Detector for Channeled ions in CNT

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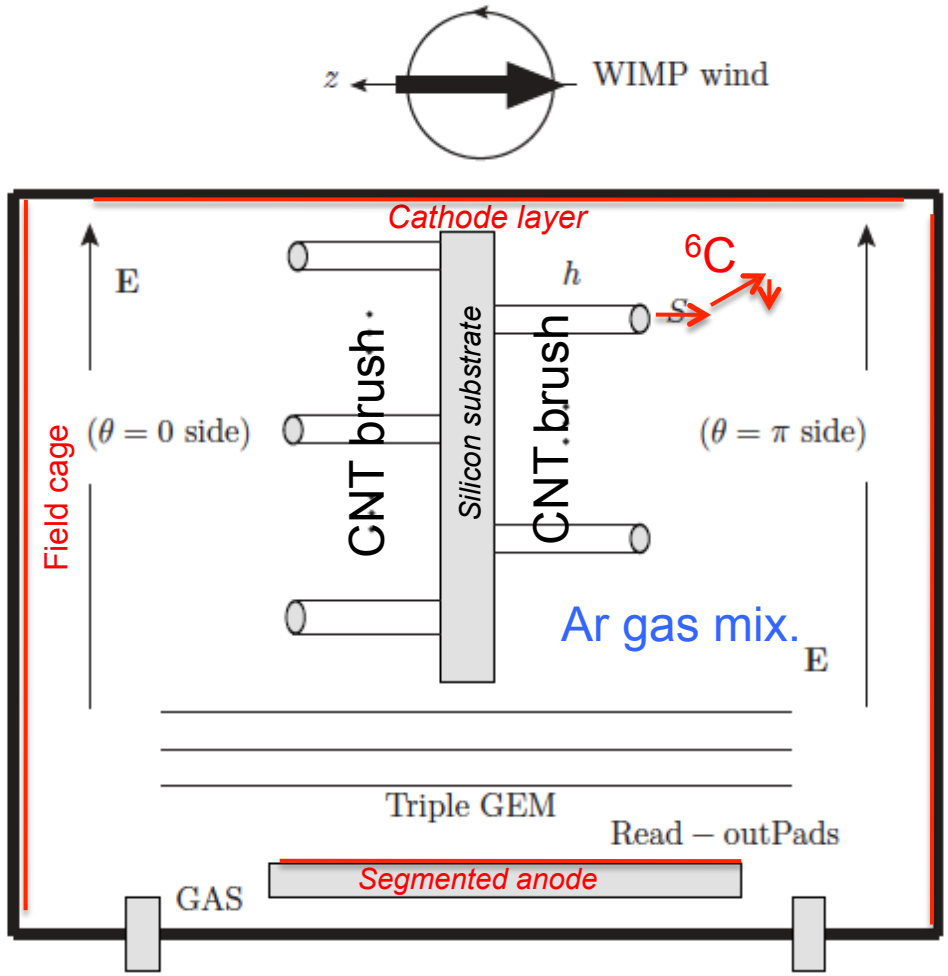
Outline

- Carbon nanotubes (CNT) in a Time Projection Chamber (TPC)
  - A detector for WIMP induced ion recoil
  - Triple-GEM TPC
- Carbon ion channeling experiments
  - Ions elastically scattered by
    - neutrons
    - electrons
- Perspectives

Read-out scheme: exiting C ion

Not to scale!

h **~100 μm**
S ~ π(**5**)^2 **nm**^{2}



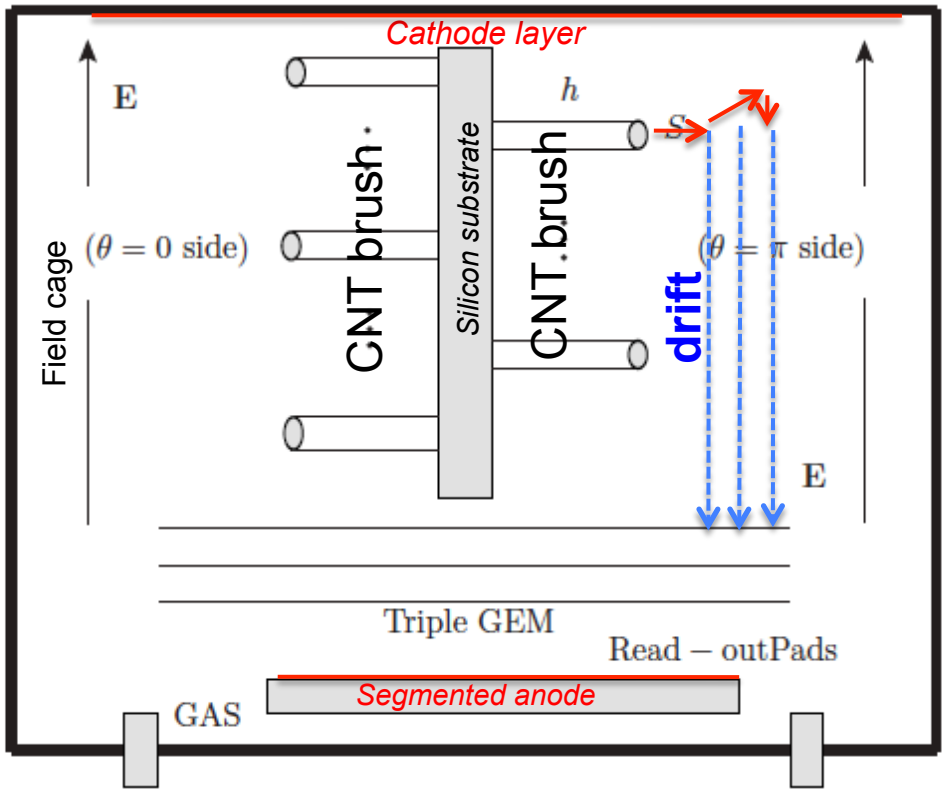
Carbon ion (few KeV to few tens KeV kinetic energy) **emerging** from CNT "brush"

Carbon ions **ranging out** In the gas

Read-out scheme: electron drift

Low pressure gas (0.1 bar)

Range of 10 KeV ^{6}C in 0.1 bar Ar
~ 1mm (TRIM)



Not to scale!

h ~100 μm
S ~ $\pi(5)^2$ nm^2

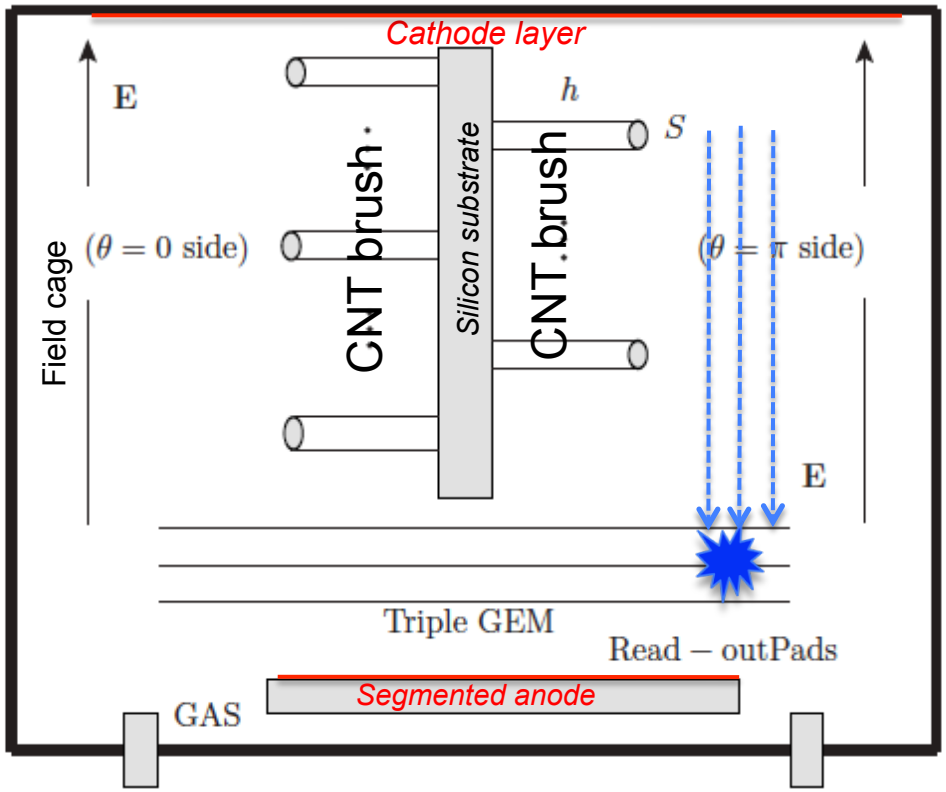
Drift distance can be
10 cm

Carbon ions **ranging out** In the gas

Electrons from ionized gas atom **drift** towards anode

Read-out scheme: amplification

Low pressure gas (100 mbar)



Not to scale!

