Conseil scientifique de l'IN2P3
27-28 octobre 2022

Proposal to upgrade the Belle II vertex detector

- Rationale for an upgrade
- Project overview
- Activities proposed by IN2P3 labs
- Request to IN2P3

Rationale for an upgrade

- → The current VXD & known limits
- → Requirements for an upgraded VXD
- → Belle II Schedule

Present situation

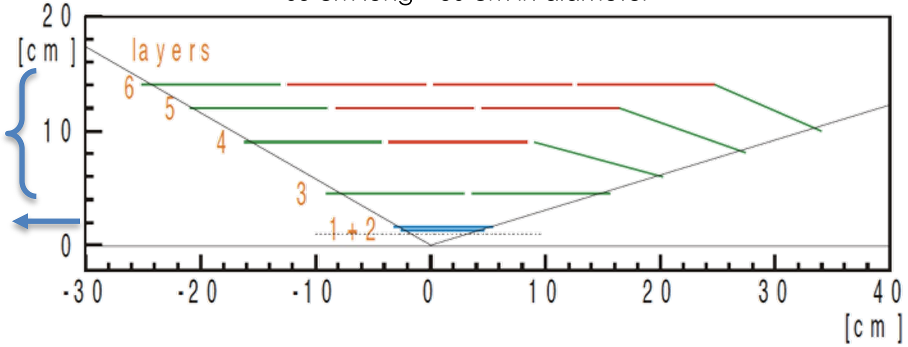
The vertex detector: VXD

- Two silicon technology system
  - **SVD**, short-integration (100-200 ns), strip sensors => fully contributing to track finding
  - **PXD**, good granularity (55-75 µm), DEPFET pixels => extrapolation precision after track finding

65 cm long – 30 cm in diameter

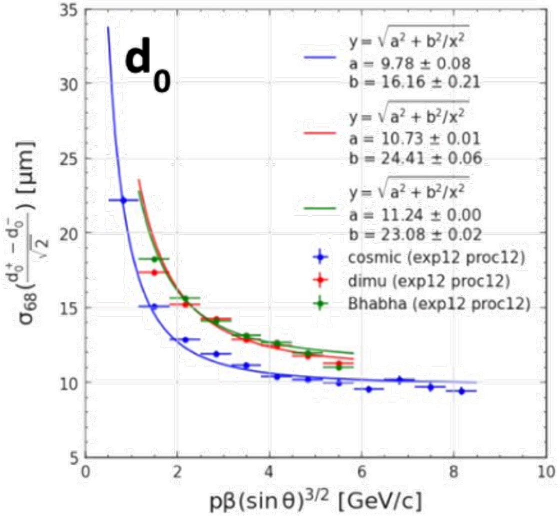
Strips 1.2 m^2

Pixels 0.3 m^2



Luminosity evolution

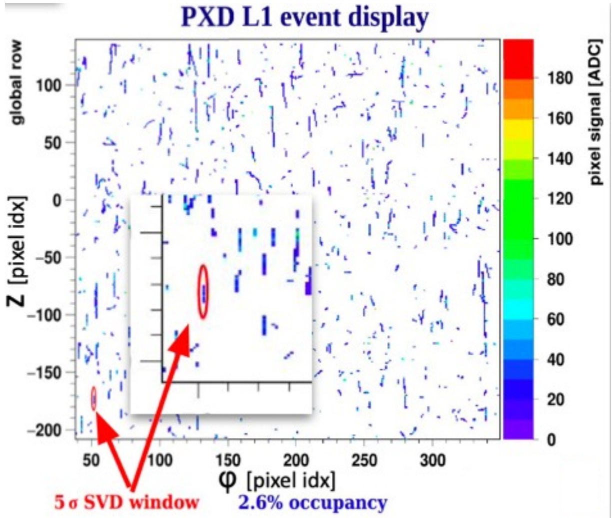
- June 2022, end of run 1
  - Max L_{peak} **4.7x10^{34} cm^{-2} s^{-1}**
  - Trigger rate ~ kHz
  - Hit rate on PXD ~3 MHz/cm^2 / occupancy ~0.2%
- Run 2 (2023-2026?)
  - Max L_{peak} **1-2x10^{35} cm^{-2} s^{-1}** still with current machine
  - Trigger rate ~ 10kHz
  - Hit rate on PXD ~7 MHz/cm^2 / occupancy ~0.5%



Very impressive start
… with challenging conditions
on detectors (beam background)

Limits

=> Beam background dominates occupancy of vertex detector



- Known limits
  - SVD & PXD max bandwidth ~3% occupancy
  - Tracking performance degrades severely beyond ~4% of SVD occupancy
  - Trigger rate of 30 kHz, limited by SVD-ROChip (3% dead time)

- Operation at increasing luminosity
  - PXD & SVD pedestal, noise increases with TID
  - PXD sensor leakage increases with TID
  - PXD gates and switchers damaged by beam loss events
  - PXD veto mode not yet effective (also not needed)

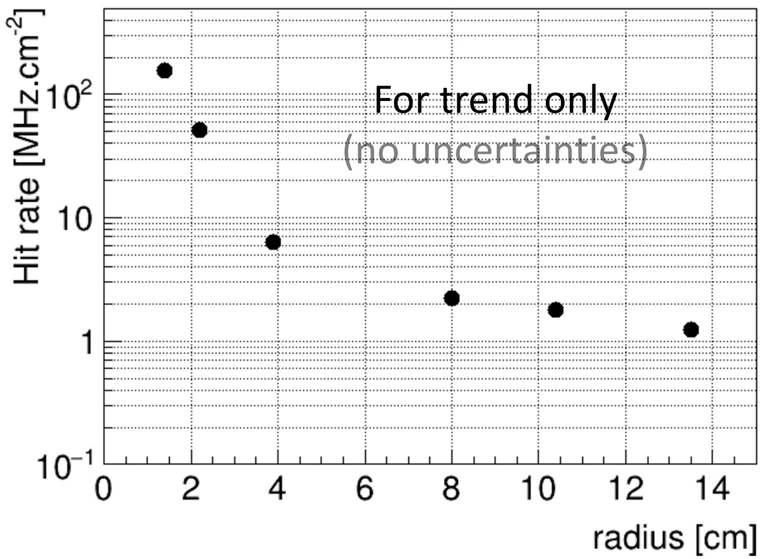
- Luminosity evolution
  - June 2022, end of run 1
    - Max L_{peak} **4.7x10^{34} cm^{-2} s^{-1}**
    - Trigger rate ~ kHz
    - Hit rate on PXD ~3 MHz/cm^2 / occupancy ~0.2%
  - Run 2 (2023-2026?)
    - Max L_{peak} **1-2x10^{35} cm^{-2} s^{-1}** still with current machine
    - Trigger rate ~ 10kHz
    - Hit rate on PXD ~7 MHz/cm^2 / occupancy ~0.5%
  - Run 3 (2028? + 5 years)
    - Max L_{peak} **6x10^{35} cm^{-2} s^{-1}** with “new machine” (Int.Reg.)
    - Trigger rate ~ 30 kHz
    - Hit rate on PXD ~15 MHz/cm^2 / occupancy ~1%

Largely unknown!

=> Belle II motivations for an upgrade:
- improved robustness against background
- Higher radiation tolerance
- Improved physics reach per ab^{-1}

Requirements for VXD upgrade

- Vertexing & Tracking performances **at least** as good as current VXD
  - Radius range 14 – 135 mm
  - angle from 17 to 150 degrees
  - Single point resolution **≲10-15 µm**
  - Total material budget **< (2x 0.2 + 4x 0.7) % X_0**
    - total power budget < 1000 W



- **Robust** against environment for inner layer **(r=1.4 cm)**
  - **Hit-rate ~ 120 MHz.cm^{-2}**
  - Total Ionizing Dose ~ 10 Mrad / year
  - NIEL fluence ~ 50x10^{12} n_{eq}.cm^{-2} / year

  Based on current extrapolation with safety factor (x5)
  bear In mind large uncertainties

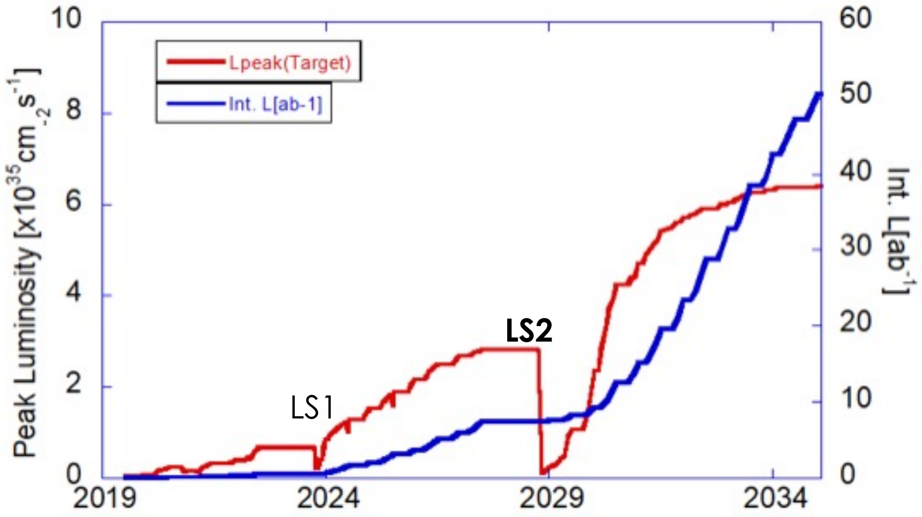
- Possibly **improve** performances
  - Impact parameter resolution
  - Tracking efficiency (p_T < 100 MeV) & Fake rate
  - Faster High Level Trigger
    - Simplified track pattern recognition

Key sensor specifications:
- Pixel pitch 30-40 µm
- Integration time ≲100 ns
- Power dissipation ≲ 200 mW/cm^2

Belle II schedule

- **2019**: Upgrade Working Group created ⟶ identification of potential timescales
- **2021**: February, Expressions of Interest for specific detectors (various proposals for VXD)
  Upgrade Advisory Committee created
- **2022**: Snowmass whitepaper on upgrades ⟶ refined timescales versus detector targets (short-, **mid-**, long- term)
  =LS1 **=LS2**
- **2023**: Conceptual Design Report (complete draft in February, publication in June)
  Focus on mid-term upgrade for $6x10^{35}$ cm^{-2} s^{-1}
  Reduced number of options for VXD
- **2024**: Technical Design Report ⟶ construction phase

=> When can we upgrade the vertex detector?
LS2 (expected 2026-27) is the first opportunity in the current plan



Current situation of concurrent proposals

Original situation & developments

- **Thin strips** for outer layers (radius > 4 cm)
  - Driven by KEK
  - ⟶ Difficulties with SNR / radiation reauirement
- **DMAPS** pixels for all layers = VTX
  - European based
  - ⟶ Ongoing discussion with BMBF
  - ⟶ good momentum on (almost) all grounds
- **SOI** pixels for all layers
  - Driven by KEK physicist
  - Still a lot to demonstrate
- **DEPFET** pixels for inner layers (radius < 4 cm)
  - HLL-Münich
  - ⟶ discontinued since no other support

Present view trend for CDR

- Thin strips considered for CDC inner layer replacement
- DMAPS-VTX as baseline option for full vertex detector upgrade
- SOI pixels has an alternative

Project overview

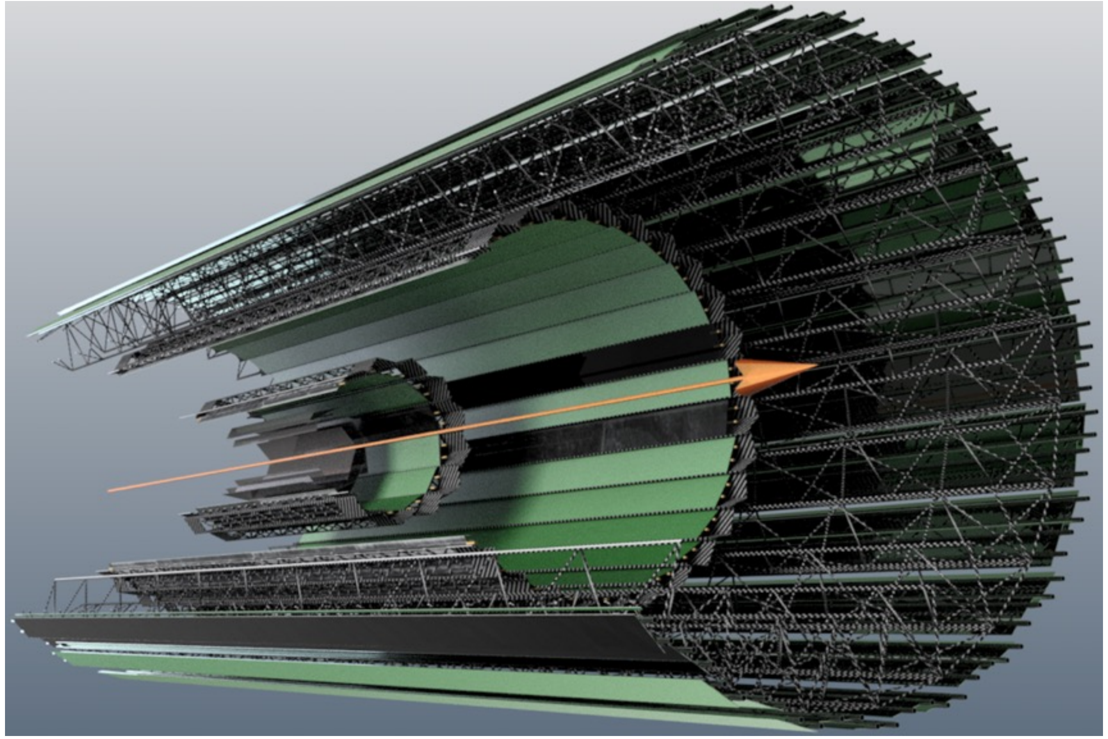
- → VTX with DMAPS concept
- → Performance studies
- → Status of the R&D
- → Schedule

VTX general concept: “simple, robust, doable”

- **5 layers**
  - Same high granularity (r,φ,z,t) sensor everywhere
  - Fast enough for including all layers in tracking
  - Total event size ~30 kBytes, easily fit HLT budget
  - Services mostly on one side (backward region)
  - Ladder concept adaptable to potential change of interaction region
- Sensor = **depleted MAPS** (OBELIX)
- 2 ladders with radius < 3 cm
  - **iVTX**, ~0.1 % X_0
  - 12 cm long
- 3 ladders with radius > 3 cm
  - **oVTX**, 0.5/0.8/0.8 % X_0 (increasing with radius)
  - 24/45/70 cm long
- Options
  - 6th layers for redundancy
  - 2 disks in forward region for soft pion acceptance

- VTX collaboration

HEPHY, Vienna
CPPM, Marseille
IJCLab, Orsay
IPHC, Strasbourg
University of Bonn
University of Dortmund
University of Goettingen
KIT, Karlsruhe
University of Bergamo
INFN, Pavia
INFN & University of Pisa
IFAE, Barcelona
IMB-CNM-CSIC, Barcelona
IFCA (CSIC-UC), Santander
IMSE-CNM-CSIC, Seville
IFIC (CSIC-UV), Valencia
ITAINNOVA, Zaragoza

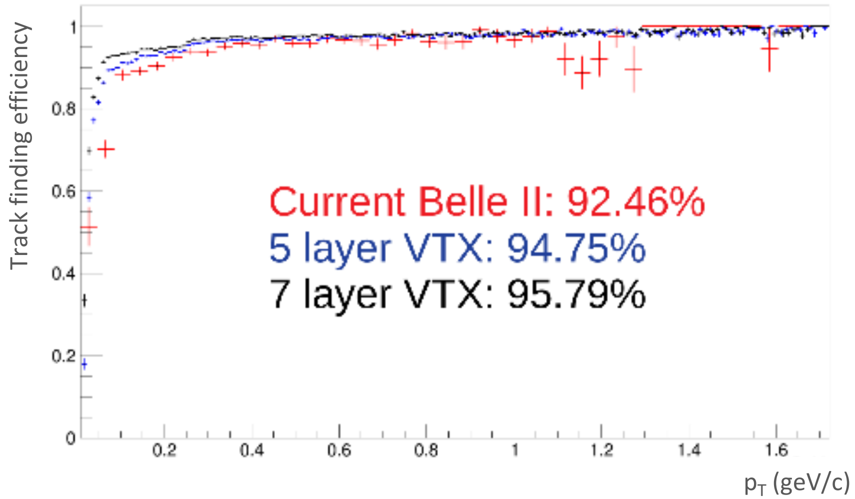


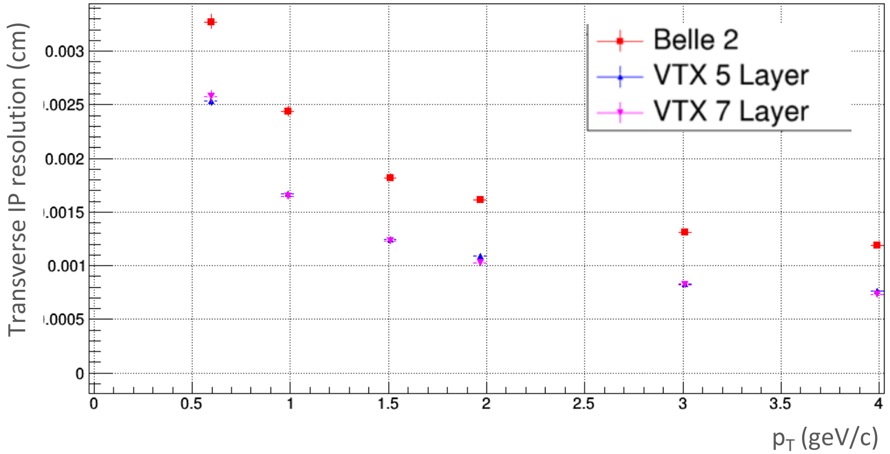
Performance studies

Göttingen, IPHC, Bonn, Pisa

- **Full simulation in Belle II analysis software**
  - 5 layer geometry implemented
    - Radius ~ current VXD
    - Material budget from sensor thickness a bit optimistic (0.1/0.1/03./0.3/0.3 %)
  - Detailed digitizer model tuned from
    - Tuned with Monopix-1 test beam data
  - Tracking algorithms re-trained
  - Estimated background at 8×10^{35} $cm^{-2}.s^{-1}$

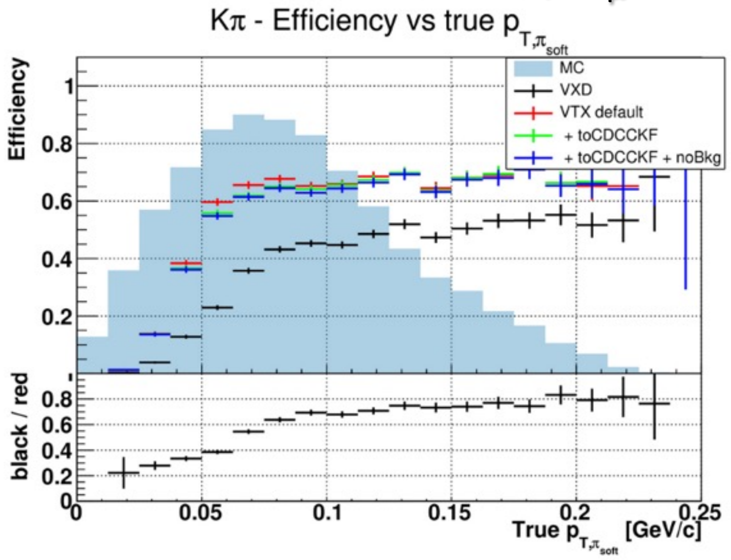
Tracking





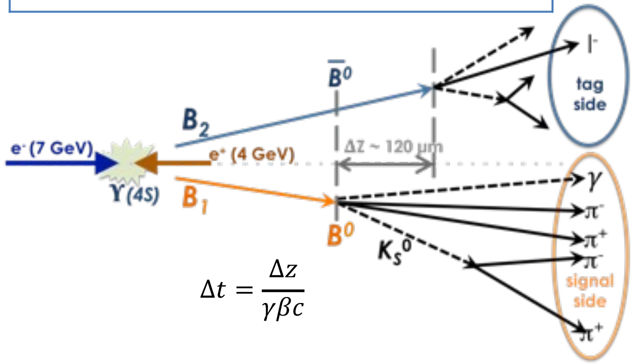
Physics Benchmarks

$B^0 \rightarrow D^{*-}(\bar{D}^0\pi^-)\,\mu^+\nu_\mu$



$B^0 \rightarrow K^0_S\,\pi^+\pi^-\gamma$

Geometry	Δt Resolution (ps)
VXD	1.12 ± 0.11
VTX 5 layers	0.82 ± 0.02



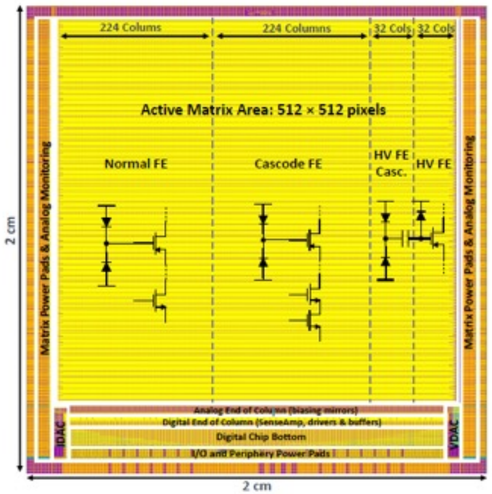
=> VTX performs slightly better / current VXD

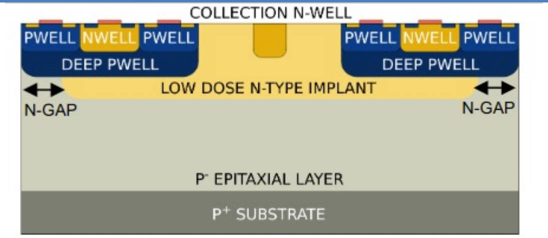
TJ-Monopix2 lab-test results

Bonn, CPPM, Göttingen, Pisa, Vienna

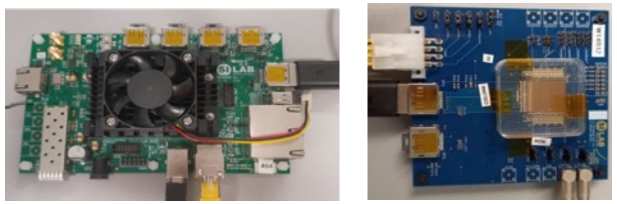
Depleted MAPS technology choice

- Tower 180 nm modified process (full Depletion) with small diode as sensing node
- TJ-Monopix2 as forerunner of OBELIX
  - 33 µm pitch, 25 ns integration, 17x17 mm² matrix
  - 4 front-end flavours (gain, speed, depletion)
    - In-pixel detection threshold + Time-Over-Threshold (ToT)
  - Various sensing volume thickness (CZ-bulk, epi-30 µm-





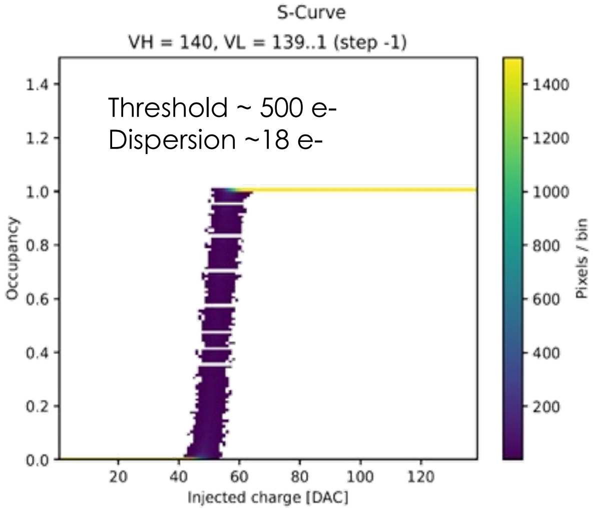
DOI: 10.1016/j.nima.2020.164403

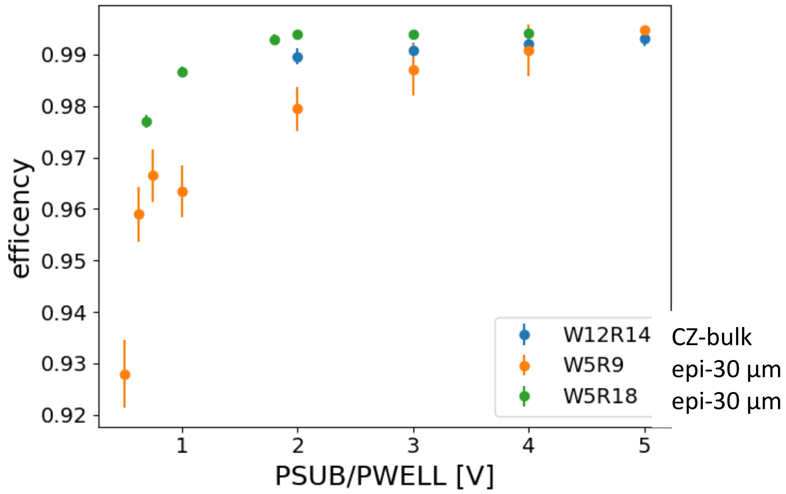


Bdaq53 acquisition system (also baseline for OBELIX)

Characterisation on-going

- In-laboratory
  - threshold (lowest value, dispersion) / noise
  - ToT calibration
- In-beam (DESY, 5 GeV electrons)
  - With large threshold ~500 e-
  - Position resolution ~9 µm slightly better than digital resolution

