The PANDORA experiment

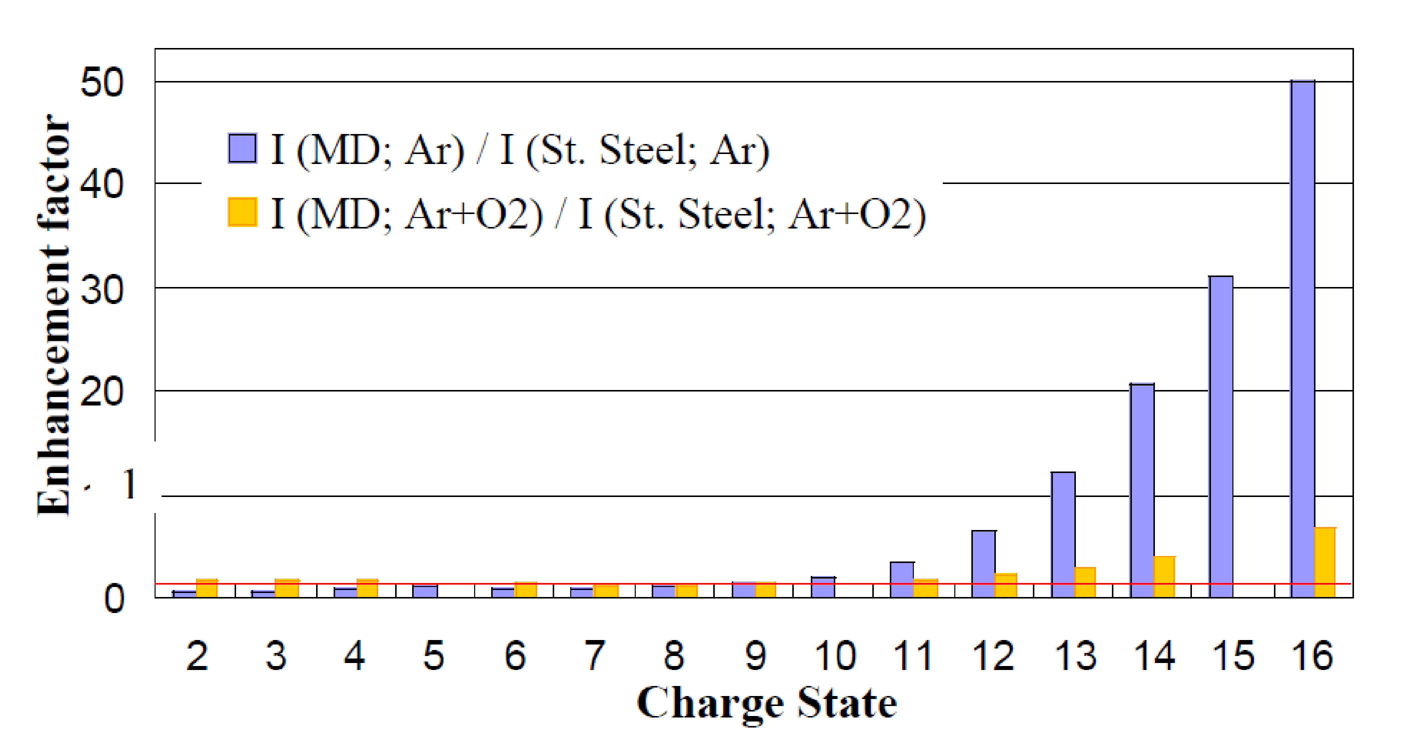
Plasma (advanced) chamber design
&
Mitigation of plasma γ self-emission

Fabrizio ODORICI - INFN Bologna

Design of an advanced plasma chamber (1)

Requirements for PANDORA: good capability to enhance the Charge State Distribution towards **highly charged ions**. For this purpose, we can equip the main chamber (made of stainless steel) with an «active» coating:

- the chamber lateral walls con be coated with a thin (2-3 mm) cylinder made of **aluminum-alumina (Al-Al2O3). Alumina** has a coefficient of secondary electron emission greater than 1 (electron donor). It means that electron losses from plasma, hitting the chamber walls, determines the injection of secondary electrons into the plasma itself. This losses compensation permits to operate with lower pressure and RF power, thus **limiting charge exchange process and recombinations** in the plasma, which is very important in order to produce highly charged ions.



