第22回高エネルギーQCD・核子構造勉強会

Friday 29 Mar 2024, 13:00 → 17:00 Asia/Tokyo

東海1号館116号室 (KEK　東海キャンパス　)

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ePIC実験測定器の技術と応用

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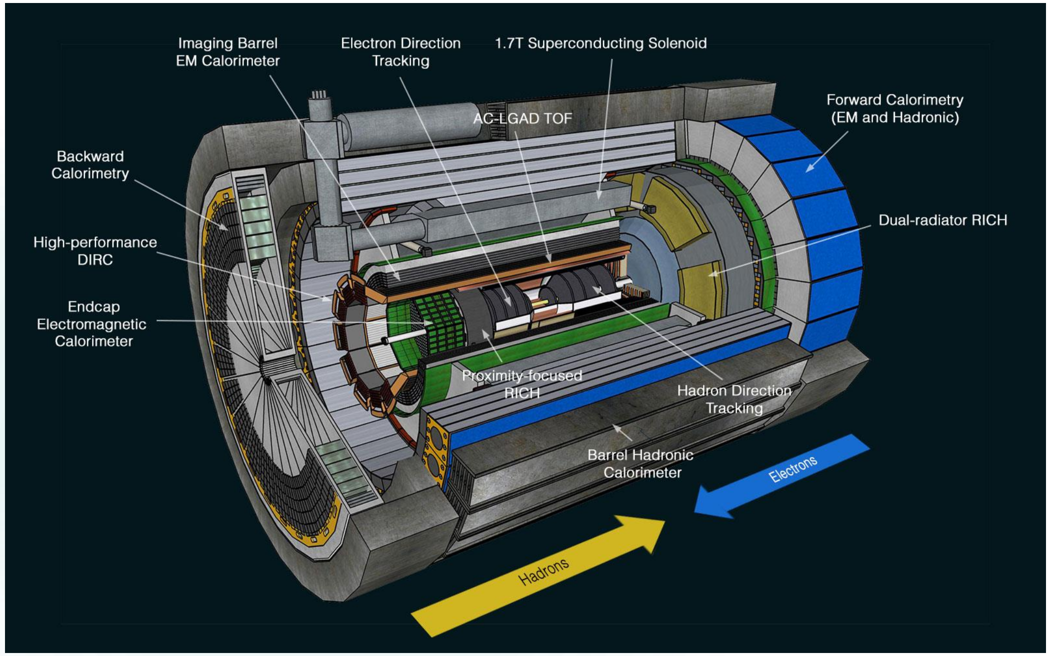
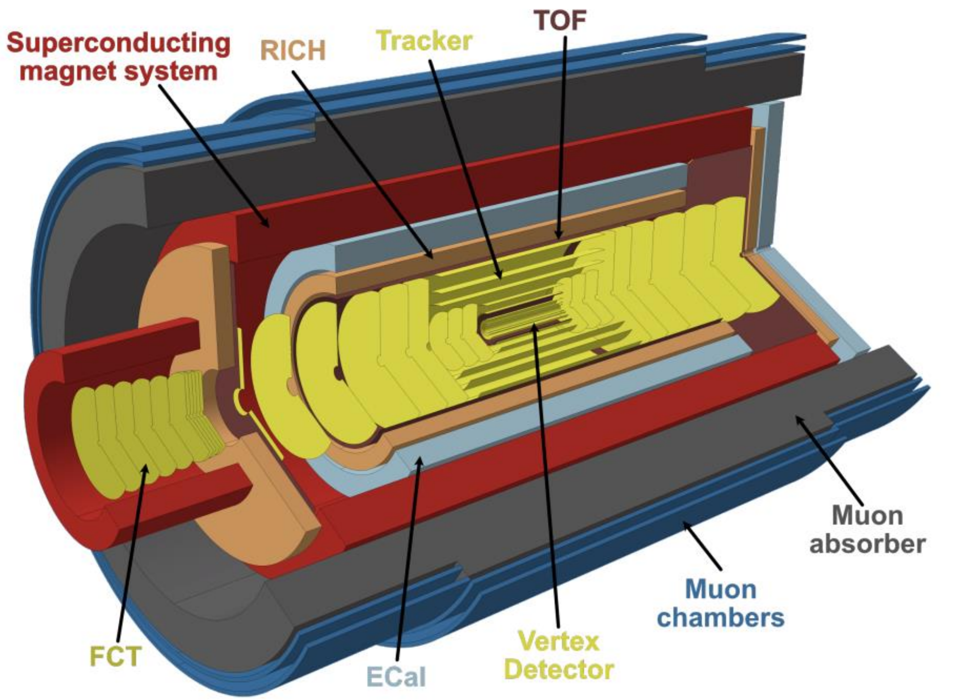
- 高エネルギー原子核物理の将来実験と測定器
  - ePIC実験とALICE3実験
- 今後の基盤となる測定器技術やシステム
  - MAPS
  - LGAD
  - Streaming DAQ

高エネルギー原子核物理の将来実験

- **ePIC実験@EIC (2030-)**

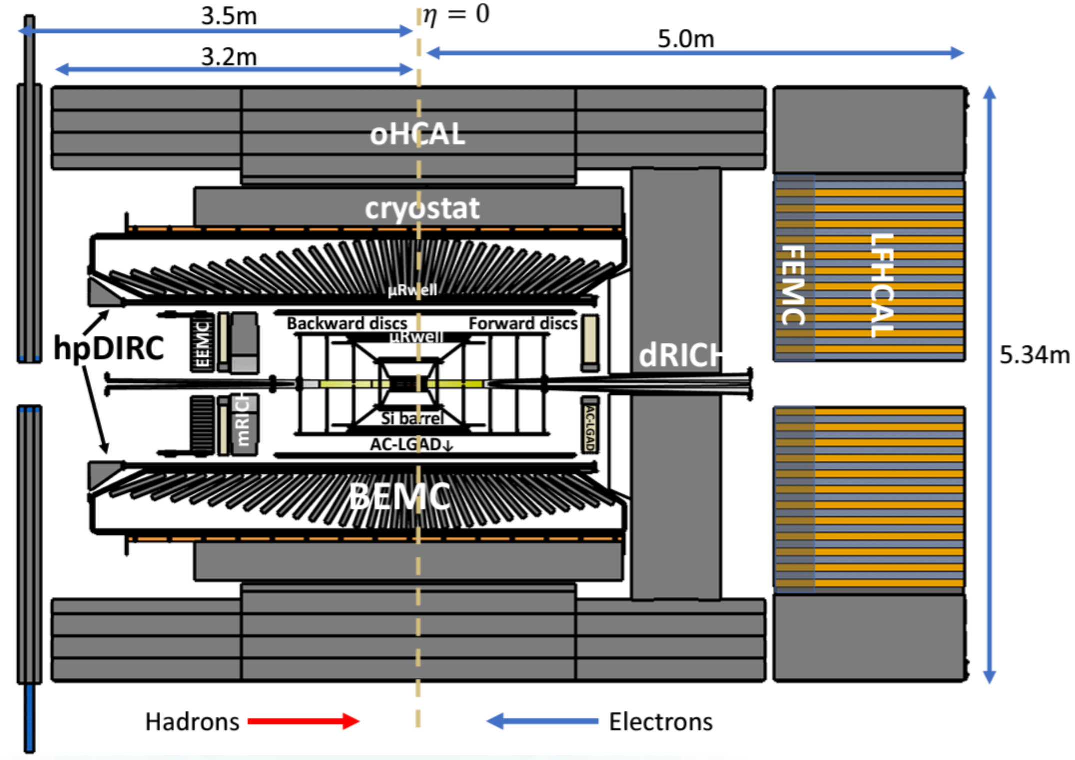


- **ALICE3実験@CERN-LHC (2035-)**

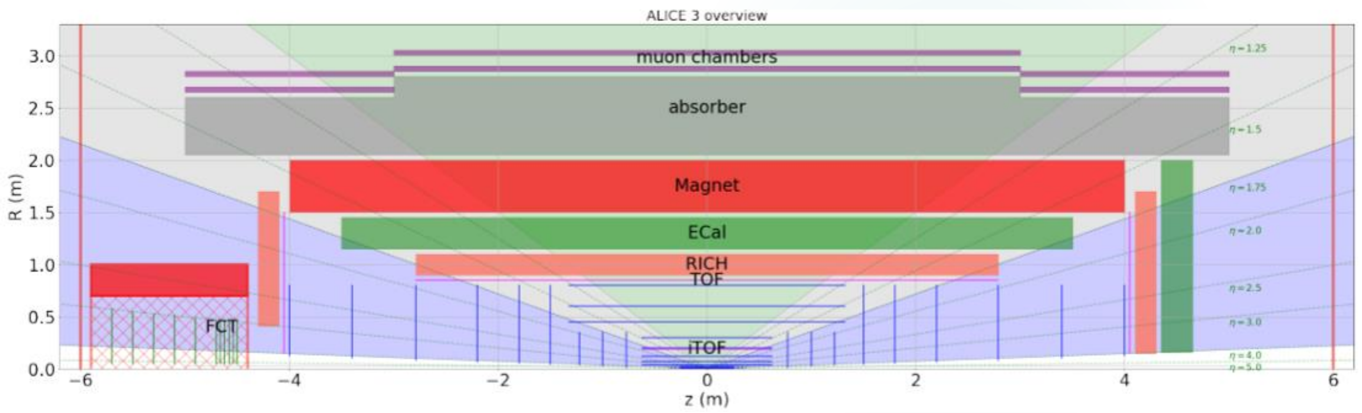


高エネルギー原子核物理の将来実験

▶ ePIC実験@EIC (2030-)



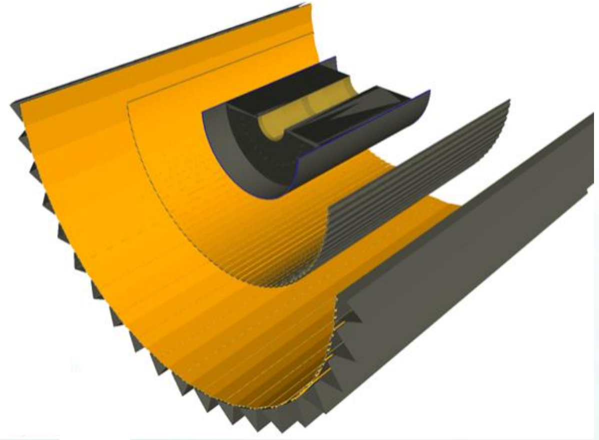
▶ ALICE3実験@CERN-LHC (2035-)

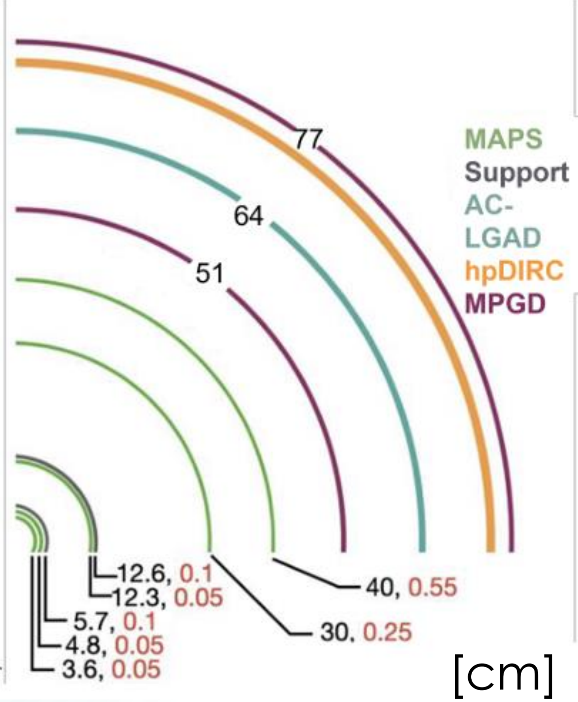


- 飛跡と衝突点同定のためのシリコンピクセル検出器
- PIDのための飛行時間検出器(TOF)
- PIDのためのRICH検出器
- 電磁カロリメーター
- （ハドロンカロリメータ）

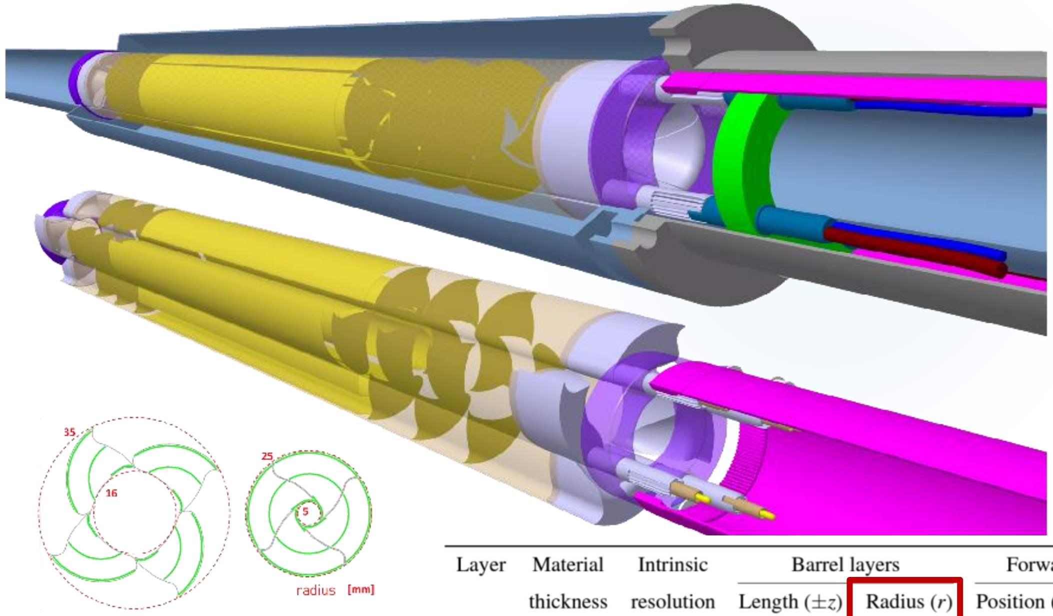
高エネルギー原子核物理の将来実験

▶ ePIC実験@EIC (2030-)





▶ ALICE3実験@CERN-LHC (2035-)

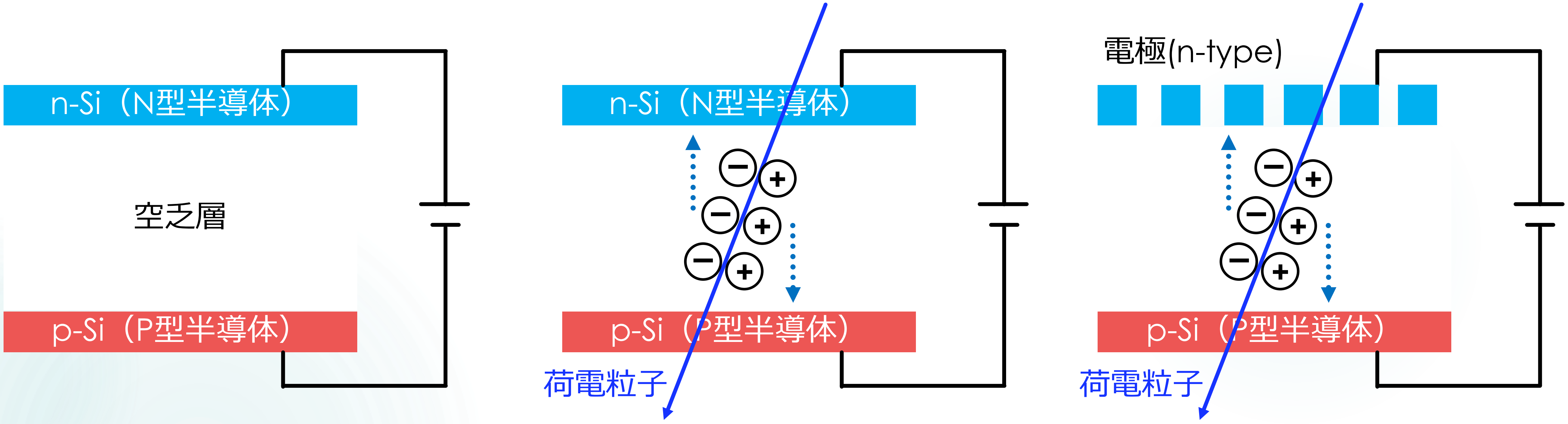


Layer	Material thickness ($\%X_0$)	Intrinsic resolution (µm)	Barrel layers Length ($\pm z$) (cm)	Barrel layers Radius (r) (cm)	Forward discs Position ($\lvert z \rvert$) (cm)	Forward discs R_{in} (cm)	Forward discs R_{out} (cm)
0	0.1	2.5	50	0.50	26	0.50	3
1	0.1	2.5	50	1.20	30	0.50	3
2	0.1	2.5	50	2.50	34	0.50	3
3	1	10	124	3.75	77	5	35
4	1	10	124	7	100	5	35
5	1	10	124	12	122	5	35
6	1	10	124	20	150	5	80
7	1	10	124	30	180	5	80
8	1	10	264	45	220	5	80
9	1	10	264	60	279	5	80
10	1	10	264	80	340	5	80
11	1				400	5	80

- 飛跡と衝突点同定のためのシリコンピクセル検出器

→ 出来るだけ衝突点近傍に置きたい。
→ 高精細なシリコンピクセル検出器が必要

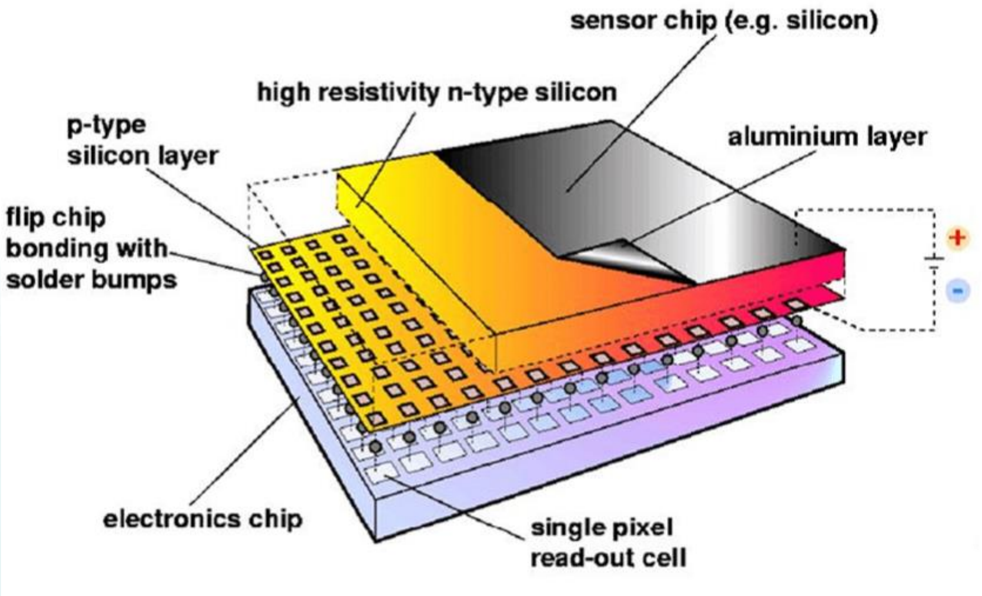
シリコン半導体検出器

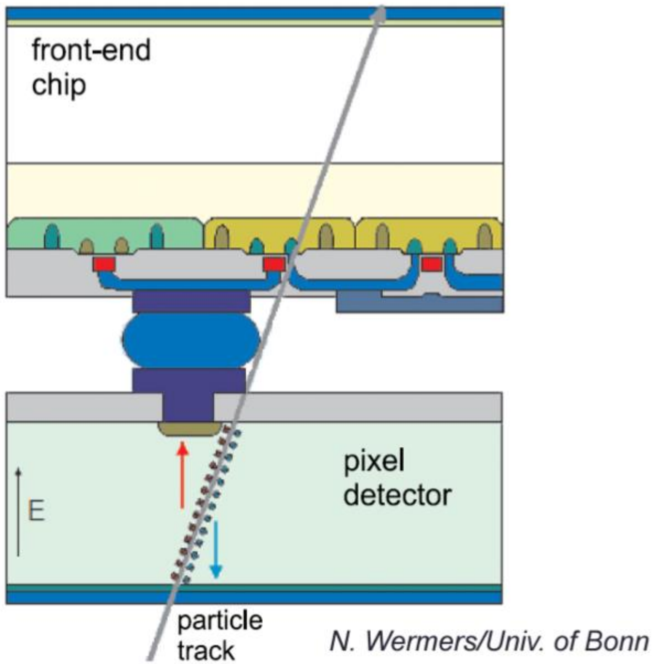


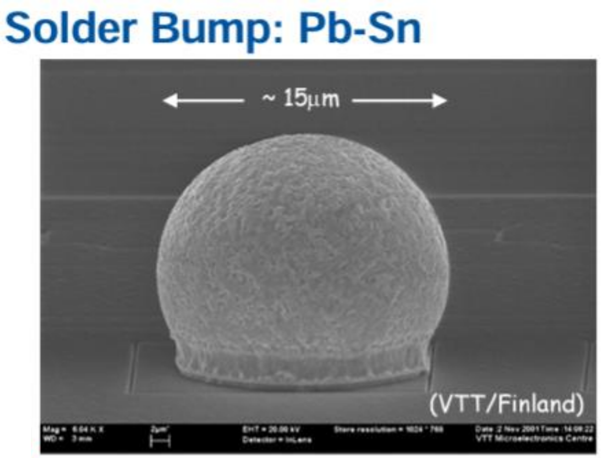
- pn 接合に逆バイアス電圧を印加すると空乏層ができる
- 荷電粒子が空乏層領域を通過すると飛跡に沿って 電子・ホール対を生成する
- 300 μm 厚センサー ~32,000 e-h ペア生成
- 電子とホールは電場に従って収集される
- 電荷を収集する電極を工夫すれば、一次元（ストリップ）、二次元（ピクセル）の位置情報を得ることができる

Hybrid ピクセルセンサー

現在の主流はハイブリッド型ピクセル検出器（ATLAS 実験など）

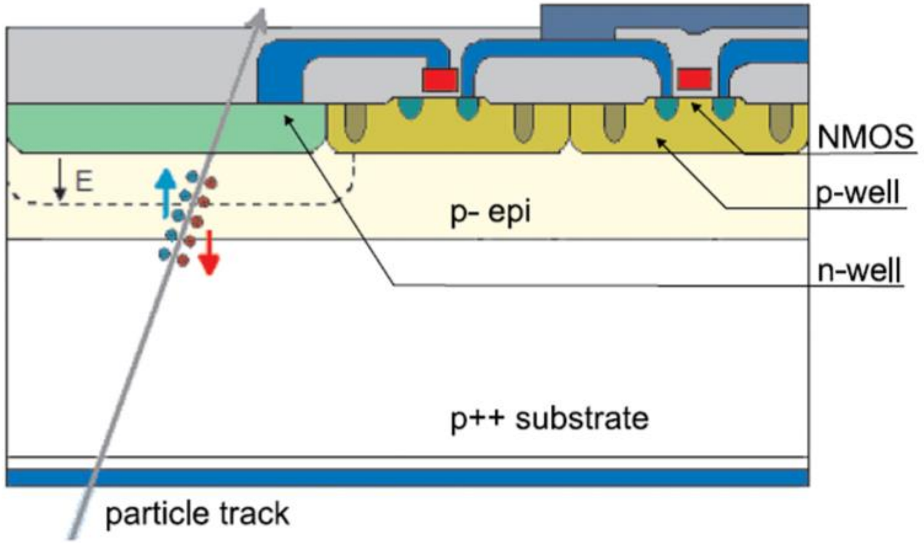






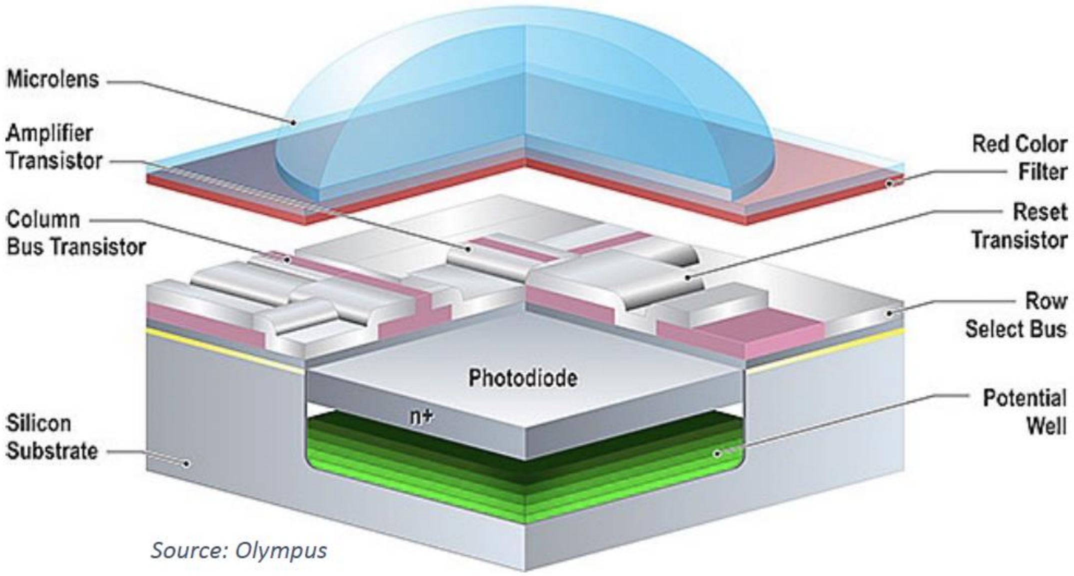
- センサーと信号読み出し回路を別々に作り、バンプボンディングにより接合する。
- バンプの大きさは数十μm 程度 → 最小のピクセルサイズは50 μm程度

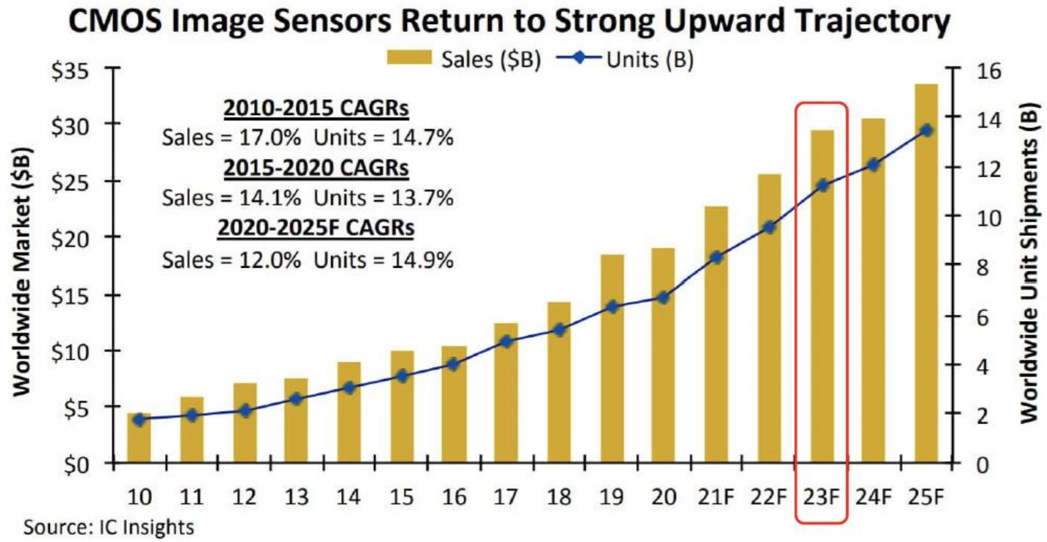
モノリシック ピクセルセンサー

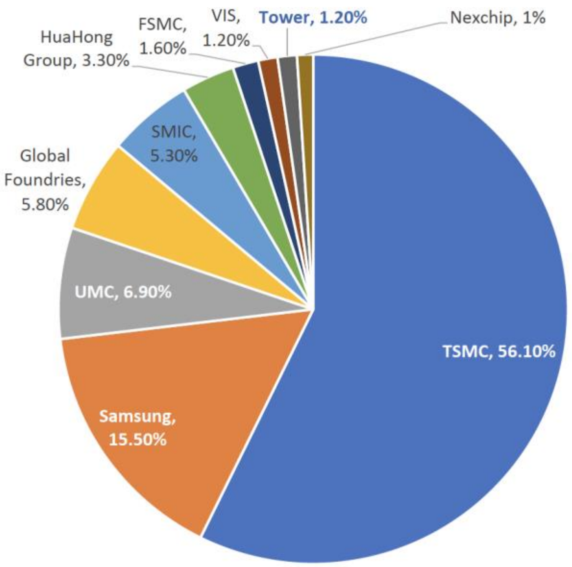


- 一枚のSiウェハーで、センサー部も読み出し回路も作ってしまう。
- バンプボンディングが不要なのでピクセルサイズを小さくできる
- しかし、ピクセル部の信号処理回路規模とトレードオフ。
- 簡単なアナログ回路だけならトランジスタ数個 ~ 10 個程度で実現可能。高度な信号処理回路（アナログとデジタルとか）を入れようとするとトランジスタ数は増える。

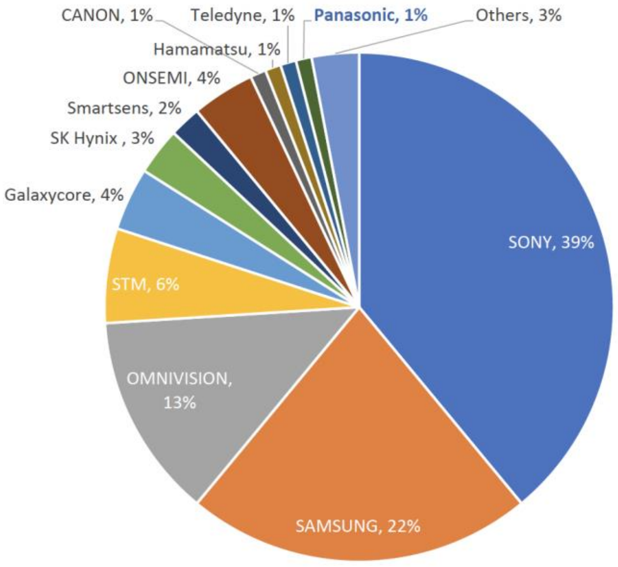
CMOS imaging sensor (CIS)







Global Top 10 **CMOS Foundries** - Market Share



Global Top 10 **CIS Companies** - Market Share

- **camera phones, vehicles, machine vision, human recognition and security, scientific/medical**
- **cellular camera phones account for 60% of the sales**

