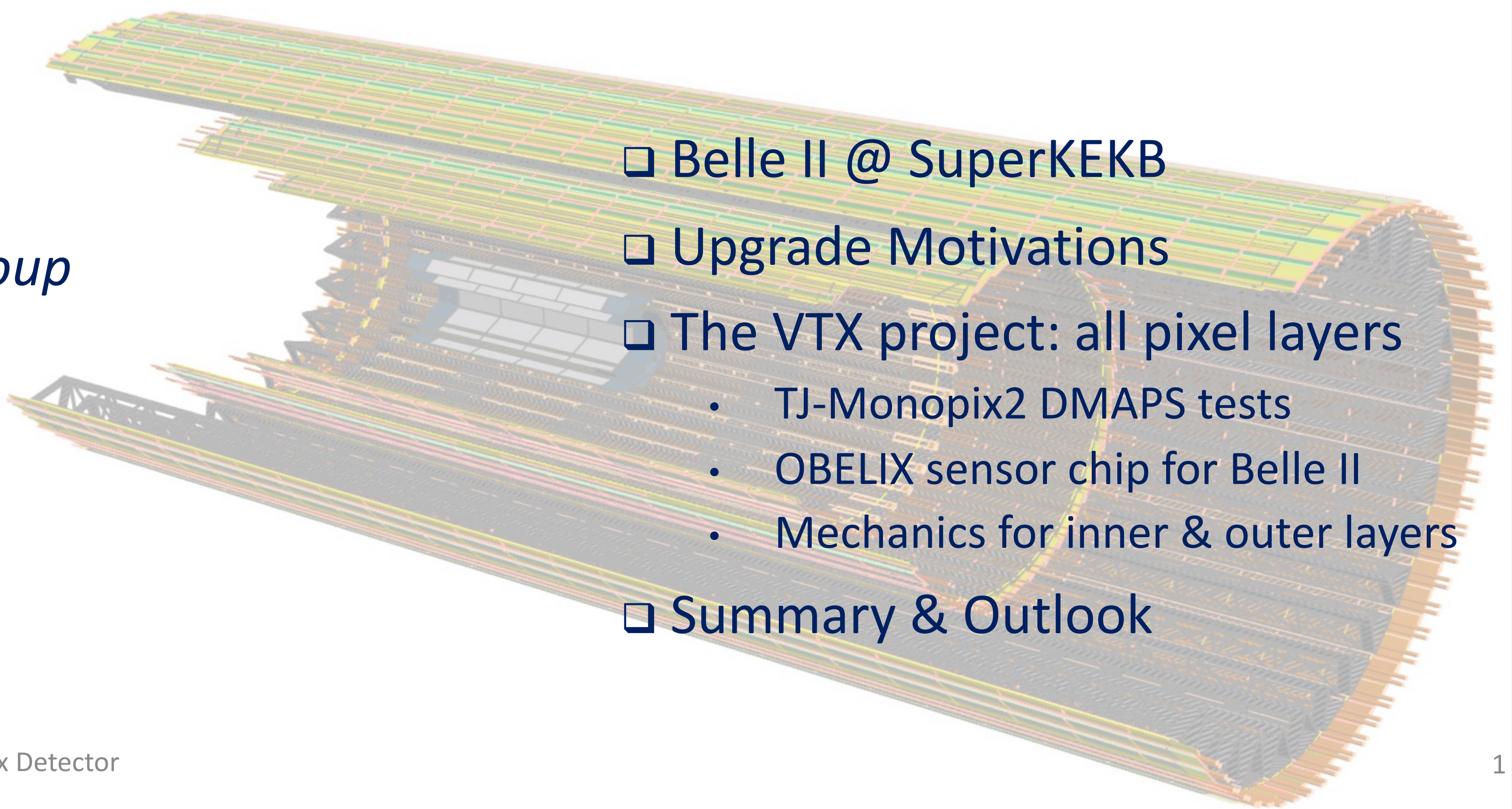
Belle II

16th Pisa Meeting on Advanced Detectors
May 26-June 1 2024

The DMAPS upgrade of the Belle II Vertex Detector



Giuliana Rizzo

for the Belle II VTX Upgrade Group

IN SUPREMÆ DIGNITATIS 1343
UNIVERSITÀ DI PISA

INFN
Istituto Nazionale di Fisica Nucleare

- ❑ Belle II @ SuperKEKB
- ❑ Upgrade Motivations
- ❑ The VTX project: all pixel layers
  - TJ-Monopix2 DMAPS tests
  - OBELIX sensor chip for Belle II
  - Mechanics for inner & outer layers
- ❑ Summary & Outlook

Belle II @ SuperKEKB

- Luminosity frontier experiment to search for Physics beyond the Standard Model
- SuperKEKB collider in KEK, Tsukuba - Japan
  - $e^+ e^-$ asymmetric collision at the $\Upsilon(4S)$ resonance
  - High current / nano-beams
  - Challenging background conditions

Target

$\mathcal{L} = 6\text{x}10^{35}$ cm^{-2} s^{-1}

$\int \mathcal{L}\, dt = 50$ ab^{-1}

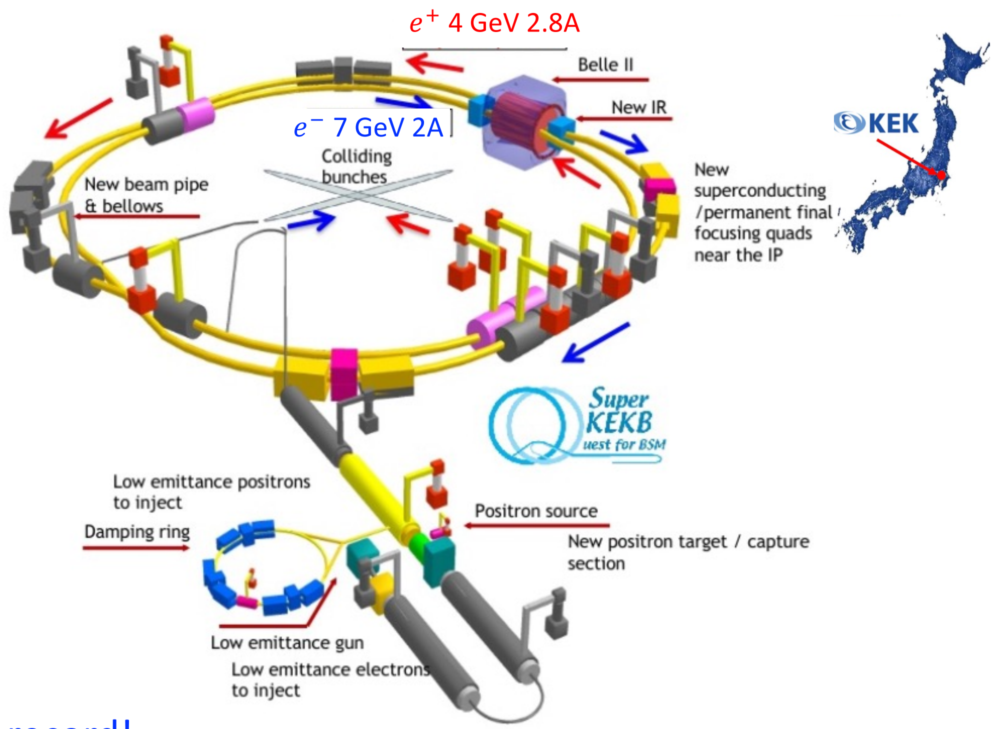
- Run 1: 2019 -2022
  - Pixel Detector (PXD): layer 1 + only 20% of layer 2
  - Full 4-layers strip detector (SVD)
  - First physics paper in January 2020

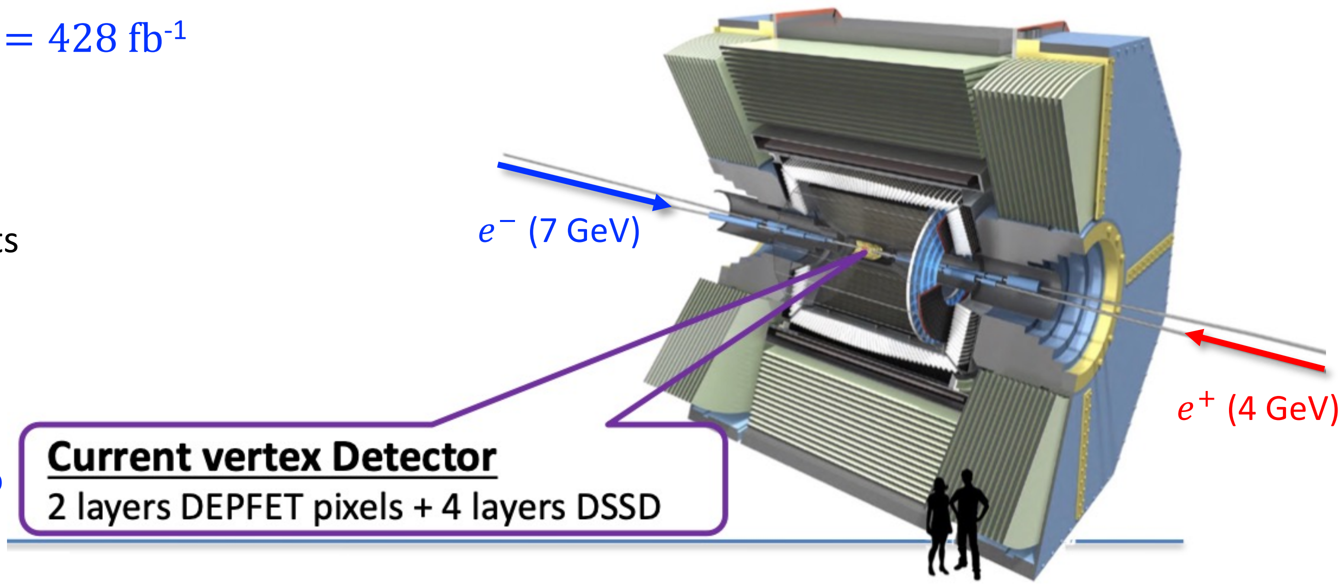
Achieved

$\mathcal{L} = 4.7\text{x}10^{34}$ cm^{-2} s^{-1} world record!

$\int \mathcal{L}\, dt = 428$ fb^{-1}

- Long Shutdown 1 (June 2022- end of 2023)
  - several accelerator and detector maintenance & improvements → installation of the complete 2 layers PXD + current SVD
- Run 2: started in Jan 2024
  - Instantaneous luminosity ramping up in next years
  - Path to reach $2\text{x}10^{35}$ cm^{-2} s^{-1} identified, but still large factors to reach the target peak luminosity of $6\text{x}10^{35}$ cm^{-2} s^{-1}





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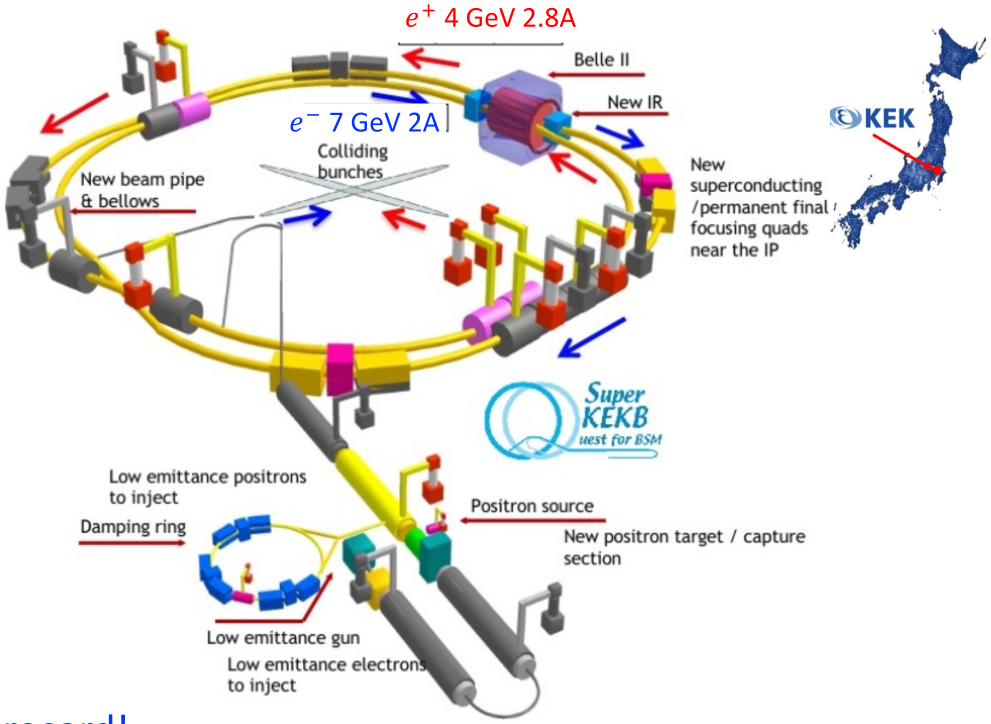