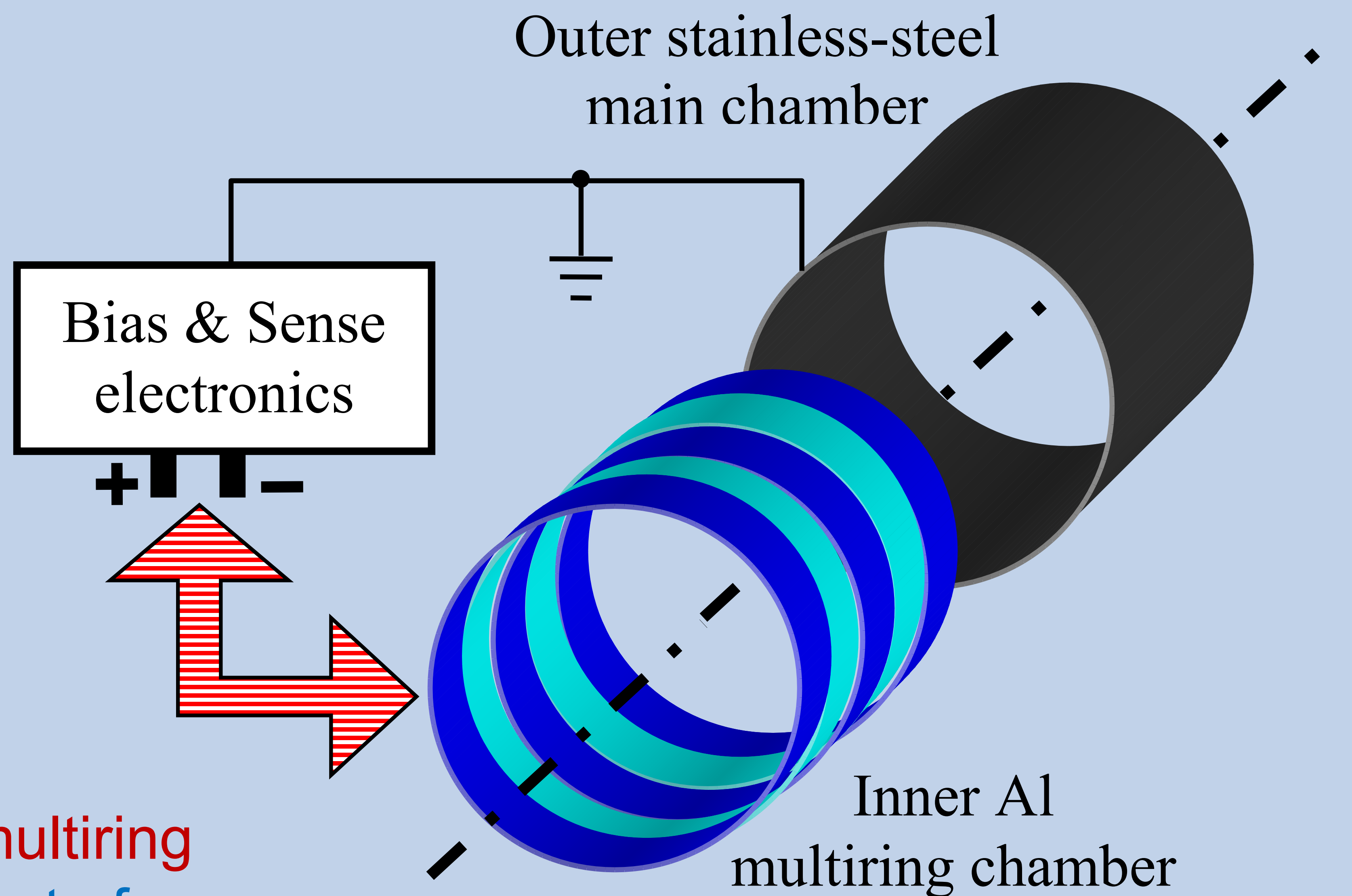
Results from IKF ECR
(Ar @ Prf = 800 W)

S. Gammino et al., "Electron Donors …", INFN/TC-03/08, 18 Giugno 2003

Design of an advanced plasma chamber (2)

- The **Al-Al2O3** cylinder will be subdivided into electrically isolated rings (up to 16 (or 32) elements), so as to allow a differentiated bias. Each ring will then be connected to ground by a polarization and current measurement circuit, exercising a double function: firstly, leakage currents can be measured according to an axial segmentation, and secondly it will be possible to optimize the configuration of the wall bias in a differentiated way, to minimize radial losses and optimize the characteristics of the plasma.

The active control of the bias voltages and the plasma leakage-current reading will be managed by a computer. A software will allow to search for the best bias configuration for each working condition (pressure, RF power, magnetic trap configuration, gas mixture, etc.).

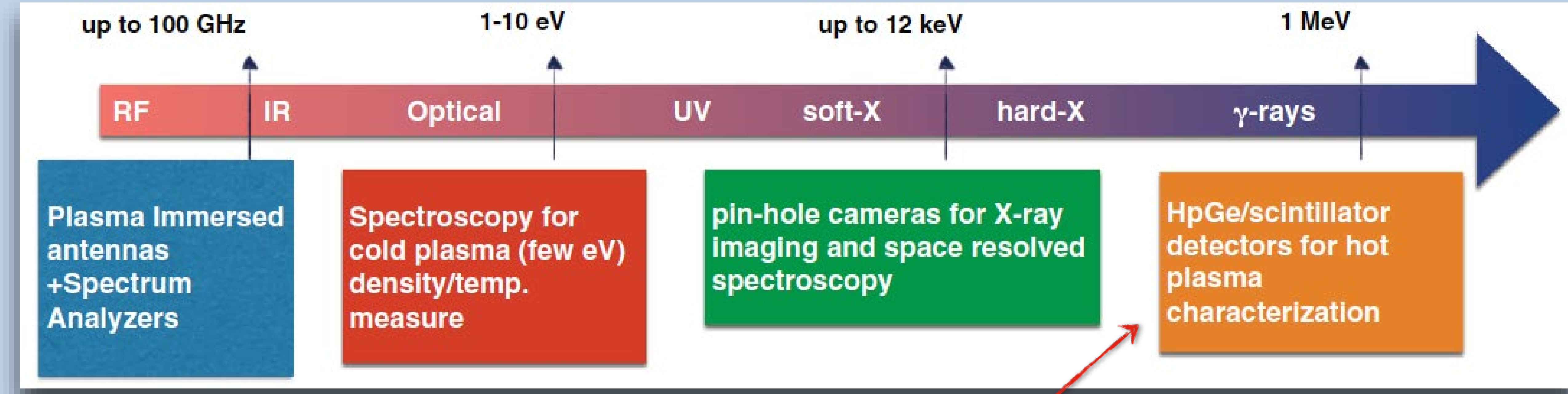


Segmentation design of the multiring chamber still to be defined. Test of a prototype on AISHA ECR @ LNS (2020-21)

