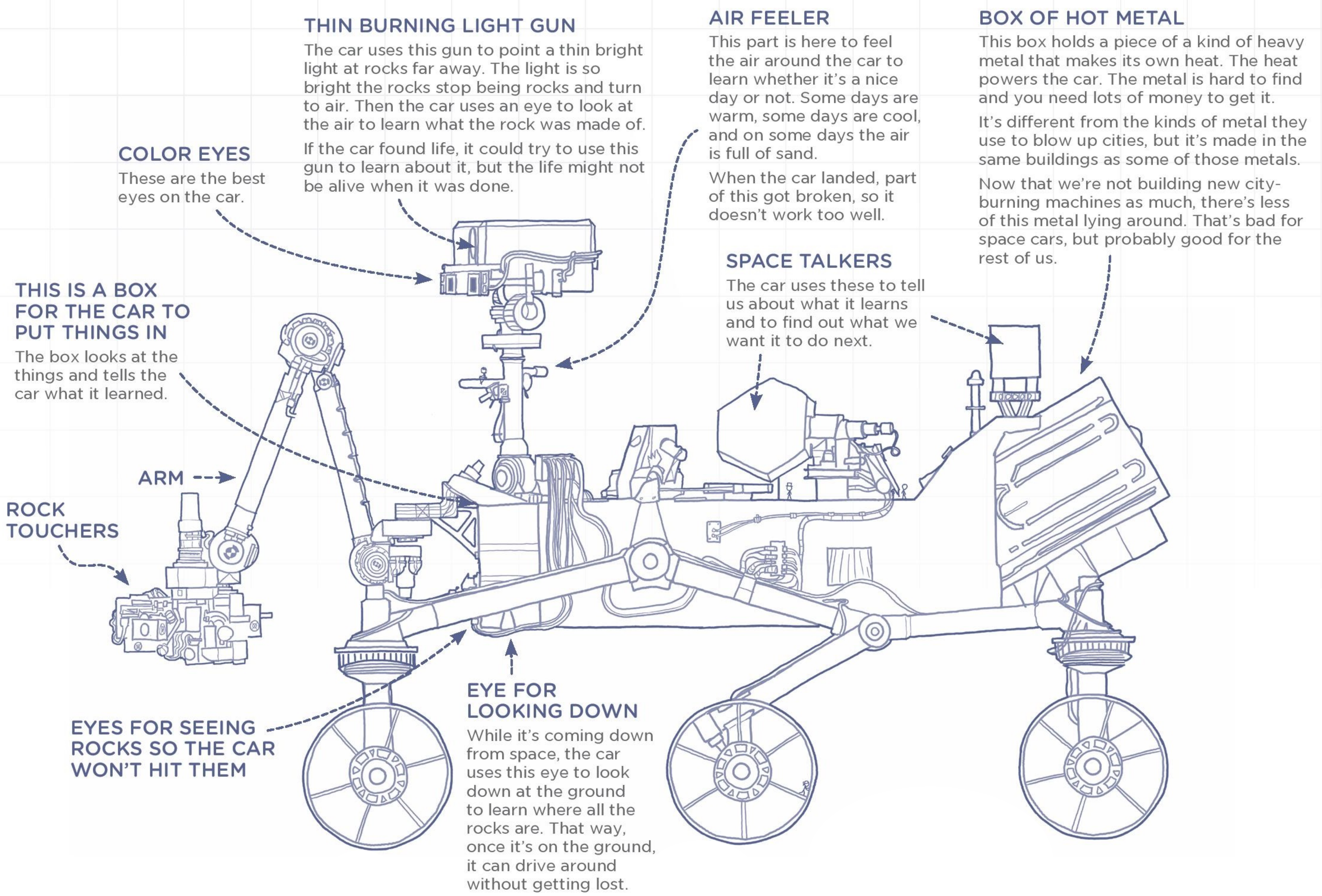
Detector technologies and challenges for future facilities

(In 15 minutes)

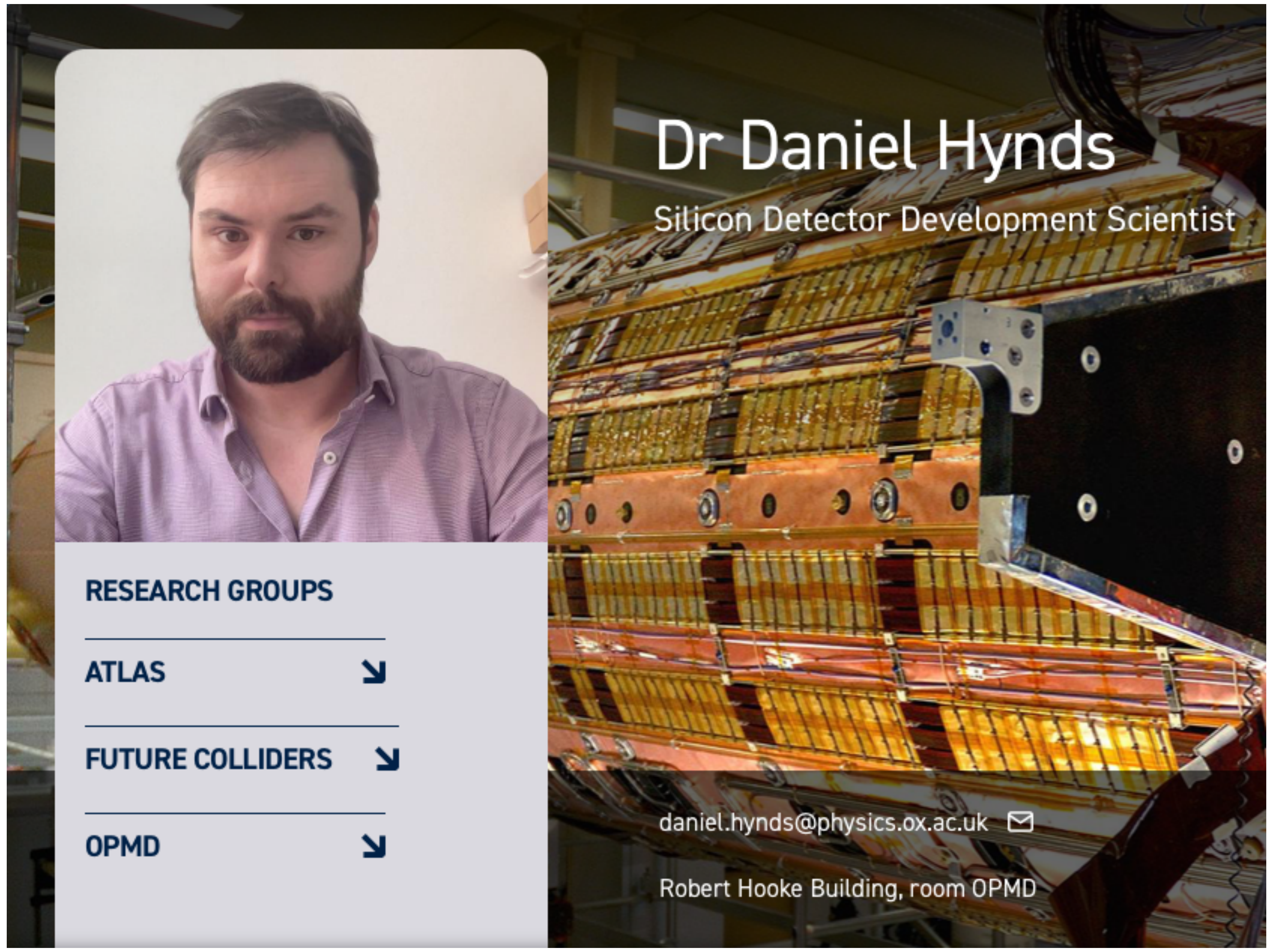
Daniel Hynds

SPACE CAR FOR THE RED WORLD



My background

PhD in Glasgow	2010 - 2014
CERN Fellow	2014 - 2018
Nikhef Postdoc	2018 - 2020
Oxford Staff	2020 - now



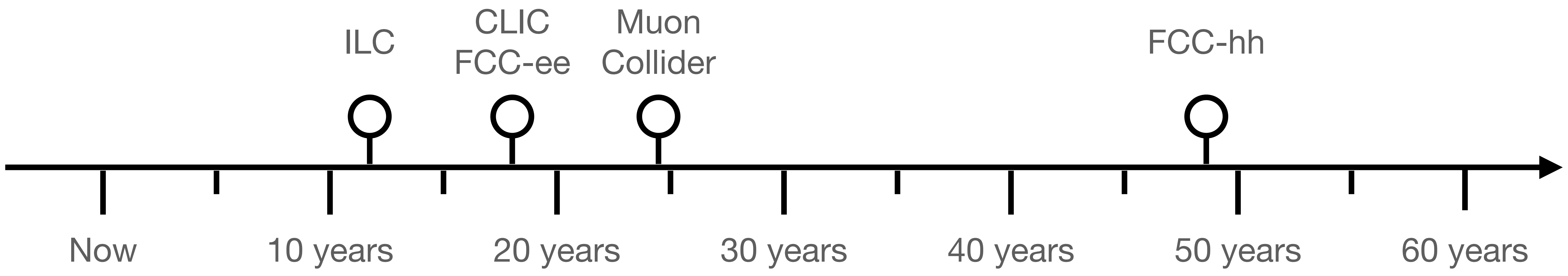
Mostly silicon pixel detector R&D and detector construction for LHCb and ATLAS

- From “blue sky” to detector-specific, including simulations, software development, etc

Event reconstruction, triggering

- Detector-scale MC simulations and pattern recognition

Future facilities

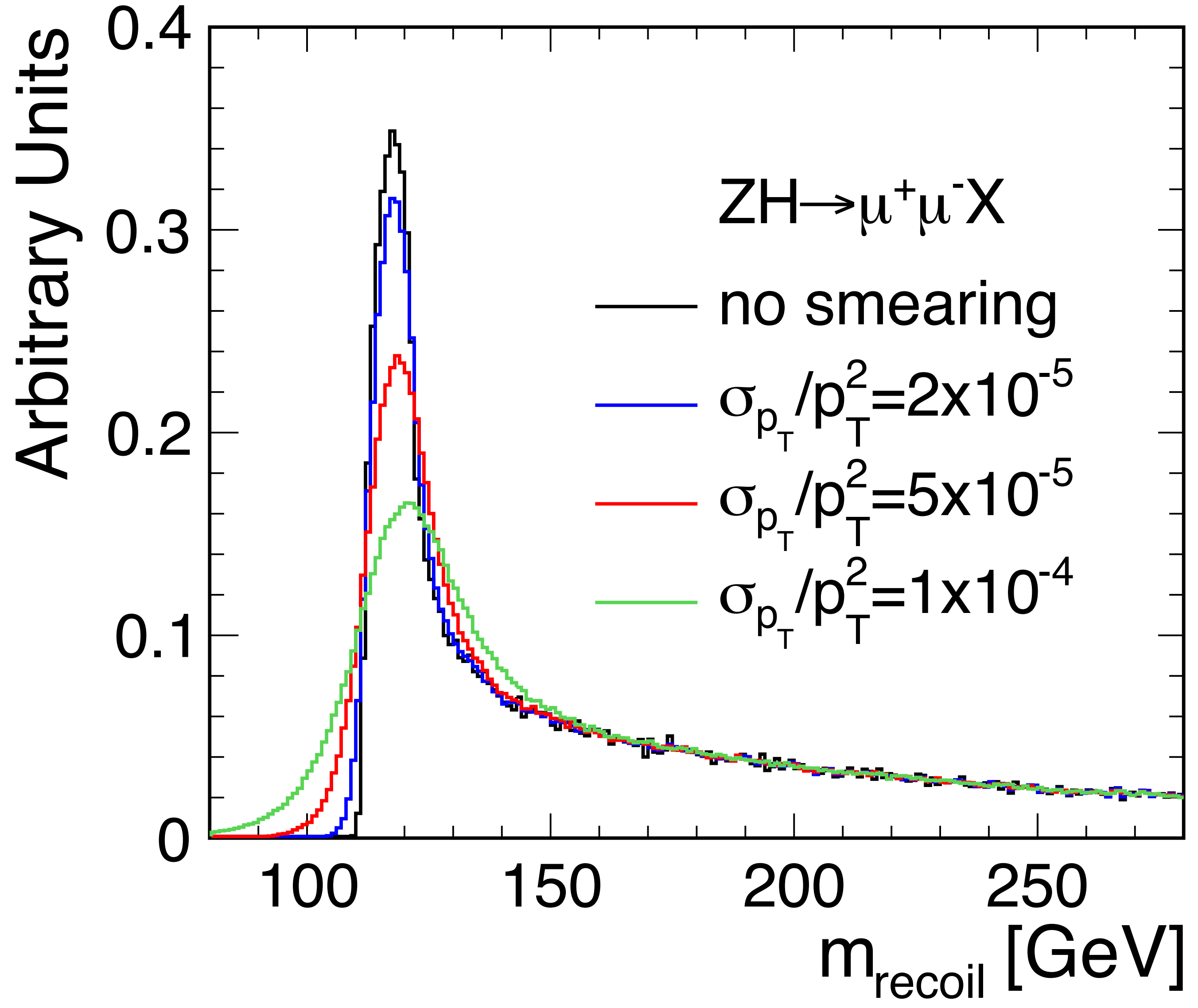


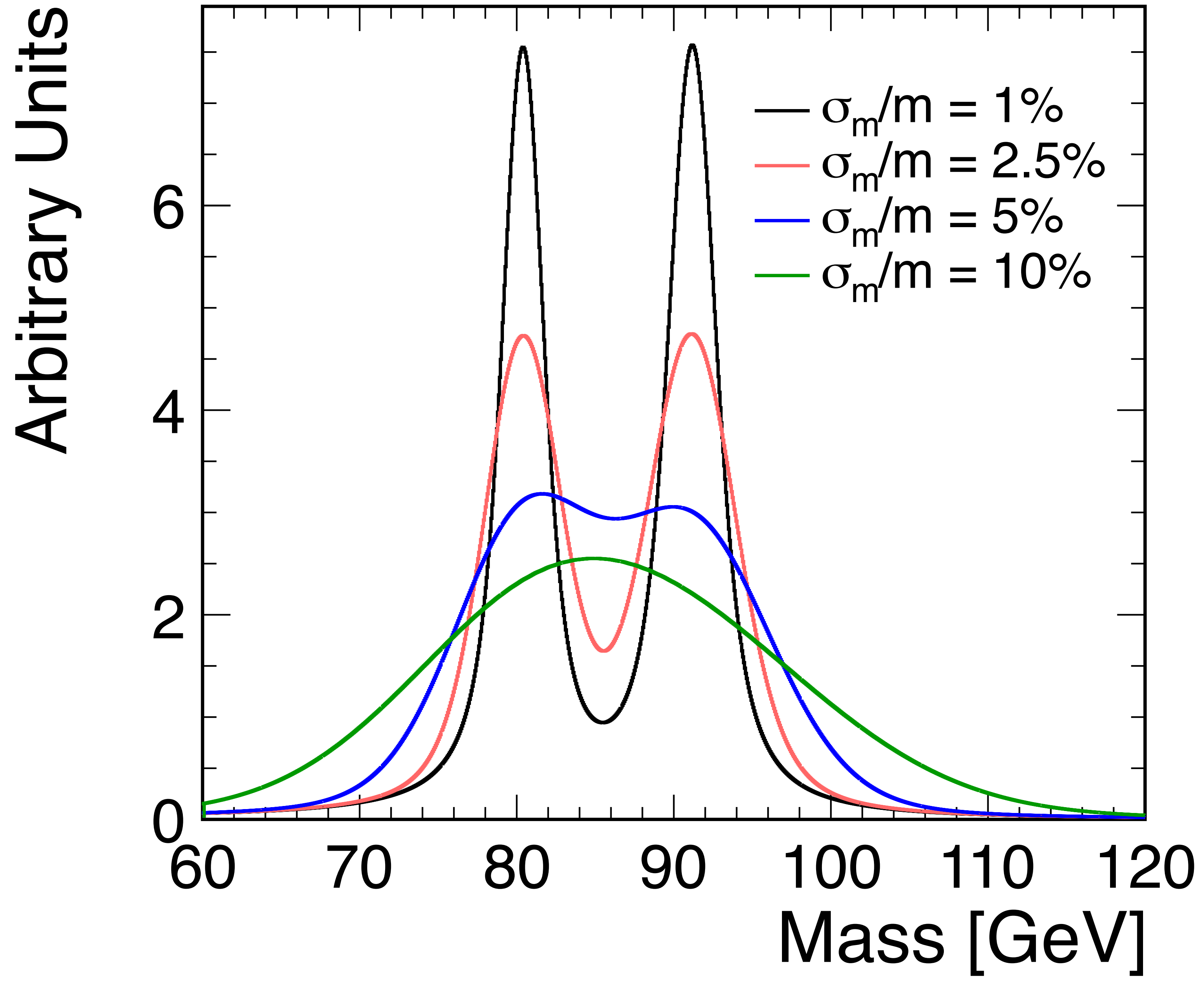
Detectors at lepton colliders

At all of the proposed lepton colliders, there are many similarities between the detector requirements

- Accurate vertex and tracking performance (low mass, precise) - few microns hit resolution
- Excellent mass resolution to distinguish Z and W jets - typically using Particle Flow Analysis (PFA)
- Dedicated calorimeters for luminosity measurements - many measurements rely directly on the beam luminosity

In some cases, particularly calorimetry, there are dedicated hardware R&D collaborations that are pan-experiment





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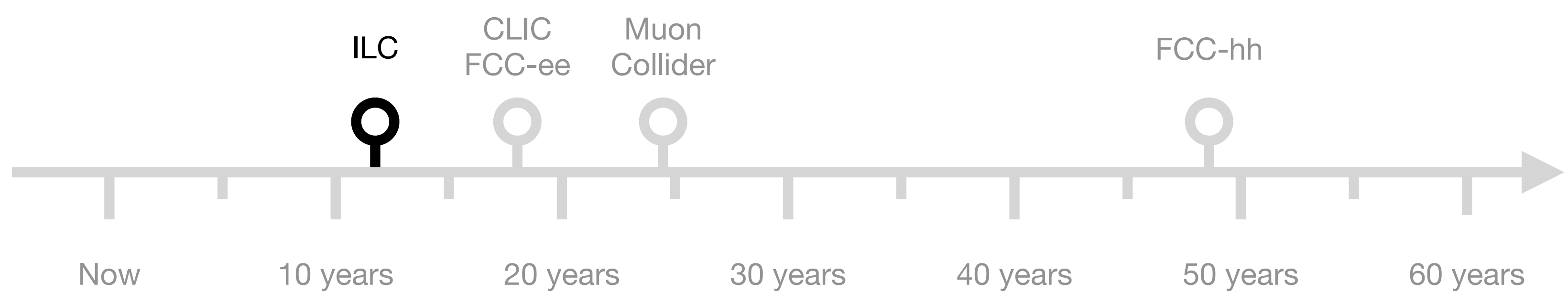
The International Linear Collider

