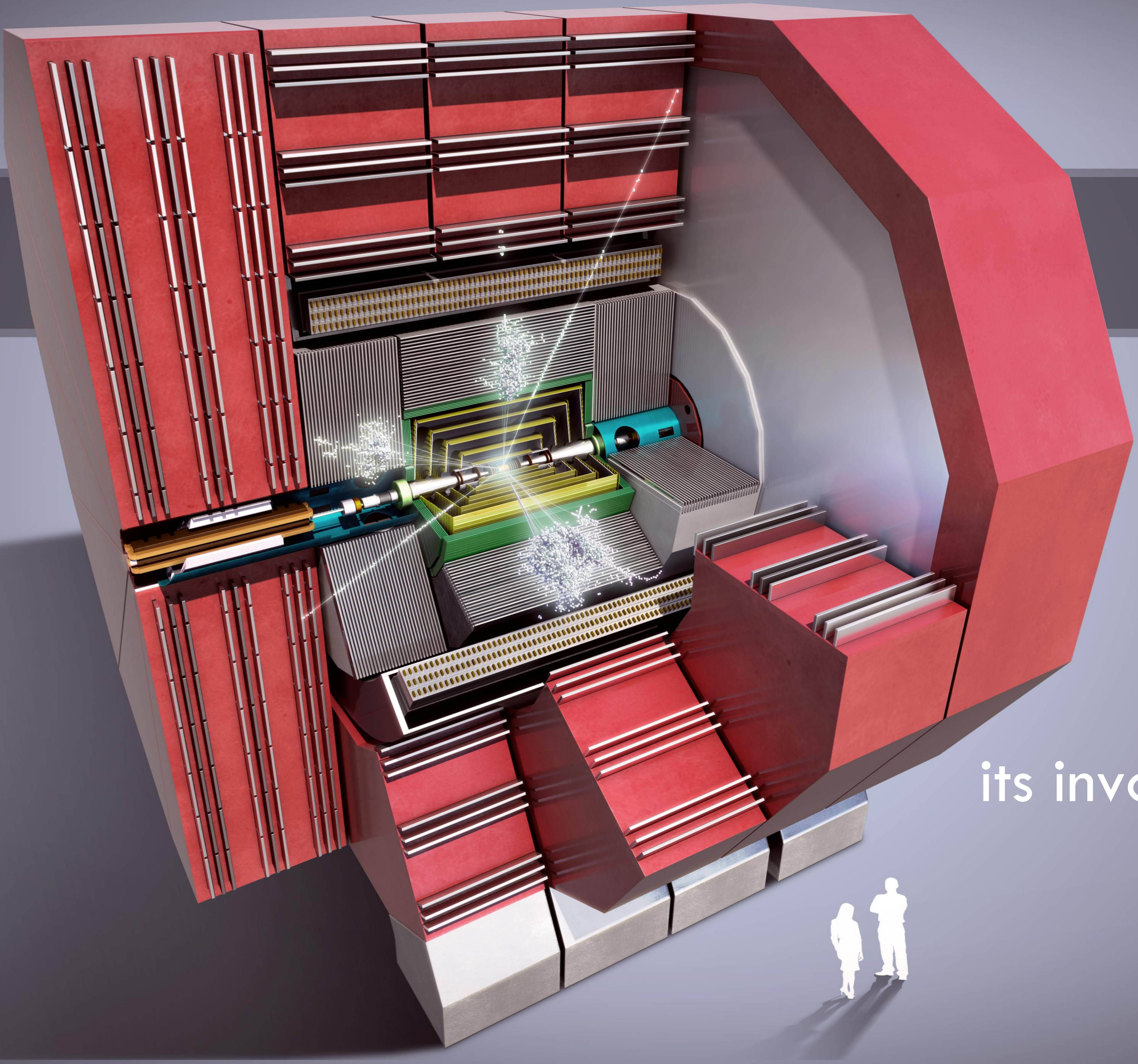


Detector

On behalf of the CLICdp Collaboration:

‘The CLIC project and its involvement in CMS HGCAL’

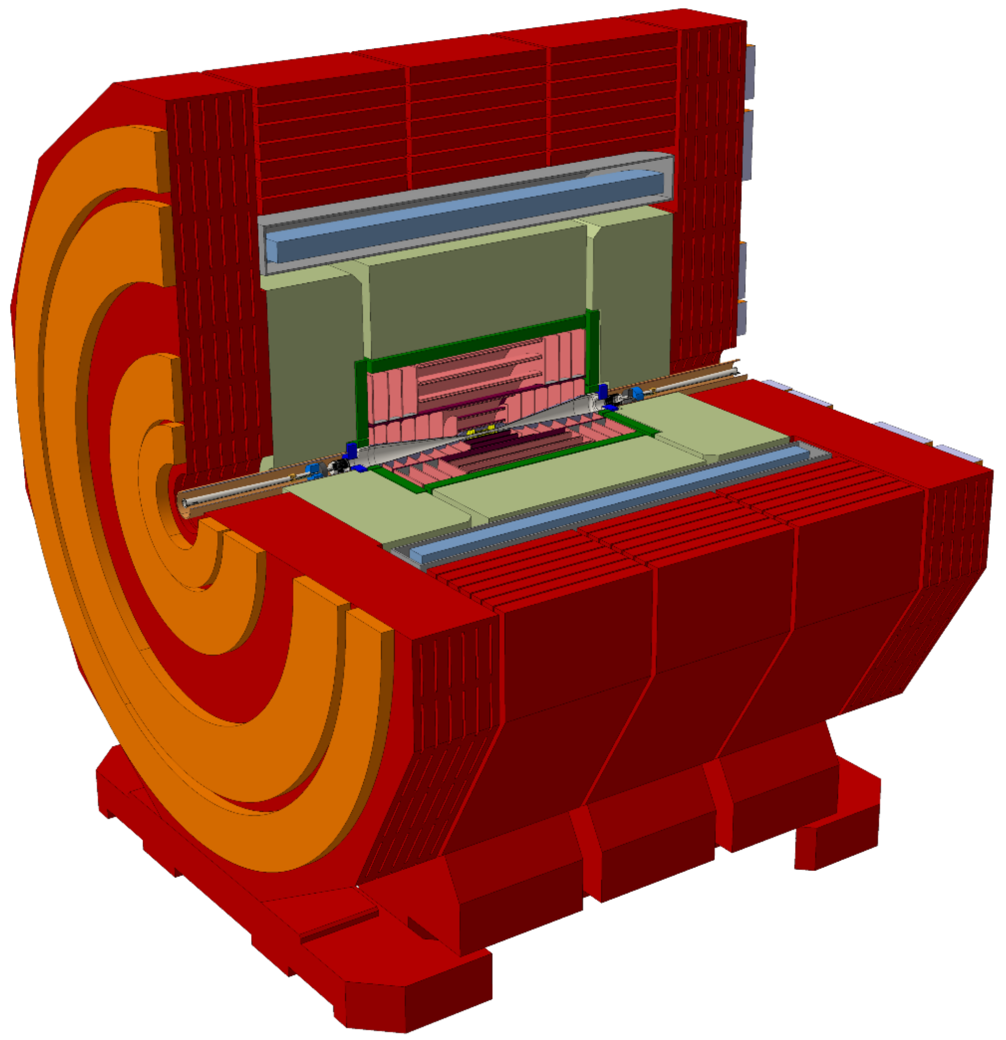
Andreas Alexander Maier
EP-LCD Group, CERN
andreas.alexander.maier@cern.ch

CEA Saclay Seminar, 13th of March 2017

Outline

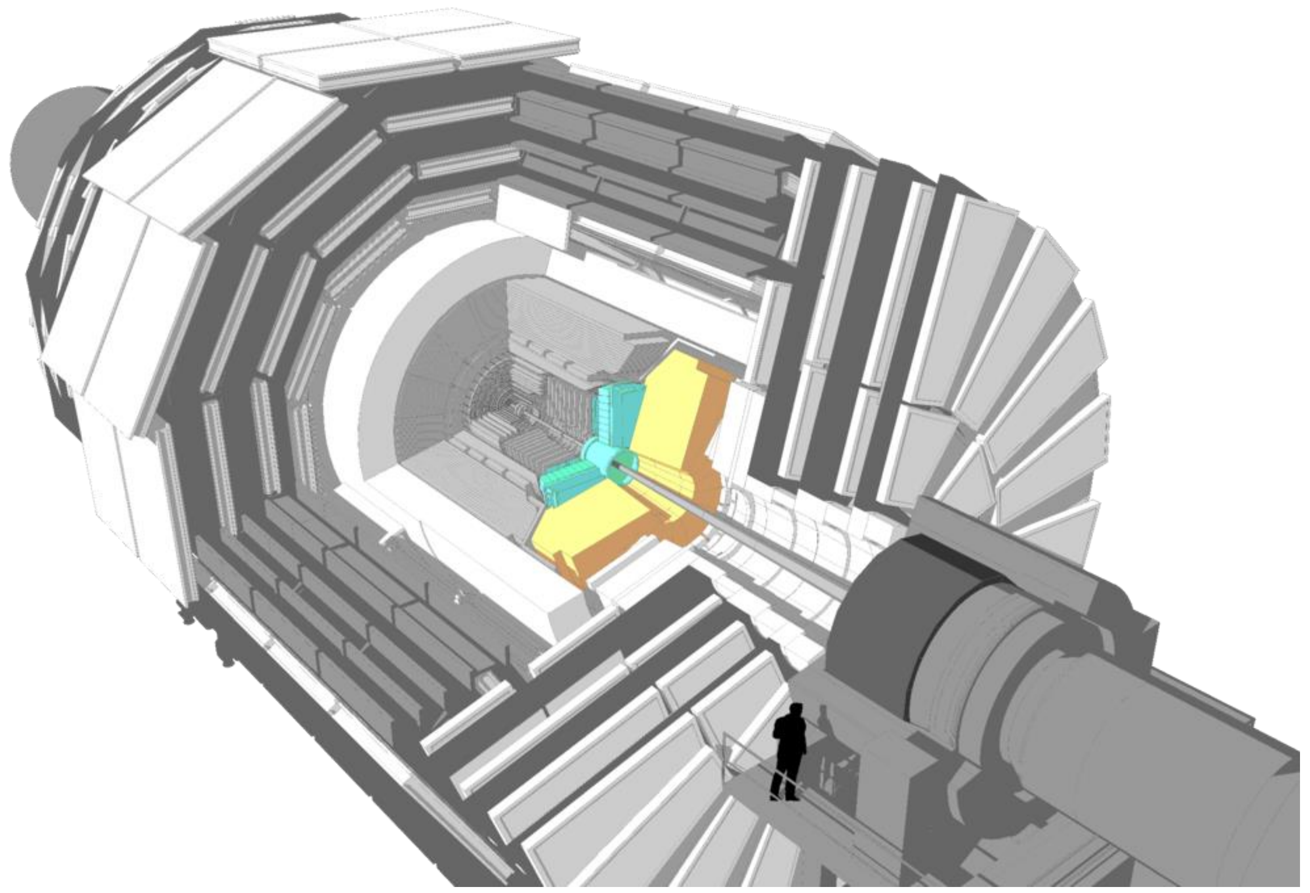
CLIC - The Compact Linear Collider

- CLIC Environment and Physics
- CLIC Detector Overview



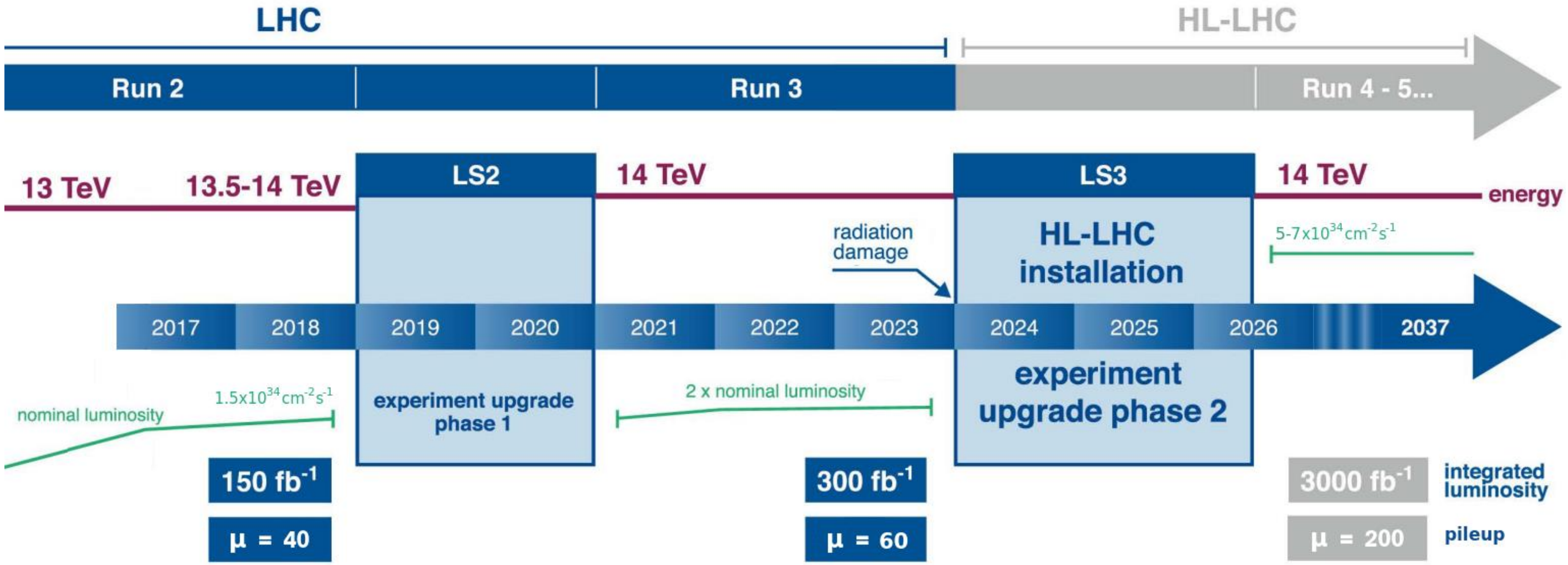
HGCAL – The High Granularity Calorimeter for CMS

- HGCAL Project Overview
- Sensors for the HGCAL



Conclusions & Summary

What comes after LHC?



?

2035 - ...

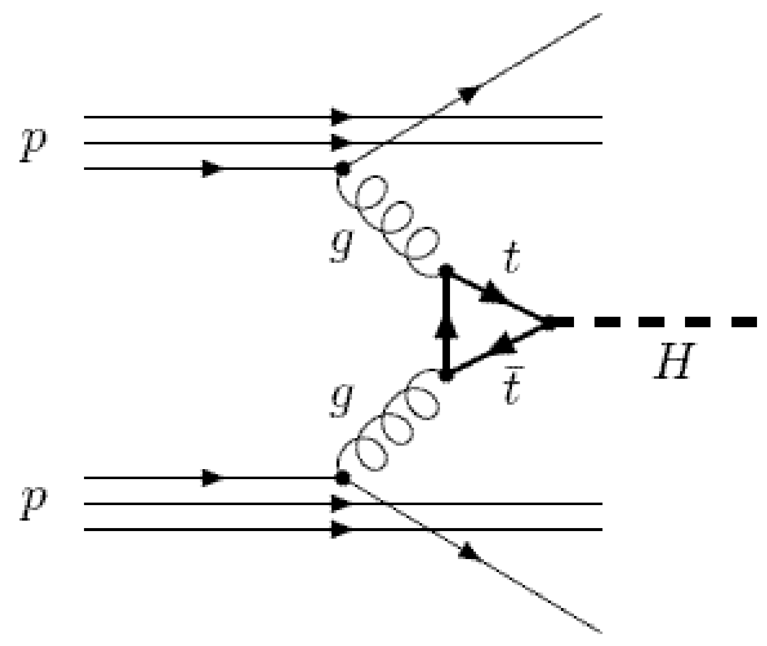
- LHC experiments prepare for HL-LHC challenges:
  - Pile-up
  - Radiation damage
- Hope for interesting physics: SUSY? Extended Higgs-sector?
- Regardless of finding: need an option for the post-LHC era!

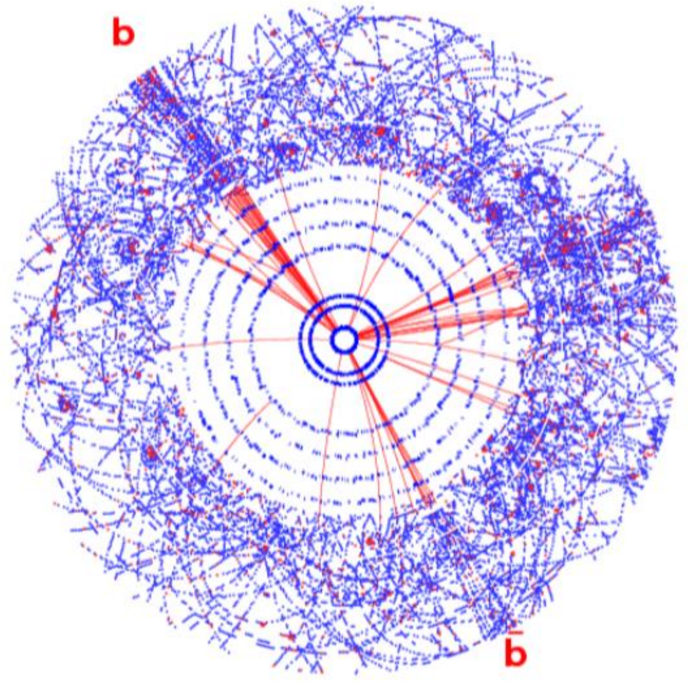
Lepton or hadron collider?

Hadron vs. Lepton Colliders

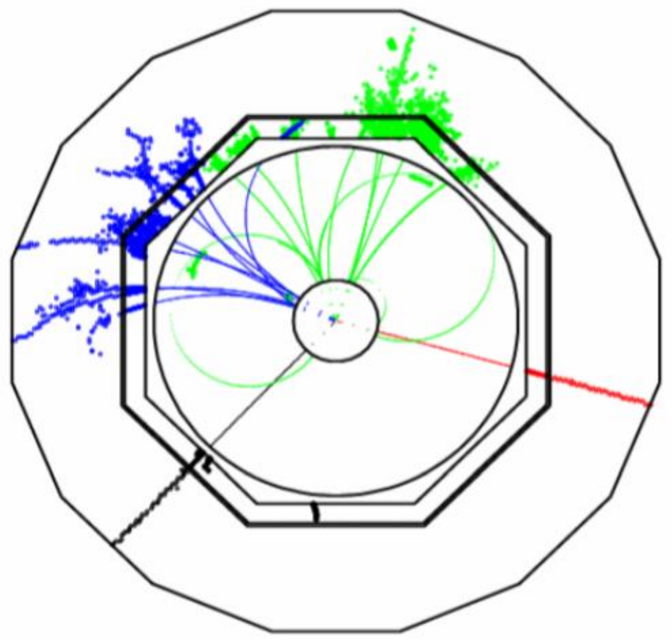
from discovery to precision

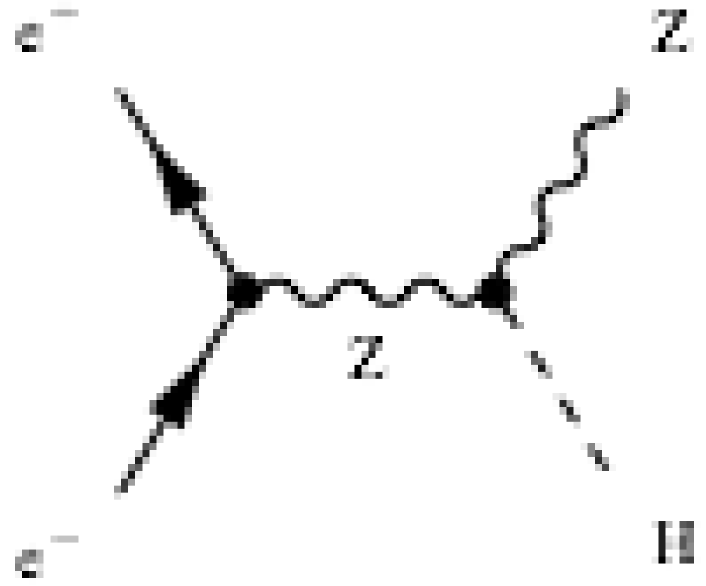
$\mathrm{H} \to \mathrm{b}\bar{\mathrm{b}}$ @ LHC





$\mathrm{ZH} \to \mu^+\mu^-\mathrm{b}\bar{\mathrm{b}}$ @ e^+e^-

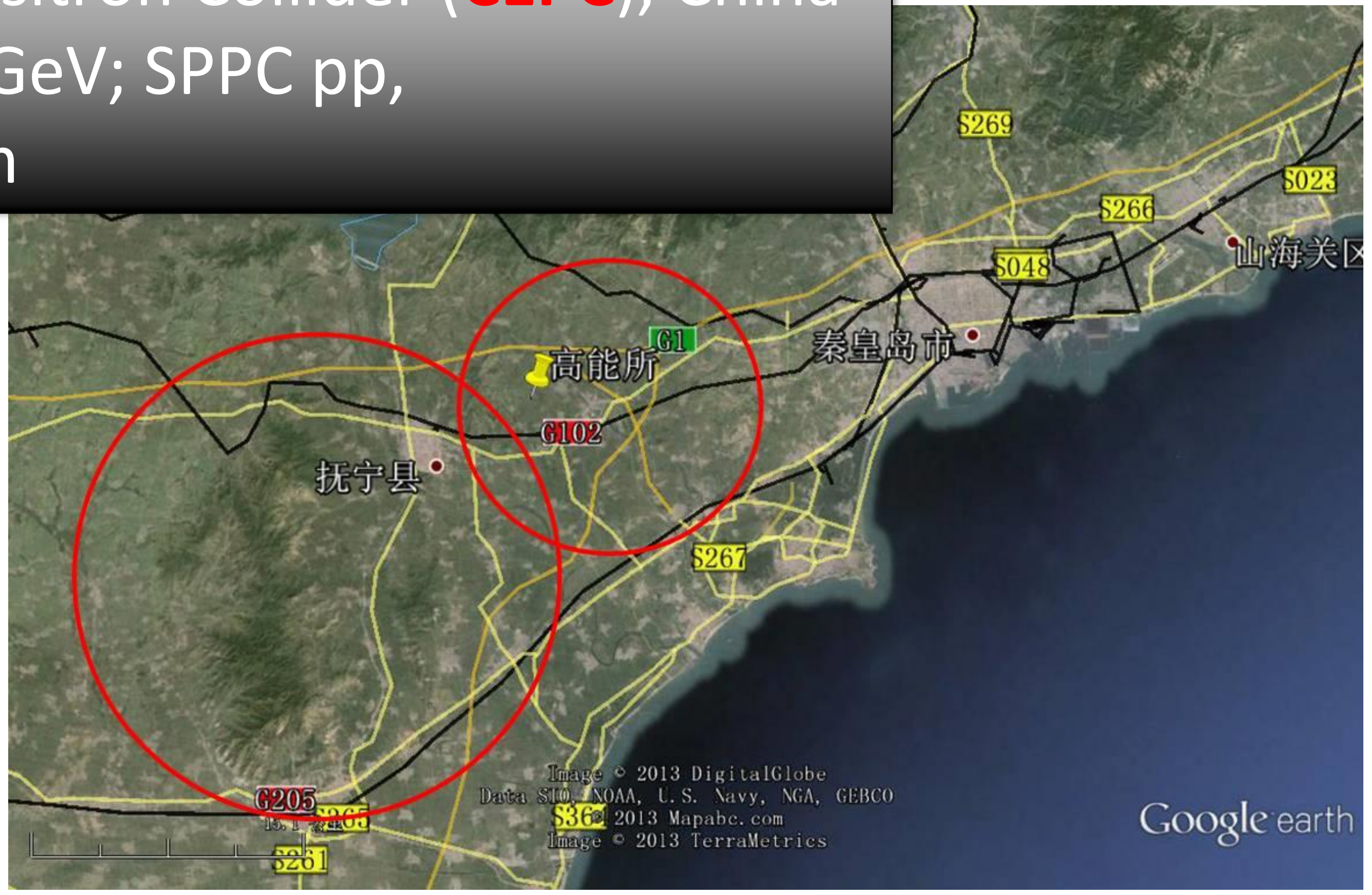




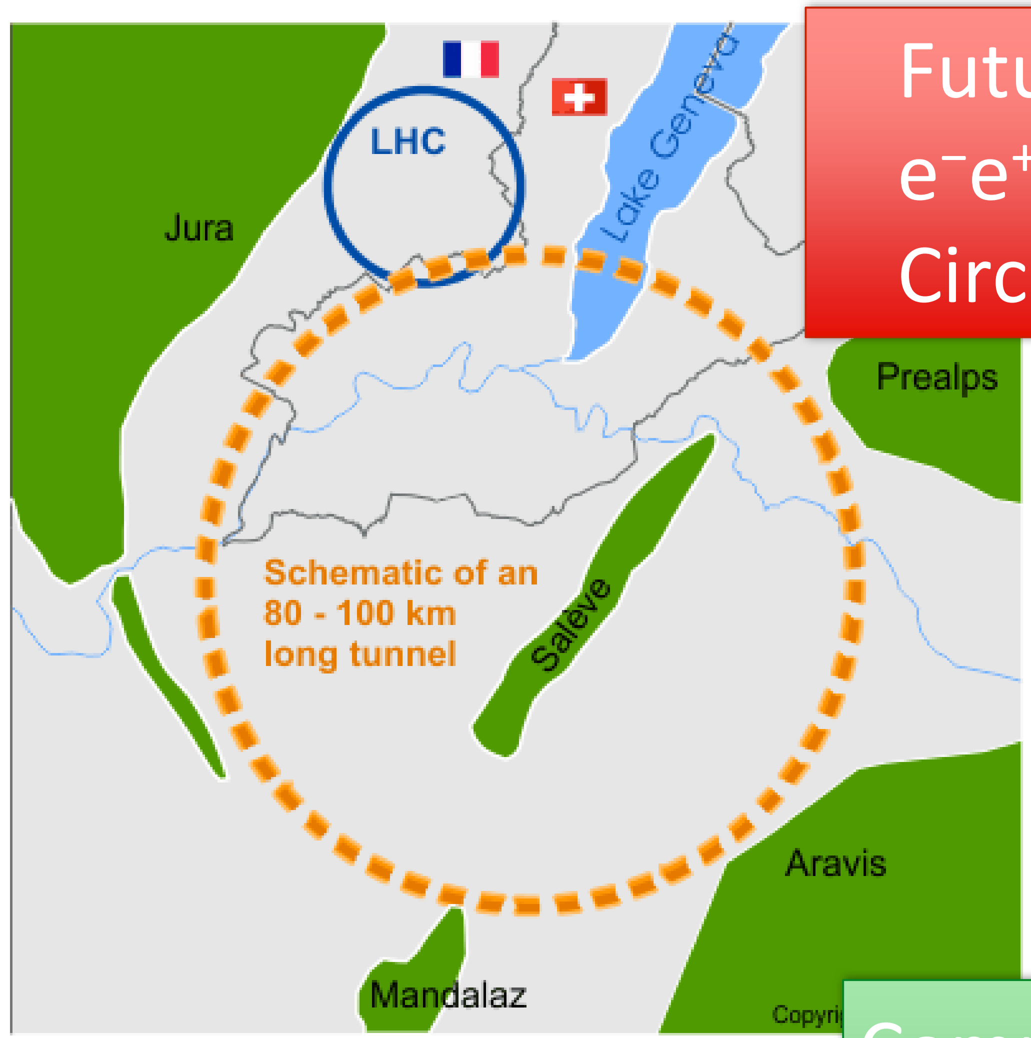
Hadron collider	Lepton collider
Protons are compound objects → Initial state not known event-by-event → Limits achievable precision	Electrons/Positrons are point-like → Initial state well defined (energy, polarization) → Recoil mass analyses possible → High-precision measurements
High rates of QCD backgrounds → Complex triggering schemes → High levels of radiation	Cleaner experimental environment → Trigger-less readout → Low radiation levels
High-energy circular colliders feasible	High-energy requires linear colliders

Studies of High-Energy e^+e^- Colliders

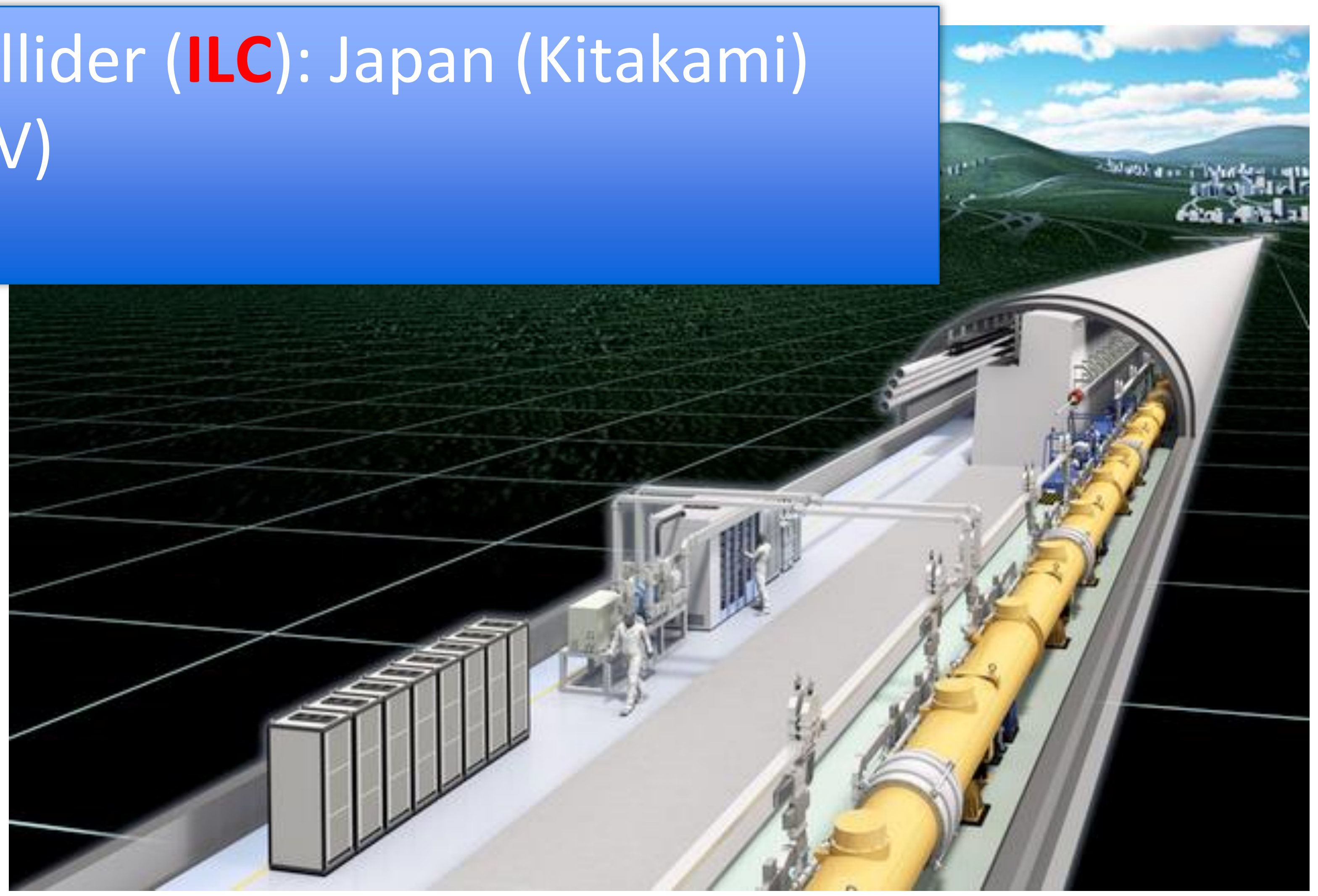
Circular Electron Positron Collider (**CEPC**), China
e^-e^+, $\sqrt{s}$: 240 – 250 GeV; SPPC pp,
Length: 54 – 100 km



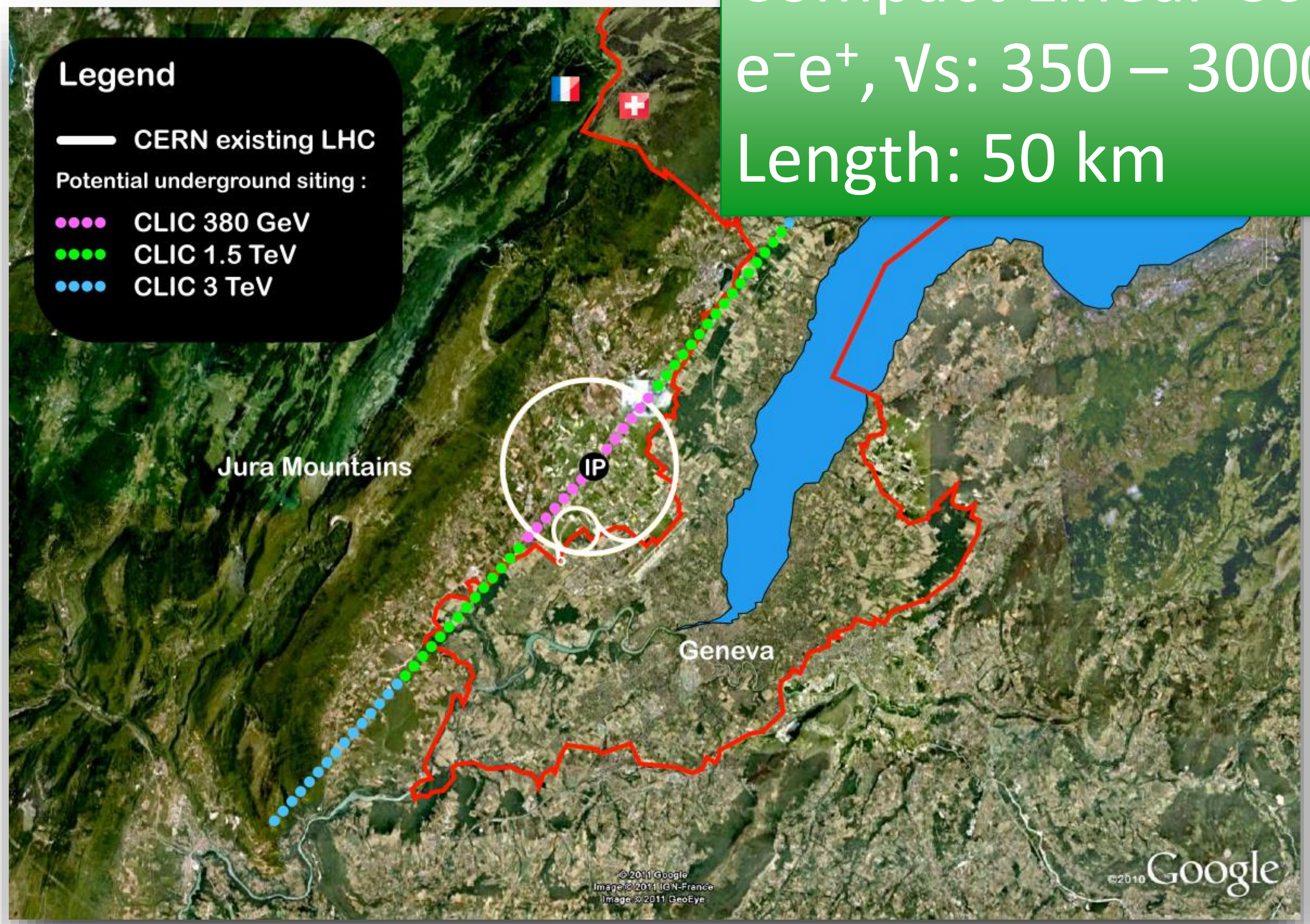
Future Circular Collider (**FCC**): CERN
e^-e^+, $\sqrt{s}$: 90 - 350 GeV; pp, $\sqrt{s}$: ~100 TeV
Circumference: 90 - 100 km



International Linear Collider (**ILC**): Japan (Kitakami)
e^-e^+, $\sqrt{s}$: 500 GeV (1 TeV)
Length: 31 km (50 km)