Mitigation of plasma γ self-emission

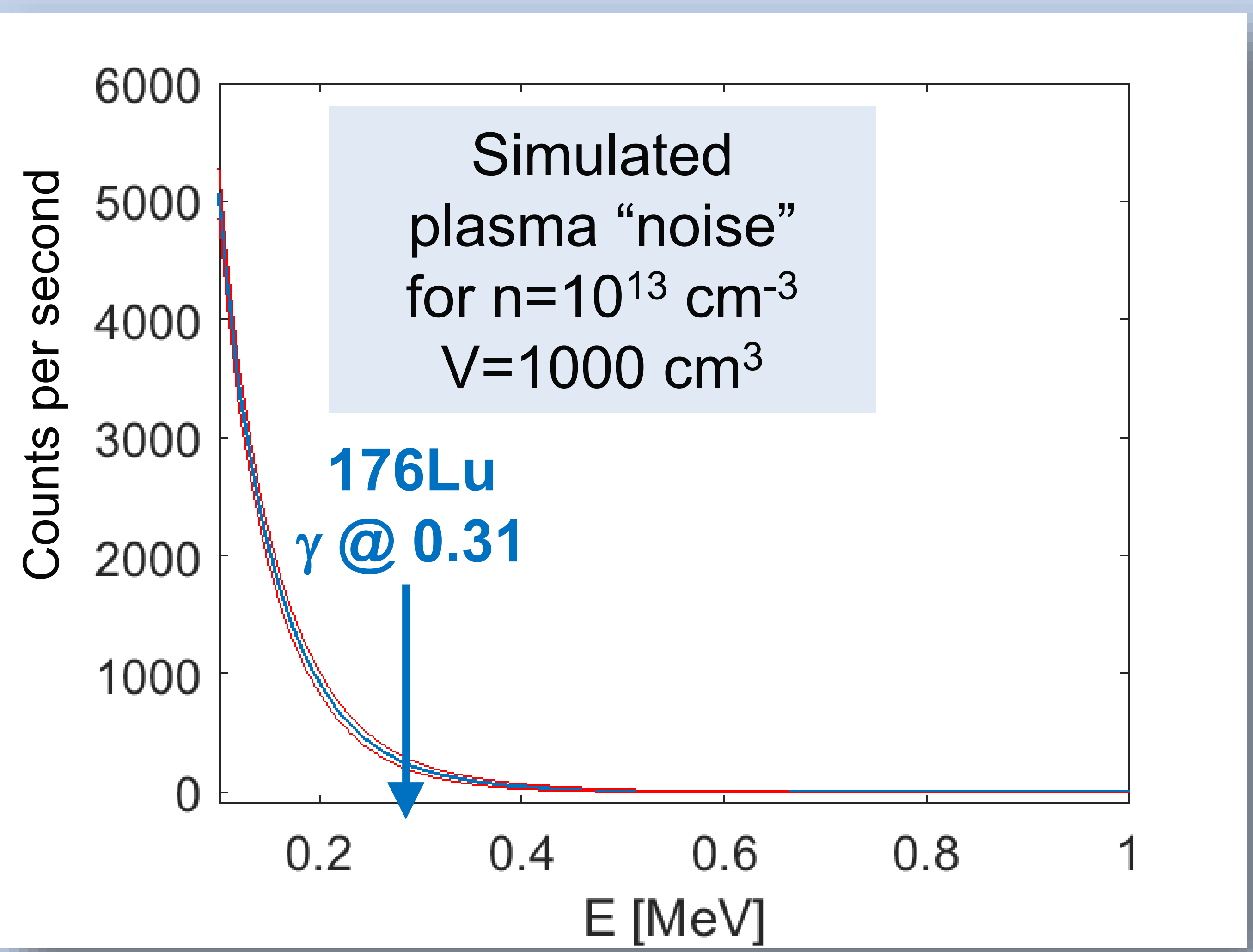
Requirements for PANDORA 1.0: low γ background for clear signal detection and "short" data taking periods. Physics cases, decay signature & detection:

Isotope	$T_{1/2}$ (yr)	Eγ (keV)
^{176}Lu	3.78×10^{10}	88-400
^{134}Cs	2.06	>600
^{94}Nb	2.03×10^{4}	>700

