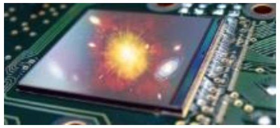
PICSEL



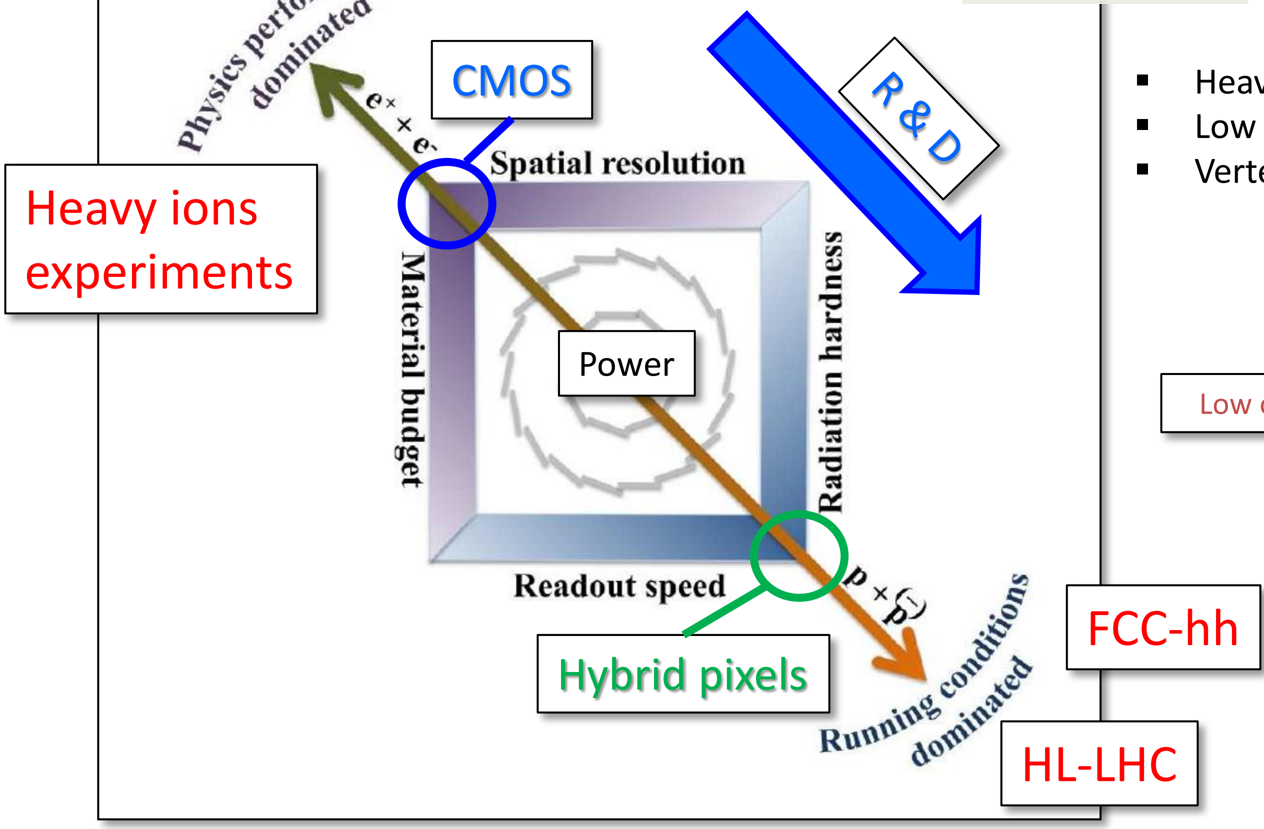
Plateforme C4PI

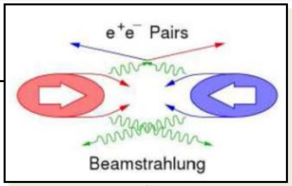
CMOS pixel sensors (CPS) & FCC(ee)

Auguste Besson

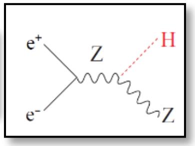
On behalf of the PICSEL group & C4PI Platform @IPHC

Vertex detector technology figure of merit





e⁺e⁻ requirements



- Heavy flavor tagging (b, c, τ)
- Low momentum tracking (pT ~ 100 MeV/c)
- Vertex/Jet charge determination

Spatial resolution
σ_{sp} ~3 μm (pitch ~ 17 μm)

Low occupancy

Material Budget
~ 0.15% X_0 / layer

Impact parameter

$$\sigma_b < 5 \oplus \frac{10}{p\beta \sin^{\frac{3}{2}}\theta}\ \mu m$$

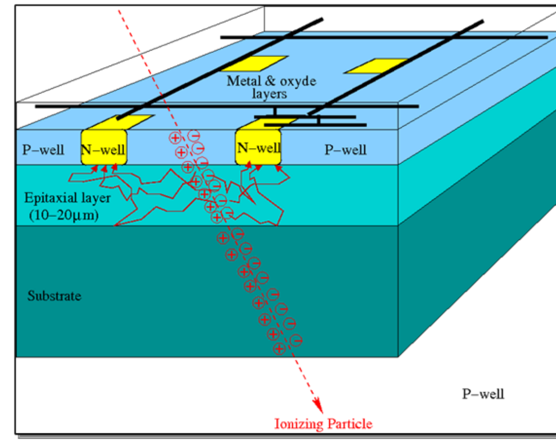
Time resolution
O(1-4 μs)

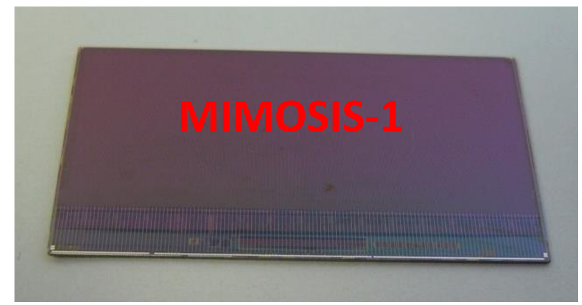
Challenge:

⇨Keep excellent spatial resolution, low material budget, moderate Power consumption and push towards better time resolution

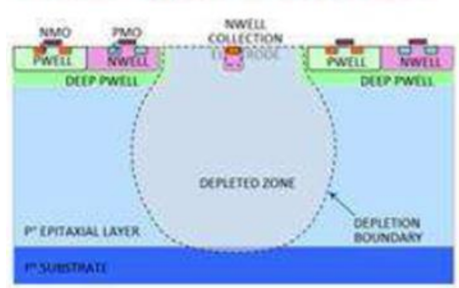
CMOS pixel sensor (CPS) for charged particle detection

- Main features
  - ✓ **Monolithic** (Signal created in low doped thin epitaxial layer ~10-30 µm)
  - ✓ Thermal diffusion of e- (Limited depleted region) + drift
  - ✓ Charge collection: N-Well diodes (Charge sharing)
  - ✓ Continuous charge collection (No dead time)
- Main advantages
  - ✓ **Granularity**
  - ✓ **Material budget**
  - ✓ Signal processing integrated in the sensor
    - Low signal & **Low Noise**
  - ✓ Flexible running conditions (Temperature, Power, Rad. Tol.)
  - ✓ **Industrial** mass production
    - Advantages on costs, yields, fast evolution of the technology,
    - Possible frequent submissions
- Main limitations
  - ✓ Industry addresses applications far from HEP experiments concerns
  - ✓ **Needs adapted processes**

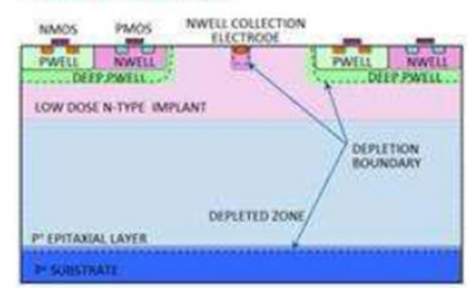




Standard (std): no full depletion



Modified (mod): full depletion, faster charge collection

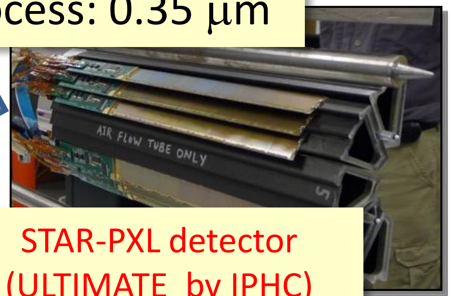


CPS @ IPHC (PICSEL & C4PI): on the road to Higgs factories

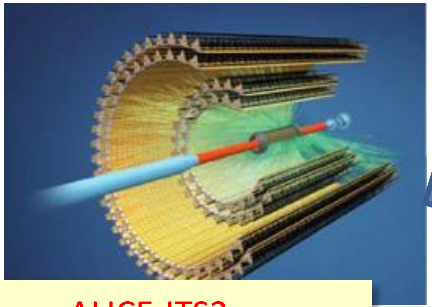
EUDET beam telescope
(Mimosa 26 by IPHC)
~ 15 copies since 2009

