Future Detectors, Strategies, Physics and Detectors

Swathi Sasikumar on behalf of the Future Detectors Group

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MPP Project Review 2021

13th December 2021

MAX-PLANCK-INSTITUT
FÜR PHYSIK

Future Detectors Group at MPP

The Core Group of Future Detectors in 2021:

Postdocs: Thibaud Humair, Swathi Sasikumar, Hendrik Windel , Christian Graf
PhD Students: Thomas Kraetzschmar, Lorenz Emberger
Master Students: Fabian Hummer, Ivan Popov, Justin Skorupa

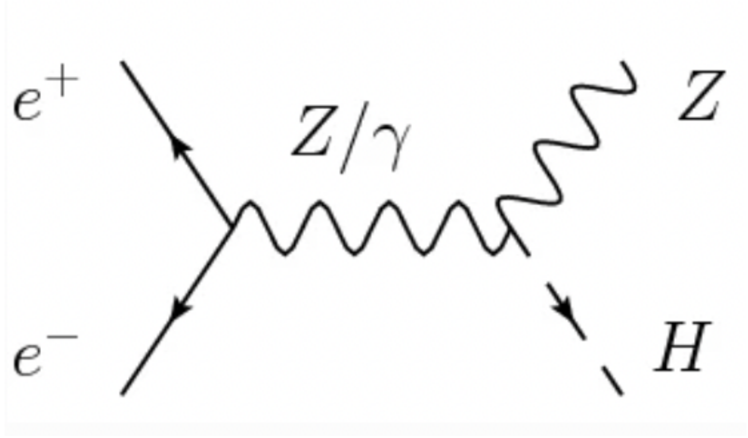
Group Leader: Frank Simon

- Chair of the LHC Experiments Committee
- Chair of CALICE Institute Board
- Member of CLICdp Executive Team
- Member of the ILC IDT WG3 Executive Board
- Co-coordinator of FCC Physics and Detector Physics program Working Group

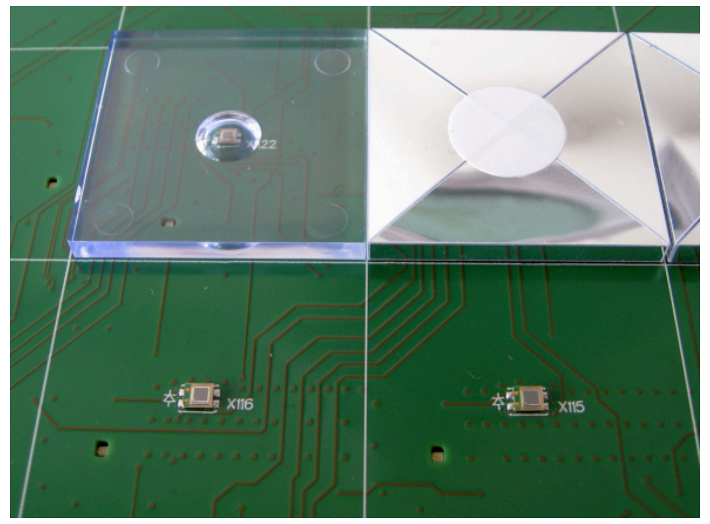
- Very grateful for collaboration with Technical Departments and BELLE/BELLE II group

The Projects in the Group

Physics with e^+e^- colliders



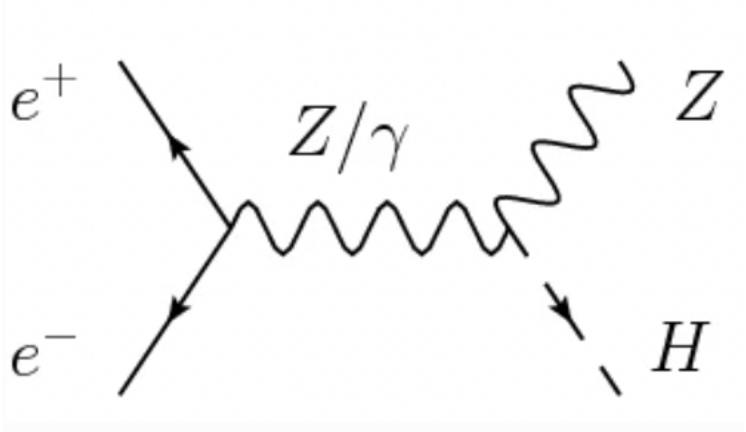
Detector Studies



Developing highly granular calorimeters

The Projects in the Group

Physics with e^+e^- colliders



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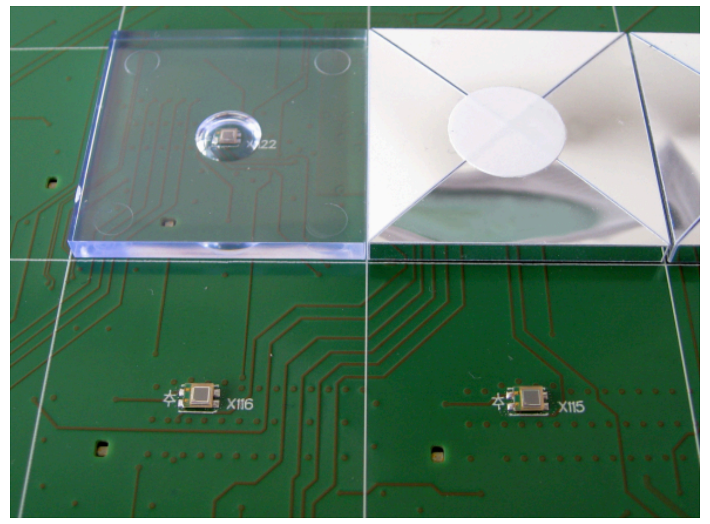
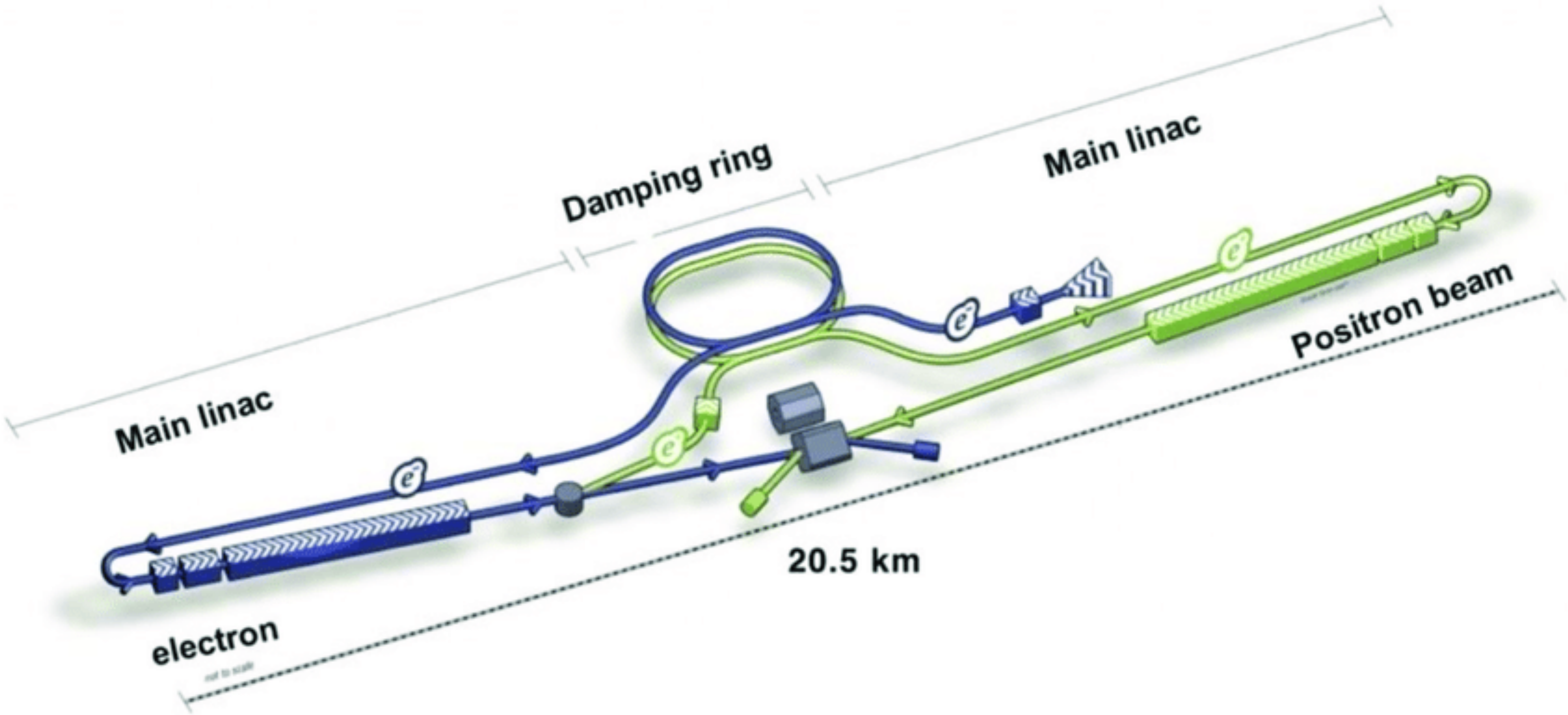


Developing highly granular calorimeters

CALICE Technologies beyond Linear Colliders

Future e^+e^- colliders

- The ILC: To be operated at a CME of 250 GeV. (Upgrade to 500 GeV - 1 TeV) - Under discussion in Japan



Future e^+e^- colliders

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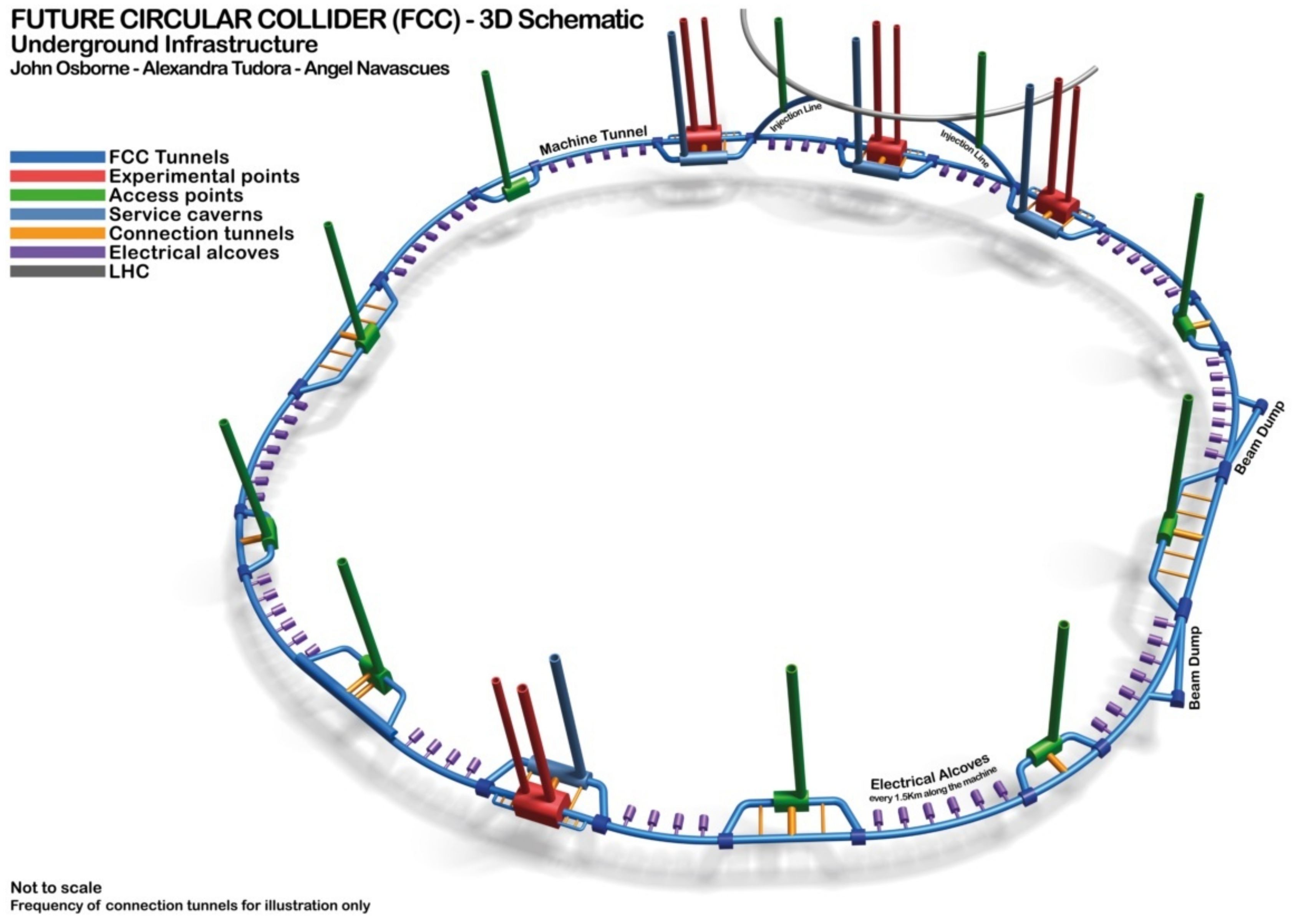
- Future Projects at CERN
  - The FCC-ee collider: Circular 100km collider at CERN, 90 GeV - 365 GeV



