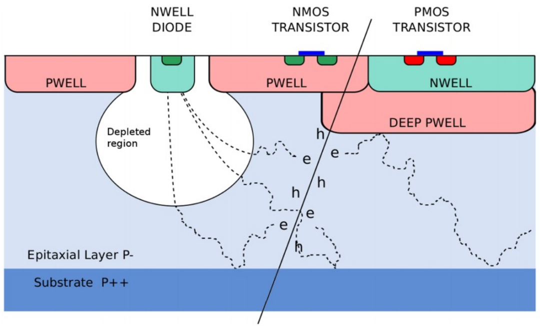
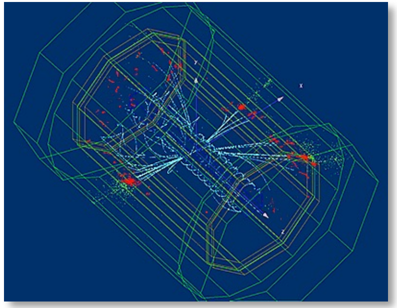
PICSEL

Jeremy Andrea, Jérôme Baudot, Auguste Besson, **Ziad El Bitar**, Ajit Kumar, Emmanuel Medernach, Meena Meena, Gaëlle Sadowski, Serhiy Senyukov

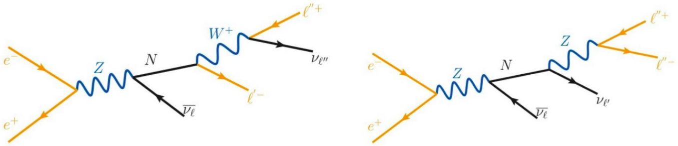


Instrumentation :

- CMOS R&D (lightweight, highly granular)
- Mechanics and integration

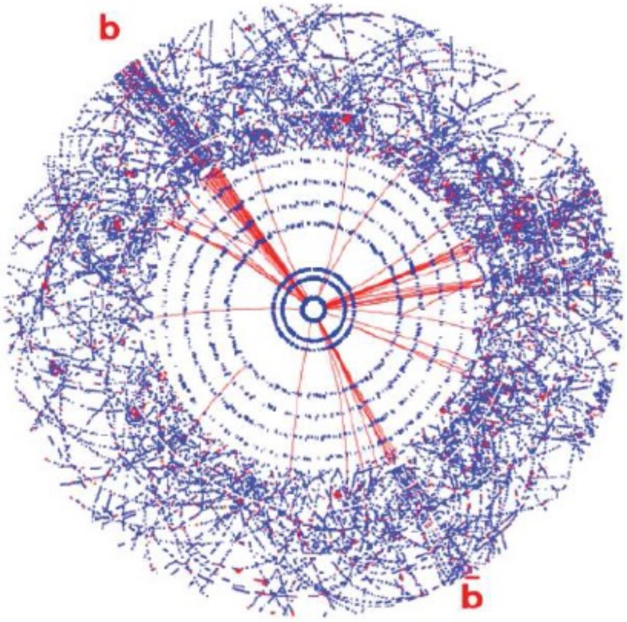


Simulation

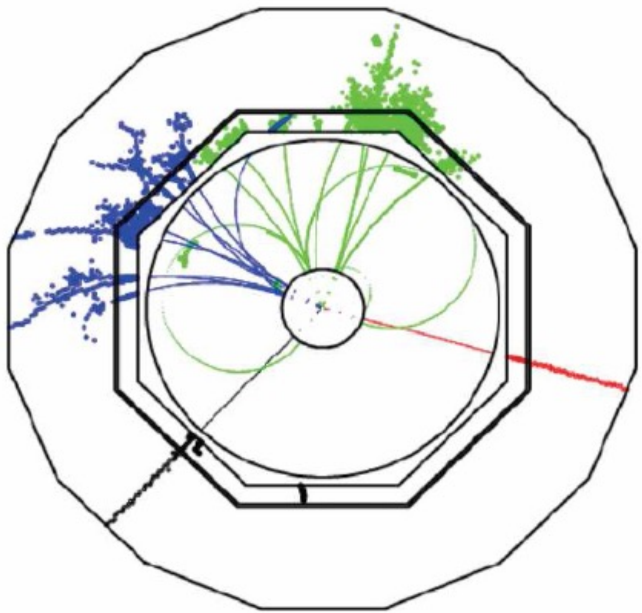


Phenomenology

WHAT DOES A COLLISION LOOK LIKE



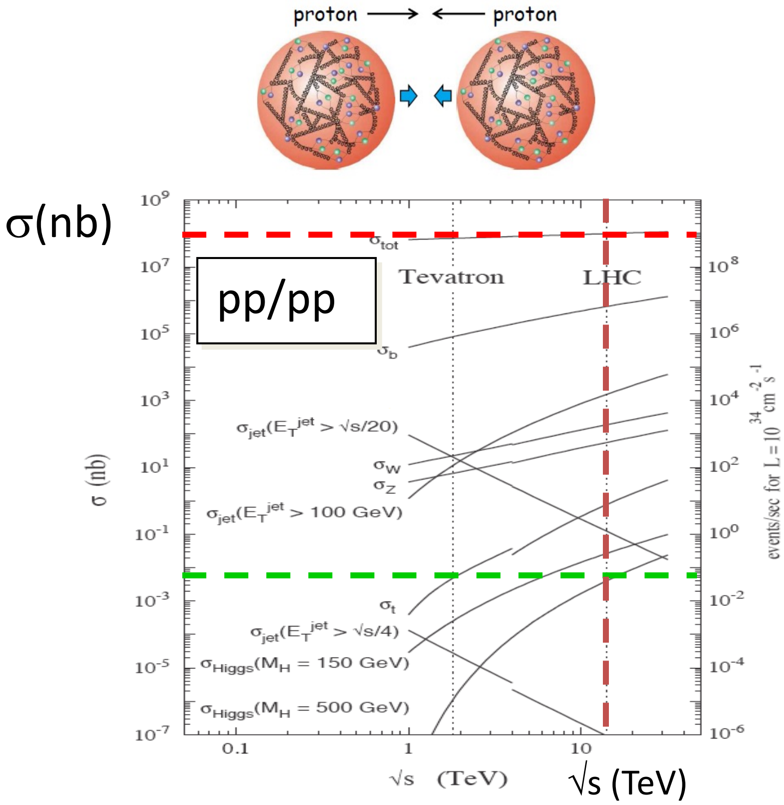
$pp \rightarrow H + X$

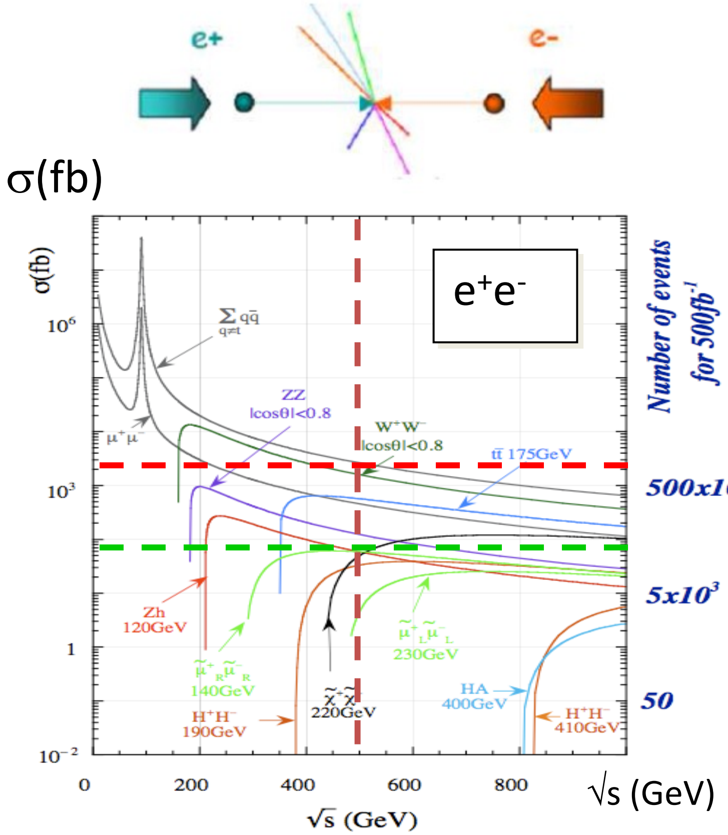


Pedro Castro

$e^+e^- \rightarrow HZ$

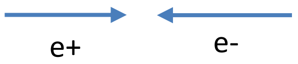
Motivation for an electron-positon collider