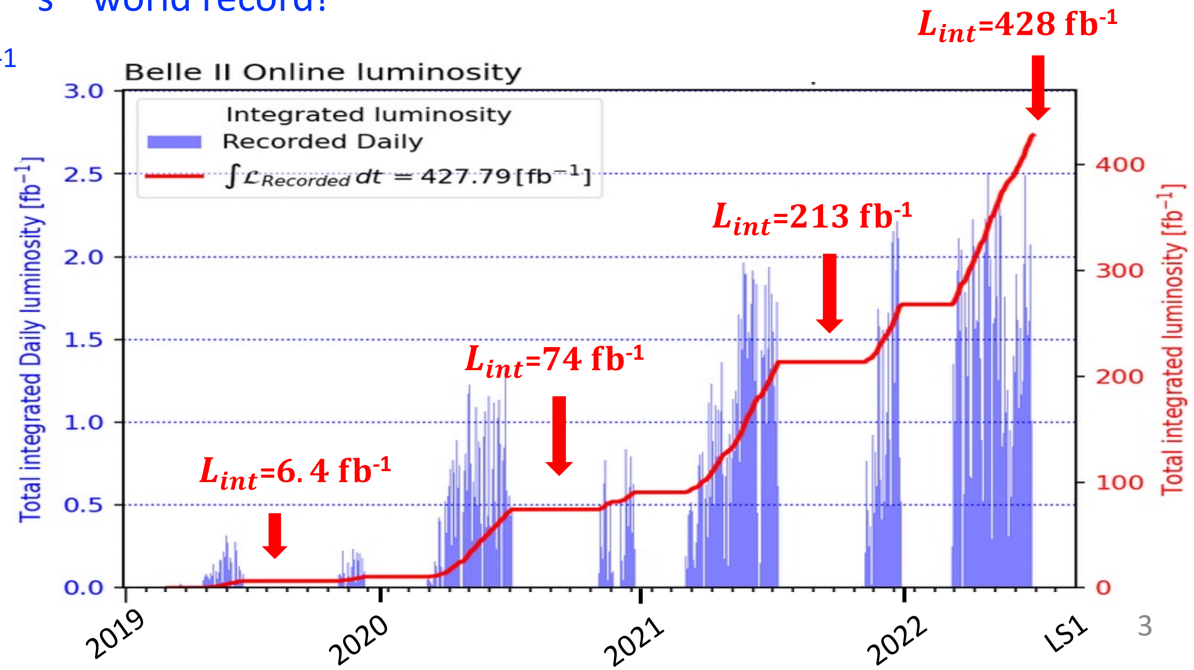

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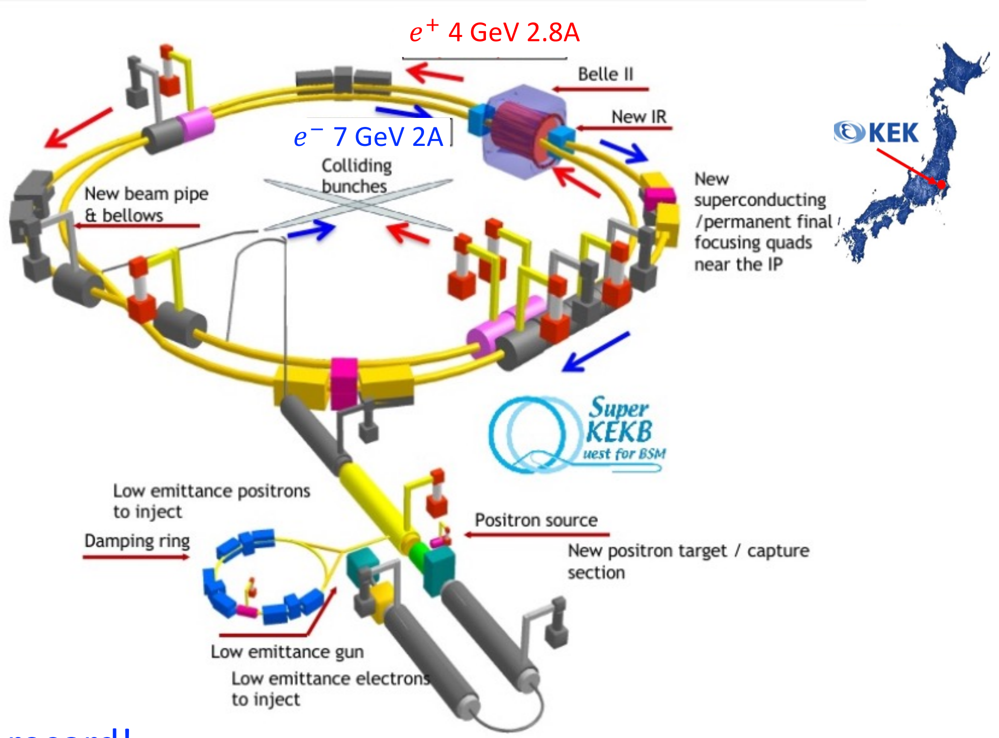

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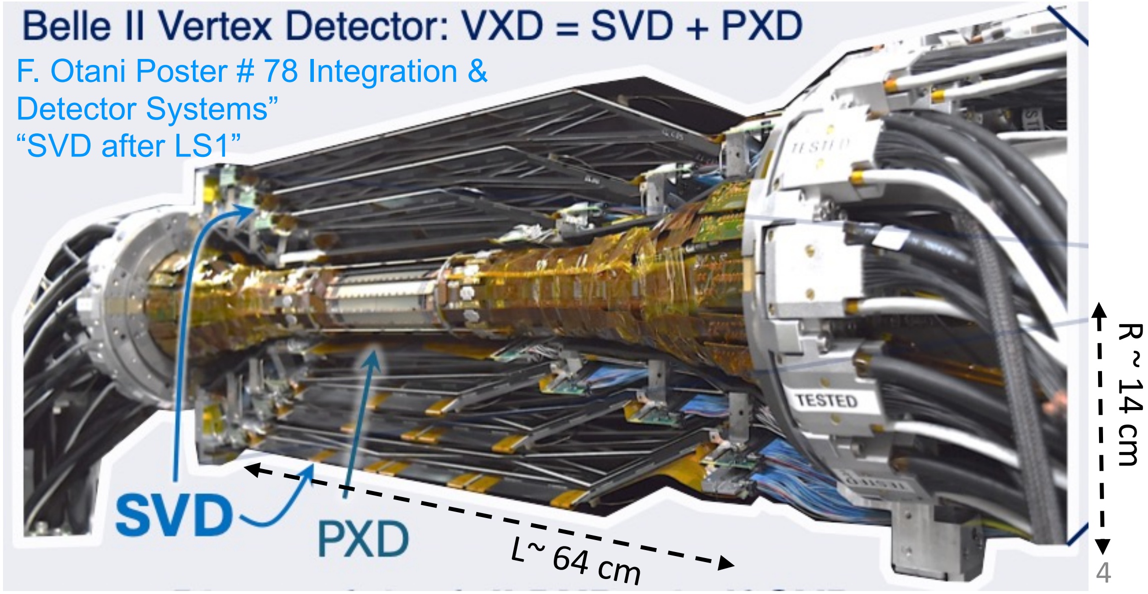

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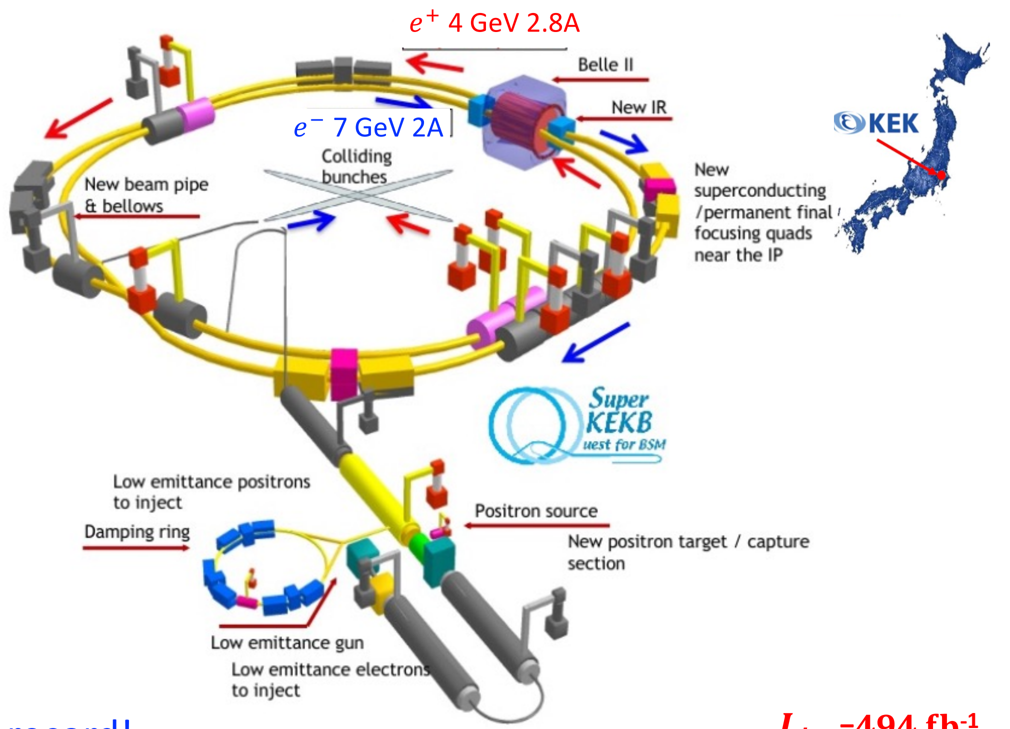
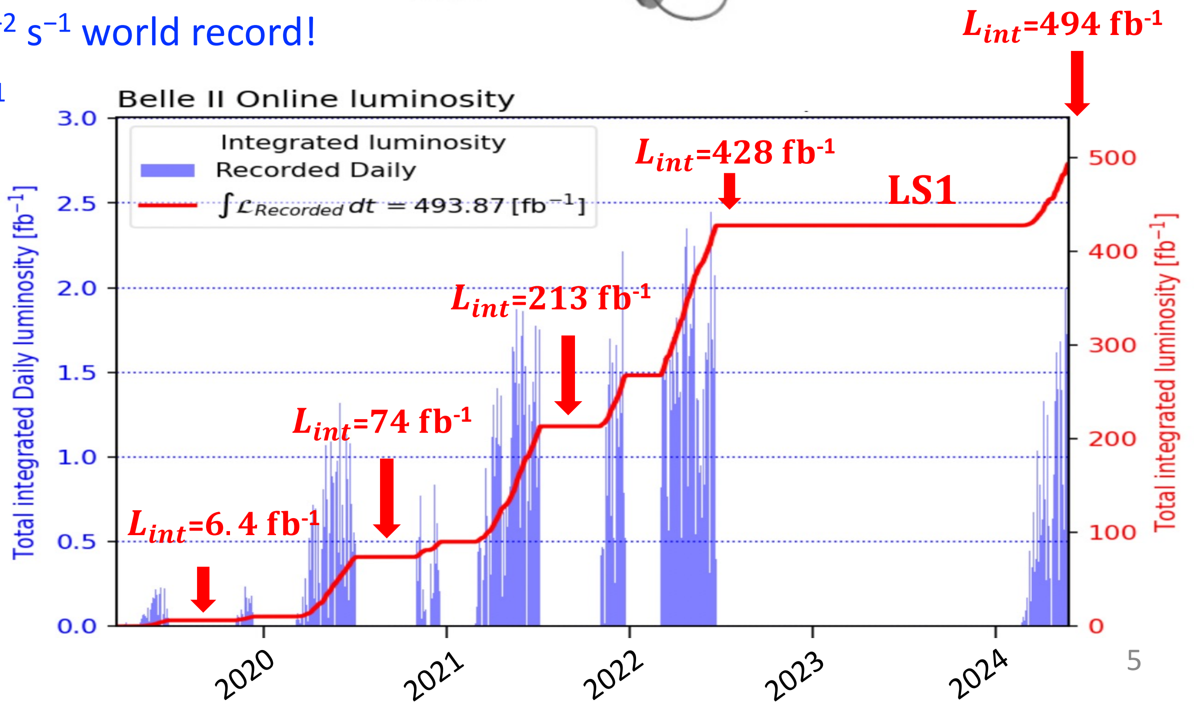
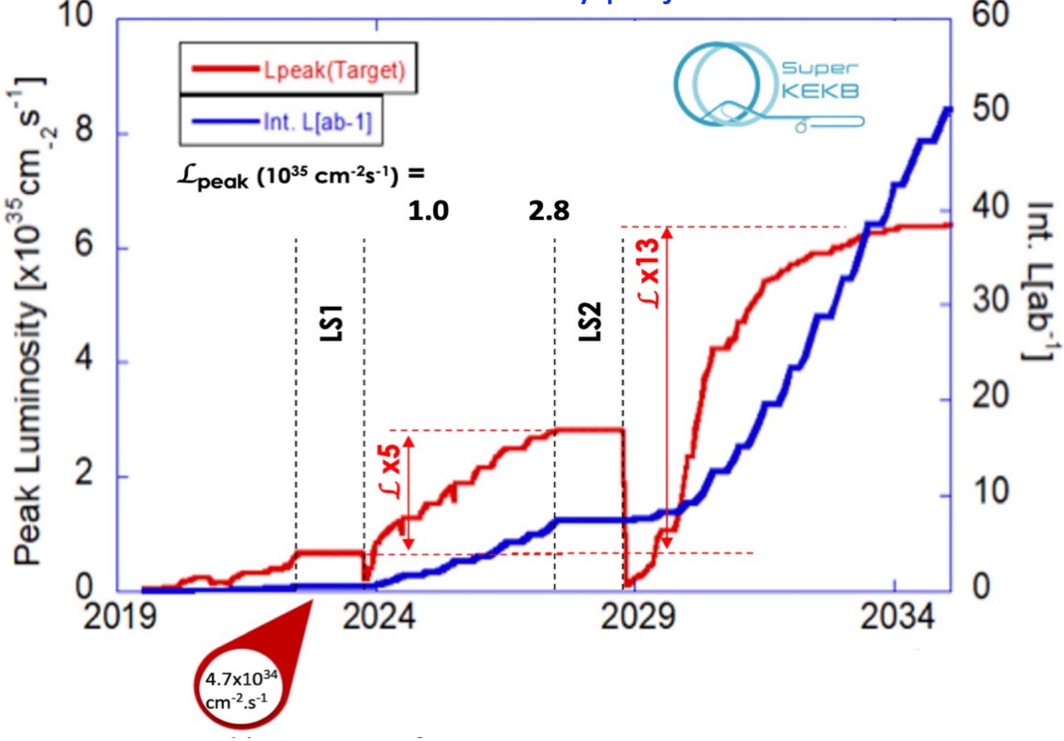




Belle II Upgrade Motivations

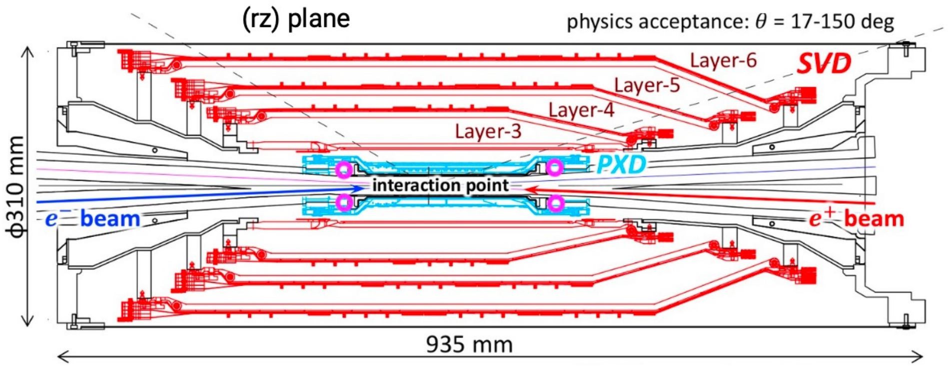
Luminosity projection

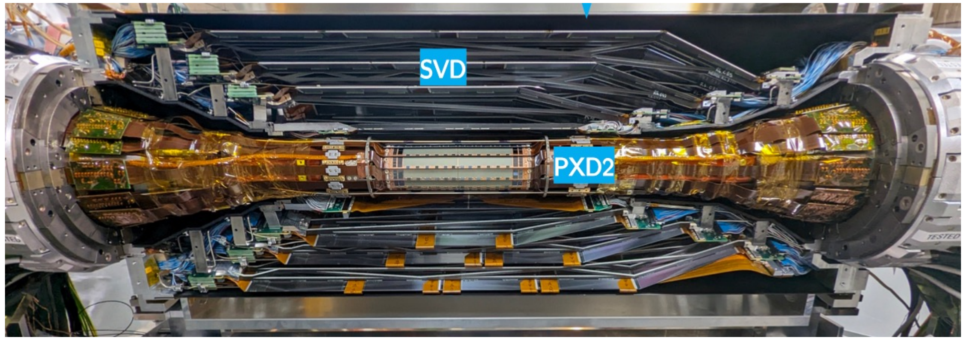


- Steep path to higher luminosity
  - x13 in peak luminosity, x2x2 in beam currents, x3 smaller beam size
  - Machine performance and stability
  - Backgrounds in the detector
- Upgrade of accelerator complex required to reach 6×10^{35} cm^{-2} s^{-1} it may include a major redesign of the Interaction Region (IR)
- Long Shutdown 2 (LS2) ~2027-2028 provides a window of opportunity for a significant detector upgrade
- Belle II Upgrade Program started:
  - To improve detector robustness against backgrounds & provide larger safety factors to run at high luminosity
  - Increase longer term subdetector radiation resistance
  - Develop the technology to cope with a replacement of the VXD, needed in case of major IR redesign
  - Prepare a safety net in case of failure of detector components or accidents
  - Improve physics performance: get more physics per ab-1
- Framework CDR ready: available on arXiv soon
  - several possible detector improvements with different time scales & readiness → New Vertex Detector proposed

