FCC Detectors

Luc Poggioli

- FCC-hh
- FCC-ee
- R&D
- Next

FCC-hh

From HL-LHC to FCC-hh

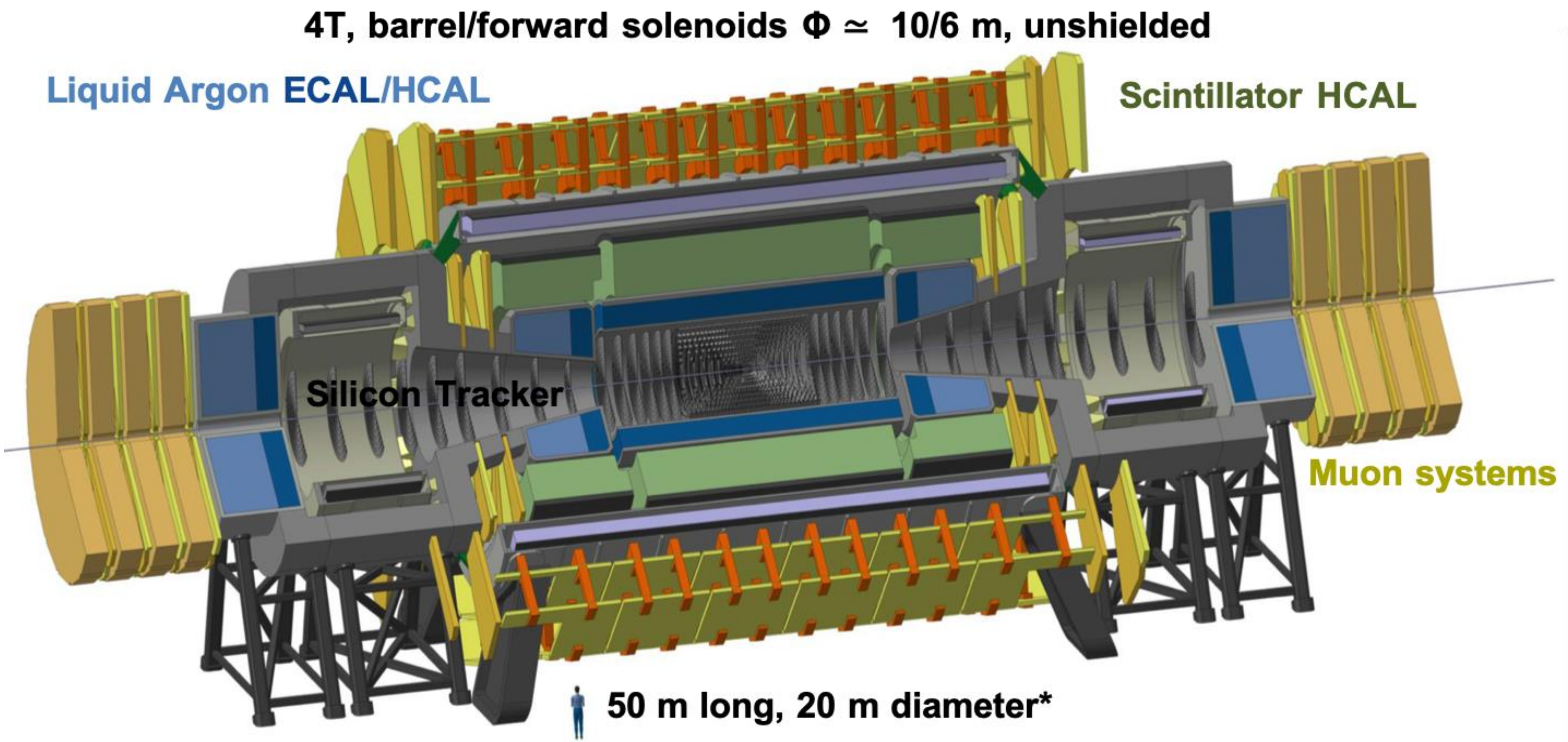
- FCC-hh vs HL-LHC (most parameters x 10-100)

	pp rate GHz	PU	Track density GHz/cm $^{-2}$	Neutron fluence 10^{16}cm^{-2}	Ionizing dose MGy	Jet >50GeV kHz	W kHz	Z kHz	tt kHz	Δ(2 vtx) mm	L1 R/O 40MHz TB/s
FCC-hh	31	1000	10	80	300	105	400	120	11	0.12	200
HL-LHC	4	200	0.7	4	13	1	15	3	0.05	1	25

