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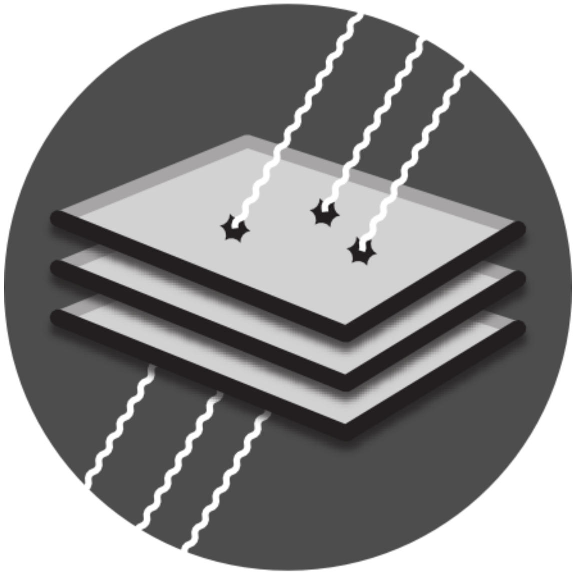
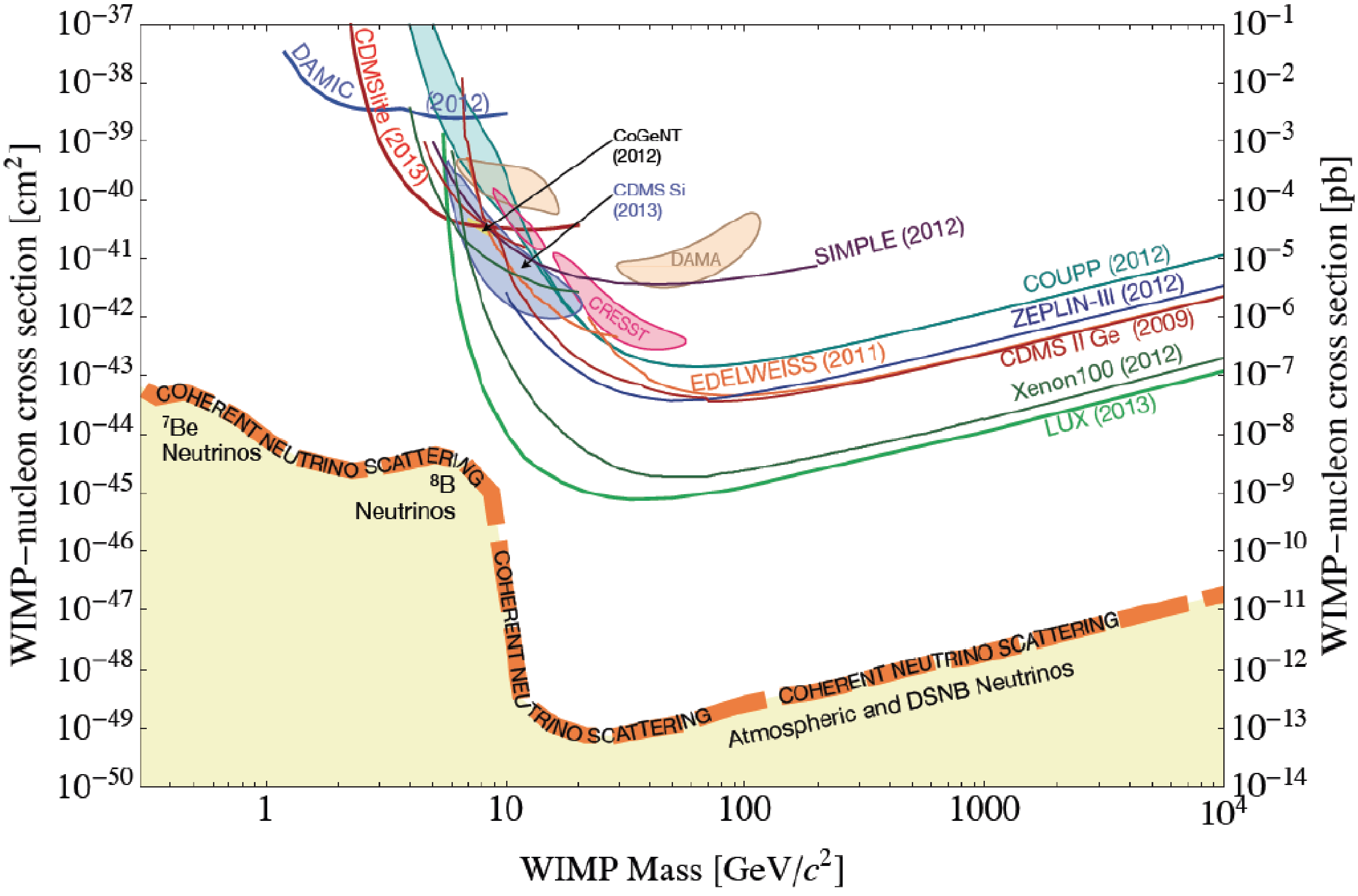
DAMIC — Direct search for low mass DM with CCDs



Juan Estrada – DAMIC Spokesperson

18-Dec-2014

DAMIC Science



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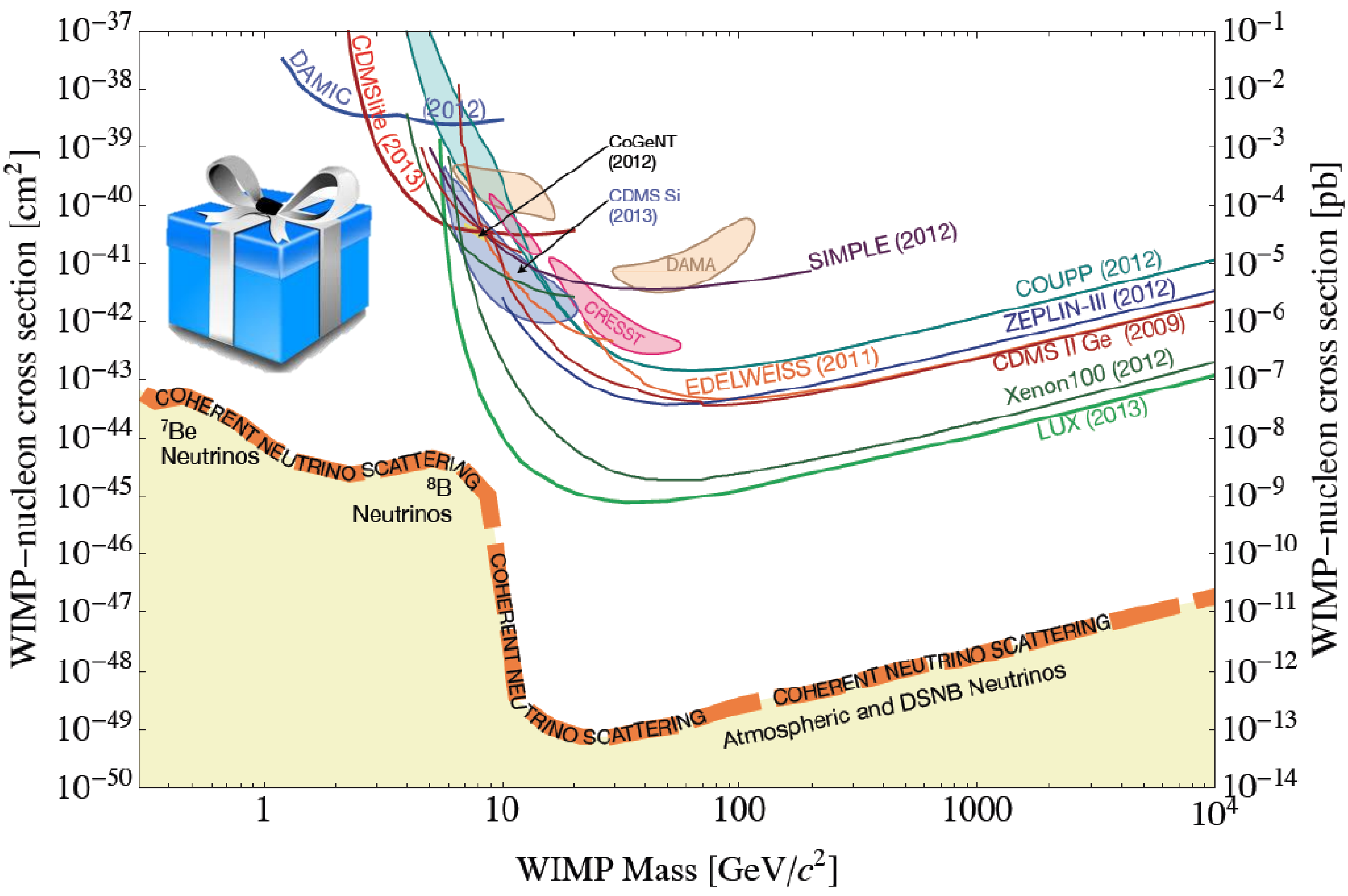
DAMIC Science



