Plasma Diagnostics and neutron detection

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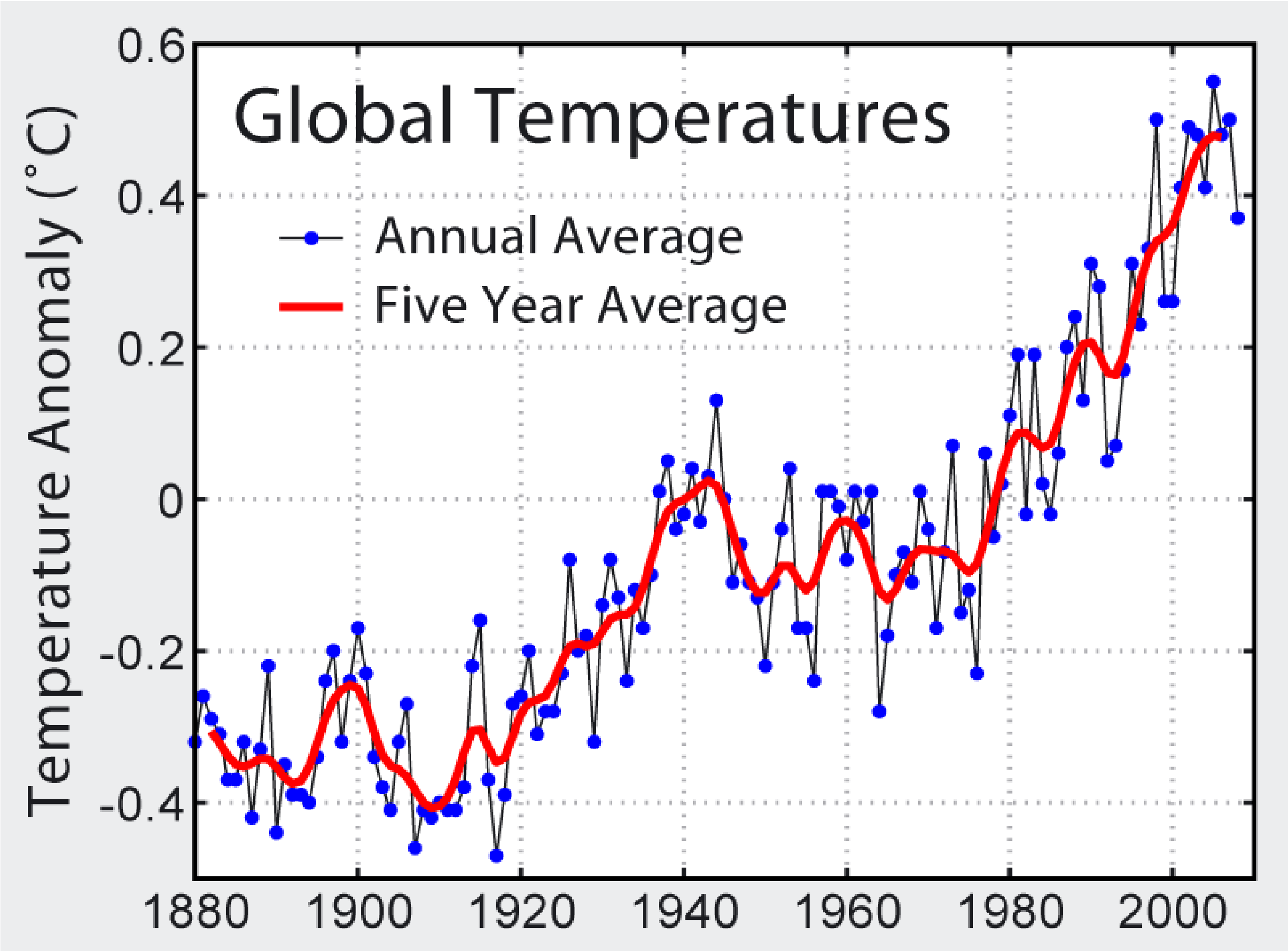