Current Vertex Detector (VXD)

- Two technology system
  - Low mass ladder design with total material budget of 3.8% X0
  - Spatial resolution 10 -25 µm
- PXD:
  - 2 Layers of DEPFET pixel sensor: R=1.4-2.2 cm
  - Thin sensors (75µm) & air cooling → 0.25% X0/layer
  - Small pixel pitch (50-75 µm) but long integration time (20µs)
  - Occupancy limit 3%
  - Cannot contribute to track finding
  - Delicate detector → damages in high dose beam aborts!
- SVD:
  - 4 layers of double sided strip detector: R=3.9 -14 cm
  - DSSD 300 µm + "Origami" chips on sensor design & CO_2 evaporative cooling → 0.75% X0/layer
  - Very good cluster time resolution 3 ns, but long strips (6 cm)
  - Occupancy limit 6%, using also the hit-time for BG rejection
  - Trigger latency limited to 5 µs by readout chip





✓ Excellent VXD performance in current conditions @ occupancy < 1%

- Large uncertainty on background extrapolation @ target luminosity & with possible new IR → 3 BG scenarios
- Limited safety margin & performance degradation possible in the high BG scenario:
  - PXD layer1 up to 2% occupancy (32 MHz/cm2 hit rate)
  - SVD layer3 up to 9% occupancy (9 MHz/cm2 hit rate)

➢ May reach limits of current detector @ target luminosity → higher space & time granularity in all layers

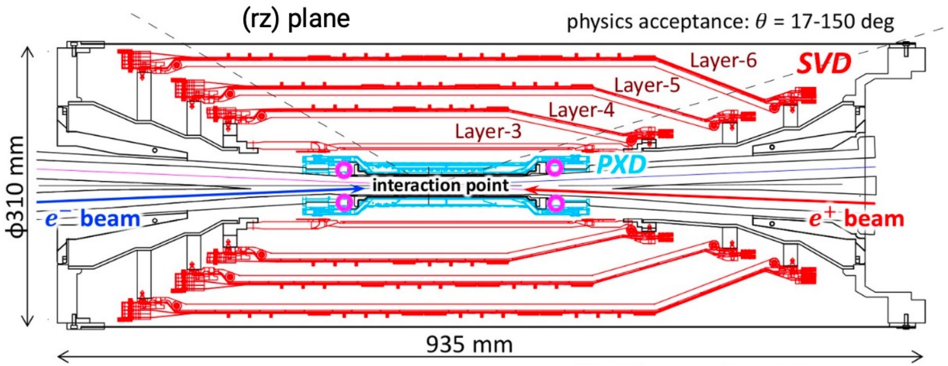
VXD upgrade needs

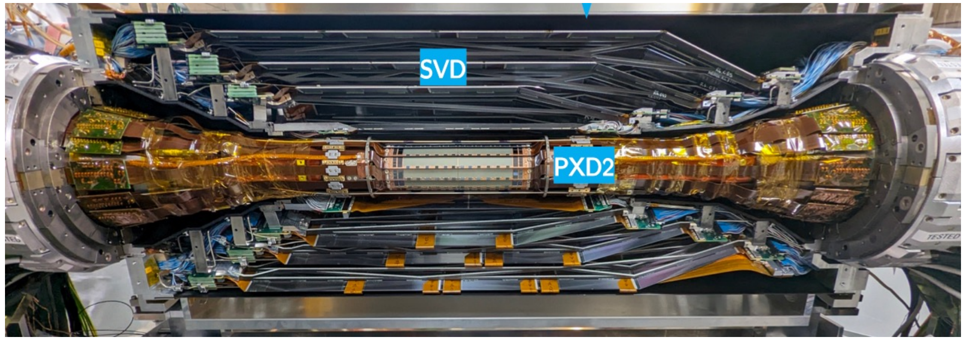
❑ Vertex detector upgrade requirements

- Radiation levels:
  - TID ~ 100 Mrad
  - NIEL ~ $5x10^{14}$ neq/cm^2
- Hit rate up to 120 MHz/cm^2
- Fast timestamping: 50-100 ns
- Resolution < 15 um → pitch 30-40 um
- Power dissipation ≤ 200 mW/cm^2
- Operation simplicity & reduced services

❑ Spec's match core features of the **D**epleted **M**onolithic **A**ctive **P**ixel **S**ensors (DMAPS) developed for ATLAS

→ TJ-Monopix sensors, TowerJazz 180 nm process





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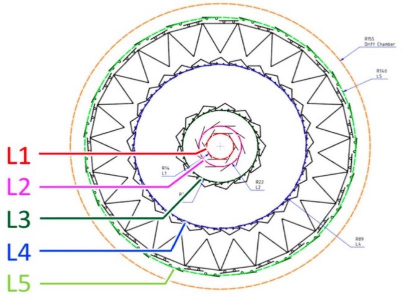
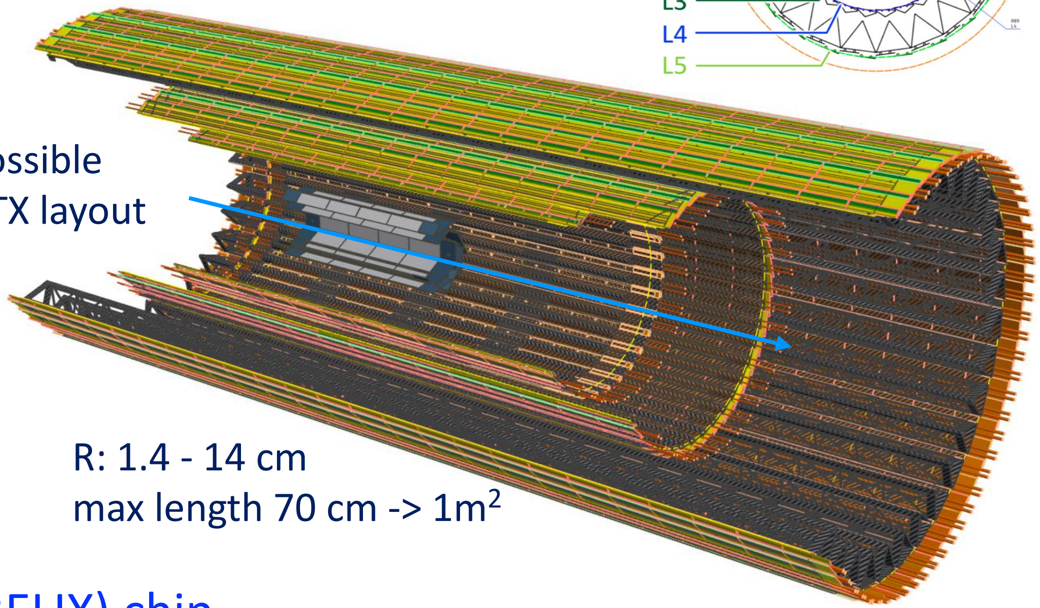
Vertex detector upgrade: the VTX project





❑ Concept = 5 straight layers with DMAPS pixel sensors

- Higher space-time granularity & lower material budget
  - Reduce occupancy to improve tracking in high background
  - Better tracking & vertex resolution at low momentum
- Lighter services & "easy" geometry
  - adaptable to potential changes of Interaction Region

❑ Technical choices

- Identical pixel sensor on all layers: **O**ptimized **BEL**le II p**IX**el (OBELIX) chip
  - Thin DMAPS sensor, derived from TJ-Monopix2, with 33 um pitch & 50-100 ns timestamping
  - Operated at room temperature, power consumption 120-200 mW/cm^2 (hit rate 1- 120 MHz/cm^2)
- **iVTX**: innermost 2 layers, all-silicon, self-supported (PXD-inspired), air cooled (0.2 % X0)
- **oVTX**: 3 outer layers, Carbon fiber frame (ALICE-ITS2 inspired), water cooled (0.3 - 0.8% X0)
- Total material budget reduced to 2.4% X0

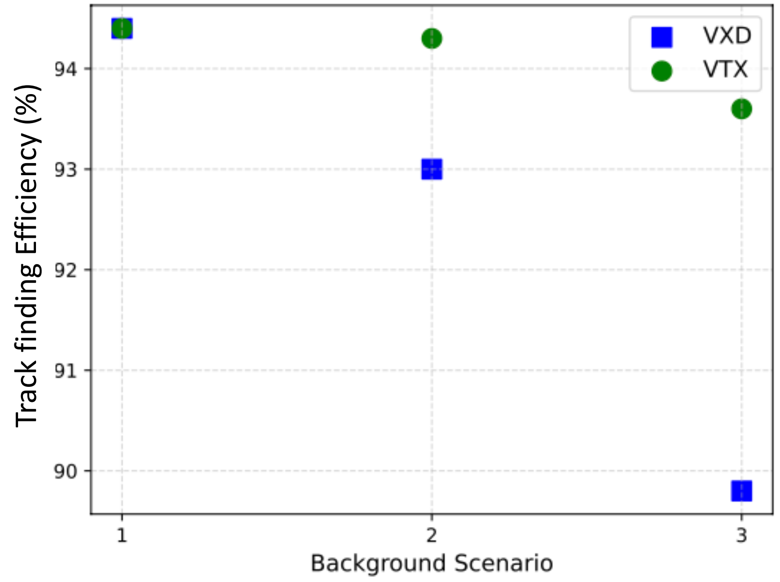
	L1	L2	L3	L4	L5	Unit
Radius (mm)	14.1	22.1	39.1	89.5	140	mm
# Ladders	6	10	17	40	31	
# Sensors	4	4	7	16	2x24	per ladder
Expected hit rate*	19.6	7.5	5.1	1.2	0.7	MHz/cm2

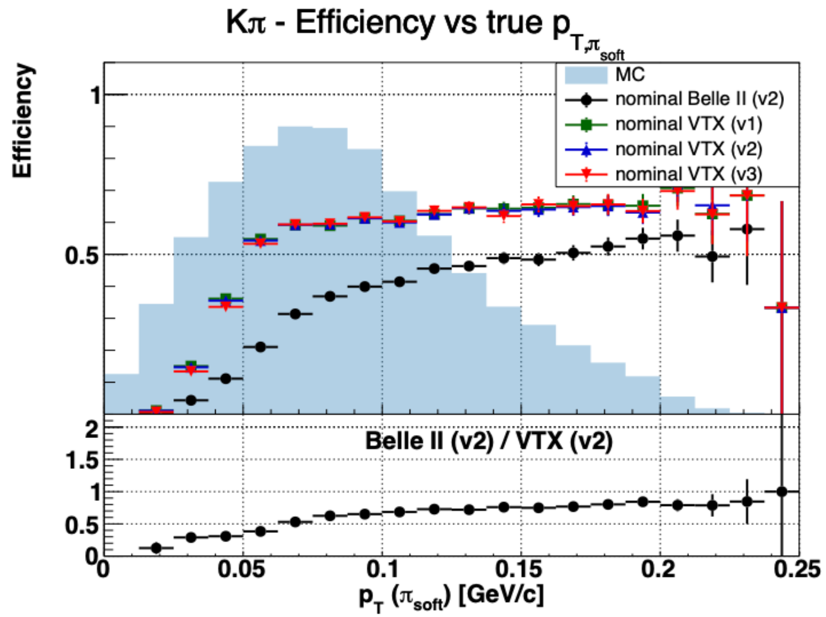
**Large uncertainty on BG extrapolation/possible changes in IR region*

VTX tracking performance

- VTX performance studies: on benchmark channels, full simulations of signal events overlaying 3 possible background scenarios: optimistic:v1, intermediate:v2, conservative:v3
- Fully pixelated VTX with high space & time granularity in all layers
  - reduction in occupancy by a factor 200
  - all layers included in pattern recognition
- VTX:
  - better tracking efficiency than current VXD for full tracking (VTX tracking combined with Central Drift Chamber)
  - less sensitive to the background level than current VXD
  - better low momentum tracking efficiency than current VXD
    - Reconstruction efficiency for $B^0 \rightarrow D^{*-} l^+ \nu_l$ as a function of the $\pi-$ soft transverse momentum from the decay $D^{*-} \rightarrow D^0 \pi^-$, with $D^0 \rightarrow K^- \pi^+$

Track finding Efficiency for diffentent Background Scenarios

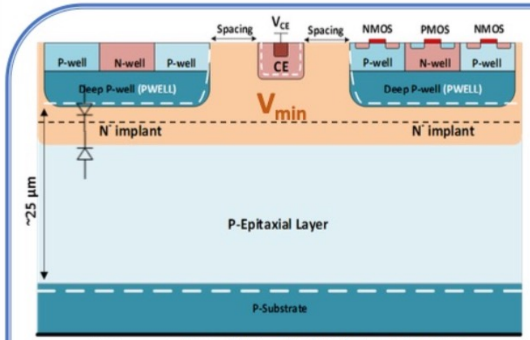




TJ-Monopix2

❑ TJ-Monopix2 as forerunner of OBELIX

- Developed for ATLAS (ITK outer layers), TJ 180 nm (same as ALPIDE) but modified process to improve rad hardness & faster redout → core features matching Belle II needs
  - 33x33 µm2 pitch, 25 ns integration, large matrix 2x2 cm2
  - 7 bit ToT information, 3 bit in-pixel threshold tuning
  - Column drain readout capable to handle >> 120 MHz/cm2 -> triggerless in TJMP2
  - Various sensing volume thickness (epi-30 um, CZ-bulk)
  - F. Huegging Poster on "Recent results on DMAPS Monopix sensors"
    # 299 in Solid State Poster session
- OBELIX design based on the TJMP2 matrix with new digital periphery with trigger logic for Belle II + optional features to allow Track Trigger capability & additional finer timestamping for outer layer hits, low rate.
- Detailed characterization of TJ-Monopix2 to validate key performance crucial for OBELIX design



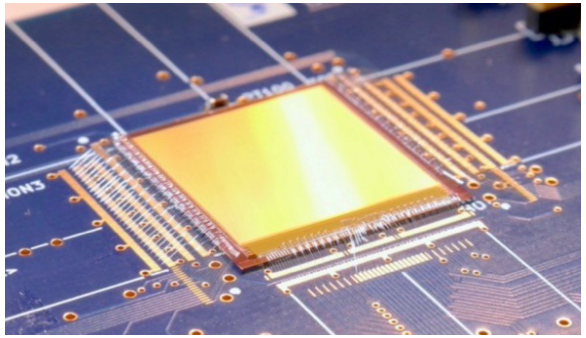
W. Snoeys et al. https://doi.org/10.1016/j.nima.2017.07.046