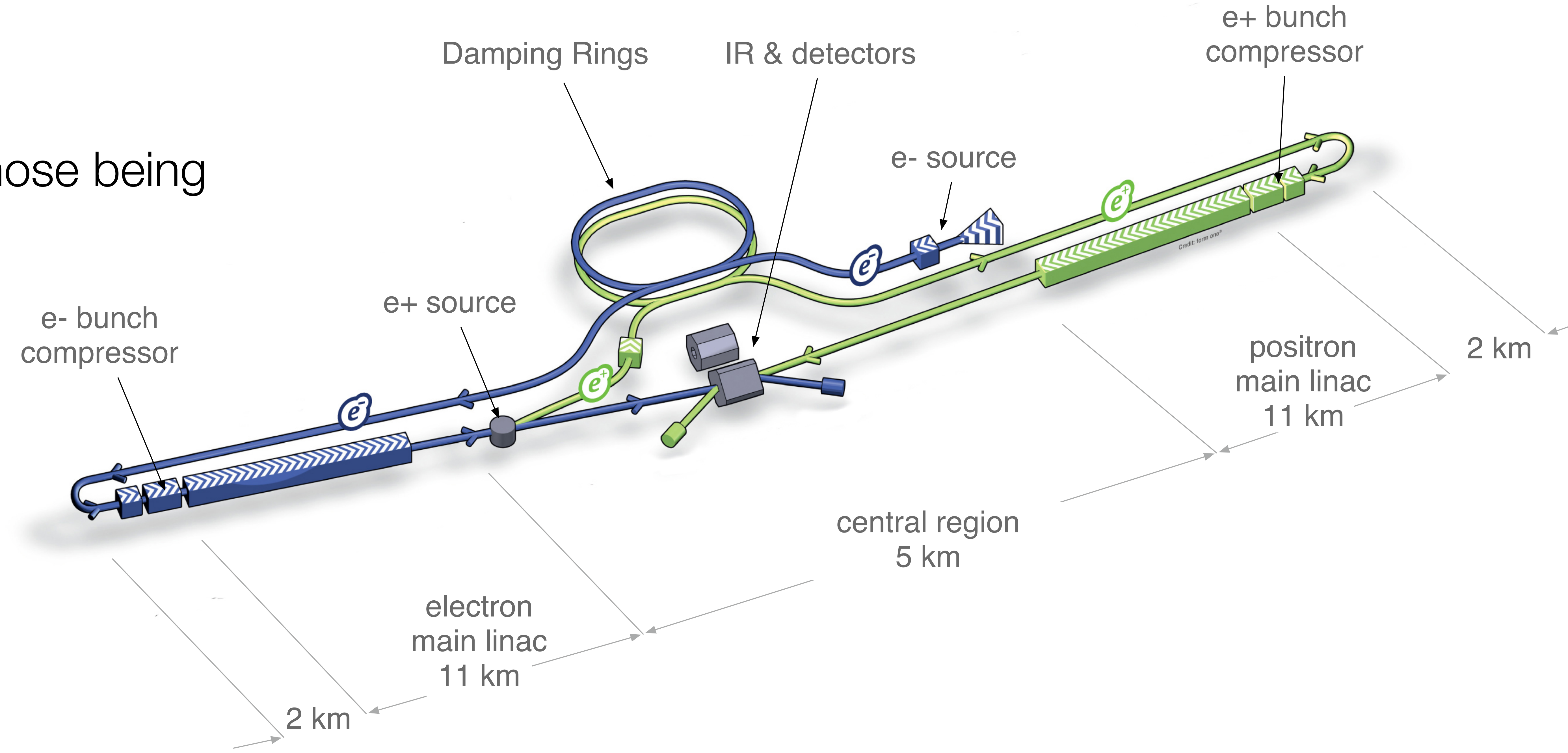


The ILC is the longest-running of the future accelerator options, and has quite a developed array of simulation tools, detector concepts, demonstrators…

- TDR published 10 years ago

The beam conditions for ILC are the most gentle of those being considered

- Bunch train of 727 us, repeated at 5 Hz (bunch spacing 554 ns)
- Integrate over the full bunch crossing, no precision timing, focus on low power
- Two detector concepts at IP



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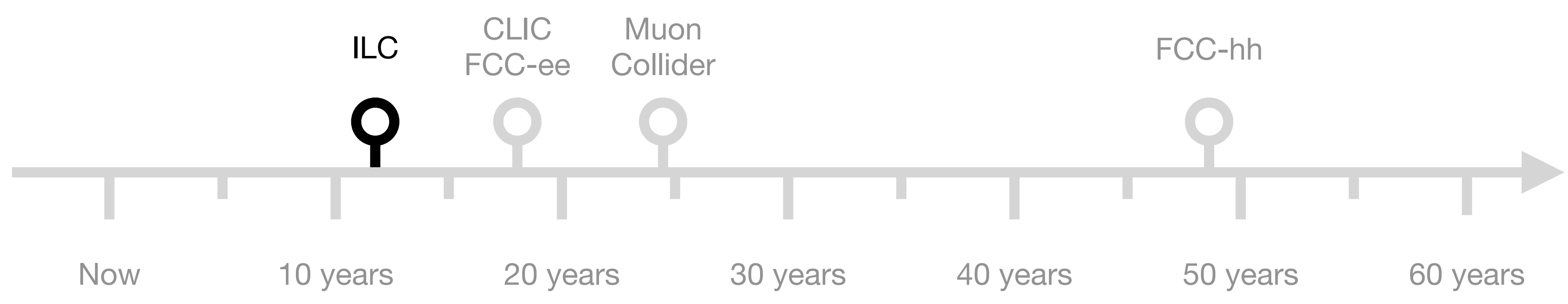

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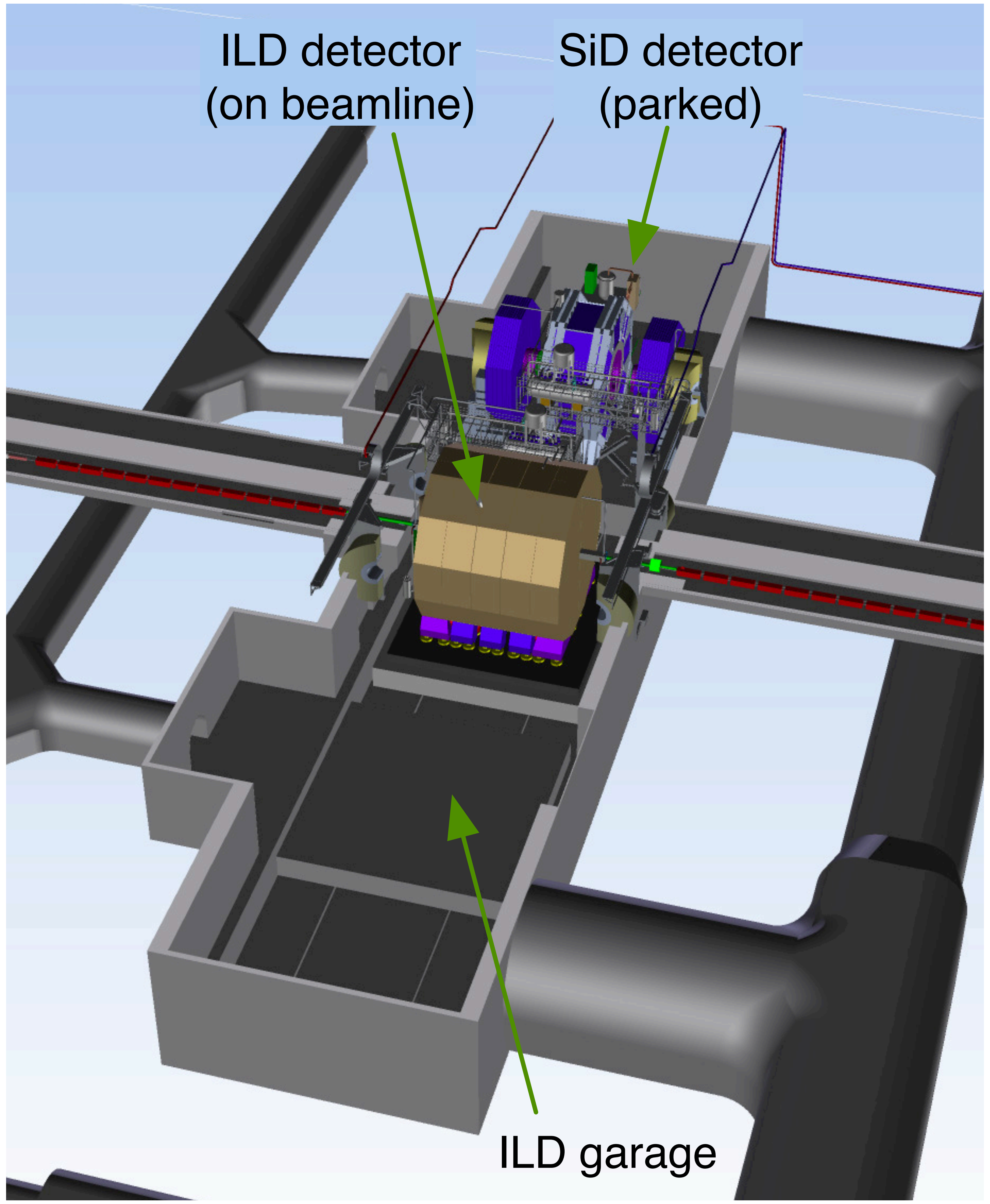
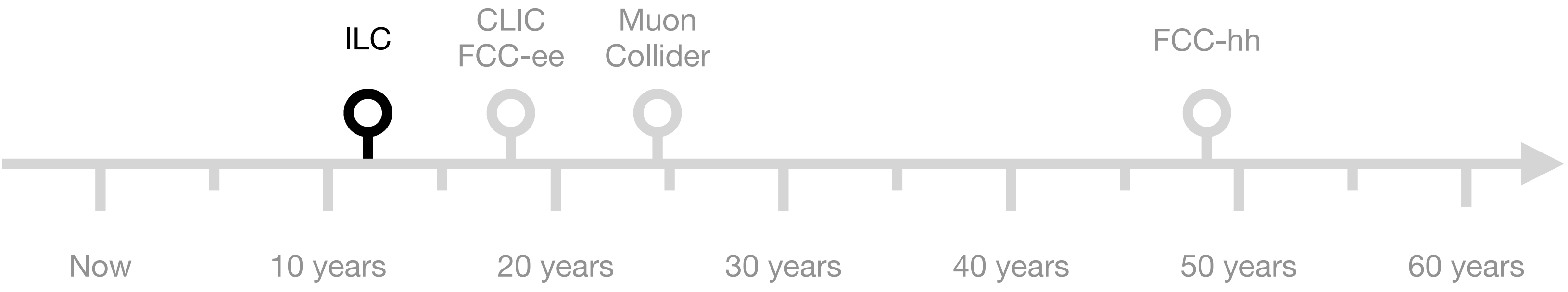
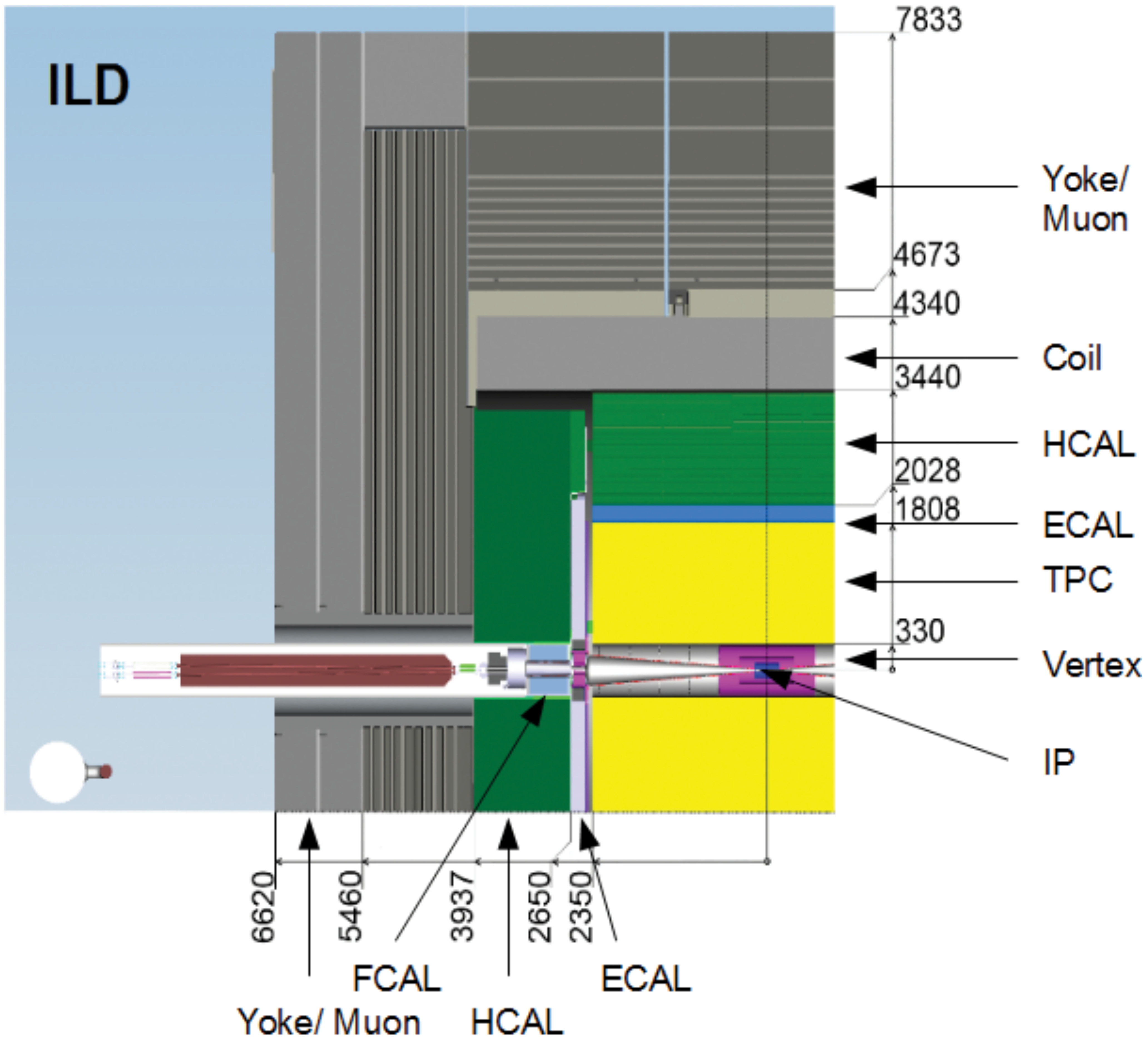
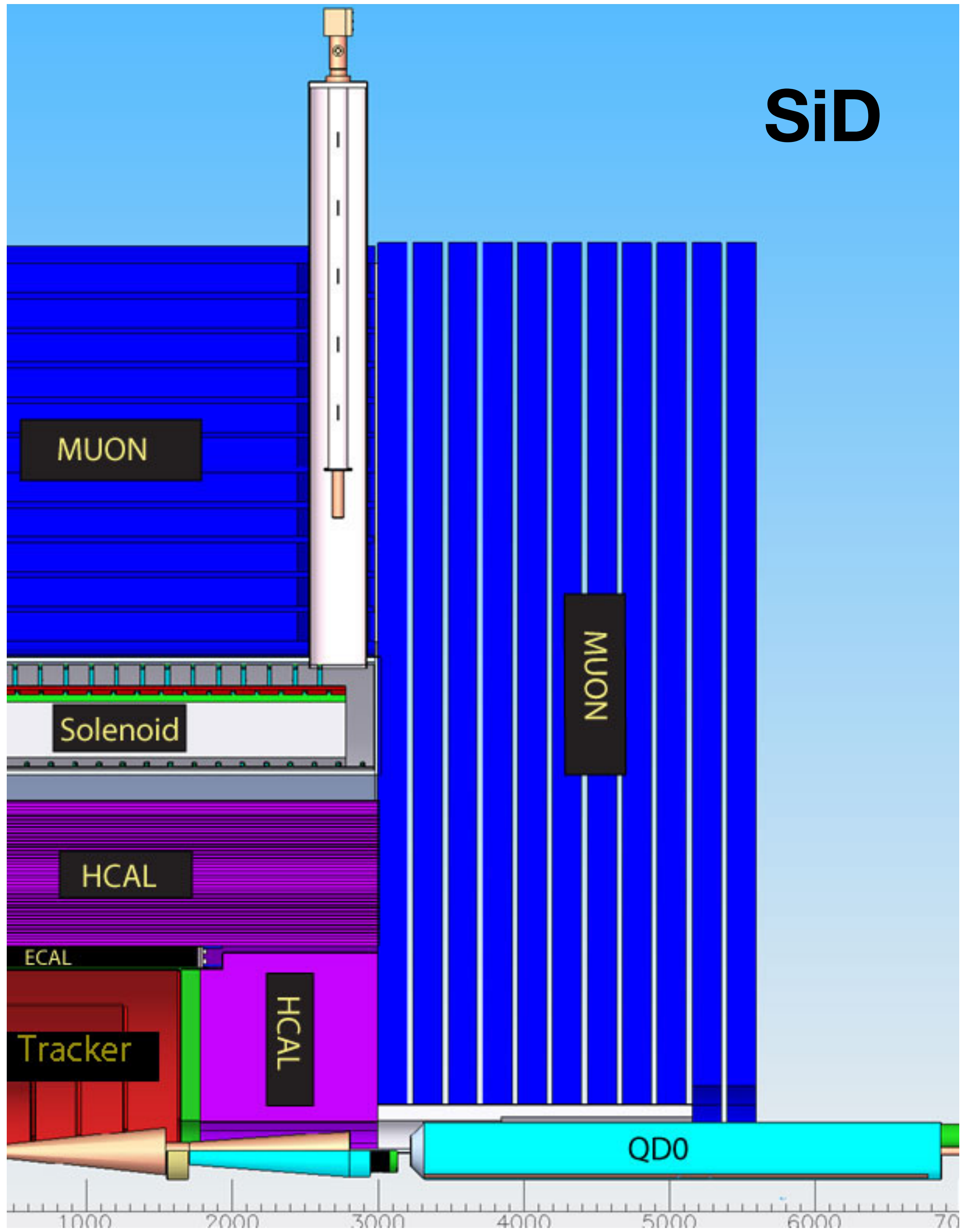


