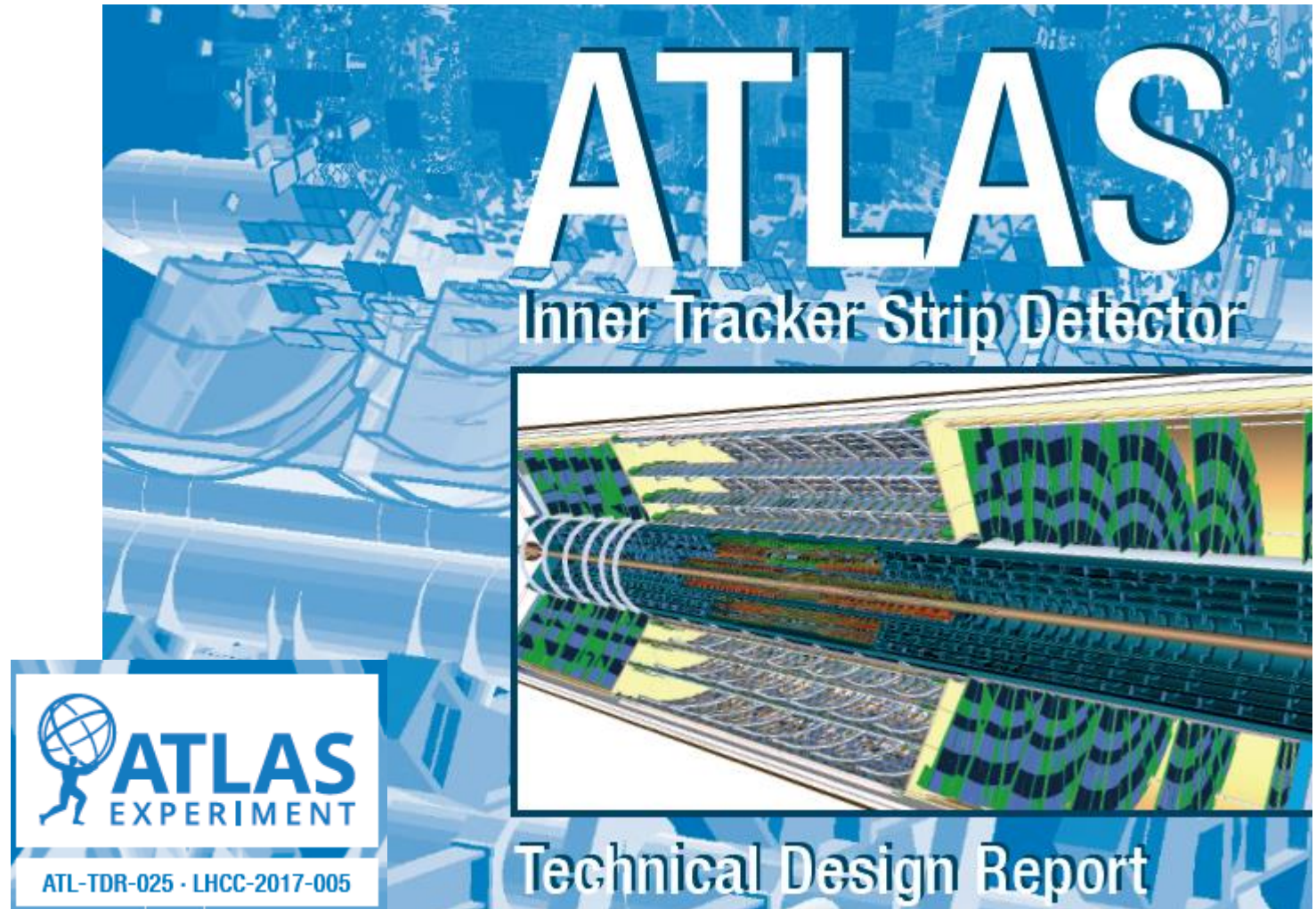


ATLAS ITk microstrip detector @HL-LHC

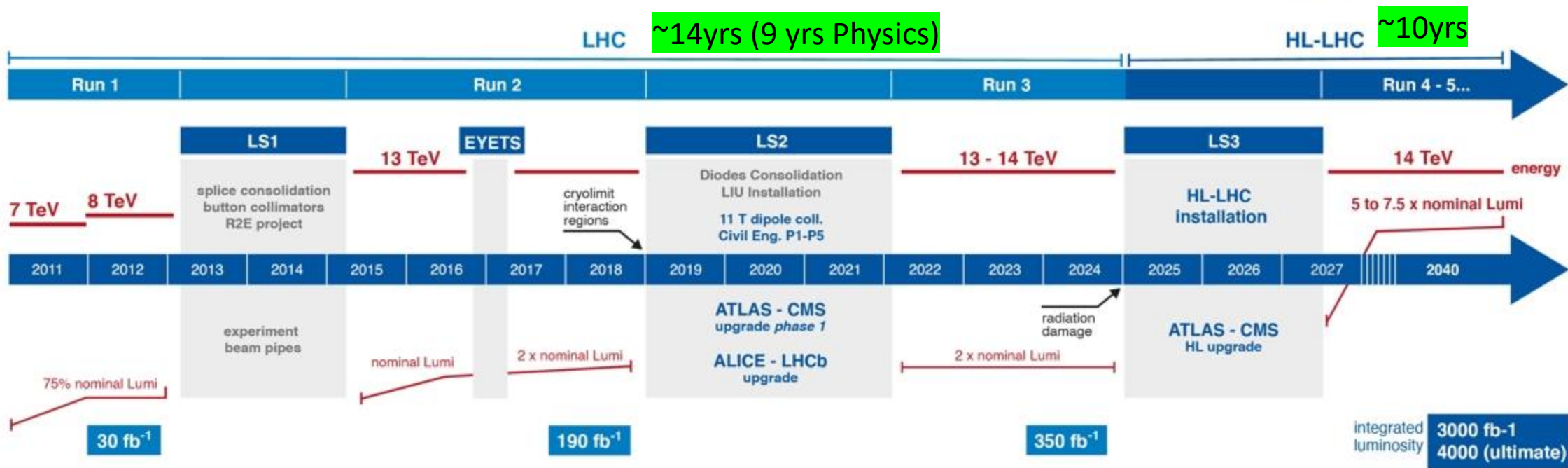
T. Ishii (U. Tsukuba B4)
K. Saito (U Tsukuba M1)
S. Hirose (U. Tsukuba)
K. Hara (U. Tsukuba)
K. Nakamura (KEK)

Final Design Review (FDR): April 2019
Sensor pre-production delivery: Jan-Mar 2020
Production Readiness Review (PRR):





LHC / HL-LHC Plan



HL-LHC TECHNICAL EQUIPMENT:



HL-LHC CIVIL ENGINEERING:



