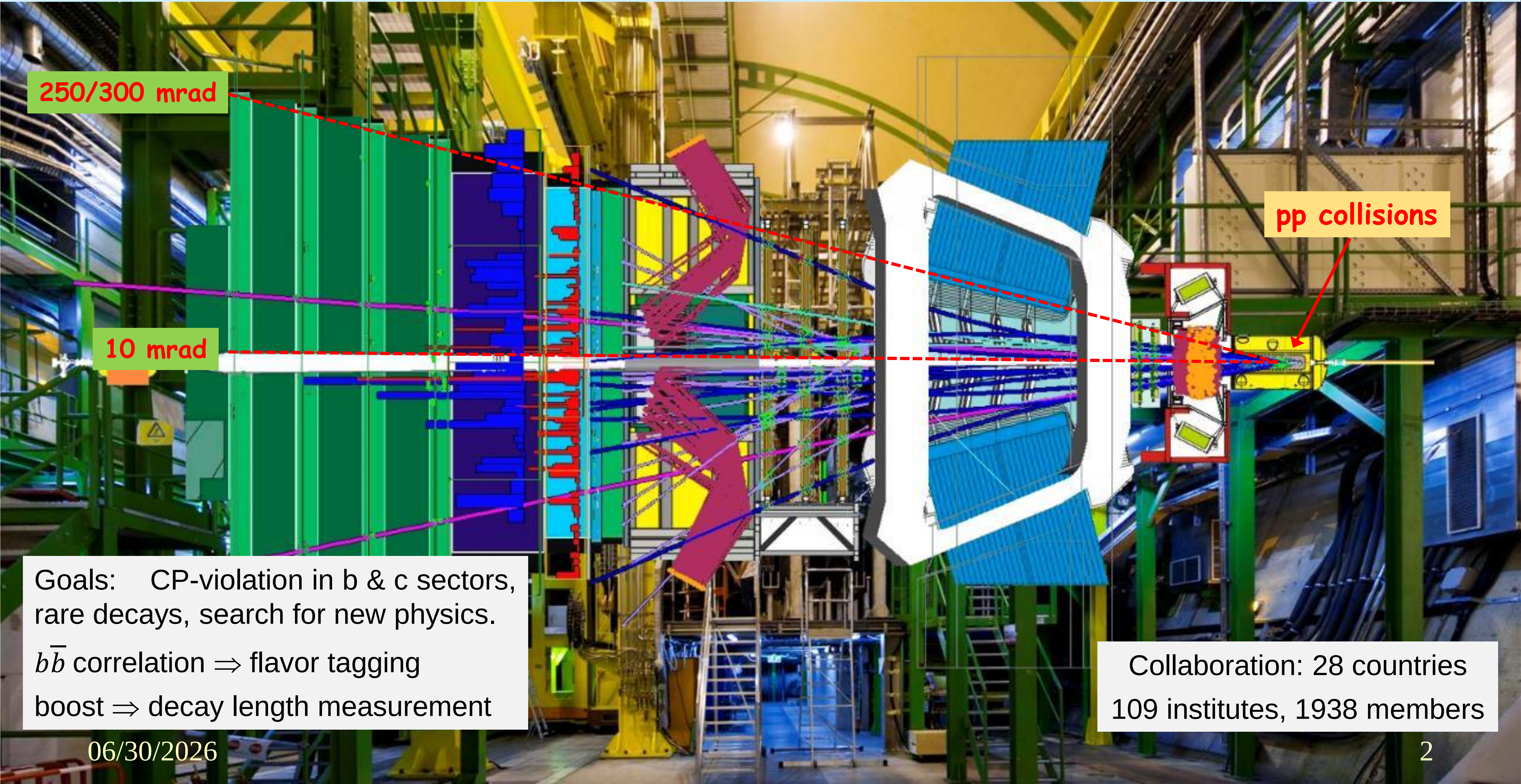
R&D of CMOS-based LHCb Tracking Detector

Jianchun Wang (IHEP, CAS)

17th Workshop of The FCPPN/L
June 29 - July 3, 2026, Lyon, France

LHCb – A Forward Spectrometer @ LHC



Goals: CP-violation in b & c sectors, rare decays, search for new physics.

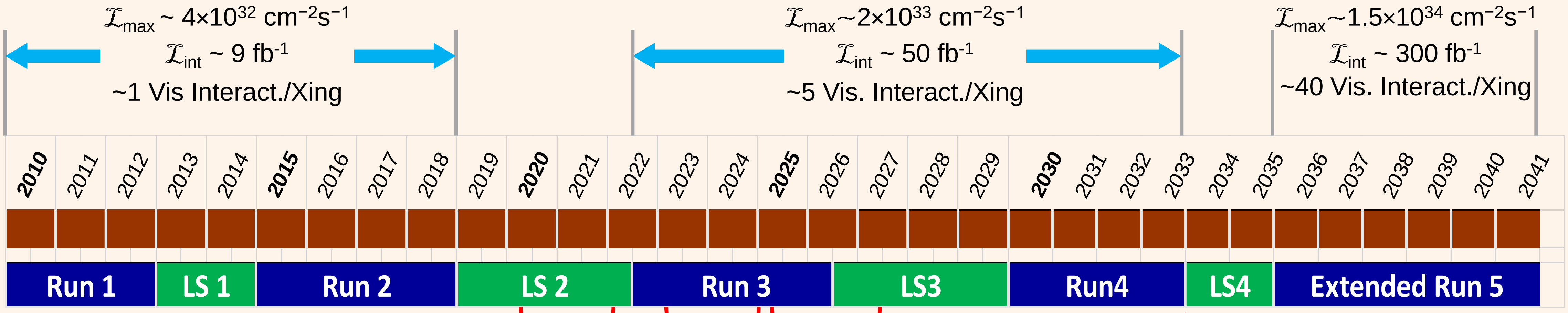
$b\bar{b}$ correlation $\Rightarrow$ flavor tagging

boost $\Rightarrow$ decay length measurement

Collaboration: 28 countries

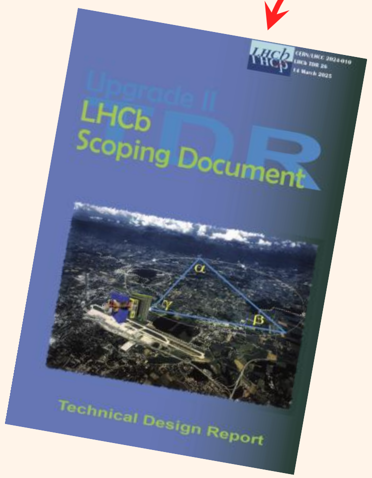
109 institutes, 1938 members

LHCb Timeline



Upgrade II detectors must be fully prepared for installation in the experimental hall

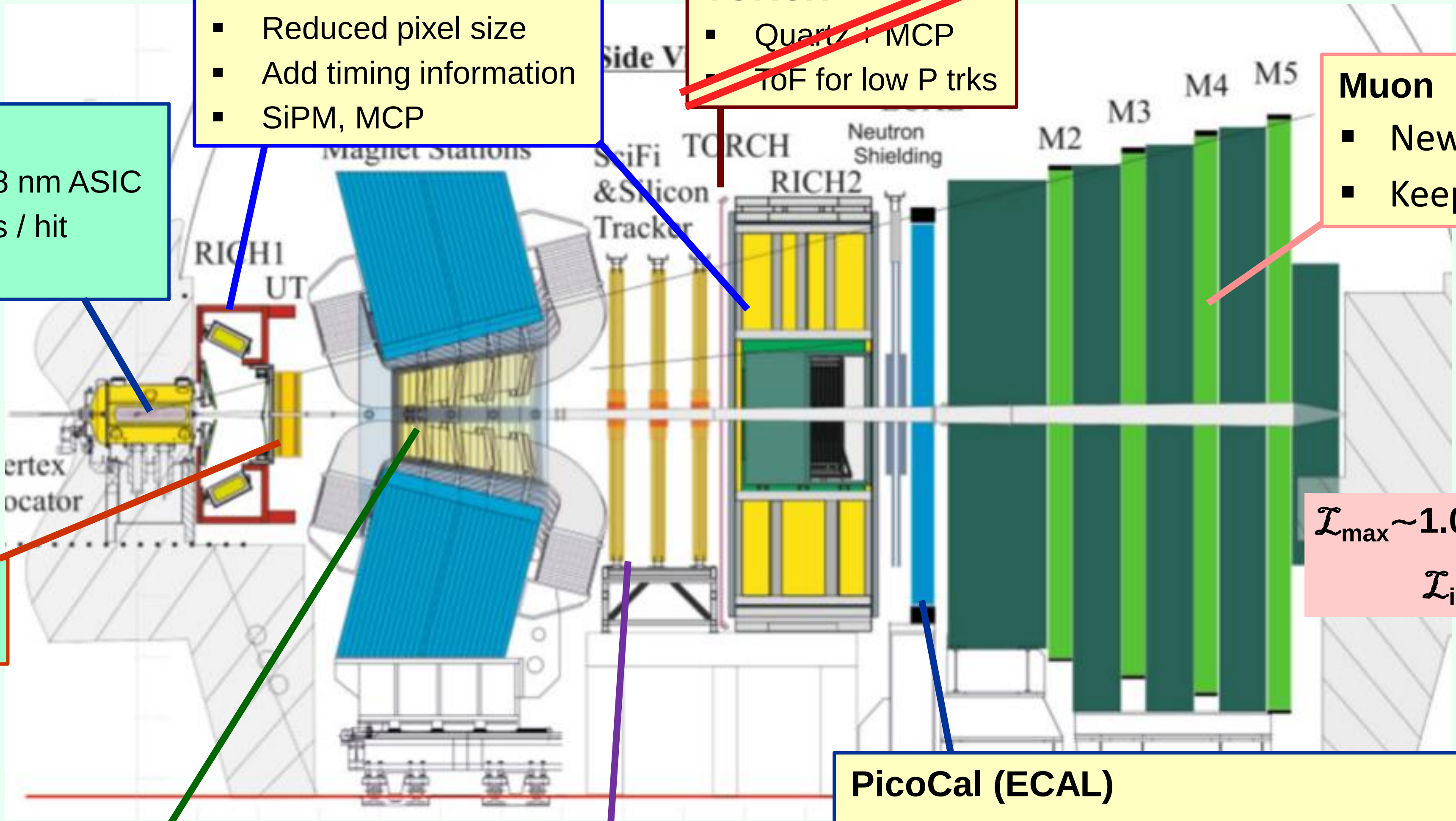
Framework TDR
LHCC-2021-012



Scoping document
LHCC-2024-010

Subsystem(s)	Date of TDR
VELO	Q1/2027
Tracker (UP, MT)	Q4/2026
PID (RICH, PicoCal, Muon)	Q4/2026
Data processing	Q3/2026