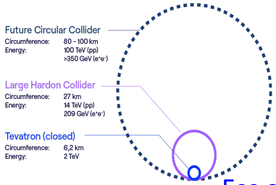


DIFFERENT SCENARII

Linear Collider

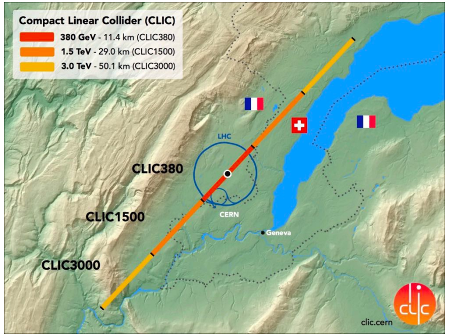


Circular Collider

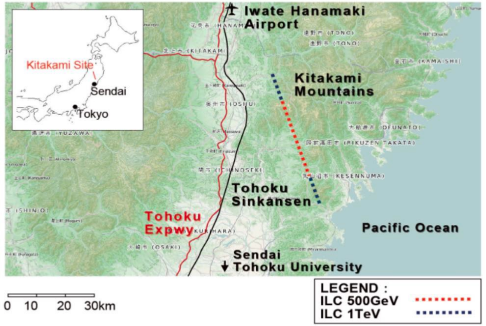


Fcc overview

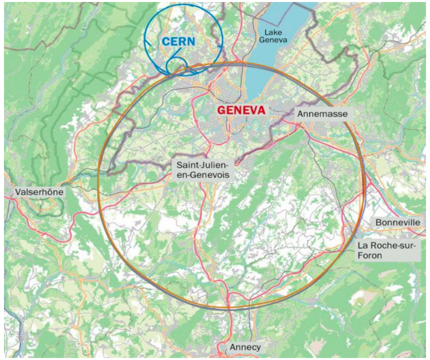
CLIC @ CERN
√smax =380-3000 GeV



ILC in Japan
√smax =250-1000 GeV

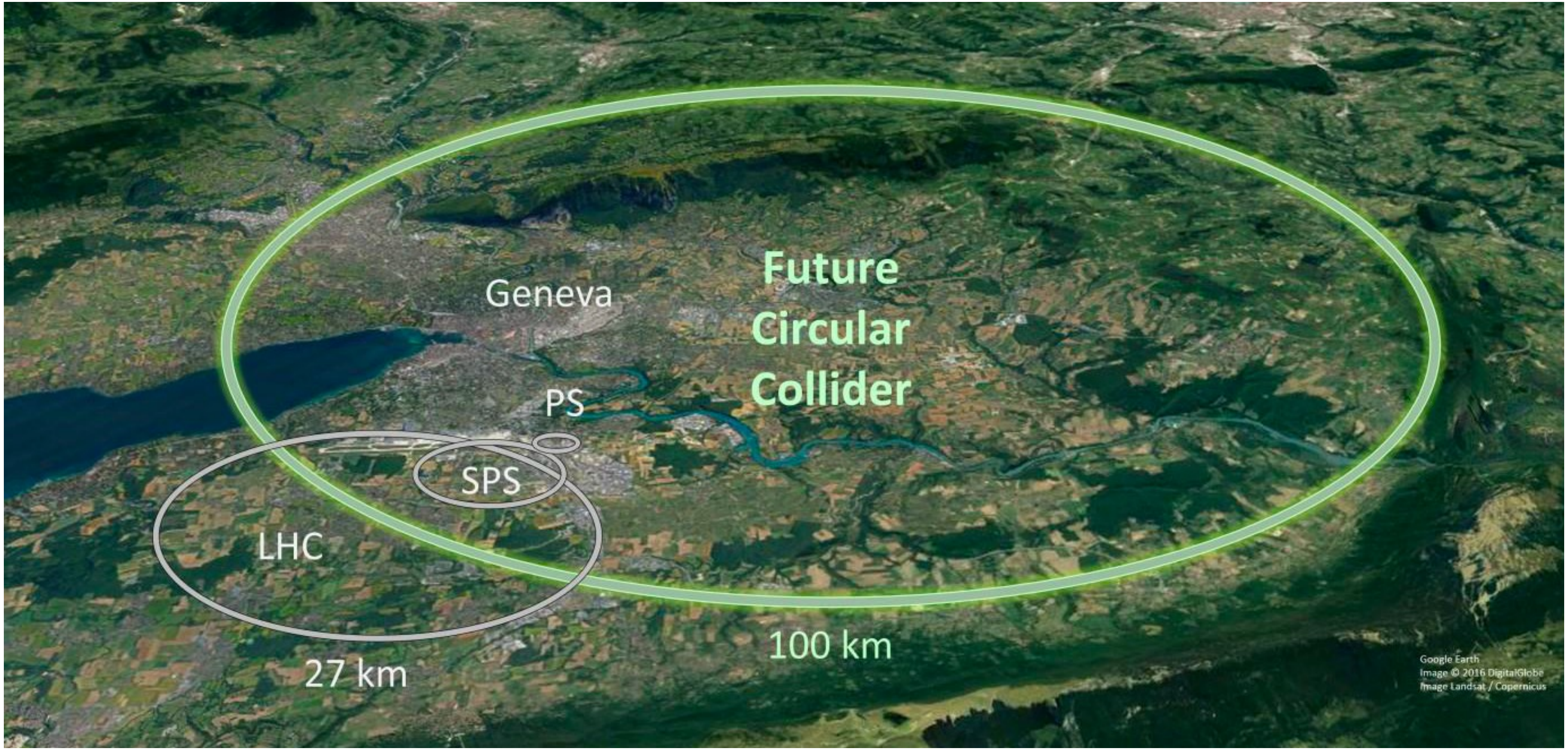


FCC-ee @ CERN
√smax =240-365 GeV



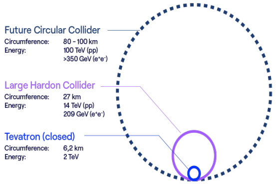
CEPC in China
√smax =240-360 GeV

THE FUTURE CIRCULAR COLLIDER (FCC)



Ambition physics studies

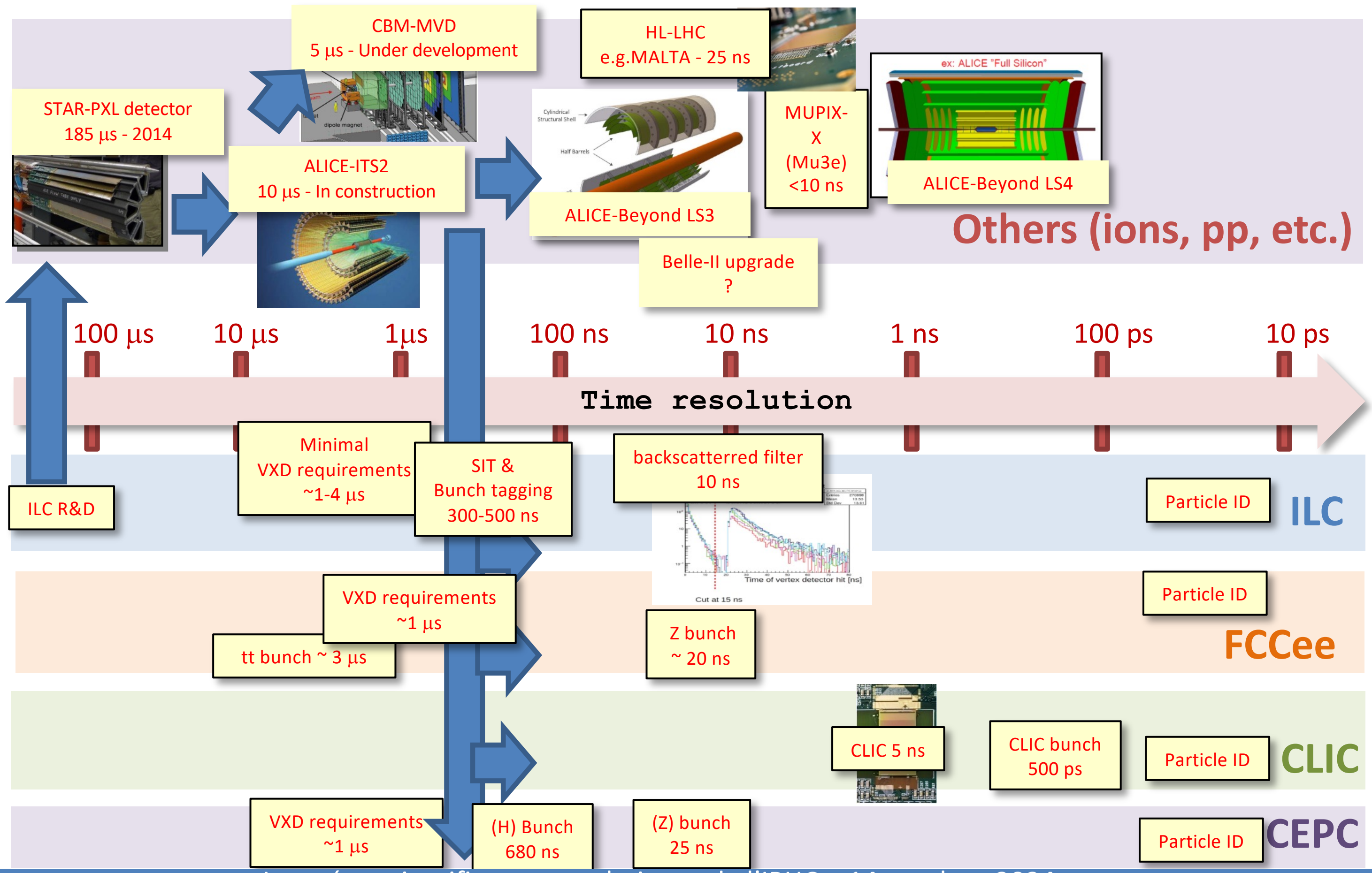
	Higgs factory	Flavor "boosted" B/D/τ factory	QCD – EWK most precise SM test	BSM feebly interacting particles
Physics Landscape @ FCCee	m_H, σ, Γ_H self-coupling $H \to bb, cc, ss, gg$ $H \to inv$ $ee \to H$ $H \to bs$, … **Top** m_{top}, Γ_{top}, ttZ, FCNCs	CKM matrix CP measurements Charged LFV Lepton Universality τ properties (lifetime, BRs..) $B_c \to \tau \nu$ $B_s \to D_s K$ $B_s \to K^* \tau \tau$ $B \to K^* \nu \nu$ $B_s \to \varphi \nu \nu$ …	m_Z , Γ_Z , Γ_{inv} $\sin^2\theta_W$, R^Z_ℓ , R_b, R_c $A_{FB}^{b,c}$, τ pol. α_S m_W, Γ_W	Heavy Neutral Leptons (HNL) Dark Photons Z_D Axion Like Particles (ALPs) Exotic Higgs decays
Detector requirement @ FCCee	track momentum resolution (low X_0) IP/vertex resolution for flavor tagging PID capabilities for flavor tagging Hadron energy resolution (stochastic and noise) and PF	track momentum resolution (low X_0) IP/vertex resolution PID capabilities Photon resolution, pi0 reconstruction	acceptance/alignment knowledge to 10 µm magnetic field uniformity lumiCal coverage down to 60 mrad	Large decay volume High radial segmentation - tracker - calorimetry - muon impact parameter resolution for large displacement triggerless

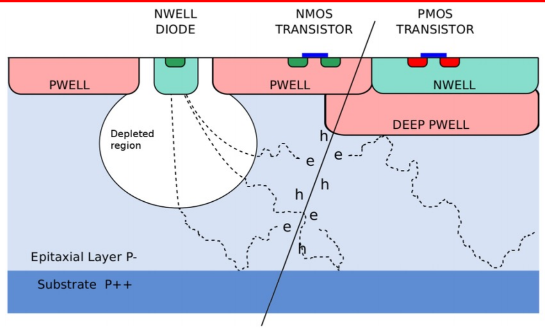


M. Selvaggi, FCC Week 2023

WHILE WAITING: 5, 10, 15 YEARS …NEED FOR MILESTONES PROJECTS

TIME RESOLUTION SCALE IN THE CONTEXT OF ELECTRON POSITRON COLLIDER



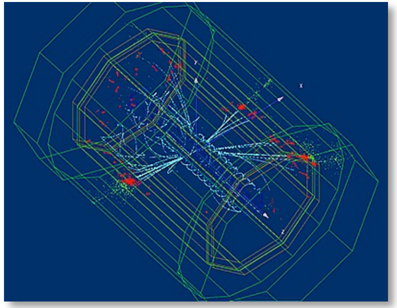


Instrumentation :

