Faculté de physique et ingénierie
Université de Strasbourg

Belle II

IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

M2 PSA Internship defense

Triggering possibilities with an upgraded Belle II vertex detector

Mattéo Maushart | IPHC-TYL | June 20th 2024

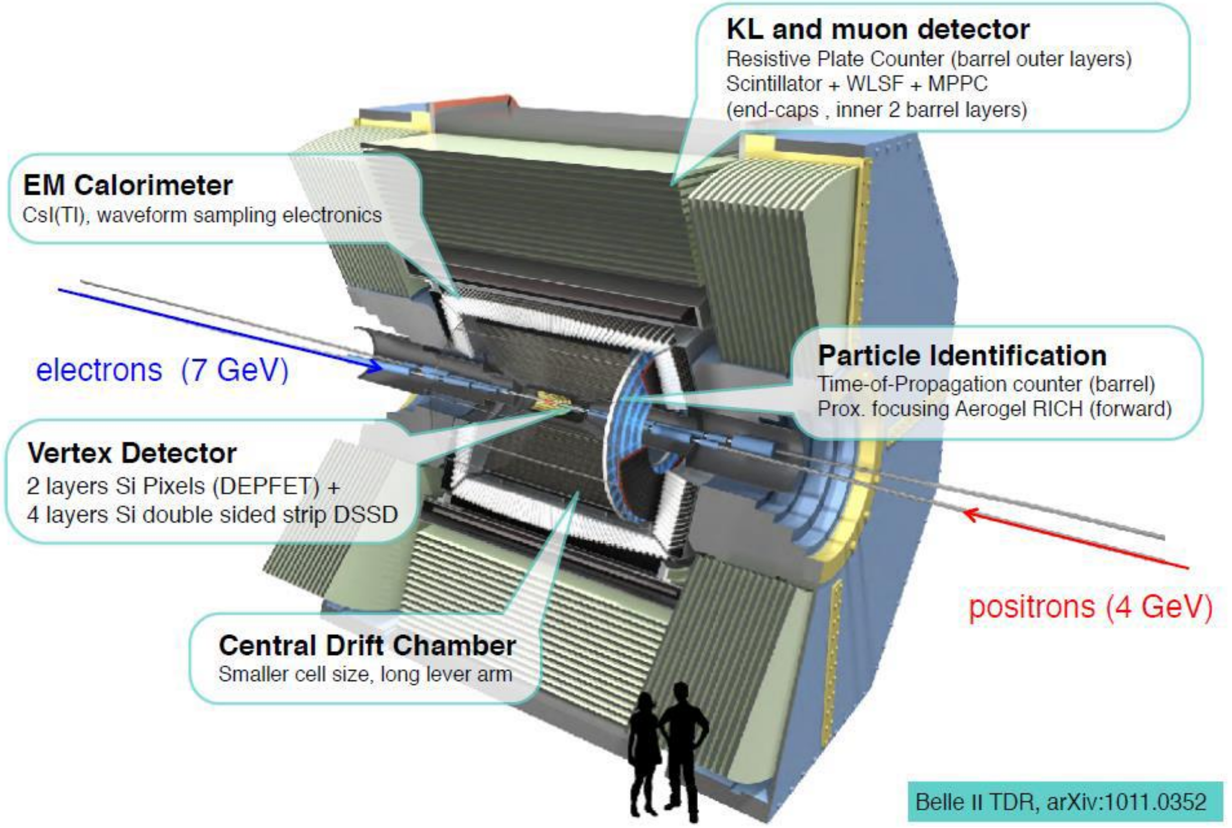
Outlines

1. Belle II Experiment and need for a trigger
2. Vertex detector upgrade and information dedicated to trigger
3. Fast Track Reconstruction Algorithm
4. Single Track Events Results
5. Outlooks

Belle II and SuperKEKB

- Goal : Search for hints of 'New Physic' in $b\bar{b}, c\bar{c}$ and $\tau\bar{\tau}$ events

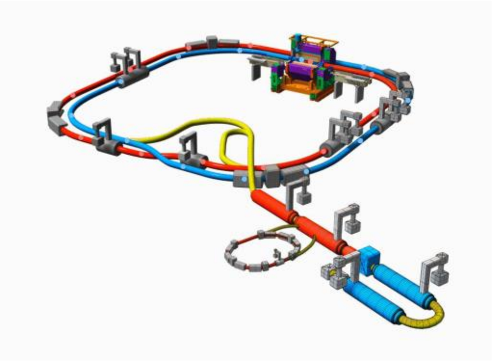
- Composed of multiples detectors
  - Each providing a different type of information
  - Tracking done by VXD and CDC



Schematic of Belle II

Belle II and SuperKEKB

- Goal : Reach $\mathcal{L} = 6.0 \times 10^{35}\ cm^{-2}s^{-1}$
  - Collect targeted amount of data in ~15 years