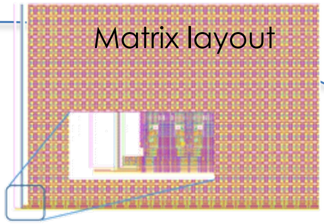




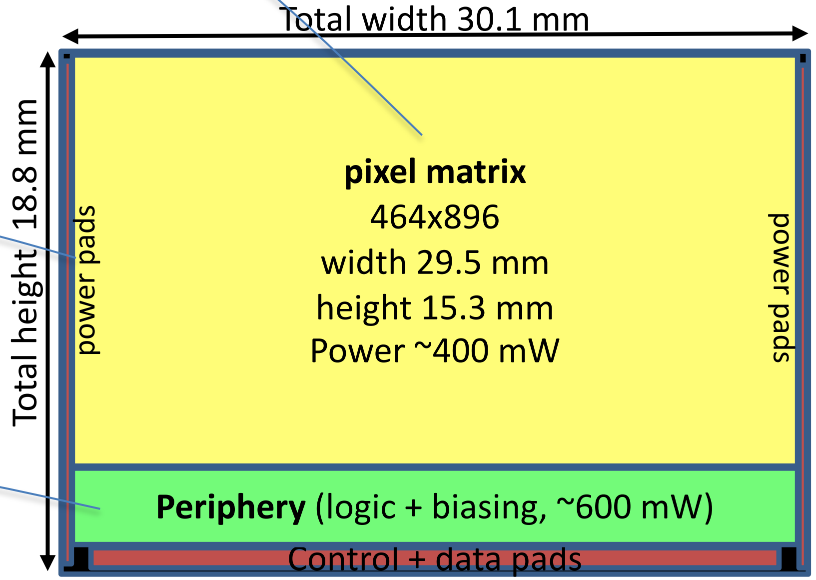
OBELIX (Optimized BELle II pIXel) sensor

IPHC, CPPM, Dortmund, Vienna, Bonn

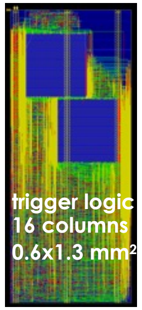
- **Pixel matrix**
  - Copied from TJ-Monopix2 => radiation tolerance granted
  - Lower frequency ~10-20 MHz => time-stamp precision 100-50 ns
  - Possible power optimisation/speed
    - INFN-Pavia / Uni.Bergamo

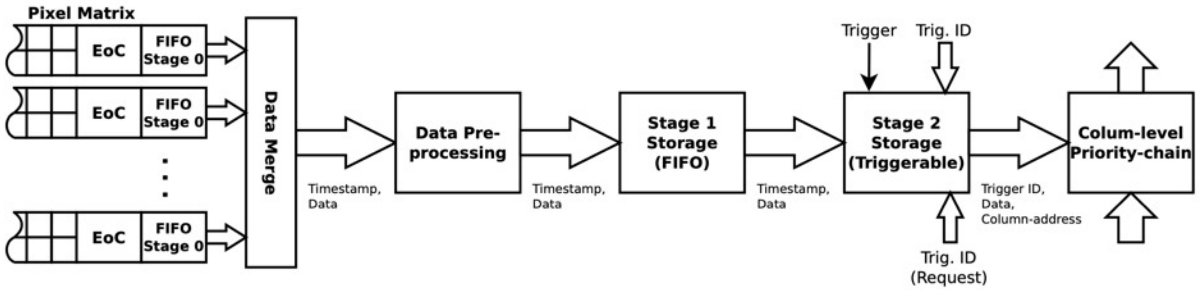


- **Power pads**
  - Power regulators added => simplified system integration
  - But area limited to <150 μm

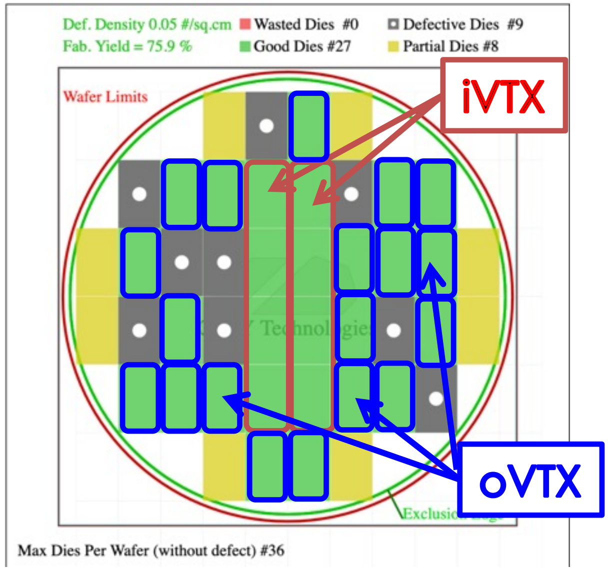


- **Periphery**
  - New end-of-column adapted to Belle II trigger
    - Timestamped hits stored in memories
    - Read-out when timestamp matched with trigger
  - Single output at 320 MHz average bandwidth/sensor 140 Mbits/s
  - RD53 control/readout protocol
  - Biasing generation and monitoring





Size optimized to maximize (8) sets of 4 contiguous sensors



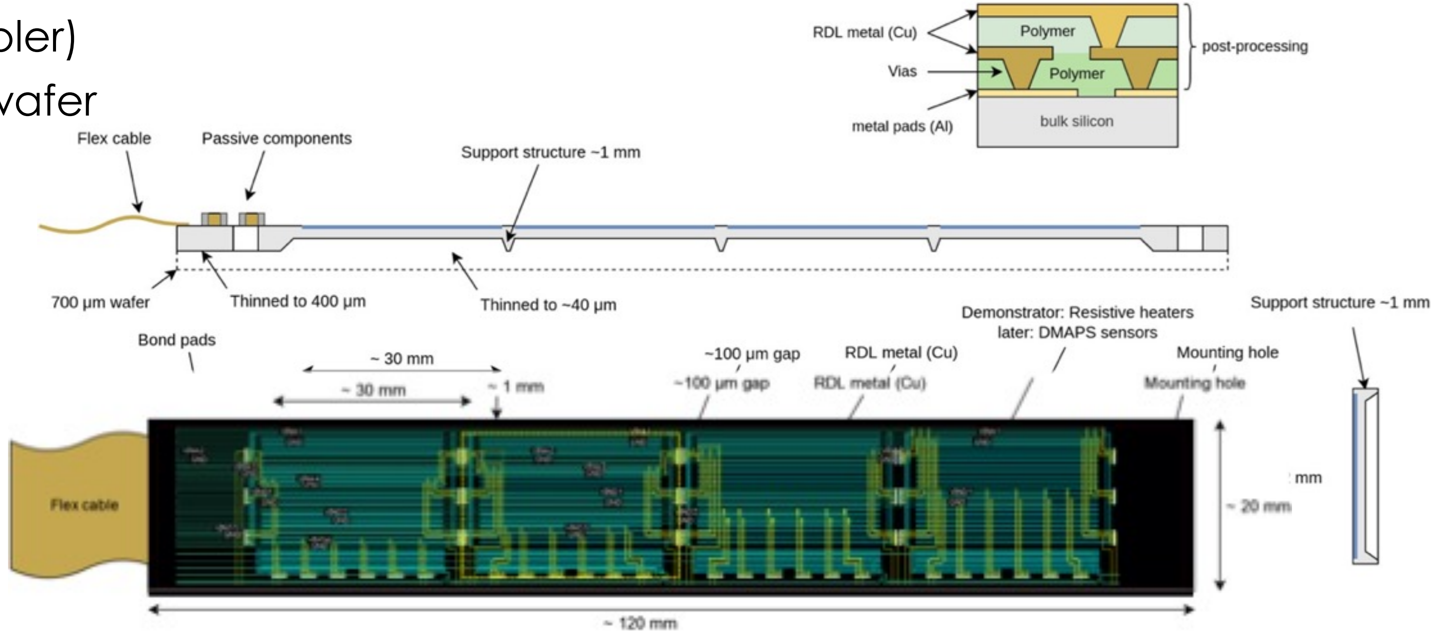
=> Design progressing for submission early in 2023

iVTX inner layer concept

Valencia, Bonn, IJClab

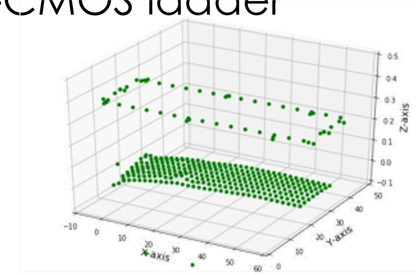
All-silicon module < 0.15 % X_0

- Inherited from the PXD-DEPFET concept (but simpler)
- 4 contiguous sensors diced as a block from the wafer
- Redistribution layer for interconnection
- Heterogeneous thinning for thinness & stiffness



Prototyping

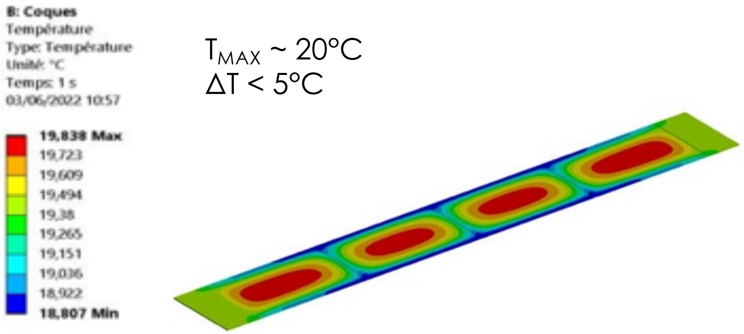
- With existing 10 cm^2 HV-CMOS ladder
  - Planarity demonstration



- On-going at IZM-Berlin with dummy Si
  - True iVTX geometry => Spring 2023

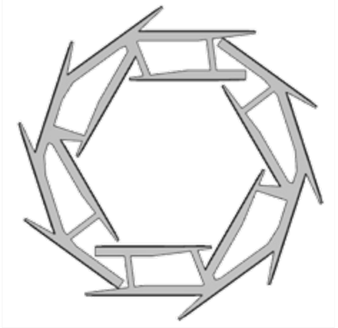
Simulation on cooling

- Dry air cooling 15°C
- Assume 200 mW/cm^2



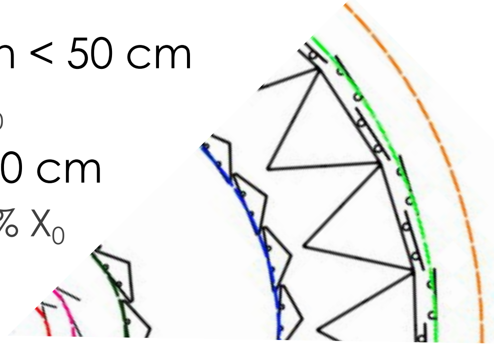
T_{MAX} ~ 20°C
$\Delta T < 5$°C

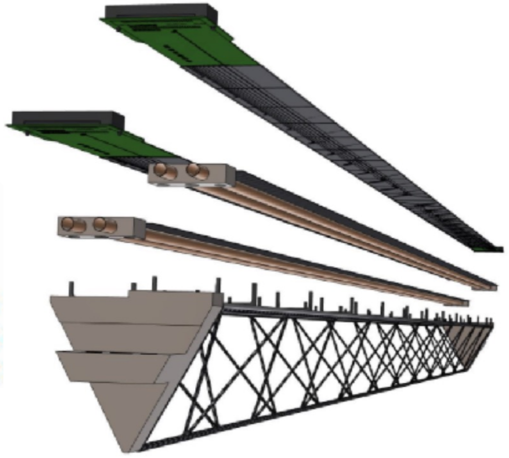
Windmill support structure
radii =14 + 22 mm



oVTX outer layer concept

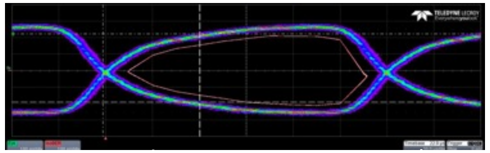
- **Long ladders**
  - Inherited from ALICE-ITS2
    - Carbon-fiber truss support frame
    - Cold-plate with water coolant
    - Long-flex for power & data
  - L3-4, radius 4-9 cm, length < 50 cm
    - Single sensor row, ~0.5 % X_0
  - L5, radius 14 cm, length 70 cm
    - Double sensor rows , ~0.8 % X_0

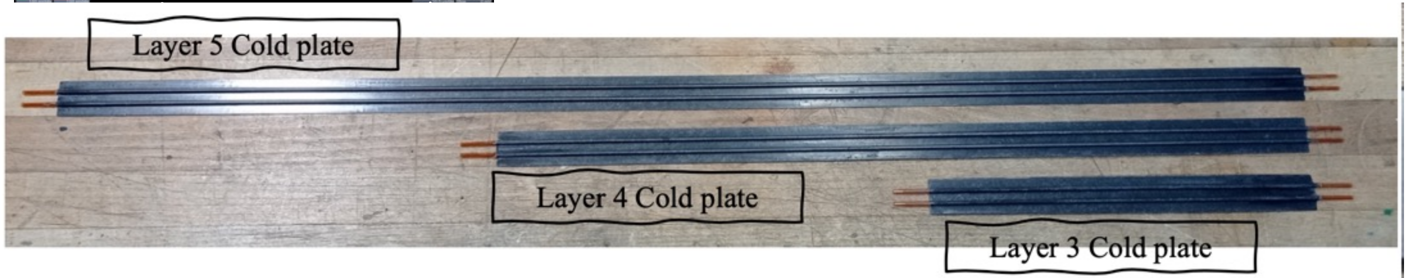




- **Prototypes for L5 under test**
  - Deformation & vibration
    - Max sagitta ~500 µm
    - First resonance f=250 Hz
  - Signal propagation
  - Cooling at $T_{ambient}$ ~24°C
    - Leakless water flow at T_{in} = 10°C
    - Heaters dissipating 200 mW/cm^2
    - 22°C < $T_{sensors}$ < 26°C

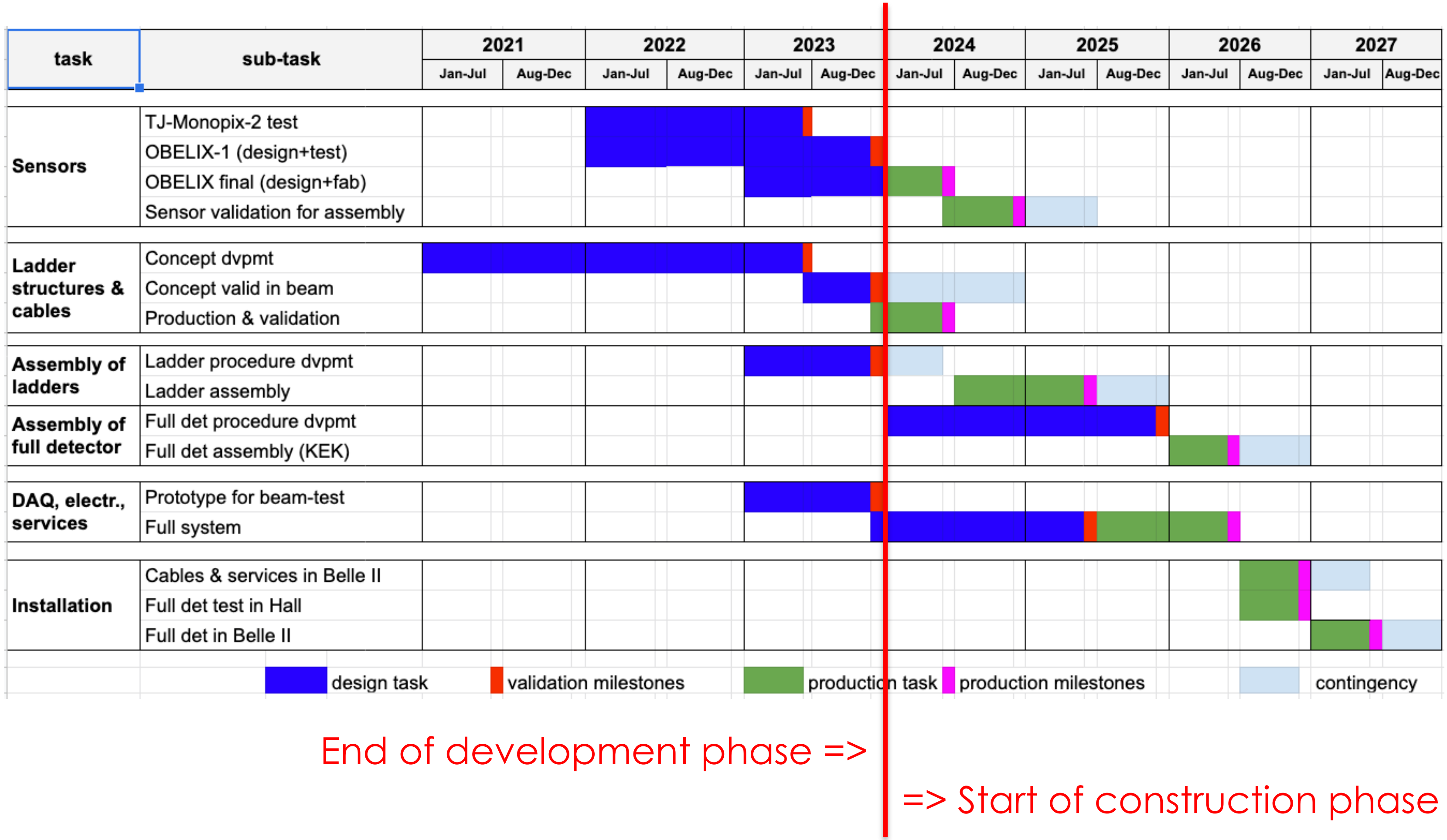
See: F.Bosi
Mechanics forum 2022





VTX Schedule

An aggressive chart, set to reach installation in 2027



- Assumption/construction
  (4 days/week, 3weeks/months)
  (10 to 20% spares)

- wafer probing ~6 months
  - 140 wafers with 1 wafer/day
  - 2 sites
  - dicing in parallel
- iVTX ladders ~ 10 months
  - 20 ladders needed
  - 2 ladders/month
  - only at IZM
- oVTX modules ~8 months
  - 100 modules needed
  - 3 modules/week
  - 2 sites
- oVTX ladders ~10-15 months
  - 60 ladders needed
  - 2 ladders/month
  - 2-3 sites

Activities proposed by IN2P3 labs

- → The OBELIX sensor
- → Data acquisition system
- → Thermo-mechanics of the beam pipe & inner layers
- → Designing & producing the VTX layers
- → Installation & running

Snapshot

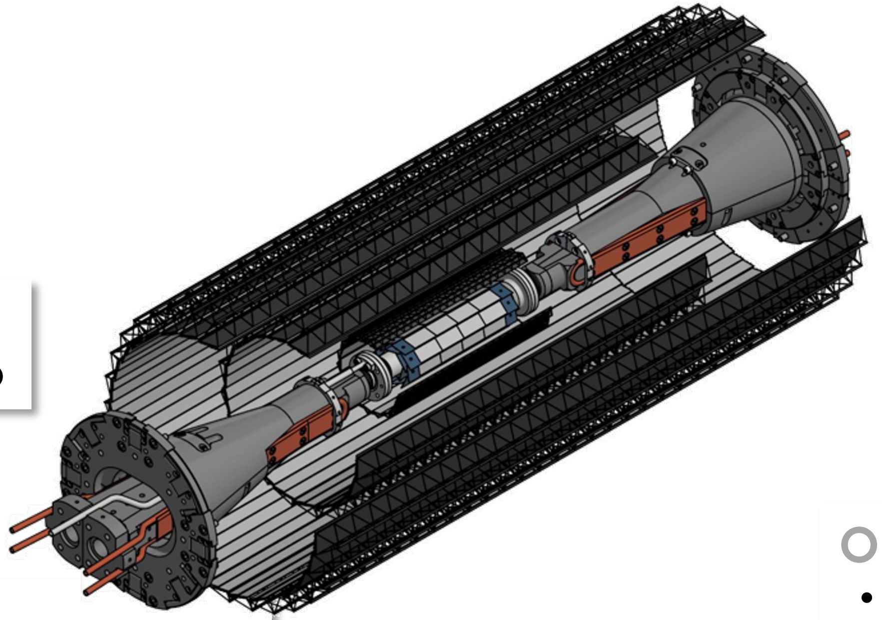
Reconstruction, Performance
- all

Electronic system

DAQ
- IJClab
- Provider of the boards chosen by Belle II

Sensor
- CPPM, IPHC
- Leader of OBELIX design

Integration, assembly
- Contribution CPPM, IJClab



iVTX, oVTX concepts
- Contribution IPHC, CPPM, IJClab

Installation & operation
- all

Online software
- Contribution IPHC

Thermo-mechanics
- IJClab
- Key partner for beam-pipe /iVTX with KEK

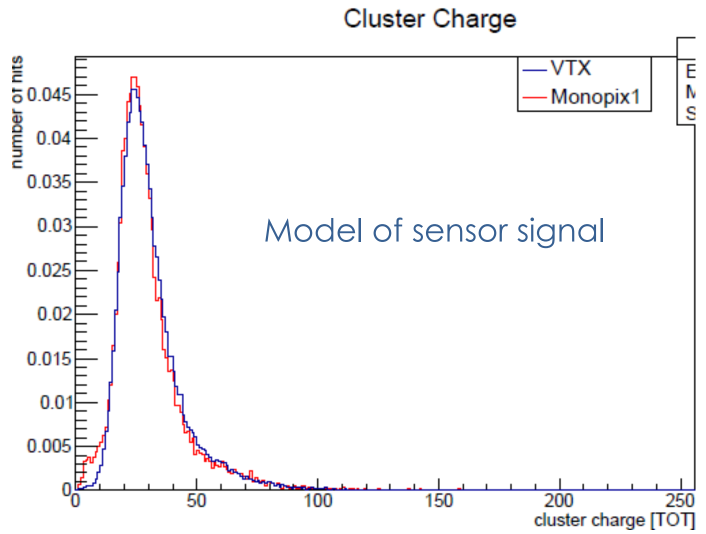
HLT
- IJClab

Performance, reconstruction, HLT

ALL

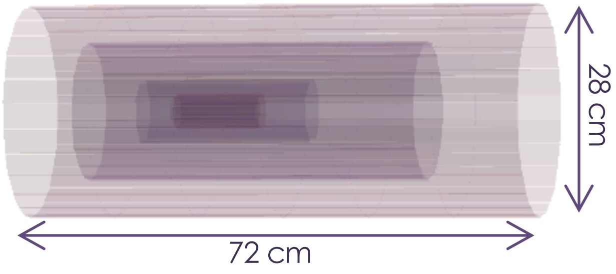
On-going activities

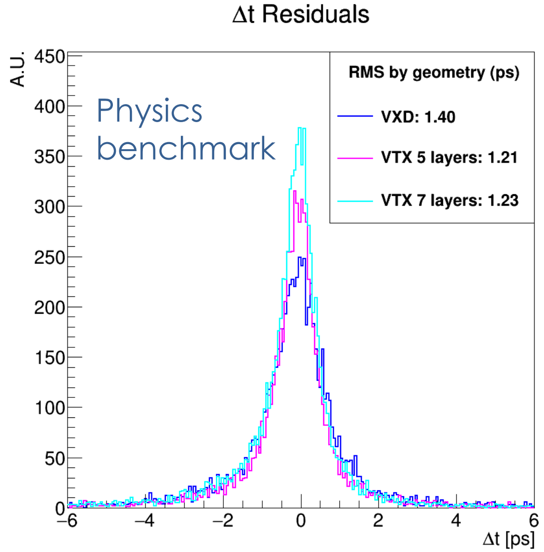
- Optimisation of HLT reconstruction => Effective triggering
  - IJClab
- Implementation of upgraded geometries in full simulations
  - Tracking optimisation studies
  - Physics benchmark studies => Till TDR 2023
  - CPPM, IPHC



Proposed activities

- Contribution to VTX reconstruction software
- Optimisation of HLT to benefit from VTX precision





Independent of technology chosen for upgrade

Sensor design & test

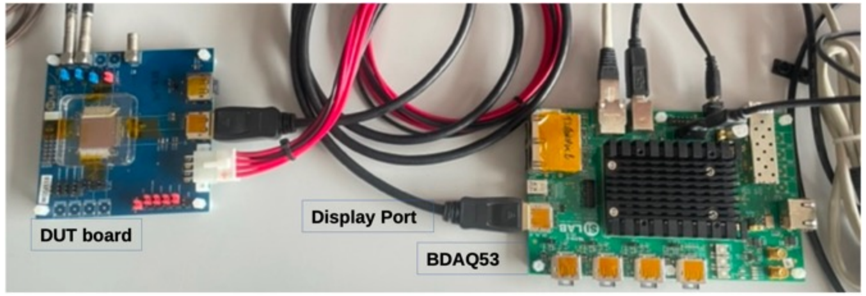
IPHC, CPPM

▪ On-going activities

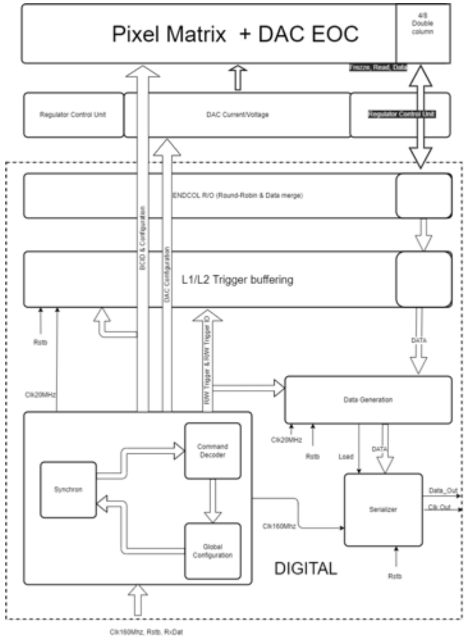
- Characterisation of TJ-Monopix2 matrix ⟶ mid-2023
  - CPPM
- Design then tests of OBELIX-1 ⟶ early 2024
  - Organisation of design & submission: IPHC
  - Pixel matrix: IPHC
  - Digital control: CPPM
  - Verification: CPPM, IPHC
  - Tests: CPPM, IPHC