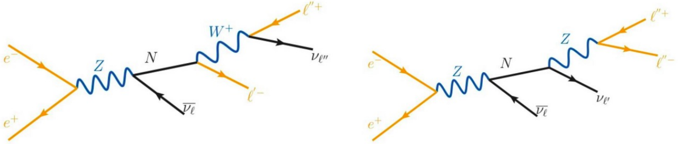
- CMOS R&D (lightweight, highly granular)
- Mechanics and integration

Strong collaboration with

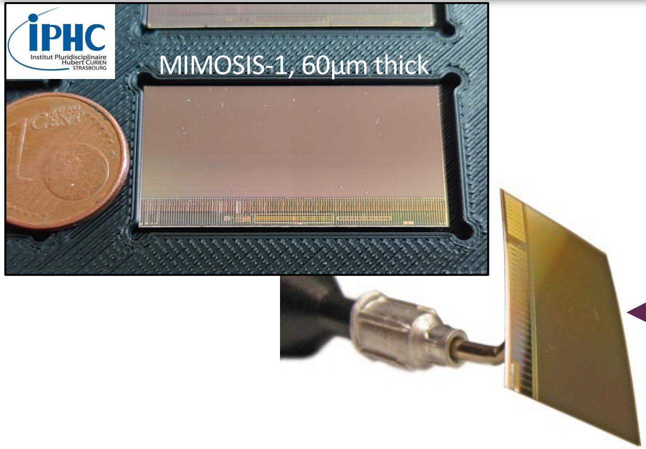
C4PI-Platform



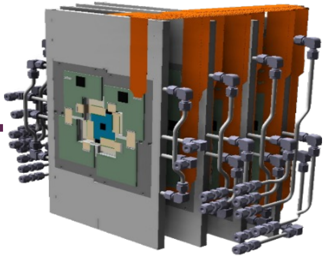
Simulation



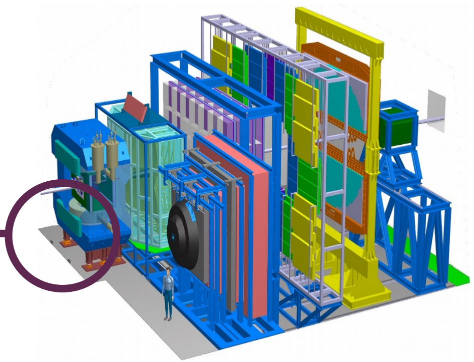
Phenomenology



CMOS Monolithic
Active Pixel Sensor*



CBM Micro Vertex Detector
(MVD)



CBM – Experiment @ FAIR

The CBM – MVD will operate at:

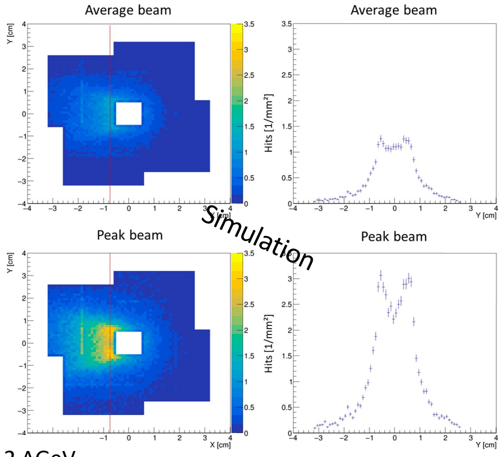
100 kHz Au+Au collisions @ $E_{kin} \leq 10\ A\mathrm{GeV}$
10 MHz p+Au collisions @ $E_{kin} \leq 29\ \mathrm{GeV}$

(up to 100x higher rates in absence of MVD)

Parameter	Value
Technology	TowerJazz 180 nm
Epi layer	$\sim$ 25 µm
Epi layer resistivity	$> 1k\Omega cm$
Sensor thickness	60 µm
Pixel size	26.88 µm $\times$ 30.24 µm
Matrix size	1024 $\times$ 504 (516096 pix)
Matrix area	$\approx$ 4.2 cm^2
Matrix readout time	5 µs (event driven)
Power consumption	40-70 mW/cm^2

* Picture displays a Mimosa28 CMOS sensor. Indeed the final CMOS sensor used in the MVD will Mimosis.

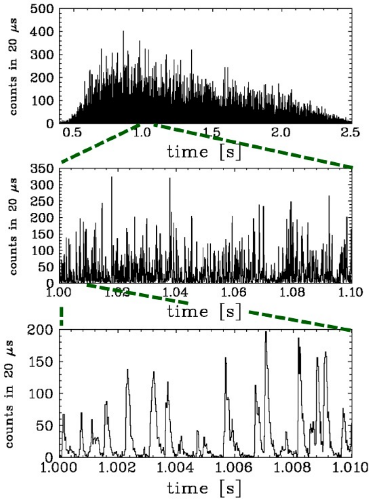
MIMOSIS REQUIREMENTS



Au+Au @ 12 AGeV

…in space.

MVD: Very inhomogenous particle flow in space and time



…in time.

	Requirement
Spatial / time resolution	~5 µm / 5 µs
Sensor thickness	~50 µm
Radiation doses (non-ionizing)	~ 7 x 10^{13} n_{eq}/cm^2
Radiation doses (ionizing)	~ 5 MRad
Rate capability (mean/peak)	(20/80) MHz/cm²
Readout mode	Continuous

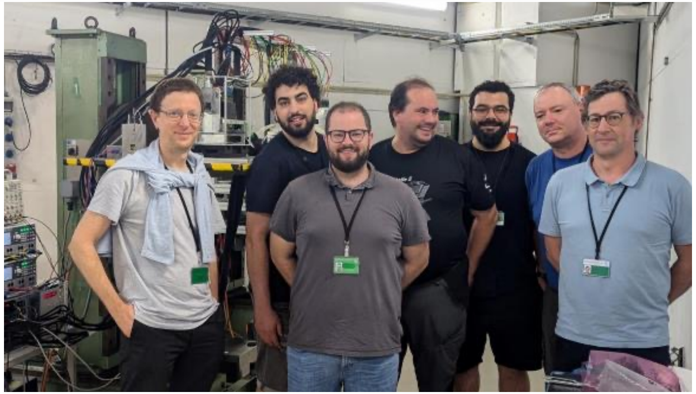
Established by ALPIDE
(Sensor of ALICE ITS2 upgrade)

per year
no safety factor

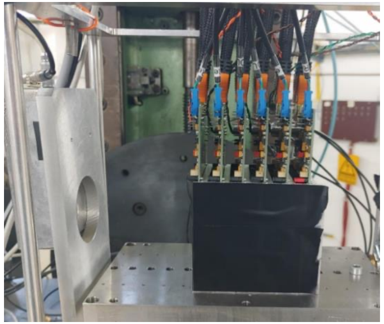
≈10 x ALPIDE

Incompatible with ALPIDE
> 20x internal bandwidth needed

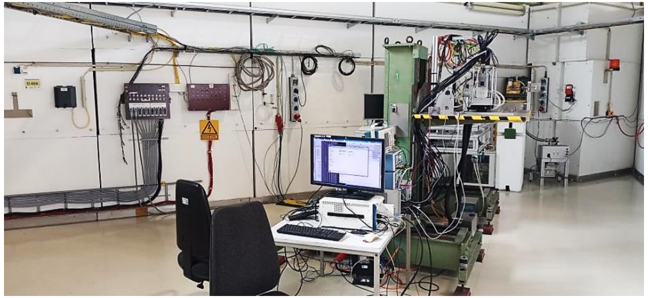
CHARACTERIZATION OF CMOS SENSORS @ CERN, DESY



Auguste Besson | Hasan Darwish | Ben Arnoldi | Mathieu Goffe | Ali Al-tingun | Michael Deveaux | Mathieu Specht

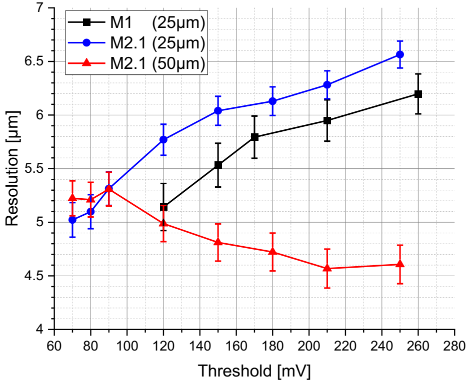


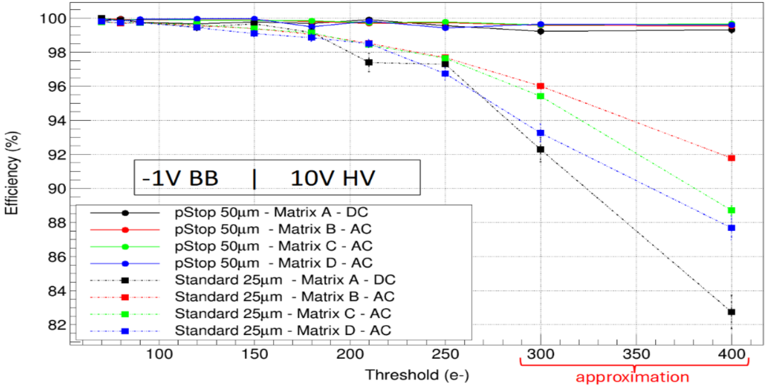
MIMOSIS-2.1 telescope



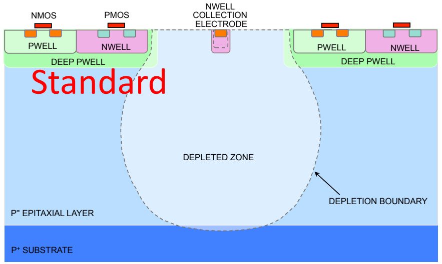
Experiment room

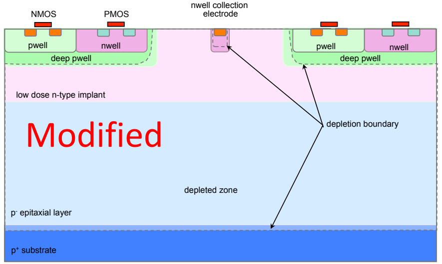
Vital requirements



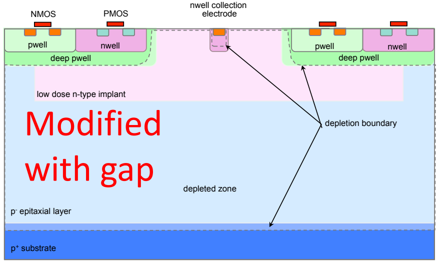


EXPLORING NEW TECHNOLOGIES : TPSCO (65 nm)