h ~100 μm
S ~ $\pi(5)^2$ nm^2

Triple GEM **amplification** stage

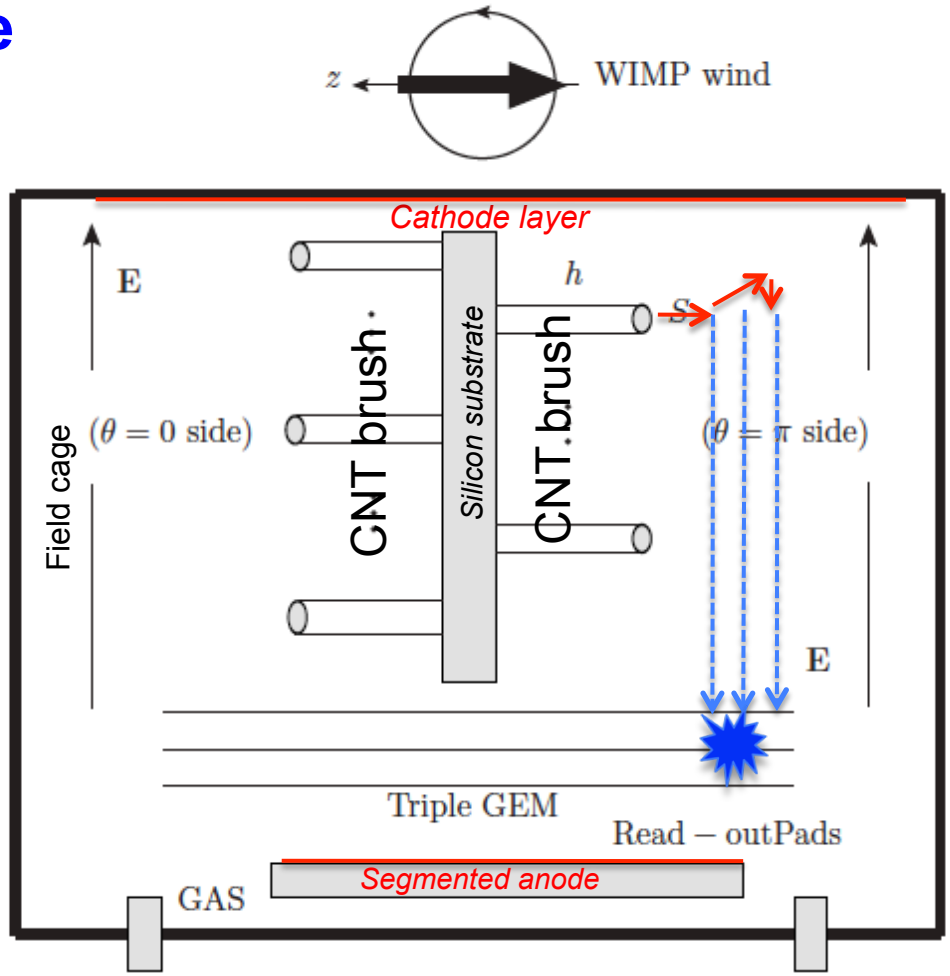
Electric signal **induced** on anode

Read-out scheme: measurements

Low pressure gas TPC

Not to scale!

h ~100 μm
S ~ π(5)² nm²



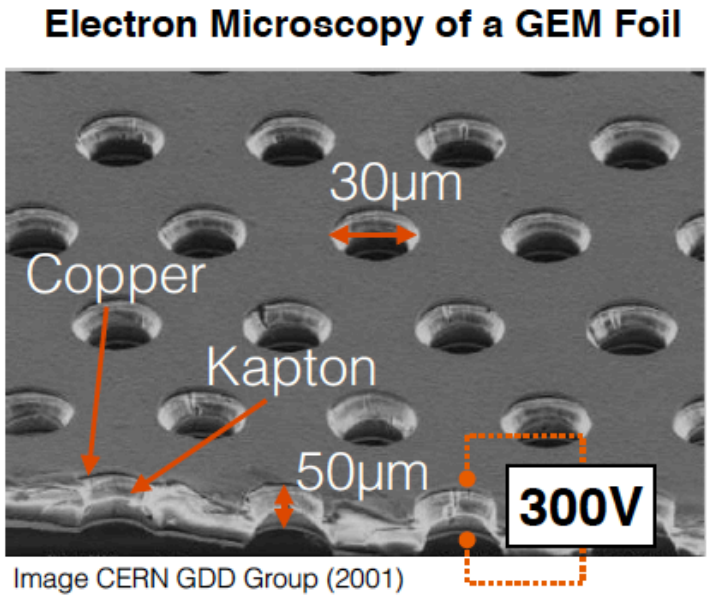
Must be able to measure:

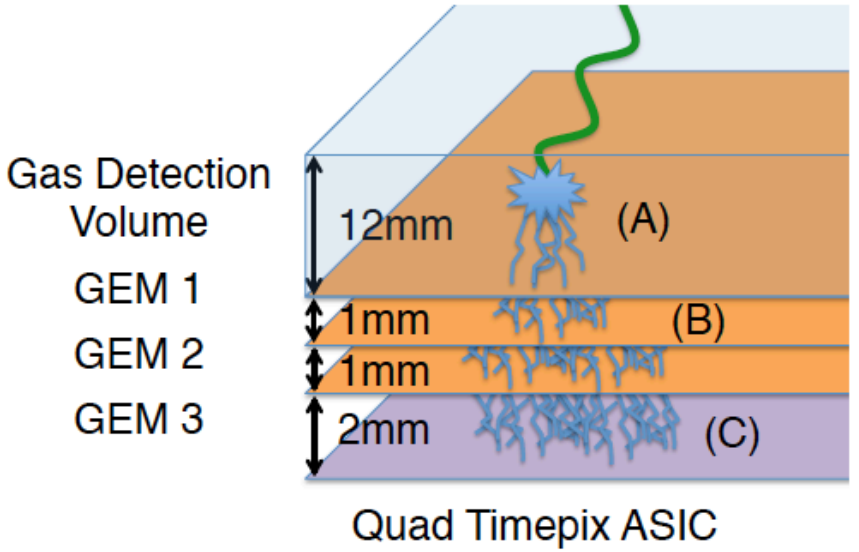
- Kinetic **energy** **(total ionization)**

- **range** **(segmented anode)**

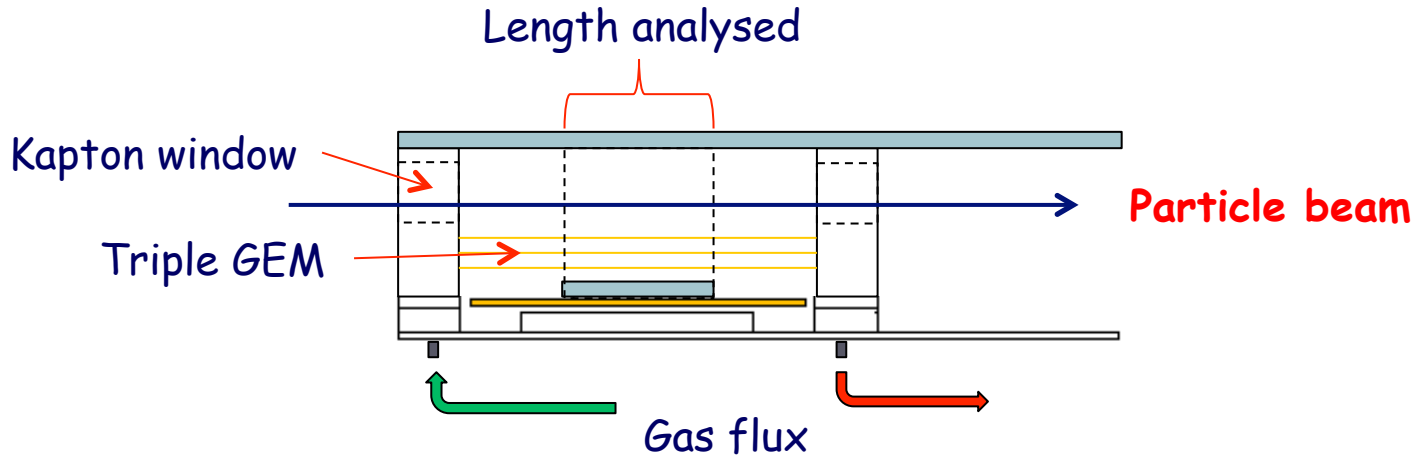
- **average direction** **(relative electrons time-of-flight)**

