Simulation and analysis of the LUCID experiment in the Low Earth Orbit radiation environment

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A brief history of LUCID

In 2008, the **Simon Langton Grammar School for Boys** entered a satellite experiment design competition run by the British National Space Centre (now **UK Space Agency**) and **Surrey Satellite Technology Limited** (SSTL).

- The Langton Ultimate Cosmic ray Intensity Detector (LUCID) would use Timepix detectors, developed by the Medipix Collaboration, to measure the space radiation environment in Low Earth Orbit.
- Designed by students, built by SSTL, now due to launch in February 2014.
- LUCID now part of CERN@school, supported by UK Science and Technology Facilities Council (STFC) Large Award ST/J000256/1.

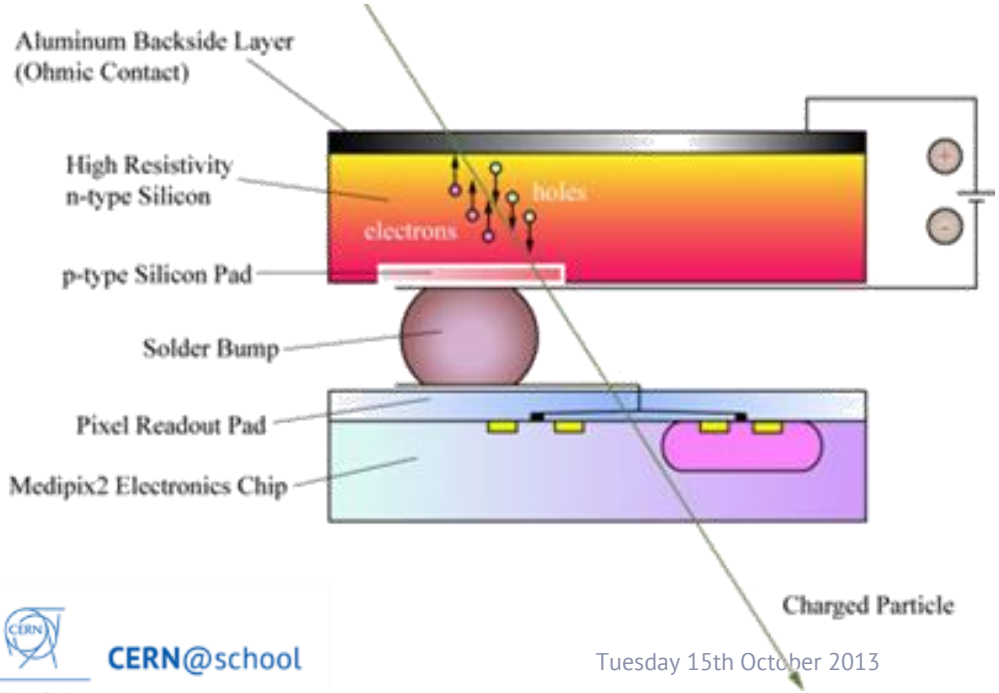
Overview

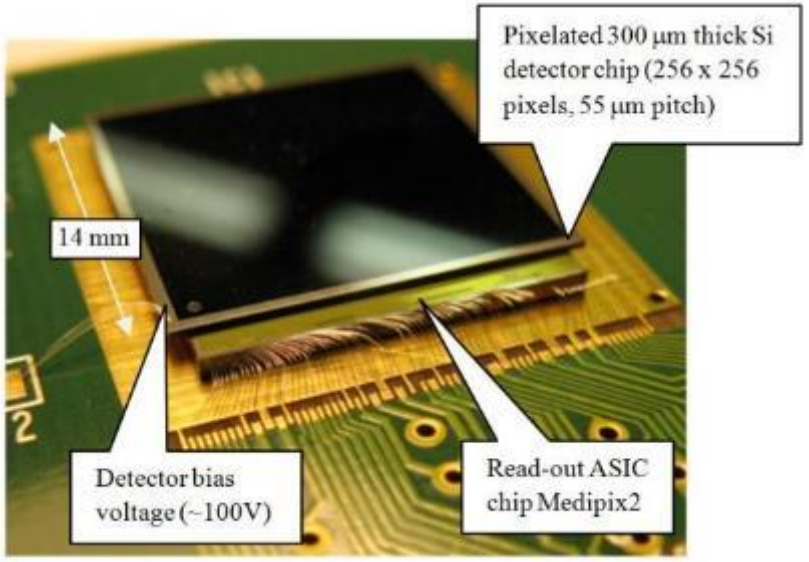
- Introduction:
  - *A brief history of LUCID, the Timepix detector, the LUCID experiment, TechDemoSat-1.*
- Simulating LUCID:
  - *GEANT4, experiment geometry, particle sources from SPENVIS, simulation management.*
- Simulation results:
  - *Trapped protons, trapped electrons, estimated data rates, discussion, further work.*
- Summary and conclusions.

The Timepix detector

The Timepix hybrid silicon pixel detector (Llopart et al. 2007), developed by the Medipix Collaboration, features a 300 μm thick silicon sensor bump-bonded to a Timepix readout chip. 256 × 256 pixels of pitch 55 μm provide 65,536 readout channels from the 1.98cm^2 sensor element.

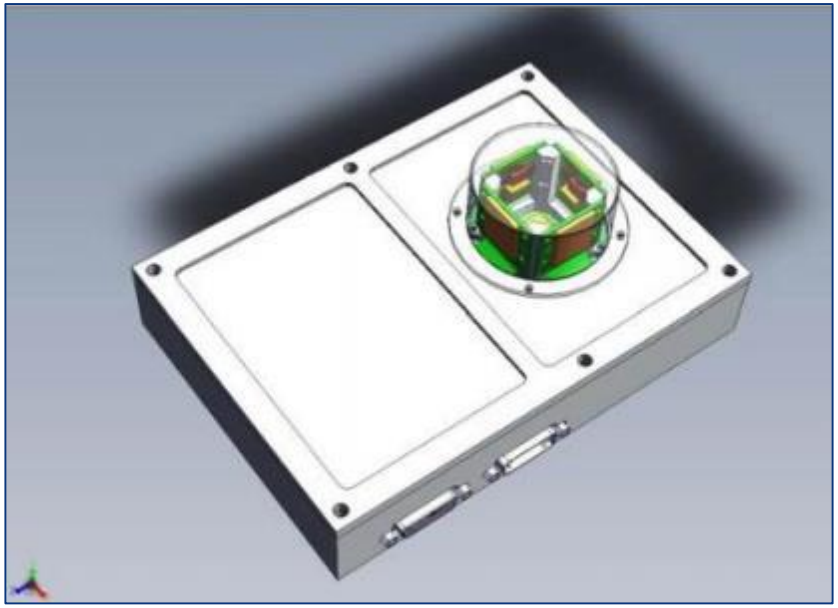
It can be used to detect ionising radiation, make energy measurements (with calibration) and perform particle identification (to an extent). It has never been used in ***open space***.





