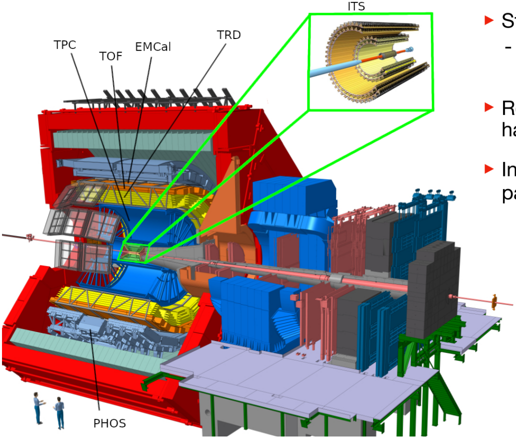
A truly cylindrical inner tracker for ALICE

Alperen YÜNCÜ
on behalf of ALICE

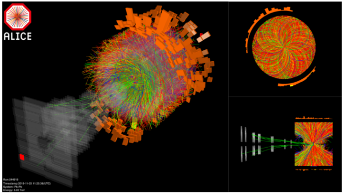
June 15, 2022

ALICE

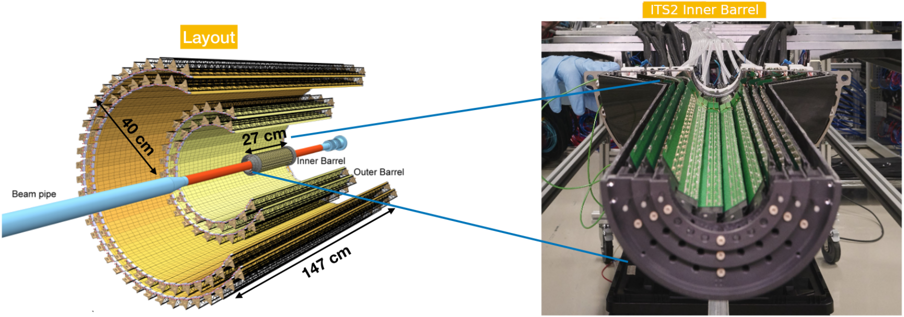
Detector and main goals



- Study of QGP in heavy-ion collisions at LHC
  - i.e. up to O(10k) particles to be tracked in a single event
- Reconstruction of charm and beauty hadrons
- Interest in low momentum (≲1 GeV/c) particle reconstruction

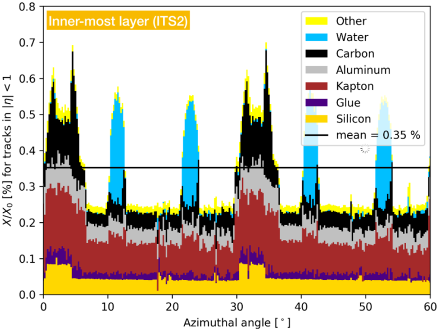


Current Inner Tracking System (ITS2)



- ITS2 is expected to perform according to specifications or even better
- The inner barrel is ultra-light (0.35% X_0 per layer) but still most of the material comes from supports $\Longrightarrow$ further improvements seem possible
- Key questions:
  - Can we get closer to the interaction point?
  - Can we reduce the meterial budget even further?

Motivation for ITS3



- Observations:
  - $0.35\ \%\ X_0$ per layer
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  - Irregularities due to support/cooling

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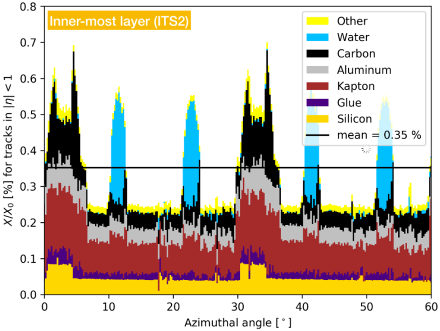

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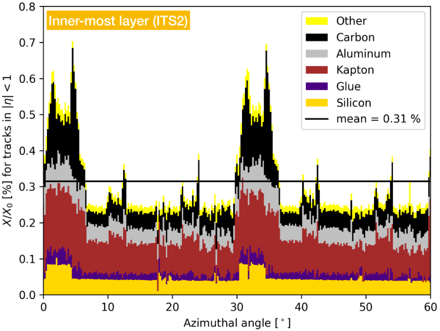