O(100 μs)

Process: 0.35 μm



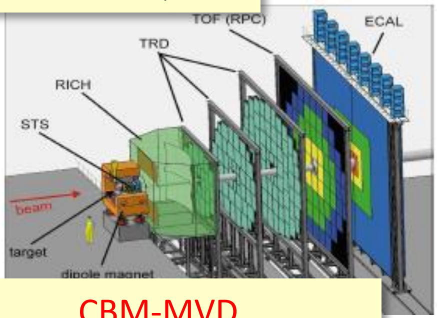
STAR-PXL detector
(ULTIMATE by IPHC)
2014-16



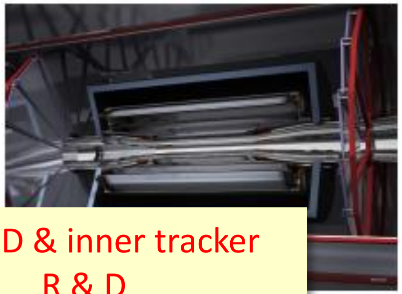
ALICE-ITS2
(ALPIDE by CERN & IPHC)
In construction

O(10 μs)

Process: 0.18 μm



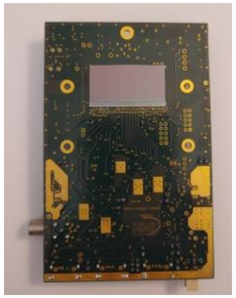
CBM-MVD
(MIMOSIS by IPHC & IKF)
Under development



ILC VXD & inner tracker
R & D

O(1 μs)

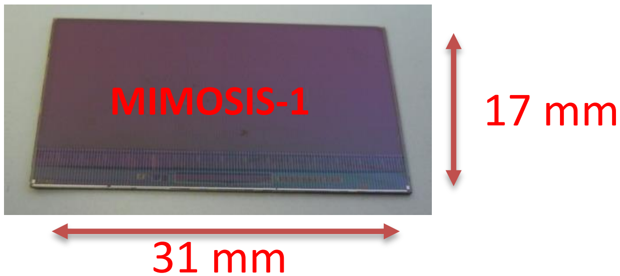
- IPHC: R&D started in ~1999
  - ✓ Take advantage of mid-term projects to get closer to ILC vertex detector requirements
- Today (➪~2023)
  - ✓ CBM-MVD: MIMOSIS chips



- Other activities:
  - ✓ Integration (double sided ladders)
  - ✓ SOI
  - ✓ Double-tier
  - ✓ Faster charge collection time
  - ✓ multiples other applications (X-ray, β imaging, etc.)

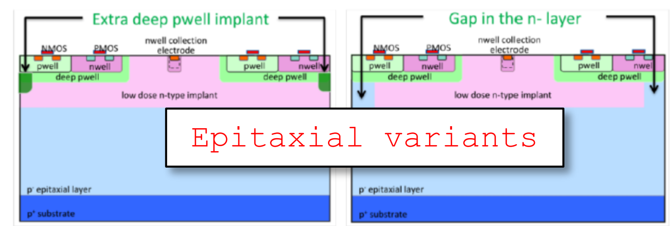
Current development: Mimosis chip for CBM

- **MIMOSIS = a milestone for Higgs factories (5 µm / 5 µs)**
  - ✓ Increased Bandwidth (2Gbit/s output) and radiation hardness w.r.t. ALPIDE

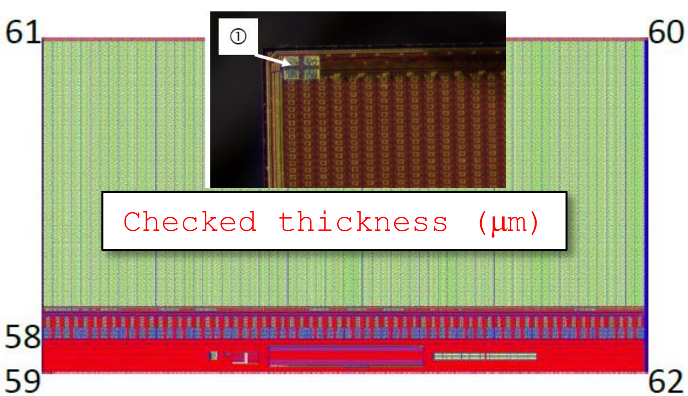


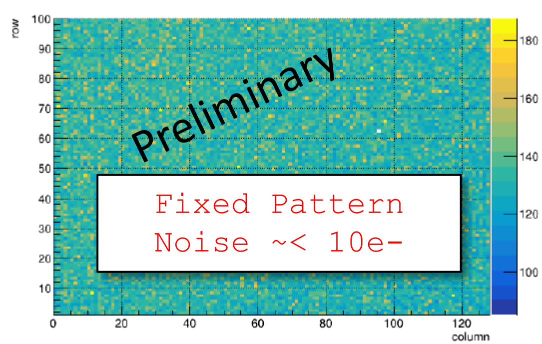
Parameter	Value
Technology	TowerJazz 180 nm
Epi layer	$\sim 25\,\mu m$
Epi layer resistivity	$> 1k\Omega cm$
Sensor thickness	50 µm
Pixel size	$26.88\,\mu m \times 30.24\,\mu m$
Matrix size	1024×504 (516096 pix)
Matrix area	$\approx 4.2\,cm^2$
Matrix readout time	5 µs (global shutter)
Power consumption	40-70 mW/cm^2

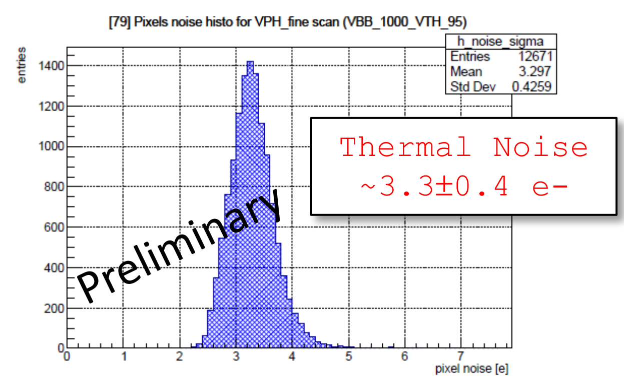
- MIMOSIS-1: 1st full size prototype
  - ✓ Fabricated in 2020 (18 wafers)
  - ✓ 6 epitaxial variants have been produced to study charge collection
    - Thinned down to 60 µm, radiation tests
  - ✓ Functionnal, lab tests ongoing
  - ✓ Test beam foreseen in 2021



Carlos, TREDI 2019, Results of the Malta CMOS pixel detector prototype for the ATLAS Pixel ITK

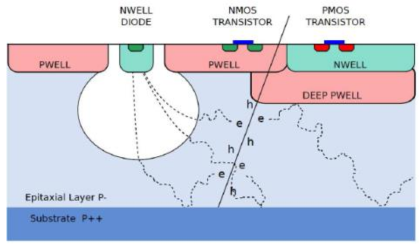






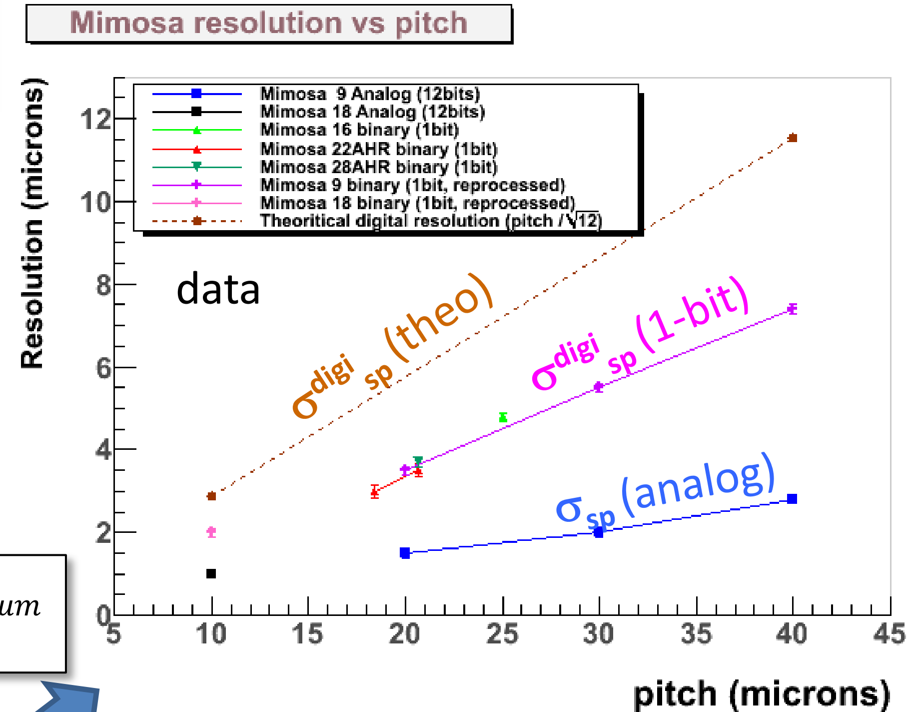
Sensitivity to spatial resolution

- Epitaxial layer
  - ✓ Pitch
  - ✓ Thickness
    - >~ 20 um
  - ✓ Depletion
  - ✓ Doping profile
  - ✓ Collecting diode & preamp.
  - ✓ N bits to encode the charge (ADC?)



