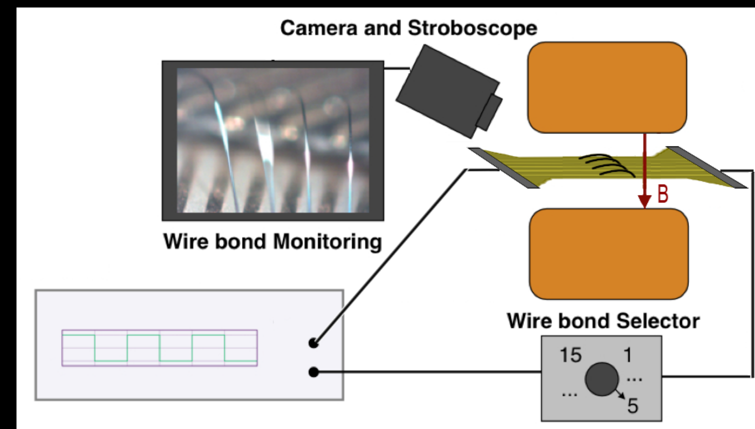
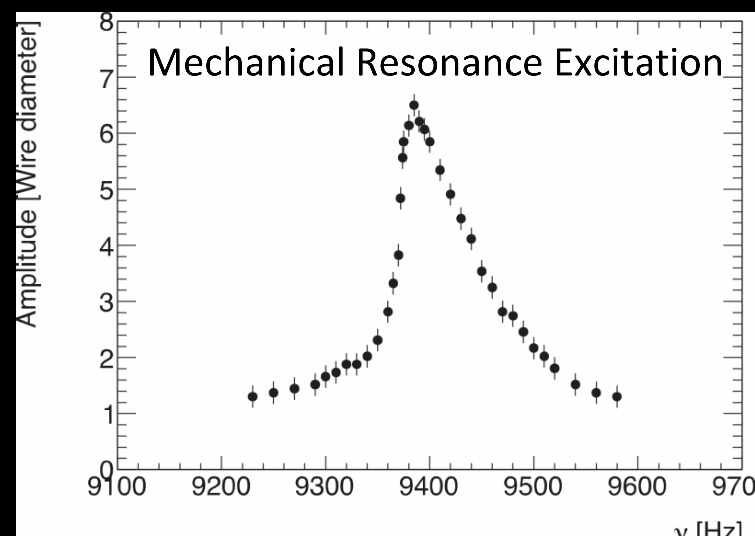
Feedback From IBL Experience

Joe Izen – U.T. Dallas

- Condensation-induced Corrosion
  - Thermal cycling at U. Genève
  - Cold QA box in SR-1
  - Cold ToothPix prototype stave study
- Periodic Resonant Lorentz Forces
  - The CDF-problem rediscovered
- Polyurethane (PU) coating encapsulation
  - Attempted by IBL Stave Task Force
  - Kill two birds with one stone?
  - Insufficient time to perfect for IBL

Corrosion residues





2.8 mm 25μ Aluminum Wire Bond

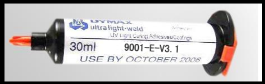
B.Mandelli, Studies of IBL wire bonds operation in an ATLAS-like magnetic field and evaluation of different protection strategies, https://ieeexplore.ieee.org/document/7581879/

Candidate Encapsulant Polymers

- "PolyUrethane" = Alkyd + some PU resin for toughness.
- Alkyd = fatty acid-modified polyester + other additives
  - Alkyd properties vary with fatty acid length, amount of crosslinking

- PolyUrethane: Cellpack D2091 liquid
  - Formulated for electrical insulation. (Composition proprietary)
  - Tested for: Radiation, CTE, Resonance suppression, spraying, encapsulation
- Long oil alkyds: marine spar varnishes (Epifanes, McCloskey 7509)
  - Formulated for flexibility. (Composition proprietary)
  - Spraying tests underway

- UV-cured epoxy: Dymax® 9001, 9103:
  - CTE issues. Short span potting possible as for ATLAS Pixel disks



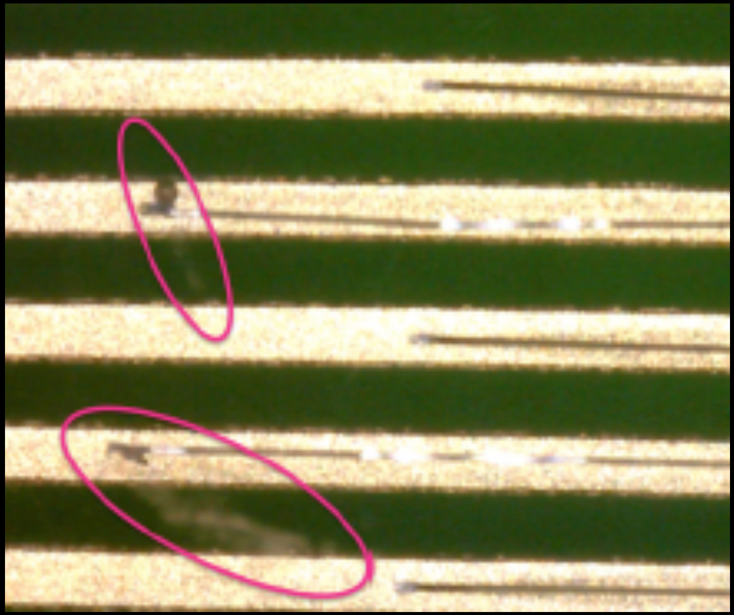
- Sylgard® 186 silicone elastomer: used by CDF, CMS
  - Silicone elastomer rad. hardness problematic. OK for ITk Strip?

