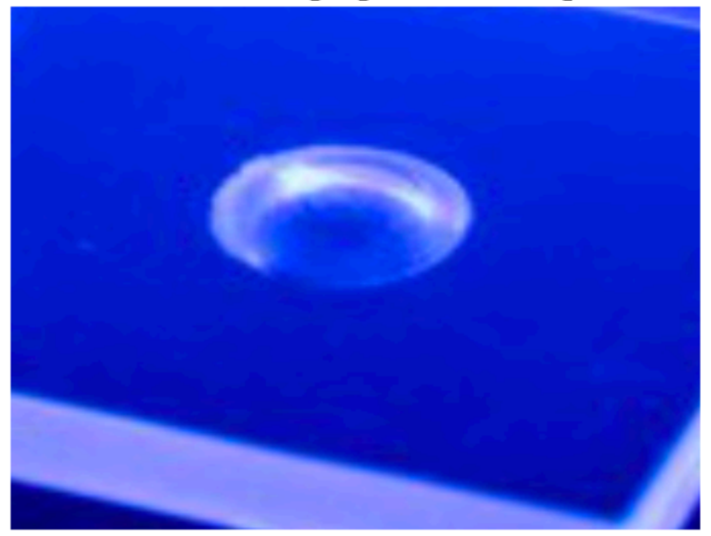
- Can provide an additional dimension in calorimetry: Separation of electromagnetic and hadronic processes based on time evolution
- Also: Dual readout - signal-based separation of em and hadronic components - now moving towards high granularity



3x3 cm² Glass tile



3x3 cm² Plastic Tile

# Revolution of the current design

*Is it worth revisiting established choices?*



- The fundamental design choices for the current LC detector concepts were made ~15 years ago
- The sequence of energy stages has changed - at least for ILC: Now a first phase at 250 GeV (and below)

➫ For some speculation on experiment staging, see Karsten Büsser this morning

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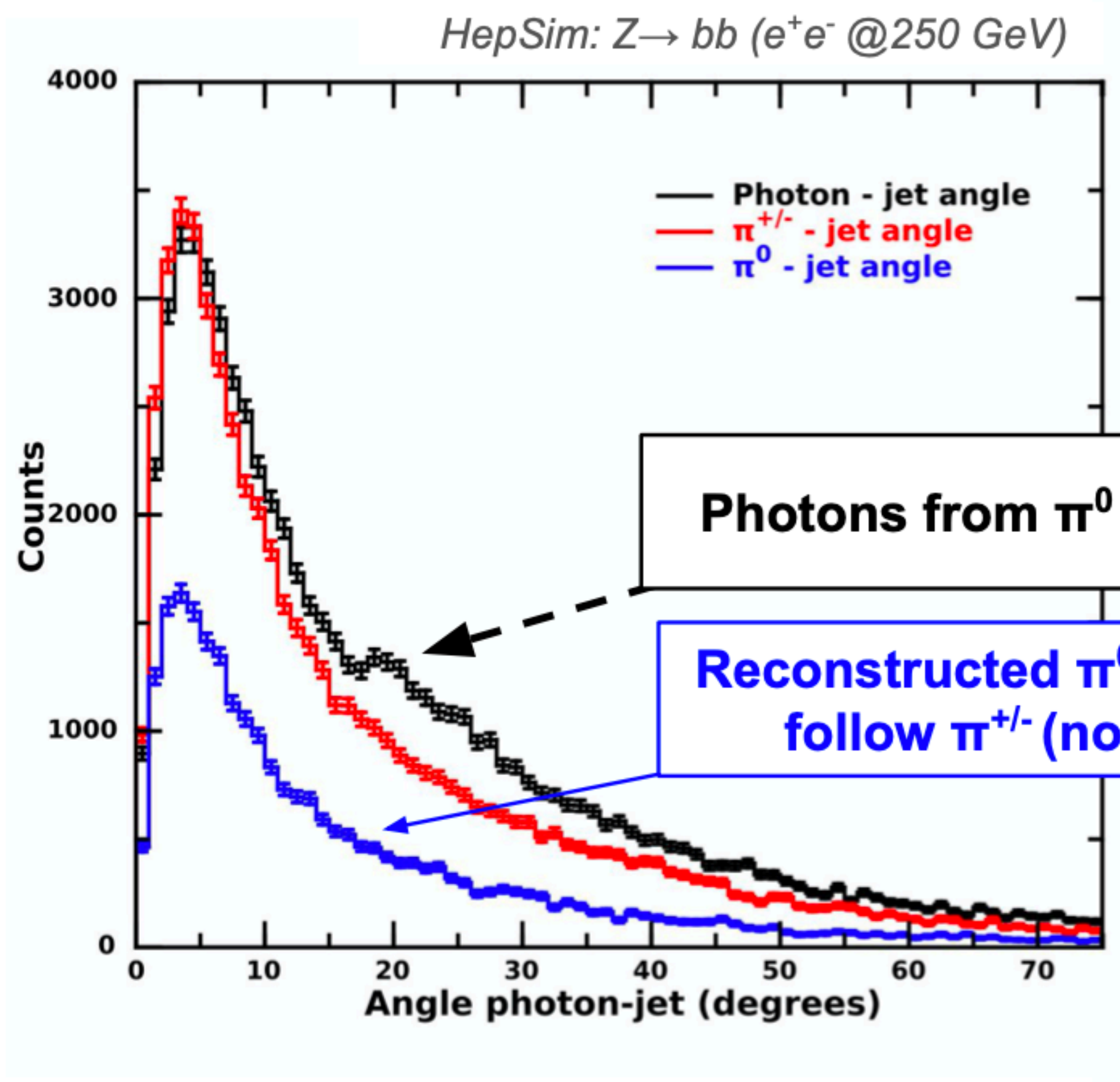