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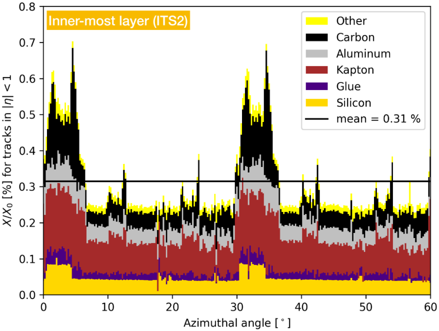

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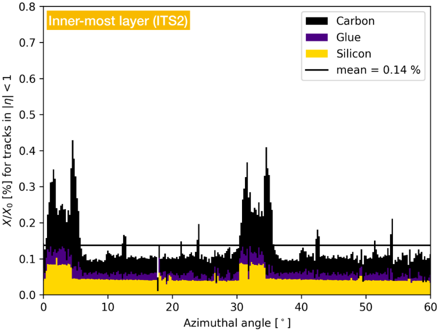

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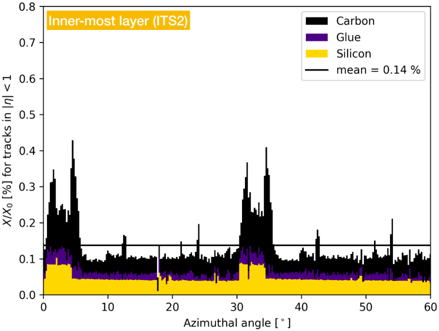

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  - Benefit from increased stiffness by bending Si wafers into cylinderical shape

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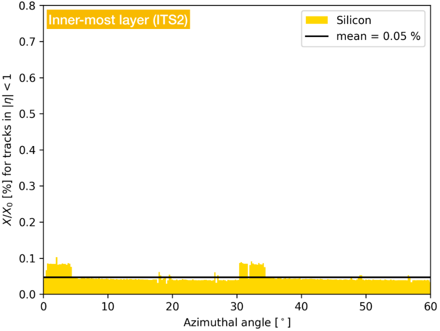

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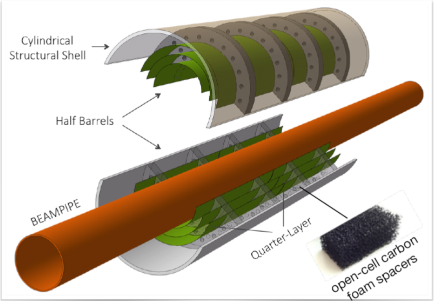
- Removal of mechanical support
  - Benefit from increased stiffness by bending Si wafers into cylinderical shape
  - $0.05\ \%\ X_0$ per layer

ITS3 detector concept

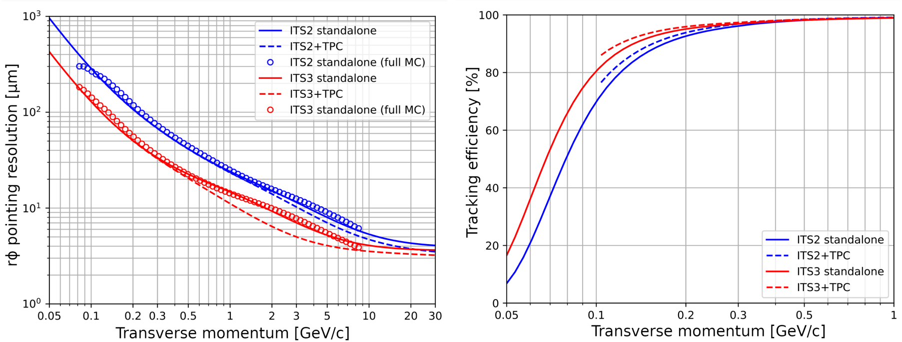


Beam pipe Inner/Outer Radius (mm)	16.0/16.5		
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	280		
Pseudo-rapidity coverage	±2.5	±2.3	±2.0
Active area (cm²)	610	816	1016
Pixel sensor dimensions (mm²)	280 x 56.5	280 x 75.5	280 x 94
Number of sensors per layer	2		
Pixel size (μm²)	O (10 x 10)		