- Parylene conformal coating
  - Thin coating. Rad hardness needs testing, unlikely to suppress all oscillations

Corrosion Protection

IBL Task Force Encapsulation Test: Withstand Immersion in DI Water

Without encapsulation

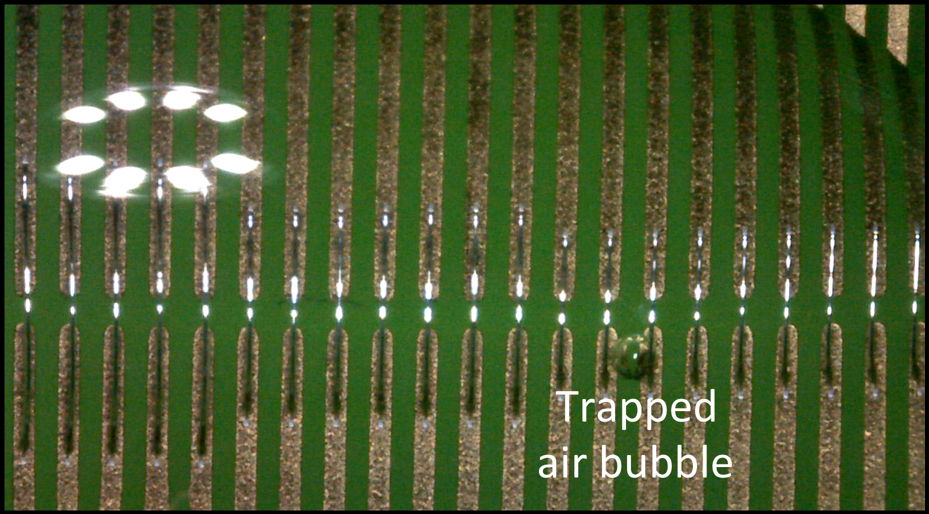


Hydrogen bubbles and plumes

$Al + 3H_2O \rightarrow Al(OH)_3 + 3H_2 \uparrow$

- A. Honma: Most PCBs at CERN vulnerable
- Possibly catalyzed by trace halides in PCB
- Corrosion at metallurgically disturbed feet