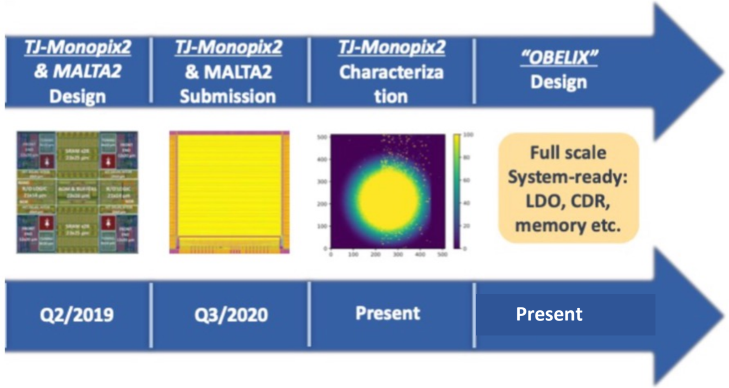
$C_d \leq 3fF$ $\quad P \approx \frac{S}{N} \approx \frac{Q}{C_d}$

DMAPS in TJ 180 nm: Concept

- Small sensor capacitance (Cd)
  - Key for low power/low noise
- Radiation tolerance challenges
  - Modified process
  - Small pixel size
- Design challenges
  - Compact, low power FE
  - Compact, efficient R/O

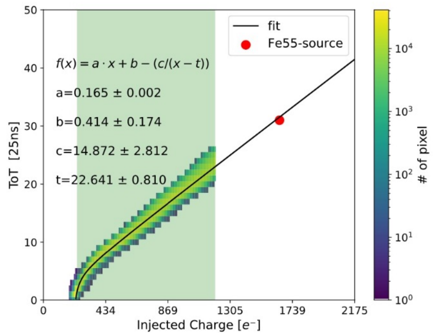
TJ-Monopix2: Proof-of-principle for Belle II VTX – OBELIX

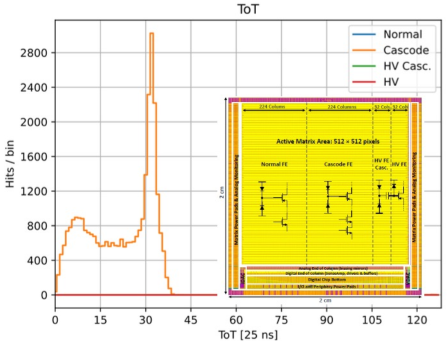




TJ-Monopix2 characterization

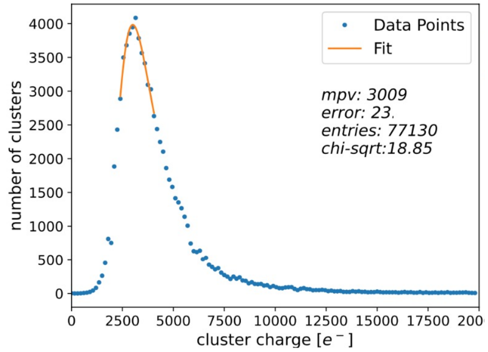
- ❑ Detailed characterisation of TJMP2 to validate key performance

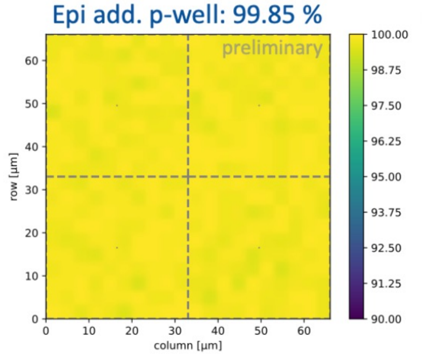




TJMP2 sensor is divided in 4 regions with different pixel FE

- In-laboratory:
  - Threshold / noise
    - → stable operation down to THR~ 250 e- (MIP signal in 30 um Si MPV~2500 e-)
    - → THR dispersion 17e-, Noise ~ 8 e-
  - ToT calibration
- Several beam test campaigns (DESY, 5 GeV electrons)
  - July 2022: not-irradiated sensors & high threshold 500 e- (un-tuned chips)
    - Efficiency ~99%
    - Position resolution ~9 µm
  - July 2023: low threshold 250-300 e- & irradiated sensor 5x10^{14} neq/cm^2
    - Confirmed good performance & high efficiency after irradiation, increasing bias



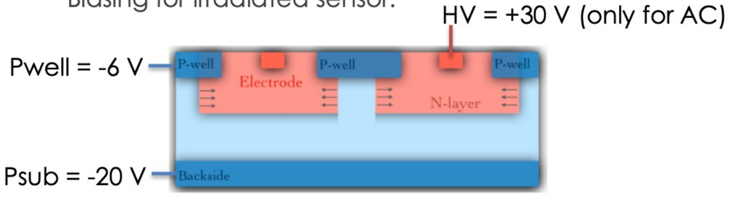


Irradiated sensor

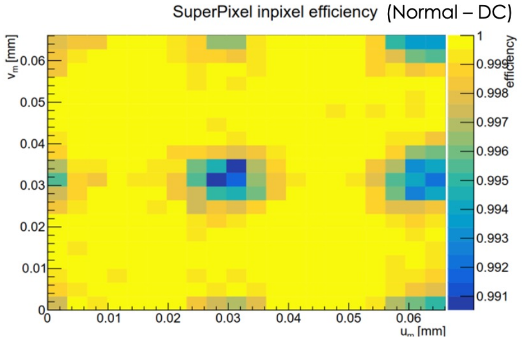
- 5 x 10^{14} n_{eq}/cm^2 (with 24 MeV protons)

ampli	coupling	Efficiency (%)
Normal	DC	99.99
Cascode	DC	99.79
Normal	AC (HV)	99.13
Cascode	AC (HV)	98.11

– Biasing for irradiated sensor:



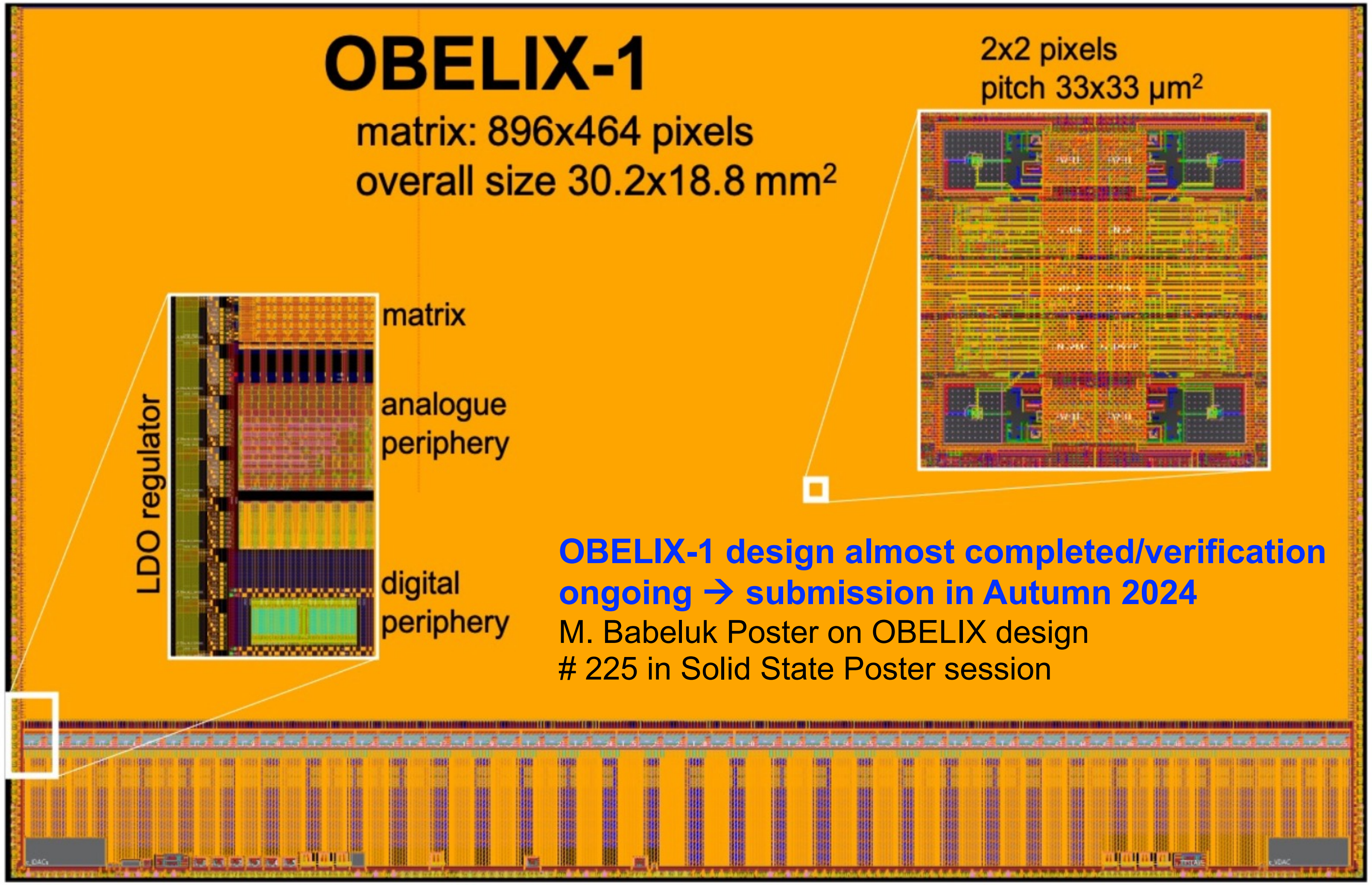
- July 2024: repeat on irradiated sensor with high fluence & TID 100 Mrad



OBELIX-1 specifications & layout

Pitch	33 µm
Signal ToT	7 bits
Time stamping	50 To 100 ns
Fine time * stamping	~5 ns for hit rate < 10 MHz/cm^2
Hit rate max for 100% eff.	120 MHz/cm^2
Trigger handling	30 KHz with 10 µs delay
Trigger * Output	~10 ns resolution with low granularity
Power (with hit rate)	120 to 200 mW/cm^2 (1 to 120 MHz/cm2)
Bandwidth	1 output 320 MHz

*** optional features**

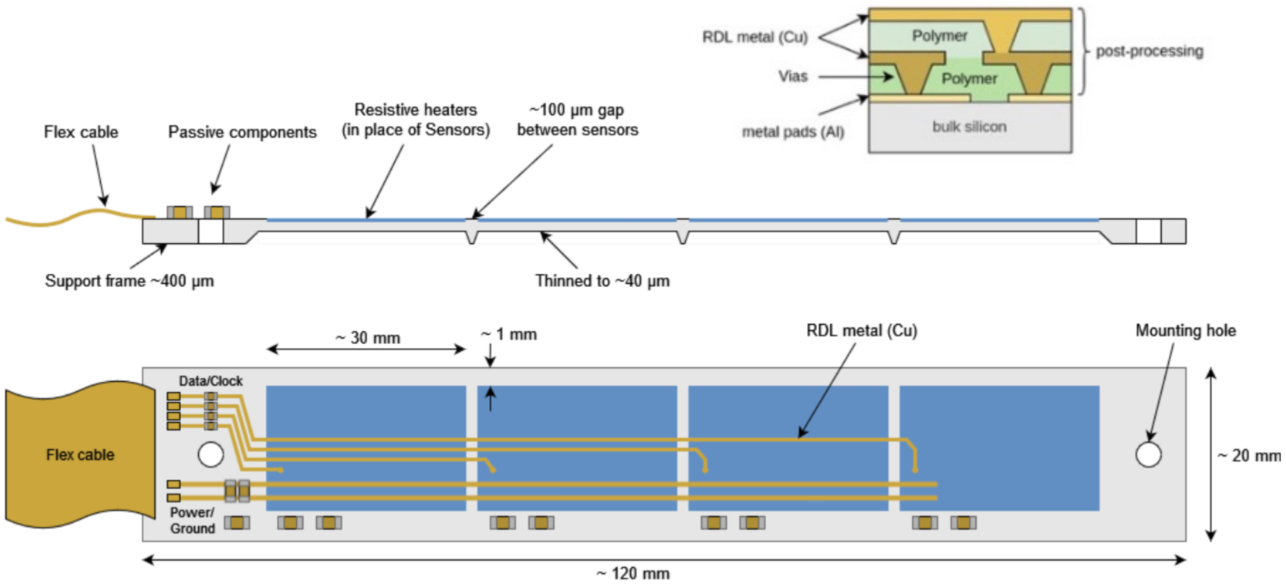


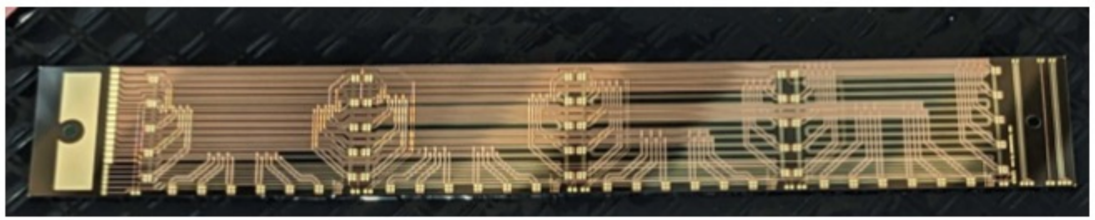
OBELIX-1 design almost completed/verification ongoing → submission in Autumn 2024

M. Babeluk Poster on OBELIX design
225 in Solid State Poster session

iVTX

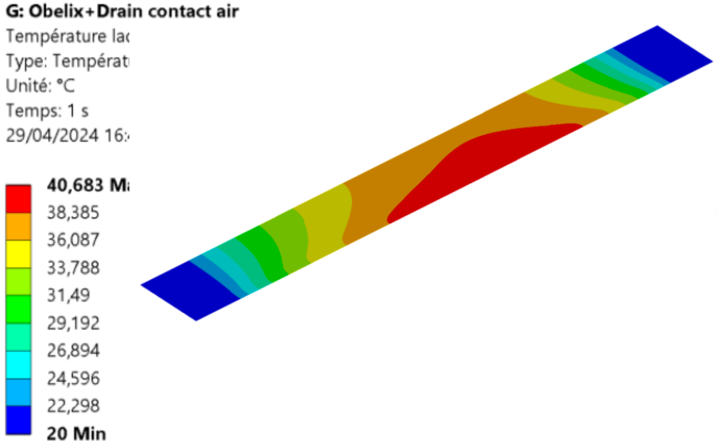
- All-silicon module < 0.2% X0
  - 4 contiguous OBELIX sensors diced as a block from the wafer, thinned to 50 um, except in some border area ~400 um thick, to ensure stiffness
  - Post-process redistribution layer for interconnection
- Prototypes:
  - First real-size ladder at IZM-Berlin with dummy Si & resistive heater to test cooling too