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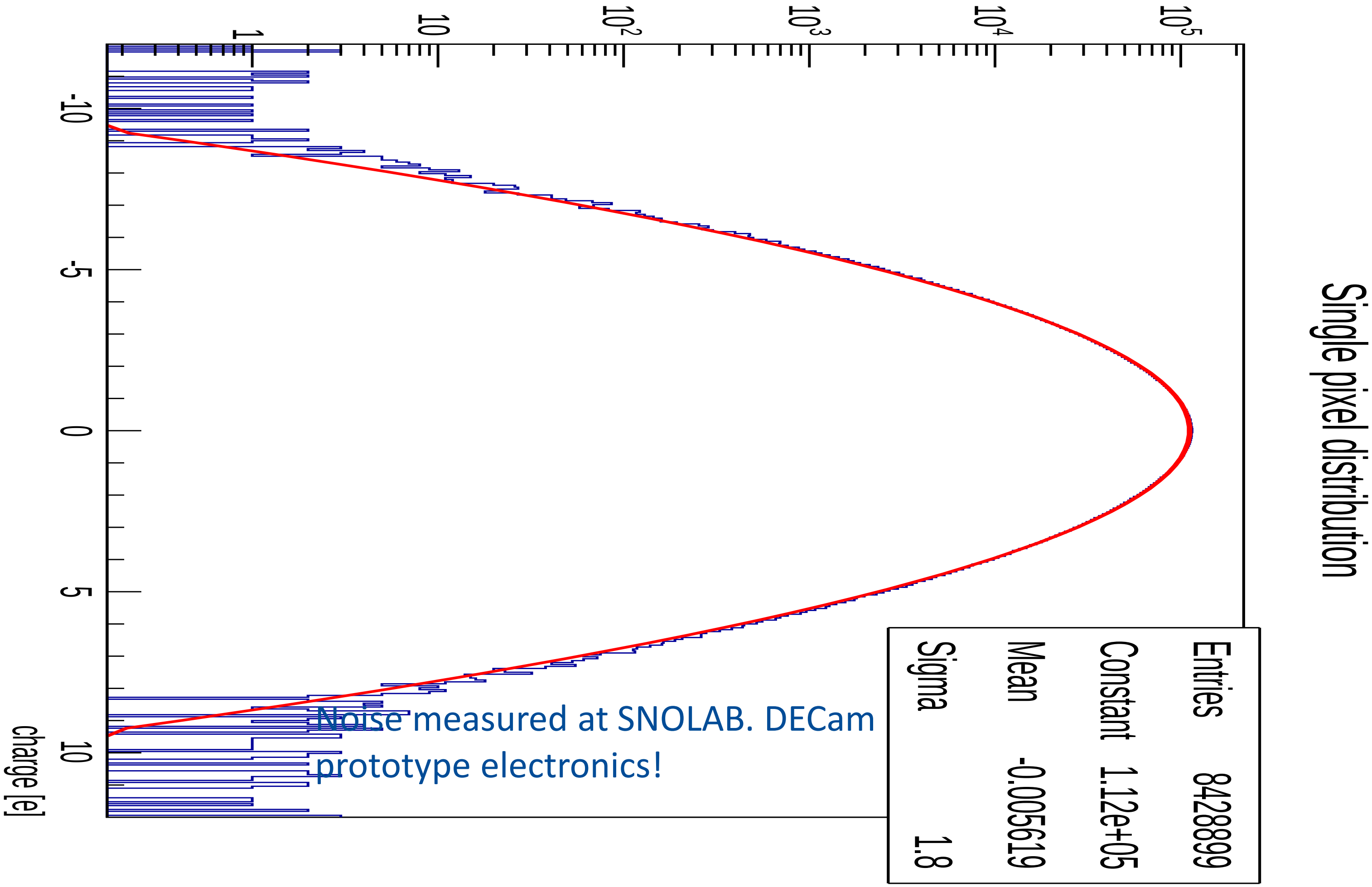
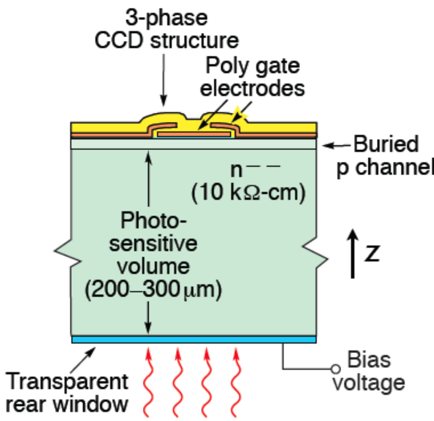
1.8 e- RMS noise: this is what makes DAMIC unique:



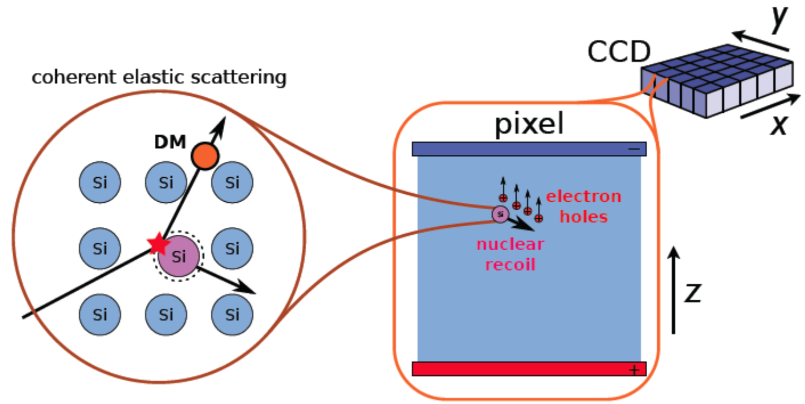
Noise measured at SNOLAB. DECam prototype electronics!

1e ≈ 3.6eV → 40eV threshold is possible (x10 lower than closer competitor)

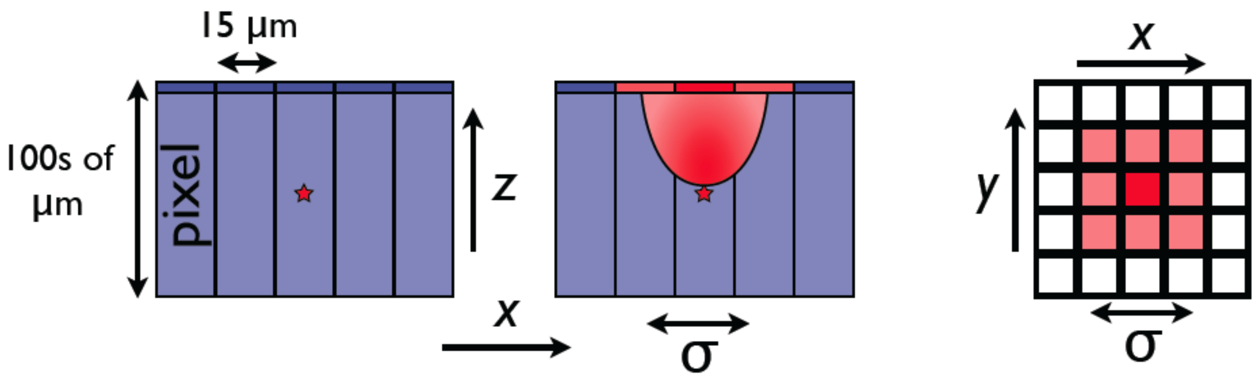
Enabling Technology : thick CCD detectors



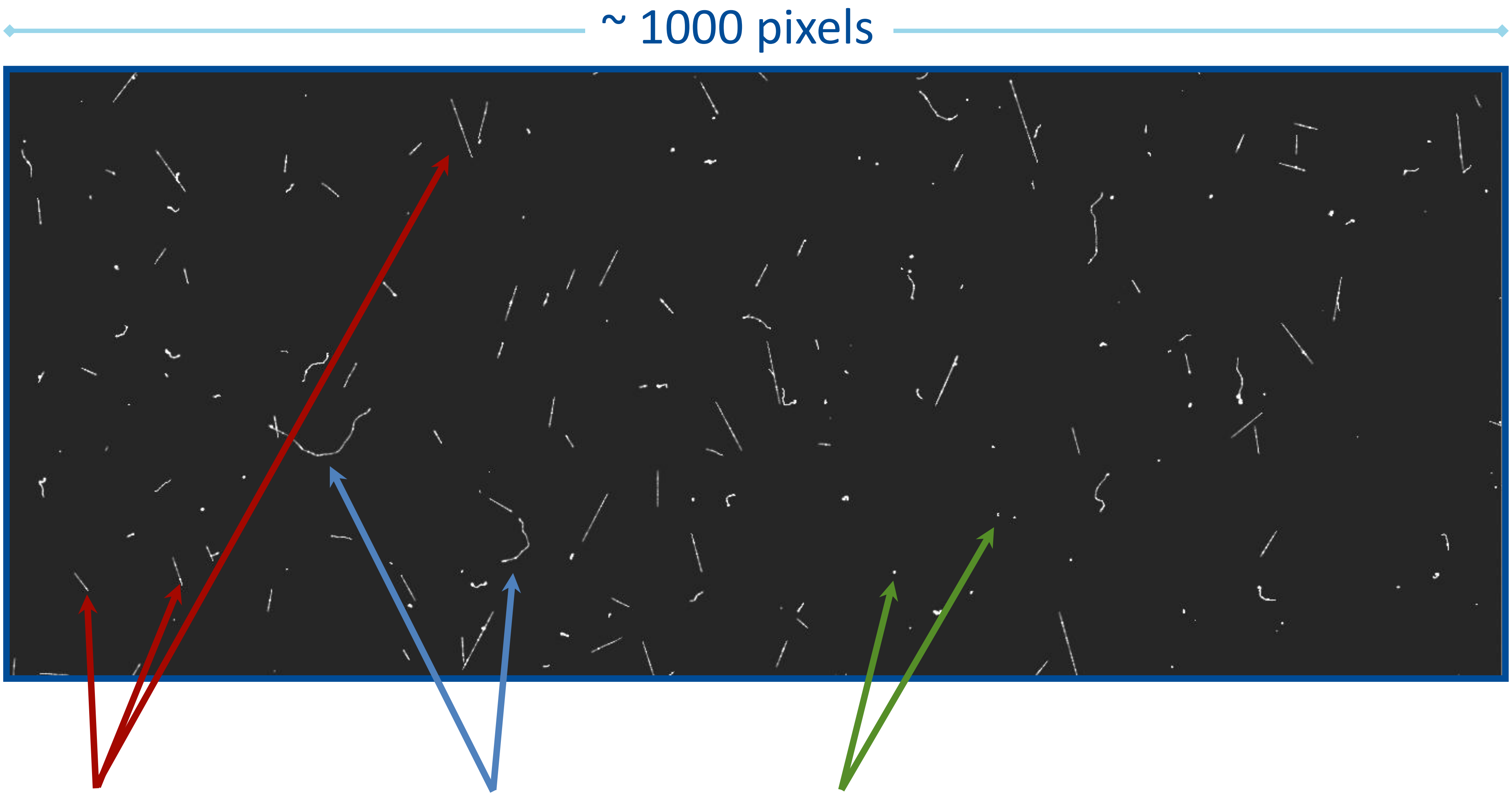
(a) A CCD pixel



(b) WIMP detection principle



[DECam detectors](#) are 250um thick and 8 Mpix, 1g per CCD. DAMIC started with this.
DAMIC-100 is now going to 675 um thick and 16 Mpix, 5.2g per CCD. In 2014 installed the first 675um detectors, provided by **[LBNL](#)** to test the concept.



muons, electrons and diffusion limited hits.

nuclear recoils will produce diffusion limited hits

Dark Matter is expected to produce nuclear recoils

Collaboration : started forming in 2012, formalized 2013

Two universities from the US, one National Laboratory and 5 institutions from abroad.