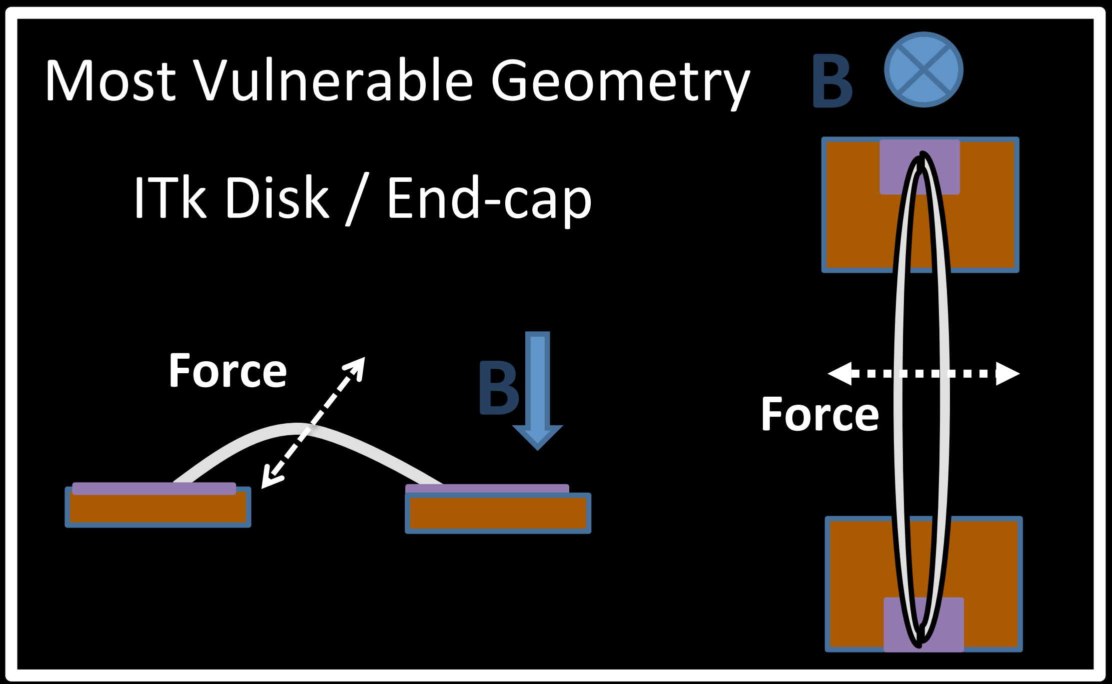
Cellpack PU encapsulation



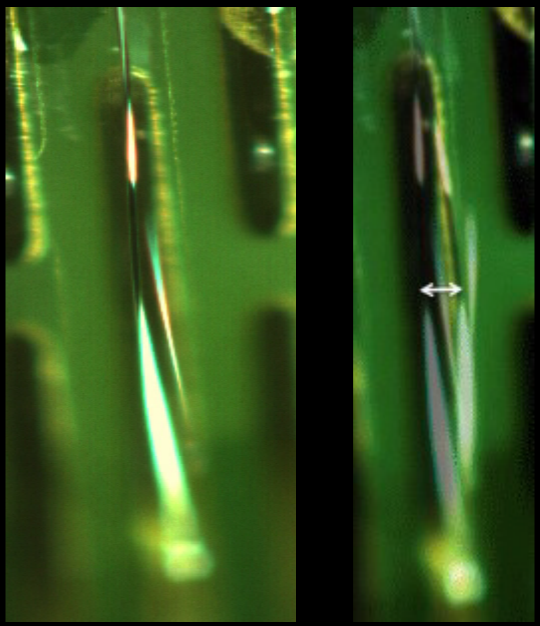
Corrosion Protection

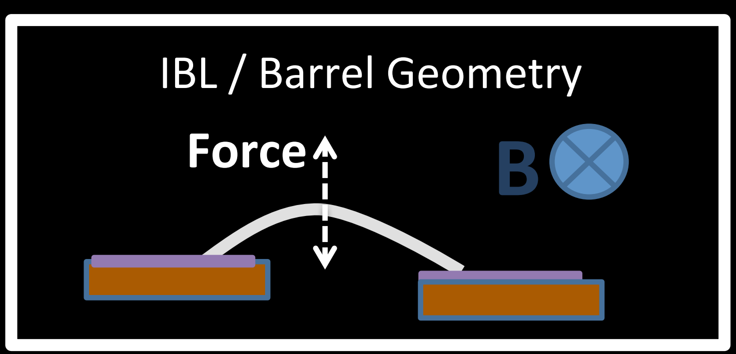
- PU coating O.D. from 50 μ to 110 μ
- Thermal cycled after 0 and 0.9 MGy
  350 cycles (-30 – +50) ℃
- No corrosion
- No thermal expansion (CTE) problems

Periodic Lorentz Forces



"Guitar" Mode

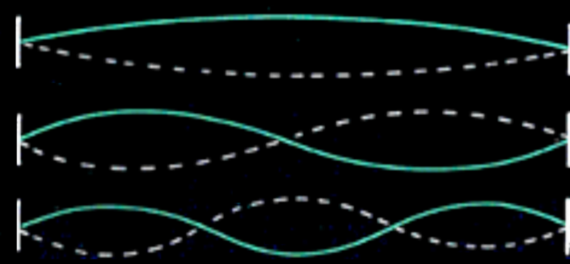




Barrel "Up and Down" mode hard to excite
Prefers to couple to "Guitar Mode"!

IBL (like SCT) is protected by firmware.

Beware Sub-Harmonics



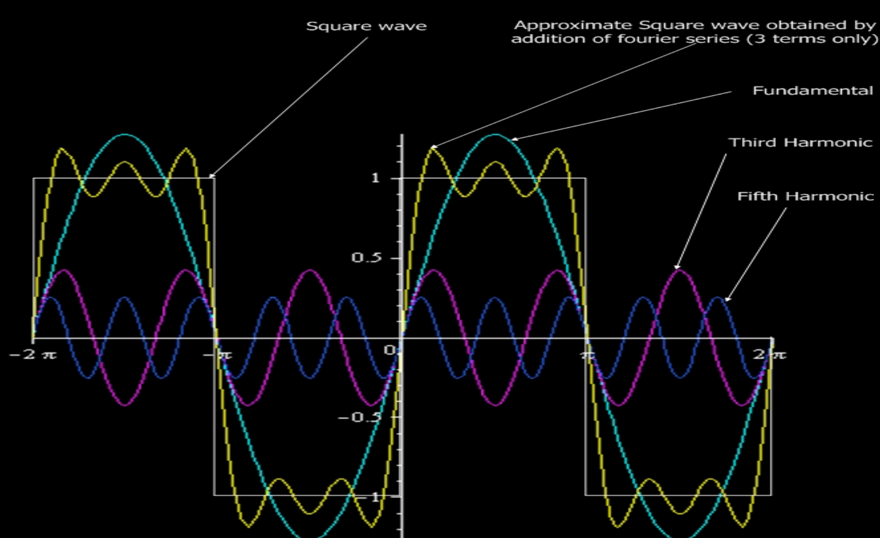
Observed

Not observed

Not observed

- Higher harmonics difficult to excite
- Lorentz force pushes entire wire in same direction

Odd Fourier components of Sub-Harmonic square waves are dangerous



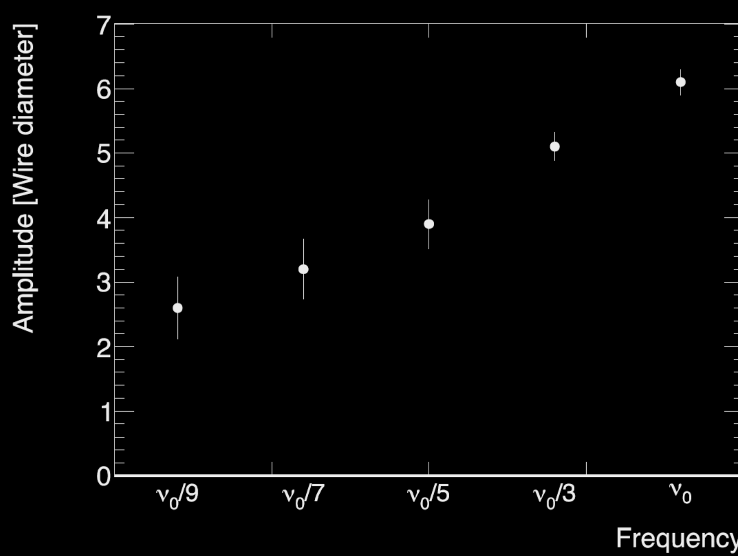
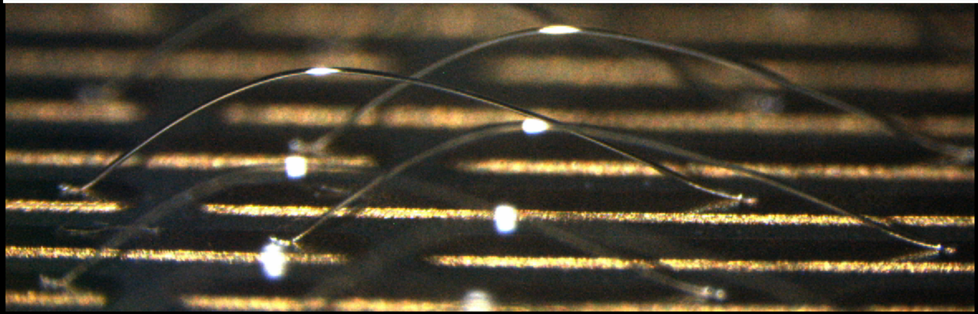