- Key ingredients:
  - 280 mm wafer-scale sensors, fabricated using stitching (Tower Partners Semiconductor (TPSCo) 65 nm CMOS Imaging Sensor (CIS) process)
  - Thinned down to 20-40 μm (0.02-0.04% X_0), making them flexible
  - Bent to the target radii
  - Mechanically held in place by carbon foam ribs
- Key benefits:
  - Extremely low material budget: 0.02-0.04% X_0 (beampipe: 500 μm Be: 0.14% X0)
  - Homogeneous material distribution: negligible systematic error from material distribution

THE WHOLE DETECTOR WILL COMPRISE SIX (!) SENSORS (CURRENT ITS IB: 432) AND BARELY ANYTHING ELSE

ITS3 performance



- Improvement on pointing resolution is factor of 2 over all momenta.
- Large improvement on tracking efficiency especially for low momenta.

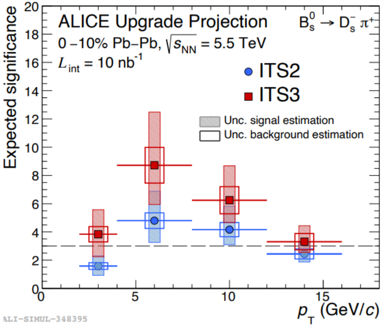
Measurements that will benefit from the ITS3 Upgrade

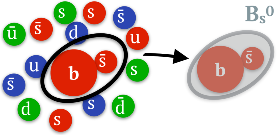
- Low-mass dileptons
- Beauty-strange mesons
  - exclusive reconstruction of B_s^0
  - non-prompt D_s^+ ($50\,\%$ from $B_s^{0,+}$ and $50\,\%$ from B_s^0)
- Beauty baryons
  - non-prompt Λ_c^0
  - exclusive reconstruction of Λ_b^0
- Charm strange and multi-strange baryons
  - Ξ_c^0(cds),Ξ_c^+(cus),Ω_c^0(css)
- Searches for light charm hypernuclei
  - bound state of a Λ_c^+ and a neutron (c-deuteron)
  - bound state of a Λ_c^+ and a deuteron (c-triton)

Expected performance: B_S^0 mesons

- Study beauty-quark hadronisation mechanism
- B_s^0 production expected to be enhanced
- hadronisation of beauty quarks via recombination and enhanced strange-quark production in the QGP

$$B_s^0 \to D_s^- \pi^+ \to \phi \pi^- \pi^+ \to K^+ K^- \pi^- \pi^+$$

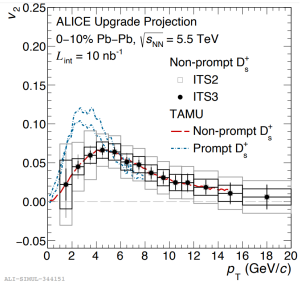


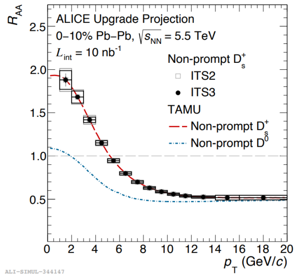


- Improvement by a factor 2 in significance with ITS3
- provide access to B_s^0 measurement at very low p_T

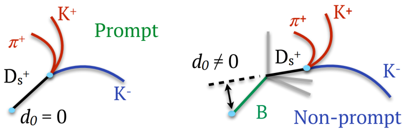
PLB 735, 445-450 (2014)

Expected performance: D_S^+ Mesons





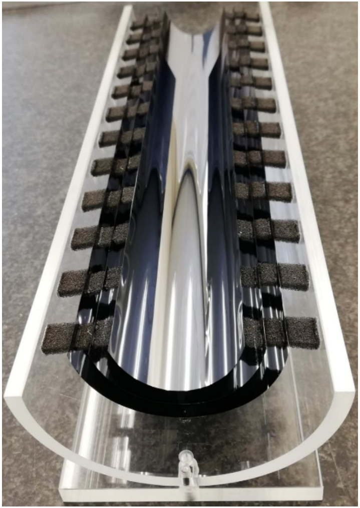
$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$