The LUCID experiment

The Langton Ultimate Cosmic ray Intensity Detector experiment features five Timepix detectors in an open-faced cube, housed in a ~0.7mm aluminium "dome", to measure the LEO radiation environment.



Data taking/transmitting capabilities:

- Shutter frequency: ~4Hz
- Transmission: 80Mbs^{-1} (20Mbs^{-1});
- Storage: 2GB;
- Operational 2 out of every 8 days.

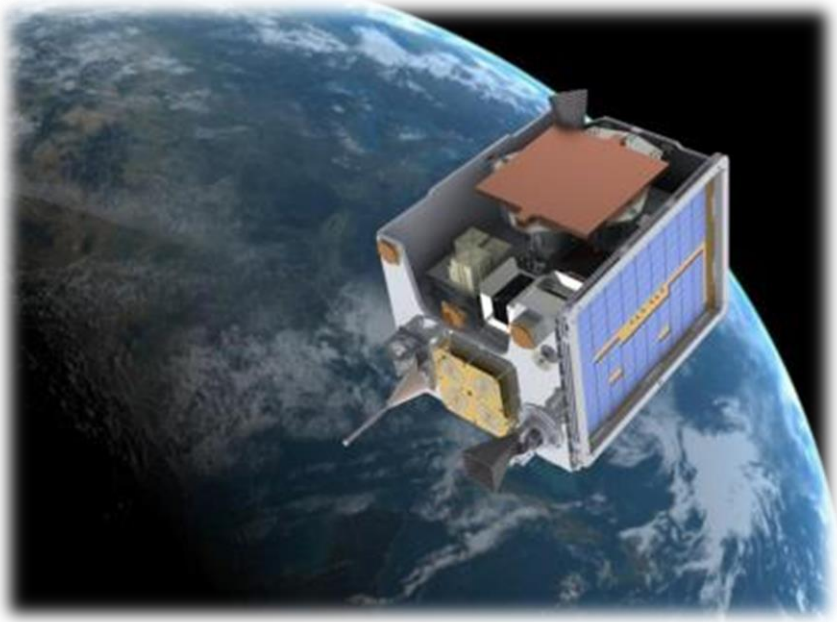
TechDemoSat-1

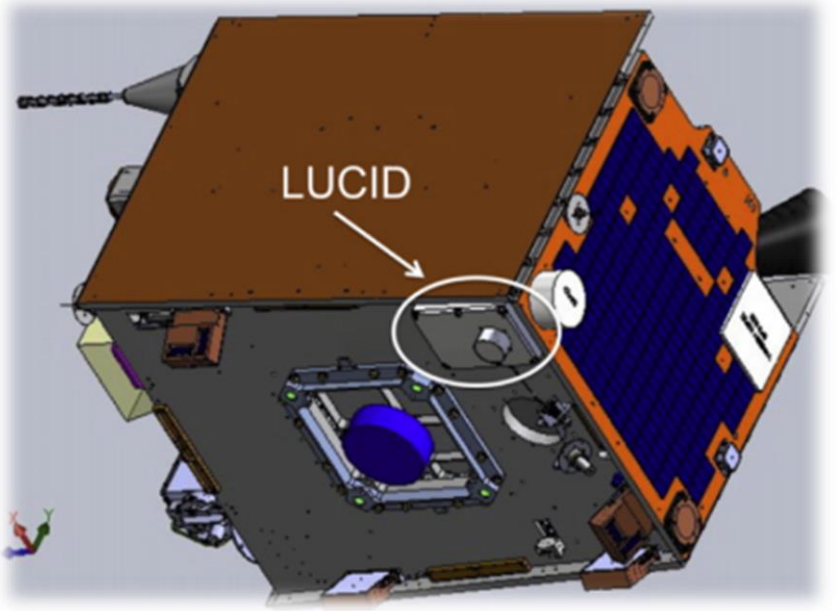
LUCID will launch aboard **TechDemoSat-1** from Baikonur Cosmodrome aboard a Soyuz 2b launch vehicle in February 2014.

- TechDemoSat-1 is an "in-orbit test facility" from SSTL supported by the UK Technology Strategy Board;
- Many scientific payloads from UK academic institutions/labs, of which LUCID is one.

