lisa pathfinder

Test mass charging in LISA:
confronting simulations with observations

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Outline

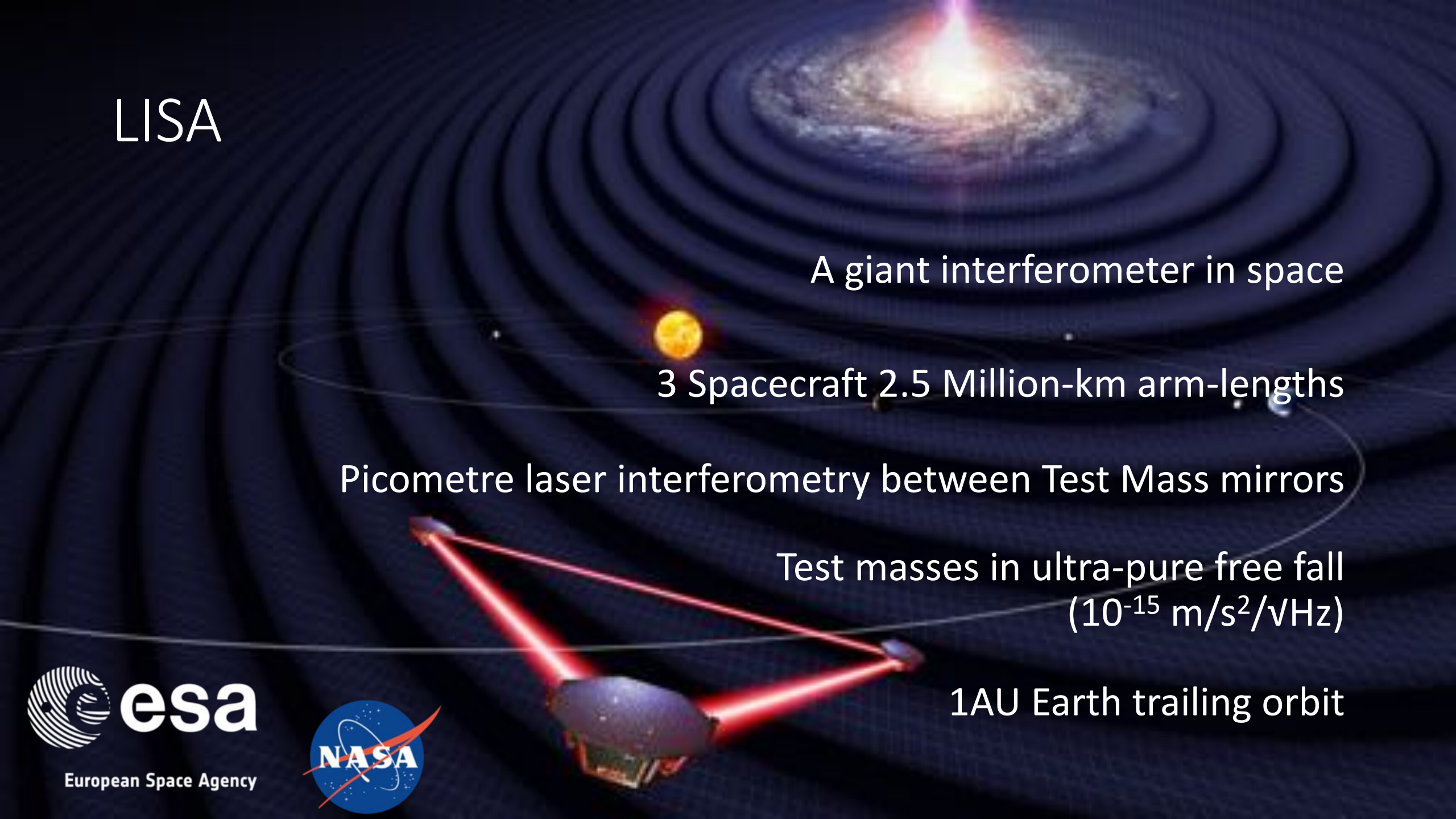
Background and history:

- LISA
- Previous work

LISA Pathfinder simulations and measurements:

- On board measurements of particle flux
- Test mass charging
- Model refinements

LISA



A giant interferometer in space

3 Spacecraft 2.5 Million-km arm-lengths

Picometre laser interferometry between Test Mass mirrors

Test masses in ultra-pure free fall
(10^{-15} m/s^2/√Hz)

1AU Earth trailing orbit

esa
European Space Agency

NASA

Charging

Cosmic rays/solar particles responsible

Test masses (TMs) at the heart of the spacecraft behind significant shielding

Charge build up gives rise to electrostatic force within 6-degree of freedom capacitive sensor

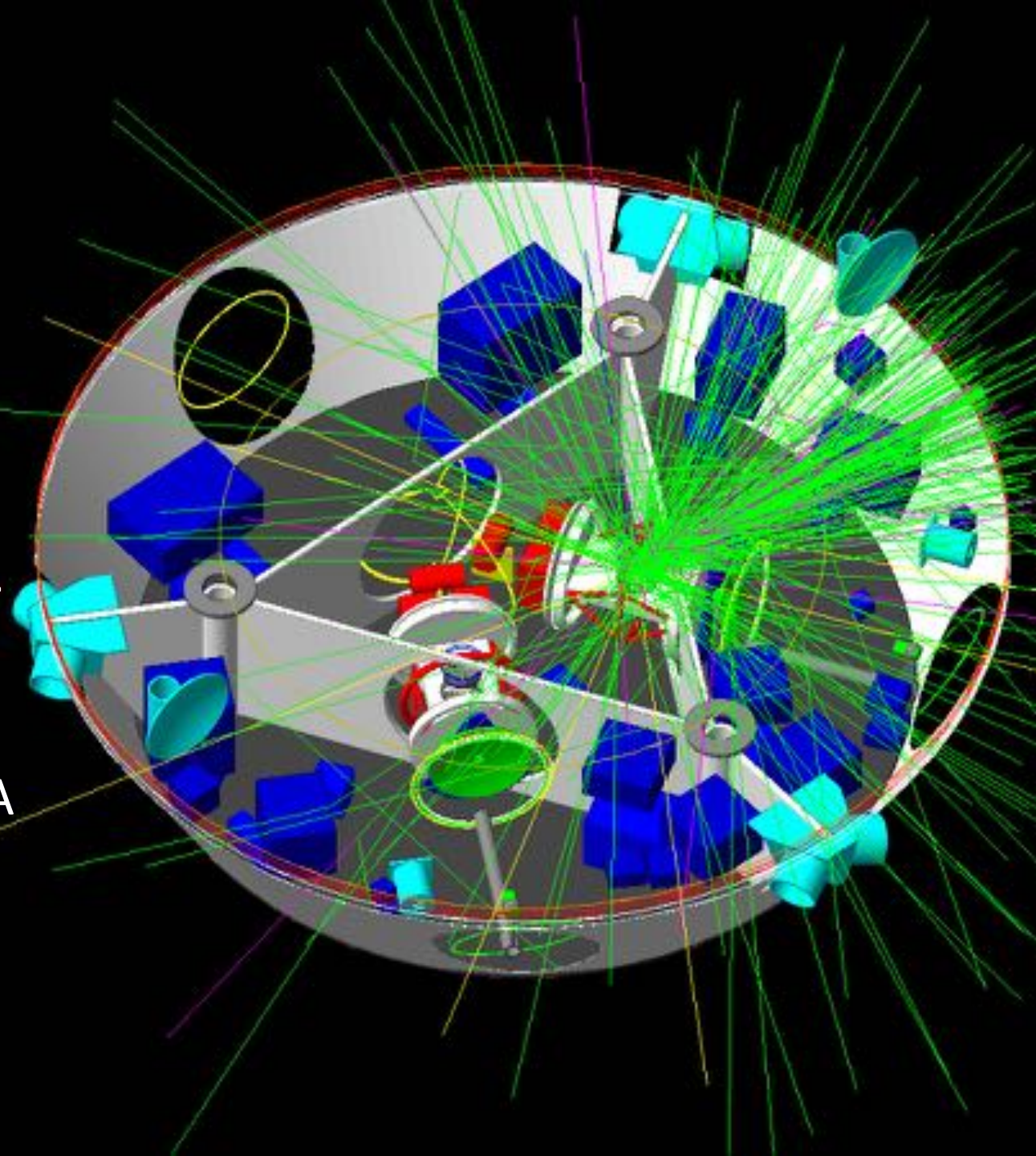
SEPTIMESS ca. 2004

TM Charging calculations made with GEANT4 at Imperial College London under subcontract from QinetiQ

