The FCC-hh,-eh and -ee tracking detector concepts and their estimated performance

Julia Hrdinka

On behalf of the FCC study group

Details:
see last talks of FCC week & CDR volumes

The future begins now

We are at a very compelling point in physics…

- A successfull Run2 just finished
- preparations for Run3 and HL-LHC upgrade ongoing
- So far no signs for new physics at TeV-scale
- Theory can not provide a definite answer

The future begins now

dark matter, neutrino oscillations, matter-anti matter inbalance, hierachy problem, fate of the universe…???

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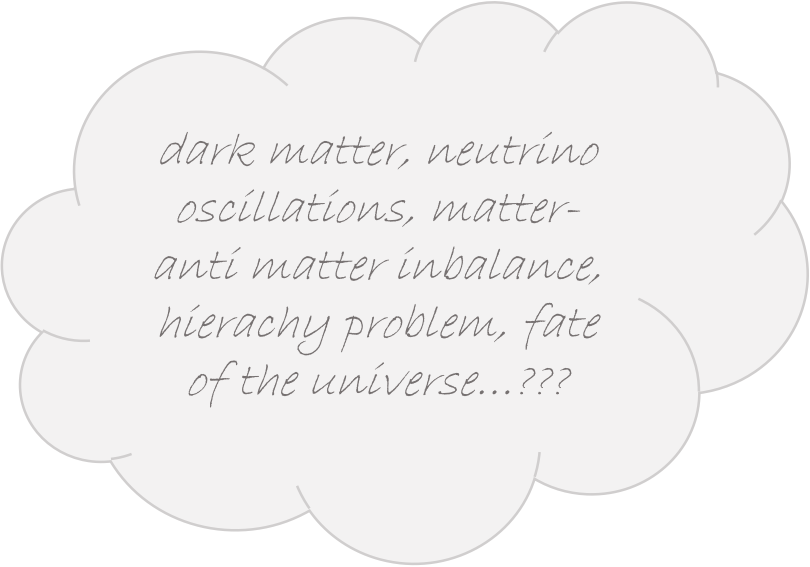
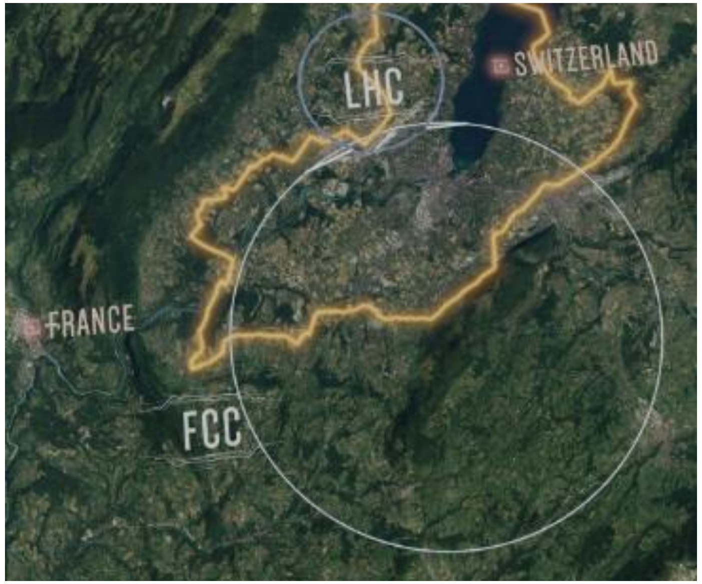


FCC – Future Circular Collider (ee,hh,eh)
International study for post LHC possibilities

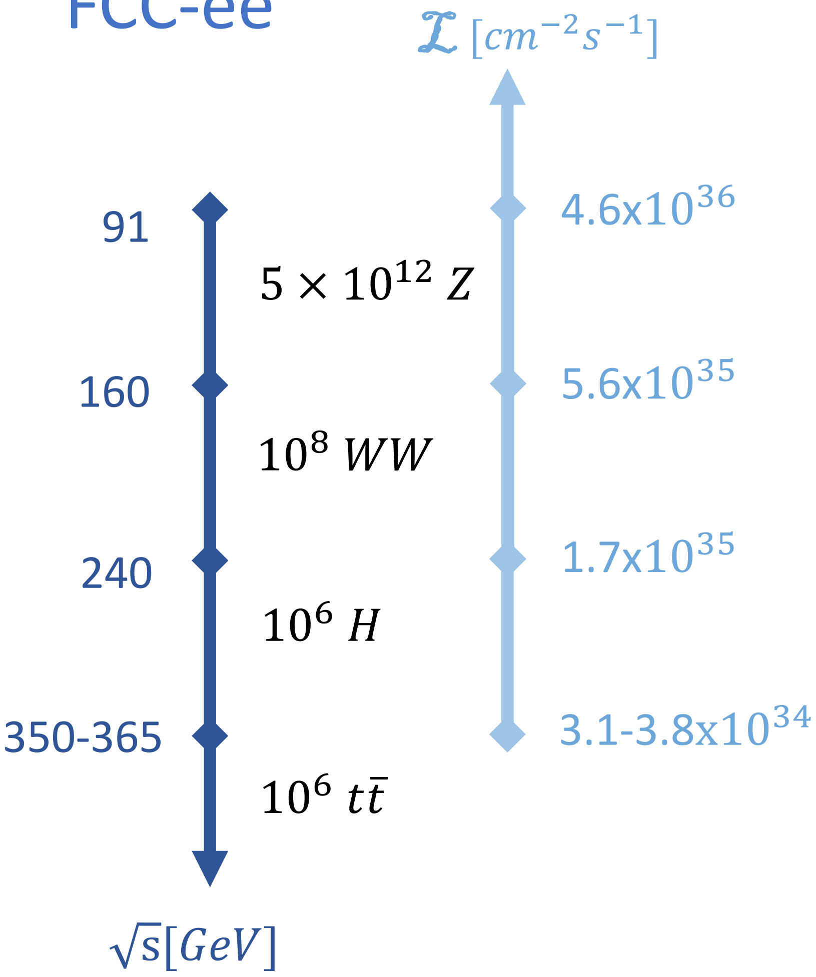
- Builds on LHC legacy
- Exploiting energy and luminosity frontier
- [conceptual design report] for european strategy update 2019



100 km cirumference

The FCC programm

FCC-ee



$\Rightarrow$ 15 years of operation possible, starting in end 2030s

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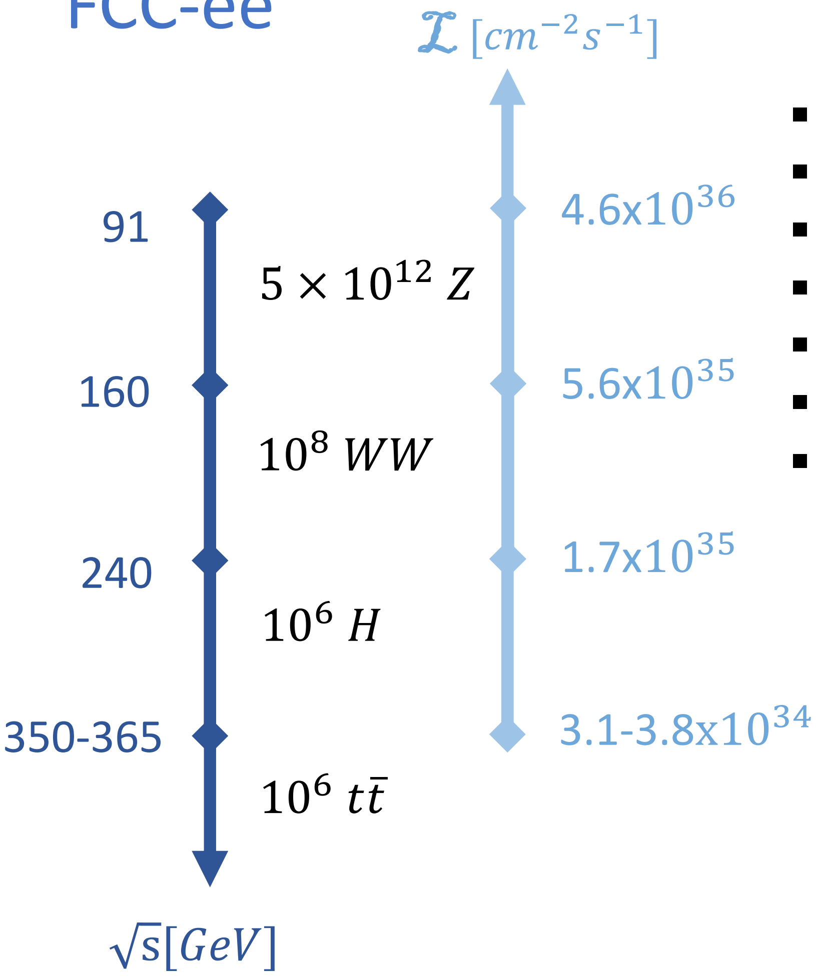

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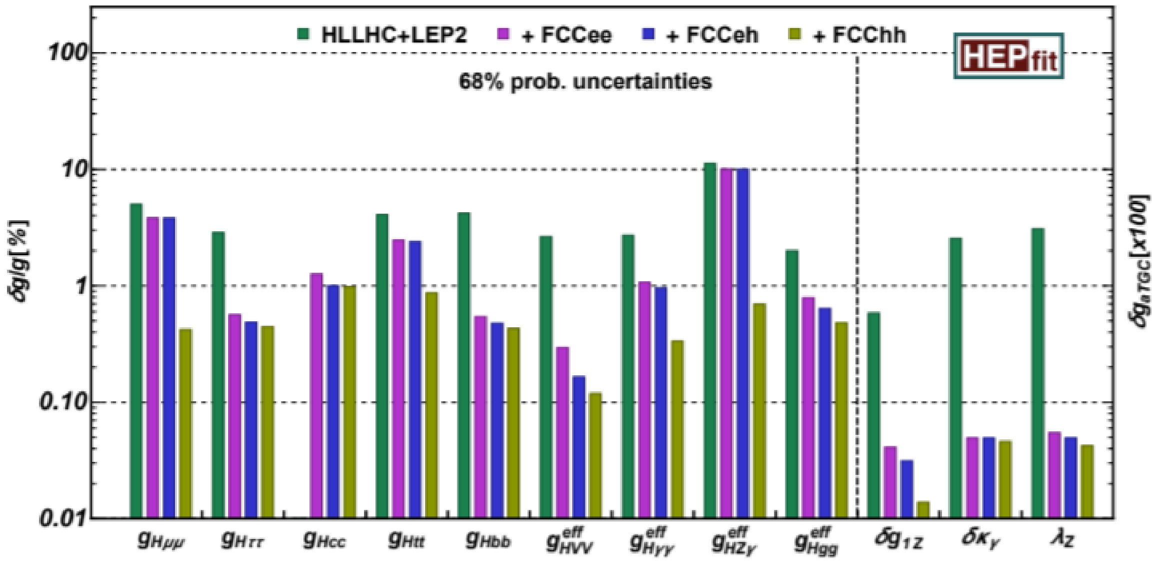
FCC-eh

- $\sqrt{s}$=3.5 TeV
- L = 1.5 x 10^{34}cm^{-2}s^{-1} (1000xHERA)
- <μ>=1
- 2x10^{6} Higgs
- Optional, concurrent to FCC-hh
- ERL provides 60 GeV electrons
- Radiation: 10^{15}n$_{eq}$ / cm^{2}

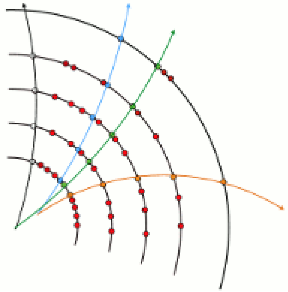
FCC-hh

- $\sqrt{s}$=100 TeV
- L = 30 x 10^{34}cm^{-2}s^{-1}
- 1000 Events/BX
- Main challenges: civil engineering & dipole magnets (16T)
- Cryogenics needs to compensate for SR
- Discovery potential & precision



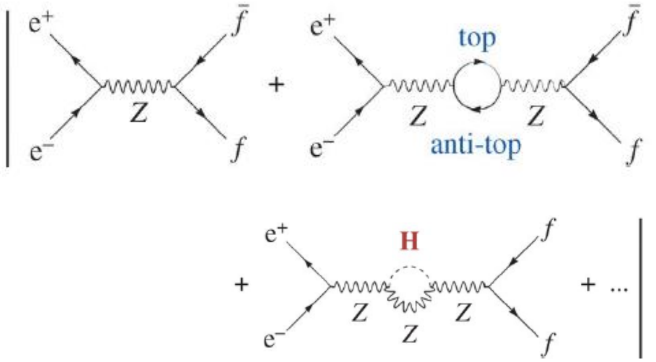
$\Rightarrow$ 25 years of operation possible, starting in mid 2060s

$\Rightarrow$ $> 20\ ab^{-1}$



FCC Tracking Overview

FCC-ee



- Clean environment
- Small number of tracks
- Extreme statistical precision

$\Rightarrow$ Extremely precise tracking (good position & momentum resolution)

$\Rightarrow$ Light tracker

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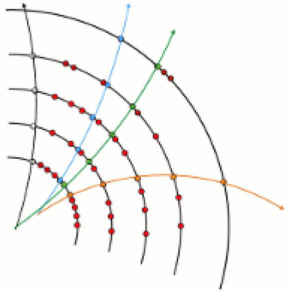

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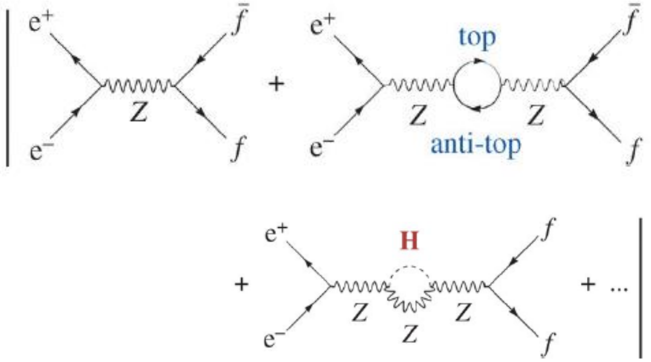

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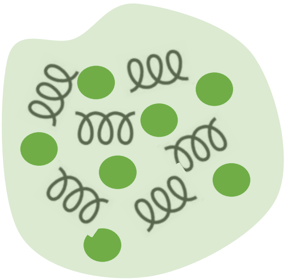
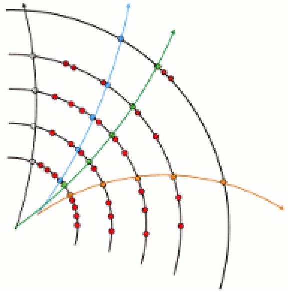


- Study PDF's in unprecedented precision
- observe large Q^2 & low x events
- Demanding forward region

⇒ e^- & p scattered up to tens of TeV

⇒ large acceptance vertexing

⇒ High resolution



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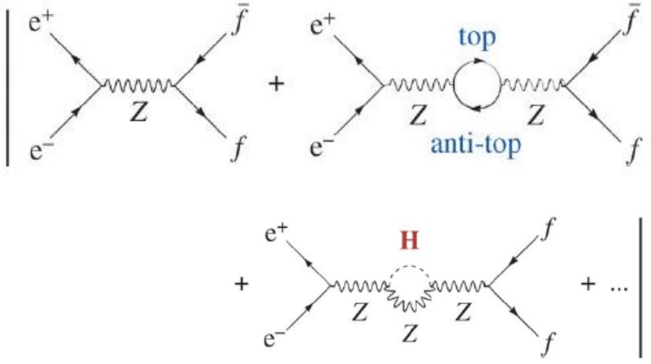

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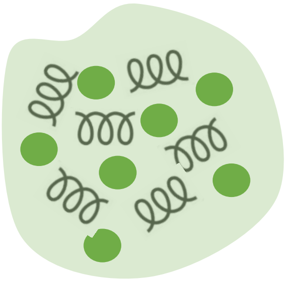

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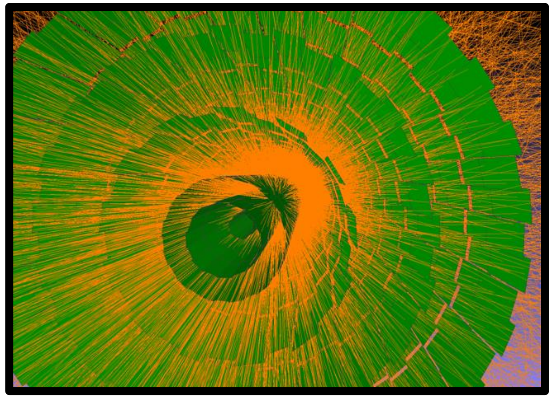
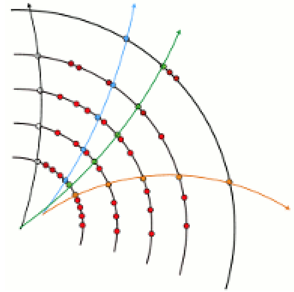


$\boldsymbol{\mu = 1000}$

- Extreme PU & radiation environment (5xHL-LHC)
- Large number of tracks
- Resolve boosted objects (τ,t,b,c)
- Cover Large p_T range ($O(4)$)

FCC Tracking Overview



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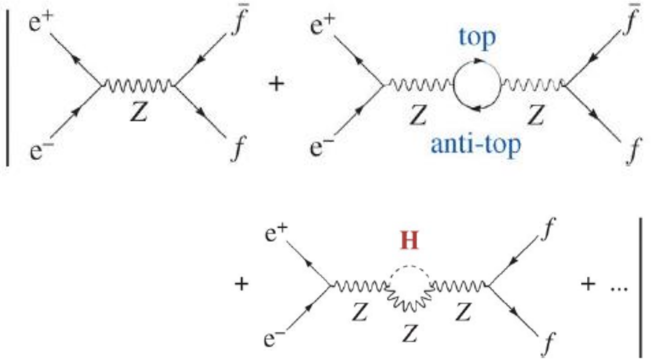

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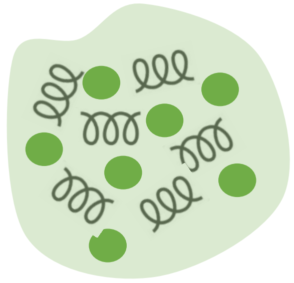

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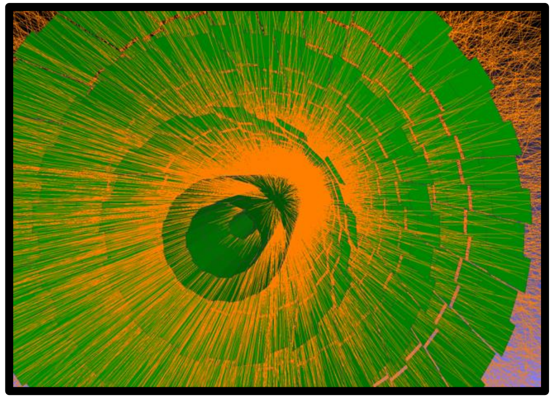

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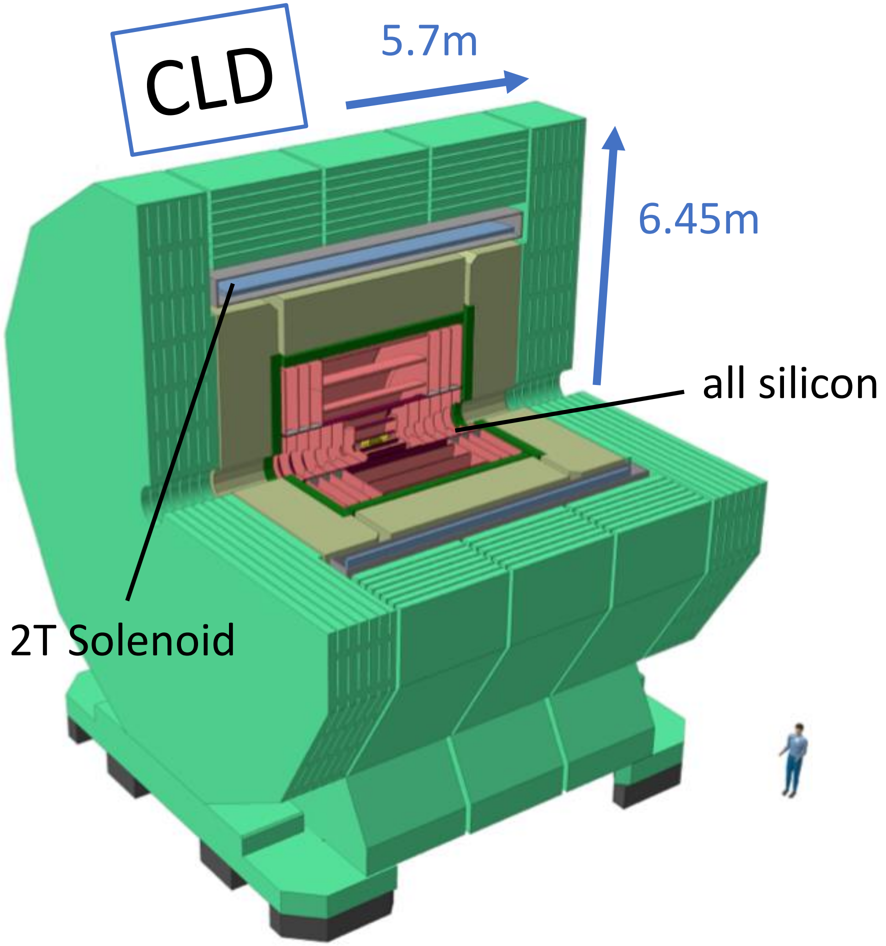
- Cover Large p_T range ($\mathcal{O}(4)$)

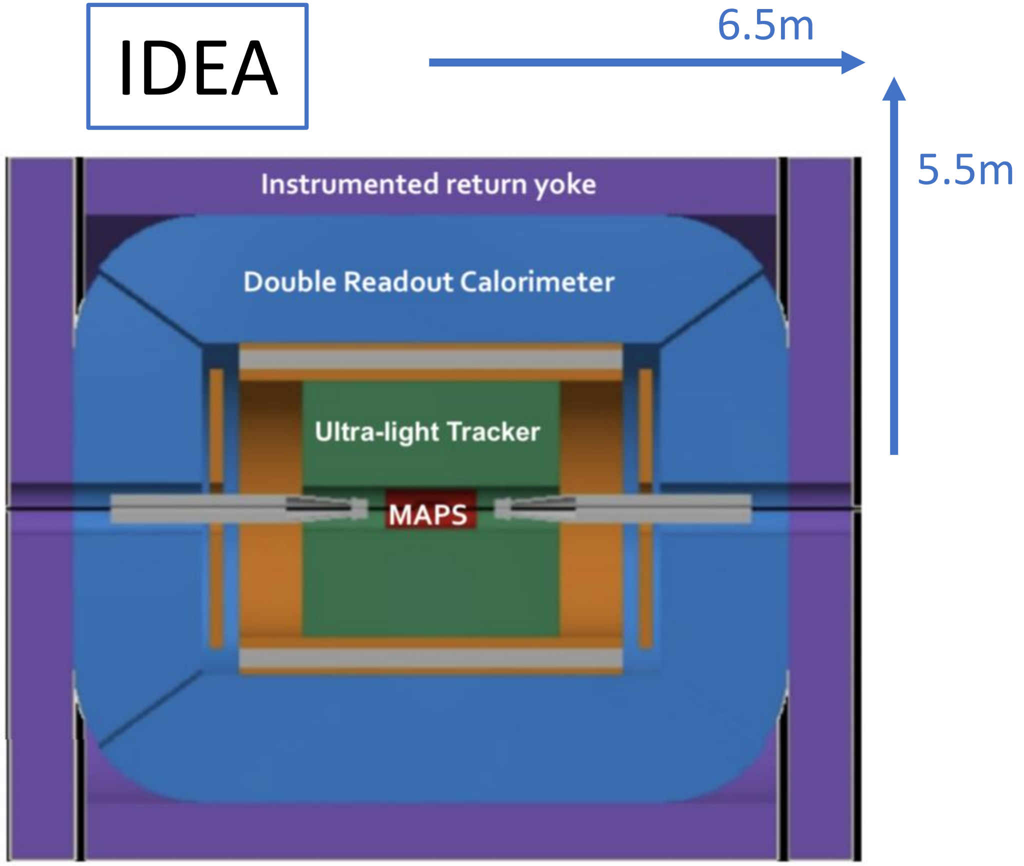
⇒ *These 3 programs include entire track reconstruction spectrum of last decades (LEP,HERA,LHC)*

FCC-ee

FCC-ee – Detector Options

- Improve statistical precision of EW & Higgs by $O(1)$-$O(2)$
- Probe new physics effects from 10-100 TeV (indirect)
- To maximize luminosity: Final focusing quadrupole inside detector @2.2m from IP





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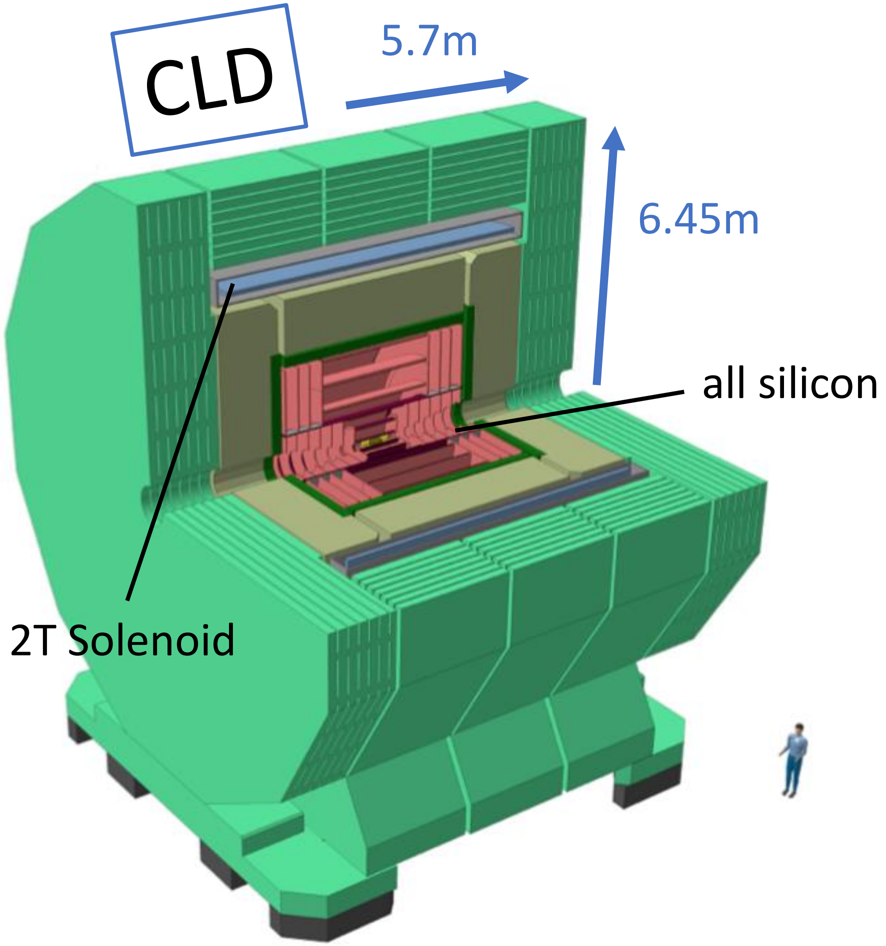