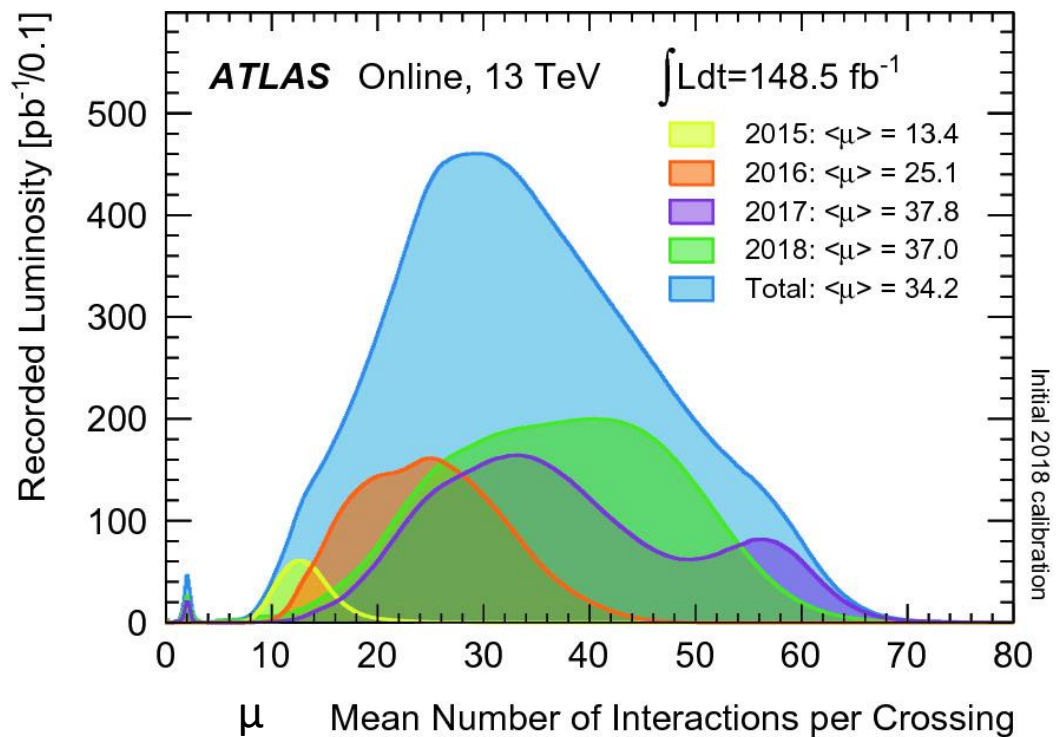
Higgs

now

HL-LHC physics

HL-LHCでは、LHC(350/fb)の10倍のデータ量(4000/fb)の取得をめざす

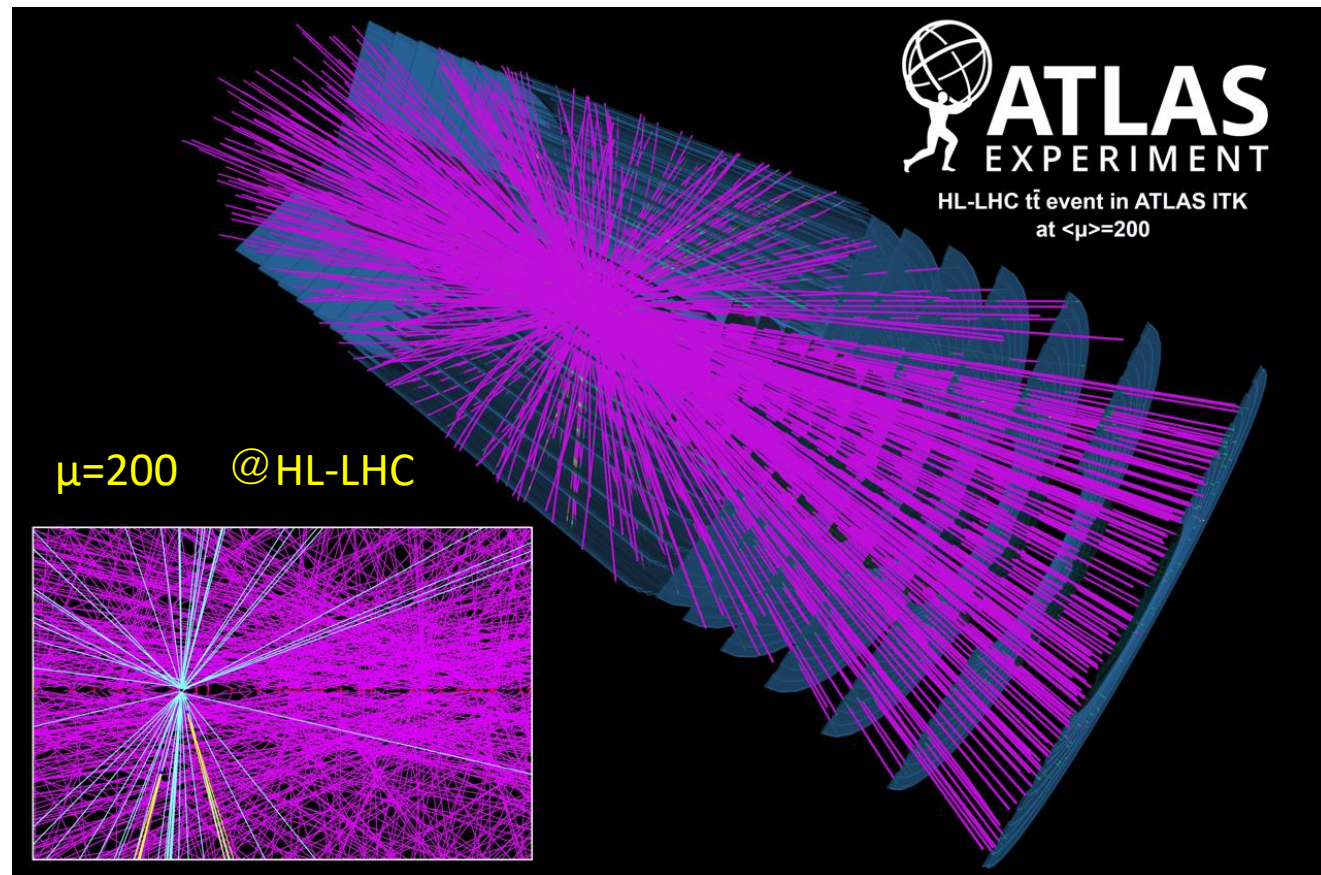
HL-LHC飛跡検出器への要求



10^{11} p/bunch

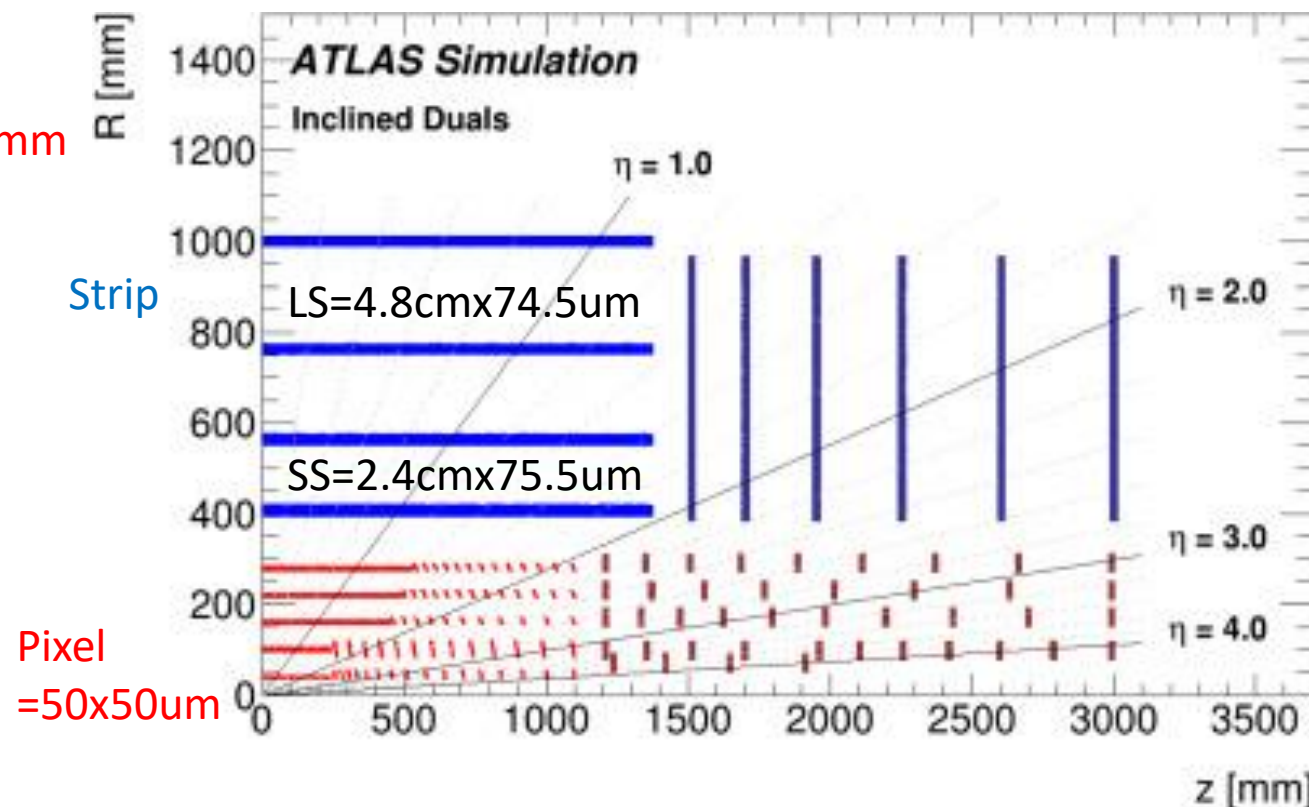
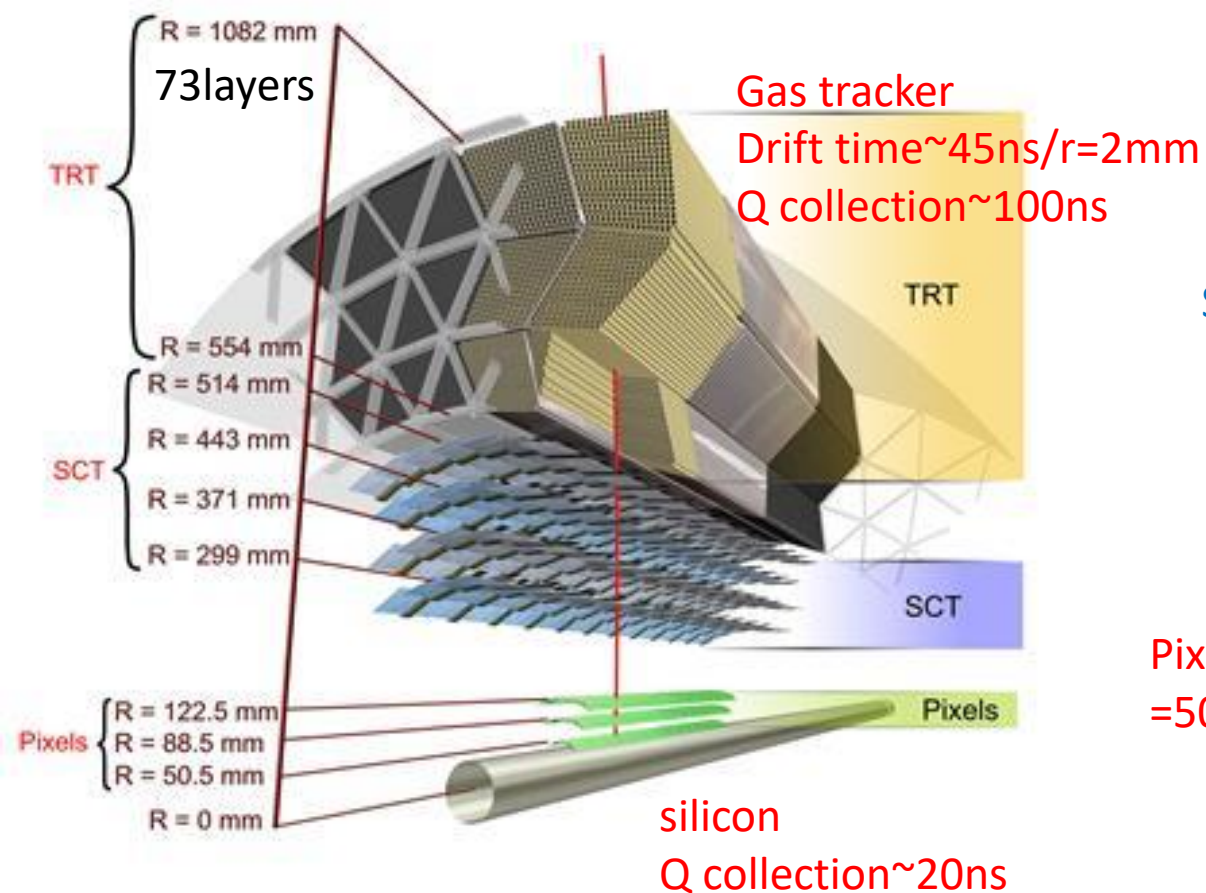


一度(25ns間隔)に複数のpp衝突がおきる



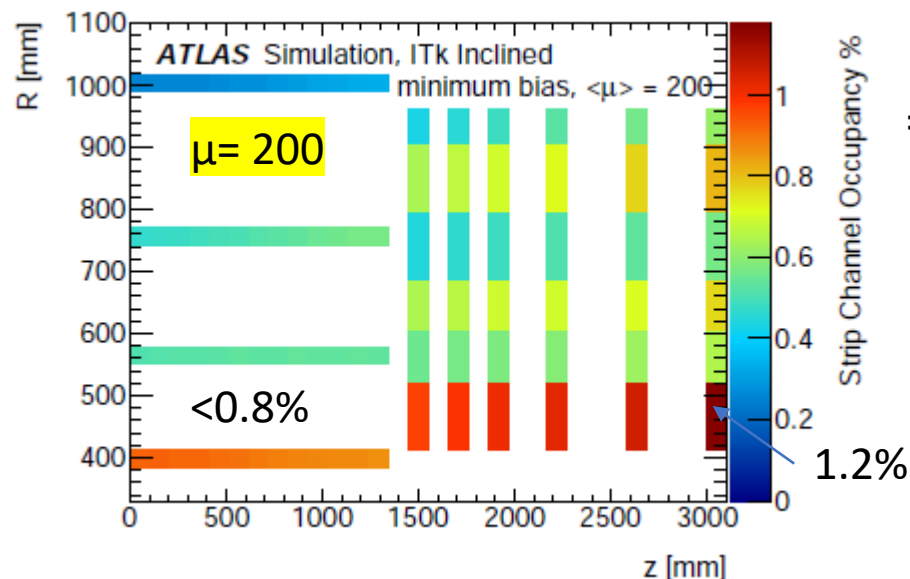
- ✓ 検出器でのpileupを下げる
 - ⇒すべて高速応答可能なSiのシステム
 - ⇒channelサイズを小さく：strip:12cm⇒2.4cm/4.8cm
- ✓ 放射線耐性
 - ⇒p型シリコン検出器

ATLAS内部飛跡検出器 IDからITKへ



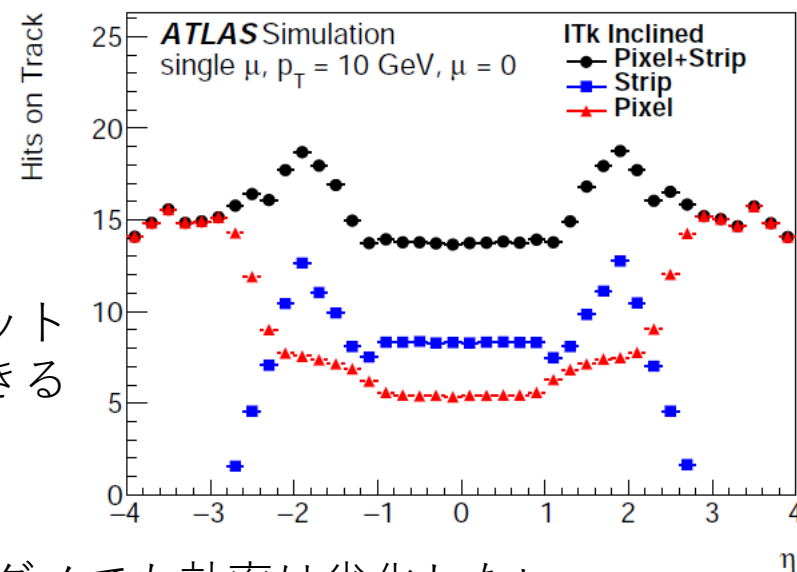
Current Inner Detector ID \Rightarrow HL-LHC Inner Tracker ITk

