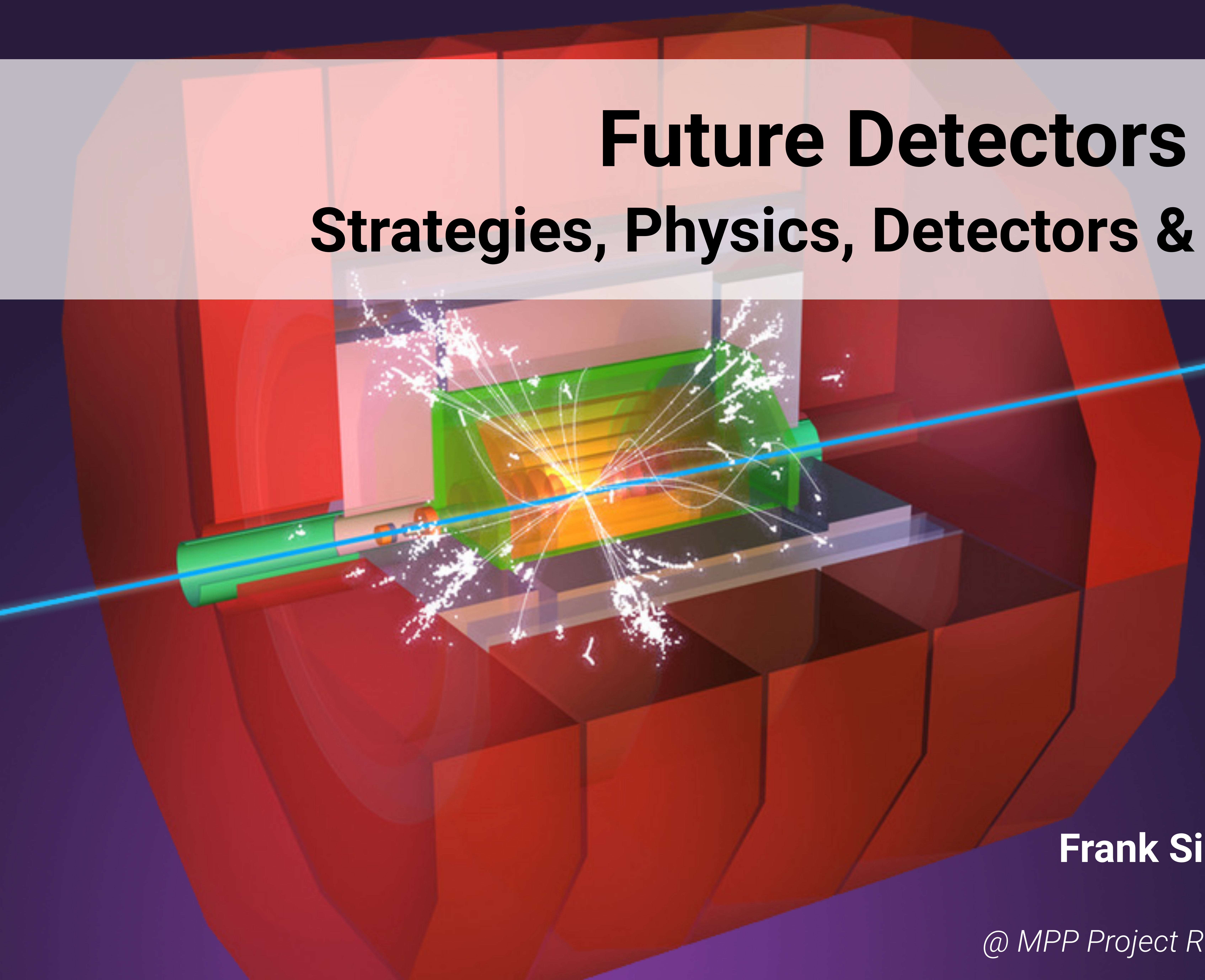
Future Detectors

Strategies, Physics, Detectors & Spin-Offs



Frank Simon

MAX-PLANCK-INSTITUT FÜR PHYSIK

@ MPP Project Review 2020

The Future Detectors Group

… in 2020

MAX-PLANCK-INSTITUT FÜR PHYSIK

The Core Group

- *Post-Docs*
  Thibaud Humair, Miroslav Gabriel (until 08/2020), Christian Graf (since 08/2020)
- *PhD Students*
  Lorenz Emberger, Christian Graf (until 07/2020), Thomas Kraetzschmar, Hendrik Windel
- *Master Students*
  Malinda de Silva (until 01/2020), Christian Winter (until 01/2020), Ivan Popov, Justin Skorupa
- *Technical Students* (for parts of 2020)
  Fabian Hummer
- *Group Leader*
  Frank Simon

Close collaboration with:

- Belle / Belle II group
- the **Technical Departments**

With key roles in collaborations and in the community, among them:

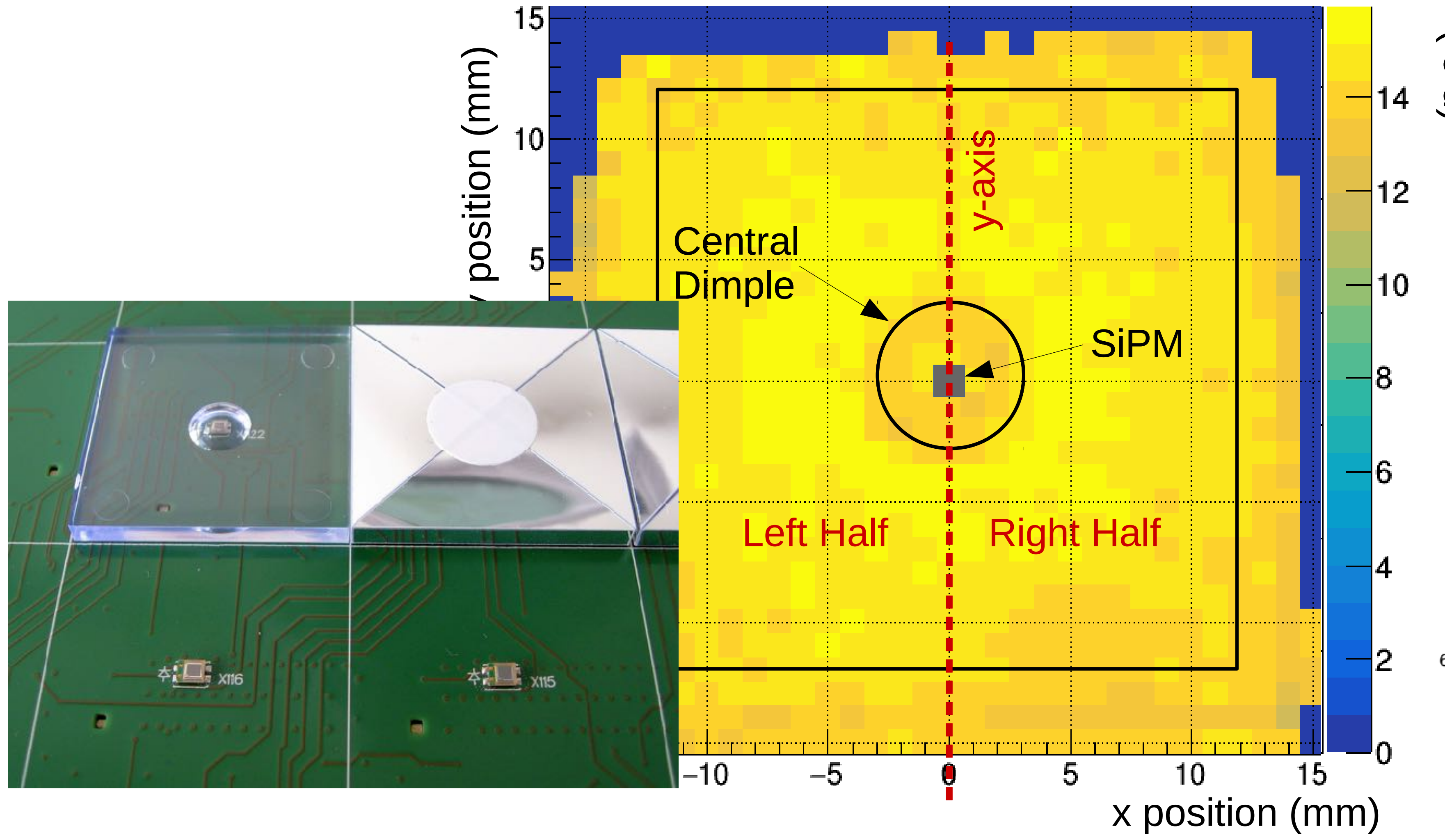
- Chair of the LHC Experiments Committee
- Chair of CALICE Institute Board
- Member of the CLICdp Executive Team
- Member of the ILC IDT WG3 Executive Board

Outline: The Projects in the Group

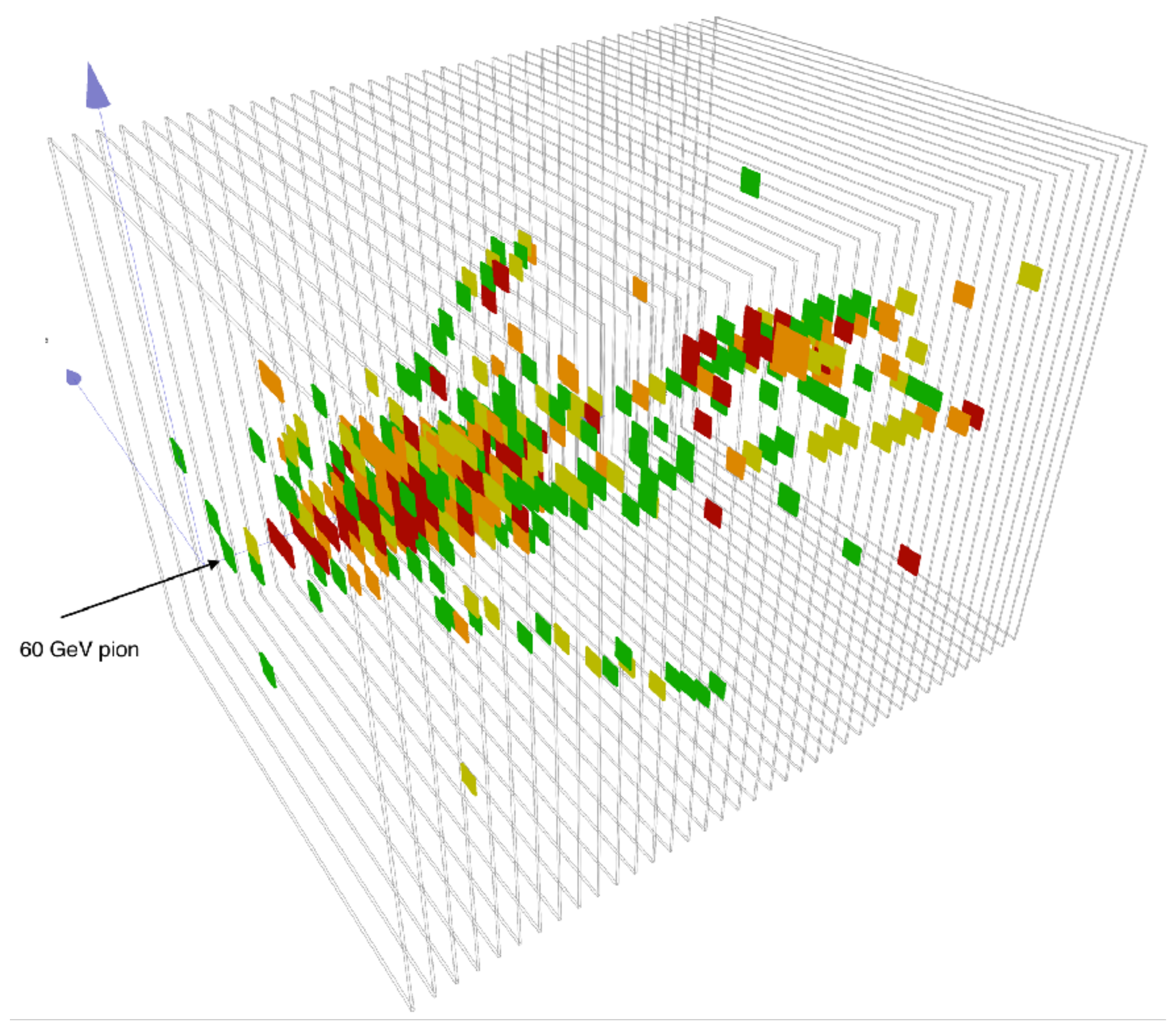
Detectors & Physics

MAX-PLANCK-INSTITUT FÜR PHYSIK

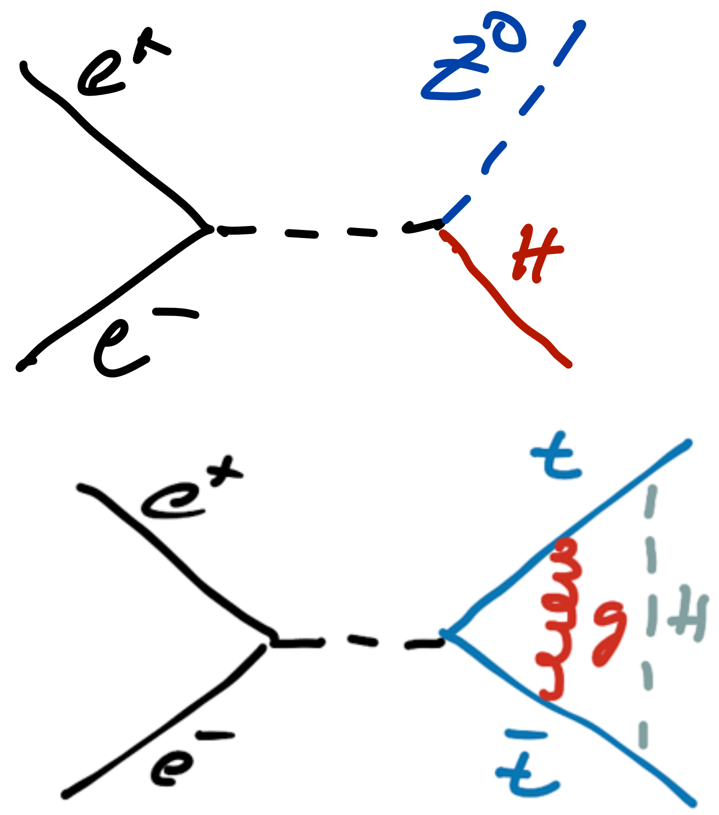
Highly granular calorimeters



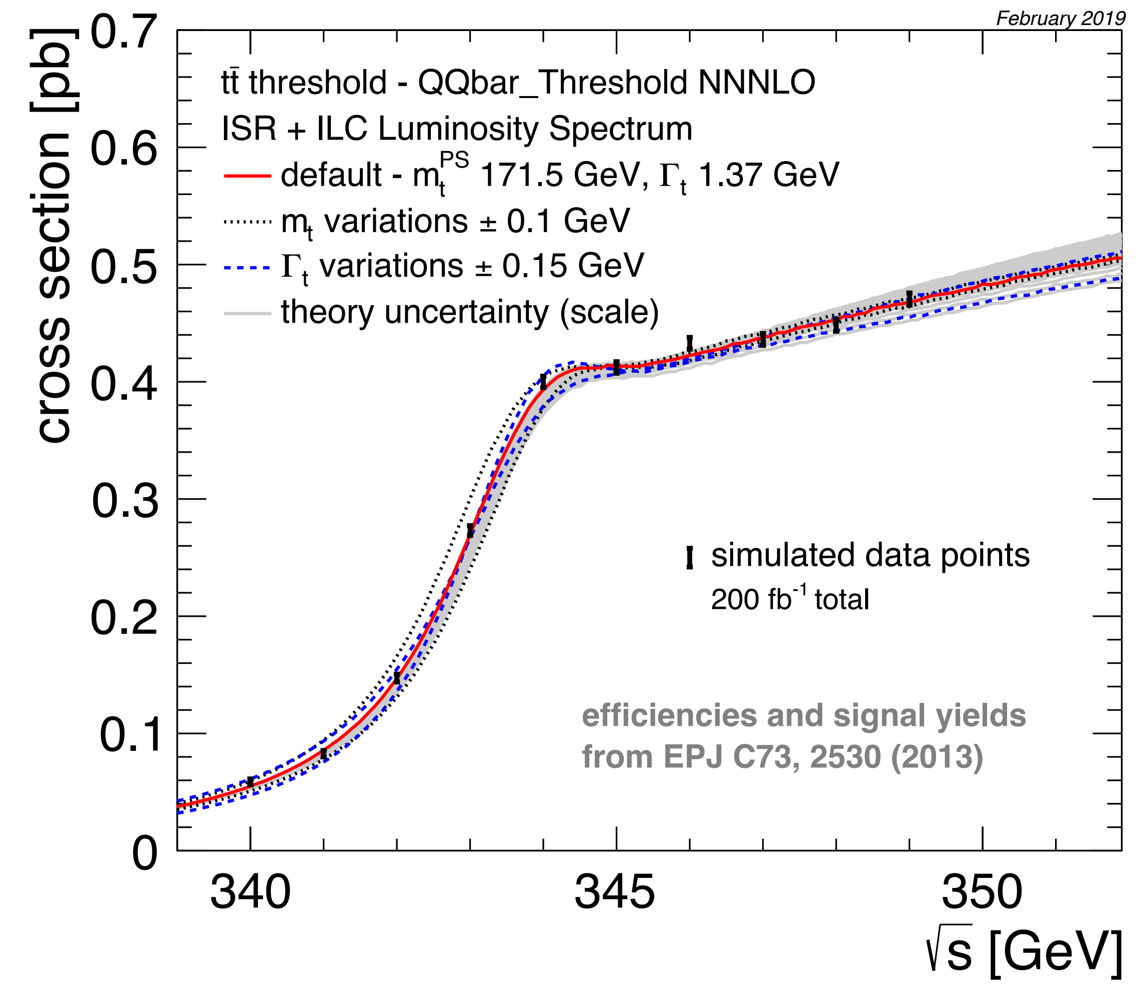
CALICE



Physics at e+e- Colliders



ilc
CLIC
FCC hh ee he



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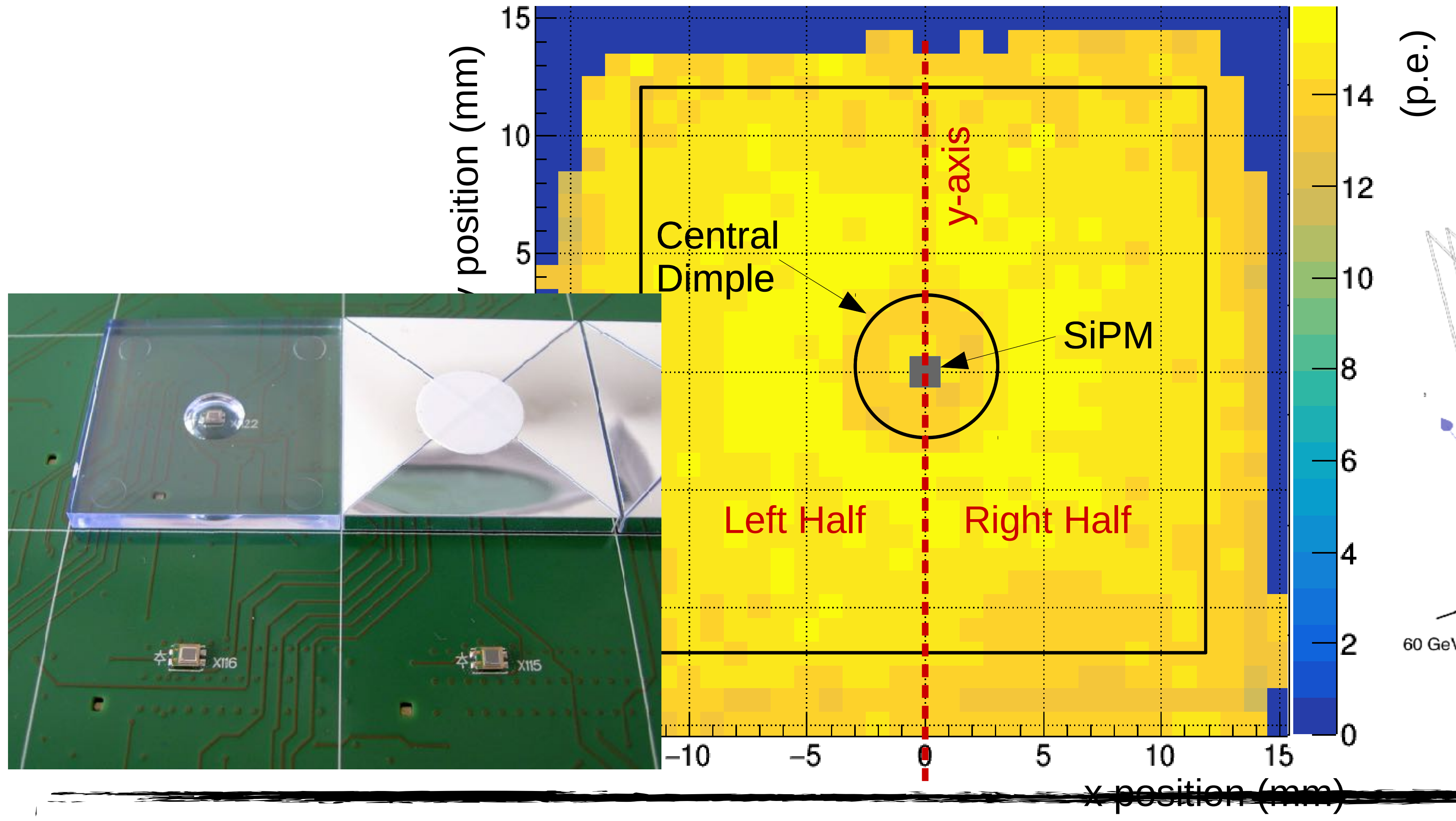