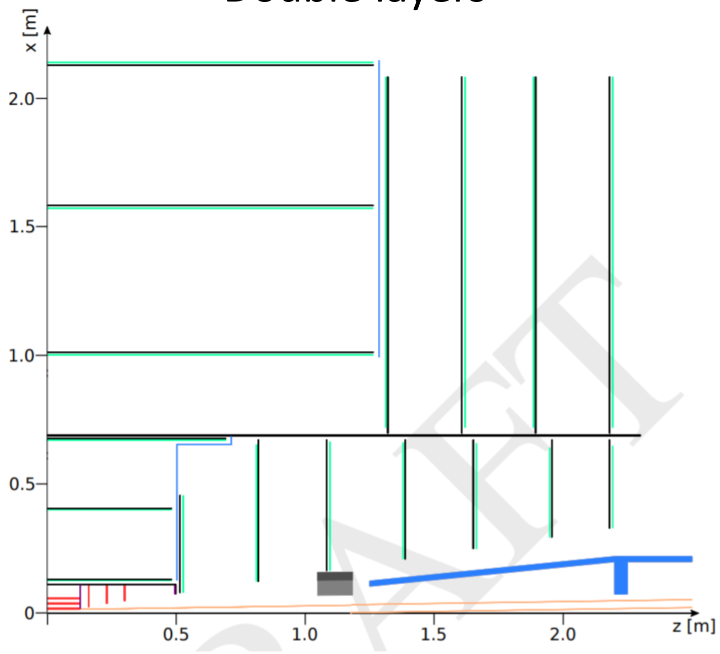
CLD (CLIC-Like Detector)

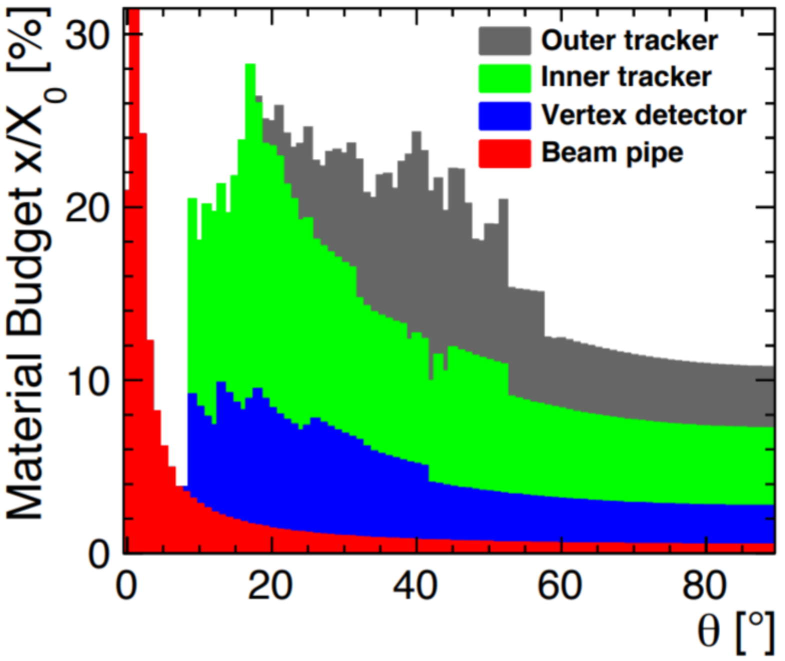
Vertex Detector

- First layer: 17mm
- $25 \times 25\ \mu m^2$ pixels
- $50\ \mu m$ sensor thickness
- Single point resolution: $3\ \mu m$
- Double layers

Tracking Detector

- Silicon pixel and microstrip
- Single point resolution: $7\ \mu m \times 90\ \mu m$





In total $\sim 196 m^2$ silicon

η=0

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CLD (CLIC-Like Detector)

Full simulation + track reconstruction studies using ILCSoft (see E. Brondolins talk: **New developments in conformal tracking for the CLIC detector**)

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Tracking Detector

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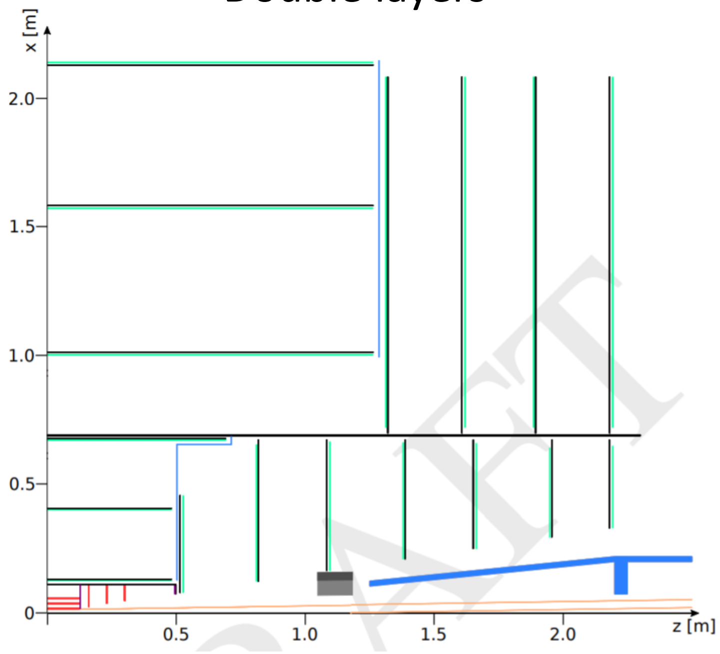
Performance

- Tracking efficiency single muons
  - Prompt: fully efficient (99%/100% in forward/central region)
  - Displaced: 100% ($p_T > 1GeV$), 96% ($p_T > 0.1GeV$)



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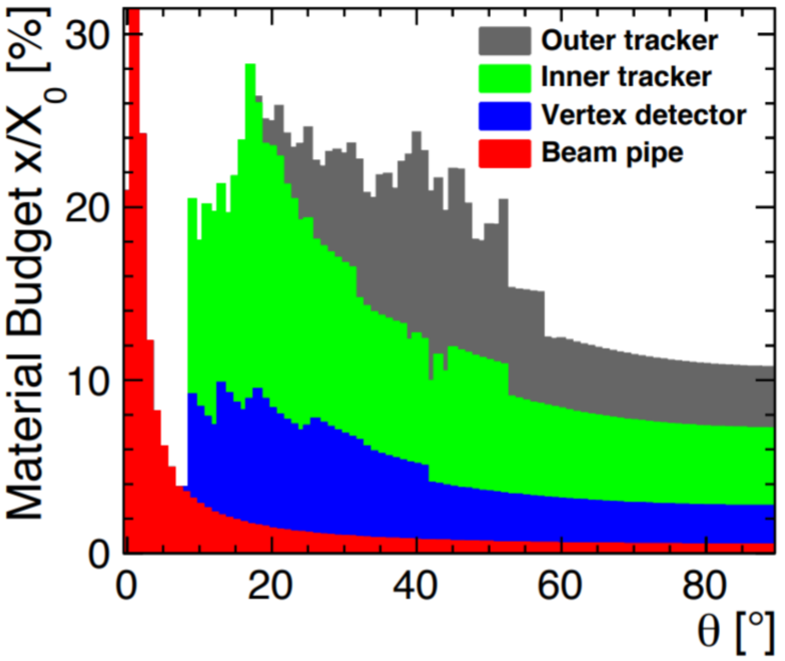

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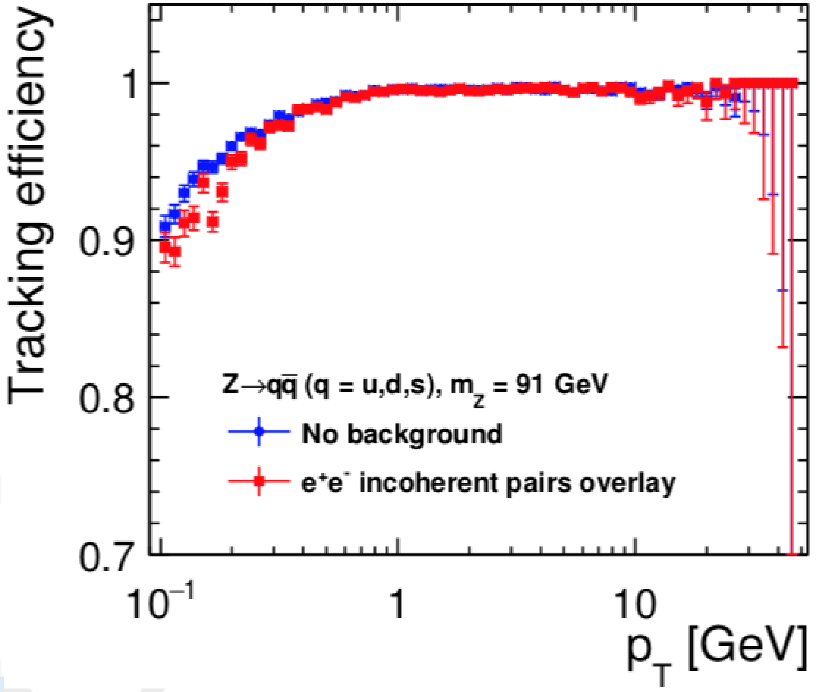

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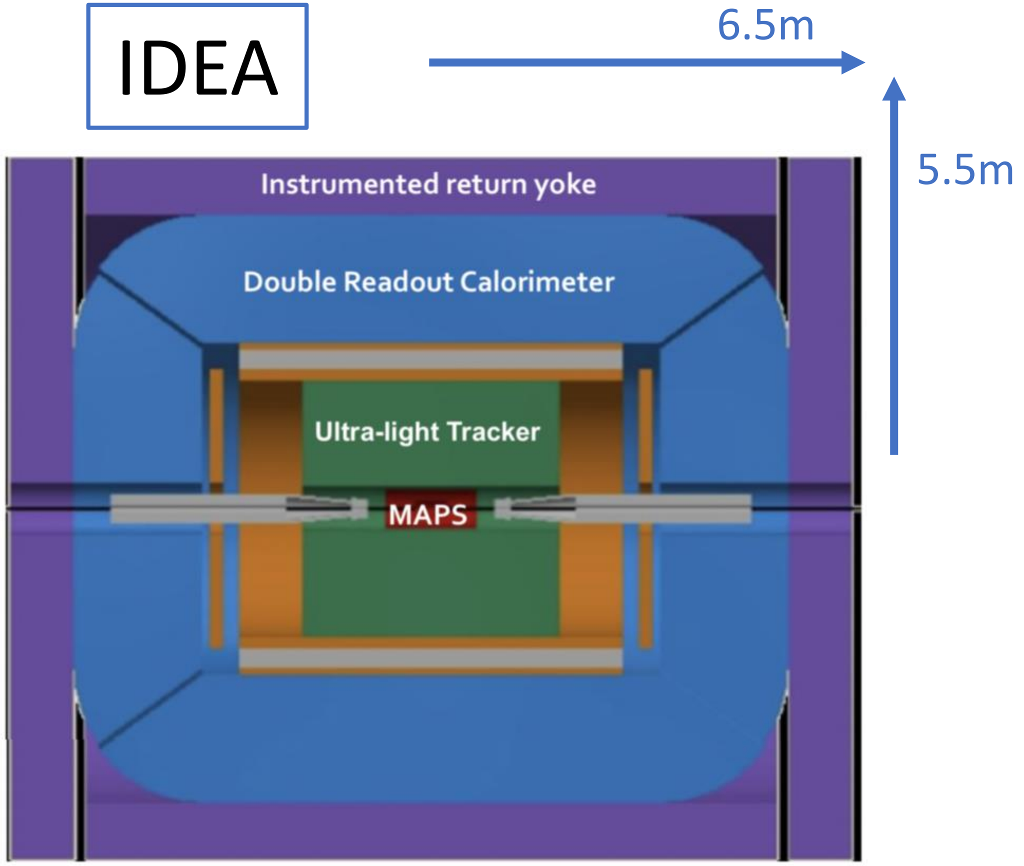
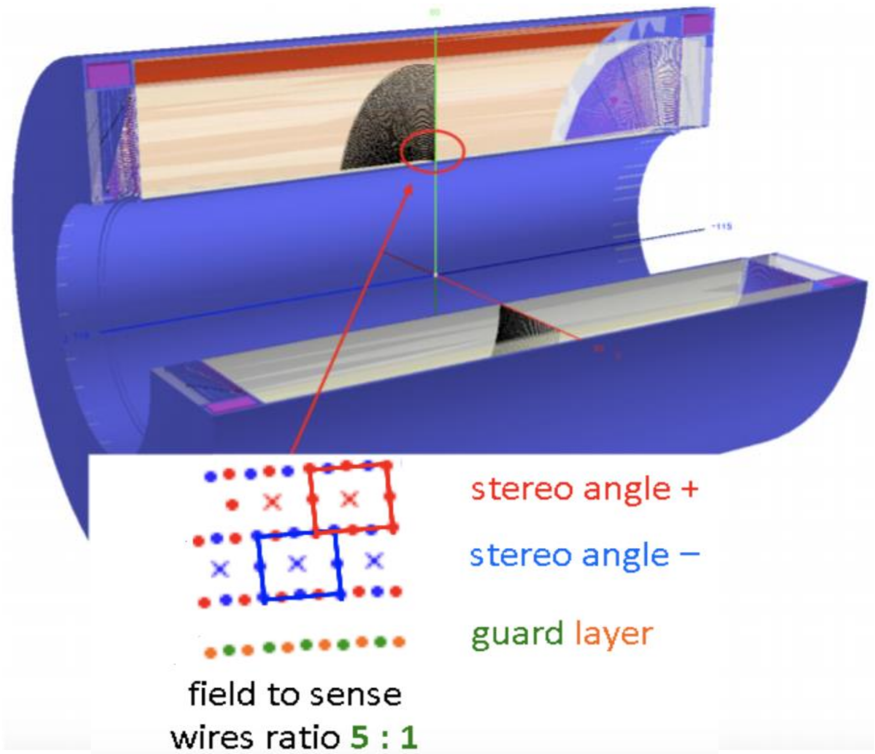


IDEA (International detector for e^+e^- accelerators)

Vertex Detector

- Orientation on ALICE ITS upgrade
- MAPS (Monolithic active pixel sensors)
  - $5\mu m$ position resolution
- Light: 0.3(1)% X_0 per inner(outer) layers



Drift Chamber (DCH)

- Following model of KLOE and MEG2 DC
- Tracking & Particle identification
- 90% He-$10\%\mathrm{iC_4H_{10}}$ (isobutane)
- Highly transparent
  - 1.6 -5% X_0 in total

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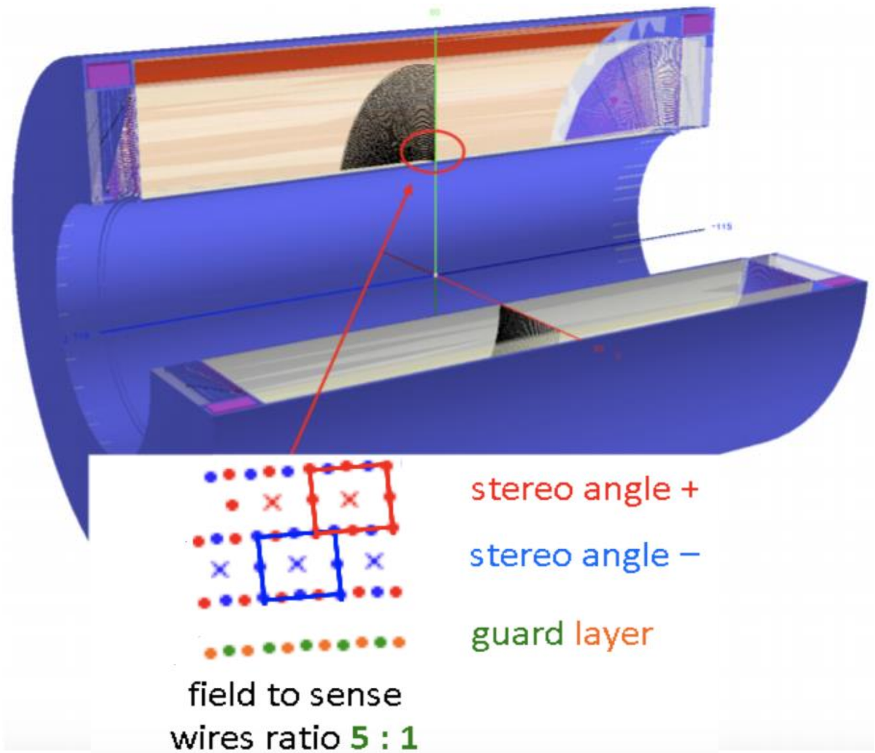
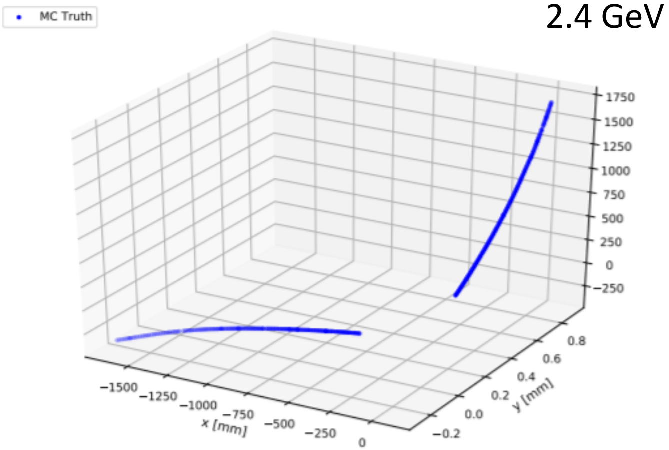
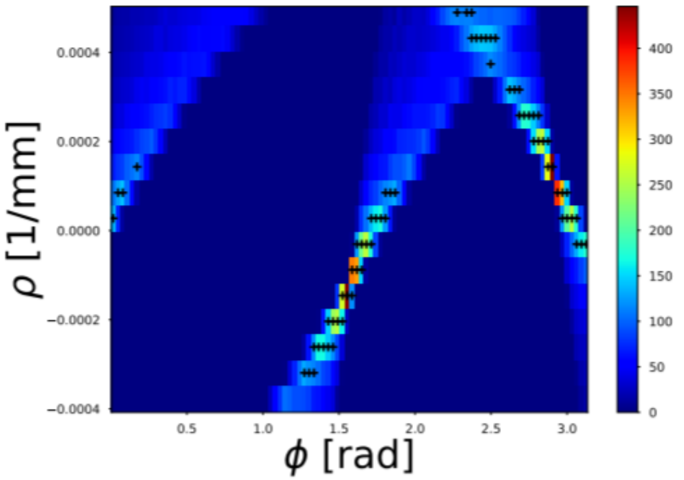
Full simulation & reconstruction

- Long term plan
  - FCCSW, TrickTrack & ACTS (see Back-up)
- Currently
  - hough transform (see) & conformal mapping (see E. Brondolins talk)
  - Work in progress





2.4 GeV muon



Beam induced backgrounds

Synchrotron radiation

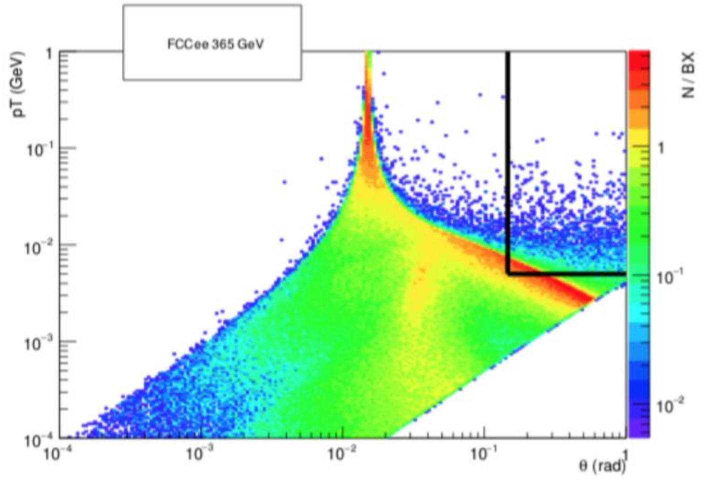
- $@\sqrt{s} = 356\text{GeV}\ 6.6 \times 10^4\ \text{hits/BX}$
  =>$350\ \text{hits/BX}$ with shielding in VXD

$\gamma\gamma \to \text{hadrons}$

- Negligible: $< 10^{-2}\ \text{events/BX}$

Incoherent e^+e^--pairs (IPC)

- largest impact: 1 event/BX
- $1100\ \text{hits/BX}$ in VXD



e+e- produced with E>5MeV

(*) assuming average cluster size 5/2.5 for pixel/strip and safety factor 3

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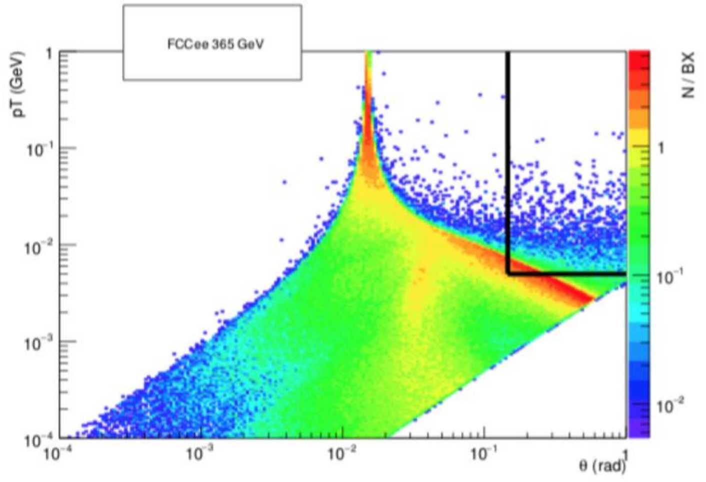
CLD

- CLD Occupancy(*) < 1% for all $\sqrt{s}$-options
- Highest rates in two innermost layers



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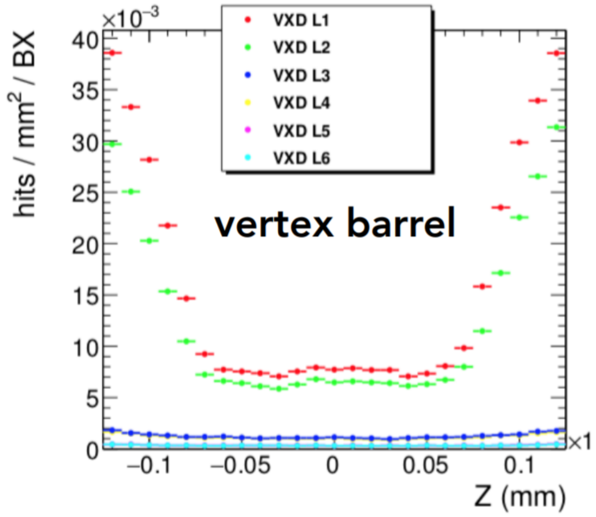

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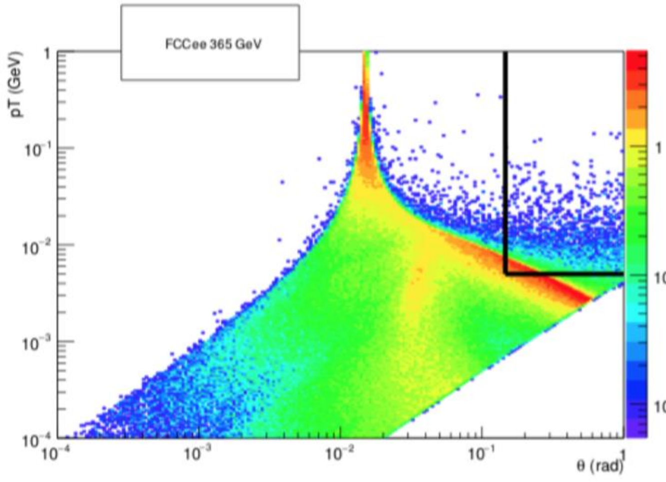

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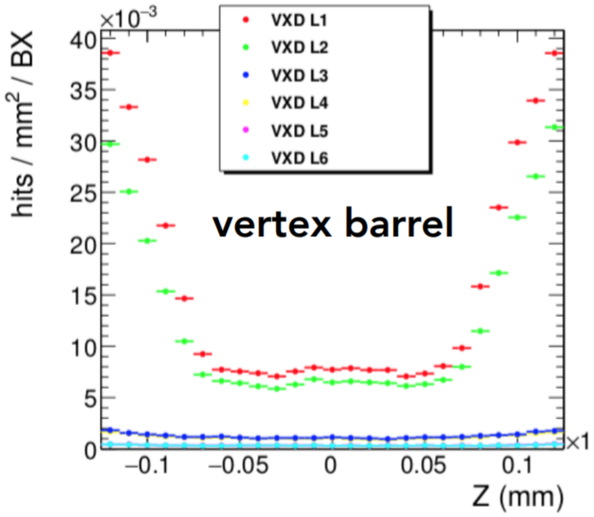
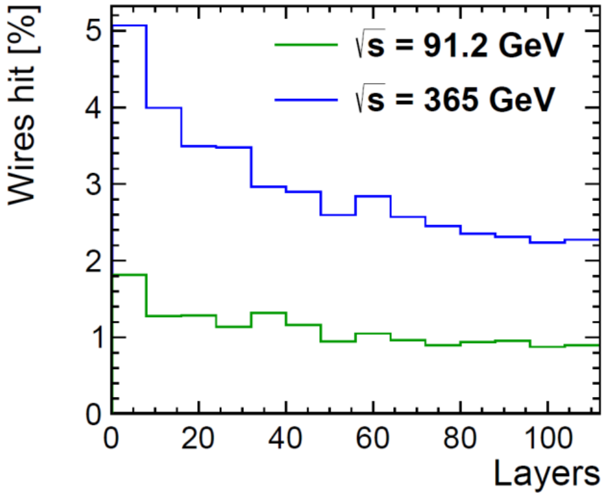