The Phase II Upgrade



VELO → TV
- 3D Si Pixel, 28 nm ASIC
- Timing ~ 50 ps / hit
- New RF-foil

RICH1, RICH2
- Reduced pixel size
- Add timing information
- SiPM, MCP

~~**TORCH**~~
- ~~Quartz + MCP~~
- ~~ToF for low P trks~~

Muon
- New G-RWELL (inner)
- Keep MWPC (outer)

$\mathcal{L}_{max}$~1.0-1.5×10^{34} $cm^{-2}s^{-1}$

$\mathcal{L}_{int}$ ~ 300 fb^{-1}

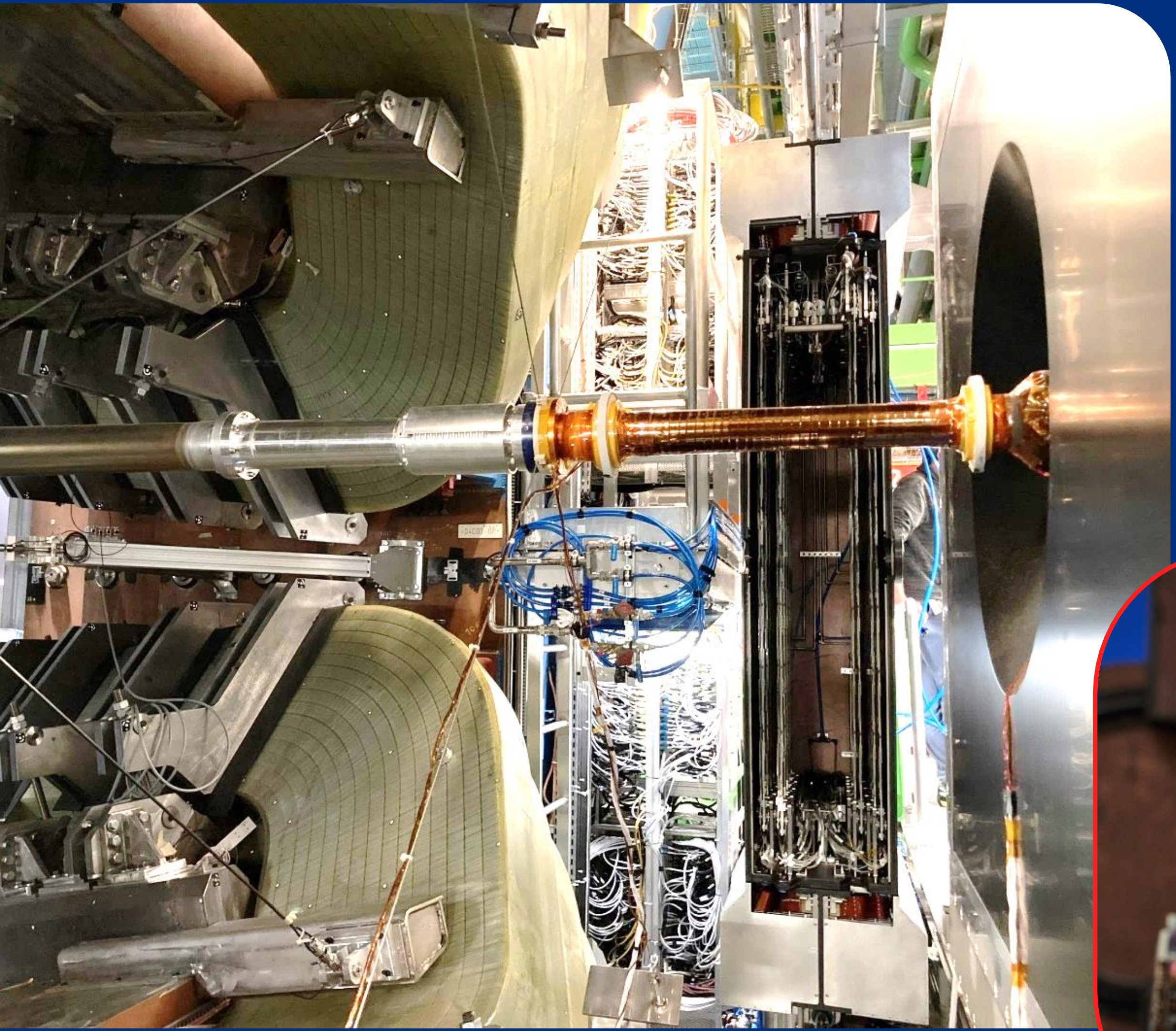
UT → UP
- **MAPS pixel**

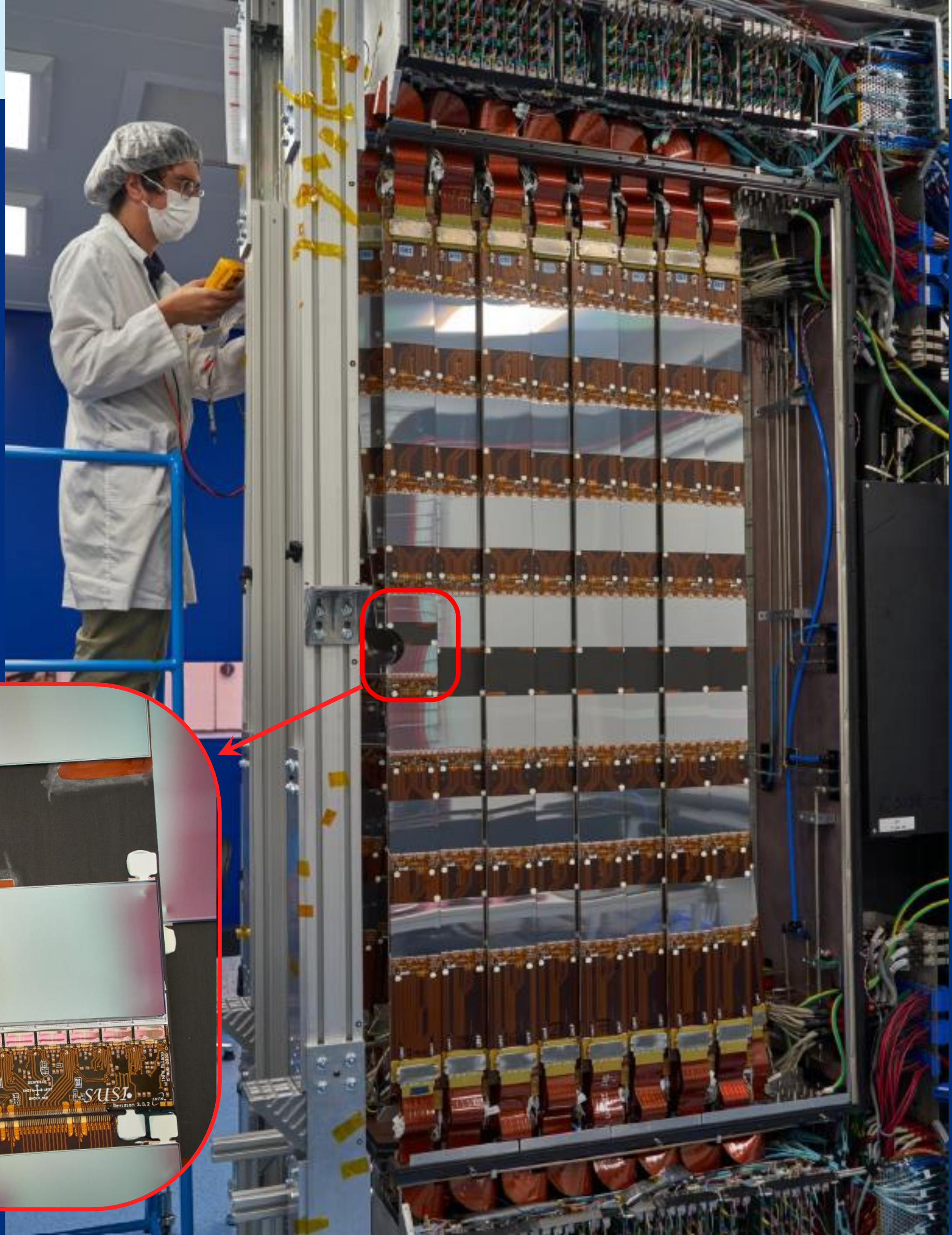
~~**Magnet Stations (MS)**~~
- ~~Scintillating bar~~
- ~~Low P particles~~

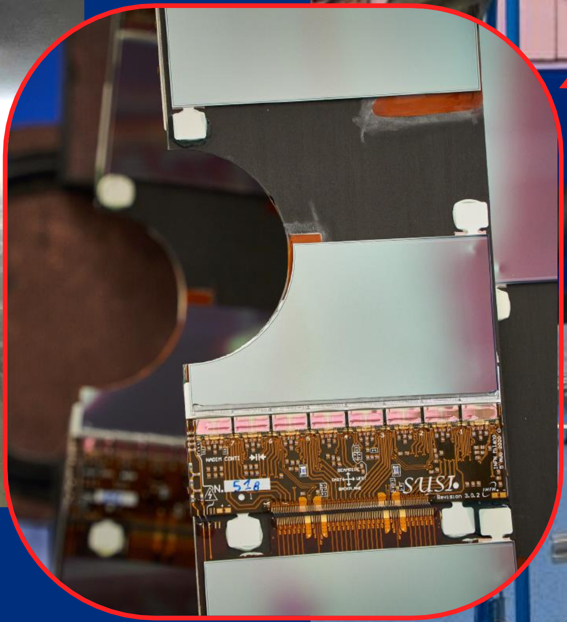
SciFi → MT
- **MAPS pixel (inner)**
- SciFi (outer)

PicoCal (ECAL)
- Timing, longitudinal segmentation
- SPACAL with radiation hard crystals
- Keep Shashlik for outer region