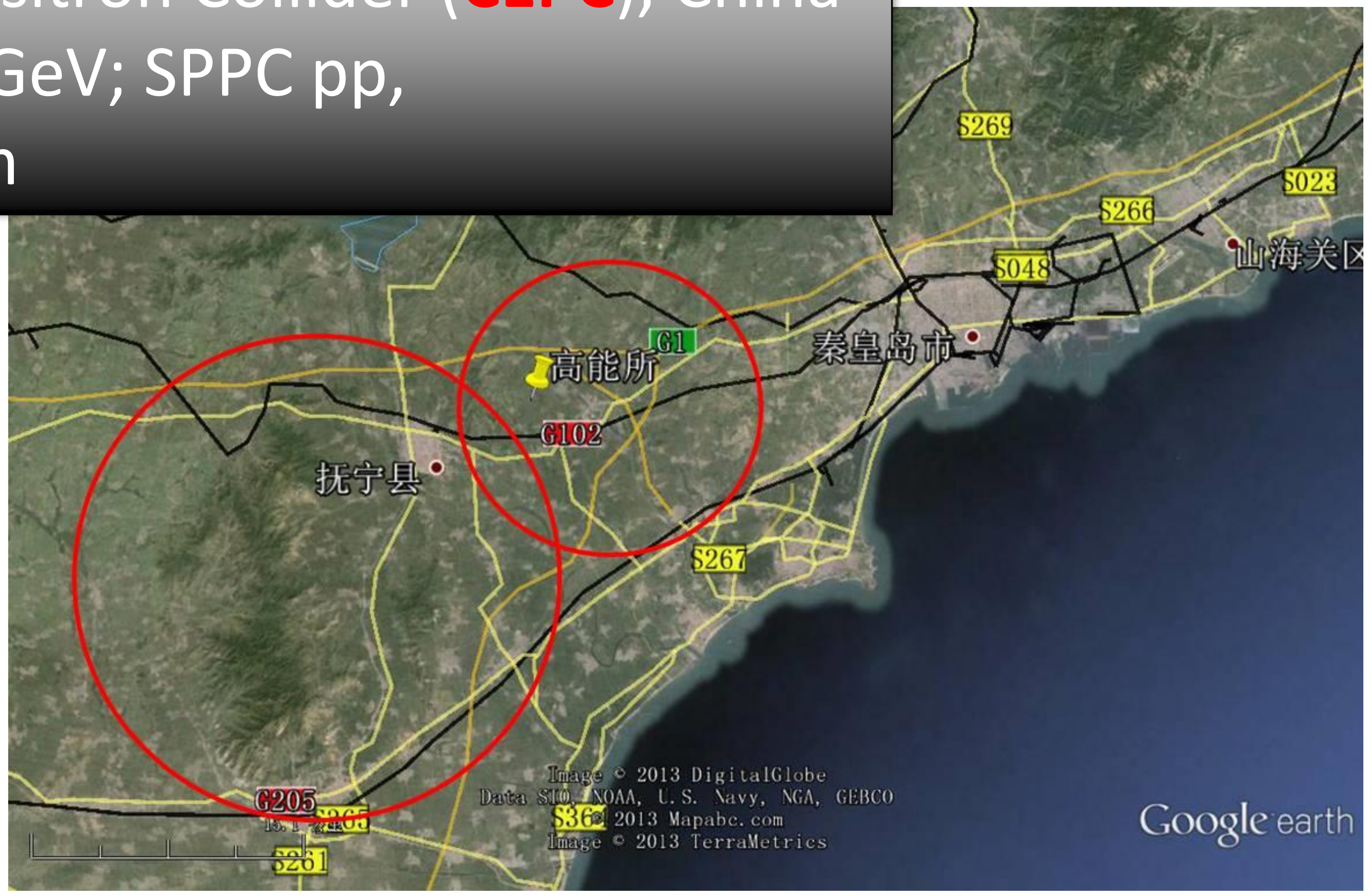


Compact Linear Collider (CLIC): CERN
e^-e^+, $\sqrt{s}$: 350 – 3000 GeV
Length: 50 km



Studies of High-Energy e^+e^- Colliders

Circular Electron Positron Collider (**CEPC**), China
e^-e^+, $\sqrt{s}$: 240 – 250 GeV; SPPC pp,
Length: 54 – 100 km



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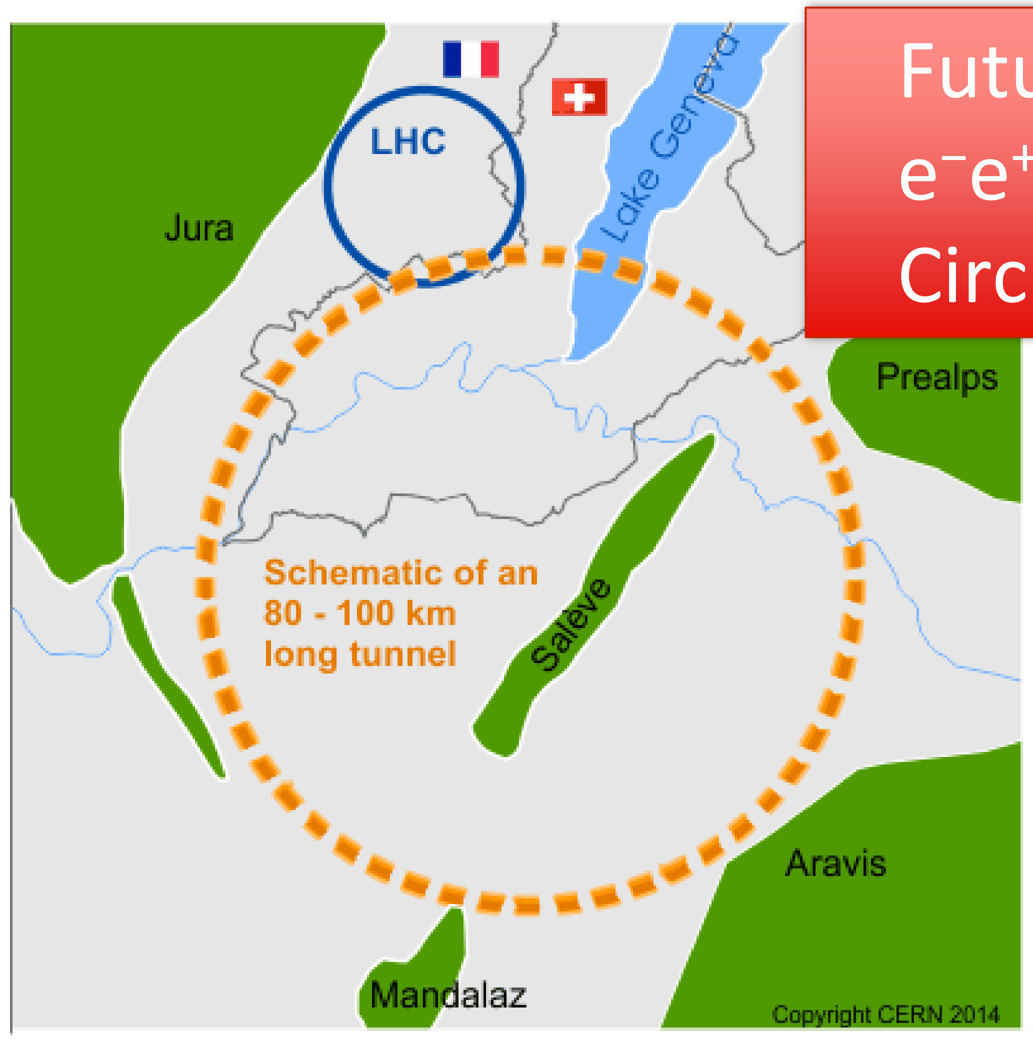

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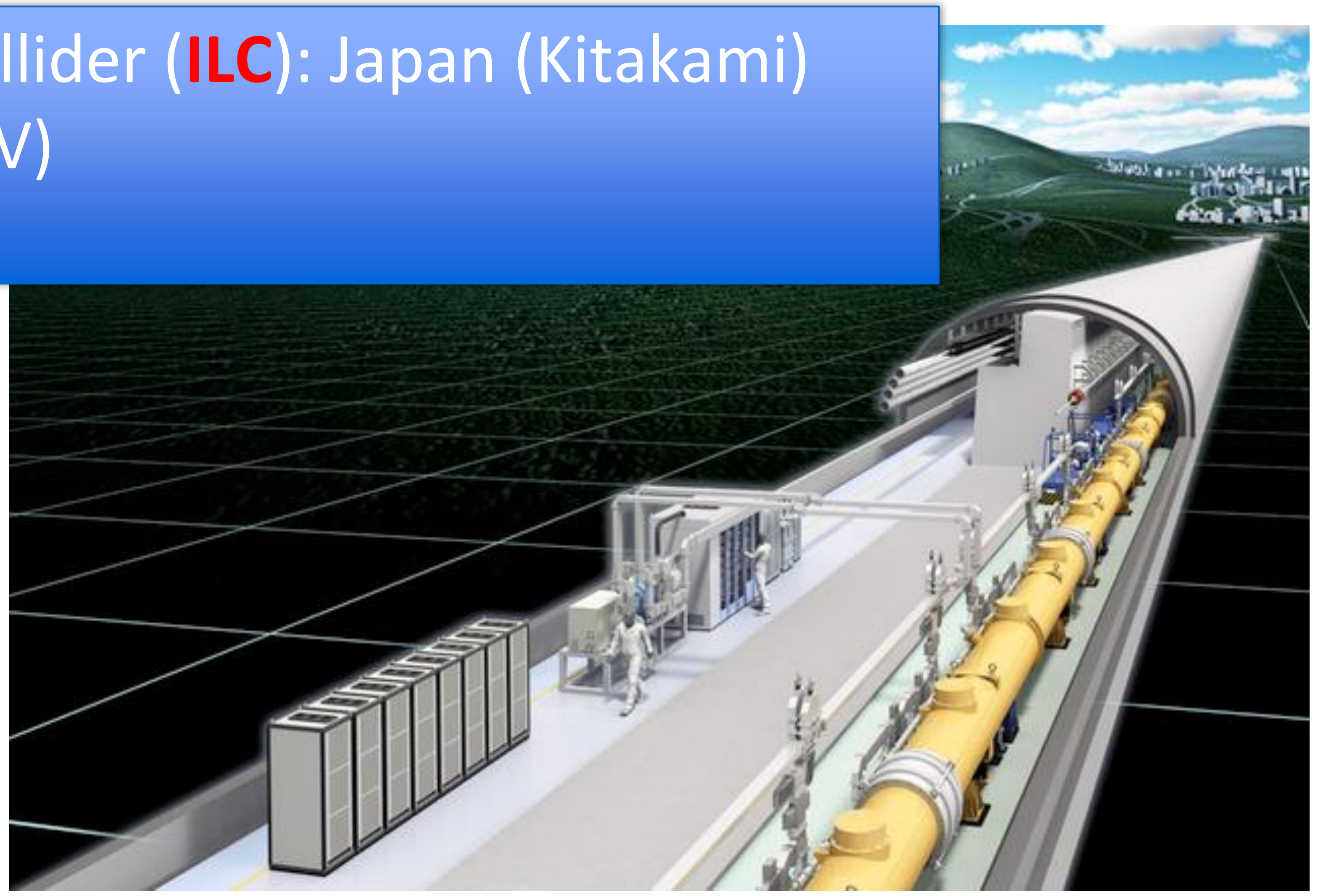
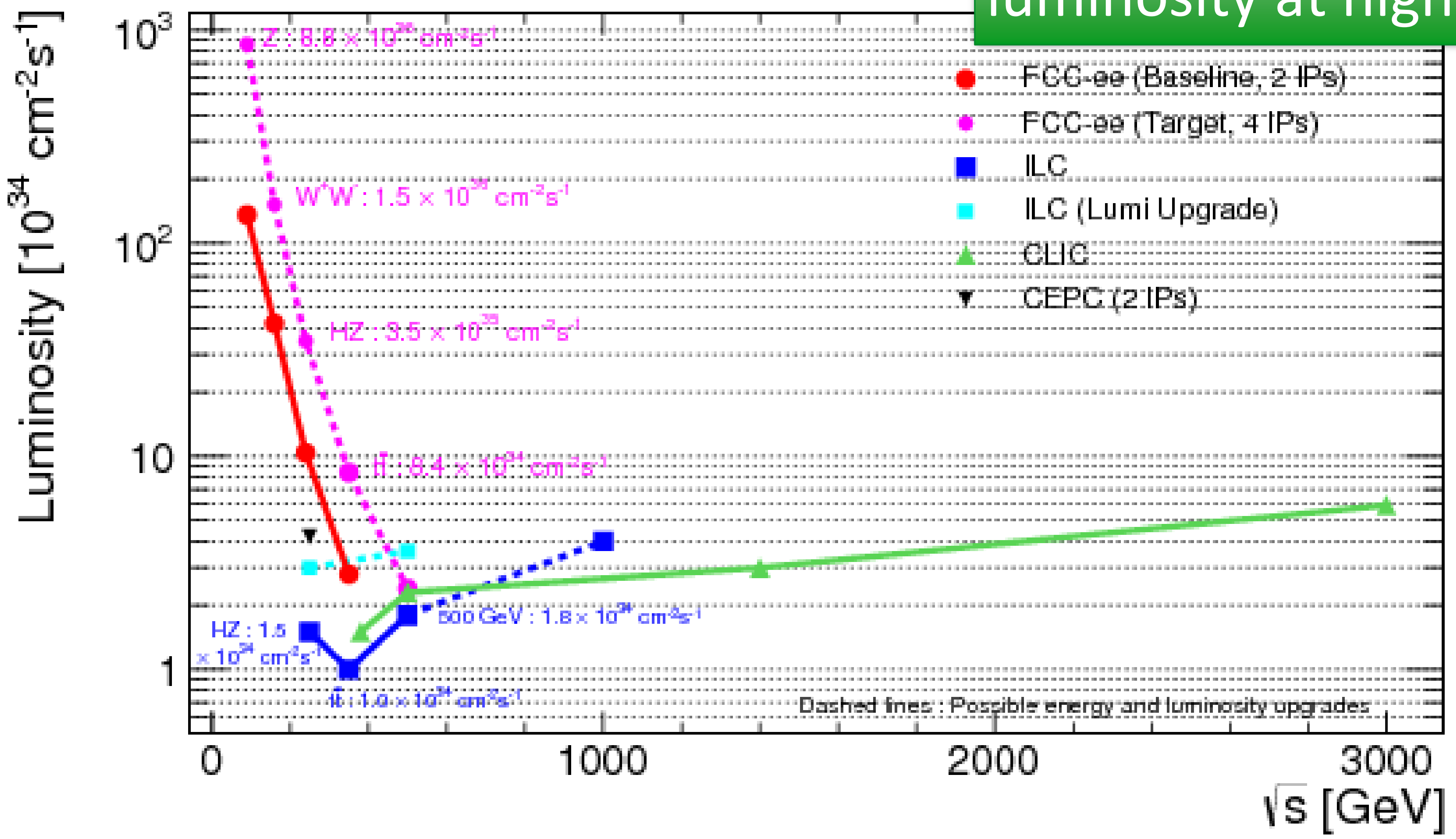
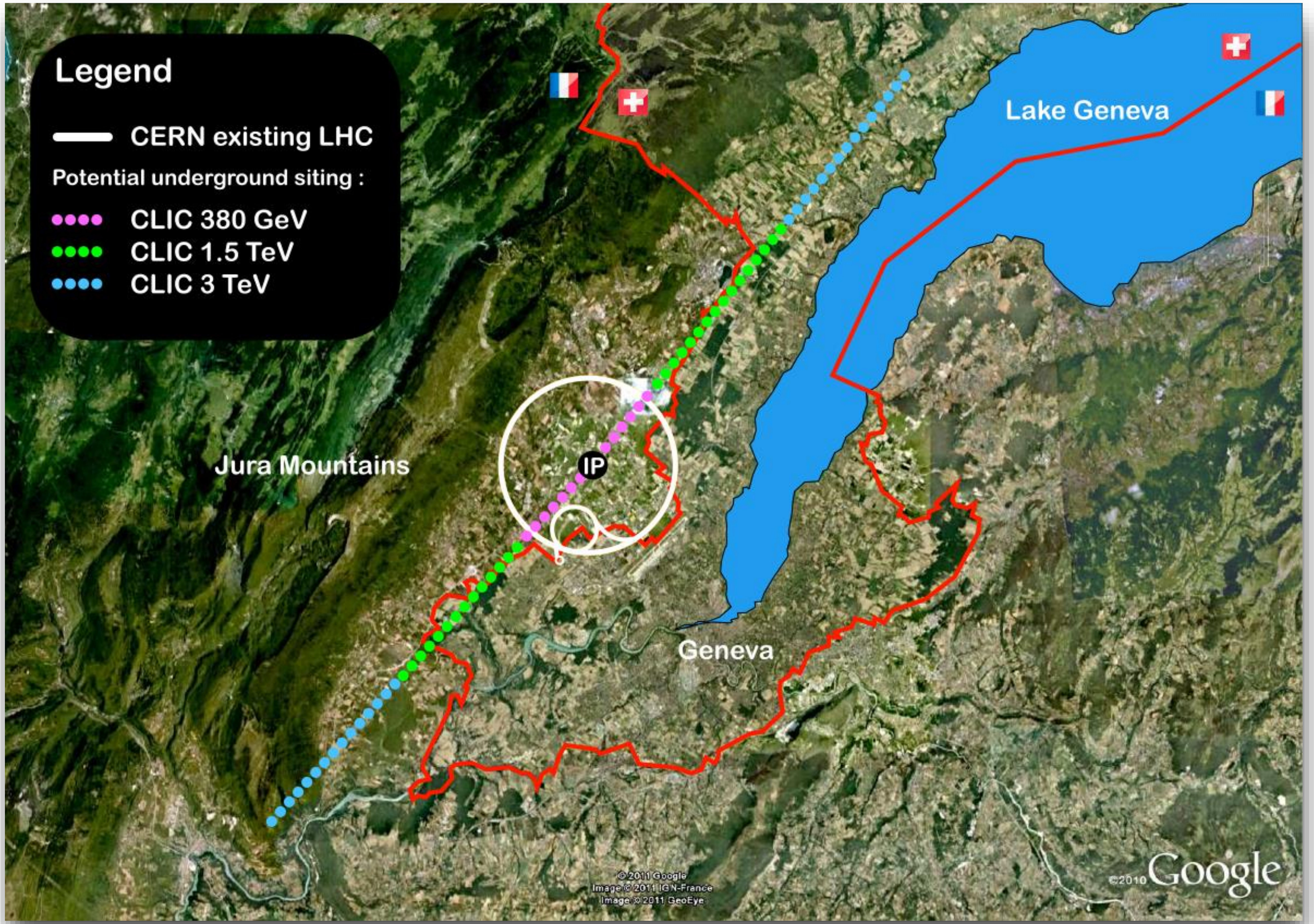


CLIC has outstanding luminosity at high energy!



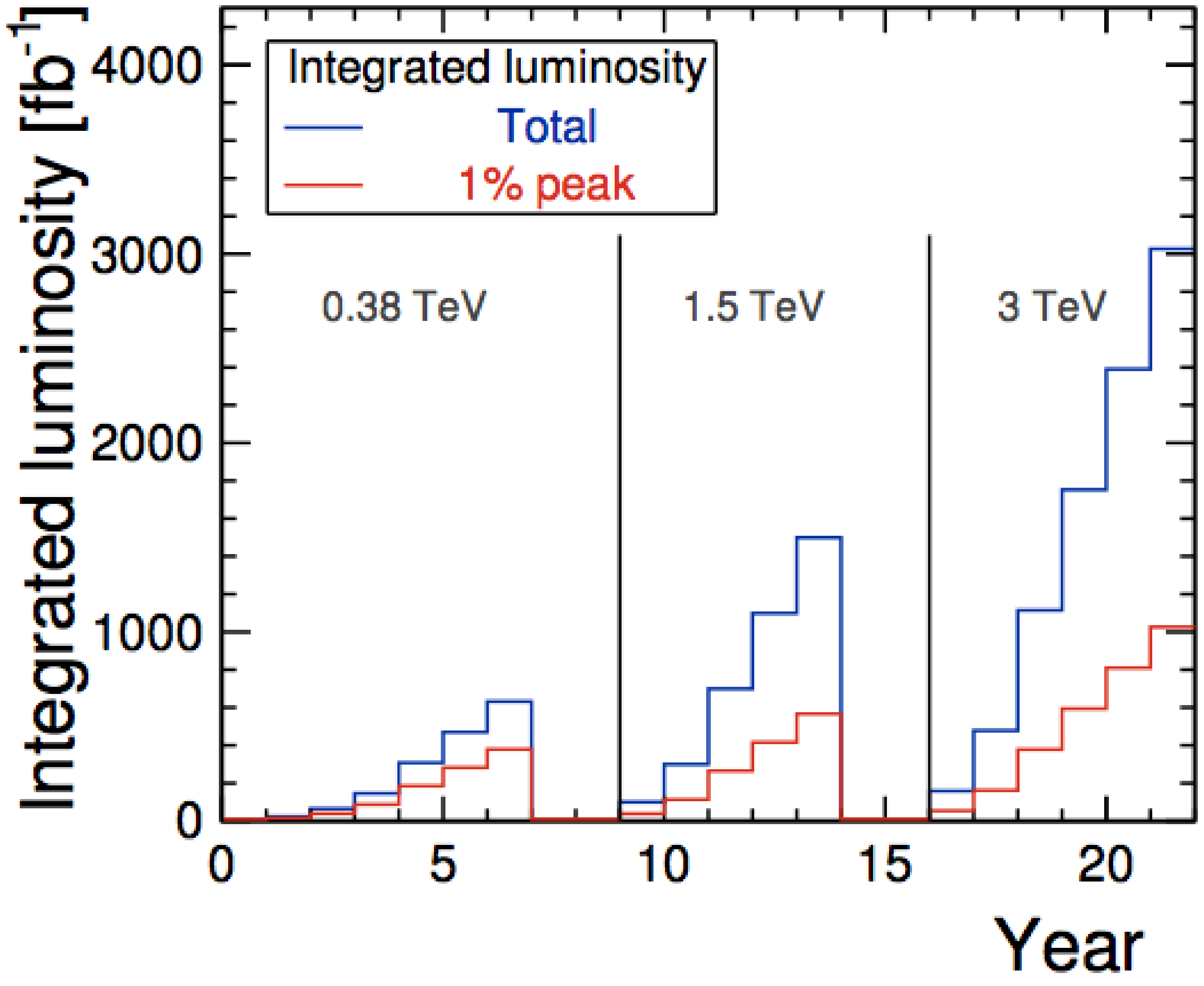
CLIC - Compact Linear Collider - e^+e^-

- CLIC is a proposed e^+e^- linear collider at CERN
- Two-beam acceleration scheme (drive/main beams)
  - High accelerating gradient of 100 MV/m
  - About 150’000 room temperature RF cavities
  - Allows a 3 TeV collider to be built in only 50 km (compact)
- Staged construction optimal for physics:
  - Successive upgrade steps to higher energies, each with its own physics program
- Rich physics program over ~ 20 years (with 5-7 years at each stage)



Physics at CLIC - A Staged Program

Each stage corresponds to 5-7 years



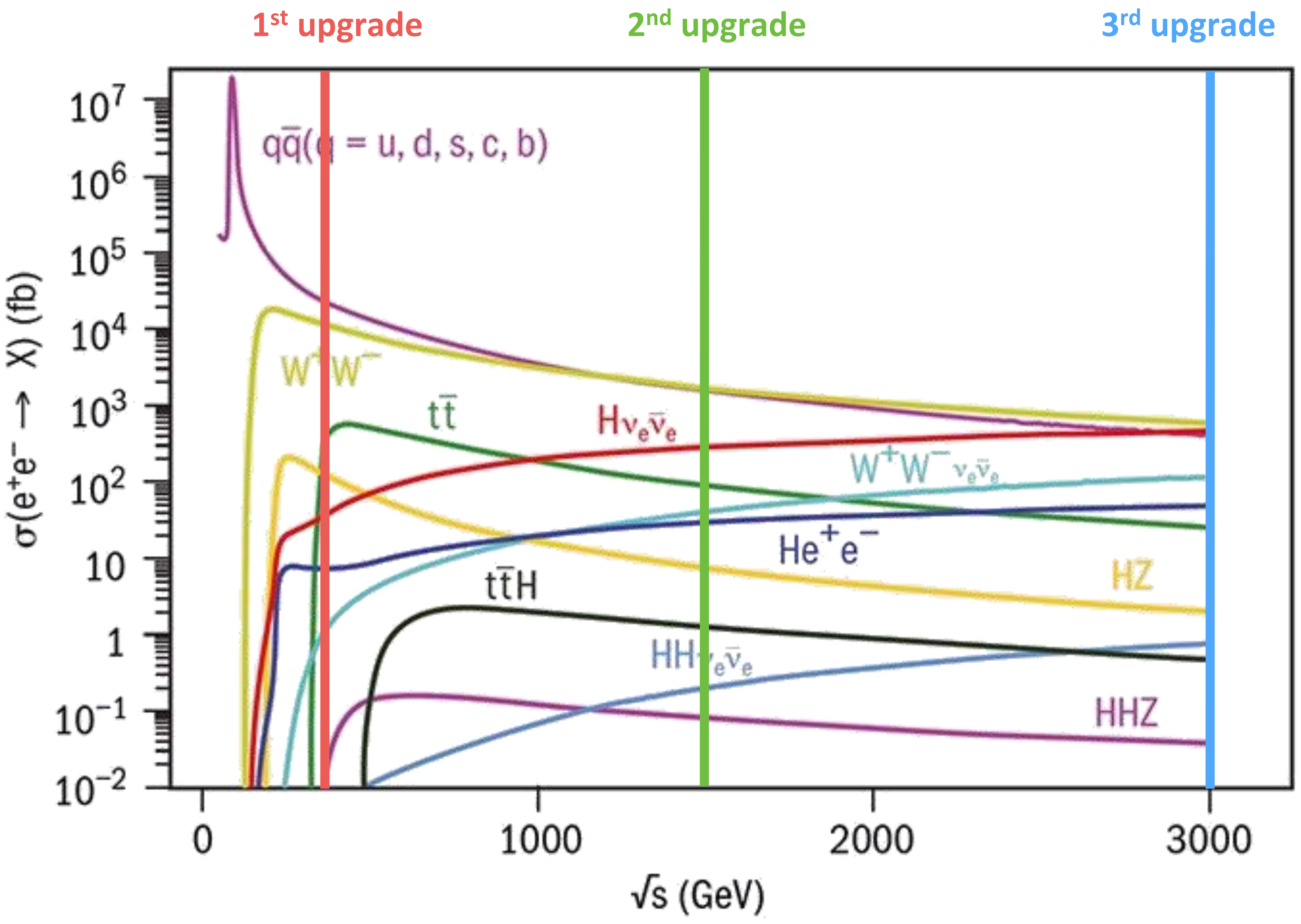
1) $\sqrt{s}$ = 380 GeV (500 + 100 fb^{-1})
- Higgs/Top precision physics
- Top mass threshold scan (350 GeV)

2) $\sqrt{s}$ = 1.5 TeV (1.5 ab^{-1})
- Target: Precision SUSY, BSM reach
- Higgs/Top precision physics
- Rare Higgs decays
- Top Yukawa coupling

3) $\sqrt{s}$ = 3 TeV (3.0 ab^{-1})
- Target: Precision SUSY, BSM reach
- Higgs self-coupling
- Rare Higgs decays

Staging can be adapted to possible LHC discoveries
New CLIC staging baseline in CERN yellow report: CERN-2016-004

Physics at CLIC - A Staged Program



s-channel thresholds [GeV]:
160 WW, 215 HZ, 340 HHZ, 350 tt, 500 ttH

Slow rise for t-channel processes:
$e^+e^- \to$ Hνν, He^+e^- , HHνν, WWνν

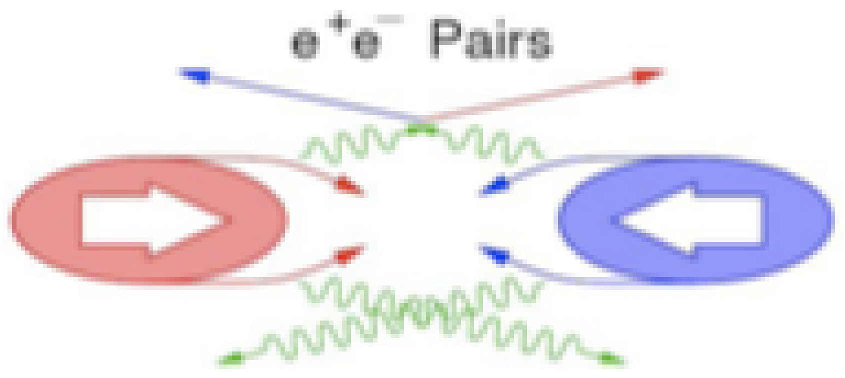
Standard Model
- Z, W, H, t production
- Understanding, "bookkeeping"

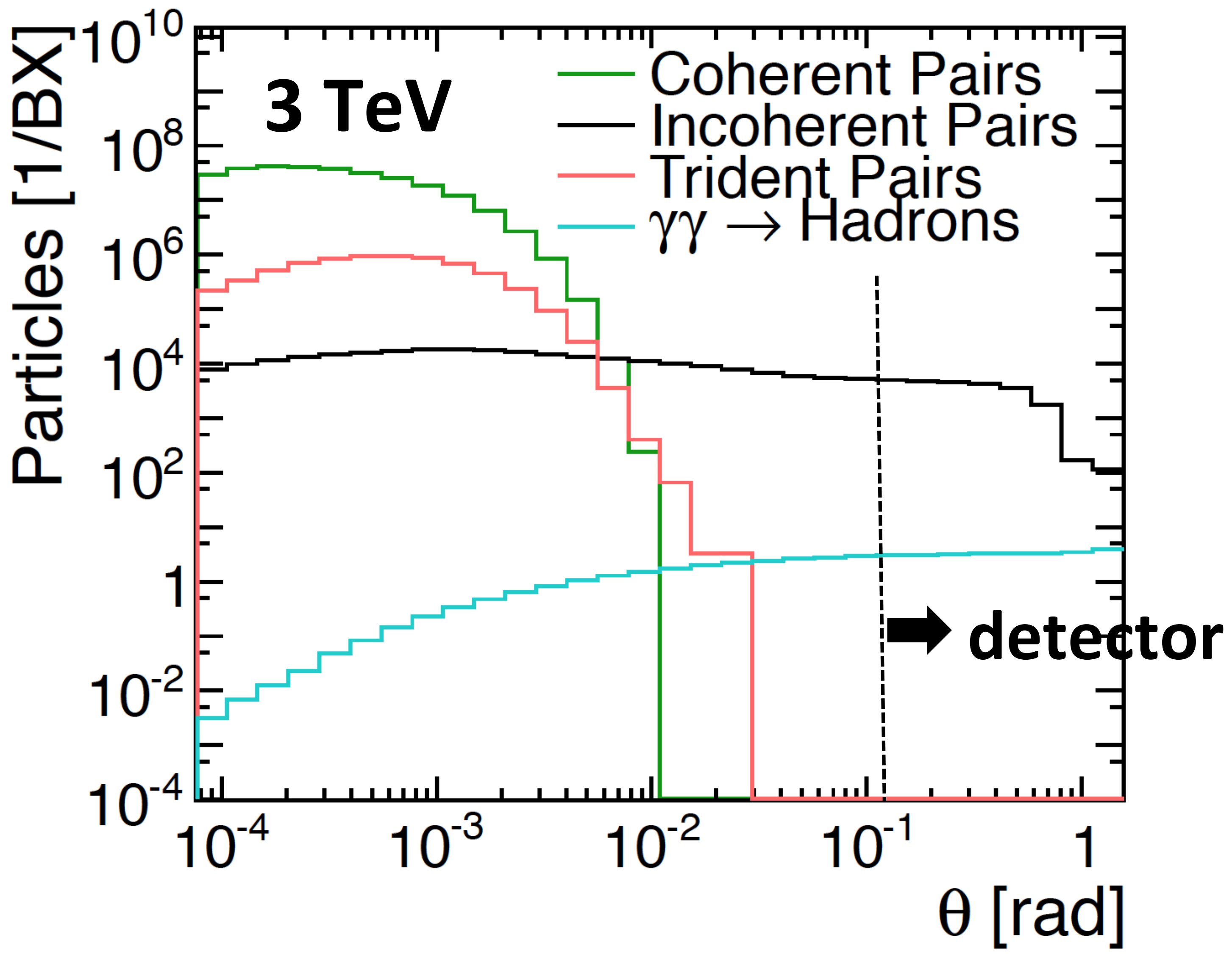
Most promising physics areas:
- Higgs physics
- Top quark physics
- BSM physics

Significantly higher precision than HL-LHC for many observables
More information: arXiv:1608.07538

CLIC Accelerator Environment

- Small beam size (σ_x/σ_y = 40/1 nm) at IP leads to very high Beamstrahlung, even in the absence of a 'hard' interaction (~1 hard interaction per bunch train)





- **Coherent e^+e^- pairs**: 7 x 10^8 per BX, very forward
- **Trident e^+e^- pairs**: 10^6 per BX, forward
- **Incoherent e^+e^- pairs**: 3 x 10^5 per BX, rather forward, high occupancy, impact on detector design
- ***γγ* → hadrons**: 3.2 events per BX at 3 TeV, main background in calorimeters and trackers, impact on physics

➢ Reduced to manageable level by combined p_T and timing cuts in the sub-detectors