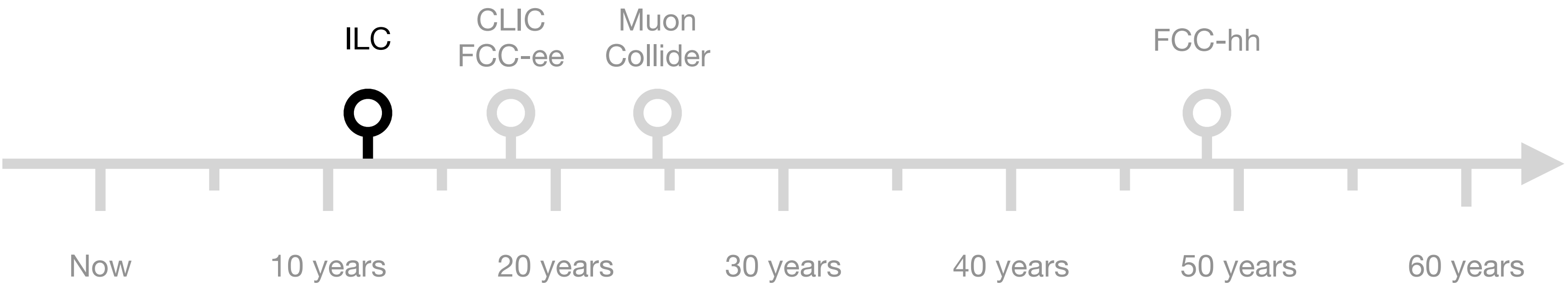
Push me pull you





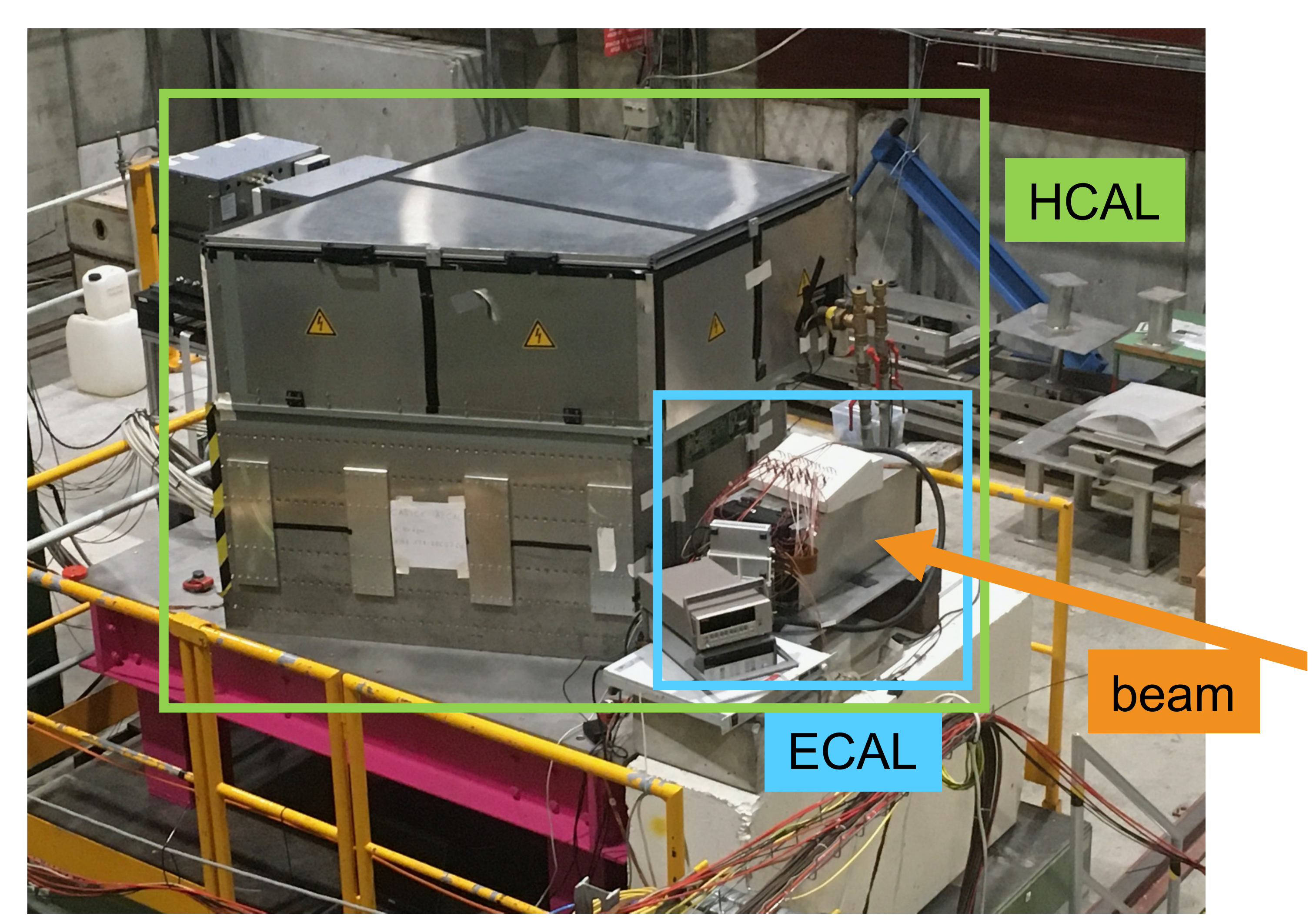


The ILC - a long history of R&D



Detector development for the ILC has a long history - easily 20 years

- As time went on and no project was approved, it morphed into more generic R&D cf. EUDET, AIDA
- Many collaborations on low-mass ladders (PLUME), calorimetry (CALICE), particle flow (PANDORA)
- Low-mass telescopes for testbeams at DESY and CERN - Mimosa family of MAPS detectors



Detector concepts “frozen” long ago, clearly would be re-opened in the event that the ILC was approved

- Most effort has however now moved on, simulation efforts stagnant, not much hope in general

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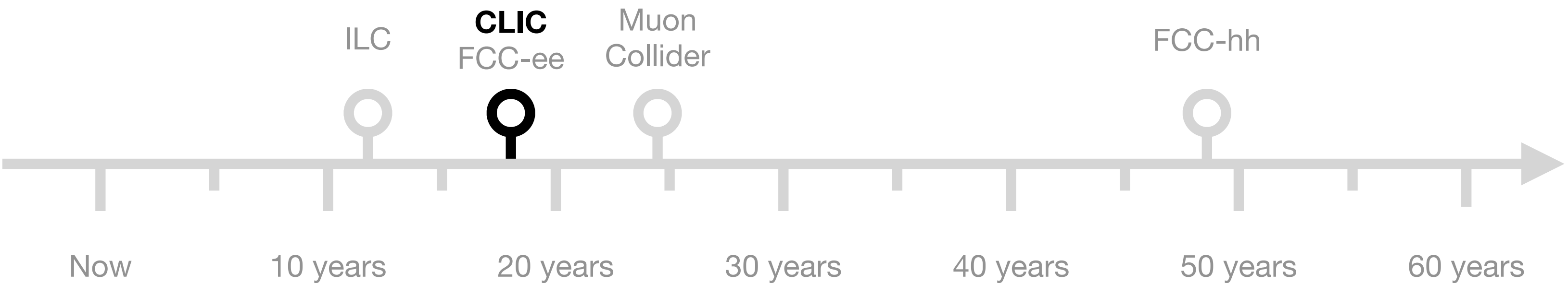
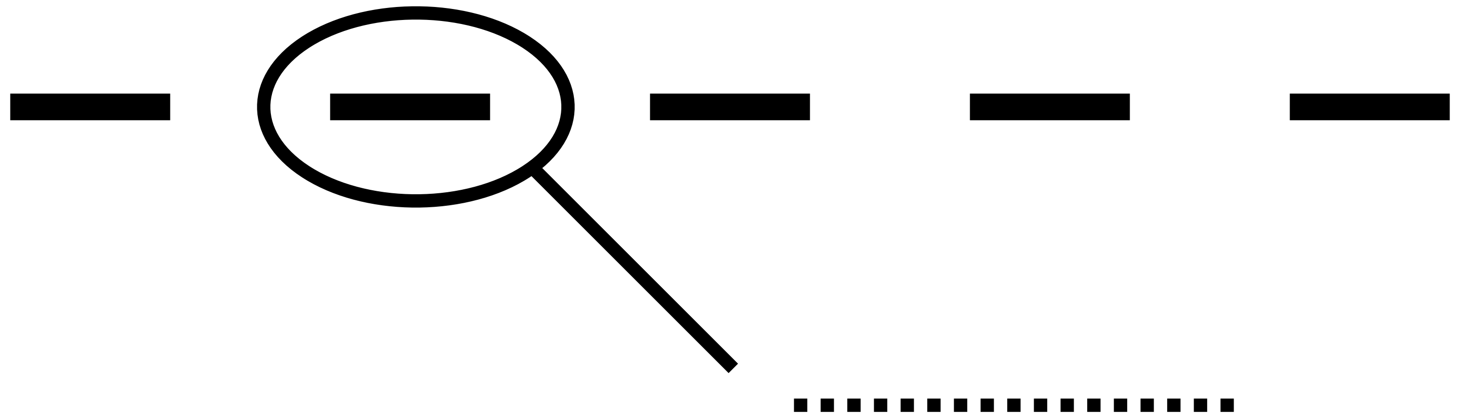
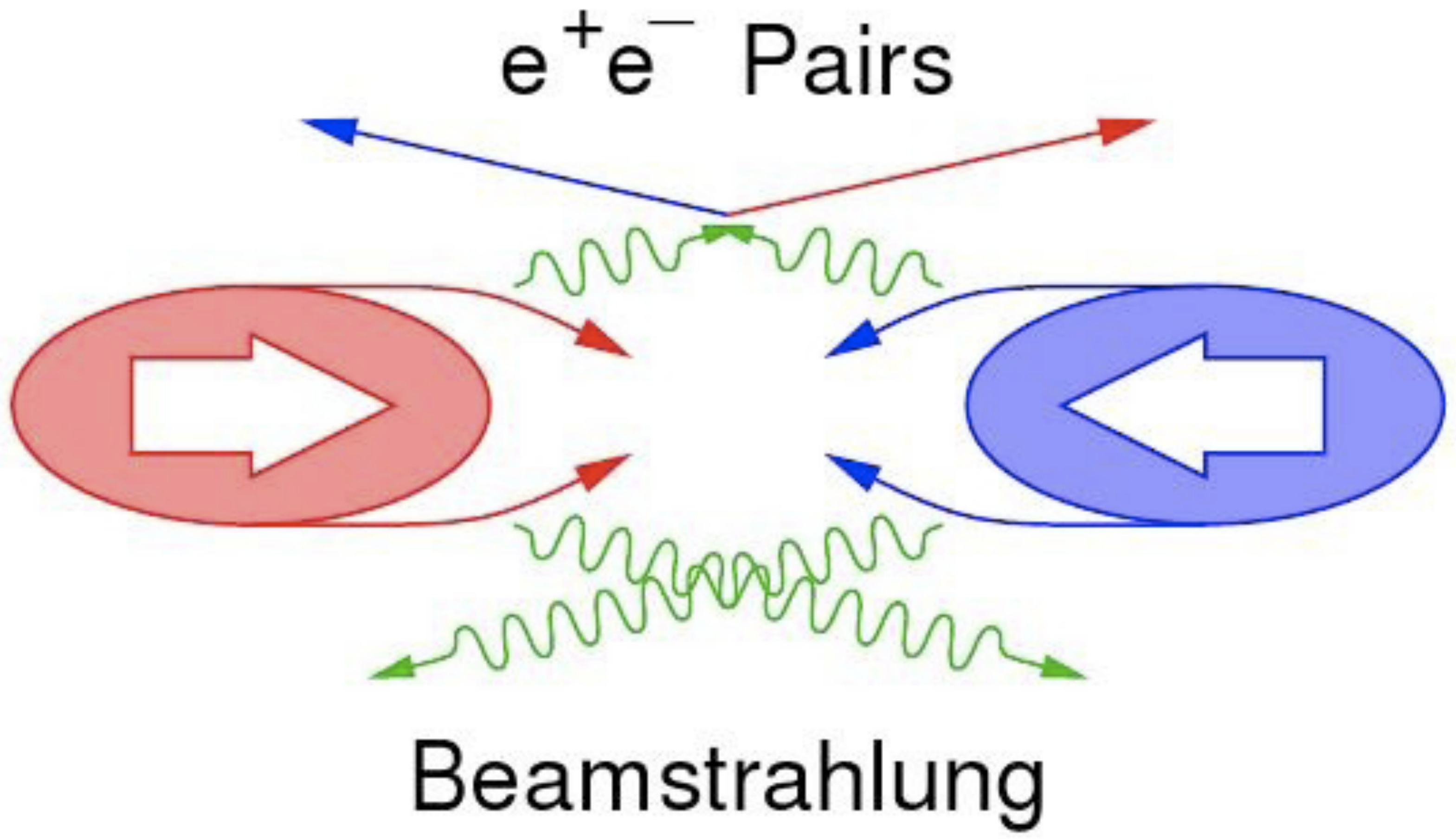


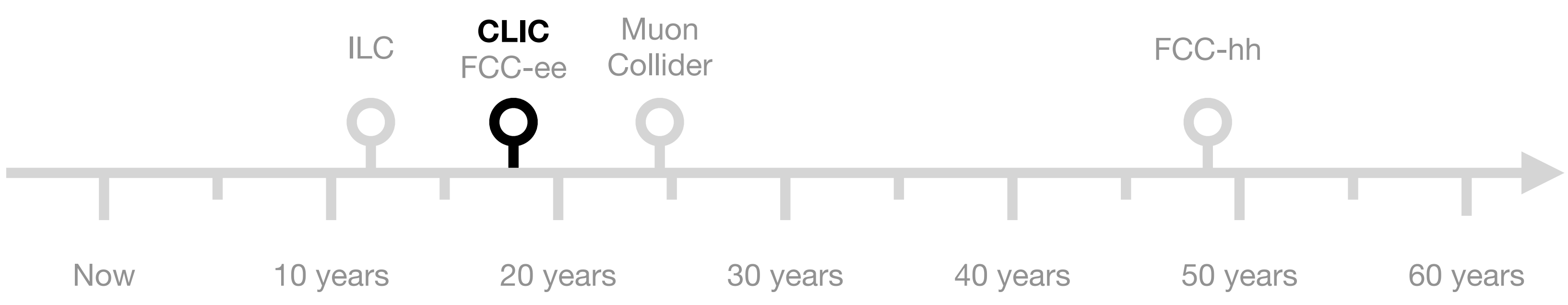
CLIC proposed as the CERN-based linear collider option

- Novel "two-beam acceleration"
- Bunch structure and luminosity goals have a large impact on the detector design
  - Power-pulsing possible for all sub-detectors (turn off for ~20 ms)
  - Beam-induced backgrounds give rise to the need for timing in each layer (10 ns time slices)





The CLIC detector model

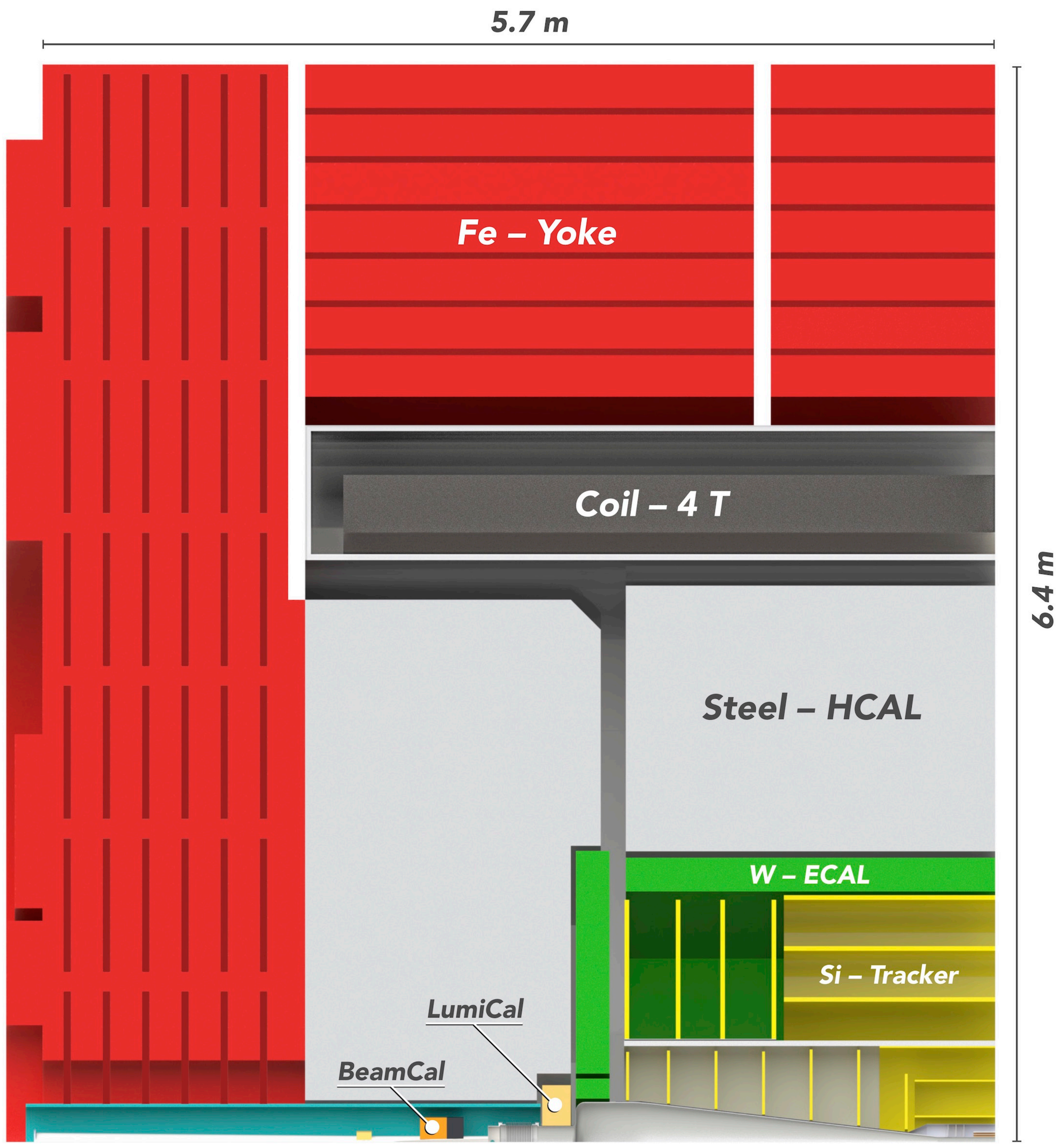


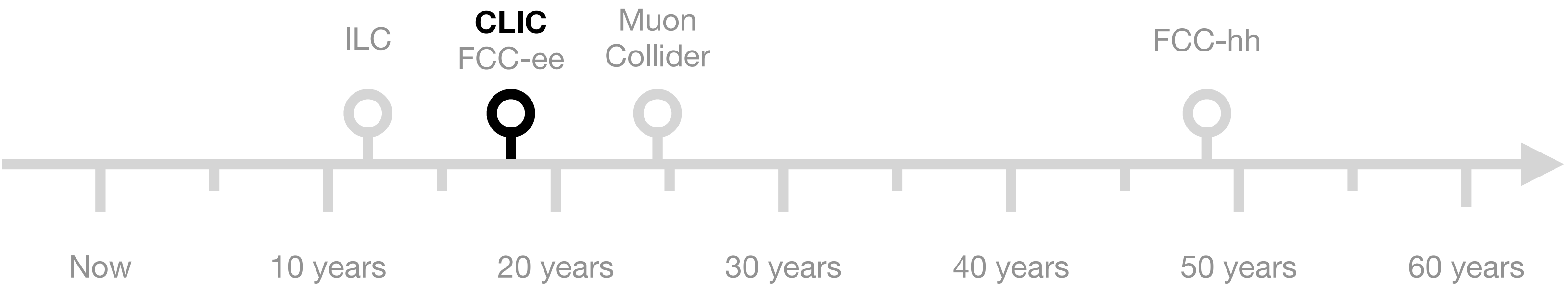
CLIC started with two detector designs inherited from the ILC