UT Micro-strip Detector



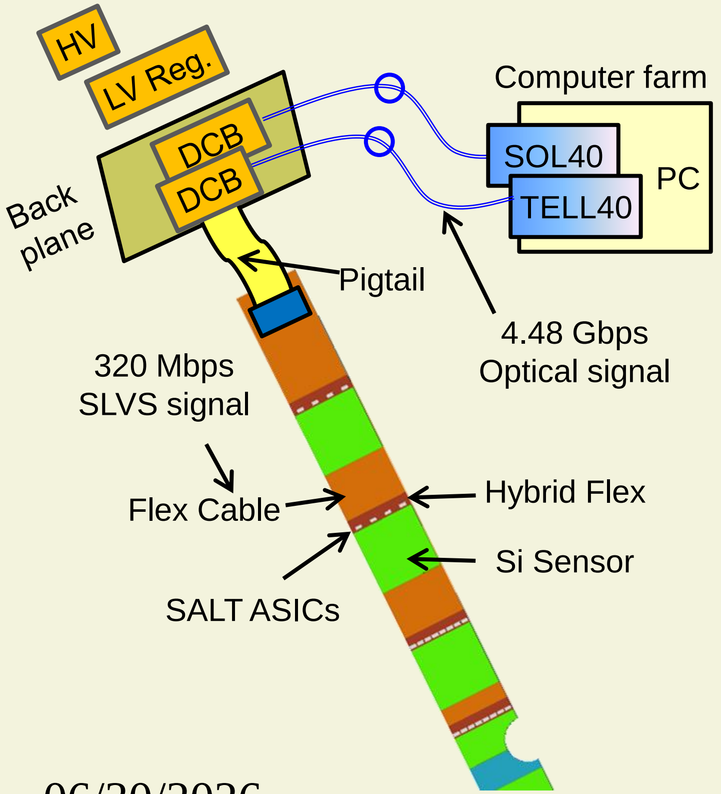


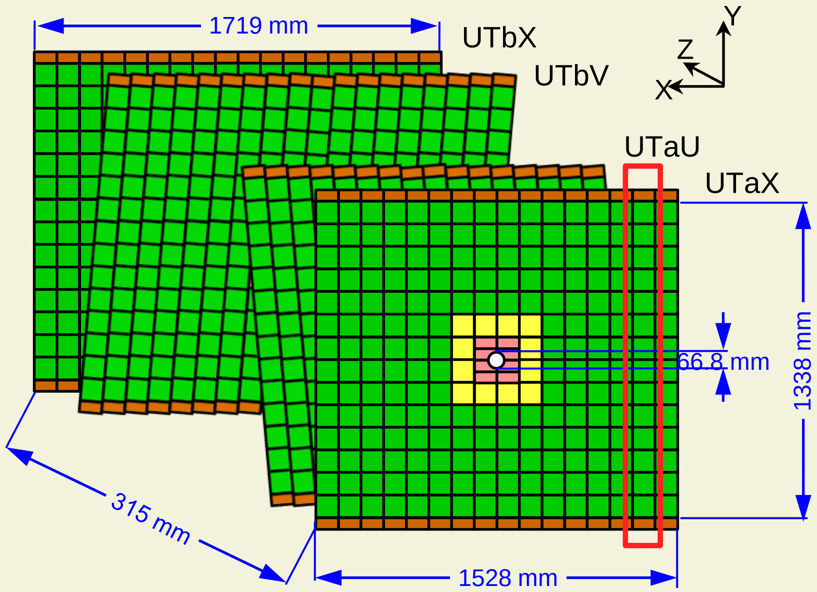


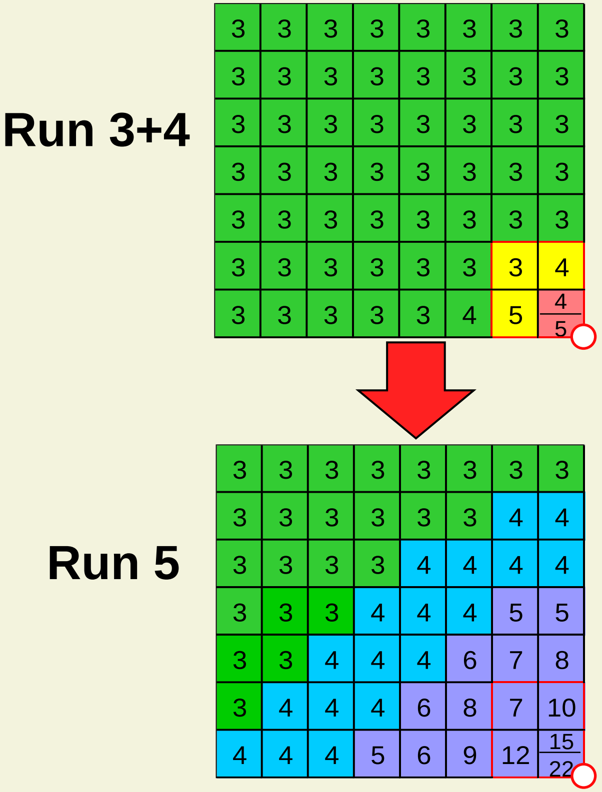
UT Micro-strip Detector

Sensor	A	B	C	D
Pitch (μm)	187.5	93.5	93.5	93.5
Length (mm)	~100	~100	~50	~50
Strips/sensor	512	1024	1024	1024
SALTs/sensor	4	8	8	8

- Much improved coverage and segmentation comparing to TT
- Read out at 40 MHz by custom SALT ASICs in the sensor proximity
- Digital events packed in SALT, sent out at the end of detector via optical fibers







- The occupancy at the center reaches **~10%**
- Max **5 e-ports** in SALT, besides of limitation from flex cables
- Sensors had been validated for radiation-resilience up to 50 fb^{-1} in the central region, now they need to endure 300 fb^{-1} if no replacement

Members of The Upstream Pixel (UP) Tracker Project

CCNU	CSU	HNU	HTU	IHEP	IPT	IRFU
Wuhan	Changsha	Changsha	Xinxiang	Beijing	Ulaanbaatar	Saclay

13 UP groups from 4 countries:

China, France, Mongolia, USA

PL: Jianchun Wang

DPL: Benjamin Audurier

LLR	LZU	NPU	Subatech	SYR	UCAS
Palaiseau	Lanzhou	Xi’an	Nantes	Syracuse	Beijing

Project Work Packages

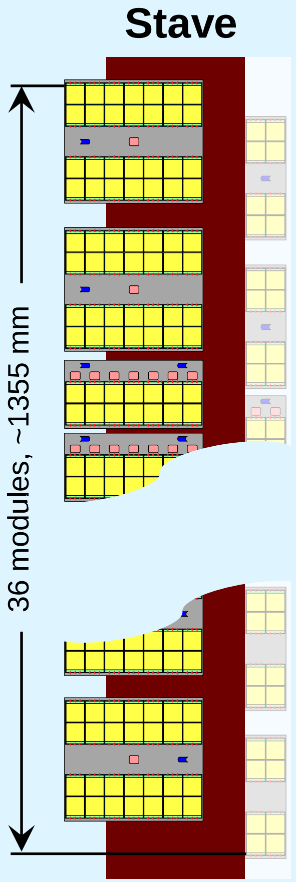
PL: Jianchun Wang (IHEP, UT/UP)

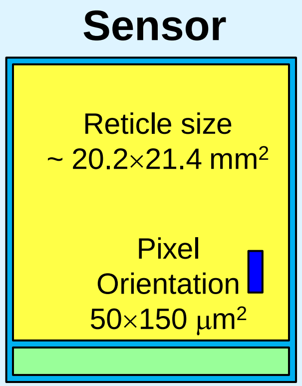
DPL: Tomasz Skwarnicki (Syracuse, UT), Benjamin Audurier (IRFU, UP)

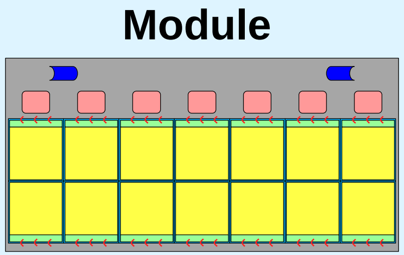
TDR Preparation
M. Artuso / Syracuse

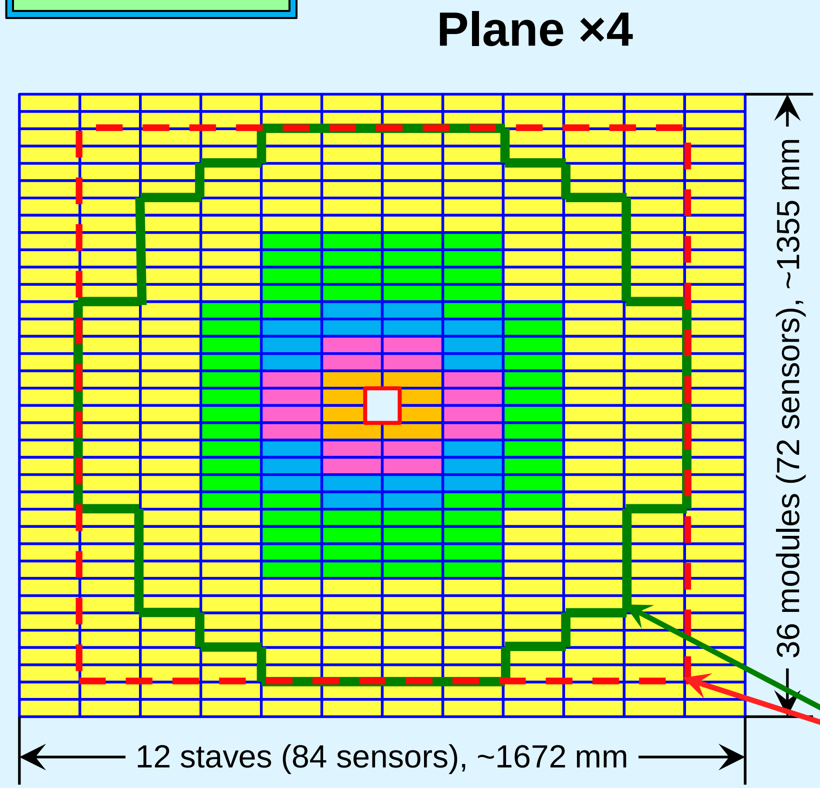
- **Simulation, Reconstruction & Performance**
  S. Blusk / Syracuse
  X. Yuan / IHEP
  - **Detector Descr. & Simulation Software**
    X. Zhou / CCNU
  - **Reconstruction & Performance Study**
    P. Li / UCAS
- **Sensor Development**
  F. Guilloux / IRFU
  Y. Li / IHEP
  - **Sensor Chip Design**
    X. Wei / NPU
    Y. Zhou / IHEP
  - **Sensor Chip Evaluation**
    E. Niel / LLR
    H. Zhang / IHEP
- **Module and Stave**
  R. Mountain/Syracuse
  J. Yu / HNU
  M. Guittiere/Subatech
  - **Design and Prototyping**
    X. Yuan / IHEP
    T.Bigourdan /Subat
  - **Stave Mechanical & Thermal Study**
    Y. Yang / HNU
    A. Cadiou / Subat
  - **Module Evaluation**
    C. Riccio / IRFU
- **Mechanics and Cooling**
  A. Cadiou / Subatech
  - **Mechanical Support**
    M. Guillamet / Subat
  - **Detector Integration & Installation**
    M. Guillamet /Subat
    B. Khanji /Syraucse
  - **Cooling System**
    H. Wu / Syraucse
- **Data Acquisition Infrastructure**
  K. Chen / CCNU
  Z. Xu / IHEP
  - **Readout Scheme**
    J. Wang / IHEP
  - **UP-specific Firmware**
    K. Chen / CCNU
  - **Control & Monitoring**
    Z. Xu / IHEP
  - **DAQ system before Final**
    M. Artuso /Syracuse
- **Electronics**
  K. Liu / LZU
  C. Renard / Subatech
  - **Design of FE Electronics**
    Z. Fu / LZU
  - **HV & LV Systems**
    K. Li / HTU

