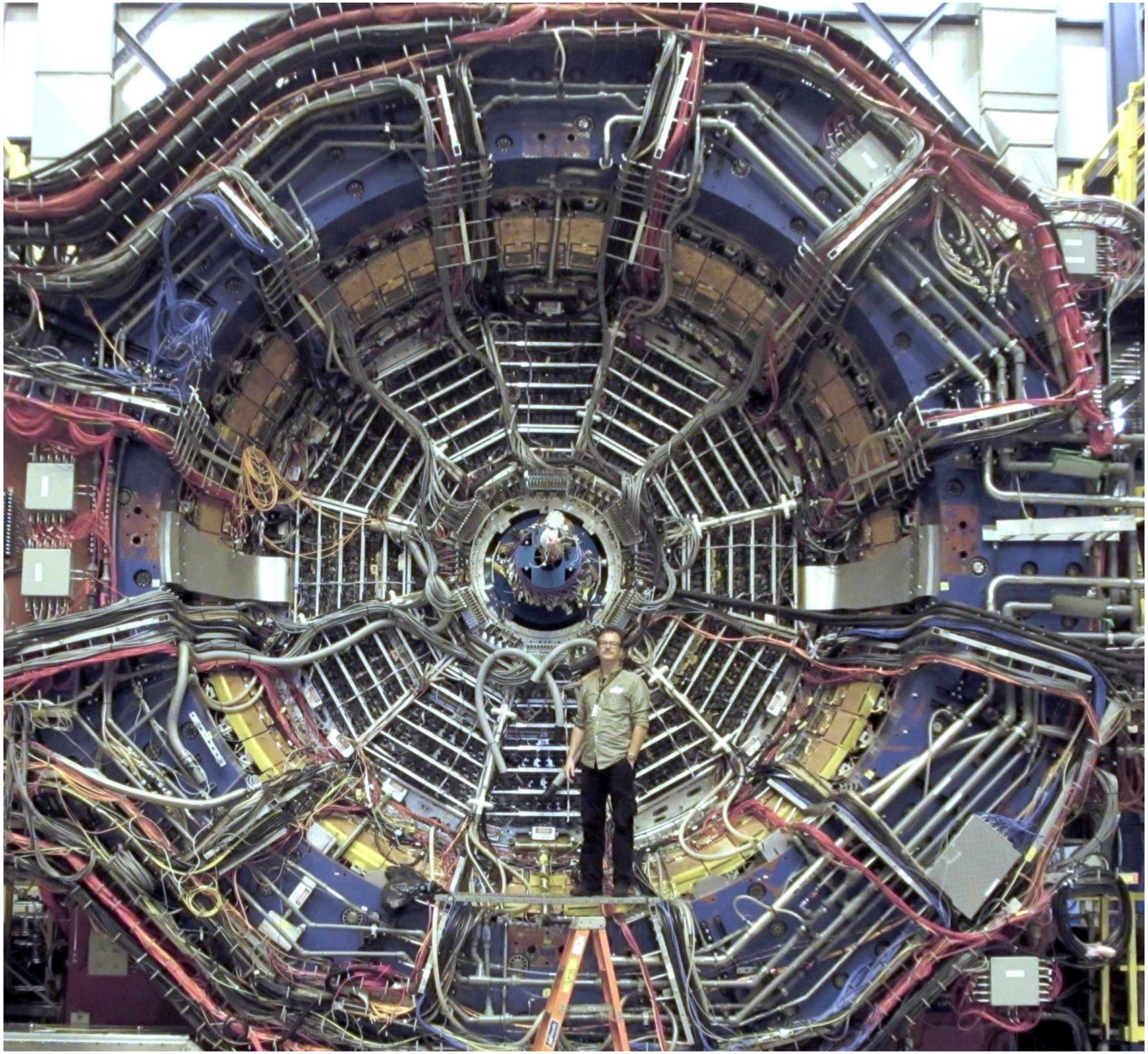
The iTPC PadPlane and Strongback

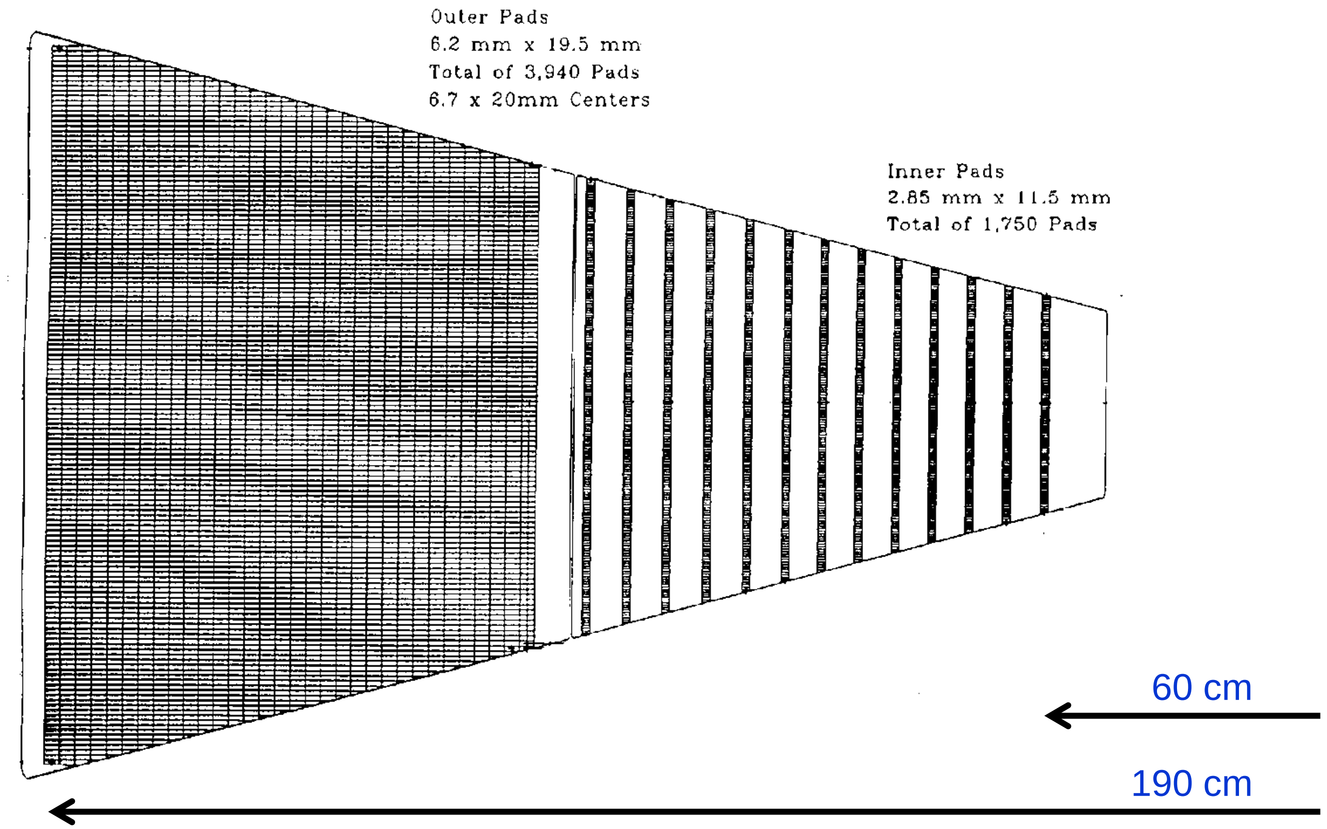
Jim Thomas, Bob Scheetz, John Hammond, Eric Anderssen, Jon Wirth, Hui Wang, Irakli Chakaberia, Yuri Fisyak, and a cast of thousands

September 13th, 2016

The STAR Detector at RHIC



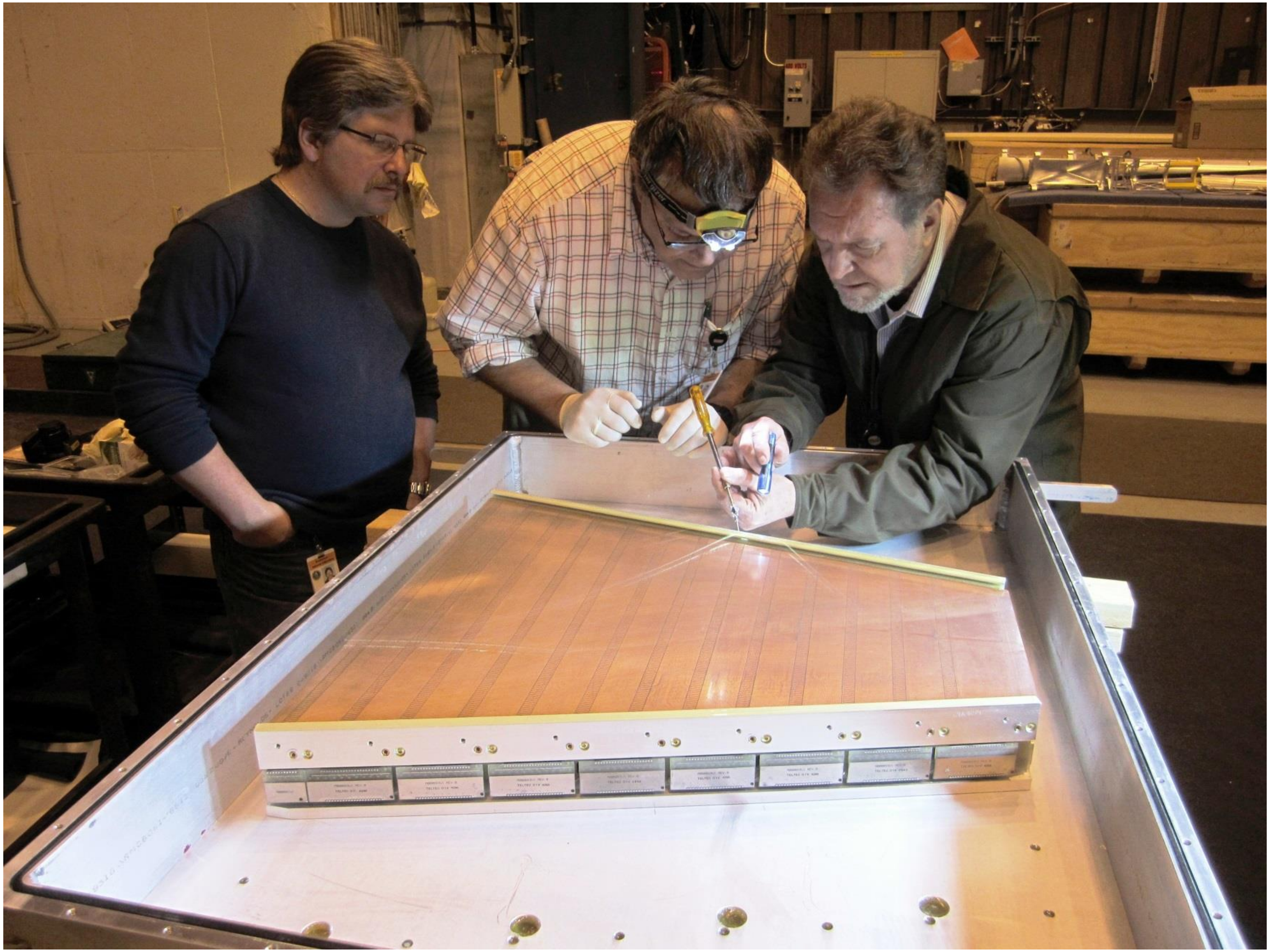
Goal: Hermetic coverage & better acceptance



- Currently, the outer pad plane is hermetic while the inner pad plane is not
  - Goal: Add more pad rows on the inner sector, 2X total pad count