Orbit parameters

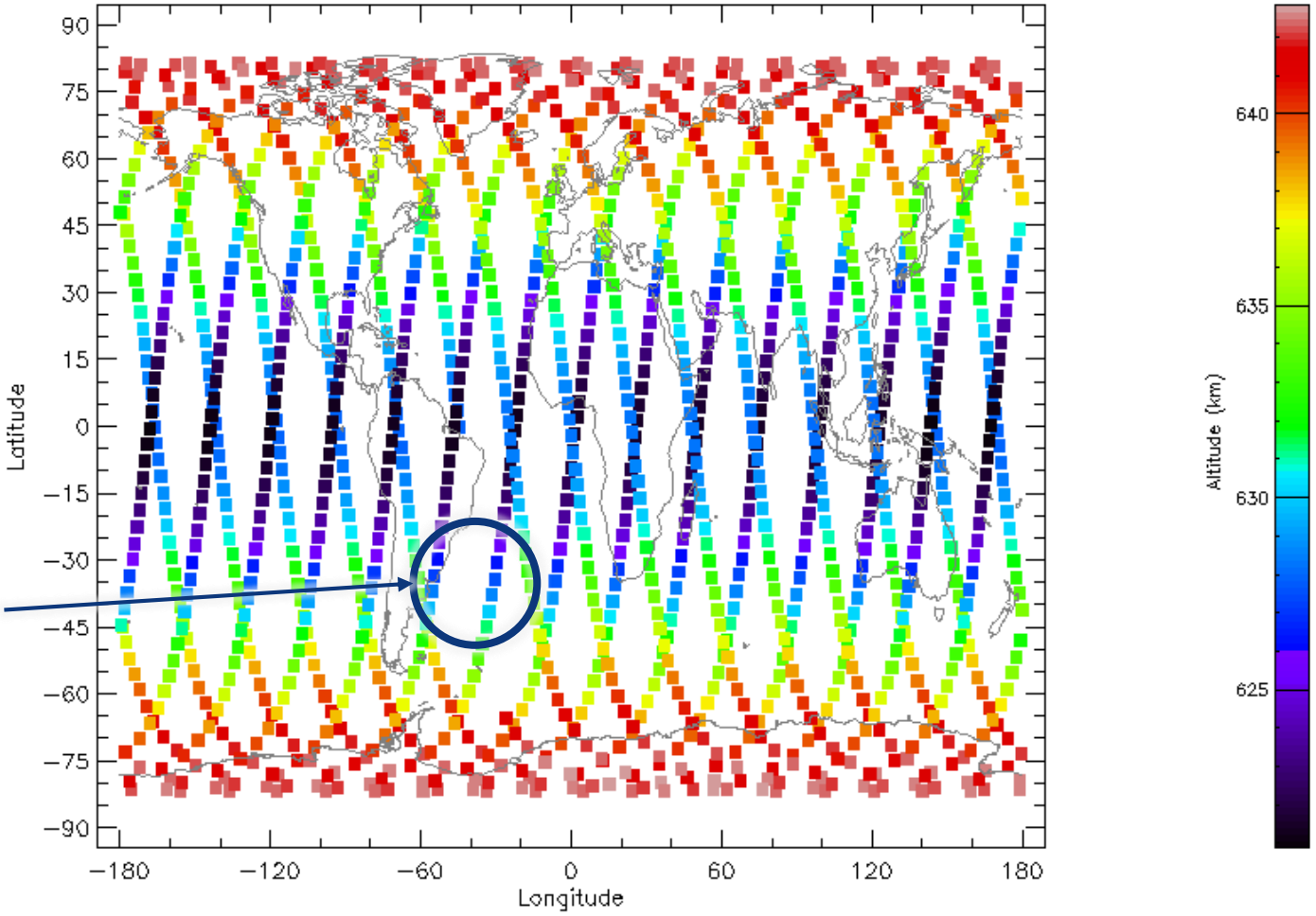
- *Altitude*: 635km;
- *Orbit*: sun synchronous;
- *Inclination*: 98.4°;
- *LTDN*: starts at 0900, with drift of 40 minutes per 6 months.
- *Dominant radiation sources*: trapped protons and electrons, outer electron belts (poles).





TechDemoSat-1

South Atlantic Anomaly (SAA)



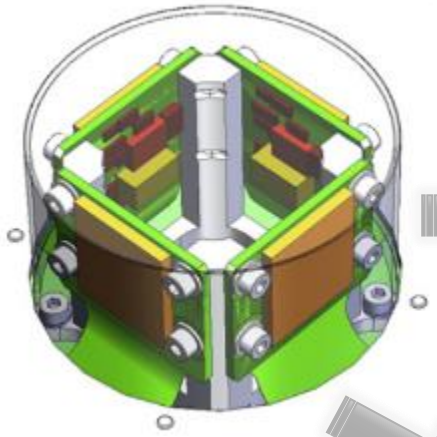
Aims and objectives

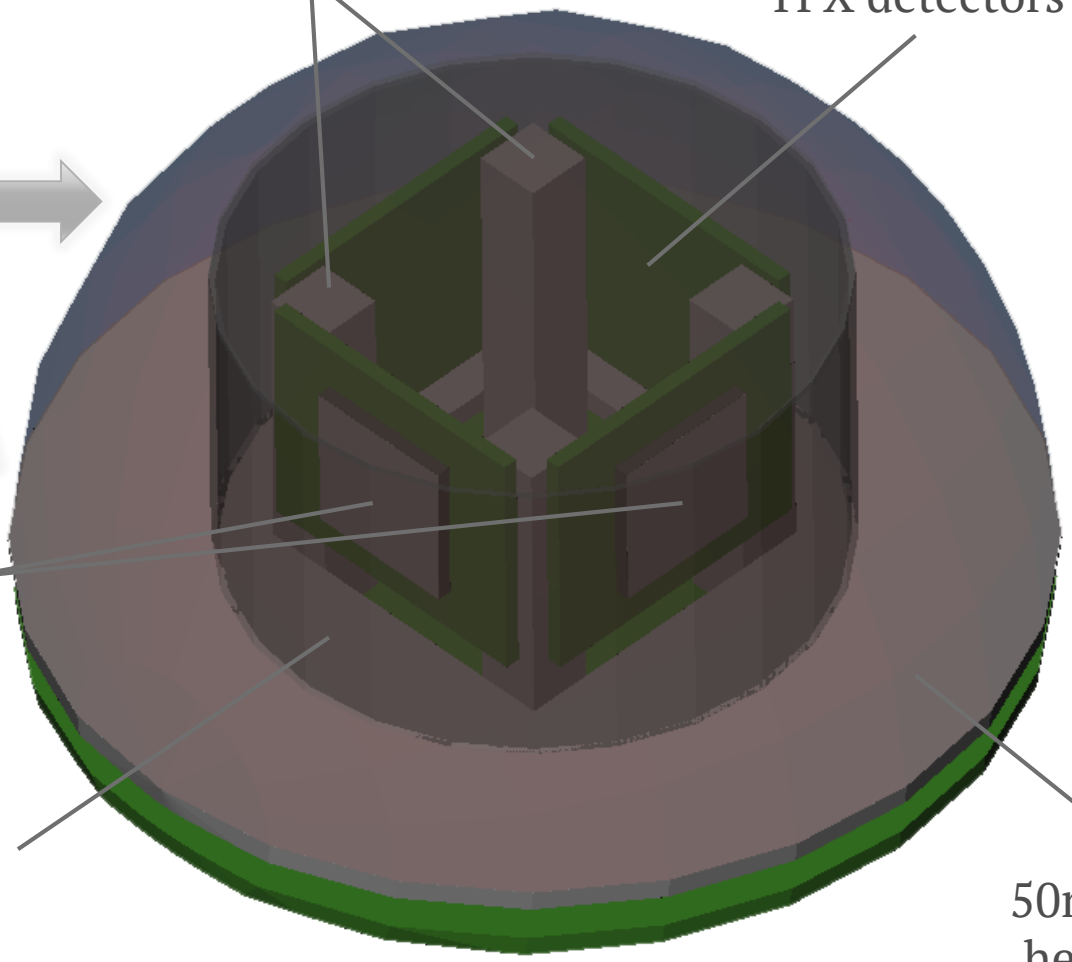
- Scientific goals of LUCID:
  - *Directionality of particles* (assumed to be isotropic):
    - Pattern recognition and estimate angle of incidence
  - *Particle spectra*:
    - Measure particle intensities and their change over time
    - Determine dose (J/kg) and LET spectrum
  - *Solar flares/SPEs*:
    - Difference in time between electron and proton surges
    - Log sun activity for mission life time (> 50% solar cycle)
    - Forbrush Decrease.
- Goals of the work presented here:
  - Provide estimates of the expected data rates that LUCID will see;
  - Establish modelling and simulation workflows for the experiment;
  - Groundwork for more complicated/computer intensive simulations.