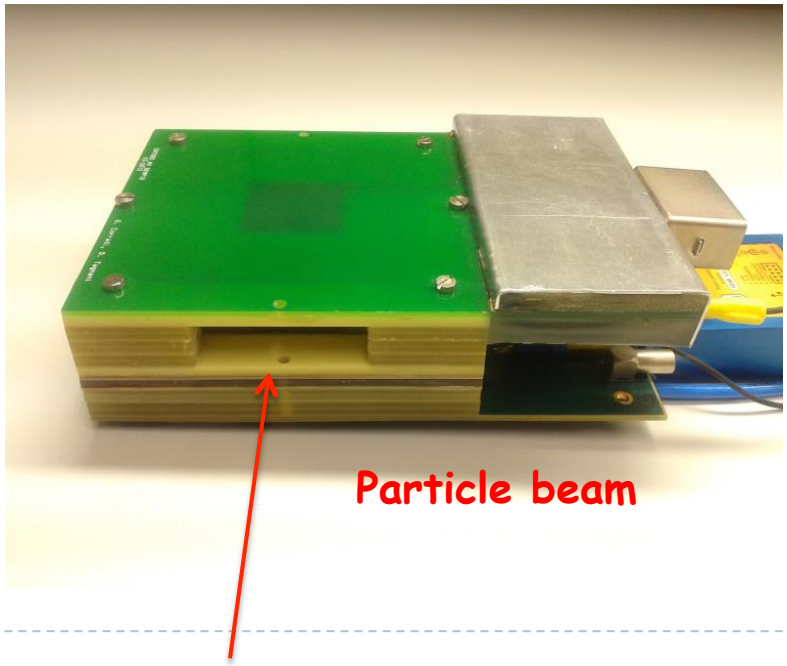
GEM and read-out pad concept





GEMpix detector

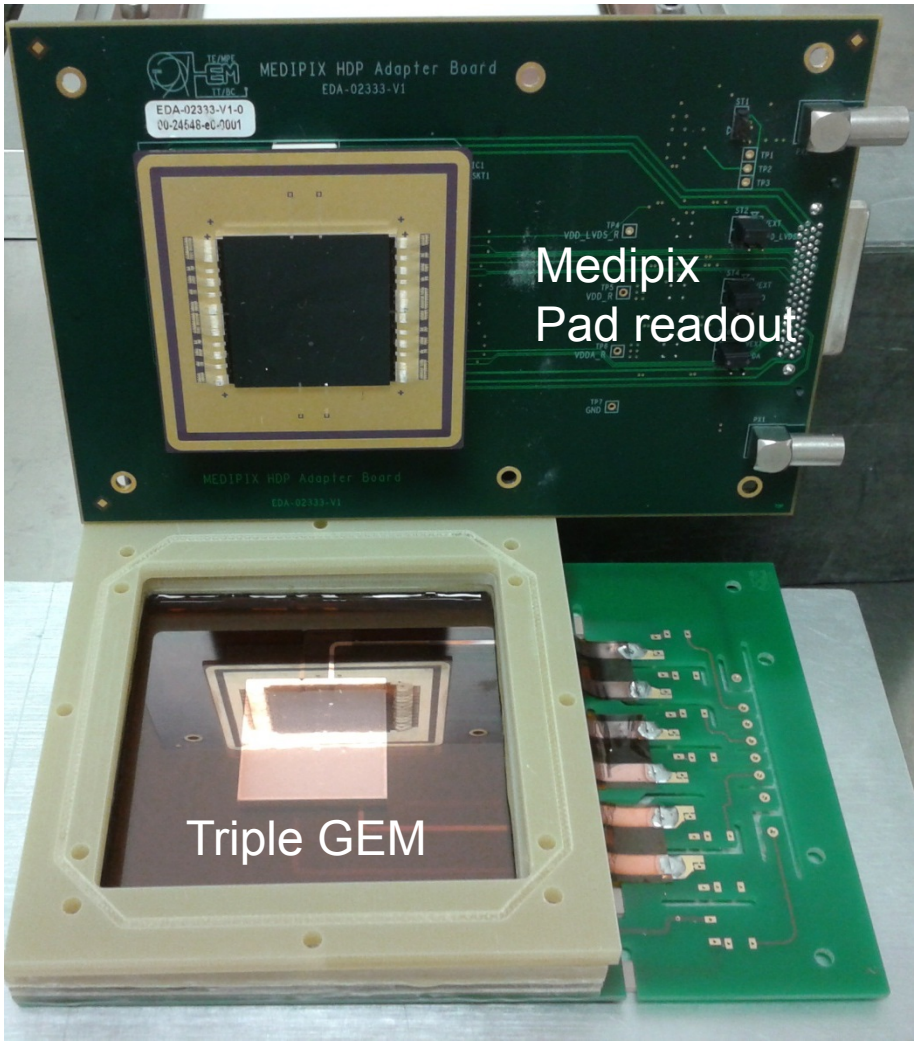




Developed for
various applications
(neutron beam monitoring,
hadrotherapy beam monitoring,…)

F.Murtas (LNF-CERN)

Segmented anode



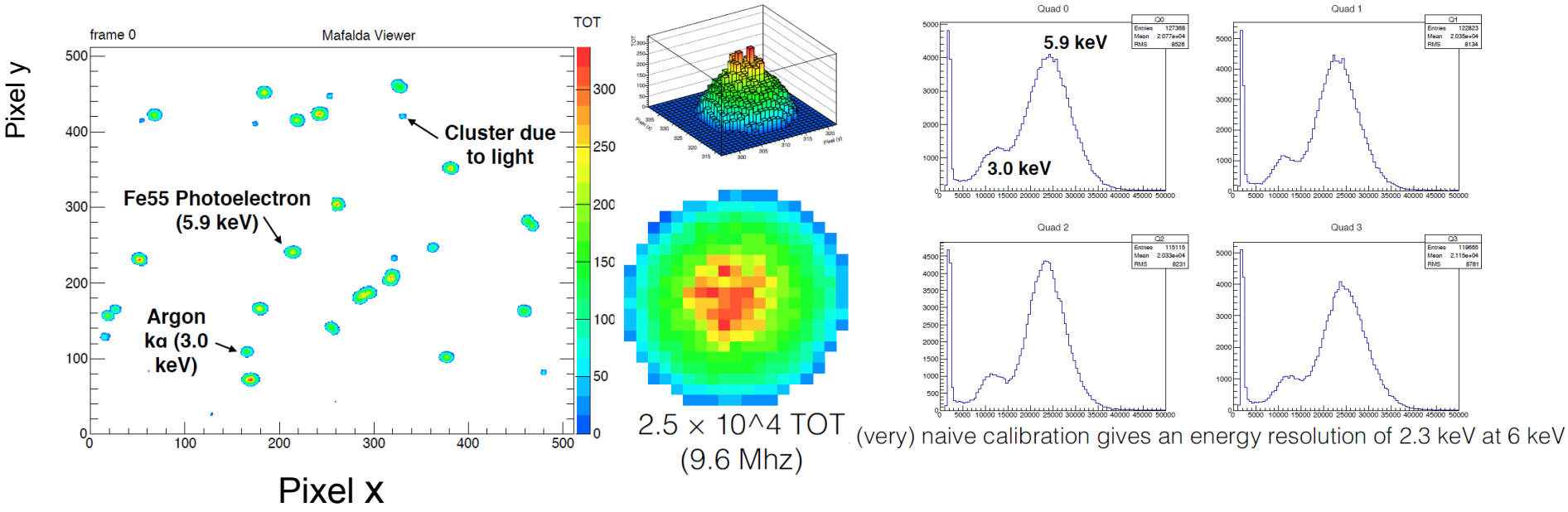
Anode is an ASIC used to read-out signals from **four** 512x512 **55μm** silicon pixel sensors (MEDIPIX)

In this configuration silicon pixels are removed: the **charge signal is generated in the Triple GEM**

GEM(Medi)**pix**
Detector
3x3 cm^2 active area

X ray KeV detection

- GEMPix exposed to ^{55}Fe 5.9 KeV gamma source



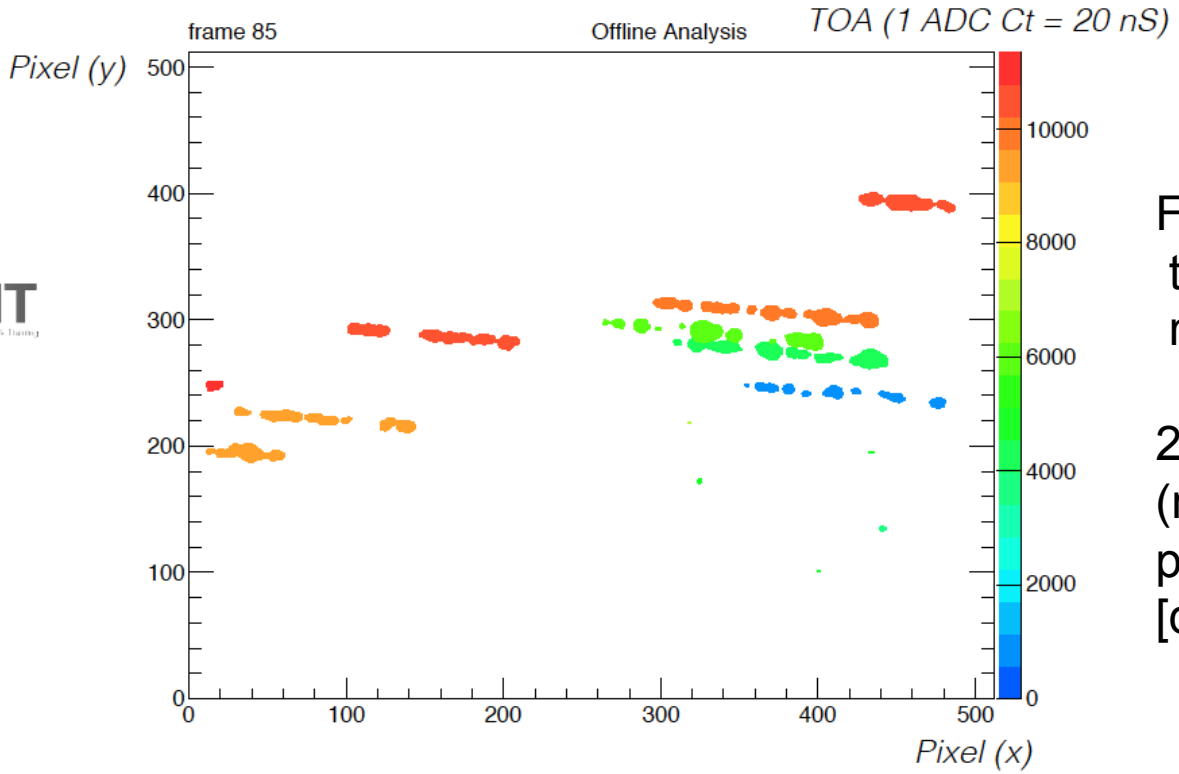
(very) naive calibration gives an energy resolution of 2.3 keV at 6 keV

For each pixel the deposited charge is measured (Medipix)
X-ray seen as a cluster of pixels

Energy resolution **~2 KeV** already obtained.