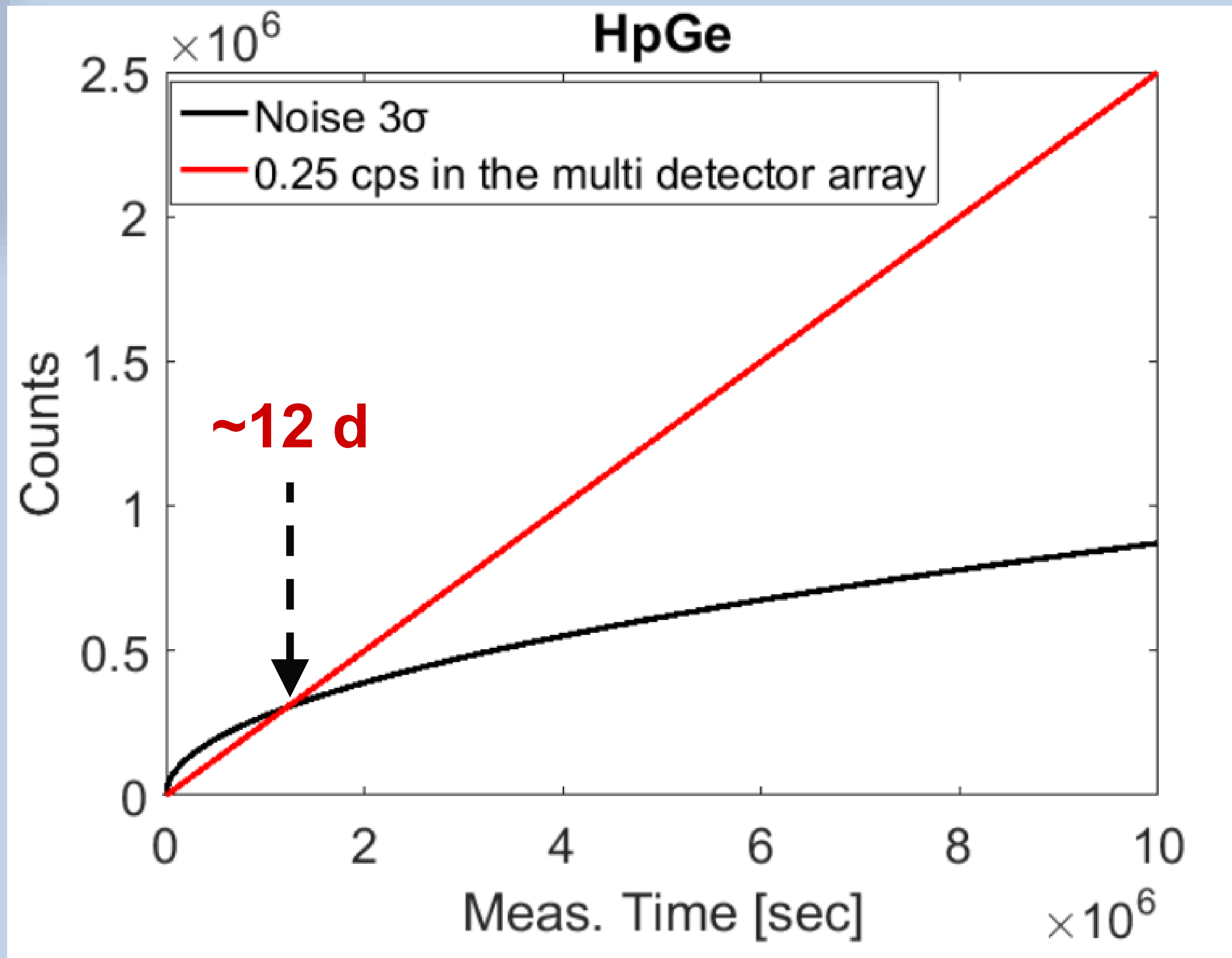


High Purity Ge detectors will be used for decay signatures

Plasma γ self-emission: GEANT4 simulation (TDR 3.0 fig. 54 p. 63)



“Noise” spectrum scaled to detection efficiency (14 Ge) in order to evaluate the run-time to have Signal/Noise >3



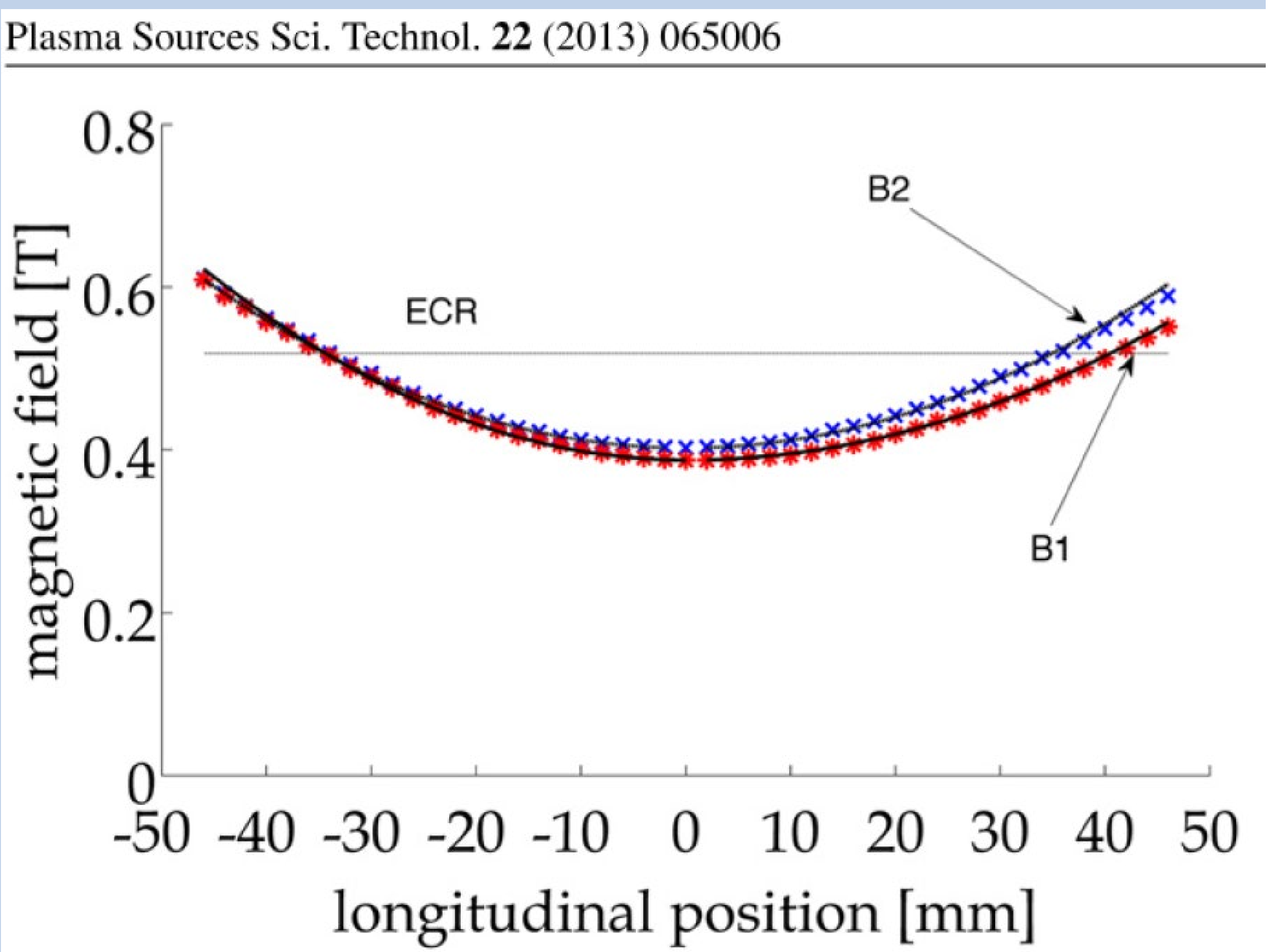
For 176Lu the run-time to have Signal/Noise >3 should be greater than 12 days