- Constraints
  - Physics boost -> increase in rapidity acceptance by >1 unit
  - Radiation resistance
  - Pile-up -> Granularity (calorimeter, tracker), timing
- R&D
  - Ultra-rad hard Si sensors dvt, low power rad hard optical links, high granularity LAr calorimetry, high precision timing detectors

FCC-hh Detectors (Baseline)

CDR



Baseline: Si tracker, LAr for EM, Scintillating tile + WLS + SiPM

FCC-ee

Constraints & challenges

A. Blondel

- Constraints
  - Very large statistics -> need small systematics (10^{-5}) to match
  - Events rates ->100 KHz, Bunch spacing ~ 20 ns / NO power pulsing
  - Complex interaction region -> MDI design crucial
- Challenges
  - Rare processes → acceptance closure, sensitivity to displaced vtx
  - Luminosity measurement at 10^{-5} (rel), 10^{-4} (abs)
  - Acceptance definition at $\leq 10^{-5}$
  - Optimal b/c/gluon separation
  - PID
  - Determination of point-to-point scan energies at 10 keV level

In detail (1)

A. Blondel

- Detector acceptance
  - Essential for R_{lep} & leptonic x-section measurements
    - Systematic errors ~2-3 10^{-6}
  - To be defined with precision linked to lepton angular acceptance
    - For acceptance limit at 15 degrees -> angle known with 3.5 μrad precision
  - Hermitic detector, ie no cracks
- Luminosity measurement (For Z run especially)
  - Inner limit of detector acceptance know to 1μm @ 1m from IP
- Stability of momentum measurement (for Z run especially)
  - Affects mass, width, assymmetries, WW threshold
  - Magnetic field in tracker to be stable, or monitored, at O(10^{-6})

In detail (2)

A. Blondel

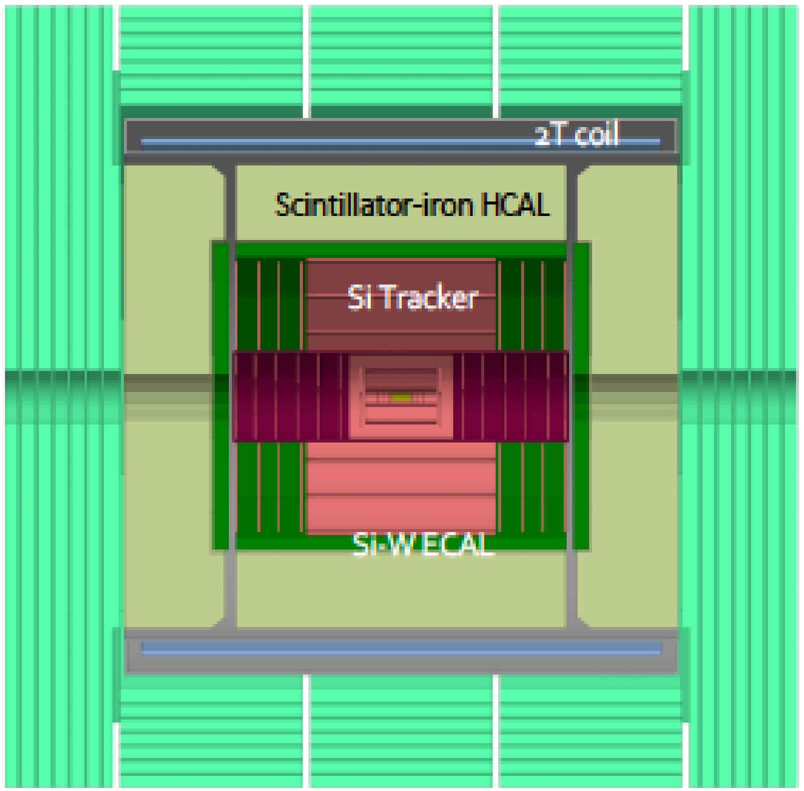
- b/c/gluon separation
  - Essential for flavor physics, Higgs & Top
  - Powerful vertex detector essential (beam pipe diameter 2cm)
- Particle Identification
  - Critical for flavor physics
  - Should cover sub-GeV (TOF) up to ~50 GeV (Cerenkov, dE/dx)
    - π/K/p separation over the full kinematical range
    - Electron/muon up to 45 GeV
- Electromagnetic energy resolution
  - Crucial for flavor physics 3%/$E^{1/2}$
    - Limits strongly the technology available (ie Crystals)