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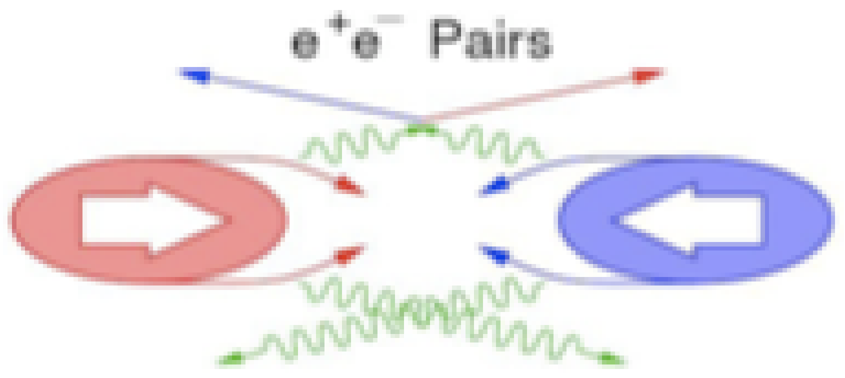
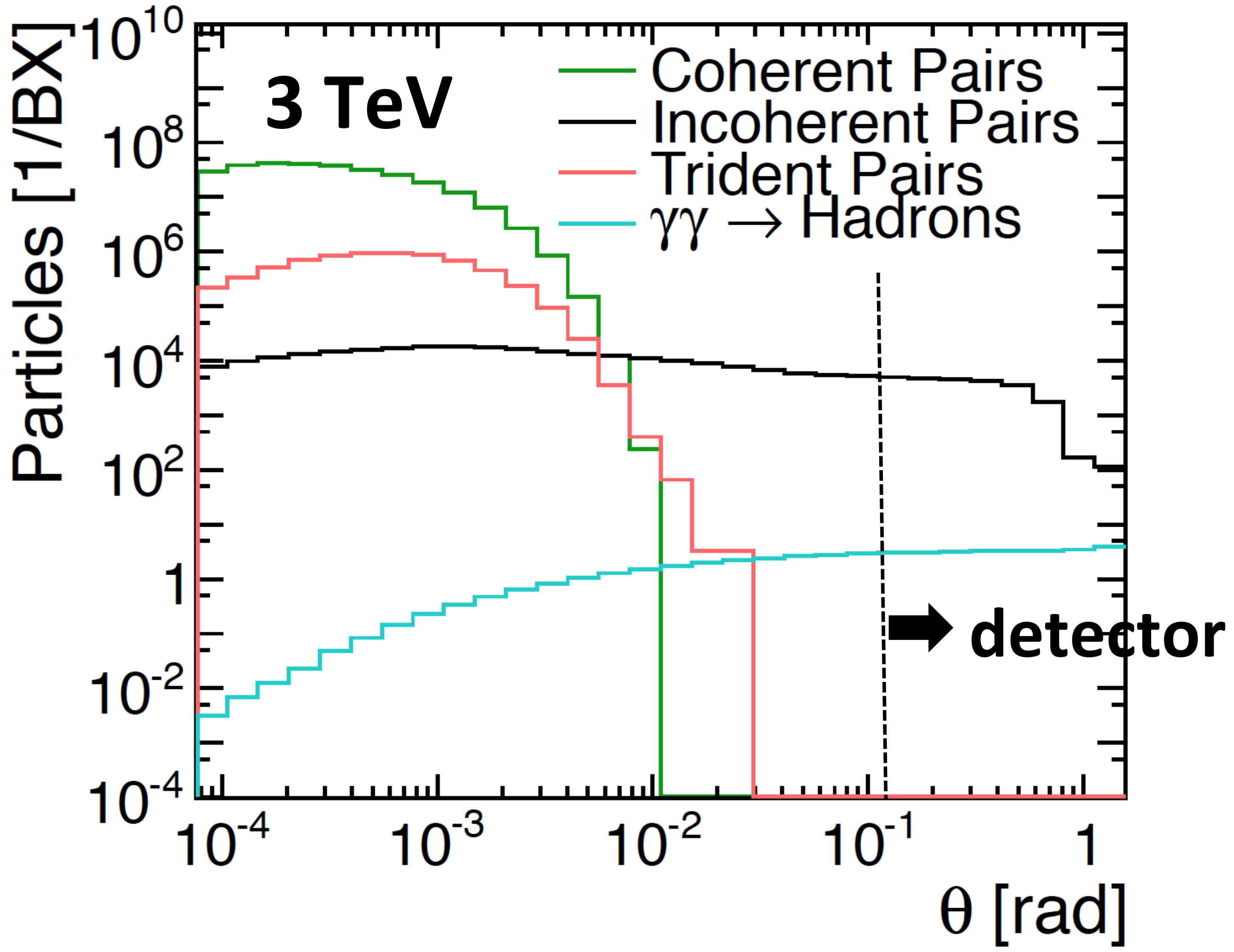
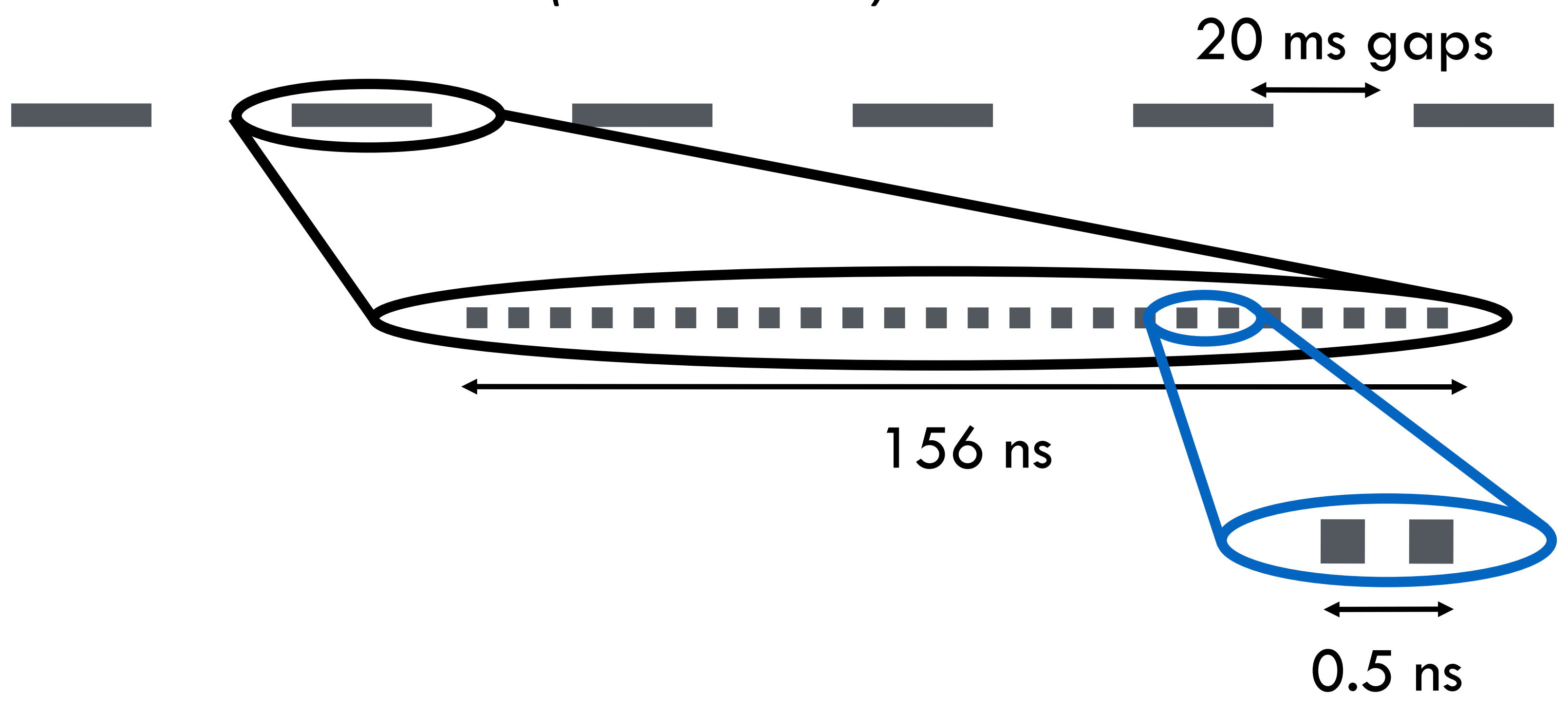
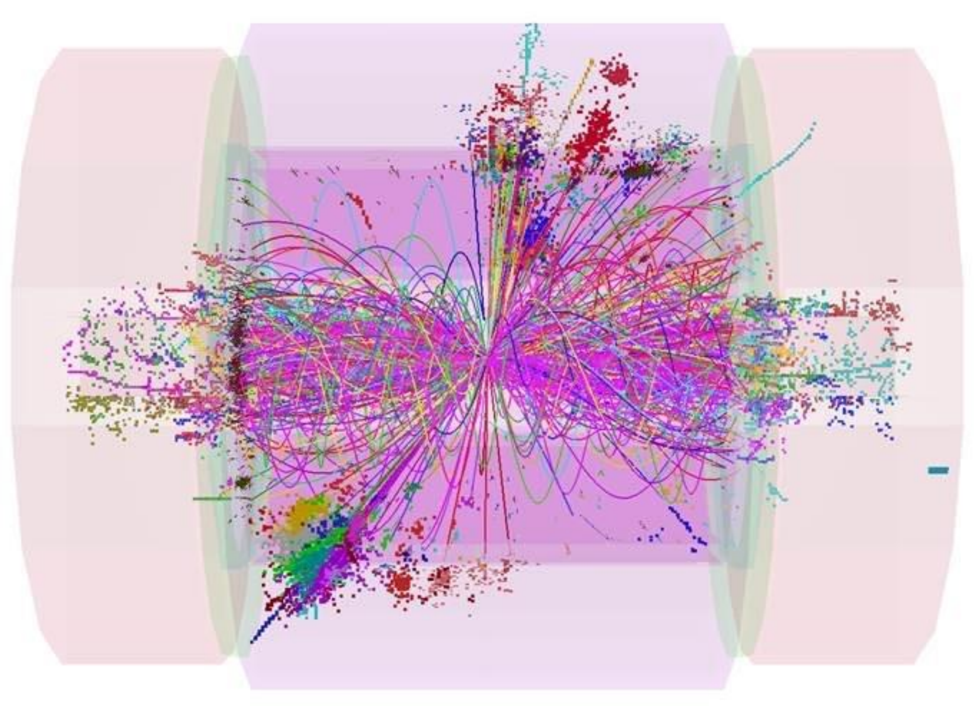




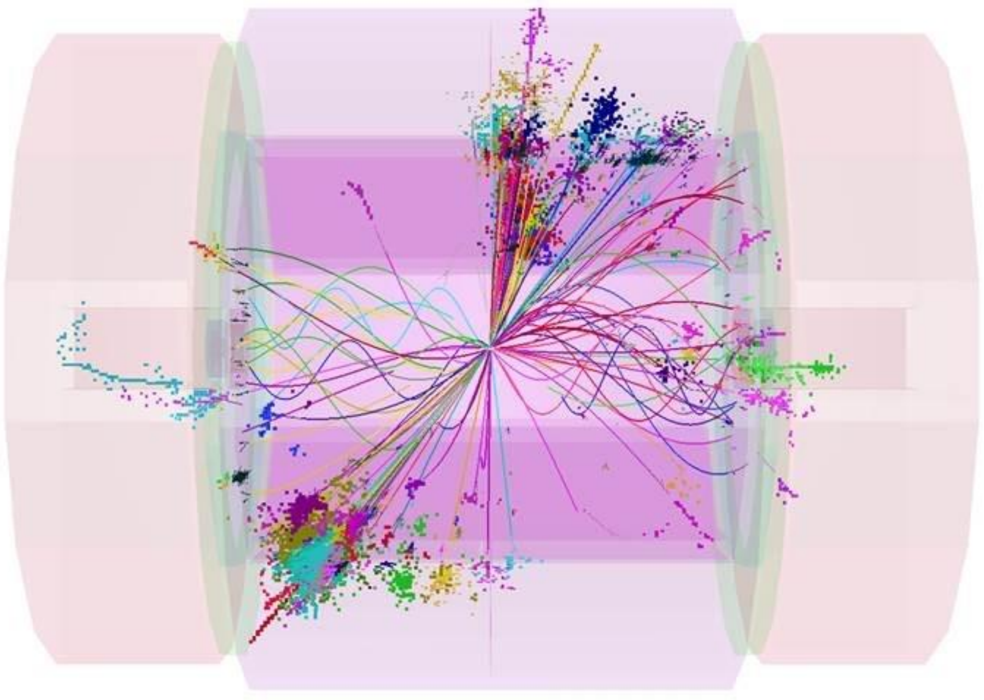
CLIC beam structure *(not to scale)*



$$e^+e^- \to H^+H^- \to t\bar{b}b\bar{t} \to 8\,\text{jets}$$



1.2 TeV background in reconstruction time window



85 GeV background after tight cuts

CLIC Accelerator Environment

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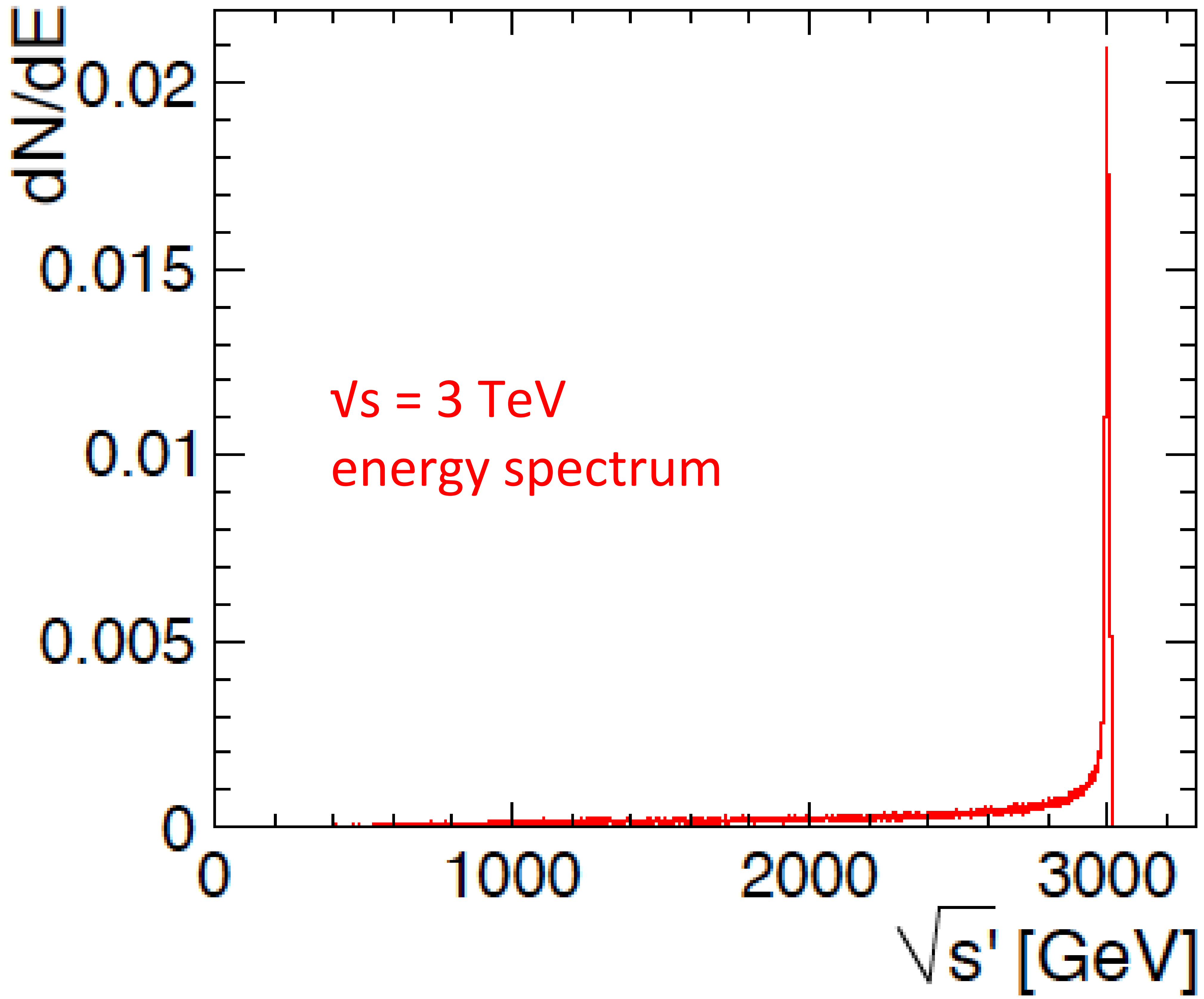
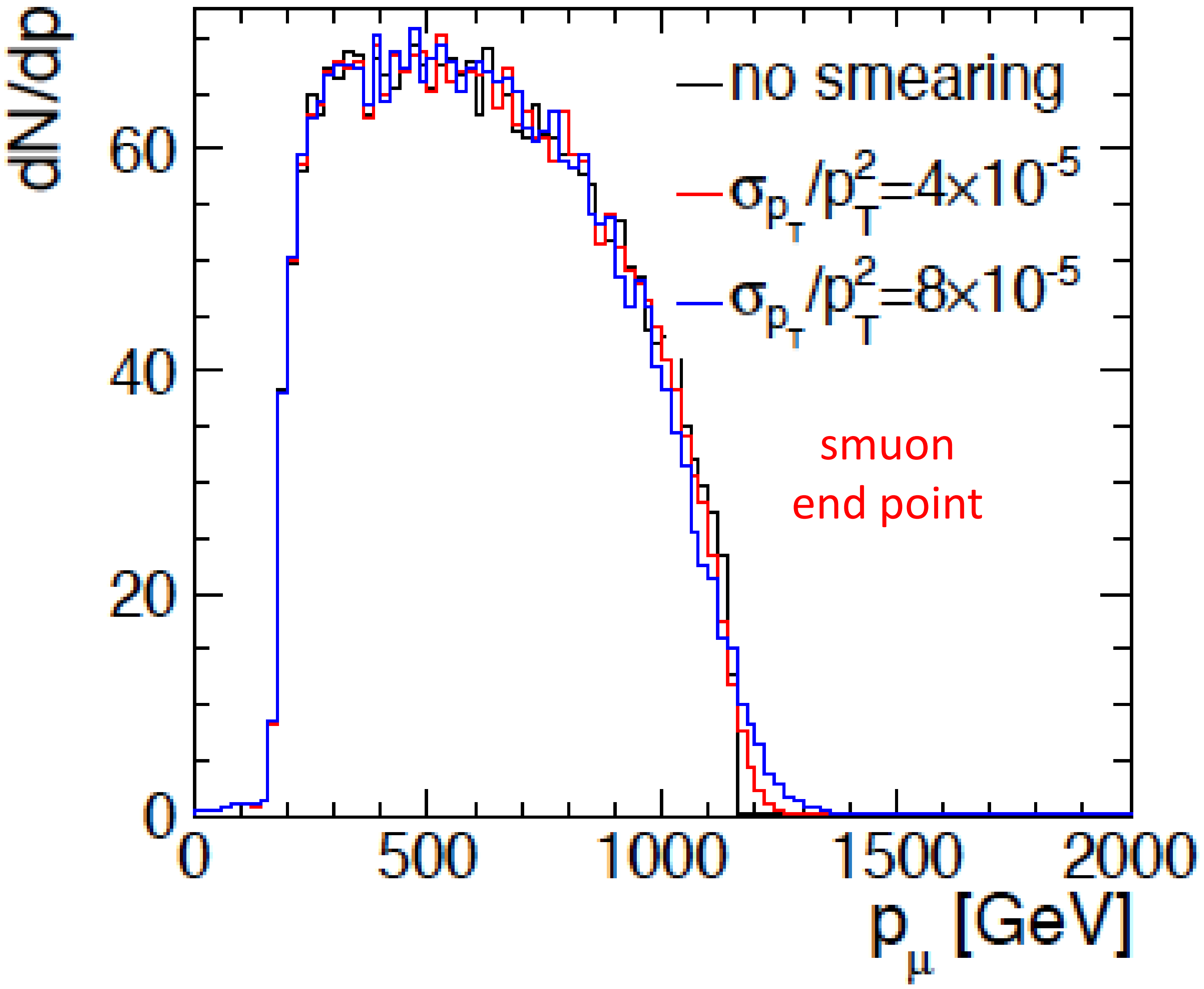
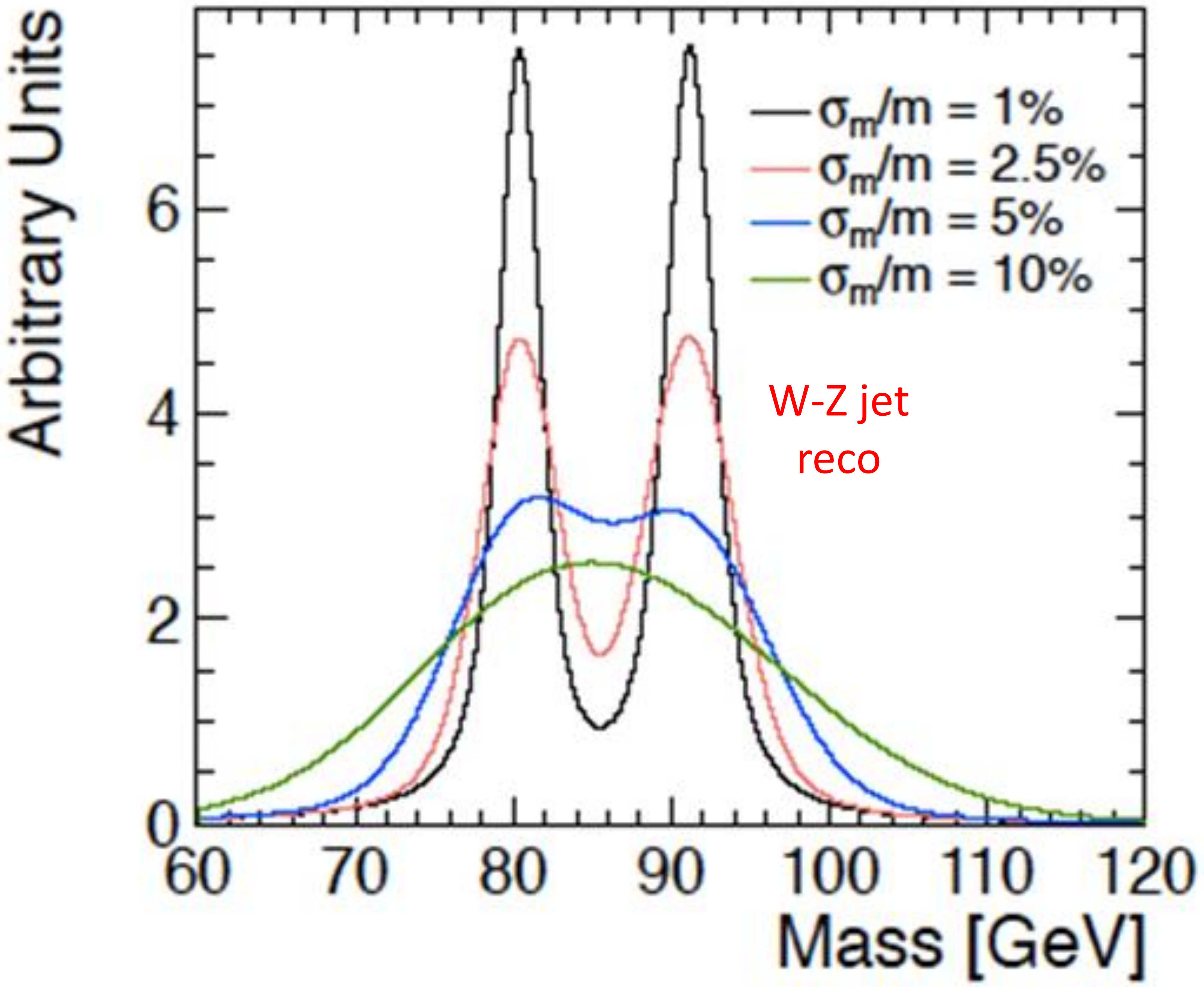


- Energy losses right at the interaction point
  - Most processes are studied well above production threshold and profit from full luminosity (at 3 TeV: 5.9 x 10^{34} $cm^{-2}s^{-1}$)

➢ 1% most energetic collisions 2.0 x 10^{34} $cm^{-2}s^{-1}$

Detector Requirements

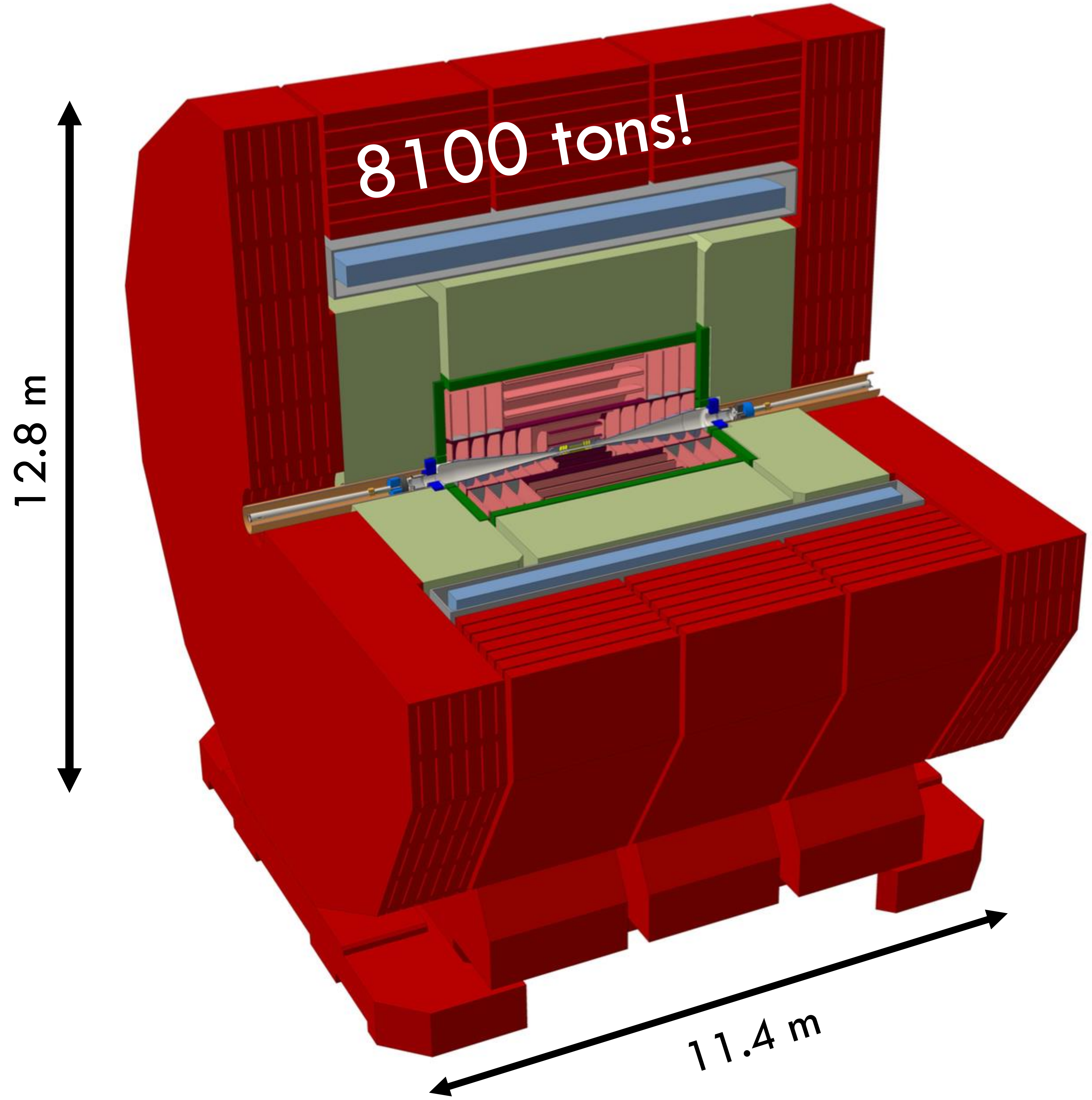




- Track momentum resolution: $\sigma_{p_T}/p_T^2 \sim 2\times10^{-5}\,\mathrm{GeV}^{-1}$
  - e.g. leptonic Z decays in ZH events, smuon endpoint
- Jet energy resolution: $\frac{\sigma_E}{E} \sim 3.5-5\,\%$
  - e.g. hadronic Z decays , W/Z/h di-jet mass separation
- Impact parameter resolution: $\sigma_{r\phi} = 5 \oplus 15/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}$
  - for flavor tagging and vertex reconstruction

- Angular coverage
  - Lepton identification in WW fusion events, missing energy
- Background suppression:
  - ~10/10/1 ns hit time-stamping in vertex/tracker/calorimeter
  - High granularity calorimeter

CLIC Detector Overview



- The CLIC detector is inspired by the **ILC detector designs**
- Low mass tracking system with separate vertex detector and tracker
- Fine grained calorimetry system (ECAL and HCAL) using particle flow
- Enclosed in a 4 T superconducting solenoid magnet (R_{in} = 3.4 m)
- Iron **return yoke** instrumented with **muon chambers**
- Complex forward region: LumiCal (luminosity monitoring), BeamCal (extended coverage)
- **Power-pulsed** operation (switch off between bunch trains)
- **Triggerless** readout

The CLIC Vertex Detector

Extremely low mass, 0.2 % X_0 per detection layer

- Remove cooling pipes, replace with ***forced air flow***
- Arrangement of the detector into ***double layers***, to allow sharing of support structure

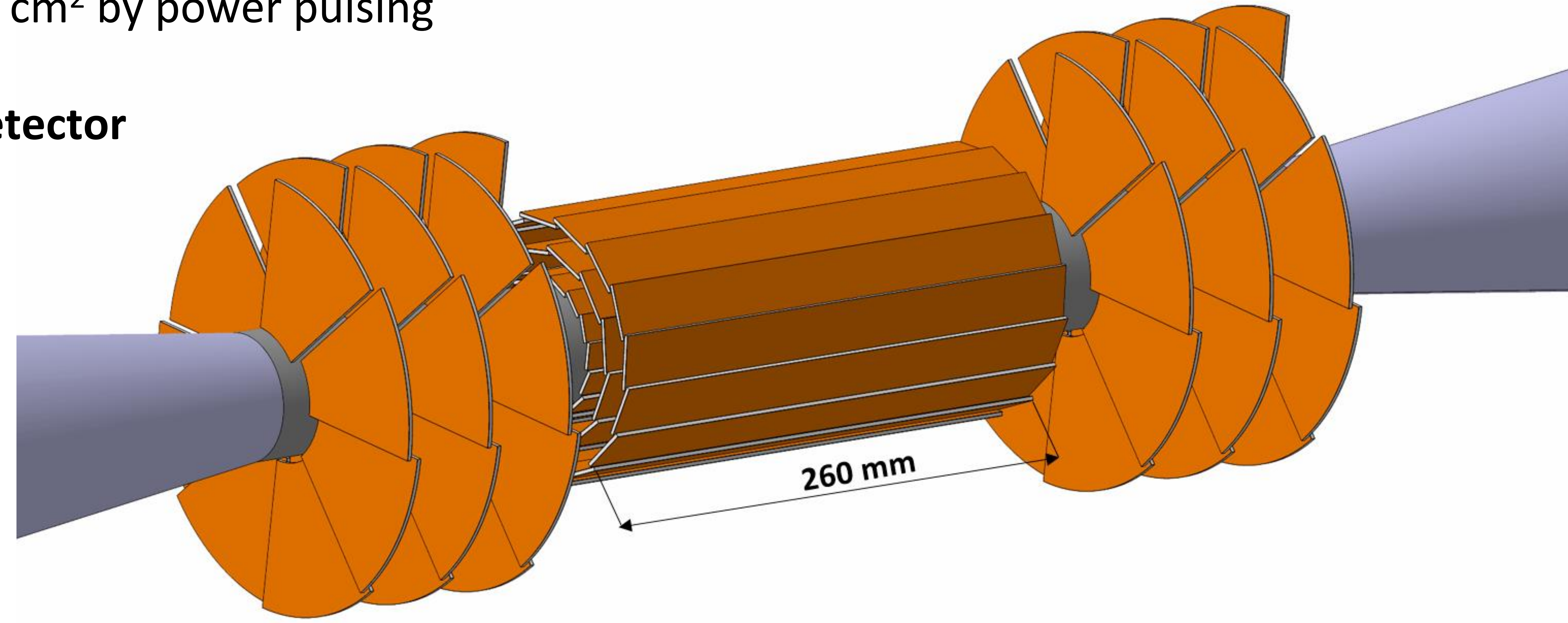
Demanding performance requirements

- A single **hit resolution** of ~3 µm for transverse IP resolution $5 \oplus 15/p[\mathrm{GeV}]$ µm
- **Fast signal** generation and time-stamping into 10 ns slices to reduce background
- **Low power** consumption of 50 mW / cm^2 by power pulsing

Current technology baseline **hybrid pixel detector**

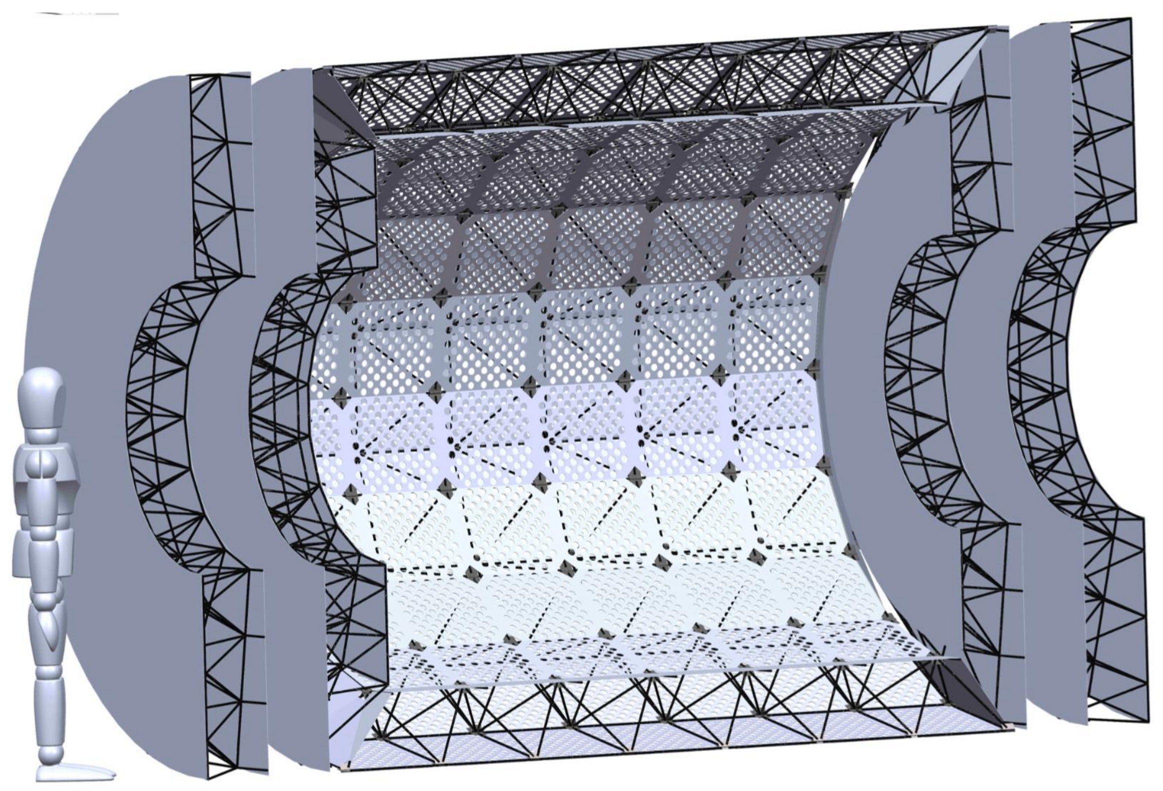
- Pixel size of 25 µm × 25 µm
- ASIC thickness of 50 µm
- sensor thickness of 50 µm

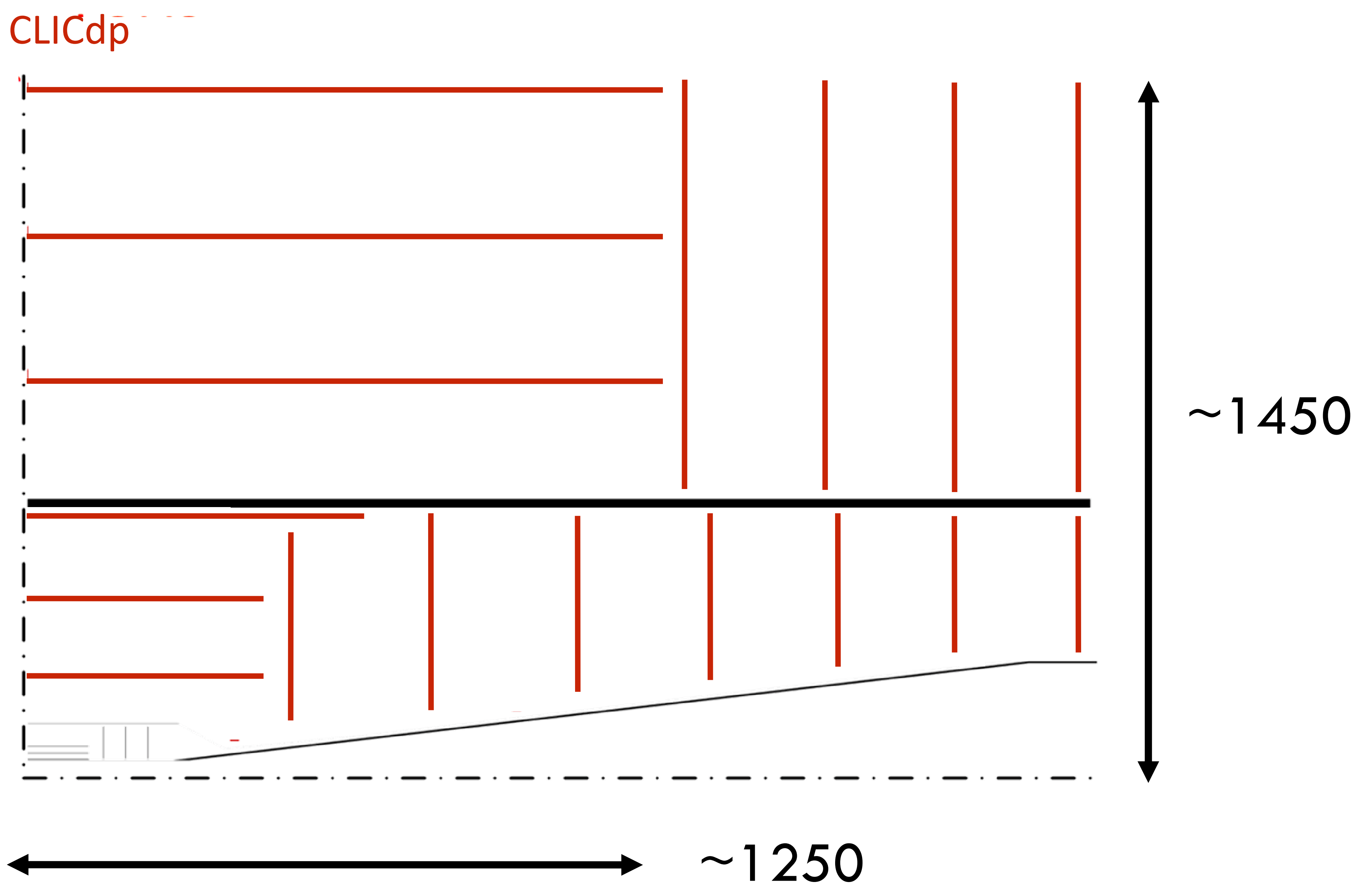
Radiation level 10^4 lower than at LHC!