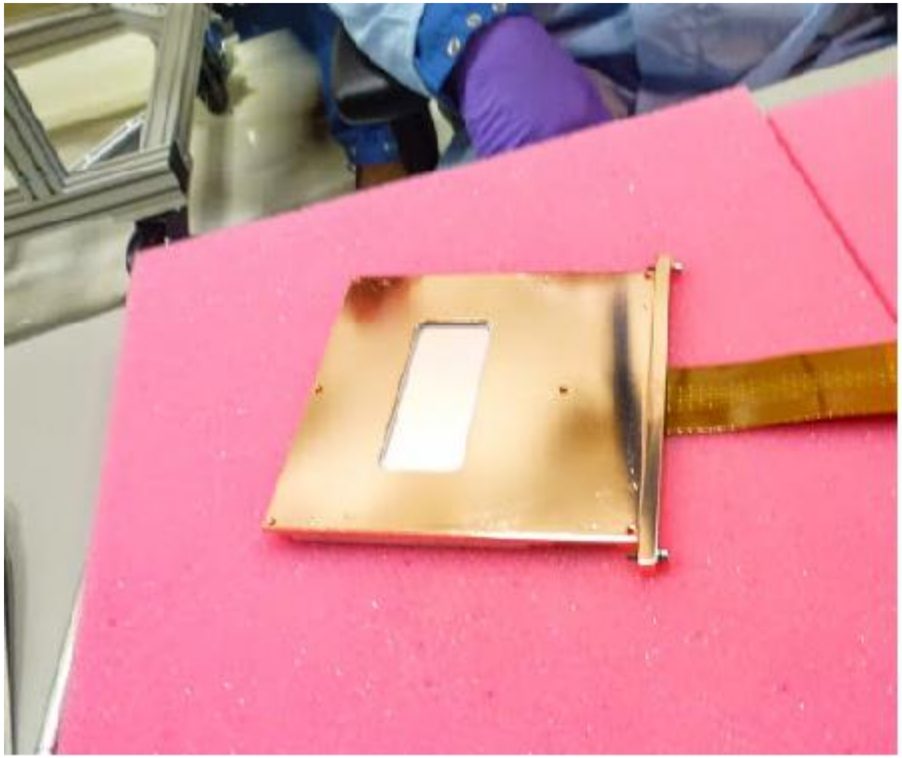
Centro Atomico Bariloche, Argentina : Xavier Bertou
Fermi National Accelerator Laboratory, USA : Gustavo Cancelo, Juan Estrada
Universidad Federal Rio Janeiro, Brazil: Joao de Mello Neto
Universidad Nacional de Asuncion, Paraguay: Jorge Molina
Universidad Nacional Autonoma de Mexico: Alexis Aguilar, Juan Carlos D'Olivo, Frederic Trillaud
University of Chicago , USA : Paolo Privitera
University of Michigan, USA : Tom Schwarz, Dante Amidei
University of Zurich, Switzerland: Ben Kilminster

Spokesperson: Dr. Juan Estrada (FNAL)
Collaboration Board Chair: Prof. Ben Kilminster (U. of Zurich)
SNOLAB Experimental Forum Representative: Prof. Paolo Privitera (U.Chicago).
Technical Coordinator: Dr. Javier Tiffenberg (FNAL)
Analysis Coordinators: Dr. Alvaro Chavarria (U.Chicago) and Dr. Javier Tiffenberg (FNAL).

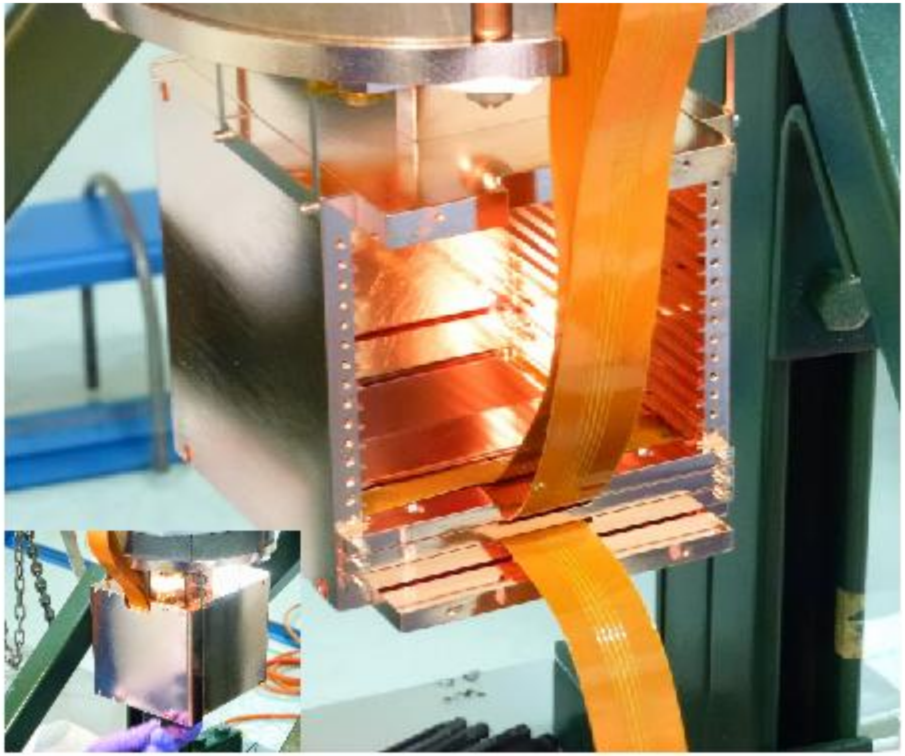
DAMIC Collaboration Contributions

Institution	PI	DAMIC-100 construction	DAMIC-100 running
CAB, Argentina	Xavier Bertou	Data analysis, CCD test	Data analysis, nulear recoil calibration
Fermilab, USA	Juan Estrada	½ CCDs, CCDs packaging and test, cryog., vacuum vessel, DAQ, Data analysis, slow control, poly and lead shield.	Install., commissioning, Technical coord., Data Analysis coord., nucl. recoil calibration
U. Chicago , USA	Paolo Privitera	½ CCDs, CCDs test, ancient Lead, Si supports, screening, UPS, Data analysis, MCNP simulation	Install., commissioning, Data Analysis coord., MCNP simulation, nucl. recoil calibration
UFRJ, Brazil (joined August 2014)	Joao de Mello Neto	UPS, slow control	Slow control, MCNP simulation, Data analysis
U. Michigan, USA	Tom Schwarz	CCD box, CCD packaging parts, DAQ, CCD test, readout cable assembly	DAQ, nucl. recoil calibration, Data analysis
UNA, Paraguay	Jorge Molina	GEANT4 simulations	GEANT4 simulation, Data analysis
UNAM, Mexico	Juan Carlos D'Olivo	CCD test, readout cable	Data analysis
U. Zurich, Switzerland	Ben Kilminster	Lead shield, cable assembly, CCD test	nucl. recoil calibration, Data analysis

Experimental Design : Sensors



Thick CCDs
16 Mpix , 675 um thick, 5.2 g
(8Mpix prototype shown here)



Stack of 18 CCDs
(8 sensor prototype shown here)

Experimental Design: Shield

Stack mounted inside copper vessel. Inner lead shield inside vacuum. Detectors operated at -140C. Innermost inch using ancient lead.

Copper vessel inside lead and poly shield.

Location

Installed at SNOLAB at the end of 2012.

Great support by the SNOLAB technical staff. Daily operations supported by SNOLAB personnel at no cost to the project.

Experimental Design

Experiment in a truck at Fermilab 11/2012.

Upgrade 12/2014

Nitrogen gas bag. 12/2014

Typical DAMIC upgrade mission (1 week)

