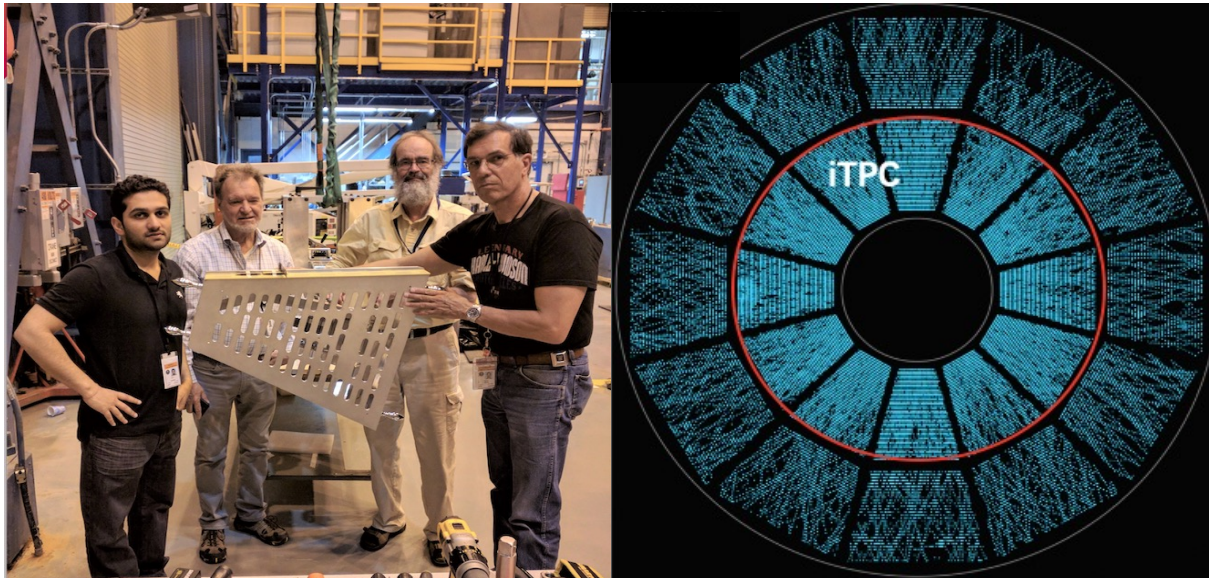


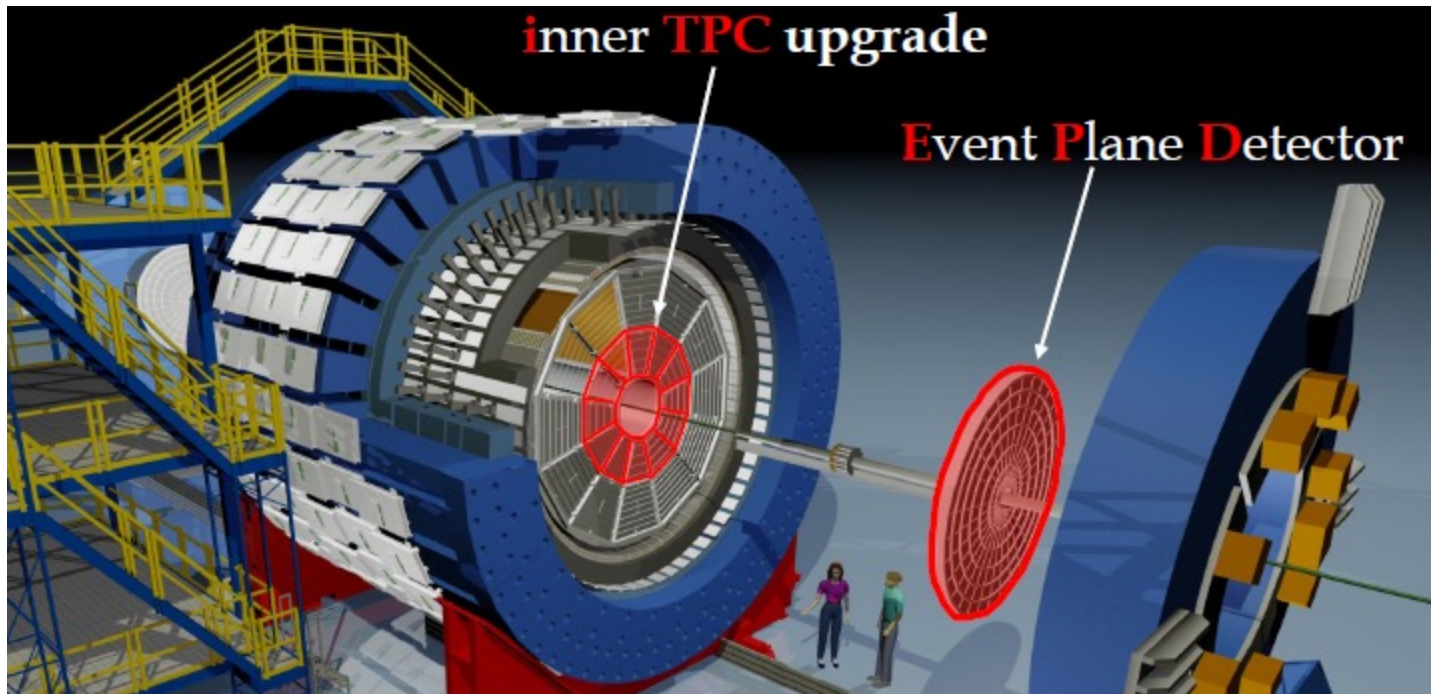
Flemming & STAR Inner TPC Upgrade

Qinghua Xu, Shandong University



@Flemming's retirement celebration
Feb. 11, 2022

Upgrade of iTPC readout at STAR

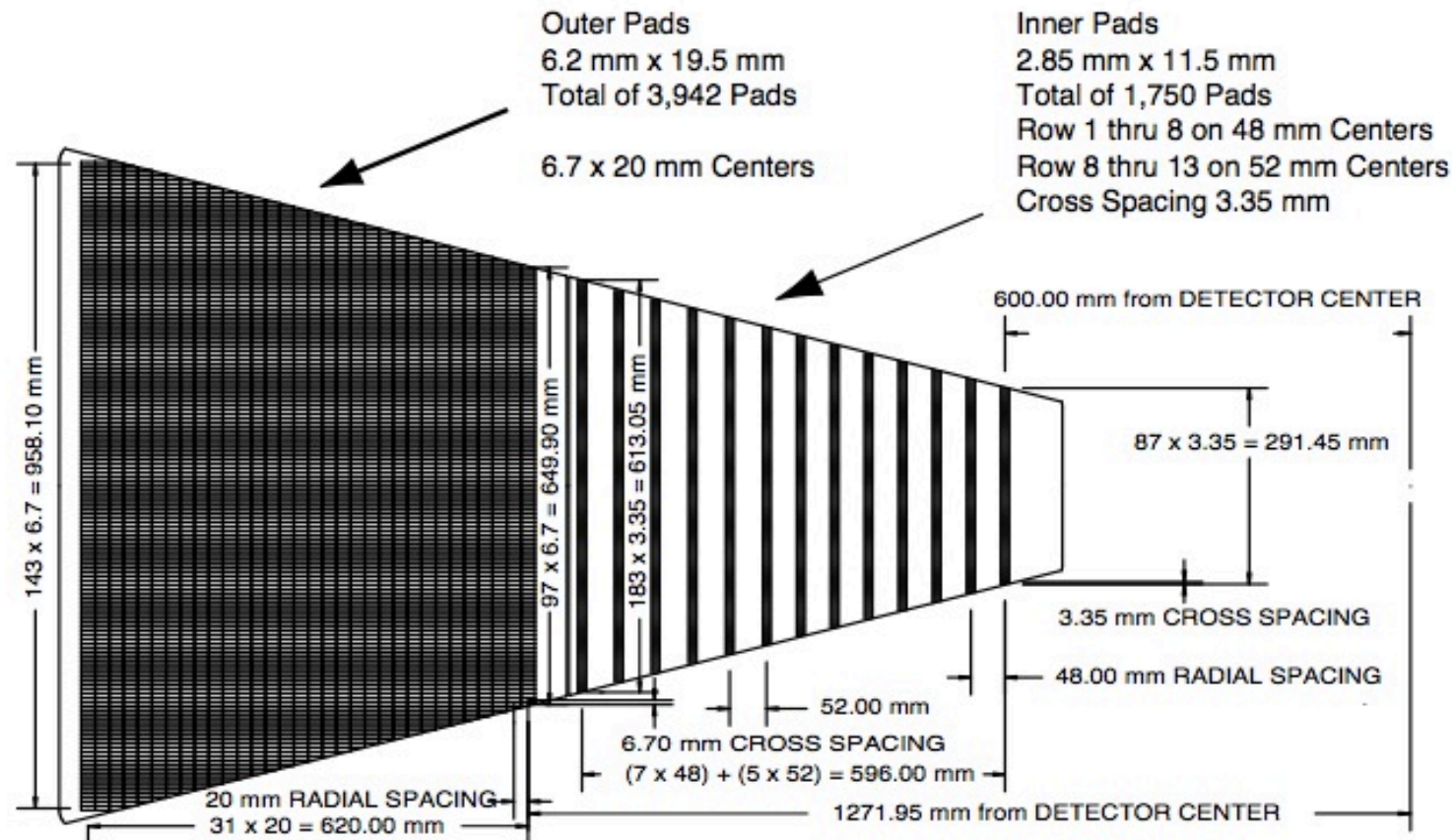


iTPC Upgrade:

- Rebuilds the inner sectors of the TPC
- Continuous Pad Coverage 45- \rightarrow 72 rows
- Improves dE/dx (15-30%)
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut-in from 125 MeV/c to 60 MeV/c

Upgrade of iTPC readout at STAR

- Increase the segmentation on the inner pad plane, coverage 20%→100%
- Renew the inner sector wires which are showing signs of aging
- Eliminate the space charge distortion due to Grid Leak



The upgrade will provide **better momentum resolution, better dE/dx resolution, and improved acceptance: $|\eta| < 1.0 \rightarrow |\eta| < 1.5$**

Summary of iTPC upgrade event timeline (Zhangbu 02/13)

- Discuss the necessary tracking upgrade between $-2 < \eta < -1$ for eSTAR (2011)
- Identify iTPC as a crucial step for eSTAR upgrade (10/11)
- Discussion of possible iTPC upgrade before eRHIC
Jim Thomas (LBL), UCLA Upgrade Workshop, December 2011
- iTPC Upgrade group discussions/talks at BNL (02/01/2012)
<http://drupal.star.bnl.gov/STAR/event/2012/02/14/estar-task-force-biweekly-meeting>
- iTPC session at BNL upgrade workshop (06/11/2012)
decision to move toward an iTPC project
outline the necessary steps
- Upgrade Session at STAR Collaboration Meeting (08/07/2012)
Establish iTPC geometry for simulation, possible collaboration institutes
Establish simulation/tracking framework (09/12)
- Cost Estimates and Technical Driven Schedule
to Steve Vigdor and Tribble Committee (09/12)
- Possible Chinese group involvements (10/12)
- STAR R&D Review (10/12)
- Upgrade Workshop (11/12)
- Engineer Drawing and procedure recovery from original TPC (02/2013)
- Electronics R&D prototype and pad plane with ALICE (03/2013)
- Draft Proposal to upgrade group (2013) Proposal to Collaboration
- Prototype Sector (2013—2014)

To do (an incomplete list) (Jim Thomas, 06/12)

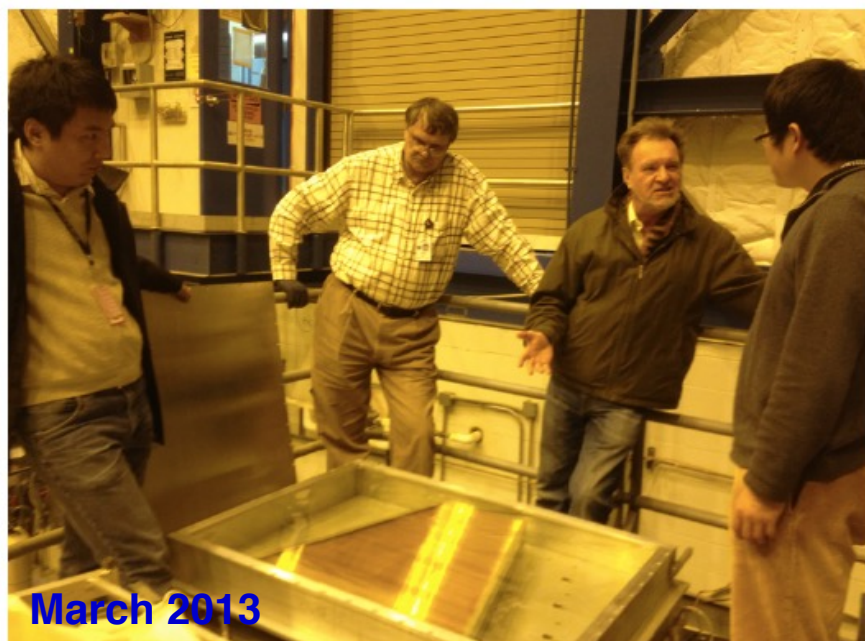
- Form a study group
 - pad plane simulations
 - final configuration needs to be found and evaluated ☒ (08—12/12)
 - physics plan
 - with simulations ☒ (08/12--)
 - engineering plan ☒ (02/13)
 - with preliminary drawings and evaluation of existing resources
 - cost estimate ☒ (09/12)
 - R&D proposal to STAR ☒ (10/12)
 - proposal by Christmas (09/12--)
- Build a team of physicists
 - LBL and BNL + others ☒ (06/12--)
- Find mechanic engineer ☒ (02/13)
 - transfer 2D to 3D and look for holes in the engineering plan
- Find/Develop lab space ☒ (08/12—10/12)
 - Check out wire winding machine and design a factory



A small factory is required

iTPC activities @ SDU (Q. Xu, 09/2013)

- October 2012, Zhangbu visited SDU and discussed iTPC project with us. We decided to join.
- March 2013, Chengguang Zhu and Qinghua Xu visited BNL. We looked at the spare TPC sectors and discussed with experts.
- May 2013, Zhangbu visited Jinan and further discussion on iTPC.
- August 22, Zhangbu brought a TPC model to SDU.
- Started working on small size iTPC prototype this August.



