Test of Single Event Effects on ITS3 monolithic sensors

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On behalf of the ALICE Collaboration

U.S. DEPARTMENT OF ENERGY
Office of Science

This work is supported by DOE EPSCoR

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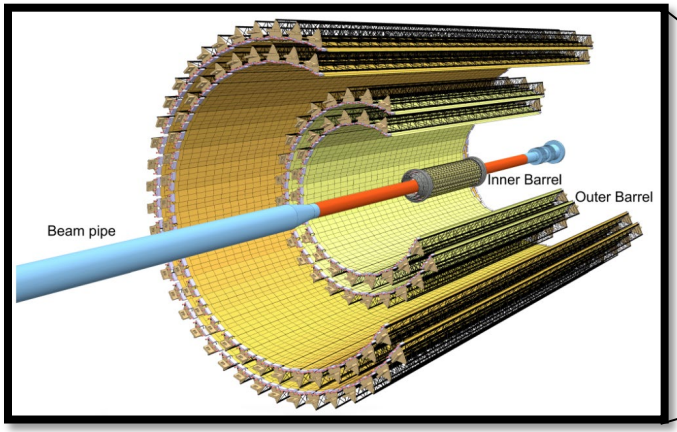
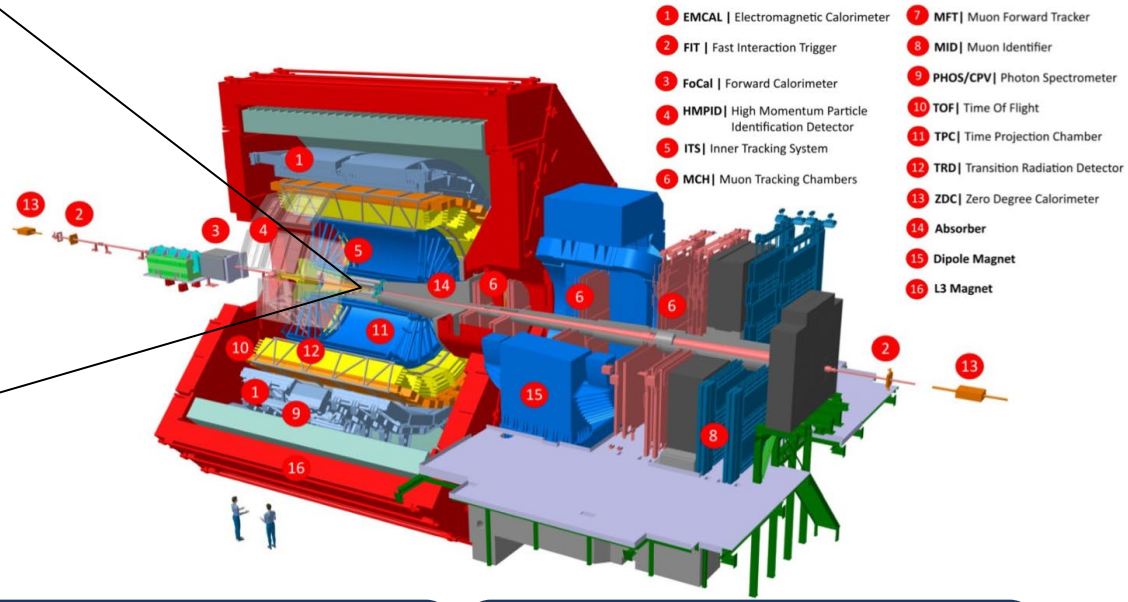
THE UNIVERSITY OF KANSAS

Outline

- Monolithic sensors for the ALICE: ITS and FoCal
- Stitched Monolithic Pixel Sensor (MOSS) for ITS3
- Stitched Monolithic Sensors for EIC
- Characterization of Single Event Effects

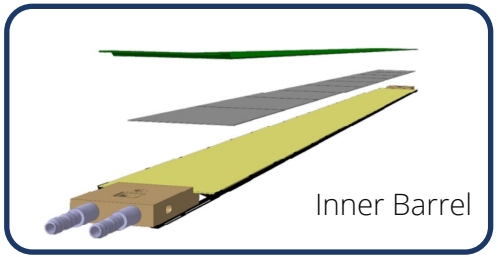
The Inner Tracking System (ITS2) of the ALICE Experiment

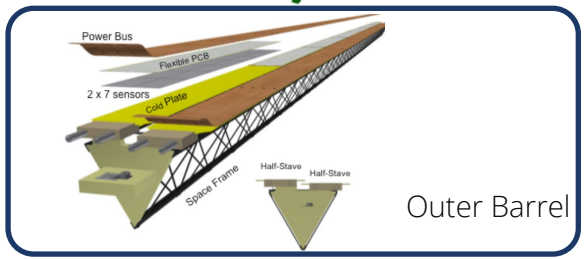




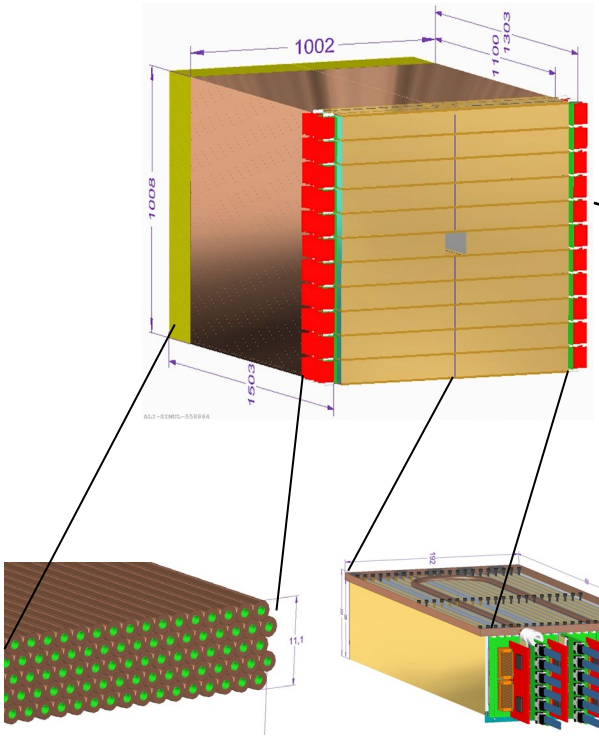
7 layers

- All silicon pixels
- Rate capability ~100 kHz Pb+Pb
- 24k chips
- 10 m^2
- 12.5 GPixel