Future e^+e^- colliders

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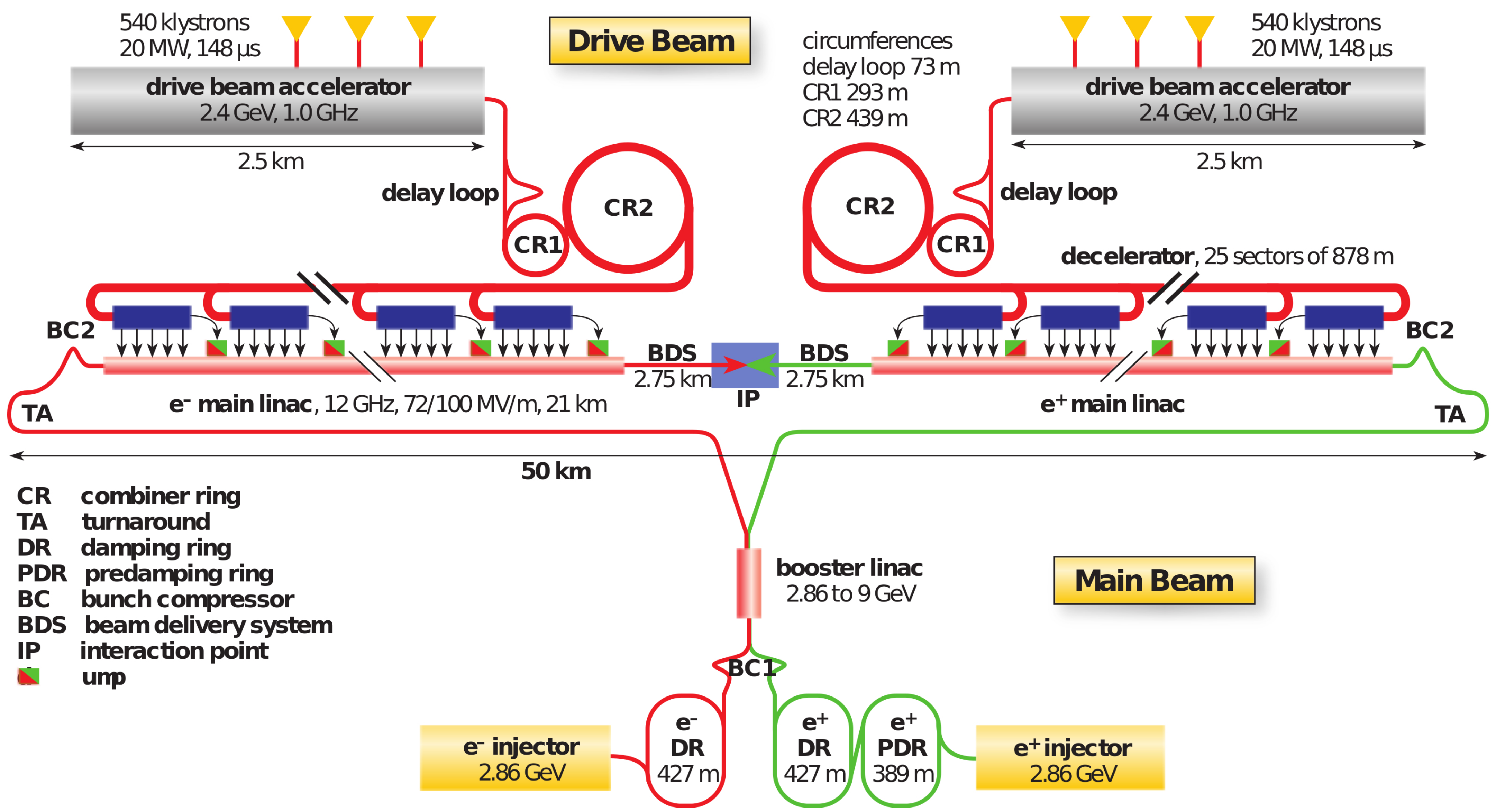
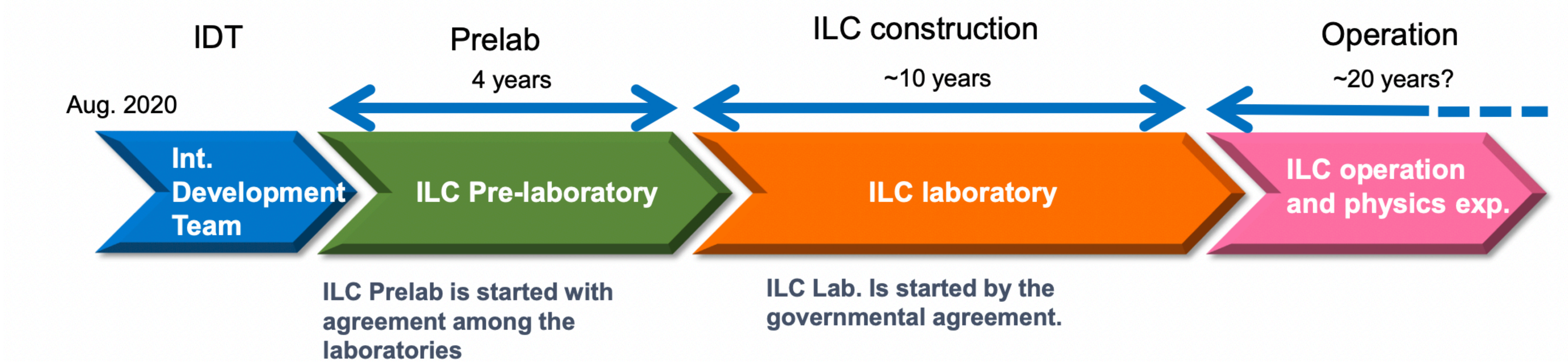
- Future Projects at CERN
  - The FCC-ee collider: Circular 100km collider at CERN, 90 GeV - 365 GeV
  - CLIC: Linear collider at CERN, 380 GeV - 3 TeV



Strategies and Plans -ILC

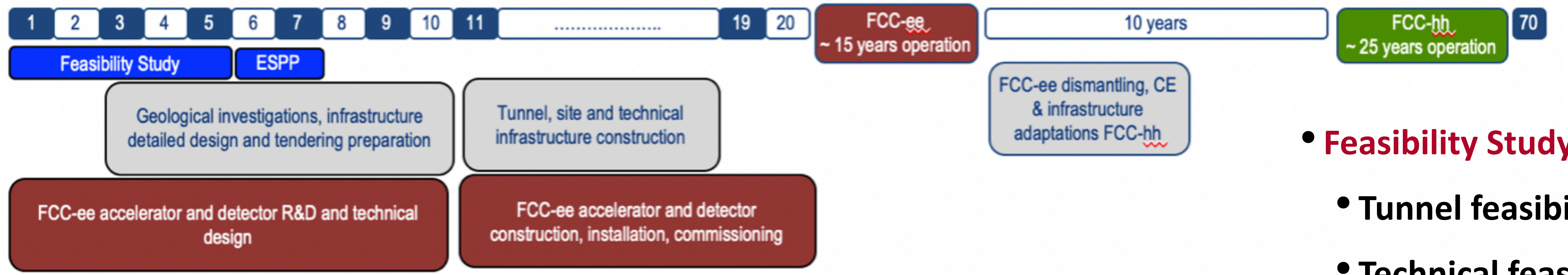
- European Strategy Output:
  - Electron positron collider as a Higgs factory highest priority
  - ILC timescale:



  - Timely realisation of ILC in Japan would be compatible with European strategy output, European particle physics community would wish to collaborate
  - The situation in Japan is still very unclear - funding for pre-lab not approved for 2022

Strategies and Plans - FCC-ee

- FCC timescale and plans:Europe together with its international partners investigate the possibility of a future collider at CERN with e^+e^- Higgs factory as the first stage



- **Feasibility Study:**
  - **Tunnel feasibility**
  - **Technical feasibility**
  - **Funding feasibility**
  - **Consensus building**

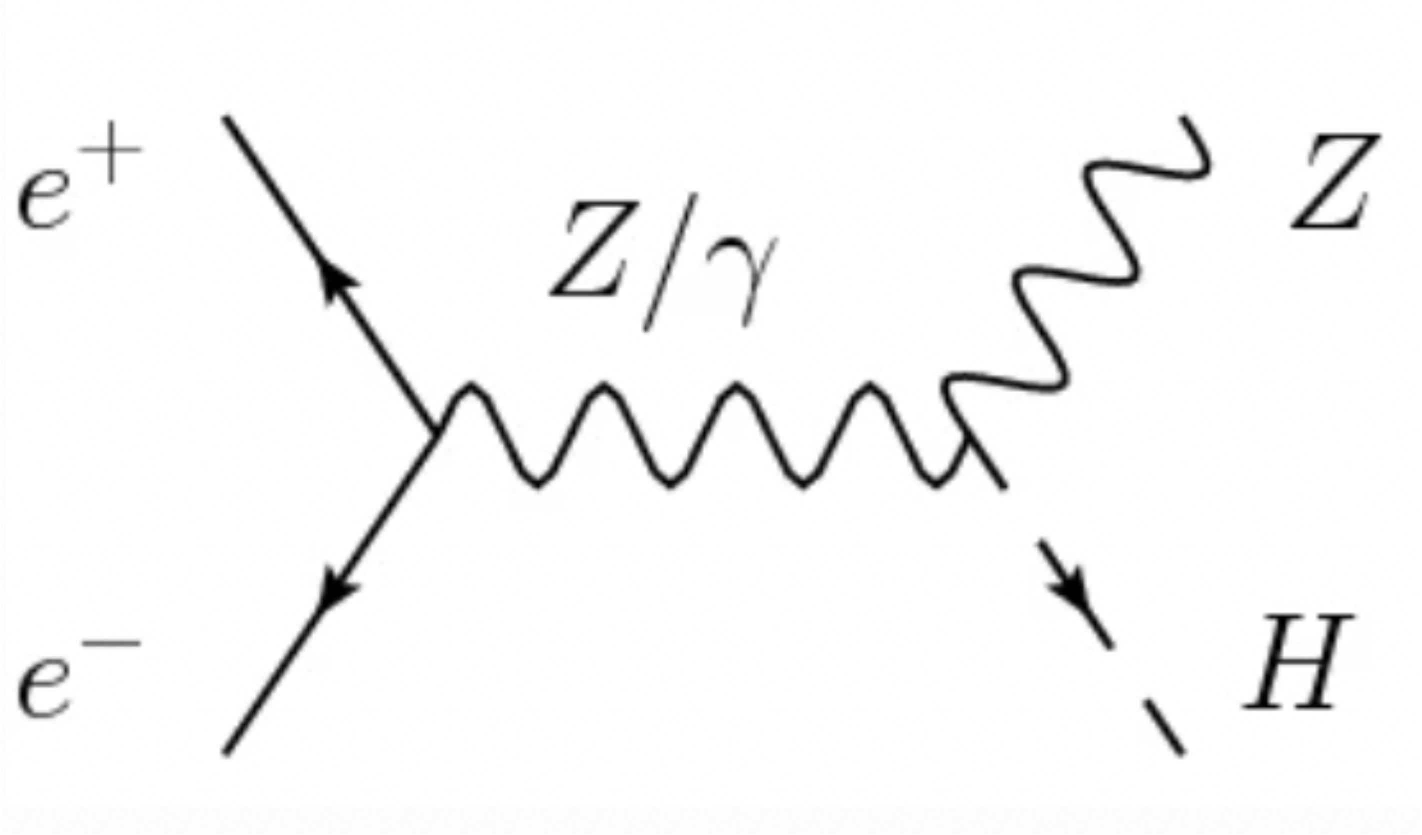
	√s		L /IP ($cm^{-2} s^{-1}$)	Int. L /IP(ab^{-1})	Comments
e^+e^- FCC-ee	~90 GeV	Z	230 $\times 10^{34}$	75	2-4 experiments
	160	WW	28	5	
	240	H	8.5	2.5	Total ~ 15 years of operation
	~365	top	1.5	0.8	

- ❑ Feasibility Study: 2021-2025
- ❑ If project approved before end of decade → construction can start beginning 2030s
- ❑ FCC-ee operation ~2045-2060
- ❑ FCC-hh operation 2070-2090++

Higgs recoil studies for ee->HZ(qq)

Swathi Sasikumar

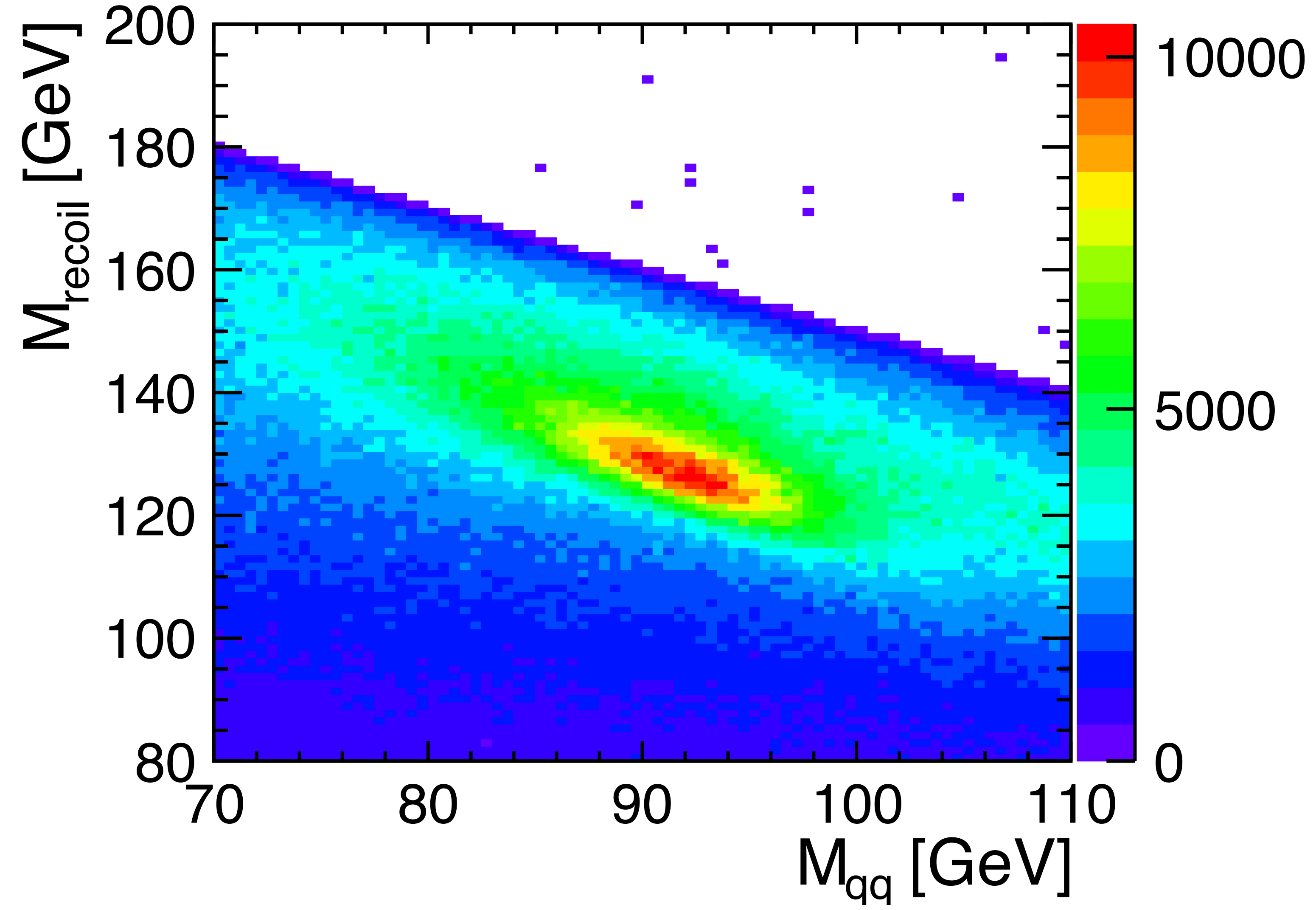
- One of the most relevant studies today: production of HZ at 250 GeV
- Study of Higgstrahlung at e^+e^- collider at 250 GeV provides the possibilities of studying H model -independently
- Several studies for HZ with Z decaying leptonically have been conducted
- However, BR for Z decaying hadronically are ten times greater than for Z decaying leptonically