CMOS imaging sensors

The inception of CMOS APS for charged particles

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 458 (2001) 677–689

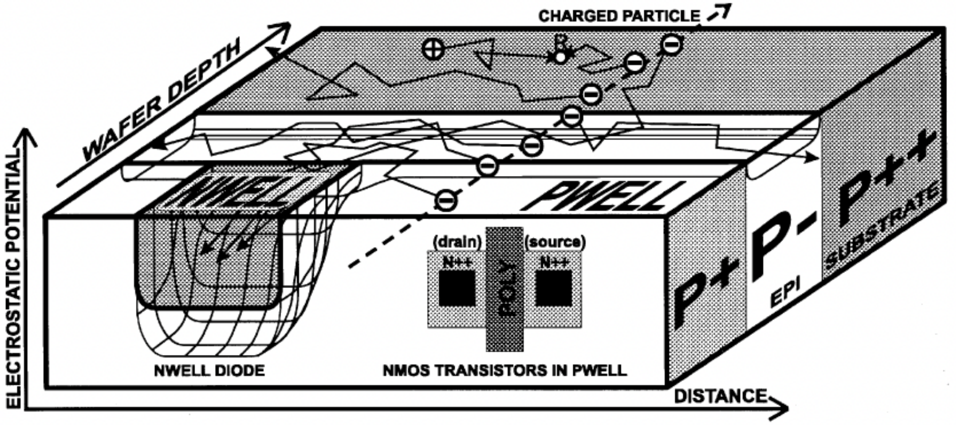
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.nl/locate/nima

A monolithic active pixel sensor for charged particle tracking and imaging using standard VLSI CMOS technology

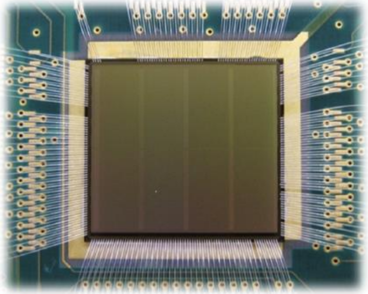
R. Turchetta[a,*], J.D. Berst[a], B. Casadei[a], G. Claus[a], C. Colledani[a], W. Dulinski[a], Y. Hu[a], D. Husson[a], J.P. Le Normand[a], J.L. Riester[a], G. Deptuch[b,1], U. Goerlach[b], S. Higueret[b], M. Winter[b]

[a]LEPSI, IN2P3/ULP, 23 rue du Loess, BP20, F-67037 Strasbourg, France
[b]IReS, IN2P3/ULP, 23 rue du Loess, BP20, F-67037 Strasbourg, France



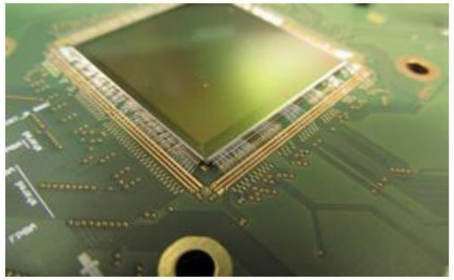
Since then, there have been a lot of developments. 100% efficiency and CMOS electronics integrated in the pixel matrix

TPAC - for ILC ECAL (CALICE)



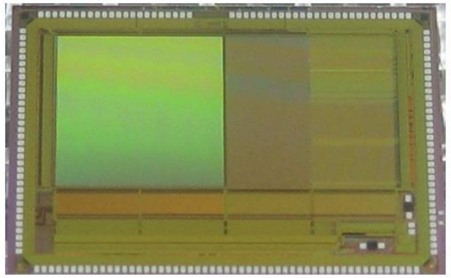
50μm pixel 2008

PIMMS – for TOF mass spectroscopy



70μm pixel 2012

CHERWELL – Calorimetry/Tracking



48 μm x 96 μm pixel 2013

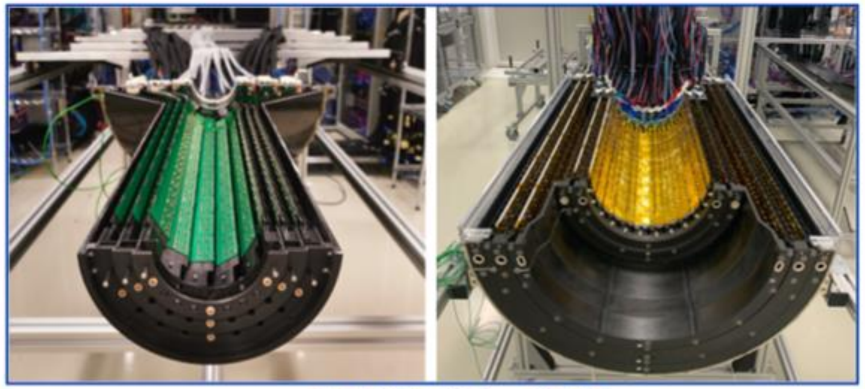
ALPIDE – Tracking

27 μm x 29 μm pixel 2016

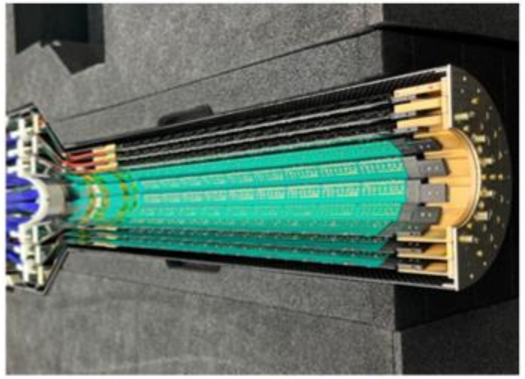
MAPSセンサーの大型実験応用

L. Musa, QM2023

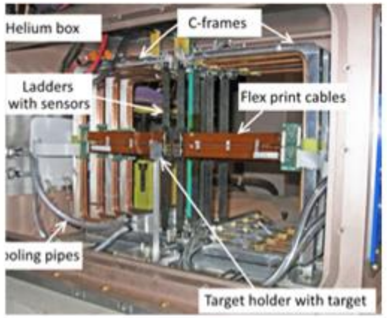
STAR HFT – 2014
ULTIMATE



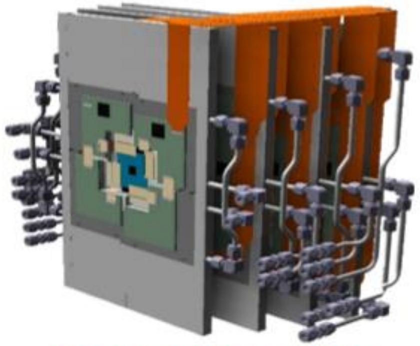
ALICE ITS2 – 2021
ALPIDE



sPHENIX MVTX - 2023
ALPIDE

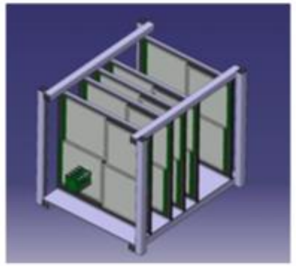


NA61 prototype
ALPIDE

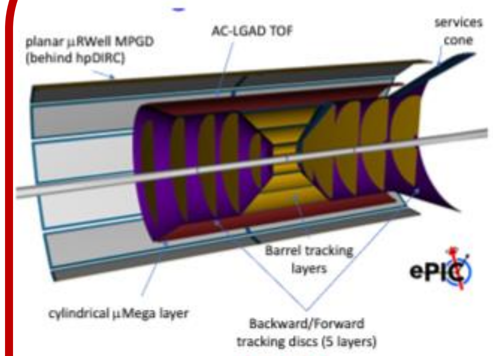


CBM MVTX – 2027
MIMOSIS

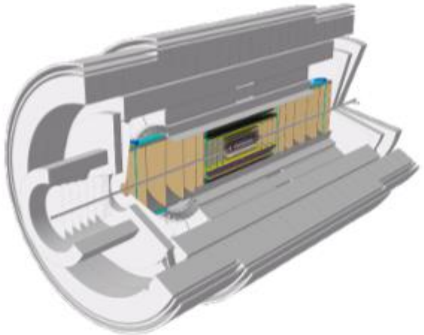
ALICE ITS3 – 2028
“Wafer-scale MOS”



NA60+ - 2028
(based on ALICE ITS3)



EPIC
(based on ALICE ITS3)



ALICE3
next generation

NA60+

L. Musa, QM2023

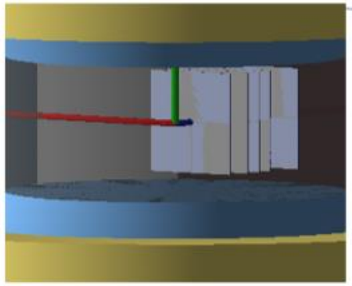
Beam energy scan ($\sqrt{s_{NN}}$: 6.3 – 17.3 GeV) for precision studies of: hard processes, electromagnetic

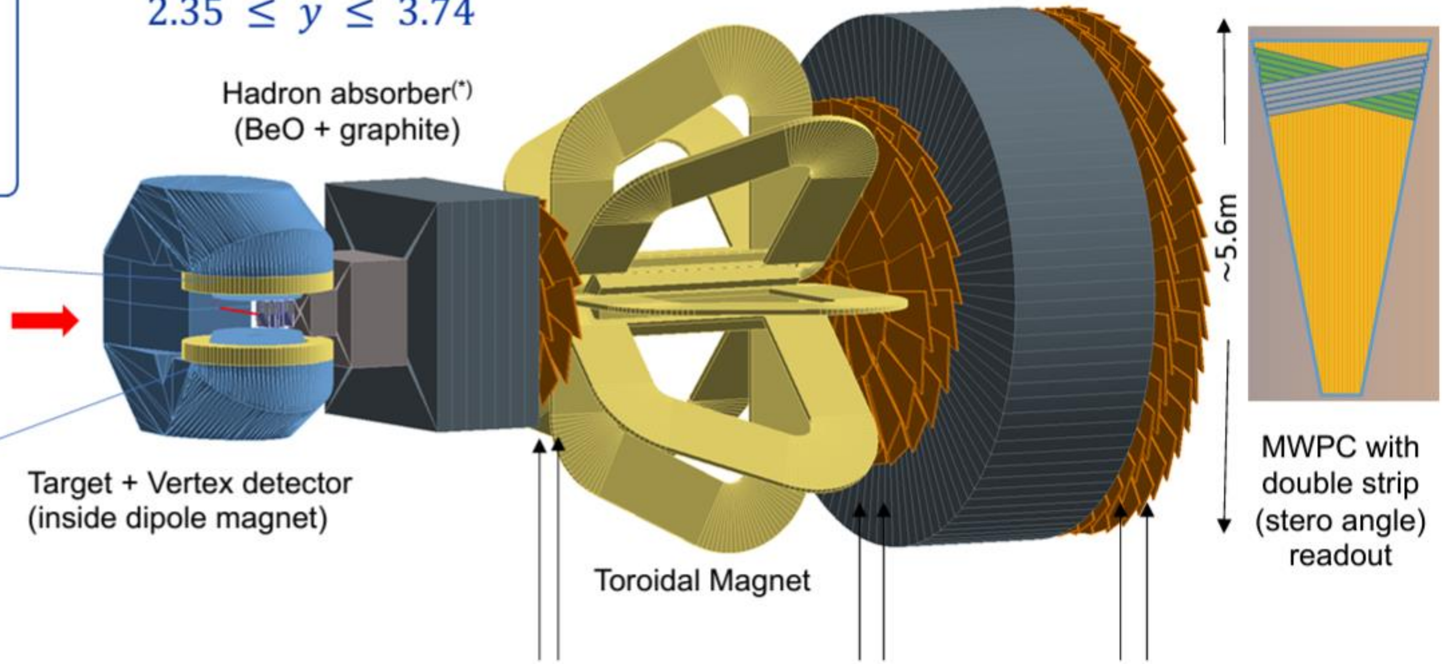
Roadmap
- Technical proposal: **2024-2025**
- Constr. & Installation: **2026-2028**
- Data taking: **2029 - 2037**

EoI in 2019 https://cds.cern.ch/record/2673280
LoI in 2022 CERN-SPSC-2022-036 ; SPSC-I-259

follows design of NA60 but with better-performing detectors

rapidity (high-E)
$2.35 \leq y \leq 3.74$



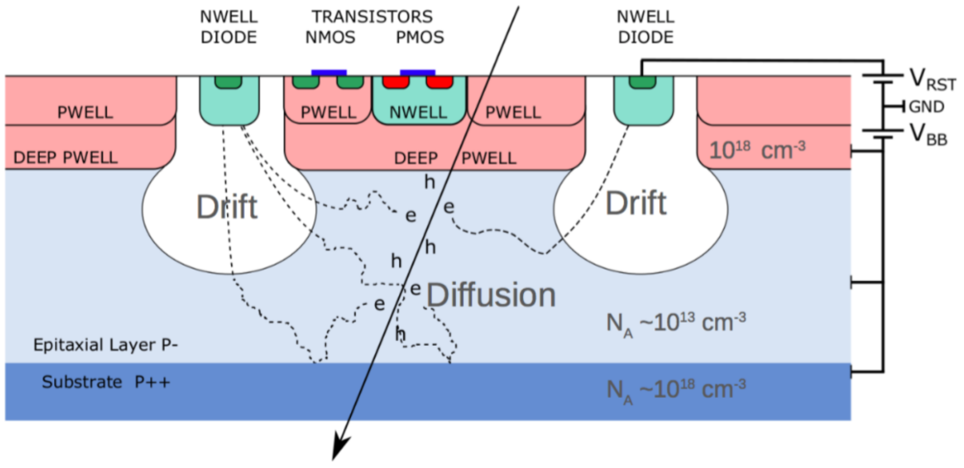


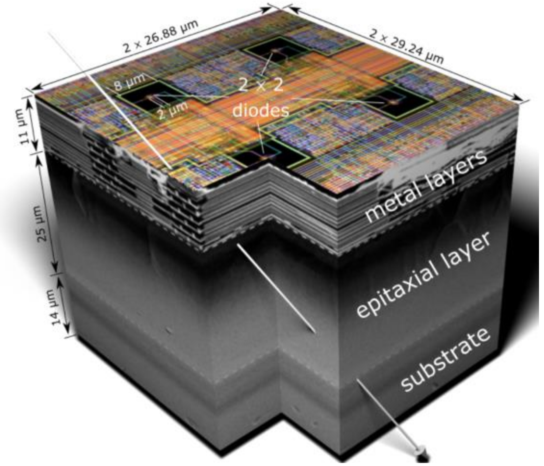
Muon Spectrometer (6 stations) on rails to adjust position depending on energy

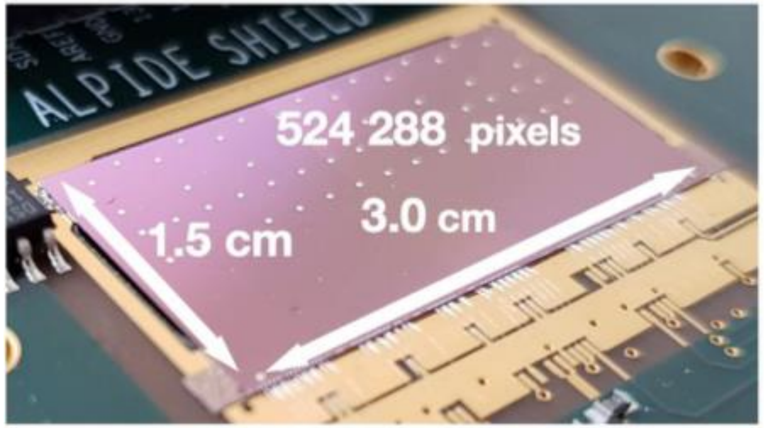
5-plane vertex detector based on MAPS (ALICE ITS3)
- Spatial resolution: 5μm
- X/X_0: 0.1% /plane

Muon tracking stations: MPGD (GEM, MicroMeagas) or **MWPC** (baseline) with total active area $100m^2$, spatial resolution (radial direction) $\sim 200\mu m$, max plarticle flux $\sim \mathrm{kHz}/cm^2$

ALPIDEチップ(ALICE-ITS2)

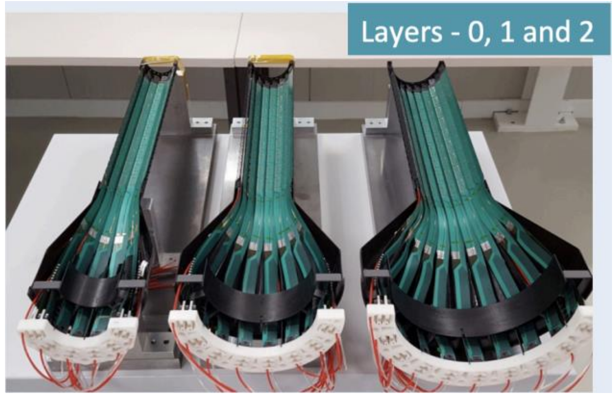


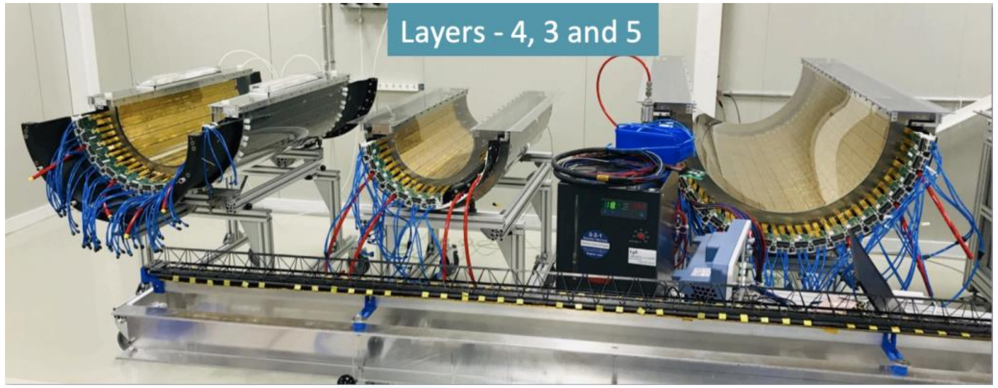




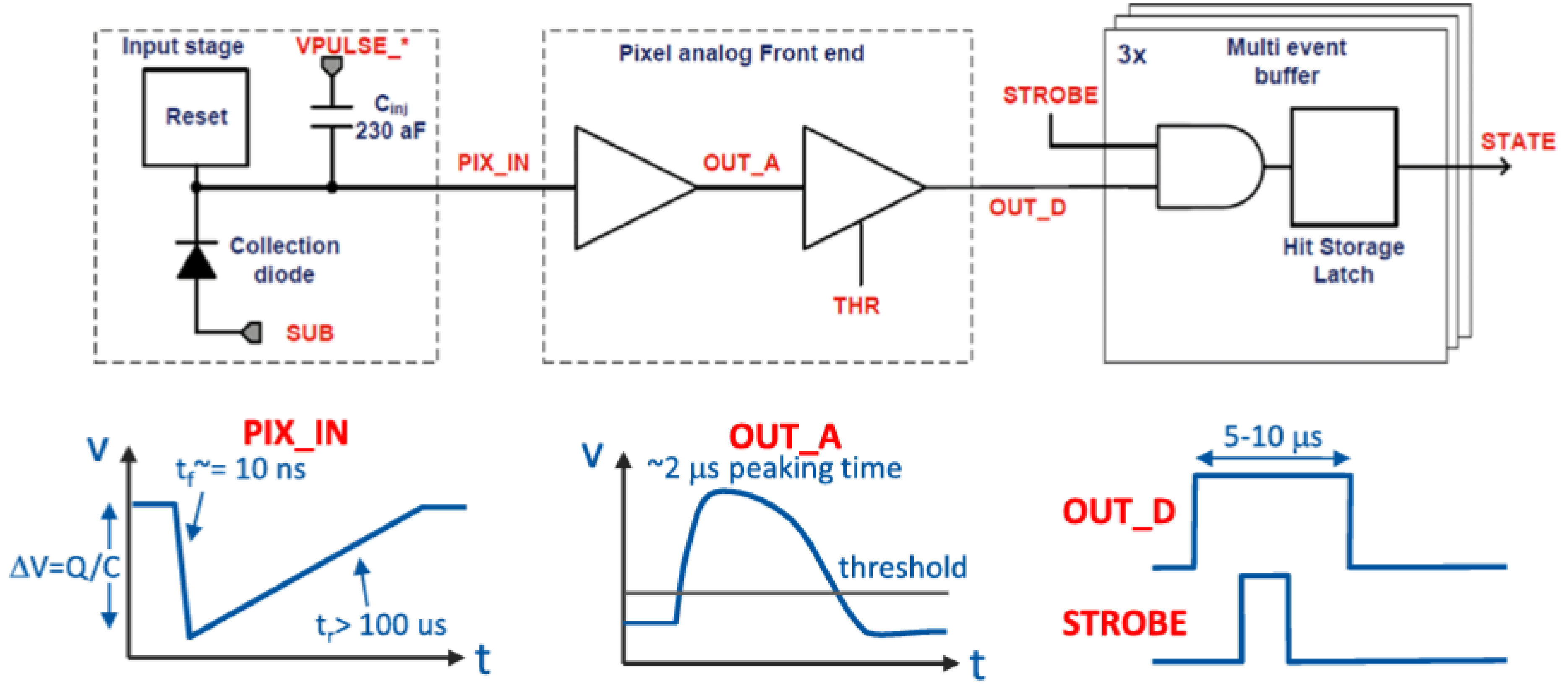
Based on MAPS technology (ALPIDE)

- 180nm technology (Tower Jazz)
- Thinner: for innermost layers ~0.30% X_0
- Smaller pixels: 27 × 29 μm^2
- **Maximum readout rate: 200 kHz**
- 130 000 pixels/cm^2
- Max. particle rate: ~100 MHz/cm^2
- Spatial resolution: ~5 μm
- Thickness: 50 μm for the inner layers
- Fake-hit rate: < 10^{-9} per pixel per event





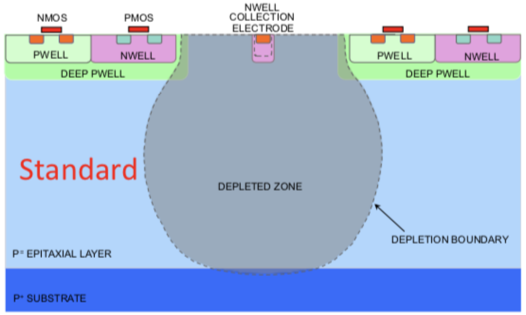
ALPIDEチップ(ALICE-ITS2)

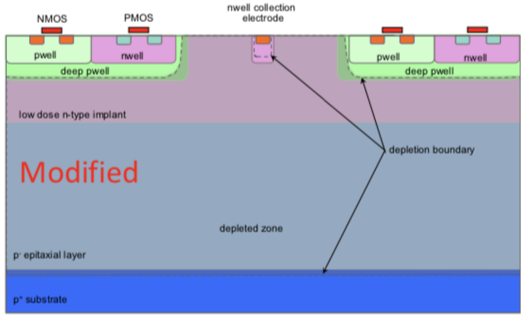


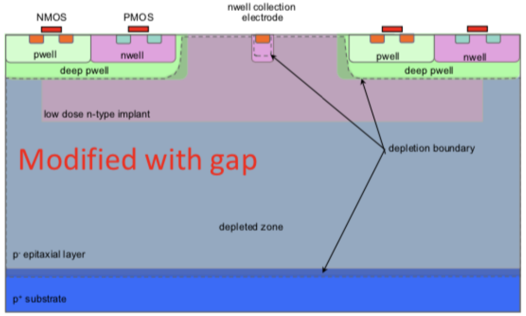
ePIC/ALICE-ITS3 : 65nm

180 nm → 65 nm technology development

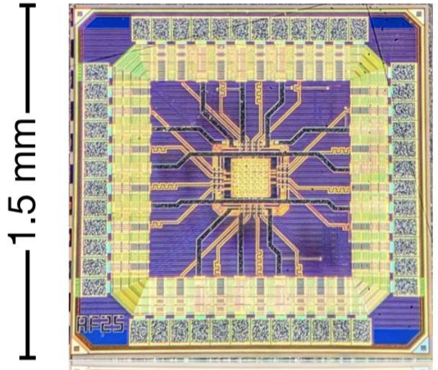
TPSCo 65 nm CMOS Imaging Technology





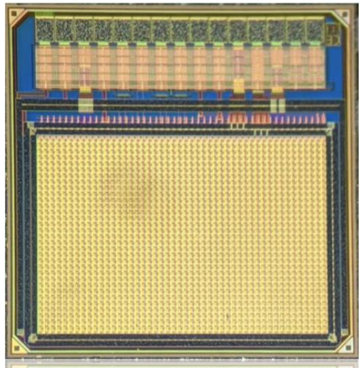


APTS



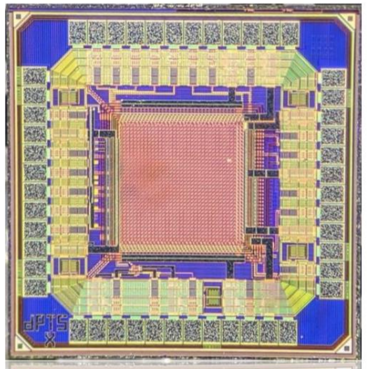
- **matrix:** 6x6 pixels
- **readout:** direct analog readout of central 4x4
- **pitch:** 10, 15, 20, 25 μm
- **total:** 34 dies

CE65



- **matrix:** 64x32, 48x32 pixels
- **readout:** rolling shutter analog
- **pitch:** 15, 25 μm
- **total:** 4 dies

DPTS

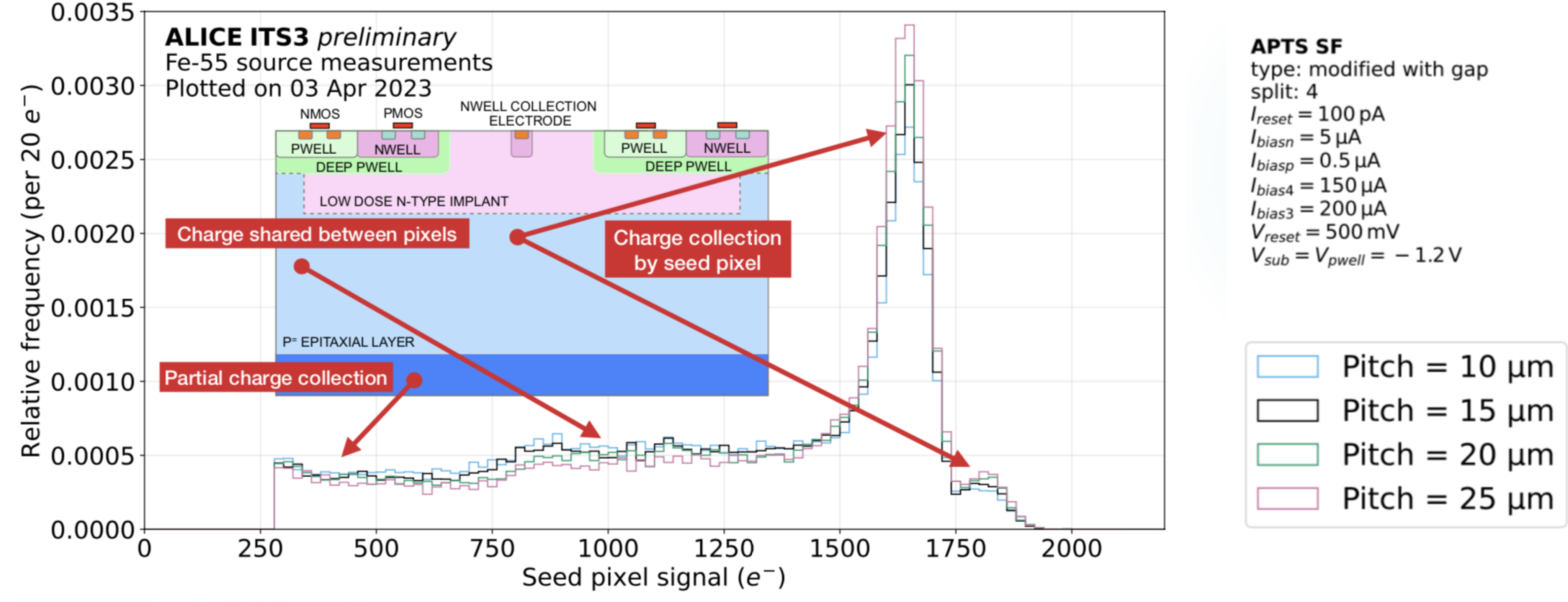


- **matrix:** 32x32 pixels
- **readout:** async. digital with ToT
- **pitch:** 15 μm
- **total:** 3 dies

