Detector concepts for FCC-ee

Future Colliders for Early-Career Researchers: CZ/SK Edition

FORTE

Co-funded by
the European Union

Filomena Sopkova, 27.9.2024

MŠMT
MINISTRY OF EDUCATION,
YOUTH AND SPORTS

The ECFA and ECR Panel

ECFA
European Committee for Future Accelerators

- **ECFA** — **E**uropean **C**ommittee for **F**uture **A**ccelerators
  - long-range planning of European high-energy facilities
  - the European countries which are Member States of CERN participate in ECFA
- Since 2020 an **E**arly **C**areer **R**esearcher (**ECR**) Panel exists
  - advisory role to ECFA
- ECFA released in 2011 a full roadmap (200 pages) based on a community-driven effort
  - Overview of future facilities (ILC, CLIC, FCC-ee/hh, Muon collider) or major upgrades (ALICE, LHC-b) and timelines, Ten "General Strategic Recommendations"
    - The most urgent R&D topics identified as Detector R&D Themes
  - Approved by CERN in fall 2022

CERN will host DRD collaborations

Fully Approved for an initial period of 3 years by CERN Research Board in December 2023

- Gaseous Detectors (DRD1) [ex RD51]
- Liquid Detectors (DRD2)
- Photodetectors & Particle ID (DRD4)
- Calorimetry (DRD6)

Presented at March open DRDC session: https://indico.cern.ch/event/1356910/

Conditionally approved

- Semiconductor Detectors (DRD3) [ex RD50, RD42,..]

Both aim for approval now

- Quantum Sensors (DRD5)
- Electronics (DRD7)

Letter of Intent submitted

- Integration (DRD8) Full Proposal to be written by the end of 2024

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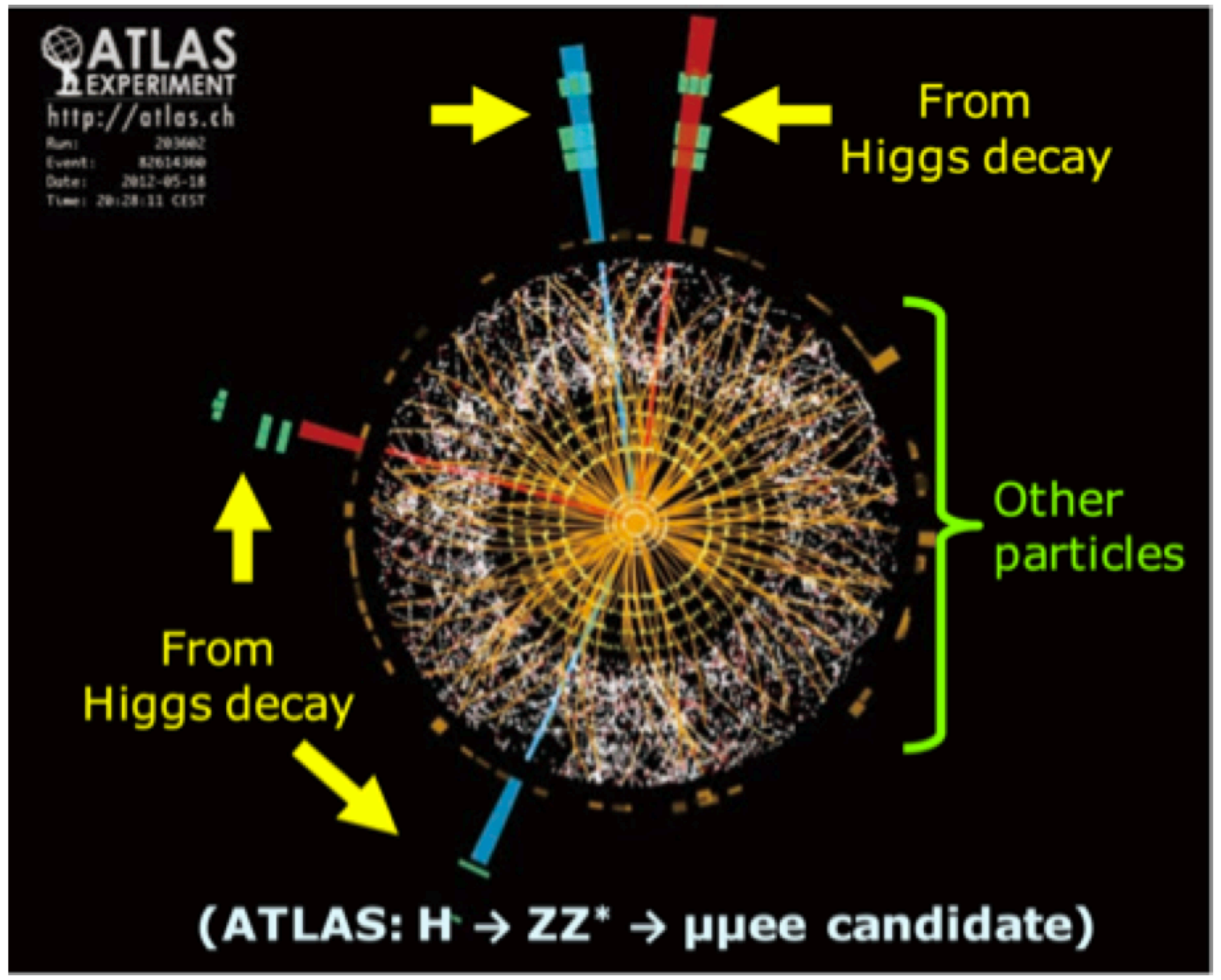
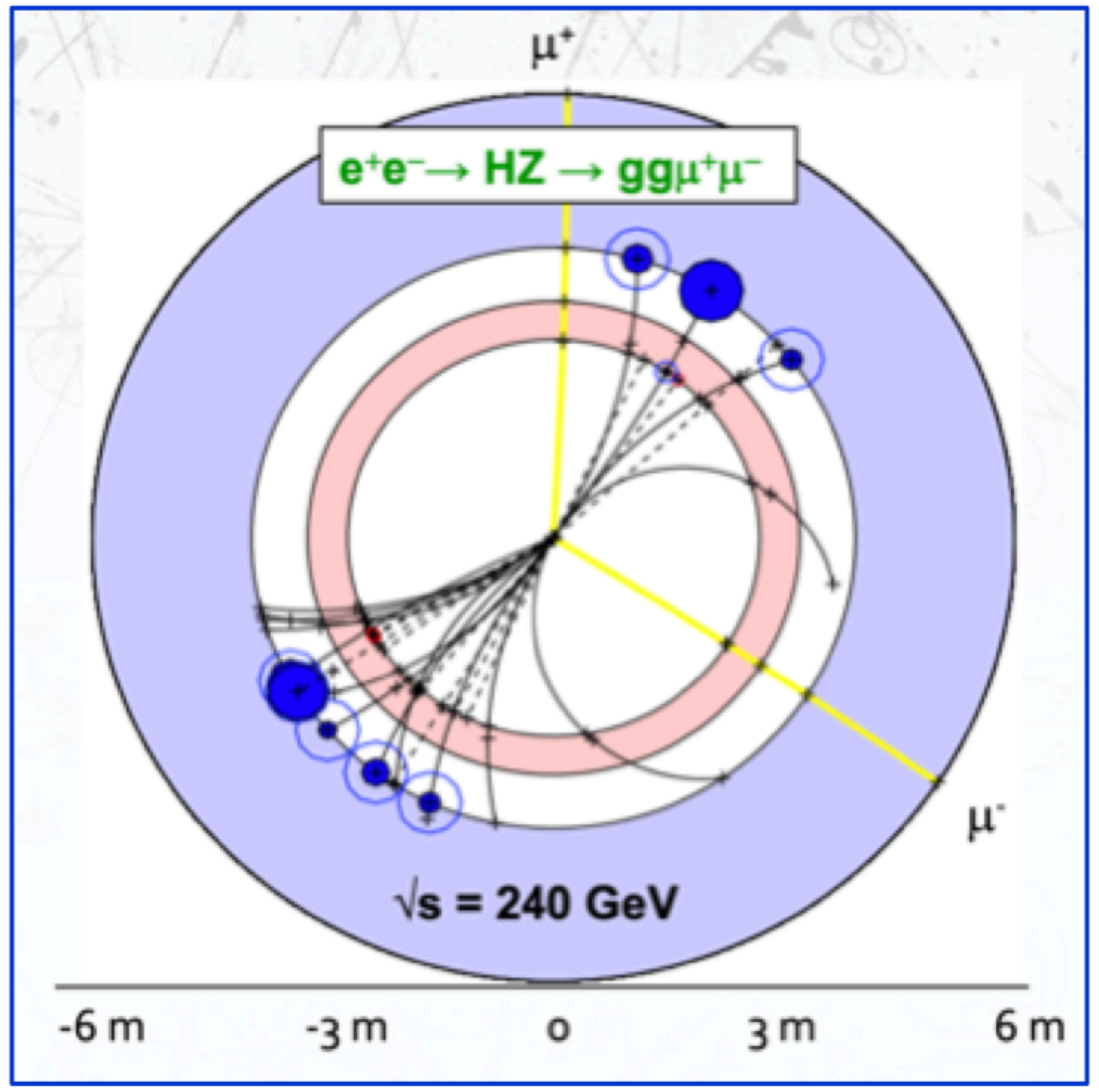
pp collisions vs. e^+e^- collisions

Higgs event in pp



Higgs event in e^+e^-



pp: look for striking signal in large background

- High rates of QCD backgrounds
  - ➢ Complex triggering schemes
  - ➢ High levels of radiation
- High cross-sections for coloured states
- High-energy circular pp colliders feasible
  - ➢ Large mass reach ➞ direct exploration
- S/B ≈ 10^{-10} before trigger; S/B ≈ 0.1 after trigger