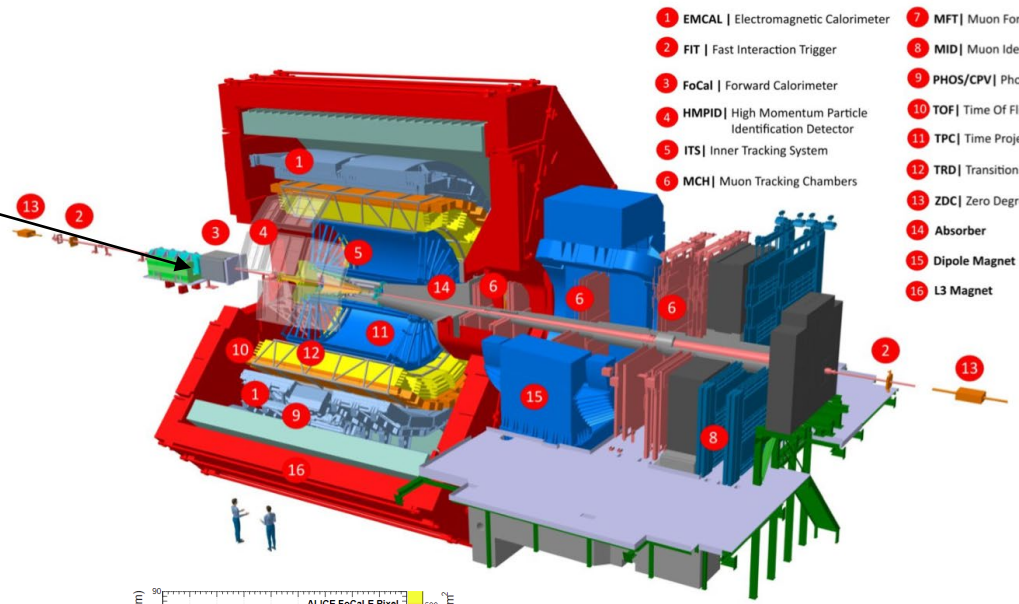


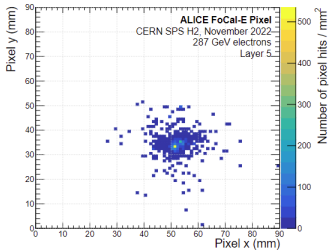
FoCal: Forward Calorimeter for ALICE detector for Run 4 of the LHC



FoCal-H
Transversally segmented spaghetti calorimeter
Tot thickness ~ 6 λhad

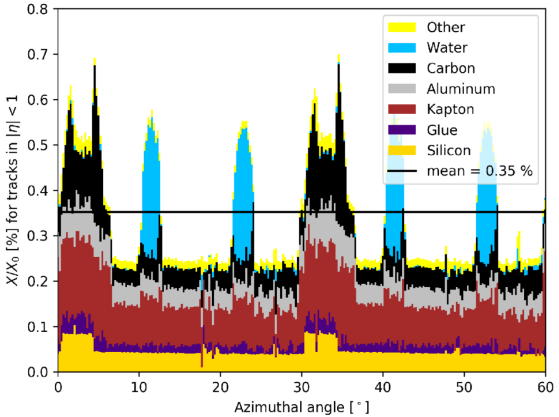
FoCal-E
20 Layers (LG + HG Si detectors + W absorbers). Tot (~ 20 X_0)



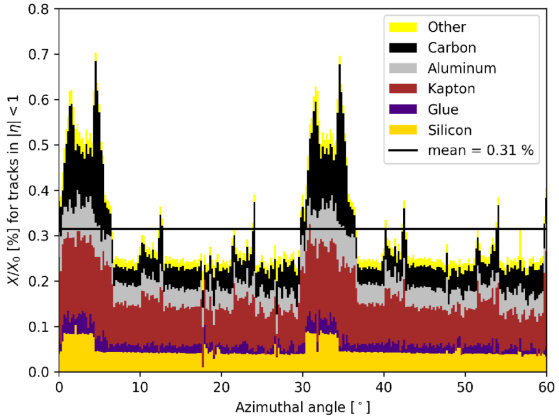


High spatial resolution of ALPIDES guarantees 2 photons discrimination

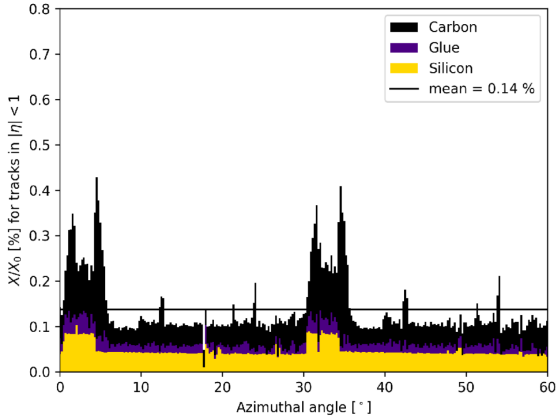
Limitation of ITS2: toward ITS3



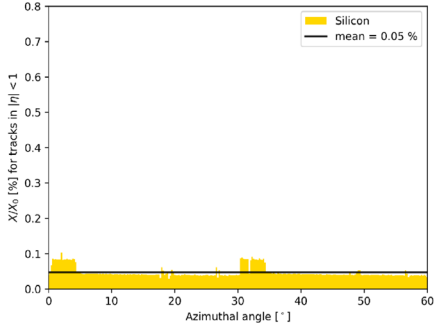
Si makes only **1/7th** of total material!!



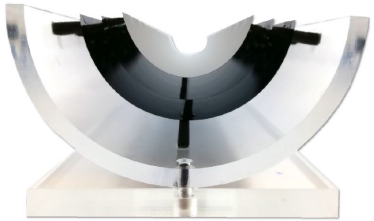
Removal of water cooling - **possible** if power consumption stays below 20 mW/cm2