Expected performance

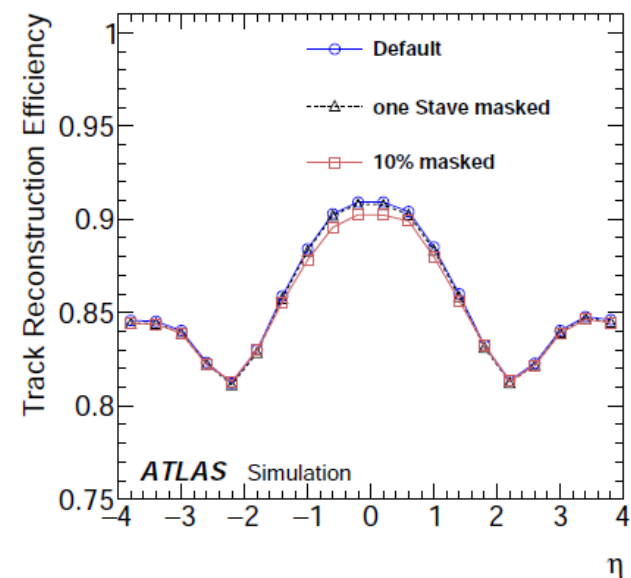
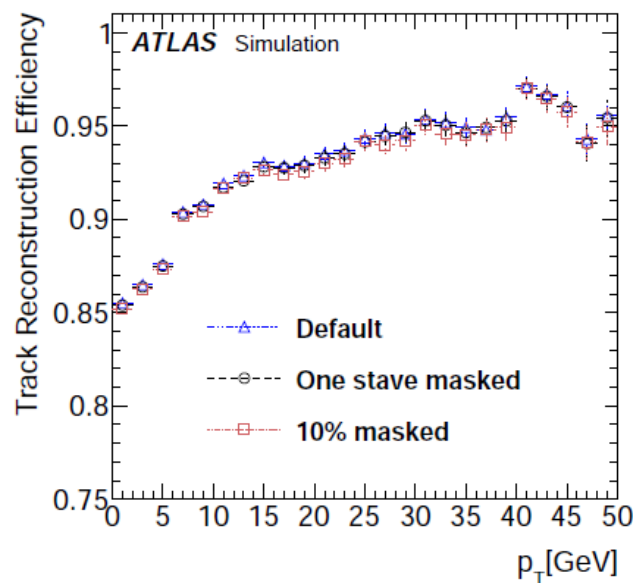
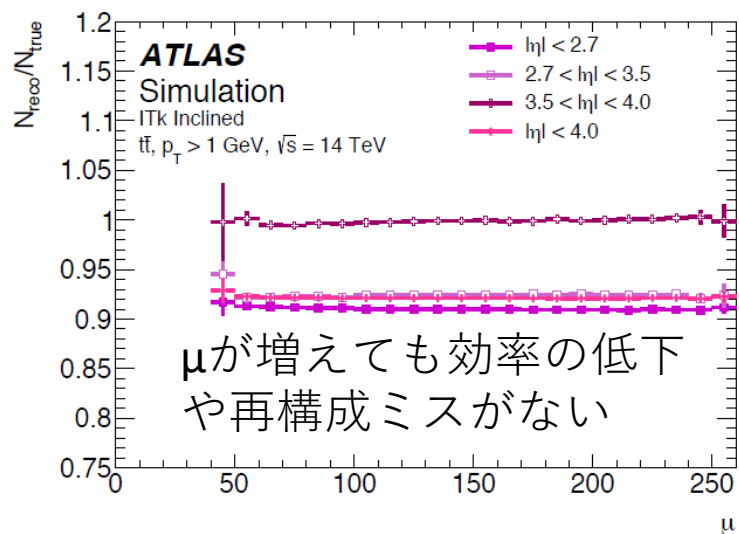


ヒット占有率<1%
⇒データ転送での
ロスなし

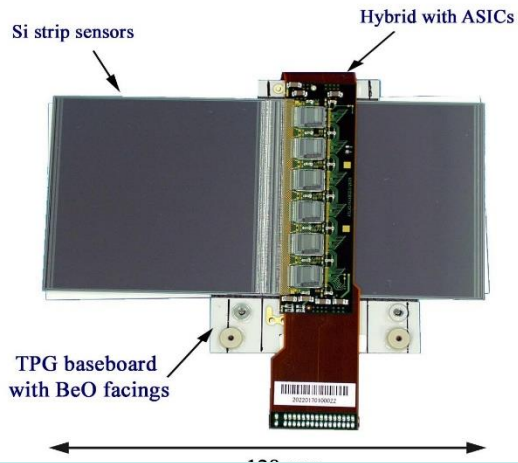
全領域で14ヒット
以上を確保できる



一部の検出器(層)がダメでも効率は劣化しない

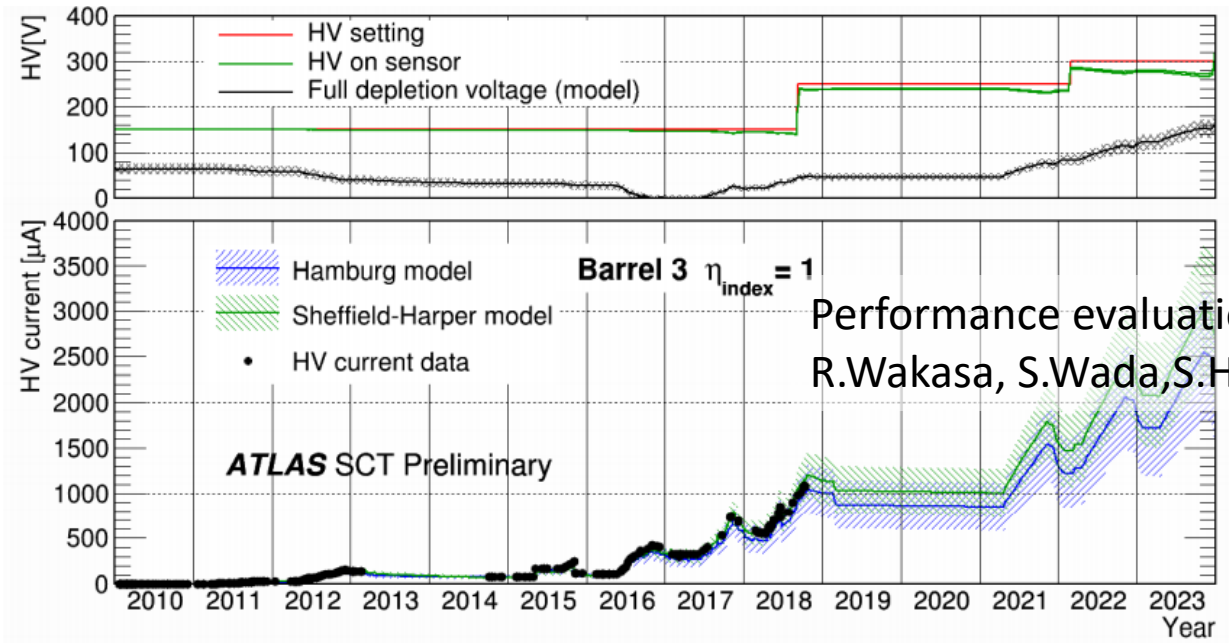


ATLAS Strip Detector



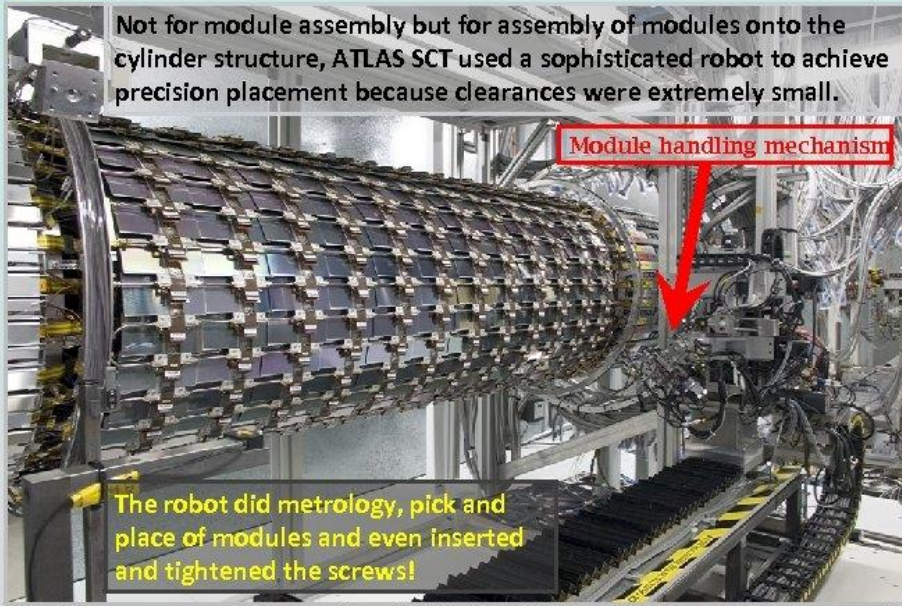
SCT
4" Hamamatsu
p⁺-on-n

500V max allowed ←



Performance evaluation by
R.Wakasa, S.Wada, S.Hirose et al.

Other Examples in LHC Experiments



Not for module assembly but for assembly of modules onto the cylinder structure, ATLAS SCT used a sophisticated robot to achieve precision placement because clearances were extremely small.

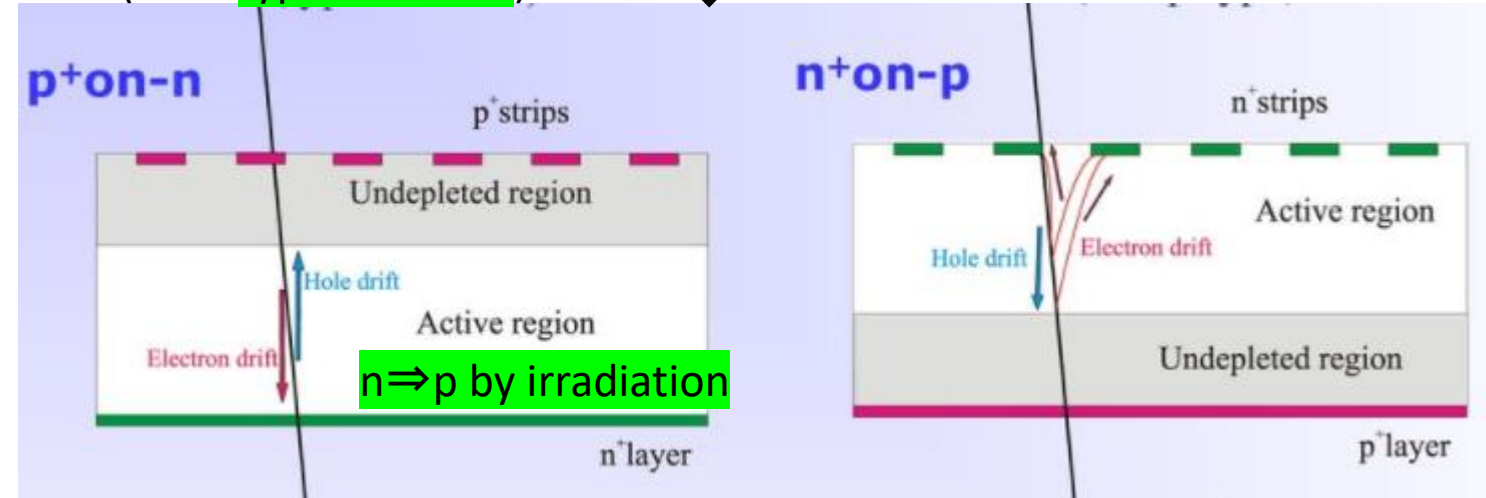
Module handling mechanism

The robot did metrology, pick and place of modules and even inserted and tightened the screws!

