The Diamond Beam Monitor for Luminosity Upgrade of ATLAS

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for the ATLAS DBM Collaboration

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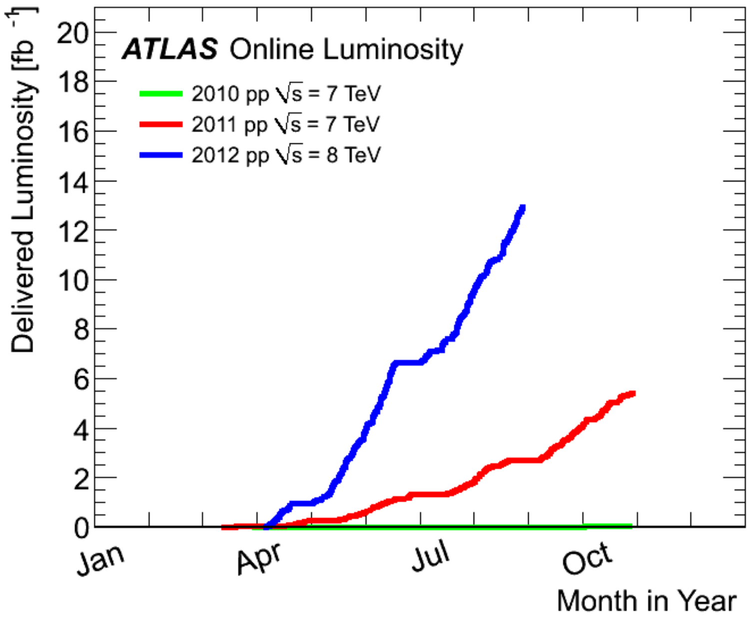
Outline of Talk

- Motivation
- The ATLAS DBM Concept
- DBM Mechanics
- DBM Status
- Radiation Studies
- Summary

Diamond Beam Monitor Motivation

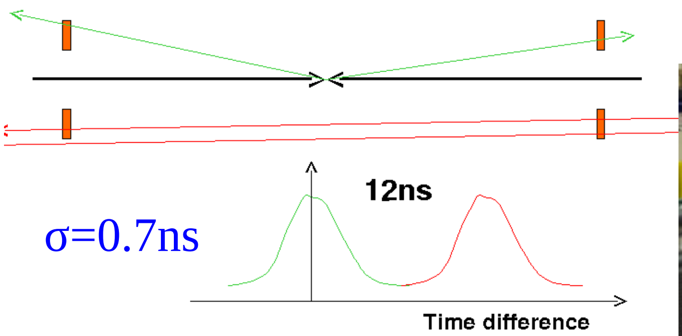
- Luminosity at the LHC is rising rapidly – now ~$7x10^{33}cm^{-2}s^{-1}$



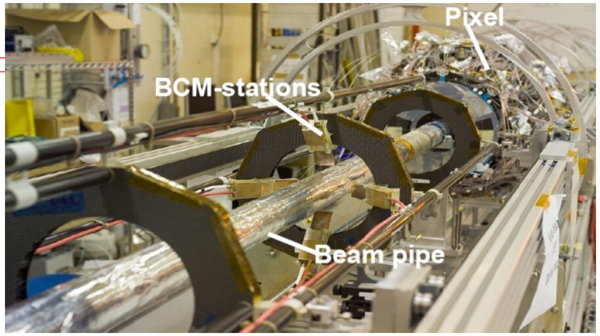
- Luminosity is a counting issue – requires good segmentation in space or time
- Problems occur when particle multiplicity reaches a point where all segments have high probability of having a hit in every bunch crossing

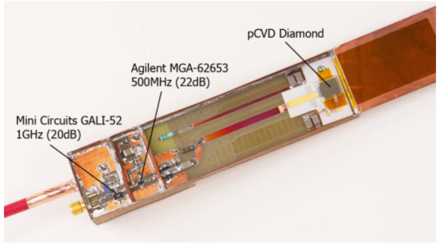
DBM Motivation: lessons learned

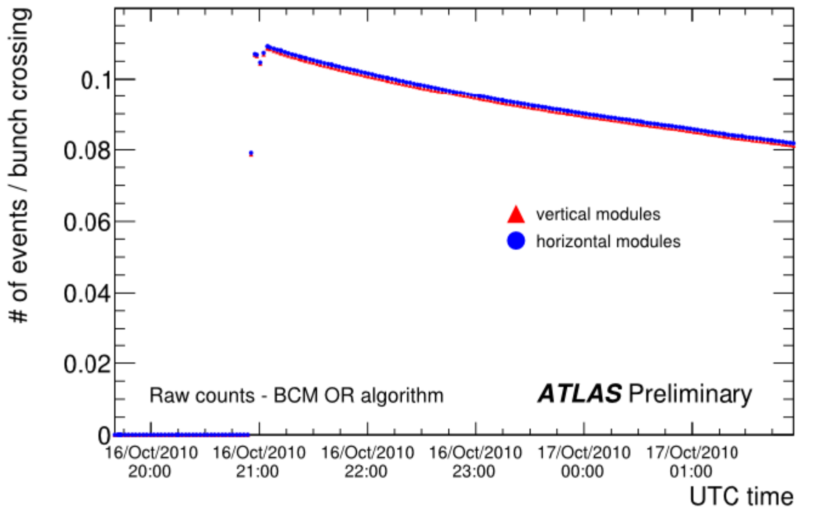
- Luminosity measurement with the ATLAS diamond BCM

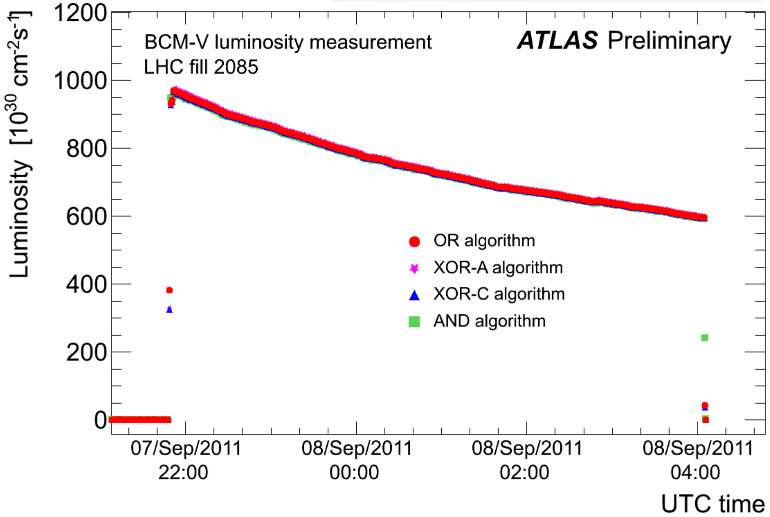


Single Particle Counting: single ch/detector
in-time Luminosity
out-of-time Background





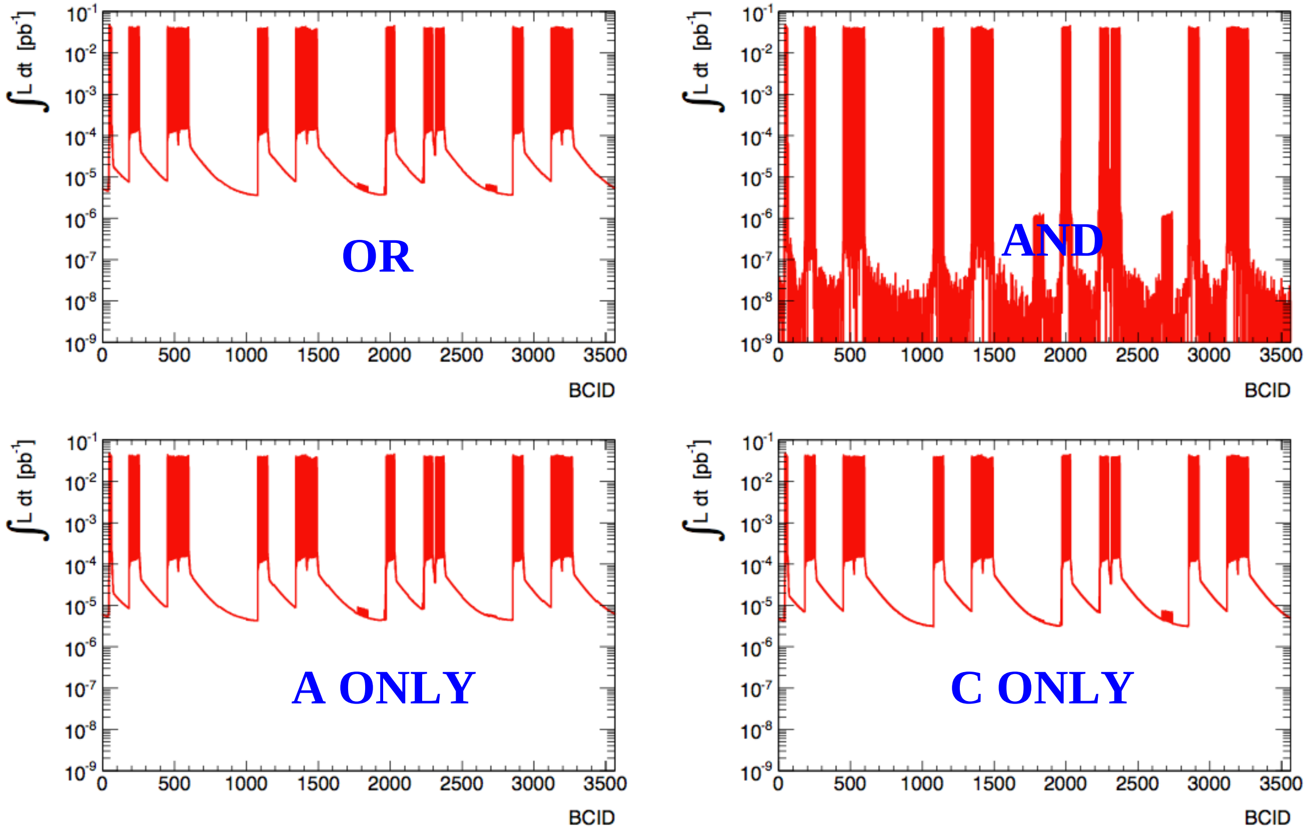




- Speed, robustness, stability required for good luminosity

DBM Motivation: lessons learned

- The BCM rate (speed) is BCID aware

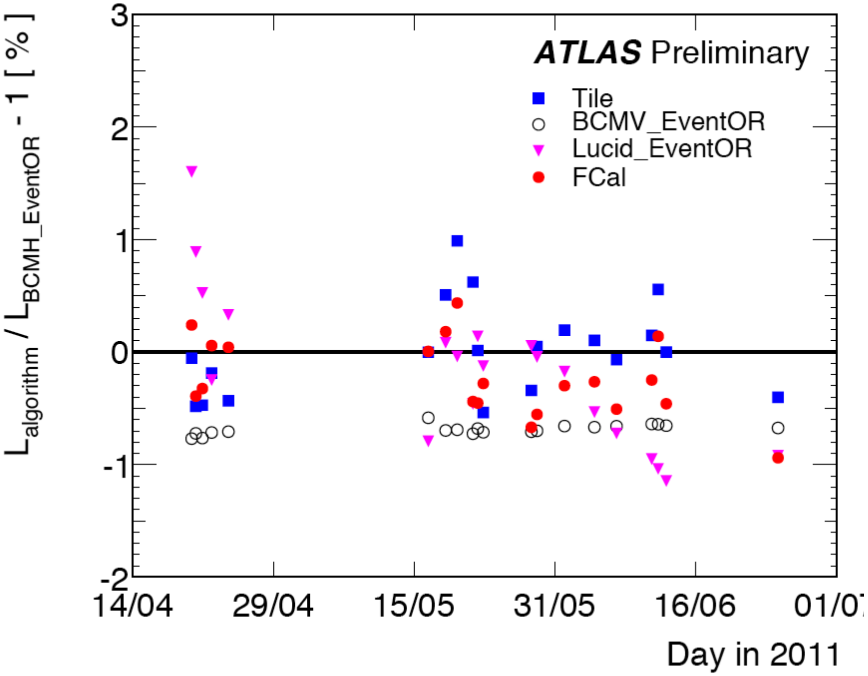


- Provides robust rate measurements, ~ 10^{-3} backgrounds

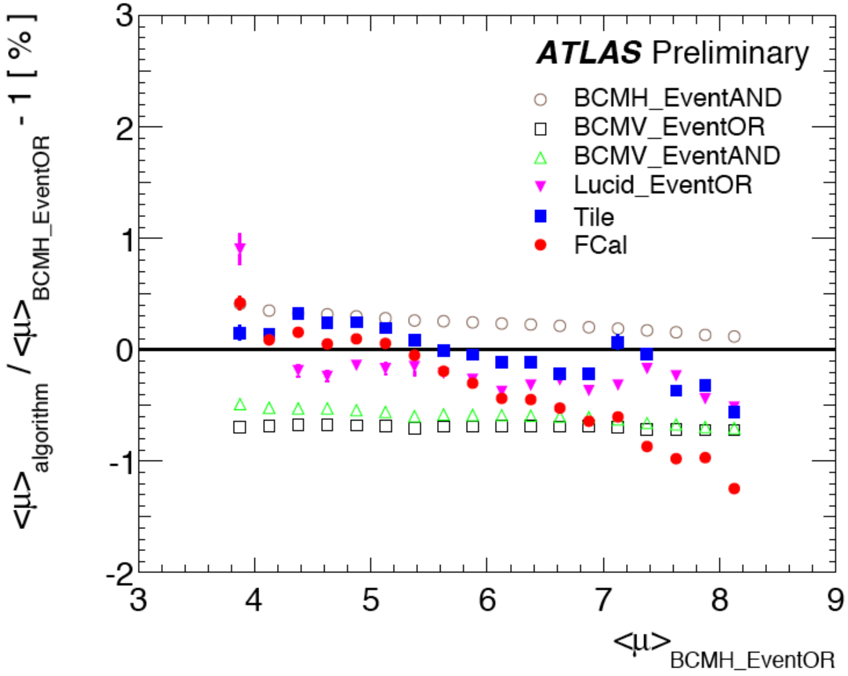
DBM Motivation: lessons learned

- Two independent luminosity measurements BCMH and BCMV:

Stable over months



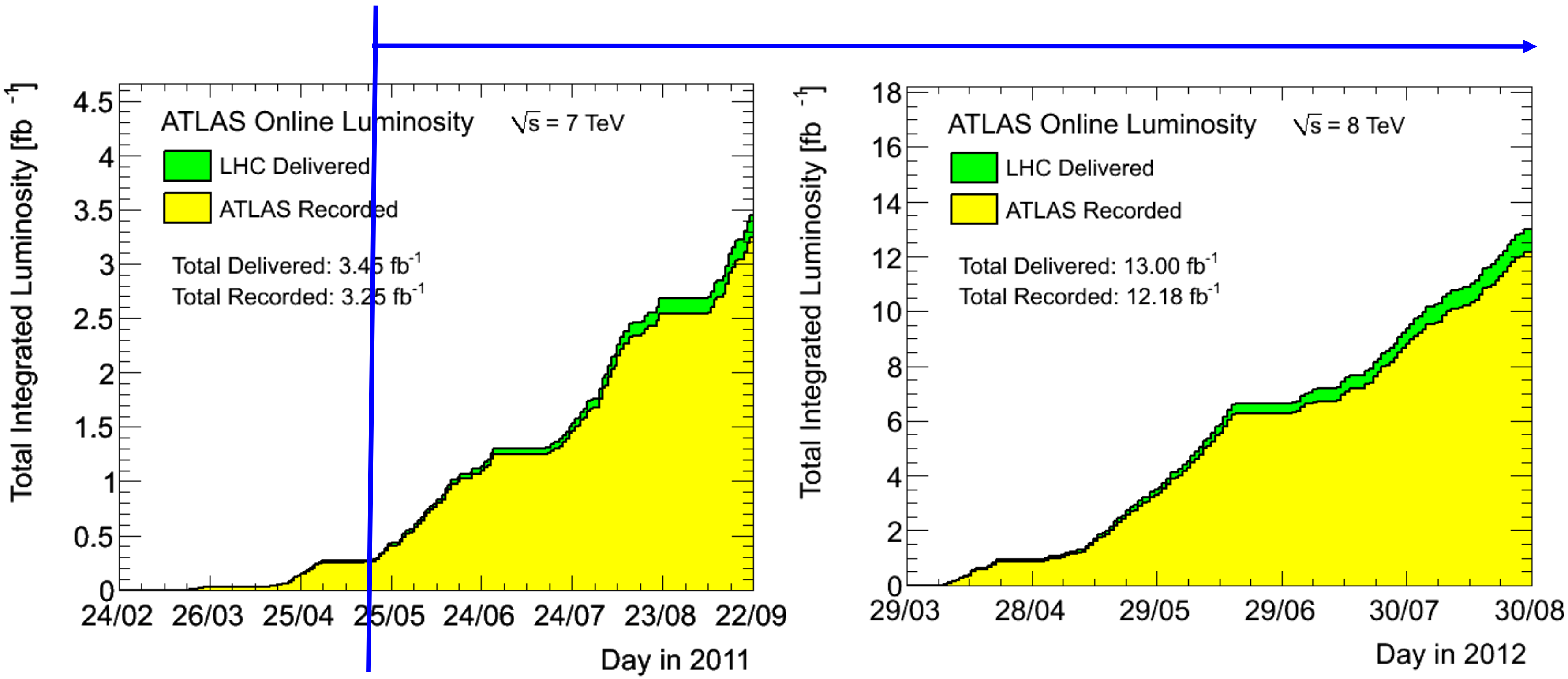
Stable against pile-up



- In 2011 BCM achieved a 1.9% luminosity measurement!

DBM Motivation: lessons learned

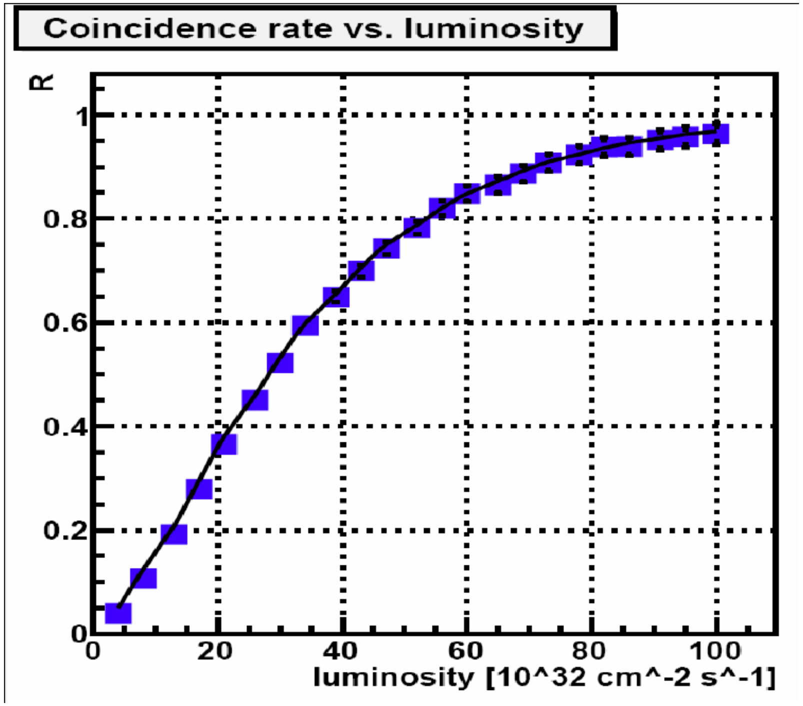
- The BCM is preferred ATLAS luminosity device since early 2011:



- Calibrated in Van der Meer scans
- Operates when other systems are not active!

DBM Motivation

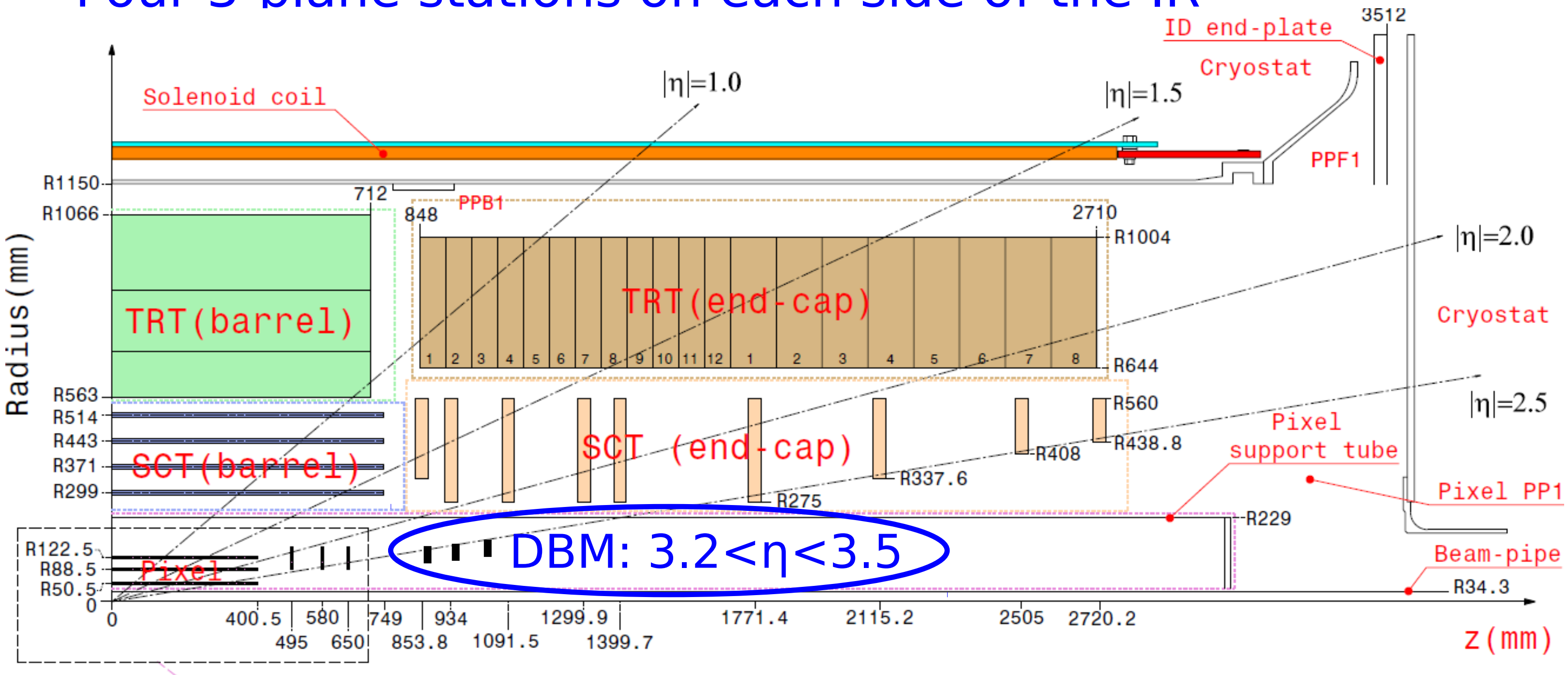
- But the BCM will begin to saturate at $\sim 10^{34}$ cm^{-2}s^{-1}:



- More segmentation → Diamond Beam Monitor (DBM)

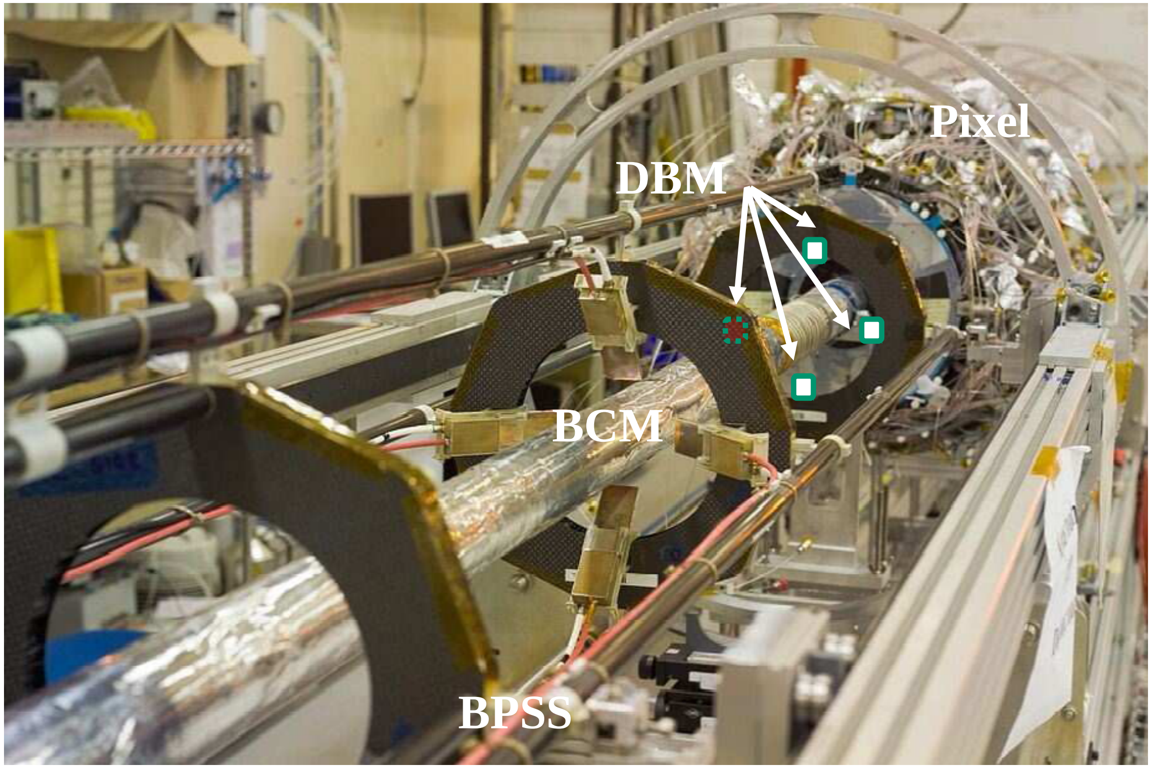
The ATLAS DBM Concept

- Build on success of BCM – pixelate the sensors
  - Use IBL diamond pixel demonstrator module
  - Install during new Service Quarter Panel (nSQP) replacement
  - Four 3-plane stations on each side of the IR