Conceptual Design in FTDR & Scoping Document









Challenges due to the higher luminosity

- Much increased track density requires better granularity (MAPS), especially in the central area (hit rate ~160 MHz/cm^2)
- Bandwidth up to **9 Gb/s** for ~20×20 mm^2 active area
- Radiation hardness up to 3×10^{15} n_{eq}/cm^2, or 240 Mrad TID (safety factor included)

Data / Control connection to lpGBTs

Ring	**5**	**4**	**3**	**2**	**1**	**All**
e-links / sensor	1	1	1	1-3	2-7	
Gbps / e-link	0.32	0.64	1.28	1.28	1.28	
lpGBT / module	0.5	1	2	7	14/10	
Num of modules	1312	240	80	64	32	1728
Num of data lpGBTs	656	240	160	448	384	1888
Num of ctrl lpGBTs	656	240	80	192	144	1312

Dual-module

Scoping scenarios, to be validated by physics performance and optimized together with other subdetectors: TV, MT, …

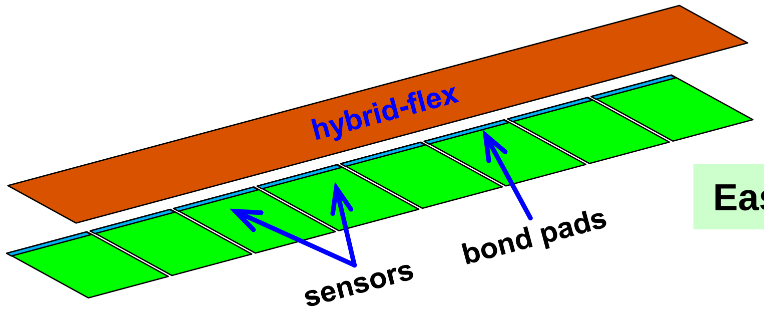
UP workshop at IRFU Saclay

October 23-24, 2025

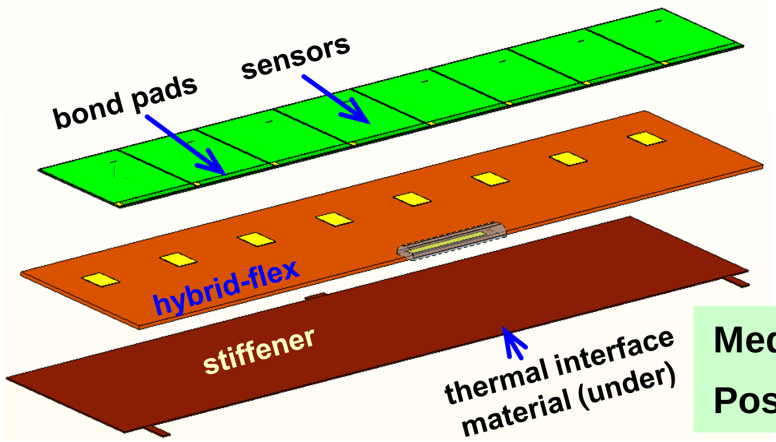
LHCb Upgrade II workshop at LLR Palaiseau

March 11-13, 2026

Detector Optimization

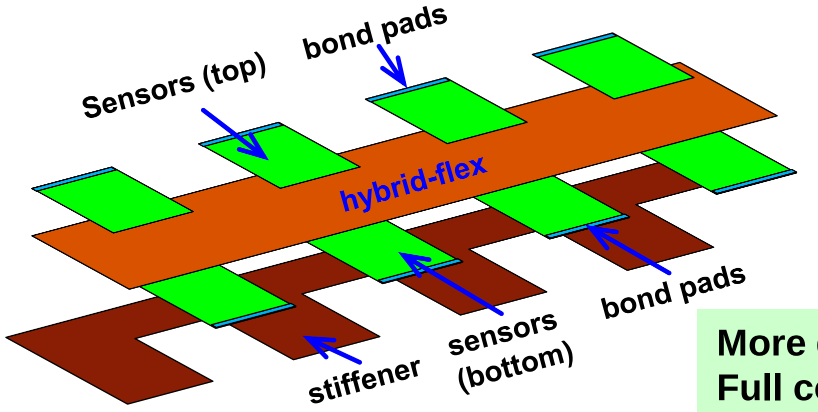


Easier to produce



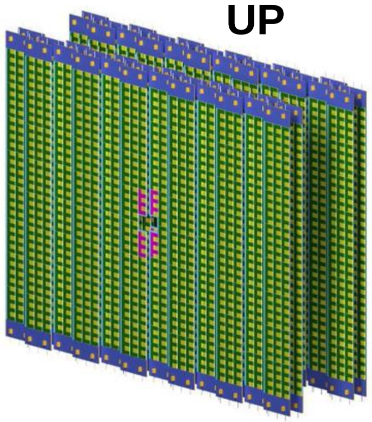
Medium difficult to produce

Possible to replace module

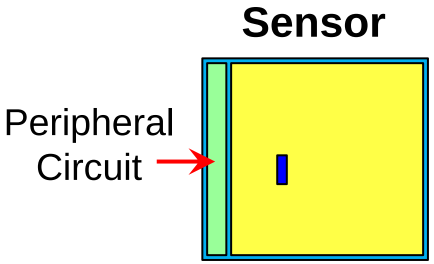


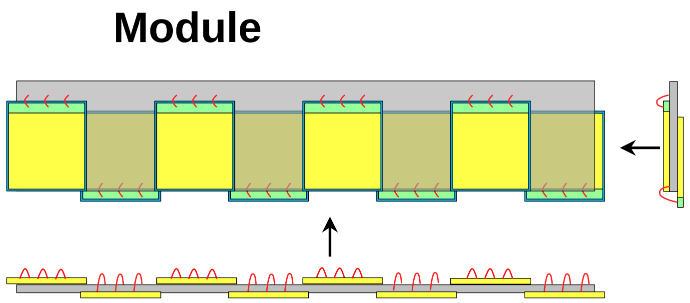
More difficult to produce

Full coverage

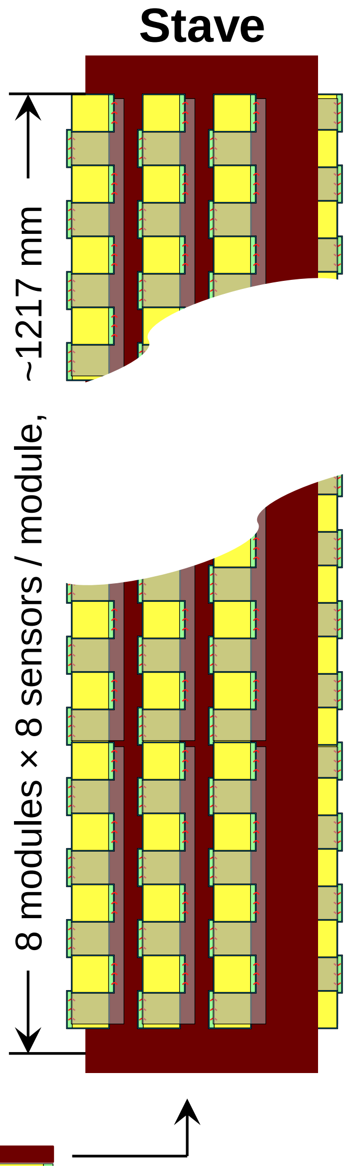


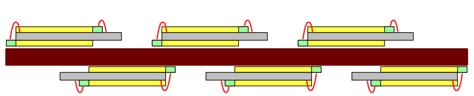
Sensor y-overlaps in a module
Module x/y-overlaps in a stave
Stave x-overlaps in a plane





avoid inefficiency from guard ring,
dicing margin, & safety gap

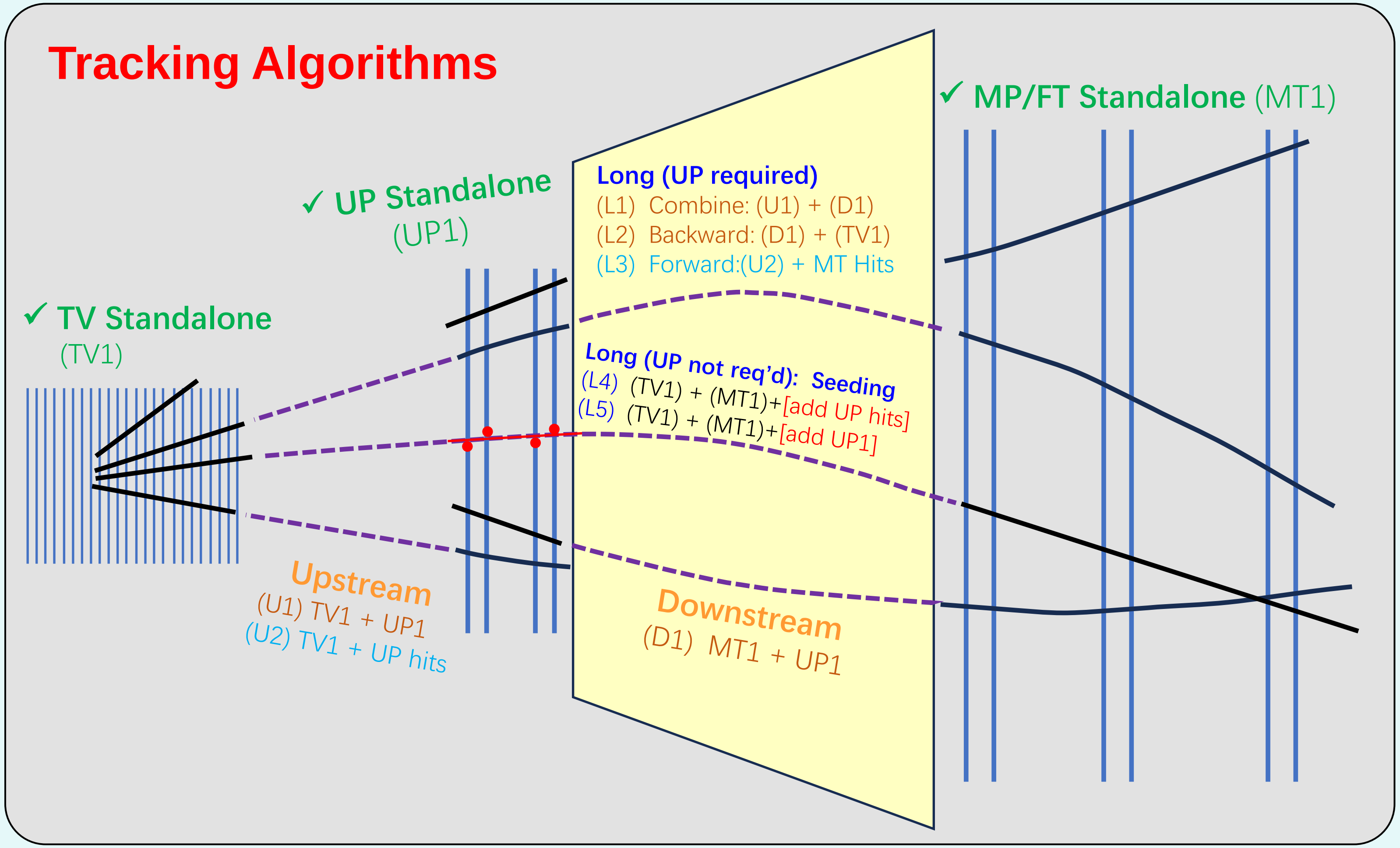




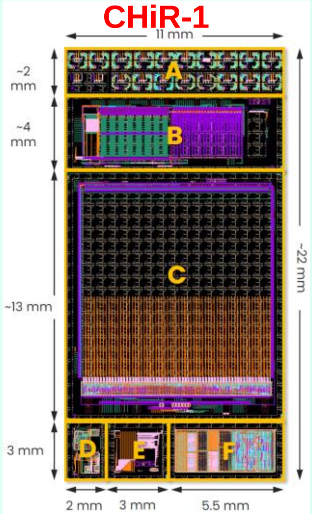
Reconstruction of Charged Particle Tracks