High energy tracks detection

Sample frame - 3 GeV mixed proton (2/3), pi+ (1/3) beam on SPS H6, 30 deg angle of incidence



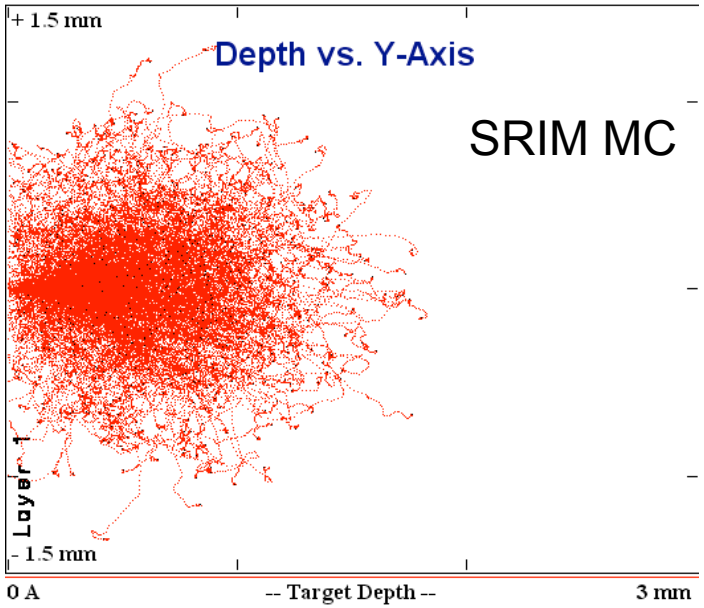
TOA Mode (48 Mhz), 1 Count ~ 20 nS, 0.25 mS frame, chamber gain = 1350 V, gas = ArCO2CF4, drift field = 0.666 kV/cm

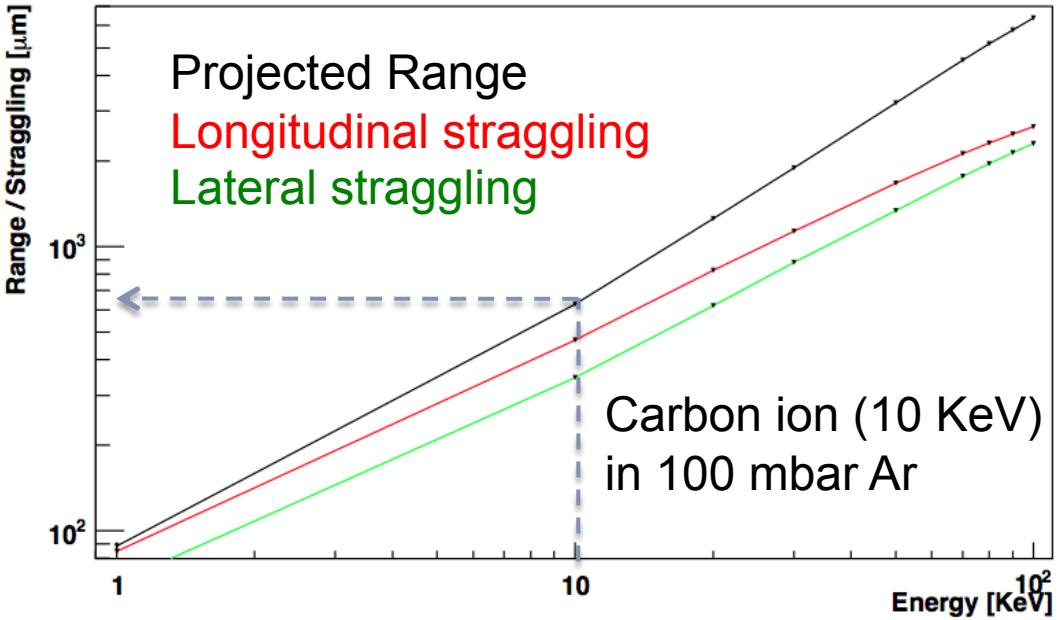
For each pixel a time of arrival is measured (Timepix)

20 ns clock allows good (relative) vertical position resolution [drift time]

Range of few KeV ion in Ar

Carbon ion (10 KeV)
in 3mm thick 100 mbar Ar

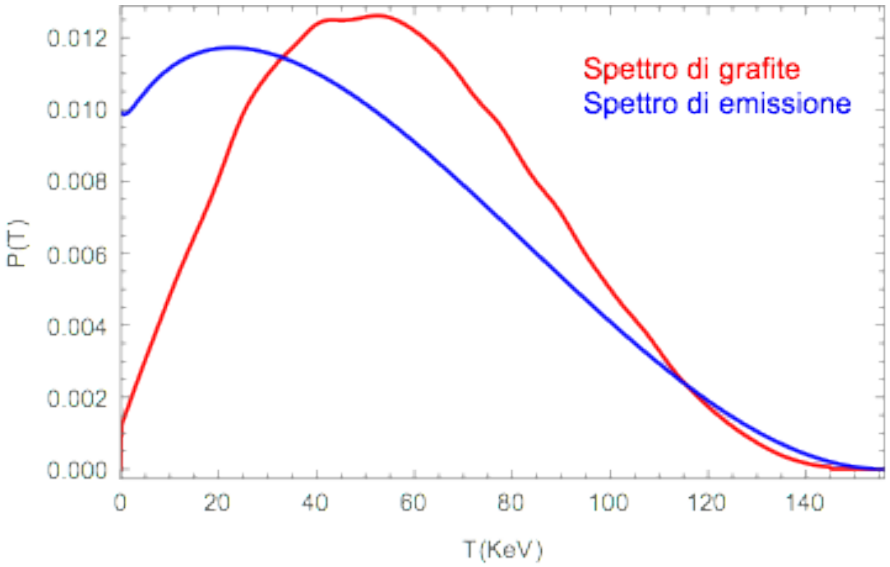




Even with large spread of ionization, the range measurement might help to identify the signal

^{14}C background

- Carbon most common isotope is ^{14}C
  - Beta emitter, cosmo-genic (^{14}N transmutation by cosmic rays)

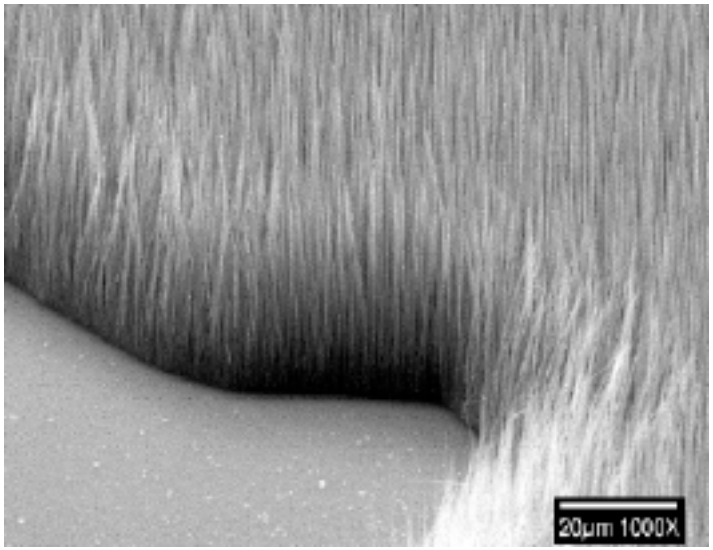


7% of emitted beta from 14C decay are emerging from a 10x10x0.1mm^3 graphite block

Natural isotope concentration (10^{-11}) is unacceptable.

Using pure precursor of hydrocarbures in CNT synthesis can reduce it to 10^{-18} (see BOREXINO)

How to pack enough mass ?



- Simple-man calculation:
- About 10^{16} 1nm diameter SWCNT can fit on a 10x10 cm^2 substrate
- Surface density of a graphene layer: 1/1315 g/m^2
- About 2 g CNT on 100cm^2
- CNT ropes?