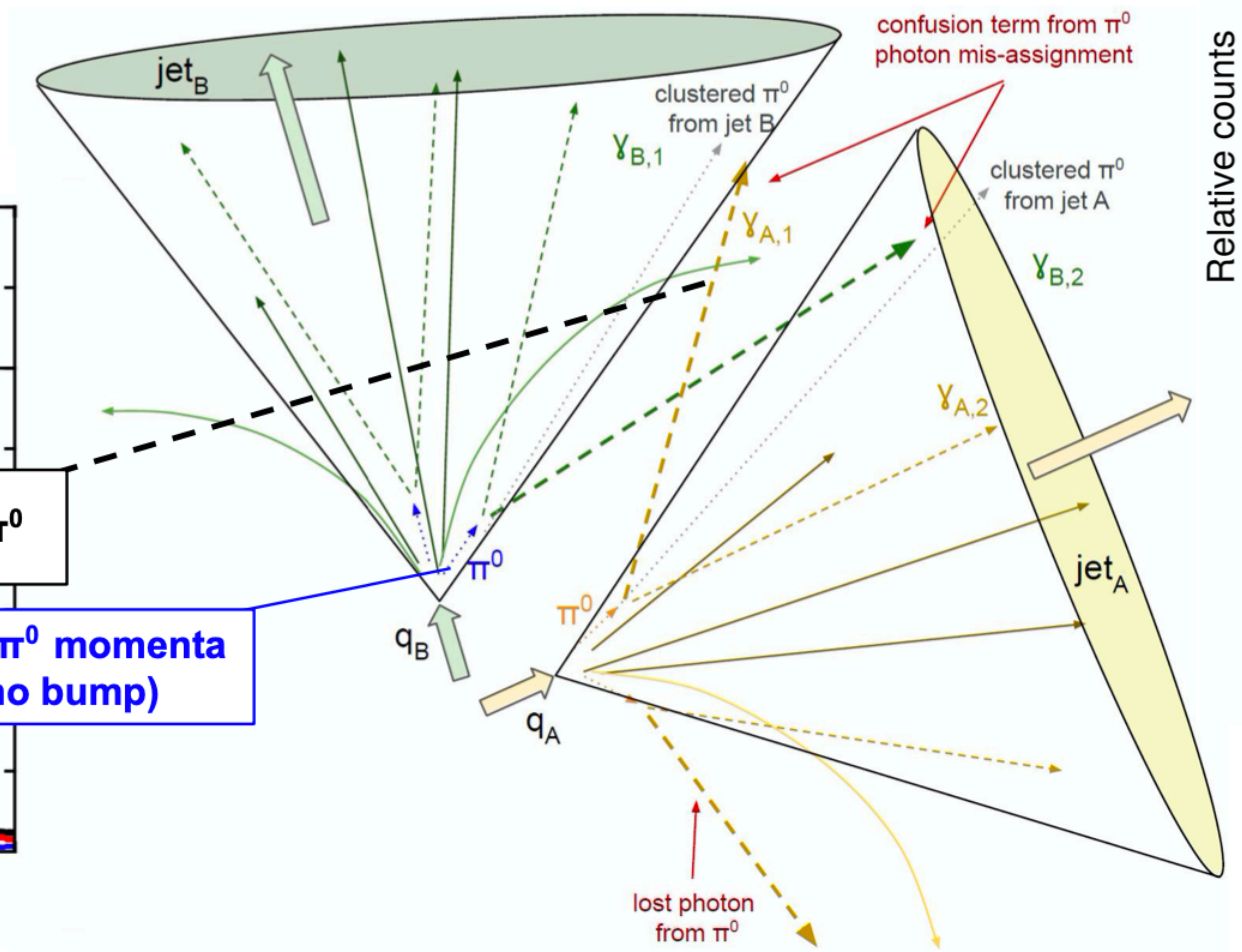