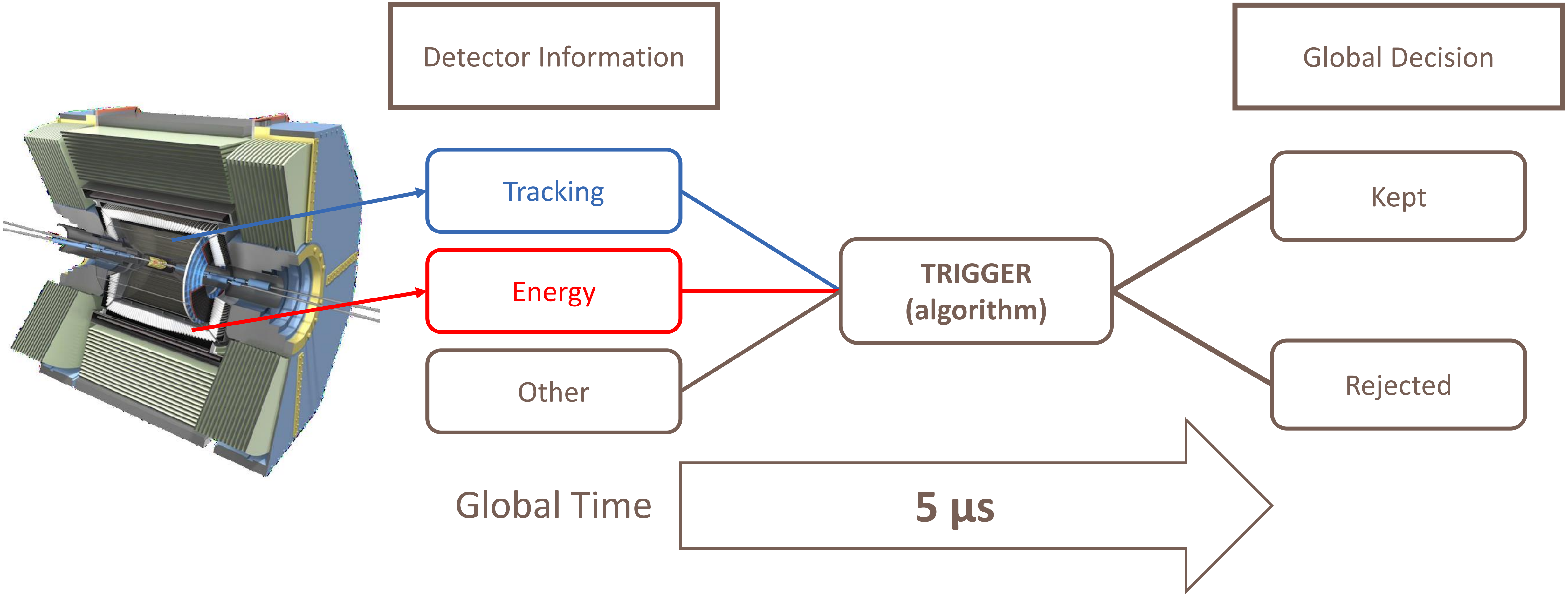


- SuperKEKB, 2019, Tsukuba, Japon
  - Highest luminosity in the world ($\mathcal{L} = 4.7 \times 10^{34}\ cm^{-2}s^{-1}$)

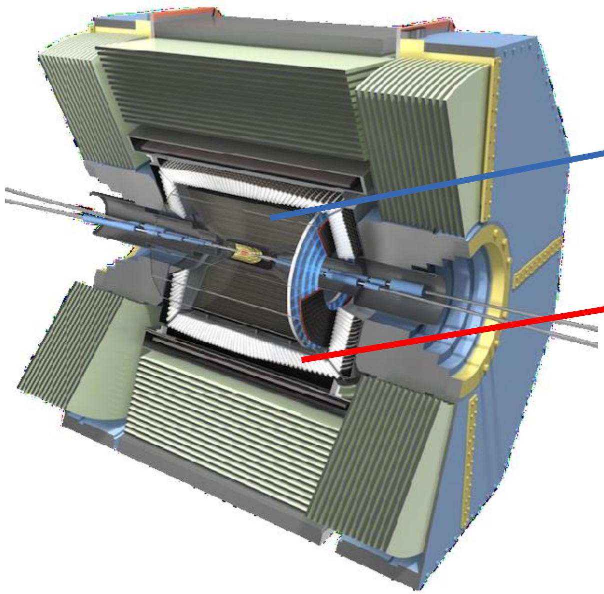
- Asymetric e^+/e^- collider (4 GeV/7 GeV)
  - Frequency beam crossing: 250 MHz
  - ➢ **Only a tiny fraction produces interesting physic !**

Process		Rate @ designed Lumi.
e^+e^- bunch collision		~200MHz
Bhabha scattering ($e^+e^- \to e^+e^-$)	background >~300kHz	>~50kHz
Storage beam BG		>~150kHz(ECL 2022) >~100kHz(CDC 2022)
Injection beam BG		~1MHz instantly
~~Two photon ($e^+e^- \to e^+e^-e^+e^-$ etc.)~~	Physics target ~15kHz	~~~10kHz~~
$e^+e^- \to \gamma\gamma$		~2kHz
Continuum ($e^+e^- \to$ uubar,...)		~2kHz
$e^+e^- \to \Upsilon(4S)$		~1kHz
$e^+e^- \to \mu^+\mu^-$		~0.6kHz
$e^+e^- \to \tau^+\tau^-$		~0.6kHz
dark matter/new particle ?		???

Trigger in Belle II



Trigger in Belle II



Detector Information

Tracking

Energy

Other

Menu selection

τ event
- 1 or 3 charged tracks.
  - 2-track (full or short) + opening angle > 90°
  - ECL energy sum > 1 GeV
  - 3 ECL clusters, 1 of E > 300 MeV
  - CDC-KLM matching

TRIGGER (algorithm)

