Geant4 Simulation of Test-Mass Charging in the LISA Mission

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Test-Mass Charging I

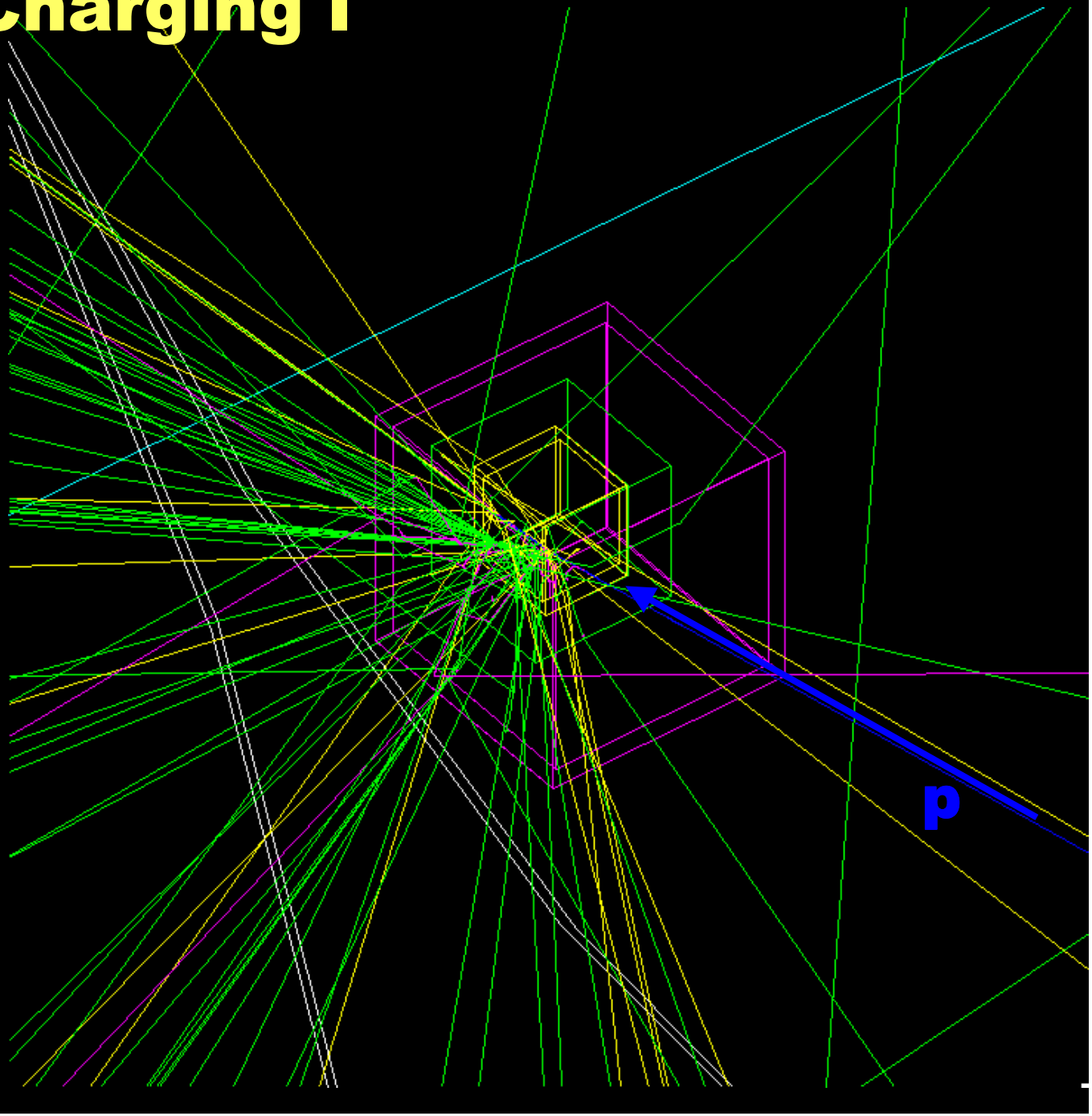
charging rate

fluctuations

Lorentz
+
Coulomb
forces

shielding

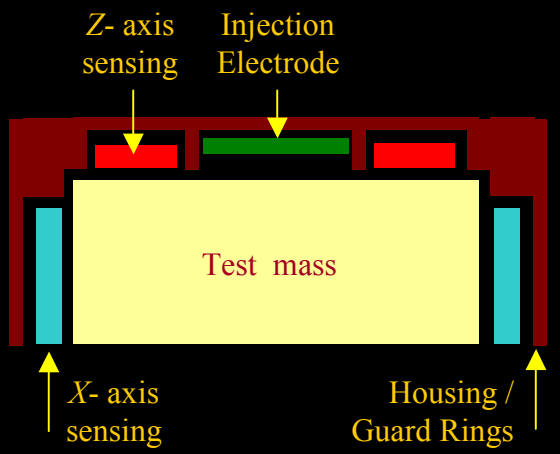
charge
management
system



Test-Mass Charging II

Requirements (0.0001 – 0.1 Hz)

- **Acceleration noise < 4×10^{-16} m/s^2/Hz$^{1/2}$**
- **Positional accuracy < 1×10^{-9} m/Hz$^{1/2}$**
- **Test mass attitude < 4×10^{-7} rad/Hz$^{1/2}$**