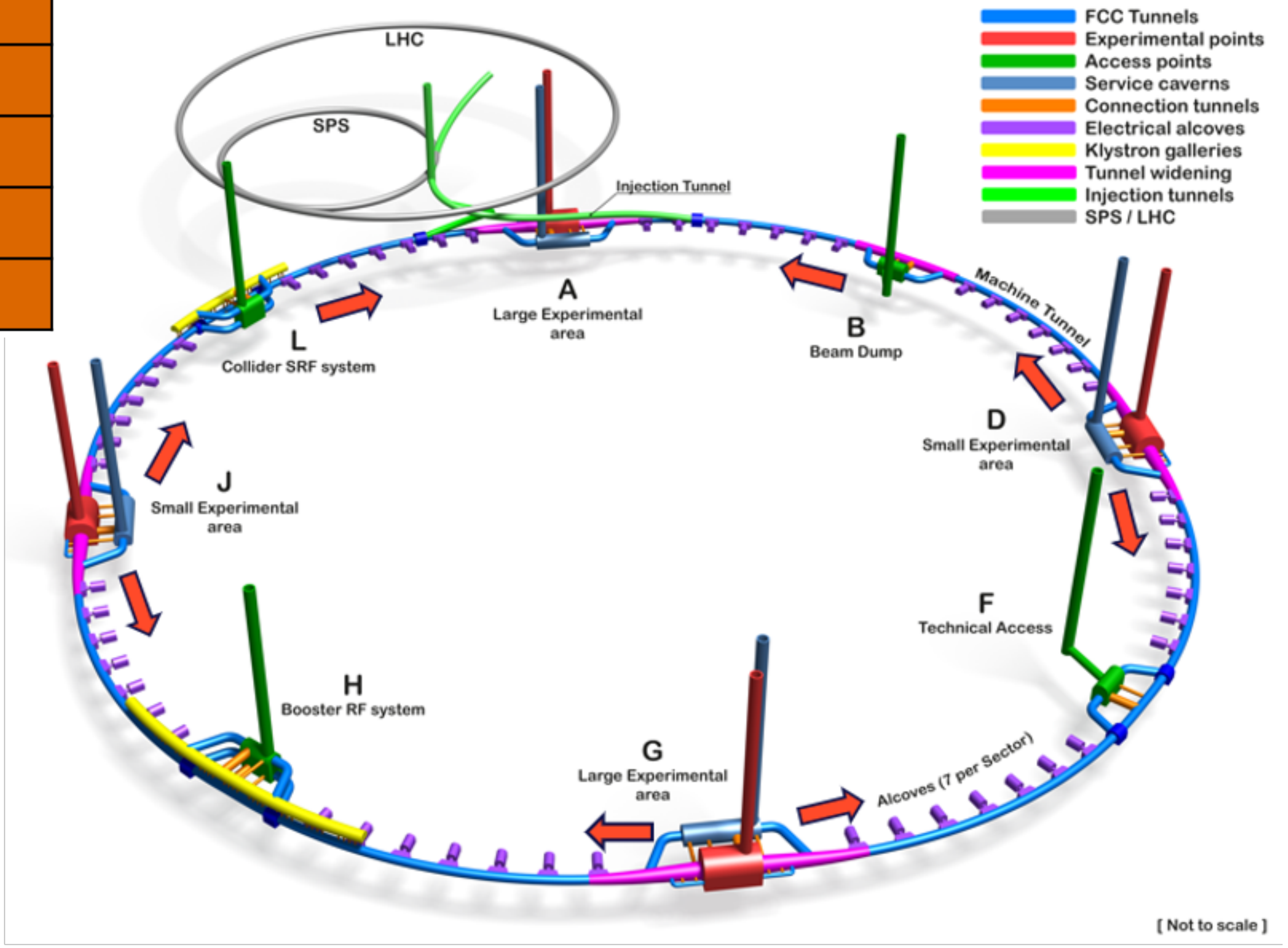
e^+e^-: detect everything; measure precisely

- Clean experimental environment
  - ➢ Trigger-less readout
  - ➢ Low radiation levels
- Superiour sensitivity for electro-weak states
- Limited direct mass reach
- S/B ≈ 1 ➞ precision measurement
  - ➢ Exploration via precision

FCC-ee as Higgs & EW & top factory at highest luminosities

FCC-ee parameters		Z	W^+W^-	ZH	ttbar
√s	GeV	91.2	160	240	350-365
Luminosity / IP	10^{34} cm^{-2} s^{-1}	140	20	5.0	1.25
Bunch spacing	ns	25	160	680	5000
"Physics" cross section	pb	35,000	10	0.2	0.5
Total cross section	pb	70,000	30	10	8
Event rate	Hz	100,000	6	0.5	0.1
"Pile up" parameter [μ]	10^{-6}	2,500	1	1	1

- 8 surface points:
  - 4 experimental areas
- detector concepts under study
- possibility to specialised detectors to maximise physics output
- FCC integrated project allows seamless continuation of HEP after HL-LHC



FCC in perspective

a great Higgs factory and so much more

FCC-ee

EW & QCD

- 5×10^{12} Z and 10^8 WW events
  - $m_Z, \Gamma_Z, \Gamma_{inv}, \sin^2\theta_W, m_W, \Gamma_W,$
- 10^6 tt events
  - $m_t, \Gamma_t,$ EW coupling
- indirect sensitivity of new physics

Higgs factory programme

- 1.2×10^6 ZH events at $\sqrt{s} = 240$ GeV
- 75×10^3 WW -> H events at $\sqrt{s} = 365$ GeV
- Higgs coupling to fermions
- electron self coupling in s-channel $e^+e^- \to H$ at $\sqrt{E} = 125$ GeV

Feebly coupled particles BSM

- opportunity to directly observe new feebly interacting particles with masses below m_Z
- axion-like particles, dark photons, heavy neutral leptons
- long lifetime LLPs

Heavy Flavour programme

- 10^{12} bb/cc; 1.7×10^{11} $\tau\tau$ produced in clean environment
- CKM matrix, CP measurements flavour anomaly studies, lepton universality

Detector requirements

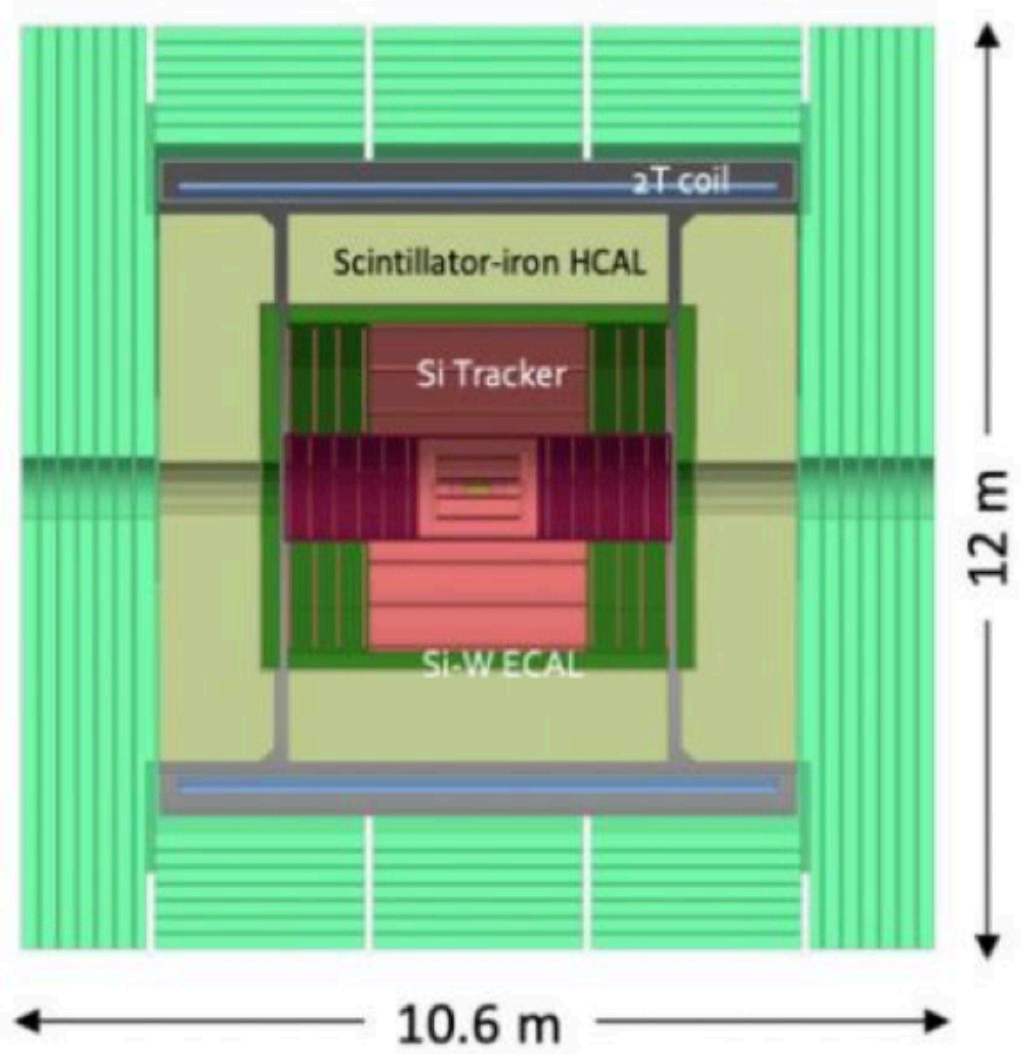
The detector requirements for a Higgs factory have been extensively studied by the Linear collider community

- **They need to be revised for FCC-ee**:
  - different experimental environment
  - momentum resolution "as good as we can get it"
  - Jet energy resolution of $30\,\%/\sqrt{E}$ in multi-jet environment for Z/W separation
  - Excellent π^0/γ separation and measurement for tau physics
- K/π separation over wide momentum range for b and τ physics
- Large decay lengths -> extended detector volume
- Precise timing for velocity (mass) estimate
- Sensitivity to far detached vertices
  - tracking: more layers, continuous tracking
  - calorimeter: granularity, tracking capability