SCT (after type inversion)



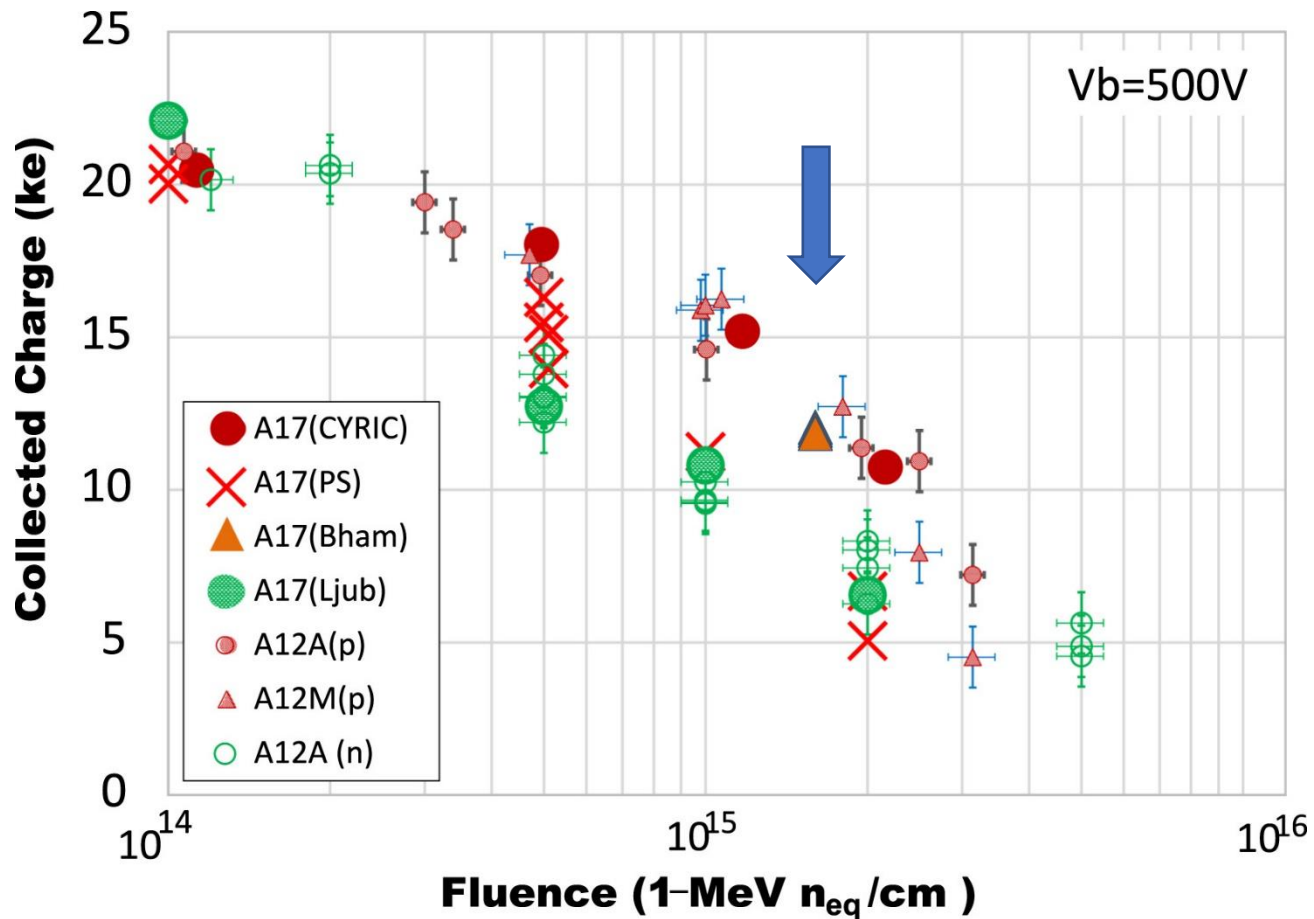
ITk strip (started R&D in 2005)



< full depletion required >

< partial depletion possible >

ITk p-type sensor charge collection



1. < partial depletion possible >

2. < large enough charge collection @500V due to collecting fast electrons = less trapping >

Noise $\sim 600e \Rightarrow S/N \sim 7000/600 > 11$

Sufficient charge collection after $1.6 \times 10^{15} n/cm^2$

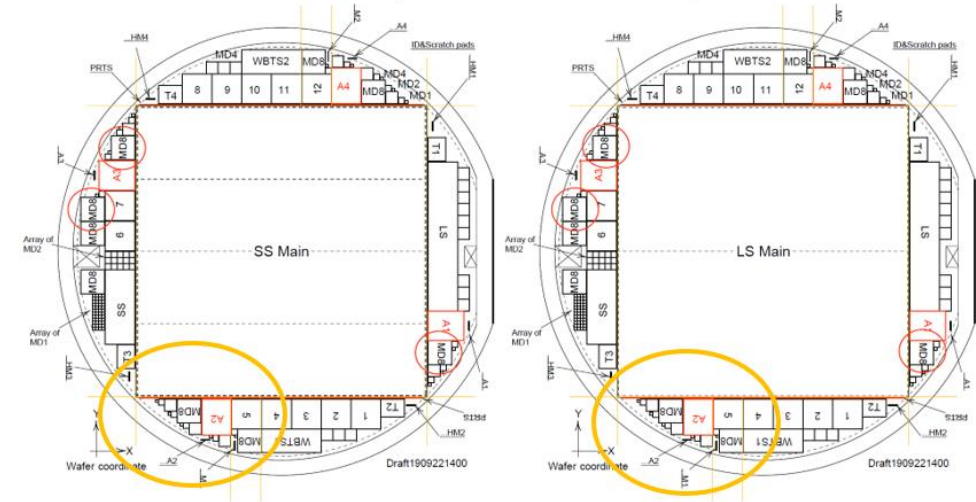
Max. fluence after $4000/fb \times 1.5$

All silicon sensors (strip+ pixel) are with p-type silicon

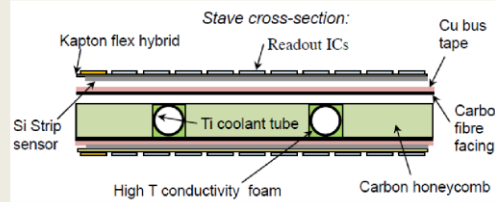
ITk Barrel sensor & module

14 modules both sides ($\pm 20\text{mrad}$)
Capton hybrid glued on sensor top
ABC130->ABCStar:(256ch)x10/row in stave

Wafer layouts - 18SS, 18LS



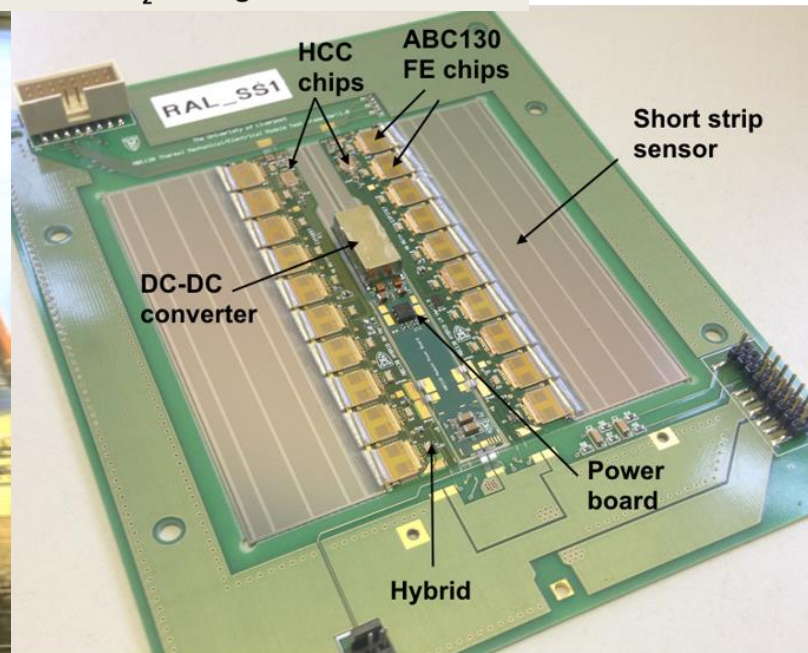
- Glue modules directly to mechanical support.



- Carbon fibre sandwich, provides rigid, lightweight 0 CTE support structure.
- Evaporative CO₂ cooling.

10x10cm on 6" wafer

All (barrel+endcap) sensors will be fabricated by Hamamatsu Photonics

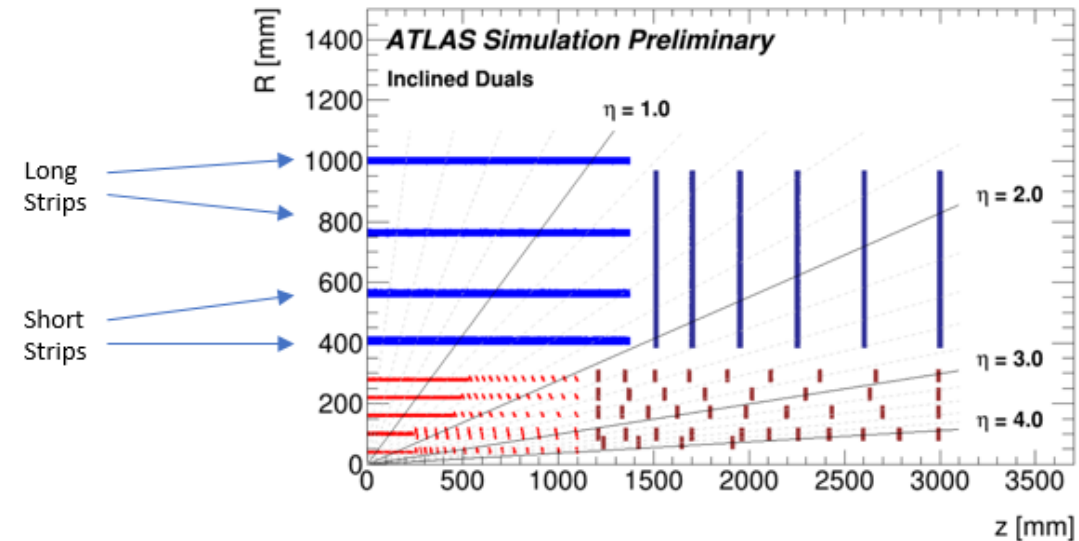


#ITK strip sensors

sensors

Barrel Layer:	Radius [mm]	# of staves	# of modules	# of hybrids	# of ABCStar	# of channels	Area [m ²]
L0	405	28	784	1568	15680	4.01M	7.49
L1	562	40	1120	2240	22400	5.73M	10.7
L2	762	56	1568	1568	15680	4.01M	14.98
L3	1000	72	2016	2016	20160	5.16M	19.26
Total half barrel		196	5488	7392	73920	18.92M	52.43
Total barrel		392	10976	14784	147840	37.85M	104.86

End-cap Disk:	z-pos. [mm]	# of petals	# of modules	# of hybrids	# of ABCStar	# of channels	Area [m ²]
D0	1512	32	576	832	6336	1.62M	5.03
D1	1702	32	576	832	6336	1.62M	5.03
D2	1952	32	576	832	6336	1.62M	5.03
D3	2252	32	576	832	6336	1.62M	5.03
D4	2602	32	576	832	6336	1.62M	5.03
D5	3000	32	576	832	6336	1.62M	5.03
Total one EC		192	3456	4992	43008	11.01M	30.2
Total ECs		384	6912	9984	86016	22.02M	60.4
Total		776	17888	24768	233856	59.87M	165.25



