Future Detectors

- Calorimetry, Background Monitoring & Physics at Future Colliders -

Frank Simon

Max-Planck-Institute for Physics

MPP Project Review

München, December 2019

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

The Future Detectors Group

… in 2018

The Core Group

- *Post-Docs*
  Marco Szalay
- *PhD Students*
  Lorenz Emberger (since 08/2018), Miroslav Gabriel,
  Christian Graf, Yasmine Israeli,
  Thomas Kraetzschmar (since 07/2018),
  Hendrik Windel
- *Master Students*
  Daniel Heuchel (until 01/2018), Malinda de Silva
  (since 10/2018), Christian Winter (since 10/2018)
- *Technical Students (for parts of 2018)*
  Sejla Hadzic, Guia Resina, Malinda de Silva
- *Group Leader*
  Frank Simon

Close collaboration with:

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

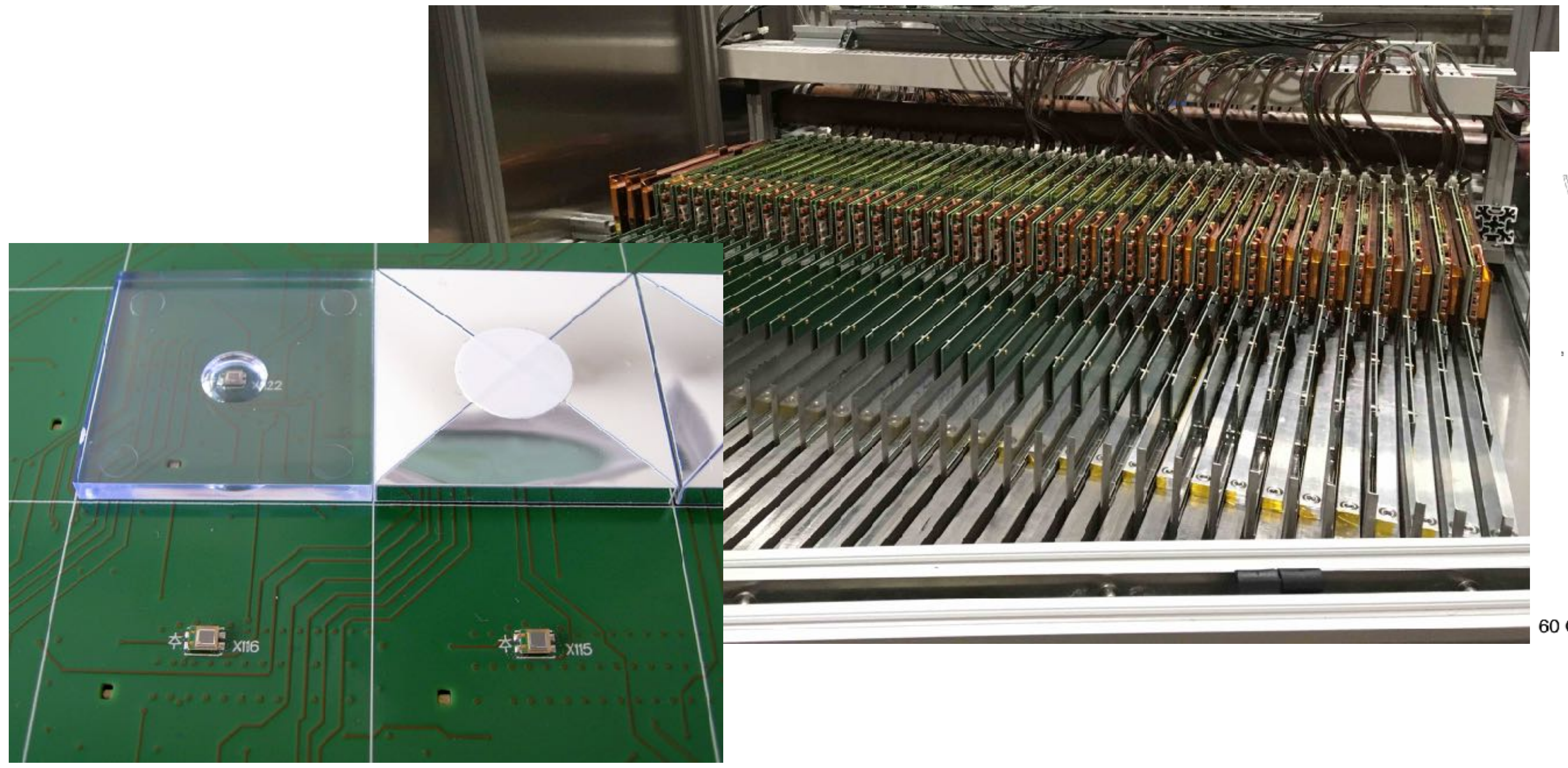
With key roles in collaborations and projects, among them:

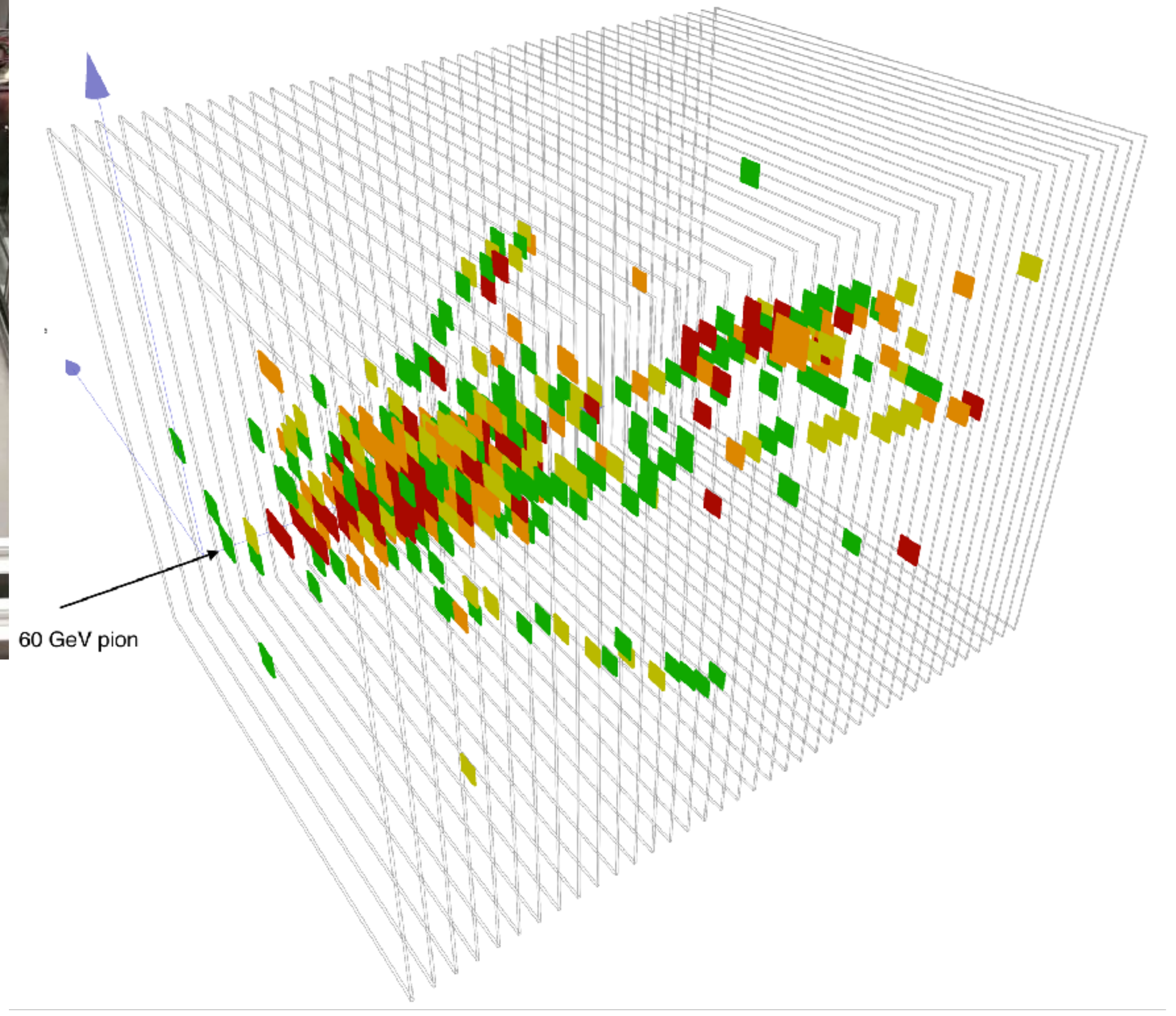
- Spokesperson of the CALICE collaboration
- Member of the CLICdp Executive Team
- Member of the ILC Physics Group

Outline: The Projects in the Group

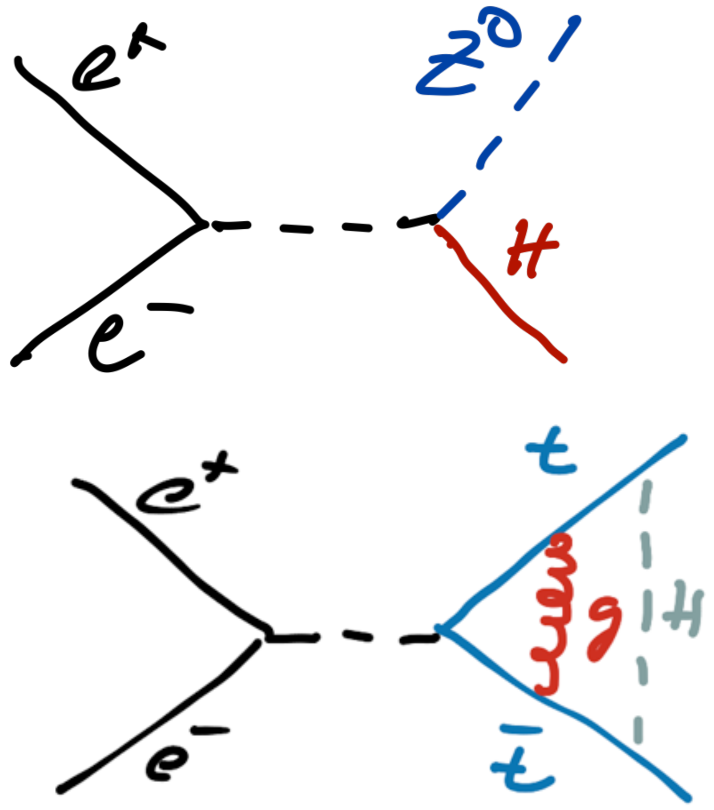
Focus on Detector Development and Physics Studies

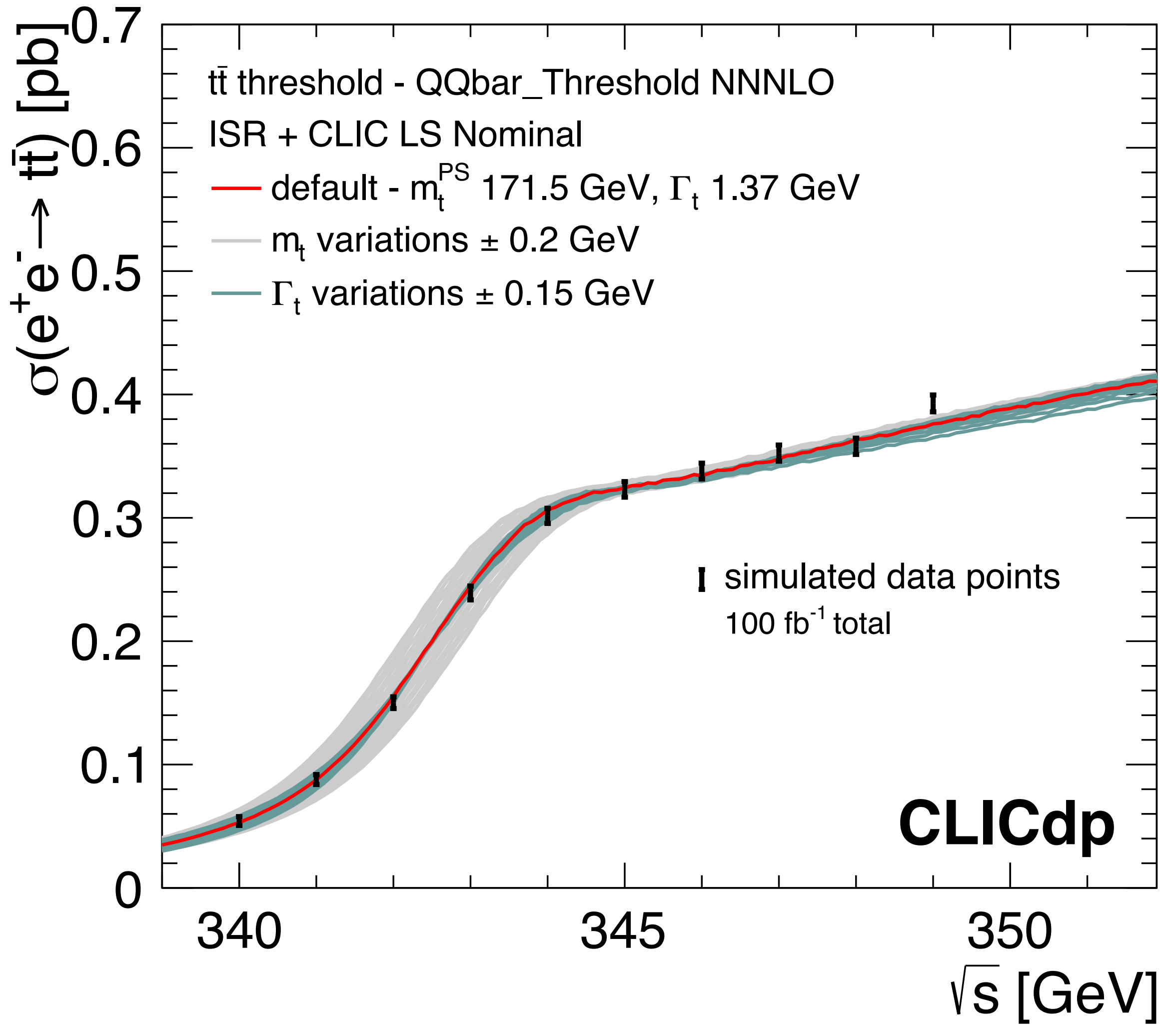
Highly granular calorimeters





Physics at e+e- Colliders





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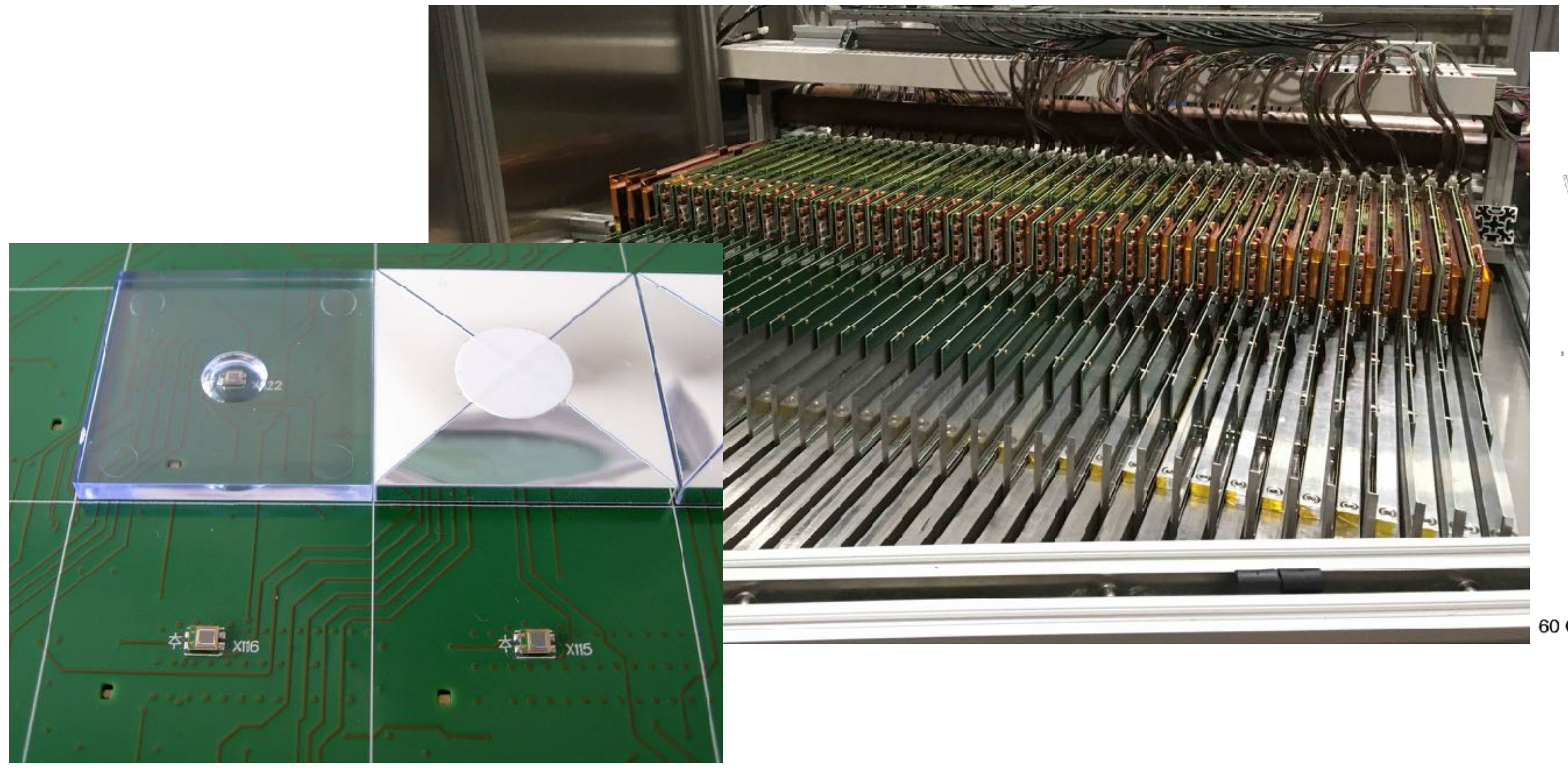

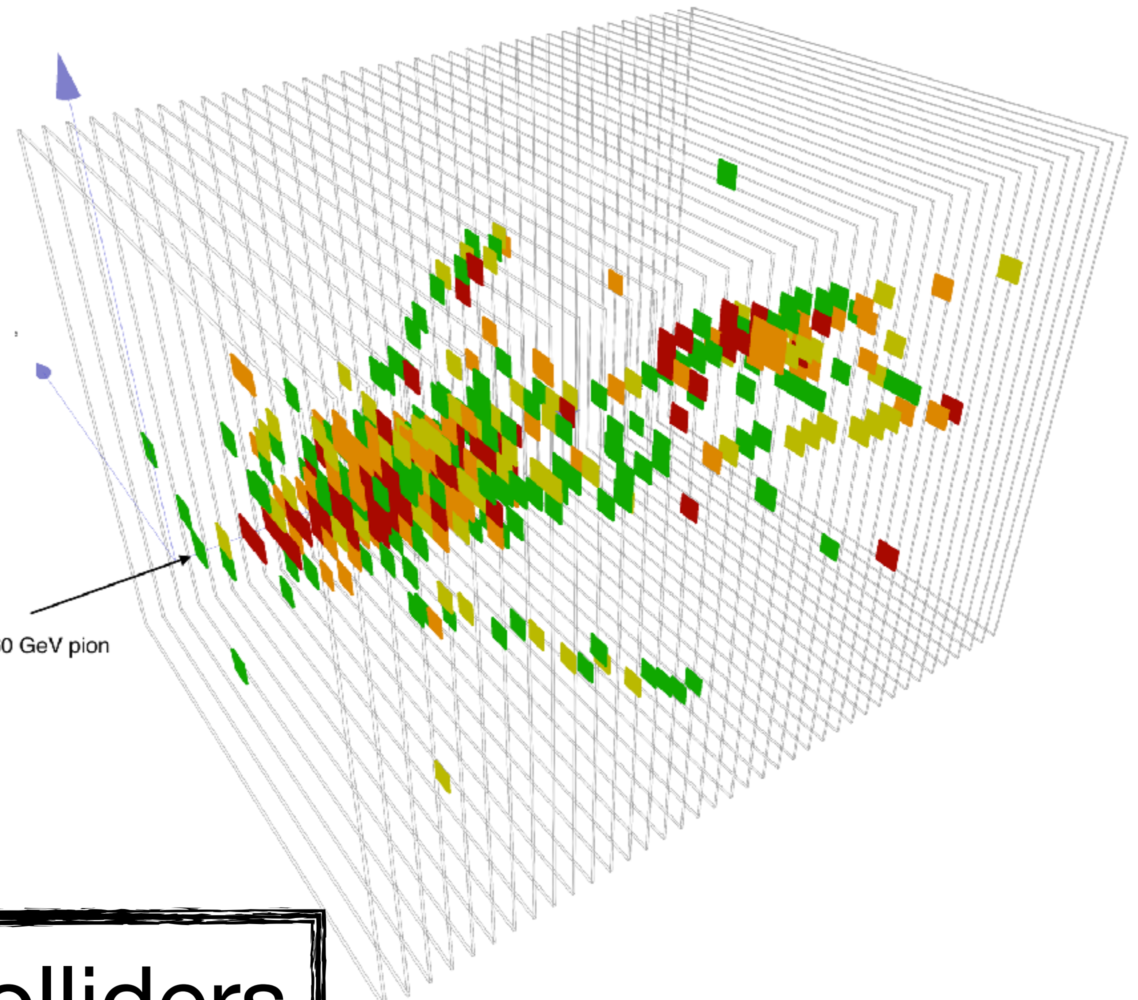

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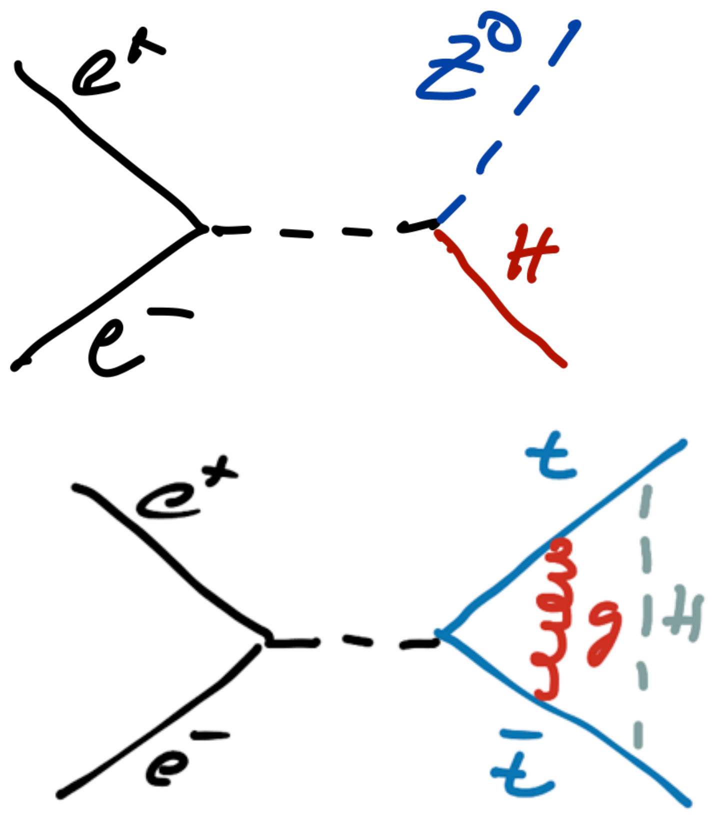
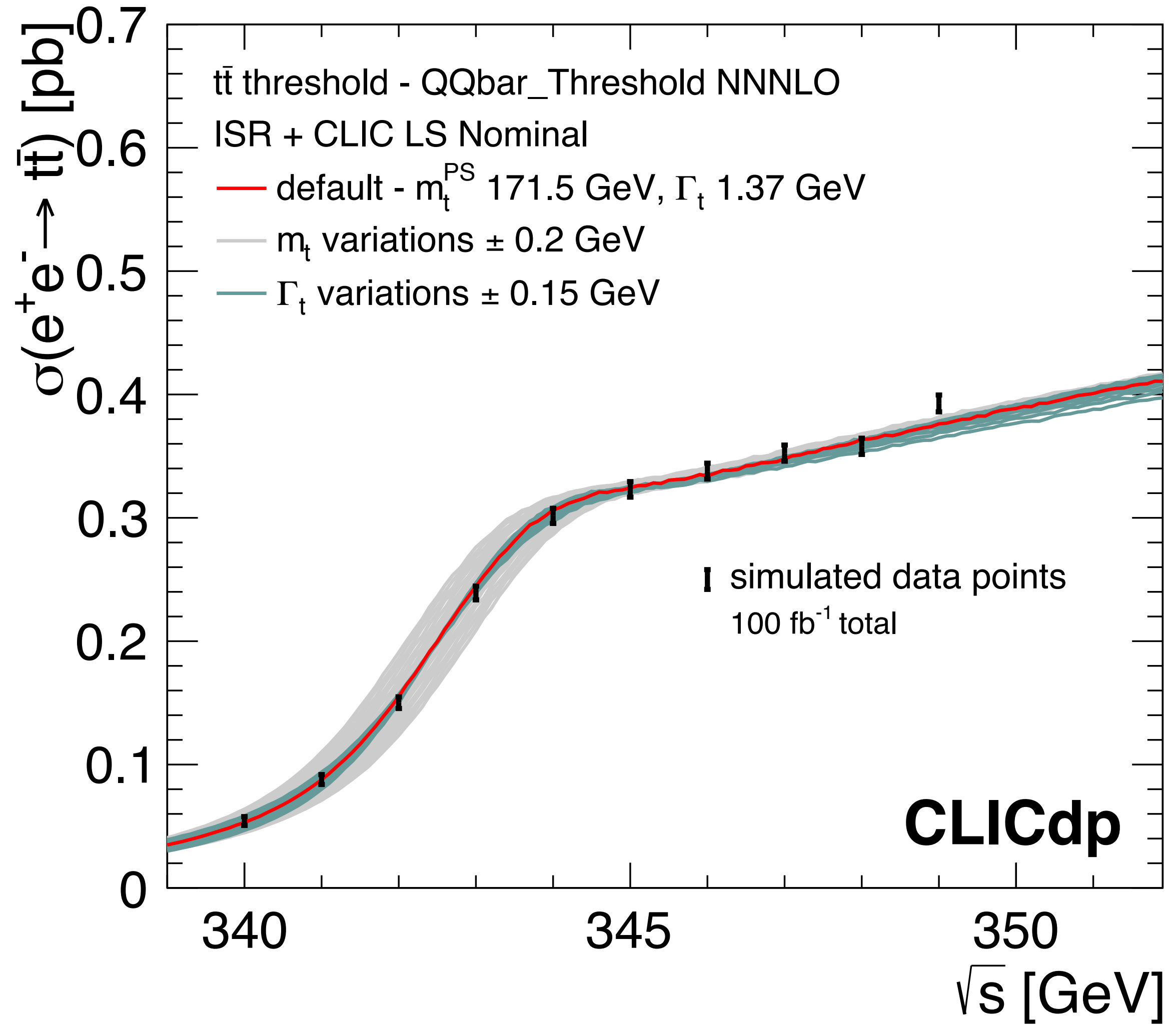
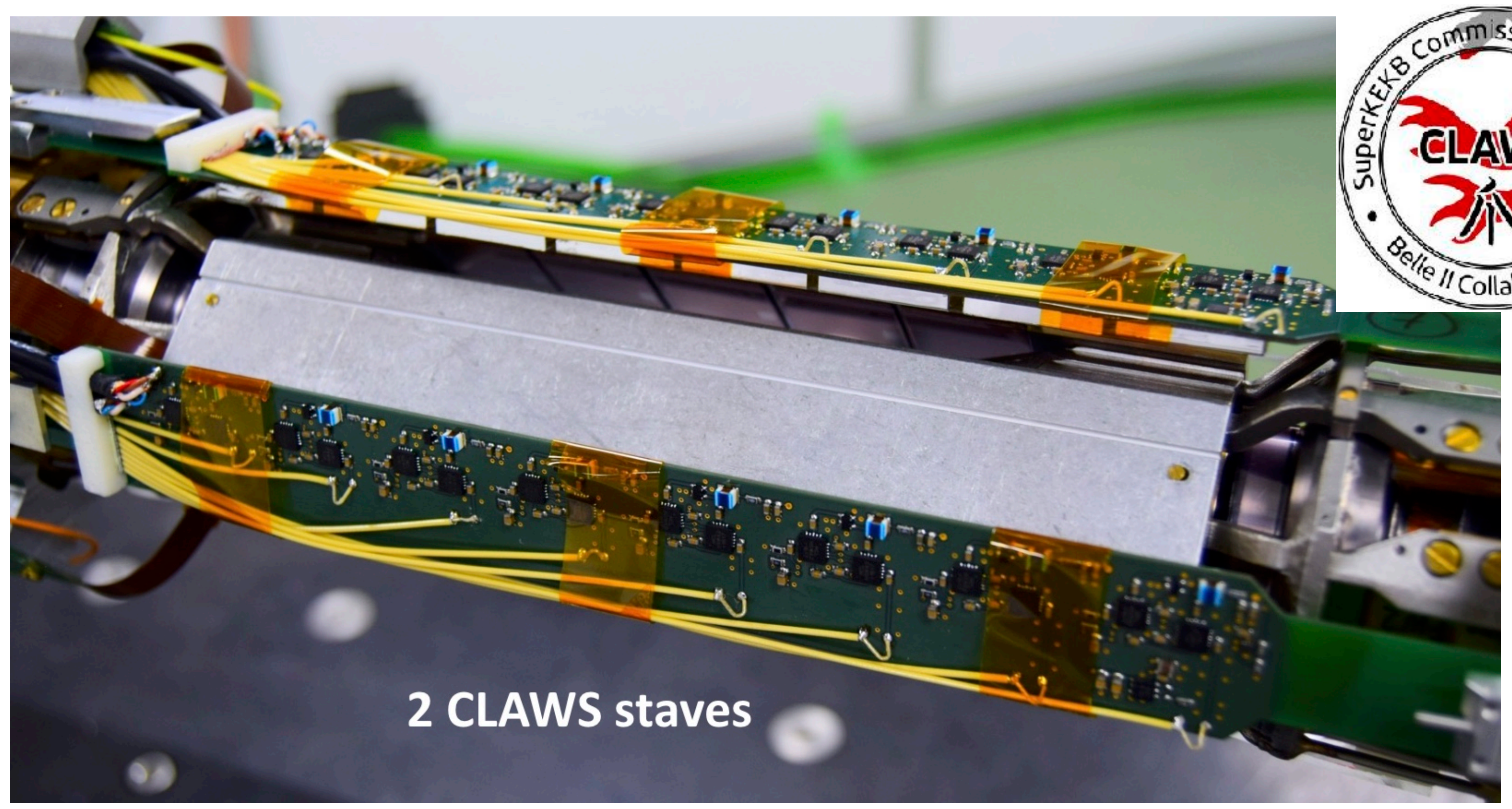
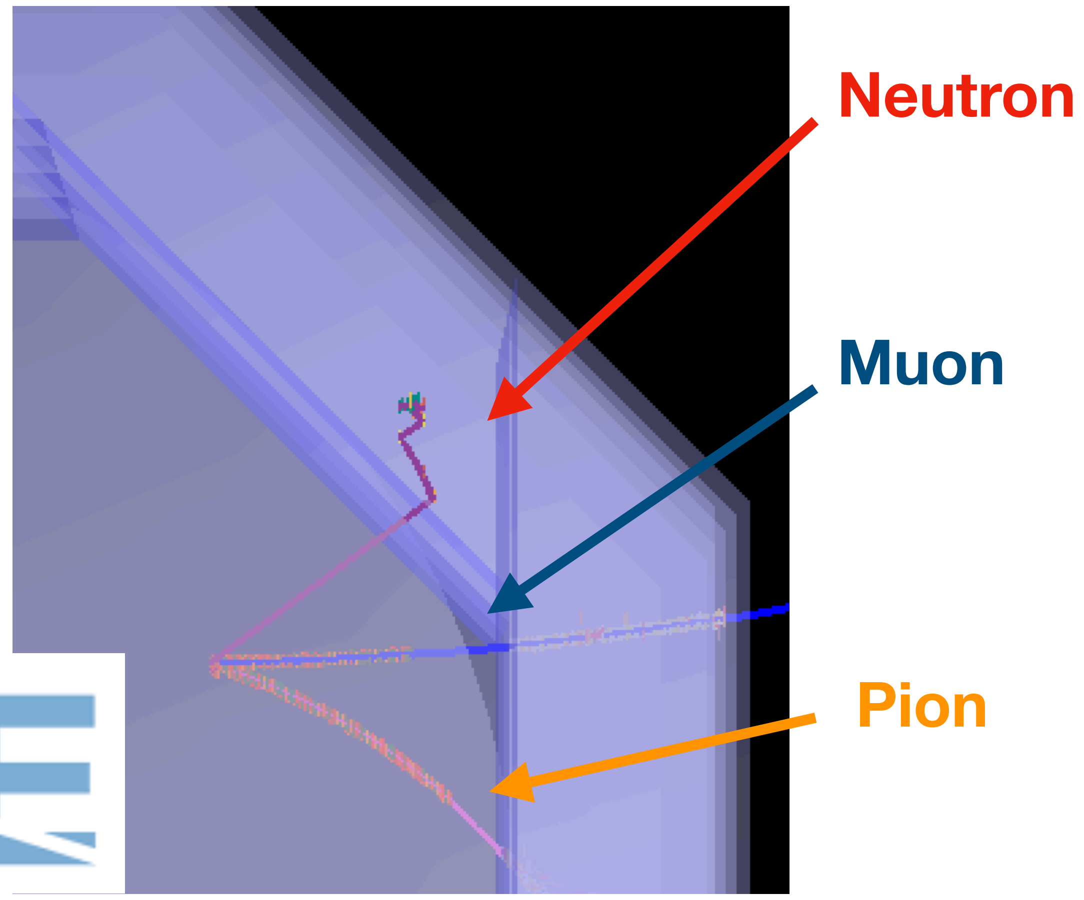




CALICE Technologies beyond Linear Colliders

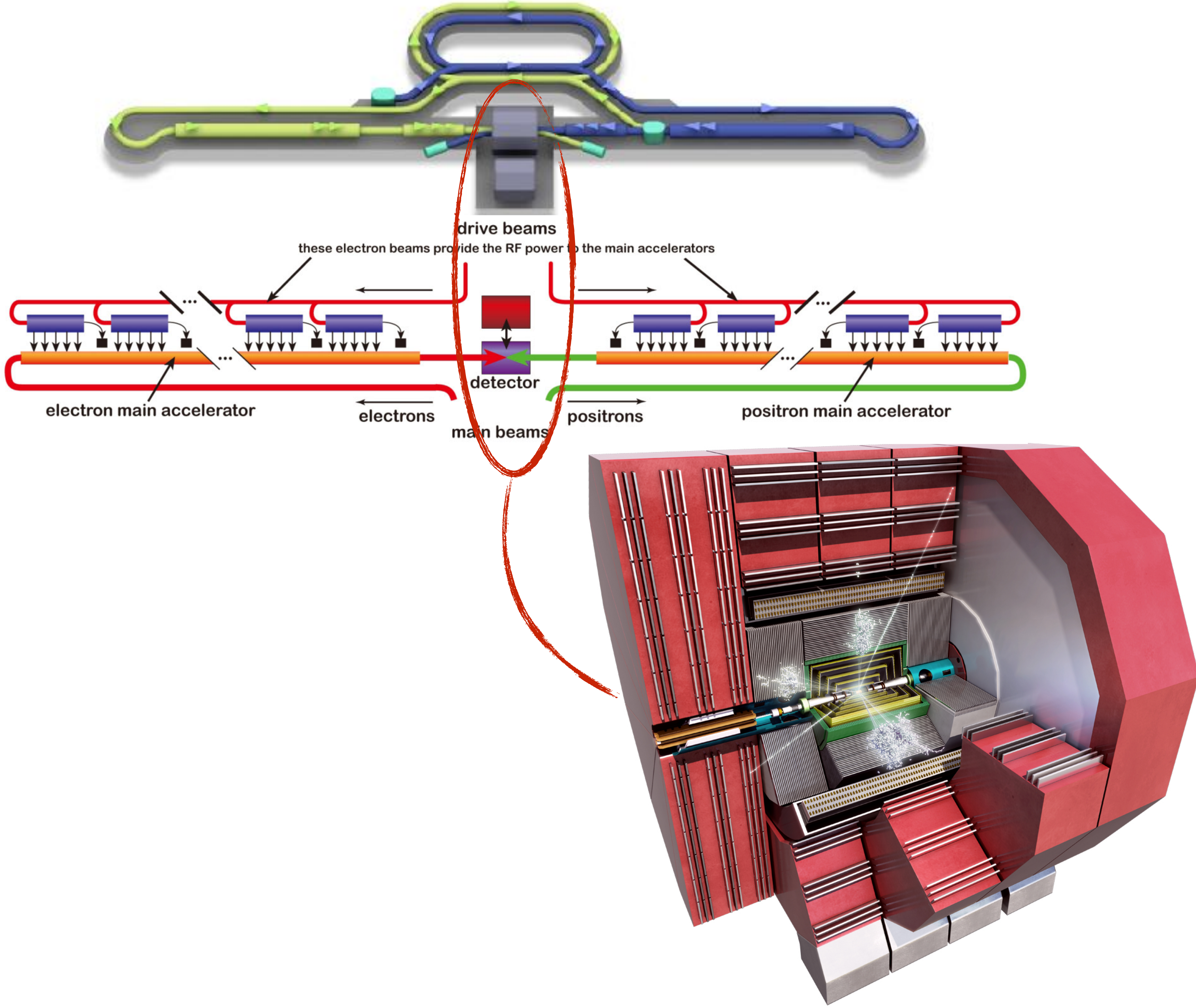




The Context: Future e+e- Colliders and Beyond

Accelerator-based Precision Experiments with Leptons

- The main driver of the activities:
  Experiments at future linear colliders
  - **ILC**: 250 GeV (500 GeV with upgrade) under discussion in Japan
  - **CLIC**: Staged machine, 380 GeV - 3 TeV a possible future project at CERN



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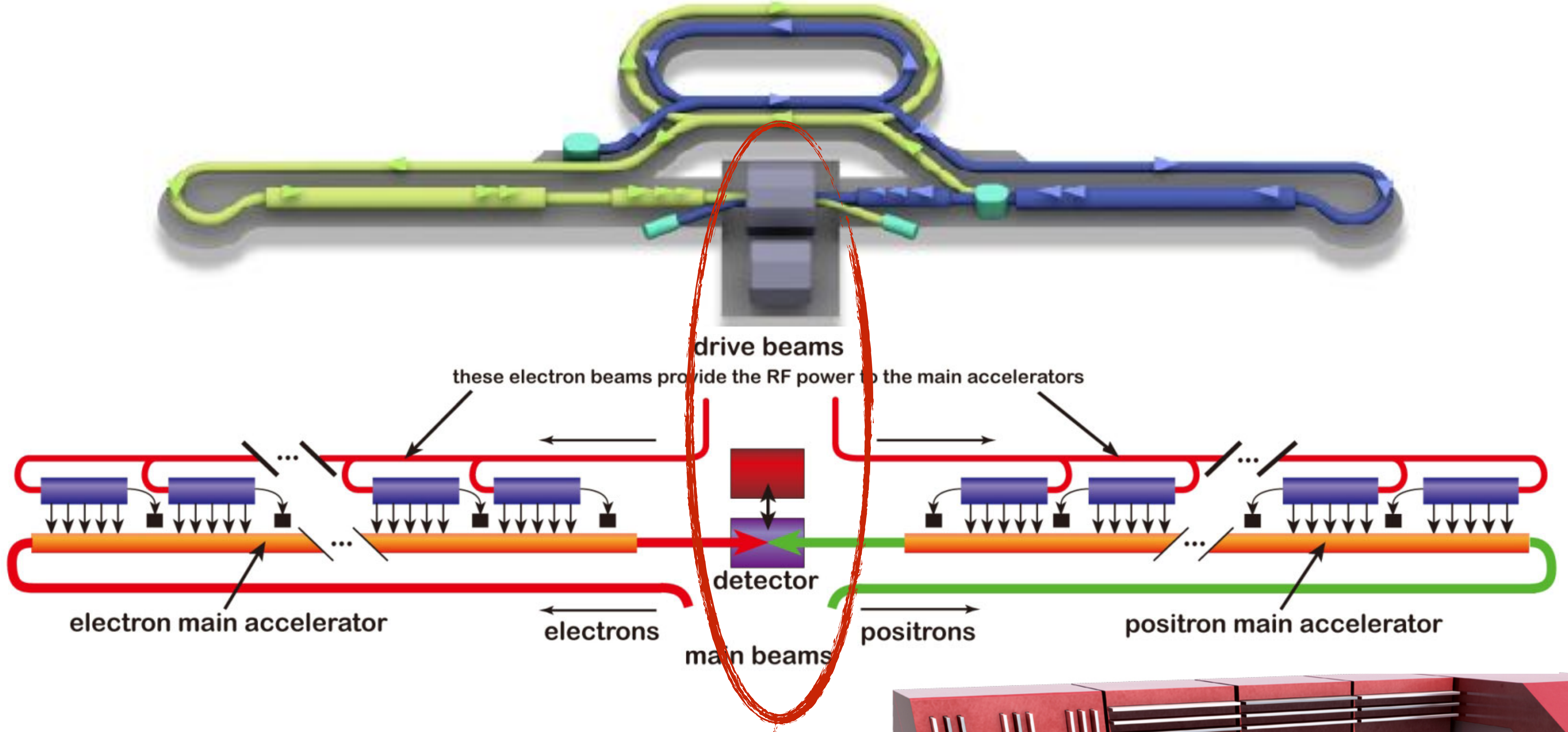

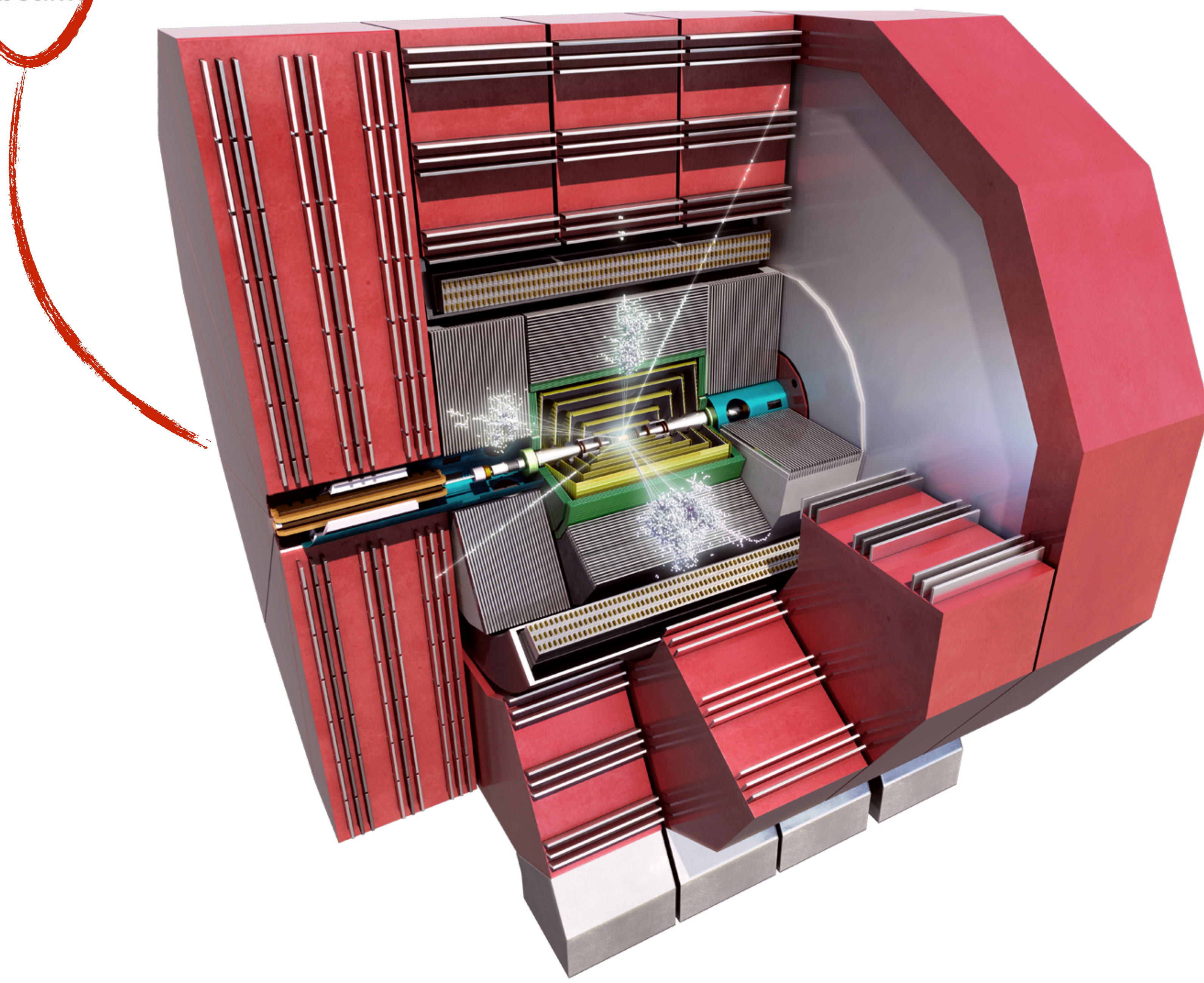

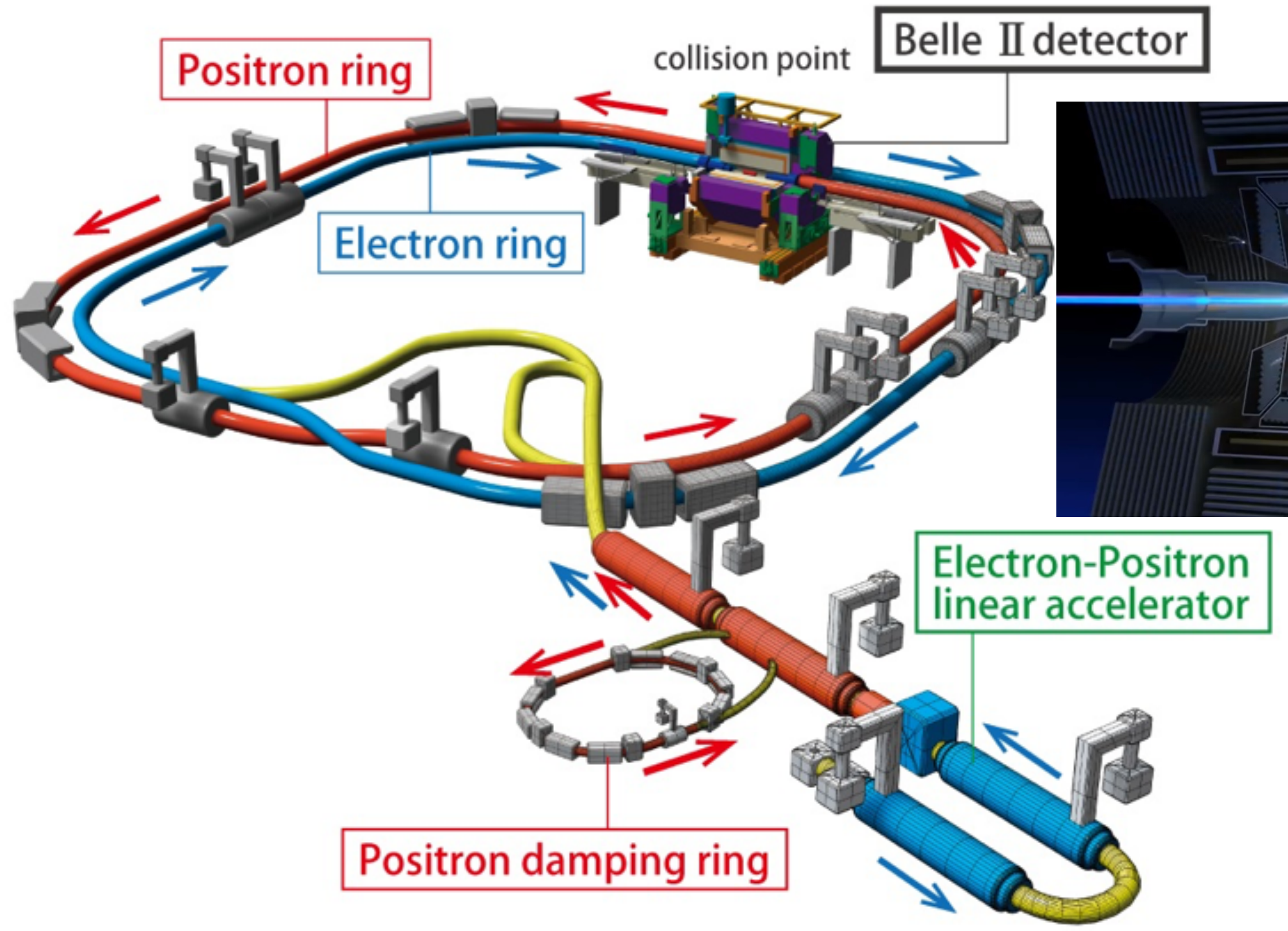

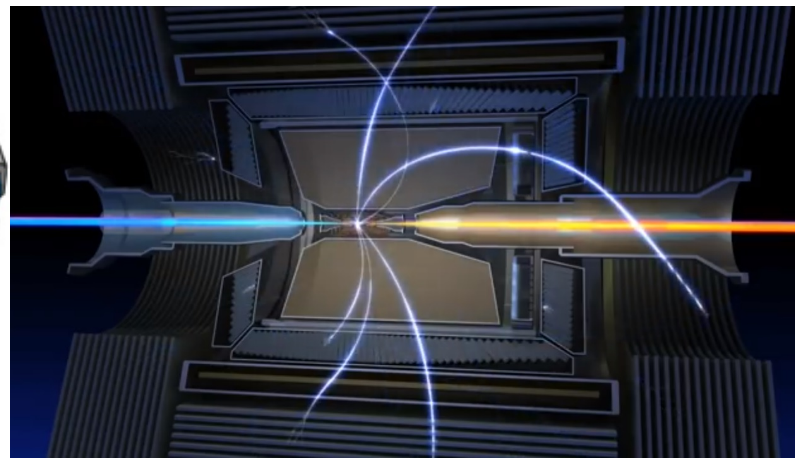

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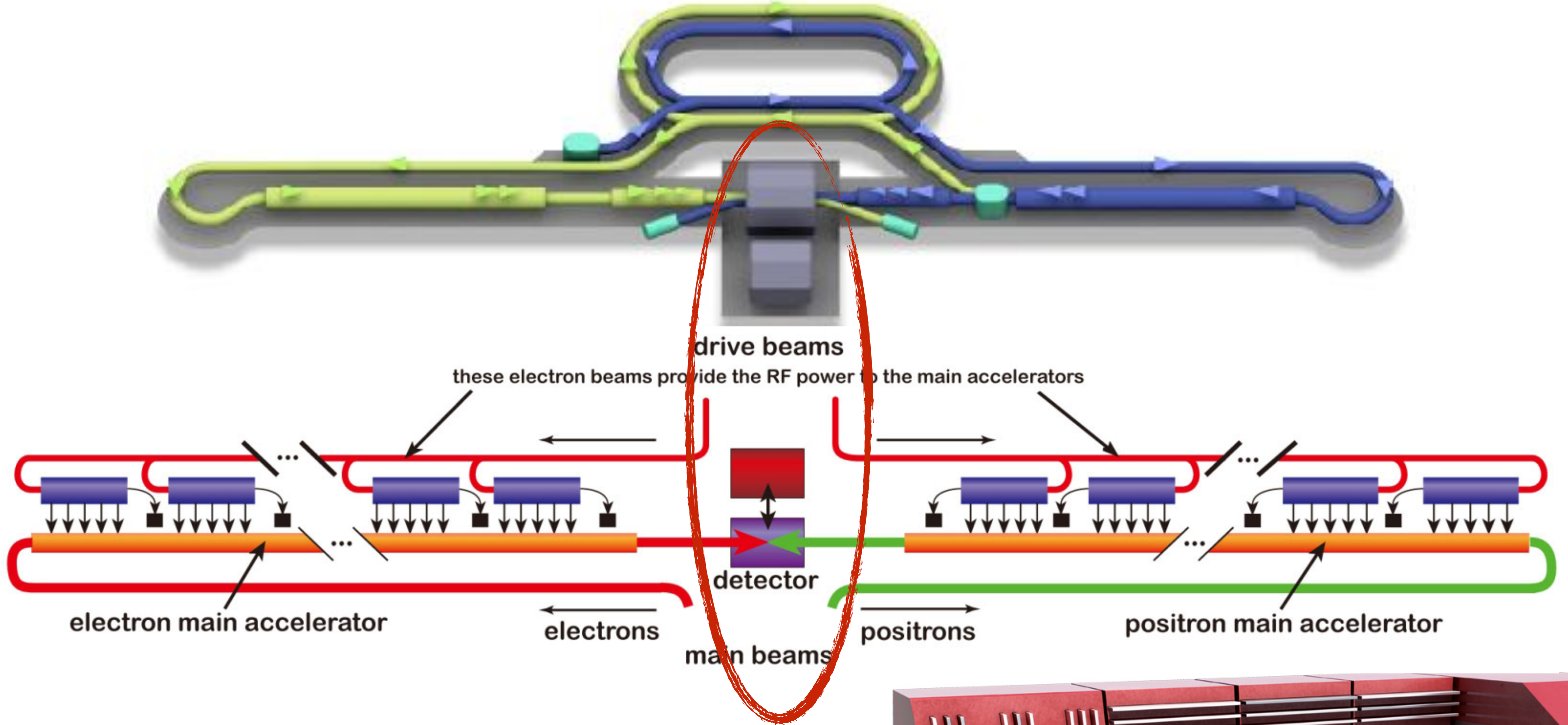