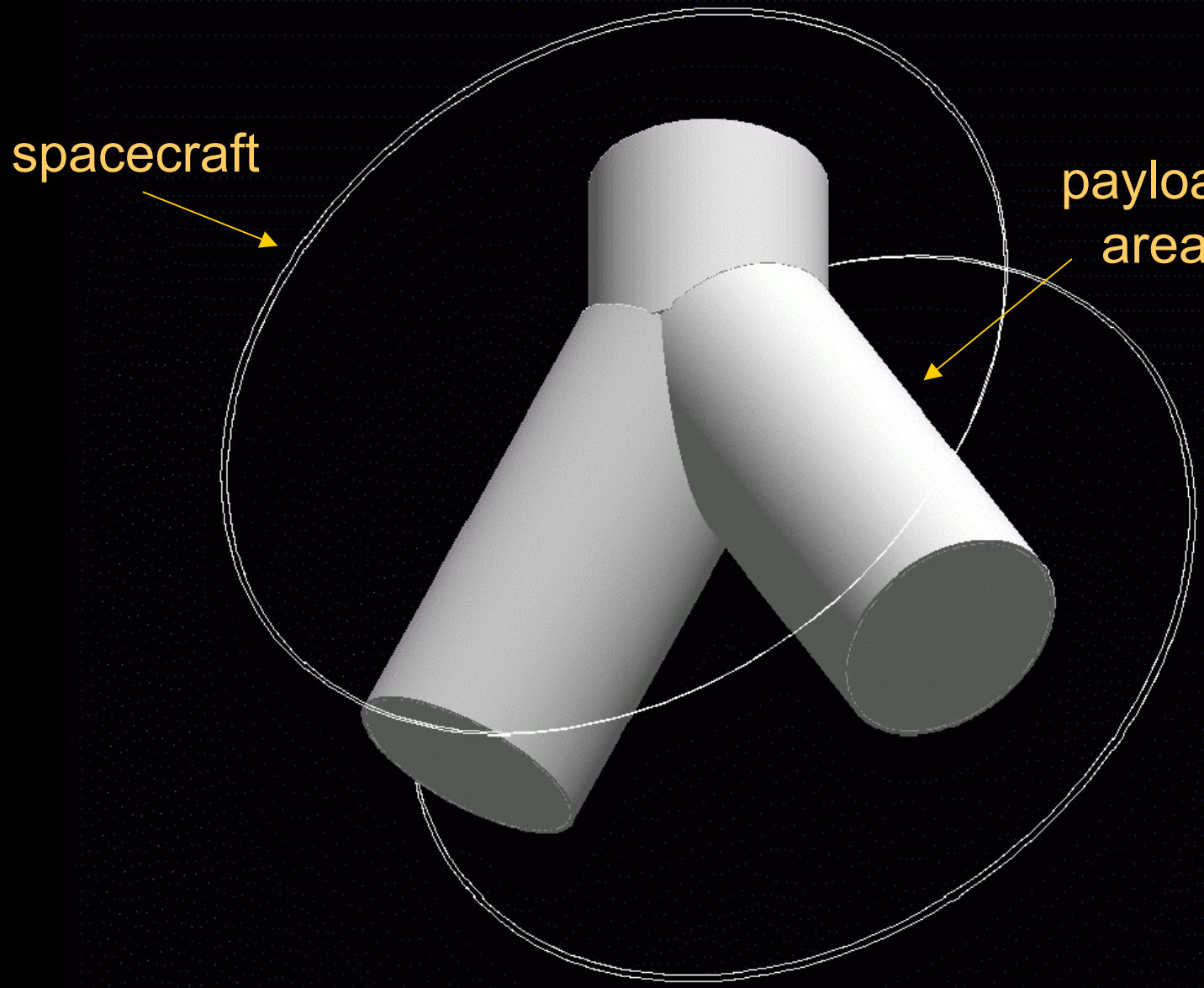
Lorentz Forces

$$\mathbf{a} = \frac{\dot{\bar{Q}}\, t}{m}\, \mathbf{v} \times \bar{\mathbf{B}} + \frac{\delta Q}{m}\, \mathbf{v} \times \bar{\mathbf{B}} + \frac{\dot{\bar{Q}}\, t}{m}\, \mathbf{v} \times \delta\mathbf{B}$$