The ATLAS DBM Concept

- 24 diamond pixel modules arranged in 8 telescopes provide
  - Bunch by bunch luminosity monitoring
  - Bunch by bunch beam spot monitoring
- Installation in July 2013



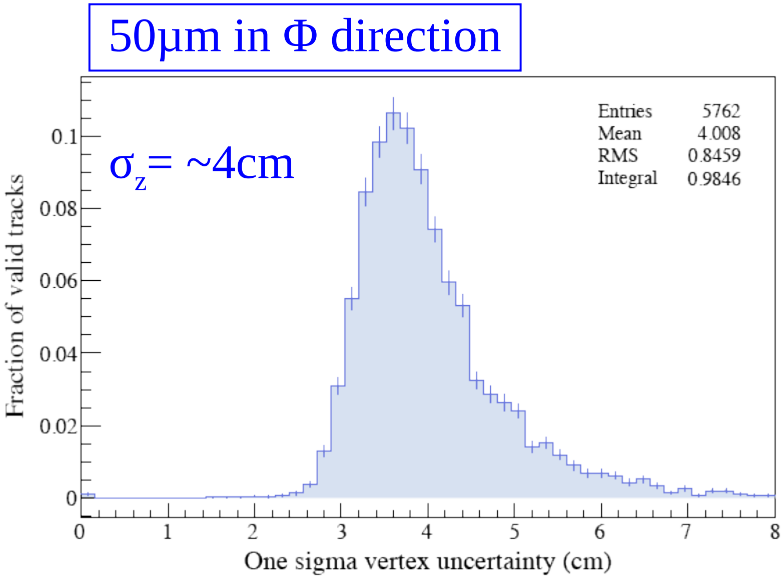
The ATLAS DBM Specs and Collaboration

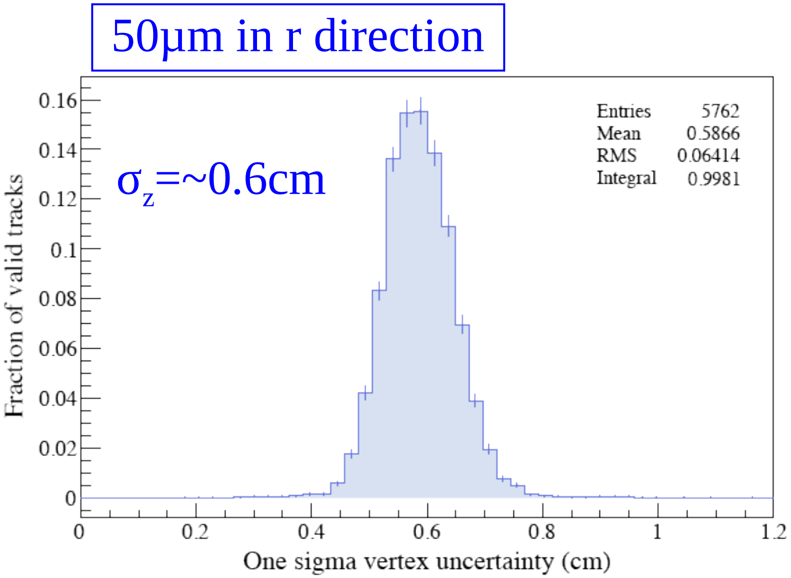
- Specs:
  - Bunch by bunch luminosity monitoring (<1% per BC per LB)
  - Bunch by bunch beam spot monitoring (unbiased sample, ~ 1cm)
- Installation in July 2013

Bonn CERN Göttingen Ljubljana N.Mexico OhioSt Toronto

The ATLAS DBM Tracking Simulation

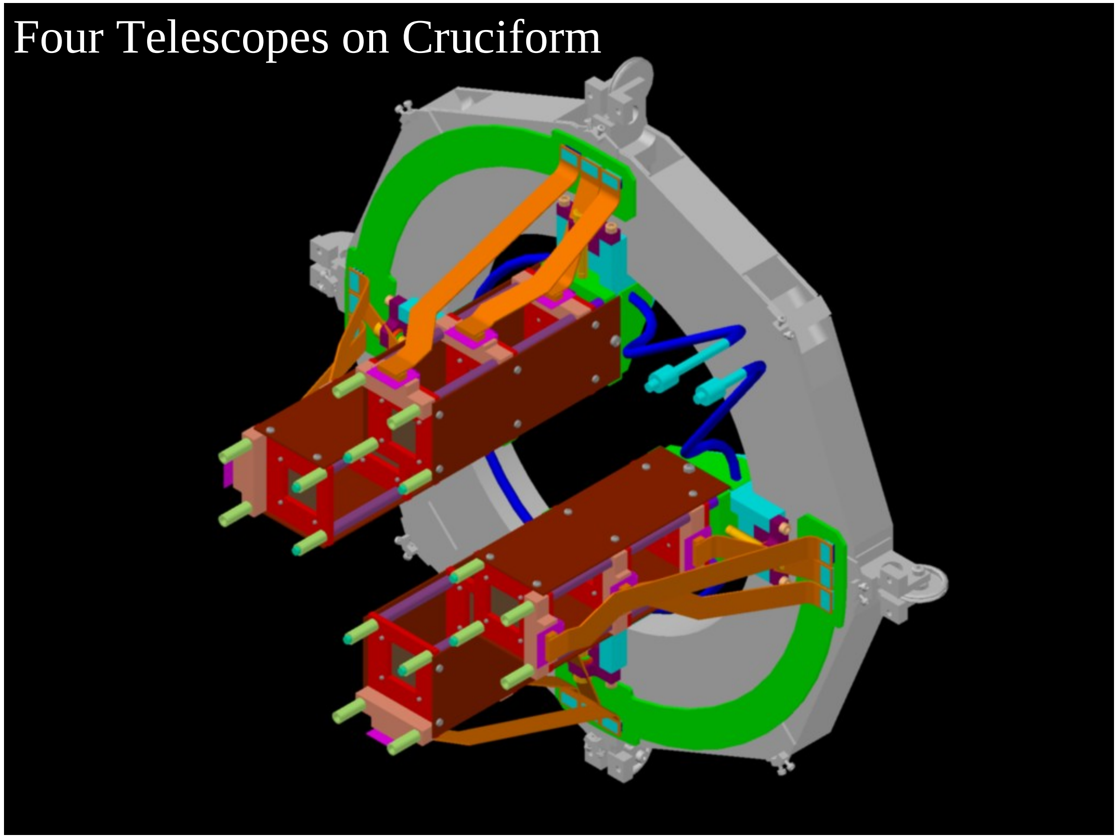
- Simulate DBM to find orientation and resolution
  - Focus on z vertex resolution (momentum resolution bad)

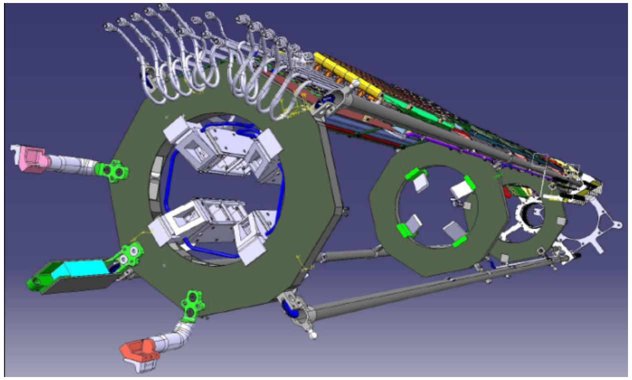


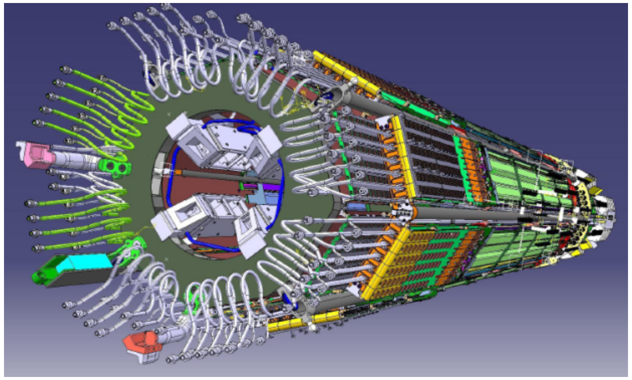


The ATLAS DBM Concept

- Mechanics finalized – use as many IBL parts as possible
- Mechanical simulations complete → Al, AlN, Peek