ePIC/ALICE-ITS3 : 65nm

APTS – Fe-55 lab tests

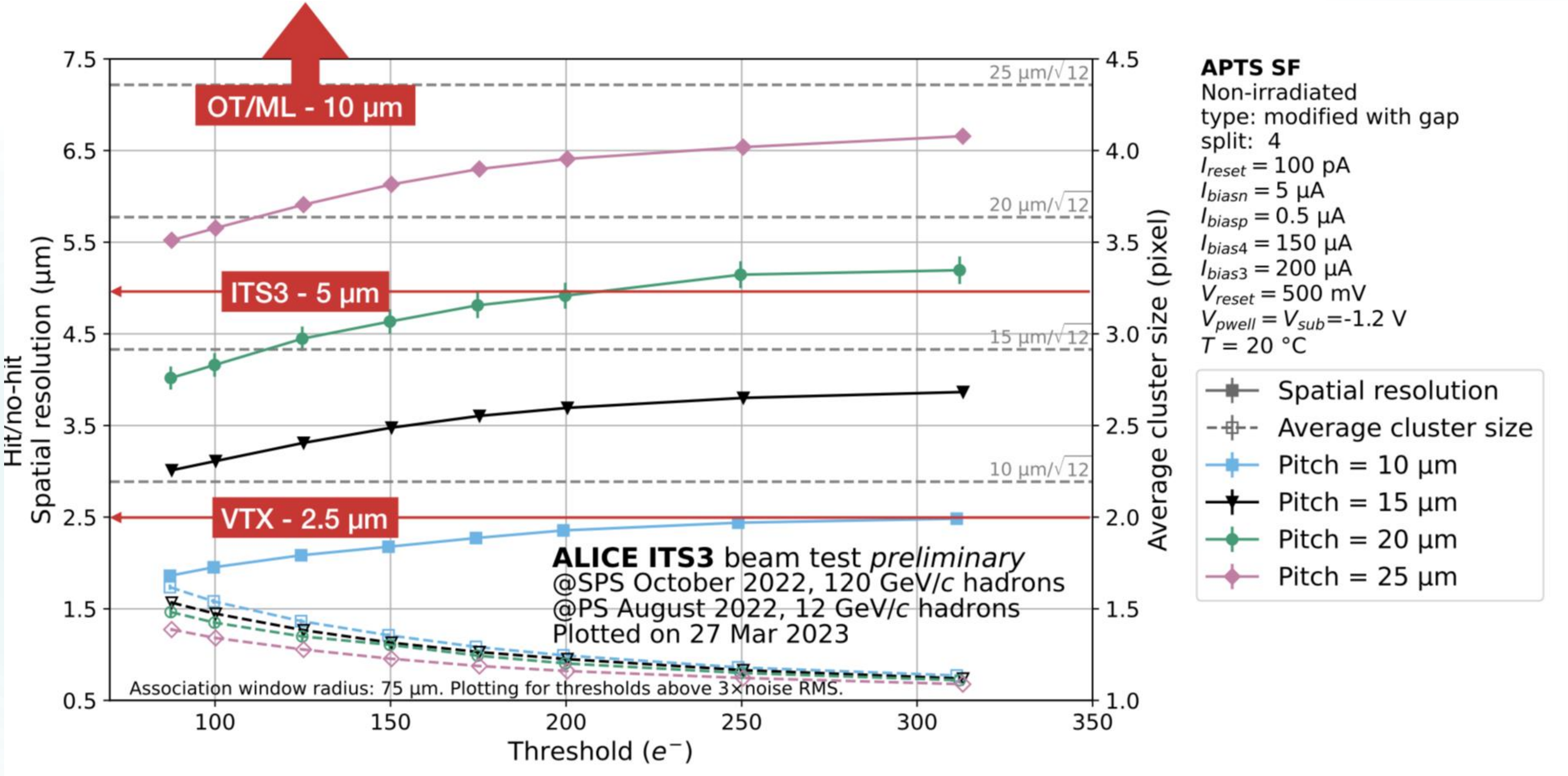
Modified with gap



Pixels of pitches of 10-25 µm show similar results indicates that the charge collection is very efficient

ePIC/ALICE-ITS3 : 65nm

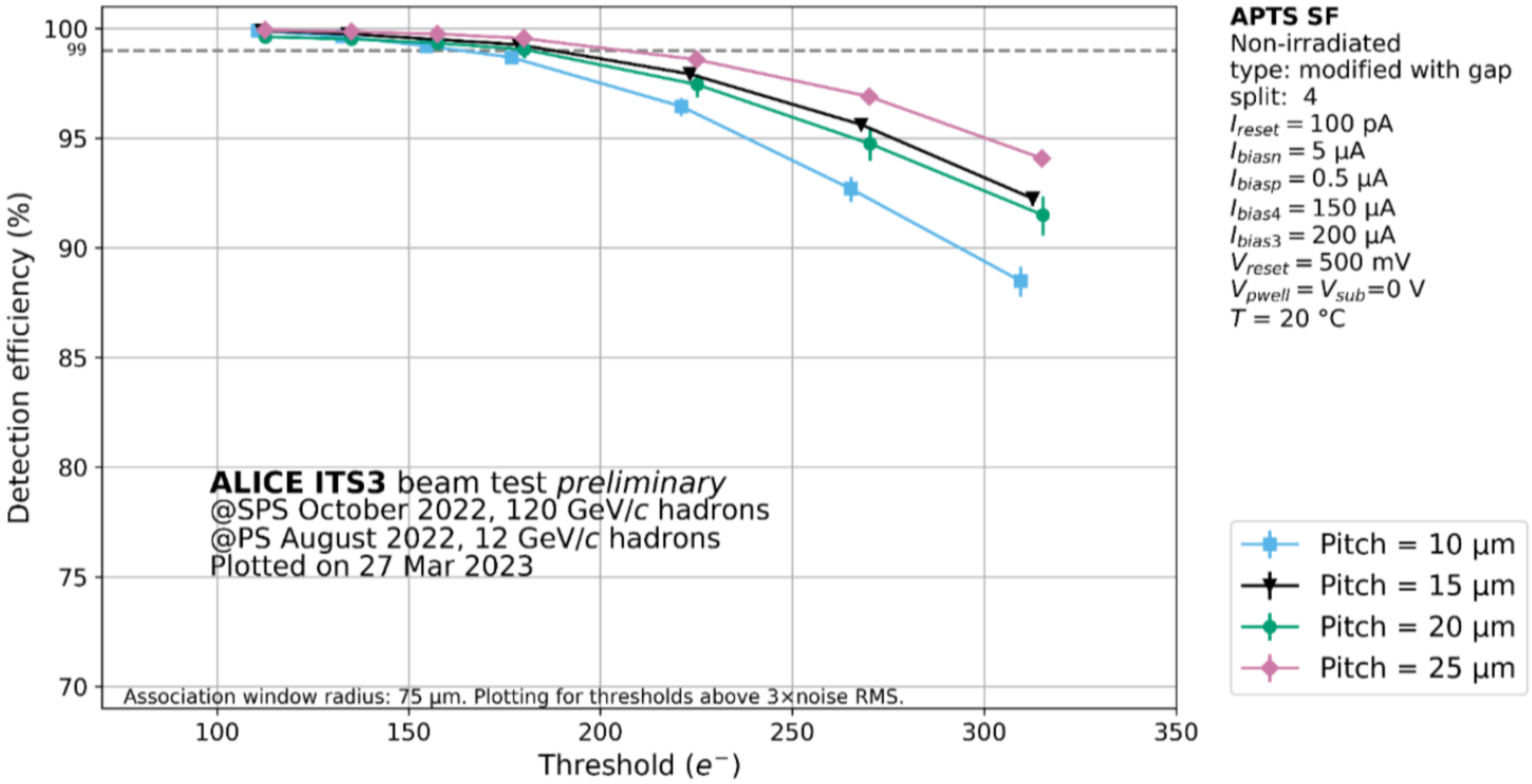
APTS – beam tests



ePIC/ALICE-ITS3 : 65nm

APTS – beam tests

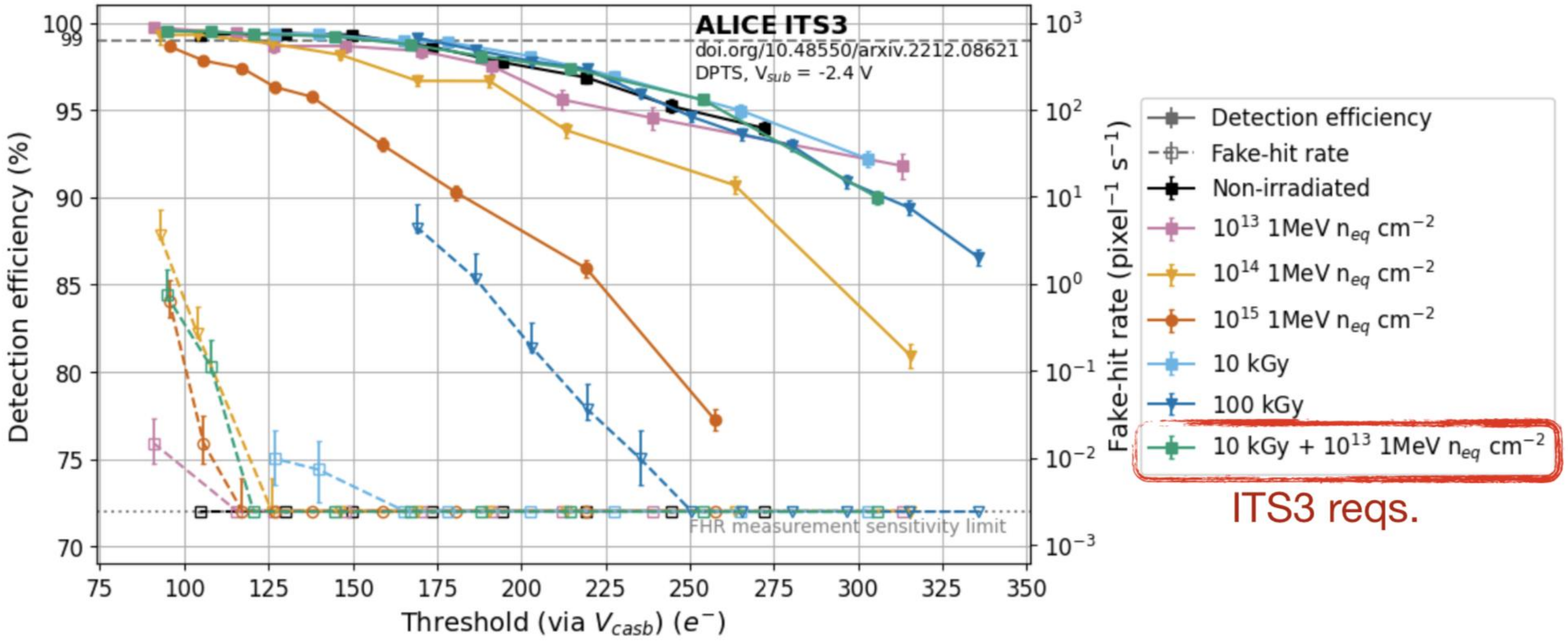
- Detection efficiency increases with pixel pitch
- Interplay between:
    - Less efficiency at pixel border
    - Less border contribution for larger pixels



ePIC/ALICE-ITS3 : 65nm

DPTS – Detection efficiency

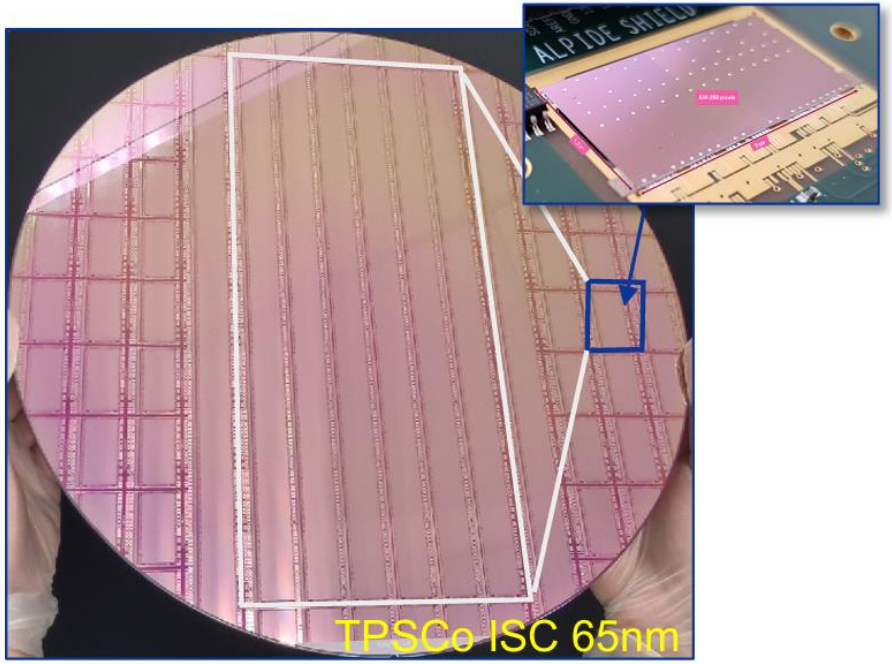
[doi:10.48550/arXiv.2212.08621]



ePIC/ITS3: Wafer-size sensor

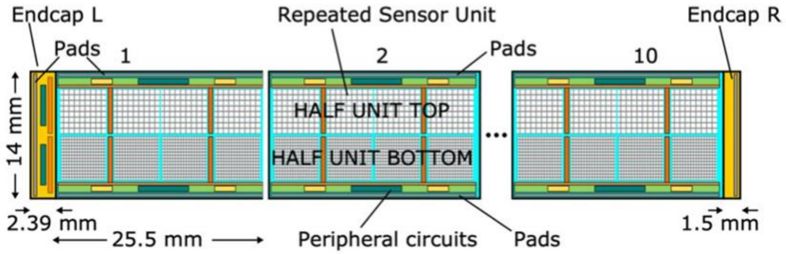
Wafer-size curved sensors → Nearly massless truly cylindrical detectors
TPSCo ISC 65nm CMOS Imaging 300mm wafers + stitching

300 mm wafers



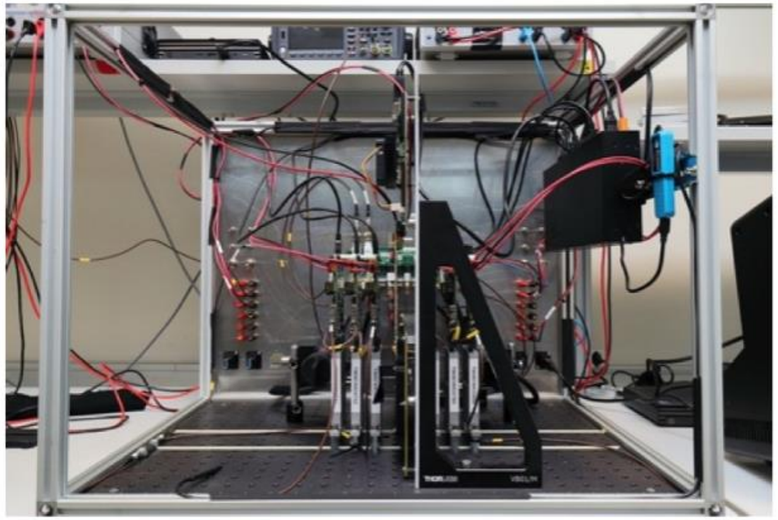
from reticle-size to wafer-size

thin (<50μm CMOS can be curled)



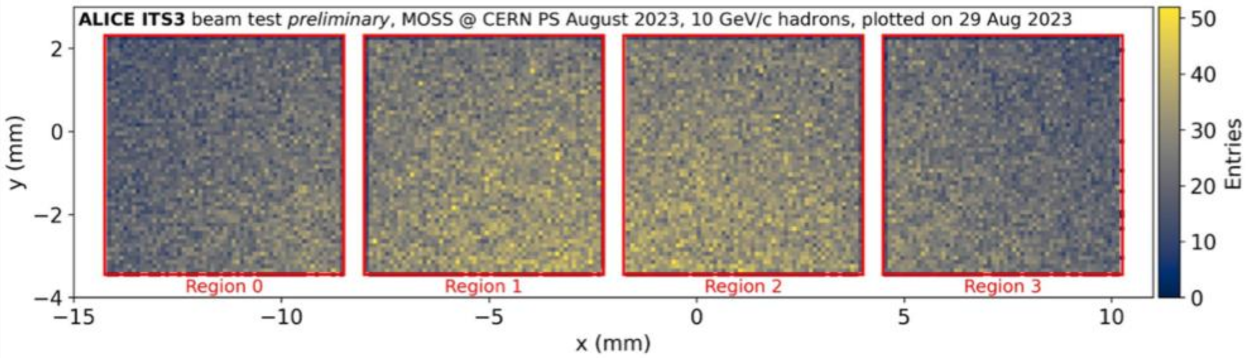
"**MOSS**": 14 x 259 mm, 6.72 MPixel
(22.5 x 22.5 and 18 x 18 μm^2)
- conservative design, different pitches

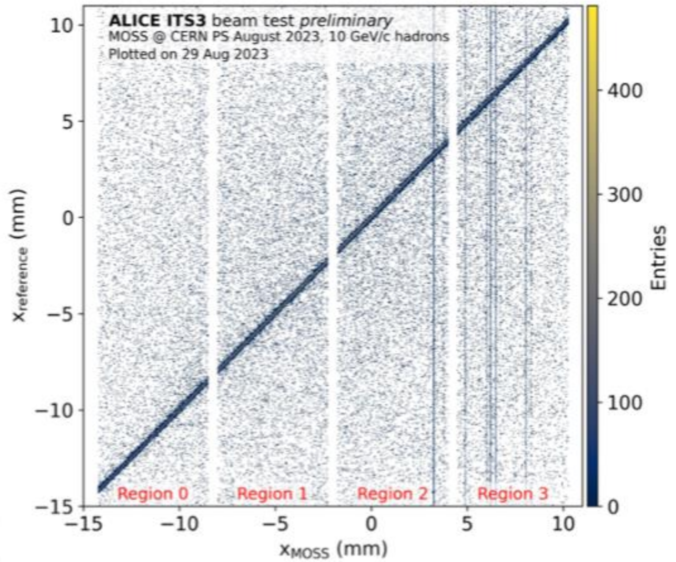
ePIC/ITS3: MOSS testing



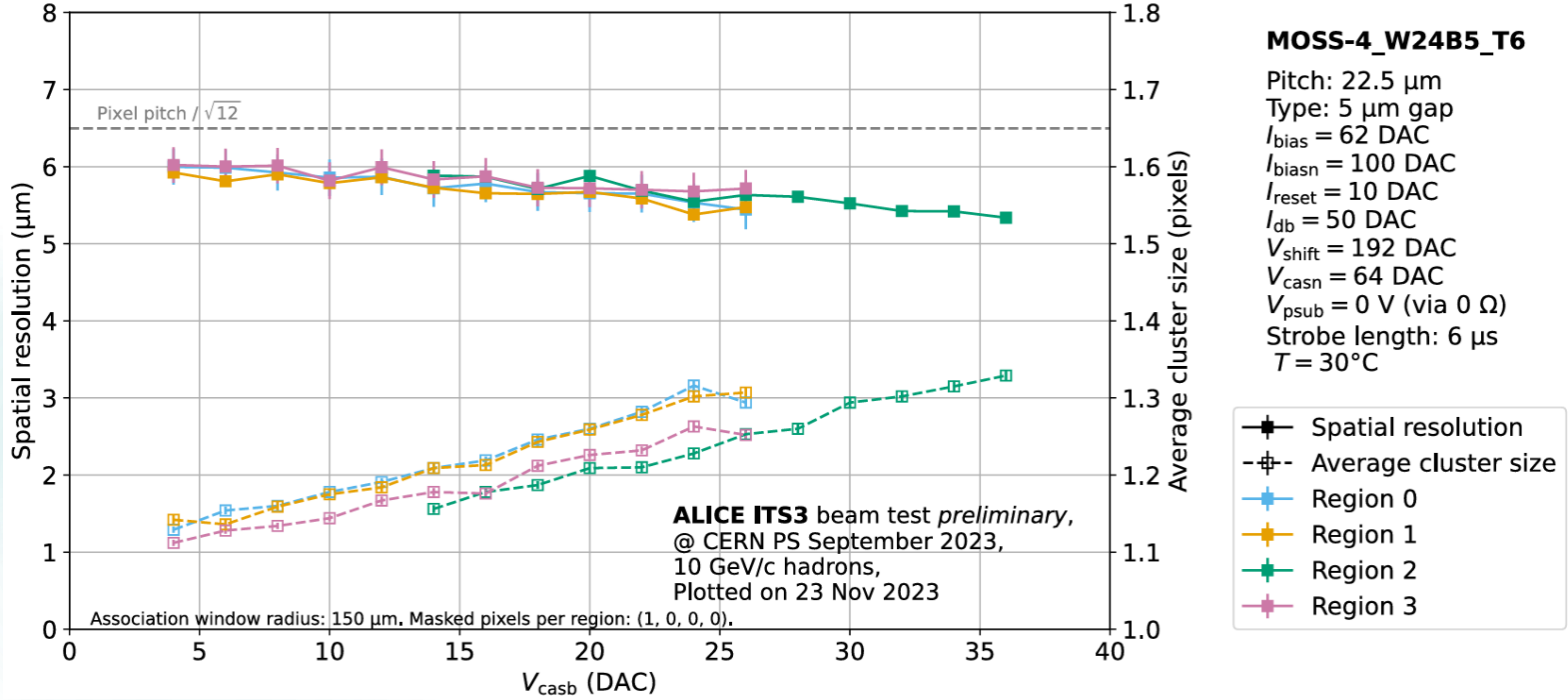
- Confirmed basic functionalities at lab
  - ✓ Careful and gentle powering
  - ✓ Yield assessment by baby MOSS too
- 3 beam test campaigns at PS
  - ✓ 3 ALPIDEs + MOSS + 3 ALPIDEs

Hit map





ePIC/ITS3: MOSS testing

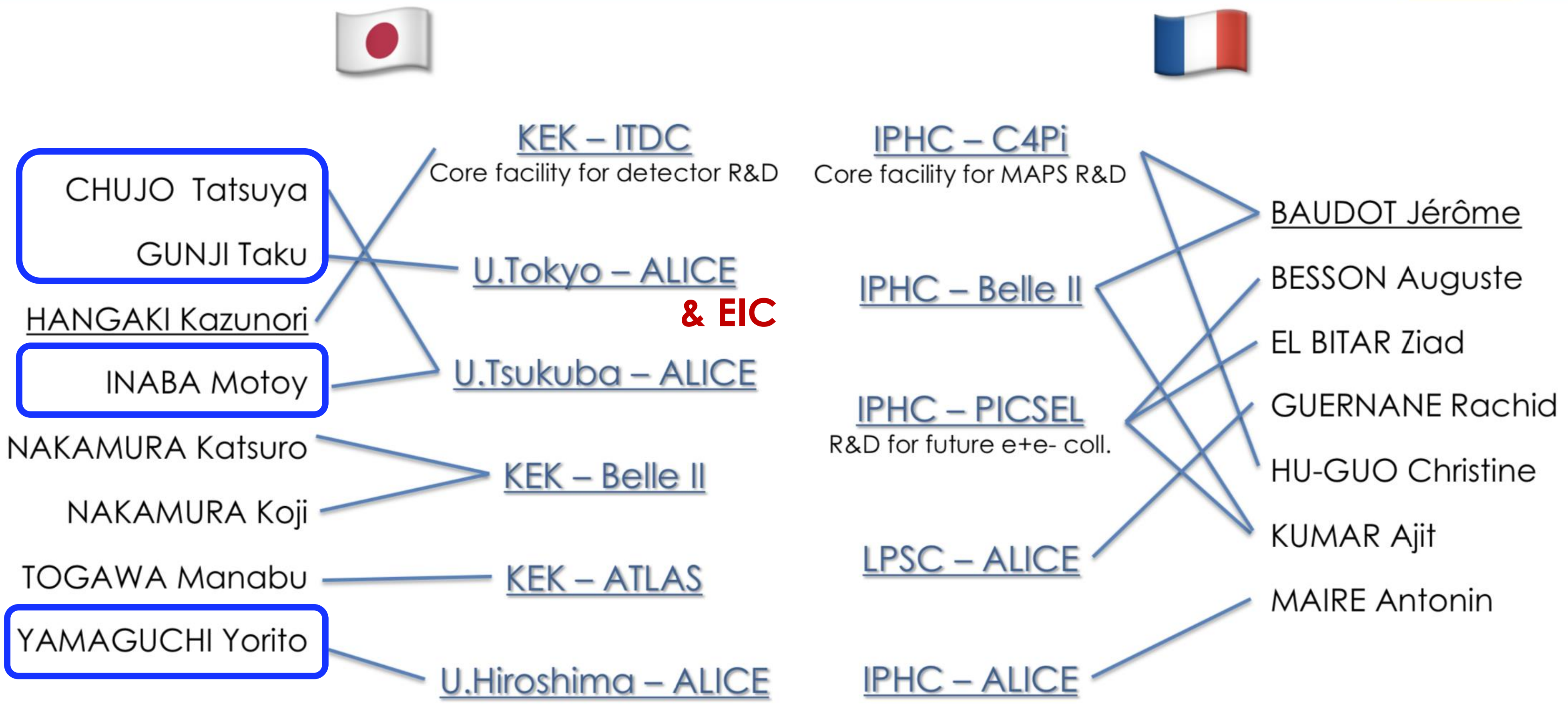


MOSS-4_W24B5_T6

Pitch: 22.5 μm
Type: 5 μm gap
$I_{bias} = 62$ DAC
$I_{biasn} = 100$ DAC
$I_{reset} = 10$ DAC
$I_{db} = 50$ DAC
$V_{shift} = 192$ DAC
$V_{casn} = 64$ DAC
$V_{psub} = 0$ V (via 0 Ω)
Strobe length: 6 μs
$T = 30°C$

日本グループの活動

R_DR_29 Collaboration

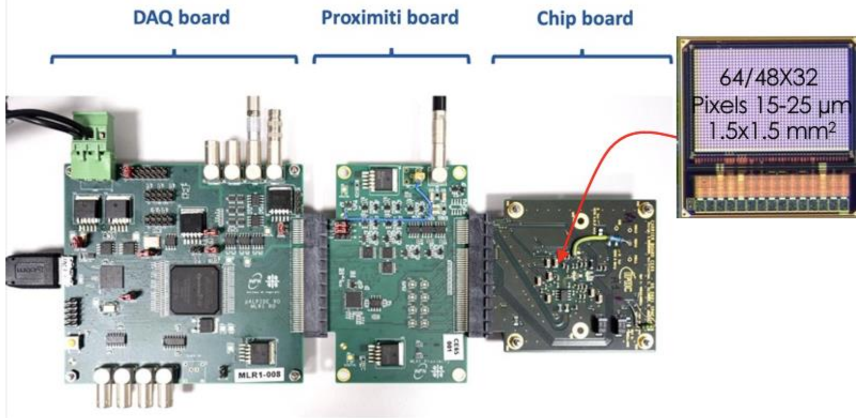


日本グループの活動

Short-term activities

- Contribution to OBELIX-1 design
  - Still possibilities in analogue parts: DAC, ADC
- Tests of TJ-Monopix2
  - Same DAQBoard53 system than OBELIX-1 will use
    - IPHC can provide its own system for Summer (more systems to be produced soon)
  - **Goals: learn how to tune the thresholds over the matrix**
    start thinking integration in beam line (telescope?)
  - Reporting on VTX Monday meeting 9:00 PM (JST)

- Tests of CE-65v1 or v2
  - System distributed by ALICE-ITS3 (availability to be checked)
  - **Goals: learn analogue output characterisation (calib…)**
    specific measurements on v2 not yet performed
  - Reporting in ALICE-WP3 Tuesday meeting 4:00 PM (JST)
- **MOSS characterization**
- **Allpix2 simulation**

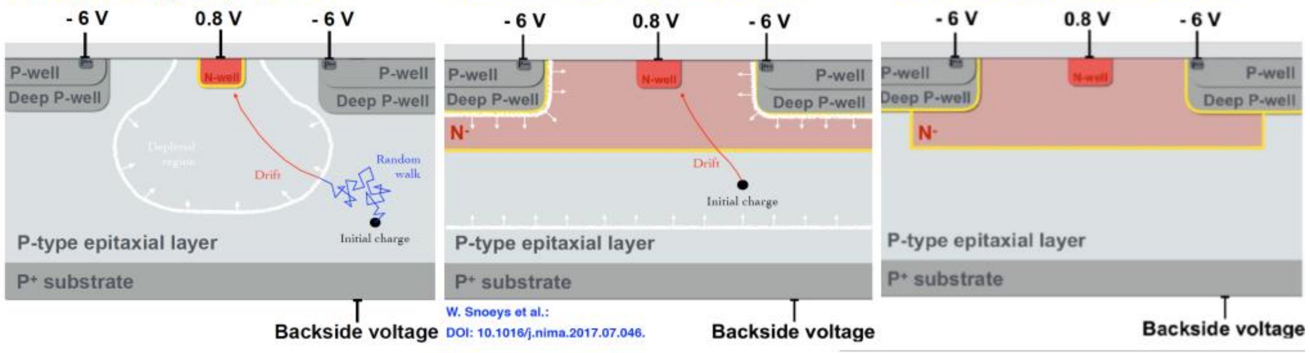


CE65 variants

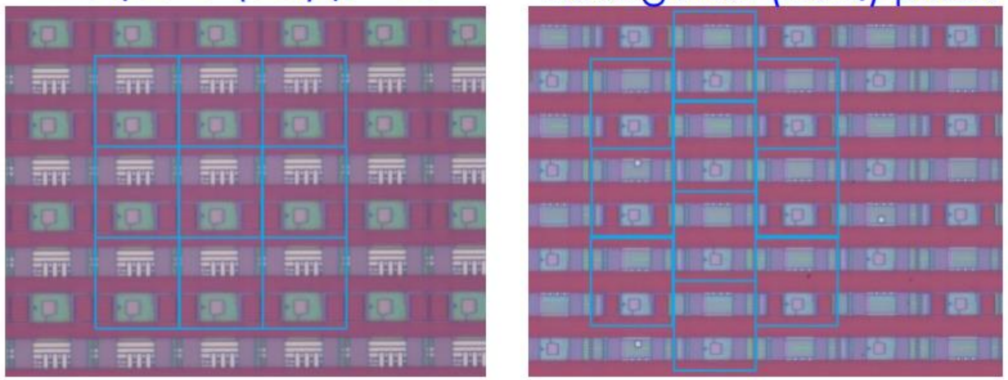
- Reference configuration
  - 22.5 SQ GAP

- Specific studies
  1. Influence of diode conf on baseline 22.5 SQ.
     - 22.5 SQ STD, 22.5 SQ BLK, 22.5 SQ GAP
  2. Influence of pitch in SQ pixels in GAP.
     - 15 SQ GAP, 18 SQ GAP, 22.5 SQ GAP
  3. Influence of HSQ vs SQ in GAP.
     - 18 SQ GAP, 18 HSQ GAP, 22.5 SQ GAP, 22.5 HSQ GAP
  4. Influence of pitch in SQ pixels in STD.
     - 15 SQ STD, 18 SQ STD, 22.5 SQ STD
  5. Influence of HSQ vs SQ in STD.
     - 18 SQ STD, 18 HSQ STD, 22.5 SQ STD, 22.5 HSQ STD
  6. Influence of pitch in SQ pixels in BLK.
     - 15 SQ BLK, 18 SQ BLK, 22.5 SQ BLK
  7. Influence of HSQ vs SQ in BLK.
     - 18 SQ BLK, 18 HSQ BLK, 22.5 SQ BLK, 22.5 HSQ BLK