FCC-ee Detectors

CDR

Two integration, performance and cost estimates

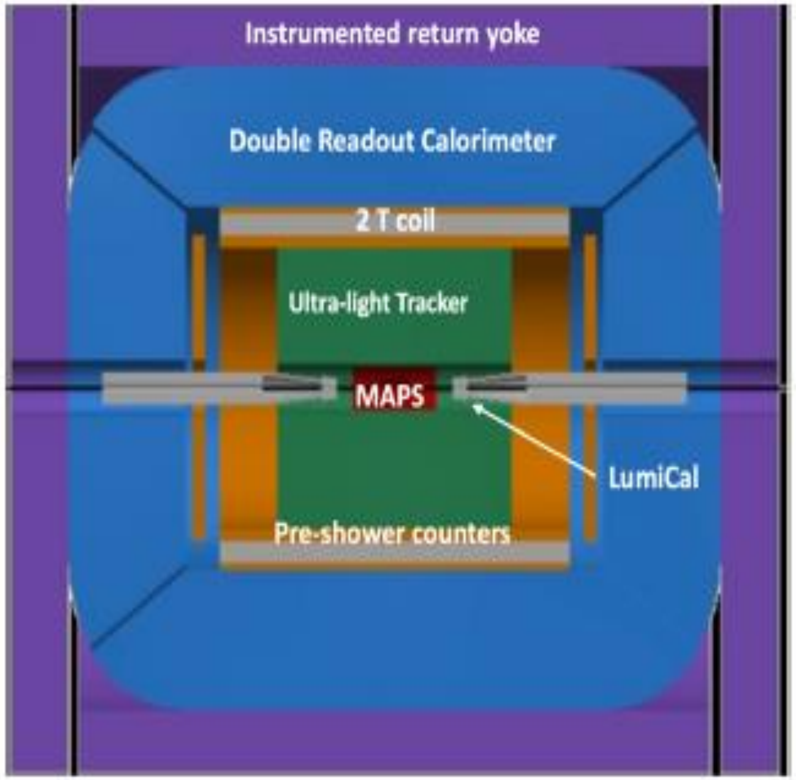
- **CLD** Linear Collider Detector group at CERN -> adaption of CLIC-SID detector for FCC-ee
- **IDEA**, detector specifically designed for FCC-ee (and CePC)



CLD

6.45 m

5.7 m



IDEA

5.6 m

6 m

CLD
2T Coil outside Calo
Full Si tracker
Si/W HG EM calorimeter
Fe/Scint. HG HAD calorimeter
Muon detector with RPC

IDEA
Ultra-thin Coil inside Calo
Si vertex ALICE MAPS
Ultra-light drif chamber MEG2
Dual readout calorimeter
Equipped return yoke

Si for tracking/vertexing (1)