Realistic flux models for GCR and solar particle events

Simulation of charging of LISA and LISA Pathfinder geometry

G4 advanced example

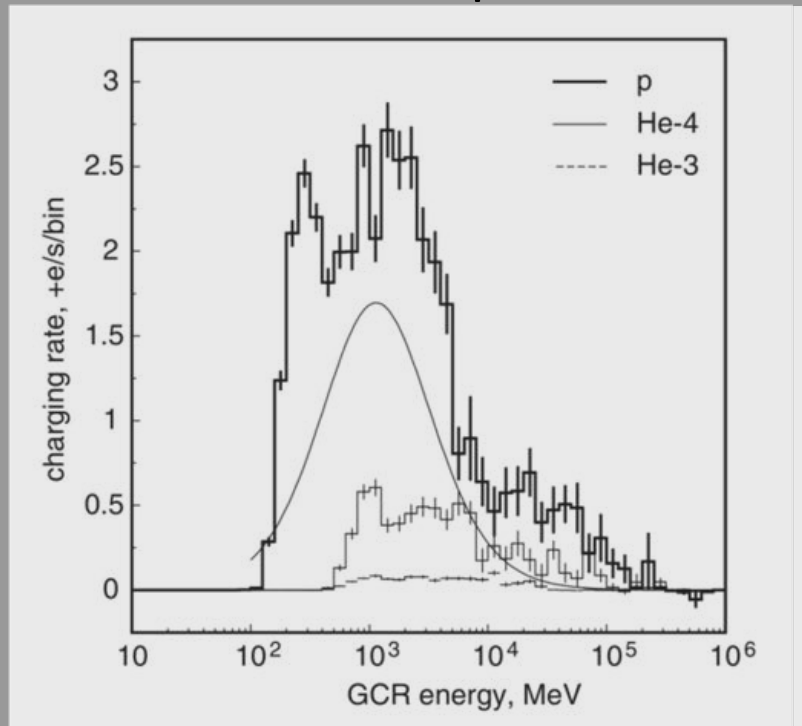


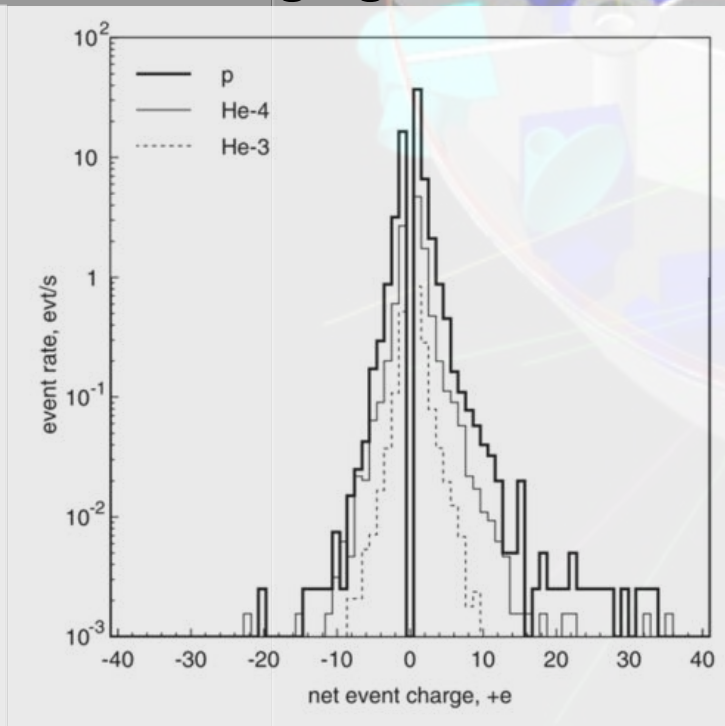
Astroparticle Physics 22 (2005) 451–469

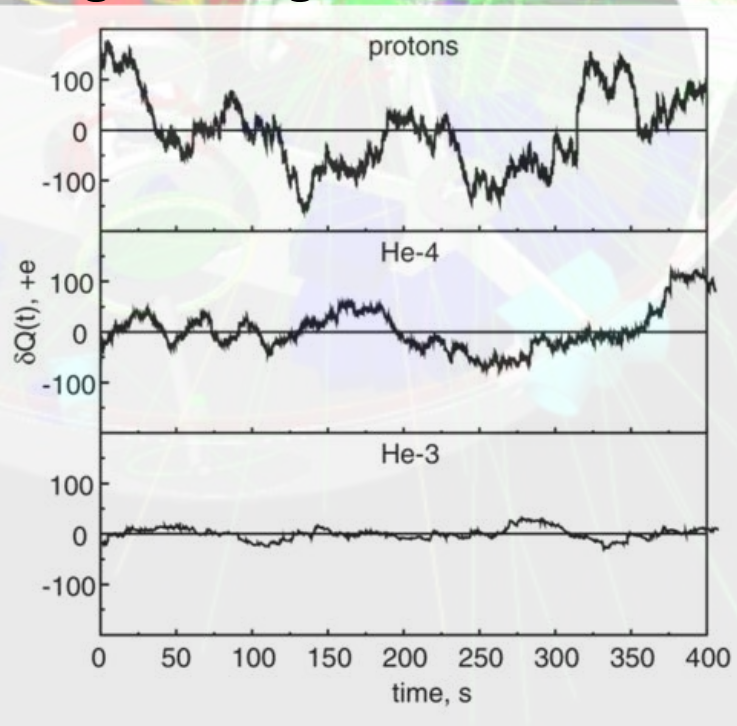
Charging results

Key findings:

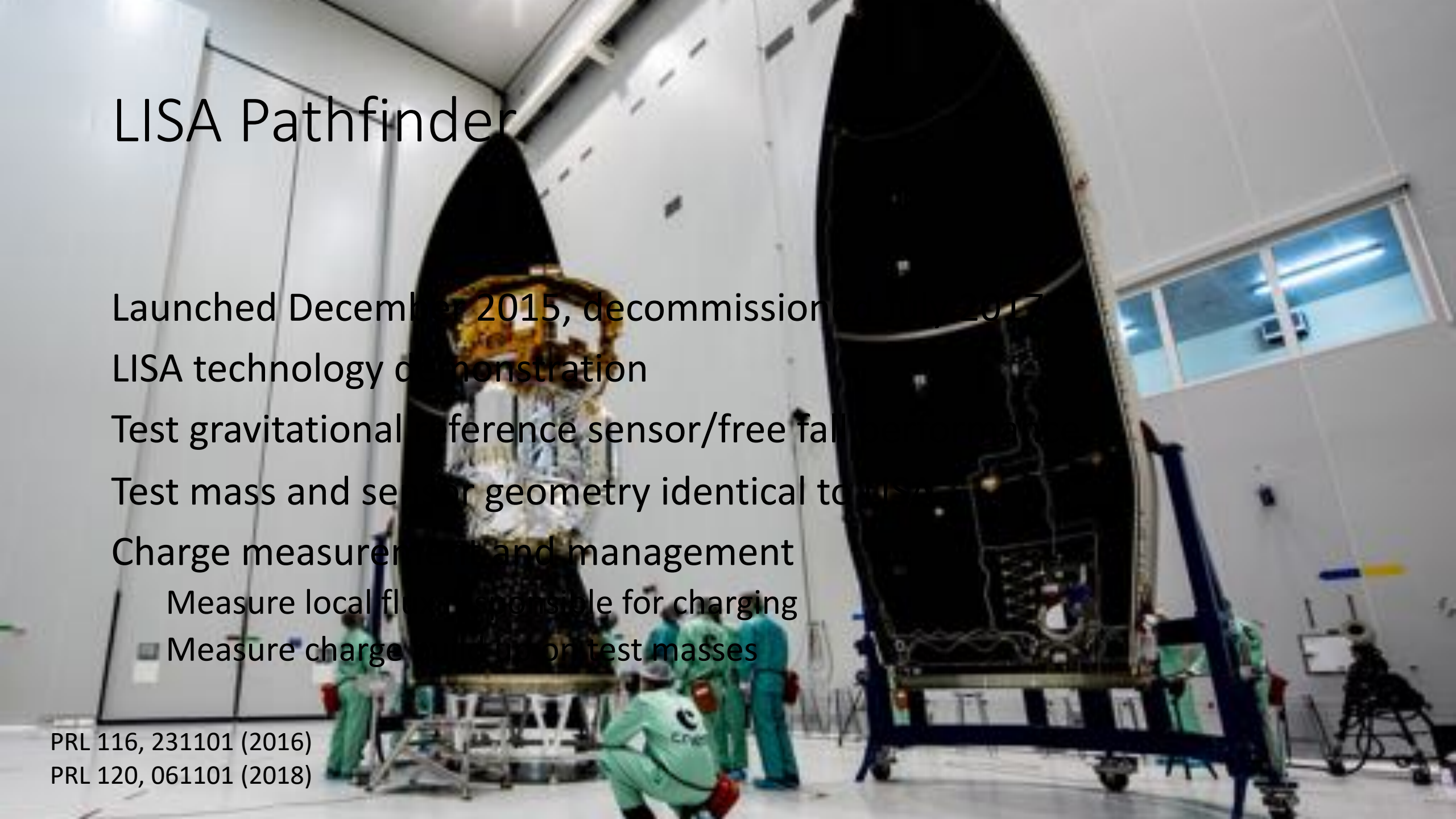
- Spacecraft shielding corresponds to ~100 MeV/nucleon (10 g/cm^2 Al)
- Charge rates predicted around 50 e/s at solar minimum (balance of + and –)
- Noise corresponds to effective charging current of 300 single charges/s







LISA Pathfinder



Launched December 2015, decommissioned 2017

LISA technology demonstration

Test gravitational reference sensor/free fall

Test mass and sensor geometry identical to LISA

Charge measurement and management

- Measure local fluctuations responsible for charging
- Measure charge build-up on test masses

PRL 116, 231101 (2016)
PRL 120, 061101 (2018)

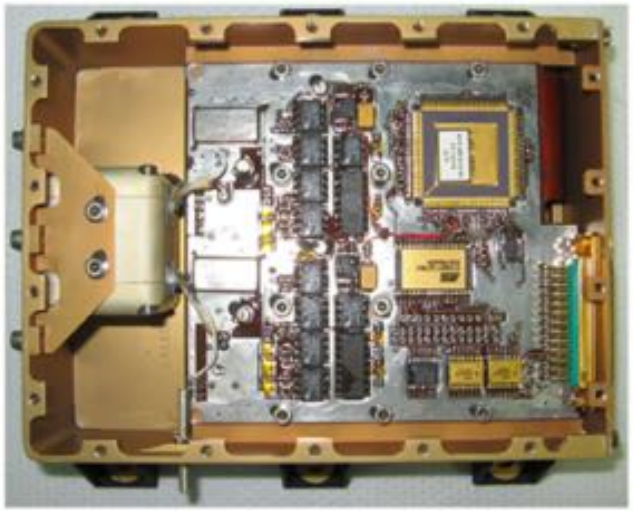
LISA Pathfinder: Particle monitor

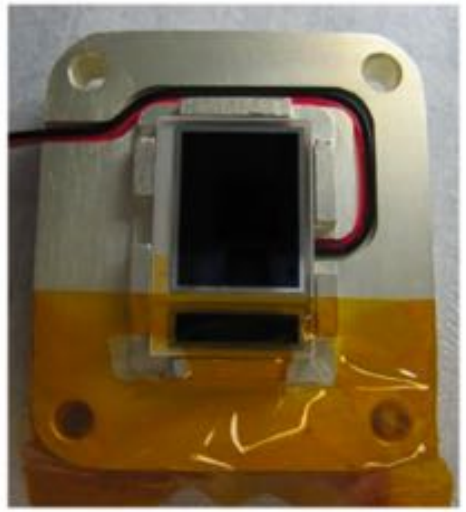
Simple telescopic Si PIN diodes 1.4 cm^2 area (Fermi LAT spares)

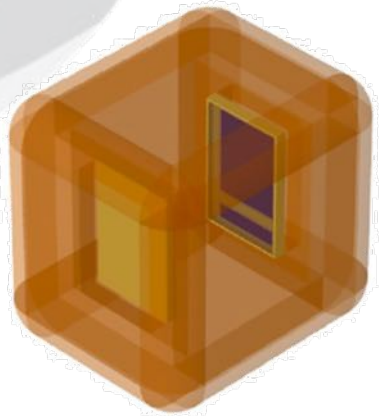
Isotropic count rates and deposited energy information

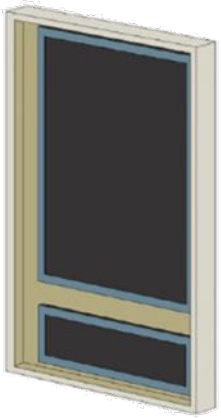
Looking for % level fluctuations in particles >~ 100MeV/nuc

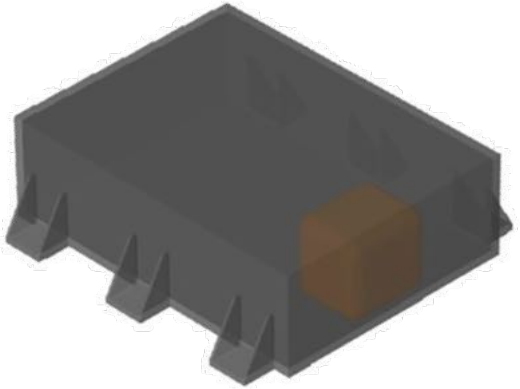
GEANT4 model validated in beam tests at PSI











