ISAC & Active detectors

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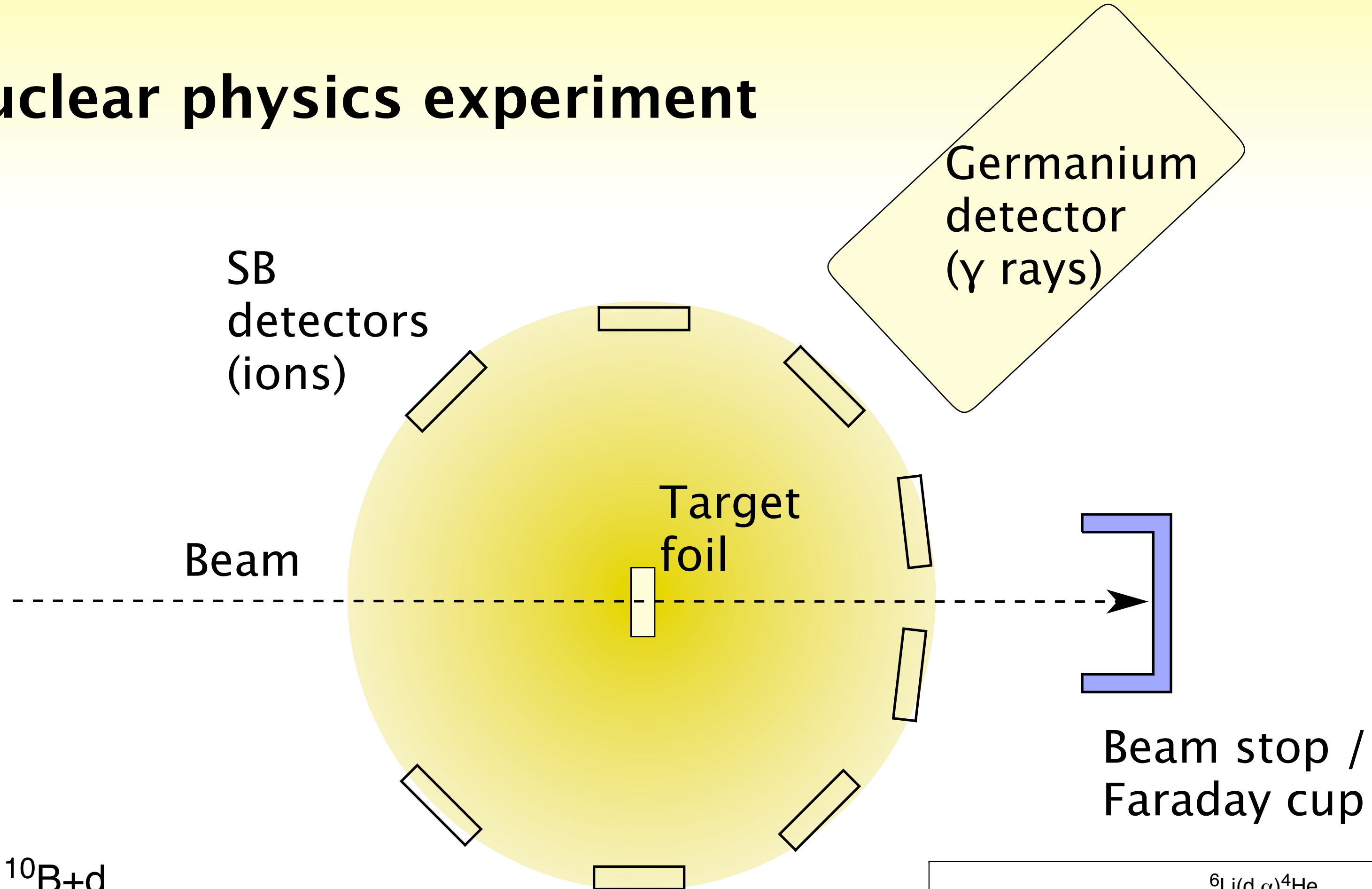
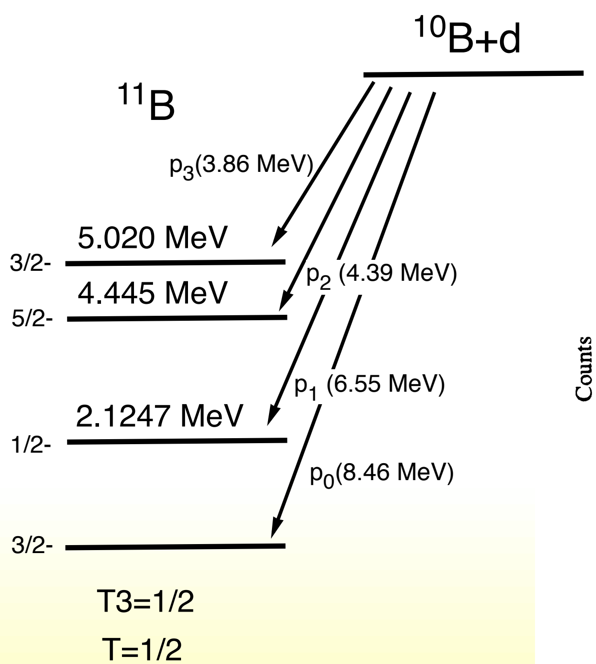
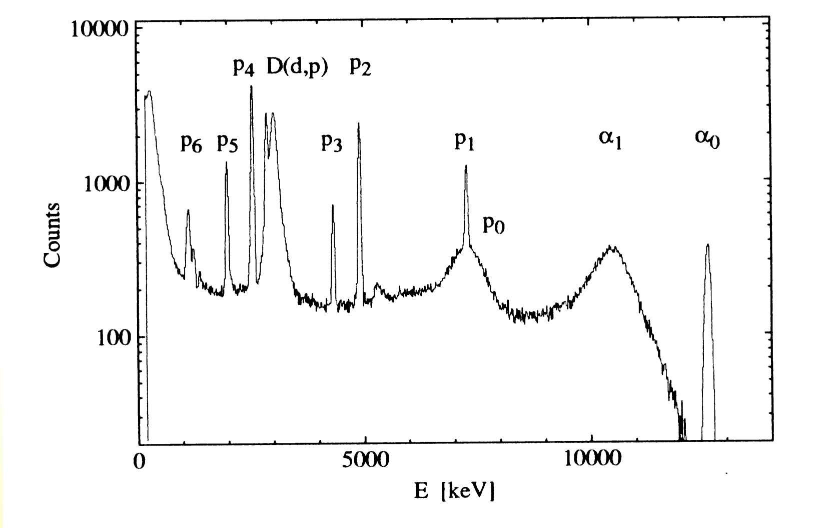
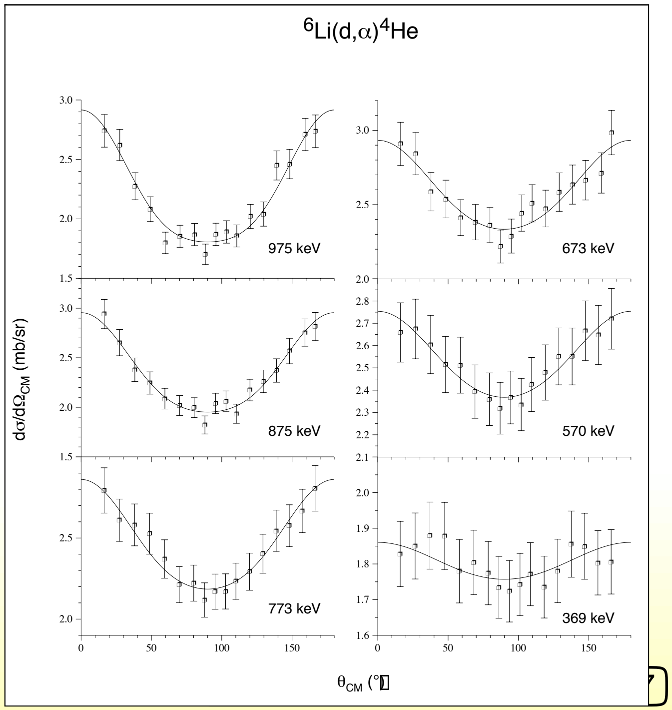
Triumf Summer Institute
July 16, 2007

A typical nuclear physics experiment









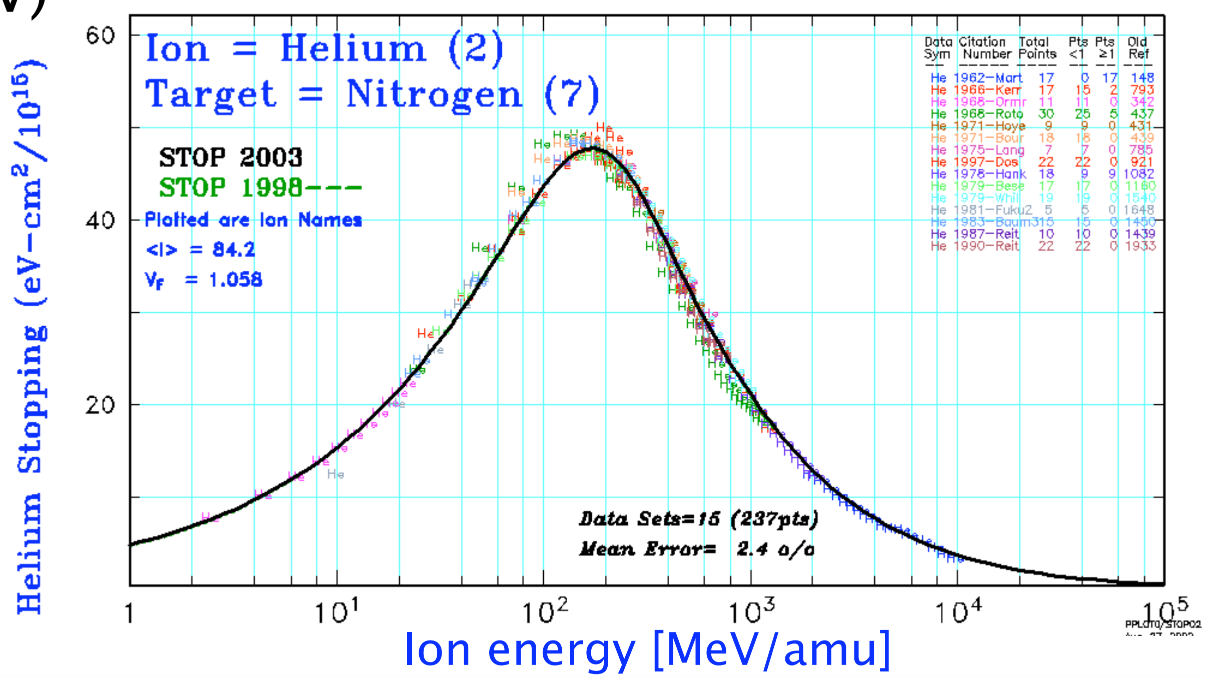
Why no ionization chambers?