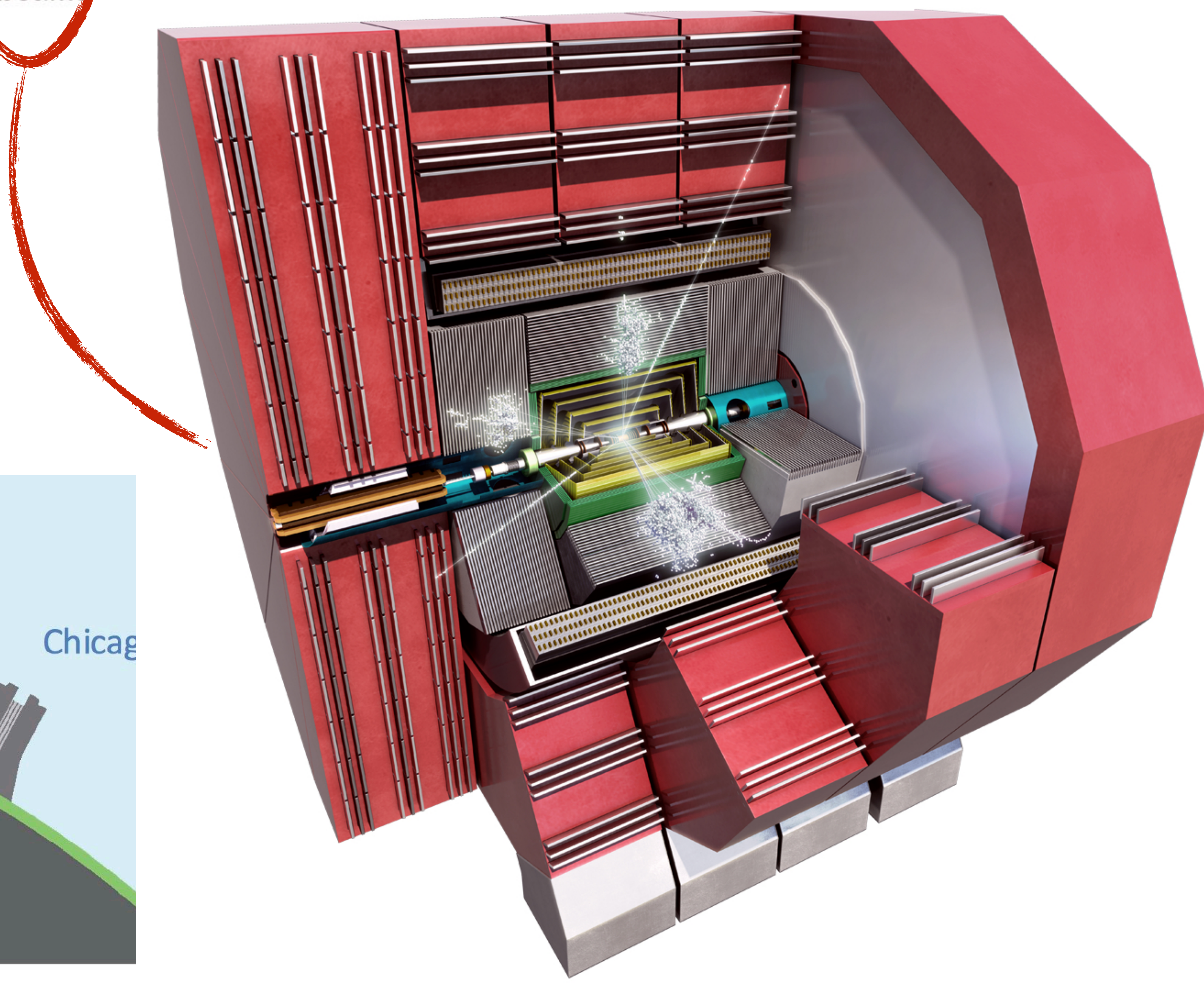

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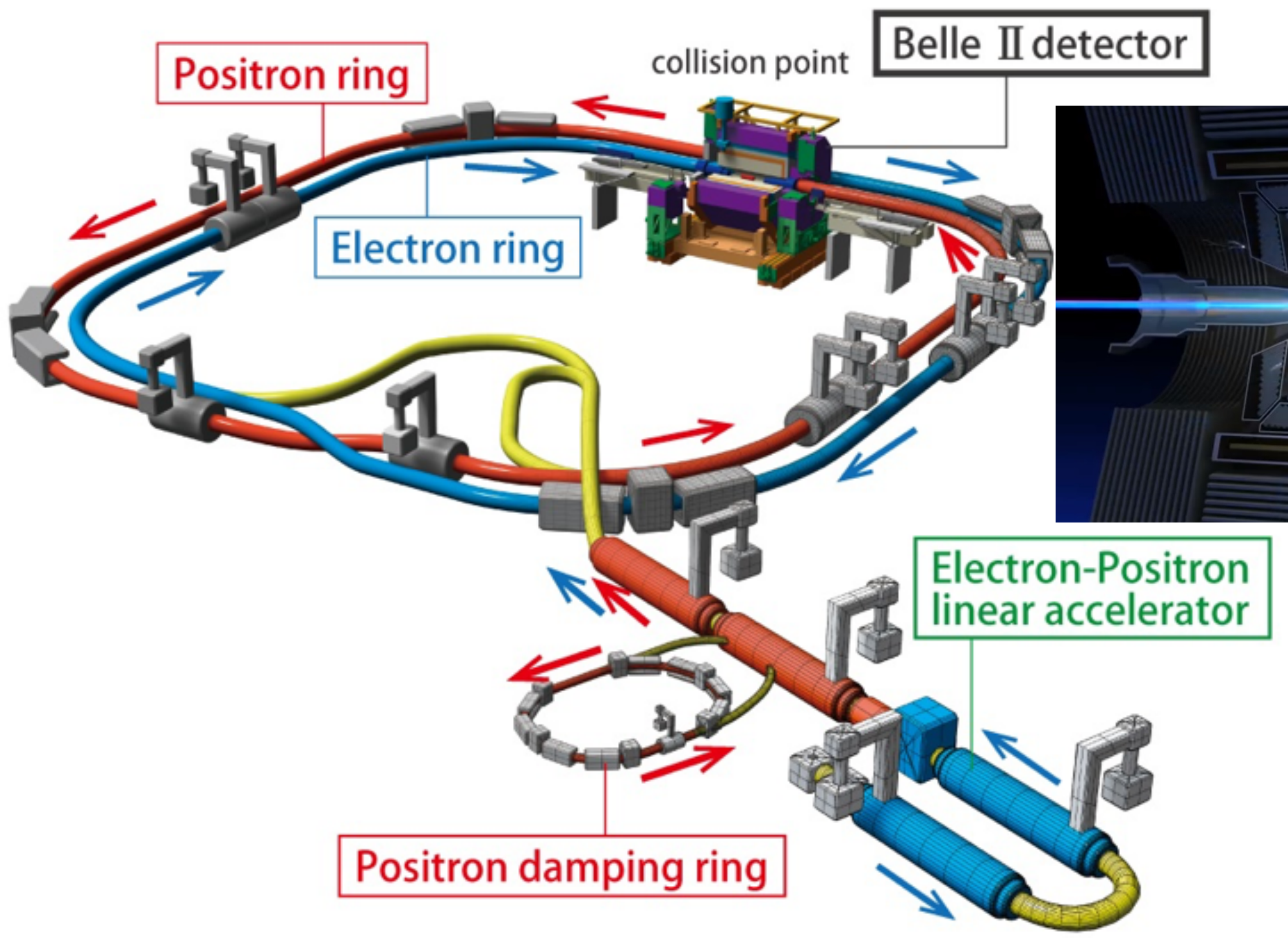
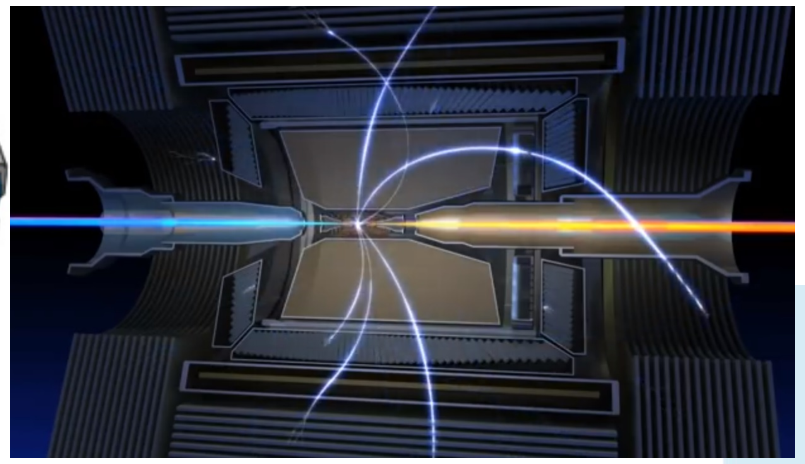
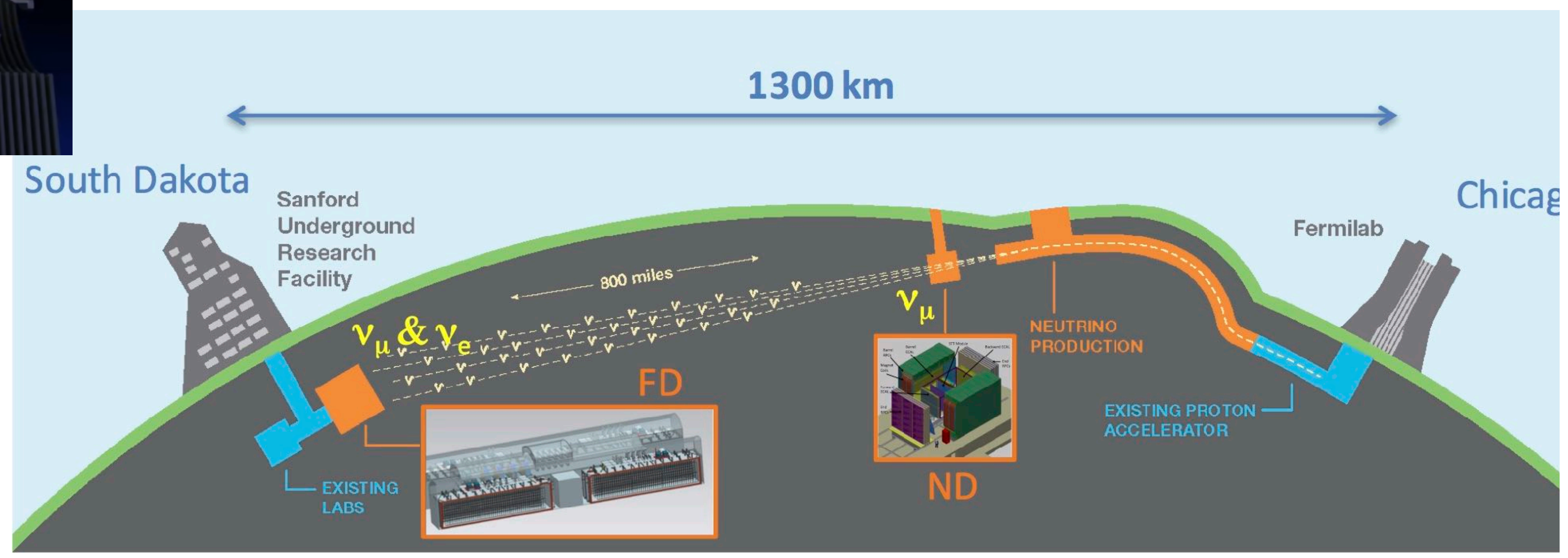




- The long baseline neutrino experiment **DUNE**



The CALICE AHCAL Prototype

Constructed by German CALICE Groups

- Demonstration of scintillator-based imaging calorimetry with the “Physics Prototype” (data taking 2007-2011)
- Development and improvement of individual components: Scintillator tiles, ASICs, photon sensors …

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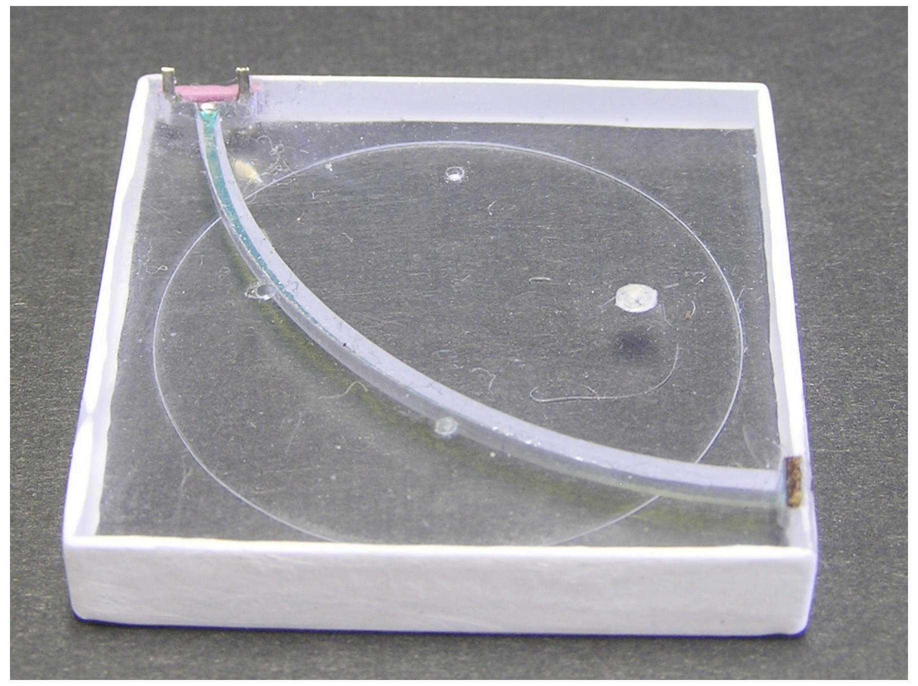

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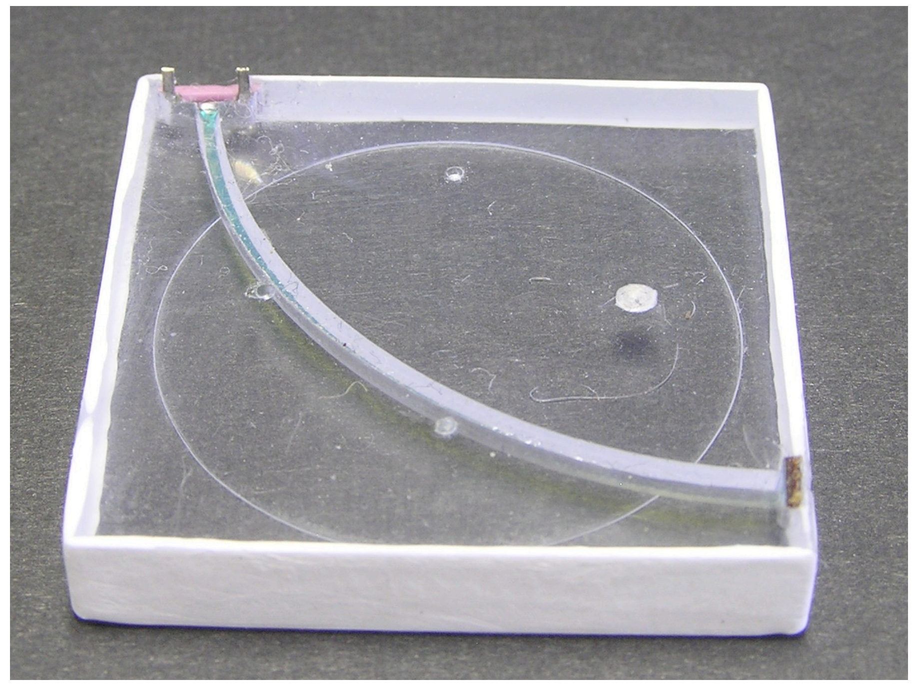

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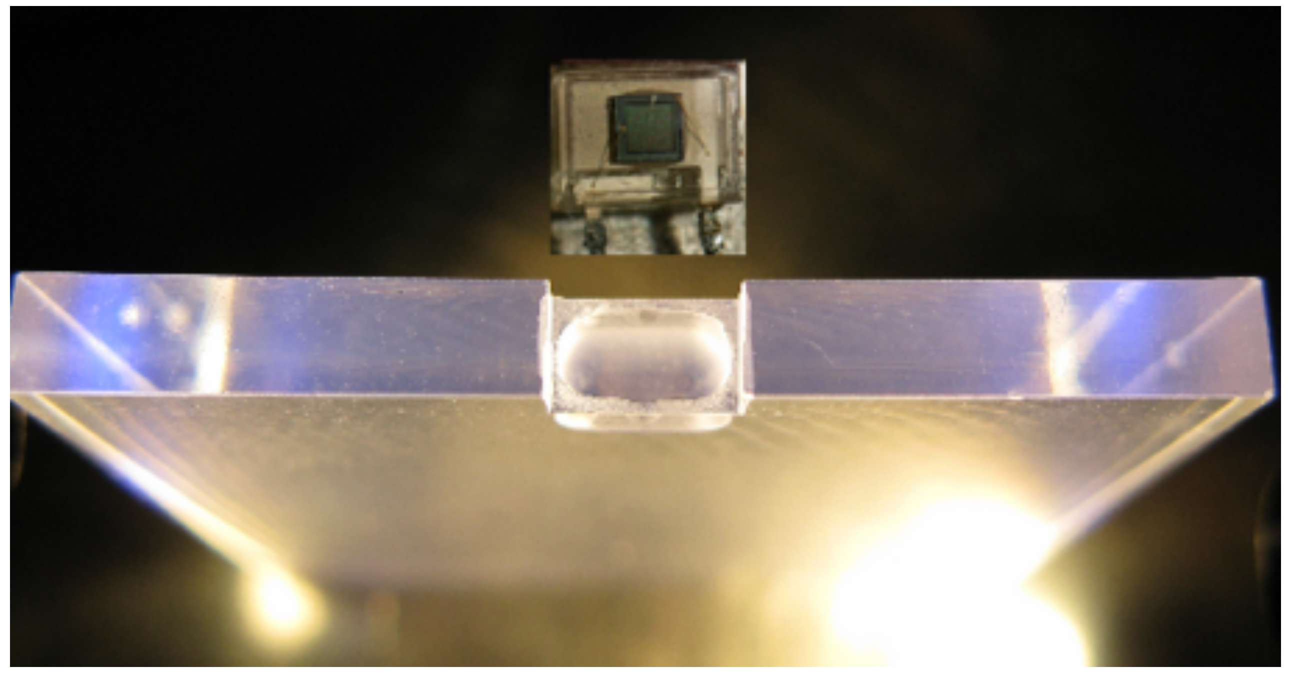

Direct coupling of tiles and photon sensors

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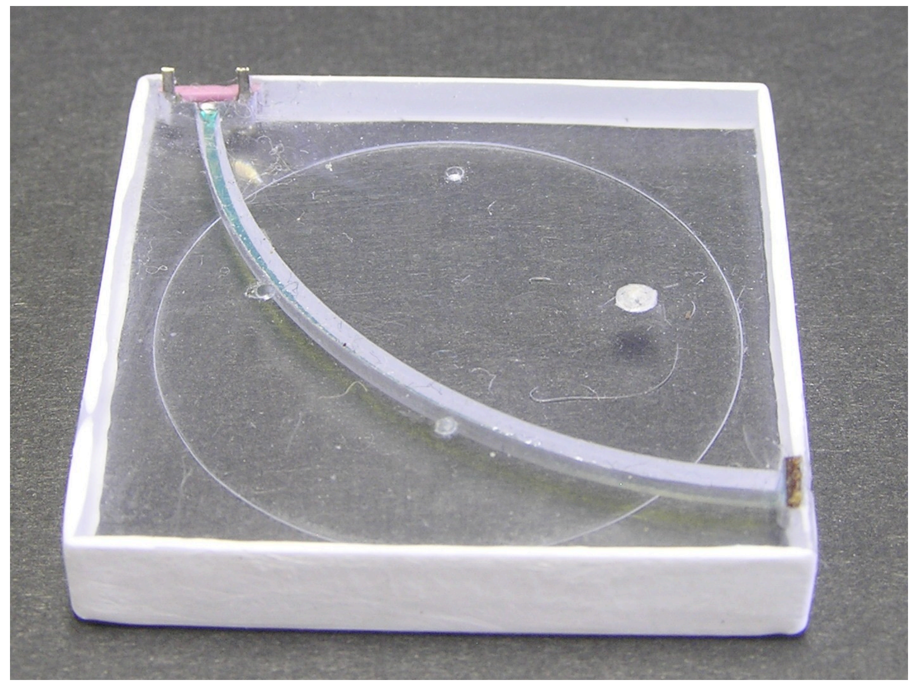

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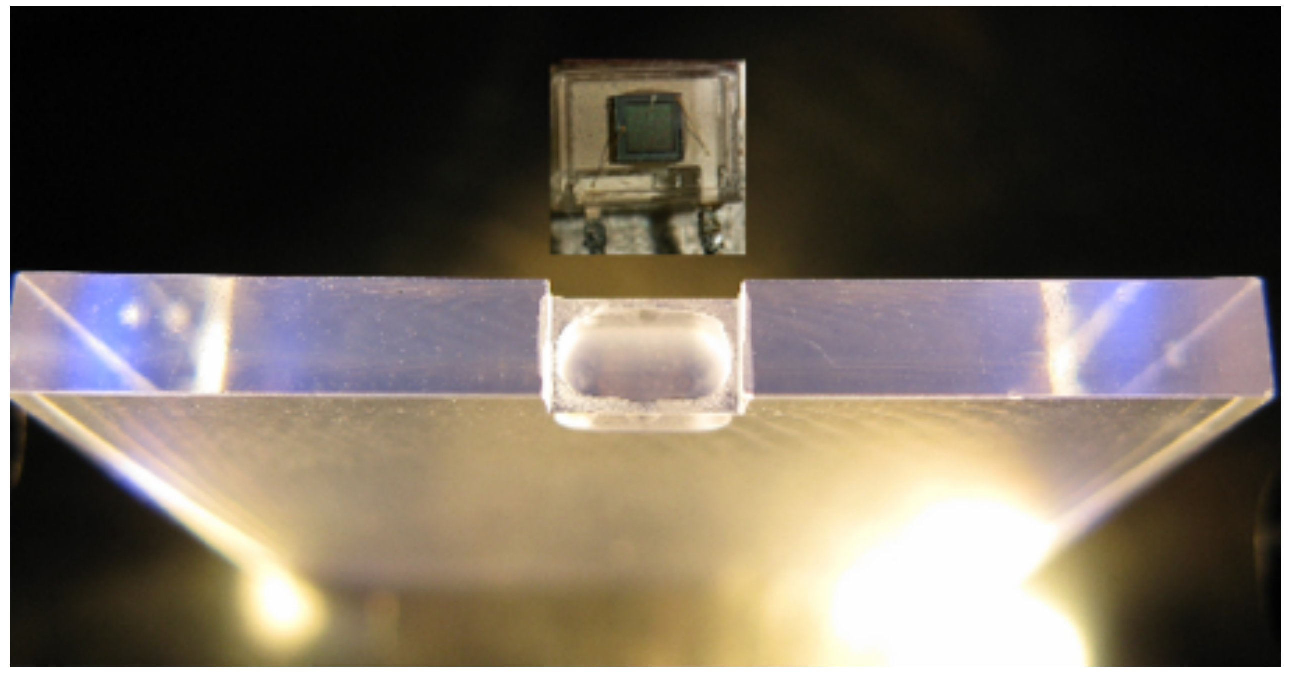

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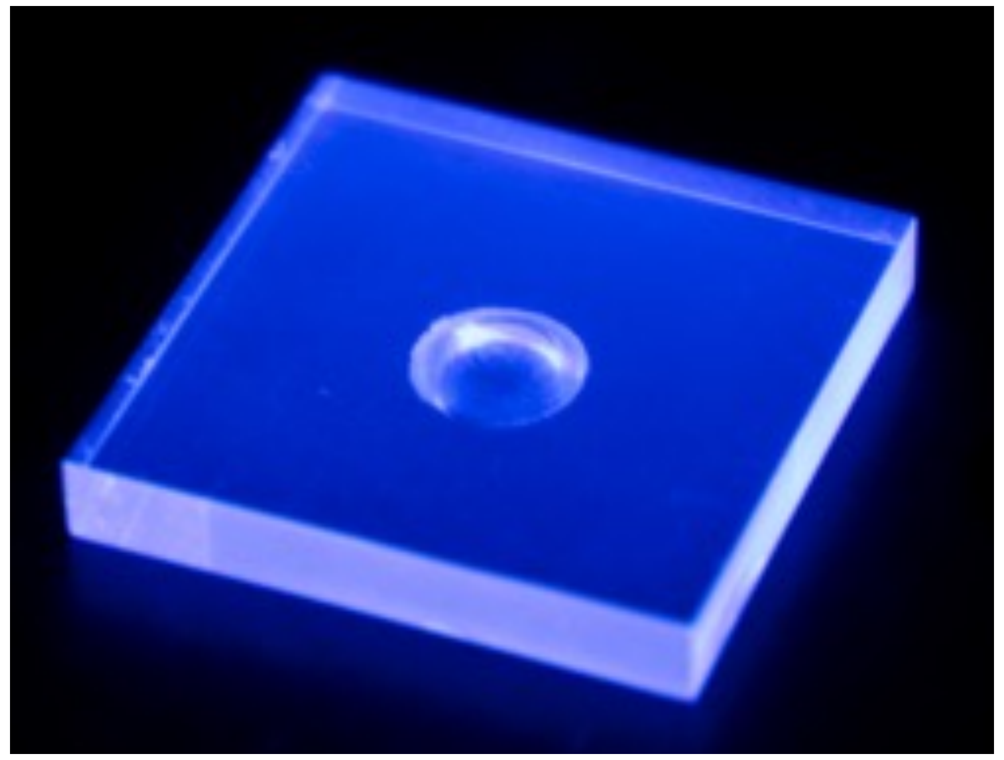

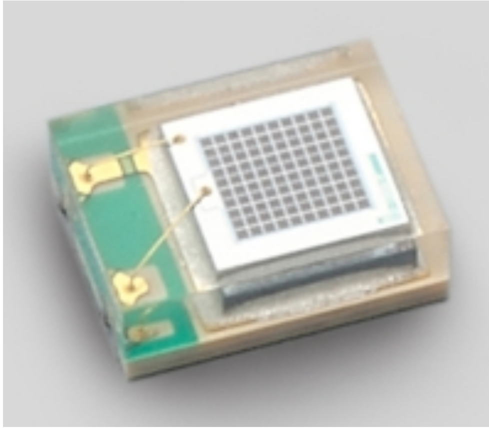

SMD SiPMs, modification of direct coupling

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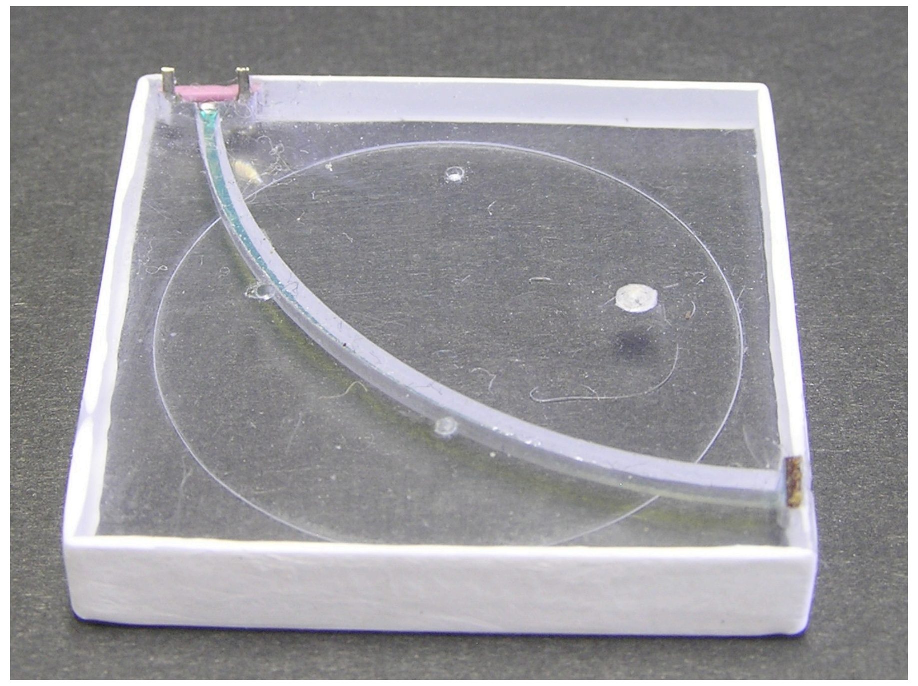

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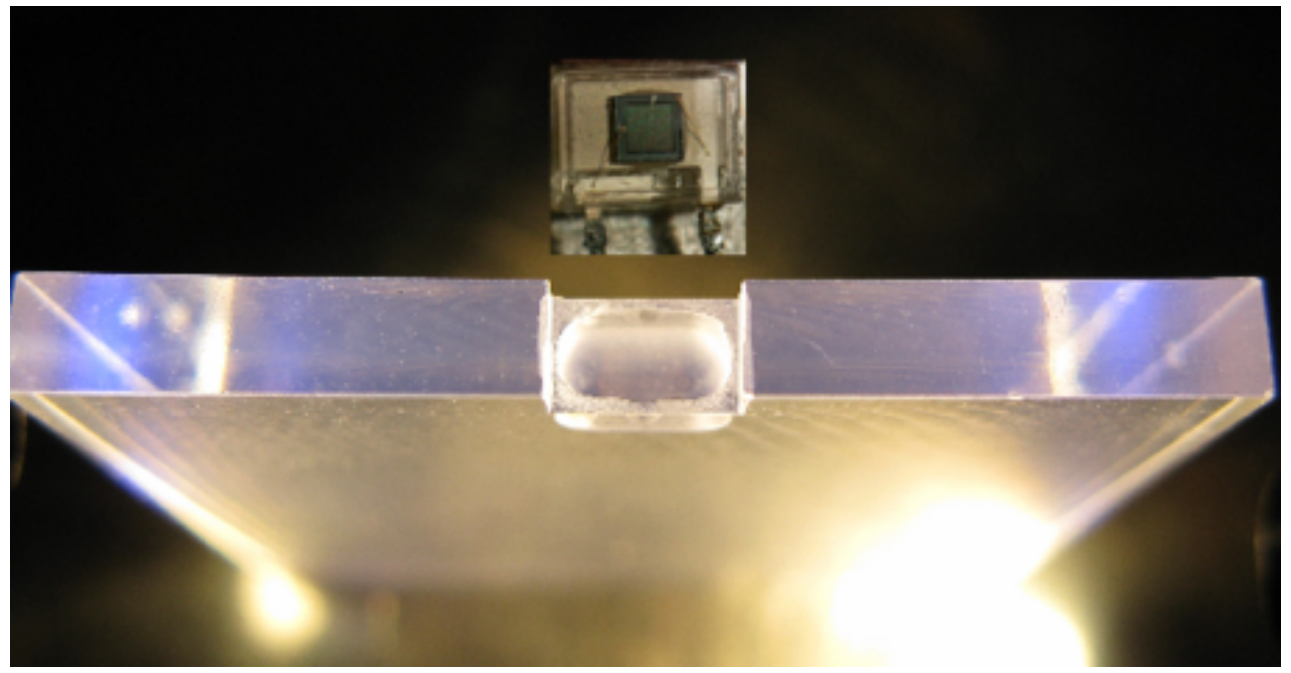

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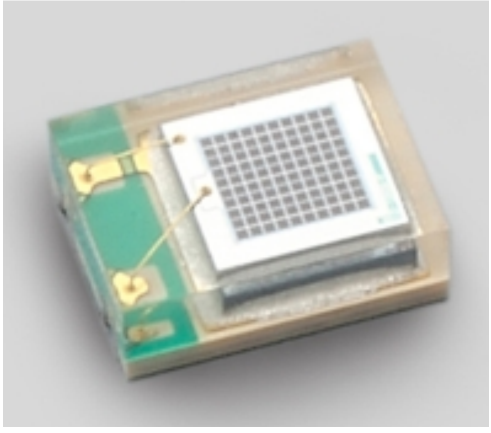

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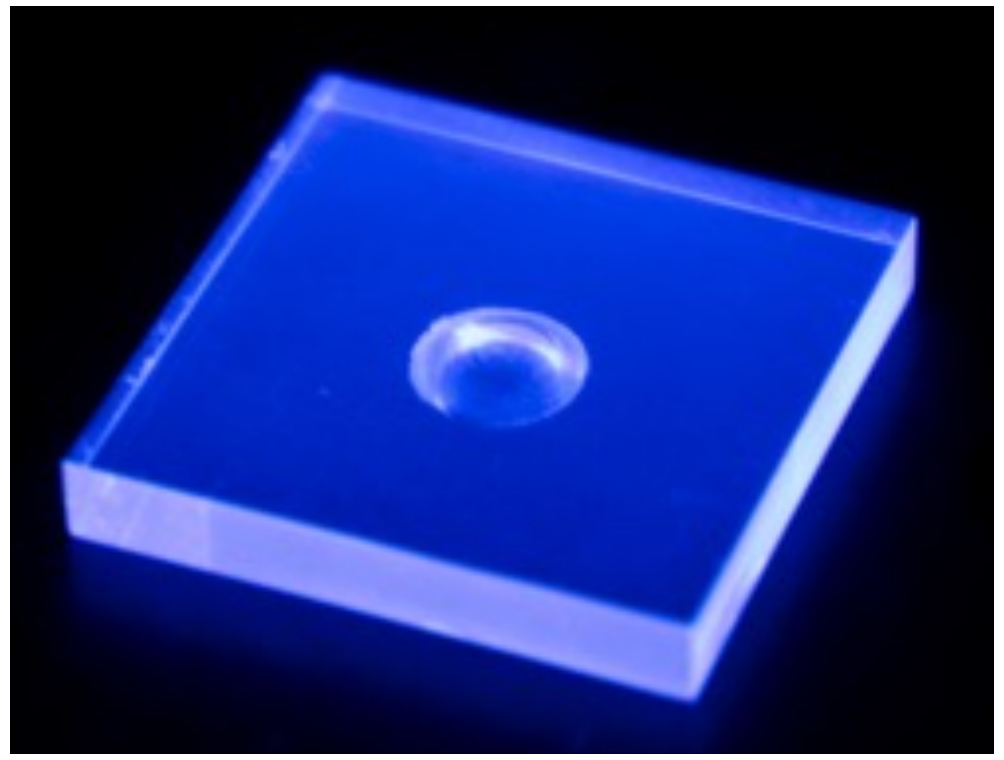

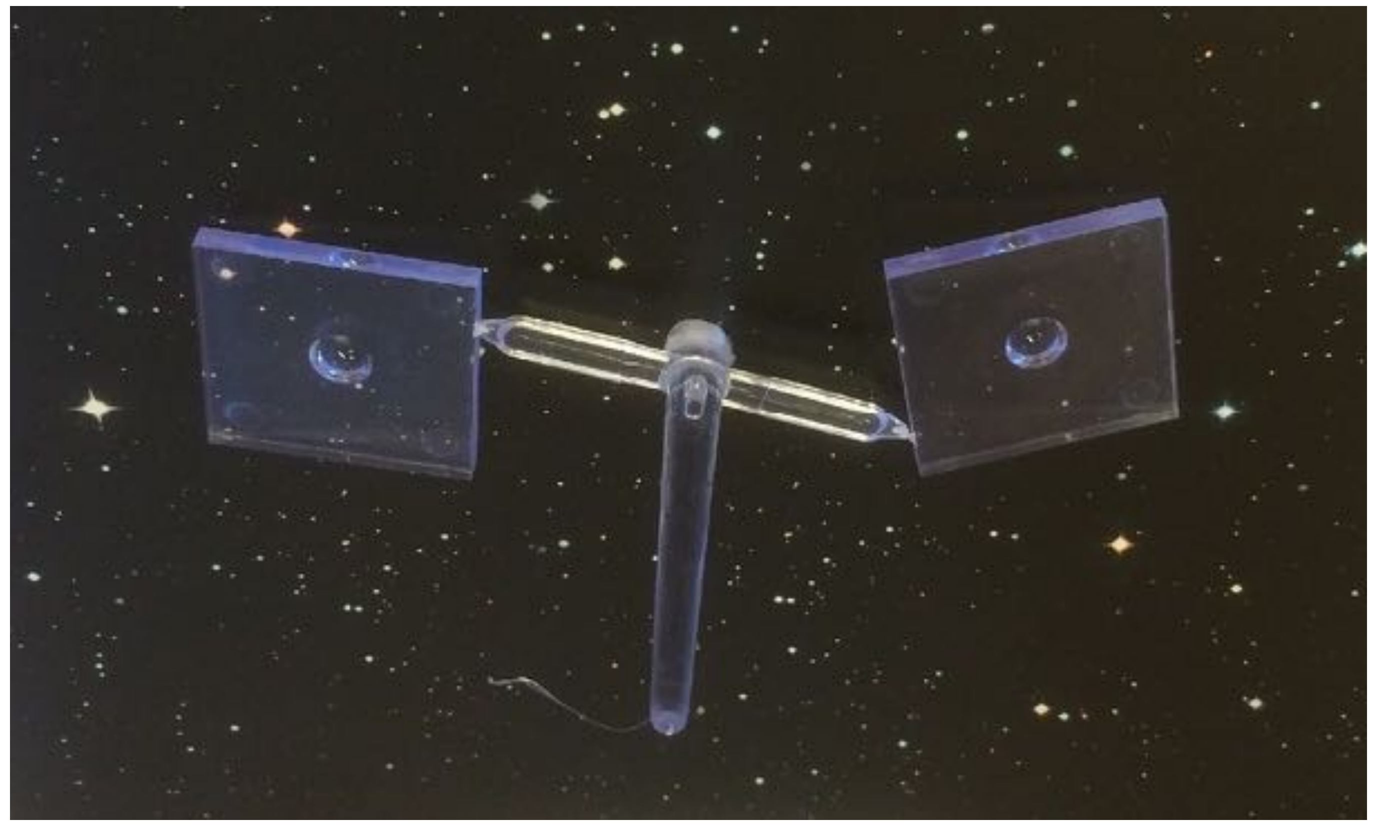

mass production by injection moulding

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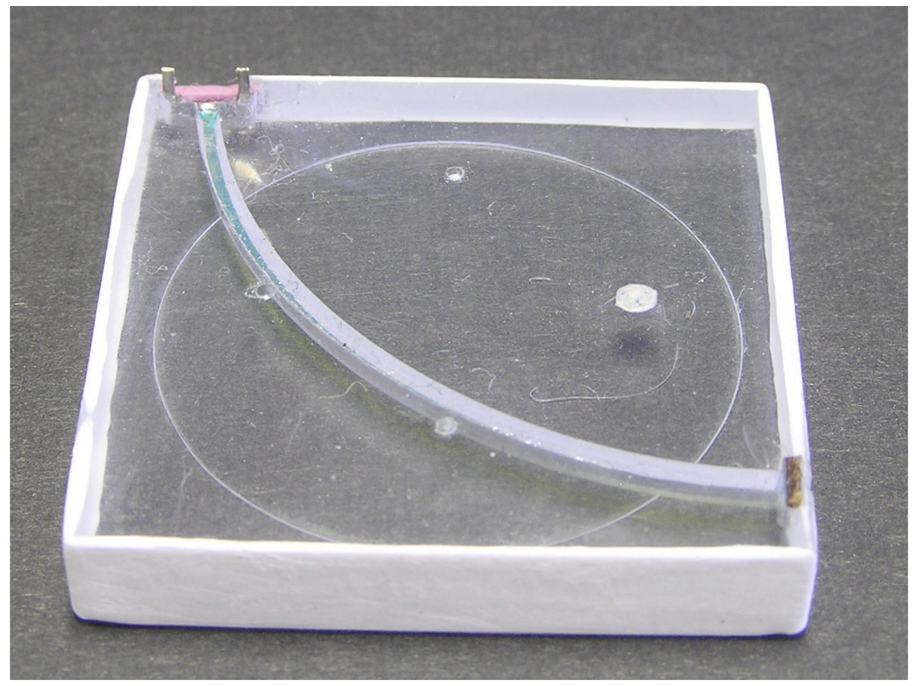

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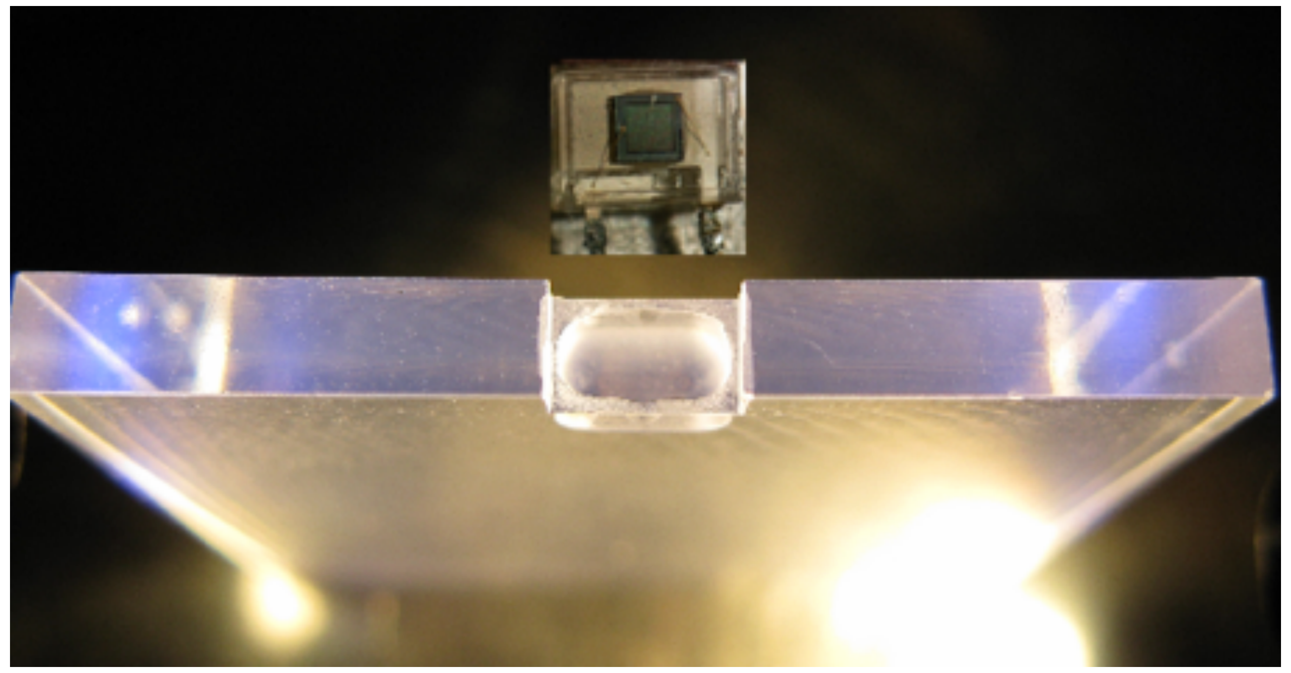

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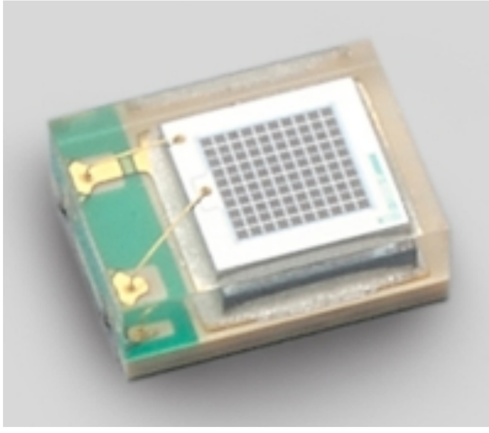

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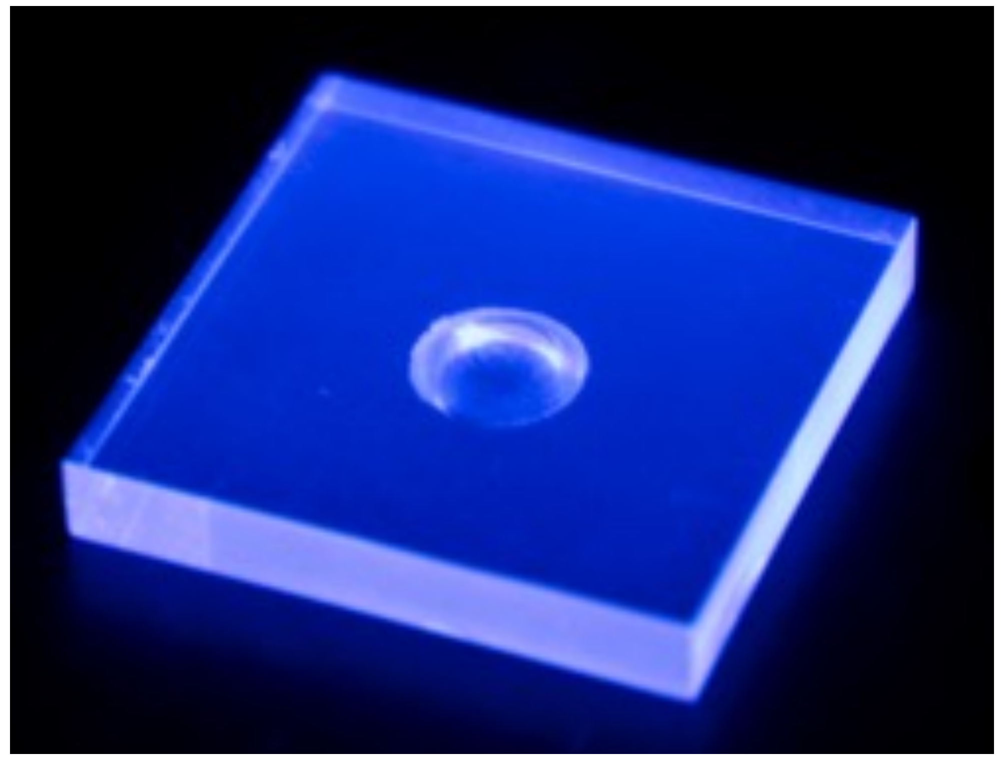

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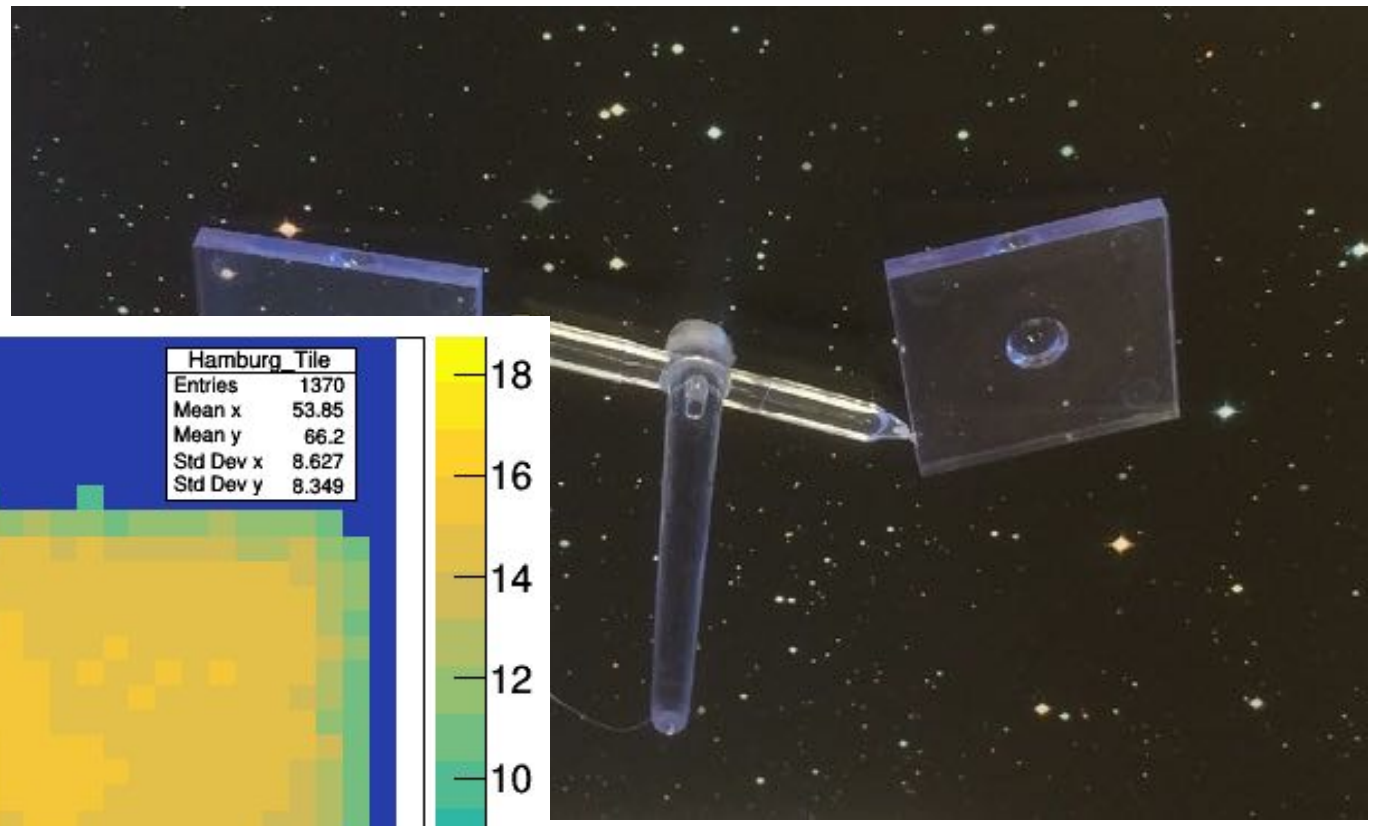

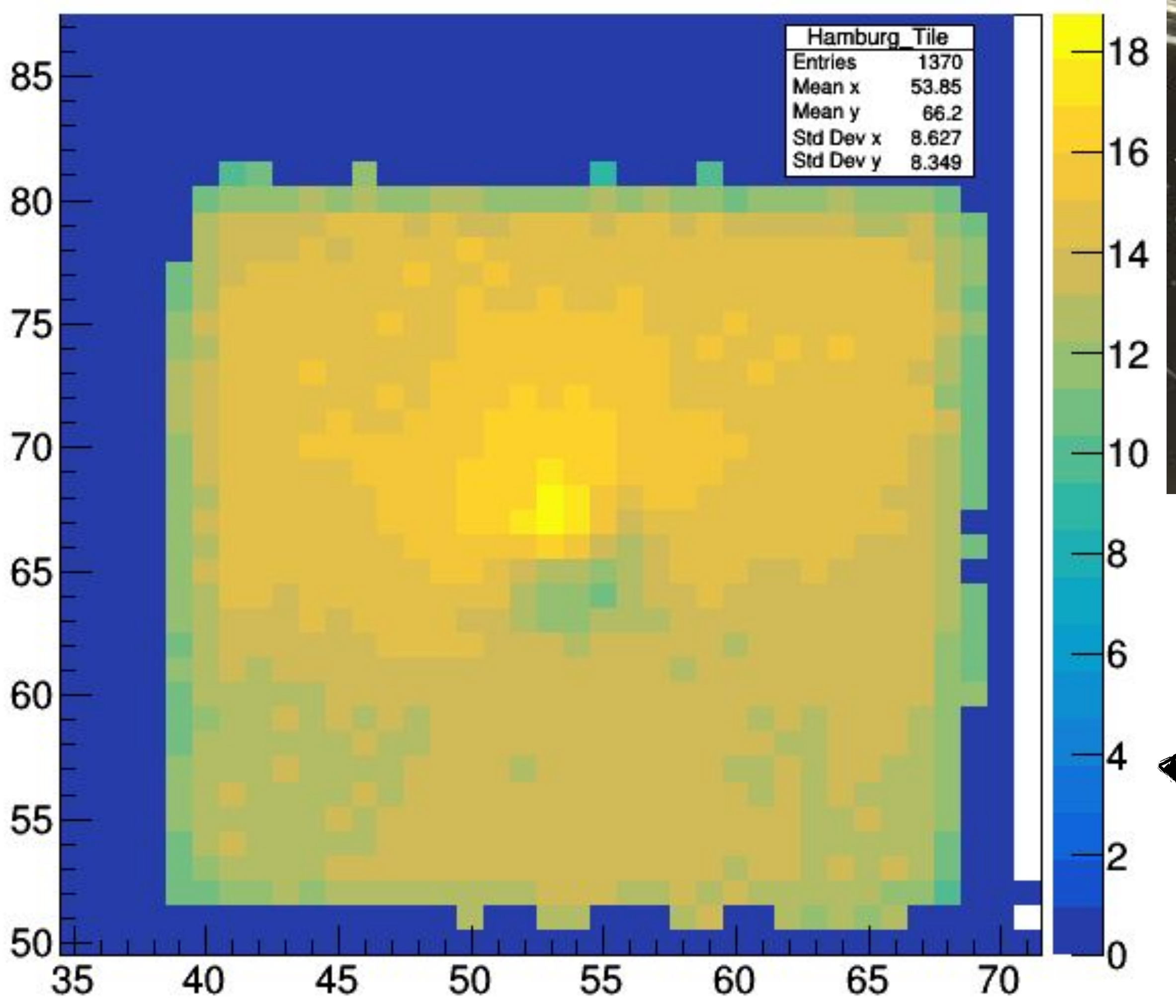

verification of tile performance

The CALICE AHCAL Prototype

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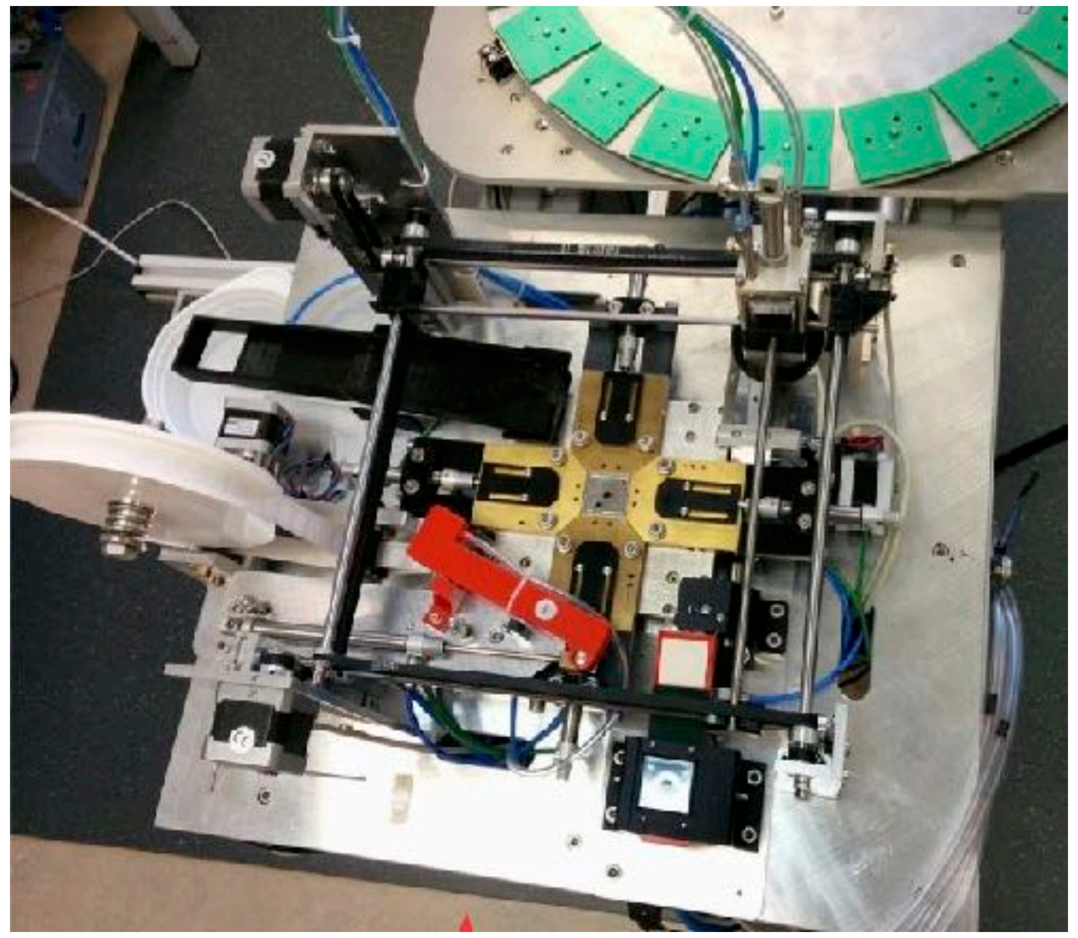
- Mass production, assembly, QA and integration from October 2017 to April 2018