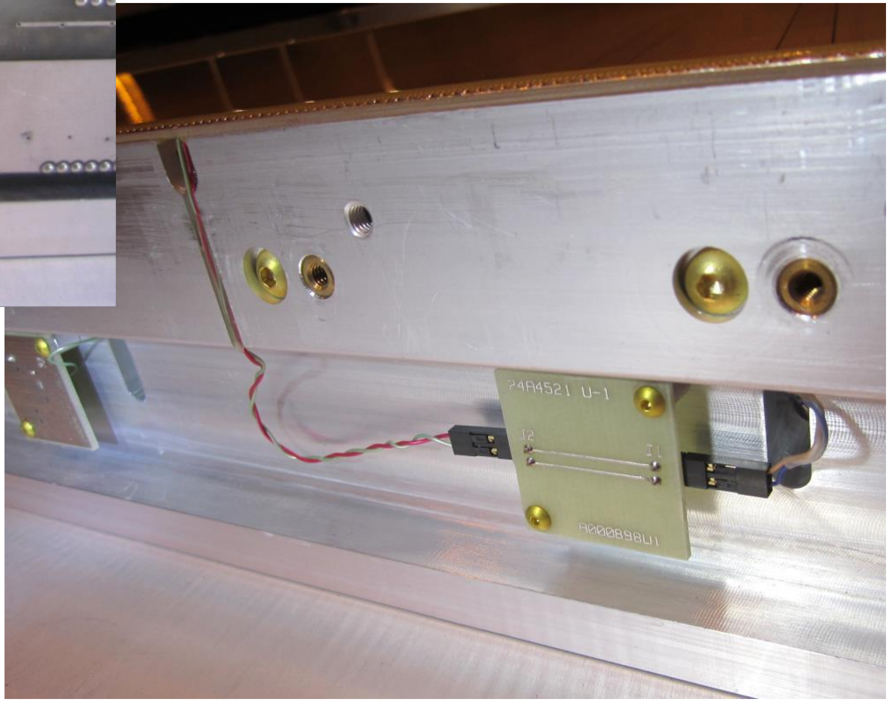
The upgrade will provide better momentum resolution, better dE/dx resolution, and improved acceptance at high η

A Spare Inner Sector (Circa 1995)



Electronics on sides – all Bromine Free boards

- **Careful choice of materials required to avoid electro-negative contamination**



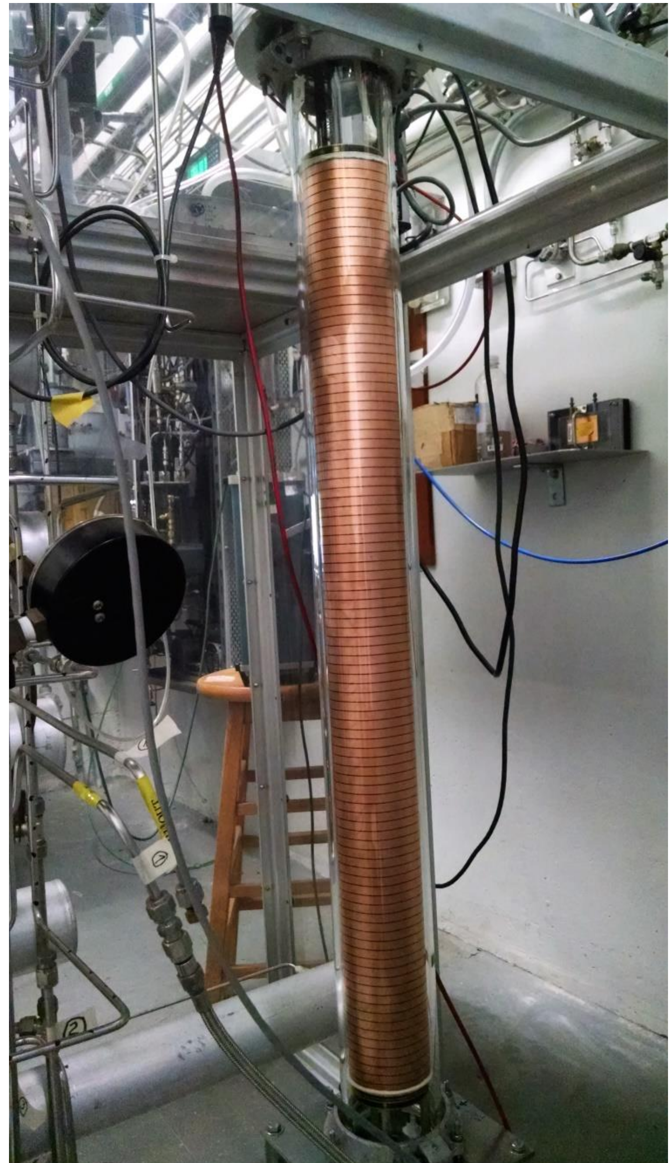
- **PadPlane**
- **Electronics Boards**
- **Epoxy**
- **Solder (flux)**

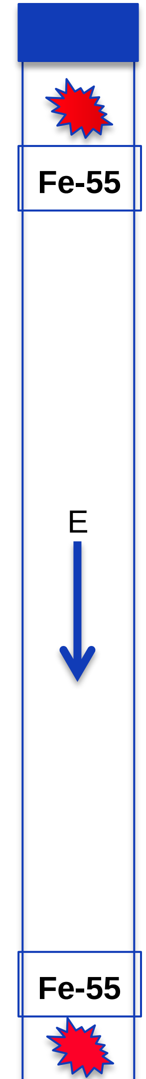
The “LBL Canary Chamber”

- **Previously used for PEP-4, EOS, STAR & EXO**

- **How to measure electronegative impurities in gas due to materials contamination?**
  - **Drift e$^-$ through 1 m of TPC gas (P10)**
  - **Gas circulates through sample chambers & drift volume**
- **Sample chambers and control systems not shown**

- **Now installed and working at BNL 09/05/2016**
  - **Tests will start this week**
  - **e.g. Padplane, ABDB & wiremount boards**





MWPC

Documentation from the original project

- The documentation from the original project (circa 1995) is extremely good
  - Engineering drawings for every part (dwg & pdf)
  - Electronics drawings for every board (pdf)
  - Technicians Notebooks, notes & fully documented procedures
  - QA plans and Travelers for every sector
  - And most important … Jon Wirth (retired) is enthusiastic about participating in the new project ☺
- Thus, we are standing on the shoulders of giants (I. Newton, 1676)
  - Very little “new” engineering required
    - Primarily, translation of old (2D) drawings into modern 3D CAD
  - A minimum of new features added (other than additional pad rows)
  - PadPlanes and Strongback fab is primarily a technical project
  - Archeology required to establish precise technical procedures
    - The Archeology project was time consuming but is now complete

As much as possible, we are doing what was done before using the same materials & techniques

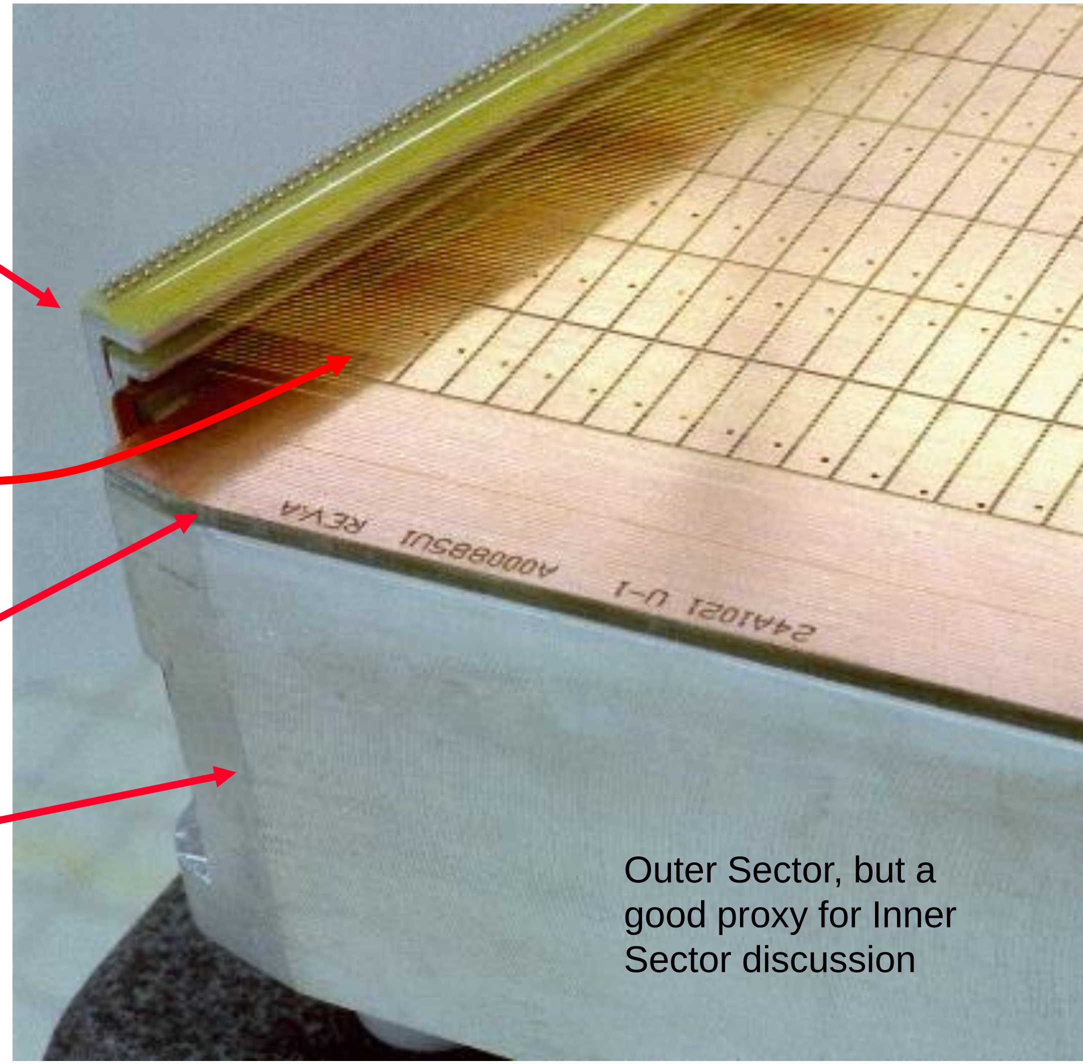
Major Items: Definition & Scope

Wire Mounts for Grids

Wire Planes:
Gated Grind, Cathode
Grid, and Ground Grid

Pad Plane with larger (5x16)
pads, hermetic coverage

Strongback



Outer Sector, but a
good proxy for Inner
Sector discussion

Major Tasks

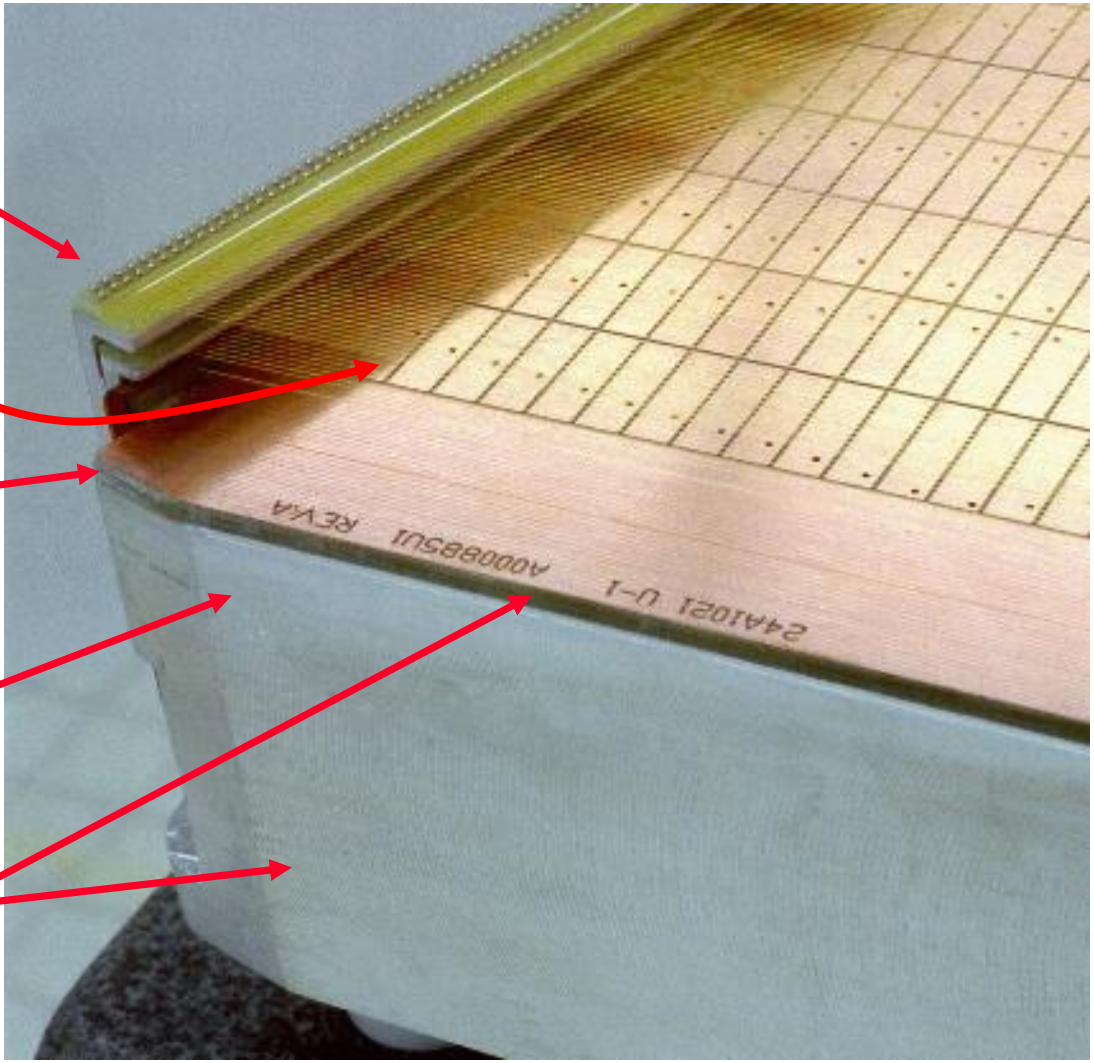
Fabricate, Align and Pin Wire Mounts (BNL & LBL)