DCH

- 3% average occupancy
  - manageable (MEG2 experience)
- Exploit DCH timing measurements for reduction



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⇒ Not expected to significantly affect tracking performance

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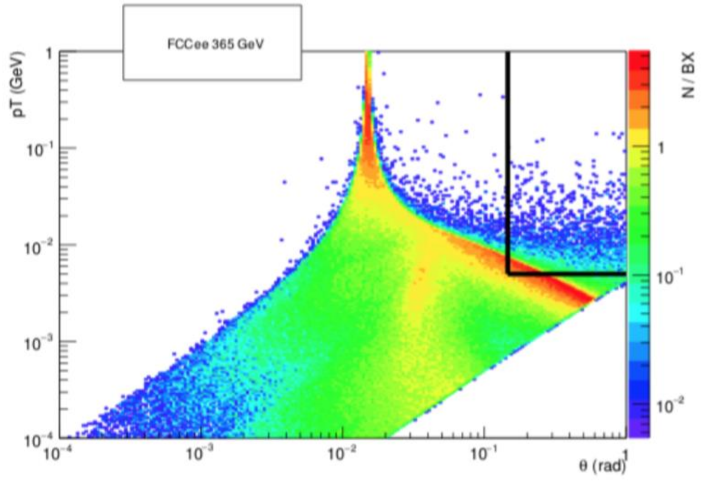

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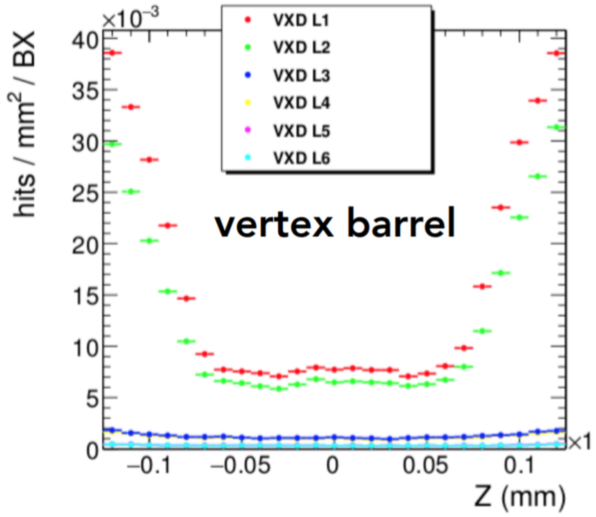

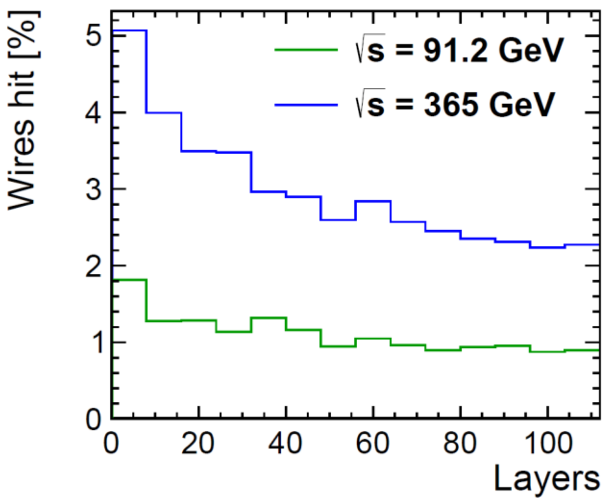

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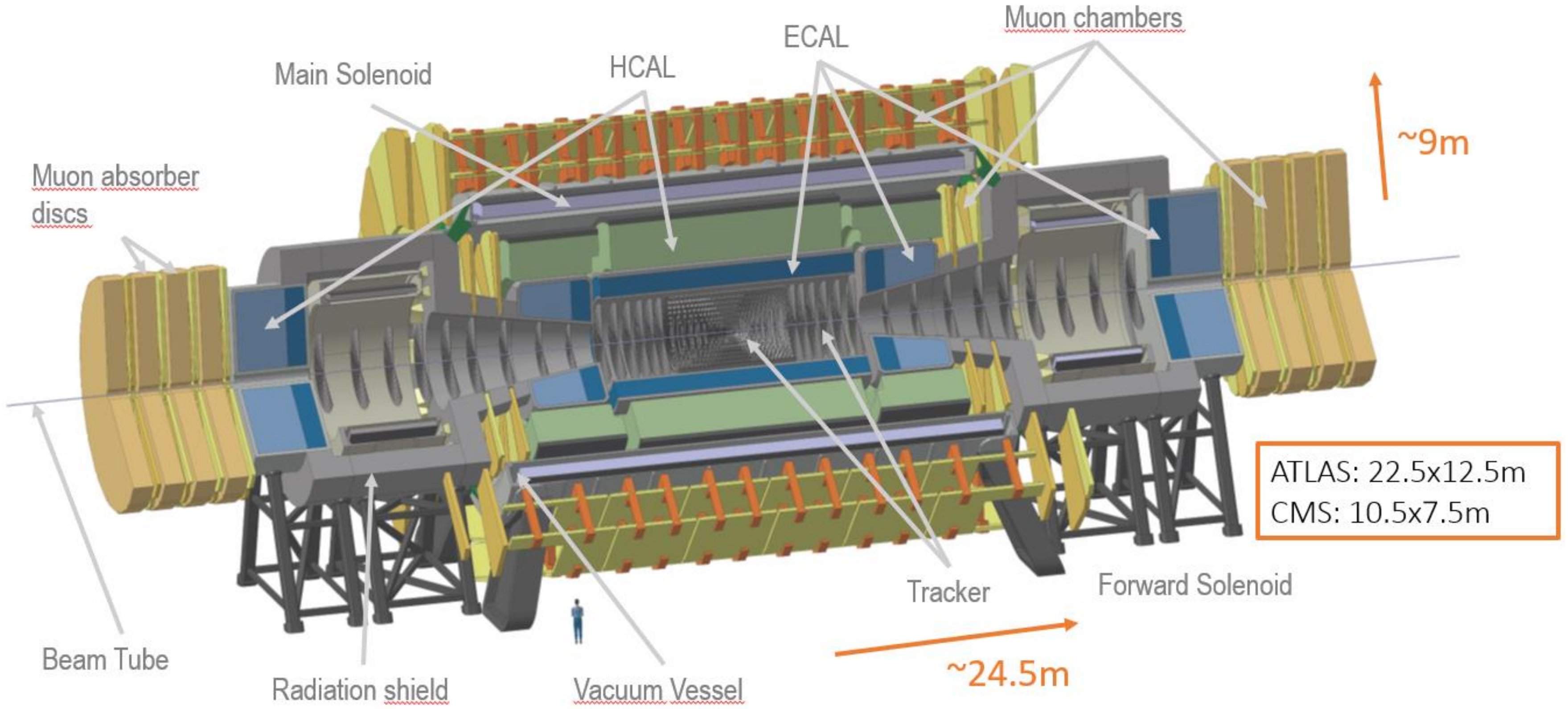
FCC-hh

The FCC-hh reference detector

Multipurpose detector
- absence of clear direction of new physics requires broad scope of detector acceptance

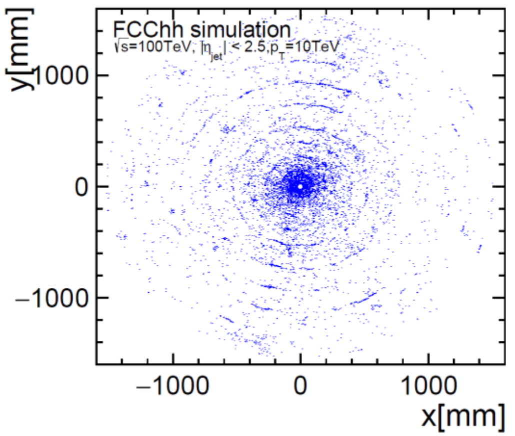
Large η-acceptance
- physics is highly boosted
  - VBF jet peak |η|=4.4 (LHC: 3.4)
  - 90% $H \rightarrow 4l$ |η|<4.8 (LHC: 3.8)

High granularity
- Resolve boosted objects (τ,t,b,c)
- Extreme PU environment
  - <μ>=1000 (5xHL-LHC)

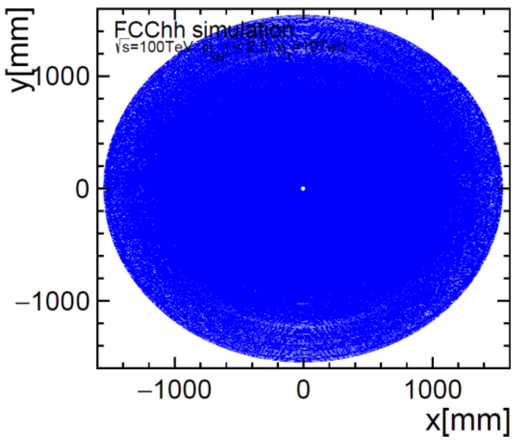


ATLAS: 22.5x12.5m
CMS: 10.5x7.5m

Space-points 10 TeV b-jets

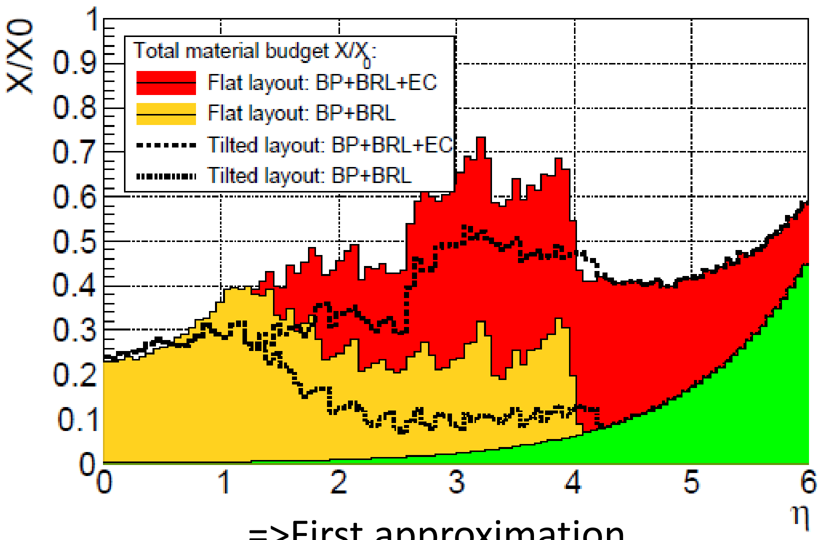


Space-points 10 TeV b-jets @<μ>=1000

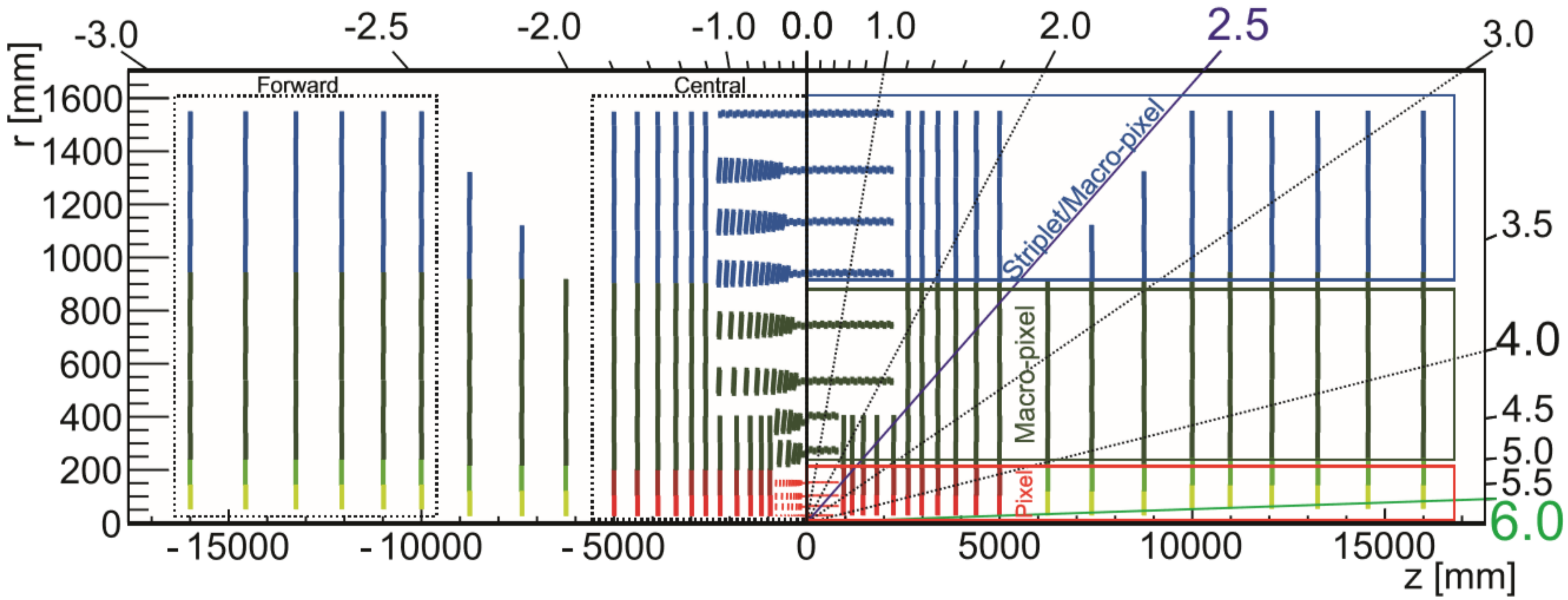


Tracking detector

- Tracking up to |η| ≈ 6, high precision up to |η| ≈ 4
- $\frac{\delta p_T}{p_T} = 10 - 20\% \; @ \; p_T = 10 \; TeV$
- Remain sensitive to low p_T $(\sim GeV)$ $\Big\}$ $\sim O(4)$
- b-,c-,τ- tagging capabilities to high η despite huge pile up



=>First approximation
(technologies not known yet)



pixel
- 25x50μm
- 1-1.5% X_0
- 490 M channel

macro-pixel
- 33.3x400μm^2
- 2% X_0
- 9964 M channel

Strip
- 33.3x50/1.75mm^2
- 2.5% X_0
- 5461 M channel

In total $\sim 430m^2$ (~2xCMS) silicon for flat layout, 10% less for tilted layout

Extreme radiation and pile-up environment

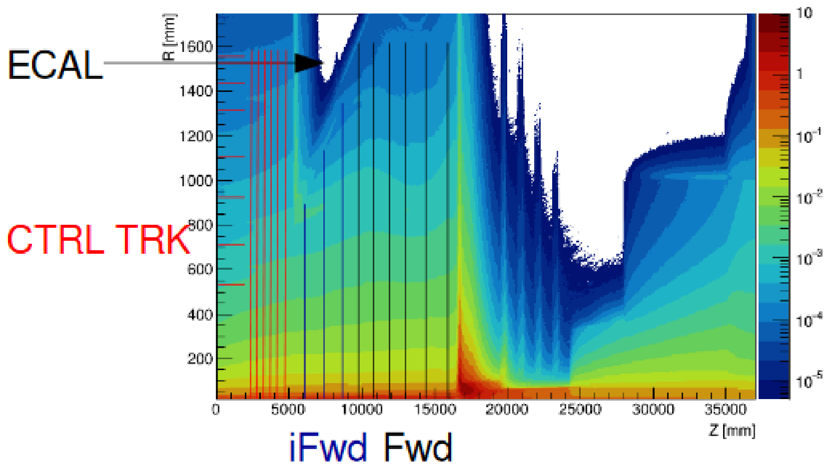
Radiation:

- Maximum expected fluence
  ~ 10-100 x HL-LHC
  ~100-1000 x LHC
- First IB Layer (2.5cm): ~5-8*$10^{17} n_{eq}$ / cm^2
- External part (after 40cm):

~5*10^{15} n_{eq} / cm^2

⇒ could use HL-LHC technologies

Charged particles fluence [cm^{-2}] per 1 pp collision



Extreme radiation and pile-up environment

Radiation:

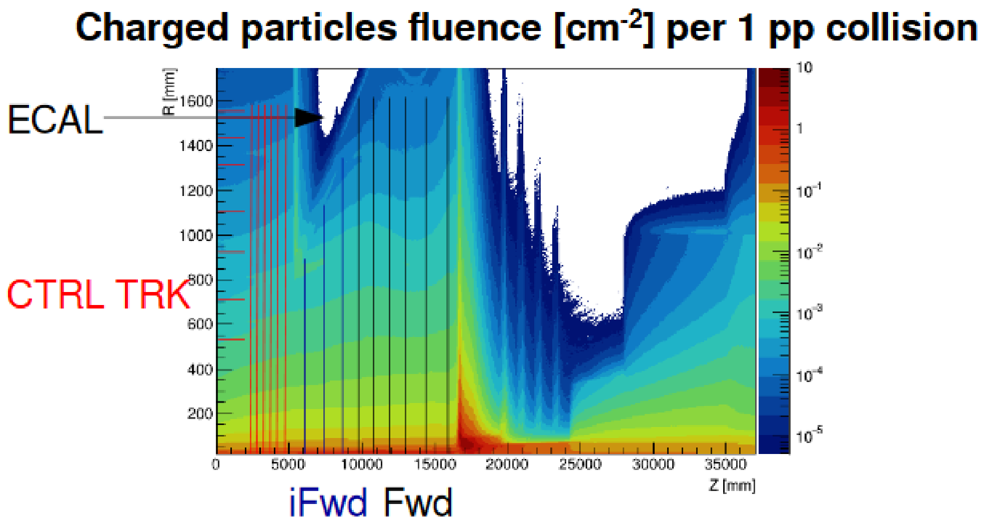
- Maximum expected fluence
  ~ 10-100 x HL-LHC
  ~100-1000 x LHC
- First IB Layer (2.5cm): ~5-8*$10^{17} n_{eq}$ / cm^2
- External part (after 40cm):

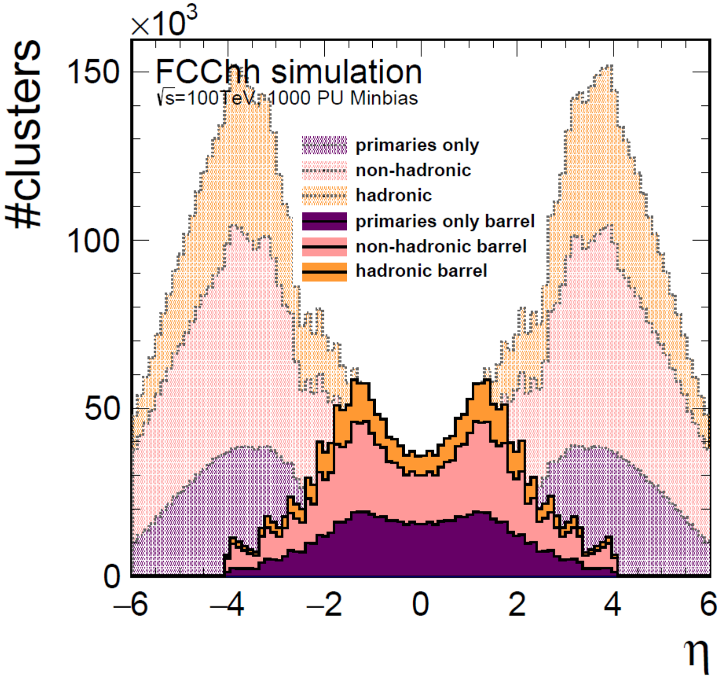
~5*10^{15} n_{eq} / cm^2

$\Rightarrow$ could use HL-LHC technologies

Clusters:

- MinBias @ <μ>=1000
- Full simulation, geometric digitization & clusterization
- Seconaries give rise by 70%





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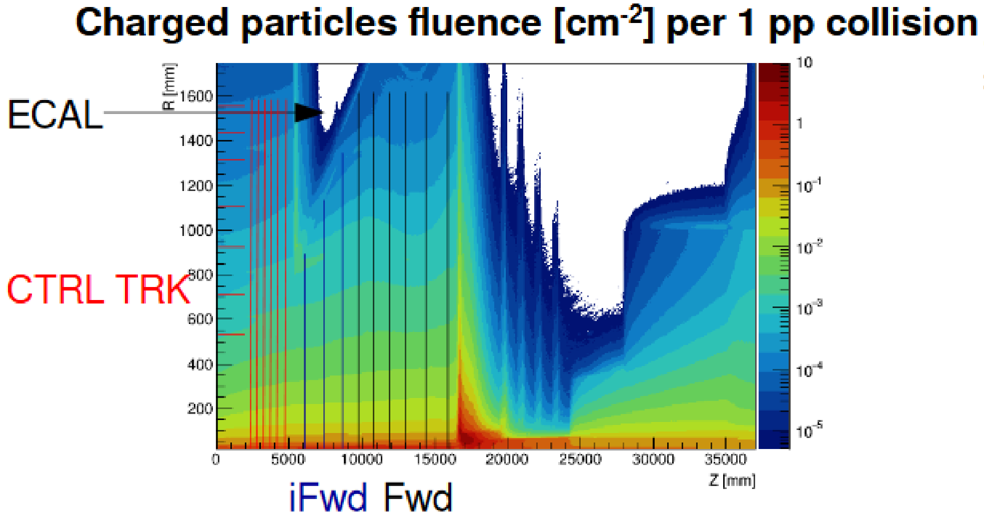

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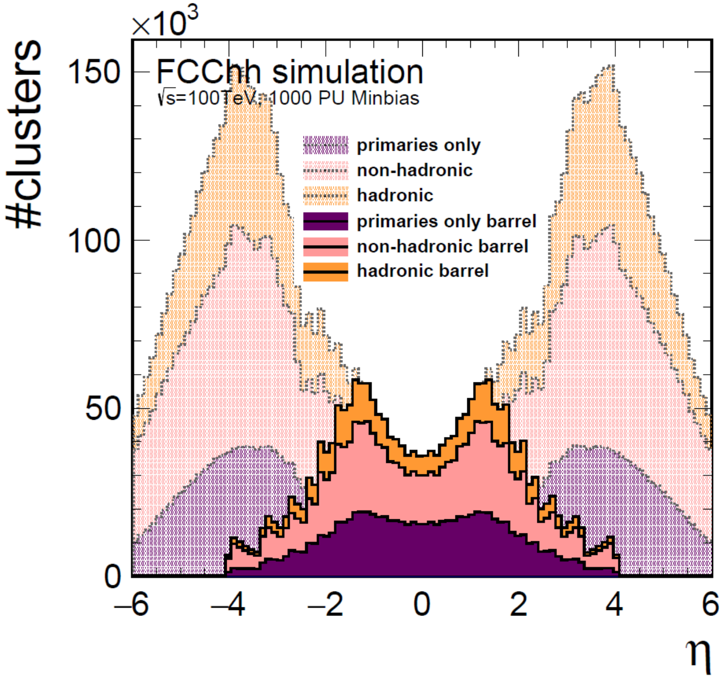
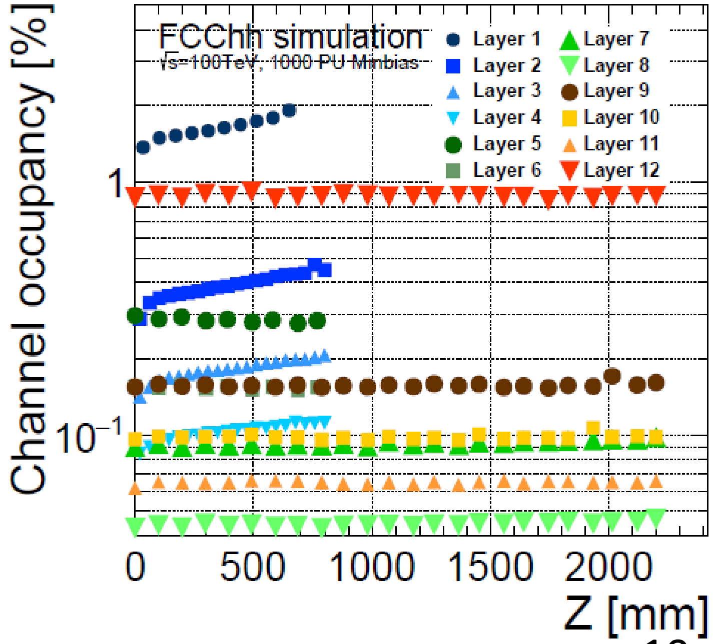


Channel Occupancy:

- In total 9-10M clusters
- ~30M activated pixels
- 2-3 PB/s @ first trigger level
  (assuming binary Readout 40 MHz event rate)

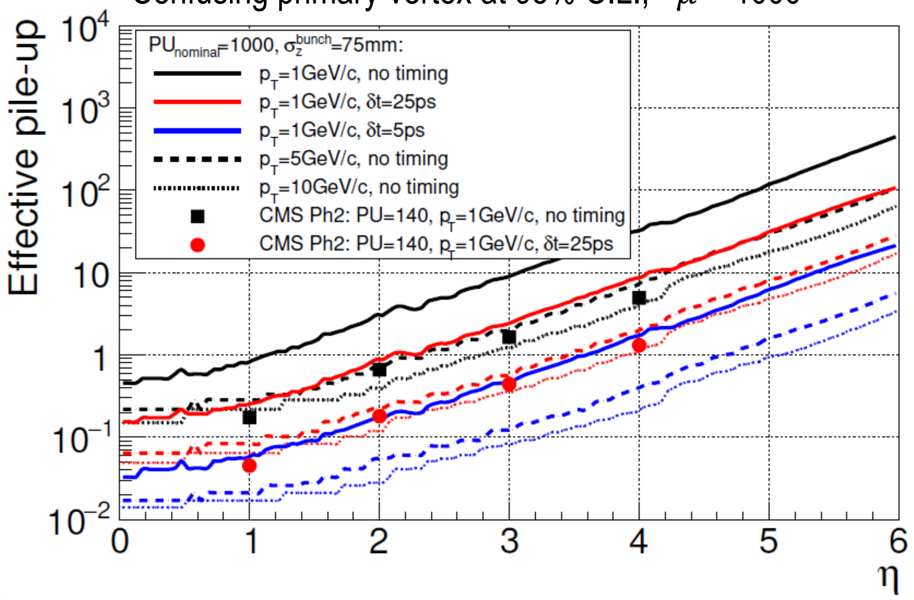


Pile up mitigation using timing detectors

Primary Vertexing

- $8.1\ \text{vertices/mm}^{-1}$, $2.43\ \text{vertices/ps}^{-1}$
- Enhance by timing resolution of single layer
- Still difficult for η>4