Current Detector Concepts

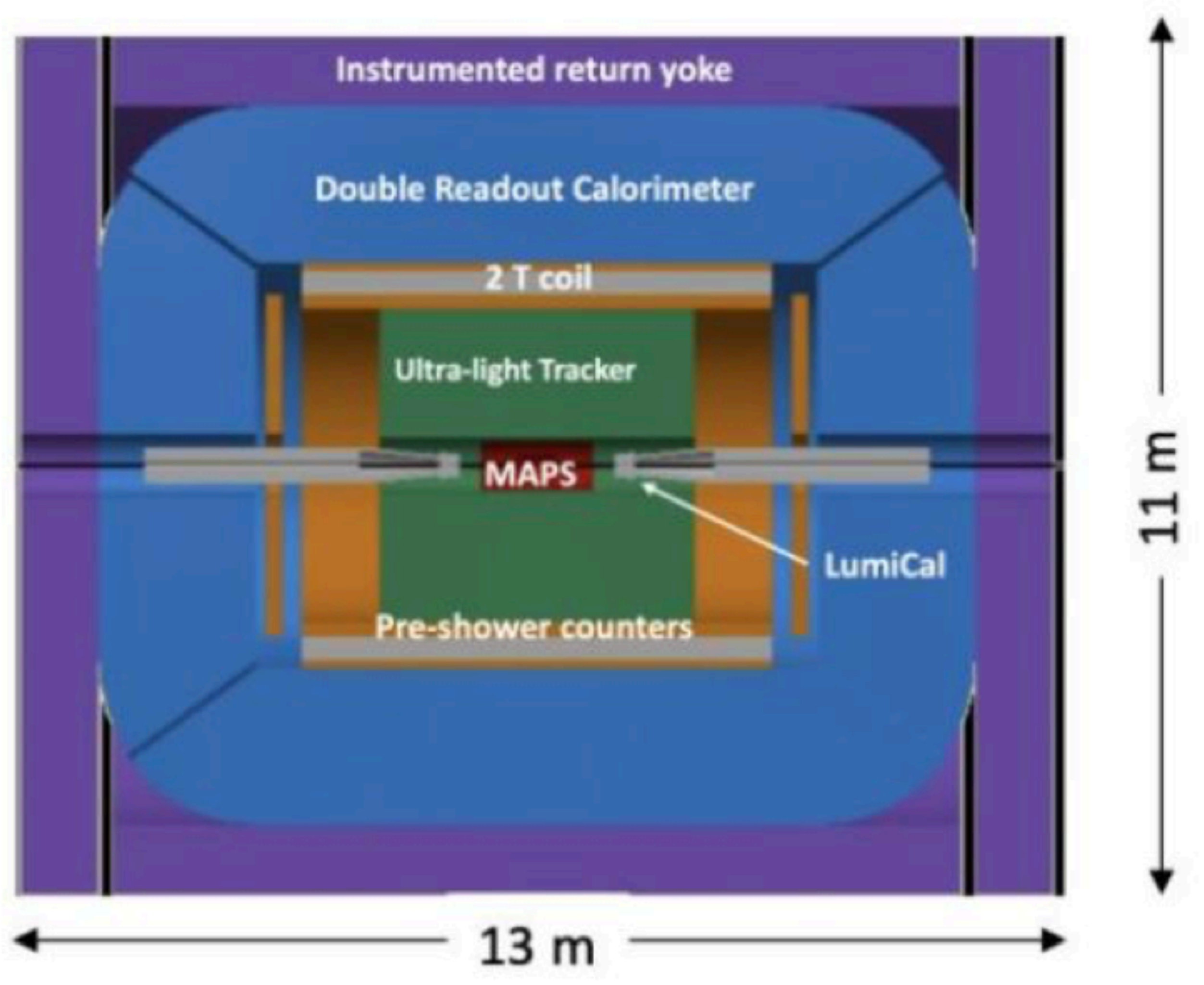
defined by calorimetry

CLD



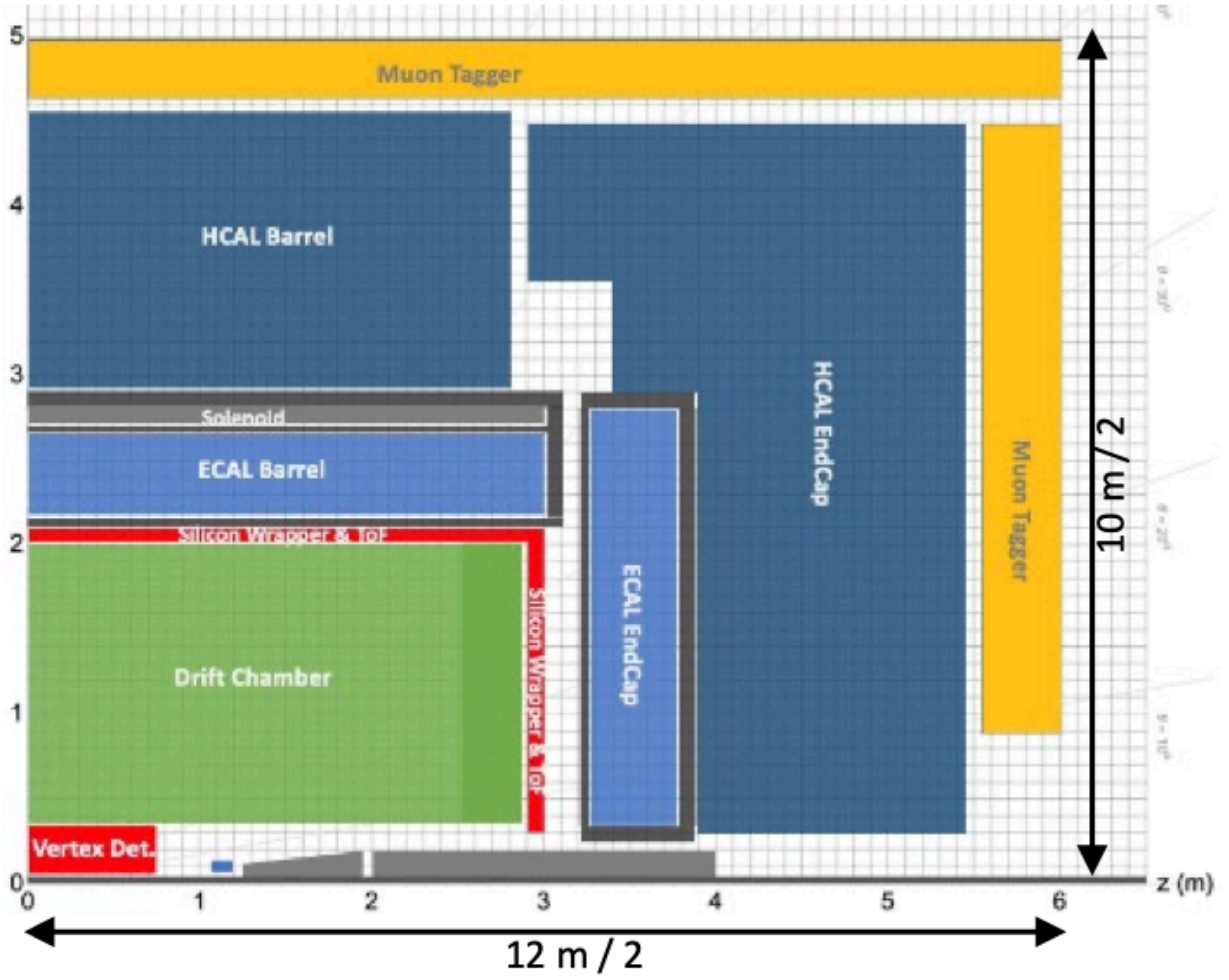
- well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker , study TPC option viability
- CALICE-like calorimetry - Si-W granular ECal
- large coil, muon system

IDEA



- A bit less established design, still ~15y history
- Si vtx detector; ultra light drift chamber with powerful PID; compact, light coil
- monolithic dual readout calorimeter;
  - possibly augmented by crystal ecal
- muon system

ALLEGRO



- Si vtx detector; ultra light drift chamber (or Si)
- High granularity Noble Liquid ecal as core
  - Pb/W+LAr (or denser W+LKr)
- Tile-like hcal
- coil inside same cryostat as LAr, outside ecal
- muon system

Calorimetry

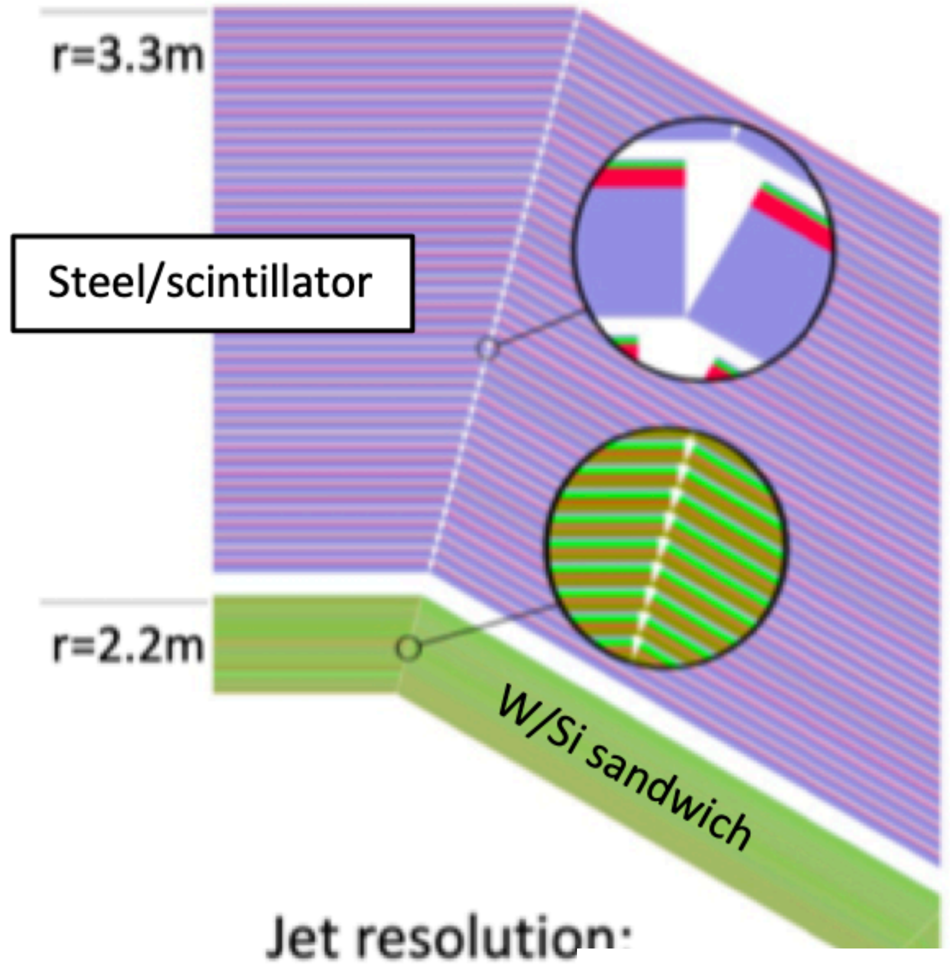
- Measurement of energy and direction of jets and isolated particles, in particular neutrals γ, π^0, n, K_L^0
  - Sensitivity down to few 100 MeV
- Particle identification: discrimination of e/π, μ/h, γ/π^0