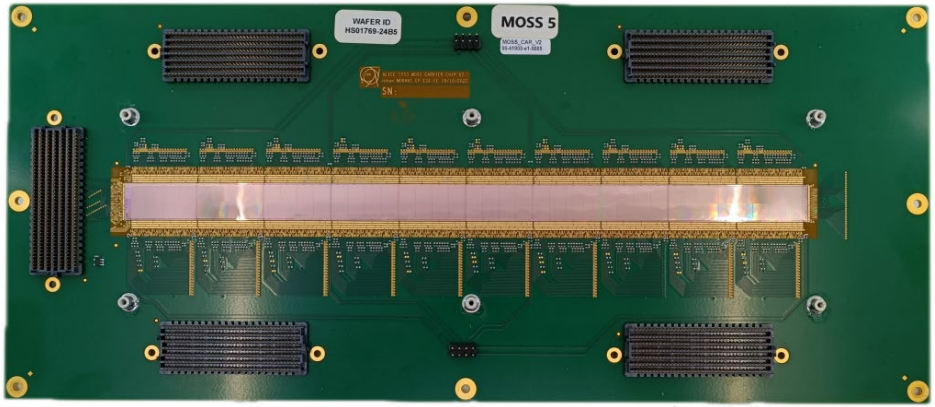
Removal of the circuit board (power+data) - **possible** if integrated on chip



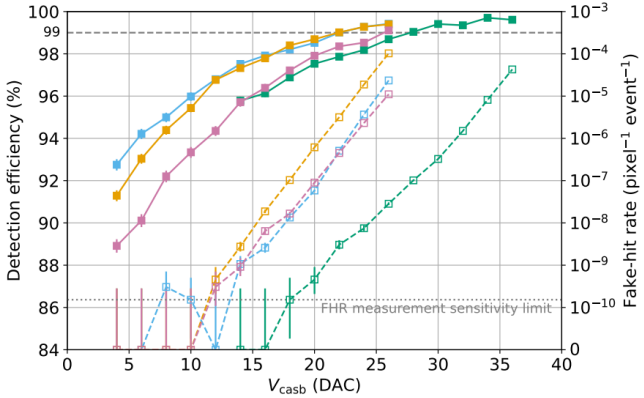
Removal of mechanical support - **benefit** from increased stiffness by rolling Si wafers

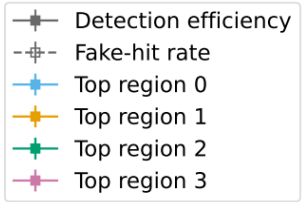


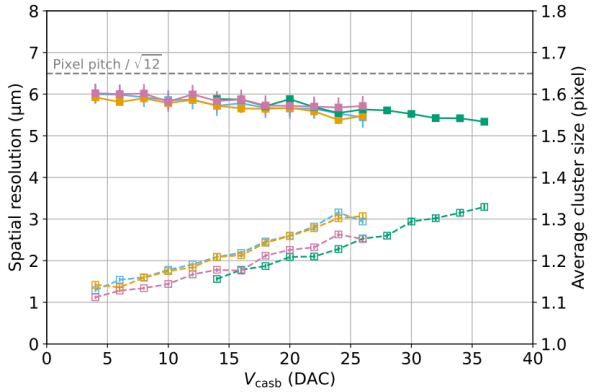
MOSS: prototype of monolithic stitched sensor



Detection efficiency and resolution measured with MOSS at the CERN PS using a MOSS wire-bonded on its carrier card

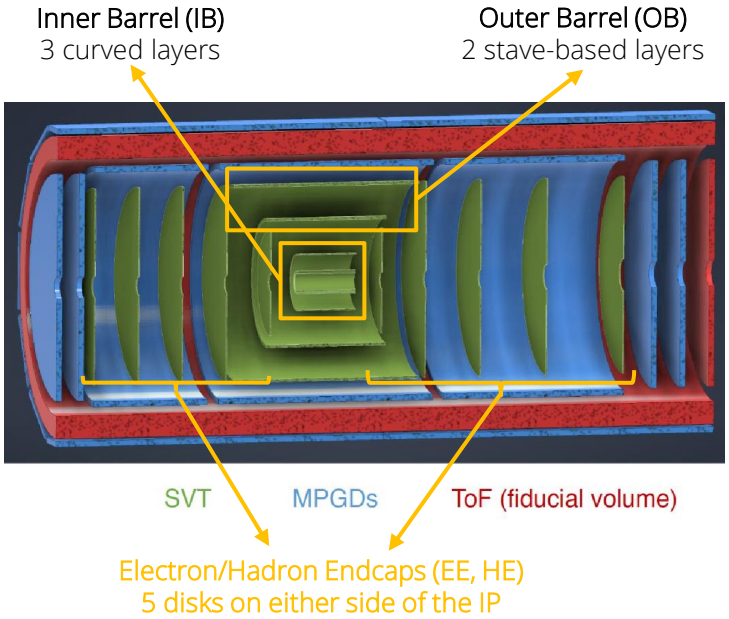




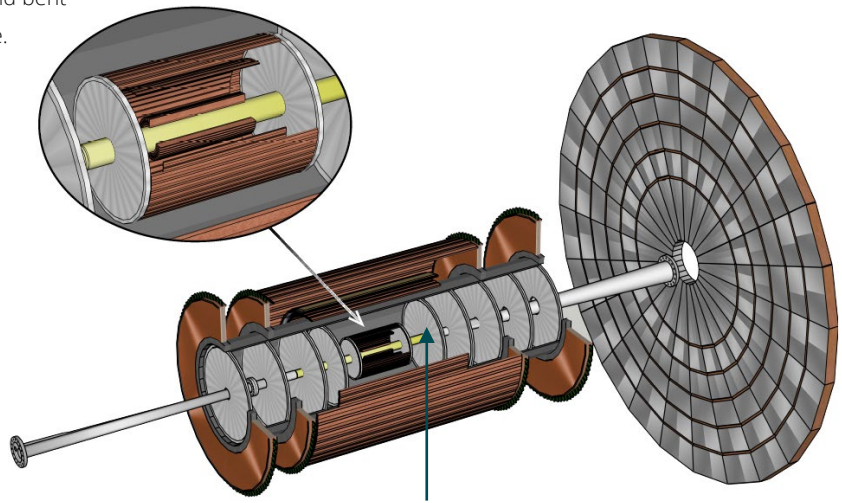


Inner Tracker for ePIC at the EIC

Silicon Vertex and Tracker (SVT)



ITS3 wafer-scale stitched sensor, thinned and bent around beam pipe.

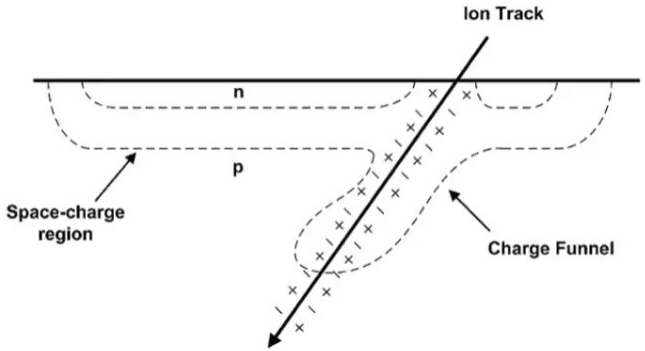


Barrel layers and disks

EIC Large Area Sensor (LAS), i.e. ITS3 sensor size optimized for high yield, low cost, large area coverage.