Global Decision

Kept

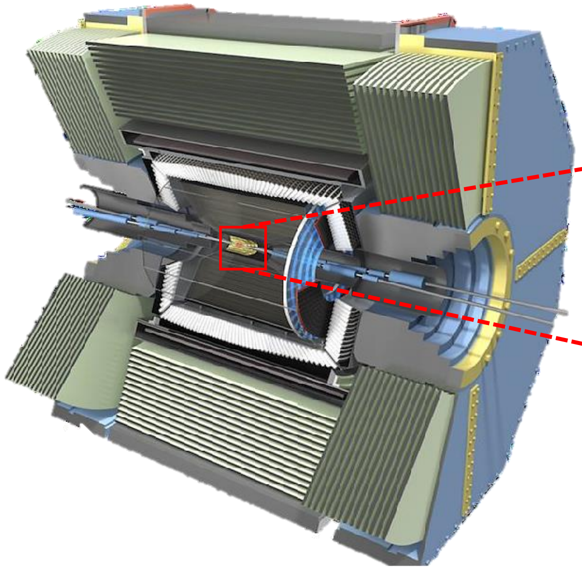
Rejected

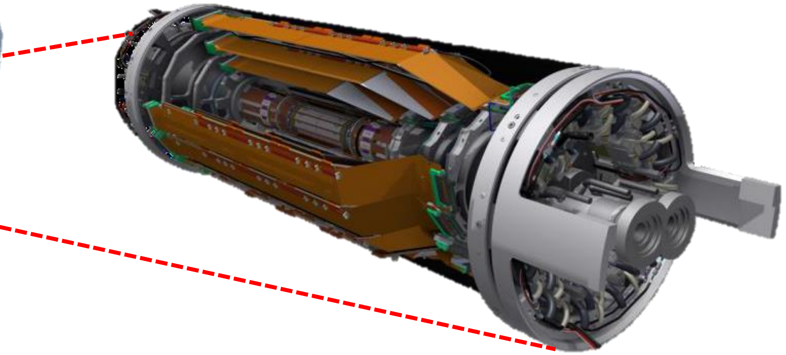
Global Time

5 μs

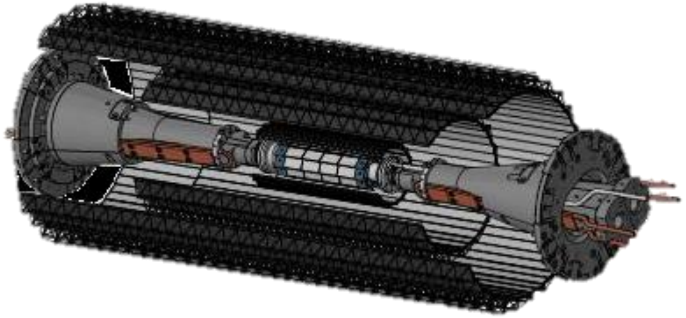
Vertex Detector Upgrade

- Increasing collision rate to reach experiment objectives
  - ➢ Need a higher granularity ⇨ New vertex detector !
  - ➢ More difficult triggering ⇨ **Could the new detector contribute to the trigger ?**



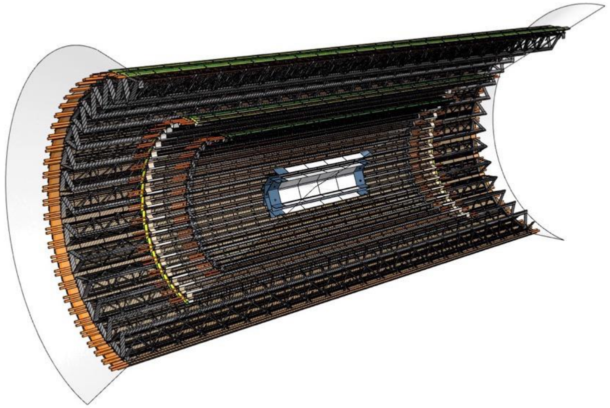


Current inner vertex detector (VXD)



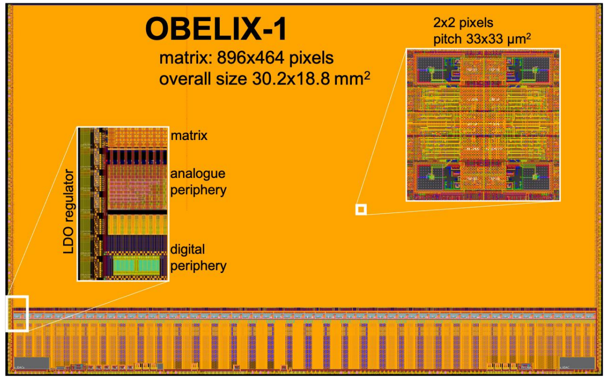
Future inner vertex detector (VTX)

VTX detector : Design



VTX detector

- 5 Layers of MAPS
(Monolithic Active Pixel Sensor)