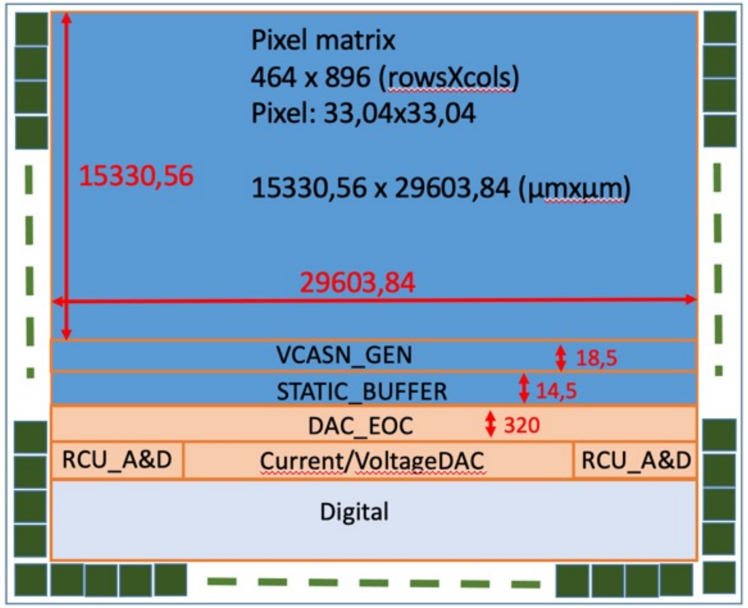
▪ Proposed activities

- Design then fabrication of OBELIX-2
- Validation of OBELIX-2 with numerous tests



Setup @ CPPM





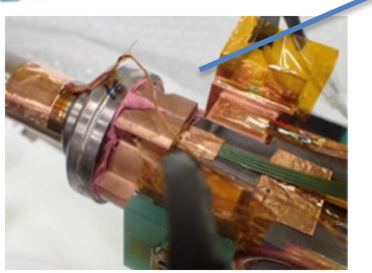
Sensor planning @ CPPM & IPHC

Thermo-mechanics for beam-pipe and iVTX

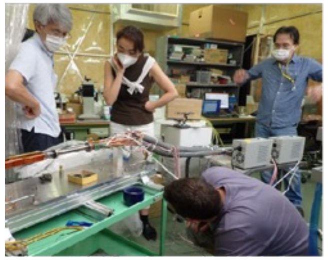
IJClab

On-going activities

- Improvement of current beam-pipe cooling
- Installation of PXD2 during LS1
- Simulation for iVTX air-cooling concept

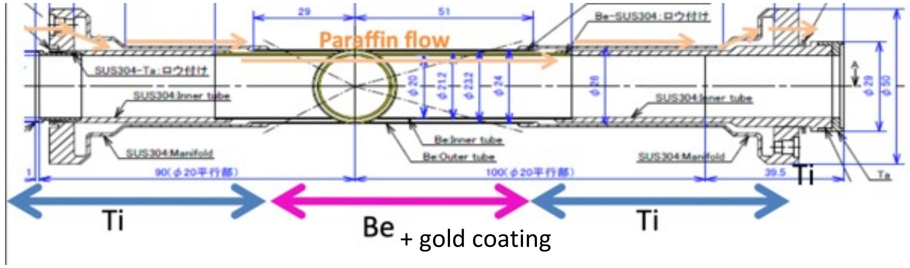


Simulations, design and test of new cooing block



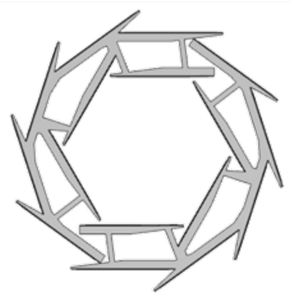
Proposed activities @ IJClab

- Follow beam-pipe fabrication process
  - Includes various base-materials & coatings
  - Cooling mechanism



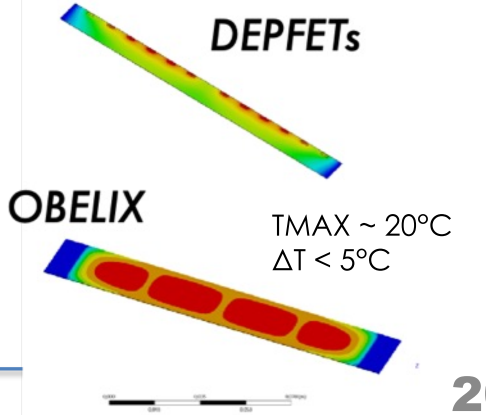
- Development of iVTX support & cooling

Independent of technology chosen for upgrade



Windmill support structure (Valencia)

Simulation of air colling with 200 mW/cm^2 dissipation



Integration and assembly

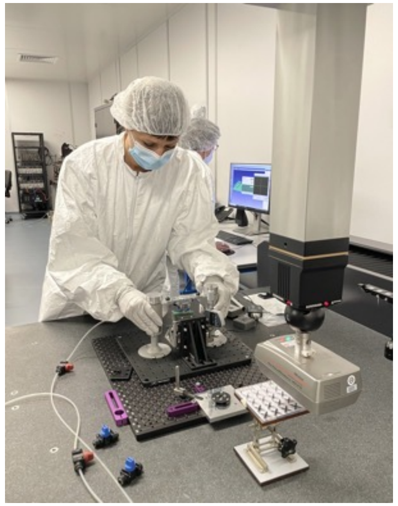
all

■ On-going activity

- Contribution to iVTX ladder R&D
  - Prototype all-silicon concept in 2023

{ – Redistribution layer concept
– Air cooling }

Know-how @ IPHC: light module assembly



Know-how @ CPPM: module handling

■ Proposed activities

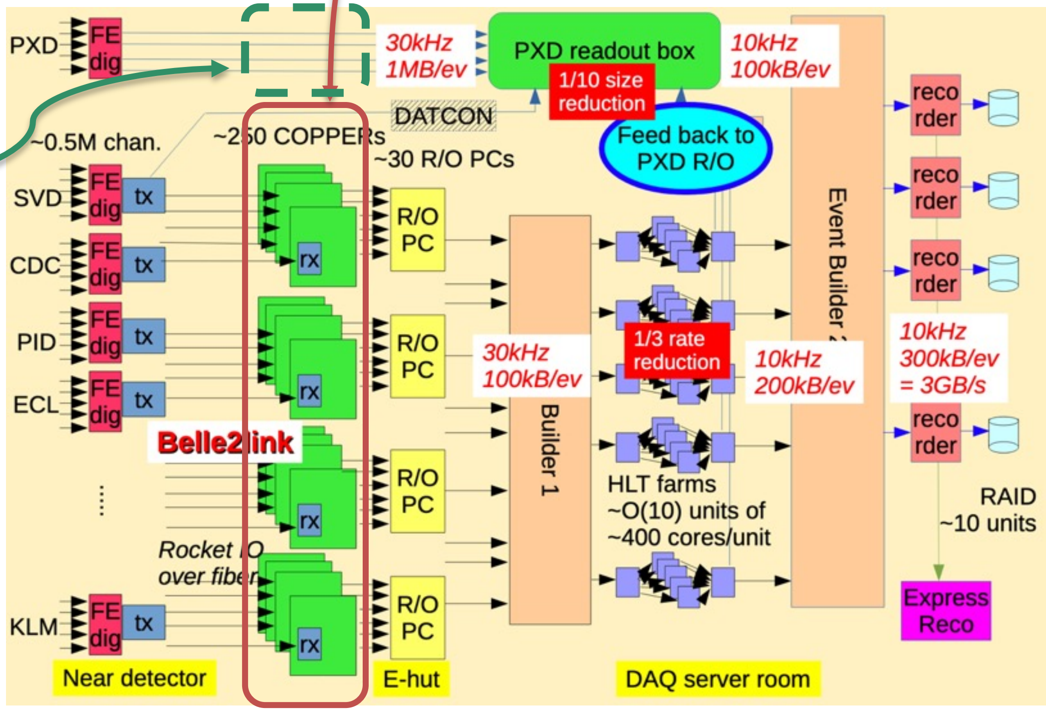
- Sensor probe test for production
  - Fraction (to be defined) of the ~140 wafers
  - IPHC (C4Pi - microtech)
  - Requires new prober @ IPHC
- Development of VTX assembly procedure
  - Module handling, alignment and attachment to ladders/structure
  - CPPM
- Production of modules
  - Fraction (to be defined) of ~2300 sensors to modules
  - IPHC (C4Pi - microtech)

DAQ

IJClab, CPPM

- <u>On-going activity</u>
  - Provider of PCIe40 boards
    ⟶ currently being deployed in Belle II (2021-23)

- <u>Proposed activity</u>
  - Investigate new board generation PCIe400
  - Adaptation of PCIe40(0) for VTX
    - 1 board covers VTX data-throughput



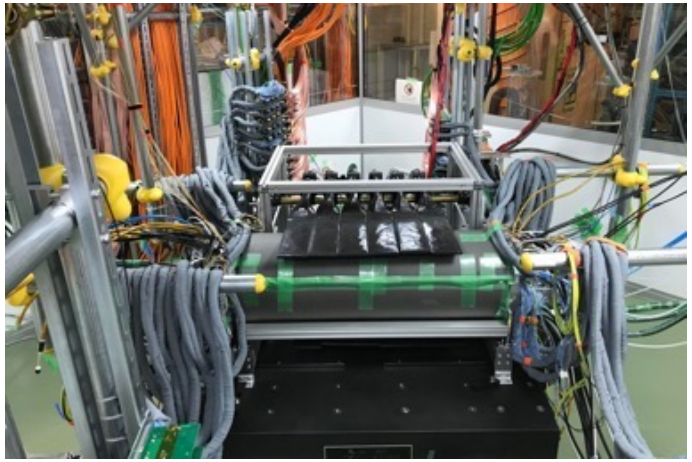
Independent of technology chosen for upgrade

Proposal for installation & operation

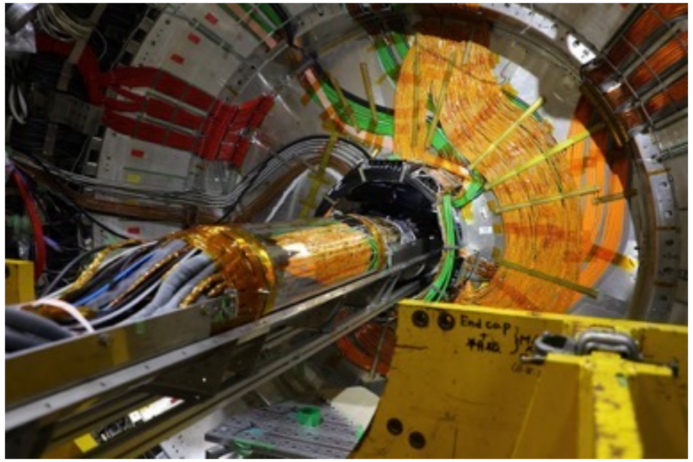
ALL

- **Installation, commissioning during final year**
  - Assembly of VTX-shells/ladders around beam pipe/on-support
  - Long-term test outside Belle II but in Tsukuba (experiment) hall
  - Cabling, service installation
  - Insertion of VTX into Belle II
  - Commissioning tests

> - Start in 2026
> - IN2P3 contribution (size & type) will depend on person-power



VXD installation (2018) examples



- **Operation**
  - On-going contribution on SVD: Expert shifts; Online sw maintenance; Offline sw dvpmt

  - Effort should continue for visibility
    - Slow-contribution depends on person-power granted by labs

Request to IN2P3

- Person-power
- Budget

Person-power

Task		FTE	IN2P3 contributors	timeline	collaboration with
Performance	physicists	-	J.Baudot, G.Dujany, C.Finck, E.Kou, G.Mancinelli, I.Ripp-Baudot, J.Serrano, K.Trabelsi	whole project duration	performance group
	postdocs	-	TBD		
	doc	-	TBD		
Sensor (design & test)	physicists	1	M.Barbero, J.Baudot, C.Finck	till end of 2024	Bergamo, Bonn, Pavia, Dortmund, Valencia, Vienna
	engineers	4	P.Barillon, P.Breugnon, C.Hu, L.Federici, D.Fougeron, P.Pangaud, H.Pham, I.Valin		
	CDD	1	A.Kumar, D.Xu		
	doc	0.3	R.Boudegga		
DAQ	physicists	0.2	P.Robbe	at least till 2027	KEK
	engineers	0.3	D.Charlet		
Beam-pipe	physicists	1	E.Kou, F.LeDiberder, M.Winter	till installation in 2027	KEK
	engineers	1	D.Auguste, J.Bonis, Y.Peinaud		
Assembly	physicists	0.1	M.Barbero, J.Baudot	2023 to 2025	Pisa, Valencia, Vienna
	engineers	1	F.Agnese, O.Claus, E.Vigeolas, C.Wabnitz		
	CDD	0.5	TBD		

} #FTE staff evolving with time

} In parallel with physics analysis

} In parallel with other technical activities

} Depends on accepted production volume

Budget

Notes:
- estimate assumes 1USD=1EUR
- sensor invoice in USD

Overall VTX budget

Component	Development	Production	Total (k$)
Sensors	380	920	**1300**
Ladders	120	730	**850**
Assembly	130	630	**760**
DAQ & services	280	1060	**1340**
Installation	-	100	**100**
Total	**900**	**3500**	**4500**

- Still a preliminary estimation
  - Currently 5% contingency for prod. costs
- Assumptions for sensor cost:
  - 2 runs OBELIX-1 & 2
  - 50 dies/wafer, 60% yield, 20% spare
  - 2200 sensors needed => 141 wafers

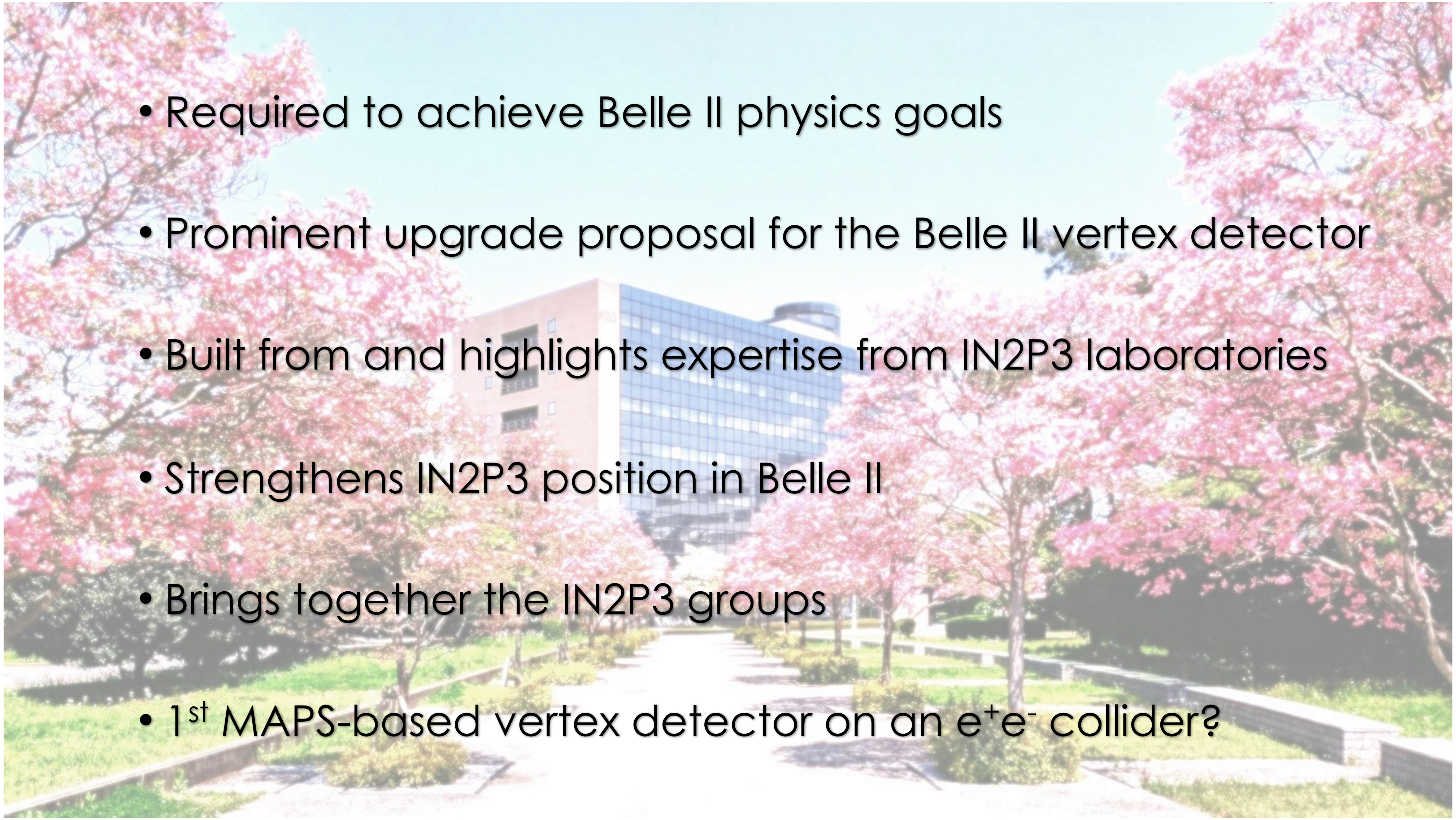
Request to IN2P3

- Reflects barycentre of activities
- Cover ~1/3 of overall sensor cost

Task	Development		Production	
	cost (k$)	Timeline	cost (k$)	Timeline
Sensors	130*	2021-23	360	2023-24
Ladders	-	-	-	-
Assembly	30*	2022-23	50	2024-25
DAQ	-	-	40	2025-26
Beam-pipe	10*	2022-23	60	2024-27
Installation	-	-	60	2026-27
Total	**170**		**570**	

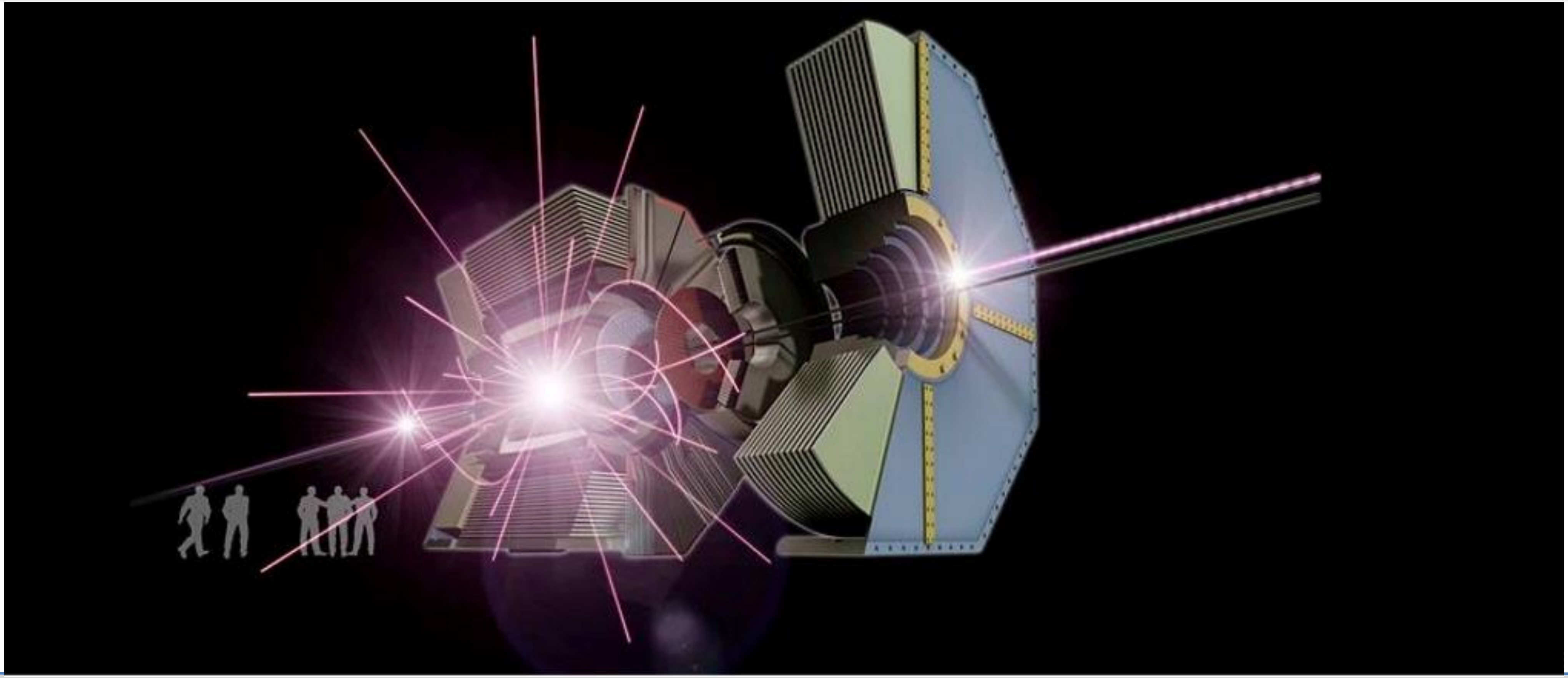
- Support already acquired for Development: 100 kEUR from IN2P3 + 30 kEUR from Idex

Conclusion on the VTX project



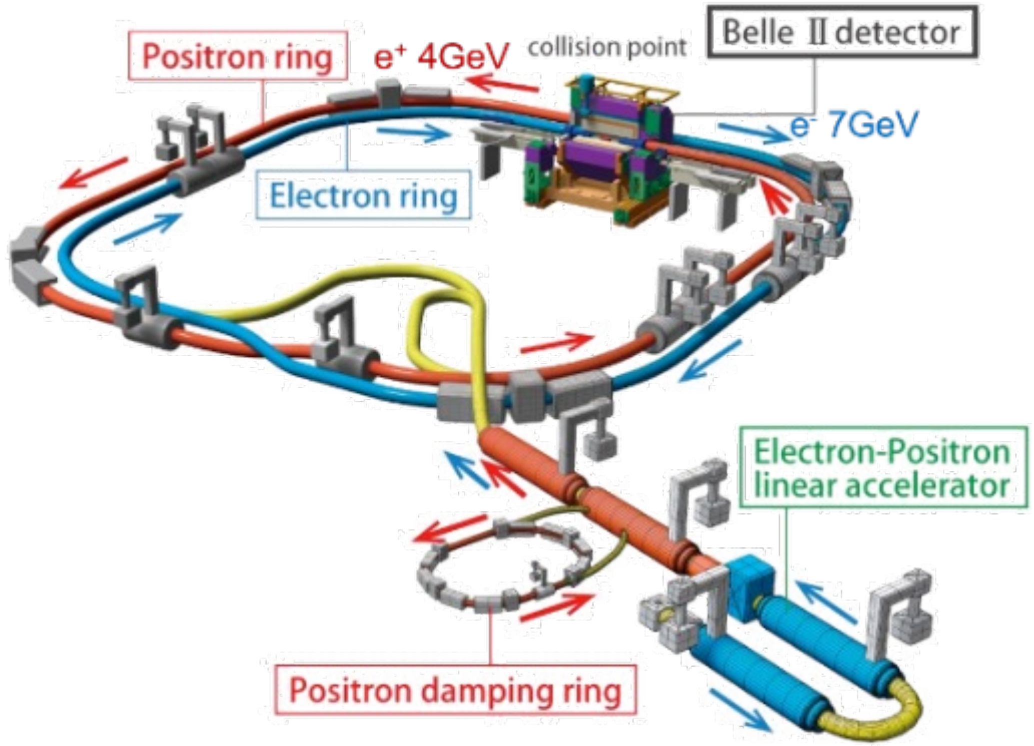
- Required to achieve Belle II physics goals
- Prominent upgrade proposal for the Belle II vertex detector
- Built from and highlights expertise from IN2P3 laboratories
- Strengthens IN2P3 position in Belle II
- Brings together the IN2P3 groups
- 1st MAPS-based vertex detector on an e^+e^- collider?