Important characteristics

- Electromagnetic energy resolution
- Hadronic energy resolution
- Jet energy resolution - a key benchmark of the e^+e^- detector performance
- Granularity (transverse and longitudinal)

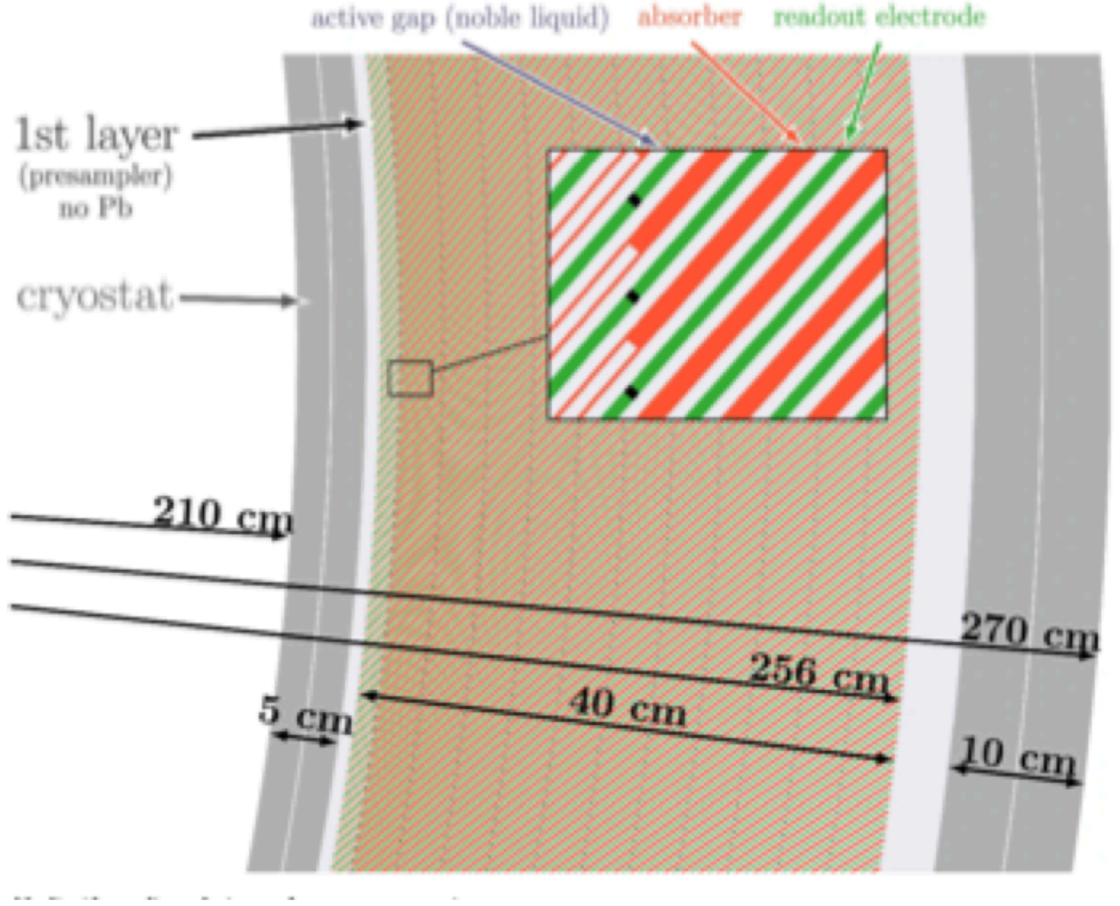
- Two different but complementary approaches considered:
  - High granularity calorimeter - Particle Flow algorithm
  - Dual Readout (DRO) calorimeter

CLD ultra granular calorimetry

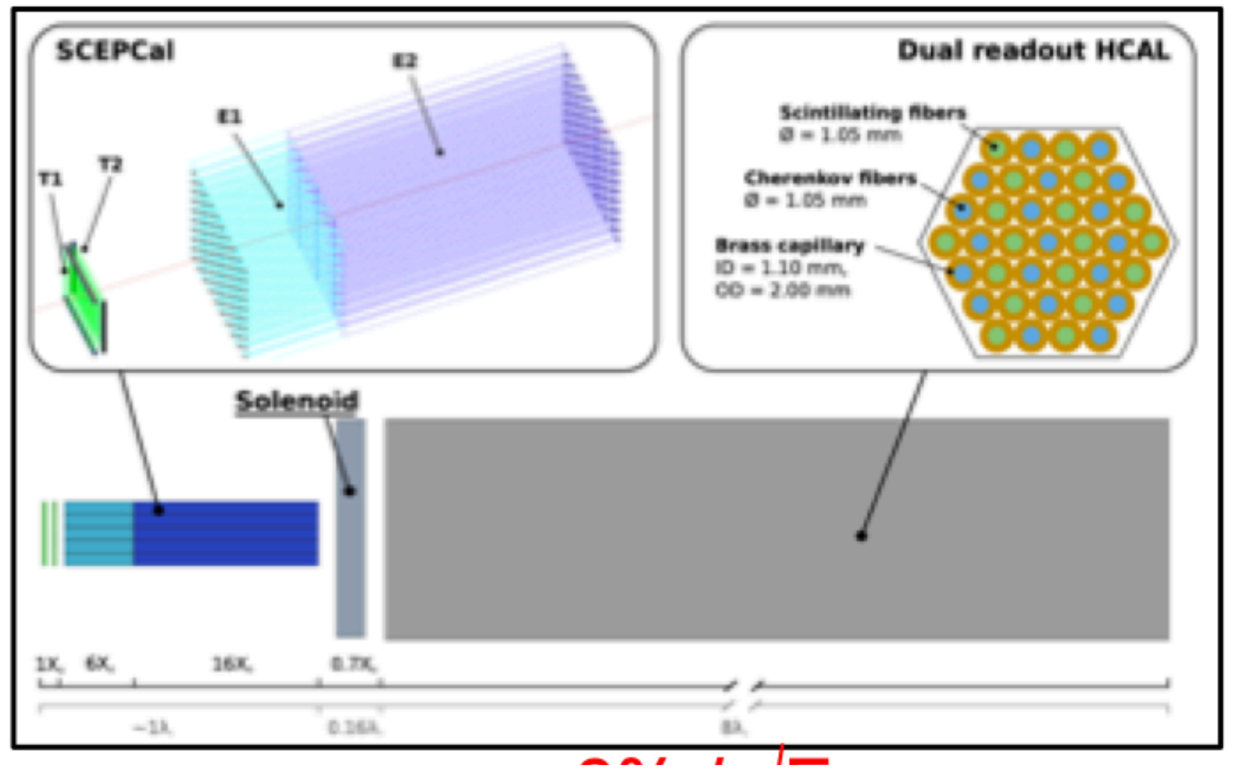


Jet resolution:
~4% at 50 G

Allergo Noble Liquid ECAL



IDEA w crystal ECAL and DR Fibre HCAL



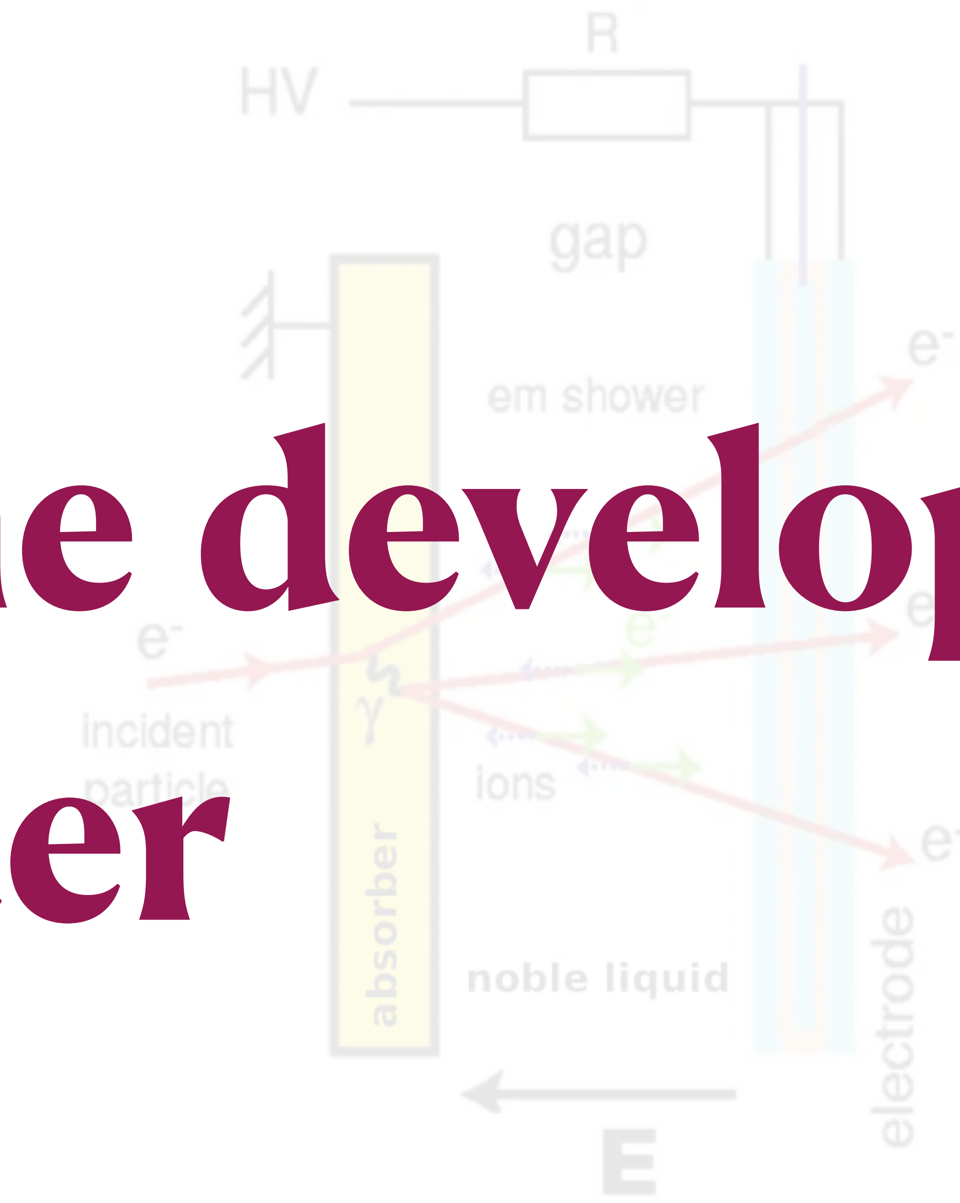
Noble liquid Calorimetry in ALLEGRO

- ALLEGRO - A Lepton coLlider Experiment with Granular calorimetry ReadOut
- High granular noble liquid ECal - PFlow reconstruction
- Optimised for full FCC-ee physics program