The CLIC Tracker

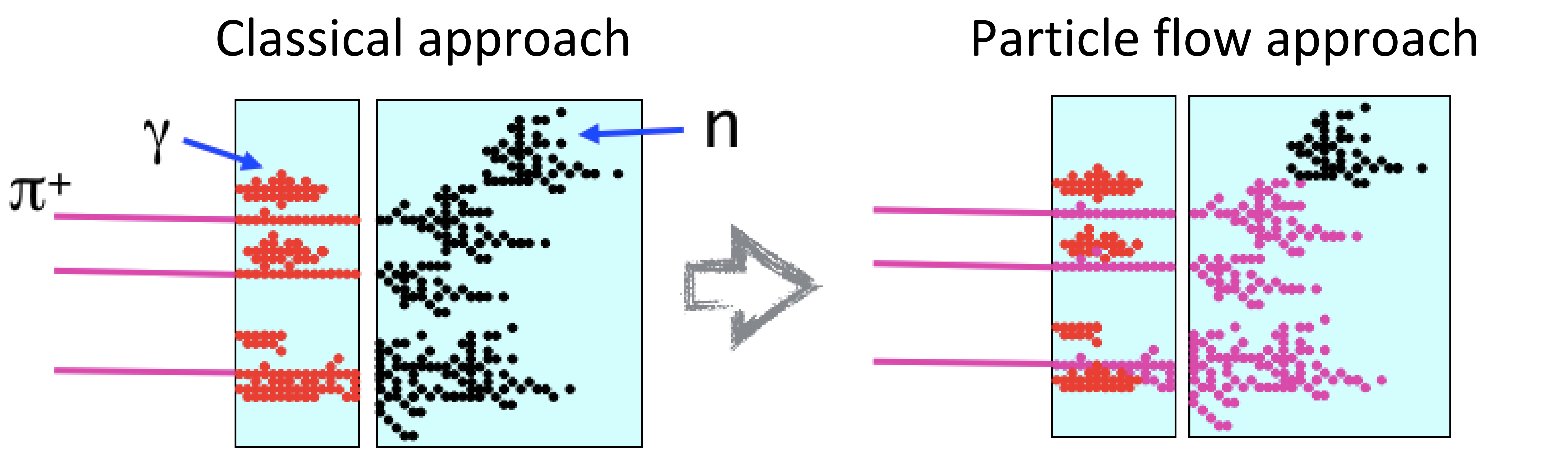
- Large tracking volume proposed:
  - area of silicon ~100 m^2
- Material budget for the tracker is 1-2 % X_0 per layer
  - Mechanical challenge!
  - Power budget of < 150 mW / cm^2
  - Air cooling not feasible in such a large volume -> water cooling
  - Single hit resolution of 7 µm in the bending plane
  - Momentum resolution of $\sigma_P / p_T^2 \sim 2 \times 10^{-5}$ GeV^{-1}
- Current technology baseline monolithic CMOS
  - Long pixels with maximum size of 30 µm × (1-10) mm
  - Sensor thickness of 200 µm





Particle Flow Calorimeters

Goal: Jet energy resolution 4-5% *(at ATLAS 5% JER for E > 1 TeV)*



$$E_{JET} = E_{ECAL} + E_{HCAL}$$

$$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$$

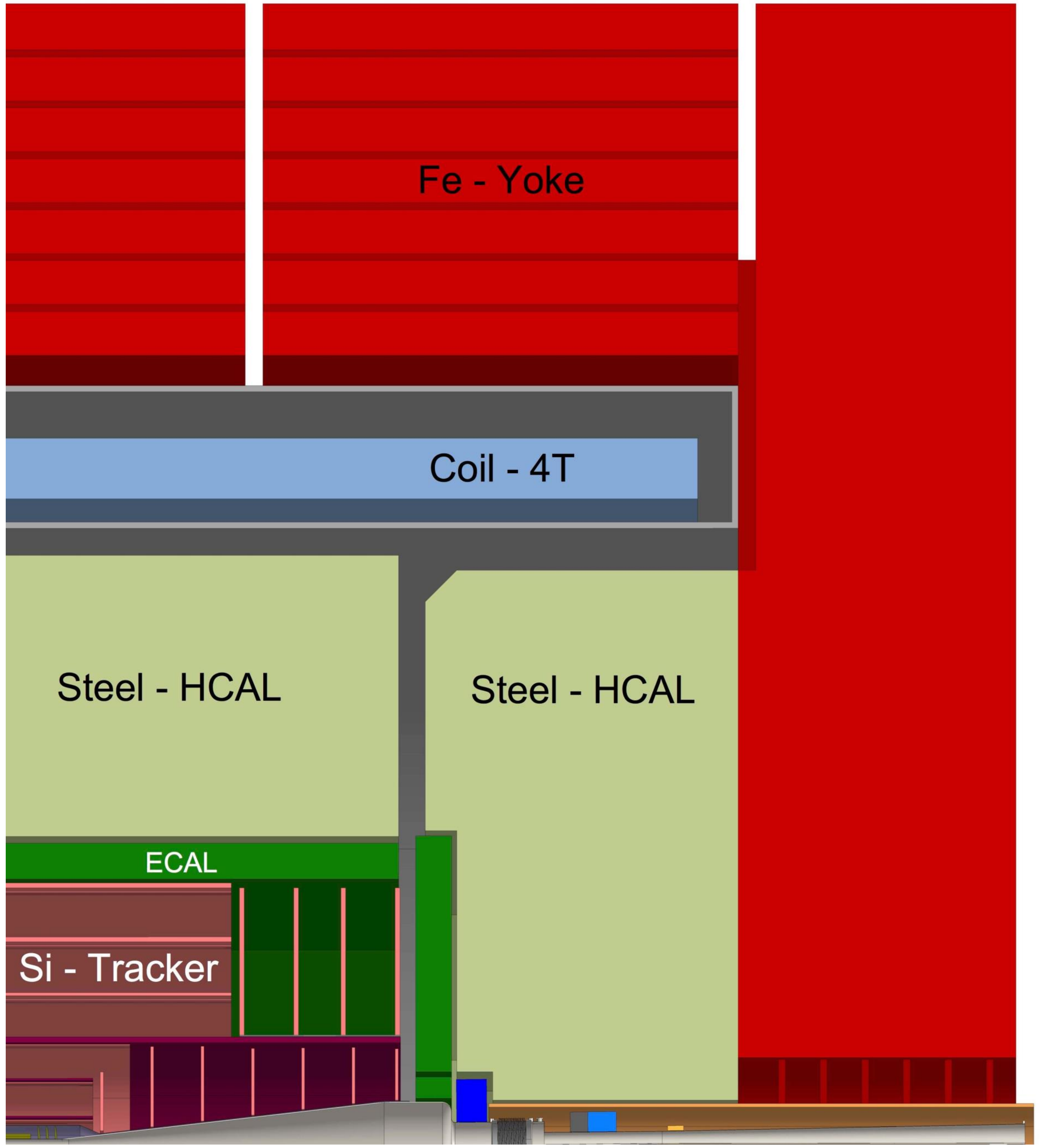
Typical jet composition:
- 60% charged particles
- 30% photons
- 10% neutrons

Always use the best info you have:
- 60% => tracker 🙂 🙂
- 30% => ECAL 🙂
- 10% => HCAL 🙁

- **highly granular calorimeters** to resolve deposits from different particles and
- **sophisticated software** to make correct associations

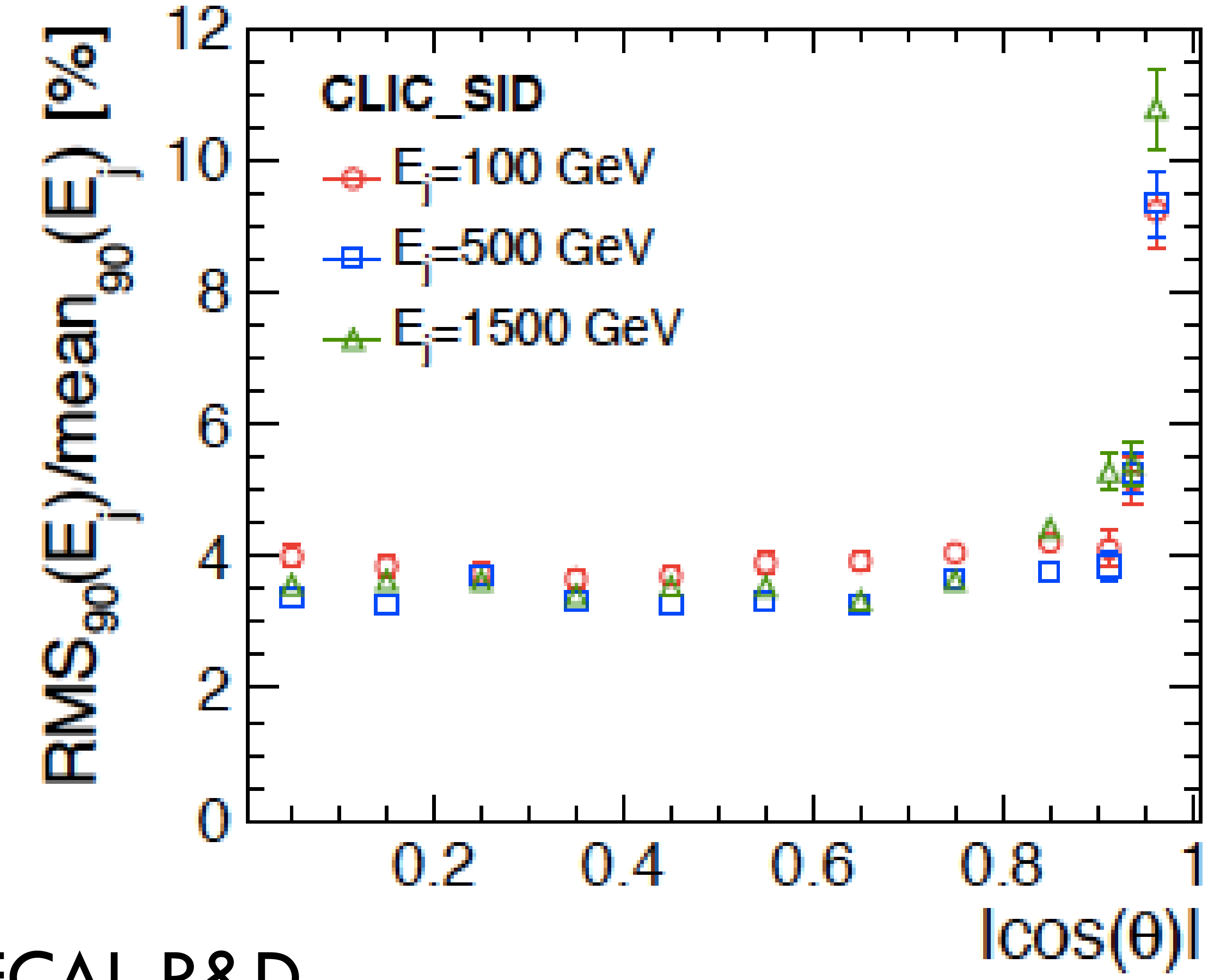
➢ joint efforts in linear collider community (CLIC, ILC, FCCee, CALICE, etc.)!

The CLIC Calorimeter



- Jet energy resolution drives the overall detector design
  - Fine-grained calorimetry + Particle Flow Analysis (PFA)

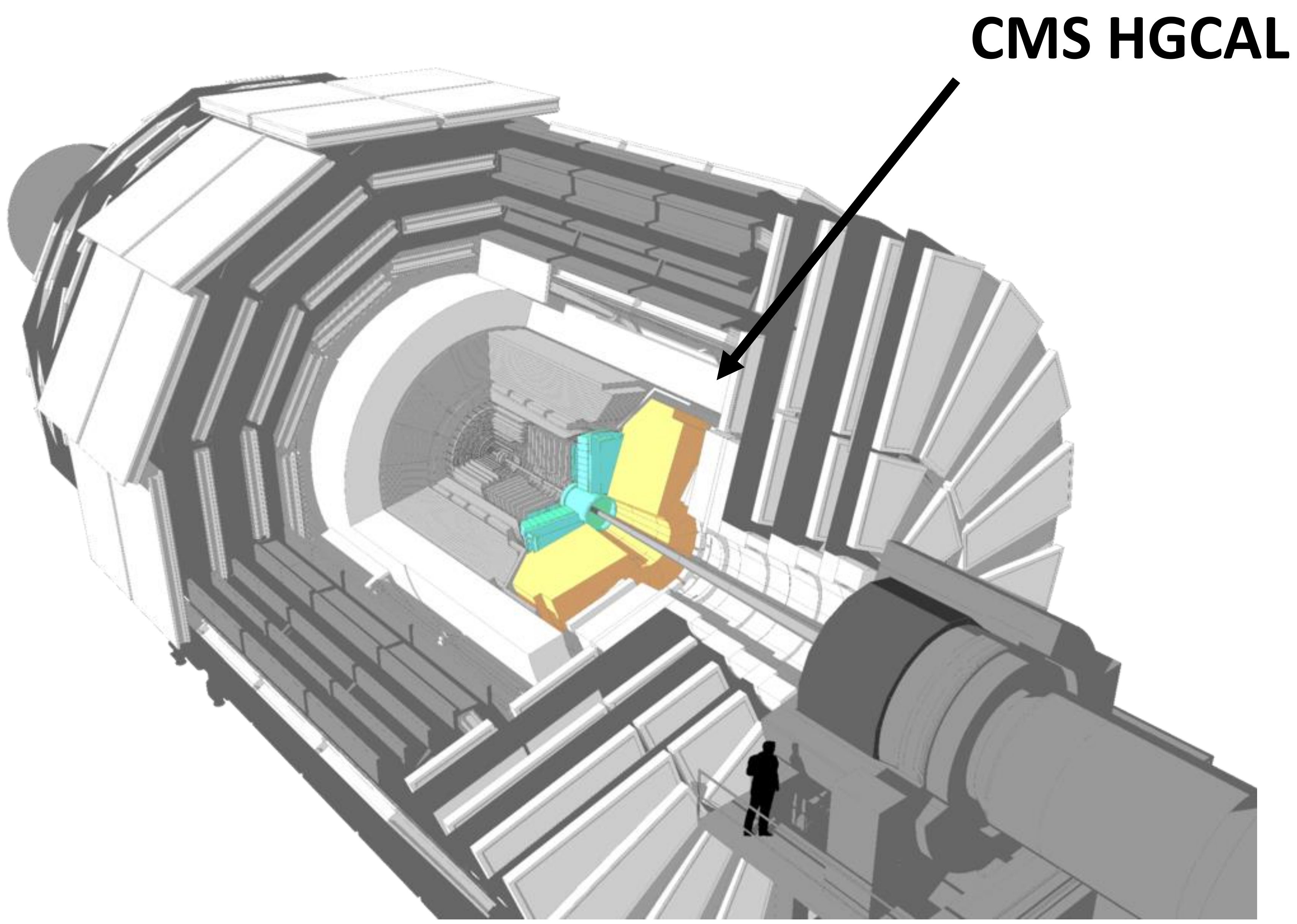
- ECAL - 40 layers of W absorbers interleaved with Si sensors of 5x5 mm^2 (corresponding to 23 X_0)
- HCAL - 60 layers of steel absorbers interleaved with scintillator tiles of 30x30 mm^2

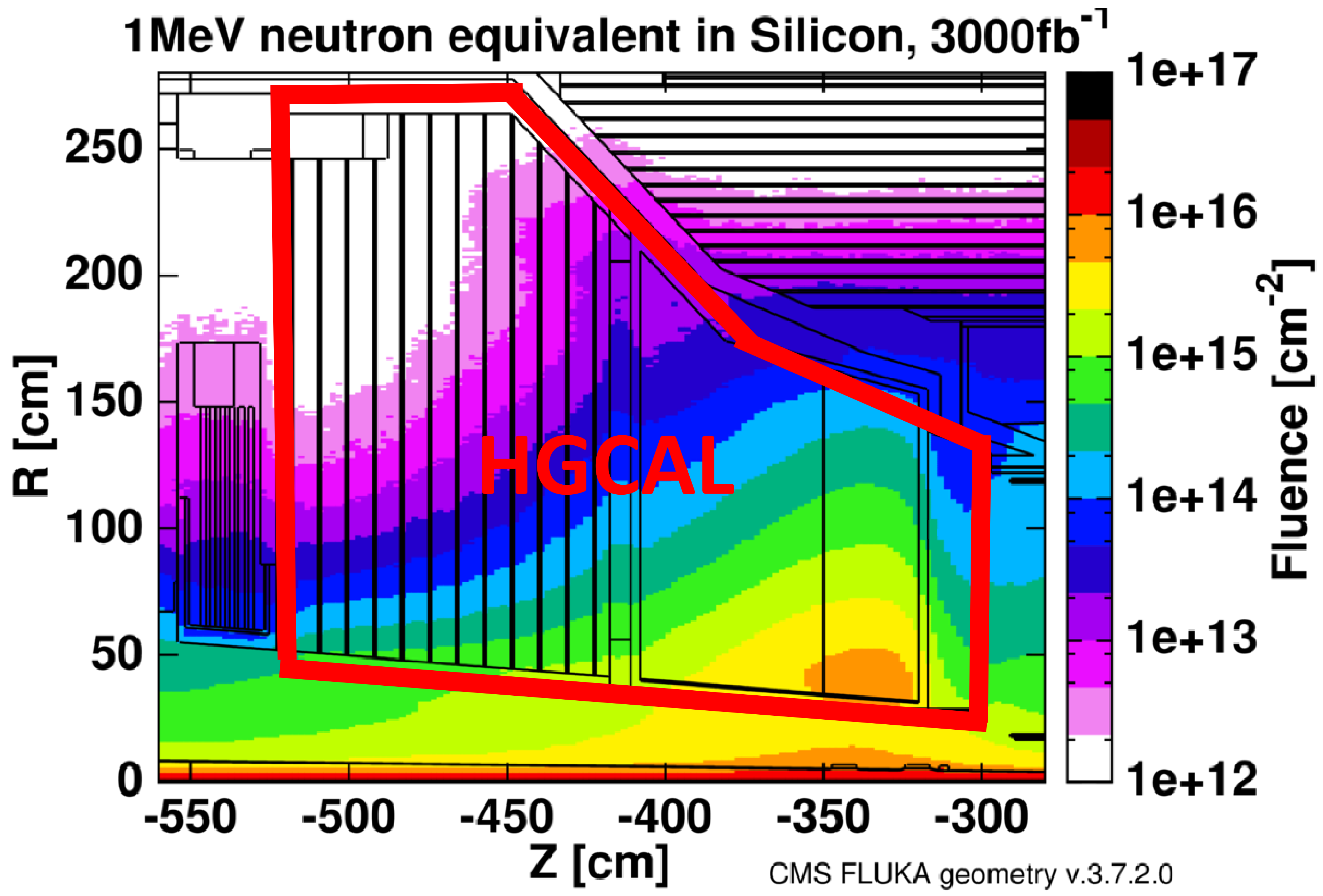


➢ CLICdp contributes to CALICE and FCAL R&D
  - have constructed and tested fine-grained SiW ECALs
  - CLICdp now also contributes to the CMS High Granularity Calorimeter (HGCAL) upgrade!

CMS HGCAL as "prototype" for a CLIC calorimeter!

The CMS HGCAL Project





Answer to HL-LHC challenges:

- **Pile-up:** up to μ=200
  timing information valuable for mitigation
- **Radiation exposure:** up to 10^{16} neq/cm^2
  Si will studied and under control for high fluences

➢ Replace entire endcap calorimeter, with a radiation-hard, fast timing, **High Granularity Calorimeter (HGCAL)**

Project details:

- HGCAL for particle flow has been intensively studied by CALICE
- Active development in
  - TDAQ, electronics architecture
  - Particle flow and physics performance
- TDR by end of 2017

Technical proposal: https://cds.cern.ch/record/2020886/files/LHCC-P-008.pdf

The HGCAL Layout

Active elements:

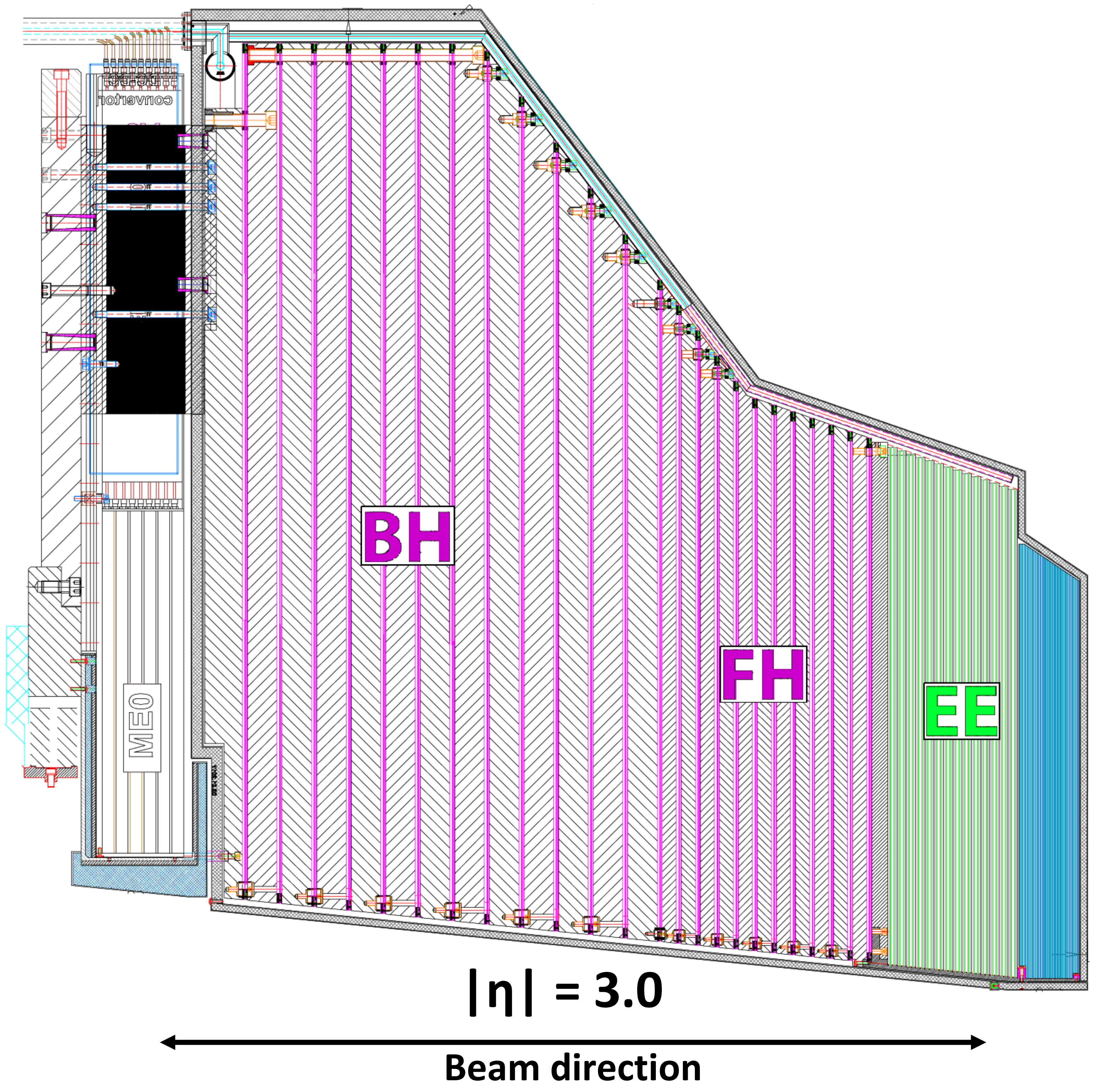
- Hexagonal Si sensor modules consisting of several 100 hexagonal sensor cells
- Cassettes”: multiple modules mounted on cooling plates with electronics and absorber
- Scintillating tiles with SiPM readout in lowradiation regions

Key parameters:

- 600 m^2 of silicon
    - hexagonal shape saves space on wafer
- Power at end of life ~60 kW per endcap
    - 25% due to leakage current
- CO_2-cooled operation at -30°C

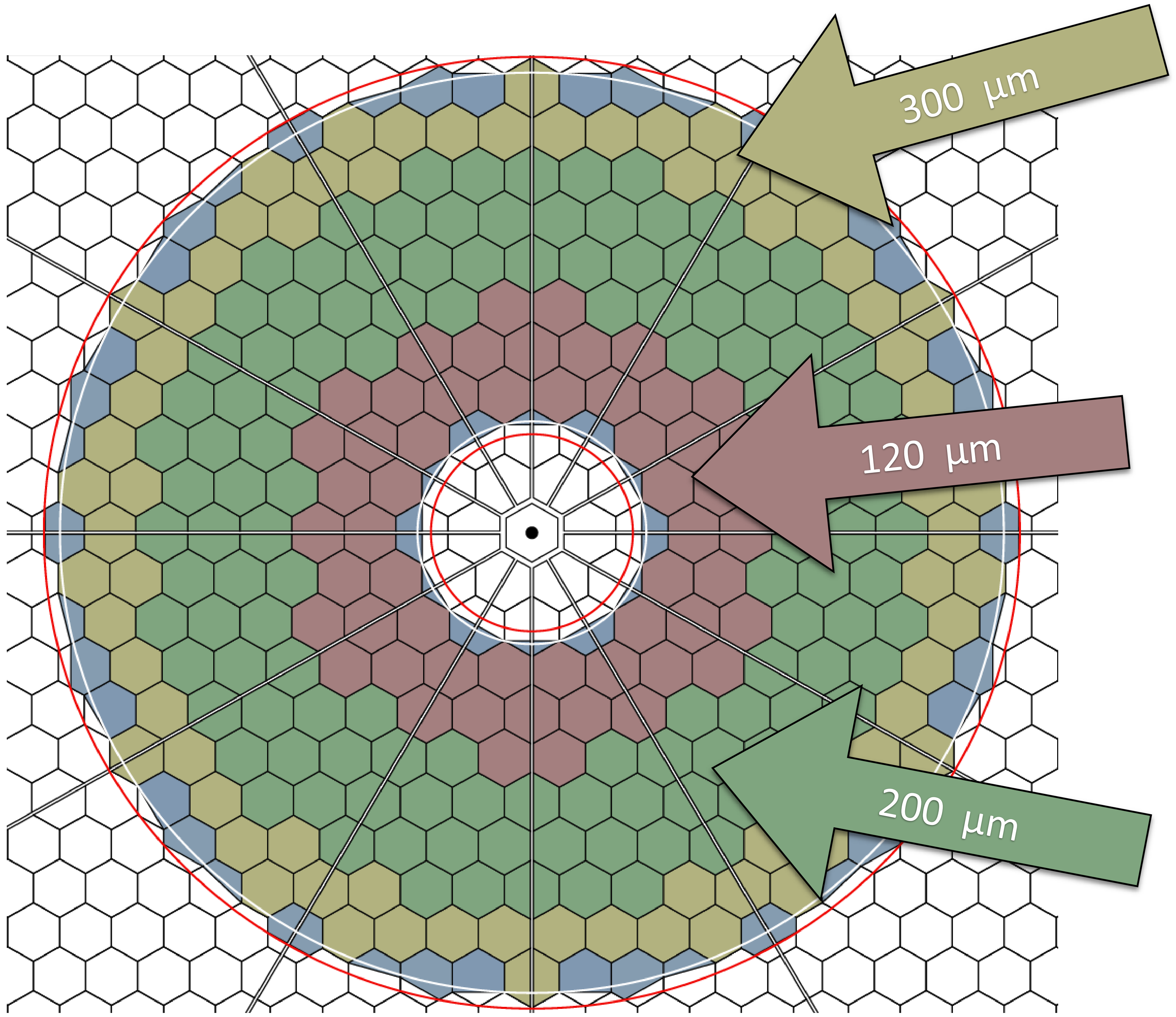
Main components:

- EE – Si, Cu & CuW & Pb absorbers: 28 layers: 25 Xo + ~1.3 λ
- FH – Si & scintillator, steel absorbers: 12 layers: ~3.5 λ
- BH – Si & scintillator, steel absorbers: 11 layers: ~5.5 λ

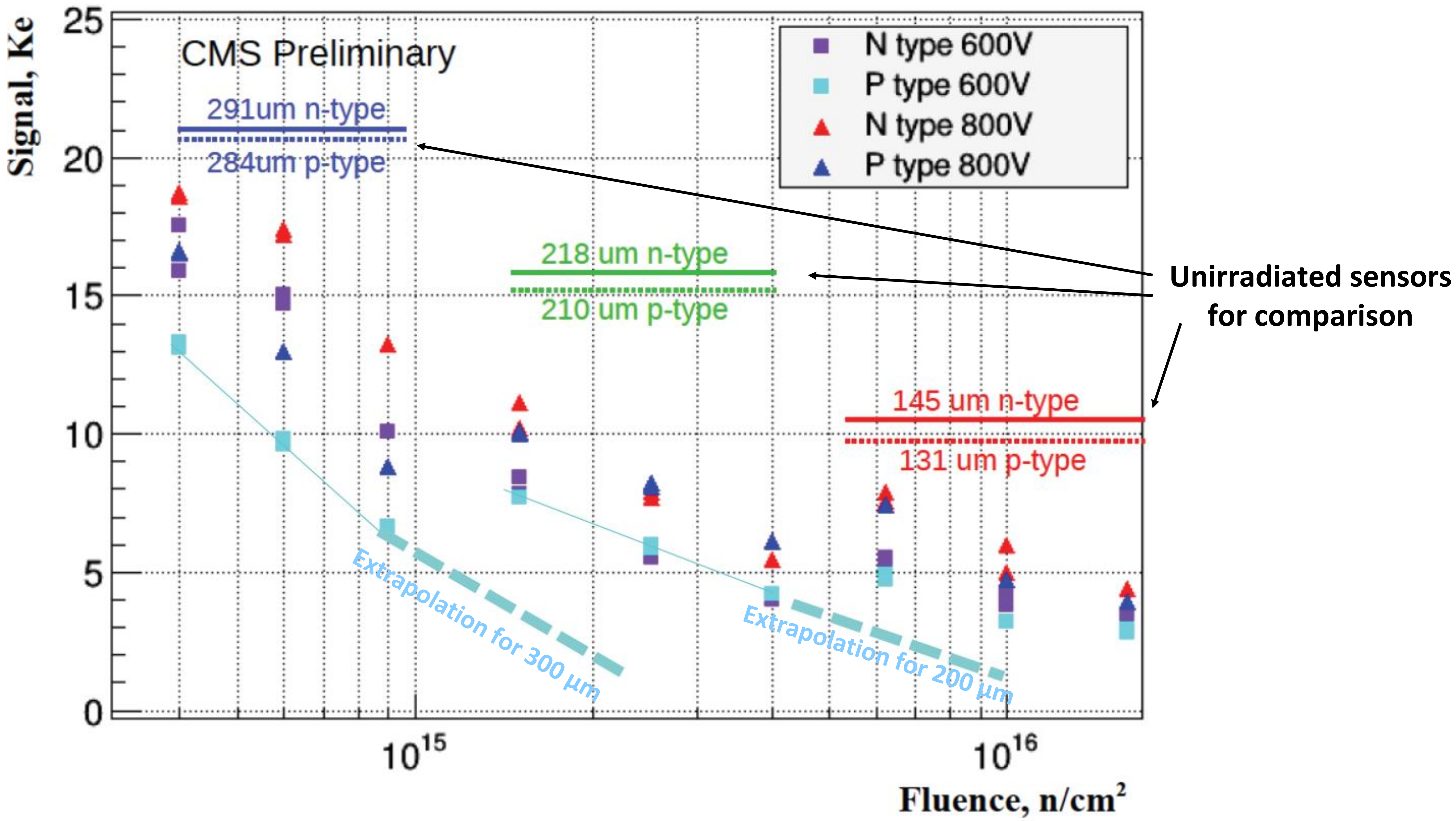


EE: Electromagnetic Endcap
FH: Front Hadronic Calorimeter
BH: Back Hadronic Calorimeter

The HGCAL Design

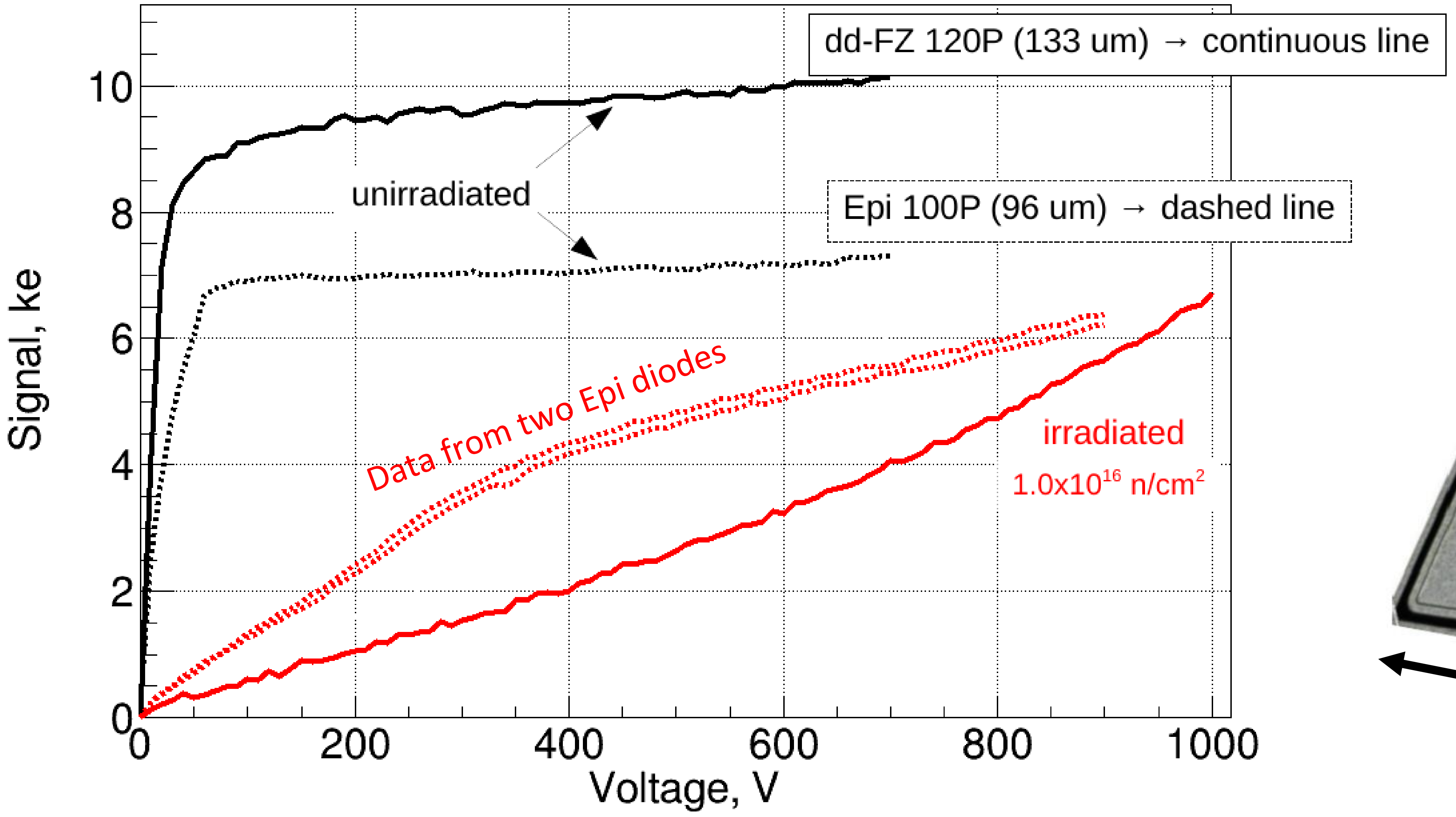


Full HGCAL cut in x-y plane

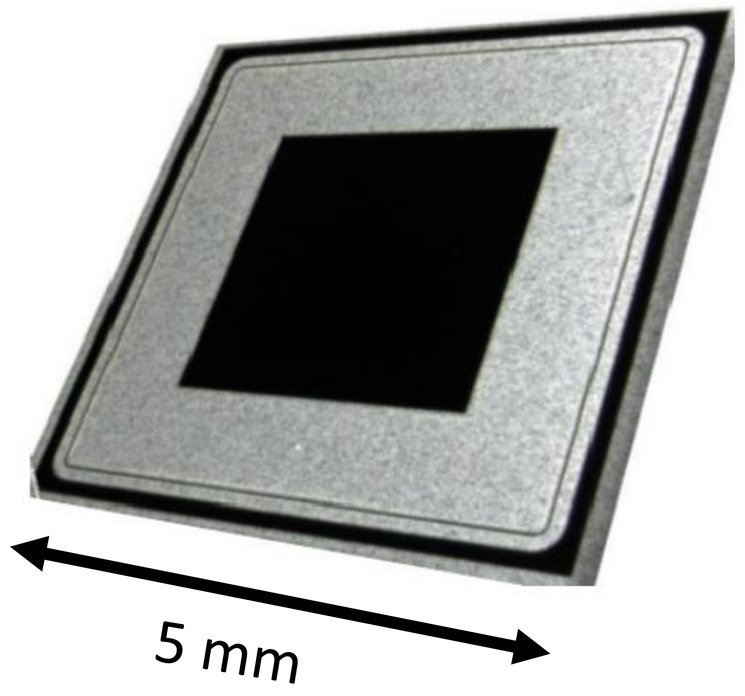


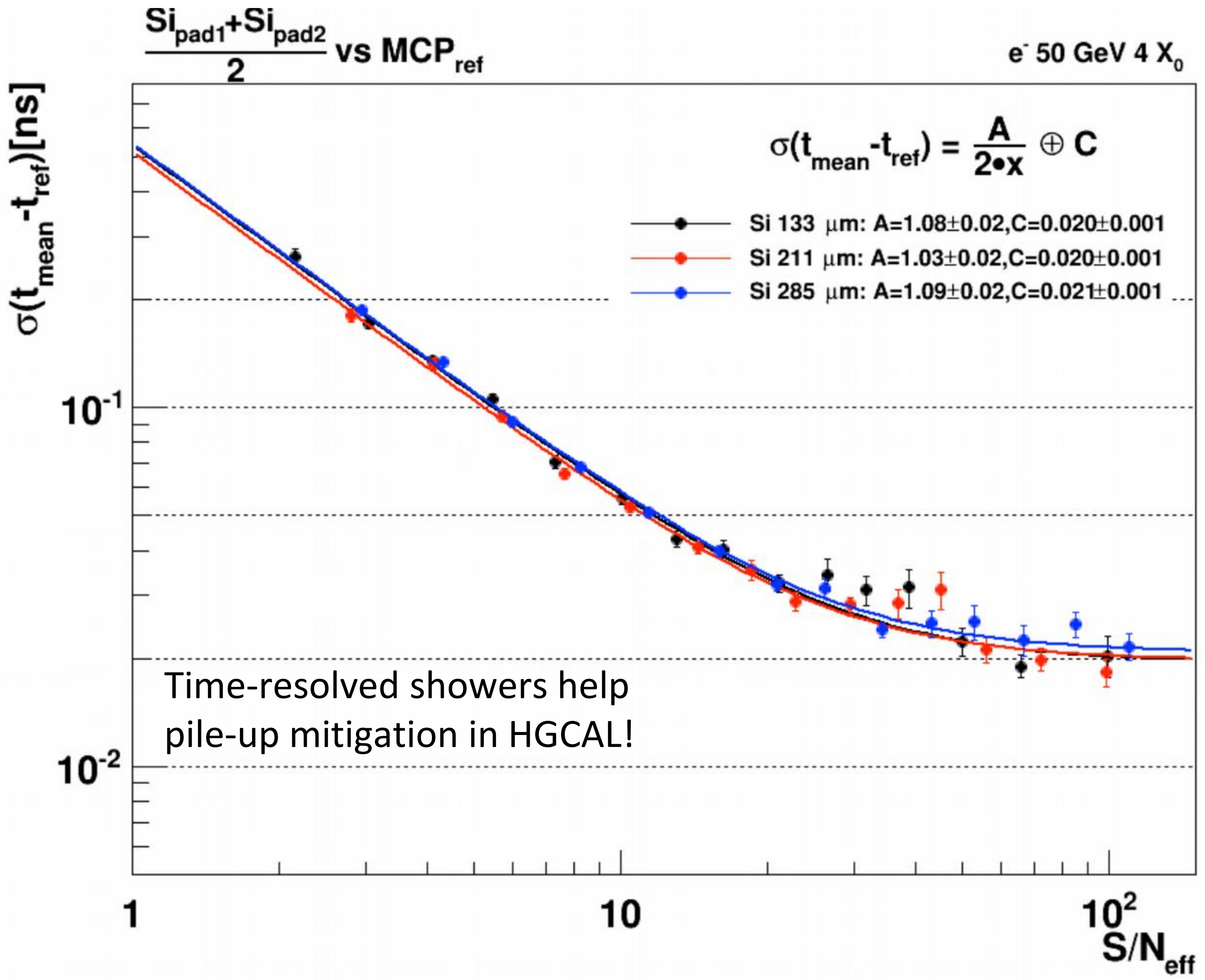
- Thinner Si sensors for high fluence regions → better signal at high fluence
  - high-η region: sensors with **120 µm** active thickness
  - lower-η regions: **200 µm** & **300 µm** active thickness
- Smaller cell size in central region → less occupancy, less noise

