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Imperial College – LISA and LISAPF

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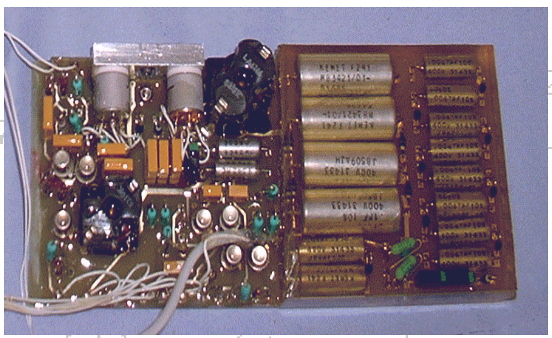
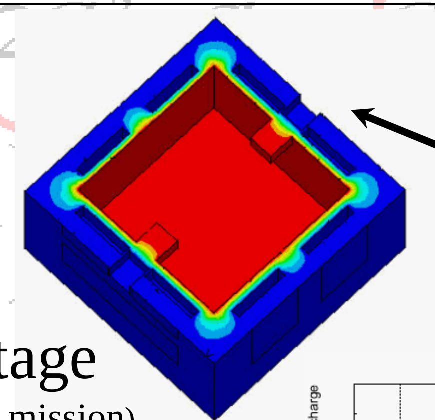
T.J. Sumner – ICL lead and LIST

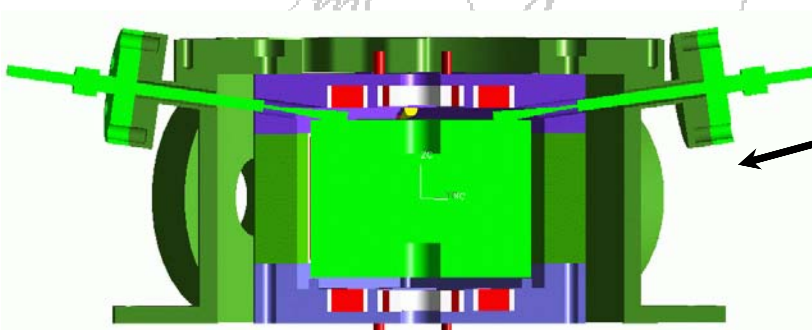
Henrique Araujo, Markus Schulte, Diana Shaul, Christian Trenkle (now Astrium), Simon Waschke, Peter Wass (now Trento)



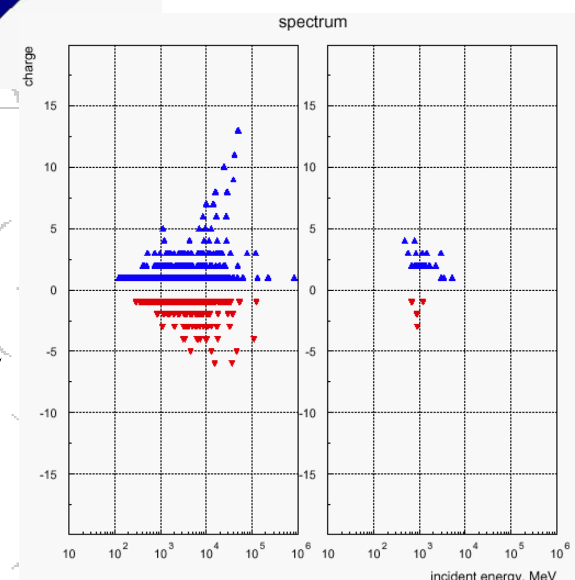
Heritage
(10 year mission)



Electrostatic Modelling



LTP EM Design



GEANT Modelling

Charging of isolated proof-masses in satellite experiments

- Effects of free charge
  - Lorentz force
  - Electrostatic forces from mirror charges
  - Spring Constants
  - Forces from applied voltages
- Charging Estimates
  - Rates
  - Timelines
- Charge Management
  - Measurement procedures
  - Discharge procedures

Lorentz force noise

$$F_l = Q\bar{v} \wedge \bar{B} \quad - Q\bar{E}_{Hall}$$

Metallic Enclosure (Blaser)

$$F_l = \eta Q\bar{v} \wedge \bar{B}$$

$$(a_n)^2 = (\eta Q v \delta B_n)^2 + (\eta \delta Q_n v B)^2$$

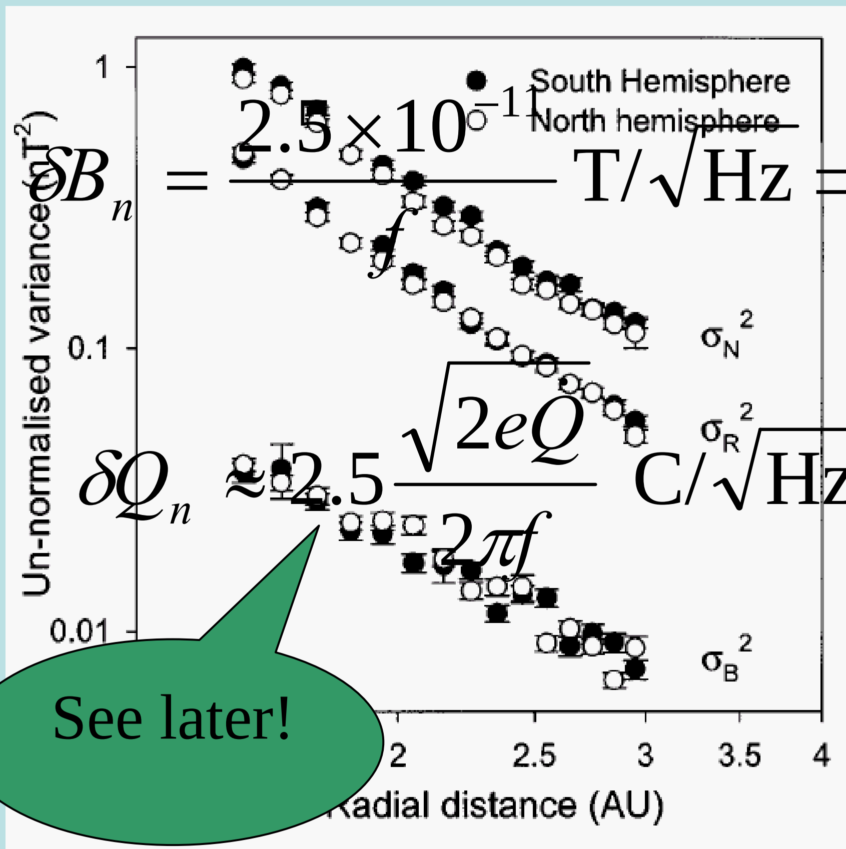
Lorentz force noise

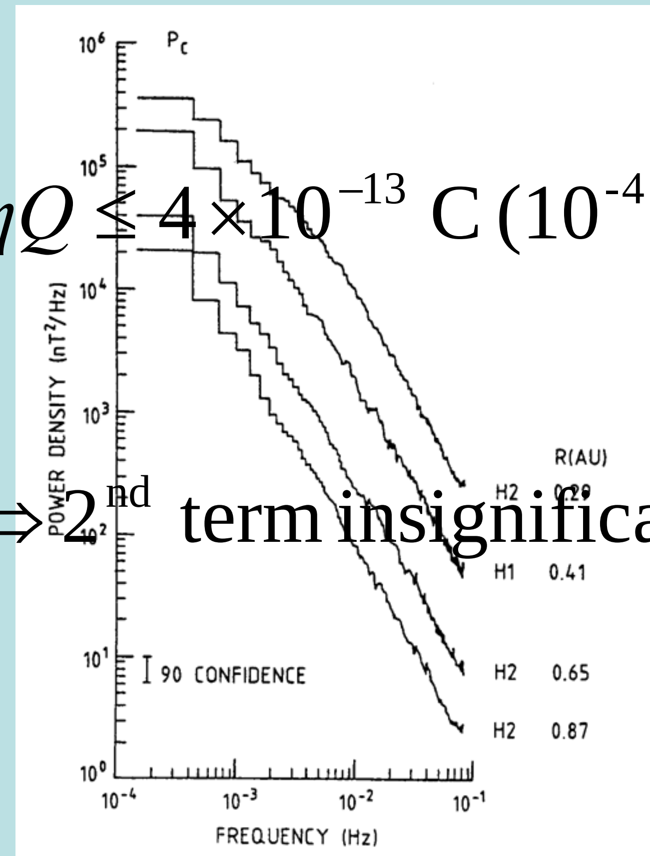
$$\left(a_n\right)^2 = \left(\eta Q v \delta B_n\right)^2 + \left(\eta \delta Q_n v B\right)^2$$

$$\delta B_n = \frac{2.5\times10^{-11}}{f}\ \mathrm{T}/\sqrt{\mathrm{Hz}} \Rightarrow \eta Q \le 4\times10^{-13}\ \mathrm{C}\ (10^{-4}\ \mathrm{Hz})$$

$$\delta Q_n \approx 2.5\frac{\sqrt{2eQ}}{2\pi f}\ \mathrm{C}/\sqrt{\mathrm{Hz}} \Rightarrow 2^{\mathrm{nd}}\ \text{term insignificant}$$

See later!





Electrostatic forces

$$F_k = -\frac{\partial E}{\partial k} = \frac{1}{2}\sum \frac{\partial C_i}{\partial k} V_i^2 + \frac{Q^2}{2C^2}\frac{\partial C}{\partial k} - \frac{Q}{C}\sum_{i=1}^{n} V_i \frac{\partial C_i}{\partial k}$$

$$F_k = \frac{Q^2}{2C^2}\frac{\partial C}{\partial k} = \frac{Q^2}{2C^2}\left(\frac{\partial C_r}{\partial k} + \frac{\partial C_l}{\partial k}\right) \approx \frac{Q^2}{2C^2}\left(\frac{4\varepsilon A}{d^3}\Delta d - \frac{\varepsilon \Delta A}{d^2}\right)$$

$$\Rightarrow a(t) \approx \frac{\dot{Q}^2 t^2}{2mC^2}\left(\frac{4\varepsilon A}{d^3}\Delta d\right) \Rightarrow \text{constrains } T_d \text{ - } \Delta d \text{ parameter space}$$

$$\Rightarrow (a_n)^2 \approx \left(\frac{Q^2}{2mC^2}\frac{4\varepsilon A}{d^3}\left(1 + \frac{2}{C}\frac{4\varepsilon A}{d^3}(\Delta d)^2\right)\delta d_n\right)^2 + \left(\frac{Q\delta Q_n}{mC^2}\frac{4\varepsilon A}{d^3}\Delta d\right)^2$$

$$\Rightarrow k \approx \frac{Q^2}{2C^2}\frac{4\varepsilon A}{d^3}\left(1 + \frac{2}{C}\frac{4\varepsilon A}{d^3}(\Delta d)^2\right)$$

Electrostatic forces

$$F_k = -\frac{\partial E}{\partial k} = \frac{1}{2}\sum \frac{\partial C_i}{\partial k} V_i^2 + \frac{Q^2}{2C^2}\frac{\partial C}{\partial k} - \frac{Q}{C}\sum_{i=1}^{n} V_i \frac{\partial C_i}{\partial k}$$

Common-mode voltage effects disappear to first order in force

Differential-mode voltages used for charge measurement – see later

$$\Rightarrow (a_n)^2 \approx \left(\frac{\delta Q_n}{mC}\Delta V \frac{\partial C_r}{\partial k}\right)^2 + \left(\frac{Q}{mC}\delta V_n \frac{\partial C_r}{\partial k}\right)^2$$

$$+\left(\frac{Q}{mC^2}\frac{\partial C}{\partial k}\Delta V \frac{\partial C_r}{\partial k} + \frac{Q}{mC}V_{cm}\frac{\partial^2 C_r}{\partial k^2}\right)^2 \delta k_n^2$$

$$\Rightarrow k \approx \frac{Q}{C^2}\frac{\partial C}{\partial k}\Delta V \frac{\partial C_r}{\partial k} + \frac{Q}{C}V_{cm}\frac{\partial^2 C_r}{\partial k^2}$$

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Summary of Charge Limits

Effect	Limit (C)
Lorentz Noise	4×10^{-11} (10^{-4} Hz)
Displacement Noise	4×10^{-11}
Charge Noise (Δd)	1.4×10^{-11} (10^{-4} Hz)
Stiffness (assymmetry)	**3×10^{-12} (≡70mV)**
Stiffness (ΔV_{dm})	10^{-8}
Stiffness ($1V_{cm}$)	4×10^{-13}
Potential (noise)	10^{-2}
Potential (noise) ($1V_{cm}$)	3×10^{-11}
Assumptions!!	
Δd	$10\mu m$
δV_n	$10\ \mu V/\sqrt{Hz}$