D. Contardo

See Giovanni's talk

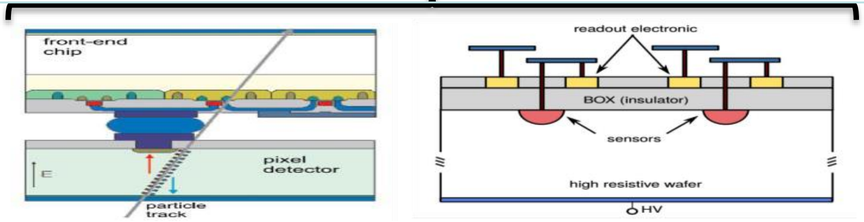
- eg CLD full Si

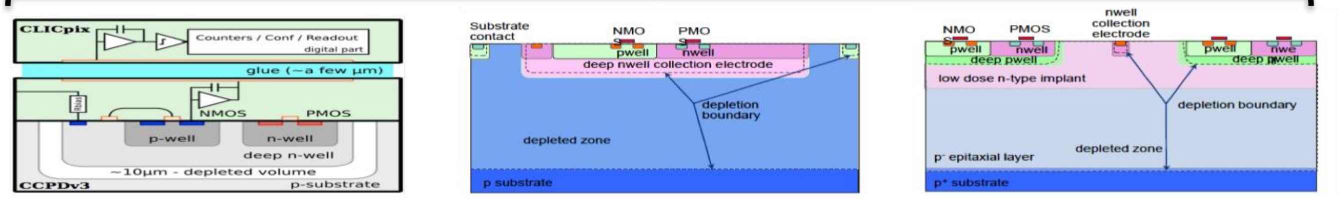
CLD vertex: 3 double layers 0.6% X/X_0 at 17, 37, 57 mm, 3 µm hit resolution
CLD tracker: Si 3/7 layers/disks (inner) + 3/4 layers/disks (outer) (12-40-70-100-160-210 cm)
- Hit resolution 1st layer 5 µm x 5 µm, next layers 7 µm x 90 µm, 1-1.5% X/X_0 per layer

- Technologies

Hybrid design, high depletion voltage planar or 3D Si-sensors, bump(wire) bonded to ASIC
- Most radiation tolerant , high rate capabilities
- LHCb Velo upgrade, ATLAS CMS upgrades
  - ≃ 10 µm resolution
  - ≃ 2 x 10^{16} neq/cm^2, sensors
  - ≃ 0.5-1 Grad, 3 GHz/cm^2 TSMC 65 nm ASIC

Monolithic Active Pixels**, electronics grown on Si sensor in CMOS standard process
- Lightest & most precise, radiation tolerance & rates limited
- ALICE ITS2, Belle-II
  - ≃ 5 µm resolution, ≃ 0.3% X_0 /inner layer
  - ≃ 2 x 10^{13} neq/cm^2 and ≃ 3 MRad
  - Binary readout sparsified, ≃ 5 µs integration time





Planar/3D sensors finer pitch for resolution

HV/HR modified for rad. tol. + faster(precise time) & higher rate readout

3D Connection to ASIC, SoI TSV, CC glue

Si for tracking/vertexing (2)

D. Contardo

- FCC-ee needs can be fulfilled with relatively standard MAPs and some work on hit resolution
  - Other recent progress may also be beneficial
  - Cylindrical mechanical designs -> further reduce material
- FCC-hh, -> deeper submicron technologies & 3D integration relevant steps wrt increased rates and radiation tolerance
  - Planar/3D high depletion voltage sensors remain best option at this stage (still far from ultimate needs)
- Developments
  - To achieve best hit resolution, lowest X/X_0 and power consumption

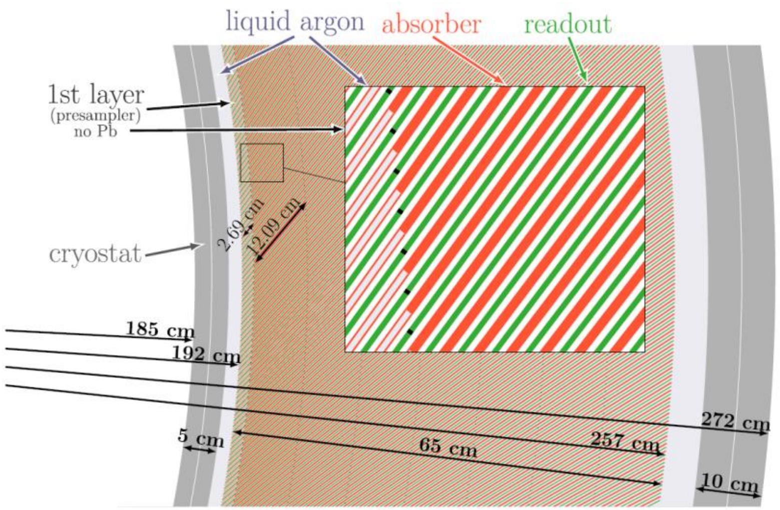
Calorimetry (1)