Simulation with GEANT4

- **GEANT4** has been used to simulate the detector, its surroundings and the particle source(s) in order to obtain data rate estimates.
  - Particular inspiration from J. Idarraga (*CERN/Medipix*):
    - Allpix – full chain simulation of Medipix family (and others);
    - Ultimately, LUCID will be modelled with Allpix, but such detail is not needed for these estimates.
  - Method:
    - Model the experiment **geometry**;
    - Model the Low Earth Orbit **particle source(s)**;
    - Obtain pixel hit rates, combine with flux values to get [bs^{-1}] estimates.
  - The default GEANT4 physics settings have been used.

Geometry




Support posts
PCB mounts for TPX detectors
Timepix detectors (including TPX0, through gap)
Aluminium "dome" (cylinder with roof), thickness ~0.7mm
50mm radius hemisphere

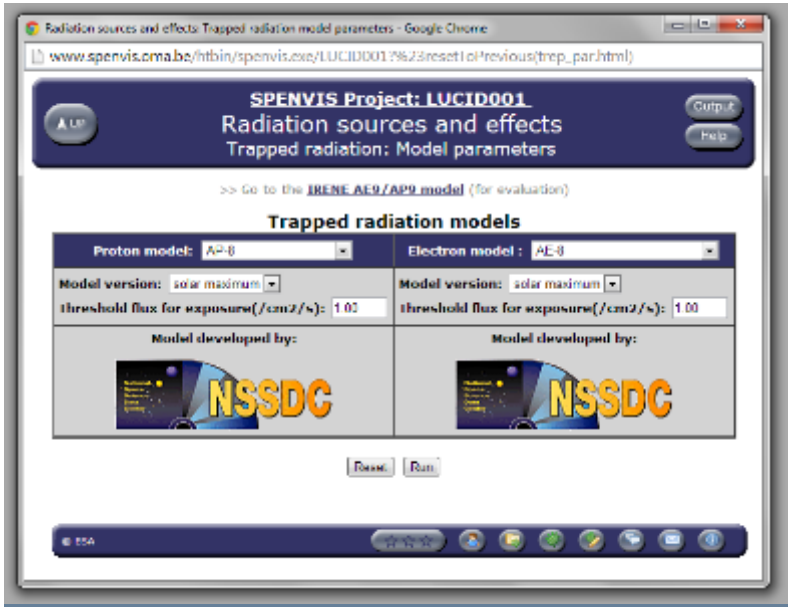
Particle source(s)

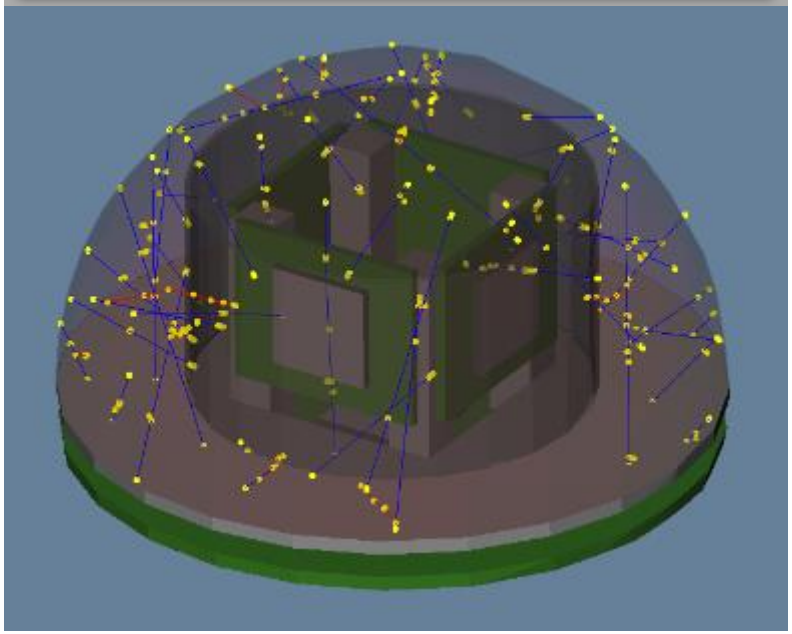
SPENVIS

- ESA-backed "Space Environment Information System" web portal.
- *Spacecraft coordinate generators*:
  - Input LUCID orbit details.
- *Trapped radiation models*:
  - AP-8 for protons and electrons;
  - Int. and diff. flux spectra.