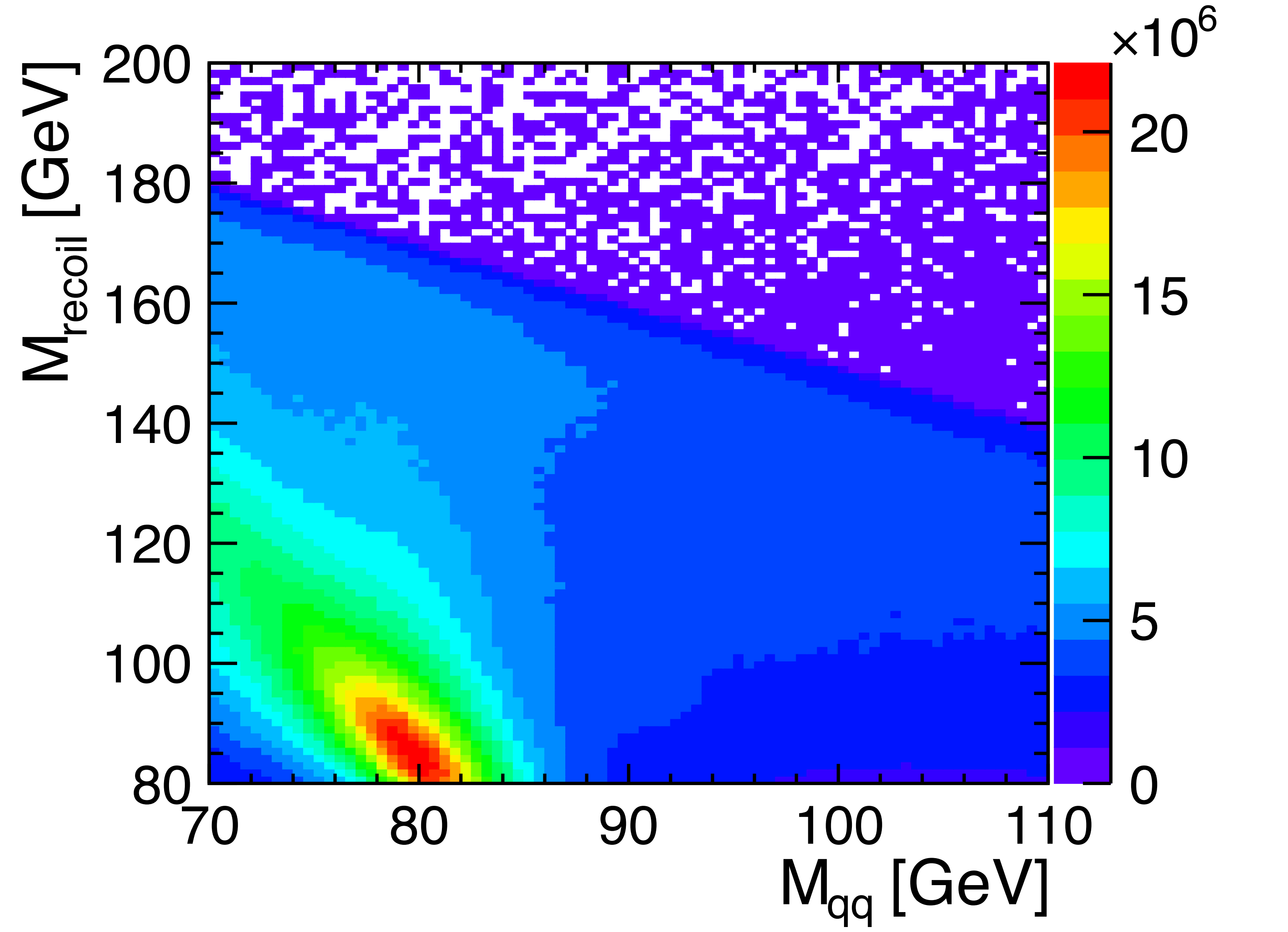


Higgs recoil studies for ee->HZ(qq)

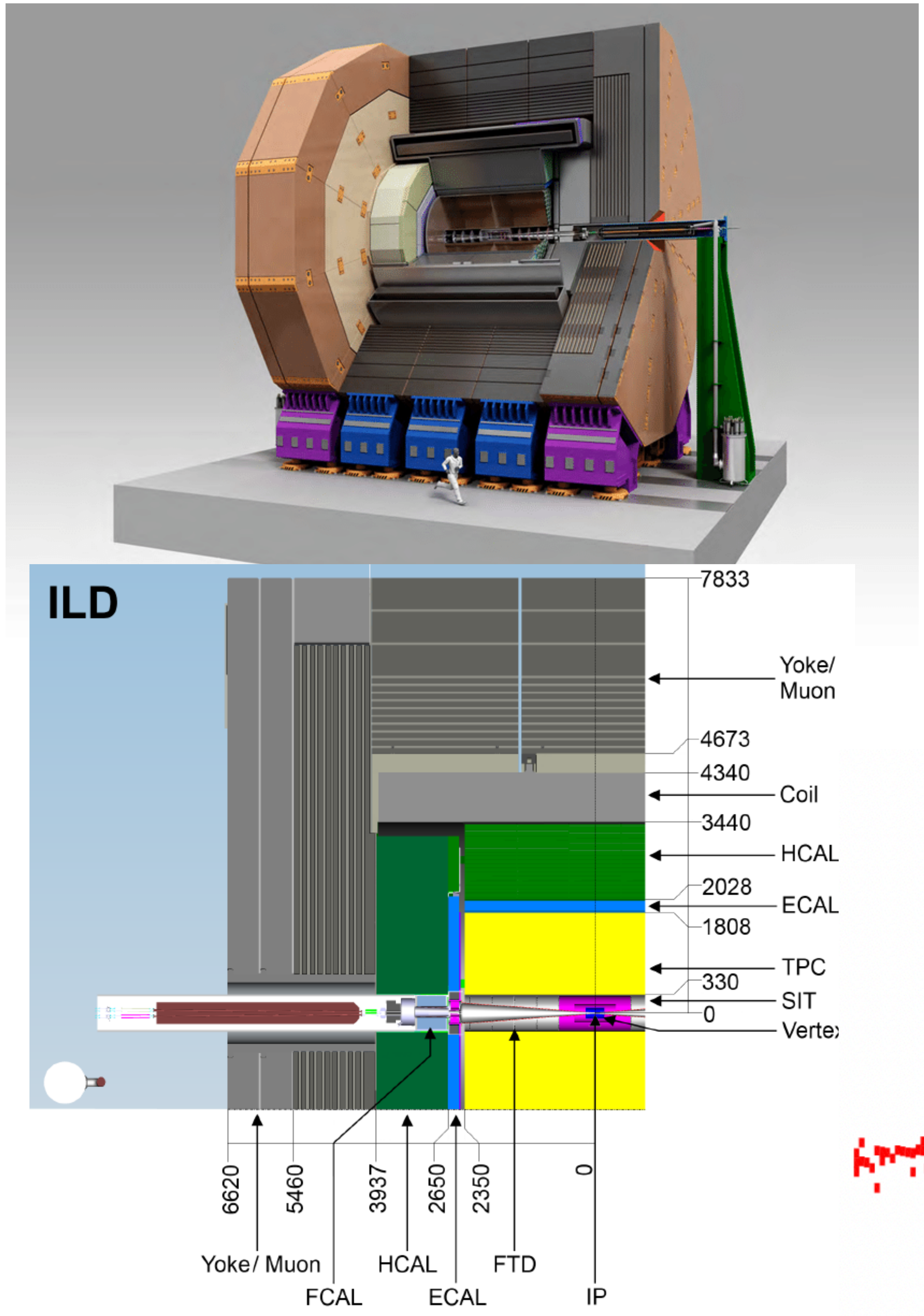
Swathi Sasikumar

- Model-independent study for such a process started with simulated data from ILD (detector for ILC)
- Challenges:
  - Huge backgrounds with large number of jets from the processes like ee->qq, qqqq
  - When Higgs decay hadronically, distinguishing jets for Z and H becomes challenging
- A comparatative study of ILD with FCC-ee also being made

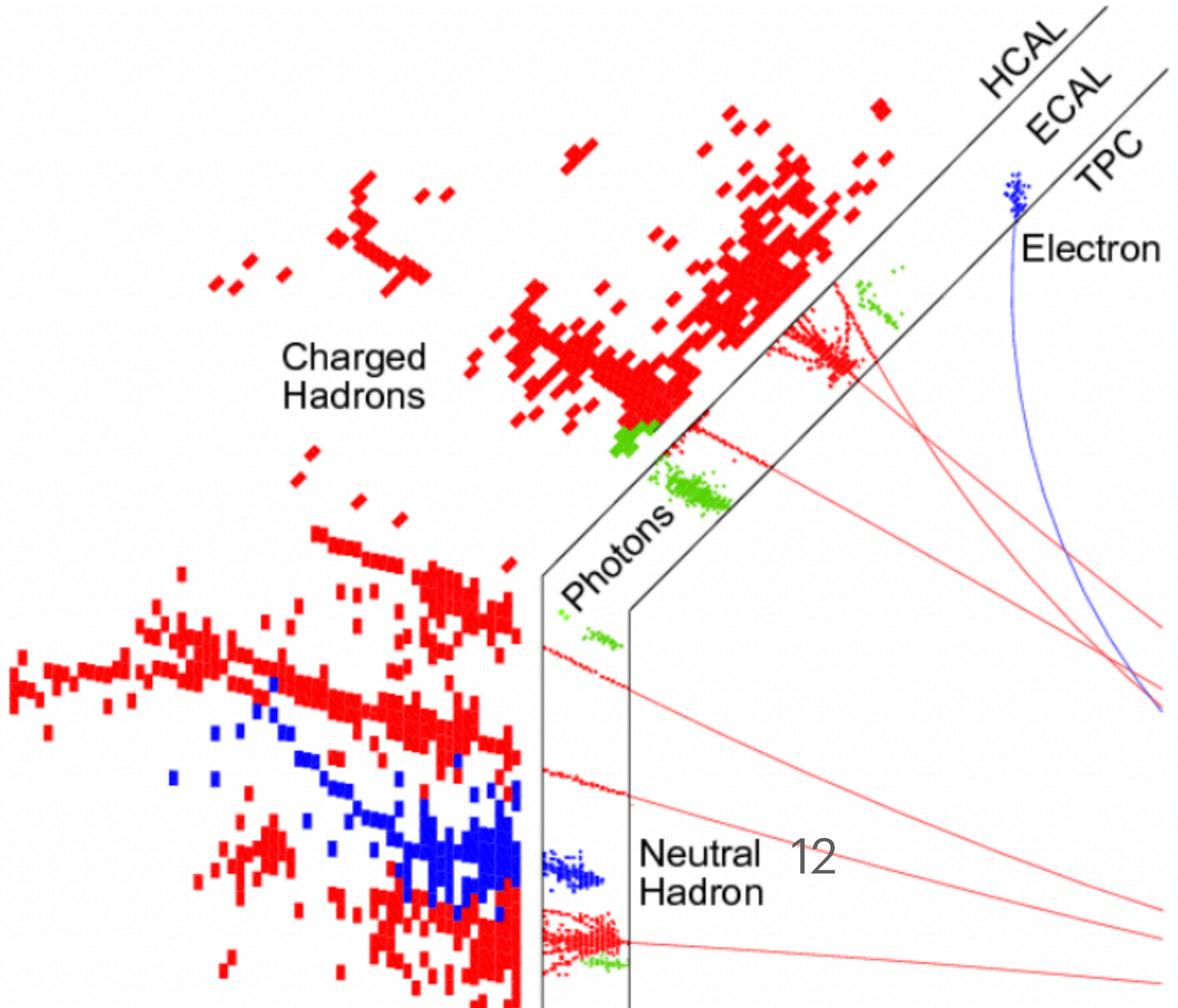




Highly Granular Hadronic Calorimetry



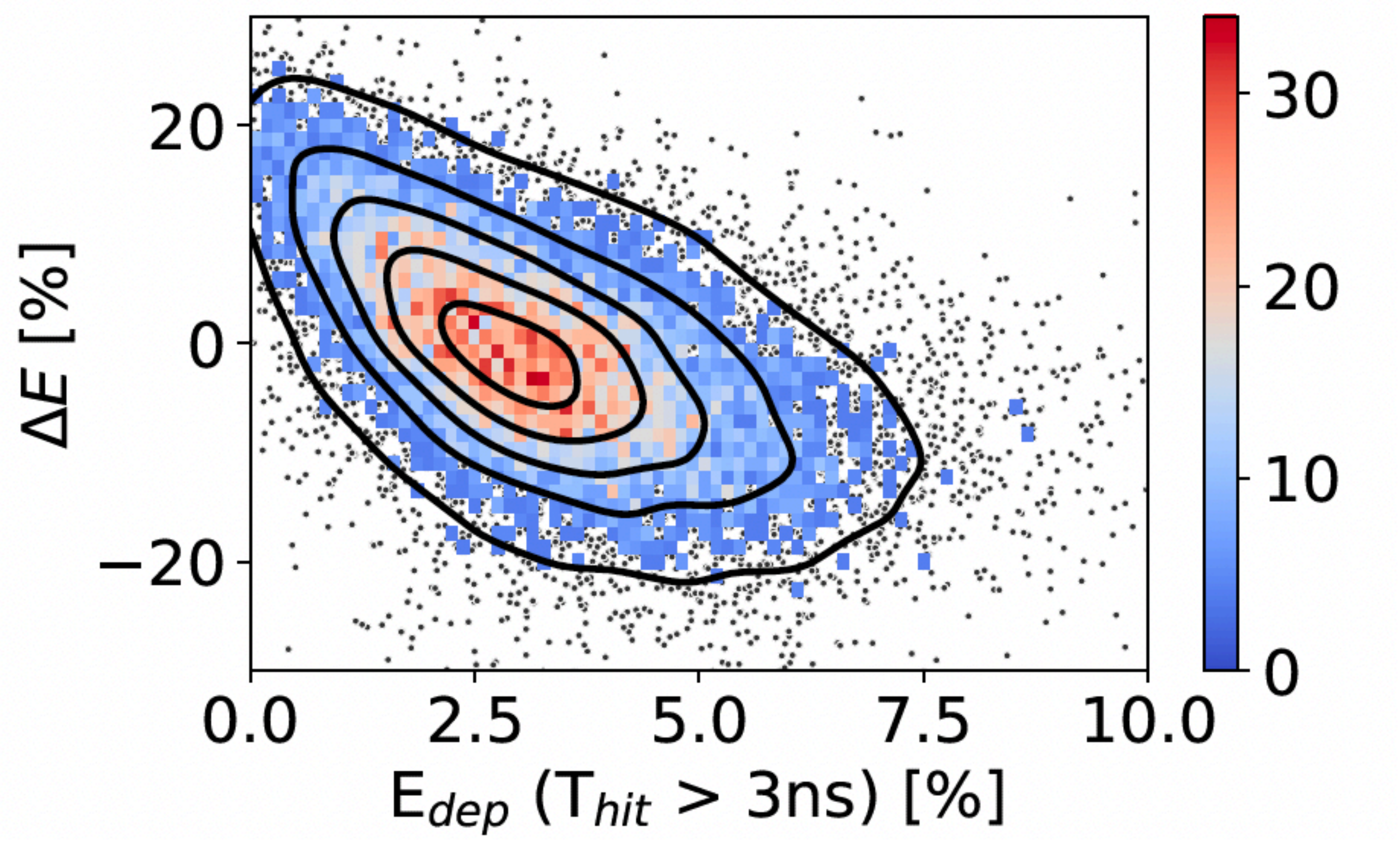
- For best jet energy resolution: Reconstruct all particles in an event as precisely as possible, combining information of all detector systems : Particle Flow - the basis of detector concepts for linear and circular colliders
- Requires highly granular calorimeters for best possible pattern recognition and particle separation
- Good hadronic energy resolution important for the reconstruction of neutrals and to help with track cluster matching

