ATLAS High Granularity Timing Detector (HGTD)

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Outline

- ATLAS funding situation
  - OTP situation and upgrade connection
- Brief description of project
- Situation with the ATLAS project (people involved, budget, timeline)
  - Project already approved by ATLAS as a Phase-II project
  - Next target: TDR — March 2019
- HGTD Tasks for China
  - Sensor development and production
  - ASIC design
  - Module and stave construction
  - Potentially, front-end and readout electronics
  - Simulation work
- Manpower
- Budget required

ATLAS China Membership

Active members: 248; IHEP: 61; USTC: 72

Total number of authors: 99 IHEP: 27; USTC: 36

short name	name	active members	physicist	PhD std	master	ugraduate	eng PhD	eng	eng std	tech	admin
Beijing IHEP	Institute of High Energy Physics, Chinese Academy of Sciences	61	17	16	2	0	16	5	4	1	0
Beijing Tsinghua	Tsinghua University	9	2	4	0	3	0	0	0	0	0
Hefei	University of Science and Technology of China	72	24	19	12	3	2	1	10	1	0
Hong Kong CUHK	Chinese University of Hong Kong	23	5	6	0	2	0	3	1	0	6
Hong Kong HKU	University of Hong Kong	5	2	3	0	0	0	0	0	0	0
Hong Kong HKUST	Hong Kong University of Science and Technology	5	3	2	0	0	0	0	0	0	0
Nanjing	Nanjing University	19	5	5	3	6	0	0	0	0	0
Shandong	Shandong University	23	6	9	6	0	2	0	0	0	0
Shanghai	Shanghai Jiao Tong University	23	8	13	1	0	1	0	0	0	0
TDLI	Tsung-Dao Lee Institute	7	2	1	0	3	0	0	0	0	1
	total:	248	74	78	24	17	21	9	16	2	7

3.4% of the collaboration ==> M&O funding: 2.74%

ATLAS-China Contribution Situation

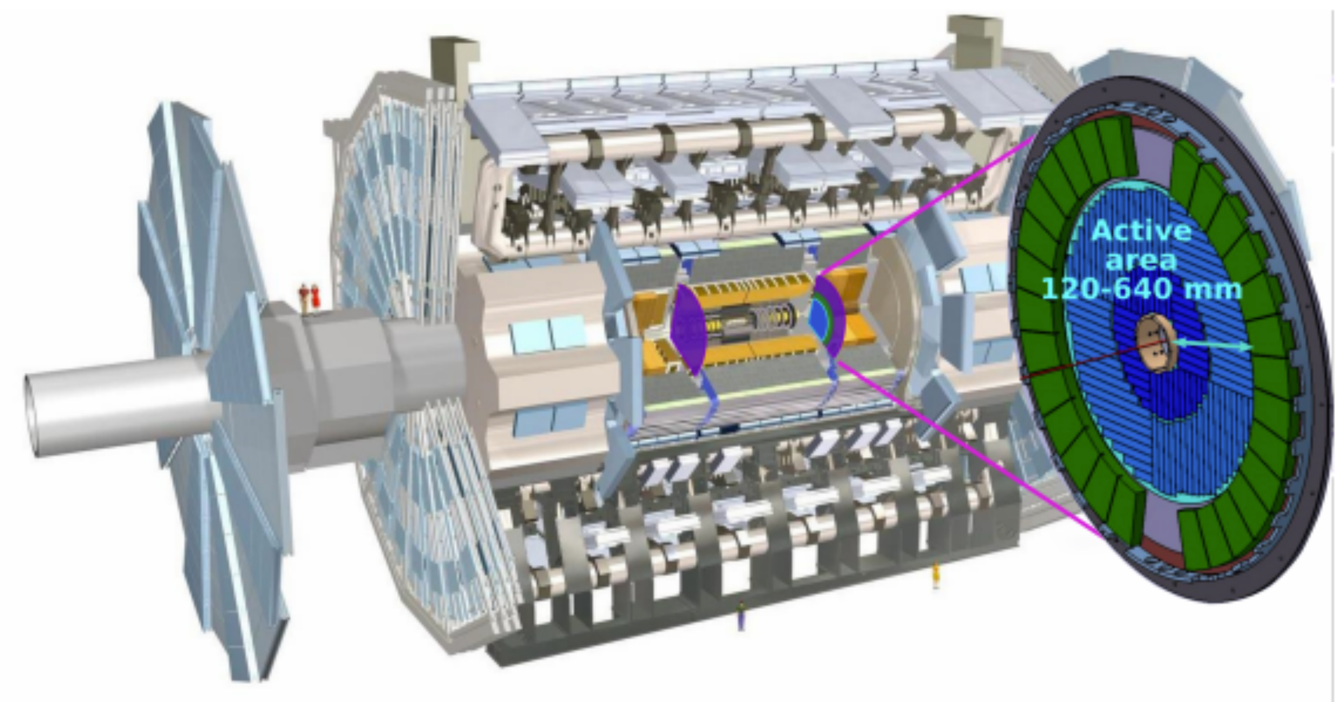
- ATLAS China authors: 3.4% of ATLAS collaboration
  - M&O authors: **2.74%**
- Total Core cost of phase II upgrade: 269 MCHF
  - (including 24M CHF common fund)
- China Fair-share contribution:
  - Author based: 9.1 MCHF (excluding common funds: 8.3 MCHF)
  - M&O based: **7.4 MCHF** (excluding common funds: **6.7 MCHF**)
- Core funding currently expected (MOST +NSFC):
  - 2.746 MCHF + 0.627 MCHF = 3.372 MCHF
- Excluding common funds:
  - Fair-share: 6.7 MCHF ==> Planned: 2.7 MCHF

Problem:
Missing: 3 MCHF
60% of fair share

Not easy to find funds and not easy to find suitable projects

Introduction to ATLAS HGTD

- ATLAS will upgrade endcap calorimeter in 2026
  - Aim for High-Granularity Timing Detector (HGTD)
  - LGAD will be used for timing and energy measurement



Pseudorapidity coverage: $2.4<|\eta|<4.0$

Radial extension: 12 cm $< R < 64$ cm

z position: 3.5 m

Thickness in z: 7.5cm

2 double planar layers per endcap

Requirements:

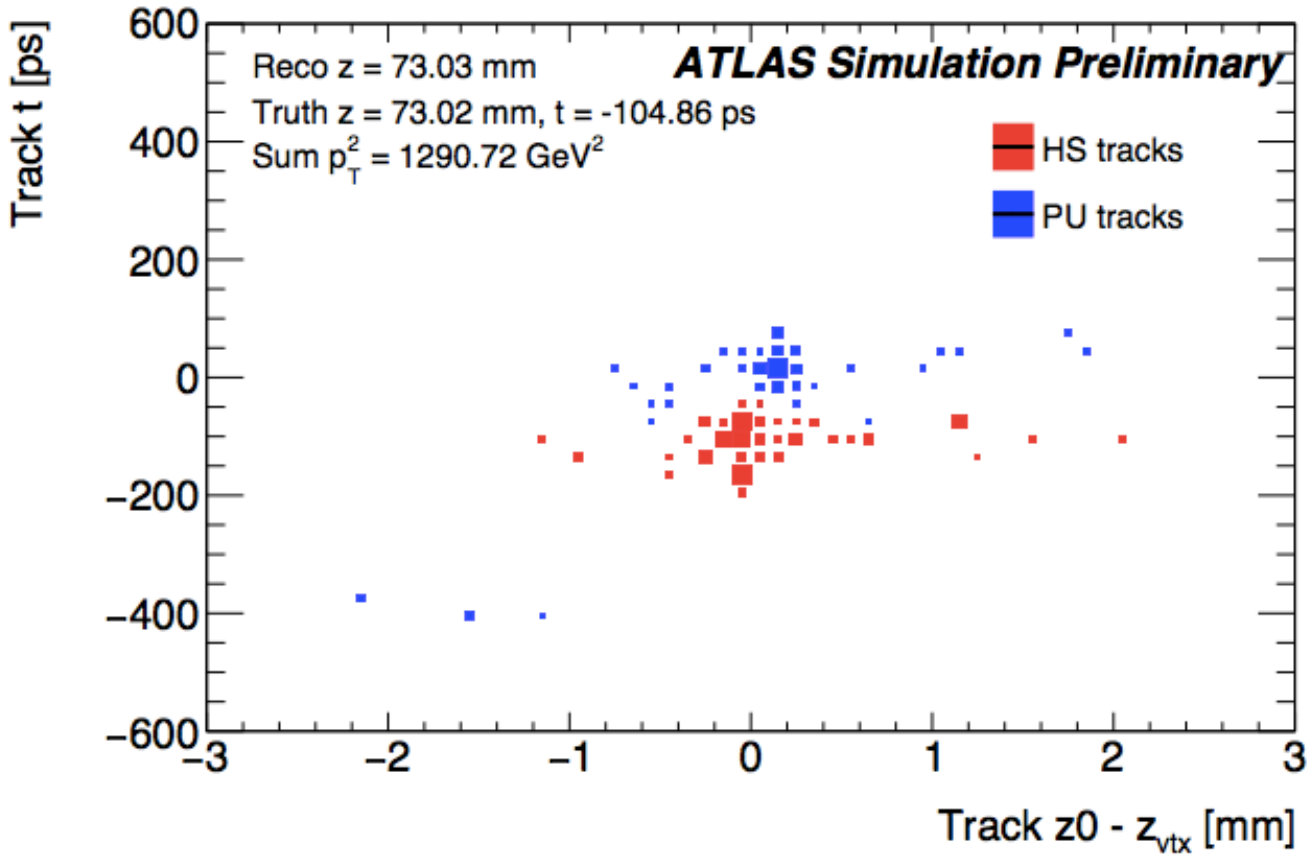
- Excellent time resolution (30ps/track), flat in η
- radiation-hard (up to 3.7×10^{15} n_{eq}/cm^2 and 4.1MGy)
- Low occupancy

- **Low Gain Avalanche Detector sensors (LGADs)**
- **Pixel size: 1.3x1.3 mm^2**
  - Occupancy lower than 10%, low electronic noise
- **2 double planar layers per endcap**
  - Average number of hits per track = 2-3, depending on R

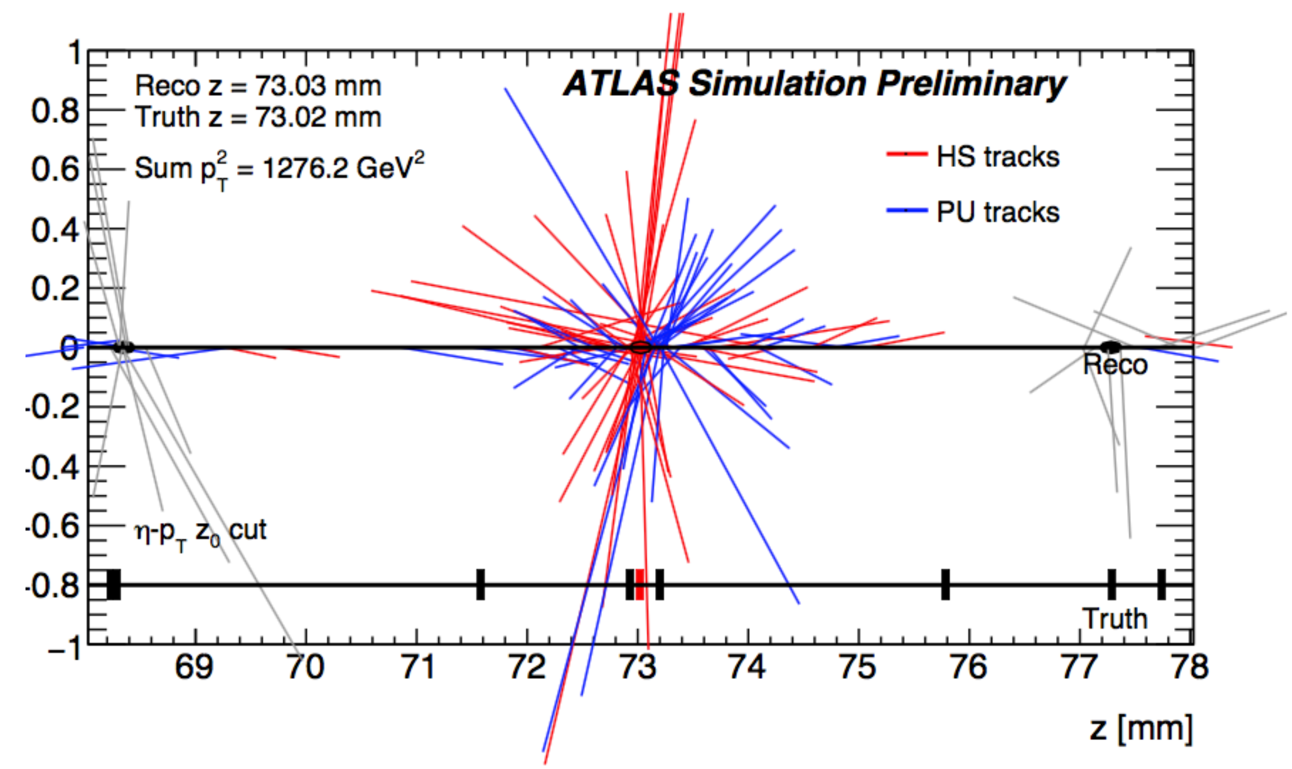
Physics motivation

- Pileup is the major challenges at HL-LHC
  - Track from different vertexes close in space, but well-separated in time.
  - Explore the spread of the collision to reduce pileup background by timing
  - Need 30ps timing resolution to reduce the pileup background by a factor of 6
- Significant impact on some physics case
  - VBF Higgs ,Weak mixing angle measurement