The "***SiPM-on-tile***" technology - mass production



semi-automatic wrapping of 22k scintillator tiles

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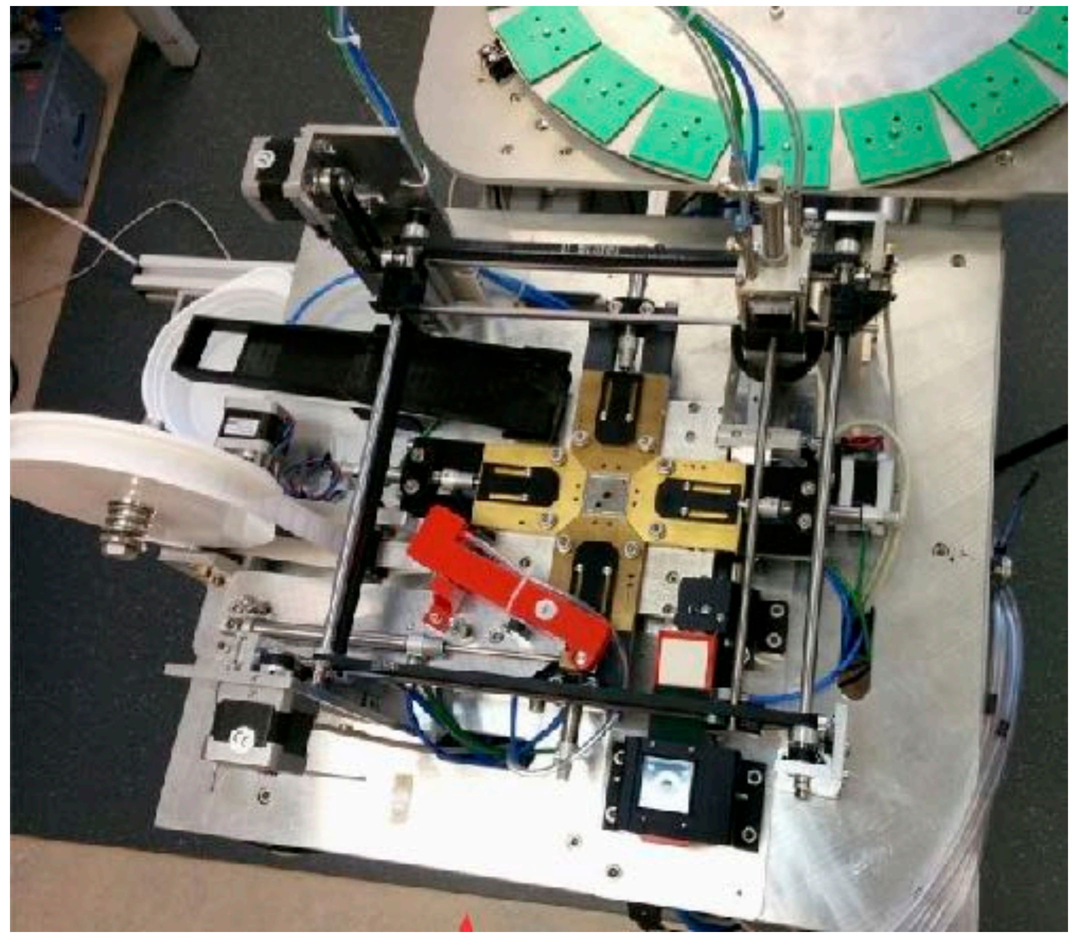

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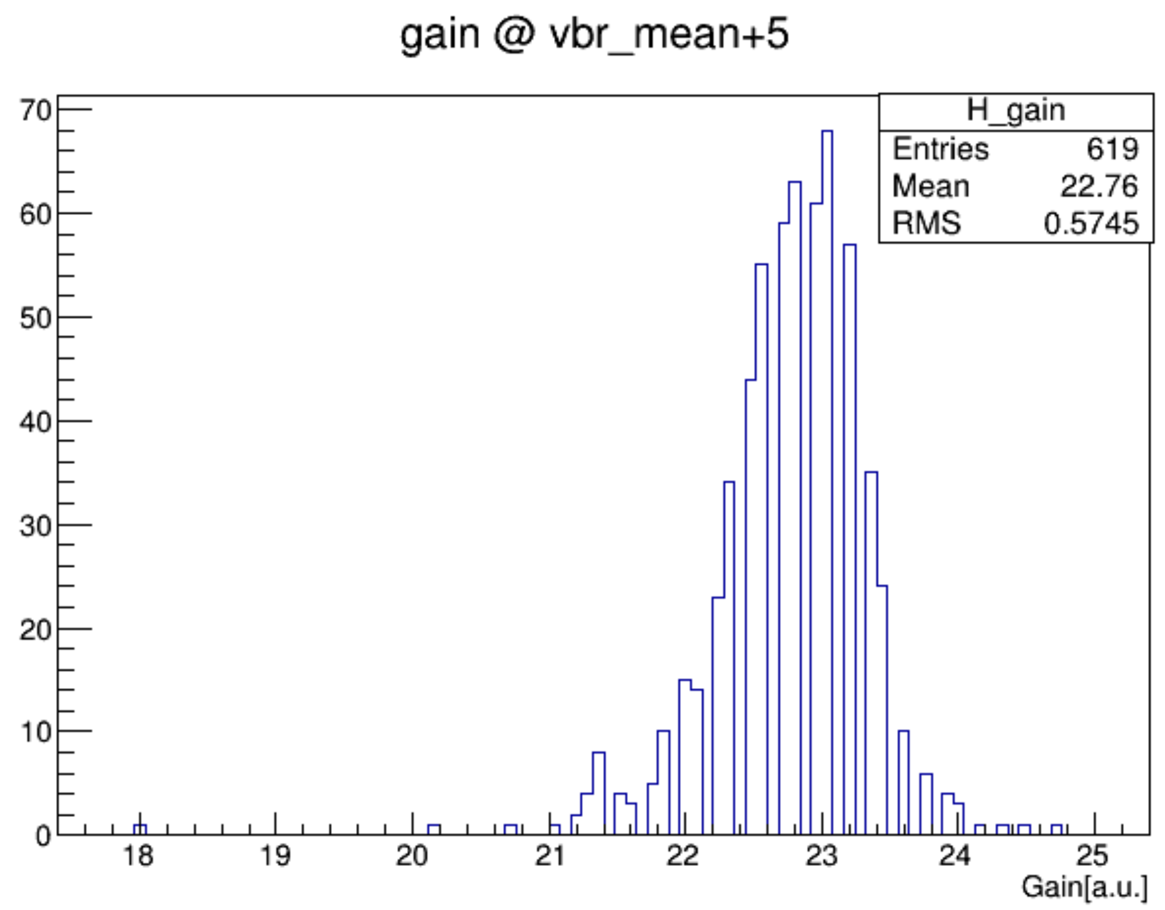

spot testing of few % of 22k SiPMs

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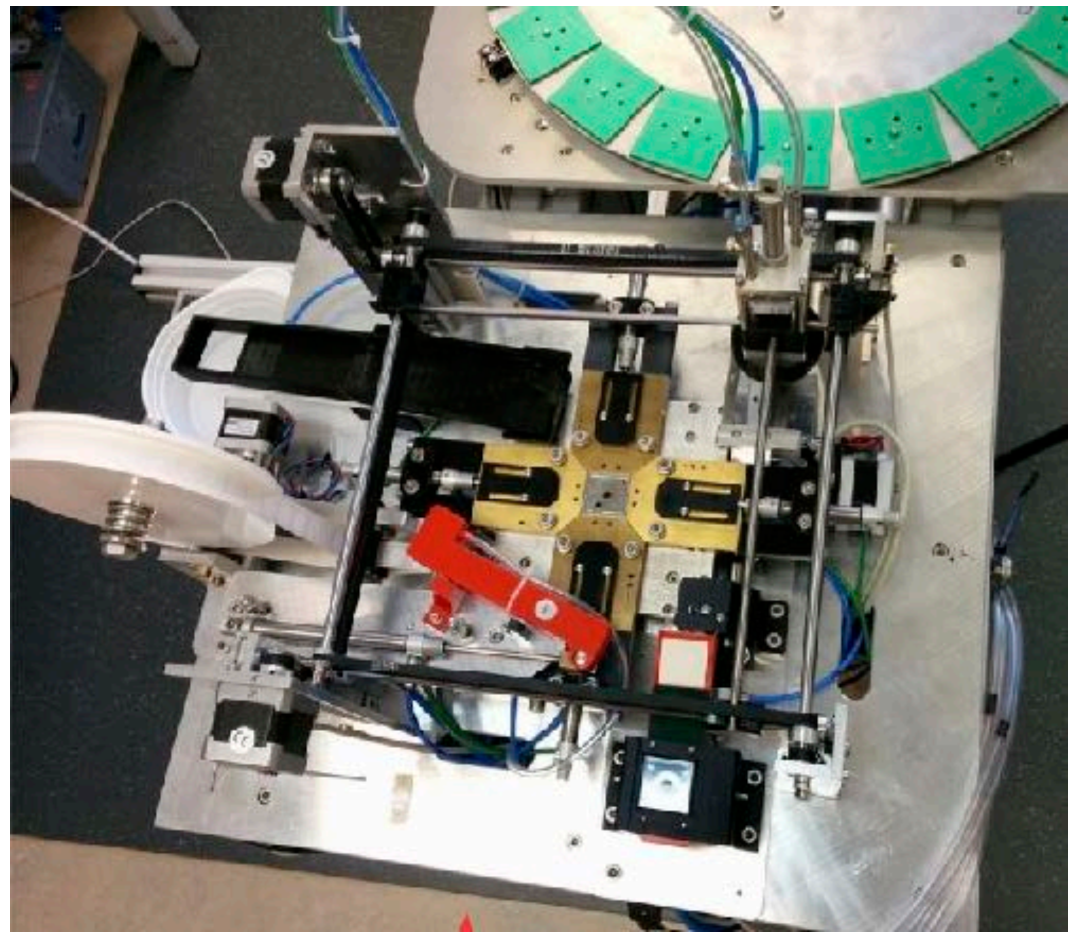

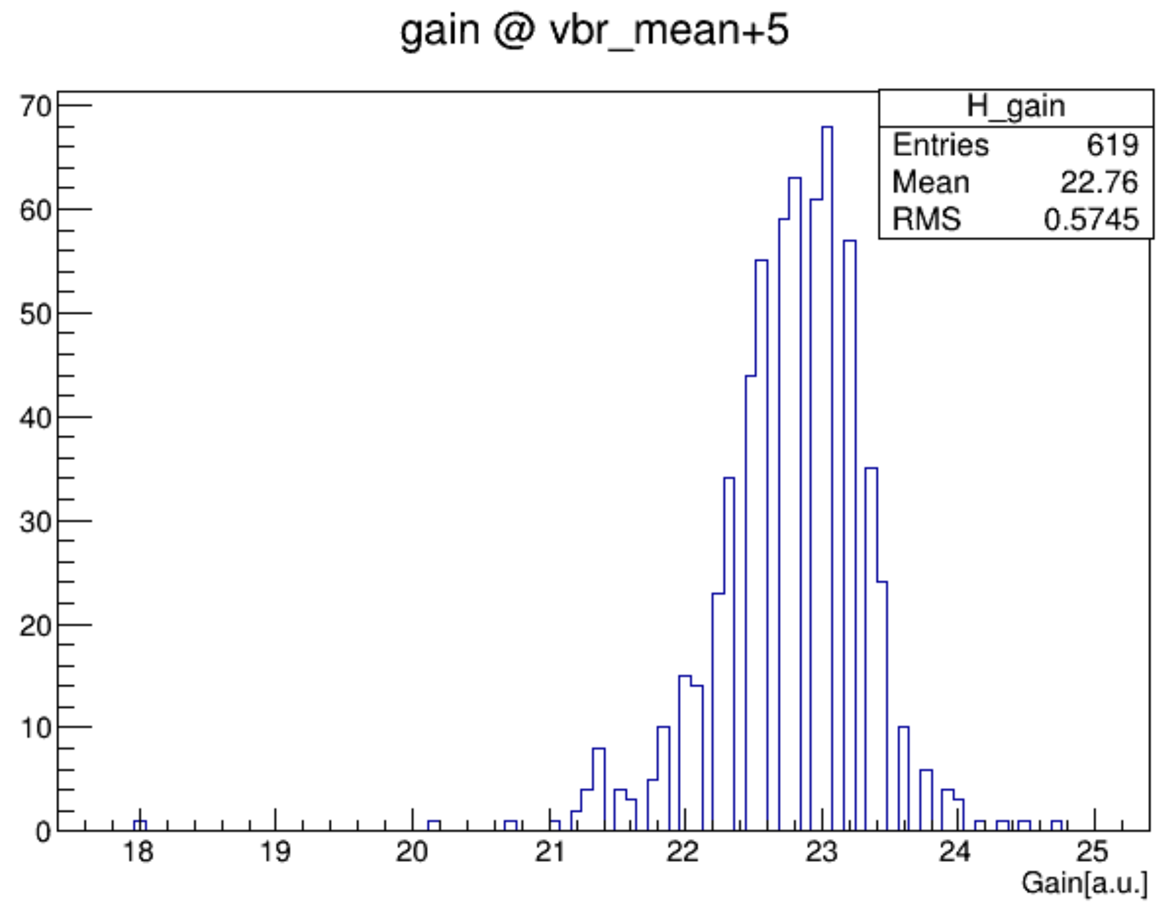

semi-automatic wrapping of 22k scintillator tiles

spot testing of few % of 22k SiPMs

Automatic assembly of 160 HBUs

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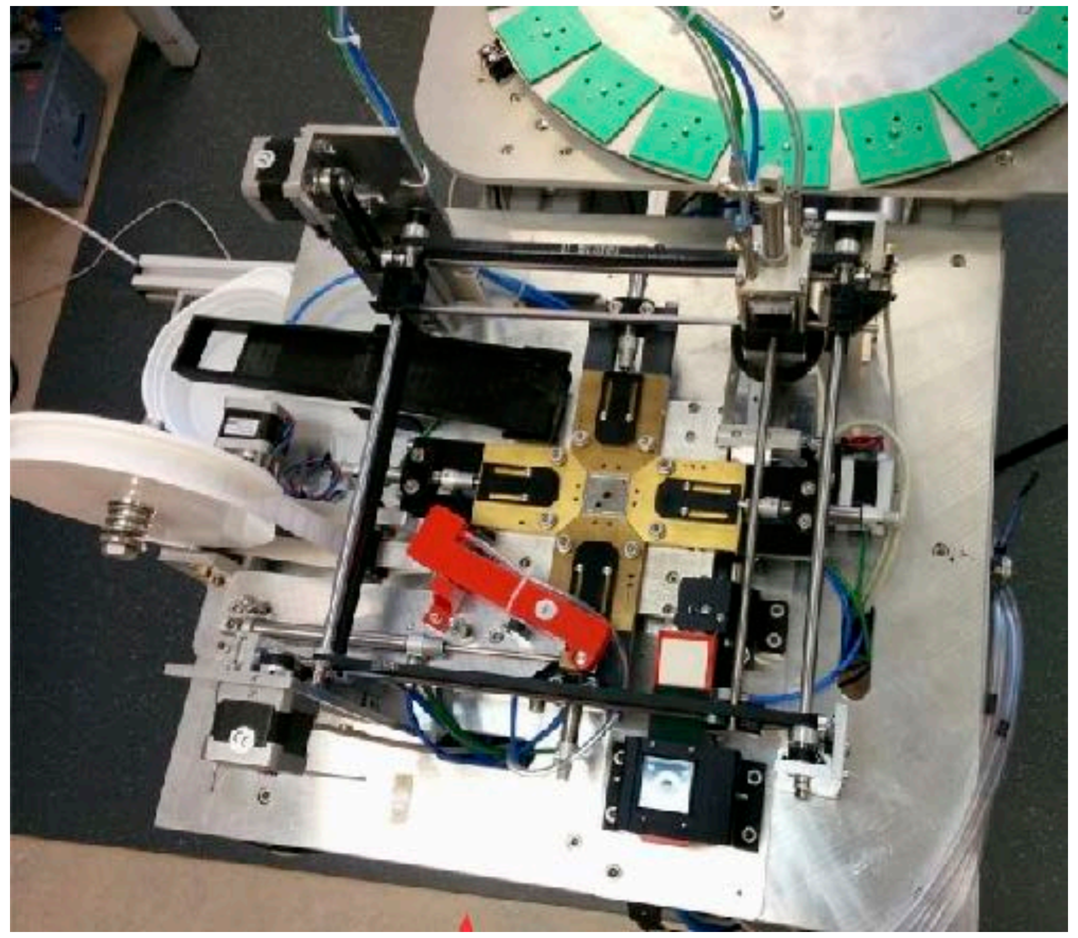
Test of each board with cosmics / beam at DESY

Development of control & reconstruction software to be ready for data from day 1 of beam

The “***SiPM-on-tile***” technology - mass production



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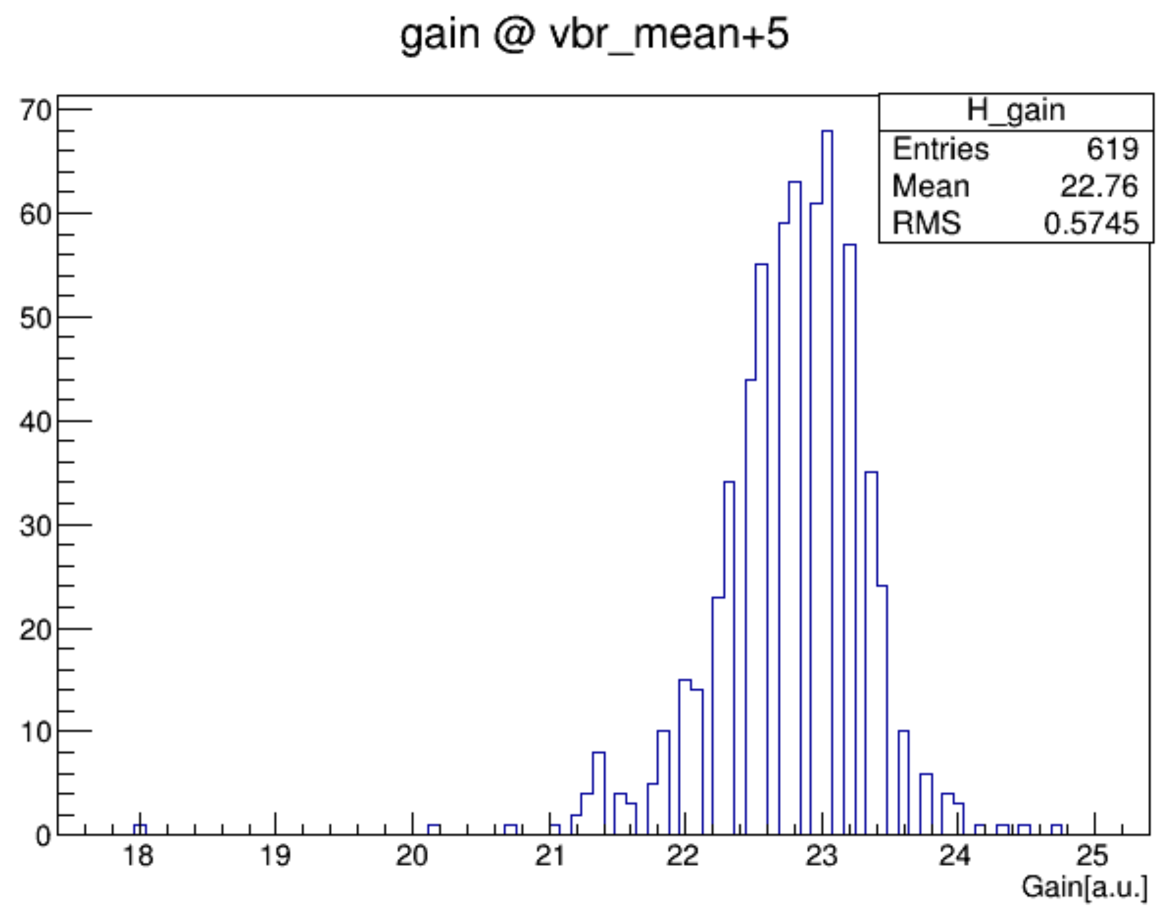

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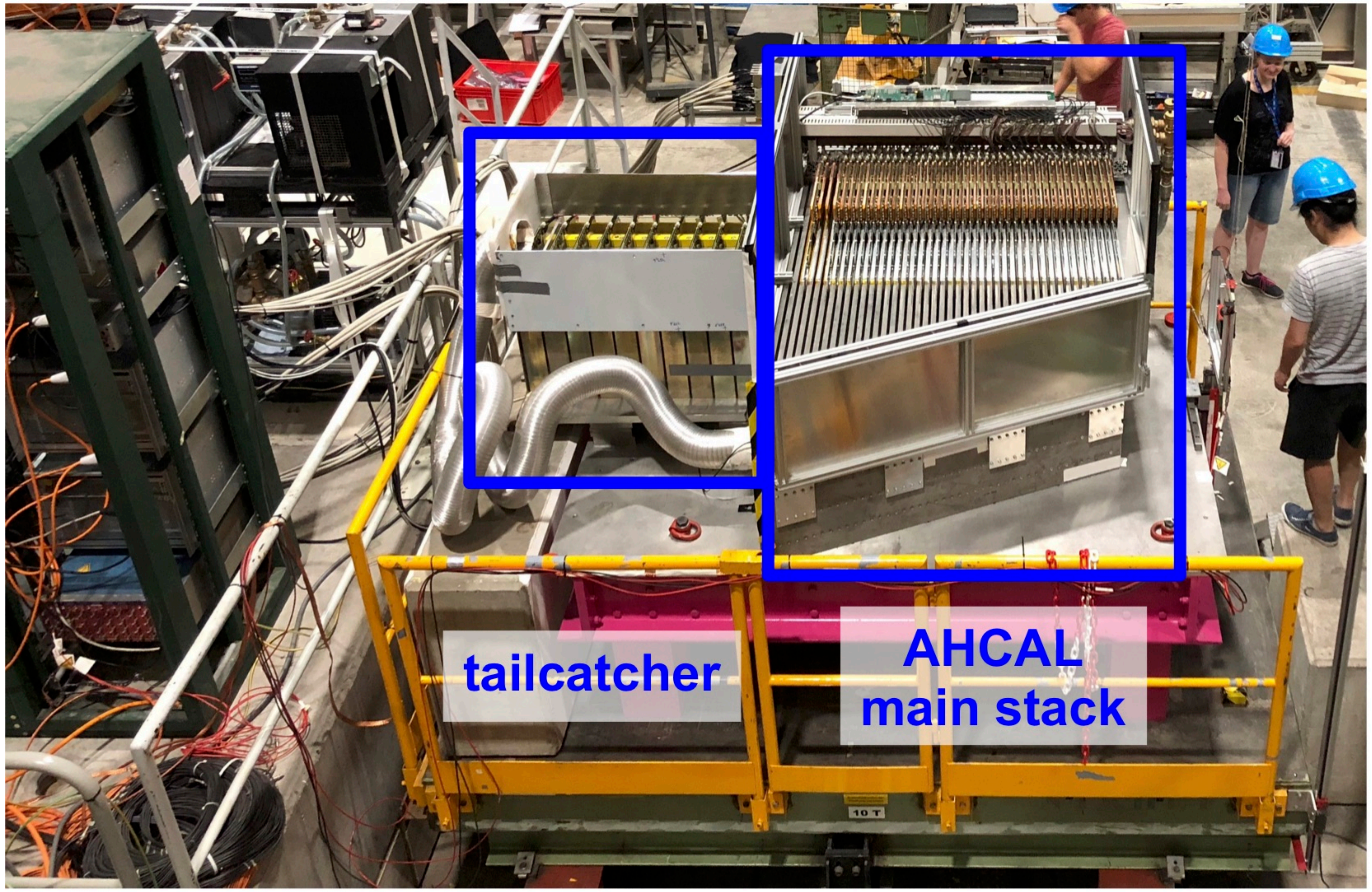
Successful Test Beams

- In May and June 2018: Test beam at CERN SPS - the smoothest CALICE test beams ever.



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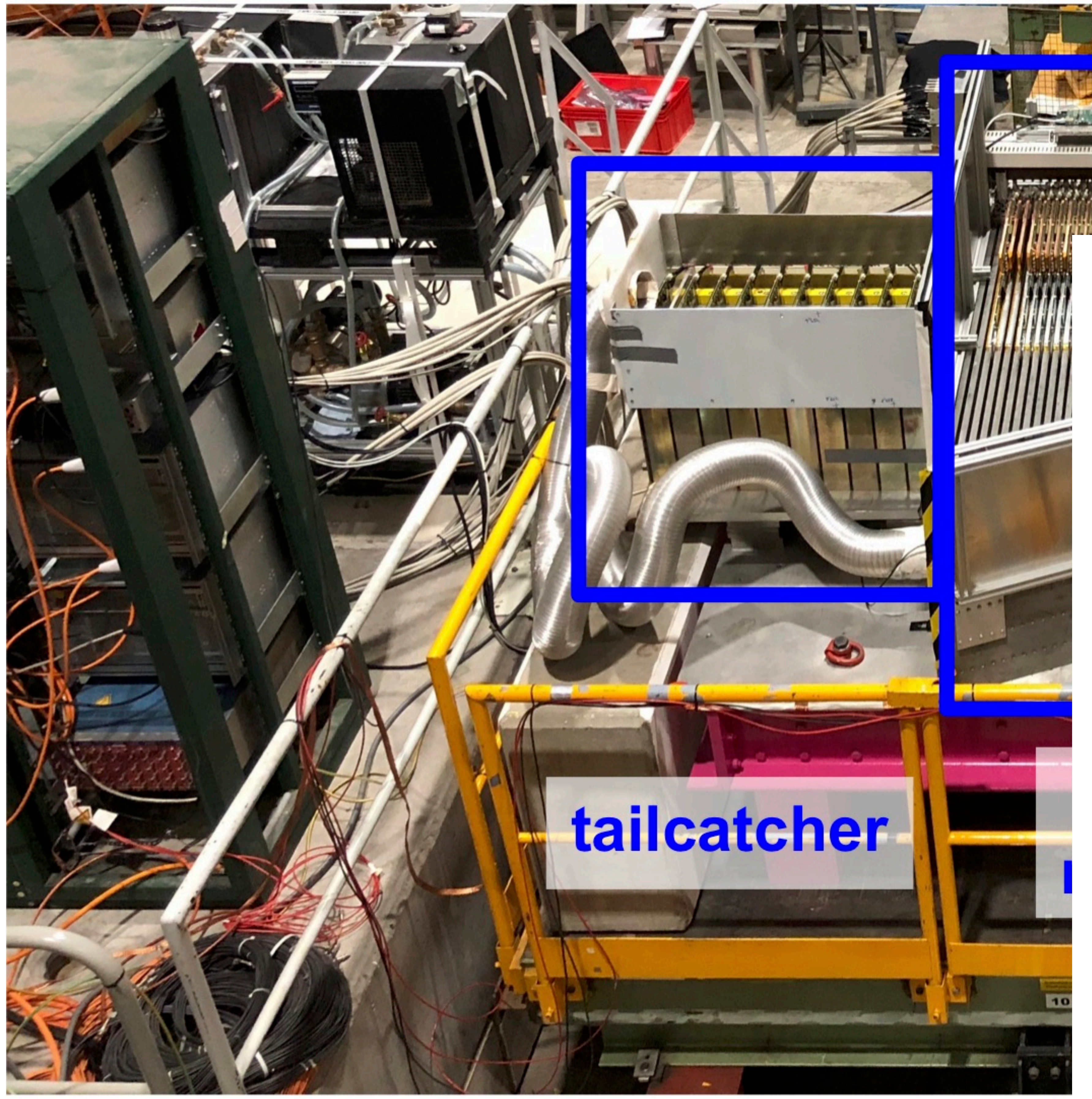
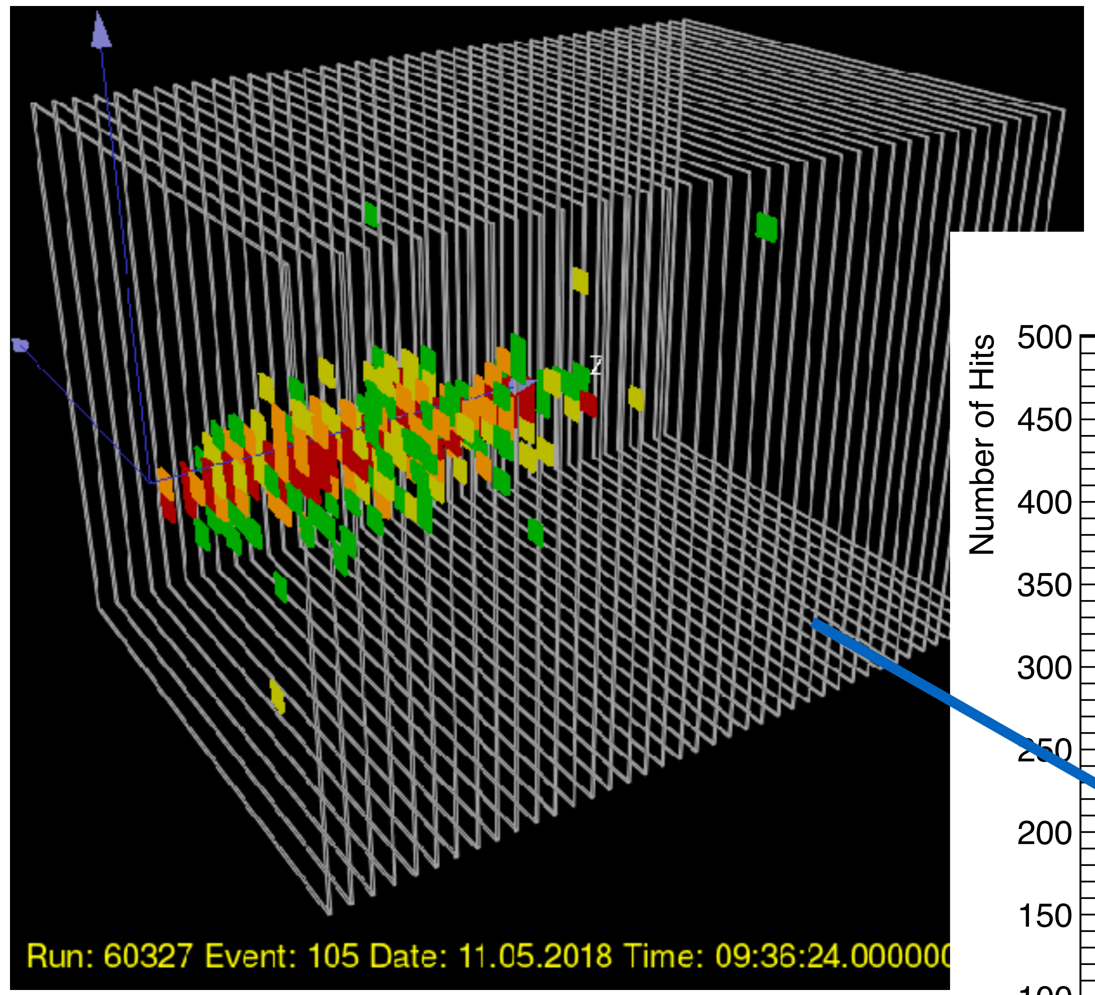
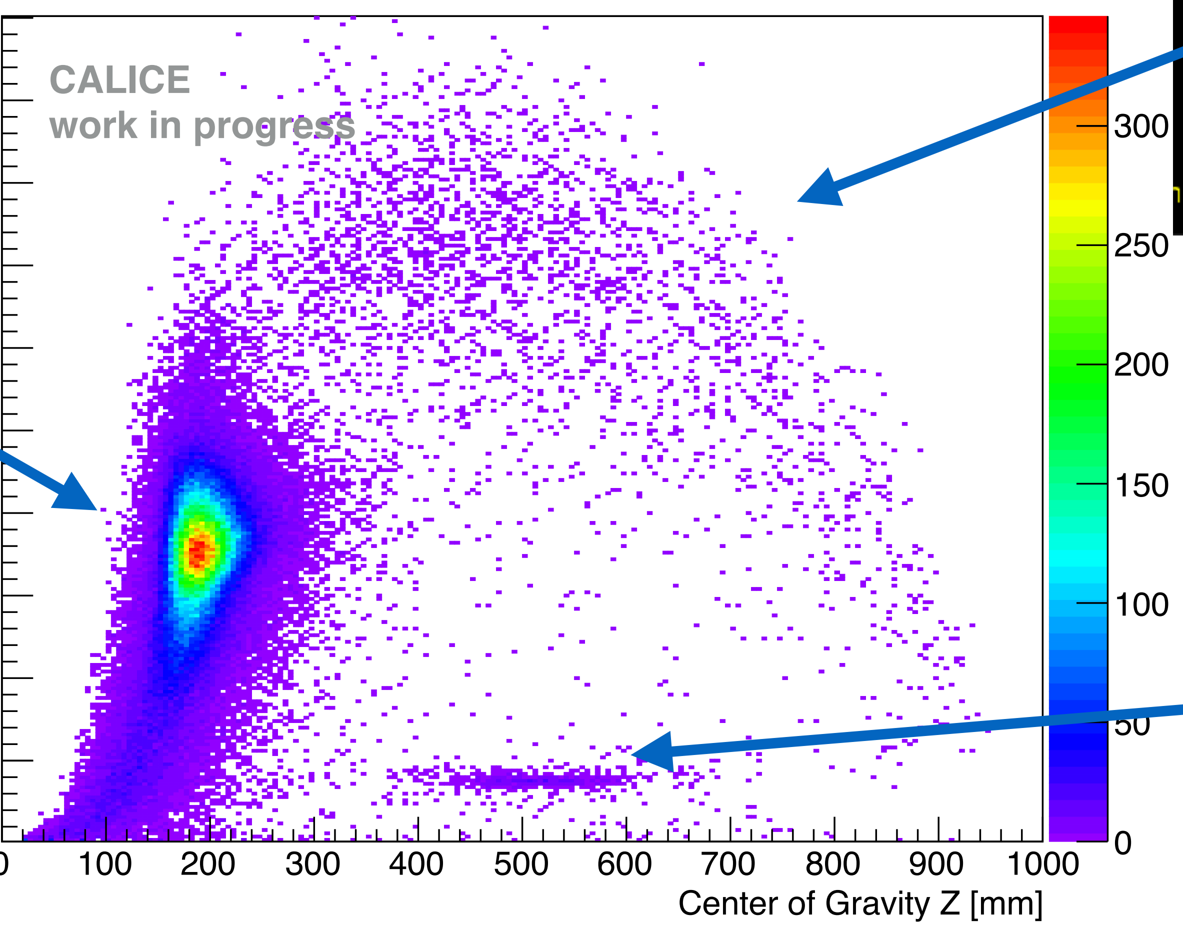


electron shower

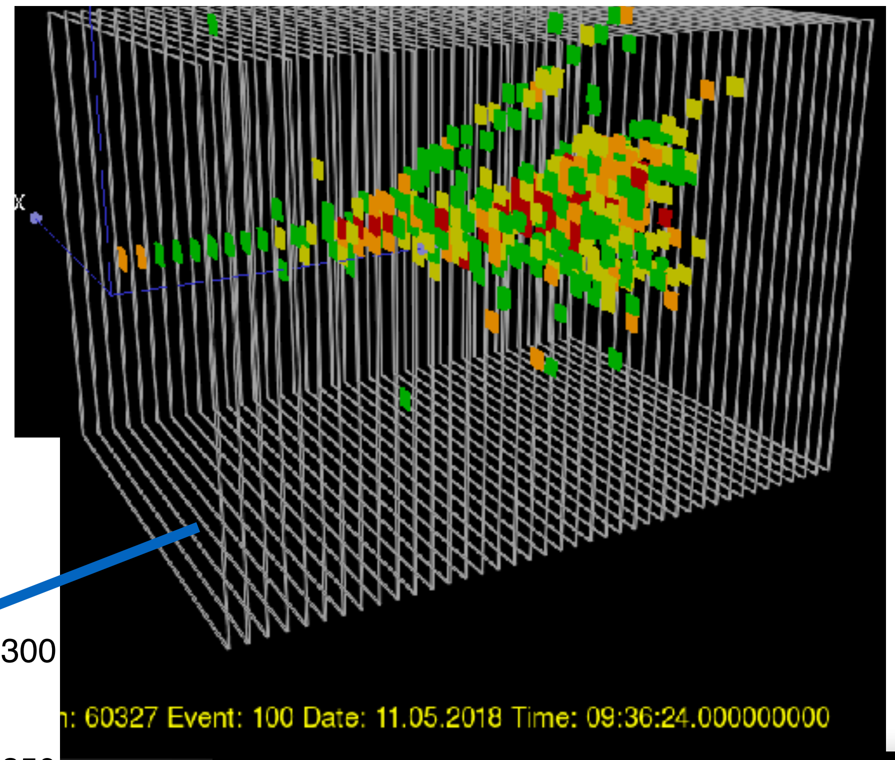


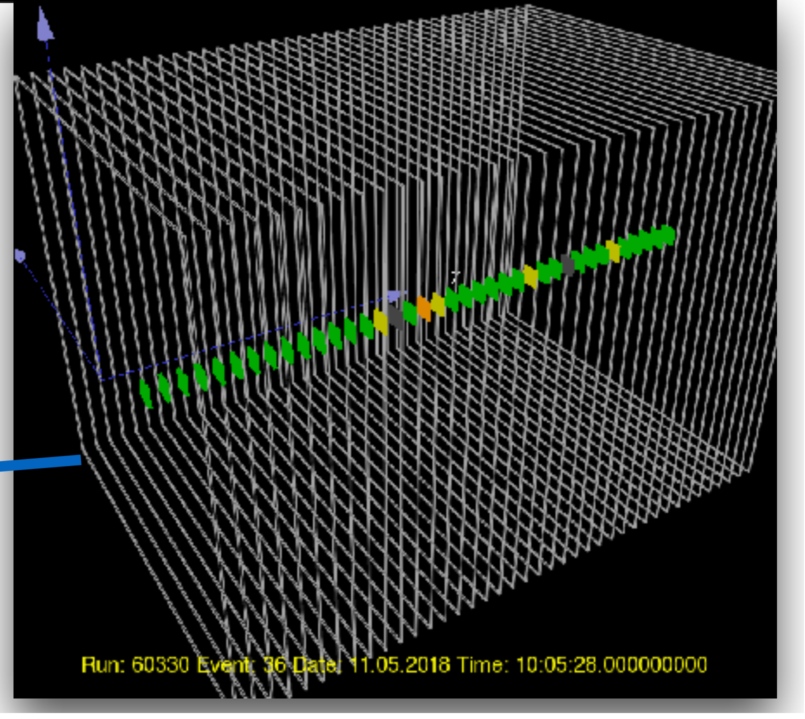
online data

50 GeV electron beam with pion and muon contamination



pion shower



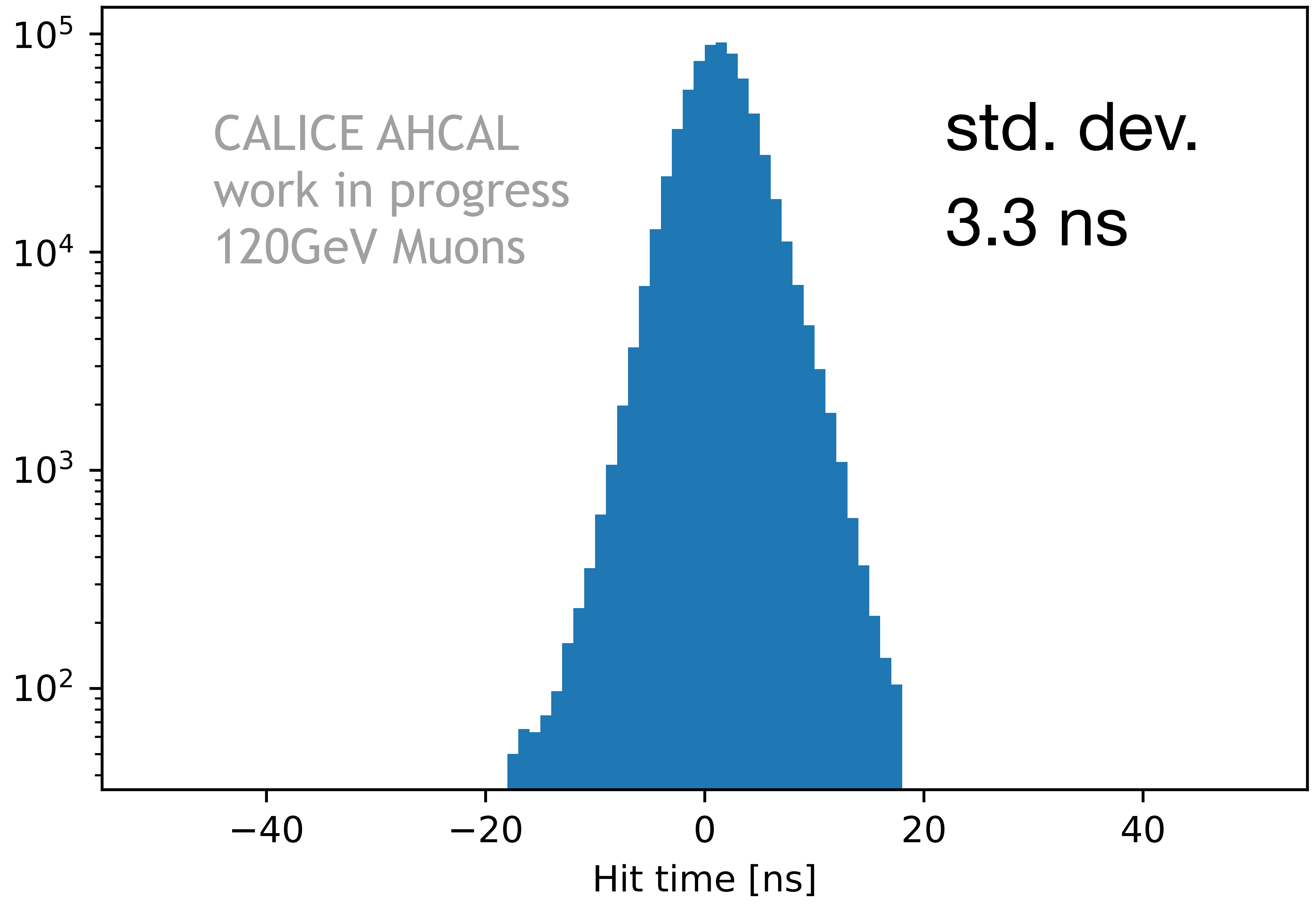


muon track

Timing & Energy Reconstruction in the AHCAL

Understanding & Exploiting the New Capabilities

- Ongoing analysis on new data set: working on calibration of time reconstruction, including corrections for ASIC “features”



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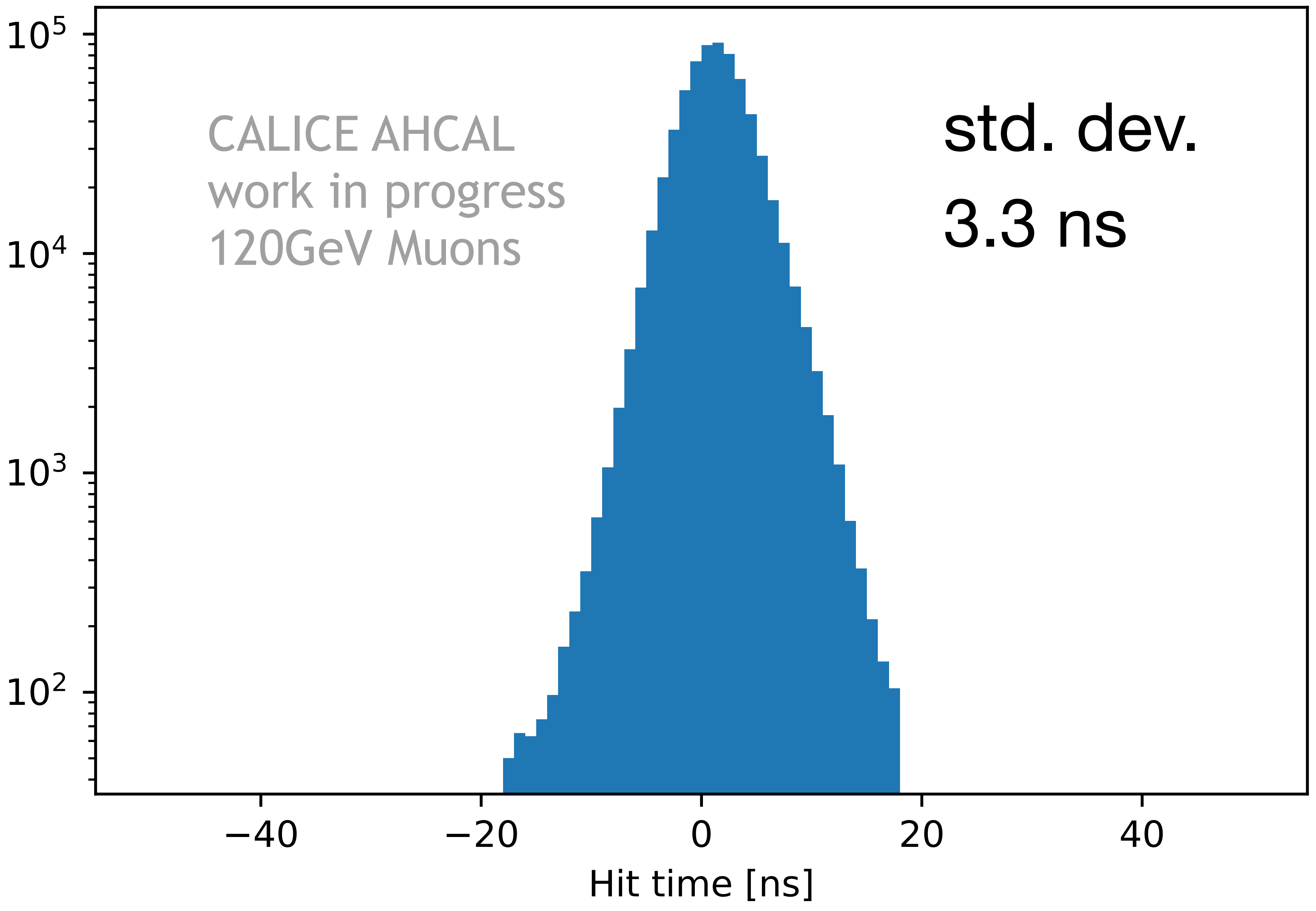
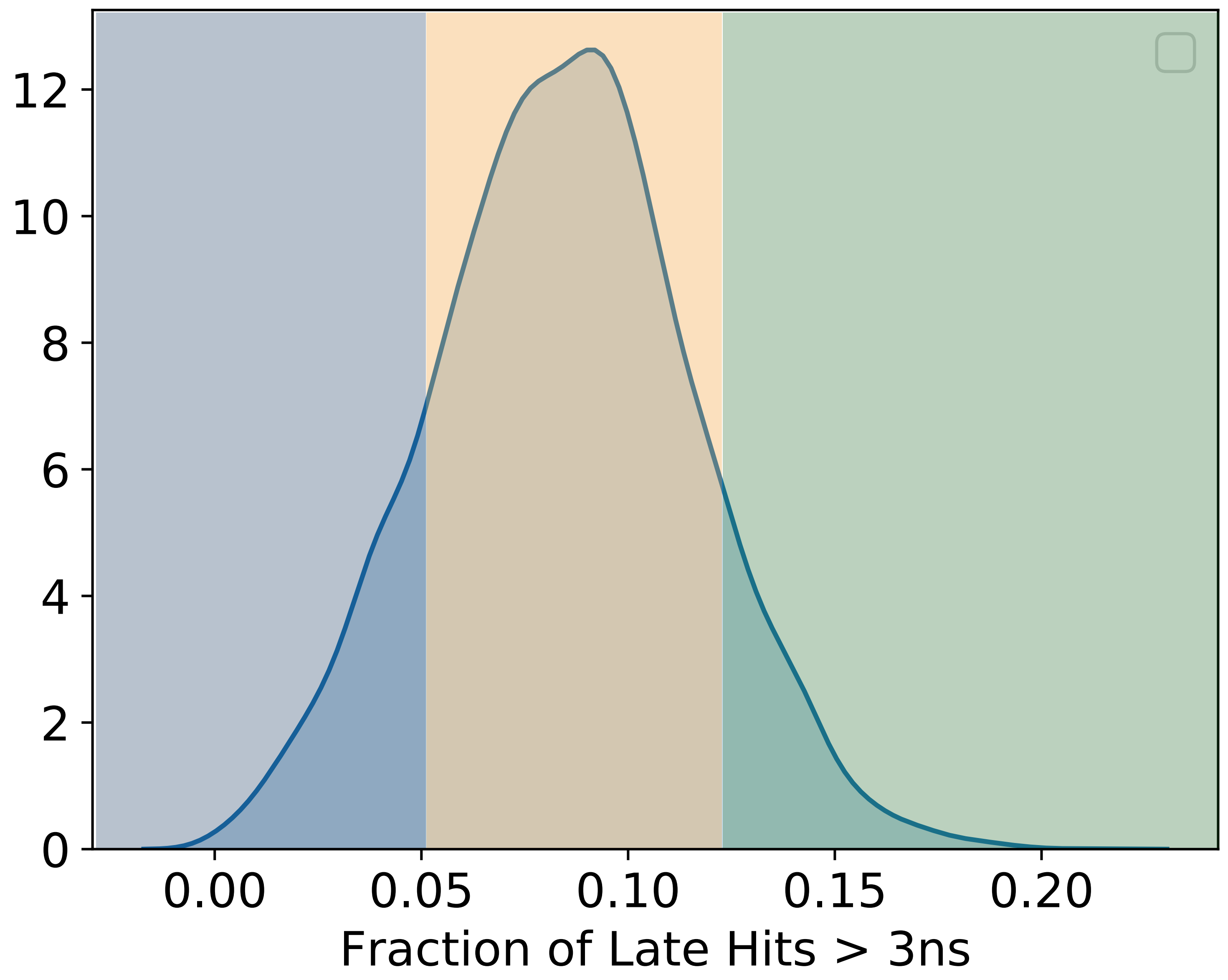
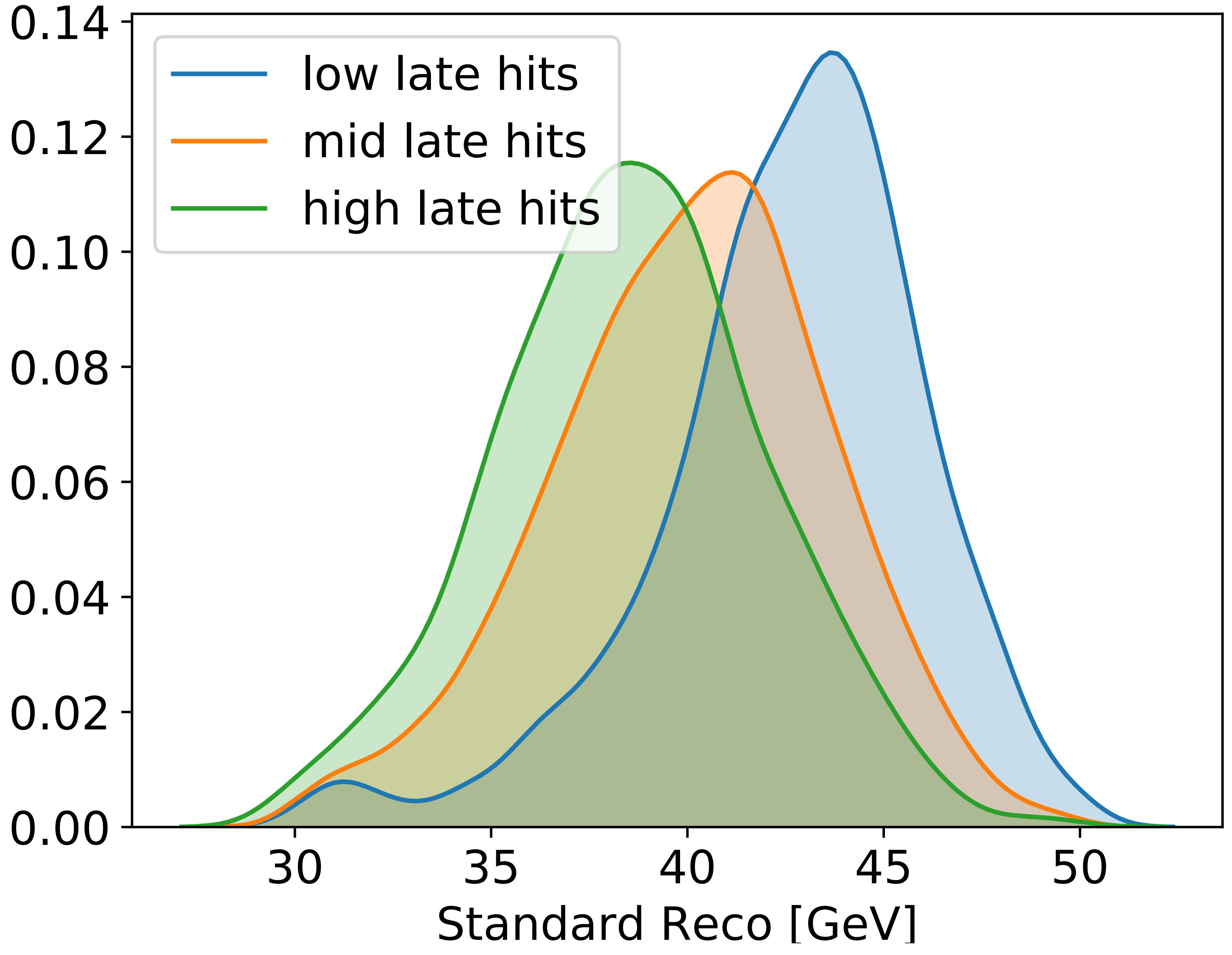