GEANT4 General Particle Source (GPS)

- Hemi-spherical surface, energy sampled from flux spectra energy bins;
- *Right*: 50 10-20 MeV protons ("dome" made partially transparent for clarity).





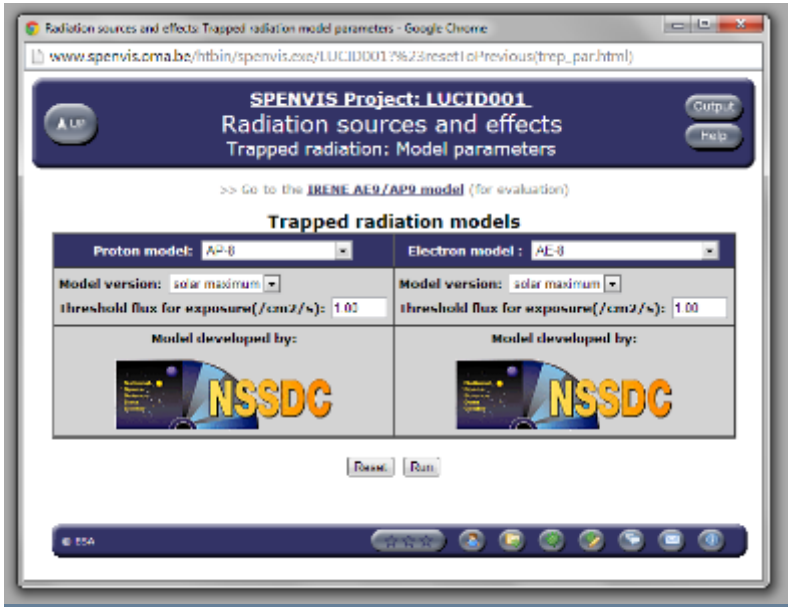
Particle source(s)

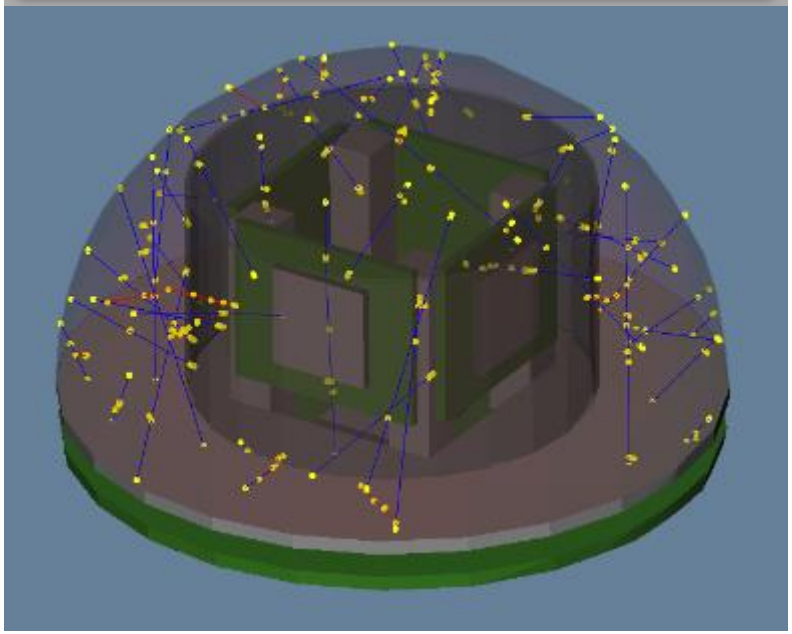
```
# Source particle type
/gps/particle proton

# Source particle energy
/gps/ene/type Lin
/gps/ene/min 10.0 MeV
/gps/ene/max 15.0 MeV
/gps/ene/gradient 0.0
/gps/ene/intercept 1.0

# Source particle geometry
/gps/pos/type Surface
/gps/pos/shape Sphere
/gps/pos/centre 0. 0. 0. mm
/gps/pos/radius 49.9 mm
/gps/pos/confine PseudoDetector_phys
/gps/ang/type cos

# Run the simulation.
/run/beamOn 50
```