Fig. 5. Oscillation amplitude expressed in wire diameter (25 μm) for frequencies of 1/3, 1/5, 1/7, 1/9 of the resonance frequency ν_0 for a wire of 2.8 mm length. The resonance frequency ν_0 for this particular wire is 10030 Hz.

B.Mandellini, https://ieeexplore.ieee.org/document/7581879/

Resonance Oscillation Tests

Sample	f_{res} [kHz] mean, range	Q mean, range	I_{p-p} [mA] to break B = 1.7 T, End-cap geometry Room temperature
2.8mm uncoated PCB C3, N_{wires}=17	11.78 (11.68 –11.97)	92 (69 – 117)	4 mA one wire
2.8mm potted PCB D2, N_{wires}= 8	14.95 (13.80 – 16.17)	68 (60 – 77)	12 – 15 mA one wire
2.8 mm PU light PCB C10, N_{wires} =15	9.28 (8.88 – 9.76)	36 (26 – 46)	32 – 40 mA one wire
2.8 mm PU heavy PCB C9, N_{wires}= 8	(8.1 – 14.1)	(7 – 14)	f_{res} = 10.4 kHz: breaks @ 180 mA f_{res} = 13.3 kHz: 38.5 hours @ 180 mA



uncoated

Unprotected heel
Relatively high Q oscillator
Extremely vulnerable

IBL worst case is est. to be ~100 mA

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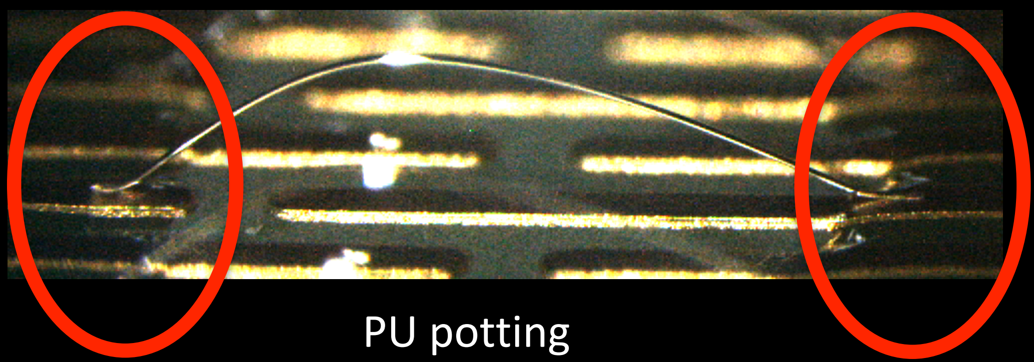

PU potting

Heel encapsulated and locked

f_{res} increases due to shortened length

Small Q decrease

Resonance Oscillation Tests

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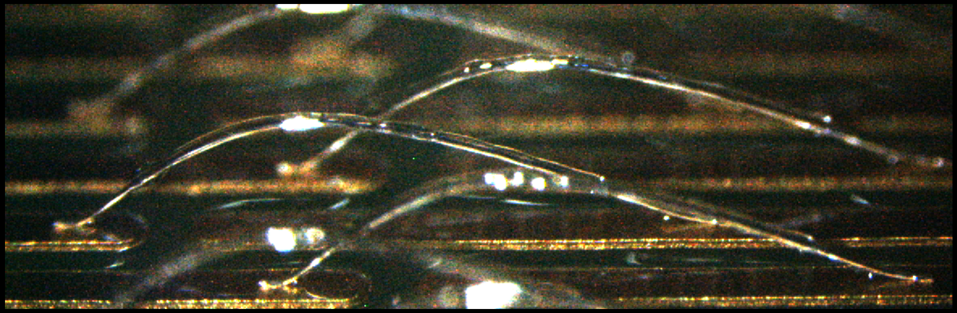

PU light coat ~50 µ O.D.

Heel encapsulated and locked
f_{res} decreases due to added mass
Q decrease due to PU flexing
Better suppression than potting

Resonance Oscillation Tests

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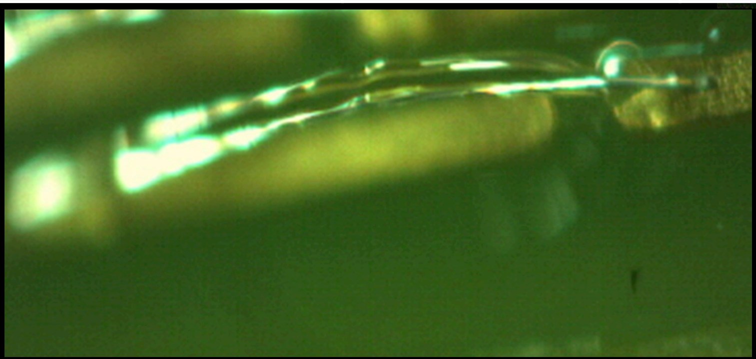