Short strips (2.4cm)

Long strips (4.8cm) x 74.5 μ m

Japan: 1/2 of barrel sensors fabrication, QC+QA

⇒ Module

⇒ Stave

⇒ Module

⇒ Petal

Pre- and Series-Production Schedule

Pre-COVID19 schedule

Estimated delay

Year Quarter Month	2020									2021				2022				2023				2024		TOTAL PRE+SERIES	
	Q1'20		Q2'20		Q3'20		Q4'20		Q1'21	Q2'21	Q3'21	Q4'21	Q1'22	Q2'22	Q3'22	Q4'22	Q1'23	Q2'23	Q3'23	Q4'23	Q1'24	Q2'24			
	1	2	3	4	5	6	7	8	9																
Short Barrel S15568-01	160	40	40	78						0	0	0	0	0	0	0	0	0	620	892	892	892	892	212	4718
- CERN (confirmed)		20		139																					
- KEK (confirmed)			159																						
Long Barrel S15568-02	160	40	40	78						892	892	892	892	892	892	892	892	892	272	0	0	0	0	0	8618
- CERN (confirmed)	17	4		138																					
- KEK (confirmed)			159																						
Ring 0 S15568-03	22	11	12							62	62	62	62	62	62	62	62	62	62	62	62	62	62	32	945
- CERN (confirmed)		7	20	18																					
Ring 1 S15568-04	22	11	12							62	62	62	62	62	62	62	62	62	62	62	62	62	62	32	945
- CERN (confirmed)		8	20				17																		
Ring 2 S15568-05	22	11	12							62	62	62	62	62	62	62	62	62	62	62	62	62	62	32	945
- CERN (confirmed)		5	40																						
Ring 3 S15568-06	45	22	23							124	124	124	124	124	124	124	124	124	124	124	124	124	124	64	1890
- CERN (confirmed)		5	25	60																					
Ring 5 S15568-07	45	22	23							124	124	124	124	124	124	124	124	124	124	124	124	124	124	64	1890
- CERN (confirmed)		5	15	45																					
Ring 6 S15568-08	45	22	23							124	124	124	124	124	124	124	124	124	124	124	124	124	124	64	1890
- CERN (confirmed)		5	25	35																					
TOTAL sensors	521	179	185	156	0	0	0	0	0	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	500	21841

6 months break

Pre-production

PRR

(Series-)production (~3.8 yrs)

Schedule revised(?)

Mid Nov

End Jan

2 months

4 months



• > 1/3 of volume

• 1-2 weeks

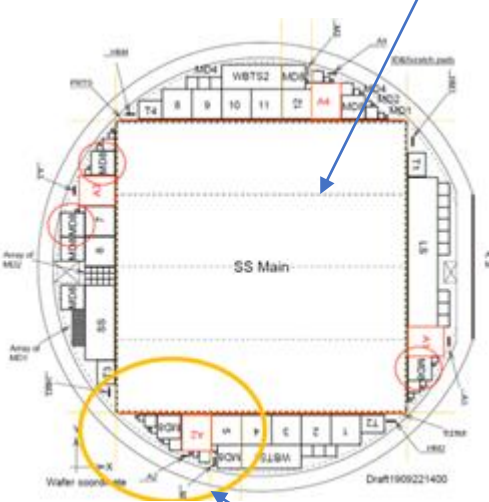
• < 2/3 of volume

• 3.8 year process

Sensor QC&QA Site Qualification

starting

QC: main sensor test



QA: test chips

Irradiations:

- Tohoku U. CYRIC 70MeV protons
- Birmingham 28MeV protons
- Ljubljana Reactor neutrons
- Prague Co-60 gammas

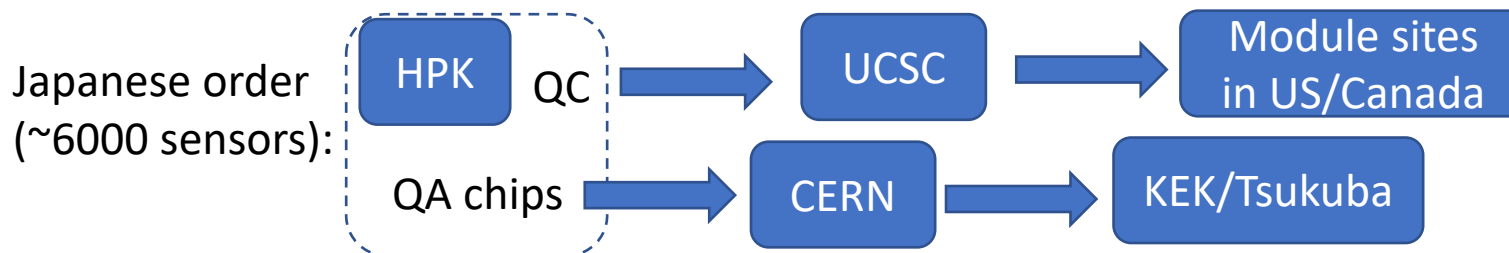
Site	QC	Irradiation	QA (CCE)	QA (TC)	Comment
Cambridge	Going on				
QMUL	Going on				
KEK/Tsukuba	Going on	OK	OK	x	QC in collaboration with HPK
SCIPP	Going on				Only long-term tests
Vancouver cluster	x				
Carleton	Going on				
Prague	Complete?	OK		x	
Birmingham		OK	OK	x	
Ljubljana		OK	OK		
Toronto			OK	x	
Valencia			OK		
CNM				x	

Strip sensors: QC items

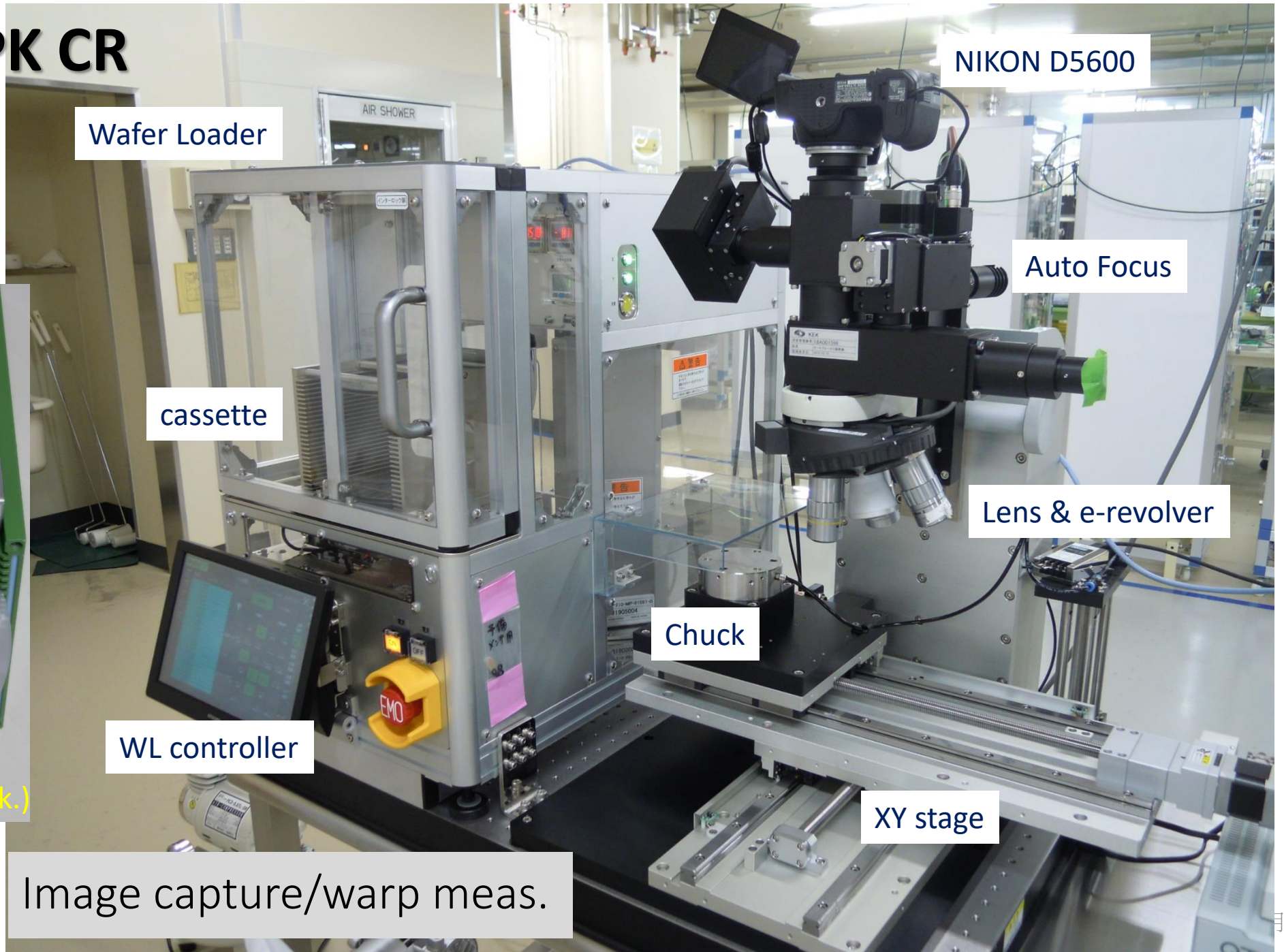
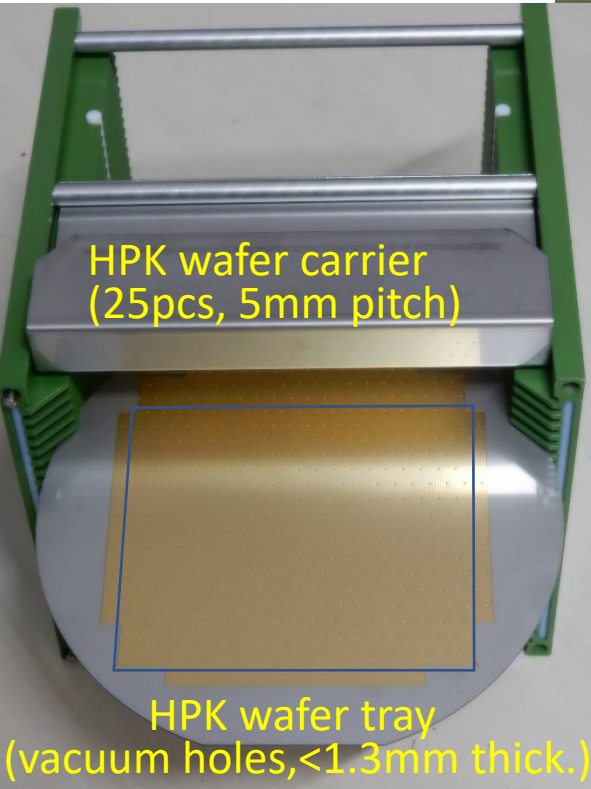
On every sensor

- Human&Machine visual inspection/capture at HPK
- IV, CV, Metrology/surface profile Auto focus microscope

item	Frac.	ATLAS	HPK/Japan	
IV/CV	100%	10V/10s;45+10-40%RH	20V/s;<60% (slow r.r. ⇒10%↑in time)	
Image	100%	2um/pixel precision	2um/pixel precision	
Warp	100%	11x11⇒3x3	11x11 (1um precision)	
I_stab	2-5%	24hrs	none	UCSC
Full strip	2-5%	Ccpl, Rbias	Use HPK scan data	
Cint....	On sampling (2-5%)		(Test with test sensor/structure)	
Bias tab	100%		none	UCSC