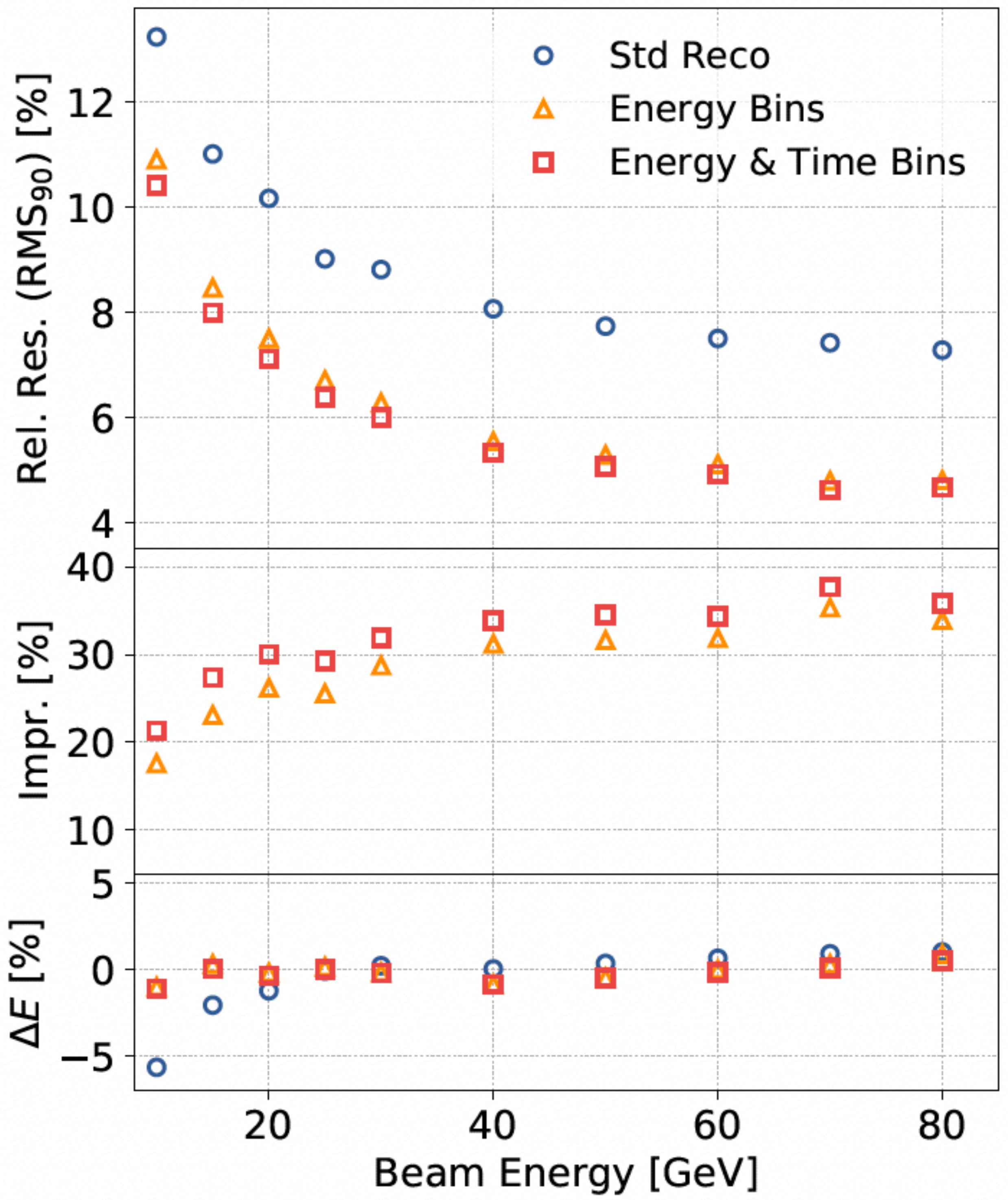


- Expanding to 5 dimensions: precise reconstruction of particle showers in space, energy density and time
- Highly granular calorimeters developed in CALICE - MPP focus on SiPM/scintillator based HCAL

Timing for better Energy Reconstruction

- The hit time distribution for 40 GeV pions evaluated - energy deposited after 3 ns are termed as late energy deposits
- For low values of late energy deposits too much energy reconstructed and high values of late energy deposits less energy reconstructed
- Software compensation can be improved by using this knowledge
- Including the time information in local software compensation improves energy resolution by 3-4% on top of what is achievable with energy density alone.
- Further potential expected with ML techniques which can be better to exploit the multi-dimensional information



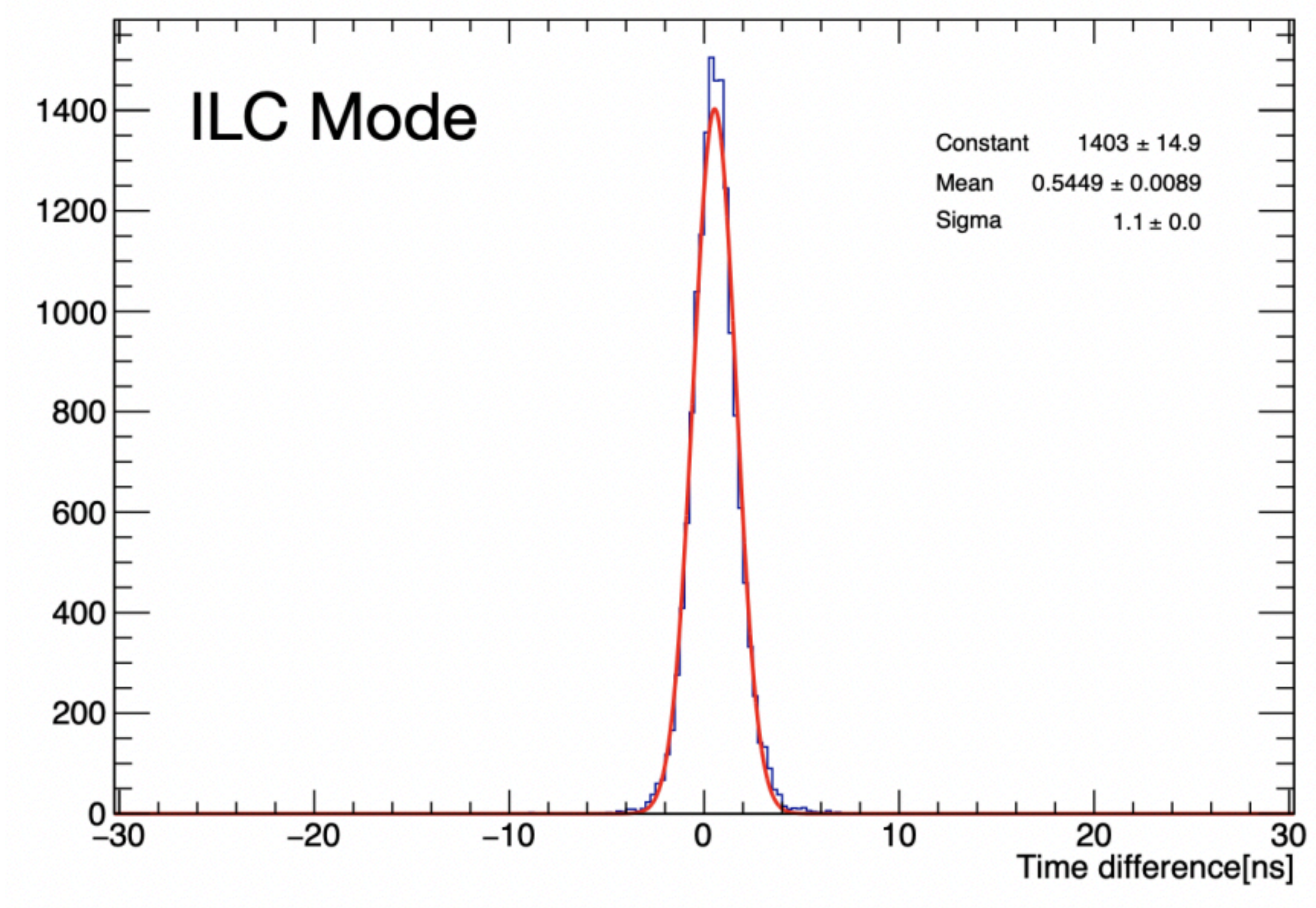


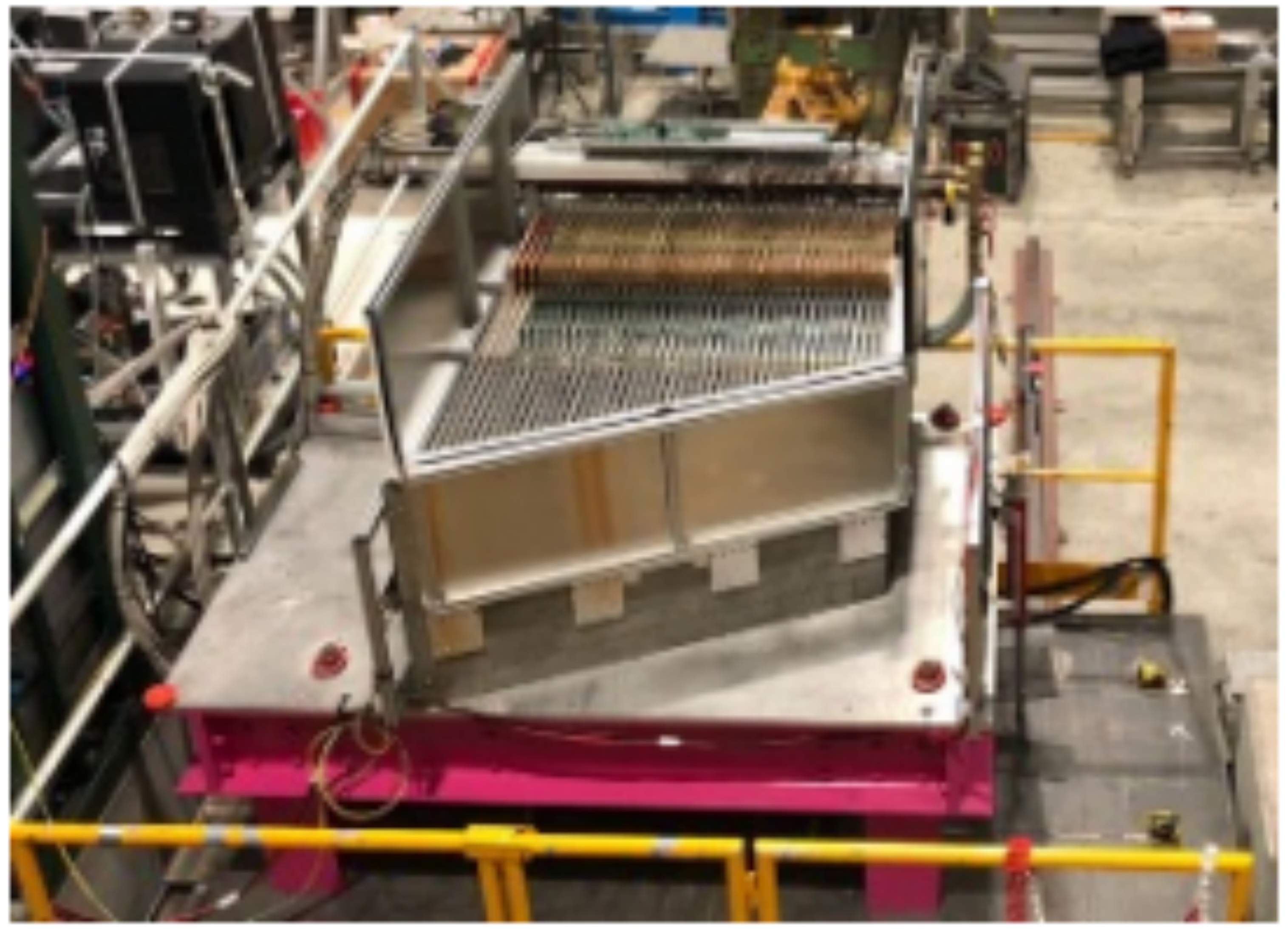
Time resolution at the Hadronic Calorimeter