- Study of potential to use ns-level timing for hadronic energy reconstruction





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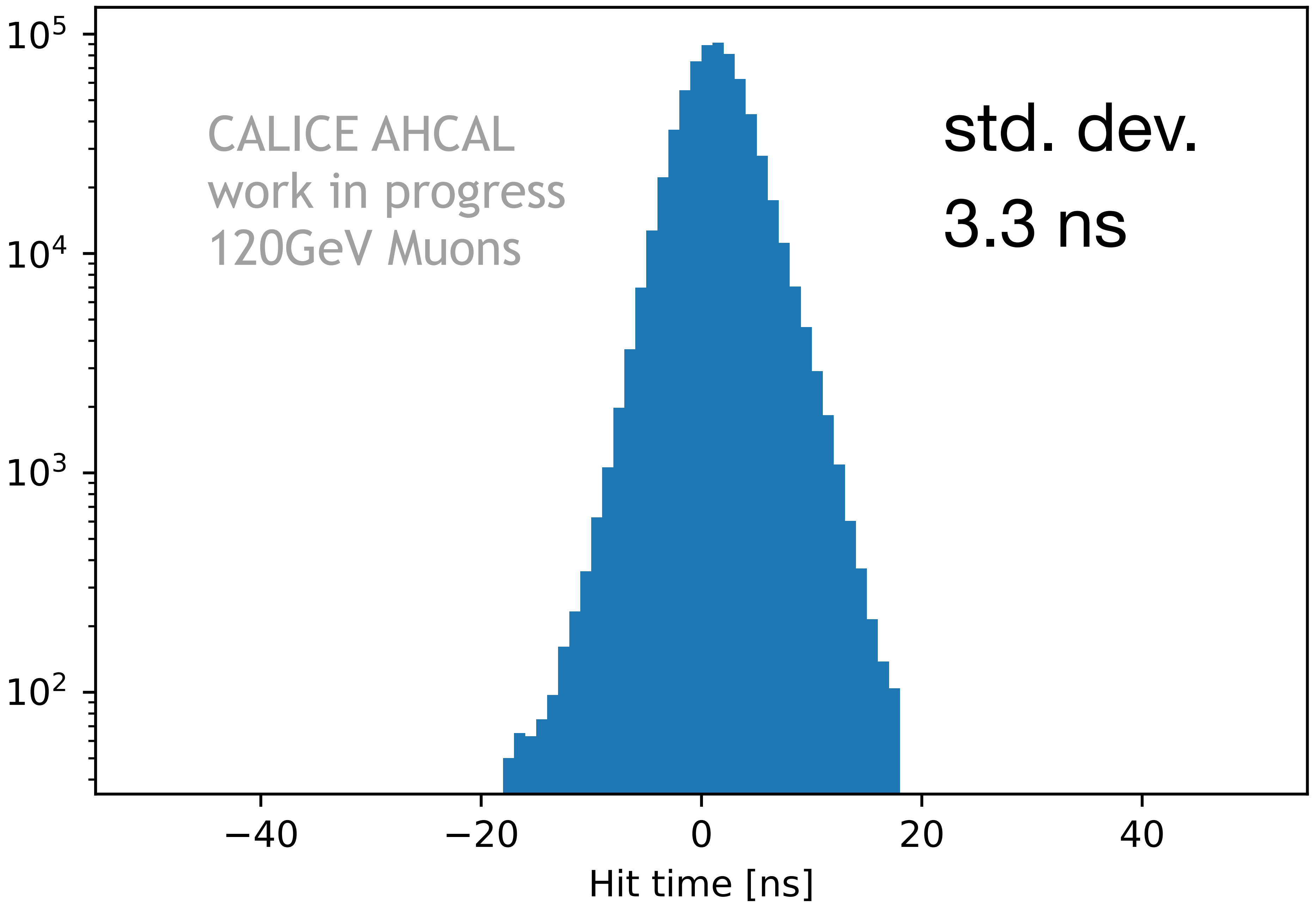

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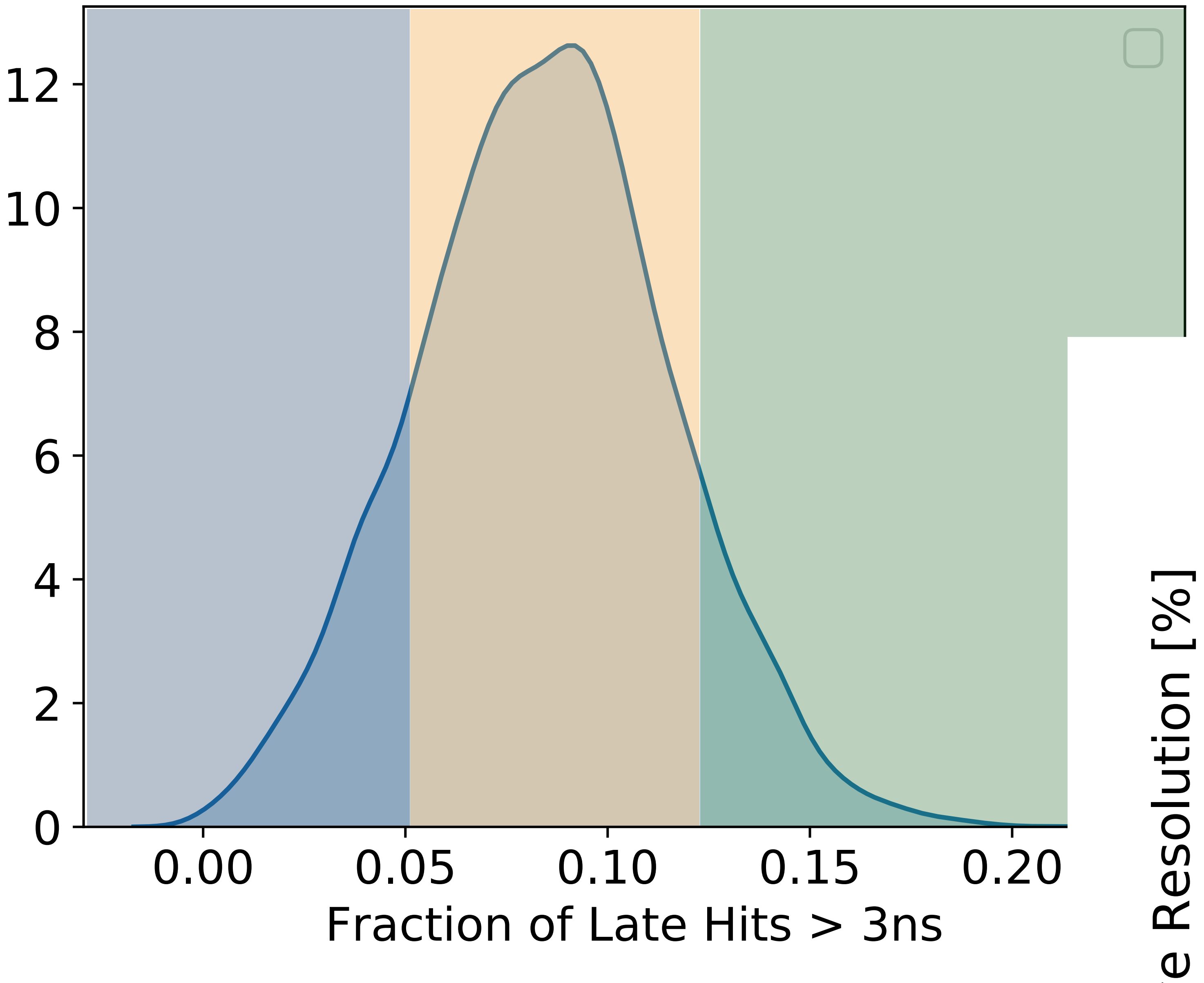
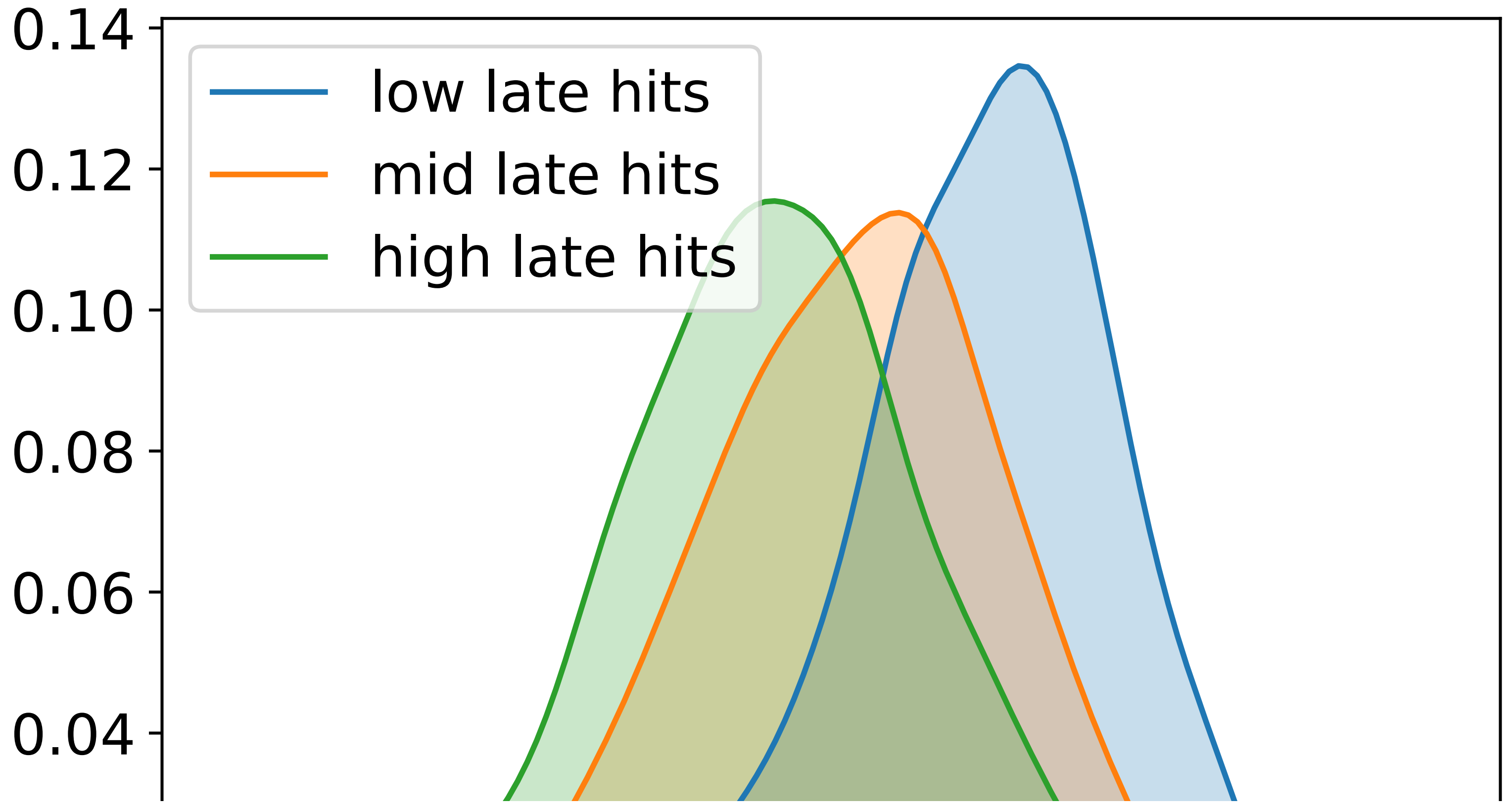
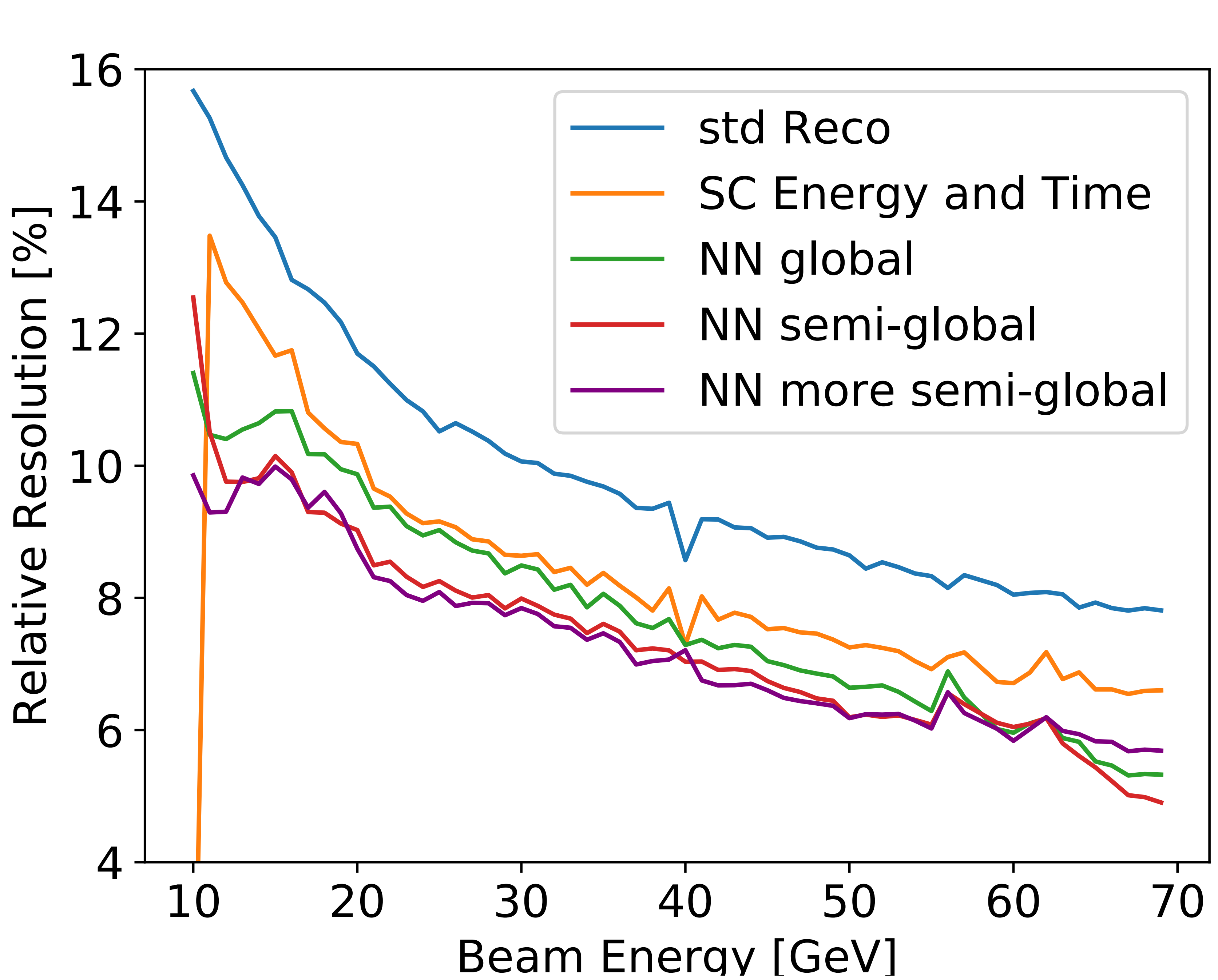




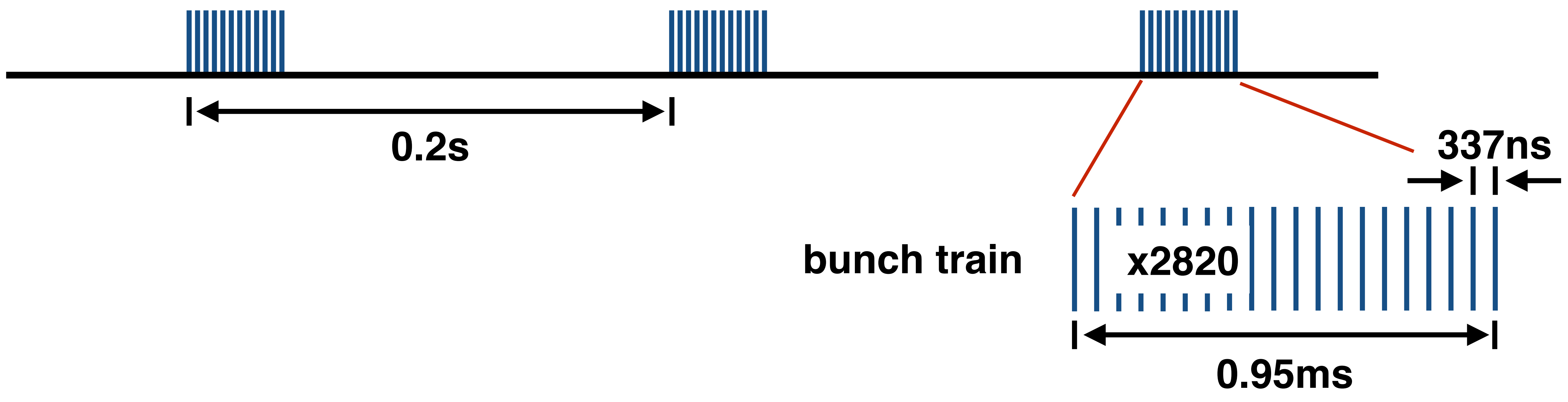
- Energy resolution with various levels of sophistication - up to Neural Network using layerwise information



CALICE AHCAL: Next Steps

More Test Beams, Better Photon Sensors…

- A key step to demonstrate: running with "ILC time structure" - higher clock speeds, better time resolution
  - Coming up at DESY in 2019



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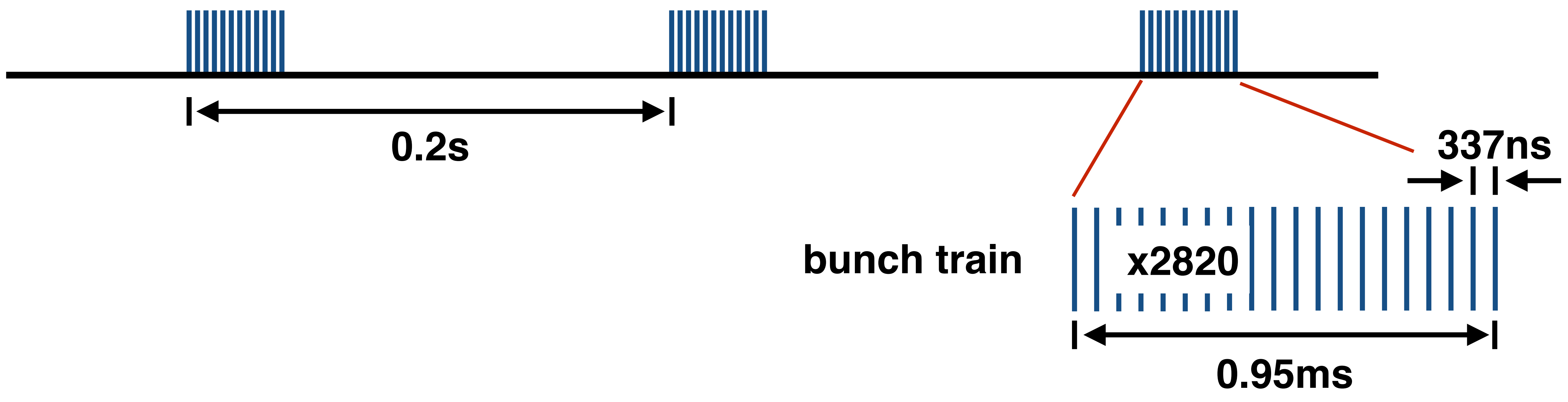
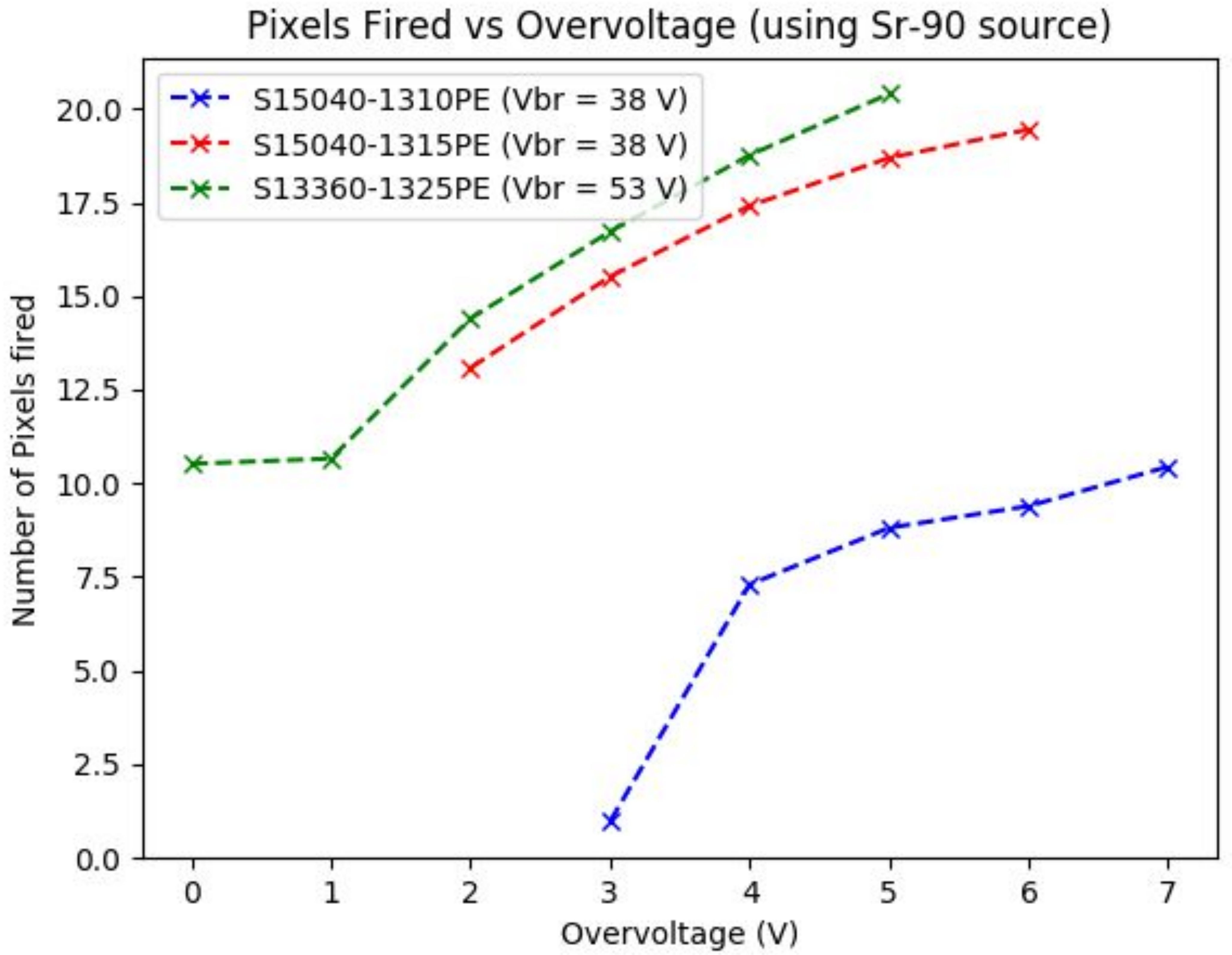




- Further develop the technology: Profit from continuing improvement of SiPMs
  - ➩ New generation of Hamamatsu MPPCs (series S15040 - received first samples for testing: High Dynamic Range - 15 µm micropixel devices now reach performance of previous 25 µm devices: ~ x 3 increase in dynamic range, improved reconstruction of electromagnetic showers

CLAWS: Measuring Injection Backgrounds at SuperKEKB

A CALICE Spin-Off

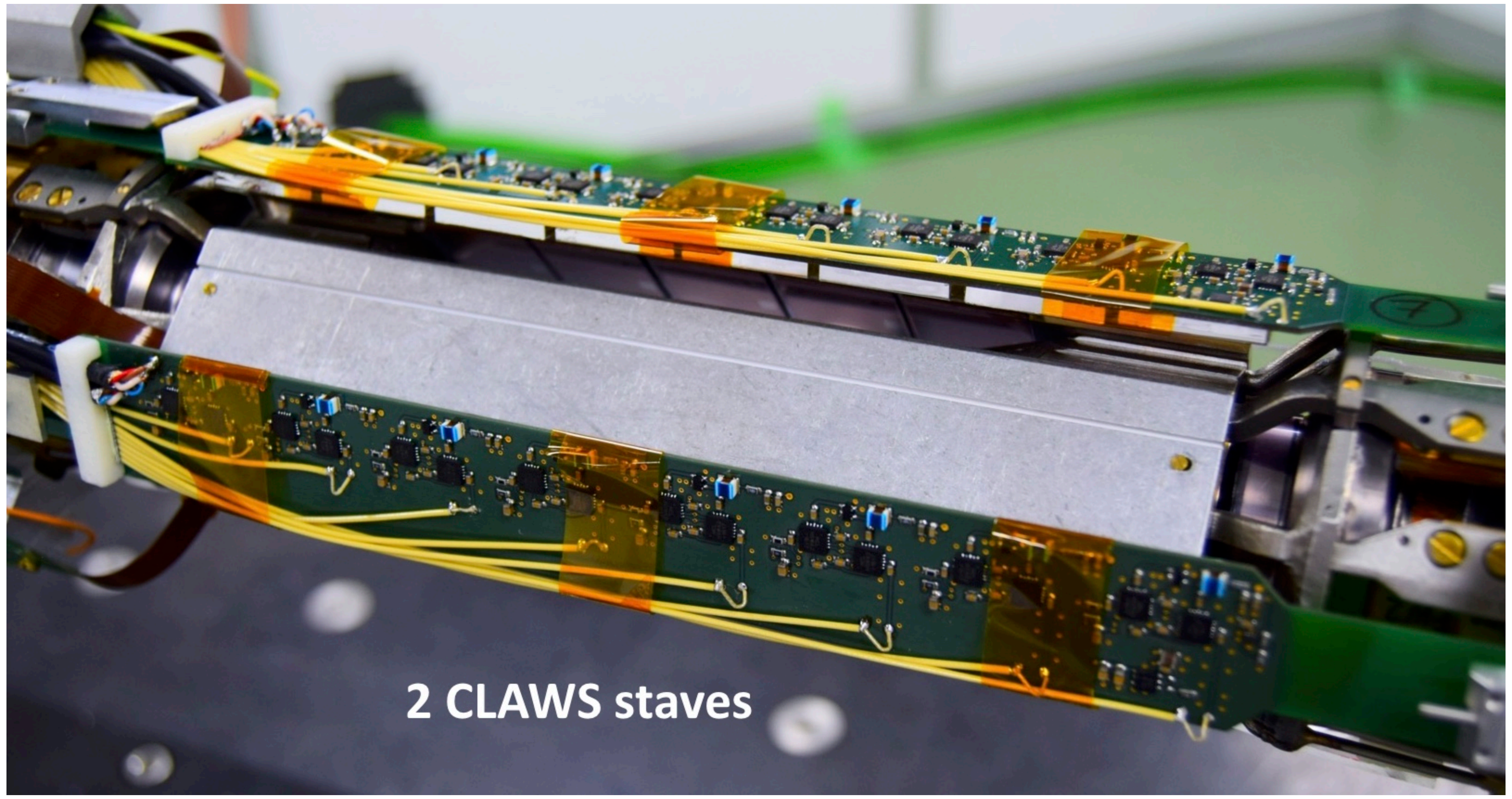
- SiPM on tile scintillator sensors from CALICE development, read out with 800 ps sampling over ms time scales:

  Monitor backgrounds at SuperKEKB

- In SuperKEKB commissioning Phase 1: The first detector at the Belle II IP to see particles (08.02.2016)

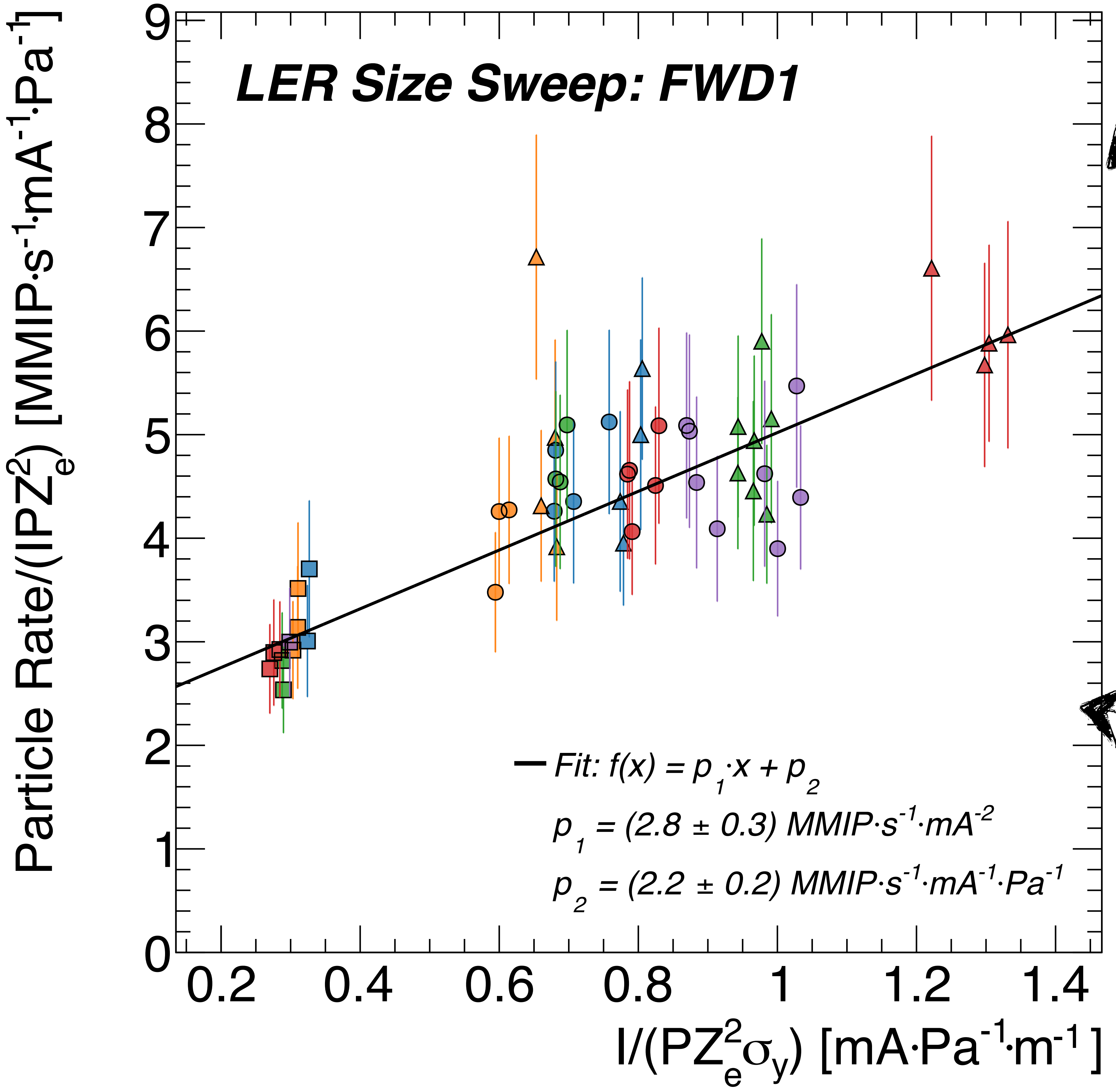
- In commissioning Phase 2: Part of the VXD volume Two ladders a 8 scintillator cells

  Data taking in Spring / Summer 2018

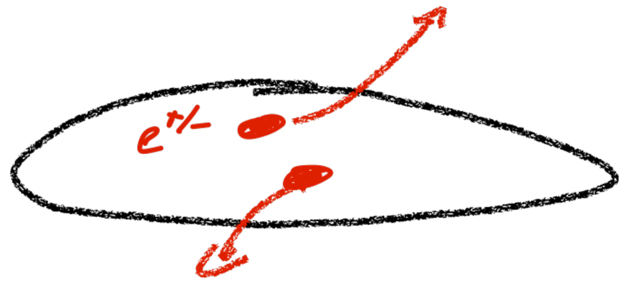


CLAWS Results

SuperKEKB Commissioning Phase I



Touschek background:
Depends on beam size



beam-gas background:
Depends on current & pressure

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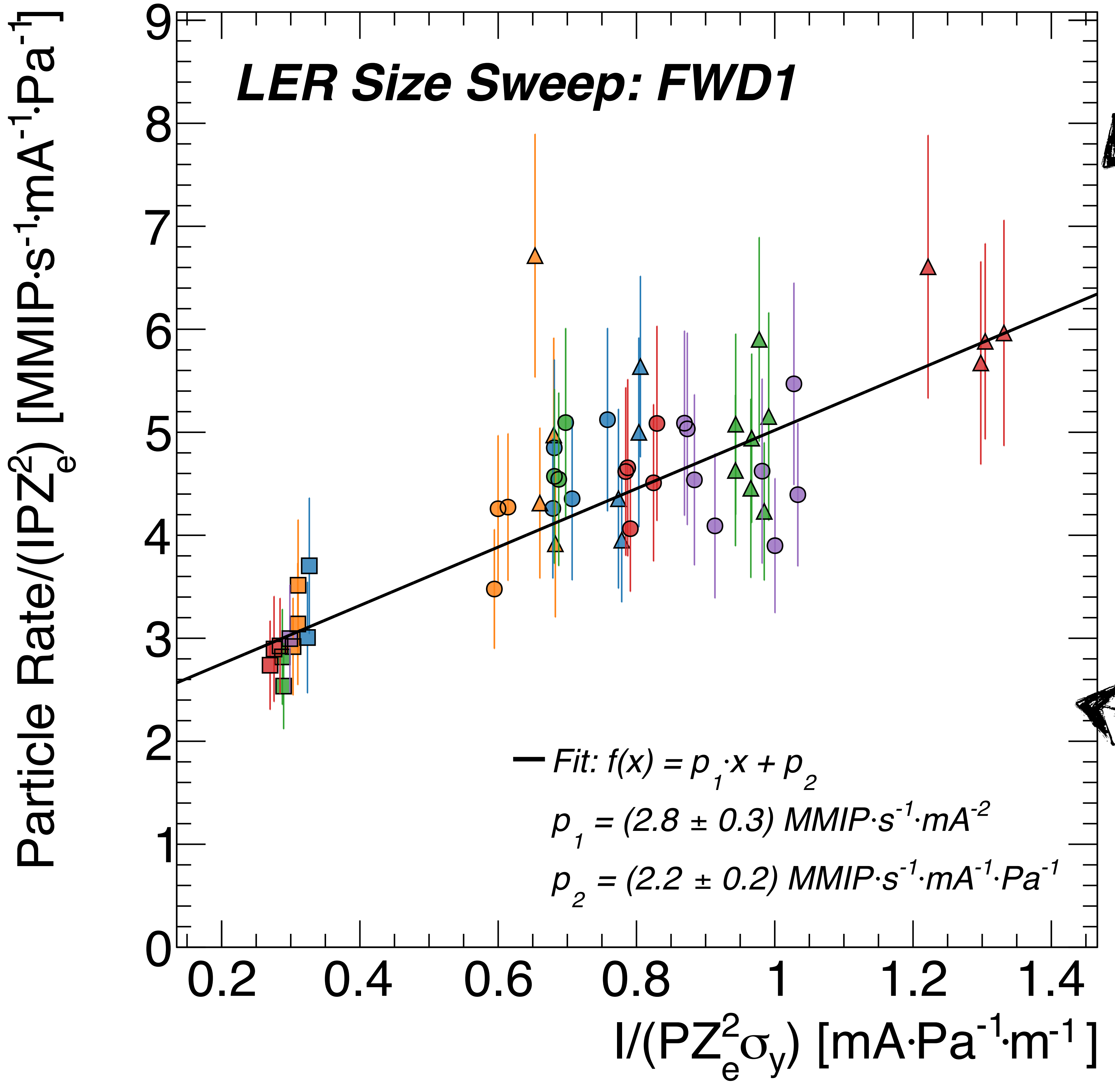

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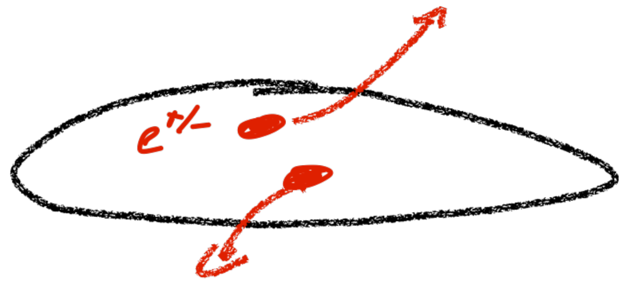
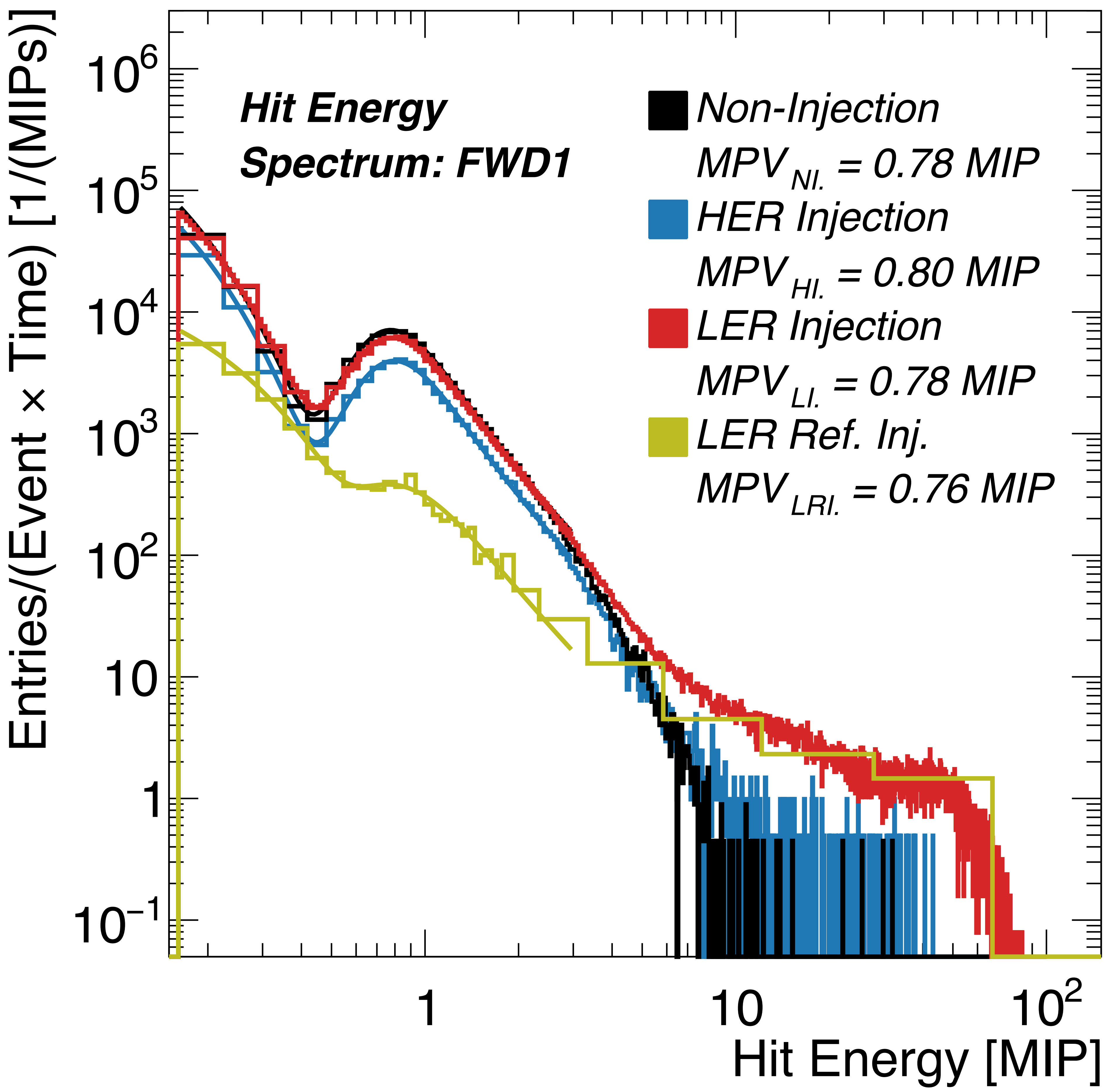
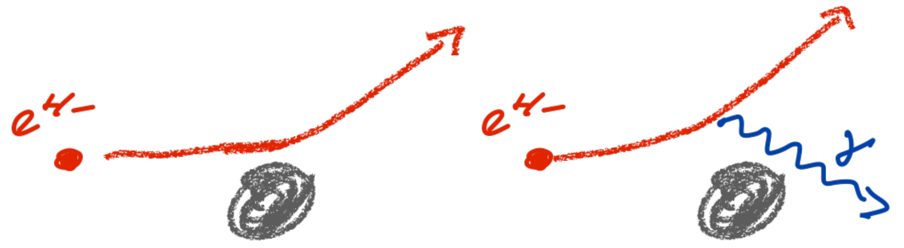




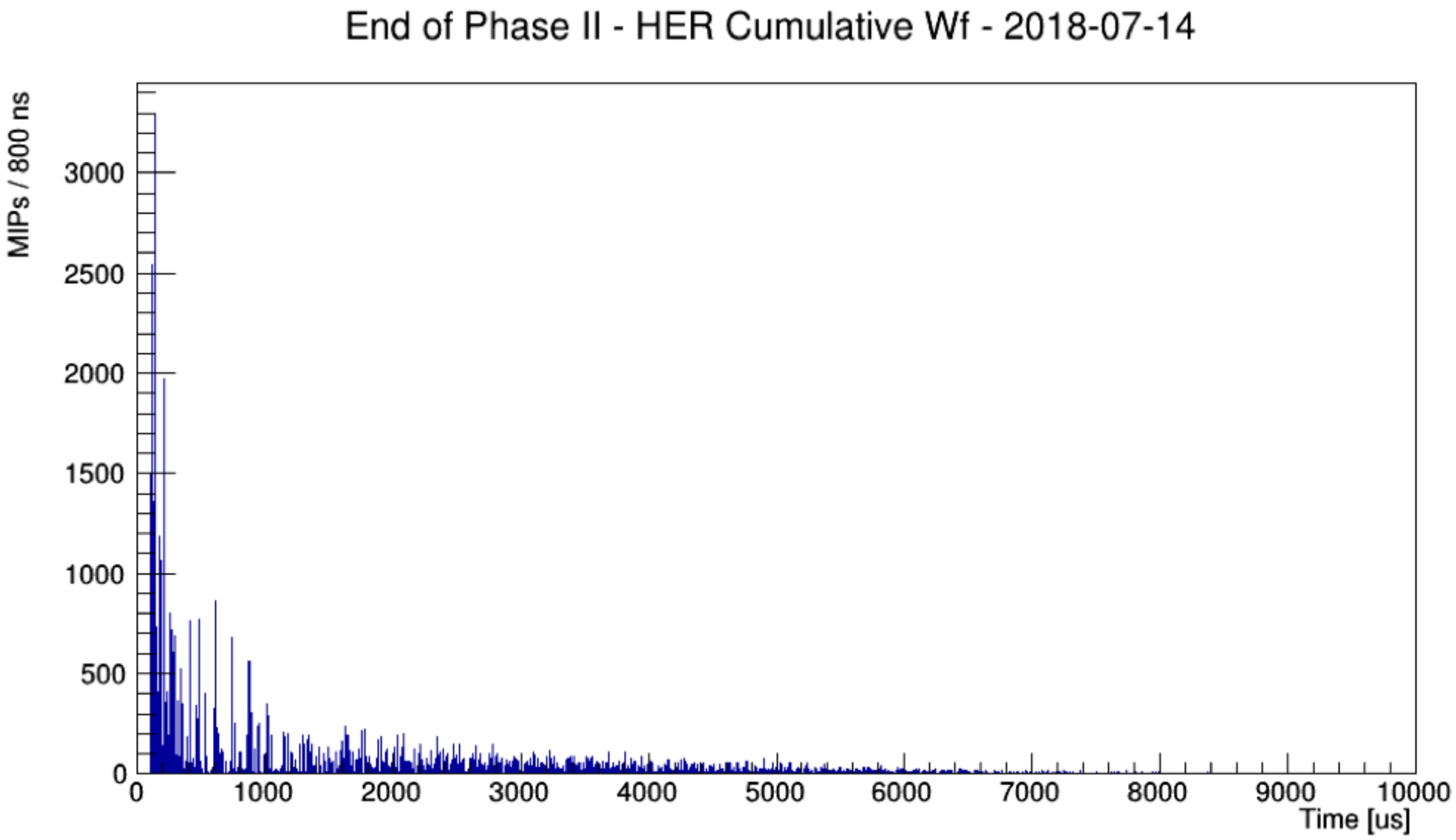


beam-gas background:
Depends on current & pressure

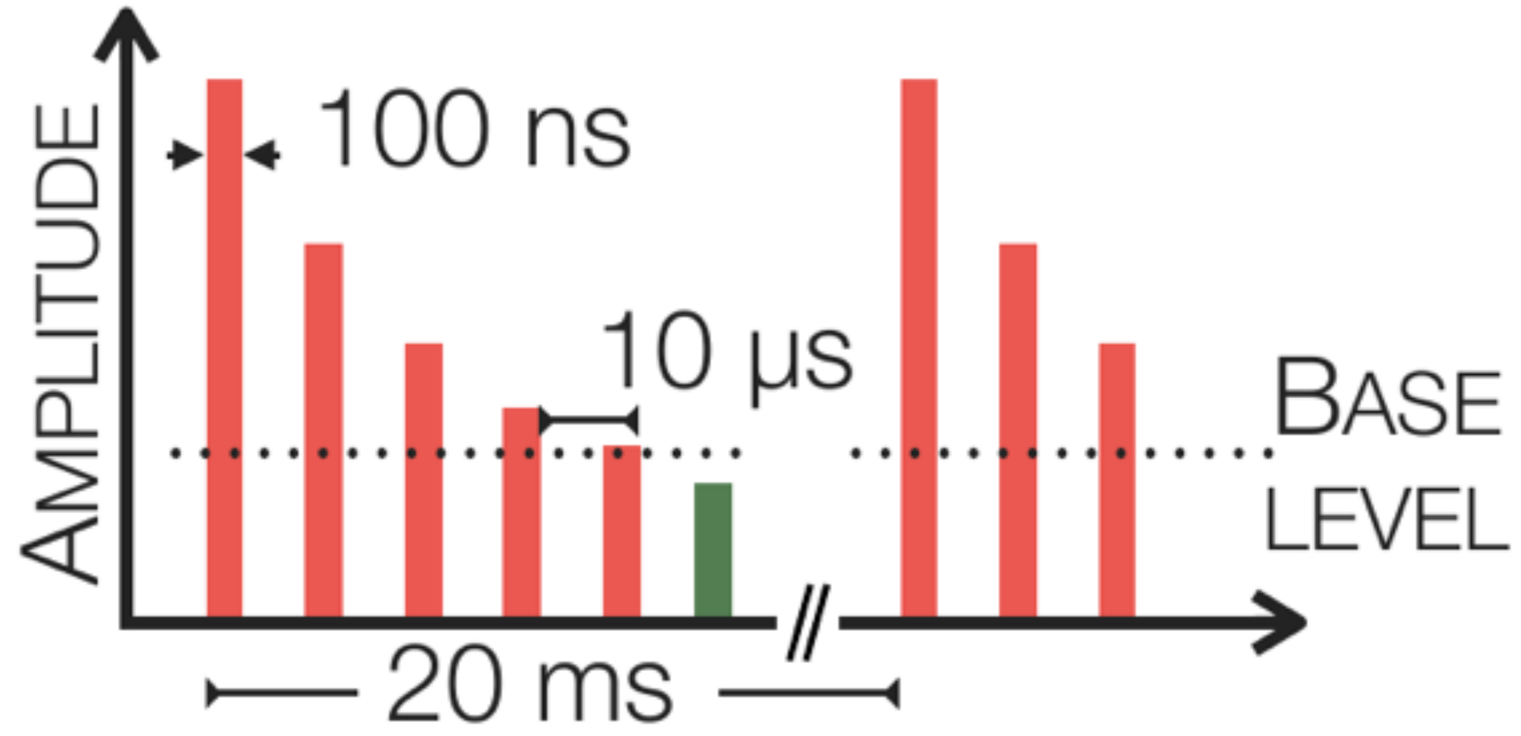
- Injections result in high-intensity background spikes

CLAWS Results

SuperKEKB Commissioning Phase II



- Observe large background signals following injections, decaying over several 100 turns



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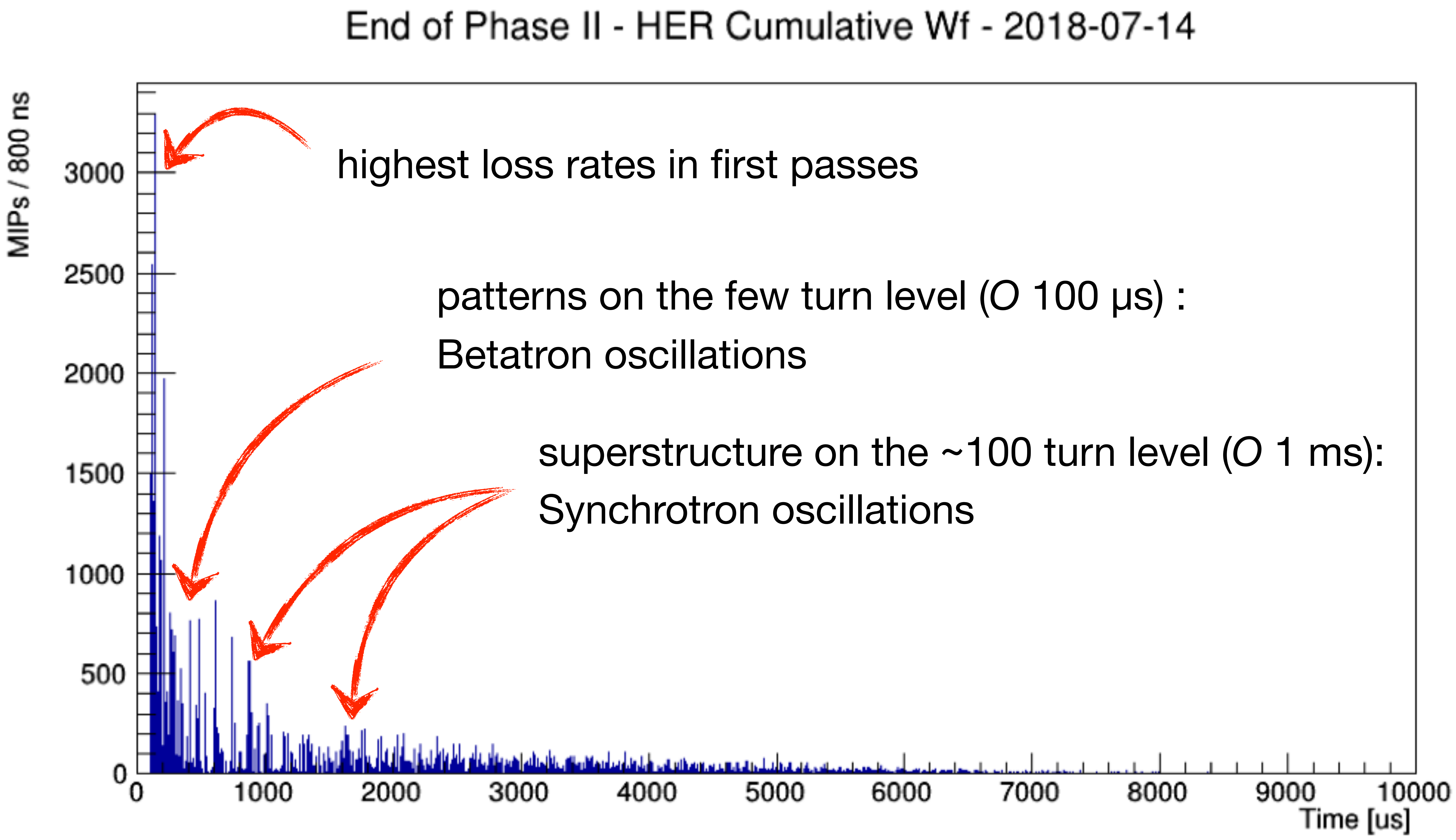