Confusing primary vertex at 95% C.L., <μ>=1000



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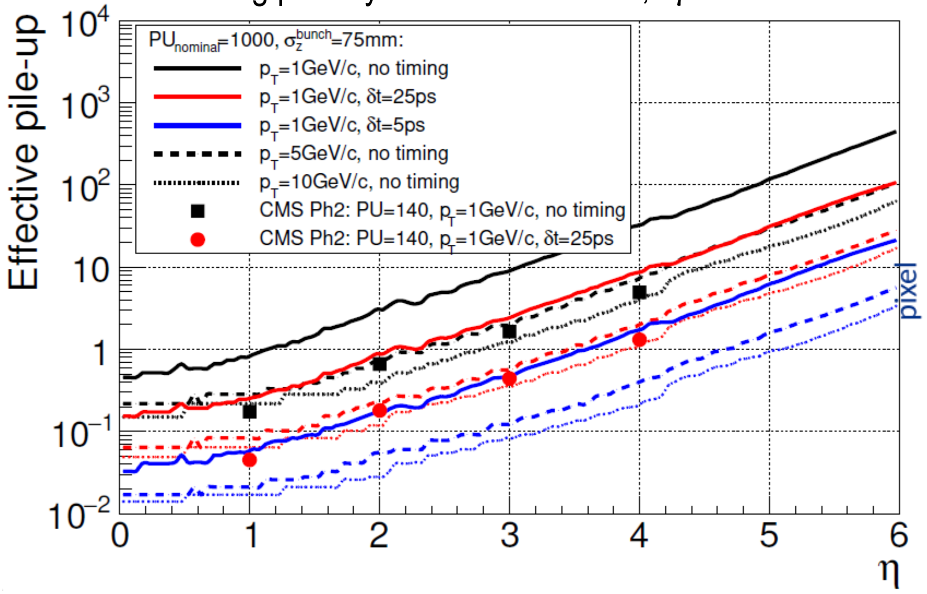
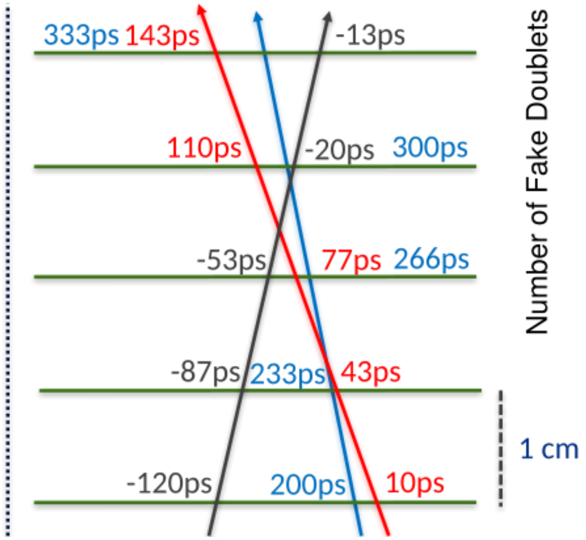
Seeding

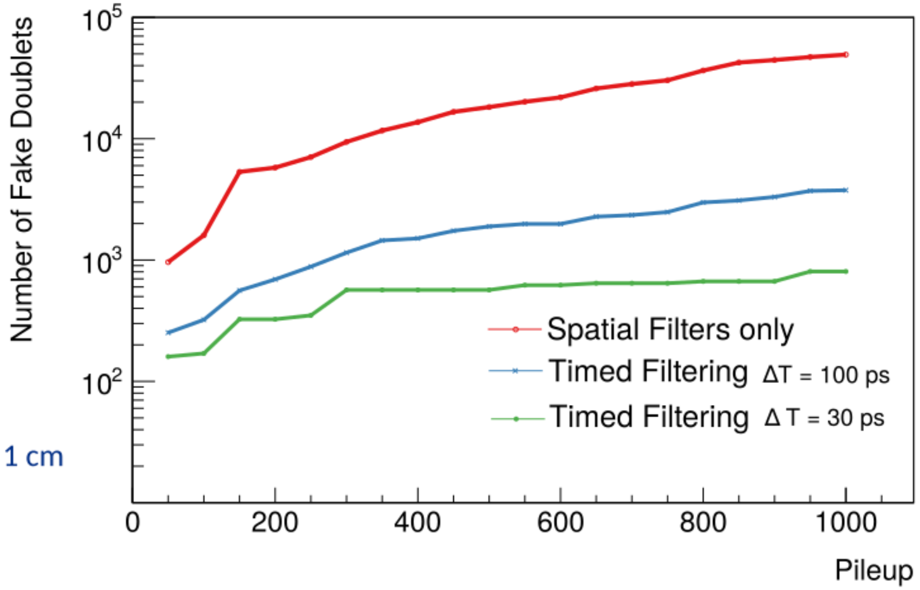
- Full simulation study
- Potential pile-up mitigation using timed track seeding
- Assuming full timing detector

Confusing primary vertex at 95% C.L., $<\mu>$=1000



Assume σ_t = 30 ps per layer





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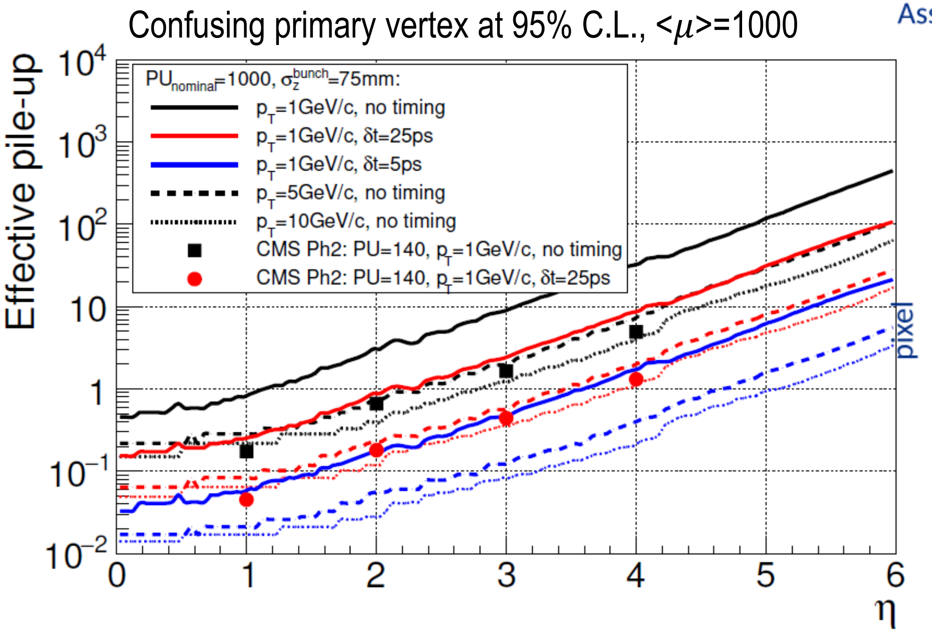
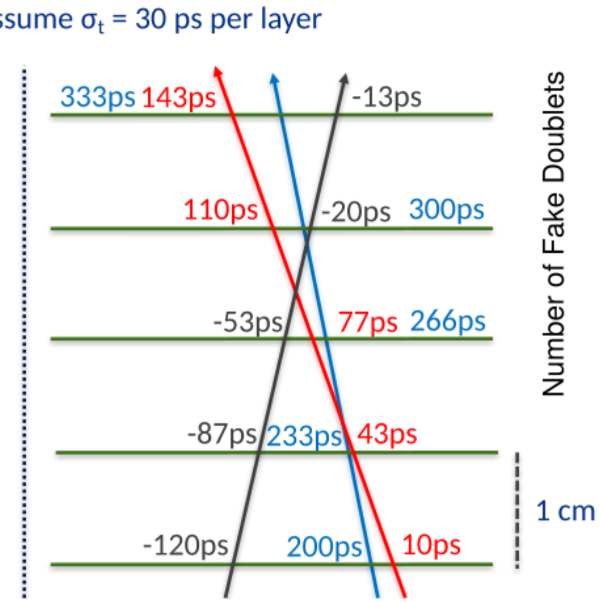
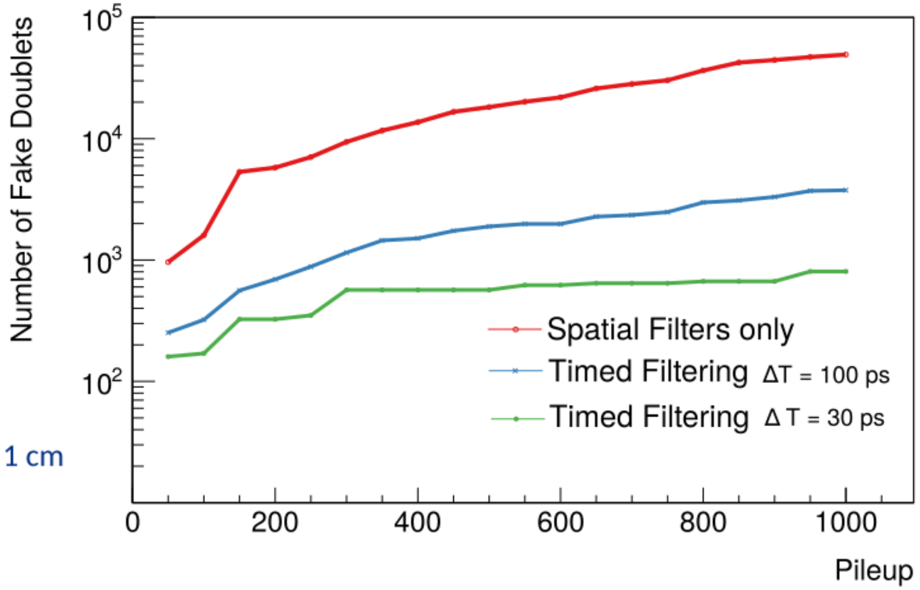






⇒ sub-nanosecond resolutions in Si-detectors already achieved

⇒ Phase II ATLAS/CMS foresee timing layers

\+ Full timing detector or timing layers found to reduce many PU effects to HL-LHC levels

\- Further increases Data rates (>= 4 bits)

FCC-eh

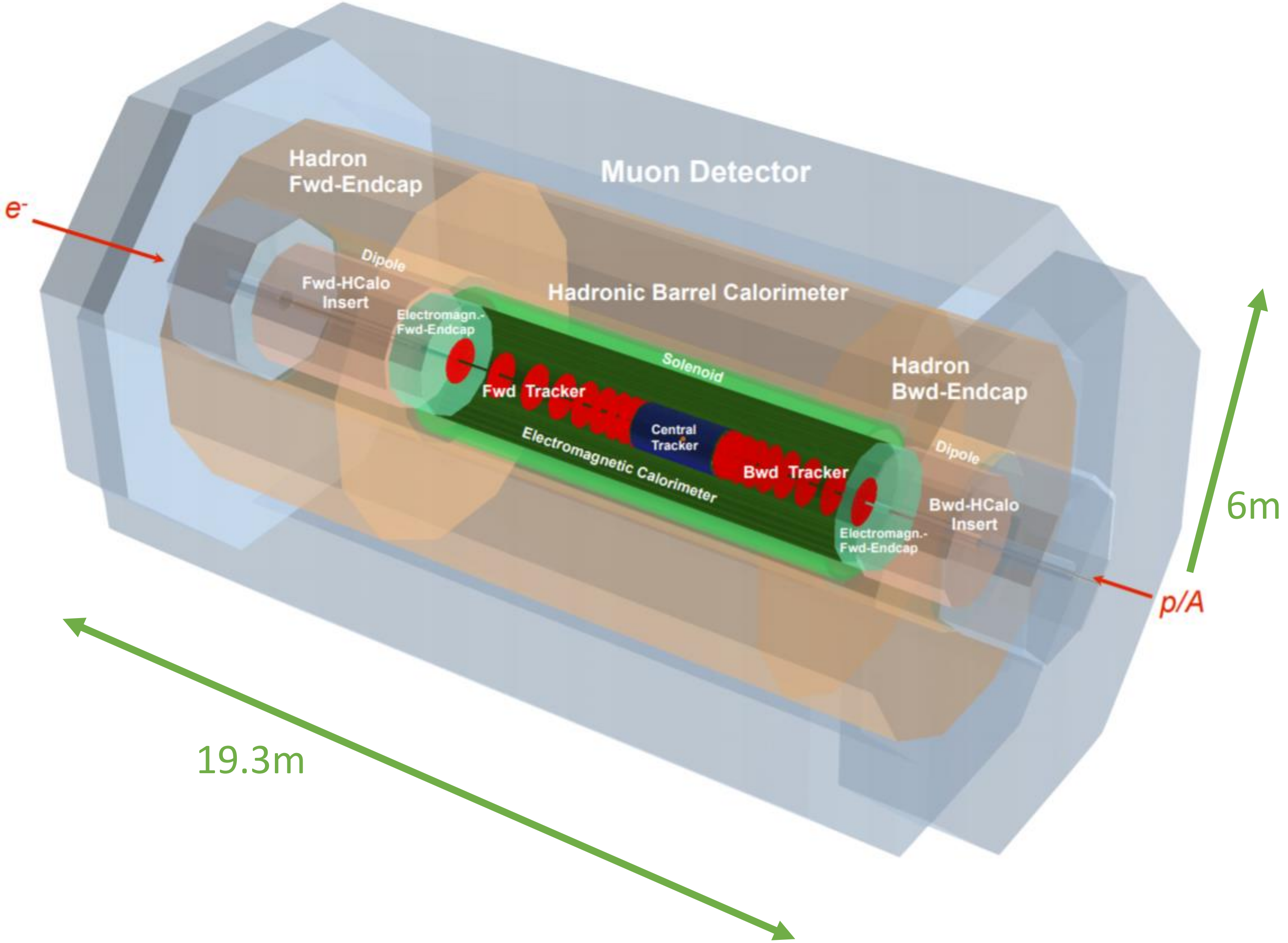
FCC-eh reference detector

Detector design see

- Concept derived from LHeC
- B-Fiel: 3.5T Solenoid
- More demanding forward region

Tracker design

- optimized for compactness & high precision
- permit particle flow
- minimize passive material



pixel

- $\sigma_{r\varphi}$=5-7.5μm
- σ_z=15μm
- 2248 M channels

strixels

- $\sigma_{r\varphi}$=7-9.5μm
- σ_z=15-30μm
- 1879 M channels

strip

- 289 M channels

Conclusion & future challenges

- First asessment of possible tracking detectors & performance (published in CDR)
- More detailed full simulation studies ongoing
- Work on fully working SW suite and full track reconstruction ongoing
- Identified challenges were more R&D is required:

FCC-ee FCC-eh FCC-hh

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FCC-ee

CLD

- Competing demands
  - Thin sensors
  - Small position resolution
- Possibility of timing layer has to be studied
- Excellent alignment to profit from position resolution

DCH

- Construction of 4m long wires (stability)
- Occupancy still under investigation

FCC-eh

FCC-hh

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FCC-hh

- High radiation environment

$\Rightarrow$ sensor technology in innermost layers still to be found

- PU is a real challenge for tracking
- Opposed requirements due to PU
  - Additional RO (timing, charge deposition)
  - Acceptable data rates

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FCC-eh

- Lower radiation levels allow to exploit HV CMOS technology
- Head-on collisions

$\Rightarrow$ dipole inside detector

- SR-fan due to e^{-}beam

$\Rightarrow$ shielding detector

$\Rightarrow$ Asymmetric beam-pipe

FCC-hh

- High radiation environment

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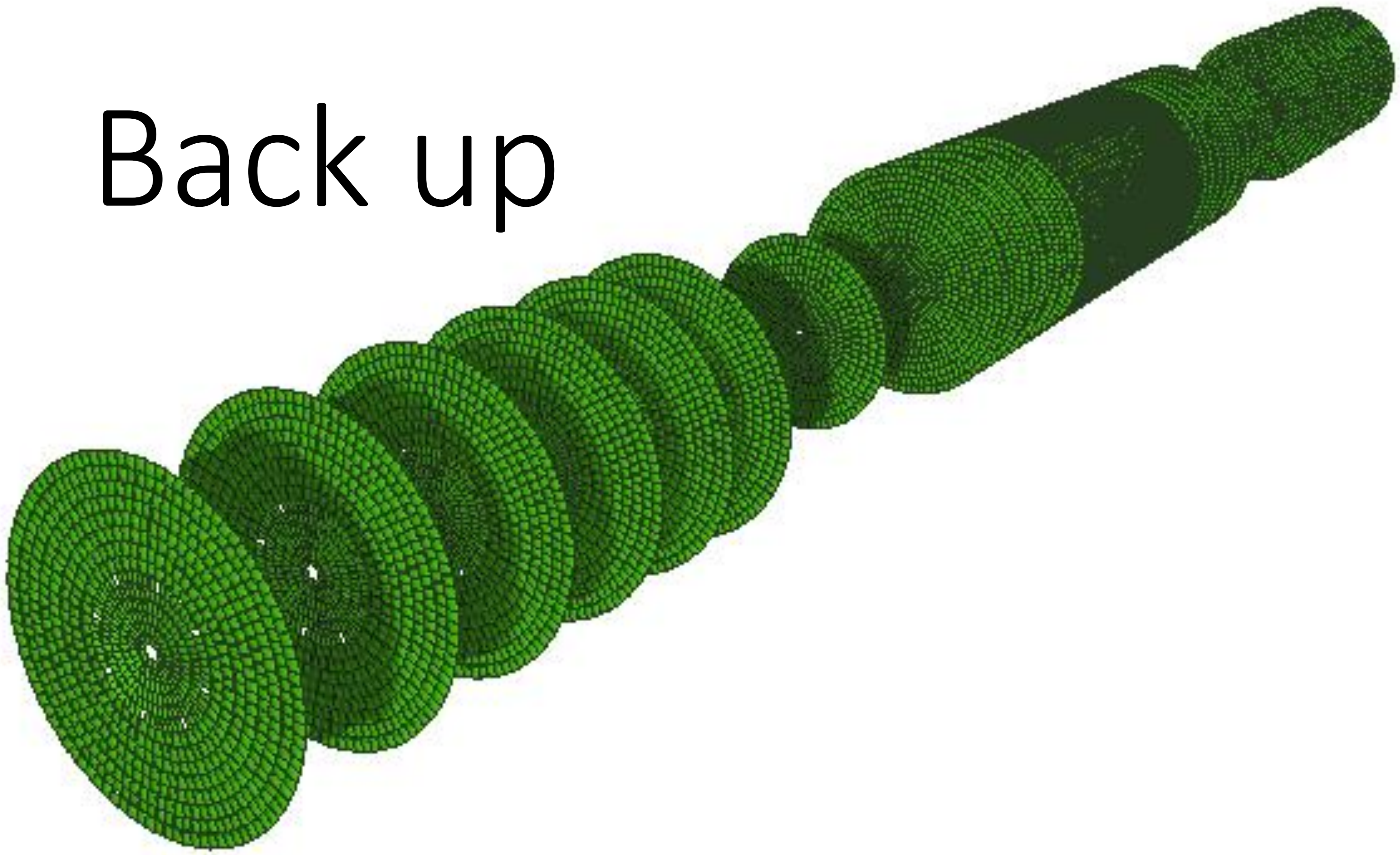
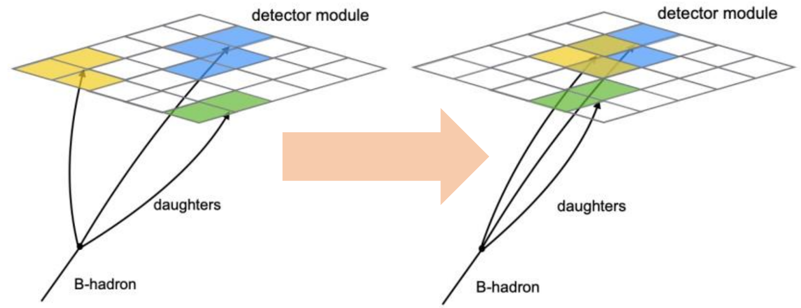
Back up



Resolving high p_T-Jets

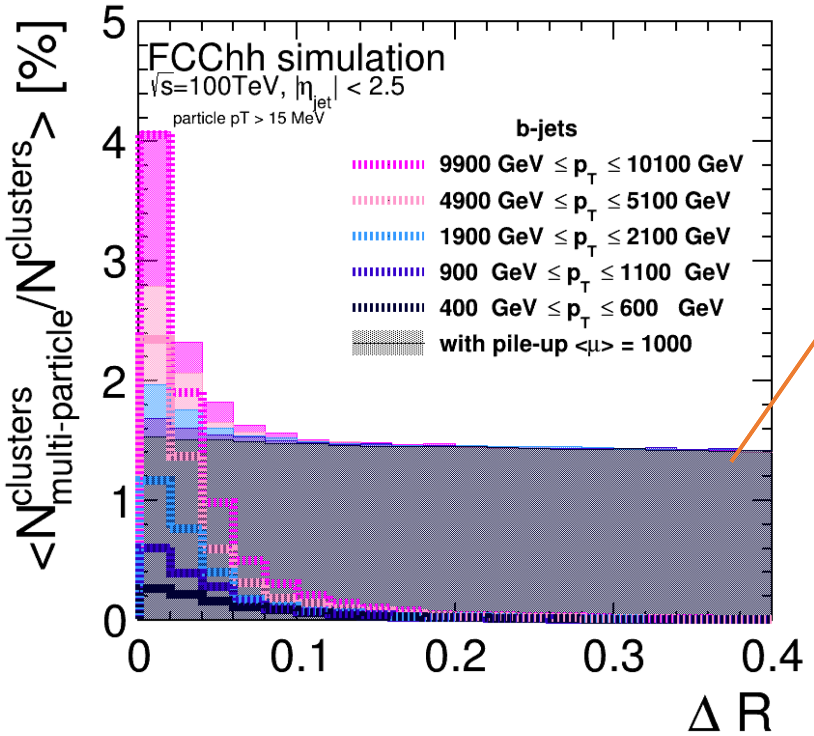


Cluster merging

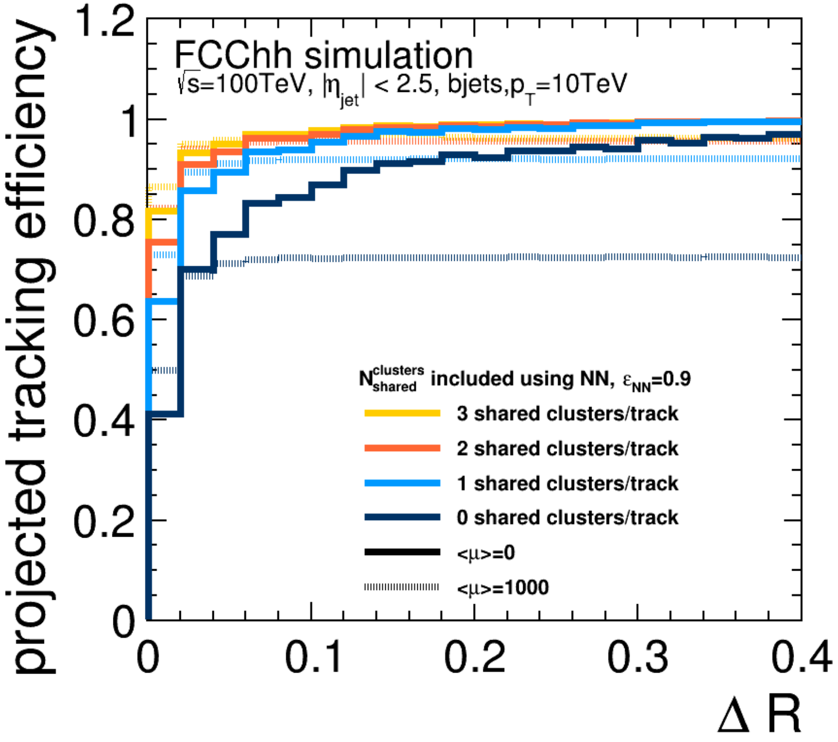
- Frequently close to jet core
  - Pixel: up to tens of %
  - Strip: PU-noise has big impact

Track reconstruction

- Projected track reconstruction efficiency significantly degraded
- ATLAS: 6.1-9.3% lost tracks for jets (200-1600 GeV)
- worsens track parameter resolutions



PU-Pedestral worse than core of 2 TeV-jet!