PU heavy coat 100+ µ O.D.

large variation in hand-sprayed sample

Heel encapsulated and locked

Extra mass suppresses amplitude

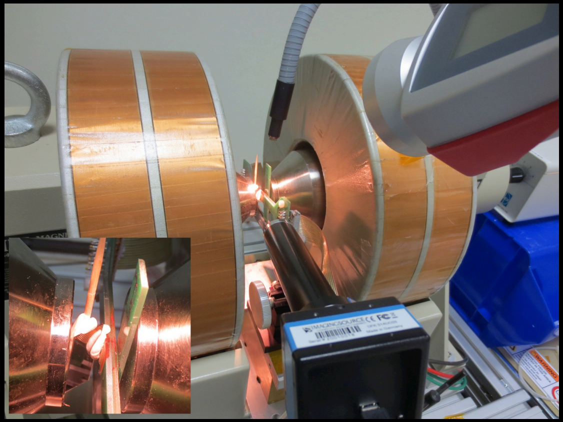
f_{res} increases due to PU stiffness

Q decreases more due to PU flexing

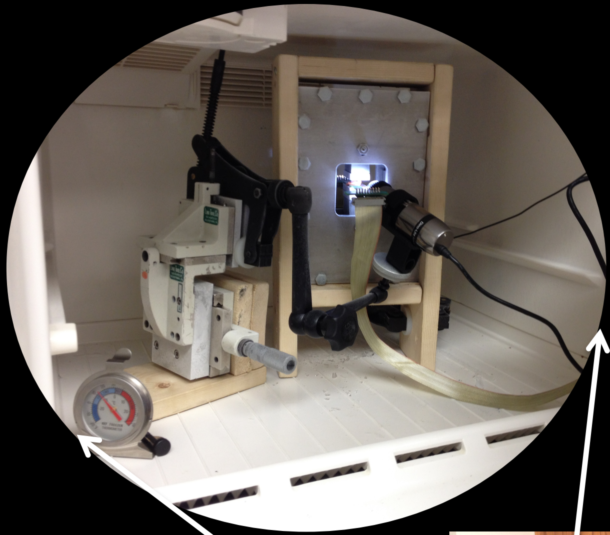
4 bullet-proof wires: > 1 h @ 180 mA_{p-p}

f_{res} = 12.1, 13.5, 11.3, 13.3 kHz

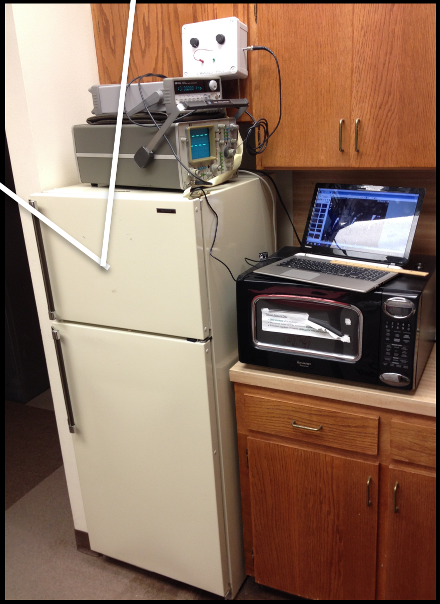
Measuring Resonances at -20 C

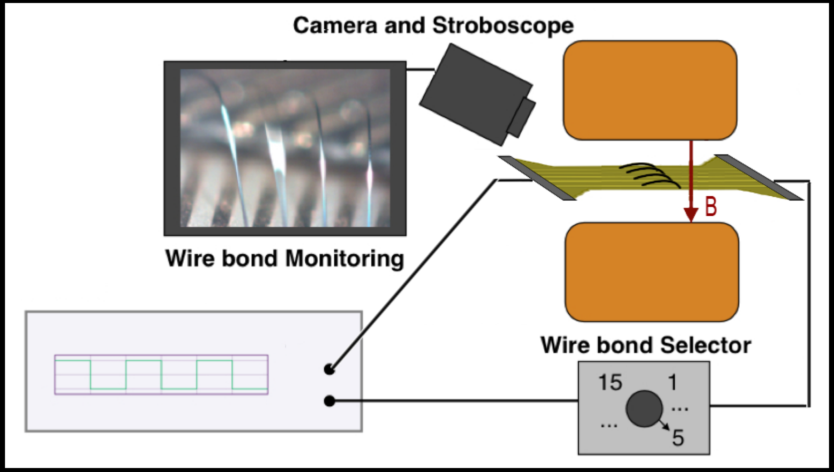


1.7 T
(water-cooled)



1 T
(neodymium)





PU Coatings at -20C

Cellpack D 9201 Urethane 2.8 mm wire bonds

			Room temp avg. values		Cold (-20C) avg. values		% change (cold/warm)	
Bond length [mm]	N wires	Mean OD [µ]	Res. Freq. [kHz]	Q	Res. Freq. [kHz]	Q	Res. Freq. [kHz]	Q
2.8	9	57 thin	9.9	59	10.3	86	+4%	+47%
2.8	13	73 med	11.0	30	12.3	42	+12%	+40%
2.8	13	112 thick	14.8	18	17.2	27	+16%	+52%
4.0	9	44 thin	7.6	66	8.0	87	+6%	+32%
4.0	11	82 med	9.9	19	11.4	32	+15%	+67%