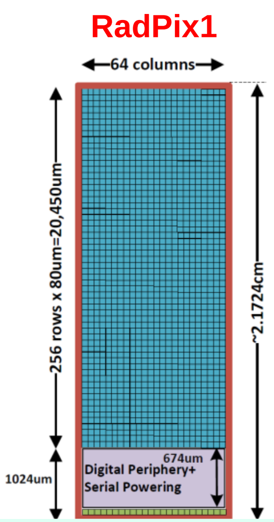
- ❑ New UP standalone algorithm ········ (UP1)
- ❑ Two new upstream algorithms
  - TV + UP1 ································ (U1)
  - TV + UP hits ···························· (U2)
- ❑ New downstream algorithm ············ (D1)
- ❑ Optimized and new Long track algorithm
  - UP required ····················· (L1/L2/L3)
  - UP not required ··················· (L4/L5)

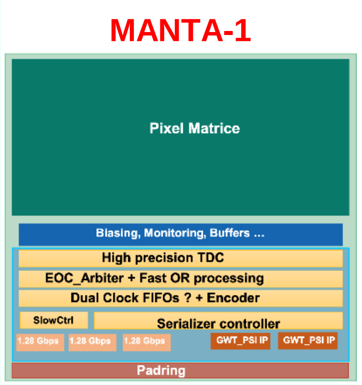
Achieved higher efficiency and lower ghost rate



Sensor Chip Development

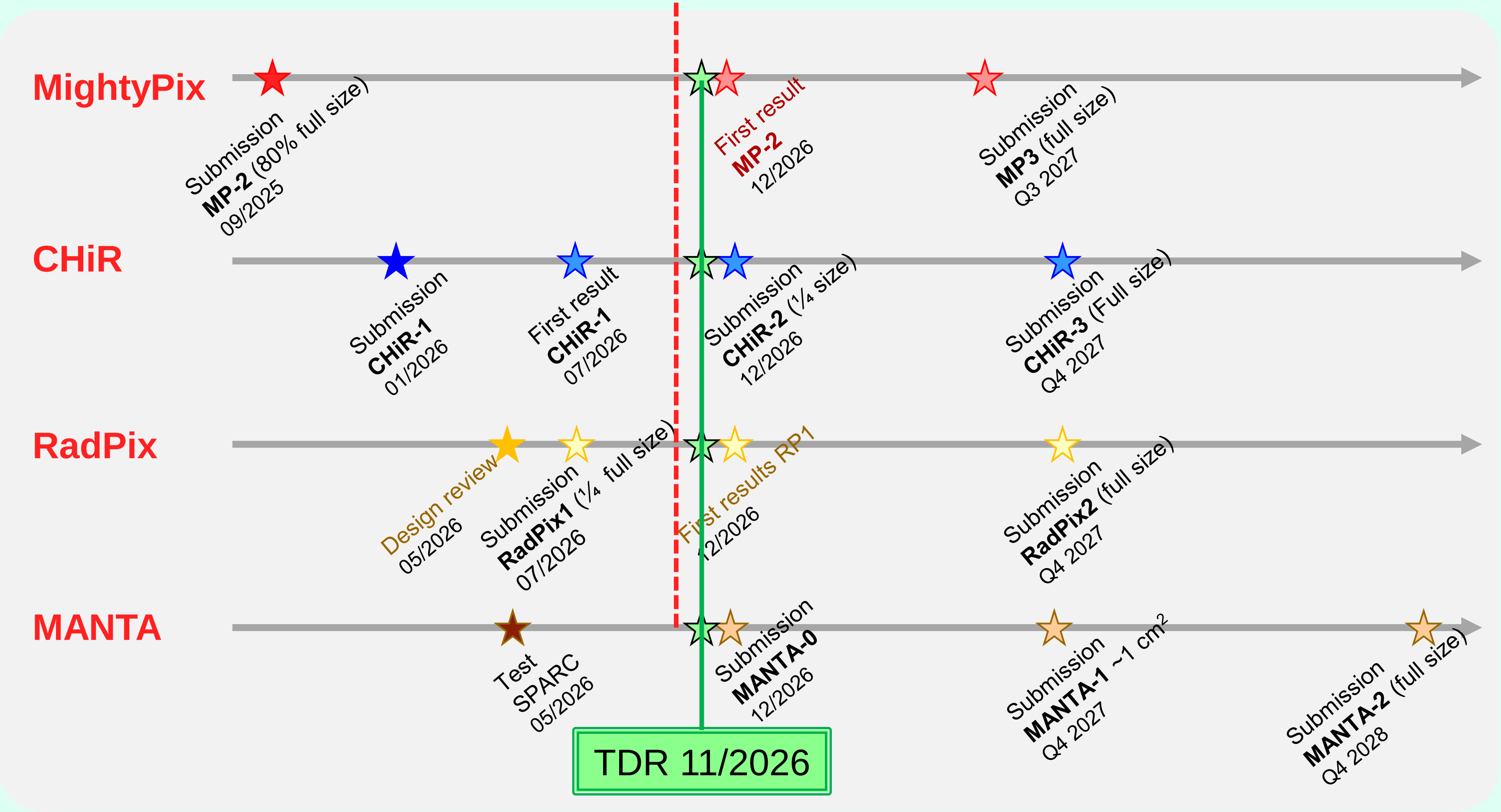




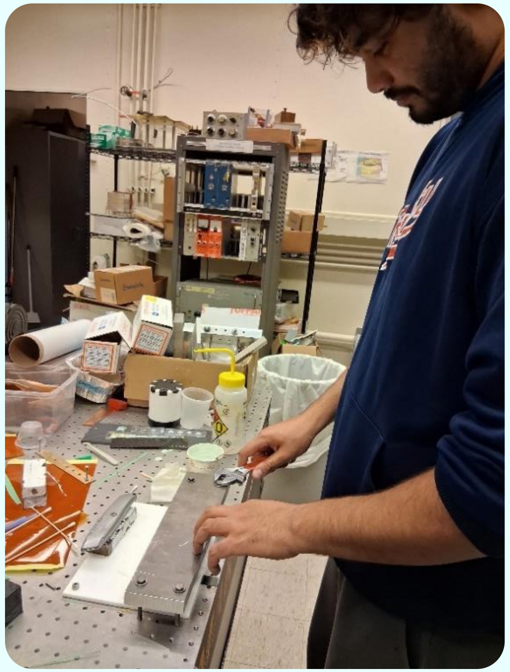


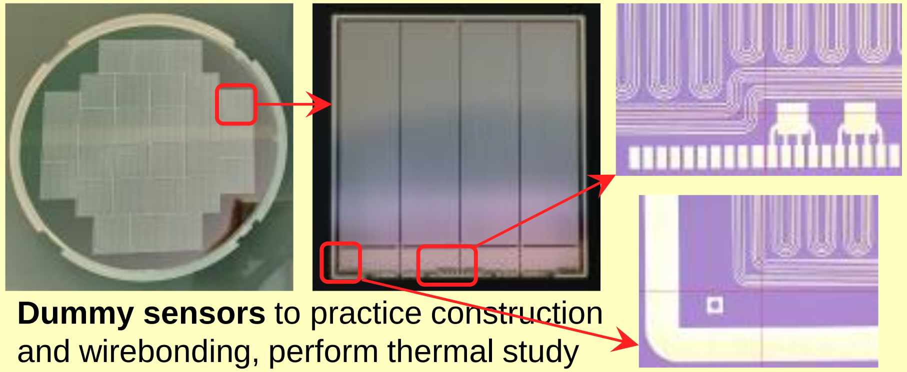
Assess the evidence of radiation hardness and serial powering

- Spatial resolution ~ 10 μm
- Time resolution 3-5 ns
- Power < 200 mW/cm²
- Rad-hard: 3×10^{15} n_{eq}/cm^2