L.Emberger, F.Hummer

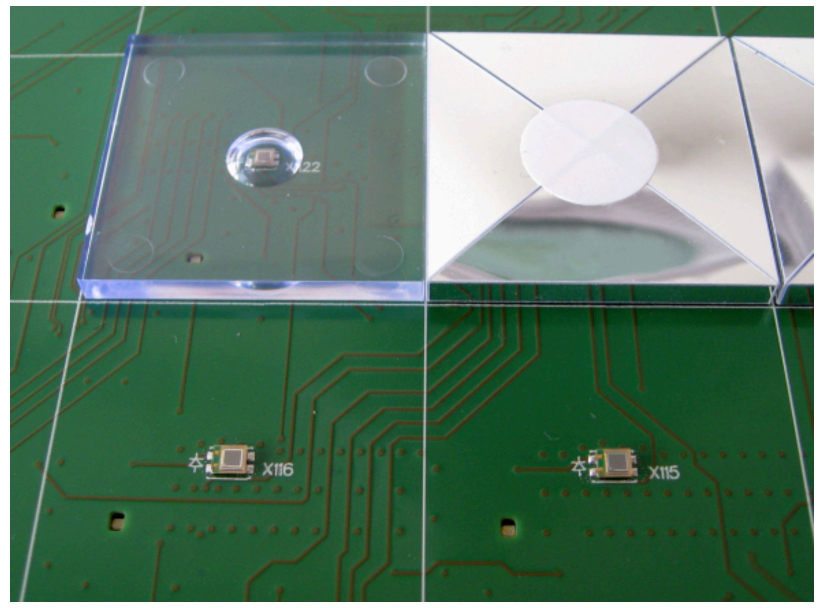
- Test beam measurements at CERN and DESY with full CALICE AHCAL calorimeter prototype (0.5m3 active volume, 22k channels) show that a single-cell time resolution of 780ps for minimum-ionising article is reached
- The hit time difference between the two channels is measured

1.1 ns / √2 = 780 ps





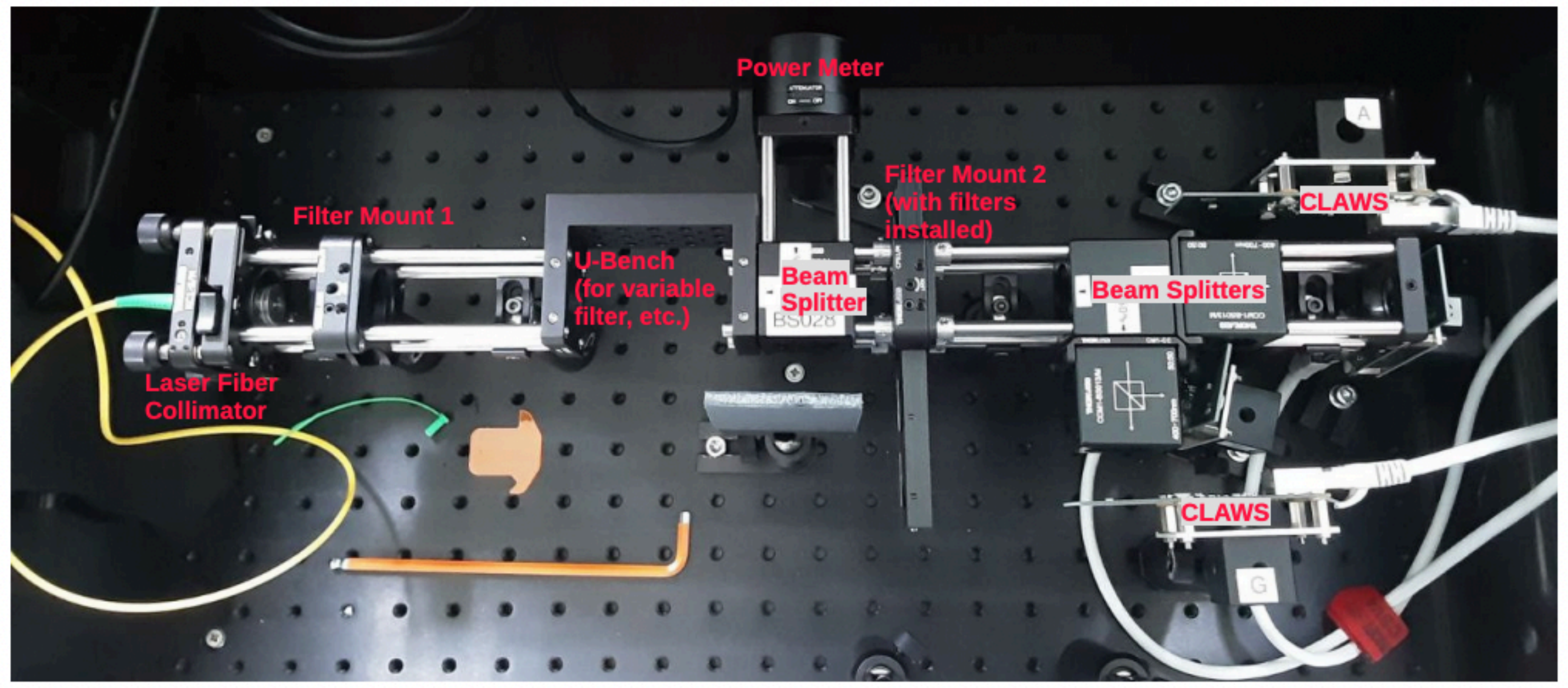
- Study of timing in software compensation shows additional potential with better resolution -> Lauched a program to explore intrinsic limitations of the SiPM-on-Tile technology

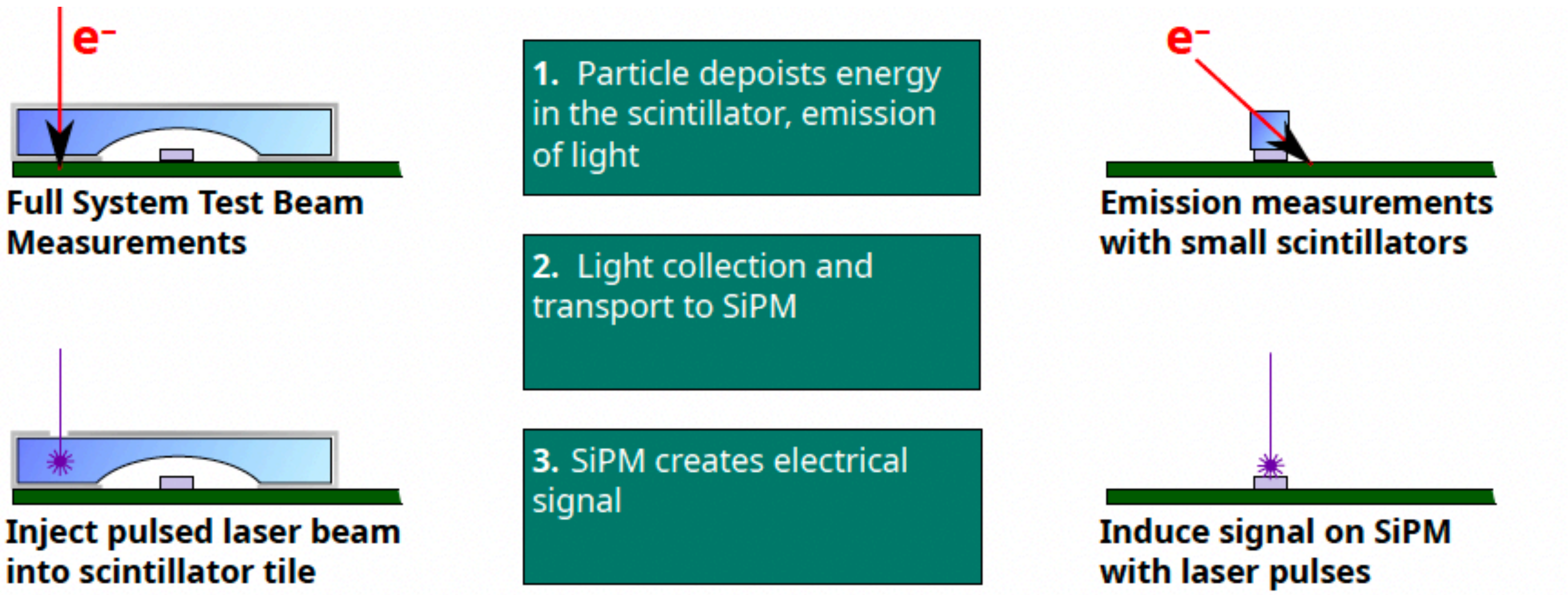


Scintillator Timing Study

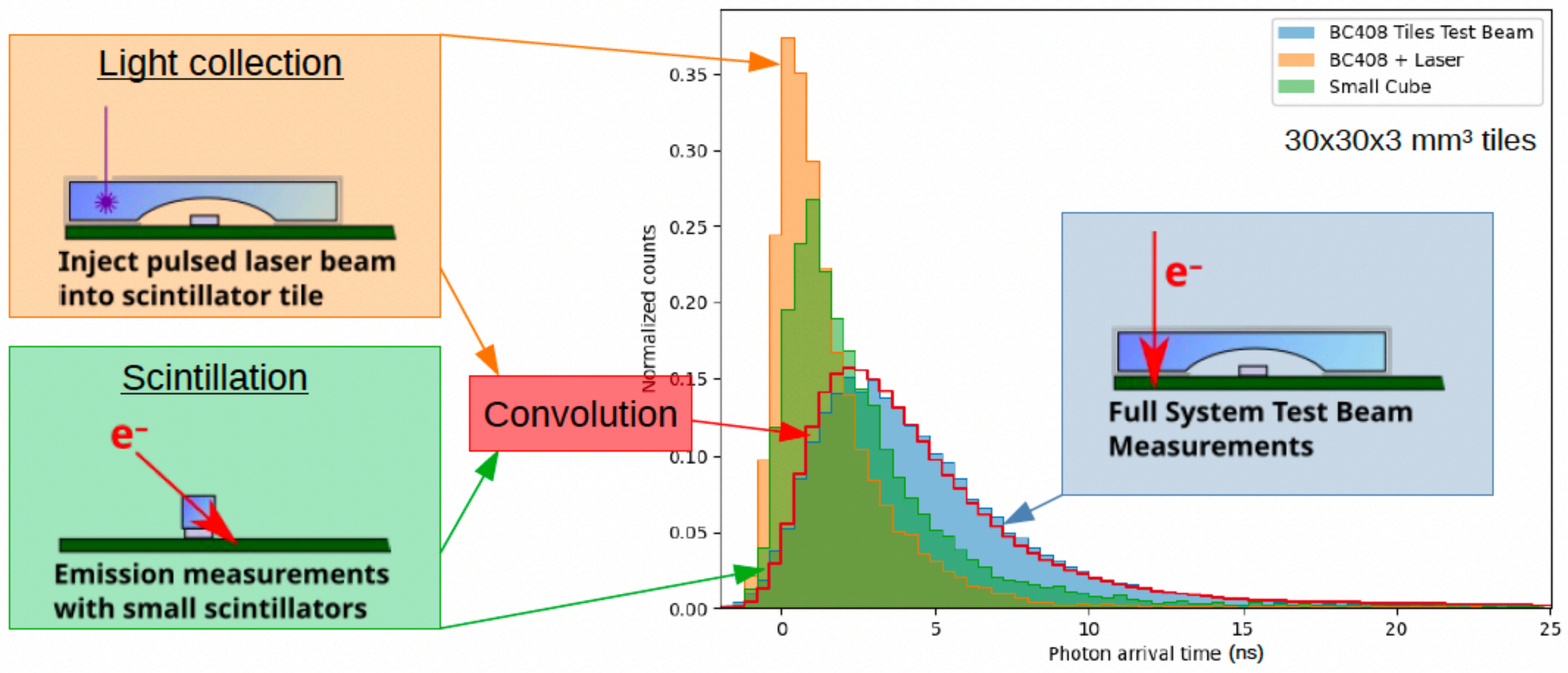
Fabian Hummer

- Investigate timing of the SiPM-on-tile technology at the microscopic level
- For this we have to understand how signal is created
- Final goal: understand how to improve the time resolution of a detector