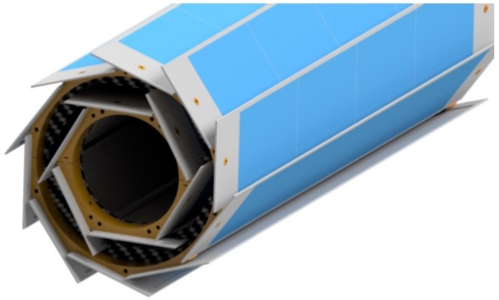




Preliminary: cooling simulation results

	Ladder only T max (ºC)	Ladder only T range (ºC)	Ladder + carbon plate T max (ºC)	Ladder + carbon plate T range (ºC)
Contact + air	44	22	41	18
Contact + water	66	41	34	12
Contact + air + water	39	17	30	9

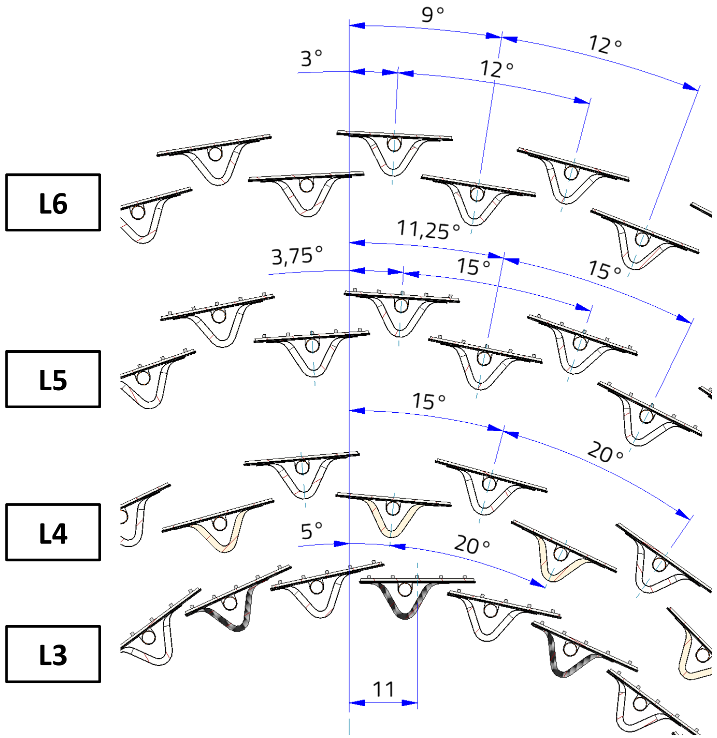


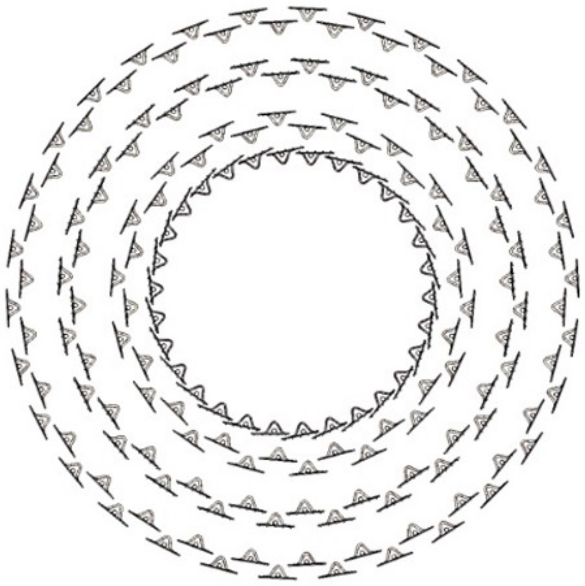


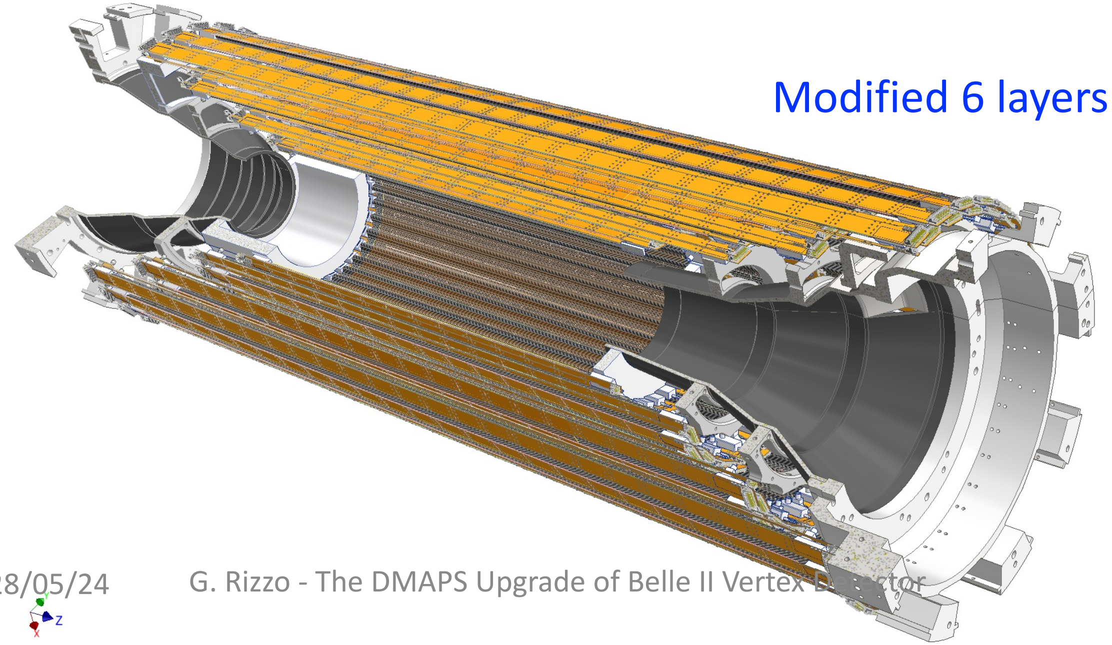
- Air cooling alone might be marginal
  - Non uniform Power: matrix 100 mW/cm^2, digital periphery ~500 mW/cm^2→ P_avg ~200 mW/cm^2
- Several options under evaluation

oVTX

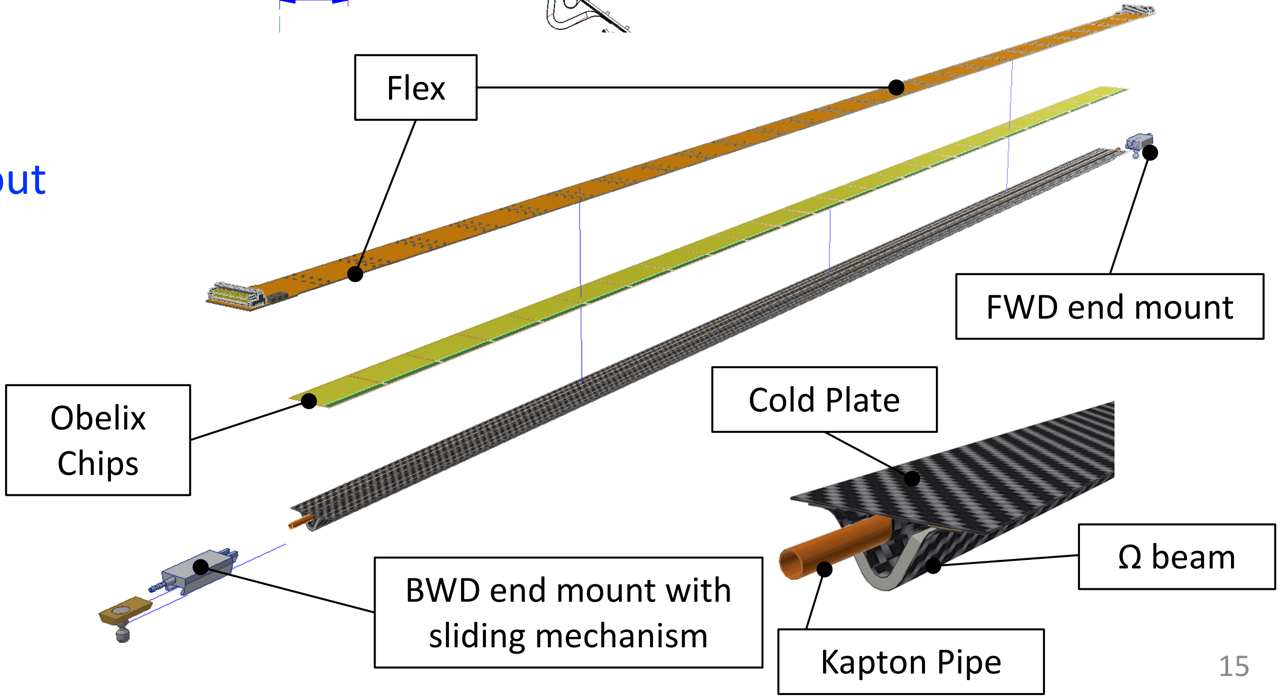
- Ladder structure (ALICE ITS2-inspired):
  - CF support structure (Ω beam), cold-plate with pipes (2 or 1 pipe) with liquid cooling
  - Chip and Flex circuit for power & signal
- Prototypes:
  - Mechanical & thermal characterization done for the longer ladder ~70 cm (outermost layer)
- Mechanical design already advanced
  - now also exploring a 6 layers option





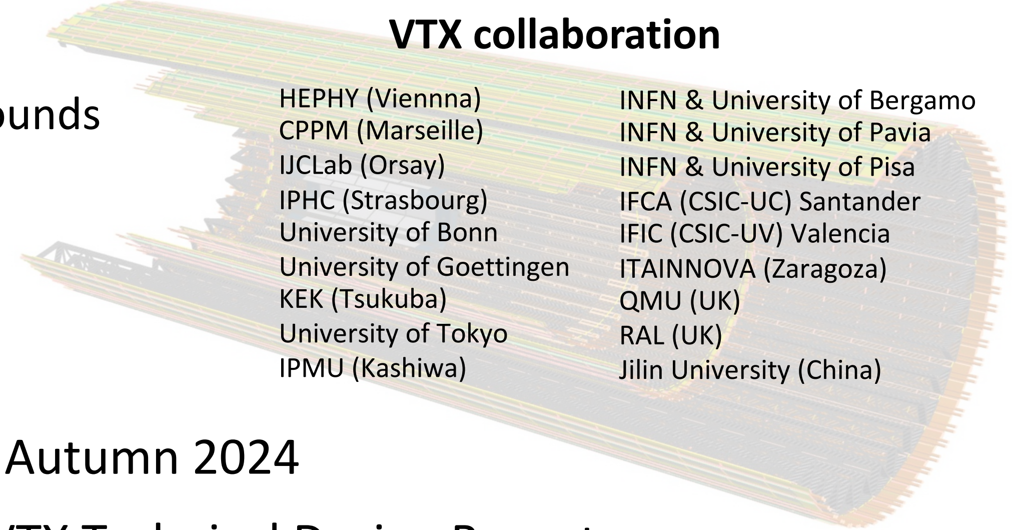


Modified 6 layers layout



Summary and Outlook

- SuperKEKB will need an upgrade to reach the target Lumi 6×10^{35} cm^{-2} s^{-1}, including a possible major redesign of the Interaction Region (IR)
- Current VXD has excellent performance now, but limited safety margin in the high BG scenario
- Long Shutdown 2 (~2028) is a good opportunity to upgrade the vertex detector
- Proposed an upgrade (VTX) based on DMAPS pixels in all layers:
  - VTX more performant and resilient against higher machine backgrounds
  - new VTX needed in case of a redesign of the IR
  - replacement of current VXD in case of severe accidents



VTX collaboration

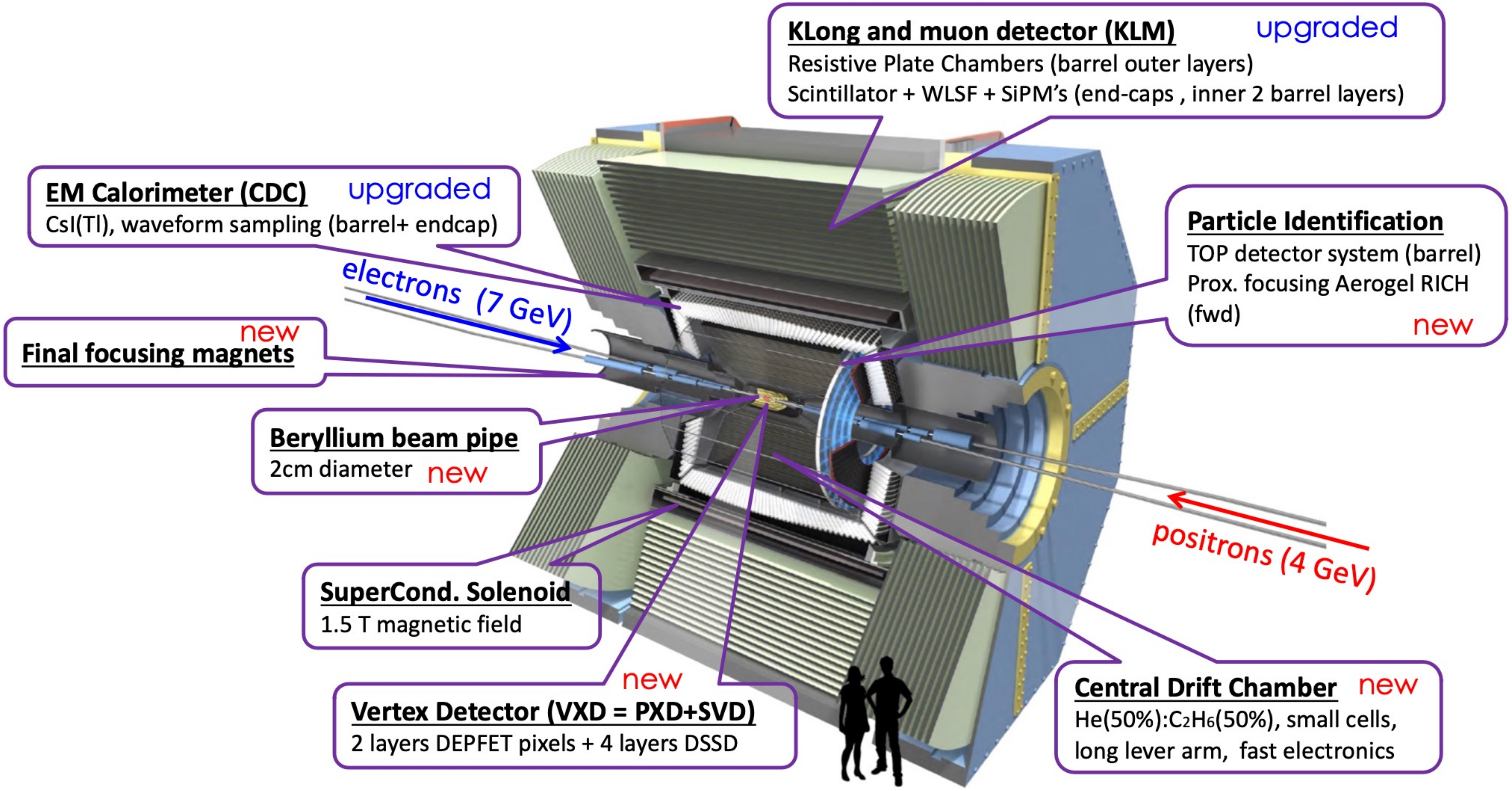
HEPHY (Viennna)	INFN & University of Bergamo
CPPM (Marseille)	INFN & University of Pavia
IJCLab (Orsay)	INFN & University of Pisa
IPHC (Strasbourg)	IFCA (CSIC-UC) Santander
University of Bonn	IFIC (CSIC-UV) Valencia
University of Goettingen	ITAINNOVA (Zaragoza)
KEK (Tsukuba)	QMU (UK)
University of Tokyo	RAL (UK)
IPMU (Kashiwa)	Jilin University (China)