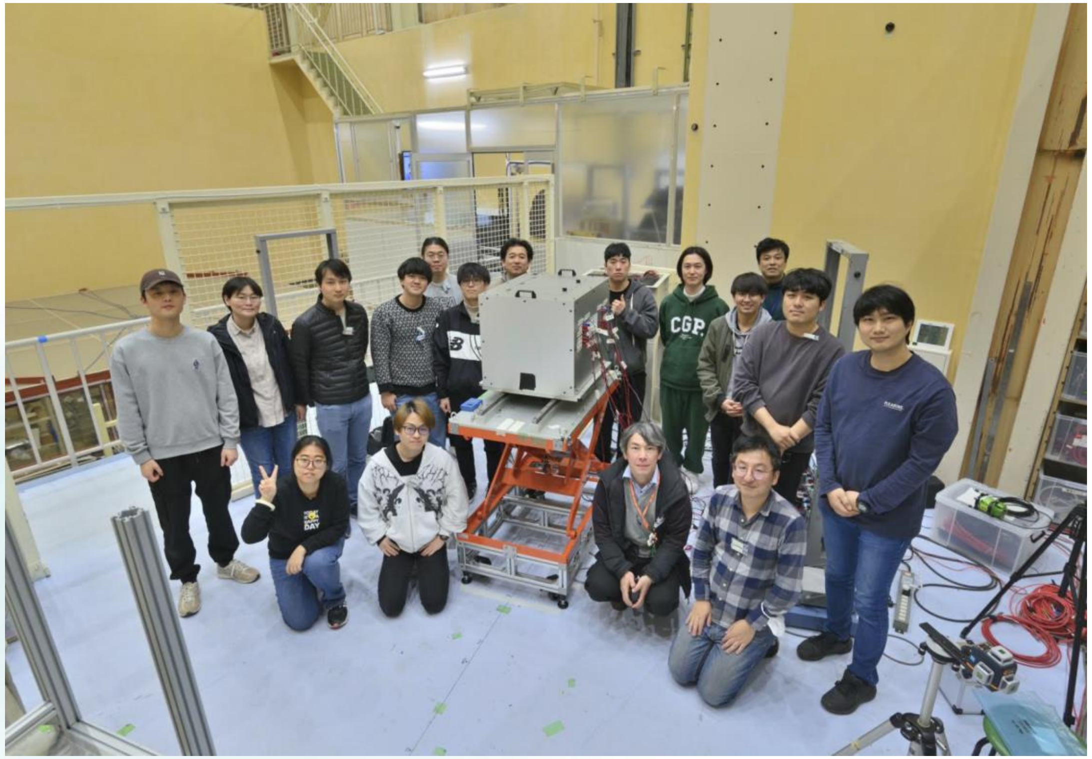
Standard (STD) diode | Blanket layer (BLK) diode | Gap layer (GAP) diode

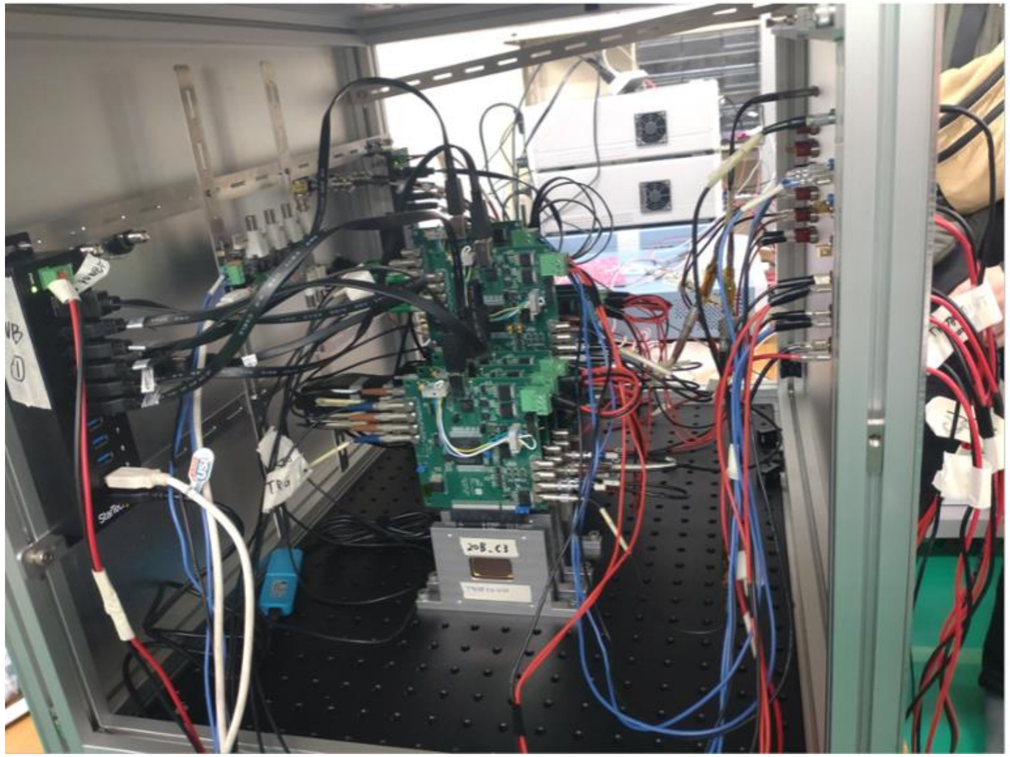


Square (SQ) pixels | Hexagonal (HSQ) pixels



MAPS testbeam at KEK





Beamtests for CE65 chip validation & performance check
Collaboration with ALICE-Korea team (ALPIDE telescope and APTS, Bent-ALPIDE)

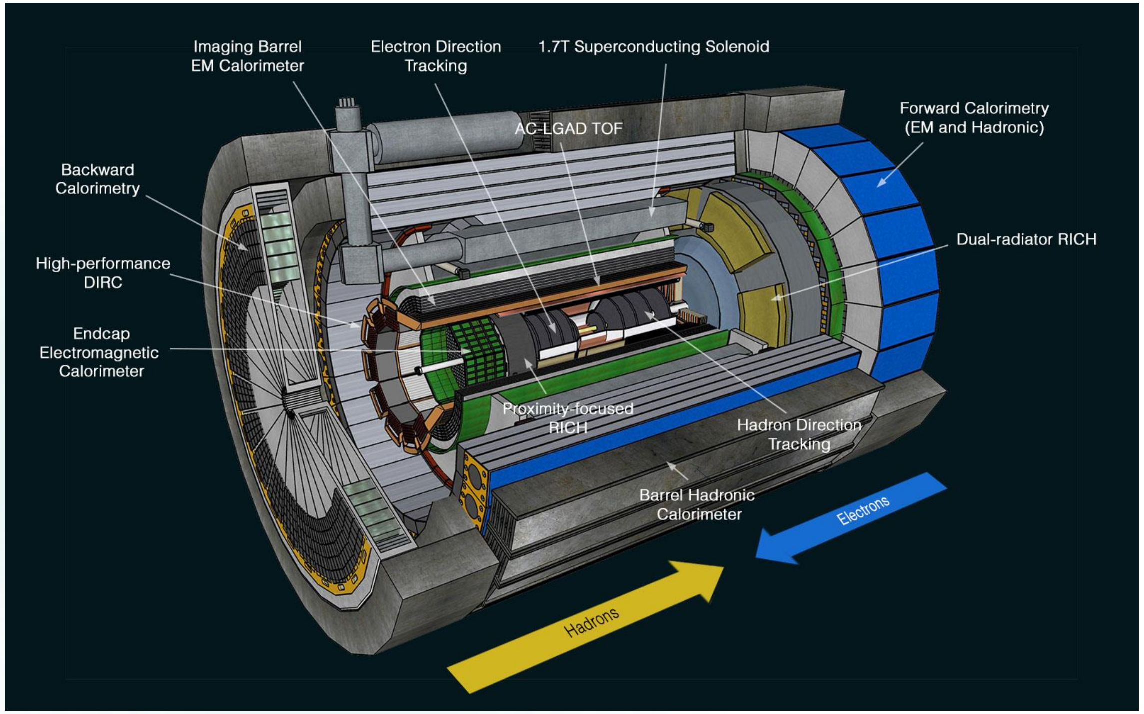
今後の目標

- ALICE3のouter trackerやePIC実験のVTXのupgrade (2040-)を狙う

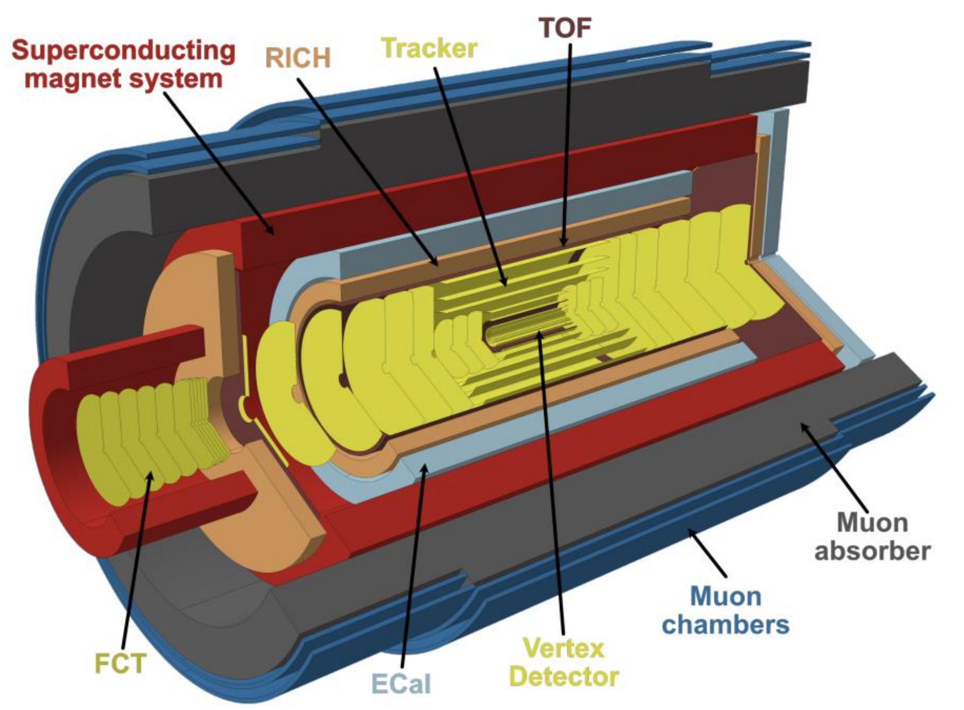
- CE65、MOSS、APTSのテストを通じて、基本的な動作を理解
- TCAD, AllPix2などのsimulation studies
- **自分たちでデザインできるように技術を身につけたい**
  - **ePIC VTXのupgrade**
  - **J-PARCのハドロン実験、E16 upgrade?**
  - **J-PARC-HI**

ePIC/ALICE3でのPID

- ePIC実験 (2030-)

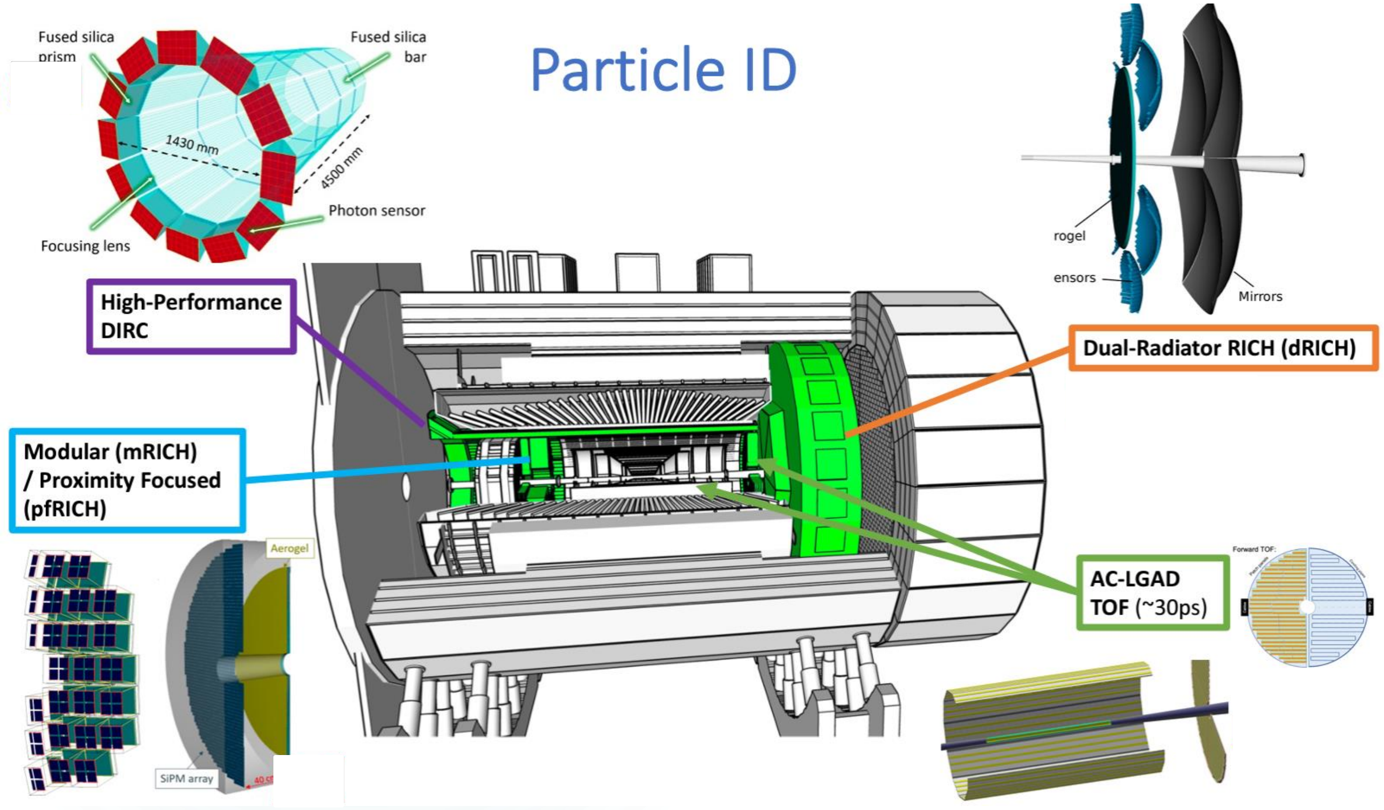


- ALICE3実験 (2035-)



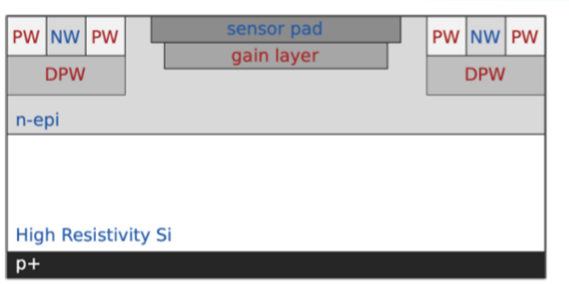
ePIC/ALICE3でのPID

- ePIC実験 (2030-)

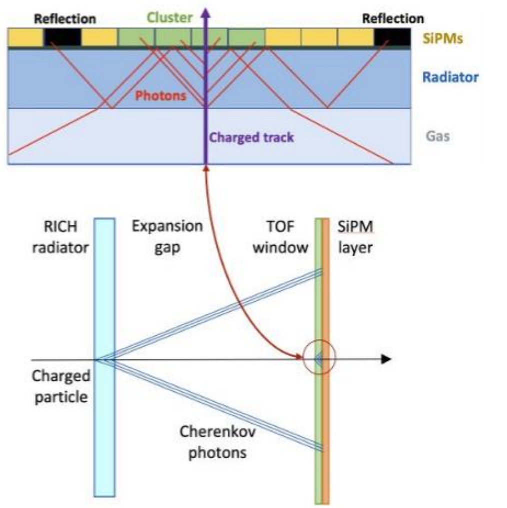


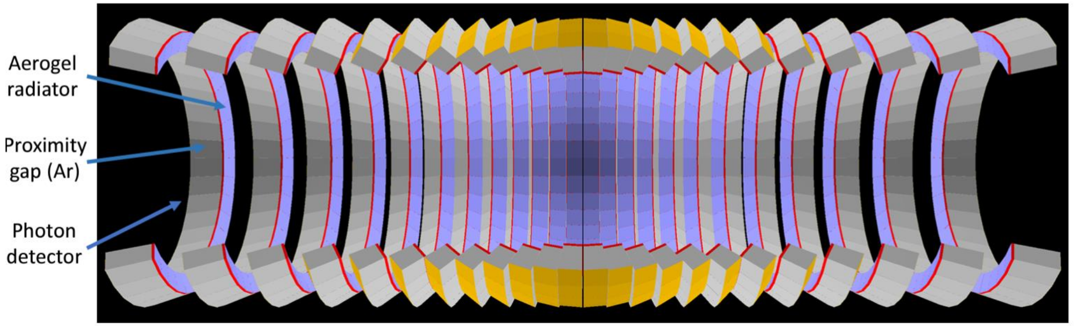
- ALICE3実験 (2035-)

CMOS-LGAD



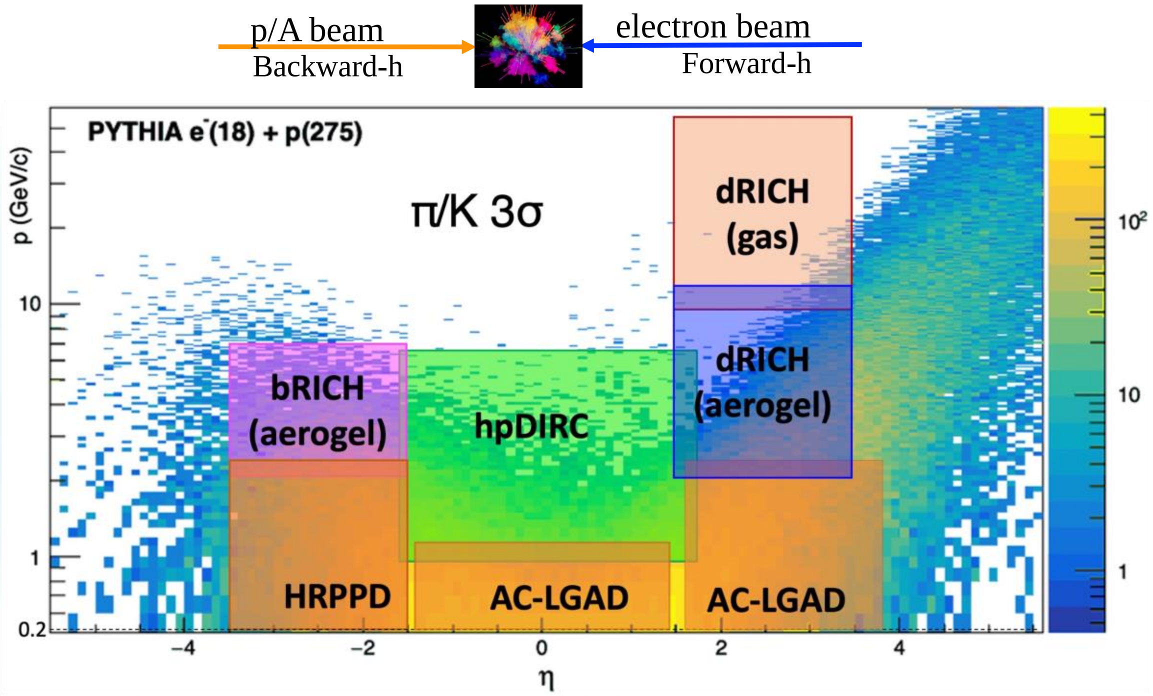
Aerogel RICH



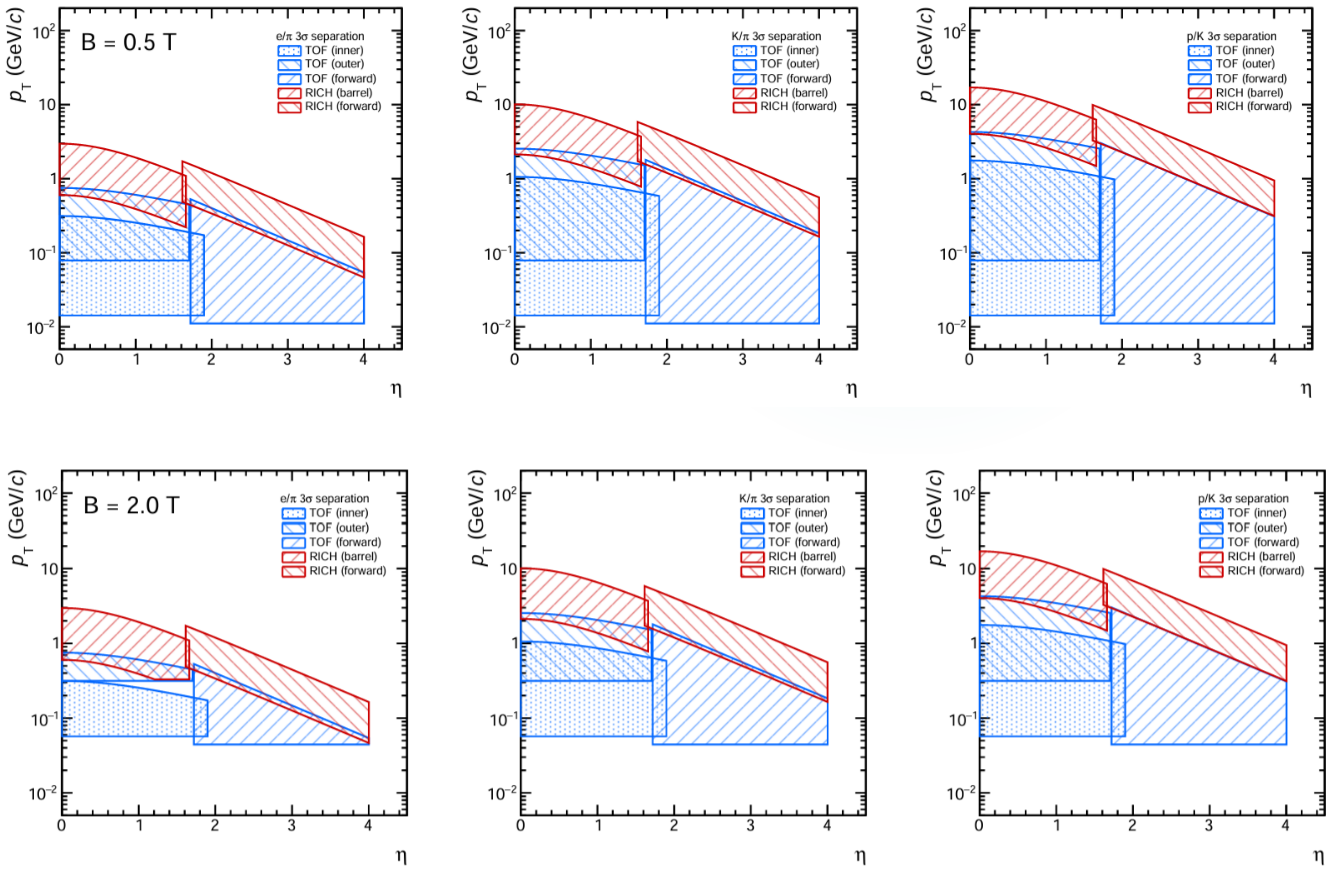


ePIC/ALICE3でのPID

- ePIC実験 (2030-)



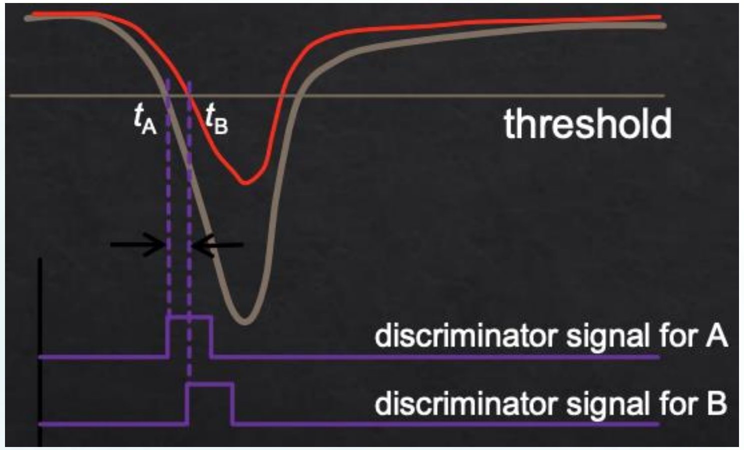
- ALICE3実験 (2035-)



シリコン検出器の時間分解能

$$\sigma^2 = \sigma_{tw}^2 + \sigma_j^2 + \sigma_L^2$$

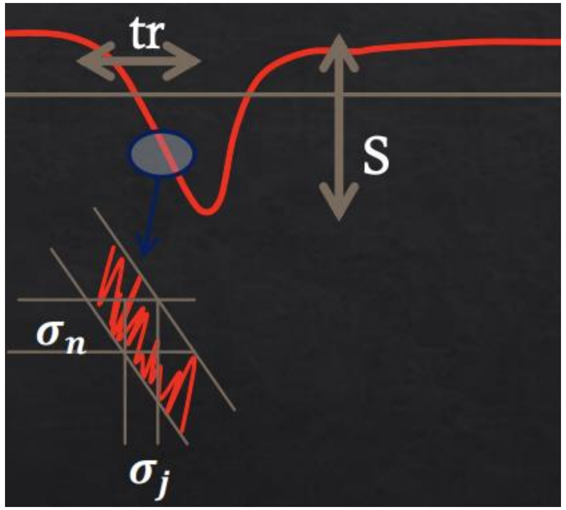
タイムウォーク



信号の大きさのばらつきによる
Over-thresholdのタイミングのずれ。CFDで補正可能

$$\sigma_{TimeSlewing} = [t_d]_{RMS} \propto \left[\frac{N}{dV/dt}\right]_{RMS}$$