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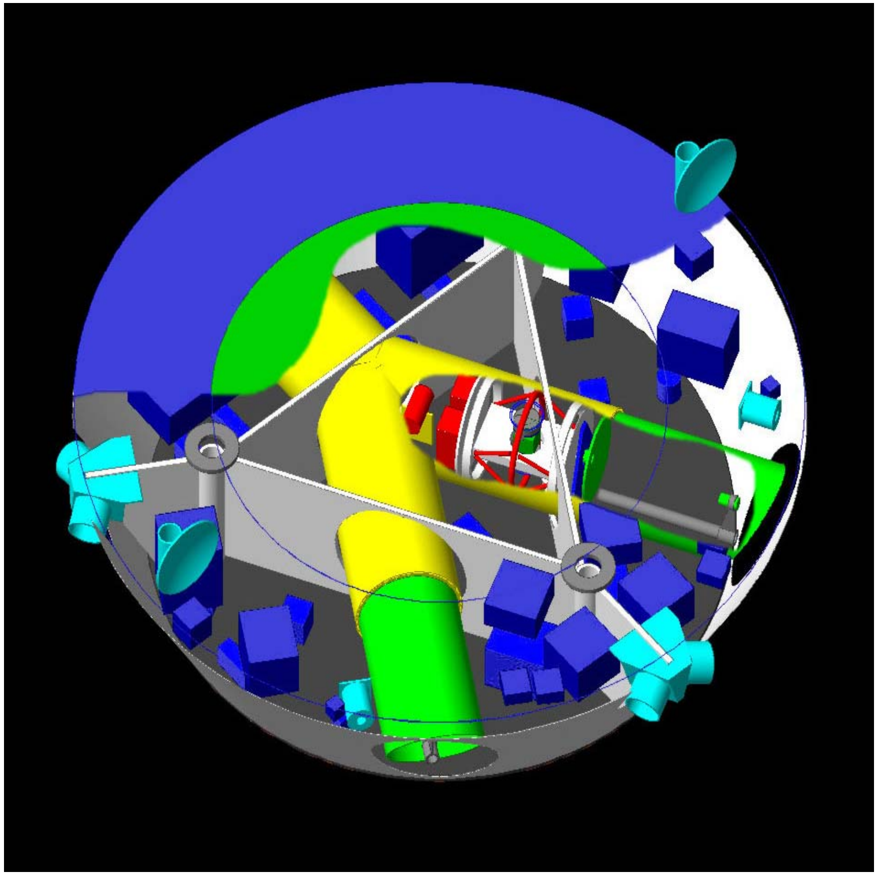
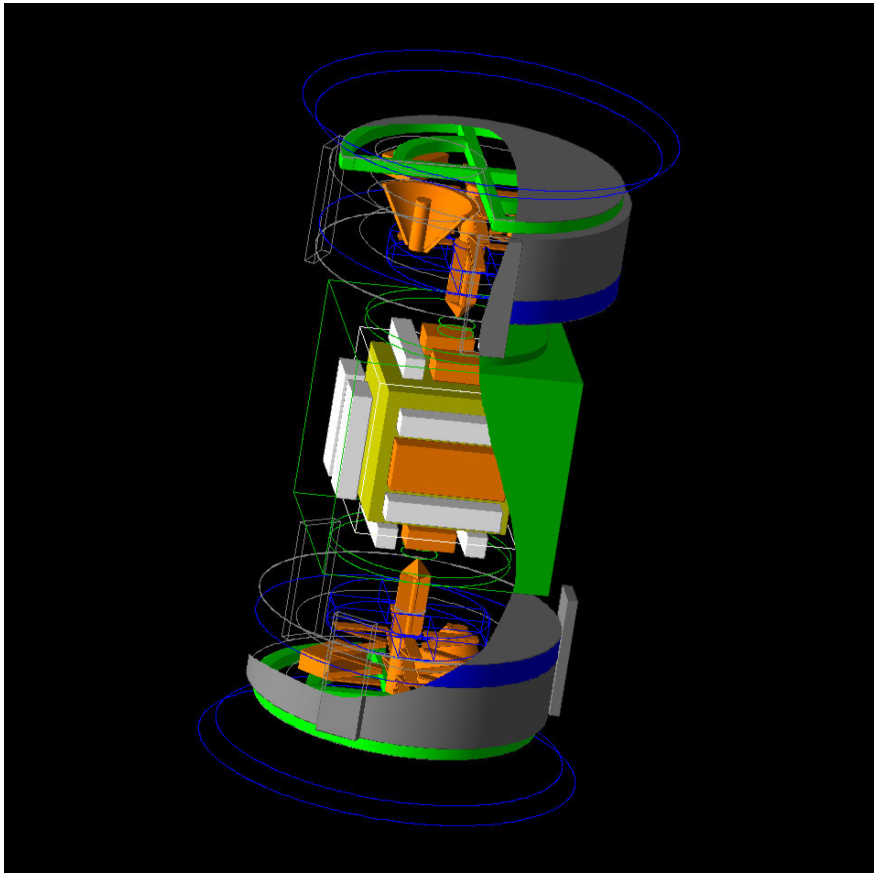
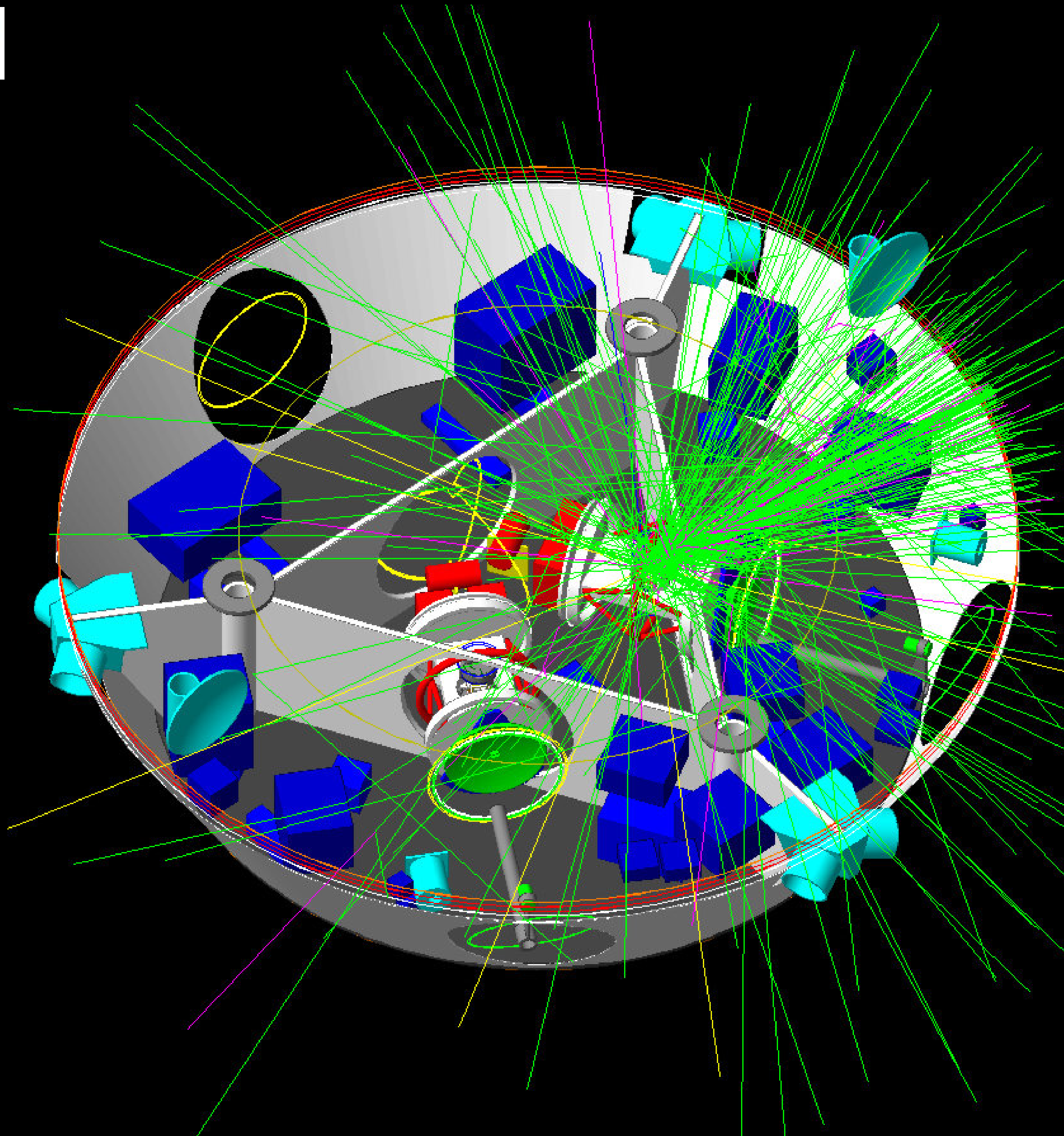
LISA Geant4 Geometry Model

- S/C: LISA Solid Model (GSFC/NASA)
- ~200 placed volumes (85% total mass)
- LTP IS: CAD (Carlo Gavazzi Space)
- 46 mm cube test mass, YZ injection







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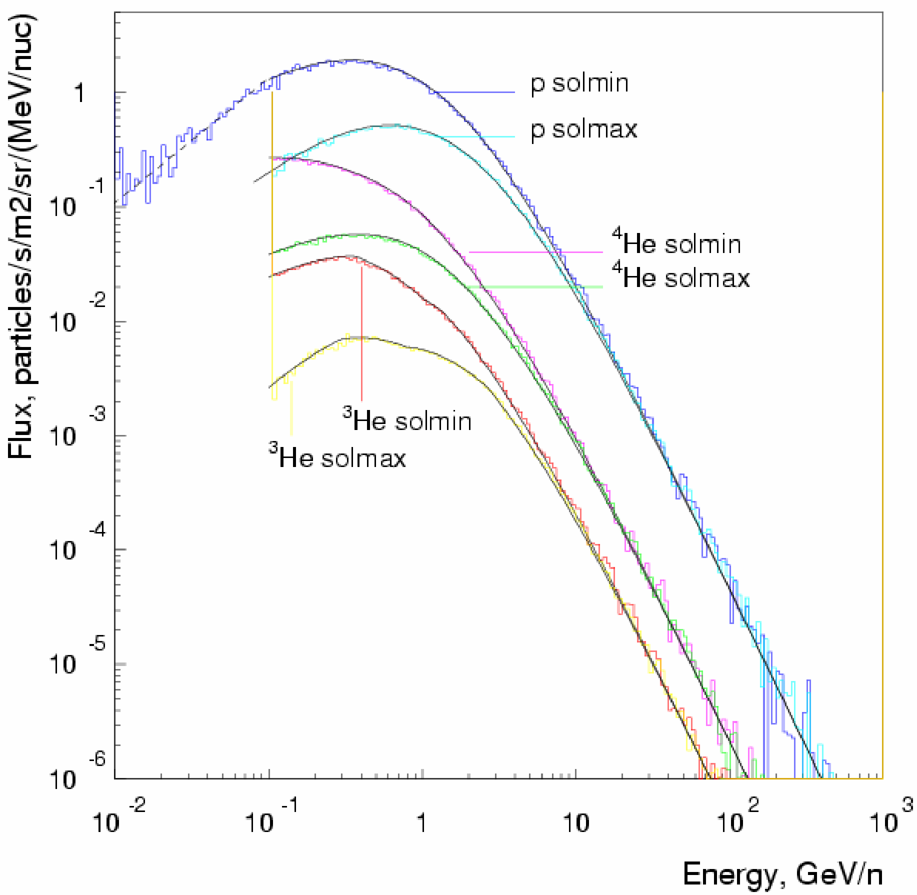
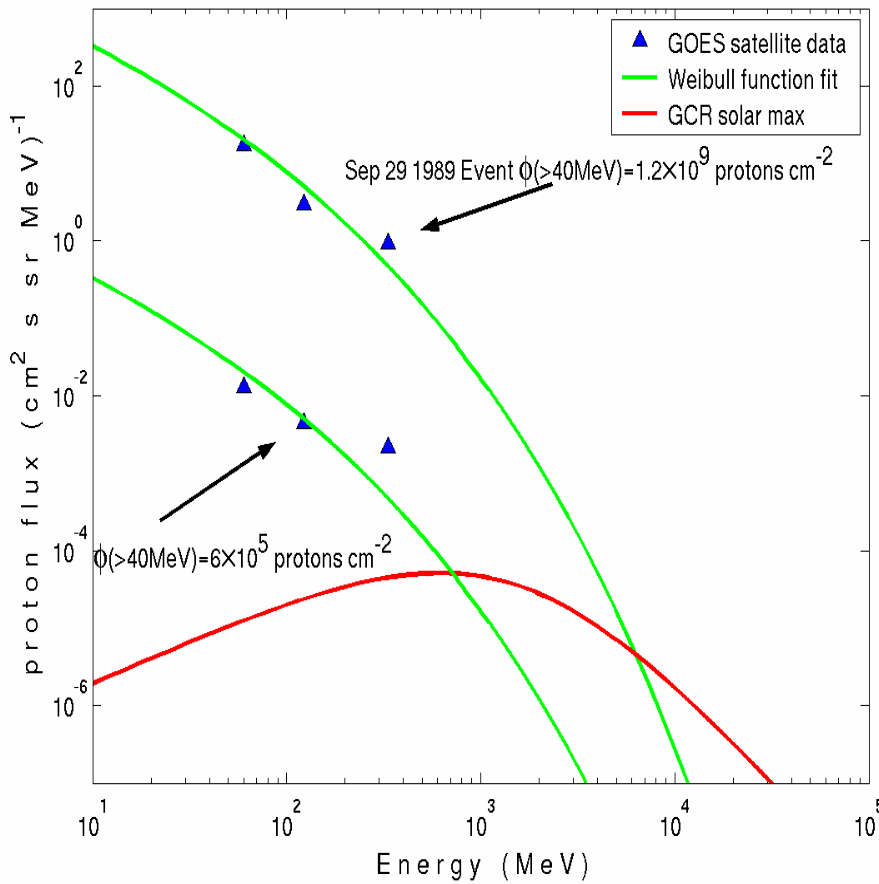
Charged Particle Environment