Bethe-Bloch formula $-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2\beta^2}{I\cdot(1-\beta^2)}\right) - \beta^2\right]$

$\approx m\, z^2/E$
m = projectile mass
z = projectile charge number
E = projectile energy

- High charge
- High mass
- “Low” energy (MeV)

--> Low range

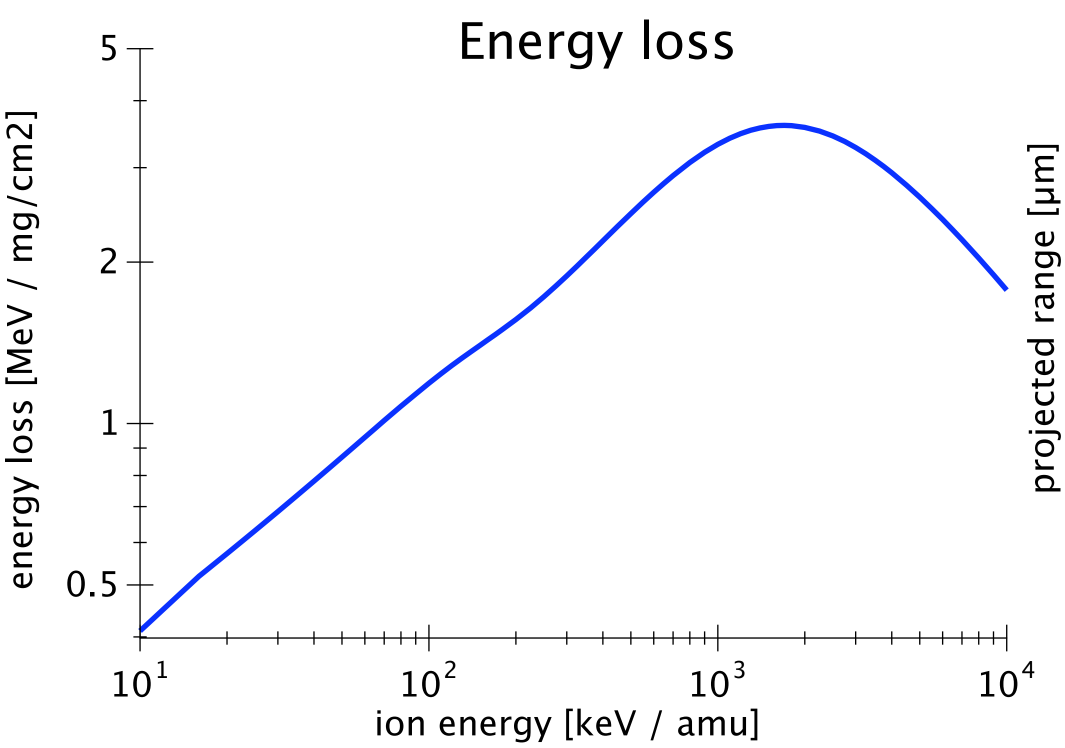


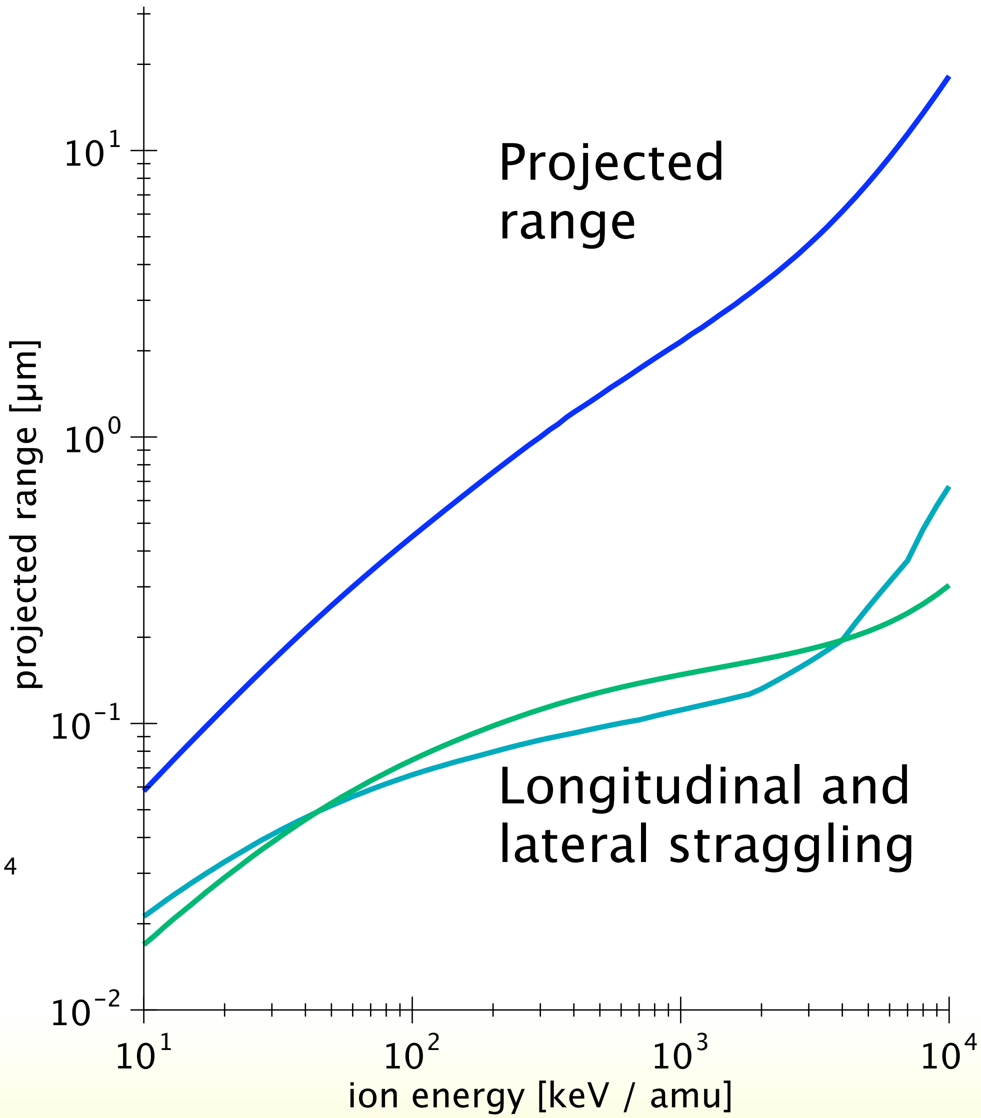
High energy resolution required (< 1%)
Particle identification often not needed