Single diode Tests



HPK





Measured properties:

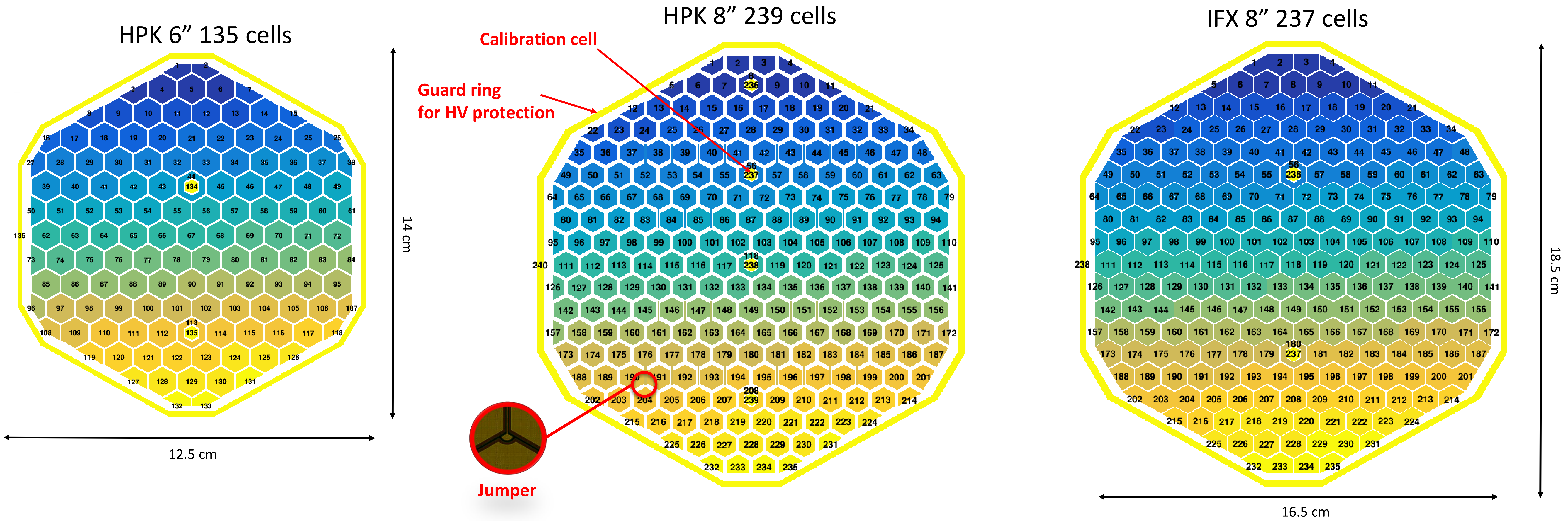
- Bulk current → power consumption, noise
- Capacitance
- CCE with laser signal
- MIP studies with beta source
- Timing performance (test beam)
- Effects of annealing

First irradiation results:

- Good signal at 1x1016 neq/cm2 within voltage range!
- Single MIP signal is resolvable from noise
- Intrinsic timing resolution of
- < 50 ps for S/N > 10
- ~20 ps for S > 20 MIPs

CCE: Charge Collection Efficiency
MIP: Minimum Ionizing Particle
dd-FZ: deep diffusion Float Zone
Epi: Epitaxial
HPK: Hamamatsu
MCP: Microchannel Plate Detector

Sensors for HGCAL



Detector optimization ongoing:

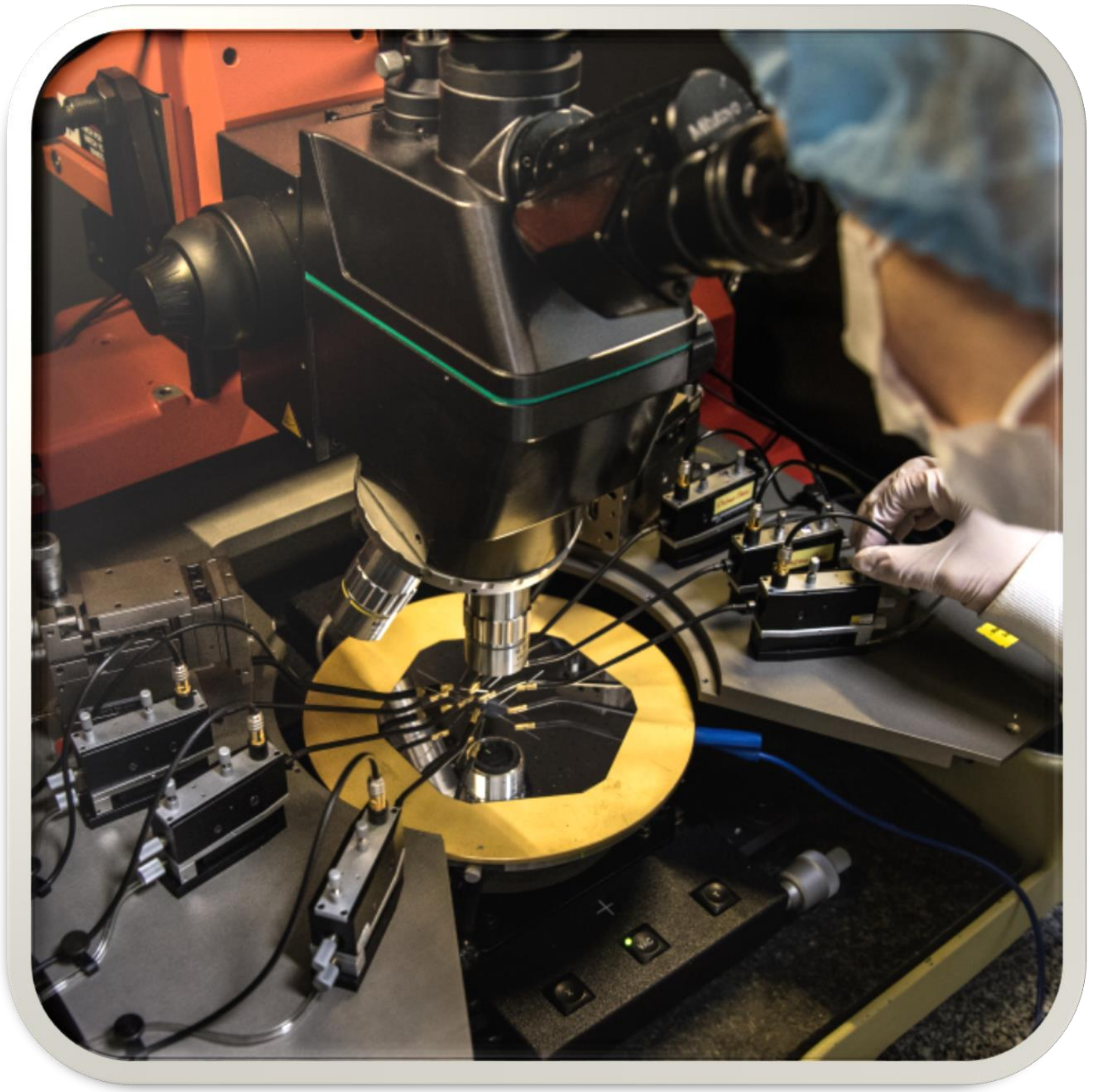
- Wafer size (6” or 8”)
- Contact pad layout for wire bonding (e.g. jumper cells)
- Sensor type (n-in-p or p-in-n)
- Interpad distance

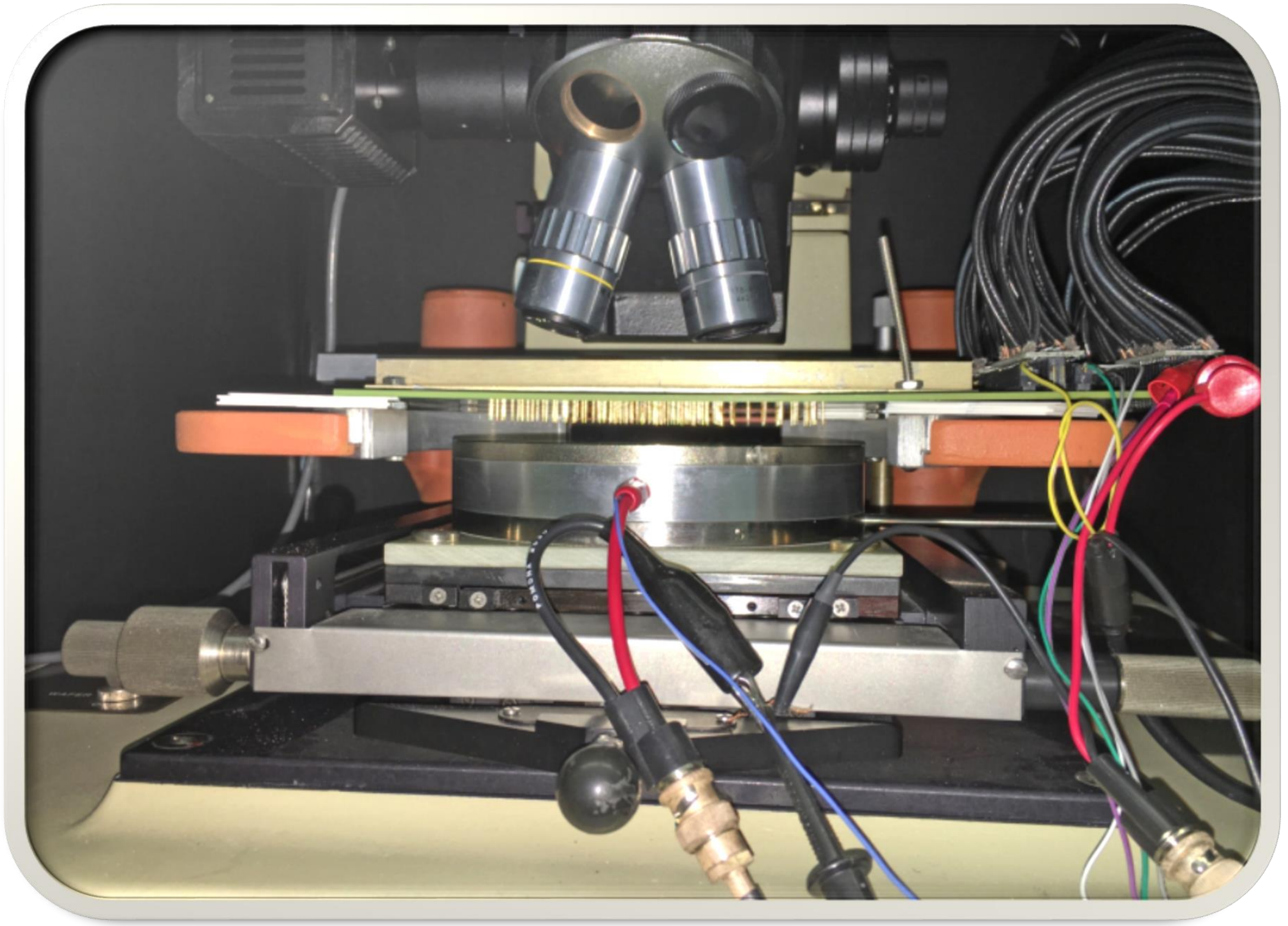
Ongoing activities:

- (Automated) sensor tests
- Design studies for TDR
- p-stop layout validation
- Radiation testing

HPK: Hamamatsu
IFX: Infineon

Probe Stations Measurements





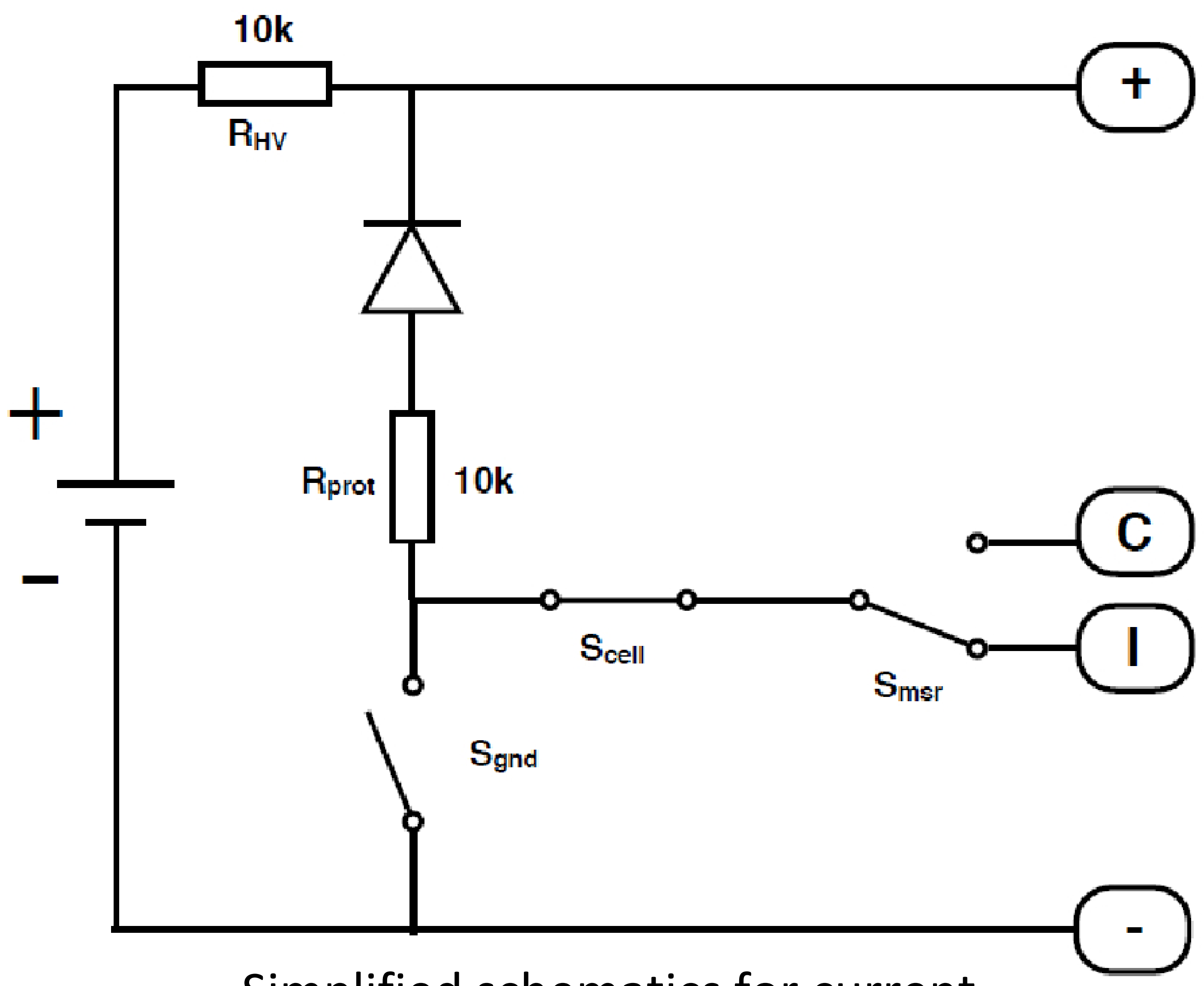
Probe needle measurements

- ✓ Very flexible
- ✗ Needle placement is time consuming
- ✗ Need to bias also six neighbours cells for reliable measurement

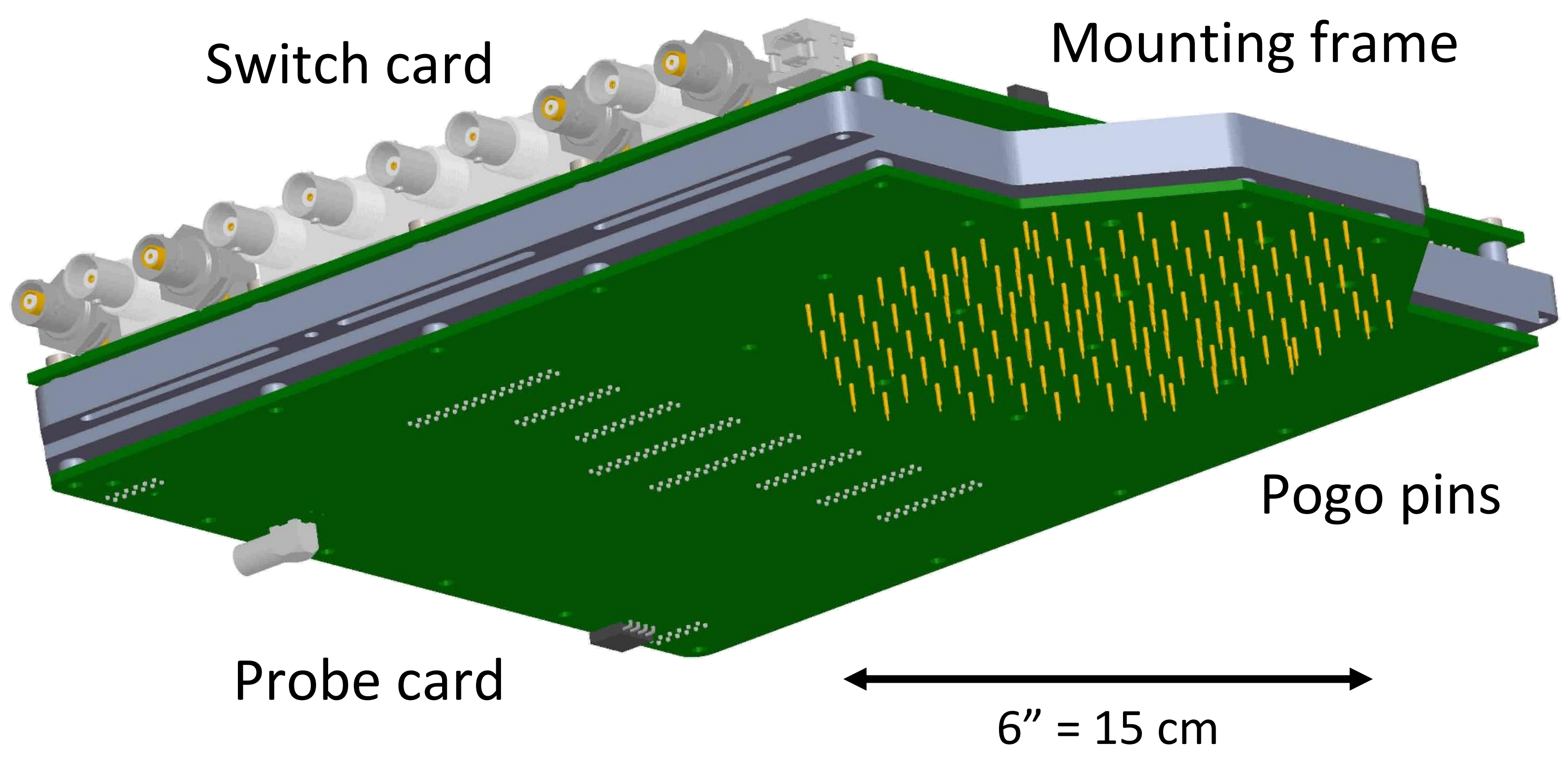
Probe card approach

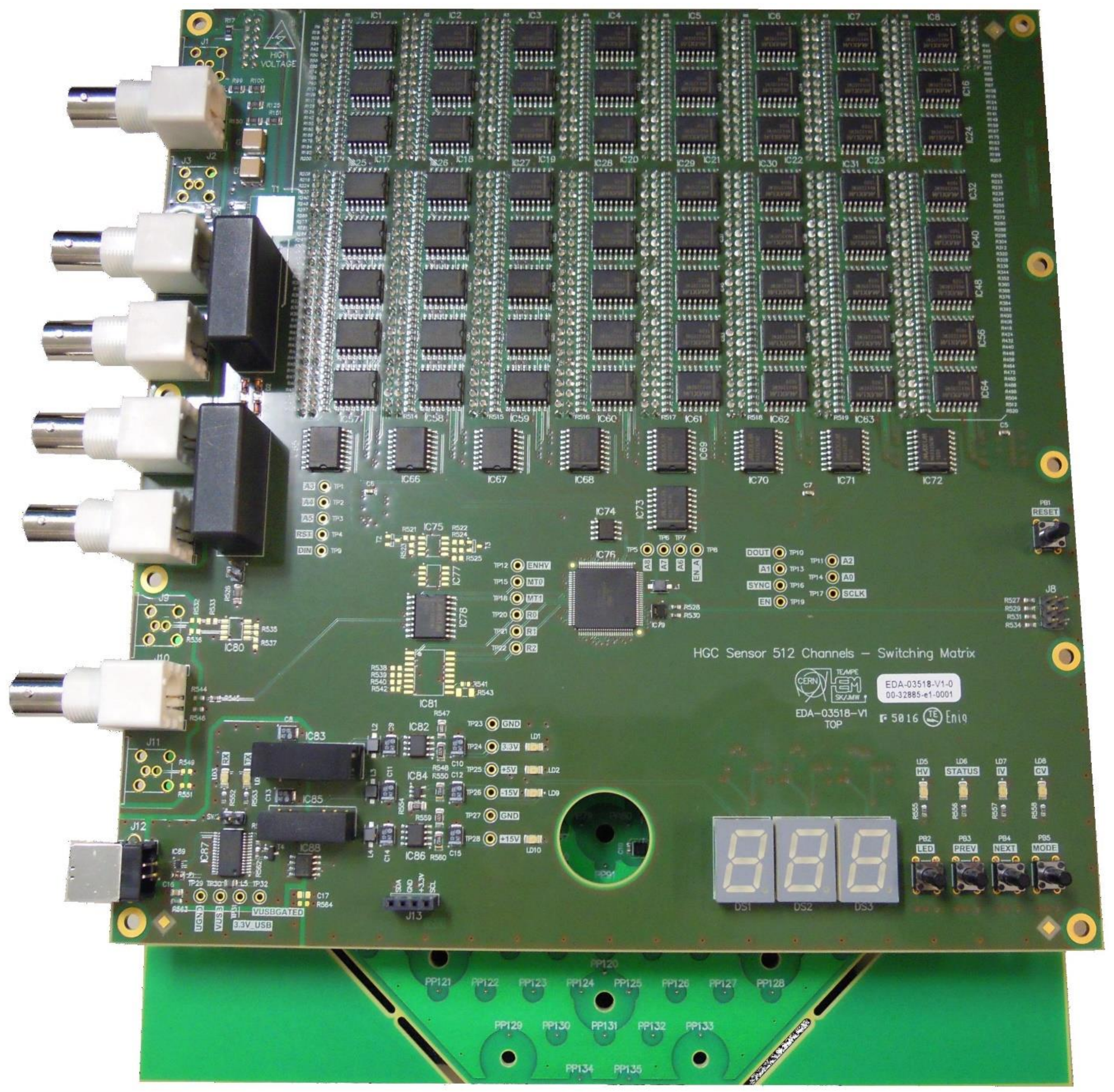
- ✓ Contact all cells with spring-loaded pins
- ✓ Alignment and contact done once for full sensor
- ✓ All neighbor cells biased (realistic test conditions)
- ✓ Automatic switching between cells (switching unit)
- ✗ One probe card each per sensor layout

The Probe- and Switch Card



Simplified schematics for current measurement



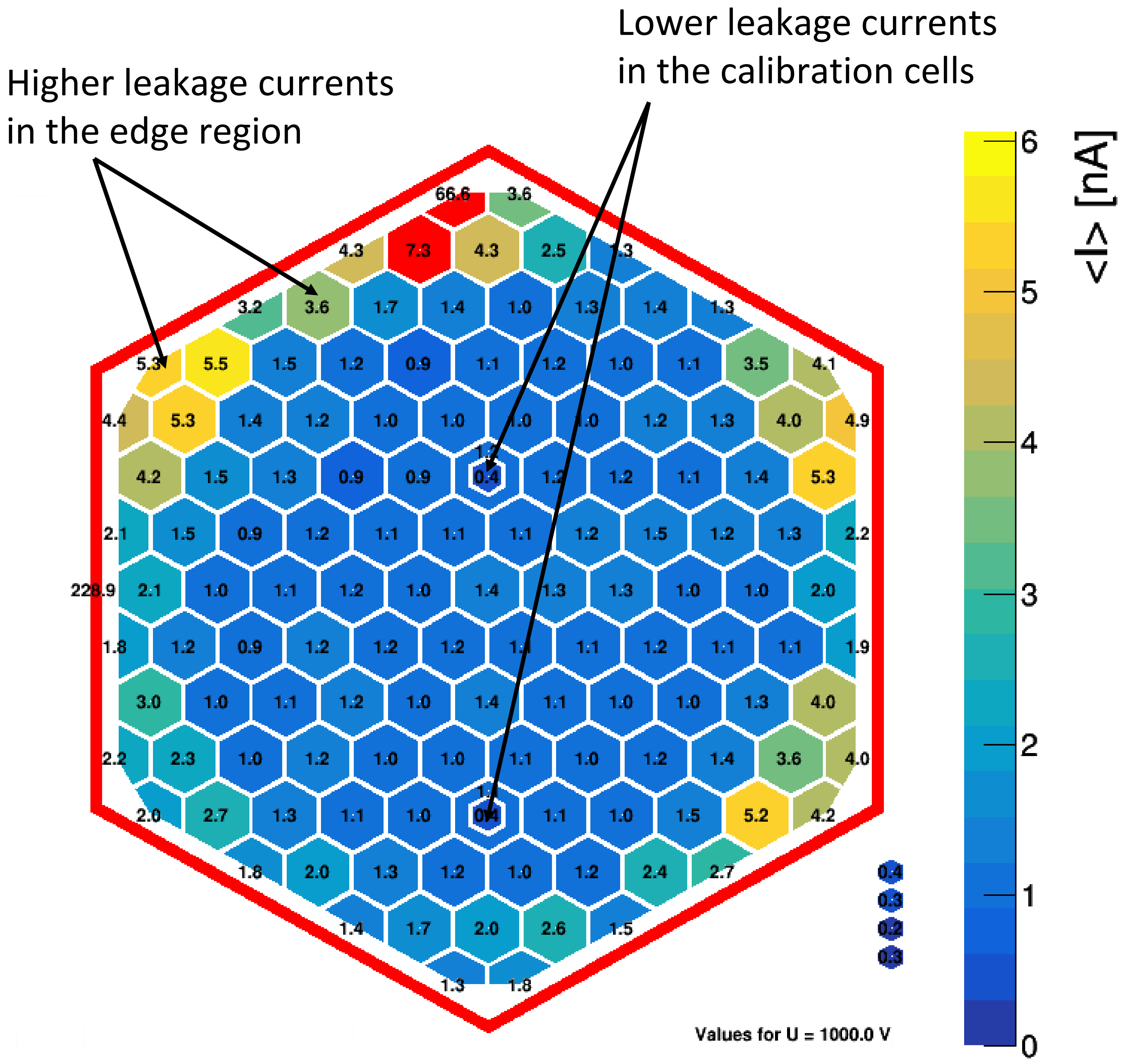


- Test up to 512 channels
- Uniform contact through spring-loaded pins (pogo pins)
- Low parasitic capacitances and leakage current

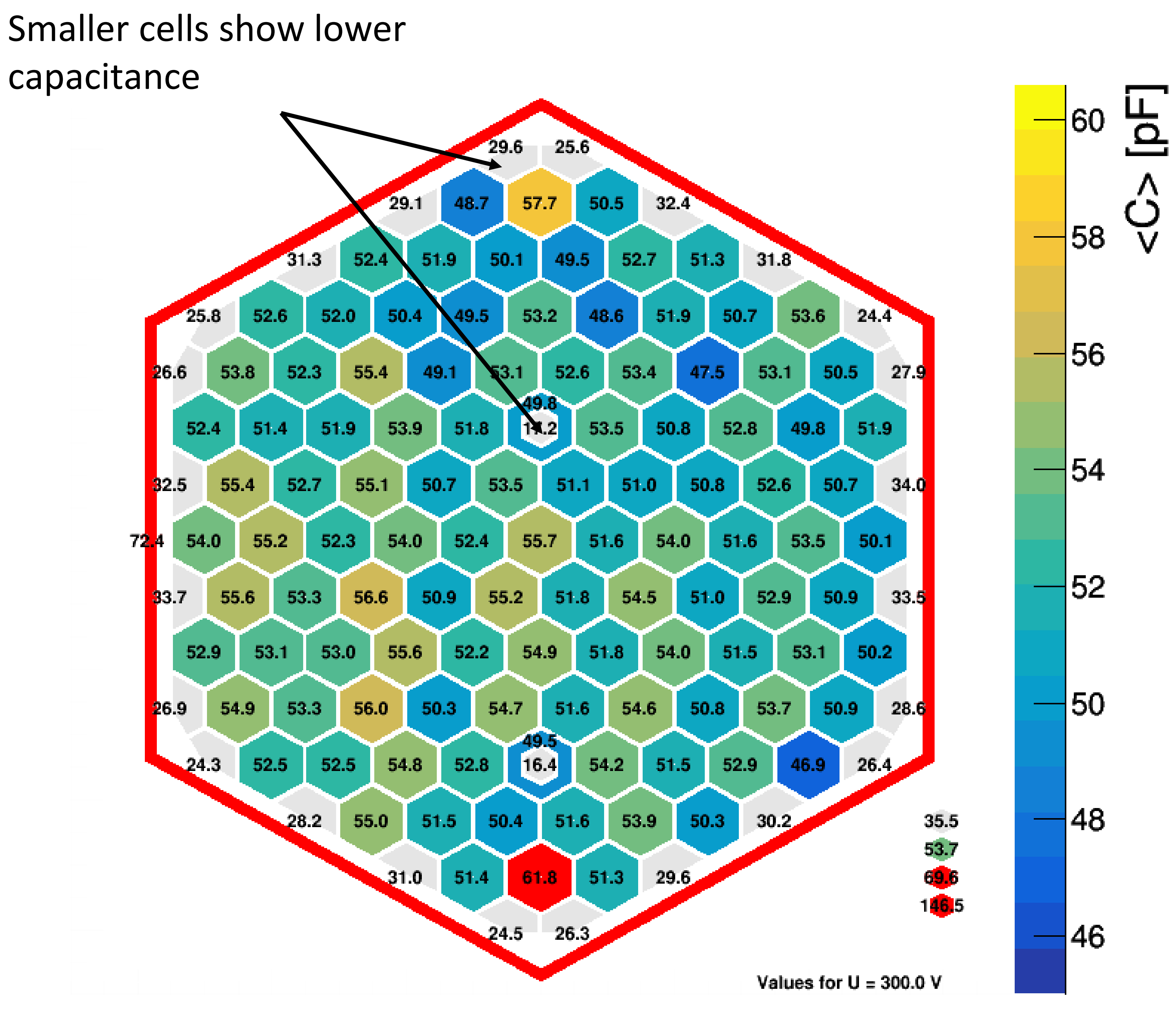
- Newly designed switching matrix placed as a plugin card
  - Firmware is finalized, integration in DAQ framework ongoing