Single Event Effects

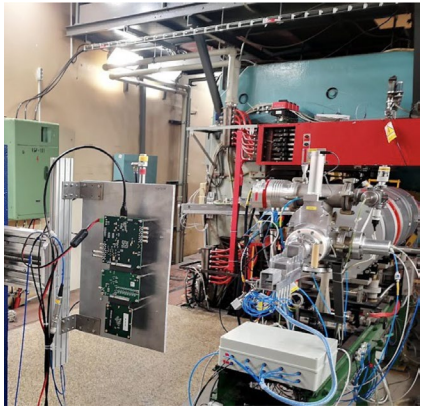
A single particle passing through the silicon is depositing energy: Linear Energy Transfer (LET)



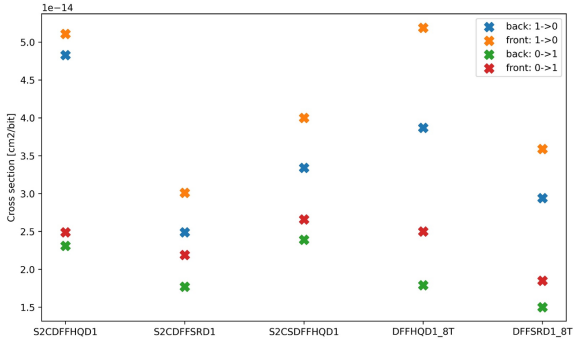
Single Event Upset (SEU):
change of state caused by one single ionizing particle

Single Event Latchup (SEL):
the inadvertent creation of a low-impedance path between the power supply rails of a MOSFET circuit, triggering a parasitic structure which disrupts proper functioning of the part, possibly even leading to its destruction due to overcurrent. A power cycle is required to correct this situation.

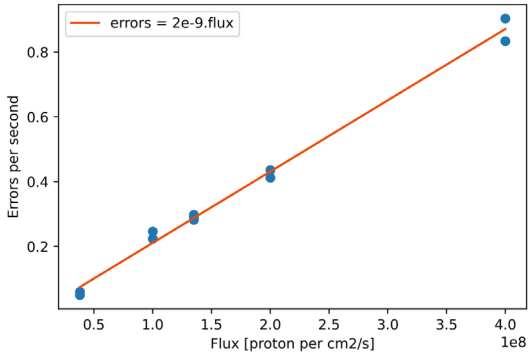
SEU tests: Nuclear Physics Institute @CAS (CZ)



SEU1



SEU2



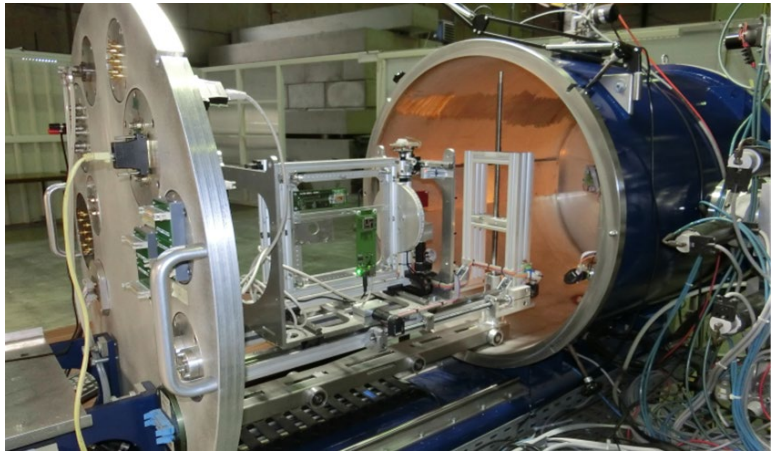
Flux of 2×10^9 protons/cm^2/s

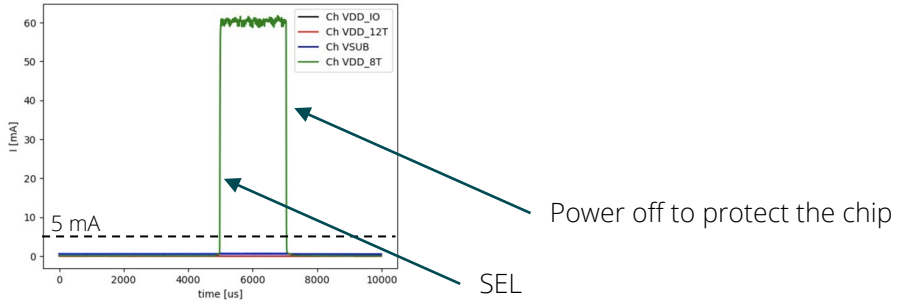
- asymmetry between 1->0 and 0->1 bit flips for all FIFOs
- significant differences between individual types of FIFO structures

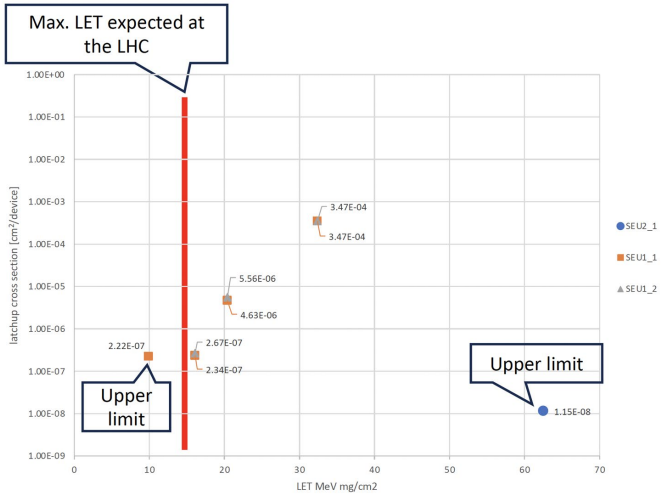
- no asymmetry between 1 -> 0 and 0 ->1 observed
- SEU occurrence linear with the beam flux

SEL tests: Heavy Ion Facility @UCLouvain (BE)