Wind wire grids
(SDU, see Qinghua Xu's talk)

Fabricate, QA check
Align (50 μm)
Glue (< 20 μm flat)
& Trim padplane (BNL & LBL)
(See Tonko Ljubicic's talk)

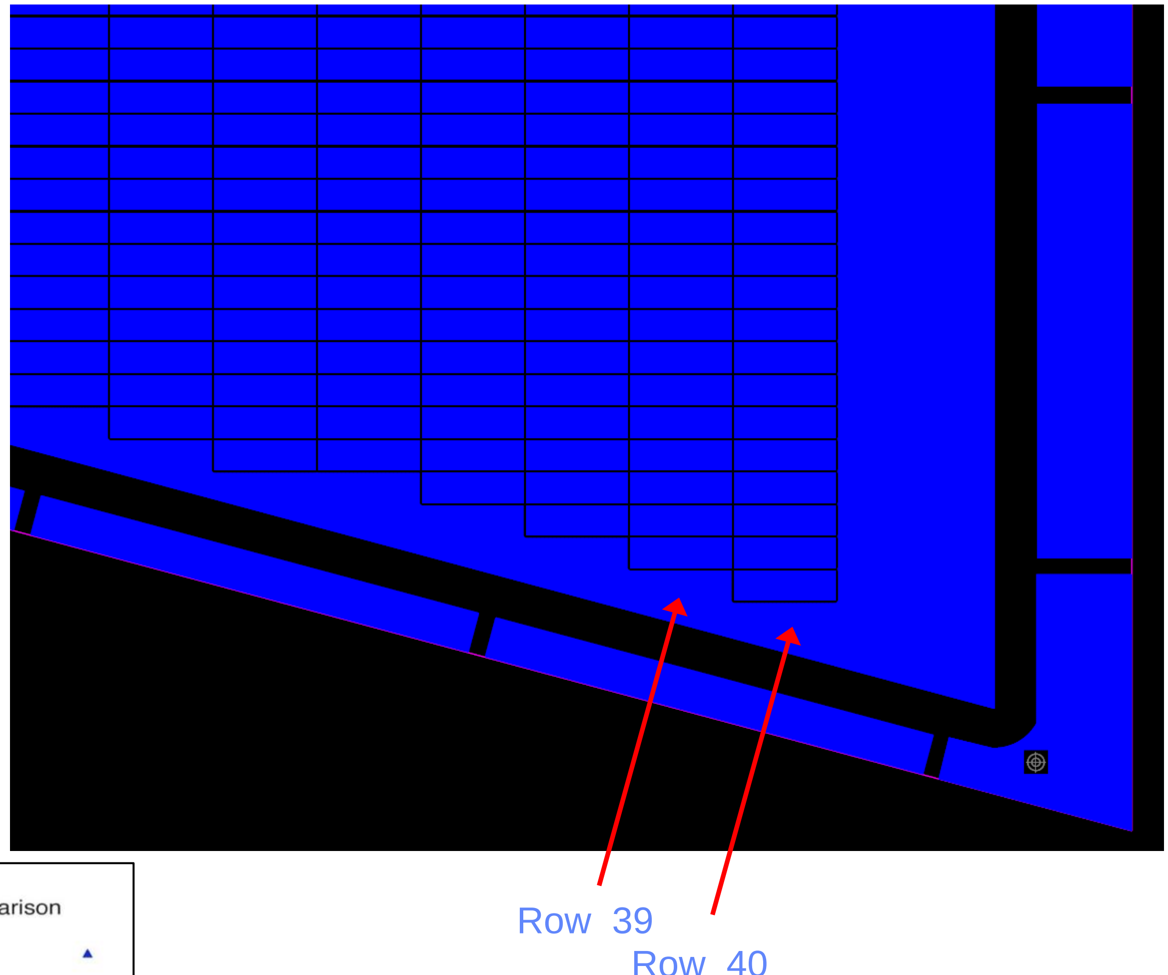
Fabricate strongback & inspect (QA) (Outside vendor)

Cut to height, machine O Ring grooves, Survey padplane & Document mech. specs (LBL)

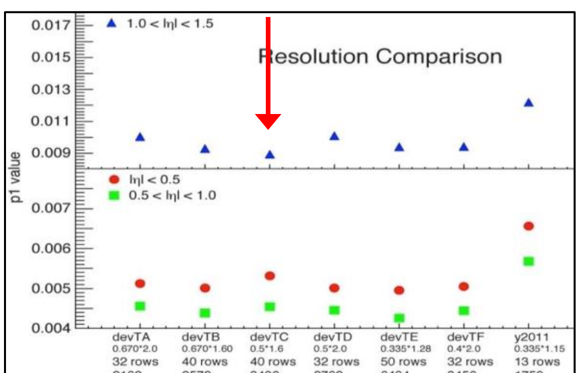


New Pad Plane design and layout

A corner of the new inner pad plane layout design by John Hammond & Bob Scheetz

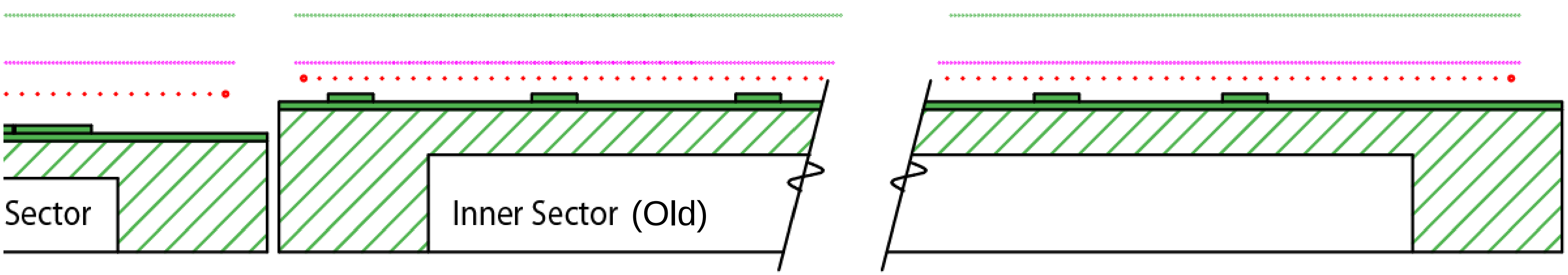


Pad Row	# of Pads
1	52
2	54
3	56
4	58
5	60
6	62
7	62
8	64
9	66
10	68
11	70
12	72
13	74
14	74
15	76
16	78
17	80
18	82
19	84
20	86
21	86
22	88
23	90
24	92
25	94
26	96
27	98
28	98
29	100
30	102
31	104
32	106
33	108
34	110
35	110
36	112
37	114
38	116
39	118
40	120
TOTAL	**3440**

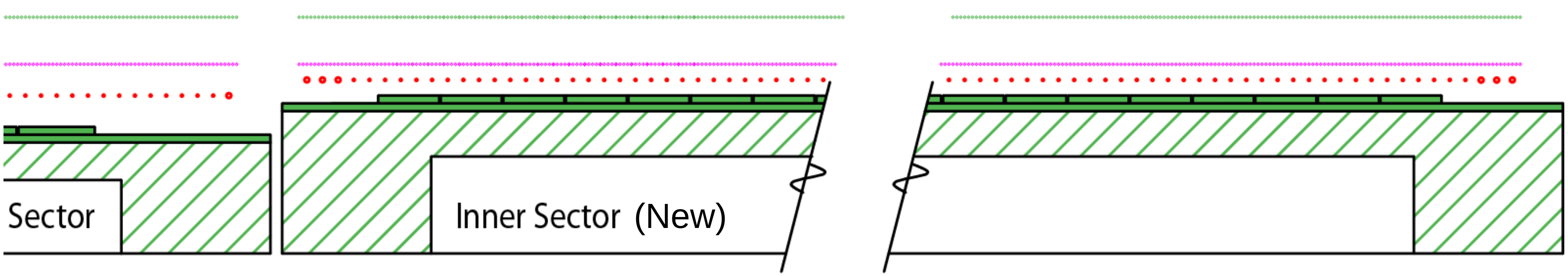


Momentum (and spatial) resolution not strongly dependent on pad design within this range … it's the extra rows that are important

40 Pad Rows fit perfectly with the existing grid



Anode wires spaced 4 mm apart (horizontally), Ground Shield and Gated grids spaced 1 mm apart



- **No need to change grid; wire locations remain the same**
- **No need to add more ABDB or wire mount channels (good)**
- **Identical pad response function on both ends of grid**

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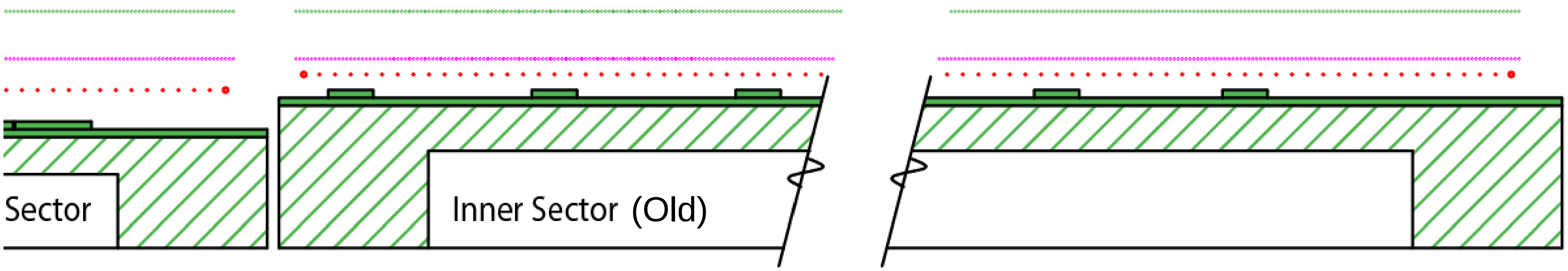

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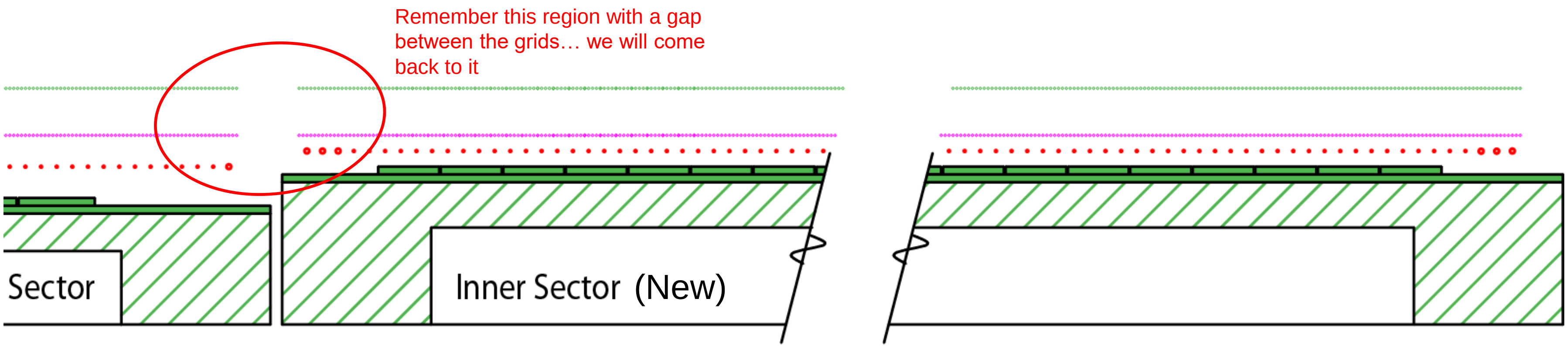