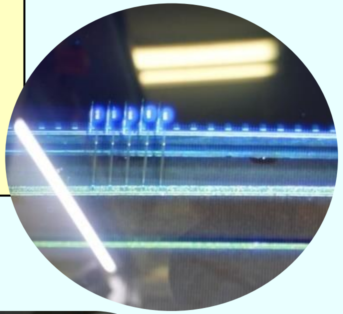


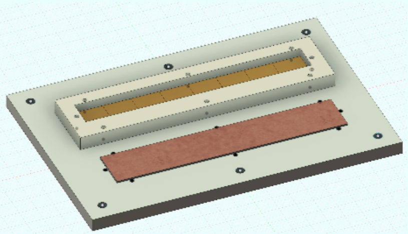
Module Prototyping

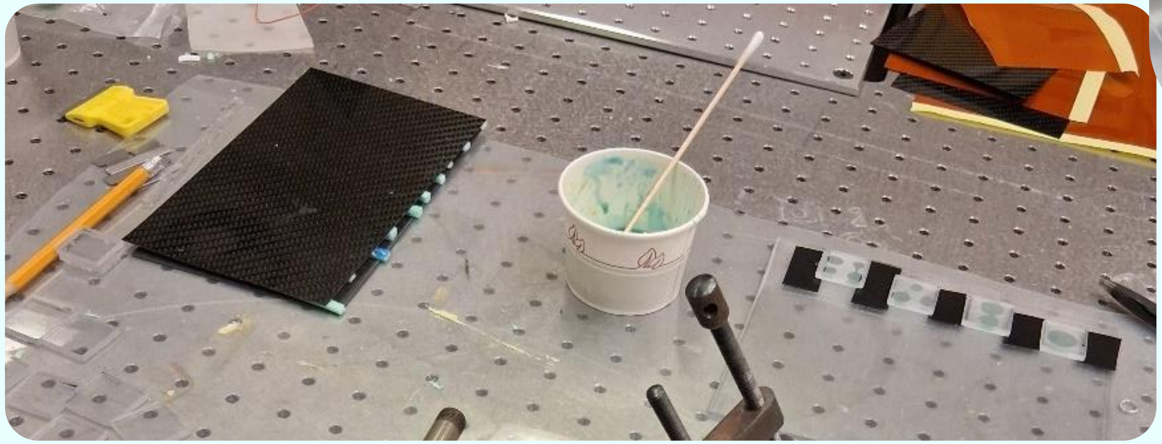


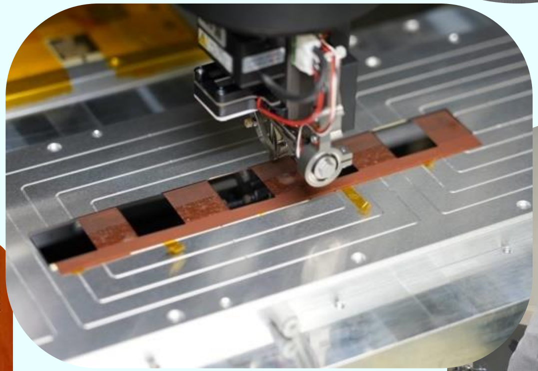


Dummy sensors to practice construction and wirebonding, perform thermal study

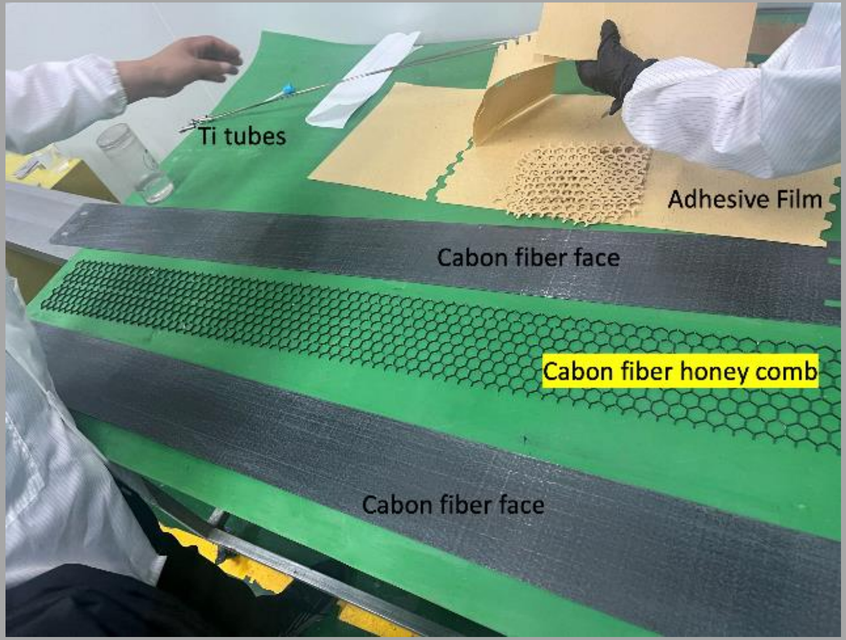


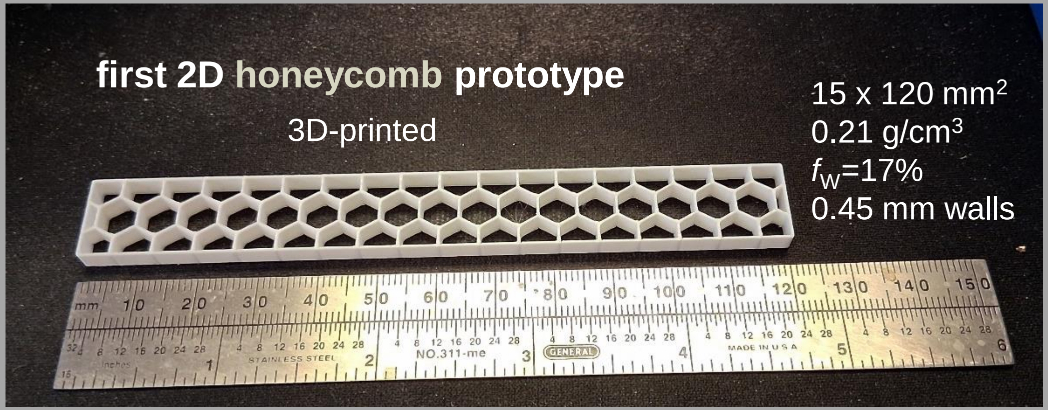




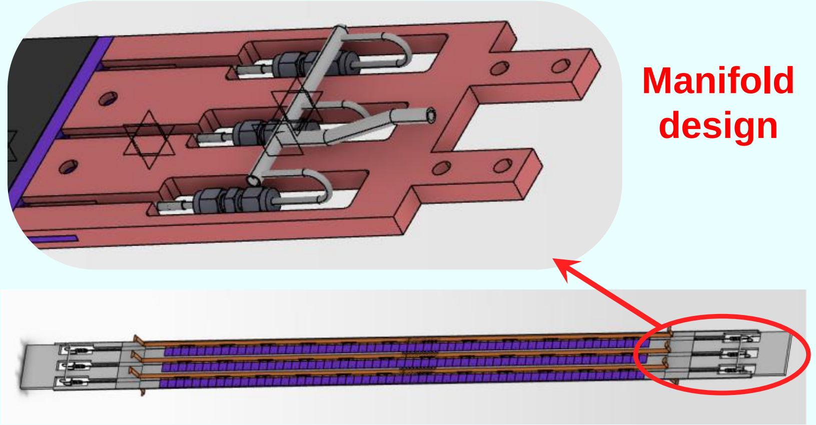


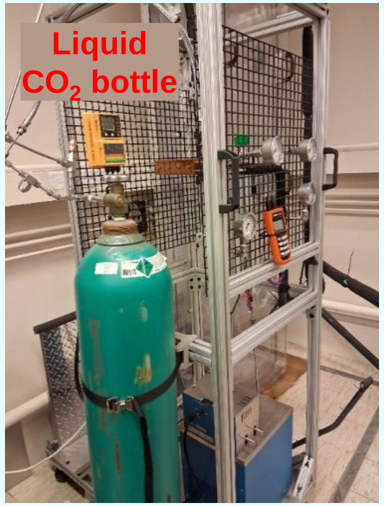
Stave Prototyping

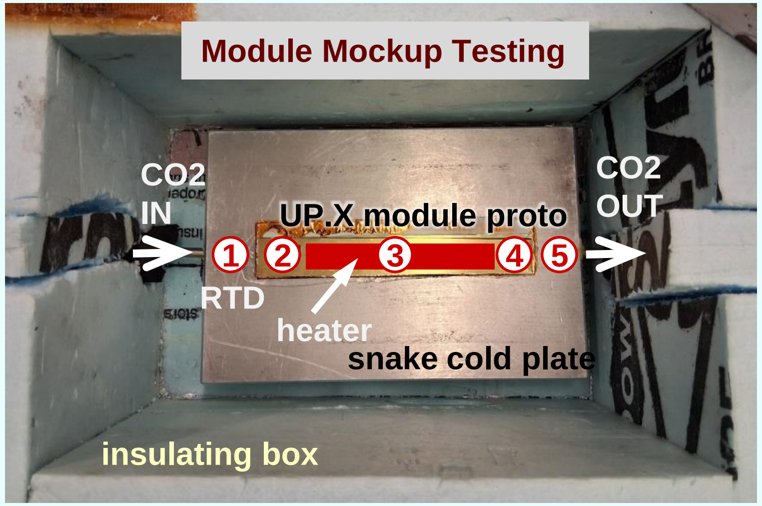




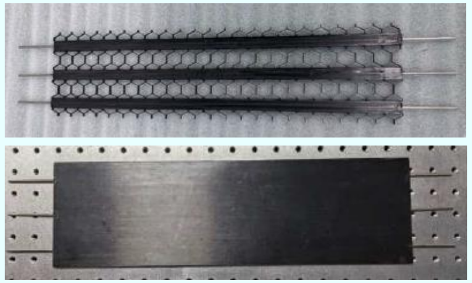
Cooling Scheme and Test

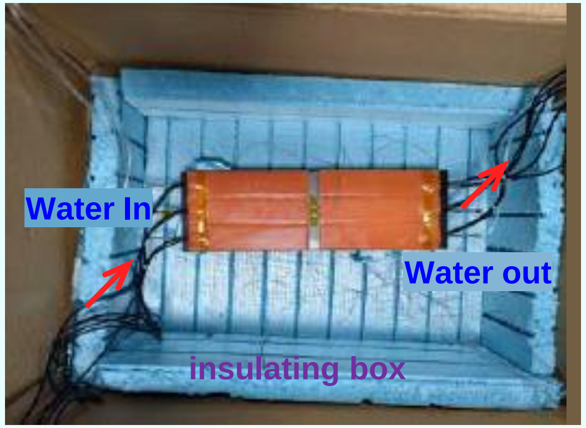




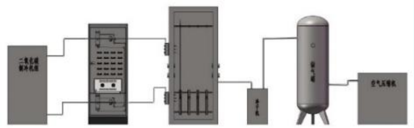


Slice System

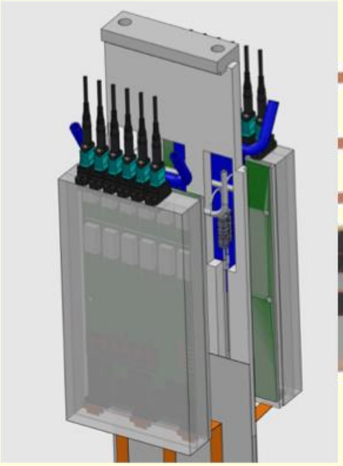


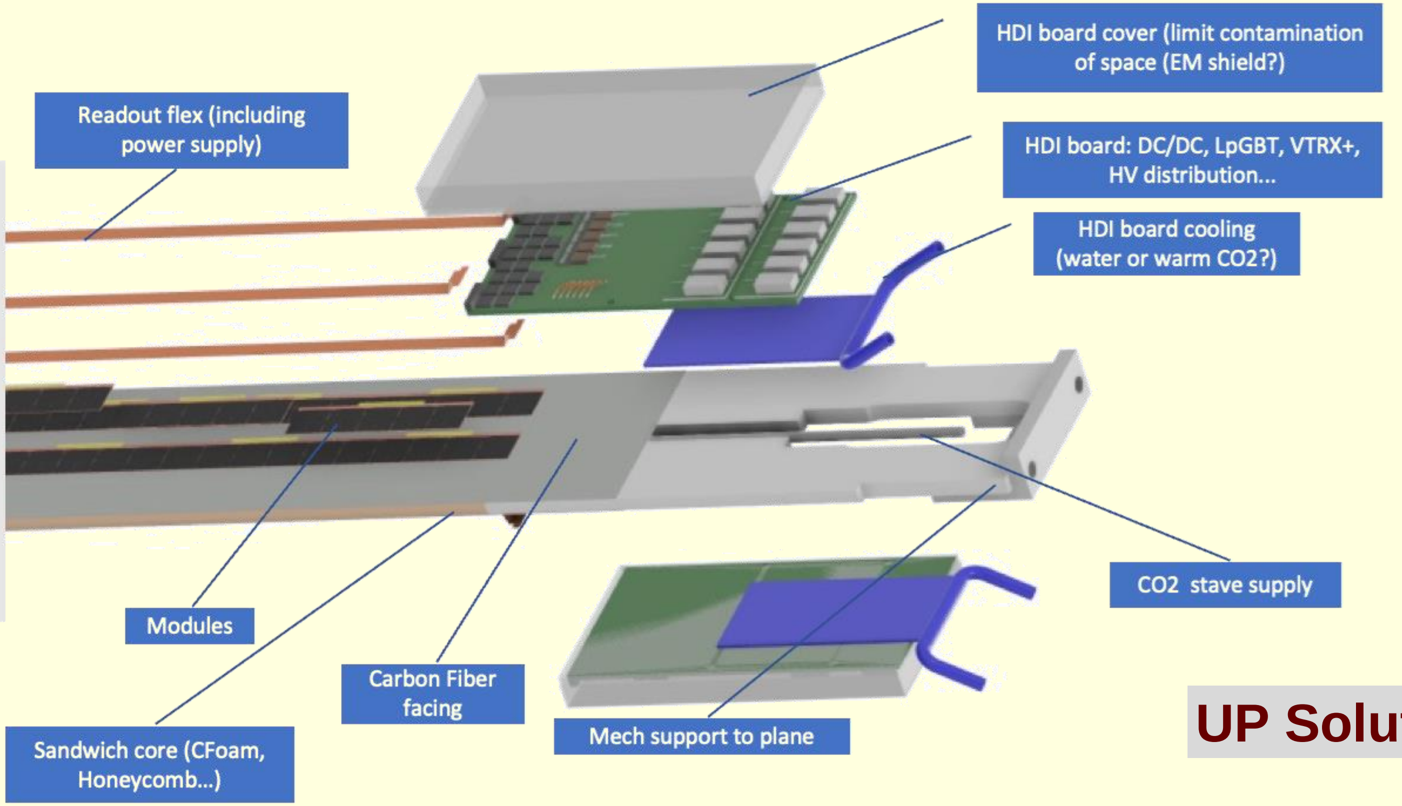


Bi-Phase CO2
cooling test system

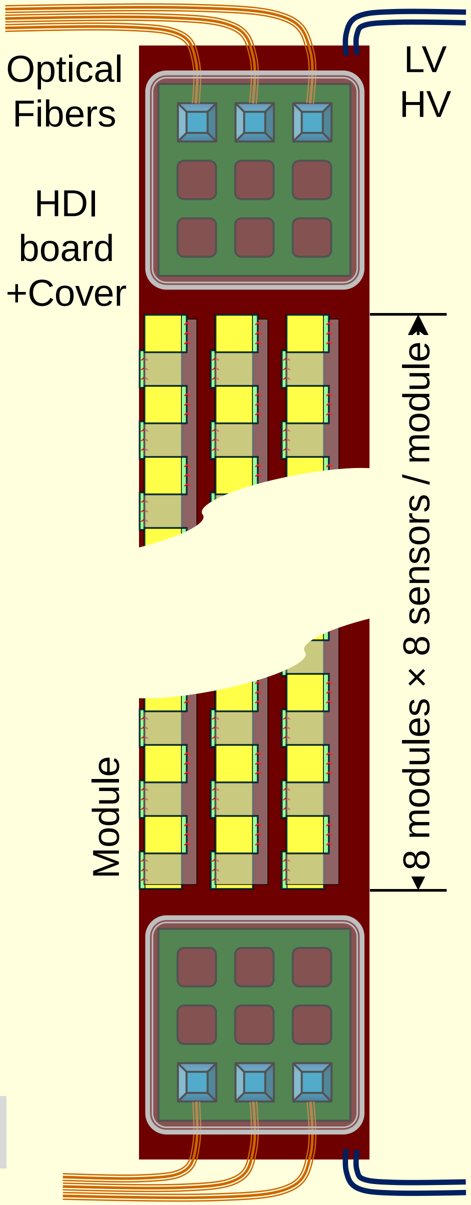


Connection of Peripheral Electronics