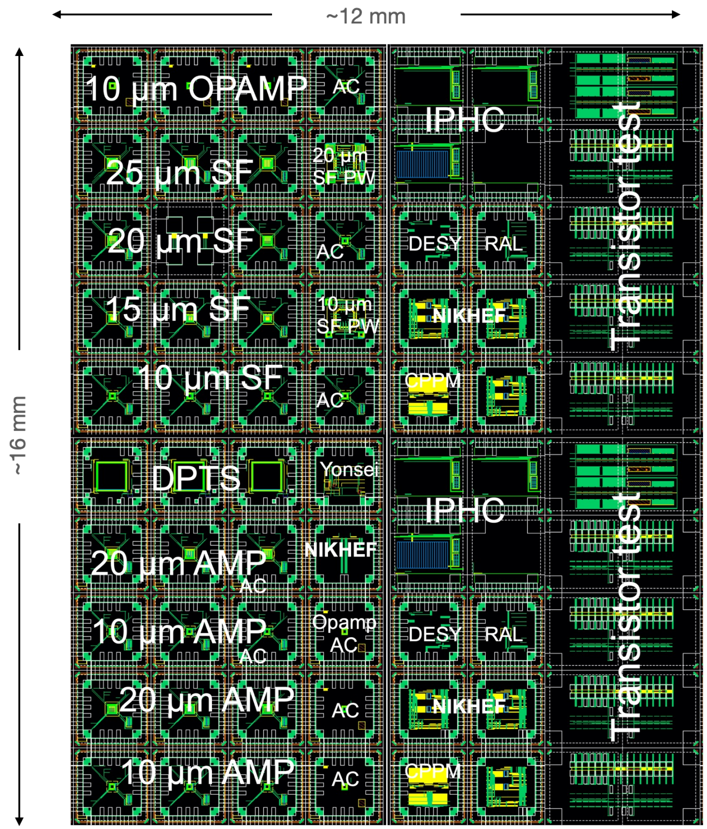




https://doi.org/10.1016/j.nima.2017.07.046



https://iopscience.iop.org/article/10.1088/1748-0221/14/05/C05013



Multi-Layer Reticle

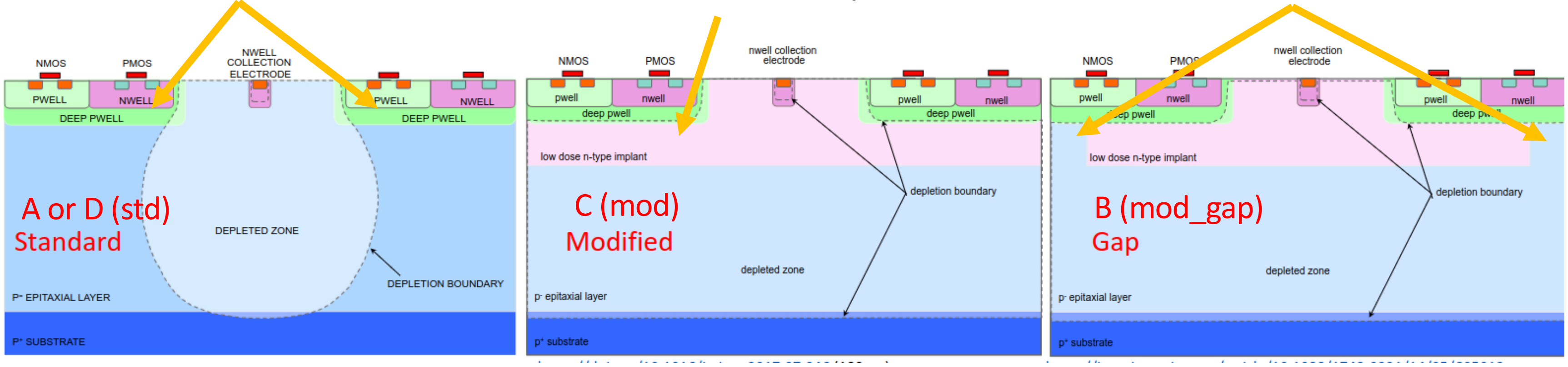
CRICUIT EXPLORATOIRE-65 nm VARIANTS

Variant	Process	Pitch	Matrix	Sub-matrix
CE65-A	std	15μm	64×32	AC/21, DC/21, SF/22
CE65-B	mod_gap	15μm	64×32	AC/21, DC/21, SF/22
CE65-C	mod	15μm	64×32	AC/21, DC/21, SF/22
CE65-D	std	25μm	48×32	AC/16, DC/16, SF/16

Prevent circuitry's nwells from collecting charge

To obtain a full depletion

To overcome the weak electric field near the edges



Beam test setup

Telescope:

Reference Arms : 4 ALPIDE planes for track reconstruction

DUT : CE65

TRG : DPTS

Test beam:

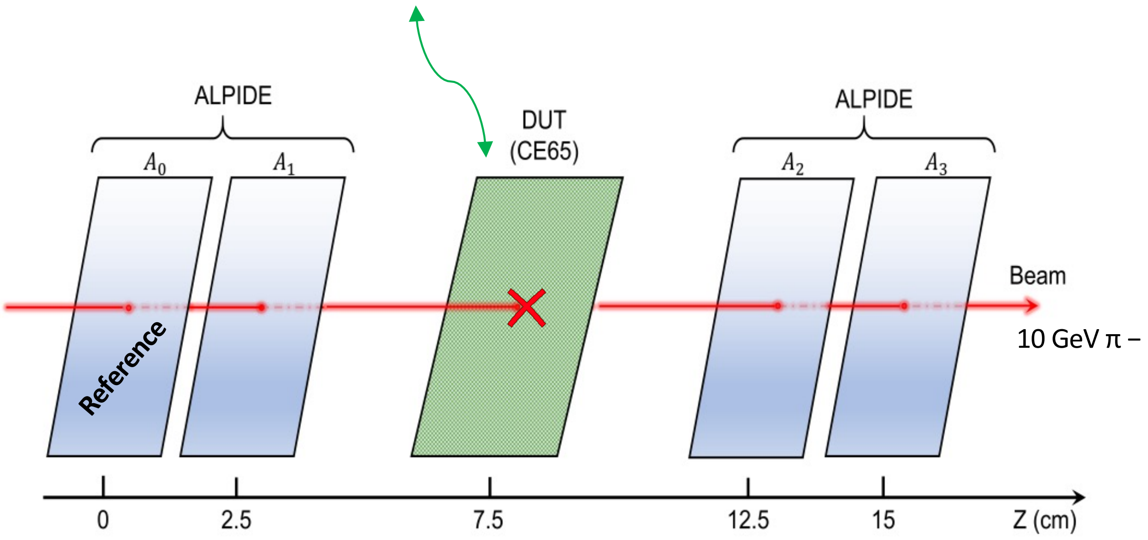
May 2022 at CERN-PS

Data acquisition:
EUDAQ2
Event reconstruction algorithm and data analysis framework:
Corryvreckan

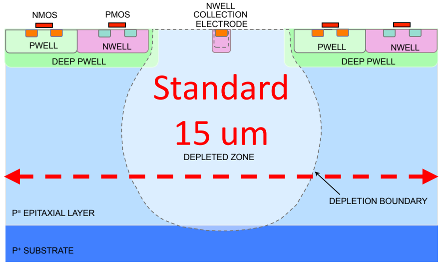
Noise run-**Beam** run:
correlated double sampling method (**CDS**)

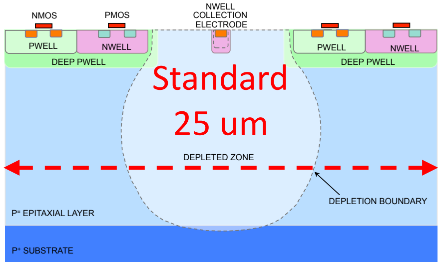
Support provided by Alice Collaboration

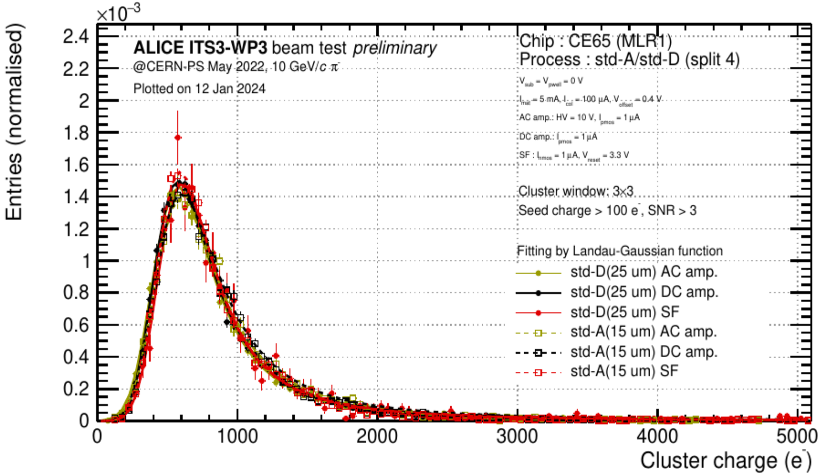
4 frames for each event → **Pedestal map**, **Noise map** } **Calibration file**