SUPPLEMENTARY SLIDES

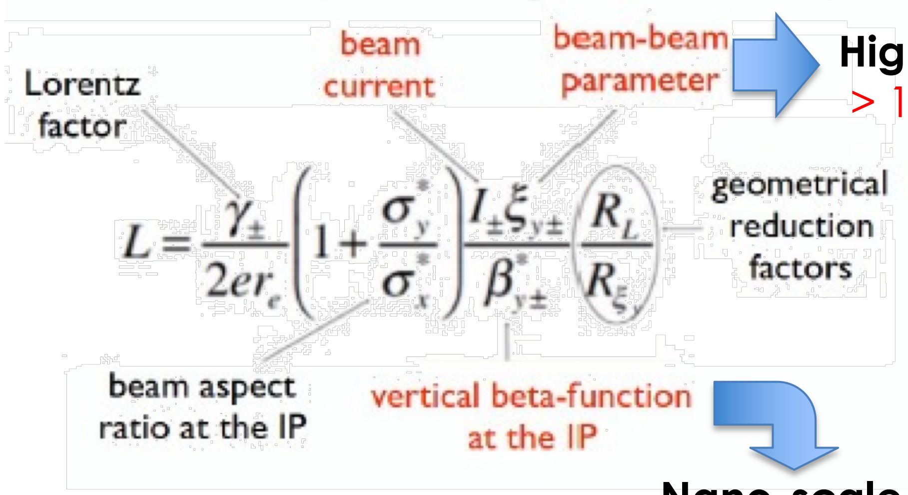


SuperKEKB

SuperKEKB collider



- Recipe to high luminosity

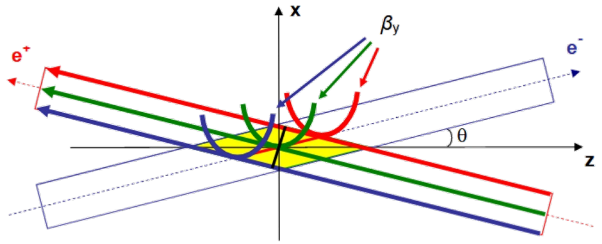


$$L = \frac{\gamma_\pm}{2 e r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$

High currents:
> 1A

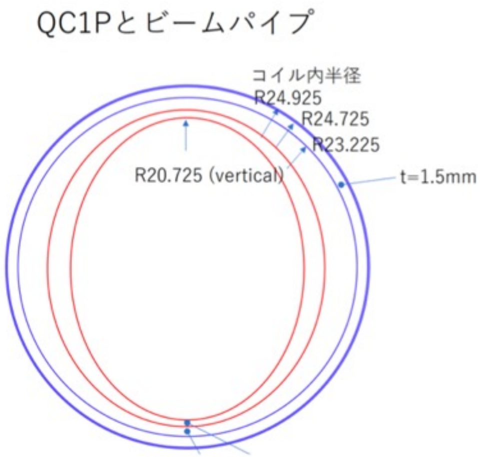
Nano-scale beam size:
$\sigma_x \times \sigma_y \sim 10\mu m \times 60$ nm
$\beta_y^* << 1$ mm

& specific beam crossing features
Crossing angle (83 mrad) + crab waist (80%)



	KEKB	SuperKEKB		
		2022	pre-LS2	post-LS2
Energy (GeV) LER/HER	3.5 / 8	4 / 7		
Current (A) LER/HER	1.6/1.2	1.4/1.1	2.5 / 1.8	2.8 / 2/0 ?
β_y^* (mm)	5.9	1.0	0.6	0.3 ?
Instant. Lumi. ($cm^{-2} s^{-1}$)	2.1×10^{34}	**4.7×10^{34}**	2.8×10^{35}	$\sim 6 \times 10^{35}$

Revisit QC1P modification

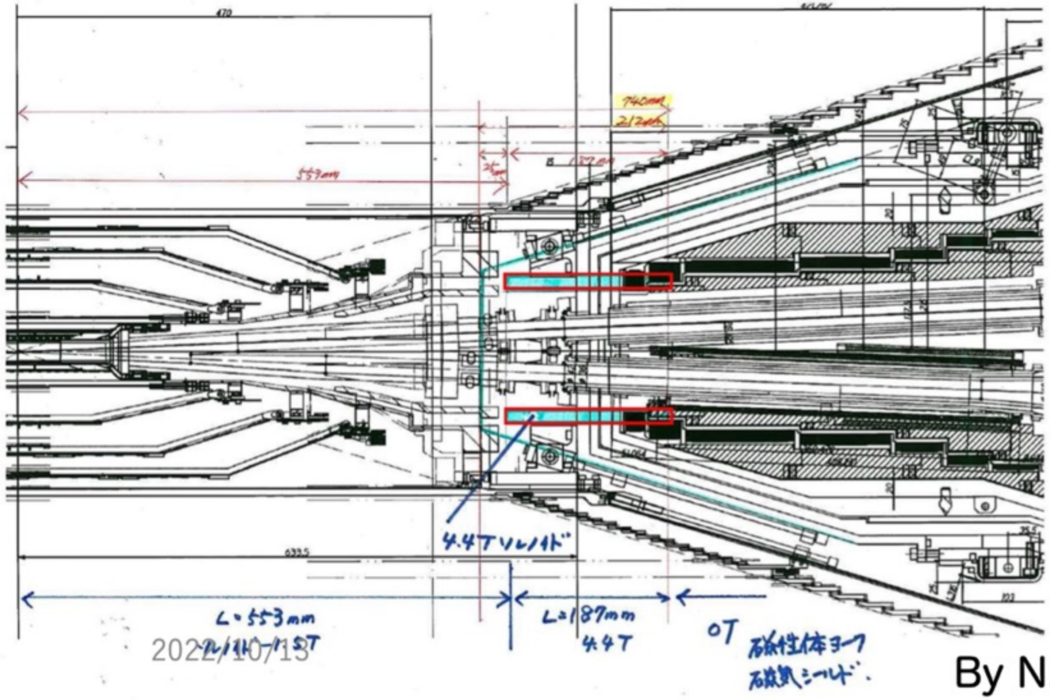


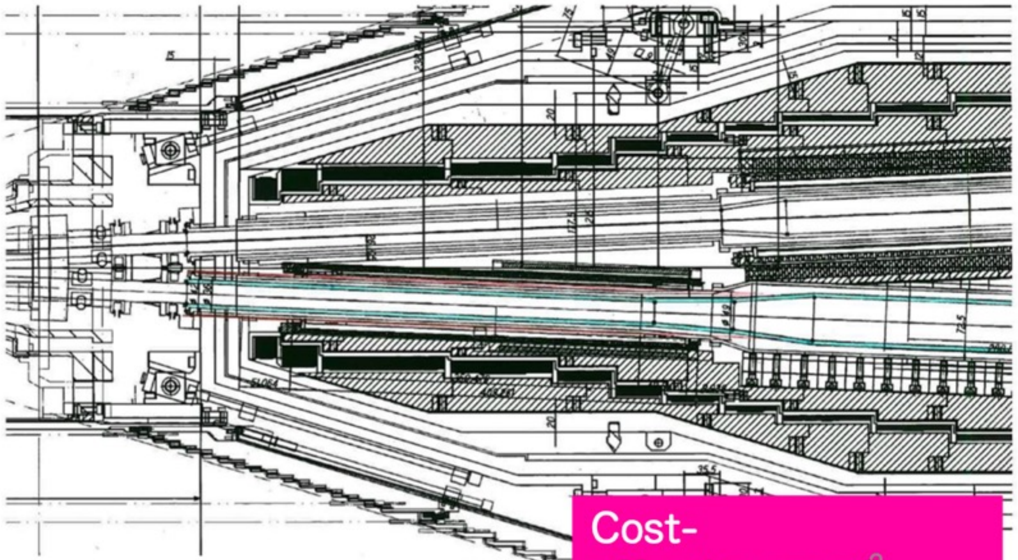
- Increase QC1P aperture (vertical) from 13mm to (18mm) 20.7 mm
  - Larger physical aperture
- Fabricate new anti-solenoid coil and move it closer to the IP
  - less x-y coupling is expected
- Cover QC1P by magnetic material
  - magnetic coupling reduction is expected

QCSシステム改善：#3について

1. 4極電磁石は、そのまま流用。
   - 補正電磁石は、QC1Pの外周部へ移動。
   - QC1Pは、磁性体ヨークを被る。対抗ビームラインも磁気シールドあり。
2. 補正ソレノイドをQC1Pの前に出す。
3. QC1Pのビームパイプ内径を大きくする。
   - これまでの提案：R13.5mm→R18mm →R20.7mm

Working with the Optics G





By N. Ohuchi on Sep.14, 2022

Cost-effectiveness ?

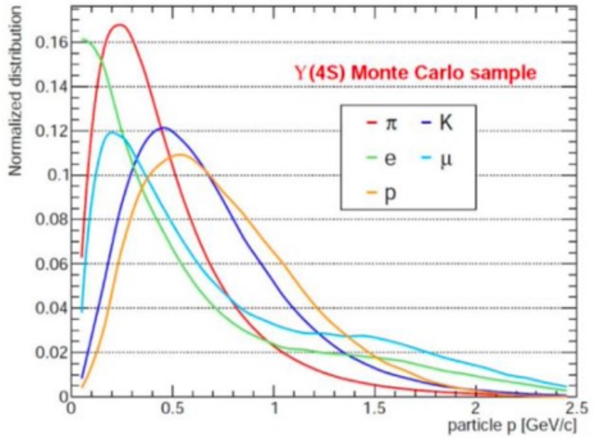
Current Belle II

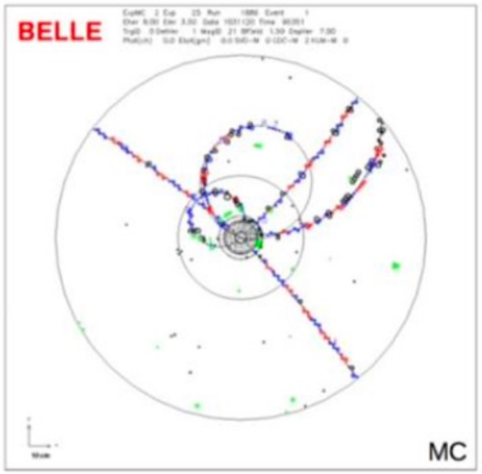
Tracking at Belle II

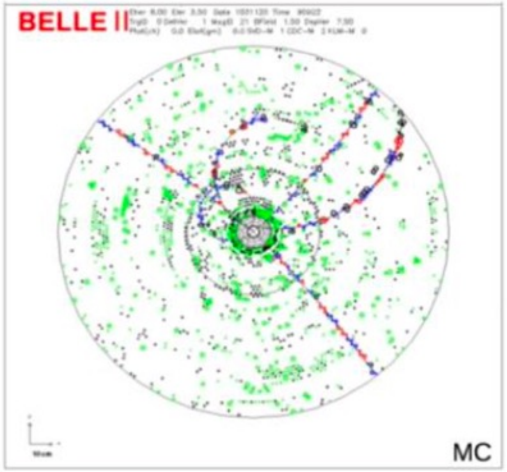
- Average track multiplicity for Υ(4S) is about **11 tracks**.
- Most of the particles that are visible in the detector have **similar momentum ranges and distributions**.
- Many tracks are at **low momentum**.
  → multiple scattering, curling tracks.

Particle types visible in Tracking Detectors of typical Υ(4S) event

Particle type	Average fraction
$\pi^{\pm}$	72.8%
$K^{\pm}$	14.9%
$e^{\pm}$	5.8%
$\mu^{\pm}$	4.7%
$p^{\pm}$	1.8%

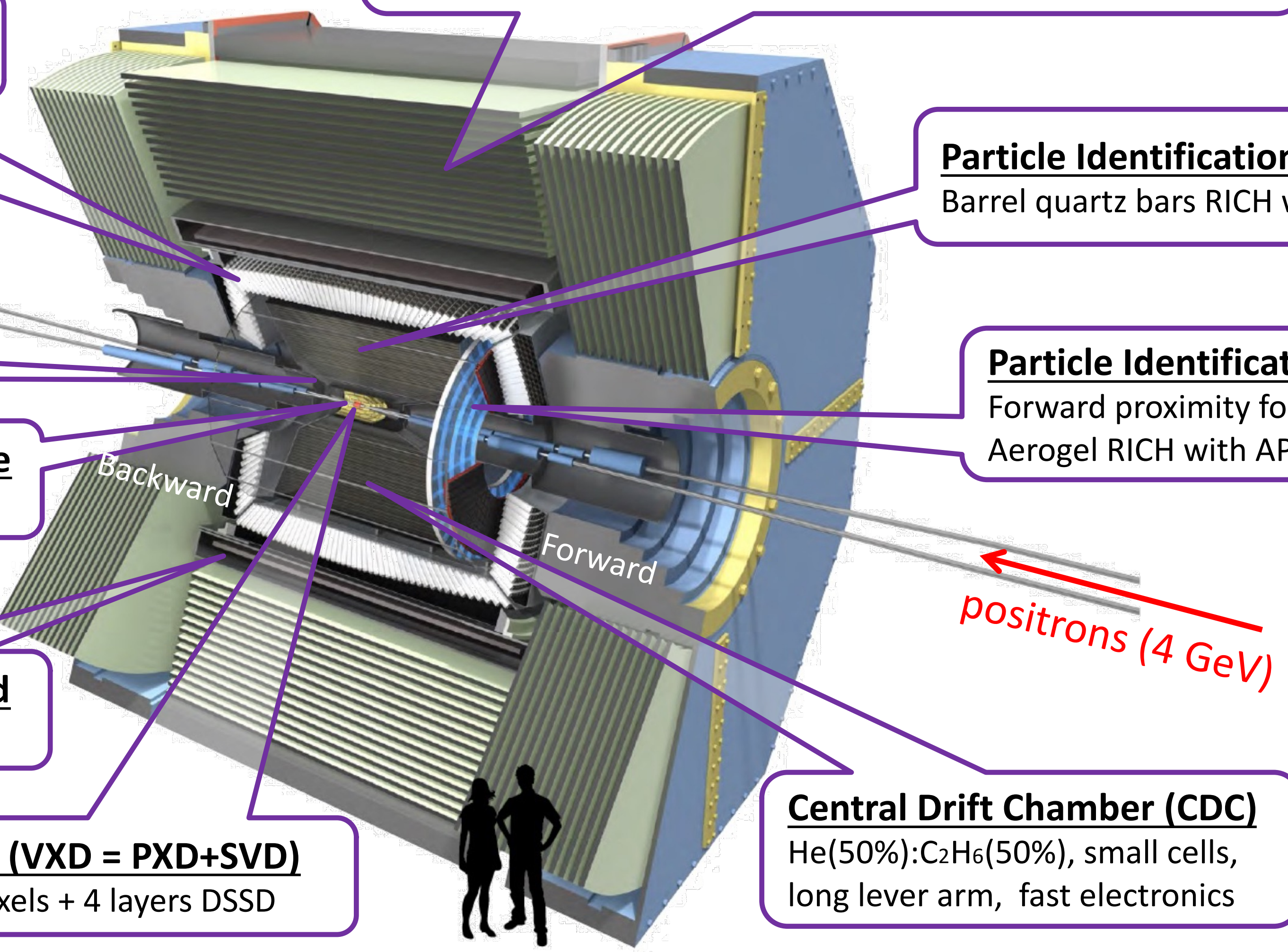






- Sizeable **beam-induced background**.
- **High occupancy** of background: 11 tracks = 10^2 signal hits vs 10^4 beam background hits.
- **Random hit** combinations, **clone** tracks.

The Belle II detector



KLong and muon detector (KLM)
Resistive Plate Chambers (barrel outer layers)
Scintillator + WLSF + SiPM's (end-caps , inner 2 barrel layers)

EM Calorimeter (CDC)
CsI(Tl), waveform sampling (barrel+ endcap)

Particle Identification (TOP)
Barrel quartz bars RICH with PMT

Final focusing magnets (QCS)

Particle Identification (ARICH)
Forward proximity focusing
Aerogel RICH with APD

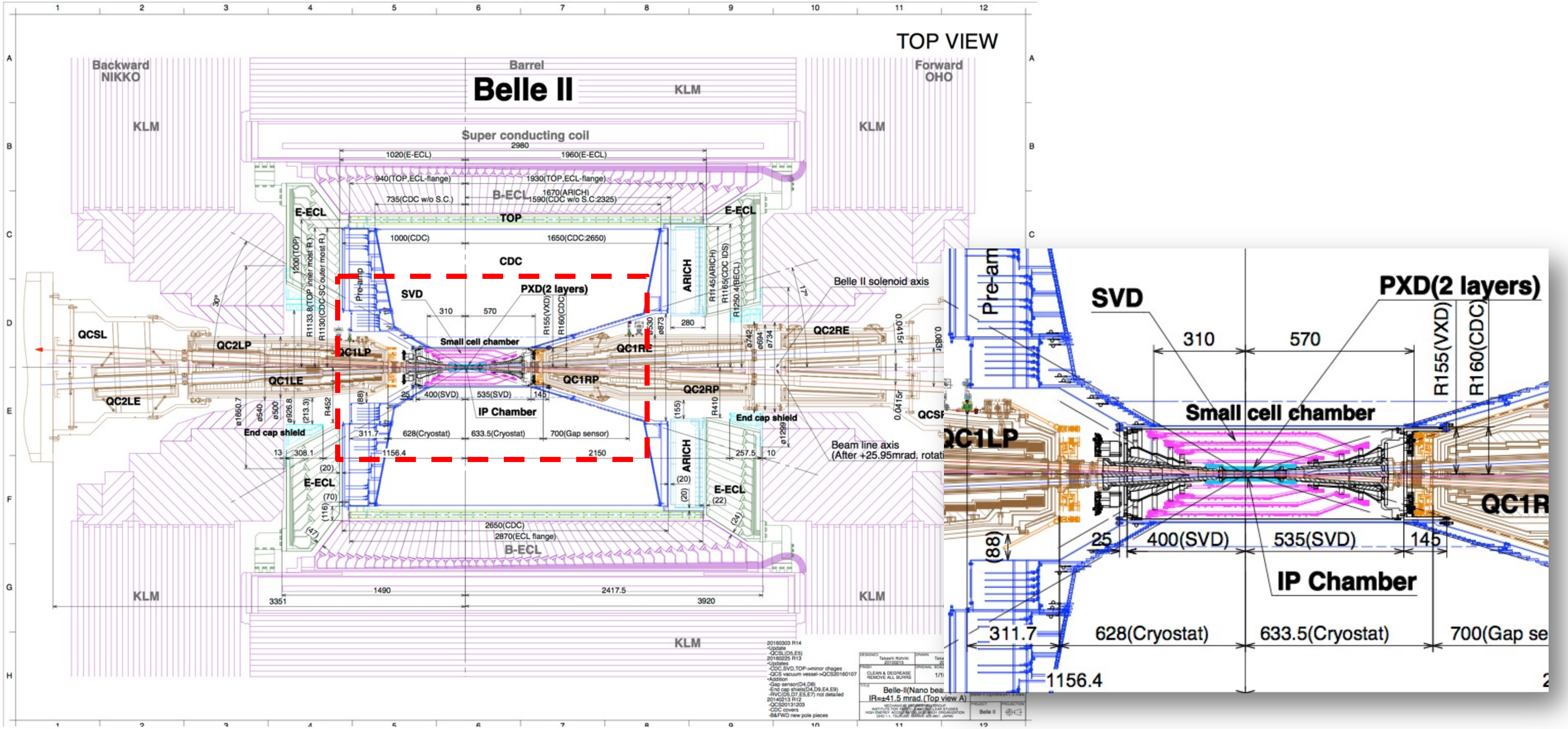
Beryllium beam pipe
2cm diameter

SuperCond. Solenoid
1.5 T magnetic field

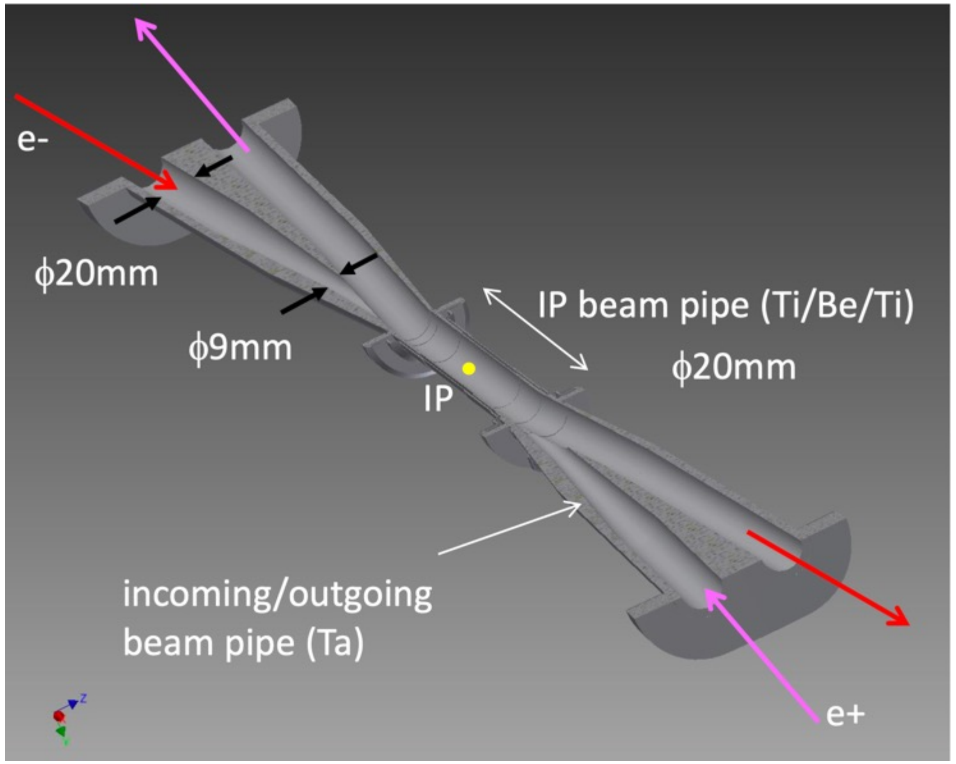
Vertex Detector (VXD = PXD+SVD)
2 layers DEPFET pixels + 4 layers DSSD

Central Drift Chamber (CDC)
He(50%):C_2H_6(50%), small cells,
long lever arm, fast electronics

The inner region



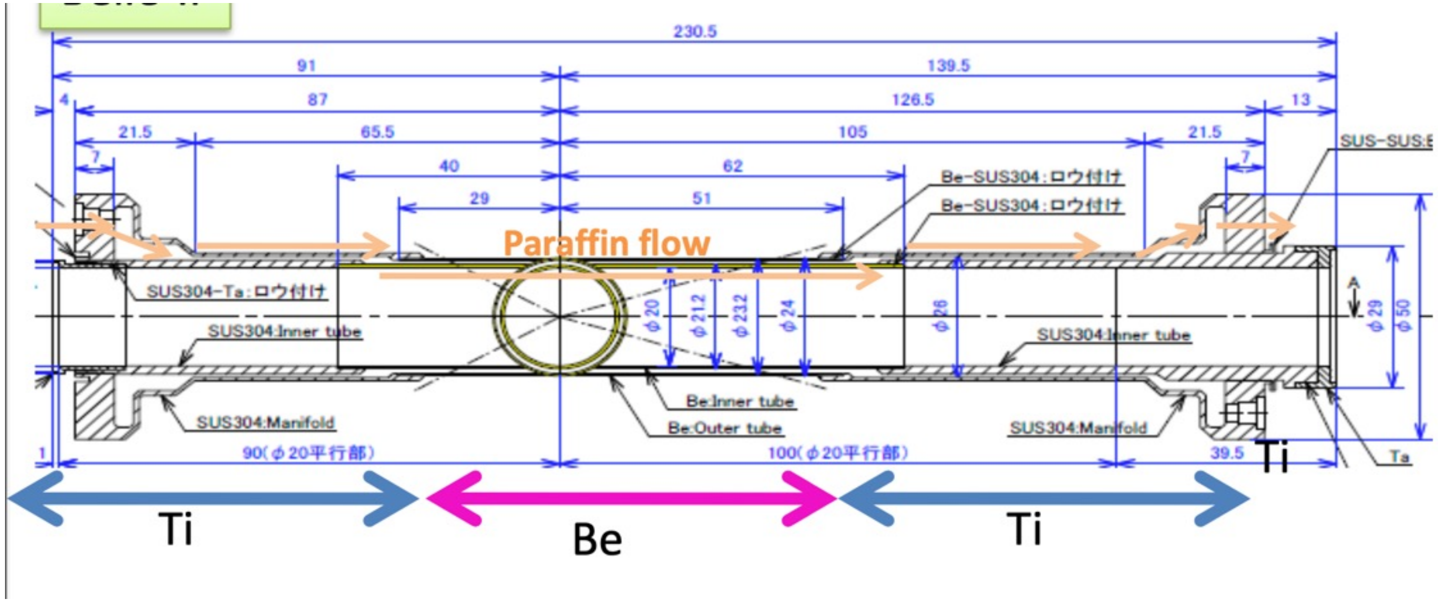
Beam-pipe details



Total radiation length = 0.8 % X_0

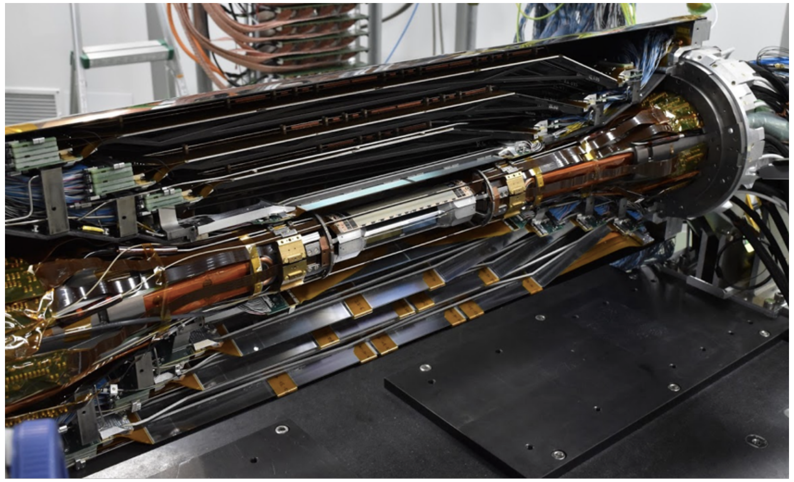
- 2x 0.5 mm berilium walls = 0.3 %
- 1 mm paraffin = 0.15 %
- 10 µm gold coating = 0.3 %

Radii: inner = 10 mm, outer 12 mm



The current VXD

- <u>Two technology system</u>
  - **SVD = Double-Sided Strip Detector**
    - Read-out sensor connected on sensor = Origami
    - Hit time-stamping σ_t ~ 2-3 ns
    - Spatial resolution $\sigma_{s.p.}$~ 20 μm

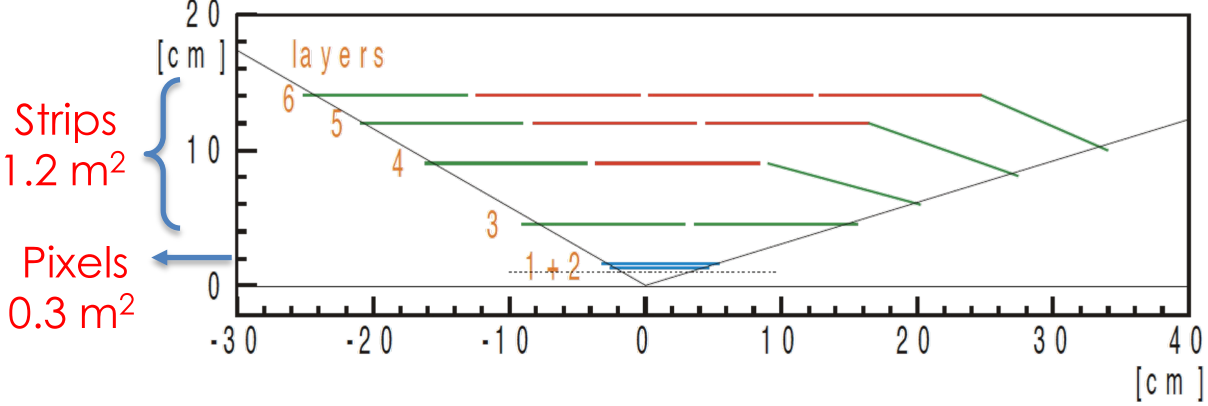


  - **PXD = DEPFET sensors**
    - Very low material budget 0.2 % X_0 / layer
    - Small first layer radius = 1.4 cm
    - Long integration time 20 μs / trigger rate & injection bkg