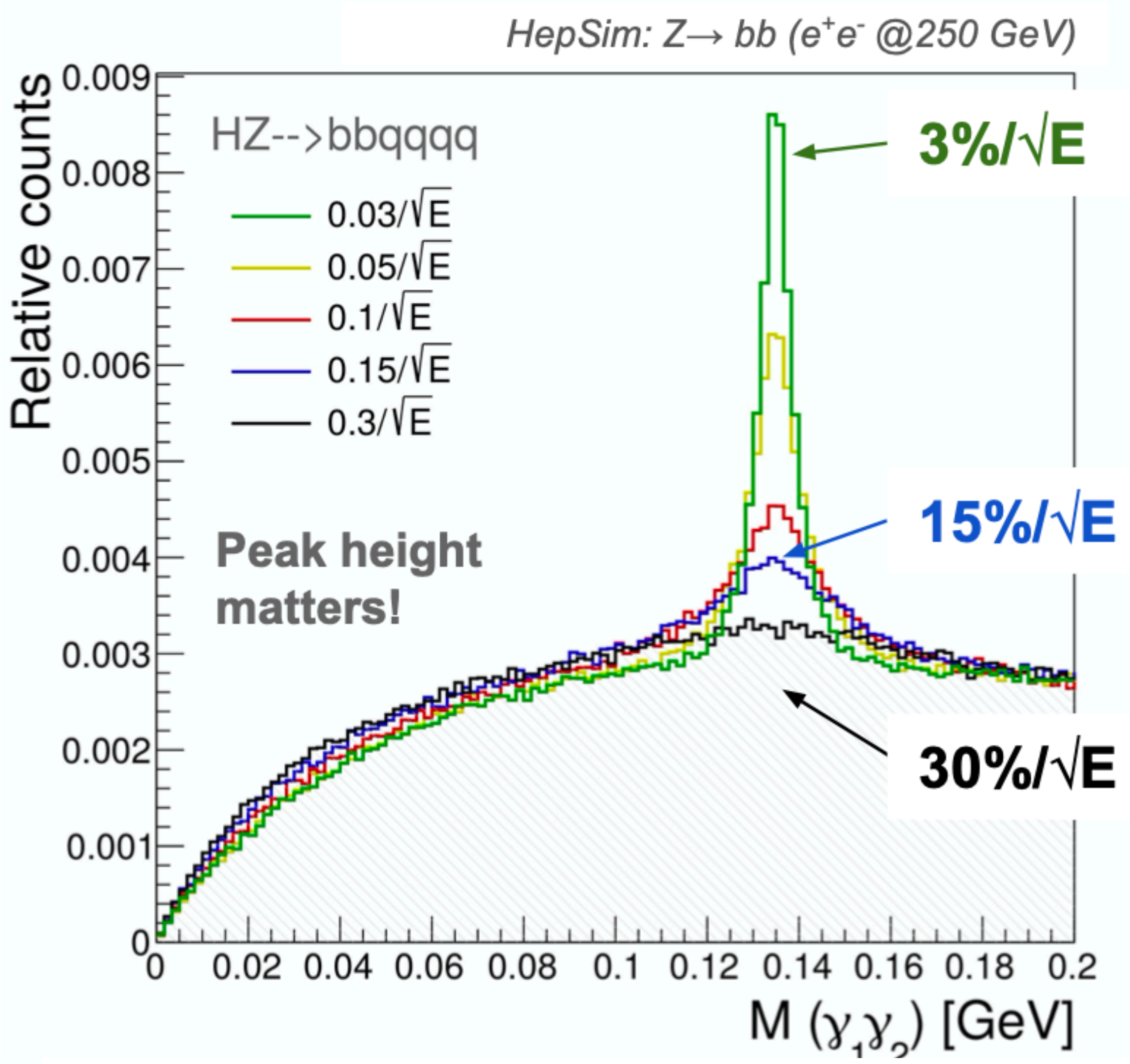


A fresh look at high-resolution ECALs?