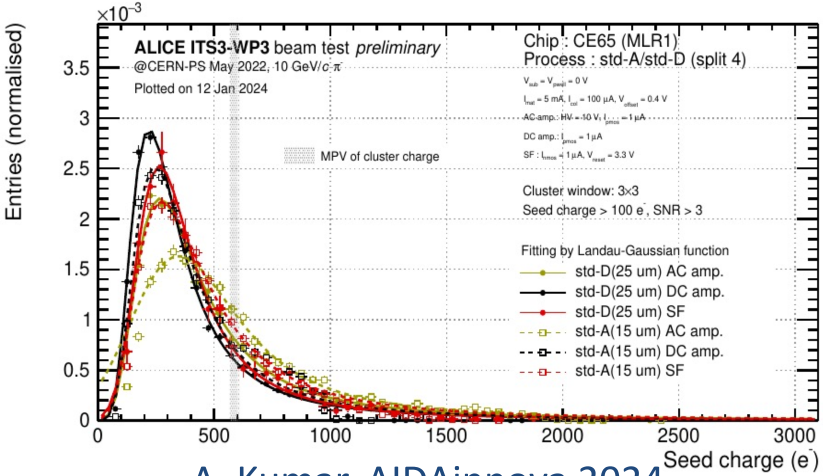


Pixel size impact



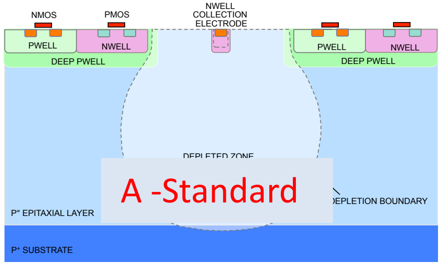


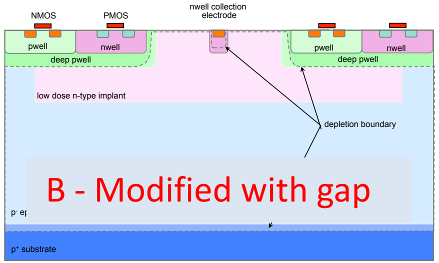


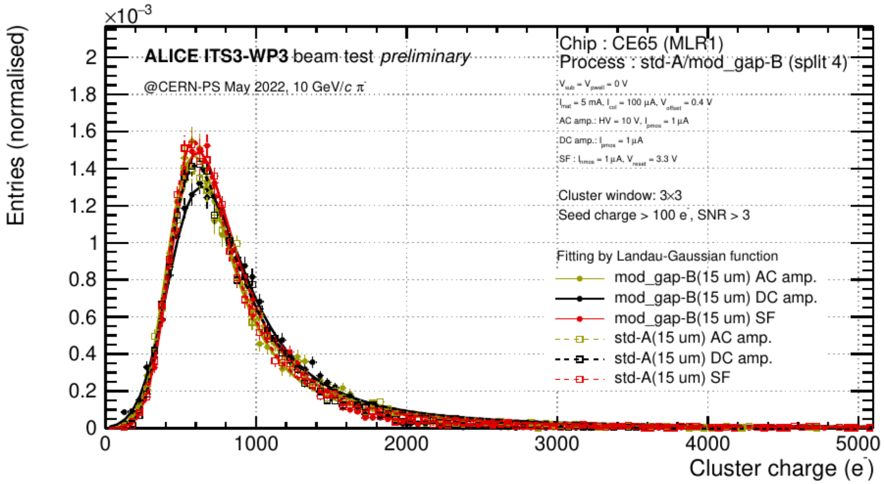


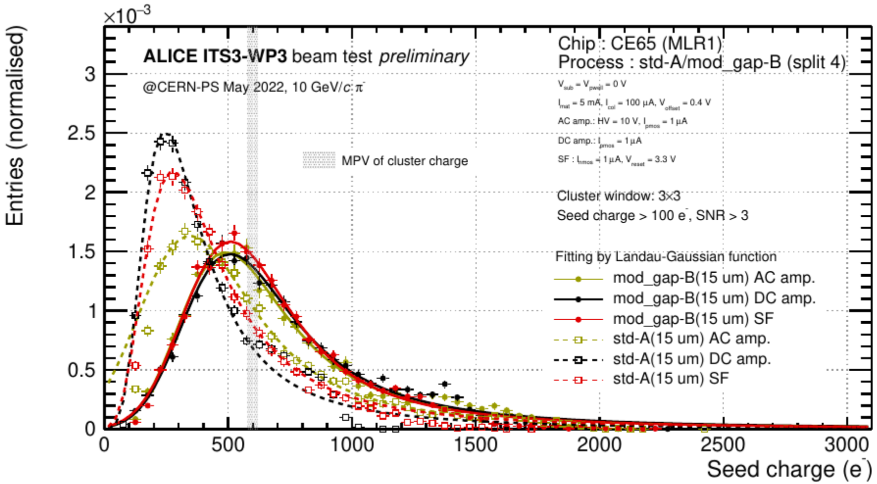
A. Kumar, AIDAinnova 2024

PROCESS MODIFICATION IMPACT

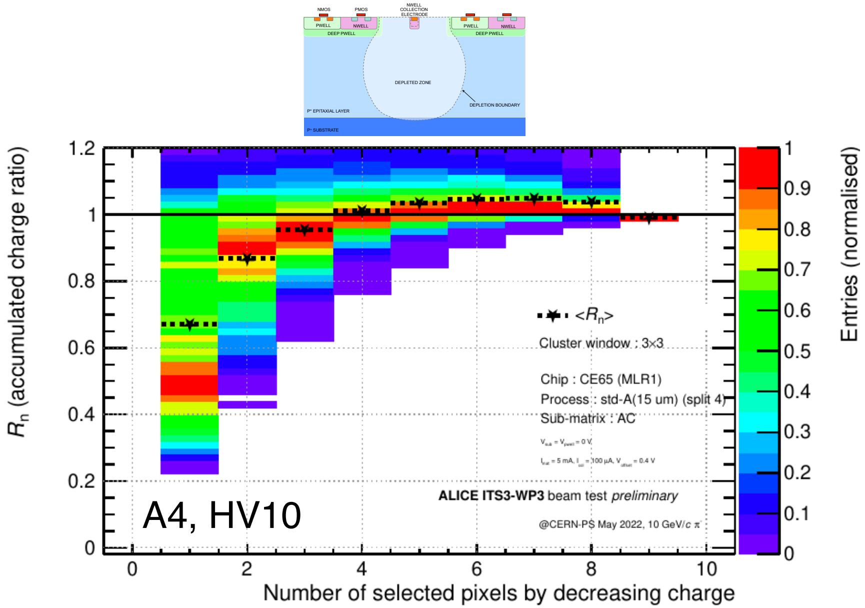


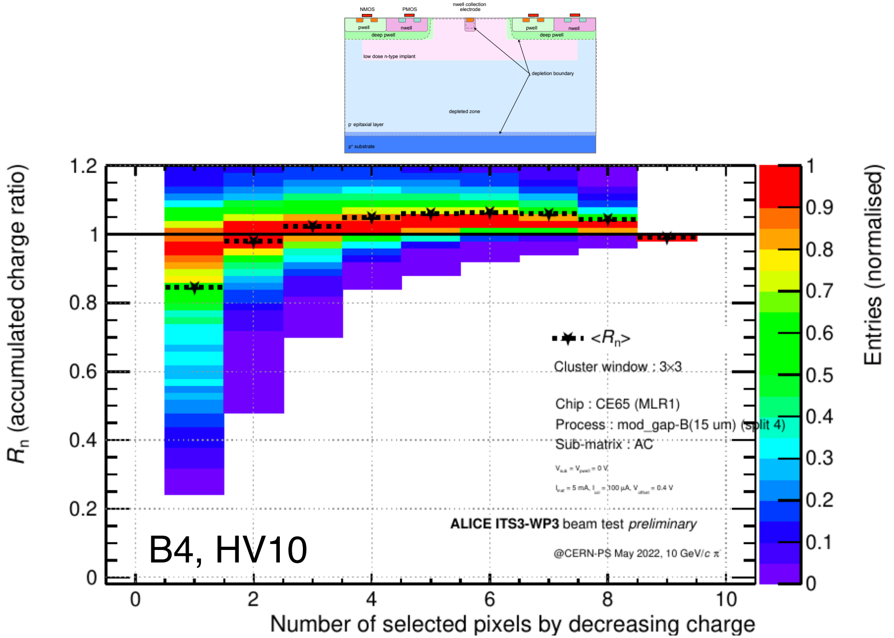






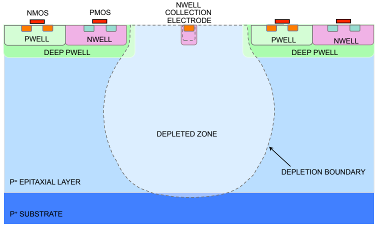
PROCESS MODIFICATION : CHARGE SHARING

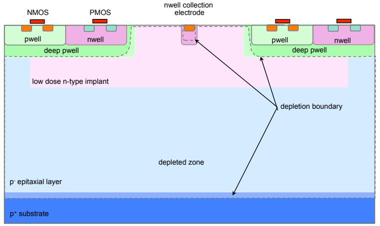


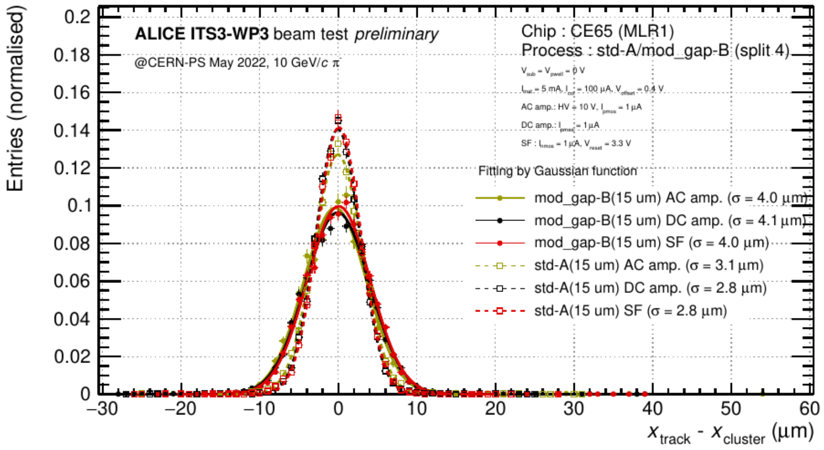


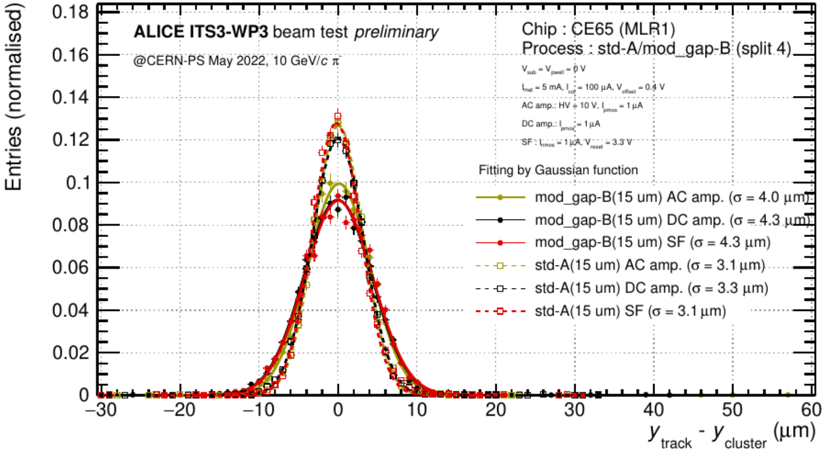
Charge sharing (std) > Charge sharing (mod)