PXD1 was incomplete
- only 10/20 ladders (8/8 inner, ½ broken, 2/12 outer) installed
  - not enough good modules available pre-2018
- good vertexing performance so far
  - but not guaranteed for higher future lumi ⇒ higher backgrounds
- suffered significant damage due to uncontrolled beam losses

ongoing efforts to install 2nd, complete PXD2 = LS1

65 cm long – 30 cm in diameter



- The plan is successful so far with occupancy < 1 %
- At nominal luminosity, tracking at ~3% occupancy

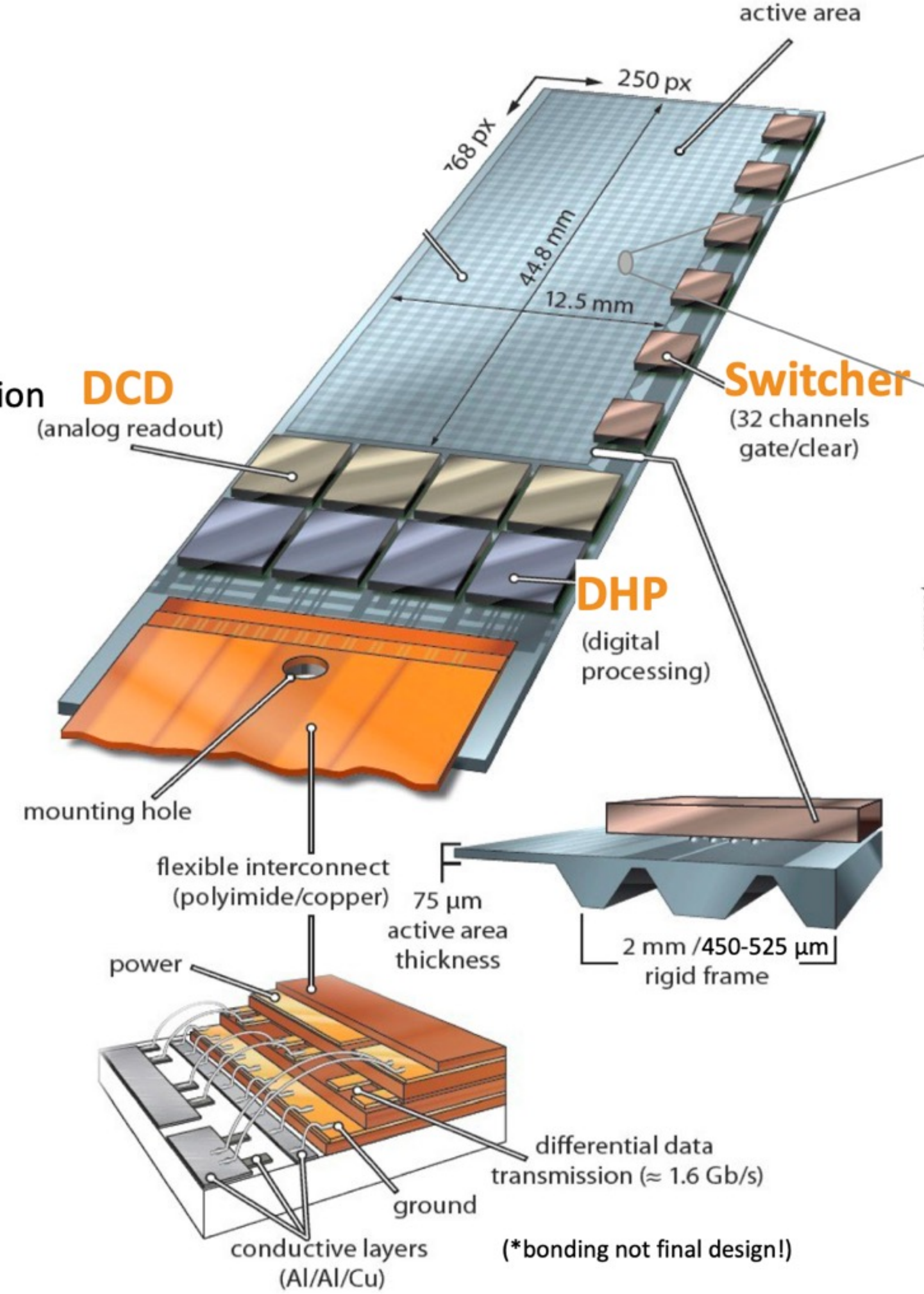
PXD Sensors

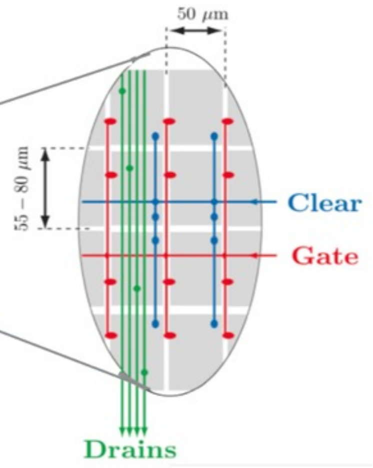
Layout

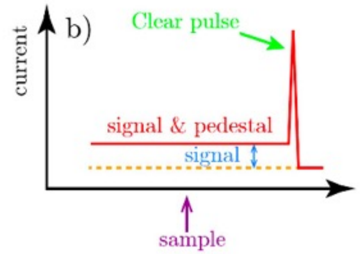
- matrix
  - 250x768 pixels, pixel size 50x(55-85) μm^2
- ASICs (custom designed)
  - *Switchers* ⟶ DEPFET control
  - *DCD* ⟶ 256 channel ADC: 8bit source currents digitization
  - *DHP* ⟶ data processing: pedestal correction, zero suppression, …
- all silicon design
  - mechanically self supporting modules
  - thinned to 75 µm (active region)
  - small total material budget ~0.21 X_0

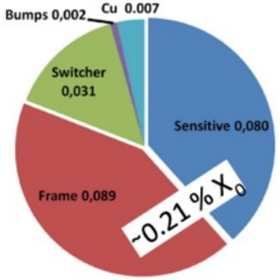
Operation

- rolling shutter read-out ⟶ low power
  50 kHz ⟶ 20 µs integration time (2x beam revo. cycle)
  dead-time free except for 100 ns read-clear cycle
- design: 1% occupancy (layer 1)
  3 % occupancy limit (DHP, DAQ, tracking)
- single point sampling ⟶ median drain current
  pedestals stored on DHP for zero suppressio
- power dissipated mainly in ASICS at end of stave
  ~ 10W/module









DESY. From A.Boltz, [CEPC 2022 workshop]

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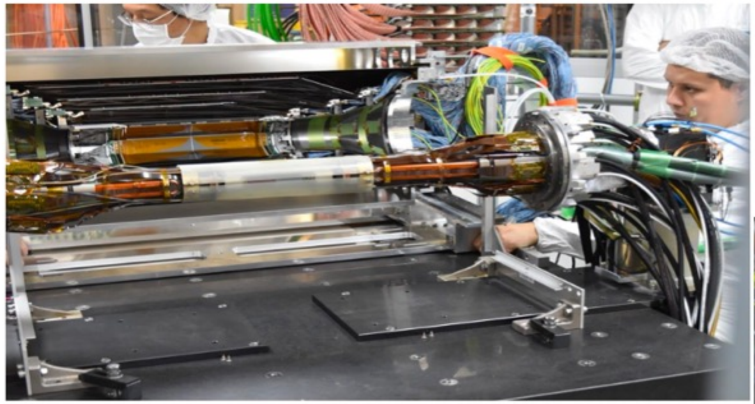
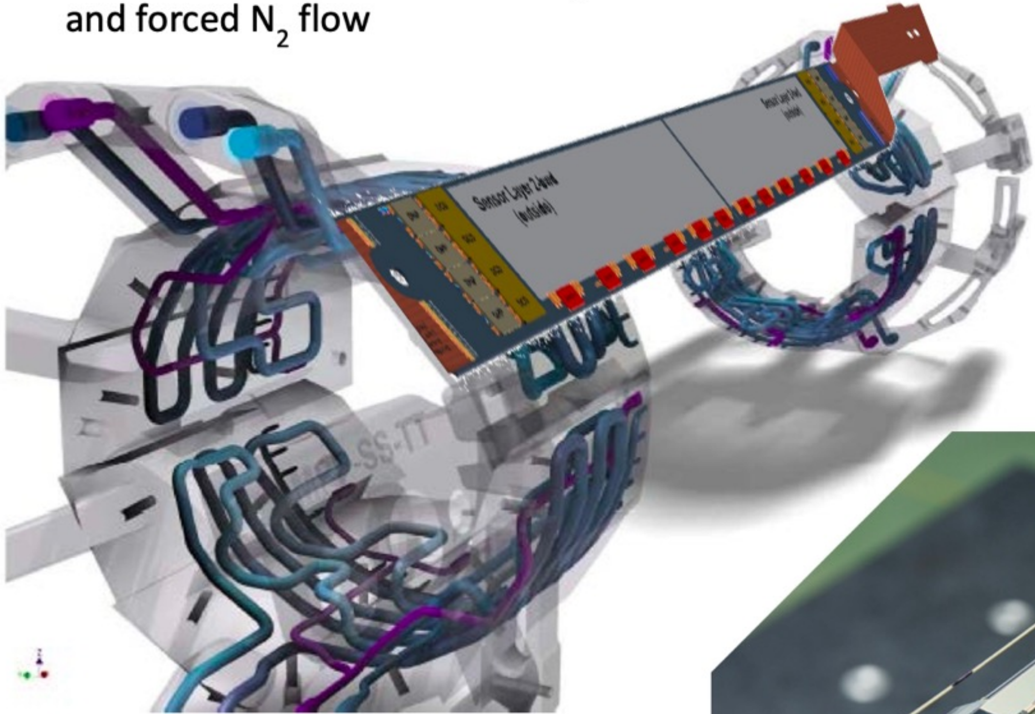
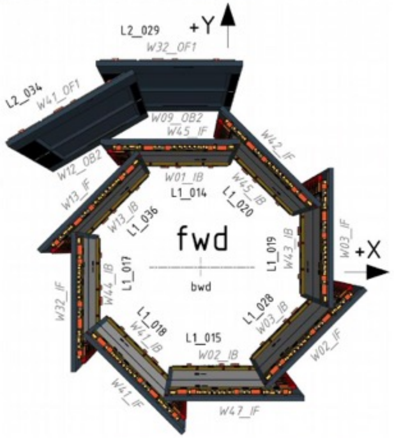
PXD in Belle II

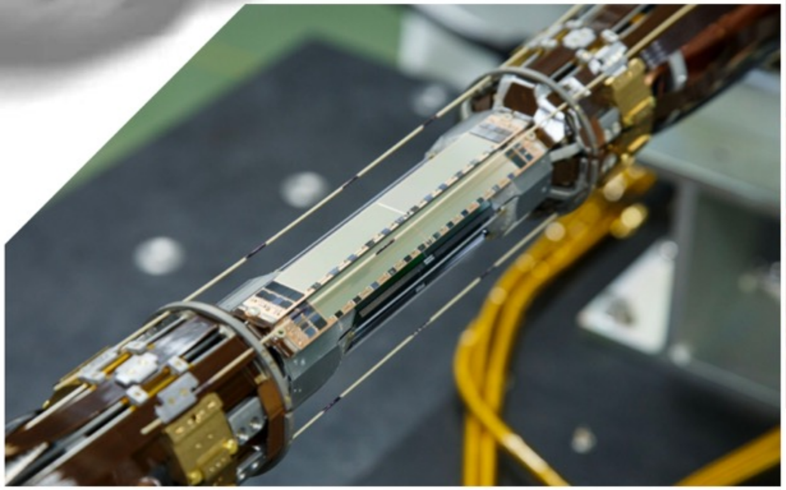
PXD assembly

- 2 PXD modules glued together ("ladder")
- 2 half shells mounted on Support and Cooling Blocks (SCBs)
- provide cooling via 2-phase CO_2 and forced N_2 flow



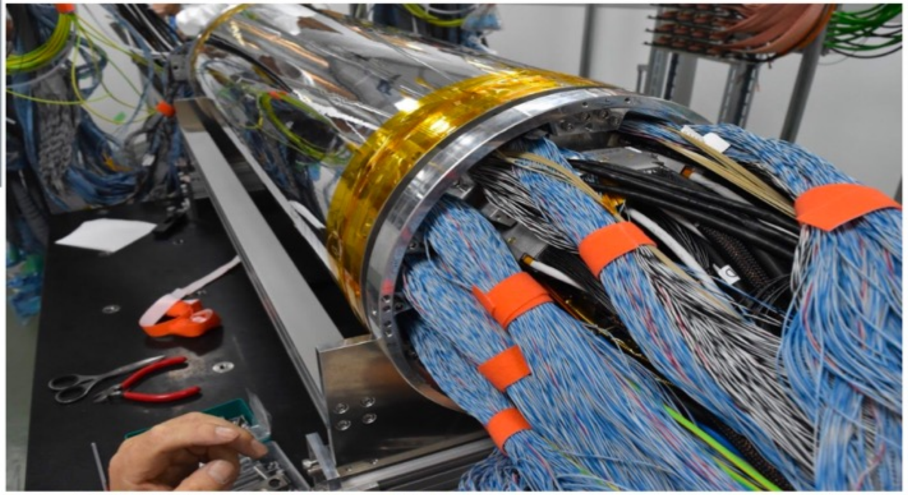


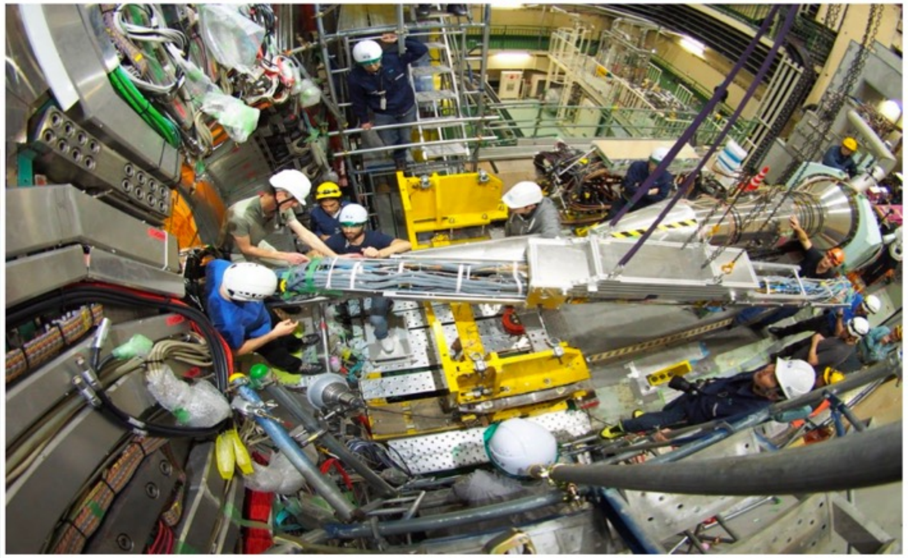




Installation 2018 at KEK

- PXD + BP + SVD marriage
- VXD installation in Belle II





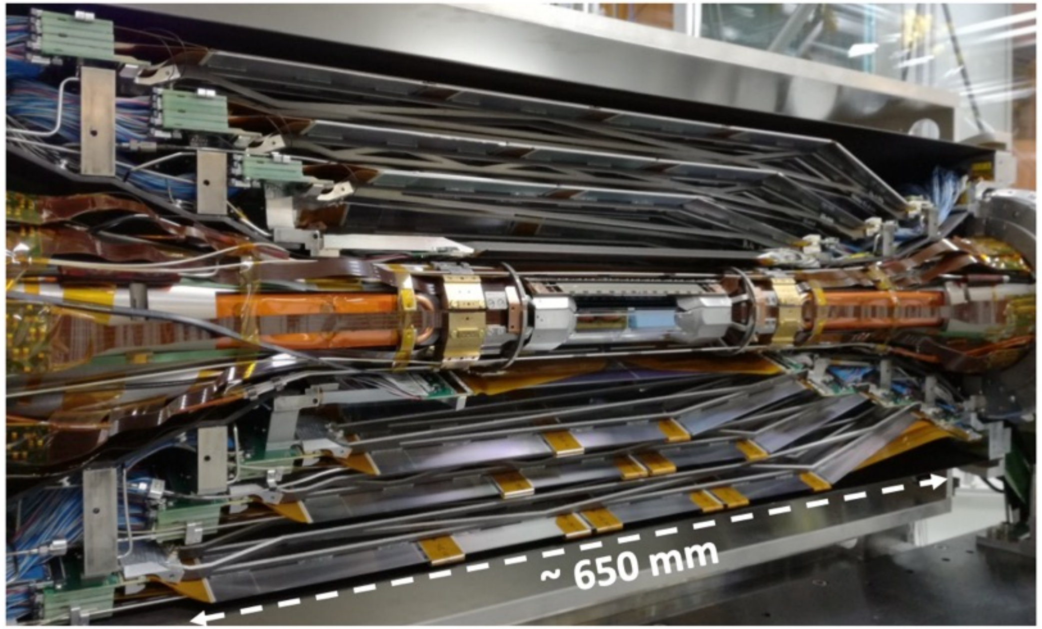
From A.Boltz, [CEPC 2022 workshop]

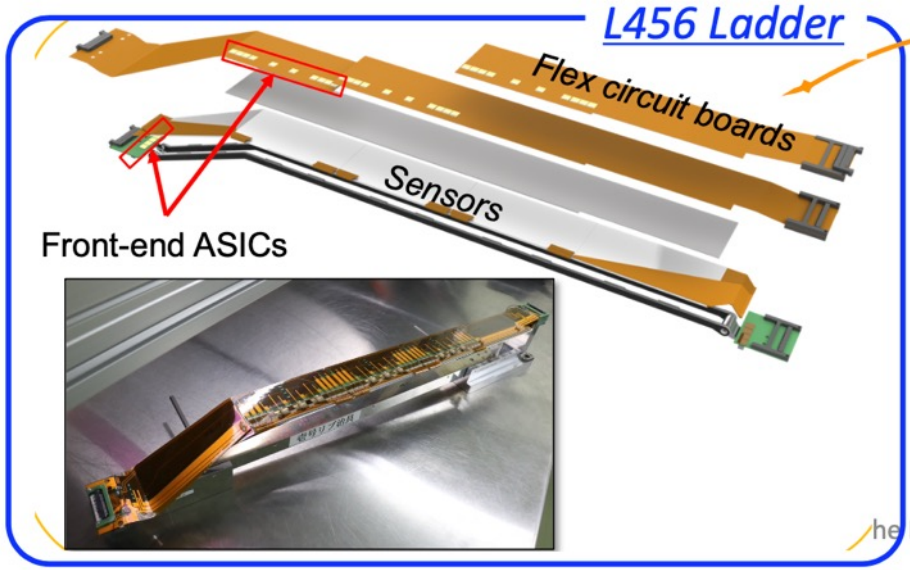
DESY.

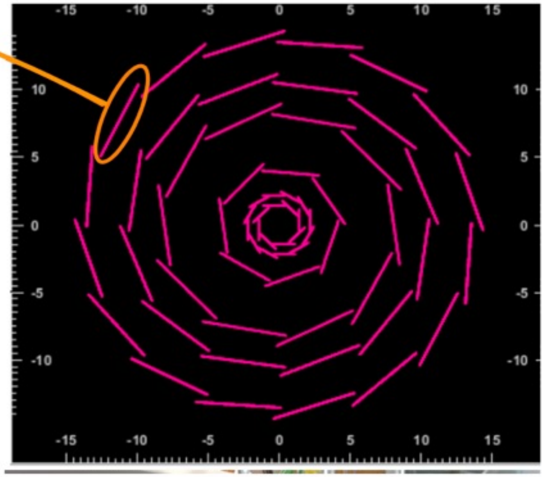
11

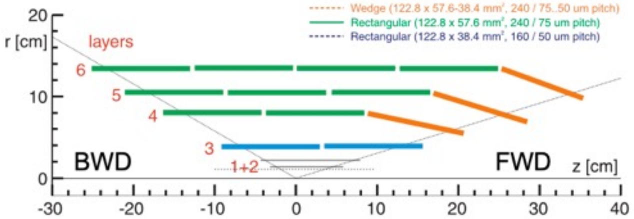
SVD in a nutshell

- 4 layers of *Ladders* mounted on end rings supported by carbon fiber structures, covering polar angle θ region from 17° to 150°
  - Barrel shape in L3
  - Lantern shape in L456 (slanted FW sensors) to reduce material
- Signals from each sensors connected with flex circuits to front-end ASICs mounted on the ladder
  - chips outside active area for L3, *chip-on-sensor* for L456 long ladders
- Evaporative CO_2 cooling (-20°C) with thin stainless steel pipes
- Total material budget 0.7% per layer - Total Silicon area 1.2 m^2







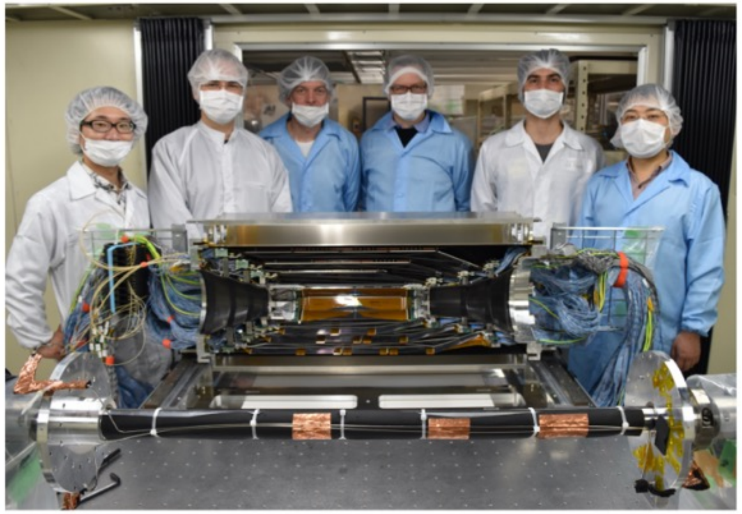


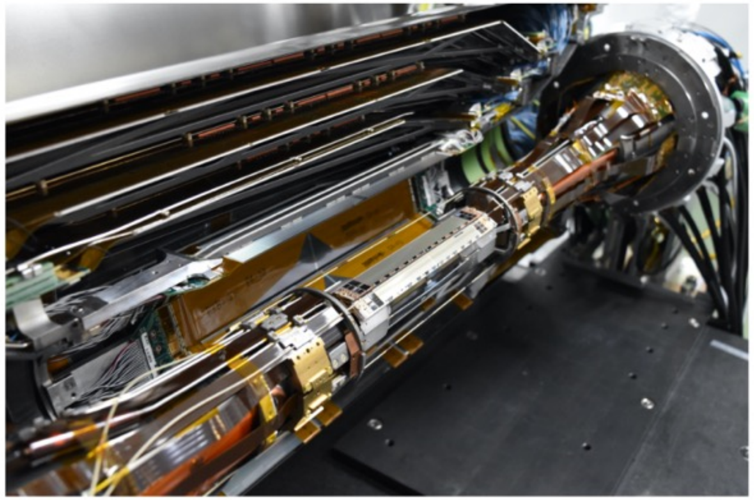
Layer	ladders	sensors	Radius (mm)
L3	7	2	39
L4	10	3	80
L5	12	4	104
L6	16	5	135

he Belle II Silicon Vertex Detector - VERTEX 2020 6

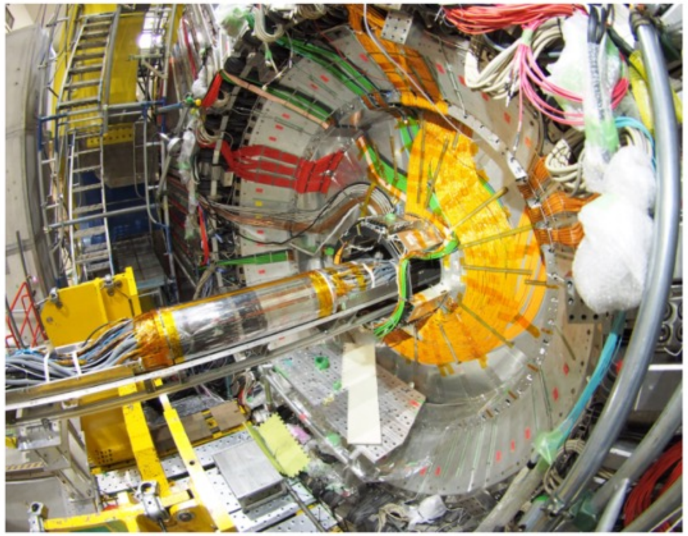
From G.Rizzo, Vertex 2020 workshop

Construction, assembly, installation





- Sep 2008: First Chip-on-sensor Origami concept
- Oct 2010: Belle II Technical Design Report
- May 2015: first completed Layer 5 ladder
- Feb/Jul 2018: first/second SVD “half shell” assembled
- Nov 2018: Installed in Belle II
- Mar 2019: First collision data with complete detector