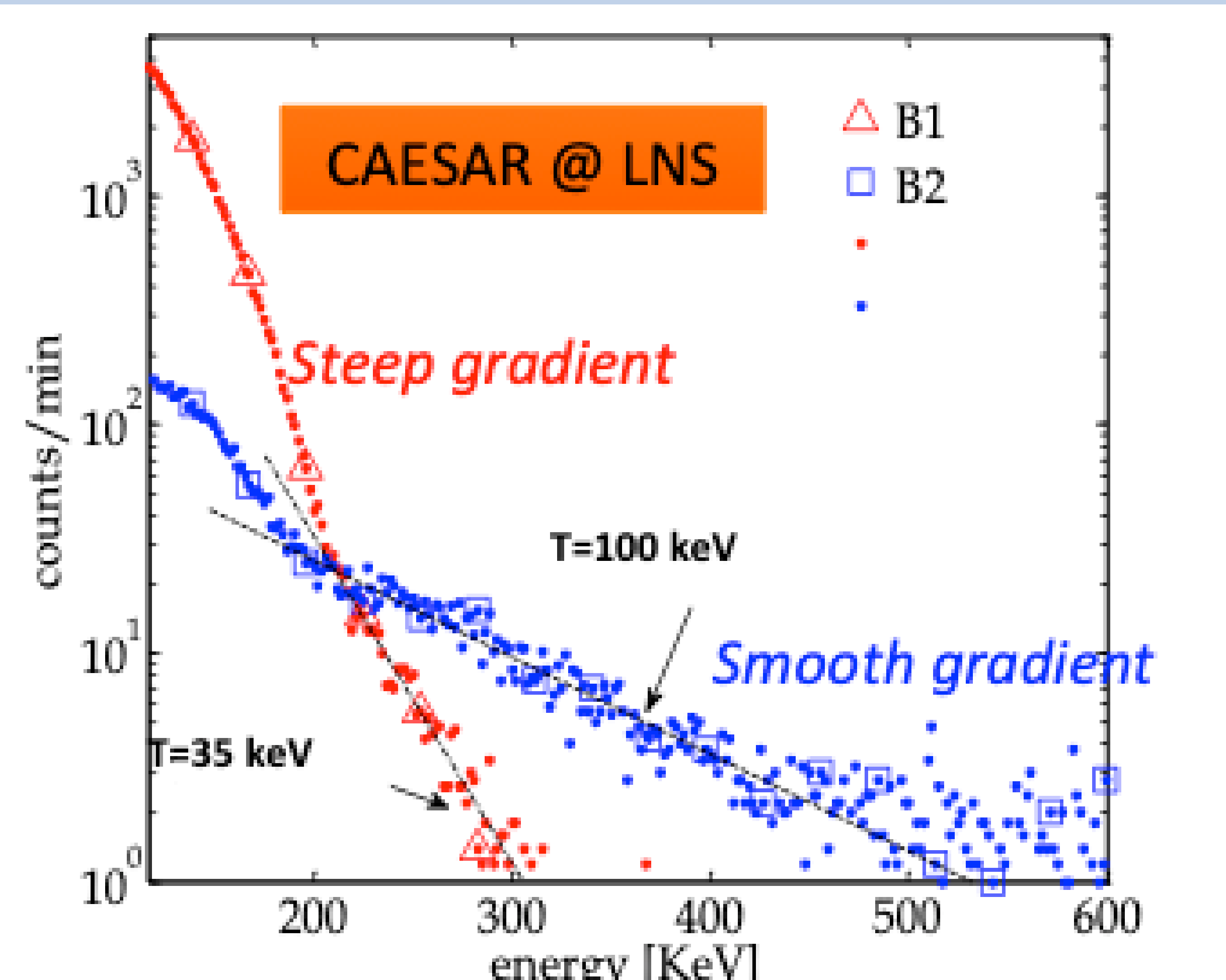
Plasma γ self-emission: experience from CAESAR ECR @ LNS

The γ spectrum-tail (above 200 keV) depends on ion-electron density and temperature. Theoretical emissivity density:

$$J_M(h\nu) = N_i N_e (Z\hbar)^2 \left(\frac{4\alpha}{\sqrt{6m_e}}\right)^3 \left(\frac{\pi}{kT_M}\right)^{1/2} e^{(-h\nu/kT_M)}$$

We found that small changes (about 5%) in the axial magnetic field profile can induce **suprathermal electrons** (3x *T* increase) with high energy γ emission.due to plasma instabilities