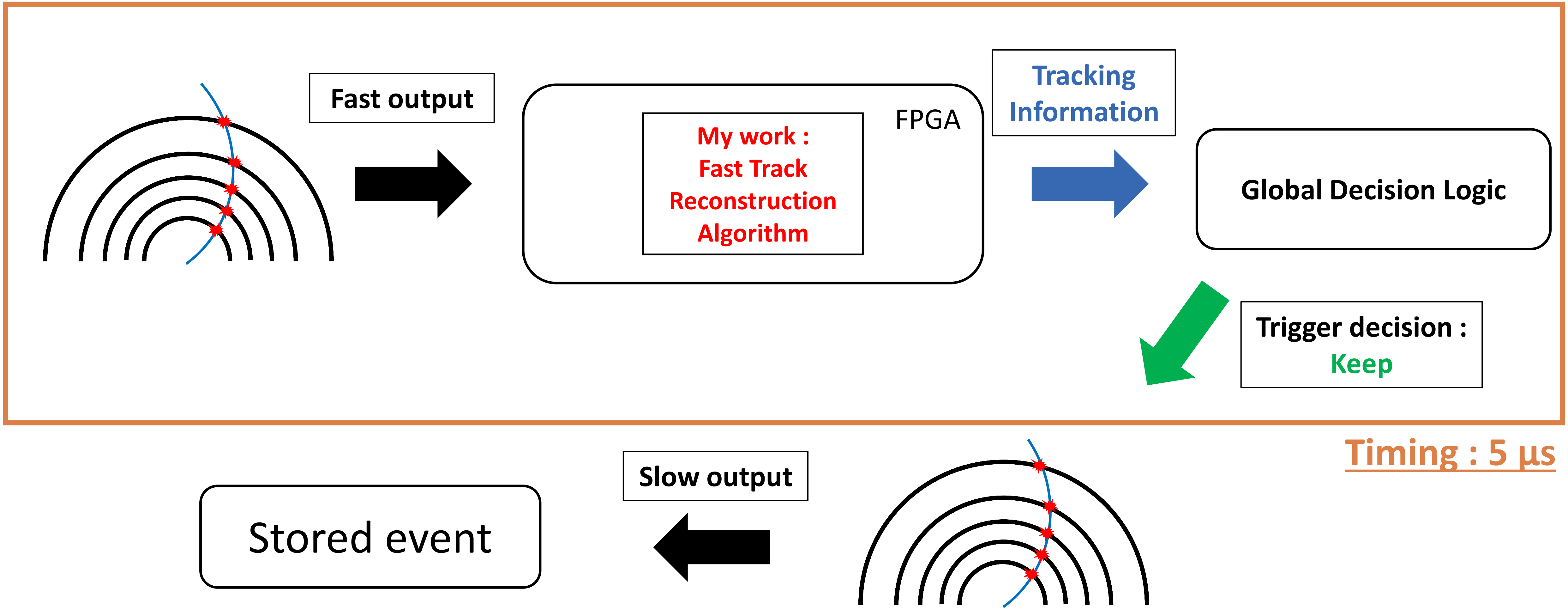


OBELIX sensor

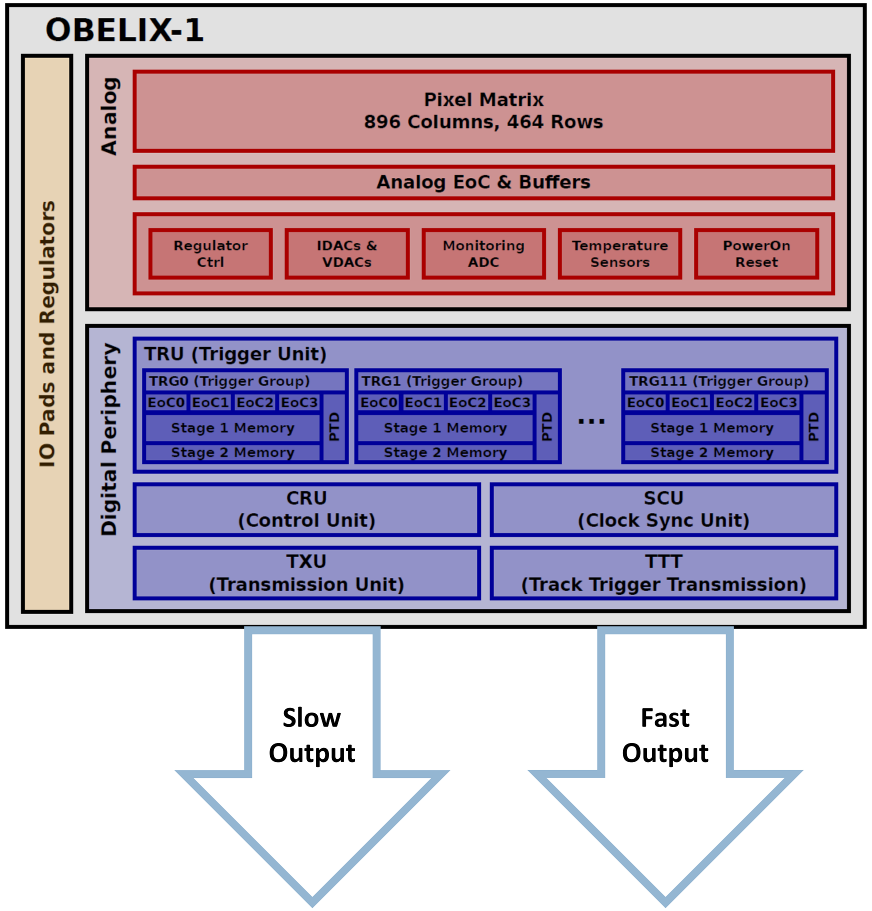
			Focus of this study		
	iVTX		oVTX		
Layer	L1	L2	L3	L4	L5
Radius (cm)	1.41	2.21	6.91	8.95	14.00
Hit Rate (MHz/cm^2)	120	~50	~6	~2	~1

	Design
Total Area (Sensitive Area)	5.68 cm^2 (4.53cm^2)
Matrix	896x464 pixel
Pixel pitch	33 μm
Integration Time	50 to 100 ns

Contextualizing my work



OBELIX sensor : Functional Implementation



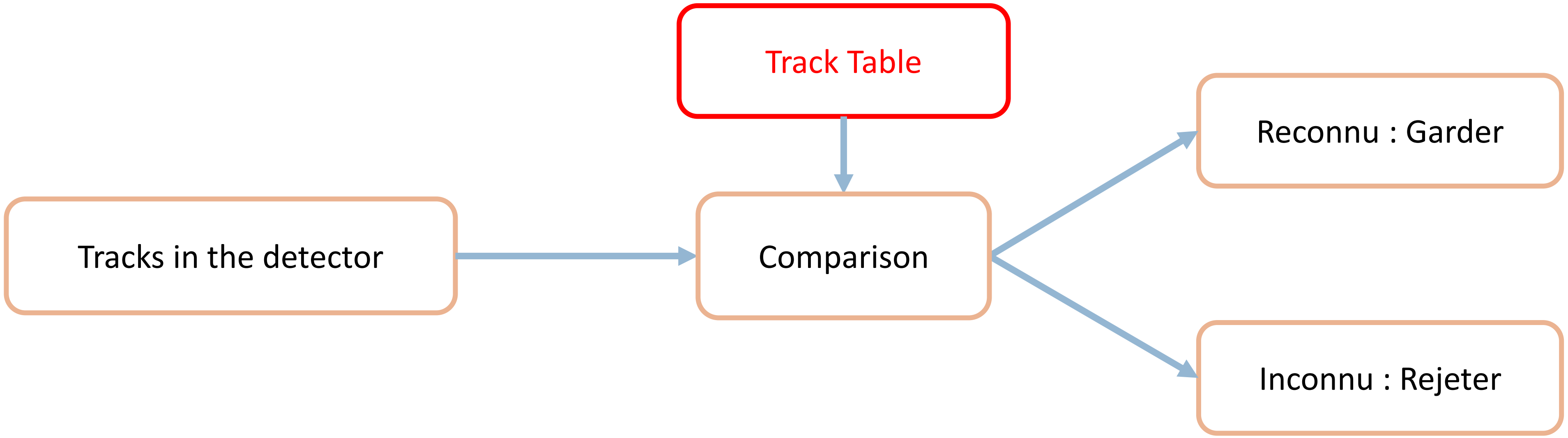
- SCU: Sync to input data stream, deserialize and generate clocks
- CRU: Parse commands and global configuration registers
- TRU: Pixel readout, storage and trigger processing
- PTD: Part of TRU for precision timing
- TXU: Data framing and serialization
- TTT: Alternative transmission for Belle II trigger contribution
- Not explicitly shown: pixel config and injection circuit

Fast output characteristics :