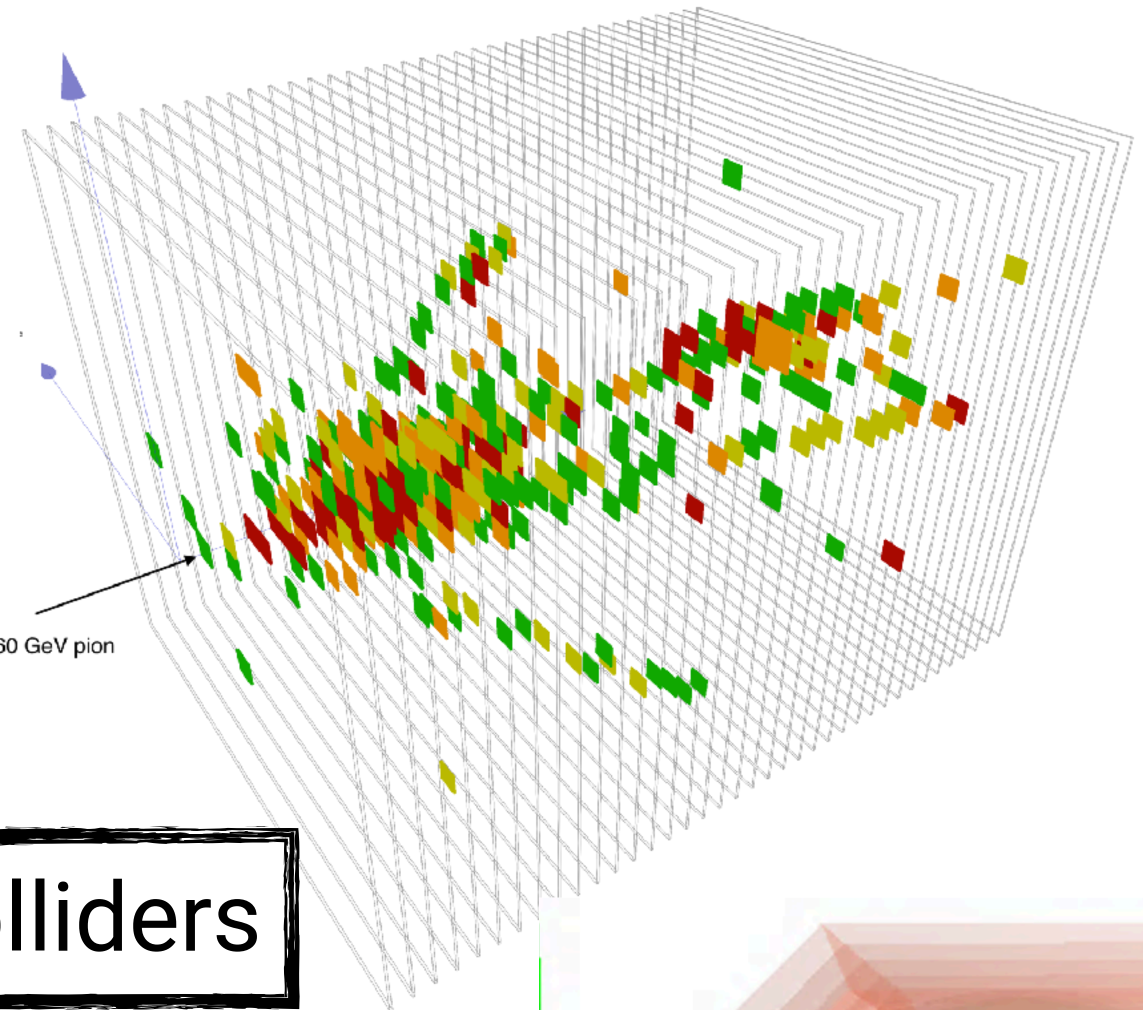

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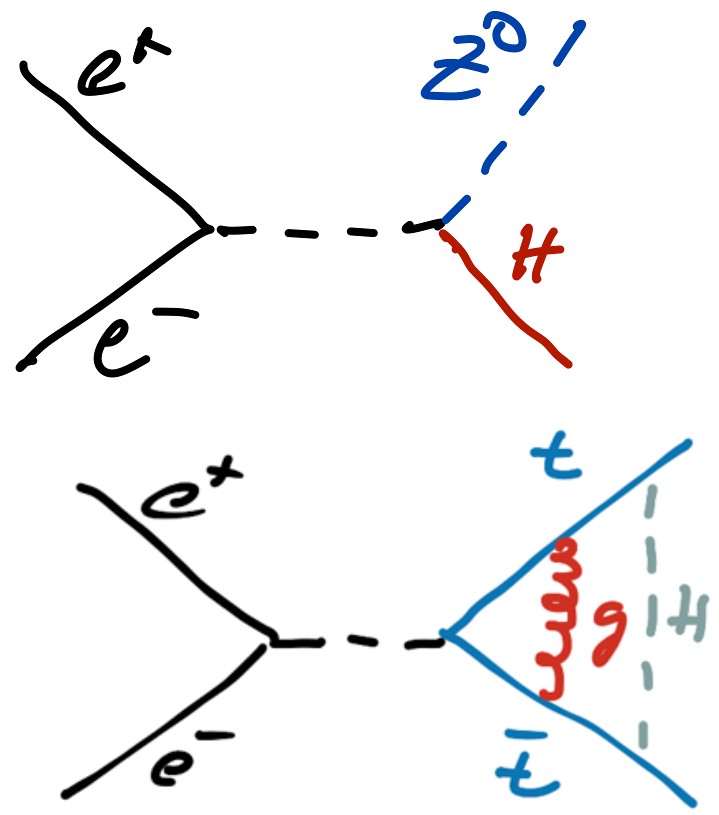
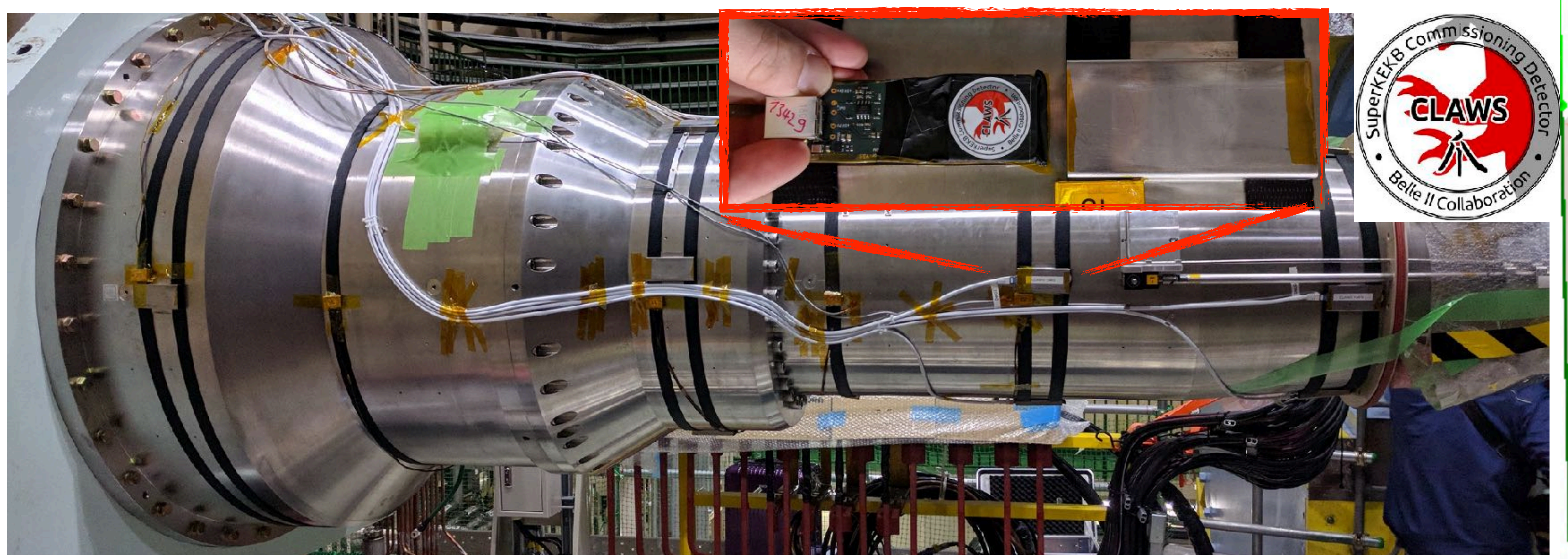
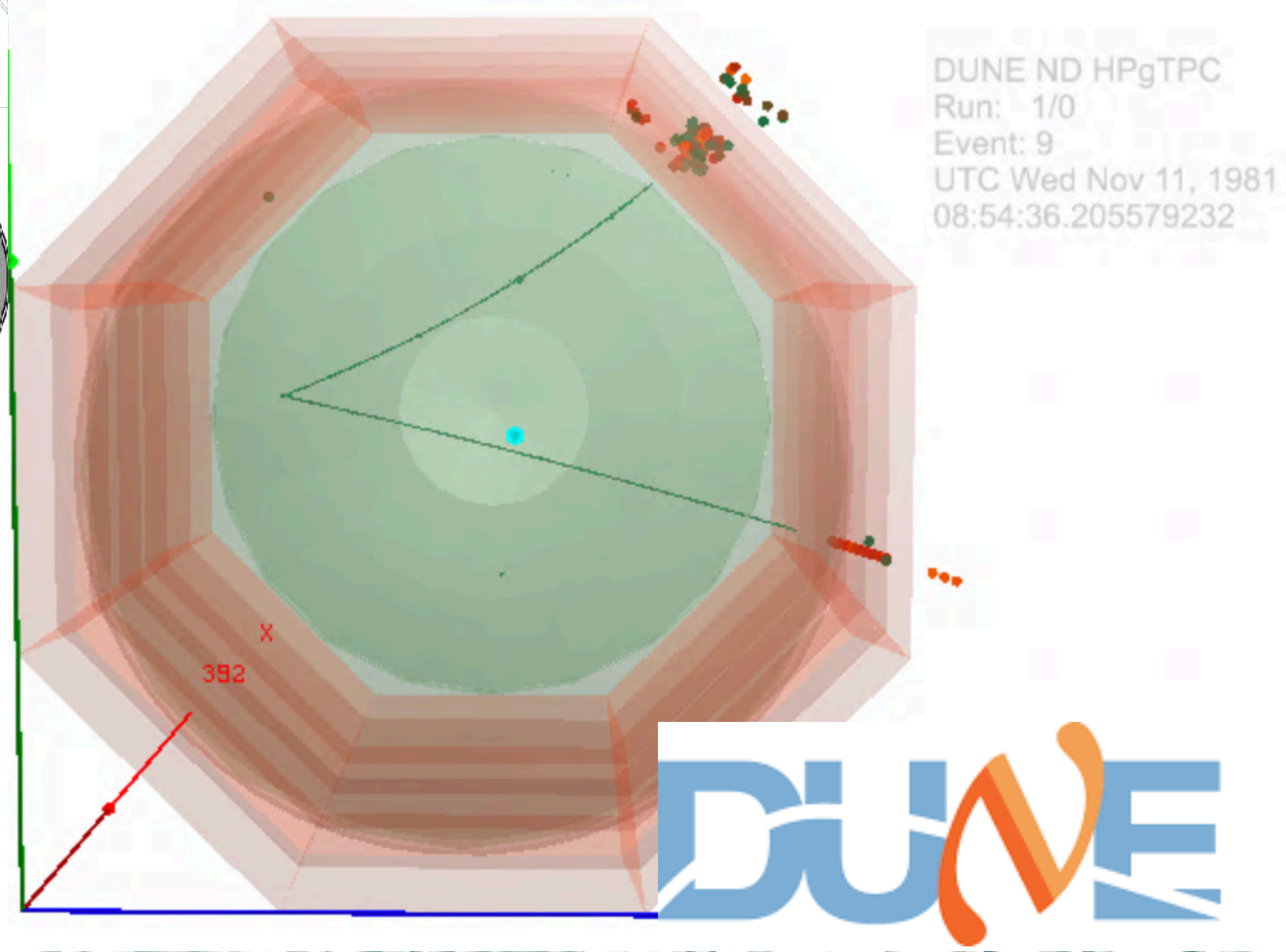
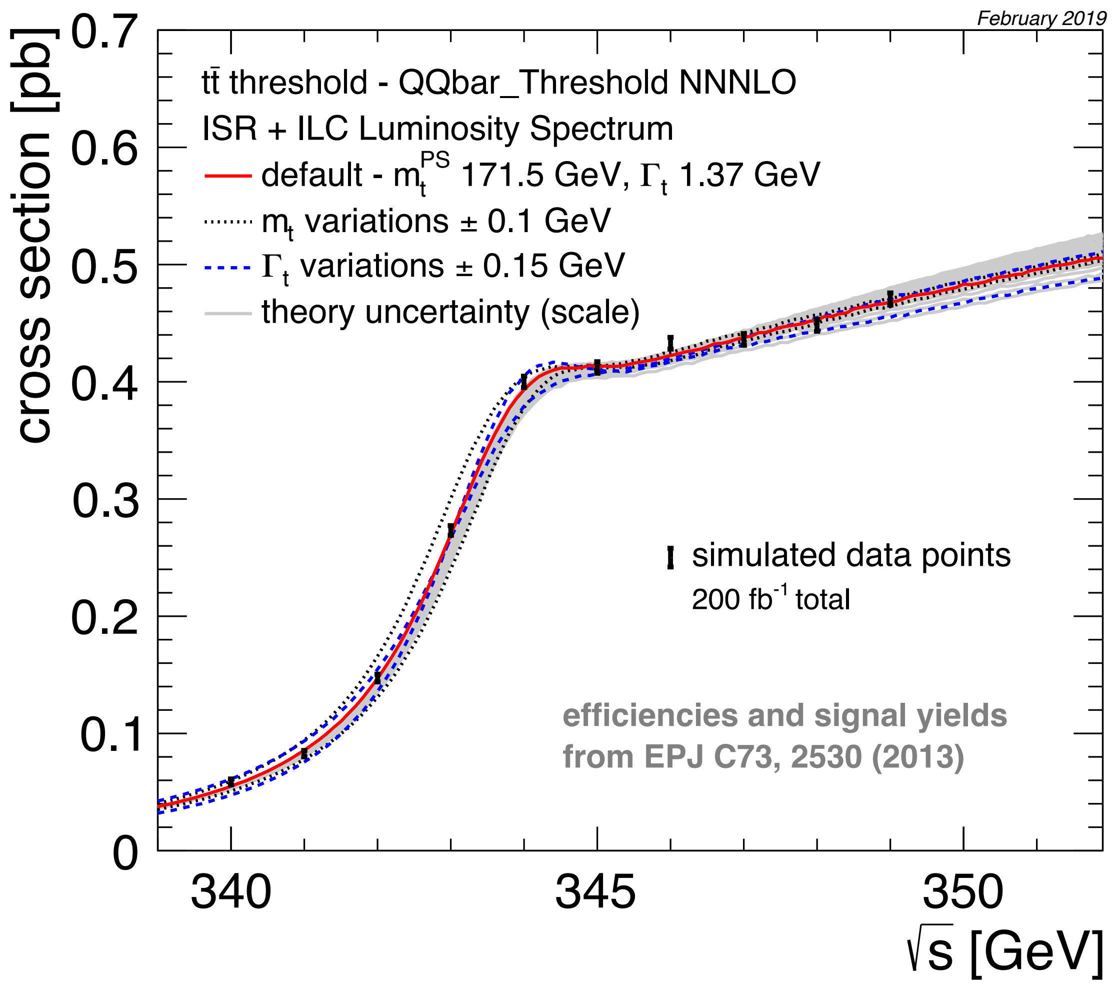


CALICE Technologies beyond Linear Colliders







The Context: Future e+e- Colliders and Beyond

Accelerator-based Precision Experiments with Leptons

- The main driver of the activities:
  Experiments at future lepton colliders
  - **ILC**: 250 GeV (500 GeV - 1 TeV with upgrade) under discussion in Japan

  CERN Future:
  - **FCCee**: Circular collider, 90 GeV - 365 GeV
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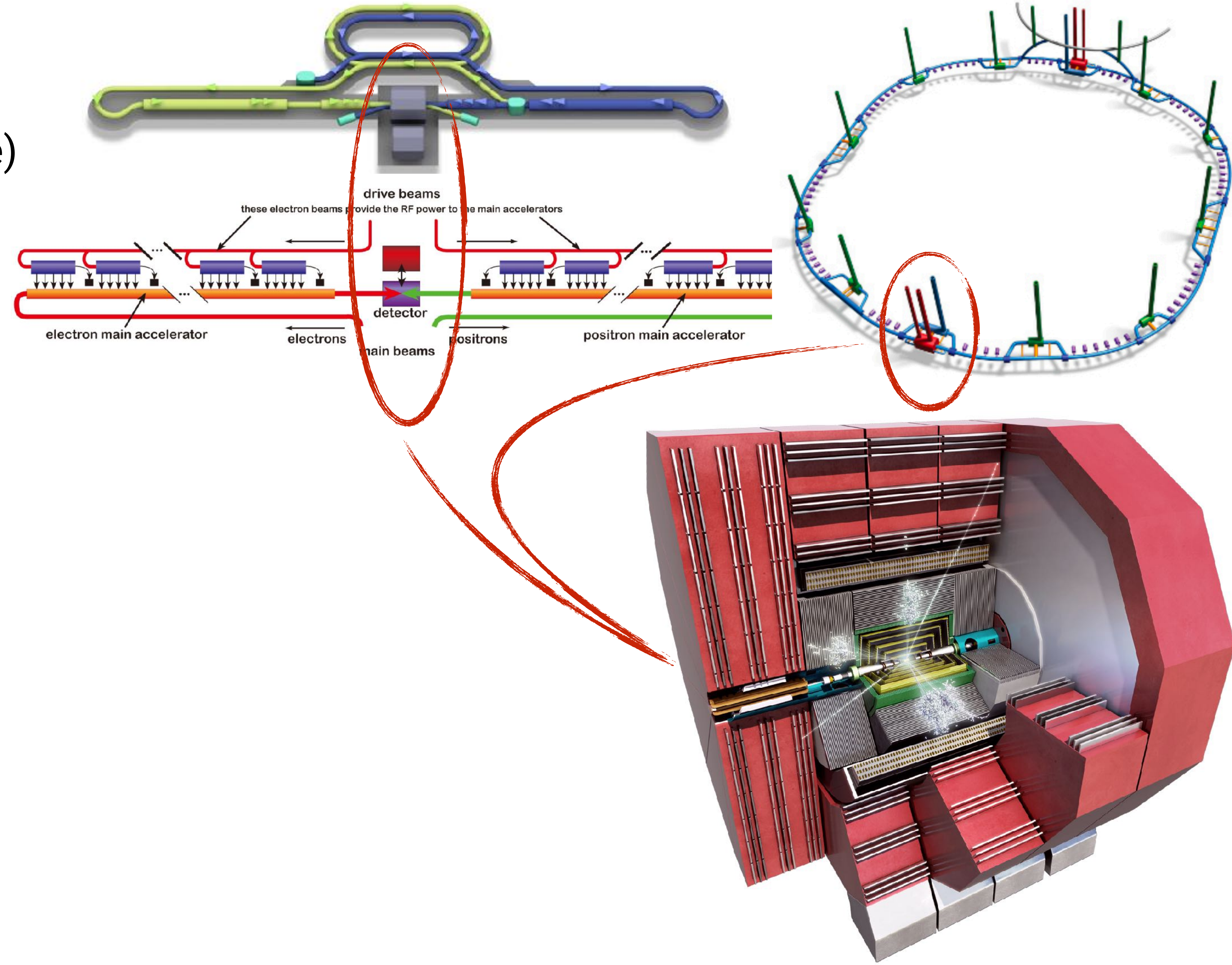

Frank Simon (fsimon@mpp.mpg.de)

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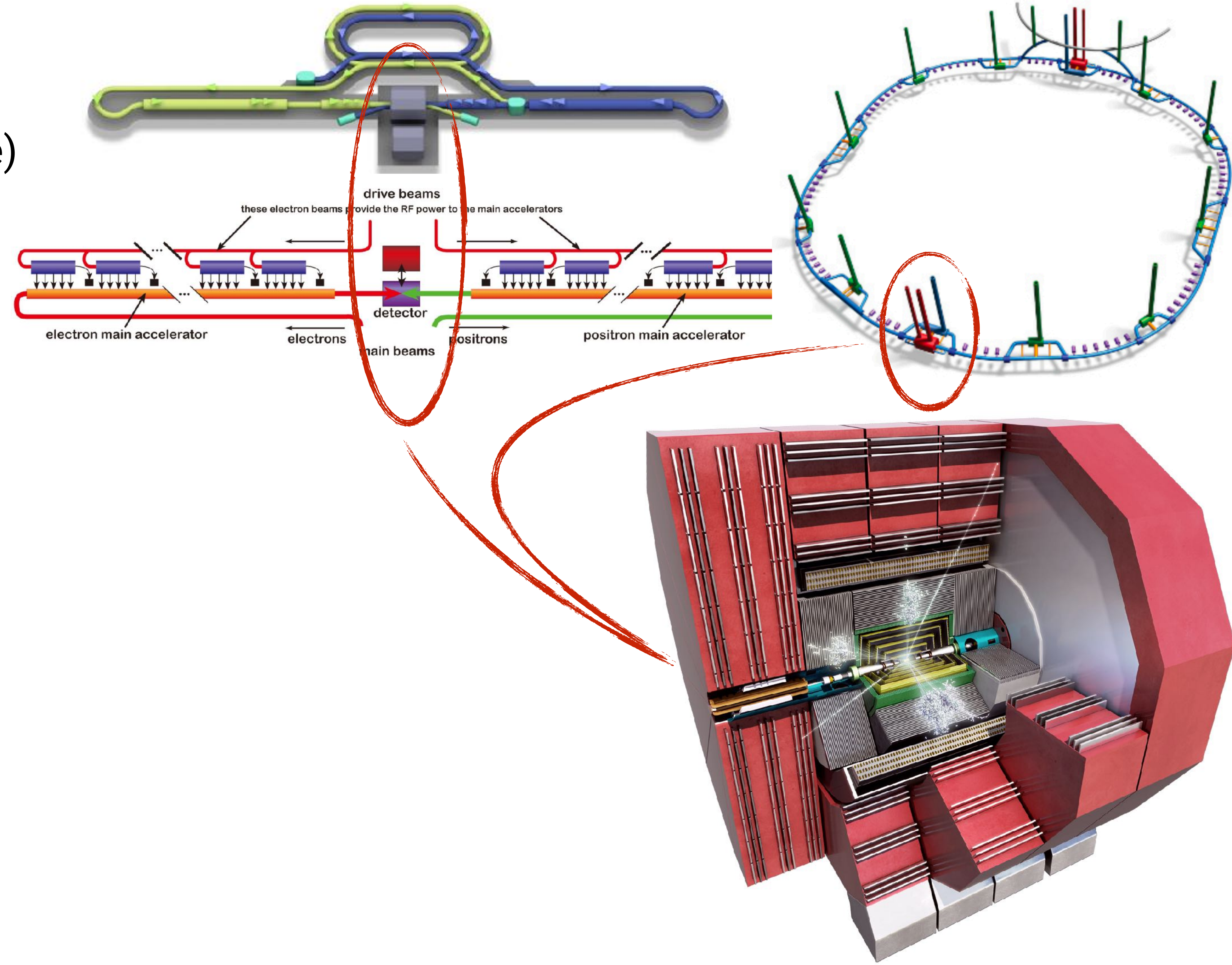

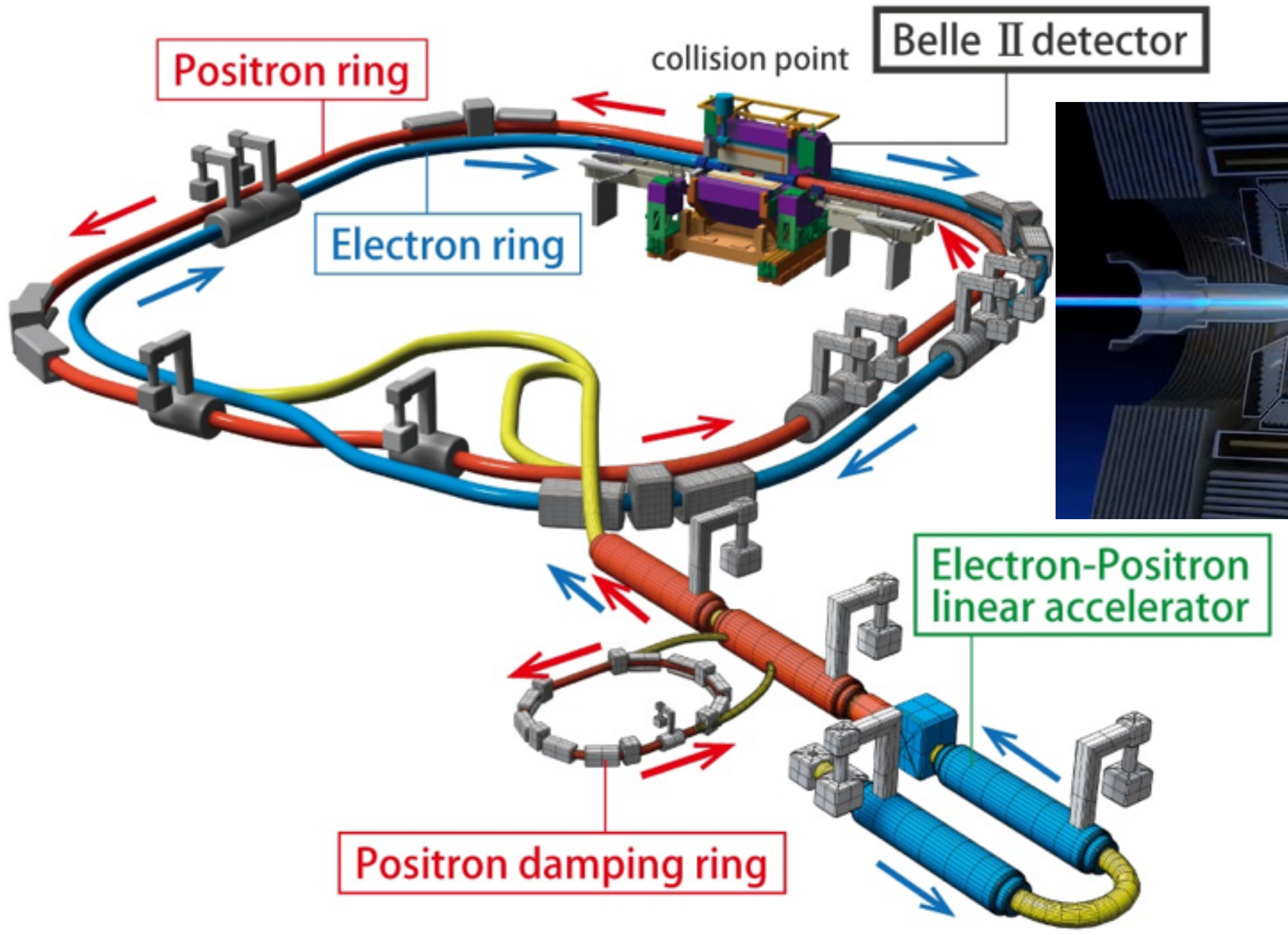

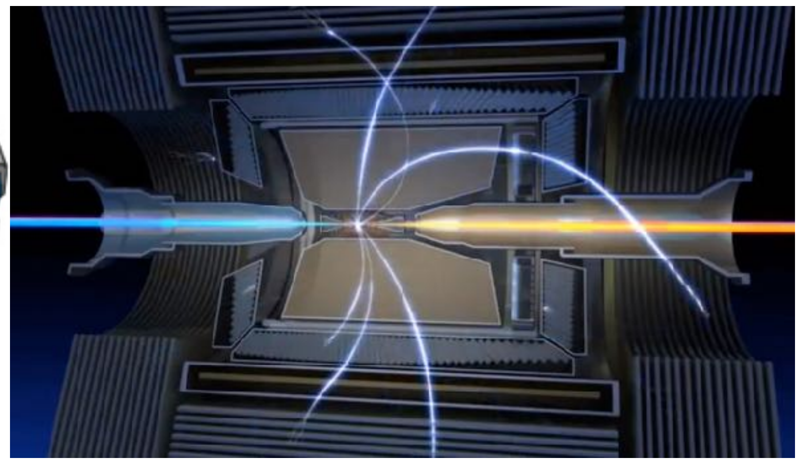

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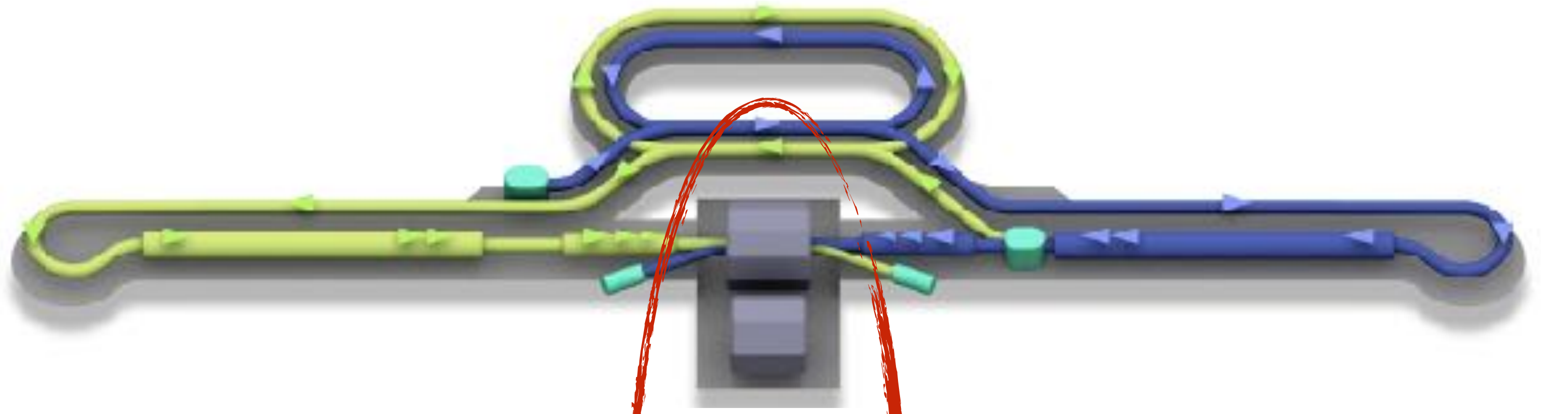
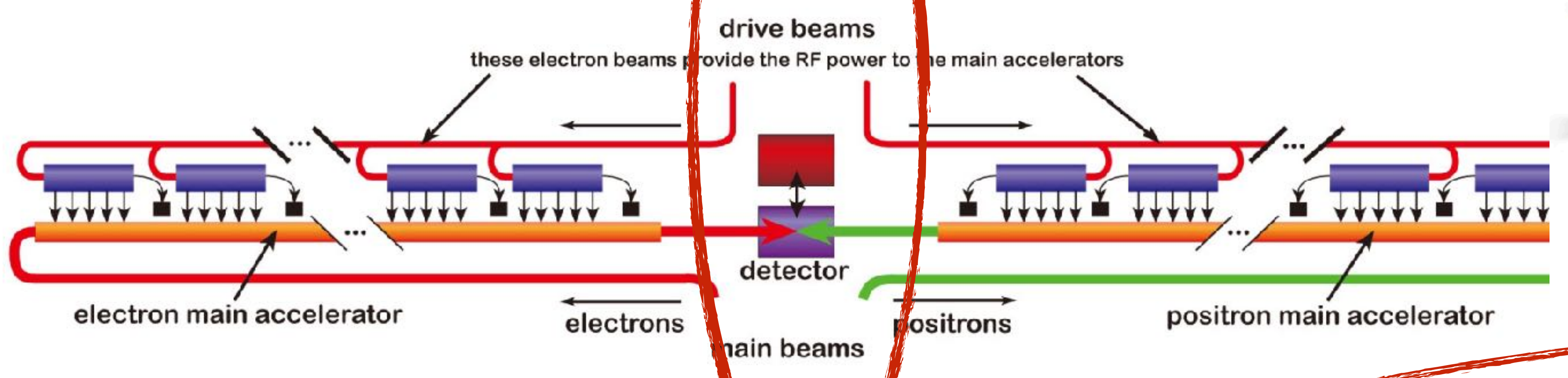
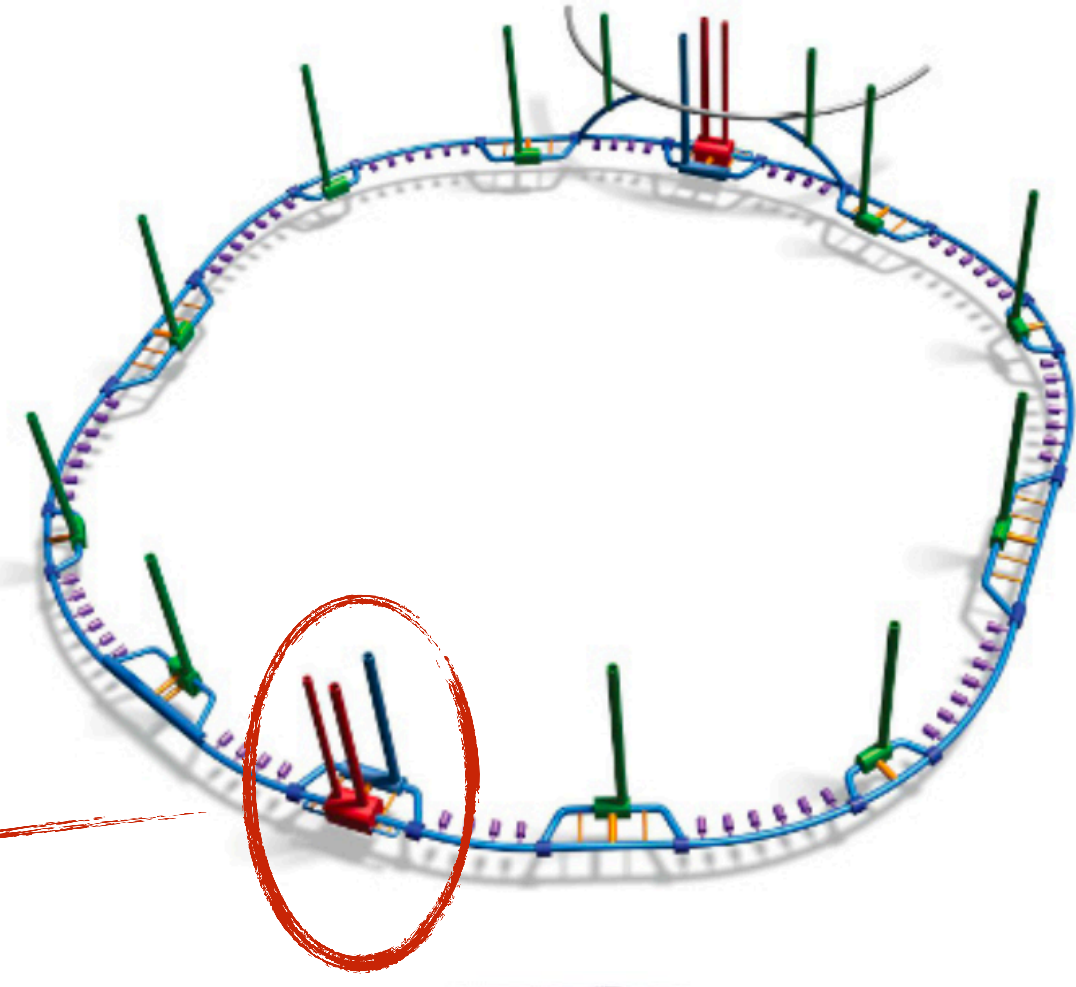
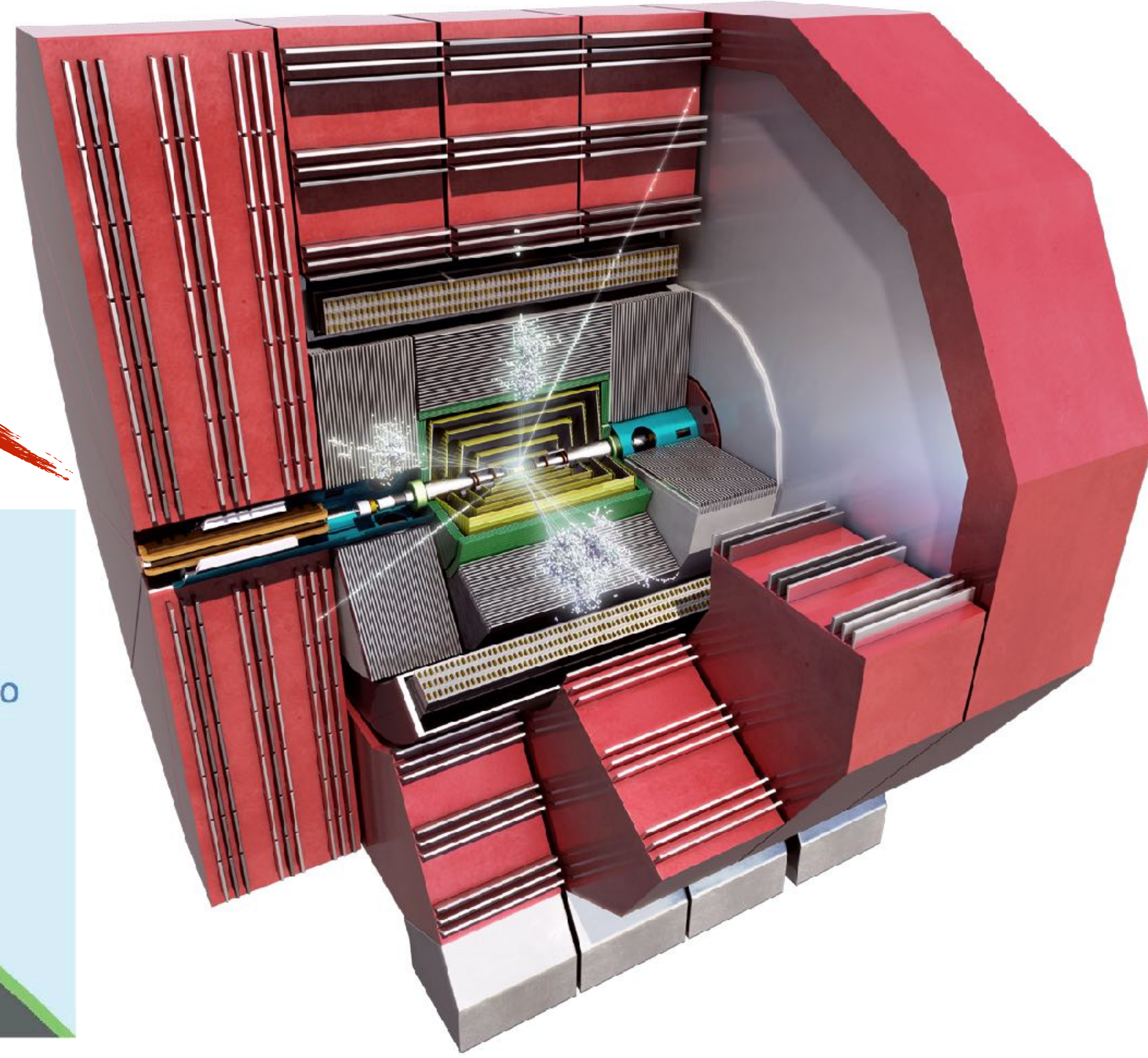
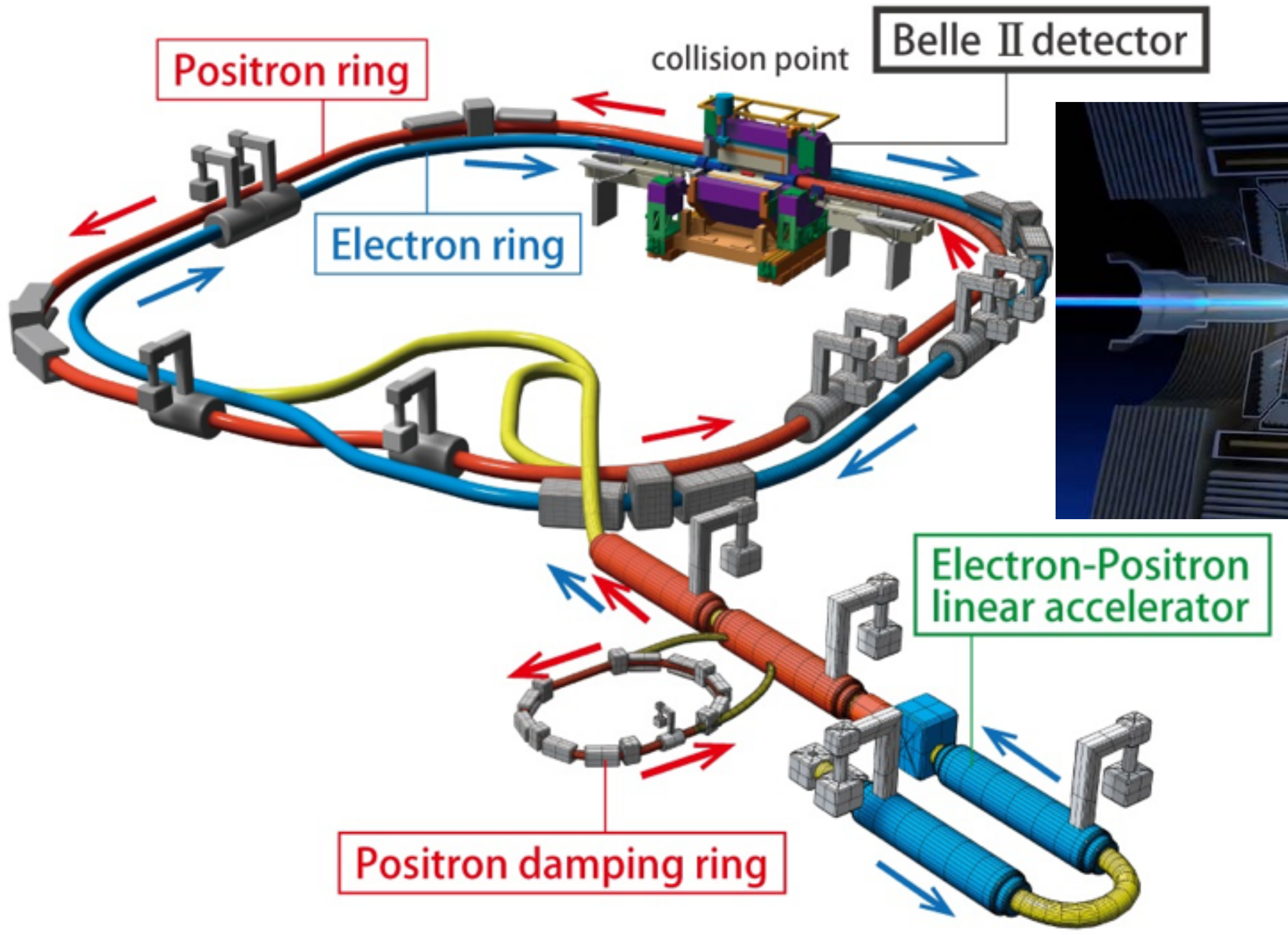
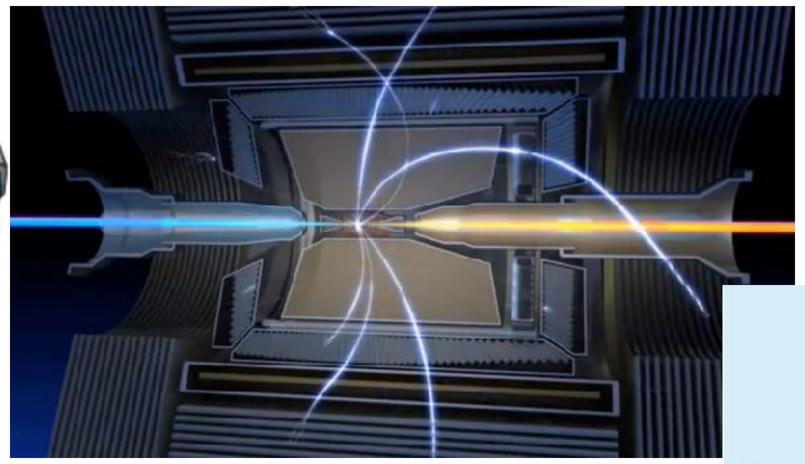