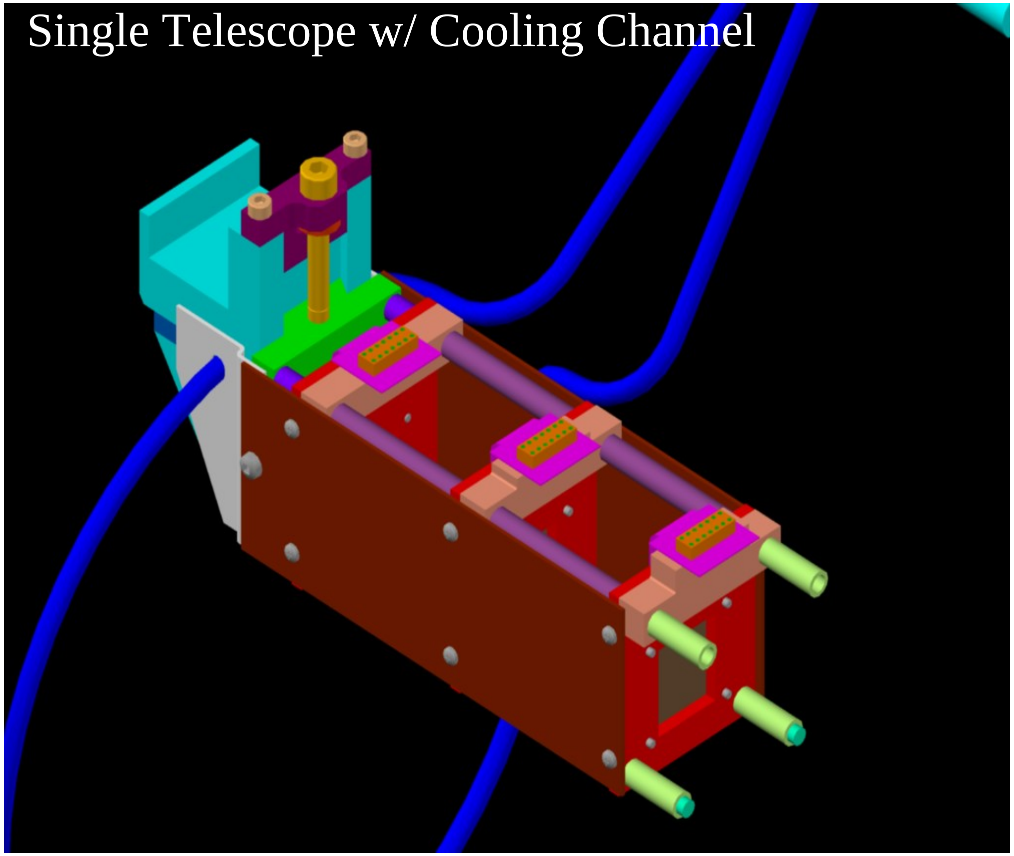


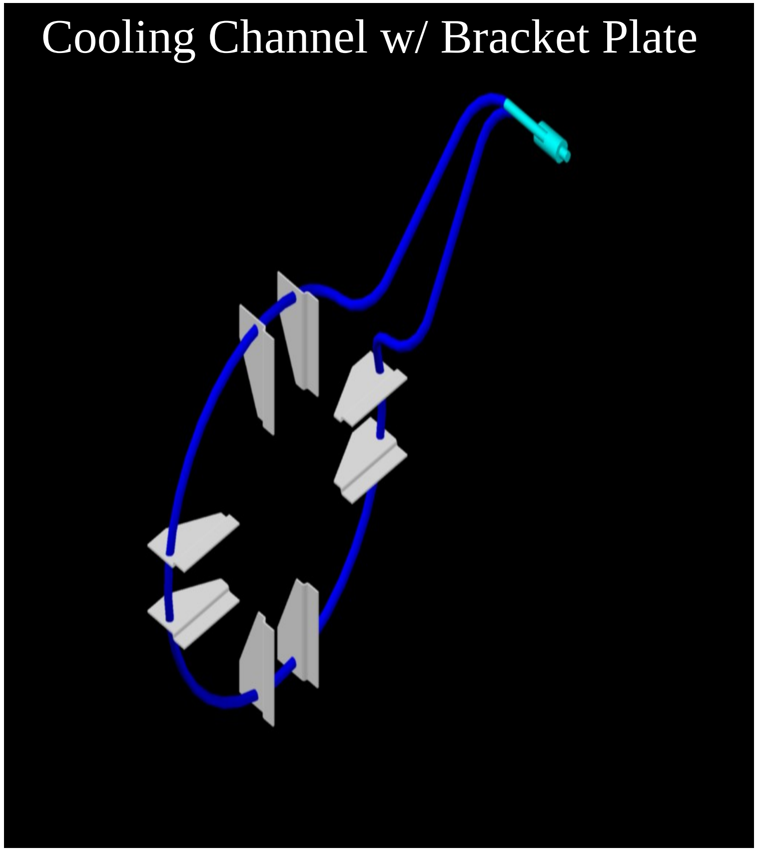




The ATLAS DBM Concept

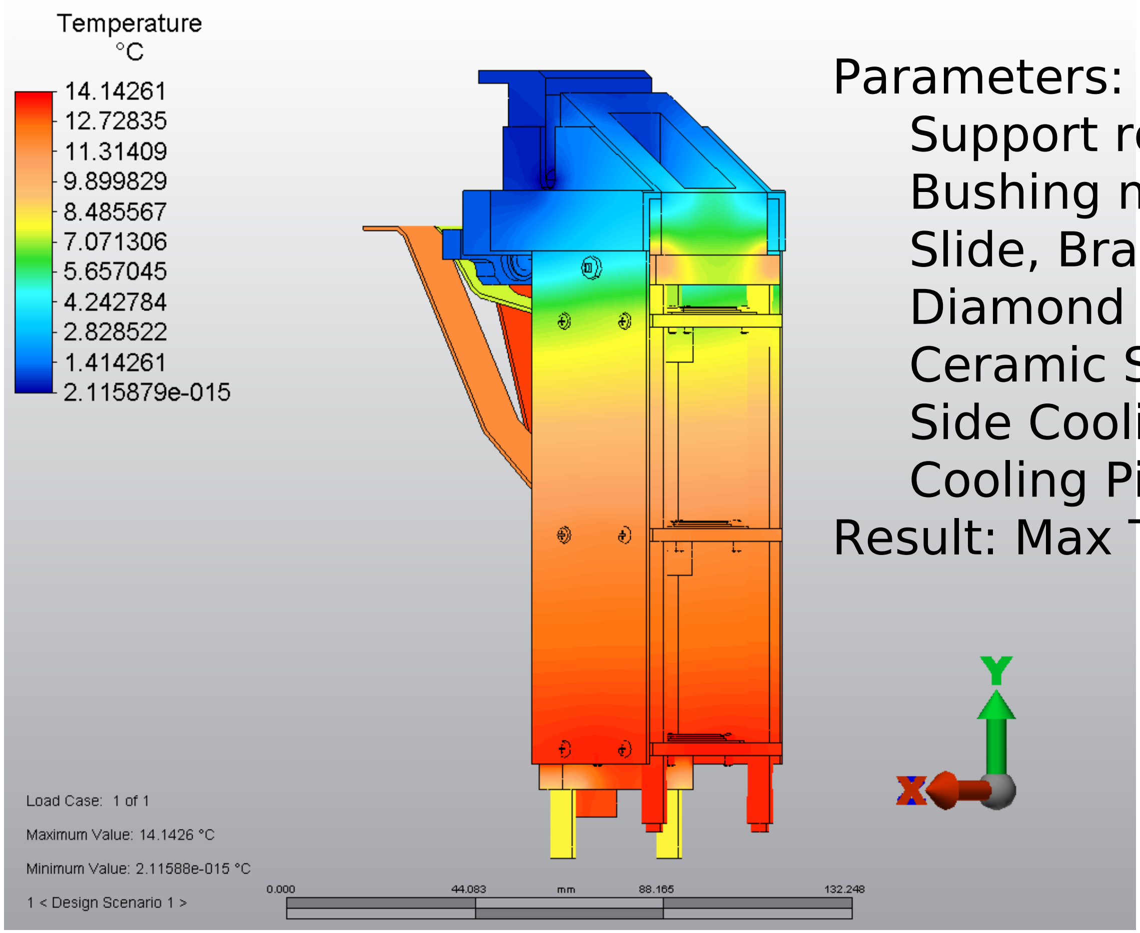
- Cooling simulations complete – transfer heat to support





The ATLAS DBM Concept

- Cooling simulations for DBM telescope w/3 x 1W + AlN side plate



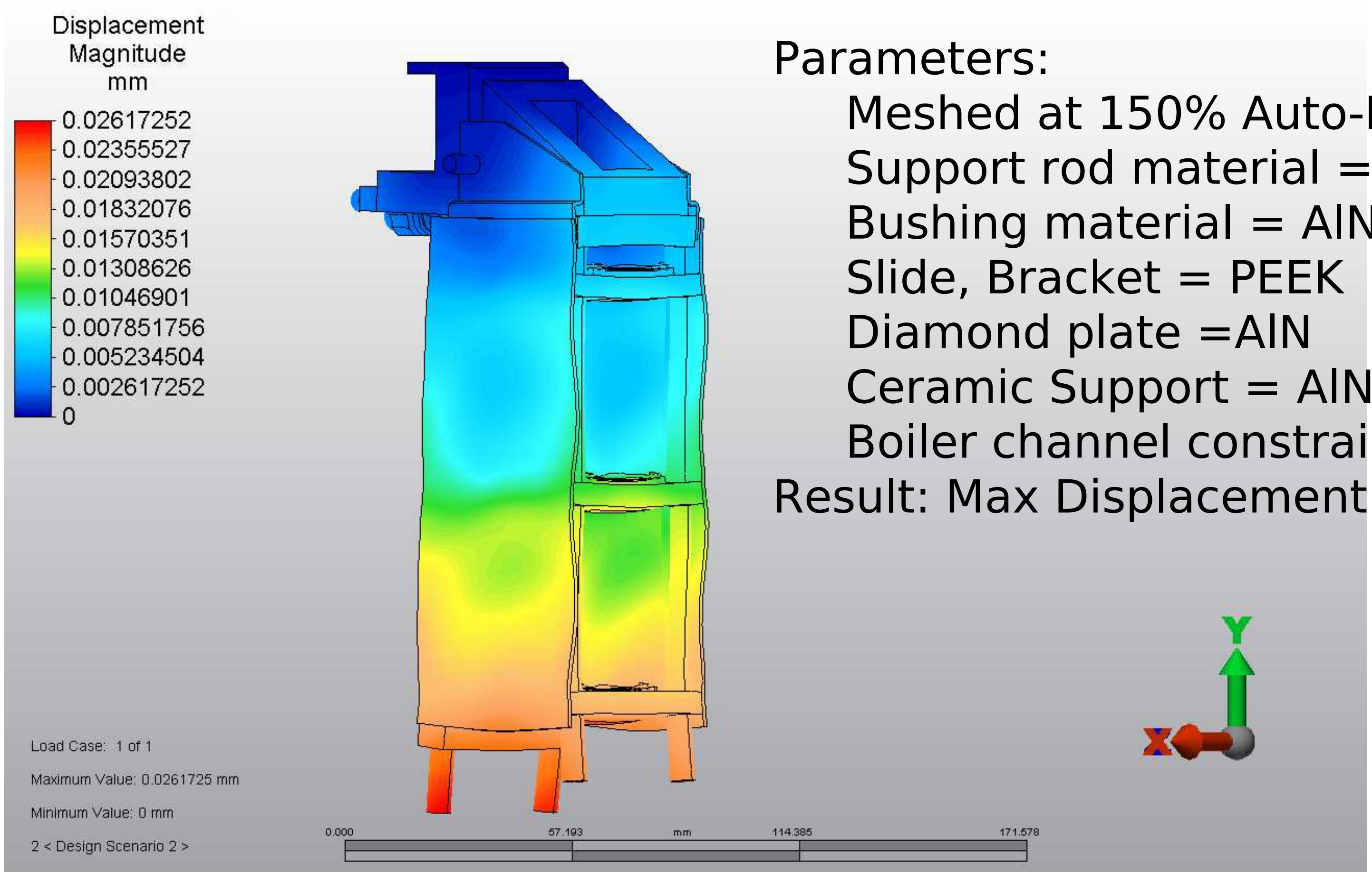
Parameters:

Support rod material = Aluminum
Bushing material = AlN
Slide, Bracket = PEEK
Diamond plate =AlN
Ceramic Support = AlN
Side Cooling Plate = AlN (1mm)
Cooling Pipe constrained to 0°C

Result: Max T = 14.2°C

The ATLAS DBM Concept

- Mechanical simulations for DBM telescope w/3 x 1W + AlN side plate



Parameters:

Meshed at 150% Auto-Mesh size

Support rod material = Aluminum

Bushing material = AlN

Slide, Bracket = PEEK

Diamond plate =AlN

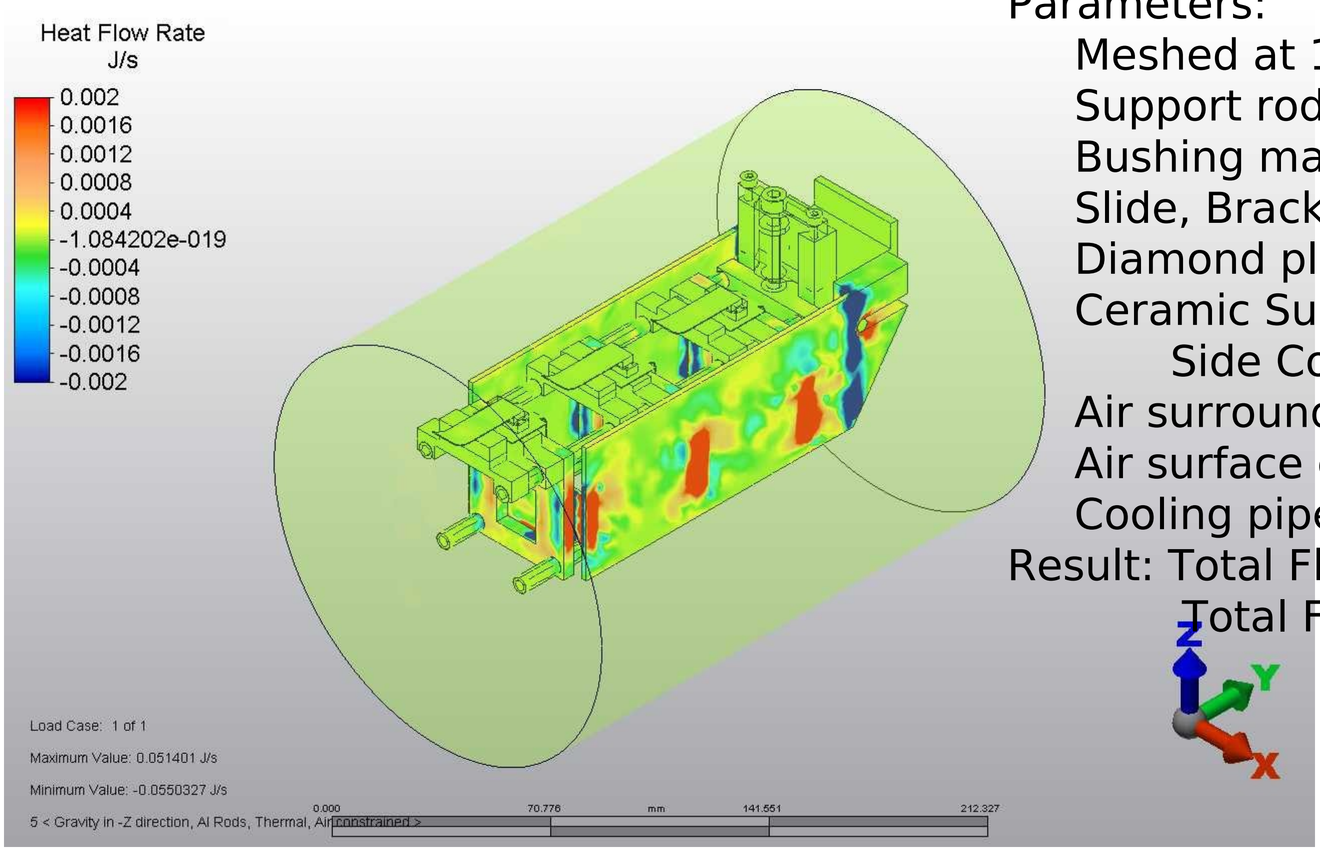
Ceramic Support = AlN

Boiler channel constrained to 0°C

Result: Max Displacement = 26.2 μm

The ATLAS DBM Concept

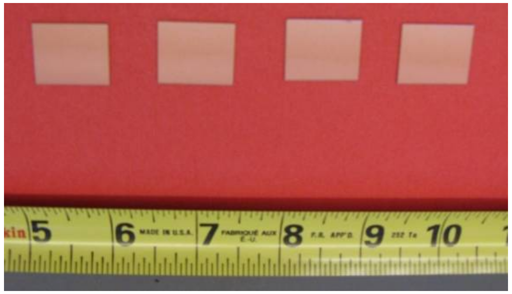
- Heat Flux through a DBM telescope w/3 x 1W

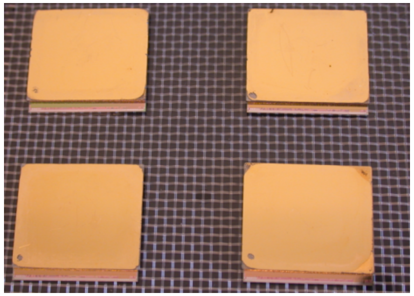


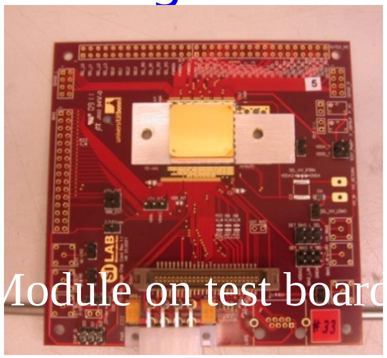
Parameters:
Meshed at 150% Auto-Mesh size
Support rod material = Aluminum
Bushing material = Aluminum
Slide, Bracket = PEEK
Diamond plate =AlN
Ceramic Support = AlN
Side Cover = AlN
Air surrounding DBM – transparent
Air surface constrained to 0°C
Cooling pipe constrained to 0°C
Result: Total Flux Out = 0.12W
Total Flux In = 3W