- One TPC-based tracker and one with all-silicon tracking

Consolidation of these into a single detector model, CLICdet

- Silicon pixel vertex detector with air cooling
- Monolithic silicon pixel tracker à la ALICE
- Tungsten ECAL
- Steel HCAL
- 4 T solenoid magnet
- Power pulsing on all sub-detectors, everything inside the calorimeter as low-mass as possible

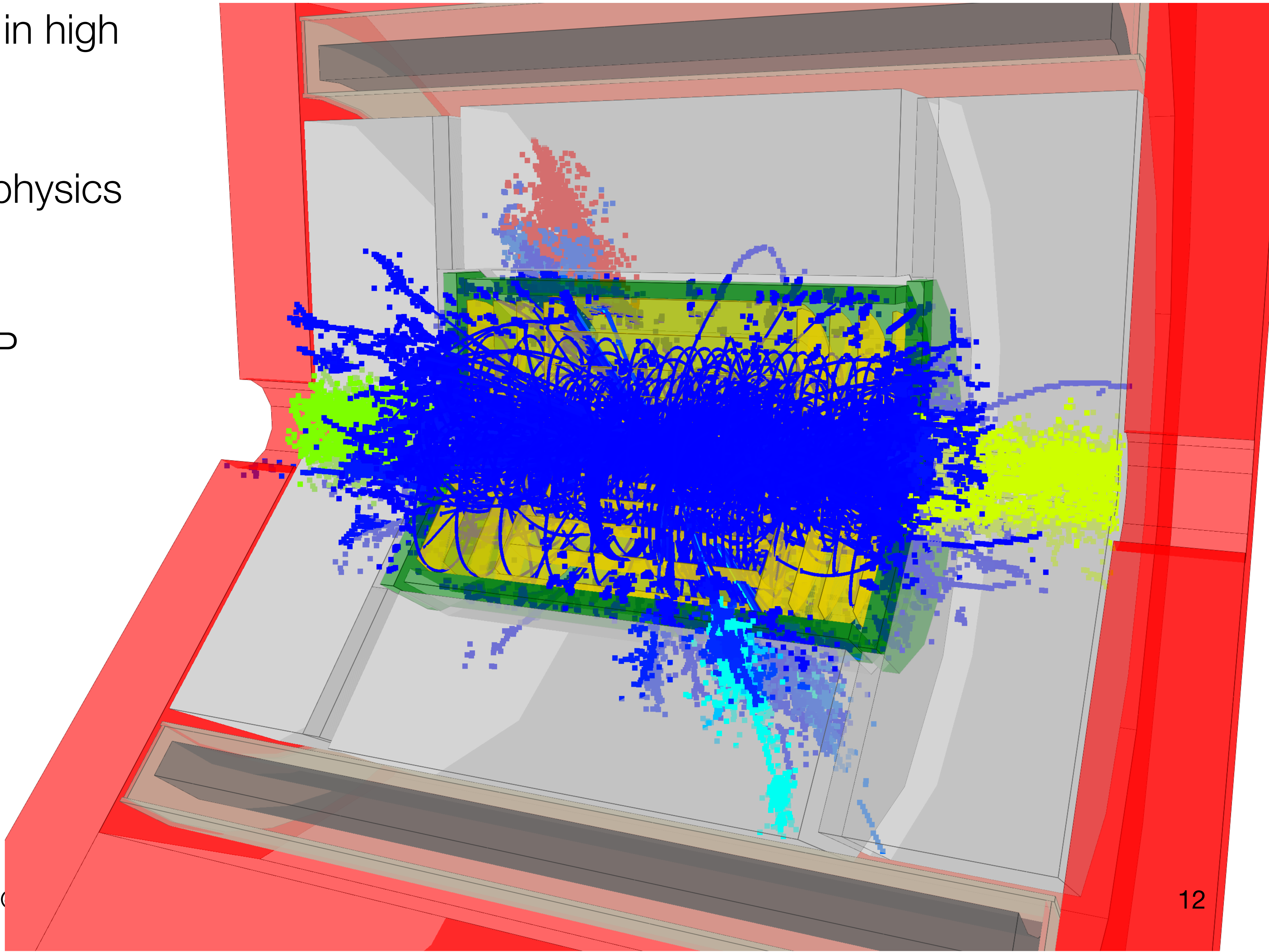




Physics focus and backgrounds

In generating the CDRs (input to European strategy), focus was on physics studies and completing the full simulation chain

- Demonstration of pattern recognition and tracking in high background environment
- Simulated physics analyses showing reach of the physics programme
- Software developed jointly with ILC, using DD4HEP geometry description from LHCb



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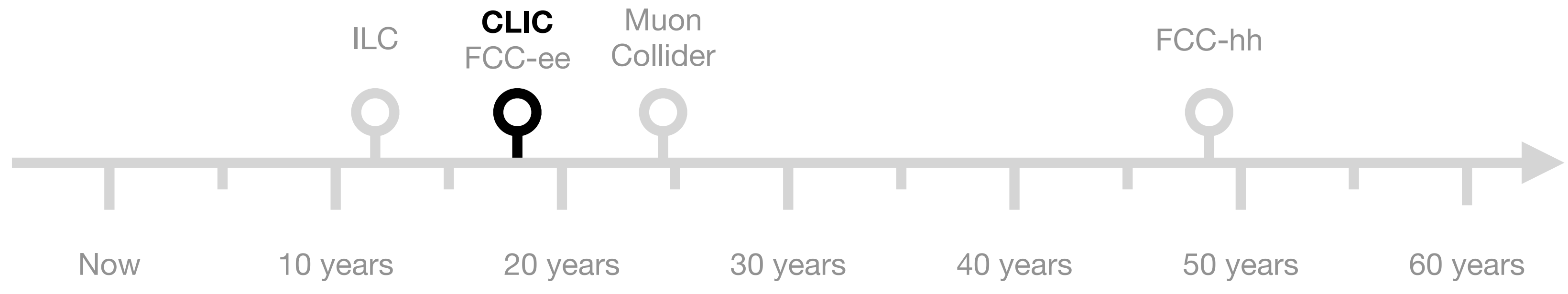

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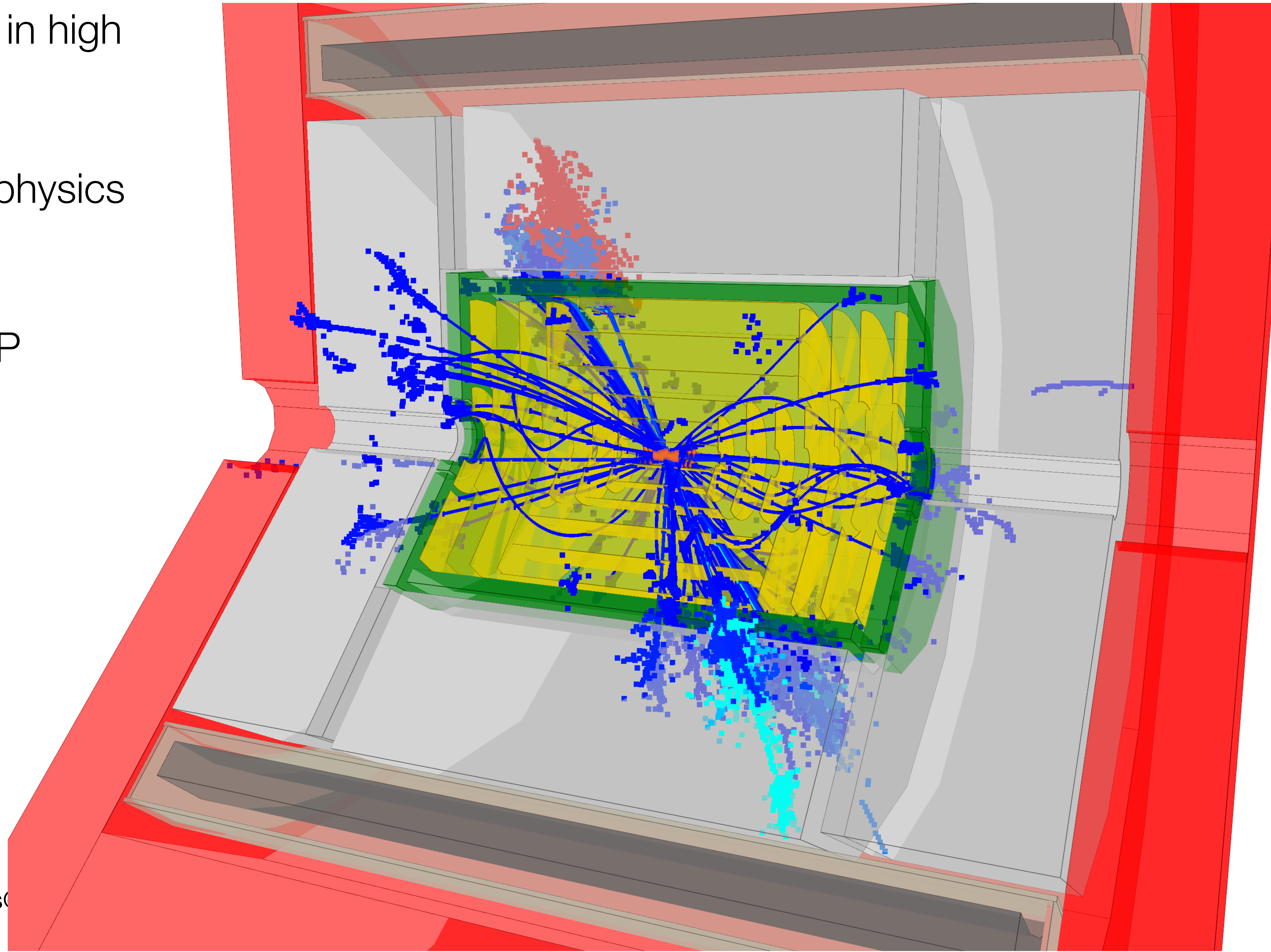

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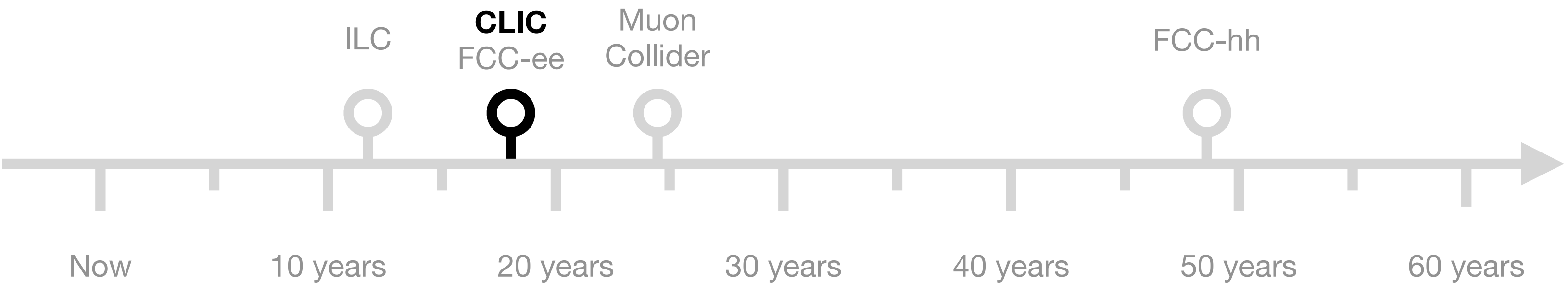

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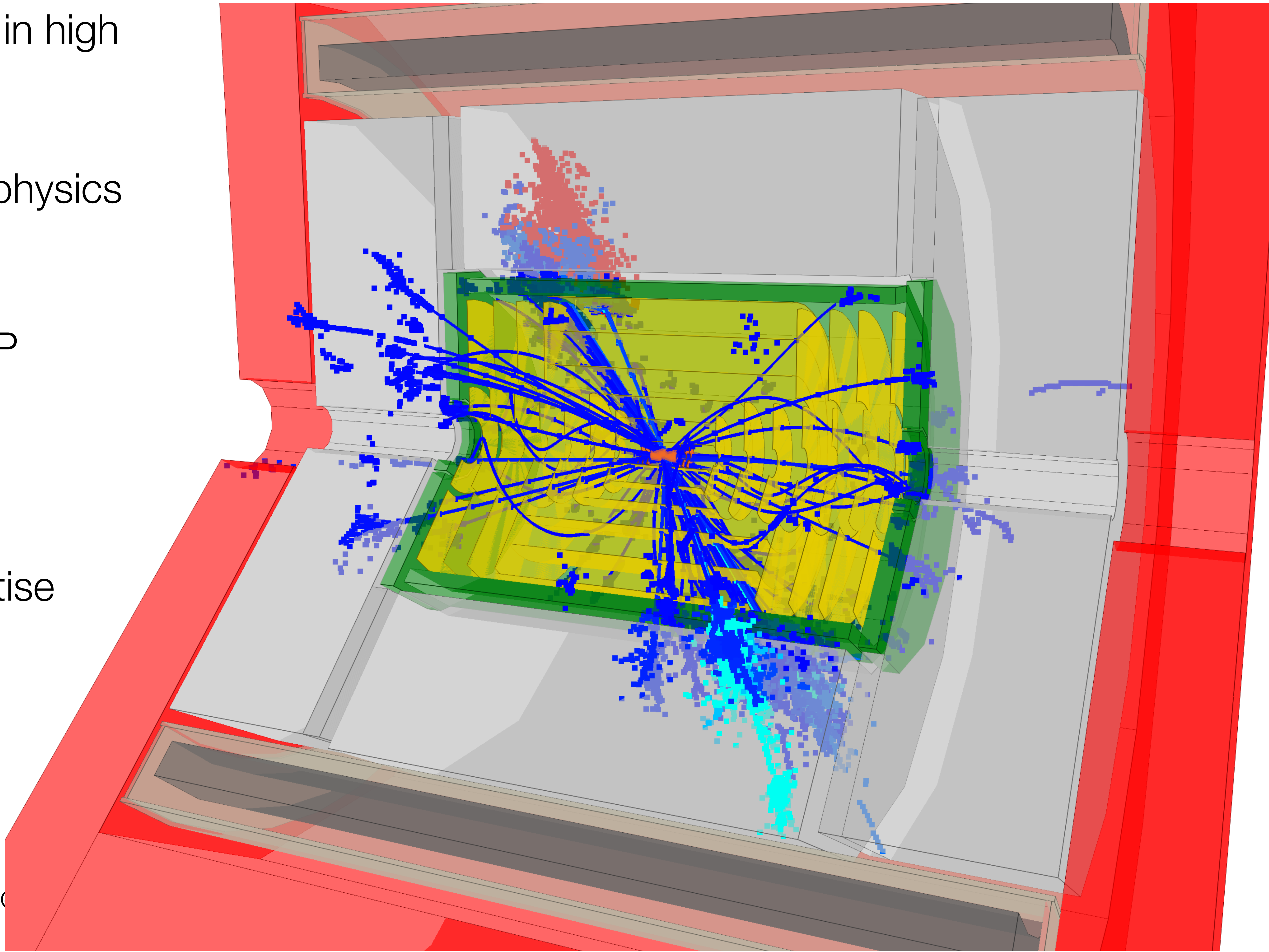
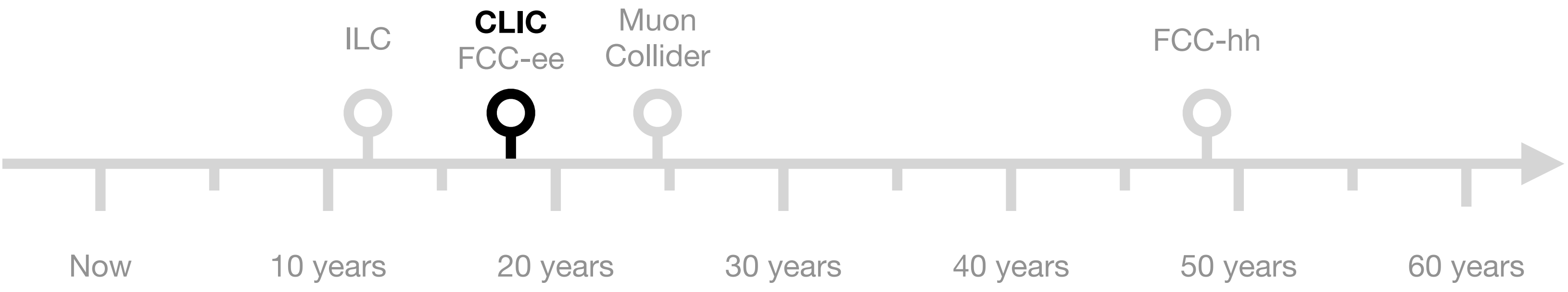
Sadly CLIC was effectively dropped (put on hold) to prioritise FCC feasibility studies