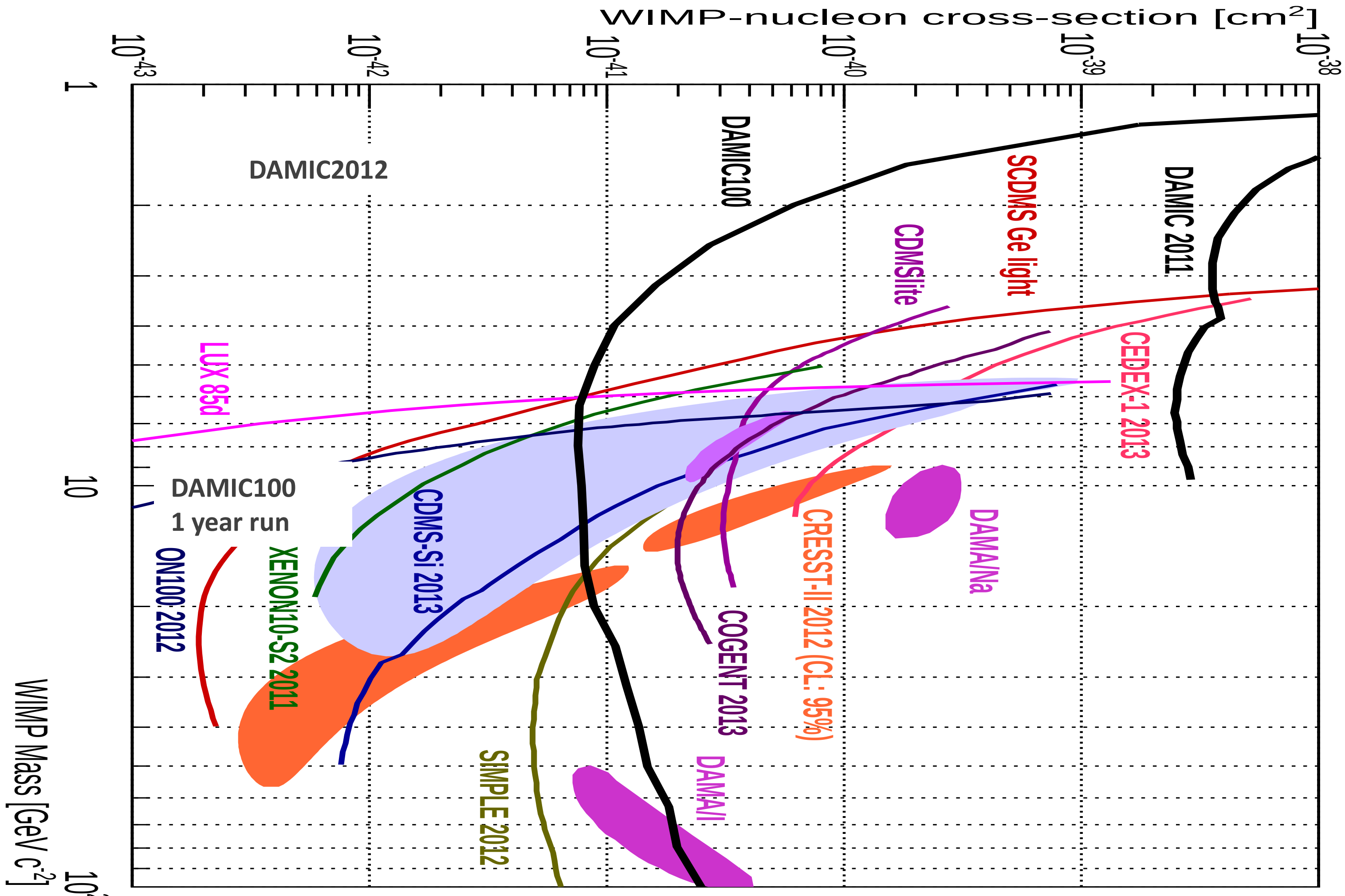
- Weekend
  - Warmup
- Monday:
  - Early team arrives to take shield apart
- Tuesday:
  - CCD team arrives
  - vessel out of shield
  - Open vacuum vessel
- Wednesday:
  - Work inside vacuum vessel (reduced number of people)
  - Install more CCDs (for example)
- Thursday:
  - Close vessel
  - Cooldown with partial Shield
  - Check status overnight
- Friday:
  - Finish closing shield

This usually involved some FNAL technical personnel, and scientific staff from FNAL and U.Chicago.

DAMIC timeline

- 2010-2011 Test at NuMI detector hall FNAL (350' underground)
  - Single DECam engineering CCD.
  - Active mass = 0.5g
  - No neutron shield
  - **Publication showing the potential of the technology (DAMIC 2012)**
- 2012 SNOLAB (6800' underground)
  - DECam engineering grade CCDs.
  - Active mass ~10g.
  - Limited by background in CCD package (ceramic) + lead shield.
  - **<u>Collaboration starts forming</u>**
- 2014 Upgrades at SNOLAB (**DAMIC-100 R&D**)
  - Silicon only package (no ceramic)
  - Ancient lead introduced in the inner shield (U.Chicago)
  - 675 um thick CCDs (not DECam anymore)
  - Active mass ~ 10g
  - **<u>Well established international Collaboration</u>**
  - **<u>Preliminary results shown today.</u>**
- Now
  - Moving to 100g.
  - Unpackaged sensors in hand at FNAL.
  - Installed last week a copper box for 18 CCDs filled with 4 sensors
  - Improves Nitrogen purge.
  - Completion of 100g upgrade expected for Summer 2015.

DAMIC100 sensitivity



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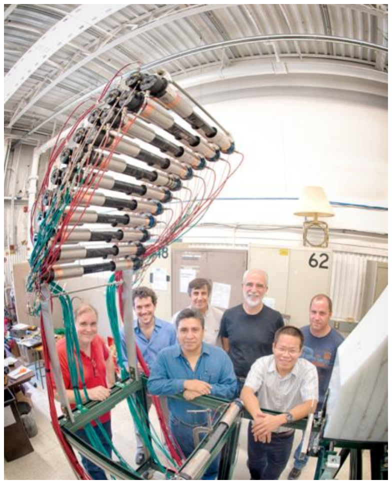
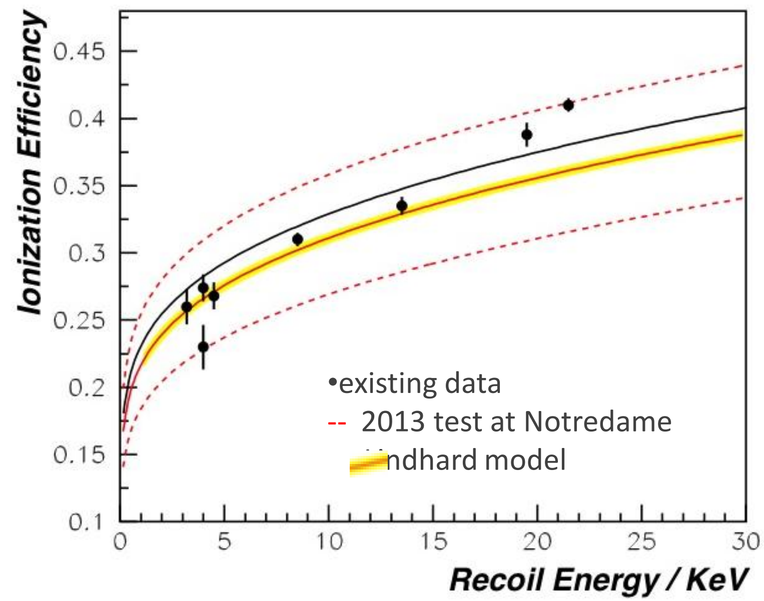
Lower threshold requires new calibration (5 efforts)

At this low threshold the quenching calibration is critical, and there no measurements below 4 keV. Ongoing efforts to do the measurement at.

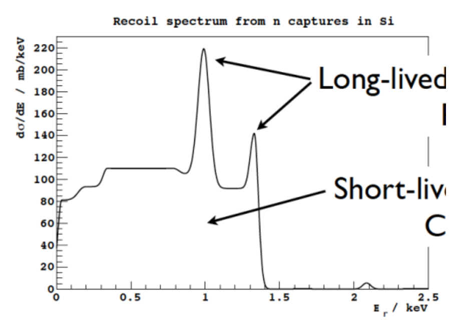


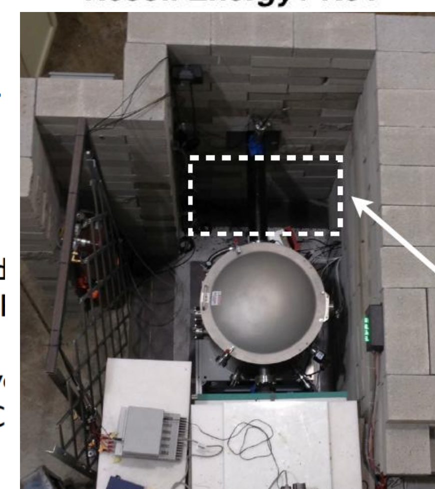


1)Neutron recoil experiment using beam at Notredame (FNAL/Michigan/Zurich /Guanajuato/FIUNA).

2)Detector activation at proton therapy facility (Warrenville,IL) to produce low nuclear recoils inside CCD. (FNAL/Chicago/UNAM).

3)Thermal Neutron capture in Si at reactor (Chicago/UFRJ/CAB)





4)Monochromatic neutron source (Chicago)
5)Silicon ions on CCD (CAB)
Funded by Collaborators (non-HEP) with some scientific involvement of FNAL.

DAMIC schedule - milestones

We are upgrading to 100g active mass. All the sensors have been fabricated, and are in hand waiting for packaging.

Strategy:
Package prototypes ➔Check background at SNOLAB ➔package a few more

1. **12/2014 (10g)** Installation of four DAMIC-100 prototypes in their final packaging at SNOLAB.
2. Evaluation of performance of prototype sensors in Milestone 1. Date: 2/2015
3. **4/2015 (32g)** Installation of four DAMIC-100 CCDs, 16 Mpixel sensors, at SNOLAB.
4. Evaluation of performance detectors installed in Milestone 3. 6/2015
5. **9/2015 (100g)** Installation of remaining DAMIC-100 detectors at SNOLAB
6. **12/2015.** Publication of result for DM search with intermediate exposure.
7. **9/2016 (30 kg-day)** Completion of 1 year run
8. **2017**. Publication of result for DM search with exposure full data set.

The fabrication of DAMIC-100 packages follows the schedule imposed by the top-level milestones. This requires the fabrication of four 8Mpix prototypes by December 2014. If good results are obtained from these prototypes, 16 Mpix detectors will be fabricated for installation in 4/2015. With the full production starting in 5/2015 for a complete installation of 100g of active mass in 9/2015.

After DAMIC-100

The current plan is to run 1-year at SNOLAB with 100g. This run will end in 9/2016.
What happens after this:

- Case 1 (extended run):
  - Results are not background limited, and the collaboration DAMIC decides to keep running without any change.
  - This requires agreement with SNOLAB.
  - Funding: repeat FY16.
- Case 1+ (extended run with upgrade):
  - The collaboration decides to upgrade.
  - Options here include lower threshold (skipper CCD or higher gain amplifier), or more massive detector.
  - In this case a new proposal will be submitted.
- Case 2 (baseline costed in budget presented for this review):
  - The collaboration decides the experiment is done
  - Decommissioning costs as submitted in the documentation for this review ($20k).