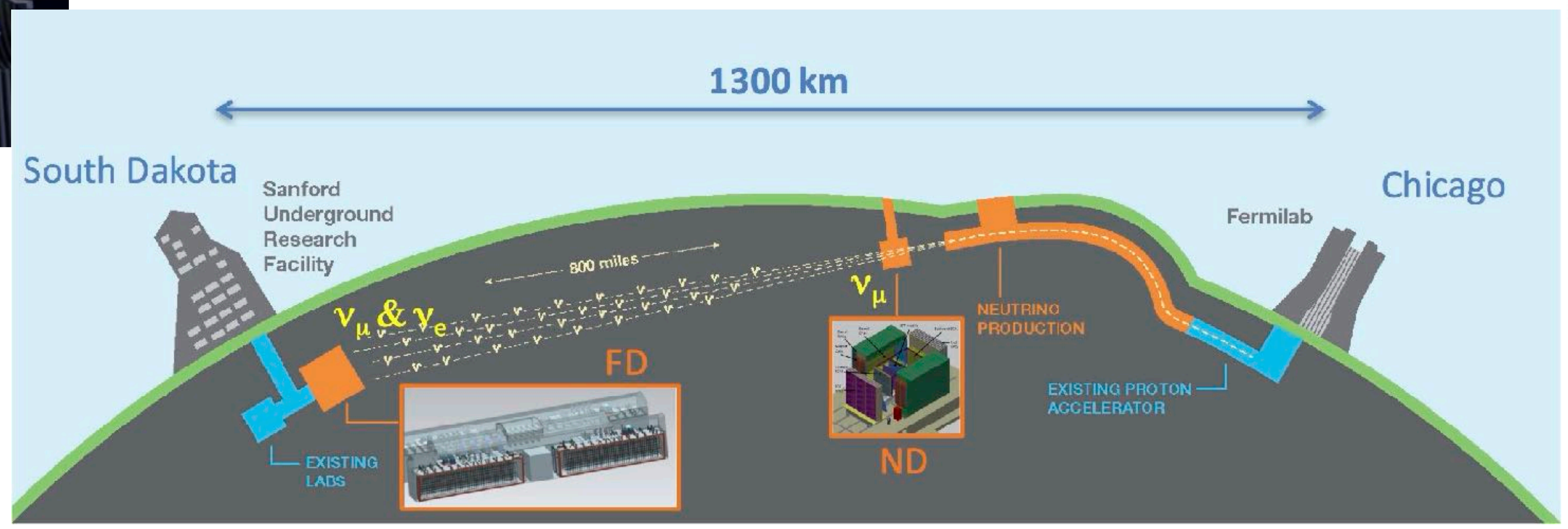








- The long baseline neutrino experiment **DUNE**



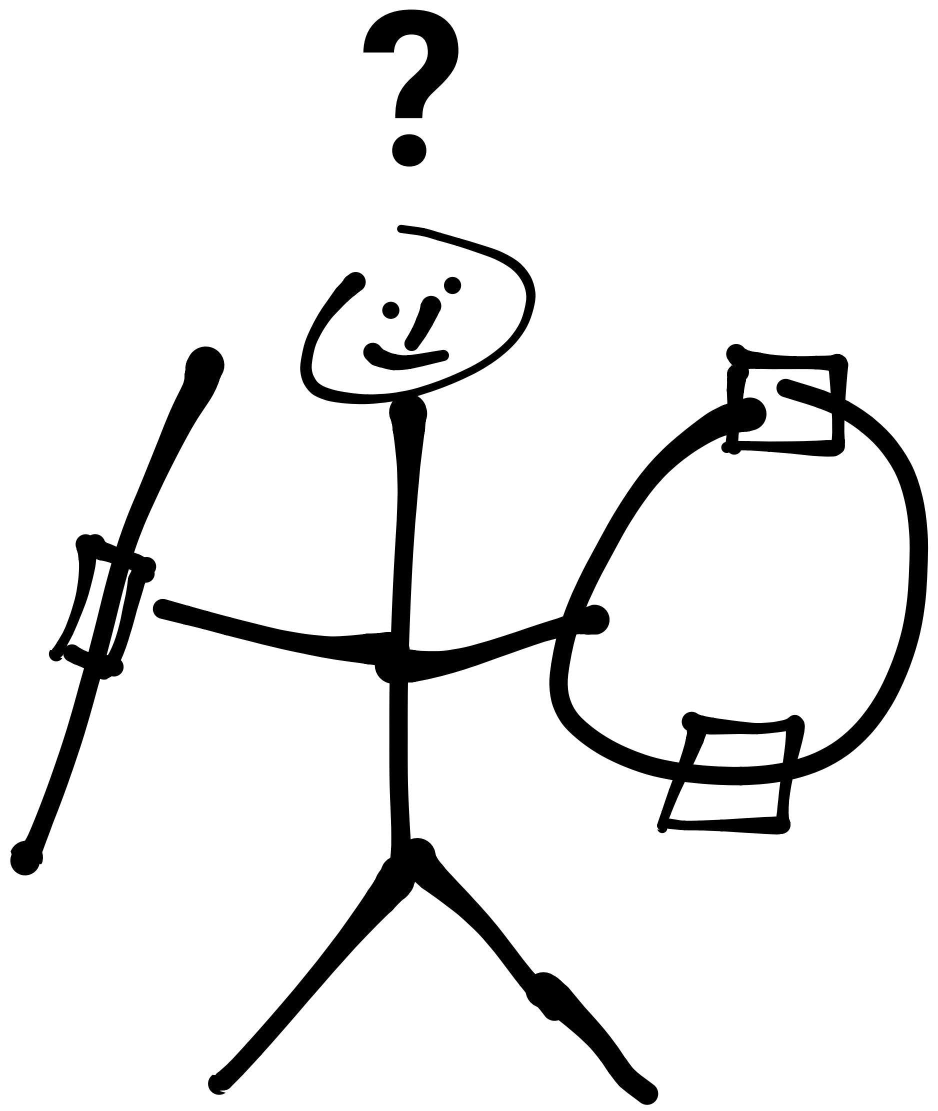
Strategies and Plans

European Input …

- Update of the European Strategy for Particle Physics, released June 2020

Key statements on future colliders:

An electron-positron Higgs factory is the highest-priority next collider.



FS, 2016

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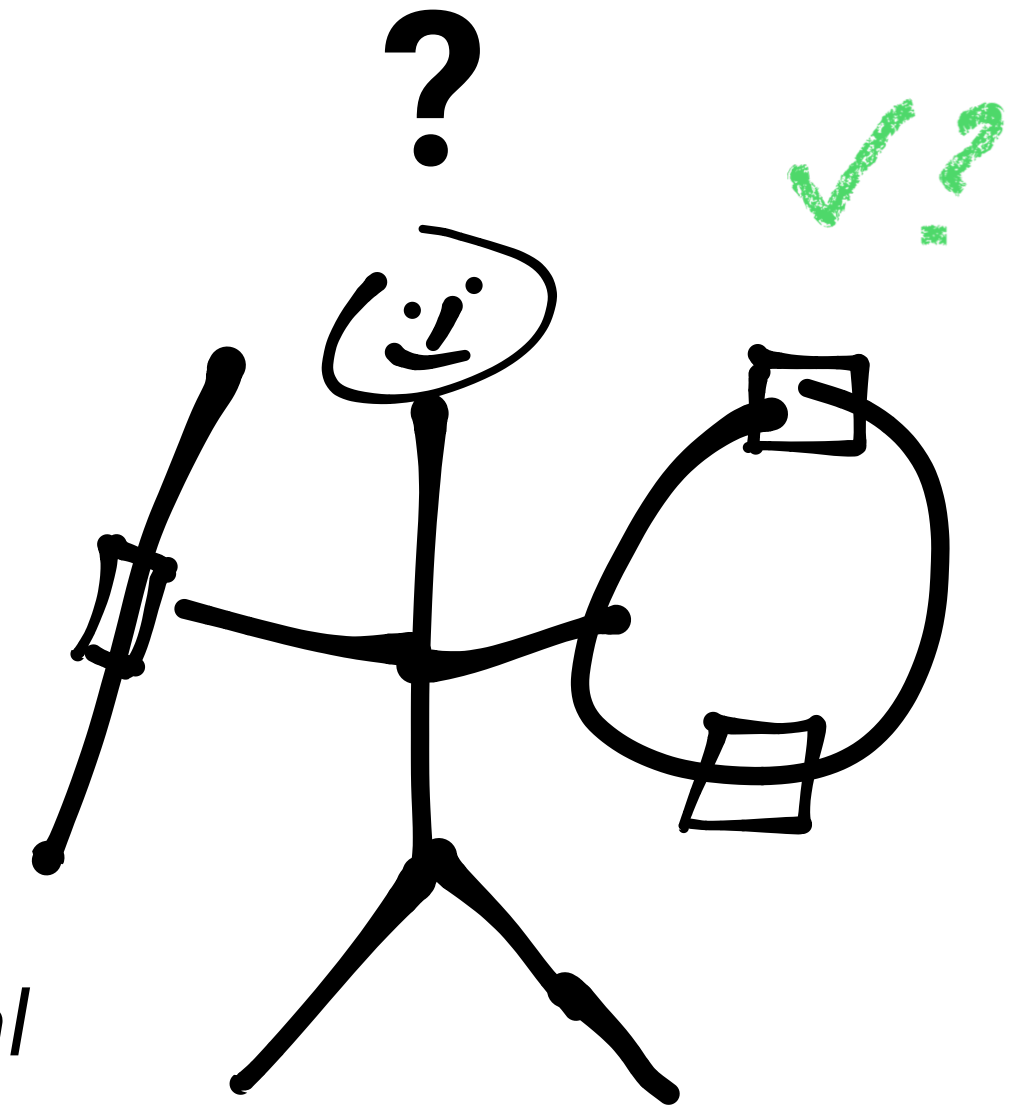

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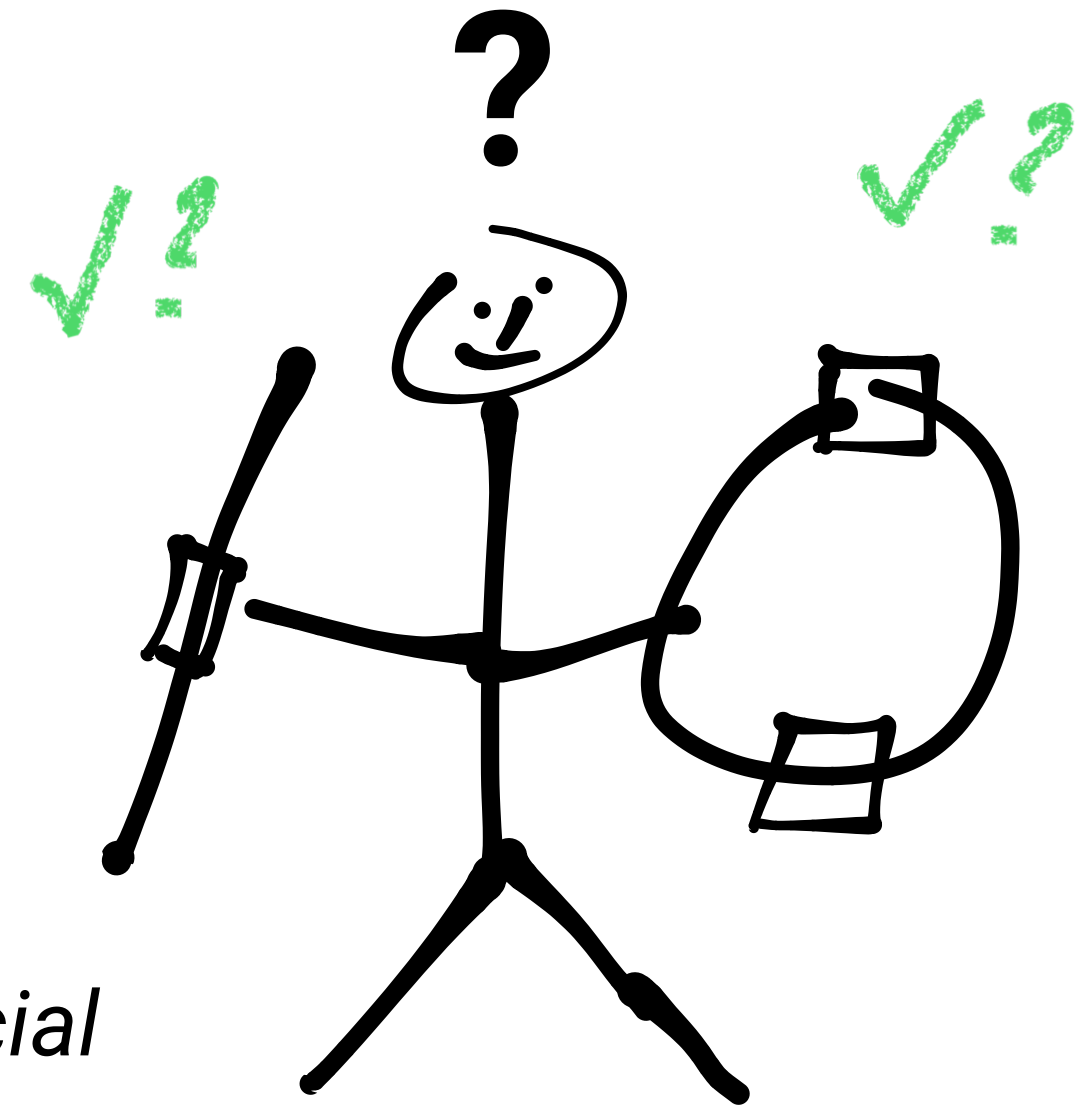

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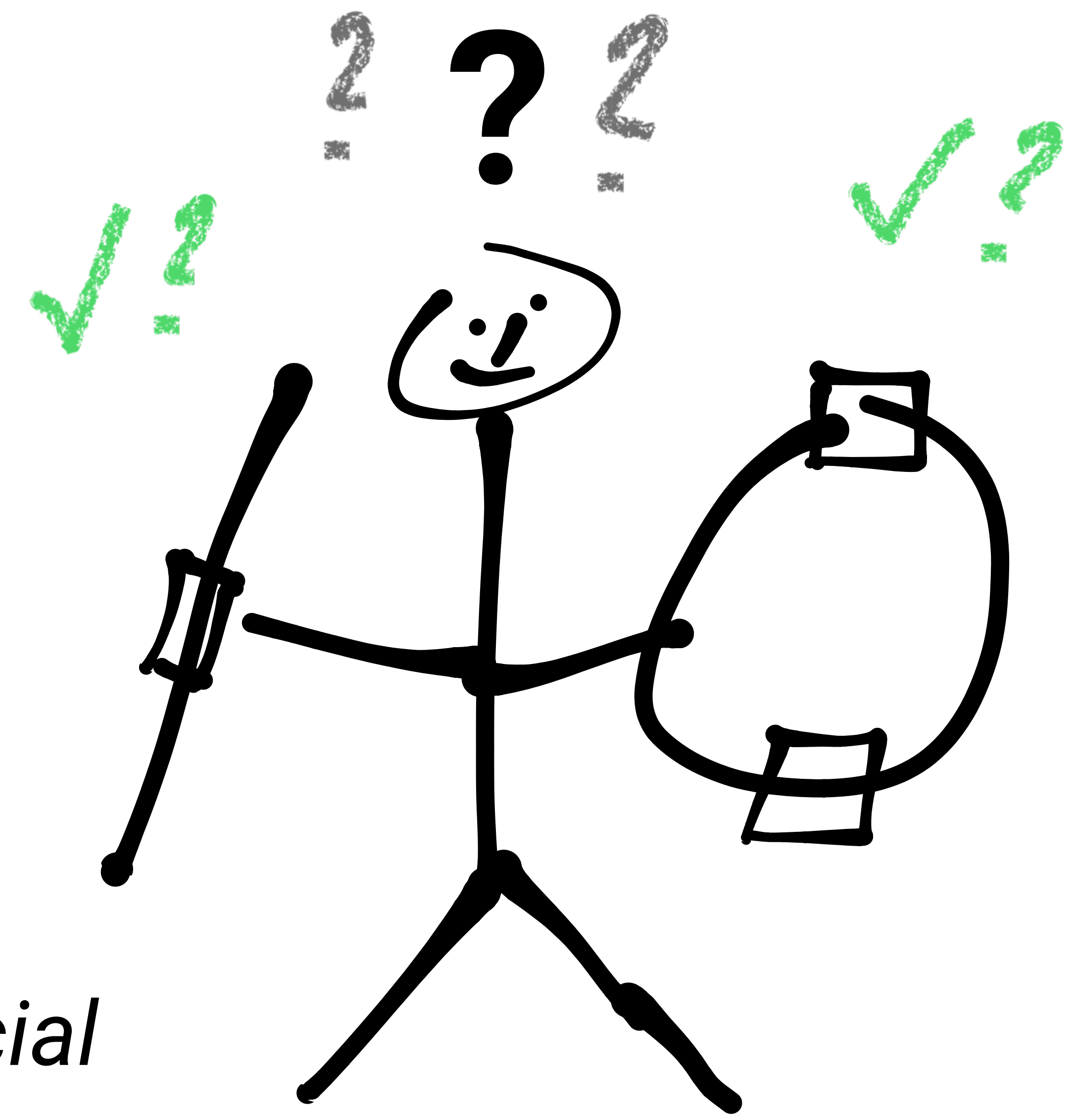

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Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders […]
The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs.

Strategies and Plans

… and Japanese Tealeaves

- The ILC status remains somewhat unclear - but (once again) we are in a phase of movement (forward?):
  - Supportive statement by ICFA in February 2020; positive statements by MEXT Minister - but also stressing need for international contributions; very strong support by US Dept. of State.
  - Noted a “climate change” in terms of project scope: First stage @ 250 GeV, but studies on energy upgrades also beyond 1 TeV now explicitly encouraged; also: Physics Beyond Colliders @ILC being looked at

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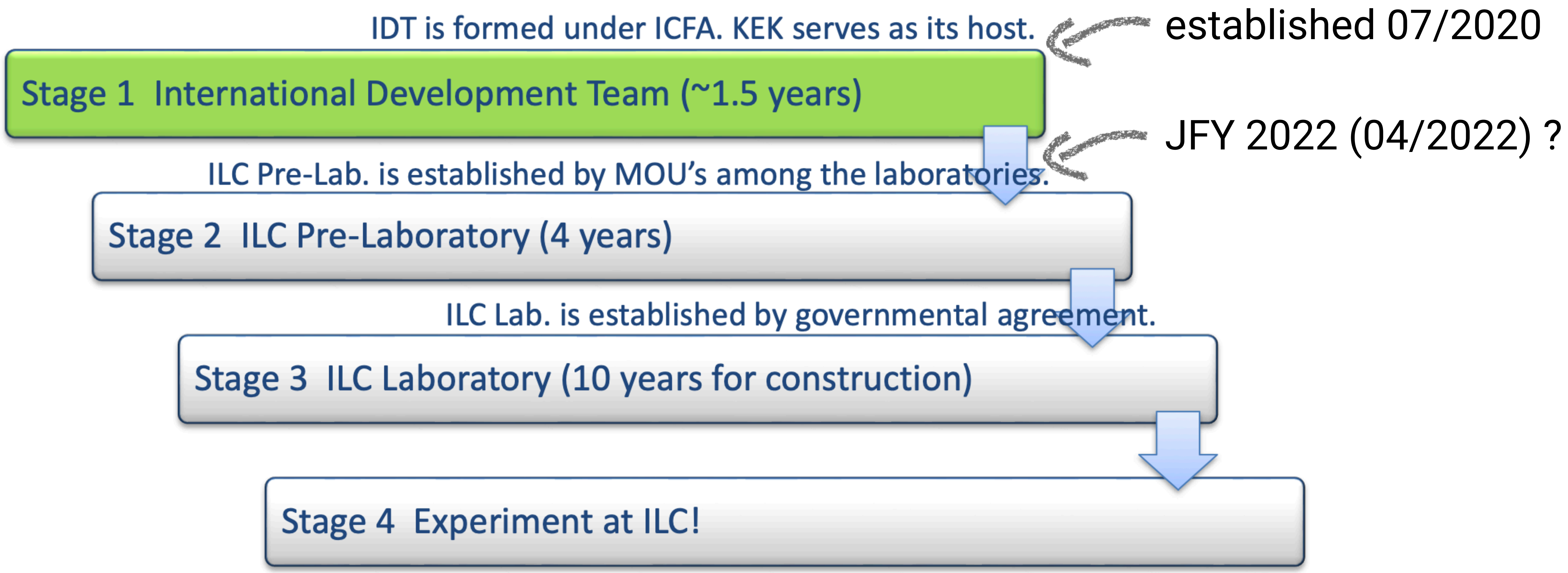
The process towards the realisation of the ILC:



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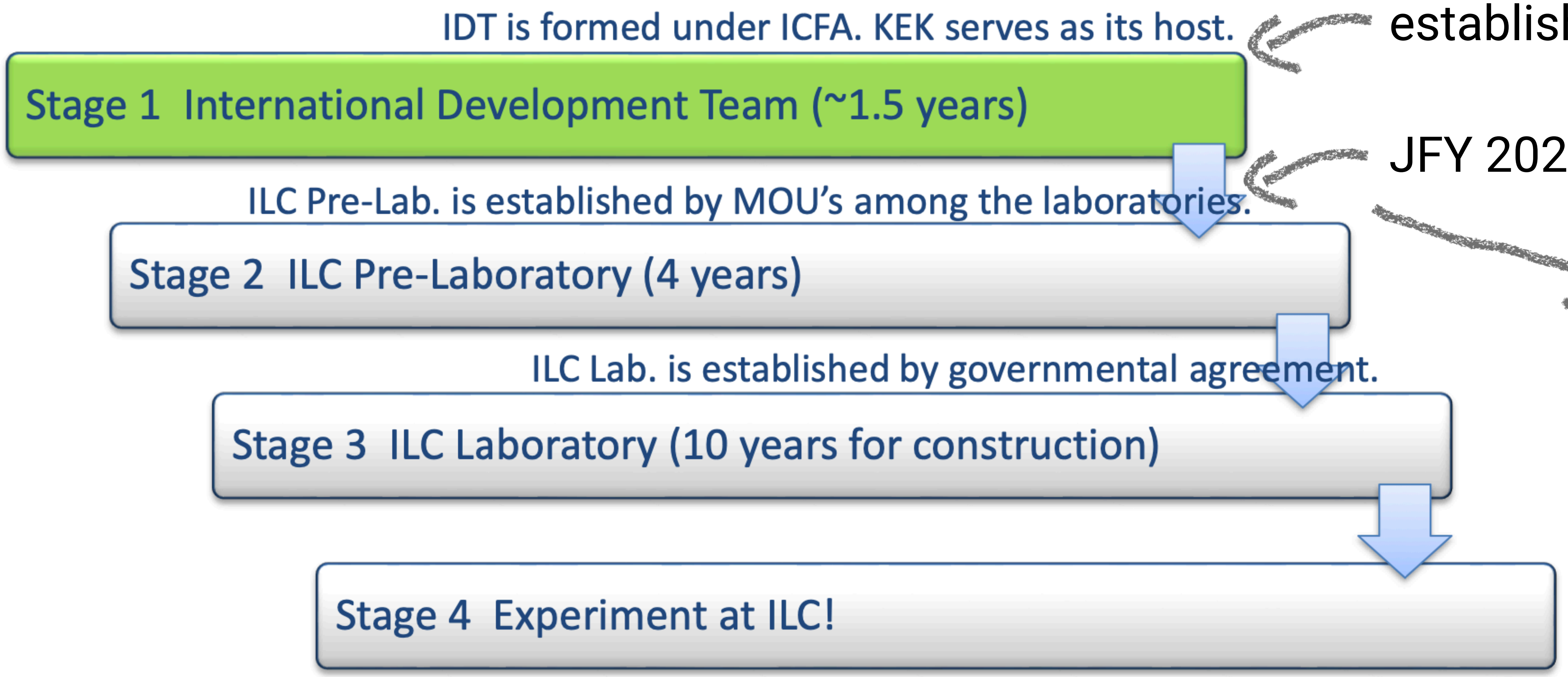


established 07/2020

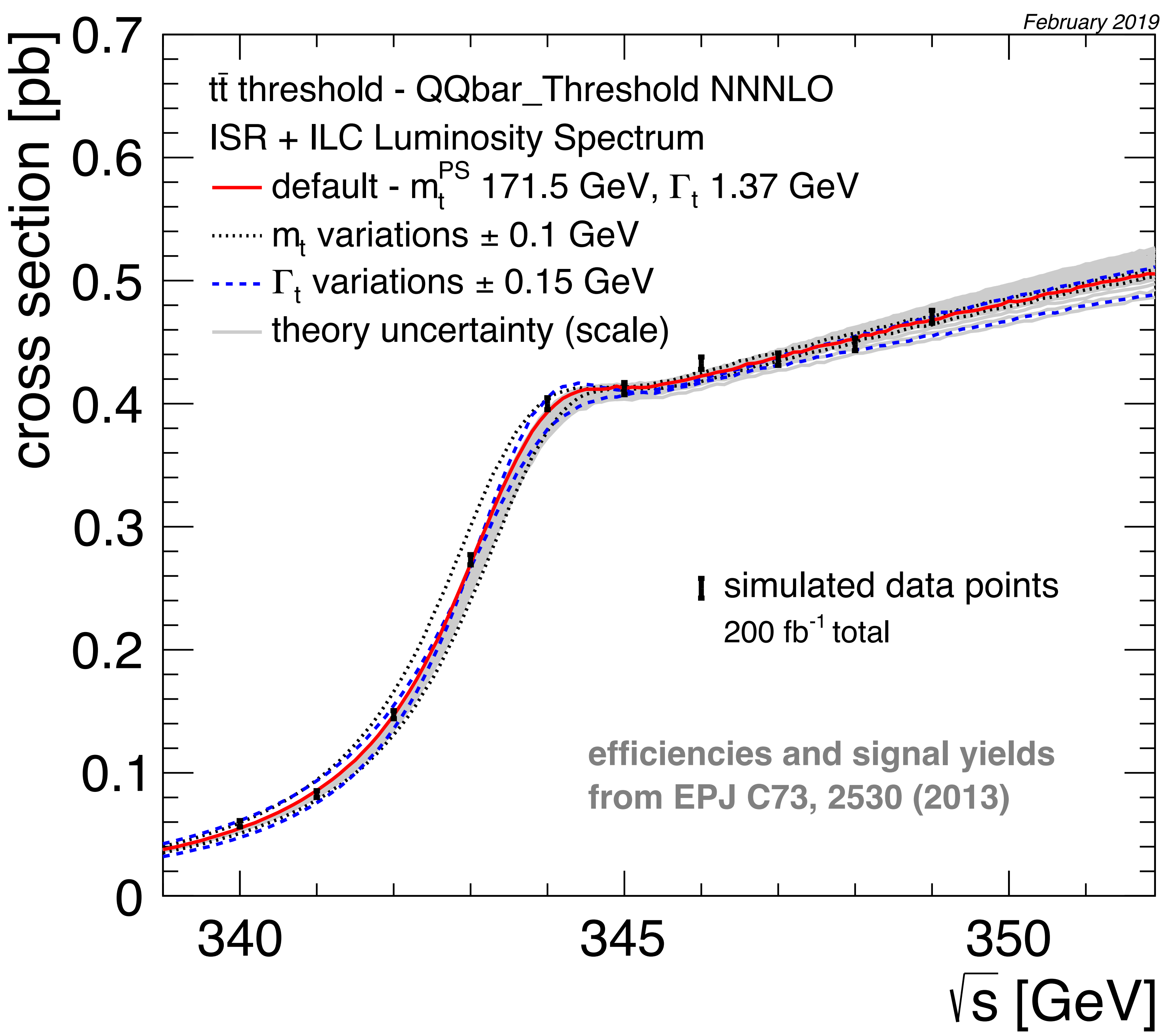
JFY 2022 (04/2022) ?