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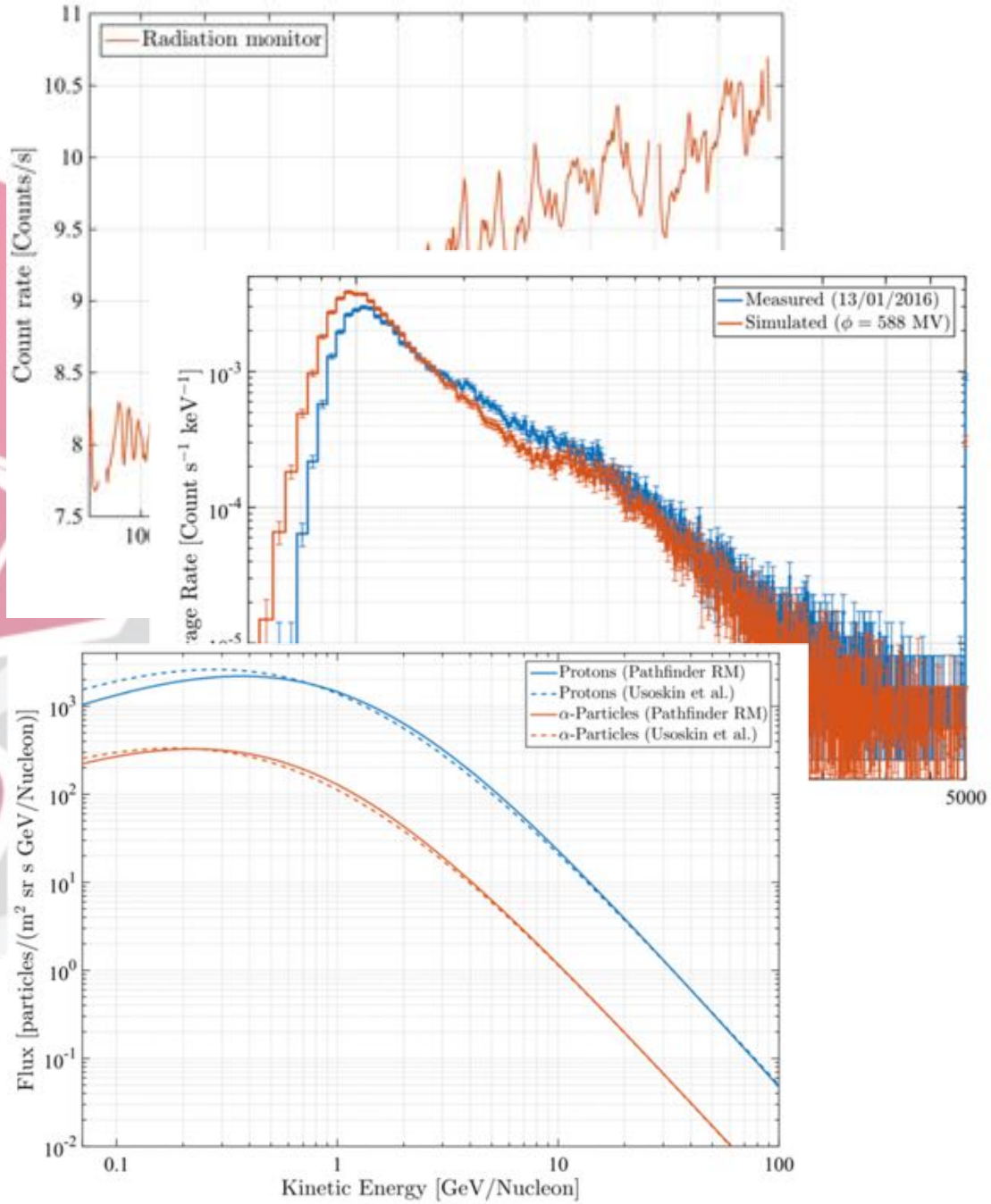
Particle monitor results

Count rate tracks cosmic ray variations over the course of the mission

Deposited energy used with GEANT4 model to fit for solar modulation ϕ

Flux predictions agree well with Neutron Monitor prediction
http://www.cosmicrays.oulu.fi/phi/Phi_mon.txt