M/Q	Ion	Energy [MeV]	Range [µm]	LET [MeV/(mg/cm²)]
3,25	$^{13}C^{4+}$	131	269.3	1,3
3,14	$^{22}Ne^{7+}$	238	202,0	3,3
3,37	$^{27}Al^{8+}$	250	131,2	5,7
3,27	$^{36}Ar^{11+}$	353	114,0	9,9
3,31	$^{53}Cr^{16+}$	505	105,5	16,1
3,22	$^{58}Ni^{18+}$	582	100,5	20,4
3,35	$^{84}Kr^{25+}$	769	94,2	32,4
3,32	$^{103}Rh^{31+}$	957	87,3	46,1
3,54	$^{124}Xe^{35+}$	995	73,1	62,5







Summary

- Monolithic sensors (ALPIDE) are currently used in ALICE: ITS and FoCal (and MFT)
- It is possible to design a wafer scale monolithic sensor that allows lower and more uniform material budget
- Technical Design report of ITS3 approved by CERN LHC Committee (LHCC) and the CERN Research board (RB)
- SEE tests performed at Louvain-la-Neuve (BE) and BASE (USA)

Z. Ye: Update on Irradiation and Beam Tests

- ER1 sensors are working and are currently characterized
- Characterization of Single Event Effects (and much more…) is needed to provide feedback to the designers for ER2 (exp. <Q1 2025)

Test of Single Event Effects on ITS3 monolithic sensors

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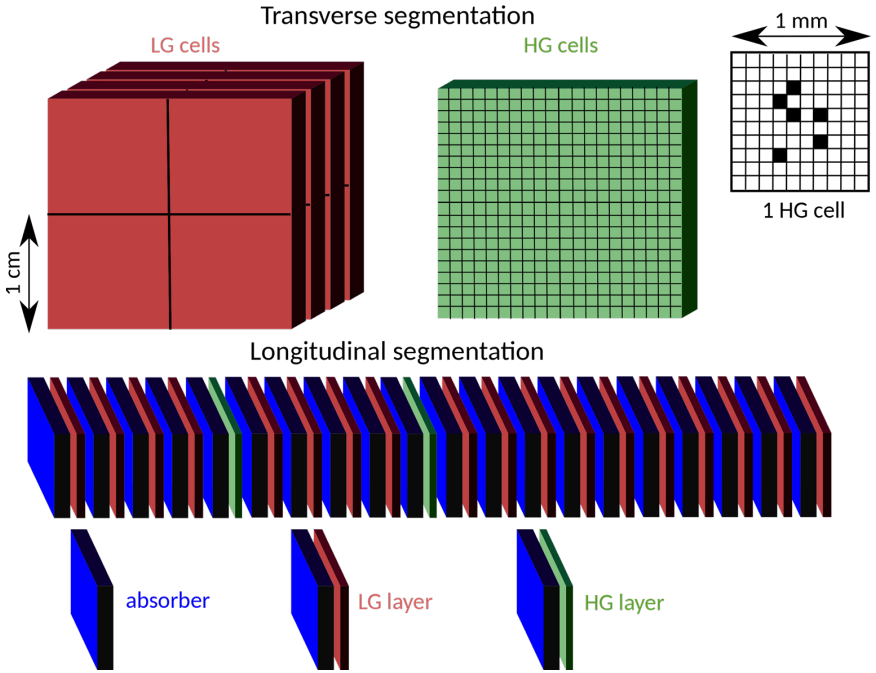
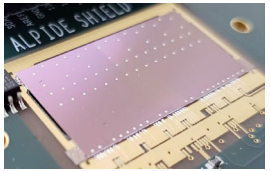
FoCal-E: low granularity pad sensors, high granularity ALPIDEs

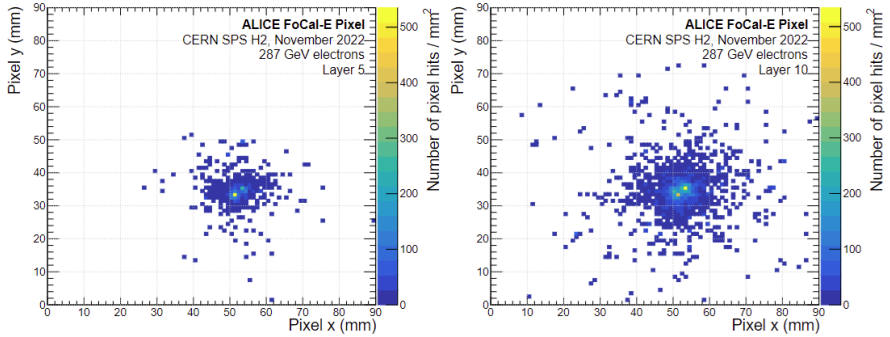
20 layers of W (each of 3.5mm thickness) and Si sensors



High granularity layers (positions 5 & 10):

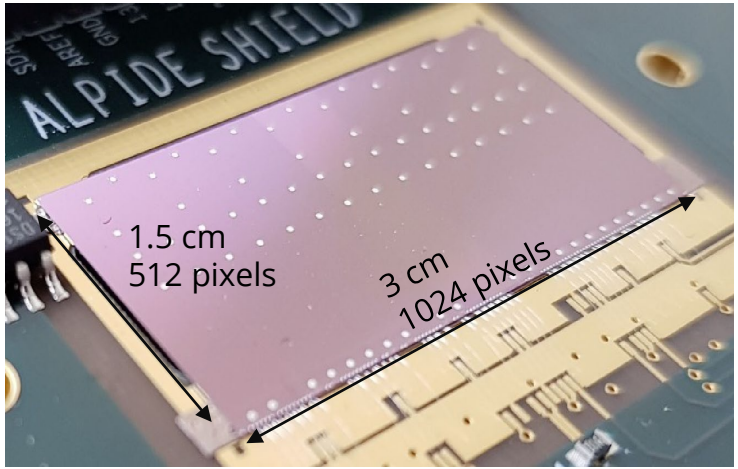
monolithic pixel sensors (ALPIDE)