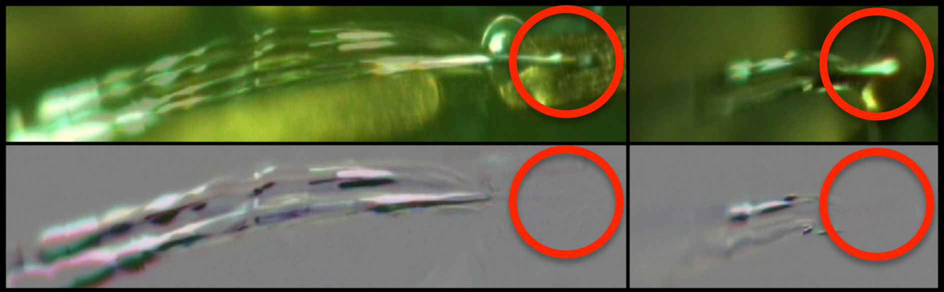
Thick (>100 µ) Cellpack PU coating

Protects against (I_{p-p}=100 mA, B=2 T) equiv. at resonance, -20 C, end-cap geometry

Thermal cycling: -30 C – +50 C No CTE issues

Candidate for ITk endcap

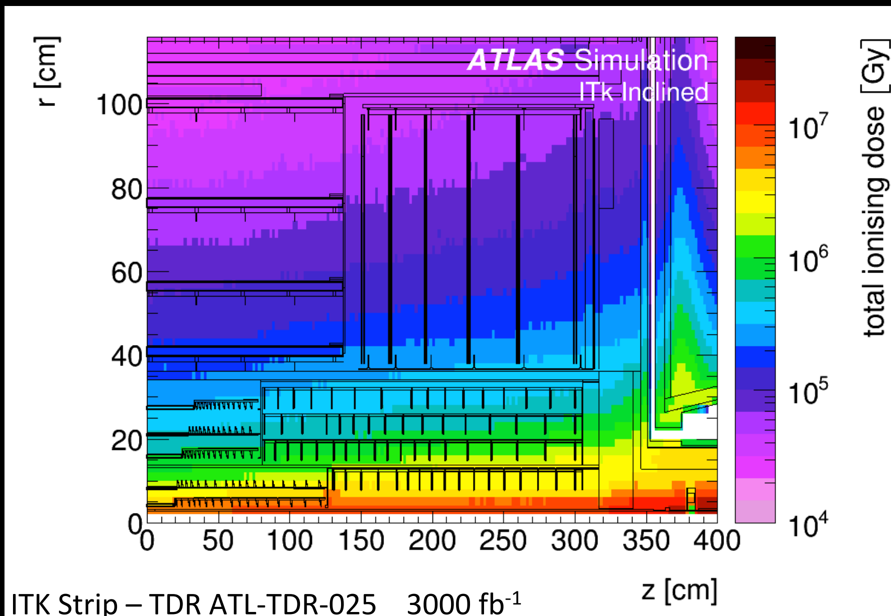
Video Frames



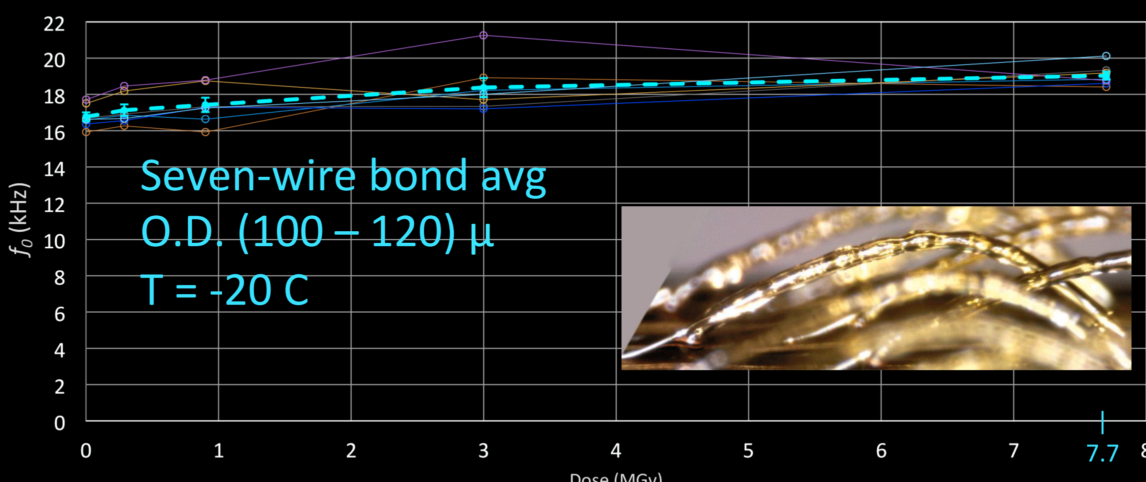
Protection mechanisms:

- immobilized wire bond heel
- higher oscillator mass
- energy dissipation (low Q)

Radiation Hardness of Cellpack D2091



Luminosity	Layer	Location	R [cm]	z [cm]	Dose [MGy]
Strips	ATL-TDR-025	includes 1.5x safety factor			
3000 fb^{-1}		Long Strips	76.2		0.1
		Short Strips	40.5		0.3
		End-Cap	38.5		0.5
Pixel	ATL-COM-UPGRADE-2017-006.	includes 1.5x safety factor			
2000 fb^{-1}	0	Flat barrel	4.0	24.3	7.2
		Inclined barrel	3.7	110.0	9.9
		End-Cap	5.1	123.8	6.3
2000 fb^{-1}	1	Flat barrel	9.9	24.3	1.5
		Inclined barrel	8.1	110.0	2.9
		End-Cap	7.9	299.2	3.2
4000 fb^{-1}	2-4	Flat barrel	16.0	44.6	1.6
		Inclined barrel	15.6	110.0	2.0
		End-Cap	15.3	299.2	3.5