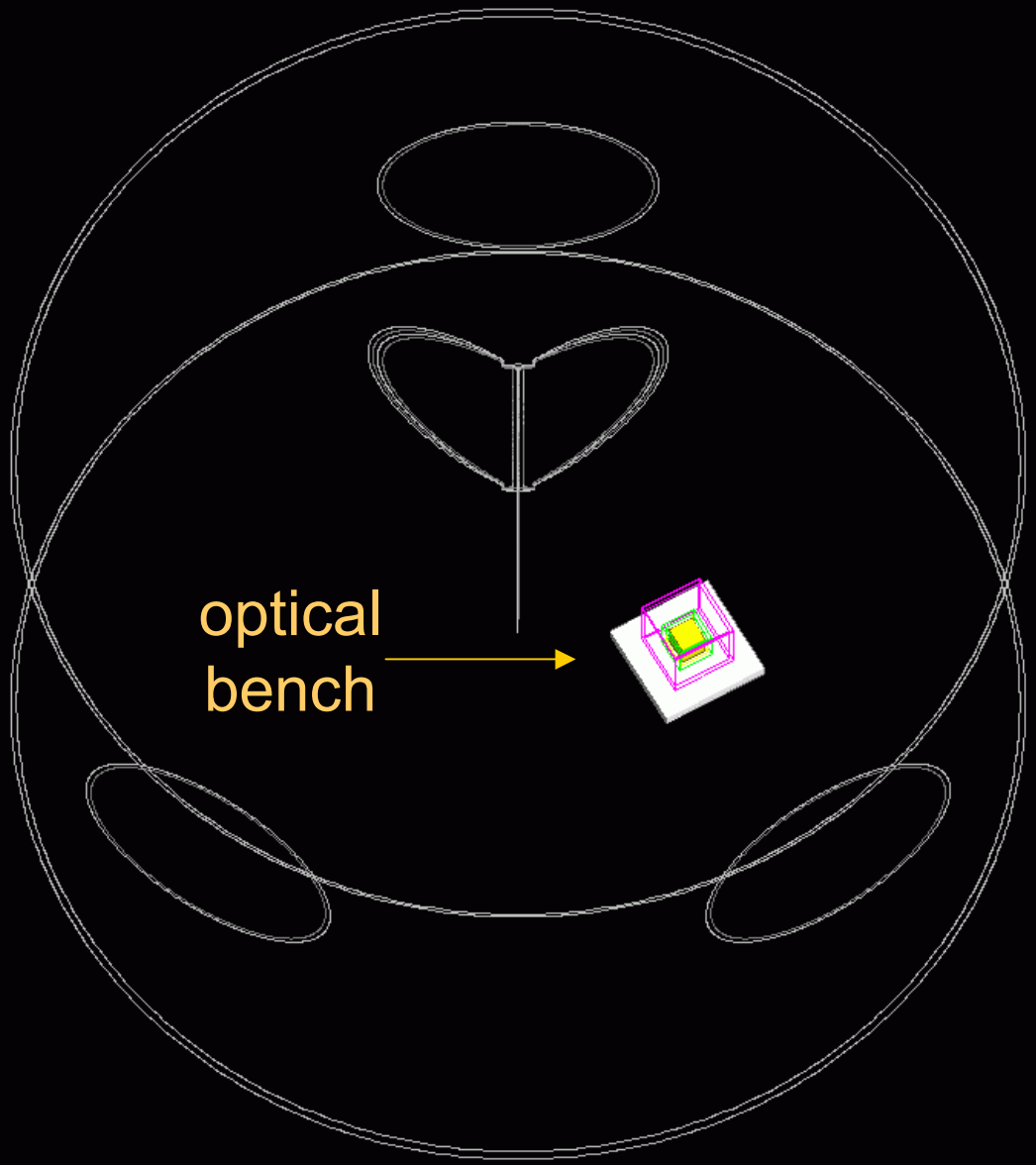
Coulomb Forces

$$(\delta a)^2 = C_1 (\delta V_i)^2 + C_2 (\delta d_i)^2 + C_3 (\delta Q)^2$$

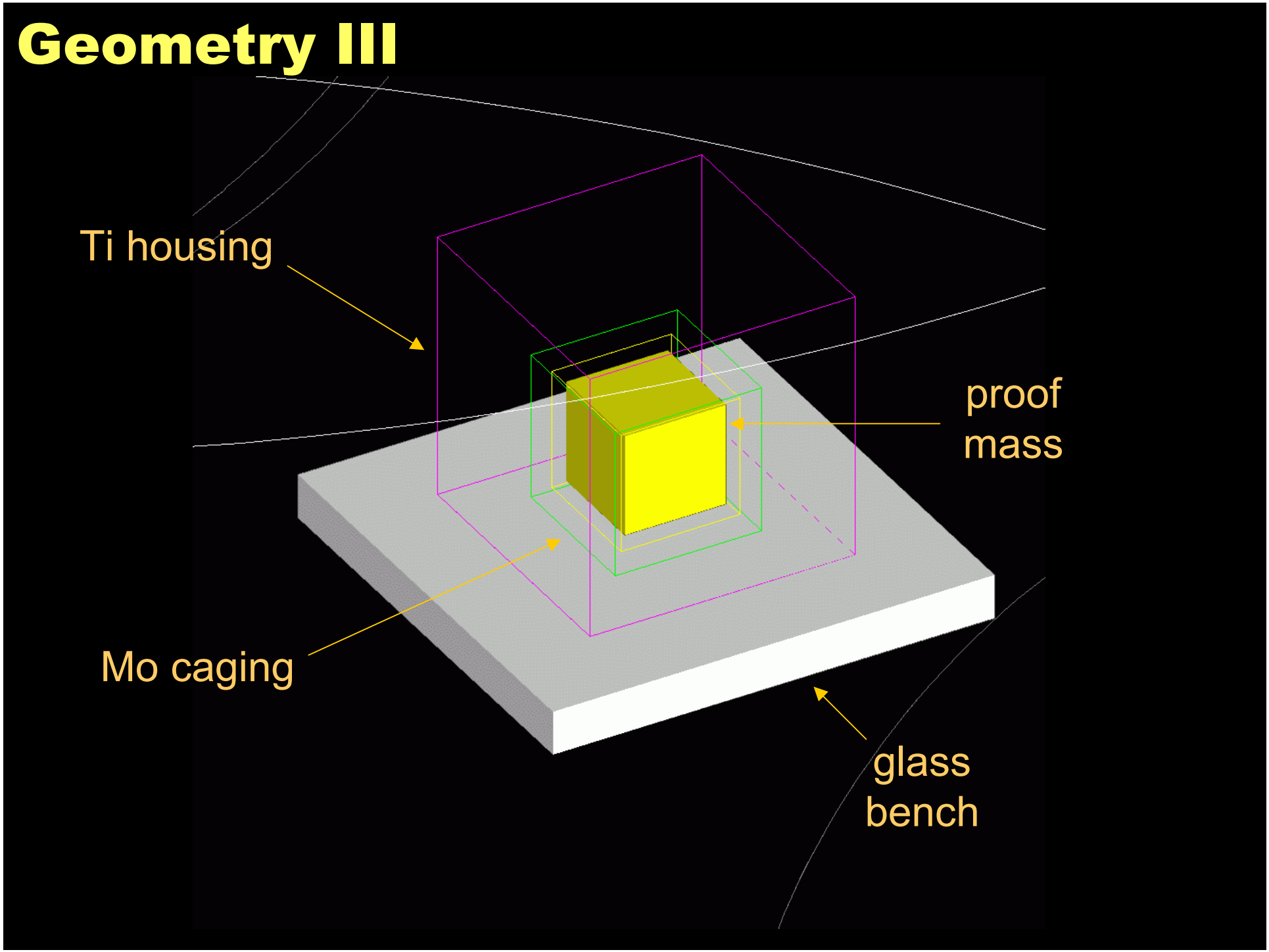
Geometry I



Geometry II



Geometry III



LISA Environment

1. Protons from solar flares

   Localised in time

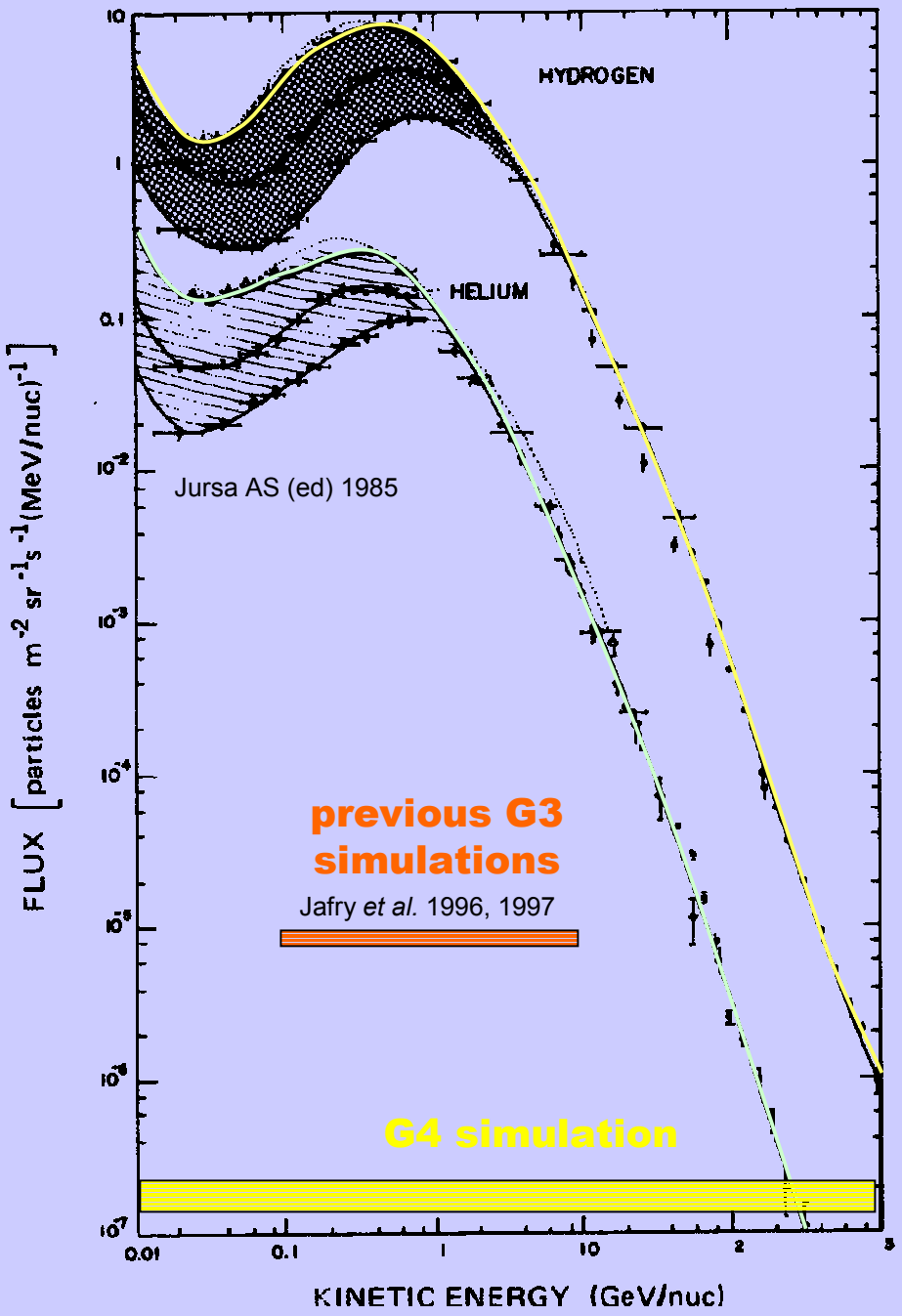
2. Galactic cosmic rays

   Protons, Alphas

   Isotropic flux

   MeV – TeV energies

   peak ~ 500 MeV/nucleon



Physics List

EM processes (LowE)

Electrons, Gammas, etc
Atomic de-excitation
Hadrons
(no hFluorescence)

Hadronic processes

Elastic (LE+HE)
Inelastic (LE+HE)
Nuclear de-excitation
Absorption/Annihilation
Photonuclear (γ, e, μ)
Neutrons (HP, LE, HE)

Decays

Decay in flight
(no RDM)