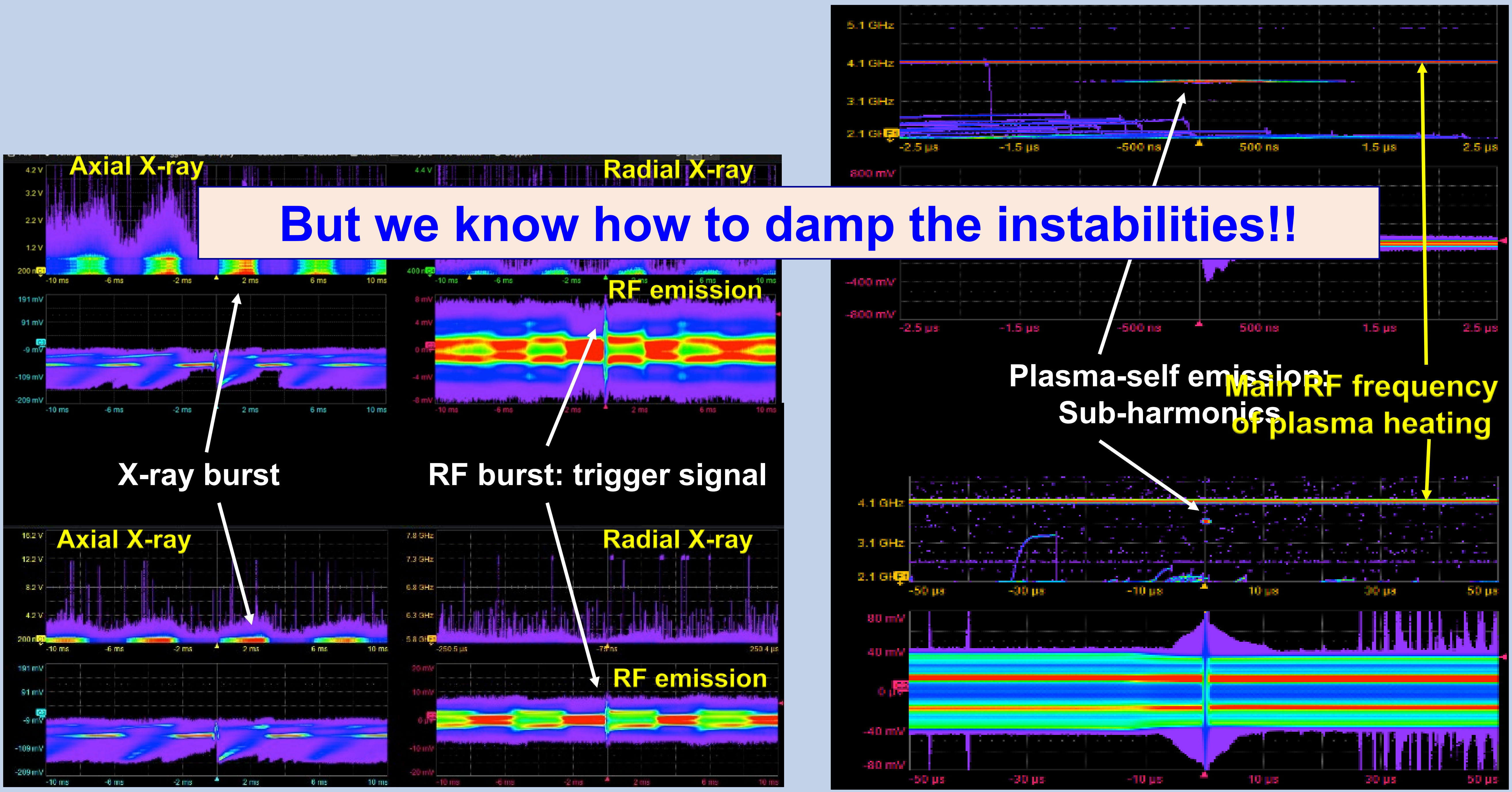




TIME-Resolved RF +Soft/Hard X ray Spectroscopy

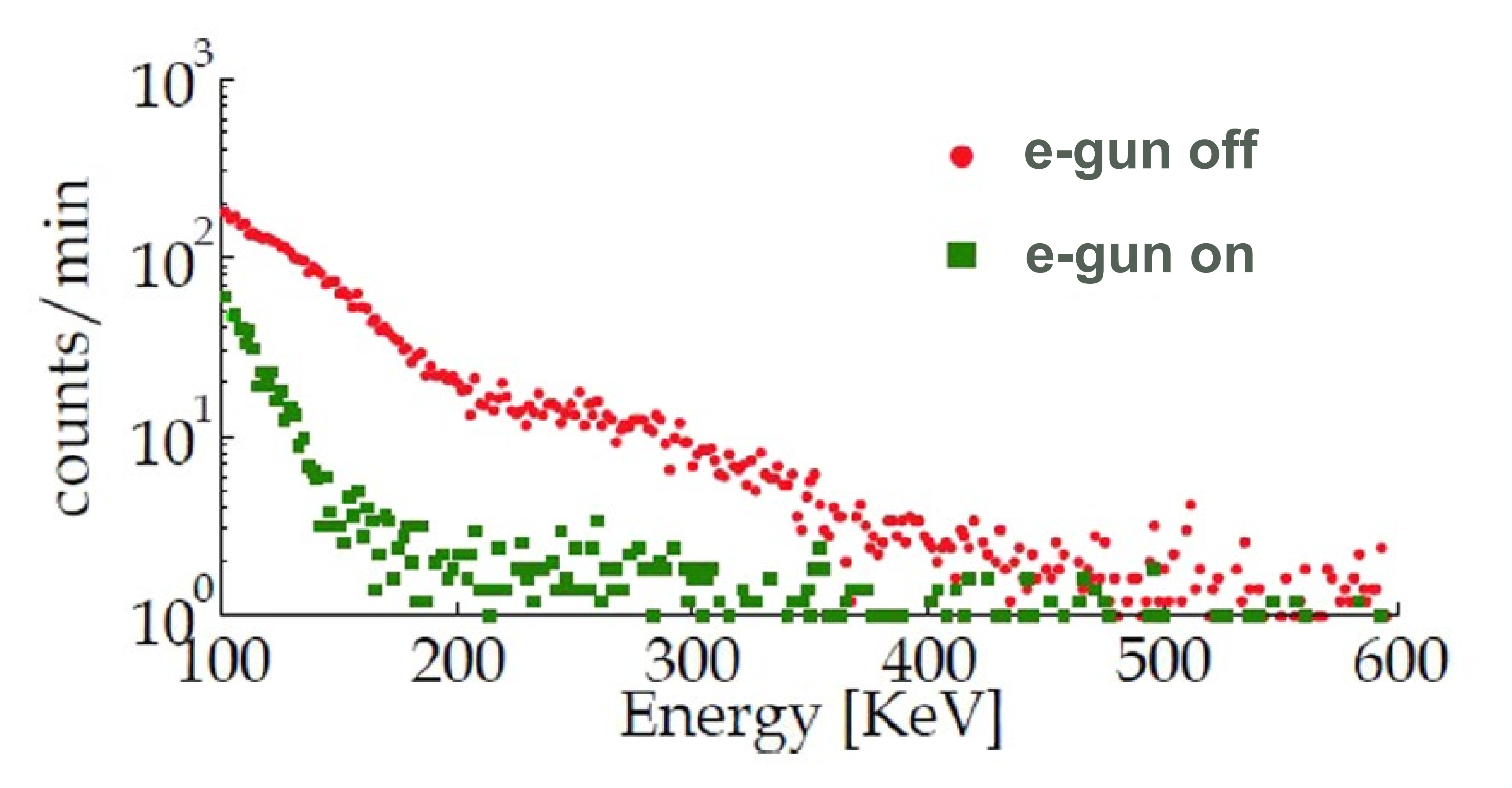
When modifying the axial magnetic field profile, the X-ray emission "jumps" and becomes pulsed