- Framework CDR ready: available on arXiv soon
- First full scale prototype OBELIX-1 sensor ~ ready → submission Autumn 2024
- Next steps: continue R&D and engineering activities → prepare VTX Technical Design Reports
- Preliminary schedule: VTX can be ready ~ 3 years after the final sensor (OBELIX-2) is submitted to fabrication
- VTX collaboration is growing, but still a lot to do in many areas

backup

Belle II detector

Upgraded or new / Belle



SuperKEKB collider

▪ Recipe to high luminosity

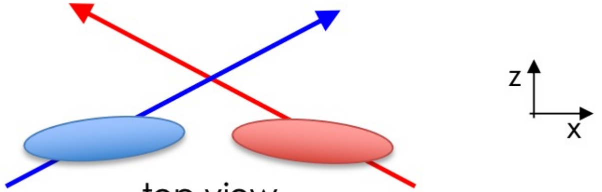
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}^*}\left(\frac{R_L}{R_{\xi_y}}\right)$$

- Lorentz factor
- beam current
- beam-beam parameter
- geometrical reduction factors
- beam aspect ratio at the IP
- vertical beta-function at the IP

High currents:
> 1A

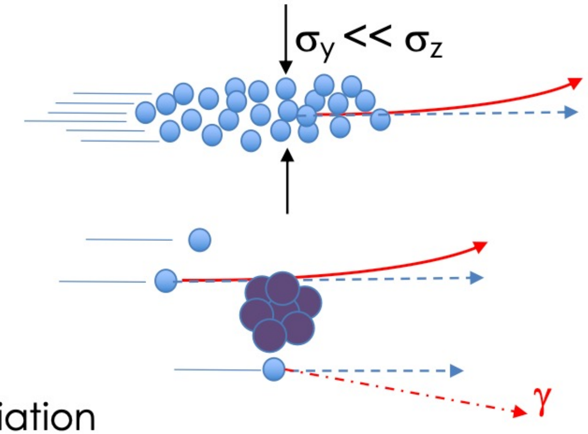
Nano-scale beam size:
$\sigma_x \times \sigma_y \sim 10\mu m \times \sim 60\ nm$
$B_y^* < 1\ mm$

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

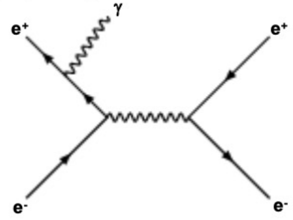


▪ Beam-induced backgrounds

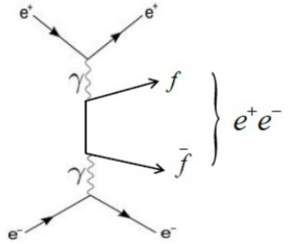
- Intra-beam scattering
- Beam-gas interaction
- Synchrotron radiation



- Luminosity driven



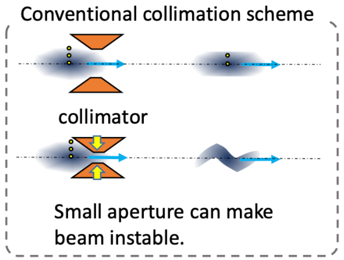
Radiative Bhabha scattering

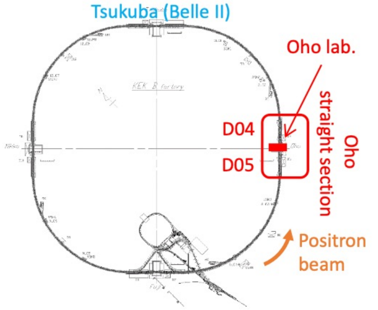


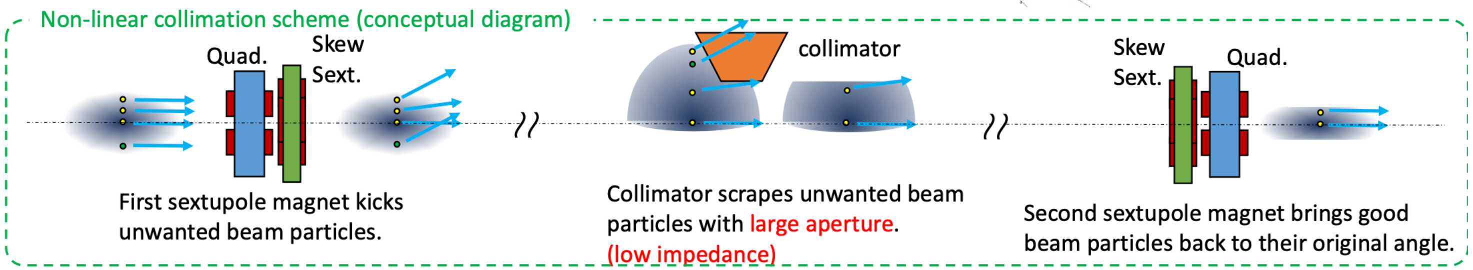
2-photon interaction

LS1 activity in a nutshell

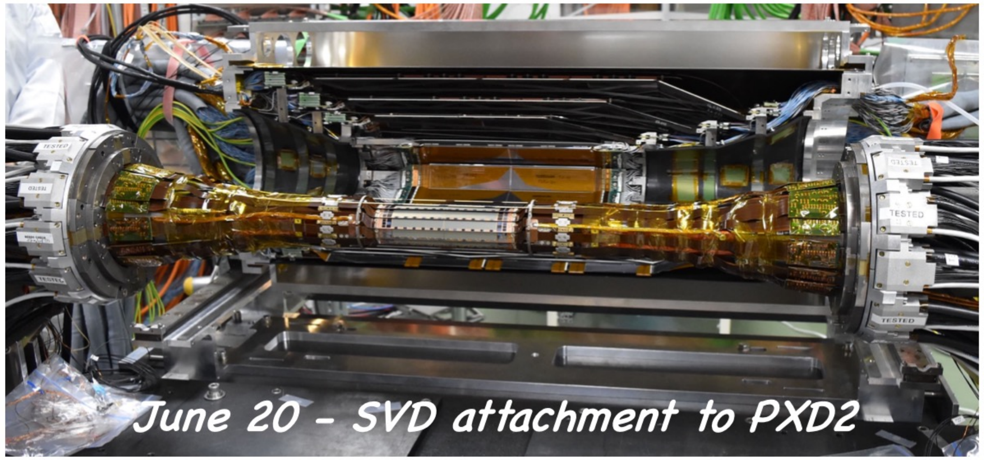
- Accelerator improvements:
  - injection system, Non-Linear Collimators, monitoring...
  - additional shielding (e.g. neutron) and increased resilience against beam BG
  - installation of additional loss monitors
- Detector:
  - Replacement of beam-pipe & installation of complete VXD: SVD + PXD2 with 2-layers
  - replacement of 50% of photomultipliers (MCP-PMT) of the central PID detector (TOP) → increased lifespan
  - improvement in CDC gas distribution & monitoring system

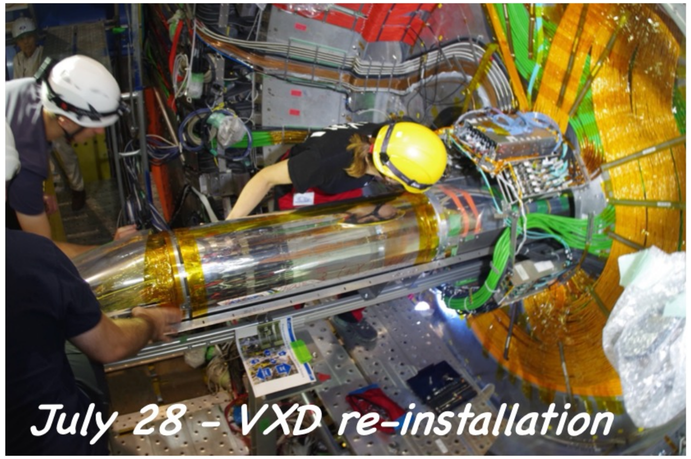


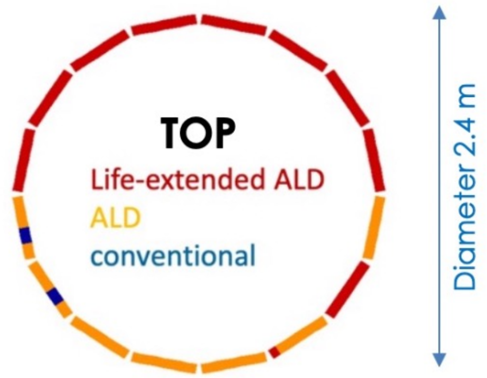




- DAQ
  - completed transition to new DAQ boards (PCIe40)
  - improved data-quality monitoring, alarm system, HV control & injection inhibit scheme

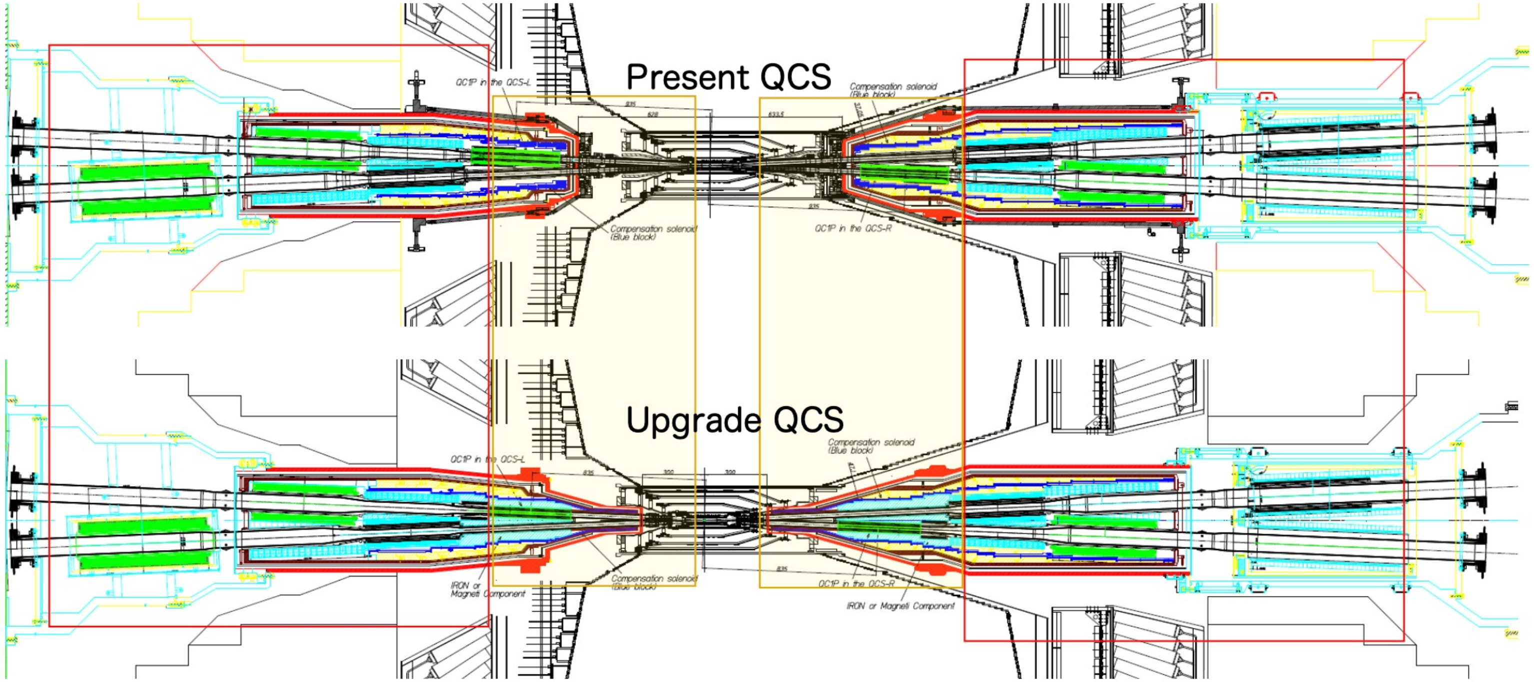

June 20 – SVD attachment to PXD2


July 28 – VXD re-installation



Path to high luminosity

- GOAL: higher luminosity while limiting beam beam effects & preserving beam lifetime
- Several modifications are considered to further improve the SuperKEKB performance
  - upgrade of the injection complex
  - new HER beam transport (BT) line
  - increase of the HER RF stations & replacement of various aging components…
- Possible modification of the IR
  - Position of final focusing magnets (QC) closer to IP
  - New QC magnets
  - Additional solenoid for lower emittance while compensating Belle II field
  - Need feed-back from 2024 beam operation
  - **Belle II envelope in interaction region still under study & schedule for LS2 is indicative**



Overview of the Upgrade program (CDR table)

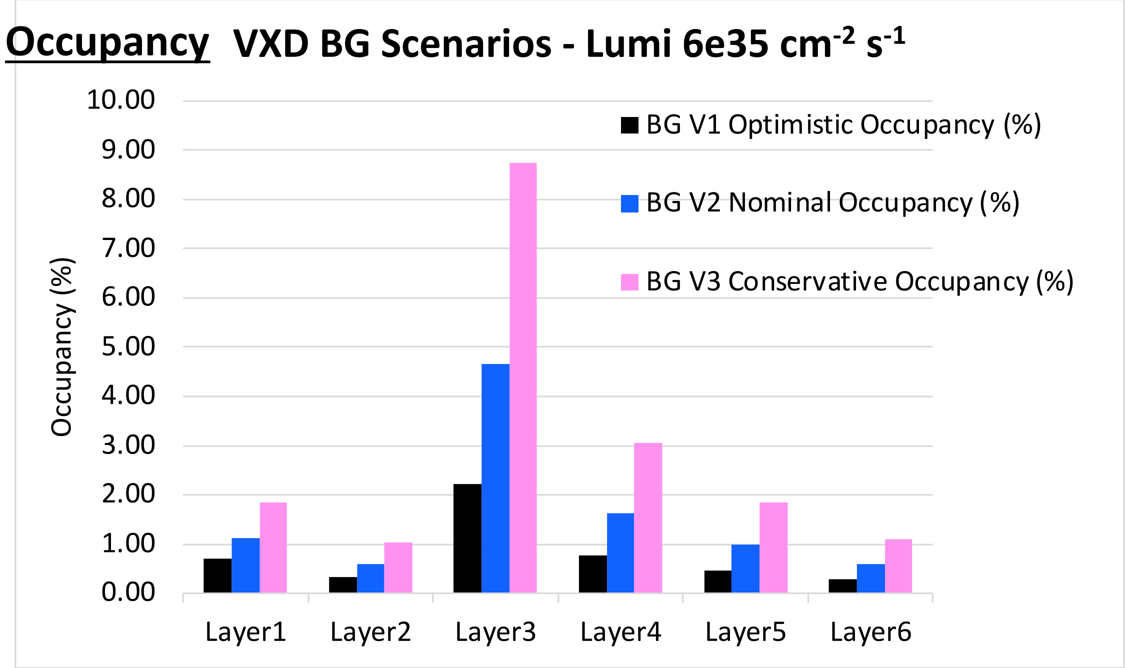
Table 1.2: Known short and medium-term Belle II subdetector upgrade plans, sorted by time scale. MDI is the Machine-Detector-Interface, while RMBA is Radiation Monitoring and Beam Abort system. Moving from inner to outer radius, the current Belle II sub-detectors are: Silicon Pixel Detector (PXD), Silicon Strip Detector (SVD), forming the VerteX Detector (VXD), Central Drift Chamber (CDC), Time of Propagation Counter (TOP), Aerogel Rich Counter (ARICH), Electromagnetic Calorimeter (ECL), K-Long Muon System (KLM), Trigger and Data aquistion (TRG/DAQ), including the High Level Trigger (HLT).