- Larger depletion means:
  - ✓ ↑ Q_{signal} & SNR
  - ✓ ↑ Radiation tolerance
  - ✓ ↑ Charge collection speed
  - ✓ ↓ Cluster size & spatial resolution

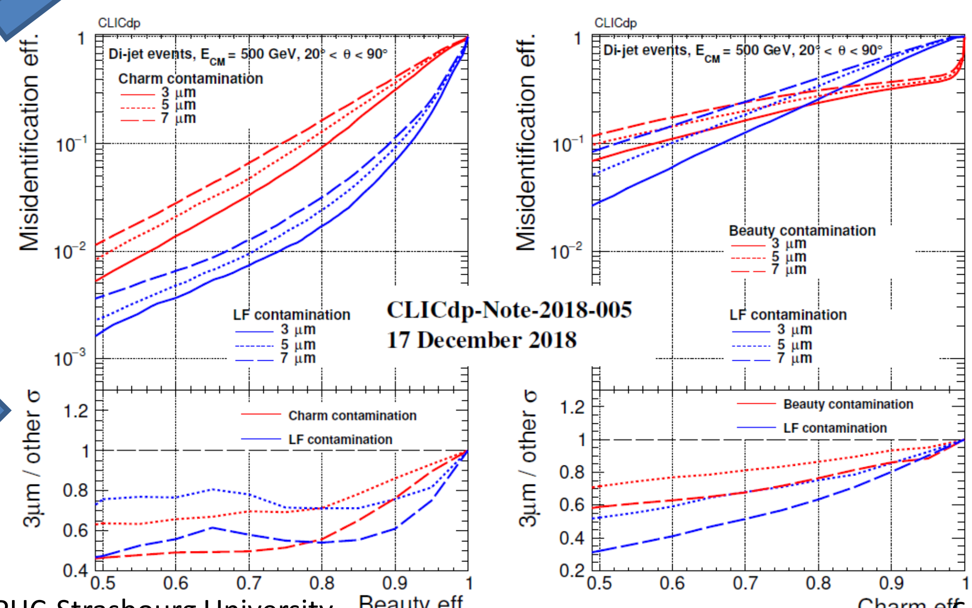
$$\sigma_b < 5 \oplus \frac{10}{p\beta \sin^{\frac{3}{2}}\theta}\ \mu m$$



⇨ σ_{sp} ~ 3 µm ⇦⇨ pitch ~ 17 µm

(assuming binary output, ~20 µm epi.thickness & partial depletion in 180nm tech.)

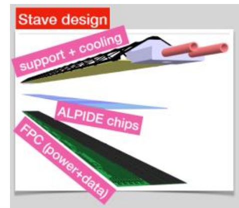
Sensitivity to b/c-tagging performances needs to be quantified in the Fcc(ee) context

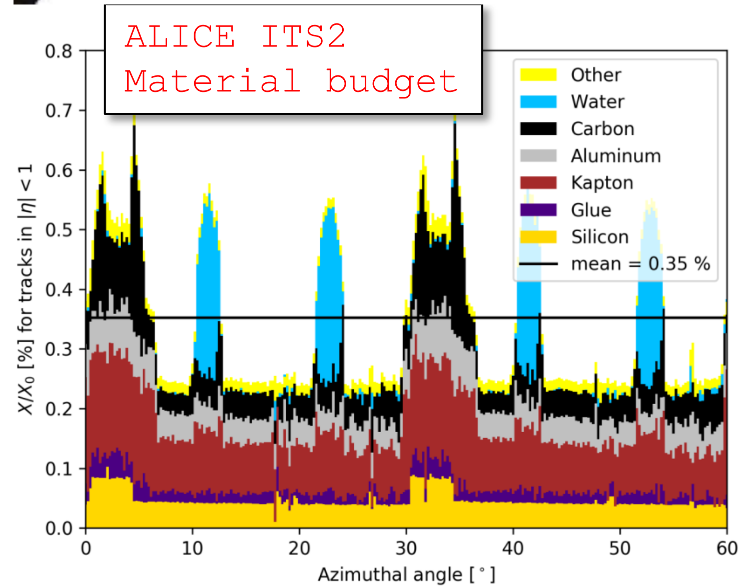


CLICdp-Note-2018-005
17 December 2018

Material budget

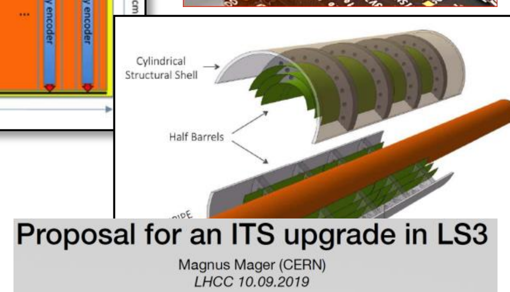
- PLUME (Bristol/DESY/IPHC) **double sided : ~<0.2%X_0/layer**
  - ✓ 0.35% X_0 reached ⇨ **~0.15% X_0/lyr doable** (with air flow cooling)
  - ✓ Combining each side for improved resolution
- ALICE ITS-2
  - ✓ Water cooling ⇨ **~0.35% X_0/lyr**





⇨ **Contribution of sensors to total material budget ~ 20-30%** (Majority from cables + cooling + support)

- Thinned silicon is flexible
  - ✓ Self supported and bent circuits + detectors !
- Industry provides stitching
  - ✓ Multi-reticle size ladders
    - ~15 cm in 180 nm, ~30 cm in 65 nm
    - Chip-to-chip interconnection
  - ✓ Very low material budget
    - **~0.05-0.10 % X_0/layer ?**
  - ✓ Allows large surfaces O(100m²)

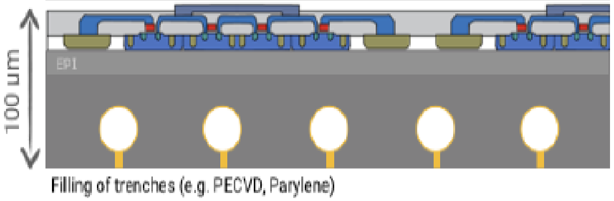


⇨ **Stitching: strong interest for ALICE upgrades and Higgs factories**

Integration & CMOS sensors

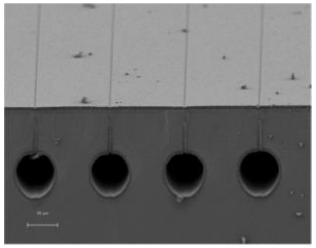
- Stewardship is not a detail…
  - ✓ Cooling, data transmission, mechanics, alignement, connectors, services, monitoring, wireless, etc.
- Generic development vs FCCee specific
  - ✓ Numerous expertises in France (e.g. LHC groups)
  - ✓ All possible synergies should be exploited

⇨ Room for ambitious R&D and potential breakthrough



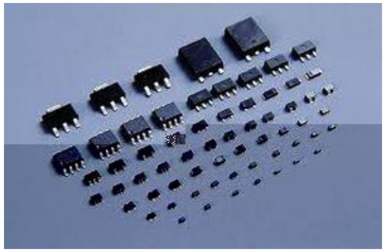
- An example of possible synergy:
  - ✓ R&D on **μ-channel cooling**
    - Relax Power consumption constraints ?
    - Allows to focus on high power dissipating regions
  - ✓ Challenges
    - Integration in the substrate
    - Connectors
    - Silicon thickness ~< O(100 μm), diameter, etc.
  - ✓ **Discussion IPHC-LAPP started** (Dec.2020)
    - plans: Simulations and first tests with dummy silicon
  - ✓ Interest for other communities (e.g. heavy ions)

cf. M.Vos, FCC workshop Nov. 2020



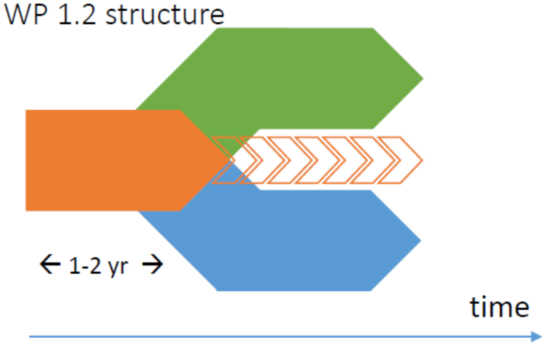
TJ-65 nm process: smaller feature size

- 65 nm feature size technology
  - ✓ (ALPIDE & MIMOSIS fabricated in 180 nm)
  - ✓ Larger wafers (⇨ 30 cm)
  - ✓ More functionalities inside the pixel
  - ✓ Keeps pixel dimensions small
  - ✓ Potentially faster read-out
  - ✓ Lower Power consumption



- **TJ-65 nm now available** (since June 2020)
  - ✓ Main driver: CERN EP R&D WP 1.2 & ALICE ITS-3 upgrades (involves other labs) ⇨ LS3 ~ 2024-26
  - ✓ Different requirements
    - EP: time resolution and radiation tol.
    - ALICE: granularity and material budget
    - Common R&D during the 1st years.