M. Aleksa, D. Contardo

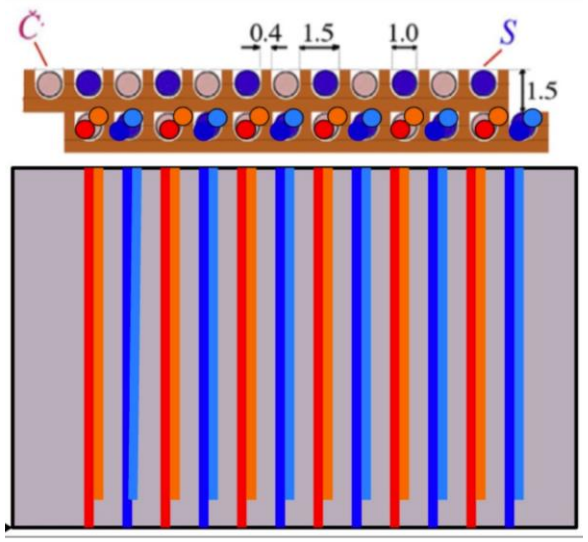
- R&D for future high-granularity noble liquid calorimetry (eg LAr) (LAL, CPPM, LAPP, OMEGA)
  - EM part only

    Finer lateral and longitudinal granularity than ATLAS (×10)
    - 8 longitudinal layers
    - ➔ 2.5 M readout channels

    ➔ **Possible thanks to straight multilayer electrodes** (PCBs, 7 layers, 1.2 mm thick)
  - Works for ee and hh



- DREAM/RD52 concept for IDEA: Dual readout
  - Both Electromagnetic AND hadronic
  - Energy response compensation measuring EM and HAD shower components in Cherenkov and scintillating fibers
  - Under study: Longitudinal segmentation



Calorimetry (2)

P.Allport, D.Contardo

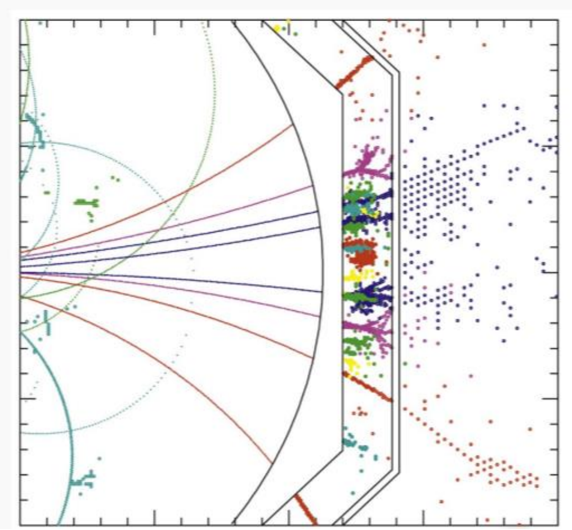
- R&D for imaging calorimetry: CALICE
  - Fine grained calorimeter segmentation optimized for optimal performance of particle flow identification and energy resolution
  - Large French involvement