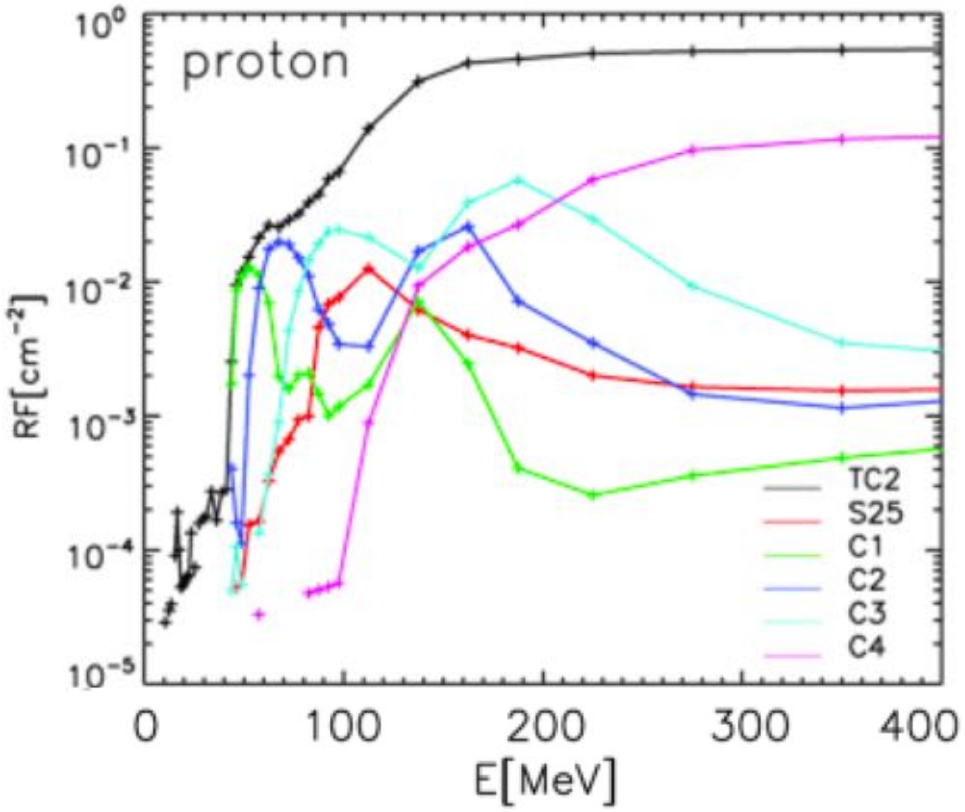
Astroparticle Physics 98 (2018) 28–37

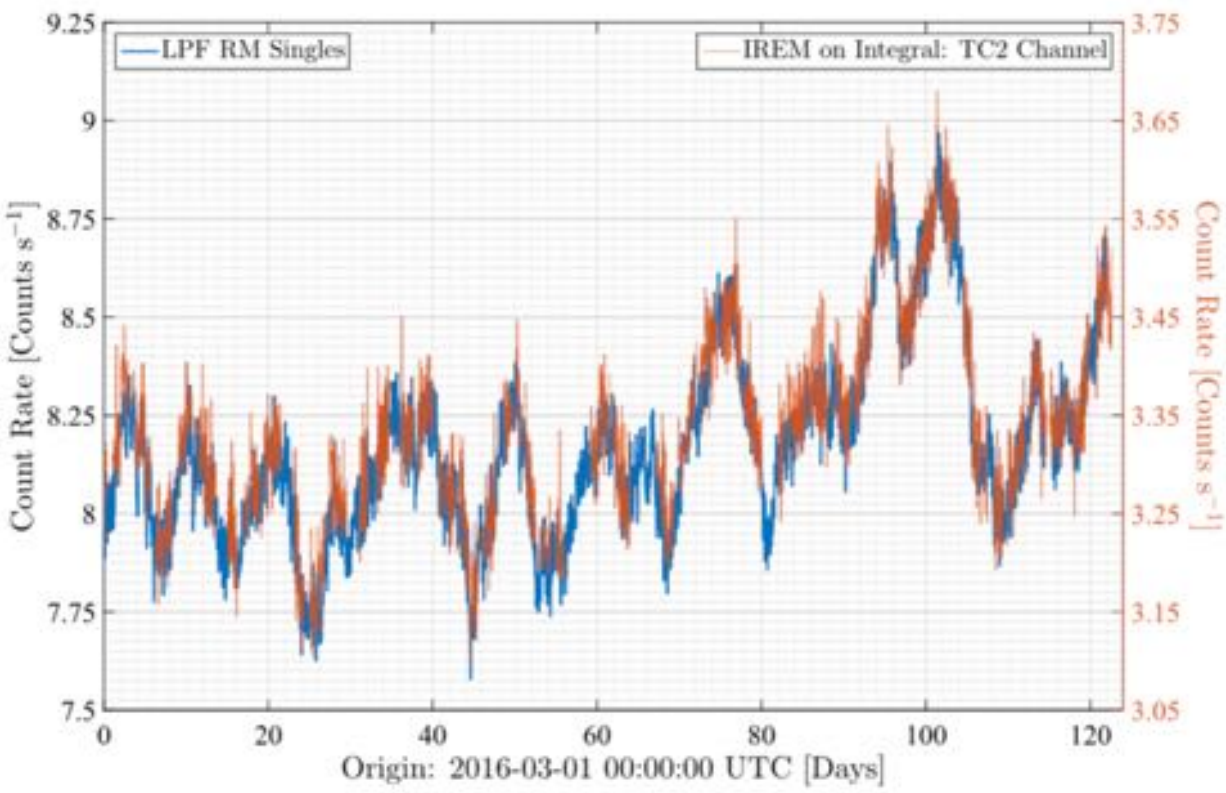
IEEE Trans. Nucl. Sci 59 Issue 4 2012

Comparison with IREM

IREM TC2 channel also has 100MeV cutoff

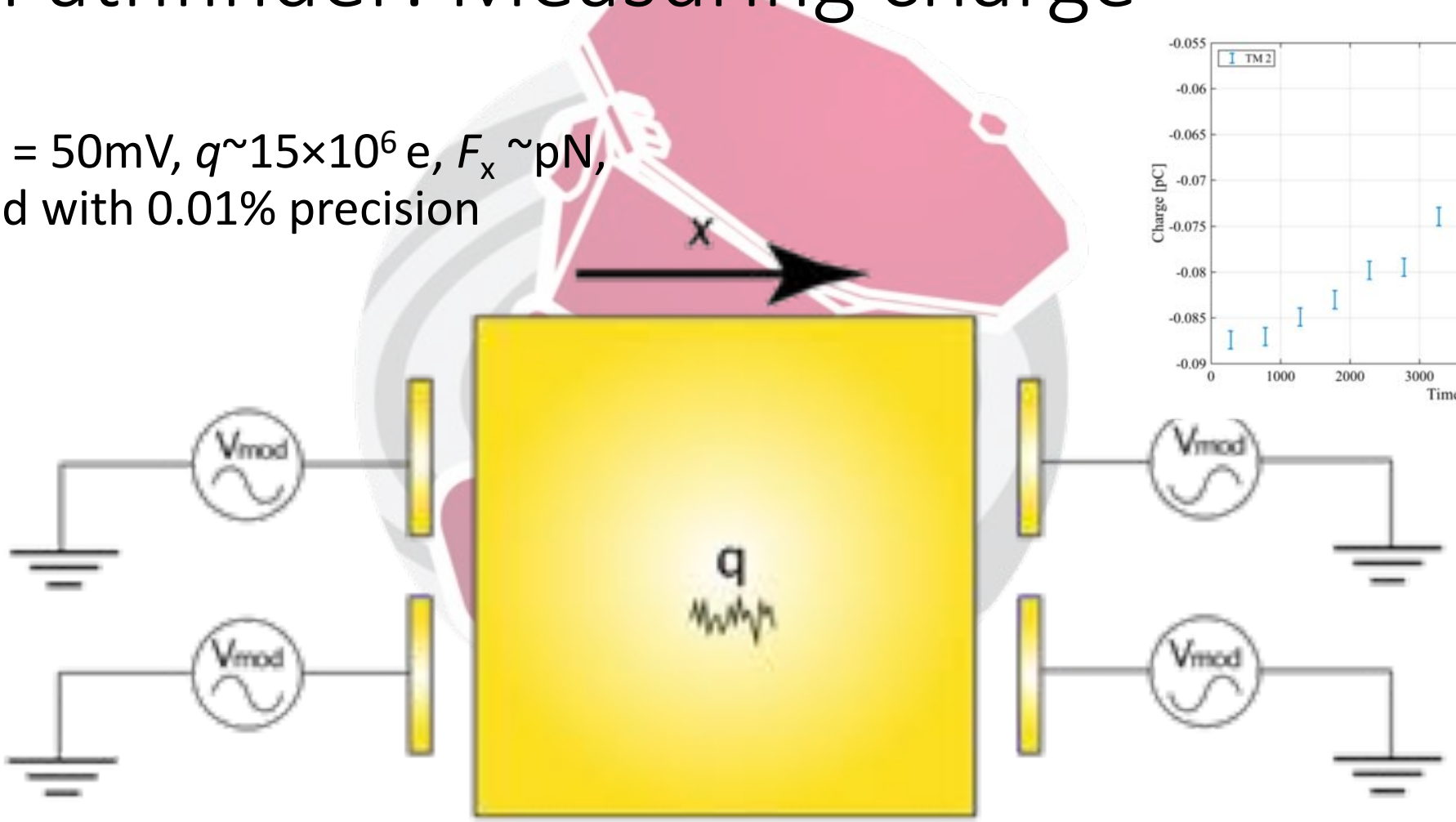
Excellent agreement with LPF Monitor





LISA Pathfinder: Measuring charge

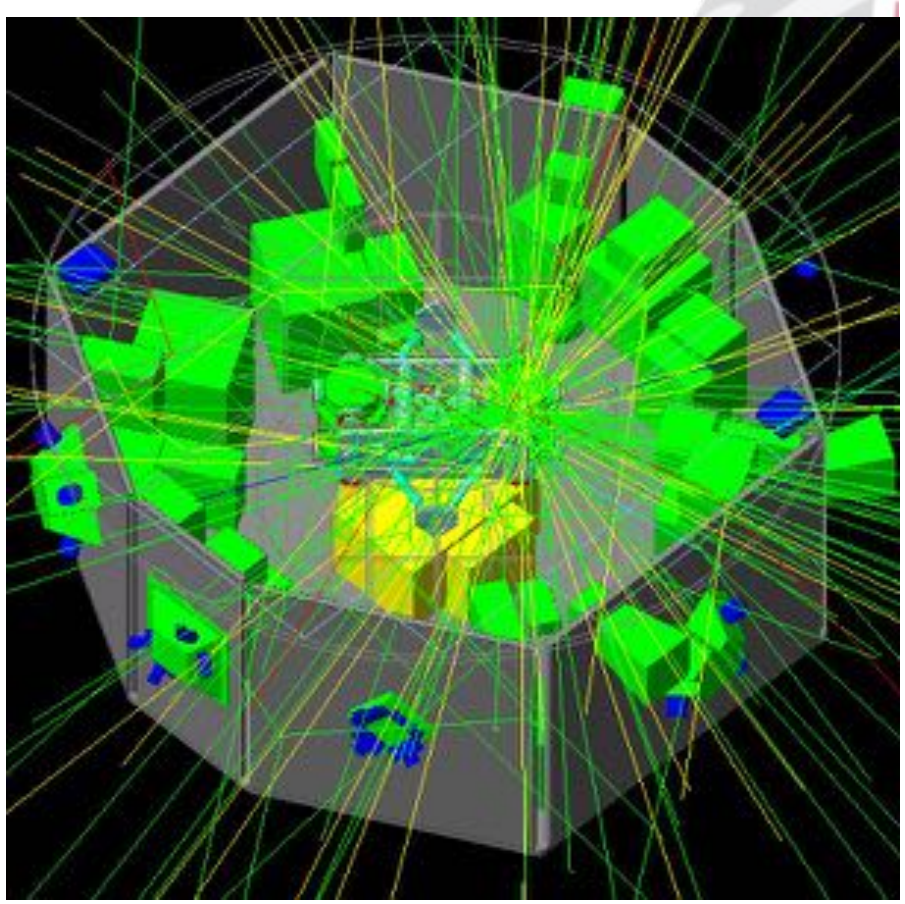
e.g. V_{mod} = 50mV, q~15×10^6 e, F_x ~pN,
measured with 0.01% precision