⇒ ATLAS Trained neural network to identify merged clusters

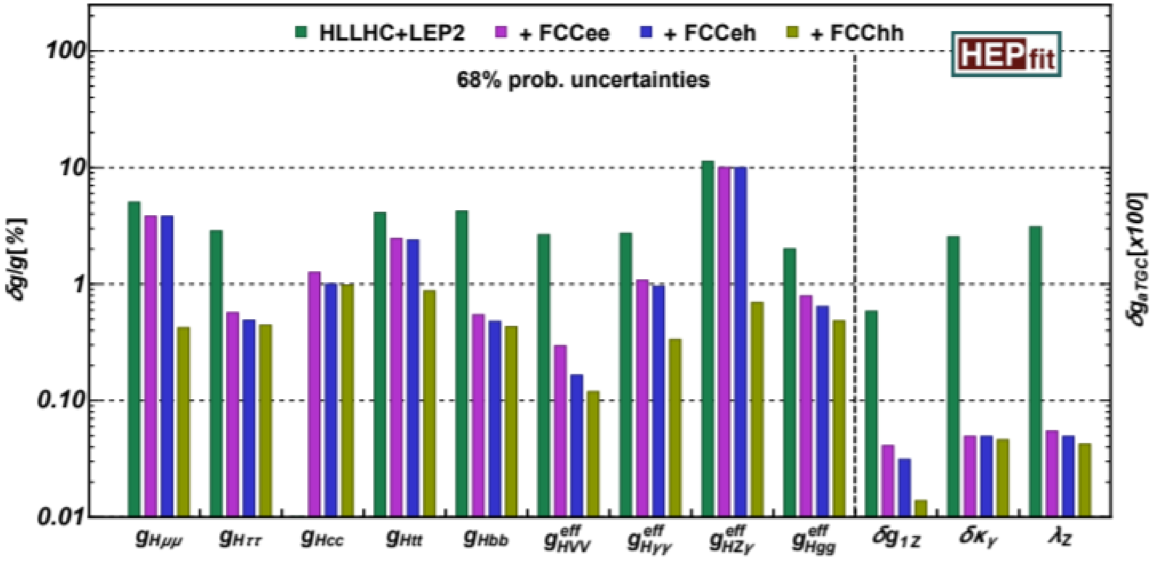
\+ Would enhance reconstruction efficiency for FCChh

\- Need to read-out charge deposition

FCC-hh & FCC-eh (concurrent,optional)

- Possibility for ion collisions
- Main challenges: civil engineering & dipole magnets (16T)
- Cryogenics needs to compensate for SR
- Discovery potential & precission
  - $20\ ab^{-1}$ per experiment
  - Higgs couplings to second generation fermions
  - Higgs self coupling: 5-7% precision
  - Study the Higgs potential and EWPT
  - BSM phenomena at 5-7 x mass range of LHC
  - Discovery potential of thermal WIMPs
- FCC-eh
  - ERL provides 60 GeV electrons
  - Study parton structure (per mille accuracy of strong coupling)

Parameters	LHC	HL-LHC	FCC-hh
Collision energy cms [TeV]	14	14	100
Dipole field [T]	8.33	8.33	16
SR power/length [W/m/ap.]	0.17	0.33	28.4
Peak luminosity [$10^{34}cm^{-2}s^{-1}$]	1	5	30
Events/bunch crossing	27	135	1000(200)
Stored energy/beam[GJ]	0.36	0.7	8.4



FCC-eh reference detector

Physics potential

- Study PDF's in unprecedented precision

$\Rightarrow$ Need to be well known for FCChh (wide kinematical region $O(8)$)

$\Rightarrow$ observe large Q^2 & low x events

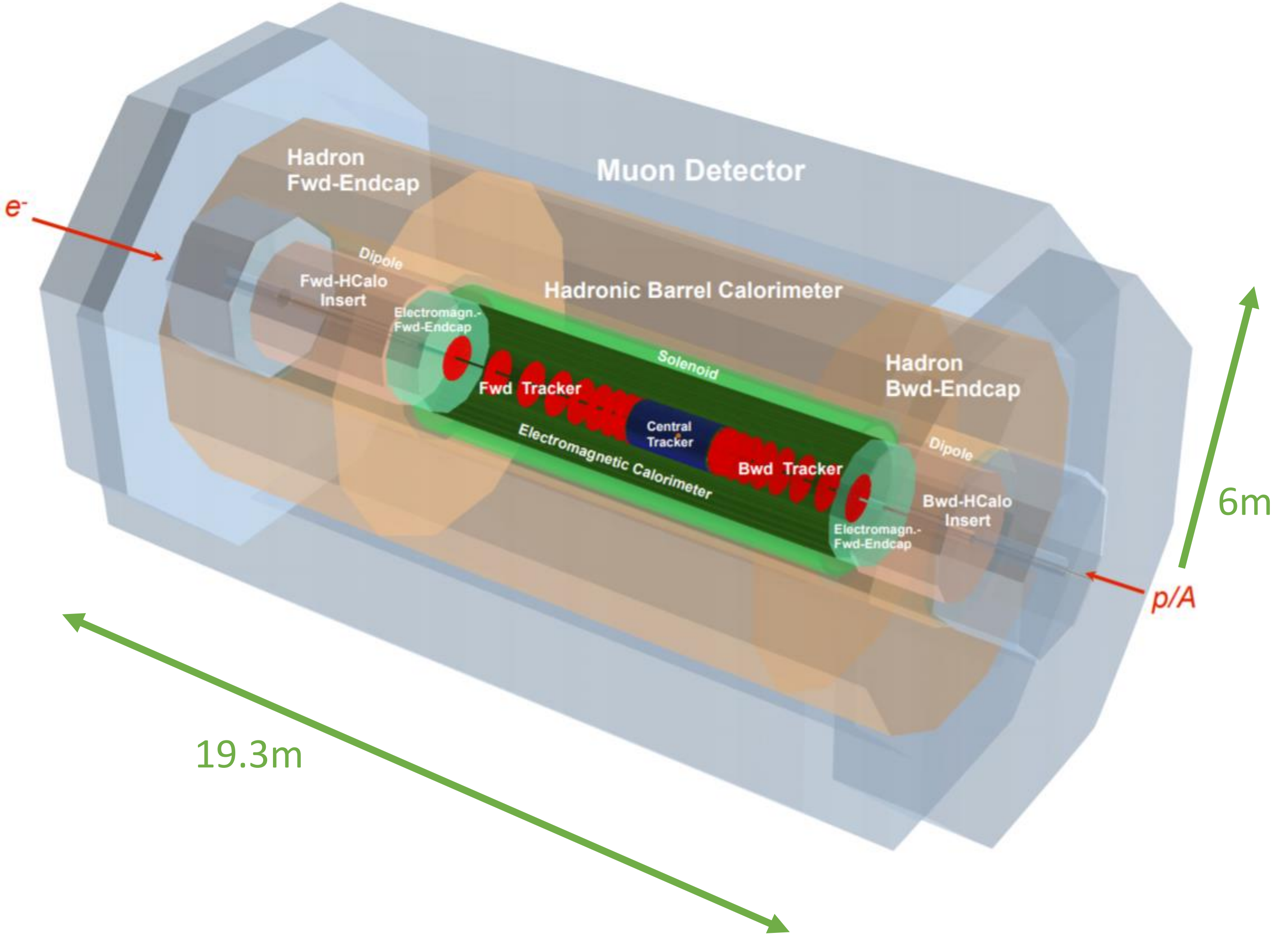
- High precision Higgs physics & BSM searches

Environment

- Radiation: $10^{15} n_{eq} / cm^2$
- Peak Luminosity: $10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$
- Int. Luminosity > 100*HERA
- $<\mu>$=1

Detector design

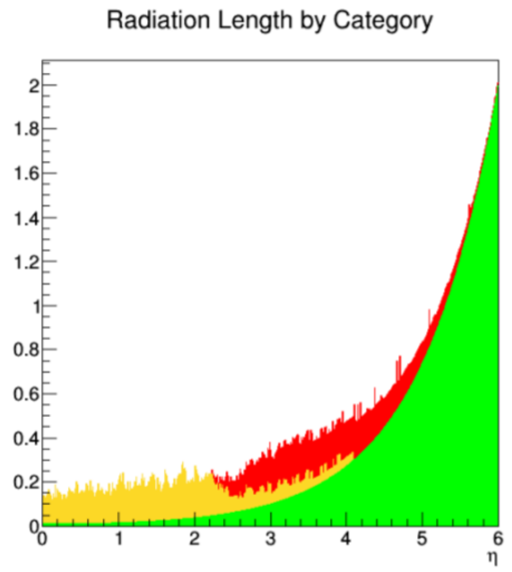
- Concept derived from LHeC
- B-Fiel: 3.5T Solenoid
- More demanding forward region

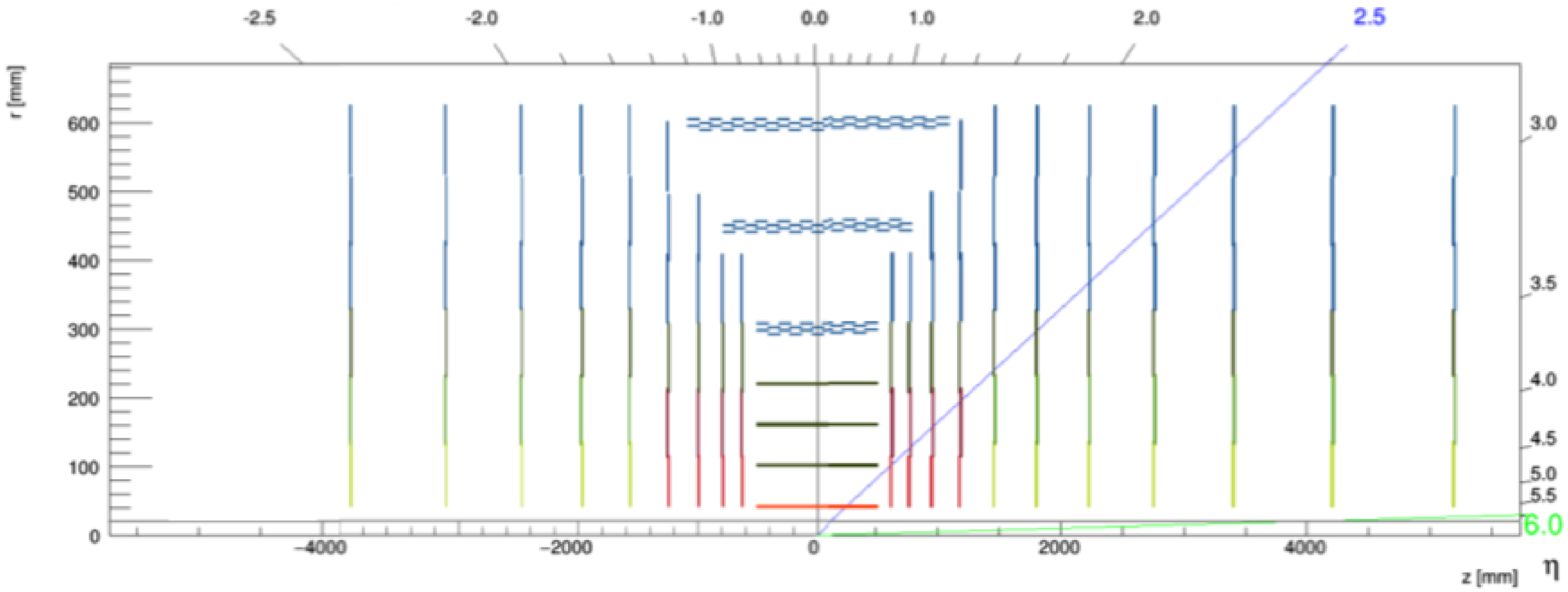


Tracking detector

- optimized for compactness & high precision
- large acceptance vertexing
- permit particle flow
- minimize passive material

Total: 50.52% X_0
Beam pipe 33.35%
Barrel modules 8.36%
EC module 8.80%





pixel

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Strixels

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Strip

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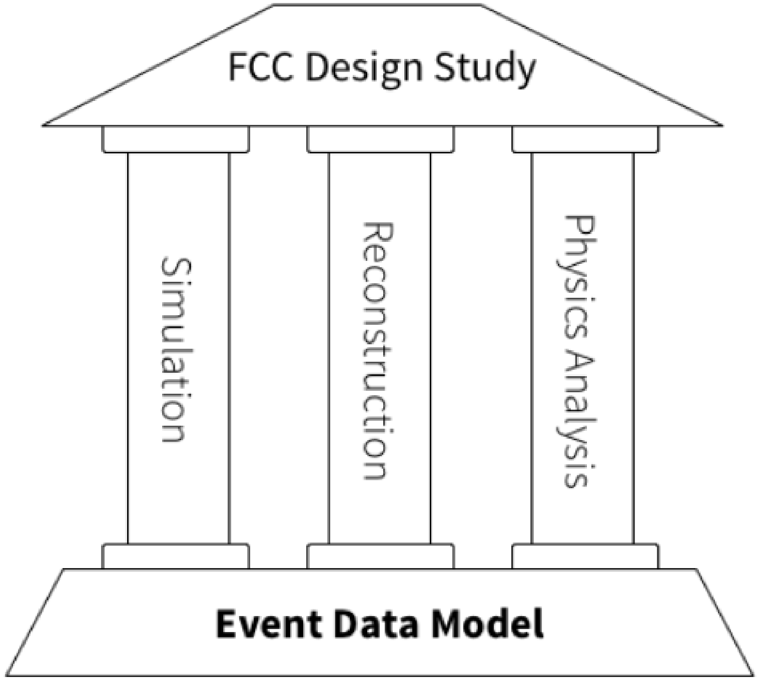
FCCSW – Common Software for ee,hh & eh

Extract LHC experiments where posible & invest new solutions if needed

- Event processing framework: *GAUDI* (LHCb, ATLAS)
- Flexible Event Data Model: *PODIO* (ILC, LHCb)
- Detector Description: *DD4hep* (ILC)
  - ⇒ One common source geometry input for all different simulation types & reconstruction (automatic transcripts)
- Simulation Kernel: *Geant4*
  - ⇒ for full, fast, parametric (Delphes, PAPAS) simulation types
- Tracking package: *ACTS* (ATLAS)
- Seeding package: *TrickTrack* (CMS)
- Physics analysis : *HEPPY* (CMS)
  - ⇒ can be run standalone

⇒ Have infrastructure for physics studies and analysis



Please find more information and tutorials here!

FCC Track Reconstruction

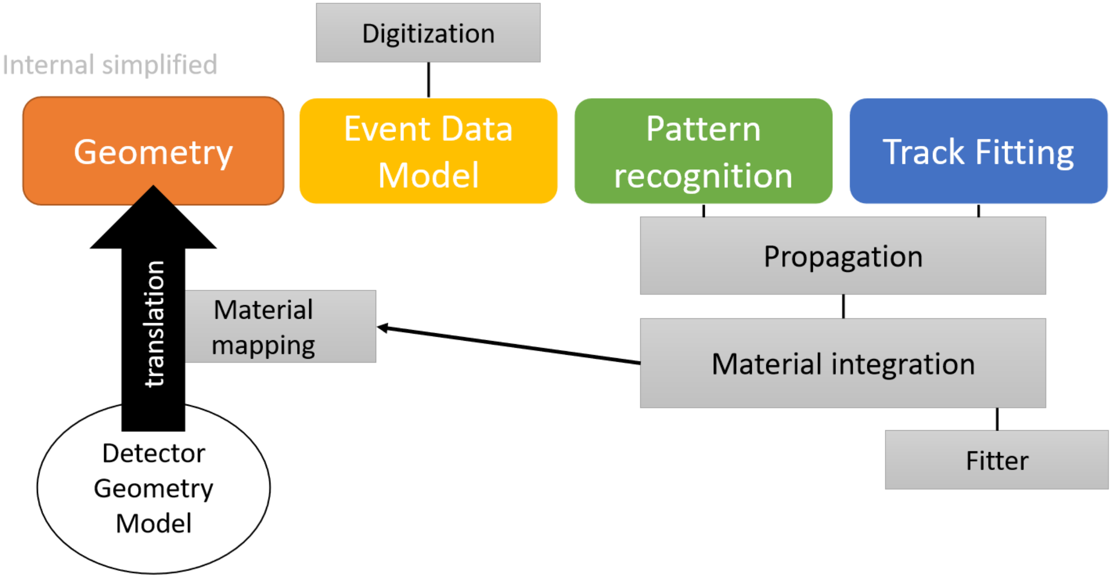
Very challenging environment: $<\mu>=1000$

Profit from

- LHC tracking software
  - $\Rightarrow$ Well tested
  - $\Rightarrow$ **High performant** (10^{10} events with 10^3 tracks/event)
- current R&D ongoing for HL-LHC ($<\mu>=$ 140-200)
- Use ACTS for tracking and TrickTrack (CMS CA adapted) for seeding

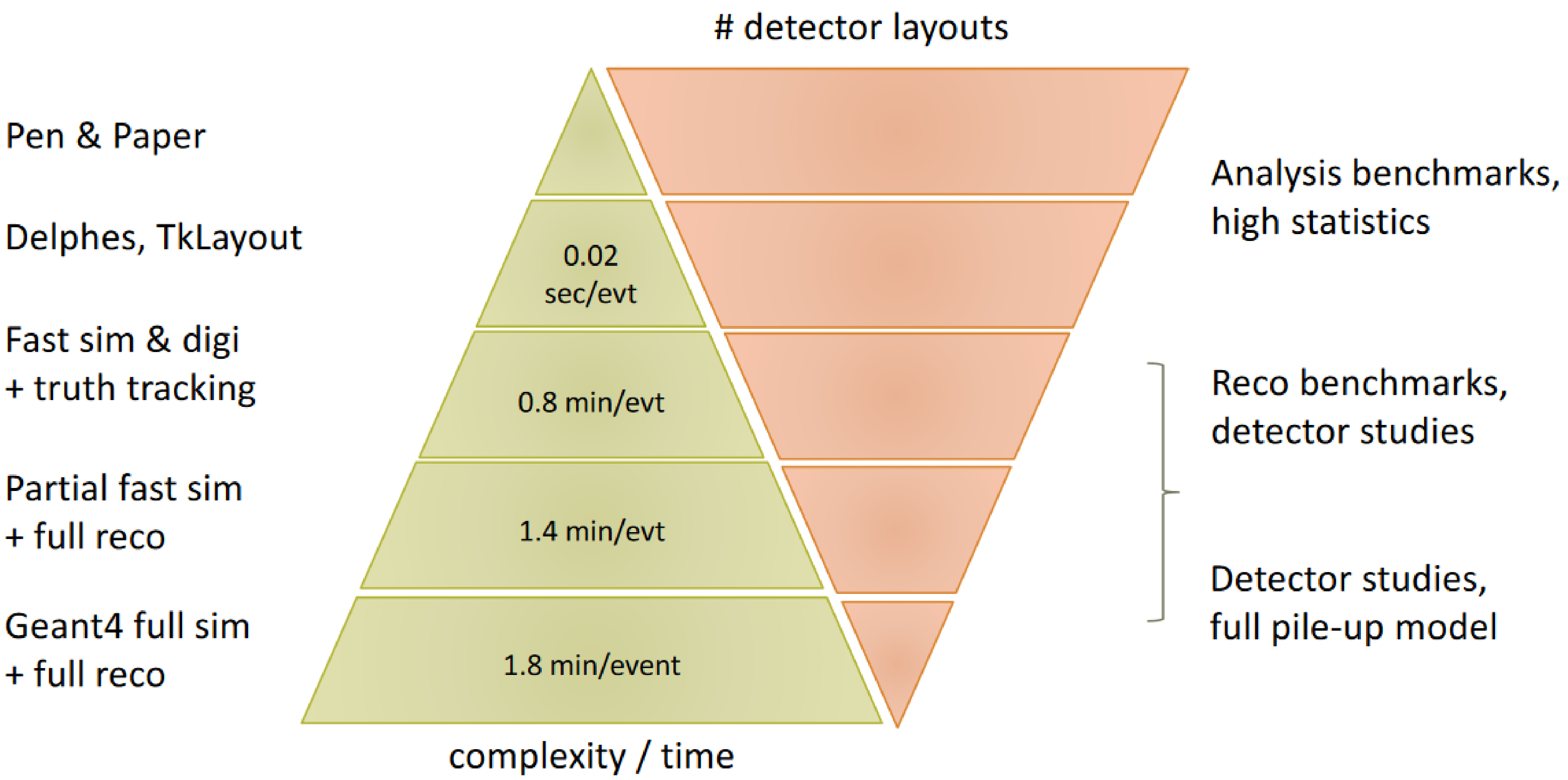
ACTS Package (details)

- Encapsulates ATLAS track reconstruction SW
  - $\Rightarrow$ Adapt to new developments in computing hardware (concurrency)
  - $\Rightarrow$ Substantial updates of algorithmic code
  - $\Rightarrow$ Long-term maintanance of SW
- Framework & experiment independent
- Minimal dependencies: Eigen, Boost
- Modular and flexible (easy extension)
- Plugins for experiment specific parts



Performance studies

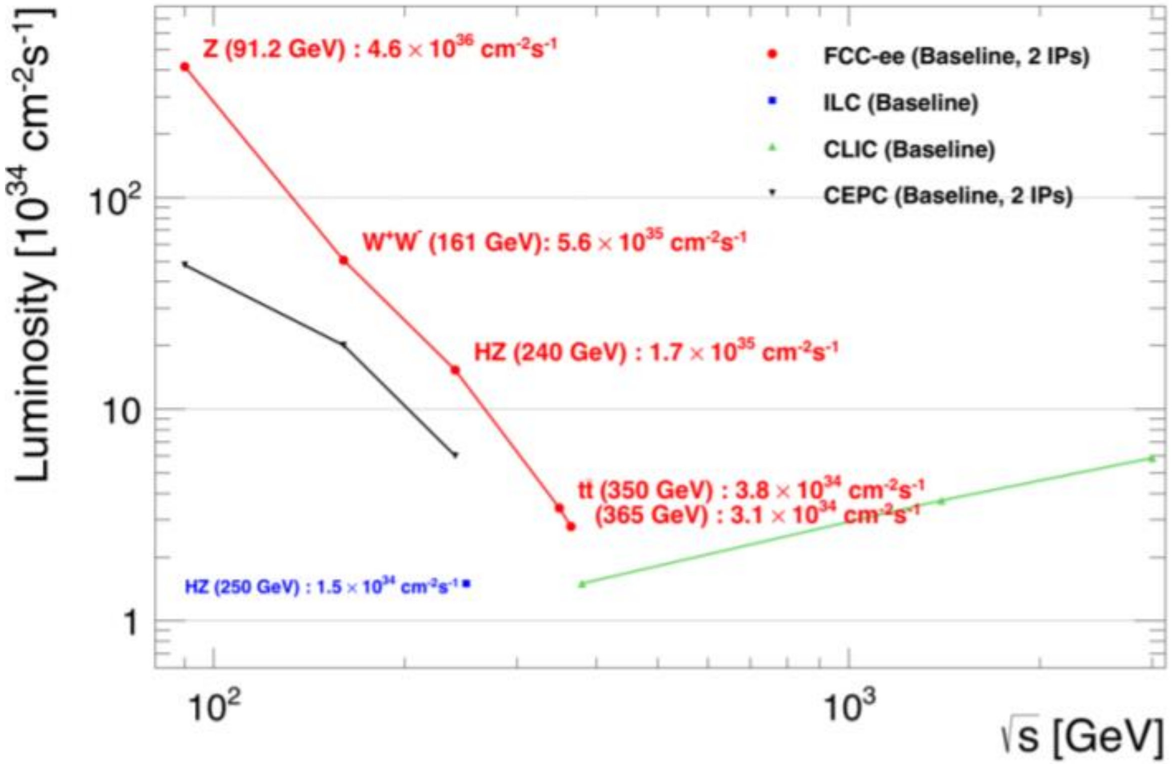
Application to answer performance questions:



Details: see backup

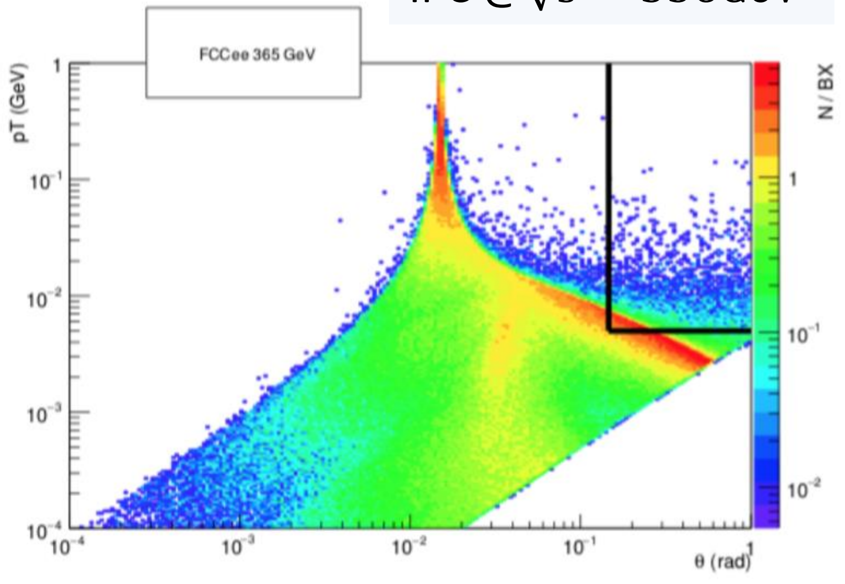
FCC-ee

- Double ring collider
- Synchrotron radiation $\leq 50\ \mathrm{MeV/beam}$
- 15 years operation
  - $\sqrt{s} \sim 91\ \mathrm{GeV}$: 5×10^{12} Z-Bosons
  - $\sqrt{s} \sim 160\ \mathrm{GeV}$: 10^{8} WW-pairs
  - $\sqrt{s} \sim 240\ \mathrm{GeV}$: 10^{6} H-Bosons
  - $\sqrt{s} \sim 350 - 365\ \mathrm{GeV}$: 10^{6} $t\bar{t}$-pairs
- Clean, well-defined environment
- Extreme statistical precission
  - SM measurements
  - Model independent Higgs
  - Flavour physics
  - rare processes & tiny deviations
  - Probe energy scales beyond direct reach



Beam induced backgrounds

IPC $@\sqrt{s} = 356\text{GeV}$

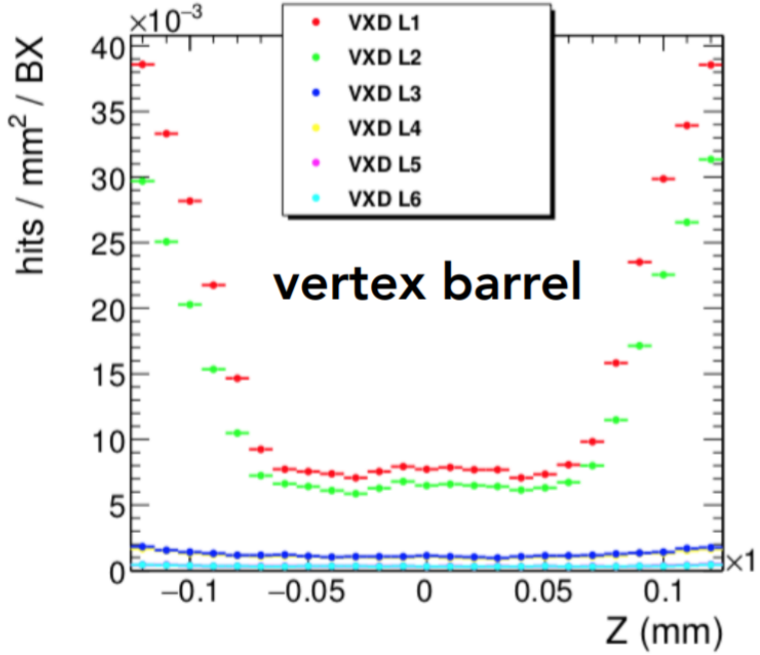


e+e- produced with E>5MeV

- Synchrotron radiation
  - $@\sqrt{s} = 91.2\text{GeV}$ No hits observed
  - $@\sqrt{s} = 356\text{GeV}\ 6.6 \times 10^4$ hits/BX
    =>350 hits/BX with shielding in VXD
- $\gamma\gamma \rightarrow$ hadrons
  - Negligible: $< 10^{-2}$ events/BX
- Incoherent e^+e^--pairs (IPC)
  - largest impact: 1 event/BX
  - 1100 hits/BX in VXD
  - Not expected to affect tracking performance