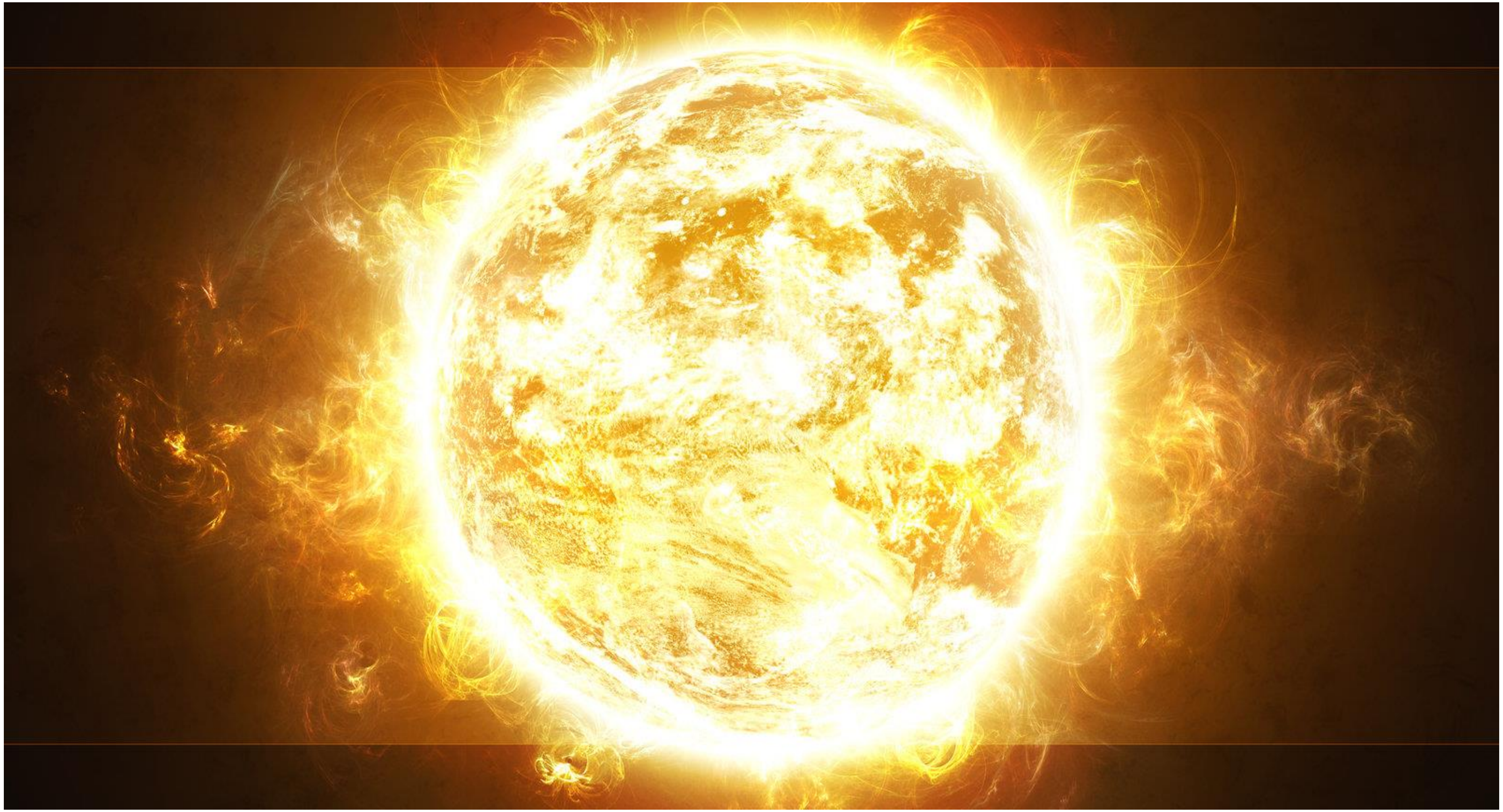
CO_2 emissions have a big impact on the planet
New clean energy sources are needed