Higgs signal and pileup are separated in time



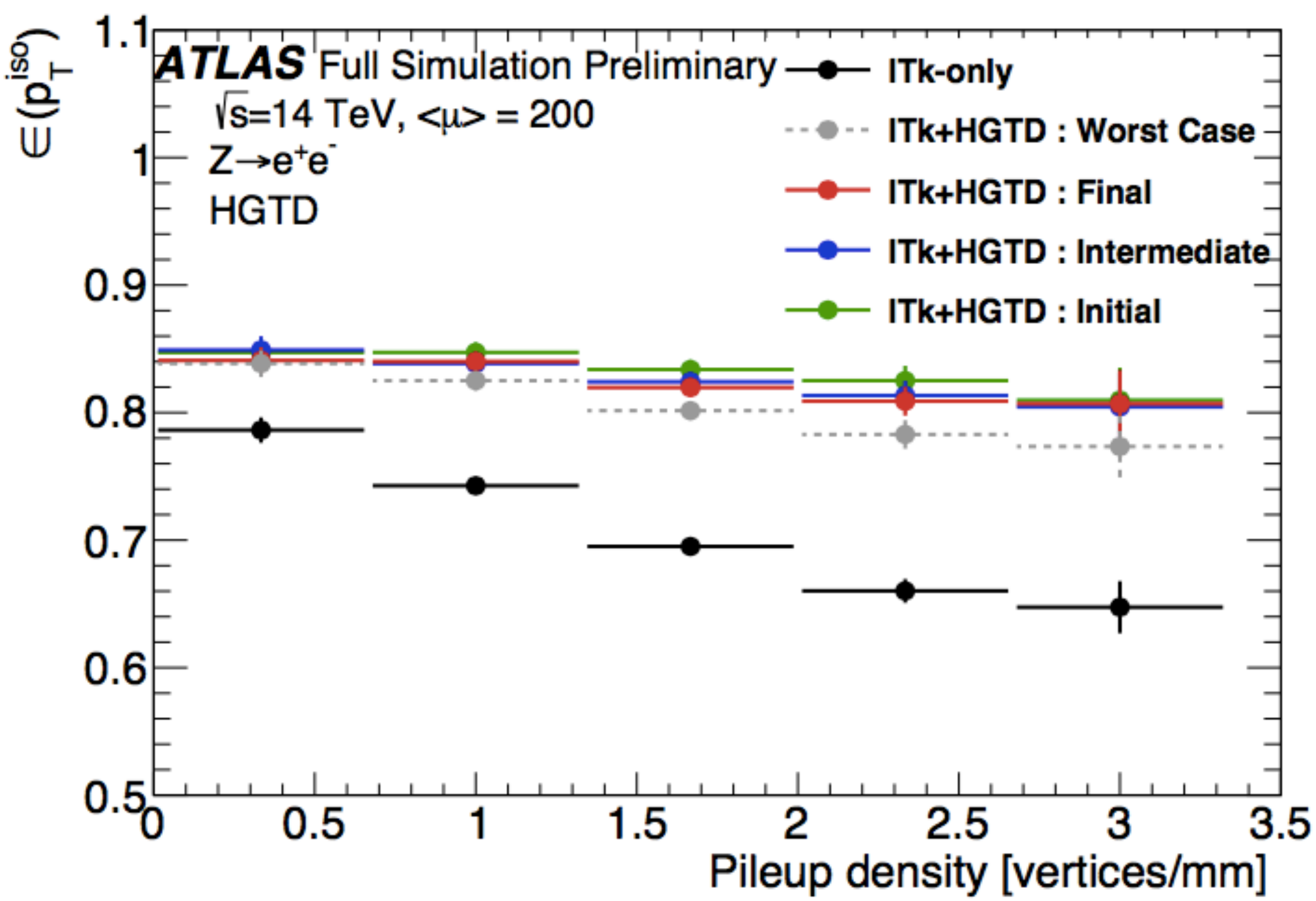
Using timing information to separate Higgs signal (red) from pileup background (blue)



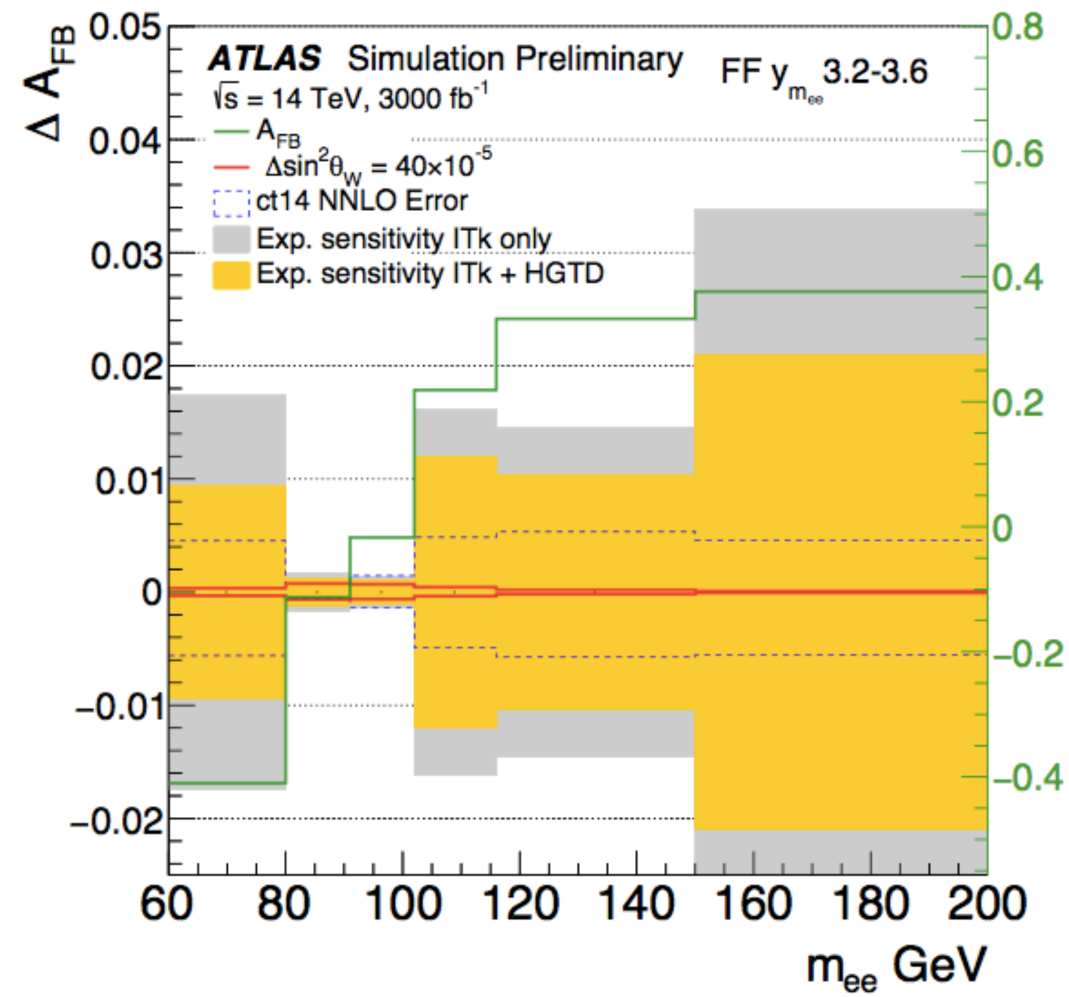
Physics case: Weak mixing angle

- HGTD can help weak mixing angle measurement
  - Central-forward(CF) and forward-forward(FF) channel is major channels
  - Forward electron is the key.
  - HGTD help to distinguish forward electron against pileup jets
  - Improve in CF channel by 13%, improve FF by 25%

Forward electron performance w/wo HGTD

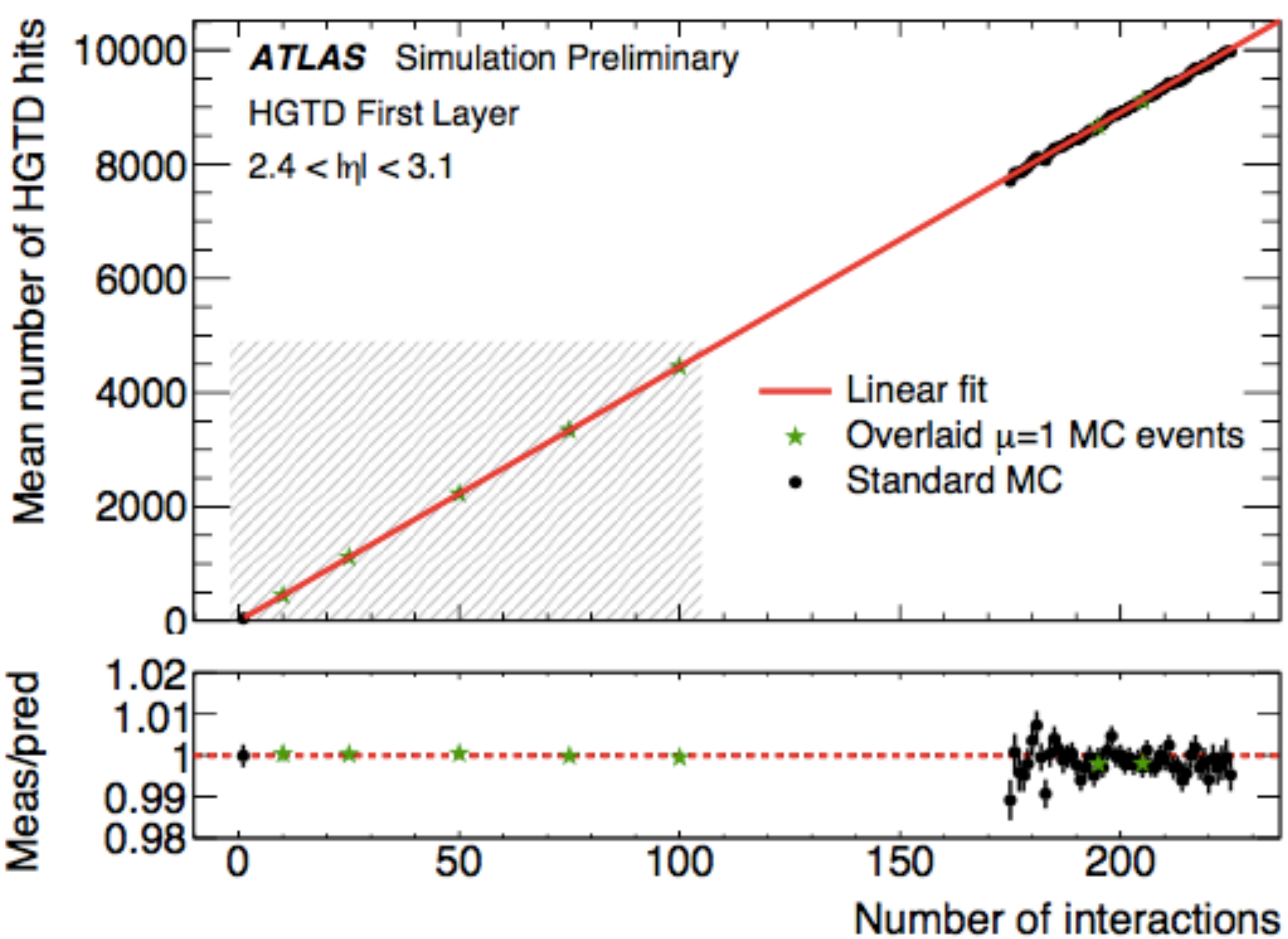


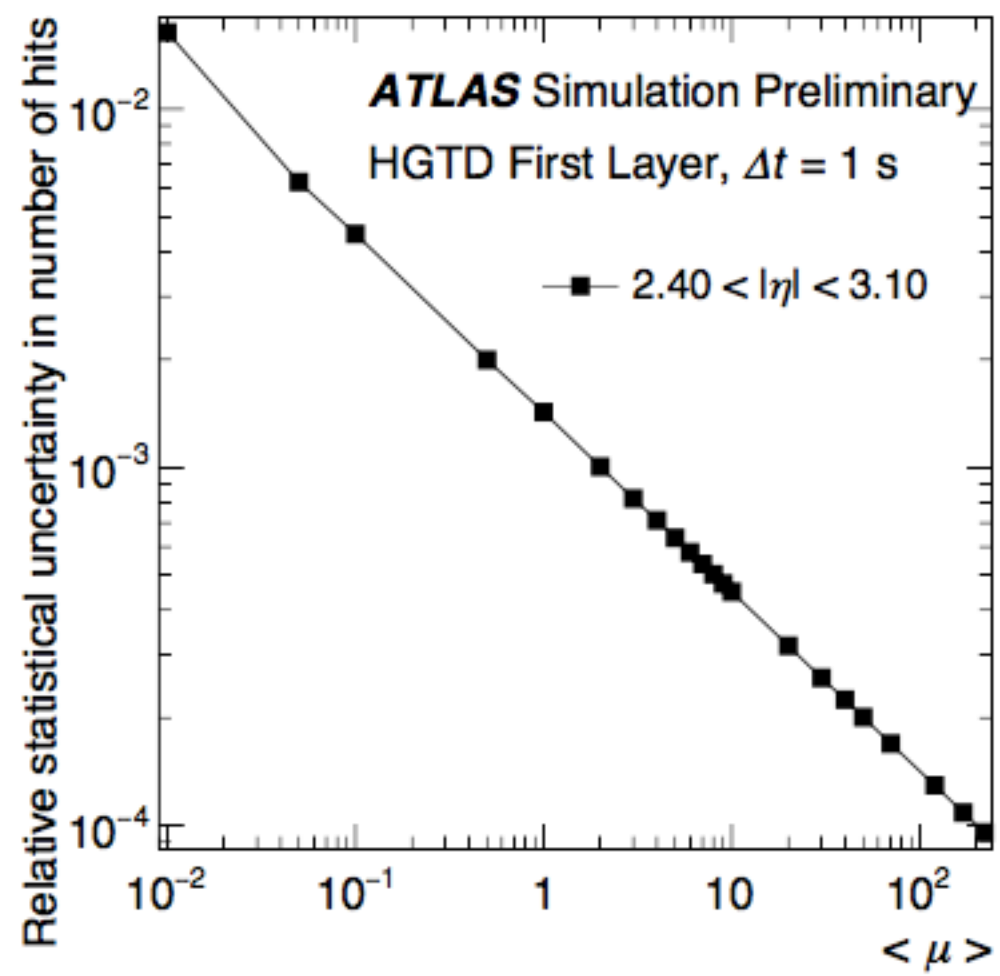
Uncertainty with ITK only (Grey)
Uncertainty with ITK+HGTD(Yellow)



Luminosity measurement

- 1% precision in Lumiosity measurement is needed in HL-LHC for Higgs
  - The high granularity HGTD gives a low occupancy
  - excellent linearity in the average #HGTD hits and #pp interactions
  - Can estimate of the bunch-by-bunch luminosity (fast readout)





Why an HGTD Project?