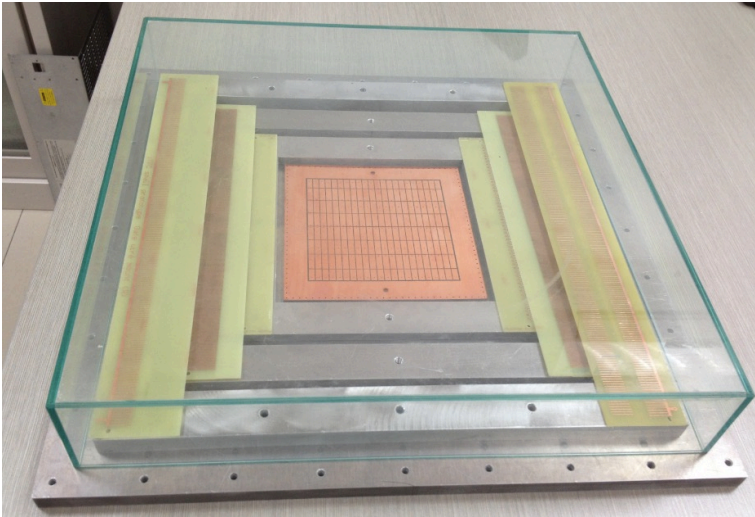
March 2013

Suggestion is Friday, March 1st, afternoon 2--5PM.
Room 2-95 building 510:

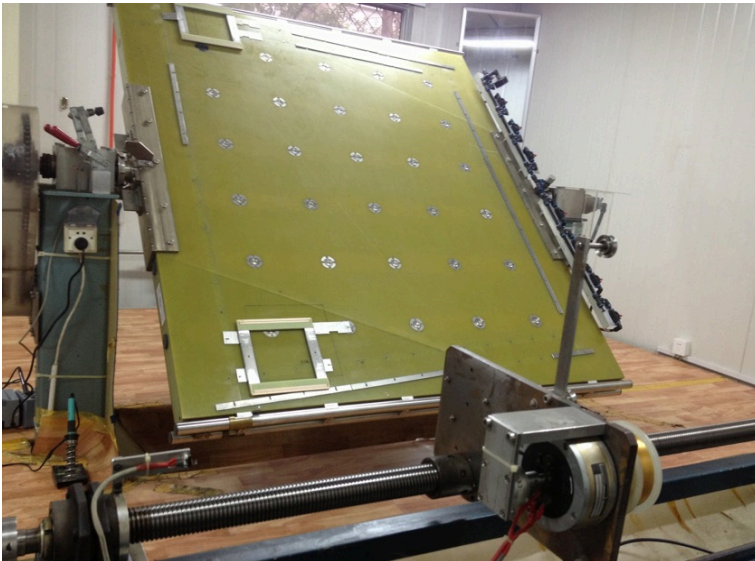
Agenda:

- a) iTPC project and latest news (Jim)
- b) simulations of configurations (Hui)
- c) TPC hardware improvements/thoughts (Alexei)
- d) Facility and plan at SDU for ATLAS and STAR (Chengguang)
- e) test stand with DAQ1000 electronics at SDU
- f) TPC spare sector hardware (visiting lab)
- g) STAR tour (depending on when the access is possible, could be Wednesday 03/06)
- h) initial funding/supports/plan/schedule for constructing a prototype sector (with the current design of strongback?)

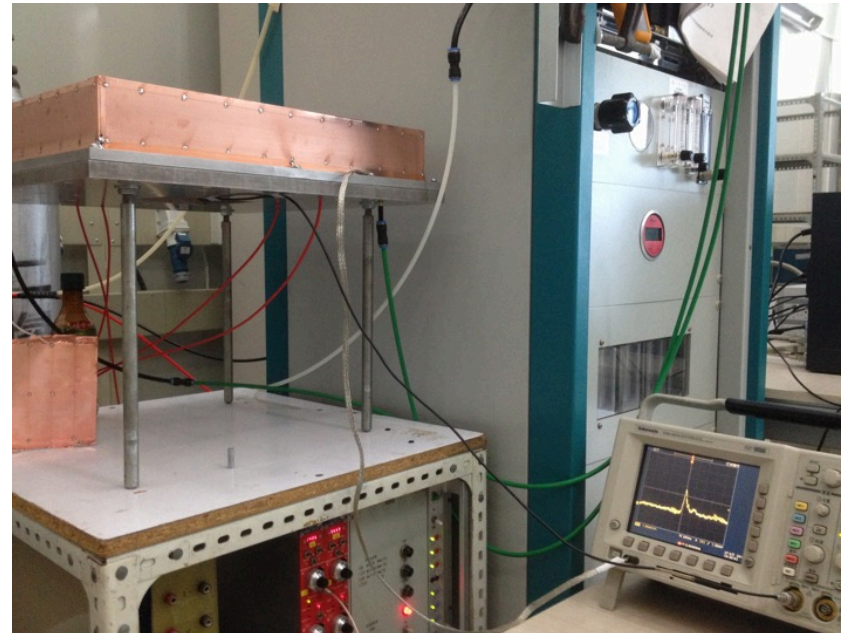
The 1st TPC prototype made in 2014 at Shandong



The size of the small TPC prototype: 50x50x10cm



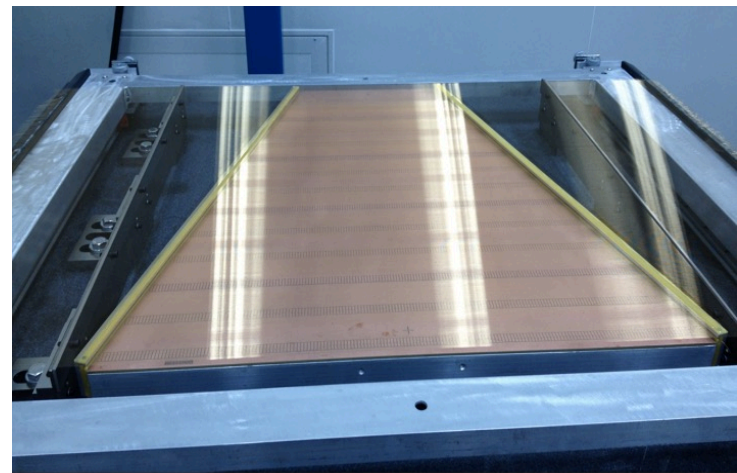
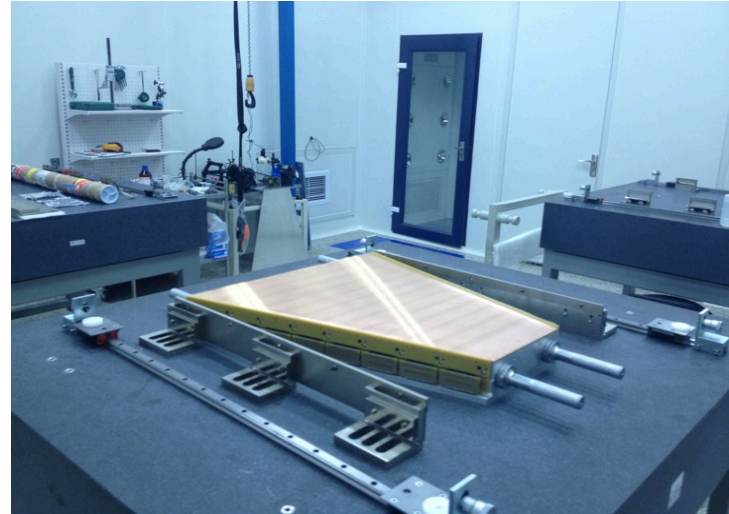
Wire winding machine



Testing the TPC prototype

MWPC prototyping at SDU

- Started the full size iTPC prototyping since September 2014.

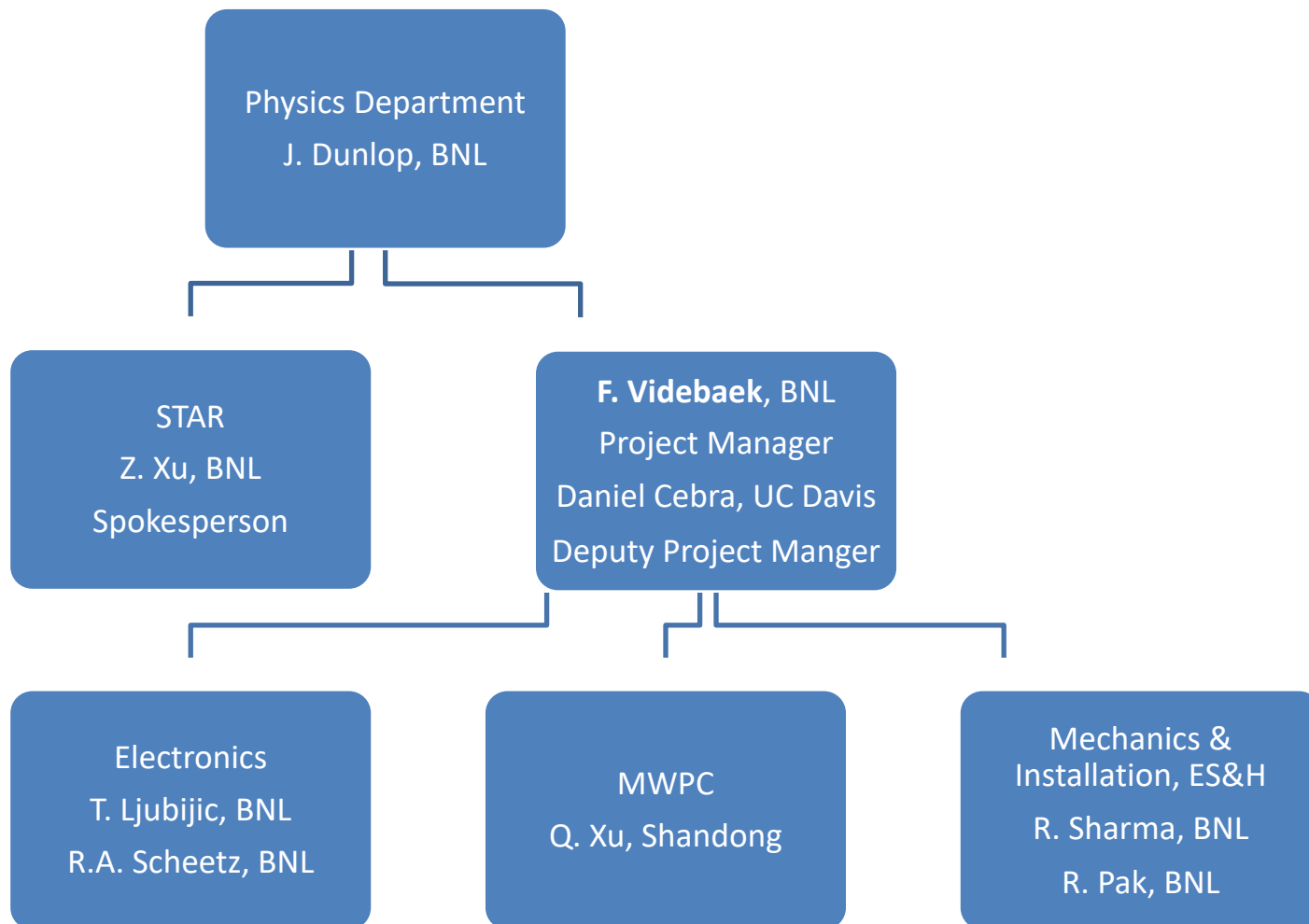


Collaboration on iTPC upgrade within STAR

components	Responsible institutes			Funding source
Electronics	BNL (ALICE Chips)	Ljubicic,	Scheetz + Electronics group	BNL/DOE
Mechanics design	LBL+BNL	Anderssen	+ 1 engineer + Sharma	R&D/STAR/DOE
Strongback	UT Austin +BNL	Hoffmann	+ UT Machine shop	UT+DOE
Insertion tool	BNL +UIC	Sharma	Scheblein	Capital/STAR/DOE
MWPC	SDU+USTC +Shanghai/LBL	Q. Xu	C.G. Zhu + technicians	NNSFC,MOST

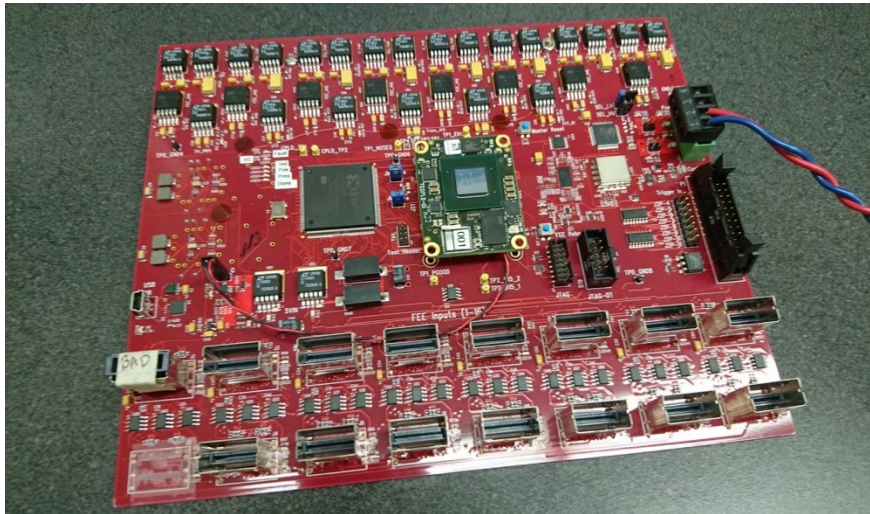
2015 +

iTPC management & collaborating institutions



- FEE based on current FEE, but using ALICE SAMPA chip
- Twice channels per FEE
- RDO similar to existing
- Developments over several years by BNL electronics group