$\Rightarrow$ Occupancy(*) < 1% for all options

$\Rightarrow$ Highest rates in two innermost layers



(*) assuming average cluster size 5/2.5 for pixel/strip and safety factor 3

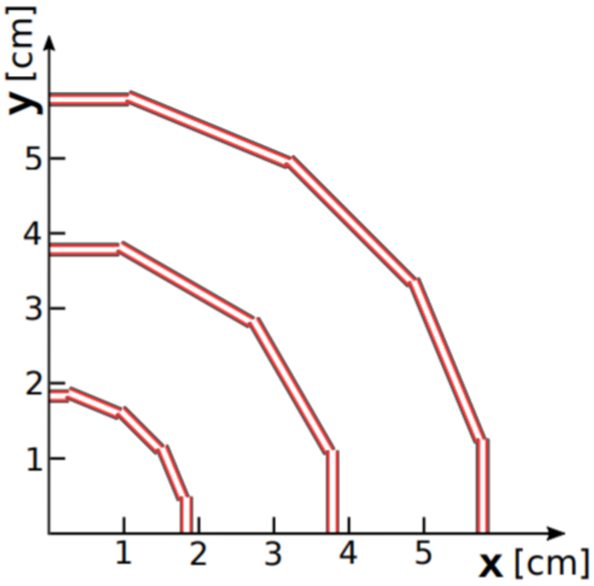
CLD (CLIC-Like Detector)

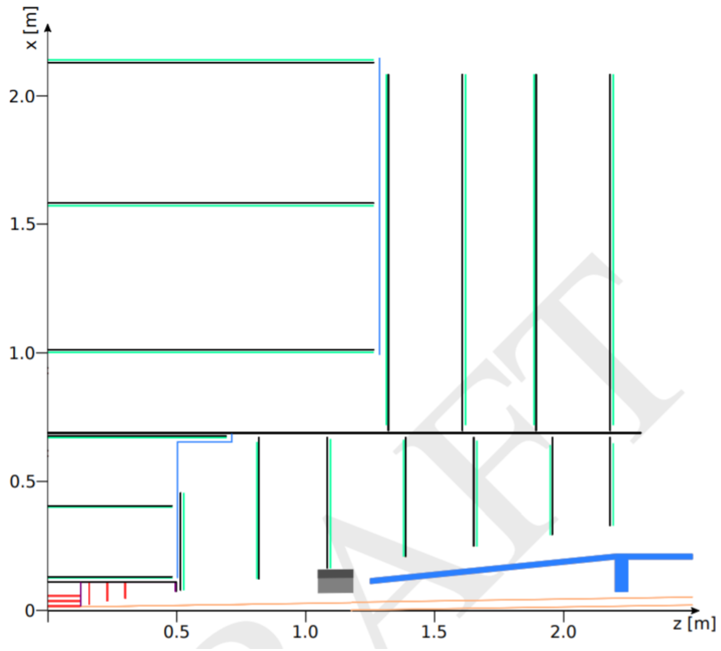
Vertex Detector

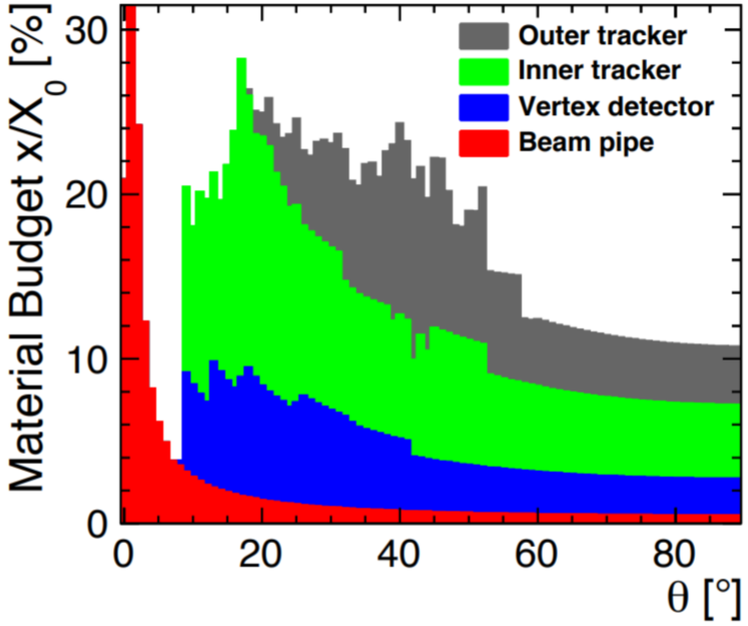
- $25 \times 25\ \mu m^2$ pixels
- $50\ \mu m$ sensor thickness
- Aim: $3 \mu m$ single point resolution
- $0.4\ \%\ X_o$ each double layer + 0.2% cooling
- Double layers
- $0.35 m^2$ silicon
- First layer: 17mm

Tracking Detector

- Silicon pixel and microstrip
- Single point resolution: $7\ \mu m \times 90\ \mu m$
- First IT disc: $5\ \mu m \times 5\ \mu m$
- $1\%\ X_o$ per layer + 2.5% (support,cooling,cables)
- $195.6 m^2$ silicon

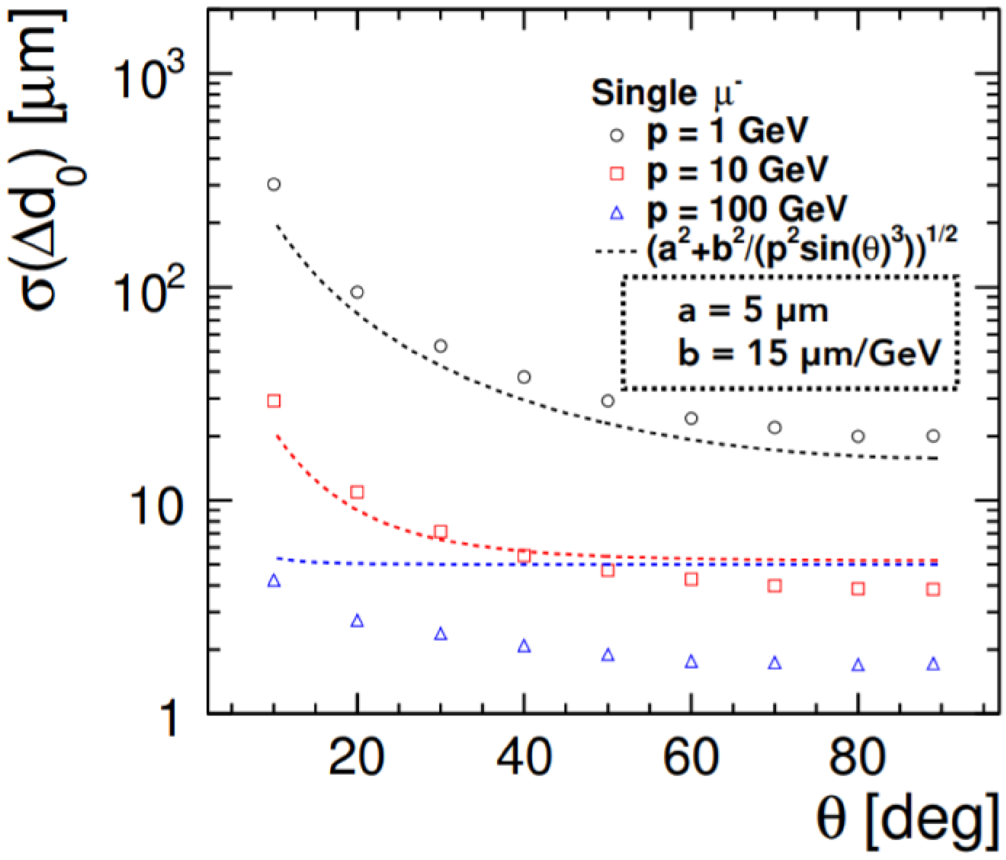


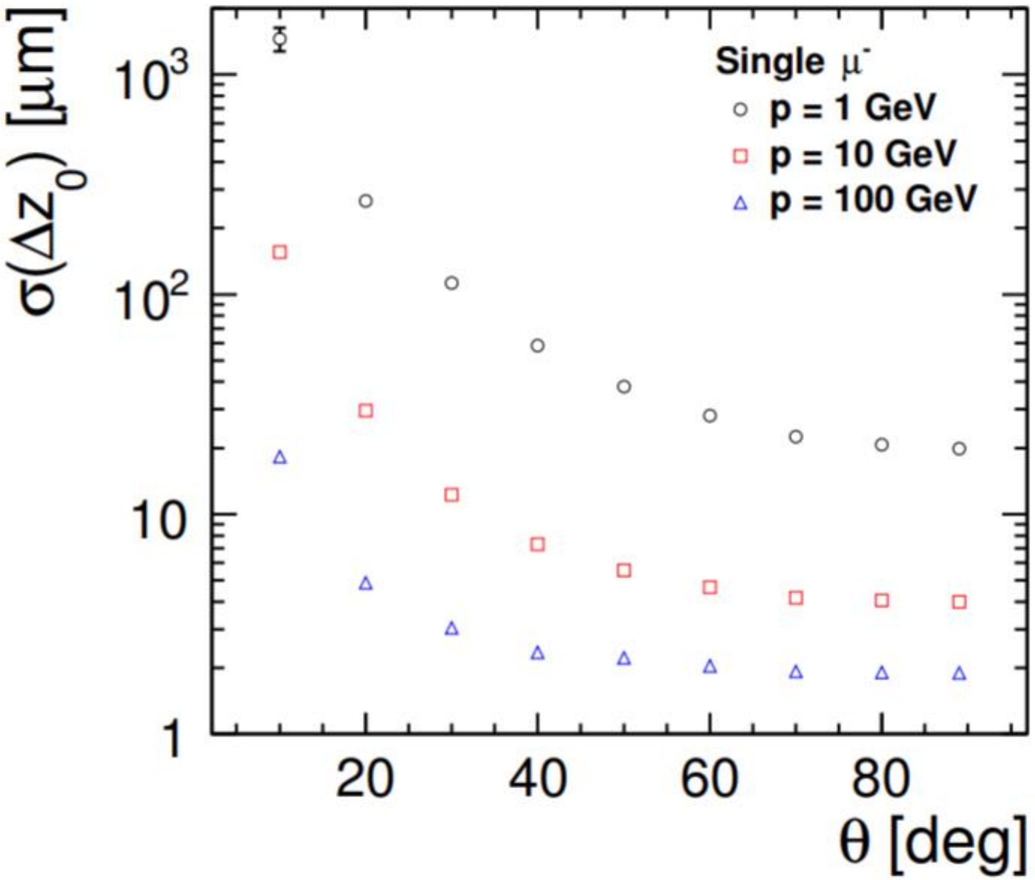




CLD – impact parameter resolution

- Determined by vertex detector
- Full simulation + track reconstruction study
- To identify secondary vertex $a = 5\mu m$ and $b = 15\mu m$ required
  - $\Rightarrow$ Met for high momentum muons in central region

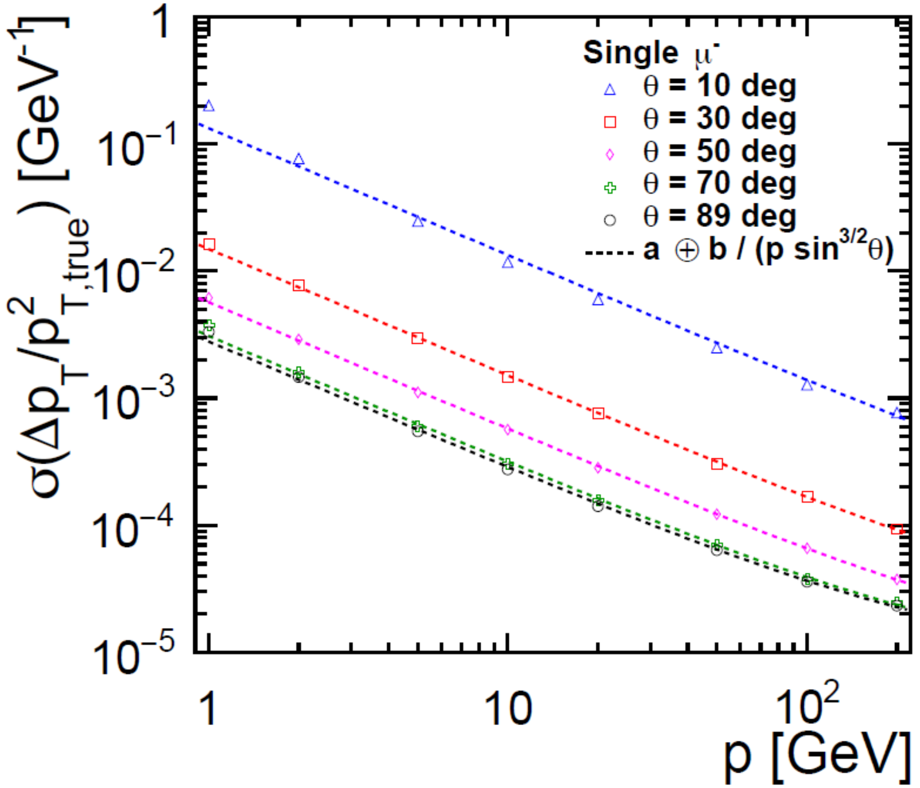


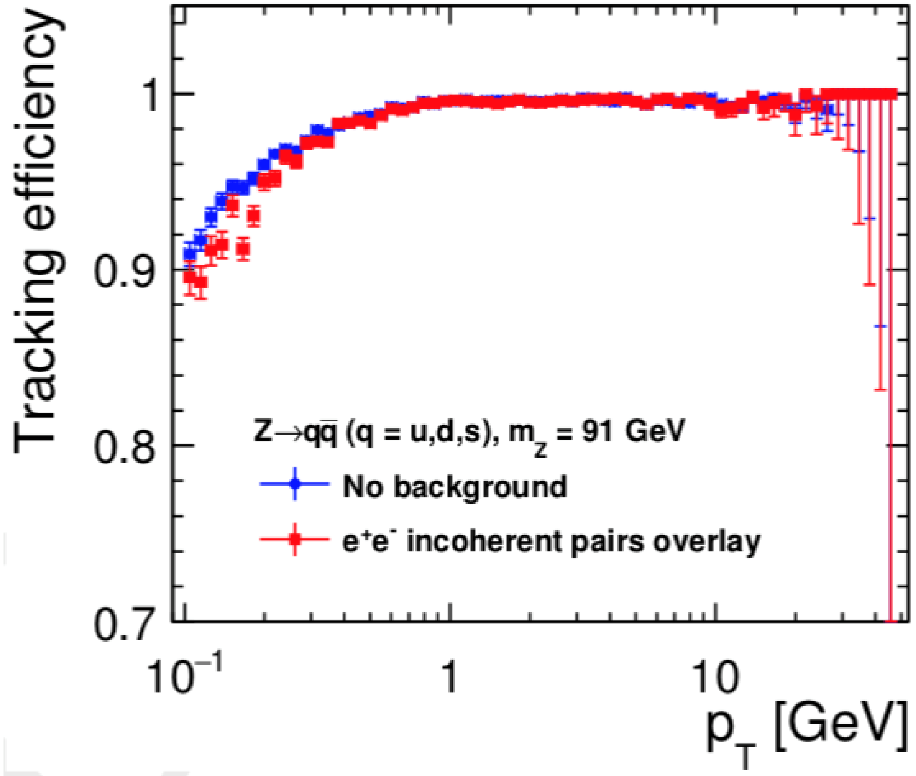


CLD - performance

Full simulation + track reconstruction study using ILCSoft (see E. Brondolins talk)

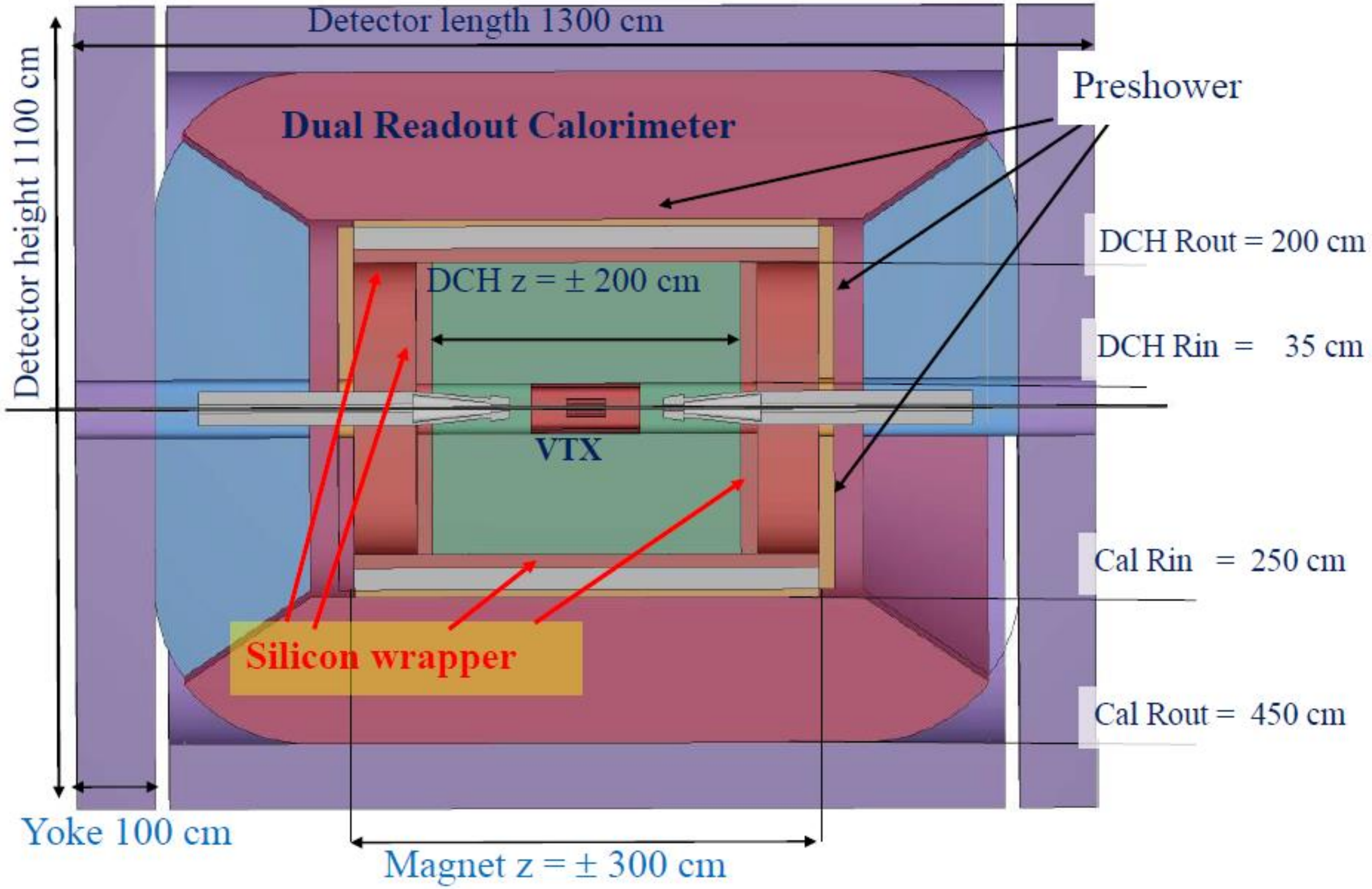
- Tracking efficiency (Fraction of reconstructed MC particles) single muons
  - Prompt : fully efficient (99%/100% in forward/central region)
  - Displaced: 100% ($p_T > 1GeV$), 96% ($p_T > 0.1GeV$)





Reconstructable:
- stable at Generator Level
- $p_T > 100MeV$
- $|\cos\vartheta| < 0.99$
- N_{Hits}=4/5 for prompt/displaced

IDEA - detailed view



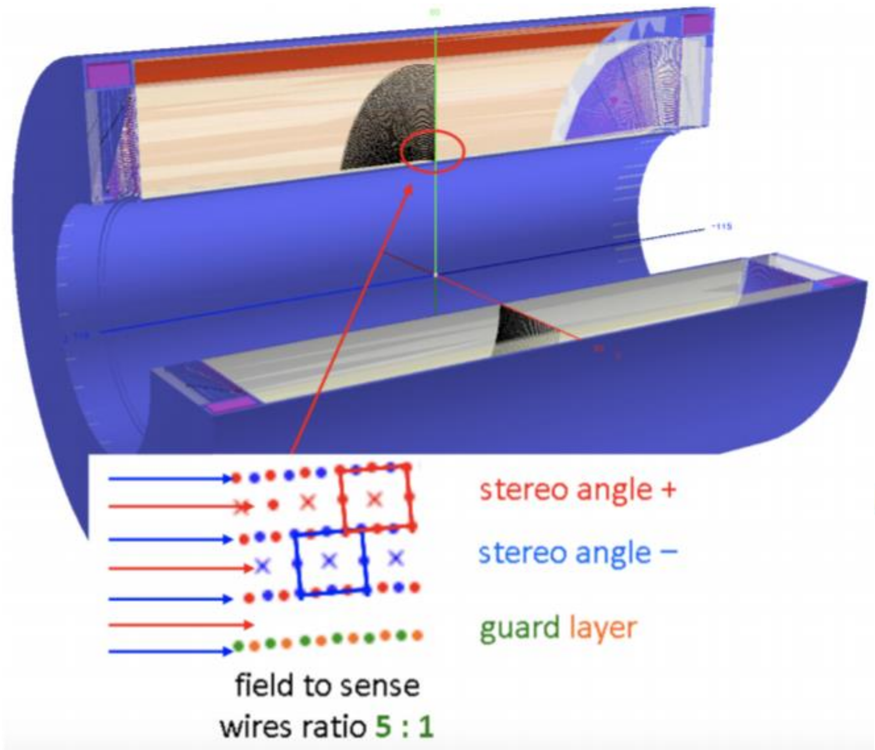
IDEA (International detector for $e^{+}e^{-}$ accelerators)

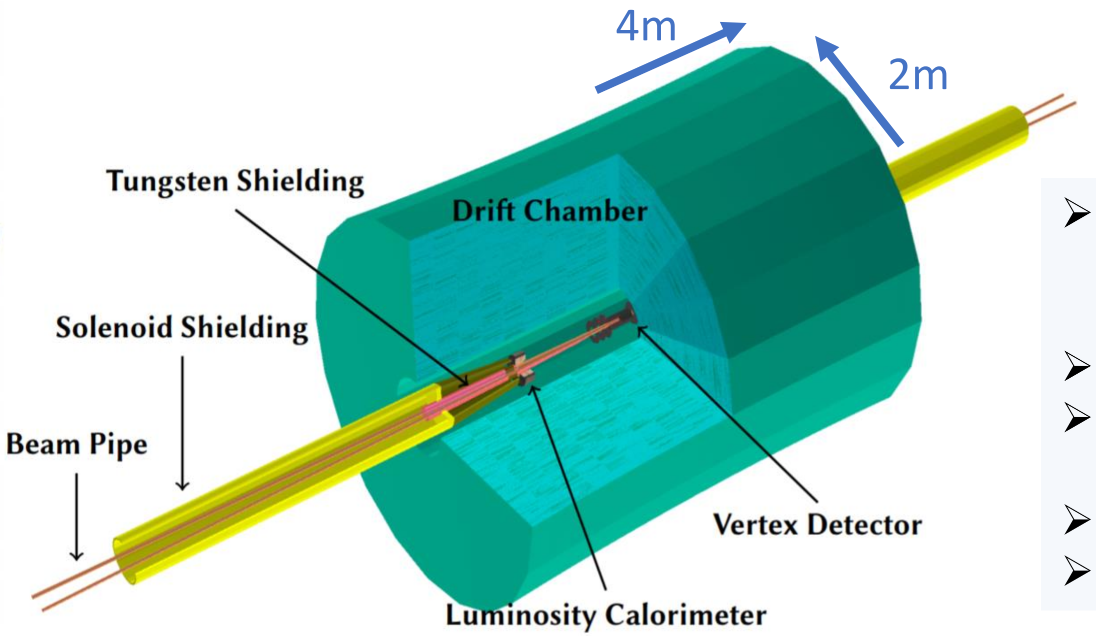
Vertex Detector

- Silicon-based
- Orientation on ALICE ITS upgrade
- MAPS (Monolithic active pixel sensors)
  - $5\mu m$ position resolution
- Light: 0.3(1)% X_0 per inner(outer) layers

Drift Chamber (DCH)

- Following model of KLOE and MEG2 DC
- Particle identification
- 90% He-$10\%\mathrm{iC_4H_{10}}$ (isobutane)
- Highly transparent
  - 1.6 -5% X_0 in total
- 2T axial magnetic field





- 112 layers divided into cells rotated by stereo angle
- 12-14.7 mm cell size
- 282240 field wires (uniform E-Field)
- 56448 sensitive wires
- wire material: Al

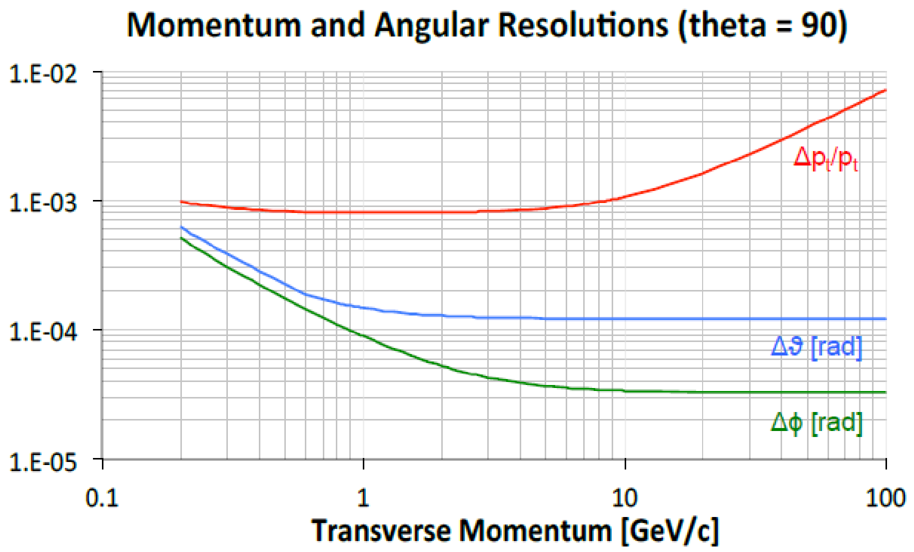
IDEA – expected performance and tracking

Analytical

- Assuming $100\mu m$ position resolution (conservative)
- Angular resolution < 0.1 mrad for p_T > 10GeV

$$\sigma\left(\frac{1}{p_T}\right) = 3\times10^{-5}GeV^{-1} \oplus \frac{0.6\times10^{-3}}{p_T}$$

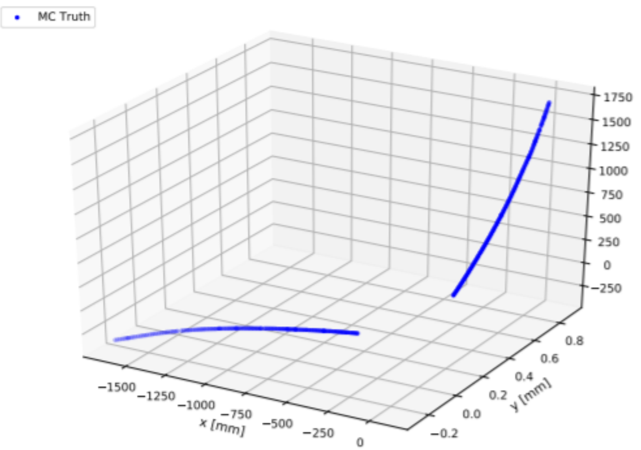
$$\sigma_{d_0} = 3\mu m \oplus \frac{15\mu m\ GeV}{p\ \sin\vartheta^{3/2}}$$