Conclusion

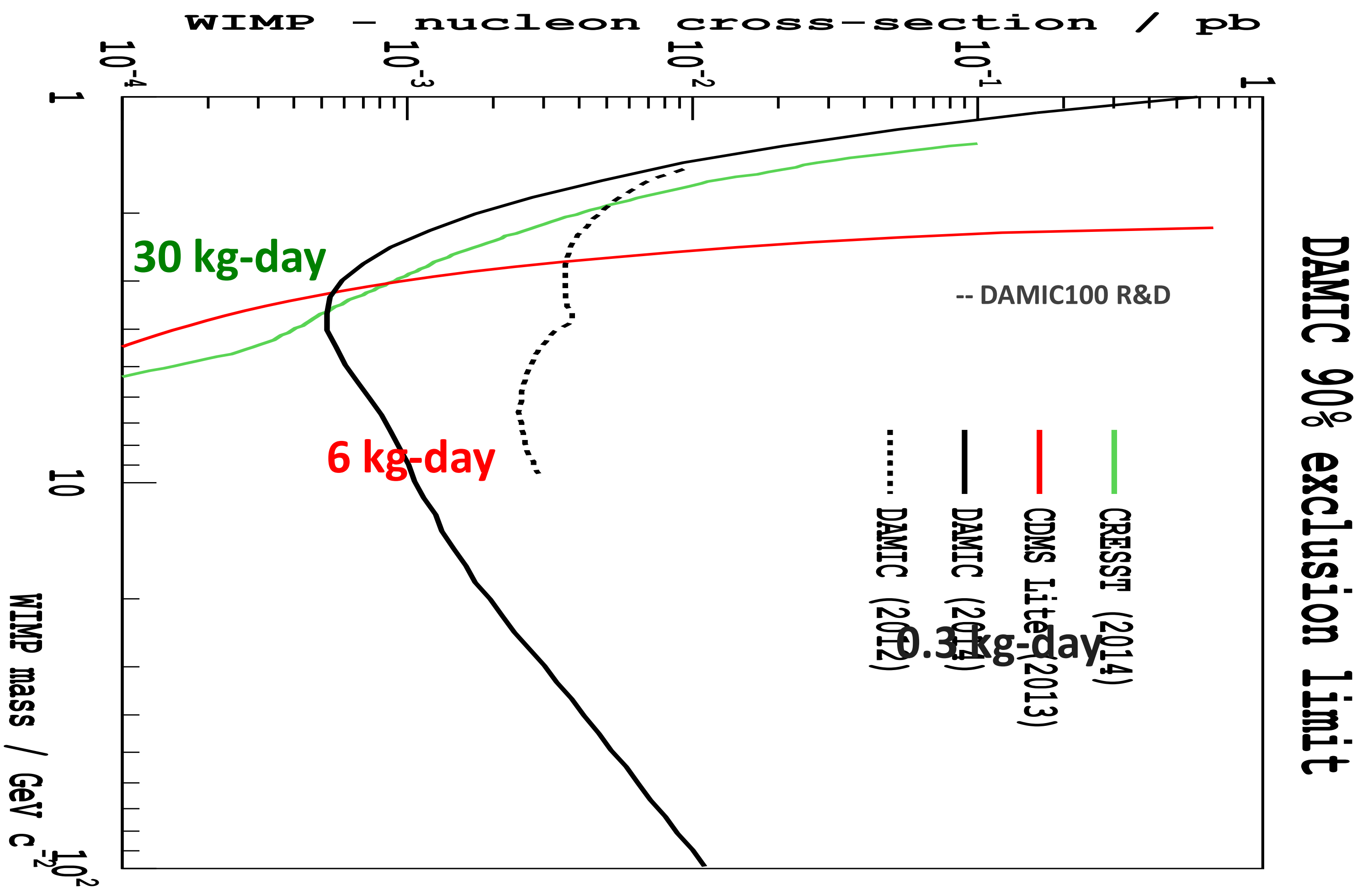
- DAMIC is successfully operating at SNOLAB since 2012.
- Strong international collaboration behind experiment.
- Successfully producing world leading results in low mass dark matter searches (see next talk by J. Tiffenberg).
- Now upgrading to 100g active mass.
- Asking HEP for support to finish the upgrade, and to operate for one year.

DAMIC Science

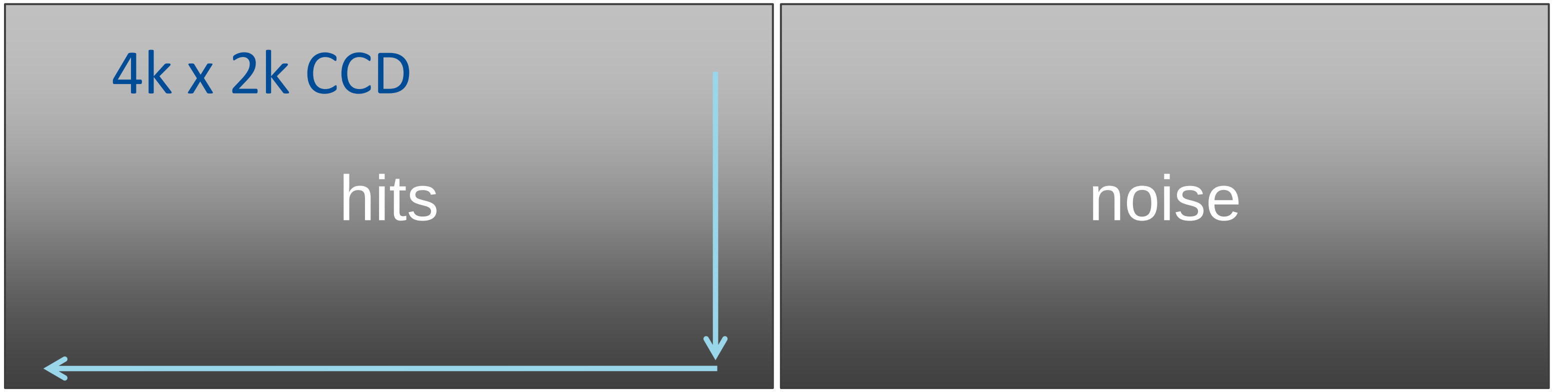
DAMIC Science

…will do it backwards.
Show the result first, and details later.

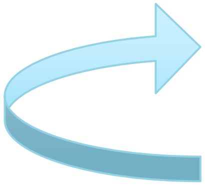
DAMIC Preliminary result – Best world limit @ low mass



Data Collection

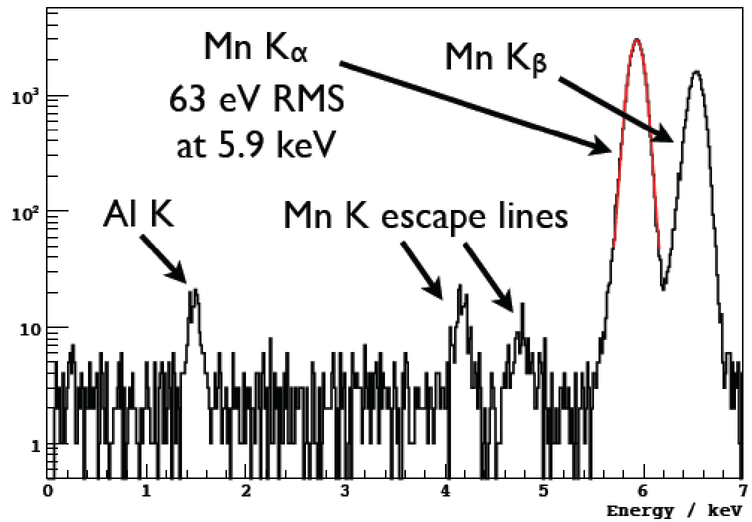


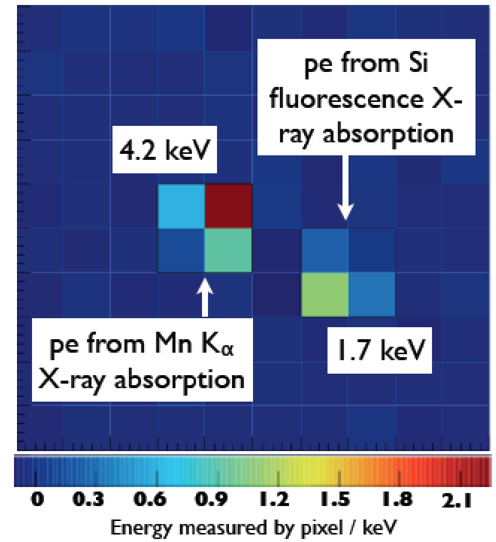
The detector has two readout channels.
Move the charge for all the pixels to one channel.
The second channel is used to monitor noise.

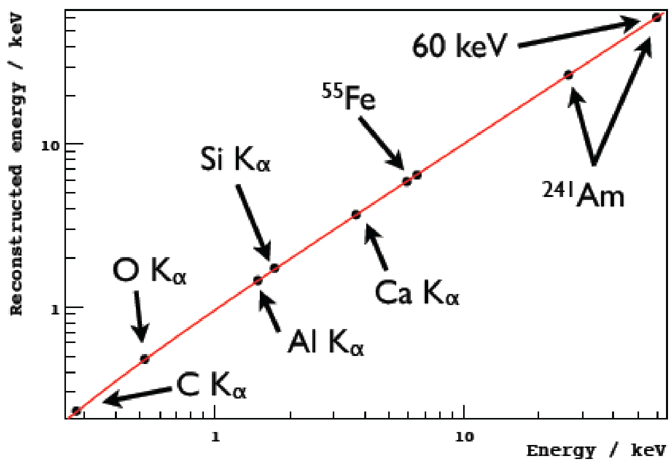


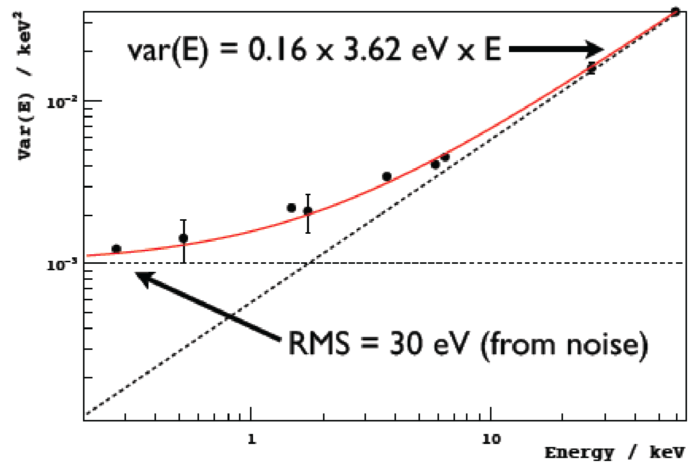
Read - blank
Wait 10,000 sec
Read – exposure with hits
Read - blank