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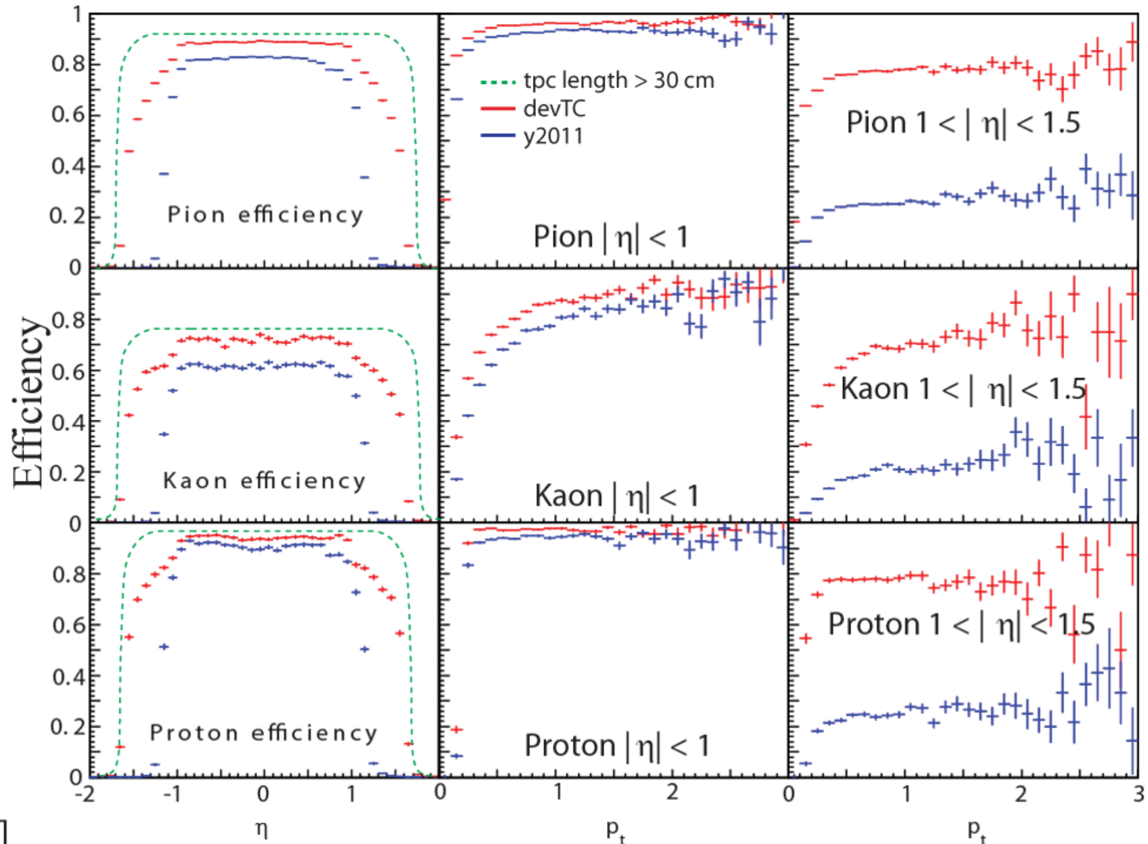
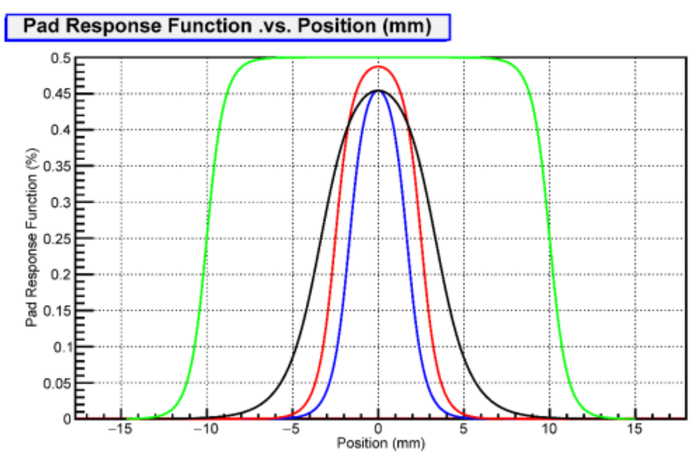
New PadPlane Performance

- **Efficiency as a function of η and p_T**
- **Acceptance increases from |η| < 1 to |η| < 1.5**





The pad response function for the outer sector is shown by the black line, the existing inner sector by the blue line, and the proposed inner sector by the red line. The pad spacing is 6.7 mm, 3.35 mm, and 5 mm respectively.

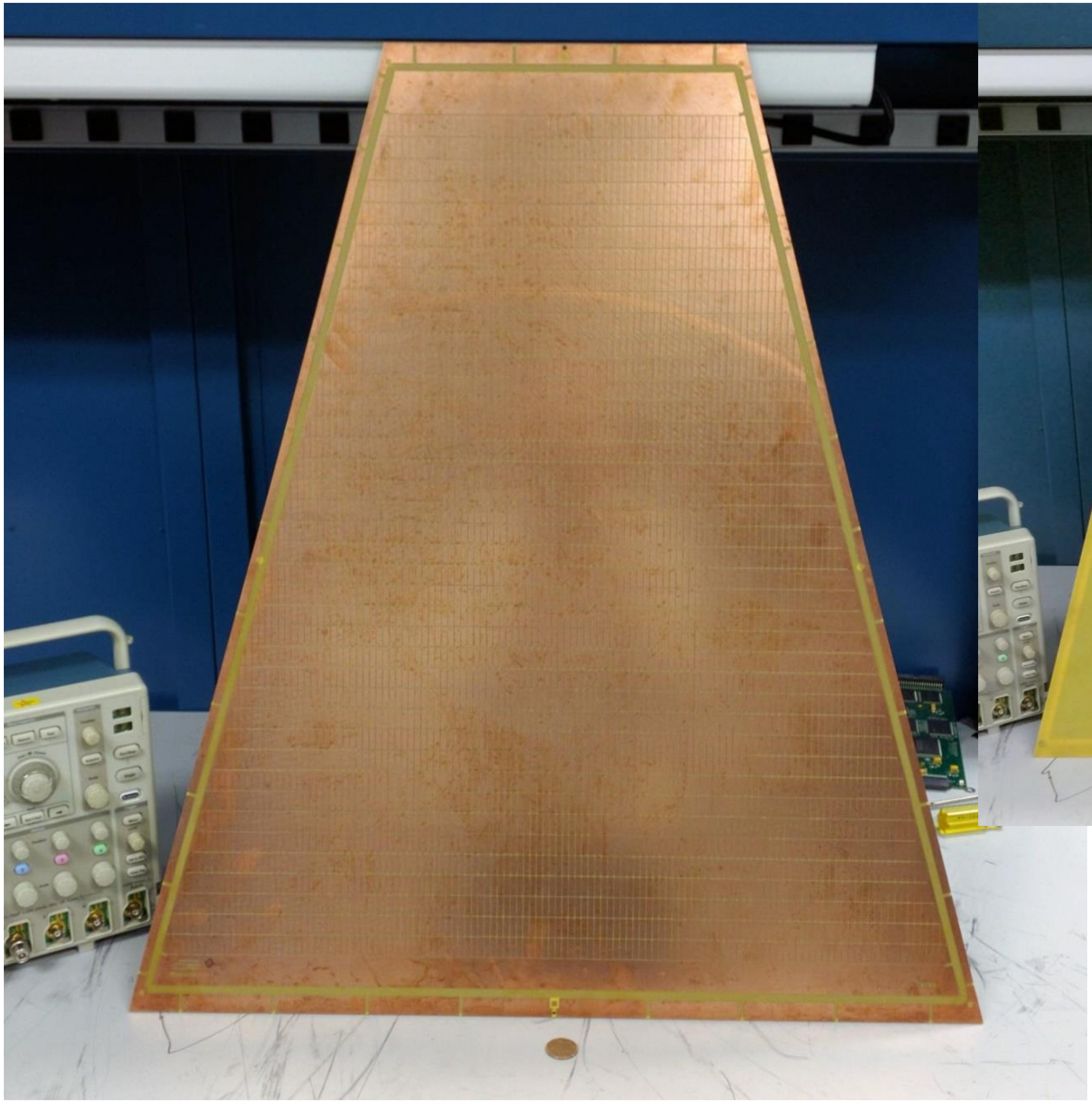
Parameters for the old and new sectors

Item	Inner	Outer	iTPC	Comment
Pad Pitch (center to center)	3.35 x 12	6.70 x 20	5.0 x 16	mm
Isolation gap between pads	0.5	0.5	0.5	mm
Pad Size	2.85 x 11.5	6.20 x 19.5	4.5 x 15.5	mm
Number of Pads	1750	3940	3496	
Anode to pad plane spacing	2	4	2	mm
Anode voltage	1170 V	1390 V	~ 1120 V	20:1 S/N
Anode Gas Gain	3770	1230	~ 2000	nominal
Anode Wire diameter	20 μm	20 μm	20 μm	Au plated W
Anode Wire pitch	4	4	4	mm
Anode Wires phase locked to pad location	3 wires, #2 over center	5 wires, #3 over center	4 wires, over center	grp centered over the pad

Pad Plane & wire planes must be flat to better than 20 μm to keep dE/dx resolution uniform to 1%

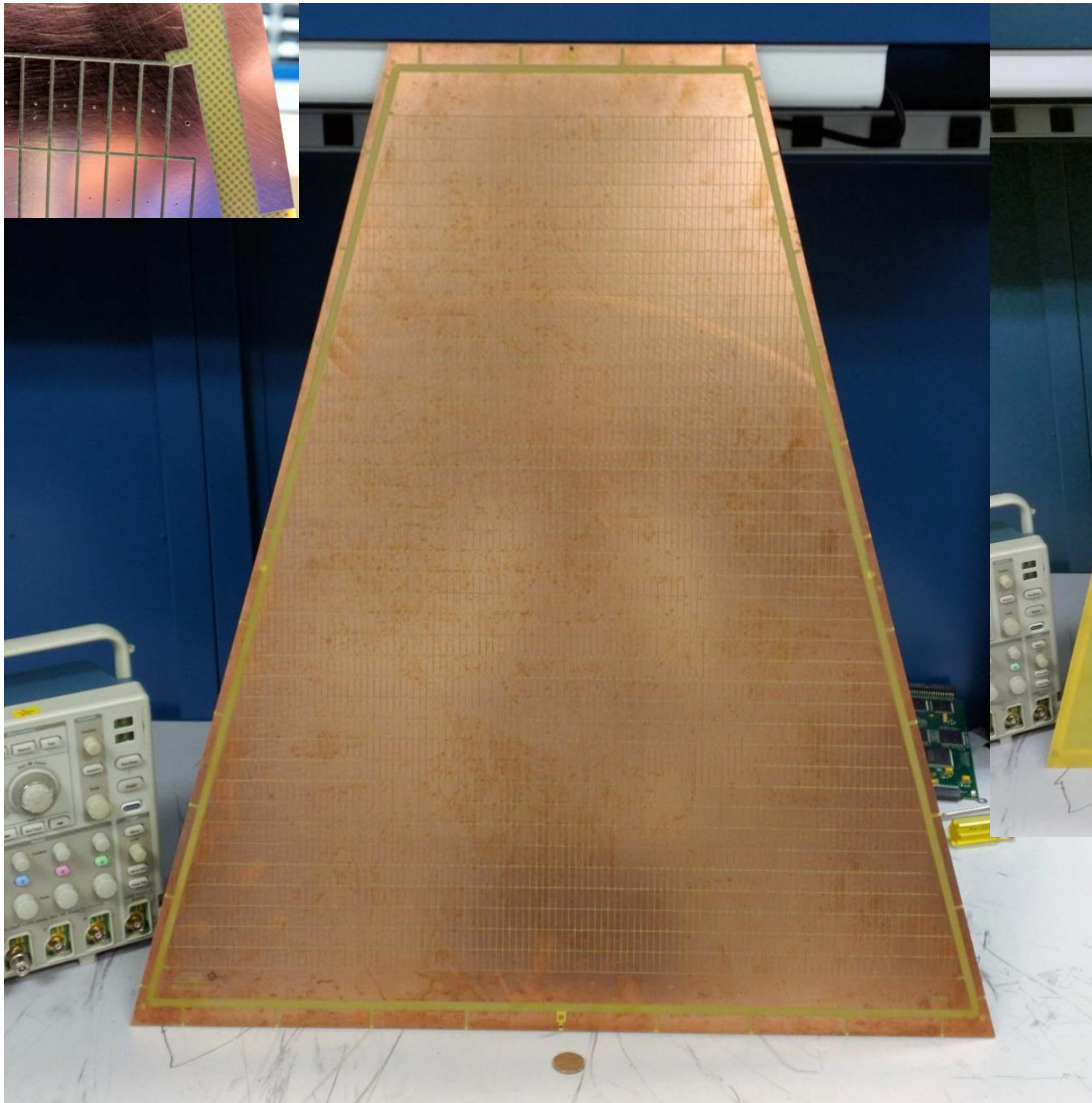
Wire	Diam. (μm)	Pitch (mm)	Composition	Tension (N)
Anodes	20	4	Au-plated W	0.50
Anodes—last wire	125	4	Au-plated Be–Cu	0.50
Ground plane	75	1	Au-plated Be–Cu	1.20
Gating grid	75	1	Au-plated Be–Cu	1.20