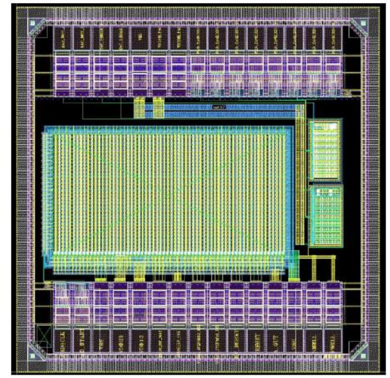
⇨ Synergy with Higgs factories requirements



⇨ Relation with foundries and access to options is a key factor

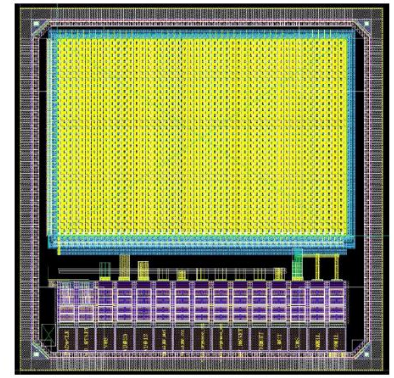
65 nm process status

- IPHC-Strasbourg:
  - ✓ Goal: **validate the process for charged particle detection**
    - **Caveat:** sensitive volume not yet optimised
  - ✓ Test structures (DACs, amplifiers, etc.)
  - ✓ Technology exploration with single rolling shutter / analog output prototype
    - pitch, N-well variants, amps, etc.
    - Testable in beam
  - ✓ Part of Cremlin+ program (1 post-doc)
  - ✓ **First submission December 1st 2020** (MLR) !
    - Expects back from foundry ~ mid-2021



Variants A/B/C

64 × 32
15 µm pitch



Variant D

48 × 32
25 µm pitch

CREMLIN PLUS
Connecting Russian and European Measures for Large-scale Research Infrastructures

- 65 nm process @IN2P3: **Expression of interest (IN2P3-GT08)**
  - ✓ IPHC – CPPM – IP2I
    - Participate to the technology validation
    - Higgs factories and beyond
  - ✓ Possible NDA issue (1 per lab)
    - Discussions ongoing
  - ✓ New partners welcome
- See also next talk (DICE, M.Barbero)

Expression of Interest to shape a consortium to develop a next generation of Monolithic CMOS Pixel Sensors in a 65 nm foundry process

J. Andrea[(1)], M. Barbero[(2)], J. Baudot[(1)], A. Besson[(1)], G. Boudoul[(3)], L. Caponetto[(3)], D. Contardo [(3)], S. Gascon-Shotkin[(3)], C. Hu-Guo[(1)], P. Pangaud[(2)], S. Muanza [(2)]
Submitted to IN2P3 prospective GT08: "Détecteurs et Instrumentation associée"
July 2020

This expression of interest summarizes an initial discussion among the authors in the framework of the ongoing IN2P3 prospective exercise and triggered by the set-up of the Future Circular Collider Master Project (FCC-physique MP). This document also follows the recognition by the European Particle Physics Strategy of an electron-positron Higgs factory as a high-priority future collider. It draws the outline of a possible collaboration among three laboratories to enhance their development potential for Monolithic CMOS Pixel Sensor (MCPS^2) in a new technology that could serve several applications.

Bandwidth and occupancy @FCCee

- Triggerless hypothesis
- Occupancies @TeraZ:
  - ✓ Expected to be ~ 10^{-3}
  - ✓ Assuming
    - Cluster multiplicity ×5
    - Safety factor ×3
    - Time resolution ~1 µs
      - (Integrate over 50BX)
    - Pitch~17 µm ⇨350000 pixels/cm²
    - 16 bits/pixel to encode data
      - (conservative)
  - ✓ Expected data flux
    - **~ 5 Gbits/cm²/sec**
    - ~ 1 Tbits for first layer/sec
    - (Worse @ R=1cm !)
  - ✓ Filtering data ?

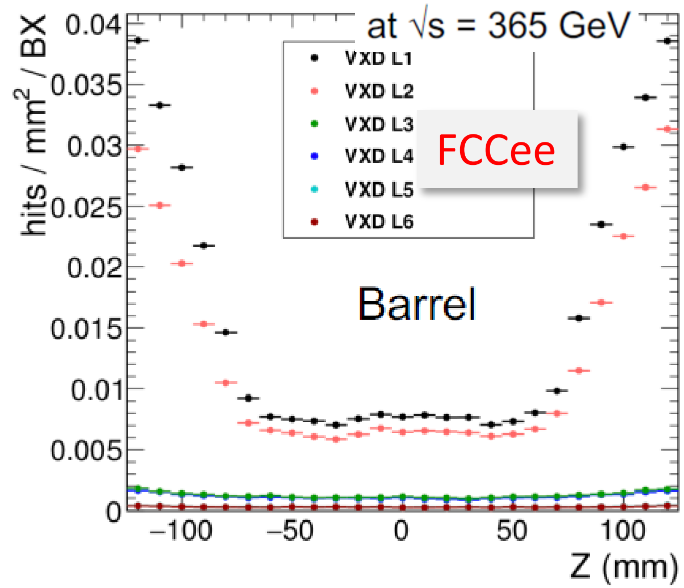
Yorgos Voutsinas, inputs from N. Alipour Tehrani, N. Bacchetta, K. Elsener, P. Janot, A. Kolano, E. Leogrande, E. Perez, O. Viazlo

CLD max. occ. / subdetector, IPC & SR		
$\sqrt{s}$ [GeV]	91.2	365
VXDB	$\sim 10^{-5}$	$\sim 4 \times 10^{-4}$
VXDE	$\sim 4.7 \times 10^{-6}$	$\sim 4 \times 10^{-4}$
TE	$\sim 1.8 \times 10^{-5}$	$\sim 3 \times 10^{-4}$

The presented occupancy / BX is rather low for VXD and Si tracker

However bunch spacing at the Z peak is 20ns

- Might be that we have to integrate over several Bxs
- Still with a time resolution of $1\mu s \rightarrow$ occupancy stays $\leq 6 \times 10^{-4}$



Summary: Synergies in CMOS R&D

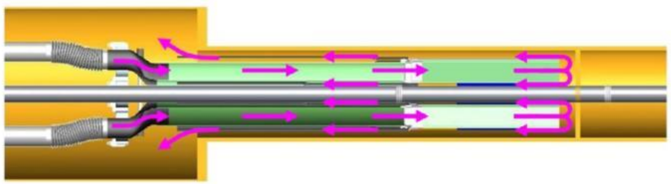
- Integration ⇨ many open issues here !

- The R&D can be considered as generic for all Higgs factories (CLIC excepted)
  - ✓ Common R&D towards faster time resolution while keeping low power, small granularity and low material budget
  - ✓ FCCee requirements more challenging w.r.t. ILC (no power pulsing allowed)
  - ✓ Price to pay might translate into
    - Additional material budget and/or alternative cooling strategy
    - And/or slightly degraded spatial resolution
- Strong dynamic of CMOS pixel Sensors R&D:
  - ✓ **180 nm : MIMOSIS series ⇨ full size prototype being tested**
  - ✓ **65 nm technology exploration**
    - First submission dec.2020 (driven by CERN and involved IPHC & CPPM)
    - IN2P3 network to reach a critical size ⇨ Expression of Interest (IPHC/CPPM/IP2I)
  - ✓ **Stitching** & large surfaces for very low mass detectors ⇨ Priority for Higgs factories in the future
  - ✓ **Synergies** with
    - CERN R&D (ALICE and EP)
    - R&D programs (e.g. AIDAInnova, CREMLIN+, etc.)
    - Heavy ion experiments (e.g. ALICE beyond LS3/4 proposal)
    - Other experiments: Belle-II, EIC, etc.