ジッター



信号に乗るノイズによる影響
ノイズの大きさと立ち上がりの速さに依存

$$\sigma_{Jitter} = \frac{N}{|dV/dt|_{V_{th}}} = \frac{t_r}{S/N}$$

ランダウノイズ

- 電子が励起する際の確率的なばらつき
- Padから遠い電子ほど信号の遅れが出る

検出器の厚さに依存

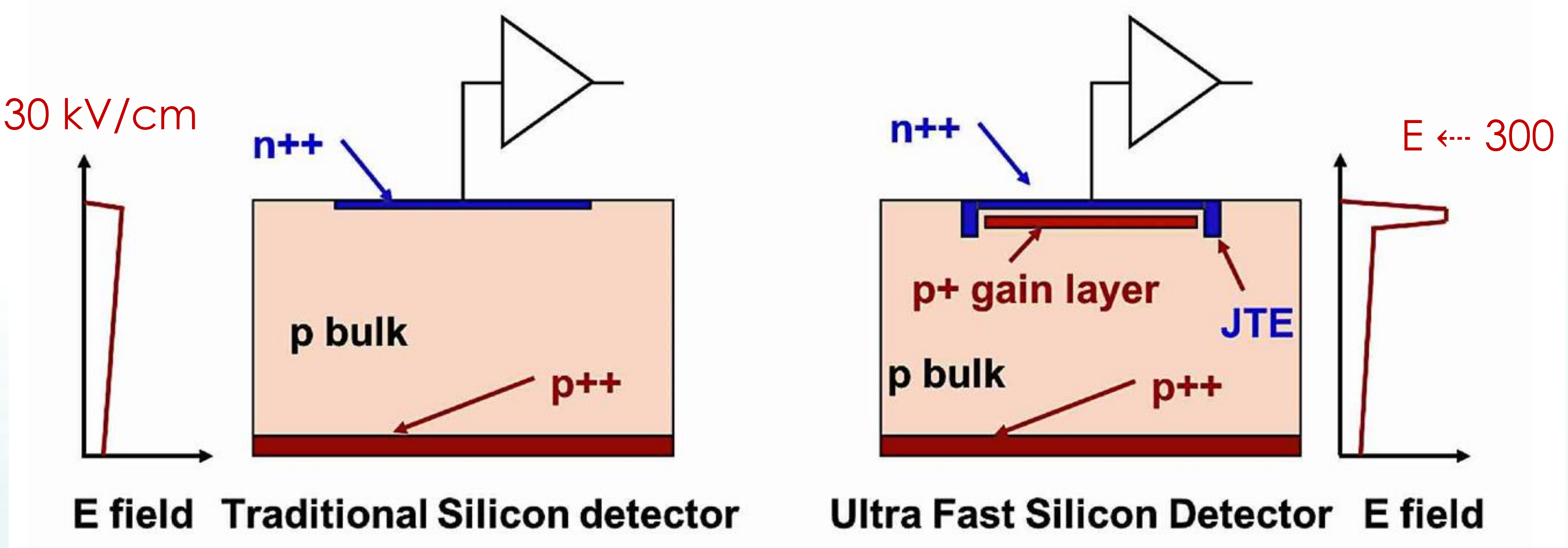
ジッターとランダウノイズの改善が必要

信号の立ち上がりが速いほど
時間分解能がよい。
低ノイズである必要がある。

LGAD検出器

E ⇠ 30 kV/cm

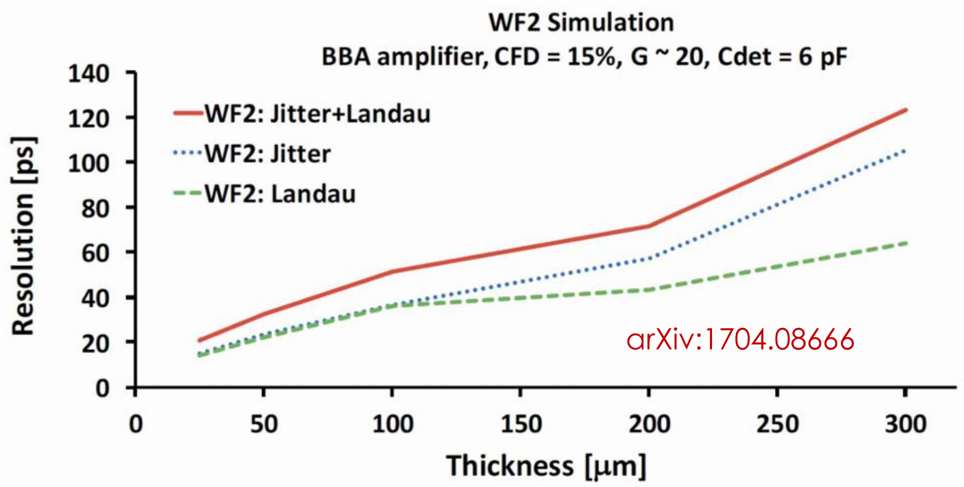
E ⇠ 300 kV/cm



- ゲインレイヤー(濃いpn接合)をPad付近に入れることで強い電場を形成
- ゲインレイヤーの強い電場で電子雪崩が起き、信号の立ち上がりが速くなる

Ramo's theorem

$$\frac{di_G}{dt} \propto \frac{G}{d}$$

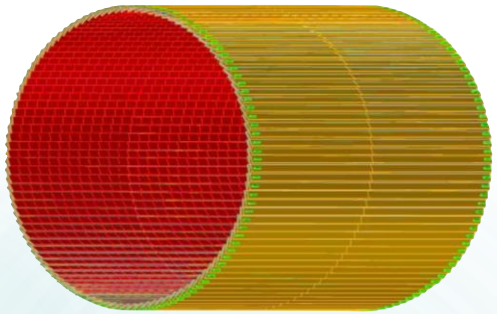


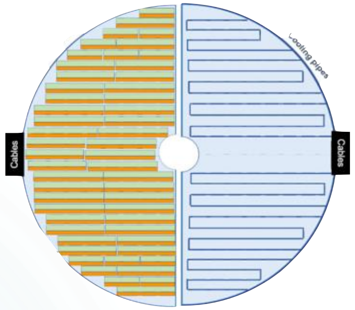
arXiv:1704.08666

LGAD検出器

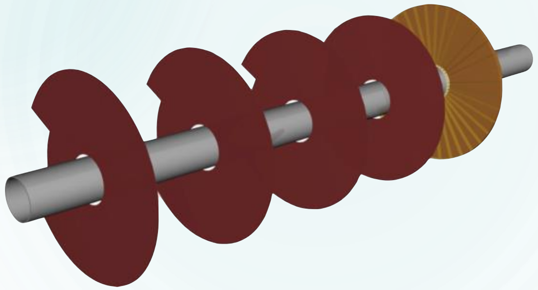
- **ePIC実験では、様々なシステムがAC-LGAD検出器を使用予定**

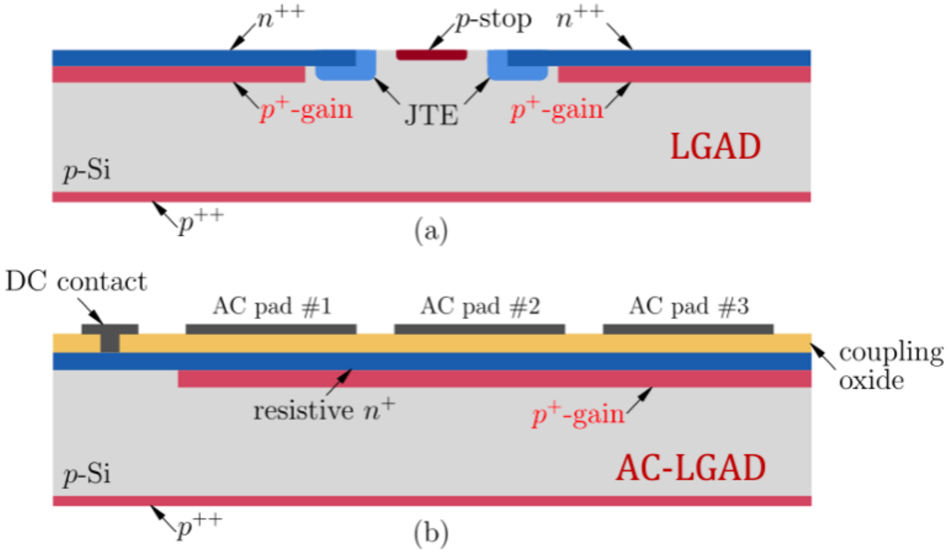
バレル ToF （ストリップ）　前方 ToF （ピクセル）



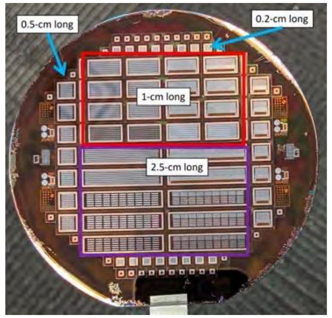


超前方飛跡検出器 （ピクセル）　ローマンポット （ピクセル）

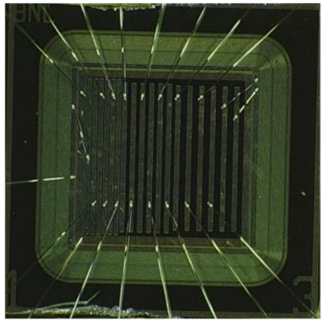




BNL 4" wafer



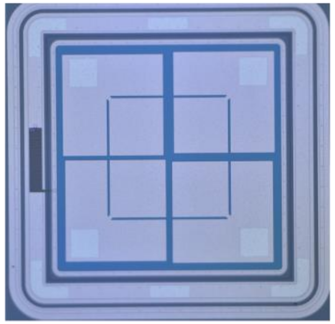
Strip type by BNL



3x3 mm² Sensor size

100µm, 150 µm, 200 µm

Pad type by HPK



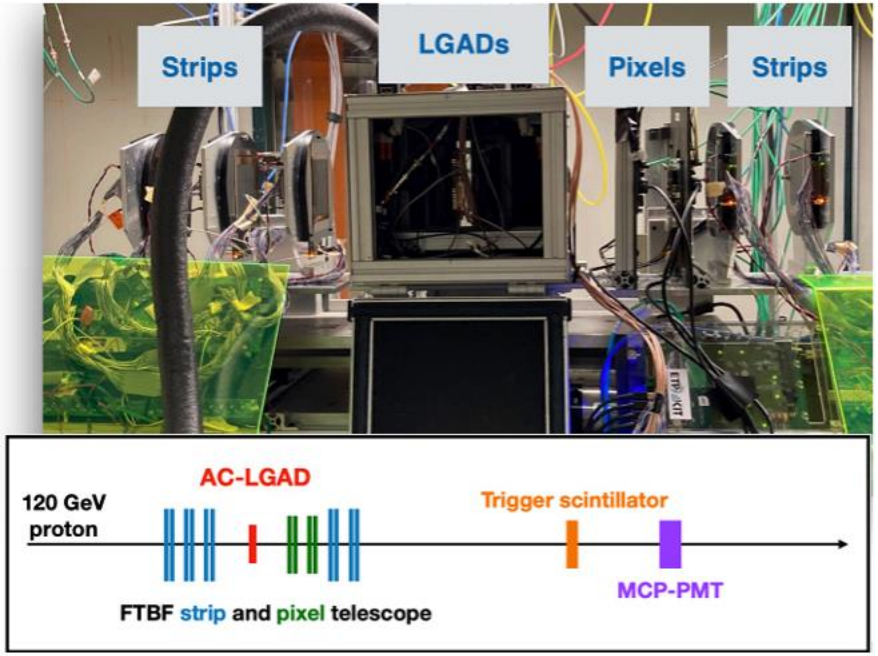
3x3 mm² Sensor size

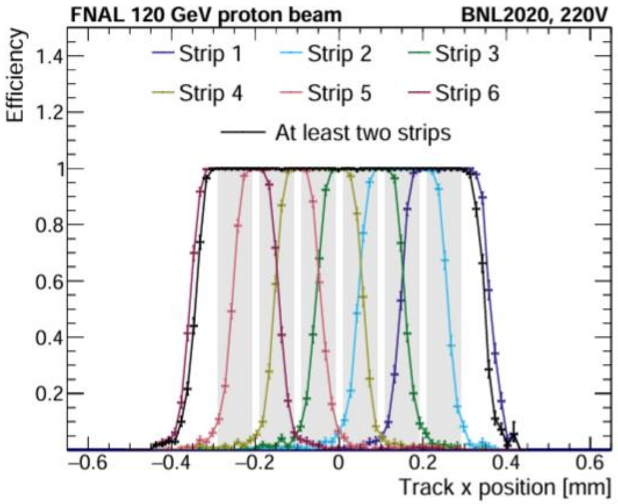
- **BNLとHPK（eRD112 – LGAD consortium）で製作**

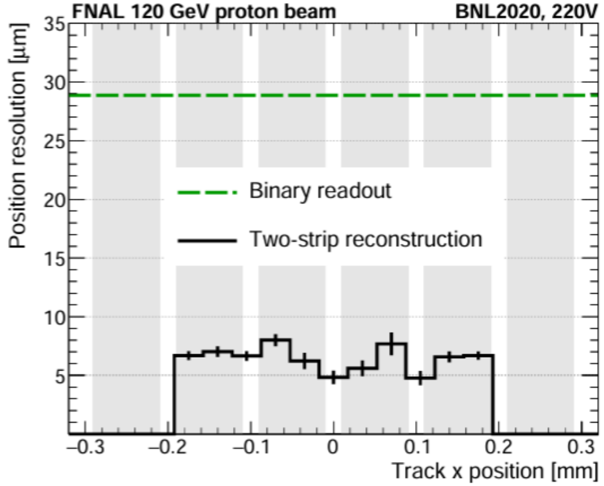
AC-LGADの性能

- **Permanent setup in FNAL test beam facility (FTBF)**

R. Heller *et al.*,
JINST 17 P05001 (2022)

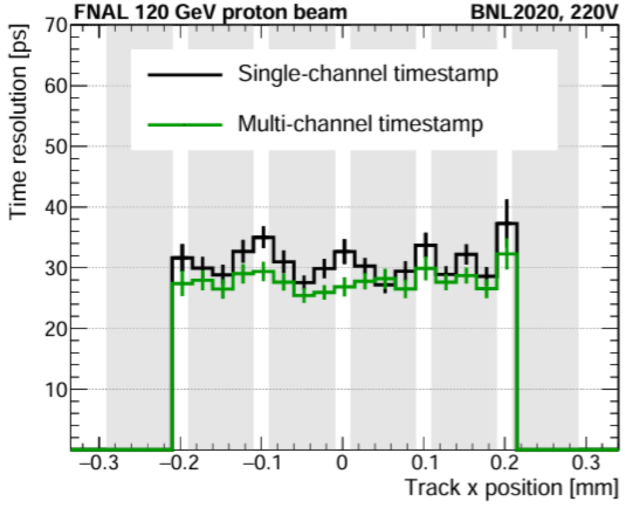






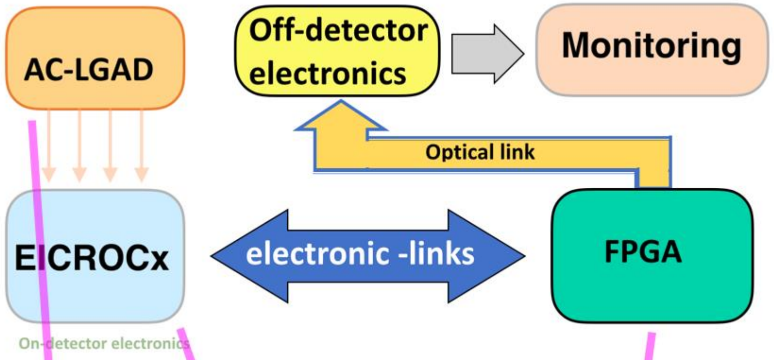
Name	Pitch	Primary signal amp.	Position res.	Time res.
Unit	μm	mV	μm	ps
BNL 2020	100	101 ± 10	≤6	29 ± 1
BNL 2021 Narrow	100	104 ± 10	≤9	32 ± 1
BNL 2021 Medium	150	136 ± 13	≤11	30 ± 1
BNL 2021 Wide	200	144 ± 14	≤9	33 ± 1
HPK C–2	500	128 ± 12	22 ± 1	30 ± 1
HPK B–2	500	95 ± 10	24 ± 1	27 ± 1

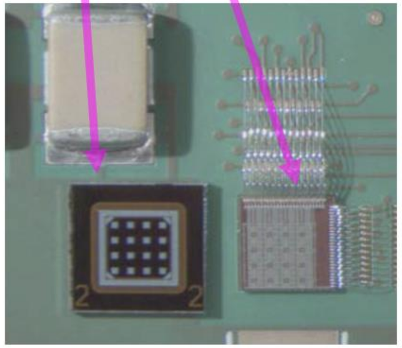
→ Designed and produced by KEK/Tsukuba with HPK



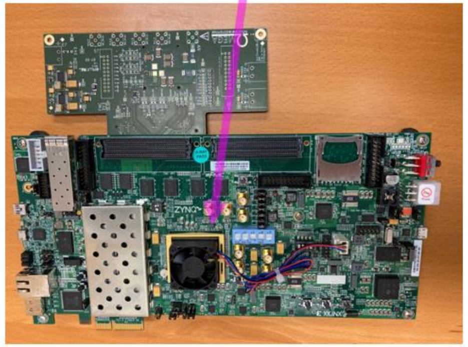
開発拠点 @ 広島大学 WPI-SKCM²

- 米国 BNL, 広島大学, … (IJCLab/Omega と協力)
- AC-LGAD 素子 + 読出 ASIC (EICROC)

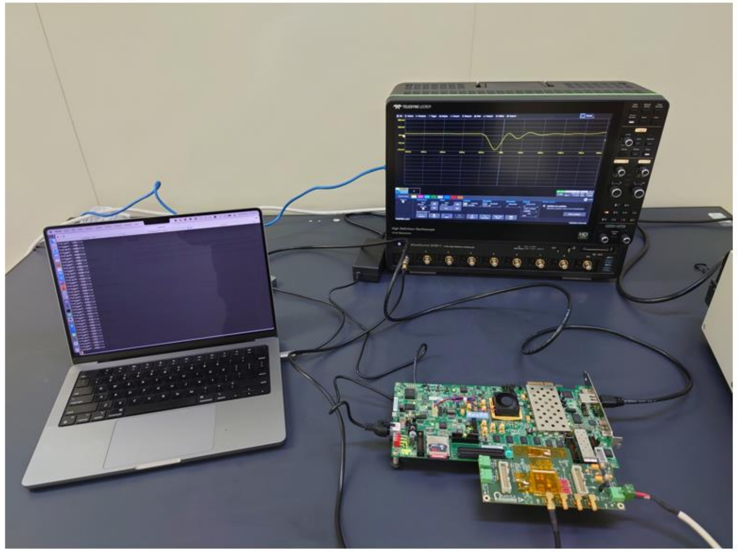




拡張基板に載った AC-LGAD と EICROC0



プロトタイプ読出基板 (Xilinx 開発キット = FPGA + ZYNQ プロセッサ)

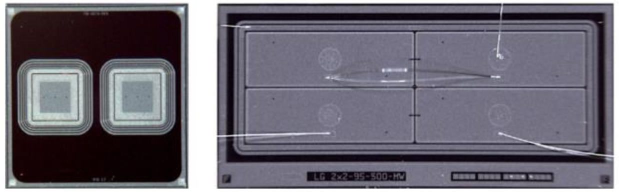


広島大学テストベンチ (一部)

開発目標 (短～中期)

- 多種アセンブリのチェーン性能評価
  - 形状などを変更した複数の BNL / 浜松製 AC-LGAD 素子
    - TCAD シミュレーションによる検出素子内部構造最適化
  - ASIC(s) + 読出基板試作機
    - ストリップ形状などの調整も含めた適合性
  - 要求性能 ~30 ps, ~30 μm 堅持
- β 線, IR レーザー, 陽子線 (FNAL), 電子線 (ELPH)
  - 時間 / 位置分解能
  - 電荷収集効率, 電極間共有
- 日本国内におけるストリップ型 AC-LGAD 技術確立
  - 設計, シミュレーション, 製作, システム統合, データ解析

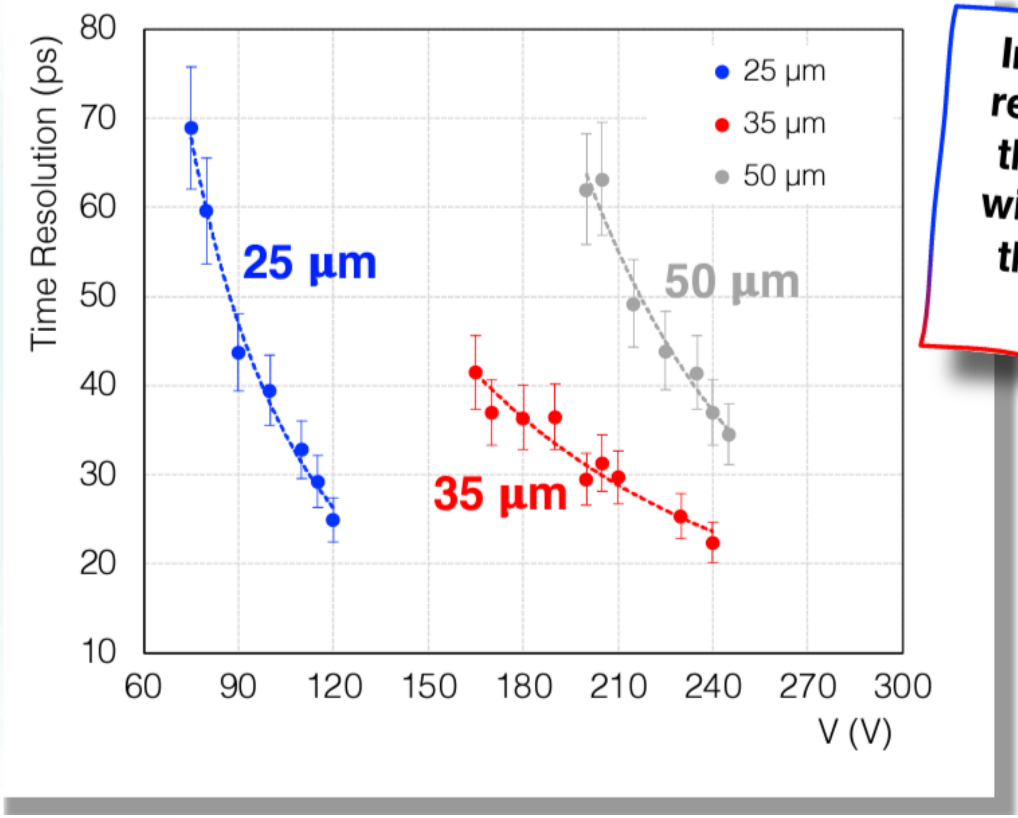
LGAD R&D for ALICE3



- **First beam test 2021 on very thin FBK LGAD: 25 and 35 μm thick**

https://link.springer.com/article/10.1140/epjp/s13360-022-03619-1

	Area	Thickness	V_{bd}	Voltage applied	Gain
FBK25	1×1 mm^2	25 μm	127.3 ± 0.1 V	75-120 V	13–57
FBK35	1×1 mm^2	35 μm	260.7 ± 0.2 V	165-240 V	10–49
HPK50	1×3 mm^2	50 μm	253.0 ± 0.2 V	200-245 V	26–61



Improved time resolution with thinner LGAD with respect to the standard 50 µm

Standard LGAD (50 µm) in line with the expectations

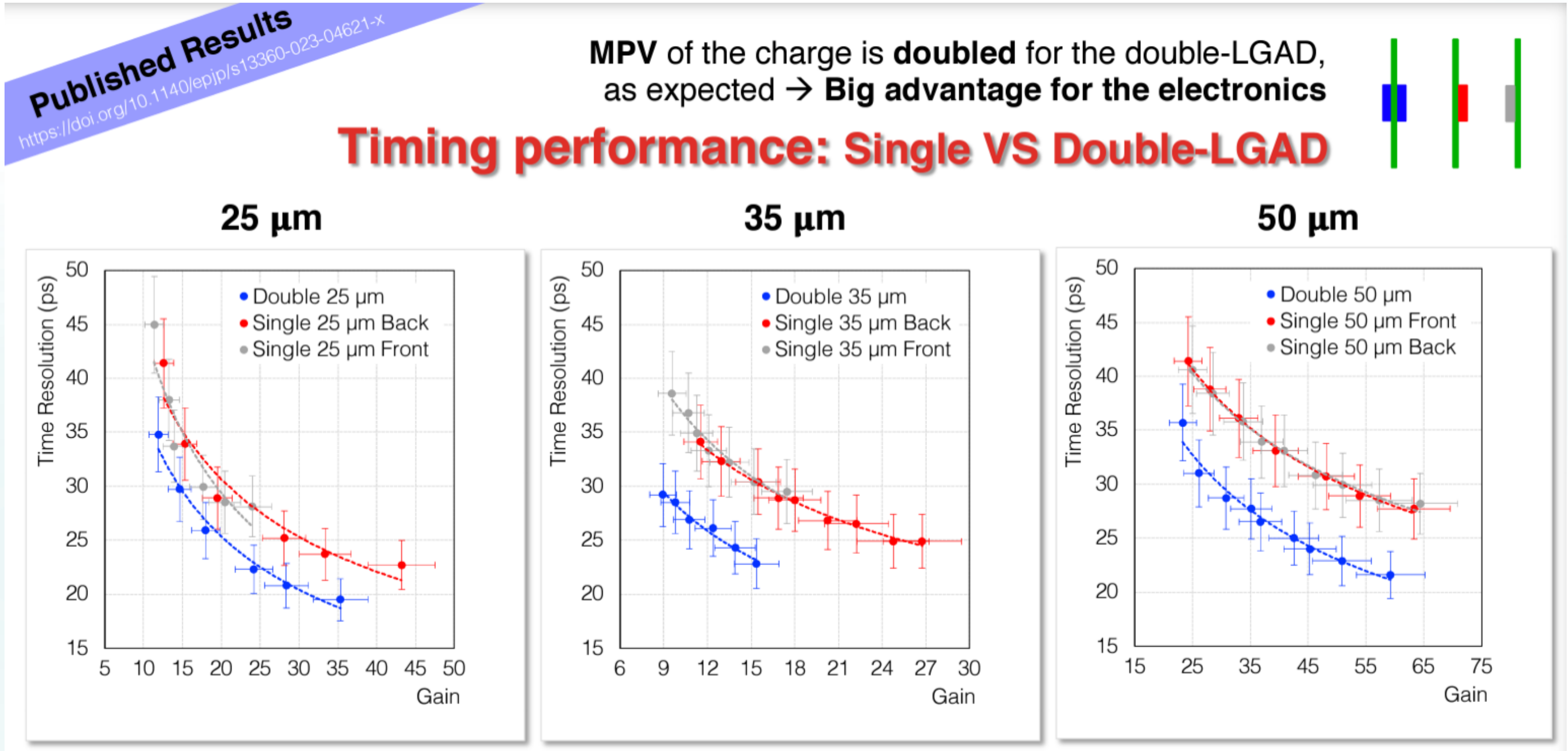
- Validation of the setup and the analysis procedure

35 µm — **22 ps** : In agreement with MC simulations

25 µm — **25 ps** : Slightly worse time resolution than what foreseen from simulations (worse S/N)

LGAD R&D for ALICE3

- **Double LGAD**

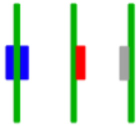


- Single LGADs: **comparable** time resolution **for a similar gain**
- **Better time resolution for a double-LGAD** in respect to single ones

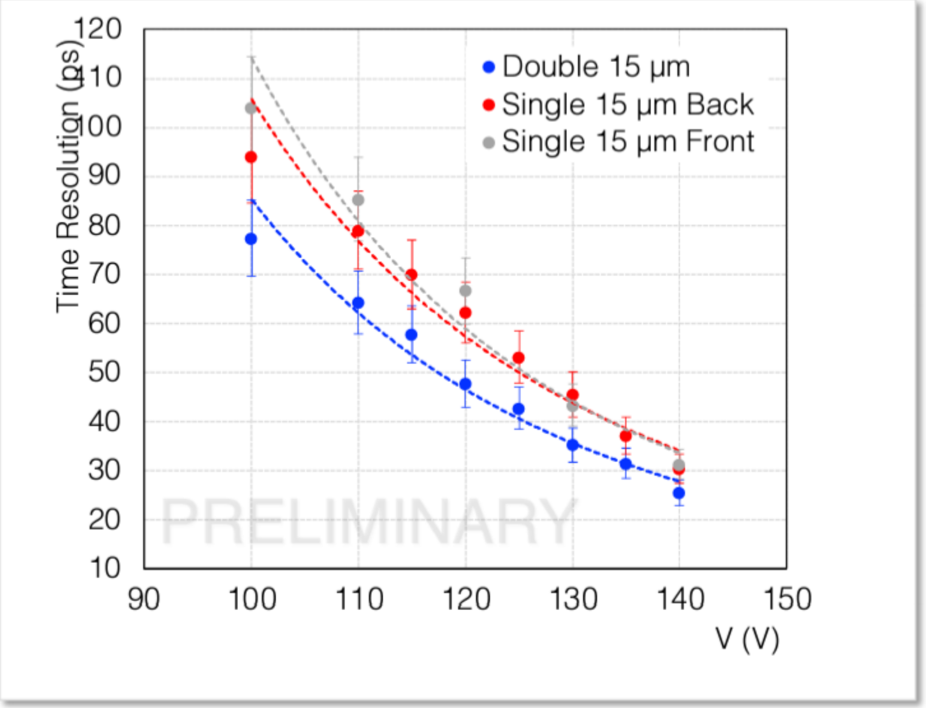
LGAD R&D for ALICE3

New Results

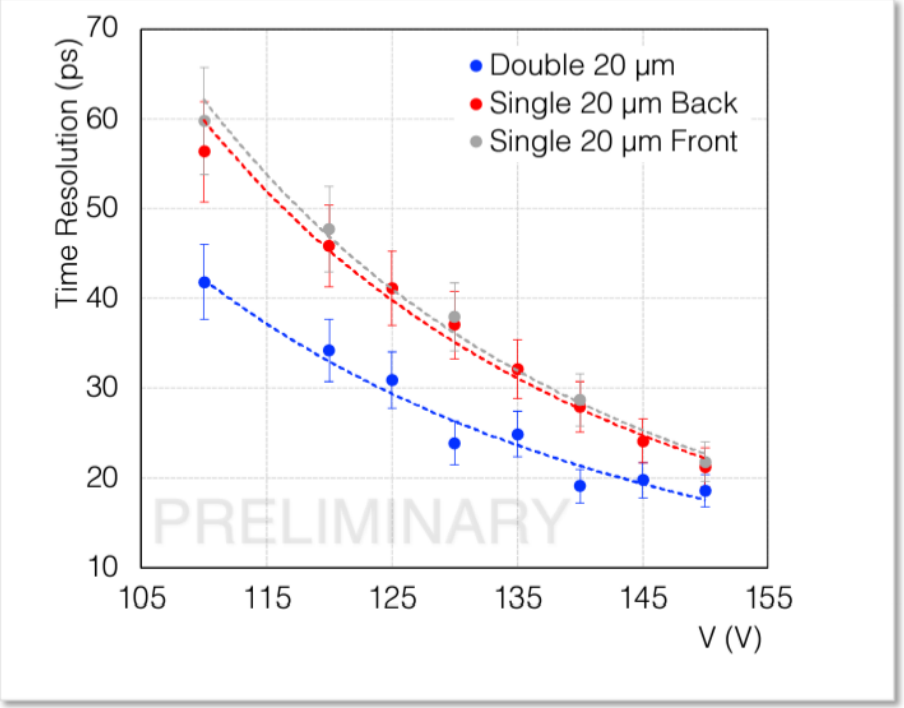
Timing performance VS Voltage
Single & Double-LGAD



15 µm



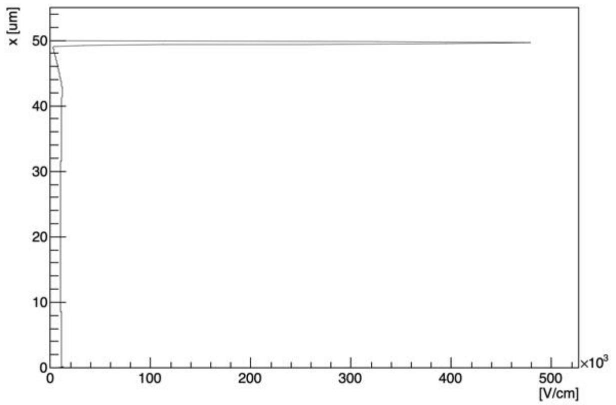
20 µm



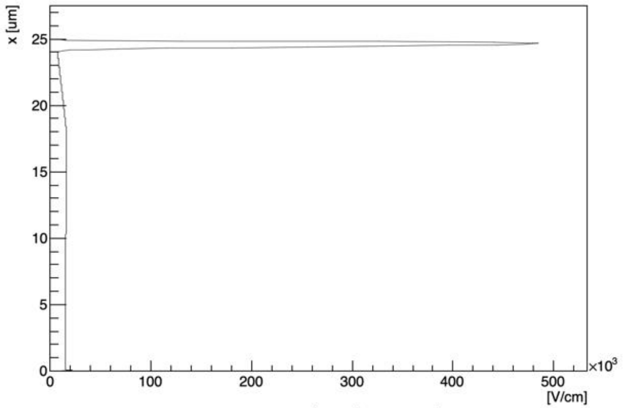
- Single LGADs: **comparable** time resolution **for a similar voltage**
- **Better time resolution for a double-LGAD** in respect to single ones

CMOS-LGADに向けたGarfield simulation

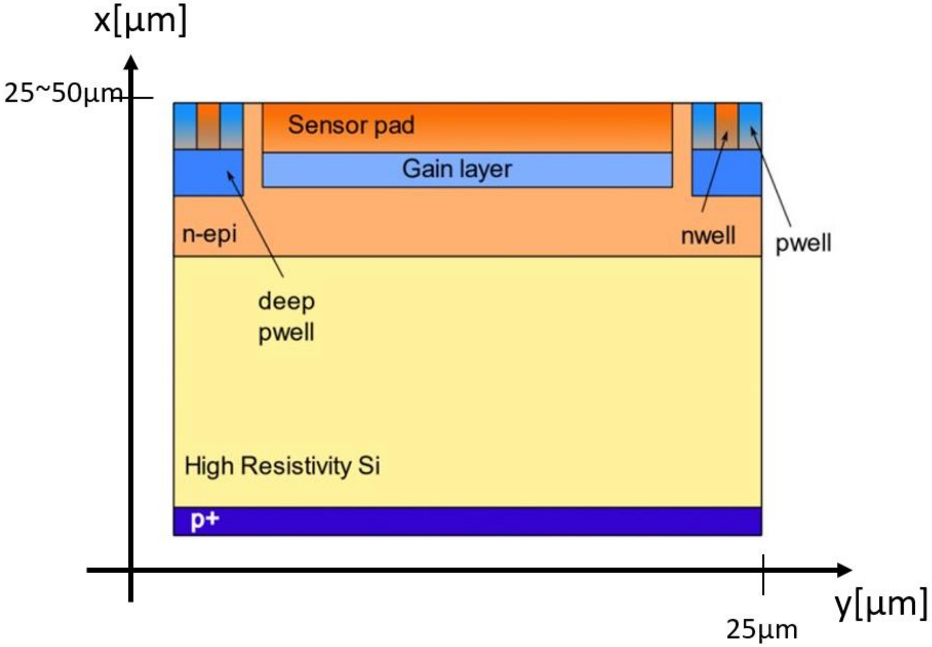
電場

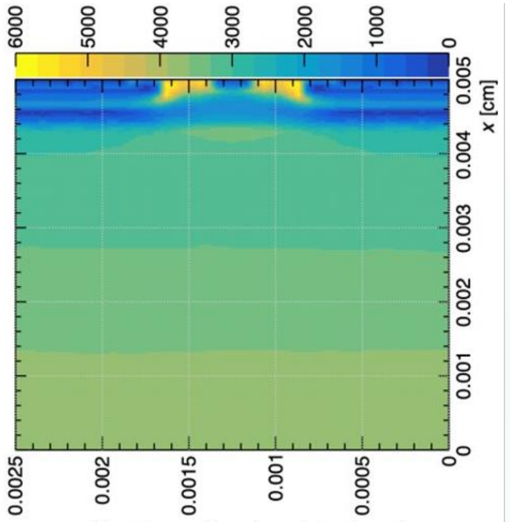


一次元モデル(50μm)