Setup @ HPK CR





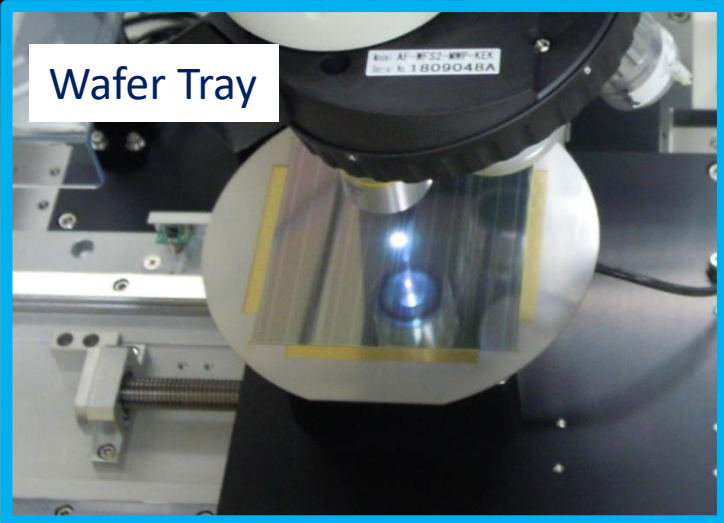
Wafer Loader
Chuck

NIKON D5600

Auto Focus
Chuo-Seiki
AF-WFS2

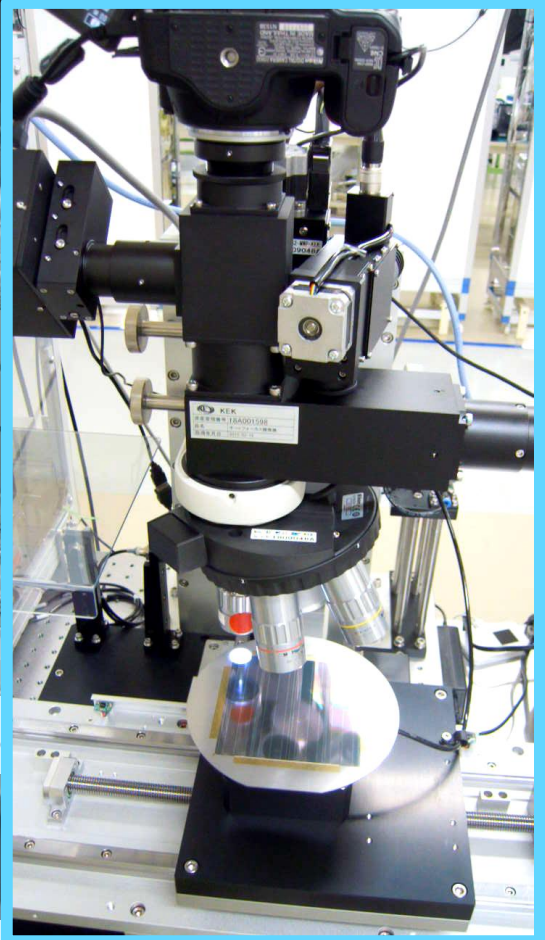
cassette

Mitutoyo
M Plan Apo



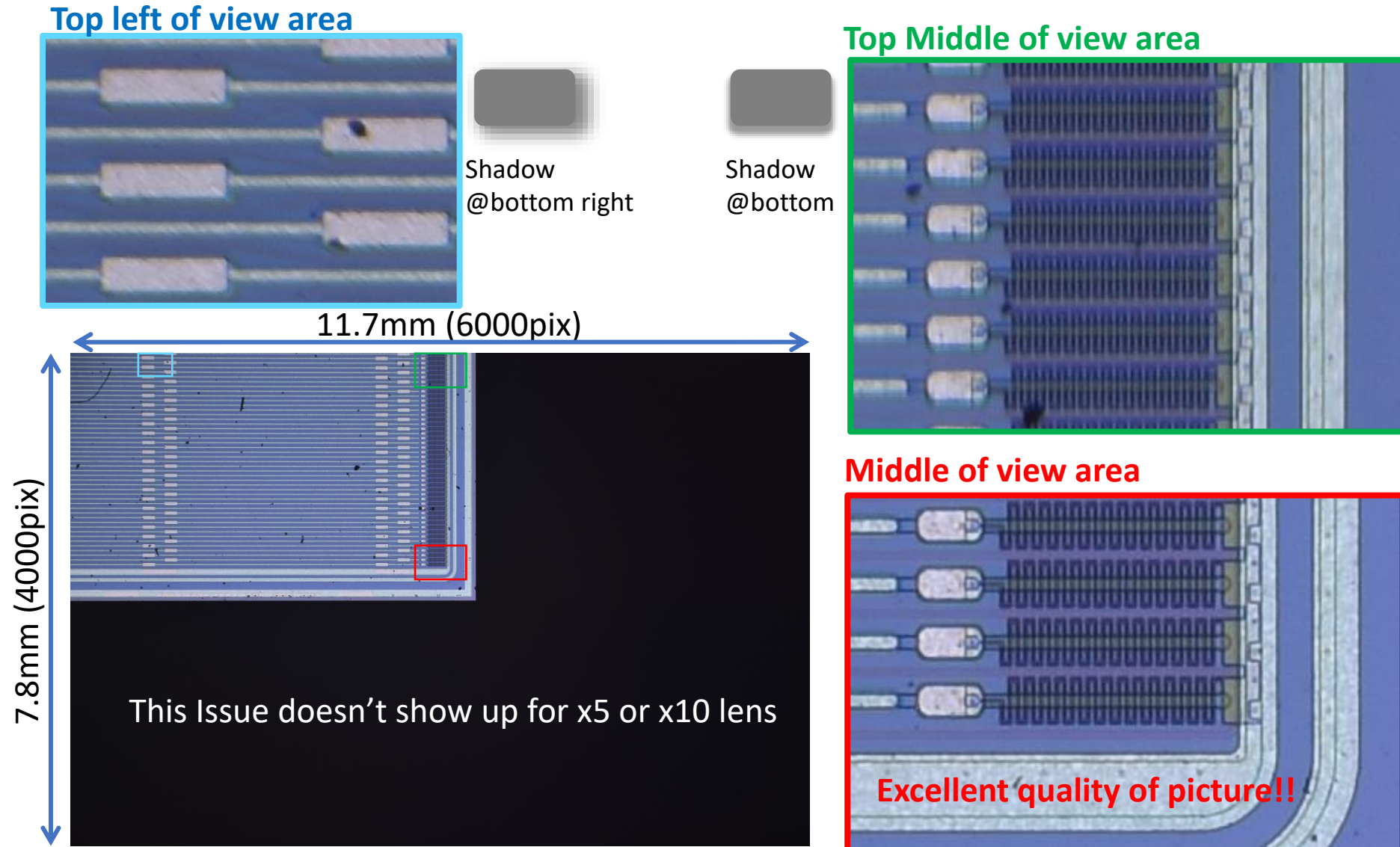
Wafer Tray

Chuck



XY s

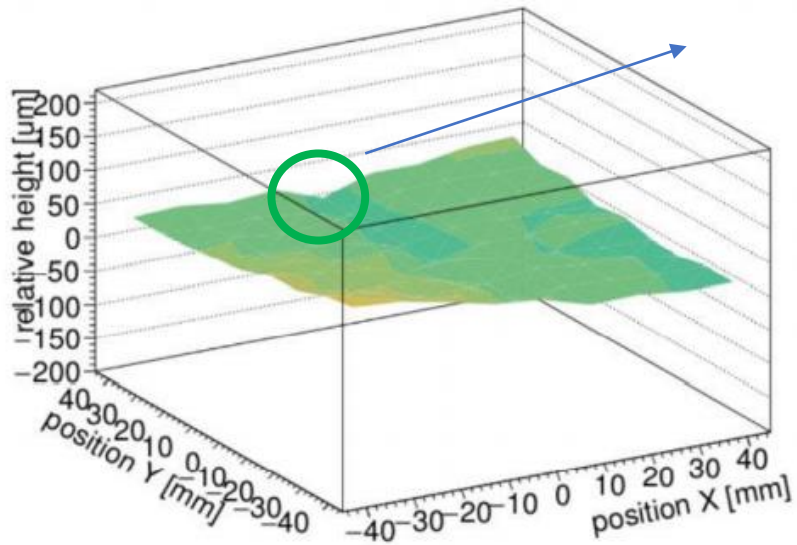
Lens aberration issue of x2 lens



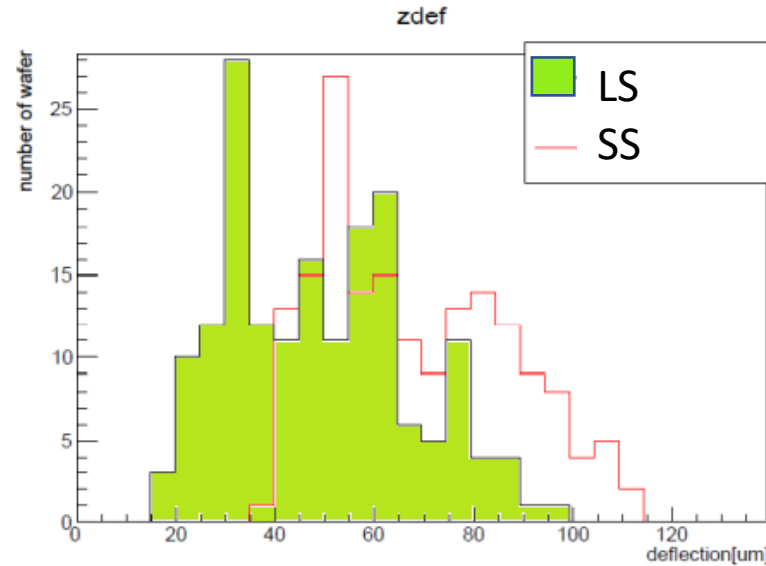
=> Allow more overlaps to use the central part of the pictures

Height Measurement: Metrology

- Scanning over sensor with auto-focus adjusting. (tracking mode)
- Measurement precision is ideally 0.9 μm .