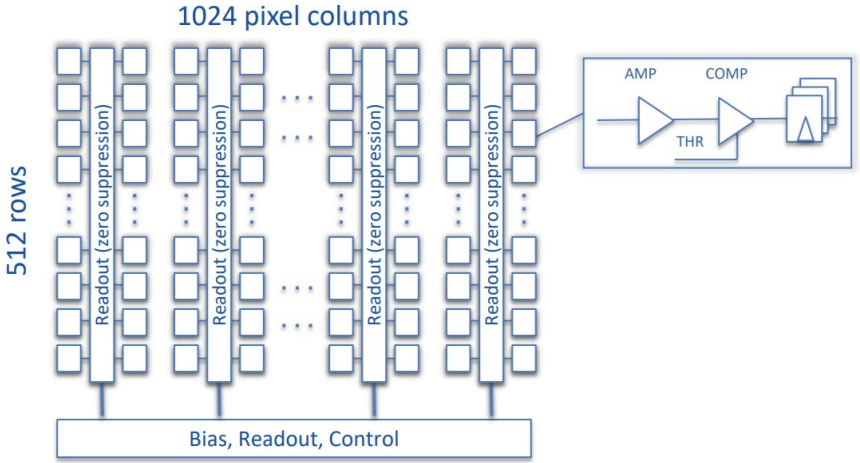




The ALPIDE monolithic sensor

Pixel Sensor CMOS 180 nm Imaging Process (TowerJazz)

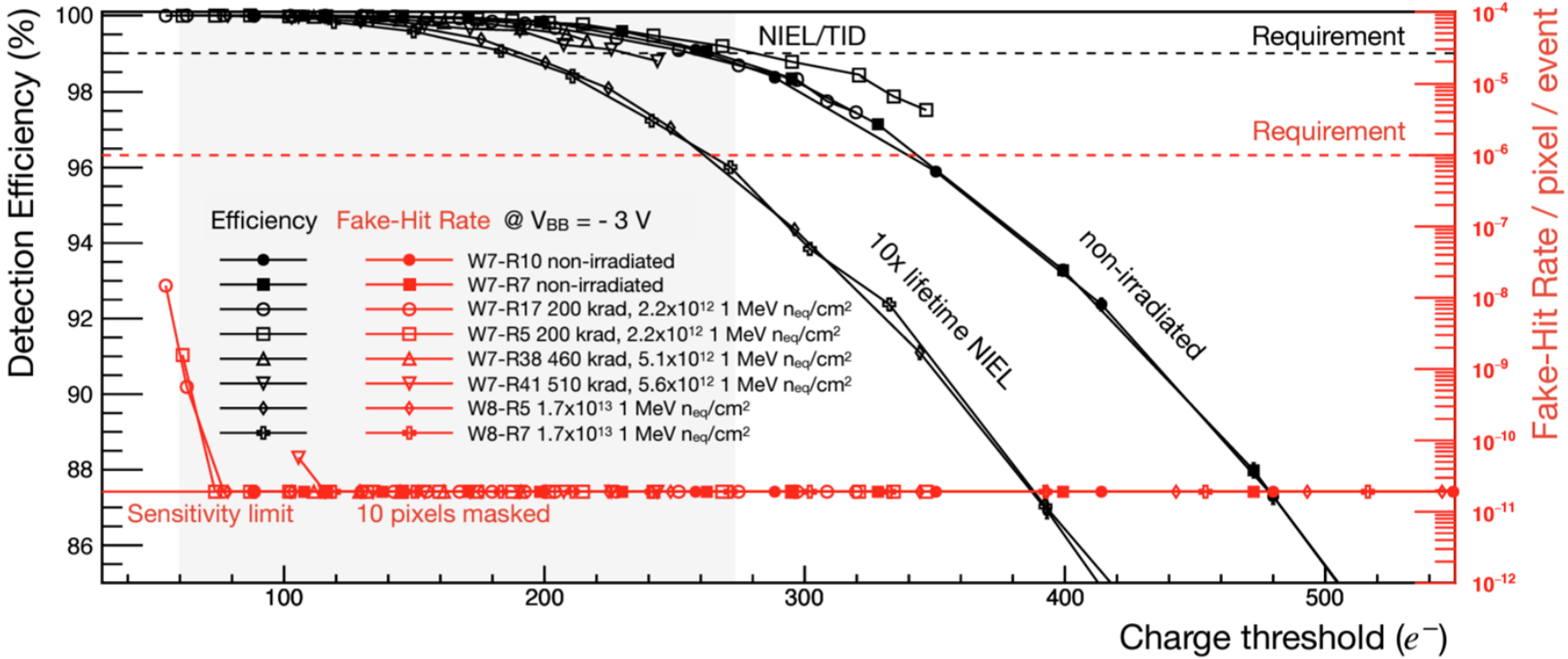




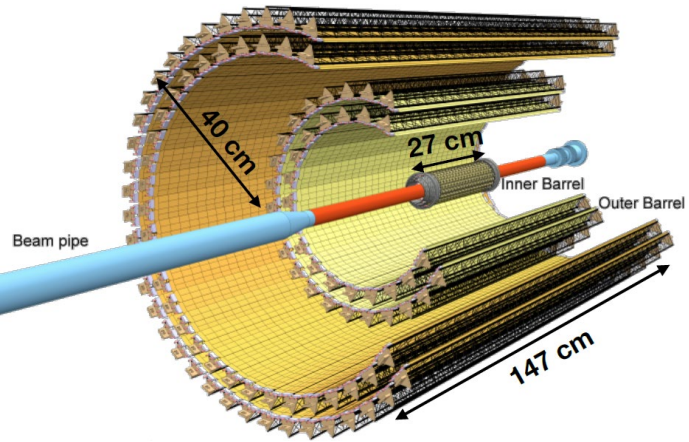
High-resitivity (>1 kΩ cm) p-type epitaxial layer (25 µm) on p-type substrate

- Small n-well diode (2 µm diameter) è low capacitance (~5 fF)
- Reverse bias voltage (-6V < VBB < 0V) to substrate to increase depletion region
- Deep p-well shields n-well of PMOS
- Continuously active front-end
- Global shutter (STROBE signal)
- Zero-suppressed matrix readout
- Triggered or continuous readout modes