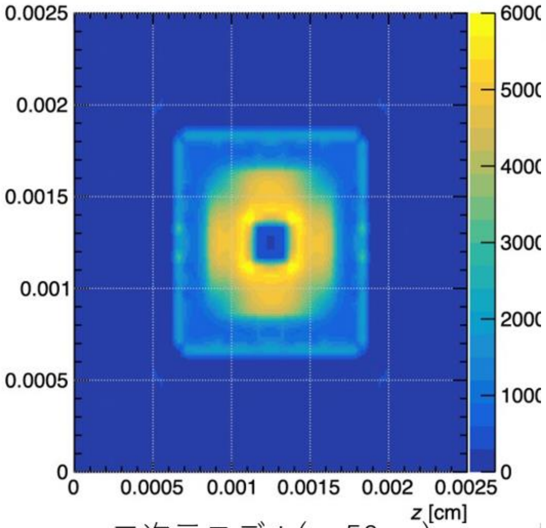


一次元モデル(25μm)





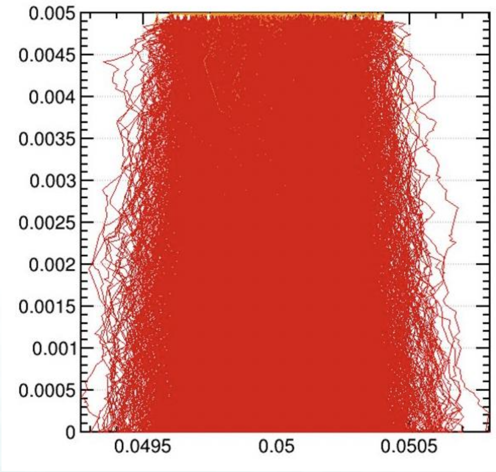
二次元モデル(y=12.5μm)



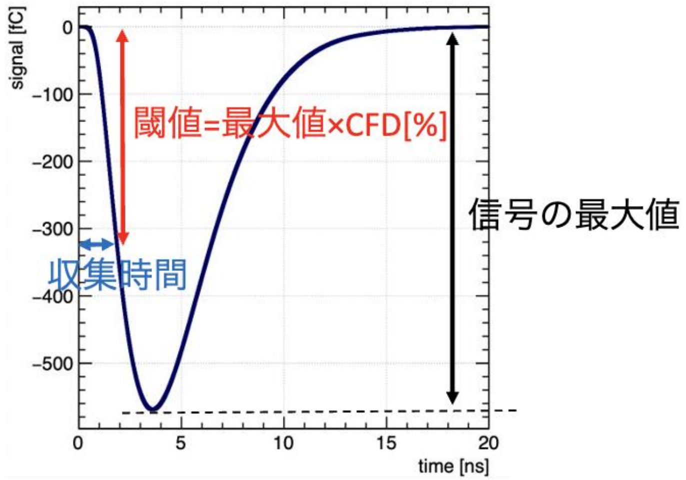
二次元モデル(x=50μm)

CMOS-LGADに向けたGarfield simulation

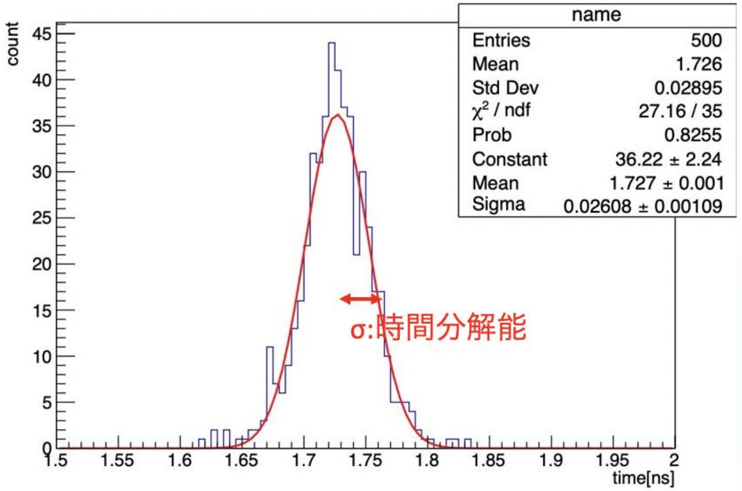
$$f(t) = g \exp(n) \left(\frac{t}{t_p}\right)^n \exp(-t/\tau), \quad t_p = n\tau,$$ (n=2.5 τ=1.5 g=50)



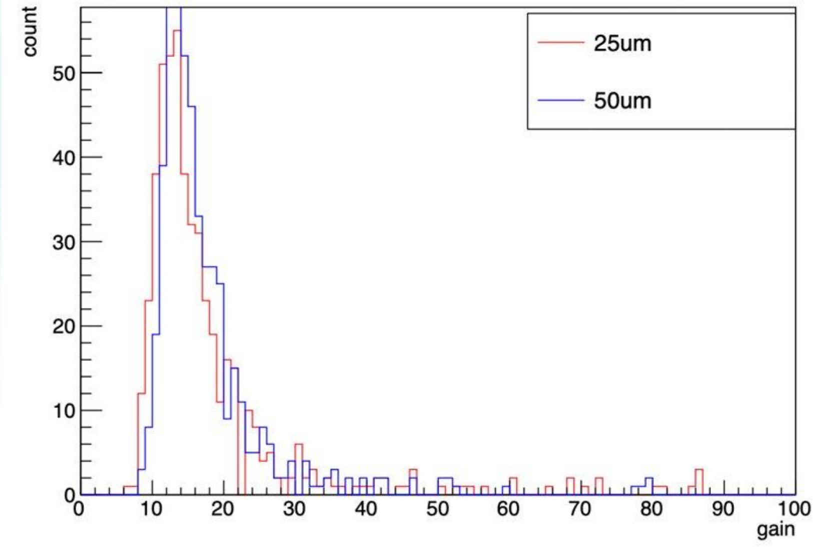
gain

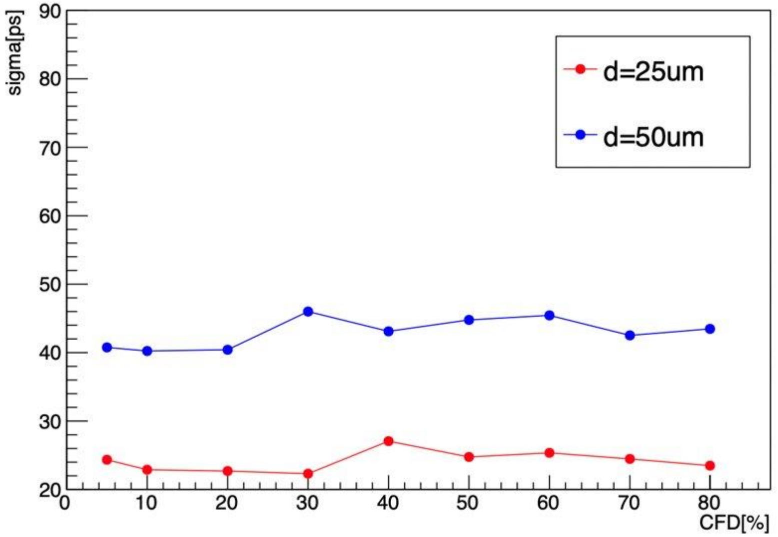


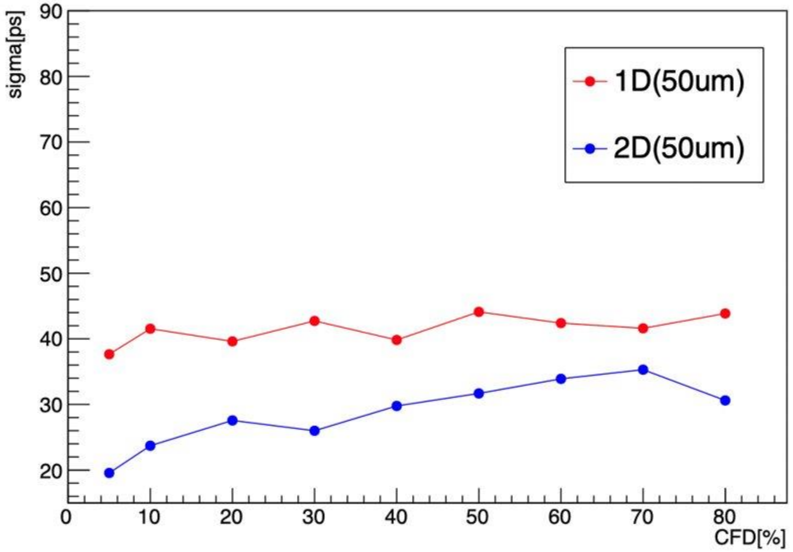
timing resolution



timing resolution







CMOS-LGAD

MadPix

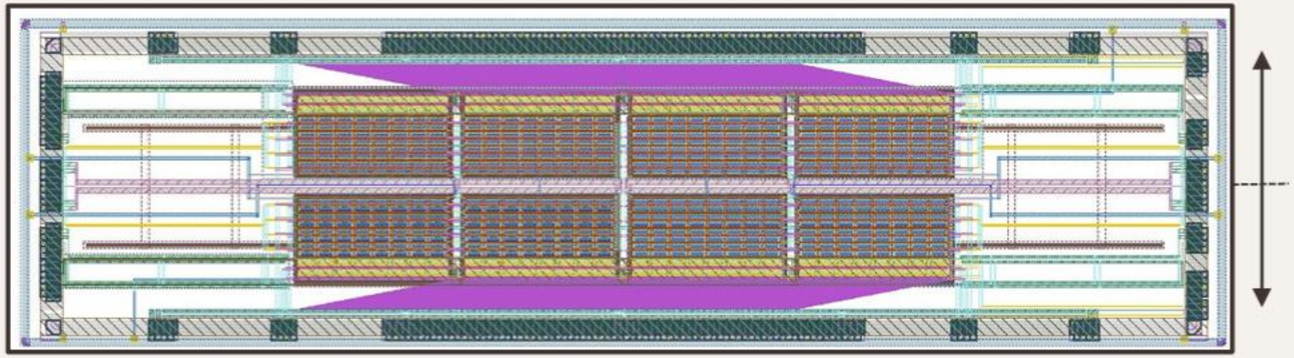
Monolithic CMOS Avalanche Detector PIXelated Prototype for ps Timing Application

First prototype with **integrated electronics** (LFoundry 110 nm) and **sensor gain**

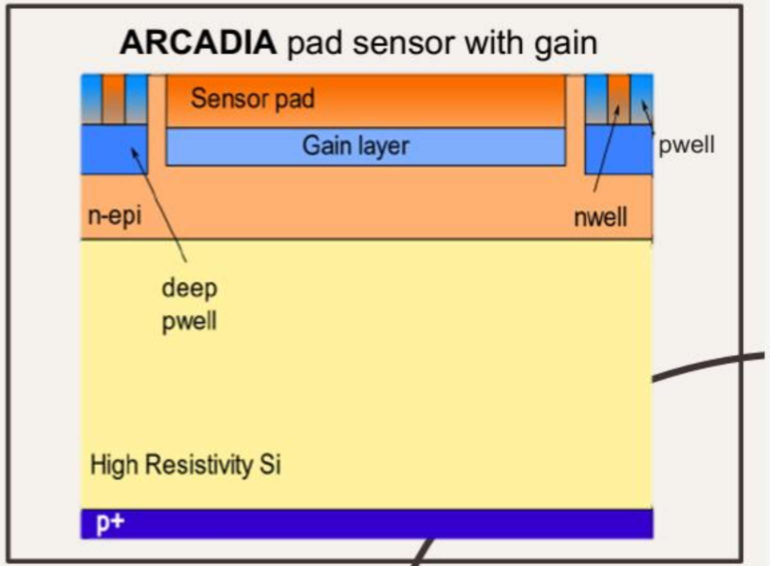
Active thickness: 48µm

- **Backside HV**: allow full depletion → -25 V to -40 V
- **Topside HV**: manage the gain → 30 V to 50 V

- 8 matrices of 64 pixels each
- 64 x 2 analogue outputs
- 4 flavours
- Pixels of 250µm x 100µm



Symmetrical



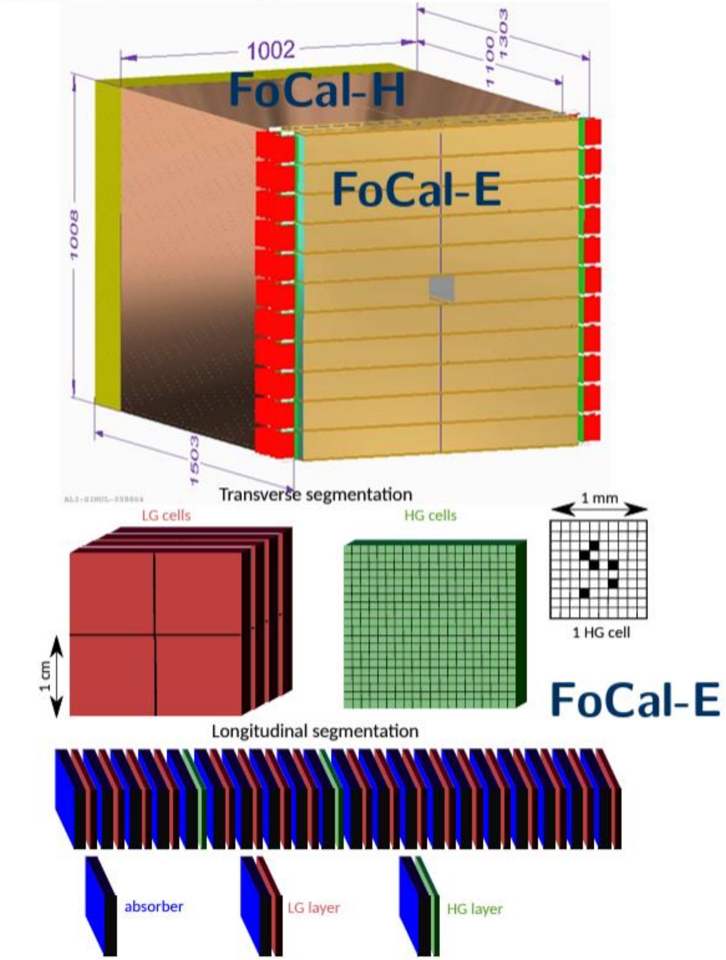
Lucio Pancheri

CMOS-LGADの今後

- レートが高い実験では、時間分解能の良い検出器がないと大変
  - しかも、ストリーミングで読んでしまうと、どのイベントからくるのか、同定が難しい
- LGADがCMOSで読み出しと一体化できれば、究極の検出器になると思う
- CMOS-LGADの開発を継続したいが（東大はGarfield simulationでのstudyをやっていたが、人がいないので継続するのが難しくなってきた）、マンパワーがない
- 何とか継続したいが、興味があればぜひ！

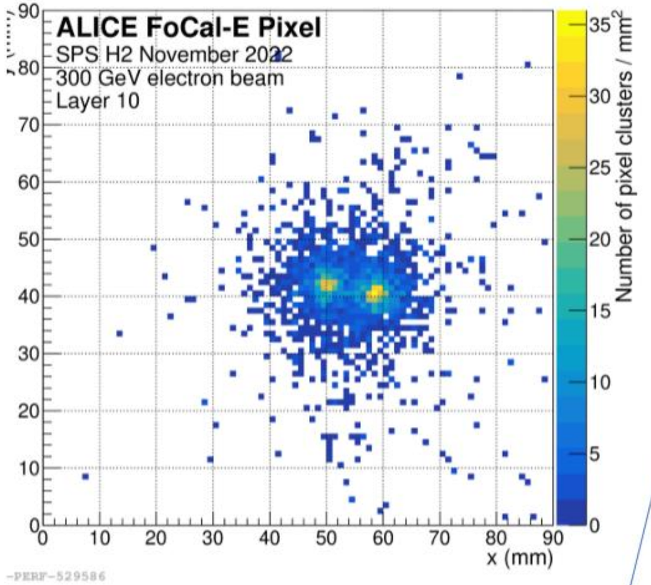
CMOS sensor imaging calorimeter

ALICE FoCal



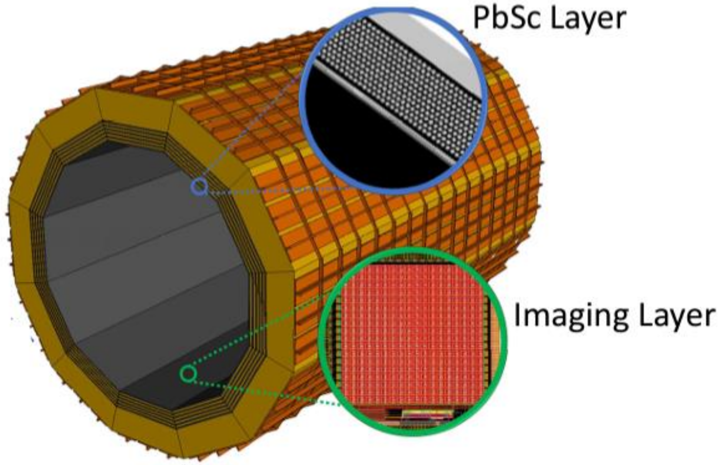
FoCal-E

Shower separation in FoCal-E pixels



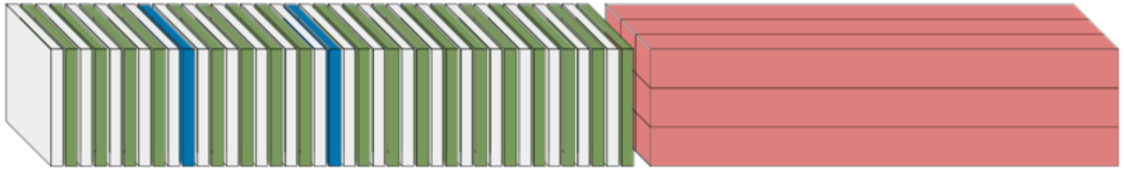
Pixel layers (ALPIDE) interleaved with Si PAD

Similar approach is also considered for the EPIC BECAL



ePIC ZDCとALICE-FOCAL

▶ ALICE-FOCAL

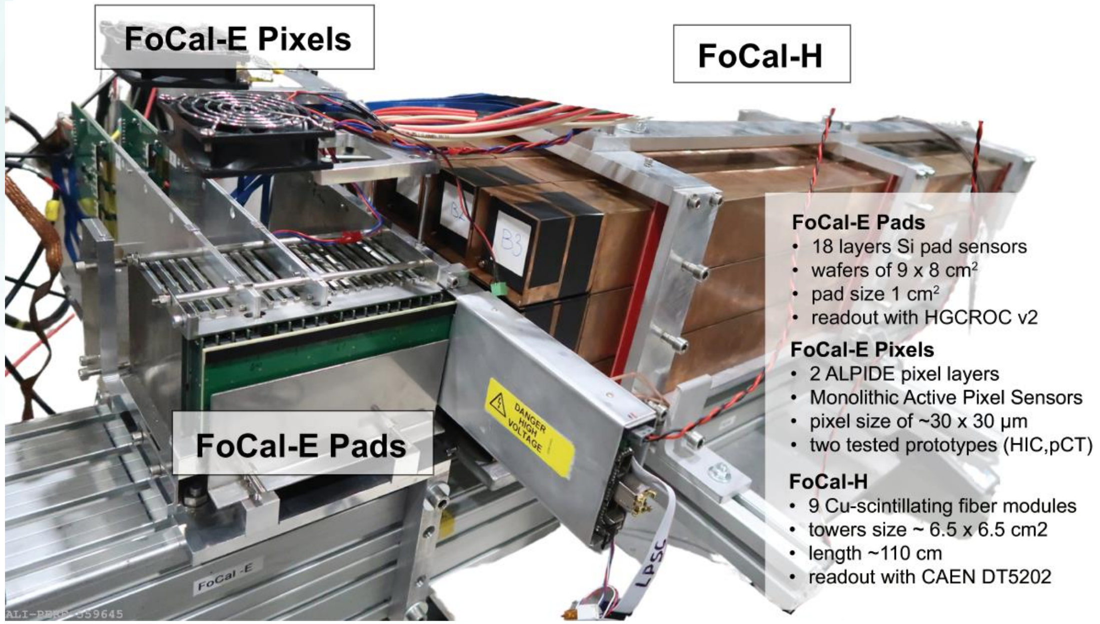


FoCal-E

- 20 tungsten layers, with thickness of 3.5 mm = 1 X_0
- 18 layers of silicon pad sensors, pad size ≈ 1x1 cm^2
- 2 layers of silicon pixel sensors, pixel size ≈ 30 x 30 μm^2

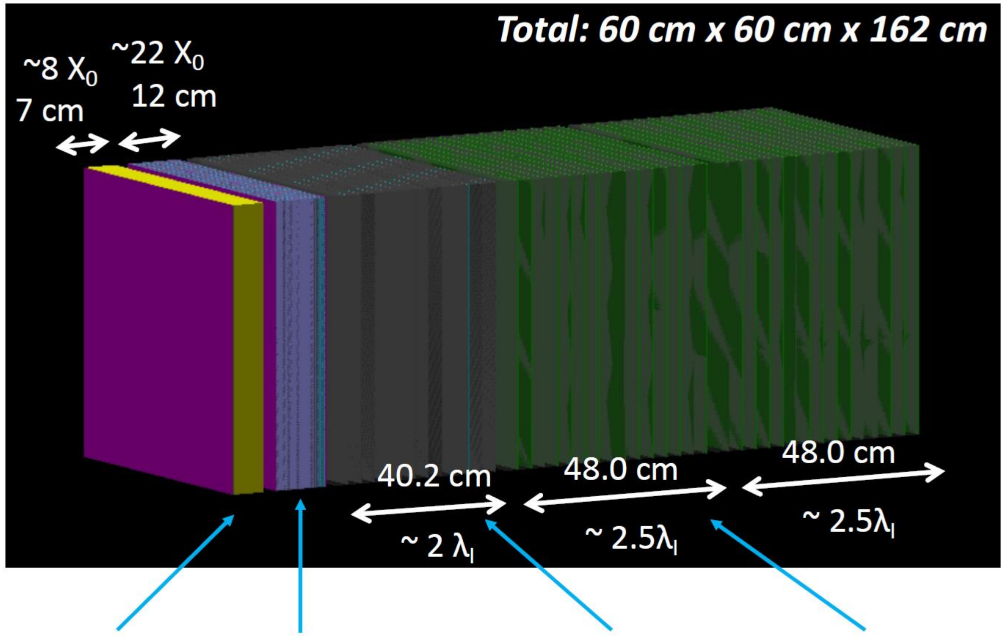
FoCal-H

- length of 110 cm
- copper "strawtubes" with 2.0 mm diameter
- scintillating fibre with ≈ 1.1 mm diameter



▶ ZDC

*note: space for readout may extend the longitudinal length.



Crystal ($PbWO_4$) + Silicon Pixel layer

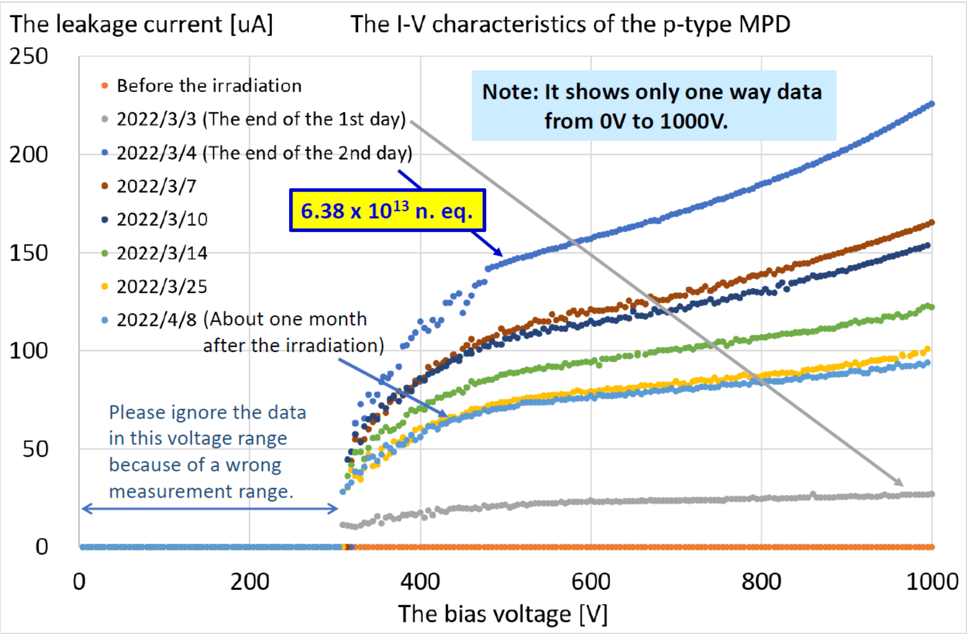
W/Si calo. 3 Pixel layers are inserted.

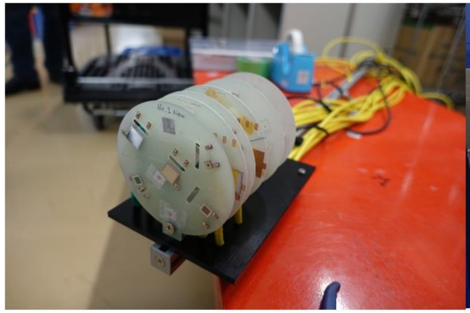
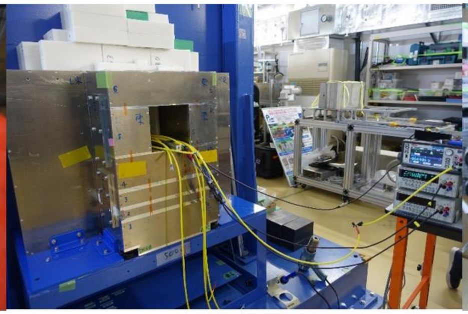
Pb/Si calo.

Pb/Sci. calo.