9/29/20 G. Rizzo – The Belle II Silicon Vertex Detector - VERTEX 2020 8

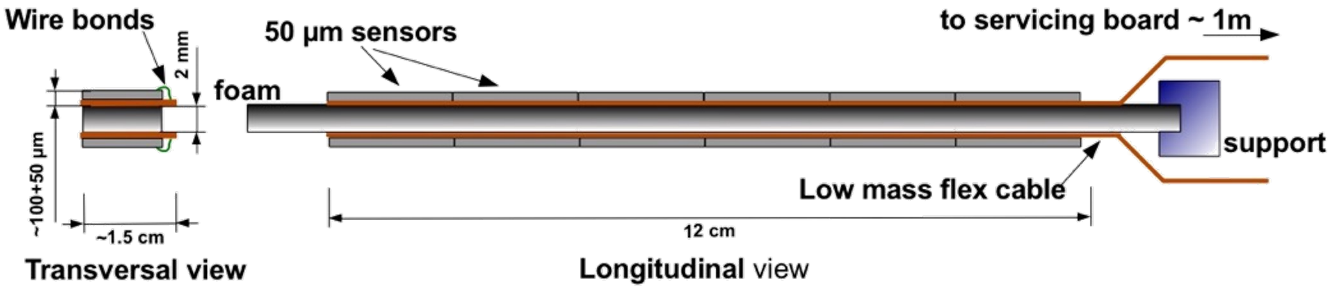
From G.Rizzo, Vertex 2020 workshop

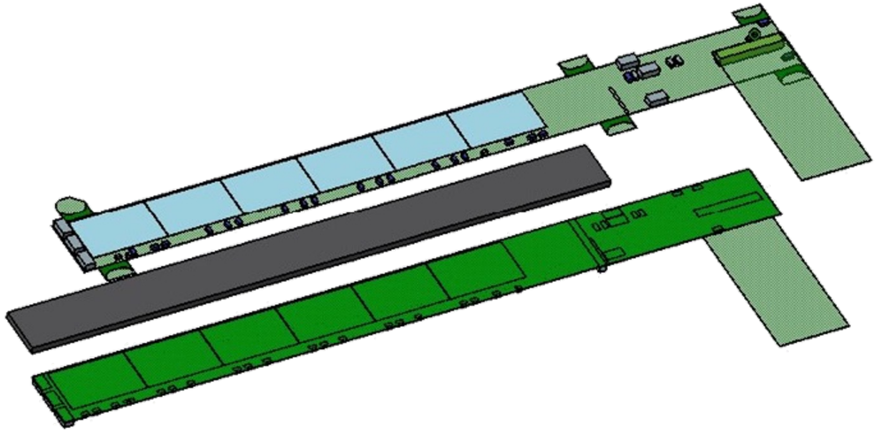
Example of VXD re-installation procedure

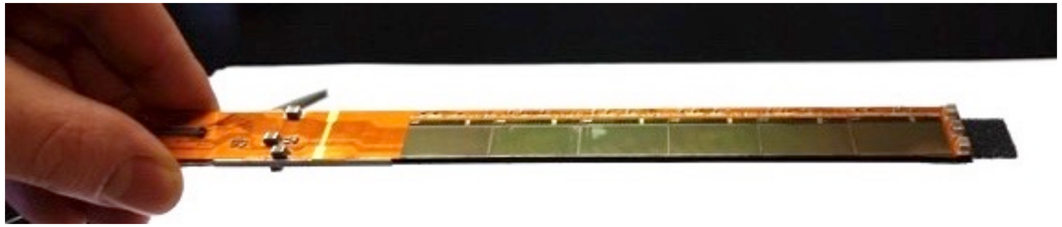
From K.Nakamura
October 2022

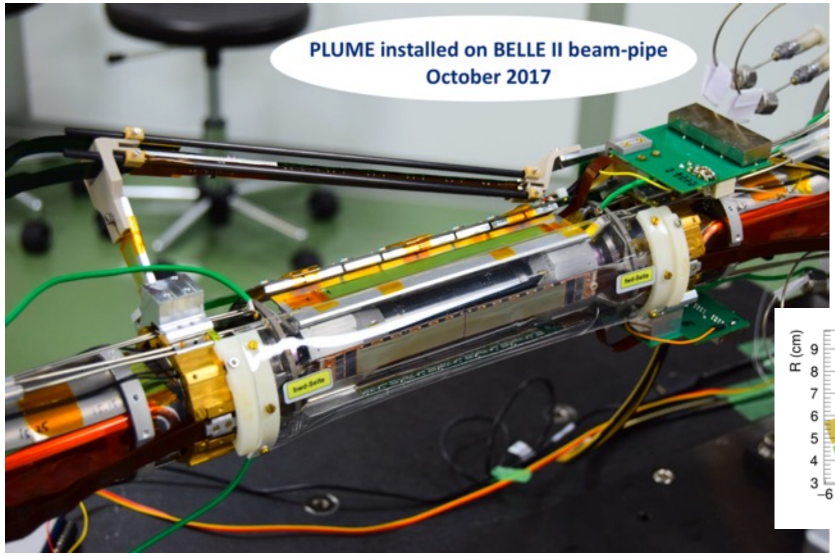
PLUME for BEAST (1^{st} MAPS on e+e- collider)

- PLUME project
  - DESY-Hambourg, Uni. Bristol, IPHC





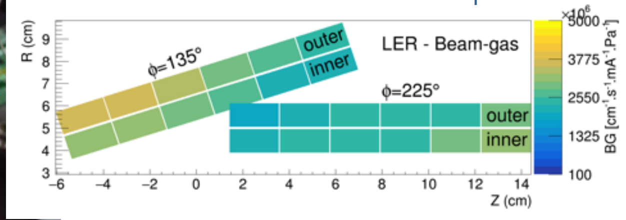




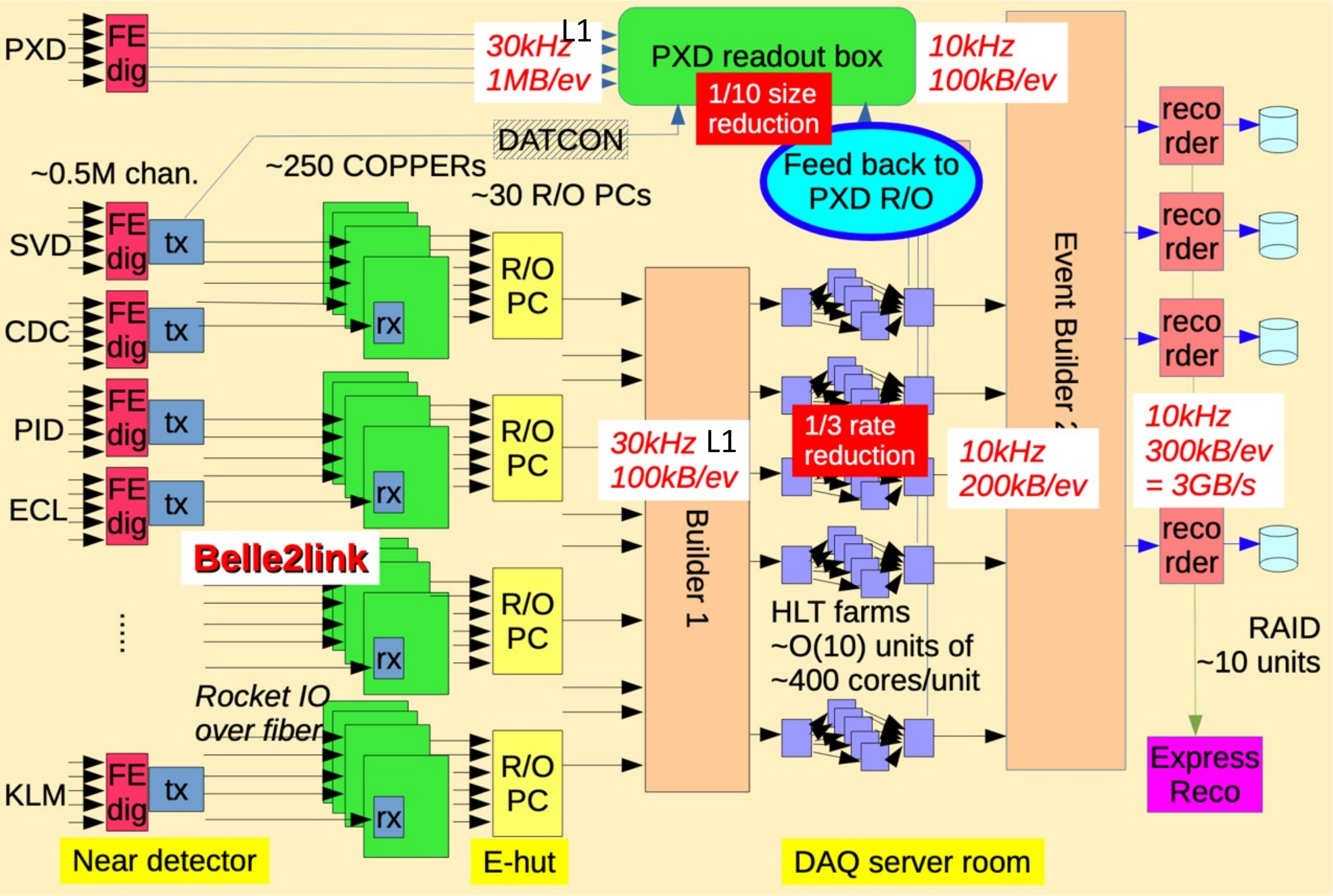
Two position measured
Thickness 2 mm
Material 0.35 % X_0
8 Mpixels, 100 µs, 10 g
9 Watts (air cooled)

Side view

Measurement example



DAQ/Trigger/HLT system overview



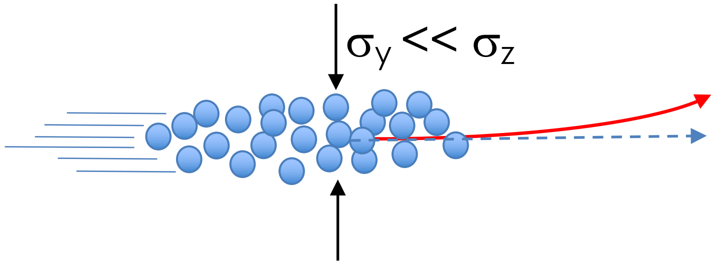
Limits

Detector	BG rate limit			Measured BG
Diamonds	1–2 rad/s			< 125 mrad/s
PXD	3 %			0.11 %
SVD L3, L4, L5, L6	4.7 %, 2.4 %, 1.8 %, 1.2 %			< 0.22 %
CDC	200 kHz/wire			27 kHz/wire
ARICH	10 MHz/HAPD			0.5 MHz/HAPD
Barrel KLM L3	50 MHz			3.8 MHz
	non-luminosity BG		luminosity BG	
	before LS1	after LS1	per 10^{35} $cm^{-2}s^{-1}$	
TOP ALD	3 MHz/PMT	5 MHz/PMT	0.9 MHz/PMT	2 MHz/PMT

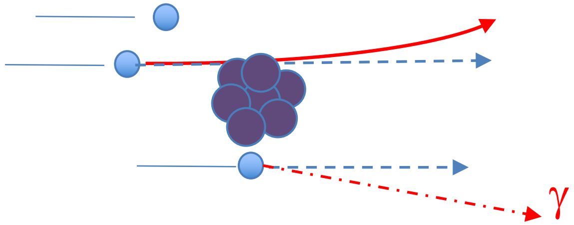
Beam induced background

Beam-induced background

- ## Single beam effects
  - Touschek ← intra-beam scattering
    - rate $\propto \frac{I_{bunch}^2 \; N_{bunch}}{(\sigma_x \, \sigma_y) \; E_{beam}^3} = \frac{I_{beam}^2}{(\sigma_x \, \sigma_y) \; E_{beam}^3 \, N_{bunch}}$

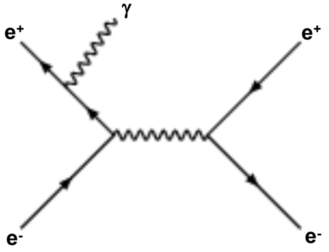


  - Beam gas ← vacuum residues
    - rate $\propto I_{\mathrm{bunch}} \times N_{\mathrm{bunch}} \times P(I)$
    - Dynamic pressure $P(I) = (p_0 + p_1 I_{beam})$

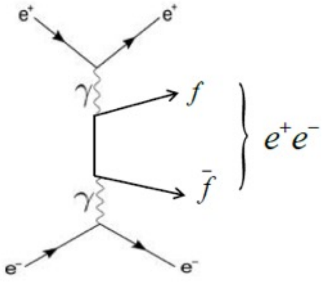


  - Synchrotron radiation ← magnet bending
    - rate $\propto I_{\mathrm{beam}}$

- ## Beam-beam effects (QED)
  - rate $\propto$ Luminosity



Radiative Bhabha scattering

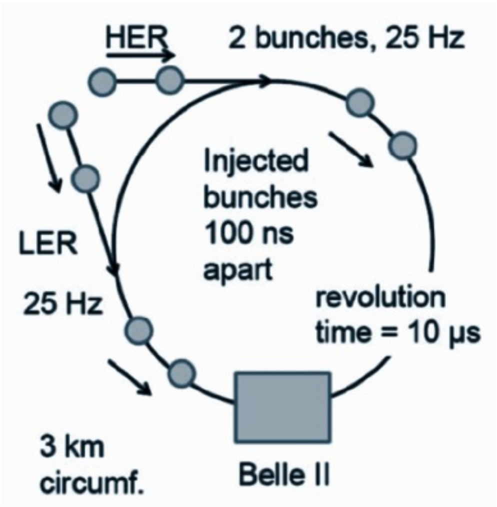


2-photon interaction

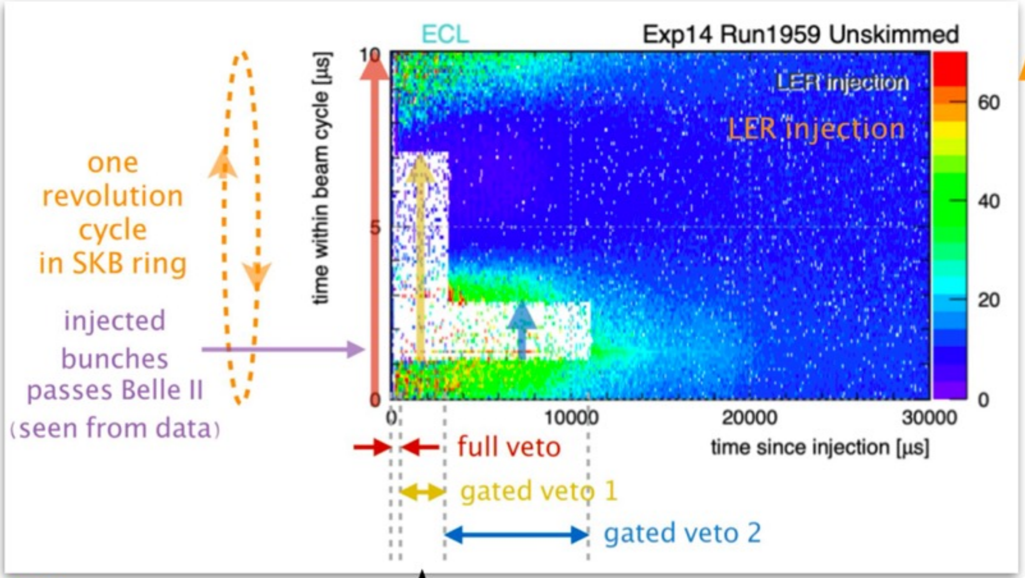
Operational Challenges

Backgrounds: injection

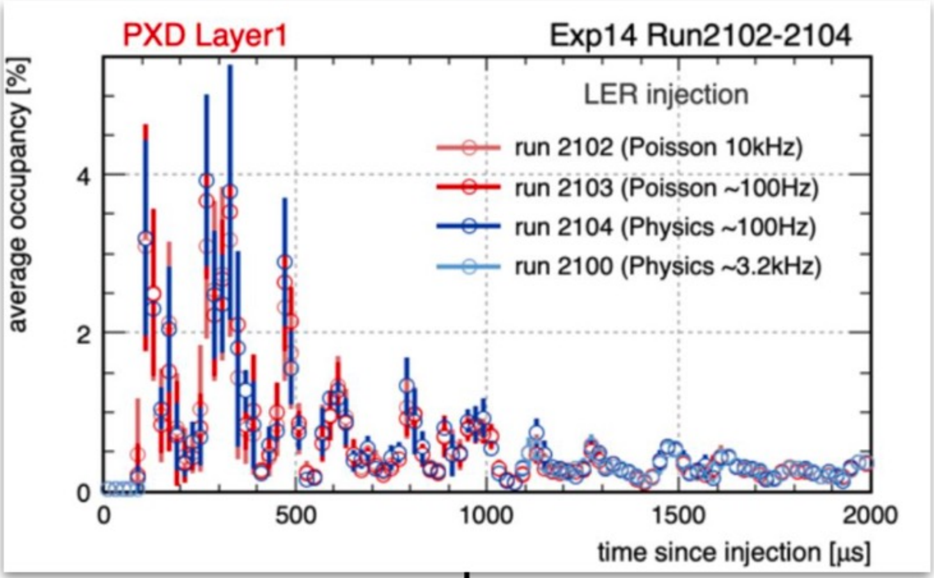
- SuperKEKB is operated in top-up mode: continuous injection up to 50 Hz
  - at design luminosity, Touschek effects limit beam lifetime to few mins
  - injected bunches produce high background rates, damping takes few ms
  - mitigation: full veto (all BII detectors) + gated veto (all but PXD)
- PXD cannot halt data collection (default operation):
  - 20 µs integration time vs 10 µs beam revolution time
  - injection spikes can saturate DAQ → not yet critical (partial data loss at sub-permille level)



Injection trigger vetoes: (on ECL occupancy)



PXD Occupancy: vetoless runs during injection

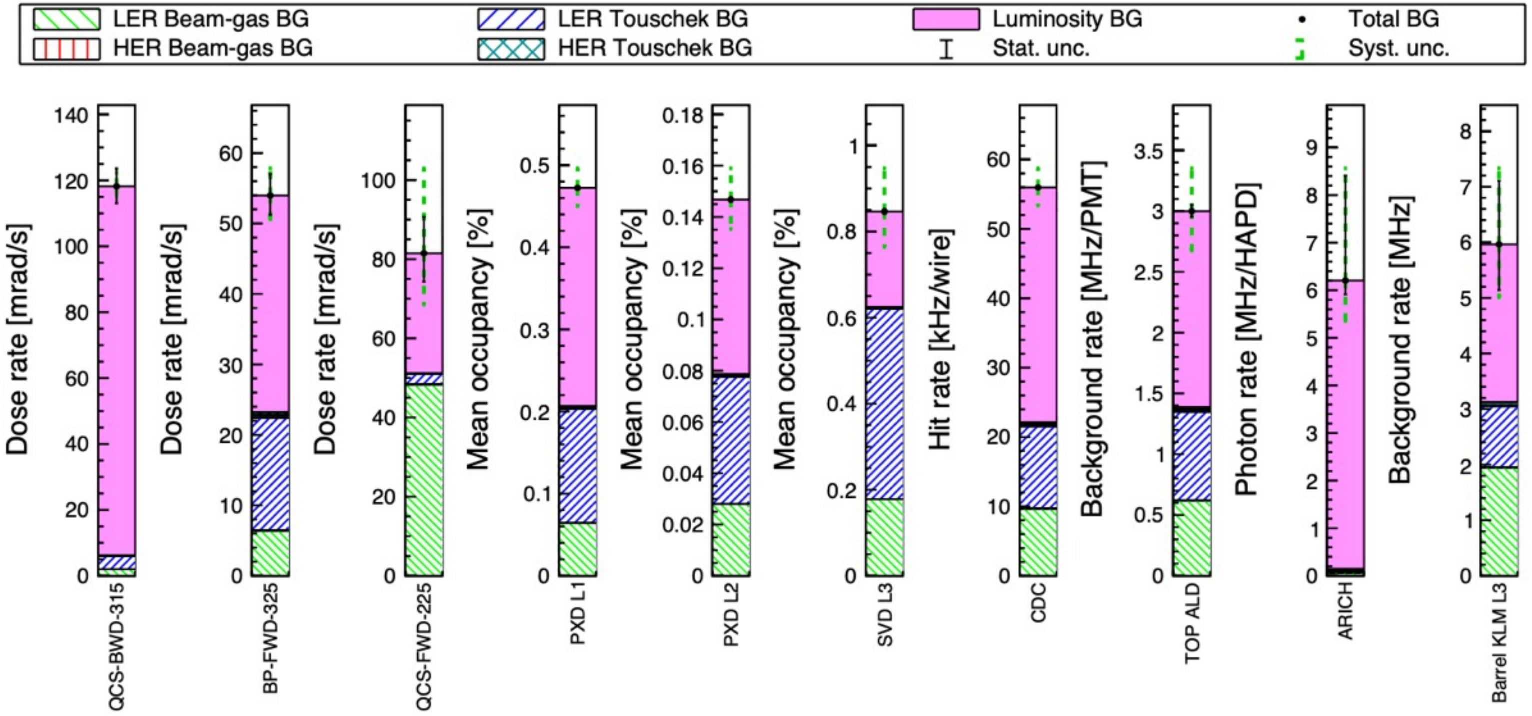


DESY.

Background estimate

Parameter	Setup-1	Setup-2	Setup-3
Date	Jan 2023	Jan 2027	Jan 2031
β^*_y(LER/HER) [mm]	0.8/0.8	0.6/0.6	0.27/0.3
β^*_x(LER/HER) [mm]	60/60	60/60	32/25
$\mathcal{L}$ [$\times 10^{35}$ cm^{-2}s^{-1}]	1.0	2.8	6.3
I(LER/HER) [A]	1.66/1.20	2.52/1.82	2.80/2.00
BD_{int} [kAh]	10	45	93
$\overline{P}$(LER/HER) [nPa]	93/23	48/17	33/15
n_b [bunches]	1370	1576	1761
ε_x(LER/HER) [nm]	4.5/4.5	4.6/4.5	3.3/4.6
$\varepsilon_y/\varepsilon_x$(LER/HER) [%]	1/1	1/1	0.27/0.28
σ_z(LER/HER) [mm]	7.58/7.22	8.27/7.60	8.25/7.58
CW	ON	ON	OFF

+ non linear collimator



About upgrades

→ mid-, short-, long-term

Subdector	Function	upgrade idea	time scale
PXD	Vertex Detector	2 layer installation	short-term
		new DEPFET	medium-term
SVD	Vertex Detector	thin, double-sided strips, w/ new frontend	medium-term
PXD+SVD	Vertex Detector	all-pixels: SOI sensors	medium-term
		all-pixels: DMAPS CMOS sensors	medium-term
CDC	Tracking	upgrade front end electronics	short/medium-term
		replace inner part with silicon	medium/long term
		replace with TPC w/ MPGD readout	long-term
TOP	PID, barrel	Replace conventional MCP-PMTs	short-term
		Replace not-life-extended ALD MCP-PMTs	medium-term
		STOPGAP TOF and timing detector	long-term
ARICH	PID, forward	replace HAPD with Silicon PhotoMultipliers	long-term
		replace HAPD with Large Area Picosecond Photodetectors	long-term
ECL	γ, e ID	add pre-shower detector in front of ECL	long-term
		Replace ECL PiN diodes with APDs	long-term
		Replace CsI(Tl) with pure CsI crystals	long-term
KLM	K_L, μ ID	replace 13 barrel layers of legacy RPCs with scintillators	medium/long-term
		on-detector upgraded scintillator readout	medium/long-term
		timing upgrade for K-long momentum measurement	medium/long-term
Trigger		firmware improvements	continuos
DAQ		PCIe40 readout upgrade	ongoing
		add 1300-1900 cores to HLT	short/medium-term

Table 1: Known short and medium-term Belle II subdetector upgrade plans, starting from the radially innermost. The current Belle II subdetectors are the Silicon Pixel Detector (PXD), Silicon Strip Detector (SVD), Central Drift Chamber (CDC), Time of Propagation Counter (TOP), Aerogel Rich Counter (ARICH), EM Calorimeter (ECL), Barrel and Endcap K-Long Muon Systems (BKLM, EKLM), Trigger and Data aquistion (DAQ). DAQ includes the high level trigger (HLT).