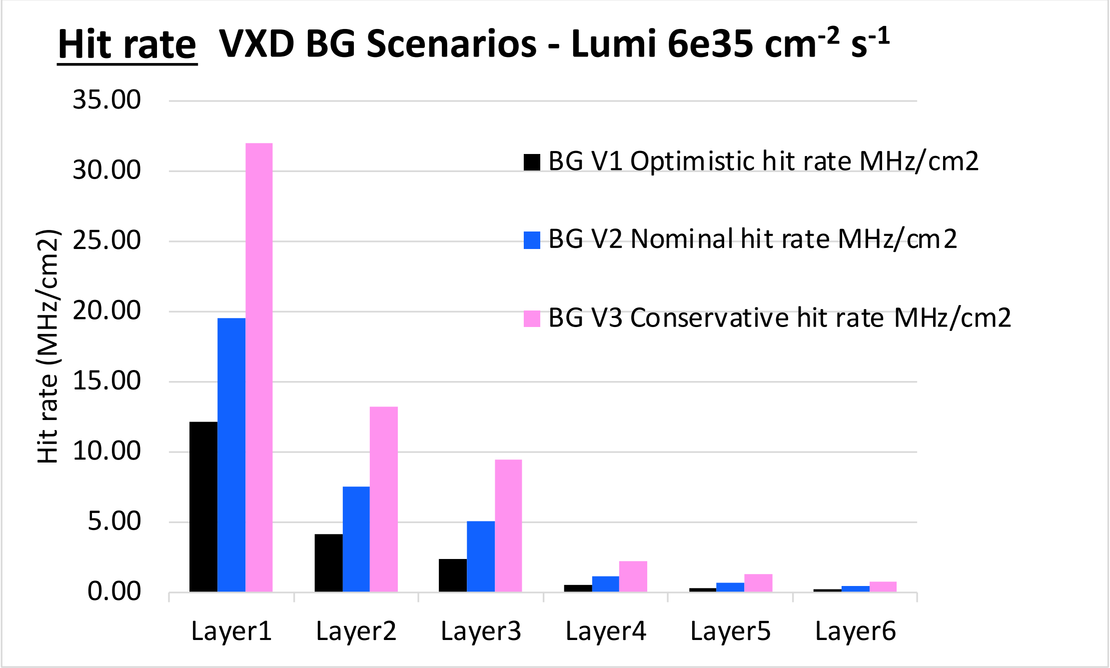
Subdetector	Function	upgrade activity	time scale
MDI	RMBA	Faster and more performant electronics	medium-term
VXD	Vertex Detector	all-pixels DMAPS CMOS sensors (VTX)	medium-term
CDC	Tracking	upgrade front end electronics	short/medium-term
TOP	PID, barrel	Replace not-life-extended ALD MCP-PMTs +SiPM option	medium-term
		Front end electronics upgrade	medium-term
KLM	K_L, μ ID	replace 13 barrel layers of legacy RPCs with scintillators	medium/long-term
		upgrade of electronics readout and proportional mode RPC readout	medium/long-term
		timing upgrade for K-long momentum measurement	medium/long-term
Trigger		hardware and firmware improvements	continuous
DAQ		add 1300-1900 cores to HLT	short/medium-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
		Complement ECL PiN diodes with APDs or SiPM	long-term
		Replace CsI(Tl) with pure CsI crystals	long-term

VXD BG scenarios at target $\mathcal{L} = 6x10^{35}$ cm^{-2} s^{-1}

- CAVEAT: Background extrapolation at target luminosity affected by large uncertainty due to SuperKEKB evolution, possible interaction region re-design
- 3 BG scenarios considered in CDR:
  - V1 Optimistic/V2 Nominal/V3 Conservative

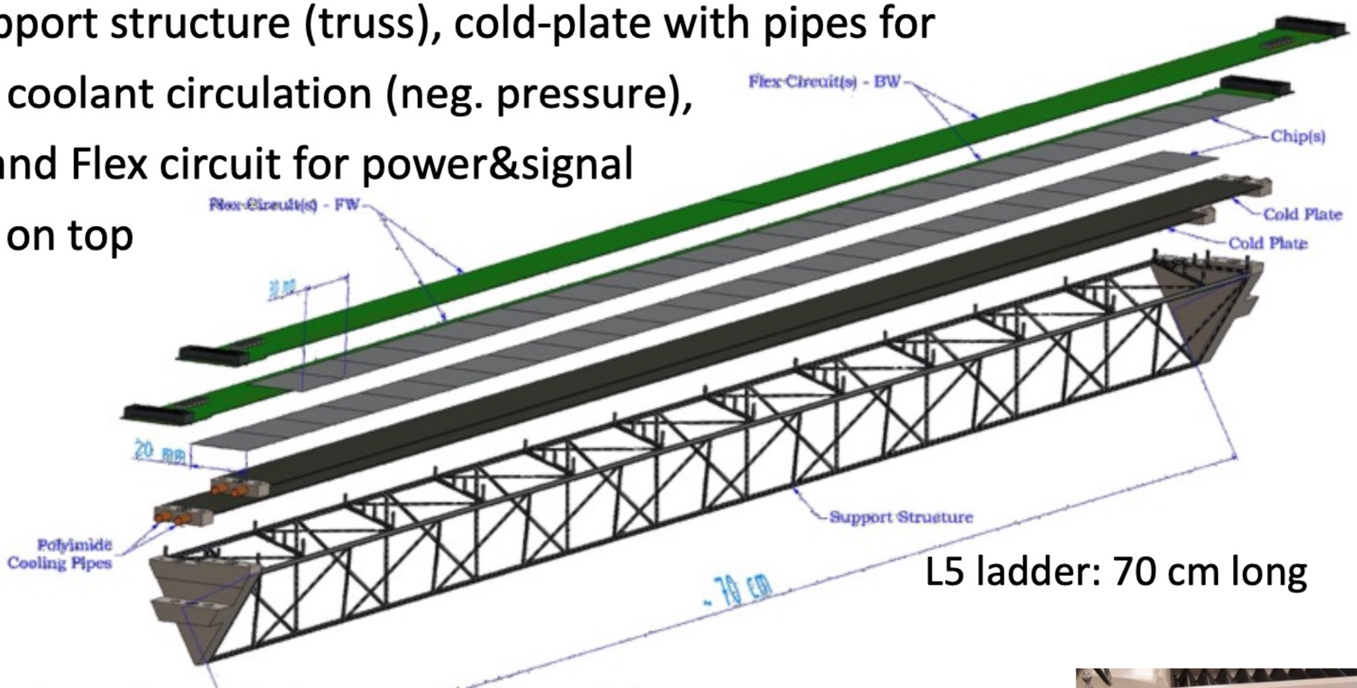
Layer	Radius (cm)	BG V1 Optimistic hit rate MHz/cm2	BG V2 Nominal hit rate MHz/cm2	BG V3 Conservative hit rate MHz/cm2
Layer1	1.4	12.1	19.6	32.0
Layer2	2.2	4.1	7.5	13.2
Layer3	3.9	2.4	5.1	9.5
Layer4	8.0	0.6	1.2	2.2
Layer5	10.4	0.3	0.7	1.3
Layer6	13.5	0.2	0.4	0.8



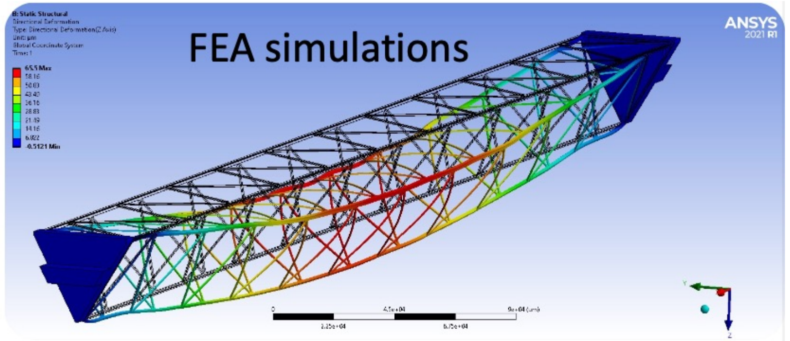


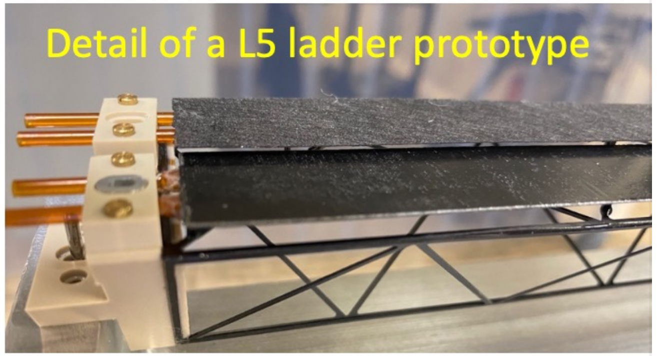
oVTX Thermomechanics

Ladder structure design inspired by ALICE ITS2, composed of:
CF support structure (truss), cold-plate with pipes for liquid coolant circulation (neg. pressure),
Chip and Flex circuit for power&signal glued on top



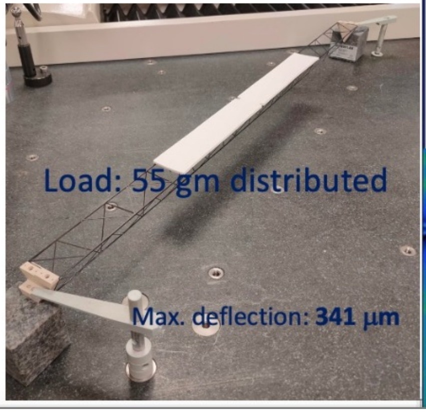
L5 ladder: 70 cm long





Performed mechanical characterization of the L5 prototype:

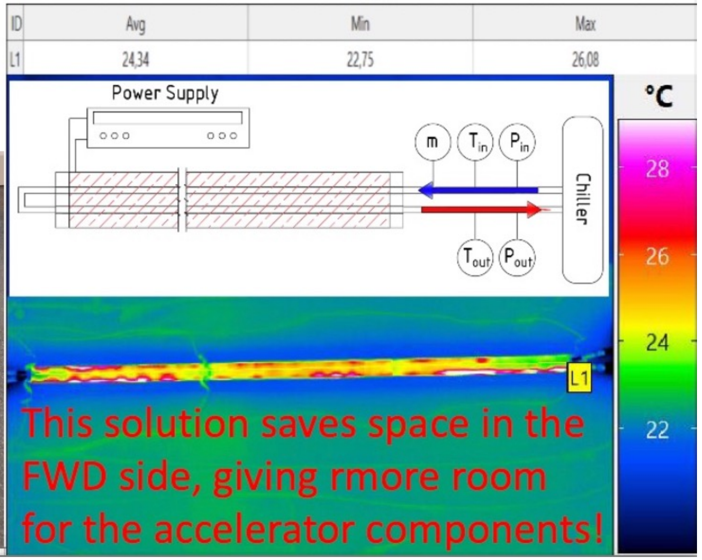
- Distortion: measurements of sagitta (< 250 um)
- Vibration: 1st resonance frequency (~250 Hz) (<< earthquake f.)



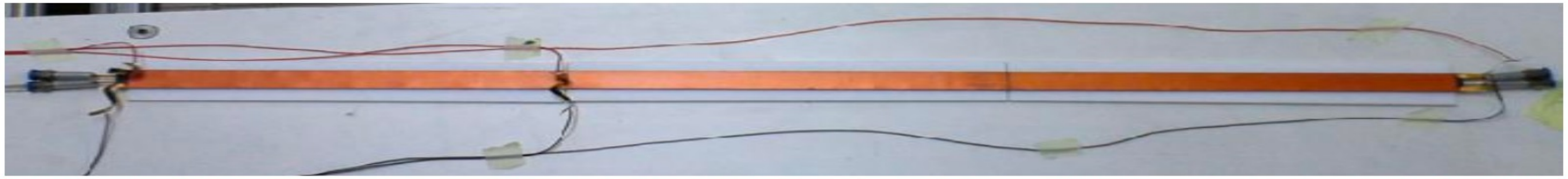
Thermal characterization:

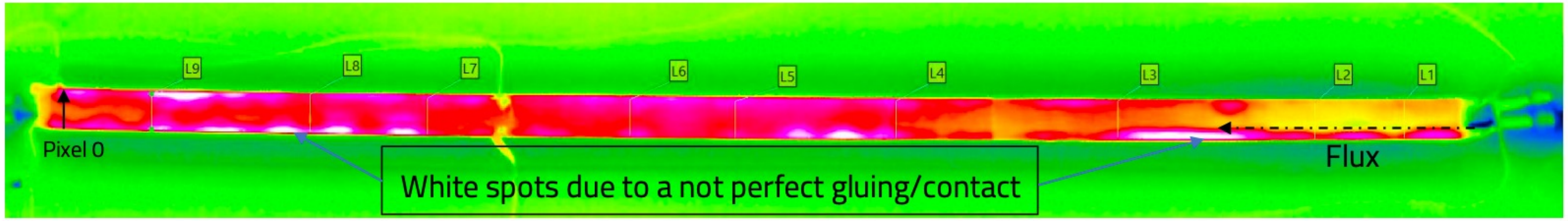
- Used Kapton heaters, inlet (T=10°C) and outlet on one side
- Uniform temperture along the ladder ΔT max=3.3 °C