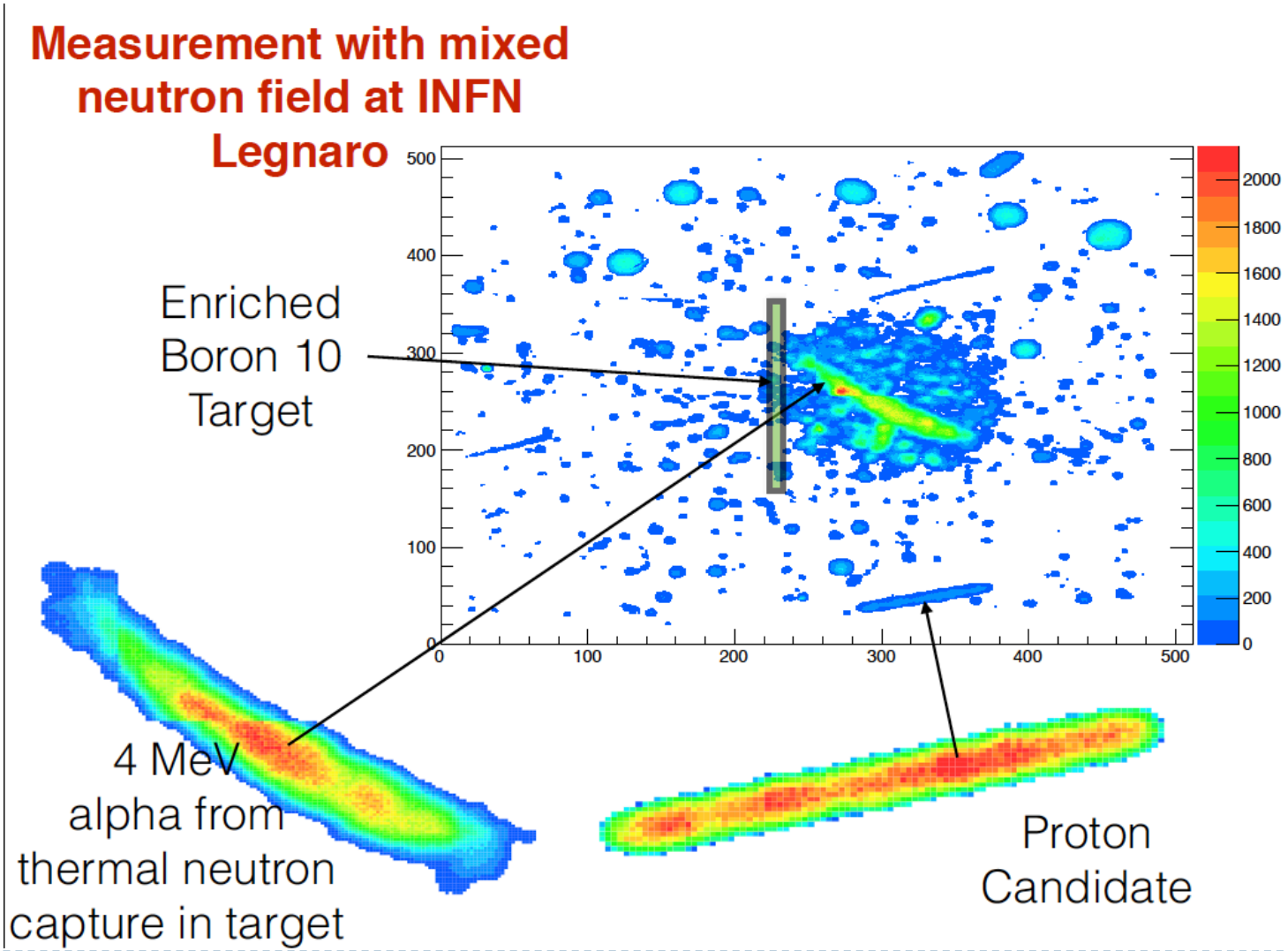
How do we test this concept ?

- GEMPix chamber is already available and suited for a proof of principle

- A WIMP – ion interaction can be reproduced in lab. by a neutron – ion elastic interaction.
  - A 50 KeV neutron is imparting a similar recoil to a carbon ion as a Galactic WIMP does.

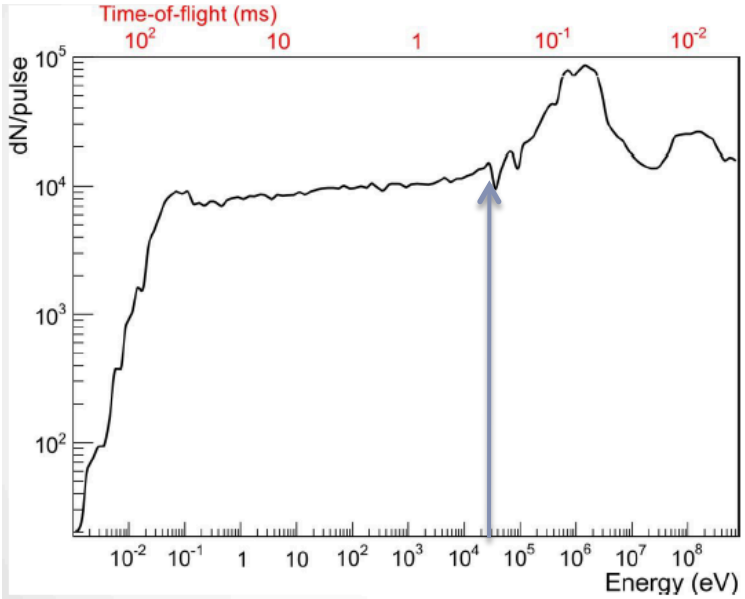
- More precisely, we first want to prove carbon ions of ~10 KeV energy are actually channeled
  - Use carbon ion beam
  - *Induce carbon ion recoil with electrons*

Neutron induced alpha recoil



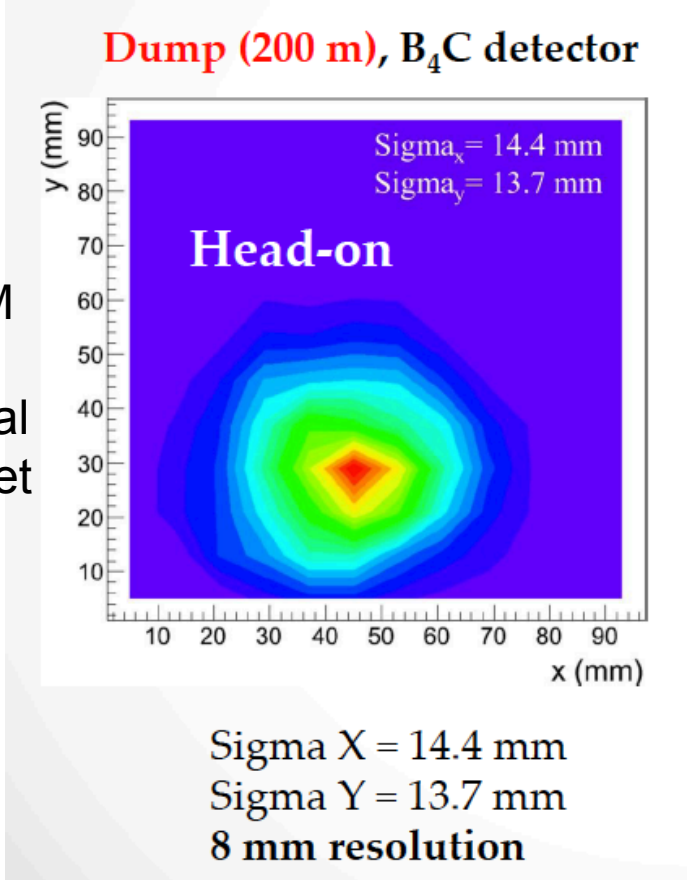
Experiment with nTOF neutrons

CERN ***nTOF*** facility: neutron from
PS 20 GeV protons
Energy measurement from time-of-flight
[precise proton extraction time]



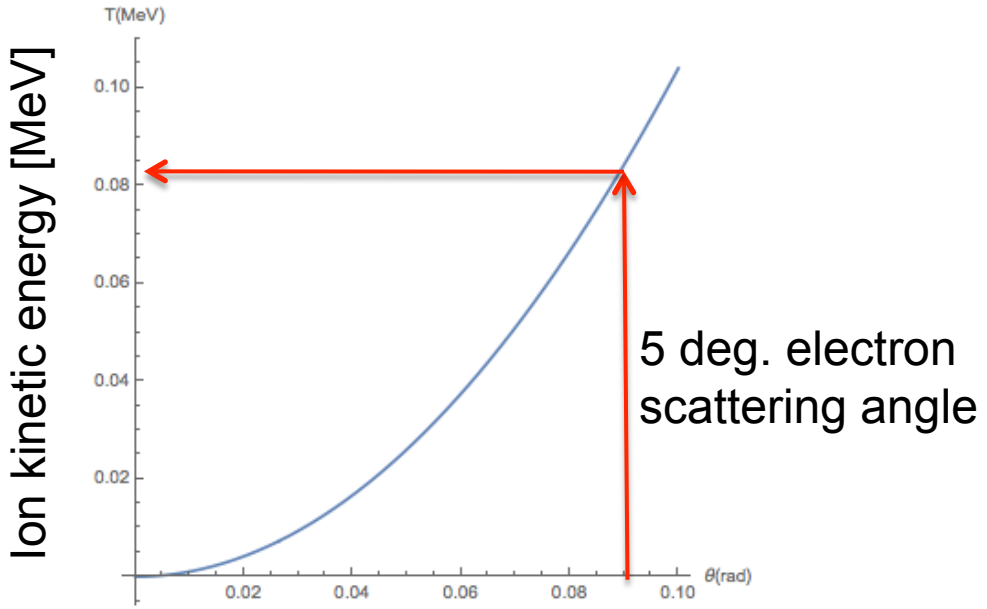
Triple GEM detectors with internal boron target