--> Solid state detectors are favoured

SRIM example

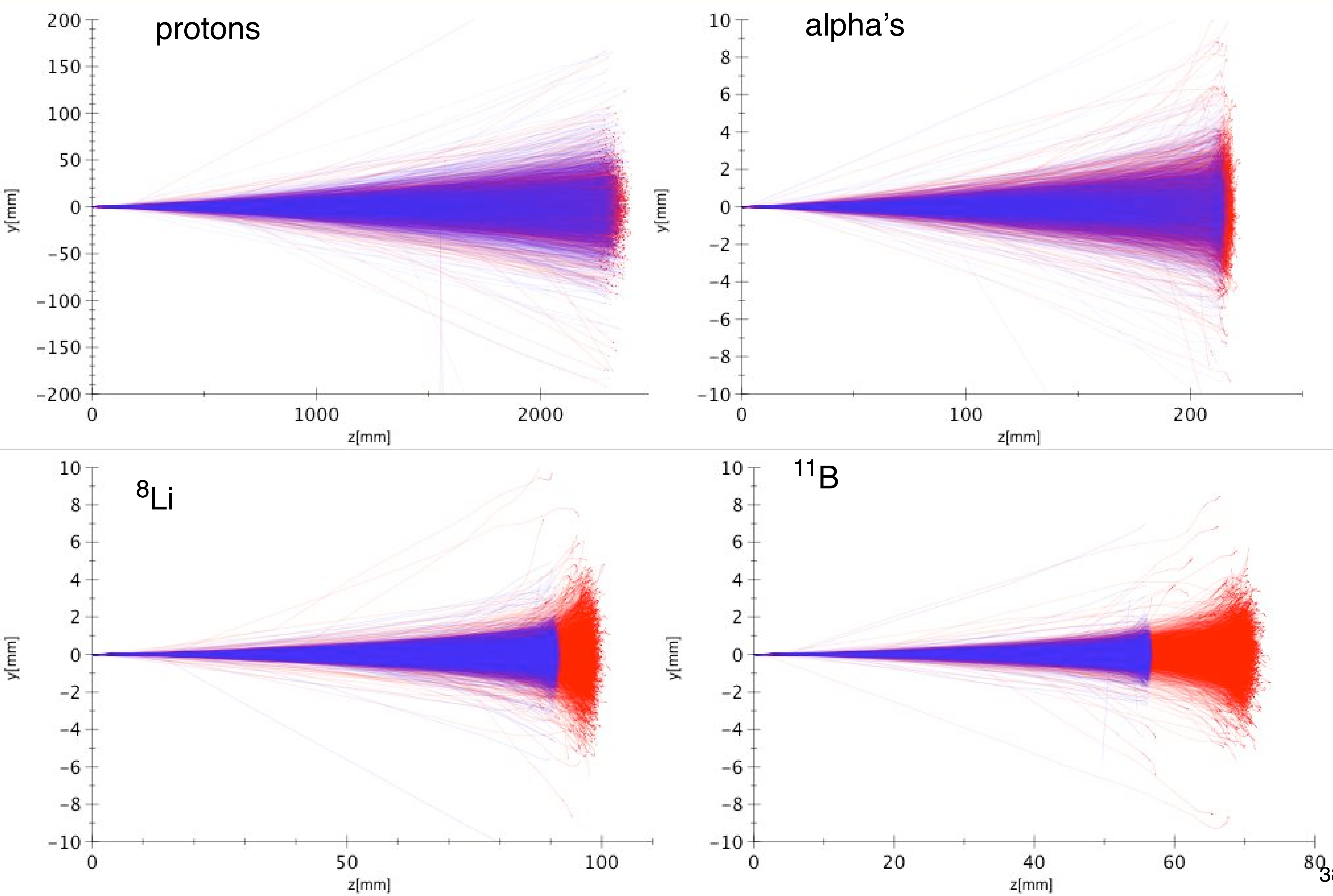
Lithium ions in carbon





The GEANT4 stopping power problem

Energy: 5.5 MeV, Target: Helium @ STP, red = SRIM, blue = GEANT4



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Motivation

Astrophysical motivation

Kinematic factor

Astrophysical S factor

$$\sigma(E) = \frac{1}{E} S(E) \mathrm{e}^{-\sqrt{\frac{E_G}{E}}}$$

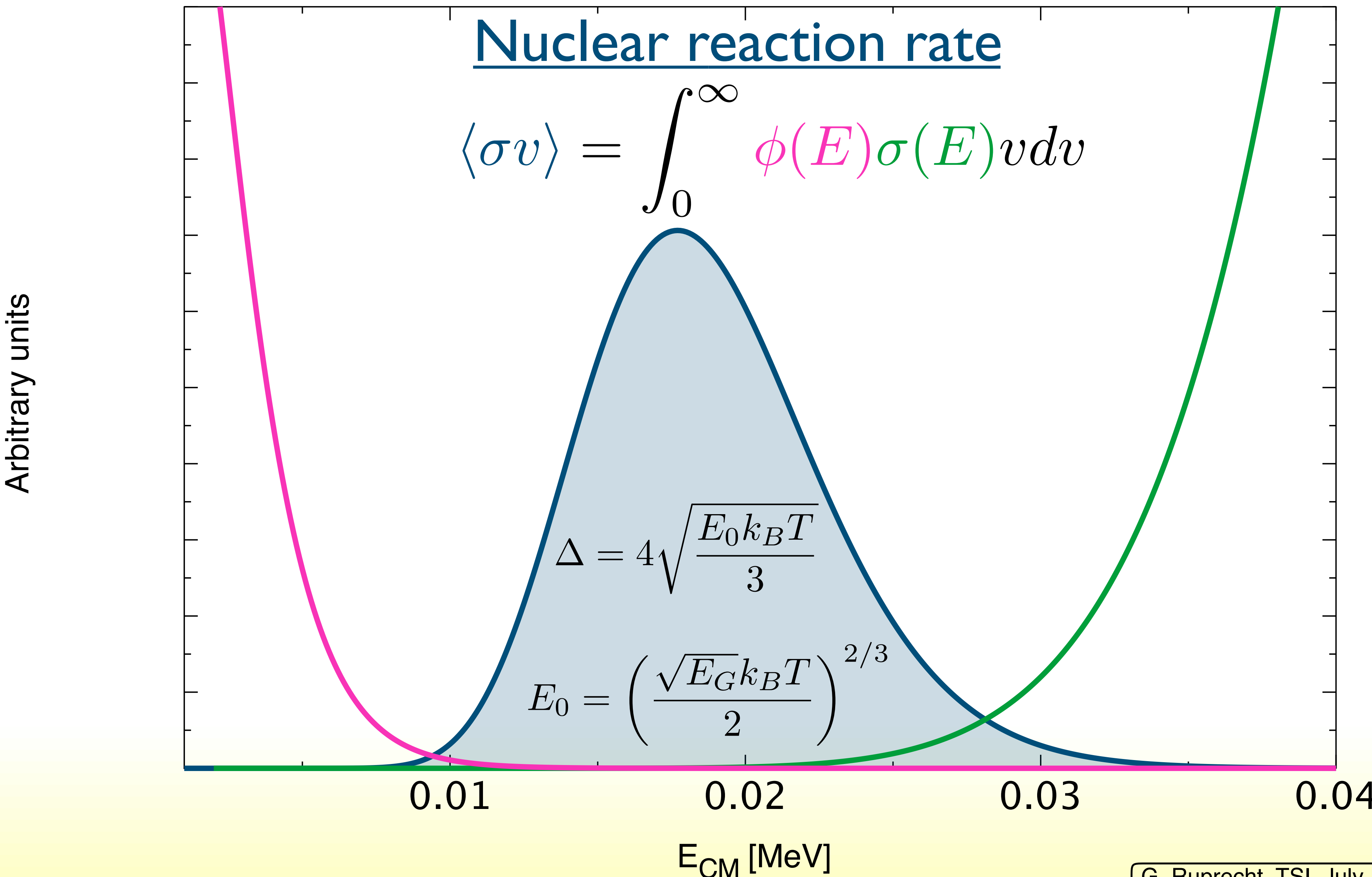
S wave penetration

The Gamow peak

T = $15 \cdot 10^6$ K (Sun)

$$\phi(E) \sim E\mathrm{e}^{-\frac{E}{kT}}$$

$$\sigma(E) \sim \frac{1}{E}\mathrm{e}^{-\sqrt{\frac{E_G}{E}}}$$



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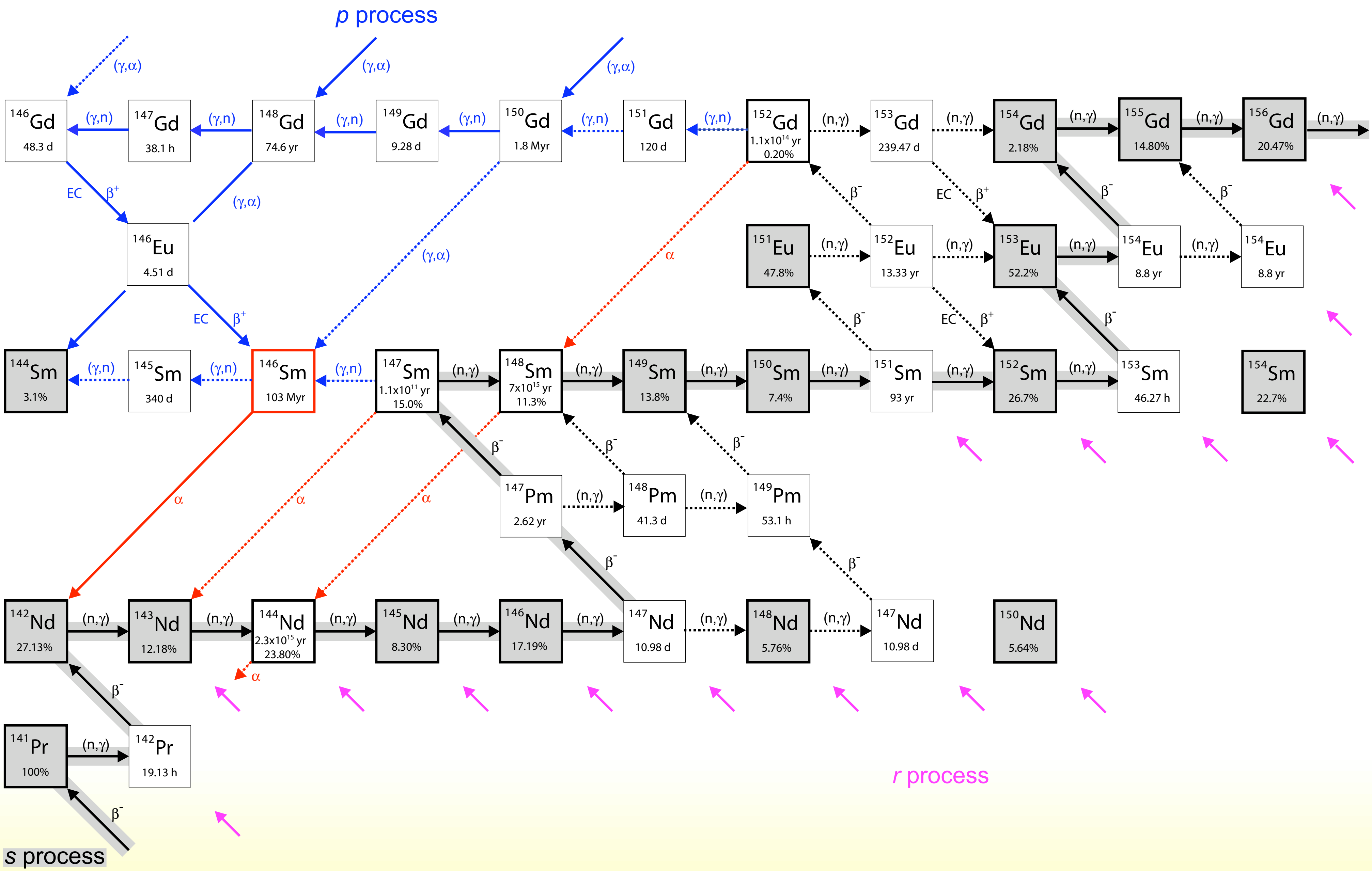
- The Gamow peak is usually far below the Coulomb barrier
- Therefore, cross-sections are very small
- This requires a high beam current

Processes involving radioactive nuclei
– Supernova astrophysics



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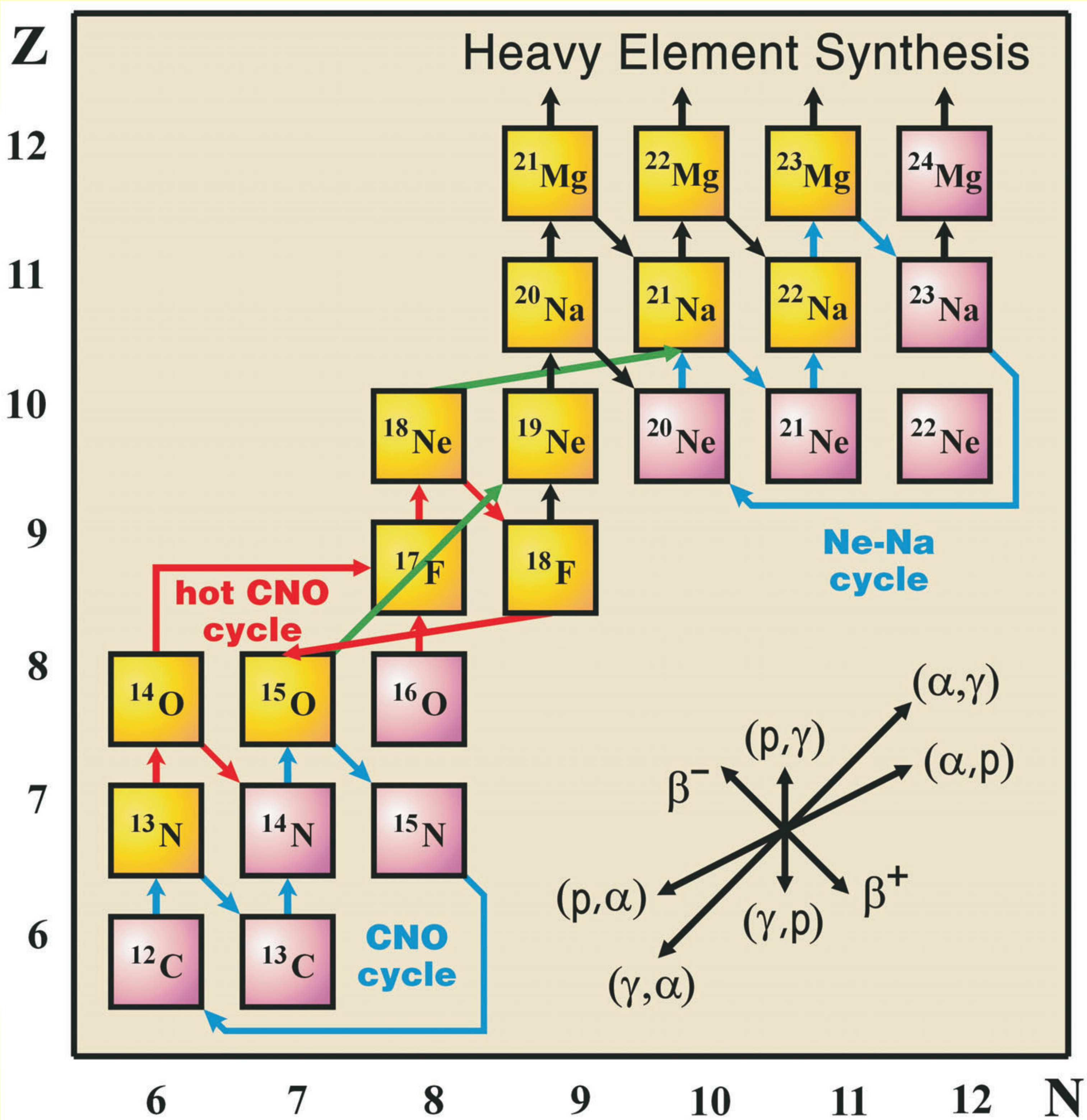

Heavy Element Synthesis
Z
12
11
10
9
8
7
6
N
6
7
8
9
10
11
12
^{21}Mg
^{22}Mg
^{23}Mg
^{24}Mg
^{20}Na
^{21}Na
^{22}Na
^{23}Na
^{18}Ne
^{19}Ne
^{20}Ne
^{21}Ne
^{22}Ne
^{17}F
^{18}F
^{14}O
^{15}O
^{16}O
^{13}N
^{14}N
^{15}N
^{12}C
^{13}C
hot CNO cycle
CNO cycle
Ne-Na cycle
(α,γ)
(p,γ)
(α,p)
β^-
β^+
(p,α)
(γ,p)
(γ,α)