Back up

FCCee: Power discussion

- No power pulsing has significant consequences
- How much power can we extract with air flow cooling ?
  - ✓ Probably ~20-25 mW/cm^2
  - ✓ STAR HFT did ~150 mW/cm^2 @ 10m/s but without disks !



The STAR MAPS-based PiXeL Detector NIM, A 907 (2018) 60-80

- What would be the power in FCCee with the current know how ?
  - ✓ Probably in the range ~ 80-100 mW/cm^2
- Is air flow cooling only possible ?
  - ✓ Yes with compromise or significant Tech. progress
  - ✓ Possible other approaches (micro-channels, etc.)
  - ✓ Don't forget power drops along cables (~50 W ?)
- How to optimize Power ?
  - ✓ Dependence on
    - Time resolution
    - Data flow (# outputs, clock frequency, etc.)
    - Spatial resolution
  - ✓ Outer layers responsible for the majority of power dissipation
    - Allow slightly degraded performances in the outer layers ?

4th FCC physics and experiment workshop

Vertex detector

- VXD has to be precise, thin, low power (no pulsing), readout electronics should integrate over less than O(1 μs) (backgrounds)
- Current requirements on impact parameter resolution inherited from former Higgs studies :

$$\sigma_{d_0} = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

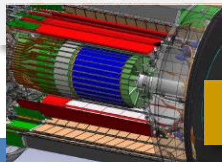
$$a \simeq 5\,\mu\mathrm{m}; \quad b \simeq 15\,\mu\mathrm{m\,GeV}$$

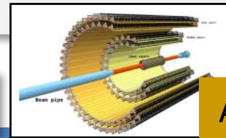
- Will be revisited in the FCC-ee context: precise Hcc, Hbb, Hgg determination
- Requirements from B-physics on the reconstruction of primary, secondary and tertiary vertices
  - E.g. with σ(PV) = 3 μm, σ(SV – TV) = 5 -7 μm, a large signal of $B \to K^* \tau\,\tau$ can be seen, likely unique to FCC
- Requirements from EW Heavy Flavor observables R_b, R_c, $A_{FB}^{b,c}$
- Requirements from lifetime measurements
  - E.g. potential to measure tau lifetime to sub-10^{-5} (i.e. GT from τ ! Universality test)
  - Requirements on (offline) alignment to be determined

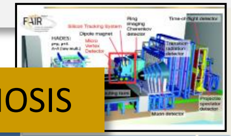
CMOS technology for Higgs factories: FCC(ee)

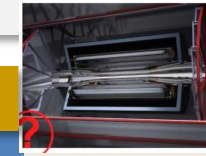
- FCCee requirements (w.r.t. ILC)
  - ✓ Beam background (drives occupancy)
    - Same order of magnitude (possibly a bit lower @ FCCee)
  - ✓ Same detector performances required (time & spatial resolution, material budget)
  - ✓ Beam structure ⇨ « continuous » data taking
    - no Power pulsing
  - ✓ Magnetic field (~ 2 T) ⇨ less bended tracks
  - ✓ Z peak : ⇨ lower radius doable
- Overall:
  - ✓ Performances requirements comparable though more challenging @FCCee in terms of Power dissipation
- The R&D can be considered as generic for all Higgs factories (CLIC excepted)

Evolving CPS





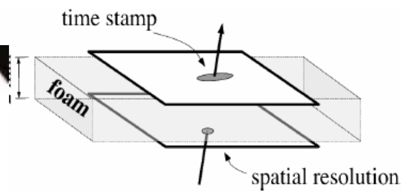


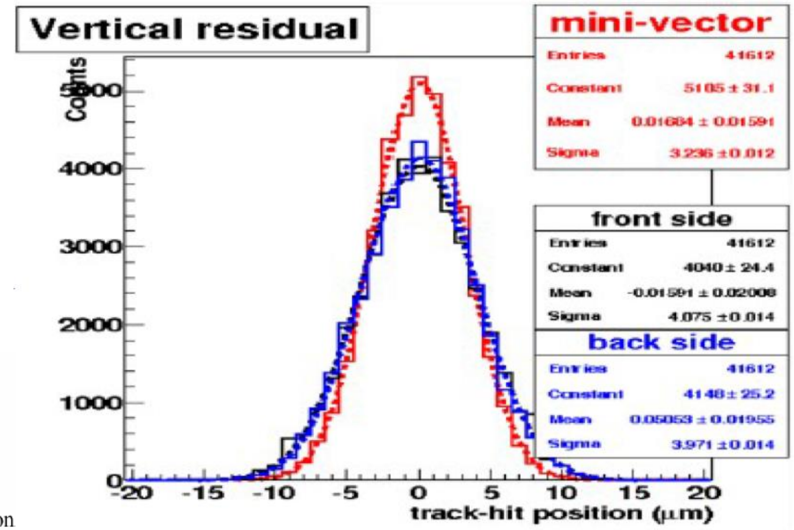


	ULTIMATE STAR-PXL	ALPIDE ALICE-ITS	MIMOSIS CBM-MVD	PSIRA proposal ILD-VXD
Data taking	2014-2016	>2021-2022	>2021	>2030
Technology	AMS-opto 0.35 μm	0.18 μm	0.18 μm	0.18 μm (conservative) < 0.18 μm ?
	4M	HR, V_{bias} ~-6V Deep P-well	HR, Deep P-well	?
Architecture	Rolling shutter + sparsification + binary output	Data driven r.o. In pixel discri.	Data driven r.o. In pixel discri.	Data driven r.o. (conservative)
Pitch (μm^2) / Sp. Res.	20.7 x 20.7 / 3.7	27 x 29 / 5	27 x 30 / <5	~ 22 / ~ 4 OR ~ 17/3
Time resolution (μs)	~185	5-10	5	1 – 4
Data Flow		~10^6 part/cm²/s Peak data rate ~ 0.9 Gbits/s	peak hit rate @ 7 x 10^5 /mm²/s >2 Gbits/s output (20 inside chip)	~375 Gbits/s (instantaneous) ~1166Mbits / s (average)
Radiation	O(50 kRad)/year	2x10^{12} n_{eq}/cm² 300 kRad	3x10^{13} n_{eq}/cm²/yr & 3 MRad/yr	O(100 kRad)/year & O(1x10^{11} n_{eq}(1MeV)) /yr
Power (mW/cm²)	< 150 mW/cm²	< 40 mW/cm²	< 200 mW/cm²	~ 50-100 mW/cm² + Power Pulsing
Surface	2 layers, 400 sensors, 360x10^6 pixels 0.15 m²	7 layers, 25x10^3 sensors > 10 m²	4 stations Fixed target	3 double layers 10^3 sensors (4cm²) 10^9 pixels ~0.33 m²
Mat. Budget	~ 0.39 % X_0 (1st layer)	~ 0.3% X_0 / layer		~ 0.15-0.2 % X_0 / layer
Remarks	1st CPS in colliding exp.	(with CERN)	Vacuum operation Elastic buffer	Evolving requirements

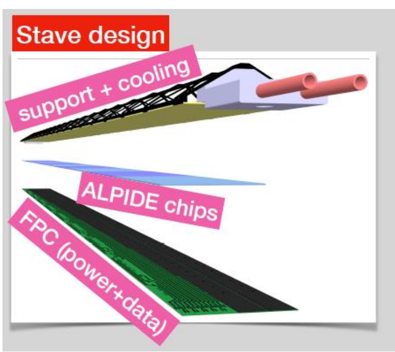
Material budget

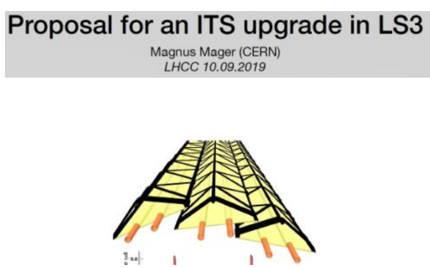
- PLUME (Bristol, DESY, IPHC)
  - ✓ Double sided ladders with minimized material budget
  - ✓ 0.35% X_0 reached ⇨ ~0.3 X_0 doable (with air flow cooling)
  - ✓ Combining each side for improved resolution