Padplane Prototype undergoing tests at BNL



- **40 Rows**
- **5x16 pads (mm)**
- **High density connectors (64 channels)**
- **Halogen free materials**

Padplane Prototype undergoing tests at BNL



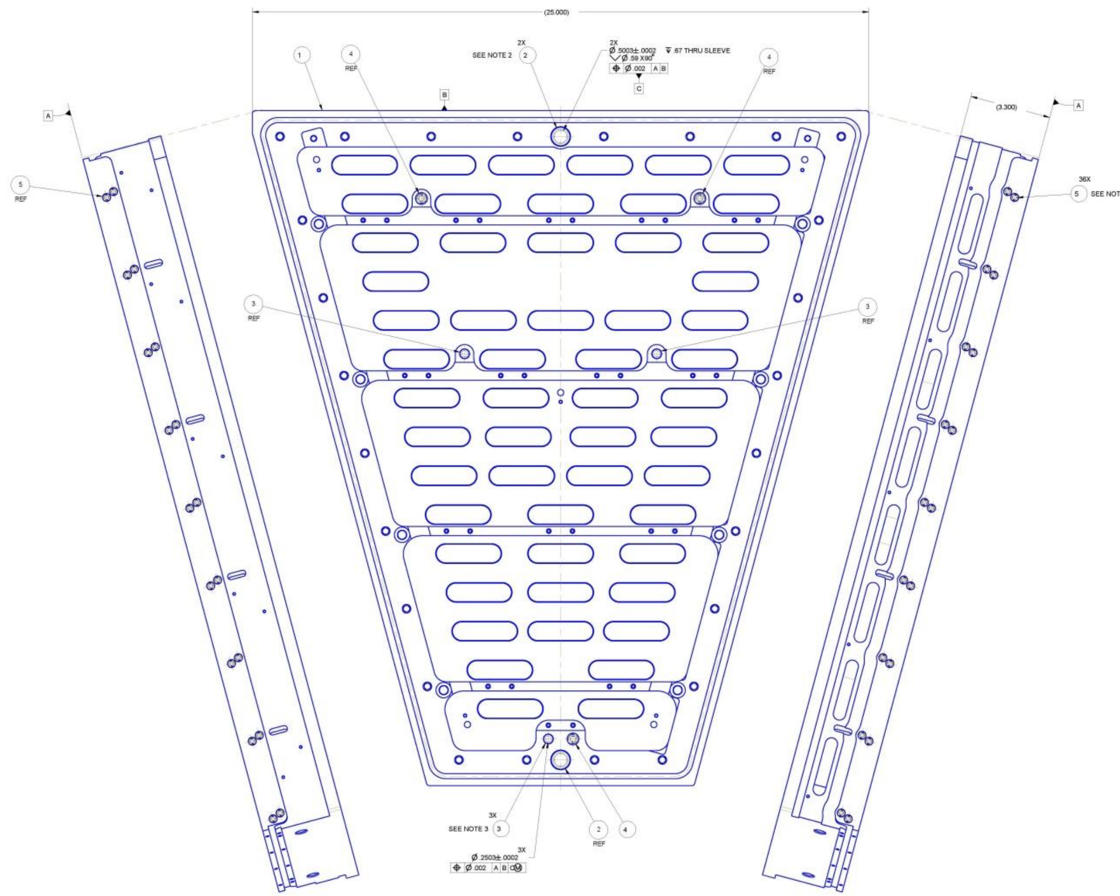
- **40 Rows**
- **5x16 pads (mm)**
- **High density connectors (64 channels)**
- **Halogen free materials**

Vacuum Check of Padplane

- **Vacuum integrity check with prototype padplane**
- **Granite tables typically flat to 5 μm**
- **Use vacuum to hold padplane on table**
  - **while gluing to strongback**

✓ **Good 09/01/2016**

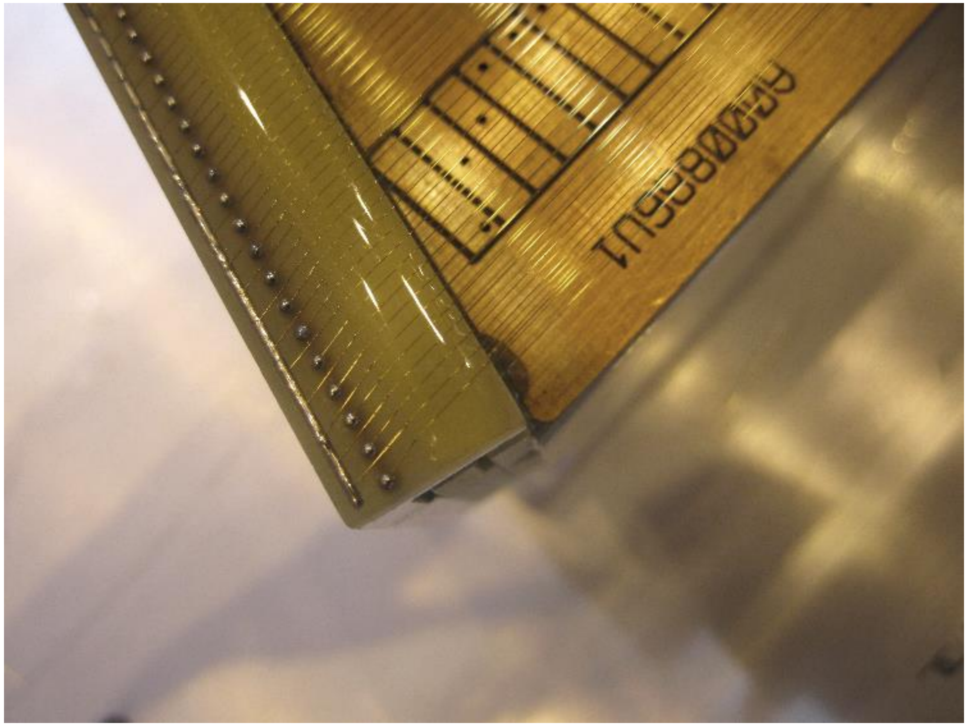
Strongback Construction is Complete 30 of 30

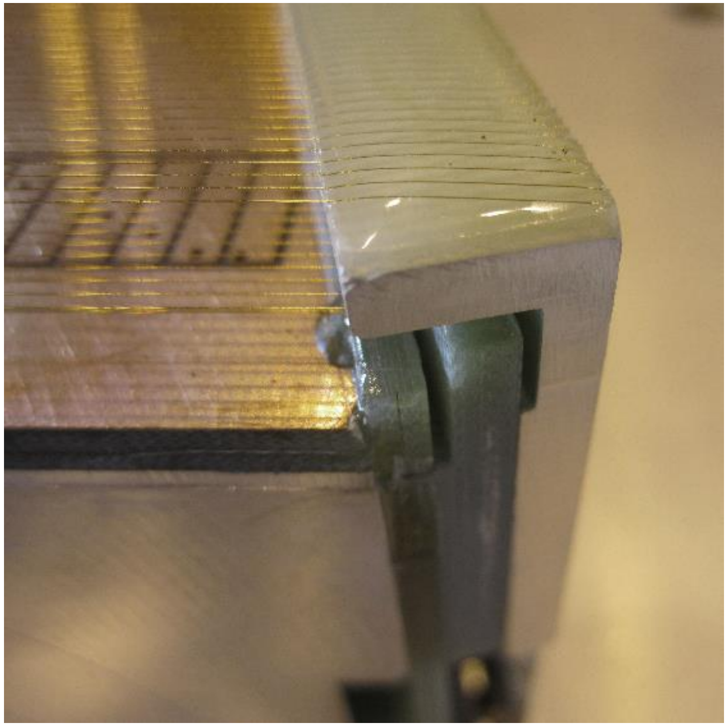


A prototype inner sector strongback is shown during fabrication at the University of Texas (circa 2013). The sector was machined out of a single piece of aluminum. Dimensions are: ~27 inches tall, ~25 inches wide and weight 55 lbs. The sector is viewed from the backside; the side upon which the electronics and cooling manifolds will eventually be mounted. More recently, 30 production strongbacks were completed at IMT Precision Machine, Hayward CA and received on 08/01/2016.

Wiremounts

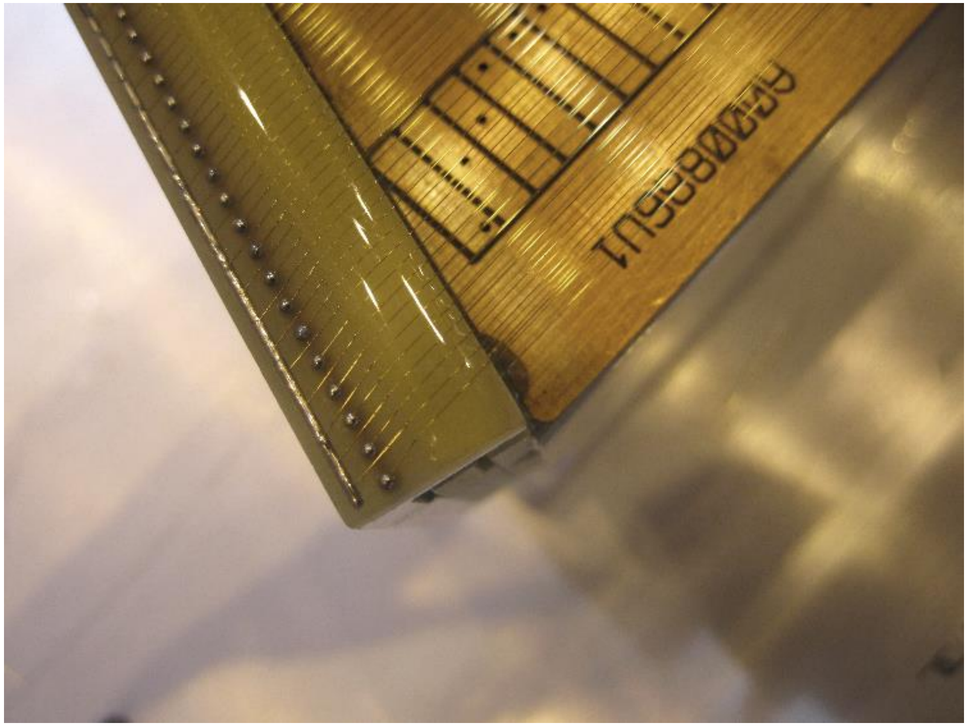
- **The Anode wires, Shield Wires, and Gated Grid wires are mounted on structures attached to the sides of the strongback**
  - **A total of 6 wiremounts – 3 left, 3 right**
  - **3 of the 6 contain circuit traces and electronic PCB boards (i.e. EE required)**
  - **3 of the 6 are blank boards or Al (e.g. blank boards go to Central Machine Shop at BNL)**
- **Blank boards and blank Al pieces are in final stages of construction**
  - **2 of 3 PCB boards have been designed, 2 of 3 prototypes complete**