- Word (10 bits)
- Sent each 29.6 ns
- 1 for a hit, 0 if no hit

Fast track recognition algorithm : LUT

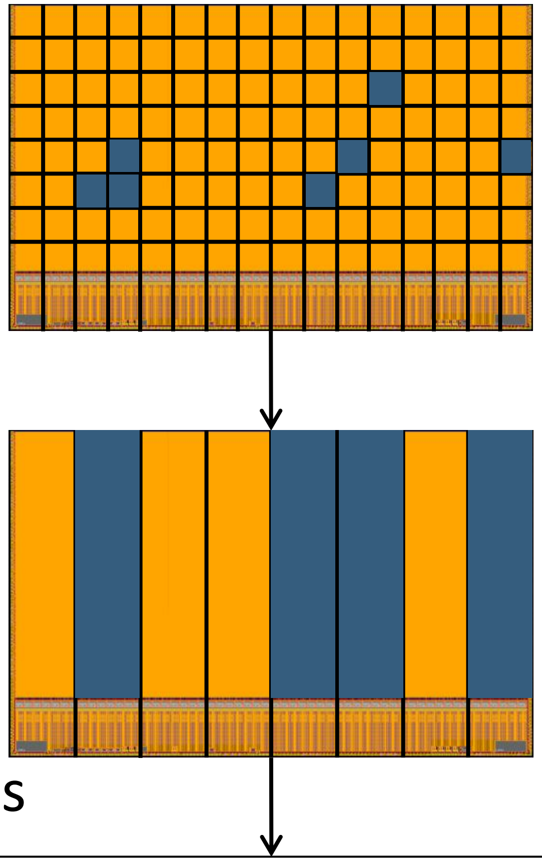
- Look-Up Table (LUT) logic:
  1. Creation of the physical track table from simulation
  2. Comparison of tracks "seen in the detector" with the table



Macropixel segmentation

- A major problem:
  - 896 x 464 pixels per sensor
  - ≈ 1,000,000,000 pixels in the detector
    - An excessive number of combinations

- Solution :
  - Macropixel : reduced spatial accuracy
  - 8 x 1 Macropixels per sensor
    - ✓ Considerable reduction in the number of combinations
    - ✓ Time-saving comparison in the LUT



A track will be the list of 3 numbers;
the list of 3 Macropixels hit by the particle

Activation Rate

Layer	1	2	3	4	5
Hit Rate (MHz/cm^2)	156.6	51.6	6.4	2.1	1.2
Area Macropix (cm^2)	0.566				
Transmission Clock (MHz)	33.9				
Average Activation Rate (Hit/Clock/Macropix)	2.615	0.862	0.107	0.035	0.020

Overflow (layers 1–2)

Low activation rate-> Usable information (layers 3–5)

Fast track recognition algorithm : Recap

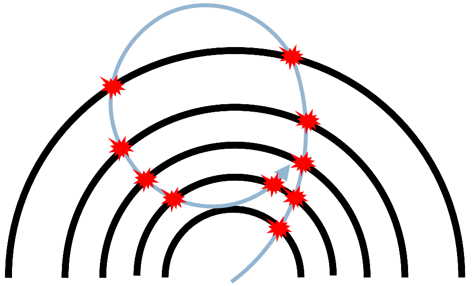
- Methods presented :
  - Tracker simulation (using Geant4-based Belle II software: basf2)
  - LUT logic (Python algorithm development)
  - Introduction of Macropixels (Algorithm development in Python)
- TRG expectations on TTT output :
  - Standalone : Nb of tracks, z-vertex and Φ angle
  - With CDC TRG : Φ angle, Track timing to match CDC
- Figure of merits :
  - Global efficiency : $\frac{Nbr\ patterns\ recognized}{Nbr\ patterns\ simulated} > 95\ \%$
  - Z-vertex Acceptance : $|z| < 5$ cm

Study case and encountered difficulties

- Study's events :
  - Particle Gun : Single track events
    - ➢ No combinatorial here
  - Table Characteristics : 10^6 tracks
    - ➢ 140 000 unique patterns stored
    - ✓ Suppress the duplicates in the table

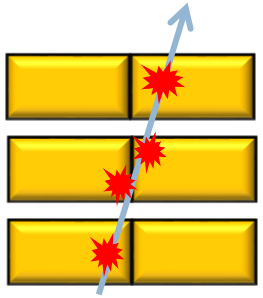
Table tracks characteristics	
Particle	$\mu^{\pm}$
Production point	$(x = 0, y = 0, z = 0)$
Range of momentum	$0.2 \leq p \leq 3.0$
Range of θ angle	$17° \leq \theta \leq 150°$
Range of φ angle	$0° \leq \varphi \leq 360°$

- Difficulties : Select the 'physical' tracks
  - ➢ Reentering particles:



Suppressed from the table

- ➢ Combinatory :