After 7.7 MGy

Coatings intact

Some yellowing

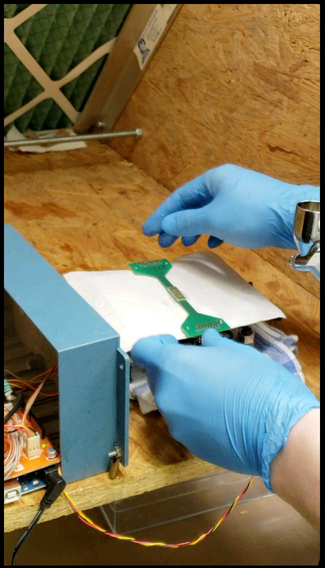
~10% increase in f_{res}

Q stable

End-Cap Protection:

$I_{p\text{-}p}$ =100 mA @ f_{res}B=2 T

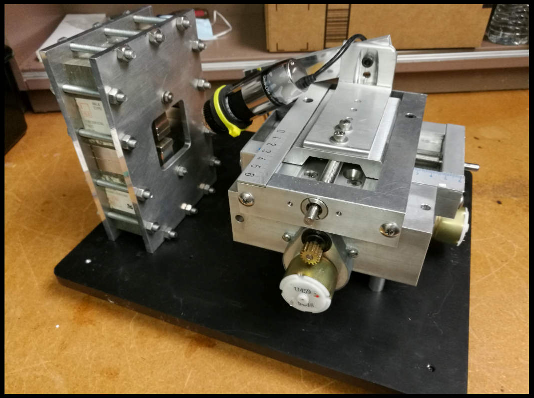
Current Work



Spraying

- Semiautomate spraying
  - Talon art supply airbrush
  - Marine spar varnishes

- Test new coatings
  - Epifanes spar varnish
  - McCloskey spar varnish
  - Parylene (from Glasgow)



Improved resonance tester

- Research industrial spray nozzles

Cellpack D2091 Spray Coatings

- Spraying feasibility demonstrated
- Corrosion protection
- No Thermal Expansion (CTE) problems
- Protection mechanisms understood
  - Encapsulated foot
  - Increased oscillator mass
  - Flexible coating lowers Q
- O.D. >100 µ protects against worst case oscillation
  - ($I_{p\text{-}p}$ =100 mA, B=2 T) equiv. @ f_{res} -20 C, end-cap
- Rad-hard: >10x ITk Strip dose, >1x ITk Pixel dose

- Further tests needed?
- Cellpack vs Other polymers: which is best?
- Scale-up to production needs to be understood.
- New technology needs risk assessment.

Acknowledgements

- UT Dallas
  - Matthew Kurth[1]: Neodymium magnet, resonance measurements
  - Yenho Chen: resonance measurements, spraying and measuring stages, spray tests
  - Andrew Marder: spray tests
  - David Taylor: Spray hood, measuring stage
- U. New Mexico
  - Sally Seidel: irradiation at Sandia
- Sandia Gamma Irradiation Facility
- U. Oklahoma
  - Rusty Boyd: wire bond test boards, climate chamber cycling
  - Dylan Frizell and Nathan Grieser : climate chamber cycling
- U. Glasgow
  - Sneha Naik, Joe Ashby, Richard Bates: wire bond test boards, spray test dummies
- CERN Departmental Silicon Facility (DSF)
  - Alan Honma, Ian McGill, Florentine Manolescu: wire bonding, test equipment, expertise
- CERN and Oslo U.
  - Beatrice Mandelli: pioneering wire bond measurements
- Department of Energy: Grant DE-SC0010384