- Sampling calorimetry relying on ionisation
- Based on alternating layers of absorbers, noble liquid and read-out electrodes
- voltage applied over noble liquid gap
  - incident particle ionises noble liquid
  - e drift to electrodes for signal pick-up

- Successfully applied in a number of HEP experiments
- Excellent energy resolution, linearity, stability, uniformity, good timing properties, easy to calibrate, high granularity

Charles Uni. is involved in the development of the noble liquid calorimeter



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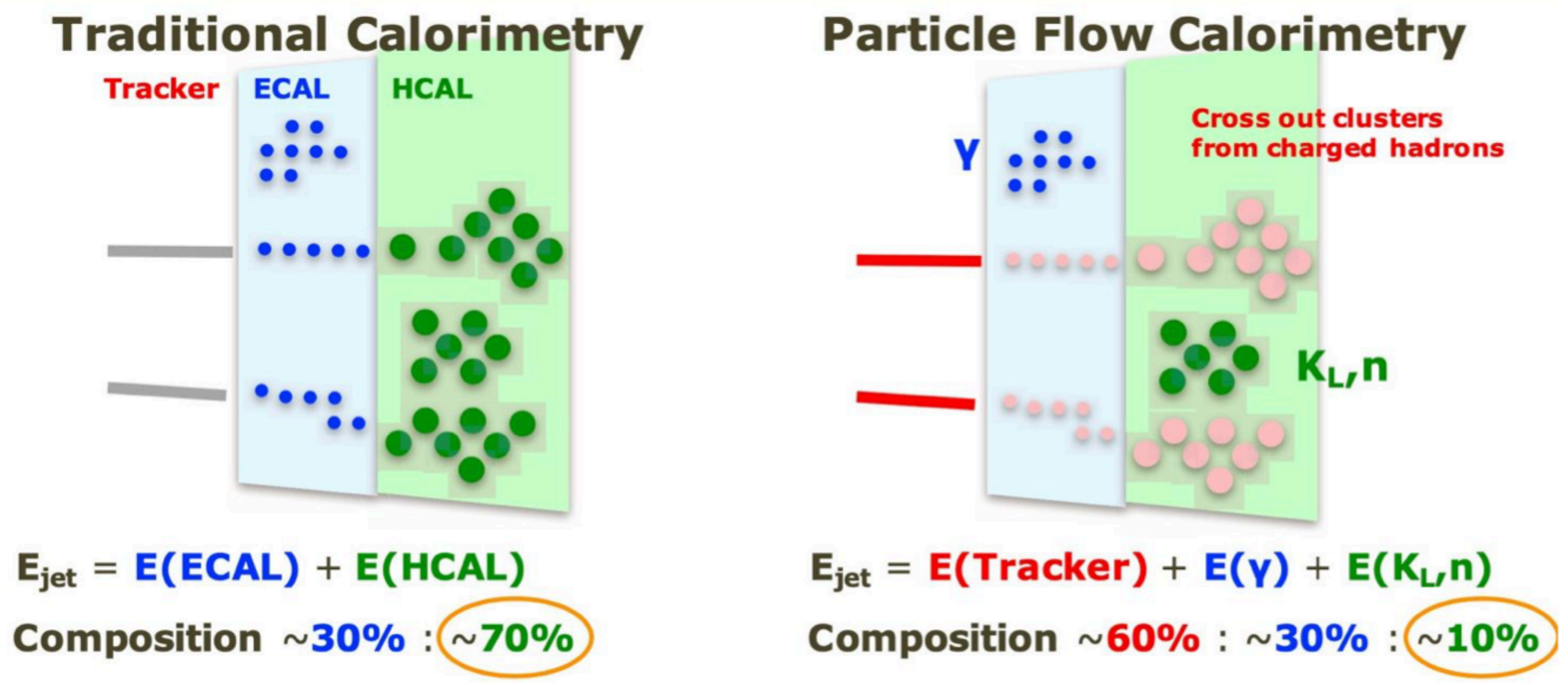

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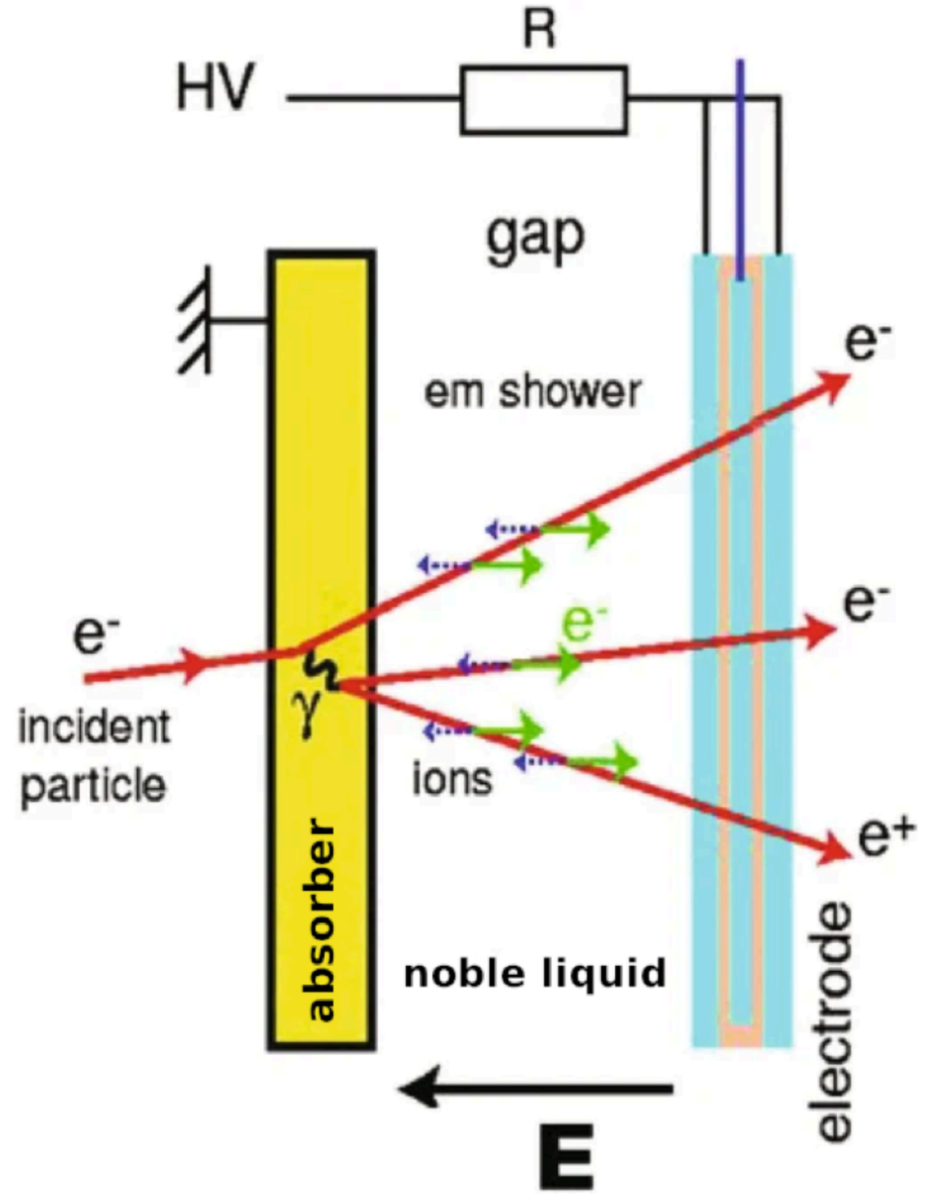

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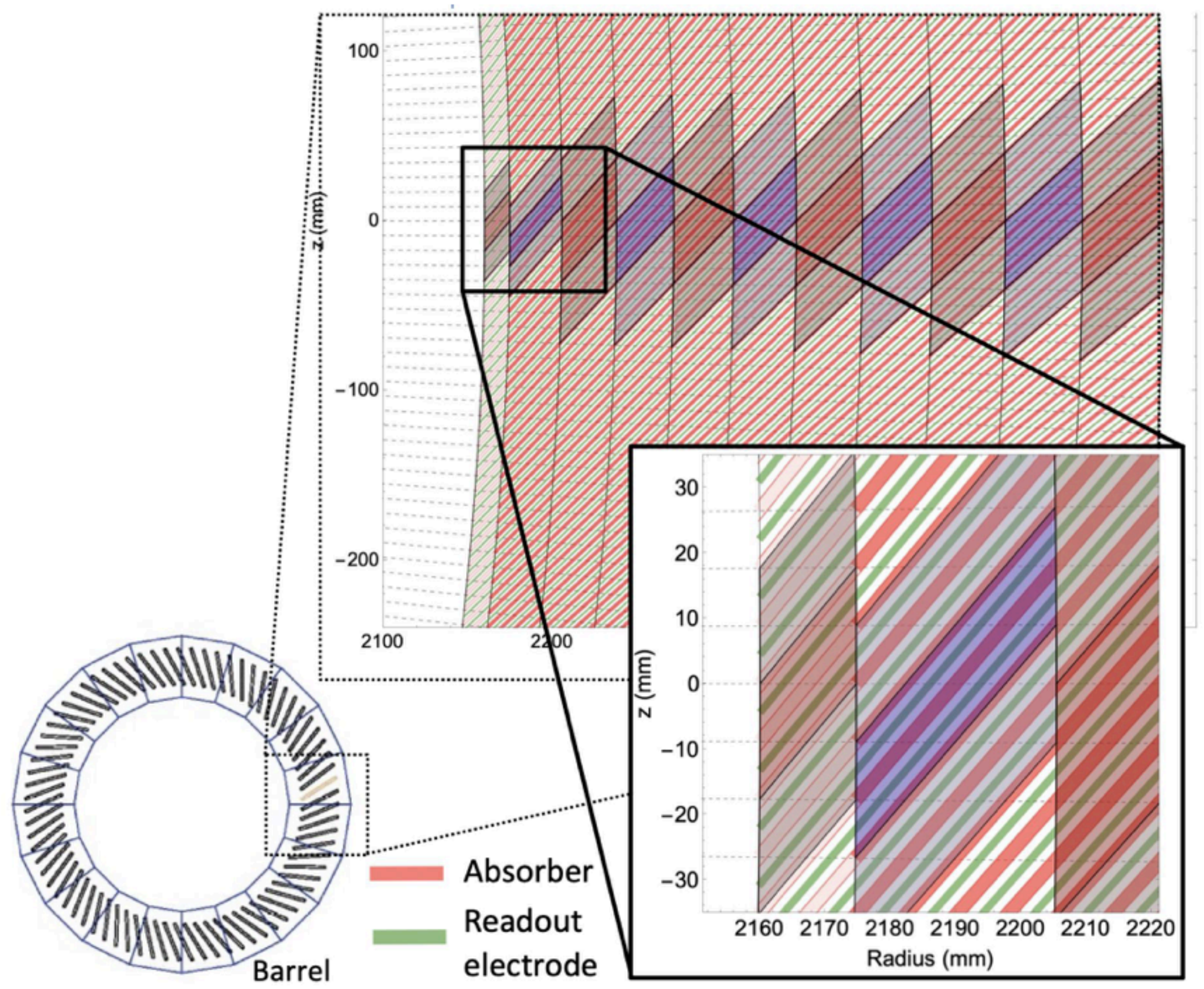
Noble liquid Calorimetry in ALLEGRO