See Rémi's talk

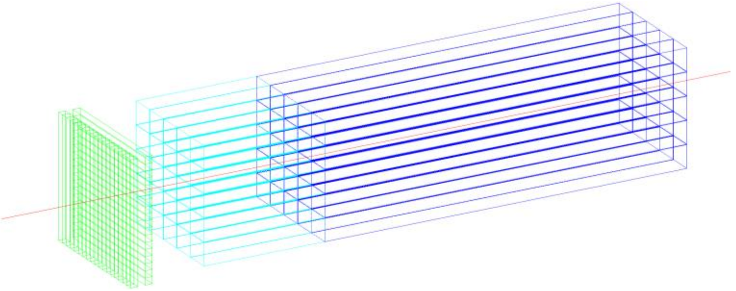
  - Si/W base for EM

Cf. CMS Endcap upgrade

ILD HGC configuration	Electromagnetic section	Hadronic section options	
Active Layer/Absorber	Si / W	Scint. tile + SiPM /Steel	Glass RPC / Steel
Number of layers	30	48	48
Cell size (cm x cm)	0.5 x 0.5	3 x 3	1 x 1
Readout	analog	analog	semi-digital
Depth number of X_0/Λ_{int}	24 X_0	5 Λ_{int}	5 Λ_{int}
Number of channels (x10^6)	100	8	70
Total area	2500	7000	7000



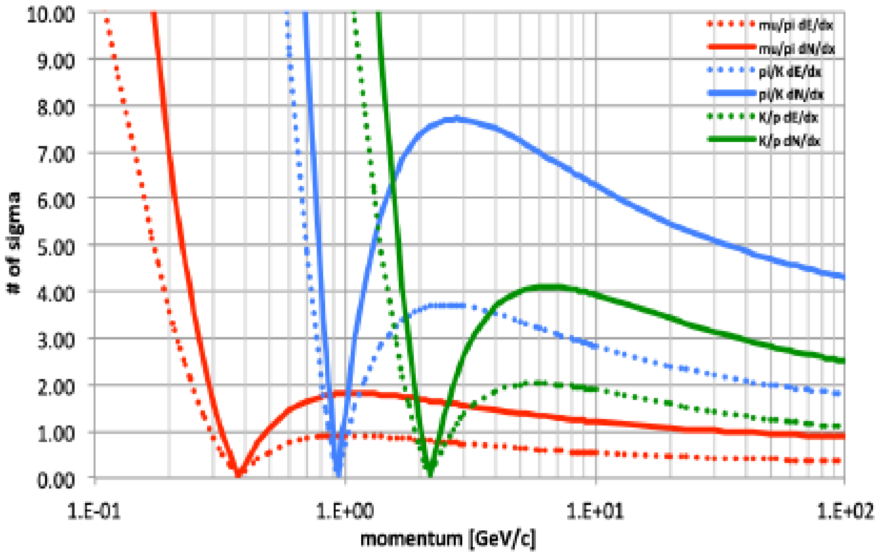
- For Hadronic calorimetry
  - Scintillating tiles/Fe à la ATLAS (with SiPM)
  - Also RPC/Fe
- Crystals
  - A la CMS. For ultimate energy resolution
  - Longitudinal segmentation under R&D

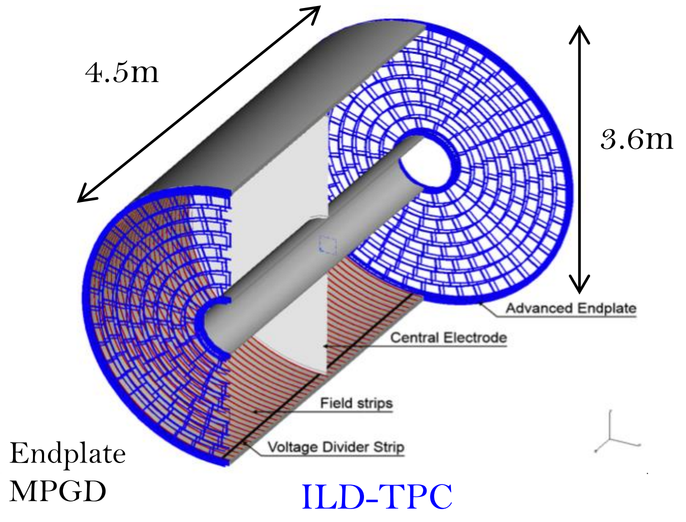


Gaseous detectors for tracking

D.Attié, D.Contardo

- IDEA Drift chamber
  - In operation in KLOE-2 & Belle-2, most recent design for MEG-II
  - Size & #layers challenging (≃ x 2 Belle-2)
- PID with 'cluster counting'
  - Classical dE/dx limited to low momentum
- TPC (Cf. ALICE upgrade)
  - Large proto for ILD@ILC
    - Needs adaptation for FCC environment
  - Readout studies with GEM/MicroMegas (MPGD: Micro-Pattern Gaseous Detectors)
  - Ion Backflow critical