- New sensor technology
- Interesting application possibilities with maturity of the technology
  - Possibility of integrating into real 4D tracking
- New project in ATLAS, so it needs manpower and funds
  - Relatively small project (8.5 MCHF), so a relatively small contribution can make us one of the leaders of the project
- Still a lot of development to be done
  - TDR is planned for March 2019
  - Still lots of opportunities for our own contributions

Current HGTD ATLAS

Country (funding agency)	Institutes/Universities
	CERN
France	LAL (Orsay), LPNHE (Paris) , OMEGA (Palaiseau)
Germany	JGU (Mainz), JLU (Giessen)
Slovenia	IJS (Ljubljana)
Spain	IFAE (Barcelona)
Sweden	KTH (Stockholm)
Taiwan	AS (Taipei), National Tsing-Hua U
USA	BNL, Ohio State U, SLAC, SMU (Dallas), Stony Brook NY, UC Santa Cruz, U of Iowa
Russia	JINR
Morrocco	Univ. Hassan II Casa Blanca

US institutions
not allowed
to contribute to HGTD core

↓

Opportunity of China

Activities	Institutes
Sensors	BNL, CERN, Dubna, IFAE, , JSI, UCSC
Electronics	AS, Tsing-Hua, CERN, Dubna, Giessen, IFAE, Iowa, KTH, LAL, Omega, SLAC, SMU, Stony Brook
Luminosity/trigger	KTH, Ohio State
Test beam	All institutes
Module assembly	CERN, BNL, Dubna, IFAE, Iowa, JSI, LAL, LPNHE, Mainz, Ohio State
Mechanics/Integration	CERN, Dubna, LAL, LPNHE
Software & Performance	Casa Blanca, CERN, Giessen, IFAE, Iowa, KTH, LAL, LPNHE, SLAC

HGTD lacking
participation of
institutes with silicon detector
infrastructure

HGTD Tasks for China

- **Sensor** design, characterization and production
  - Work already on-going at IHEP
    - Sensor design
    - Leading some LGAD sensor characterization tests
    - Participated in test beam
- **Module** assembly (including R&D) and **stave** loading
  - Bump bonding
- **ASIC** design
- Front end **electronics** and readout electronics?
- **Simulation** work and physics case

IHEP HGTD Sensor Tests

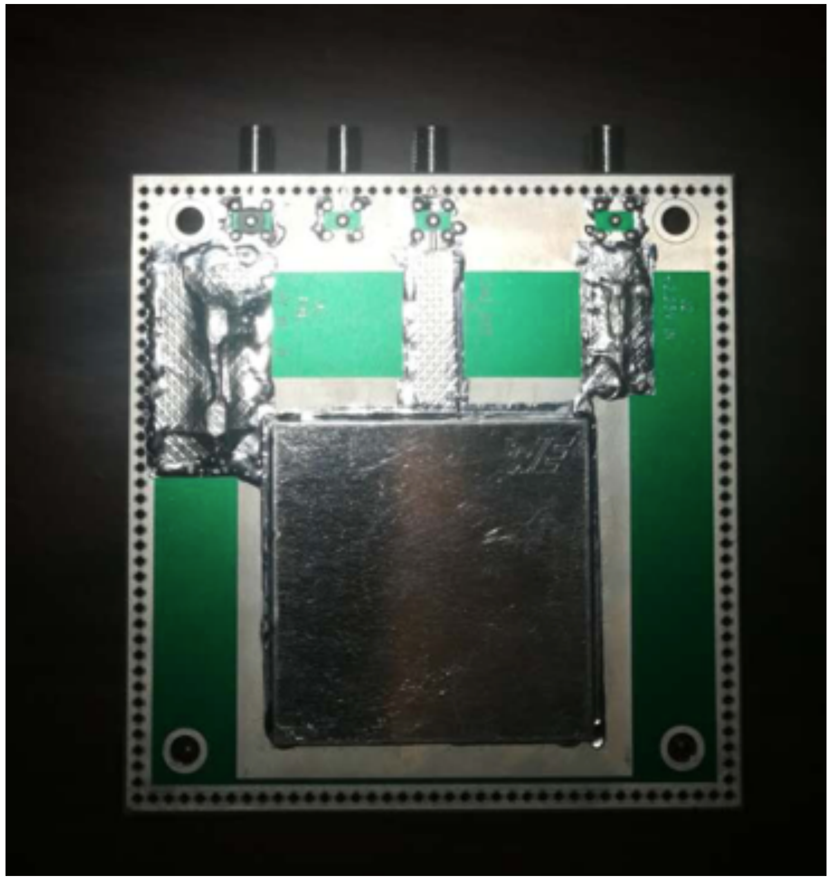
- **Leading tasks:**
  - I-V, C-V: “single” probes: singles, 2x2 arrays (cold)
  - I-V: Probe card: 5x5 arrays
- **Test beam participation**

- **Contributing tasks:**
  - TCT with Laster: 2x2 arrays
  - I-V: Probe card: 15x15 arrays
  - I-V: Breaking (X-rays)
  - ASIC Read-out

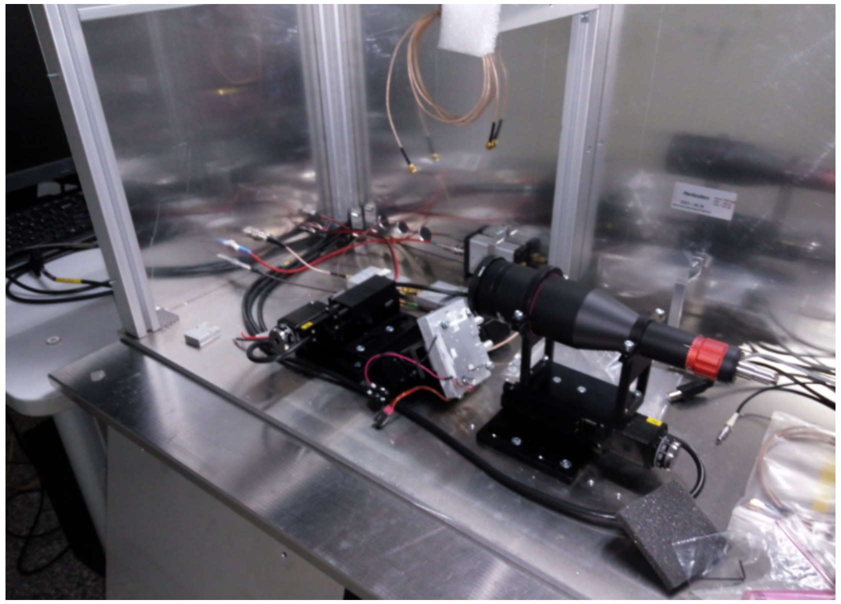
MultiRad 160

x-ray irradiator

LGAD Test board



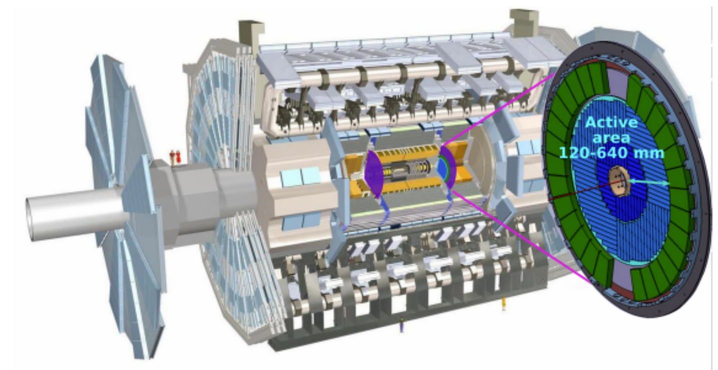
TCT laser system



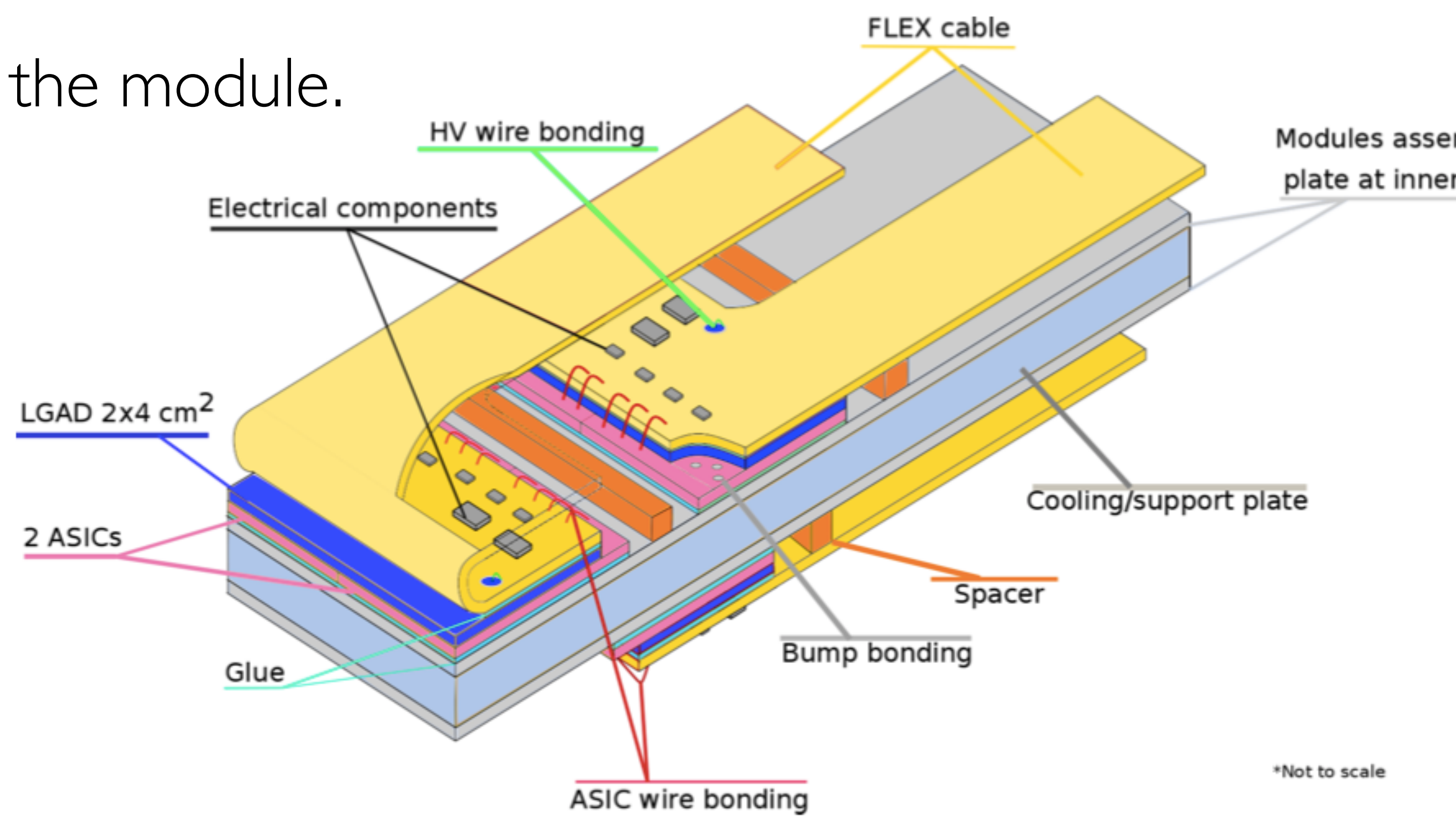
Experience: APD sensor, TCAD simulation, design and testing

Task for Module production

Aim to construct a full wheel



- Module (2cm X 4cm) = Two ASIC + one Sensor
- List of tasks:
  - Bump bonding(connect ASIC sensor)
    - Work with local foundry to improve the yield of bump bonding.
  - FLEX cable design and production
  - Cooling and mechanical design of the module.
  - Module irradiation test



Sensor/Module Task Details

- Design of radiation hard LGAD for production at local foundry
  - Try to improve radiation hardness of current sensor
  - Sensor could be used for HGTD upgrade (if not ready for qualification of the first detector installment) — needed if no further improvements in radiation hardness
- Module construction
  - Ouyang's group to lead module construction at IHEP
    - Currently 1.5 FTE: Yunpeng, Jing Dong
    - Two more technicians to join work at time of construction
  - Bump bonding to be done in China by Chinese company
    - Contacts with companies already initiated

ASIC Design Task

- ALTIROC chip: Pixel front-end chip with TDC
  - Project: Develop/include new ADC for signal amplitude measurement
- ALTIROC1 uses two TDC
  1. time of arrival (ToA) measurement
  2. time over threshold (ToT) measurement
- Current chip has problems with ToT TDC measurement
- Solution: perform an amplitude measurement instead of the ToT.
  - Develop/include an ADC instead of the second TDC
  - Can be used in addition to TDC if TDC problems get fixed
  - Timescale: ASIC ready before ALTIROC2 submission September next year.