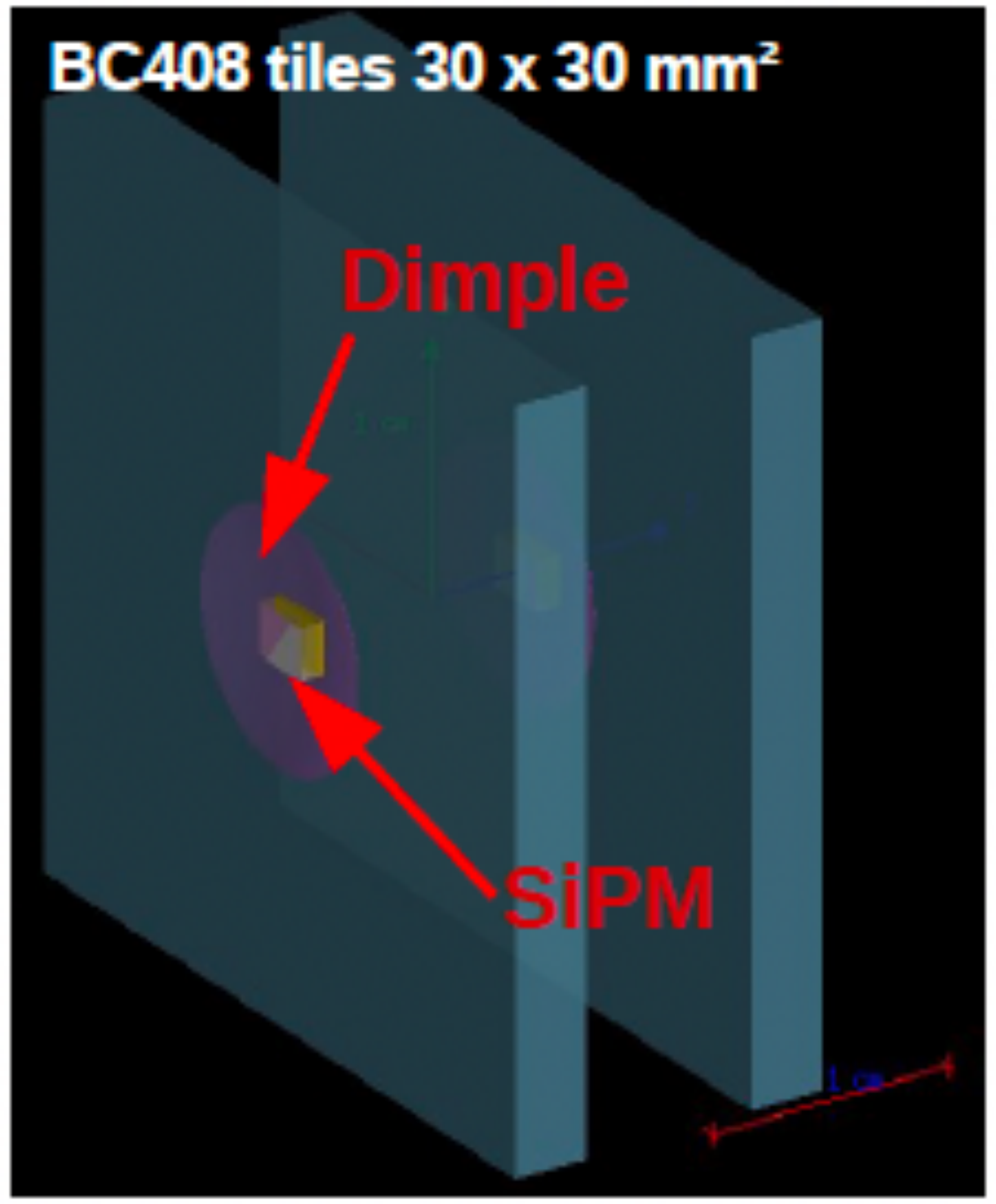
Scintillation and Light Collection

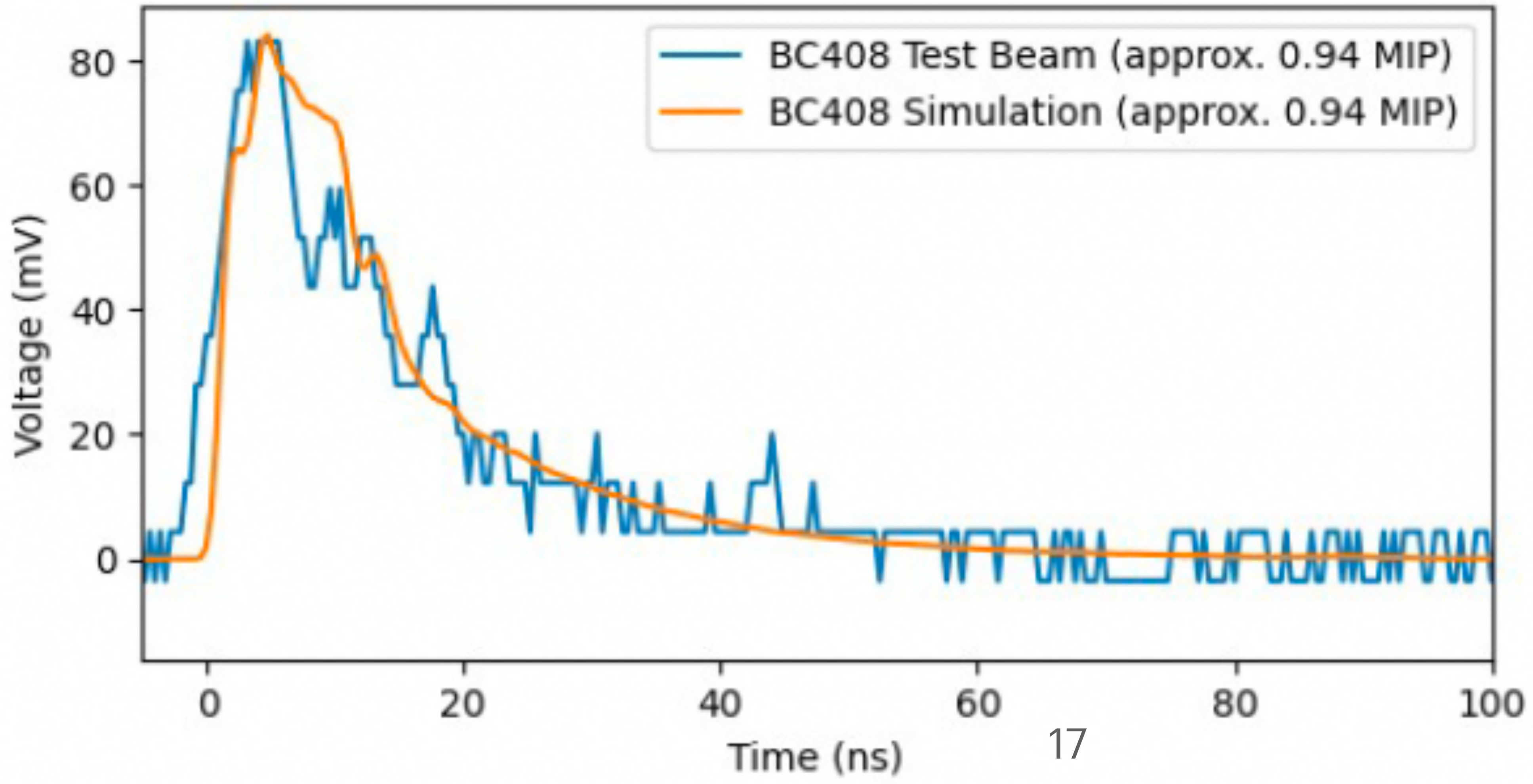


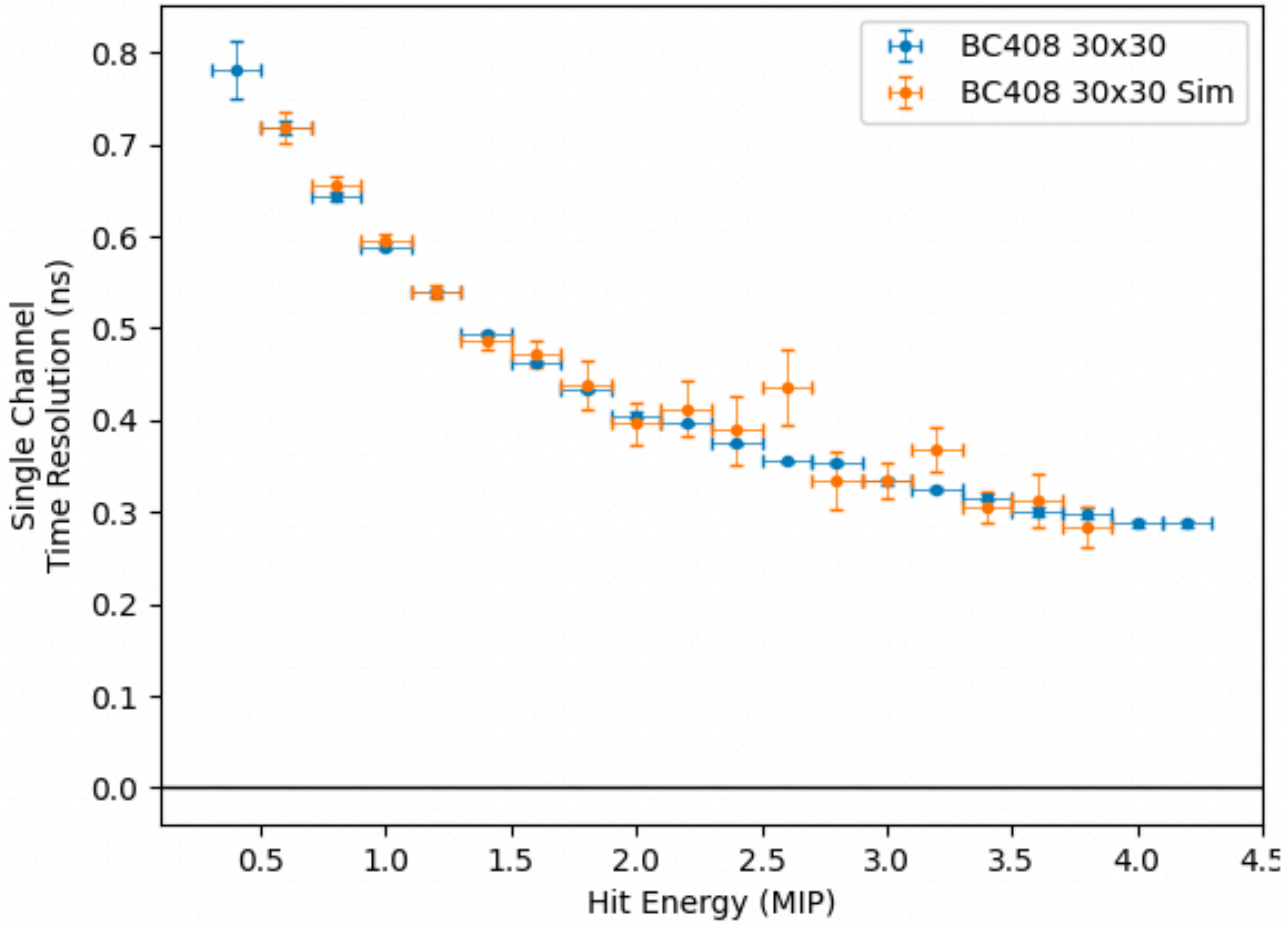
Simulation of the Time Resolution

- Geant 4 Simulation of the setup
- Generate waveforms from the list of photon hits
- Same analysis method for experiment and simulation

- Goal: Understand the process relevant for timing and extrapolate to cases that we did not measure
- Understand correlation between tile size, light yield and time resolution