PROCESS MODIFICATION : SPATIAL RESOLUTION





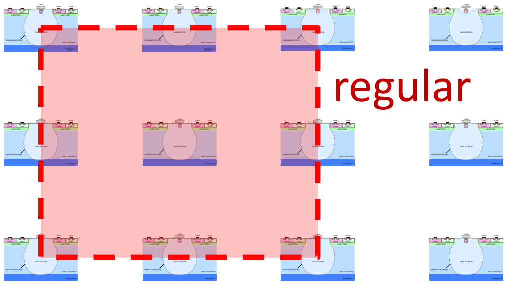


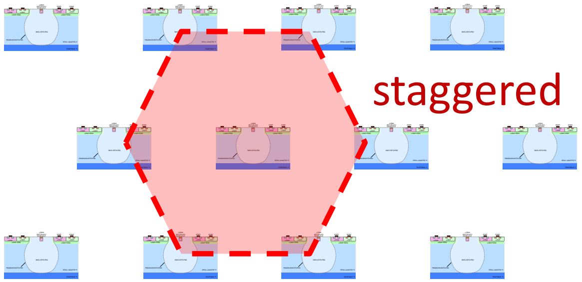


Residual (std) < Residual (mod)

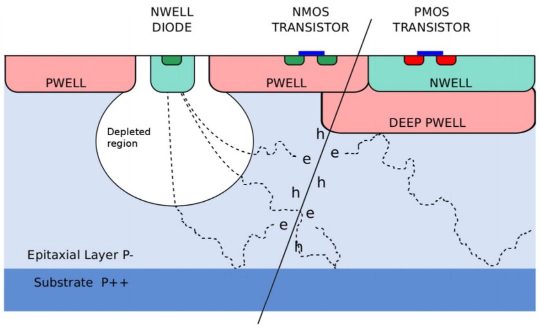
CE-65 nm (v2) …

- AC-coupled only
- Three processes variants (STD, GAP, BLANKET)
- Three pixel pitches values (15um, 18um, 22.5um)
- Arrangement variants





- An option for window readout
- Beam tests @ SPS (April 2024) & DESY (May 2024): ongoing data analysis



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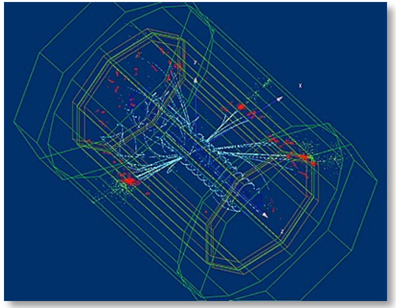
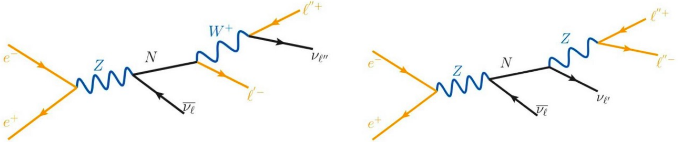


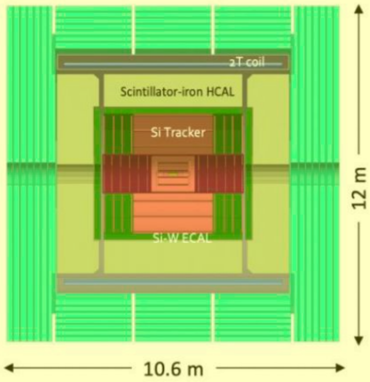
Simulation



Phenomenology

THE DETECTOR CONCEPTS

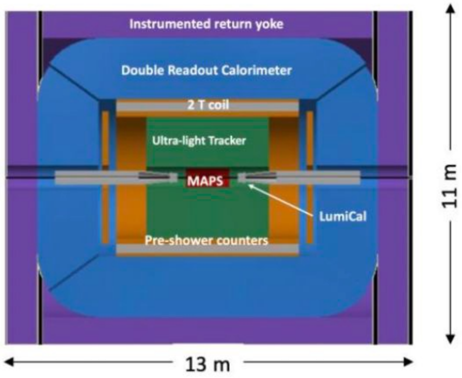
CLD



- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker;
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?
  - …

CDR

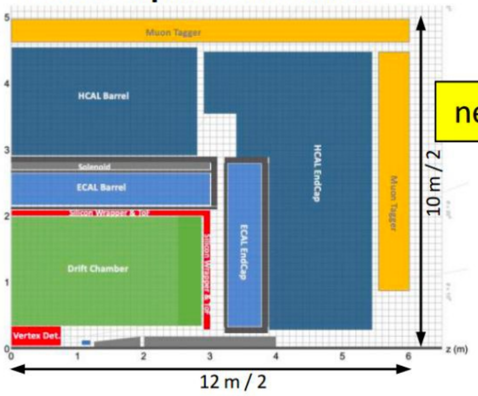
IDEA



- A bit less established design
  - But still ~15y history
- Si vtx detector; ultra light drift chamber w powerful PID; compact, light coil;
- Monolithic dual readout calorimeter;
  - Possibly augmented by crystal ECAL
- Muon system
- Very active community
  - Prototype designs, test beam campaigns, …

Noble Liquid ECAL based

new

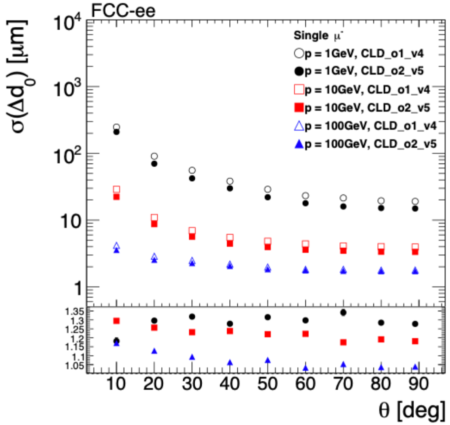


- A design in its infancy
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

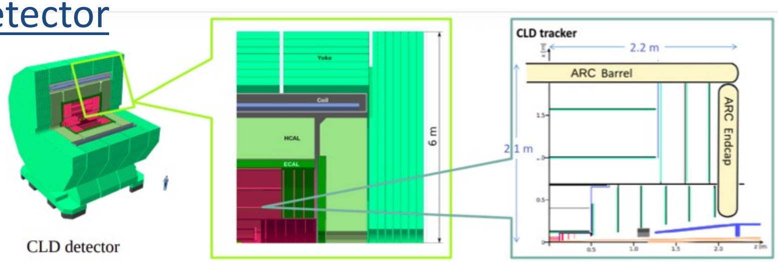
FCC-ee CDR: https://link.springer.com/article/10.1140/epjst/e2019-900045-4

FCCee activities @ IPHC : Tracking performance with CLD*

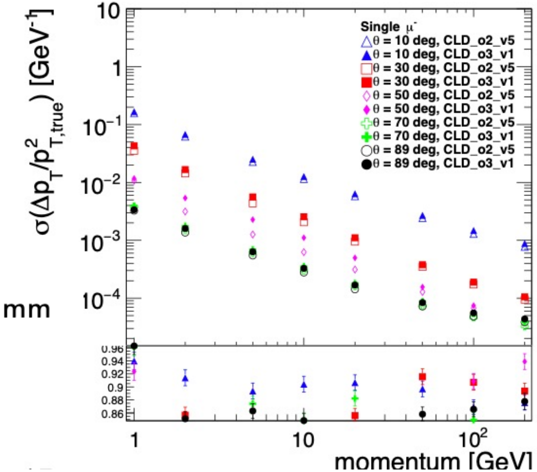
- Effect of smaller radius for vertex detector on d_0 resolution



CLD-Like detector



- Effect of shrunk Outer Tracker for the add of a PID detector on p_T resolution

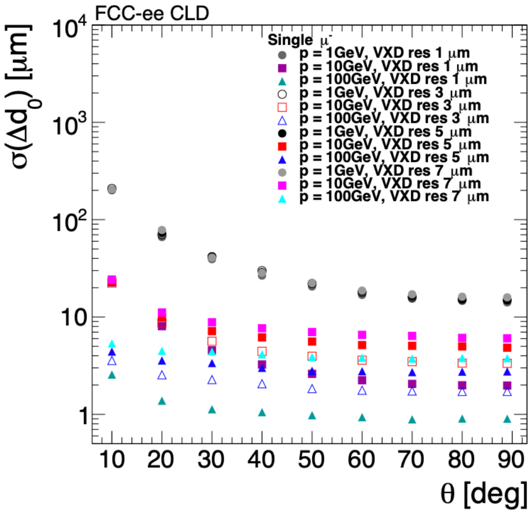


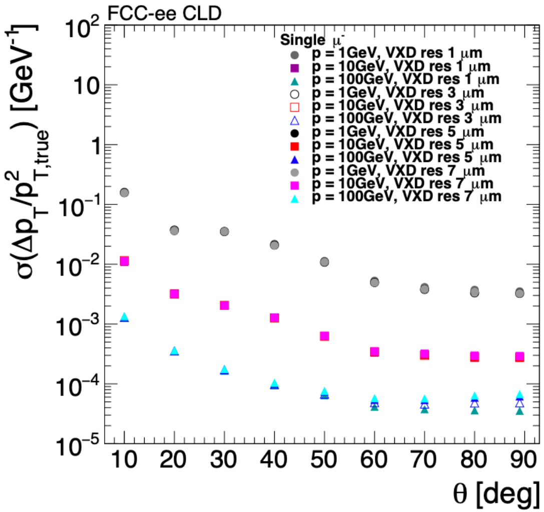
CLD_01_v04: BeamPipe material 100 % Be, BeamPipe radius = 15 mm
CLD_02_v05: BeamPipe material AlBeMet + paraffin, BeamPipe radius = 10 mm
CLD_03_v01: CLD_02_v05 with shrunk Outer Tracker + PID detector

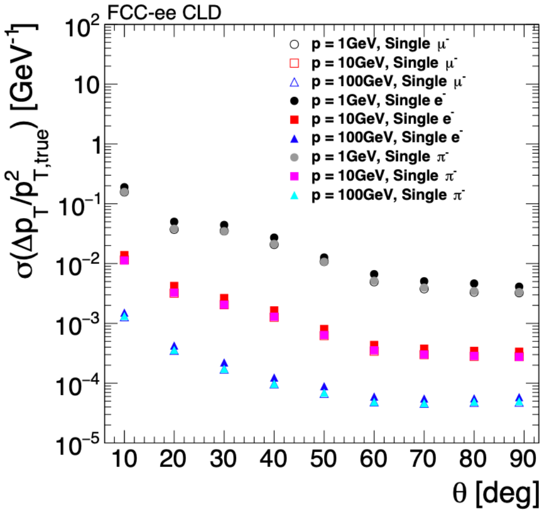
*G. SADOWSKI PhD

FCCee activities @ IPHC : Tracking performance with CLD*

- Effect of vertex spatial resolution on d_0 and p_T resolution
- p_T resolution for single μ^-, π^- and e^-