中性子照射テスト@理研RANS

- 放射線耐性
  - ePIC-ZDCでは、1年間で10^{11} – 10^{12} neutron/cm^2 以上の放射線量
  - ALICE-FoCal実験と同程度の放射線量
- 理研RANS
  - 7MeV陽子、100μA、6 x 10^{13} proton/s
    - 安定して出せる最大電流は40μA程度
    - Be標的から最大5MeVの中性子、標的から2cmで 10^8 neutron/cm^2/s程度
  - FoCal-E padのp-type/n-typeのbaby-chip/MPD、ePIC結晶カロリメータ読み出し用のAPD/SiPMをテスト
    - MPD（九州大提供）、インジウム箔、温度計でモニター

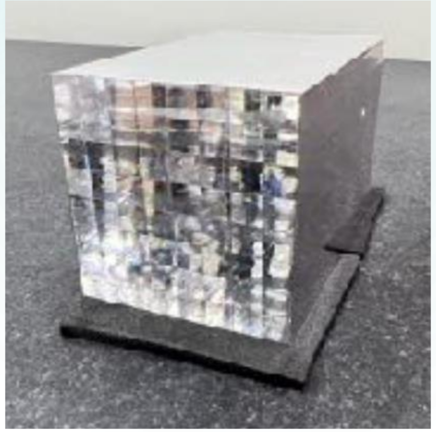
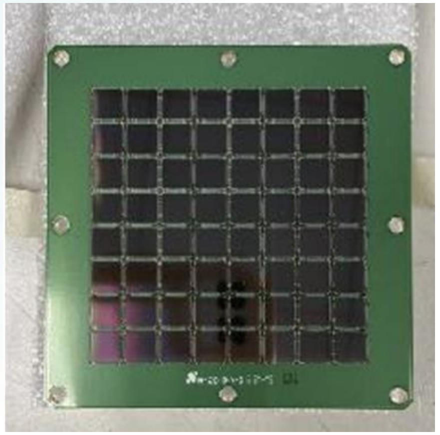
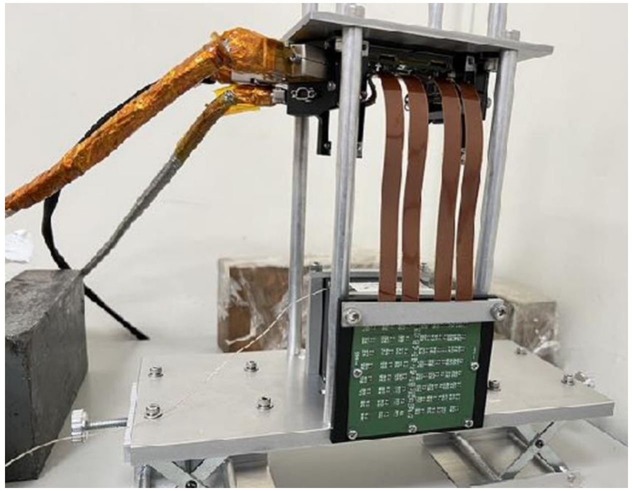
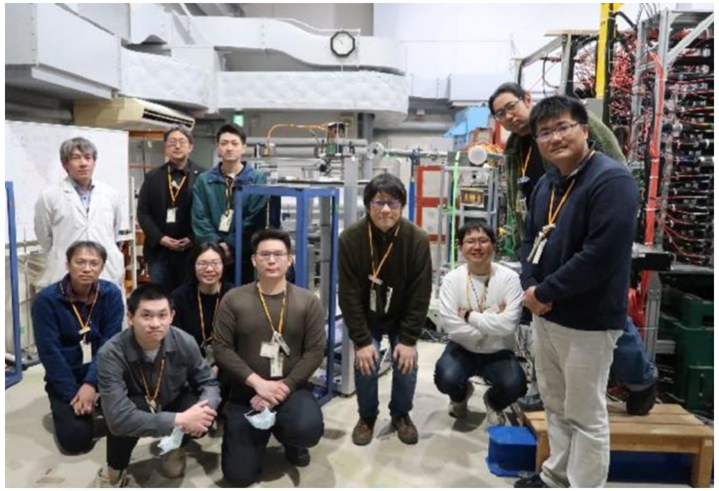



LYSOクリスタル試験

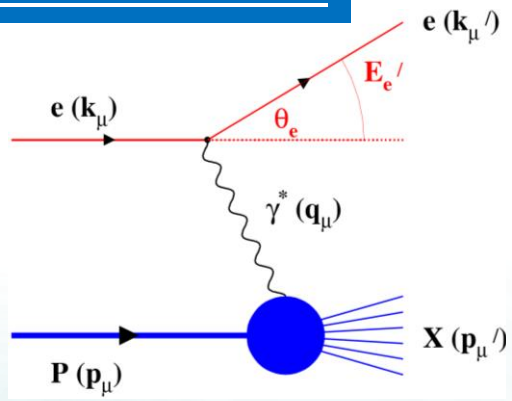
- 台湾グループがLYSO結晶のプロトタイプ検出器を製作
  - LYSO結晶、SiPM読出し
  - 今年2月テストビーム@東北大ELPH
  - 50 – 800 MeV 陽電子
  - 今年中に第2回テストビーム
    - LYSOとPWOの比較
    - SiPMとAPDの比較
    - FoCal-E Pad と組み合わせ

	X_0	LY (ph/MeV)	T dep. of LY (%/K)	Decay time (ns)	λ_{em} nm
$PbWO_4$ (CMS)	0.89 cm	200	-1.98	5 (73%) 14 (23%) 110 (4%)	420
LYSO	1.14 cm	30,000 (market standard)	-0.28	36	420
GAGG	1.59 cm	40,000－60,000		50－150	520
SciGlass	2.4-2.8 cm	>100		22－400	440-460

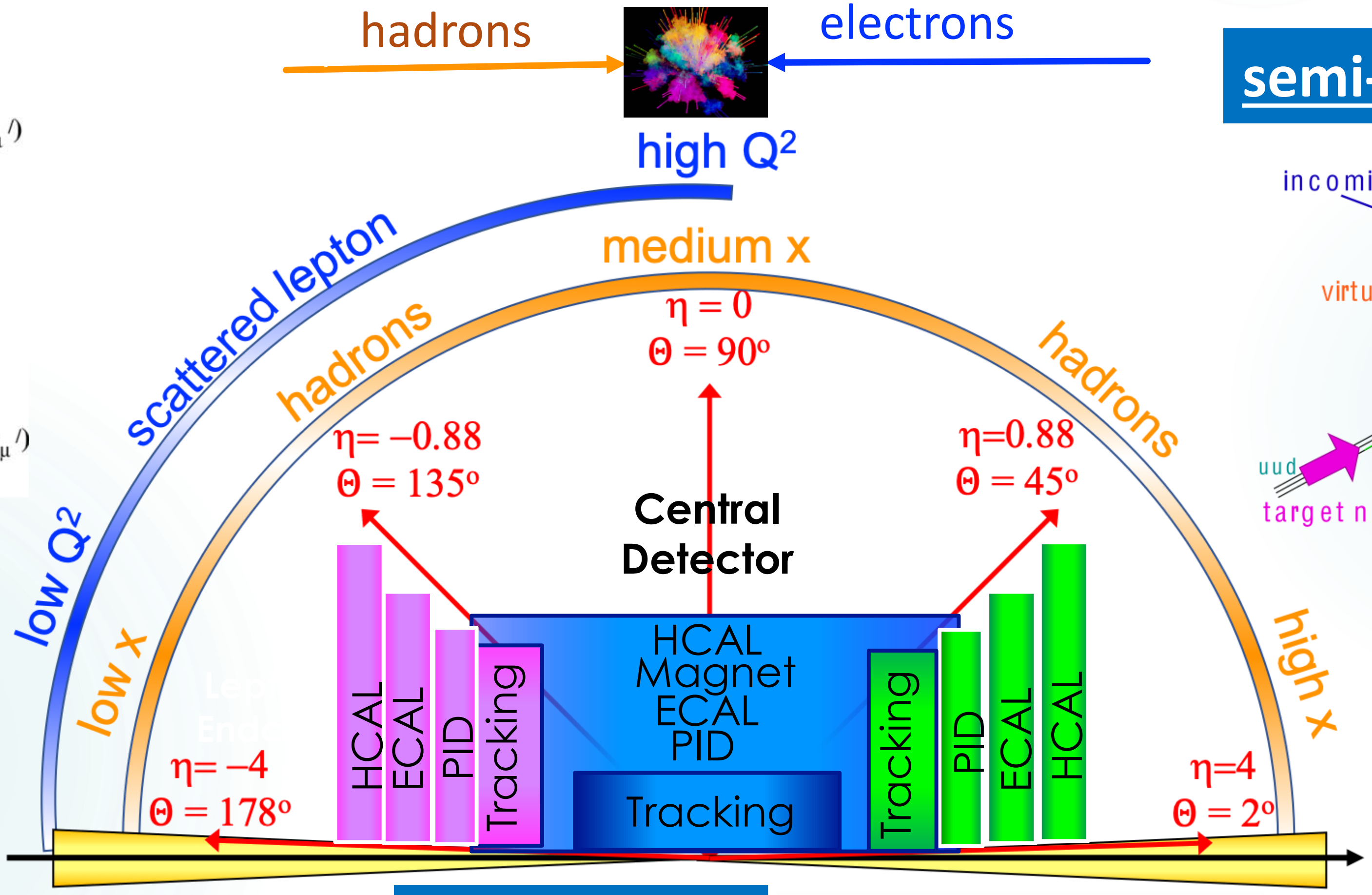





Coverage of ePIC

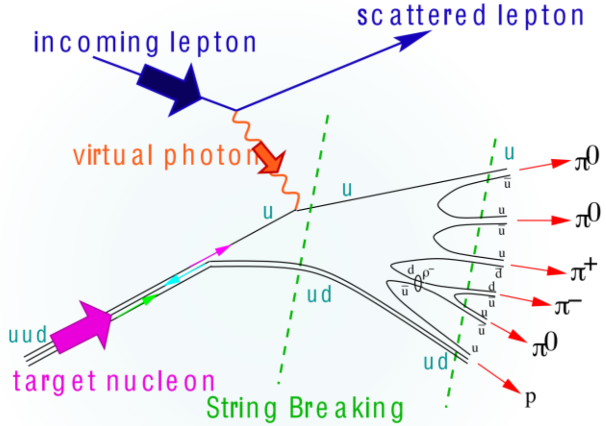
inclusive DIS:



Detect only the scattered lepton in the detector



semi-inclusive DIS



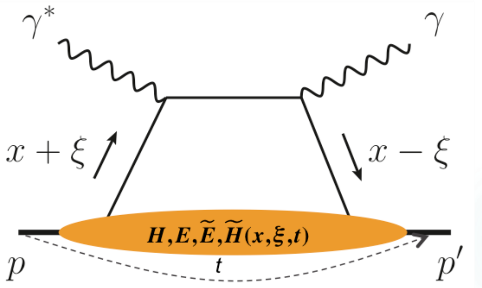
Detect the scattered lepton in coincidence with identified hadrons/jets

very low Q^2 scattered lepton
Bethe-Heitler photons for luminosity

Luminosity Detector
Low Q^2-Tagger

exclusive DIS

Detect scattered lepton, identify produced hadrons/jets and target remnants



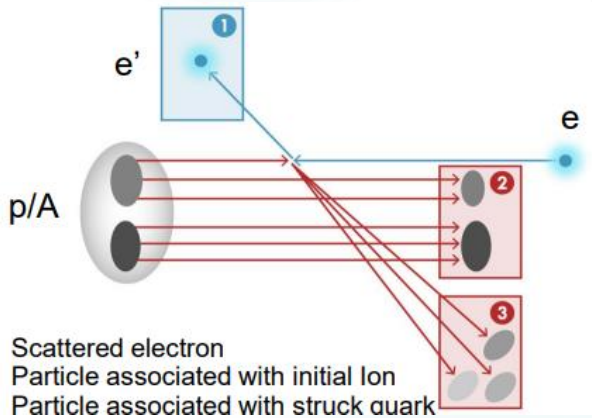
particles from nuclear breakup and from diffractive reactions

ZDC

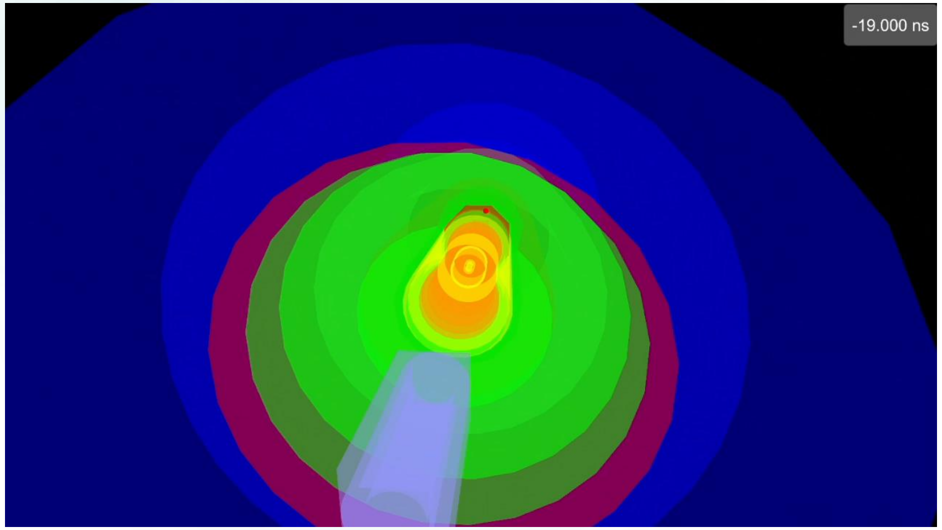
Forward Tracking

Triggerless DAQ

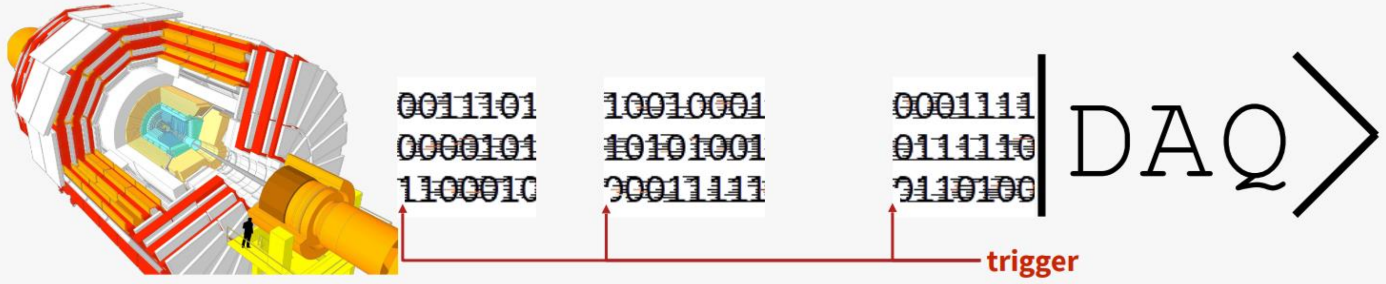
EIC Physics demands ~100% acceptance for all final state particles (including particles associated with initial ion)



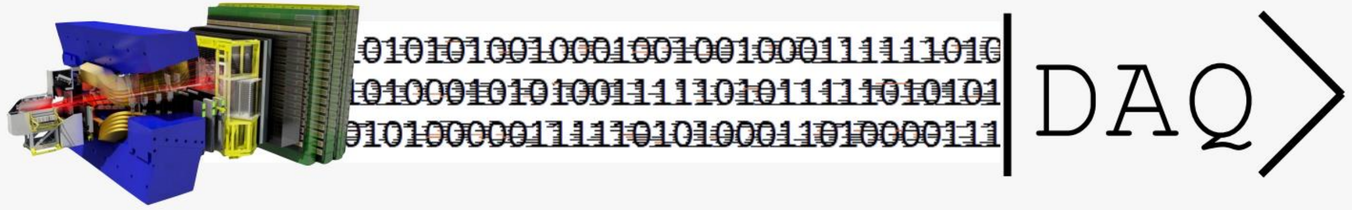
Bunch Crossing ~ 10.2 ns/98.5 MHz
Interaction Rate ~ 2 µs/500 kHz



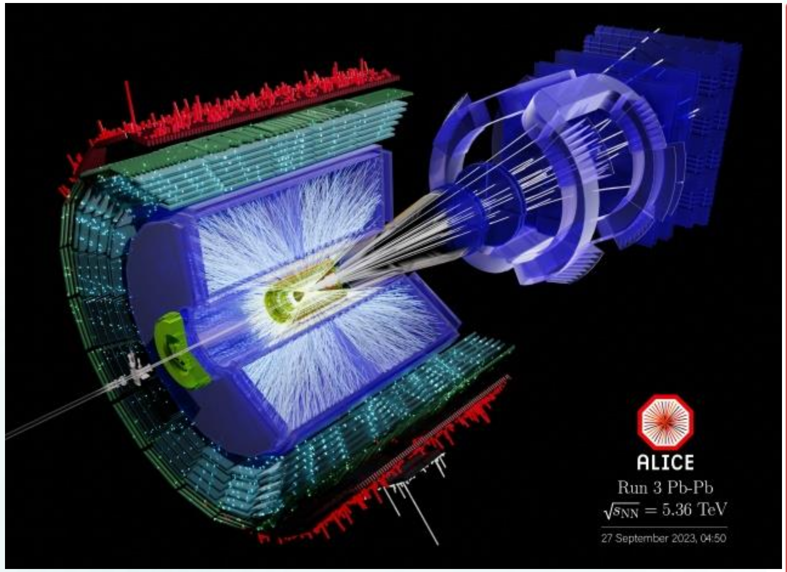
Triggered: data is readout from detector only when a trigger signal is raised

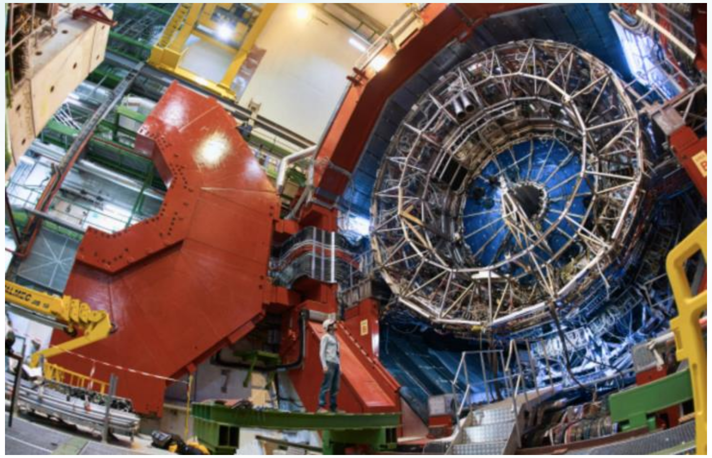


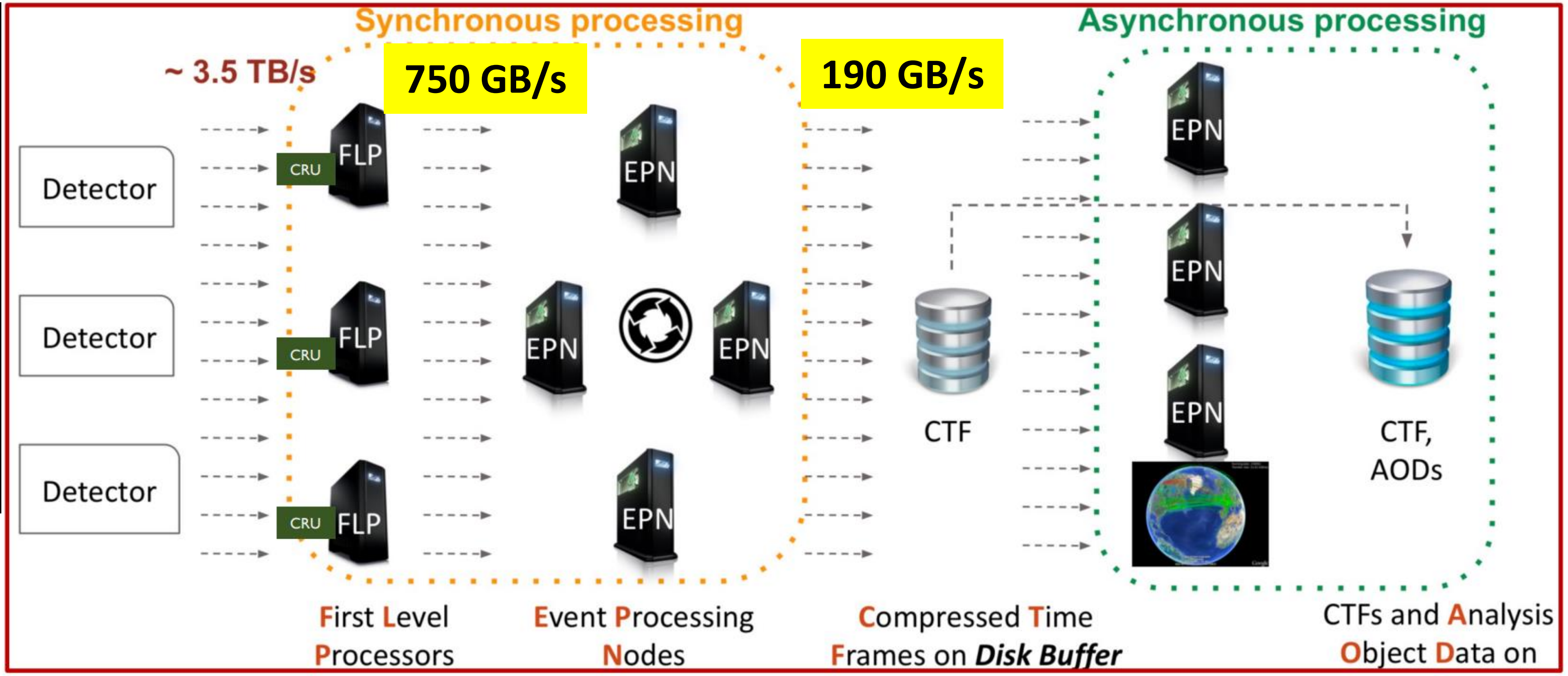
Triggerless: the detector push data at its speed and the downstream DAQ must keep the pace



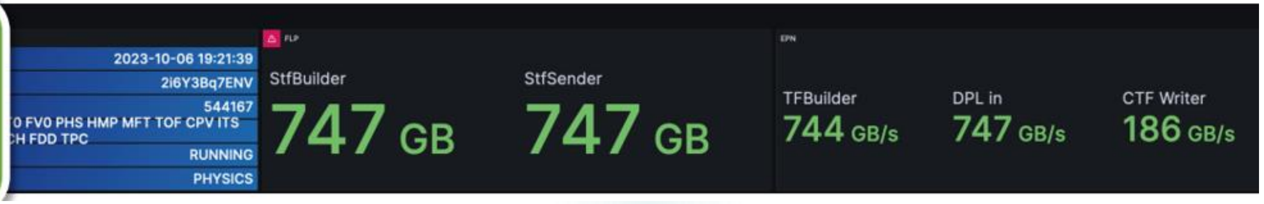
Triggerless DAQ@ALICE





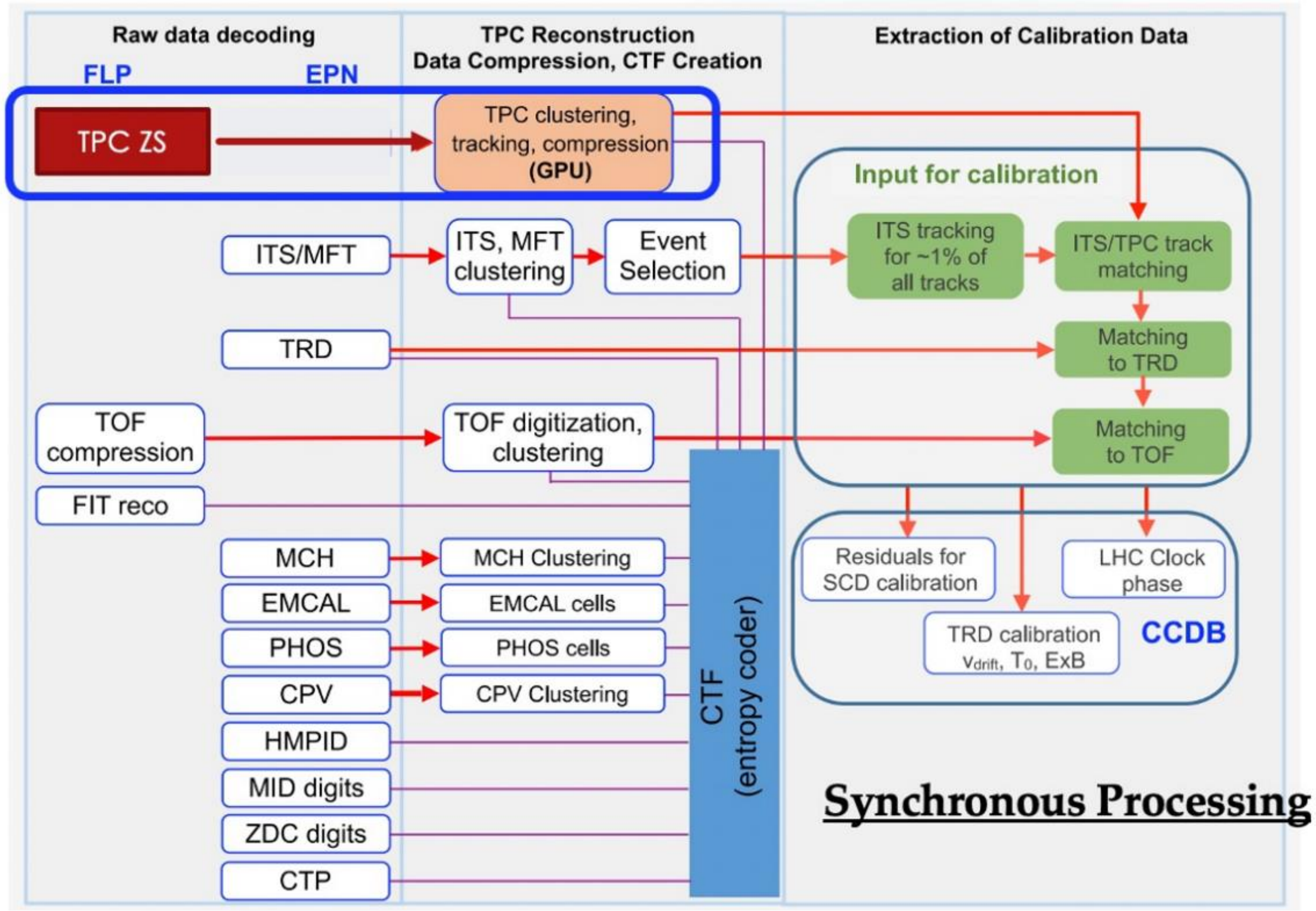


15 detectors
Data Volume as predicted
Acquisition with 364
equivalent MI50 EPNs

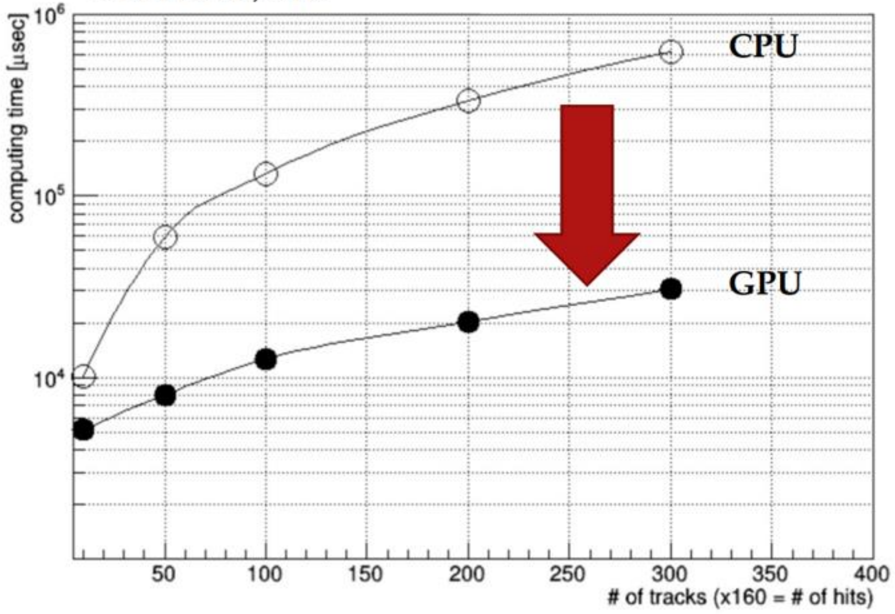


Triggerless DAQ@ALICE

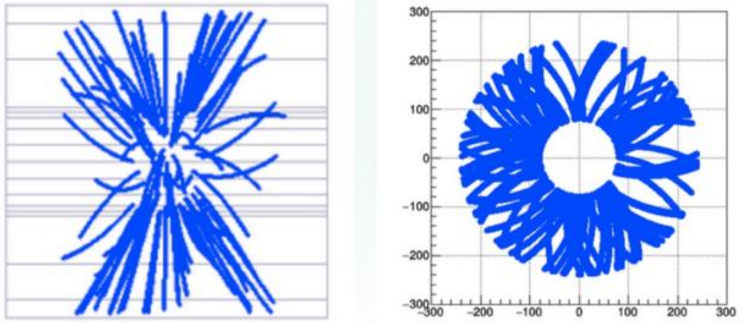
Synchronous processing of TFData in EPN (250 EPNs, 2000 GPUs)



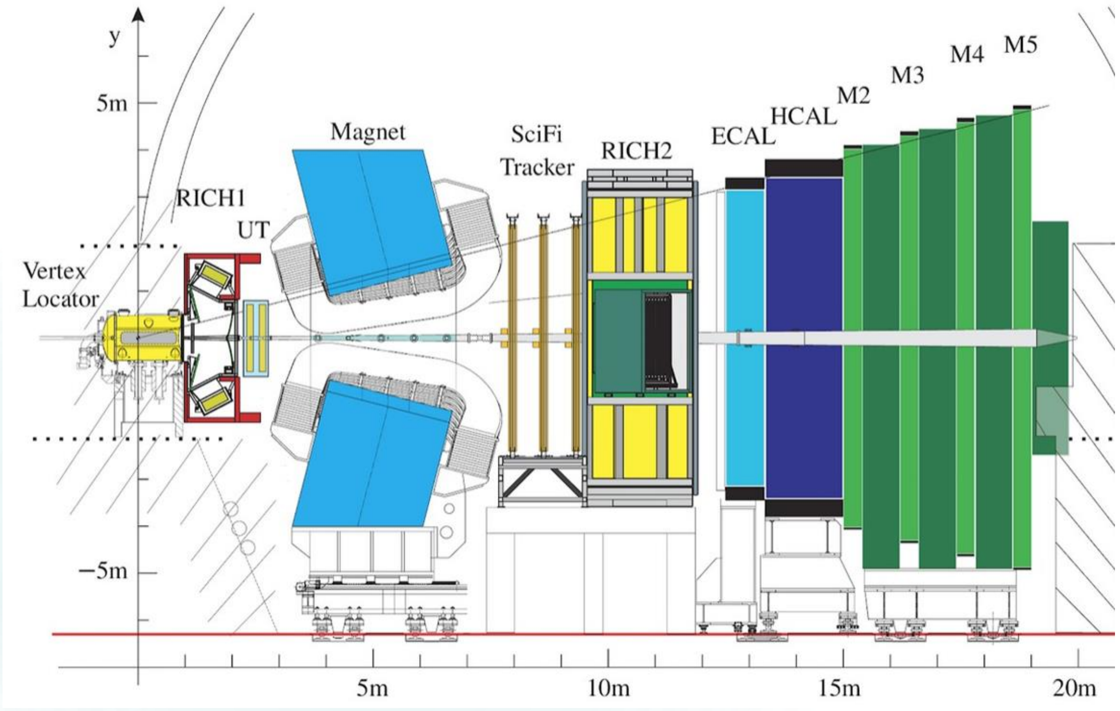
TPC tracking in GPU (2015)