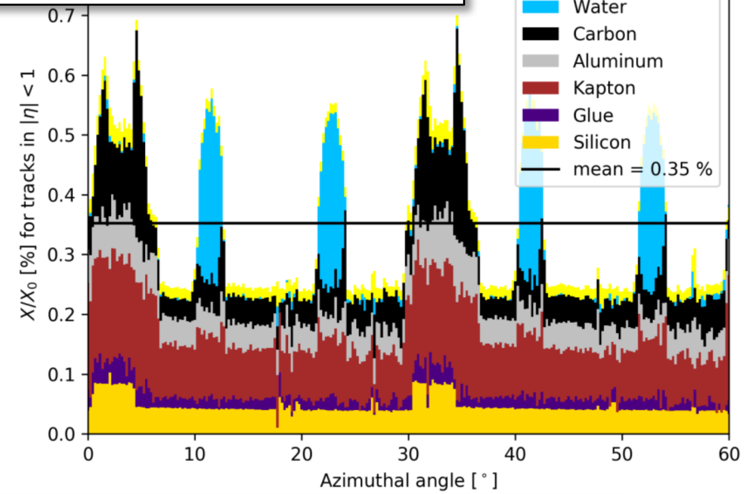


- ALICE ITS-2
  - ✓ Water cooling ⇨ ~0.35% X_0





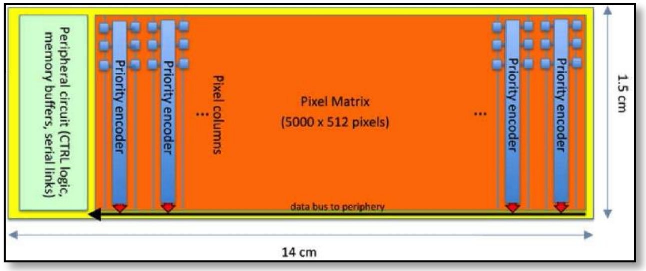
ALICE ITS2 Material budget



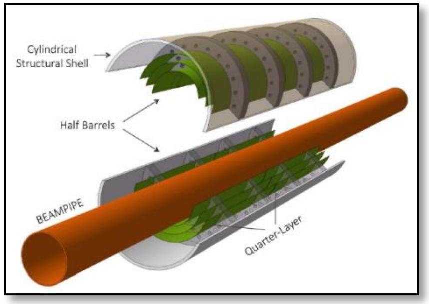
⇨ Contribution of sensors to total material budget ~ 20-30% (Majority from cables + cooling + support)

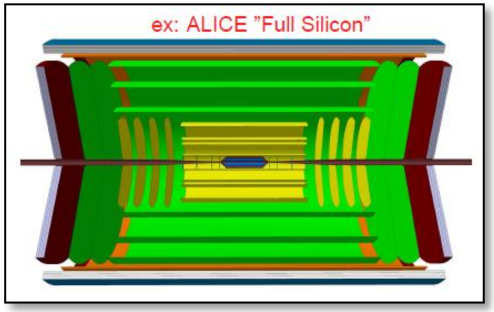
A possible answer: stitching

- Silicon is flexible
  - ✓ Self supported and bended circuits + detectors !
- Industry provides stitching
  - ✓ Multi-reticle size ladders
    - ~14 cm in 180 nm, 30 cm in 65 nm
    - Chip-to-chip interconnection
- Added value:
  - ✓ Very low material budget (~0.05-0.10 % X_0)
    - Flex cable ? Cooling ? Support ?
  - ✓ Large area detectors
    - Constant R = No overlaps or acceptance loss
    - Beam pipe as mechanical support
- ALICE R&D program
  - ✓ ALICE ITS upgrade beyond LS3
    - Exploit stitching
  - ✓ Proposal beyond LS4
    - 10 double sided layers
    - 100 m^2
- Challenge & potential issues
  - ✓ Bias voltage drops
  - ✓ Extended signal distance transport

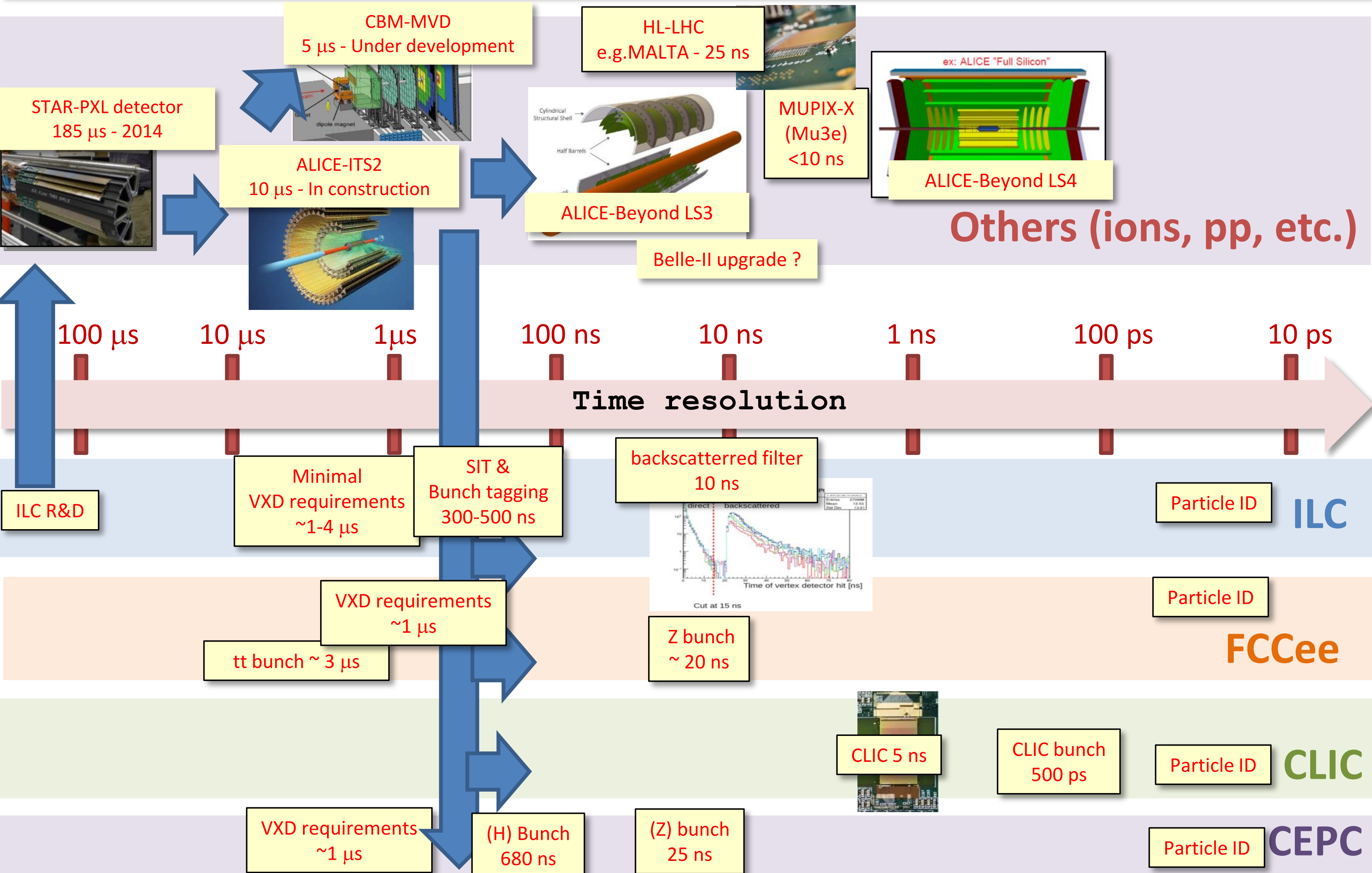


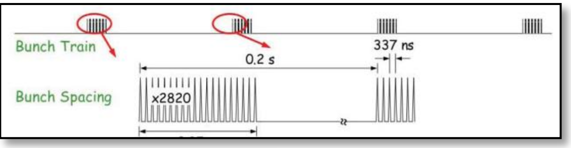
Proposal for an ITS upgrade in LS3
Magnus Mager (CERN)
LHCC 10.09.2019





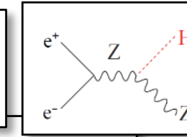
Time resolution in the context of e^+e^- colliders