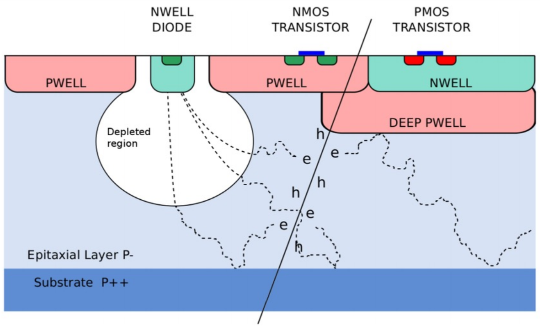






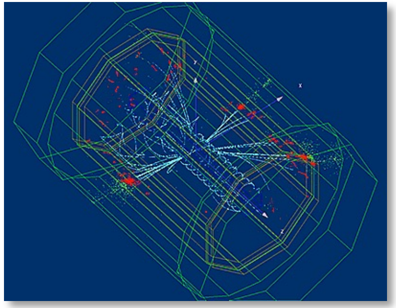
*G. SADOWSKI PhD

CLD 02 v05: VXD spatial resolution = 3 **μ**m

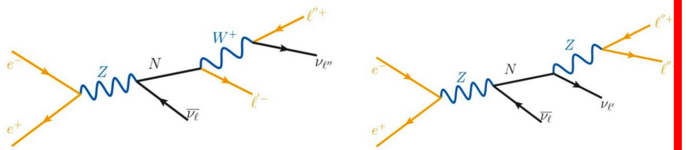


Instrumentation :

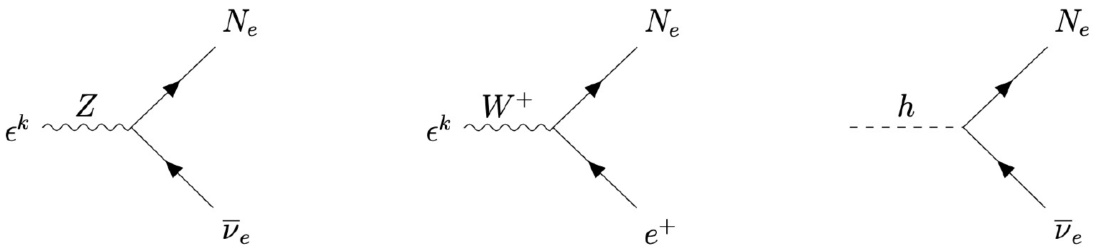
- CMOS R&D (lightweight, highly granular)
- Mechanics and integration



Simulation



Phenomenology



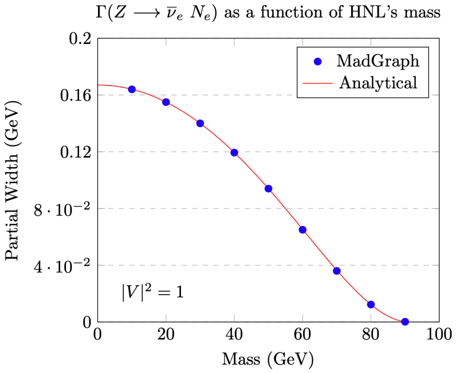
$$\Gamma(Z \longrightarrow N_e\,\overline{\nu}_e) = \frac{g_Z^2\,|V|^2\,m_Z}{192\,\pi}\left(\left(1-\frac{m_N^2}{m_Z^2}\right)^2+\left(1-\frac{m_N^2}{m_Z^2}\right)\left(1-\frac{m_N^4}{m_Z^4}\right)\right)$$

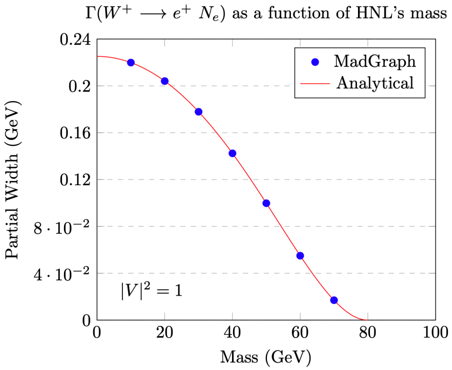
$$\Gamma(W^+ \longrightarrow N_e\,e^+) = \frac{g_W^2\,|V|^2 m_W}{92\,\pi}\left(\left(1-\frac{m_N^2}{m_W^2}\right)^2+\left(1-\frac{m_N^2}{m_W^2}\right)\left(1-\frac{m_N^4}{m_W^4}\right)\right)$$

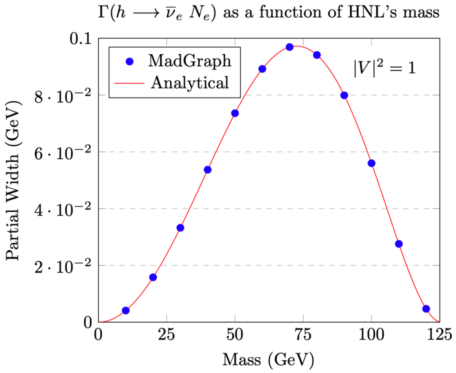
$$\Gamma(h \longrightarrow N_e\,\overline{\nu}_e) = \frac{g_W^2\,|V|^2}{64\,\pi\,m_W^2}\,m_N^2 m_h\left(1-\frac{m_N^2}{m_h^2}\right)^2$$

*S. Rejai Internship in collaboration with CMS (E. Conte)

FCCee activities @ IPHC: Mastering the workflow of the feasibility study



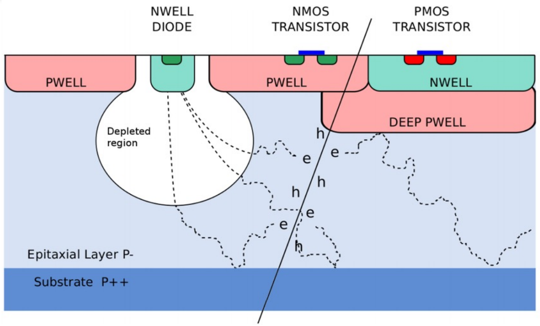




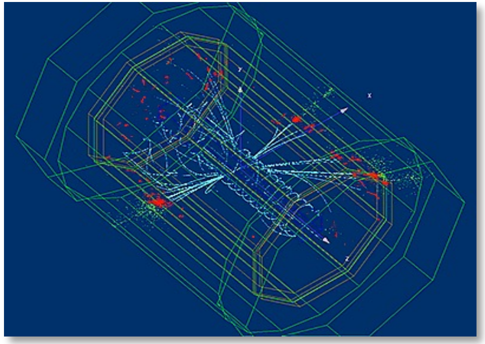
- Phenomenology*
- Delphes simulation
- FullSimulation: dd4hep
- Reconstruction: key4hep, Gaudi
- FCCAnalysis

*S. Rejai Internship in collaboration with CMS (E. Conte)