Secondaries

Cuts: (250 eV), 1um - 5um
Kill e- outside caging

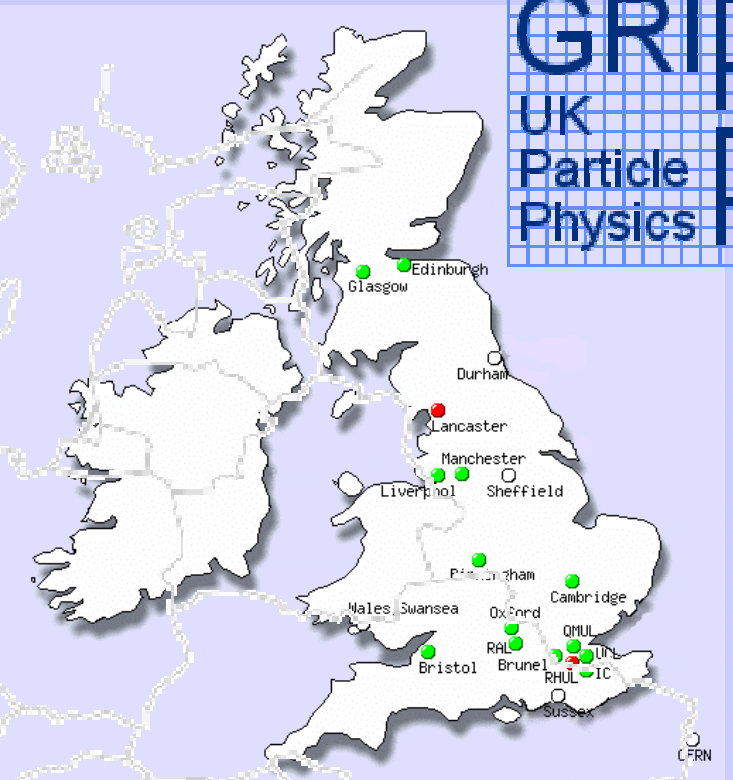
Table 1. GEANT4 Physics List

γ processes	E_{min}	E_{max}
Photoelectric effect	250 eV	100 GeV
Rayleigh scattering	250 eV	100 GeV
Compton scattering	250 eV	100 GeV
Gamma conversion	250 eV	100 GeV
Photonuclear reaction		1000 PeV
$e^{\pm}$ processes		
Multiple scattering	100 eV	100 TeV
Ionisation	250 eV	100 GeV
Bremsstrahlung	250 eV	100 GeV
Positron Annihilation	10 keV	10 TeV
Electronuclear reaction		1000 PeV
$\mu^{\pm}$ processes		
Decay in flight		
Capture at rest		
Multiple scattering	100 eV	100 TeV
Ionisation	1 keV	1000 PeV
Bremsstrahlung	1 keV	1000 PeV
Pair production	1 keV	1000 PeV
Muon-nucleus reaction	1 GeV	1000 PeV
hadron processes ($p/\bar{p}$, $n/\bar{n}$, α, ^{2}H, ^{3}H, $\pi^+/\pi^o/\pi^-$, $K^+/K^-/K^o_S/K^o_L$, $\Lambda/\bar{\Lambda}$, $\Sigma^+/\bar{\Sigma}^+/\Sigma^-/\bar{\Sigma}^-$, $\Xi^o/\bar{\Xi}^o/\Xi^-/\bar{\Xi}^-$, $\Omega^-/\bar{\Omega}^-$)		
Multiple scattering	100 eV	100 TeV
Ionisation	10 eV	100 TeV
Elastic scattering	~ 0	1000 PeV
Inelastic scattering	~ 0	10 TeV
Absorption/annihil. at rest (π^-, K^-, $\bar{p}$, $\bar{n}$)		
Capture (n only)		
Decay in flight (short-lived)		

GEANT4 on the Grid

- **Extensive physics**
- **Wide primary energy range**
- **Low production cuts**
- **Large statistics required**

1 CPU-Year for ~60 s
of cosmic-ray exposure !



G4 Parallelisation !!!

"First significant use of UK particle physics Grid"

Sat 11 May 2002 16:18 BST. Posted by Steve Lloyd

Alex Howard of Imperial College has made the first significant use of the UK particle physics Grid. Alex has submitted over a hundred jobs to 16 Grid nodes at Imperial and 8 Grid nodes at RAL running EDG middleware.

GRIDPP News

DataGRID

Results I

Charging rate

G4 result: 58 +e/s

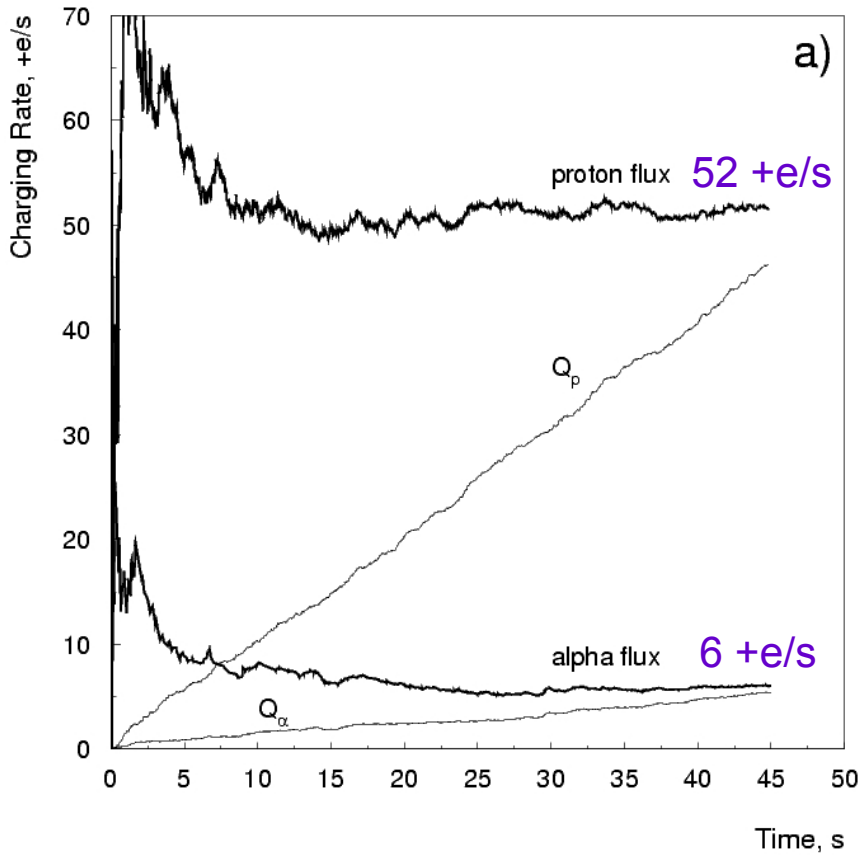
(G3 result: 11 +e/s)