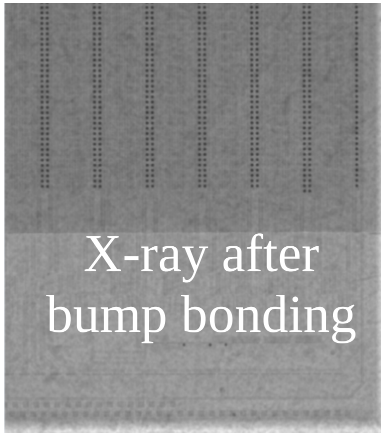
DBM Module Production

- Sensors
  - 14 old sensors in hand from E6 (UK) from IBL work
  - 10 new sensors in hand from E6 (UK)
  - 17 sensors ordered from II-VI (US)
- Quality Control
  - 5 old sensors/3 new sensors passed QC (ccd, I)
  - 9 old sensors/7 new sensors in testing
- Bump bonding
  - 4 prototype modules bump-bonded by IZM
  - 5 sensors at IZM for bump-bonding



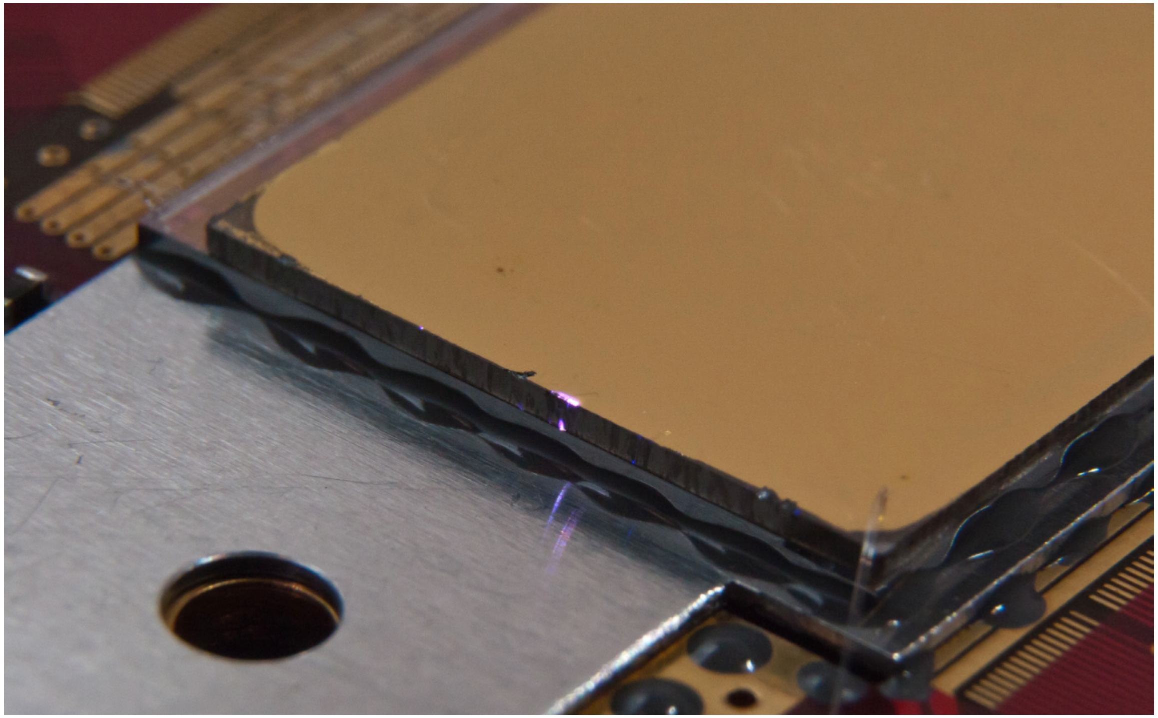






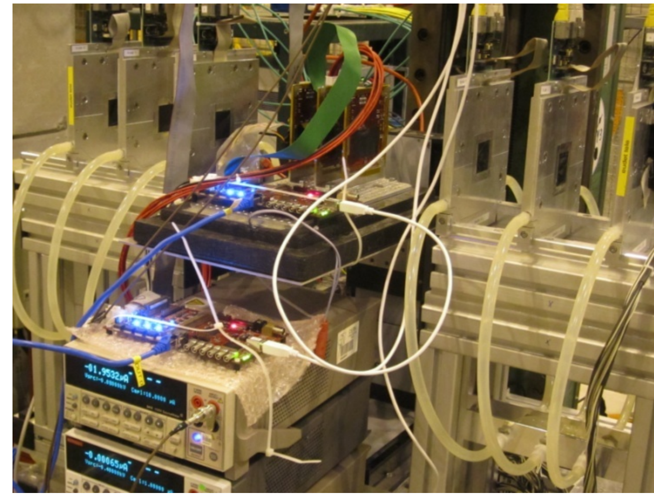
DBM Module Production Problems

- HV Problems with first modules
  - Backside metalization goes to the edge of diamond and breaks down
  - Fixed by changing back metalization procedure – no longer performed by IZM



DBM Module Testbeam

- Three Testbeam campaigns
  - Oct 11, Mar 12, Jun 12
- Learning about FE-I4 performance
  - Calibration/tunings for low threshold performance

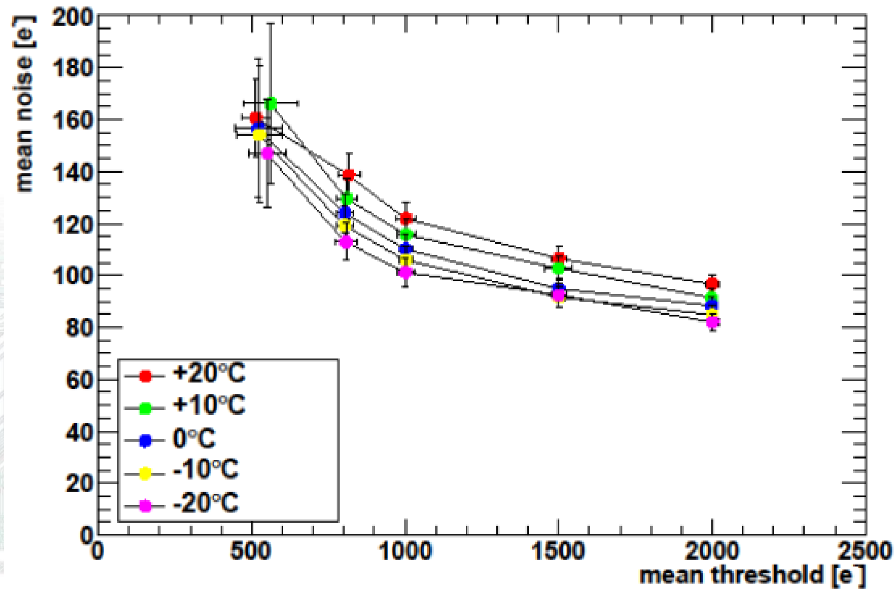


What is possible?

x = October 2011 DBM Test Beam

Gain \ Threshold	500e	800e	1000e	1500e	2000e
8ToT@3ke	x	x			
8ToT@5ke	x	x		x	
8ToT@8ke	x	x		x	x
8ToT@10ke		x			
8ToT@15ke					

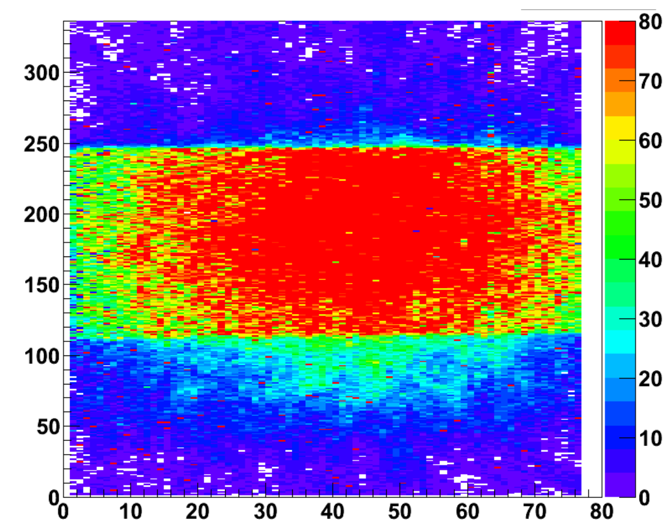
„Green Valley“

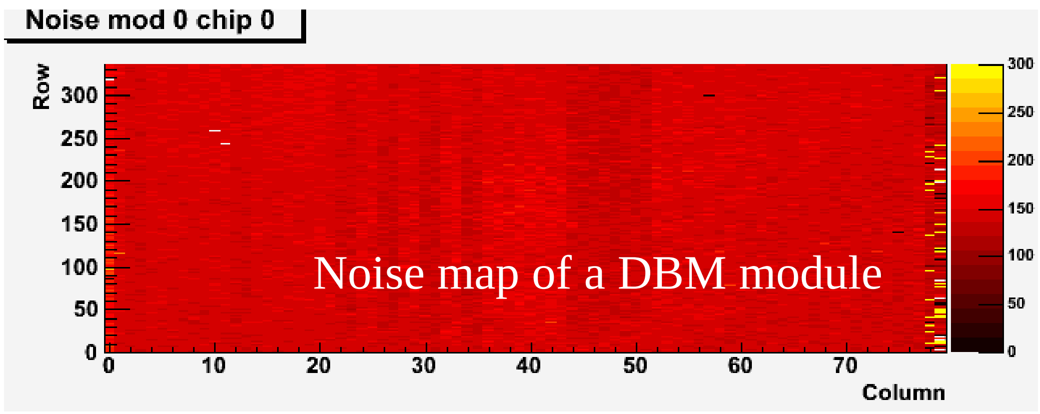


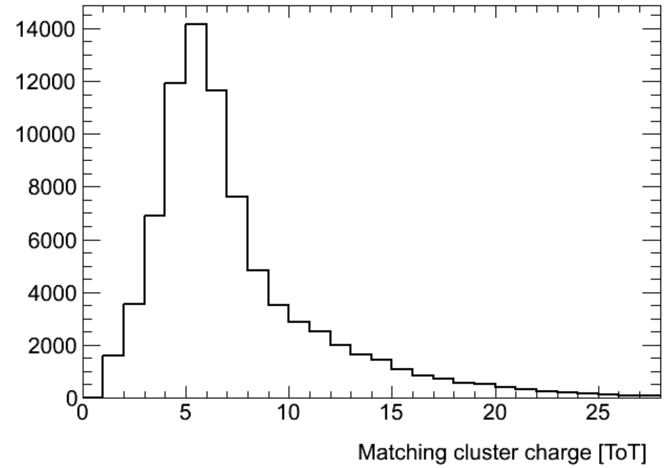
DBM Module Testbeam

Prototype Modules Tested:
- 21mmx 18mm pCVD diamond w/FE-I4A
- 336 x 80 = 26880 channels
- 50 x 250 μm² pixel cell

Results
- Noise map uniform
- Efficiency >95%







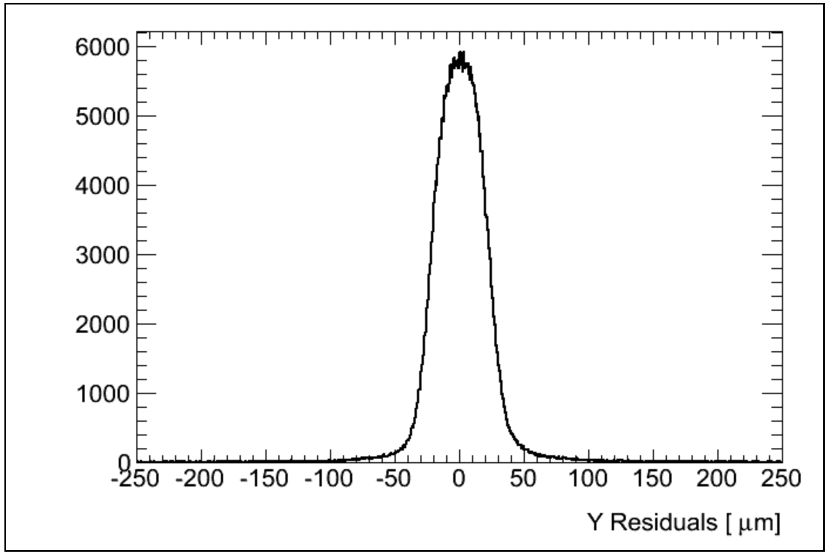
DBM Module Testbeam

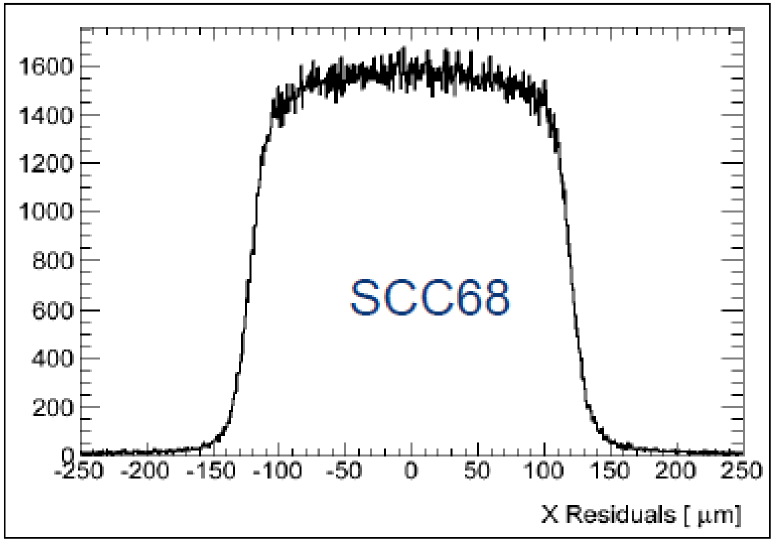
Prototype Modules Tested:

- 21mmx 18mm pCVD diamond w/FE-I4A
- 336 x 80 = 26880 channels
- 50 x 250 μm^2 pixel cell

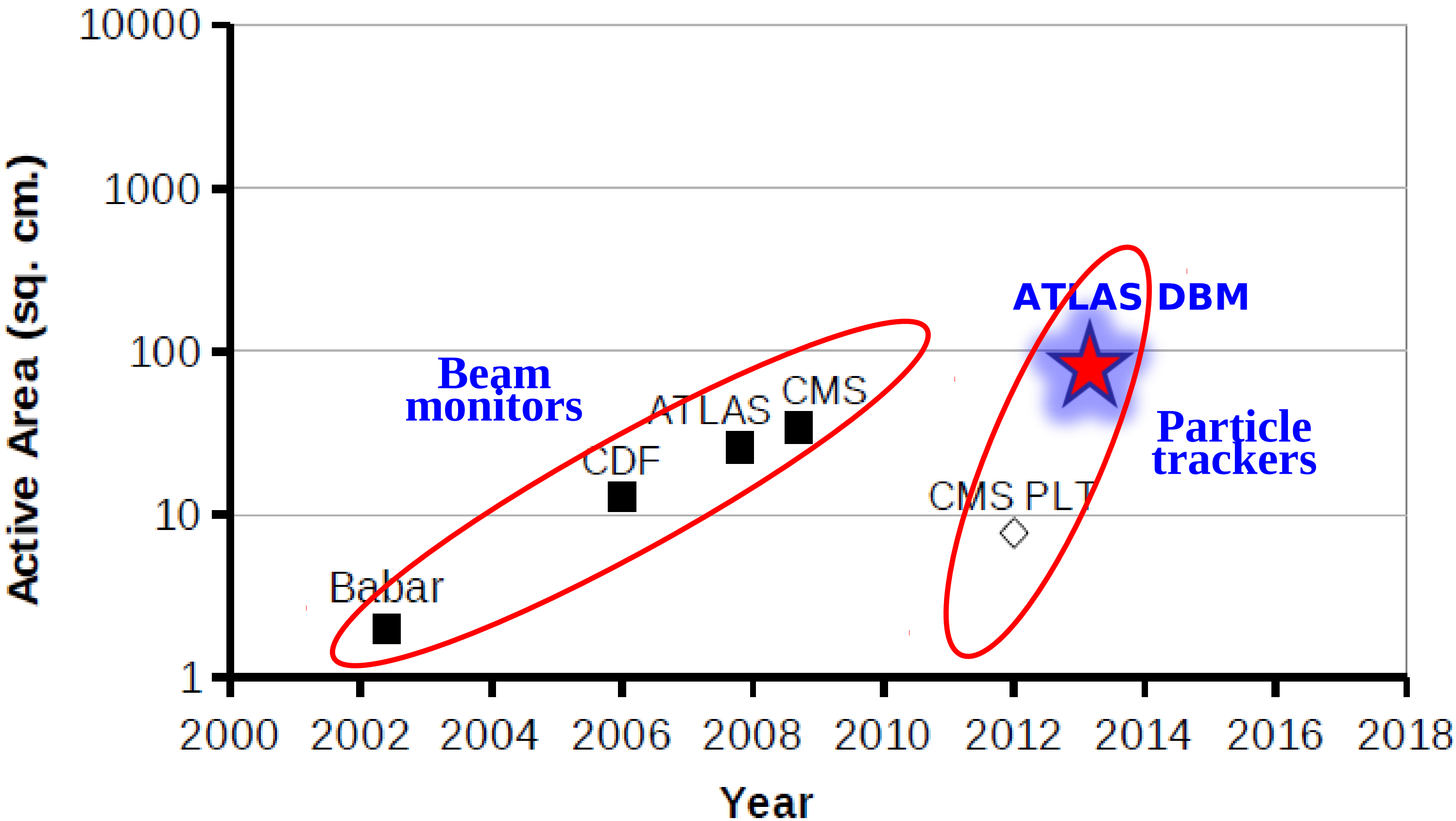
Results

- Spatial resolution looks digital





DBM and Other Diamond Projects



DBM and Radiation Damage

- Traditionally CCD was fited with the ansatz
  - We measure CCD
- Radiation induced traps reduce the mean free path (mfp)
  - CCD ~ $mfp_e + mfp_h$ in thick detectors where t>>mfp,CCD

$$\frac{1}{CCD} = \frac{1}{CCD_0} + k \times \Phi$$

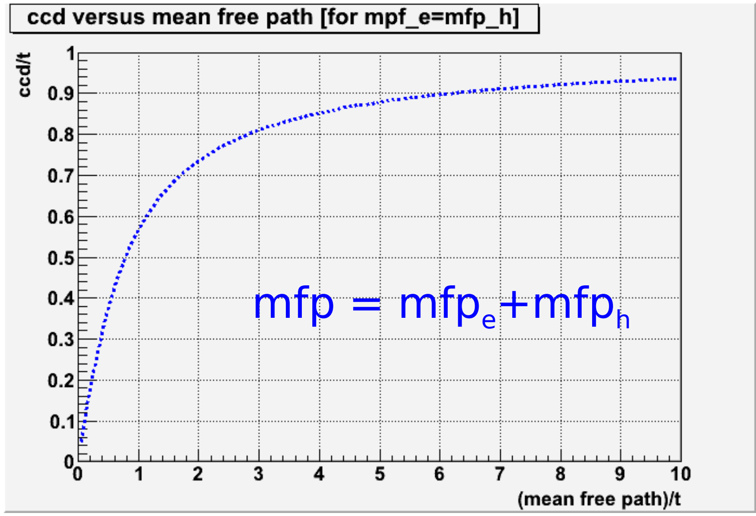
CCD=Q_{col}/(36e/µm)

$$\frac{1}{mfp} = \frac{1}{mfp_0} + k \times \Phi$$

- Relation between CCD and mfp

$$\frac{ccd}{t} = \sum_{i=e,h} \frac{mfp_i}{t}\left[1 - \frac{mfp_i}{t}\left(1 - e^{-\frac{t}{mfp_i}}\right)\right]$$

- For lack of data assume $mfp_e = mfp_h$
  - k_{mfp} insensitive to mfp_e/mfp_h

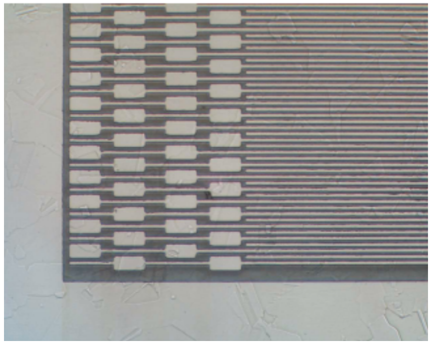


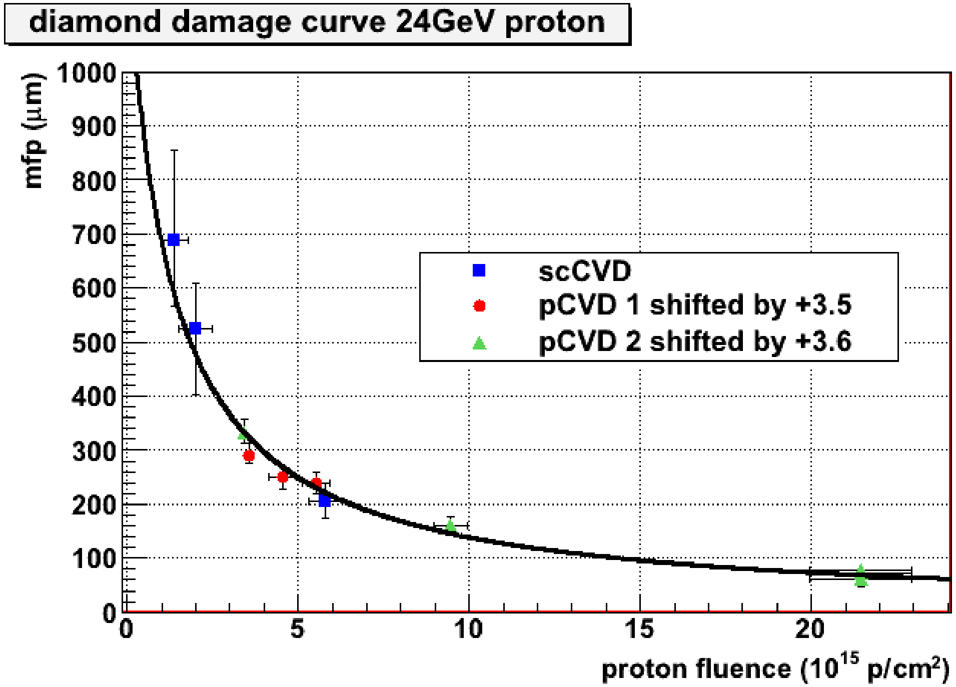
RD42 24GeV Proton Radiation Damage (PS)

- CCD evaluated with strip detectors in CERN test beam
- For mean free path expect

$$\frac{1}{mfp} = \frac{1}{mfp_0} + k \times \Phi$$

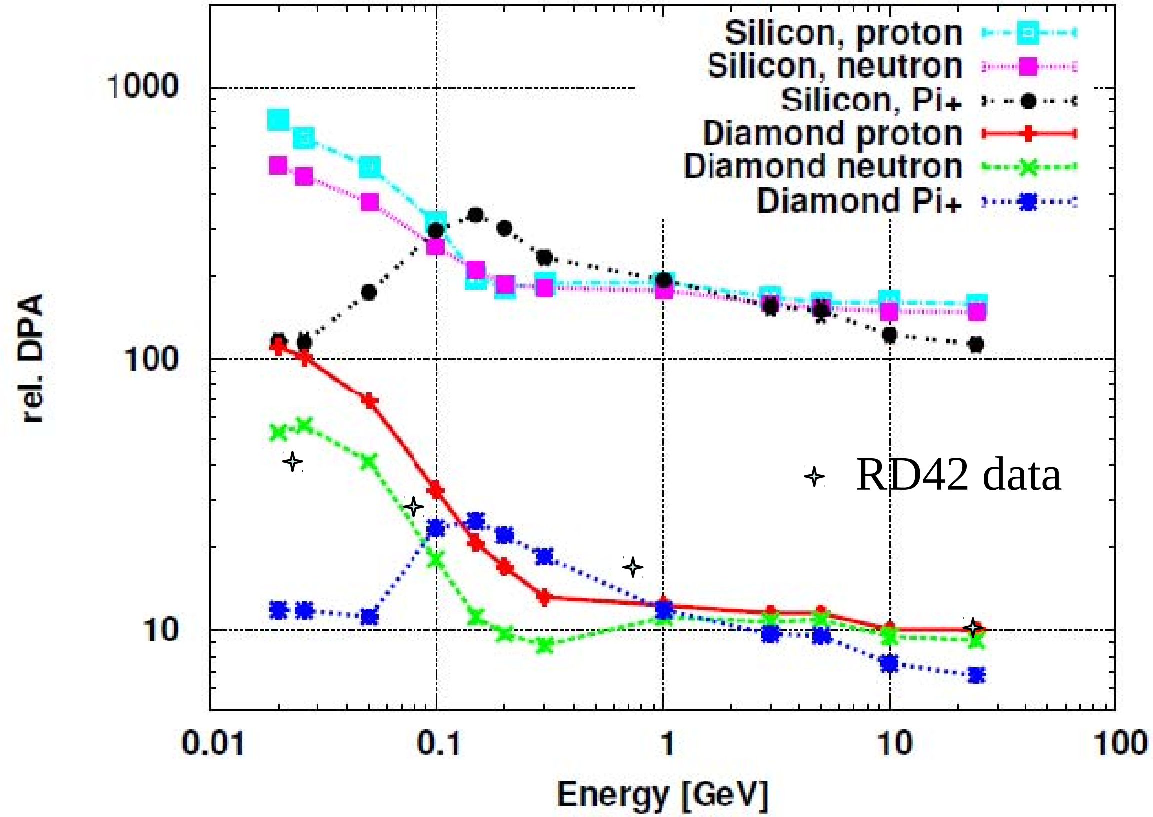
- mpf_0 is initial trapping deduced from CCD_0
- k_{mfp} is the damage constant
- pCVD and scCVD follow same curve
- $k_{mfp} \sim 0.66 \times 10^{-18}\ \mu m^{-1} cm^{-2}$