iFFE



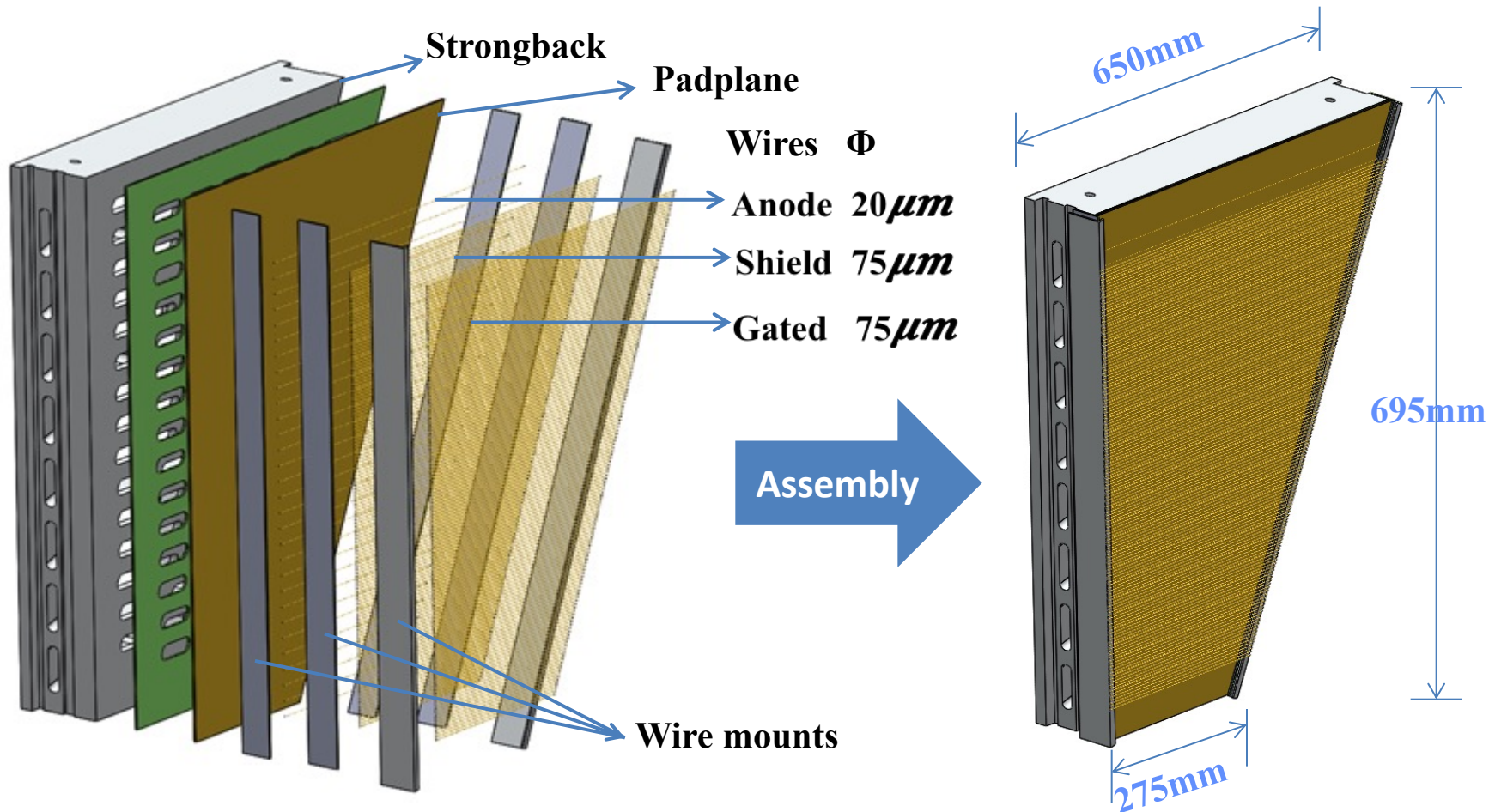
RDO -installed



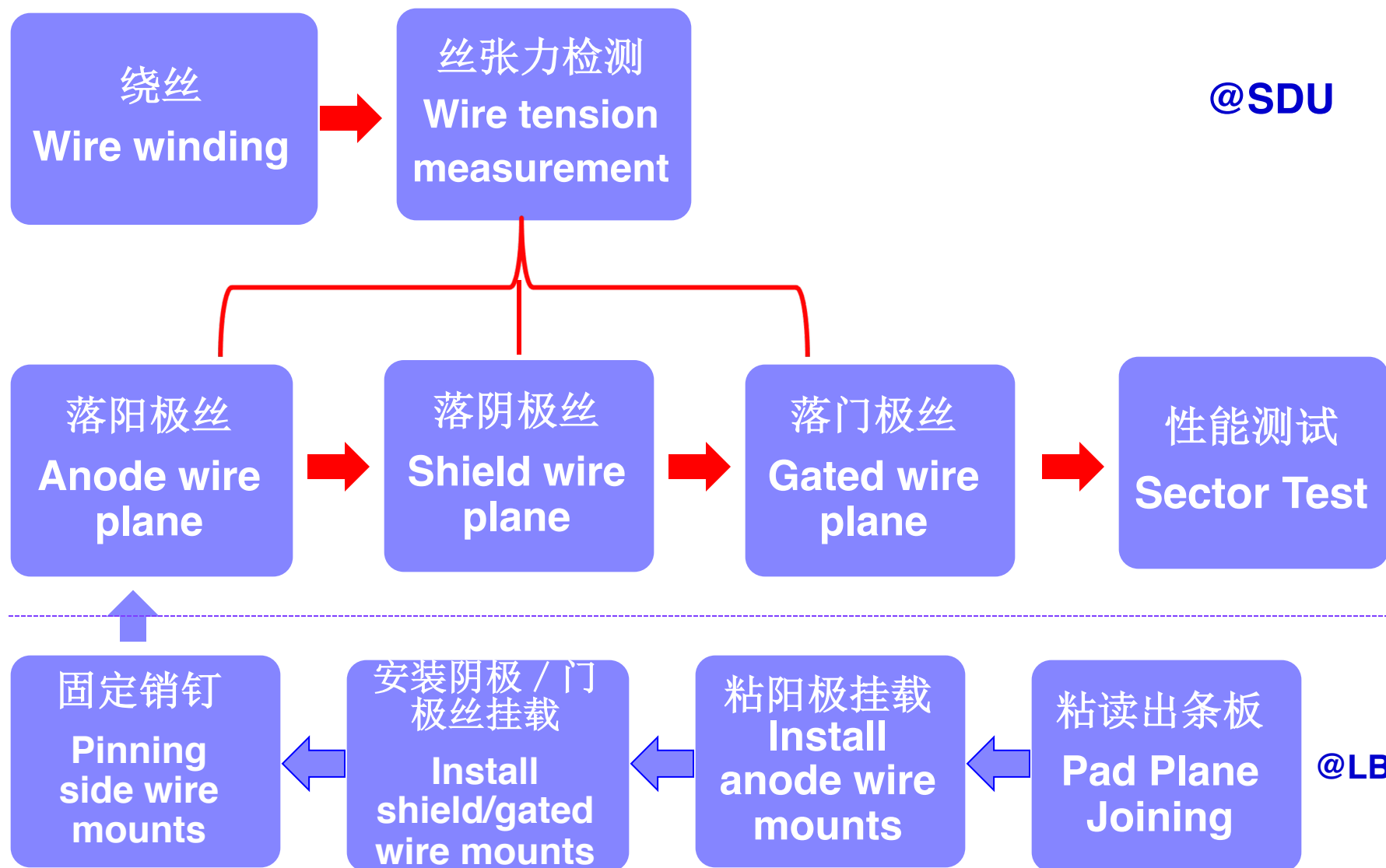
Readout board

iTPC sector components

- Sectors: strongback + padplane + MWPC



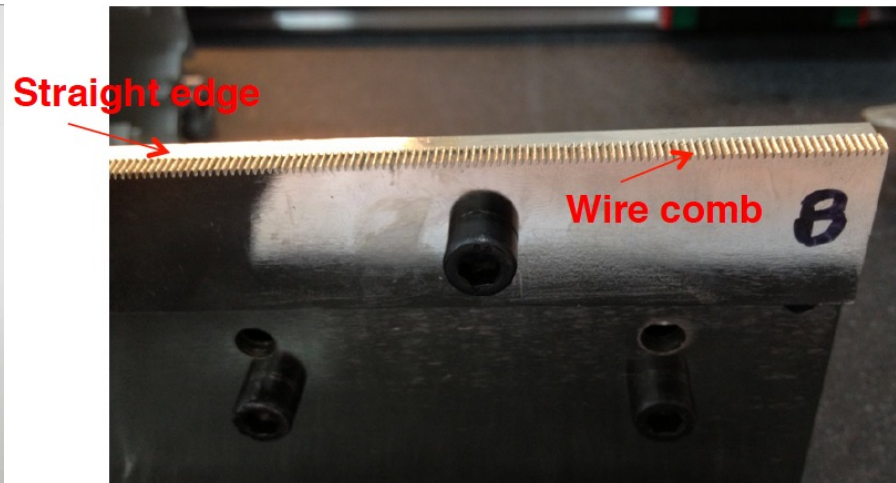
MWPC production-main steps



iTPC mechanics work at LBL

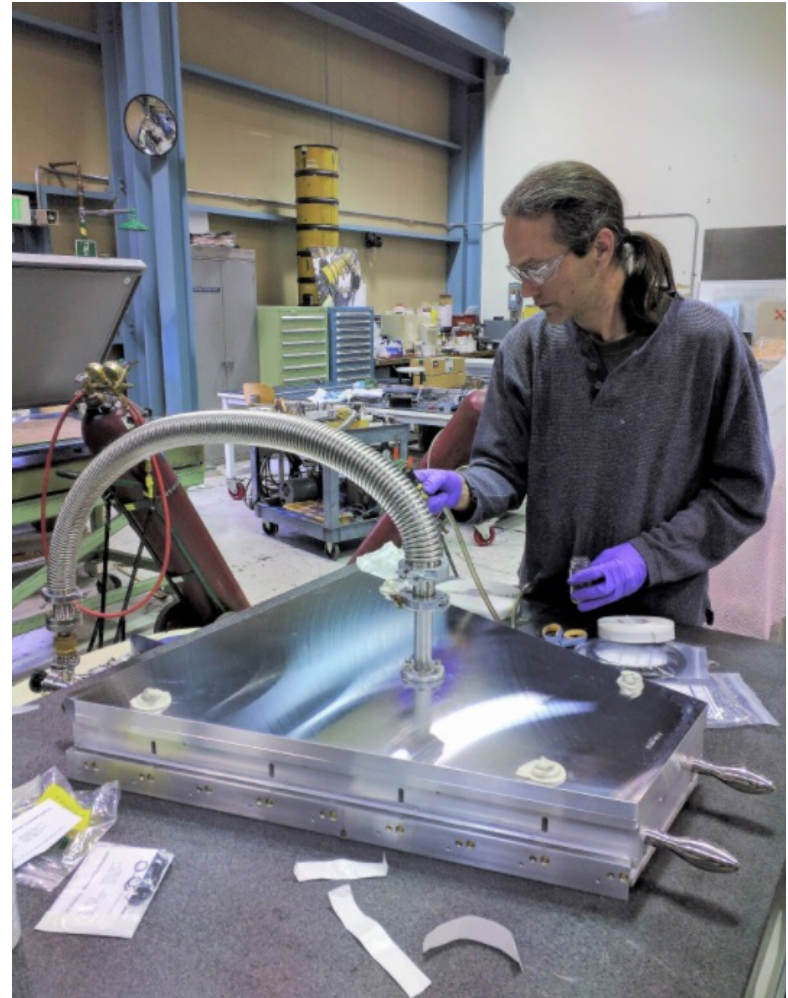
- Eric Anderssen, Jim Thomas, Howard Wieman

- Great efforts in finding original TPC documentations including original drawings, technical procedure etc.
- Help ordering materials like epoxy, winding wire in early stage, and wire combs, taper pin



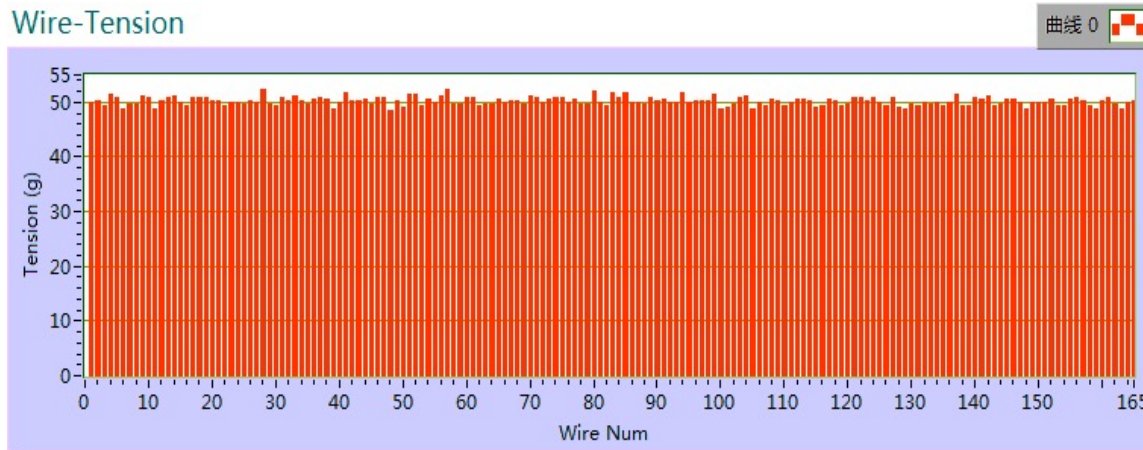
PCB binding and wire mount installation at LBL

- PCB binding and side wire mount installation at LBL:

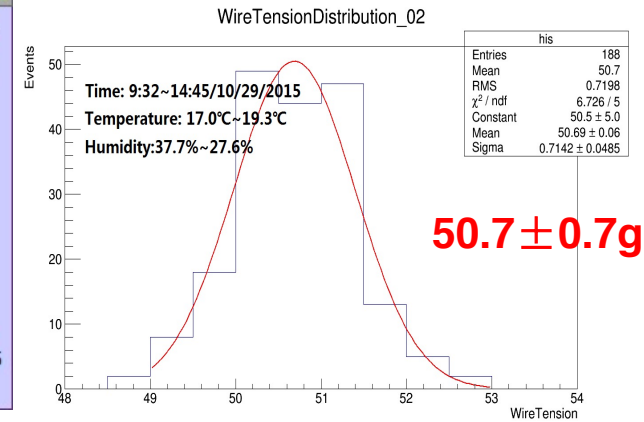


Anode Wire tension measurement

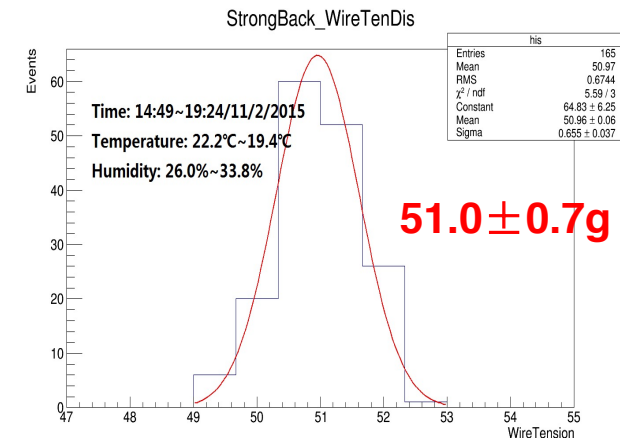
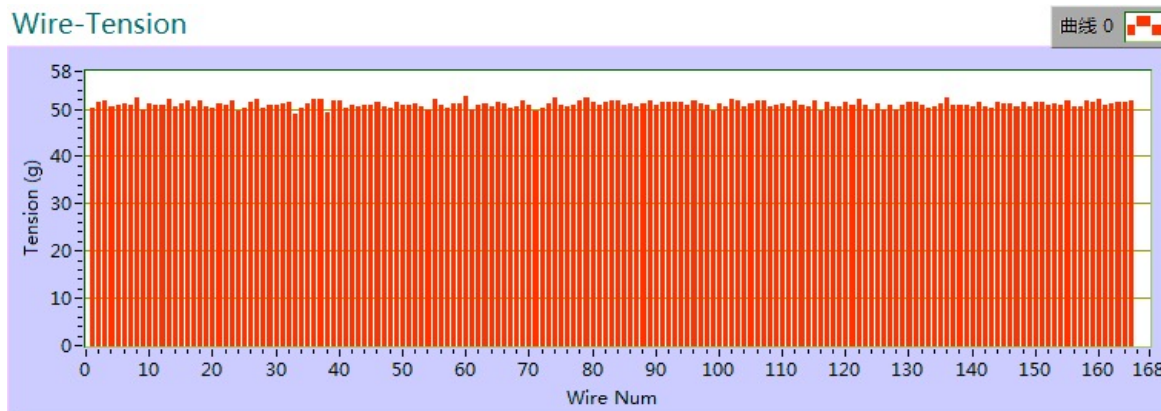
- Measured tension of 165 wires on wire frame:



Required to be $0.5 \pm 0.03\text{N}$
($51 \pm 5\text{gram}$)

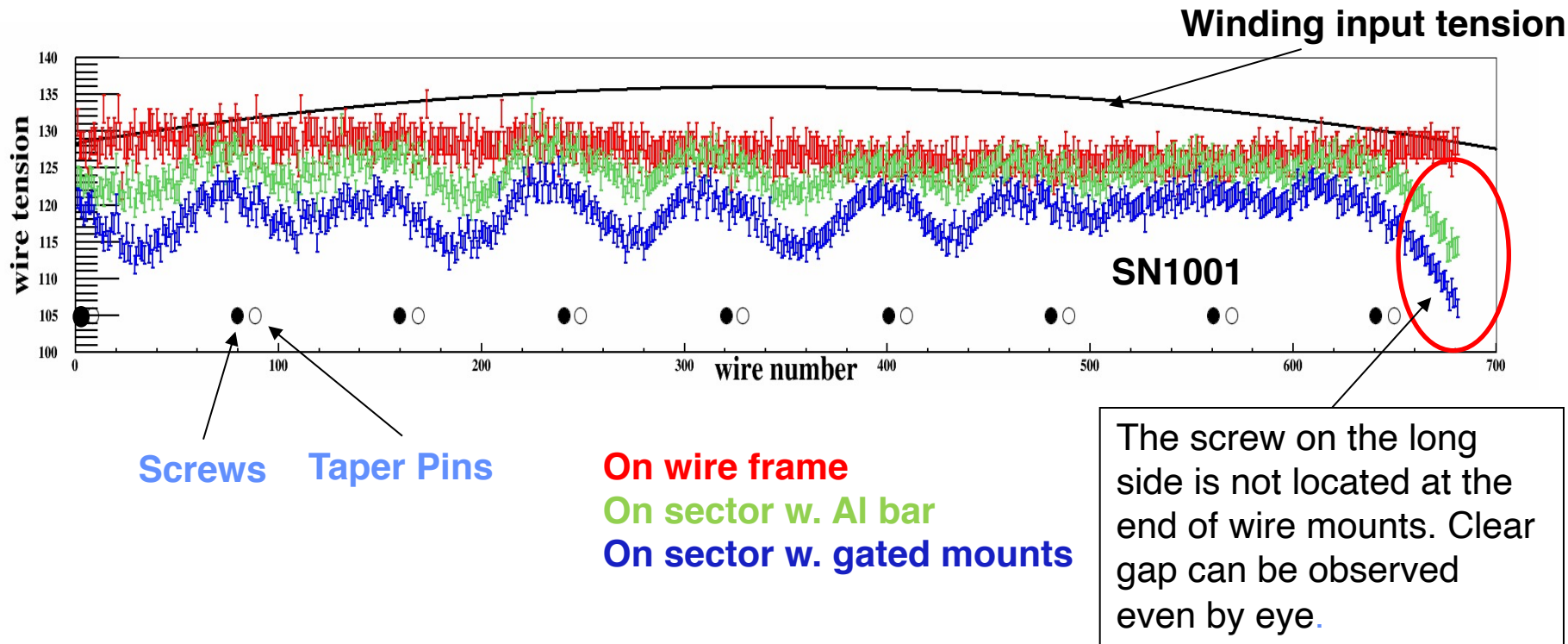


- Measured tension of 165 wires after glued on anode wire mounts:



Wire tension for shield wire grid

- Previously tension reduction observed after being mounted on sectors
- An extra Aluminum bar is now used to keep the wire tension.



- ✓ Clear dependence w.r.t screws after wire mounting.
- ✓ Clear drop on the long side due to the gap in between wire mounts.
- ✓ We believe it is now under much better control

Assembly QA plan at SDU-local travellers



iTPC 制作检查簿

iTPC Travellers Book (SDU)

Sector# 编号: _____

Date 制作时间: __月__日__



iTPC 制作进程跟踪表, v09102017

步骤	项目/item	检查表 Traveller	进度 Status
1	开箱检查（高度平整度） / inspection	Traveler 0	
2	丝轴线检查/wire	Traveler 1	
		Traveler 2	
		Traveler 3	
3	绕丝/wire winding		
		Traveler 4	
4	丝框张力检测、存储/wire tension	Traveler 5	
		Traveler 6	
5	阳极丝框用前检测/anode wire frame prior	Traveler 7	
6	阳极丝粘接/epoxying anode wire		
7	阳极丝焊接/anode wire soldering		
8	阳极丝面检查/anode wire plane	Traveler 8	
9	阳极丝连通性、短路、高压检测/A continuity	Traveler 9	
10	阴极丝挂载安装/shield wire mounts inst.	Traveler 10	
12	阴极丝框用前检查/shield wire frame	Traveler 11	
13	阴极丝粘接/shield epoxying		
14	阴极丝焊接/shield soldering		
15	阴极丝面检查 / shield wire plane check	Traveler 12	
16	阴极丝连通性检测/shield wire continuity	Traveler 13	
17	门极丝挂载安装/gated wire mounts inst.	Traveler 14	
18	门极丝框用前检查/gated wire frame	Traveler 15	
19	门极丝粘接/epoxying gated wire plane		
20	门极丝焊接/gated wire soldering		
21	门极丝短路、连通性检测/gated wire cont.	Traveler 16	
22	iTPC performance test 测试	Traveler 17	
23	问题记录表 / known issue list	Traveler 18	

24. Inspection list before shipping

S-19

All the travellers have been uploaded:

<https://drupal.star.bnl.gov/STAR/blog/qhxu/itpc-production-travellers>

iTPC review for MWPC construction -Dec .3 2016

MWPC construction review at Shandong University, Jinan, on December 3 2016.

There were presentations on iTPC project overview, the construction procedures, and testing and QA.

The committee had a longer visit to the iTPC construction facilities. The committee provided recommendations and significant comments.

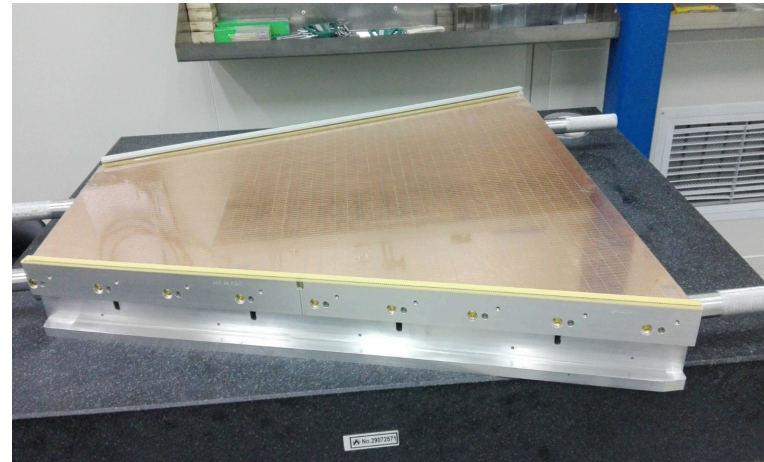
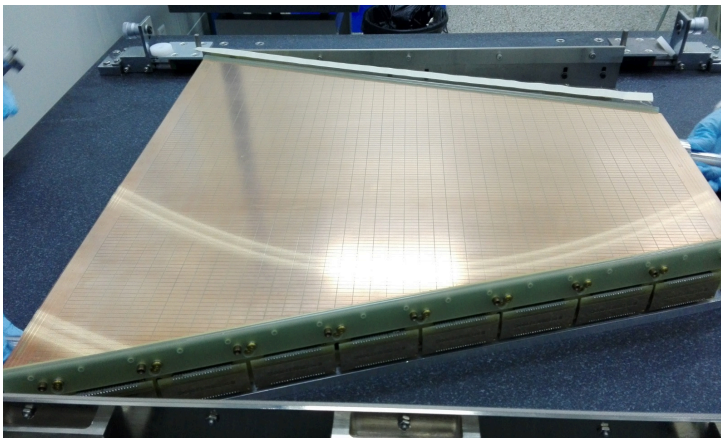
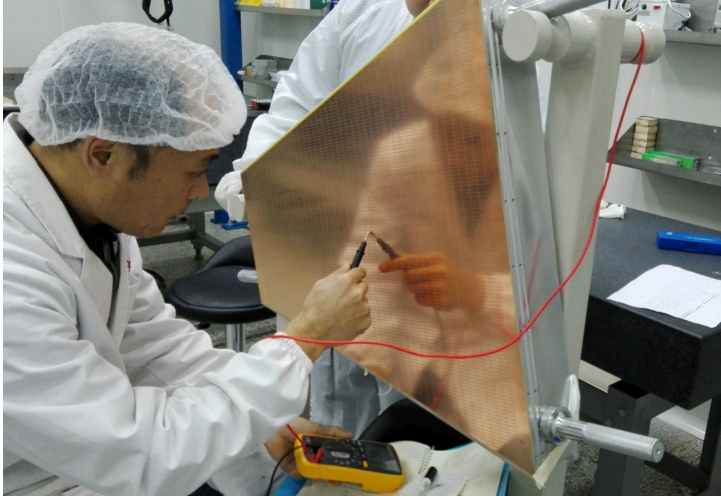


Committee members:

Flemming Videbaek, BNL, Chair; Kai Schweda, GSI; Bo Yu, BNL; Jin Li, IHEP/Tsinghua; Hongfang Chen, USTC; Jiansong Wang, IMP, CAS; Yi Wang, Tsinghua University

1st iTPC formal prototype completed

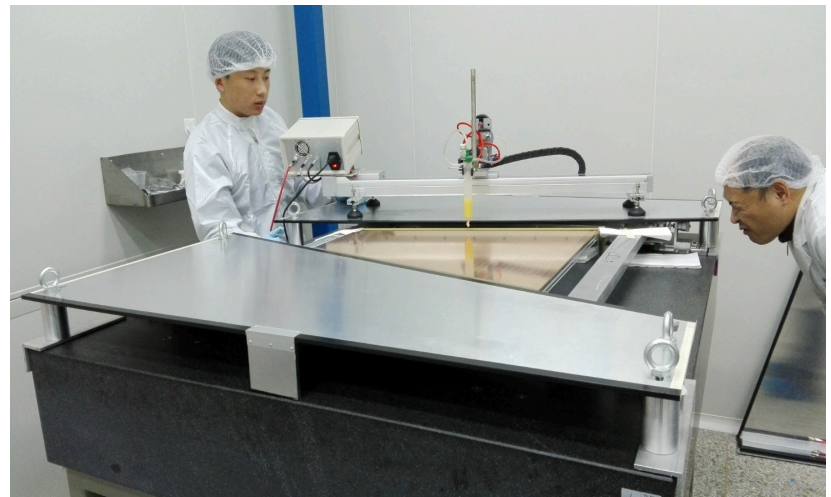
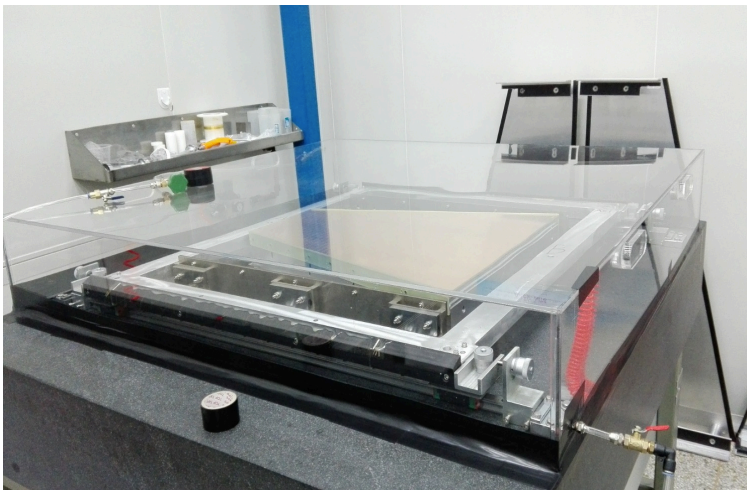
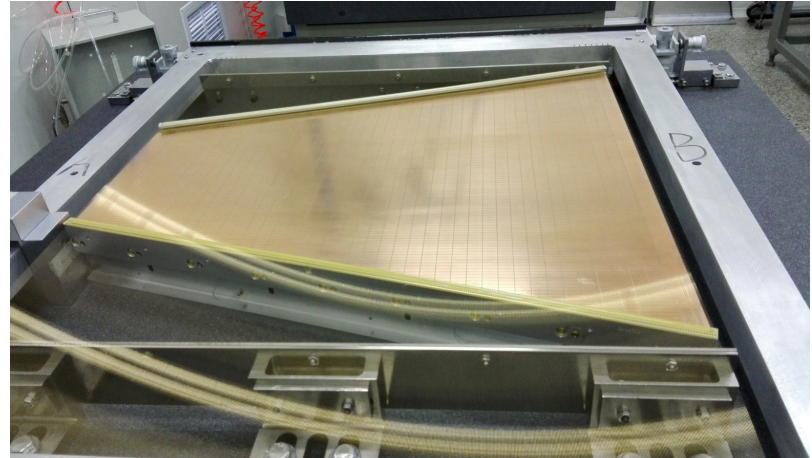
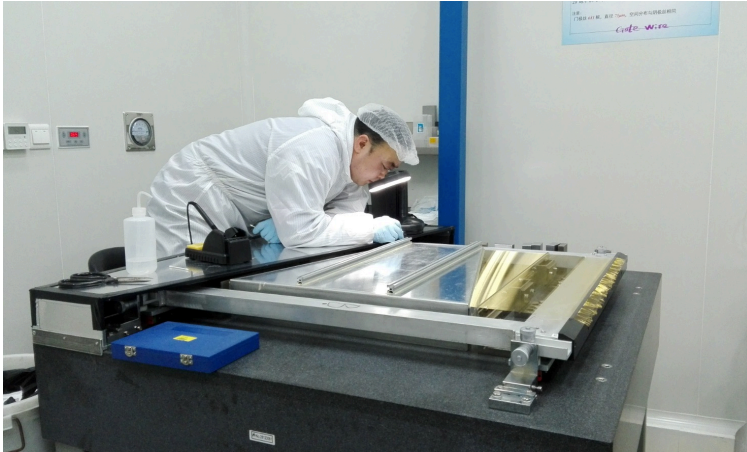
- 1st iTPC prototype with all final-design parts completed January 2017:
 - strongback and pcb board received in September, 2016
 - wire mounts arrived in November, 2016



- All the assembly procedure including MWPC was done at SDU.