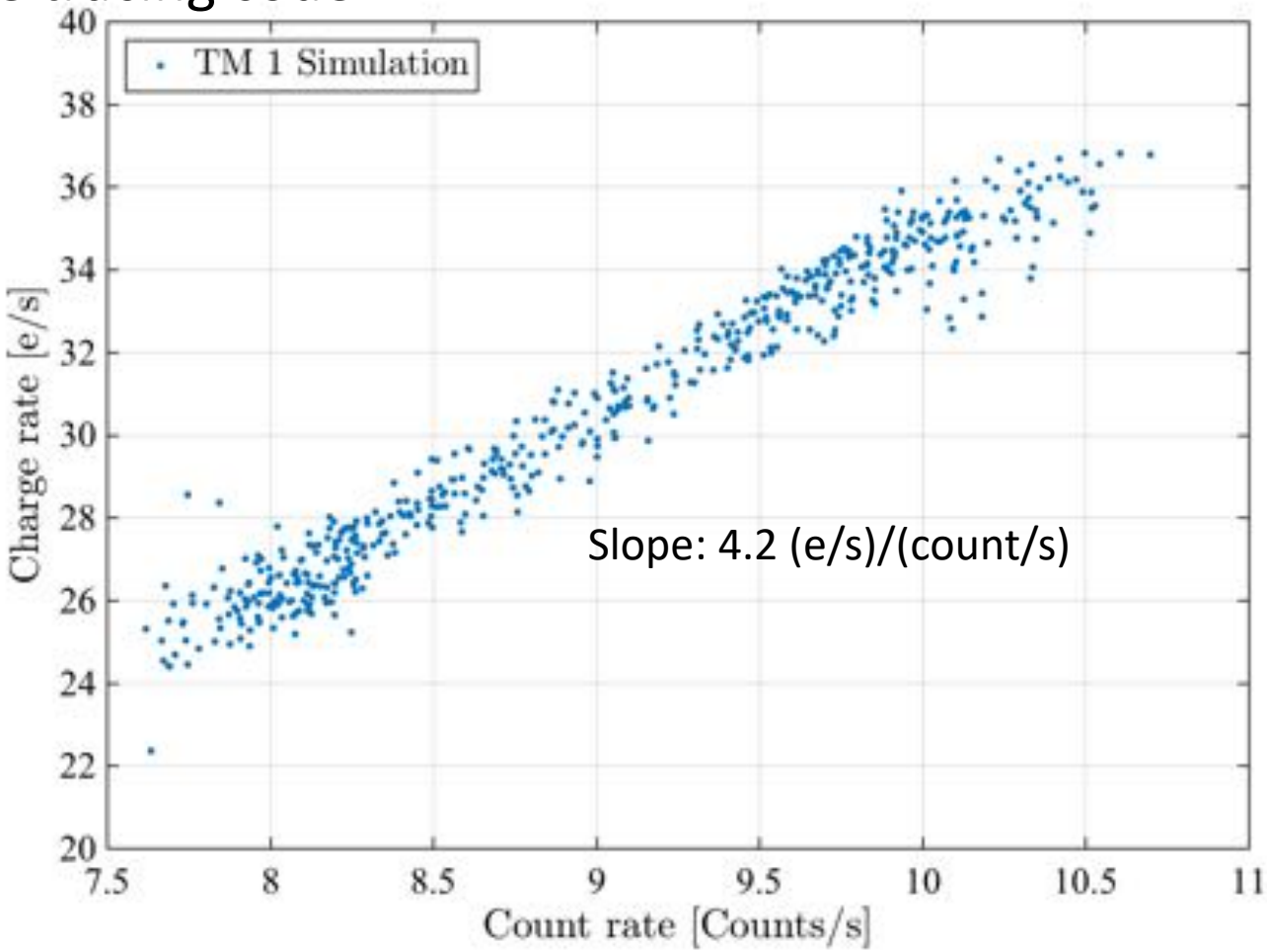


$$F_x = -4\left|\frac{\partial C_x}{\partial x}\right|\left(\frac{q}{C_{\mathrm{tot}}}V_{\mathrm{mod}}\sin\omega t\right)$$

LISA Pathfinder: Charging simulations

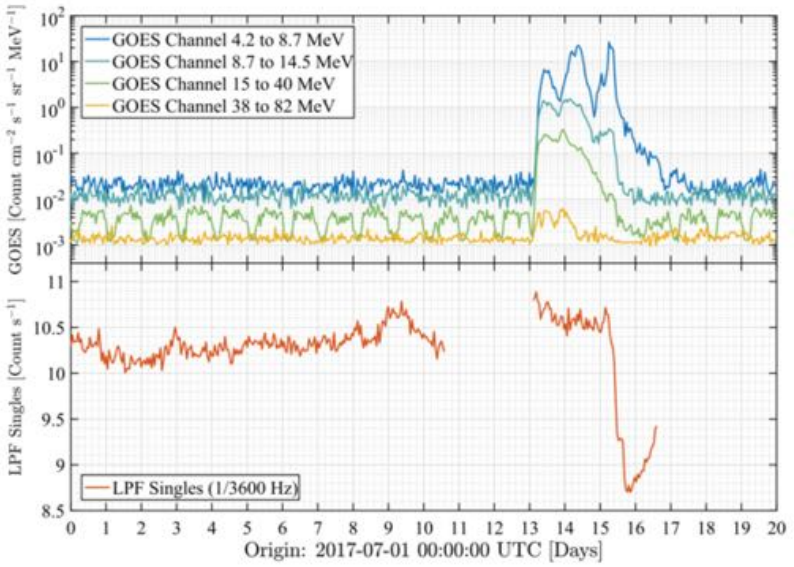
Simulate charging with GEANT4 particle tracing code