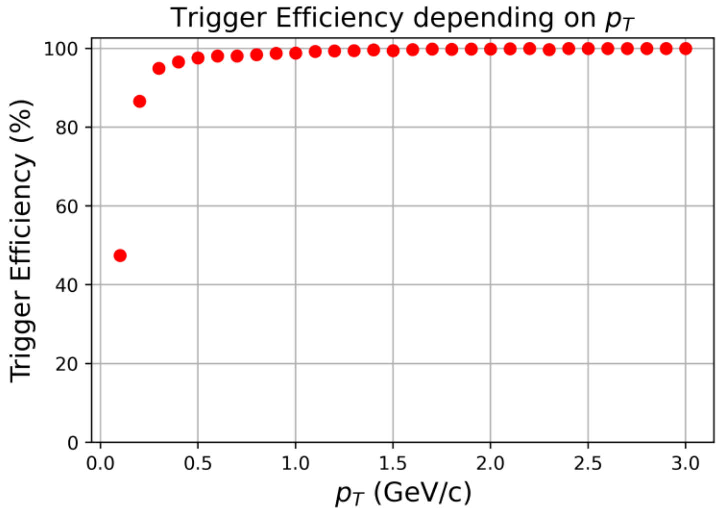
We register 2 tracks out of the cluster

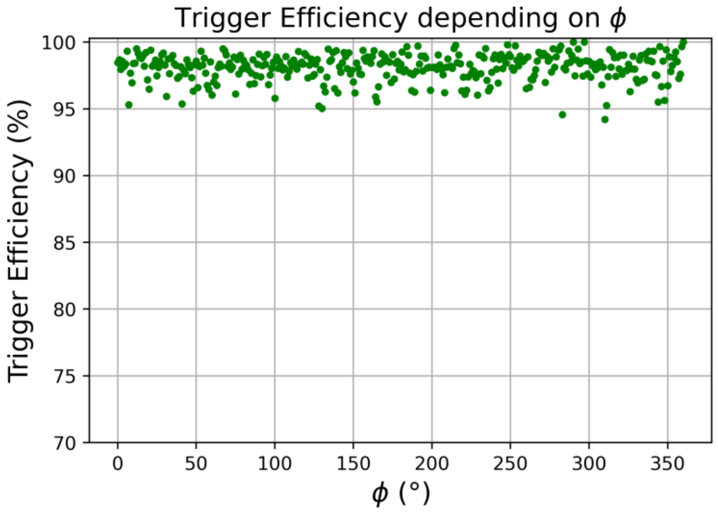
Results : Efficiency

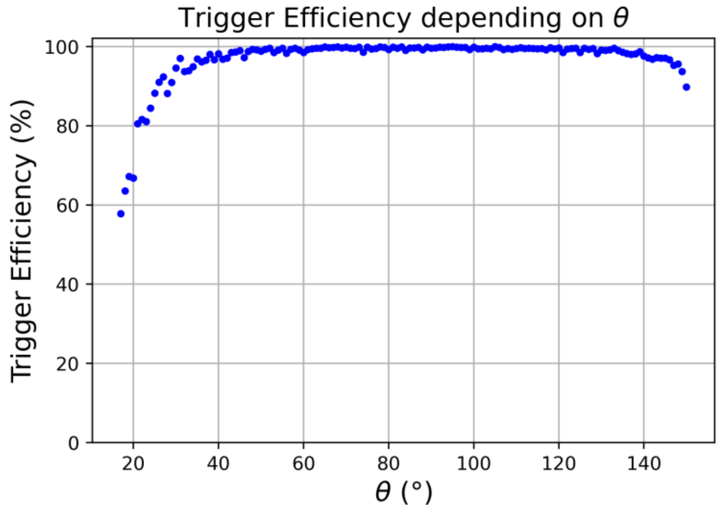
- Efficiency Test Sample : 10^5 $\mu^{\pm}$, identical to table event characteristics

Average efficiency = 98.14 ± 0.03 %

- Trigger Efficiency with respect to :
  - Transverse Momentum
  - Angle ϕ
  - Angle θ



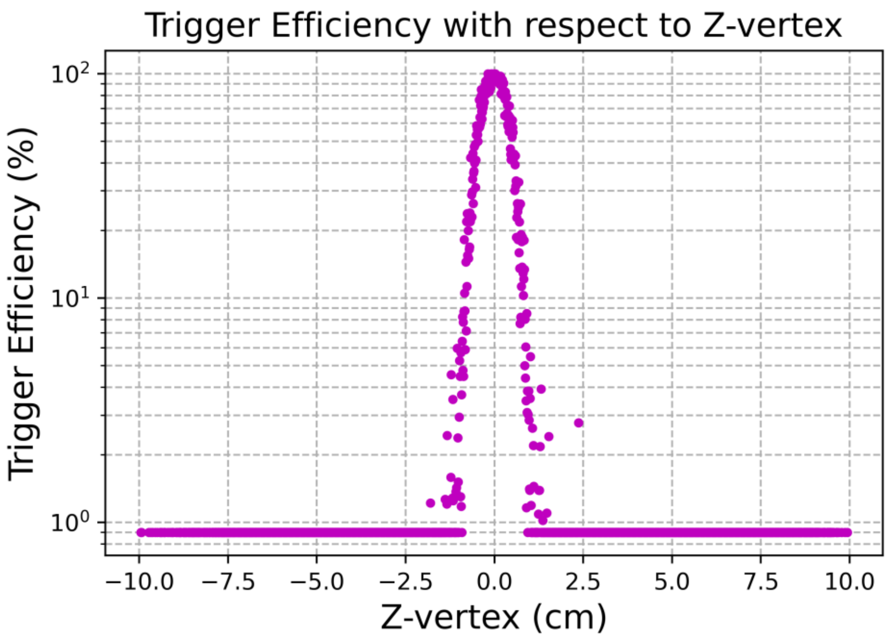




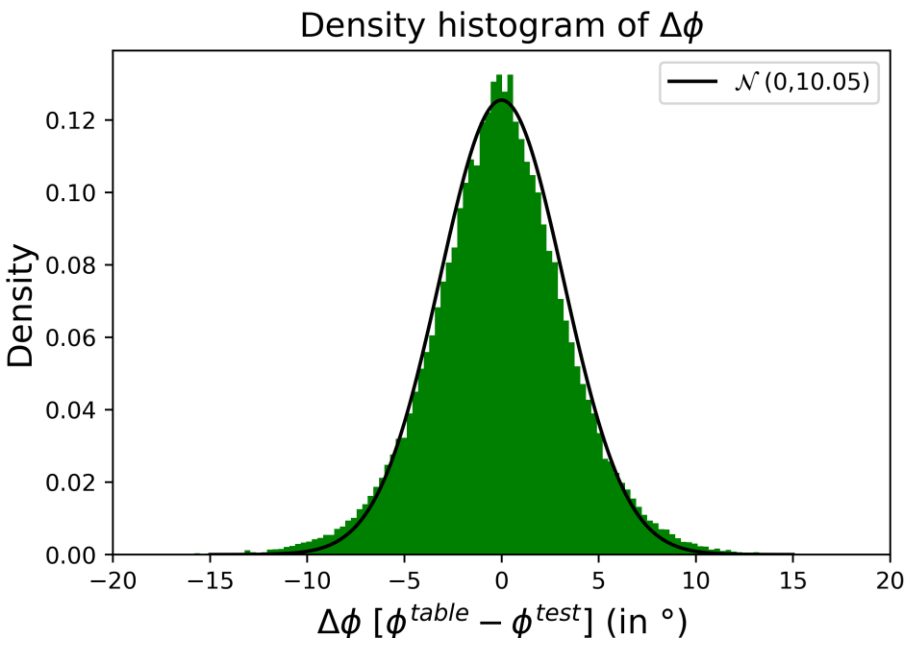
Results : Z-vertex Acceptance and ϕ Accuracy

- Acceptance test sample : $10^5\ \mu^{\pm}$, with $z \in [-10,10]\ cm$
- Accuracy test sample : $10^5\ \mu^{\pm}$, identical to table event characteristics