Galactic Cosmic Rays



Solar Flare Events



Geant4 Physics Processes

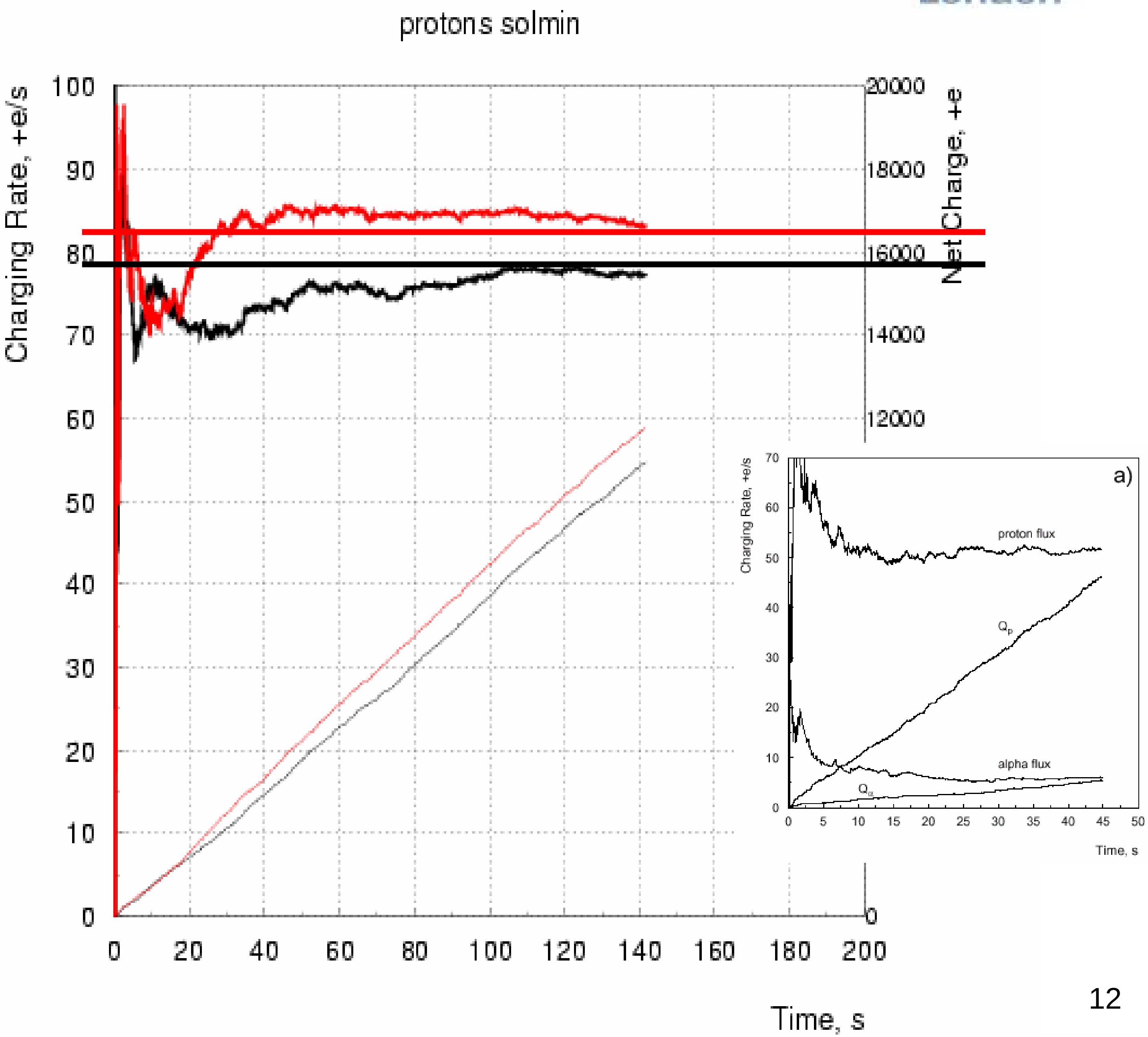
Most G4 physics, including latest developments*

- **Electromagnetics**
  - E_{th} = 250 eV
- **Photo/Electronuclear**
- **Hadronics**
  - Intra-nuclear cascades
  - for protons and light ions
- **Decays**

Hadronic Models

Particle	Model	Emin	Emax
p, n	G4PreCompound	0	70 MeV
	G4BinaryCascade	65 MeV	6.1 GeV
	G4QGSP	6 GeV	100 TeV
π+, π-	G4BinaryCascade	0	1.5 GeV
	LEP	1.4 GeV	6.1 GeV
	G4QGSP	6 GeV	100 TeV
d, t, α	LEP	0	100 MeV
	G4BinaryLightIonReaction	80 MeV	10 GeV/n
^{3}He, GenericIon	G4BinaryLightIonReaction	0	10 GeV/n
K^{+}, K^{-}, K_{0L}, K_{0S}	LEP	0	6.1 GeV
	G4QGSM	6 GeV	100 TeV
$\bar{p}$, $\bar{n}$, Λ, $\bar{\Lambda}$, Ω^{-}, $\bar{\Omega}^{-}$, Σ^{-}, $\bar{\Sigma}^{-}$, Σ^{+}, $\bar{\Sigma}^{+}$, Ξ^{0}, $\bar{\Xi}^{0}$, Ξ^{-}, $\bar{\Xi}^{-}$	LEP	0	25 GeV
	HEP	25 GeV	10 TeV
π^{-}, K^{-}	G4AbsorptionAtRest	—	—
$\bar{p}$, $\bar{n}$	G4AnnihilationAtRest	—	—
n	G4LCapture	—	—
n	G4LFission	—	—
All hadrons	G4LElastic	0	25 GeV

* Working within GEANT4 development team


protons solmin
Charging Rate, +e/s
Net Charge, +e
100
90
80
70
60
50
40
30
20
10
0
20000
18000
16000
14000
12000
0
0 20 40 60 80 100 120 140 160 180 200
Time, s
a)
Charging Rate, +e/s
proton flux
alpha flux
70 60 50 40 30 20 10 0
0 5 10 15 20 25 30 35 40 45 50
Time, s

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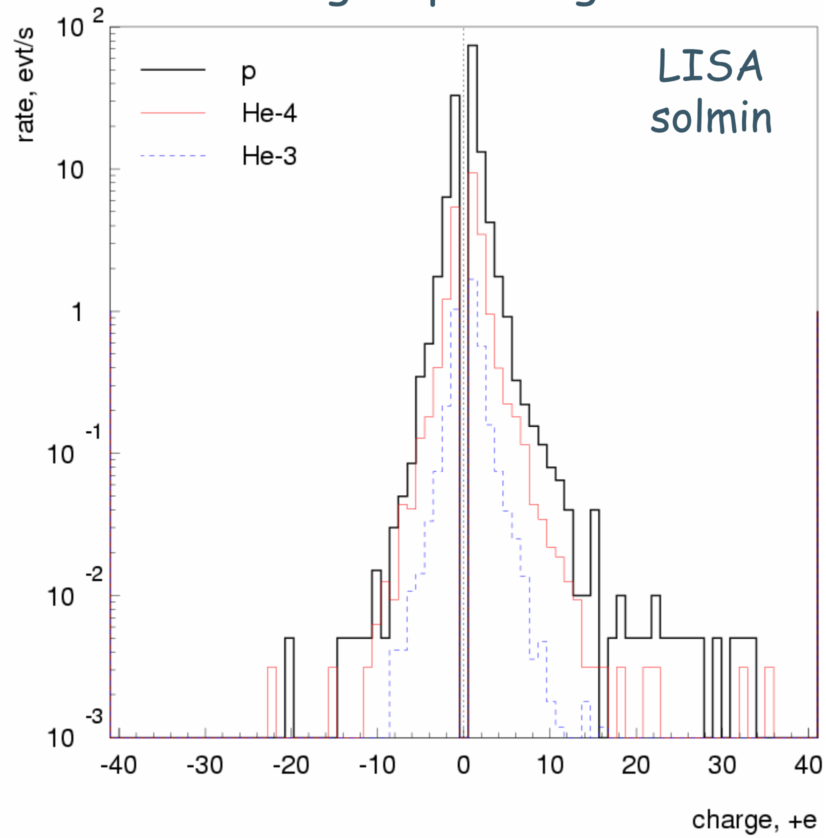
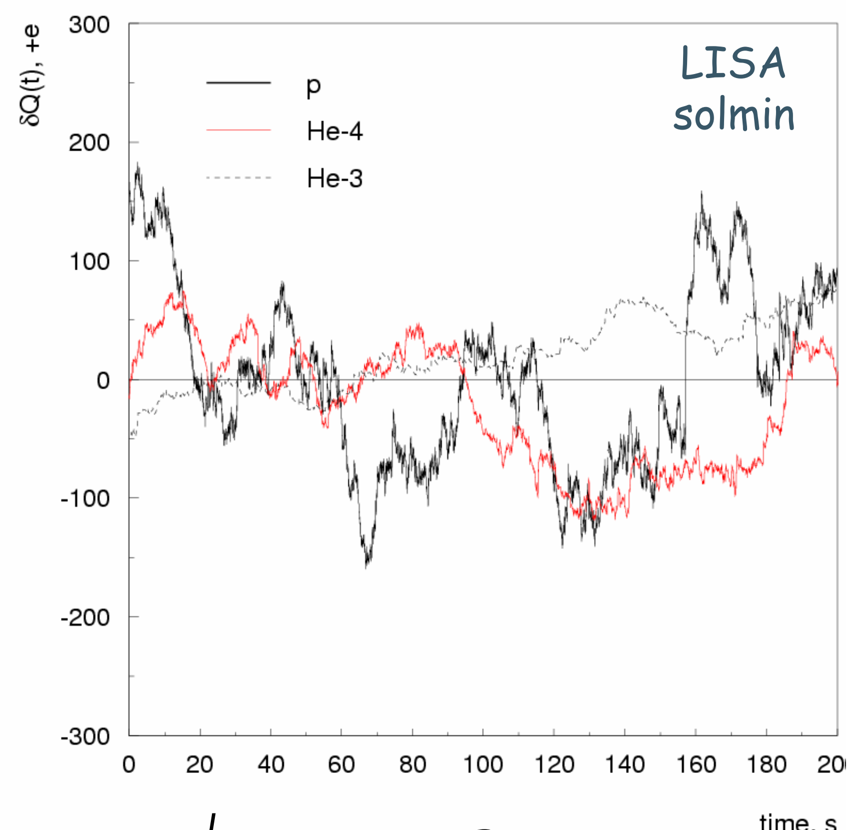
Charging Multiplicity