Diamond Radiation Tolerance

DPA based on Displacement Energy:
Si:~25eV; Diamond~42eV



From S. Mueller Thesis

- DPA scaling seems better? Predicts $k_{300MeVpi} \sim k_{70MeVp} \sim 2.6x$

Summary of RD42 Test Beam Results

Particle	Energy	Relative k
p	24GeV	1.0
	800MeV	1.6-1.8
	70MeV	2.5-2.8
	25MeV	4.0-5.0
π	200MeV	2.5-3.0

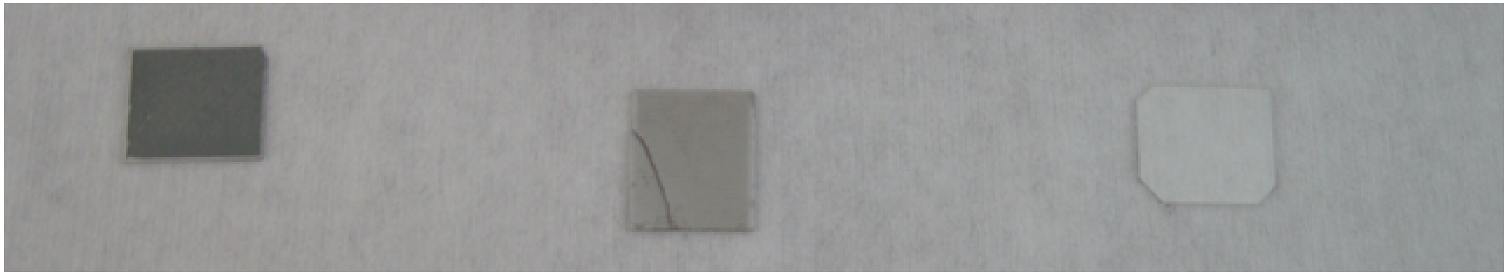
Summary

- Construction of the largest diamond pixel tracker underway
- Satisfies constraints for precision luminosity measurement
  - Bunch by bunch measurement
  - Background separation uses z resolution
- Should be robust against
  - Pile-up
  - Radiation damage

Backup Slides

DBM Detector Production Problems

- The first DBM detectors produced were re-claimed 800μm thick detectors which had to be thinned
  - Thinning recovered 14/27 detectors
  - The rest were not useable due to cracks or edge problems
  - The thinning process took longer and was harder than anticipated but was eventually solved

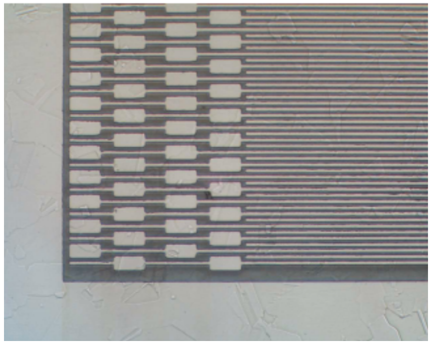


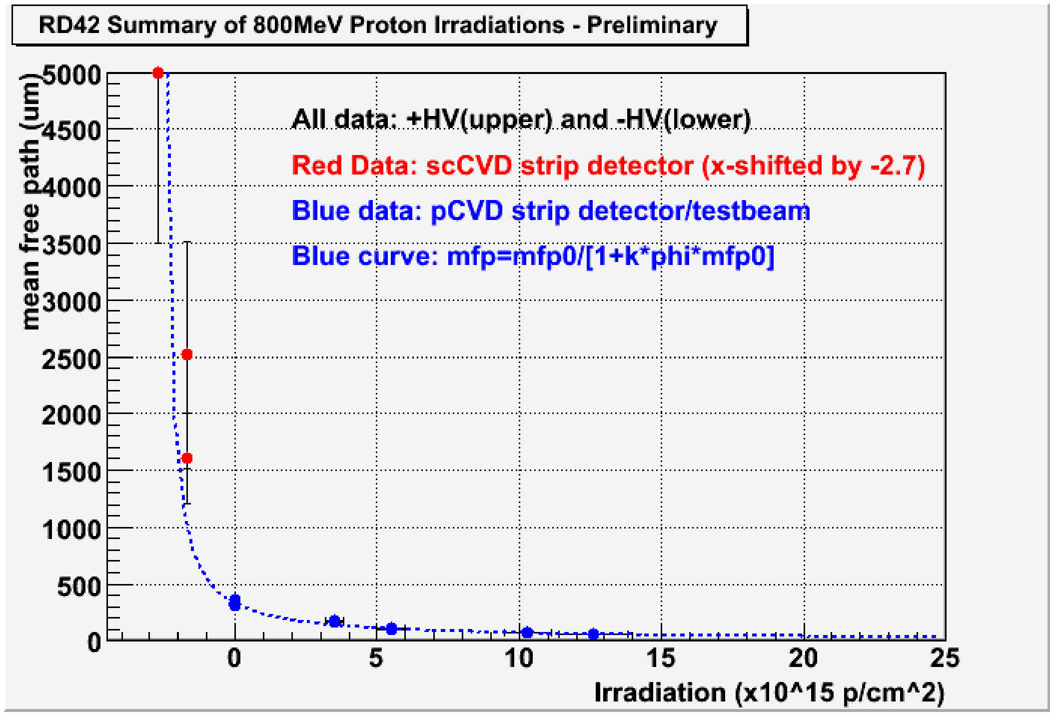
RD42 800MeV Proton Radiation Damage (LANL)

- CCD evaluated with strip detectors in CERN test beam
- For mean free path expect

$$\frac{1}{mfp} = \frac{1}{mfp_0} + k \times \Phi$$

- mpf_0 is initial trapping deduced from CCD_0
- k_{mfp} is the damage constant
- pCVD and scCVD follow same curve
- $k_{mfp} \sim 1.2 \times 10^{-18}\ \mu m^{-1} cm^{-2}$
- 70MeV protons are 1.8x more damaging than 24GeV protons



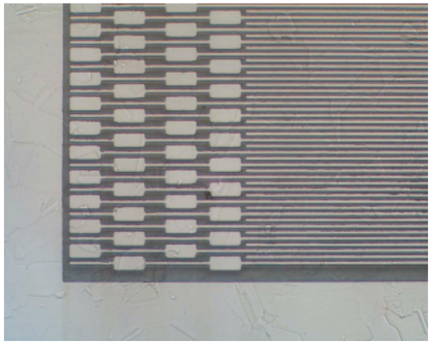


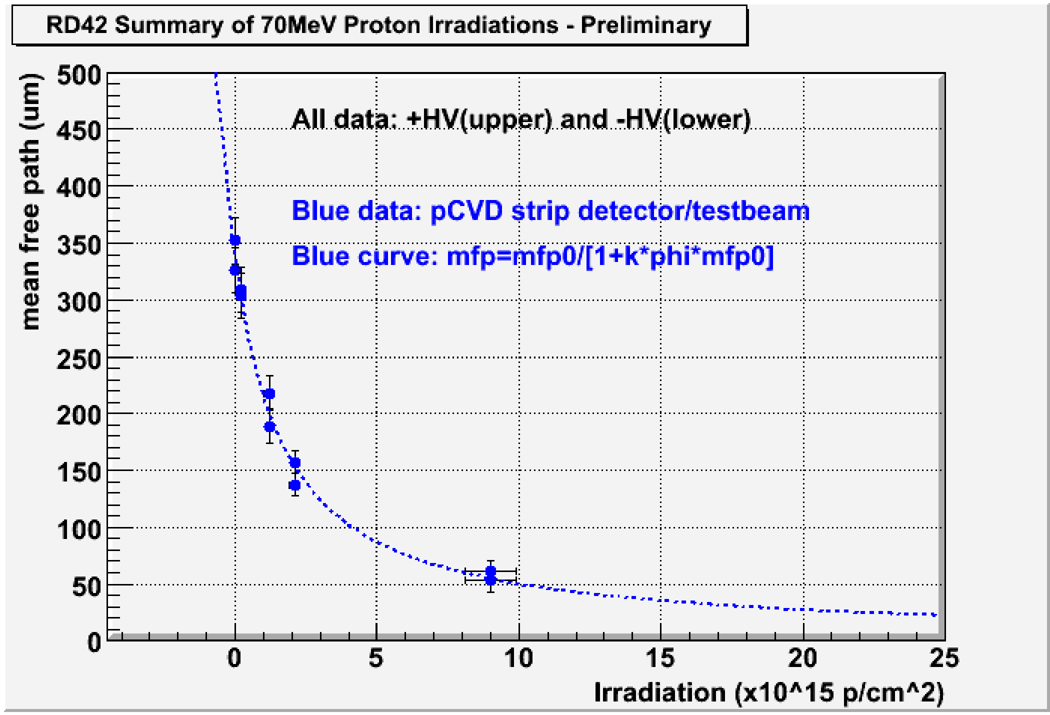
RD42 70MeV Proton Radiation Damage (CYRIC)

- CCD evaluated with strip detectors in CERN test beam
- For mean free path expect

$$\frac{1}{mfp} = \frac{1}{mfp_0} + k \times \Phi$$

- mpf_0 is initial trapping deduced from CCD_0
- k_{mfp} is the damage constant
- only pCVD measured
- $k_{mfp} \sim 1.7 \times 10^{-18}\ \mu m^{-1} cm^{-2}$
- 70MeV protons are 3x more damaging than 24GeV protons



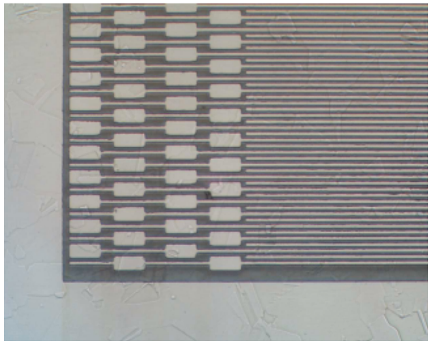


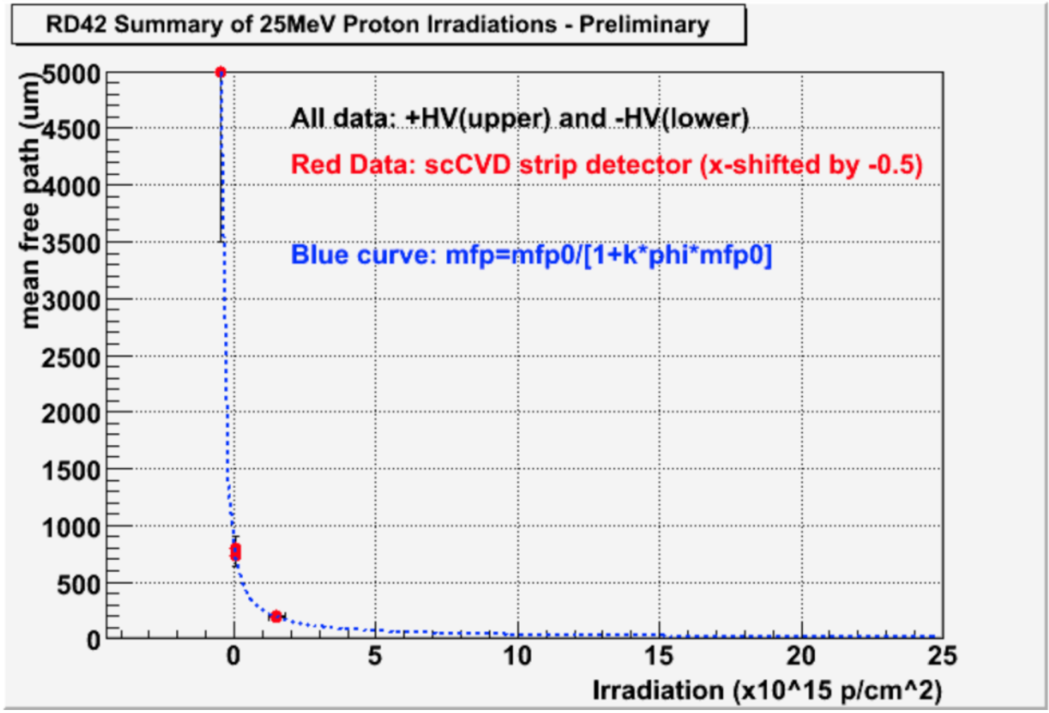
RD42 25MeV Proton Radiation Damage (KIT)