Mass production at SDU since 2017.06

- 1st package of 2 strongbacks with pcb glued arrived on **June 5, 2017** from LBL
- SN0009 and SN1001 MWPC assembly completed on July 5, 2017



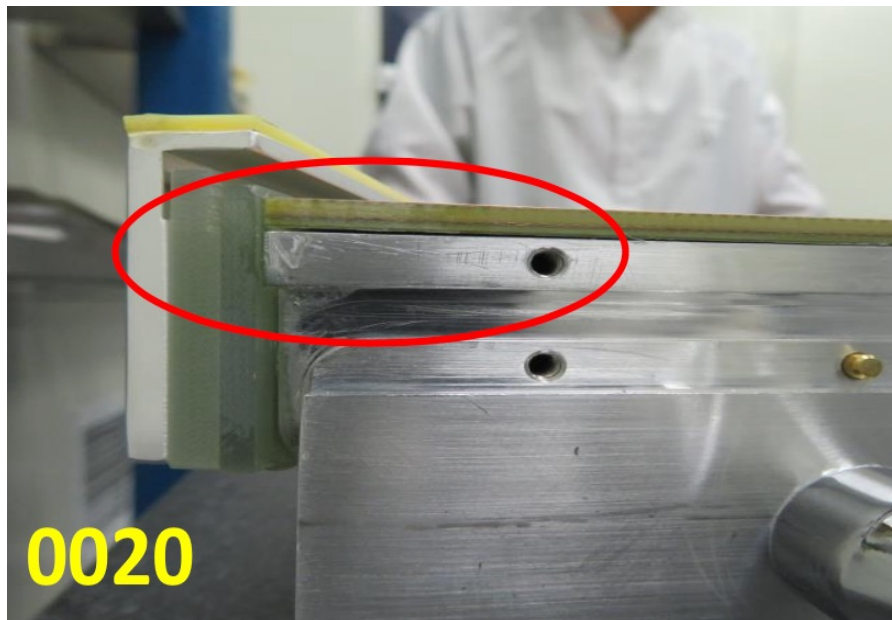
Scope of effort & status at SDU

2018.9

- Prototyping of iTPC sector -> **done 2015~2016**
- 30 wire plane production **-in parallel with assembly**
- Assembly of sectors (after pcb bonding at LBL)
- ✓ **30 completed, +2 prototypes**
- Sector test (HV burn-in, gain uniformity, stability)
- ✓ **30 sectors completed +1 prototype**
- Ship the sectors to BNL (by September 2018)
- ✓ **29 shipped to BNL, +2 prototypes**

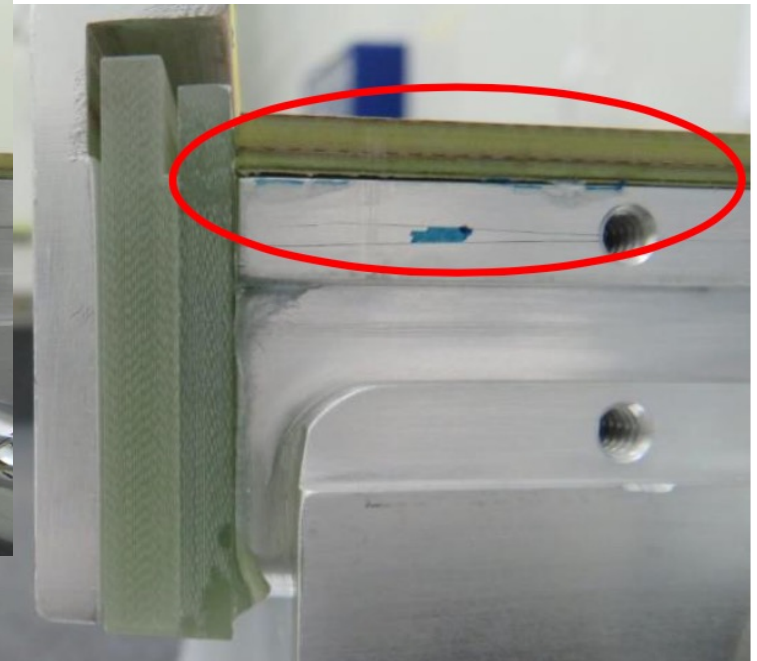
Gluing issue with sectors

- 3 sectors in the 3rd package from LBL found gluing issue
 - most probably caused low temperature during shipping
 - 2 bad sectors were shipped back to LBL on Sep. 2017
 - one with minor gluing issue was repaired at SDU
- This was overcome in later production.

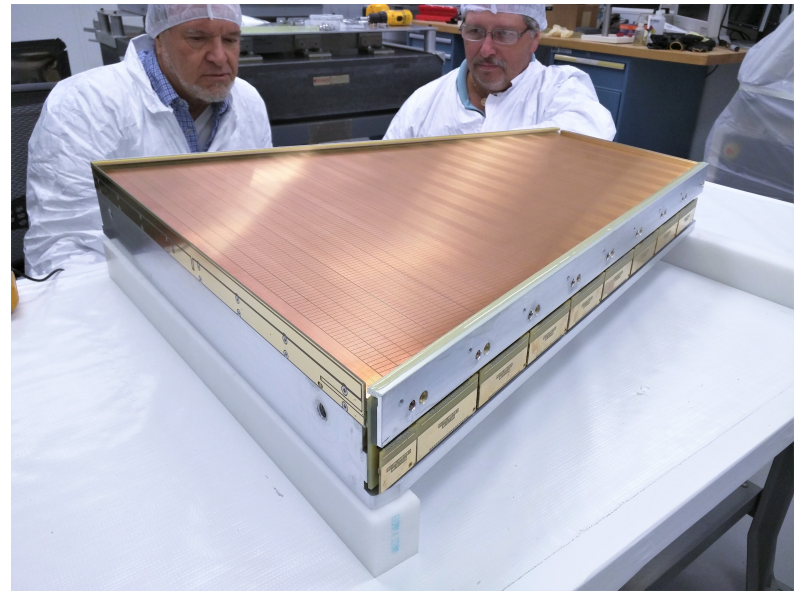
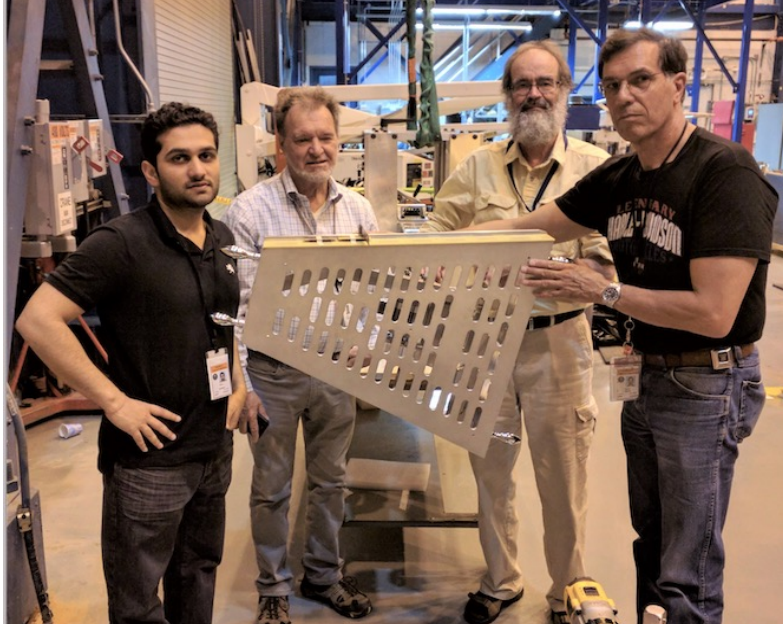


27

- pcb separated from Al.