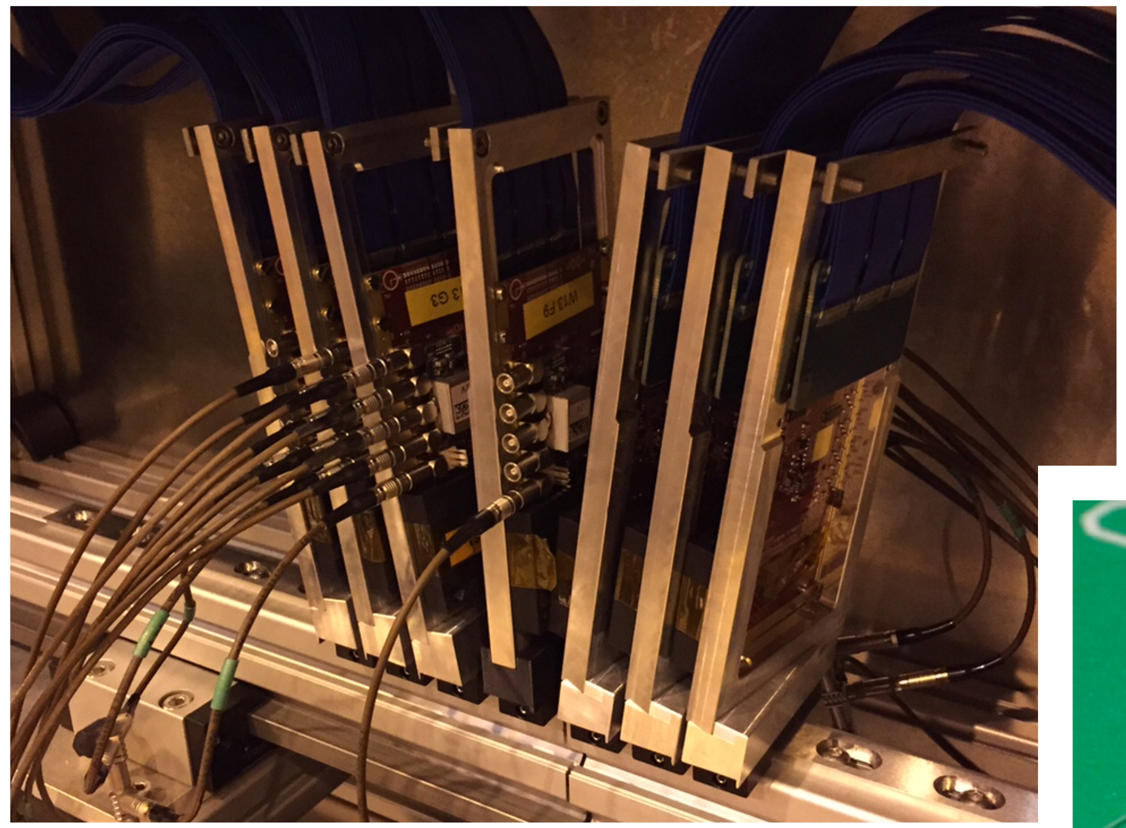


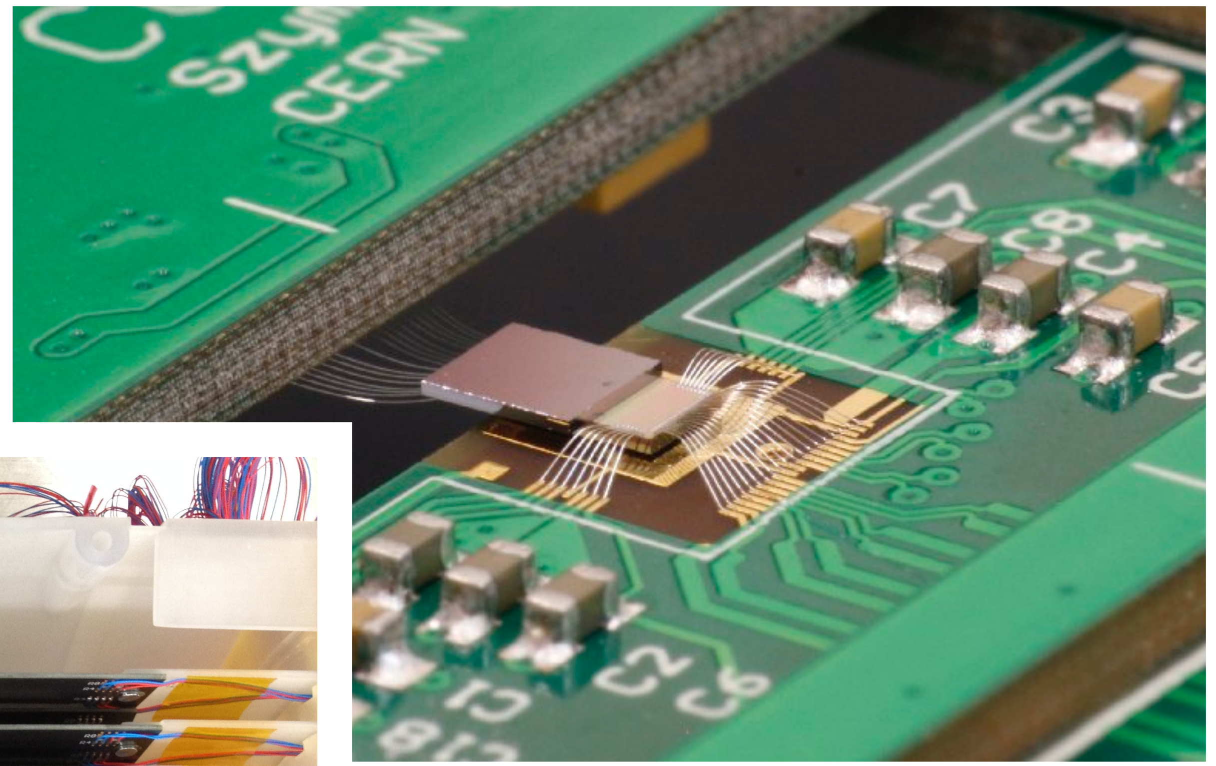


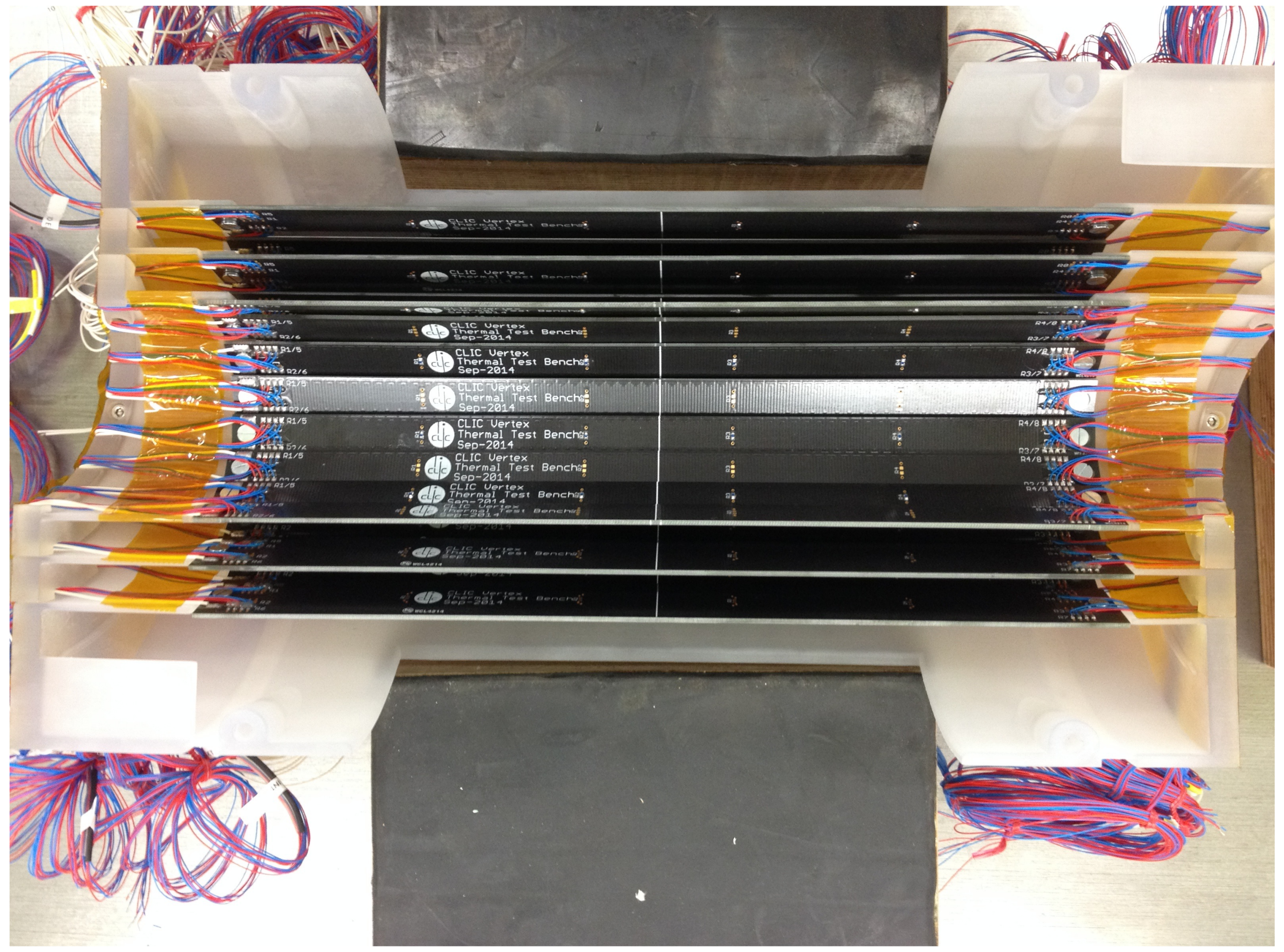
CLIC - recent innovative R&D

Focussed detector R&D aiming to show that construction of the detector was technically feasible if the project would be approved

- Calorimeter design based on CALICE prototyping and experience
- Novel silicon designs pushed by the group, linking up with LHC upgrade projects and others
- Detector simulation packages developed, new concepts pushed and tested
- Effort now expanded in scope as part of the CERN EP R&D programme







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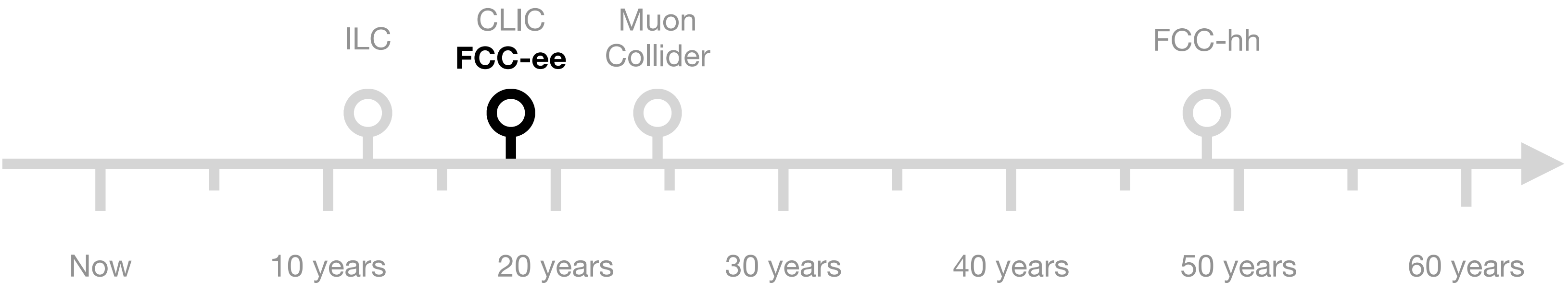
FCC-ee - environment and challenges



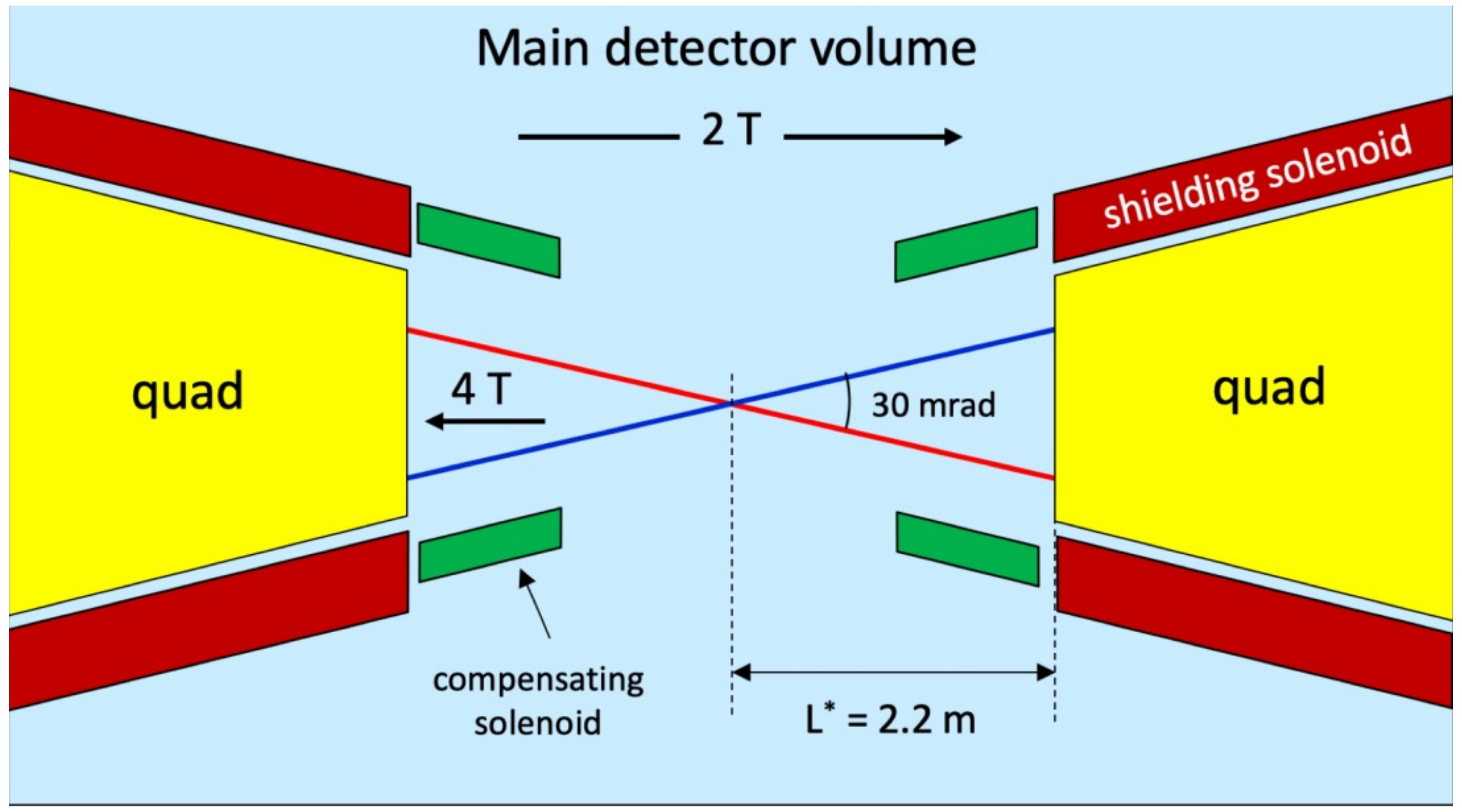
For the FCC-ee backgrounds will look very different from those at the linear collider options

- Synchrotron radiation at low radius
- More spread out in time, generally less serious effect on detector

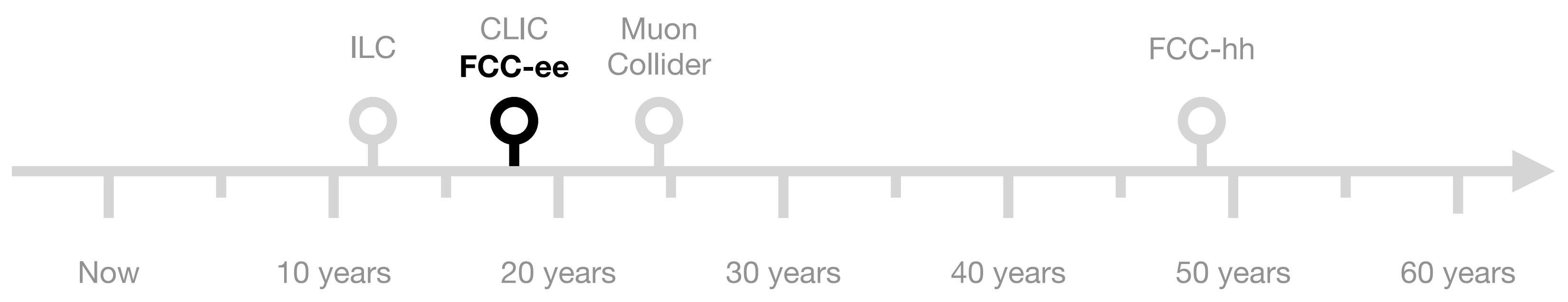
Beam parameters also have quite some impact on detector design

- Crossing angle leads to focussing quadrupoles inside the detector volume => limit on the magnetic field (tracker gets bigger)
- Continuous operation => no power pulsing => active cooling => higher mass