Close collaboration with Barcelona — also through CEPC MOST 2

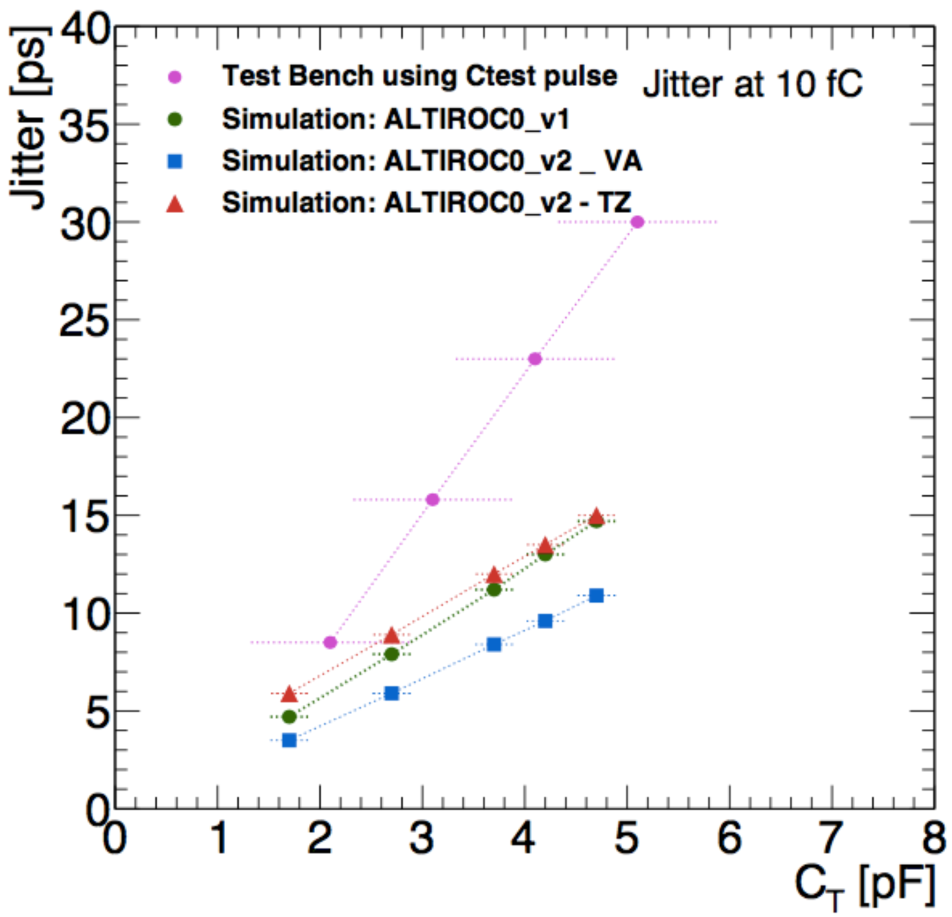
Other design work could be necessary as time progresses

ASIC for fast timing detector

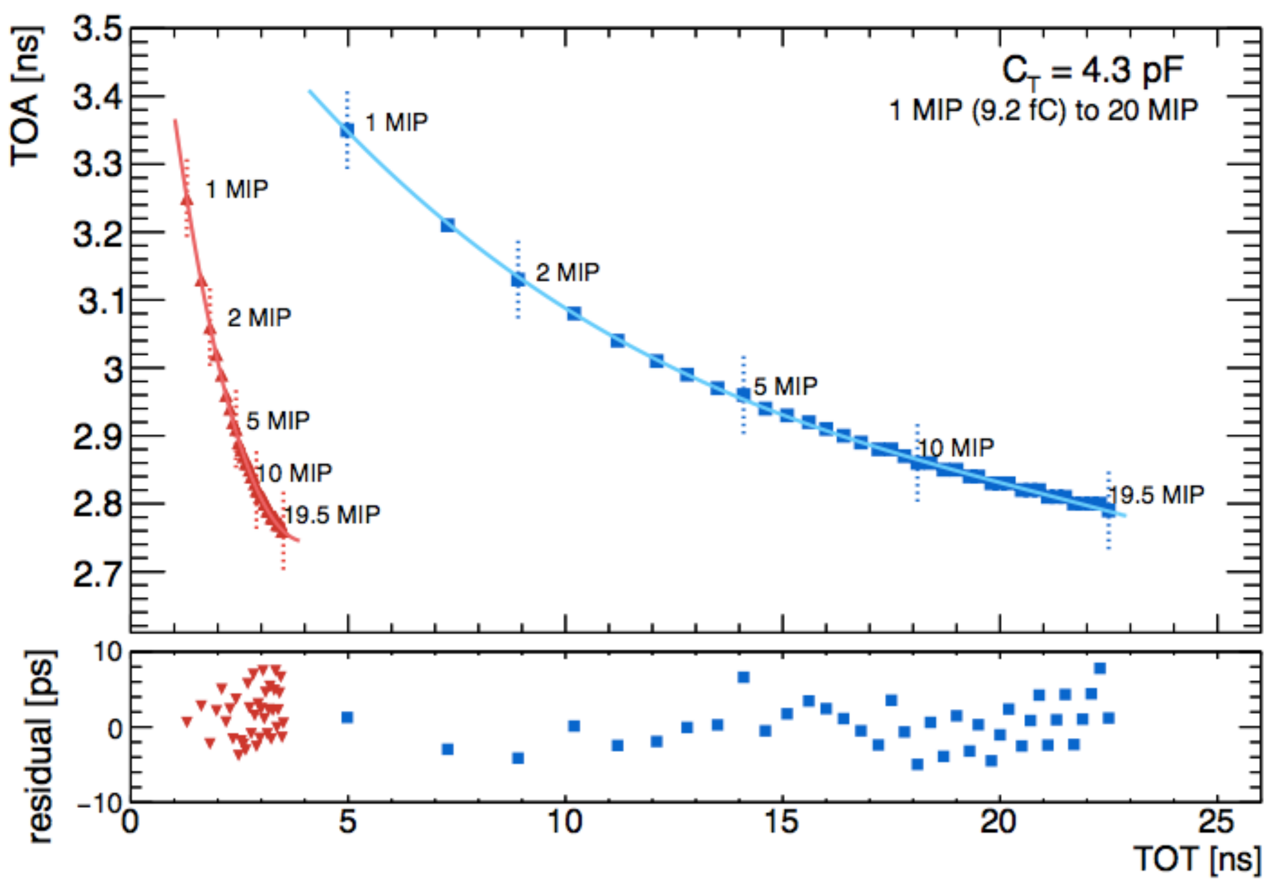
- To design ASIC for fast timing detector
  - Need to handle jitter, Time walk (TW) and TDC uncertainty
  - ASIC record Time of arrival (TOA)and Time over Threshold (TOT)
    - Correction for Time walk, precision within 10ps

$$\sigma^2_{\mathrm{elec}} = \sigma^2_{\mathrm{jitter}} + \sigma^2_{\mathrm{TW}} + \sigma^2_{\mathrm{TDC}}$$

Reduce capacitance to reduce jitter

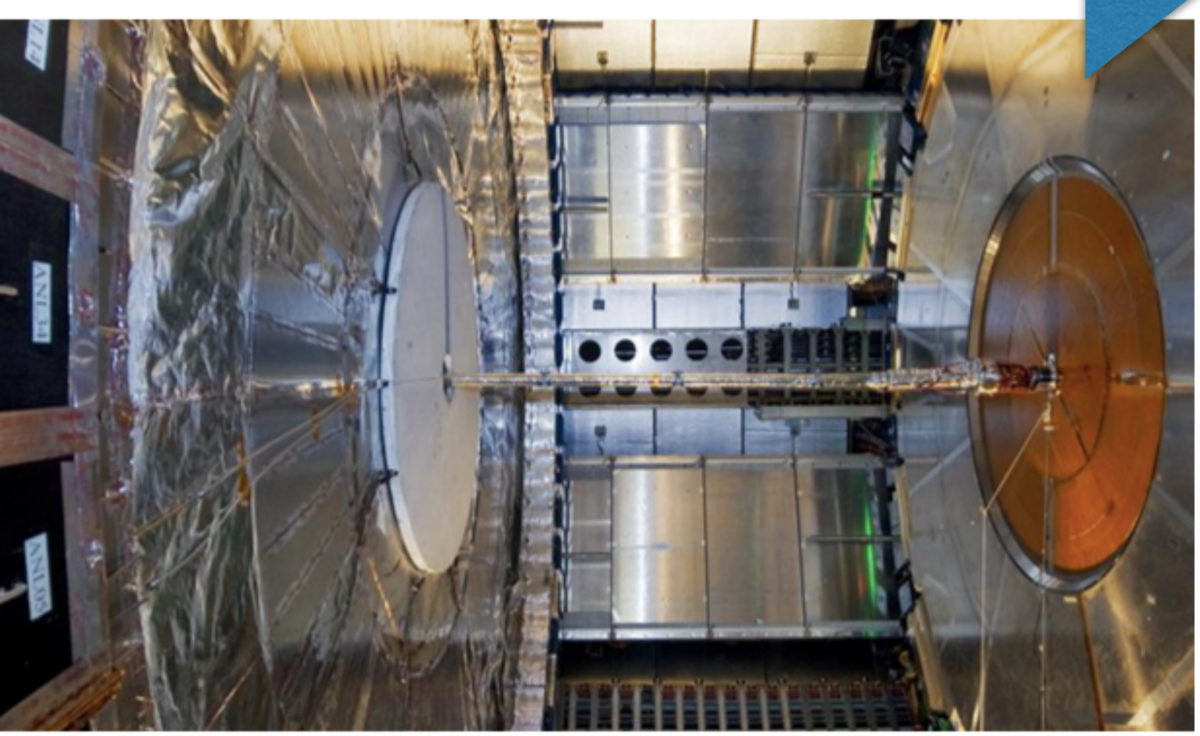


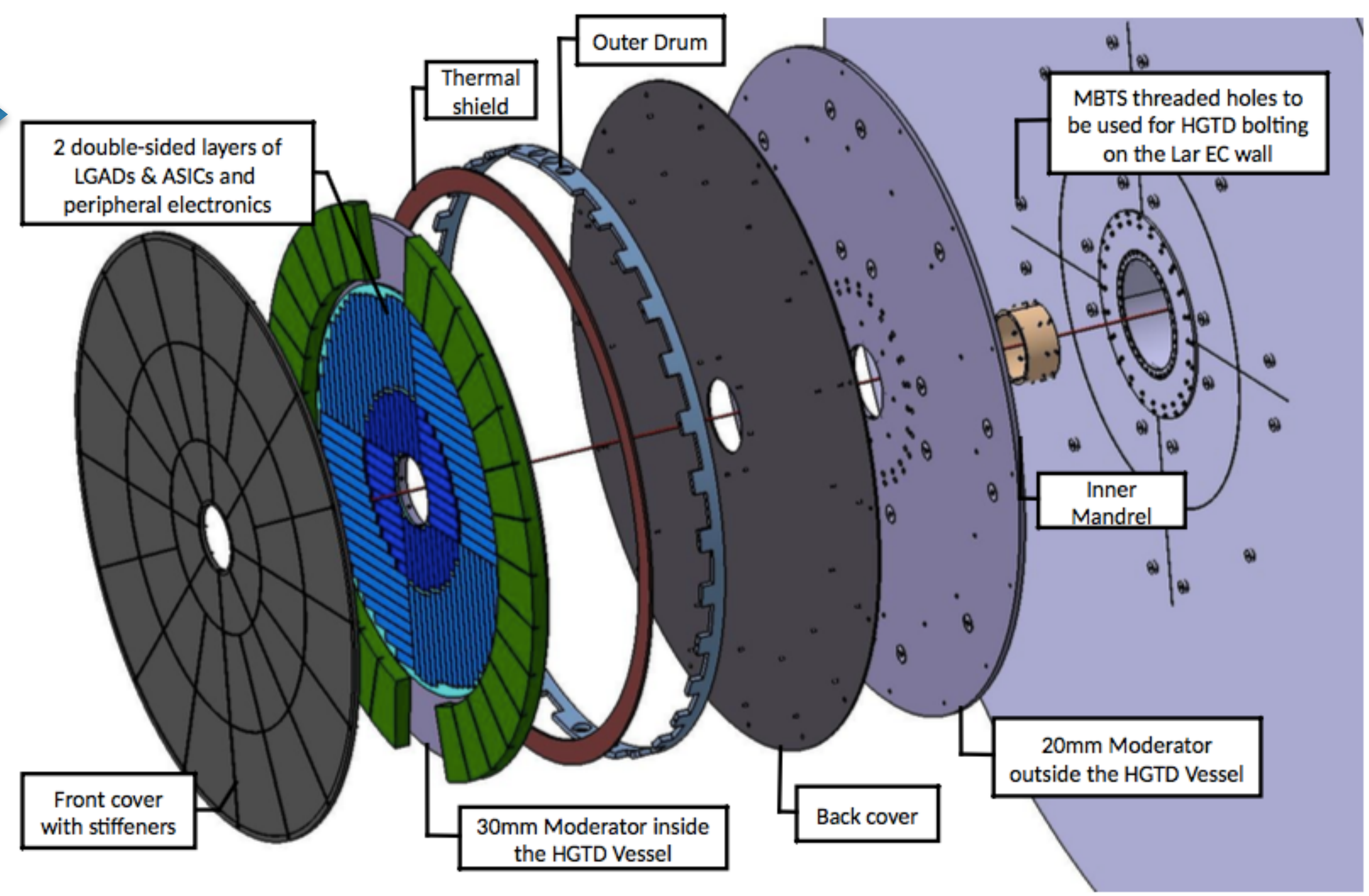
Time walk correction with TOA and TOT



HGTD Wheel assembly

- Plan to contribute wheel assembly at CERN
  - Non-core contribution, but important upgrade OTP task
  - Loading staves on the wheel at CERN
  - Detector DAQ Commissioning





IHEP Manpower

- IHEP people interested in the project:
- **ATLAS author physicists (8):** Joao Guimaraes, Ouyang Qun, Shi Xin, Zhijun Liang, Xuai Zhuang, Yanping Huang, Xu Da, Lianyou Shan
- **Other staff (5-7):** Wei Wei, Zhao Mei, Jie Zhang, Yunpeng Lu, Jing Dong (at least two new technicians at time of production)
- **Current students (2):** Suyu Xiao, Kewei Wu
- **Current postdocs (2):** Mohamad Ayoub, Ryuta Kiuchi
- Collaboration with RD50 led by Shi Xin

Several of these are already actively working on the project

Core cost of HGTD in kCHF

Item	Cost (kCHF)
Sensors	1700
Front-end ASICs	730
Bump bonding	900
Module assembly	600
Peripheral on-detector electronics (transition, optical and HV boards, optical links, services)	717
Power supplies and electronics in USA15	2027
Mechanics and integration (cooling support plates, vessel, feedthrough)	405
CO_2 cooling plant and distribution	450
Sub-total HGTD	7529
Detector readout, dataflow, and network	970
Total (kCHF)	**8499**

Total HGTD core cost: 8499 kCHF = 58.4 MRMB

Goal: take a leading role in the project

Core contribution suggestion: ~25 % ==> 15 RMB

about 2 MCHF or 66% of missing contribution to ATLAS

Preliminary funding by country

Outcome of 11 Jan informal kick-off meeting Core Contribution intentions (CHF):