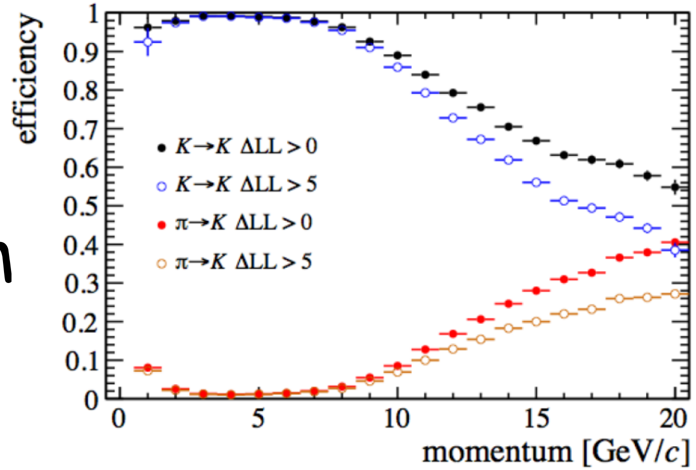




PID (Cherenkov, Scint, Si)

G.Wilkinson, D.Contardo

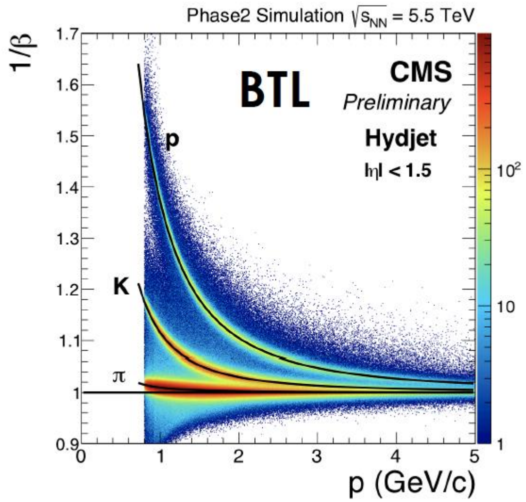
- DIRC (BaBar) / TOP counter (Belle II) /TORCH-like (LHCb)
  - Limited to lower momenta
  - Use Time Of Propagation
  - At FCC-ee radius photosensor -> resolution from ≃ 30 ps to ≃ 20 ps to get TORCH resolution



- Time Of Flight
  - Dvts for HL-LHC (ATLAS HGTD) & CMS (PID)
    - Time resolution ≃ 30 ps with thin devices

    →Can cover efficiency dip in dE/dx ID (eg coverage of up to few GeV today)
  - Other technologies than Si under study
    - Scintillator, Multigap RPCs, …

CMS PID simulation



Last points

- Today: more emphasis on ee (Timescale wrt hh)
- Some technologies OK for ee & hh
  - LAr calorimetry, TOF, Si tracking
- Real challenge for detectors
  - hh: Obvious (Cf. LHC, HL-LHC)
  - ee: Far from trivial!!! (current prejudice)
- Benchmarks (1-2yrs)
  - Physics processes -> Simulation -> detectors specifications
- ILC/CLIC/FCC collaboration possible for detectors
  - eg W/Si calorimetry, Si tracking
- But FCC-hh might need dedicated R&D, eg LAr calorimetry

Summary

- FCC-ee & hh proto detectors do exist
  - Precisions required for ee expts apply to FCC-hh both for measurements & pile-up effect mitigation
  - Synergies & benefit in developments can go both ways, but ee should exploit advantage of low rates and irradiation to reach ultimate performance
- Labo expertise
  - LAr
  - Si tracking
  - Si calorimetry
  - Timing detectors