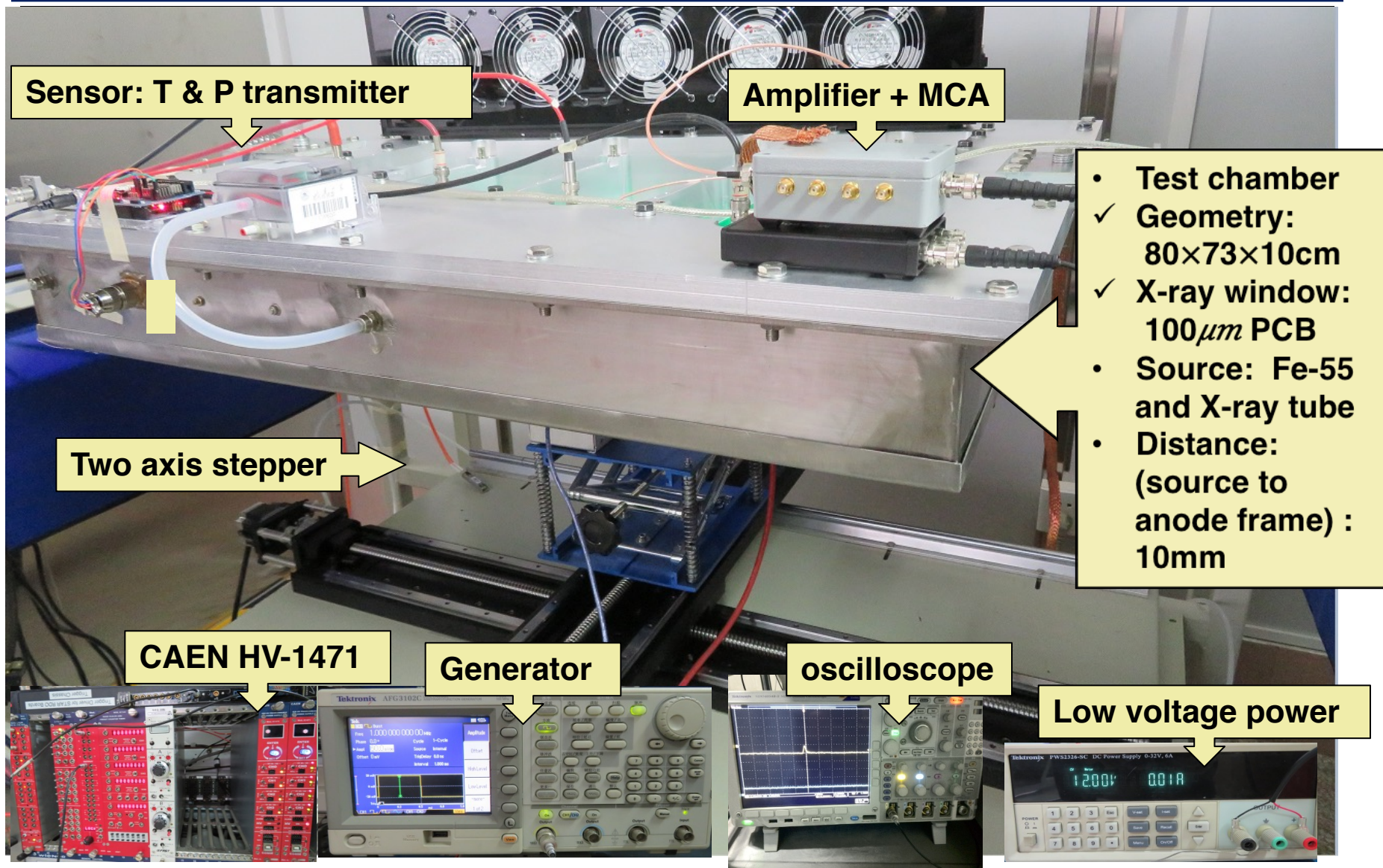


Working pictures at BNL

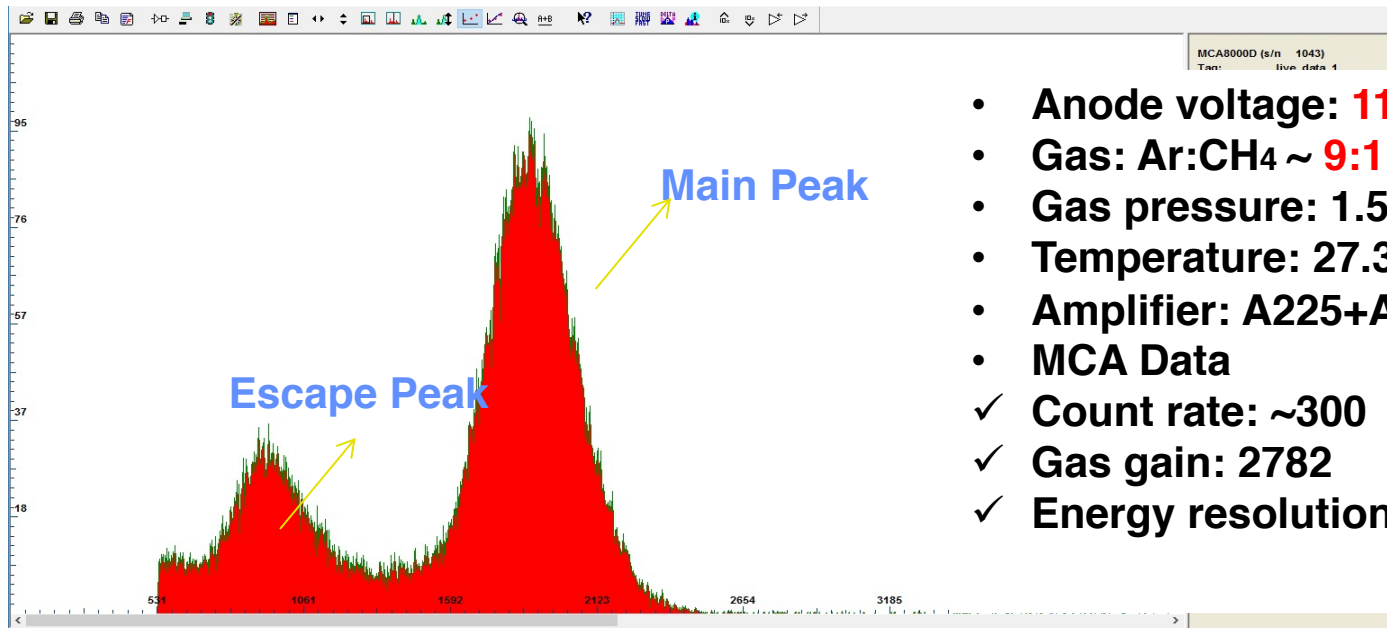


-from Jim Thomas

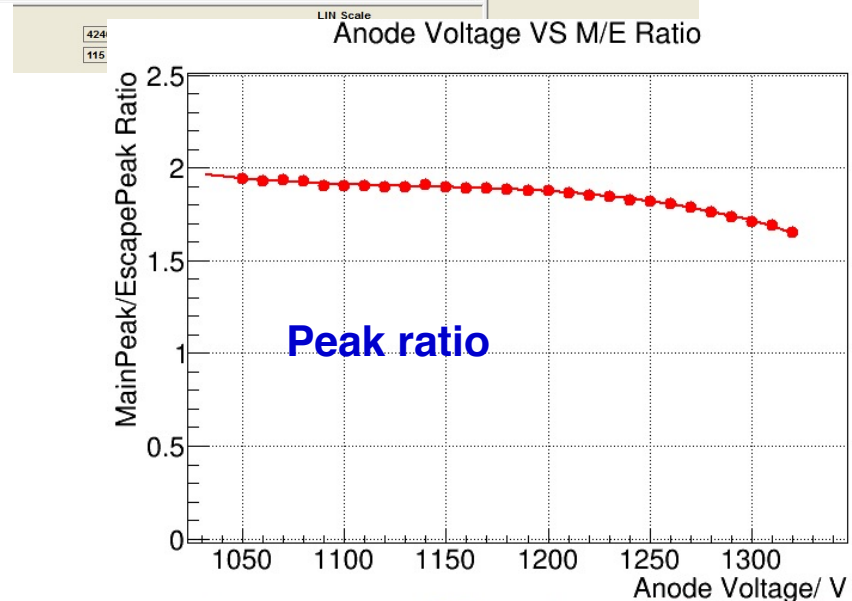
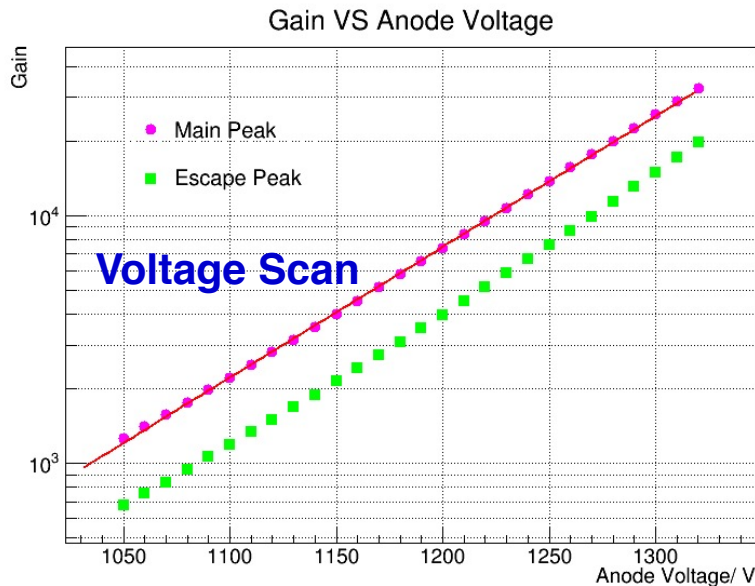
Testing system for iTPC at SDU



^{55}Fe X-ray spectrum of the single wire



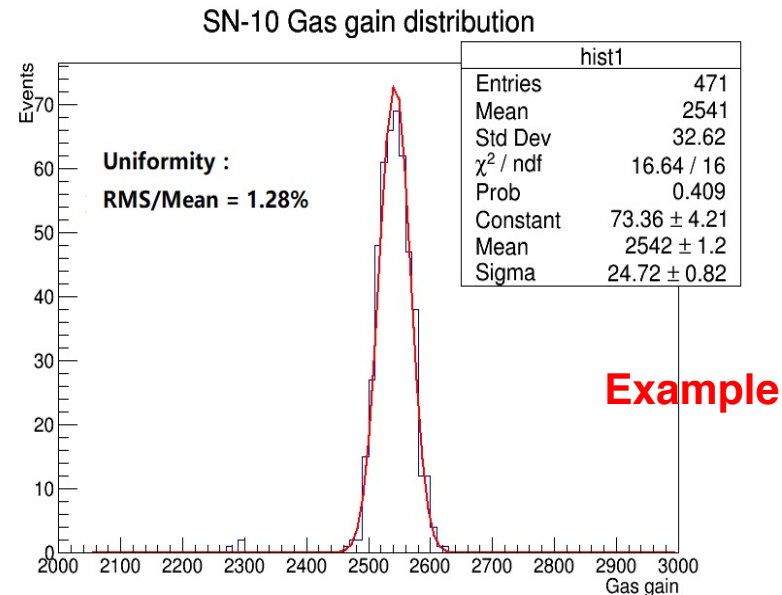
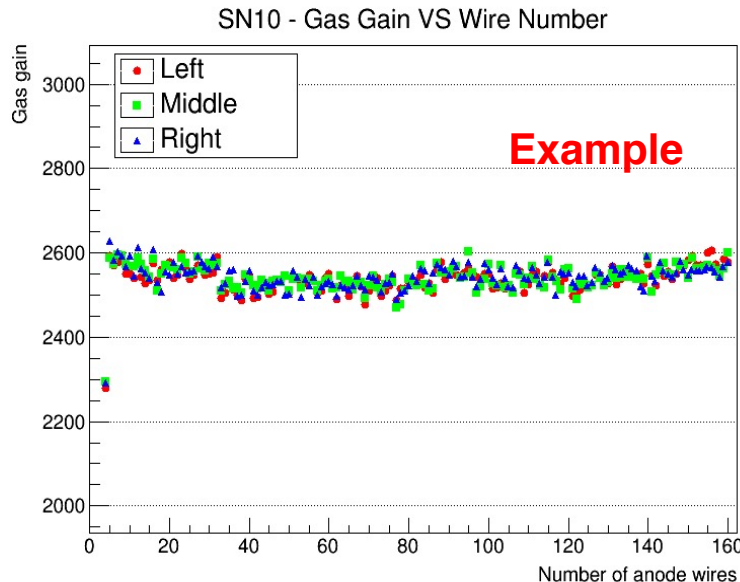
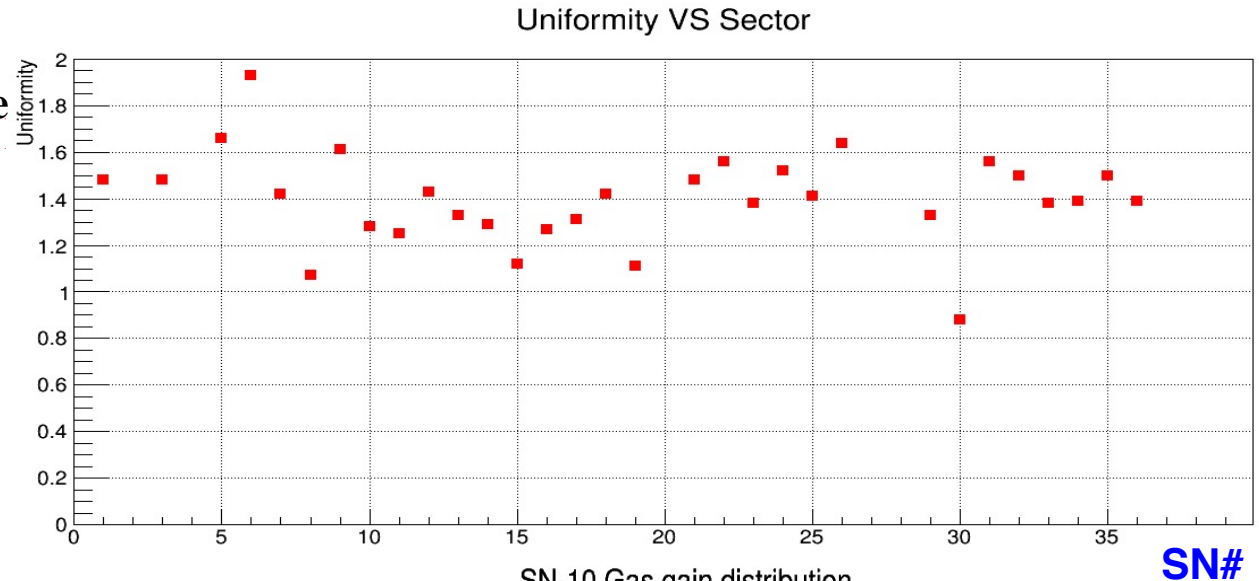
- Anode voltage: **1120V**
- Gas: Ar:CH₄ ~ **9:1**
- Gas pressure: 1.54 mbar
- Temperature: 27.3°C
- Amplifier: A225+A206
- MCA Data
- ✓ Count rate: ~300
- ✓ Gas gain: 2782
- ✓ Energy resolution(FWHM): ~20%



Gain uniformity

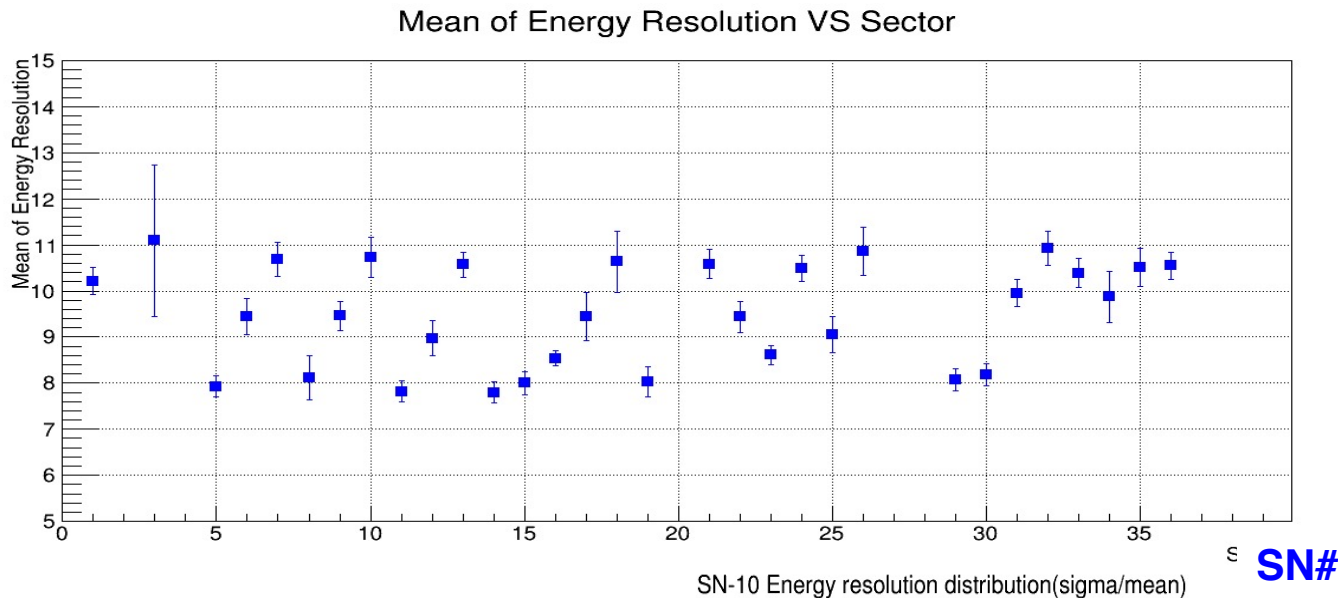
- Gain uniformity (RMS/Mean) for all formal sectors produced:

- ✓ 3 sample points per wire
- ✓ 157 wires scanned (via ABDB)
- ✓ Average value 1.5% on average, better than KPP requirement 2%.