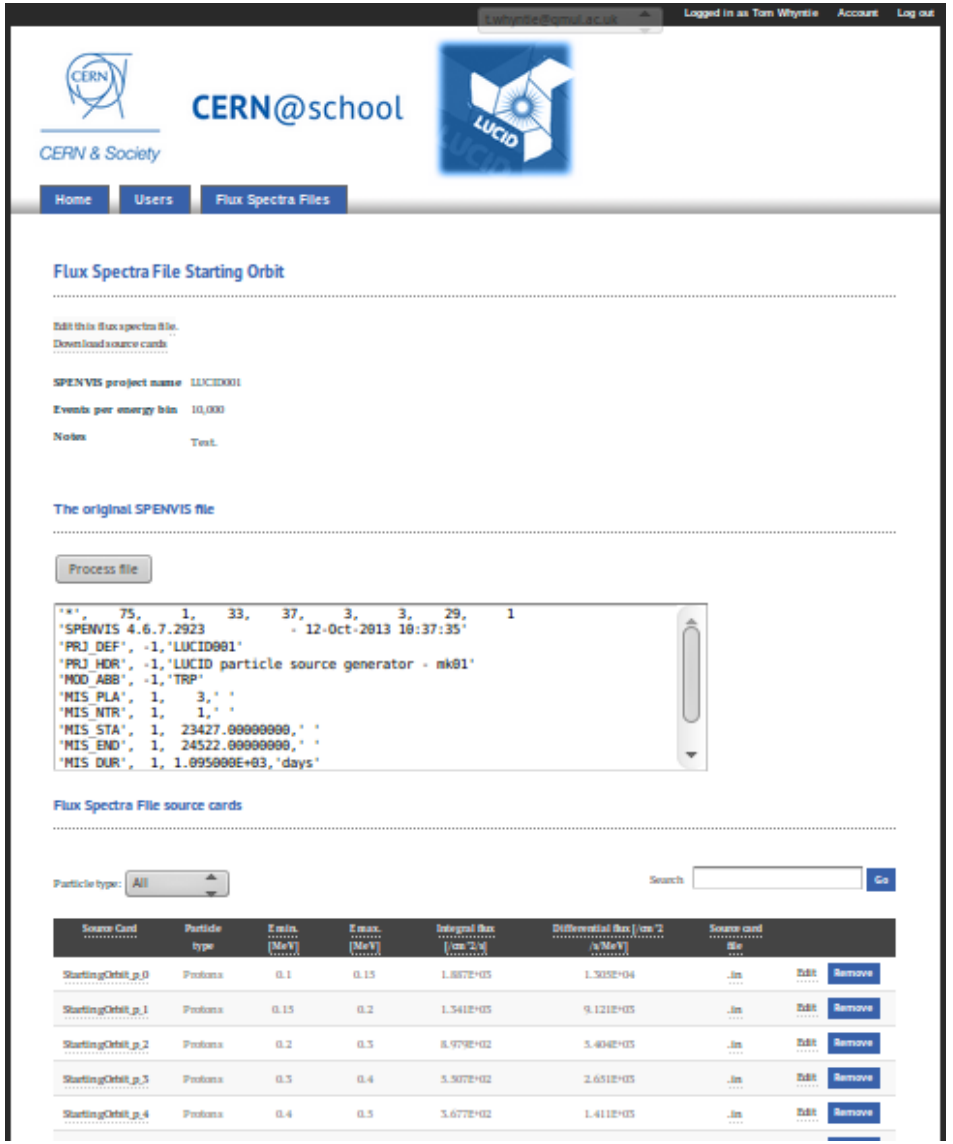




LUCIDITY

The LUCID Interactive Test sYstem:

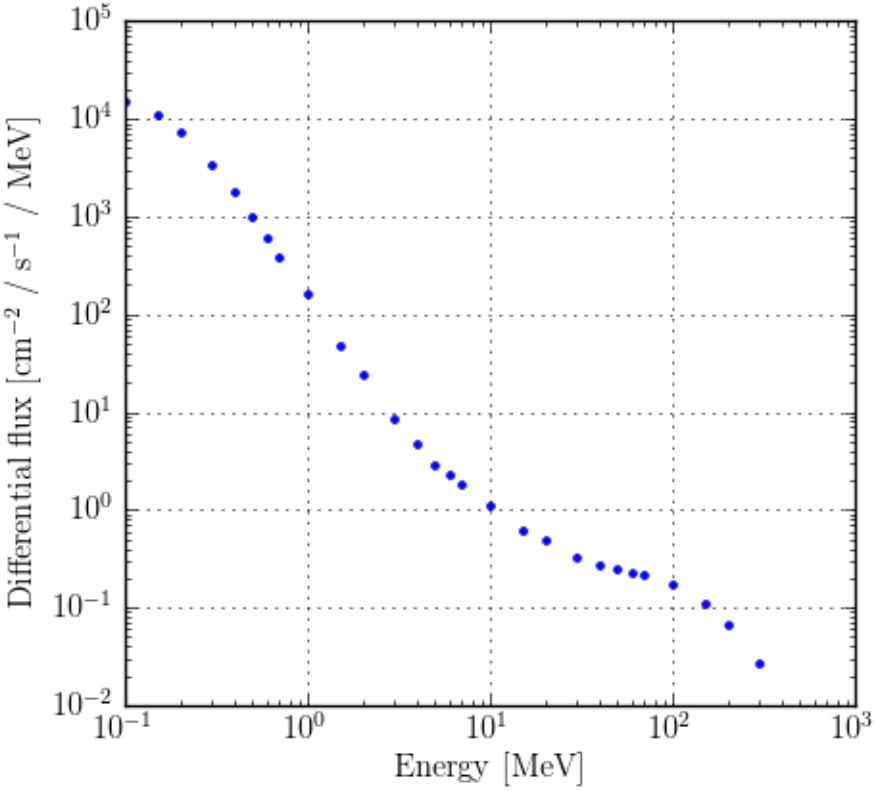
- A web portal for managing LUCID simulations, source cards, results.
- **Ruby on Rails** with a **MySQL** backend. Uses **Hobo** – a collection of gems and plug-ins for making fully-functioned web apps *quickly*:
  - http://www.hobocentral.net/
- Hosted on an **AWS VM** (Ubuntu 12.04 Server). Deployed with **Phusion Passenger**/Apache. Email with **SES**, storage with **SE2**.
- Import SPENVIS spectra, process, download GEANT4 source cards, upload simulation results.



Calculating the data rate

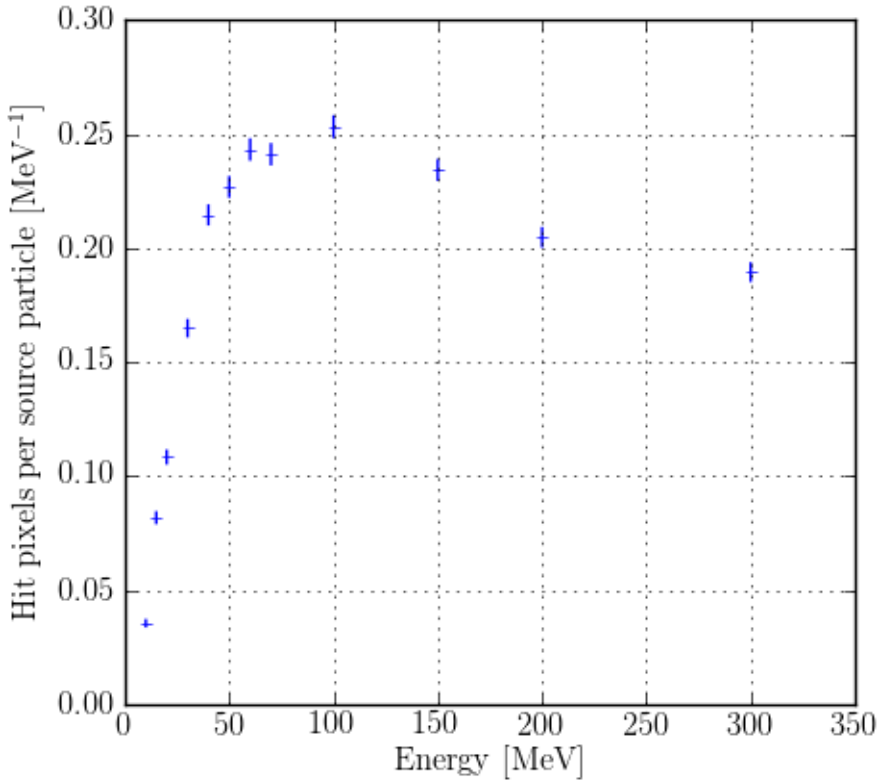
Differential data rate	=	Differential flux	Source geometry	Hit pixels per source particle	Bits per pixel
[bs^{-1} MeV^{-1}]		[particles cm^{-2} s^{-1} MeV^{-1}]	[cm^2]	[pixels $particles^{-1}$]	[b $pixels^{-1}$]
		Obtained from SPENVIS/AP-8 models.	Hemisphere (R=5.0 cm) in an isotropic source: $\frac{1}{2}\pi R^2$	Obtained from GEANT4 simulations of simplified LUCID geometry. **All five** Timepix Sensitive Detector volumes recreated, hits in 55μm pixels count only once per event.	16 bits per pixel: 14 for Time-over-Threshold value, 2 for overhead.