$$4p \longrightarrow {}^{4}He + 2e^{+} + 2\nu_e \quad (26.7\ \text{MeV})$$



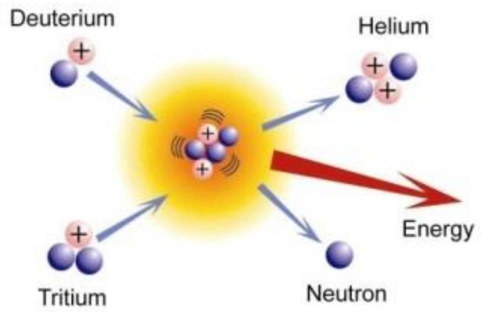
T ~ 15 million kelvin, high density

$$D + T \longrightarrow n\ (14.1\ \text{MeV}) + {}^{4}He\ (3.5\ \text{MeV})$$

T ~ 150 million kelvin, low density

Neutron emission in fusion plasmas

- Plasmas information can be provided by diagnostic systems, such as neutron and gamma-ray spectroscopy.
- Neutrons are directly produced by fusion reactions



D + D -> n + ^{3}He + Q
D + T -> n + α + Q

$$Q = \begin{cases} 3.27 MeV & DD \\ 17.6 MeV & DT \end{cases}$$

- They are not confined by magnetic field and can escape from the tokamak
- Neutron energy emitted from a fusion reaction:

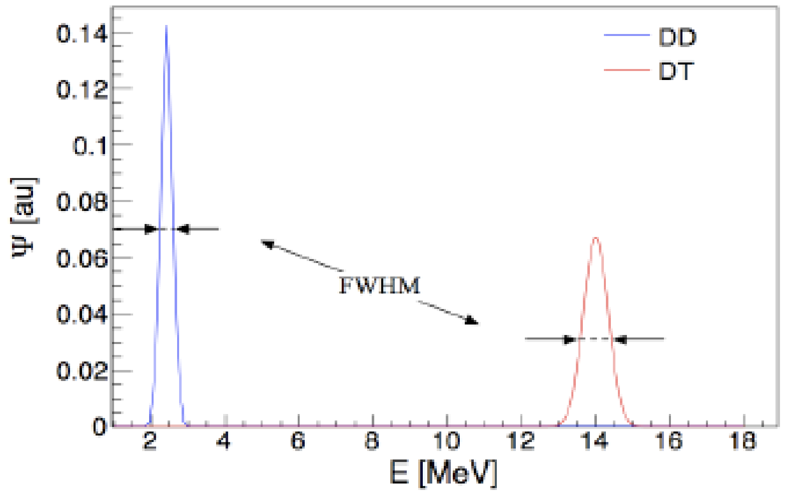
$$< E_n >= E_0 = \frac{m_r}{m_r + m_n} Q = \begin{cases} 2.45 MeV & DD \\ 14.0 MeV & DT \end{cases}$$

- If reactants are in thermal equilibrium with a Maxwellian velocity distribution and Ti << Q (valid assumption for reactor conditions)

Neutron energy distribution is well approximated to a **Gaussian** centered at 2.45 MeV or 14 MeV with a certain FWHM

$$FWHM_{dd} = 82.5 \cdot \sqrt{T_i}$$

$$FWHM_{dt} = 177 \cdot \sqrt{T_i}$$



Single-crystal Diamond Detector (SDD)

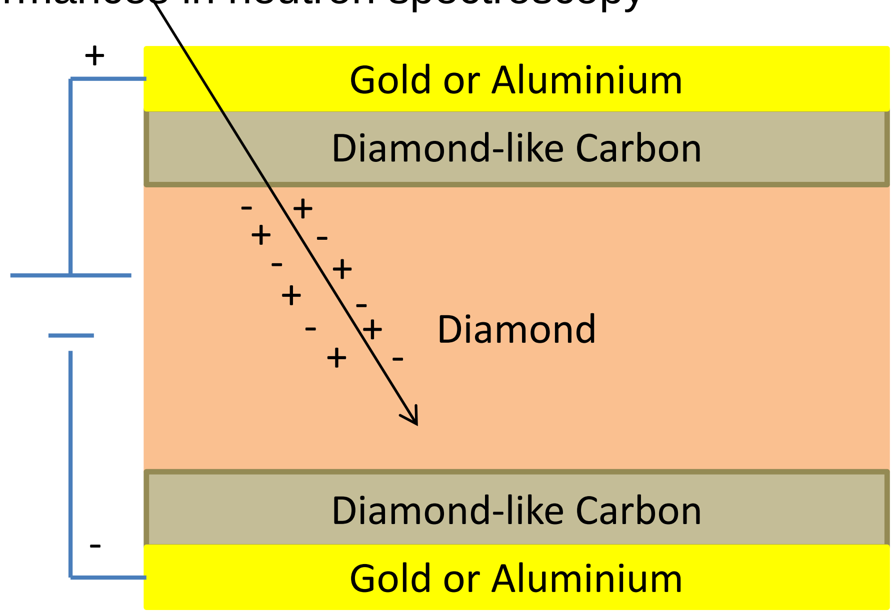
- **Good energy resolution**
- **High rate capability**