The ALPIDE monolithic sensor



The Inner Tracking System (ITS2) of the ALICE Experiment

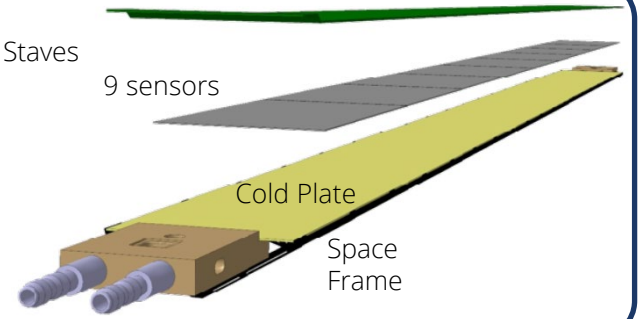


3 Inner Layers: 12+16+20 Staves

1 Module/Stave

9 sensors per Module

50 μm sensors



2 Middle Layers: 30+24 Staves

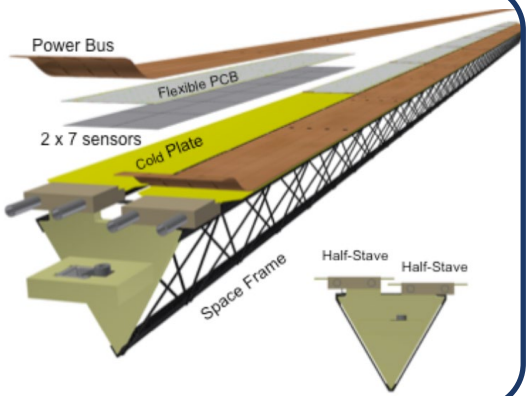
2x4 Modules/Stave

2 Outer Layers: 42+48 Staves

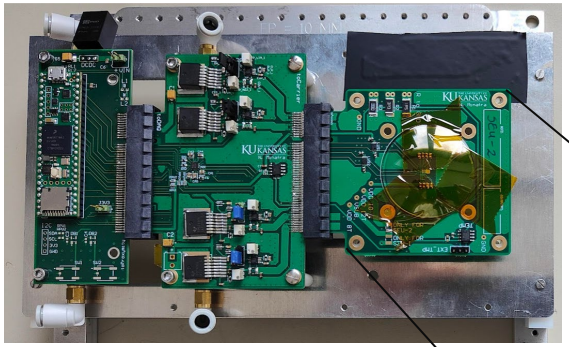
2x7 Modules/Stave

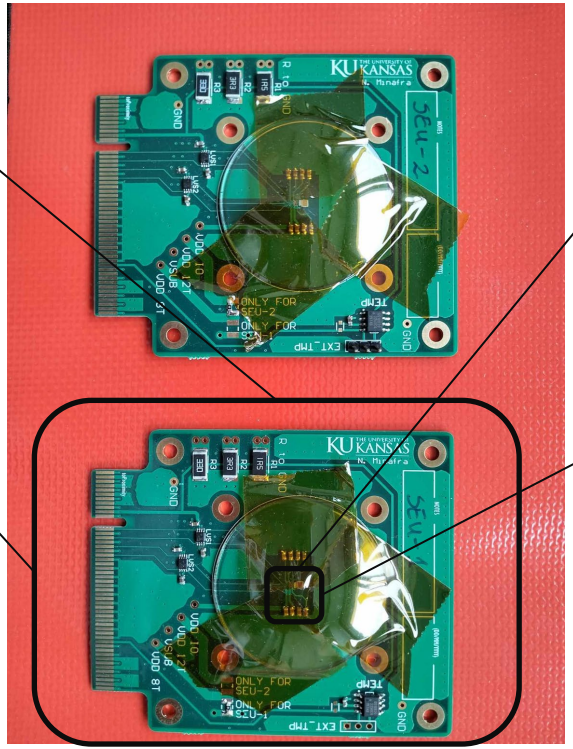
2x7 sensors / Module

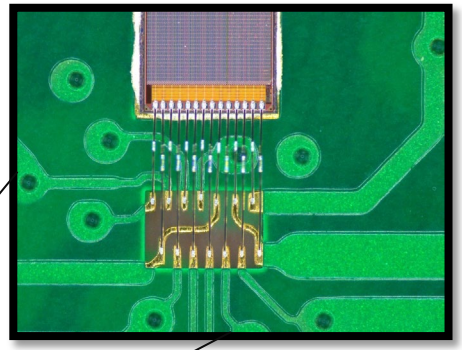
100 μm sensors



SEE Investigation

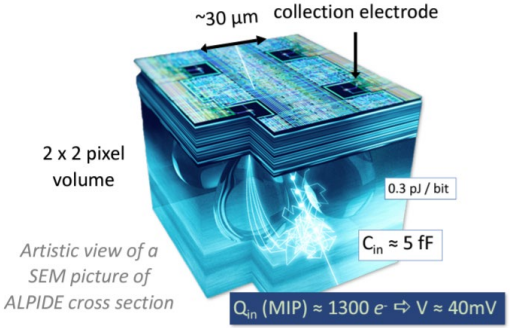






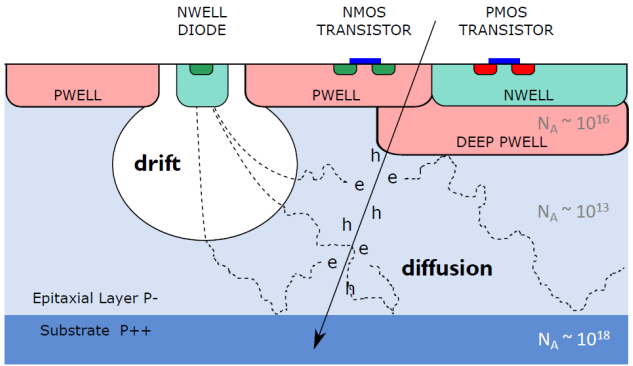
The ALPIDE monolithic sensor

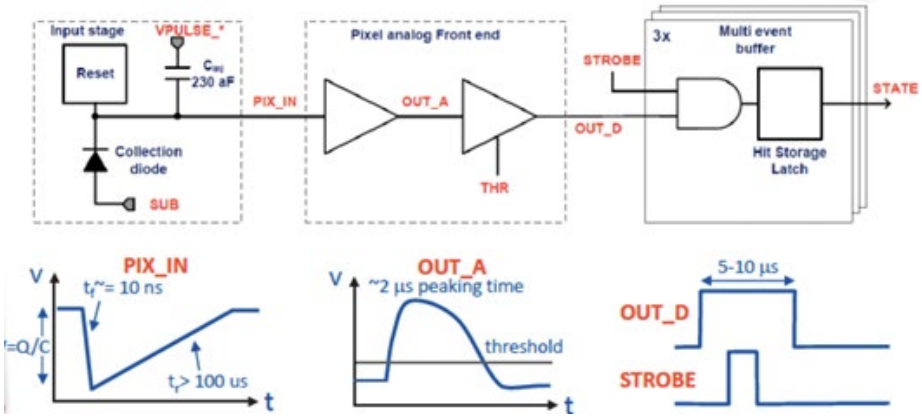
Pixel Sensor CMOS 180 nm Imaging Process (TowerJazz)