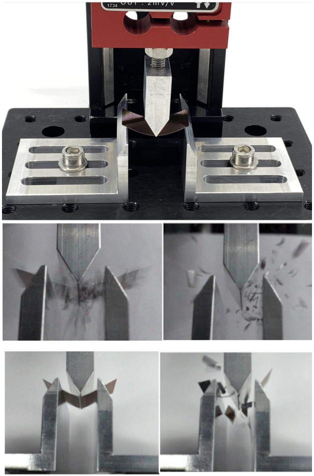
- Non-prompt D_s^+ from B decays:
  - even if not direct measurement, sensitive to B_s^0
  - larger statistical precision than exclusive B_s^0 reconstruction
- Comparison between non-prompt D_s^+ and non-strange D mesons sensitive to beauty-quark hadronisation and strangeness enhancement
- Non-prompt D_s^+ azimuthal anisotropy
  - Participation of beauty quarks in the collective motion and possible thermalisation in the QGP
  - Information about beauty-quark diffusion coefficient in the QGP
- **ITS3**:
  - sensitivity to discriminate azimuthal anisotropy for prompt and non-prompt D_s^+ (charm vs. beauty)

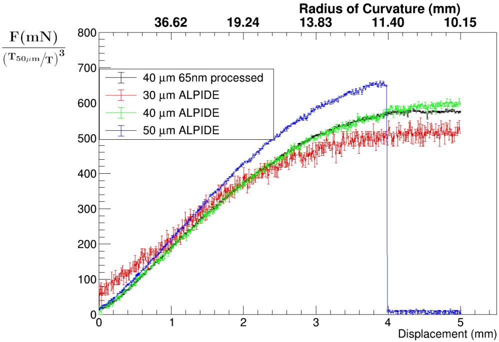
Challenges

- Questions:
  - Can silicon be bent without breaking?
  - Are ASICs still functional in bent chip?
  - Can wafer-scale, thinned sensors be integrated without additional support structure?
  - Can air cooling be effective enough?
  - Can 280 mm long silicon sensor be produced?



Flexibility of silicon



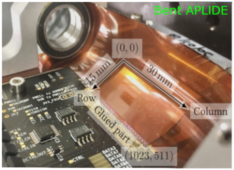


- Sensors at the current thickness($50\ \mu$m) are even flexible enough (The smallest radius in ITS3 is 18 mm)
- The thinner sensor can be bend smaller radius.

ITS3 TARGET RADIUS AND THICKNESS ARE VERY FEASIBLE

Sensor characterisation

- For last 2 years, more than 10 test beams have succesfully performed at DESY, SPS, PS...etc
- In these testbeams we have tested several setups:
  - bent ALPIDEs with several radii
  - μITS3, a mock-up for ITS3
  - MLR1 test systems



Testbeam: June 2020 (DESY)

doi.org/10.1016/j.nima.2021.166280

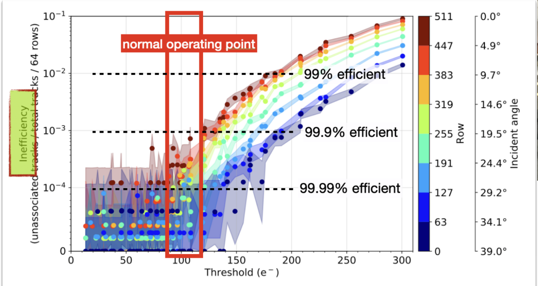
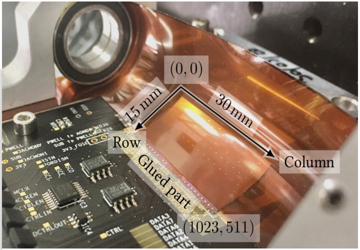
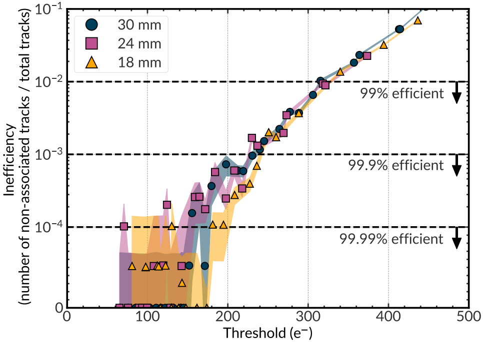


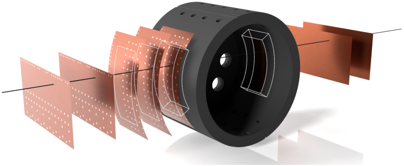
Fig. 10: Inefficiency as a function of threshold for different rows and incident angles with partially logarithmic scale (10^{-1} to 10^{-5}) to show fully efficient rows. Each data point corresponds to at least 8k tracks.