Charge Spectrogram

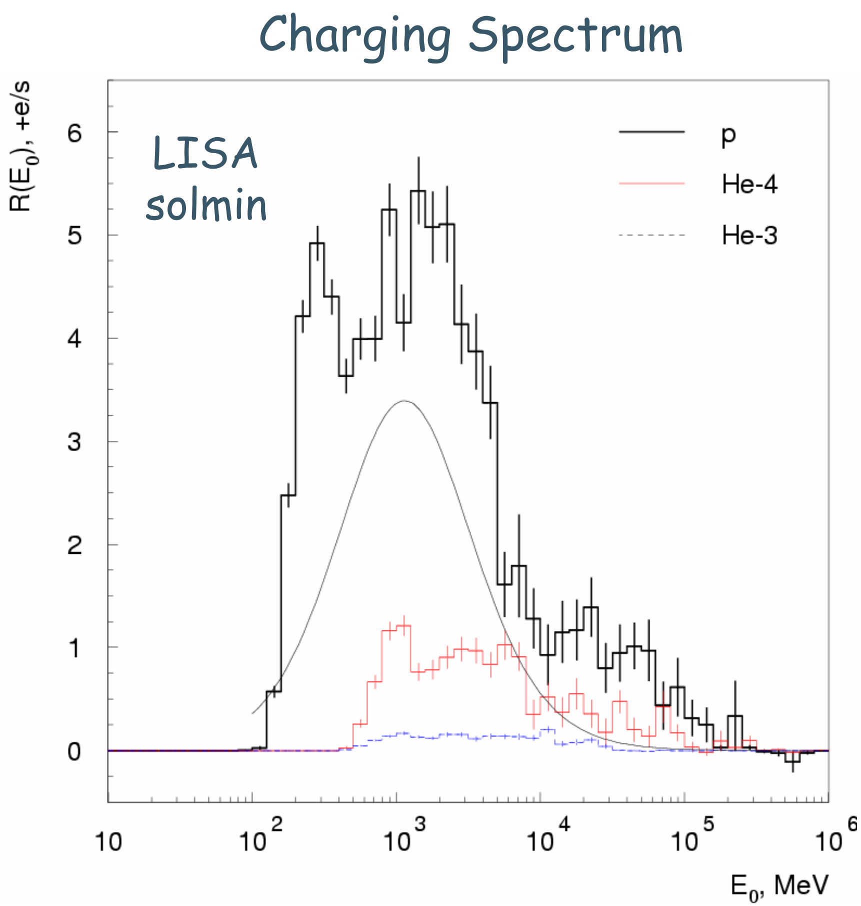


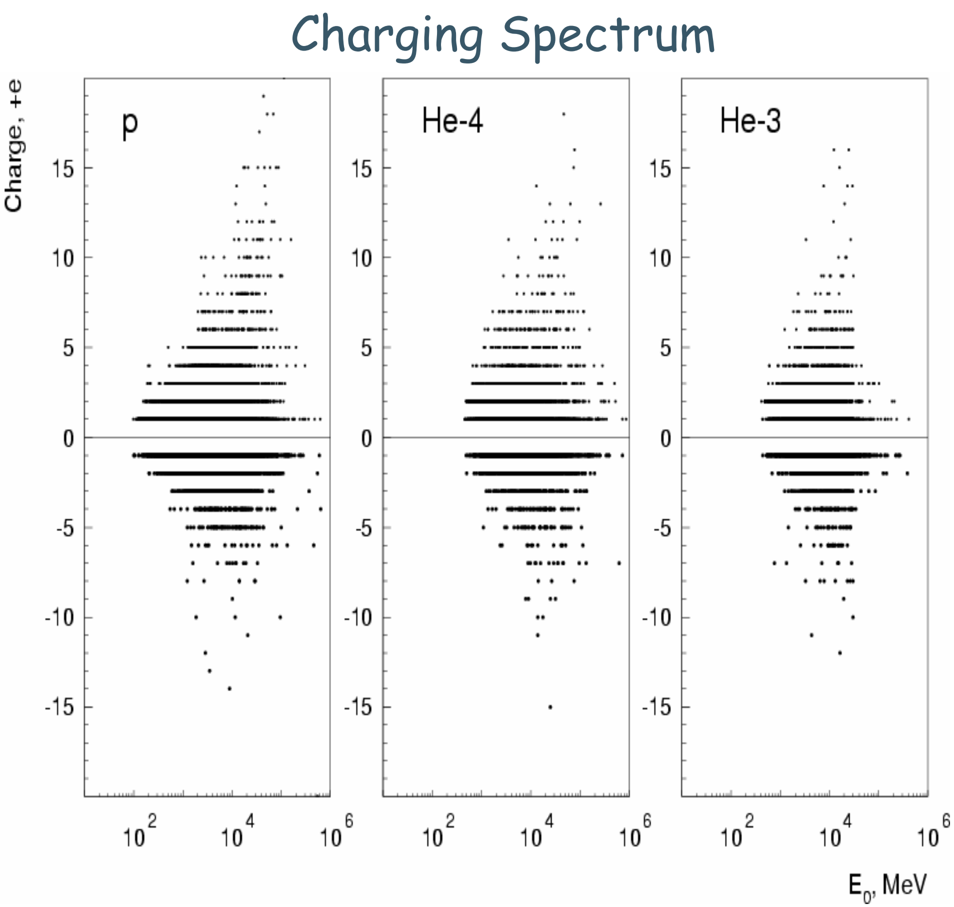
Statistical Fluctuations



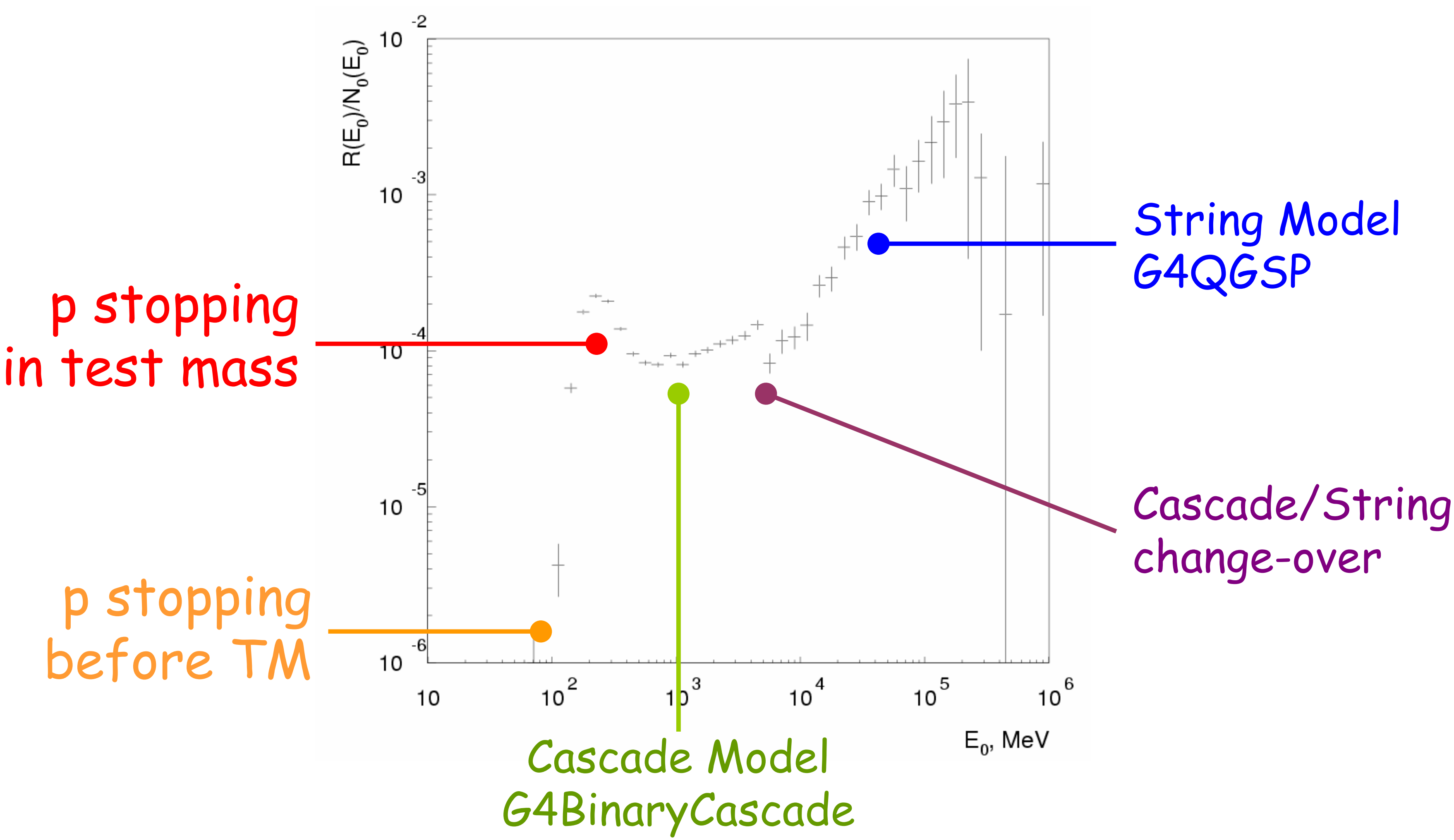
$$\delta Q = \sqrt{\Sigma(\delta Q_i)^2} \sim 2.5\ \delta Q_1$$

Charging Spectra I





Spectral Charging Efficiency



LISA Results

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primary particle	solar activity	GCR flux Φ, /s/cm^2	Φ, %	timeline N_0 (x10^6)	CPU, days	T, s	N_0/N_Q
protons		4.29	92.0	121.1	150	200	2189
He-4	min	0.315	6.8	14.4	12	321	1002
He-3		0.0591	1.3	14.1	12	1683	1073
Total		**4.66**	**100**	**149.6**	**174**	**–**	**419**
protons		1.89	91.9	53.3	70	200	1889
He-4	max	0.142	6.9	9.3	11	462	849
He-3		0.0236	1.1	8.0	10	2402	928
Total		**2.06**	**100**	**70.6**	**91**	**–**	**359**

- CERN LSF Cluster
- 2.2×10^8 Events
- several CPU Years
- 200 s exposure time

Latest LISA result

– Astropart Phys. 22, 451-469 (2005)

Rate = +50 e/s

Noise = 30 e/s/Hz$^{-1/2}$

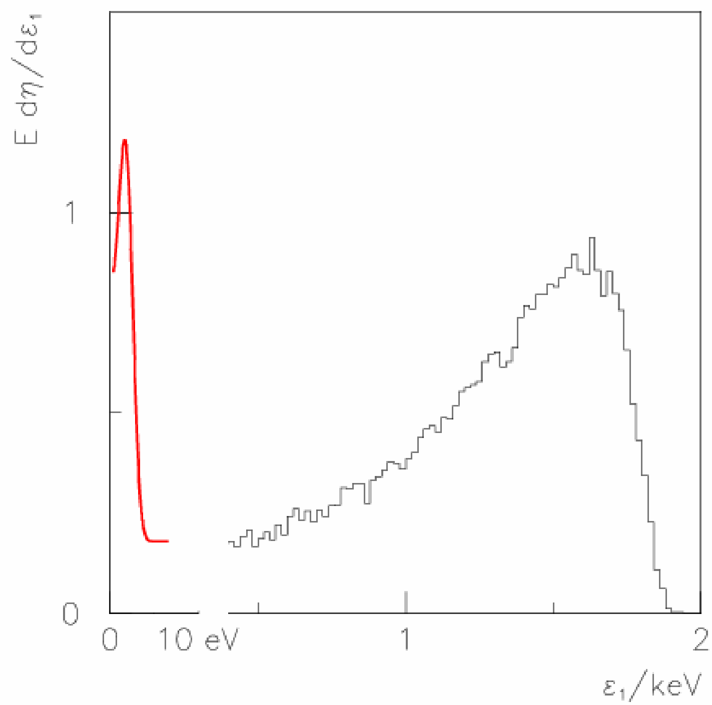
Non-Simulated Physics

- **Potential Charging Processes:**

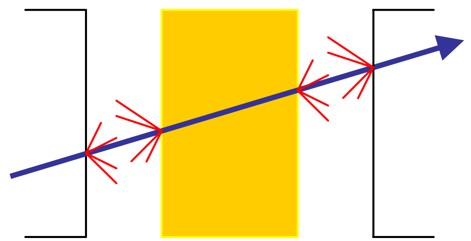
- Electron-induced kinetic emission
- Ion-induced kinetic emission

- Atom sputtering (<0.01 at/s)
- X-ray transition radiation (<1 +e/s)
- X-ray Cherenkov radiation (<1 +e/s)
- Cosmogenic activation (<<1 +e/s)
- ❑ Hadron-induced x-ray emission

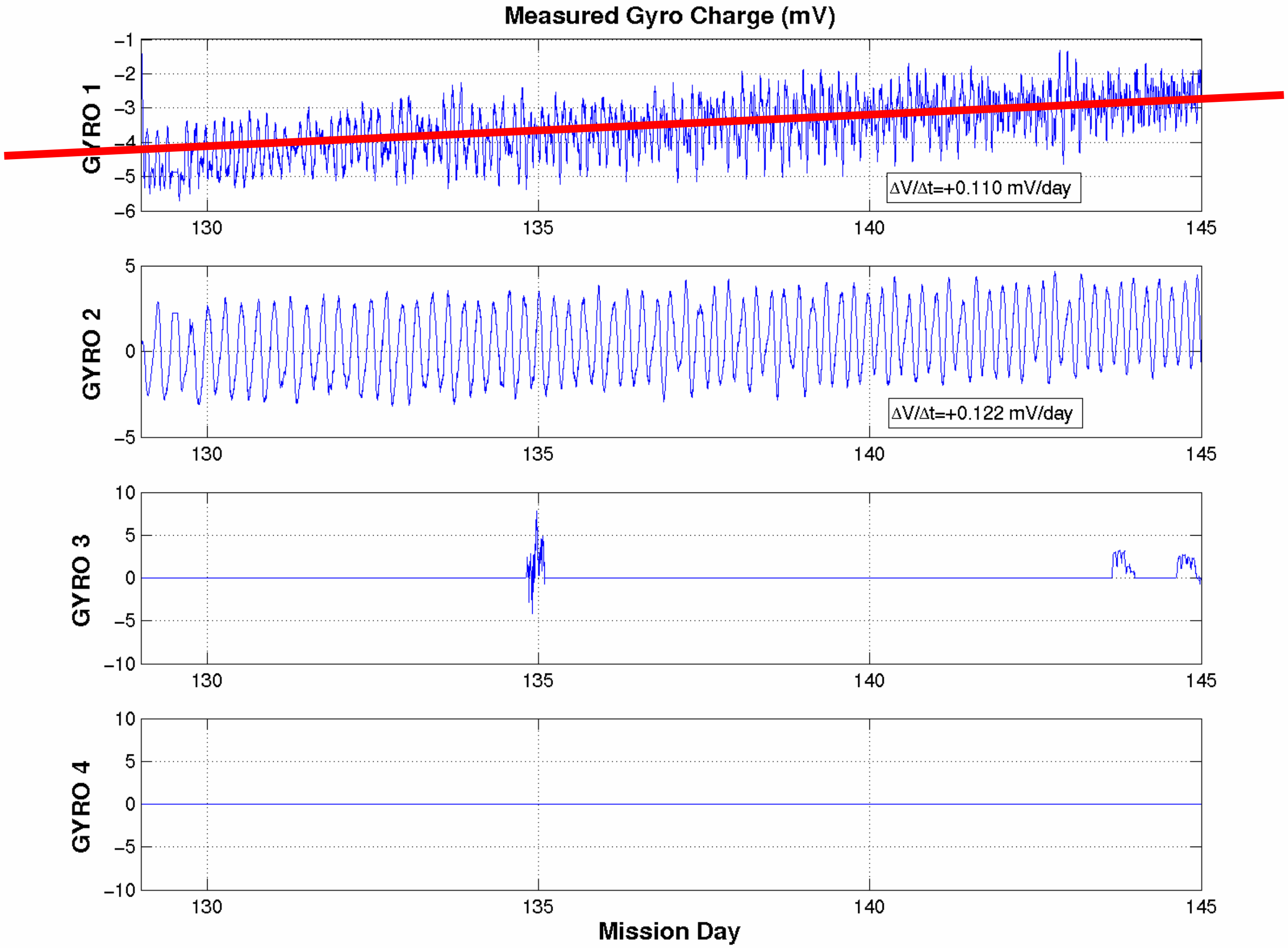
Kinetic Electron Emission



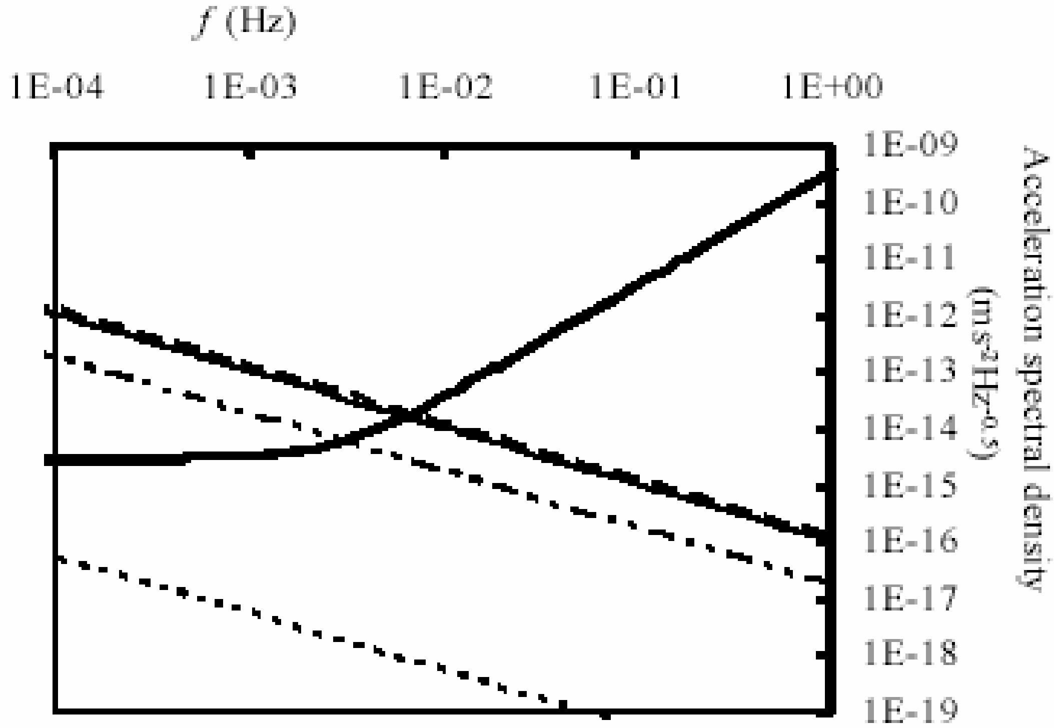
Kinetic emission of low energy secondary electrons (<50 eV) due to incident electrons (EIEE) and ions (IIEE) can be significant !