Single-crystal Diamond Detector

SDD has already shown excellent performances in neutron spectroscopy

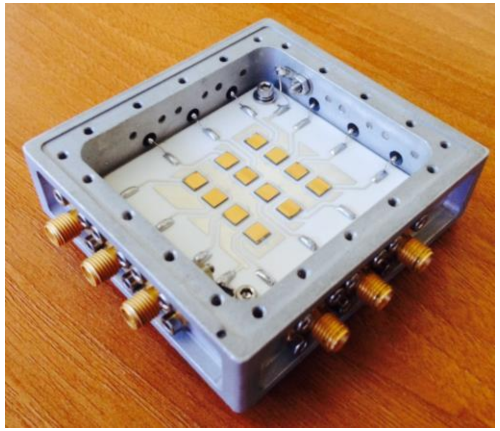
- High radiation hardness
- Fast response time
- Low sensitivity to magnetic field
- Room temperature operation
- Compact size

A charged particle passes through the diamond and ionizes it genereting electron-hole pairs ($E_{e\text{-}h}$=13 eV)

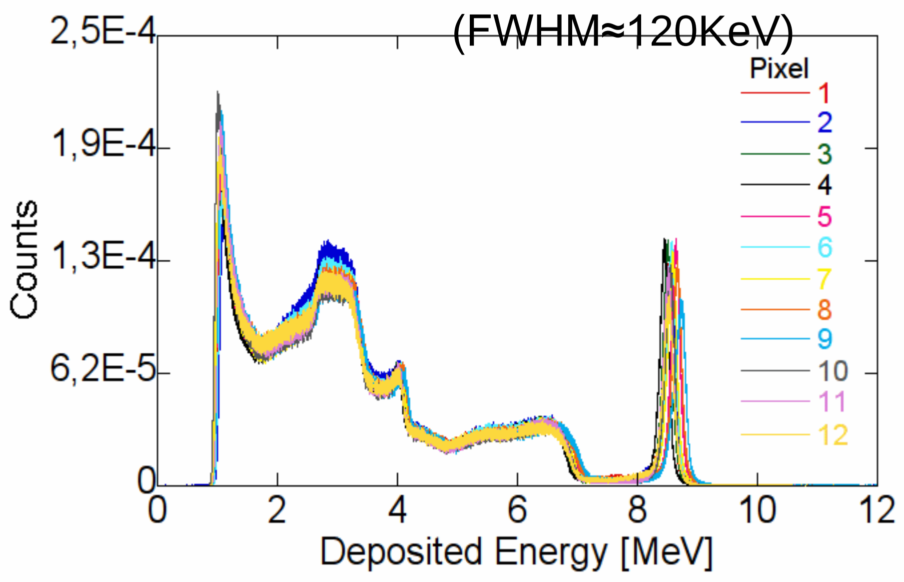


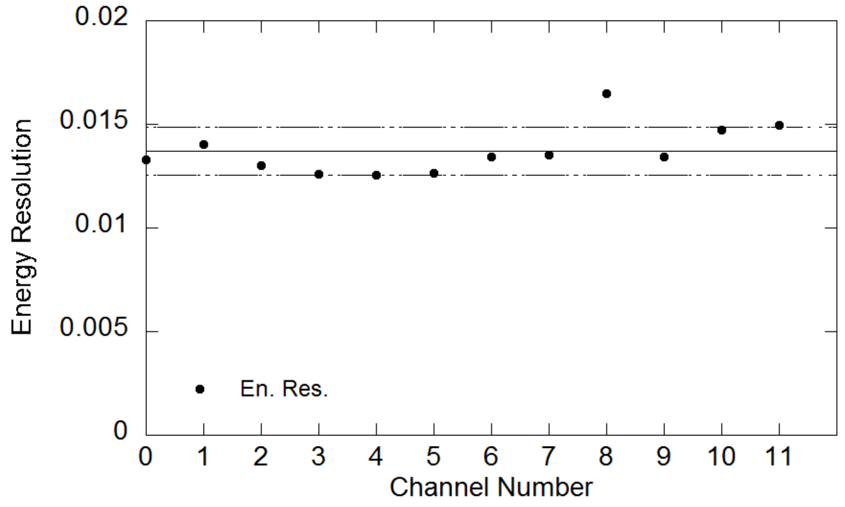
SDD Matrix as a Vertical Neutron Spectrometr

- A new system based on a 12-pixel SDD Matrix has been realized by CNR
  - 12 independent pixel
  - Single-crystal CVD Diamonds are produced by Element six Ltd
  - Dimension: Area 4.5x4.5 mm^2 - Thickness 0,5 mm



- Measurements of 14 MeV neutrons have shown:
  - Uniform response of the 12 pixels
  - Very good energy resolution ≈ 1,3 % (190KeV)→ mainly beam broading (FWHM≈120KeV)