Z-vertex Acceptance : |z| < 2.5 cm



ϕ Accuracy : Gaussian σ = 3.17°



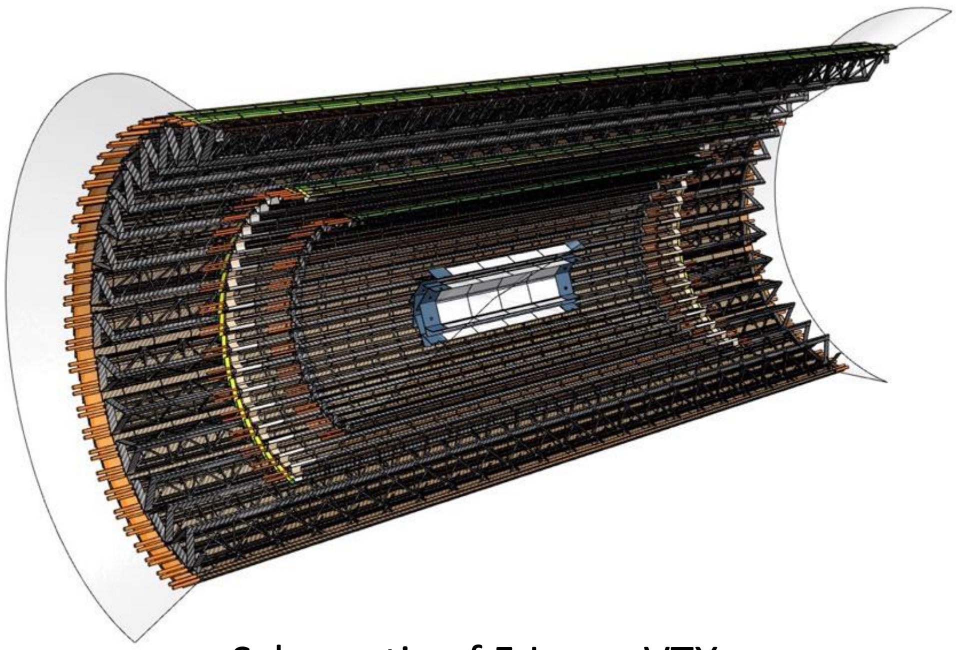
Conclusion

- First software results ⇨ Validated
  - Average efficiency = 98.14 %, Acceptance in Z < 2.5 cm, Accuracy on ϕ : σ = 3.17°
- Next steps :
  - Include multiple tracks events and background contribution
    - ➢ Closer to detector reality and estimate fake trigger rate
  - Check algorithm hardware capability
    - ➢ What usage for the Global Decision Logic ?

Backups

VTX detector : Requirements

- Better tracking robustness against background
  - Total ionizing dose: 10 Mrad/year
  - NIEL fluence: 5×10^{13}neq/cm²/year
- Improved track reconstruction for low p particles
- Higher vertex position resolution
  - ➢ $15\ \mu\mathrm{m}$ resolution
- Conserved performance for physics



Schematic of 5 Layer VTX

VTX detector : Design

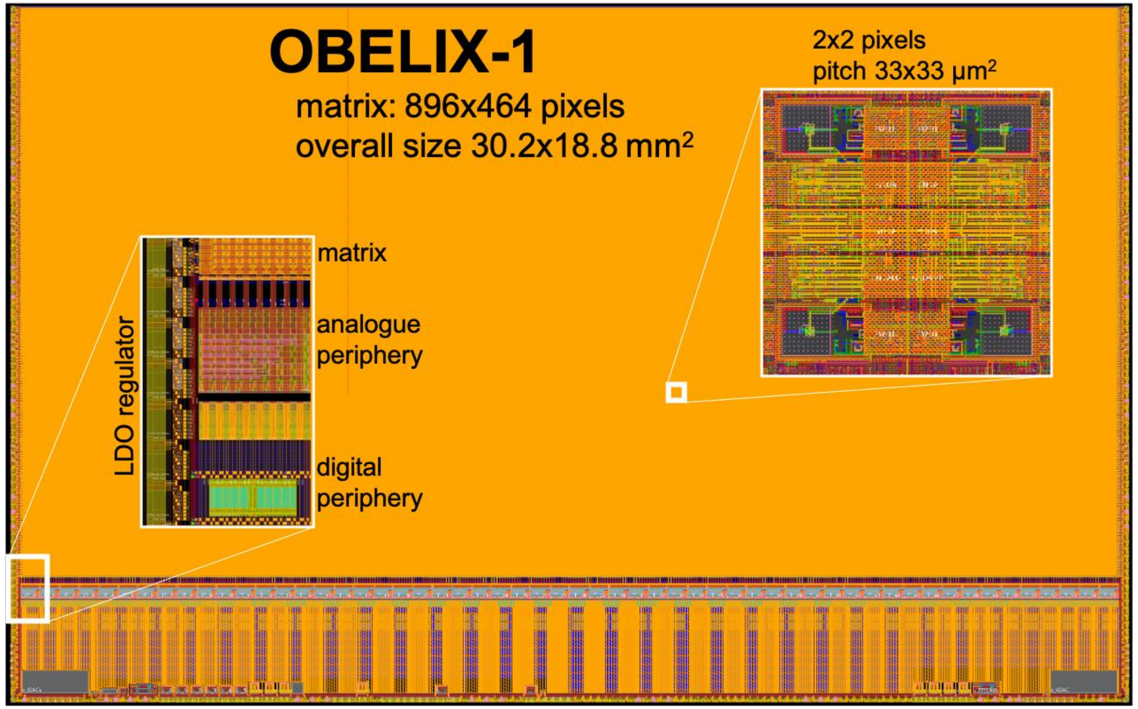
- 5 Layers of MAPS (Monolithic Active Pixel Sensor)