Impact on performance & physics

=> Snowmass Belle II : arXiv 2203.11349

Topic	VXD	CDC	PID	ECL	KLM
Low momentum track finding	✓	✓			
Track p, M resolution		✓			
IP/Vertex resolution	✓				
Hadron ID		✓	✓		
K_L^0 ID				✓	✓
Lepton ID		✓		✓	✓
π^0, γ				✓	
Trigger	✓	✓			

Topic	VXD	CDC (incl. Trigger)	PID	PID(Ω coverage)	ECL	KLM
$\mathcal{B}(B \to \tau\nu, B \to K^{(*)}\nu\bar{\nu})$	✓			✓	✓	✓
$\mathcal{B}(B \to X_u \ell\nu)$	✓		✓	✓		✓
R, Polarisation$(B \to D^{(*)}\tau\nu)$	✓				✓	
FEI	✓	✓		✓		
$S_{CP}, C_{CP}(B \to \pi^0\pi^0, K_S^0\pi^0)$	✓	✓			✓	
$S_{CP}, C_{CP}(B \to \rho\gamma)$		✓	✓		✓	
$S_{CP}, C_{CP}(B \to J/\psi K_S^0, \eta' K_S^0)$	✓	✓				
Flavour tagger	✓		✓			
τ LFV		✓			✓	
Dark sector searches		✓			✓	✓

Physics benchmarks expected for CDR

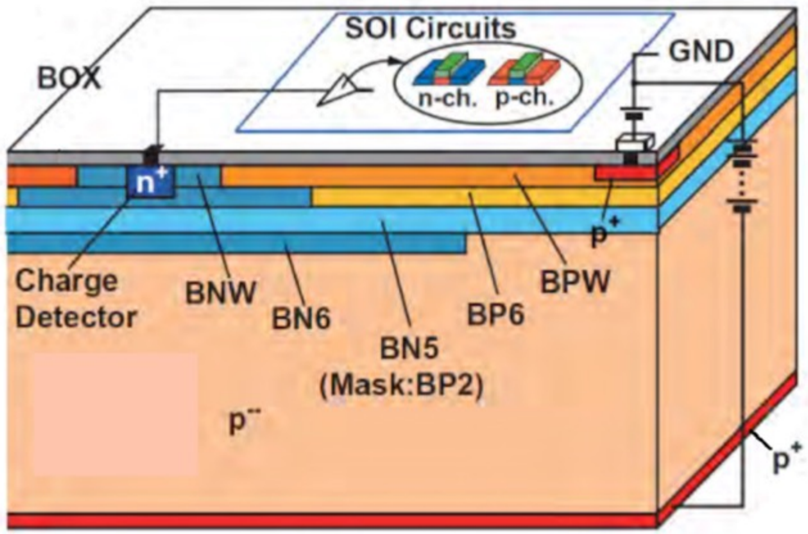
Section	Benchmark channels
1) Tracking	
1.1) Tracking efficiency	$B^+ \to \tau^+\nu$, $B \to D^{(*)}\tau\ \nu$, $B^+ \to D^0(K_S\pi^+\pi^-)K^+$
1.2) Low momentum tracking efficiency	$B \to D^*\tau\ \nu$
1.3) V0 reconstruction	$B^0 \to K_S\pi^0$, long lived DS particles
1.4) Vertexing resolution	$B^0 \to J/\psi\ K_S$
2) PID	
2.1) dE/dx resolution	$B \to KKK$
2.2) TOP and ARICH performance	$B \to K\pi$, $B \to (K^*/\rho)\ \gamma$
2.3) acceptance	(any of the above)
3) Neutrals	
3.1) γ efficiency and resolution	$\tau \to \mu\gamma$, $D^0 \to \gamma\gamma$, $B^+ \to \tau^+\nu$, $B \to D^{(*)}\tau\ \nu$
3.2) π^0 efficiency and resolution	$B^0 \to \pi^0\pi^0$, $B^0 \to K^0{}_S\pi^0$, $B^0 \to \eta' K^0{}_S$
3.3) $K^0{}_L$ reconstruction efficiency	$B^0 \to J/\psi\ K^0{}_L$, inclusive V_{ub} analyses
4) Triggers for low multi. final states	$\tau \to \mu\gamma$, single or multi-γ final state DS

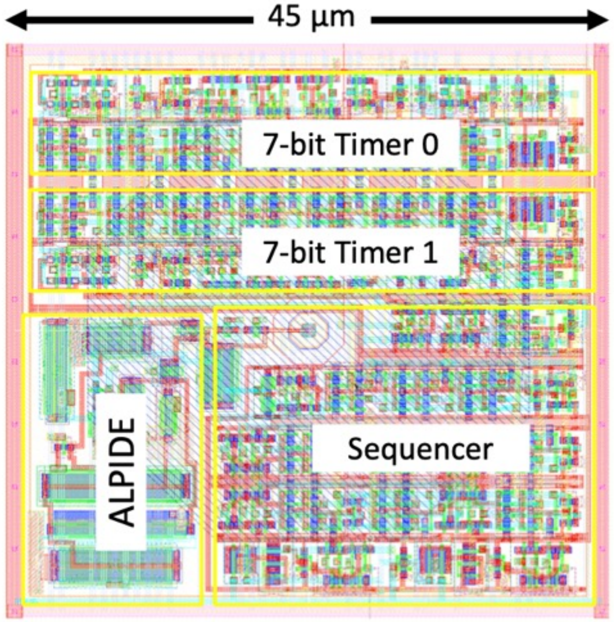
Already addressed by VTX collaboration

SOI

12

- Lapis 0.2 μm FD-SOI technology
  - Wafer: High-resistivity FZ silicon
  - CMOS circuit is separated from the wafer with BOX.
    - (Almost) no limitation in the circuit design
  - Pinned well structure (PDD), similar to that of DMAP, is used for the efficient and fast charge collection.
    - Small sensor capacitance: C_{det} = 3 fF.
- DuTiP pixel sensor designed for the Belle II upgrade
  - ALPIDE type frontend (modified for faster response) is adopted for the low power consumption
  - The hit signal is delayed with two timers and coincidence with the Belle II global trigger is taken: Background reduction
  - The hit occupancy can be reduced < 0.1% under the 113 MHz/cm2 background hit condition.
  - Smooth data transfer with the two stage FIFO.





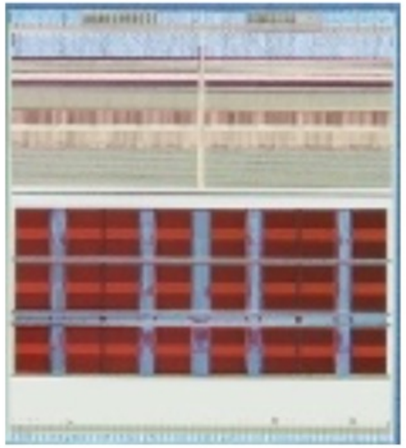
Talk by Akimasa Ishikawa (25 Oct 16:00)

2022/10/24 T. Tsuboyama @ Vertex2022 conference at Tateyama Japan

From Vertex 2022 workshop

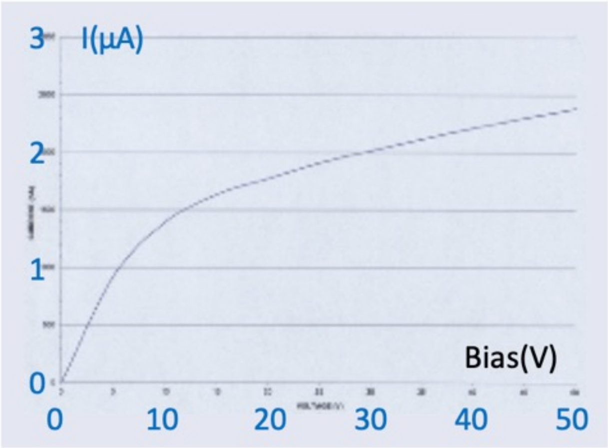
TFP Thin fine-pitch DSSD

- TFP aims the replacement of the current silicon strip layers.
- Lower material thickness using thin (150 μm thick) DSSD sensors
- A new binary readout chip SNAP128A
  - Front end optimized for 150μm double sided sensor
    - Fast shaping time
    - p/n signal flip
  - Fast strip "OR" signal for trigger generation
  - Digital pipeline: Level-1 trigger latency > 8 μs

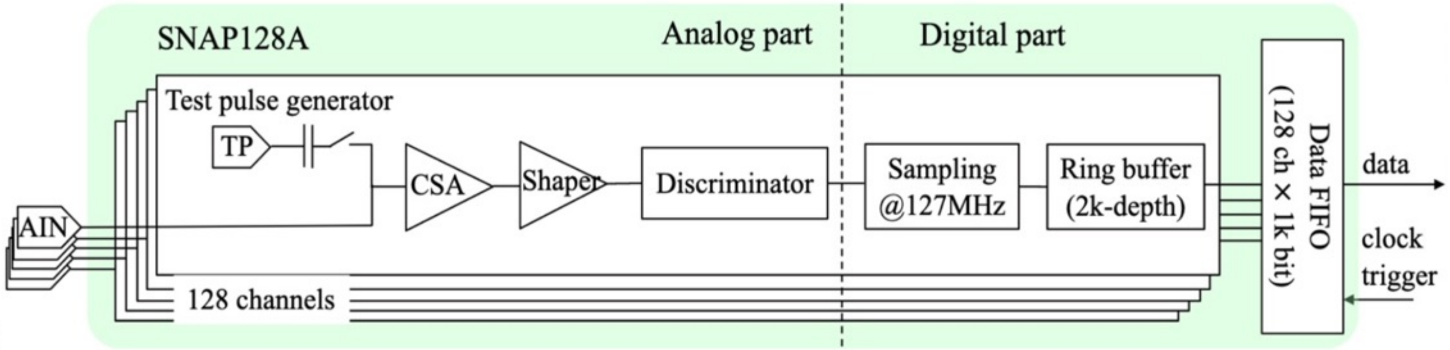


5.945 mm x 6.12 mm

Prototype 59mmx52.6mm
0.15mm (Micron (UK))



The performance is presented by Zihan Wang (Next Talk)



From Vertex 2022 workshop

On the VTX project

Requirements: reminder from July 2019

From: BELLE2-NOTE-TE-2019-011.pdf

nominal luminosity
background x5

		nominal luminosity 8×10^{35} cm^{-2}s^{-1}			upgraded luminosity 40×10^{35} cm^{-2}s^{-1}					
					nominal background			background $\times 5$		
layer	radius (mm)	hit rate (MHz/cm^2)	TID (MRad/smy)	NIEL $\times 10^{12}$ (cm^{-2}/smy)	hit rate (MHz/cm^2)	TID (MRad/smy)	NIEL $\times 10^{12}$ (cm^{-2}/smy)	hit rate (MHz/cm^2)	TID (MRad/smy)	NIEL $\times 10^{12}$ (cm^{-2}/smy)
PXD1	14	22.6	2	10.0	113	10	50	565	50	250
PXD2	22	11.3	0.6	5.0	56	3	25	280	15	125
SVD3	39	1.41	0.1	0.2	7	0.5	1	35	2.5	5
SVD4	80	0.29	0.02	0.1	1.5	0.1	0.5	8	0.5	2.5
SVD5	104	0.22	0.01	0.1	1.1	0.05	0.5	6	0.25	2.5
SVD6	135	0.15	0.01	0.1	0.8	0.05	0.5	4	0.25	2.5

VXD 2
>2026?

VXD 3
>>2030?

Requirements on sensor 1/2

- Pixel pitch
  - Spatial resolution for tracking
    - **Current SVD σ~15-20 µm ⇨ pitch < 50 µm**
  - Spatial resolution for impact parameter
    - **Actually limited by beam pipe material budget (0.8% X_0)**
    - From parametric estimation ⇨ improvements expected for σ~7-10 µm
    - Benefiting σ~5 µm would require thinner/smaller-radius beam pipe
  - Occupancy ⇨ no real constraint on pitch (< 100 µm)

Pitch ~ 30-40 µm

- Timing
  - Trigger rate 30 kHz and latency 5.5 µs
    - to separate 99% of triggers ⇨ sensitive window < 300 ns
  - Occupancy for data acquisition bandwidth
    - Sensitive window 100 ns ↔ 6 Gbps
  - Occupancy for tracking
    - See E.Paoloni's talk at 2019 CERN workshop ⇨ **50 ns range for sensitivity**
  - Recovery time wrt injection
    - Depends on trigger veto length ⇨ signal cleared < 1 µs

Driven by hit rate
using 120 MHz/cm2 gives us safety factor 5 / today's predictions

The fastest the better
⇨ Event sensitive window 50-100 ns

(already take into account possible necessity to group 2 sensor-windows)

Requirements on sensor 2/2

- **Radiation tolerance**
  - Total Ionizing Dose (TID) ➩100kGy/SNyear
  - Non-Ionizing Energy Loss ➩ 5×10^{12} n_{eq}/cm^2/SNyear
  - **Synchrotron radiation**
  - **Stormy events ➩ needs dedicated tests**

With large security factor
1 MGy & 10^{14} n_{eq}/cm^2

- **Dimensions**
  - **Thickness for material budget ➩ 50 µm**
  - Width (z) & height (rφ) constraint by technology
  - Large area beneficial for integration / material budget
    - Inner layers ➩ **12 cm length allows single output at ladder-end**
    - Outer layers ➩ the longer, the better

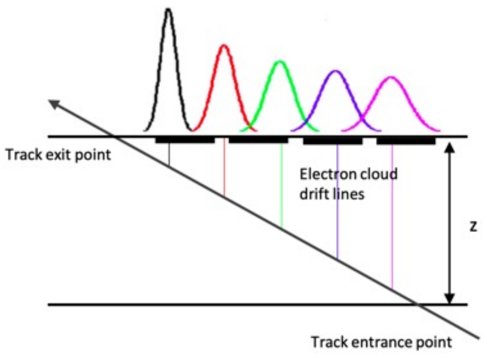
- **Power budget**
  - Stay within few kW cooling capacity (over ~1m²) ➩ **< 300 mW/cm²**
  - Service simplification ➩**warm temperature operation**

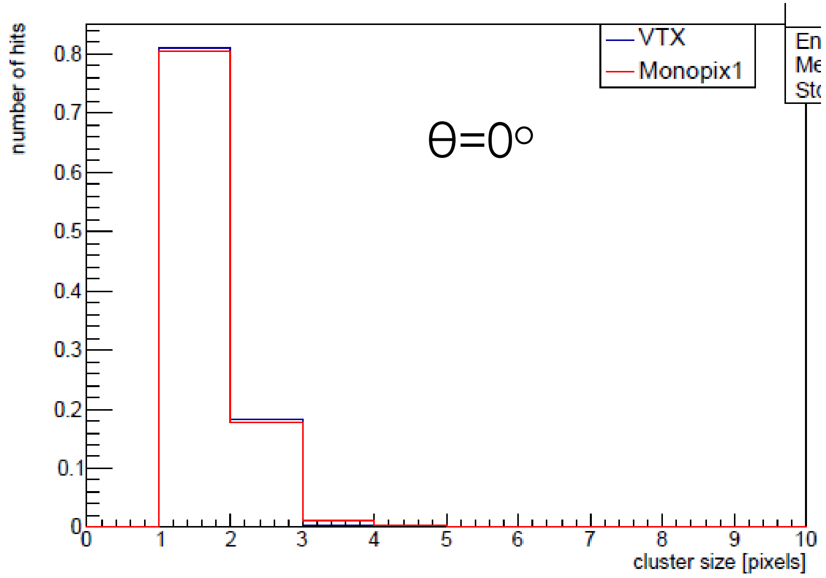
Addition to 2020/12 talk:
- Ability to **provide trigger** welcome
- "fast" OR from all pixels should be good enough
- (but what is fast?)

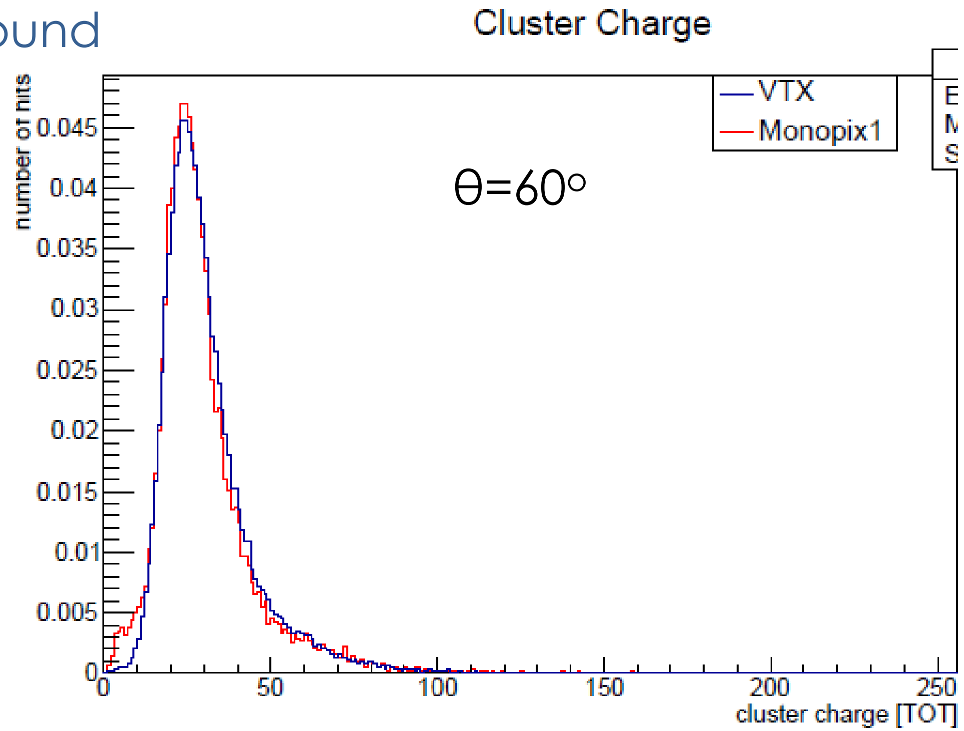
VTX simulated tracking performances

Context = full Belle II simulation framework, including background

- Realistic pixel sensor model
  - Digitizer assuming
    - fully depleted thin layer 30 μm
    - Pixel 33x33 μm^2 with 7bits Time over Threshold
  - **Tuned with Monopix-1 beam data**
    - JINST 14 (2019) C06006
    - Pitch 40x40 μm^2
    - ToT 6 bits





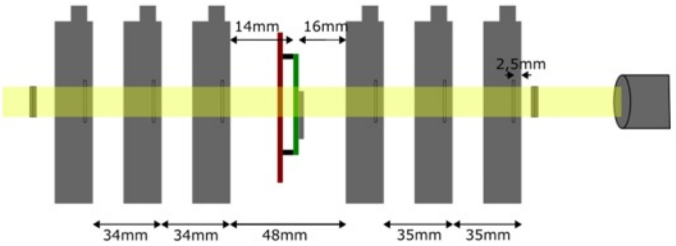


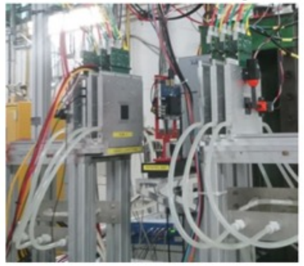
Monopix-1 data from **Bonn group**
Test-beam at DESY with 5 GeV e-

=> https://doi.org/10.5506/APhysPolB.52.909

TJ-Monopix2 test beam results

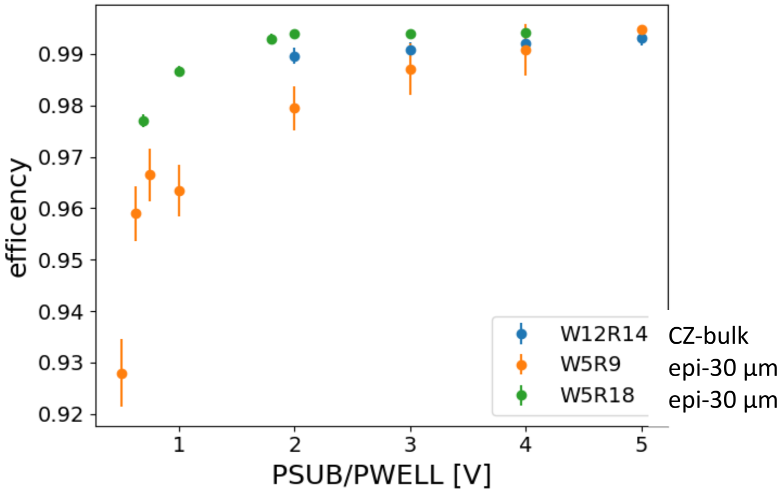
Bonn, CPPM, Göttingen, Pisa, Vienna

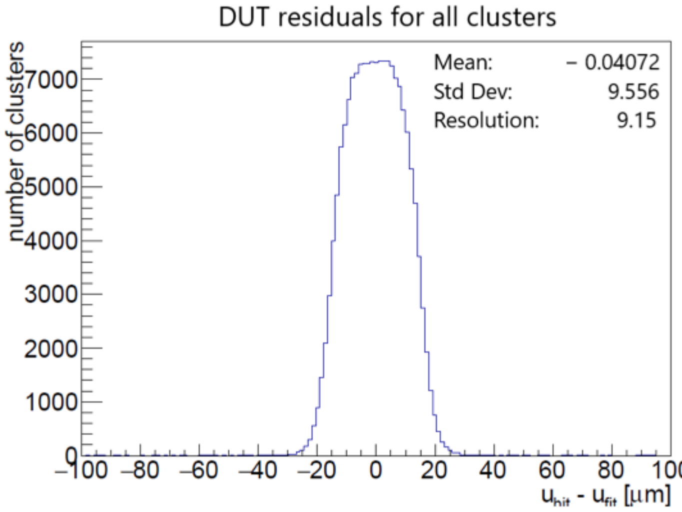




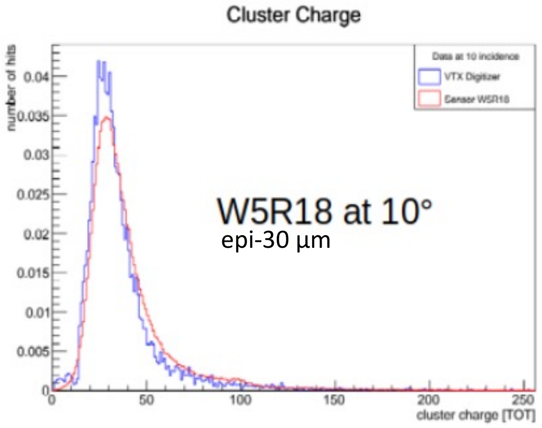
- DESY 5 GeV electron beam
  - Telescope extrapolation σ~3.5 μm
  - Large team getting experienced: hw+sw

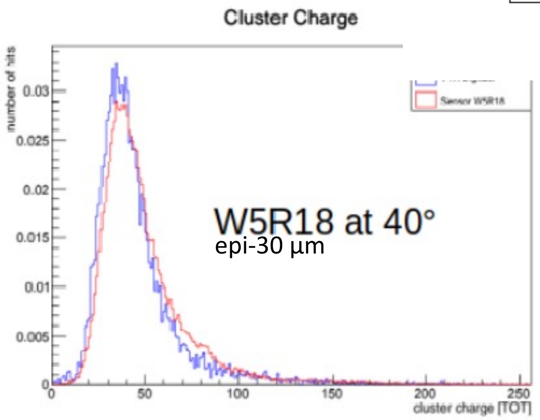
- Results with threshold 500 e-
  - Detection efficiency 99.020 ± 0.040 %
  - Position resolution ~9 μm (< digital resolution)





- Simulation
  - Tuning of model in BASF2



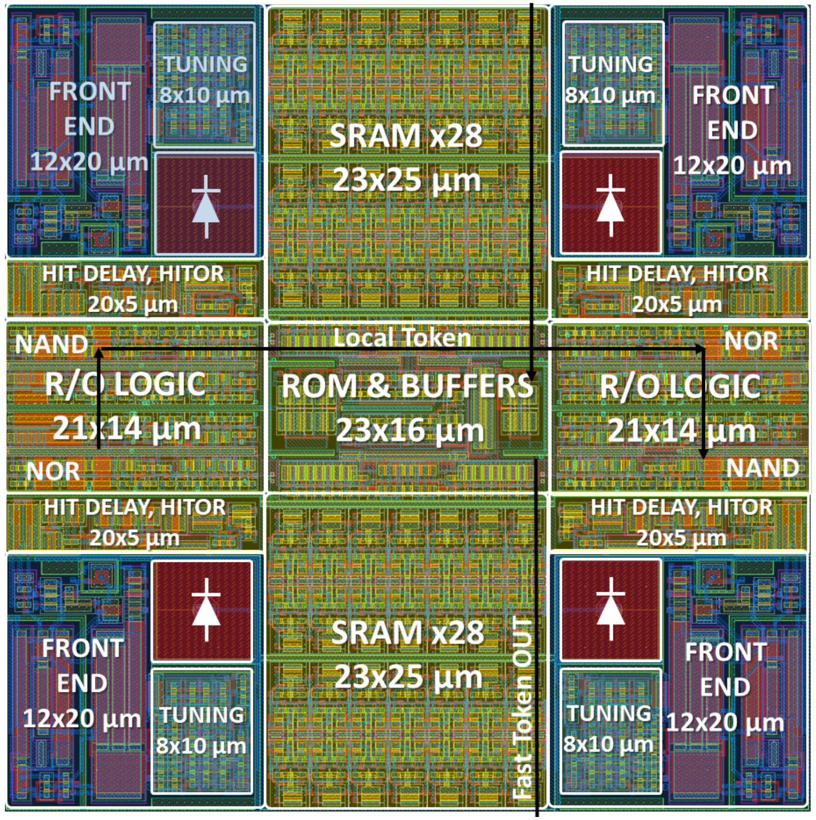


- Next steps
  - Irradiation 10^{14}-10^{15} n_{eq}/cm^2
  - Next beam test in Q1-2023

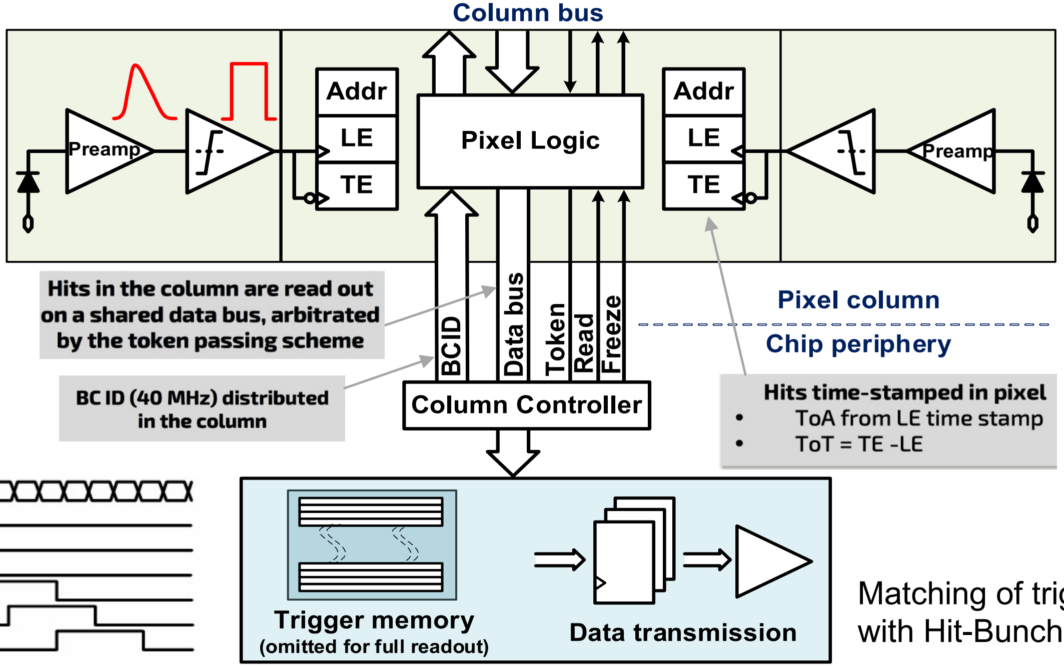
TJ-Monopix in Tower 180 nm process

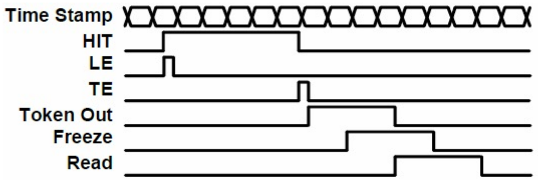
- Pixel matrix read-out architecture
  - Collaboration: Bonn, CERN, CPPM, CEA-IRFU
  - Modified process for radiation tolerance
    DOI: 10.1016/j.nima.2020.164403
  - Column-drain read-out Inherited from ATLAS FE-I3
  - Capable to handle >100 MHz/cm^2
    - Fired pixel address moves fast down to periphery