Full Wafer Measurements

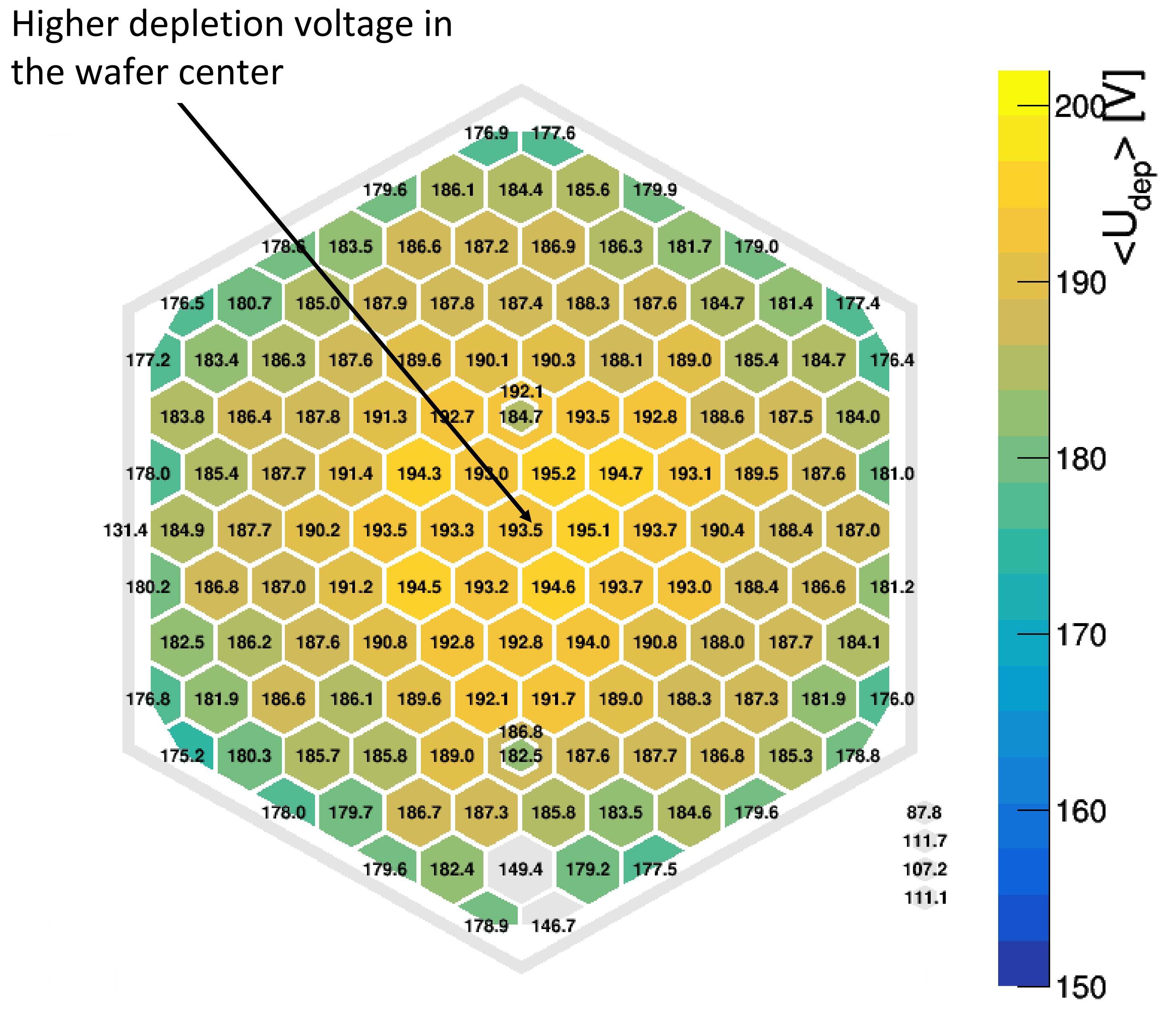
Leakage current



Capacitance



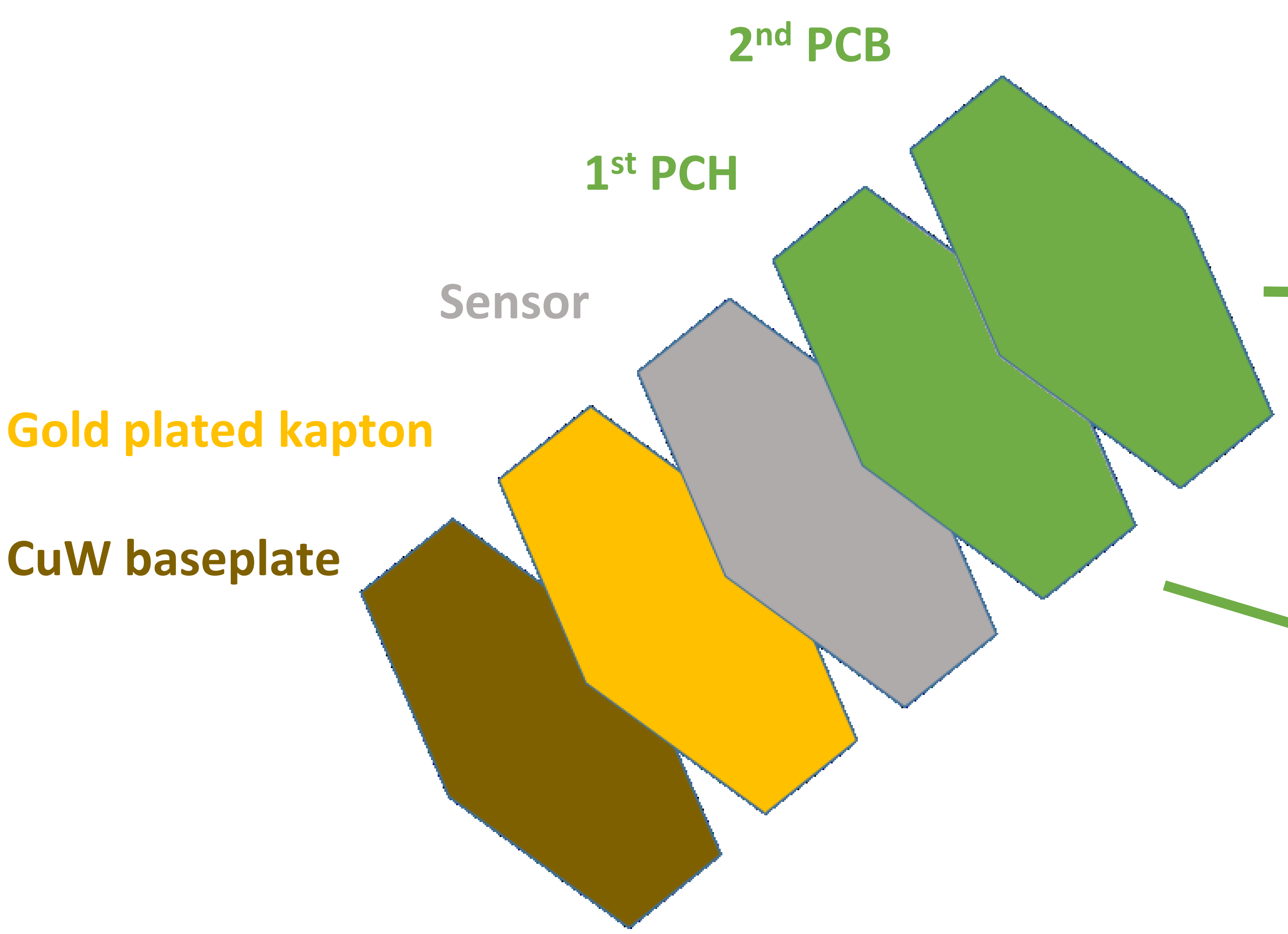
Depletion voltage

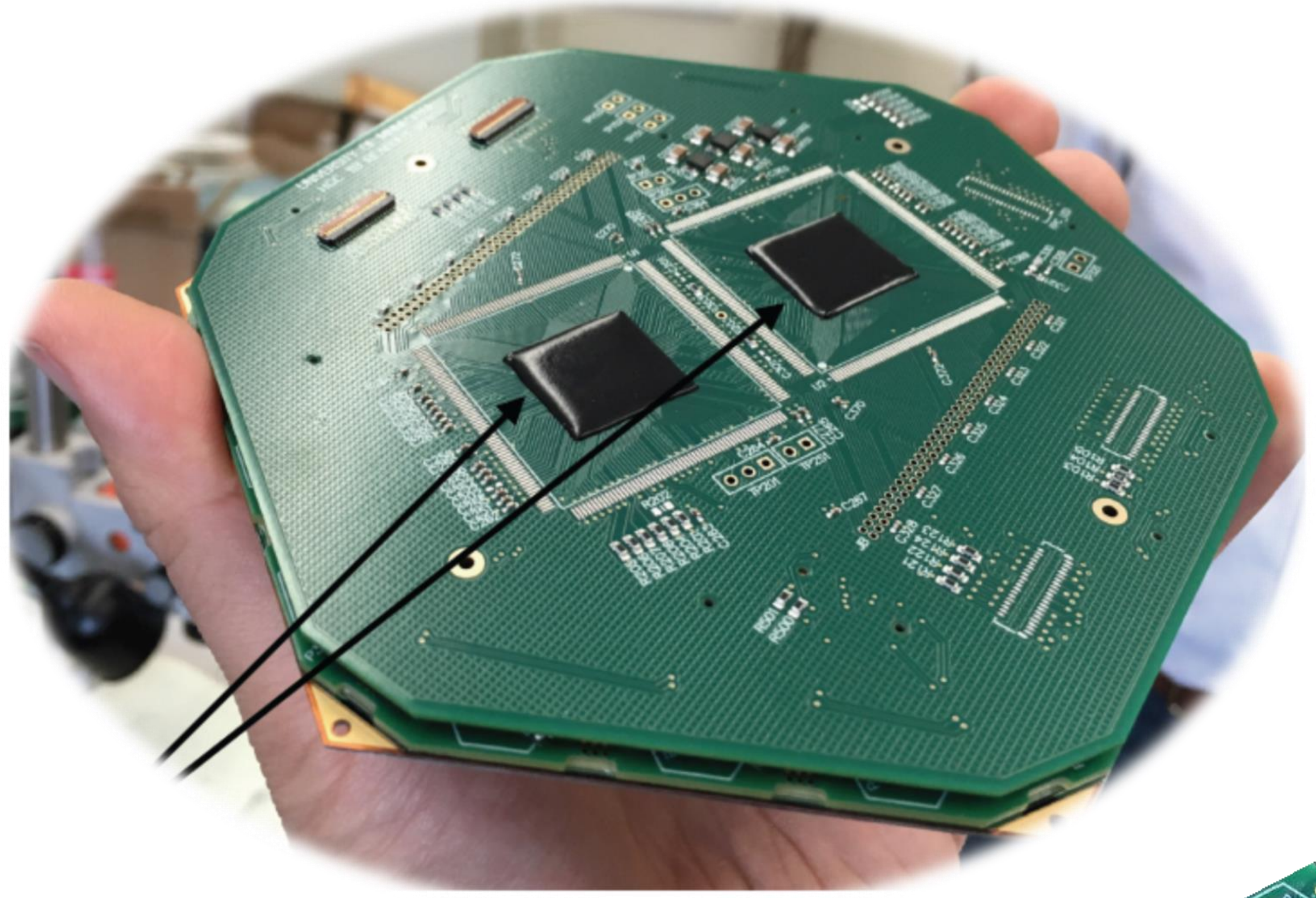


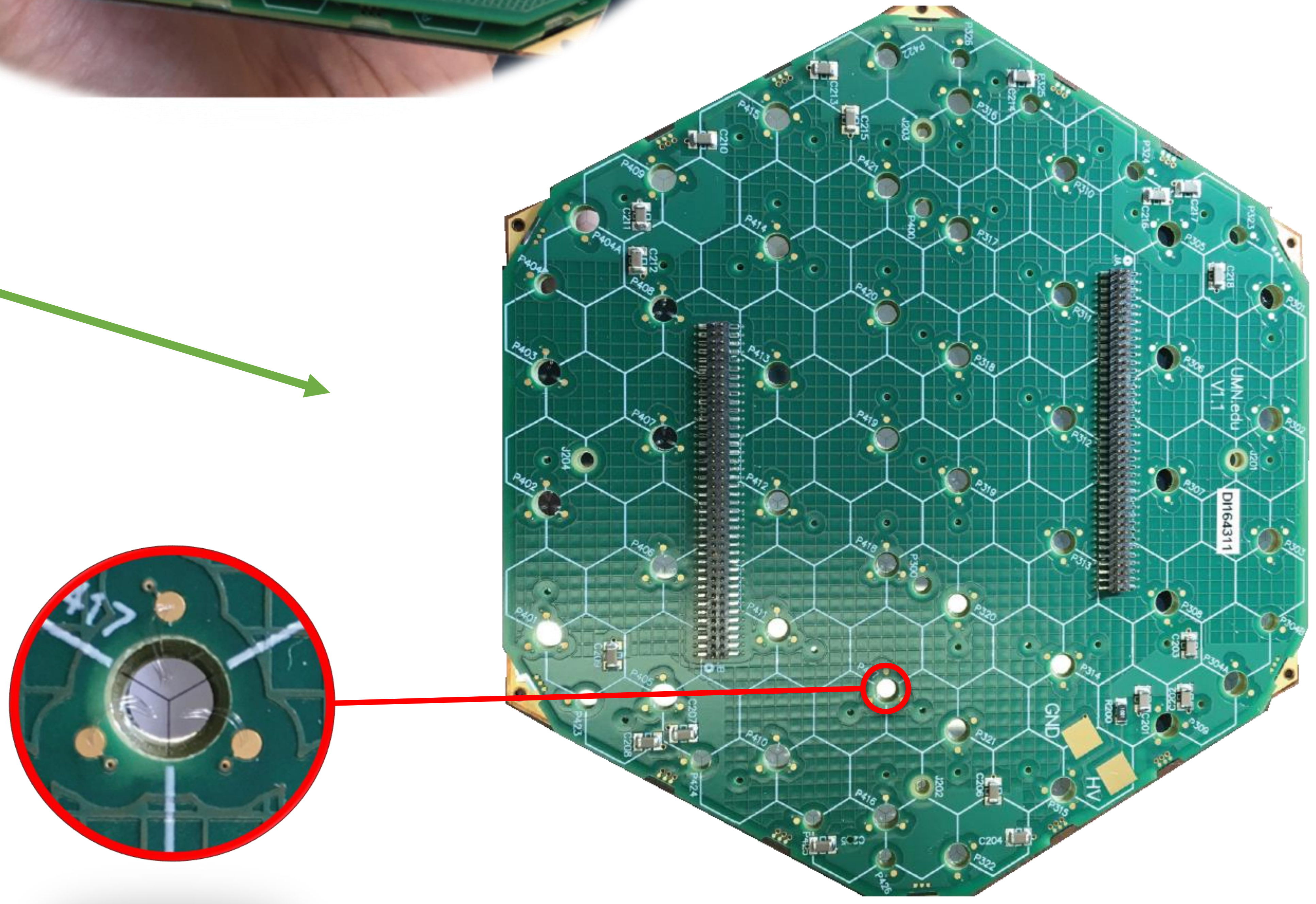
- Detector conditions: all cells biased by probe card
- Excellent performance of the tested wafers
  - Behavior as expected for IV and CV measurements
  - No breakdown until 1000 V bias voltage observed among all tested sensors

CERN laboratory is set up and ready for testing!

Modules for HGCAL

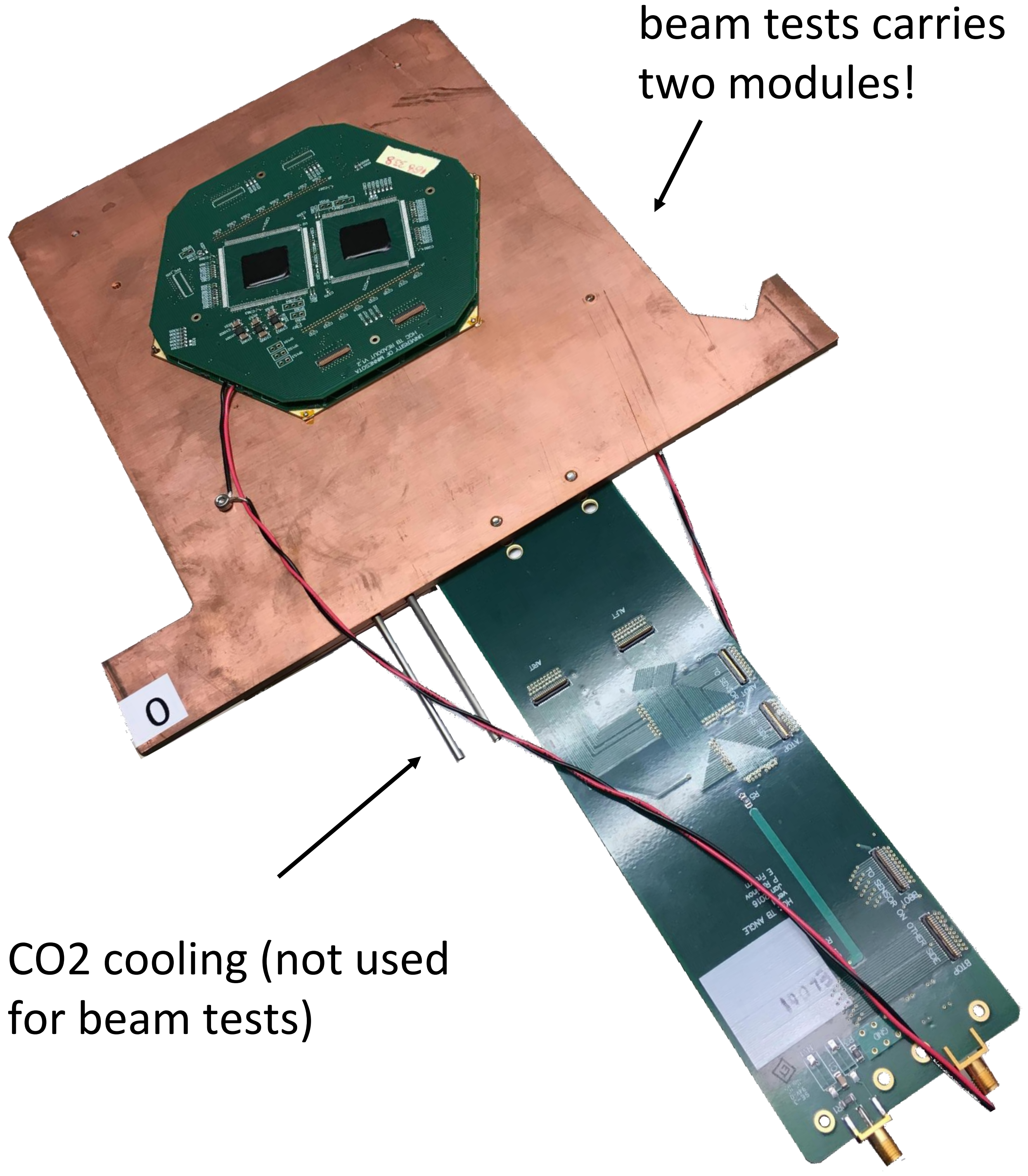


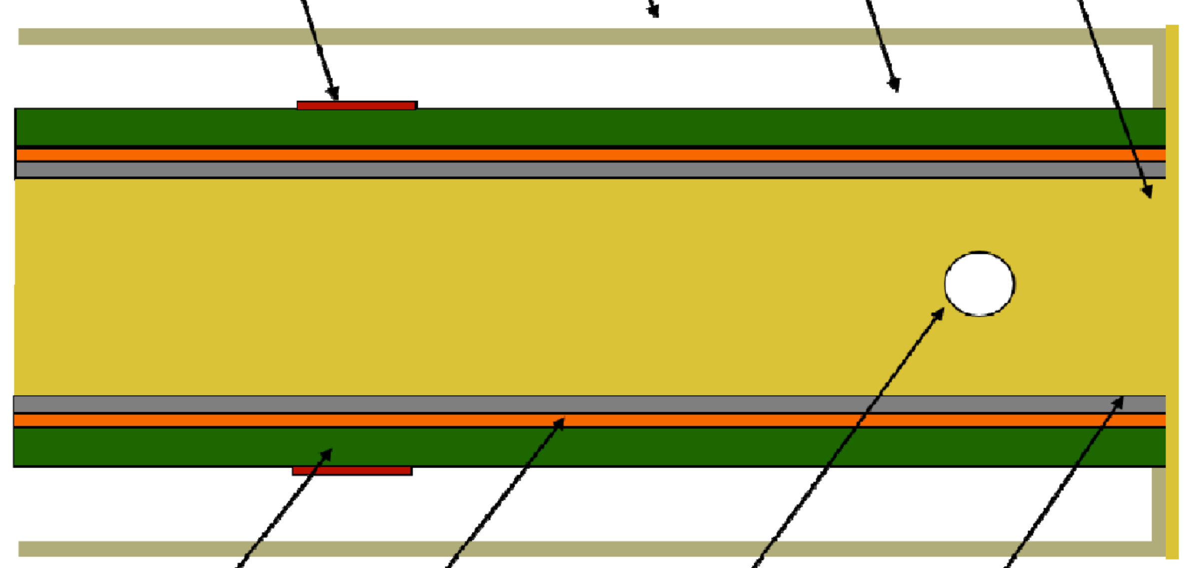


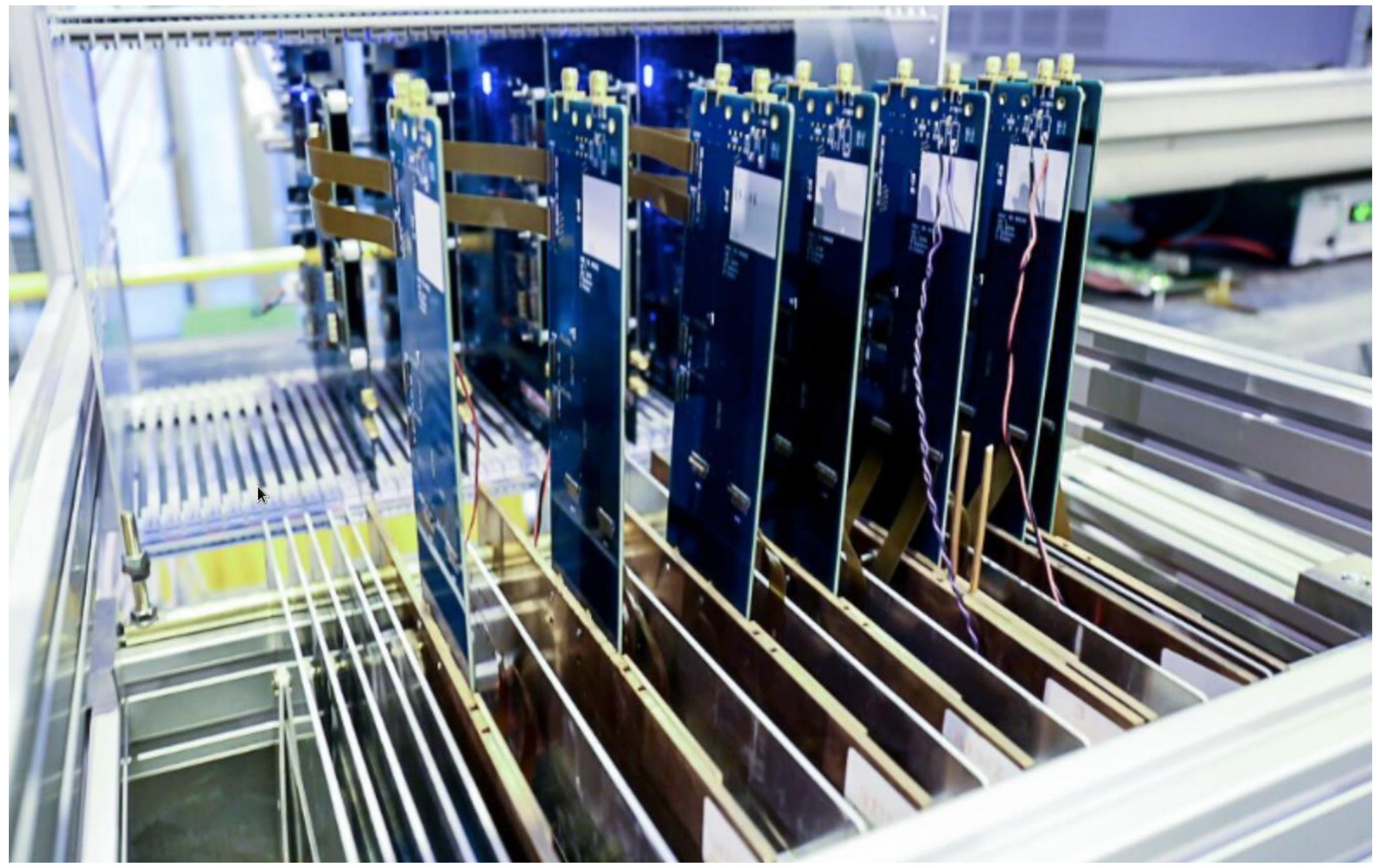


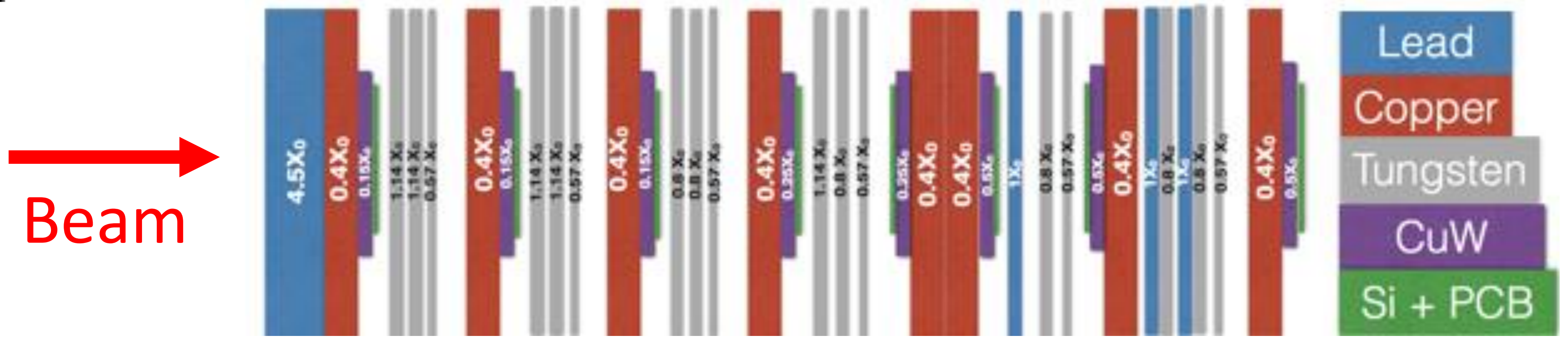
- Two PCB design chosen for 2016 for beam tests
  - different chips can easily be mounted
  - ~700 deep wire bonds on 6” module
- New SKIROC2-CMS hexaboard is on a single PCB

2016 Beam Tests









Cassettes

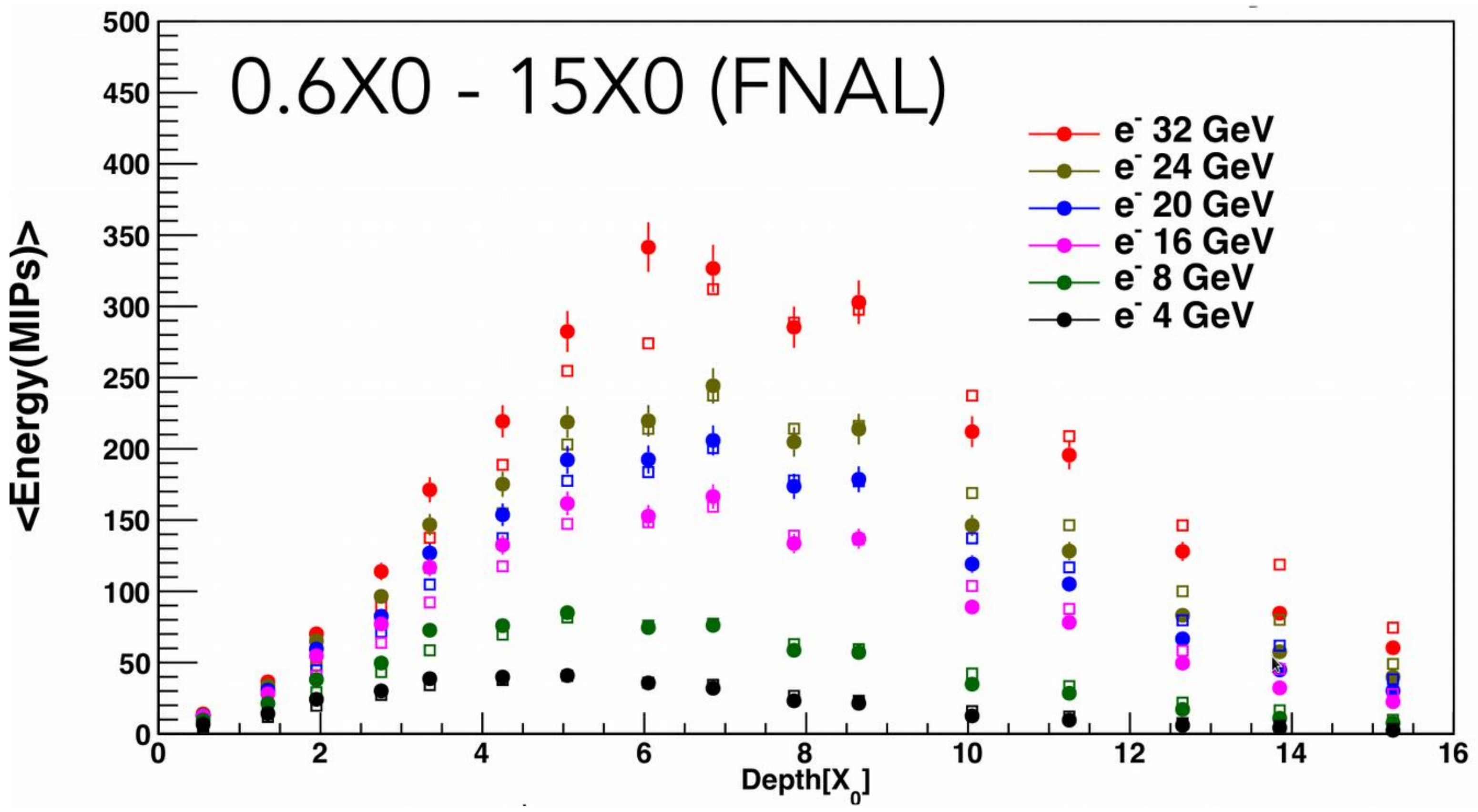
- One ore two modules mounted
- On absorber plates with electronics and cooling
- Can be easily stacked and removed from frame
- Mechanics as well as DAQ is designed scalable

FNAL

- Up to 16 HGCAL modules tested
- e- beam at 4-32 GeV
- Protons at 120 GeV
- 0.6-15 X_0 absorber configuration

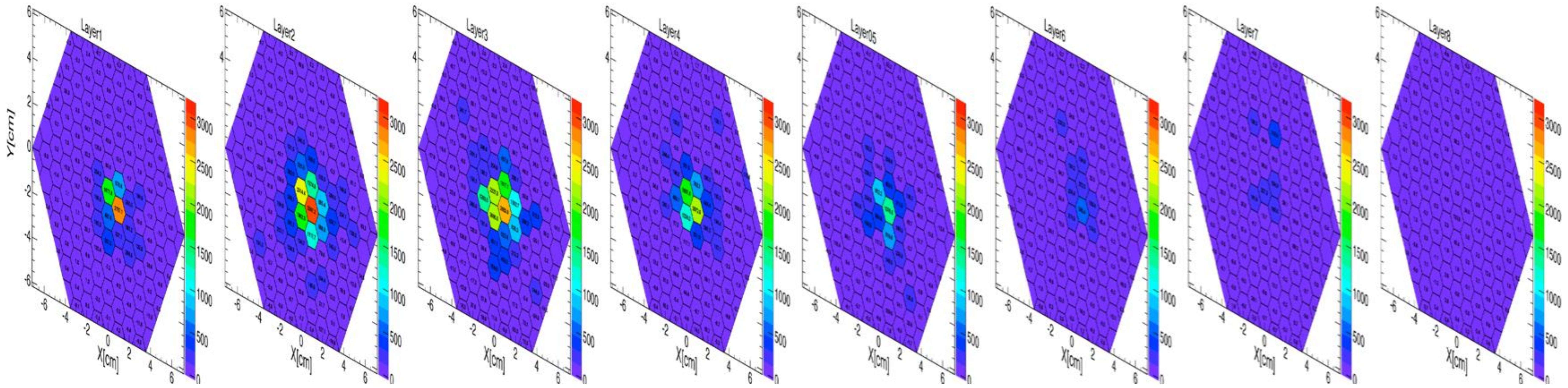
CERN

- Up to 8 HGCAL modules tested
- π/μ at 125 GeV
- e- beam at 20-250 GeV
- 6-15 X0 and 5-27 X_0 absorber configurations



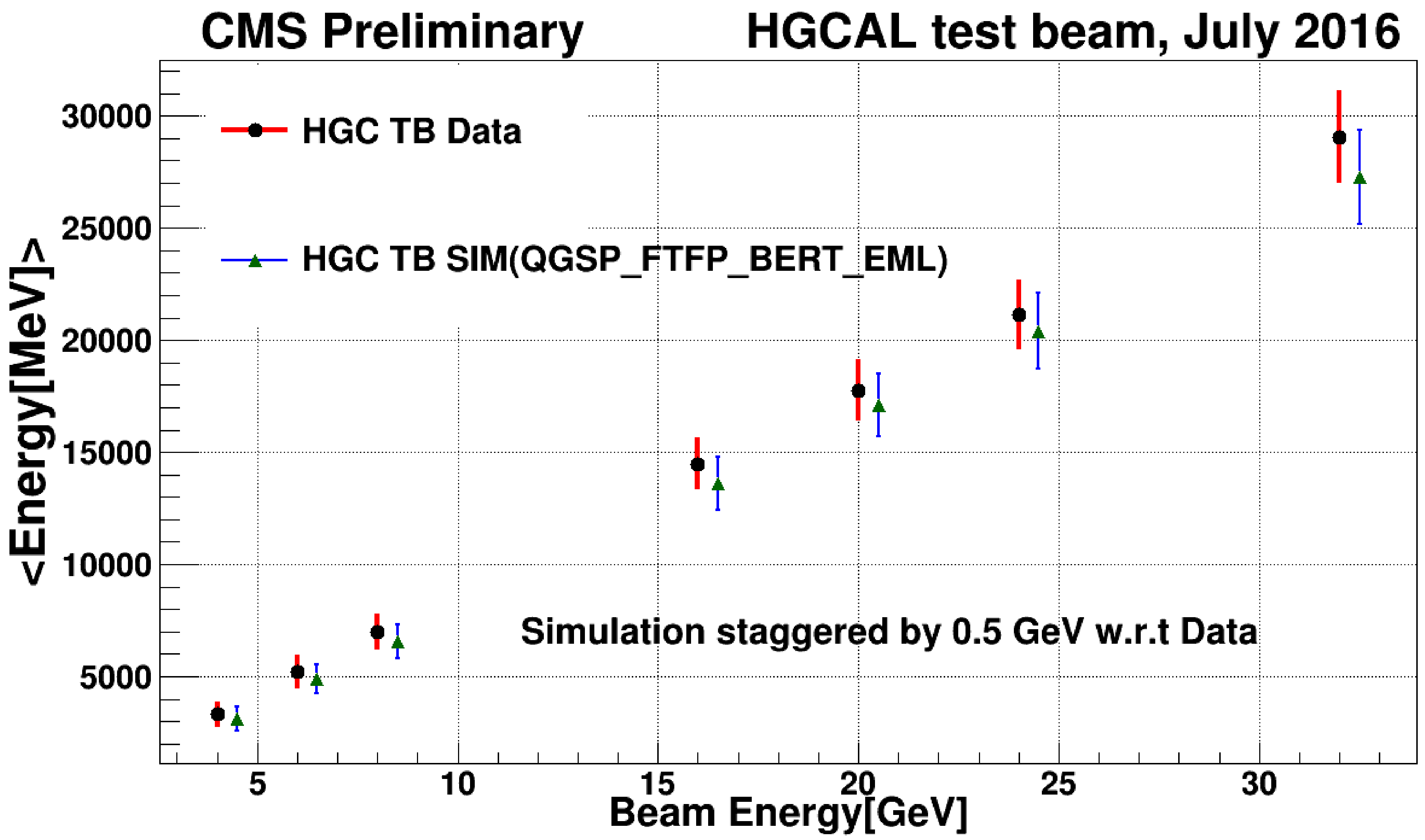
An electron shower passing through 8 layers (27 X_0)