Some typical reaction involving radioactive nuclei

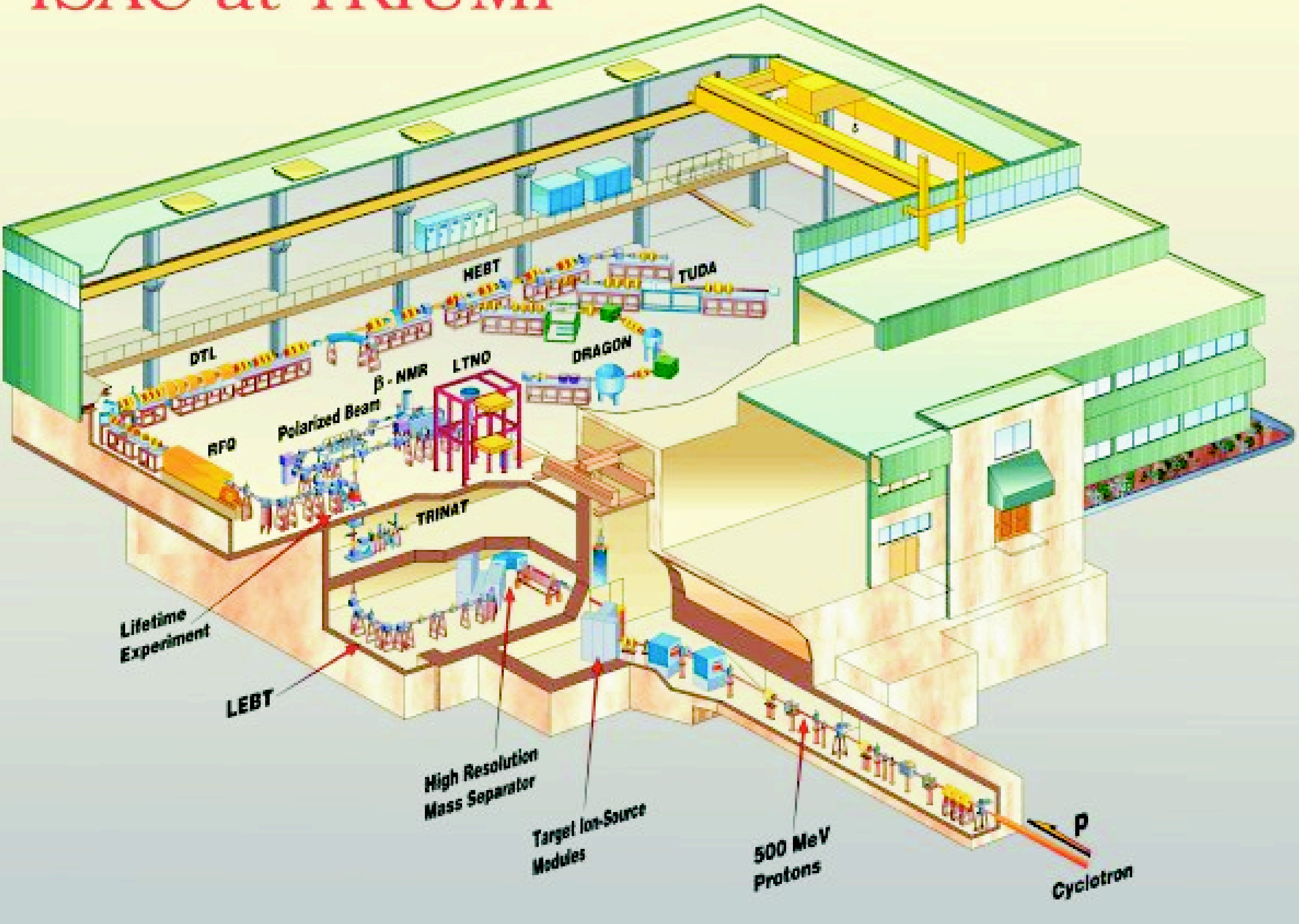
$^{18}Ne(a,p)^{21}Na$ (HCNO breakout)	$t_{1/2} = 1.7$ s
$^{8}Li(a,n)^{11}B$ (r-process)	$t_{1/2} = 0.84$ s
$^{11}Li(p,t)^{9}Li$ (halo nucleus study)	$t_{1/2} = 8.5$ ms

- Targets with half-lifes of less than a few second are very difficult or impossible to produce

- Therefore, the target has to be the projectile and must be produced on-line

--> ISOL concept (Isotope separation on-line)

ISAC at TRIUMF



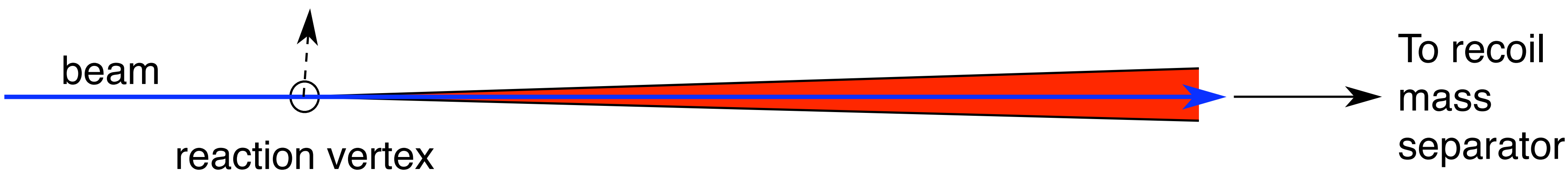
- As RIBs are secondary beams, the intensities are usually very low

- So we have low cross-sections **and** low beam currents

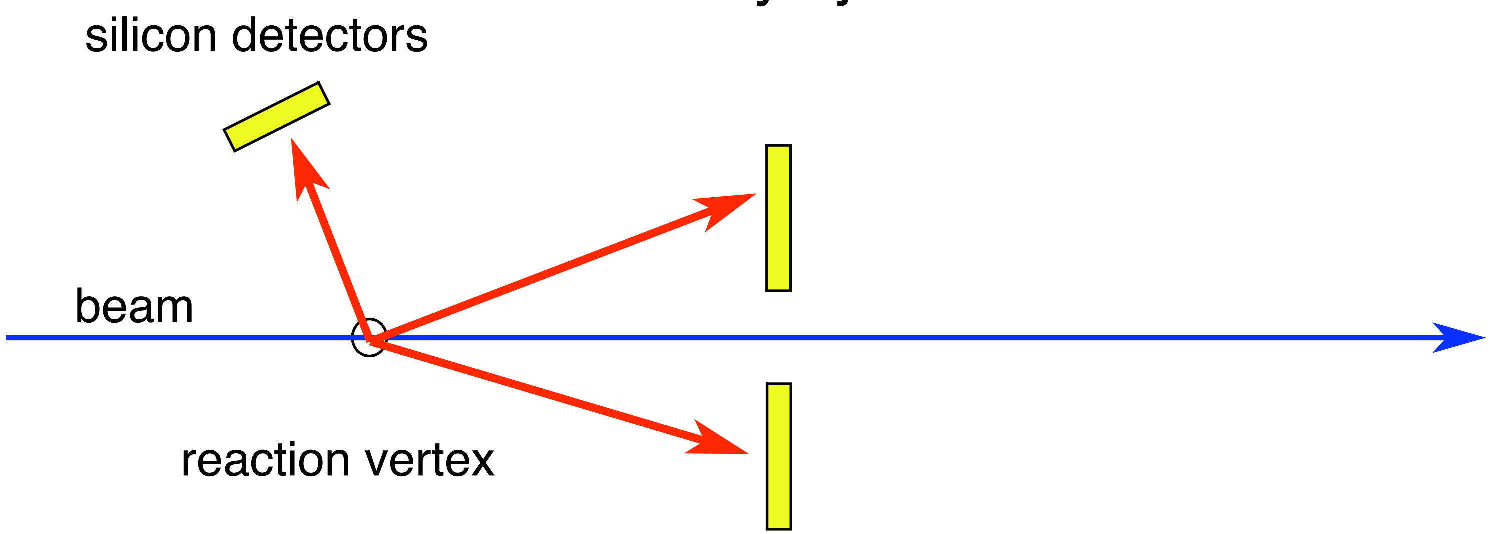
- This opens again the possibility of using an ionization chamber as target and detector