F.Murtas

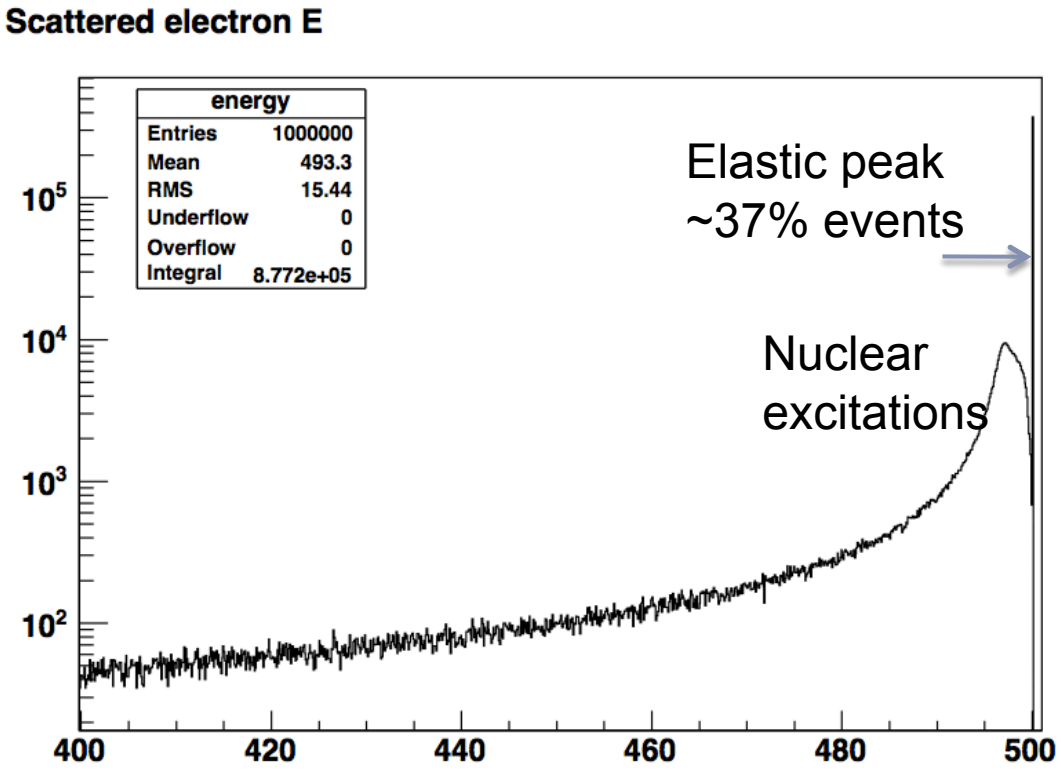


Experiment at Frascati BTF

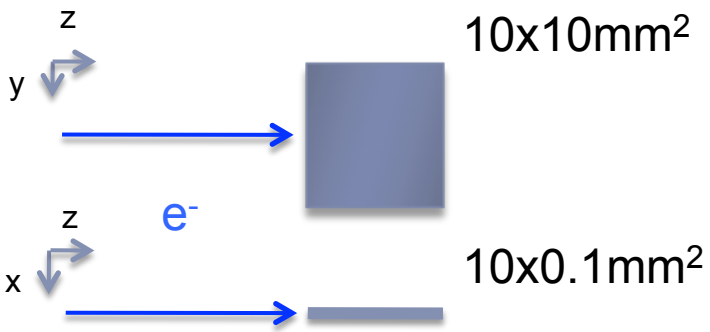
- Use electron beam at LNF BTF to “extract” carbon ions from CNT
  - One carbon ion elastically scattered by a 500 MeV electron
    - PRO: trigger on scattered electron at well defined angle: beam clearly visible
    - CON: electron beam can induce a sizeable background



Elastically scattered ions



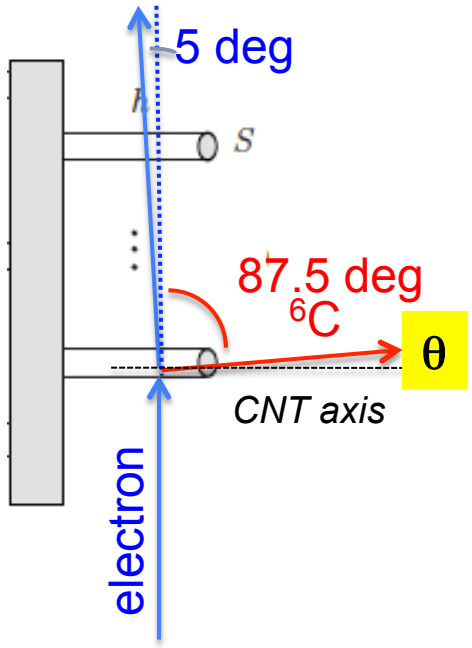
- Geant4 simulation of 500 MeV electron beam
  (no beam spread)