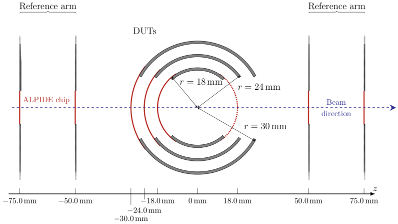


- Bent ALPIDE has high efficiency
- ASICs are functional in bent ALPIDE

Testbeam: April 2021 (DESY)

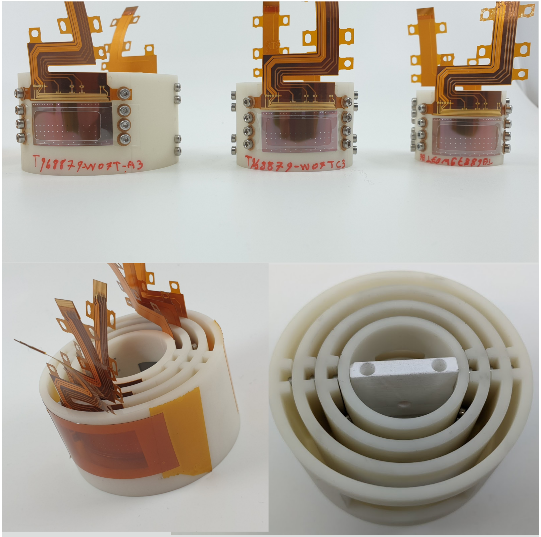






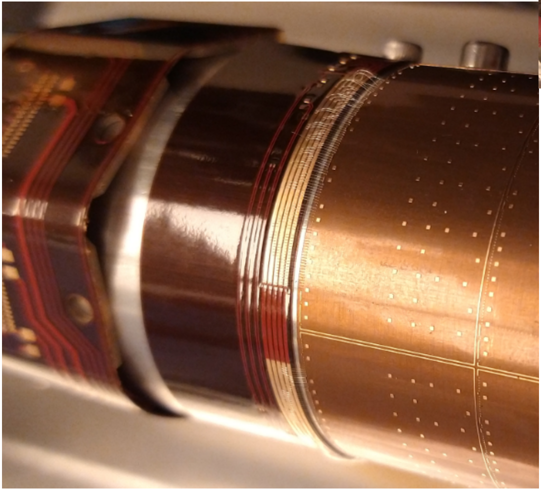
- Still has high efficiency on target radii

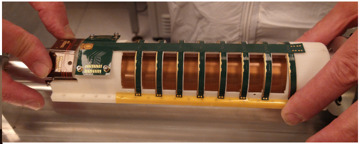
μITS3



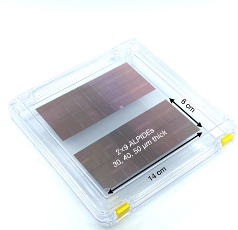
- μITS3 - mock-up of final ITS3
  - 6 ALPIDE bent to ITS3 target radii
  - Experience with handling thin, bent silicon was gained
- Also used with Cu target in the center, expect to see 120 GeV p-Cu collisions
- Analysis of μITS3 is in progress.

Super ALPIDE

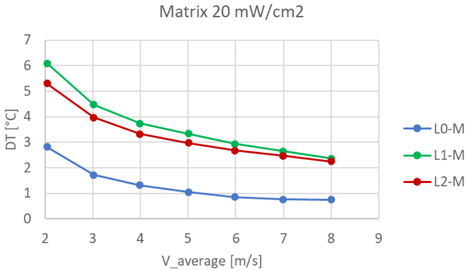


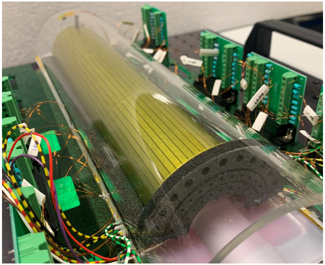


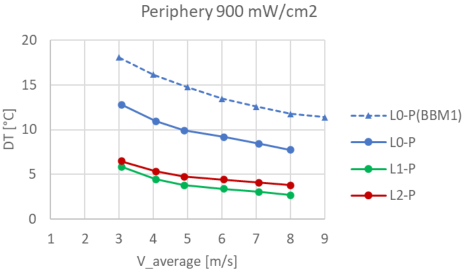
- 9×2 array of ALPIDE chips
- A mock-up sensor to investigate integration and interconnection of large-scale, thinned and bent sensors