Calibration









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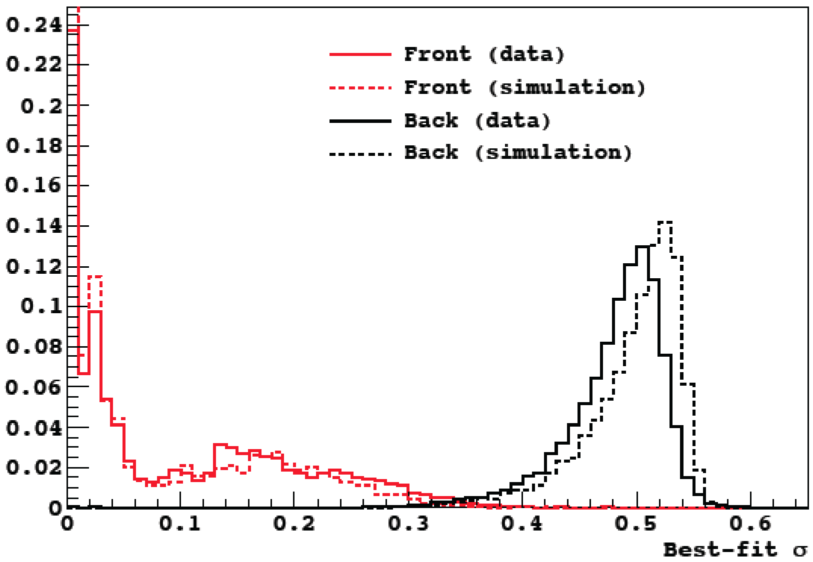
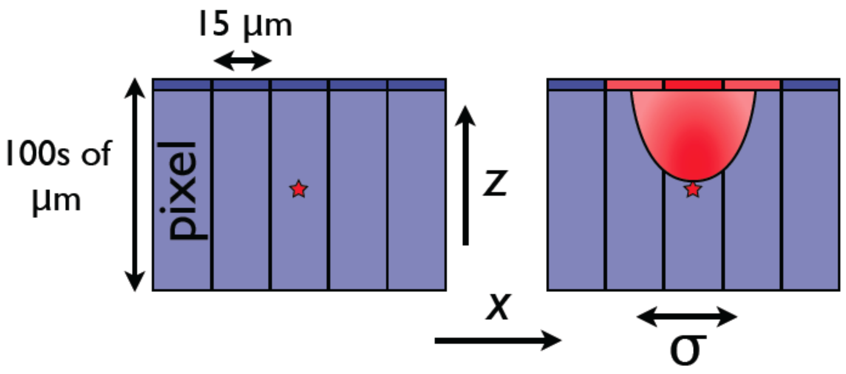
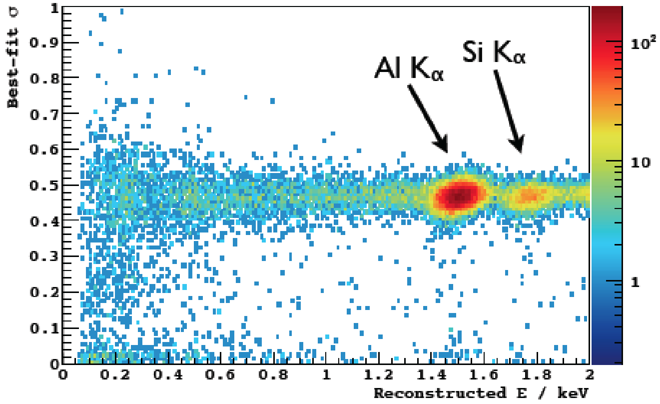
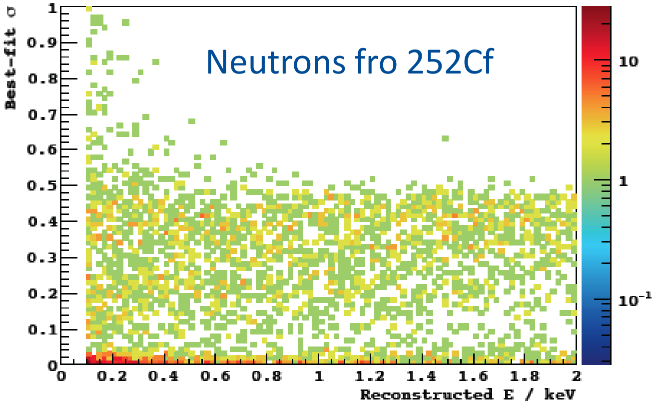
Calibration – Diffusion

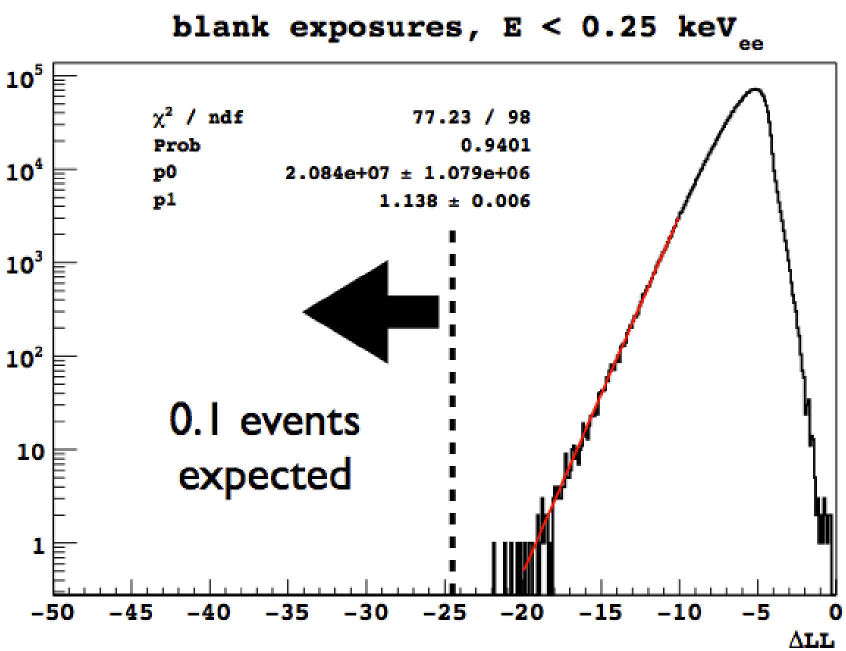


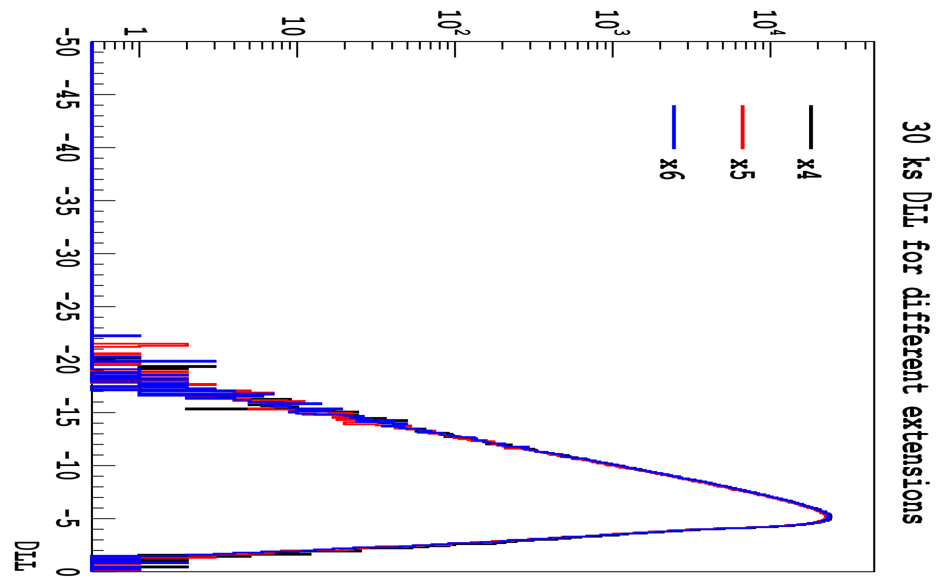






Data Analysis





Likelihood difference between noise and 2D Gaussian hit. Blanks, with no real hits, are used to determine cuts.