Heavy Ion detectors

One light ejectile (usually γ): DRAGON



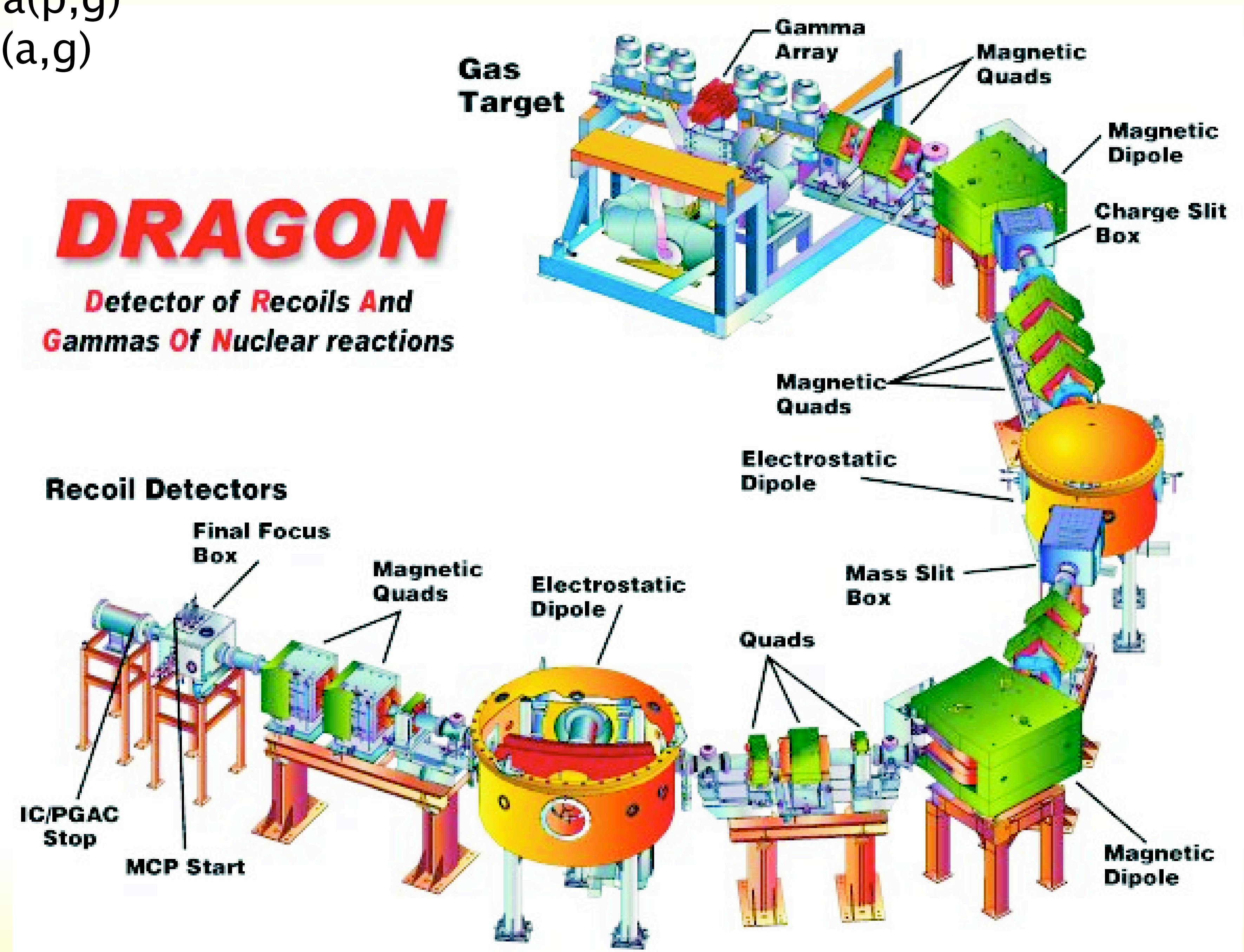
Two heavy ejectiles: TUDA



Problems

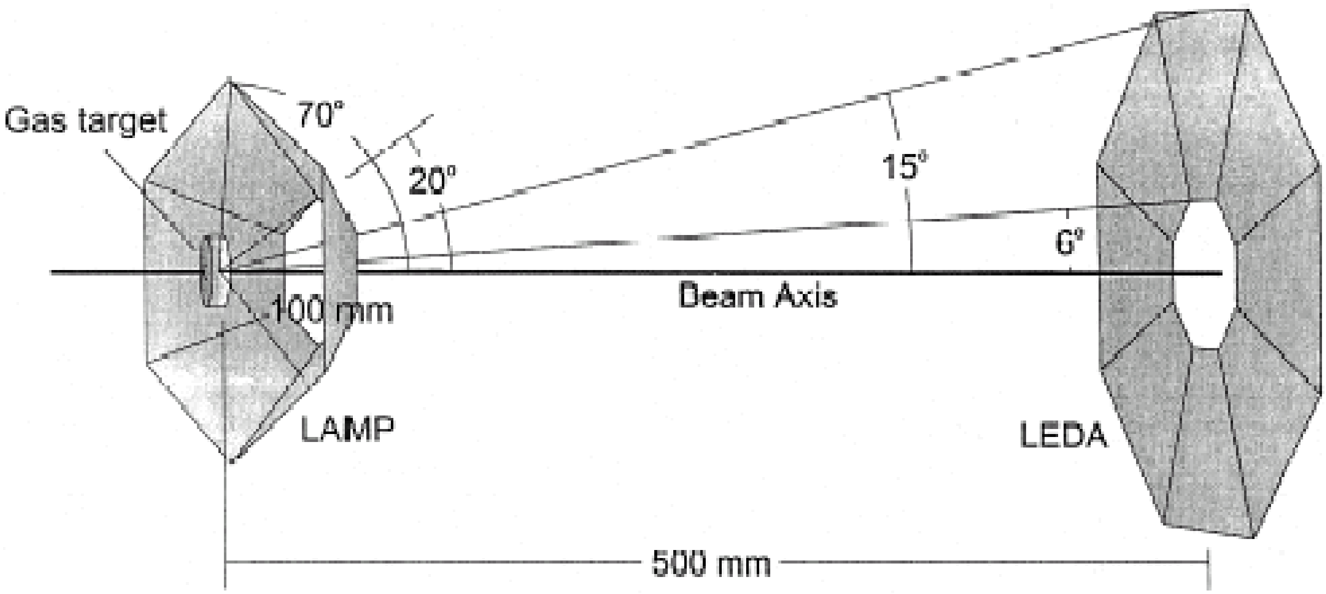
- Only a small solid angle is covered by detectors
- One detector for each angle
- Only poor information about charge in energy sensitive detectors

Examples for radiative capture:
21Na(p,g)
12C(a,g)



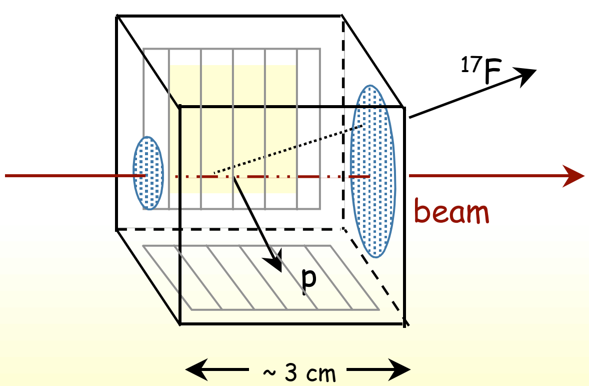
Nuclear reactions with both ejectiles nuclei

Example: 14O(a,p)17F

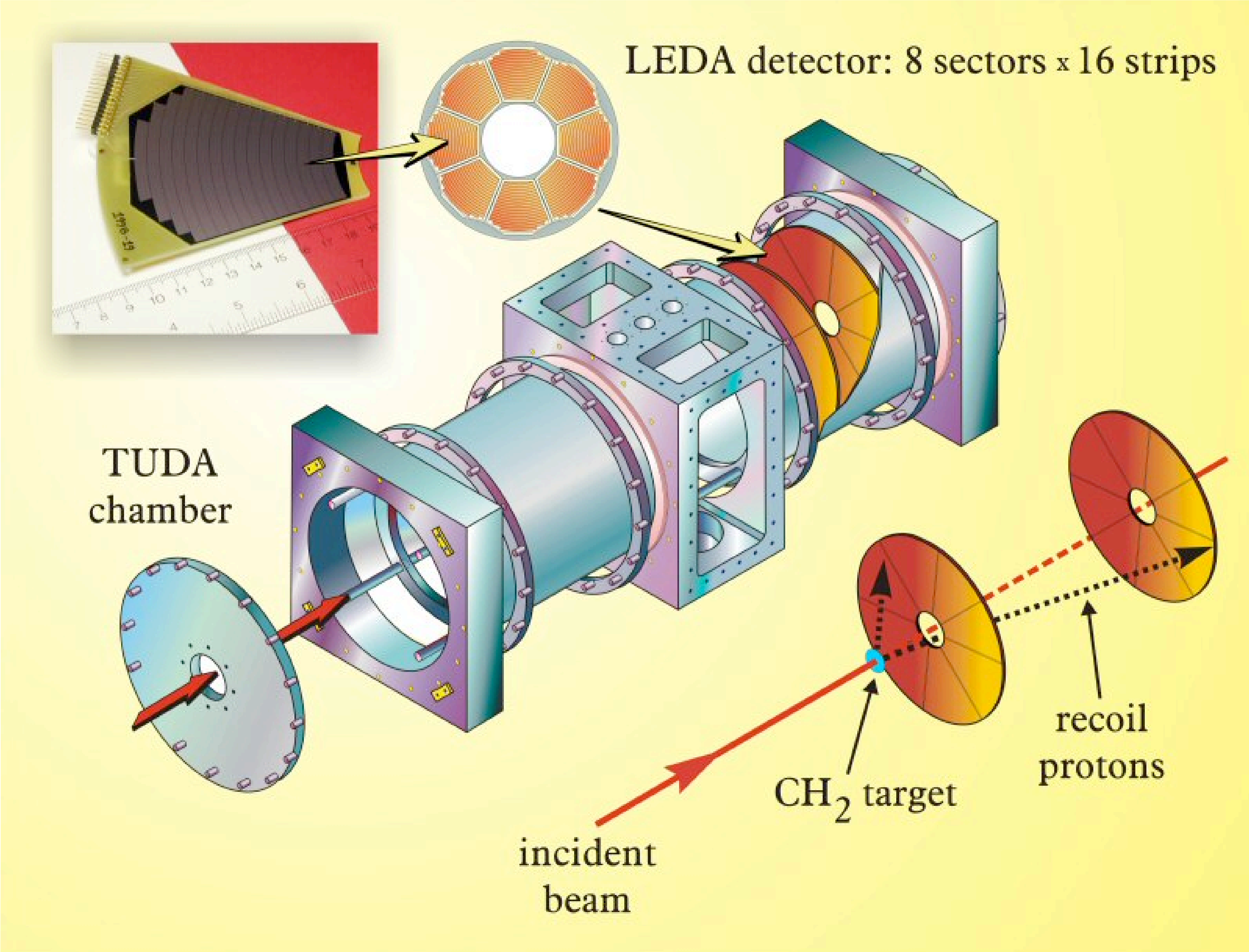


two LEDA silicon detector arrays ➔ heavy-ion detection

^4He gas target
P ~ 100 – 200 mbar



silicon strip detectors ➔ angle-integrated proton yield

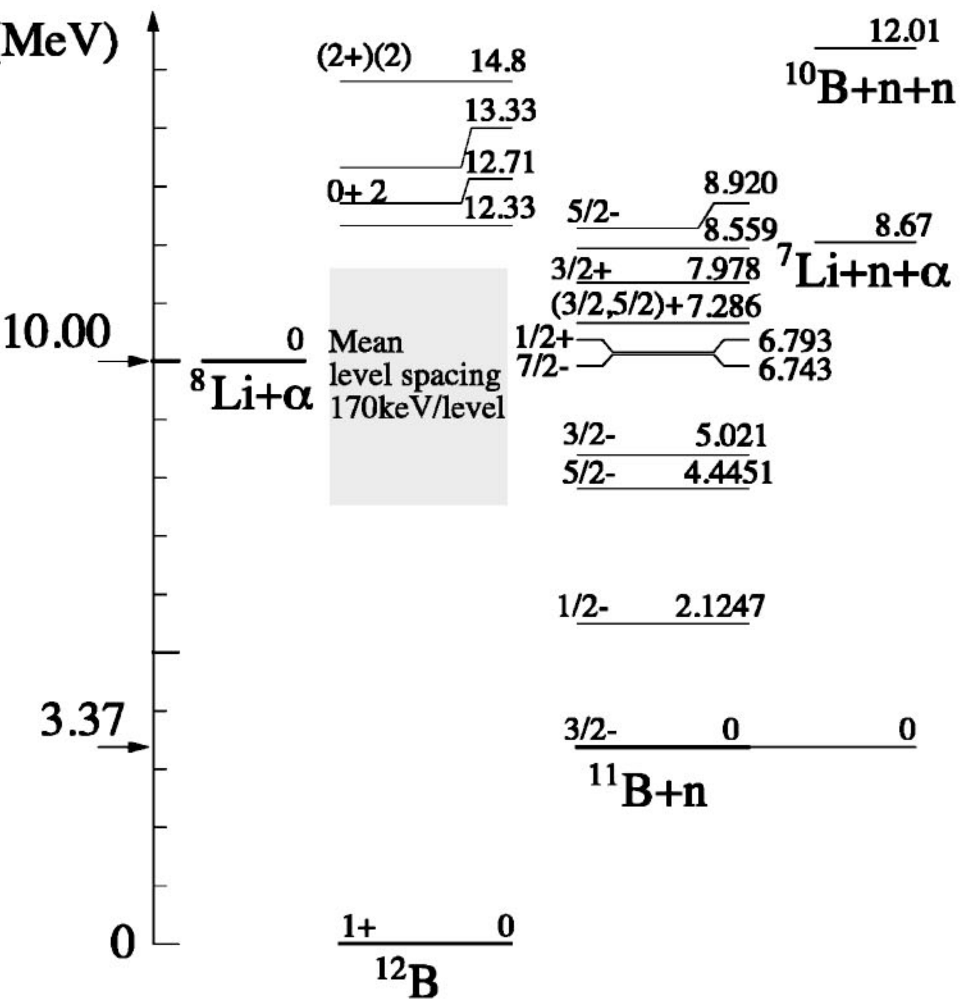

LEDA detector: 8 sectors x 16 strips
TUDA
chamber
incident
beam
CH2 target
recoil
protons