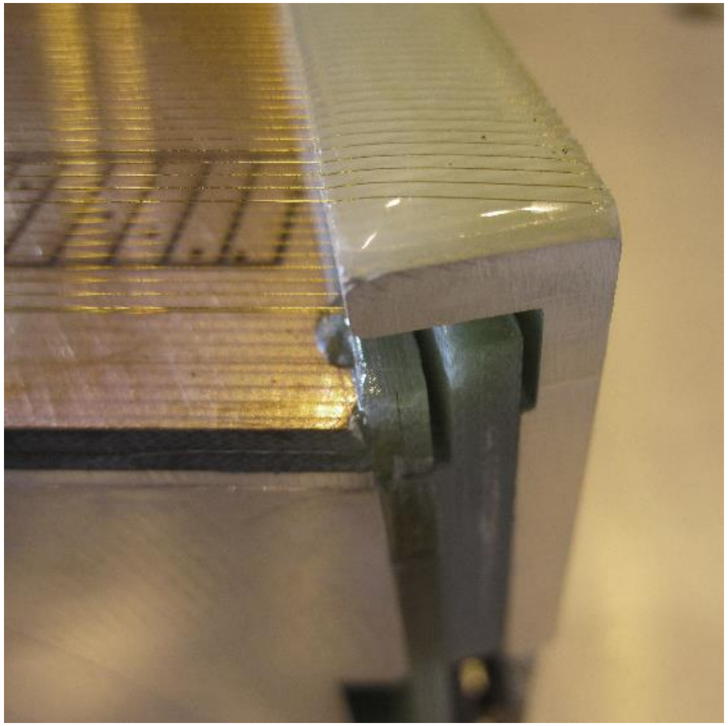




Wire locations near the gap will not change

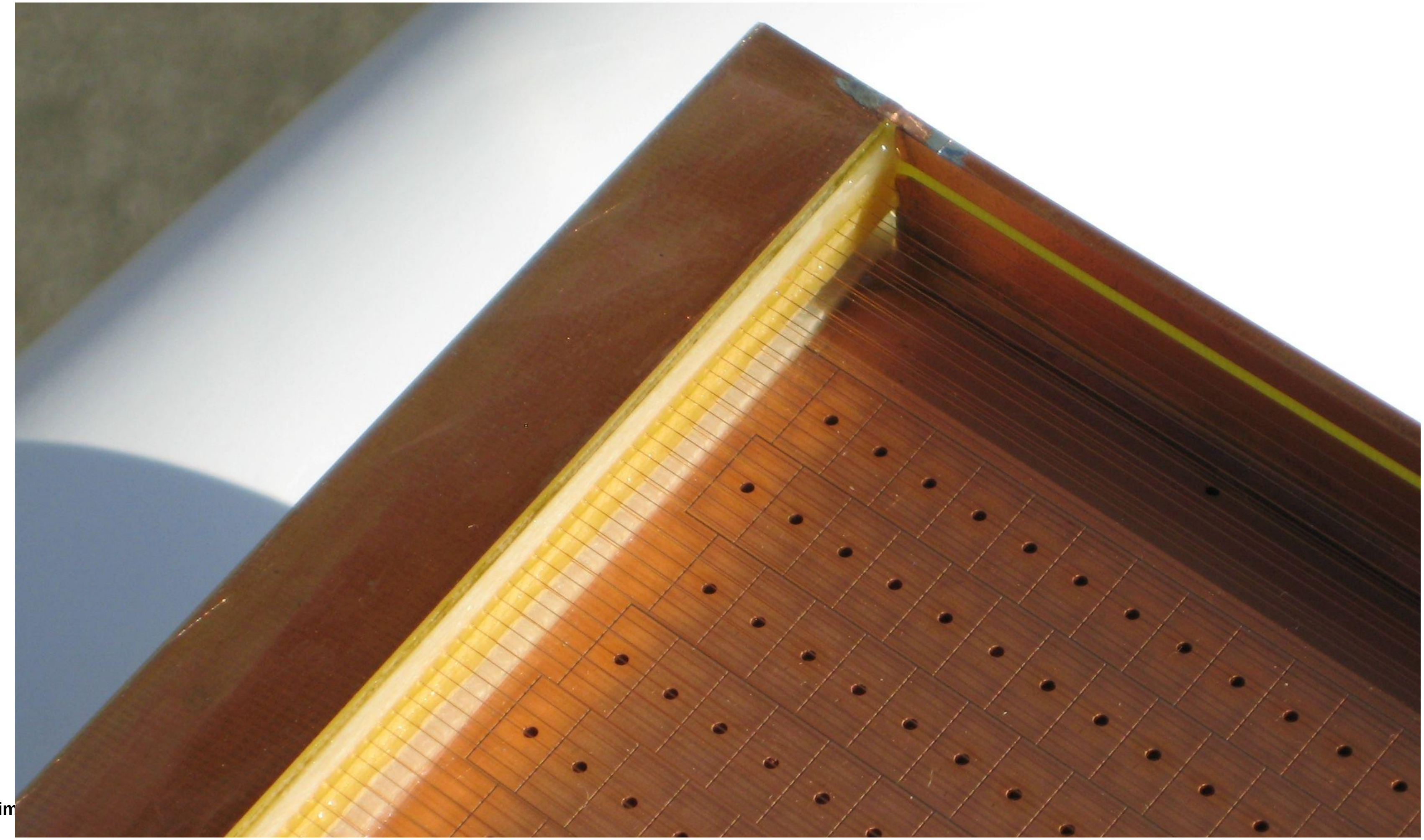
- **The location of the wires near the inner/outer gap cannot change**
  - **Position and total number of wires on each plane remains the same**
- **Because … it is not possible to add more wires**
  - **The full extent of the side mounted wire mounts are already used**
- **So we need a new solution to the Grid Leak problem**
  - **Where ions can "sneak around the corner" and flow into drift volume**





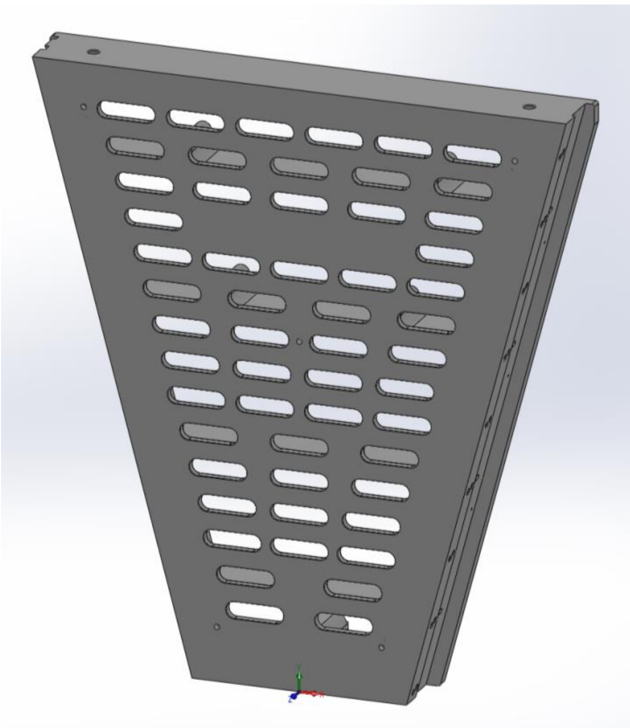
The Alice Solution to the Grid Leak problem

- **Multiple thick anode wires near the boundaries of the sectors**
- **A wall – to terminate the field lines from the Anode wires with ground potential and “cover” potential (match field gradient)**

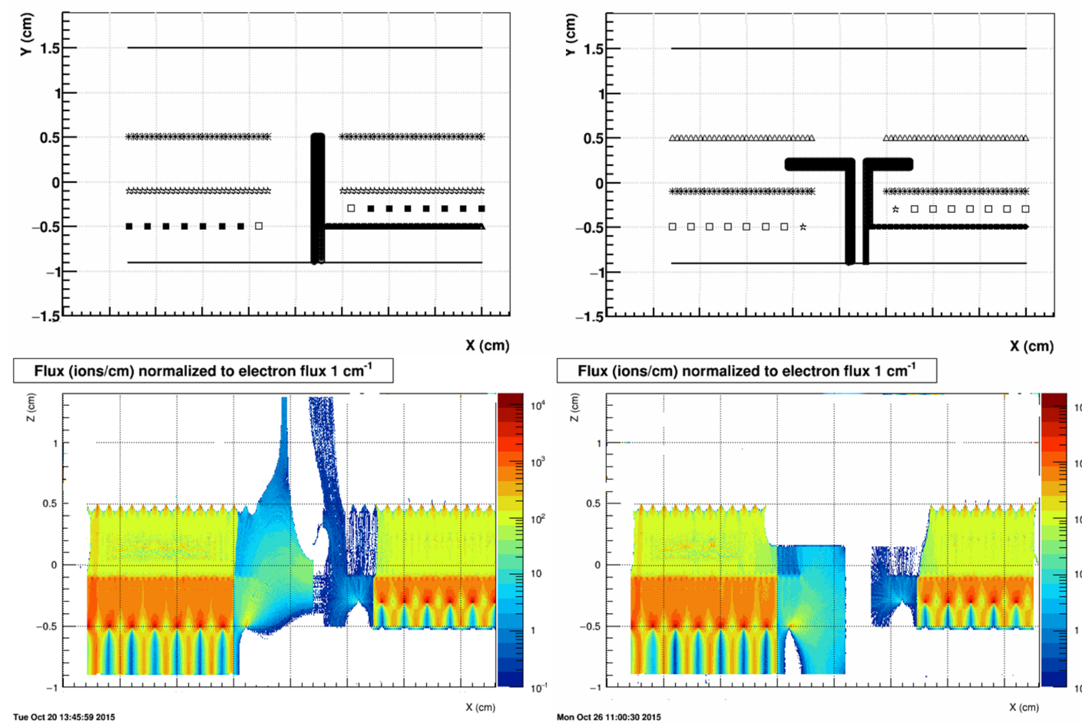


Gridleak & Changes since previous (1995) design

- **Add a "wall" to mitigate the gridleak problem (a work in progress)**
- **3D CAD design – (lowered the fabrication & inspection costs)**
- **Slots for electronics moved down by 0.221" (new HD connectors)**



Slots for electronics are lower by 0.221" than previously. Otherwise, the same.



GARFIELD simulations of ions flowing away from the STAR TPC anode wires when the Gated Grid is closed. There is a 1.2 cm gap between the Inner and Outer sectors that is not covered by the Gated Grids. This gap allows ions to flow out of the MWPC region and into the tracking volume of the TPC. Putting a -690 volt bias (left panels) on the wall reduces the flow of ions, while the "L" shaped wall (right panels) completely stops the flow of ions. The "L" shaped wall was held at 0 volts in this simulation.

Schedule Drivers

- **Strongback**
  - **We went to an outside vendor with multiple machines to fabricate the strongbacks … they gave us very fast turn around**
    - ✓ **Construction & QA complete: survey & quality looks good**
    - ✓ **Strongbacks in storage at vendor's location in Hayward**
- **Padplane & Wiremounts**
  - **Work is being done by STAR Electronics group which is one of the projects greatest strengths. However, we are a bit late … for many reasons including procurement delays and the need to share the wealth of good manpower in a competitive process with other projects**
- **Assembly has not yet started**
  - **Tooling required; and time to set up work space (1 month)**
  - **4 month build, if 100% dedicated effort. Schedule is fast paced, only three days allowed per sector (6 days including the time to watch the glue dry)**
- **Critical Path**
  - **The PadPlane and Wiremounts are sitting on the critical path**
    - **Designs are final and complete, production schedules are the issue**
  - **Berkeley assembly shops are busy with CERN upgrade work, already. Had hoped to start on August 1st to avoid this problem; likely to stretch build time to 5 calendar months from start date due to labor sharing**

Risk – high level summary

- **Technical**
  - Better than 20 μm flatness requirement for PadPlane+Strongback
    - A vigorous QA plan is essential
    - We have the elements of a good QA plan in place, inherited from the 1995 project, but we need the will and discipline to stick to it
  - Shipping & damage in transit
    - We have well developed repair procedures ⇒ schedule risk
  - Bromine free materials
- **Schedule**
  - Padplanes expected in 13 to 14 weeks, contracts not yet written
  - Materials must pass Canary test
  - Wiremounts due soon
  - Minor schedule slips could easily affect the final installation date
    - Schedule is tight
- **Management**
  - Major procurements must move quickly
    - Not always easy at a National Laboratory
  - Whenever schedules are tight, sharing manpower becomes a challenge

Cost Drivers

- **Wiremounts**
  - **$20K (estimate, 2/3 complete, multiple sources)**
- **Padplanes**
  - **$40K (out for competitive bid)**
  - **See Tonko's talk for additional details and prototyping experience**
- **Strongbacks**
  - **$100 K (procurement complete)**
  - **IMT Precision Machine in Hayward, Inspected at IMT & BNL**
- **Assembly**
  - **$600 K**
  - **Berkeley is the preferred location for the gluing of the PadPlane, and assembly of the Strongback and Wire Mounts**
    - **High precision work: close proximity to Engineers and Technicians who previously worked on STAR (circa 1995)**
    - **Nicely integrated Assembly shop, Machine Shop & Survey shop**

See Flemming Videbaek's talk & associated MS Project / Excel files for precise details