Results - protons



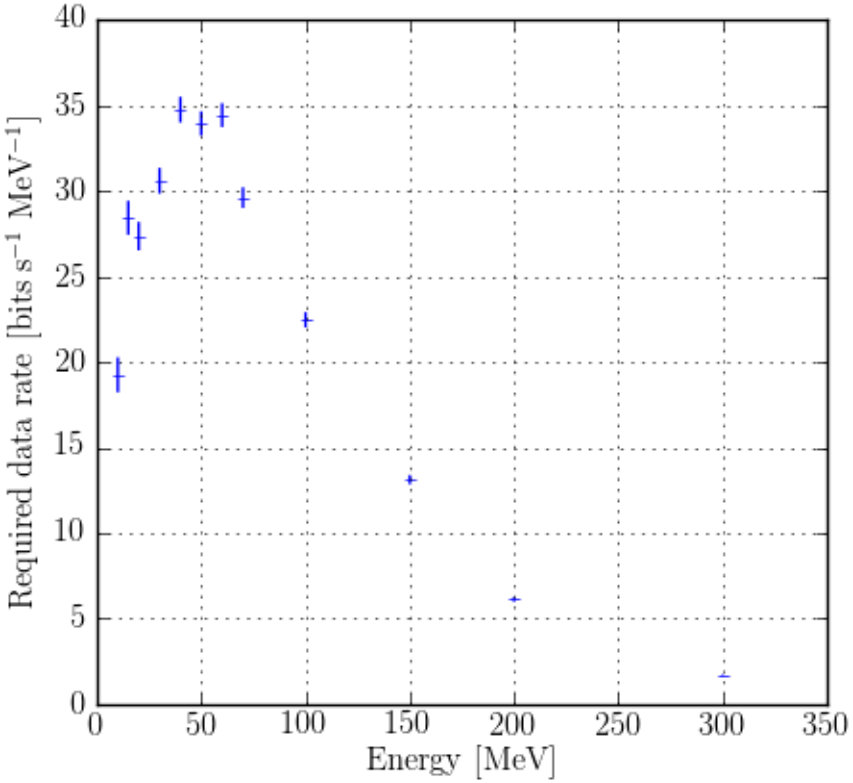
Differential flux (SPENVIS/AP-8 trapped proton model).

Results - protons



Hit pixels per source particle (SimLucid GEANT4 model).

Results - protons

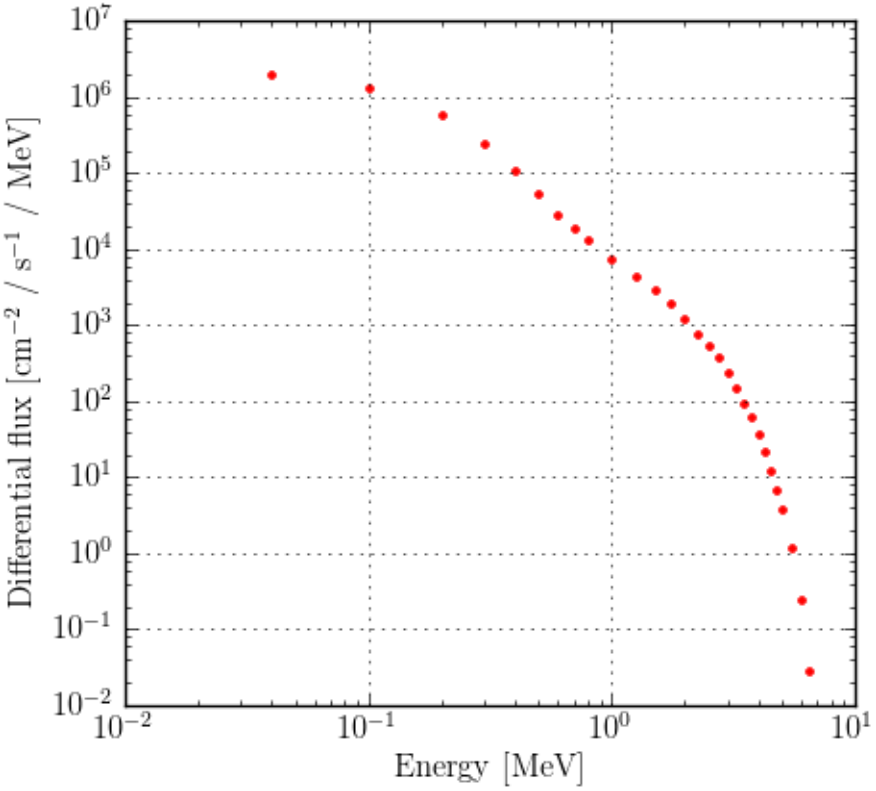


Required data rate due to LEO protons.