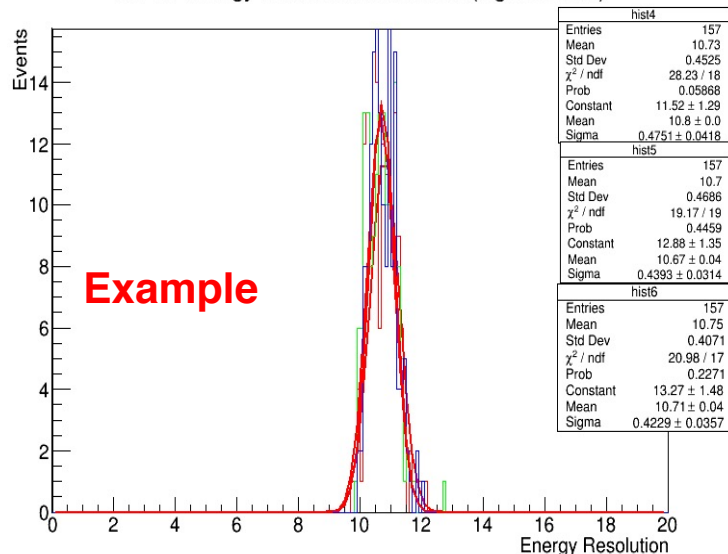
Energy resolution

- Energy resolution (Sigma/Mean) for each sector



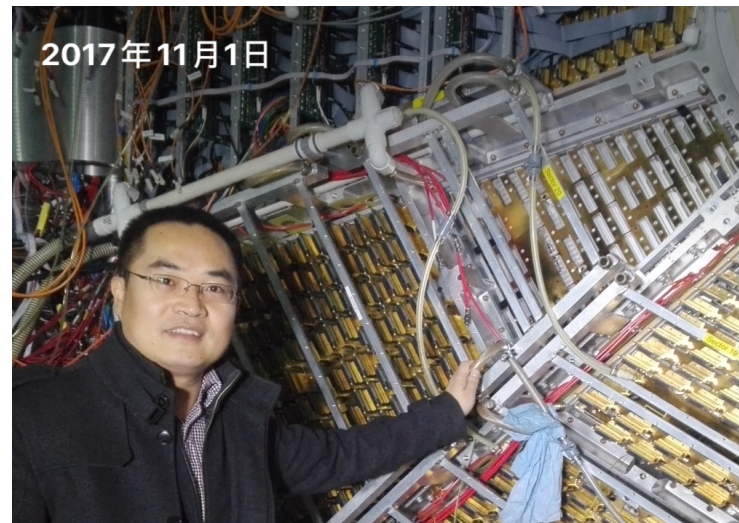
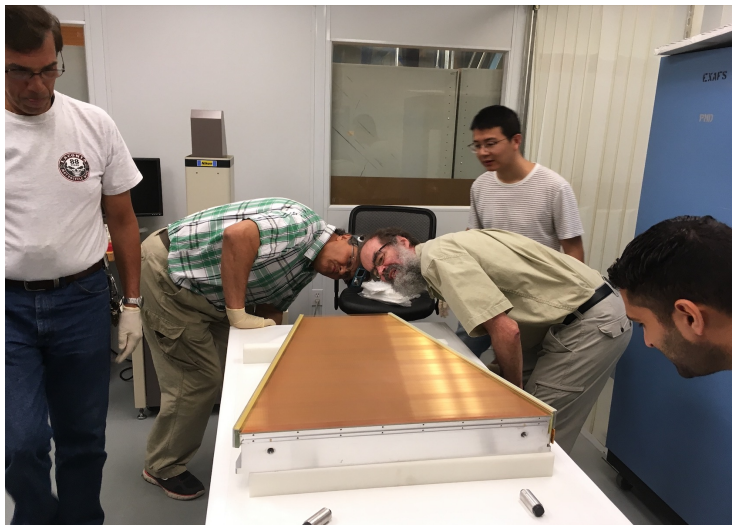
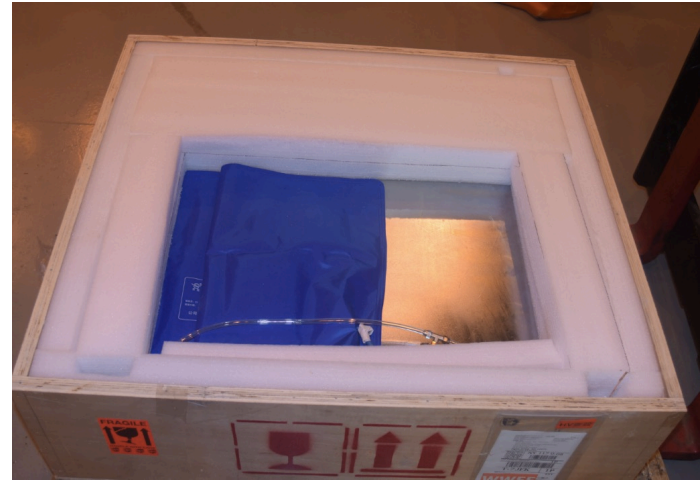
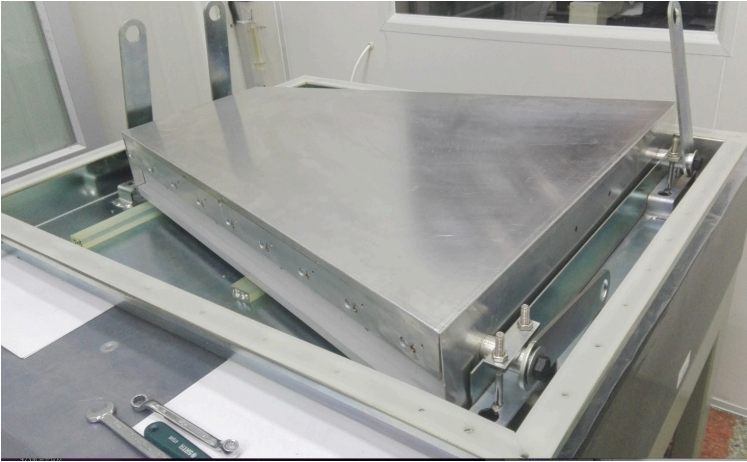
- ✓ Well below 15% (KPP requirement)
- ✓ <10% on average

Note: when the auto-test system was applied, larger resolution was observed than by hand, in particular during commissioning (like for SN3)



1st iTPC sector shipped to BNL—Sep. 2017

- 1st sector shipped to BNL in 2017, then installed at STAR for run18



Shipping summary

SN06: shipped to BNL Sep. 2017, installed at STAR Oct. 2017↵

SN22, shipped to BNL in Oct 2017↵

SN1001, shipped to BNL Dec. 2017↵

6 sectors shipped on April 26, 2018: SN09, 11, 23, 26, 29, 30.↵

4 sectors shipped on June 8, 2018: SN05, 14, 15, 16.↵

4 sectors shipped on July 24, 2018: SN08, 18, 32, 33.↵

6 sectors shipped on August 13, 2018: SN10, 13, 21, 24, 19, 34.↵

4 sectors shipped on Aug 27, 2018: SN03, 07, 35, 36.↵

4 sectors shipped on Sep. 7, 2018: SN01, 31, 17, 25.↵

SN14, 32 shipped back to SDU for repair, arrived 3 Sep, 2018.↵

SN14, 32 re-shipped to BNL on Sep 28, 2018.↵

Status at SDU Sep. 28: ↵

All shipped except SN12 (one of spares, DAQ testing for thesis work at SDU).↵

↵

Total sectors made at SDU: 32, including prototypes SN1001 & 09. ↵

..

Detailed status sheet

- From Flemming

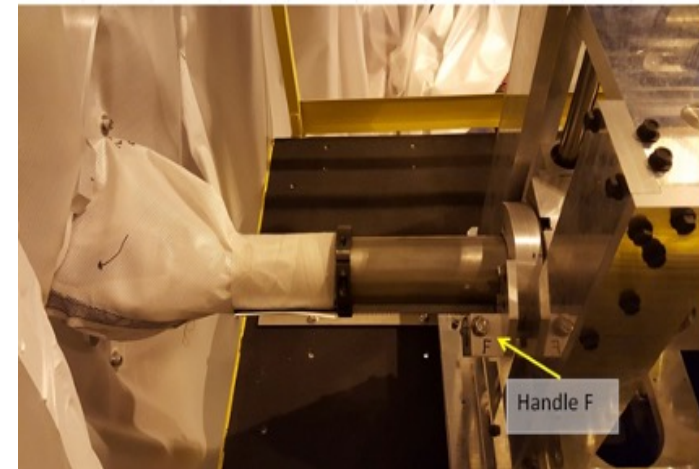
2018/9/29

Article #	Serial#	Padplane	In process	Done at LBL	shipped	At SDU	Constructi	Done	testing	Shipped2	Stat 1	Status	Travl.	Column1	Column2
1	1001			2017/3/2		2017/6/5	x	2017/7/3		2017/12/15 BNL		prototype		comment	
2	SN0009	2		2017/5/11		2017/6/5	x	2017/6/27	2017/7/30	2018/4/25 BNL		prototype	T	Need groundground fixe	
3	SN0006	4		2017/5/19		2017/6/22	x	2017/7/28	2017/8/14	2017/9/6 BNL		ok	T	Installed	
4	SN0022	3		2017/6/15		2017/6/22	x	2017/8/16	2017/9/4	2017/10/17 BNL		ok	T		
5	SN0027	10		2017/6/26		2017/8/16	-					try repair		seperated padplane shi	
6	SN0026	6	2017/6/26	2017/8/8		2017/8/16	x	2017/9/11	2017/9/30	2018/4/25 BNL		ok	T		
7	SN0020	15	2017/6/30	2017/8/8		2017/8/16	-			DEAD		discard		seperated padplane shi	
8	SN0023	16	2017/6/30	2017/8/8		2017/9/26	x	2017/10/12	2017/11/16	2018/4/25 BNL		ok	T		
9	SN0016	11	2017/7/7	2017/8/8		2017/8/16	x	2017/9/20	2017/10/23	2018/6/8 BNL		ok	T	ok, anode sidemount re	
10	SN0028	17	2017/8/8	2017/9/26						DEAD		dead		seperated padplane at	
11	SN0024	20	2017/8/8	2017/9/26		2017/11/20	x	2018/8/1	2018/8/6	2018/8/14 BNL		failed vacuum		accepted after glyptal	
12	SN0029	8	2017/8/6	2017/9/22		2017/10/10	x	2017/11/1	2017/11/30	2018/4/25 BNL		ok	T		
13	SN0030	29	2017/8/8	2017/9/22		2017/10/10	x	2017/10/23	2017/12/15	2018/4/25 BNL		ok	T		
14	SN0021	21	2017/8/8	2017/9/26								try repair		seperated padplane at	
15	SN0011	27	2017/9/26	2017/10/3		2017/11/20	x	2017/12/21	2017/1/12	2018/4/25 BNL		ok	T		
16	SN0012	23	2017/9/29 x		2018/2/23	2018/3/7	x	2018/3/30	2018/4/21	SDU		spare design	T	wire below pad plane;	
17	SN0019	24	2017/9/29	2017/10/26		2017/11/20	x	2017/12/27	2018/1/30	2018/8/14 BNL		ok	T		
18	SN0025	28	2017/9/29	2017/11/1		2017/11/20	x	2017/12/7	2017/12/29	2018/9/7 BNL		ok		ok ;vacuum problem des	
19	SN0015	22	2017/10/24	2017/12/17	2017/12/18	2017/12/27	x	2018/2/9	2018/4/12	2018/6/8 BNL		ok	T	Debonding of GG mounts	
20	SN0014	26	2017/11/3	2017/12/17	2017/12/18	2017/12/27	x	2018/1/23	2018/3/7	2018/6/8 BNL		ok	T		
21	SN0010	13	2017/11/8	2017/12/17	2017/12/18	2017/12/27	x	2018/1/30	2018/7/27	2018/8/14 BNL		OK		anode sideboard connec	
22	SN0017	18	2017/11/9	2017/12/17	2017/12/18	2017/12/27	x	2018/1/31	2018/2/8	2018/9/7 BNL		further test			
23	SN0004	30	2017/11/30							DEAD		discard		One connector damaged	
24	SN0018	33	2017/11/30	2018/1/23	2018/1/29	2018/2/6	x	2018/3/14	2018/6/22	2018/7/24 BNL			T		
25	SN0003	32	2017/11/30	2018/1/23	2018/1/29	2018/2/6	x	2018/3/19	2018/5/30	2018/8/27 BNL					
26	SN0007	31	2017/11/30	2018/1/23	2018/2/23	2018/3/7	x	2018/5/3	2018/8/20	2018/8/27 BNL				fixed wires..	
27	SN0013	34	2018/1/2	2018/2/16	2018/2/23	2018/3/7	x	2018/5/14	2018/7/23	2018/8/14 BNL					
28	SN0005	7	2018/1/2	2018/2/23	2018/2/23	2018/3/7	x	2018/4/20	2018/5/4	2018/6/8 BNL			T		
29	SN0008	19	2018/1/2	2018/2/16	2018/2/23	2018/3/7	x	2018/6/6	2018/7/13	2018/7/24 BNL			T		
30	SN0001	12	2018/1/2	2018/2/16	2018/2/23	2018/3/7	x	2018/8/9	2018/8/14	2018/9/7 BNL		repaired		shield wire re-mounted	
31	SN0031	36	2018/3/20	2018/5/9	2018/5/10	2018/5/16	x	2017/7/4	2018/8/22	2018/9/7 BNL					
32	SN0032	40	2018/3/20	2018/5/9	2018/5/10	2018/5/16	x	2018/6/4	2018/7/20	2018/7/24 BNL			T		
33	SN0033	39	2018/3/20	2018/5/9	2018/5/10	2018/5/16	x	2018/7/12	2018/7/17	2018/7/24 BNL					
34	SN0034	35	2018/3/20	2018/5/9	2018/5/10	2018/5/16	x	2018/7/18	2018/8/3	2018/8/14 BNL					
35	SN0035	38	2018/3/20	2018/5/9	2018/5/10	2018/5/16	x	2018/6/29	2018/8/12	2018/8/27 BNL					
36	SN0036	37	2018/3/20	2018/5/9	2018/5/10	2018/5/16	x	2018/6/13	2018/8/17	2018/8/27 BNL					
Repairs															
10	SN0028		2018/2/10									Leaks too much discardtest repair			
5	SN0027		2018/2/10 ok		2018/5/19	2018/5/28				DEAD		debonding, height issudebonded too severely			
14	SN0021		2018/2/10 ok		2018/5/19	2018/5/28	x	2018/6/26	2018/7/30	2018/8/14 BNL		3cm debonding repaired at SDU			
7	SN0020		2018/2/10									Leaks too much discard			