France (IN2P3): 2 M

Germany (BMBF): 0.3 M

Russia (JINR): 0.5 M

Slovenia (Ljubljana): 0.12 M

Spain (IFAE and CNM Barcelona): 1 M

Sweden (KTH Stockholm): 0.8 M

Switzerland (CERN): 2 M

Taiwan (Academia Sinica, Nat. Tsing Hua Univ.): 0.33 M

US Labs (DOE): 0.63 M

US Universities: 0.9 M

Budget

Topics	Budget
Sensor R&D and production	800万
Fast timing readout ASIC	500万
Module prototype R & D (including bump bonding)	400万
Stave R & D	300万
Backend electronics	400万

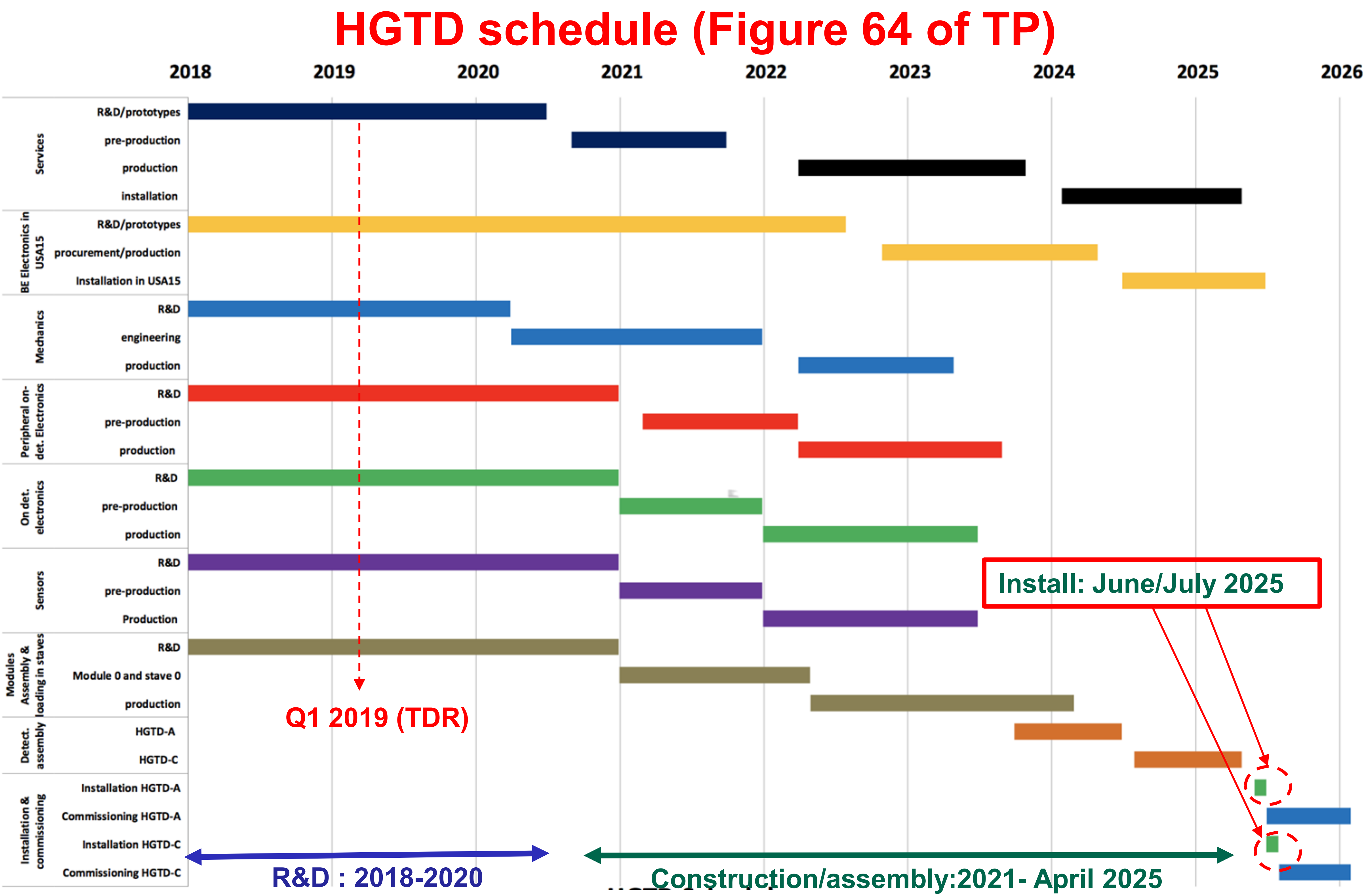
Budget (1)

- **Sensor**
  - 500万： Production (core contribution)
  - 210万: R & D
    - Special combined Wafer : 0.6万 X 50个 =30万
    - Engineering run ： 25万 X 6次=150万
    - Mask： 5万 X 6次=30万
  - 90万： Sensor testing (probe card, irradiation tests, test beam)
- **Fast timing readout ASIC**
  - 150万： Production (core contribution)
  - 350万： R & D , 175万 X 2次=350万

Budget (2)

- **Module and stave production**
  - 320万： Bump bonding production (core , for one full wheel)
  - 220万： Module assembly (core, material fee, for one full wheel)
  - 60万: R & D for bump bonding
  - 100万： Manpower for stave assembly and integrate them on the HGTD wheel
- **Electronics**
  - 130万: production (core)
  - 270万： R & D
    - optical link, on-detector electronics, backend electronics, slow control

HGTD Schedule in ATLAS



Extra slides

IHEP Infrastructure

- Existing class 1000 (ISO6) Cleanroom with 150 m^2

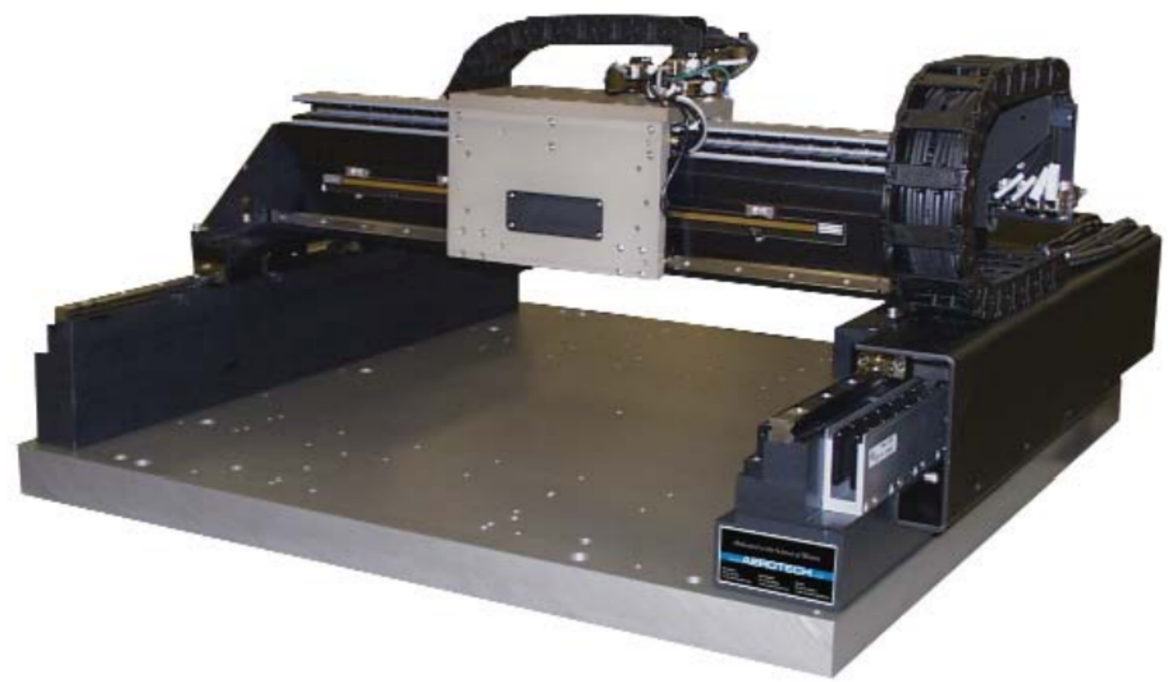
- A few other cleanrooms available at the lab
  - Electronics group clean room
  - ITK module construction clean room

Some relevant equipment

OGP Flash CNC 300
Smart scope
Visual inspections

Hesse BondJet820
Fast auto wire bonder

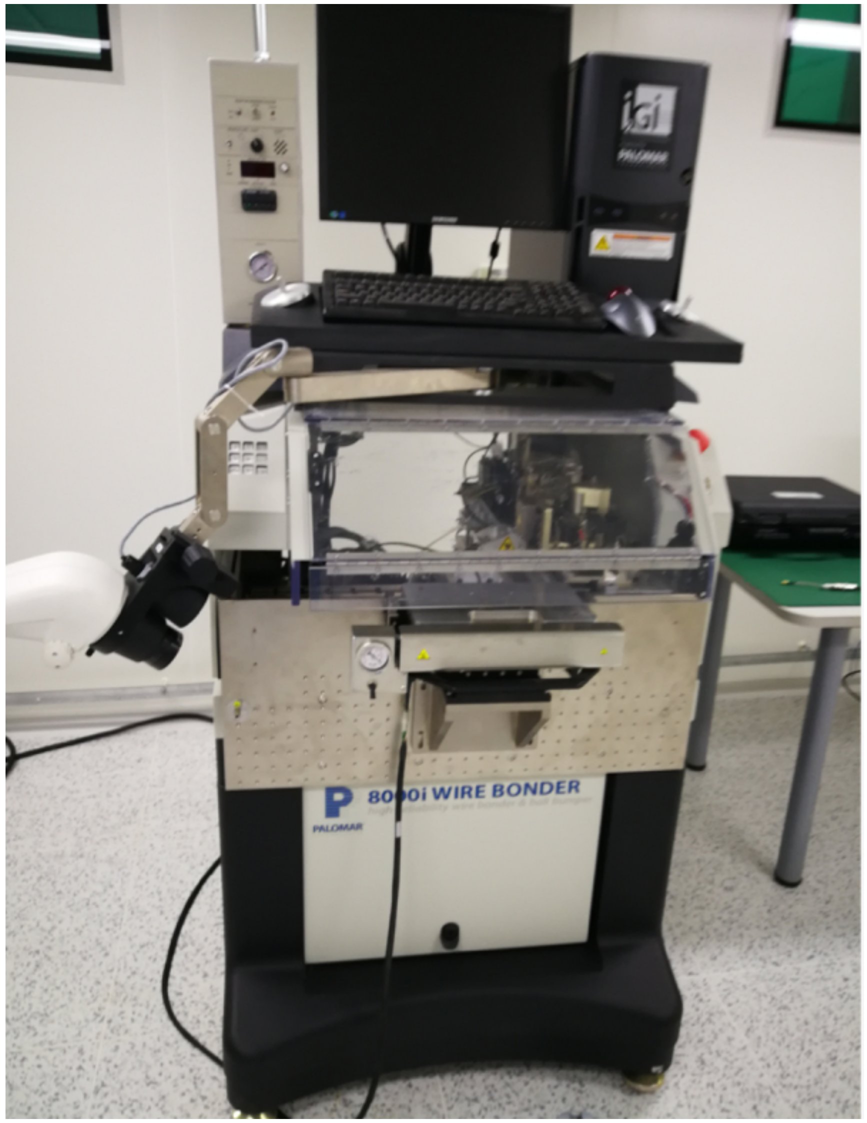
Gantry



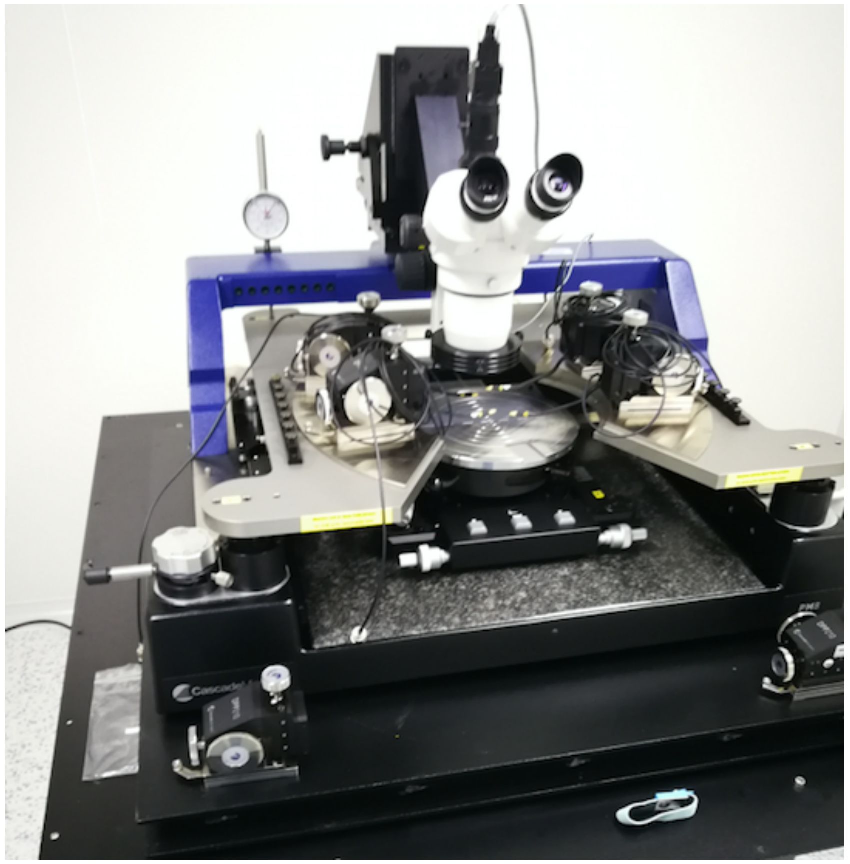
Several other equipment: probe stations, wire bonders, etc

Some relevant equipment

Palomar 8000i
Wire Bonder



Probe station



New probe station
with cold chuck

ESPEC
Controlled environment chamber

Size of ATLAS clusters

USTC-SDU-SJTU Cluster

	Authors	Oper. Task	M&O
USTC	36	32.25	15
Shandong	12	12	6
Shanghai	13	15.5	8
TD Lee	2	2.75	2
Total	**63**	**62.5**	**31**

USTC-SDU-SJTU Cluster

	Authors	Oper. Task	M&0
IHEP	27	26.5	16
Nanjing	4	7.75	4
Tsinghua	5	5	2
Total	**36**	**39.25**	**22**

- Total ATLAS China authors: 99
- Total ATLAS authors: 2940

3.4% of the collaboration
(M&O funding: 2.74%)

Institutes manpower coverage

	R&D Phase Phys.	Student	Eng.	Tech.	Construction Phase Phys.	Student	Eng.	Tech.
France (IN2P3):	4.5	1	5.4	2.1	4	1	6.5	2.8
Germany (BMBF):	1.5	2	0.2	0.2	1.6	3	0.1	0.7
Russia (JINR):	1.5	0.5	2	0.5	1.5	0.5	1.5	0.5
Slovenia (Ljubljana):	1.5	1	0.3	0.3	1.5	1	0.3	0.3
Spain (IFAE Barcelona):	2	1	0.5	0.5	1	1	1	1
Sweden (KTH Stockholm):	0.9	0.2	0.5	0.0	0.6	0.2	0.5	0.0
Switzerland (CERN):	3	0.5	3	1	4	1	3	2
Taiwan:	2	2	0.0	0.0	2	2	0.0	0.0
US Labs (BNL and SLAC):	2.3	0.3	1	0.3	2.3	0.3	2.2	2.2
US (5 Universities):	7.9	11.1*	2.2	1.4	8.9	14.2*	1.9	1.7
Sum (FTE)	**27.1**	**19.6**	**15.1**	**6.3**	**27.4**	**24.2**	**17.0**	**11.2**

*About ½ of US students are undergraduates used for testing.