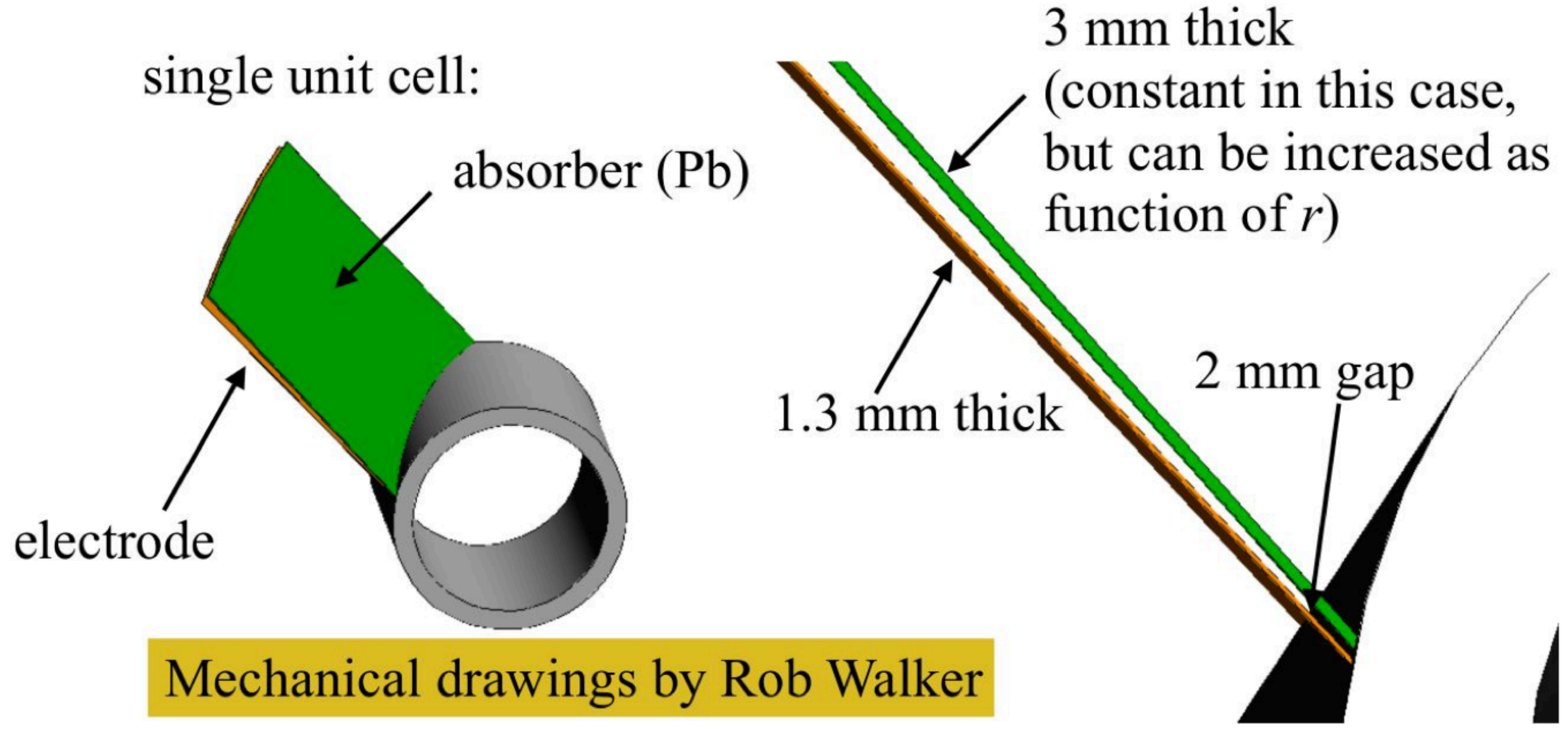
ECal barrel

- 1536 straight inclined (50.4°) 2 mm absorbers
- LKr or LAr active medium
- W or Pb absorbers
- Absorbers thicker at outer radius

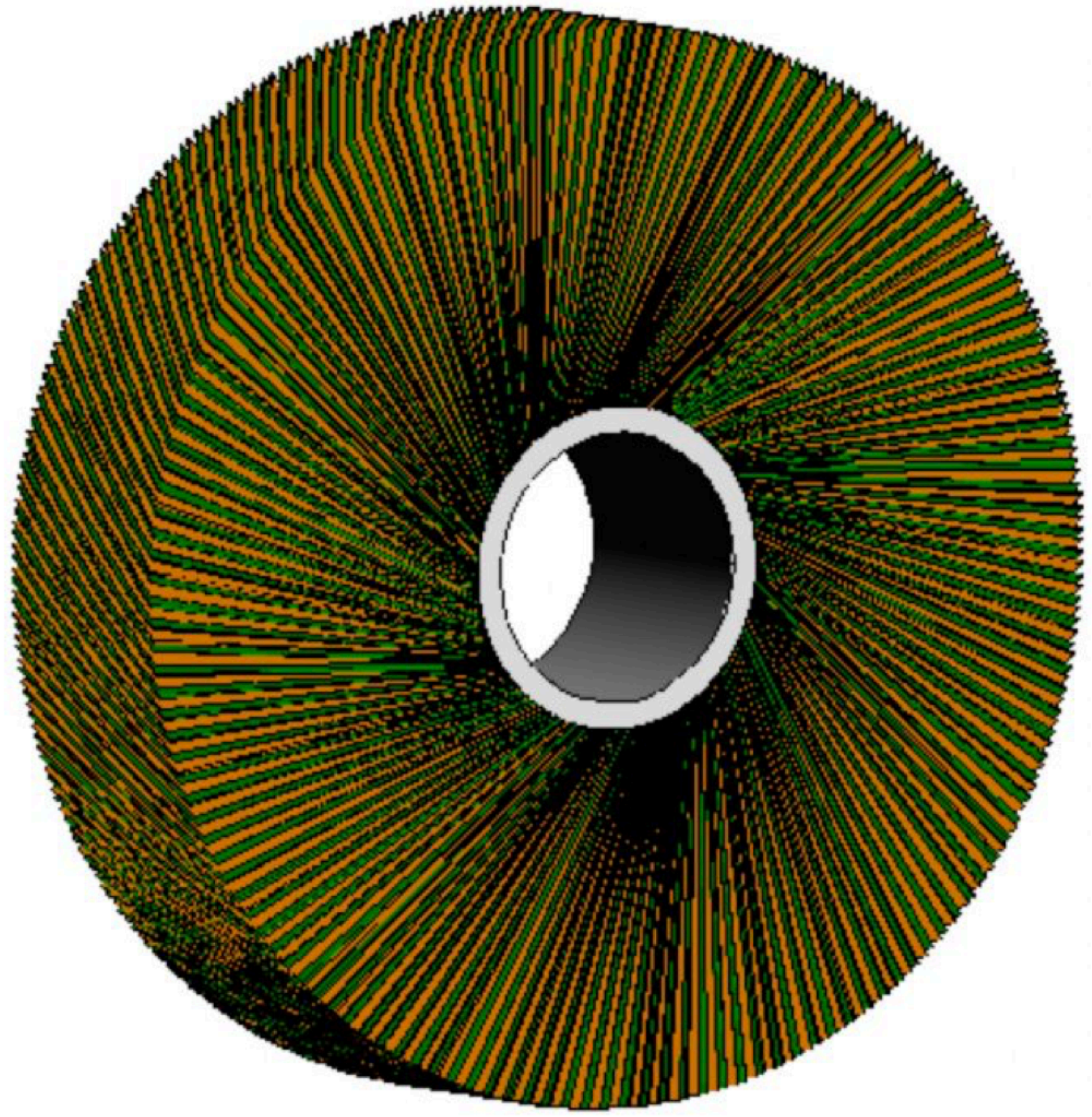
ECal endcap

- design more complex then barrel
- “turbine design”
- similar to barrel design - many thin absorber plates
- symmetric in ϕ