3 CCDs used for this analysis (one was not working well). Look very similar to blanks.

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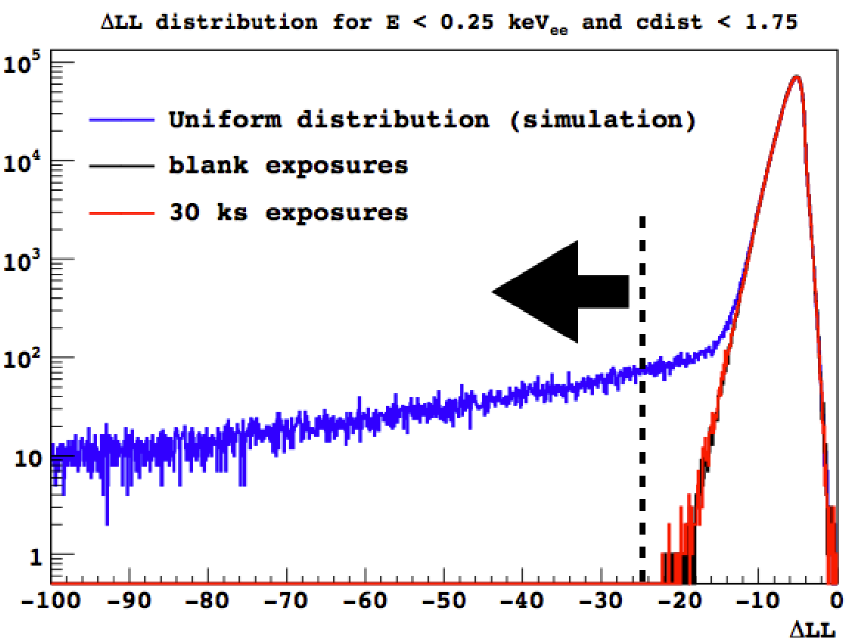
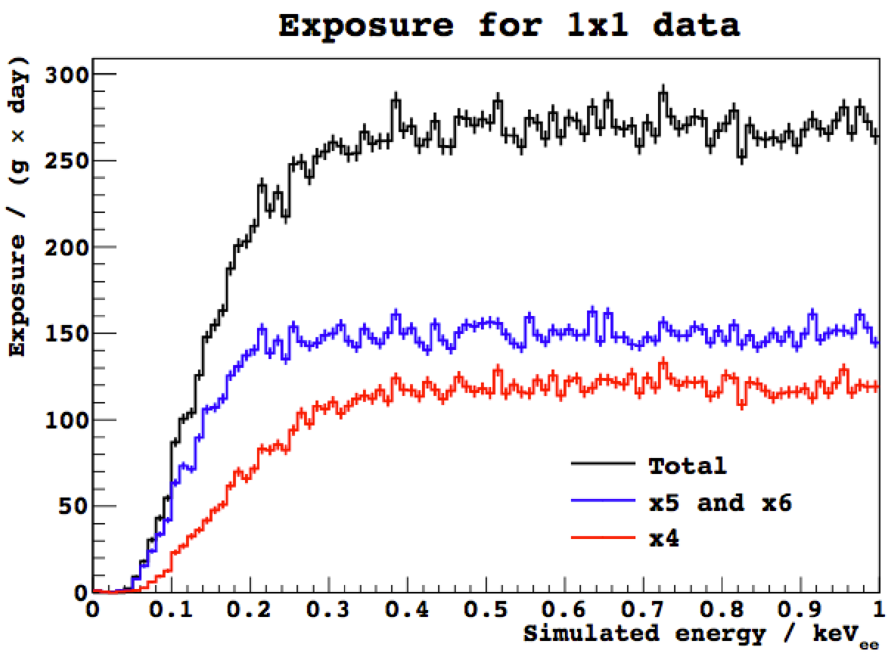
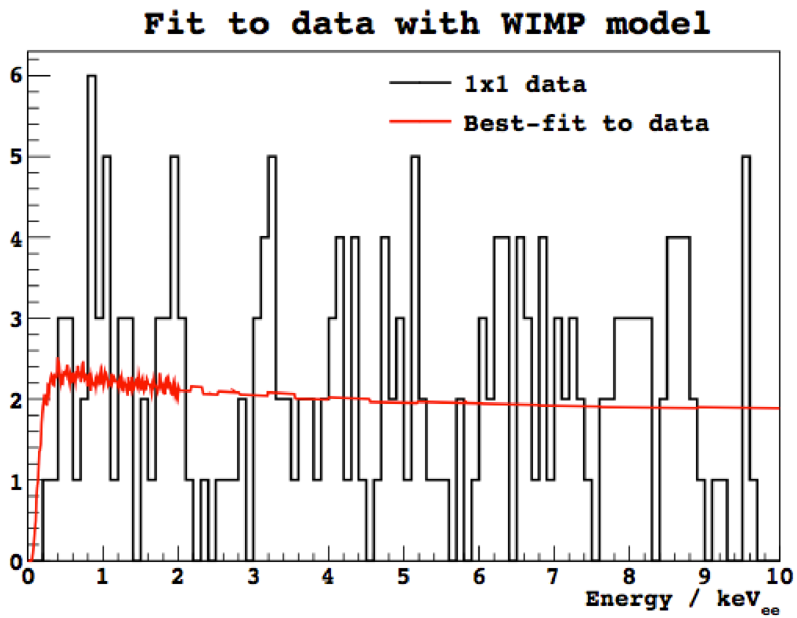
Data Analysis





Simulation used to estimate the efficiency down to threshold.
Based on this efficiency, an exposure is calculated.

No wimp detected



Best fit mass: 26 ± 46 GeV/c^2
Best fit xs: (7 ± 16) x 10^{-4} pb
Best fit c: 67 ± 13 dru
Minimum -ll: -396.5

Null hypothesis c: 74 ± 5 dru
Minimum -ll: -396.1

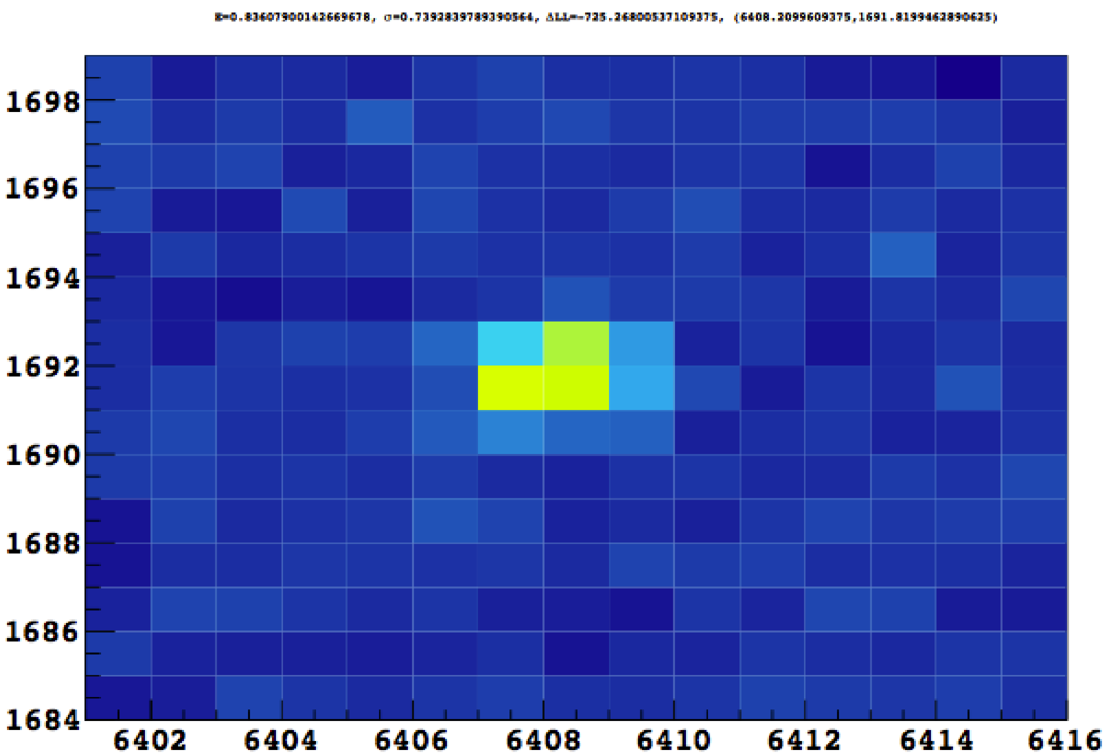
Background is still high.
We associate this to Randon in the volume around the lead shield.

We have a nitrogen gas purge, but it is not performing as it should.

Upgrade last week to address this purge performance.

Two unique capabilities in the DAMIC detector, not used for the preliminary result yet. However, they demonstrate the flexibility of this technology.

DAMIC binning:



Every pixel readout has a 2e- noise. The CCD allows you to add charge in the sensor (binning) and then readout many pixels as a single one.

This improves signal to noise, effectively increasing the efficiency at low energy.

s/n = Q / Nread σ

Reading the charge in less pixels is good!

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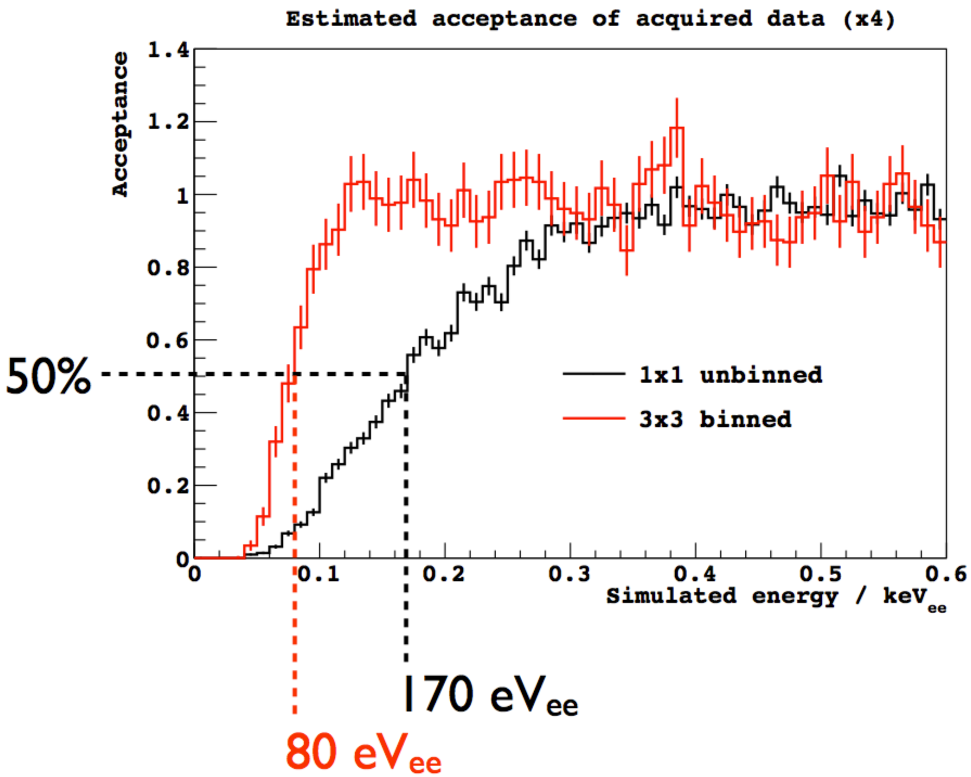
DAMIC binning: the best is yet to come



Every pixel readout has a 2e- noise. The CCD allows you to add charge in the sensor (binning) and then readout many pixels as a single one.

This improves signal to noise, effectively increasing the efficiency at low energy.

Binned data not used for preliminary result shown here.