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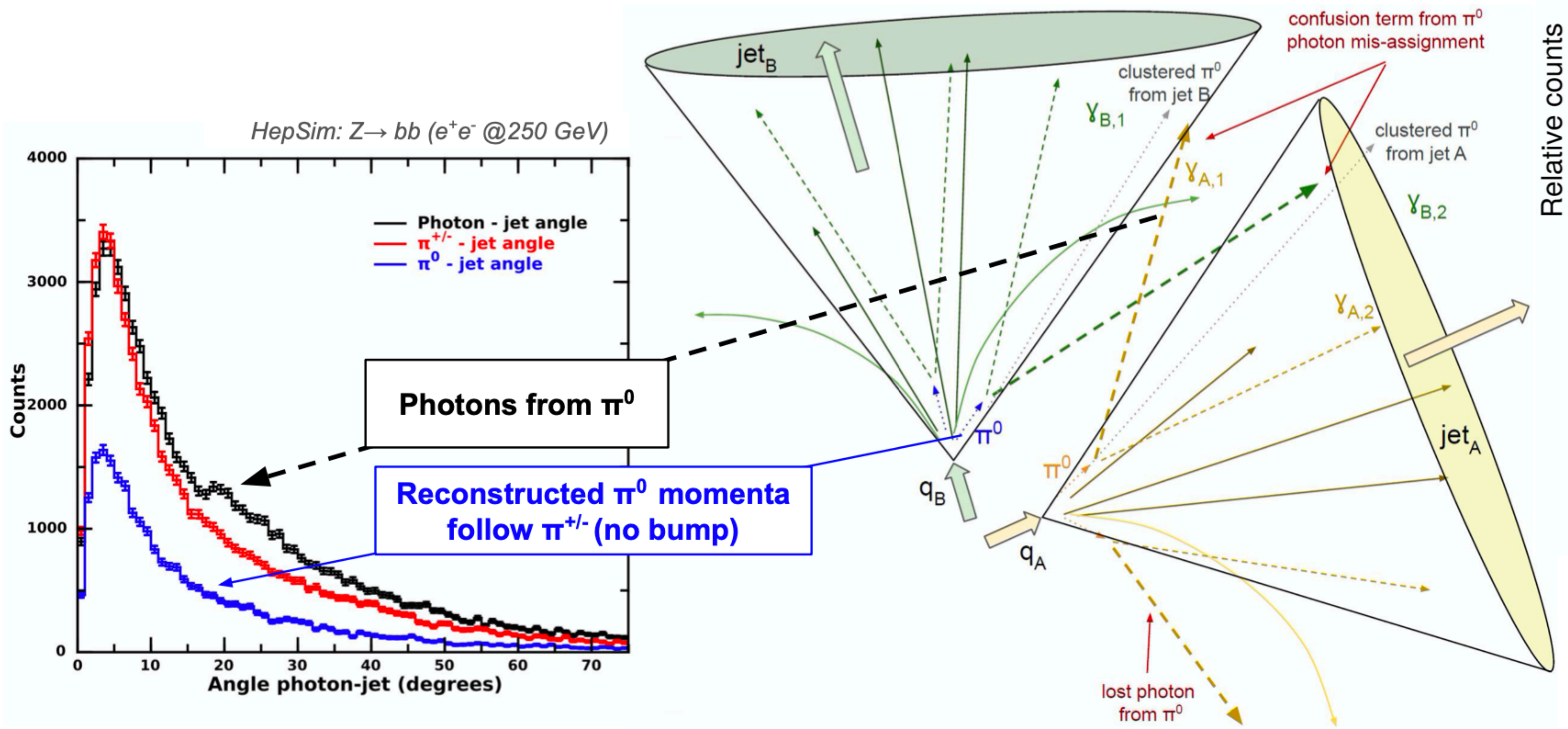
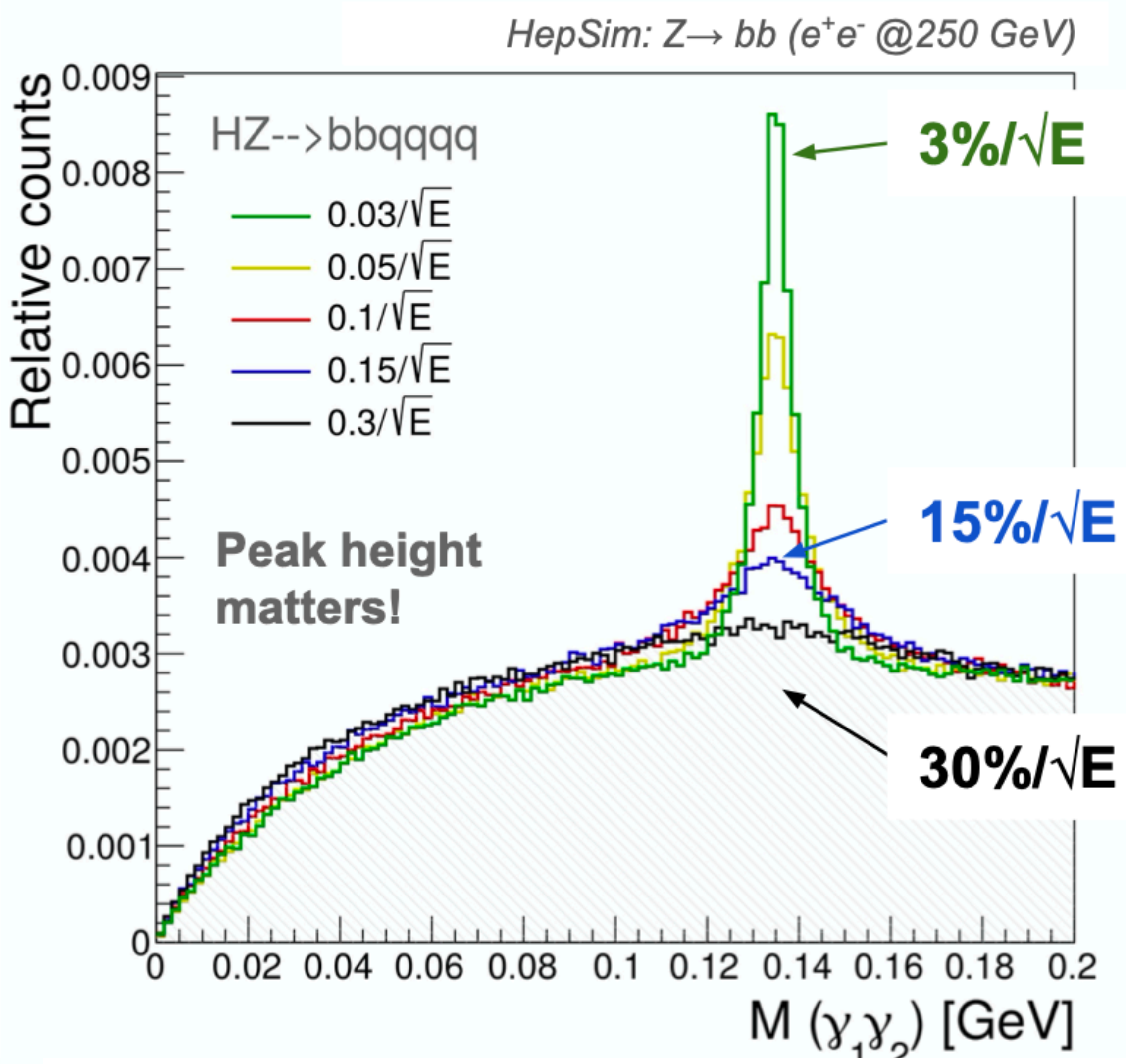
New ideas in jet reconstruction - emphasising electromagnetic resolution:




A fresh look at high-resolution ECALs?

Also other areas - technology of gaseous tracking (TPCs vs DCs) as an example.
In general: many parameters to consider - no straight-forward answers

# Summary

*… and Outlook*

- The current LC detector concepts are well-established - and have been studied in realistic simulations, in many areas validated by testbeam measurements of realistic prototypes
- Technology has evolved, enabling reduction of cost and complexity, and the addition of new capabilities

- ***Evolution*** of concepts has started, using advances of silicon technology and others
- ***Additional Capabilities*** are studied - first and foremost the use of precision timing ( << 100 ps) - benefits and technological and system-based boundary conditions still need to be understood
- **Revolutionising** of designs is not excluded - New ideas studied in the context of circular colliders may also have merits for LCs.

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MAX-PLANCK-INSTITUT FÜR PHYSIK

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This will be exciting - In many cases no immediately obvious answers - and many “dimensions” to consider from technological aspects to running and staging scenarios and sociological aspects.

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***To be continued…*** In October in Tsukuba - hopefully in person!

# Extras

# The Time Line for ILC Detectors

*To provide some background*

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

- 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

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From Hitoshi Murayama, yesterday

Bottom line (my interpretation):

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

**There is (some) time to explore new ideas!**