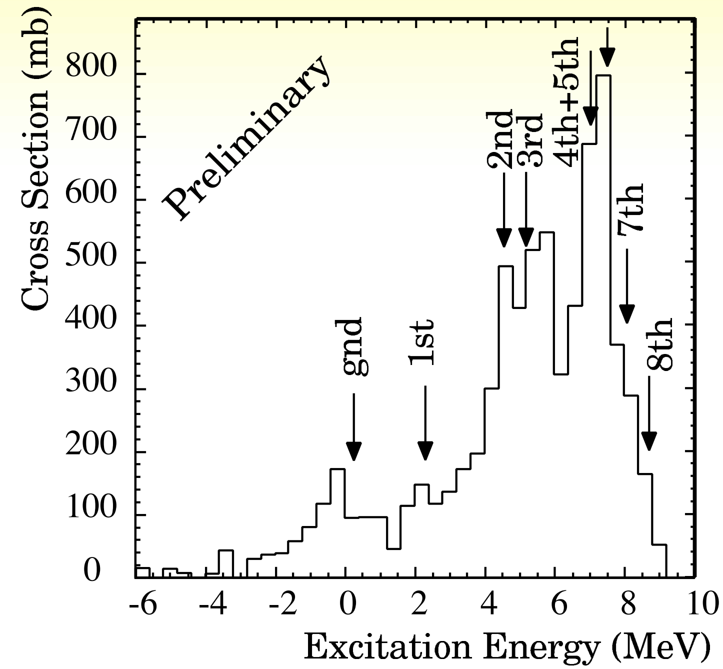
$^{8}Li(a,n)^{11}B$ measurement

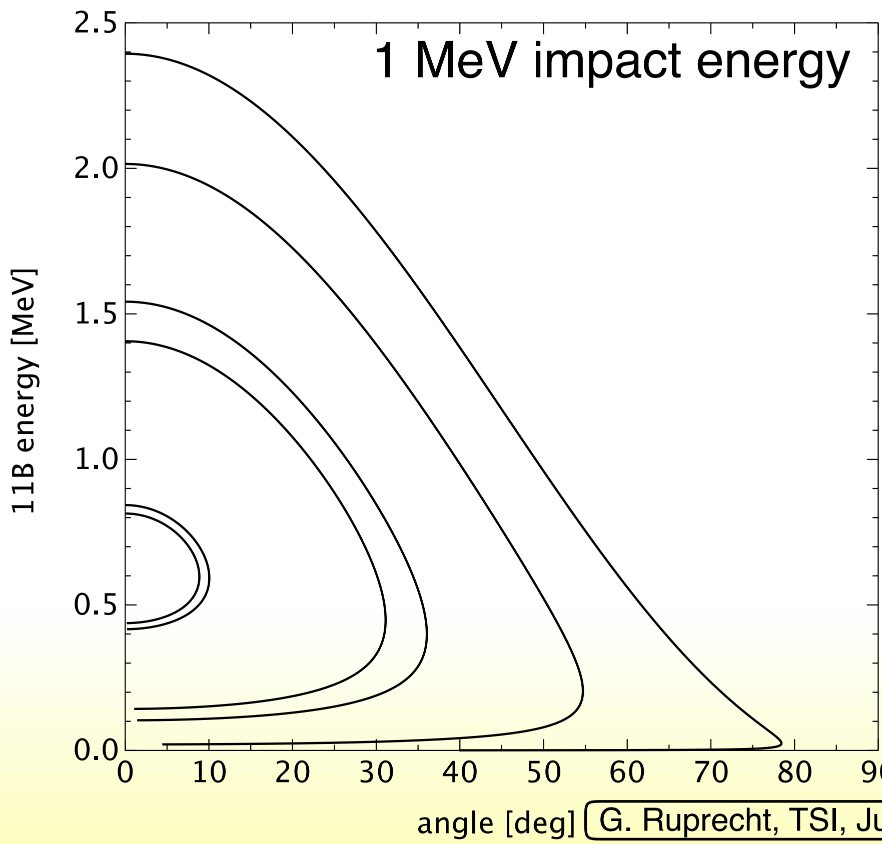
$T_9 = 0.62$

→ Gamow peak: $E_{c.m.}$ = 240 to 580 A keV

($E_{lab,\ 8Li}$ = 90 to 220 A keV)







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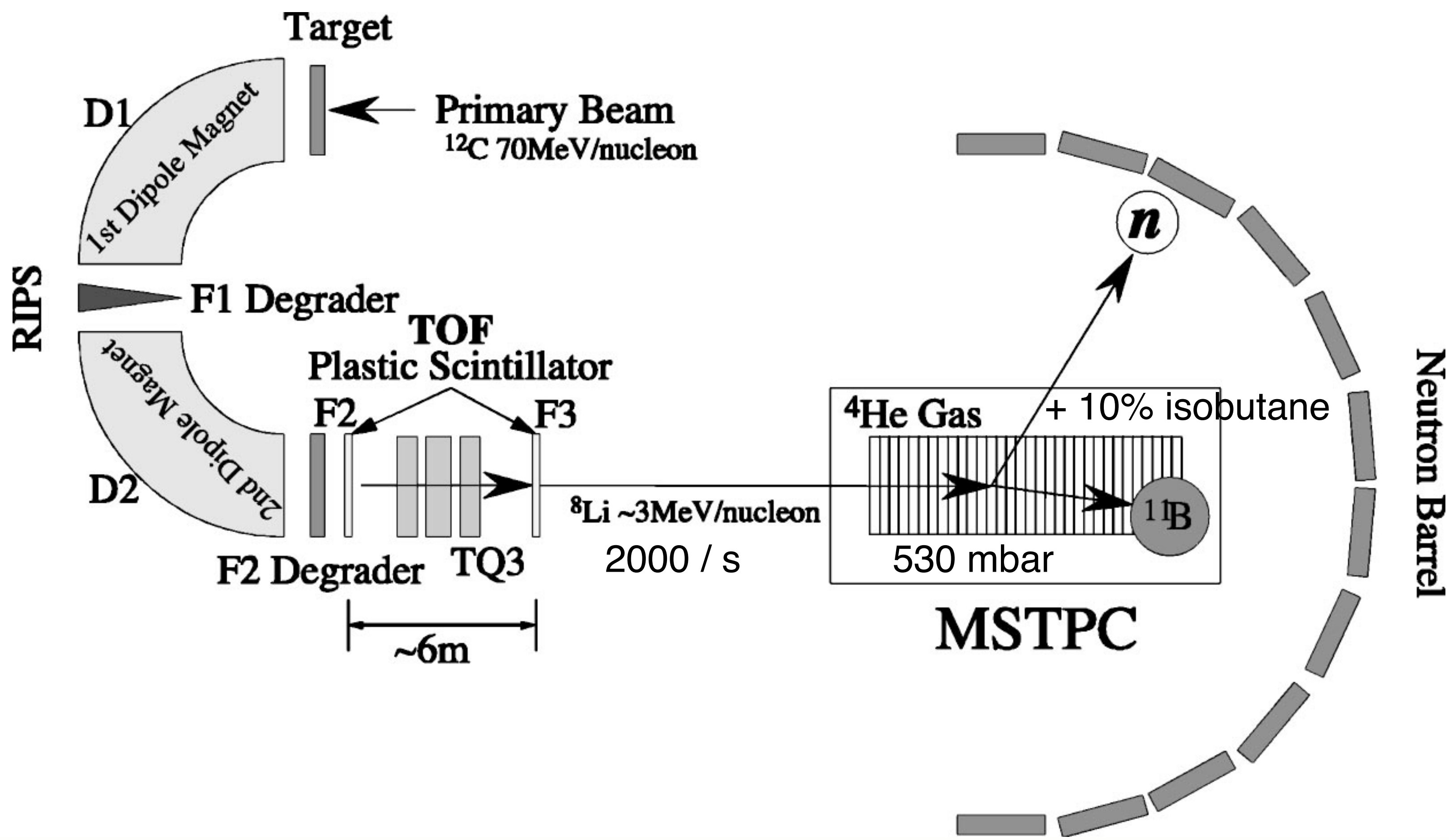
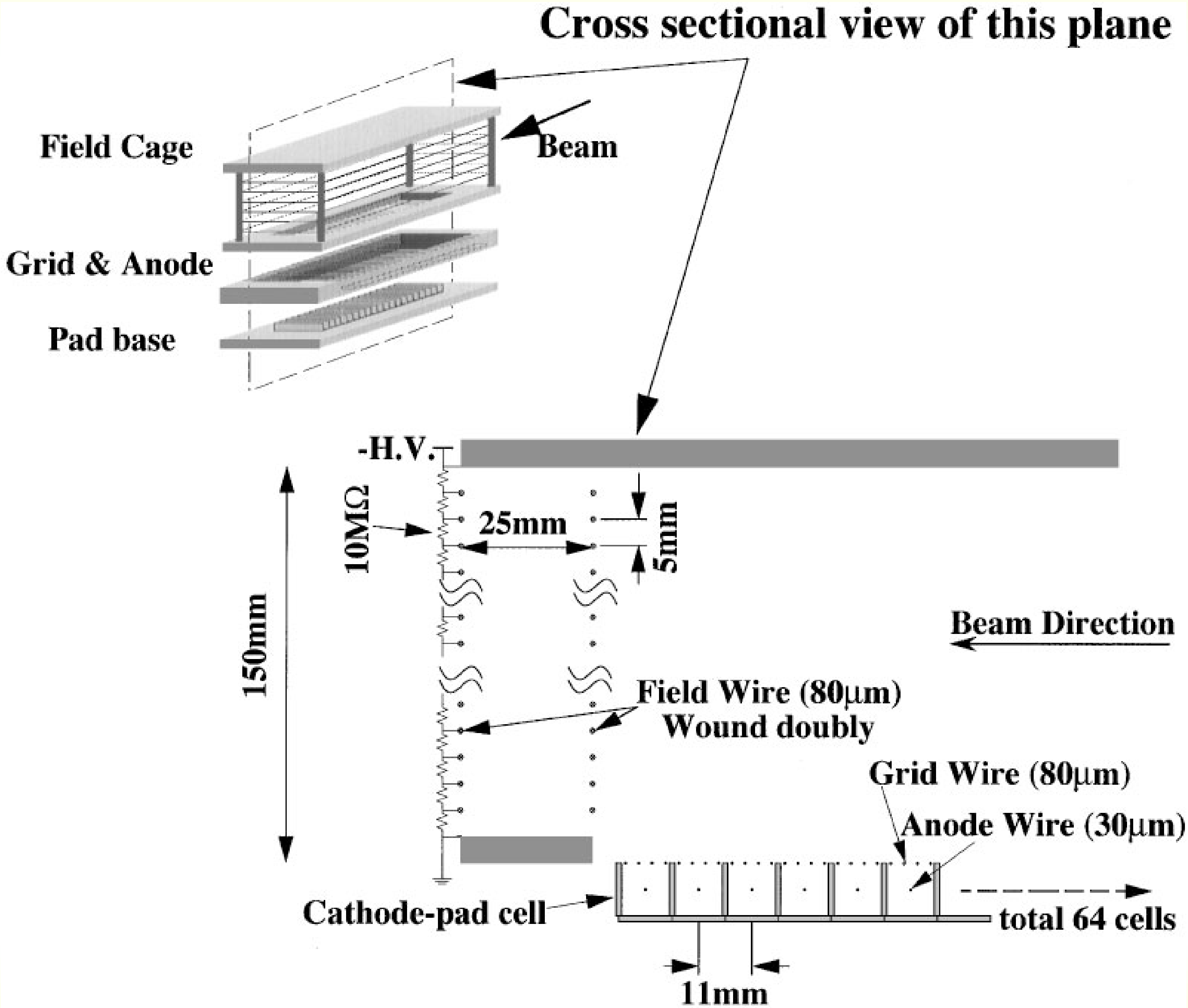
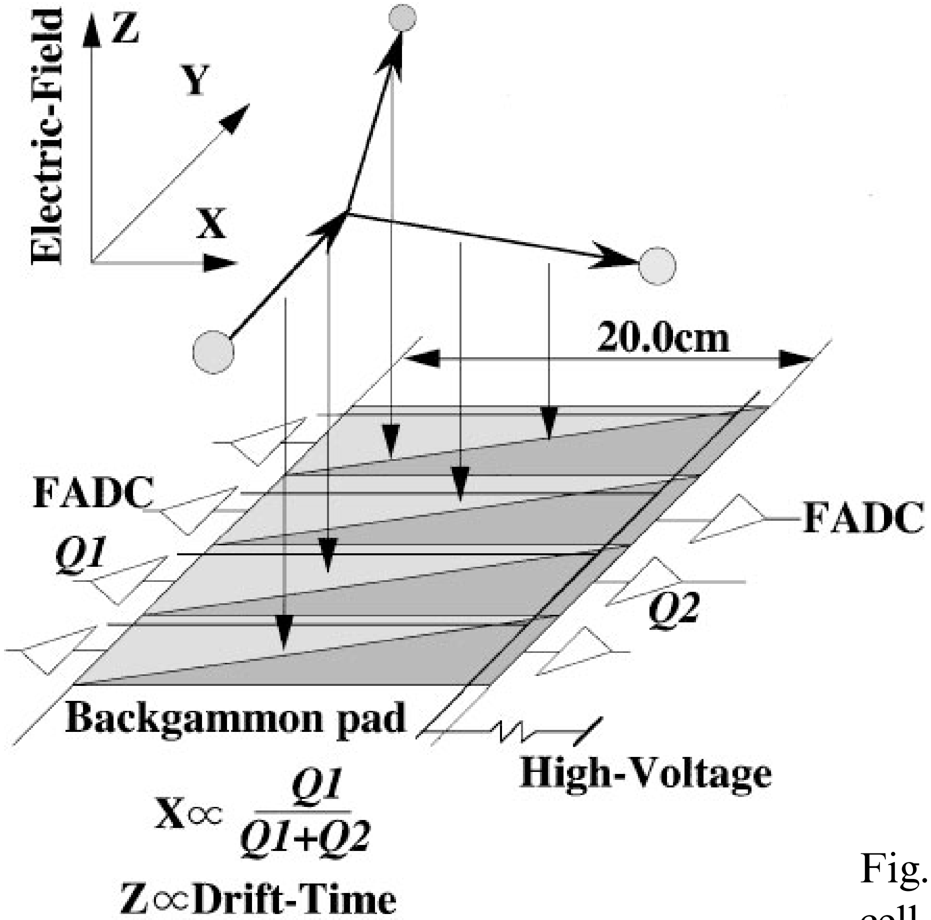
$^{8}Li(a,n)^{11}B$ measurement