GP-B Simulations

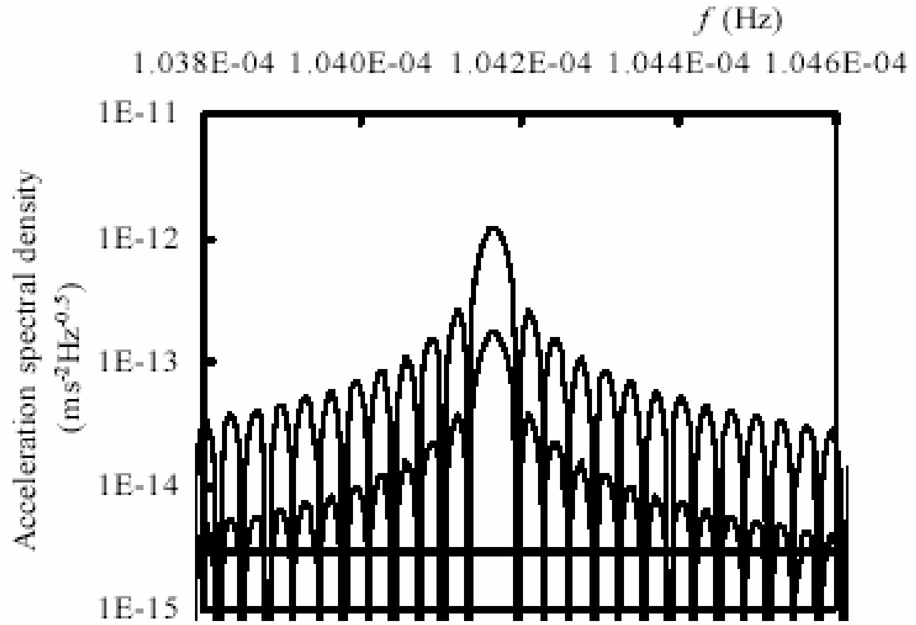


Flare result is ~2-3 times too high but does not allow for spectral modification of proton flux at GP-B orbit

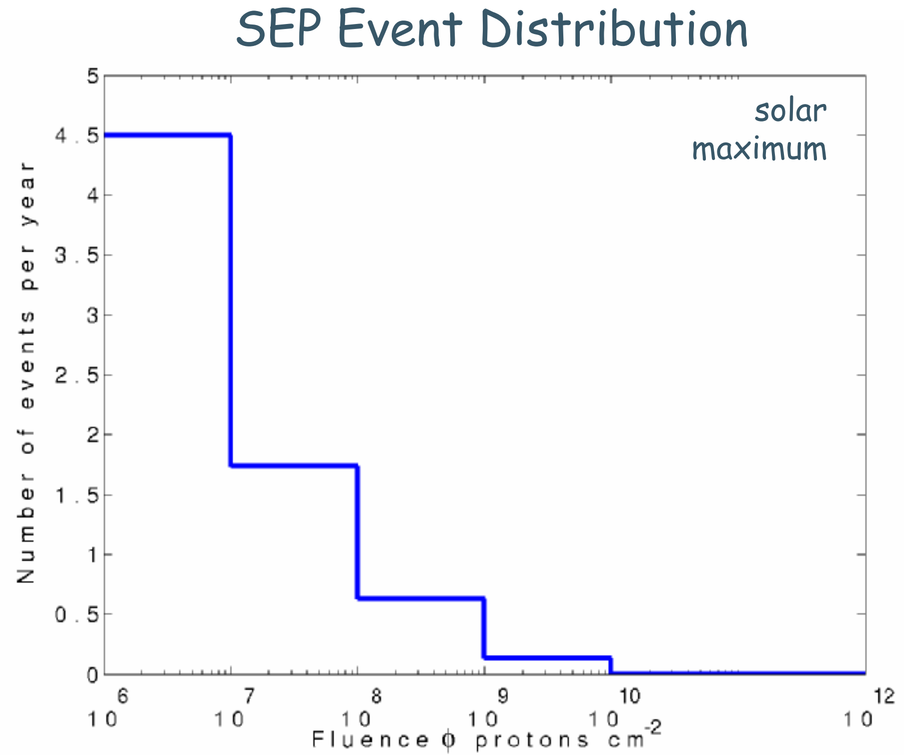


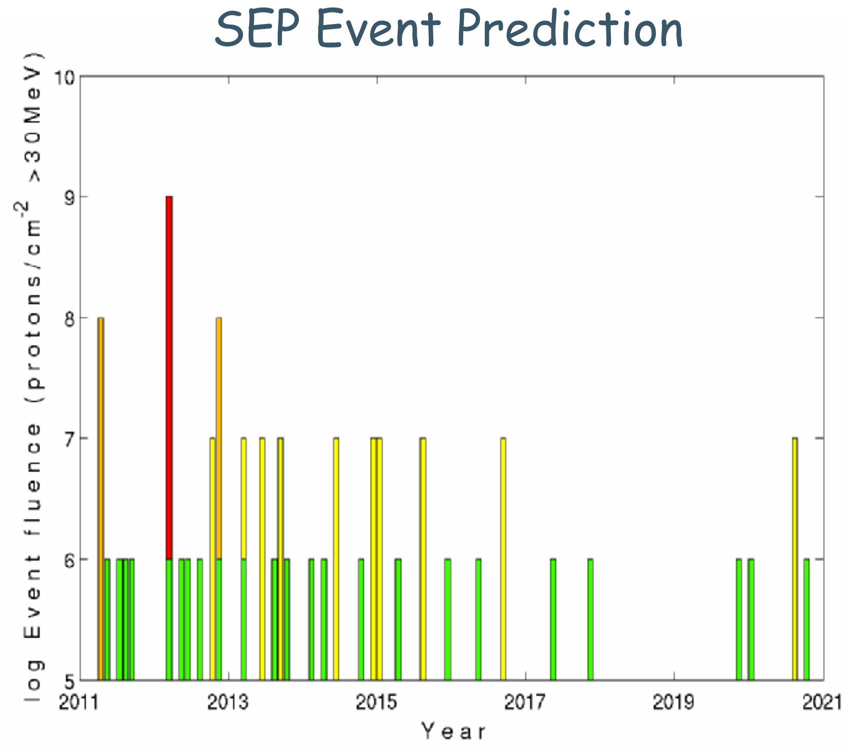
Data Analysis and Clean-up

Shaul et al., 2004



Charging from Solar Events





- Large solar flares (<1 /yr) can seriously disrupt normal operation
- More modest flares (~1/yr) can deposit >10^9 charges in ~1 day
- Small but frequent flares (>5 /yr) will contaminate the science data
- Recommendation on specification of radiation monitor for LISAPF

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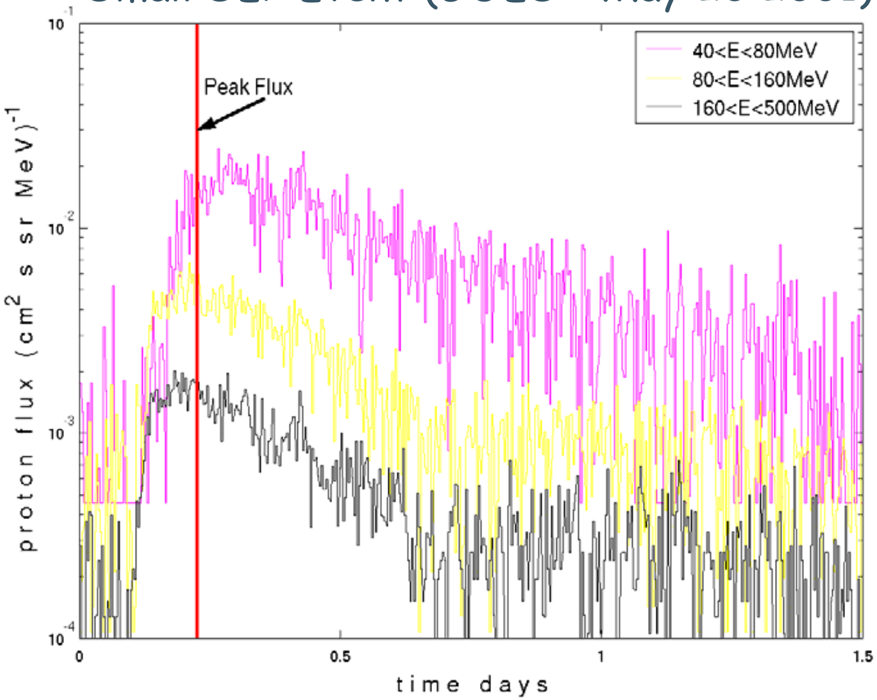
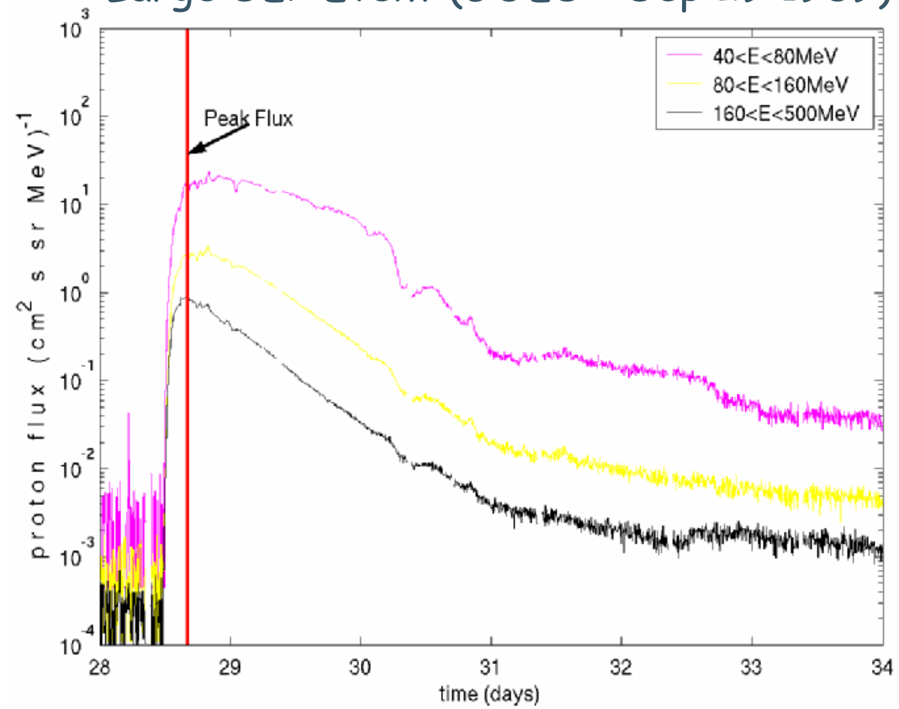
Charging from Solar Flares !

Small SEP Event (GOES - May 20 2001)



Large SEP Event (GOES - Sep 29 1989)



- Event fluence 6×10^5 p/cm^2
- Charging rate at peak flux ~160 +e/s
- Total event charge ~3×10^6 +e
- Frequency 5-10 /year

- Event fluence ~10^9 p/cm^2
- Charging rate at peak flux
- ~130 000 +e/s
- Total event charge ~5×10^9 +e
- Frequency « 1 /year

Need to characterise SEP distribution to lower fluences

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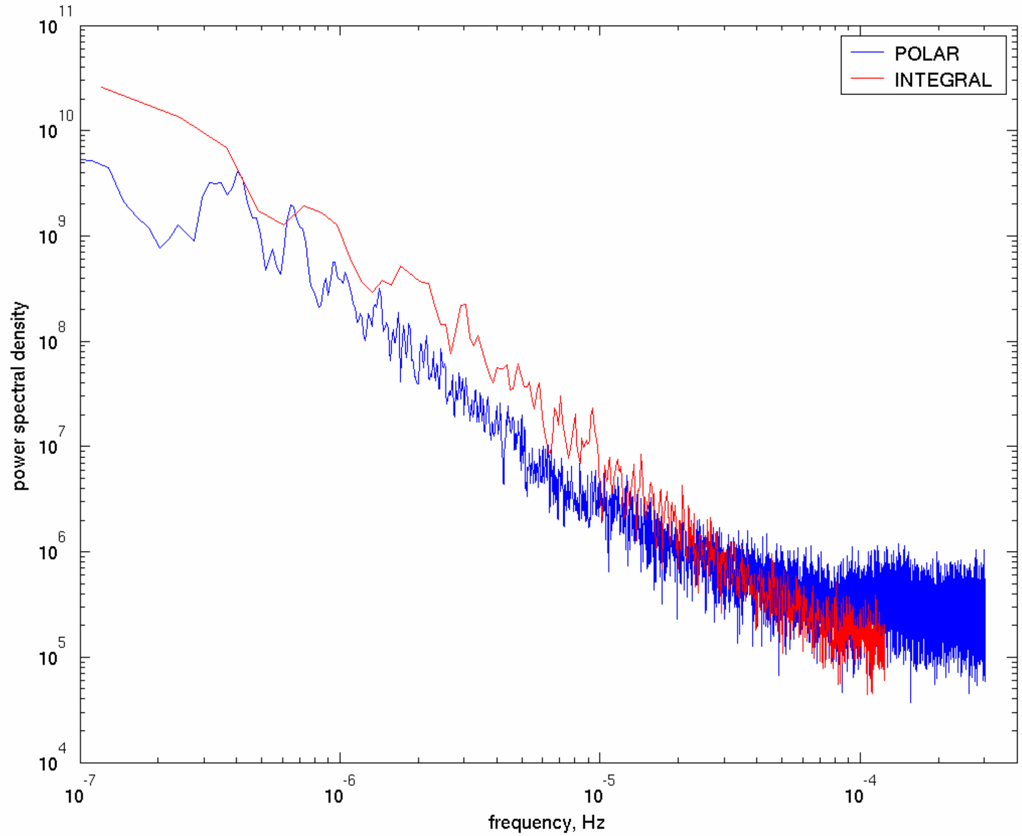
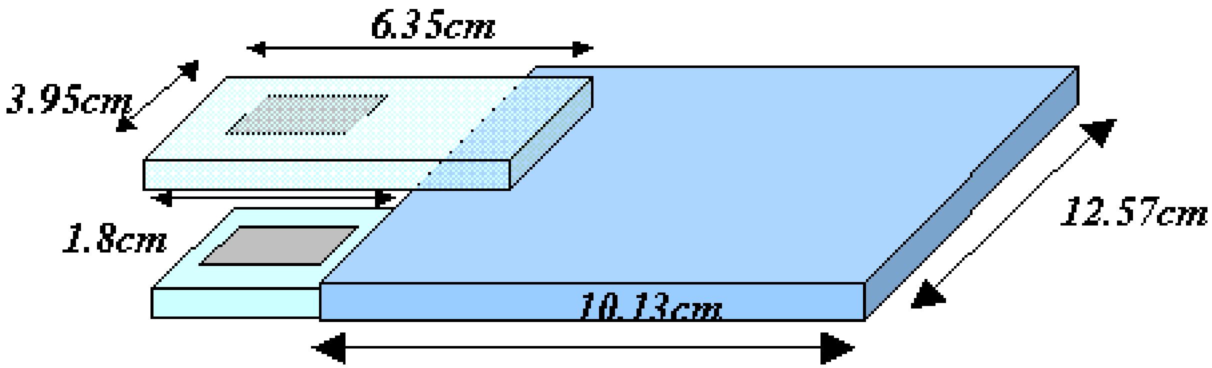
CR Variability – INTEGRAL and POLAR



No dramatic concern - some indications of isolated CR fluctuations, probably induced by solar events.