The Layout:
2x2 pixels
each 33x33 μm^2



The logic:





Matching of trigger-ID with Hit-BunchCrossingID

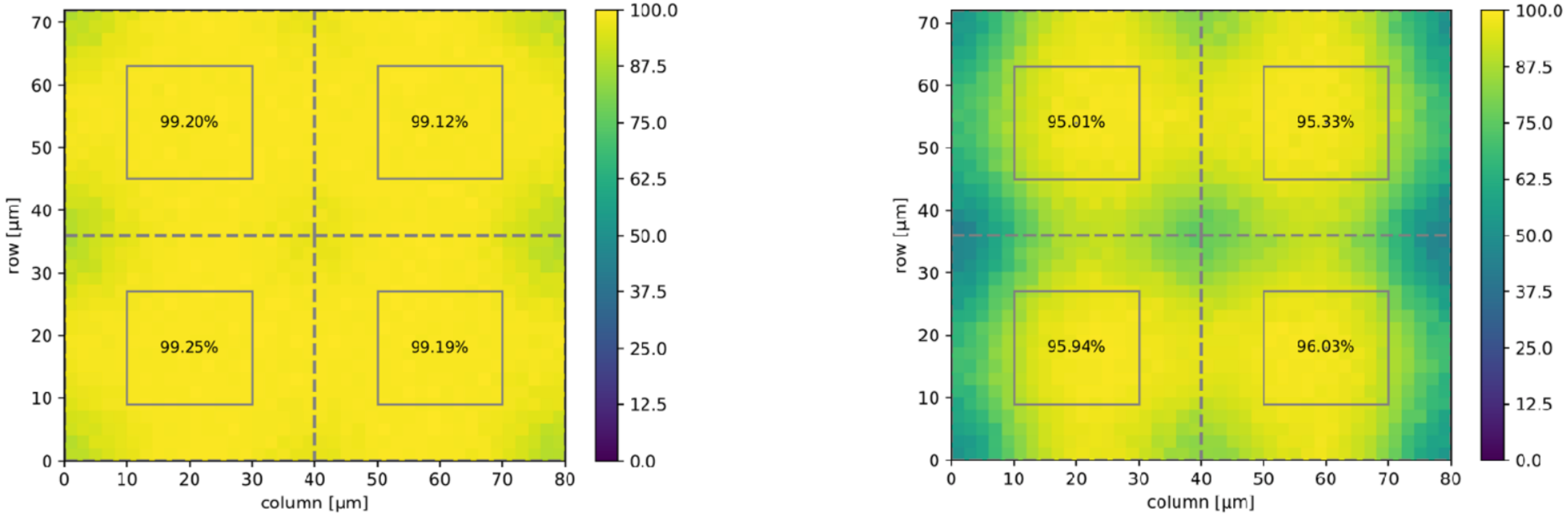
C. Bespin talk at VCI 2022 conference

TJ-MONOPIX1 EFFICIENCY AFTER MODS

- Measured $10^{15}\,\mathrm{neq\,cm^{-2}}$ irradiated chips in 5 GeV electron beam at DESY
- Efficiency improvement in epi chip from 69 % to 87 % due to sensor modifications
- More sensitive volume and therefore more charge leads to full efficiency after irradiation

300 µm Cz: 98.6 % @ 490 e-

30 µm Epi: 87.1 % @ 500 e-



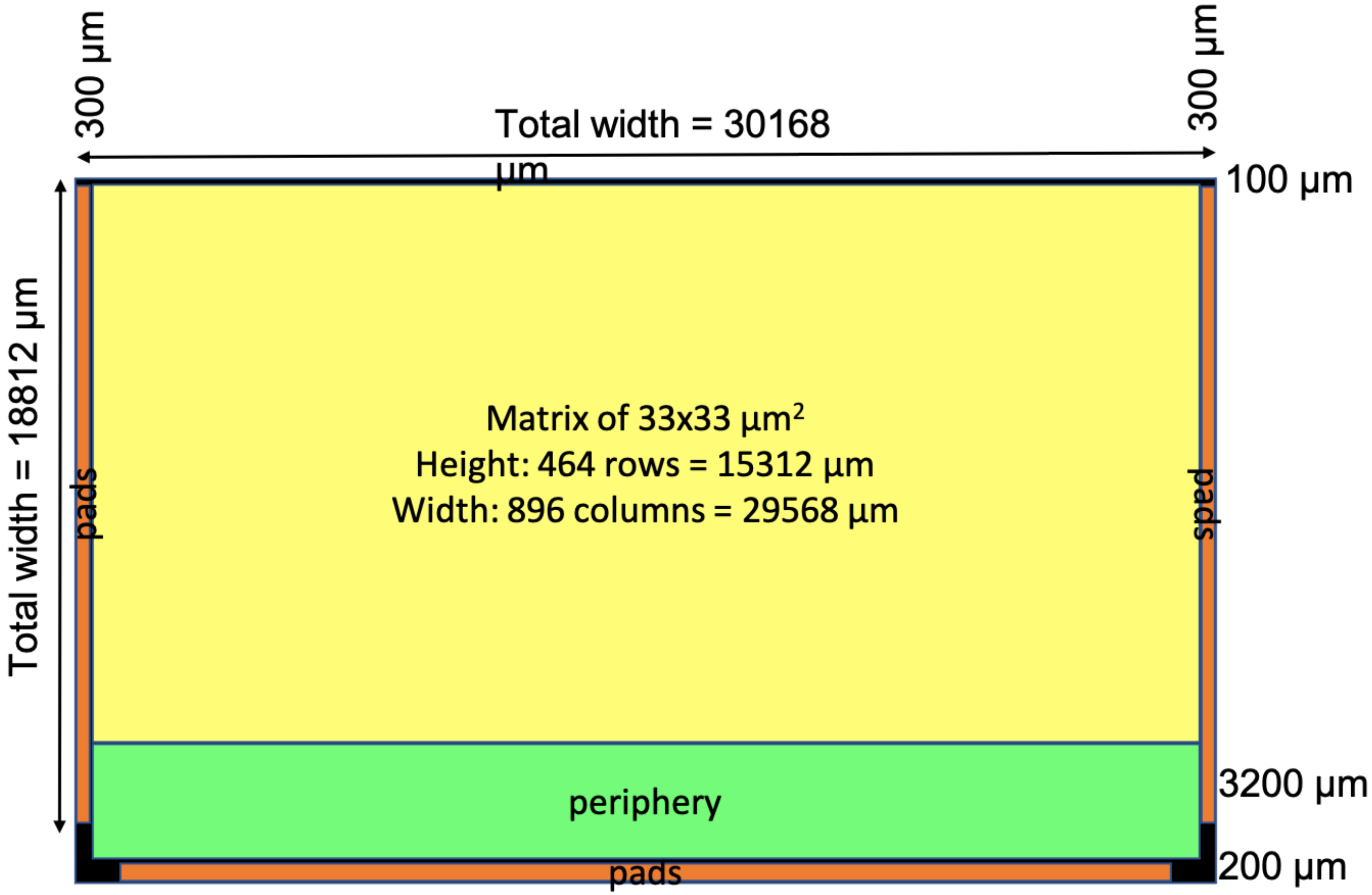
VTX sensor requirements

	Belle-II VTX
Spatial res.	< 10-15 µm
Mat. Budget inner-outer layers	0.1-0.8 % X_0/layer
Hit rate	<120 MHz/cm²
Time precision	<100 ns
Trigger (freq) (delay)	30 kHz 5-10 ns
Rad.hard. (TID) 10years (fluence)	<100 kGy $<10^{14}\ n_{eq}/cm^2$

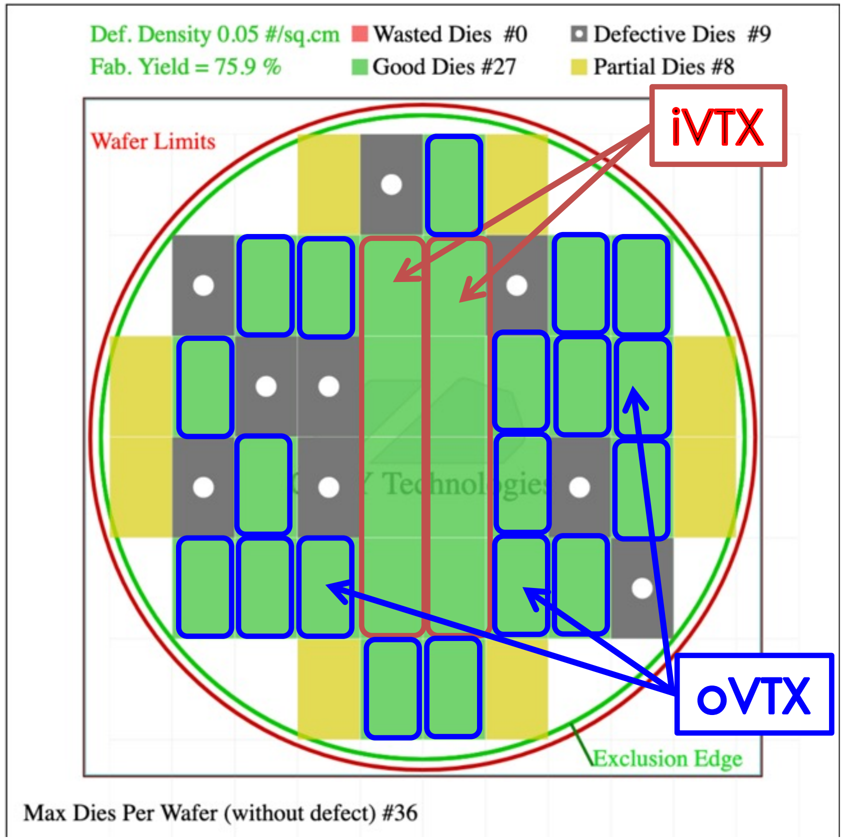
	Belle-II CMOS-MAPS	TJ-Monopix2	MIMOSIS-1
Sensitive area	~30x17 mm²	17x17 mm²	31.0x13.5 mm²
Sensitive thickness	~30 µm	25-100 µm	25-50 µm
Pitch	30 to 40 µm	33 µm	30.2x26.9 µm²
Signal digits	1 to few bits	7 bits ToT	1 bit
Integration time	**25 to 100 ns**	**25 ns**	**1-5 µs**
Hit memory for trigger	< 100 kb		
Power	<200 mW/cm²	200 mW/cm²	<100 mW/cm²
TID fluence	<100 kGy $< 10^{14}\ n_{eq}/cm^2$	100 kGy $10^{15}\ n_{eq}/cm^2$	50 kGy $< 10^{14}\ n_{eq}/cm^2$

Chosen as forerunner for OBELIX sensor

OBELIX size

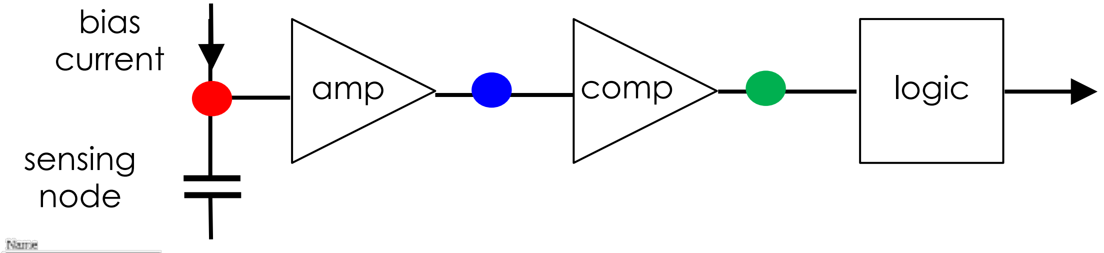


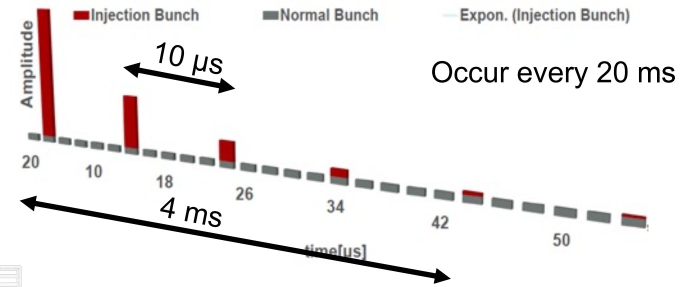
18.7 x 30.2 mm²
8 quadruplets / 36 dies



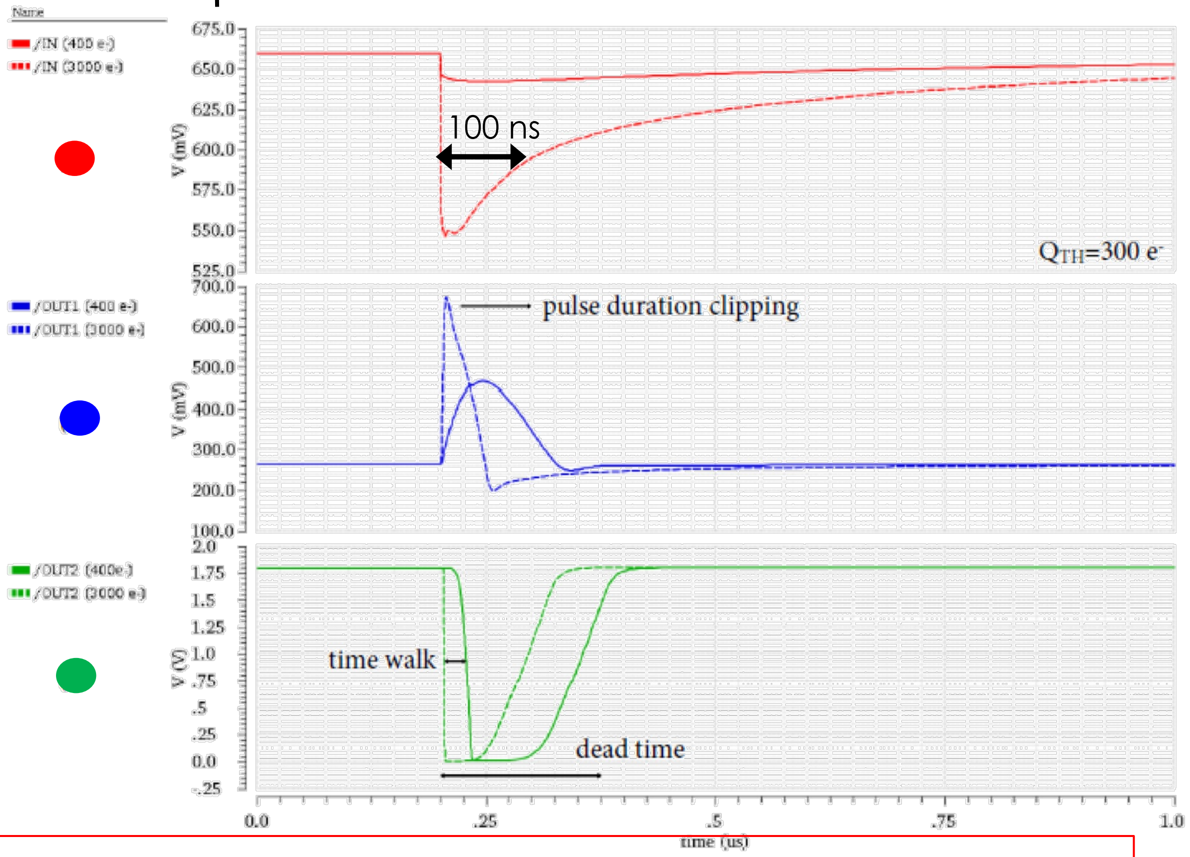
Tower Jazz 180 nm time response simulations

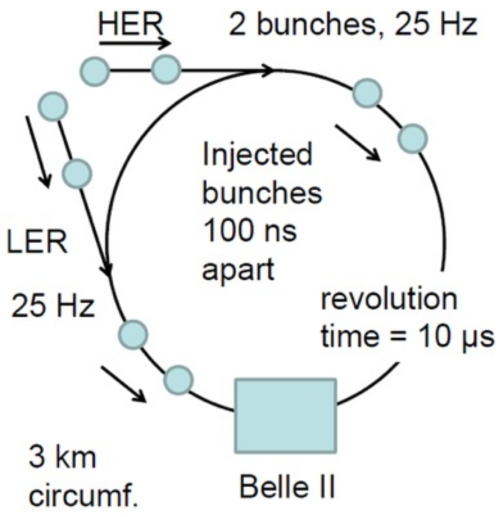
- Front-end structure in-pixel





- Simulated behavior (MALTA case)
  - From I. Berdalovich, JINST 13 (2018) C01023
  - Short recovery time for node requires I_{bias}~500 nA → 0.9 μW/pixel
  - ALPIDE with μs timing reaches 0.040 μW/pixel





⇒ Suggest gating injection for ~100-200 ns doable after comparator

Initial guess for event size & bandwidths

- Assumptions
  - “worst” case scenario / hit rate
  - Geometry presented by Benjamin used for full simulation with current VXD acceptance
  - Sensitive window = 100 ns
  - 40 bits per pixel value
  - 30 kHz average trigger

layer #	1	2	3	4	5	TOTAL
radius (cm)	1.4	2.2	3.9	9	14	
hit rate (MHz/cm^2)	156.6	51.6	6.4	2.1	1.2	
#ladders	6	10	8	18	28	70
#chips	24	40	128	576	1232	**2000**
Data size (kbits) per trigger	71.5	40.2	16.3	25.6	47.1	**201**
bandwidth (Mbits/s)	2183	1228	499	781	1439	**6130**

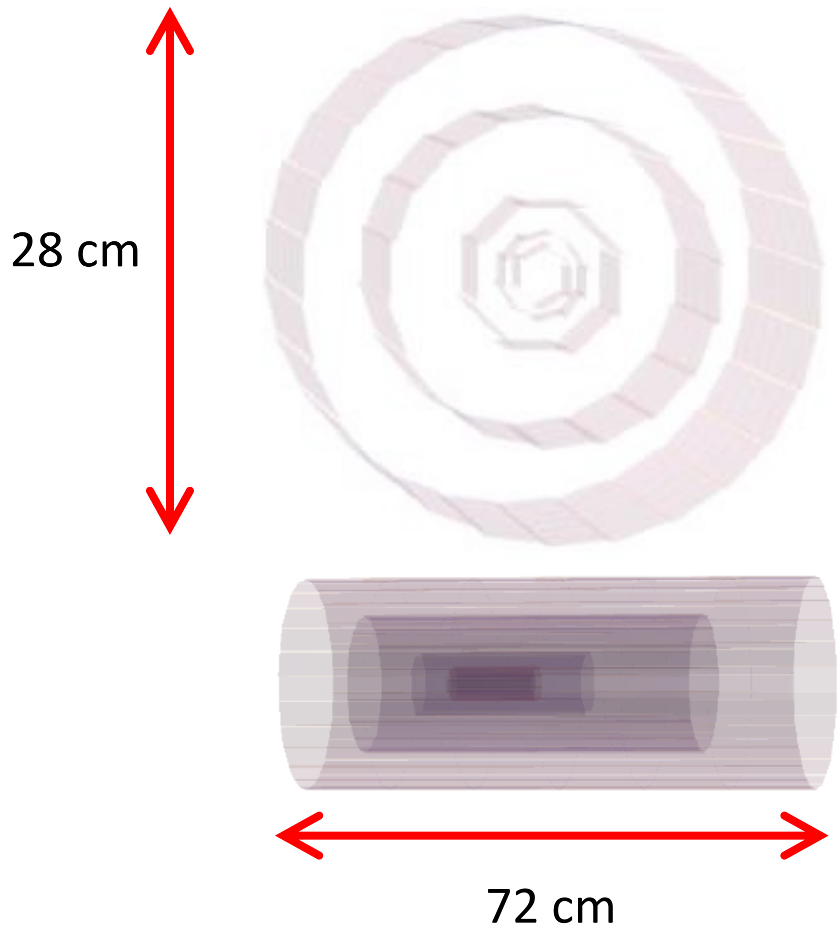
Total bandwidth for the whole VXD volume < 10 Gbits/s links

Event size ~25 kBytes

7 layers & disks scenarii in backup

Details of the 5 layer VTX geometry

VTX 5 layers



Layer no.	1	2	3	4	5
Radius (mm)	14.1	22.1	39.1	89.5	140.0
# Ladders	6	10	8	18	26
# Sensors per ladder	4	4	8	16	24

VTX by numbers

	option	5 layers VTX					
layer #		1	2	3	4	5	TOTAL
radius (cm)		1.4	2.2	3.9	9	14	
Length for acceptance (cm)		7.0	11.0	19.5	45.0	70.0	
Length using chip count (cm)		11.8	11.8	23.7	47.3	71.0	
hit rate (MHz/cm2)		156.6	51.6	6.4	2.1	1.2	
#ladders		6	10	8	18	28	70
#chips	#chips/ladder	4	4	16	32	48	
	#chip/ ladder width	1	1	2	2	2	
	total #chips	24	40	128	576	1344	2112
area using chip count (cm2)		108.7	181.1	579.5	2607.8	6084.9	9562
Max data size per trigger	per ladder (kbits)	11.8	4.0	2.0	1.4	1.7	
	total (kbits)	71.5	40.2	16.3	25.6	47.1	201
Required bandwidth	per ladder (Mbps)	360	121	61	43	51	
	total (Mbps)	2183	1228	499	781	1439	6130
# 1 GHz cables	on ladder	1	1	1	1	1	
	for layer	3	2	1	1	2	7
#Boards							
Power budget (W)	per ladder	4.5	4.5	18.1	36.1	54.2	
	total	27.1	45.2	144.5	650.2	1517.1	2384
	per sensor	1.129	1.129	1.129	1.129	1.129	

Detailed preliminary budget

task	item	# units	unit cost	develpmt	production	TOTAL	comment
Sensors	masks	1	300	300	300	**600**	two runs (dvpmt + prod)
	wafers	141	3	20	423	**443**	assume 60% yield + 20% spare & 50 dies/wafer
	handling / thinning	141	1	30	141	**171**	
	charac. & validation equipment			25	50	**75**	
			sub-total	**375**	**914**	**1289**	
Ladder structures & cables	inner layers (frame + cable)	16	10	50	160	**210**	
	outer layers (ladder + flex + cable)	54	10	50	540	**590**	
	characterisation / metrology			20	30	**50**	
			sub-total	**120**	**730**	**850**	
Assembly	tools for ladders			30	300	**330**	
	tools for full det.			50	200	**250**	
			sub-total	**80**	**500**	**580**	
Mechanical structures	beam pipe						common to all proposals
	end wheels	2	50	50	100	**150**	
	supports for boards, cables, ...				30	**30**	
			sub-total	**50**	**130**	**180**	
DAQ, electronics, services	Boards inside BII			20	60	**80**	
	Environmental monitoring			50	150	**200**	
	Boards & crates outside BII			50	200	**250**	
	cables (all types from end wheel)			50	200	**250**	Can be decreased by re-use of existing sytems
	powering system			50	150	**200**	
	cooling system			60	300	**360**	Assume partial re-use
	sub-total			**280**	**1060**	**1340**	
Installation				**0**	**100**	**100**	
TOTAL for 5 layers				**905**	**3434**	**4339**	**kUSD**
		Contingency	0.05	905	3605.7	**4510.7**	kUSD

VTX organisation

- Currently in the R&D phase
  - Global level: Carlos Marinas (IFIC Valencia)
  - Optimisation: Benjamin Schwenker (Uni. Göttingen)
  - Sensor: Jérôme Baudot (IPHC Strasbourg)
  - Integration: Stefano Bettarini (INFN Pisa)

- Proposed coordination at IN2P3
  - Scient. Jérôme Baudot + Tech. to be defined
  - Sensor: Hung Pham, Patrick Pangaud
  - Assembly: Marlon Barbero, eric Vigeolas
  - DAQ: Patrick Robbe, Daniel Charlet
  - Therm-mech: Emi Kou, Julien Bonis
  - Installation: to be defined when needed

=> Complete collaboration structure to be finalised in 2023s

Miscellaneous

ALICE-ITS3 & Belle II-VTX simultaneously @ C4Pi

- Schedules overlap

BUT

- Fits person-power & expertise available

- Sensor design: 2022-2024
  - 3-4 FTEs for each project
    => 7 FTEs in total for 10 available
  - leaving 3 FTEs for MAPS R&D (in synergy with ITS3)

- Sensor tests: 2023-2025
  - Modest requirement ~1FTE/project
  - thanks to commitment of Experiment collaboration teams

- Integration: 2023-2026/27
  - ITS3 ~R&D tasks and small production
  - VTX mostly production
  - Still close to saturate C4Pi staff in 2024-26

  => to be monitored closely

=> Detailed project planning for C4Pi under discussion with IPHC directorate, to be validated by COPIL – March 2023

About timeline: the ALPIDE-ITS case

Chip Development

Design team from CERN, INFN, CCNU, YONSEI, NIKHEF, IRFU, IPHC

2012	Explorer	20 μm x 20 μm and 30 x 30 μm pixels (analogue readout) 1.8 x 1.8 mm^2, study of pixel geometry, starting material, radiation
2013	pALPIDEss-0	Matrix with 64 columns x 512 rows, 22 μm x 22 μm pixels, 11 x 1.8 mm^2, in-pixel discrimination and buffering, zero suppression
2014	pALPIDE-1	**First full scale prototype!** 28 μm x 28 μm pixels, 15 x 30 mm^2, four sectors with variants, 1 register/pixel, no final interface
8/2015	pALPIDE-2	**Full scale prototype,** four sectors with variants, optimisation of circuits, integration in modules, no high speed serial output
10/2015	pALPIDE-3	**Full scale prototype,** eight sectors with variants, all communincation features, no ADC, no temperature sensor)
8/2016	ALPIDE	**Final chip**

February 22, 2018 P.Riedler CERN, PSI Seminar

~4 years from tech-proto to final sensor

- Few remarks
  - TJ180 nm exploration started in 2011
  - This is not a small team

+3 years for assembly

ALICE-ITS2 ~10 m^2 / Belle II-VTX ~1m^2