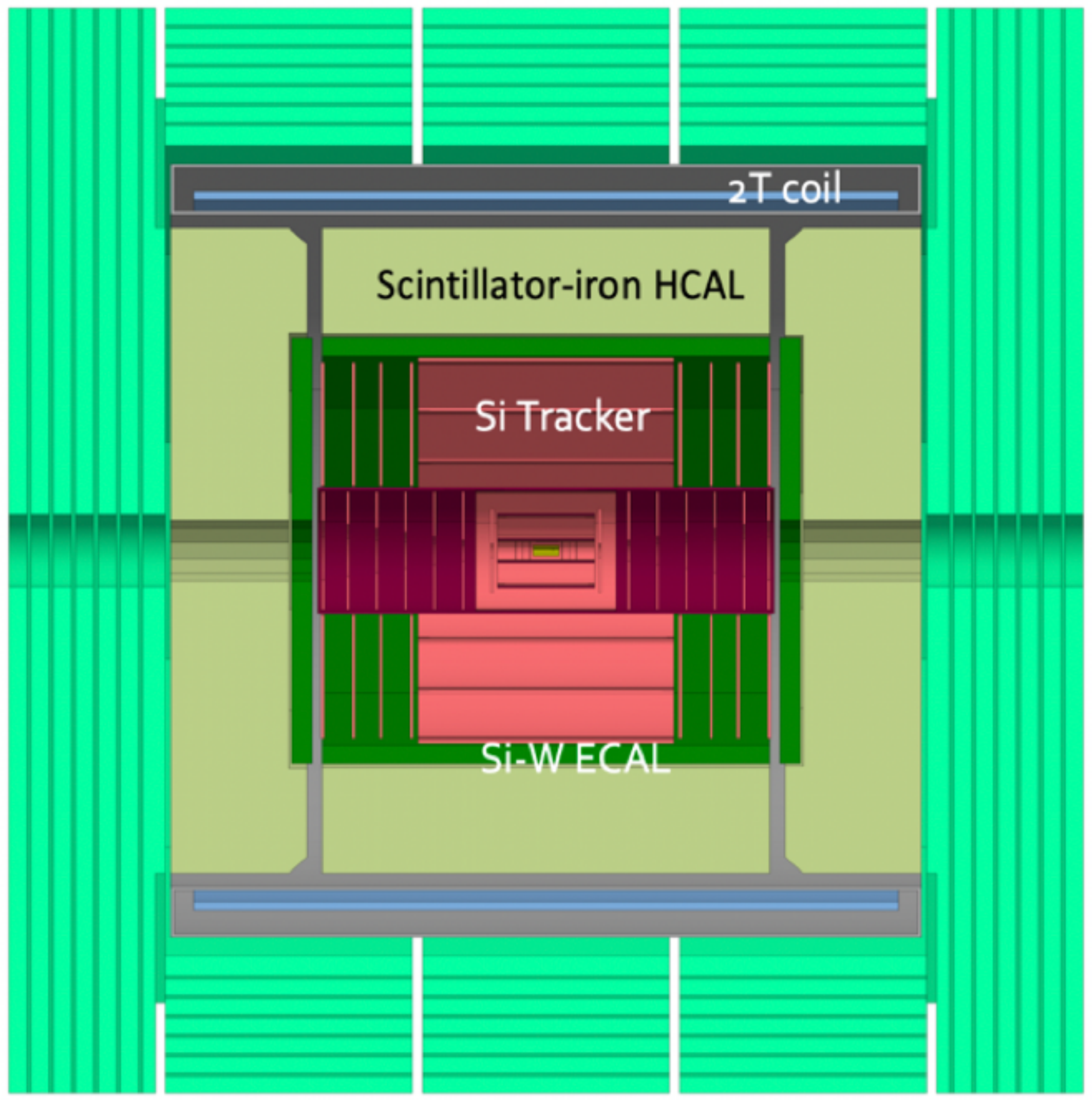
Most R&D on the moment on simulation side, try to define plausible experiments to allow physics studies to go forward ASAP



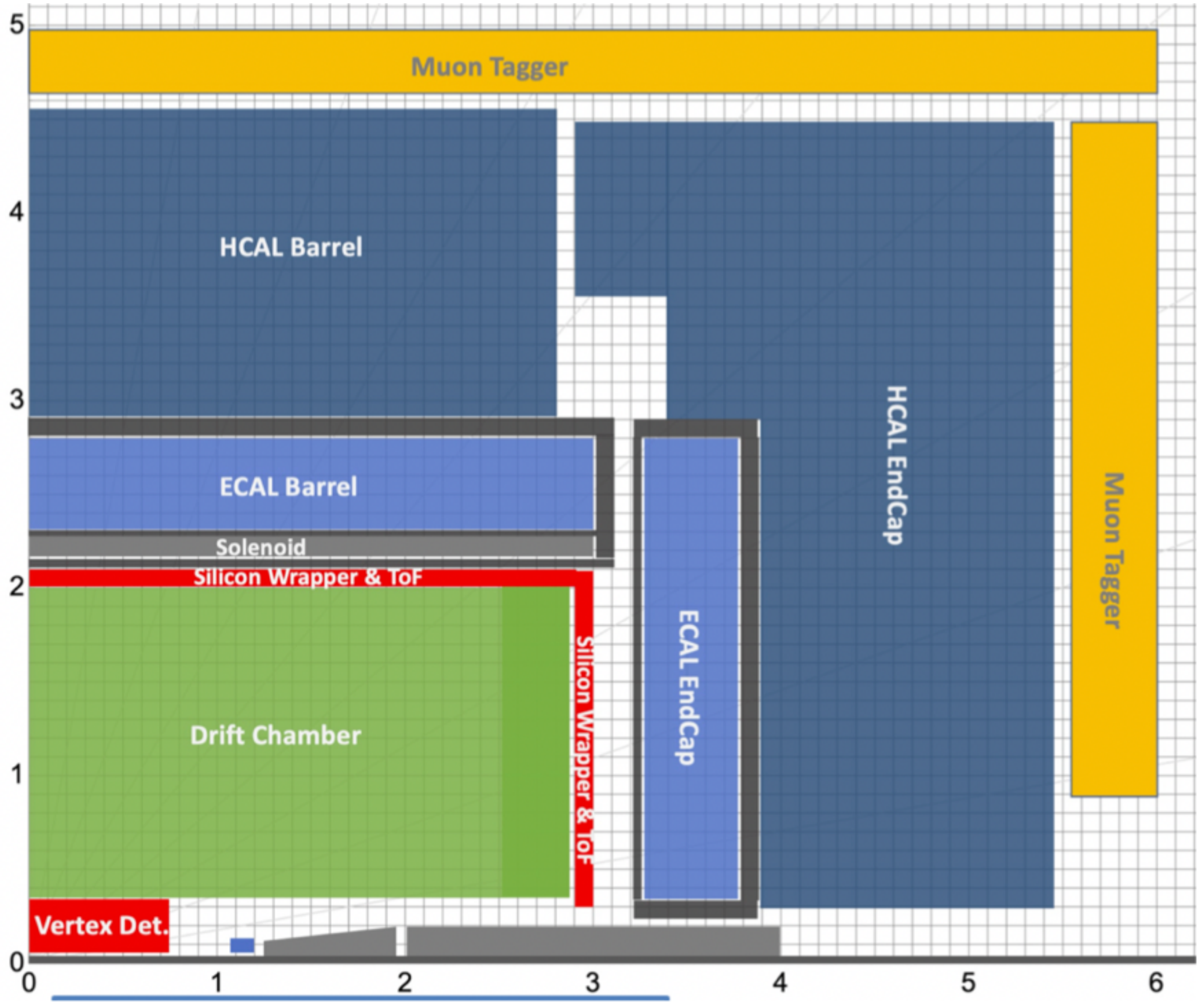
FCC-ee detector concepts



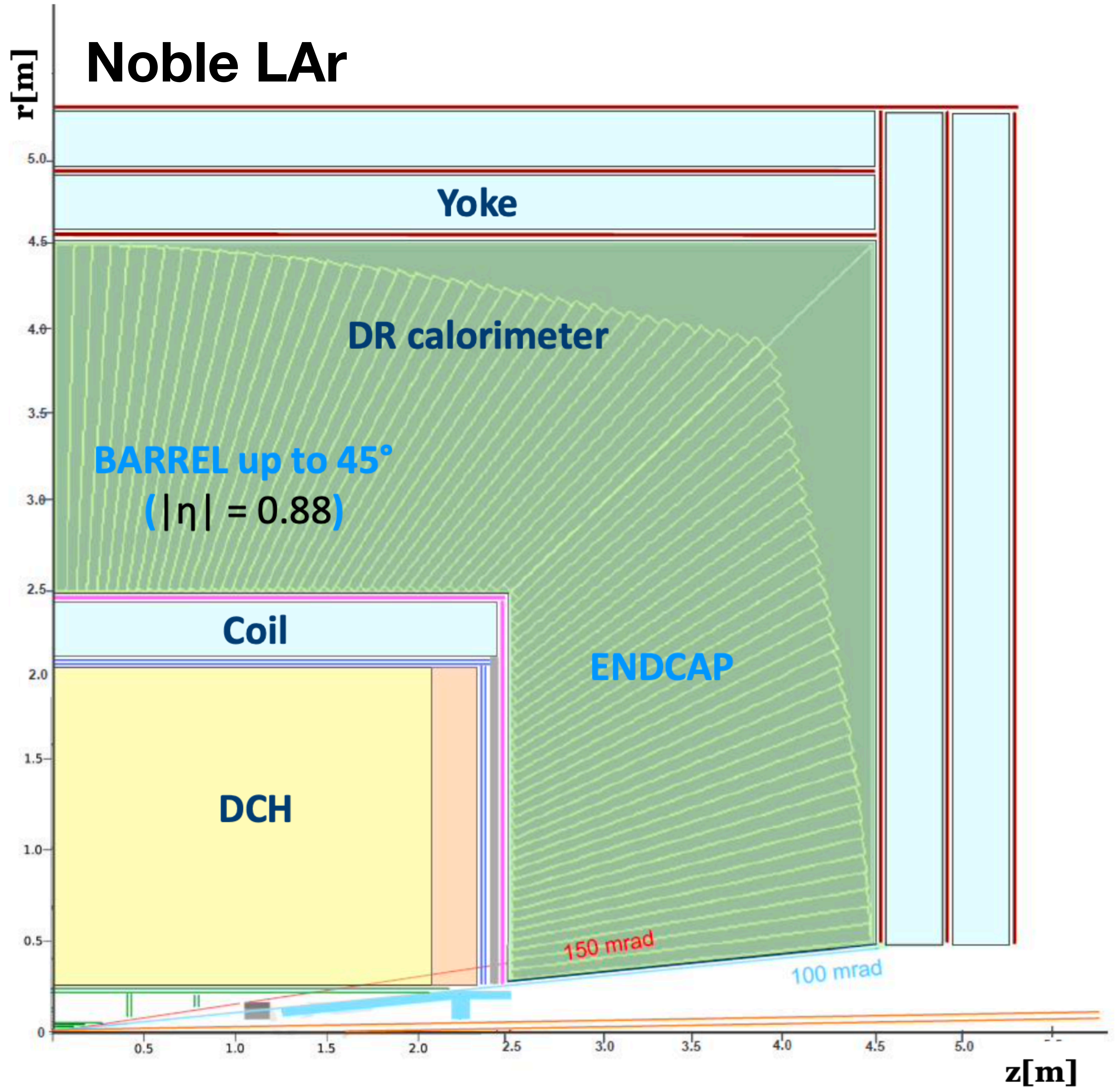
CLD



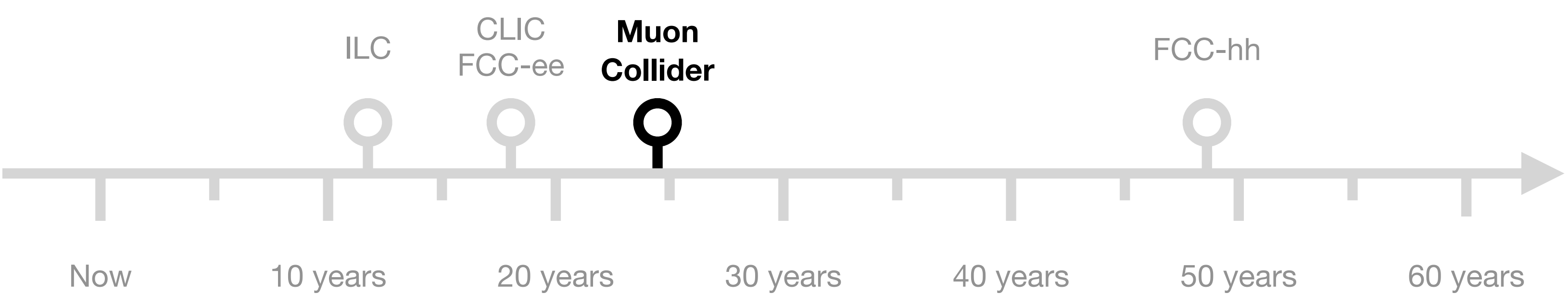
IDEA



Noble LAr

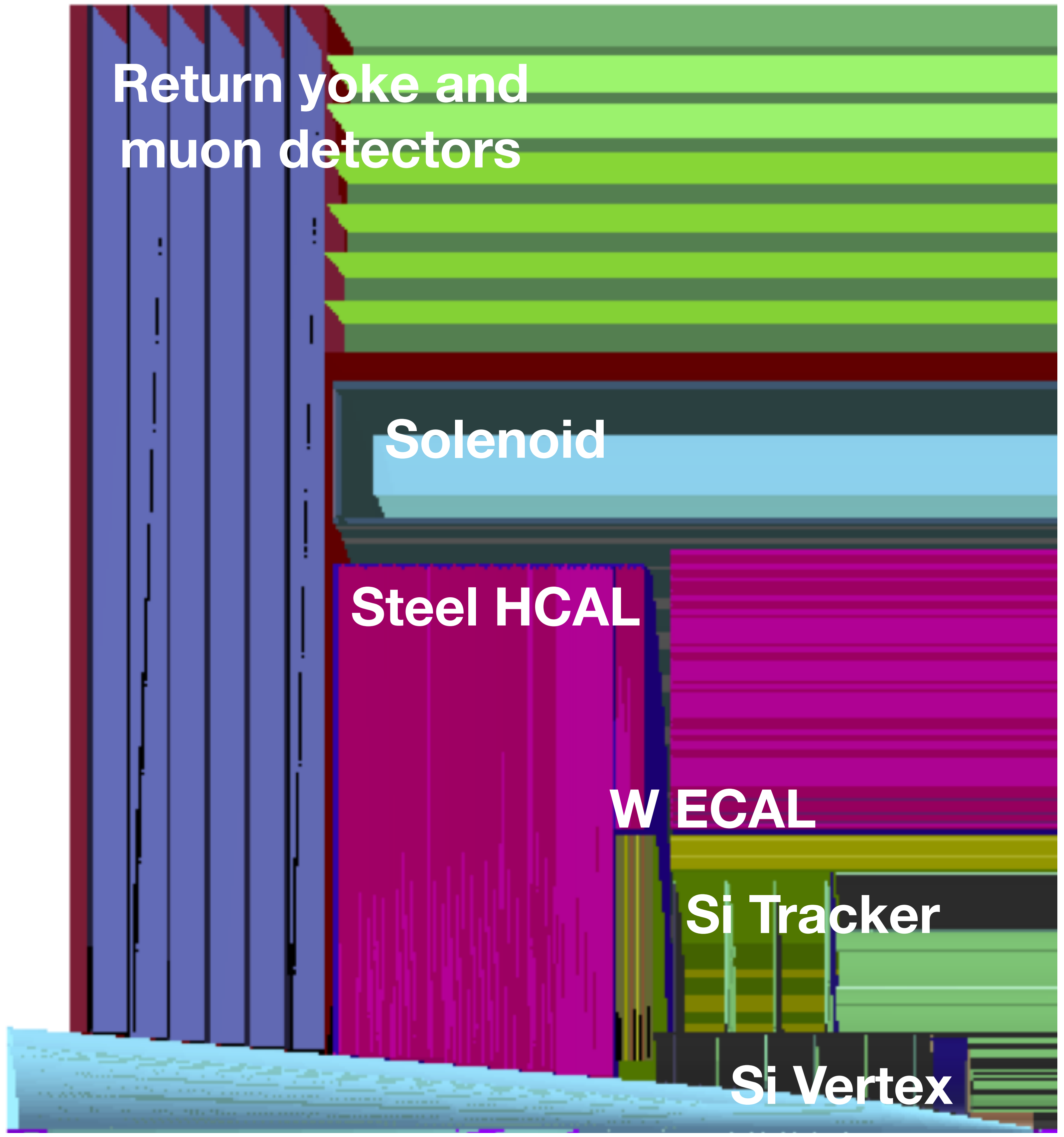


Now for something completely different…

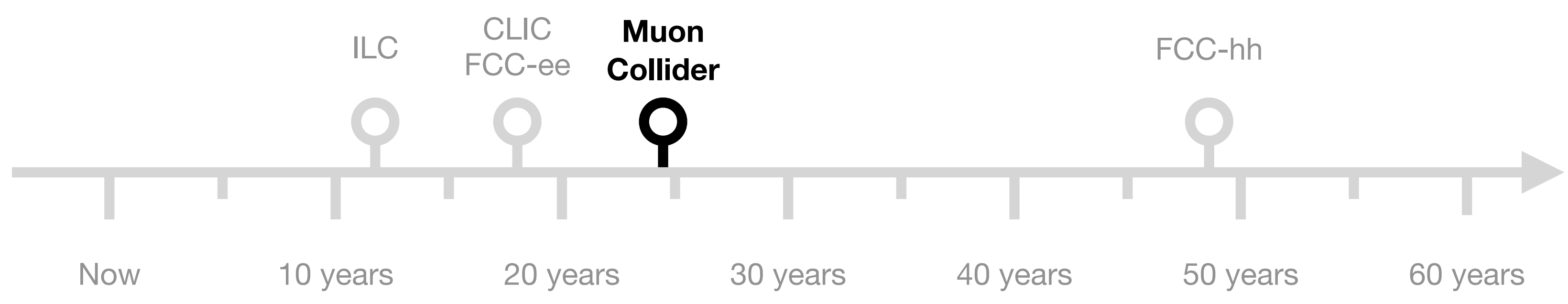


Muon collider options have not been heavily developed - only simulation work and only appearing in the last few years

- No dedicated hardware developments
- Detector design strongly based on CLIC and using LC simulation framework
- Intention is to show that precision measurements are possible