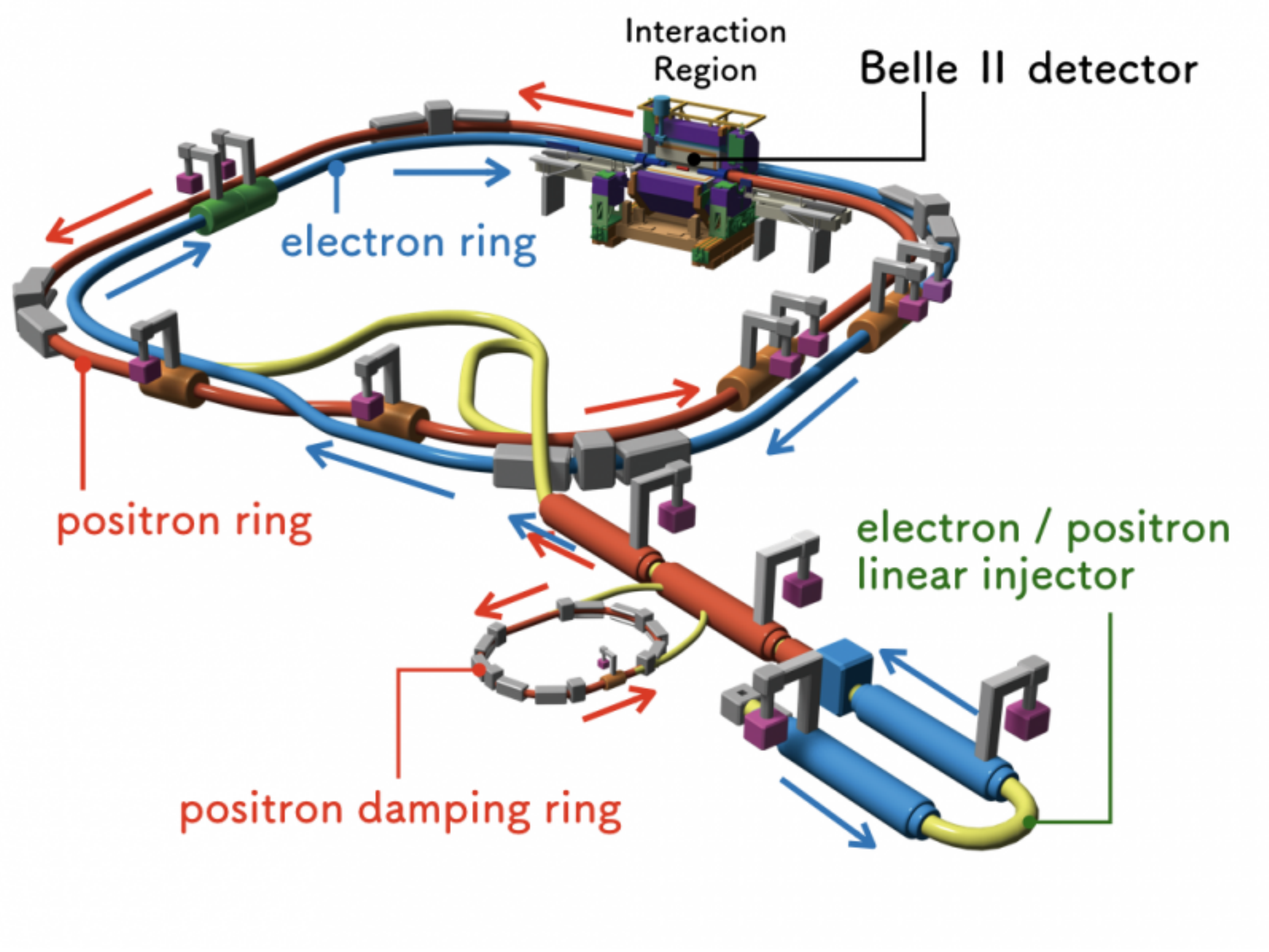




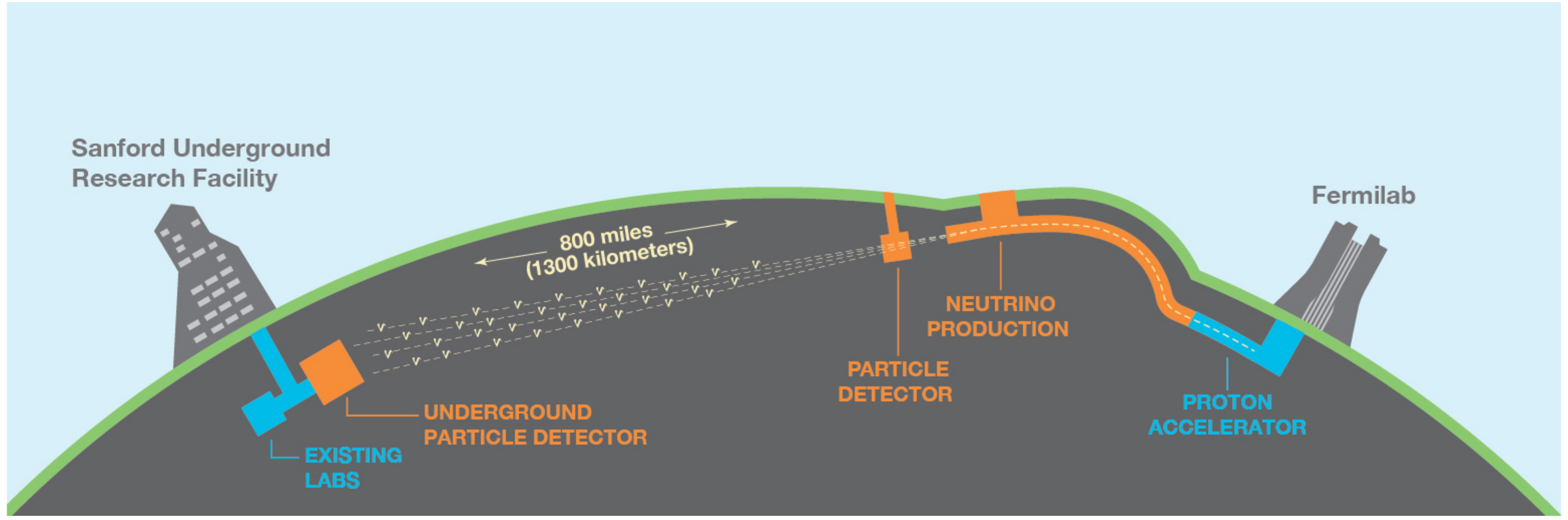


Other Experiments in the Group

- CLAWS at BELLE II experiment at SuperKEKB



- DUNE: Underground neutrino experiment

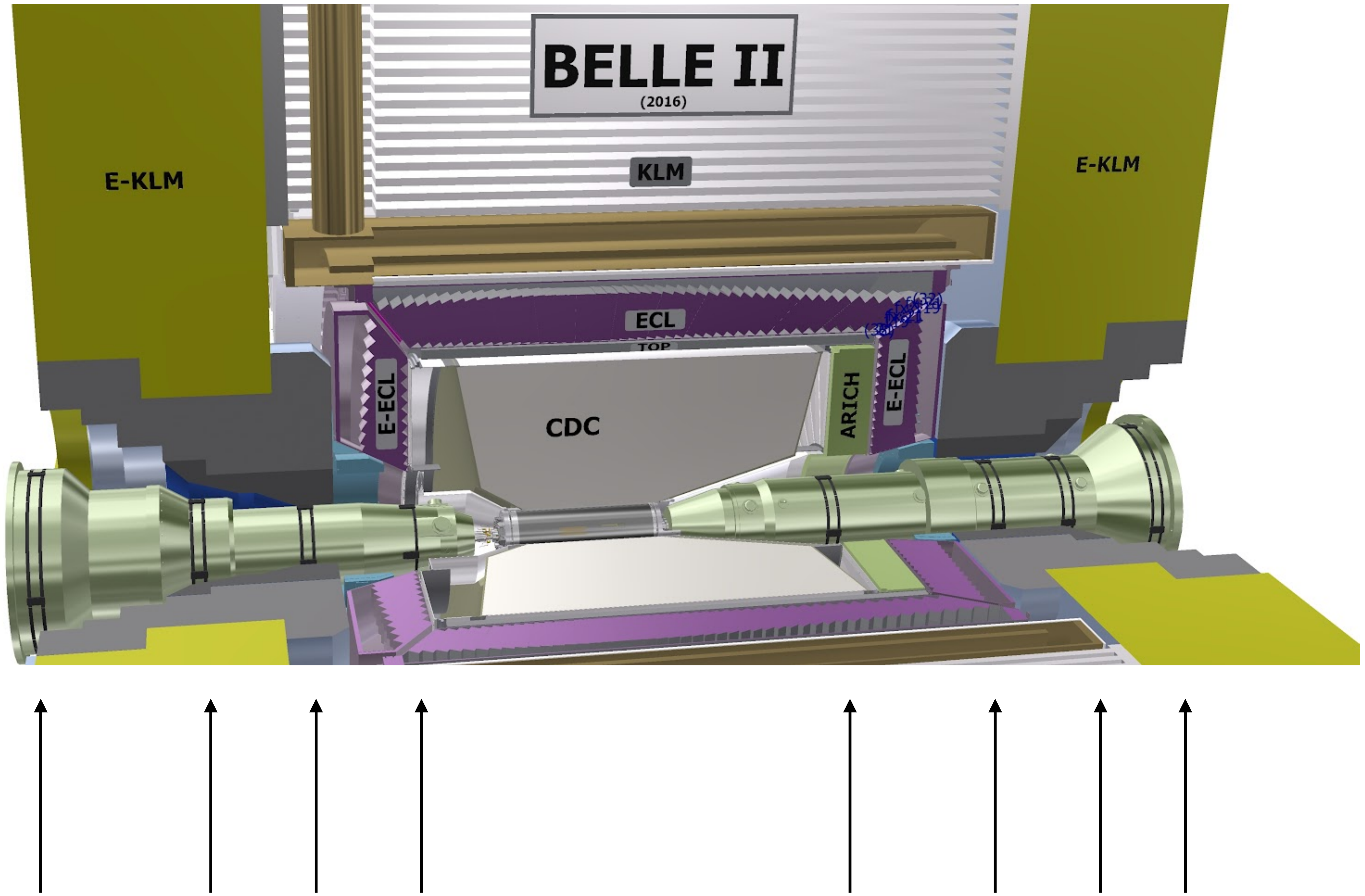


The CLAWS System

H.Windel, I. Popov

Sci**n**tillator **L**ight **a**nd **W**aveform **S**ensors:

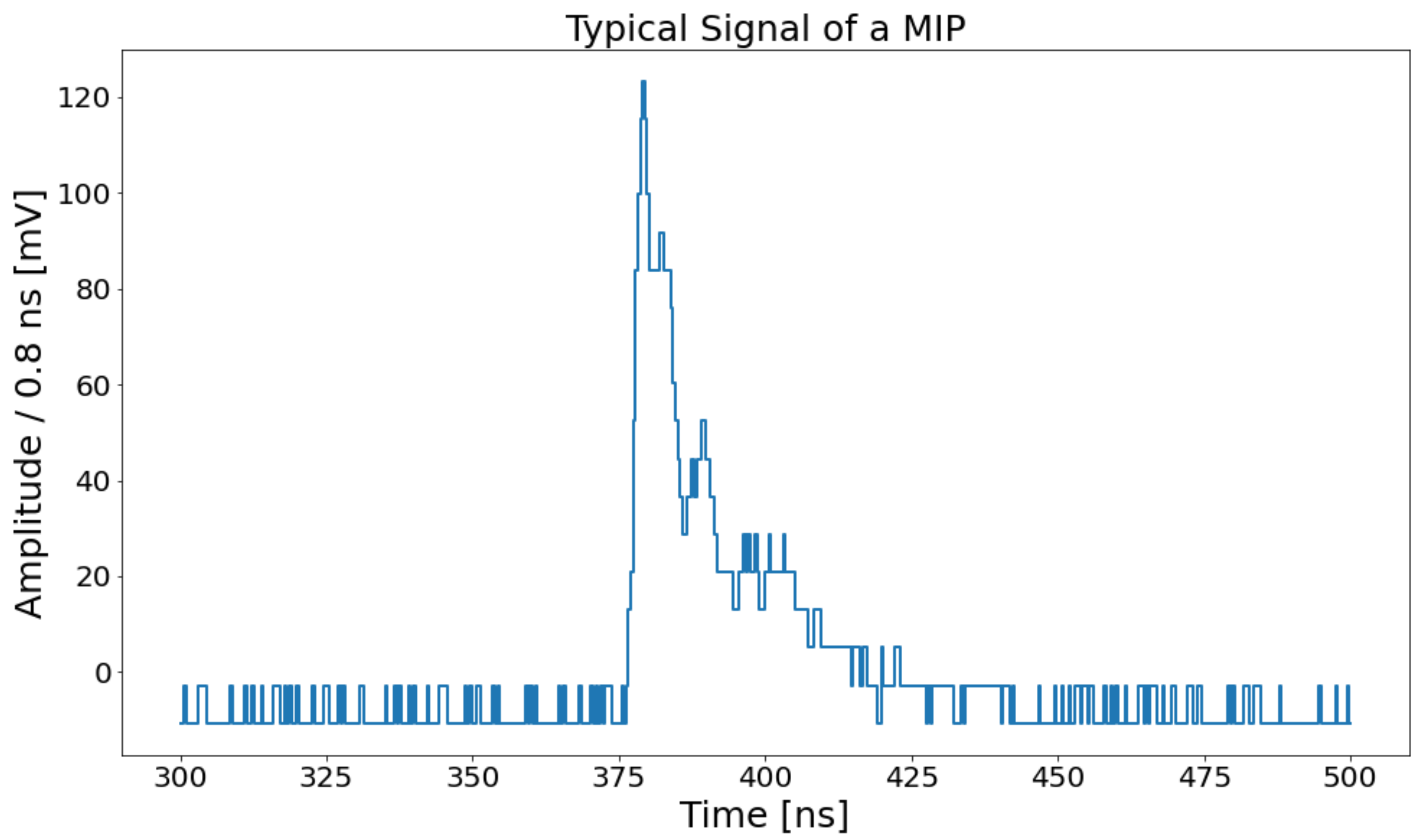
- 32 sensors in total, 16 on forward and backward side of the Belle 2 detector, mounted on the QCS with varying z and ϕ positions



CLAWS Abort Trigger Scheme

H.Windel, I. Popov

- Typical MIP signals observed by CLAWS sensors have **100-150mV** amplitude and decay over **50-70ns**



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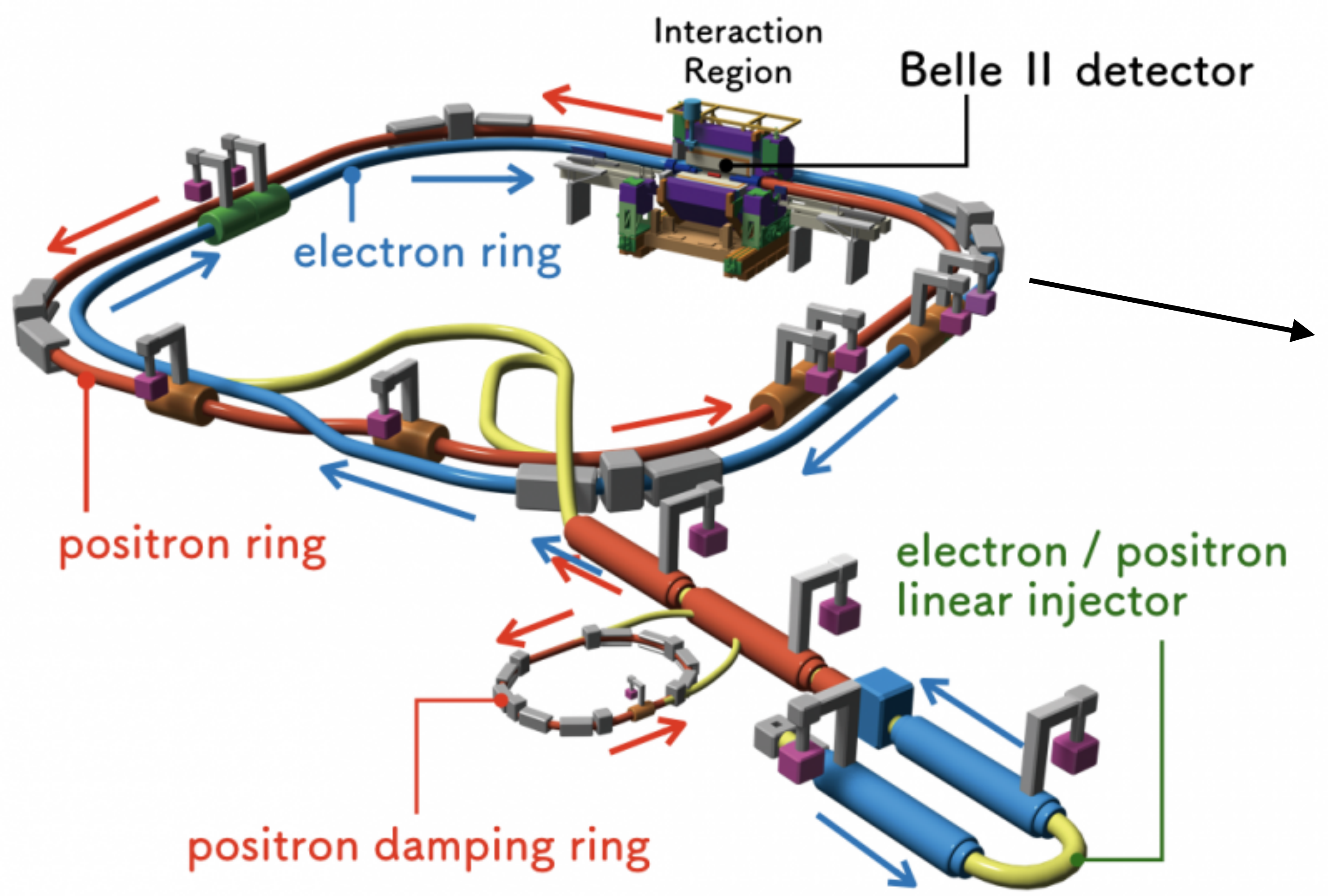
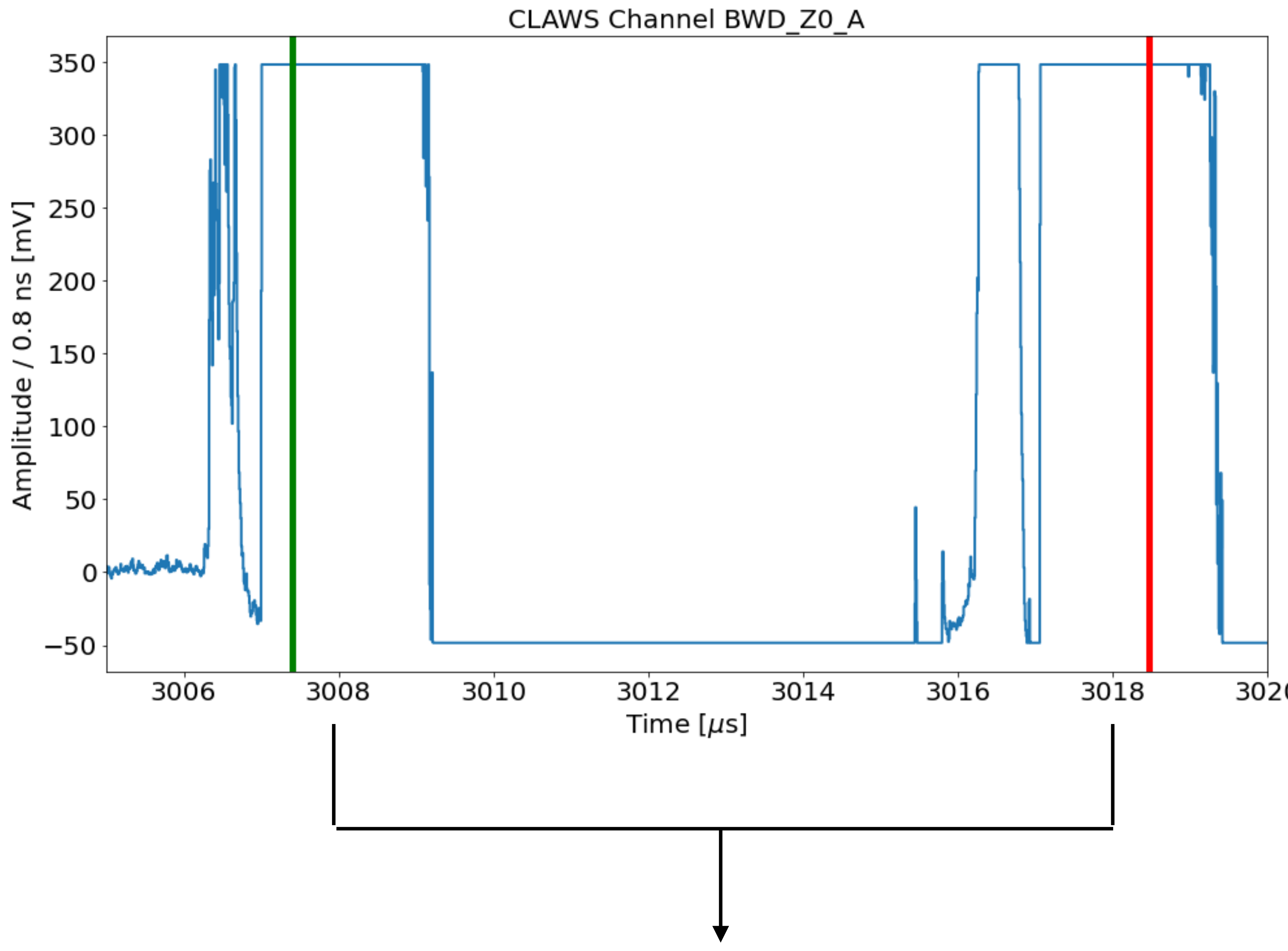
- In typical beam abort events the amplitude stays above **250mV** for a couple of μs