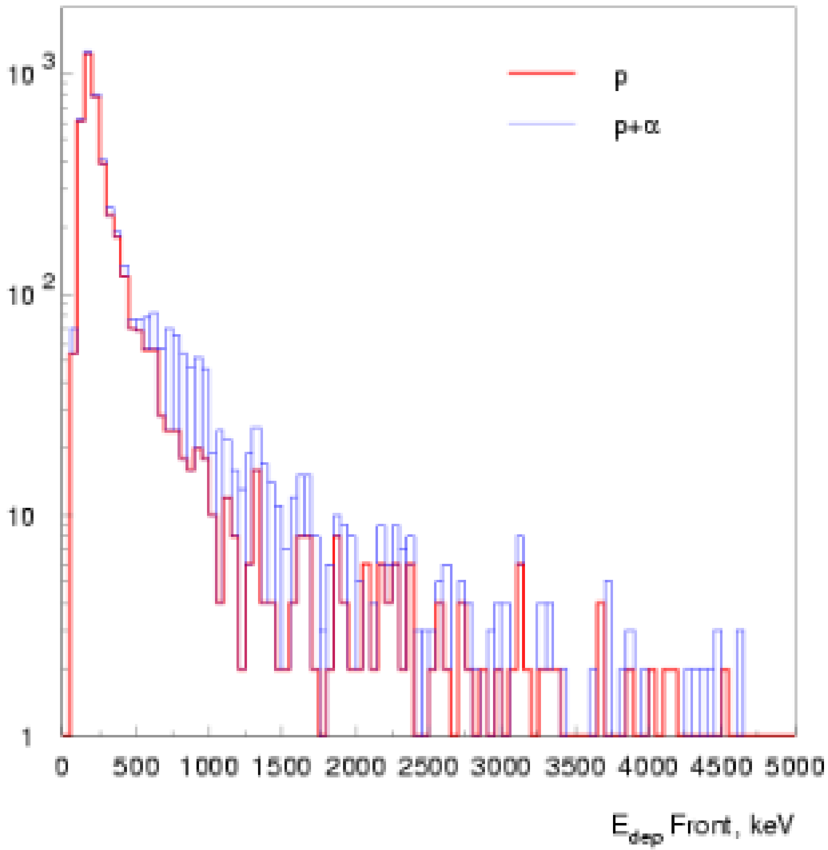
Radiation Monitor

ICL Detector concept: 2 PIN diodes in tetescopic configuration:

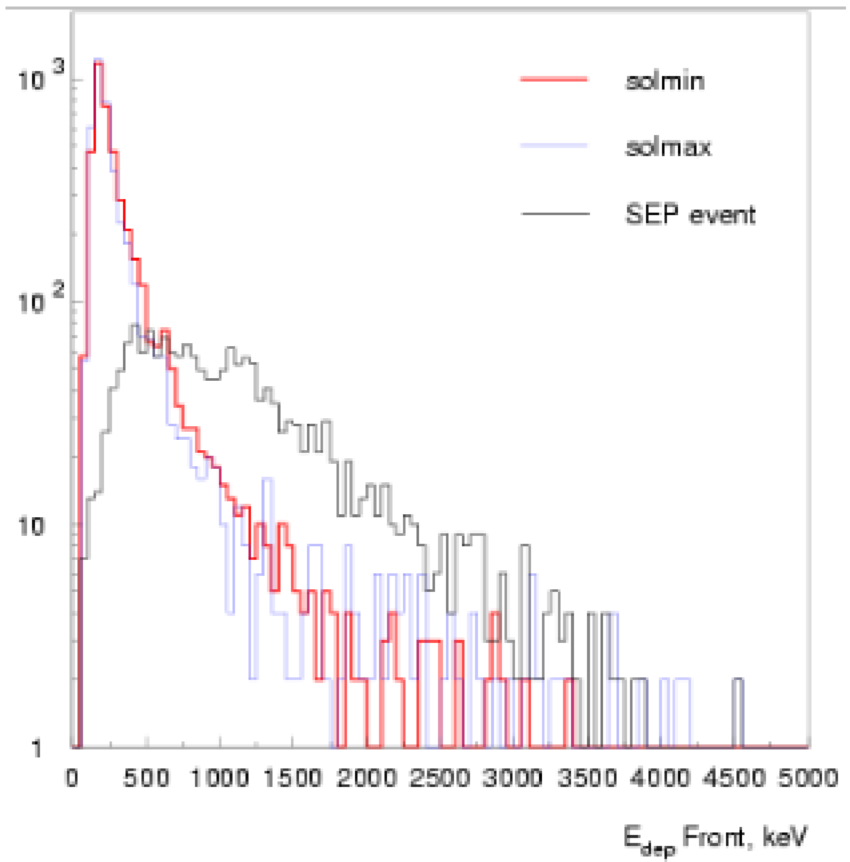


PINs have been kindly provided by GLAST collaboration

Radiation Monitor

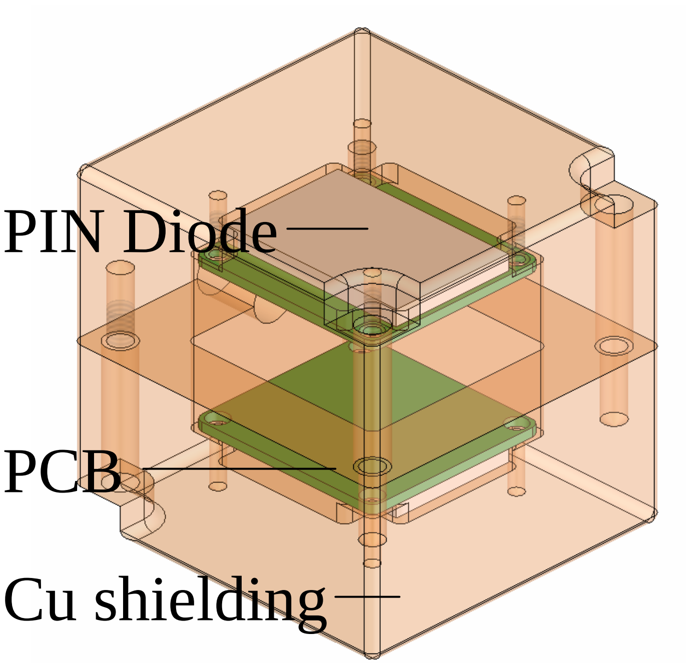


Coincidence spectrum for GCR

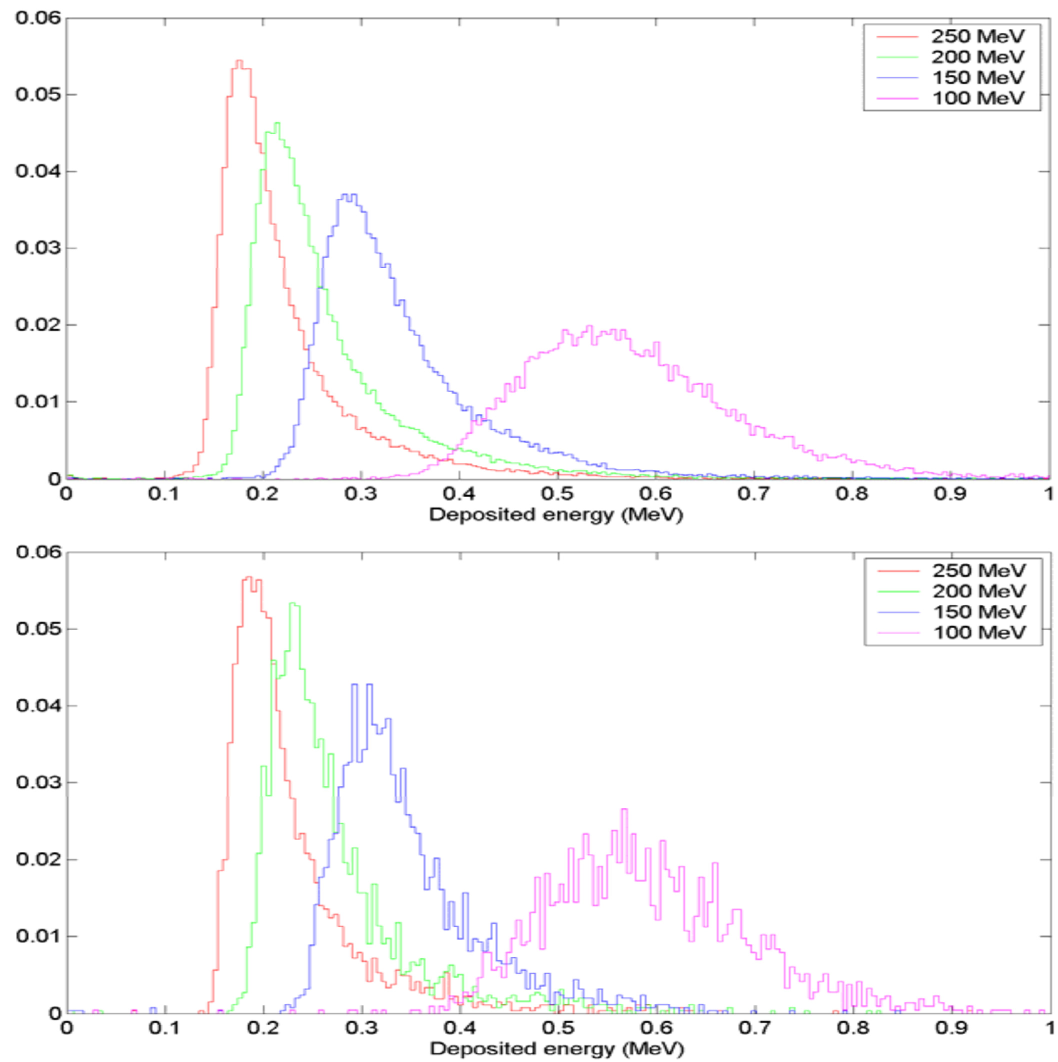


Coincidence spectrum for SEP

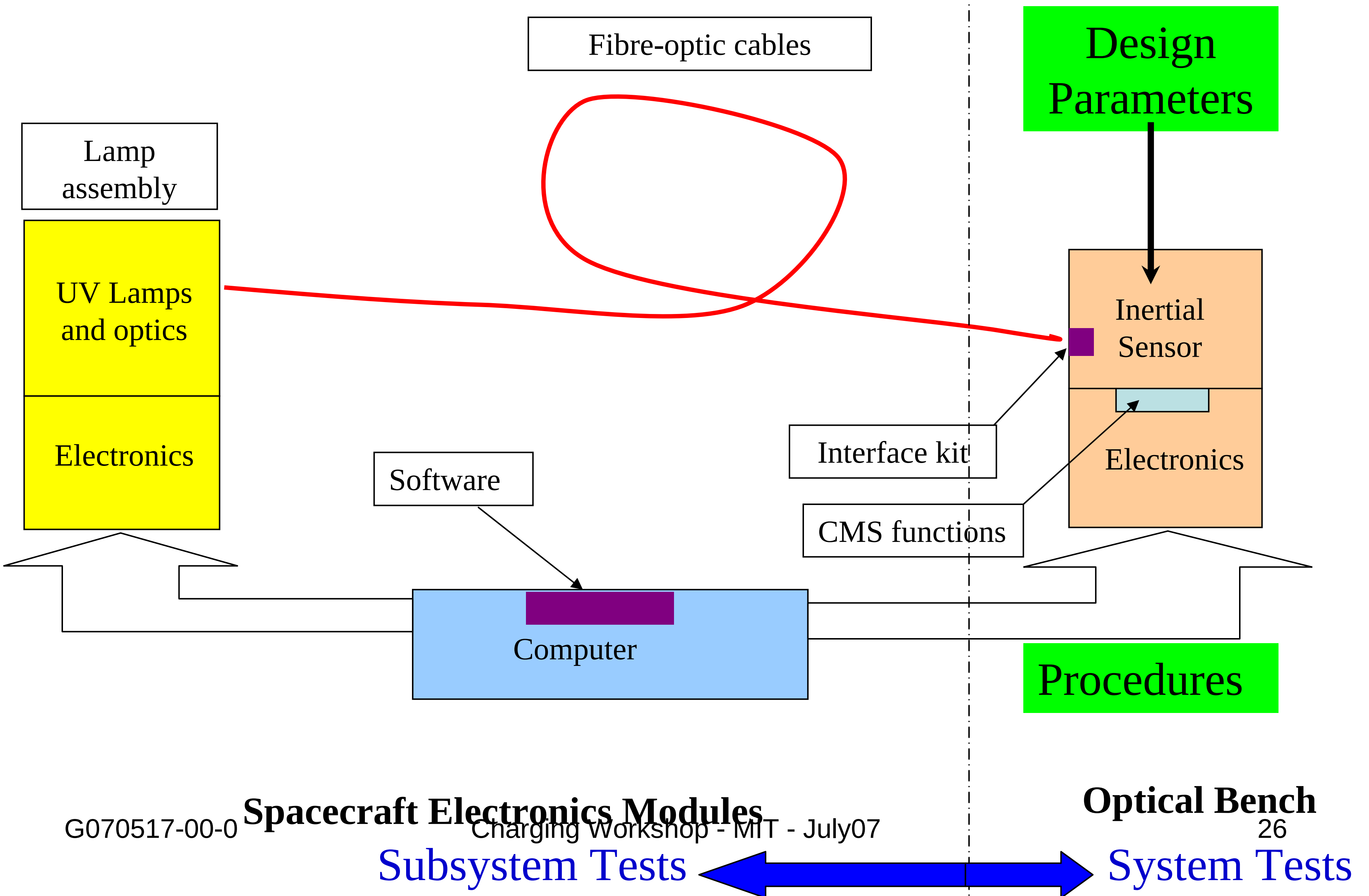
Radiation Monitor



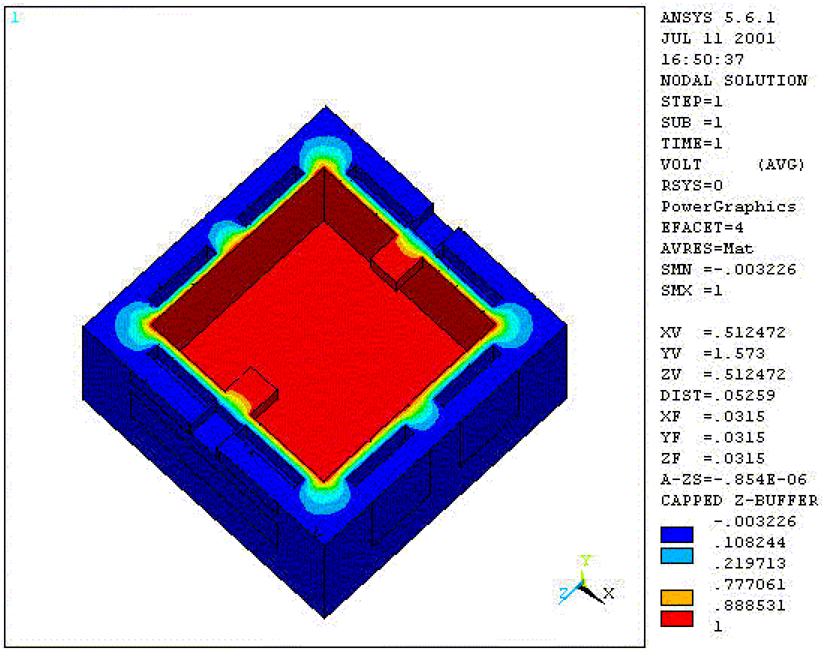
Radiation Monitor Geometry

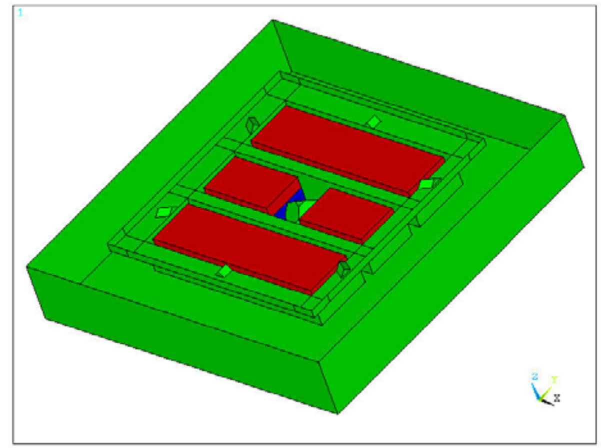


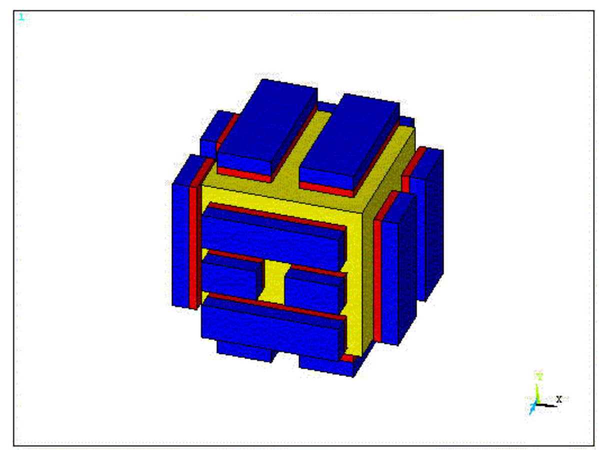
The CMS is a distributed system



Inertial Sensor Design



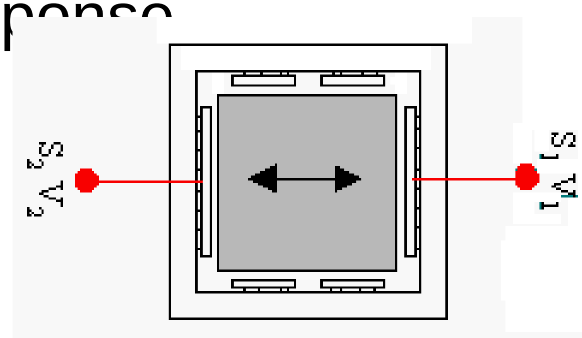




- **Electrode isolation**
- **Capacitance matrix**
- **Capacitance gradient**
- **Cross-coupling matrix**
- **Caging design**
- **Charge sensitivity – electrode layout**

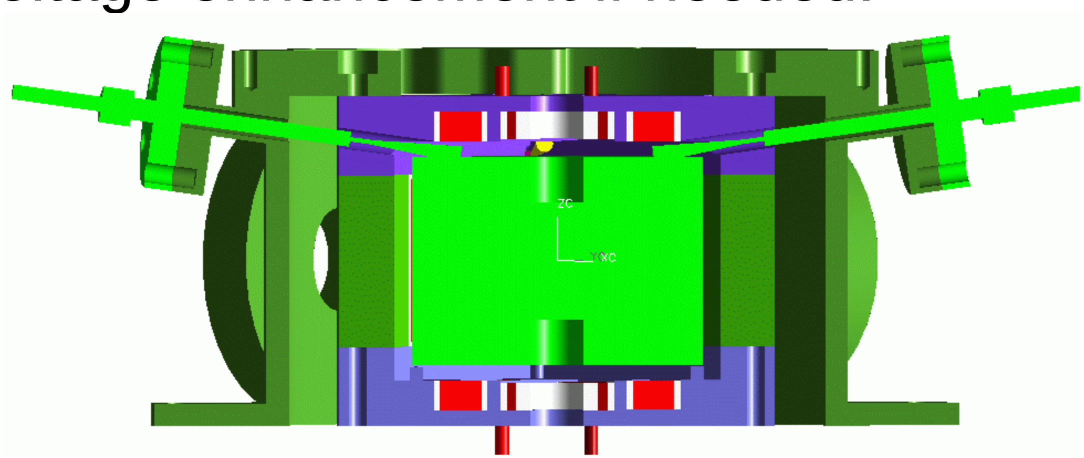
Charge Management System

- Charge Measurement using applied dither force in transverse direction with capacitive sensing of test-mass response



$$F_d = \frac{2QE\varepsilon A}{Cd}$$

- Discharge technique using differential illumination of surfaces with UV illumination, with bias voltage enhancement if needed.



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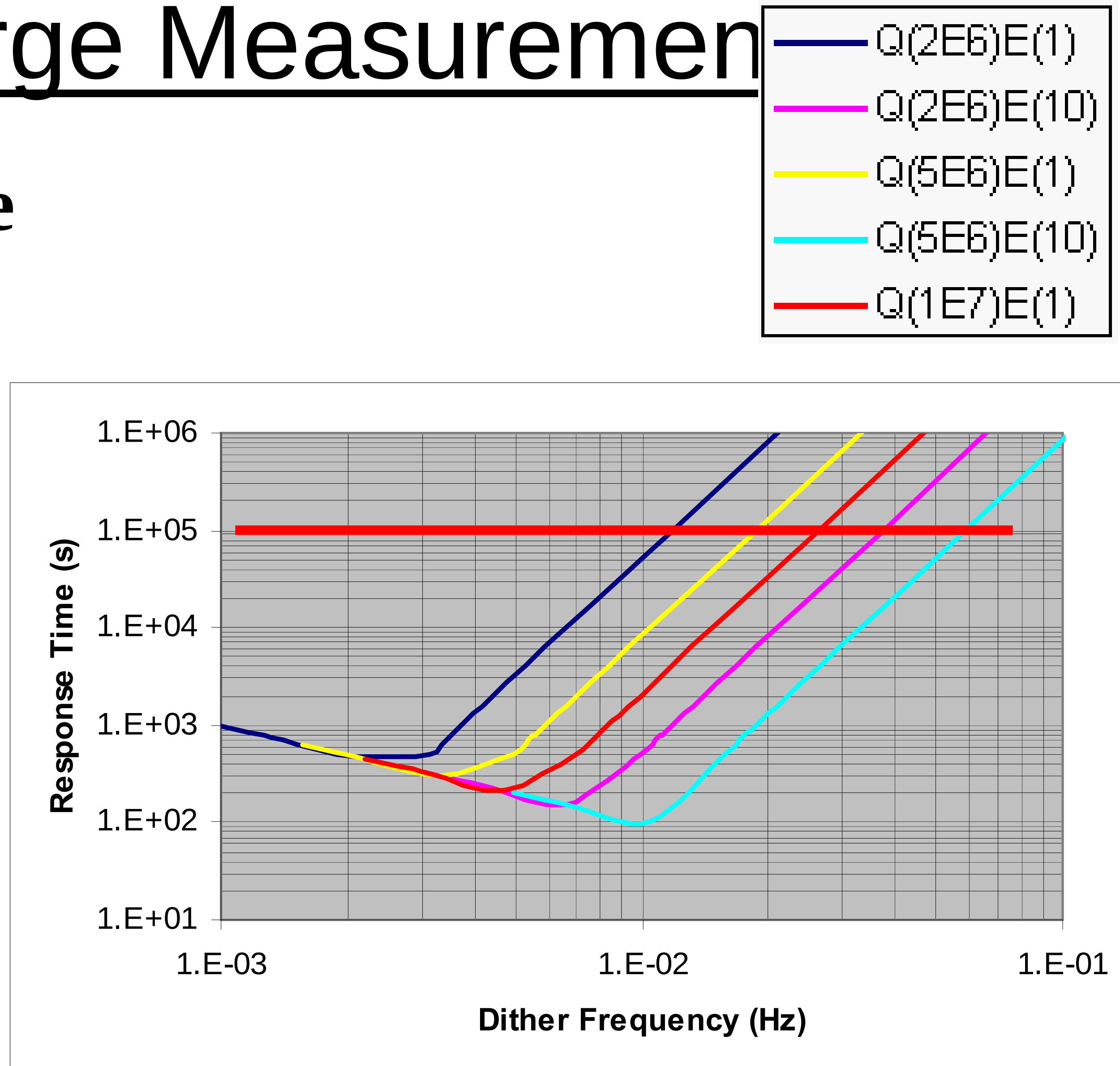
Charge Measuremen

Dither Technique

- Different gaps in each direction give different measurement authority
- Need to see dither above residual drag-free position noise
- Assume transverse dither with 1nm/√Hz position noise



$$\tau_x^{1/2} E \approx \frac{1\times10^{-9}\times w_{dx}^2}{1.7\times10^{-14}} \approx 2.9\times10^{5}\times w_{dx}^2$$

Charge Neutralisation

$$R = LT_i \eta_{lf} T_f \eta_{vc} T_{vc} \eta_{pe} \eta_t$$

$\eta_{pe} \approx 10^{-6}$ at 2537 Å is target but needs measuring for 'real' surfaces

$\Rightarrow 3 \times 10^4$ photoelectrons per second

$LT_i \eta_{lf} T_f \eta_{vc}^2 T_{vc}$ ~ 3x10^{10} photons/s

Oxford Instruments HPSUV1000 fibre

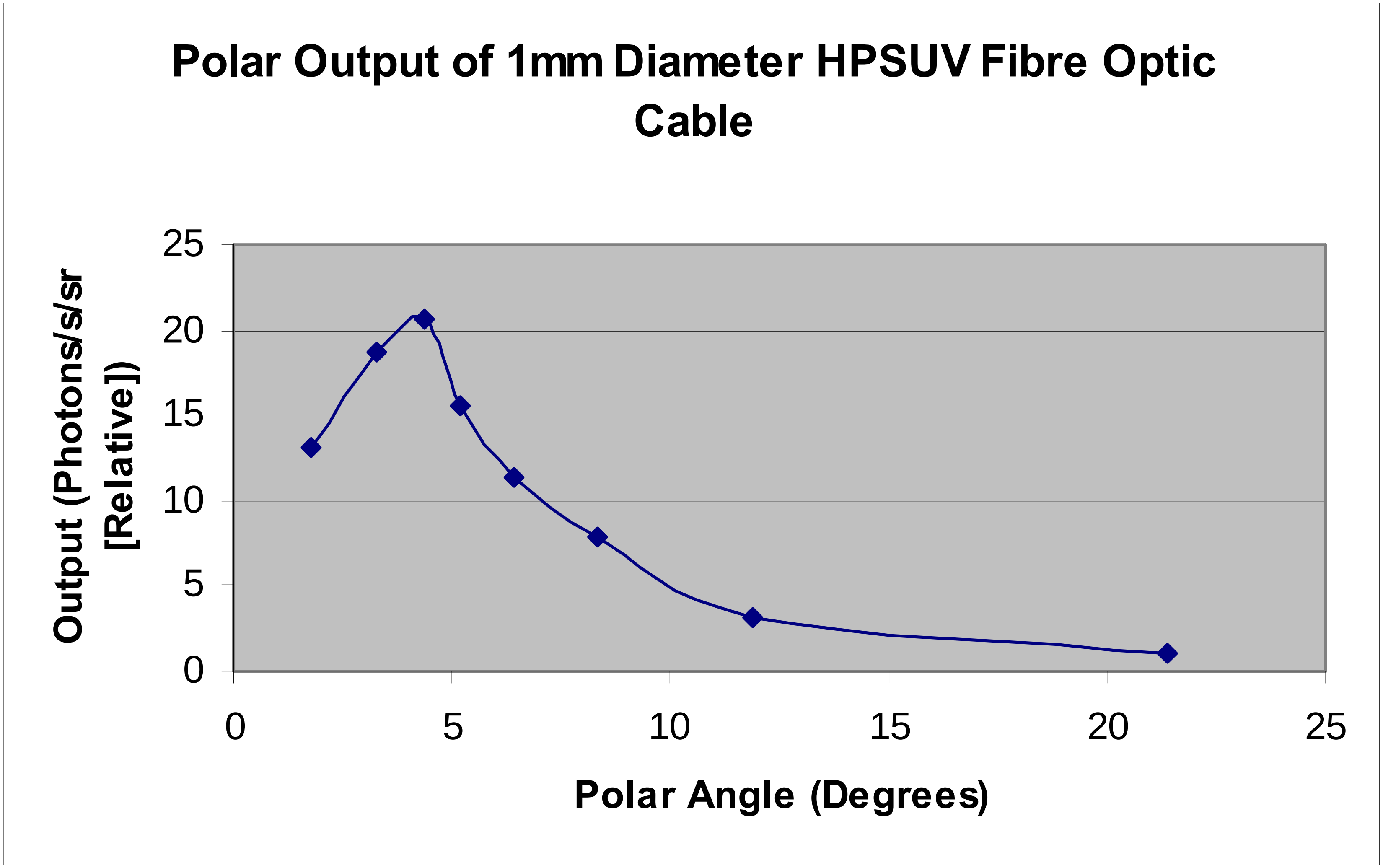
Caburn FFTUV1000 (Special – remade in titanium with epoxy seal)