- CCD evaluated with strip detectors in CERN test beam
- For mean free path expect

$$\frac{1}{mfp} = \frac{1}{mfp_0} + k \times \Phi$$

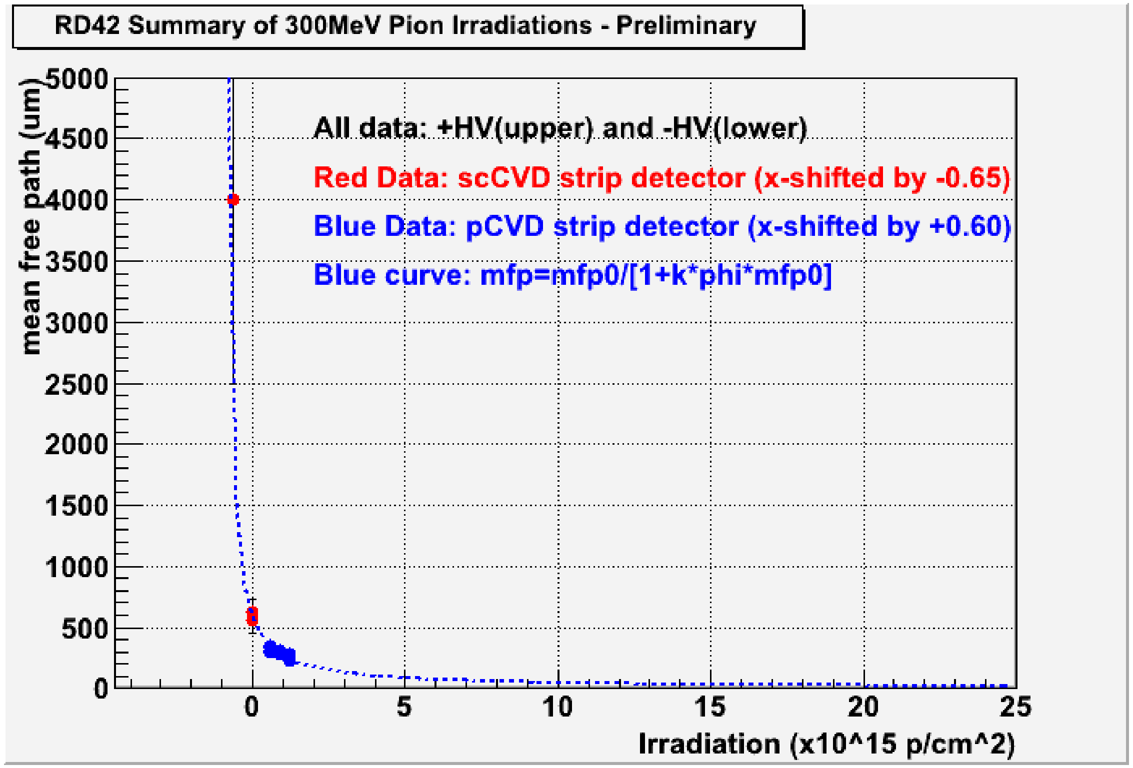
- mpf_0 is initial trapping deduced from CCD_0
- k_{mfp} is the damage constant
- pCVD and scCVD follow same curve
- $k_{mfp} \sim 2.6 \times 10^{-18}\ \mu m^{-1} cm^{-2}$
- 25 MeV protons are 4x more damaging than 24GeV protons





RD42 Pion Irradiations

- Performed at PSI with 200MeV π up to 6.5×10^{14} π/cm²



$k_{ccd} \sim 2.0\times10^{-18}\ \mu m^{-1}cm^{2}$ → 3x more damaging than 24GeV protons

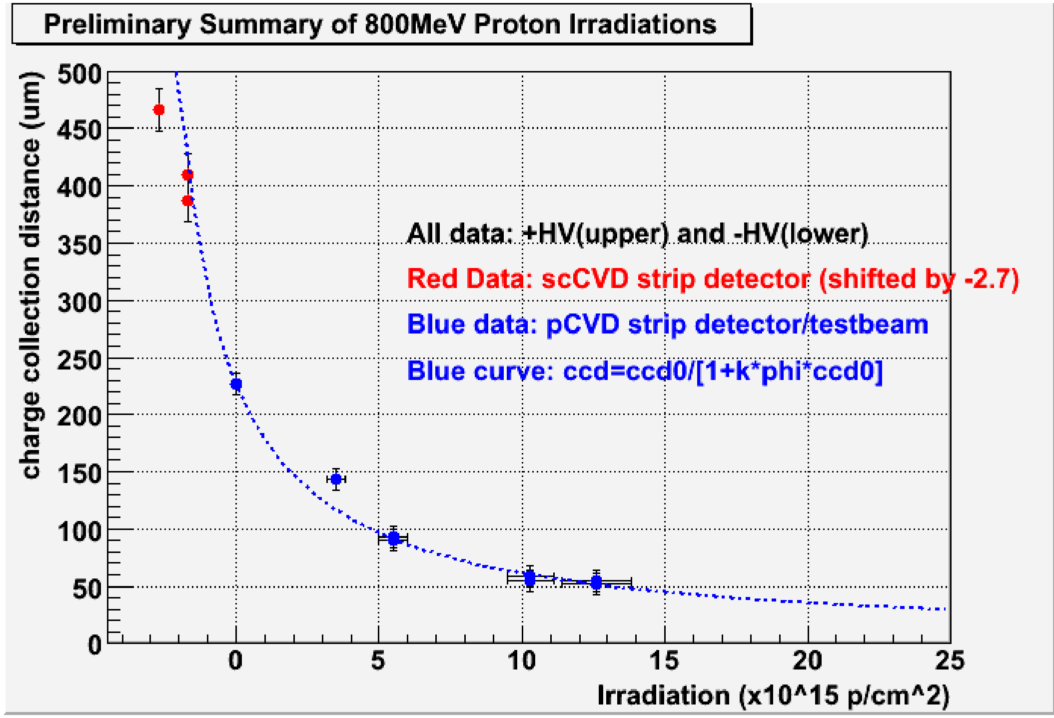
Diamond Radiation Tolerance: 800MeV protons

Recent Irradiation with 800 MeV protons at LANSCE Facility in Los Alamos, US

- Result: 800 MeV protons 1.8x more damaging than 24GeV protons

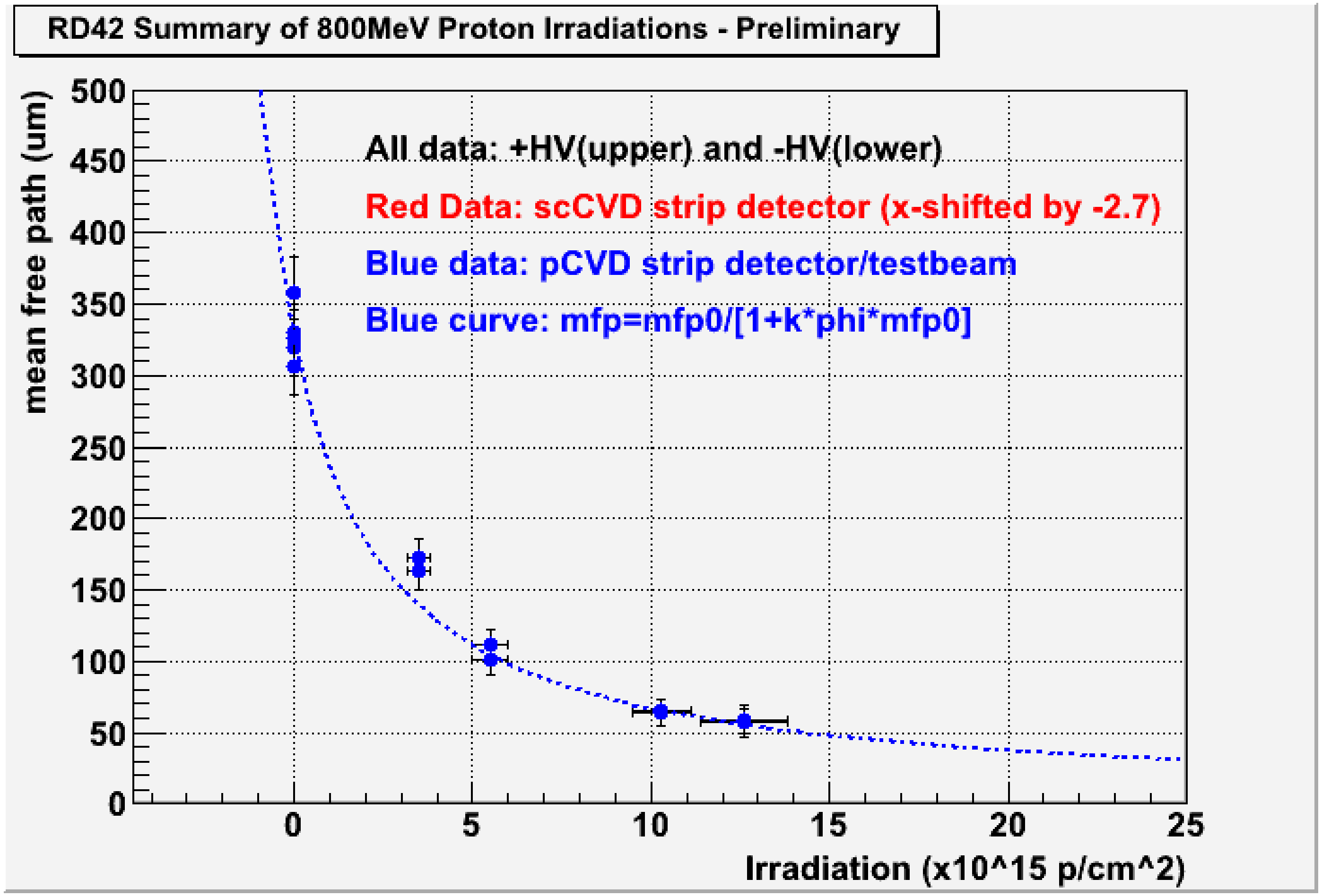
  $k \sim 1.2\text{x}10^{-18}\ \mu m^{-1}cm^{2}$

- NIEL prediction 1.8x
  - NIEL ok !
- 1 more scCVD data point irradiated in Dec 2011 [$(1.6+1.0)\text{x}10^{15}$] awaiting Jul Test Beam



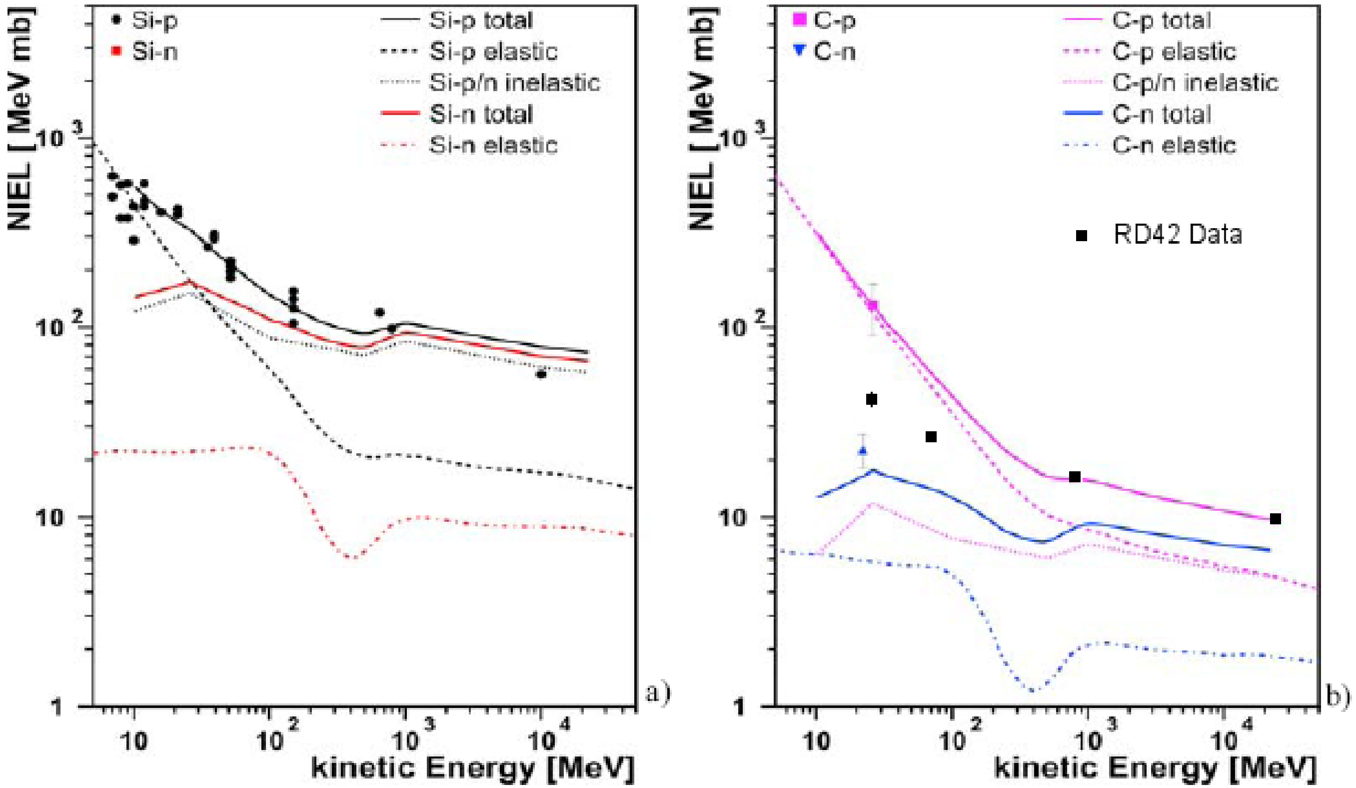
Test beam results - ccd

Diamond Radiation Tolerance: 800MeV protons



Test beam results - mfp – zoom view

Diamond Radiation Tolerance



- New results from low energy irradiations
- Deviation from calculated NIEL at low energy? NIEL violation? or is the theory incorrect? Use FLUKA-DPA scaling?