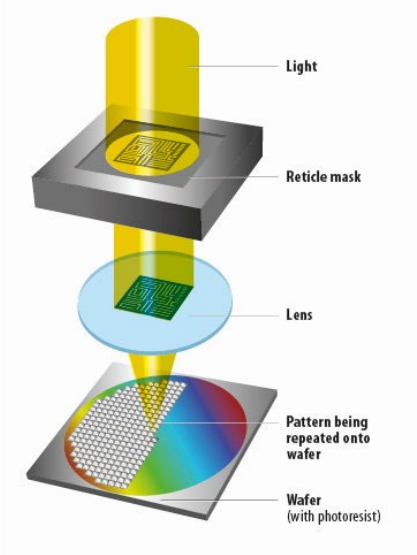
Each pixel (29 µm x 27 µm) has:

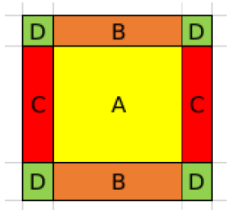
- Amplification
- Discrimination
- 3 hit storage registers (MEB)
- Test charge injection
- Masking



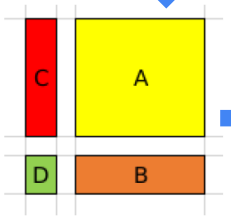


Wafer-scale sensors

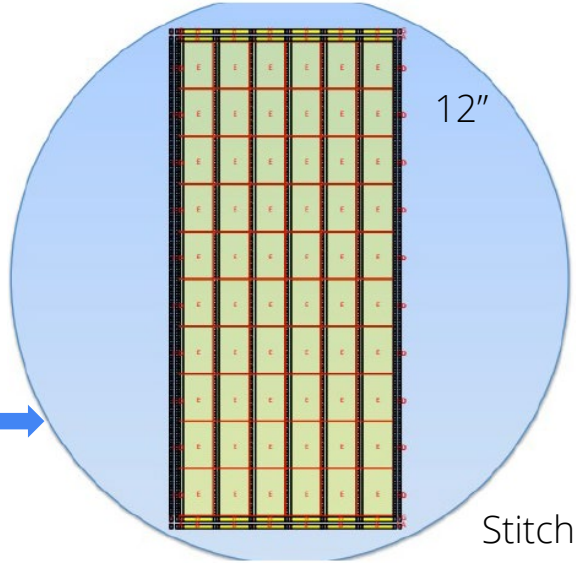




Reticle

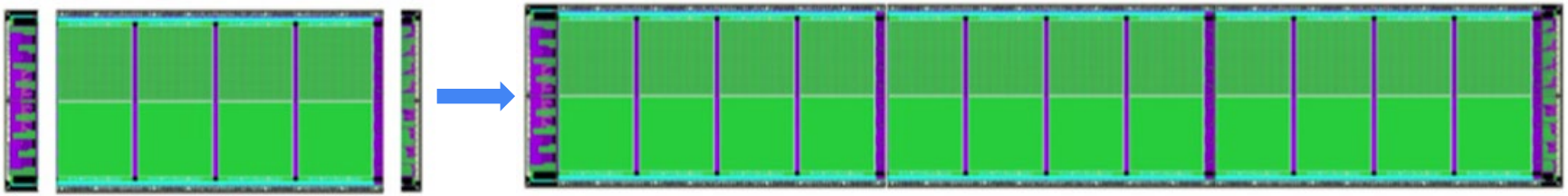


Splitted

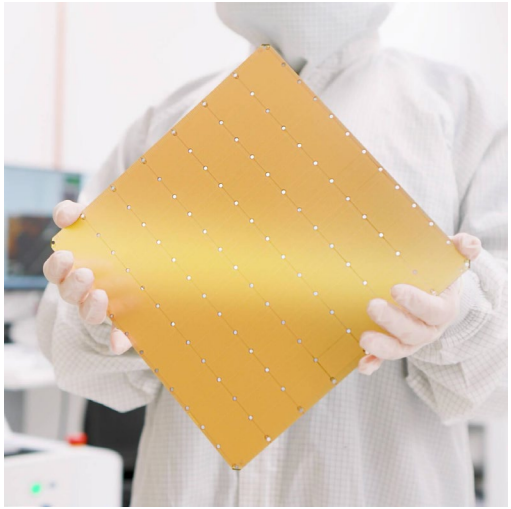


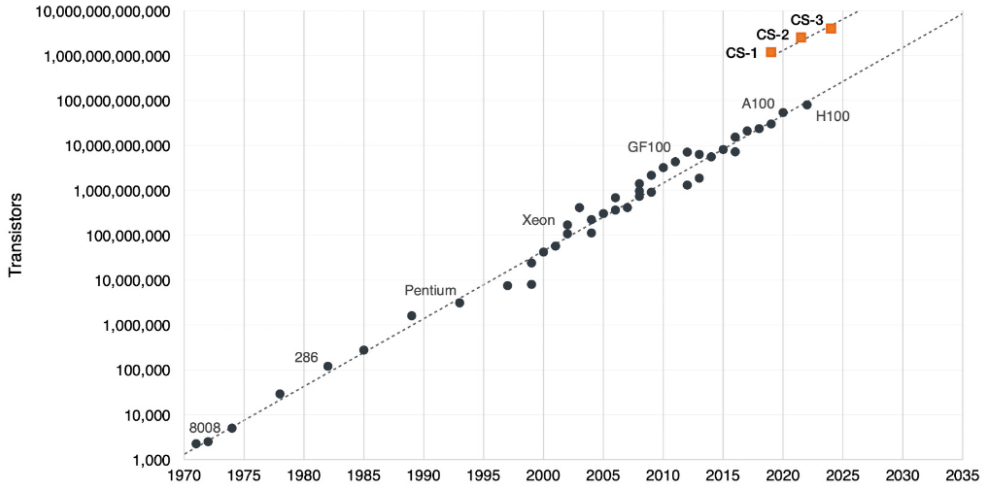
Stitched

6 wafers make the entire ITS3 production



Wafer-scale for AI





CEREBRAS WSE-3

	WSE-3	Nvidia H100	Cerebras Advantage
Chip Size	46,225 mm²	826 mm²	57 X
Cores	900,000	16,896 FP32 + 528 Tensor	52X
On-chip memory	44 Gigabytes	0.05 Gigabytes	880 X
Memory bandwidth	21 Petabytes/sec	0.003 Petabytes/sec	7,000 X
Fabric bandwidth	214 Petabits/sec	0.0576 Petabits/sec	3,715 X