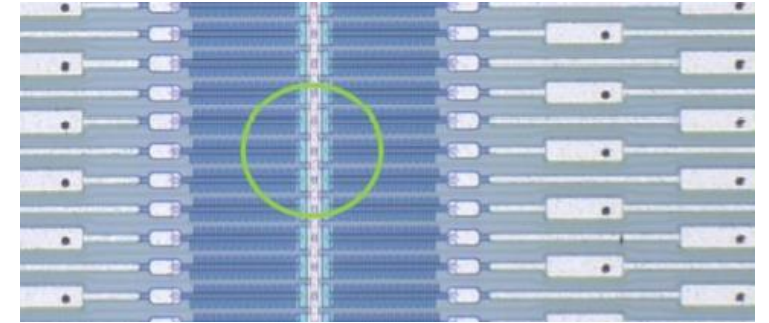


Online monitor with ROOT histogram

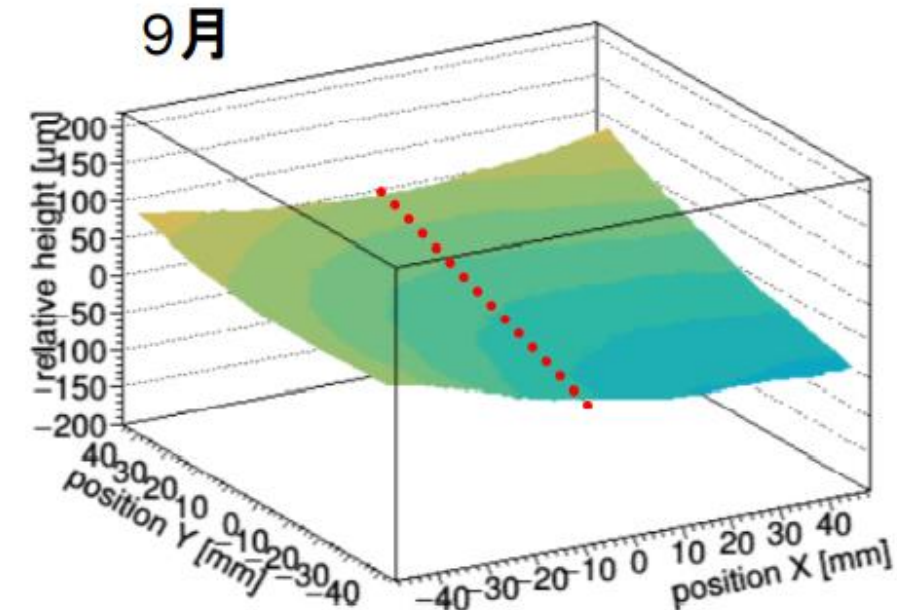


Maximum bow for all pre-production sensors:
Spec: <200 μm

Measurements of pre-production sensors (>320 sensors) finished in March

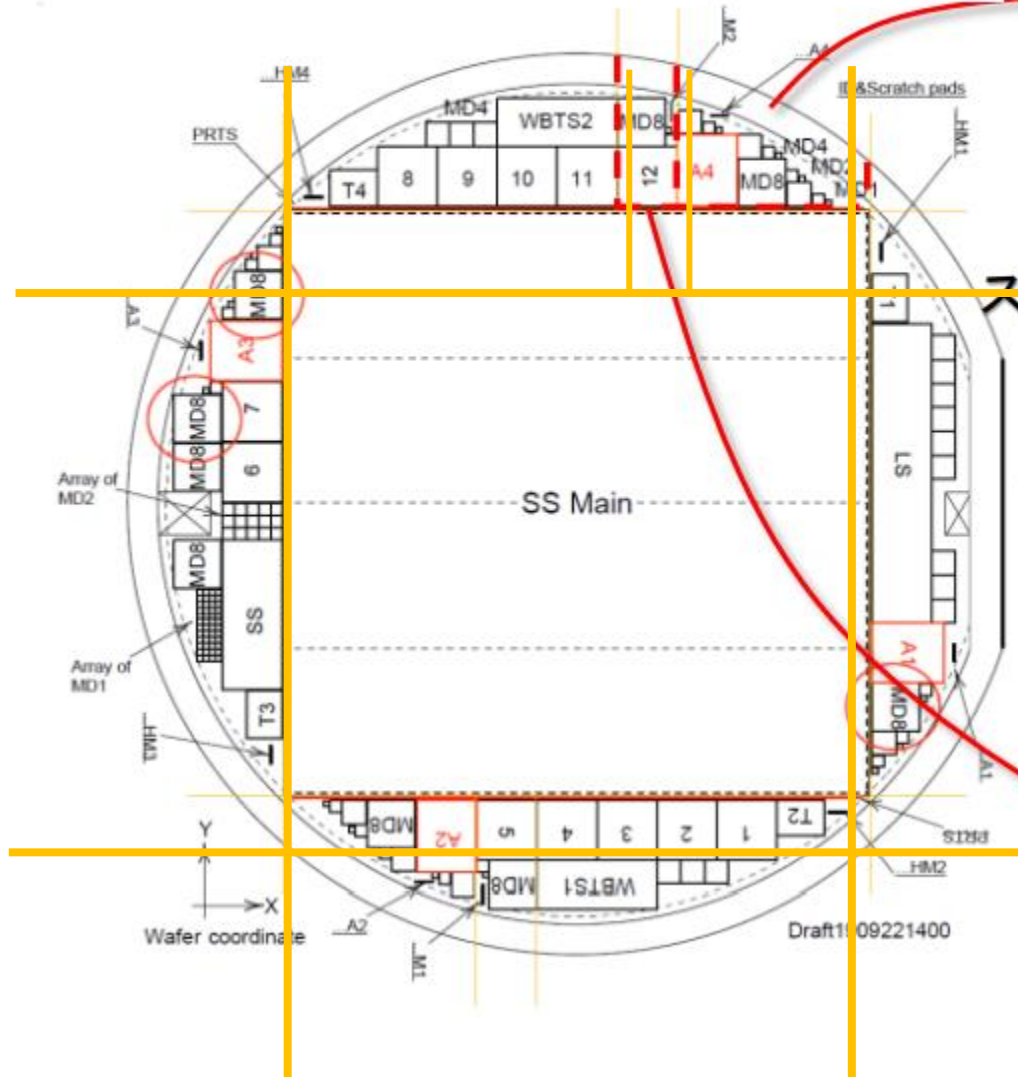
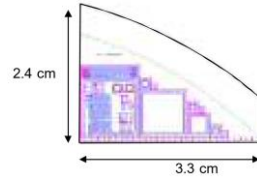


Large contrast requires fine auto-focusing adjustment \Rightarrow solved

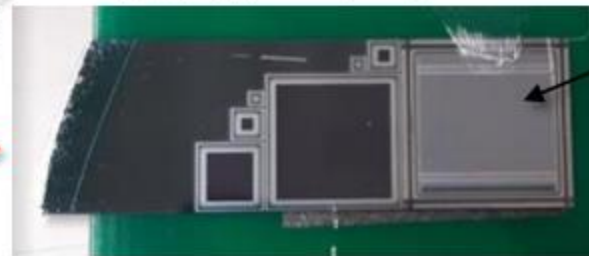
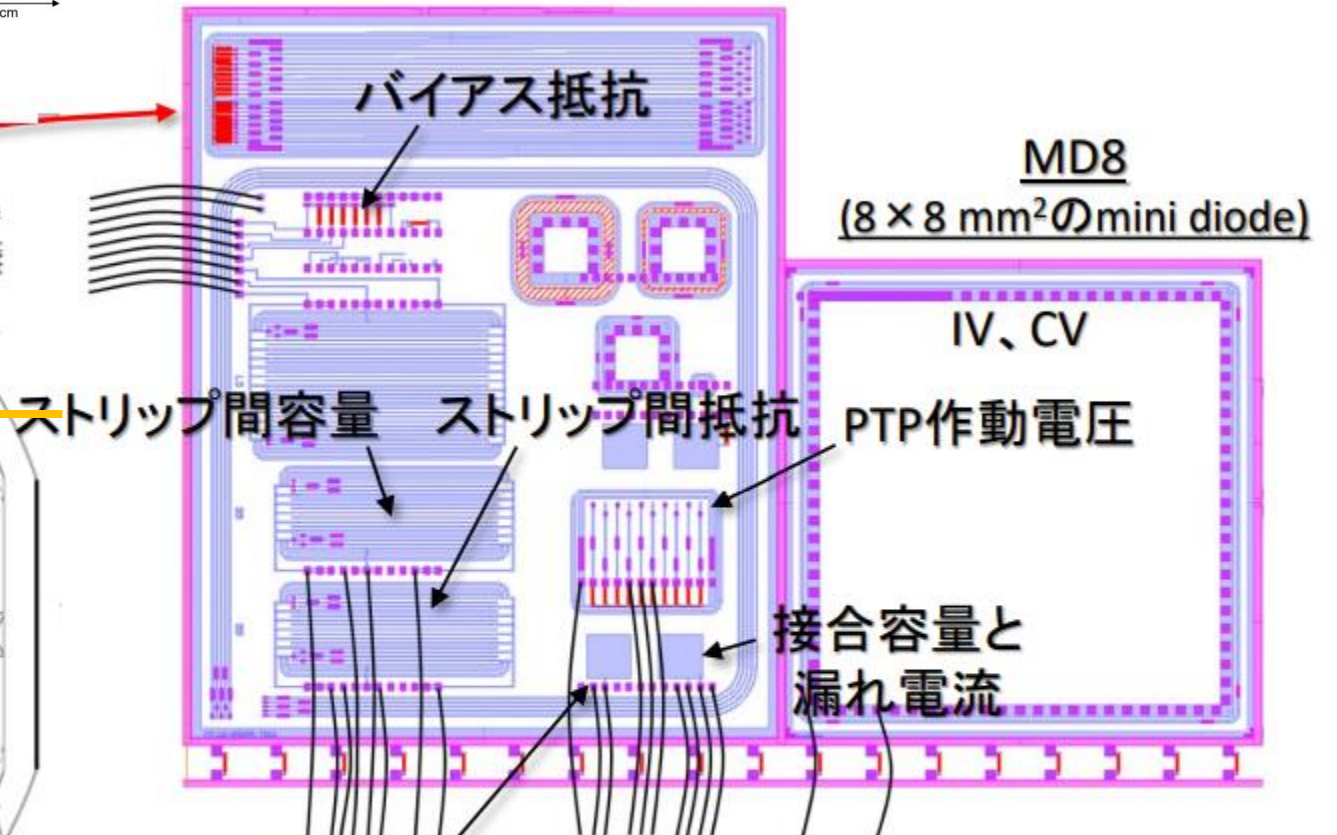


Strip QA

3 half moon's per batch (~50)

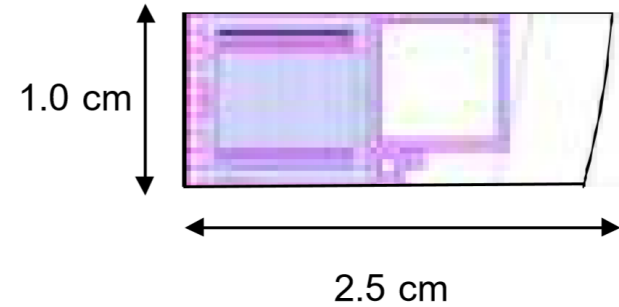


Test chip (TC)