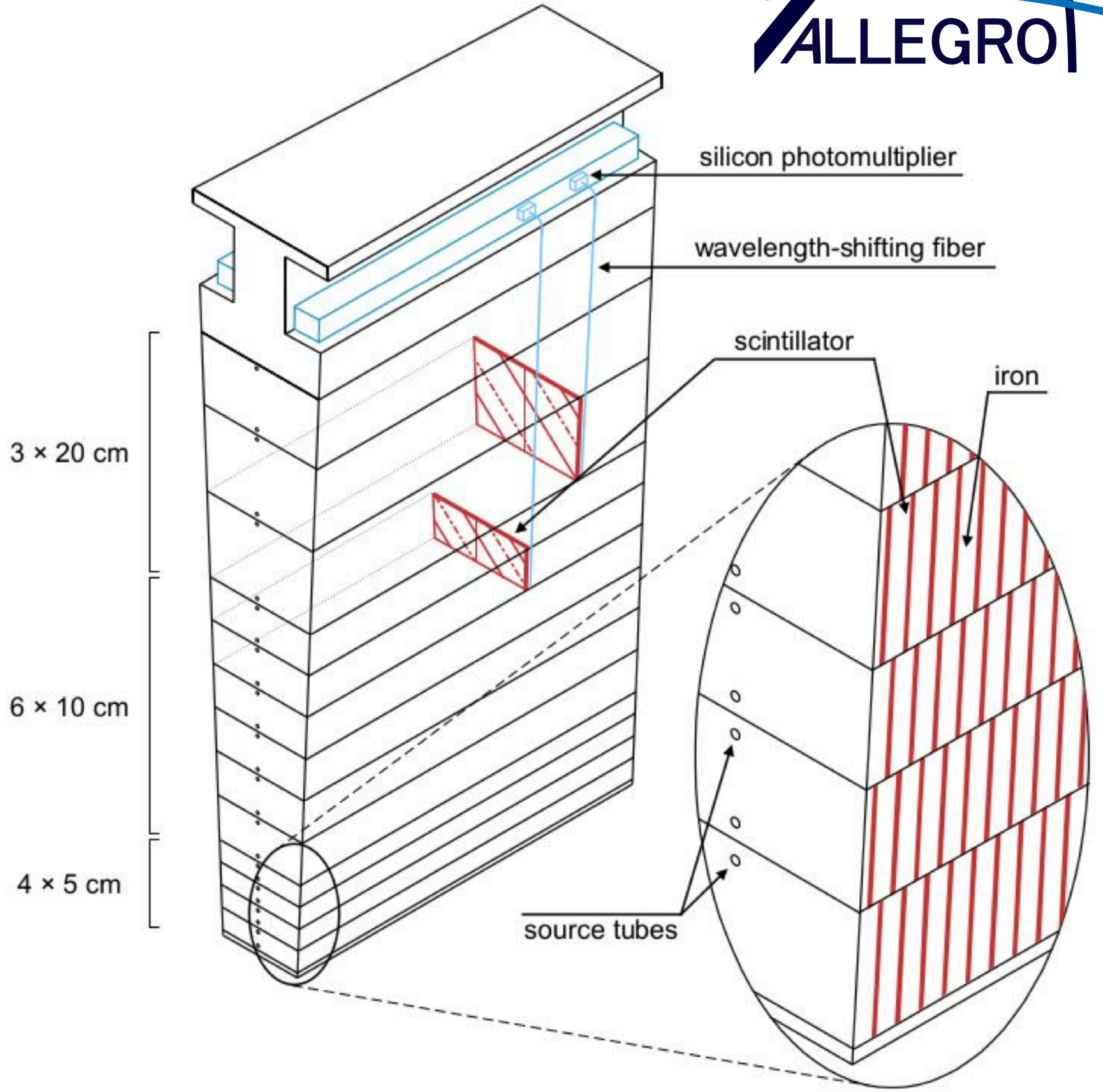
Mechanical drawings by Rob Walker

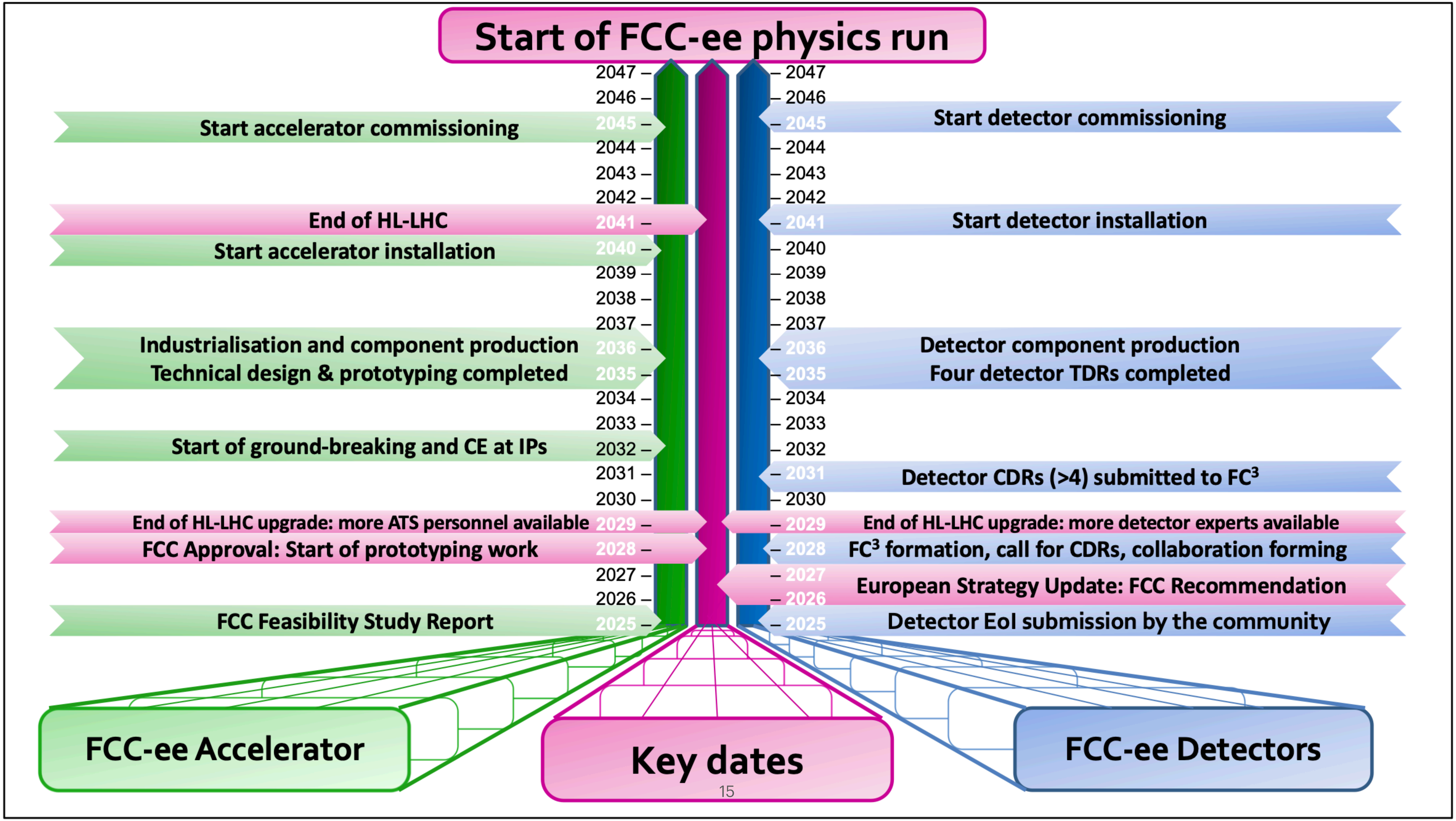


HCal in ALLEGRO

HCal barrel

- inspired by ATLAS TileCal, implemented in simulation studies
- 5 mm steel absorber plates alternating with 3 mm scintillator plates
- 1400 mm deep ($8-9\lambda$)
- Segmentation
  - $\Delta\theta \sim 22$ mrad (grouping $3-4$ tiles)
  - 128 modules in ϕ
- 13 radial layers (4×5 cm, 6×10 cm, 3×20 cm)





Start of FCC-ee physics run
Start accelerator commissioning
Start detector commissioning
End of HL-LHC
Start accelerator installation
Start detector installation
Industrialisation and component production
Technical design & prototyping completed
Detector component production
Four detector TDRs completed
Start of ground-breaking and CE at IPs
Detector CDRs (>4) submitted to FC³
End of HL-LHC upgrade: more ATS personnel available
End of HL-LHC upgrade: more detector experts available
FCC Approval: Start of prototyping work
FC³ formation, call for CDRs, collaboration forming
European Strategy Update: FCC Recommendation
FCC Feasibility Study Report
Detector EoI submission by the community
2047
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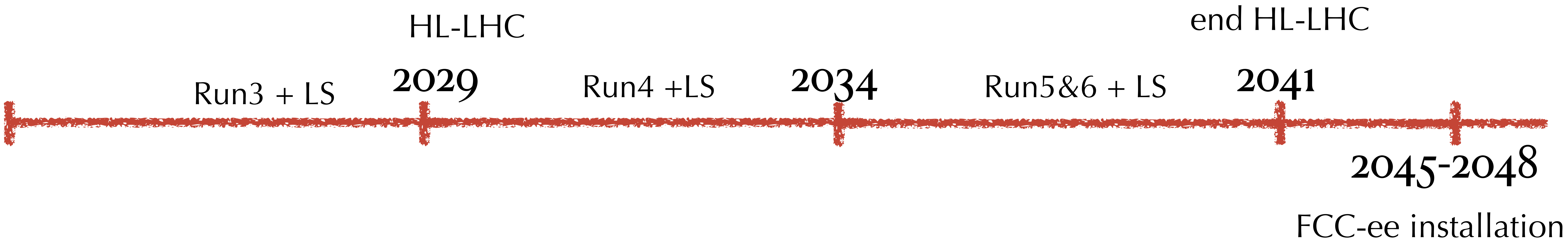
2025
FCC-ee Accelerator
Key dates
FCC-ee Detectors

A possible FCC career

A possible FCC career



PhD

- ✓ Physics on Run3
- ✓ Successful installation & commissioning of HL-LHC
- ✓ **Detector R&D**

Postdoc

- ✓ HL-LHC physics & operations
- ✓ **Experiment - specific detector prototypes for FCC-ee**

Faculty&Tenure

- ✓ Physics on HL-LHC
- ✓ **Build FCC-ee detectors**
- ✓ **FCC-ee experimental leadership/project**

We have to work to make it happen

2020 UPDATE OF THE EUROPEAN STRATEGY FOR PARTICLE PHYSICS

HiLumi HL-LHC PROJECT

FCC-ee FCC-hh

FUTURE CIRCULAR COLLIDER *Feasibility Study*

“The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques.”

“The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.”