Mizoi et al., Phys. Rev. C **62**, 065801 (2000)




Cross sectional view of this plane
Field Cage
Beam
Grid & Anode
Pad base
-H.V.
10MΩ
25mm
5mm
150mm
Beam Direction
Field Wire (80μm)
Wound doubly
Grid Wire (80μm)
Anode Wire (30μm)
Cathode-pad cell
total 64 cells
11mm



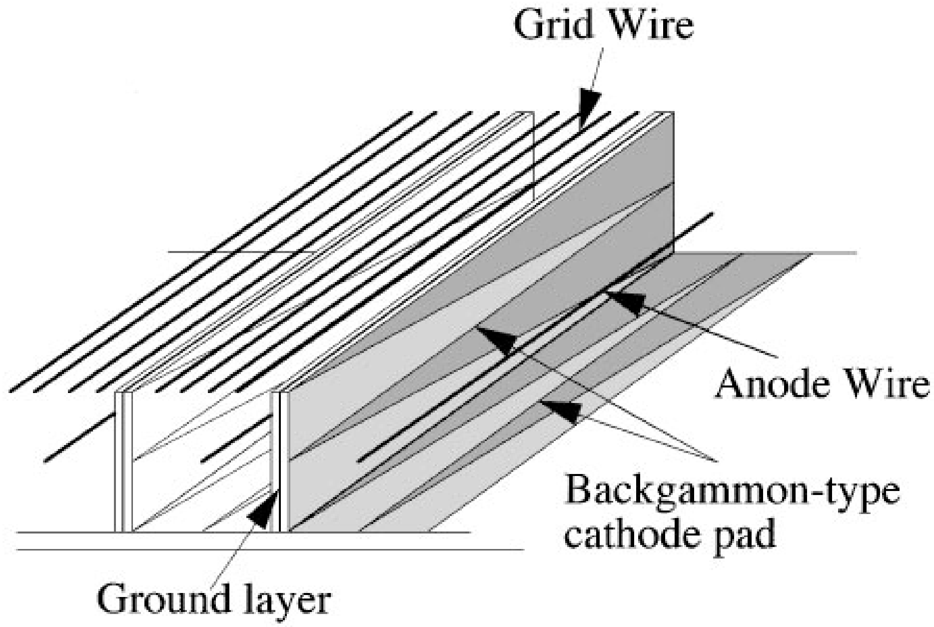
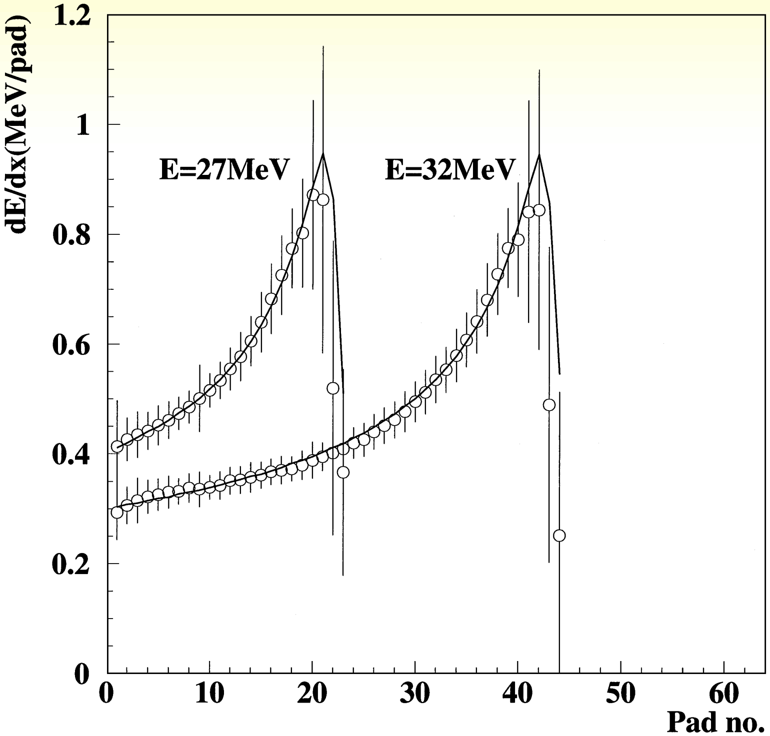
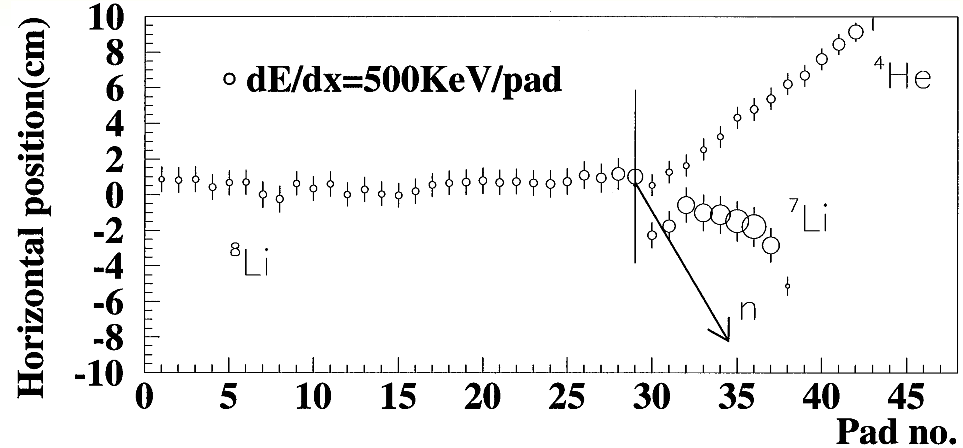
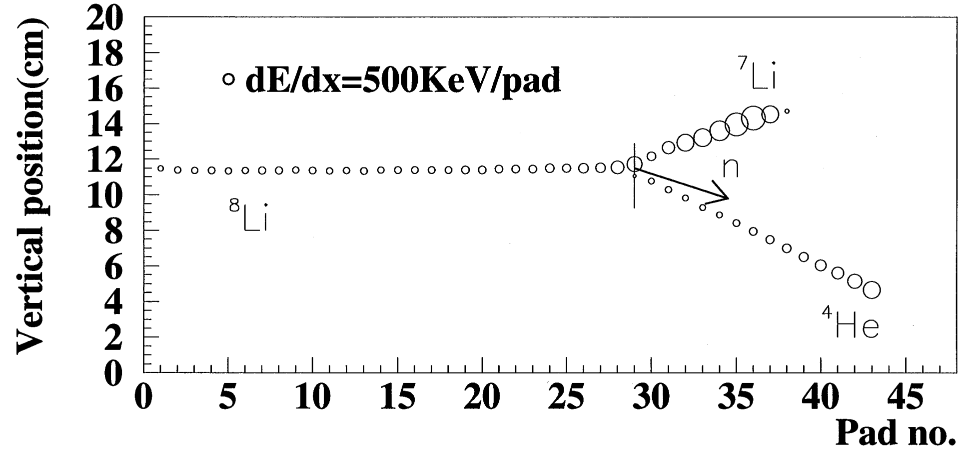
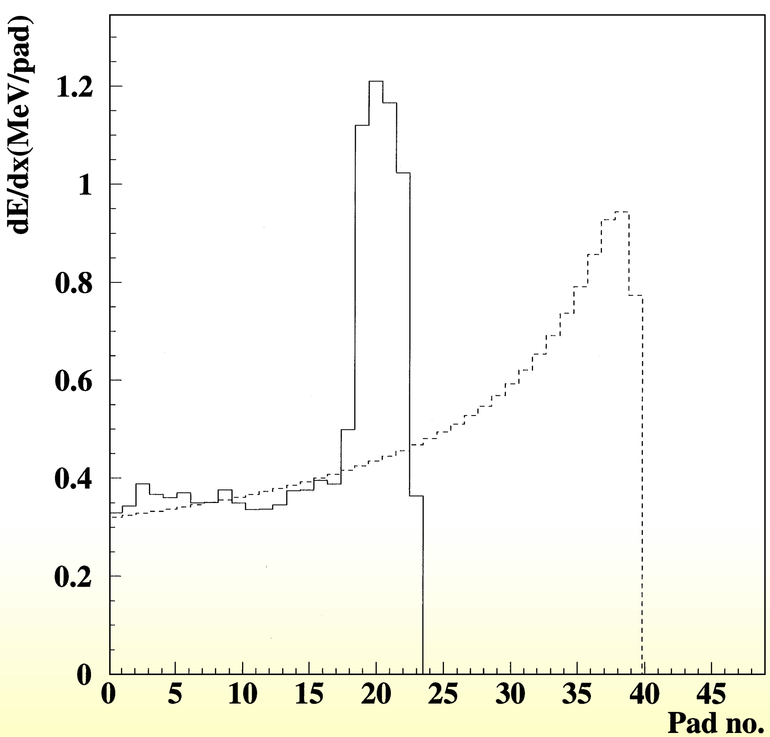


Fig. 4. Schematic view of the backgammon-type cathode-pad cell. The cathode-pads surround the anode wire. The ground layer is put between the cathode-pad layers to prevent cross talk.


dE/dx(MeV/pad)
E=27MeV
E=32MeV
Pad no.


Horizontal position(cm)
dE/dx=500KeV/pad
^{4}He
^{7}Li
^{8}Li
n
Pad no.


Vertical position(cm)
dE/dx=500KeV/pad
^{7}Li
n
^{8}Li
^{4}He
Pad no.


dE/dx(MeV/pad)
Pad no.