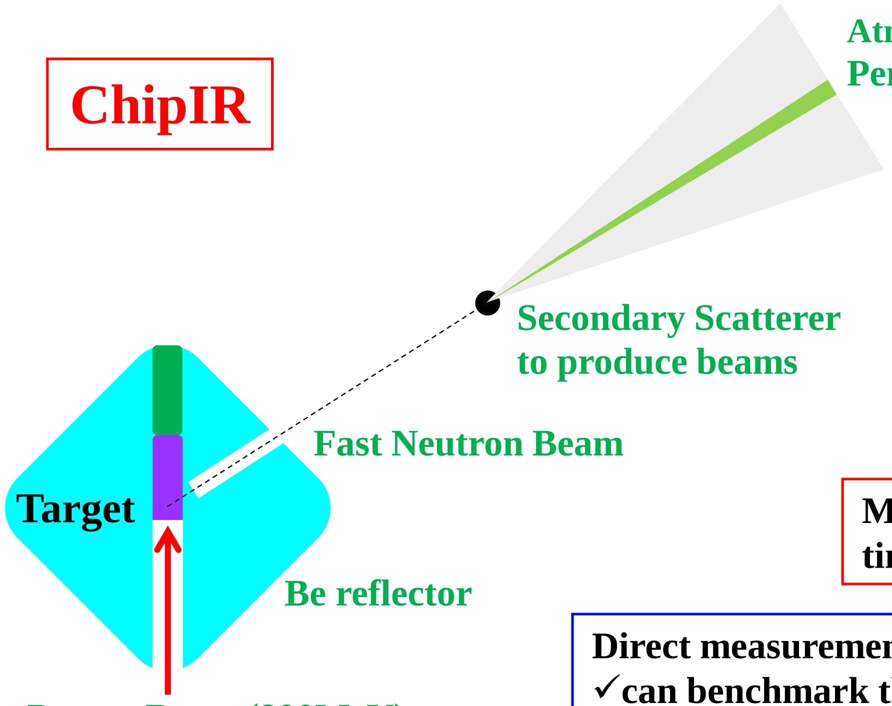


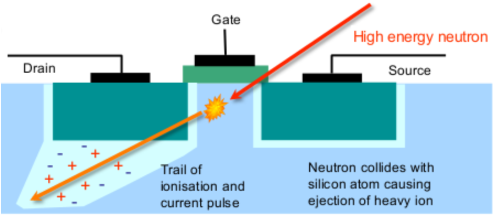
Telescope Proton Recoil Spectrometer for fast neutrons

Telescope Proton Recoil Spectrometer

❑**Why?** **Designed for the new beam-line ChipIR at the ISIS neutron source.**

ChipIR





Micro-electronic devices failure

Single-event effects (SEE)

Cosmic radiation (neutrons)

Mimic the atmospheric fast neutron spectrum with 10^8–10^9 times higher intensity at ground level

Direct measurements of the neutron energy spectrum and flux:
✓can benchmark the simulations,
✓understand the underlying physics of this kind of facility better.

Challenges

- **High energy** (up to 800MeV)
- **High intensity** (>10^6 neutrons·cm^{-2}·s^{-1} with En>10MeV)
- **Complex background** (Neutrons, Protons, Gamma rays…)

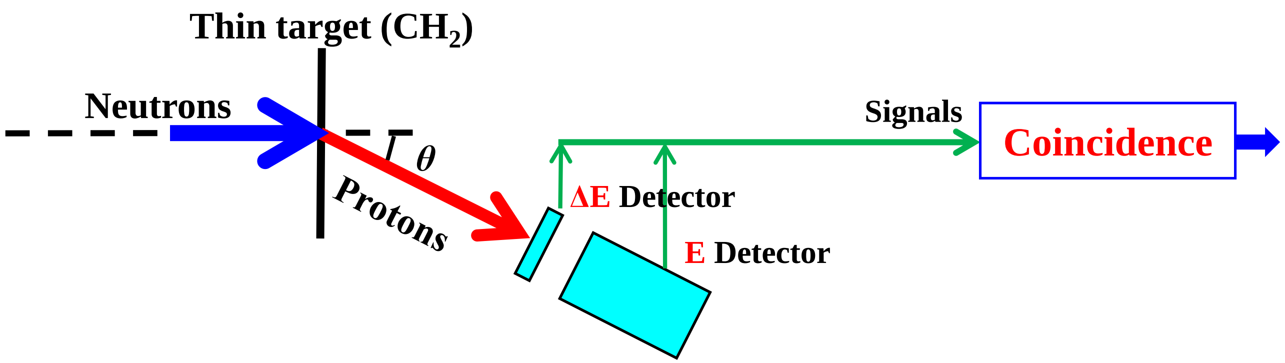
✓**Telescope Proton Recoil**
Diamond Detectors
Bonner Spheres
Fission Counters
Activation Foils