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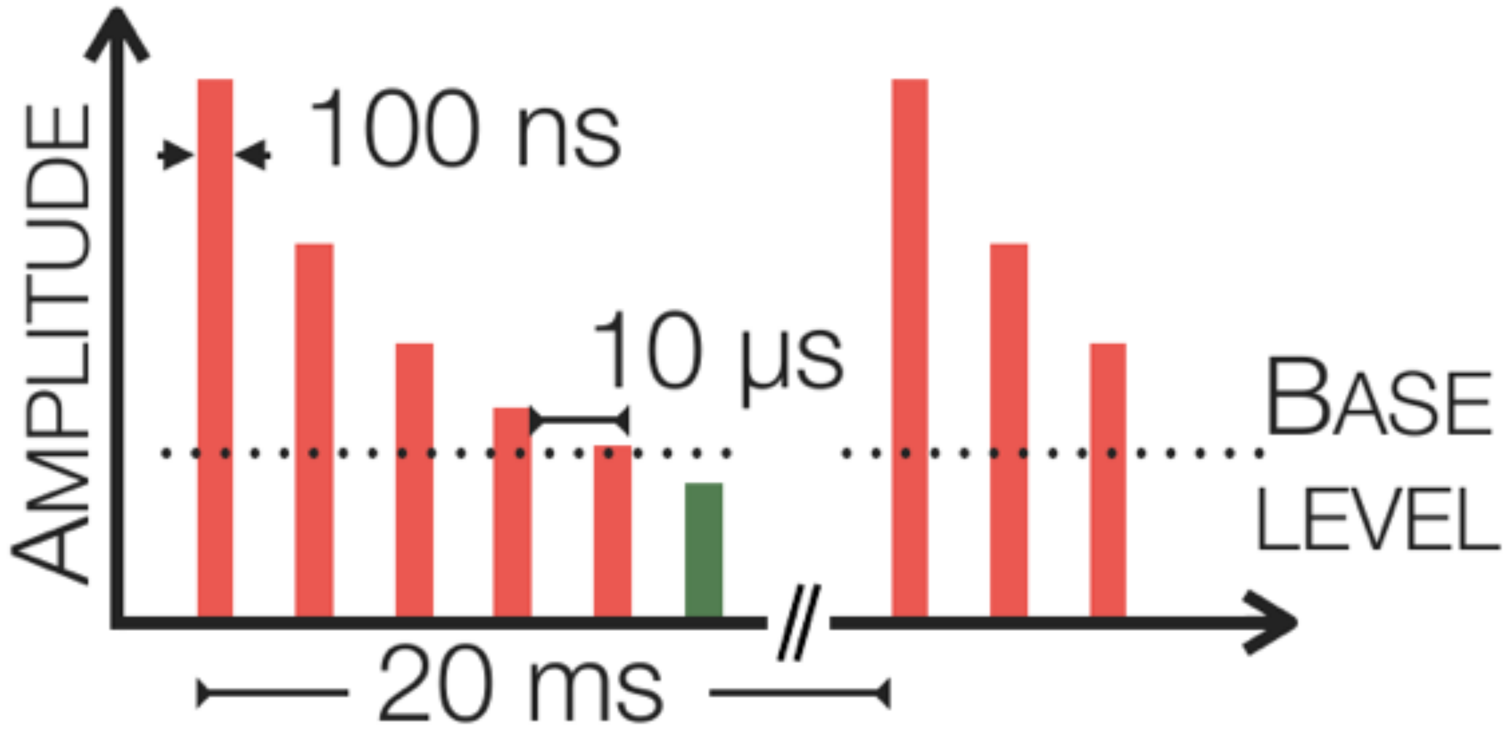

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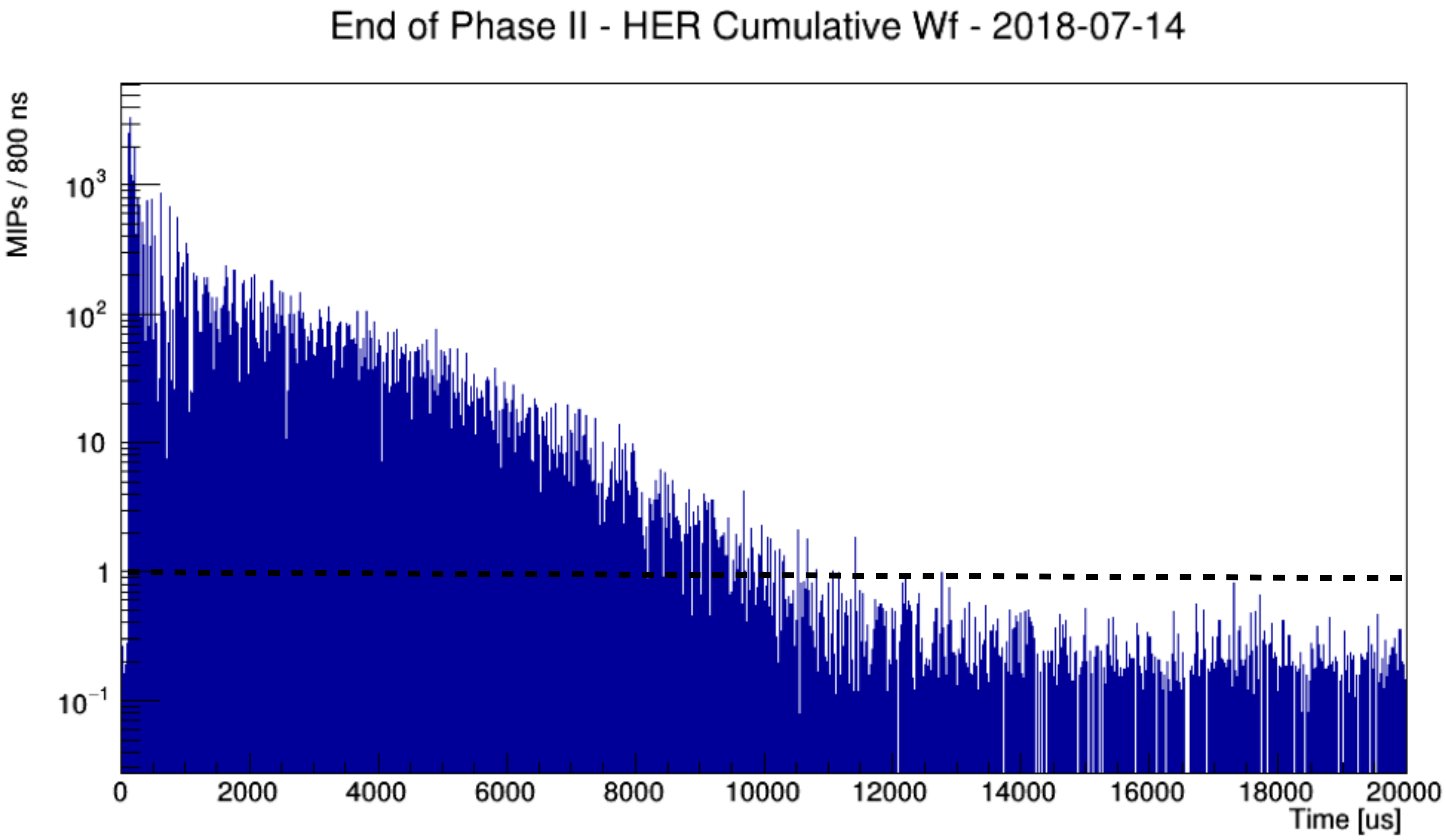
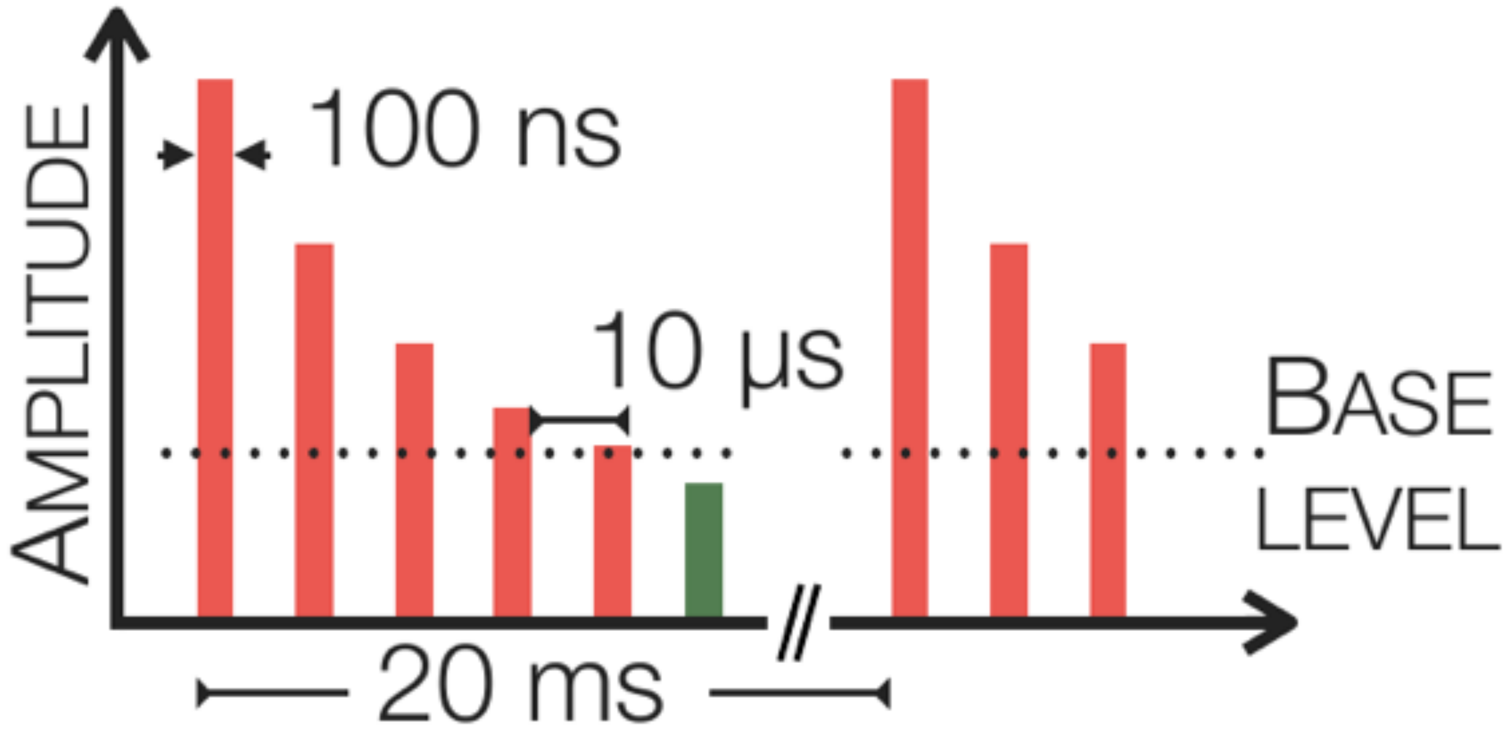


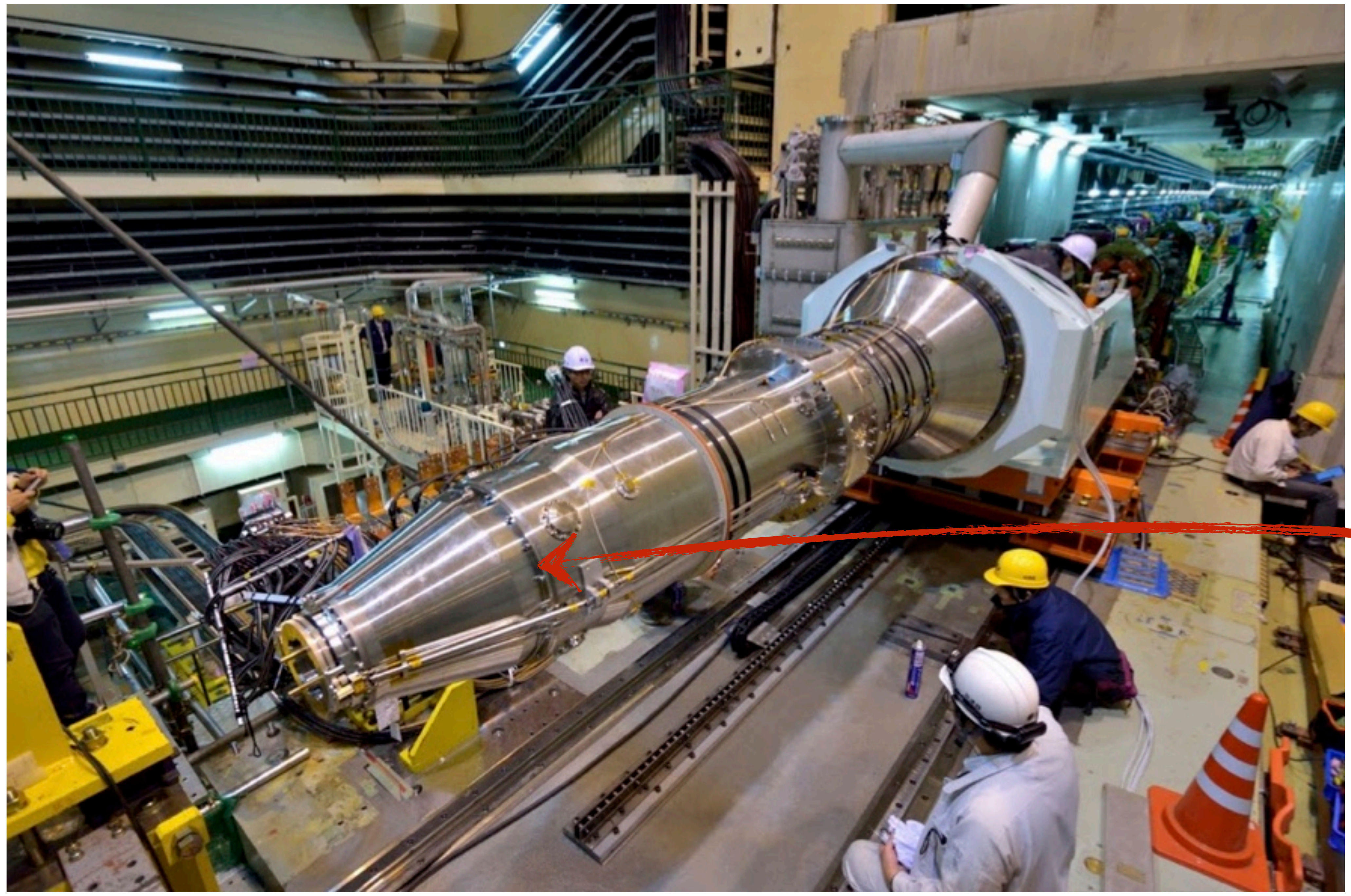
- Observe large background signals following injections, decaying over several 100 turns
- Backgrounds still take a (too) long time to reduce to acceptable levels

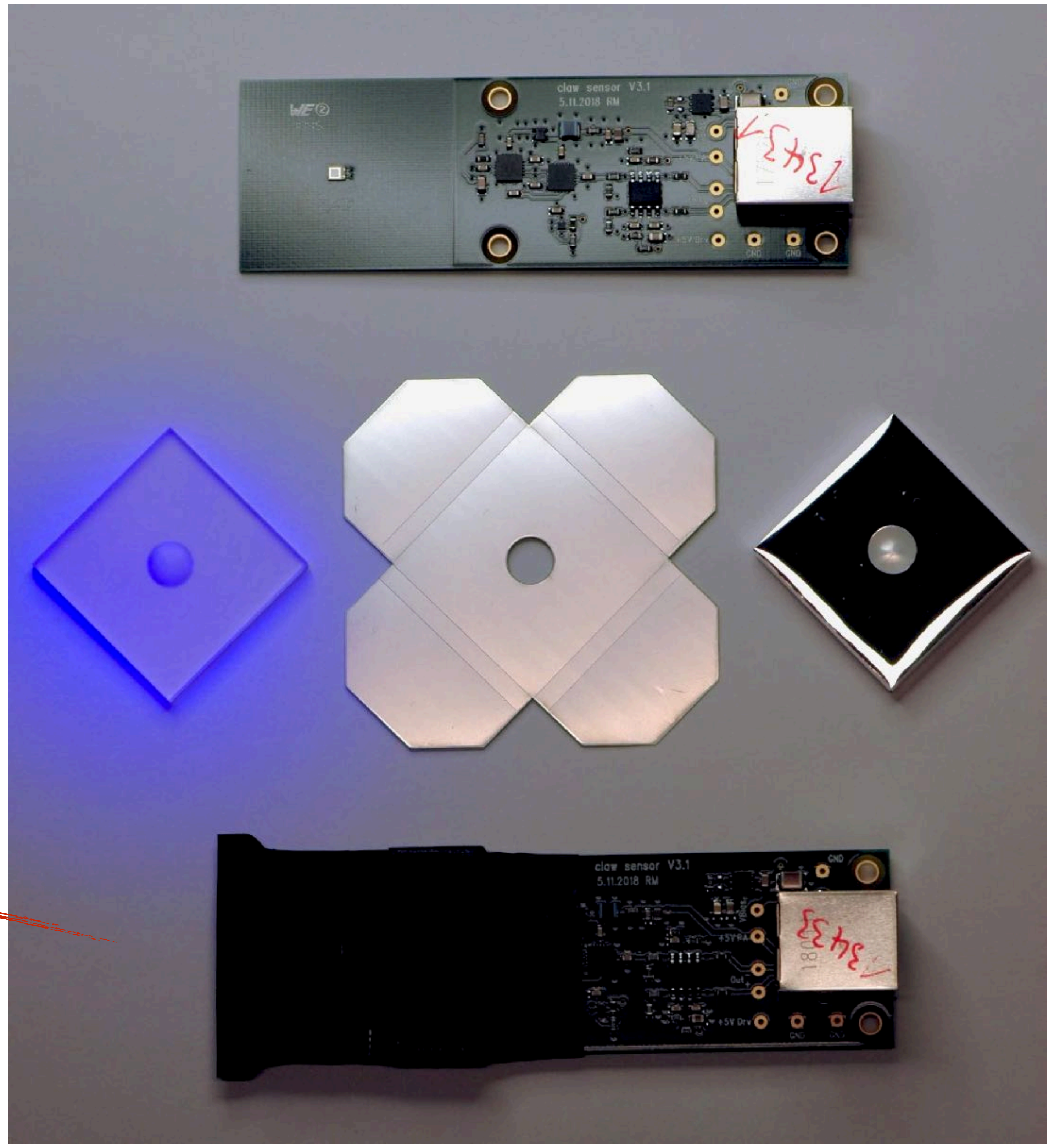


CLAWS Future

A Permanent Background Detector in SuperKEKB

- Following the success of the first two phases, CLAWS is now turned into a permanent background detector for SuperKEKB





- Substantial simplification of detectors: All supply voltages and signal lines supplied via one CAT6a cable per detector

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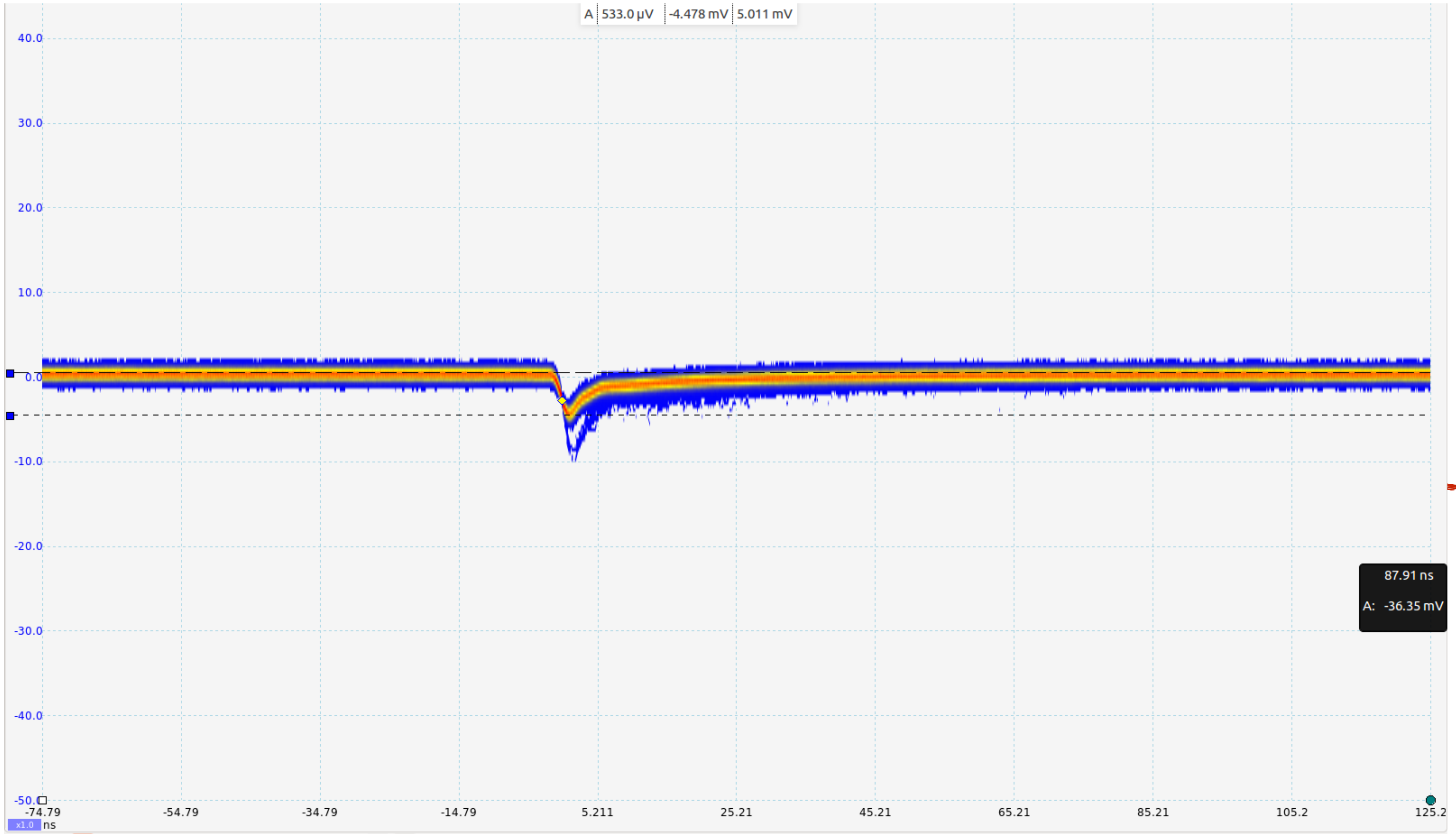
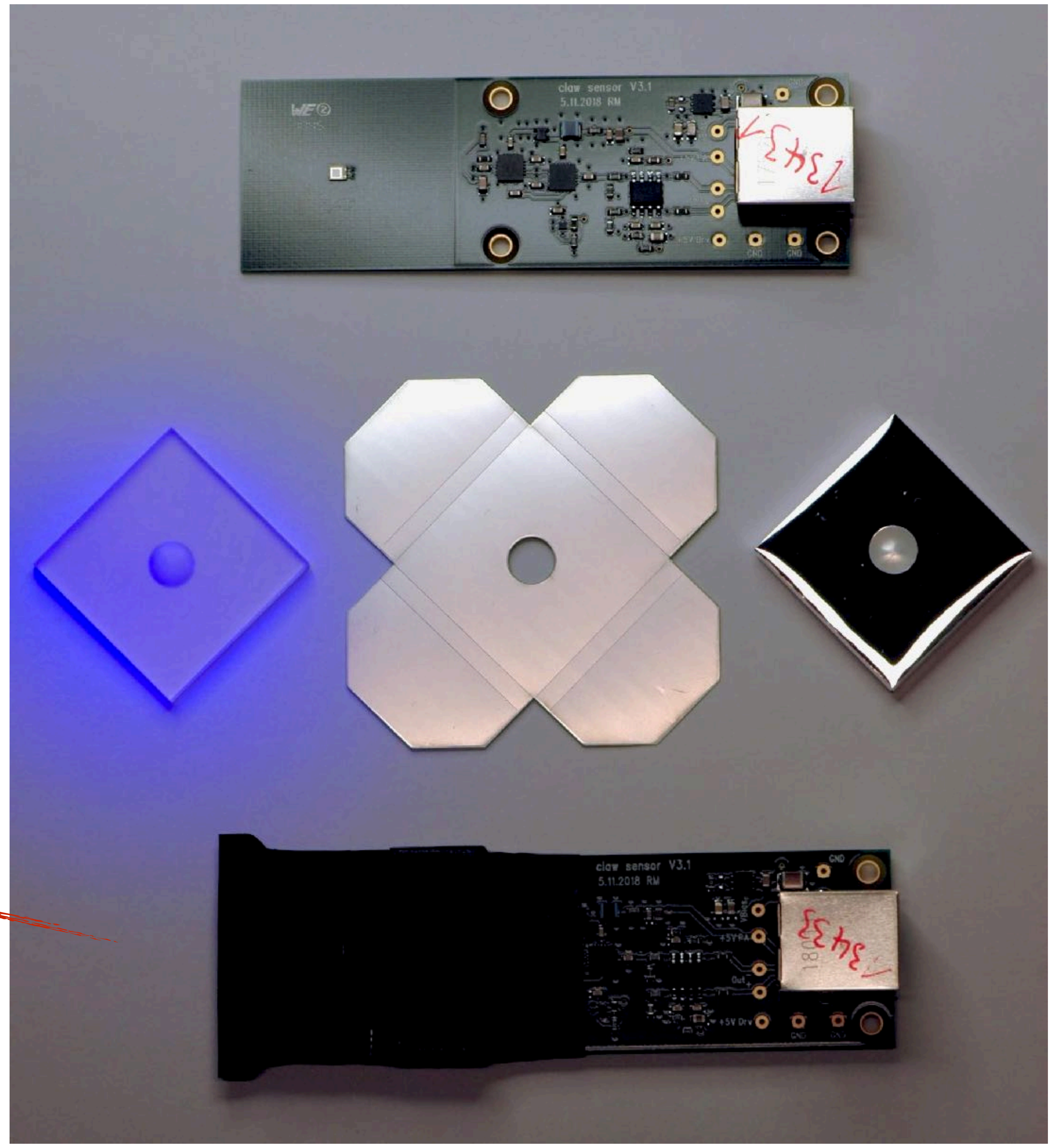




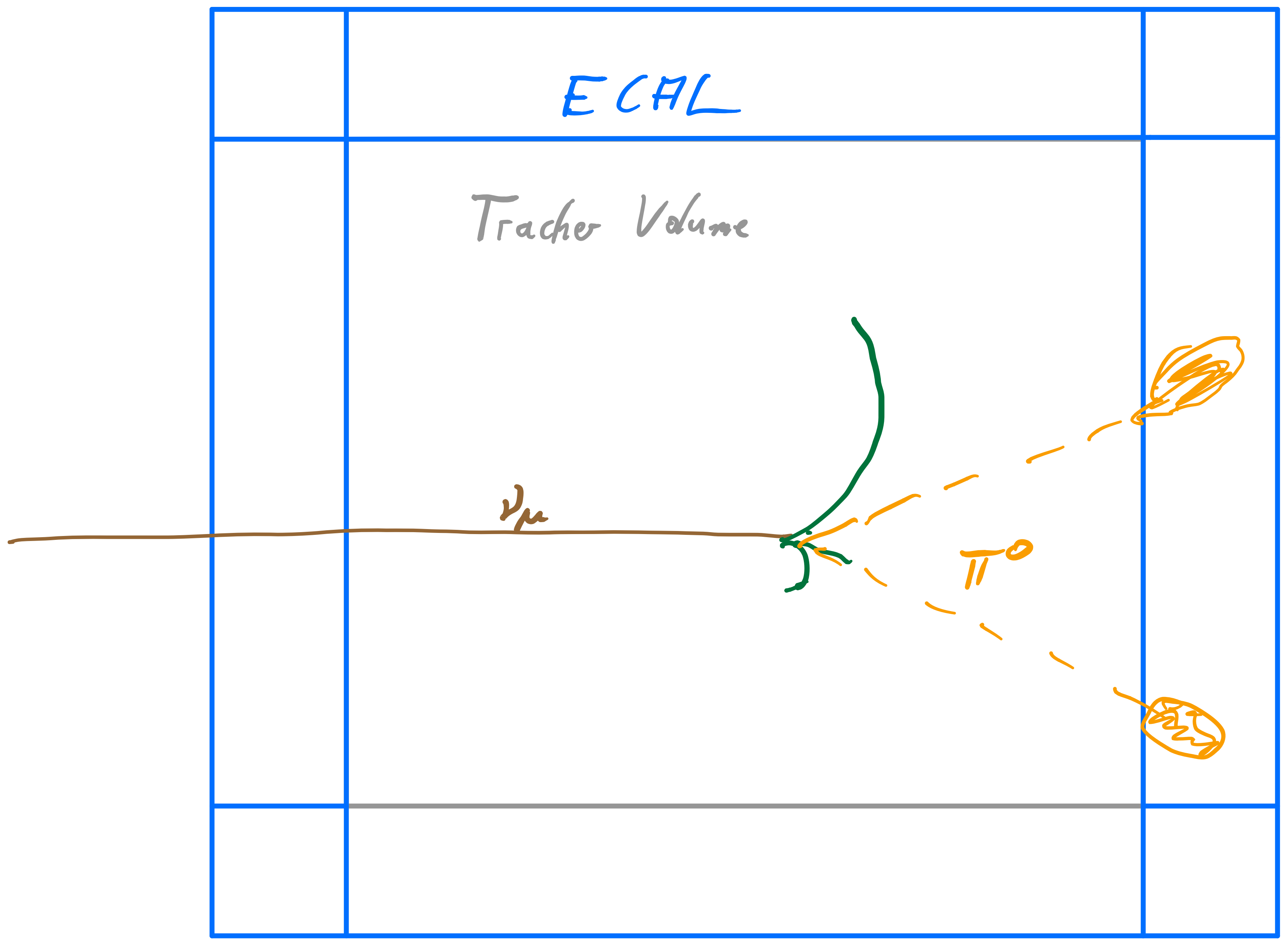
- Clean analog signal over 30 m - also 50 m cable still provides sufficient signal quality

- Substantial simplification of detectors: All supply voltages and signal lines supplied via one CAT6a cable per detector

An ECAL for the DUNE Near Detector

Extending the AHCAL Concept to Low Energies

- The Near Detector of the DUNE LBN Experiment:
  Based on a HP-TPC as magnetized tracker & target:
  Needs a powerful ECAL for γ, π^0 and neutron detection



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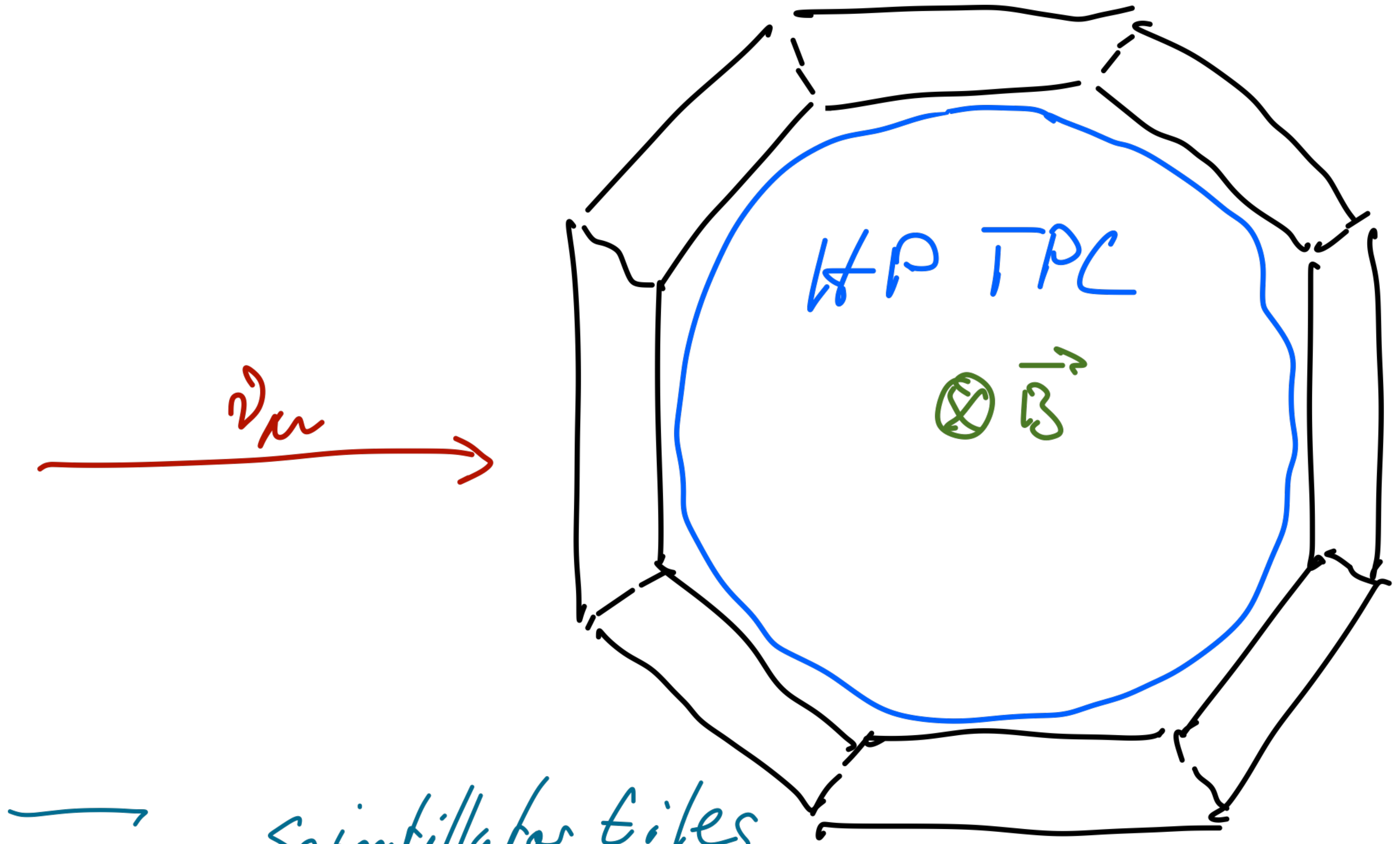
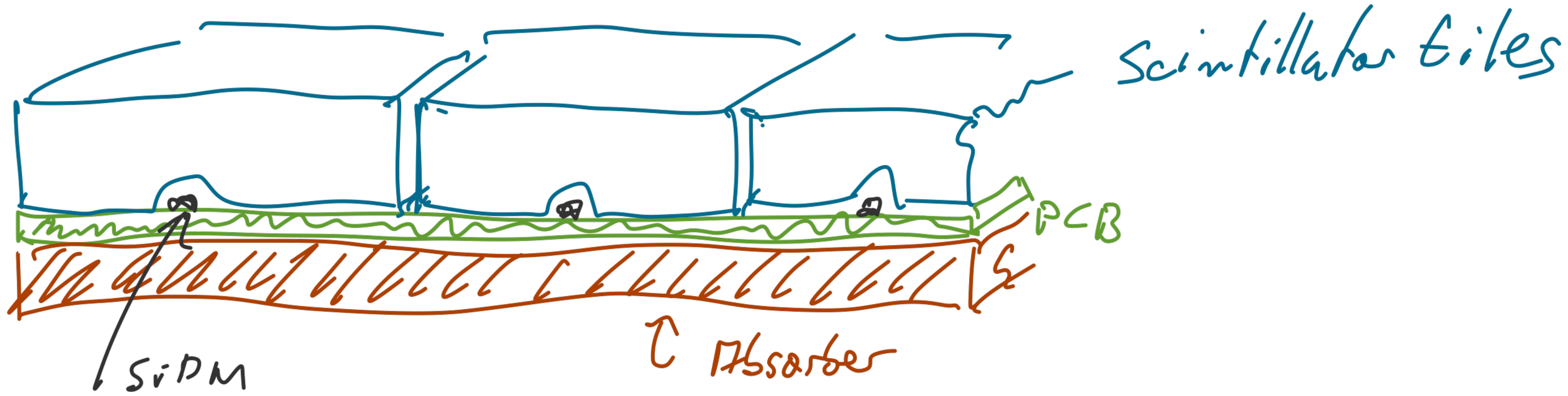
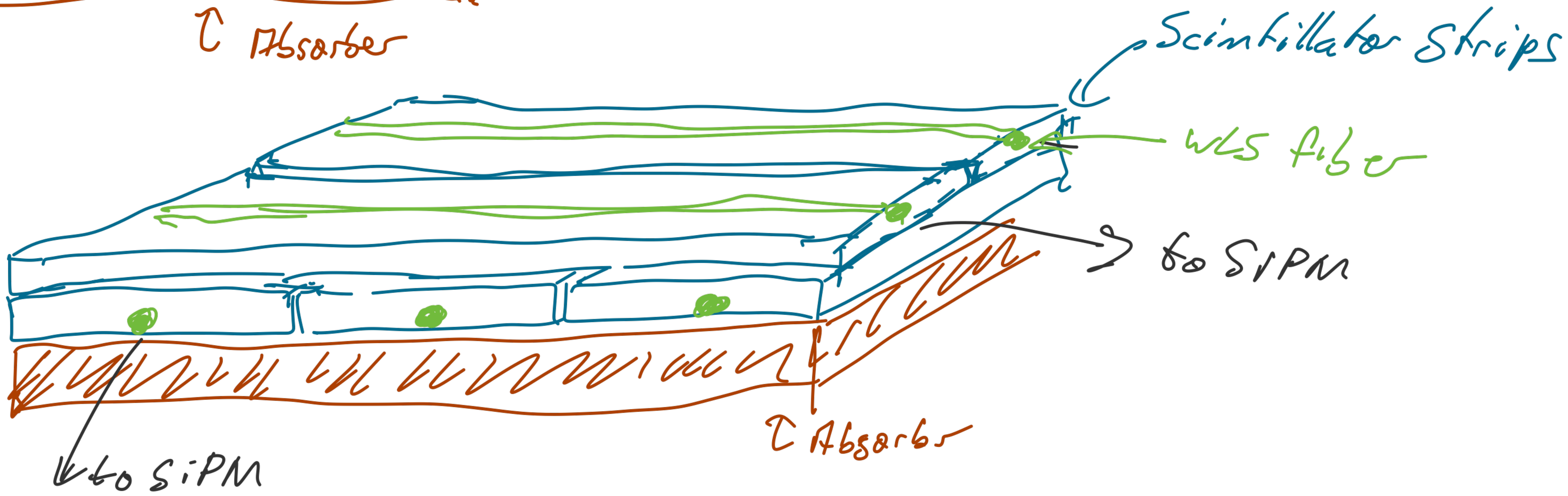
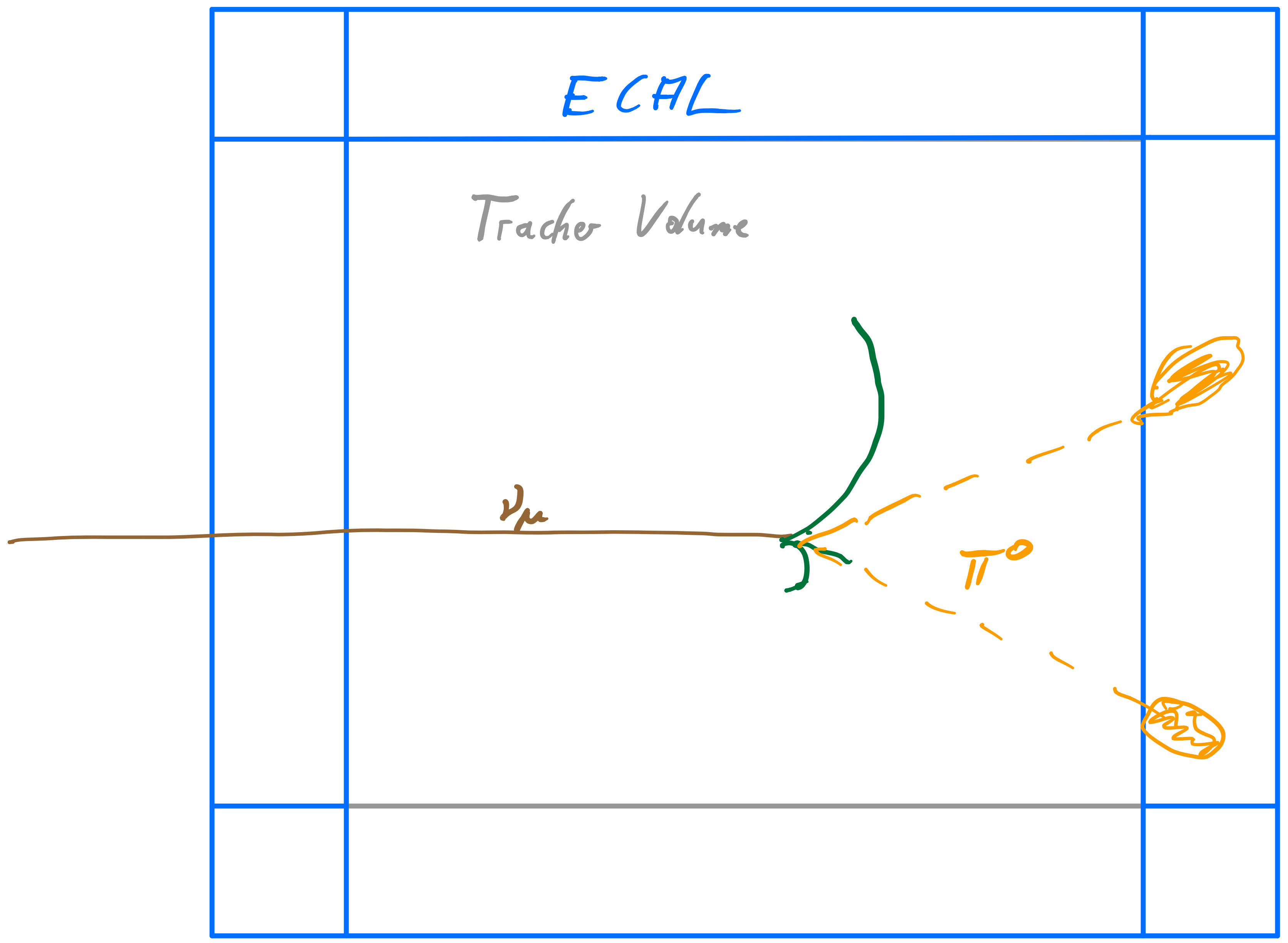
A ***Strawman Concept***

- Based on CALICE AHCAL technology, combining SiPM-on-tile and SiPM-on-strip









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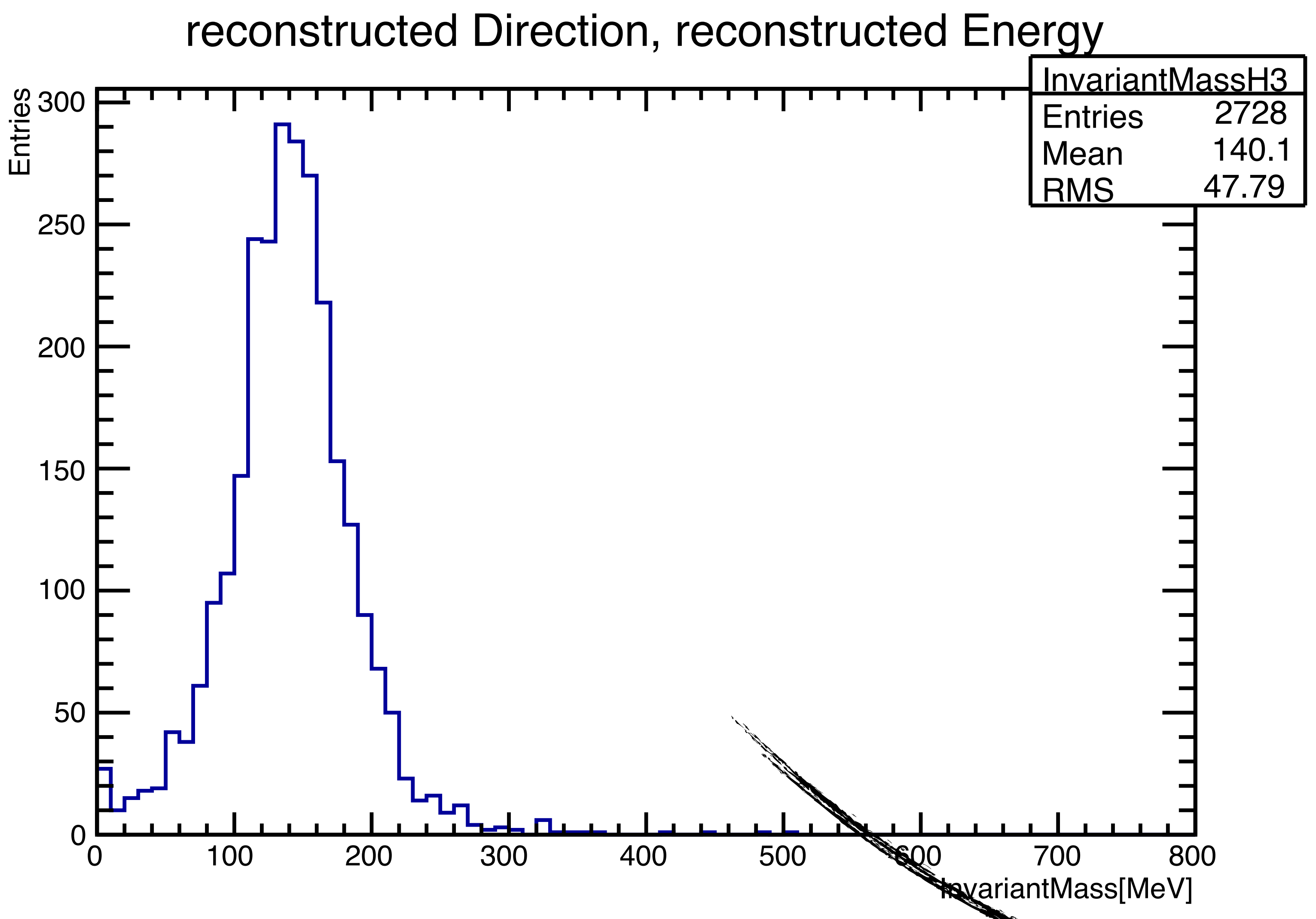
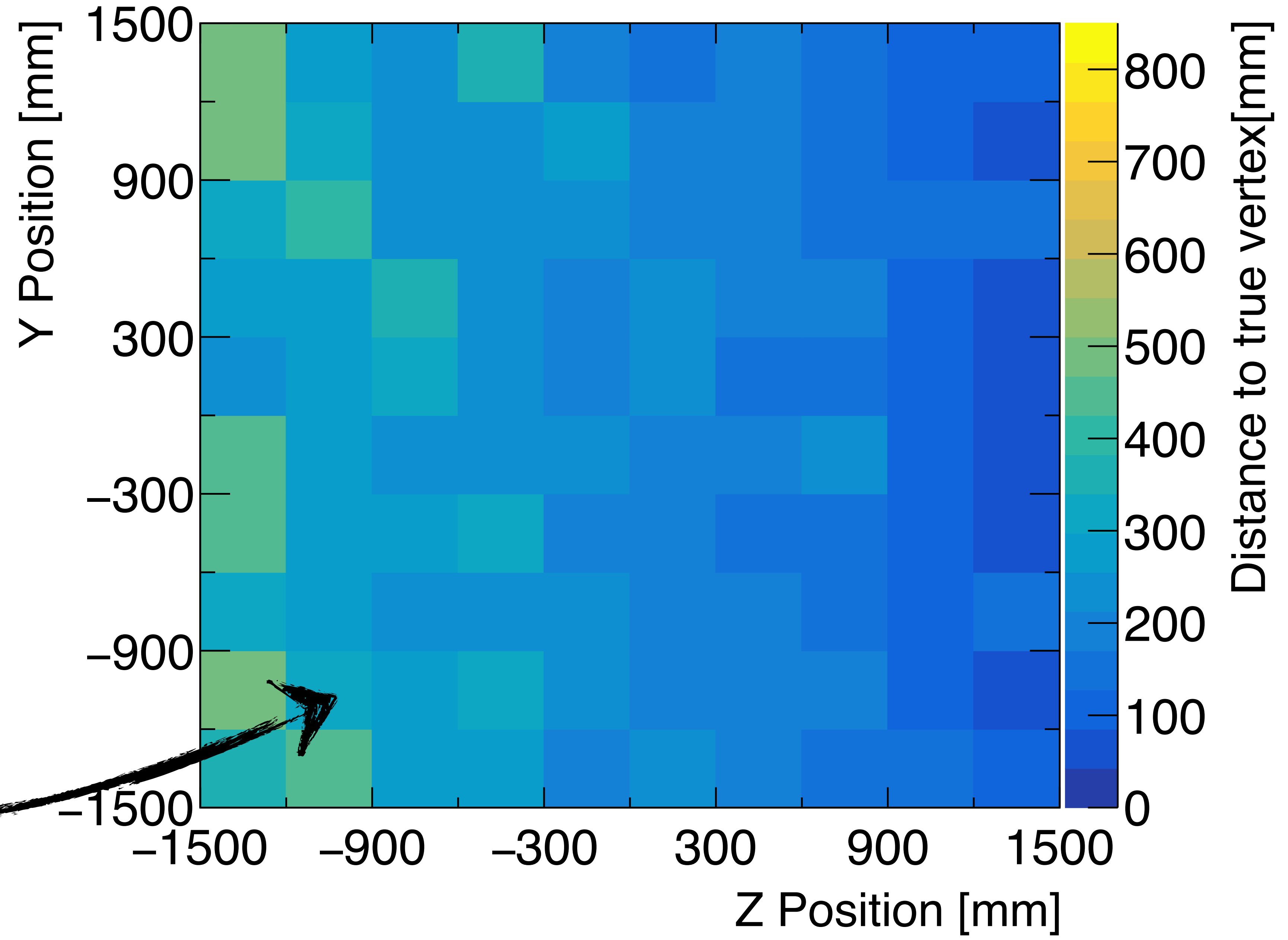
- Simulation studies to investigate the performance

  Reconstruction of π^0s with kinetic energies of a few 100 MeV





location of π^0 vertex with 20 - 30 cm precision

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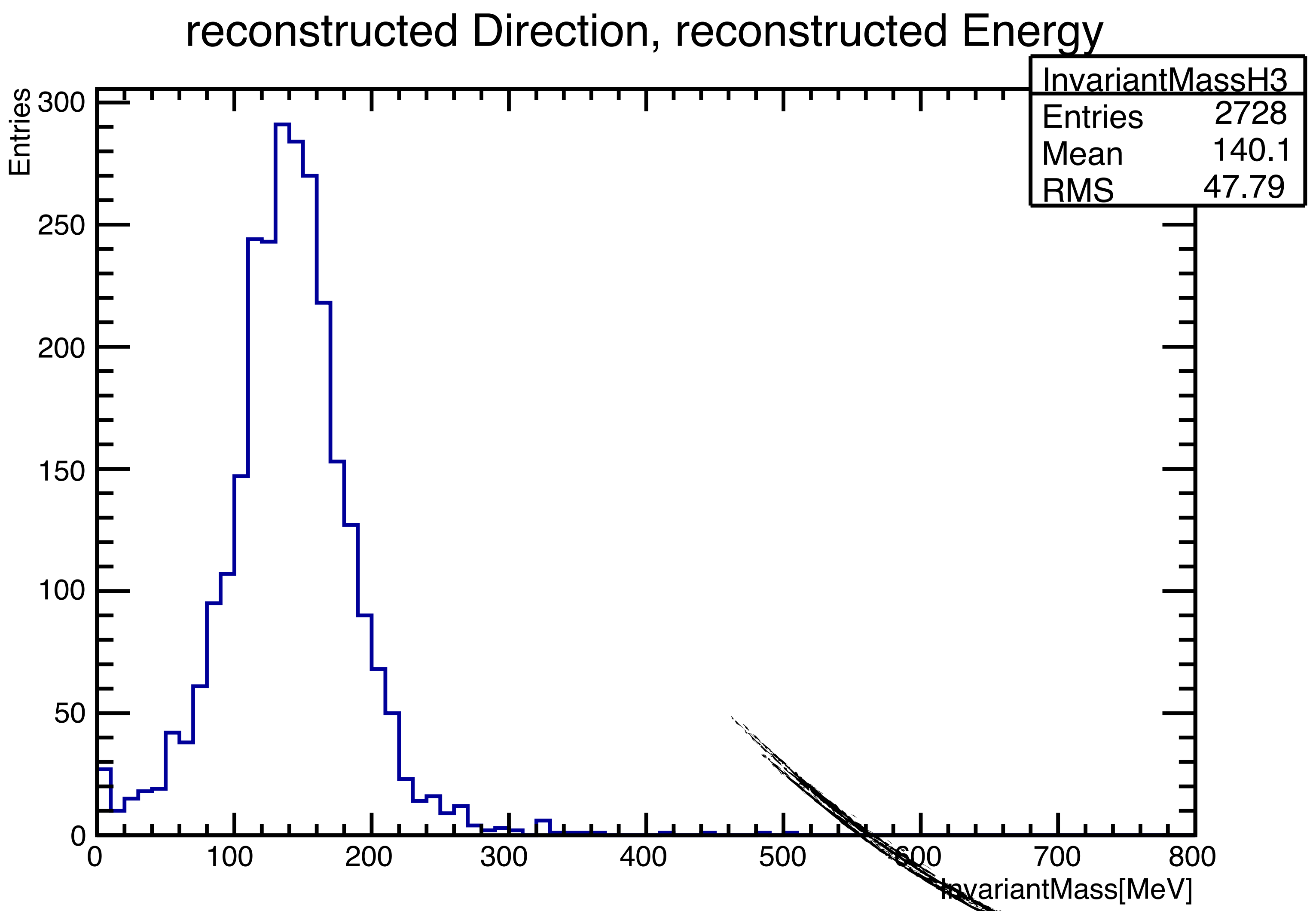