Muon collider challenges

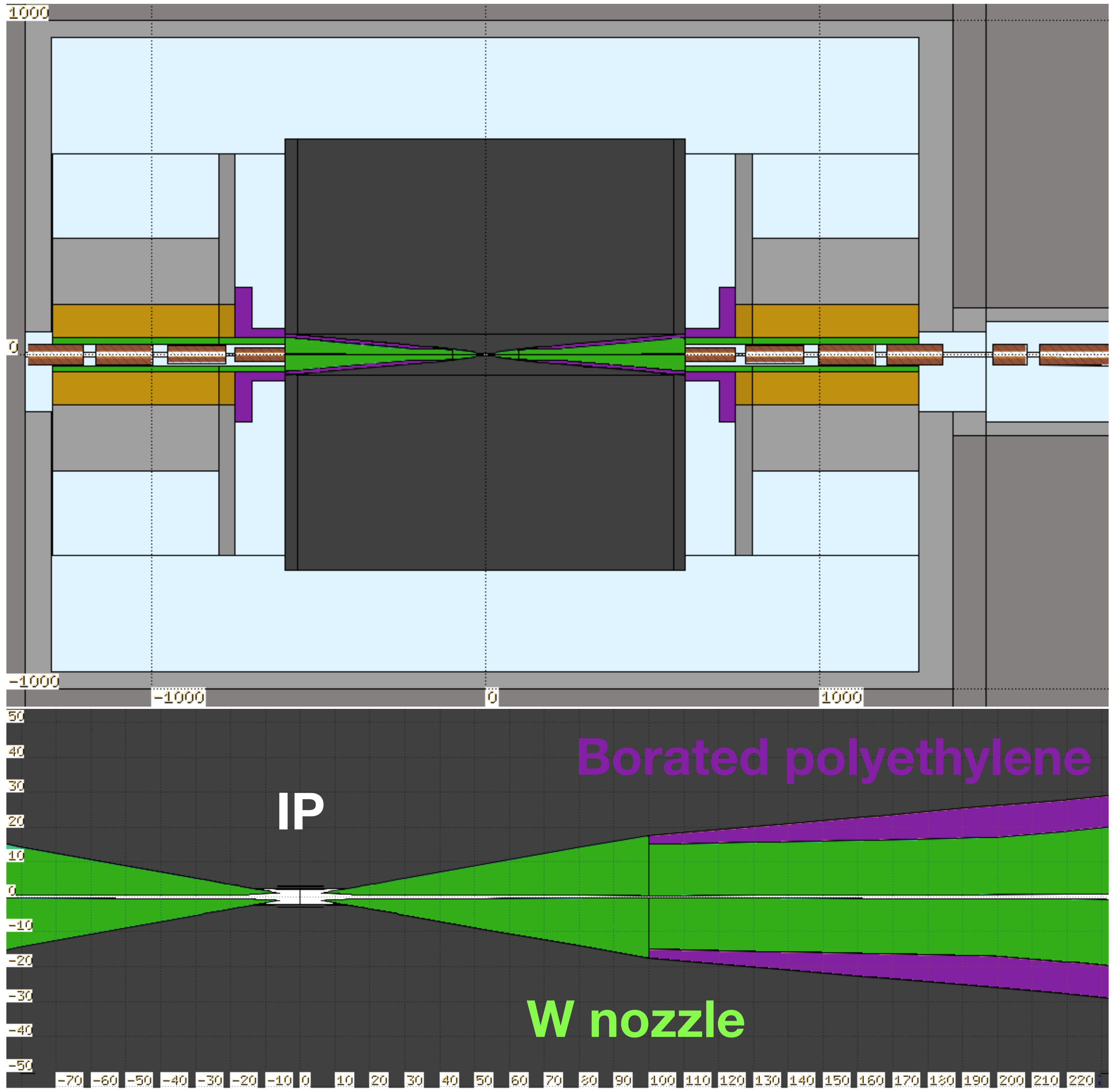


The main difference compared with linear e^+e^- machines is the beam-induced background due to muon decays

- Bunch contains 2×10^{12} muons => 4×10^5 decays per metre
- In a single bunch crossing 4×10^8 particles background
- Low momentum decay products, origin displaced from beam axis, asynchronous arrival time

Machine Detector Interface (MDI) much heavier to try and filter out these backgrounds

- Tungsten nozzles covered with borated polyethylene (BCH)
- Significant timing requirements placed on all detectors



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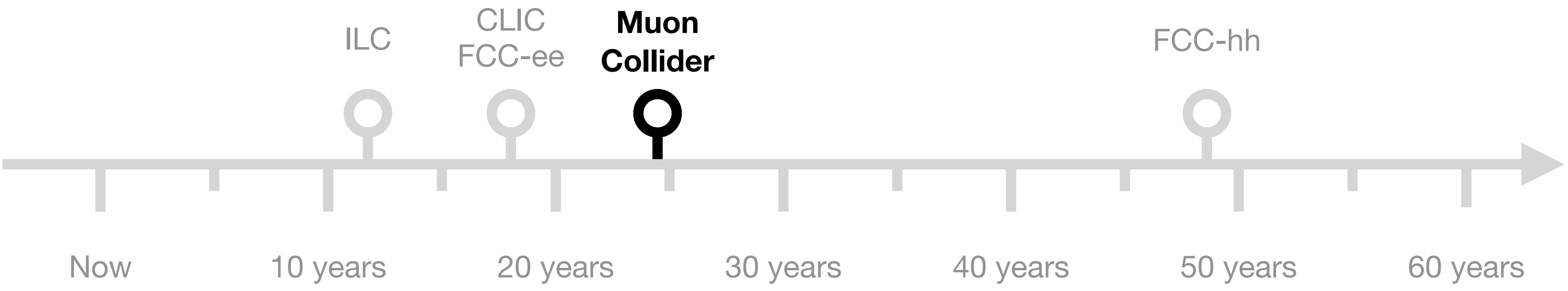
Muon collider challenges



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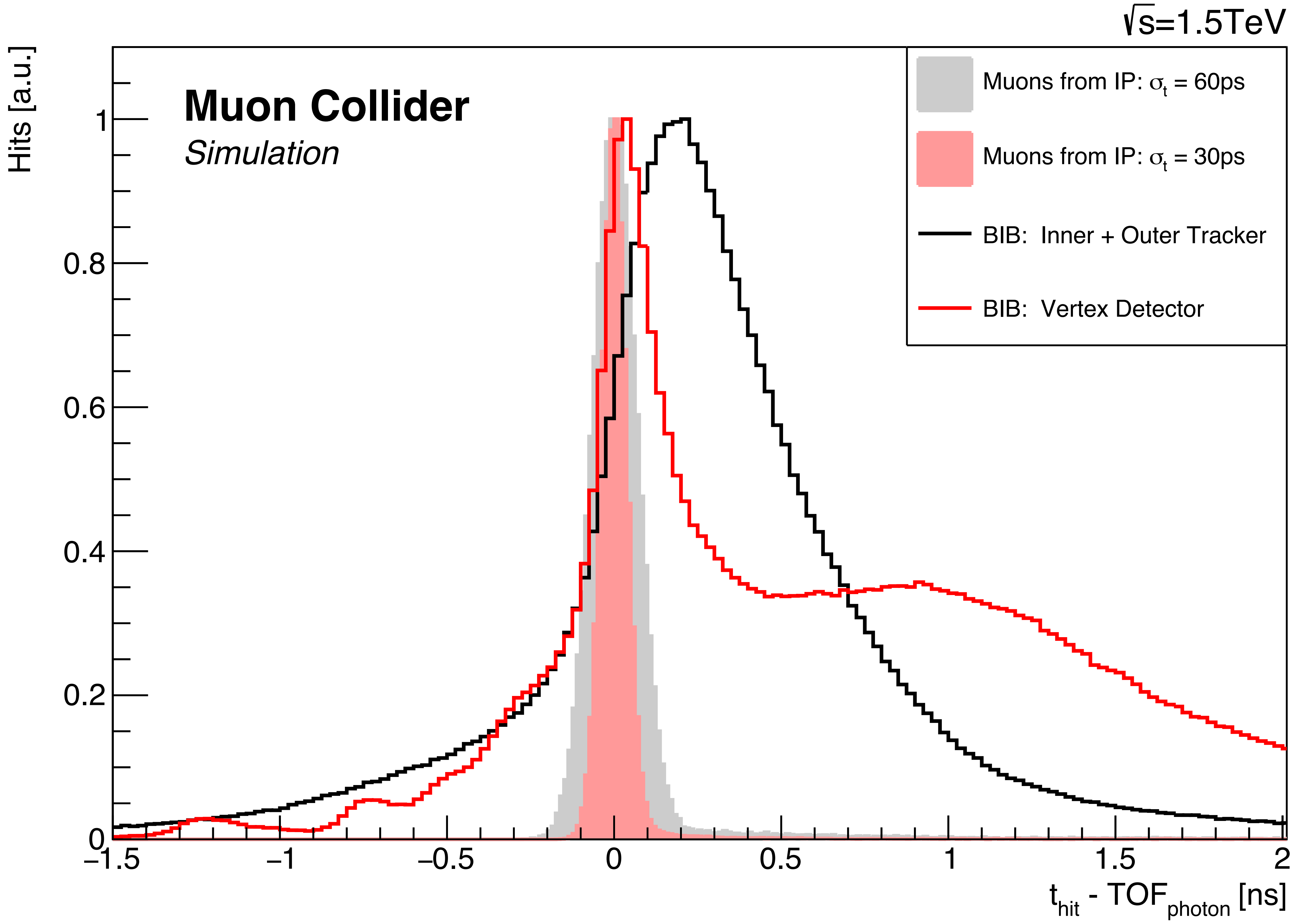
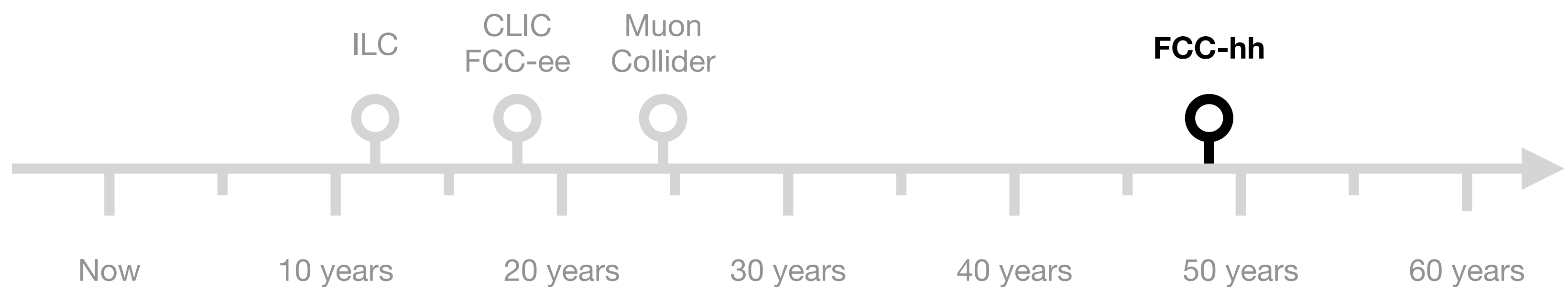


FCC-hh - environment and challenges



Initial designs of FCC-hh detector were HUGE

- Involvement mostly from ATLAS and CMS community, building on ACTS rather than LC software
- Sensible approach a few years ago: set overall budget of 1B Swiss and see what could be built

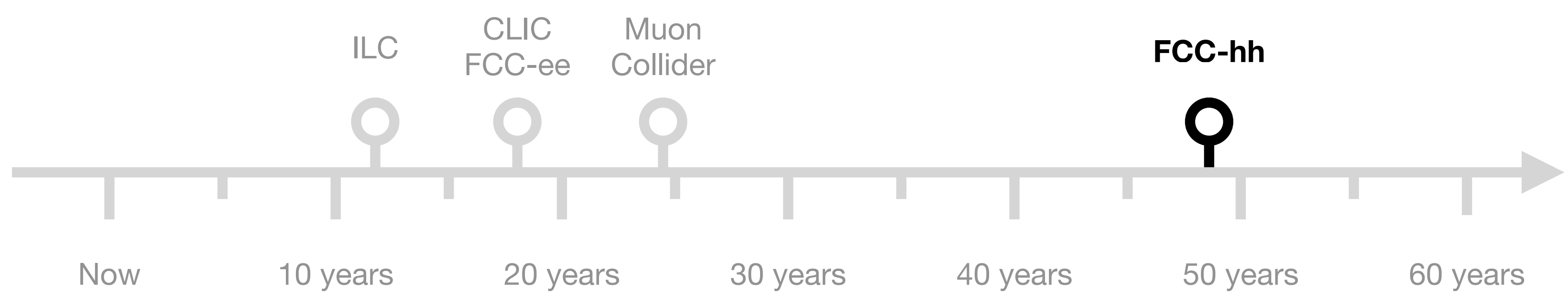
Supercharged GPD + 2 LHCb's…

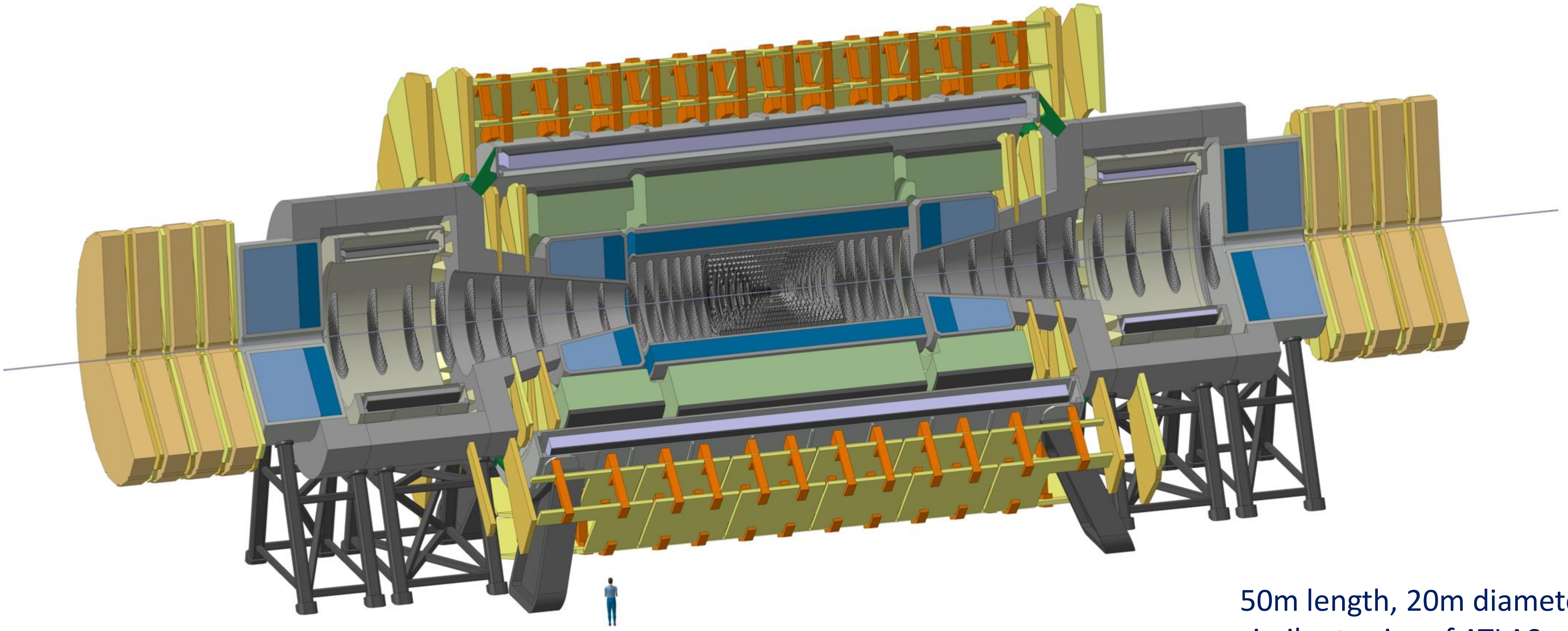
- Massive calorimeter depth to reach required interaction lengths
- 25 ns bunch spacing, looks very much like LHC on LSD

No dedicated hardware R&D but overlap with GPD high-lumi upgrades

- Clear that the detectors will be broadly similar to other hadron machine detectors - high power, lots of heat to take out, impossible data rates, complicated trigger schemes…