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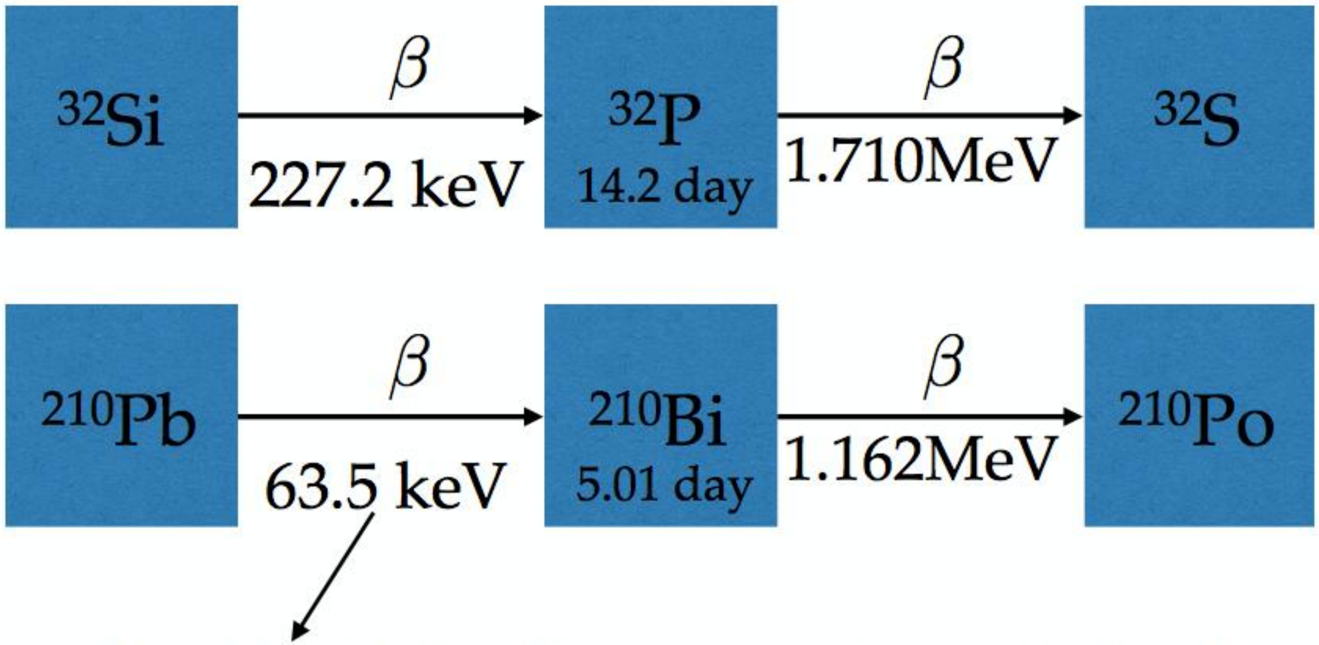
Background from Silicon : could be a limiting

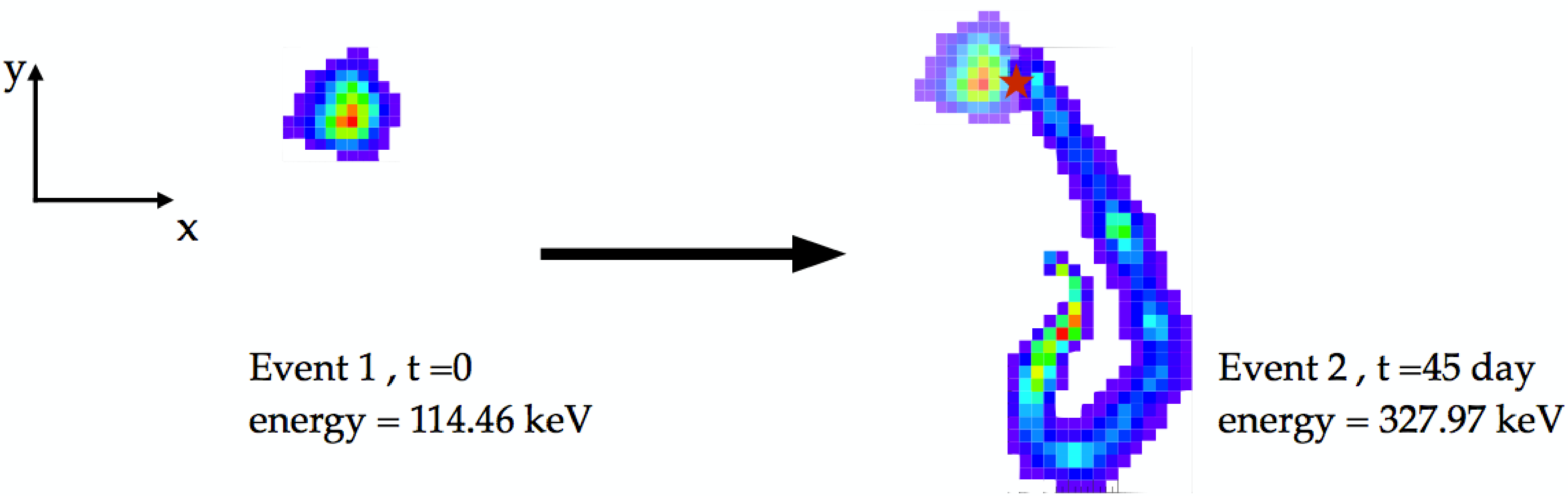


Q-value: 63.5 keV, 84% of betas with endpoint 16.5 keV, the rest energy 4% a gamma line, so, 80% would go to conversion electrons with energy around [47,63.5] keV.

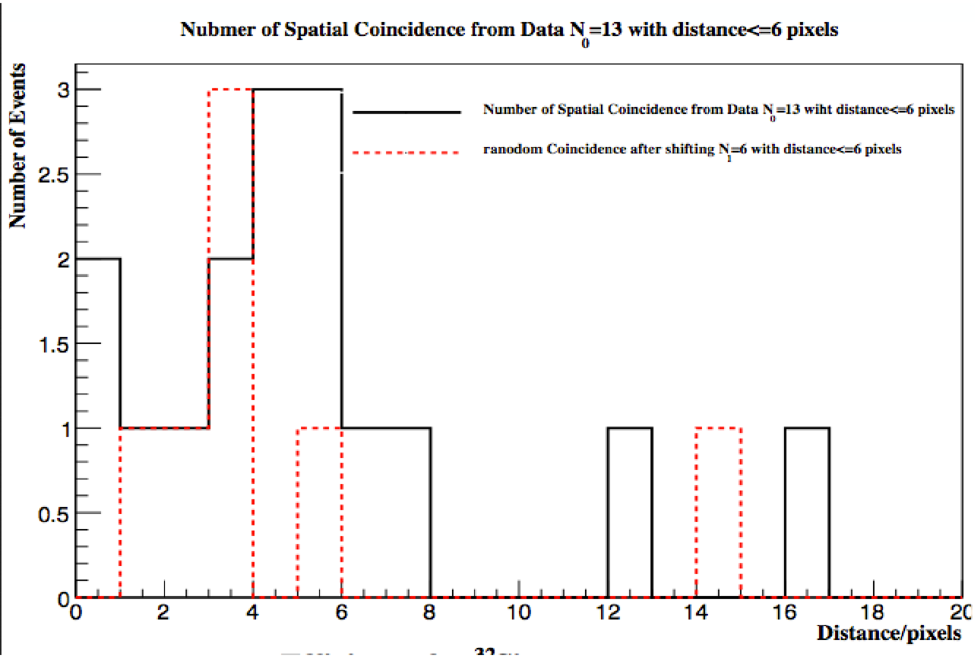
Background from Silicon

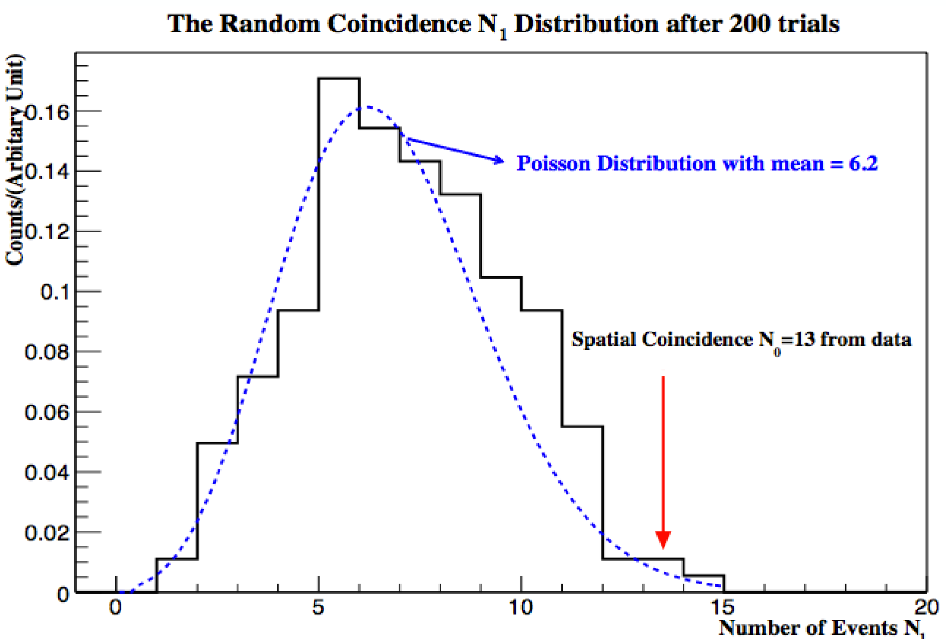
The precise position reconstruction in the CCDs allows us to study spatial coincidences of those decay chains and give a limit of ^{32}Si and ^{210}Pb in the CCD.

$^{32}\mathrm{Si} \longrightarrow ^{32}\mathrm{P} + \beta^{-}$, Qvalue $= 227.2$ keV $^{32}\mathrm{P} \longrightarrow ^{32}\mathrm{S} + \beta^{-}$ with $\tau = 14.2$ days, Q $-$ value $= 1.71$ MeV



Background from Silicon





The pixilation of the DAMIC detector allows us reject this background. This is a unique capability of the DAMIC sensors. Lower background expected in DAMIC-100 will make this measurement better, less accidental coincidences expected.