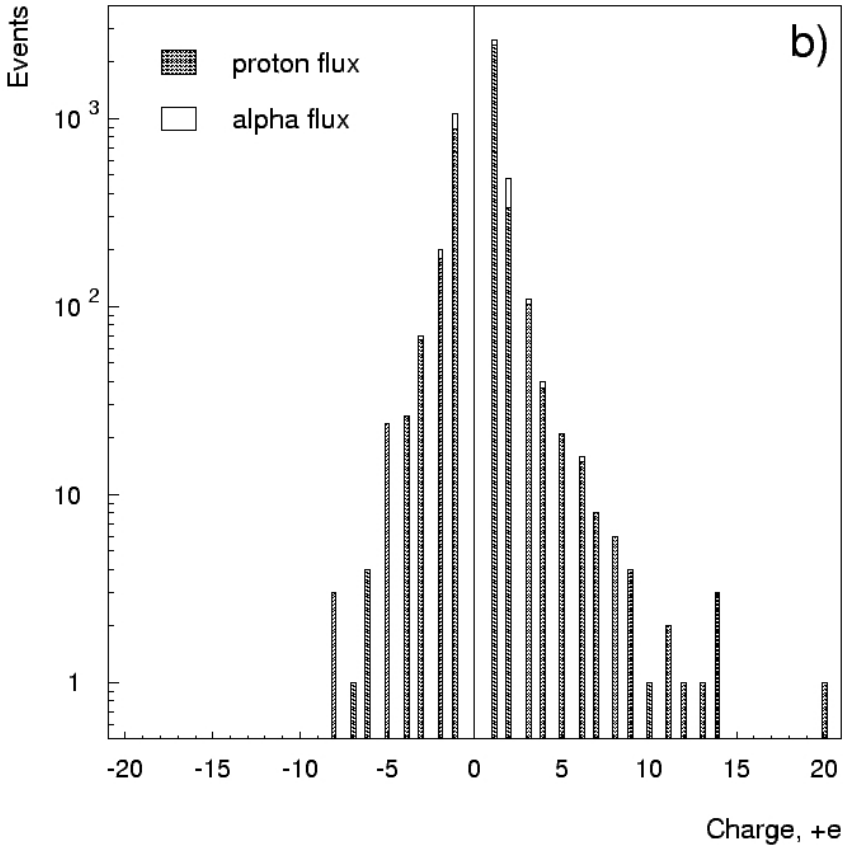
45 s exposure
~ 10,000,000 events

1 charging event
~ 2,000 events

~ 40,000 events/day/CPU

2 days in parallel !!!



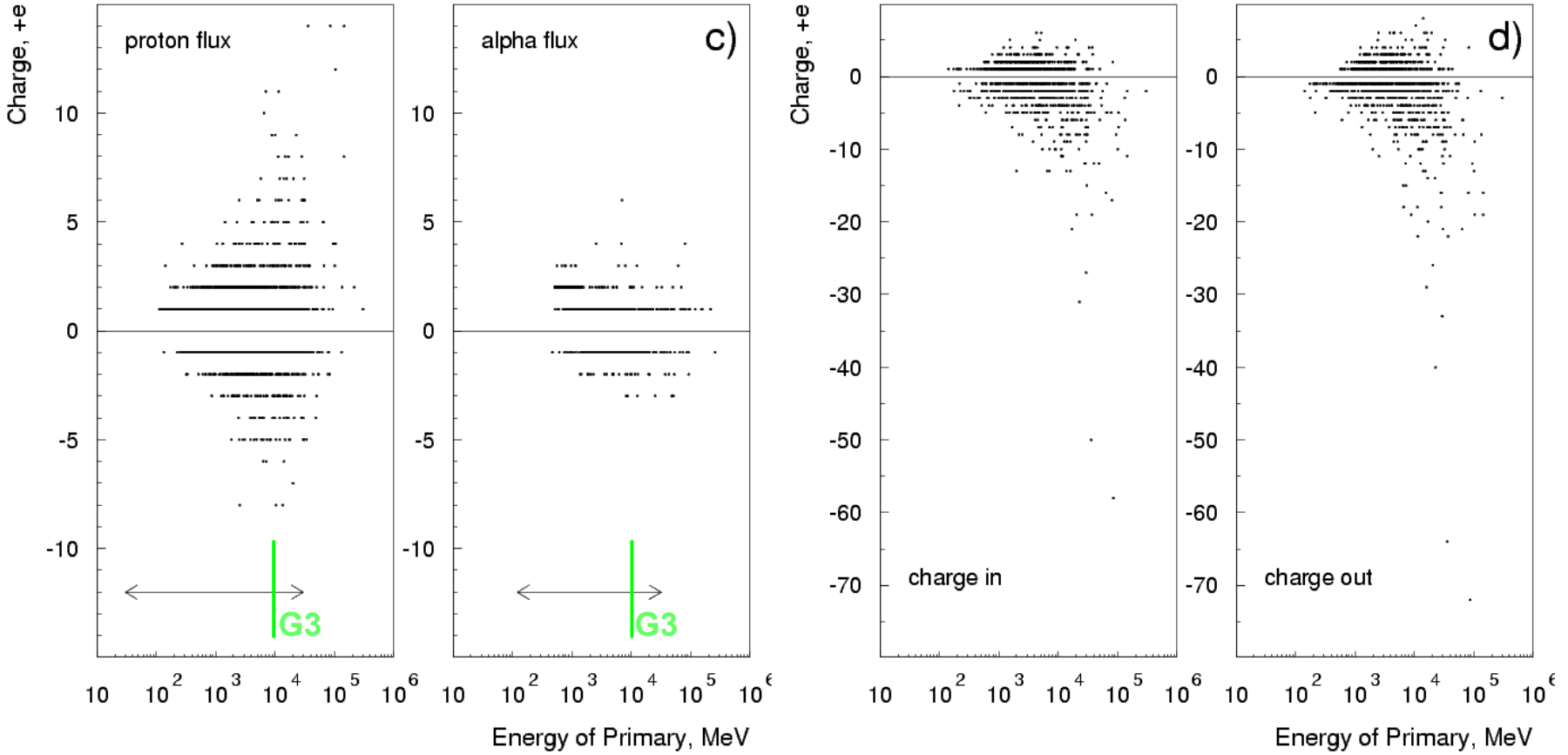


Results II

Charge spectrum

The main contributions:

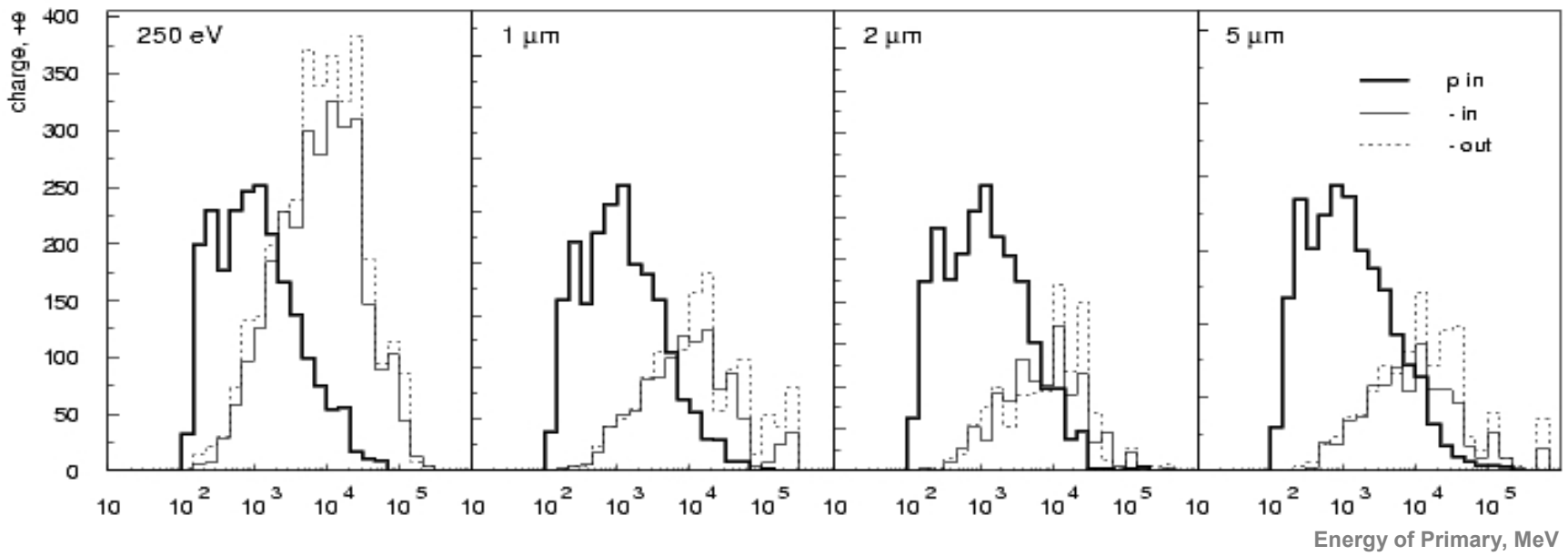
- proton/alpha stopping
- EM showers
- low energy electrons
- nuclear reactions



EM processes I

Cuts

(~0.1 um)	1 um	2 um	5 um
250 eV	8.77 keV	30.7 keV	53.2 keV
52 +e/s	41 +e/s	40 +e/s	42 +e/s



Decreasing the production threshold from 10 keV (G3, G4EM) to 250 eV (G4LowE) leads to a ~20% increase of the charging rate!

EM processes II

LowE Threshold

Lower than 250 eV ?