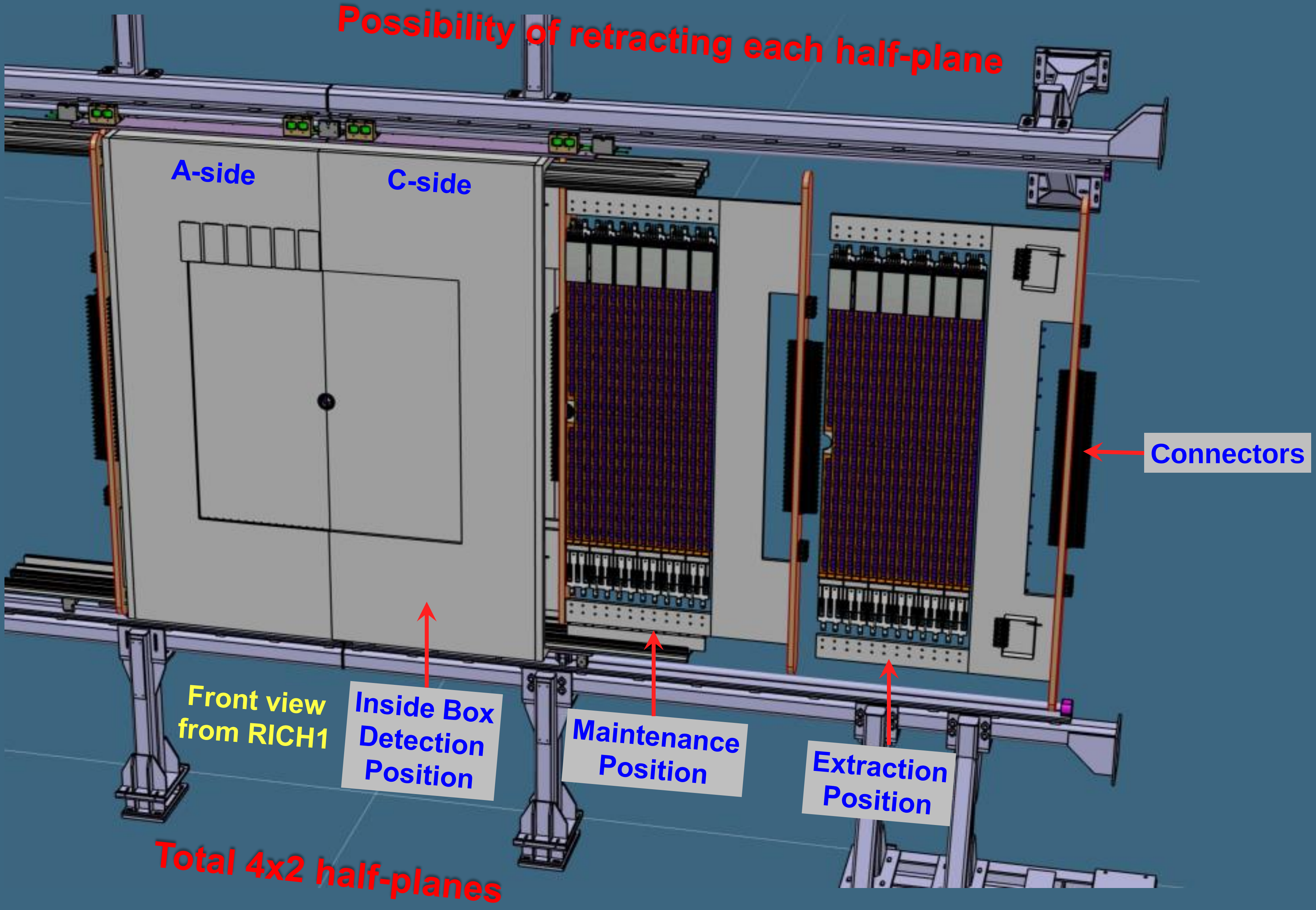


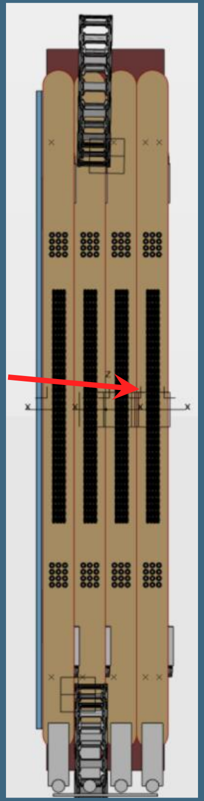


UP Solution



Detector Supporting Structure and Protection Box

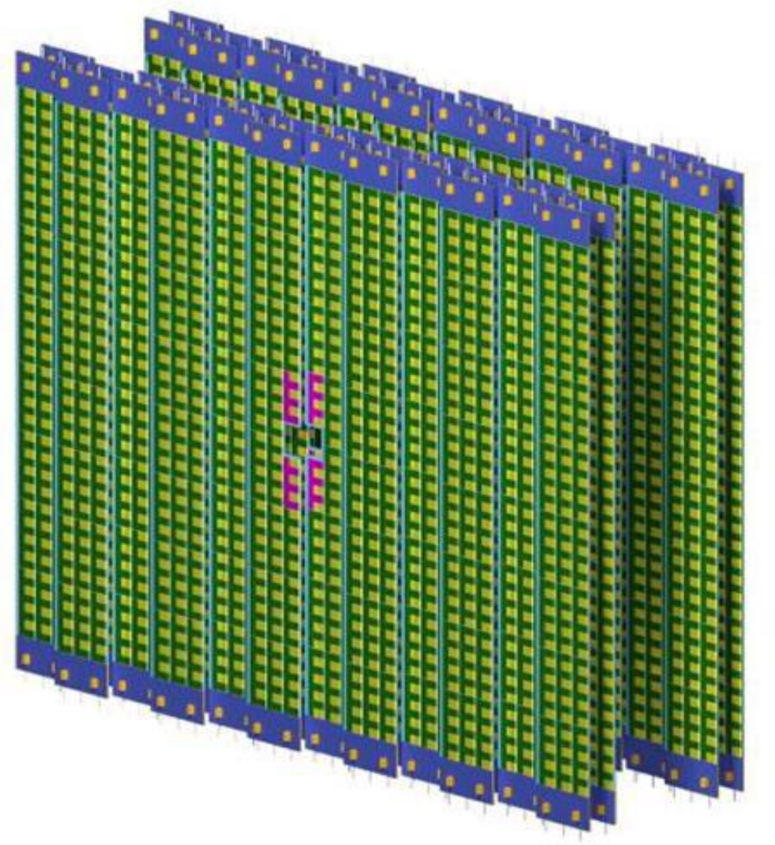




Side view

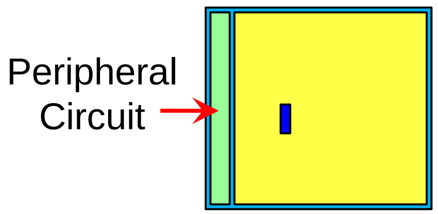
Detector Component Production

UP Detector

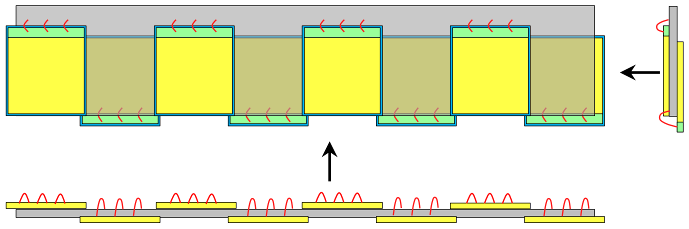


- **Production volume** (including spares):
  - ~22,000 sensors | ~2,600 modules | ~54 staves
- **Pipelined workflow:**
  - Module production: 24 months
  - Stave assembly: 8 months
  - Half-plane integration: 12 months (8 units total)
- **Production preparation**
  - Sensor chip is critical in the project. Plan to finalize the sensor design in 2028
  - A designated wafer probe test site has been identified
  - Preparing for 3-5 module / stave construction sites
  - Following closely the LHC revising timeline, and trying to reserve reasonable contingency