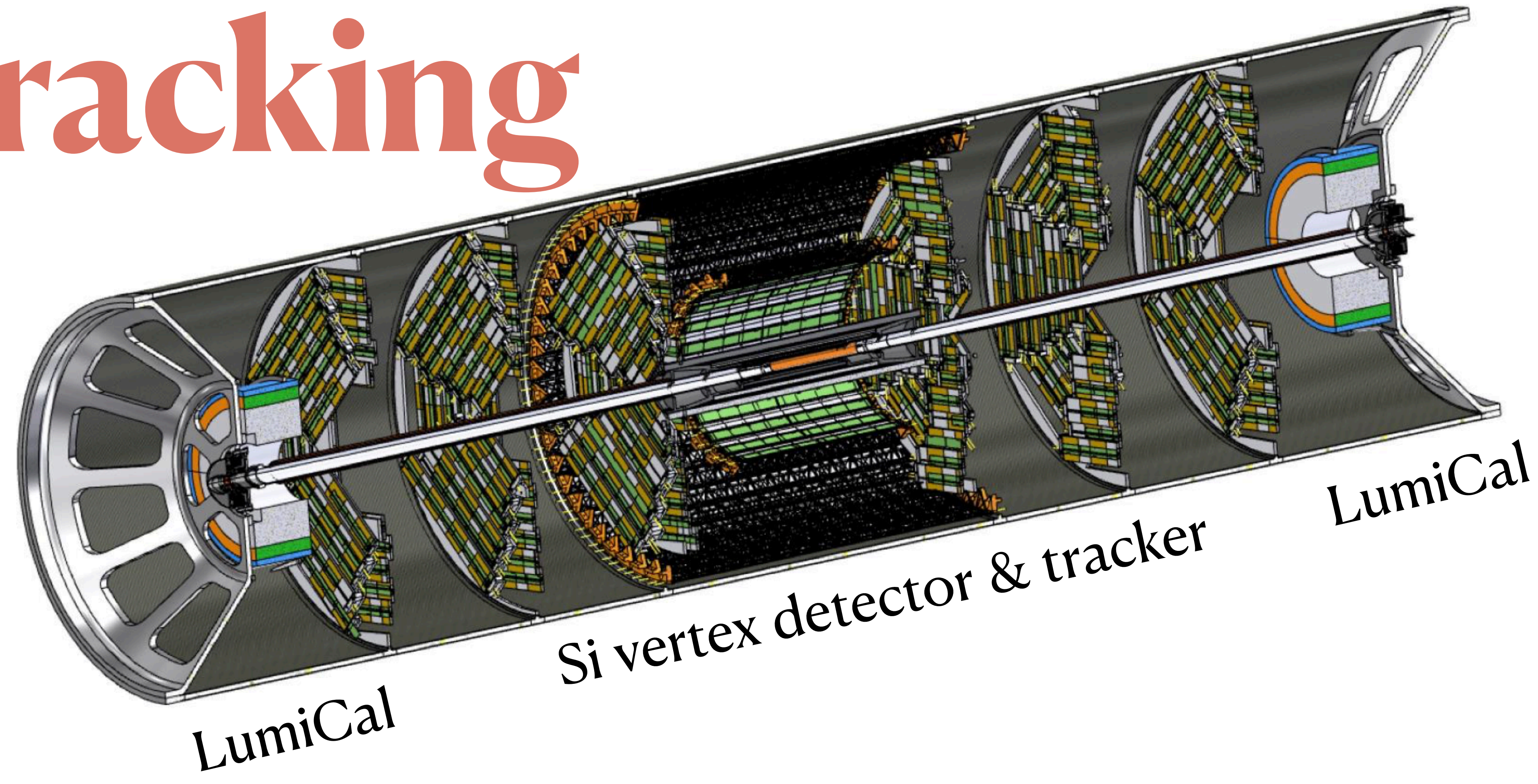
“An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy.”

“Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage.”

“Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.”

Source: https://cds.cern.ch/record/2721370

Vertex Detector & Tracking



- Interaction region detectors must be integrated with the beam pipe
- Constraints from machine detector interface
  - last focusing quadrupole at ±2.2 m from IP
  - magnetic field $\leq$ 2T for Z-pole run
  - the mounting of the vertex tracker must be done inside the support tube

Inner Vertex tracker

- Modules $25 \times 25 \mu m^2$ pixel size
- 3 barrel layer at 13.7, 22,7 and 34.8 mm radius

Outer Vertex tracker

- Modules $50 \times 150 \mu m^2$ pixel size
- Intermediate barrel at 13 cm radius
- Outer barrel at 31.5 radius
- 3 disks per side

- Challenges : material budget, power & cooling, detector stability
  - Flavour tagging: low mass, small pixel size, close to IP, low power, ..
  - Tracking: the lighter the better for momentum resolution, angular resolutions needed for control of beam energy spread
  - Large number of measurement points along the tracks is crucial for an efficient reconstruction of K, Λ or other LLP

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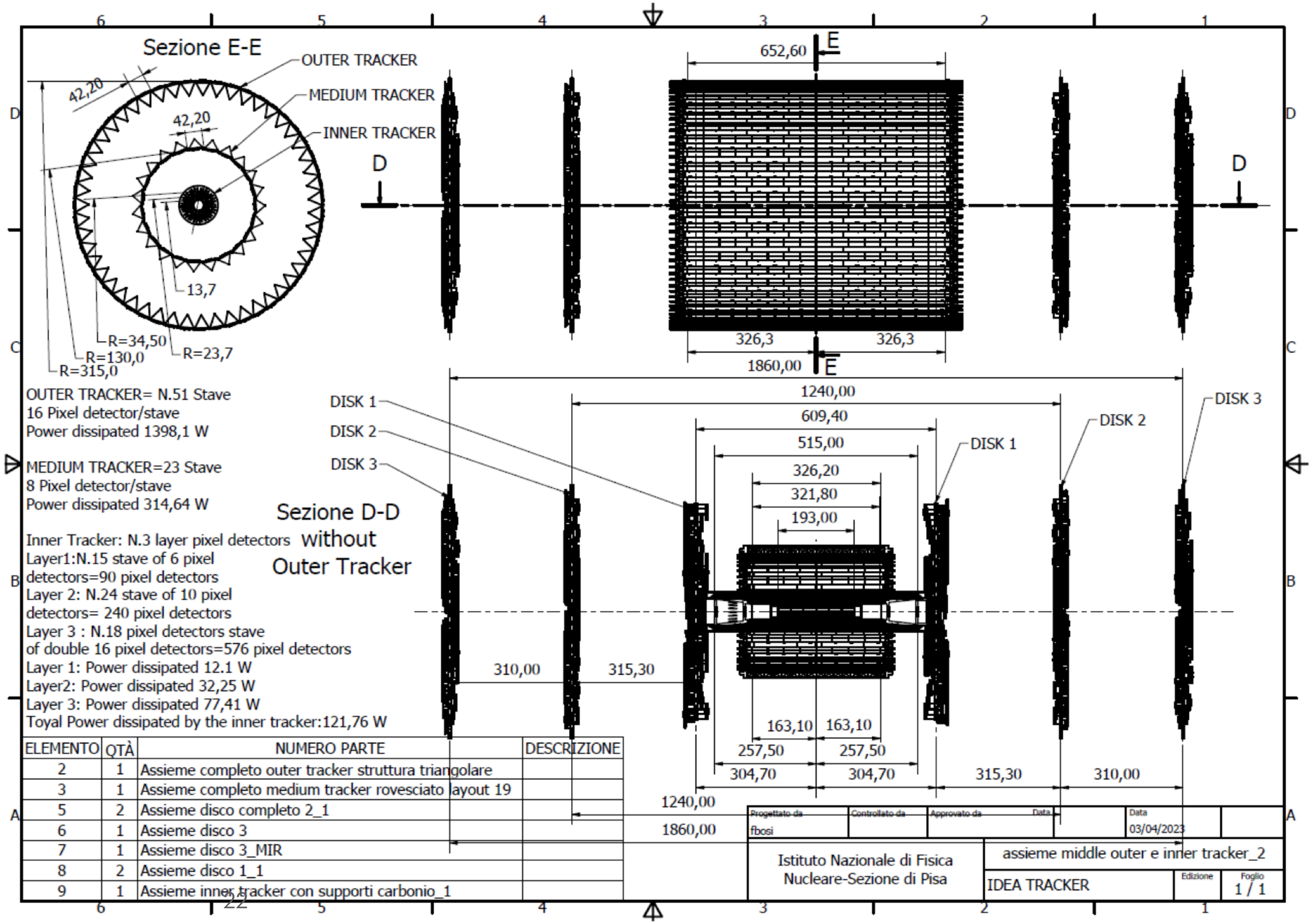
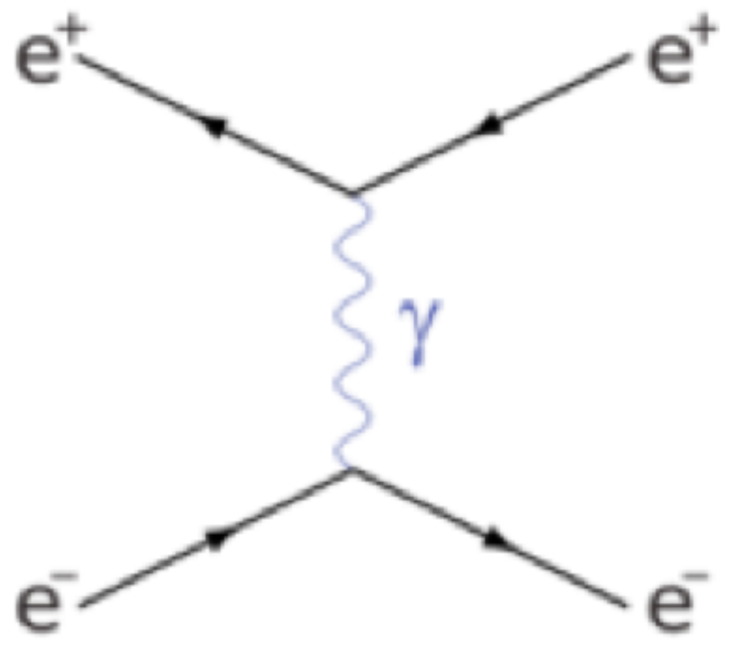


Luminosity measurement



- Measuring the rate of Bhabha events at low angles. The well known Bhabha scattering cross section will allow the precise determination of the luminosity of the ILC. Aim to achieve precision 10^{-4}

- Extend detector coverage to low polar angles - important for new particle searches with a missing energy signature