Wind Tunnel Cooling Studies

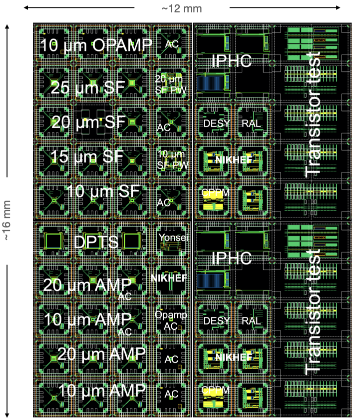






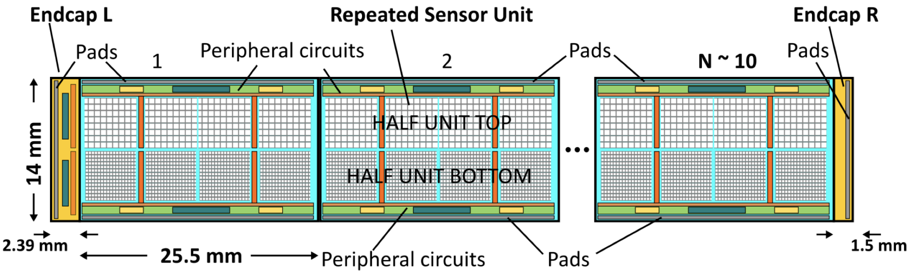
- Different power & air speed
- Carbon foam radiator are key for heat removal at periphery
  - L1 and L2 DT $< 10^{\circ}$C
  - L0 has relatively larger temperature DT to air (further optimization on L0 Carbon foam layout)
  - Power density concentrated on 2.5 mm periphery

MLR1, Test Structures for 65nm



- Tower Partners Semiconductor (TPSCo) 65 nm CMOS Imaging Sensor (CIS) Process
- Contained several test chips
  - radiation test structures
  - pixel test structures
    - DPTS
    - APTS
    - CE65
  - pixel matrices
  - analog building blocks (band gaps, LVDS drivers, etc)
- Characterisation is succesful
- High efficiency is confirmed

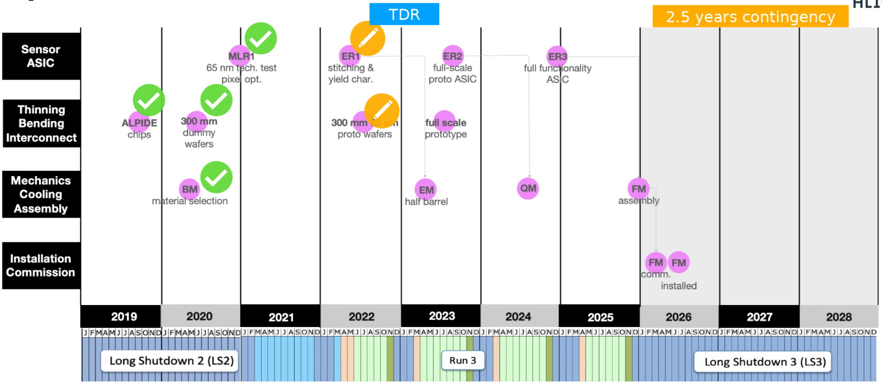
Stiching



- Stitching used to connect metal traces for **power distribution** and **long range on-chip interconnect busses for control and data readout**
- Primary goals:
  - Learn stitching to make a charged-particle detector
  - Interconnect power and signals on wafer scale design
  - Learn about yield
  - Study power, leakage, spread, noise, speed

Timeline

update on main milestones



MLR: multiple layer per reticle, **ER:** engineering run,
BM: breadboard module, **EM:** engineering module, **QM:** qualification module, **FM:** final module

Summary

- ITS3 replaces the 3 innermost layers of ALICE ITS2 by a bent, wafer scale MAPS detector which reduces material budget by factor of 7.
- Major milestones have been passed such as:
  - Full size mechanical integration prototypes exist
  - Air cooling concept verified by full size mockup
  - Bending of thinned sensors verified
  - Tower Partners Semiconductor 65 nm technology qualified
  - Building blocks and basic pixel matrices efficient
  - Successful beam characterisation of pixel sensor
- Next step to prove stitching and power/signal distribution on large structures