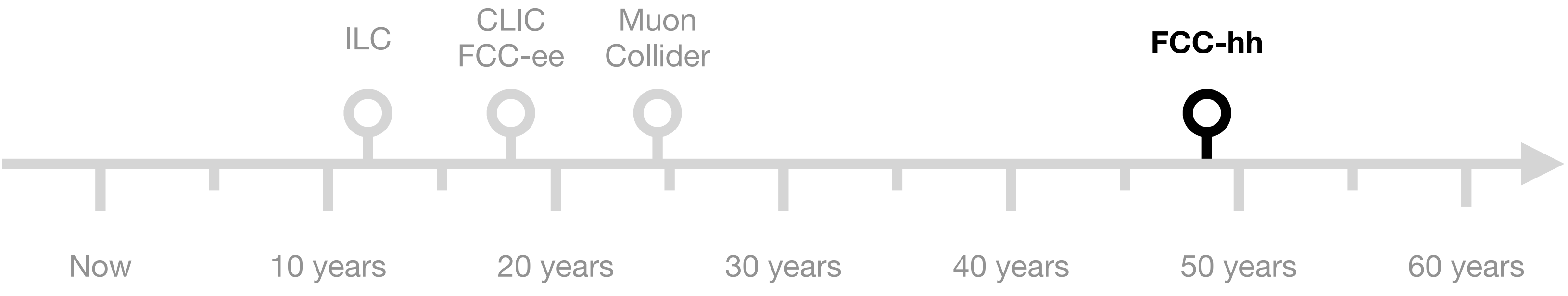
FCC-hh - environment and challenges

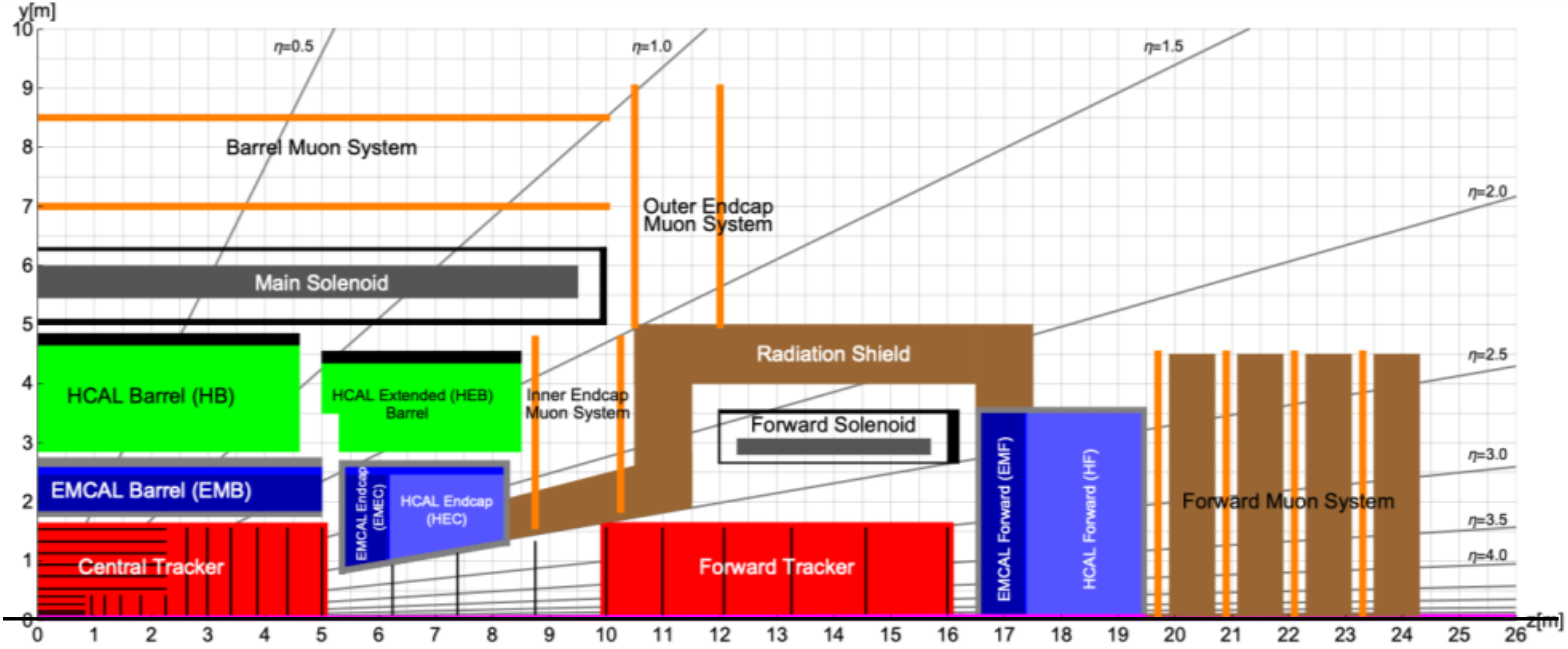




50m length, 20m diameter
similar to size of ATLAS

FCC-hh - environment and challenges





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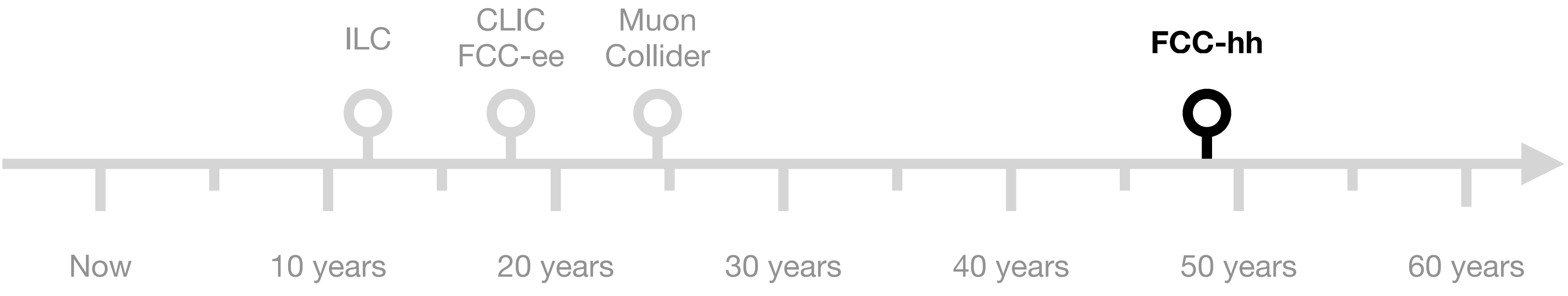
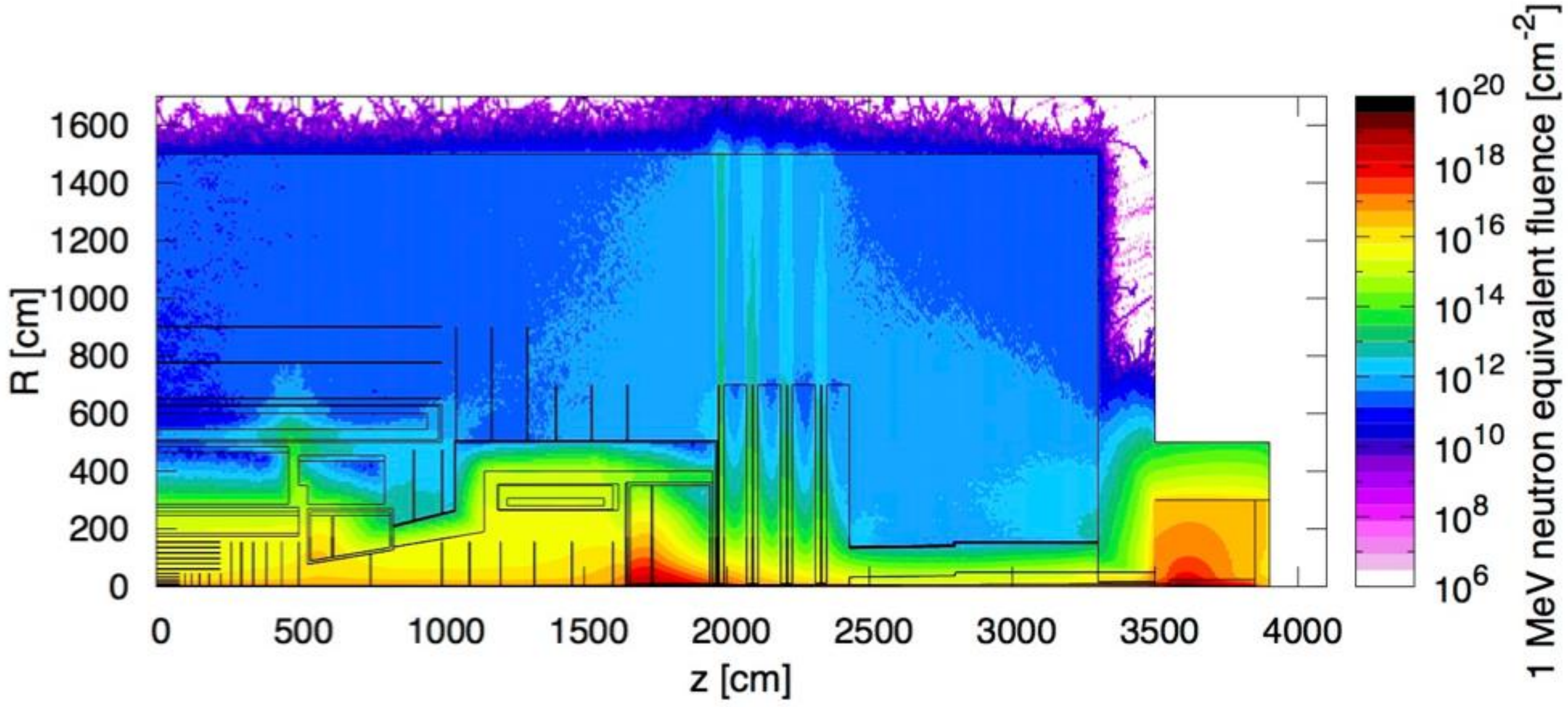


No dedicated hardware R&D at present towards the FCC hadron machine

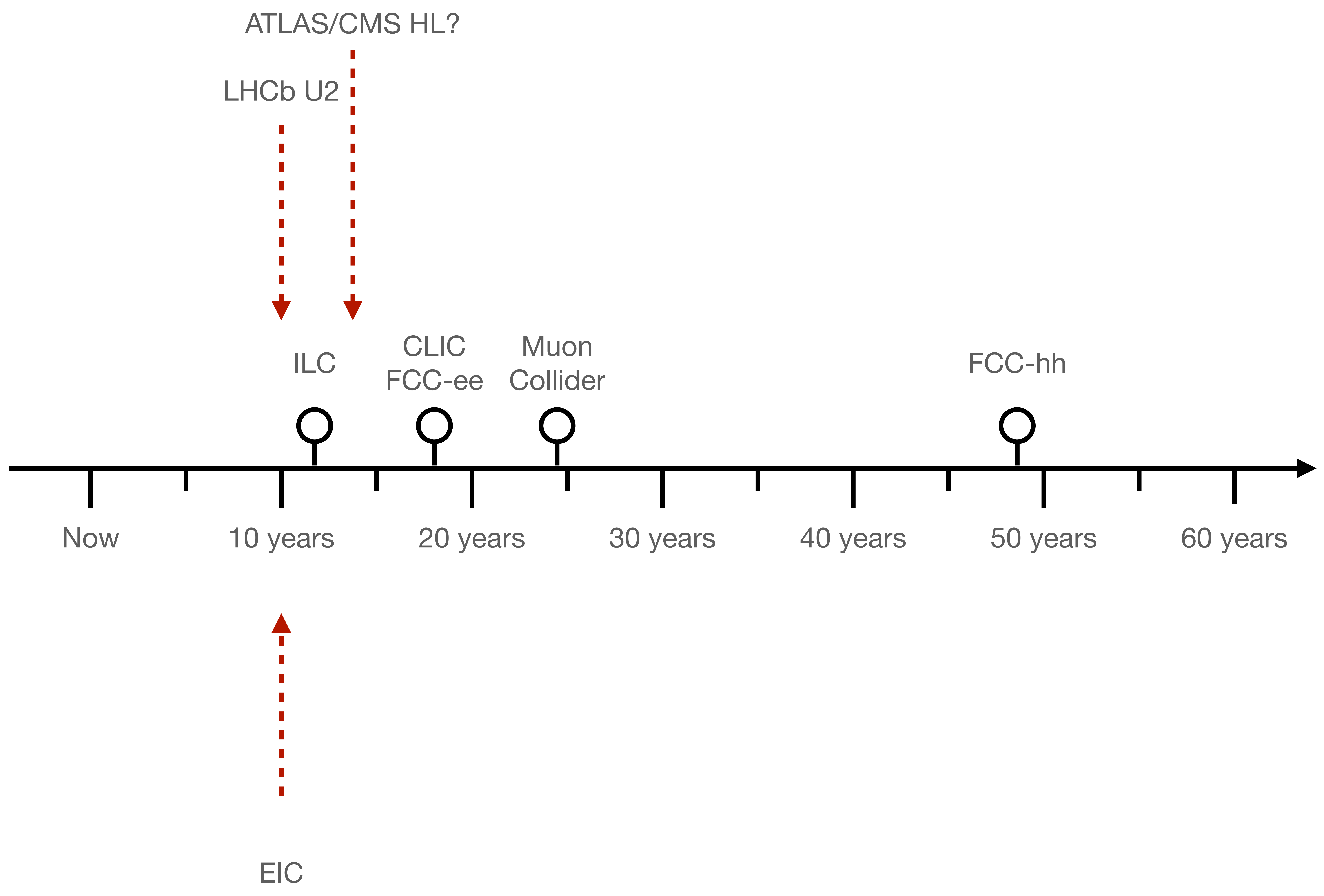
- Open question on radiation tolerance, but focus on HL-LHC at present

Majority of R&D is on detector layout and performance optimisation

- Custom software development, hybrid of separate development and LC-related
- Pattern recognition, tracking
- What might the detector look like: petabyte/second data output and



Intermediate projects



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Technology development

ECFA detector roadmap published 2021

- UK represented in organisation but almost no community engagement
- "Is R&D dead in the UK?"

Highlights technologies which need to be pursued for future experiment needs

- Covers all detector areas
- Will feed in to national prioritisation

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UK efforts to re-build an R&D community

Funding for R&D axed in 2010-ish

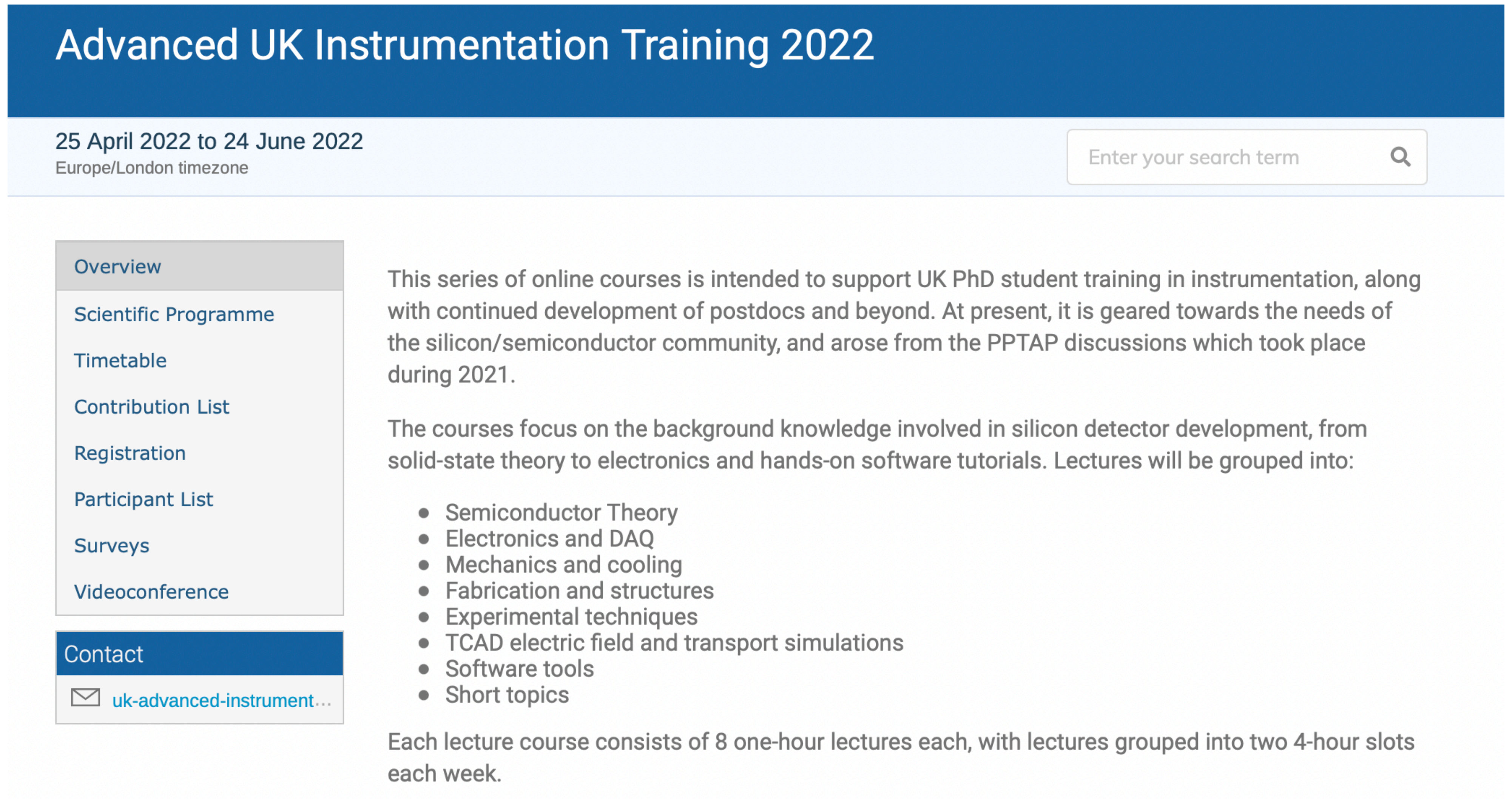
- Funding was directed towards build projects
- Very limited research still carried out under the umbrella of LHC experiment upgrades

In the last year or two, particularly during the PPTAP exercise in 2021, several issues highlighted with alarm:

- Limited expertise left in the UK
- Almost no funding for instrumentation R&D (CERN DRD involvement?)
- Significant gap between the UK and European partners

A couple of community efforts to address this:

- “Advanced UK Instrumentation Training” ran April - June 2022
- “Future UK Silicon Vertex & Tracker R&D Workshop” in Birmingham Sep 2022



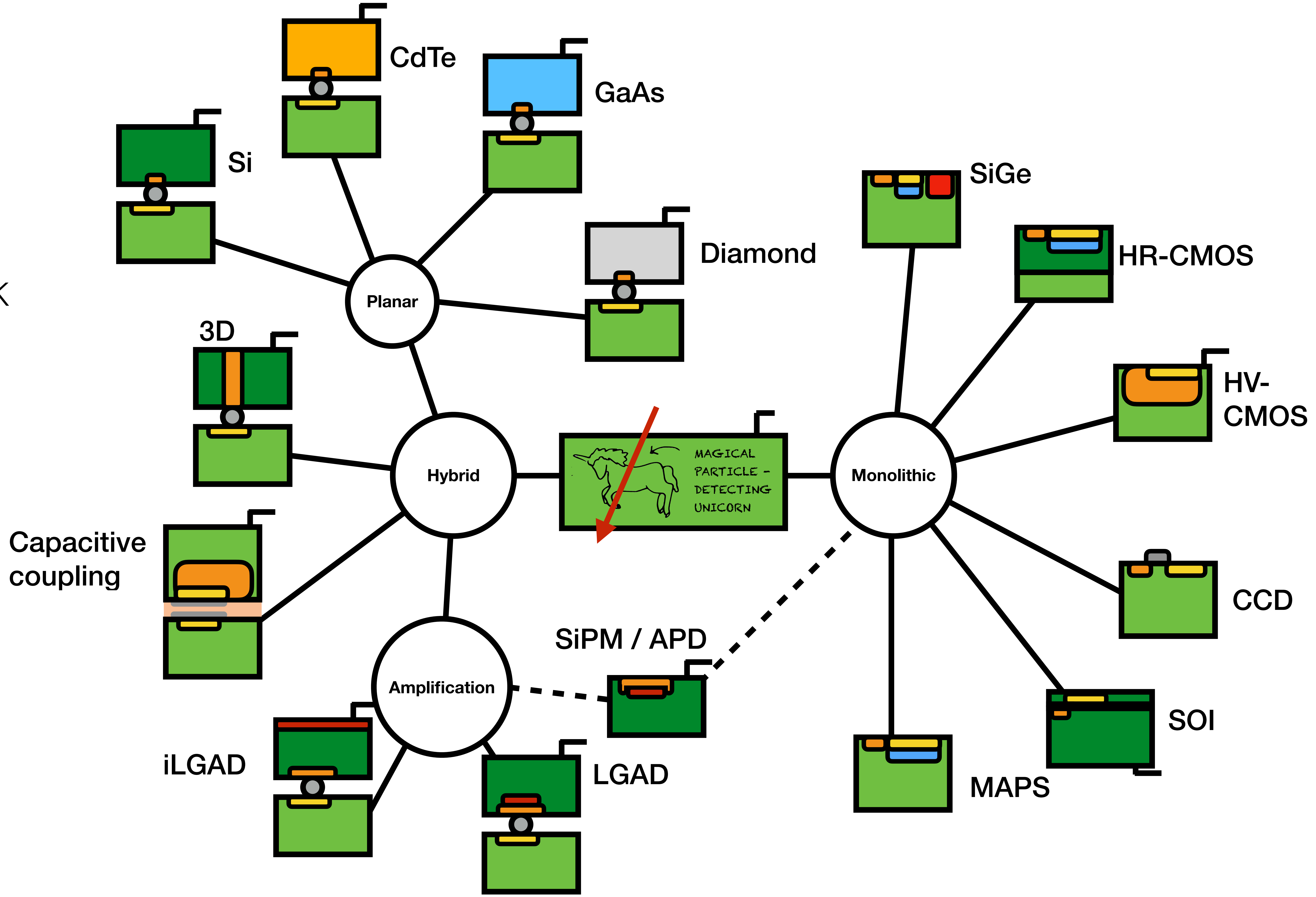
In conclusion…

Detector physics is a huge field - we haven’t even talked about technologies

- Huge amount of R&D needed and no obvious way to build expertise in the UK
- Detectors have become even more nuanced and application-specific in the last 10 years

ECR involvement in detectors should be encouraged, but unless effort is significant it doesn’t solve the problem

- New academic positions in instrumentation very rare



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