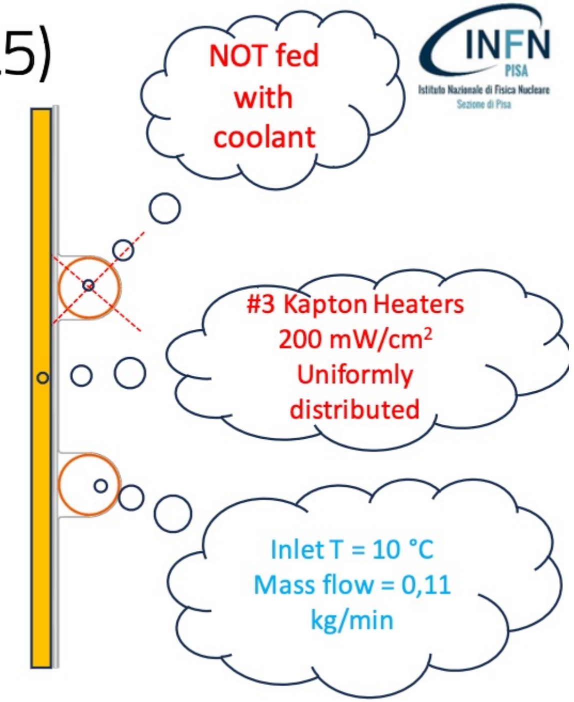
U-turn flow ΔT_{max}= 3.3 °C

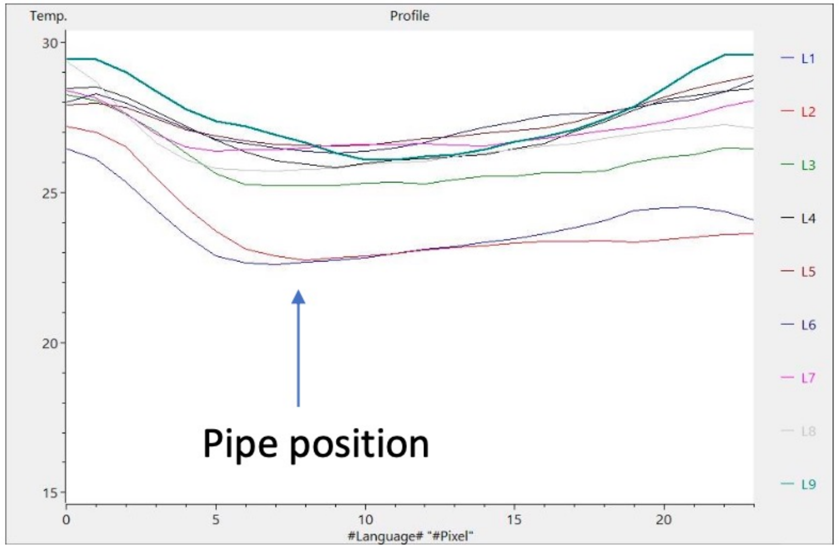


Transversal T gradient - Cold plate L6 (former L5)









Results coherent with the geometry

ID	Average	Minimum	Maximum	ΔT
L1	23,82	22,59	26,46	3,87
L2	23,84	22,74	27,20	4,46
L3	26,03	25,22	28,25	3,03
L4	27,08	25,84	28,53	2,69
L5	27,37	26,55	28,89	2,34
L6	27,35	26,33	28,74	2,41
L7	27,02	26,38	28,41	2,03
L8	26,66	25,72	29,38	3,66
L9	27,59	26,10	29,59	3,49

Transversal thermal gradient less than 5 degrees everywhere

Max temperature less than 30 degrees everywhere

3

CDR OBELIX specs vs TJMP2

Table 5.1: OBELIX sensor specifications, compared to the relevant specification of the TJ-Monopix2 sensor.

	Specification	TJ-Monopix2
Pixel pitch	$< 40\ \mu m$	$< 33\ \mu m$
Sensitive layer thickness	$< 50\ \mu m$	$30\ \mu m$ and $100\ \mu m$
Sensor thickness	$< 100\ \mu m$	-
Hit rate capability in the matrix	> 600 MHz cm^{-2}	> 600 MHz cm^{-2}
Hit rate capability at the sensor output	> 120 MHz cm^{-2}	$\gg 100$ MHz cm^{-2}
Trigger delay	$> 10\ \mu s$	-
Trigger rate	30 kHz	-
Overall integration time	< 100 ns	-
(optional) Time precision	< 50 ns	-
Total ionizing dose tolerance	100 Mrad	-
NIEL fluence tolerance	$5 \times 10^{14}\ n_{eq}/cm^2$	$1.5 \times 10^{15}\ n_{eq}/cm^2$
SEU tolerance	frequently (min^{-1}) flash configuration	-
Matrix dimensions	around $30 \times 16\ mm^2$	$19 \times 19\ mm^2$
Overall sensor dimensions	around $30 \times 19\ mm^2$	$20 \times 19\ mm^2$
Powering	through voltage regulators	-
Outputs	one at < 200MHz	one at 160 MHz

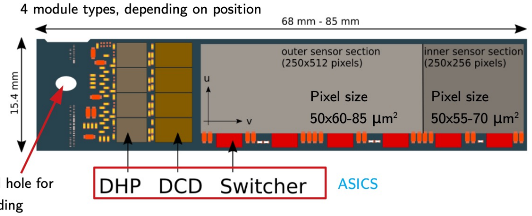
The Pixel Vertex Detector (PXD) Module

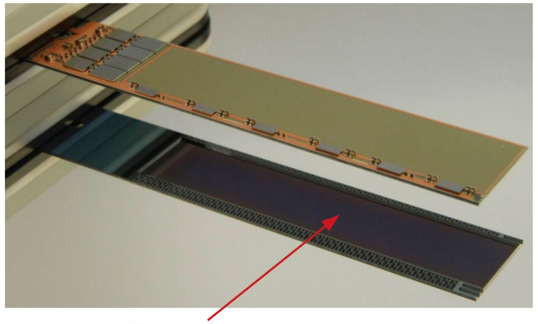
Properties:

- Self-supporting "**all-silicon**" structure
  - Support frame ~500 μm thick
  - **Monolithic** active area 75 μm thick
- **Low material budget** (~0.21% X_0)
- Pixel sizes 50 x 55-85 μm²
  (250 x 768 pixels)

Rolling Shutter Readout:

- **Switcher**: consecutive row selection for signal digitization of columns (10 MHz)
- **DCD**: 8-bit AD conversion of signal
- **DHP**: zero suppression, data formatting
- 20 μs integrated readout time
  (2x beam revolution)





Thinned backside at active sensor area

The Pixel Vertex Detector (PXD)

2 Modules = 1 Ladder:

- Glued together
- In total 20 ladders

10 Ladders = 1 Half-Shell:

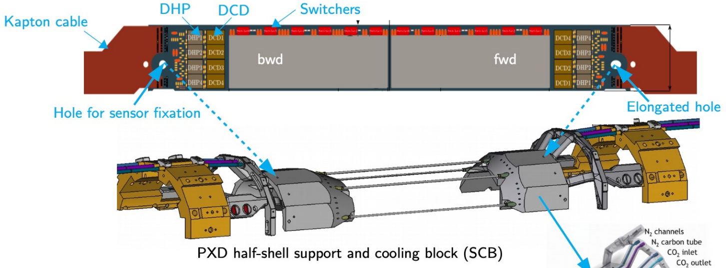
- Ladders screwed on cooling block
  - Radii: r_{L1}=14mm, r_{L2}=22mm
- Half-Shell mounted on beam pipe

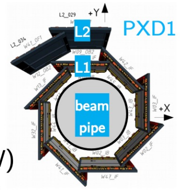
Power Consumption:

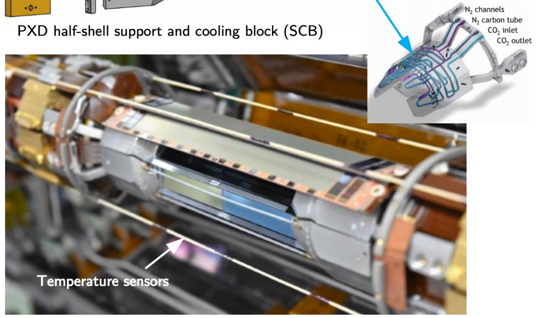
- ~9 W per module
  → ~360 W (full detector)
- Cooling
  - 2 phase CO_2: DHP/DCD (8W)
  - N_2 gas: sw.+sensor area (1W)

PXD1:

- PXD1 incomplete (effectively 1 layer)







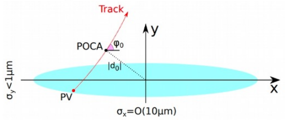
PXD1 Performance

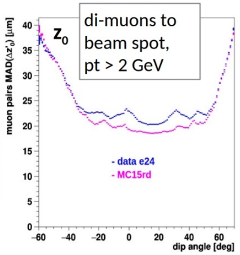
Impact Parameter Resolution:

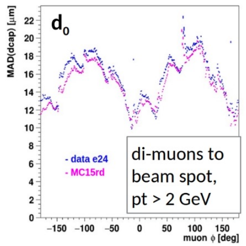
- Di-muon events (pt > 2 GeV)
  - z_0: 20 – 40 μm
  - d_0: 10 – 22 μm
- MC describes data
  - MC slightly too optimistic
    (z_0: ~3 μm, d_0: ~1.5 μm)
- ~1.5 – 2 times better than Belle

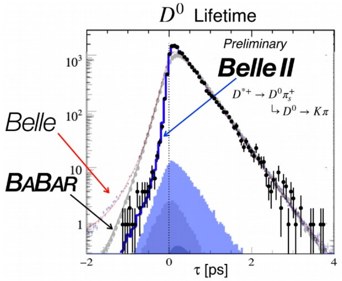
D^0 Lifetime Resolution:

- Impact of better vertex detector
- Belle II D^0 lifetime resolution
  ~2 times better



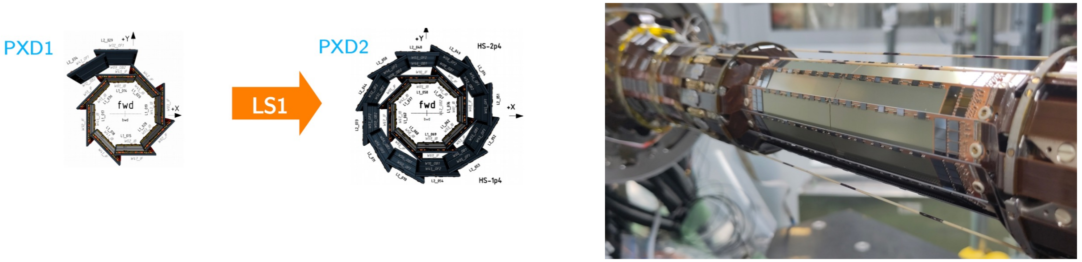




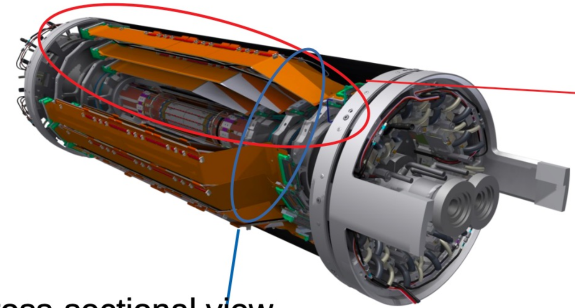


Belle II lifetime measurements with high PXD impact:

- D_s^+: arXiv:2306.00365 → PRL
- B^0: PRD 107, L091102 (2023)
- Ω_c^+: PRD 107, L031103 (2023)
- Λ_c^+: PRL 130, 071802 (2023)
- D^0/D^+: PRL 127, 211801 (2021)

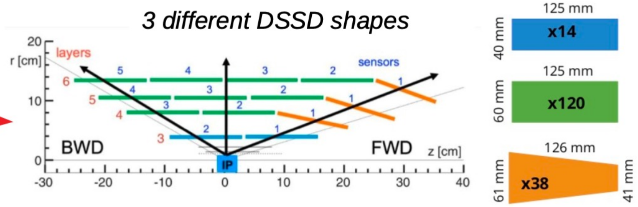


SVD structure

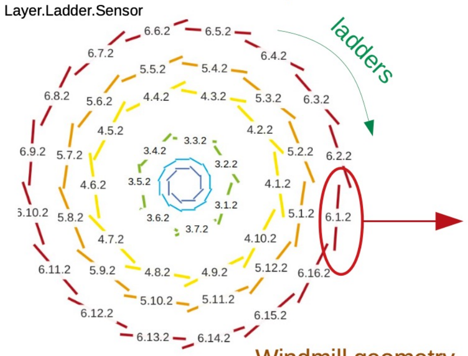


Cross-sectional view

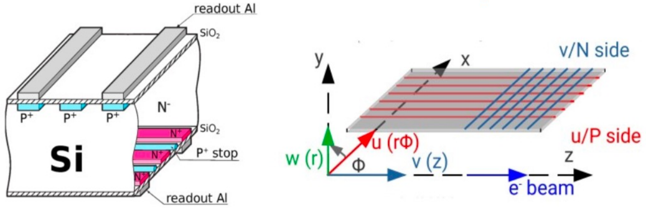
3 different DSSD shapes



Type	Number of readout strips		Readout pitch (μm)		Thickness (μm)	Manufacture
	P side	N side	P side	N side		
Small	768	768	50	160	320	HPK
Large	768	512	75	240	320	
Trapezoidal	768	512	50-75	240	300	Micron



DSSD sensors - **D**ouble-sided **S**ilicon **S**trip **D**etectors

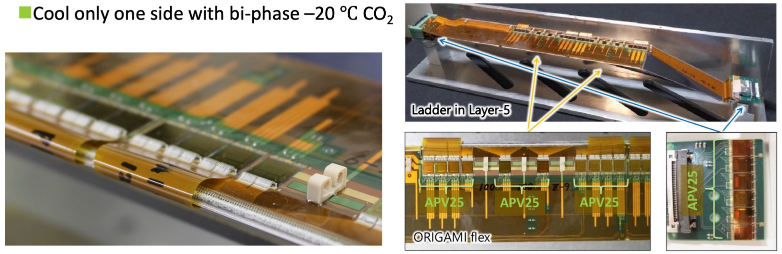


- Provide 2-D spatial information
- Depletion voltage 20-60 V,
- Operation voltage 100 V

- 172 sensors with 1.2 m^2 se
- 224k readout strips

Origami chip on sensor concept

- Readout chips directly on each middle sensor
  - Shorter signal propagation length (smaller capacitance and noise)
  - Thinned to 100 μm to reduce material budget
  - Wrapped flex to read both sides from the same side
  - Cool only one side with bi-phase –20 °C CO_2

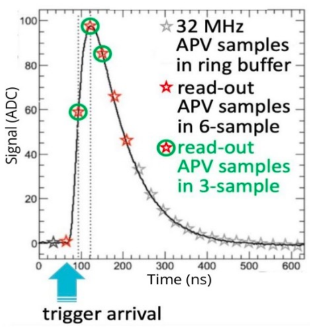


Front-end electronics

Central DSSD sensor
connected to front-en
APV25 ASICs via
flex circuits

→ „origami scheme”

Analog signal



By default:

- 6 subsequent samples readout

Alternative for high luminosity runs:

- 3/6 mixed acquisition mode
  - → allows to reduce data size due to enhanced background occupancy
  - → 3 or 6 sample mode depends on the timing precision of the trigger for particular event

Frontend ASIC APV25:

- 128 channels per chip
- 50ns shaping time
- Radiation hardness > 100 Mrad
- Power consumption: 0.4 W/chip
- Multi-peak mode at 32 MHz

- Total Power 700 W