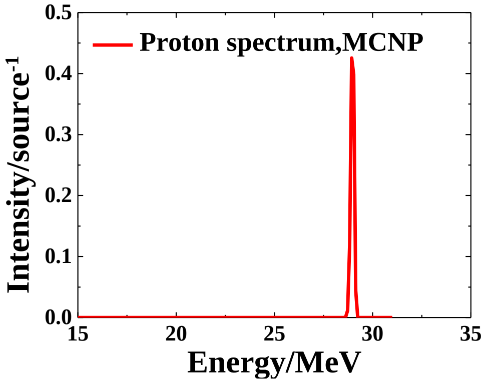
Telescope Proton Recoil Spectrometer

- **What?** Method: Using recoil proton method to detect the neutron

➢ Elastic scattering, (*n*, *p*) reaction

$$E_p=E_n\times\cos^2\theta$$





☺ **Advantages**
—Good energy resolution
—Detection efficiency can be calculated quite accurately (could be used to measure the intensity)

⃠ **Disadvantage**
—Low detection efficiency

- **How?**

➢ Design the TPR system for ChipIR with Monte-Carlo simulation
➢ Choose the type of the detectors to measure ΔE (Au-Si) and E (YAP and $LaBr_3$ crystals)
➢ Characterization of the detectors with different thickness up to 120MeV protons
Response function, light output, …
➢ Test at ISIS

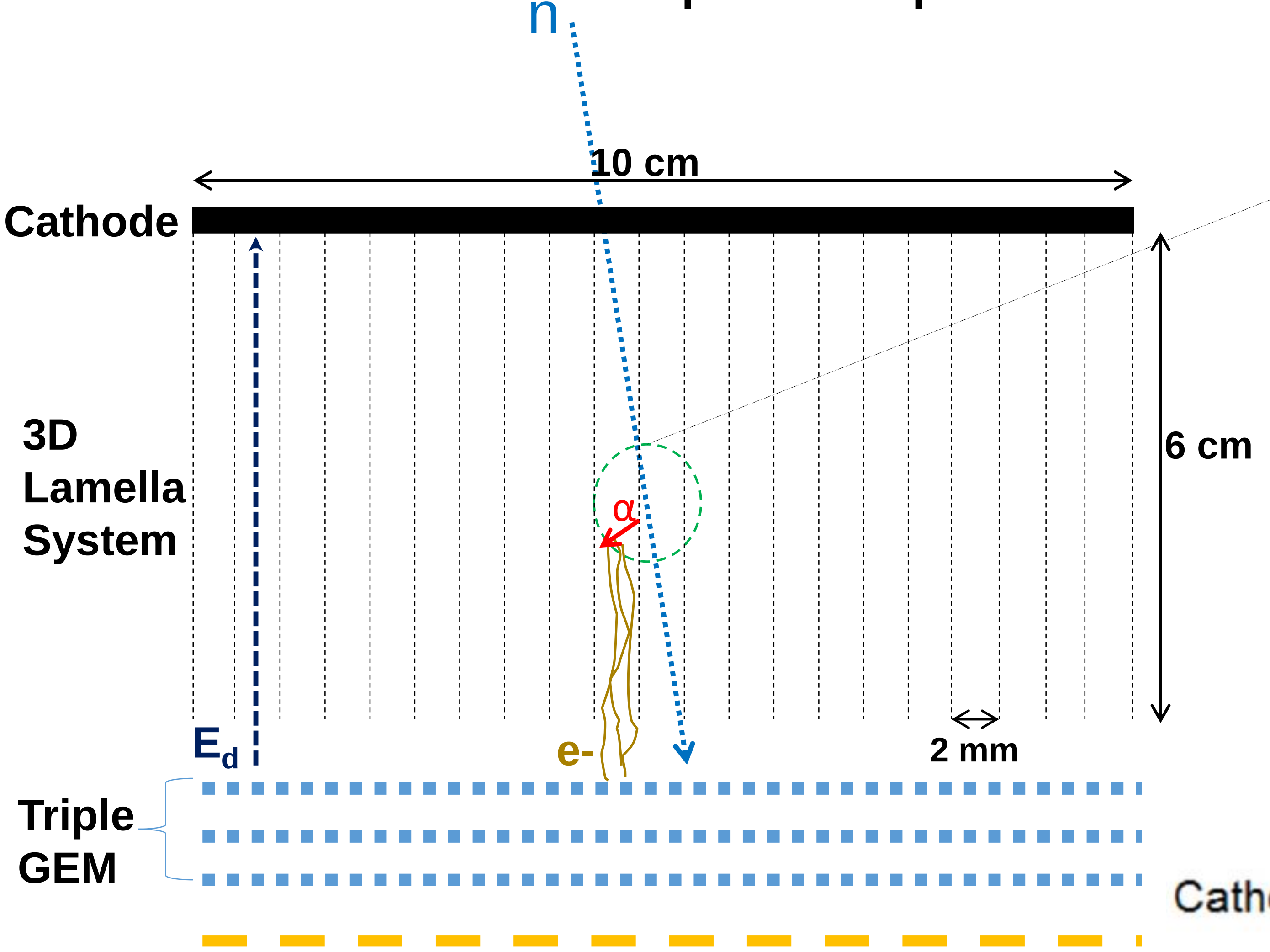
SHOULD WE DETECT THERMAL NEUTRONS WITH GEMS?