The study focuses only on oVTX

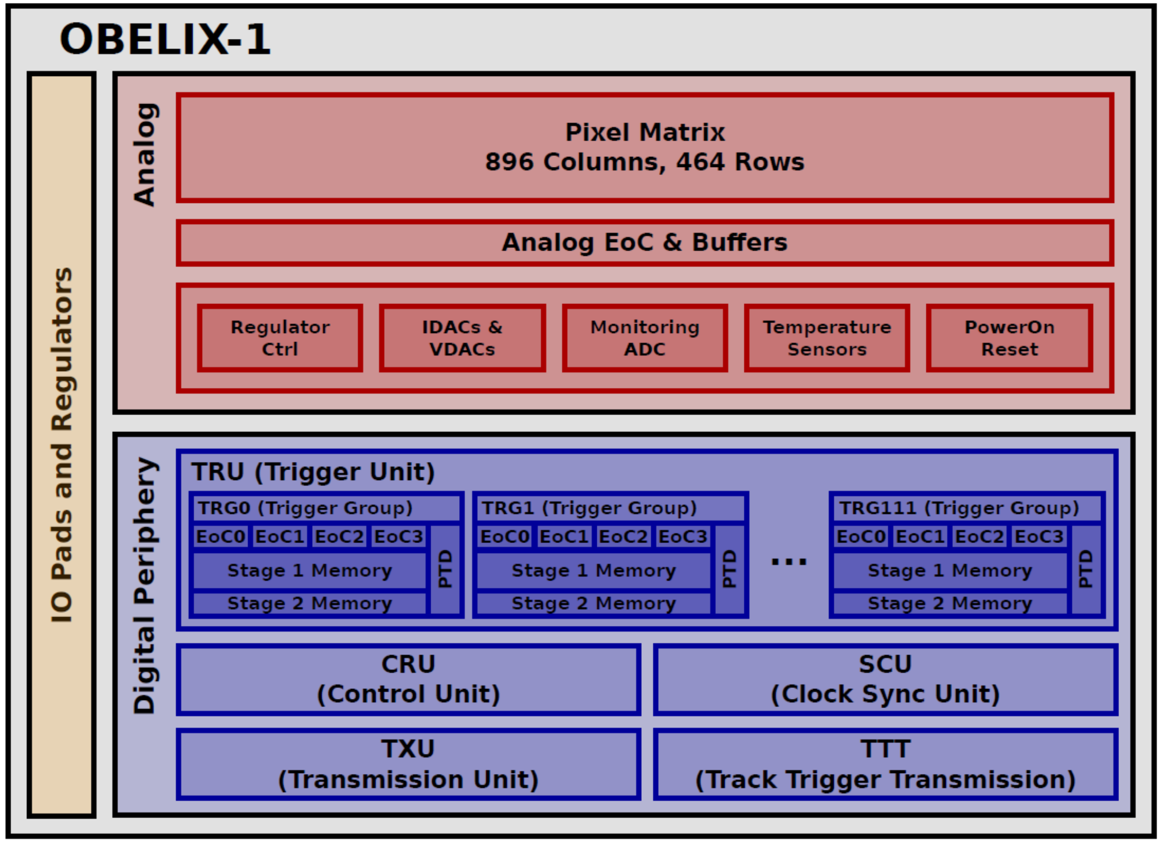
	iVTX		oVTX		
Layer	L1	L2	L3	L4	L5
Ladder	6	10	30	40	31
Sensors per Ladder	4	4	12	16	2 x 24
Distance to IR (cm)	1.41	2.21	6.91	8.95	14.00
Area cover (cm^2)	~115	~192	~806	~1382	~6000
Hit Rate (MHz/cm^2)	120	~50	~6	~2	~1

OBELIX Sensor : Design

	Design
Total Area (Sensitive Area)	5.68 cm^2 (4.53cm^2)
Matrix	896x464 pixel
Pixel pitch	33 µm
Integration Time	50 to 100 ns
Trigger handling (latency)	30 kHz (10 µs)
Data output rate	320 MHz



OBELIX Sensor : Functional Implementation



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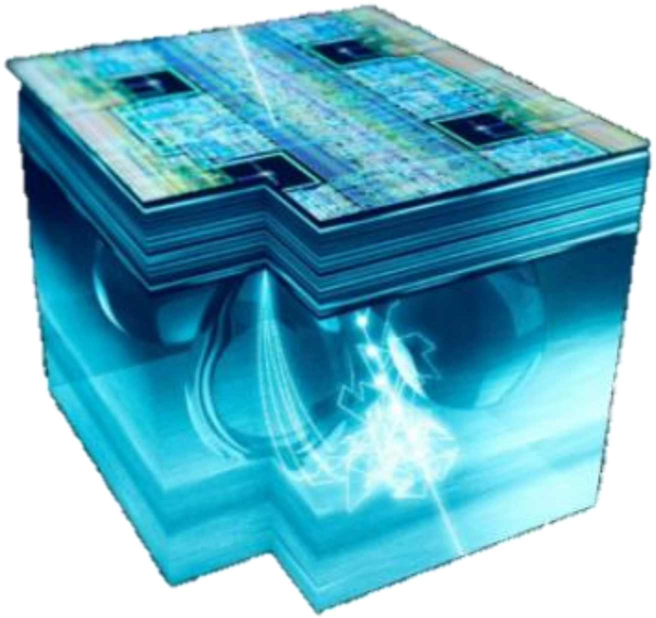
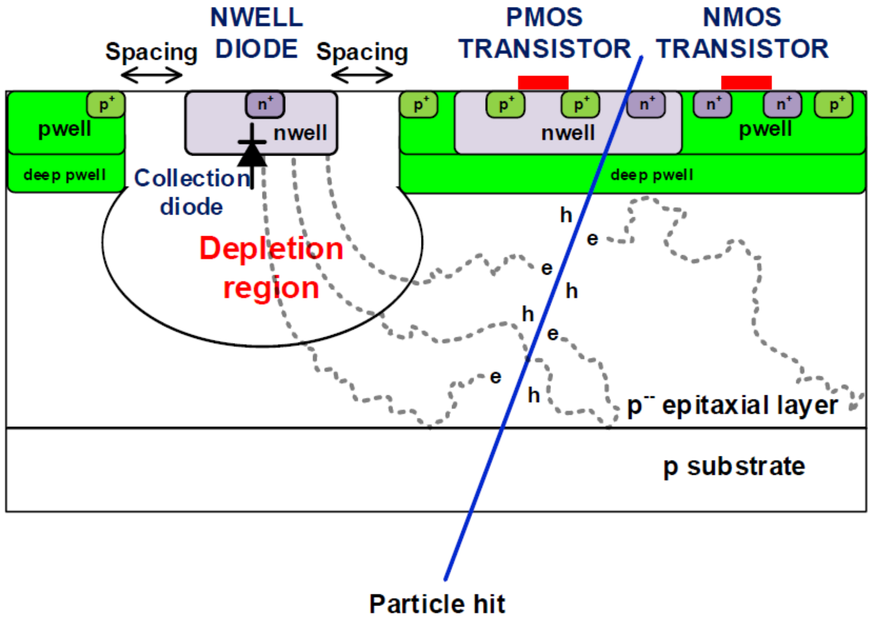
The physics behind silicon sensors



Artistic view of the interaction between a charged particle and the silicon sensor



Detailed diagram of how silicon sensors work