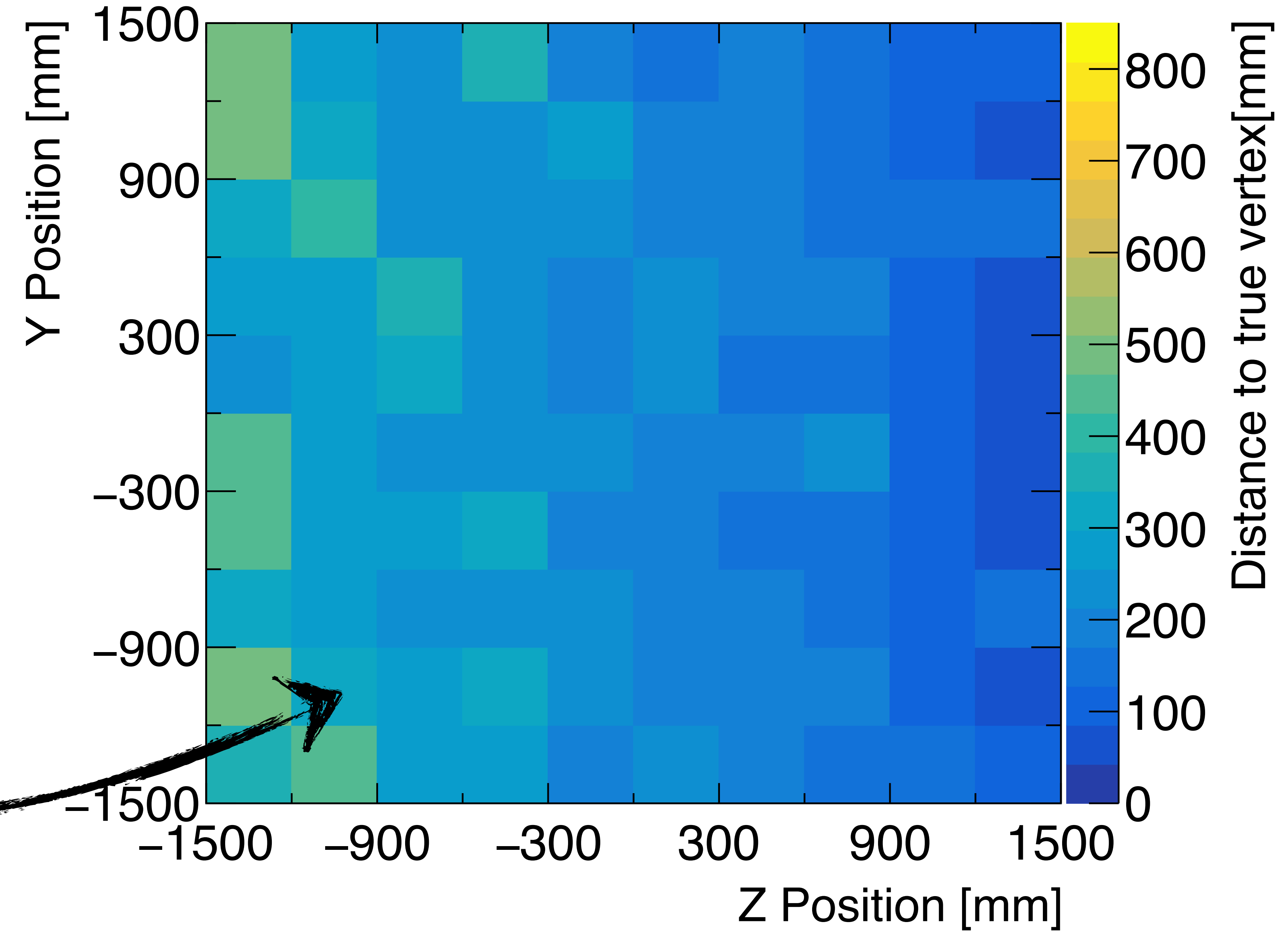

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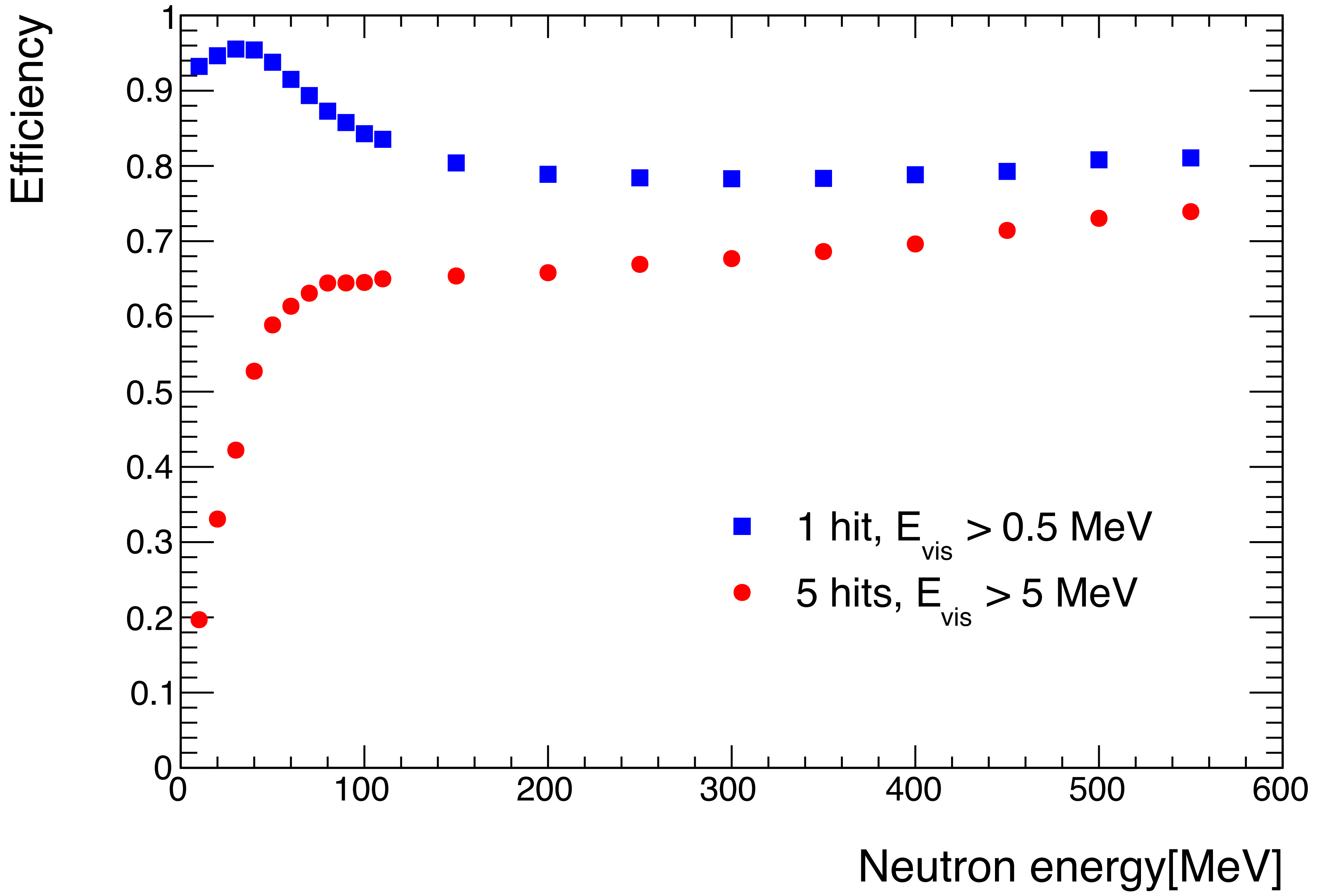
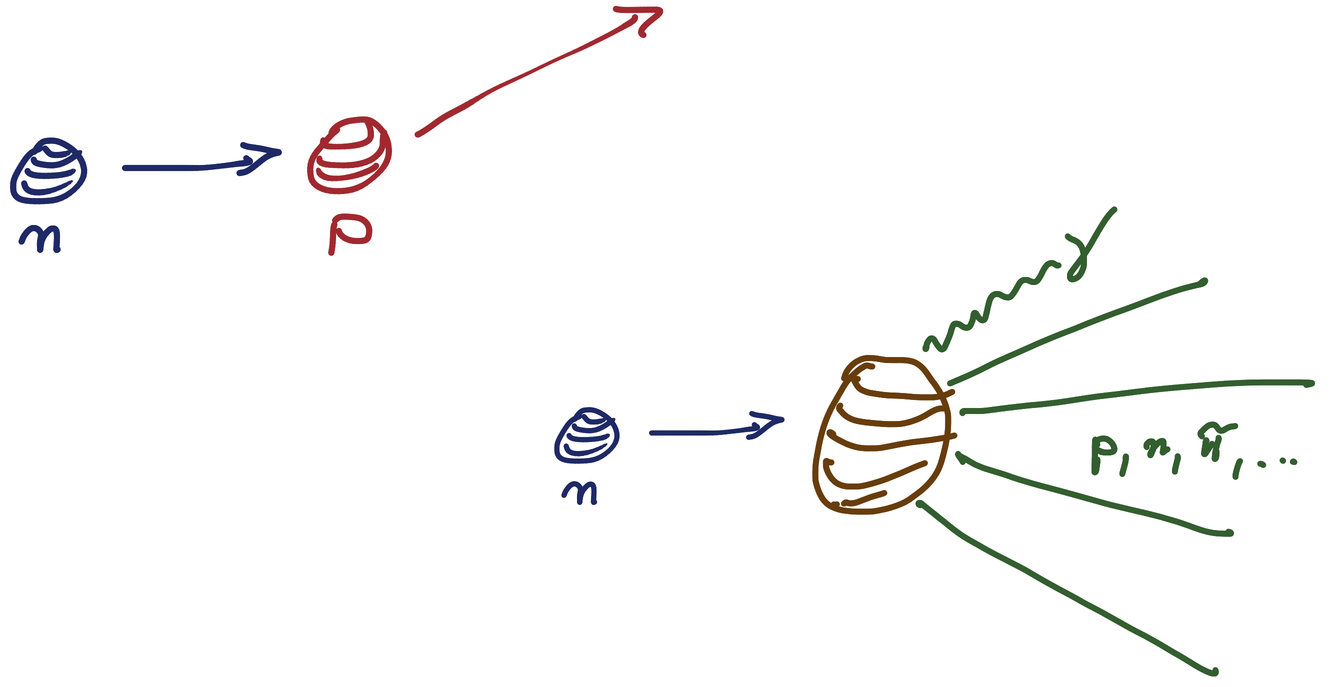


- Granularity enables efficient detection of neutrons (but clever reconstruction algorithms will be needed…)



Physics: Top & Higgs at e^+e^- Colliders

2018: Driven by ESPP Update, Large Reports

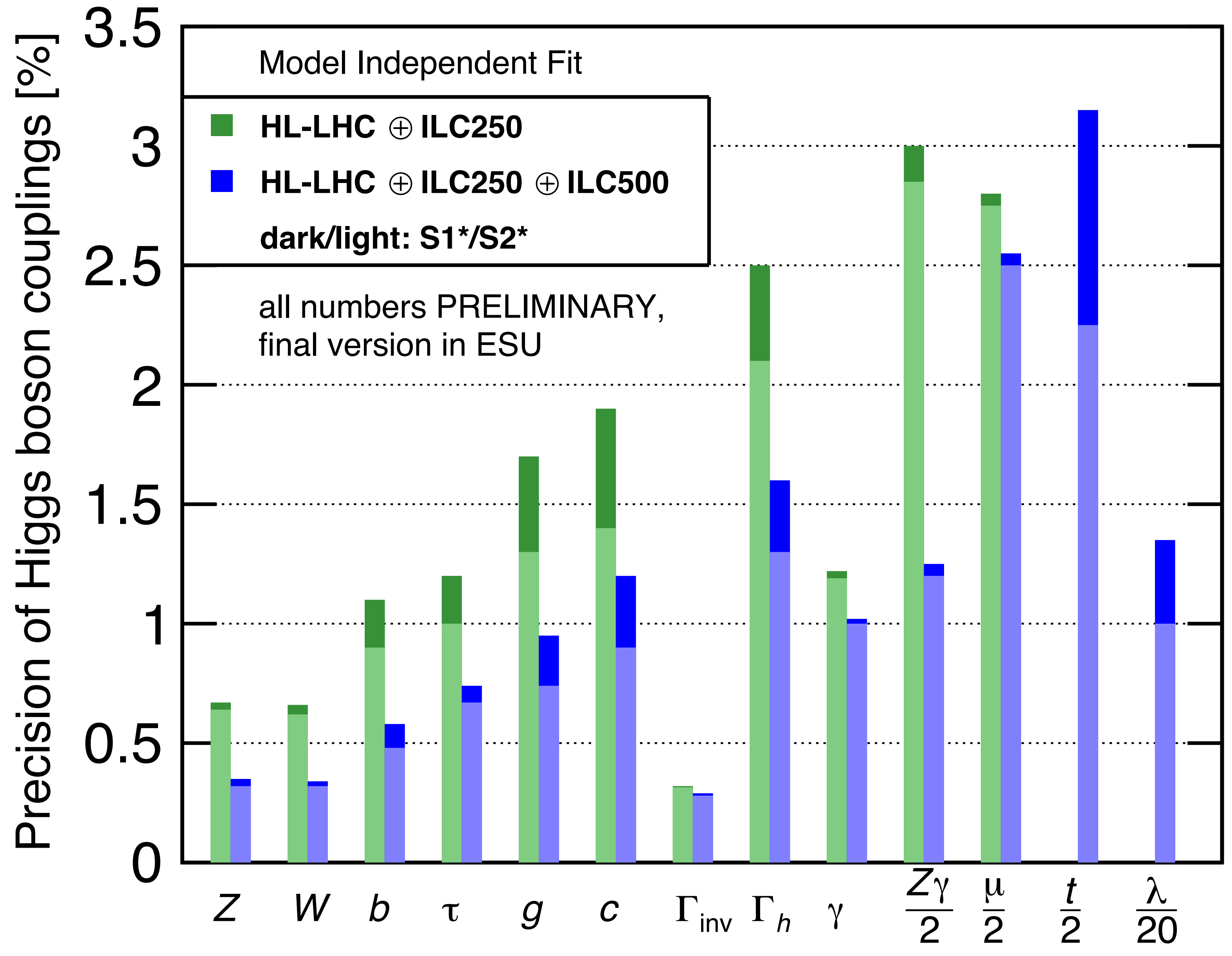
- Bringing together the studies of the physics potential of e^+e^- colliders as input to the Strategy Process

One Example:

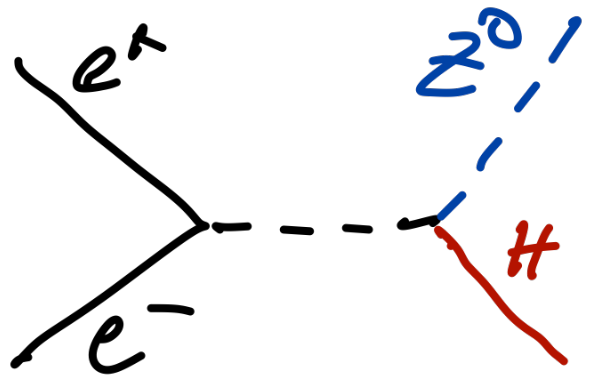
Higgs Physics at ILC

taking full simulation studies, factoring in expected systematic limitations, potential for analysis improvement…

Projections used in SMEFT fits to extract expected precision on couplings etc.



The ILC program:
starting at **250 GeV**



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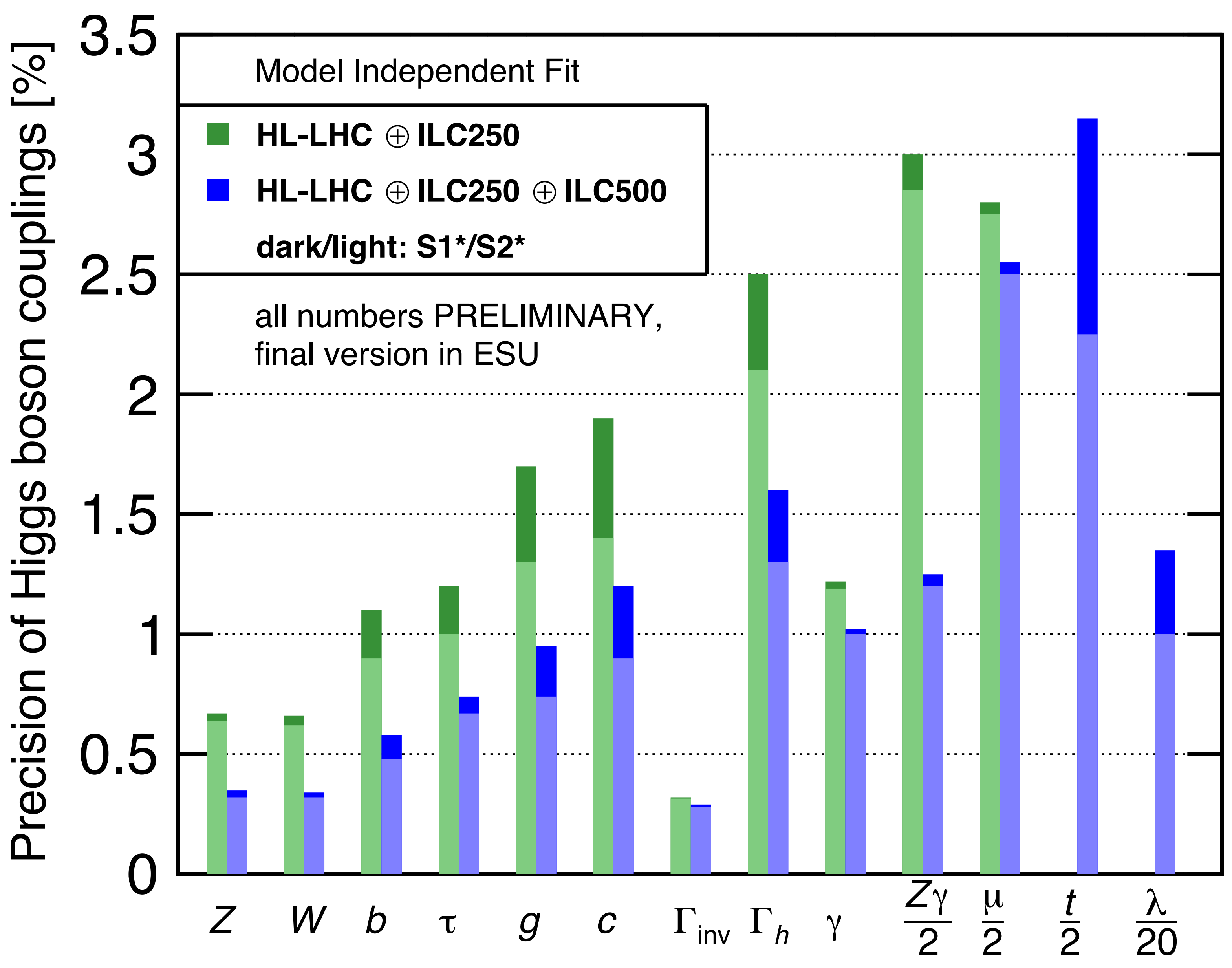

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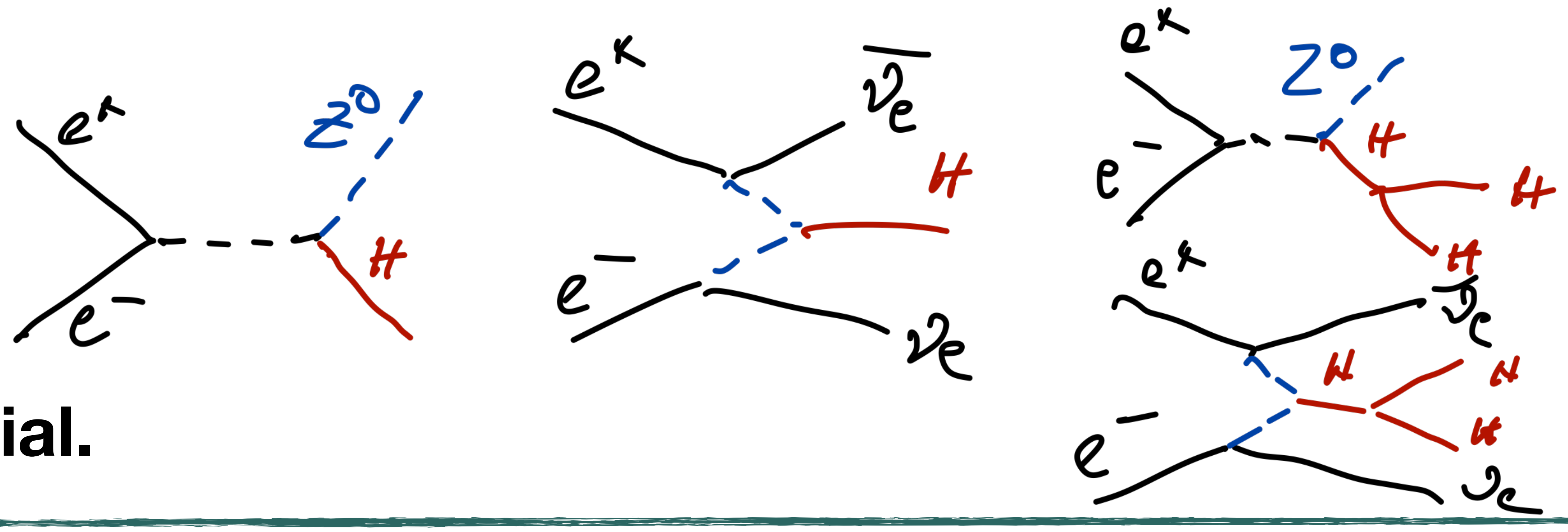

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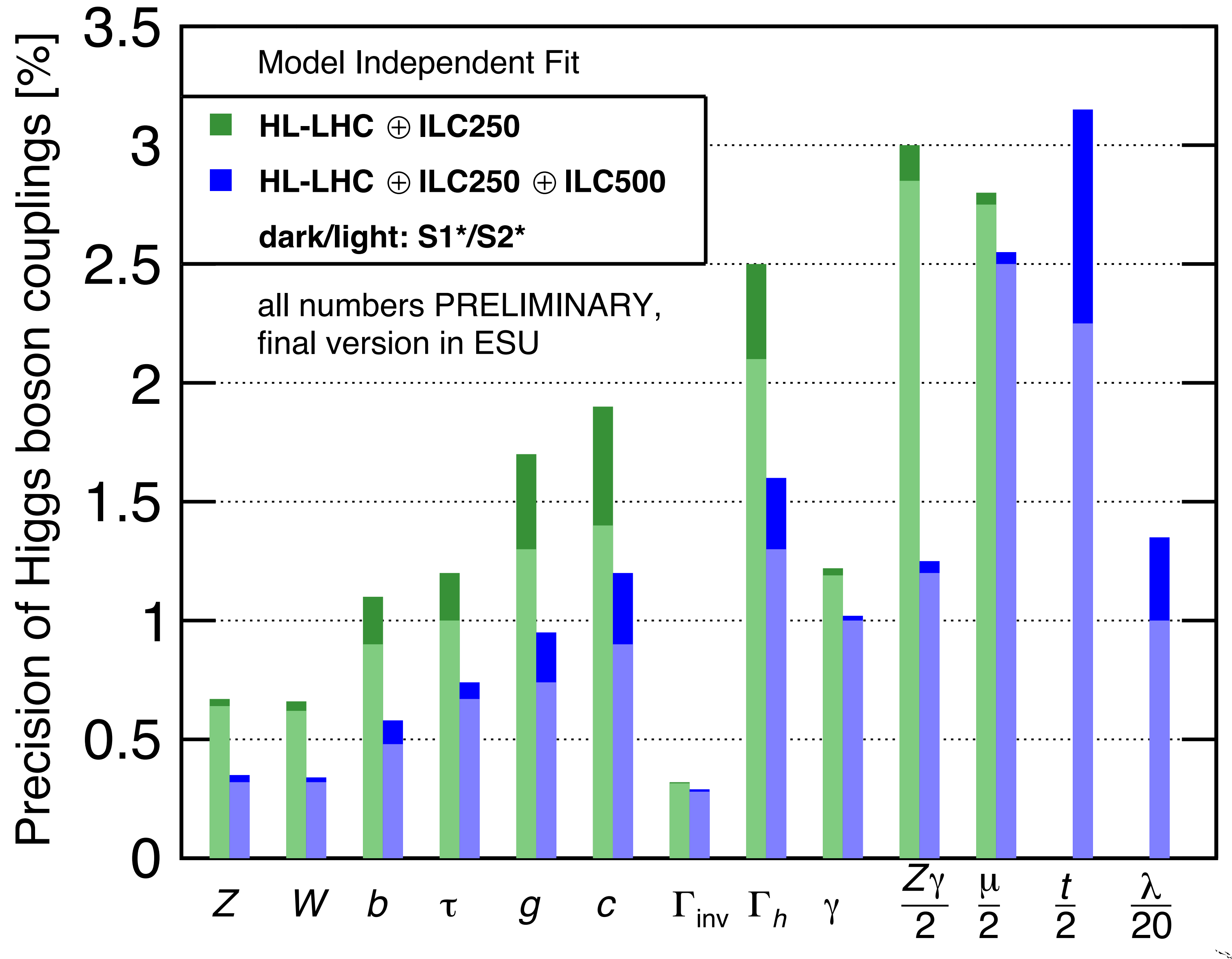

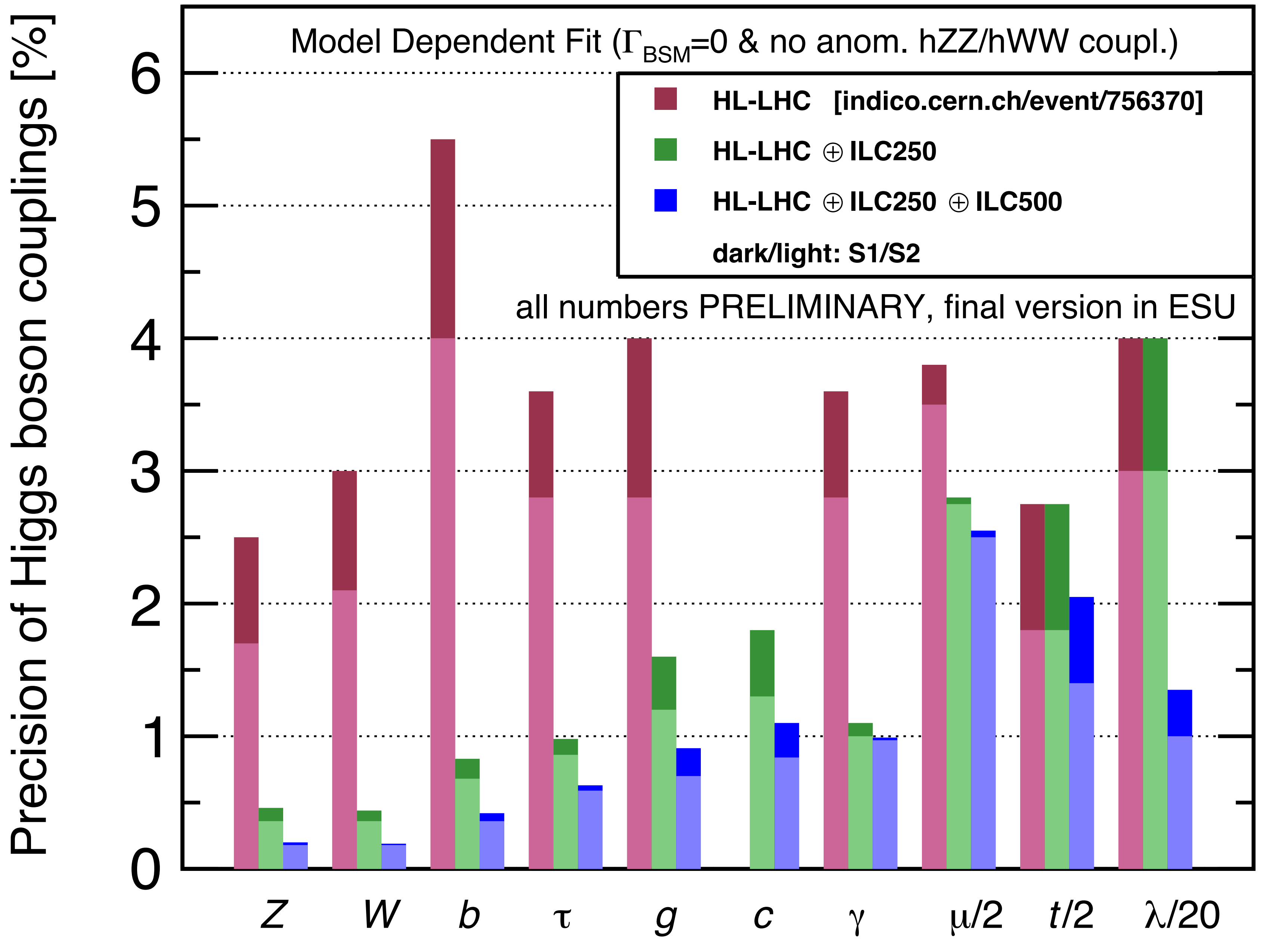

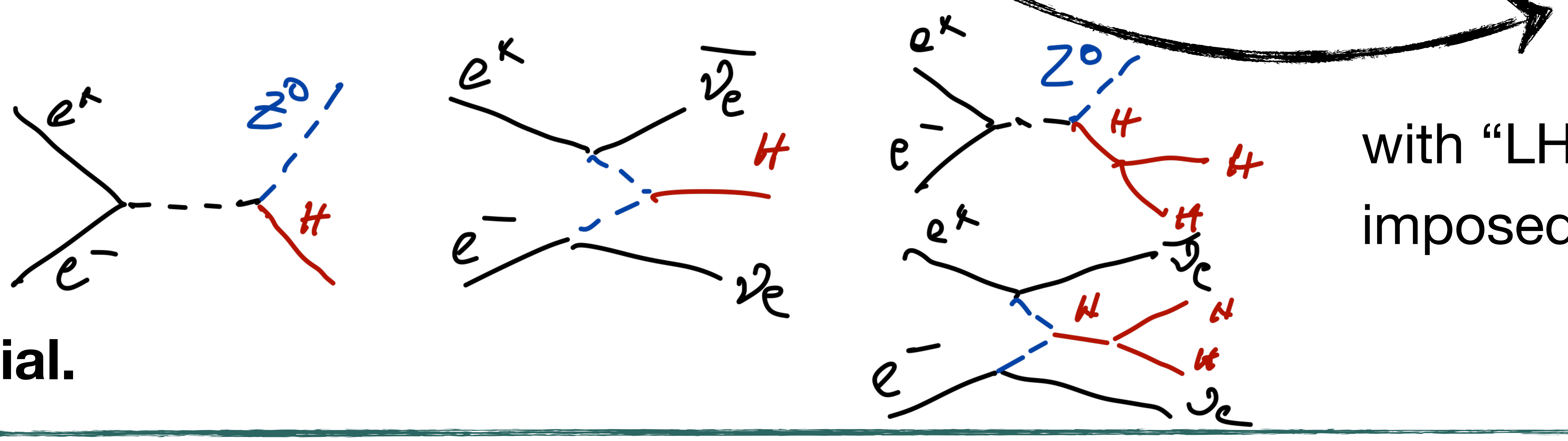

with "LHC-like" constraints imposed …

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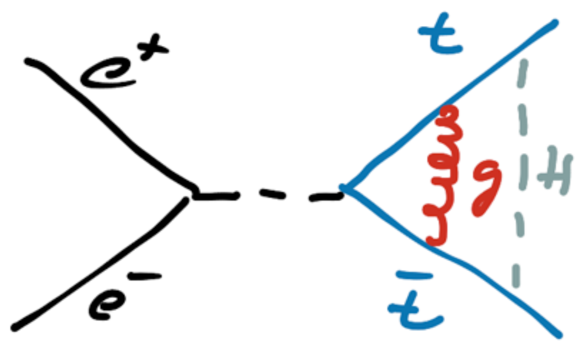
  one part: Pair production at threshold (~ 350 GeV)



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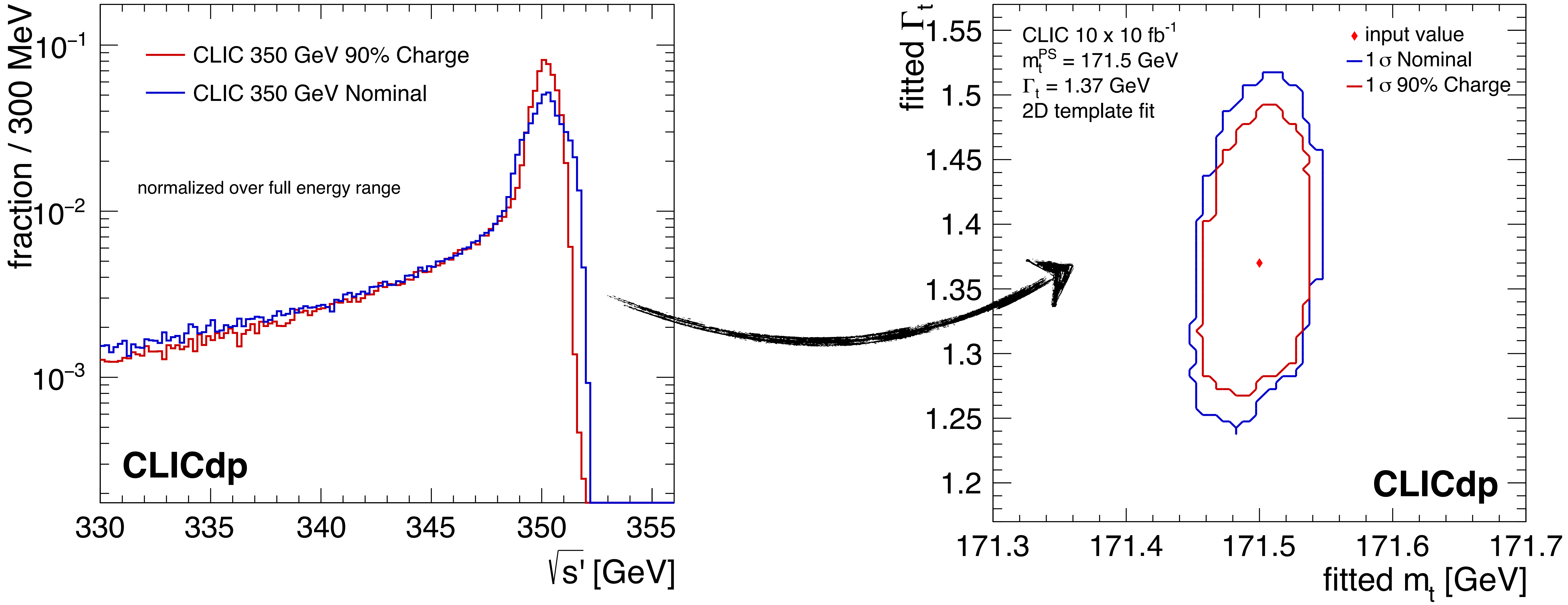

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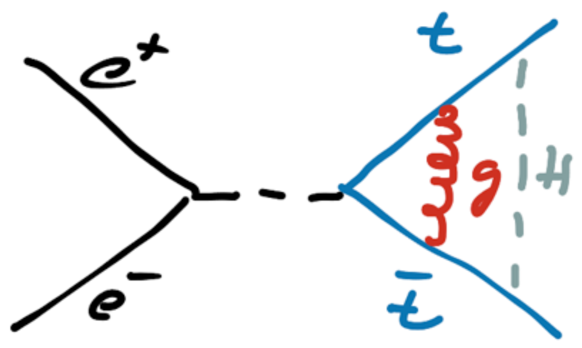

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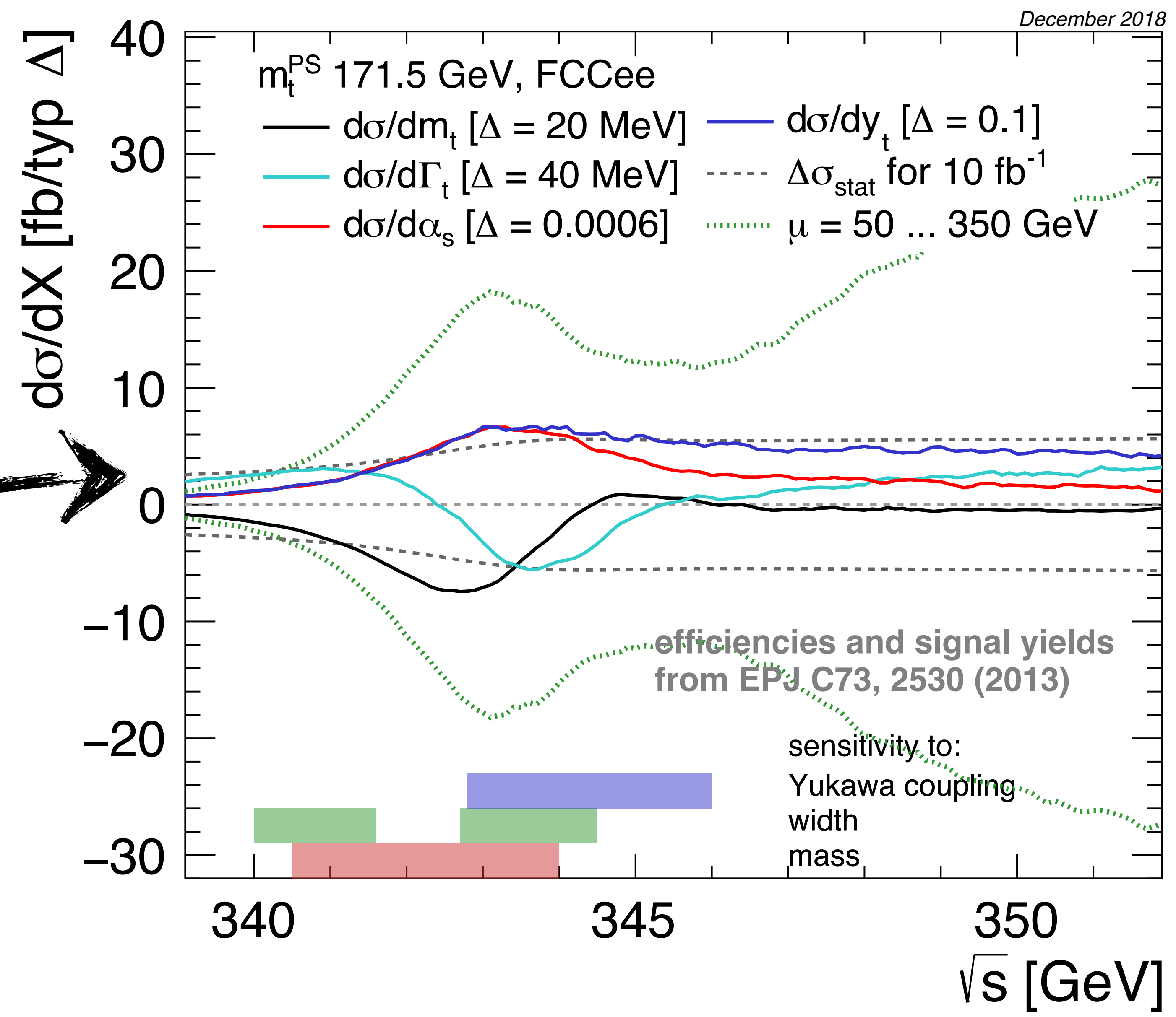
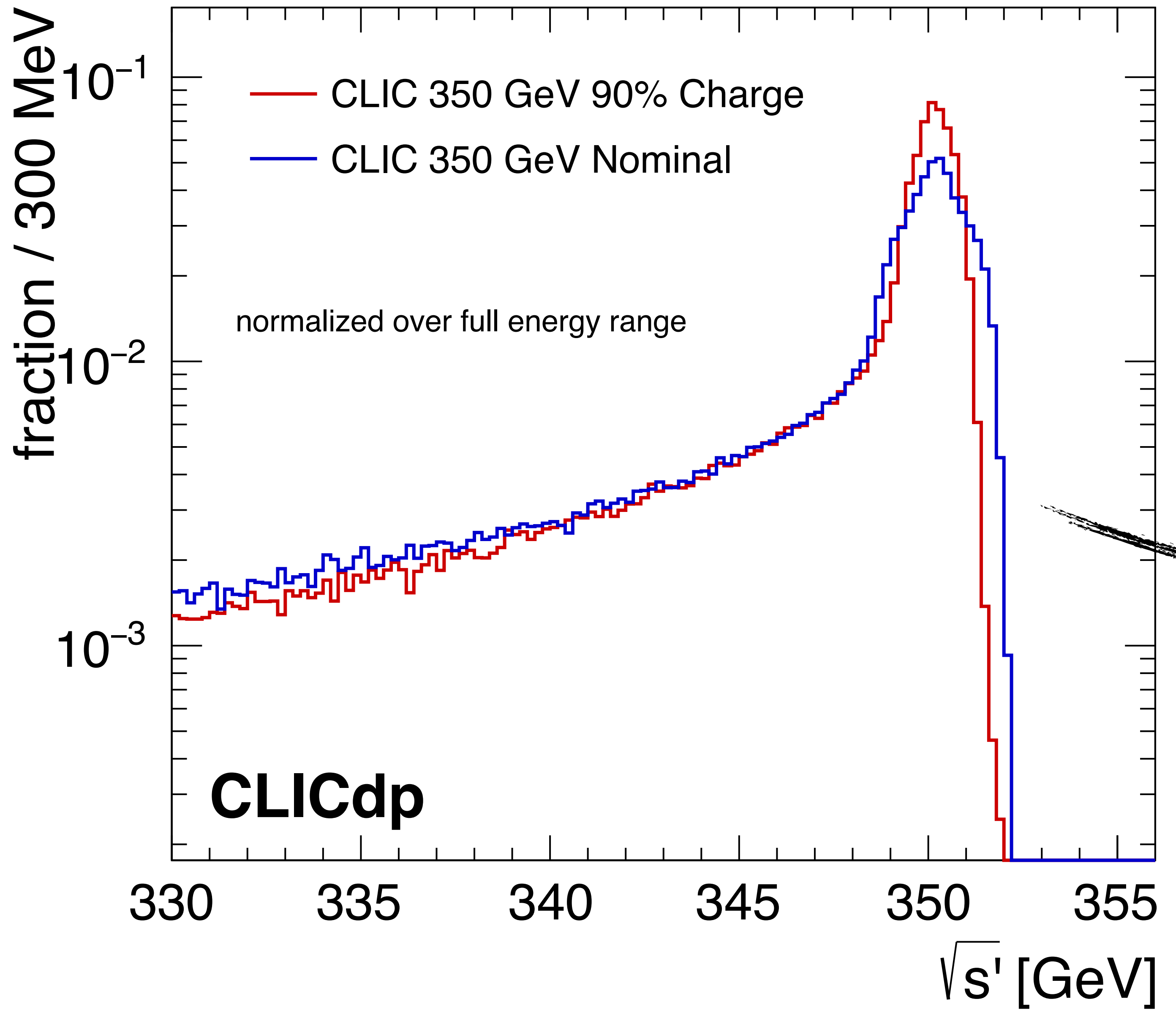
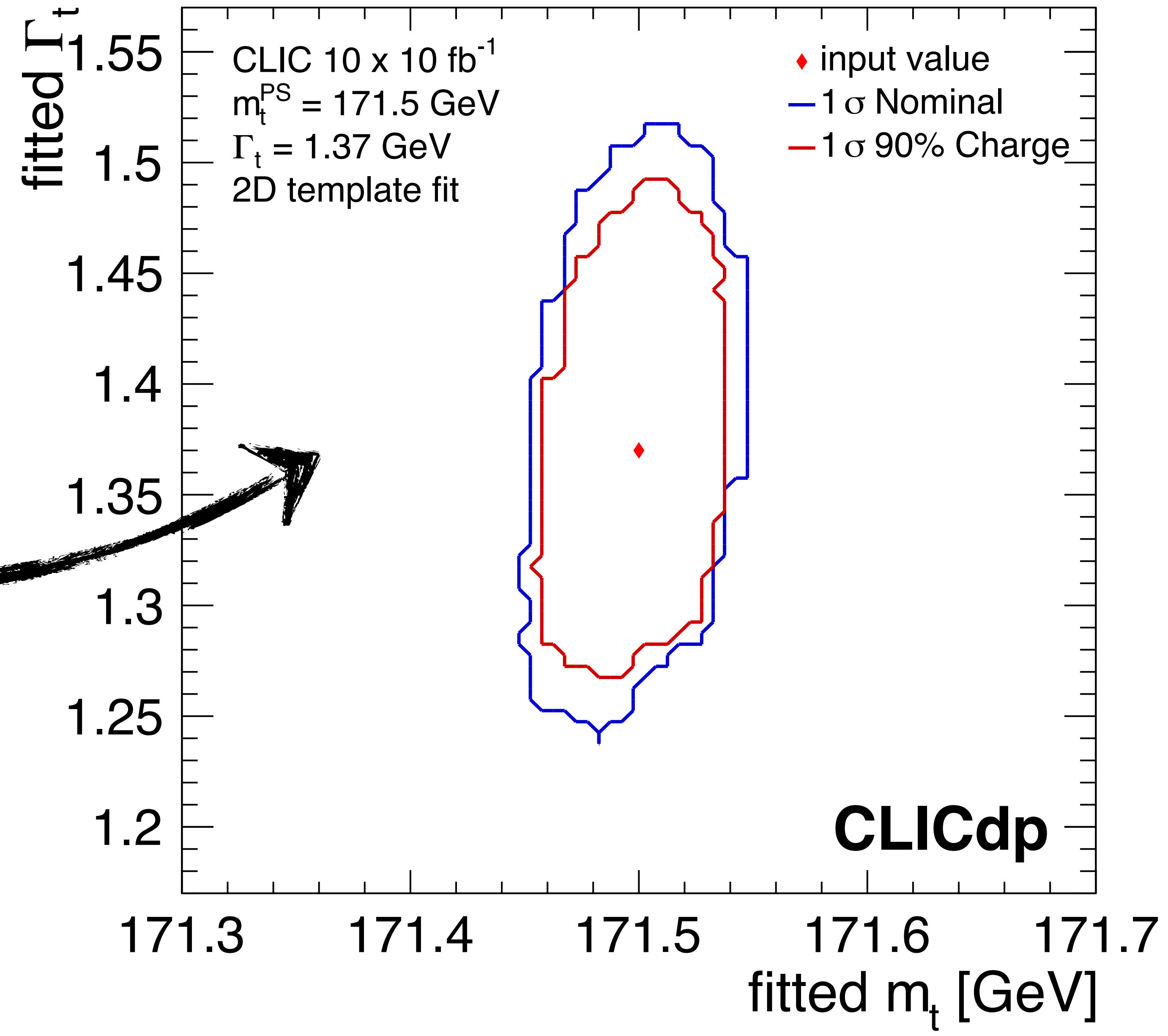
extended to ***FCCee***

- investigating the optimal range for the scan







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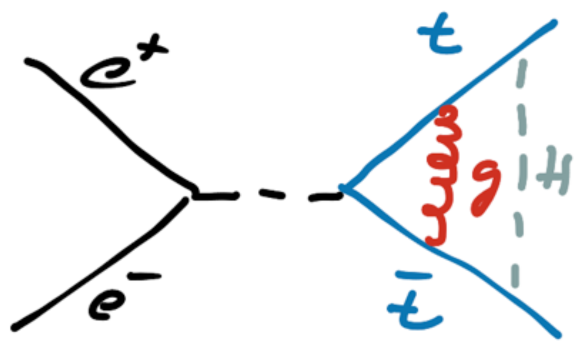

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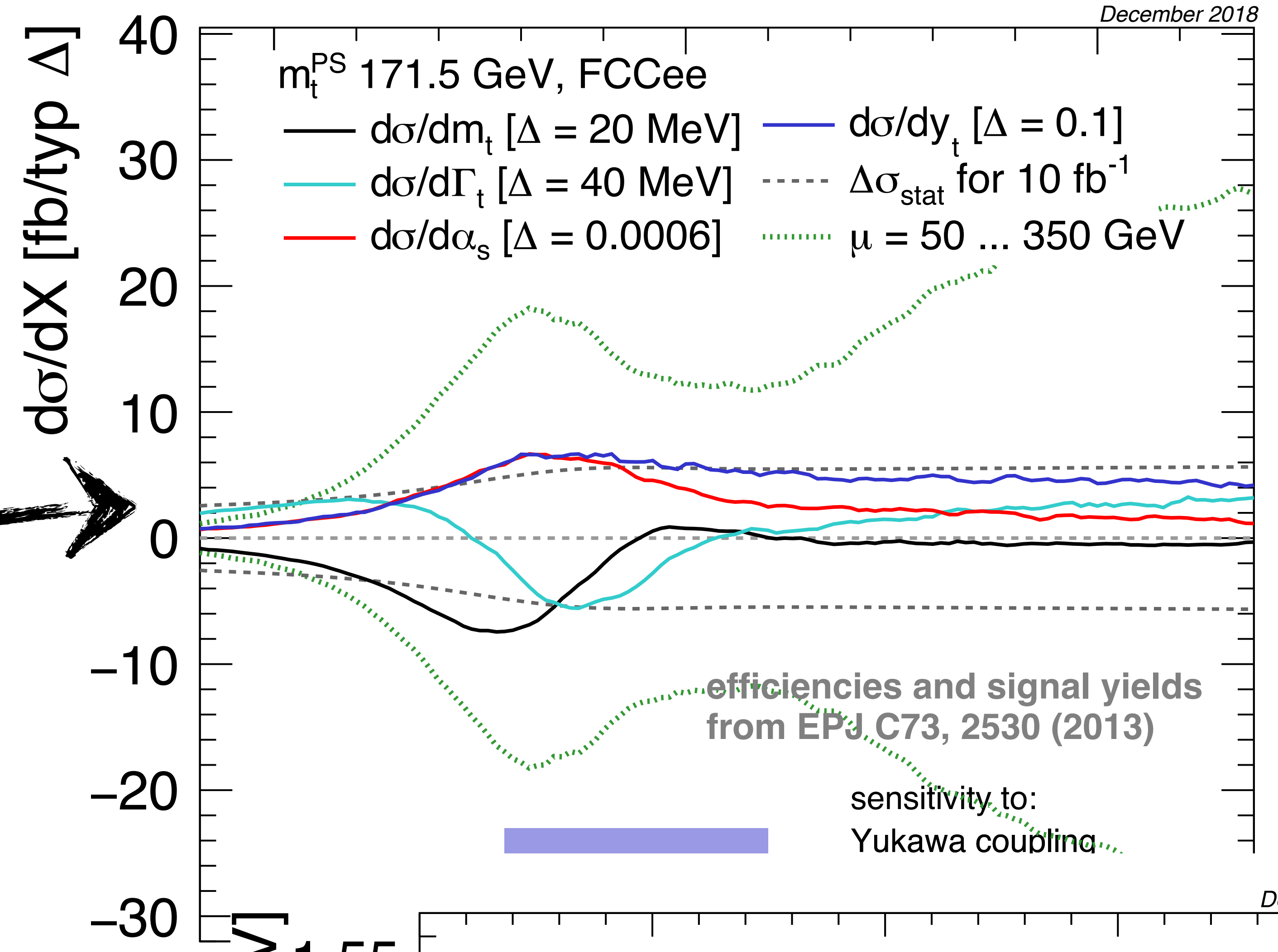