then: call for Expression of Interest for detectors / subsystems, followed by review process guided by ILCC: EoI -> LoI -> TP -> TDRs

Physics at Energy Frontier e^+e^- Colliders

Precision Measurements

- The current focus in the Future Detectors group: 350 GeV and up - primarily the domain of linear colliders



- Assuming an integrated luminosity of 200 fb^{-1} (default for ILC, FCCee, x2 of CLIC standard scenario - 10 points spaced by 1 GeV)
- Standard fit of mass only:
  ILC 12.2 MeV [stat]
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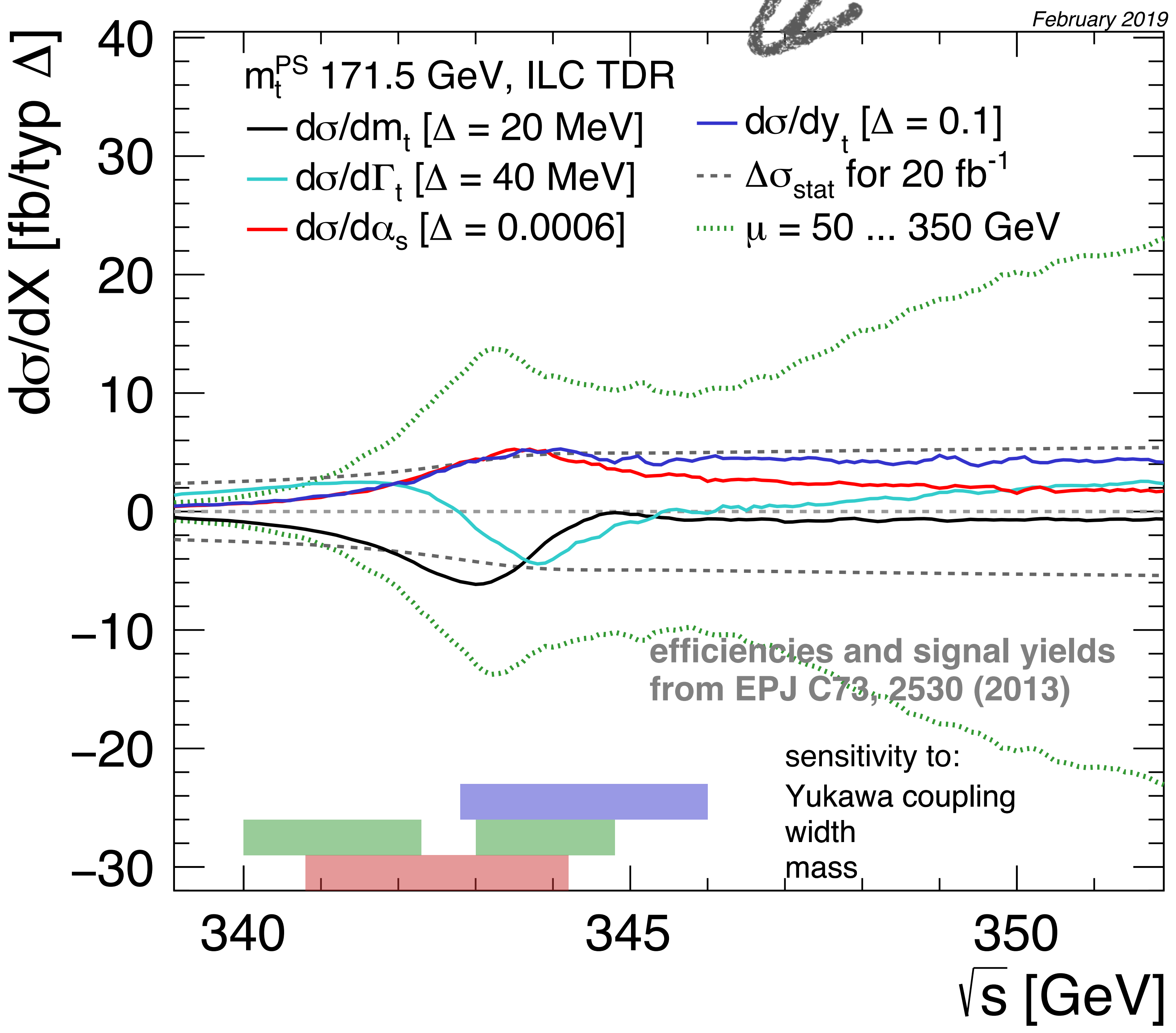
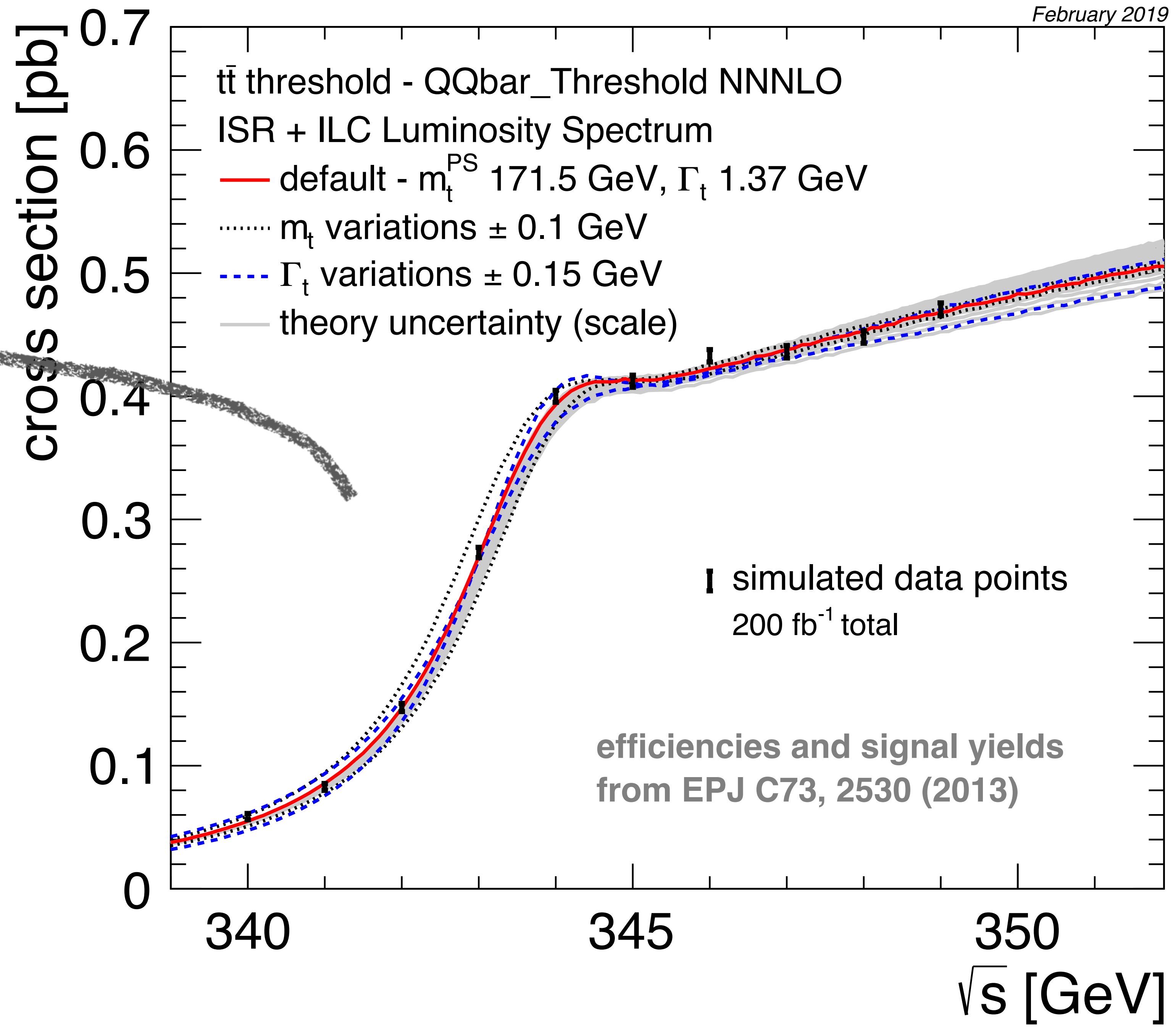
optimizing the scanning strategy





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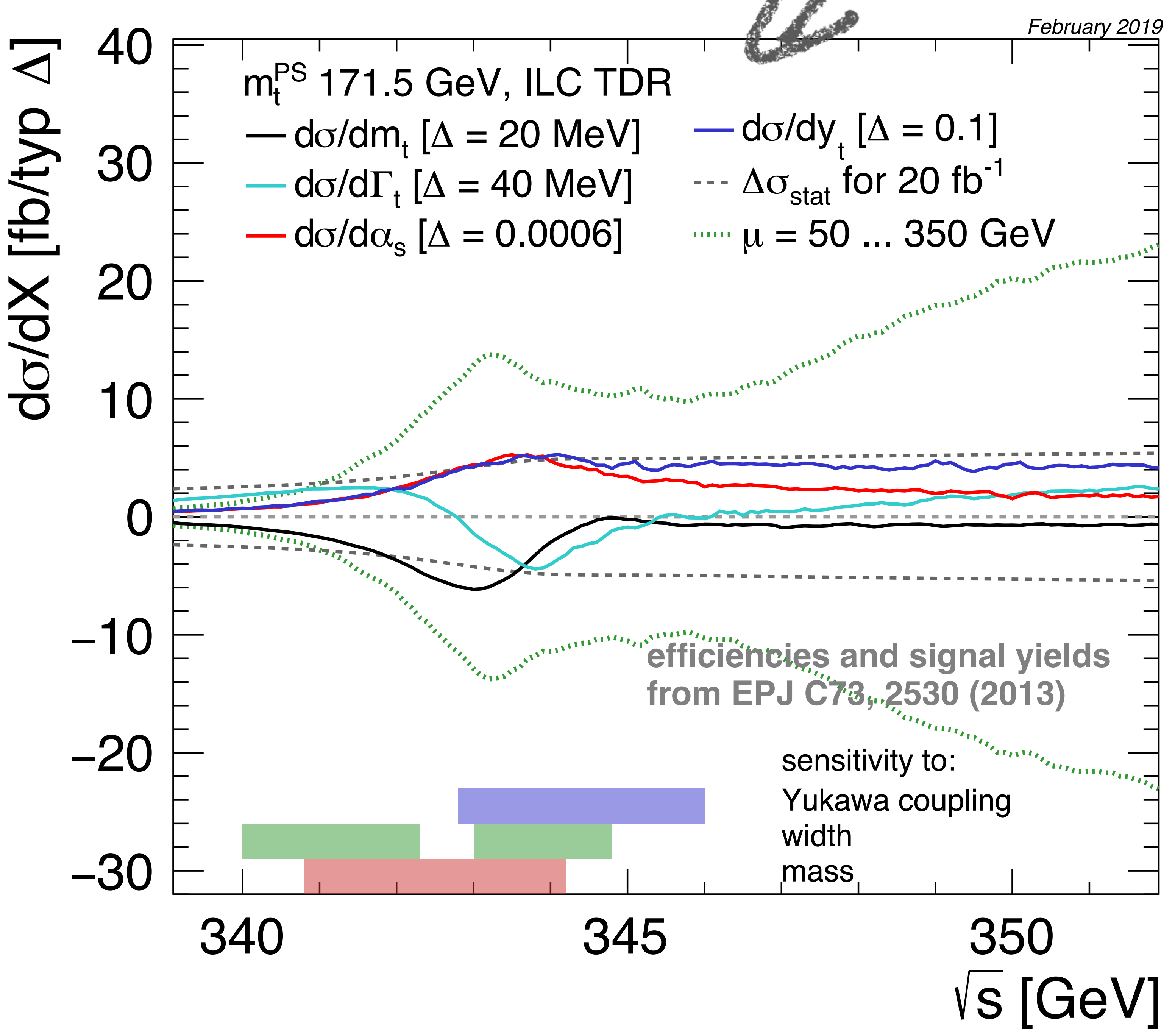

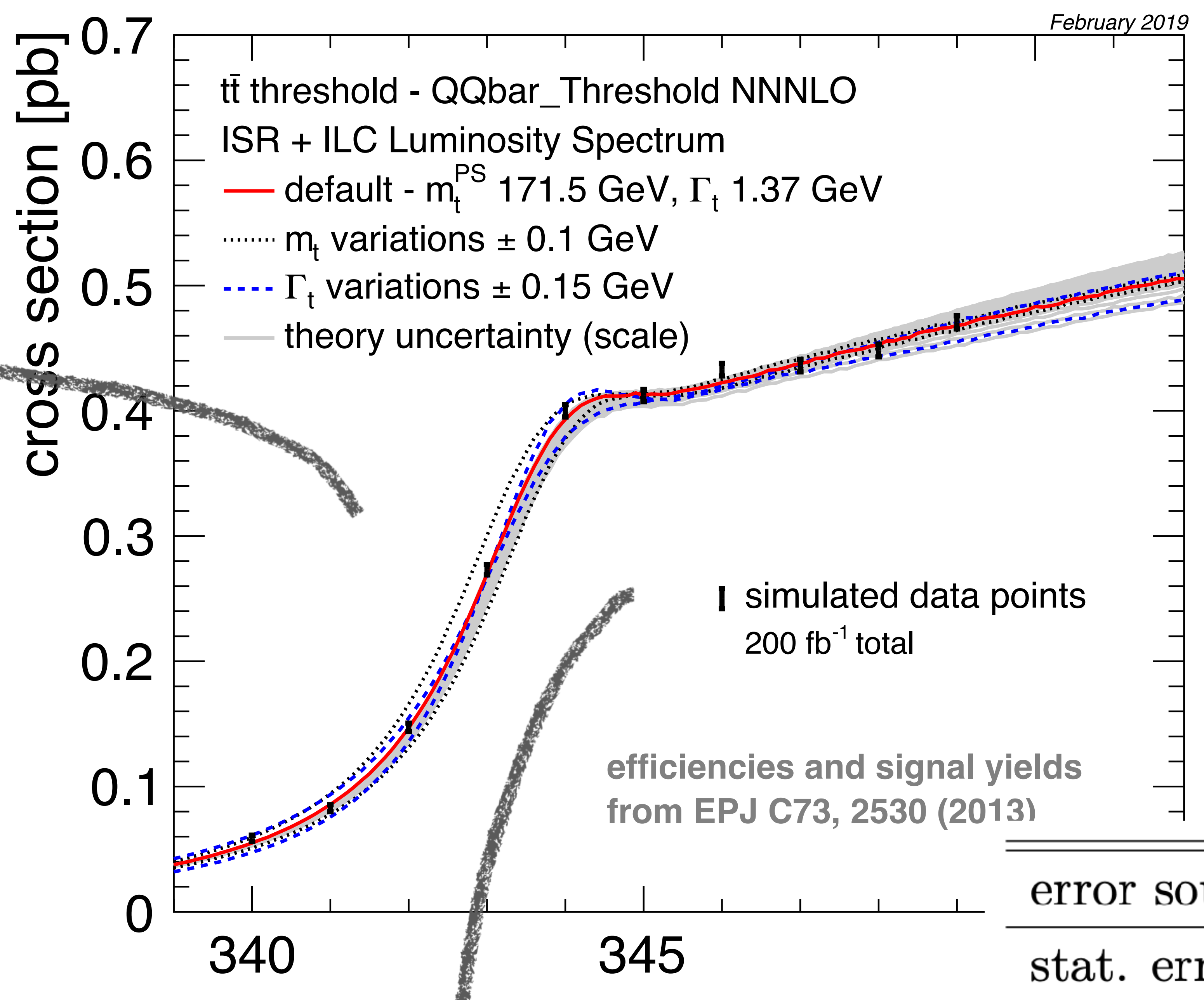

understanding uncertainties

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- Standard fit of mass only:
  ILC 12.2 MeV [stat]
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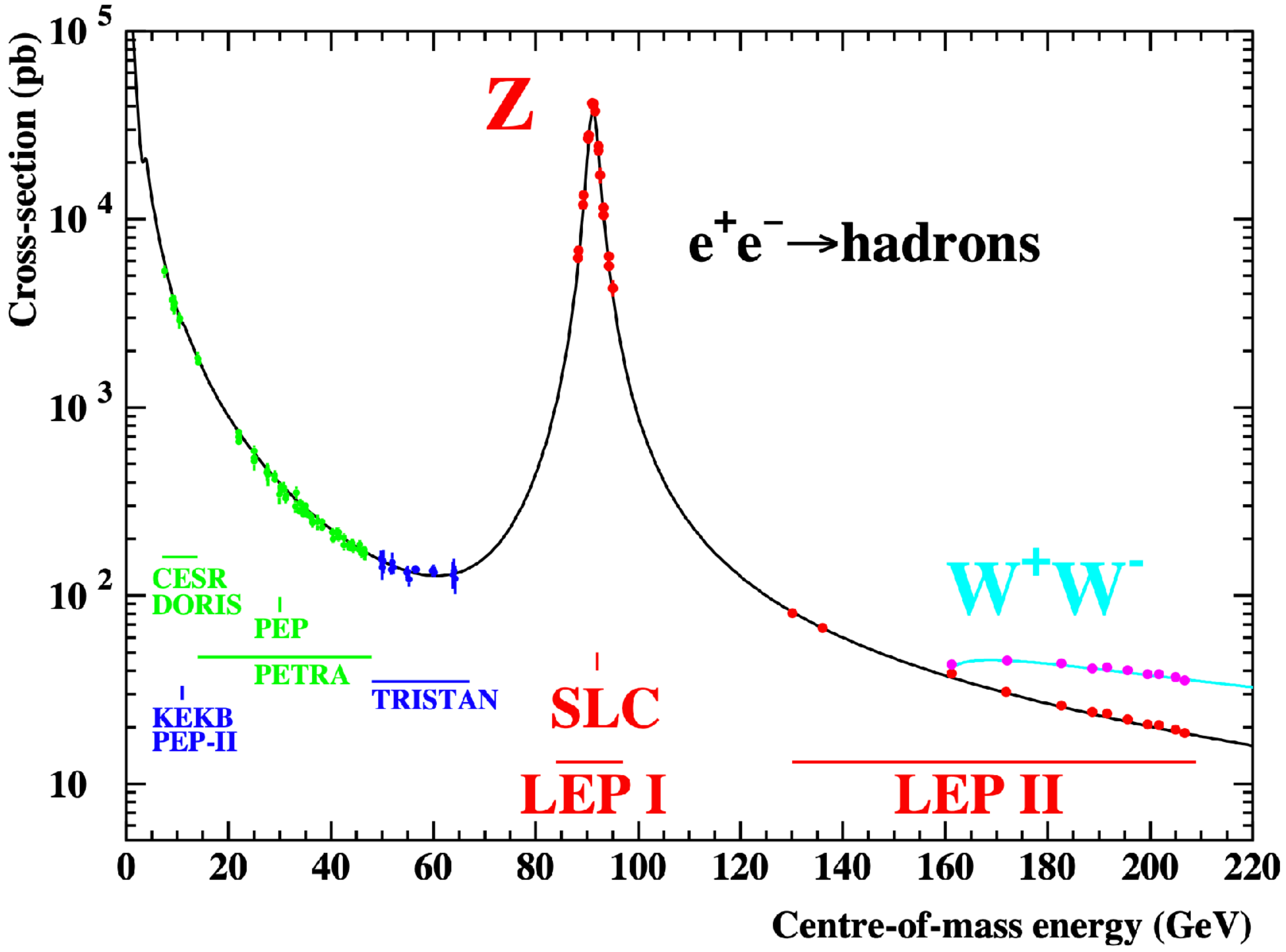
error source	Δm_t^{PS} [MeV]
stat. error (200 fb^{-1})	13
theory (NNLO scale variations, PS scheme)	40
parametric (α_s, current WA)	35
non-resonant contributions (such as single top)	< 40
residual background / selection efficiency	10 – 20
luminosity spectrum uncertainty	< 10
beam energy uncertainty	< 17
combined theory & parametric	30 – 50
combined experimental & backgrounds	25 - 50
total (stat. + syst.)	40 – 75

- MPP activities outside the Future Detector Group:
  The potential for precision QCD at lower energy stages of FCCee
  [Andrii Verbytskyi, Stefan Kluth, Giulia Zanderighi et al.]



High precision measurement of $\alpha_s(M_Z)$ in hadronic events, with the goal of sub-permille experimental precision

- Exploiting running of coupling by measuring over a wide energy range
- Above Upsilon resonances, below VV production (WW, ZZ); limit radiative return (excludes region above Z to ~ 140 GeV): Focus on 20 GeV - 91 GeV

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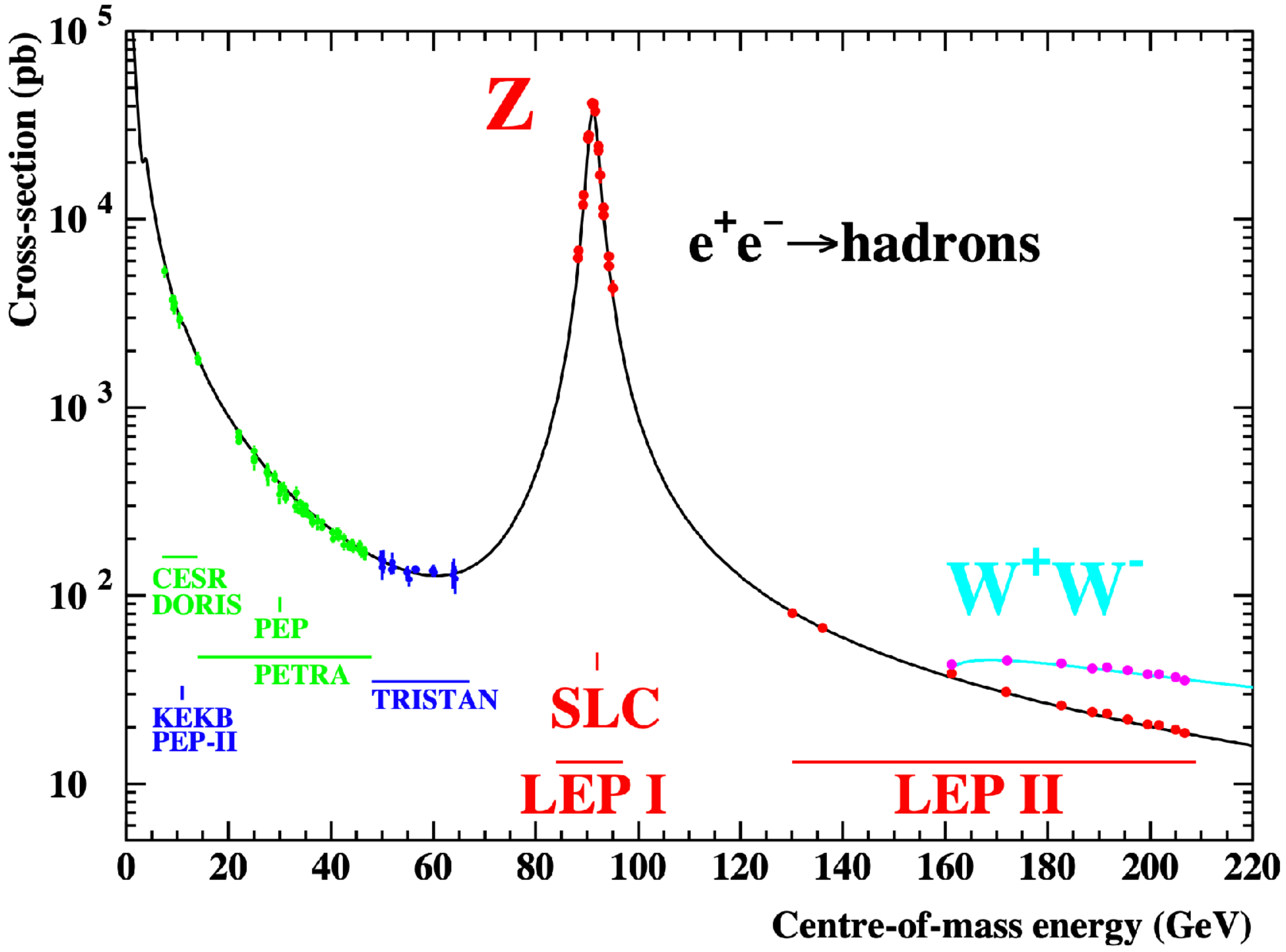

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FCCee luminosity:

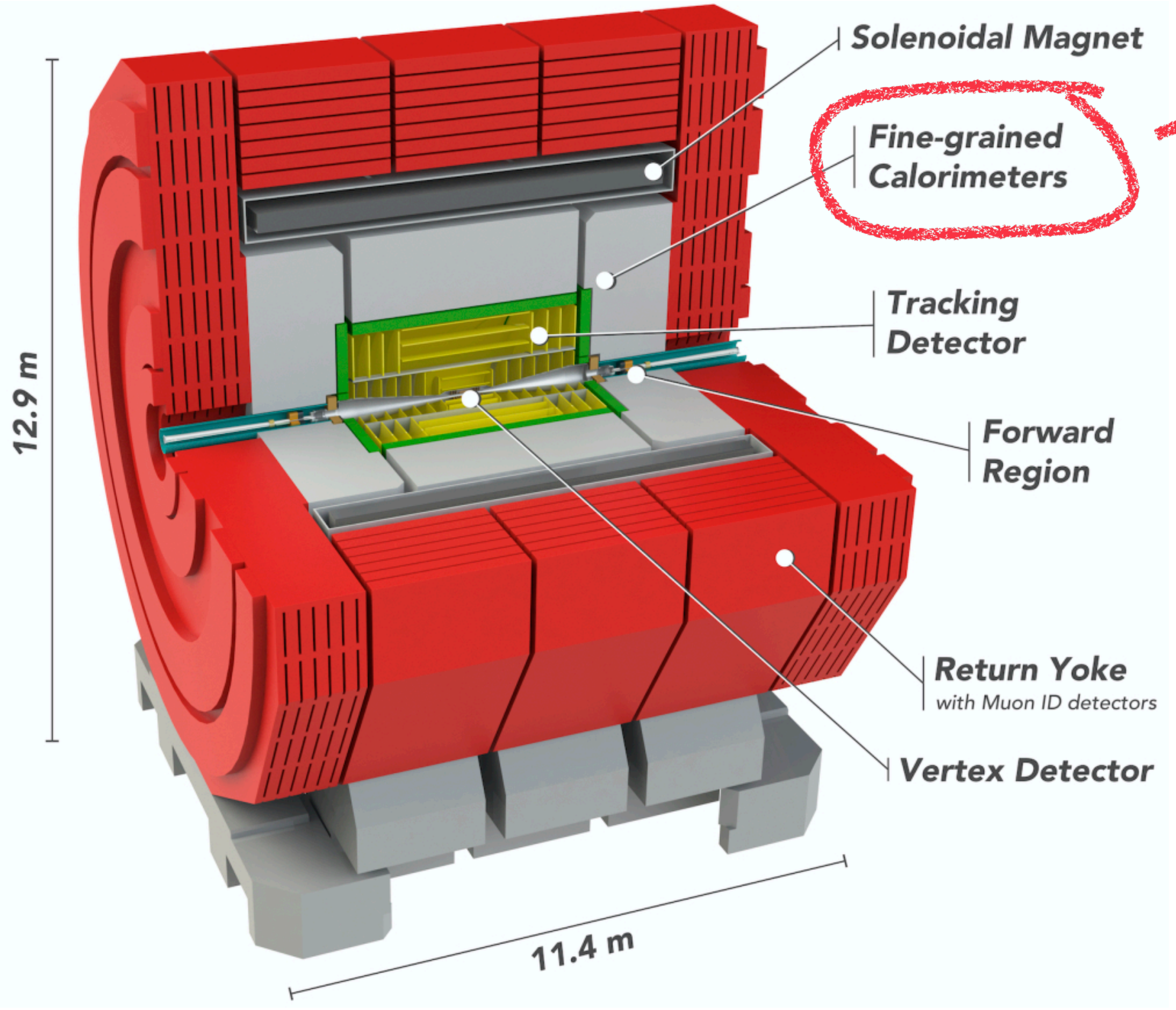
2.3 x 10^{36} cm^2/s per IP at the Z:

2.3 pb^{-1} / s => 150 - 200 fb^{-1} / day

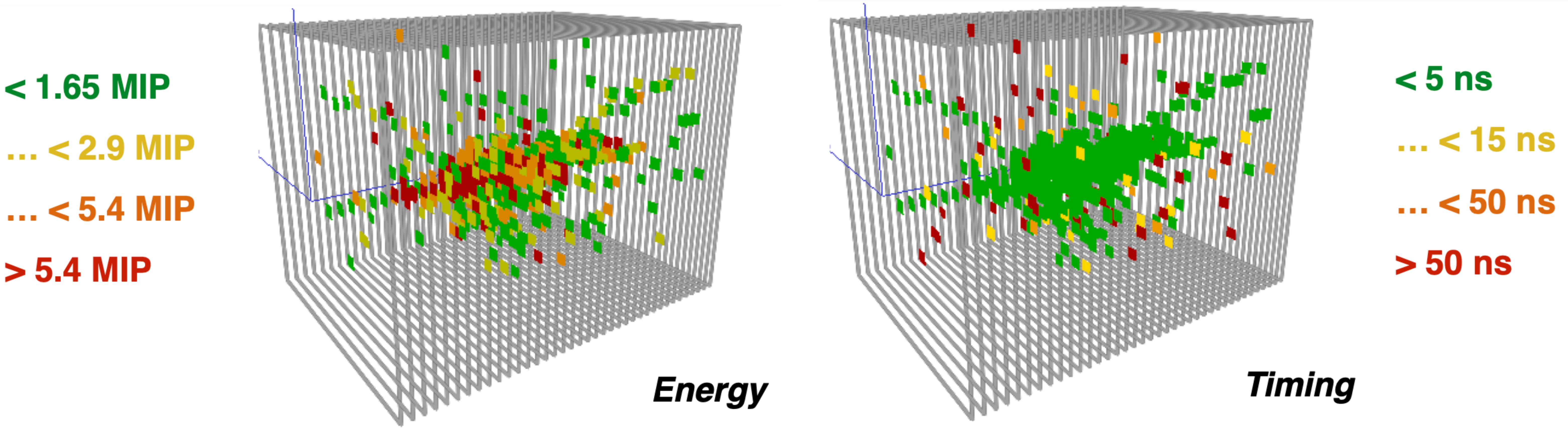
10^7 - 10^8 events / day, depending on energy point

Highly Granular Hadronic Calorimetry

Exploiting the 5th Dimension



- The defining feature of (most) detector concepts for e^+e^-: highly granular calorimeters
- CALICE AHCAL technological prototype and future full systems: 5D reconstruction of hadronic showers: ***space, energy & time***



simulations - Test beam data for hadronic showers not (yet) available with full time resolution. To come 2021/2022