One SuperKEKB beam takes 10us to make a complete revolution



A 10us periodicity between two saturated signals

CLAWS Abort Trigger Scheme

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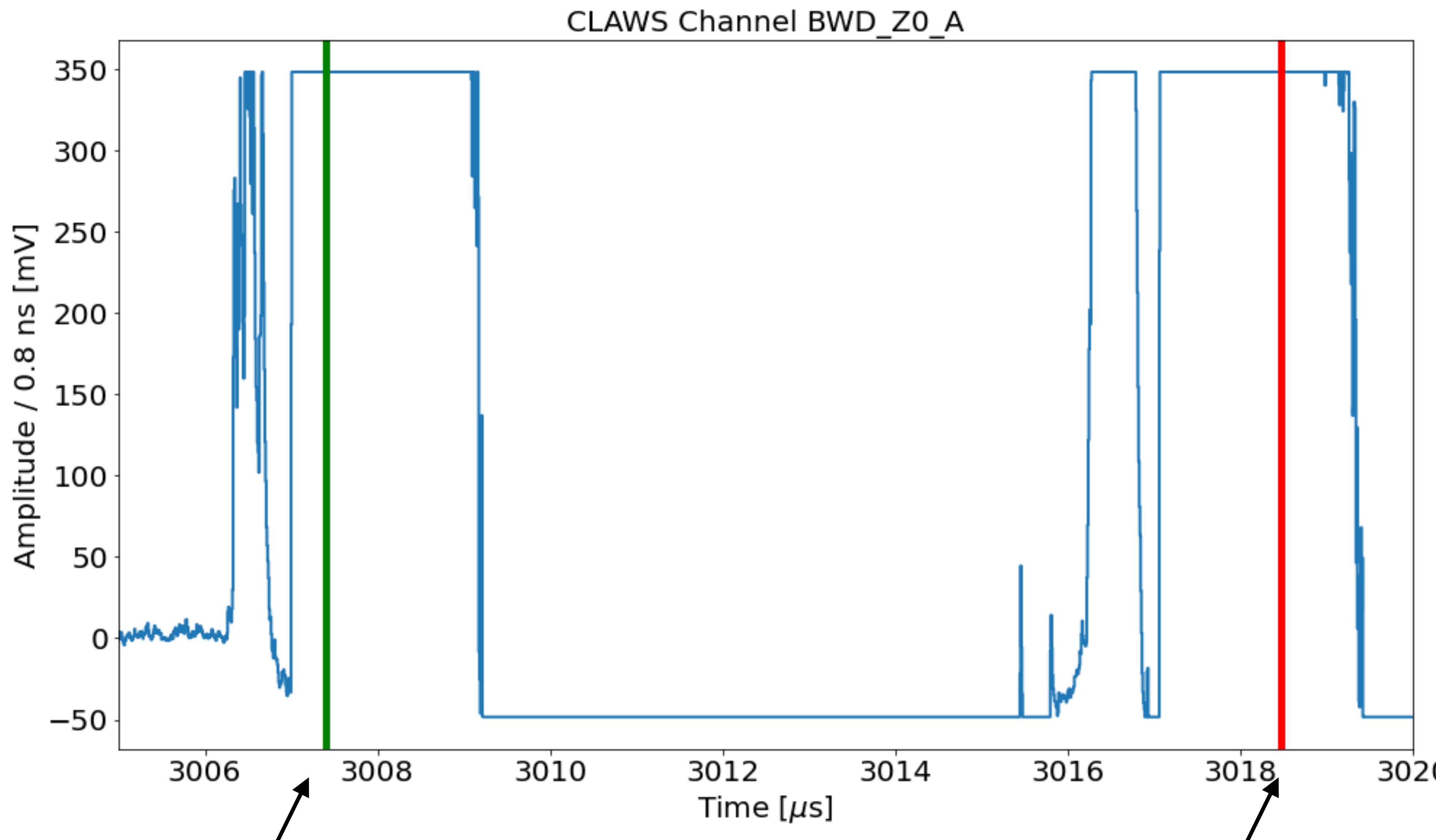
- An amplitude and duration based threshold exceeding 250 mV for at least 200 ns reacts substantially earlier than current existing systems

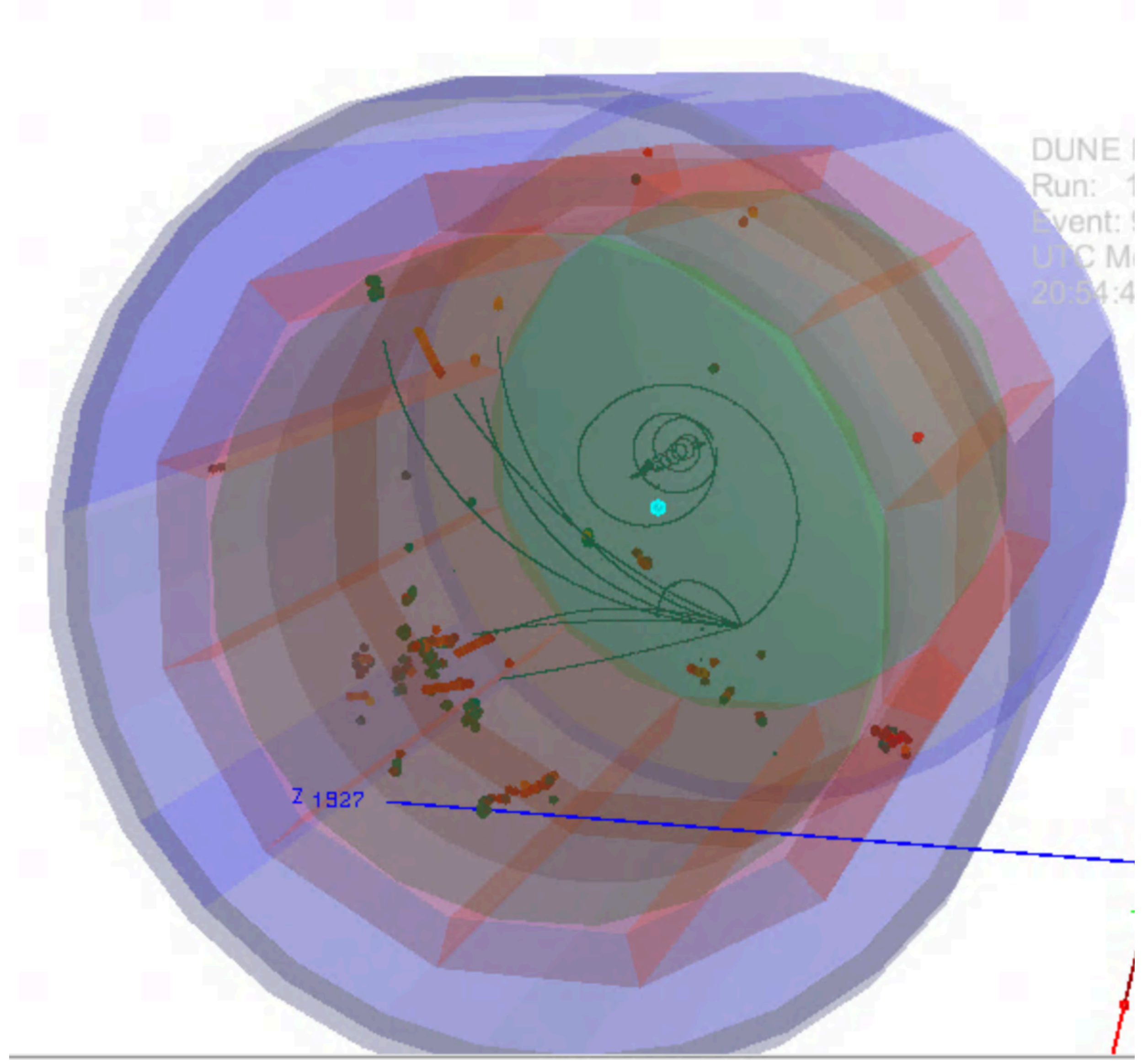


CLAWS Beam Abort Trigger Issue

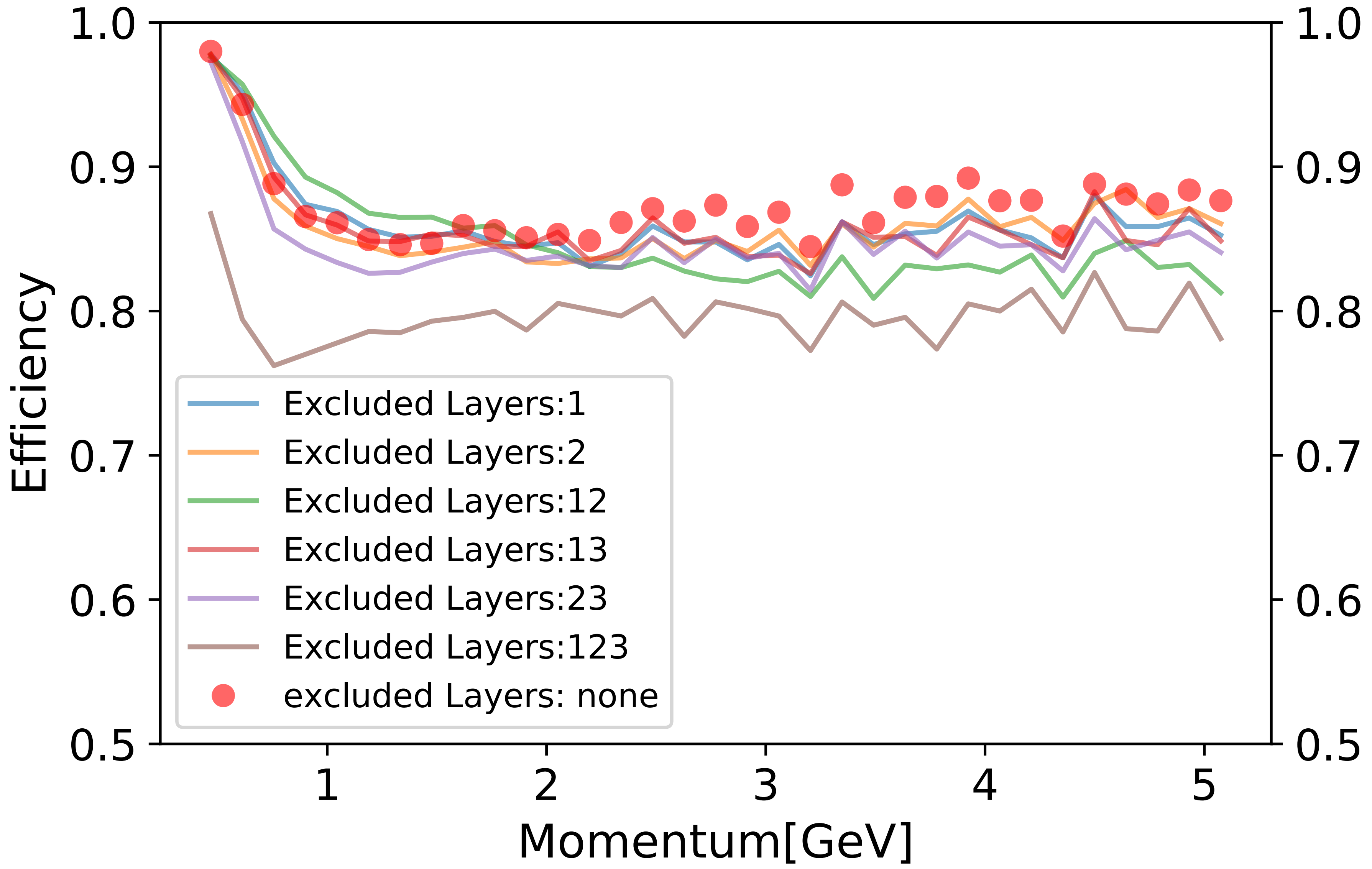
Diamond Beam Abort Trigger Issue

CALICE technologies at DUNE

Lorenz Emberger



- Electromagnetic calorimeter for DUNE ND-GAr near detector based on CALICE technology: High granularity and sub ns timing with SiPMs and scintillators
- Separation of muons and pions studied with different layers in the yoke exploiting detector granularity and muon system based on ML techniques
- Study shows that muons can be separated from pions with an efficiency above 75-90%
- Use timing to measure neutron energy via time of flight



Conclusion

- The case for e^+e^- collider very strongly recommended in the European Strategy Update
    - Prospects on ILC unclear, pending a decision in Japan
    - European focus shifting more towards FCCee
- The future detector group in MPP contributes to the physics studies for all the future machines in a variety of areas
- Model independent study of Higgs at future energy-frontier colliders conducted
- Highly granular scintillator- based calorimeters reaching the sub-ns timing domain provide wide-ranging possibilities for current and future projects