USA groups approved only for R&D.

Without China, Italy, Brazil

+Morocco: phys 0.8 ; student 0.5 ; tech =0 eng =0

ATLAS R&D funding required

Main R&D Costs 2018- 2020 (KCHF) preliminary

Item (KCHF)	2018	2019	2020	Total
Sensors	100	100	up to 100 ?	200-300
Electronics	80	275	330	**685**
Testbeams	~20	~20	~20	60
Modules assembly	10		24	34
Mechanics, services & integration	28		45	73
Total				1052-1152

2018: costs mostly on sensors and ASIC-ALTIROC was shared with few Institutes

→ **results on laboratory and test beams available for the TDR**

2019-2020:

- Larger costs mostly due to full ALTIROC iteration Version 1,2 (250k/iteration)
- Ongoing inquiry to Institutes for possible costs sharing (Abe Seiden)
- Need cost sharing agreement for Sensors/ASICS to more Institutes (similar to ITK)
- For other items expect costs to be shared w/ Institutes involved

→ **post-TDR results needed for Milestones 9-18 of TP table 18 (PDR,FDR, PRR)**

Manpower details

- **Jie Zhang**
  - PhD, rich experience on advanced digital electronics design
  - Especially on system architecture, high speed communication…
  - Interest on the digital design
  - May also contribute to the backend readout electronics
- **Mei Zhao**
  - PhD, expert on Sensor design and simulation
  - May contribute to the sensor design and manufacture
- **Wei Wei**
  - PhD, experience on mixed signal ASIC design
  - Especially on hybrid pixel detector ASIC design

Core contributions from countries to ATLAS

ATLAS Phase-II Upgrades – envisaged CORE Contributions by Funding Agency [kCHF]

	TDAQ	ITk Total	ITk Pixels	ITk Strips	ITk Common	LAr	Tile	Muons	HGTD [3]	Total	Common Fund	TOTAL[2] (incl. CF)	LUCID [4]	FWD [5]	Ta
CORE Costs[1] [kCHF]	44'880	123'226	47'804	60'638	14'784	28'385	11'573	28'403	8'499	244'966	24'420	269'386	500	800	
Funding Agency	**CORE Commitments**														
Argentina	759									759	78	837			
Armenia															
Australia	390	2'021		2'021						2'411	196	2'606			
Austria	200									200	39	239			
Azerbaijan											13	13			
Belarus							13			13	26	39			
Brazil											183	183			
Canada		5'958		5'308	650	1'573				7'531	849	8'379			
Chile								50		50	131	181			
China NSFC+MSTC		2'043		2'043				703		2'746	627	3'372			
Colombia	400									400	52	452			
Czech Republic	500	4'550	1'396	2'700	454		560			5'610	509	6'119			
Denmark	773	648		648						1'421	144	1'565			
France IN2P3	786	6'075	5'025		1'050	5'800	943		2'700	16'305	1'489	17'794			
France CEA		1'139	959		180	2'343		410		3'891	313	4'204			
Georgia							78			78	78	156			
Germany BMBF	2'760	11'677	6'068	4'300	1'310	1'450	444	1'946	300	18'578	1'998	20'576			
Germany DESY		6'034		5'344	690					6'034	483	6'518			
Germany MPI	636	493	403		90	237		2'433		3'799	274	4'073			
Greece	800							2'490		3'290	196	3'486			
Hong Kong		466	406		60			323		789	131	920			
Israel	2'503							384		2'887	379	3'265			
Italy	3'850	5'585	5'070		515	1'800	598	5'620		17'454	2'207	19'661	290		
Japan	1'643	11'638	3'577	7'051	1'010			4'281		17'562	992	18'555			
Morocco											144	144			
Netherlands	400	2'779	147	2'452	180			424		3'603	313	3'916			
Norway		1'918	1'330		588					1'918	209	2'127			
Poland	2'000	1'720		1'090	630					3'720	379	4'098			
Portugal	405						988			1'393	196	1'589			
Romania	1'735						1'174			2'909	209	3'118			
Russia		1'283	550		733	1'431	70	1'813		4'598	836	5'433			
JINR	940					1'043	48	430	600	3'061	340	3'400			
Serbia											65	65			
Slovak Republic	600					400	300			1'300	131	1'431			
Slovenia		755		695	60				120	875	104	980			
South Africa		400			400		700			1'100	118	1'218			
Spain		3'502	902	2'213	387		1'315		440	5'257	640	5'897			
Sweden	200	2'162		2'162			1'561		800	4'723	392	5'115			
Switzerland	1'500	5'275	5'075		200					6'775	326	7'101			
Taipei								502	500	1'001	104	1'106			
Turkey	500							507	250	1'257	144	1'400			
United Kingdom	3'821	16'818	5'107	11'612	99					20'639	2'494	23'134			
USA DOE	2'135	20'470	7'034	10'901	2'534	378				22'983	3'656	26'639			
USA NSF	5'940					8'441	1'882	2'899		19'162	901	20'063			
CERN	8'044	7'975	4'475	100	3'400	3'494	882	3'094	2'006	25'495	1'332	26'827			
TOTAL (kCHF)	**44'221**	**123'384**	**47'525**	**60'638**	**15'220**	**28'389**	**11'557**	**28'307**	**7'715**	**243'573**	**24'420**	**267'993**	**290**		
Uncertainty Low	73.5%	85.6%	89.9%	81.7%	88.0%	95.0%	73.7%	62.5%	87.8%	81.3%	100.0%	83.0%			
Medium	16.0%	14.1%	8.6%	18.3%	9.5%	5.0%	25.3%	34.5%		15.8%		14.4%	58.0%		
High	9.0%	0.4%	0.9%		0.4%		0.8%	2.7%	2.9%	2.3%		2.1%			
% of CORE Costs	**98.5%**	**100.1%**	**99.4%**	**100.0%**	**98.0%**	**100.0%**	**99.9%**	**99.7%**	**90.8%**	**99.4%**	**100.0%**	**99.5%**	**58.0%**		
Δ (Total - CORE Costs)	-659	157	-279	0	436	4	-15	-95	-784	-1'392		-1'392	-210	-800	

Notes

1) CORE costs as defined in the TDRs and reviewed in detail by the Upgrade Cost Group (UCG) for TDAQ, ITk, LAr, Tile, Muons. For HGTD, FWD, μ-Tagger see notes 3-6).
2) Bar scale normalised to largest entry in column.
3) The High Granularity Timing Detector (HGTD) has not yet been reviewed, the TDR will follow in 2019.
4) A new LUCID detector was originally proposed in the Scoping Document under "Forward Detectors". It is now planned as a "Small Project" with details to be worked out in the coming months.
5) The remaining Forward Detector projects (ALFA,AFP,ZDC) are not being formally proposed at this stage.
6) The μ-Tagger project is not included in the present Phase-II scope, but remains an option as a further upgrade project for installation at a later stage (>2025)

Bump bonding

ATLAS project	Technical Specification for the Bump Bonding of HGTD Modules		
ATLAS Project Document No:	*EDMS Document No.:*	*Created: 20/11/17*	*Page: 1 of 7*
ATL-COM-UPGRADE-2017-022	AT2-G-ES-0001	*Modified: 10/10/18*	*Rev. No.: 0.4*

Technical Specification for the Bump Bonding of HGTD Modules

Summary

This Memo describes the technical specifications for the bump bonding of the hybrid modules of the proposed High Granularity Timing Detector (HGTD) to be installed in ATLAS for the LHC high luminosity period.

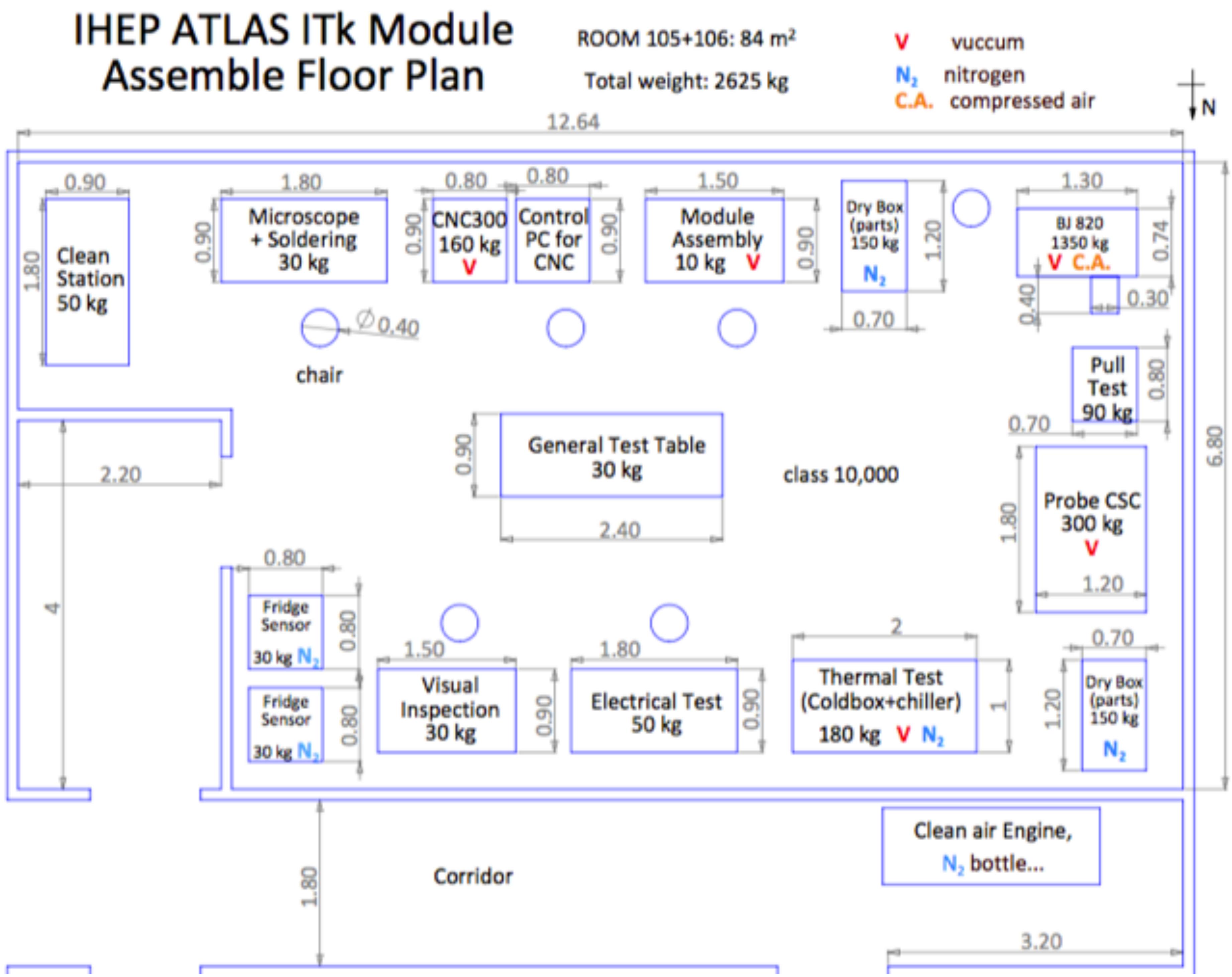
Prepared by:	Checked by:	Approved by:
S. Grinstein PH/UAT	**L. Masetti** **D. Lacour**	**A. Henriques** **L. Serin**

Distribution List

HGTD

IHEP Infrastructure

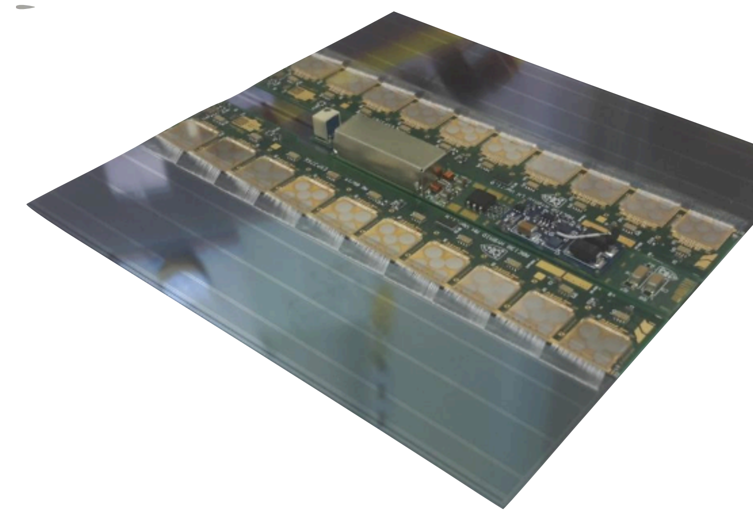
- New class 10000 (ISO7) cleanroom with 80 m² is on the way



中国科学院高能物理研究所

ITK Upgrade

- Responsible for 1000 barrel strip modules (together with RAL)
  - Production to be split between UK and IHEP
- CMOS strip sensor characterization
- Test beams at CERN and DESY
- Front-end Readout Electronics ASIC Design (ABC-star)