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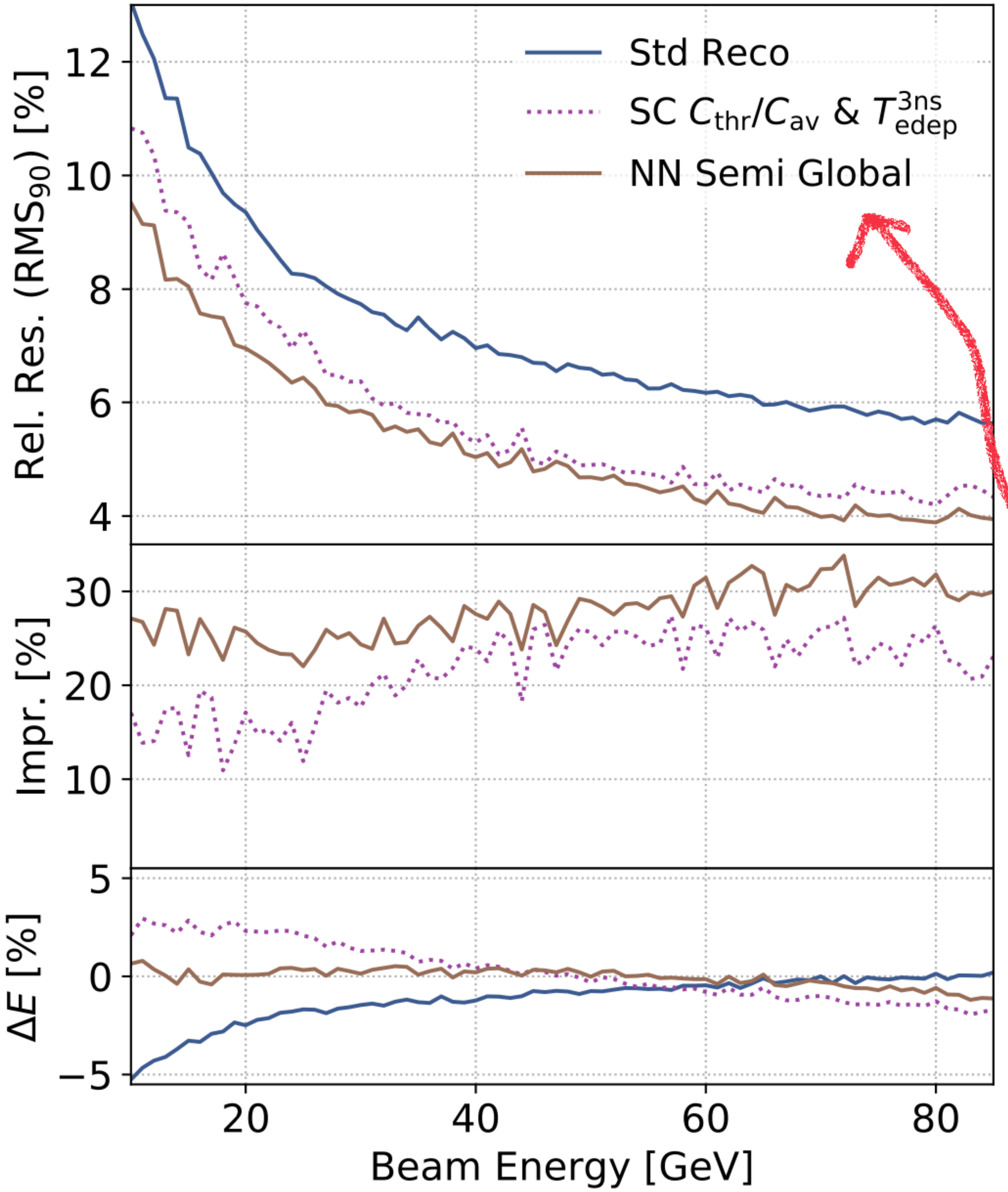

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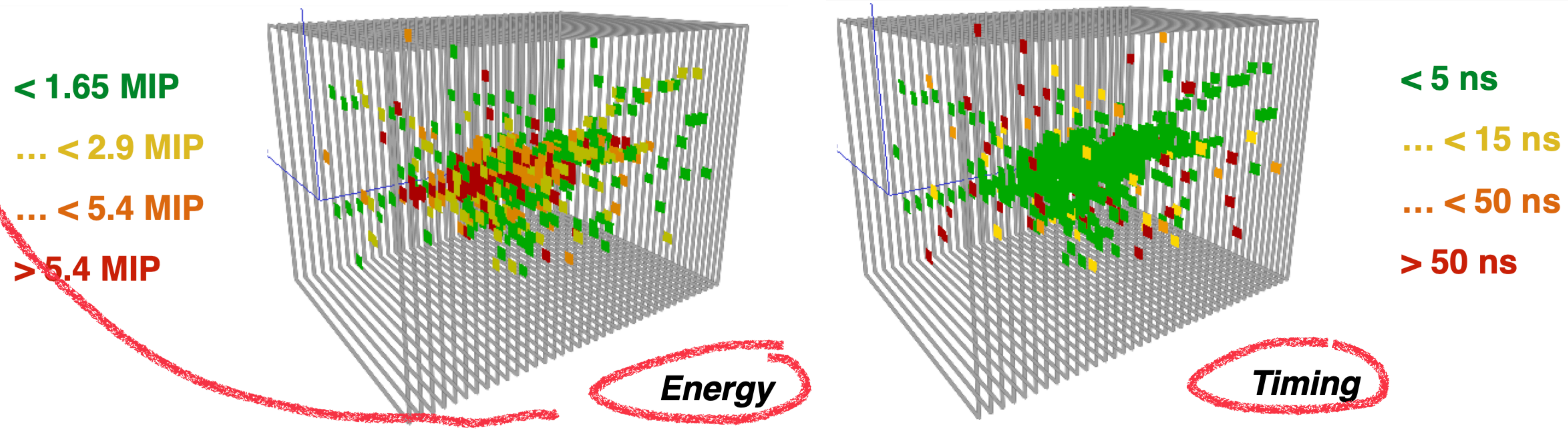

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- Information used in machine learning algorithms to improve the hadronic energy resolution: significant benefit - also successfully transferred to data (using MC-trained networks)

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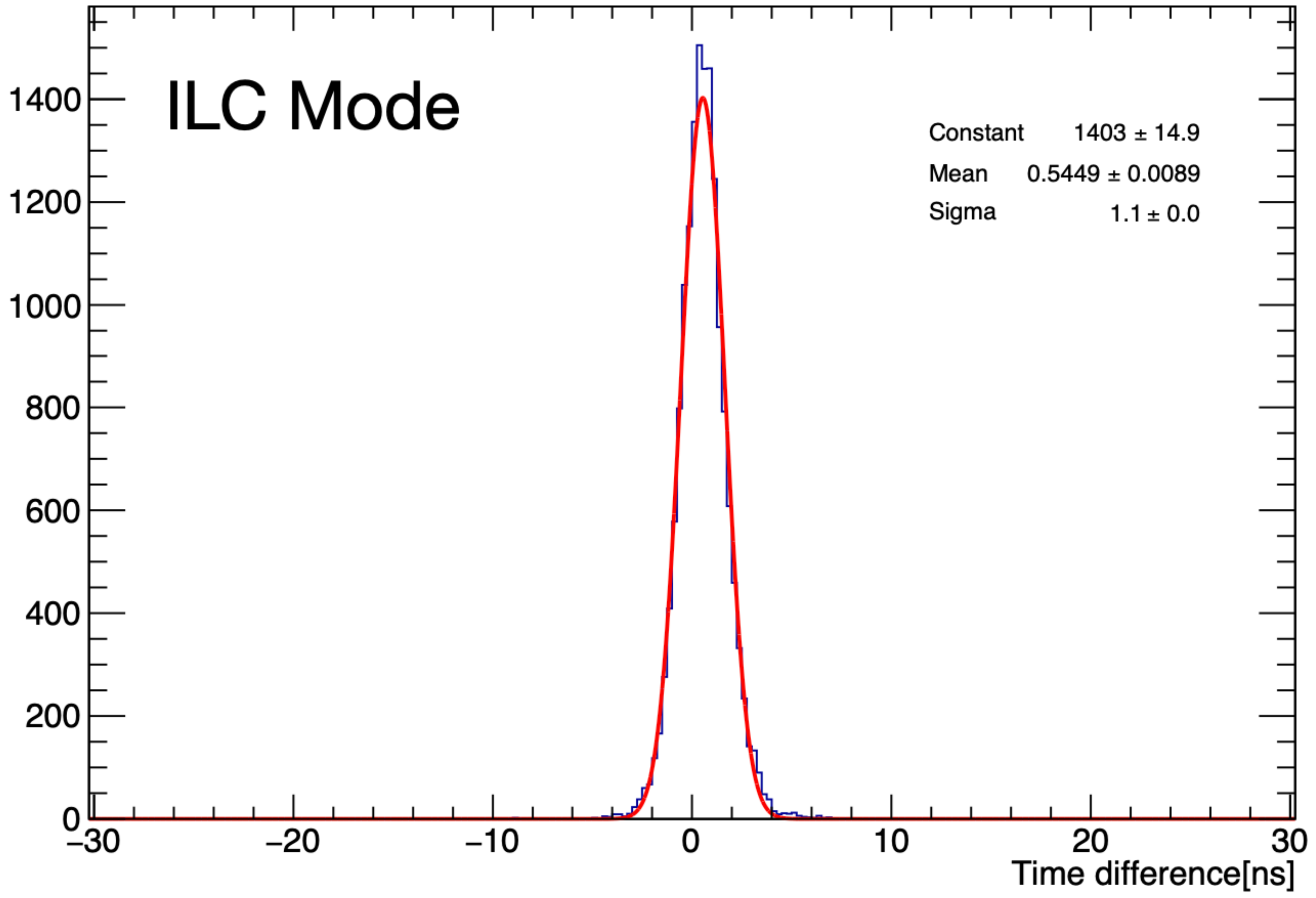
Exploiting the 5th Dimension

- Analysis of electron events with full time resolution to establish single-particle single hit performance of full system:

1.1 ns / √2 = 780 ps



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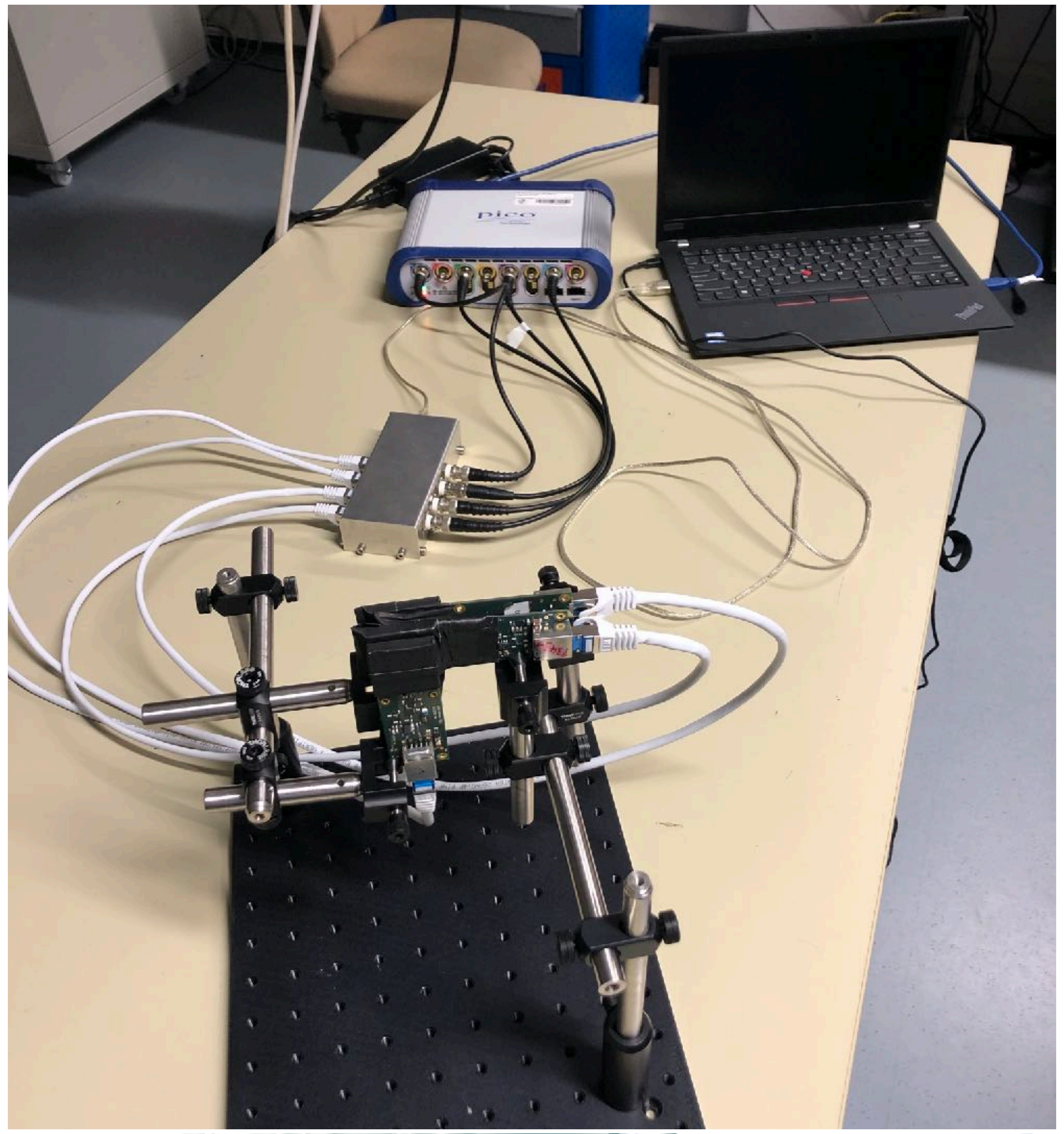
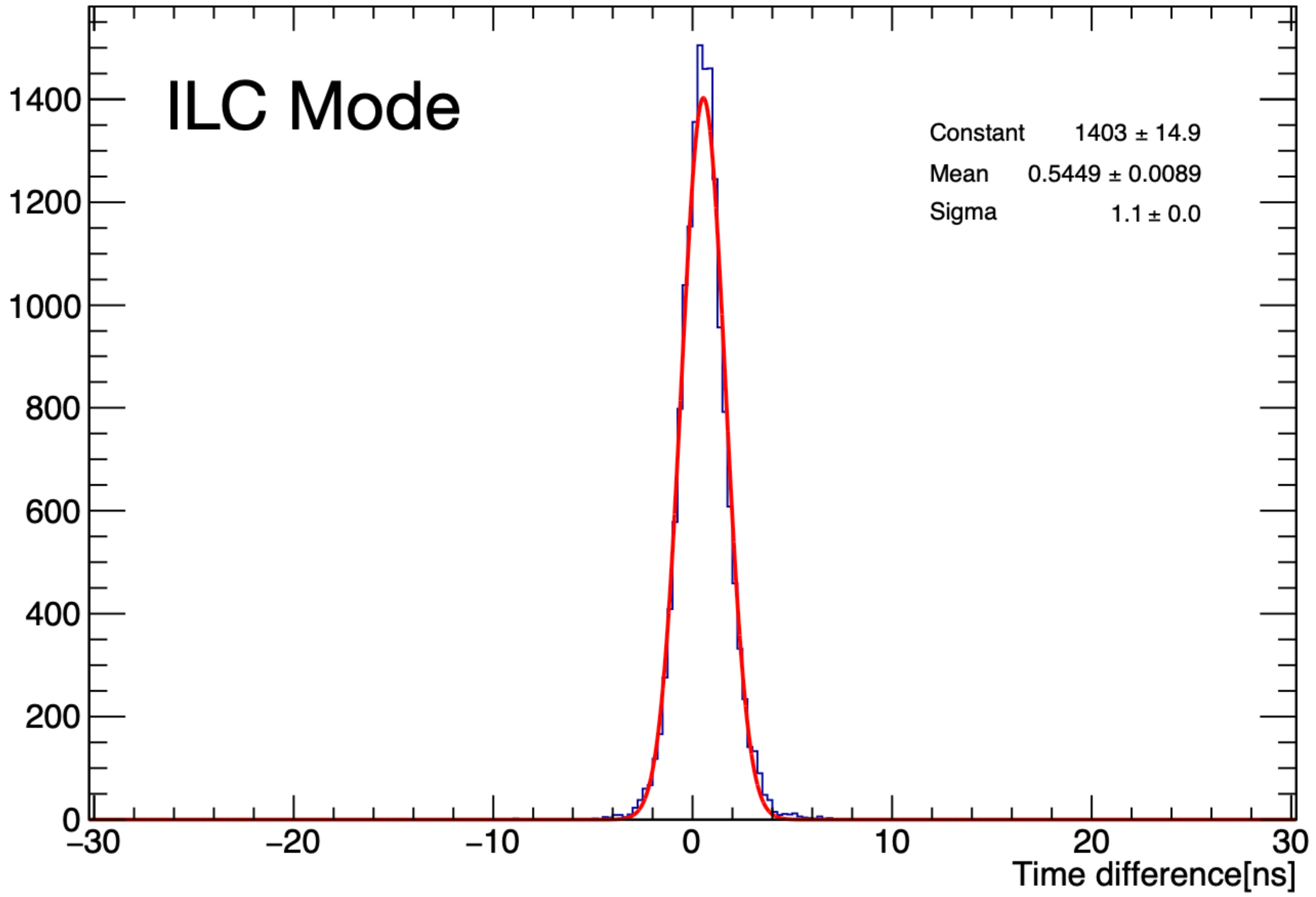
- And a project to understand the timing properties of the SiPM - scintillator tile system in detail. Test beam at DESY 10/2020



Put together a compact system with 4 scintillator tiles, digitzer and control laptop.



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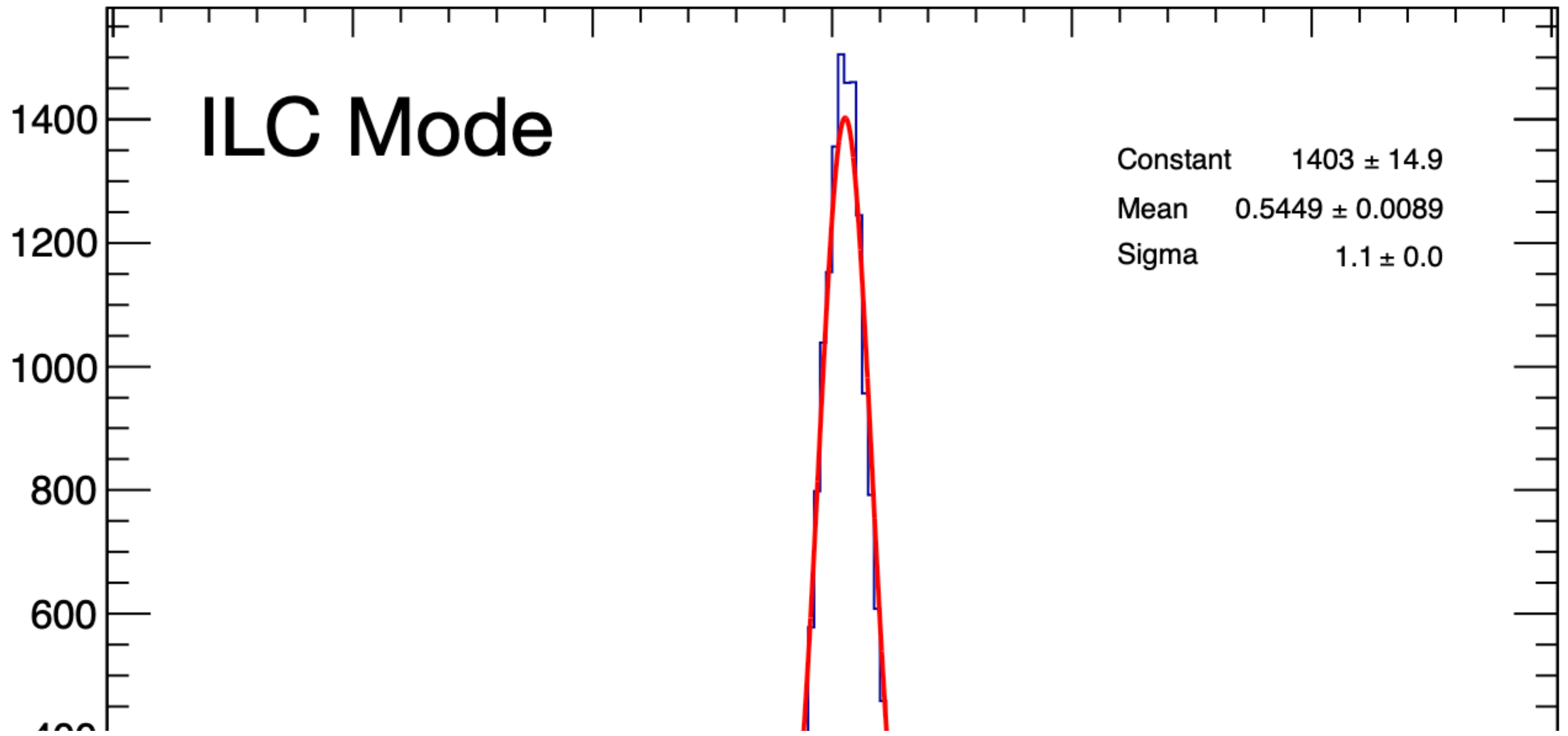
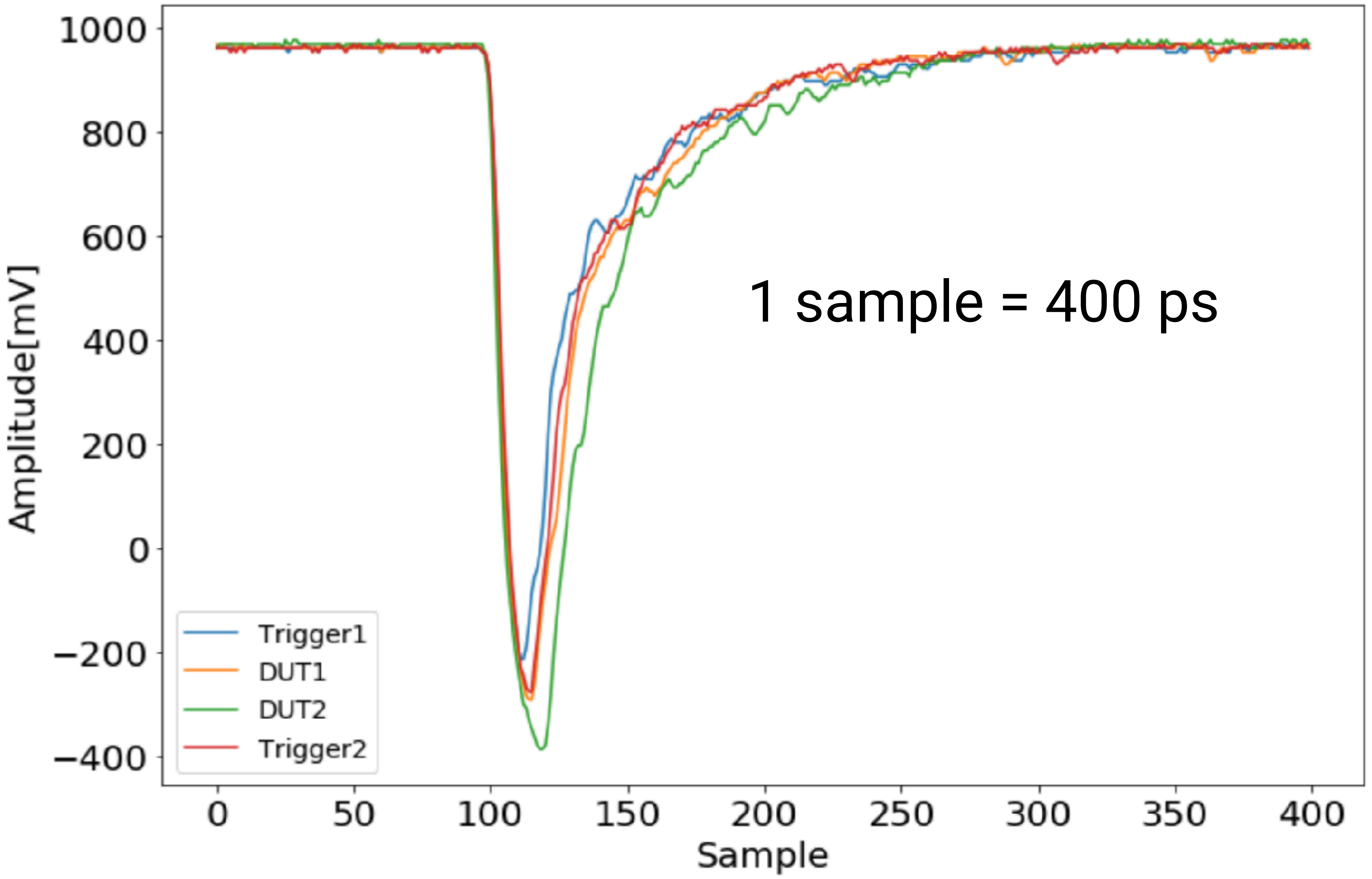


Up and running at DESY within a few hours, efficient data taking, ~ 700 M events, 11 TB recorded in 1 week

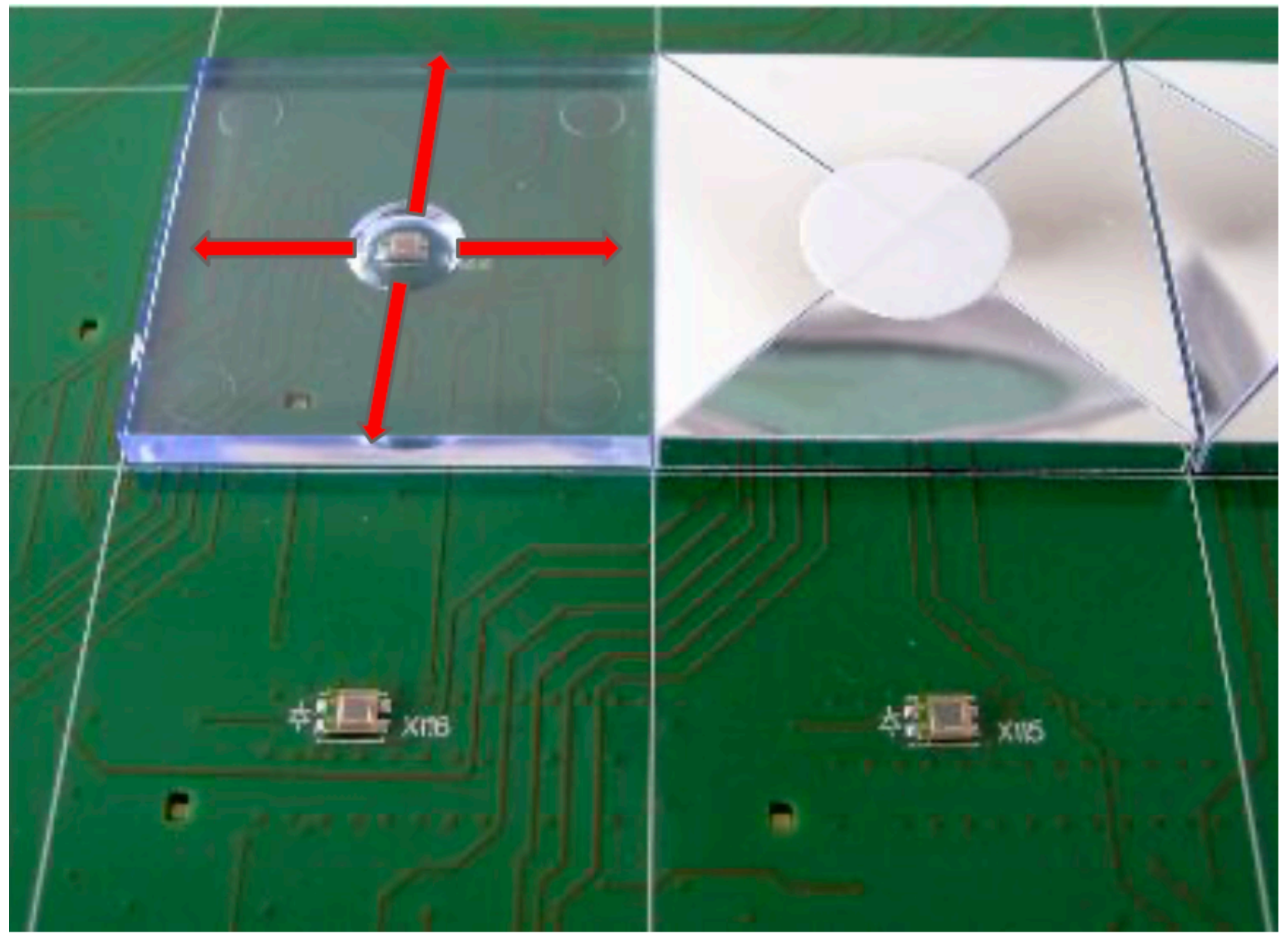


Highly Granular Hadronic Calorimetry

Towards automatic Assembly

- Full collider calorimeter systems: 10s of million of scintillator tiles

➯ Industrialisation & automatisation crucial.