- **RF burst** → trigger signal
  - Axial and radial X-ray measurements → **X-ray burst**
  - Spectrogram → **microwave plasma-self emission**

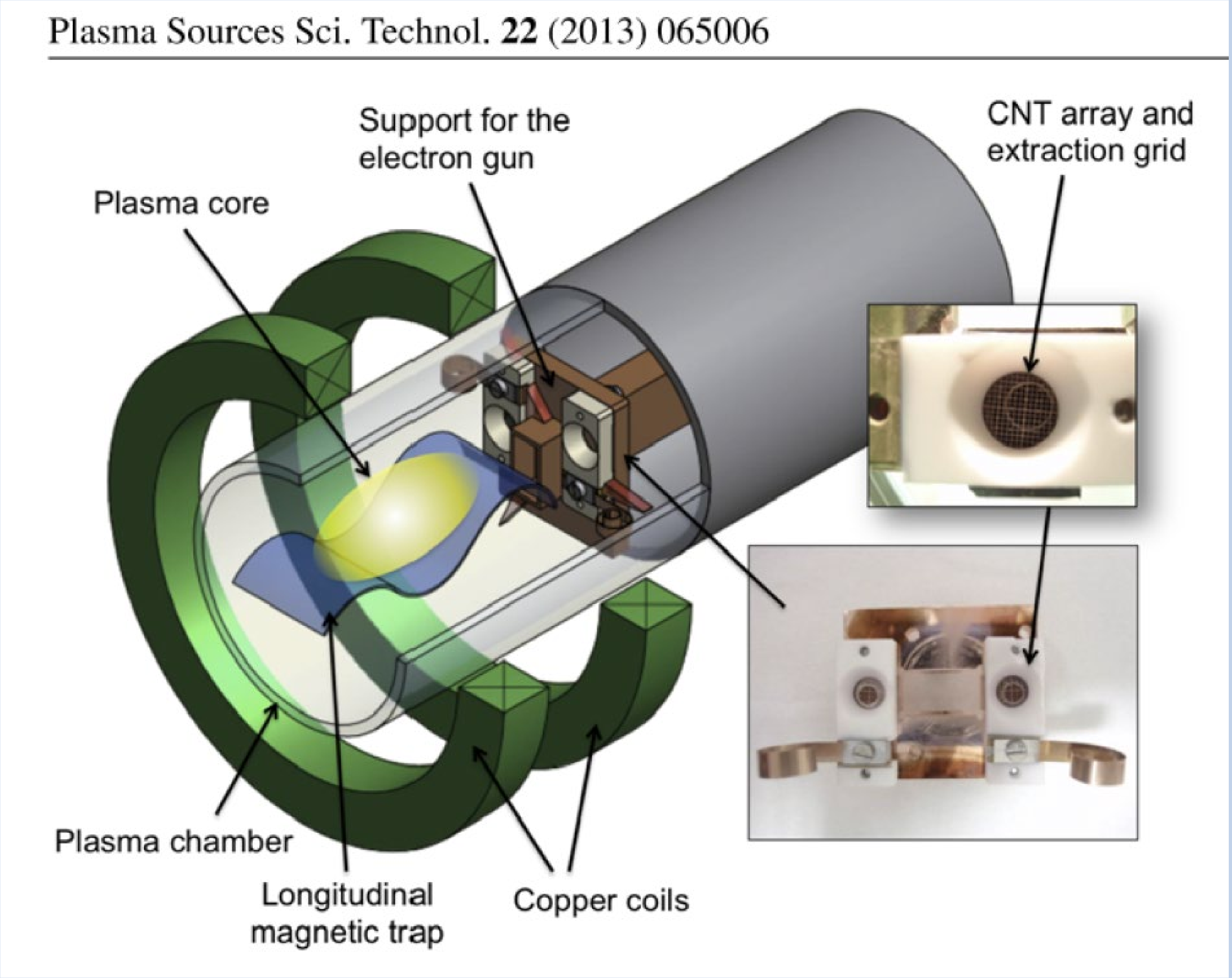


Damping of high energy γ self-emission

Previous experiments at LNS (2013) demonstrate that suprathermal electrons can been damped independently from B profile adjustments by changing the plasma density distribution, through **injection of auxiliary electrons** towards the lateral chamber walls, by **using an electron-gun**.