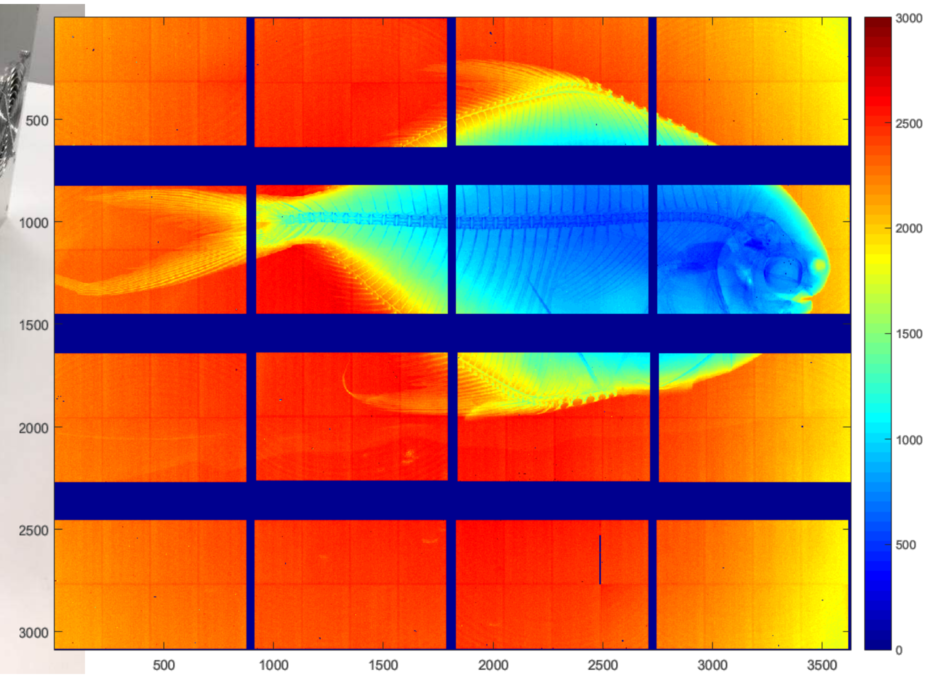


SmartScope
(OGP FLASH CNC 300)

High speed wire bonder
(HESSE BJ820)

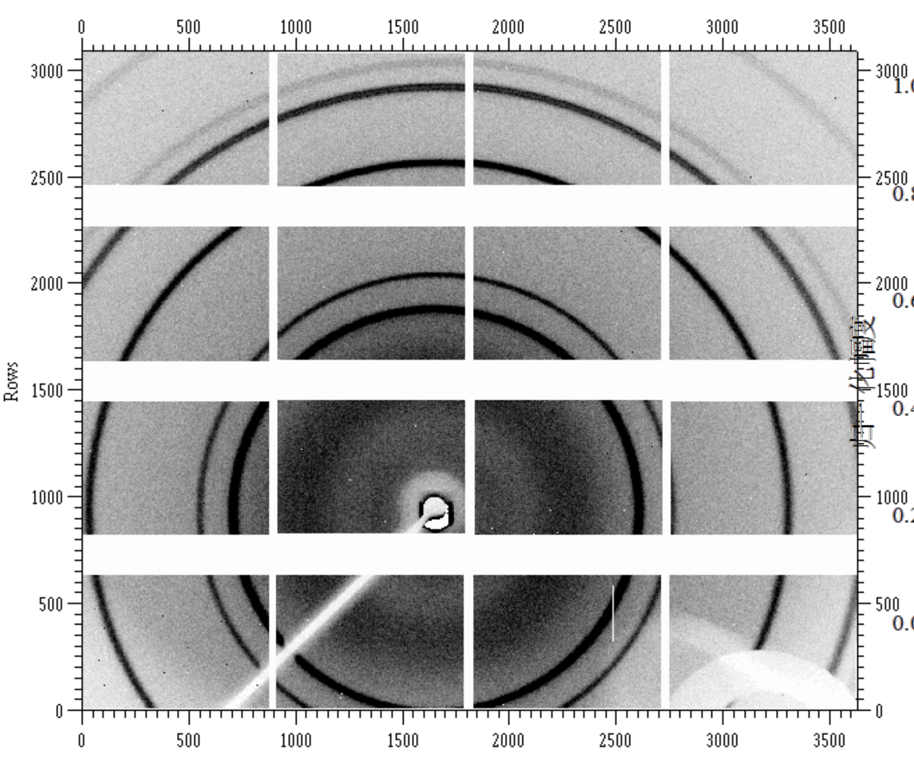
BPIX-1M System: a Hybrid Pixel Detector for HEPS

BPIX-1M system

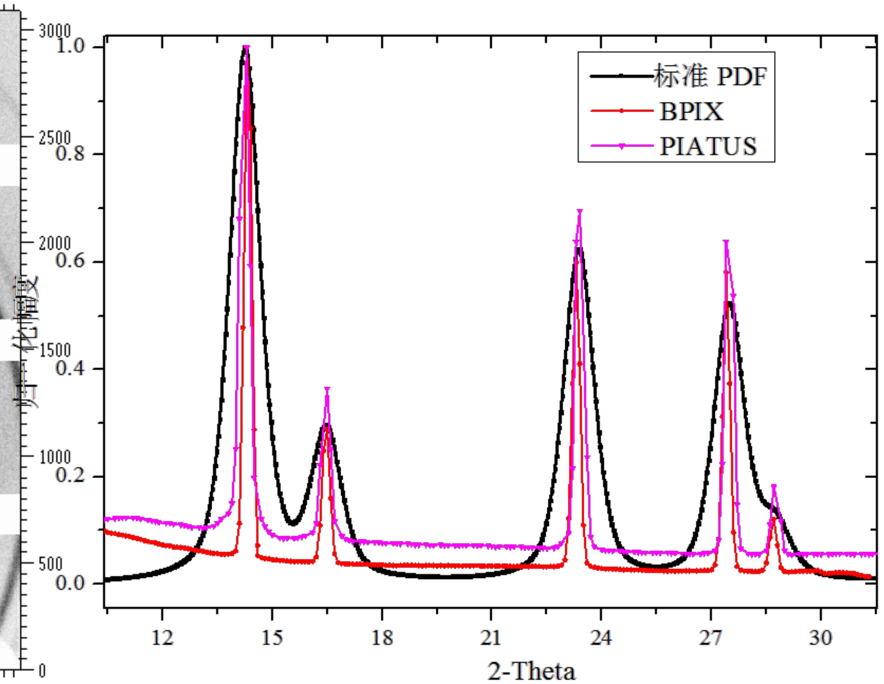


X ray imaging

- 300um Si PinN sensor + ASIC + In Bump
- Pixel size 150*150um
- Sensitive area：18cm*14.4cm
- Energy range: 6keV~19.5keV
- 20 bit counting depth
- Frame rate>1.2 kHz full system
- All key technologies (sensor, ASIC, bump bonding) done in China