Required data rate summed over all energy bins due to trapped protons in LEO:

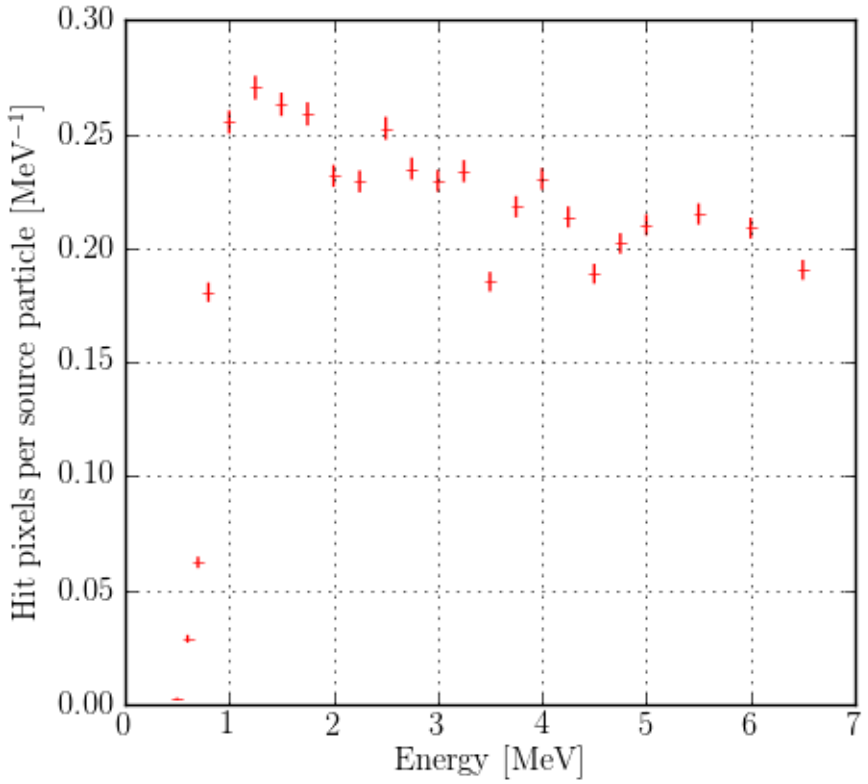
= (5.30 ± 0.04) kbs^{-1}

Results - electrons



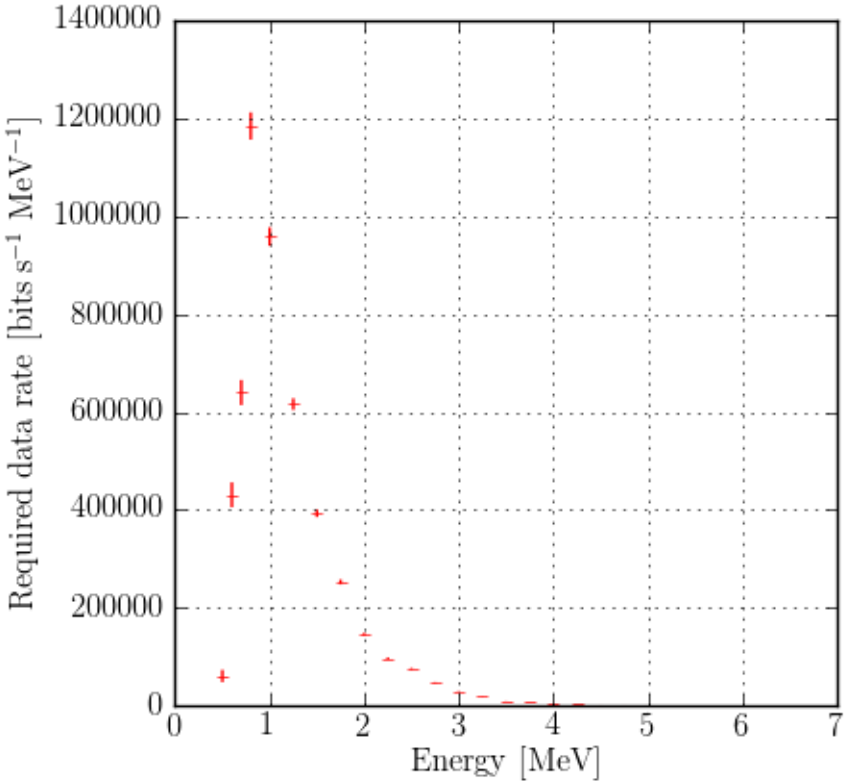
Differential flux (SPENVIS/AP-8 trapped electron model).

Results - electrons



Hit pixels per source particle (SimLucid GEANT4 model).

Results - electrons



Required data rate due to LEO electrons.

Required data rate summed over all energy bins due to trapped electrons in LEO:

= (1.01 ± 0.01) Mbs^{-1}

Results - discussion

- Observed particle rates:
  - As expected, low energy particles shielded by aluminium dome while keeping energies of interest;
  - About 1 Mbs^{-1} from trapped radiation in LEO (solar maximum) for all detectors, dominant contribution comes from electrons;
  - Errors: statistical plotted, “factor of 2” from AP-8 models.
- Comparing with LUCID technical capabilities:
  - 1 Mbs^{-1} suggests 0.2 frame s^{-1} per detector, so at 4Hz shutter speed the frame occupancy is ~5% (256x256x16 bits per frame);
  - 20 Mbs^{-1} data transfer, 2GB storage space – sufficient.
- Further work to be done:
  - Allpix full chain simulations (on Grid), other radiation environment (e.g. outer belt electrons, SAA).

Summary and conclusions

- The LUCID experiment, featuring five Timepix detectors, has been modelled in **GEANT4**.
- **SPENVIS** has been used to obtain input flux estimates for proton and electron fluxes in Low Earth Orbit.
- A web portal, **LUCIDITY**, has been developed to manage simulation parameters and results for the LUCID Collaboration.
- Simulation results indicate that the data rates required as a result of trapped protons and electrons should be within LUCID's capabilities.
- There is still plenty to do before **TechDemoSat-1** launches in February 2014!

Further information:

http://cernatschool.web.cern.ch

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@langtonstar @twhyntie @PhysicsatQM

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