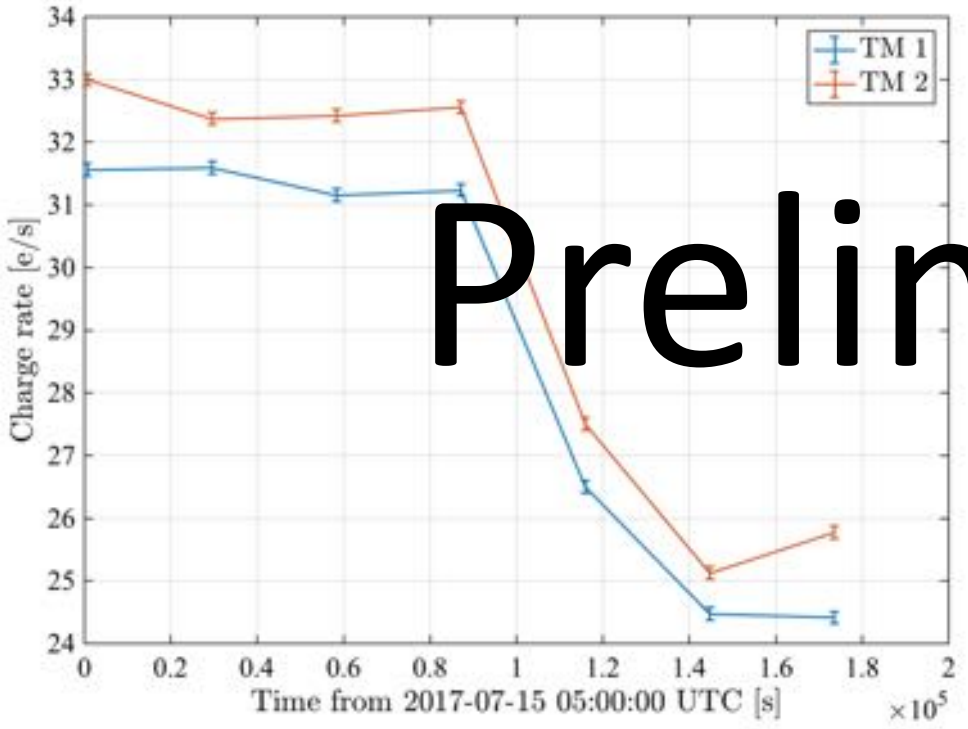




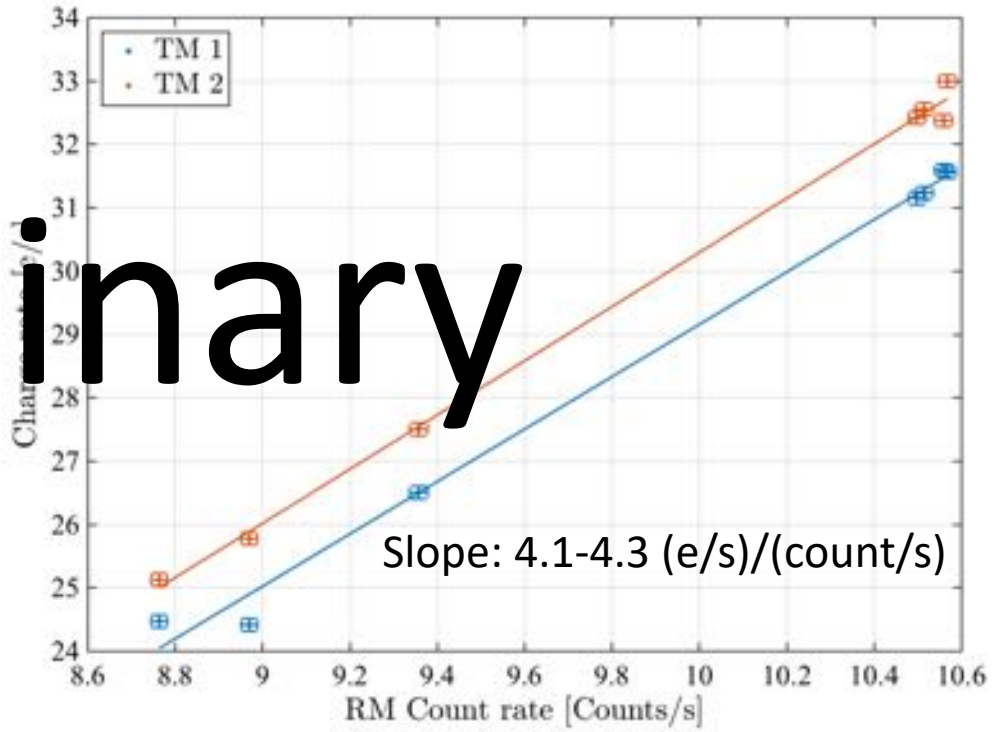
Charging results: flux variations

Cosmic ray suppression from Forbush decrease in July 2017





Preliminary



Slope: 4.1-4.3 (e/s)/(count/s)

Charging results: rates/noise

Charge rate 18-35 e/s

good agreement with simulation

But: Observed dependence on electric fields

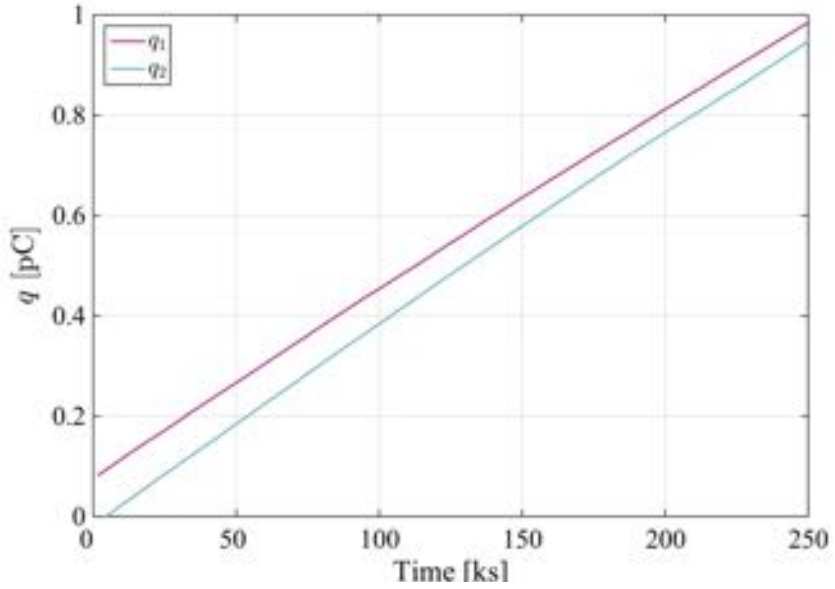
Typically overestimated by simulation

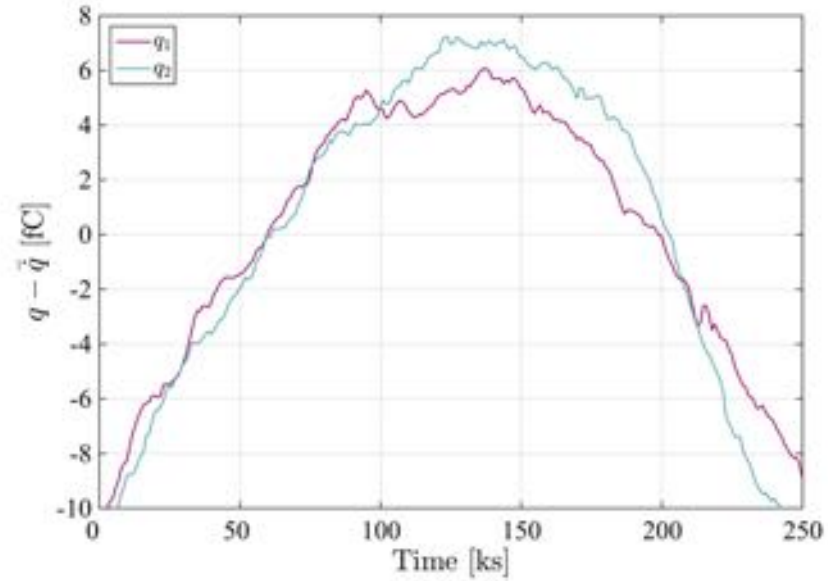
e.g. for ϕ = 437MV (2017-06-26) 29 vs 50 e/s

Charge noise higher than expected

Noise power equivalent to ~1100/s vs 300/s

Unsimulated charging population?