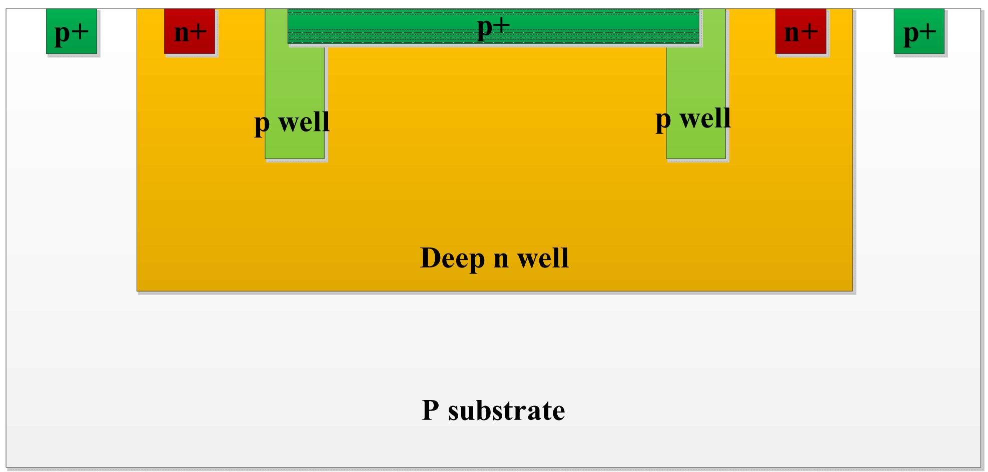
X ray diffraction on beamlines

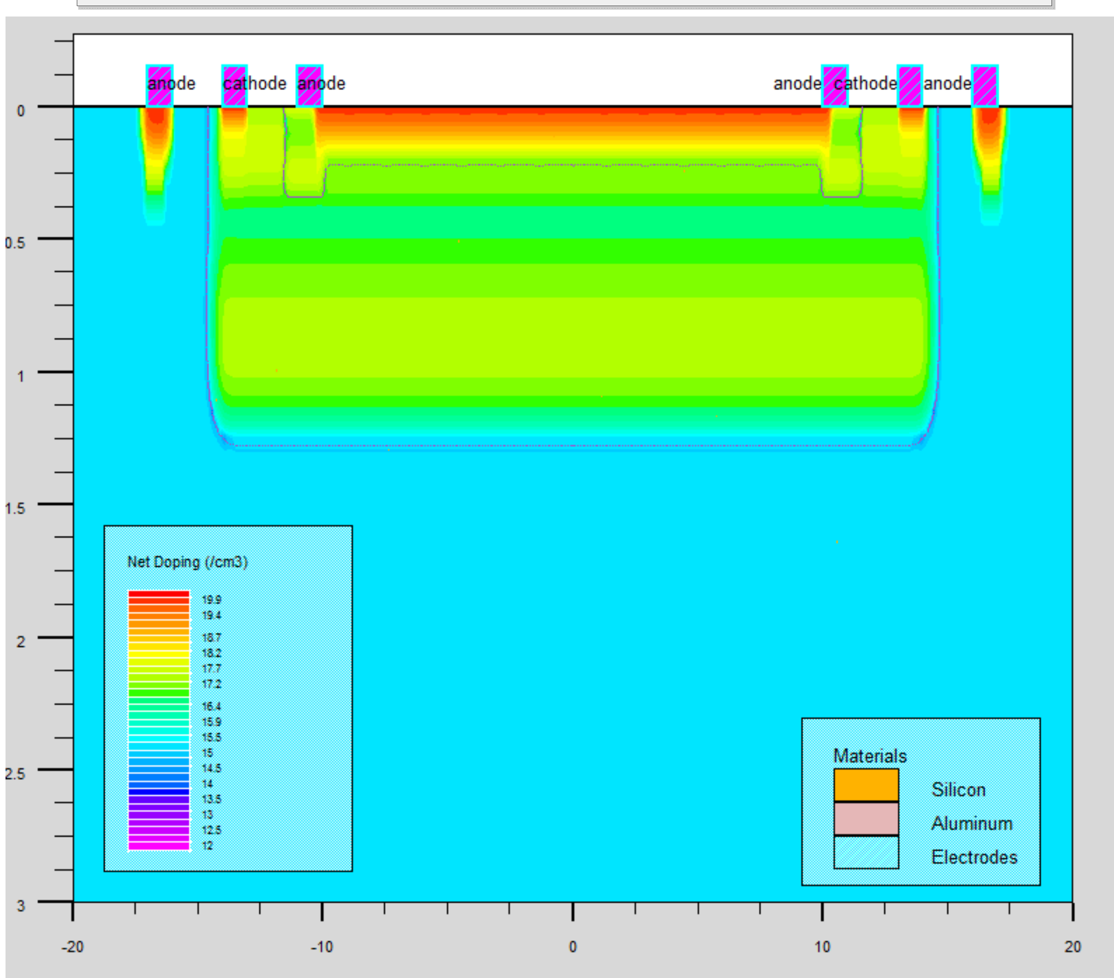


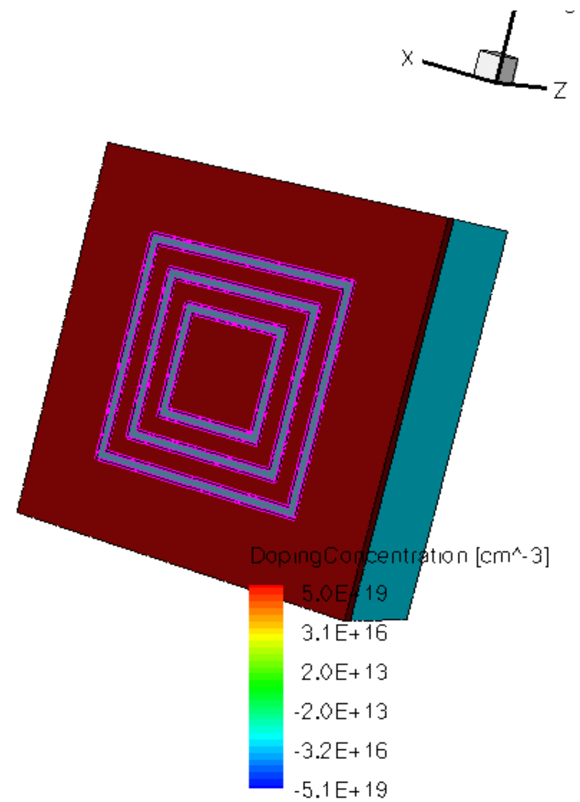
Analysis on diffraction data vs PDF

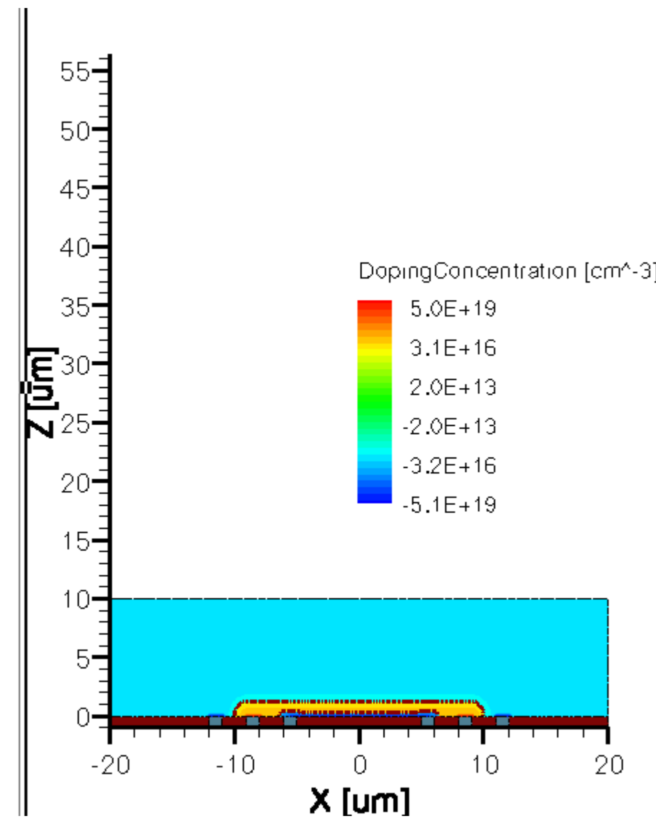
APD Sensor

- Sensor modeling and simulation







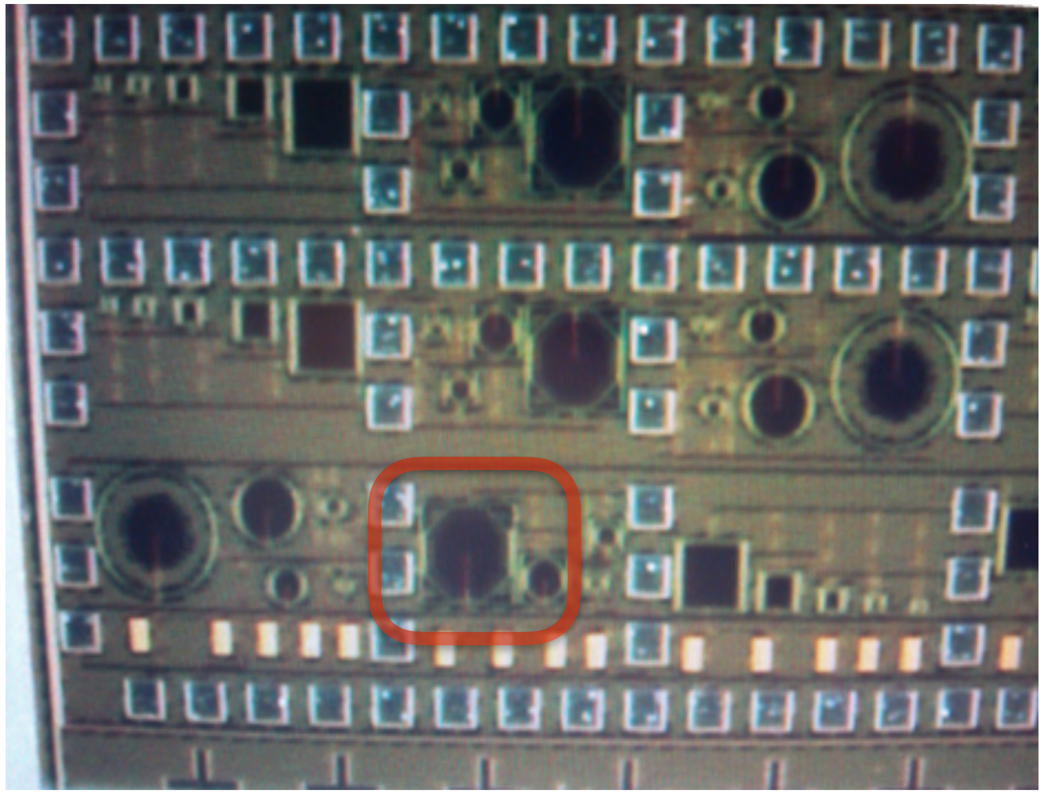


The sensor is designed for photon detector
Sensor Structure
2D\3D TCAD simulation

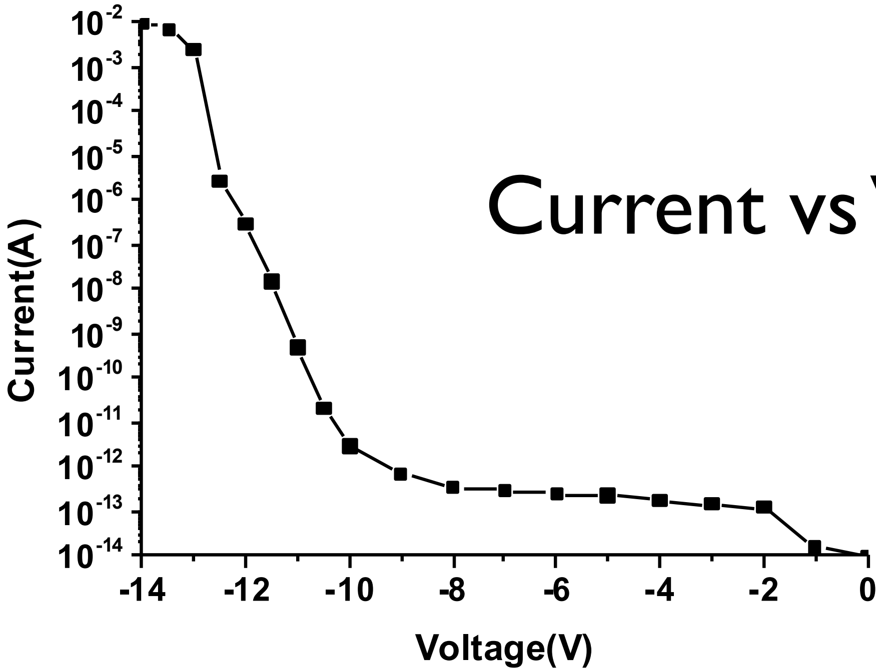
APD Sensor

- Sensors with different areas and shapes
- I - V characteristics and Signal based on 410nm incident light

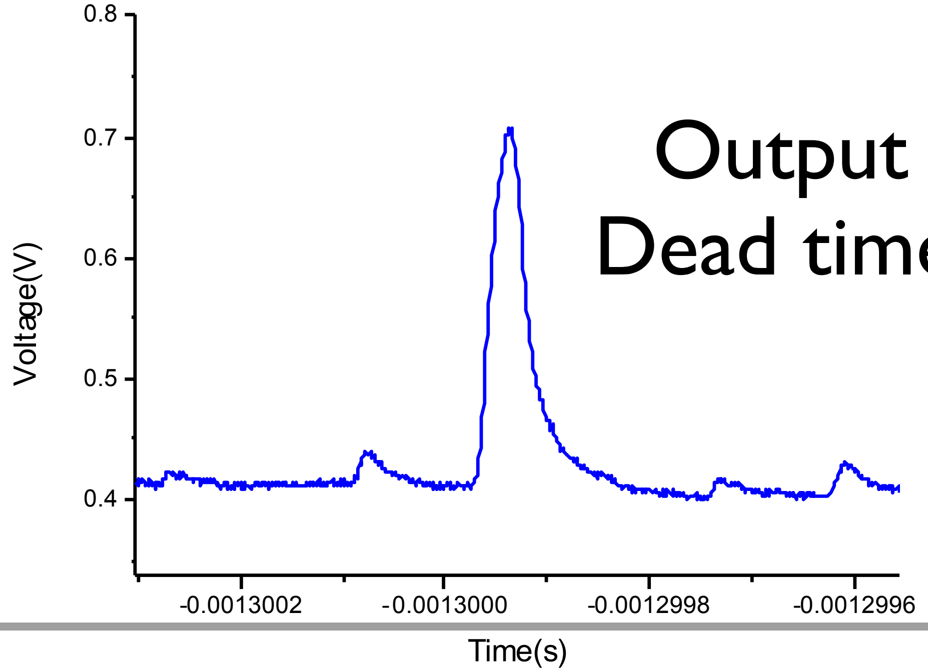
Sensor



Current vs Voltage

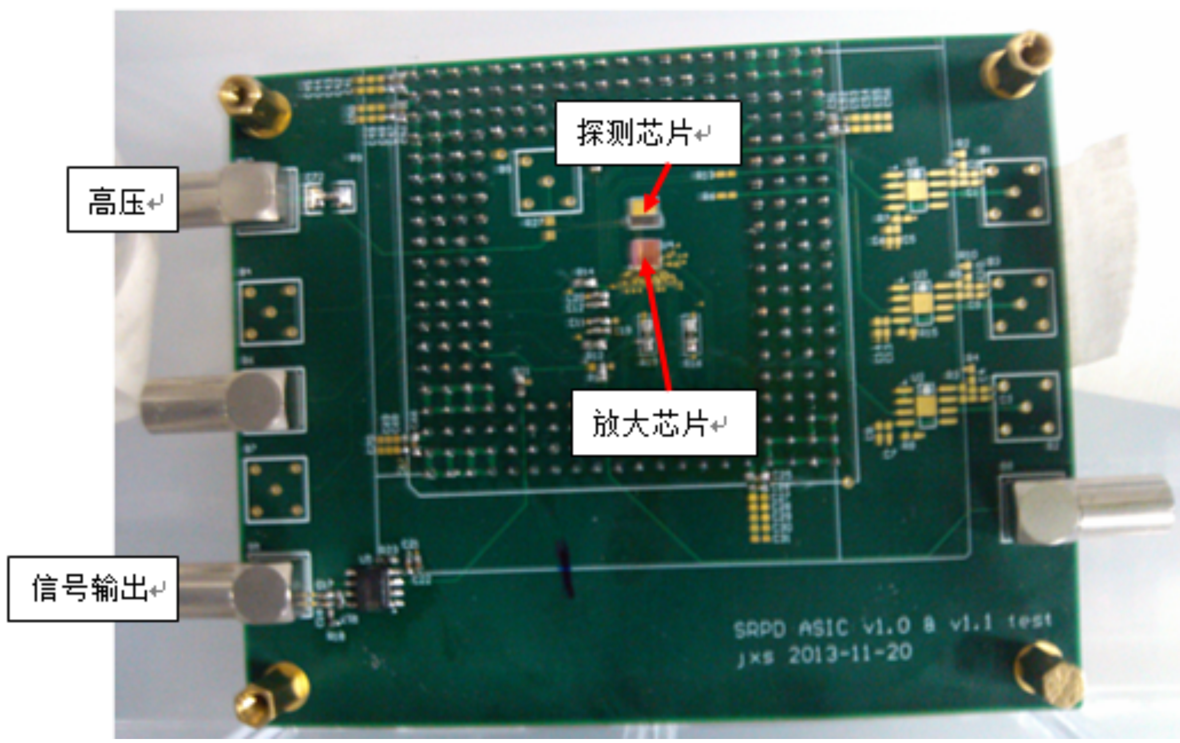


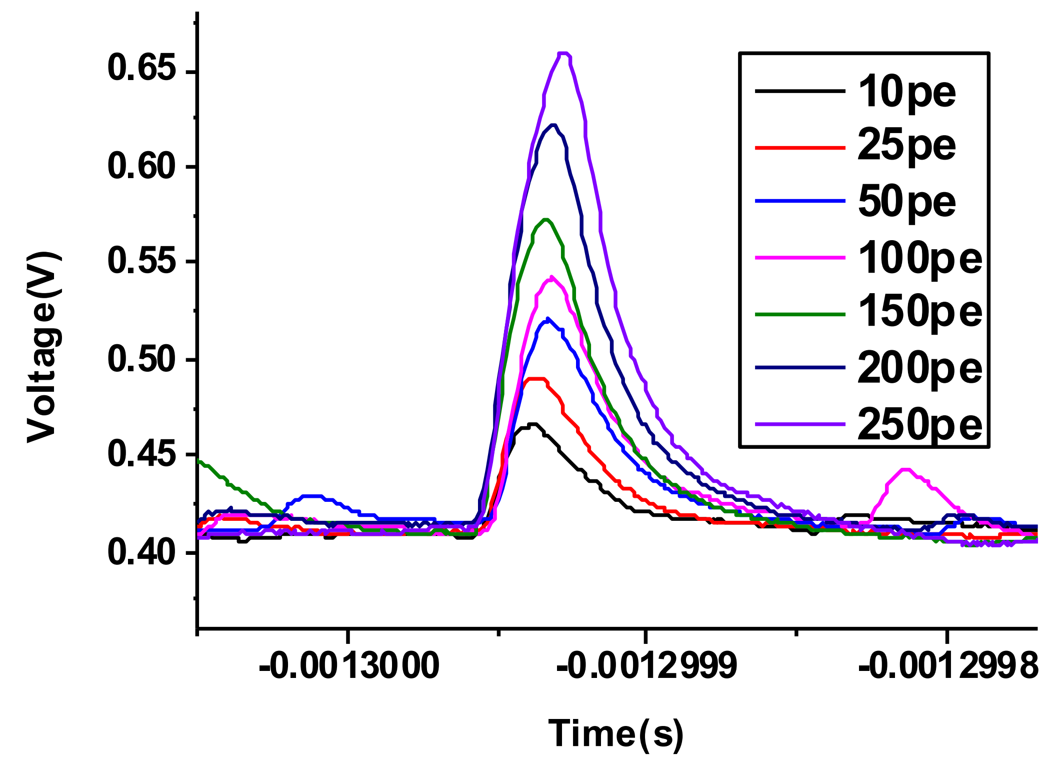
Output Signal
Dead time 125ns



APD Sensor

- Test results





- Connect sensor and amplifier on PCB
- Output signal increases as increasing numbers of incident photons
- More tests will be done on the Gain and Timing resolution
- New sensor will based on high resistivity substrate and large area 1.3*1.3 mm^2

Related ASIC/readout electronics design experience

- **Hybrid Pixel Detector Design**
  - Designed for High Energy Photon Source (HEPS)
  - Co-designed sensor + self designed ASIC + bump bonding by Chinese company + self designed readout Elec. + self designed mechanics
  - Various related pixel readout chip designed

- **JUNO underwater PMT readout**
  - Self designed ASICs for PMT & MCP-PMT
  - Large dynamic range, fast leading edge (~1.5ns)
  - High reliability requirement (over 10 years underwater, non-replaceable)

- **Low noise frontend ASIC design**
  - Involved in nEXO collaboration
  - Backup scheme for charge readout: analog serial readout
  - ~200e ENC requirement @ liquid Xeon

- **Rich experience on backend electronics**
  - Full design experience in BESIII, Dayabay, JUNO, LHAASSO electronic system