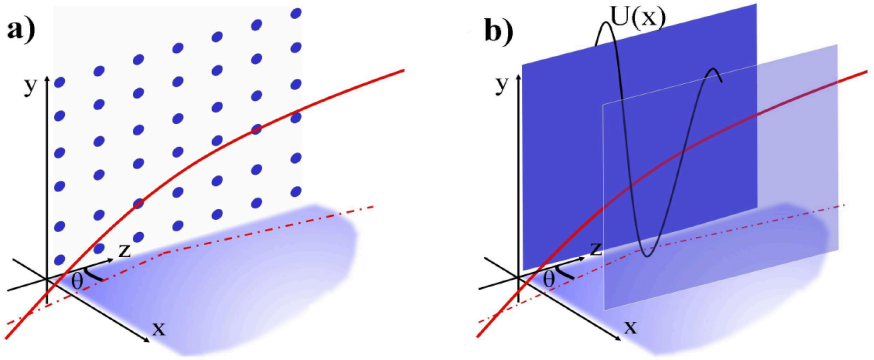


Electrons emerging from a 1 cm thick (amorphous) carbon target

Channeling of ion

Ion elastically scattered almost at 90 degree





Critical (Lindhard's) angle

$$\theta_C = \sqrt{\frac{2U_0}{E}}$$

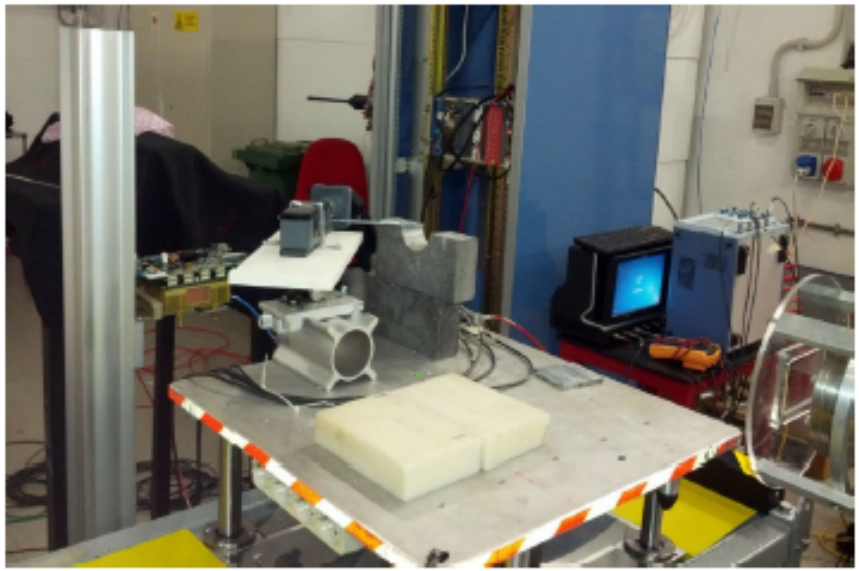
U_0: Potential well depth

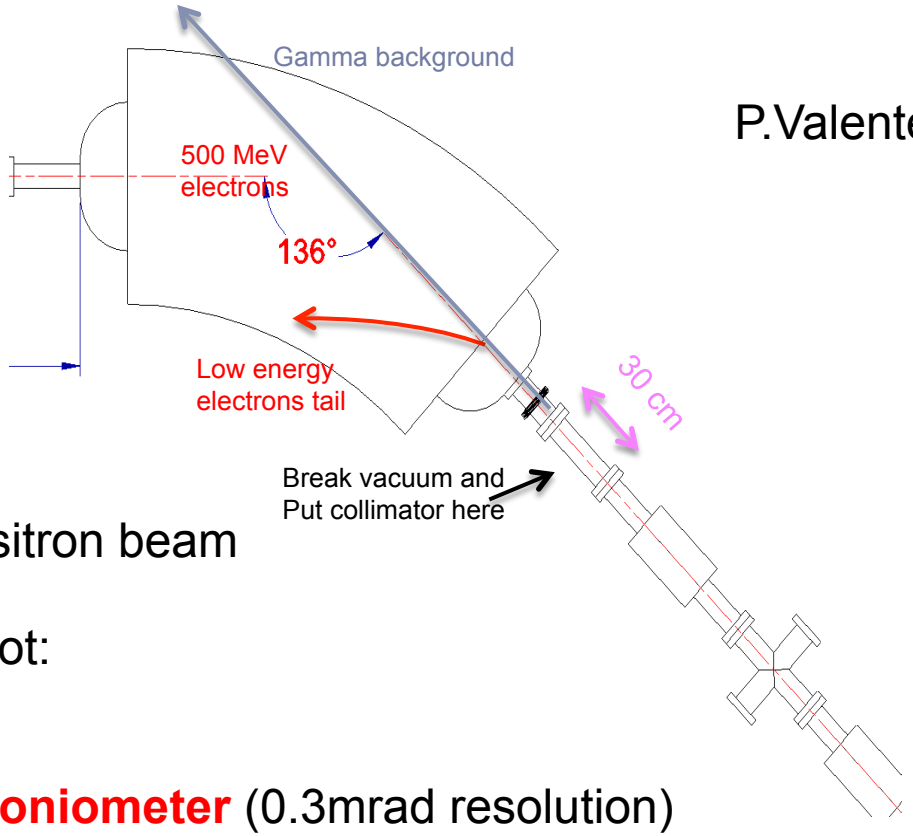
E: Particle energy

~ 8 deg for ^{6}C at 10 KeV

If $\theta < \theta_C$ ions are channeled!

Beam Test Facility at Frascati labs





P.Valente

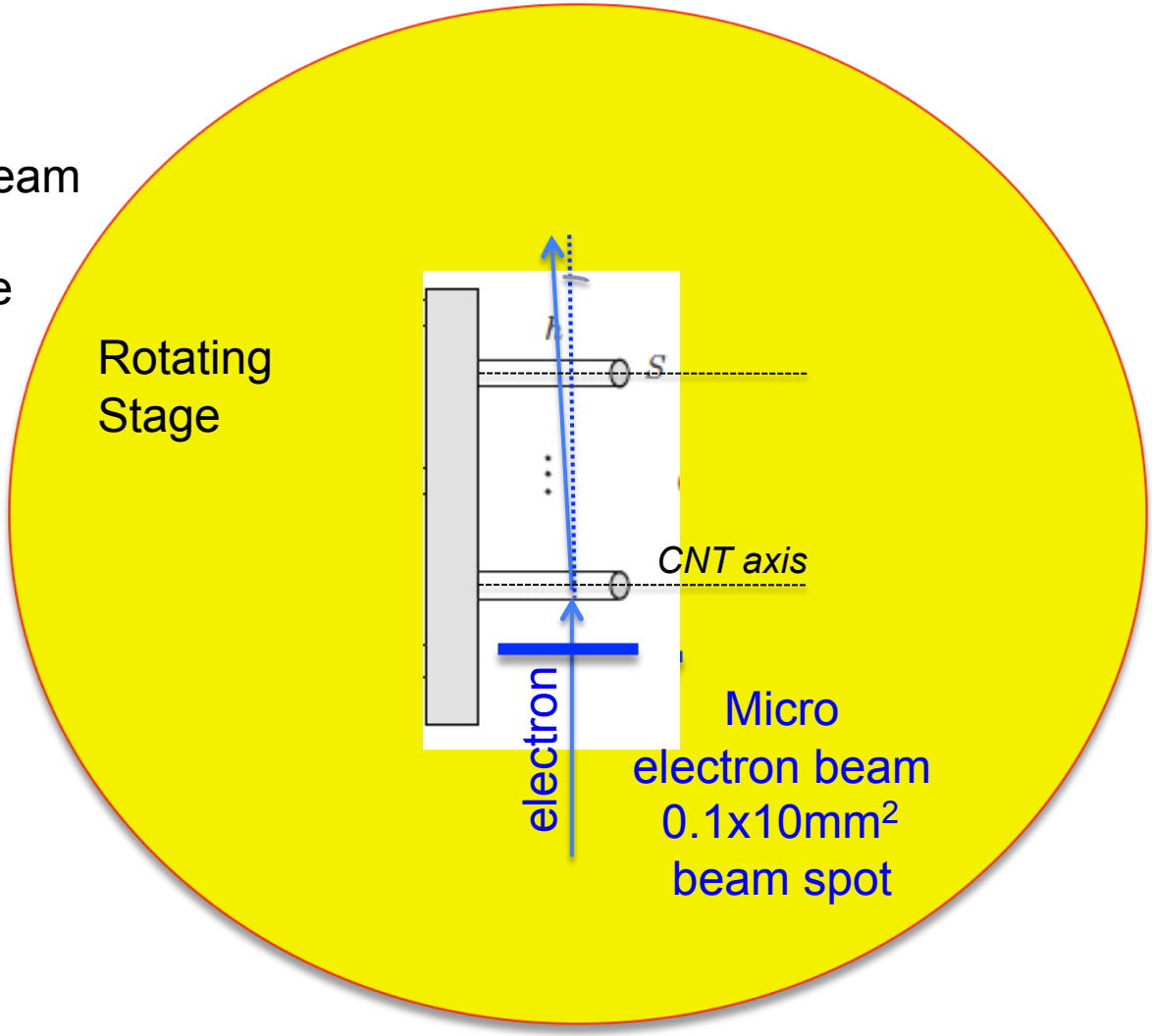
Tunable energy 50-500 MeV electron/positron beam

Few mrad divergence, few mm^2 beam spot:
to be adjusted with a collimator

Remotely controlled movable table and **goniometer** (0.3mrad resolution)

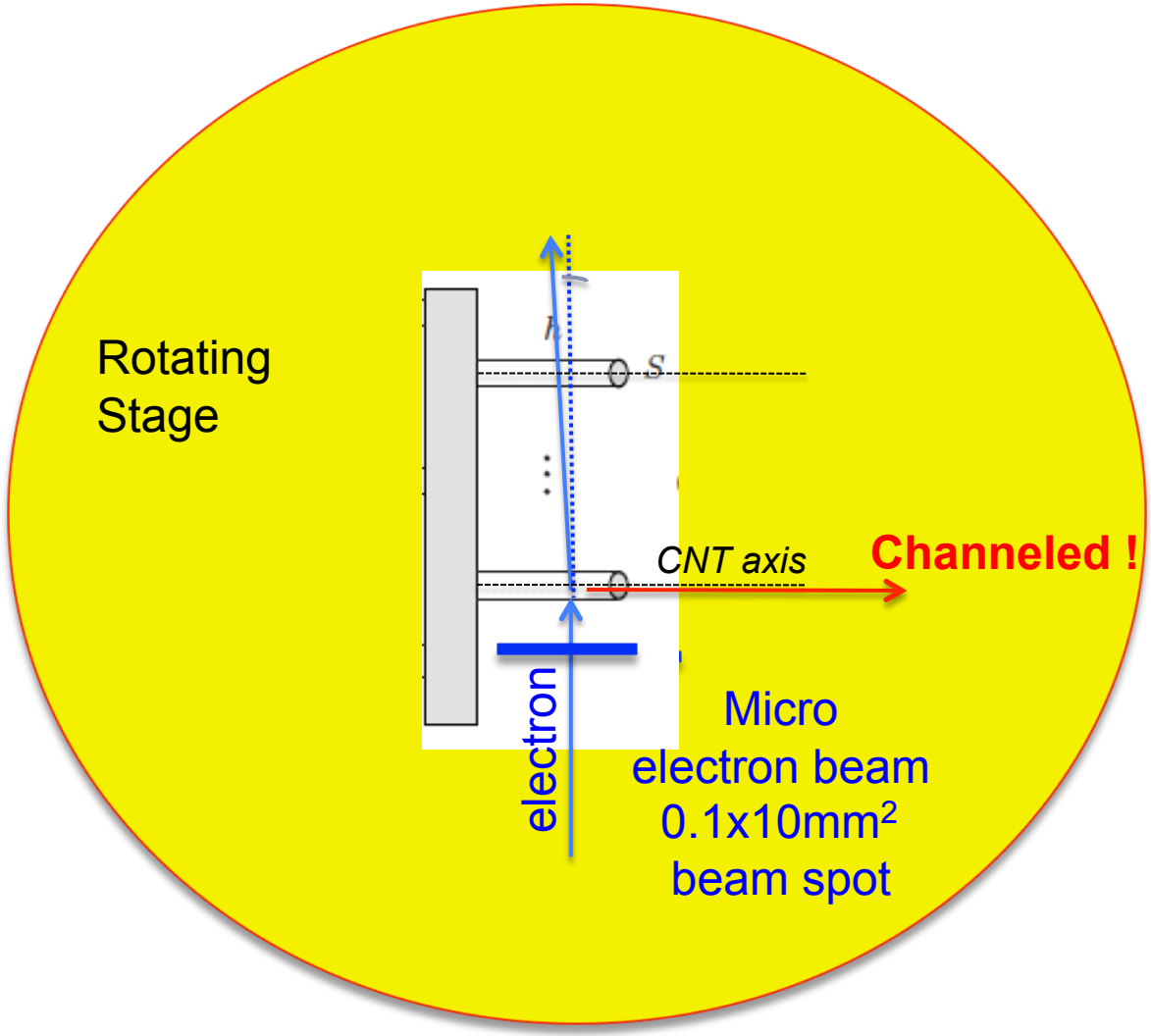
Experiment at BTF: micro beam

When micro-beam available, position can be adjusted using scattering on substrate