Materials

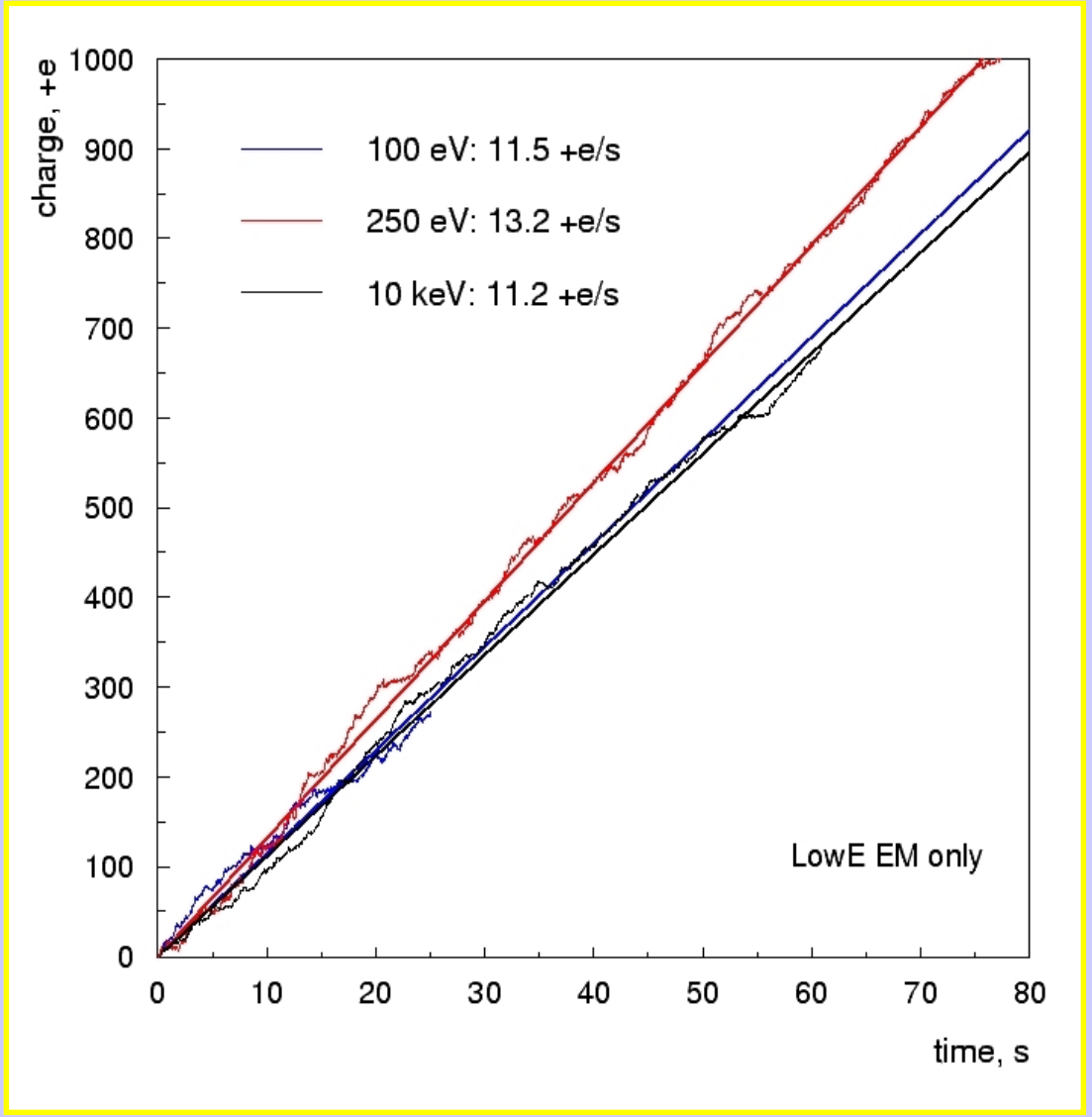
Test Mass ≠ Electrodes

hLowElonisation

hFluorescence

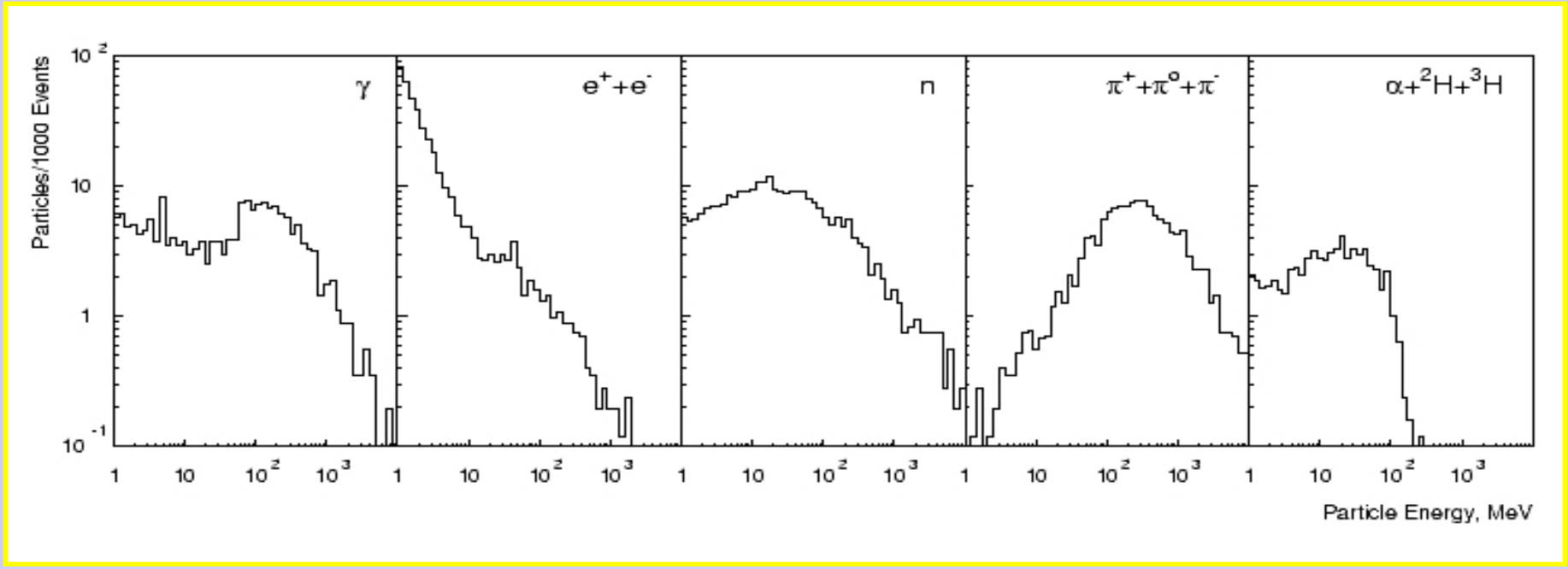
MeanExcEnergy ~ 800 eV

Cuts by region



Hadronic processes

- p, n, π , K — Inelastic < 1 TeV
- Ions, fragments — Inelastic < 1 GeV
- γ, e, μ — Photonuclear < 10 GeV
- α — Inelastic < 1 TeV



Test-Mass Charging III

Assuming a charging rate of ~ 100 +e/s

Lorentz Forces

- **Discharge rate: ~ 1 /day**

Coulomb Forces

- **Discharge rate: ~ 1 /day**
- **Displacement: < ~ 1 μm**
- **Voltage noise: < ~ 1 $\mu V/Hz^{1/2}$**
- **Voltage imbalance: < 10 mV**

These constraints are already much tighter than expected! Must continue simulation work...