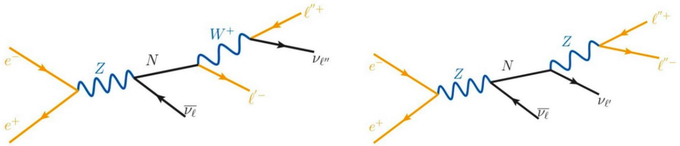
Our activities



Instrumentation



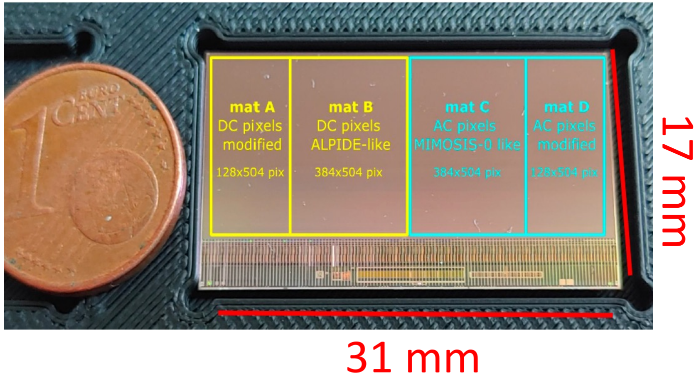
Simulation

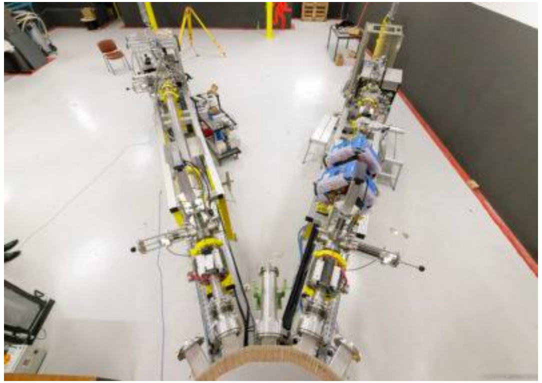


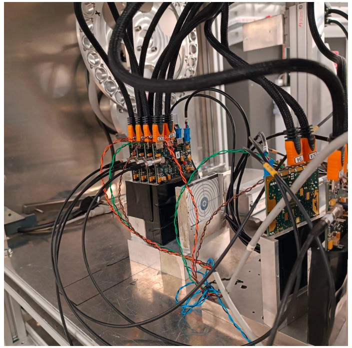
Phenomenology

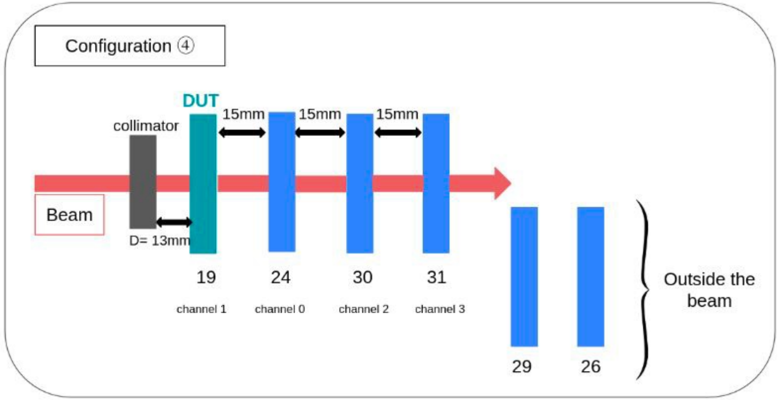
And more…

BEAM MONITORING & PROFILING FOR RADIOBIOLOGY



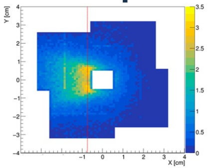


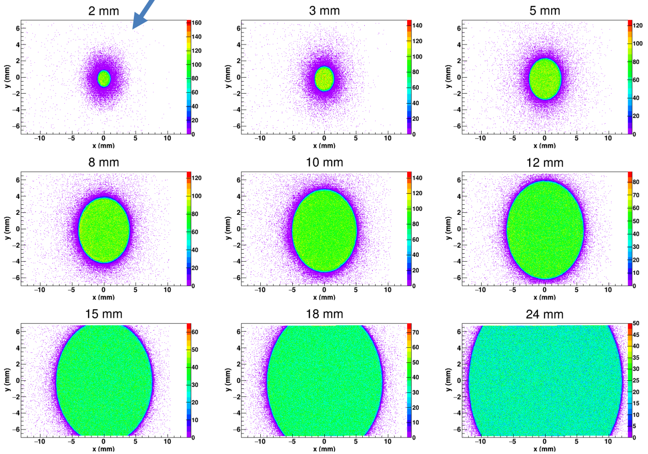




MIMOSIS @ CYRCÉ : BEAM MONITORING

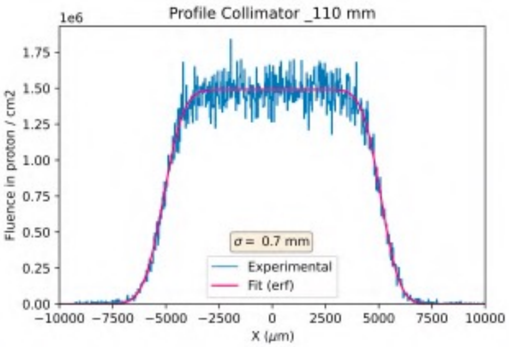
Localized irradiation
for radiation tolerance studies
In case of heterogeneous exposure



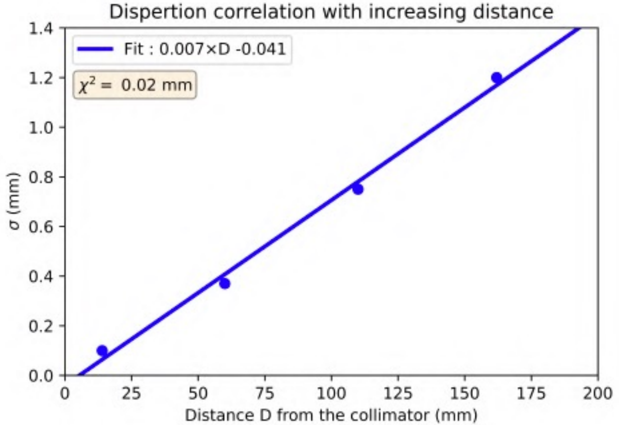


Coll. dia. (mm)	I (fA) Cyrce	I (fA) MIMOSIS	Difference
2	2.9	3.0	4.6%
3	6.5	6.4	2.4%
5	17.7	18.7	4.9%
8	44.9	47.8	6.2%
10	70.6	71.5	1.1%
12	100.6	107.4	6.6%
15	57.1	59.8	4.6%
16	67.7	72.0	6.3%
18	80.5	85.1	5.6%
24	142.9	151.9	6.4%

Dispersion estimation and homogeneity

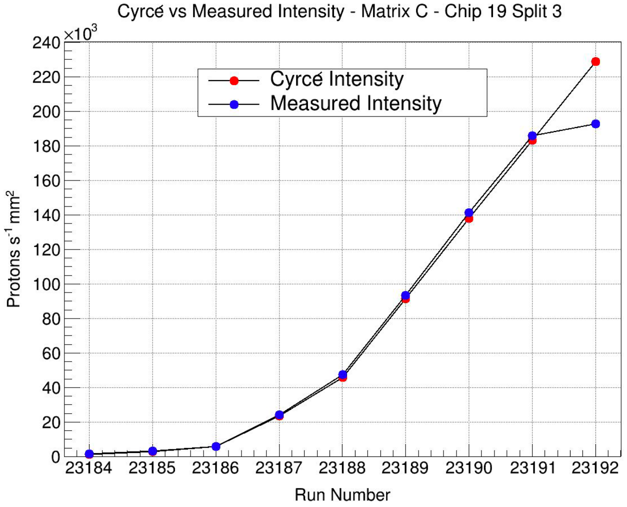


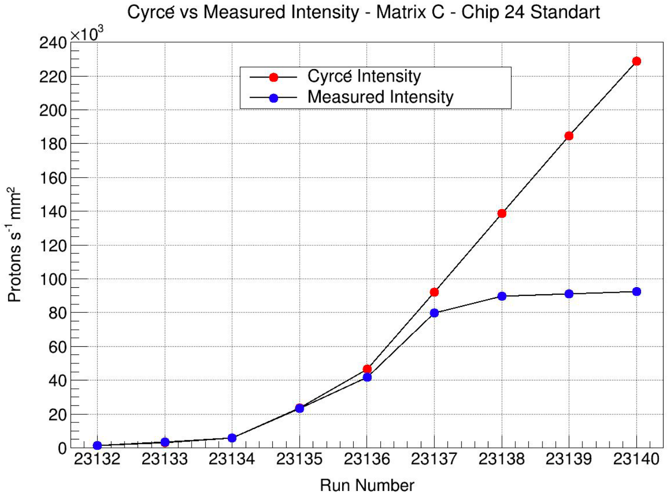
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^x e^{-\left(\frac{1}{2}\frac{x'-\mu}{\sigma}\right)^2} dx'$$



Distance (mm)	14	60	110	164
σ (mm)	0,10	0,37	0,75	1,20
µ1 (mm)	-5,05	-5,10	-5,10	-5,10
µ2 (mm)	5,02	5,00	5,10	5,00
Reconstructed diameter (mm)	10,07	10,10	10,20	10,10
Uncertainty on diameter (mm)	0,11	0,17	0,22	0,28

MIMOSIS @ CYRCÉ : READOUT CAPABILITY

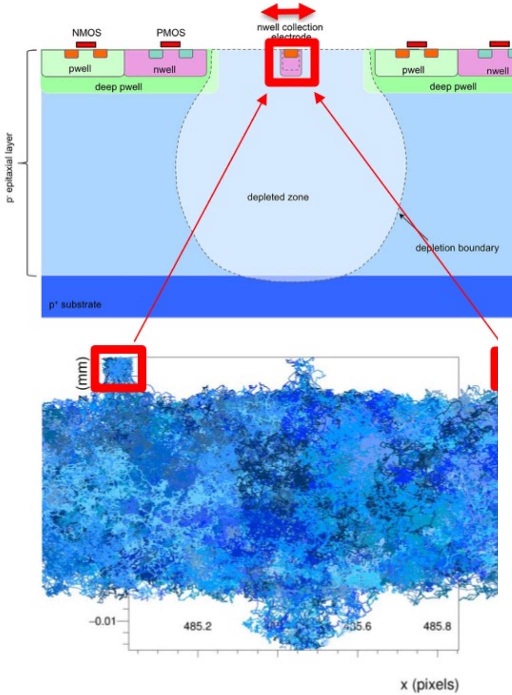


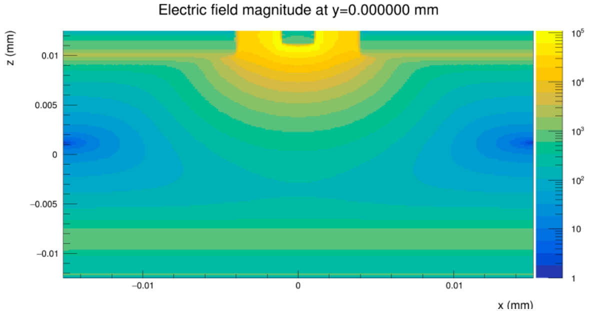


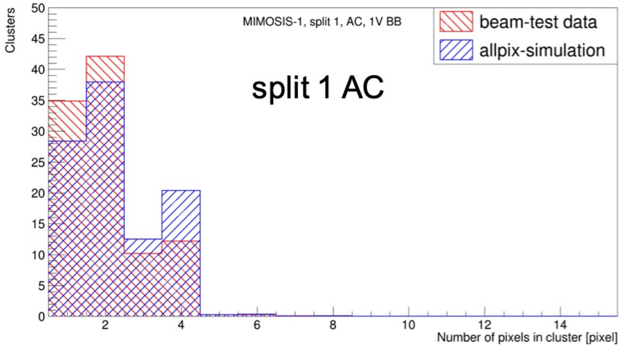
- Saturation level depends on the cluster multiplicity as expected.
- Max bandwidth at around 18 MHz/cm^2 – Average 15, max 70 MHz/cm^2
- Reminder : there is two outputs on used chips, not 8 → 18 MHz/cm^2 x 4 = 72 MHz/cm^2

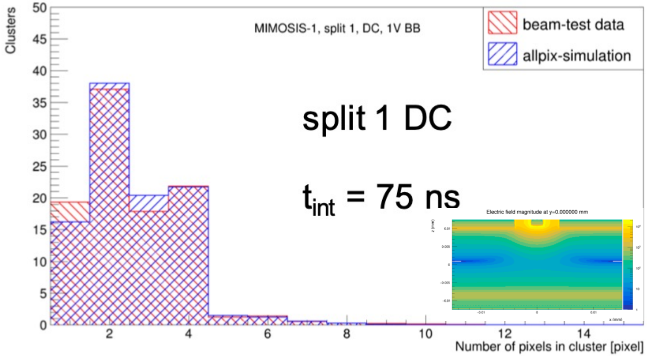
[Hasan Darwish, DPG 2024]

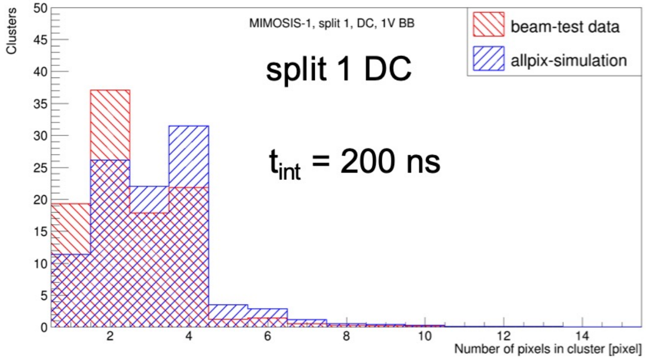
2x2x2 um collection electrode











Thanks for your attention