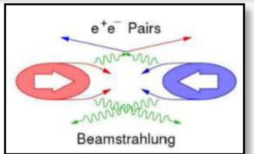


ILC VXD requirements

$$\sigma_b < 5 \oplus \frac{10}{p\beta \sin^{\frac{3}{2}}\theta}\ \mu m$$



Physics
- ⇨ Flavour tagging
- ⇨ Low pT tracks



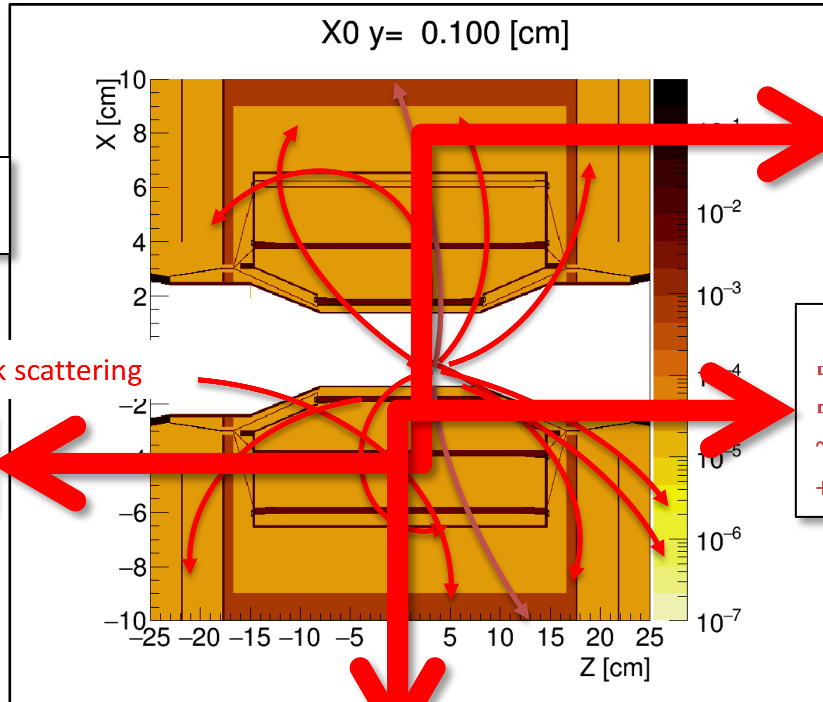
Physics (<Hz/cm^2)

Beam background (~ 5 hits/BX/cm^2 on layer 0)

Beam background

Radiation hardness
O(100kRad/yr) & O(10^{11})n_{eq}/yr

Rad.Tol. devices



Back scattering

Vertex reconstruction
- ⇨ granularity
- ⇨ Pitch ~17 um
- ⇨ (σ_{sp} ~3 um)

Material Budget
- ⇨ ~ 0.15% X_0 / layer
- ⇨ < 1% X_0 for the whole VTX
- ~ 900 µm Si
- + ~0.14% X_0 for the beam pipe

Read-out speed
O(1-10 µs)

Power consumption
~< 50mW/cm^2

Fast read-out & low Power architectures

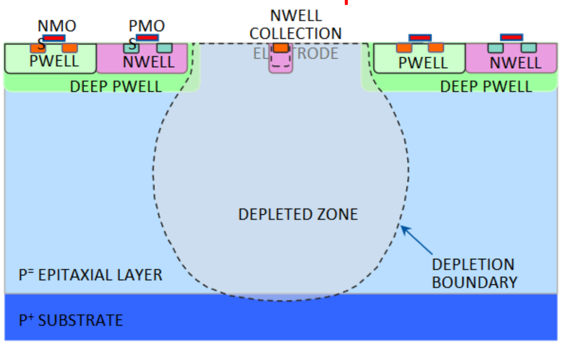
Cooling
Stiffness / Alignment

Low material detectors & supports structures

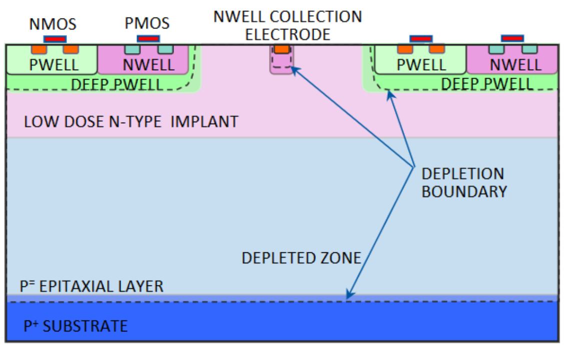
Challenge : meet the requirements all together

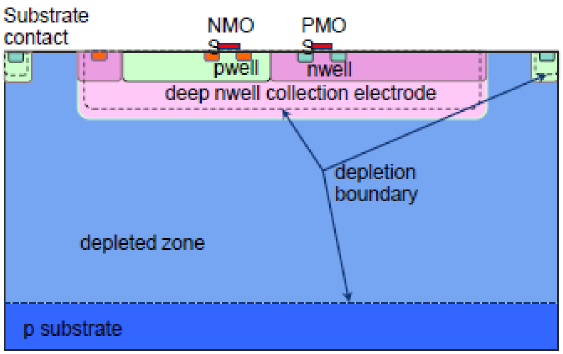
Small electrode ⟵ ⟶ Large electrode

Standard : no full depletion



Modified : full depletion, faster charge collection





- ❑ Partial depletion
  - ✓ Charge sharing ⇨resolution
- ❑ Full depletion
  - ✓ No Charge sharing ⇨ S/N
  - ✓ Charge collection time ⇨ very fast timing
  - ✓ Radiation hardness (not an issue in e^+e^- colliders)
- ❑ Capacitance
  - ✓ Analog power ~ $(C/Q)^2$

⇨ Design should favor spatial resolution and power consumption w.r.t. radiation hardness and charge collection time*

⇨ Small electrodes more adapted for Higgs factories

*Exception: CLIC

e^+e^- collider beam parameters

Linear

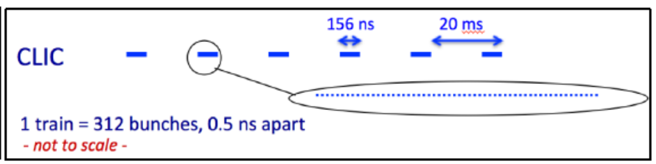
Parameter	ILC 250 GeV	ILC 500 GeV	CLIC 380 GeV	CLIC 1.5 TeV	CLIC 3 TeV
Luminosity L ($10^{34}cm^{-2}sec^{-1}$)	1.35	1.8	1.5	3.7	5.9
L > 99% of √s ($10^{34}cm^{-2}sec^{-1}$)	1.0	1.0	0.9	1.4	2.0
Repetition frequency (Hz)	5	5	50	50	50
Bunch separation (ns)	554	554	0.5	0.5	0.5
Number of bunches per train	1312	1312	352	312	312
Beam size at IP σ_x/σ_y (nm)	515/7.7	474/5.9	150/2.9	~60/1.5	~40/1
Beam size at IP σ_z (μm)	300	300	70	44	44

ILC: Crossing angle 14 mrad, e^- polarization ±80%, e^+ polarization ±30%
CLIC: Crossing angle 20 mrad, e^- polarization ±80%

Very small beams + high energy => beamstrahlung

Very small bunch separation at CLIC drives timing requirements for detector

Very low duty cycle at ILC/CLIC allows for:
Triggerless readout
Power pulsing



Circular

	FCC-ee Z	FCC-ee Higgs	FCC-ee ttbar	CEPC Z (2T)	CEPC Higgs
√s [GeV]	91.2	240	365	91.2	240
Luminosity / IP ($10^{34}cm^{-2}s^{-1}$)	230	8.5	1.7	32	1.5
no. of bunches / beam	16640	393	48	12000	242
Bunch separation (ns)	20	994	3000	25	680
Beam size at IP σ_x/σ_y (μm/nm)	6.4/28	14/36	38/68	6.0/40	20.9/60
Bunch length (SR/BS) (mm) / Beam size at IP σ_z (mm)	3.5/12.1	3.3/5.3	2.0/2.5	8.5	4.4

Beam transverse polarisation
=> beam energy can be measured to very high accuracy (~50 keV)

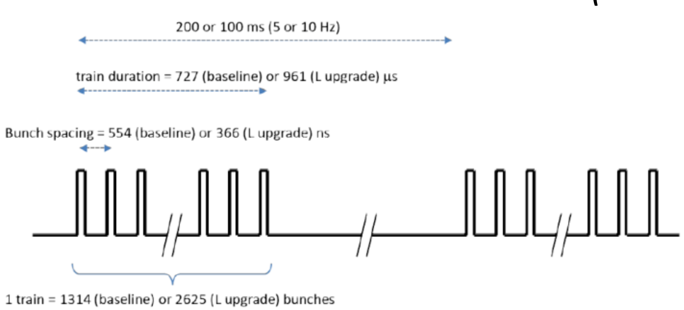
At Z-peak, very high luminosities and **very high e^+e^- cross section (40 nb)**
⇒ **Statistical accuracies at 10^{-4} -10^{-5} level** ⇒ **drives detector performance requirements**
⇒ **Small systematic errors required** to match
⇒ This also drives requirement on **data rates** (physics rates 100 kHz)
⇒ Triggerless readout likely still possible

Beam-induced background, from beamstrahlung + synchrotron radiation
- Most significant at 365 GeV
- Mitigated through MDI design and detector design

Modified from Lucie Linssen, ESPPU, 2019

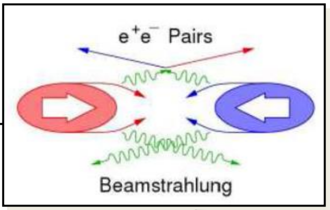
Mogens Dam / NBI Copenhagen AIDA++ Open Meeting, CERN 4 September, 2019 6

(slide from Mogens Dam/Lucie Linssen)



Occupancy and beam background (Guinea Pig)

- Assuming the same time resolution (~1-4 μs), background rates (and therefore occupancy) are comparable



Pitch ~ 17-25 μm
Cluster multiplicity ×5
Safety factor ×3-5
Time resolution ~few μs
⇨ ~Per mil level occupancy
⇨ Bunch separation ?