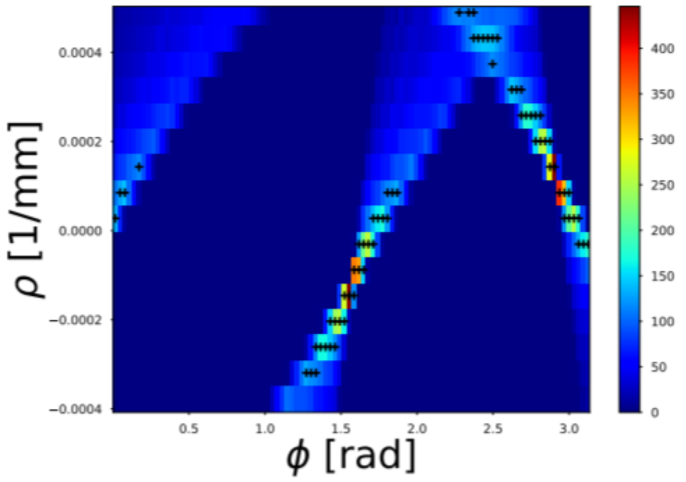


Full simulation & reconstruction

- Long term plan
  - using ACTS (see later)
- Currently
  - Using conformal mapping & hough transform (see)
  - Work in progress

2.4 GeV muon





CLD Software

- Benefit of using fully performant iLCSoft (ILC,CLIC)
  - Detector description: DD4hep
  - Event Reconstruction: Marlin
  - Track Pattern Recognition: Conformal Tracking
    - Transform circles passing through algorithm of a set of axis onto stright lines in new uv plane
    - Make straight line search in 2D
    - Use cellular automaton
    - Simple linear fit to differntiate between track candidates
  - Particle Flow Reconstruction: PandoraPFA

FCC-hh detector requirements

Orientation on LHC detectors & upgrades

- Possibly 2 high luminosity detectors

Discovery & precision machine

- SM precision measurements
- multi-TeV jets, leptons, γ (up to 50 TeV)
- Moderate pT BSM

$\Rightarrow$ *multi-purpose detector*

Highly boosted objecst

$\Rightarrow$ *Extend η acceptance*

Granularity

- Channel occupancy (1000 PU)
- Resolve highly boosted objects (τ,t,b)

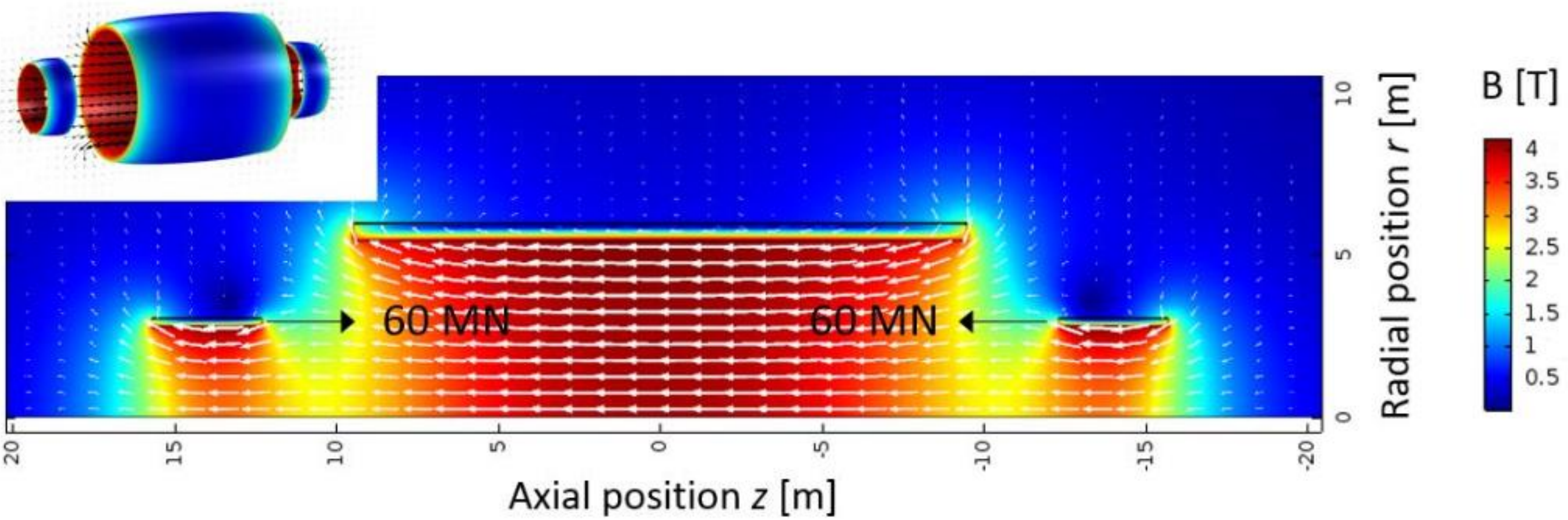
$\Rightarrow$ *tracking precision $< 5\mu m$ precision in $r\varphi$ for vertexing*

$\Rightarrow$ *transverse granularity in cal 4 x LHC*

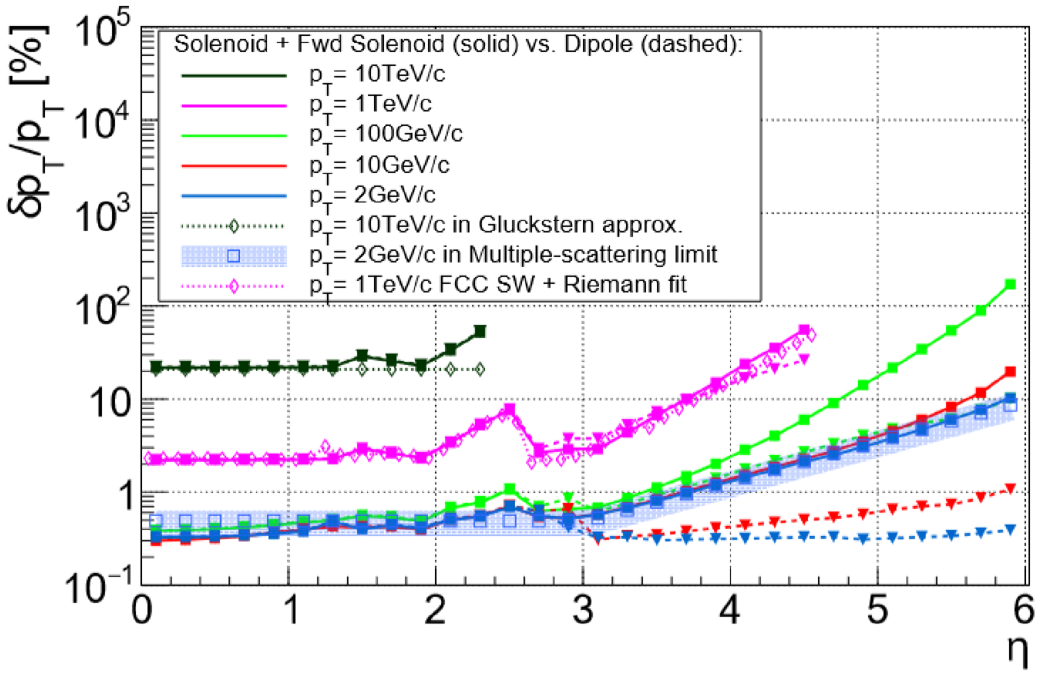
Parameters	LHC	HL-LHC	FCC-hh
$\sigma_{inel}[mb]$	80	80	103
$\sigma_{tot}[mb]$	108	108	150
RMS luminous region σ_Z [mm]	45	57	49
Line PU density $[\mathrm{mm}^{-1}]$	0.2	1.0	8.1
Time PU density $[\mathrm{ps}^{-1}]$	0.1	0.29	2.43
N_{ch} per collision	70	70	122
<p_T>[GeV/c]	0.56	0.56	0.7
VBF jet peak [|η|]	3.4	3.4	4.4
90% $H \rightarrow 4l$ [|η|<]	3.8	3.8	4.8

FCChh magnet system studies

- **4T/10m solenoid**
- **Forward solenoids** for high η-acceptance (alternative: dipoles)
- 60 MN net force on forward solenoids handled by axial tie rods
- No return yoke since since stray field can be handled
- **Stored energy: ~13.4 GJ**



Tracking performance studies

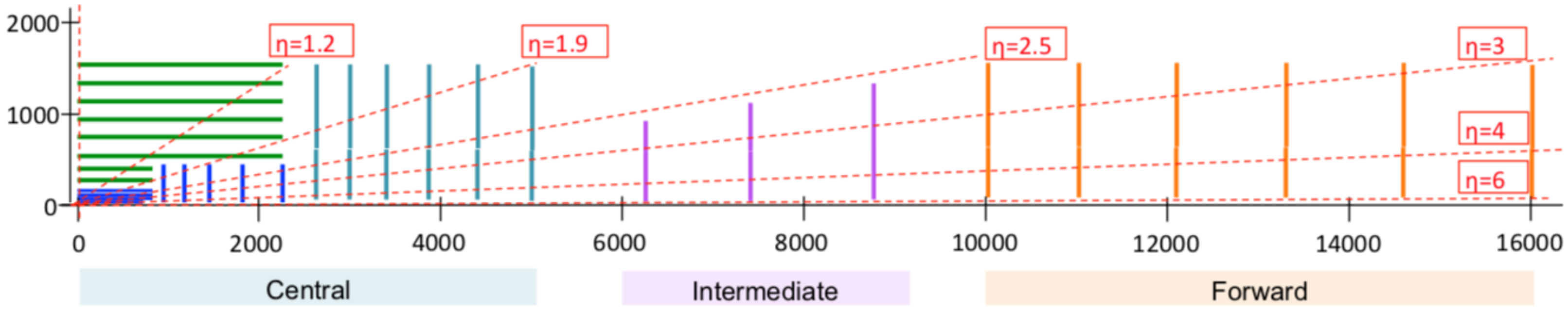


Transverse momentum resolution

- Improves ~1/N_{layers} but decreases with passed material
- MS limit $\frac{x_{tot}}{X0}$ $\sim 0.45 \pm 0.25$ @ $|\eta| = 0$
- $\frac{\delta p_T}{p_T}$ ~ 20% for 10TeV tracks

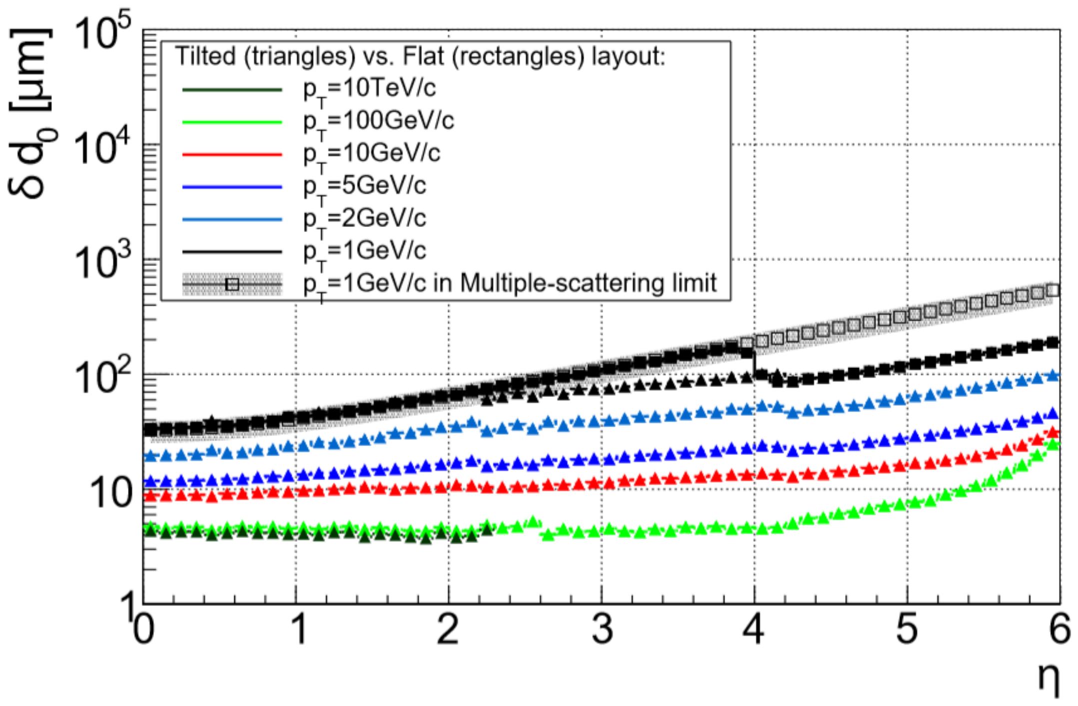
Magnetic field

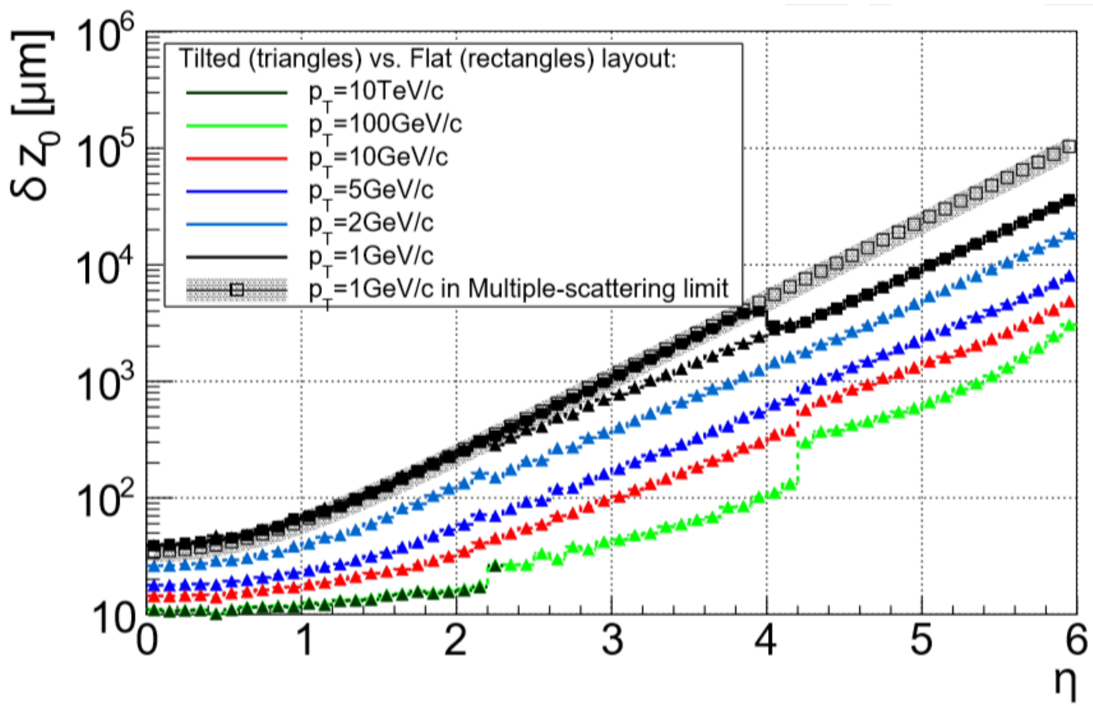
- Two magnet scenarios
  1. Central solenoid + forward solenoids
  2. Central solenoid + forward dipoles
- 4T/10m solenoid
- Forward solenoids for high η-acceptance
- No return yoke: stray field can be handled



Using tkLayout-tool
(Analytical track propagation, taking material scattering and magnetic field into account)
See for FCChh results

Expected FCChh impact parameter resolution





- Good d_0 resolution needed for jet-tagging
- Good z_0 resolution needed to identify primary vertex

Using tkLayout-tool
(Analytical track propagation, taking material scattering and magnetic field into account)
See for FCChh results

FCChh Kinematics

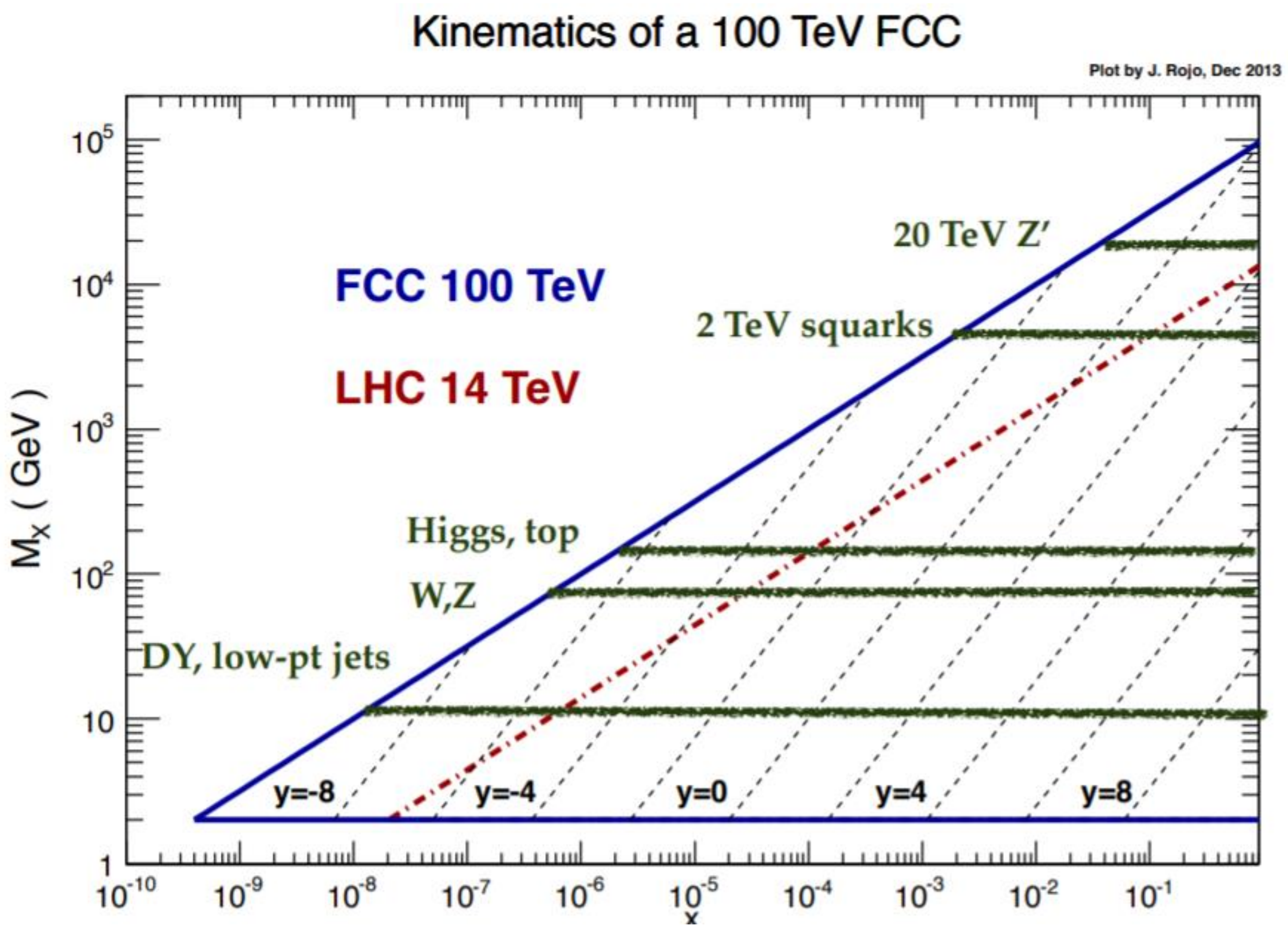


Figure taken from [here]

Kinematical coverage of FCC-hh compared to LHC

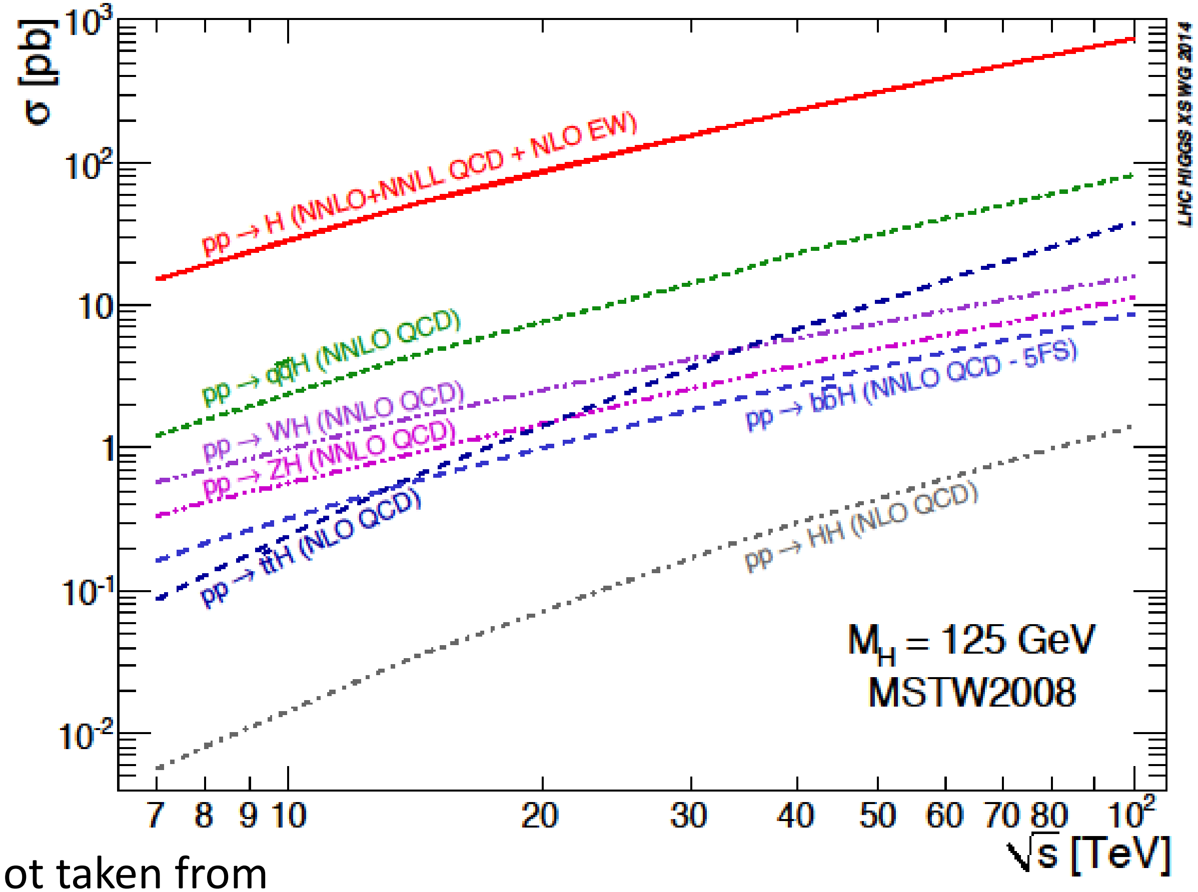
- M_x…mass of produced final states
- x…fraction of momentum of the parton with respect to the hadron
- Dotted lines: regions of constant rapidity

- ➢ FCC-hh reach highly extended
- ➢ Possible BSM particles up to tens of TeV produced in central region
- ➢ SM physics can be highly boosted

Higgs cross sections

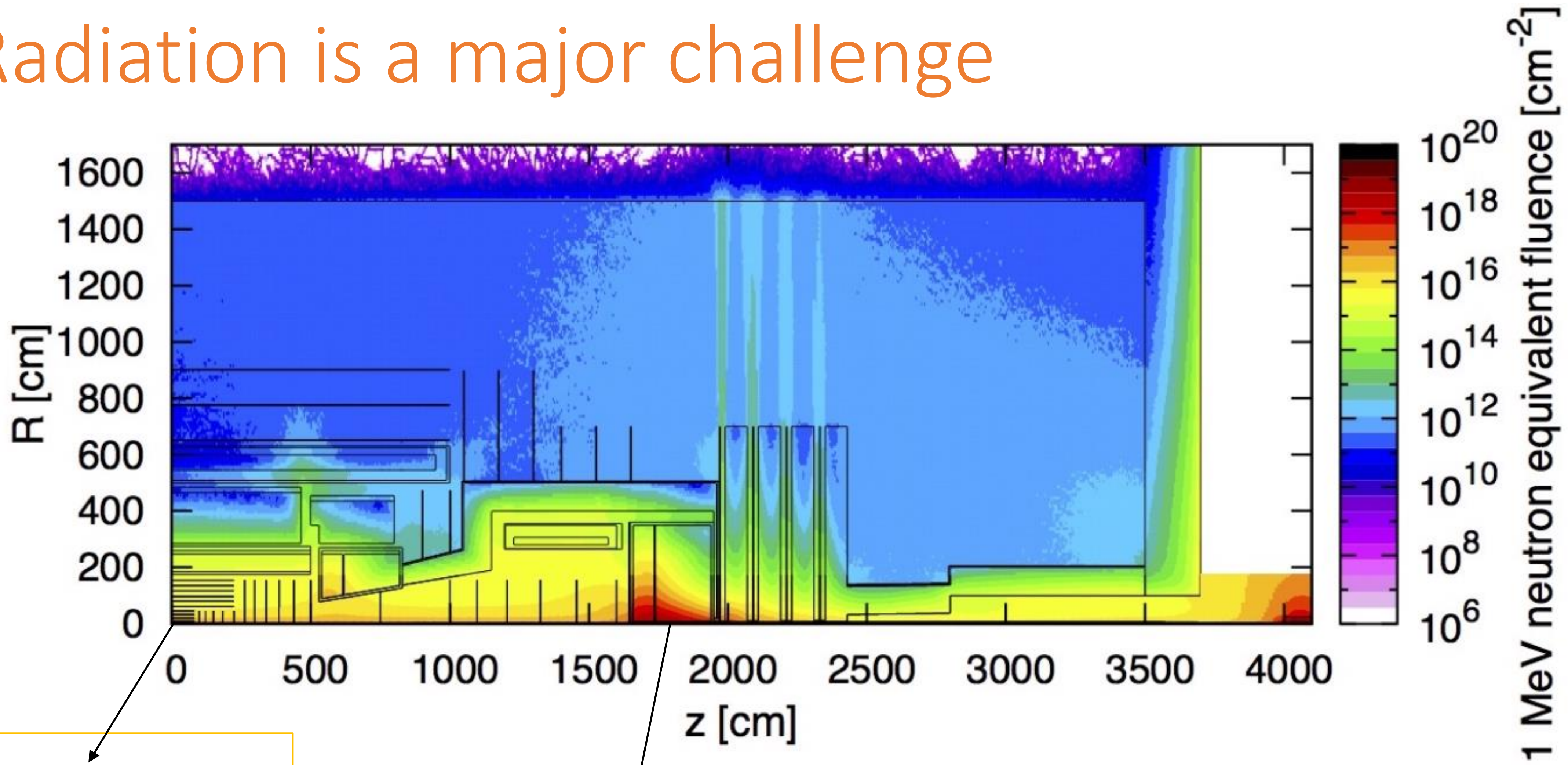
Higgs production cross sections at different center of mass energies