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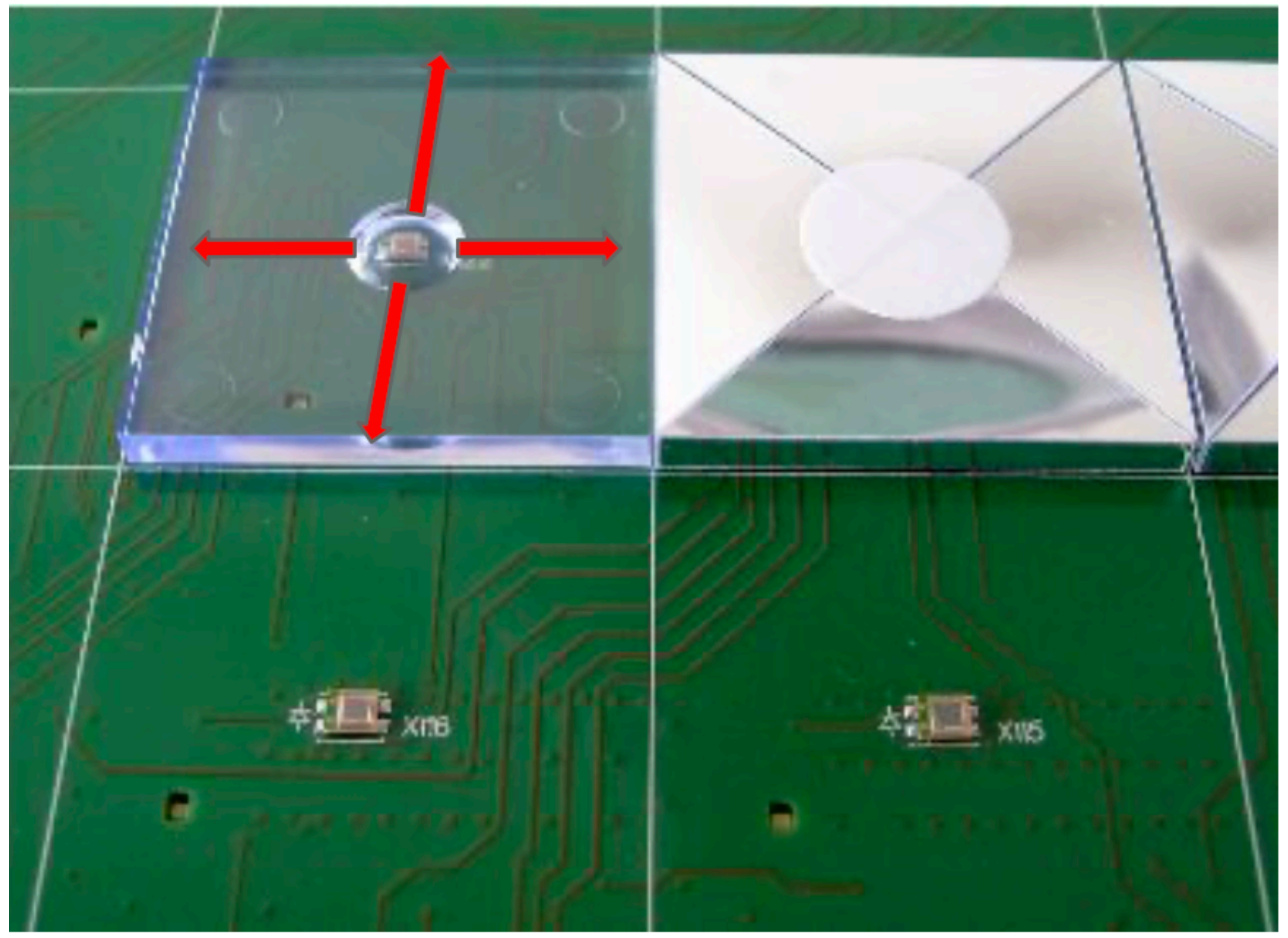
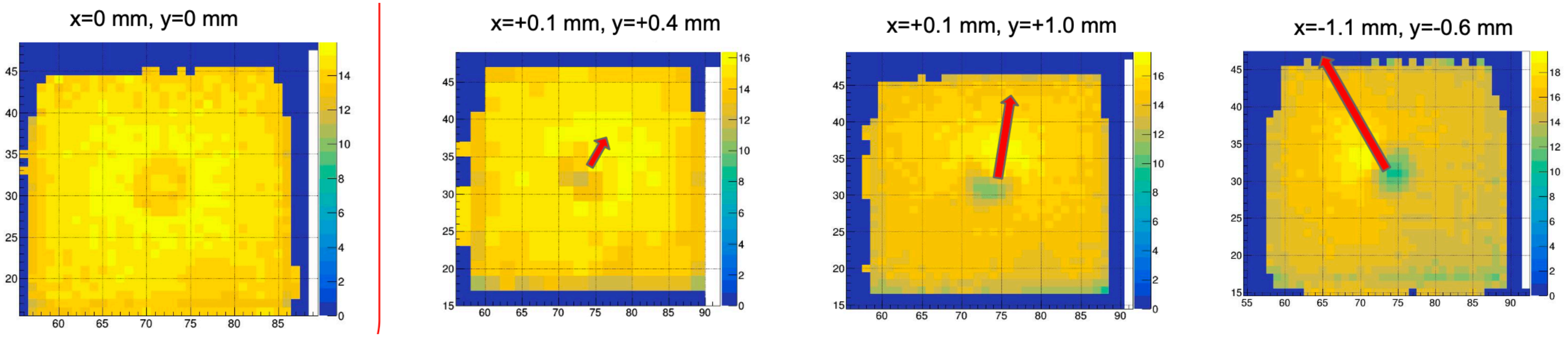
- Full collider calorimeter systems: 10s of million of scintillator tiles

➩ Industrialisation & automatisation crucial.





- A misalignment results in non-uniformities of the scintillator response. Detailed study for different geometries.

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JINST 15, P06030 (2020)

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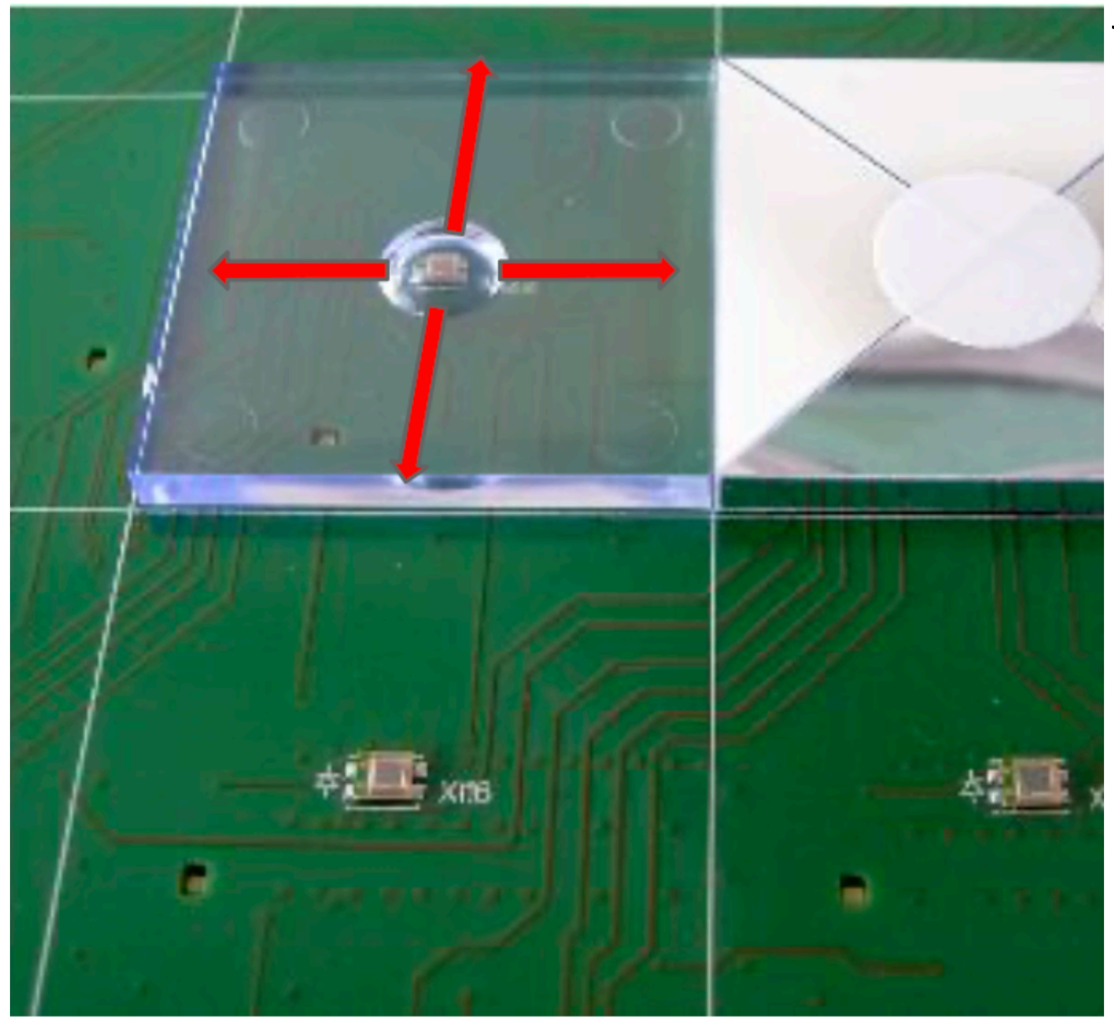
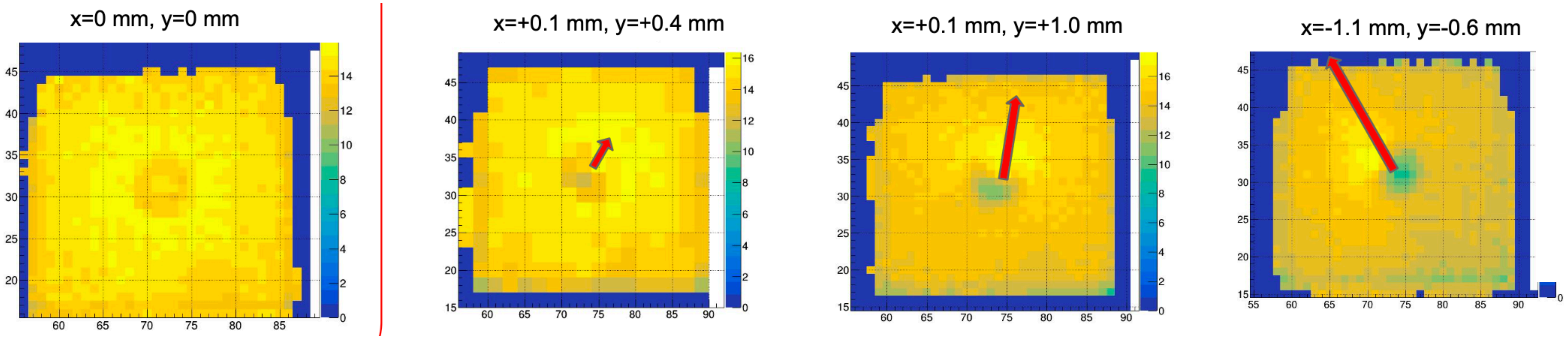
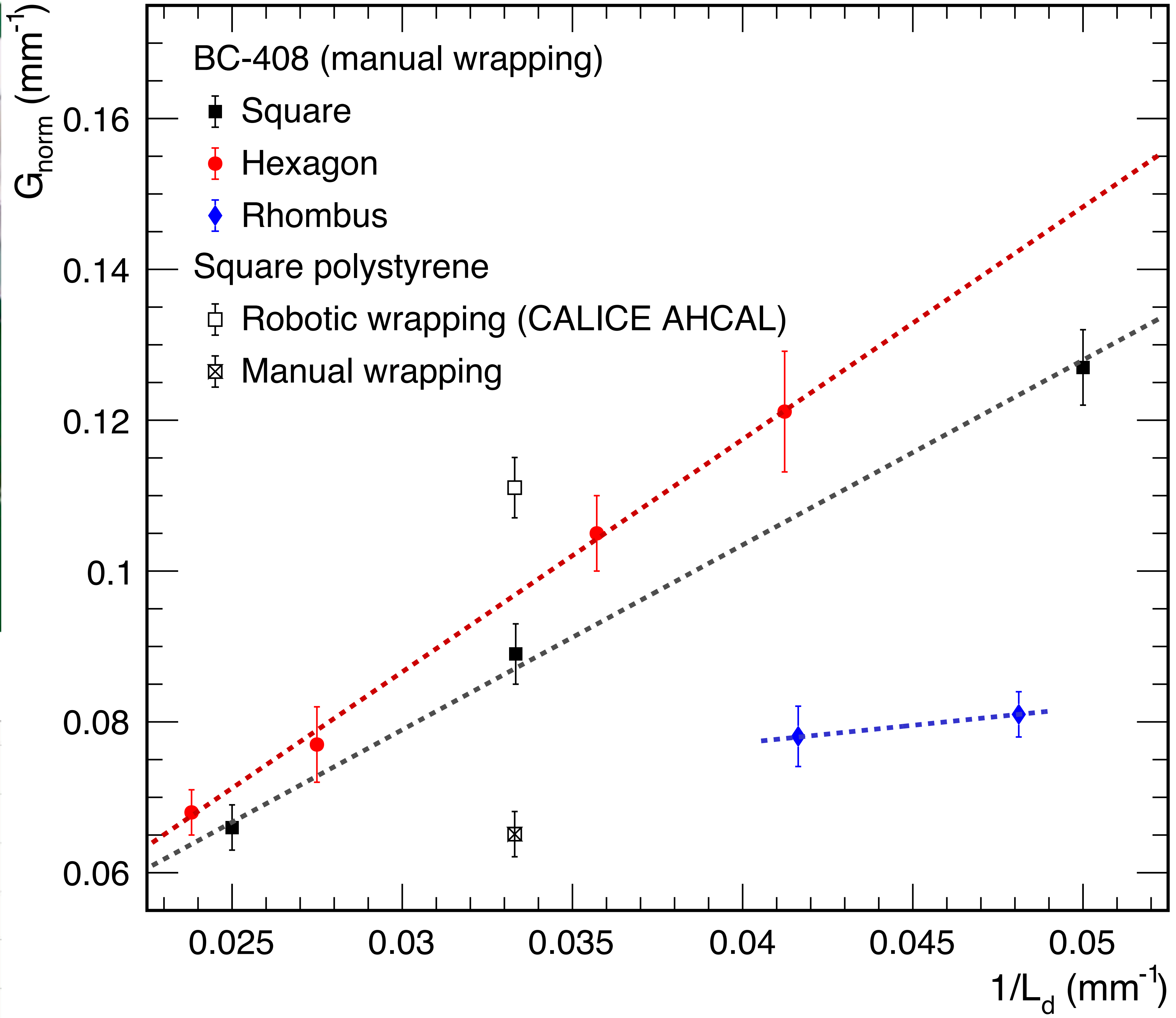






- A misalignment results in non-uniformities of the scintillator response. Detailed study for different geometries.

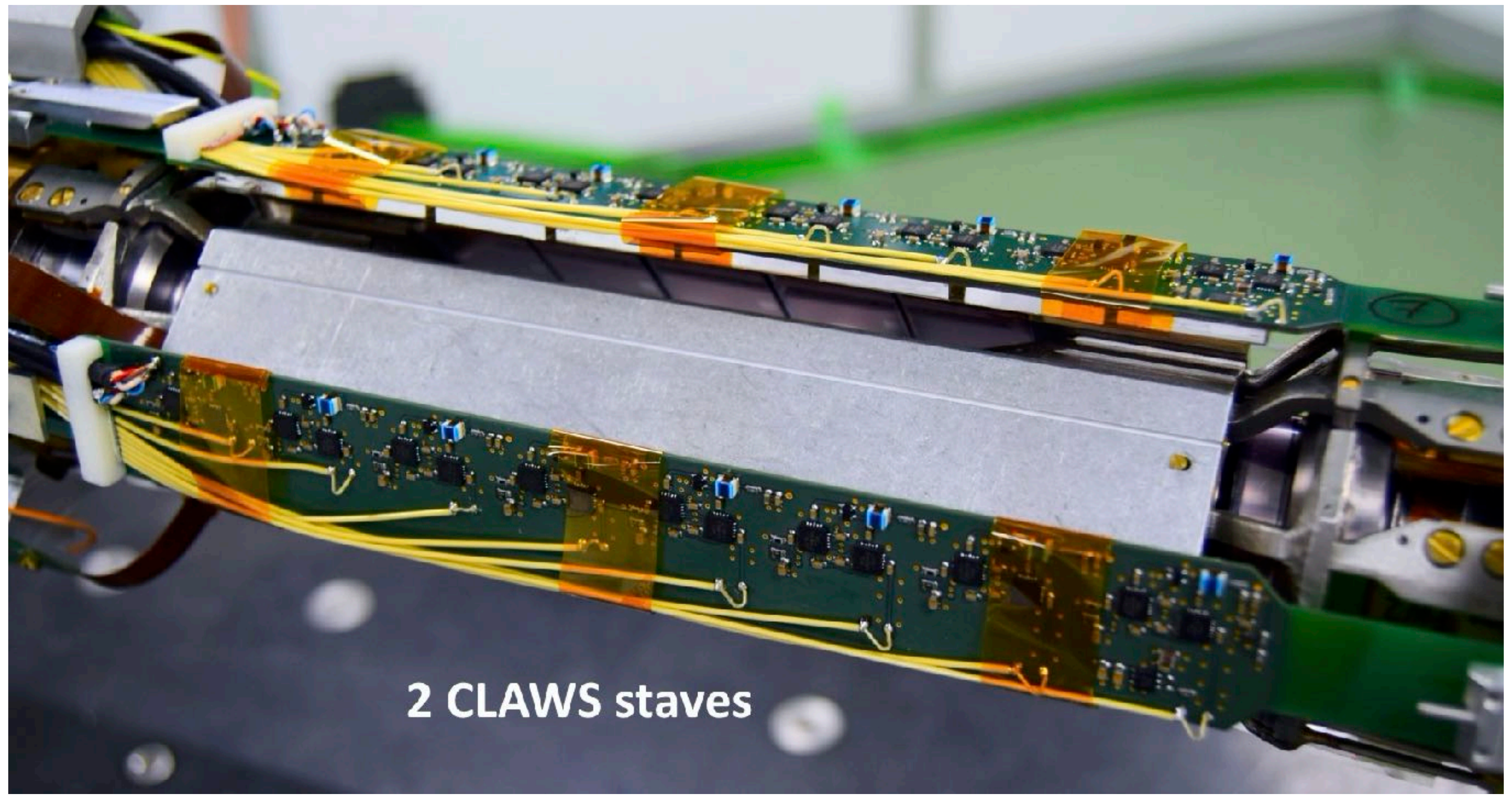
- To limit impact on calorimeter response: asymmetry < 5%

➯ Placement accuracy < 500 μm

Injection Background in SuperKEKB

Understanding a new Accelerator with CALICE Technology

- The CLAWS system: Detailed studies of injection background in SuperKEKB commissioning from Phase I - Phase III with different dedicated SiPM-on-Tile systems



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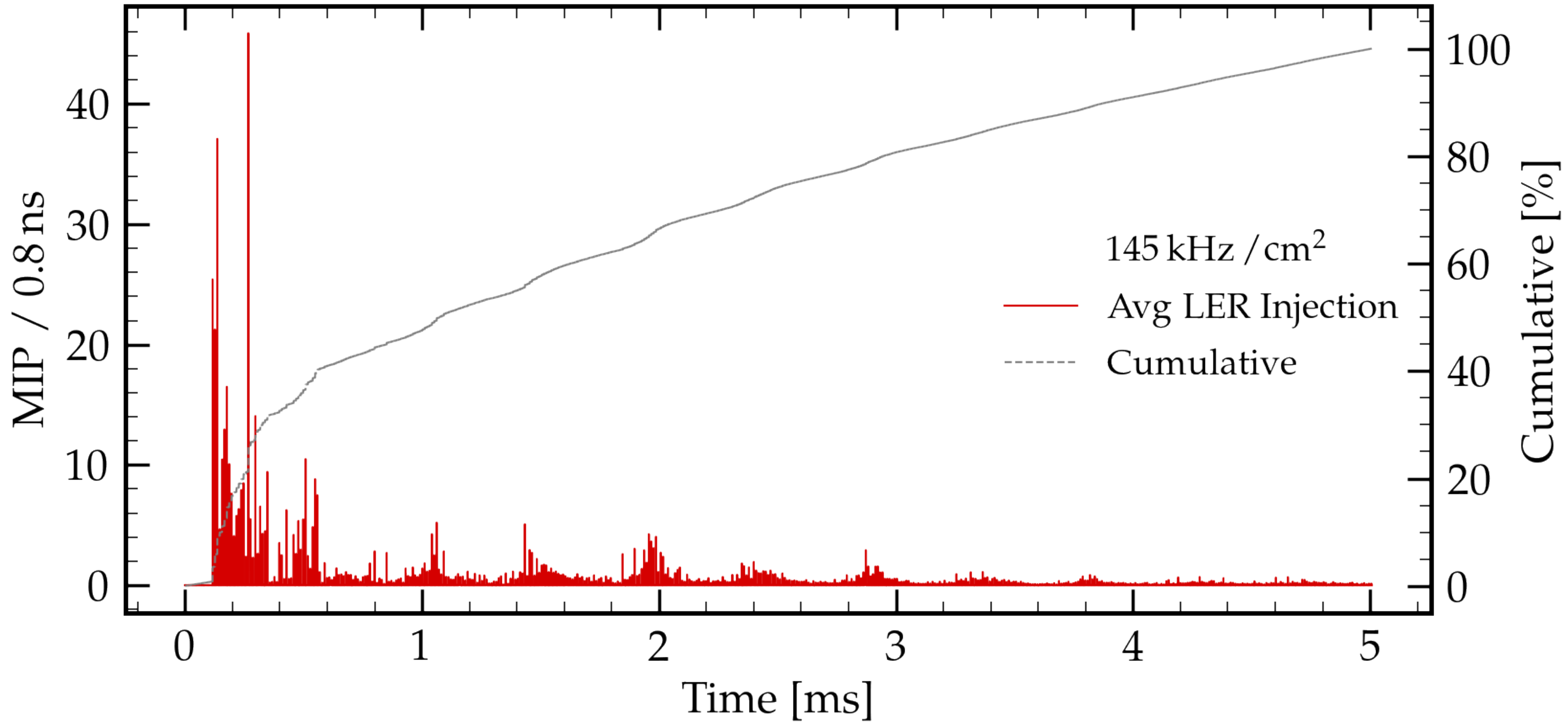

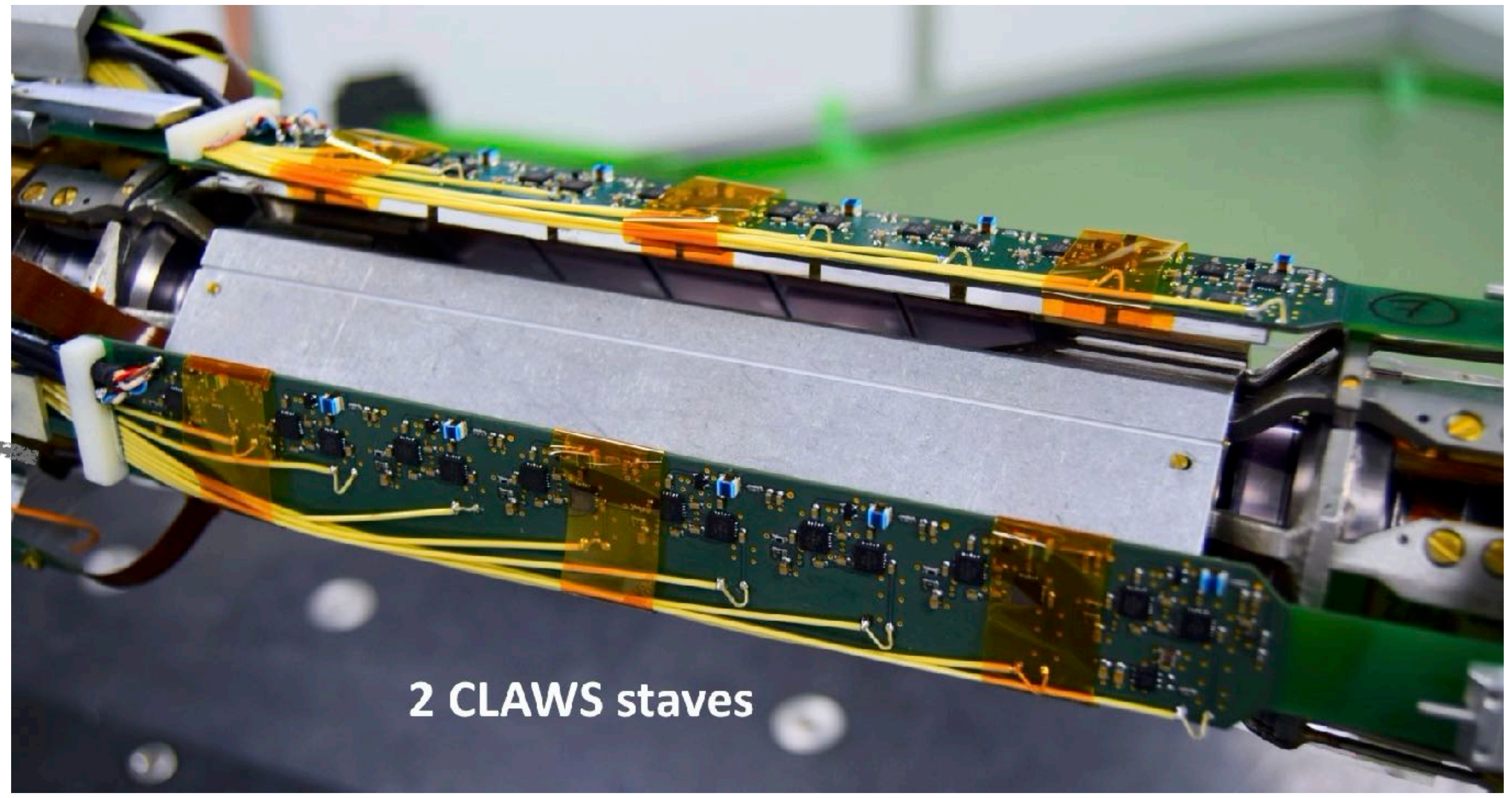

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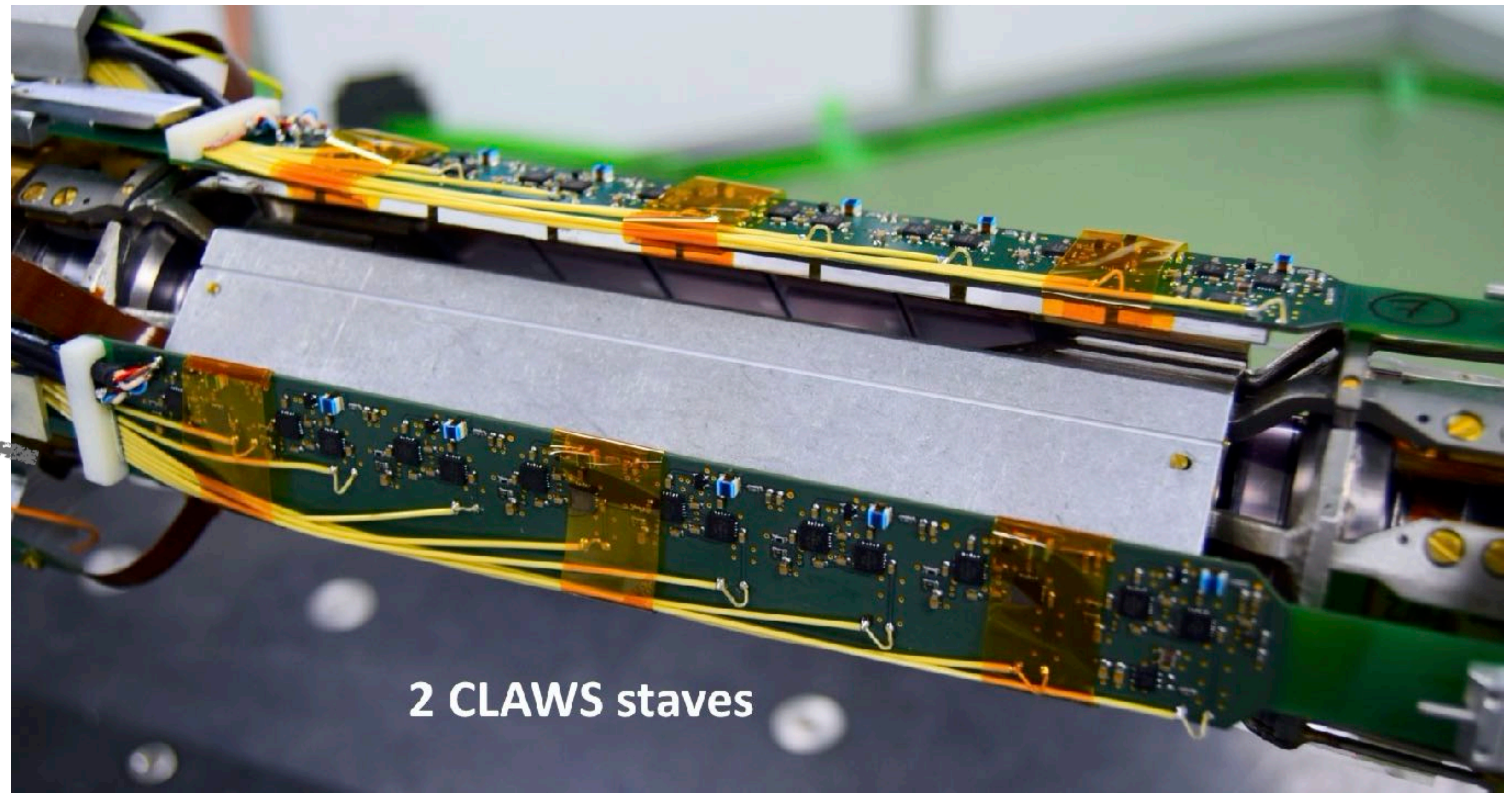
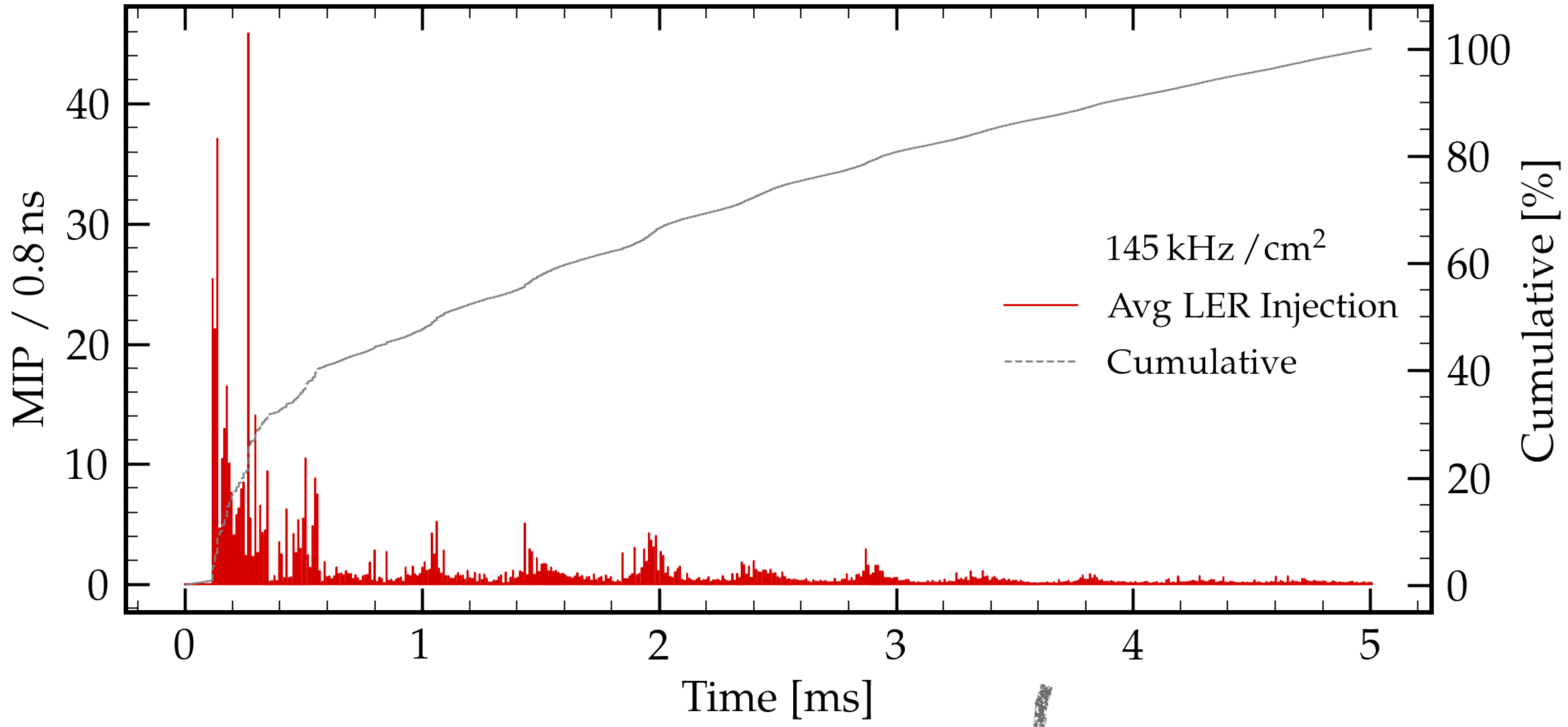
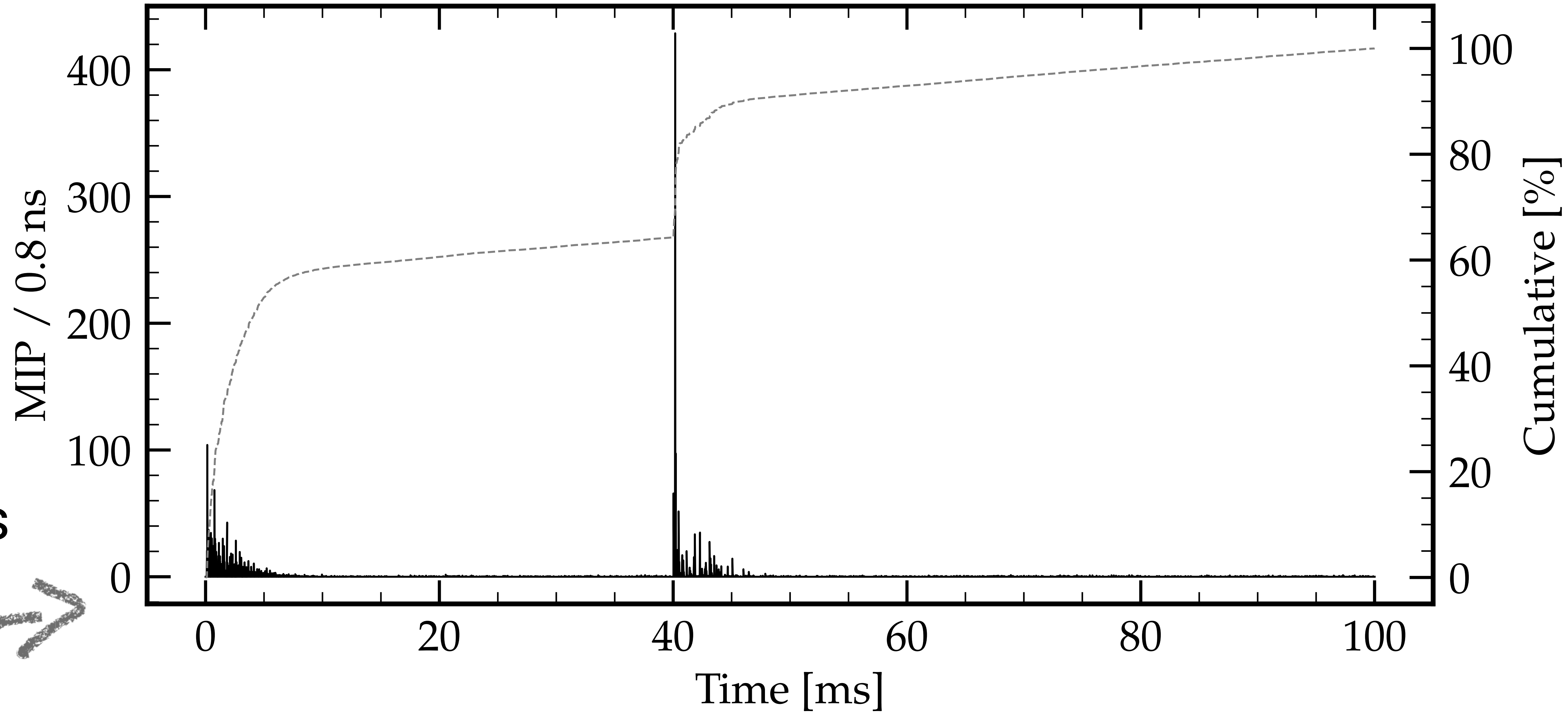