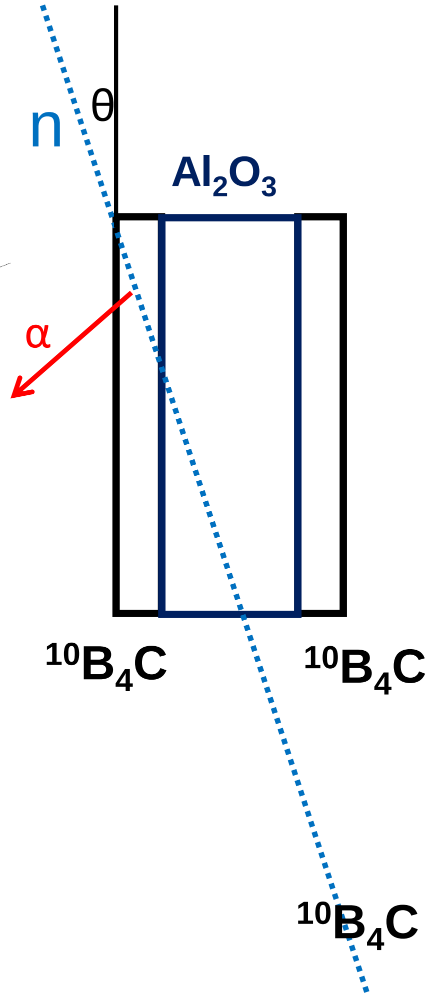
- GEM detectors born for tracking and triggering applications (detection of charged particles)....
- ...but if coupled to a solid state converter they can detect
  - Thermal Neutrons → ^{10}Boron converter
    - Neutrons are detected using the productus (alpha,Li) from nuclear reaction ^{10}B(n,alpha)7Li
    - **Face ^{3}He world shortage**

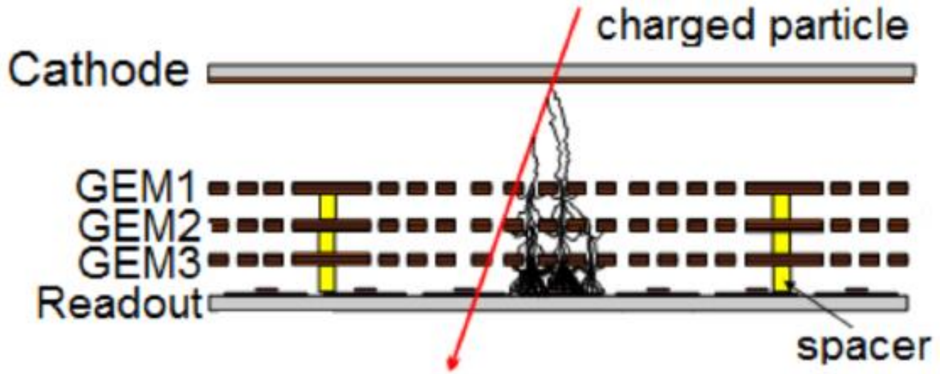
- GEMs offer the following advantages
  - High rate capability (up to MHz/mm^2) suitable for high flux neutron beams like at ESS
  - Submillimetric space resolution (suited to experiment requirements)
  - Time resolution from 5 ns (gas mixture dependent)
  - Possibility to be realized in large areas and in different shapes
  - Radiation hardness
  - Low sensitivity to gamma rays (with appropriate gain)