- Higgs cross section by order of magnitude compared to HLC
- $t\bar{t}H$ raised by factor 55
- HH increased by factor 40



Plot taken from https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HiggsEuropeanStrategy

Radiation is a major challenge



Tracker:
First IB Layer (2.5cm): ~5-8*$10^{17}n_{eq}$ / cm^2
External part (after 40cm): ~5*10^{15} n_{eq} / cm^2
(could use HL-LHC technologies)

Forward Calorimeter:
5 x $10^{18}n_{eq}$/cm^2

Maximum expected fluence
~ 100 x HL-LHC
~ 1000 x LHC

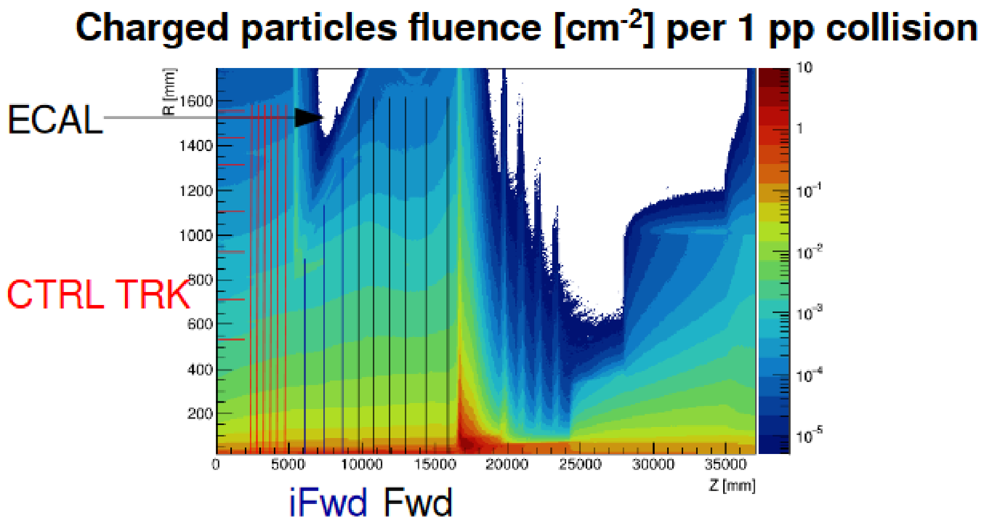
Extreme radiation and pile-up environment

Radiation:

- Maximum expected fluence
  ~ 10-100 x HL-LHC
  ~100-1000 x LHC
- First IB Layer (2.5cm): ~5-8*$10^{17} n_{eq}$ / cm^2
- External part (after 40cm):

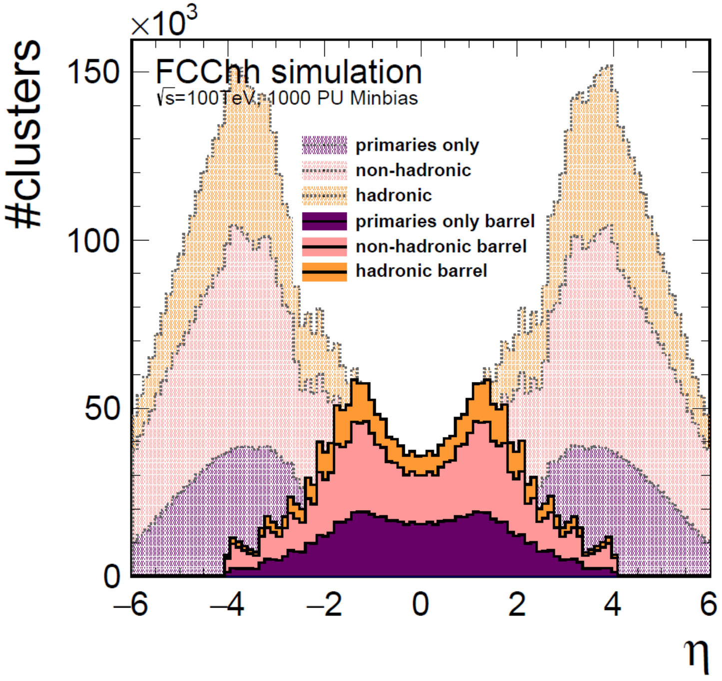
~5*10^{15} n_{eq} / cm^2

⇒ could use HL-LHC technologies



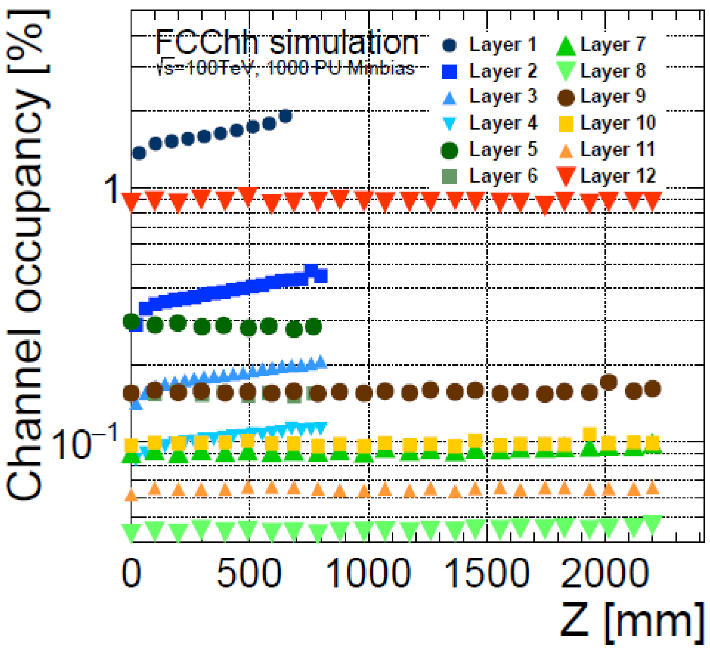
Clusters:

- MinBias @ <μ>=1000
- Full simulation, geometric digitization & clusterization
- Seconaries give rise by 70%



Channel Occupancy:

- In total 9-10M clusters
- ~30M activated pixels
- 2-3 PB/s @ first trigger level (assuming binary Readout 40 MHz event rate)



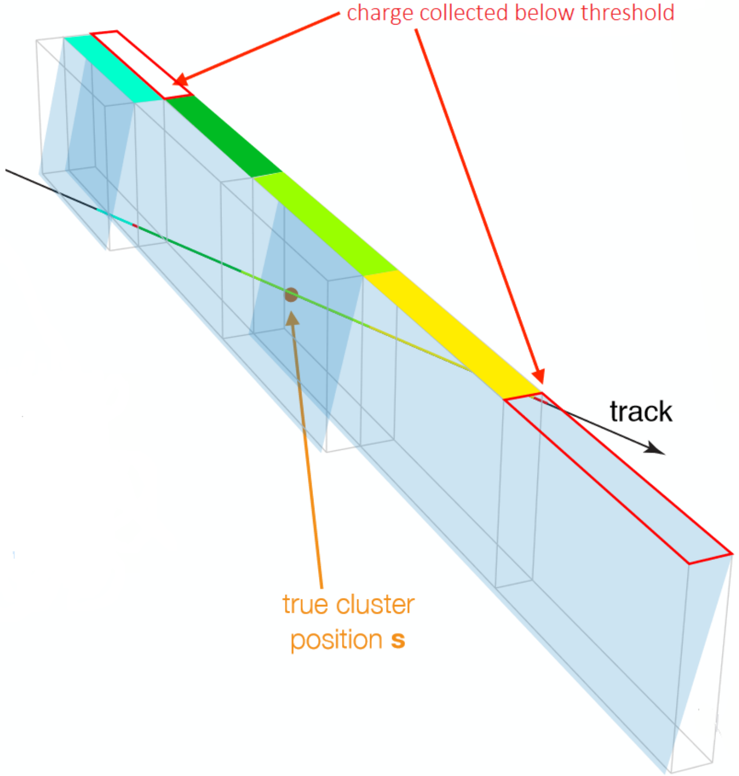
Digitization inside FCCSW using ACTS

Close to realistic detector response

- ➢ Translate hit into measurement

Depends on technologies used for specific detector

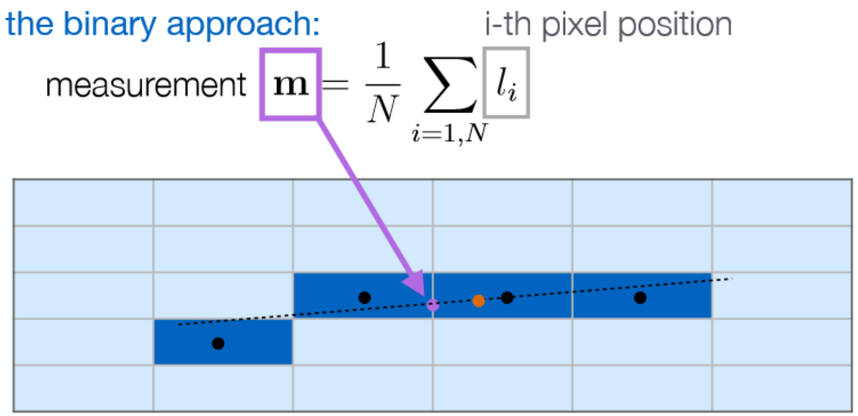
- ➢ Use purely geometric approach
- ➢ Flexible
  - Mimic analogue/digital readout
  - Can take lorentz angle into account
- ➢ Can use either full or fast simulation hits as input
- ➢ Uses the granularities of FCChh reference design v3.03



⇒ Allows to test digital/analogue readout
⇒ Allows to study readout of detector
⇒ First studies using digitzation in second part of talk

Digitization – creating measurements

- Determines cells hit by particle
- Create clusters from neighbouring cells using **connected component analysis** (boost)
  - Labels connected cells which will be merged into one cluster
  - Allows single clusters from multiple particles



Digitization – creating measurements

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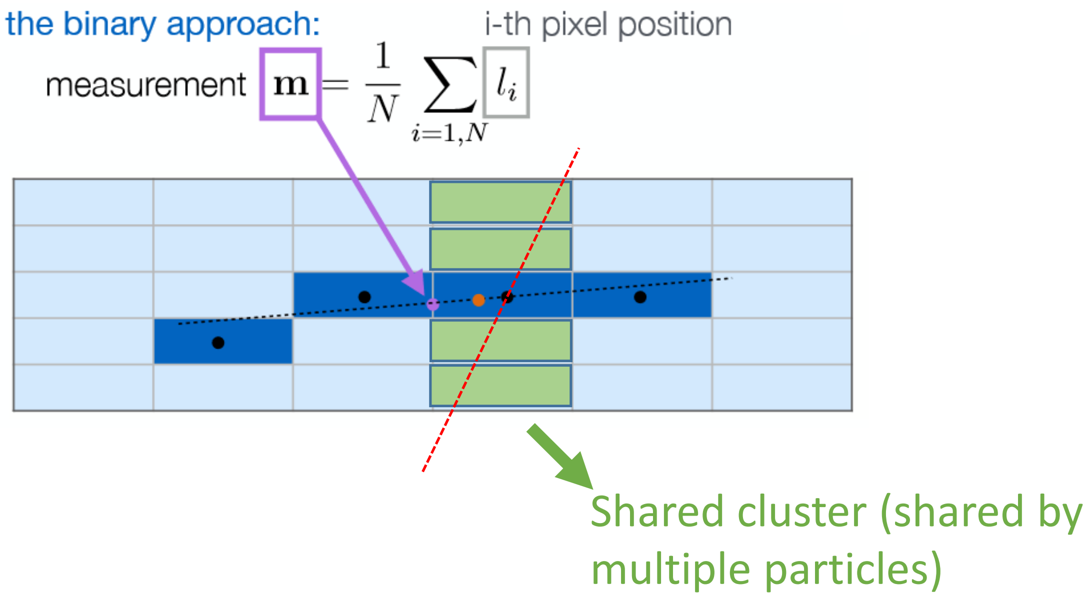


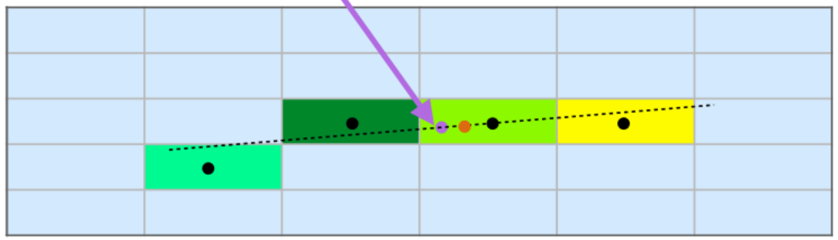
Digitization – creating measurements

- Determines cells hit by particle
- Create clusters from neighbouring cells using **connected component analysis** (boost)
  - Labels connected cells which will be merged into one cluster
  - Allows single clusters from multiple particles

the charge-weighted approach :

$$\boxed{\mathbf{m}} = \frac{1}{\sum_{i=1,N} q_i} \sum_{i=1,N} \boxed{q_i} l_i$$

charge collected in cell i

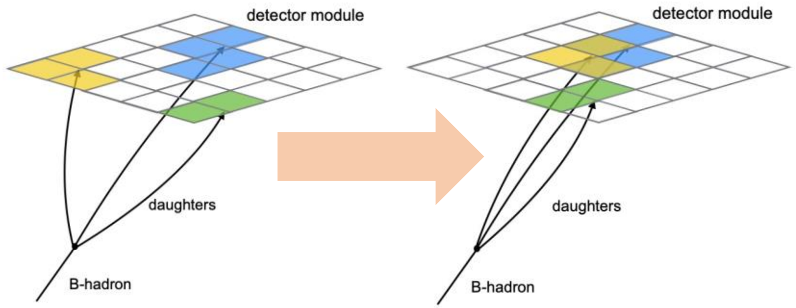


Resolution depends on:

- readout granularity
- Incident angle (i.e. cluster shape)

Cluster errors (residuals to truth position) => realistic resolution estimate

Resolving high p_T-Jets



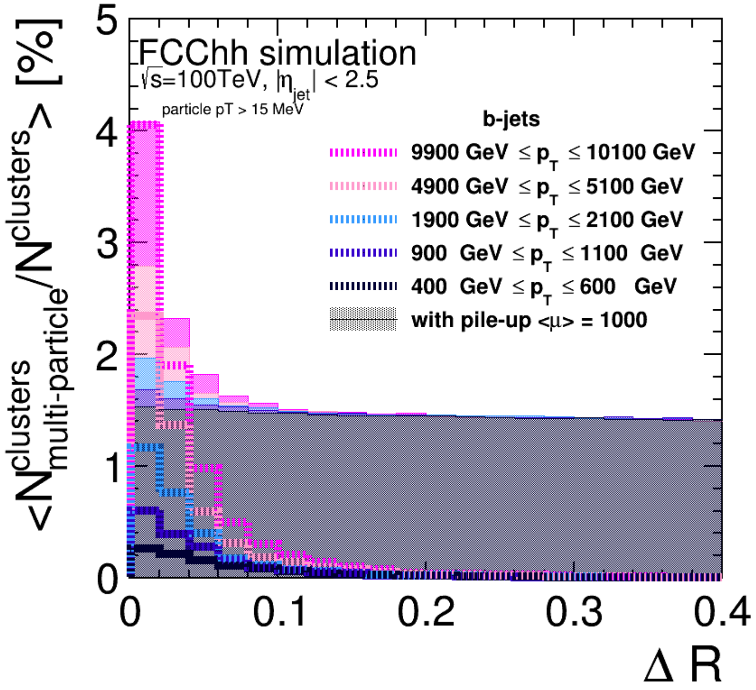
Cluster merging

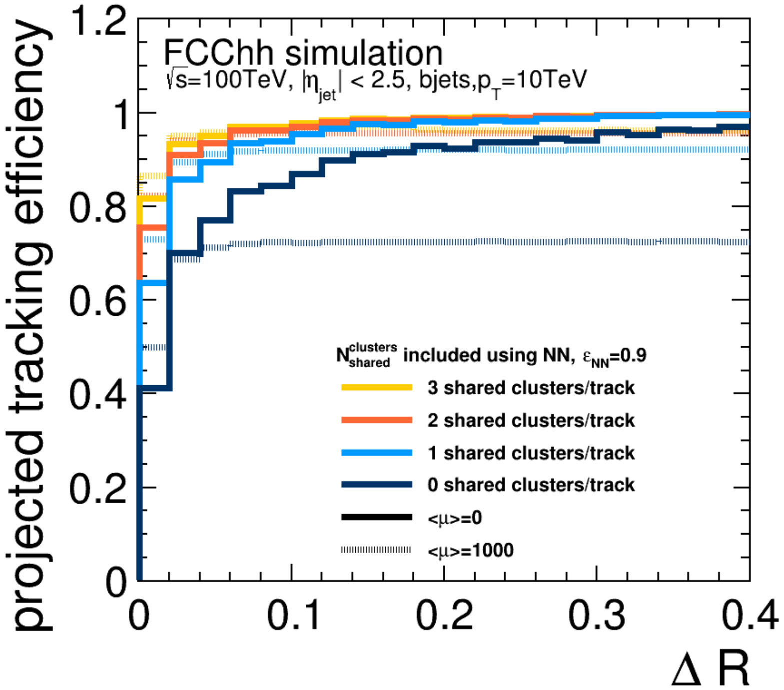
- Frequentlty close to jet core
  - Pixel: up to tens of %
  - Strip: PU-noise has big impact

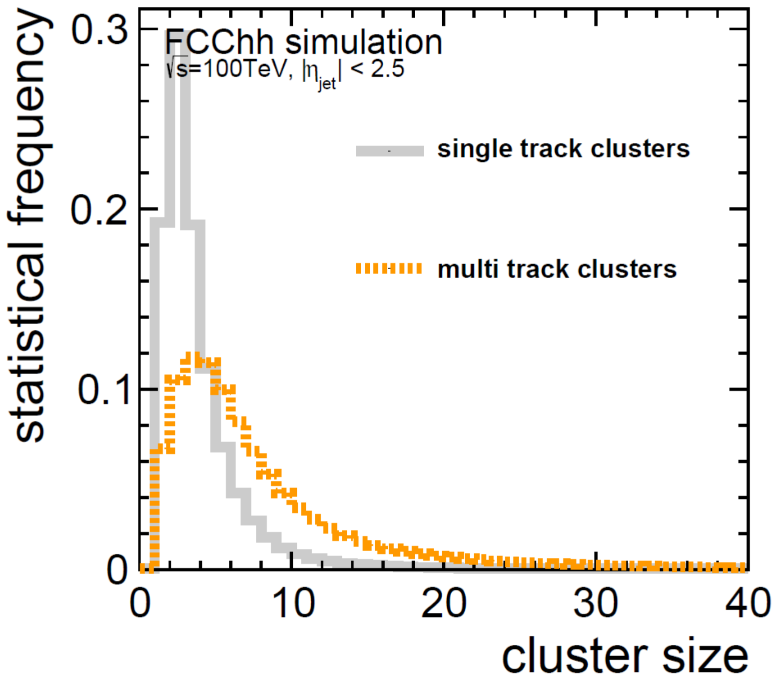
Track reconstruction

- Projected track reconstruction efficiency significantly degraded
- ATLAS: 6.1-9.3% lost tracks for jets (200-1600 GeV)

- worsens track parameter resolutions



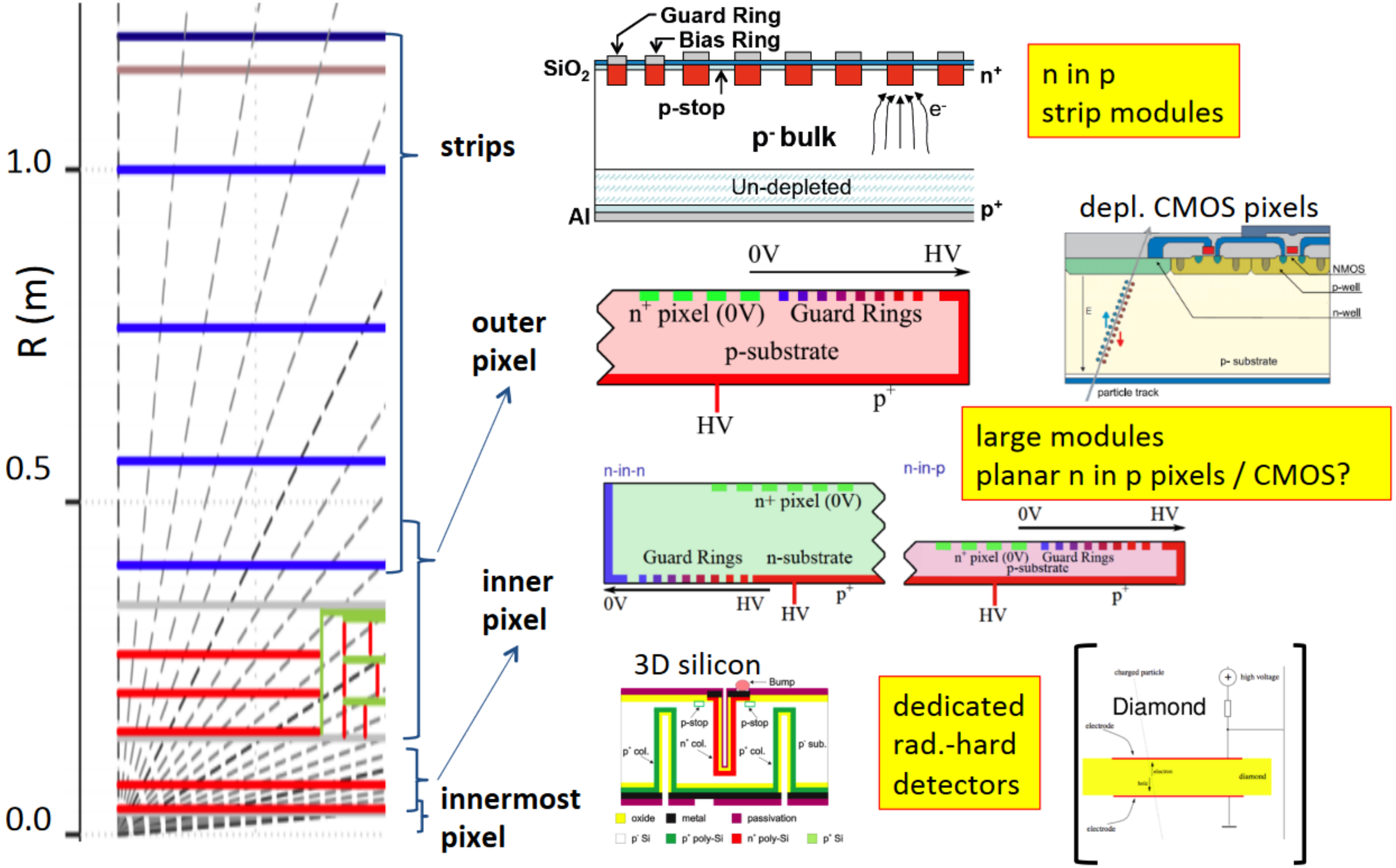




⇒ ATLAS Trained neural network to identify merged clusters

\+ Would enhance reconstruction efficiency for FCChh   − Need to read-out charge deposition

Silicon sensor R&D ongoing



Requirements

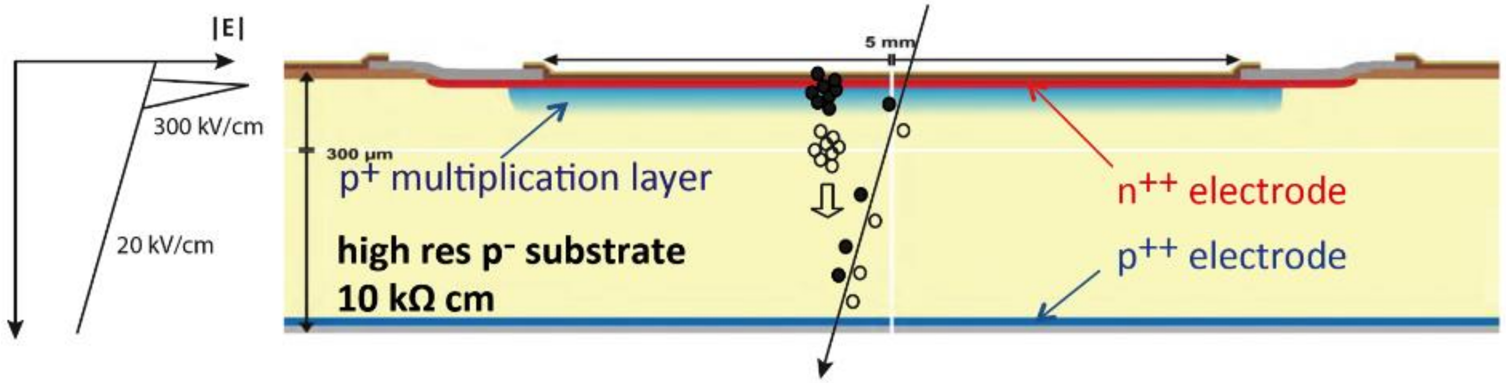
- High hit-rate capability
- High radiation tolerance
- Minimal power
- Cheaper (cover large area)
- Light
- Increased granularity
- Pattern recognition and identification at large background and pile-up levels

Timing information in Si detectors

How to get in 10ps timing range with Si detectors?

Exploit „in-silicon“ charge amplification

- ➢ In Geiger-mode fashion (like in gas RPC)
- ➢ **L**ow **G**ain **A**valanche **D**etecors (linear mode)
  - Separate ‚collection‘ of charge from gain



Additional References

- CLD Tracking
- IDEA Tracking
- IDEA Beam-backgrounds
- FCCeh Detector
- FCChh Tracker design
- FCChh tracking and flavour tagging performance
- TrickTrack Seeding for FCChh
- FCChh Occupancy&Data Rates
- ACTS Homepage