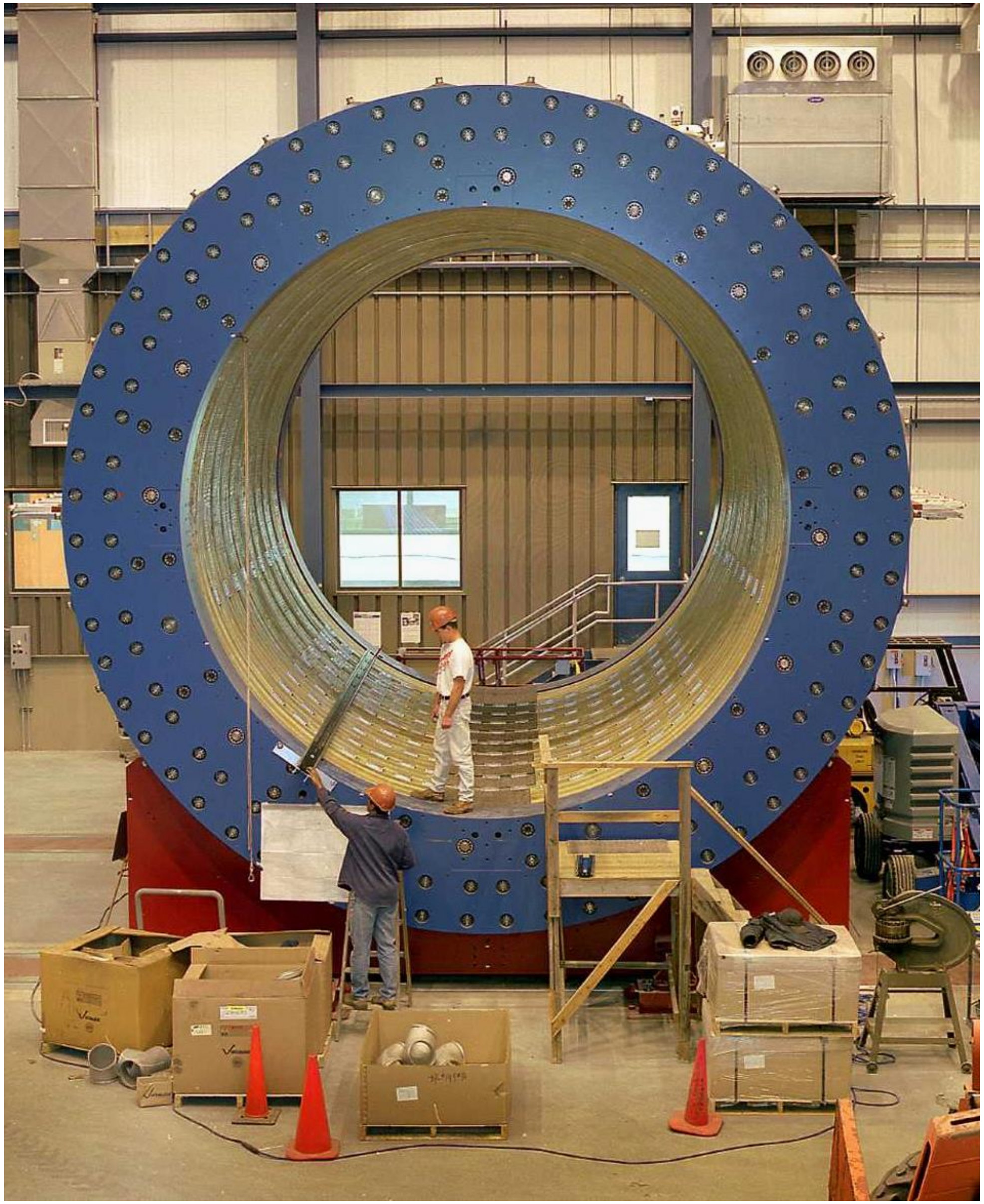
Summary

- **New PadPlanes**
  - 40 pad rows, 5 mm x 16 mm pads (center to center spacing), full coverage
  - Added additional fiducial marks, alignment holes and improved air paths
- **Wires**
  - Exactly the same as before: same wire count, same composition, same diameters, same tension, same locations, same ABDB board design, etc.
  - Substitute 3 "fat" wires for 3 "thin" wires on each end of the Anode grids
- **Strongback is 99% the same as before**
  - Re-use the existing cooling manifolds (etc.)
  - Re-use the existing hole pattern in the front face but shifted down 0.221"
- **1% Changes to the strongback**
  - Add a "wall" on either end of padplane to help terminate the grid leak
  - Mill out a step on either end of the strongback for mounting Grid Leak walls
- **Cost and Schedule concerns – its all about the schedule …**
  - Very tight schedule. Scheduled wisely but no scheduled float.
  - Final PadPlane and Strongbacks were due in Berkeley on August 1st, PadPlanes likely not available for production work until after the New Year

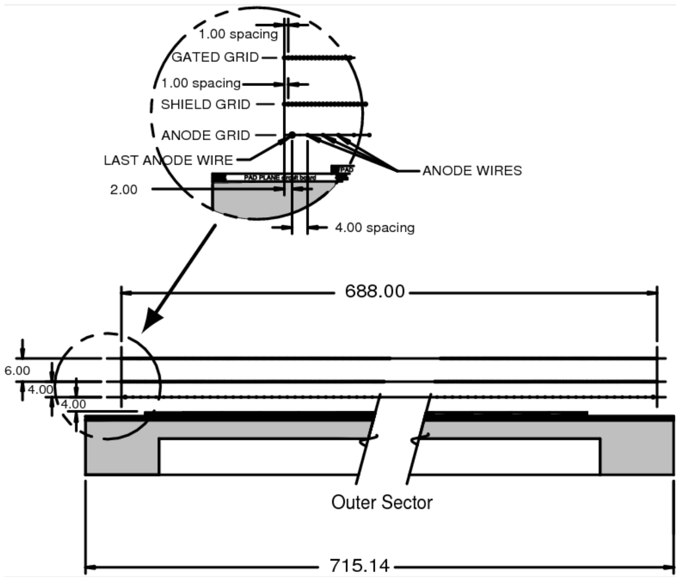
Backup Slides

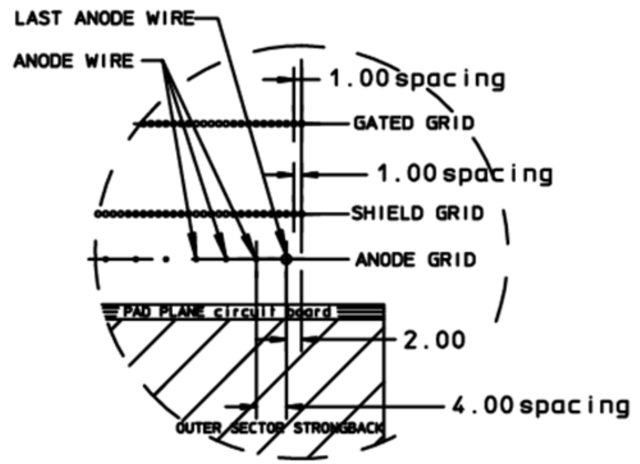
STAR without the TPC

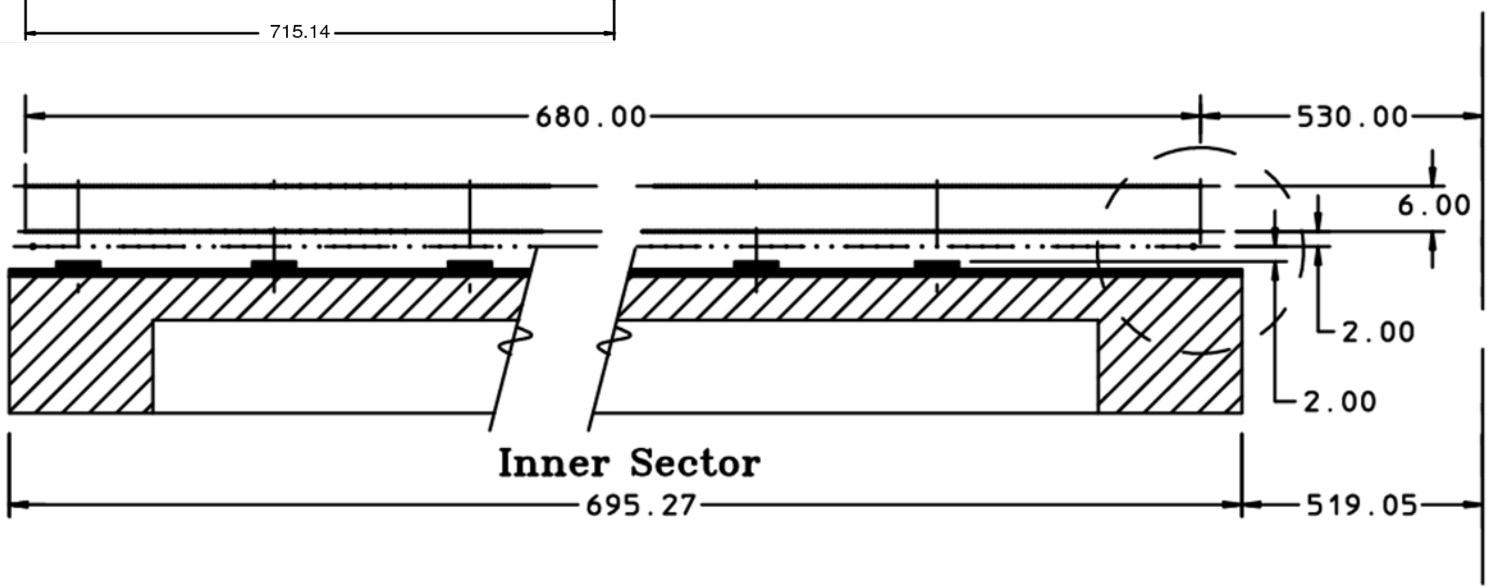
- **The TPC is the heart of STAR**



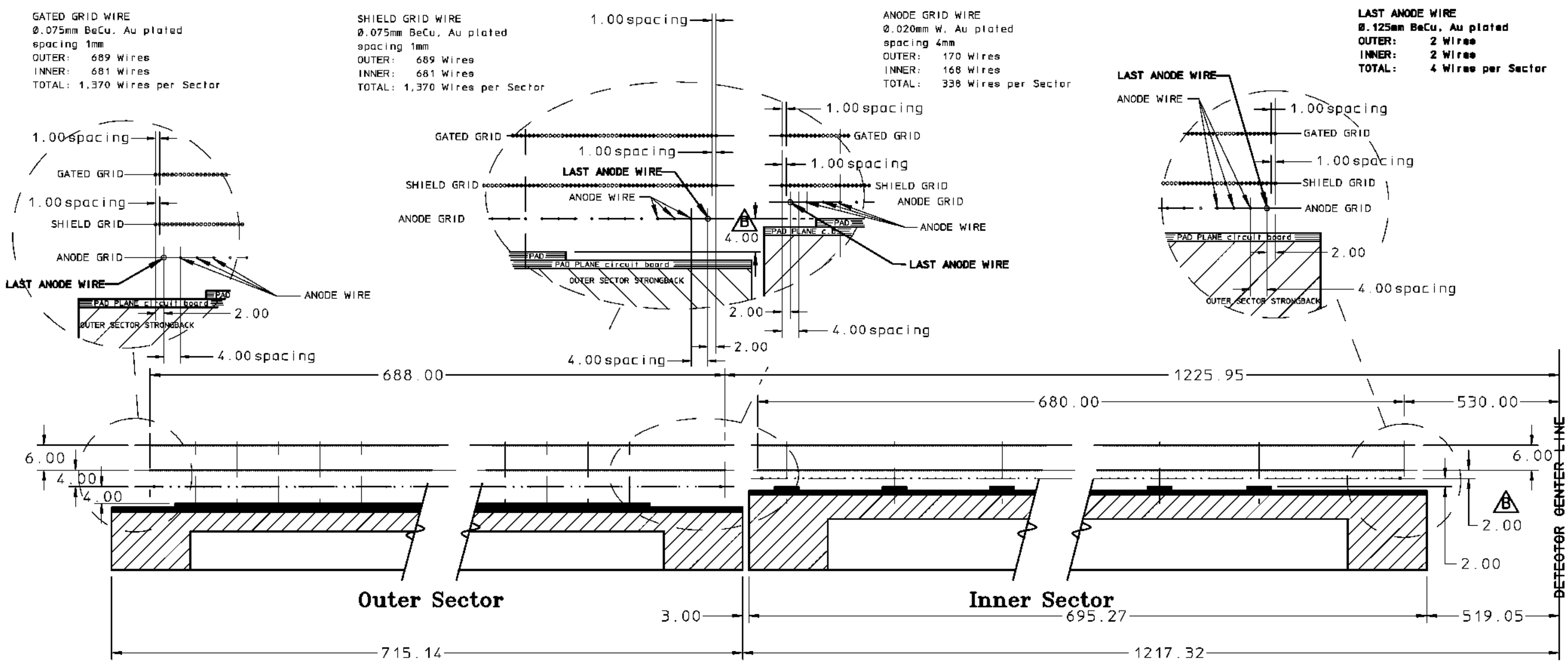
Inner sector detail







Inner / Outer sector detail



- Note that inner and outer pad planes are not at the same height
- Pad plane to wire grid heights not the same (4/4/6 vs 2/2/6)
- 3 mm gap between sectors, this is an issue during installation