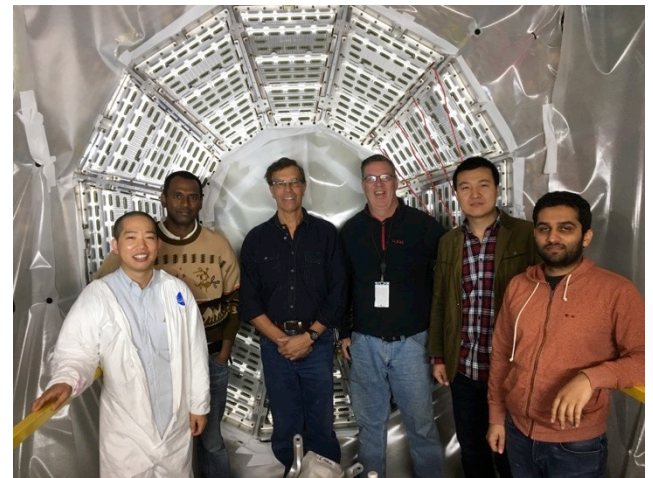
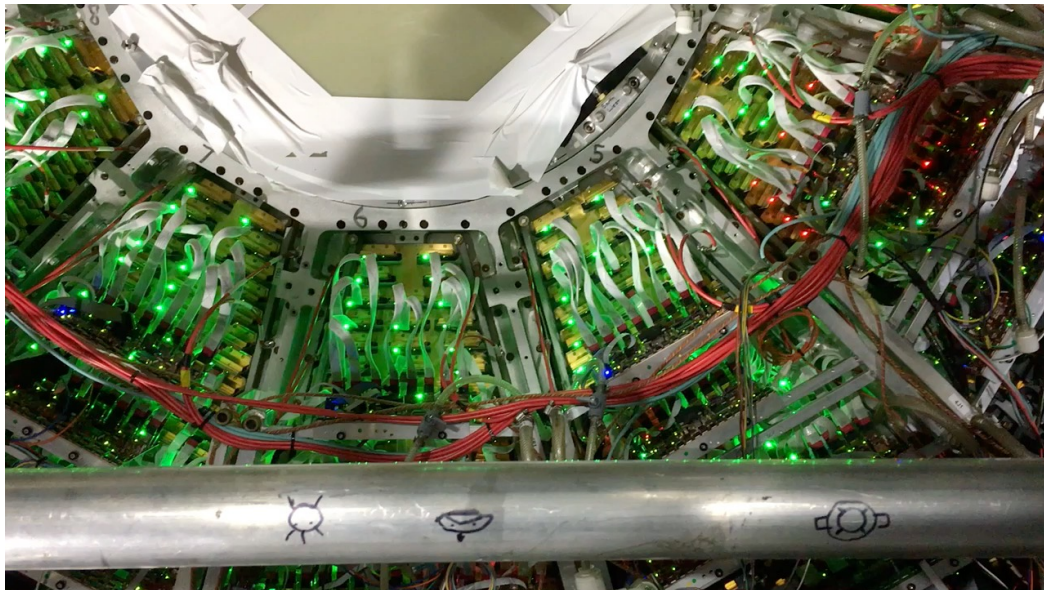
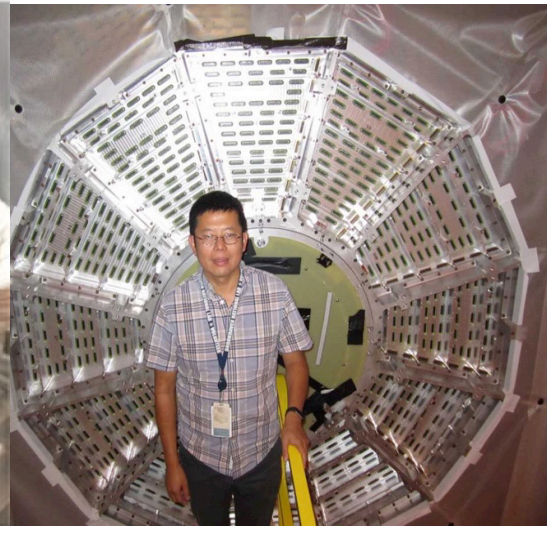
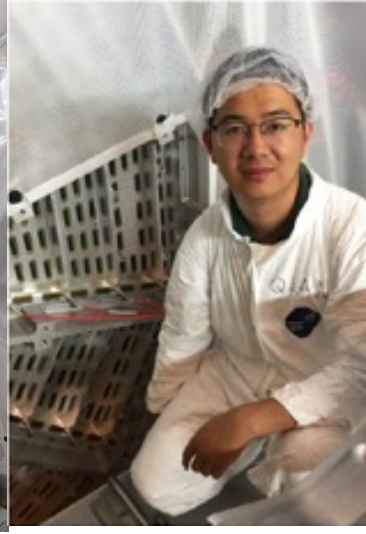
LBL Summary	Number
Good	27
prototype	2
wire below	1
Repaired	2
Discarded	4
	36

SDU summary	Production	Testing	Shipped
Prototypes	2	1	2
Assembled	29	29	29
wire below	1	1	
Total:	32	31	31

iTPC installation



East Side Sector Installation Complete 9/26, 2018
West Side Sector Installation Complete 10/25,2018
Electronics Installation Completed Jan, 2019



iTPC readout performance during running

KPP/UPP -- dead channels, gain & noise (9,10,11)

- UPP: percent of dead channels at run-start <3%

- **measured 0.3 %** ✓

- KPP: gain uniformity <10%

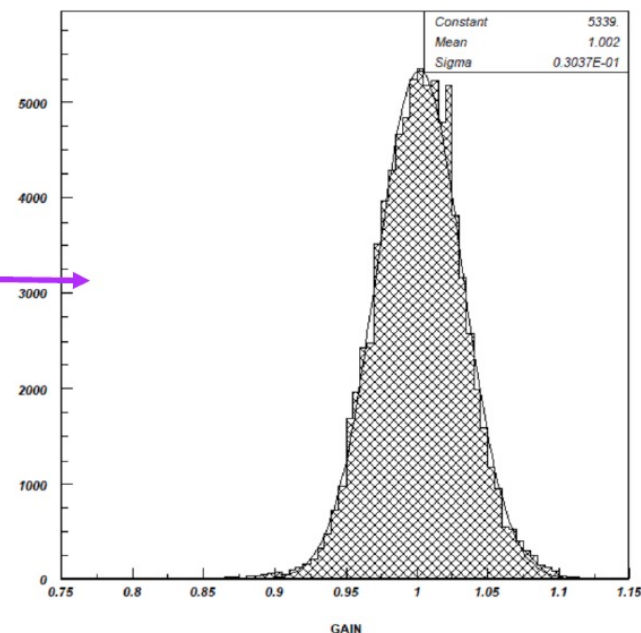
- **measured 3 %** ✓

- Corrected online to within .1%

- KPP: noise <2 ADC channels

- **measured 0.7 - 1.1** ✓

- depends on the padplane location and trace length



Baseline Schedule

-Flemming

Fiscal years	2016				2017				2018				2019			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Mechanical																
padplane																
Strongback padplane production																
Padplane Assembly																
Assemble MWPC																
Sector Installation																
Electronics																
RDO																
SAMPA																
FEE																
Electronics installation																
Roll-in and commissioning																
Insertion Tool																

The schedule was essentially held

- MWPC production tight due to delivery of strongback/padplanes
- Electronics FEE schedule as planned, installation complete by early January
- The complete milestone schedule with baseline and forecast in close-out report

Total Cost: 3.6M\$ DoE + 1M \$ China(NNSFC,MoST,SDU)

Summary of iTPC

Executive Summary

-DoE closeout review in 2019

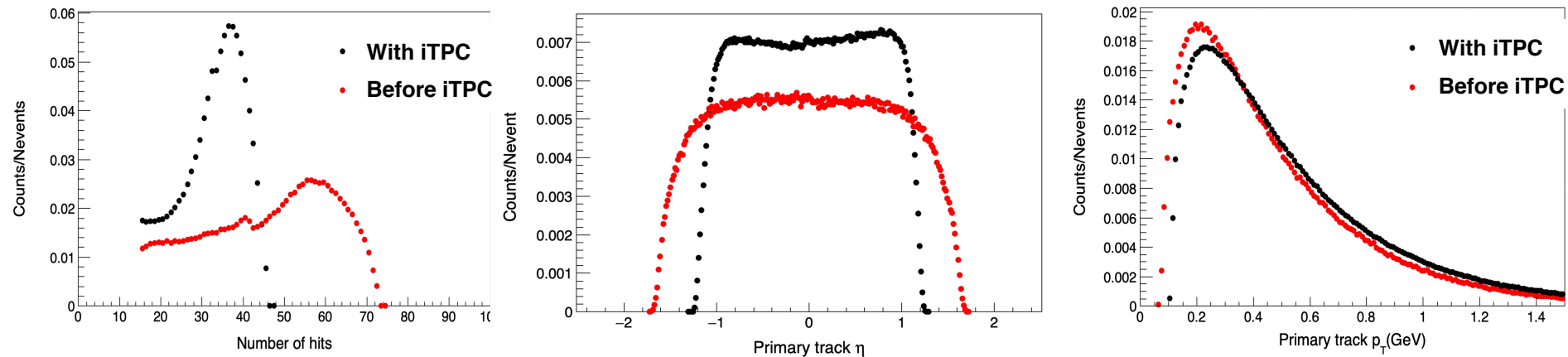
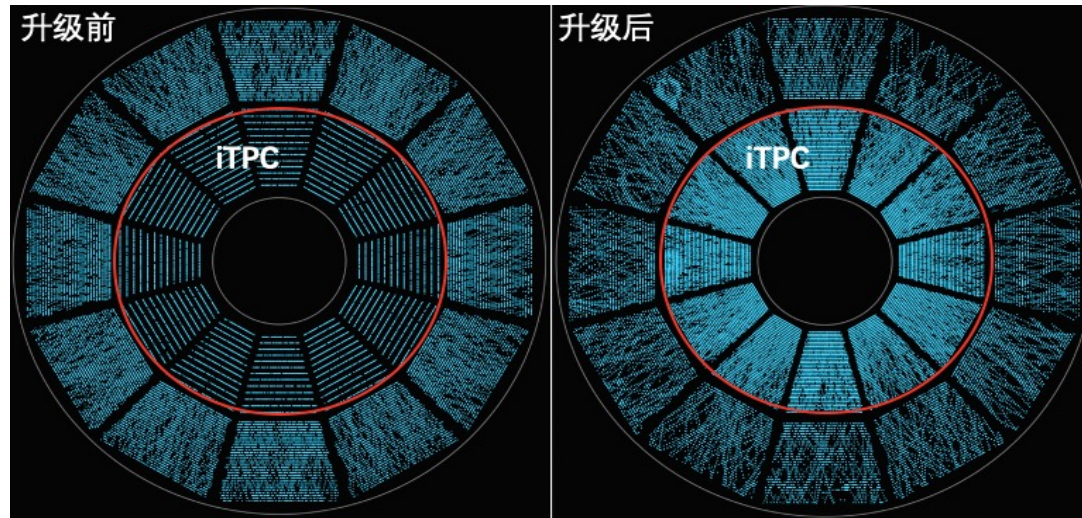
The Department of Energy (DOE) Office of Nuclear Physics (NP) Facilities and Project Management Division held a Project Closeout/Transition to Operations Review of the Solenoidal Tracker at RHIC (Relativistic Heavy Ion Collider) inner Time Projection Chamber (iTPC) at Brookhaven National Laboratory (BNL) on May 2, 2019, via web-conference capabilities.

The panelists found that the STAR iTPC project has achieved all technical, cost, and schedule baseline and performance specifications. The project is considered complete.

All deliverables of the project were met. The full TPC required 24 iTPC modules plus two spares. Five spares have been provided. All the project Key Performance Parameters (KPPs) were met or exceeded. The performance of the TPC was characterized as “spectacular.” It was also noted that even with some operational hurdles such as an inelegant magnet quench, the total number of non-working channels is still under the 3% required in the Ultimate Performance Parameters (UPPs).

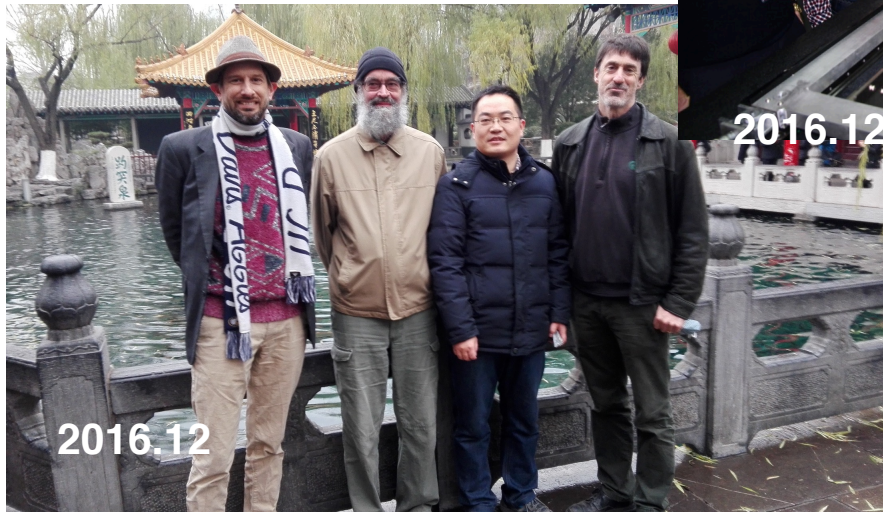
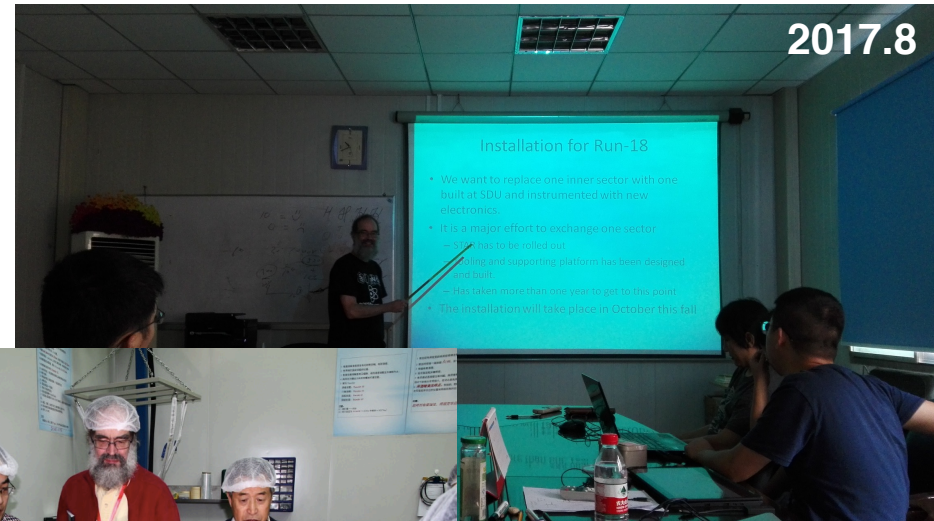
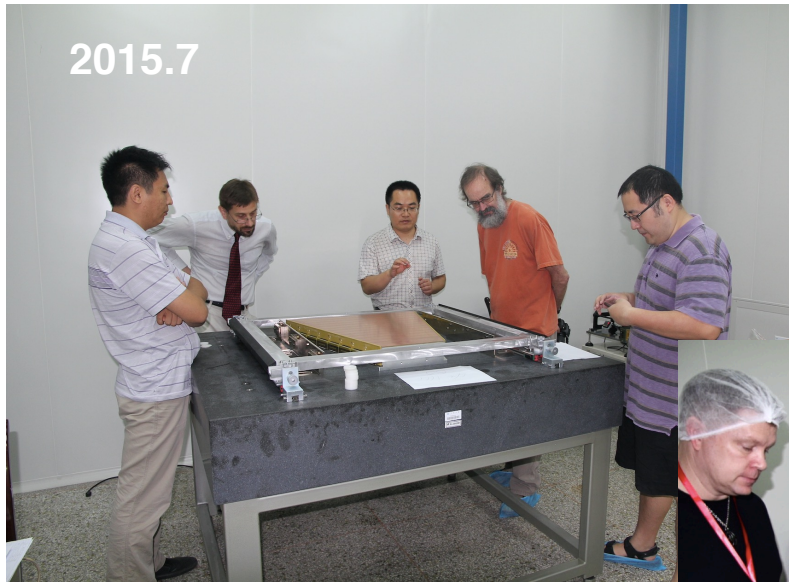
Summary of iTPC

- Improvement in tracking at STAR, achieved during BES-II (2019-2021)



- Looking forward to the exciting physics results with iTPC

Pictures of Flemming visiting Shandong



Congratulations to your retirement, Flemming!



Pre-QM meeting at Qingdao, 11/2019

Wish I could join such a dinner at BNL today!

Enjoy your new phase of life, Flemming!



-SDU campus in Qingdao