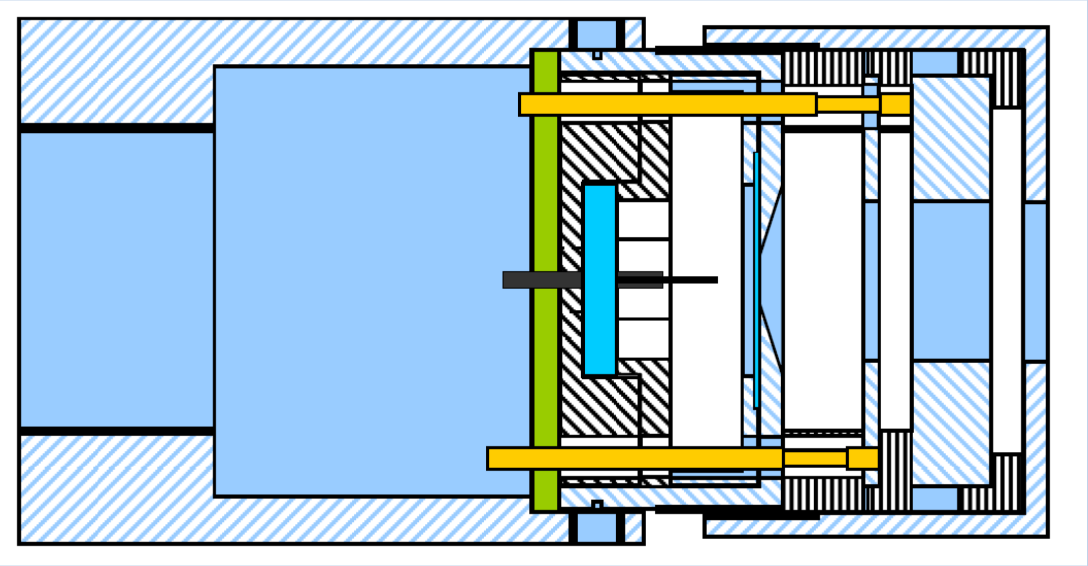
e-gun inside the CAESAR ECR plasma chamber @ LNS (2013)



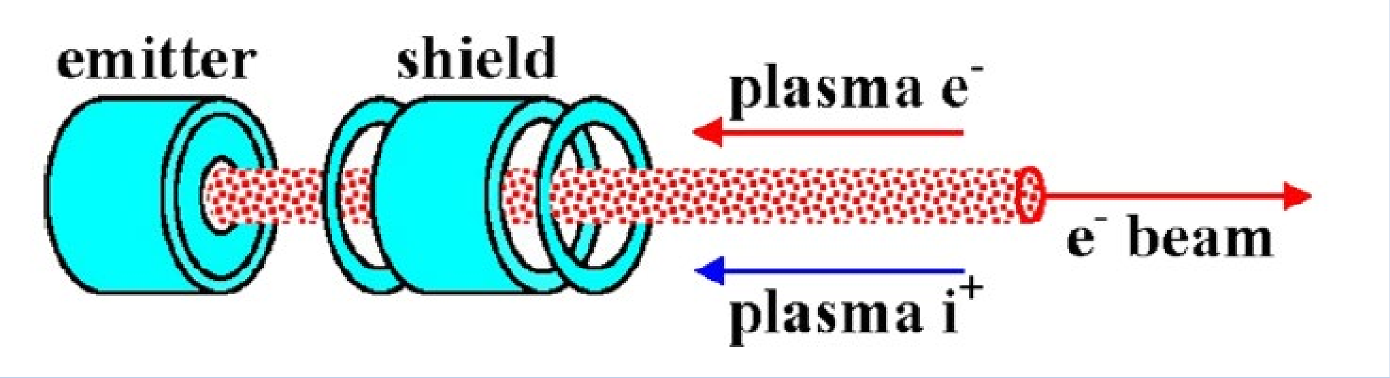
Electron-gun for PANDORA's chamber (1)

In order to improve the signal-over-noise ratio, PANDORA will be equipped with an electron gun, positioned outside the chamber, with the following requirements:

- dedicated chamber access, oriented along the axial magnetic field
- adjustable e-beam intensity & energy, up to 10 mA & 2 keV
- water-cooled & motorized cathode replacement
- shielded against milling of plasma ions & electrons



Mechanical design & working principle of a previous (2014) e-gun for plasma chambers



Hardware shopping list

Description	Q,.ty	Cost [k€]	financed	notes
PWS 100V 10mA, 32 ch (CAEN) for bias of plasma multi-ring chamber	1	11	Yes	
DAQ 32 ch with programmable logic (CAEN), for acquisition of pulsed e-beam	1	7.5	NO	Postponed to e-gun construction
Multiring plasma chamber construction – **Prototype** to be tested on AISHA @ LNS	1	3	Yes (66%)	Wait final project
Multiring plasma chamber construction – **Final version**	1	6	Yes (50%)	Wait final project
e-gun construction, with motorized cathode replacement, cooling & spare parts	1	12	Yes (50%)	Wait final project
Apparatus (e-gun & multiring chamber) control system: PC + interfaces + opto-links	1	5	Yes	