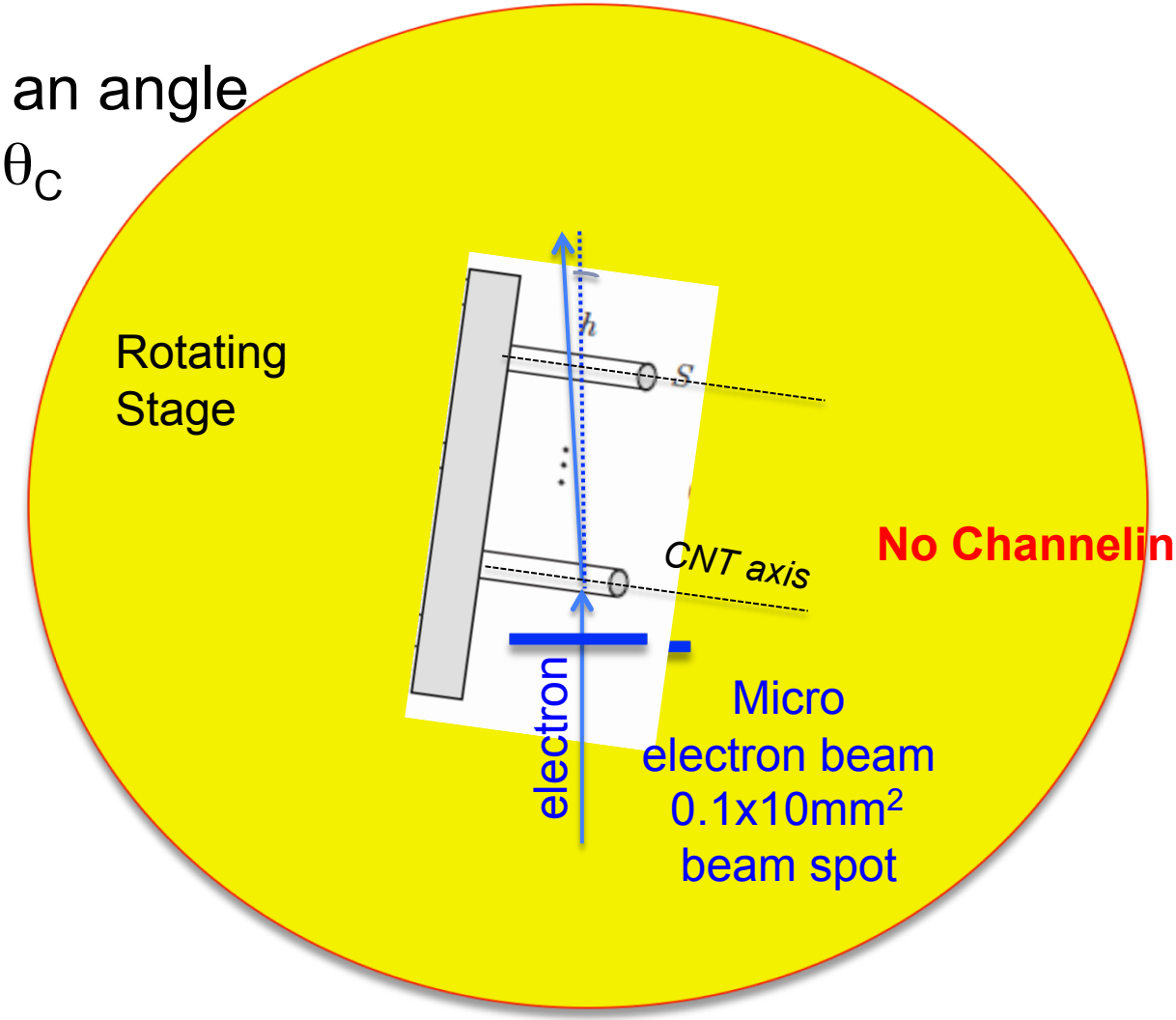
Experiment at BTF:channeling

$\theta < \theta_c$



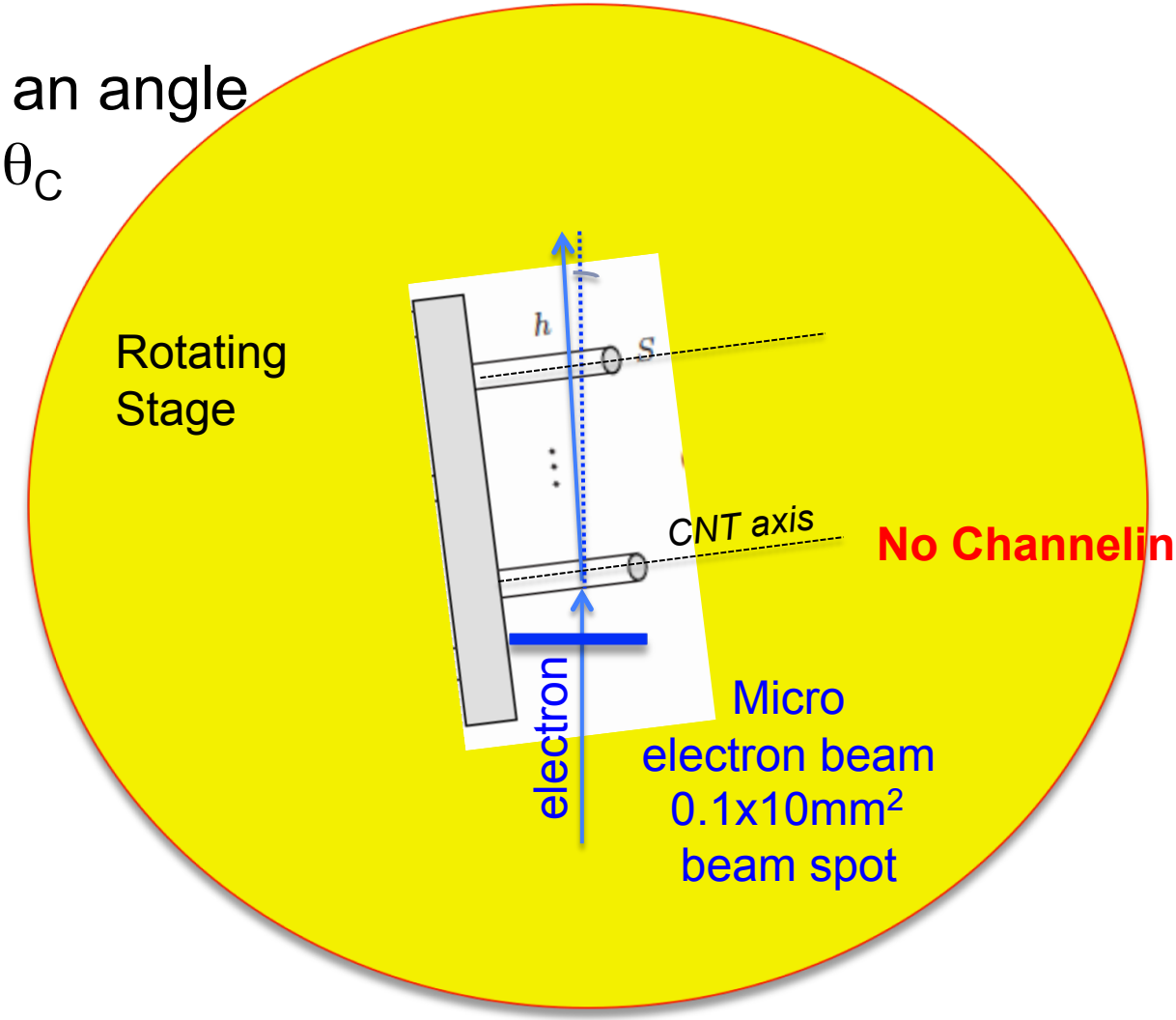
Experiment at BTF

Rotation by an angle wider than θ_C



Experiment at BTF

Rotation by an angle wider than θ_C



Signature of ion channeling

- Intercept beam with CNT
  - Beam can be positioned by looking at scattering on silicon substrate
- Perform an angular scan
  - At each point of the angular scan record the number of ion tracks
- Distribution of ion track rate versus rotation angle should have a maximum when CNT axis is parallel to ion emission direction
  - Such distribution should have **width** of about θ_C

With a 5 10^4 electron per second on a 1 cm thick CNT brush
we should expect ~1 event per second

Prespectives

- Demonstration of CNT capability to channel very low energy ion is a prerequisite for a DM directional detector based on CNT.

- We plan to make test at INFN BTF and CERN nTOF with electron and neutron
  - Carbon beam would also be useful (but experimentally more problematic).