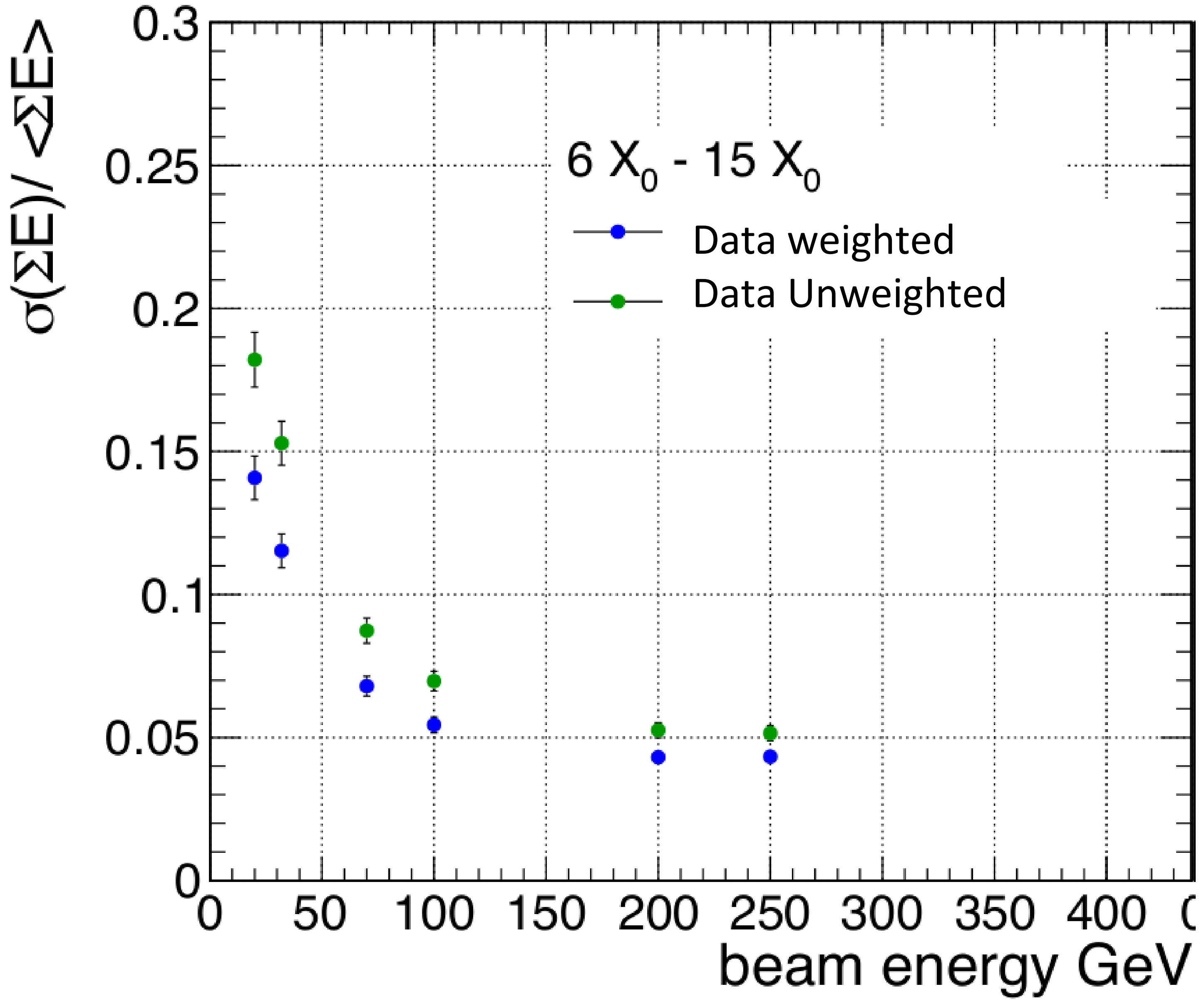
250 GeV e-



$5X_0$ $8.5X_0$ $12X_0$ $15X_0$ $17X_0$ $19X_0$ $21X_0$ $27X_0$

Test Beam Results





Results

- Energy response is linear
- Shower profile and energy resolution agree well with simulation
- dE/dx weighting improves energy resolution by ~20%

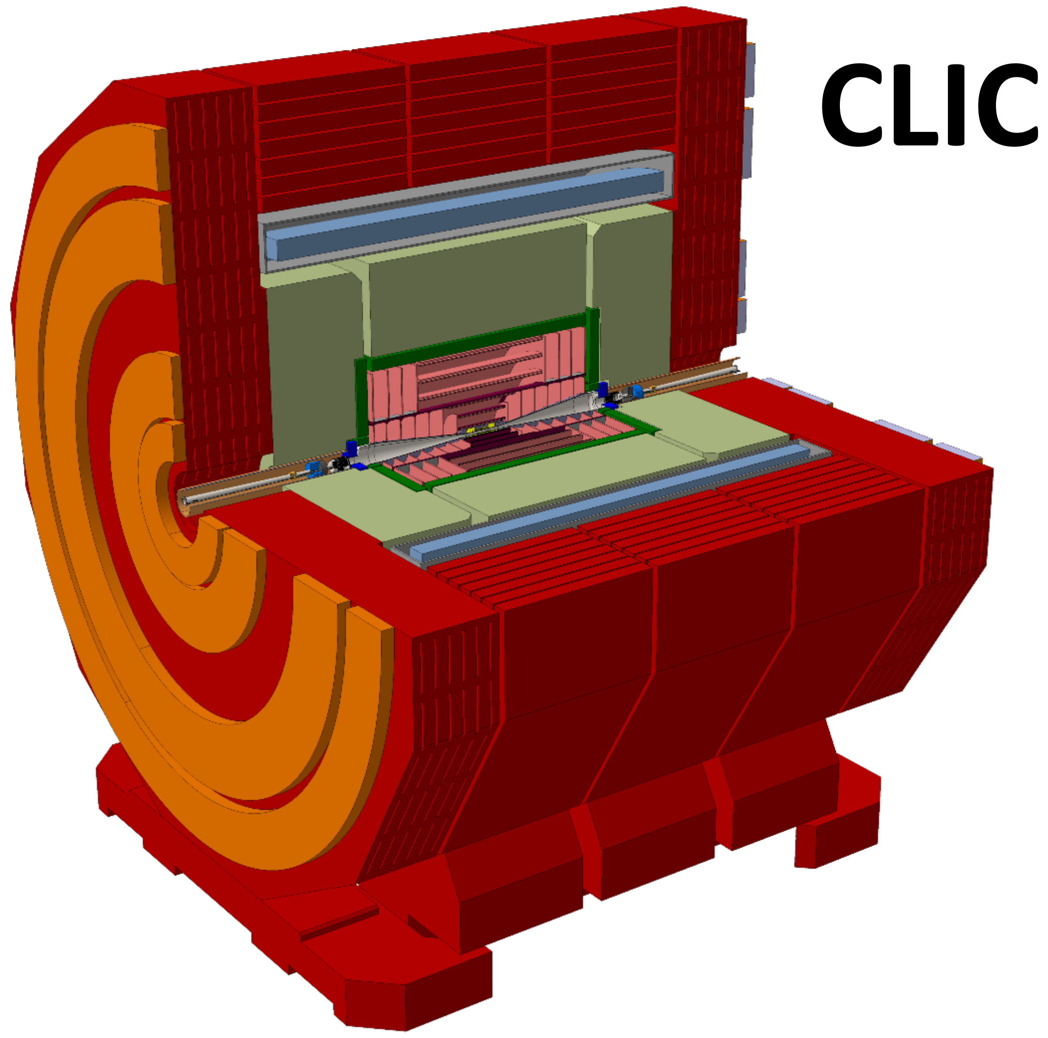
Series of beam tests planned for 2017

Conclusions and Summary

The CLIC project

- CLIC is the proposal for **a multi-TeV** e+e- collider at CERN
  - **Powerful** tool to address the open questions in particle physics
  - **Affordable** first stage at 380 GeV, **upgradable** to 3 TeV
  - Well-established and **flexible** physics (potential LHC/ HL-LHC discoveries)
- Feasibility demonstrated through extensive simulation and prototyping, accelerator and detector R&D

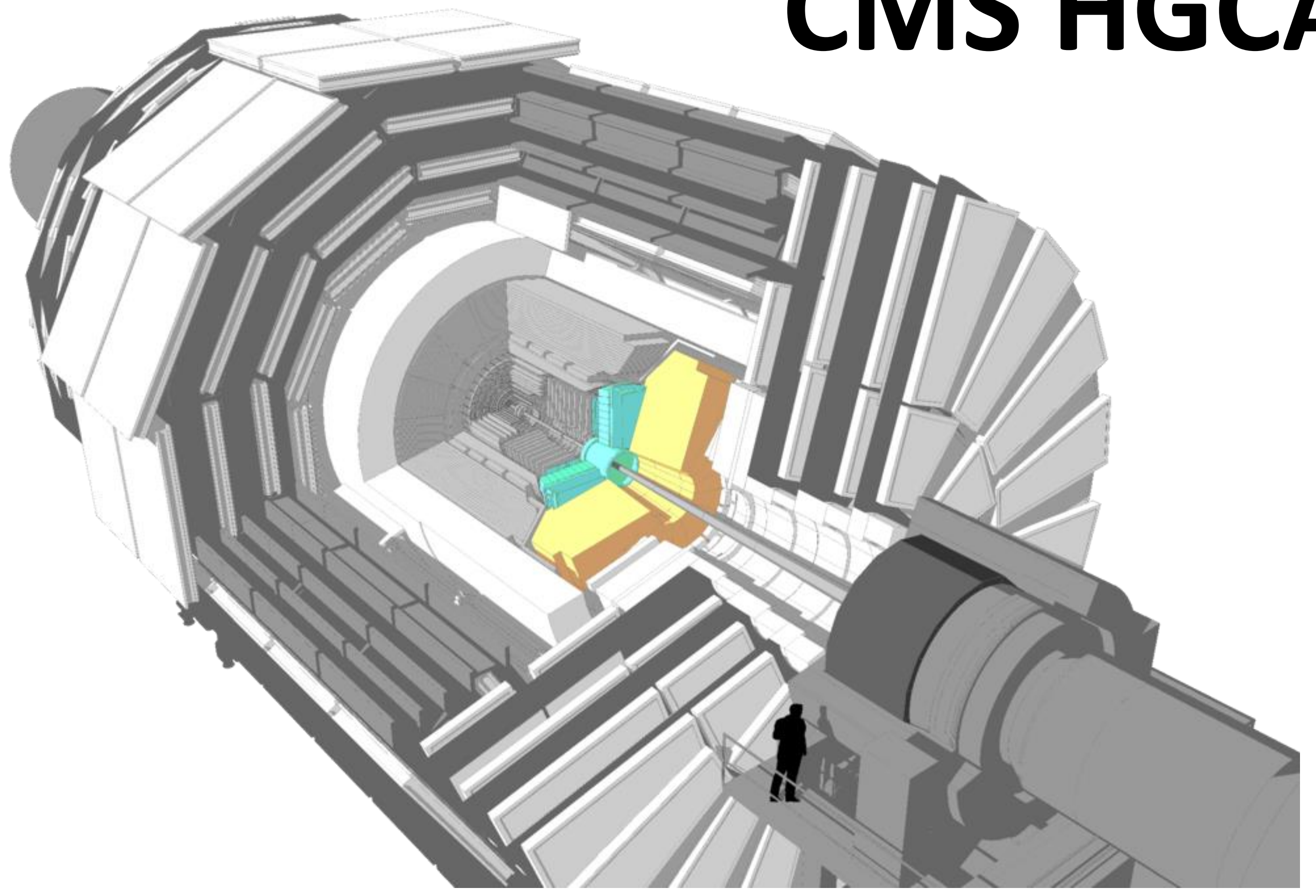
More information:
- CLIC detector and physics: https://clicdp.web.cern.ch
- CLIC accelerator: http://clic-study.web.cern.ch

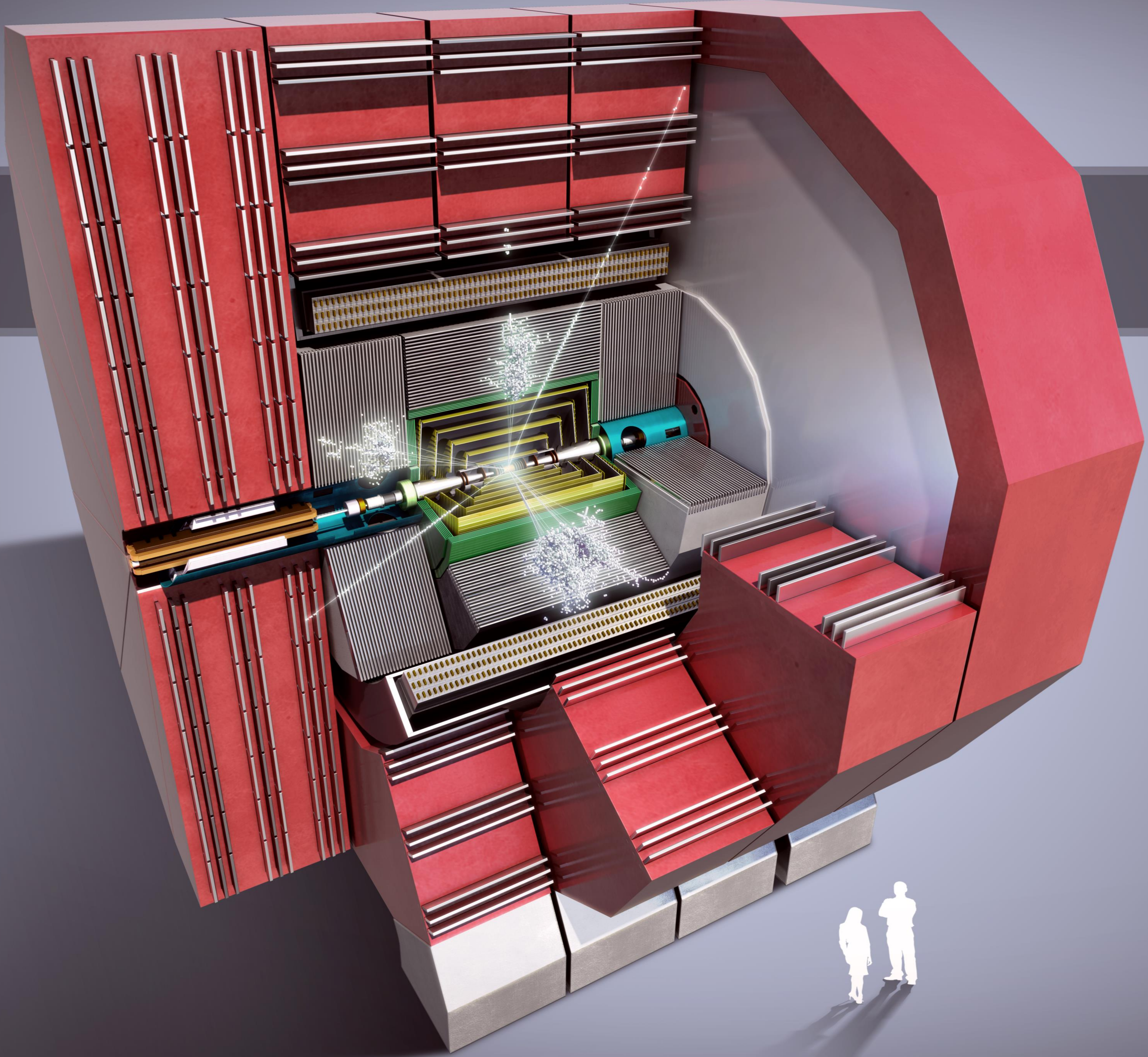


The HGCAL project

- Good progress on the way to a full HGCAL
- Series of beam tests to understand and demonstrate detector performance
- Sensor testing ongoing
- Potential timing precision of < 50 ps
- Main design decisions in the coming months leading to TDR end of 2017

More information in Technical Proposal: https://cds.cern.ch/record/2020886/files/LHCC-P-008.pdf





CLIC Detector

On behalf of the CLICdp Collaboration:

Thank you for your attention!

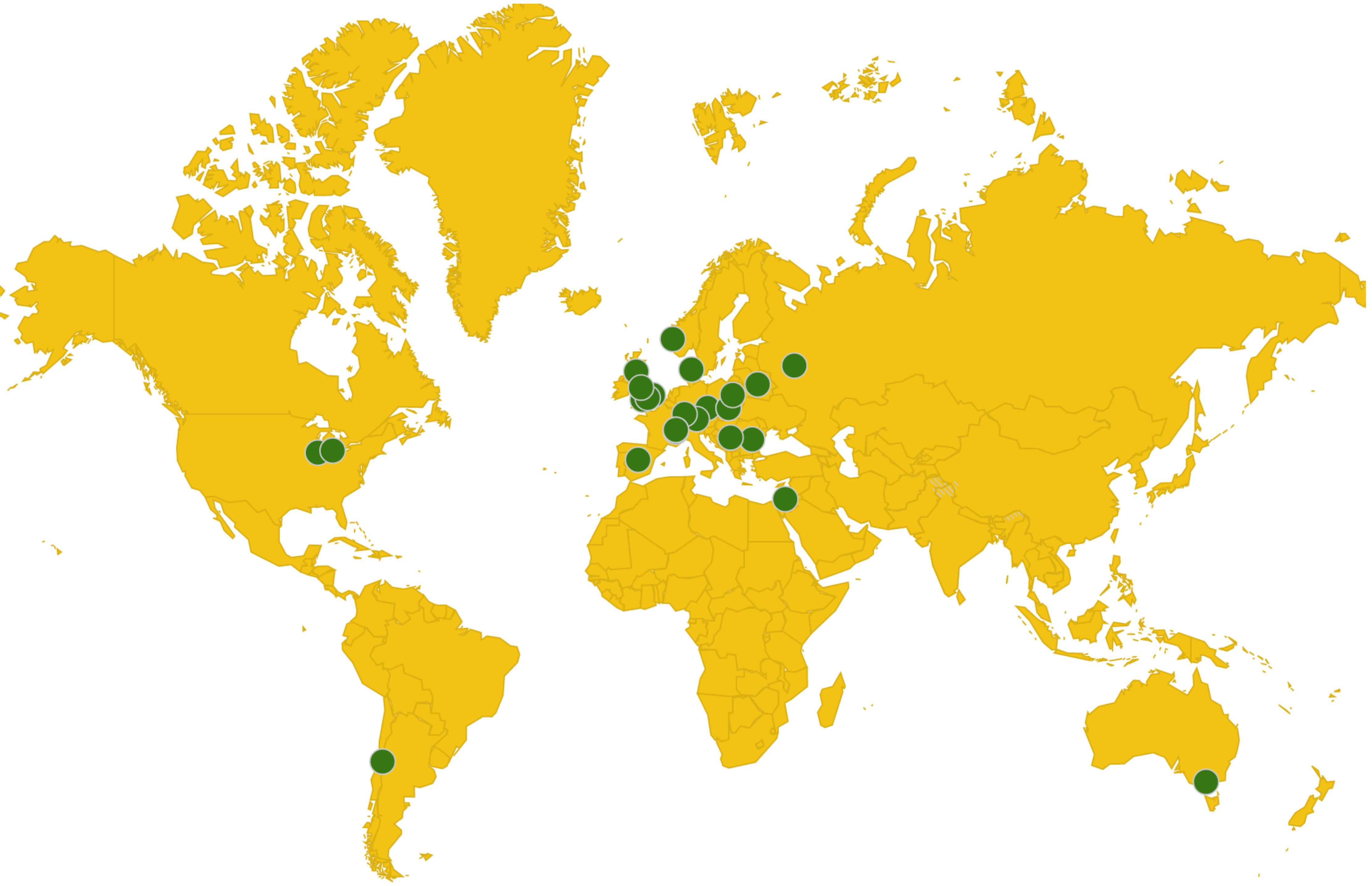
Andreas Alexander Maier
EP-LCD Group, CERN
andreas.alexander.maier@cern.ch
CEA Saclay Seminar, 13th of March 2017

CLICdp Collaboration

CLICdp Collaboration:

150 members from 28 institutes

http://clicdp.web.cern.ch

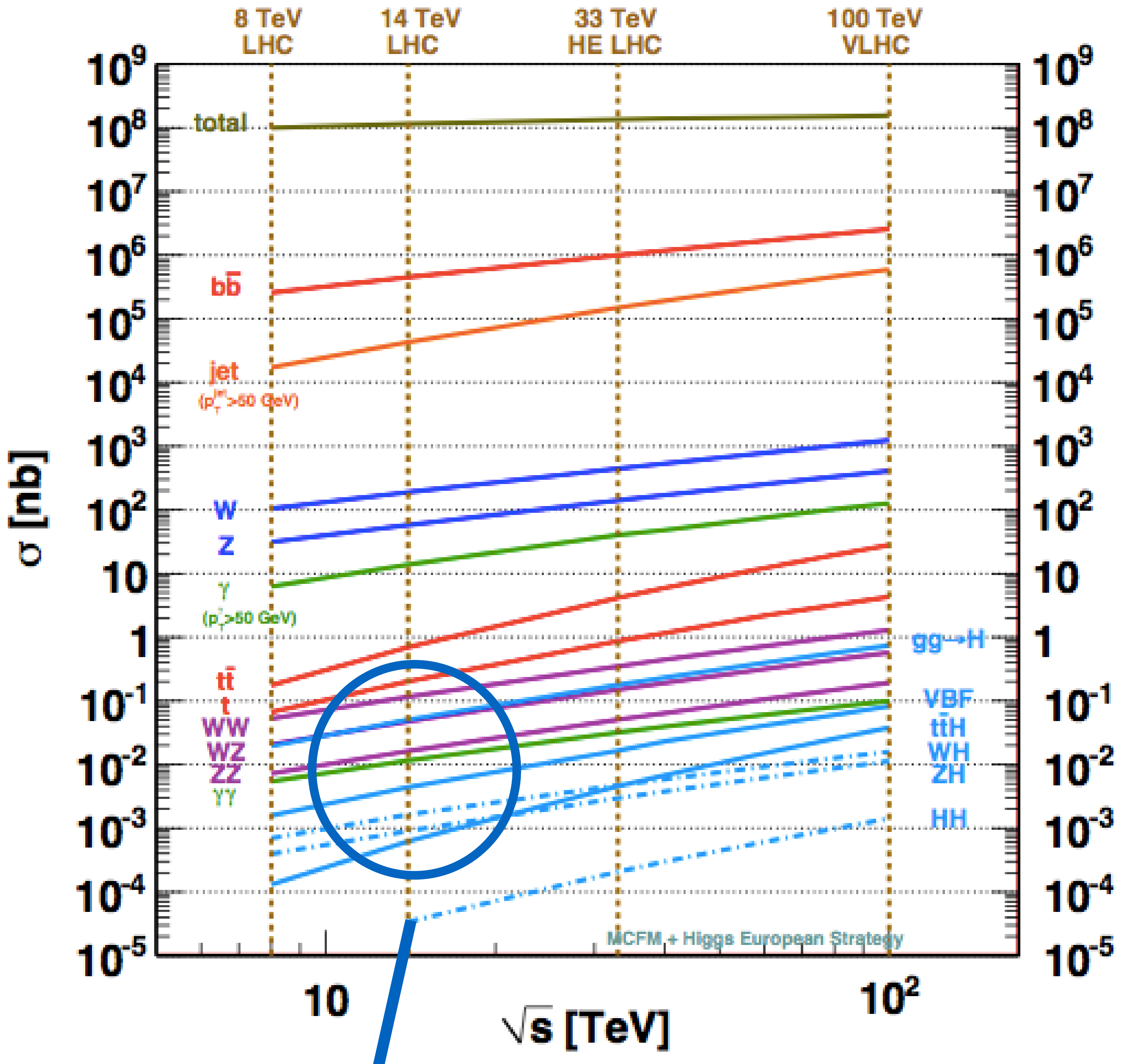


CLIC detector and physics study (CLICdp):

- Physics prospects and simulation studies
- Detector optimization and R&D for CLIC detector
- Series of reports planned for the European Strategy for Particle Physics around 2020

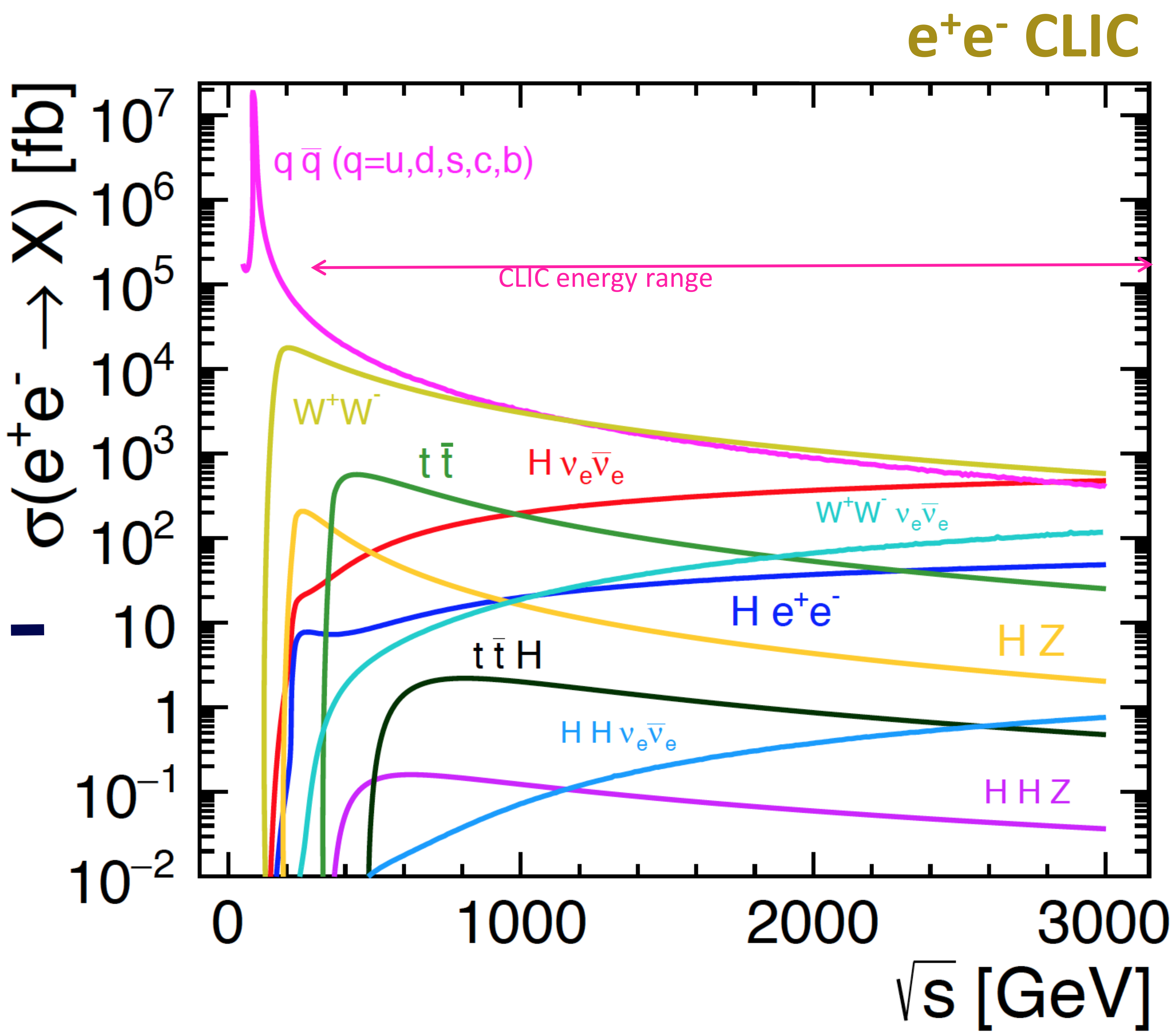
Hadron vs. Lepton Colliders

from discovery to precision



> 100 million events per "interesting event"!

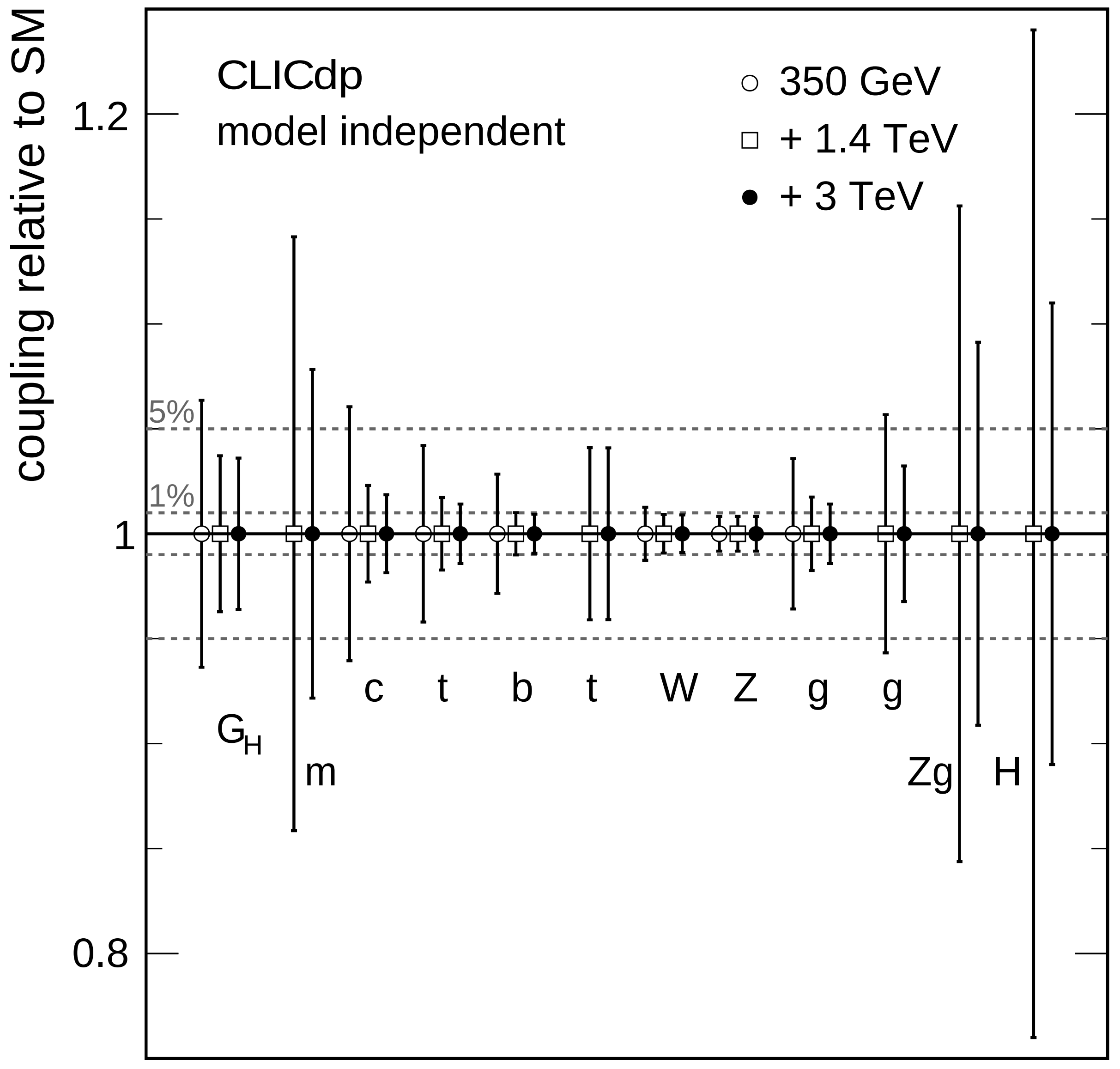
e⁺e⁻ collisions are very clean!



at LHC much of the interesting physics needs to be found among a huge number of collisions

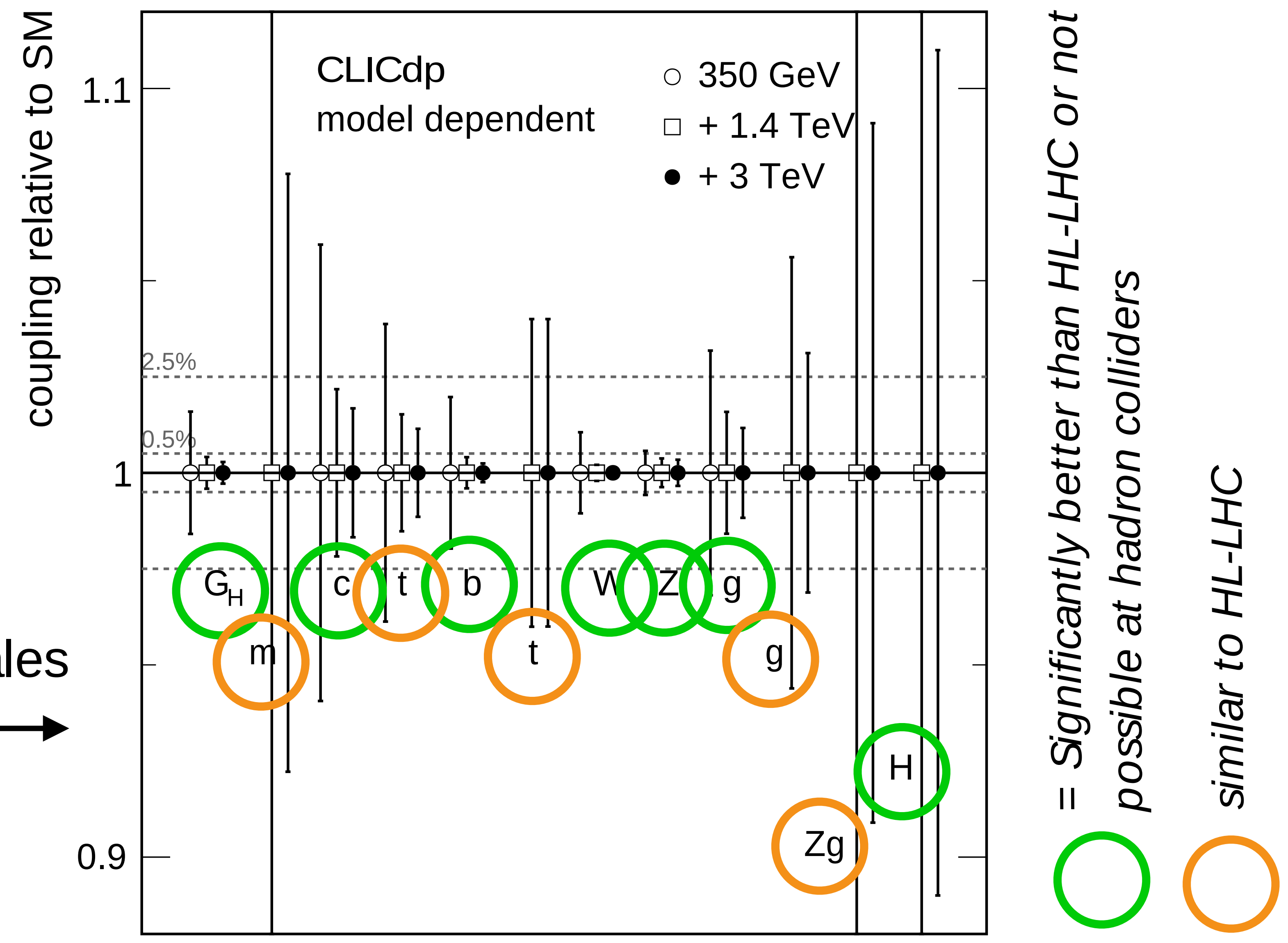
arXiv:1608.07538

Model-independent global fits



Note the different scales

Model-dependent global fits



Constraining "LHC-style" fits assuming no invisible Higgs decays (model-dep.)