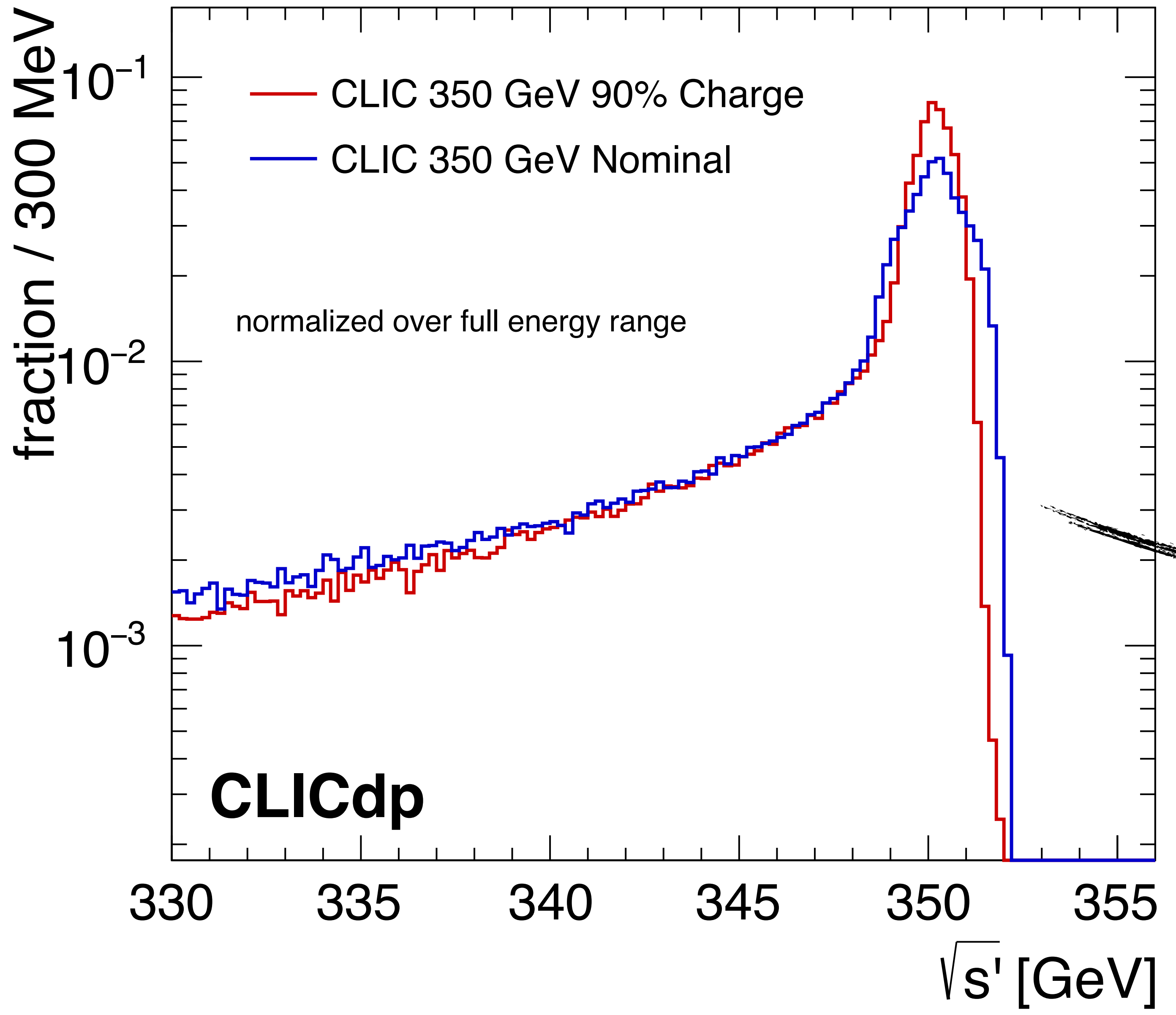

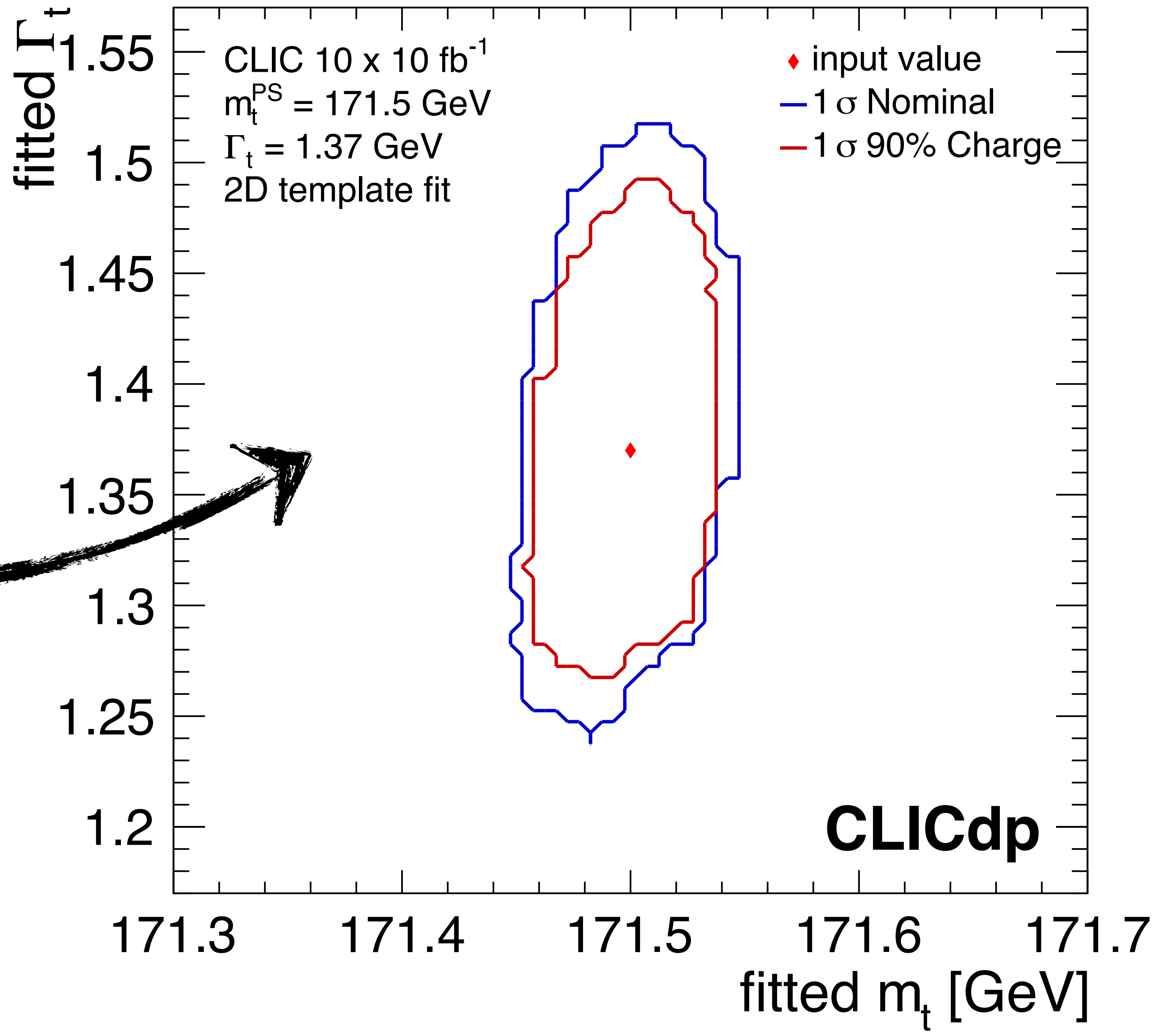

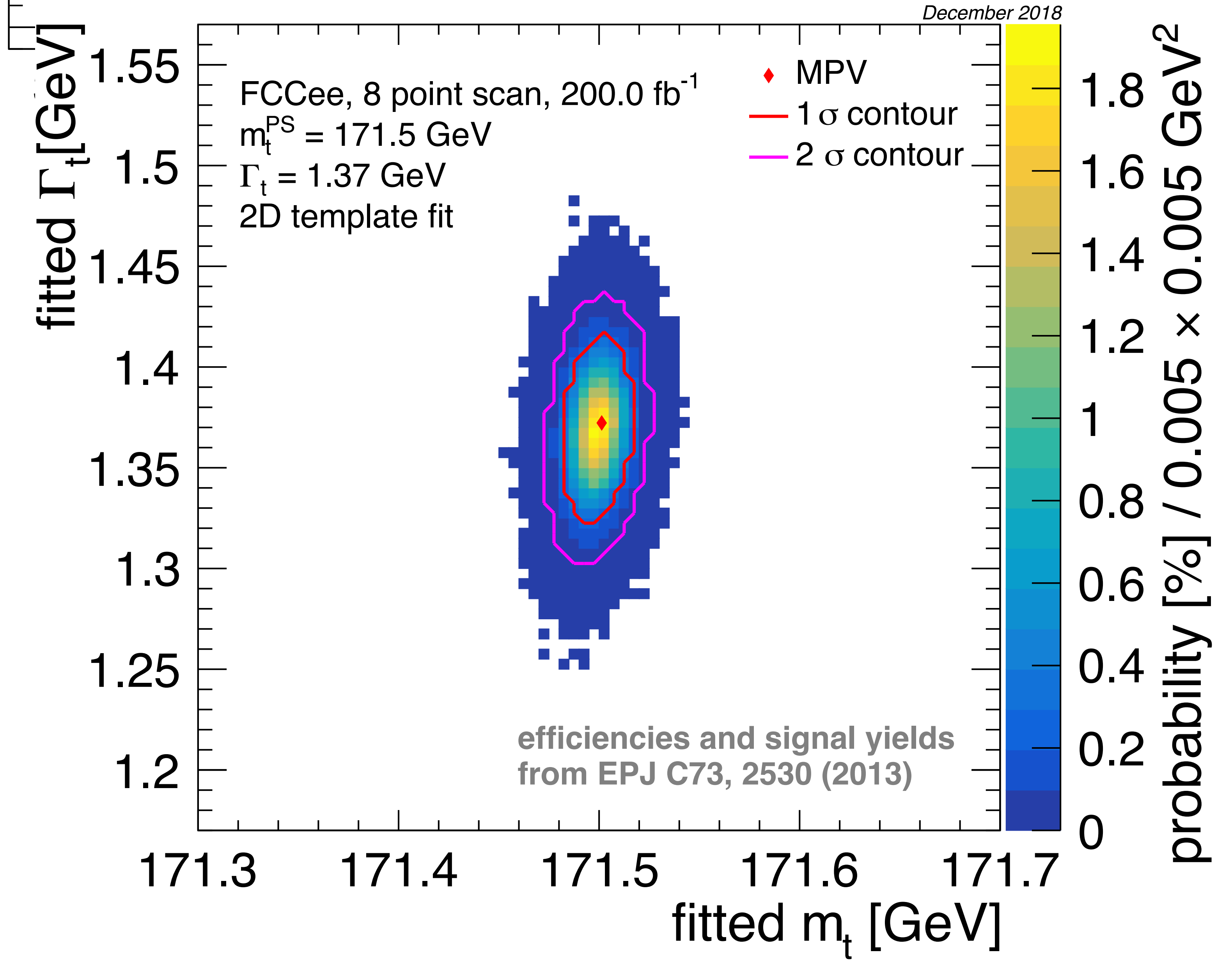

The “Strategic Landscape”

Decisions for Projects - and the Path Forward

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

Extras

The Path towards the Real Axis

Waiting for Green Light… and for Strategies

- Decisions on next generation of facilities expected in the coming year(s):
  - Statement from Japan on ILC expected in coming weeks - possible site in Kitakami, north of Sendai
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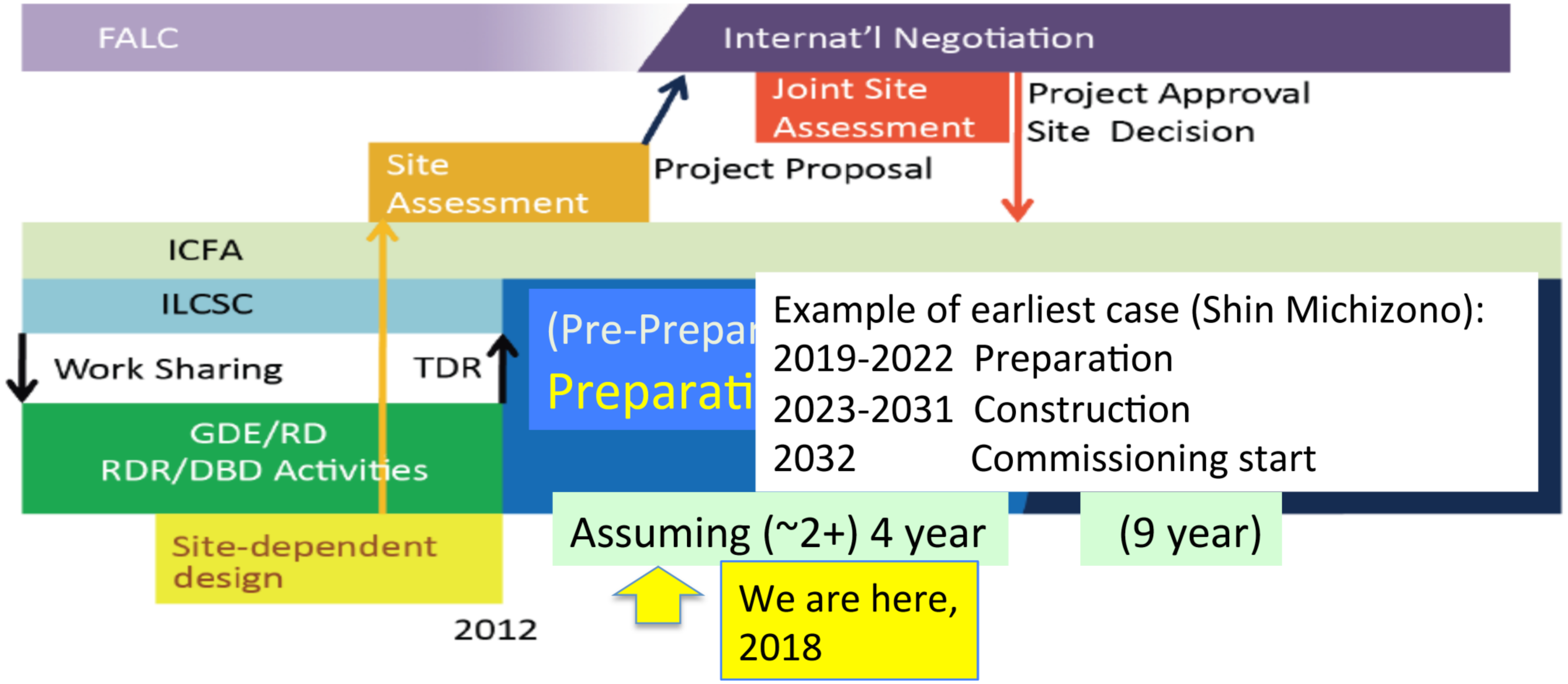
ILC Time Line: Progress and Prospect



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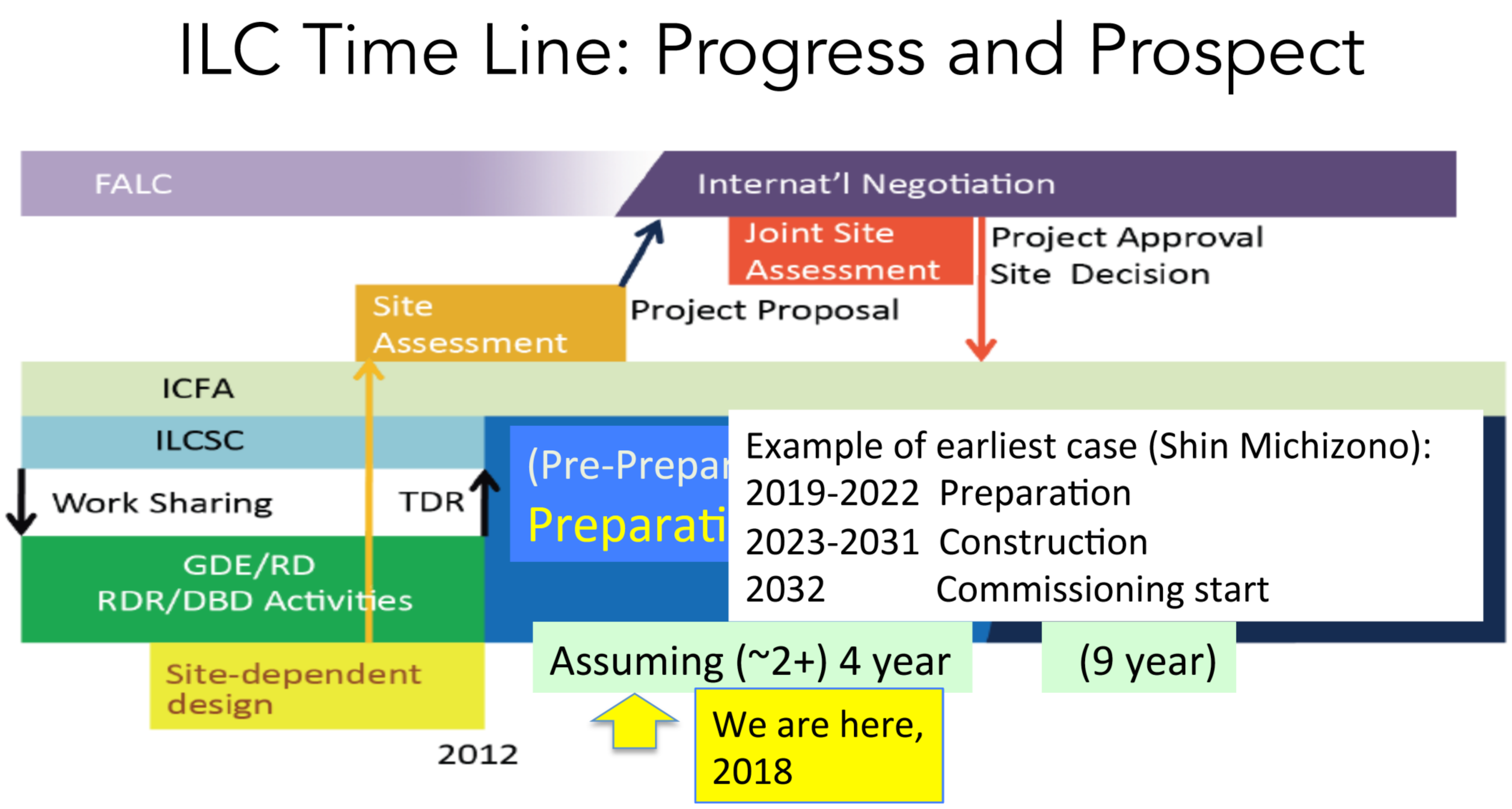
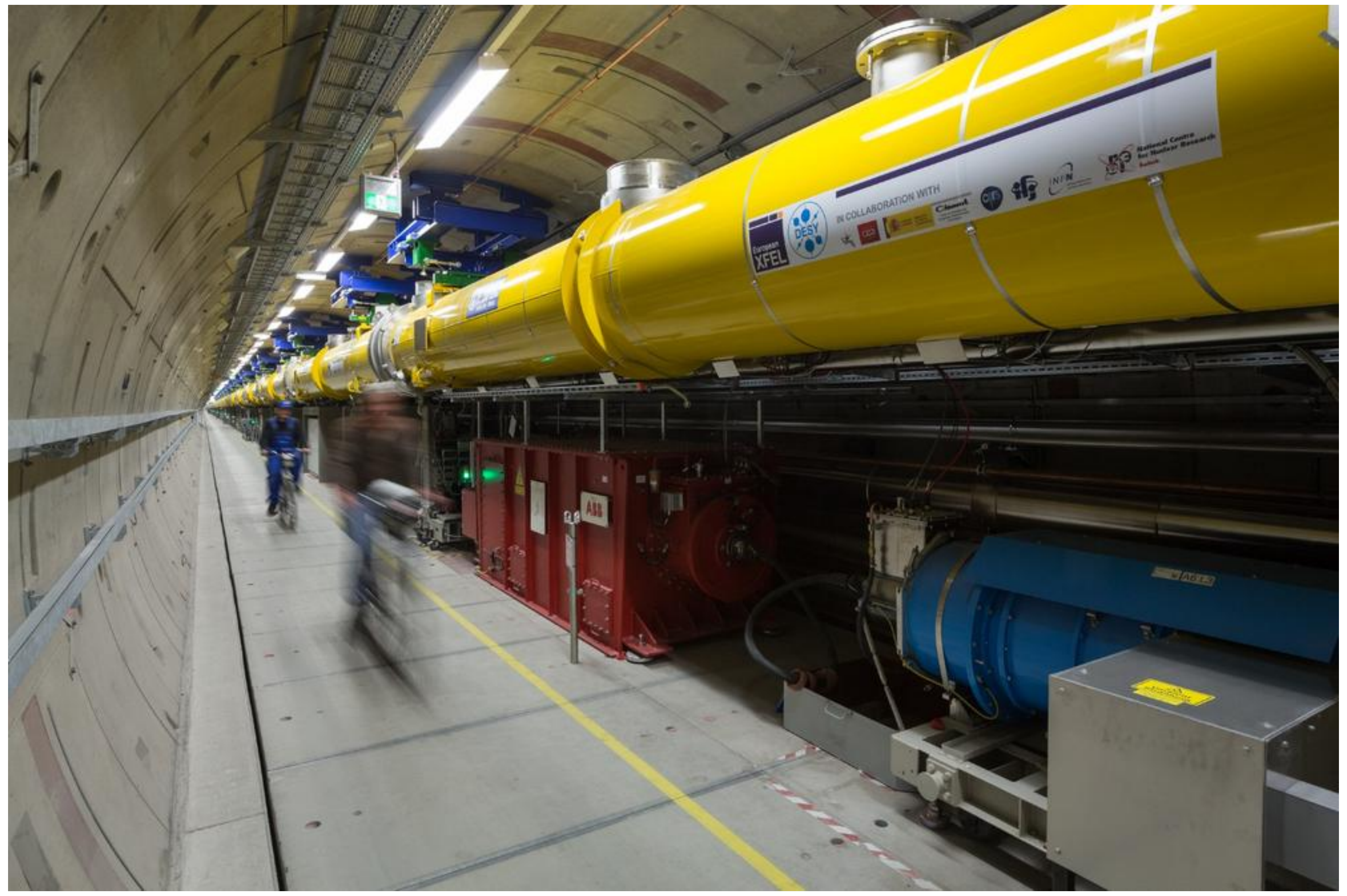


- ILC technology ready:
  European XFEL at DESY in operation, a 10% prototype of ILC main LINAC



Schedule: CLIC

The Road to Physics

2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions

Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start

Ready for construction; start of excavations

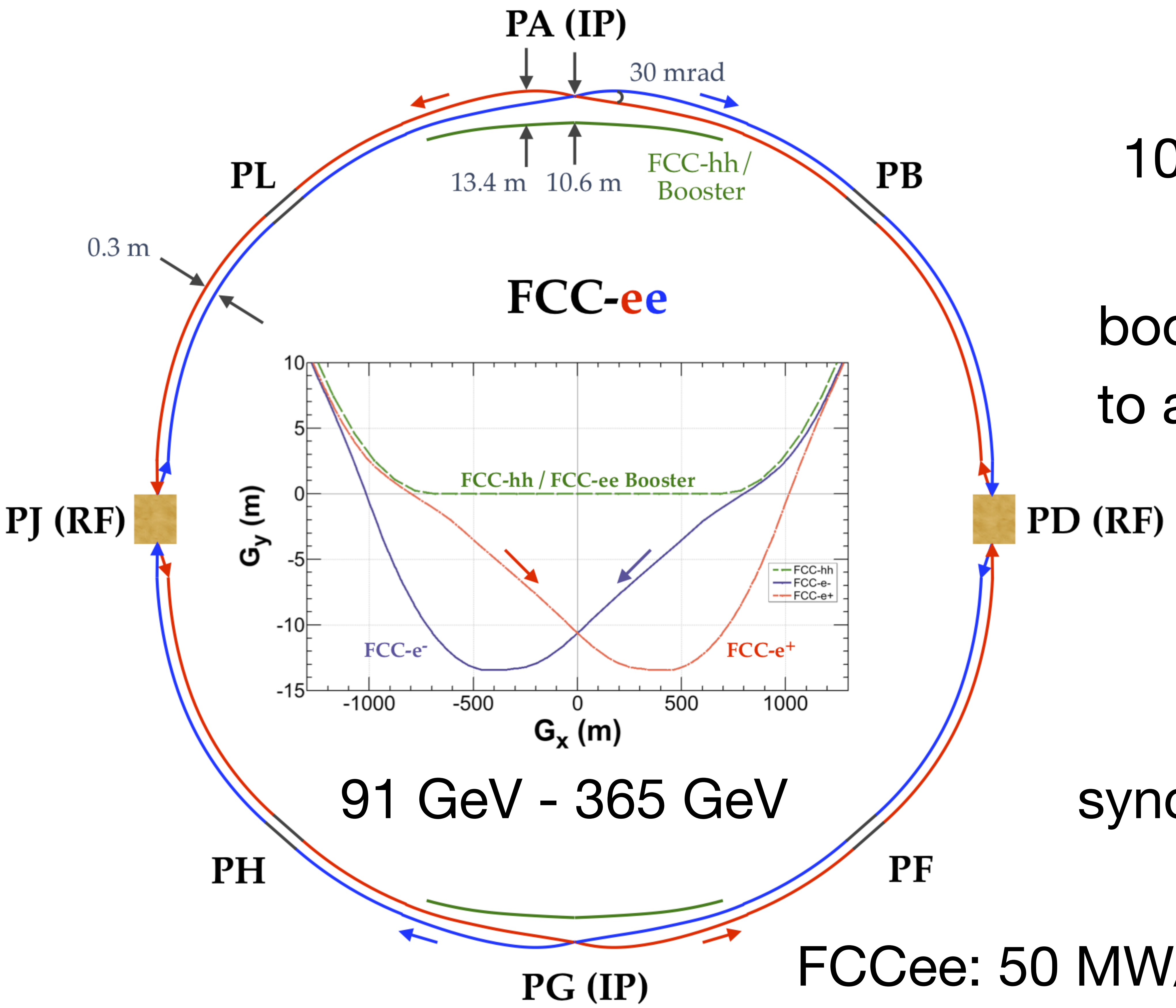
2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion

The Facilities: Rings

FCCee, CEPC

- “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, …



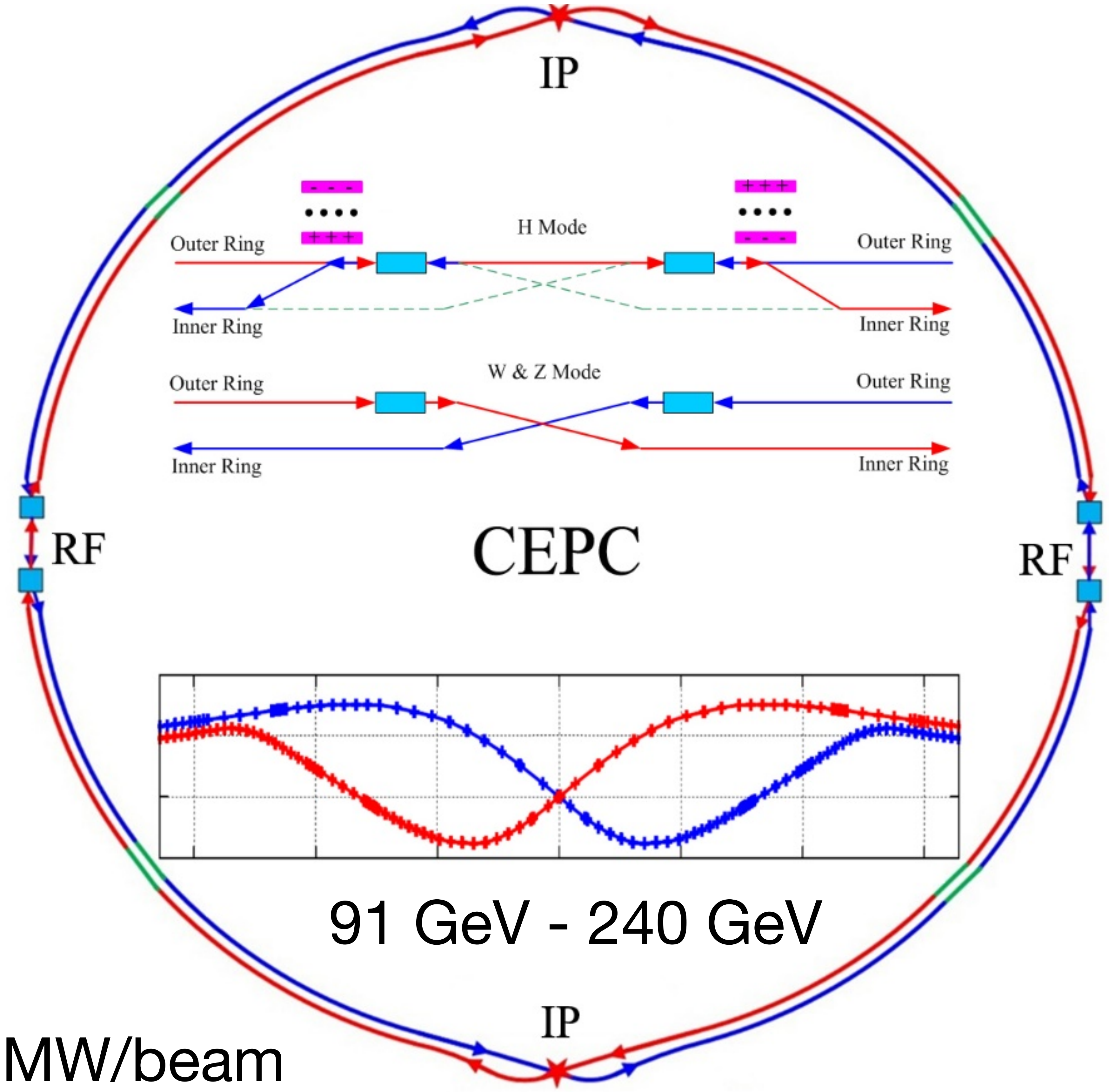
91 GeV - 365 GeV

100 km circumference

booster synchrotron required to achieve high luminosities

synchrotron radiation power:

FCCee: 50 MW/beam CEPC: up to 30 MW/beam



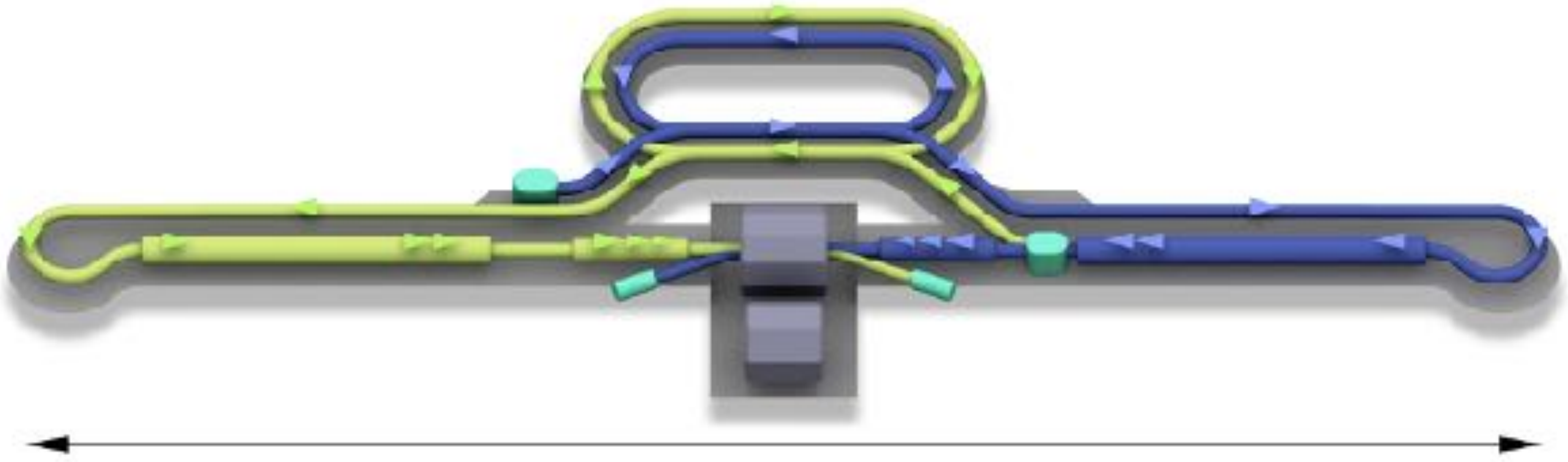
91 GeV - 240 GeV

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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superconducting RF

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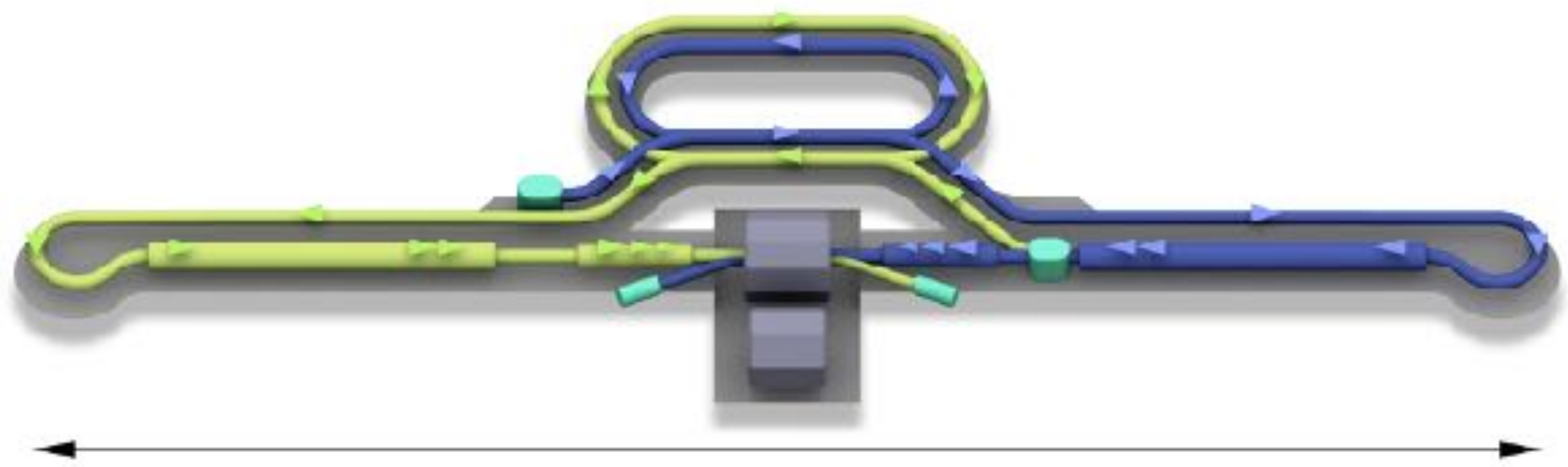

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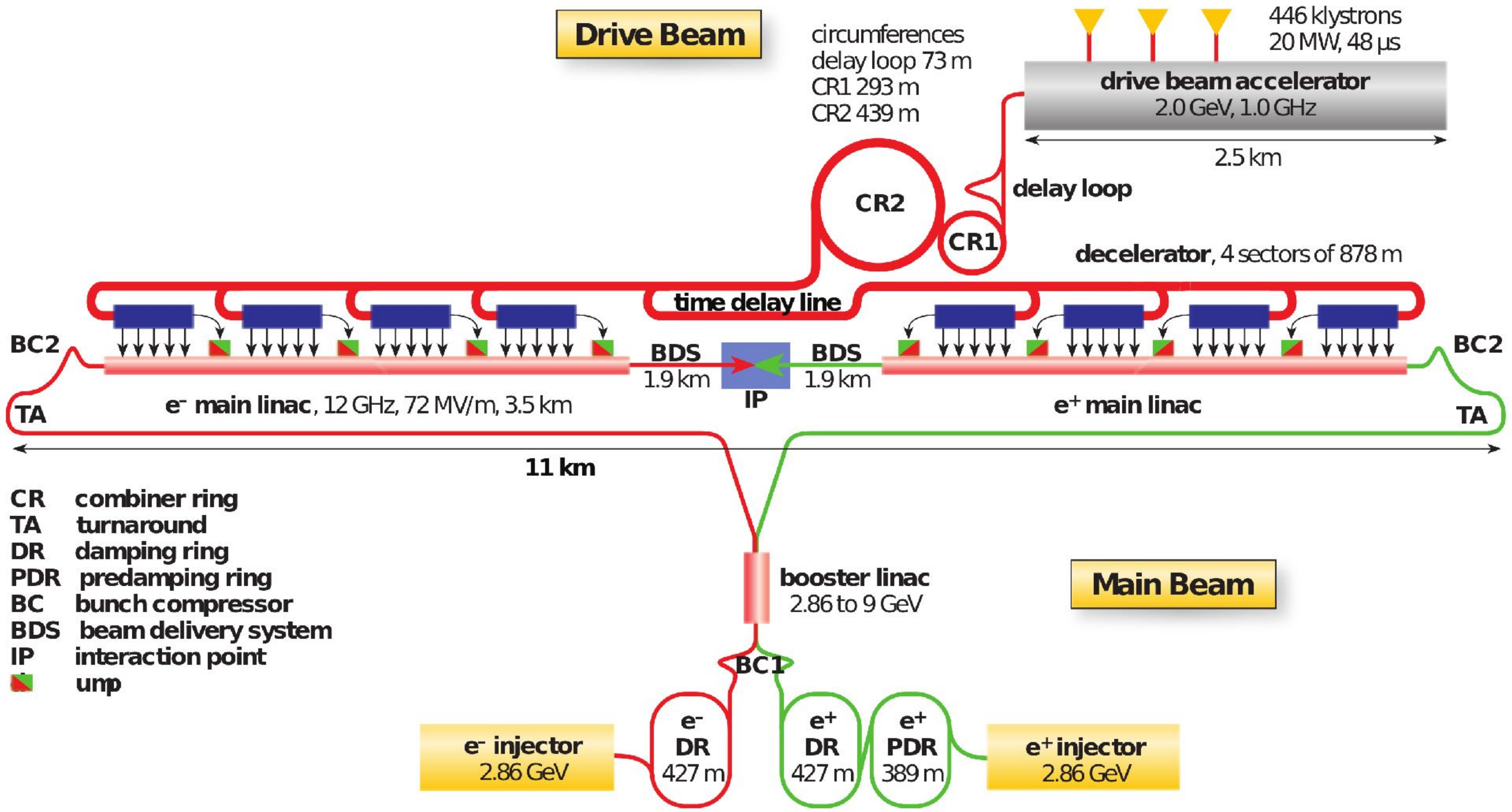
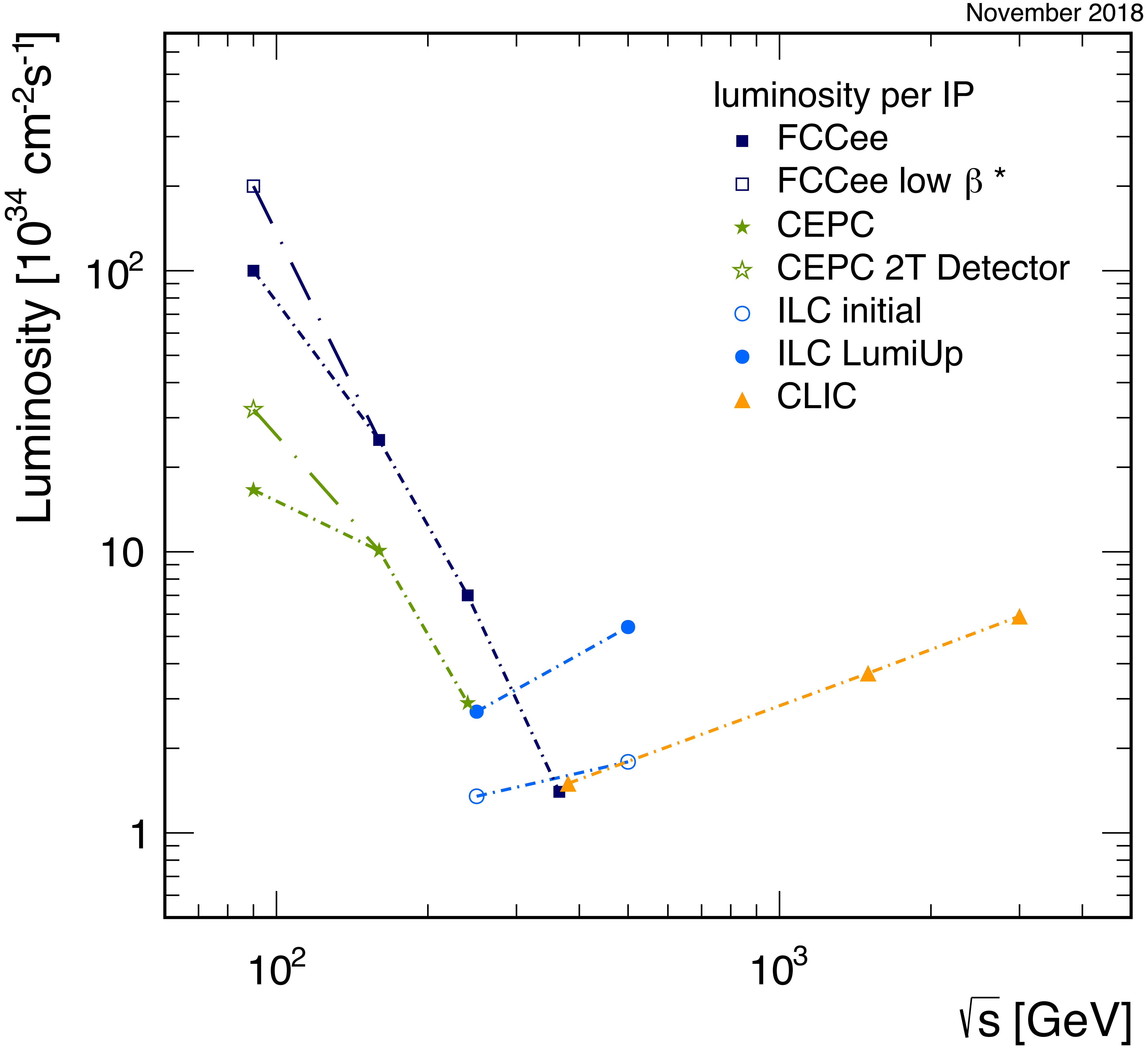
CLIC (Compact Linear Collider)



2-beam acceleration

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



- 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

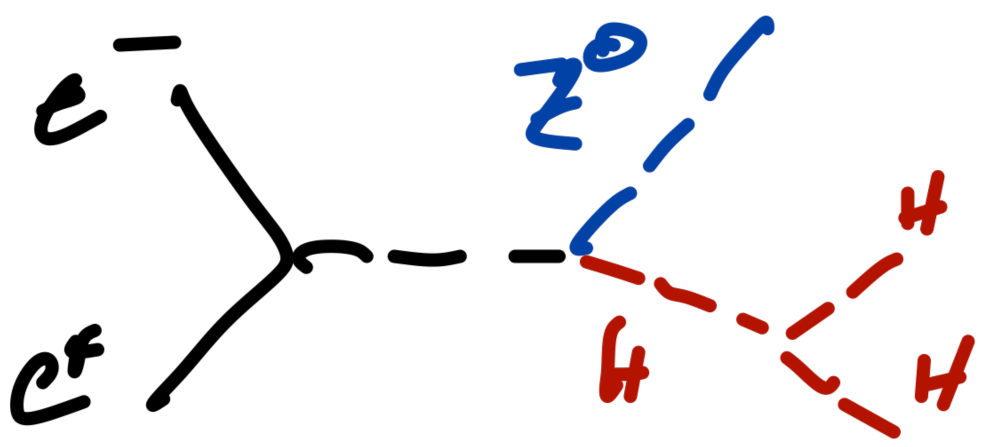
Cross-over of luminosity curves in the focus region of Higgs physics

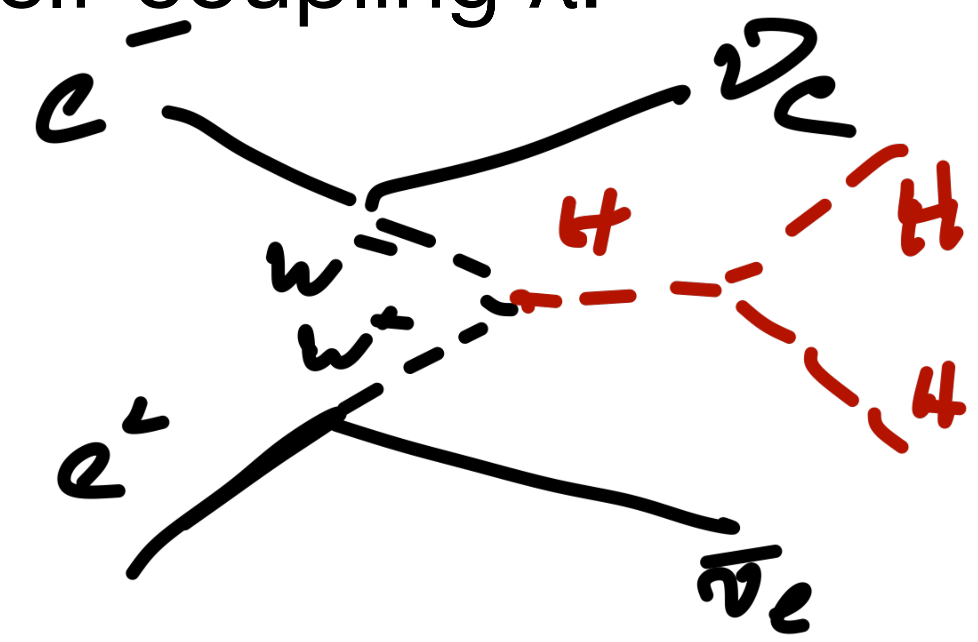
- Choice of collider energy reflects luminosity evolution with energy: For circular colliders, 240 GeV provides highest ZH statistics, for linear colliders 250 GeV is better

Measuring the Higgs Self-Coupling

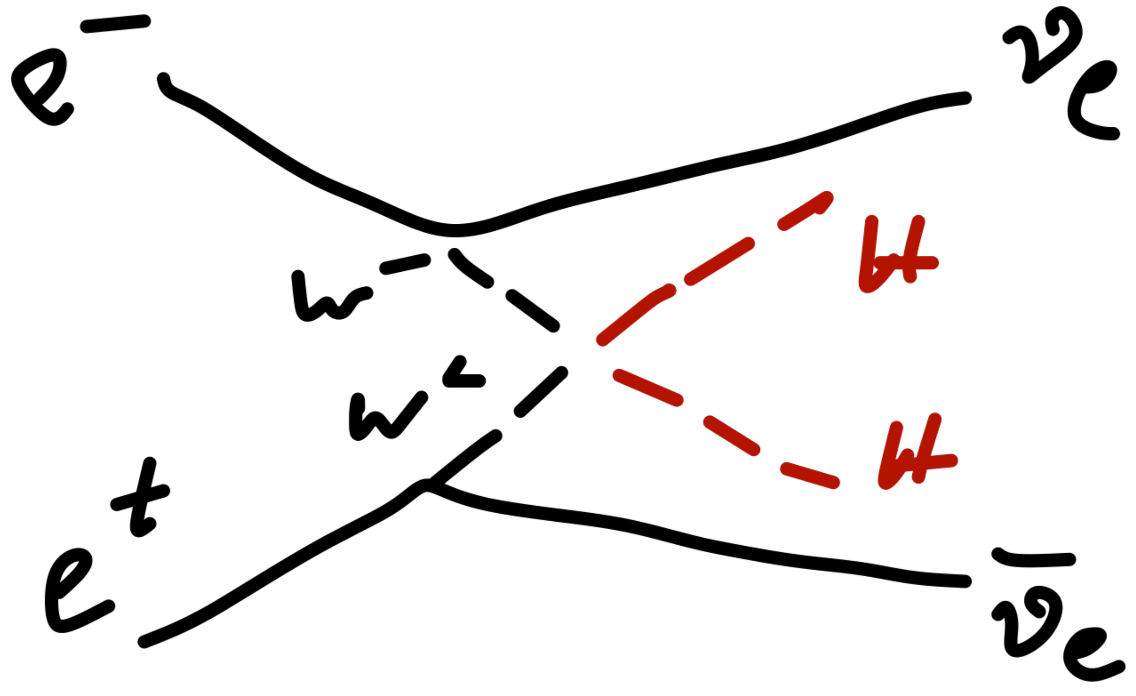
Requires higher Energies - may be the ultimate Challenge in Higgs Physics

- Two processes with double Higgs final states provide access to the self-coupling λ:





the final state also receives contributions from the quartic coupling



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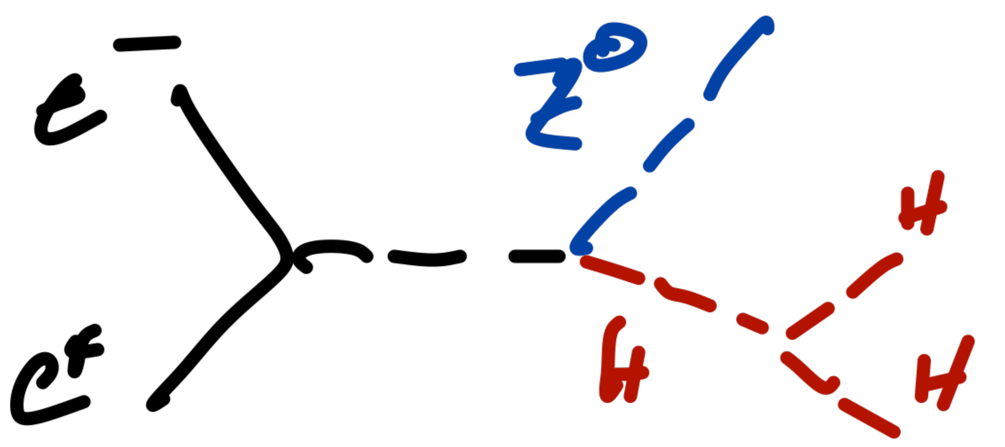
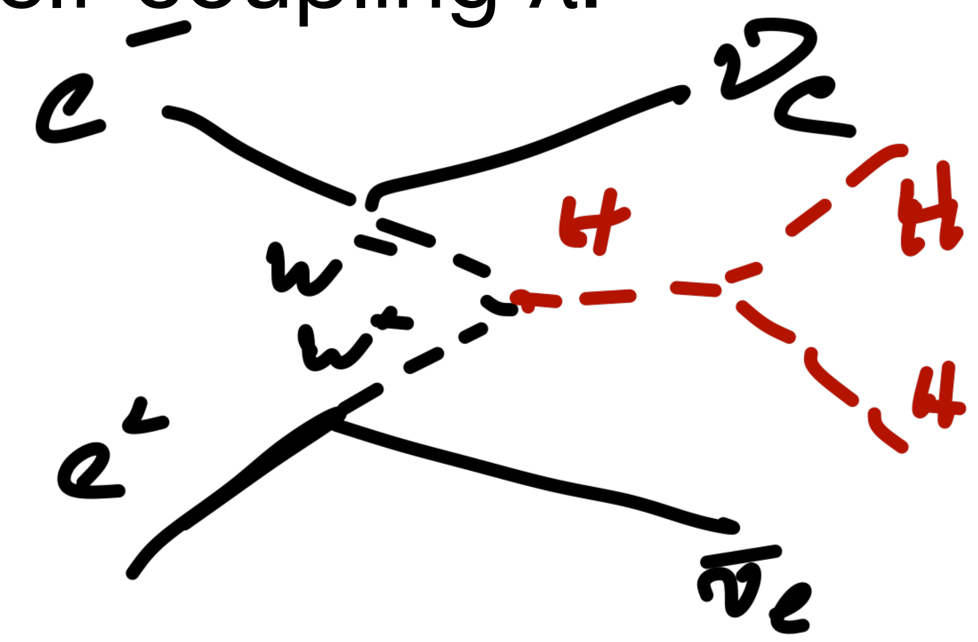
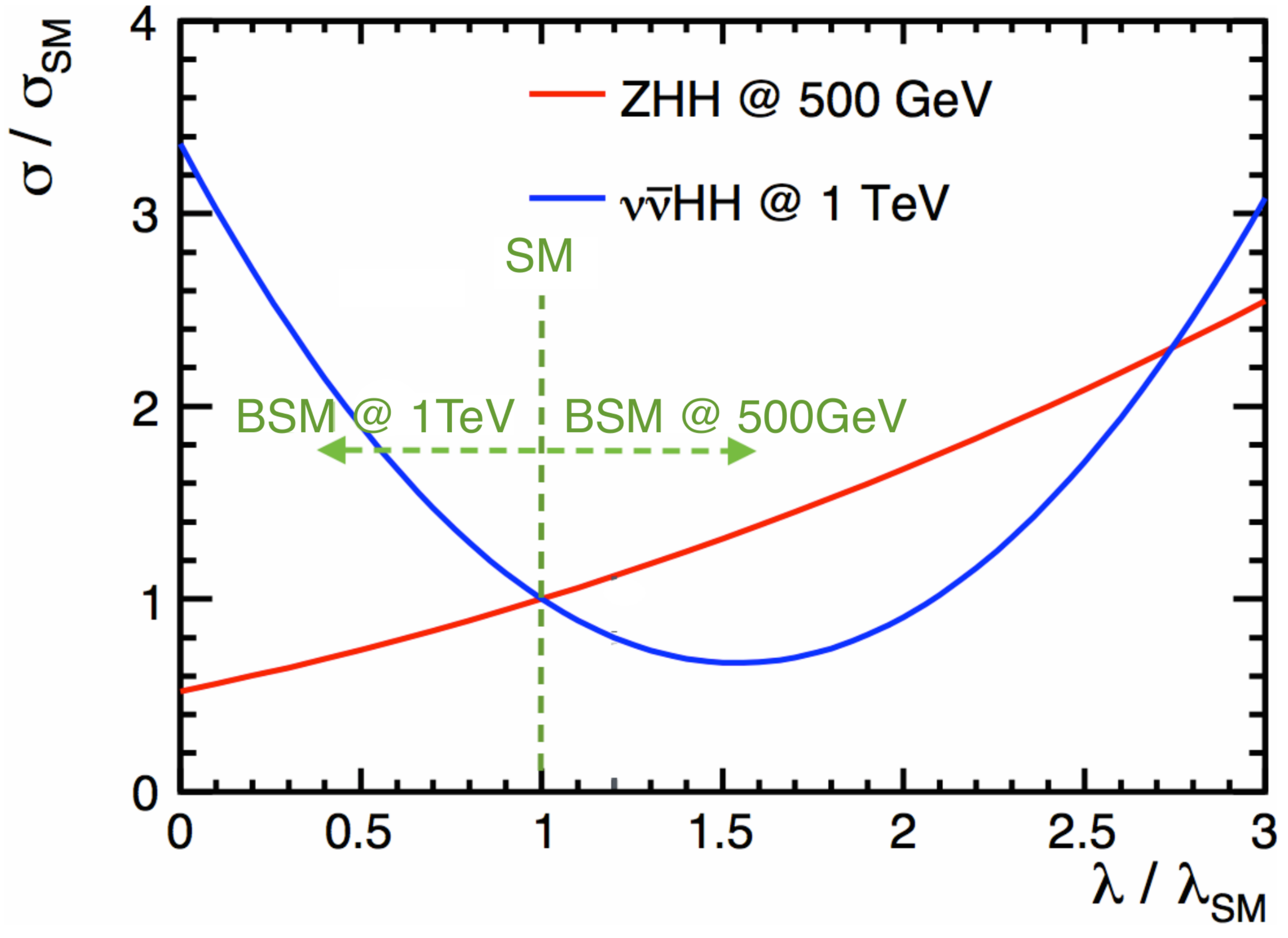




cross section depends non-linearly on λ, measurements at different energies / of different processes lift degeneracies



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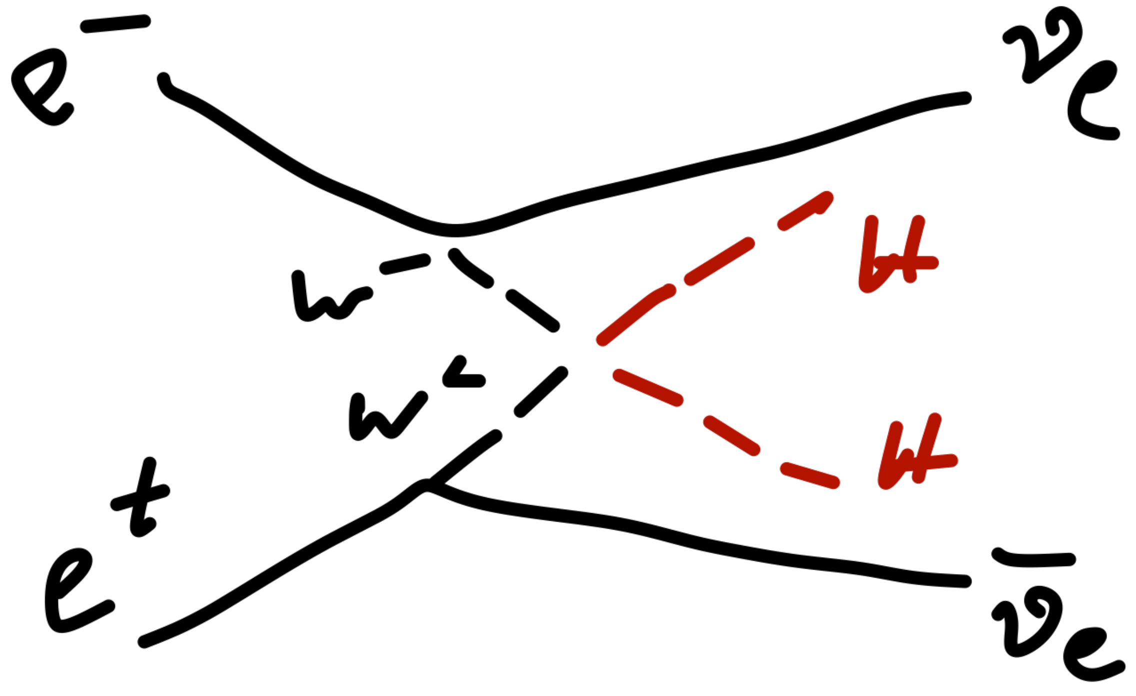