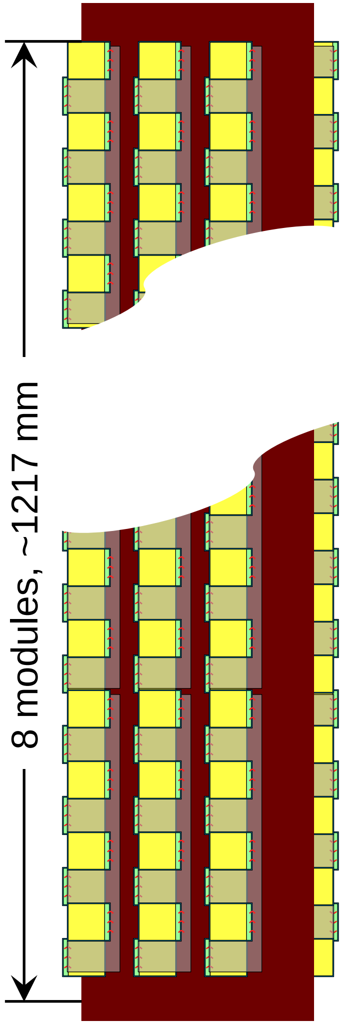
Sensor



Module

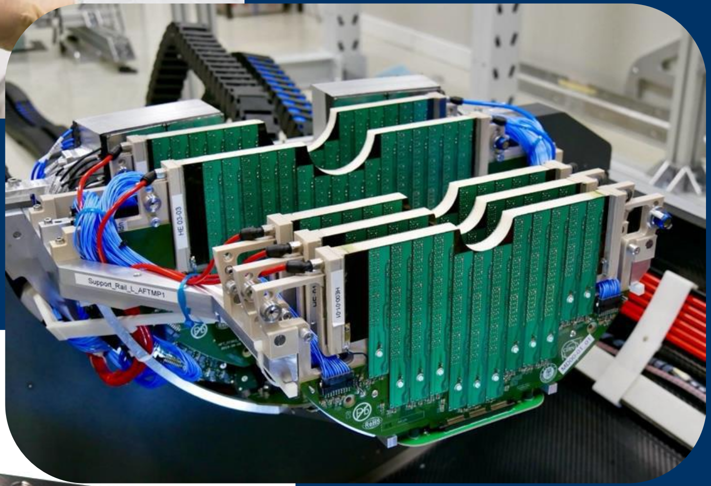


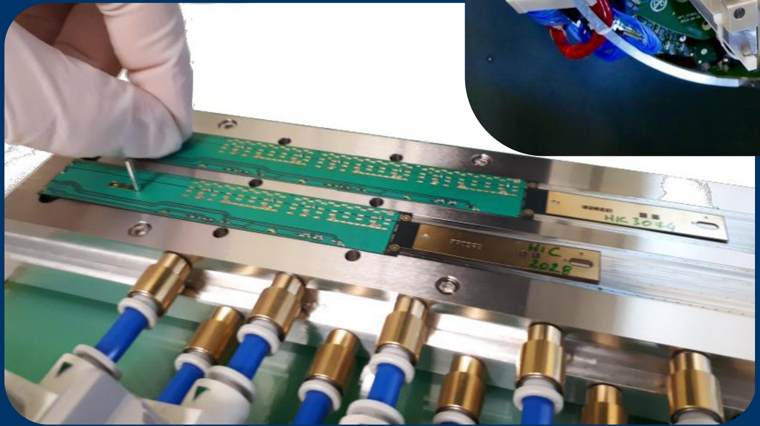
Stave



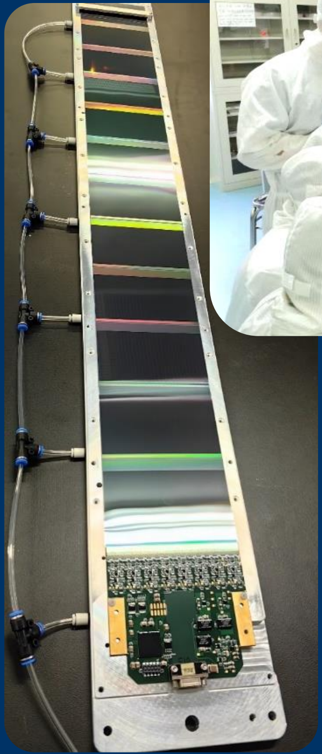
LHCb UT construction at SYR

ALICE MFT construction in IRFU lab@CERN



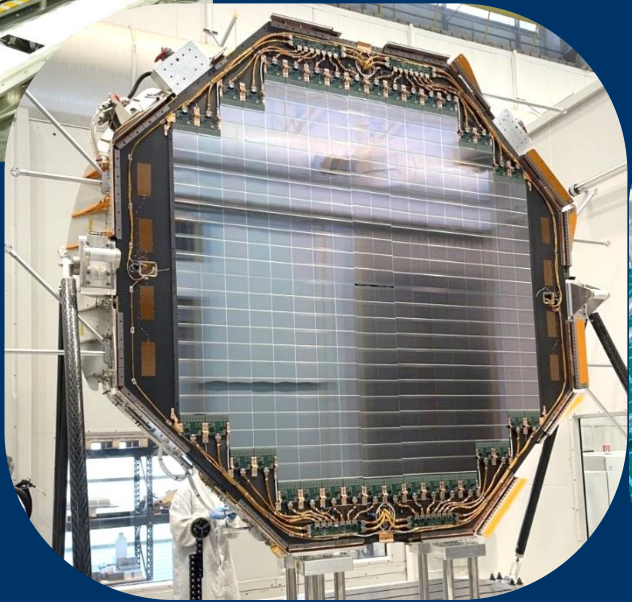


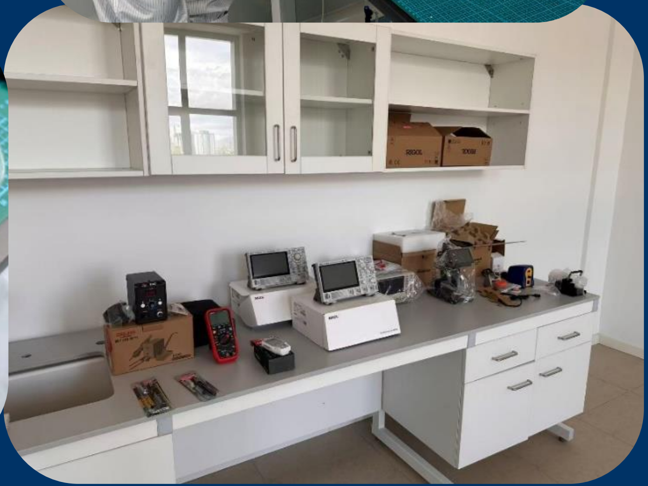
CNC 5-axis Machining Center

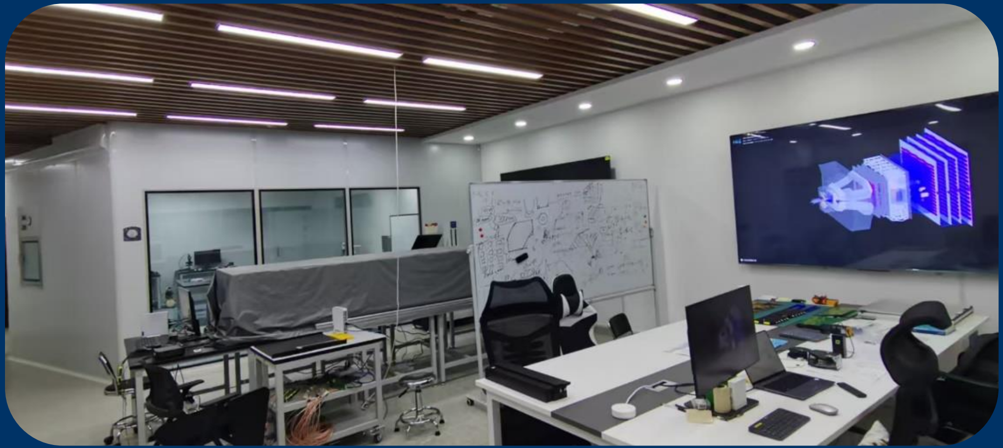


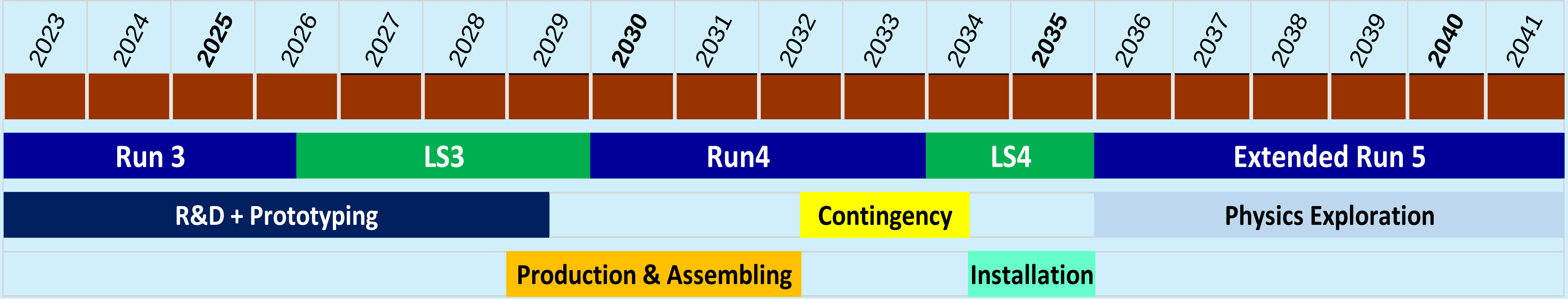
AMS L0 tracker construction at IHEP

LZU & IPT prepare to share responsibilities









Thanks to the supports from FCPPN/L,

the Chinese and French UP teams will continue to work closely
to ensure a successful UP detector upgrade

Thanks for your attention !