Phys. Rev. Lett. **118**, 171101 (2017)

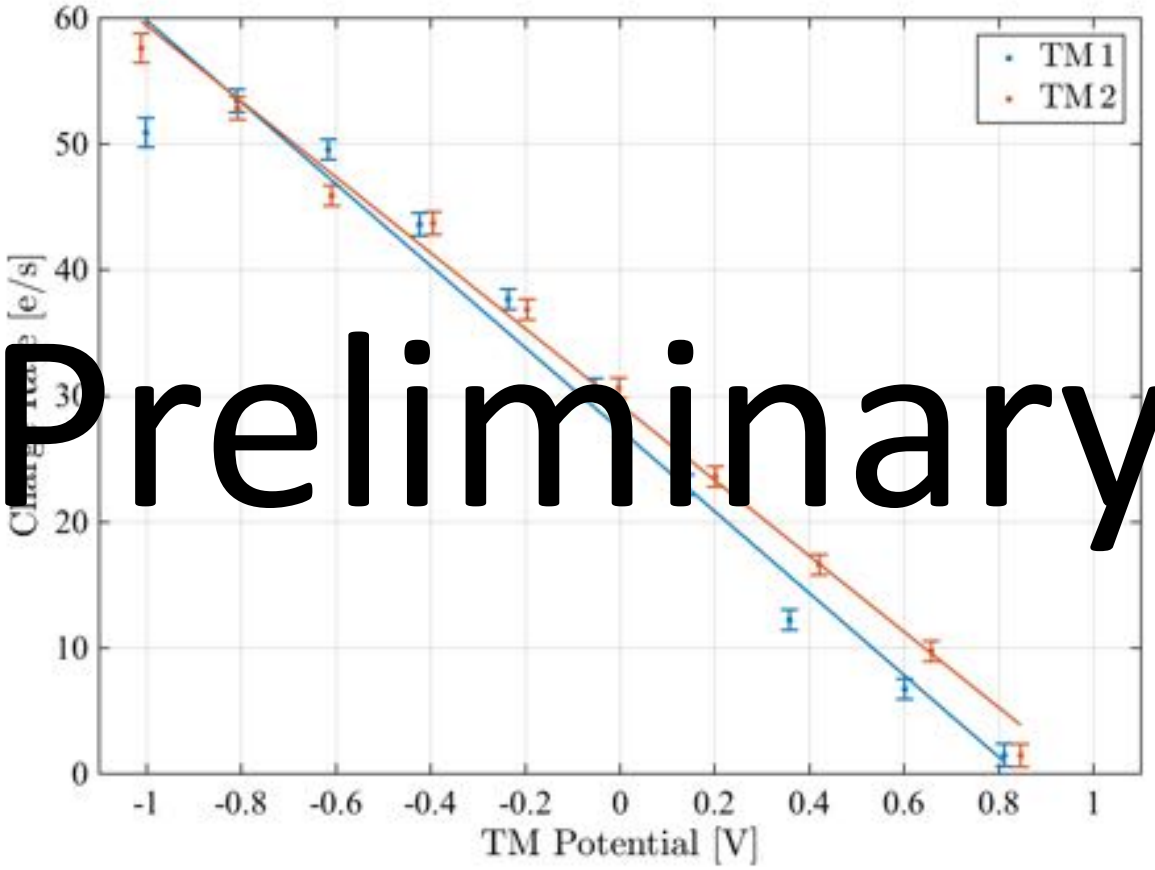
Charging results: low-energy component

G4 secondary creation extends to 250 eV

Limitation of GEANT4 in 2004

Charge rate dependence on electric field

Evidence for significant number of
secondary particles with energy <1 eV



Preliminary

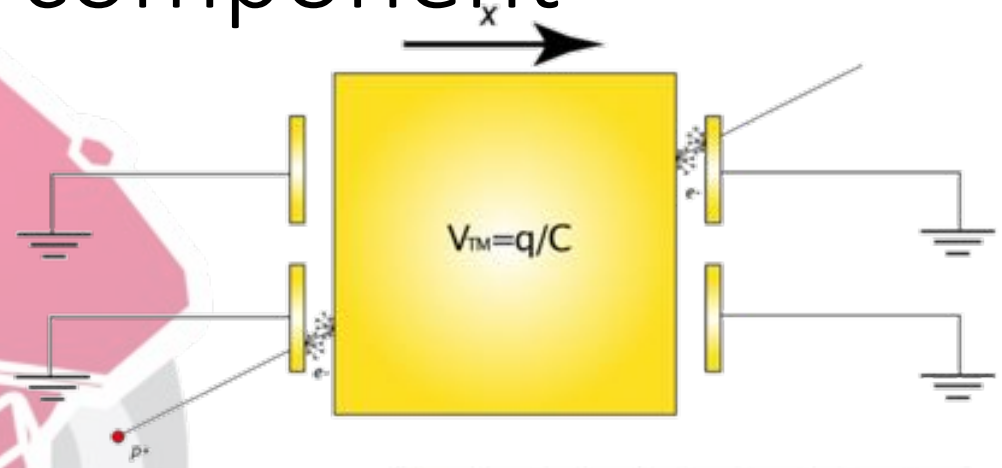
Charging results: low-energy component

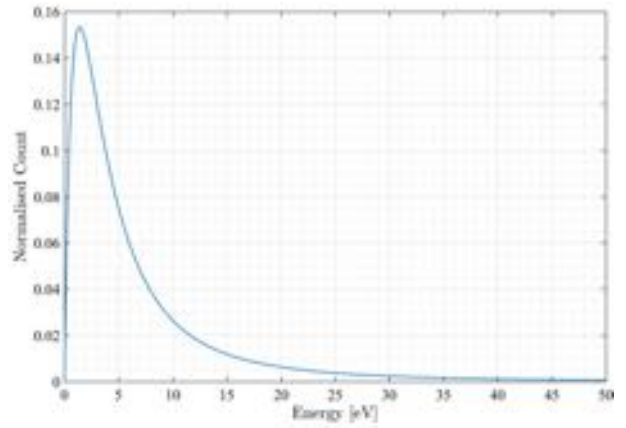
Secondaries at surfaces can be significant
- Not created in G4 model

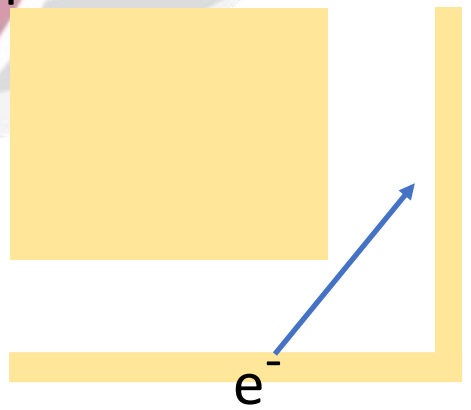
Calculate yield from high-energy energy primaries
- Track particles at TM and surrounding surfaces in G4
- Literature from electron microscopy

Geometrical asymmetry and electric fields can create additional net rate

...work in progress







Conclusions/Outlook

Charging simulations have been validated against in-orbit data

- Remaining uncertainty created by geometry implementation/physics models

Energy scales eV to TeV are relevant to charging rate and noise

- Experimental validation of low energy component would be valuable

In-situ particle detector gives valuable insight into charging

- Could be more valuable in distributed system like LISA