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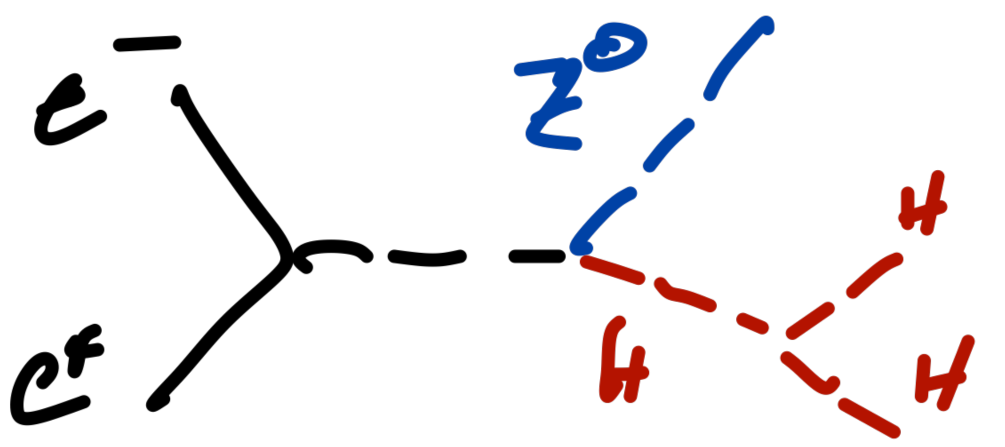

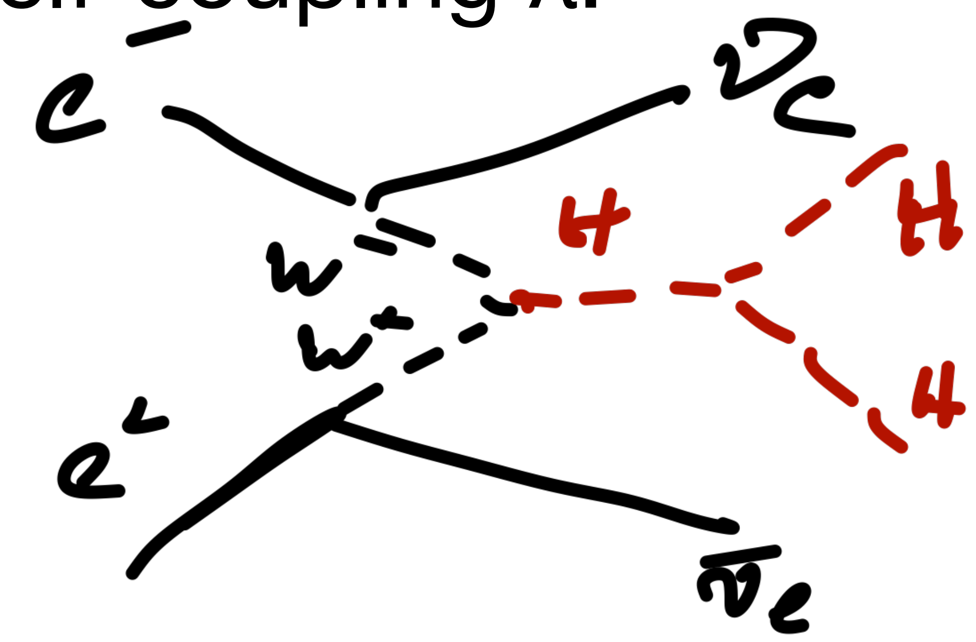

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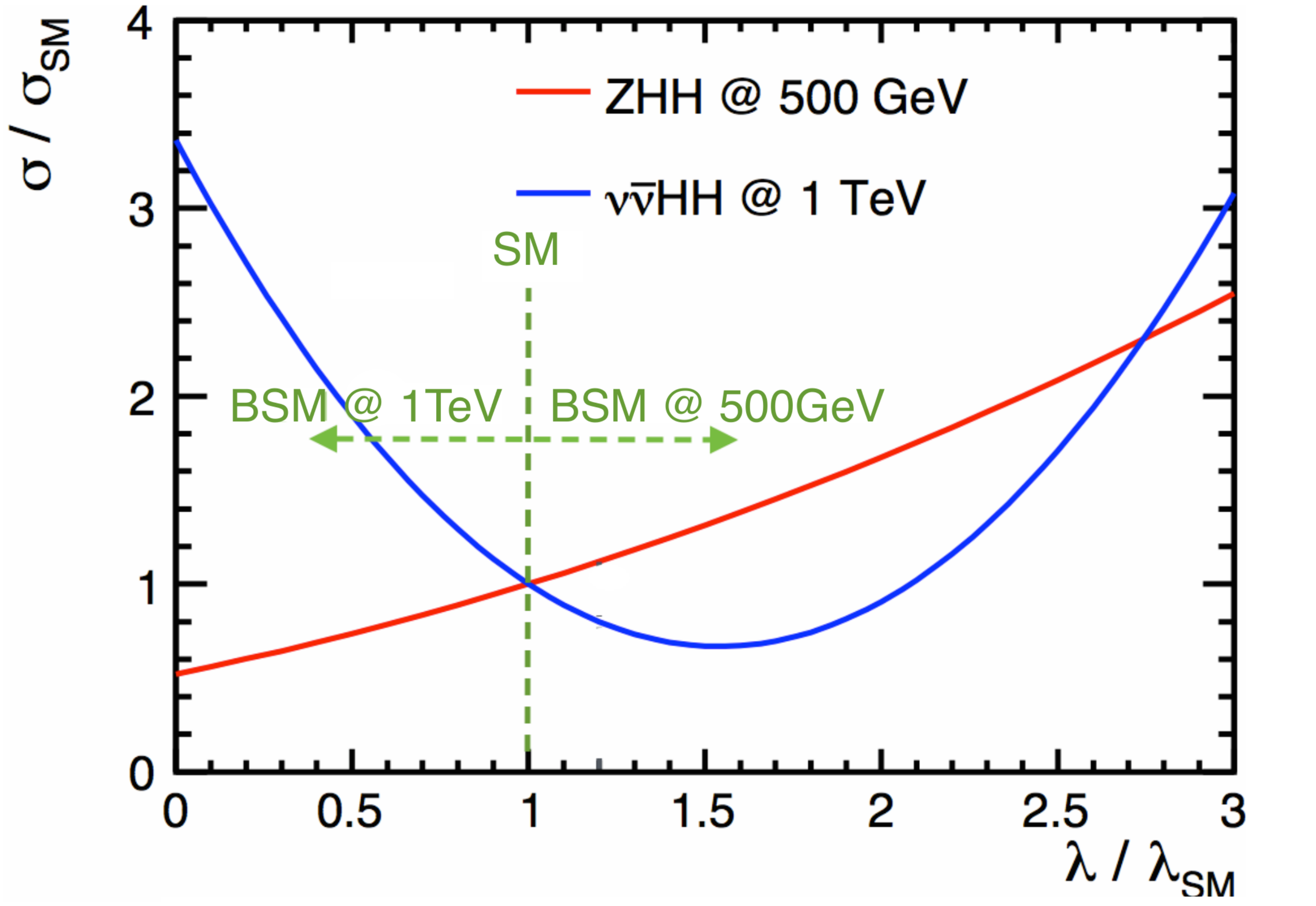

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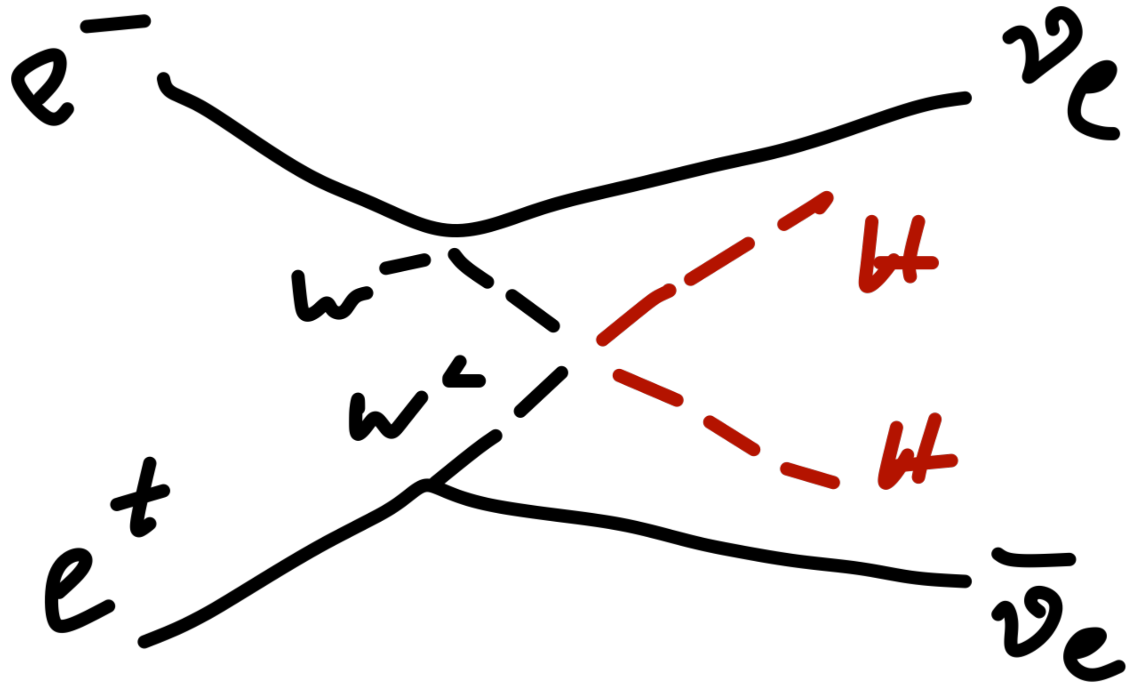


ILC: Using the ZHH process

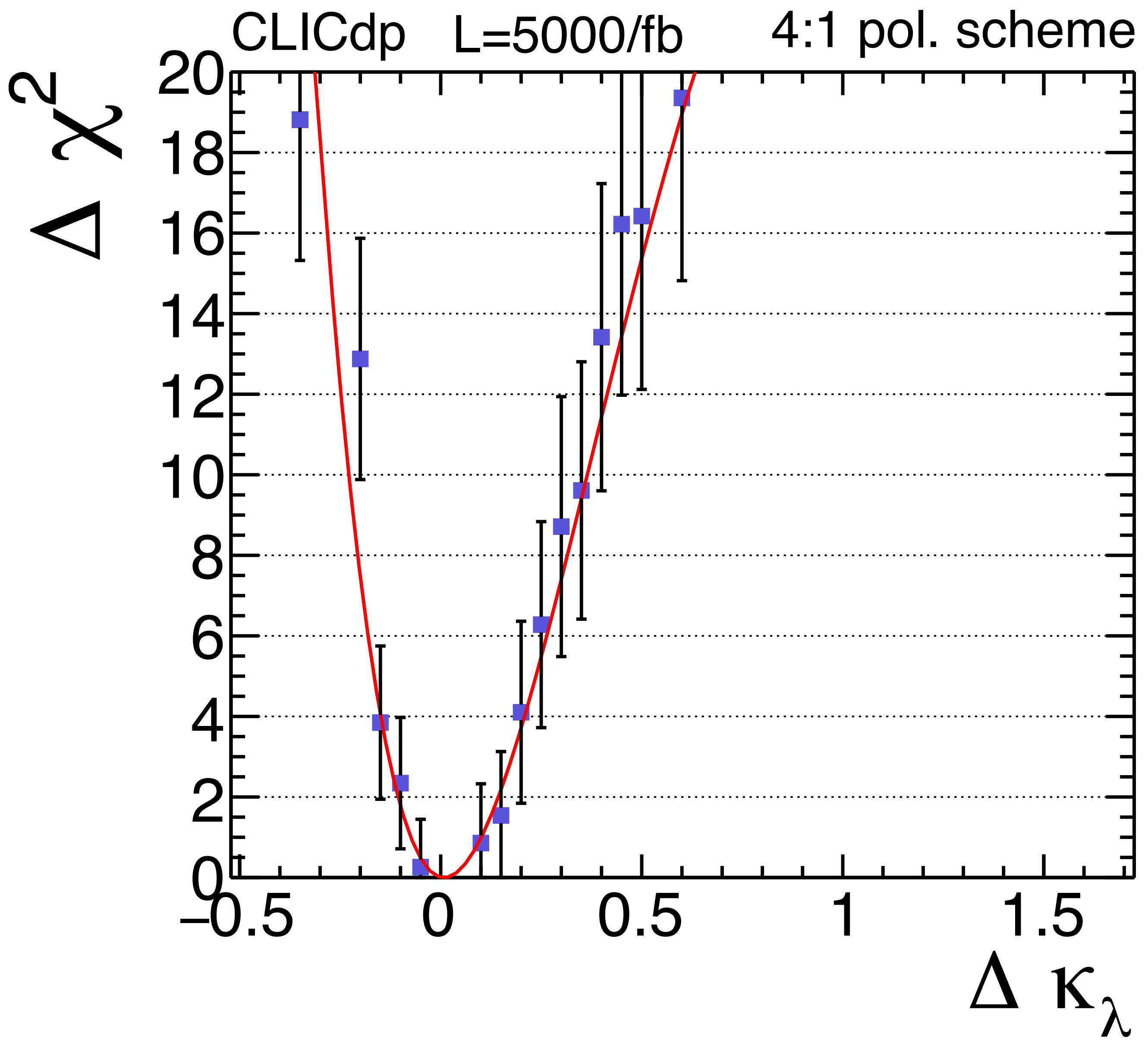
$\Delta\lambda/\lambda \sim 27\%$ with 4 ab^{-1} @ 500 GeV

CLIC: A combination of ZHH (1.4 TeV) and ννHH (1.4 TeV + 3 TeV), combining cross section and M_{HH} differential

$\Delta\lambda/\lambda \sim [-7\%, +11\%]$ with

2.5 ab^{-1} @ 1.4 TeV, 5 ab^{-1} @ 3 TeV

➾ ~ 10% measurement feasible - but only at multi - TeV collider



Interpreting Higgs Measurements

A Word on Fits

- The Higgs coupling measurements at any present and future collider unfold their full potential in global fits of all observables - possibly beyond Higgs measurements alone
  - The evaluation of the potential of future colliders is based on such fits using projected precisions on various Higgs (and other) measurements as input

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Typical fits used in this context:

- **“Model-independent” fit**

minimize a χ² with all measurements:

$$\chi^2 = \sum_i \frac{(C_i - 1)^2}{\Delta F_i^2}$$

$$C_{\mathrm{ZH}} = g^2_{\mathrm{HZZ}}$$

$$C_{\mathrm{ZH,H}\to b\bar{b}} = \frac{g^2_{\mathrm{HZZ}} g^2_{\mathrm{Hbb}}}{\Gamma_{\mathrm{H}}}$$

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ΔF_i: uncertainty of measurement (σ or σxBR)

total width as a free parameter: no constraints imposed on BSM decays

N.B.: Not fully model independent, does not account for certain possible BSM features of HV couplings

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- **“Model-dependent κ” fit**

the same as the MI fit, with the total width constrained to the sum of the SM decays

$$\kappa_i^2 = \frac{\Gamma_i}{\Gamma_i|_{\mathrm{SM}}} \qquad \Gamma_{\mathrm{H,md}} = \sum_i \kappa_i^2 \, BR_i$$

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- **"Model-independent EFT" fit**

  A global fit of Higgs and other EW observables parametrizing deviations from the SM by various operators - allows for couplings not included in κ fit, includes connections between W and Z couplings

Perspectives on Precision

Still in flux - Meant as a rough Guide

- Comparisons of the potential of different colliders are non-straightforward: The projections are based on different levels of realism / pessimism / optimism in detector modeling, analysis techniques, systematic uncertainties and machine parameters / running scenarios,…

Here: Taking the “model independent” fit results - combine the projected uncertainties on σxBR

	ILC 250	ILC 500	CLIC 380	CLIC 3 TeV	CEPC	FCCee 240	FCCee 365
$\delta g_{HZZ}/g_{HZZ}$	0.38	0.30	0.6	0.6	0.25	0.25	0.22
$\delta g_{HWW}/g_{HWW}$	1.8	0.40	1.0	0.6	1.4	1.3	0.47
$\delta g_{Hbb}/g_{Hbb}$	1.8	0.60	2.1	0.7	1.3	1.4	0.68
$\delta g_{Hcc}/g_{Hcc}$	2.4	1.2	4.4	1.4	2.2	1.8	1.23
$\delta g_{Hgg}/g_{Hgg}$	2.2	0.97	2.6	1.0	1.5	1.7	1.03
$\delta g_{H\tau\tau}/g_{H\tau\tau}$	1.9	0.80	3.1	1.0	1.5	1.4	0.80
$\delta g_{H\mu\mu}/g_{H\mu\mu}$	5.6	5.1		5.7	8.7	9.6	8.6
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$	1.1	1.0		2.3	3.7	4.7	3.8
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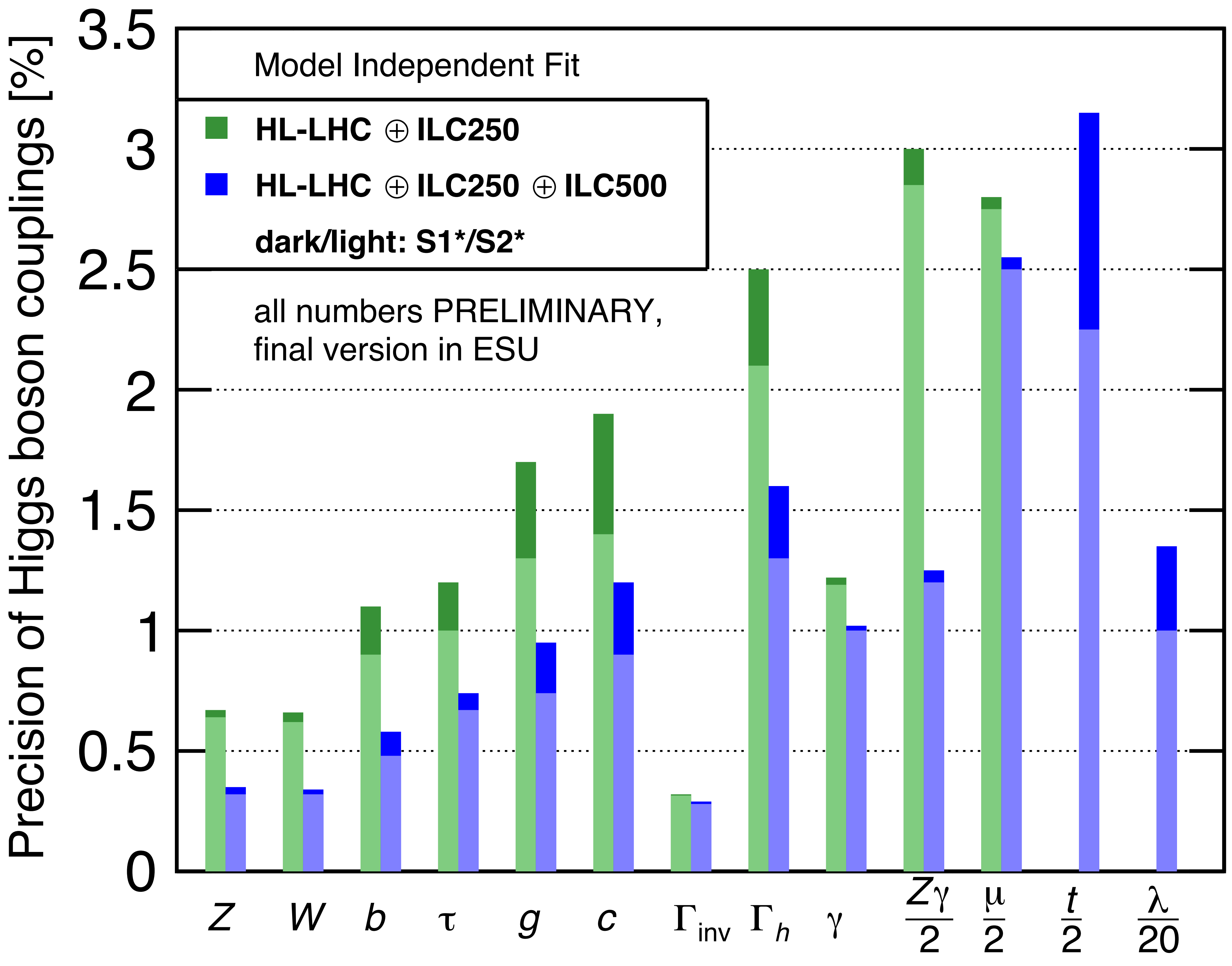
A Closer Look at ILC - in relation to LHC

Based on preliminary numbers in preparation for the ESU



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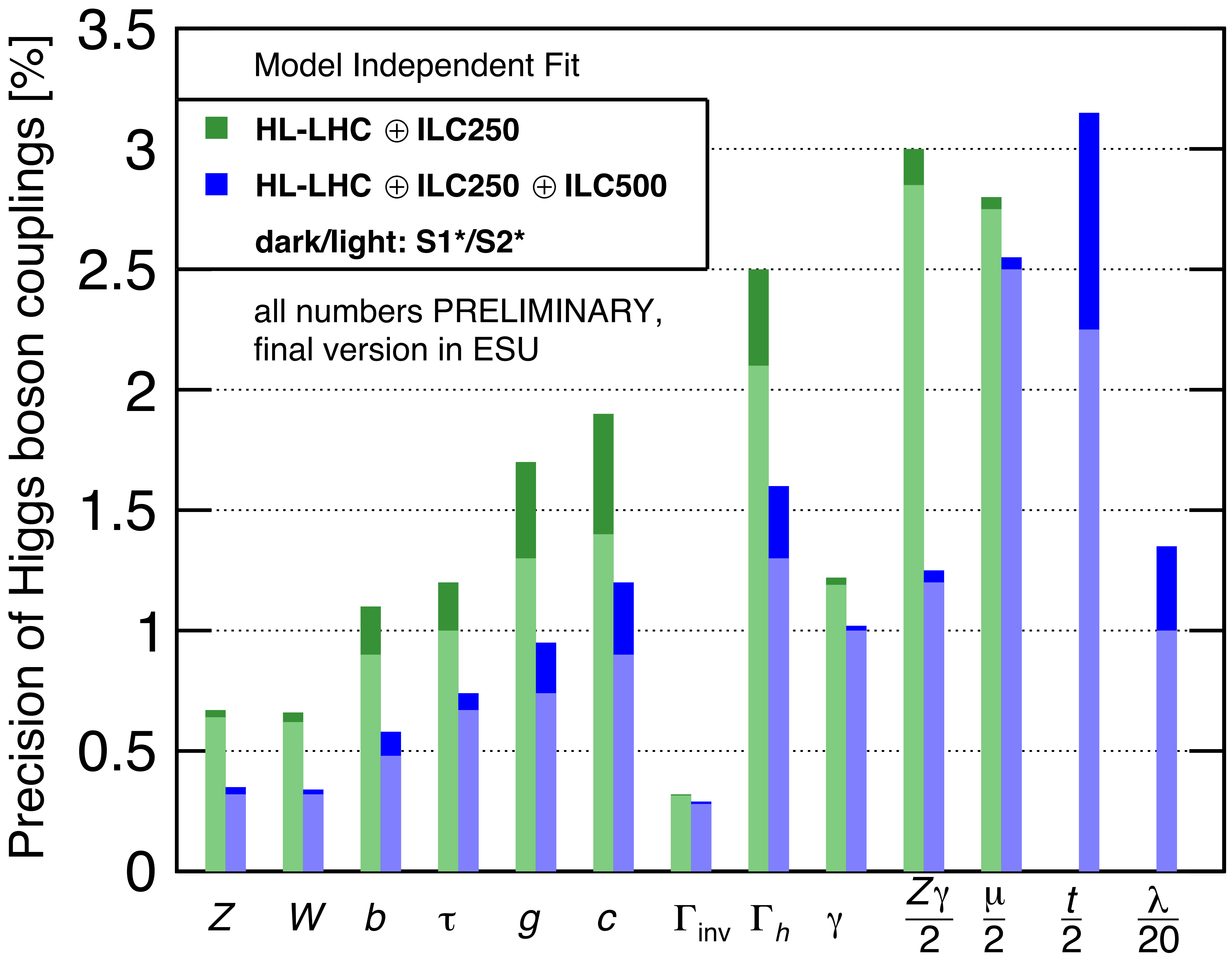

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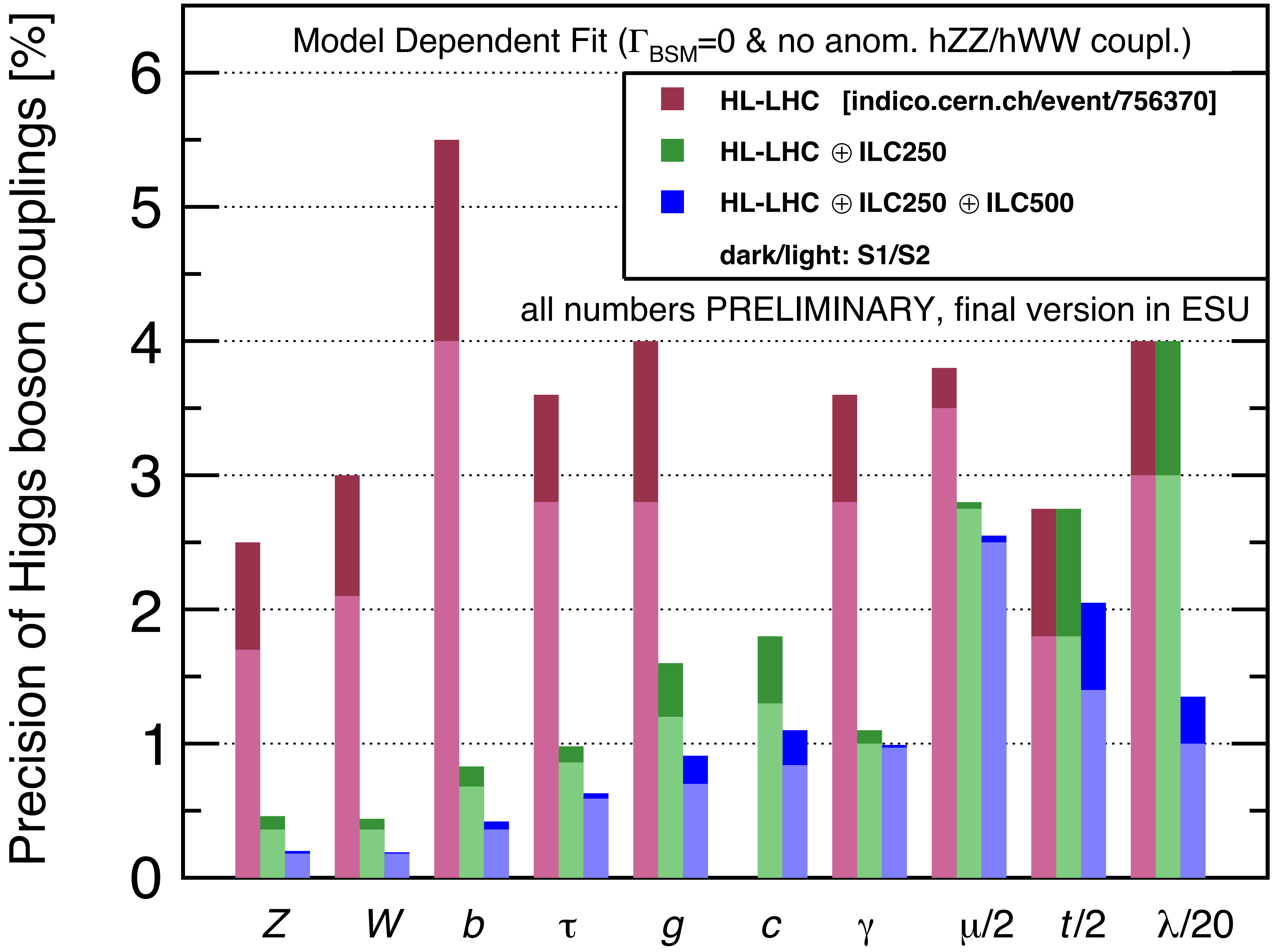
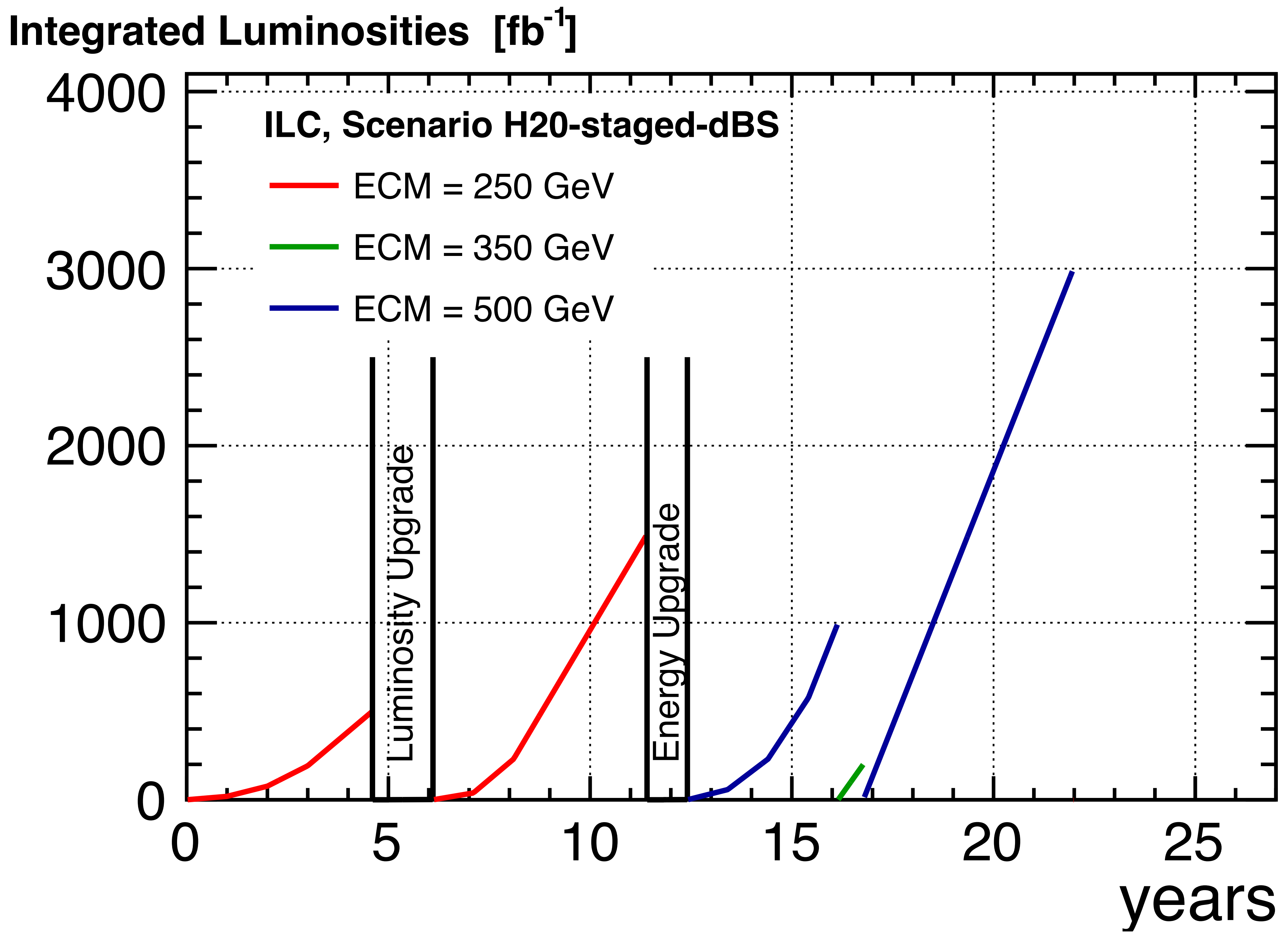


- ILC (and other e^+e^- colliders) go substantially beyond HL-LHC precision for a model-dependent analysis of Higgs results - 1 order of magnitude improvement in key channels

Discovery Stories in the Higgs Sector

An ILC Example



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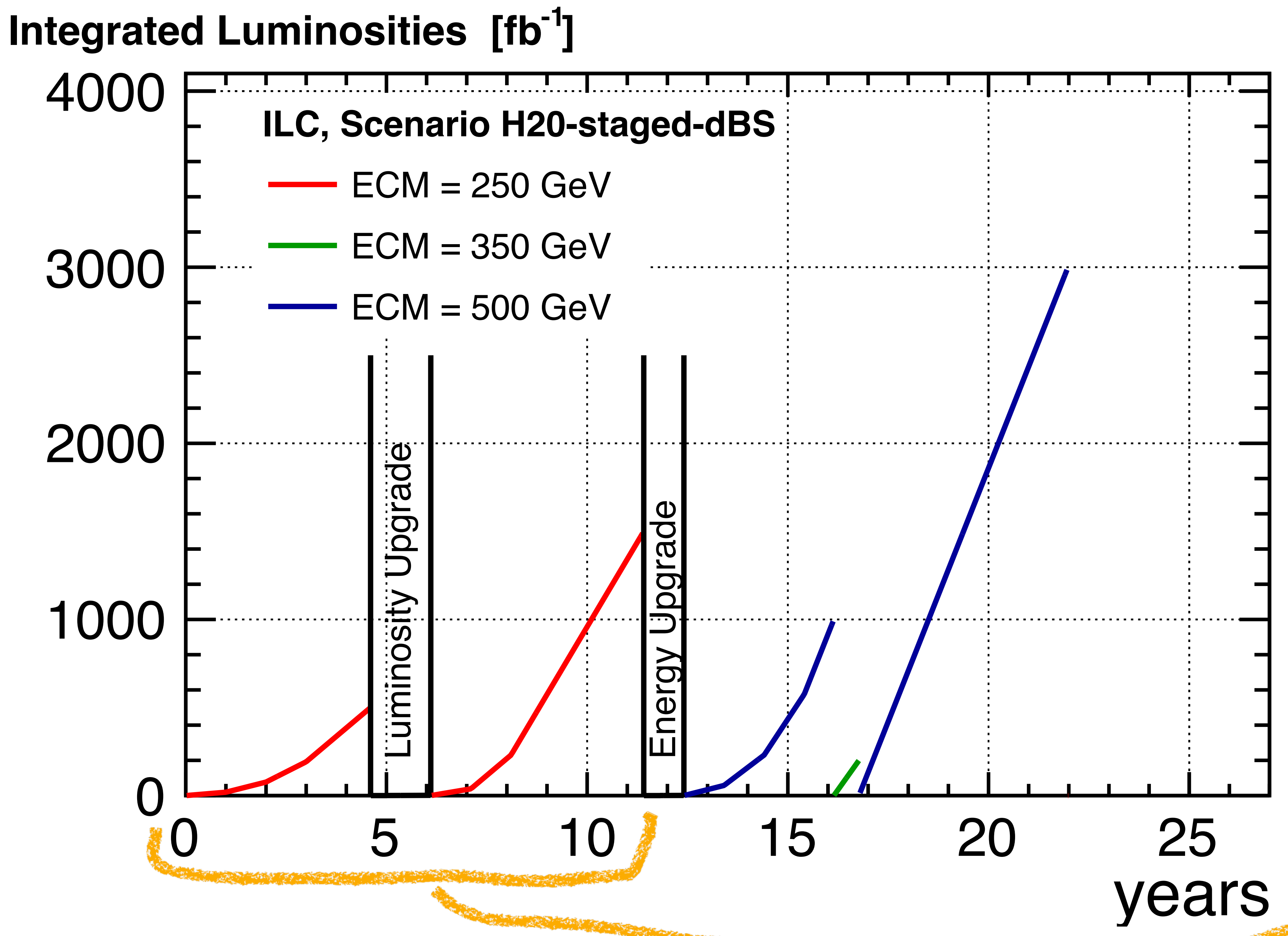

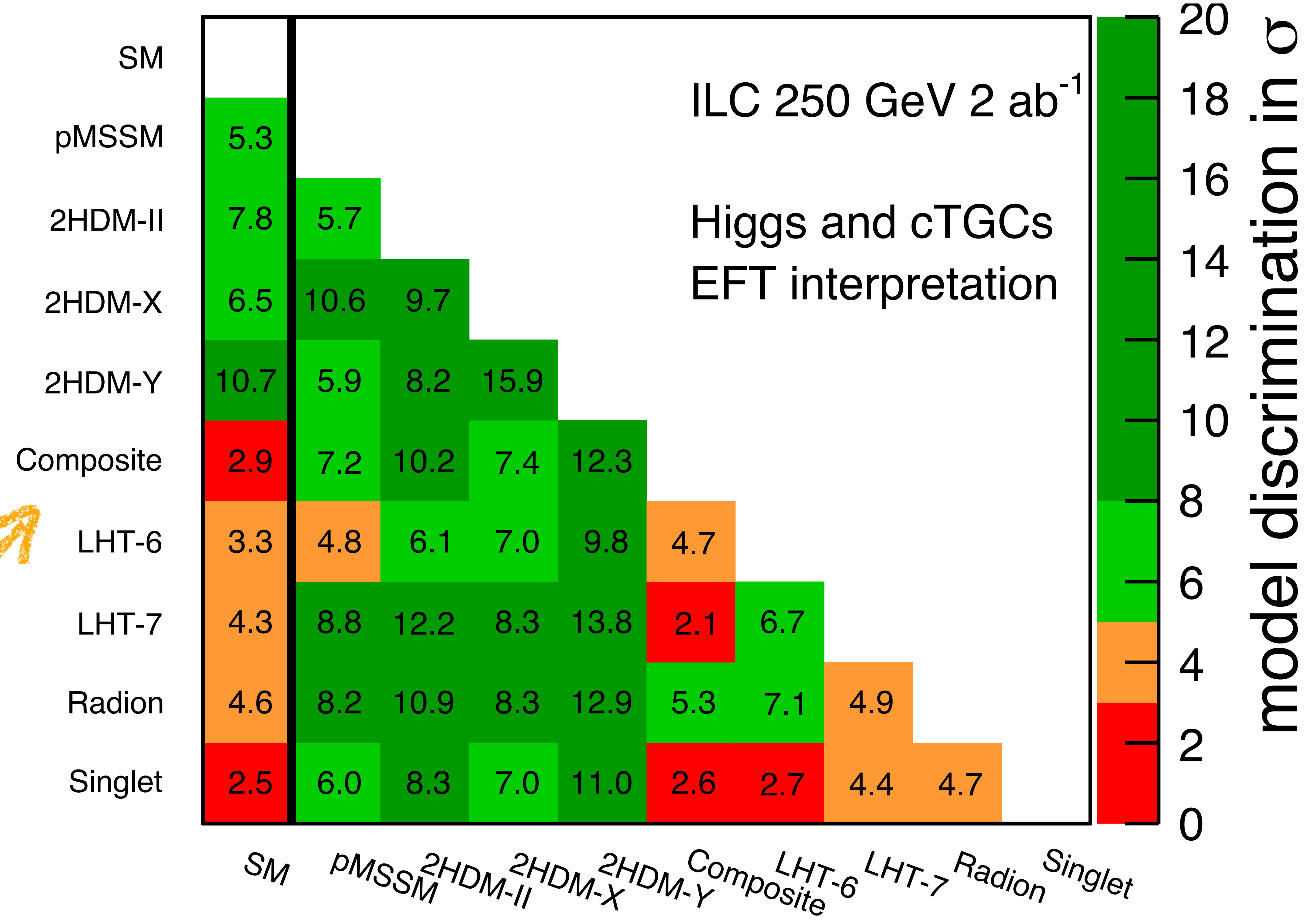

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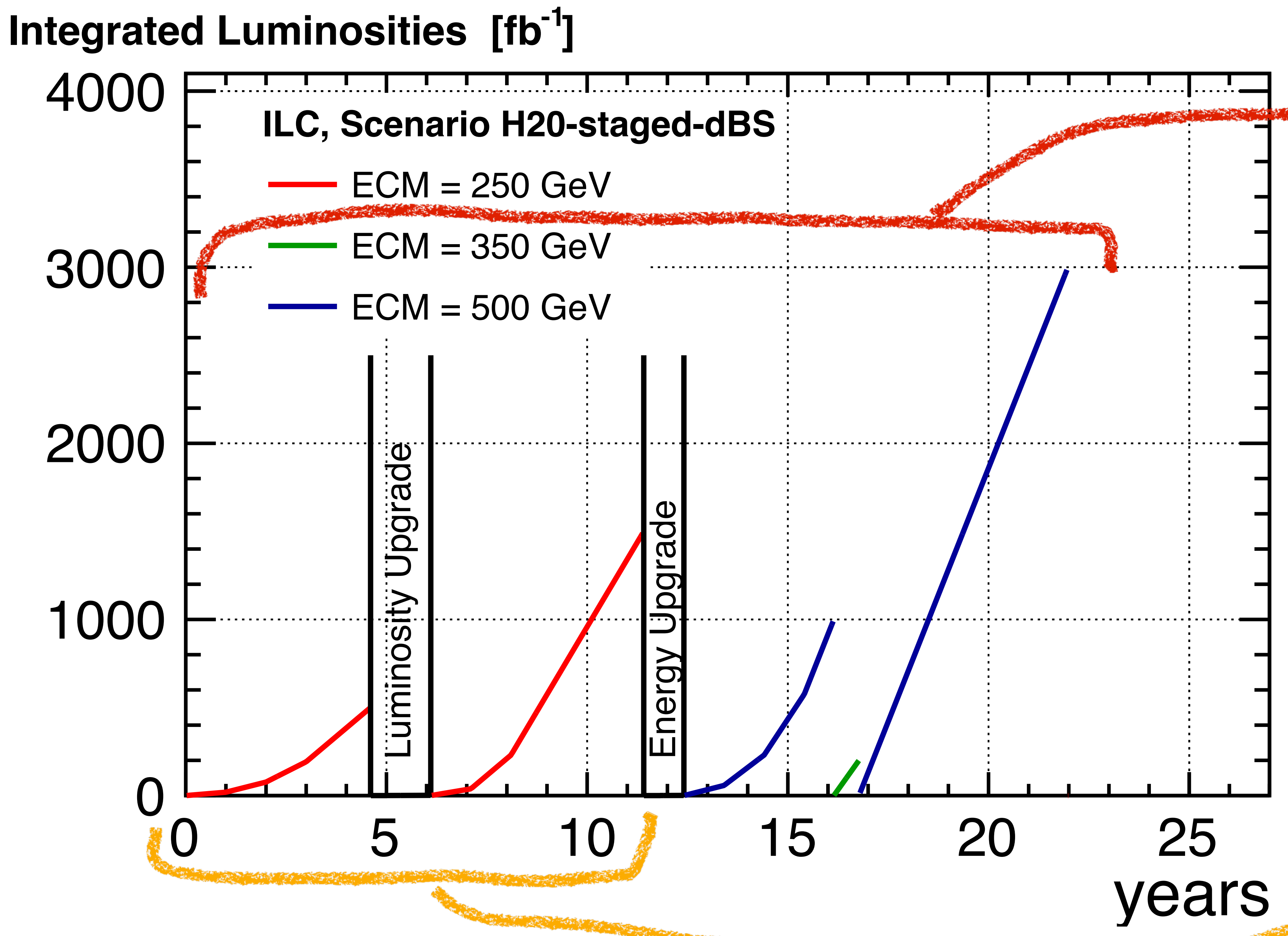

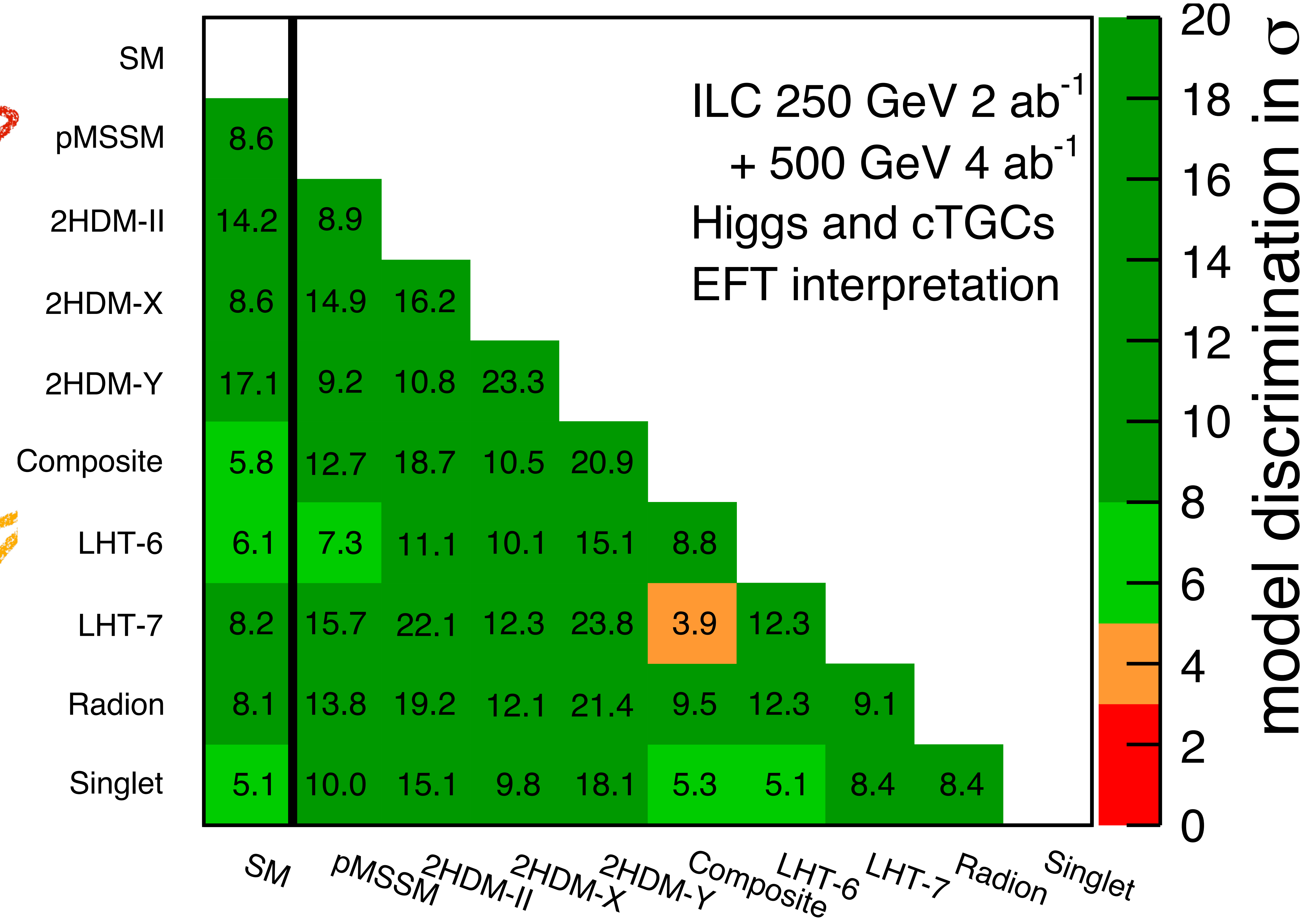

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- Discrimination power between models illustrated with EFT fit of ILC projections
  - higher energy may be decisive

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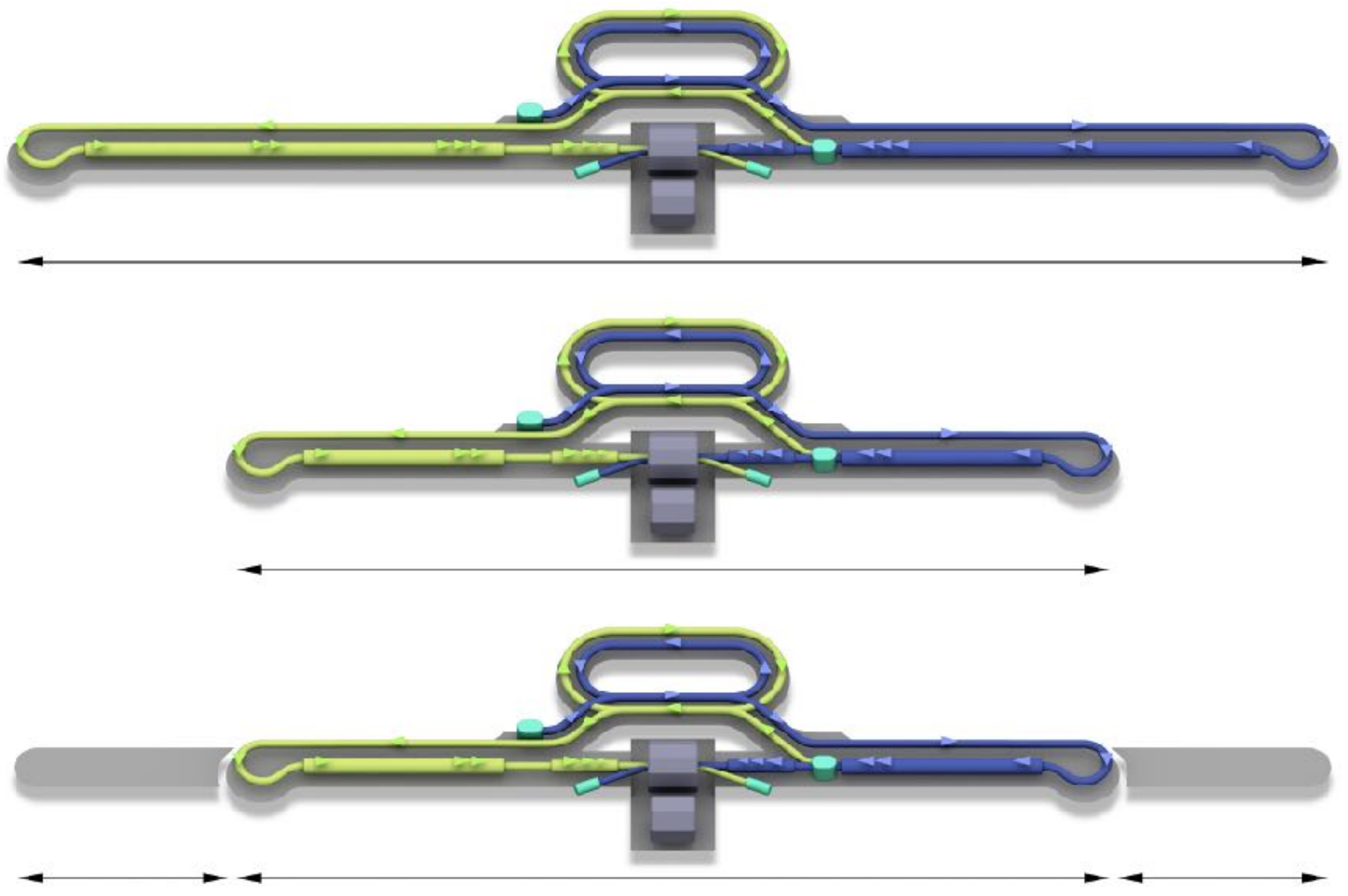
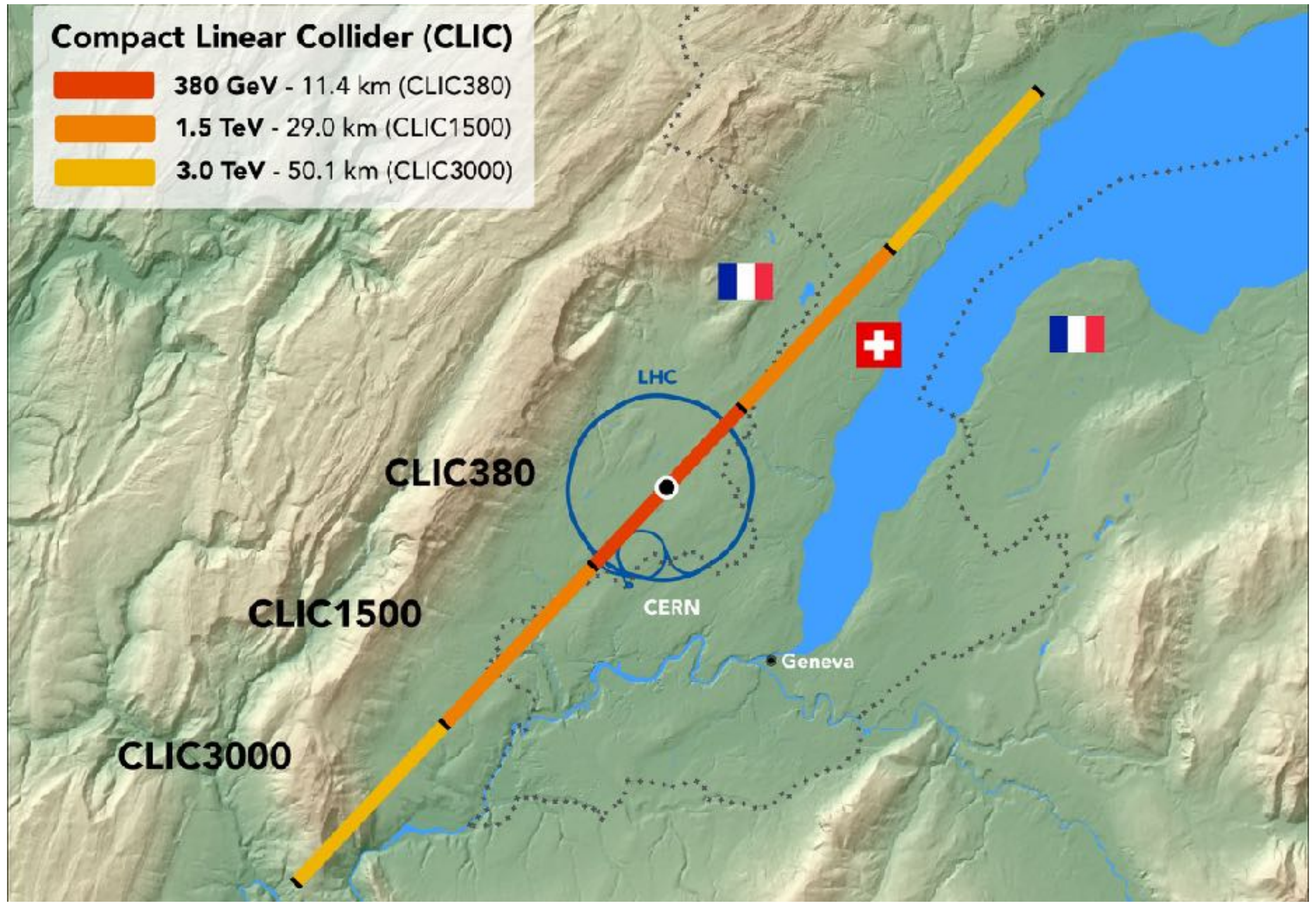
Linear Colliders

Plans for Facilities

- Concrete worked-out designs for both facilities
- ILC: Technical Design Report in 2013



- CLIC: Conceptual Design Report in 2012



- Now proposed as a 250 GeV machine, upgradeable to 500 GeV, with ultimate potential to 1 - 1.5 TeV
- A staged machine, with an initial energy of 380 GeV and ultimate energy of 3 TeV