[1] Currently at Institute of High Energy Physics, Beijing China

References

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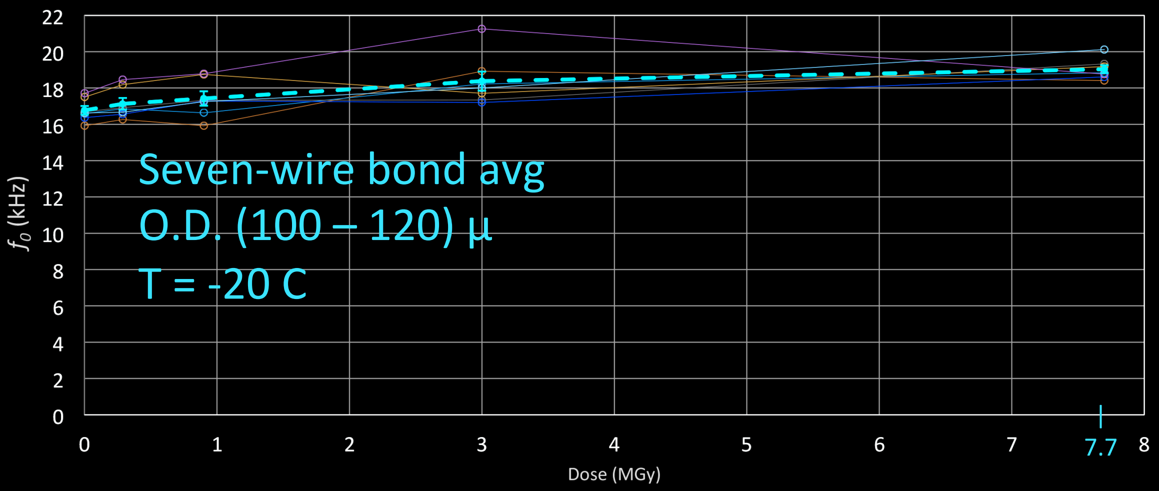
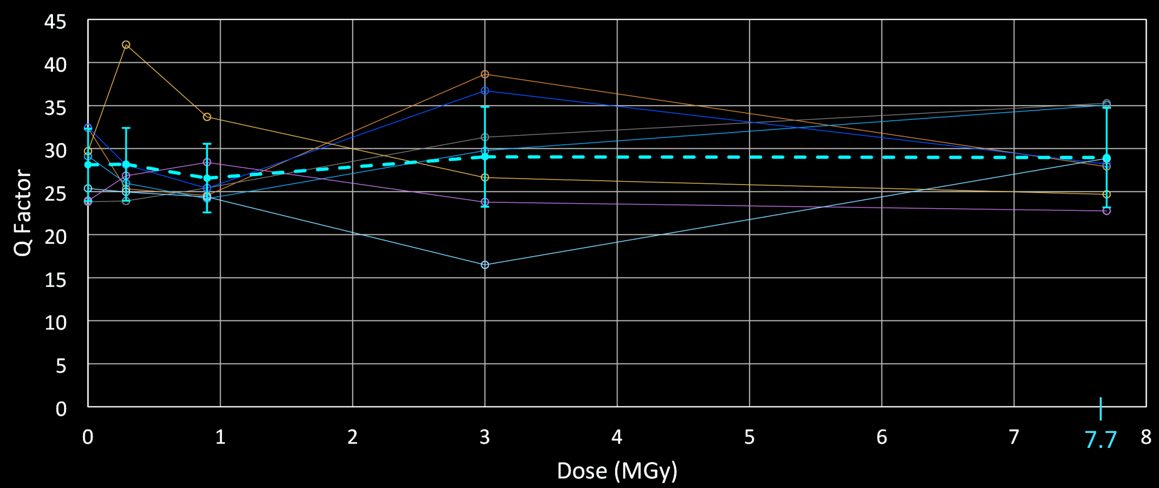
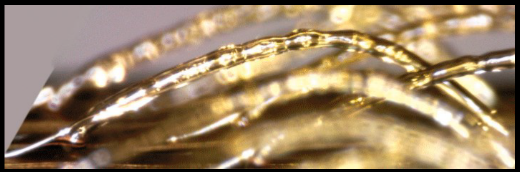
- J.M. Izen, Y. Chen, M. Kurth, Effect of radiation and temperature on resonance properties of polyurethane-coated wire bonds, JINST 12 (2017) no.04, C04012, https://doi.org/10.1088/1748-0221/12/04/C04012, April 2017.

Radiation Hardness of Cellpack D2091







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Corrosion Studies

A. Honma

https://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=283860, November 2013.

Results on further corrosion studies

Have performed a fair number of DI water droplet corrosion attack tests on PCBs brought to us or which we have in storage. The results on 8 different PCBs :

CMS pixel proto with no encapsulation (from Gino Bolla)

- 100 feet - 5 bubblers (flex PCB1, unknown source)
- 100 feet - 0 bubblers (flex PCB2, unknown source)

Rusty's Atlas pixel PCBs

- 440 feet, 8 bubblers (on flex PCB)
- 36 feet, 2 bubblers (on rigid PCB)

Ian's bond test square

- 400 feet, 9 bubblers (rigid PCB, unknown source)

CMS preshower hybrid with large continuous backplane

- 500 feet, 0 bubblers (flex/rigid PCB from GS – now SwissPCB)

CMS tracker hybrid no components, on APV glue pads

- 300 feet, 6 bubblers (flex PCB from Cicorel) – one mid-span break!

ENEPIG test piece that went through accel ageing: large chip glue pad

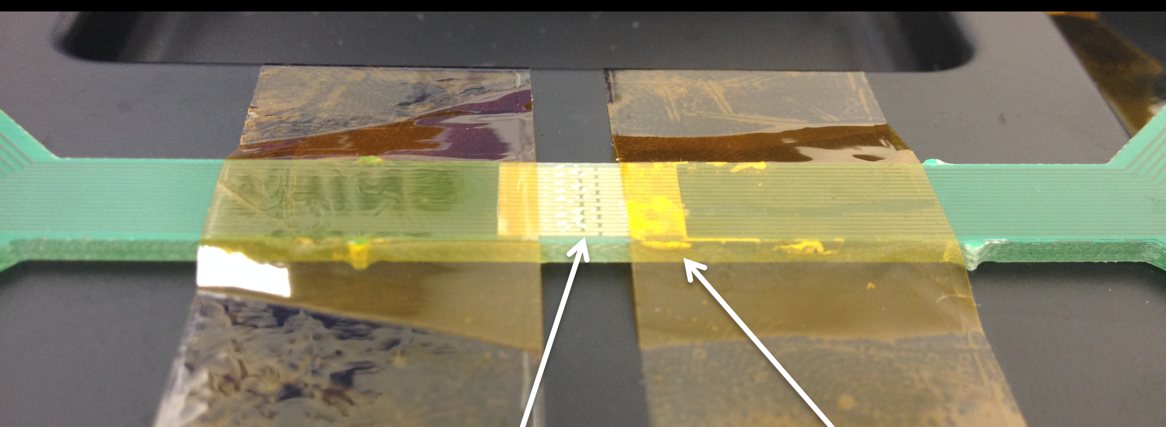
- 200 feet, 20 bubblers (rigid PCB from Eltos – Italy)

- “Seems most PCBs have the DI water droplet corrosion problem.”

Preliminary test of Masking

Mask portion of wire bond pad with Kapton®
Wire bond rework option

Clean Edge



Coated wires

Protected masked region