ILD @ 250 GeV

	hits/BX			hits/BX/cm^2		
	mean	±	RMS	mean	±	RMS
VXD 1	914	±	364	6.64	±	2.65
VXD 2	545	±	207	3.96	±	1.51
VXD 3	129	±	60	0.213	±	0.100
VXD 4	107	±	53	0.177	±	0.088
VXD 5	40	±	26	0.043	±	0.029
VXD 6	34	±	24	0.037	±	0.026

Daniel Jeans, Akiya Miyamoto

FCCee occupancies

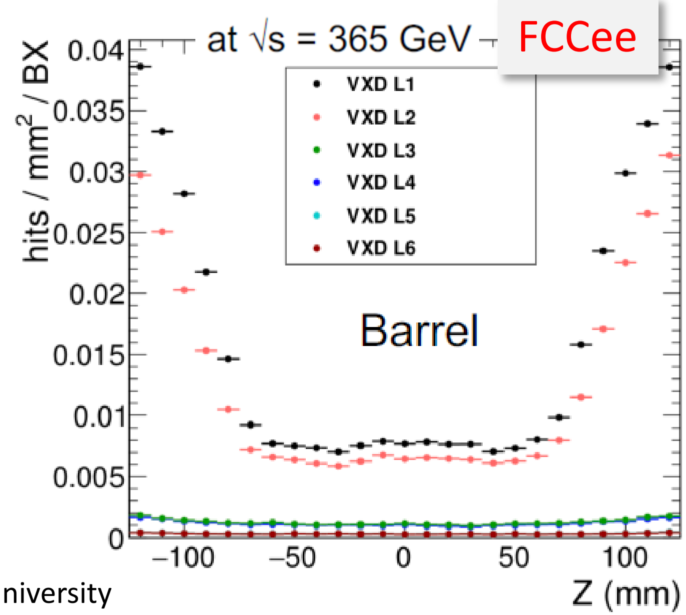
CLD max. occ. / subdetector, IPC & SR		
$\sqrt{s}$ [GeV]	91.2	365
VXDB	$\sim 10^{-5}$	$\sim 4 \times 10^{-4}$
VXDE	$\sim 4.7 \times 10^{-6}$	$\sim 4 \times 10^{-4}$
TE	$\sim 1.8 \times 10^{-5}$	$\sim 3 \times 10^{-4}$

The presented occupancy / BX is rather low for VXD and Si tracker

However bunch spacing at the Z peak is 20ns

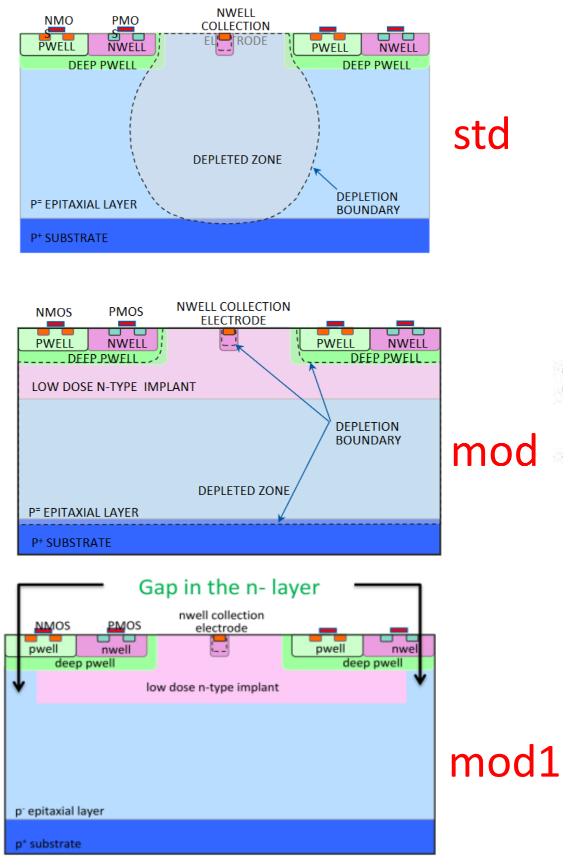
- Might be that we have to integrate over several Bxs
- Still with a time resolution of $1\mu s \rightarrow$ occupancy stays $\leq 6 \times 10^{-4}$

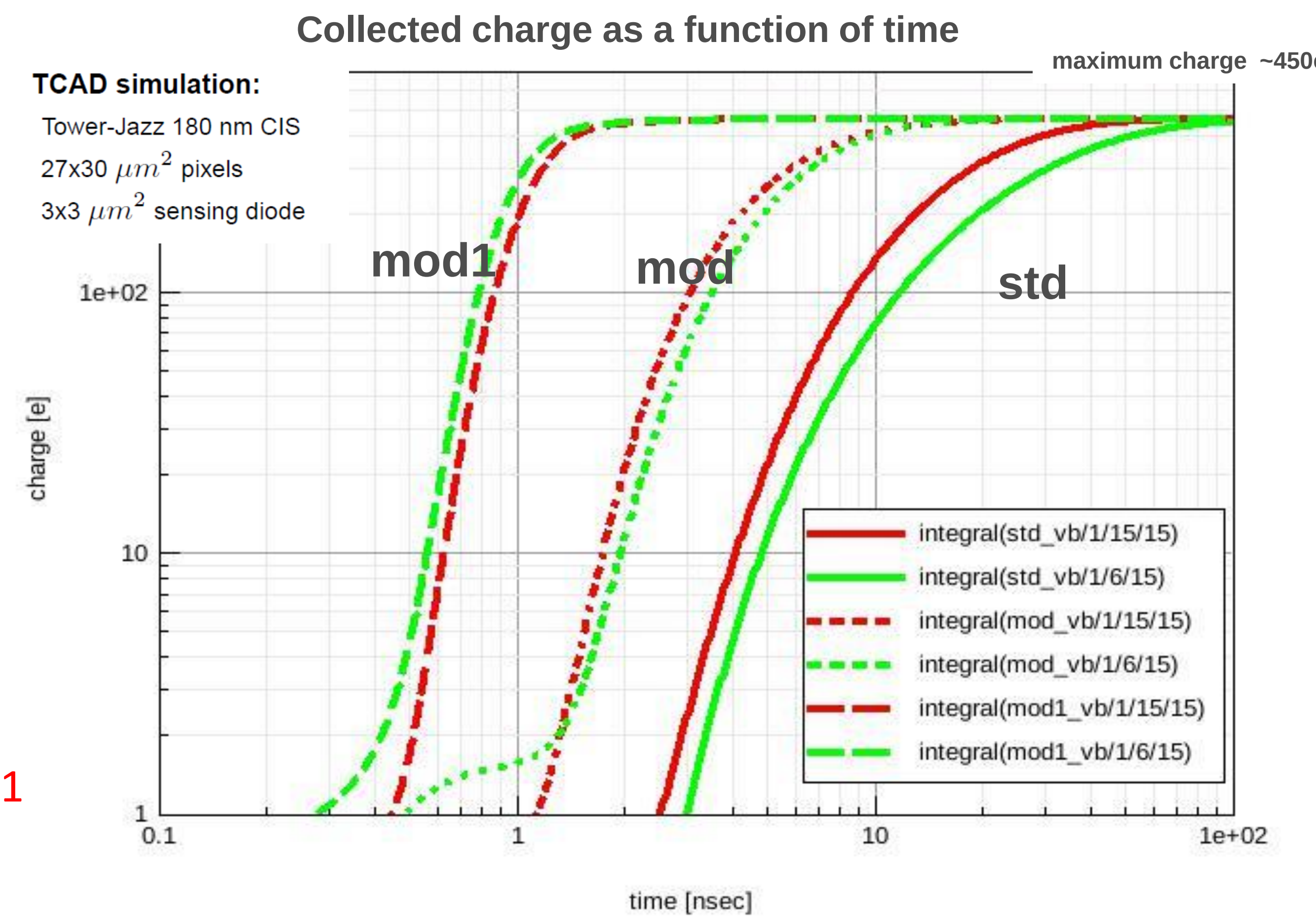
FCCee



Yorgos Voutsinas, inputs from N. Alipour Tehrani, N. Bacchetta, K. Elsener, P. Janot, A. Kolano, E. Leogrande, E. Perez, O. Viazlo

Charge collecting time simulations





- Shorter collection time
  - ✓ Improves radiation tolerance
  - ✓ Necessary for ultimate time resolution < 100 ns
    - "QUARTET", R&D transverse project of IN2P3 (IPHC, CPPM, OMEGA)