Location of Wires and Pads

Radius (Y)	Description
0.00	Center of STAR Detector (vtx)
498.80	Bottom of Full size PC Board
512.70	Tertiary Fiducial L & R
519.05	Strongback Bottom Edge
530.00	Gated Grid Wire 1
531.00	Gated Grid Wire 2
532.00	Anode Wire 1 & GG W-3
536.00	Anode Wire 2 & GG W-7
540.00	Anode Wire 3 & GG W-11
540.25	Secondary Fiducial
544.00	Anode Wire 4 & GG W-15
548.00	Anode Wire 5 & GG W-19
558.00	Pad Row 1 - Center
574.00	Pad Row 2 - Center
1166.00	Pad Row 39 - Center
1179.45	Primary Fiducial
1182.00	Pad Row 40 - Center
1192.00	Anode Wire 166 & GG W-663
1196.00	Anode Wire 167 & GG W-667
1200.00	Anode Wire 168 & GG W-671
1204.00	Anode Wire 169 & GG W-675
1204.85	Alternate Primary Fiducial
1208.00	Anode Wire 170 & GG W-679
1209.00	Gated Grid Wire 680
1210.00	Gated Grid Wire 681
1214.32	Strongback Top Edge
1220.67	Tertiary Fiducial L & R
1235.42	Top of Full size PC Board

Repeat pad rows every 16 mm

GATED GRID WIRE
Ø.075mm BeCu , Au plated
spacing 1mm
OUTER : 689 Wires
INNER : 681 Wires
TOTAL : 1,370 Wires per Sector

SHIELD GRID WIRE
Ø.075mm BeCu , Au plated
spacing 1mm
OUTER : 689 Wires
INNER : 681 Wires
TOTAL : 1,370 Wires per Sector

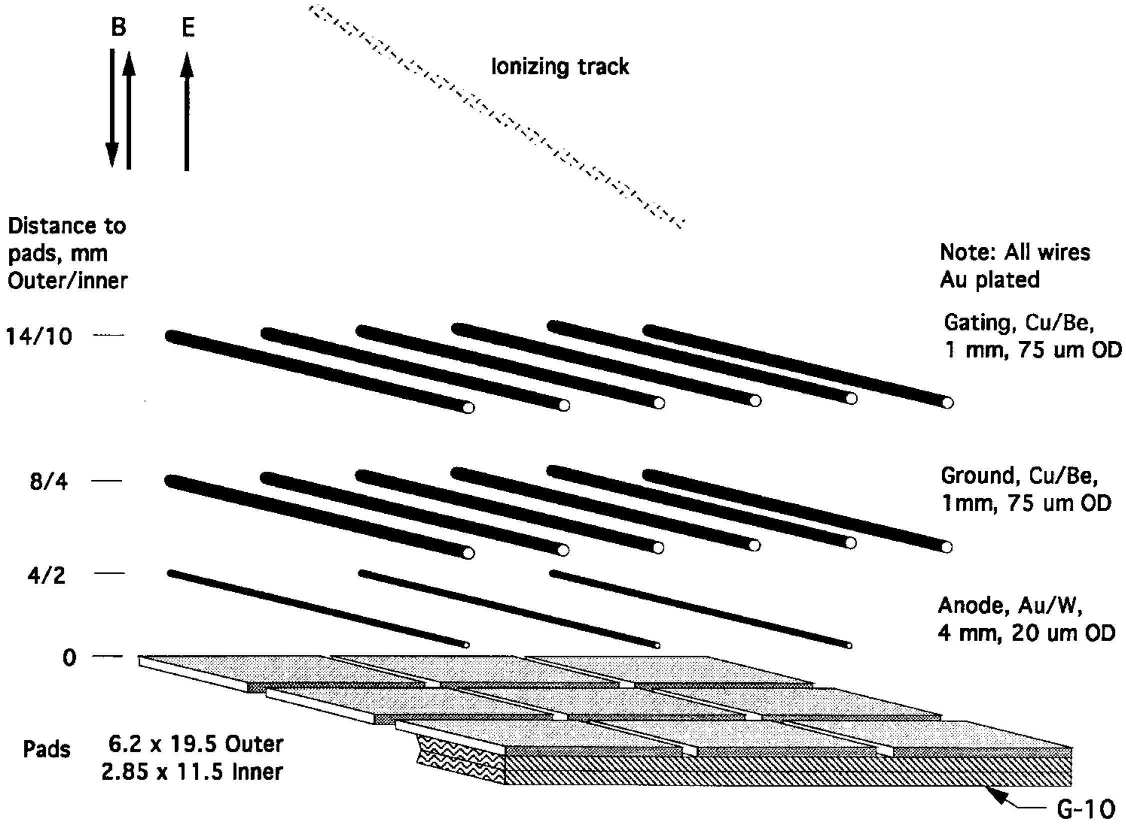
ANODE GRID WIRE
Ø.020mm W, Au plated
spacing 4mm
OUTER : 170 Wires
INNER : 164 Wires (168 in old design)
TOTAL : 334 Wires per Sector (338 in old design)

LAST ANODE WIRE
Ø.125mm BeCu , Au plated
OUTER : 2 Wires
INNER : 6 Wires (2 in old design)
TOTAL : 8 Wires per Sector (4 in old design)

References:
LBL Drawings
24A055,
24A373,
24A374

Wire Locations are the same as before except for the replacement of 6 thin anode wires with larger diameter anode wires (0.020 mm ⇒ 0.125 mm)

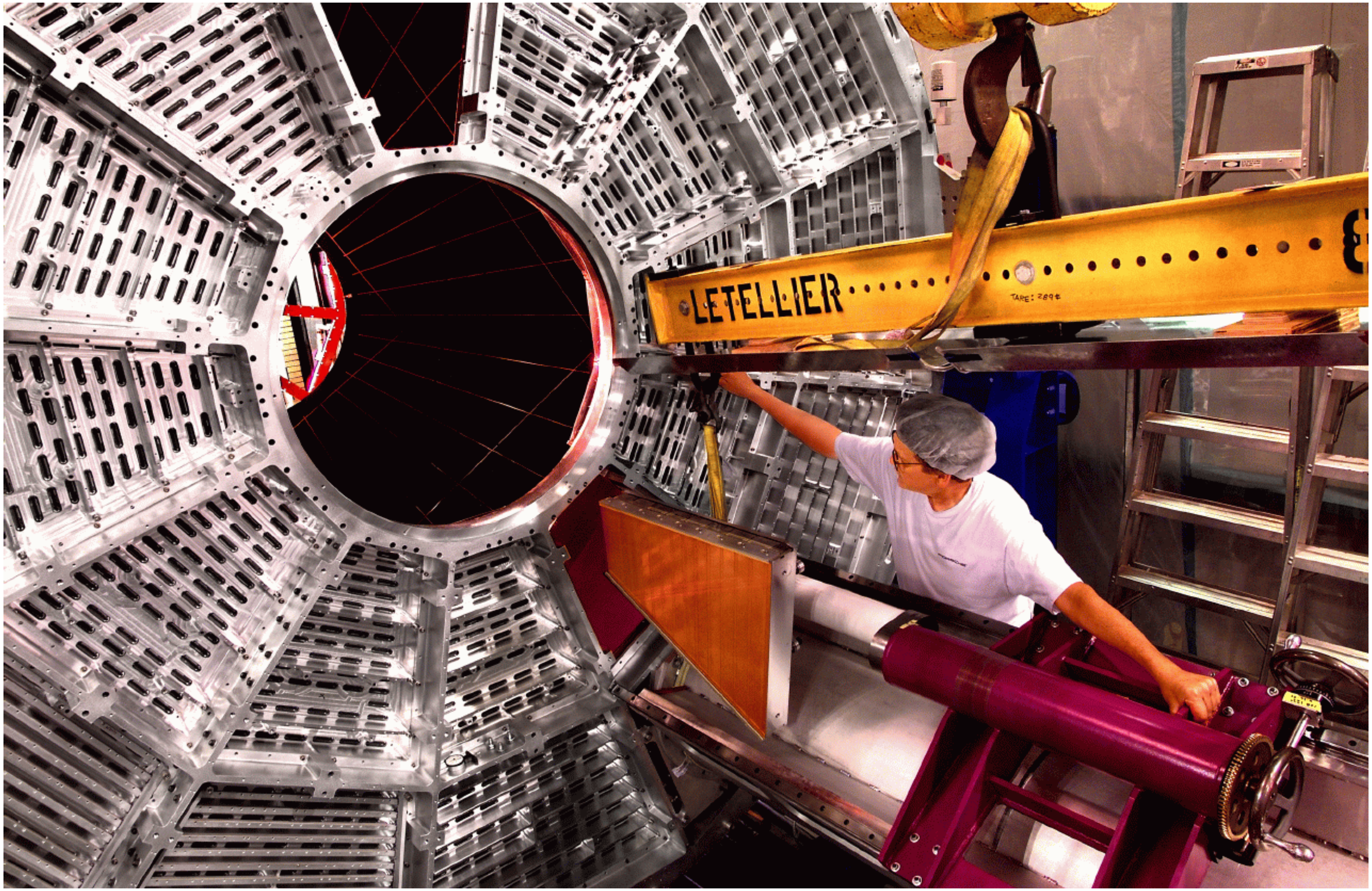
Sector Wire Geometry – special notes



Wires are phase locked to the pad locations. 4 wires located over each pad row. We can probably tolerate a phase shift of 100 microns.

Ground wires placed directly over the Anode wires to limit sparking to pad plane.

Sector Insertion – special tools required



Critical Dimensions for the TPC

Item	Dimension	Comment
Length of the TPC	420 cm	Two halves, 210 cm long
Outer Diameter of the drift volume	400 cm	200 cm radius
Inner Diameter of the drift volume	100 cm	50 cm radius
Distance: cathode to ground plane	209.3 cm	Each side
Cathode	400 cm diameter	At the center of the TPC
Cathode potential	28 kV	typical
Drift gas	P10: 90% Ar, 10% CH_4	He-Ethane as an option
Drift Velocity	5.45 cm/μsec	typical
Transverse diffusion (σ)	230 μm/√cm	135 V/cm & 0.5 T
Longitudinal diffusion (σ)	360 μm/√cm	135 V/cm & 0.5 T
Magnetic Field	0, ±0.25 T, ±0.5 T	Solenoidal

Weight of TPC (lb.)

Item	Max LBNL	Max BNL Lift	Installed Wt. w/ CTB	Installed Wt. w/ TOF	Basis
IFC	107	107	107	107	close est
OFC	4991	4991	4991	4991	close est
Wheel	3100	3100	3100	3100	measured
Wheel Brkts/Adj	227	227	227	227	rough est
TOF rails	1080	1080	1080	1080	exact
Outer Sectors	2520	2520	2520	2520	measured
Inner Sectors	1752	1752	1752	1752	close est 75# ea,
Gas Manifolds at wheel	0	0	200	200	removed for lift
FEE	128	1539	1539	1539	measured
FEE Manifolds	480	480	480	480	rough
RDO	51	607	607	607	close est.
RDO manifolds	15	360	360	360	rough
RDO/FEE Cable	39	468	468	468	close est
Dist Manif/hose	240	390	390	390	rough
CTB modules (120 ea.)	0	660	3960	0	measured/ 33# ea.
TOF modules (120 ea.)	0	0	0	4800	Est, G.Mutchler 9/98
TOF cables/hose	0	0	240	240	rough
RDO elect. brkts	24	24	24	24	rough
SVT, Cone Assy &SSD	0	0	365	365	Mech Des Rev 3/98
FTPC	0	0	809	809	FDR action item 1
TOTAL	14753	18304	22409	23249	

Average mass distributions (±10°, 1.5 < η < 2.0)

FEE	3.60 %
FEE mounting bracket	3.45 %
FEE rib	0.45 %
FEE socket	0.15 %
Cooling manifold	3.25 %
RDO card	0.90 %
Ribs	2.70 %
Sector G10	0.45 %
Sector Aluminum	3.20 %
Cables	~1% (estimate)
FEE sub Total	**7.65%**
Total	**19.15%**

Table 6: The *average* radiation length budget for the components associated with a TPC inner sector (circa 1993) averaged over the fiducial volume of the sector. The average takes out the lumps in the mass distribution (for better or worse) but also illustrates how the budget for the Al on the front face compares to the electronics and cooling budget. The sector data have been averaged over a range from 1.5 < η < 2.0 and -10 < ϕ < 10 degrees. Geant simulations courtesy of Irakli Chakaberia.