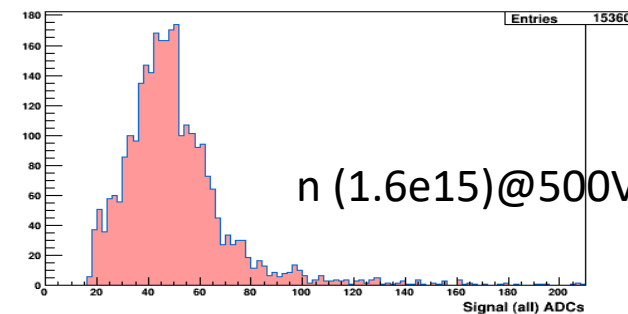
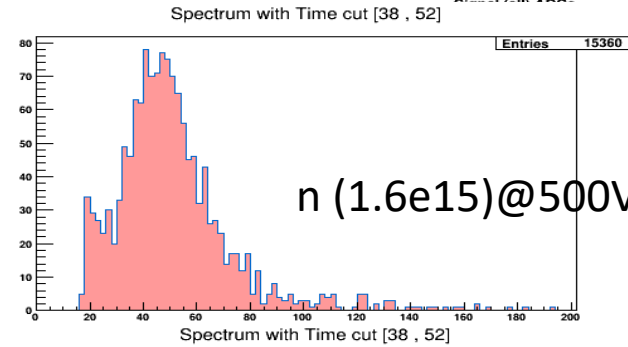
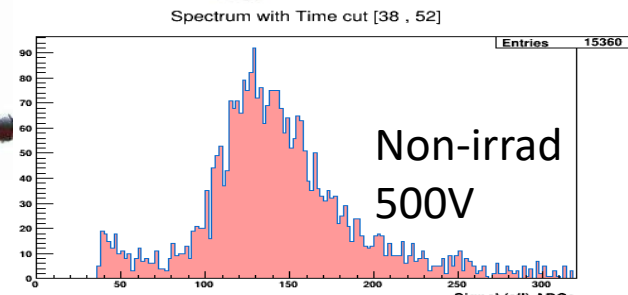
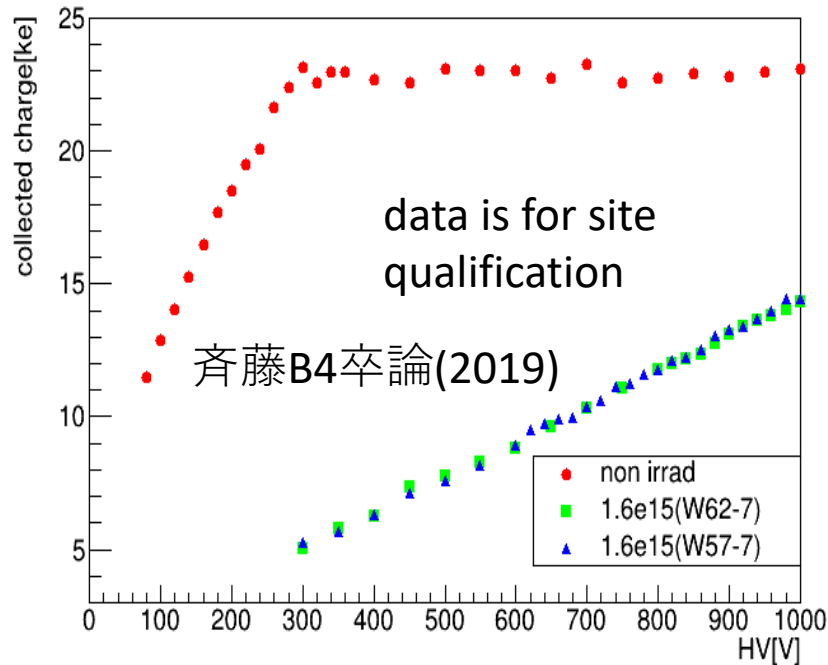


Mini sensor
(1 × 1 cm²)
CCE用

Strip QA : CCE- mini

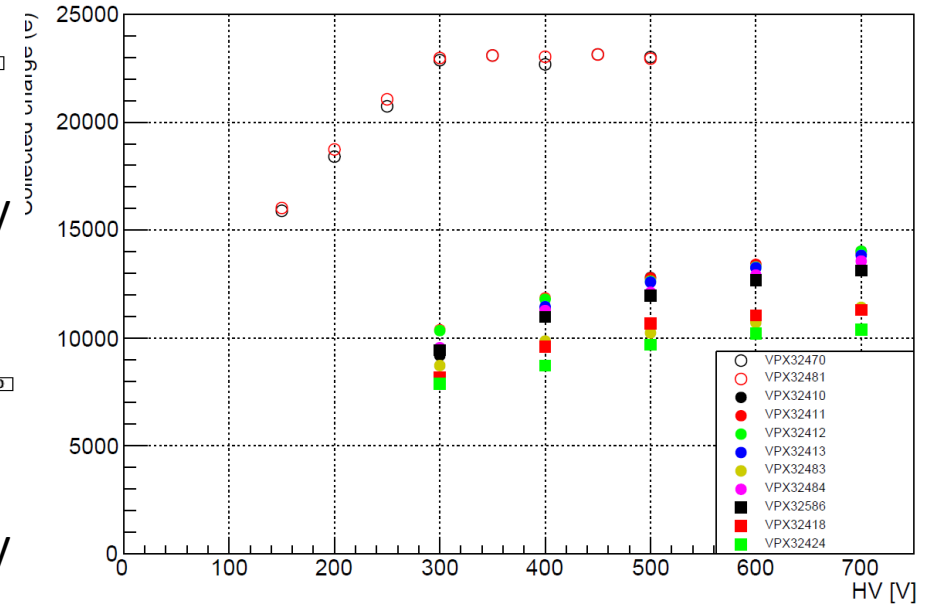


Two n-irrad samples delivered for site qual.

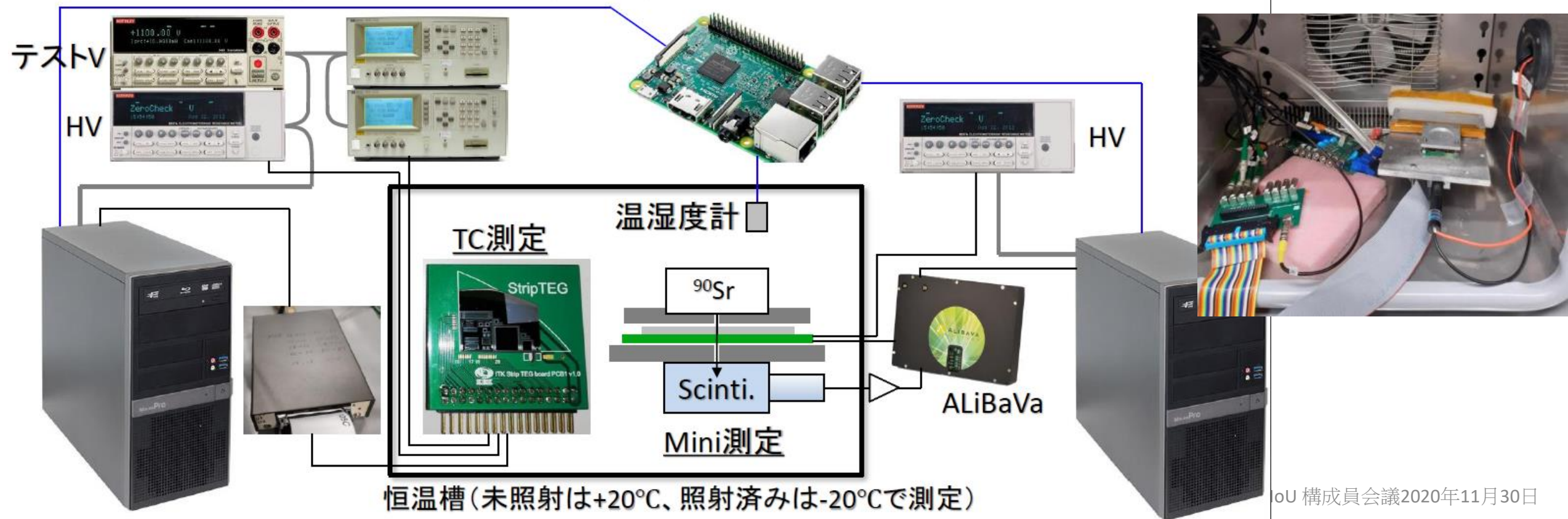
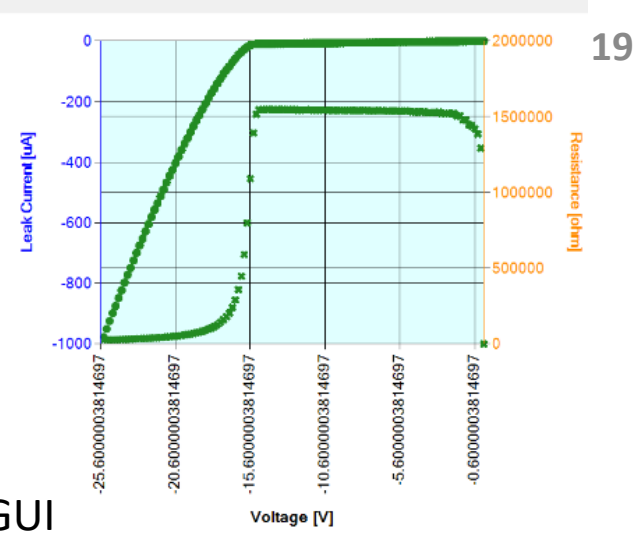
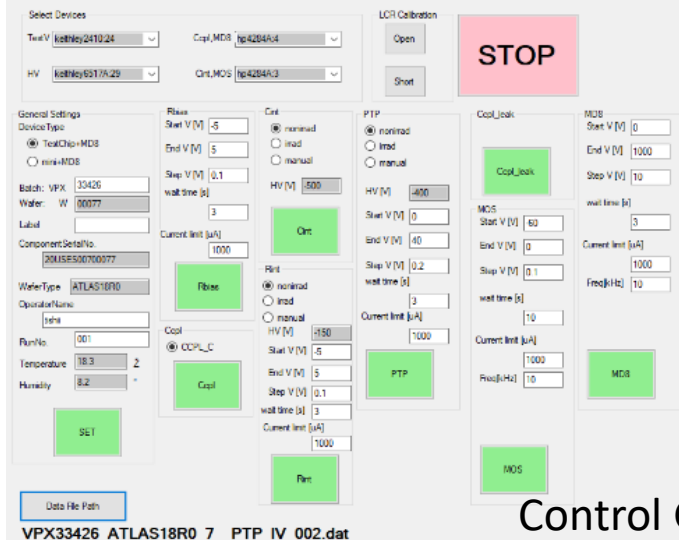
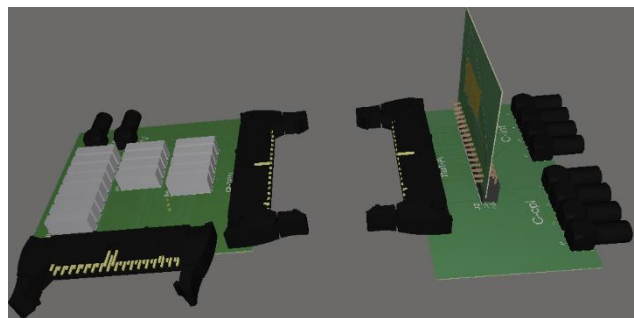


Pre-production mini's

- non-irradiated
- 1.6×10^{15} n/cm² irradiated



QA: test system



Summary of TC&MD8 measurements

		Proton irradiated				Site qualification	
items		Requirement	Un-irrad	4.68 $\times 10^{14} n_{eq}/cm^2$	1.54 $\times 10^{15} n_{eq}/cm^2$	Un-irrad	Co-60 660 kGy
T E S T	バイアス抵抗(20°C) (-20°C)	1.5 ± 0.5MΩ	1.456MΩ 1.729MΩ	1.836MΩ	1.794MΩ	1.555MΩ	2.195MΩ
	ストリップ間容量	<1pF/cm	0.814pF/cm	0.974pF/cm	0.891pF/cm	0.876pF/cm	0.952pF/cm
	ストリップ間抵抗	>15MΩ	ほぼ絶縁	120MΩ@5V	27MΩ@5V	0.57GΩ	6.96MΩ
C H I P	PTP作動電圧	(<100V)	13V(20°C)	26.4V	25.4V	15.8V	9.1V
	結合容量@1kHz	>20pF/cm	20.5pF/cm	22.7pF/cm	22.1pF/cm	23.21pF/cm	23.46pF/cm
	酸化膜厚	none	655nm	-	-	650nm	659nm
	酸化膜リーク電流	<10nA@100V	<0.4nA	<0.4nA	<0.4nA	0.278nA	0.162nA
M D 8	全空乏化電圧	<350V	300V			235.6V	238.2V
	リーク電流@500V	<100nA/cm ²	10nA/cm ²	10uA/cm ²	12nA/cm ²	11nA/cm ²	6.2nA/cm ²

Irradiated (un-irradiated) samples are measured at -20°C (20°C)
Requirements mostly apply for non-irradiated samples

Conclusions

ATLAS-Japan (Tsukuba/KEK) is responsible for ½ of ATLAS ITk Barrel strip sensors
Pre-production (5% of total) of strip sensors is finished – under evaluation for PRR

QC site qualification is under way

- cross checks with other sites are under way

QA-CCE: site qualified

QA-TC&MD8; site qualification under way

Production should start 2021 Q2 and will continue for 3.8 years