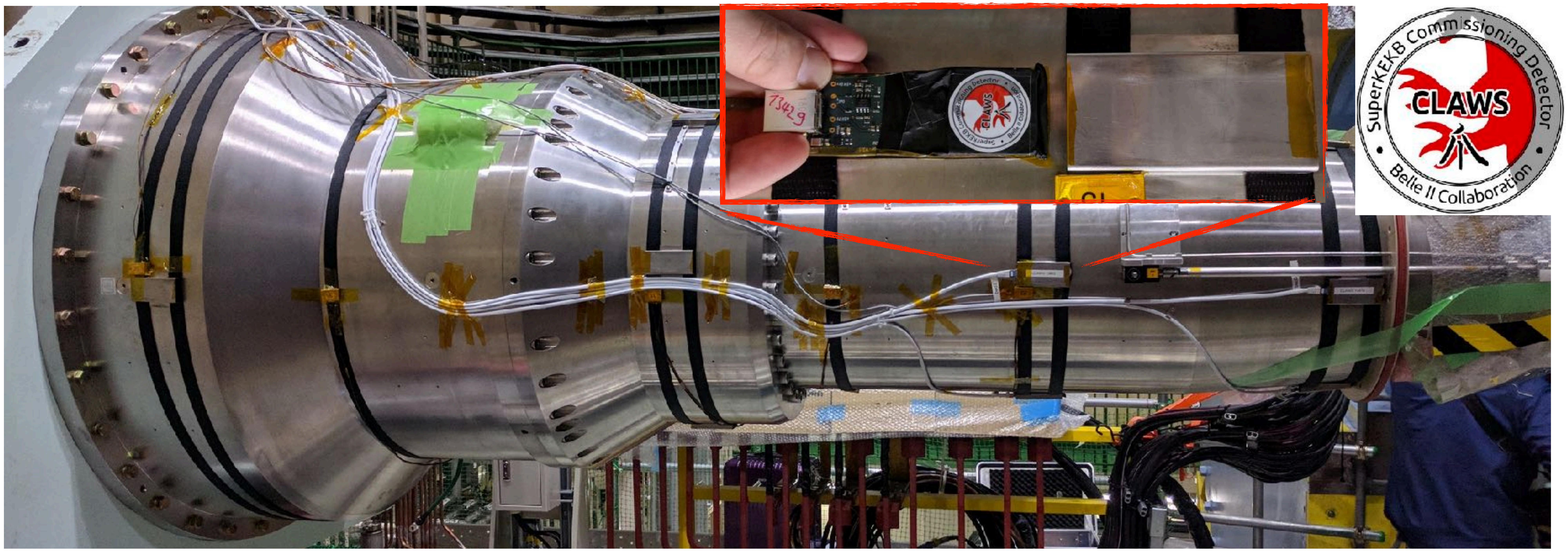


- Continuous monitoring of particle rates for 100 ms (10 000 accelerator turns) after the injection



A Fast Beam Abort for SuperKEKB

A Spin-off of CALICE Technology



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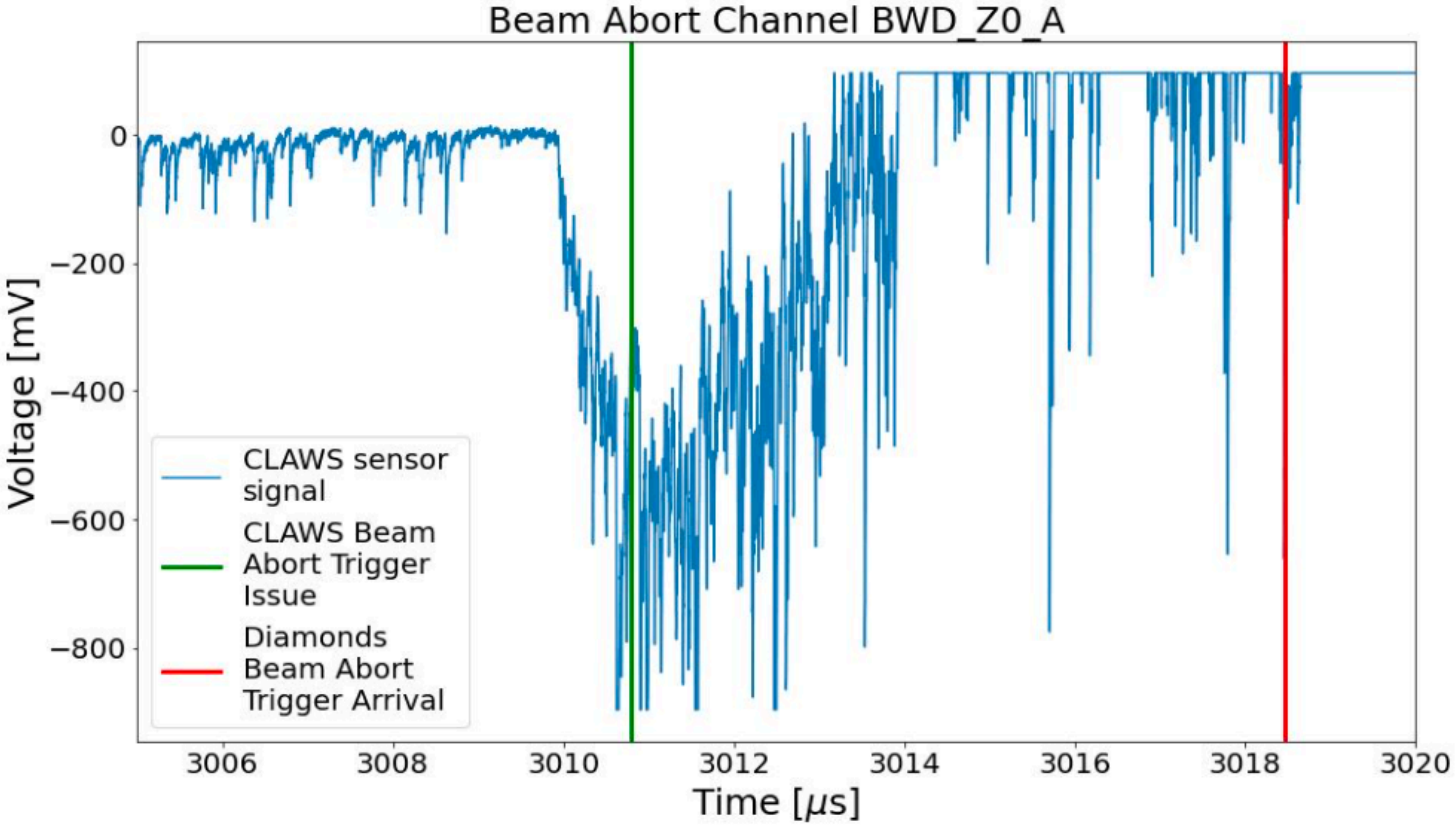

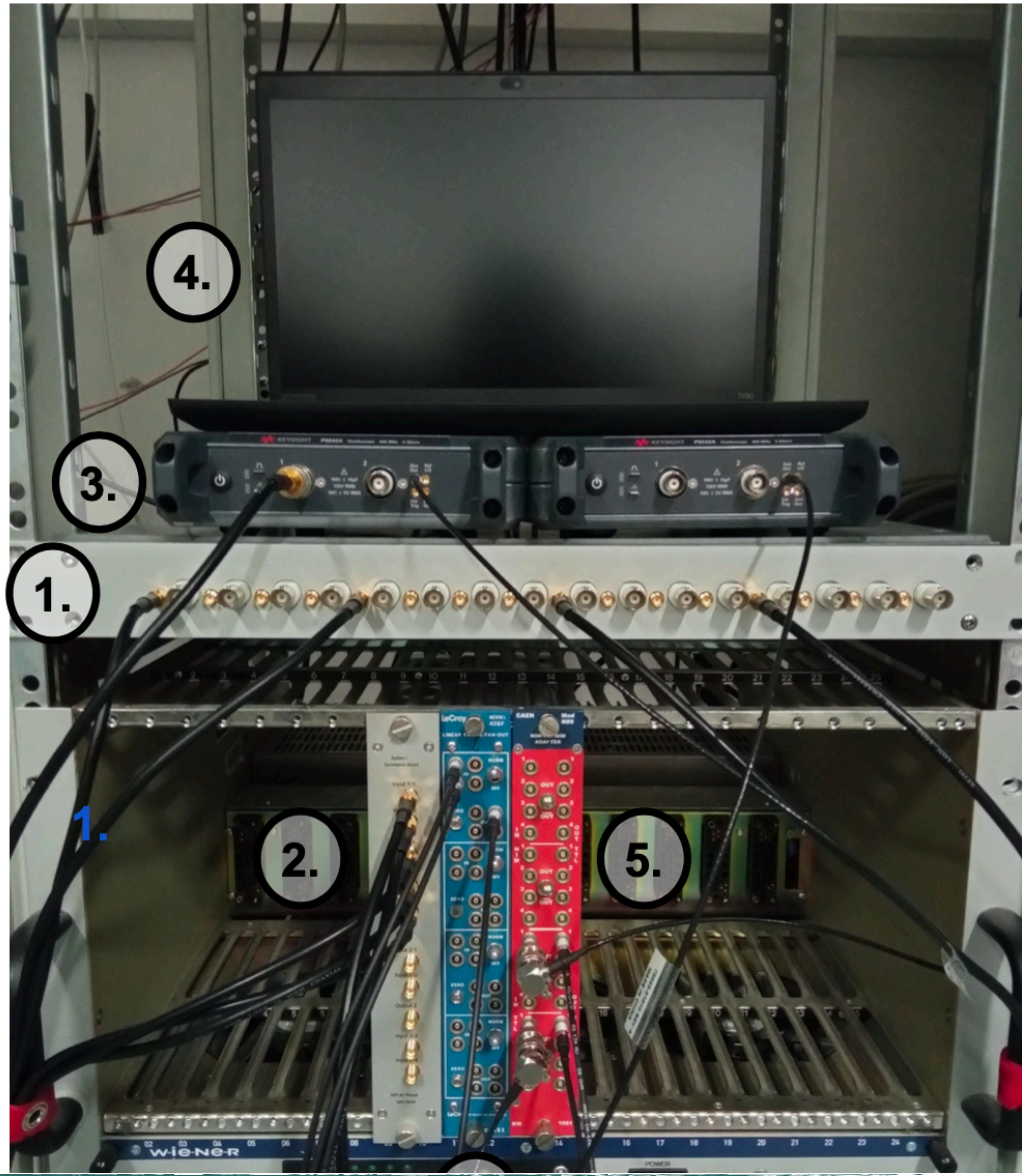

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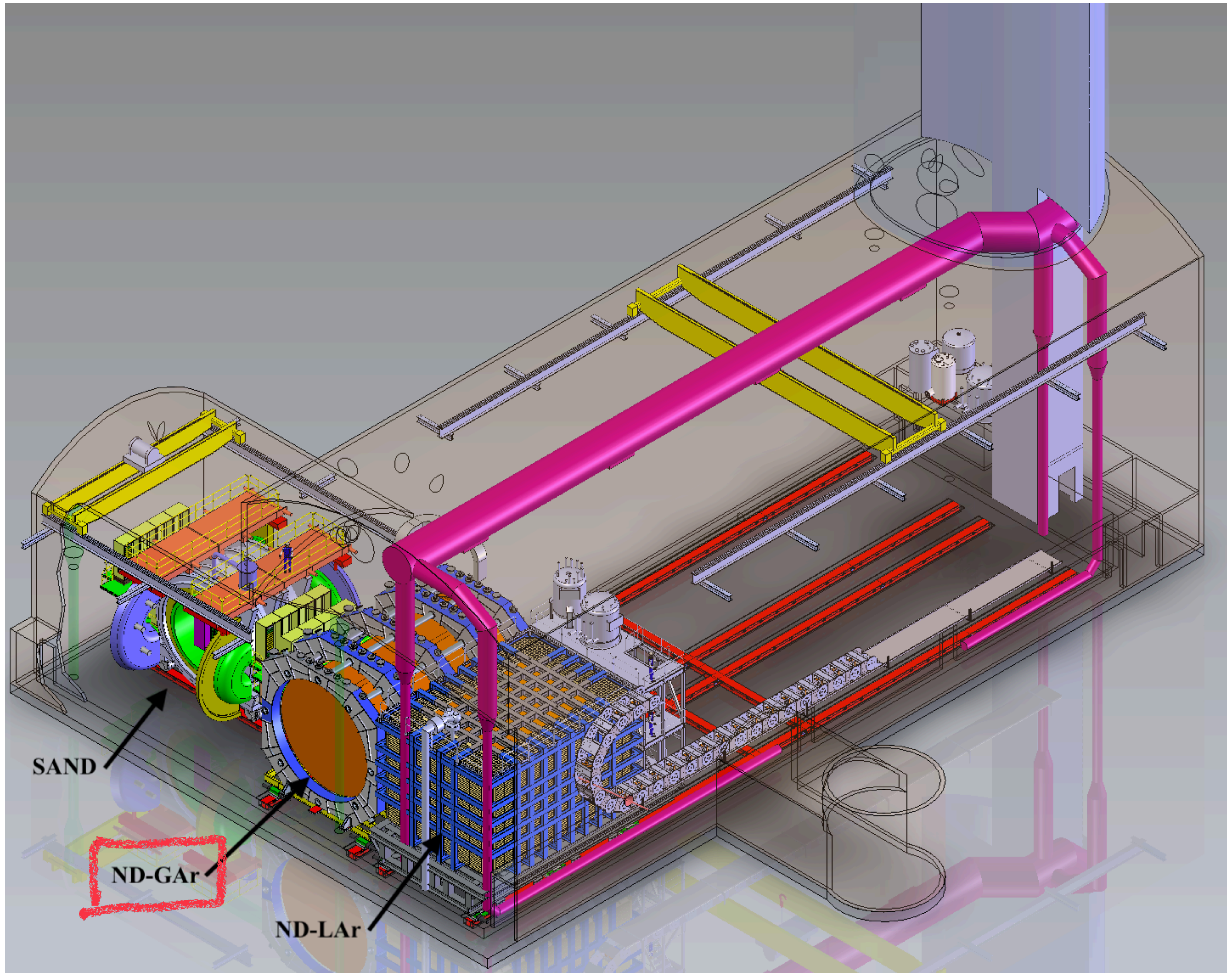
SiPM-on-Tile Technology for Neutrinos

Evolving ECAL Concept for DUNE

- A first conceptual design for the DUNE Near Detector complex has been established



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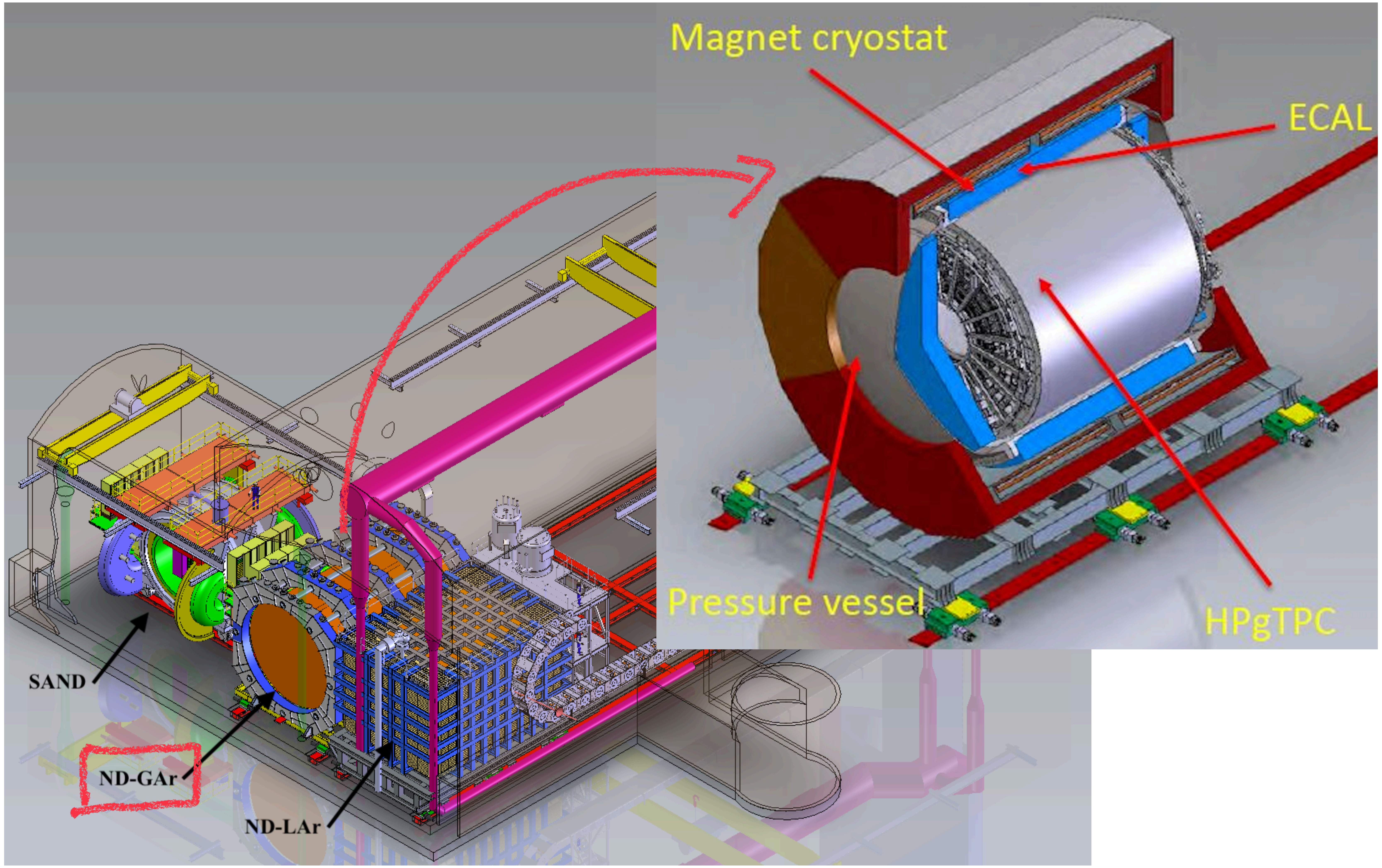

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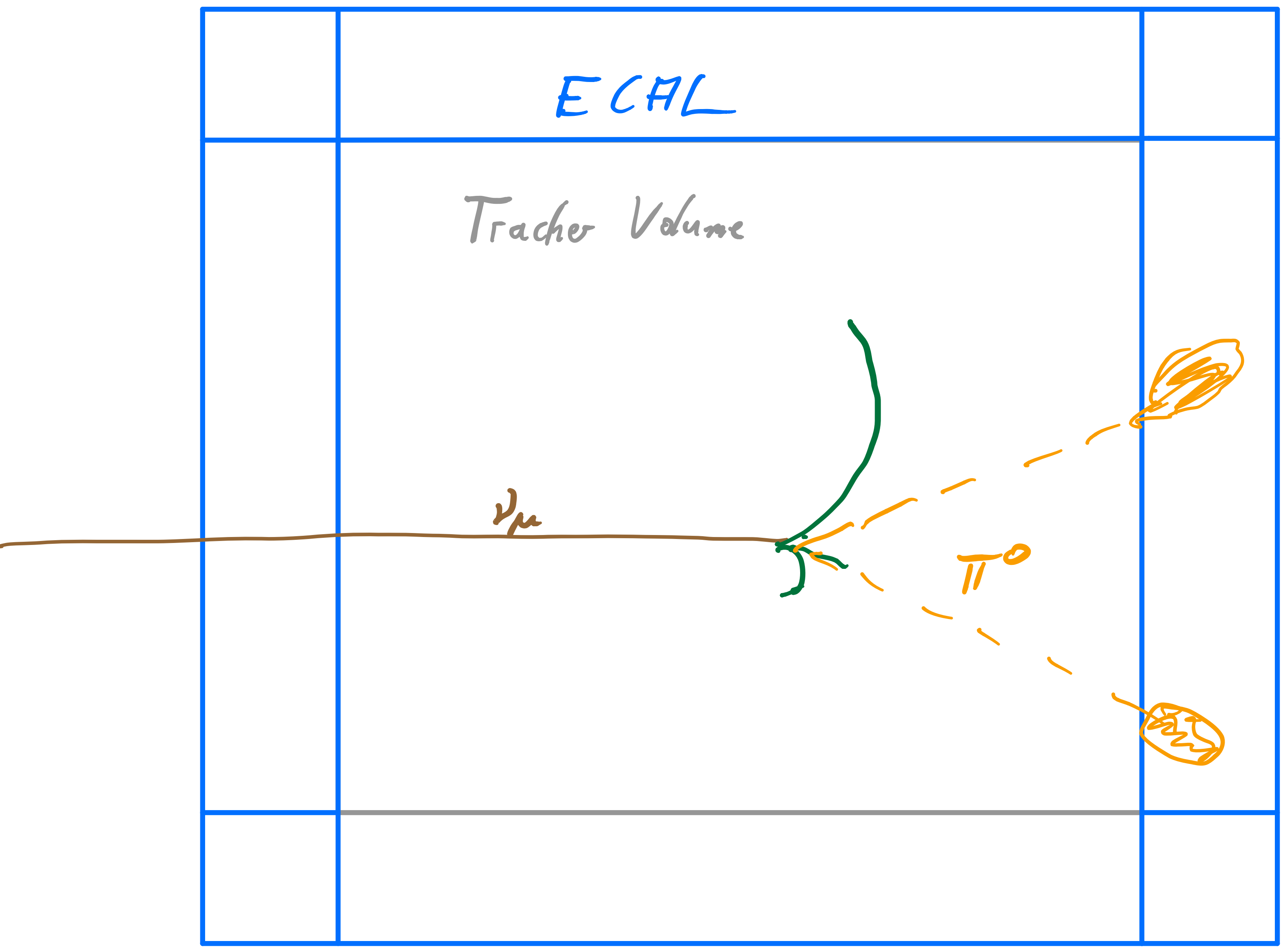
SiPM-on-Tile Technology for Neutrinos

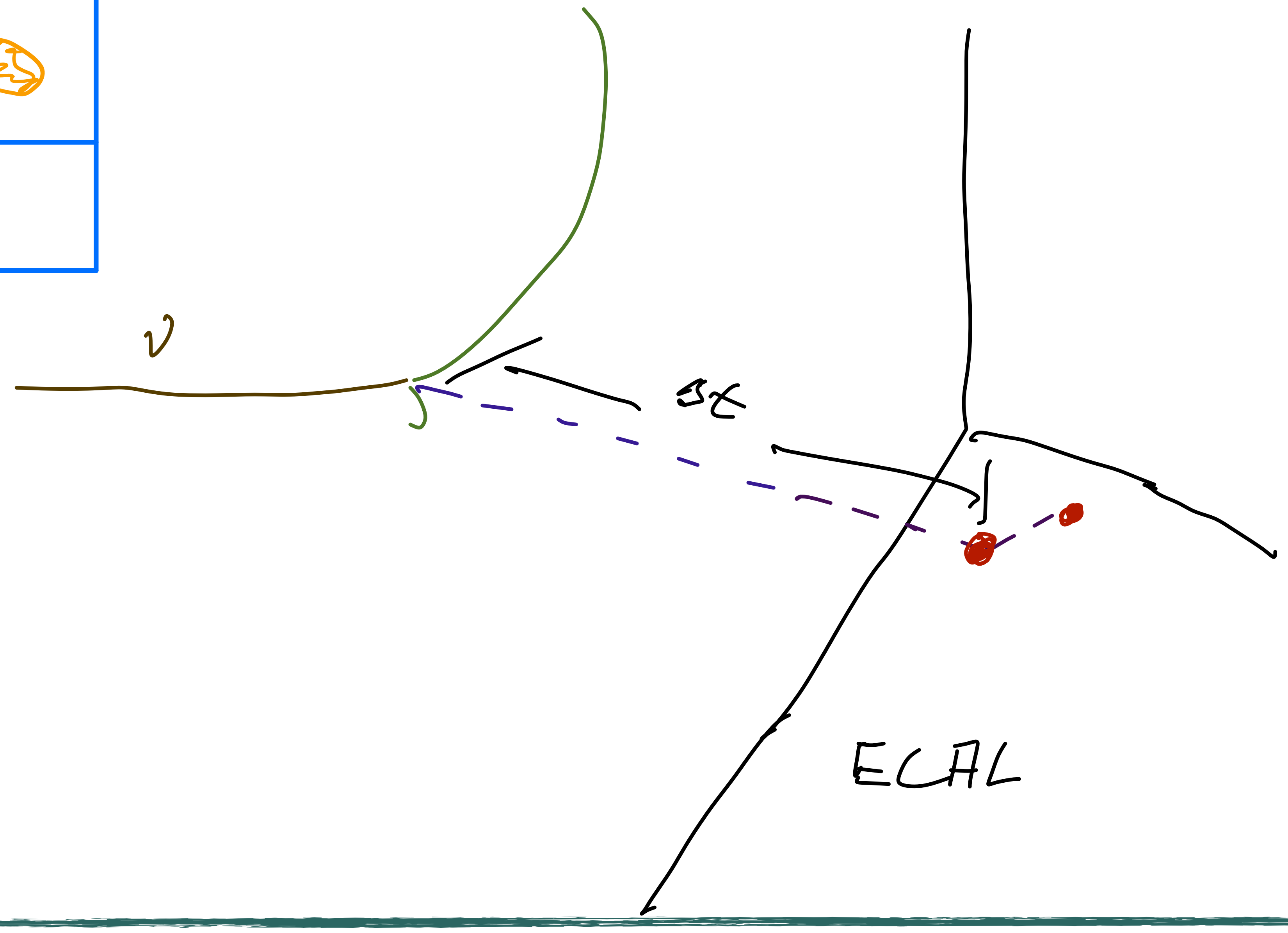
Evolving ECAL Concept for DUNE

- Key capabilities of the calorimeter



neutron reconstruction: position and time resolution for energy via time-of-flight

π^0 reconstruction: energy, position and angular resolution



SiPM-on-Tile Technology for Neutrinos

Evolving ECAL Concept for DUNE

DUNE

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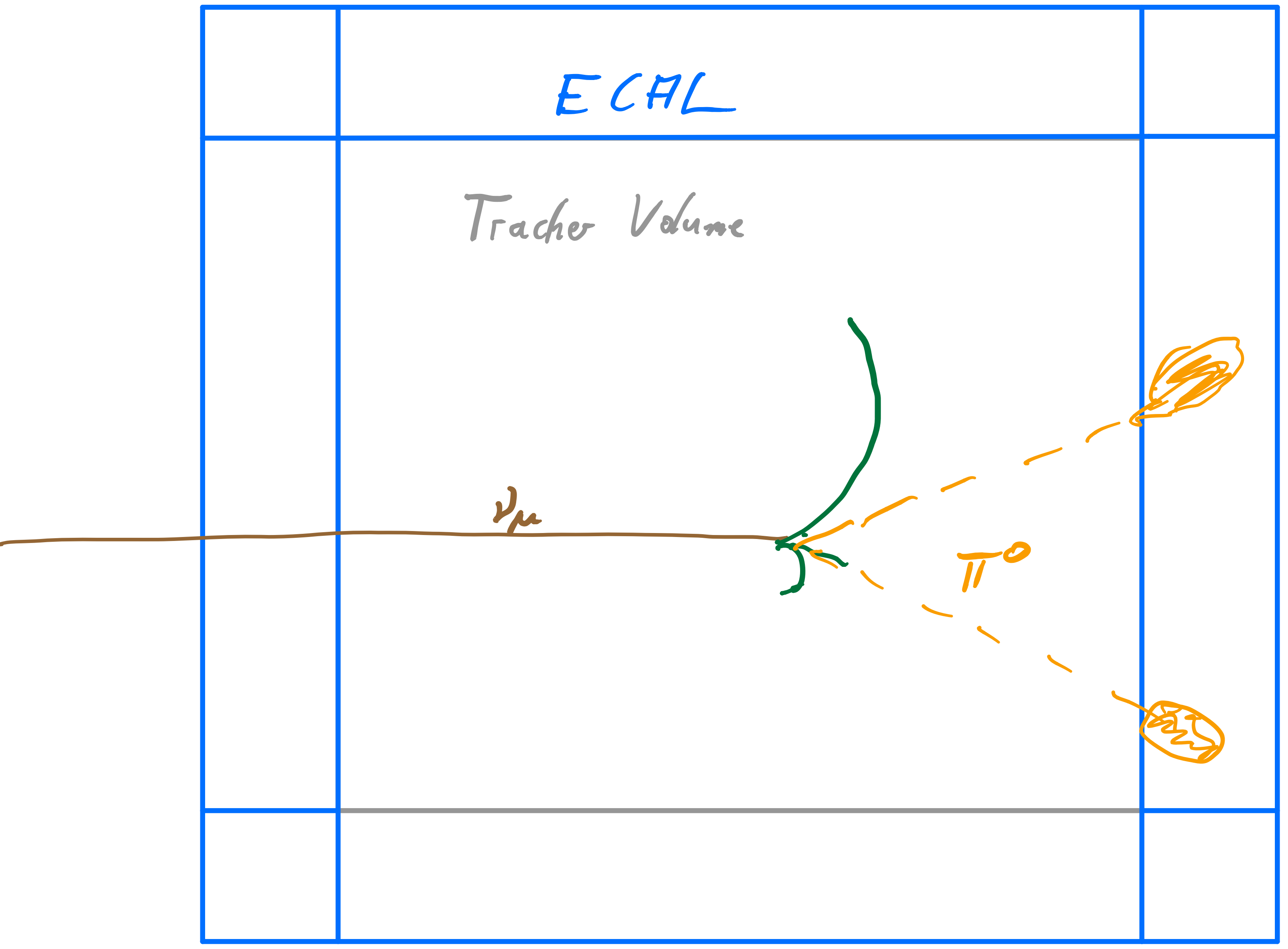