Charge Transport - η_t

- Dual Surface Illumination with dc bias voltage to modify ballistic trajectories
  - —2.1 V/m/eV gives $\delta Q/\delta t \sim 15$ charges/s
  - —80 V/m/eV gives $\delta Q/\delta t \sim 6\times10^3$ charges/s
  - —500 V/m/eV gives $\delta Q/\delta t \sim 3\times10^4$ charges/s
- Differential Surface Illumination using individual lamp currents to modify electron fluxes
  - —$L(\phi)$ and $L(I)$

Charge Transport

- Polar Ouput



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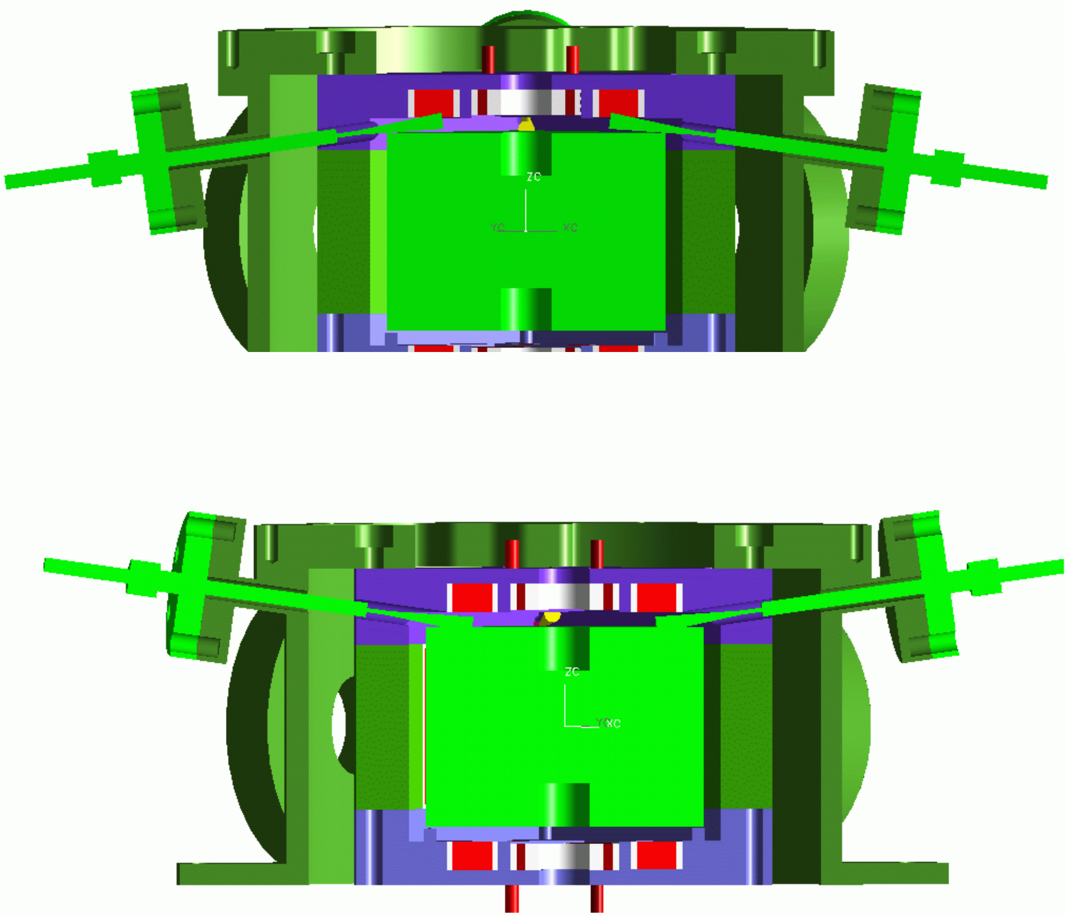
Charge Transport

- Differential Surface Illumination



Electrode:Housing:TM

1	: 1.3	: 0.1
1	: 1.1	: 13.1

$-3.9\text{x}10^3 < \dot{Q} < +3.5\text{x}10^3$ /s

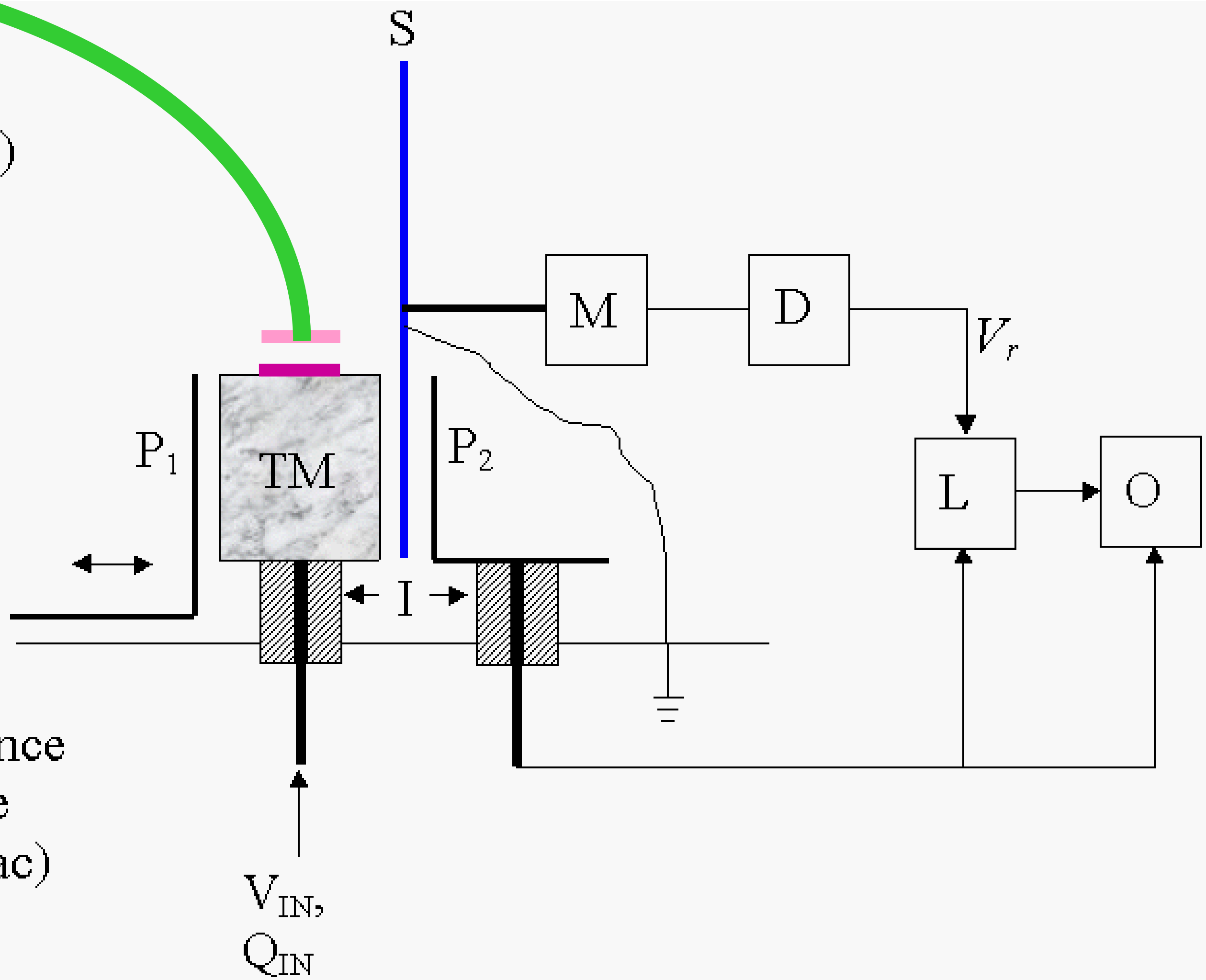
Add dc bias to drive harder when required

⇒ x5

Charge Transport Test Rig

P_2 sees ground plane(s) and charged plane (TM) alternately.

S - sectored disk
M - motor
D - synchronous drive
L - lock-in amplifier
O - oscilloscope
I - insulators
P_1 - adjustable capacitance
P_2 - signal pick-up plate
V_r - reference voltage (ac)
V_{IN}, Q_{IN} - dc inputs

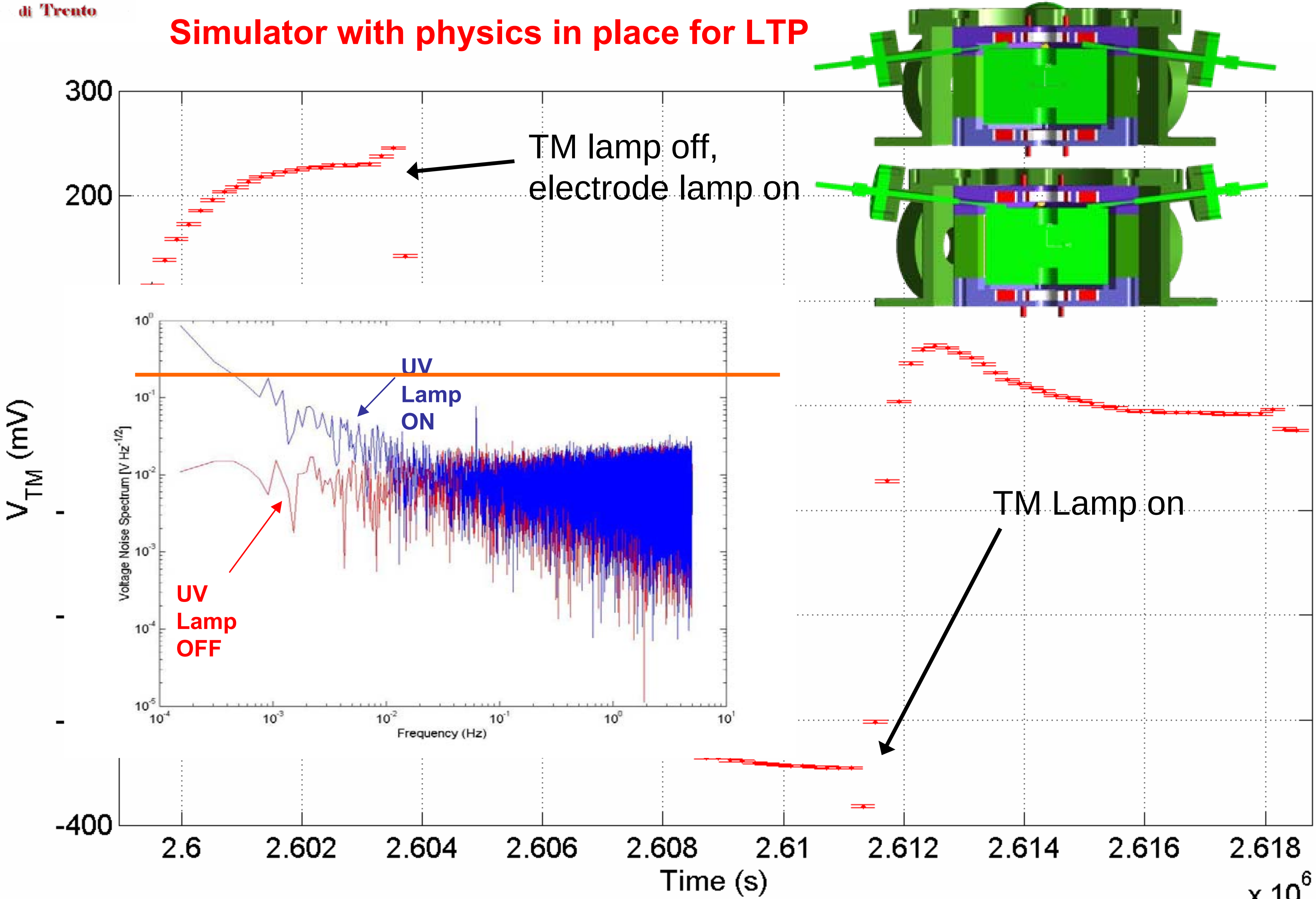


Università degli Studi di Trento

Imperial College London

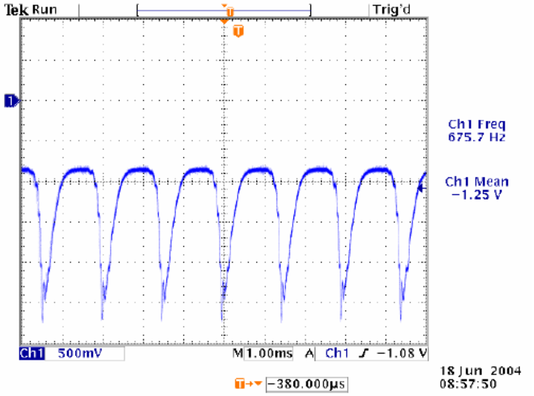
Charge control with lamps

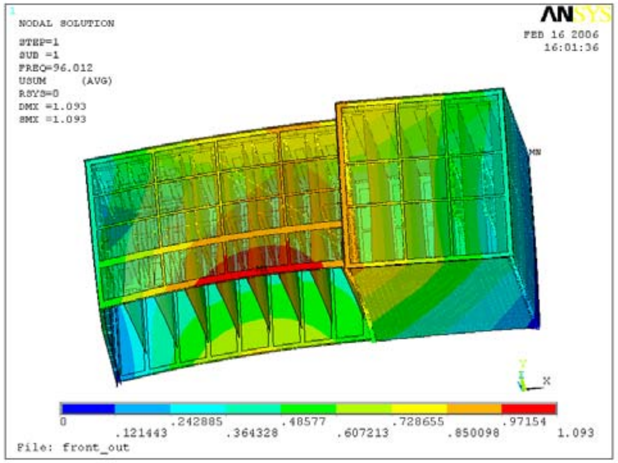
Simulator with physics in place for LTP



LISAPF Lamps

- Derivative of those used on EINSTEIN and ROSAT – 6,000 hr lifetimes
- Low pressure electric discharge cf rf discharge used on GPB.
- 8 housed in 3.5kg package for LISAPF
- 100:1 dynamic range using PWM at kHz frequencies
- 3W per lamp

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RSYS=0
DMX =1.093
SMX =1.093
ANSYS
FEB 16 2006
16:01:36
MN
0
.121443
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.364328
.48577
.607213
.728655
.850098
.97154
1.093
File: front_out