Accuracy on Higgs couplings:

- MI: down to ~1 %

  Absolute MI couplings measurable from ZH recoil analysis!
- MD: ~0.1-1 %

Accuracy on Higgs boson width:

- ~3.6 % (MI)
- ~0.2 % (MD, derived)

Accuracy on Higgs mass:

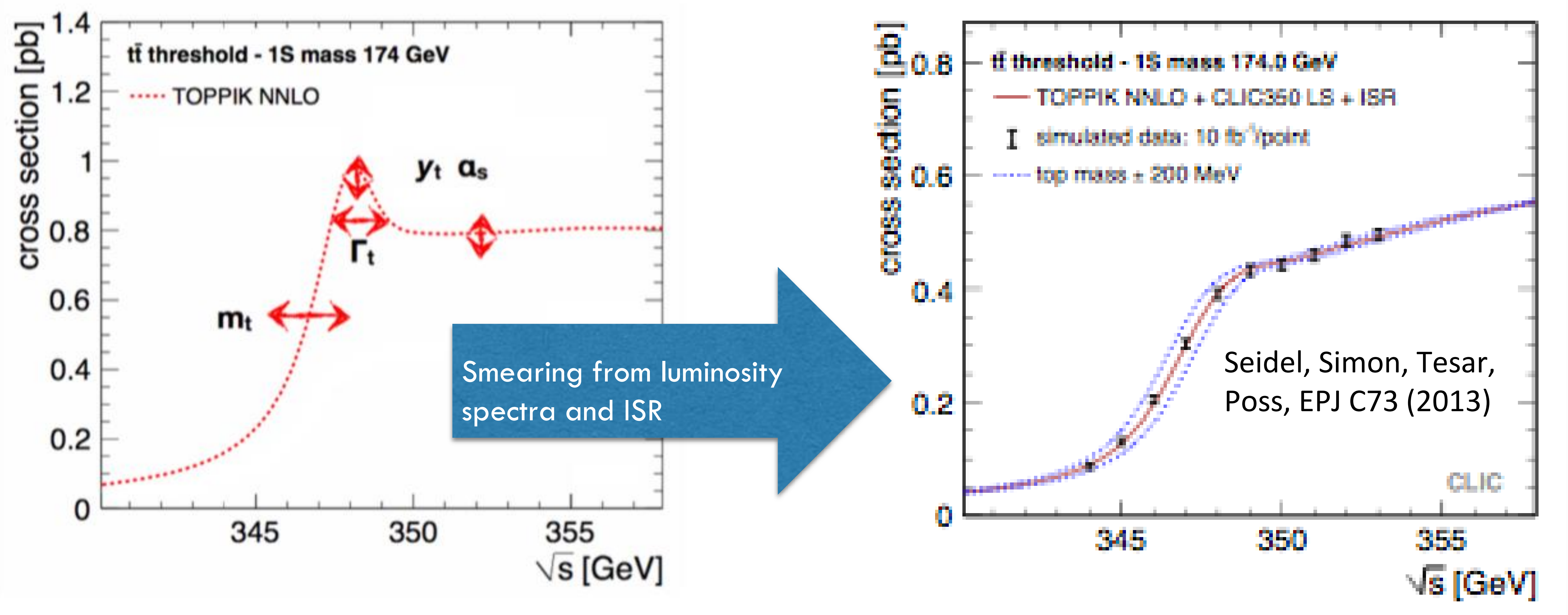
- 24 MeV precision (HL-LHC: ~50 MeV per experiment)

Top Physics at CLIC

Top quark mass threshold scan

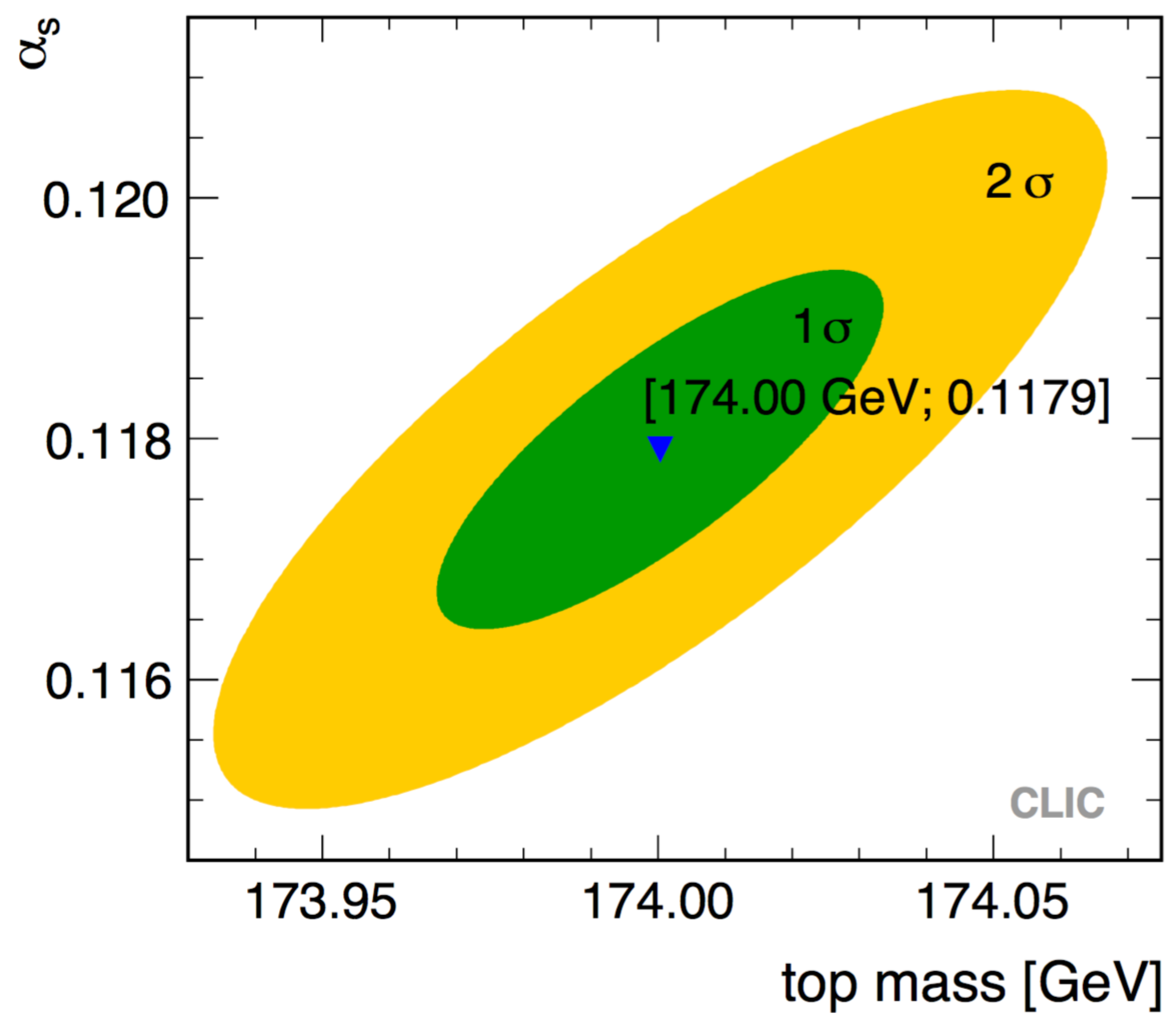
Top mass measurements (run at 350 GeV with 100 fb^{-1})

- Threshold scan (analogous to the LEP2 WW mass scan)
- **Shape** (position, slope) depends strongly on mass and width
- **Normalisation** sensitive to α_S and top Yukawa coupling

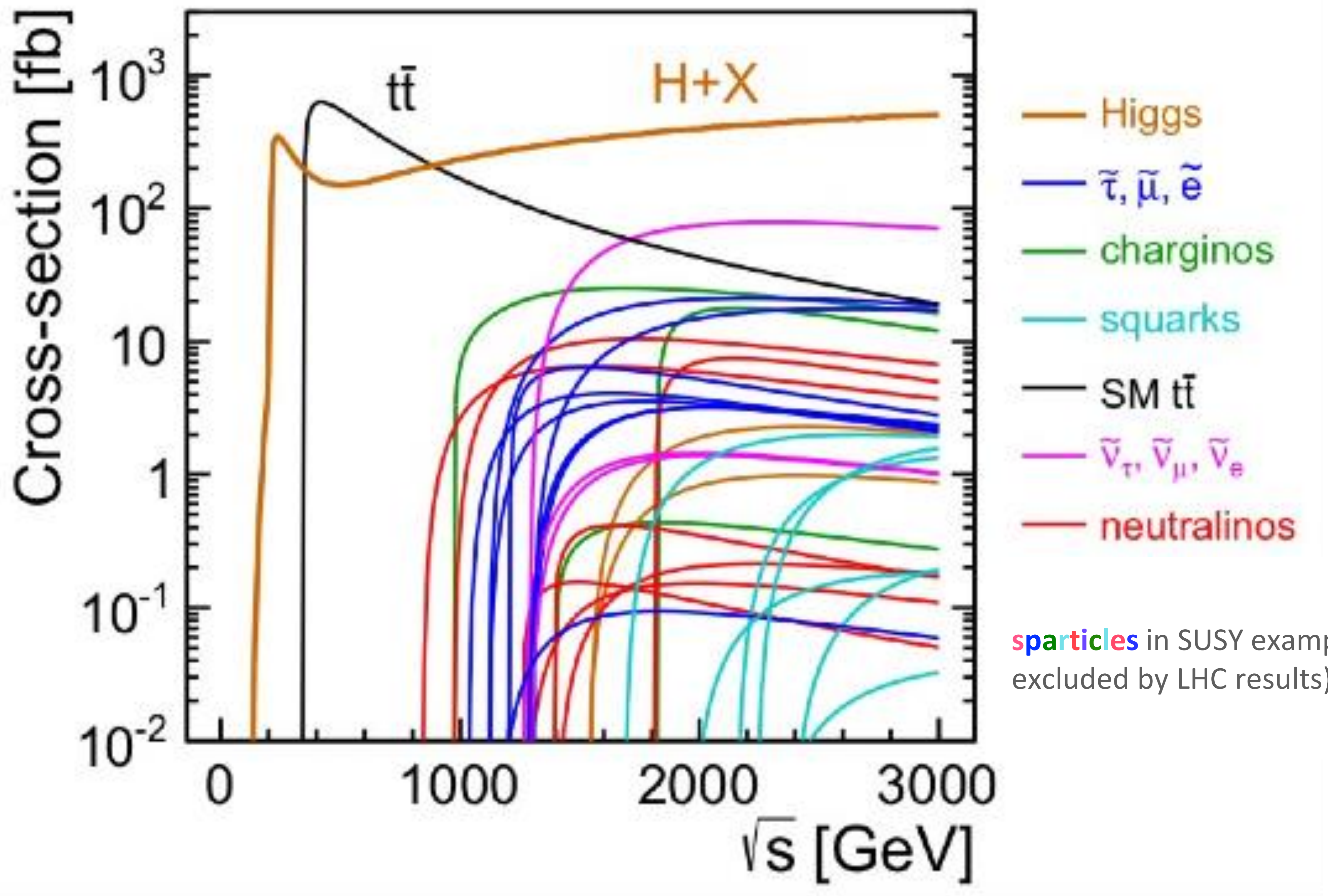


- Extraction of the theoretically well-defined 1S top mass with a statistical precision of about 20 MeV
- Main theoretical uncertainties:
  - The uncertainty in the NNNLO description of the threshold shape
  - The conversion of the threshold mass to the MS-bar scheme
- **A total uncertainty on the top quark mass of about 50 MeV seems feasible**

➢ Beyond the capabilities of HL-LHC



BSM Physics at CLIC



sparticles in SUSY example (not excluded by LHC results)

- Clean collision environment is suited to study non-colored TeV-scale particles such as e.g. sleptons, gauginos, and neutralinos
- These might be hidden in the large QCD backgrounds at the LHC
- In general always able to measure the mass and production cross-sections to order of 1%

Indirect searches

Indirect searches through precision observables

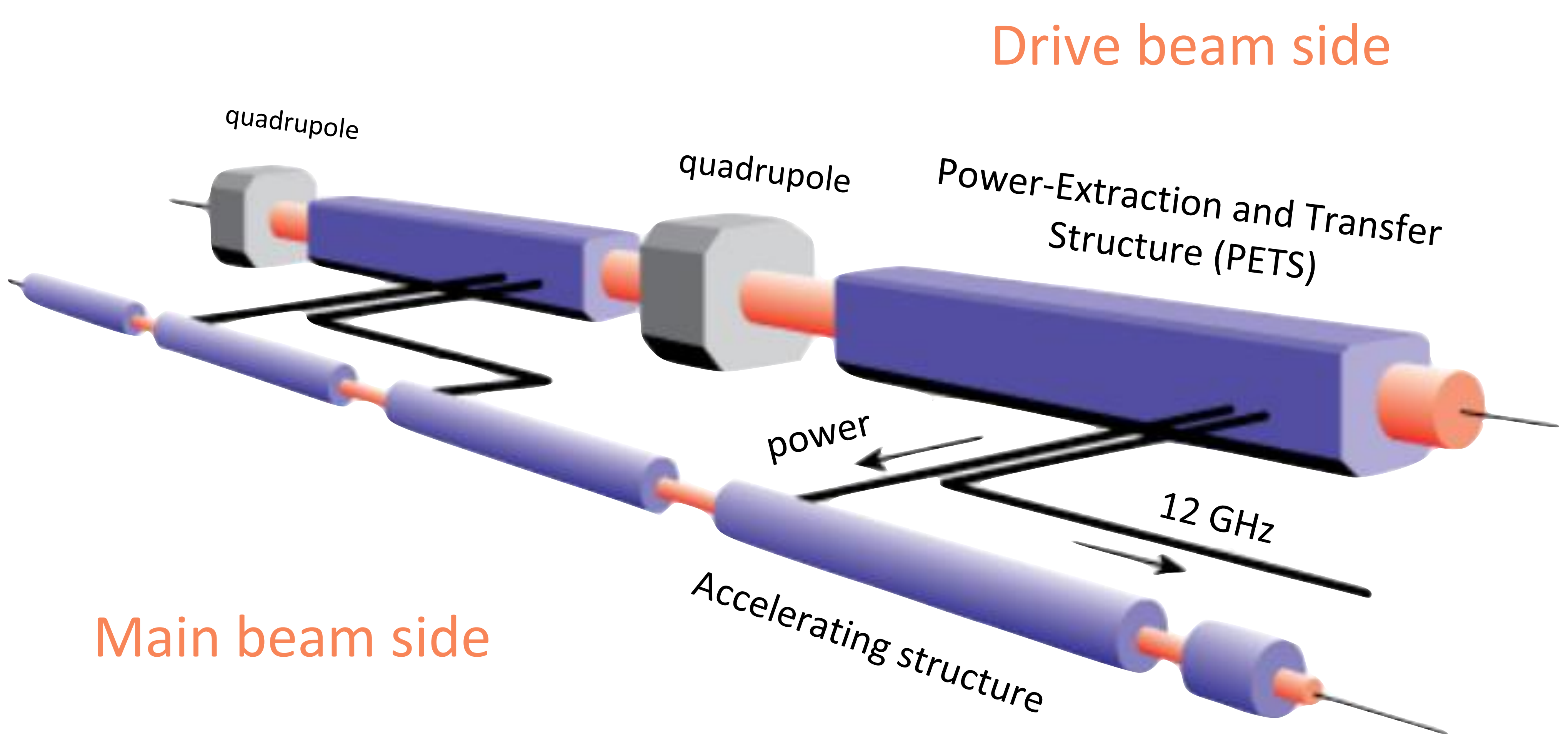
- BSM discovery potential beyond the center-of-mass energy of the collider
- For example Z' model and Higgs compositeness models can be probed up to scales of tens of TeV

Direct searches

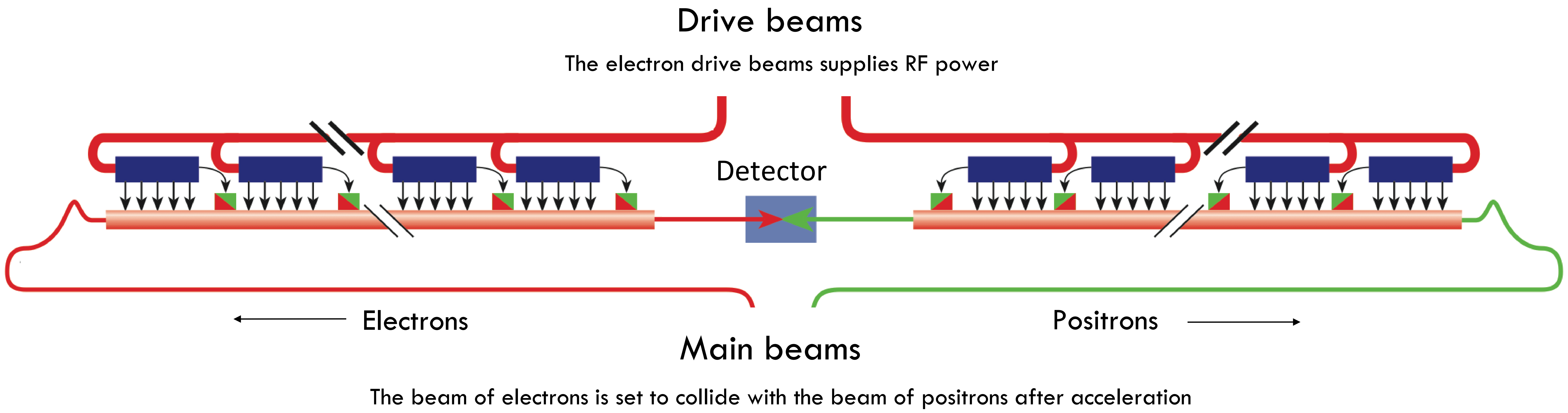
Direct production of new particles

- Possible up to the kinematic limit ($\sqrt{s}/2$ for pair production)
- Precision measurements of new particle masses and couplings
- Complements the HL-LHC program to measure heavy SUSY partners

- Drive beam accelerated to a few GeV using conventional klystrons
- Frequency increased using a series of delay loops and combiner rings
- Drive beam decelerated through a series of Power Extraction and Transfer Structures (PETS) which decelerate the dense beam and extract its kinetic energy
- This energy is fed via an RF field in a waveguide to a second beam, which is much less intense. Since there are far fewer particles in this ‘main beam’, each one is accelerated to higher energy (from 9 GeV to 1.5 TeV)



- Concept demonstrated at a dedicated test facility at CERN (incl. step-up in frequency of the drive beam, power extraction, and acceleration of main beam in excess of the required 100 MV/m)



CLIC Cost and Power

How much will CLIC cost?

- 1st stage of the ~50% more than the cost for the LHC: ~6700 MCHF (mostly excavation and two-beam modules)
- Detector like ATLAS or CMS: ~500 MCHF (mostly calorimeters, superconducting coil, return yoke)

	CLIC_ILD (MCHF)	CLIC_SiD (MCHF)
Vertex	13	15
Tracker	51	17
Electromagnetic calorimeter	197	89
Hadronic calorimeter	144	86
Muon system	28	22
Coil and yoke	117	123
Other	11	12
Total (rounded)	560	360

arXiv:1202.5940

How much power will CLIC use?

- Low power consumption in stand-by or "waiting-for-beam" mode compared to superconducting technology.
- A preliminary analysis of the overall CLIC energy consumption per year:
  - 1st stage ~ LHC consumption
  - 2nd stage ~ total CERN consumption
  - ➢ Work on-going for further reduction!

$\sqrt{s}$ (TeV)	$P_{nominal}$ (MW)	$P_{waiting\ for\ beam}$ (MW)	P_{stop} (MW)
0.38	252	168	30
1.5	364	190	42
3	589	268	50

ILC and CLIC Accelerator Parameters

	ILC at 500 GeV	ILC at 1 TeV	CLIC at 380 GeV	CLIC at 3 TeV
L (cm^{-2}s^{-1})	1.8×10^{34}	3.5×10^{34}	1.5×10^{34}	5.9×10^{34}
$L_{0.01}$ (cm^{-2}s^{-1})	1.0×10^{34}	1.2×10^{34}	0.9×10^{34}	2.0×10^{34}
$L_{0.01}/L$	58%	59%	60%	34%
BX separation	554 ns	366 ns	0.5 ns	0.5 ns
#BX / train	1312	2450	356	312
Train duration	727 µs	897 µs	178 ns	156 ns
Repetition rate	5 Hz	4 Hz	50 Hz	50 Hz
Main linac gradient (MV/m)	31.5	38.2	72	100
Duty cycle	0.36%	0.36%	0.00089%	0.00078%
σ_x / σ_y (nm)	474/5.9	481/2.8	≈ 150 / 3	≈ 45 / 1
σ_z (µm)	300	250	70	44

- Parameters of the proposed CLIC staging scenario
- Can be adapted to changes in the physics landscape (e.g. LHC observations)
- Power estimates scaled from CDR, with room for improvement

CLIC - Timeline

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)

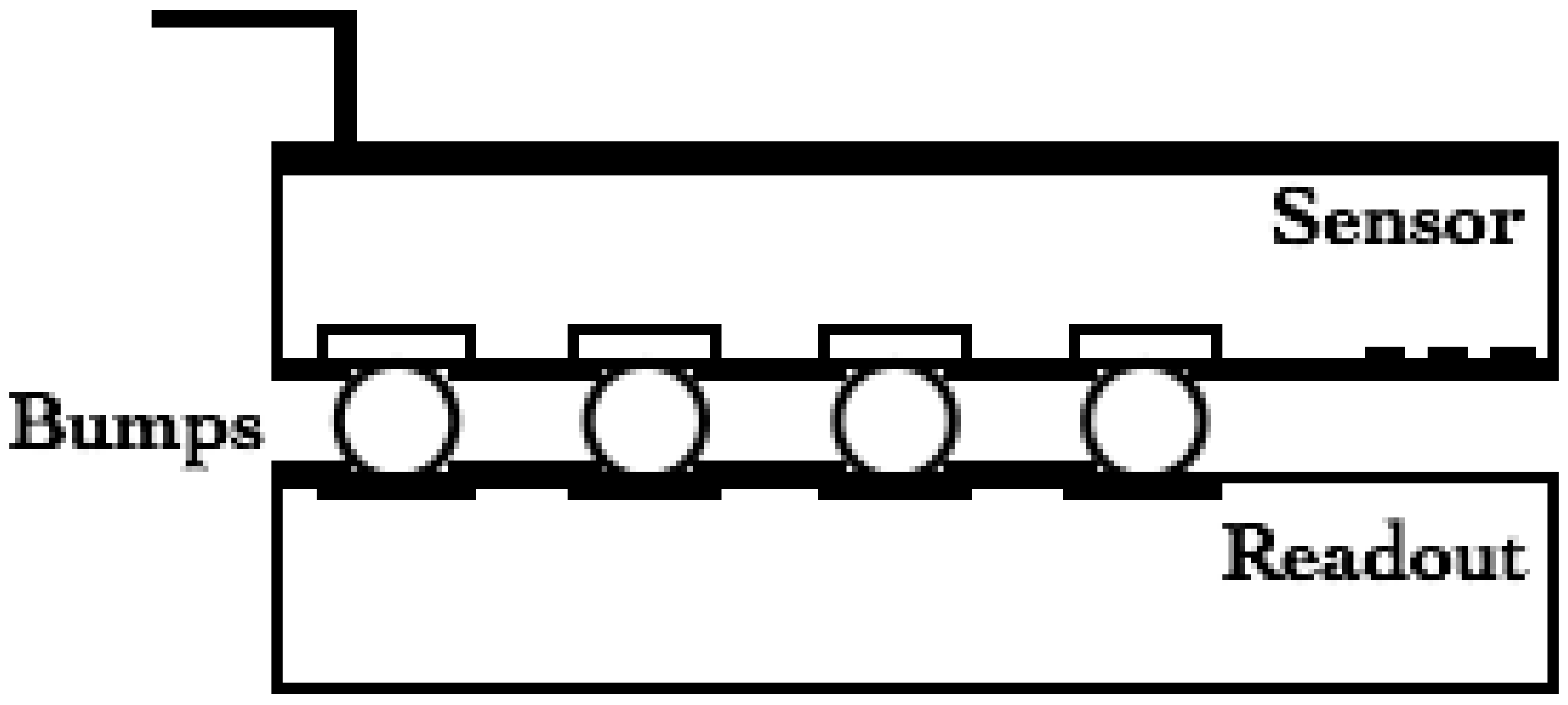
2025 Construction Start

Ready for construction; start of excavations

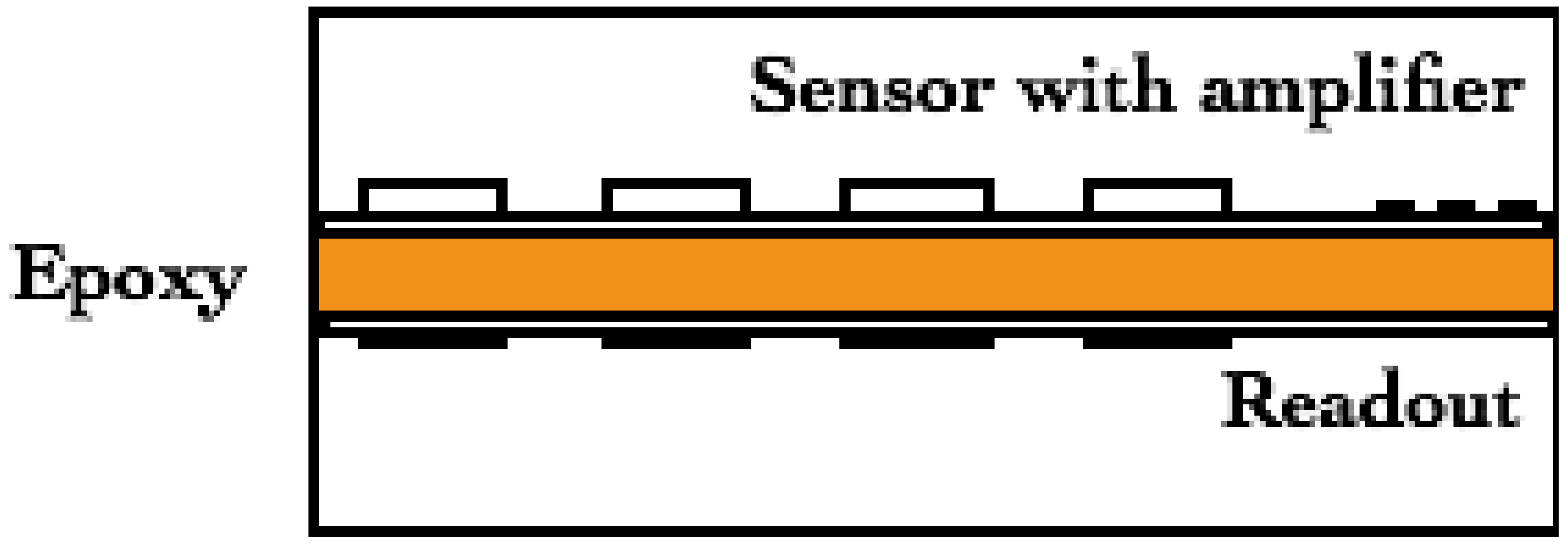
2035 First Beams

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

CLIC Pixel Technology



Bump-bonded assembly



AC-coupled assembly

CLICpix first pixel chip in 65 nm technology

- Collaboration with LHC upgrades

Two lines of utilization studied

- Bump bonded to planar sensor
- Capacitively coupled to active sensor (HV-CMOS)

Promising:

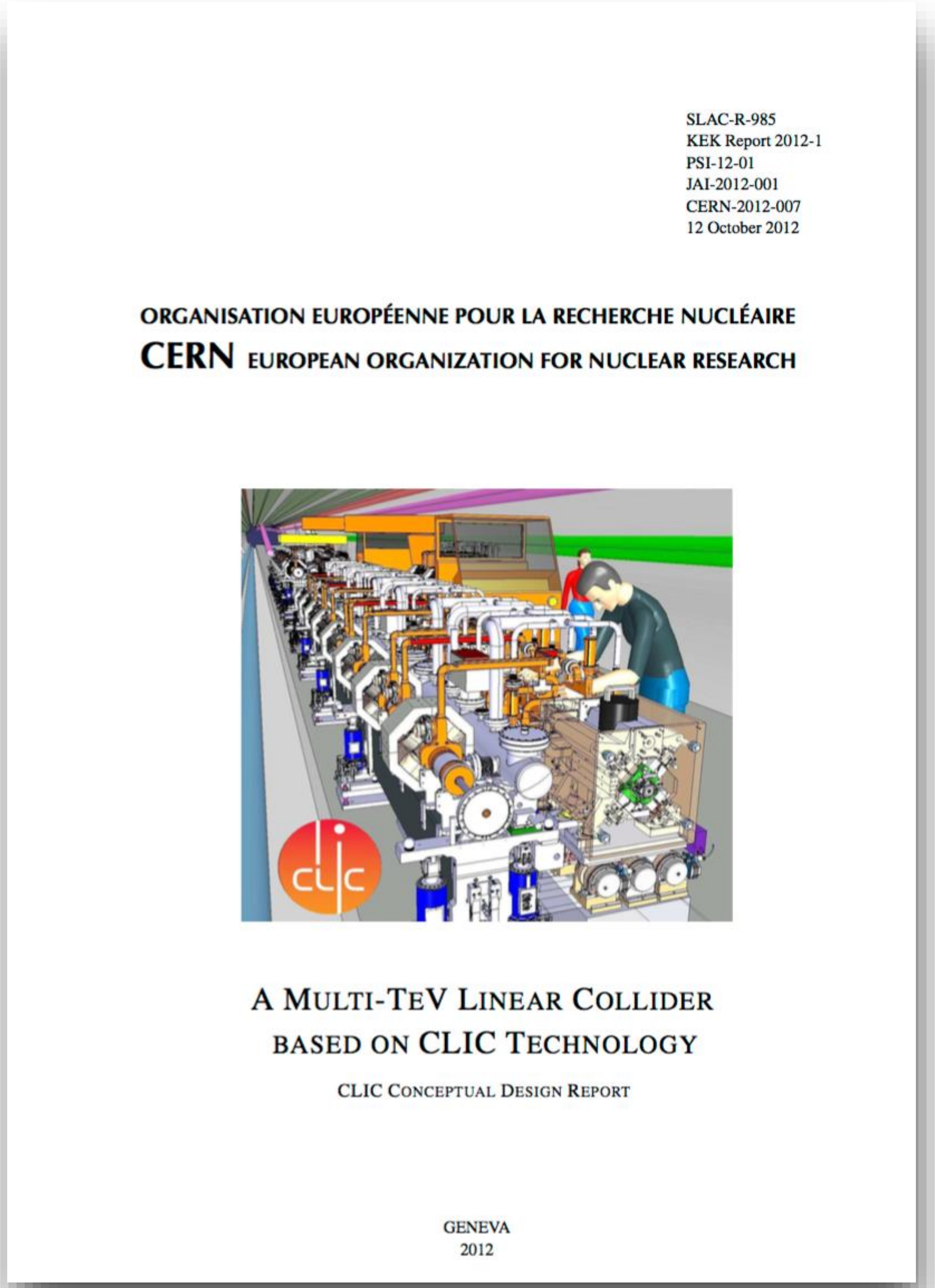
- Monolithic chips
- Silicon On Insulator technology

CLIC BSM Discovery Reach

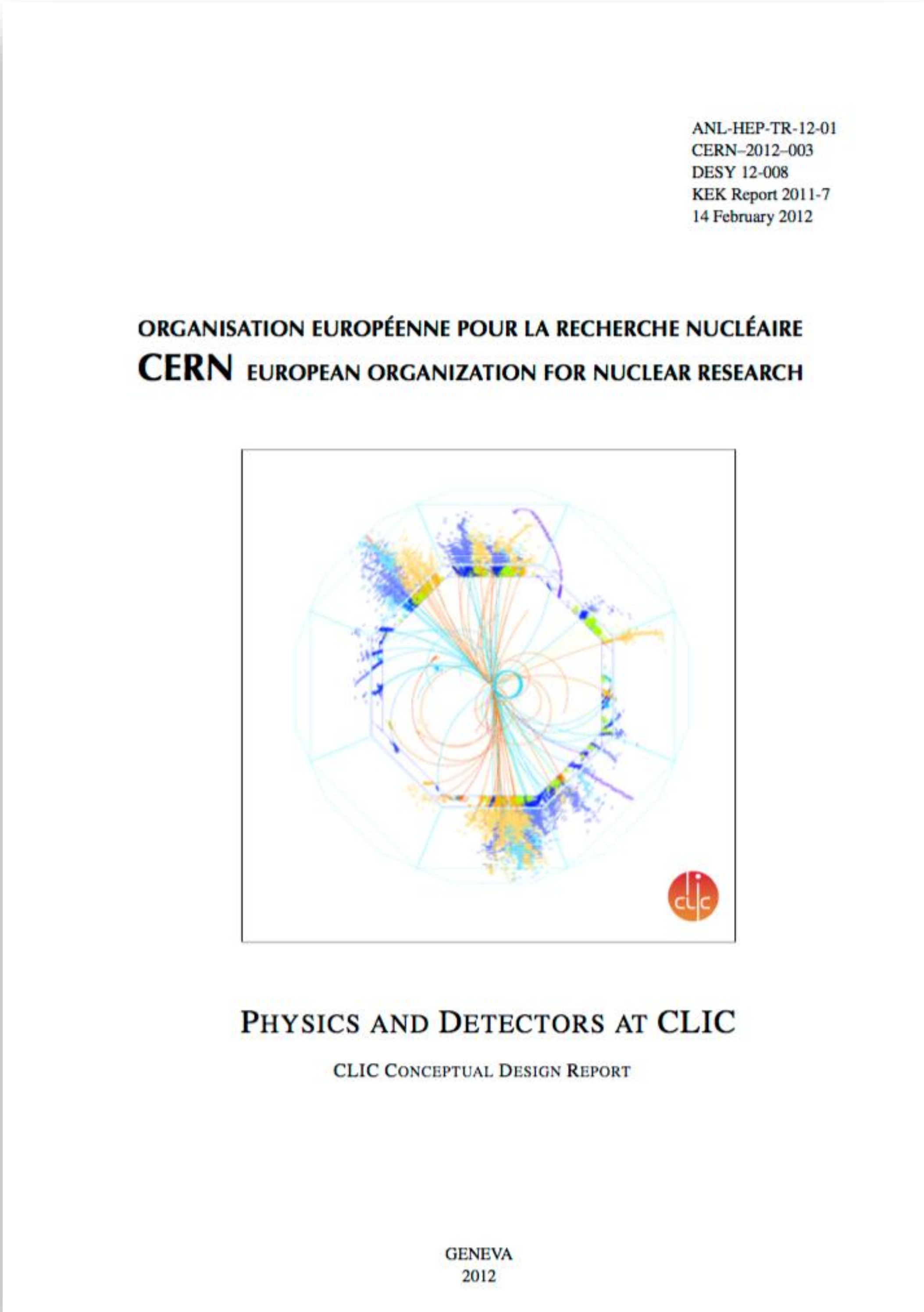
New particle / phenomenon	Unit	CLIC reach
Sleptons, charginos, neutralinos, sneutrinos	TeV	≈1.5 TeV
Z' (SM couplings)	TeV	20
2 extra dimensions M_D	TeV	20-30
Triple Gauge Coupling (95%) (λ_γ coupling)		0.0001
Vector boson scattering $\Delta F_{S,0,1}$	TeV^{-4}	5
μ contact scale	TeV	60
Higgs composite scale	TeV	70
Electron size (test of QED extension)	m	3.1×10^{-20}

- CLIC discovery reach for BSM phenomena
- Studied for 2 ab^{-1} at 3 TeV
- Depending on the exact models used, quoted values generally extend significantly beyond the HL-LHC reach

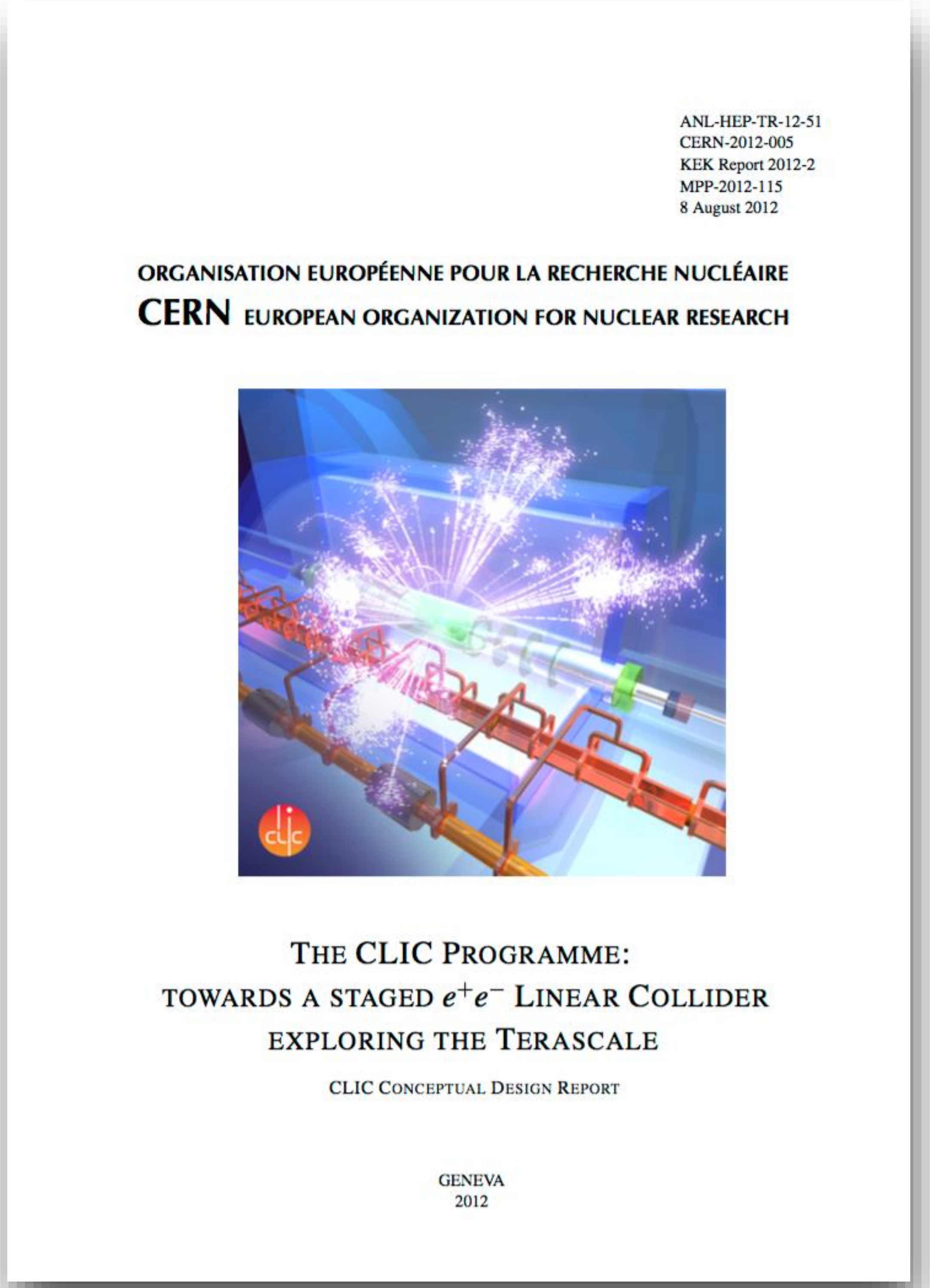
CDR - 3 volumes CLIC conceptual design report



Volume 1 "A multi TeV Linear Collider based on CLIC Technology"



Volume 2 “Physics and Detectors at CLIC”



Volume 3 "The CLIC Programme: towards a staged e^+e^- Linear Collider exploring the Terascale"

The HGCAL Schedule