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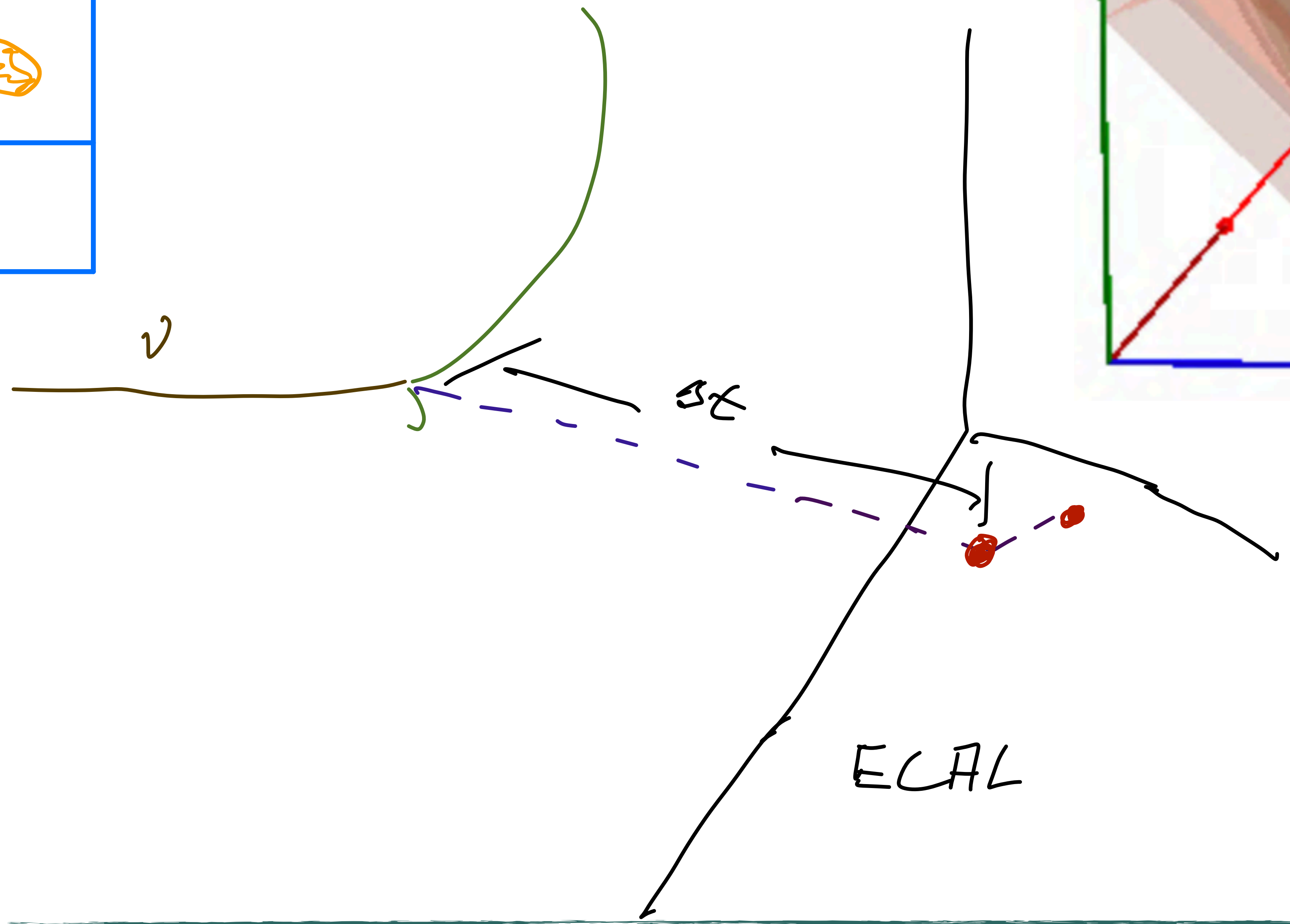

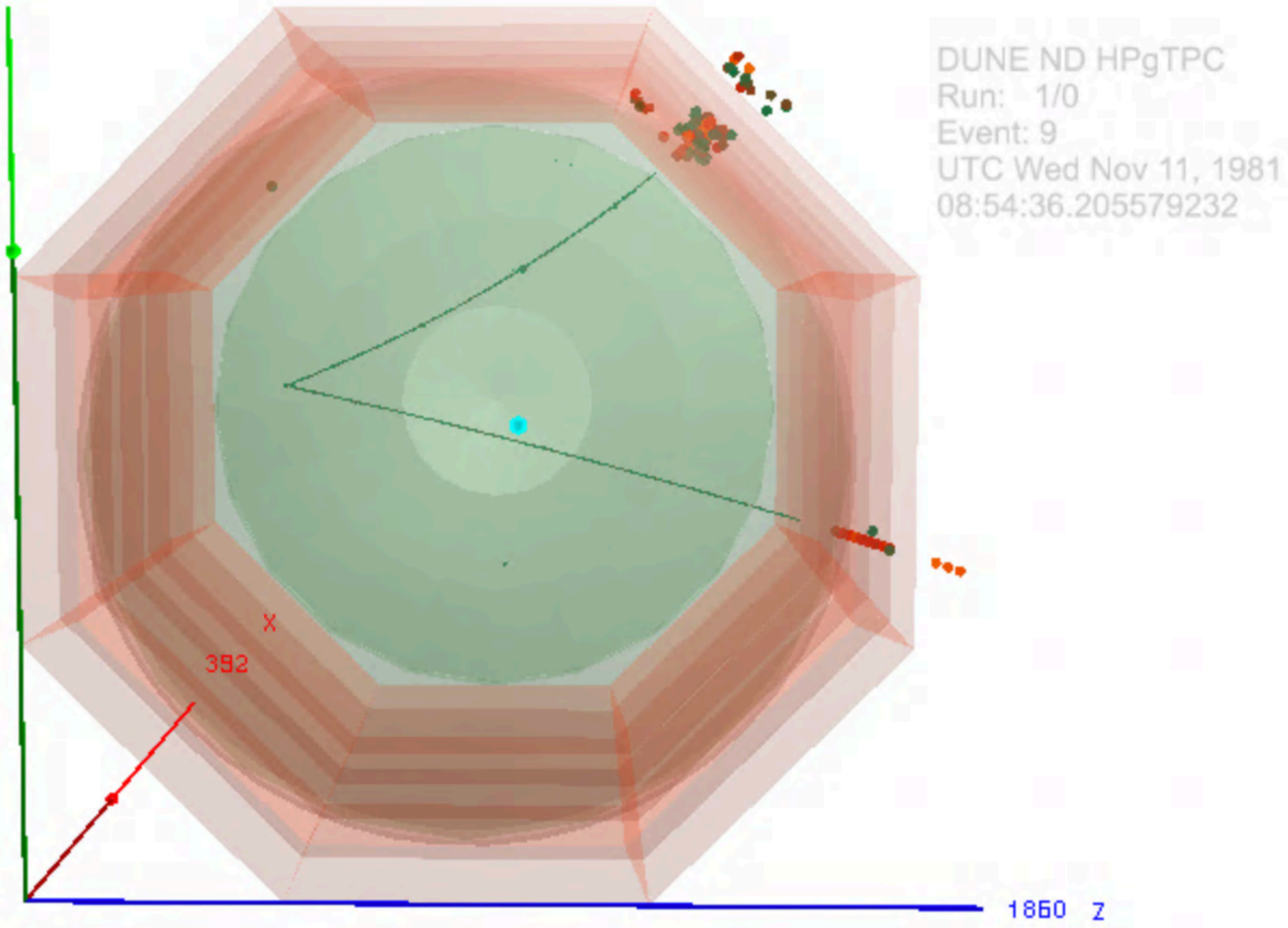

Now under study: Particle ID - separation of μ/π, exploiting detector granularity + muon system, based on ML techniques

Conclusions

… and a look ahead

MAX-PLANCK-INSTITUT FÜR PHYSIK

- The case for an e^+e^- Higgs Factory has emerged strong from the European Strategy Updated
  - The European focus has shifted towards FCCee - but decisions are deferred until the next update
  - ILC once again moving forward in Japan - but the outcome remains uncertain

- MPP with contributions to the physics studies for all future machines - in a variety of areas.

- Highly granular scintillator-based calorimeters reaching the sub-ns timing domain - and provide possibilities for current and future projects from background monitoring at SuperKEKB to DUNE and future energy-frontier colliders.

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➯ Highly visible contributions by MPP, and a range of opportunities!

Extras

Project Timelines

My own Interpretation - With a good Dose of Optimism

MAX-PLANCK-INSTITUT FÜR PHYSIK

The Facilities: Rings

FCCee, CEPC

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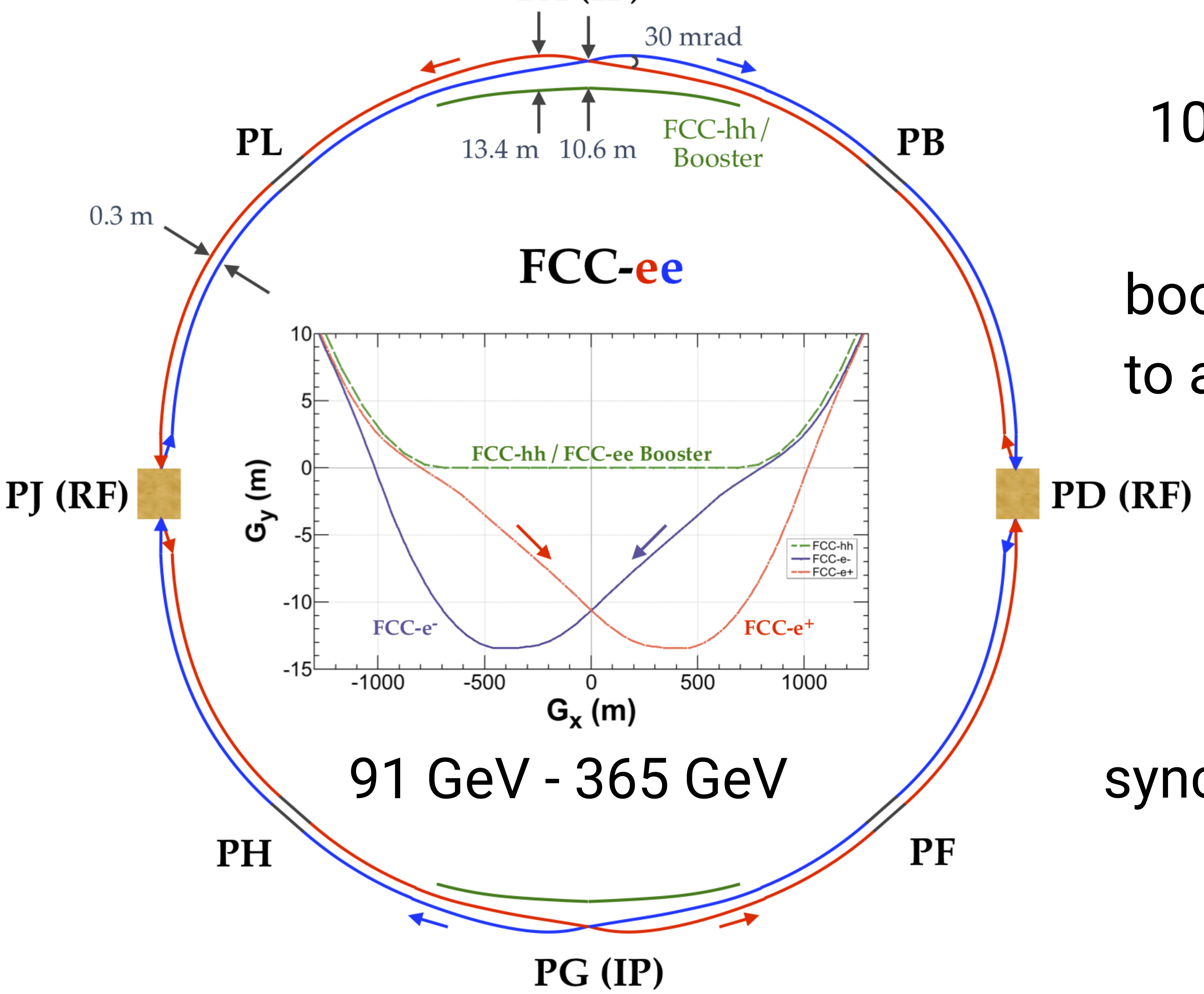
- “Low tech”, large circumference accelerators - as a first stage of the scientific exploitation of a circular tunnel - later followed by a high-energy hadron collider
  - Add state-of-the-art ingredients: Nano-beams, high-gradient SCRF, …

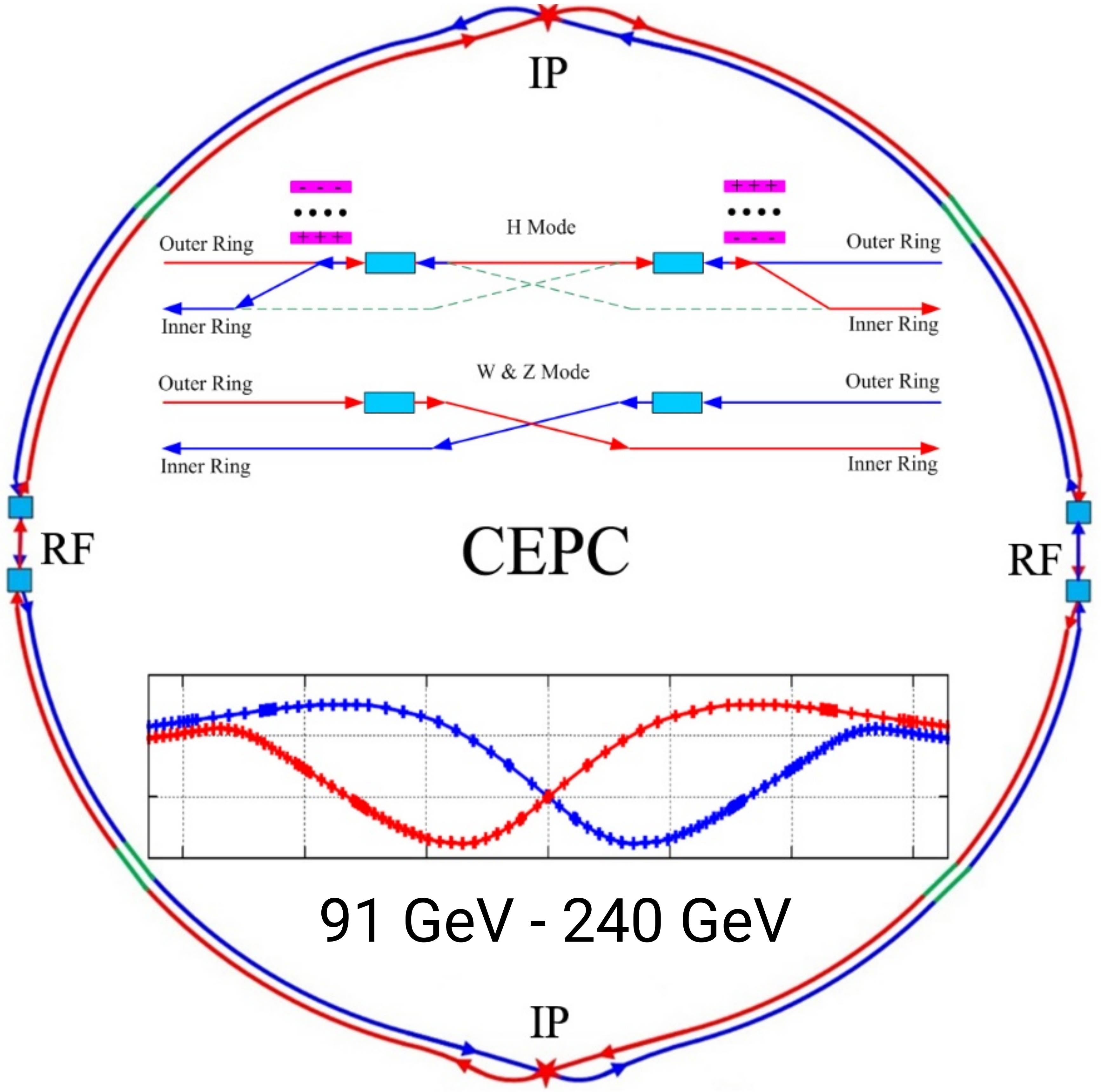


91 GeV - 365 GeV

100 km circumference

booster synchrotron required to achieve high luminosities

synchrotron radiation power:



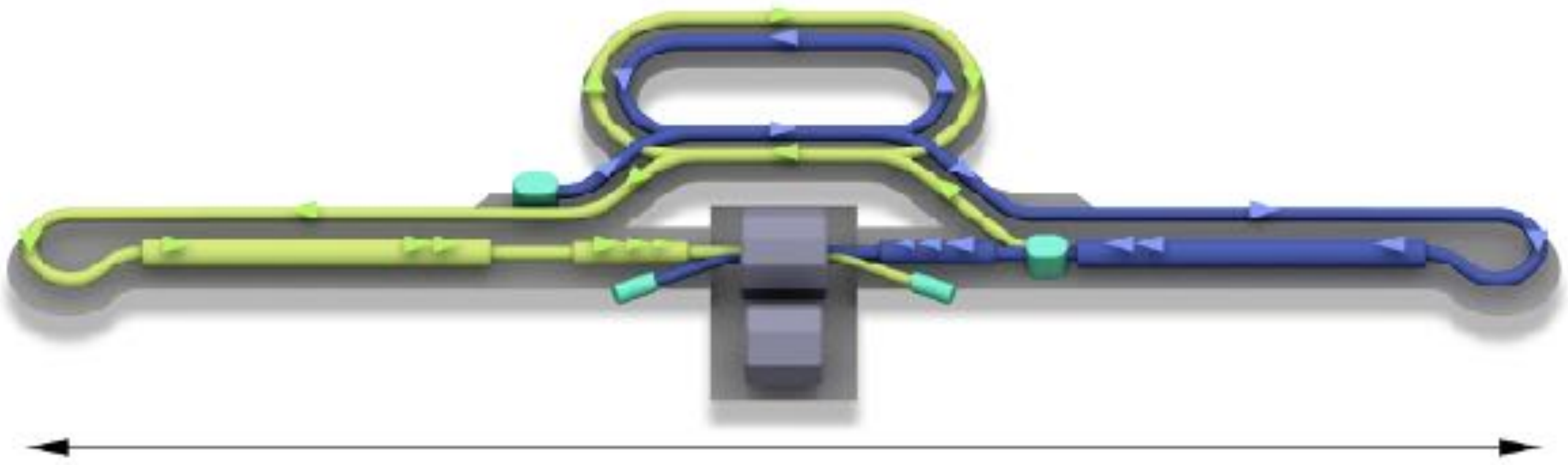
91 GeV - 240 GeV

The Facilities: Linear Colliders

ILC, CLIC

- High gradient linear accelerators - intrinsically upgradeable in energy (increase in length, higher-gradient acceleration technologies)

ILC (International Linear Collider)



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~ 30 km for 500 GeV

superconducting RF

baseline 250 GeV, full TDR energy 500 GeV, potential to 1+ TeV

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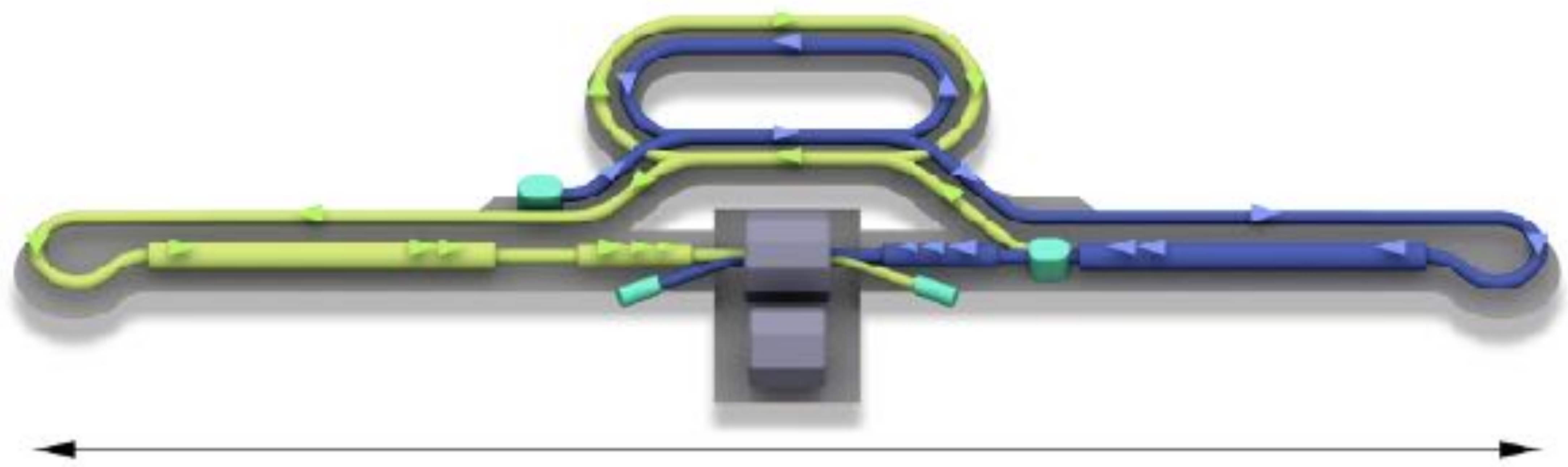

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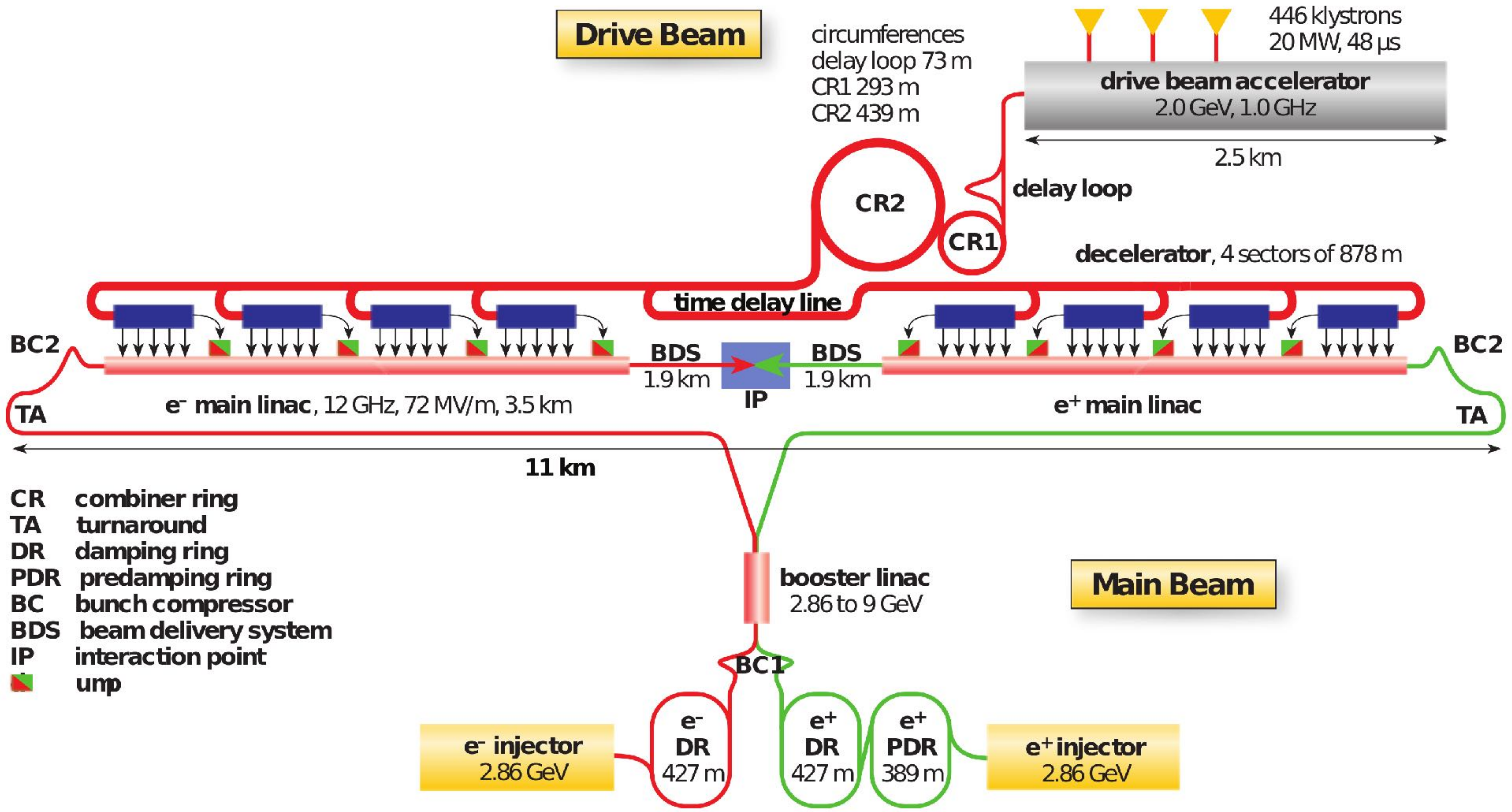
CLIC (Compact Linear Collider)

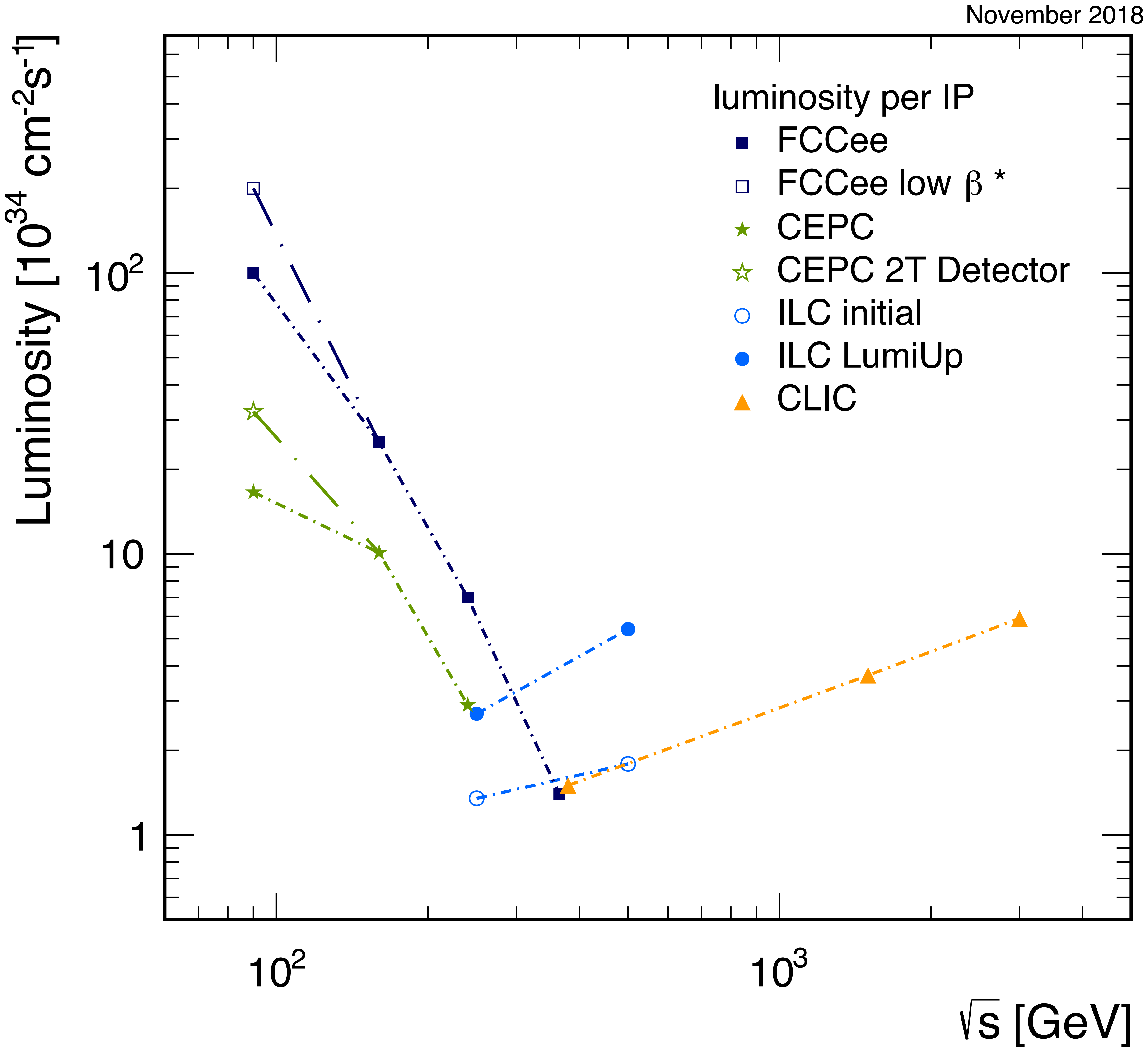


2-beam acceleration

three stages from 380 GeV (11 km) to 3 TeV (50 km)

e^+e^- Colliders: Luminosities

In Relation to the Higgs Physics Program



- NB: Circular colliders can have more than one IP (default: 2), while for linear colliders several detectors do not result in an increase in statistics

Cross-over of luminosity curves in the focus region of Higgs physics

- Choice of collider energy reflects luminosity evolution with energy: For circular colliders, 240 GeV provides highest ZH statistics, for linear colliders 250 GeV is better