G. Croci et Al JINST 7 C03010; *F. Murtas et Al*, JINST 7 P07021; *G. Croci et Al,* NIMA 720, 144;
G. Croci et Al, NIMA, 712, 108; *G. Croci et Al*, JINST 8 P04006; *G. Croci et Al*, NIMA 732, 217;
G. Albani et Al, JINST 10 C04040; *G. Croci et Al*, EPJP 130, 118; *G. Croci* et Al, EPL, 107 12001
G. Croci et Al, Prog. Theor. Exp. Phys. 083H01;

Scheme and Principle of operation





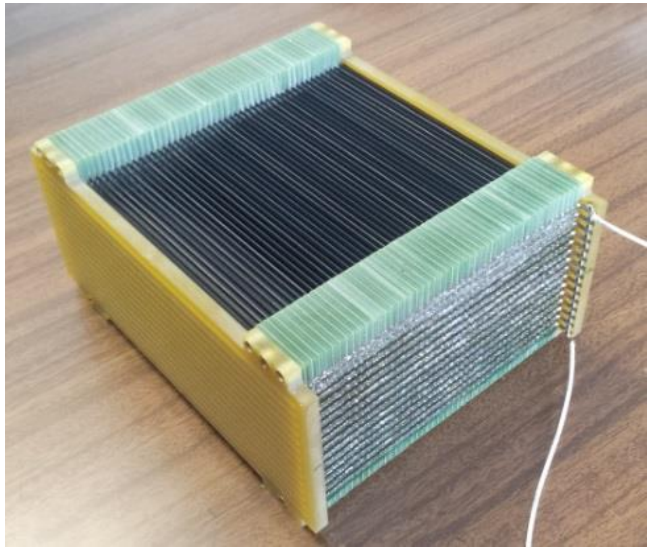


Padded Anode

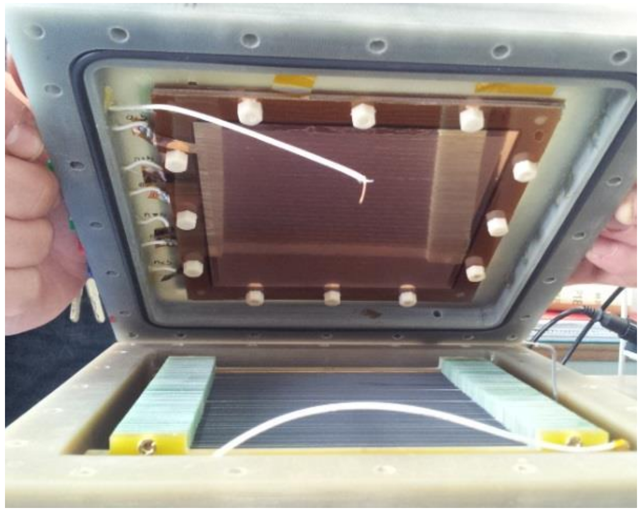
Alumina Lamellas coated on both sides with $^{10}B_4C$

Using low θ values (few degs) the path of the neutron inside the B_4C is increased → Higher efficiency when detector is inclined

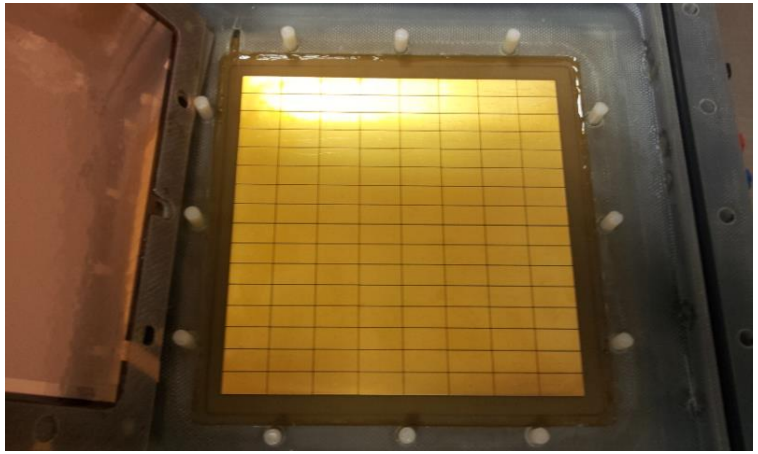
Detector Assembly



The full Lamella System. A total of 48 lamellas have been mounted mounted. Their distance is 2 mm



Assembly with Triple GEM detector



128 Pads of area 6x12 mm^2 have been used as anode

Thanks for your attention!