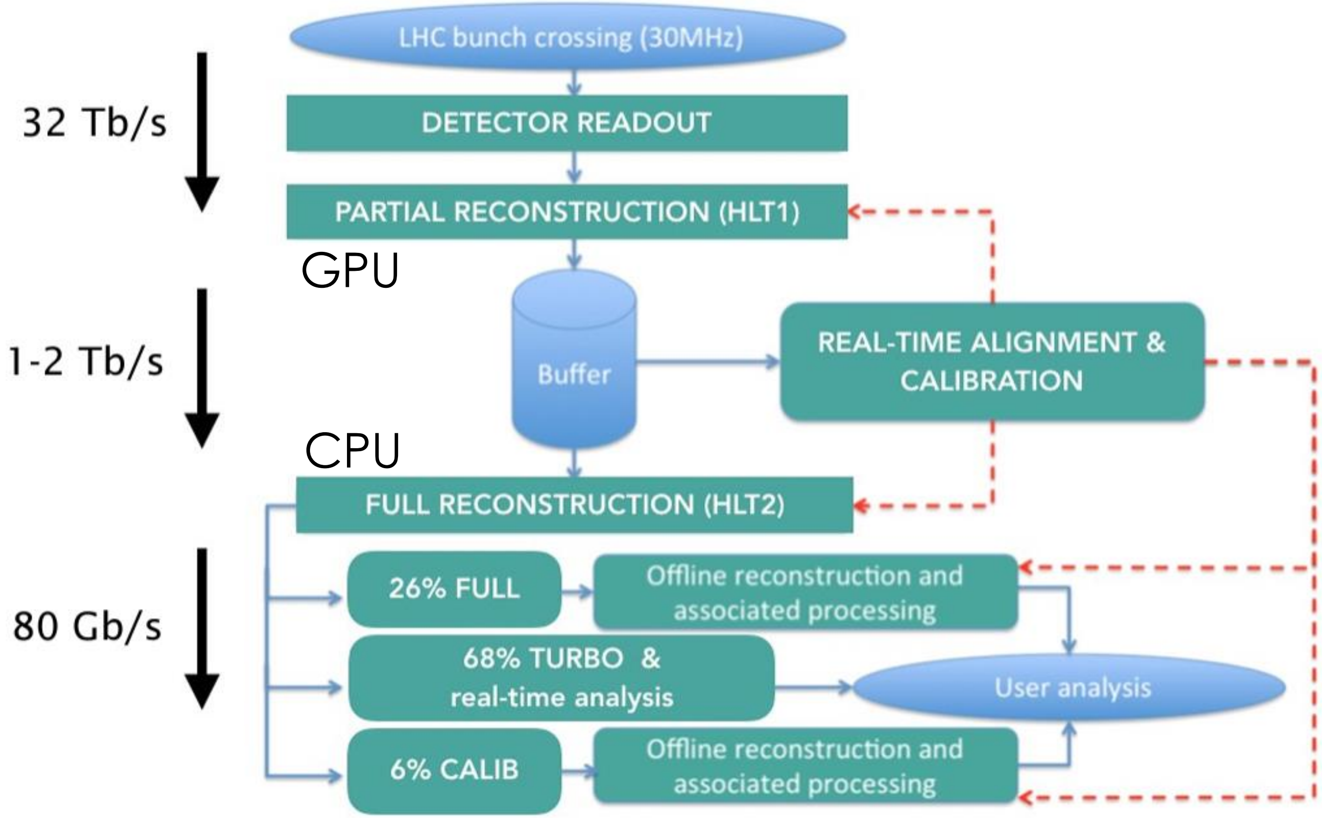
TPC Tracking



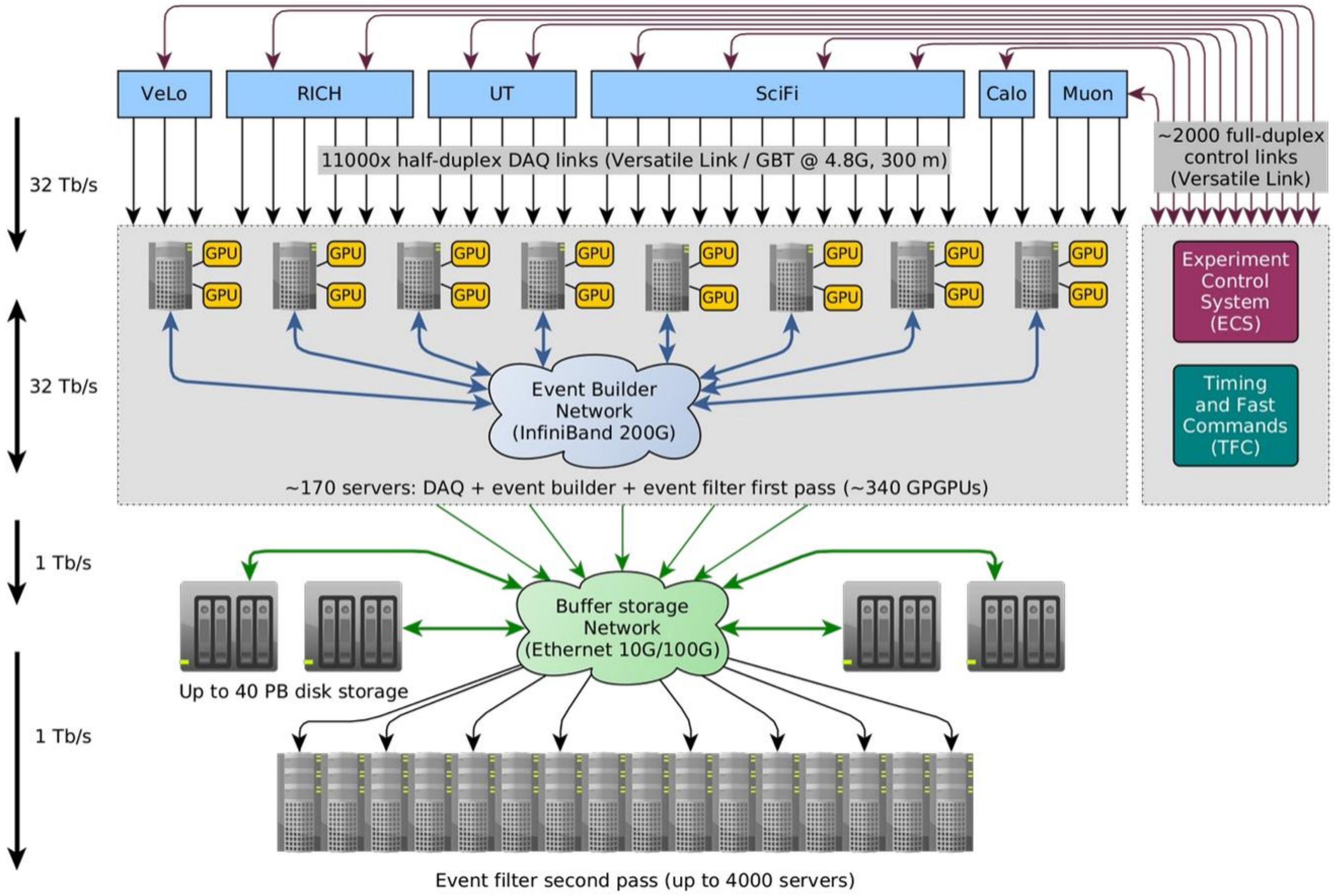
Triggerless DAQ@LHCb



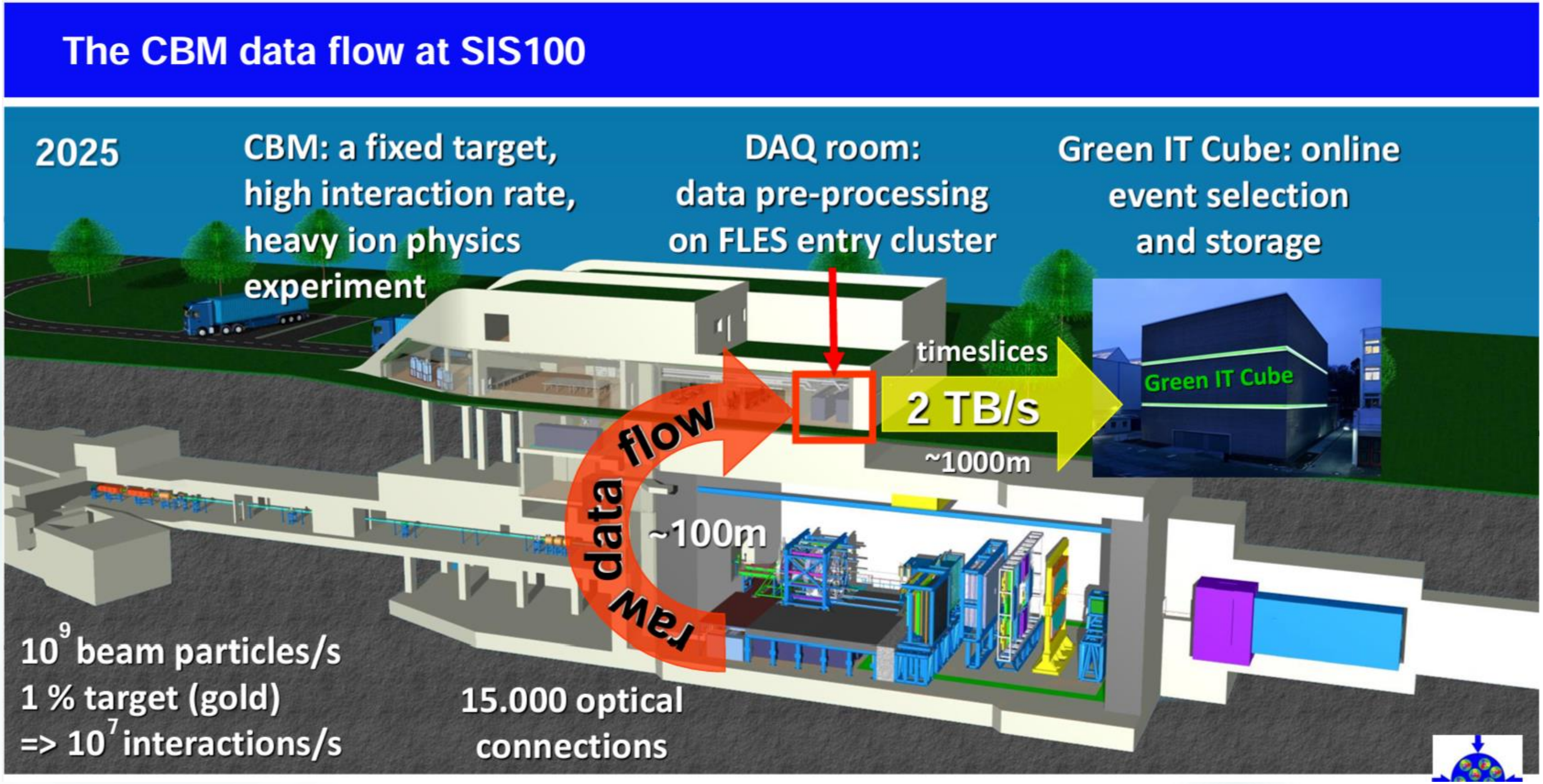
p-p bunch crossing rate: 30 MHz



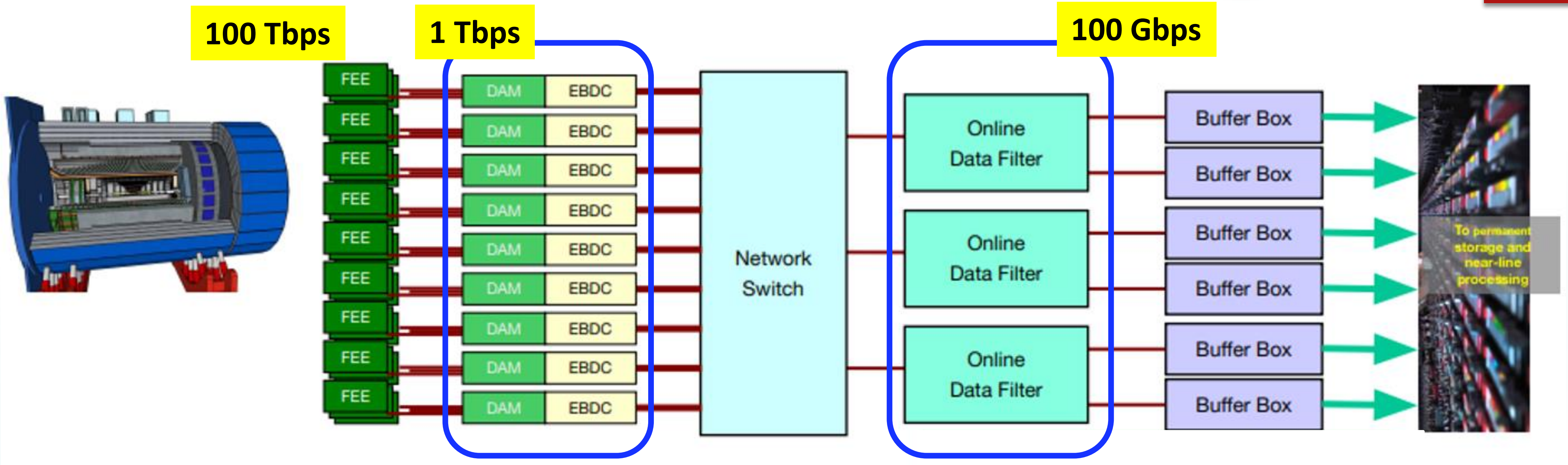
Triggerless DAQ@LHCb



Triggerless DAQ@CBM



Streaming DAQ@ePIC



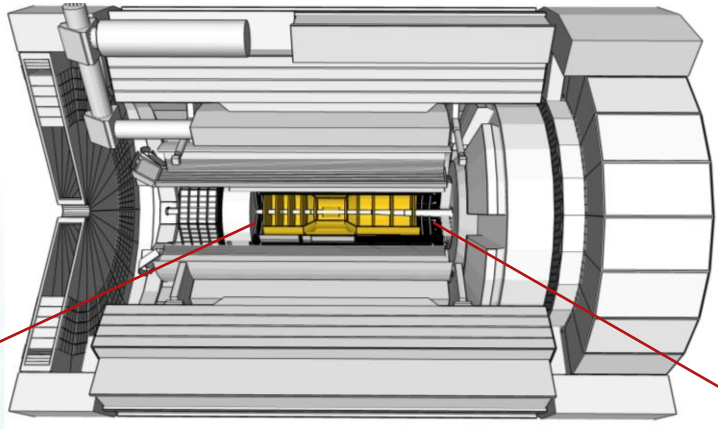
FELIX FLX-182 from ATLAS/Omega group at BNL
Versal Prime FPGA, PCIe Gen4x16,
24 FireFly links@25Gb/s (next version has 48 link capability)

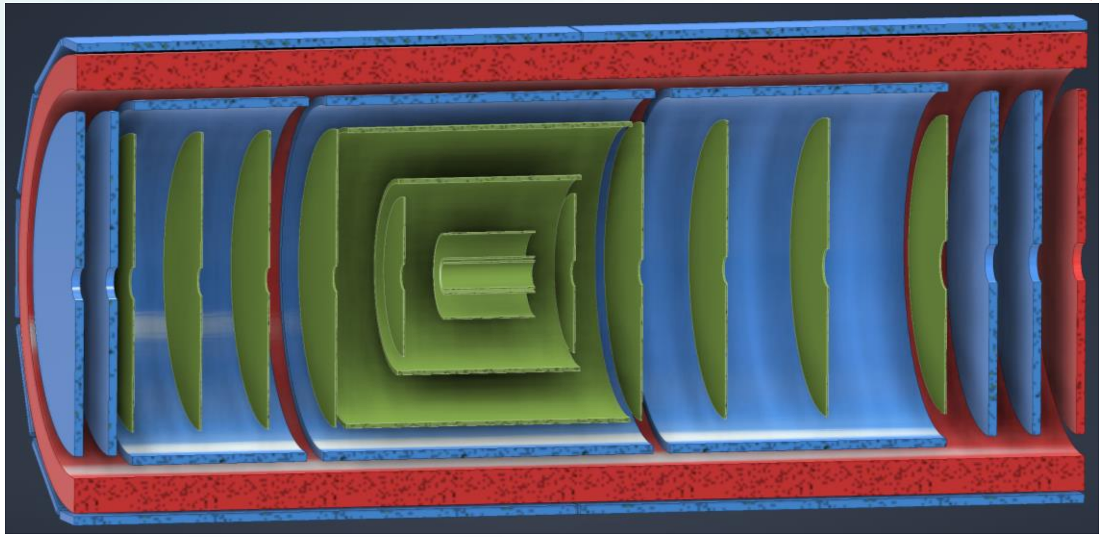
GPU-based online processing

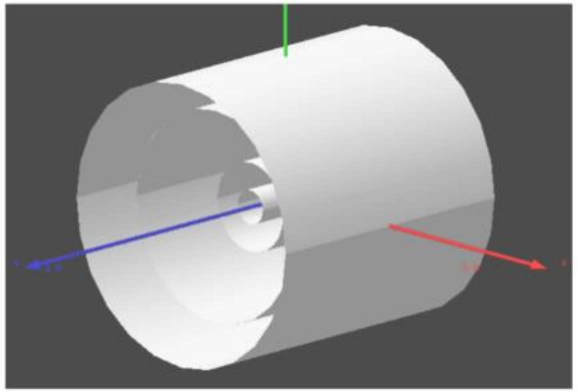
ALICE EPN node
8 GPUs (AMD MI50/MI100)

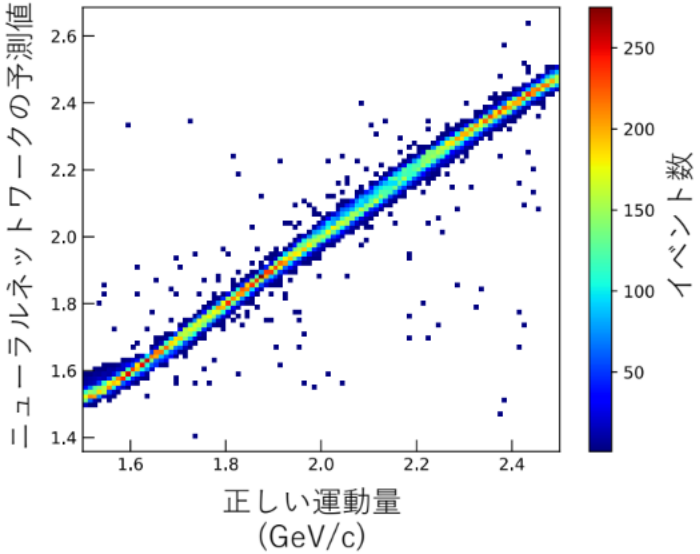
Current activities – I for ePIC

AI/ML based-online processing on FPGA (hls4ml) for MAPS Si layers









Performance Estimates

- **Timing**
  - **Summary**

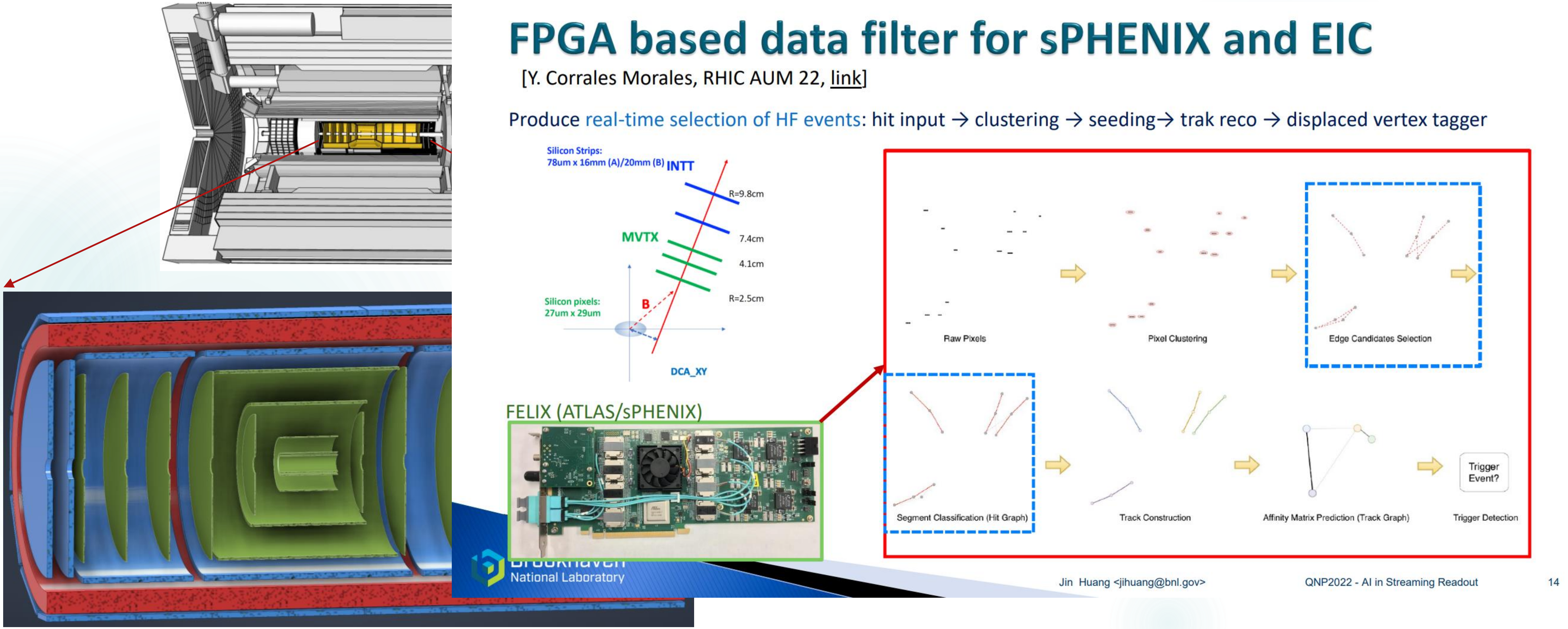
Clock	Target	Estimated	Uncertainty
ap_clk	5.00 ns	4.258 ns	0.62 ns

- **Latency**
  - **Summary**

Latency (cycles)		Latency (absolute)		Interval (cycles)		Type
min	max	min	max	min	max	
4	4	20.000 ns	20.000 ns	1	1	function

Current activities – I for ePIC

AI/ML based-online processing on FPGA (hls4ml) for MAPS Si layers

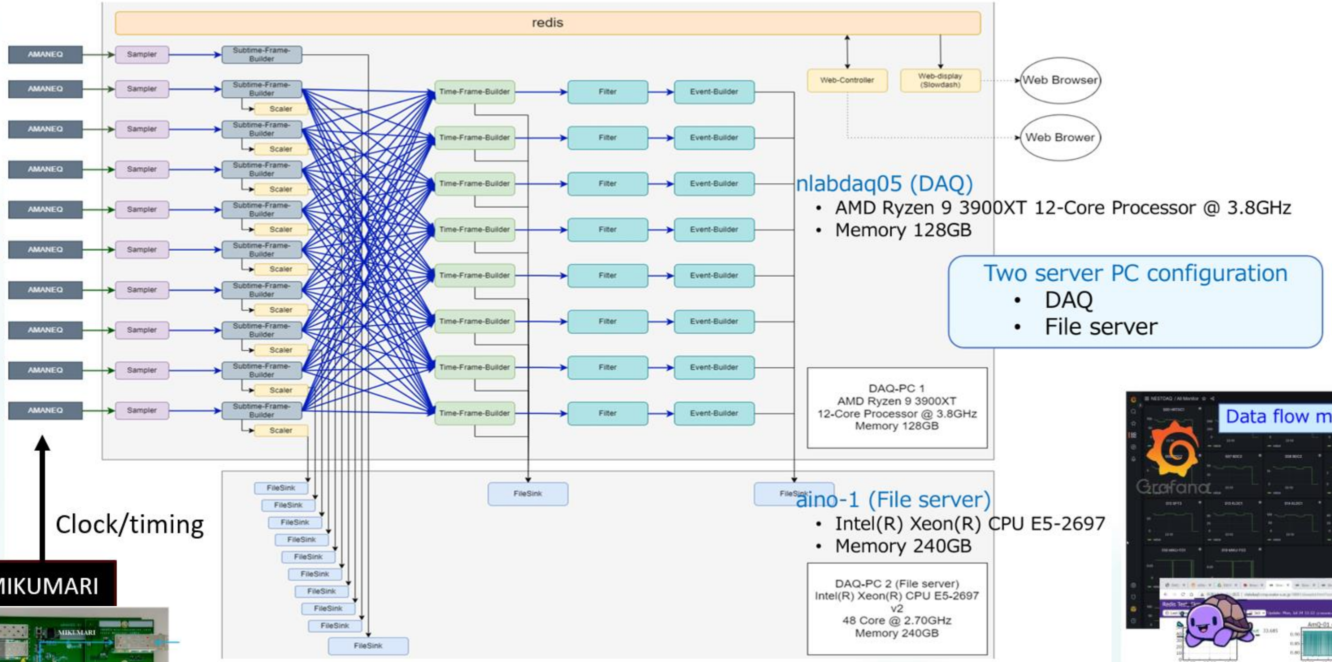


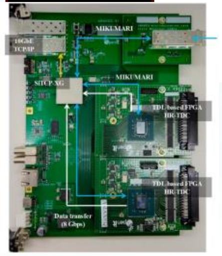
Current activities – II for ePIC

- **SPADI-Alliance collaboration**

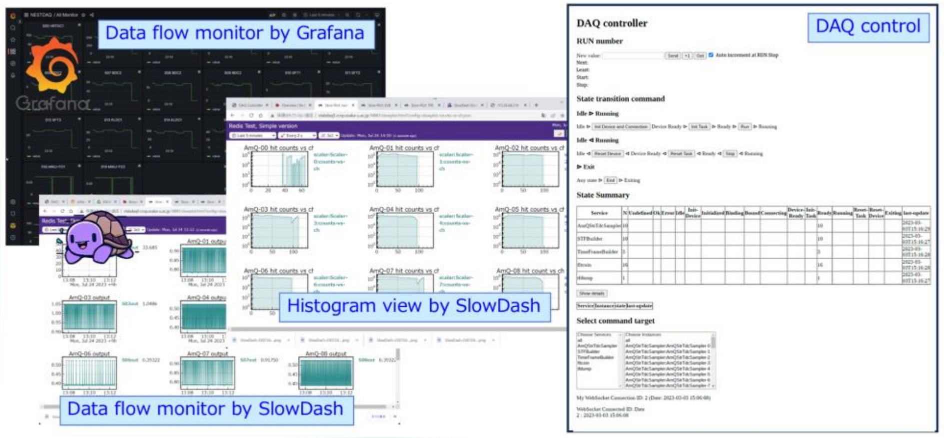
SPADI Alliance
Signal processing and data acquisition infrastructure alliance

  - **Standardization of streaming DAQ in many facilities (RIBF, J-PARC, etc)**
- **Framework for streaming DAQ/Computing based on FairMQ and Redis**





Beamtest at J-PARC
Physics run at RCNP

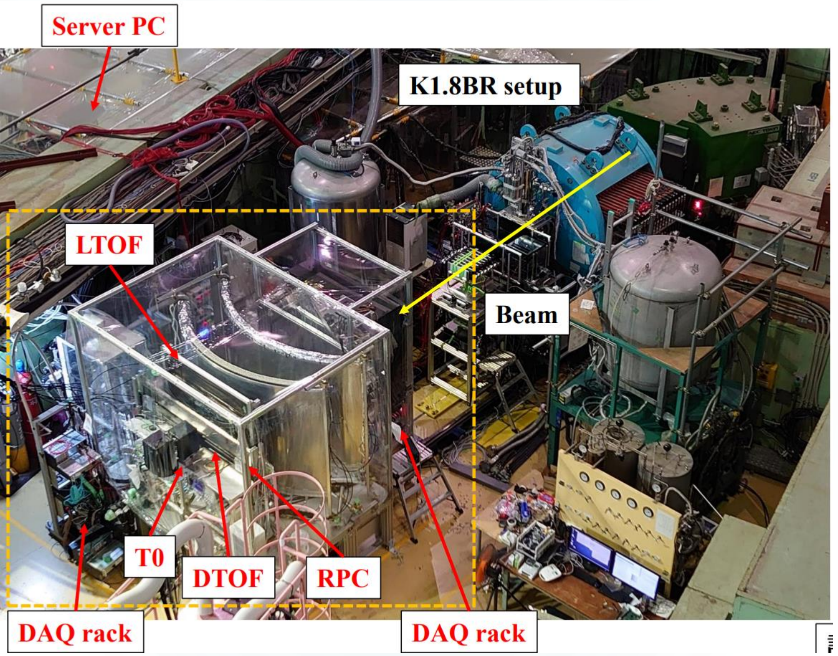


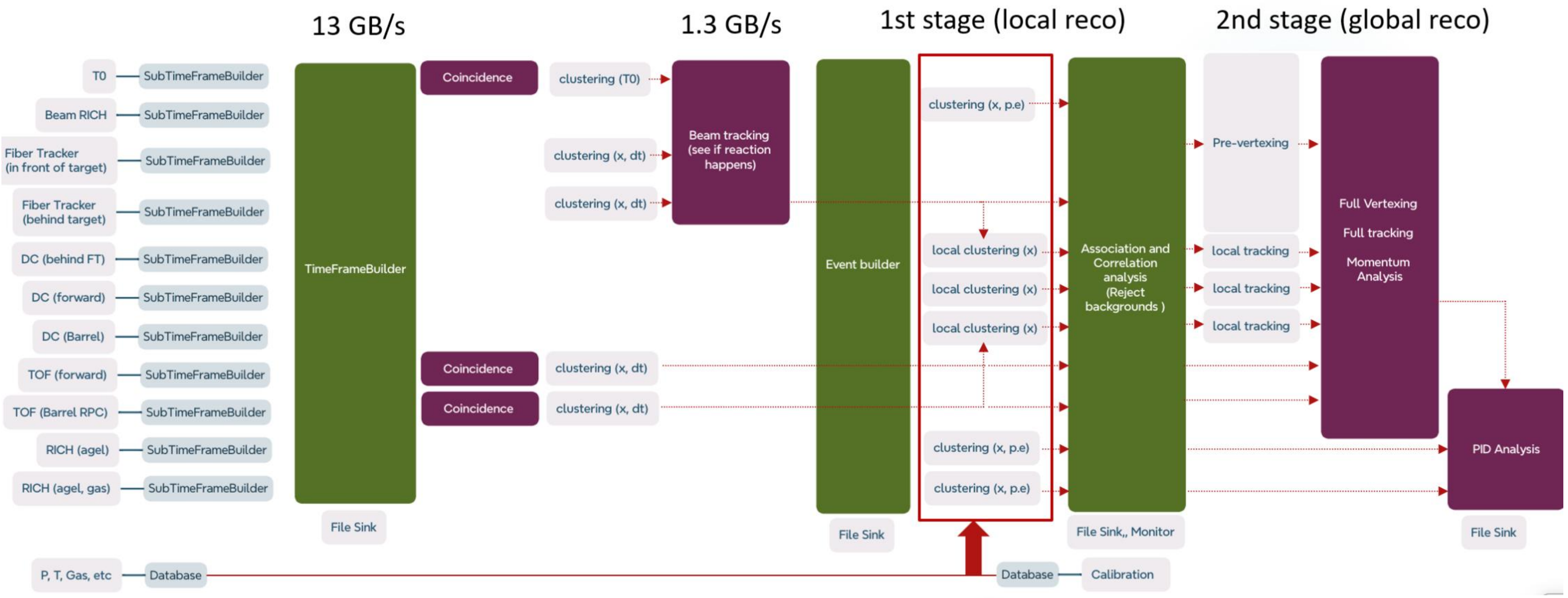
nestDAQ (network based streaming DAQ)

Using nestDAQ at JLab under discussion

Current activities – III for ePIC

- **Preparation for the beamtest of E50 at J-PARC in April and May**
  - **E50 could be one of the testbeds of streaming DAQ for ePIC**
  - **Deployment of GPU data processing**





今後の予定

- nextDAQをJlabのbeam dump experiment (dark photon search)に応用
- Timeframe data のOnline data filtering
  - DAM (Versal FPGA)でのfiltering (local reconstruction)
  - GPUでのfilterin (global reconstruction)
  - simulationによるbenchmarkingとresource estimate
- E50でのonline filteringの試験
  - E50での経験がそのままePICに活かされる（と予想）

まとめ

- 高エネルギー原子核実験の今後の基盤技術
  - MAPS、LGAD、Streaming DAQ
- 高レートかつ高精度が必要な実験で必要になる技術
  - あとは、高集積回路技術（インターポーザー、チップレット）とデータ転送
- 一緒に共同で開発しませんか？
  - 将来のJ-PARCでの実験に有益

Backup slide