ISAC II Experiments

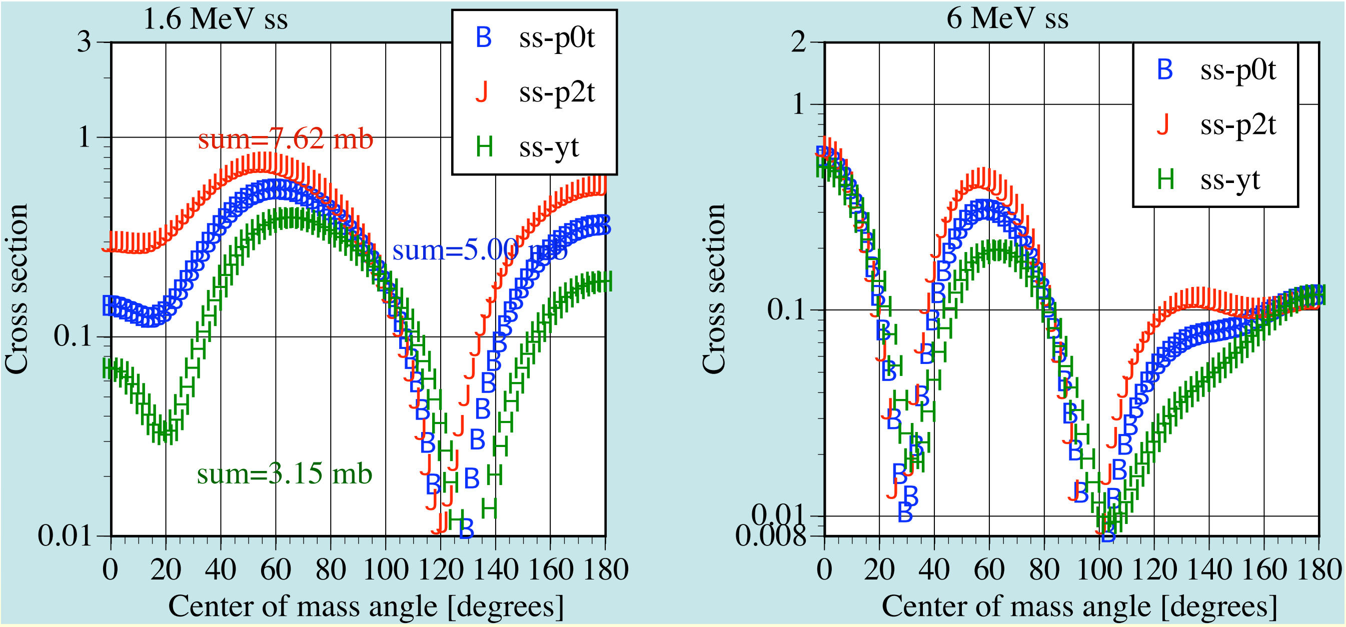
E1055: two neutron correlations

p(^{11}Li, ^{9}Li) t at 39.6 MeV

E1078: study of ^{10}Li (an unbound subsystem of ^{11}Li)

p(^{11}Li, d)^{10}Li at 55 MeV

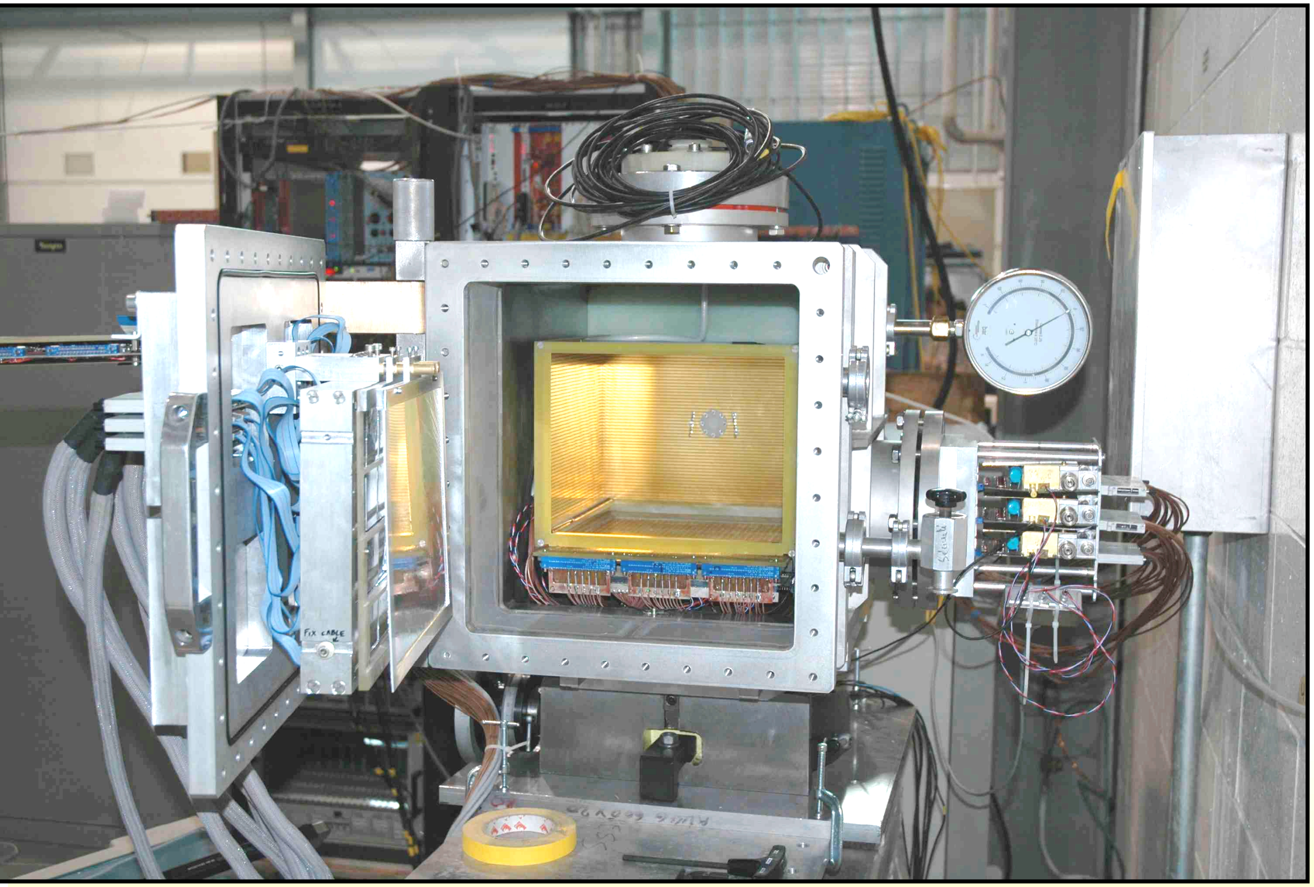
Sensitivity of the (p,t) reaction to the neutron correlations

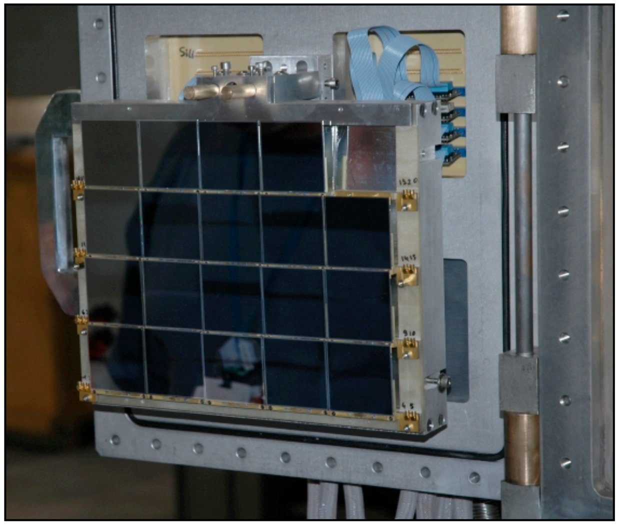


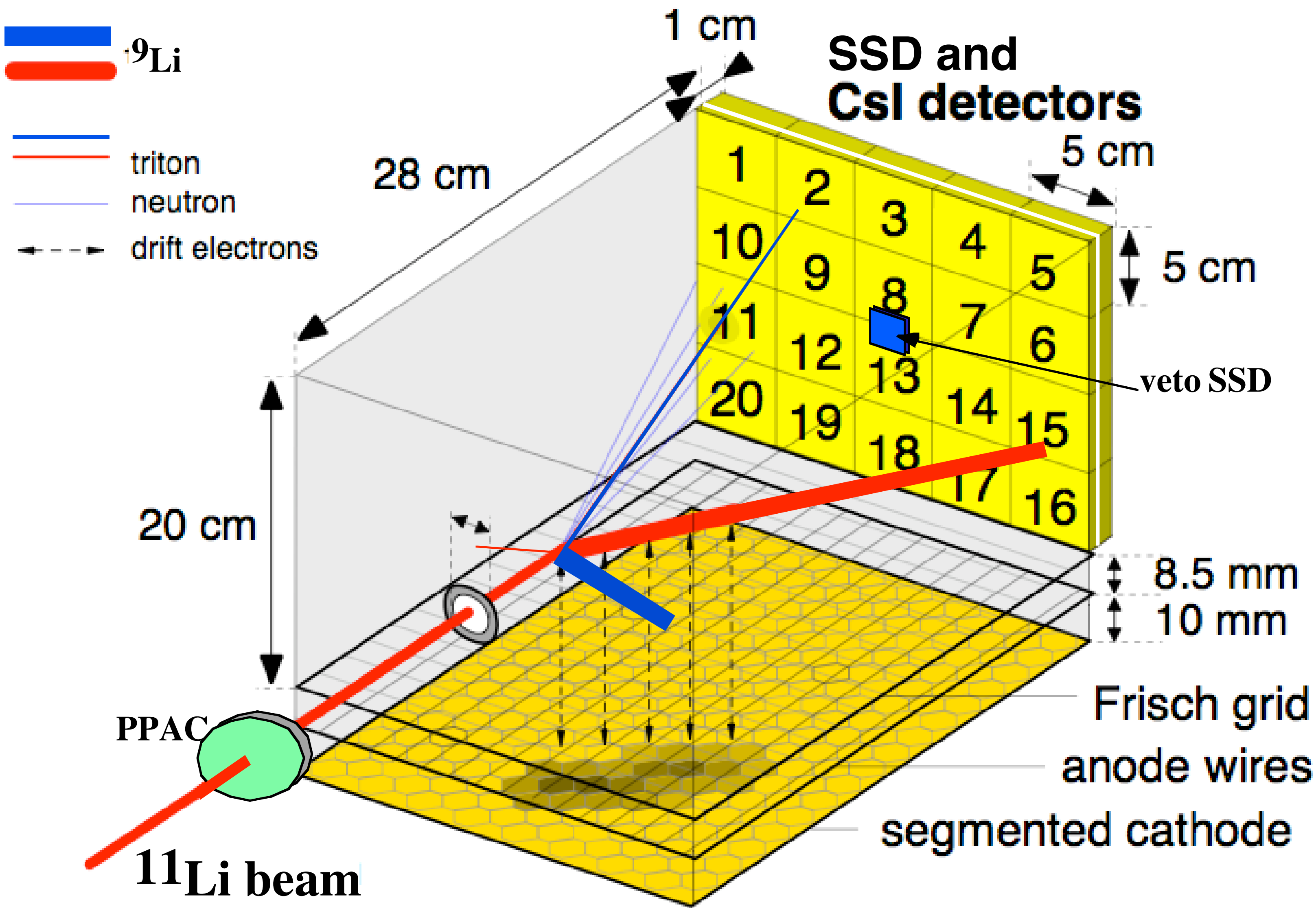
Active Target MAYA

- Because of ^{11}Li is so precious, a detection system that can detect all particle in any direction is necessary.
- Inverse kinematics requires a detection of very low energy particles thus limits the thickness of the target.
- MAYA is an active target in which the target gas works also as detector.

- This detector is developed at GANIL and shipped for the experiments from France.







C_4H_{10} @ 0.5 atm

Range (^{11}Li) = 22.3cm

r = 29 mg/cm^2

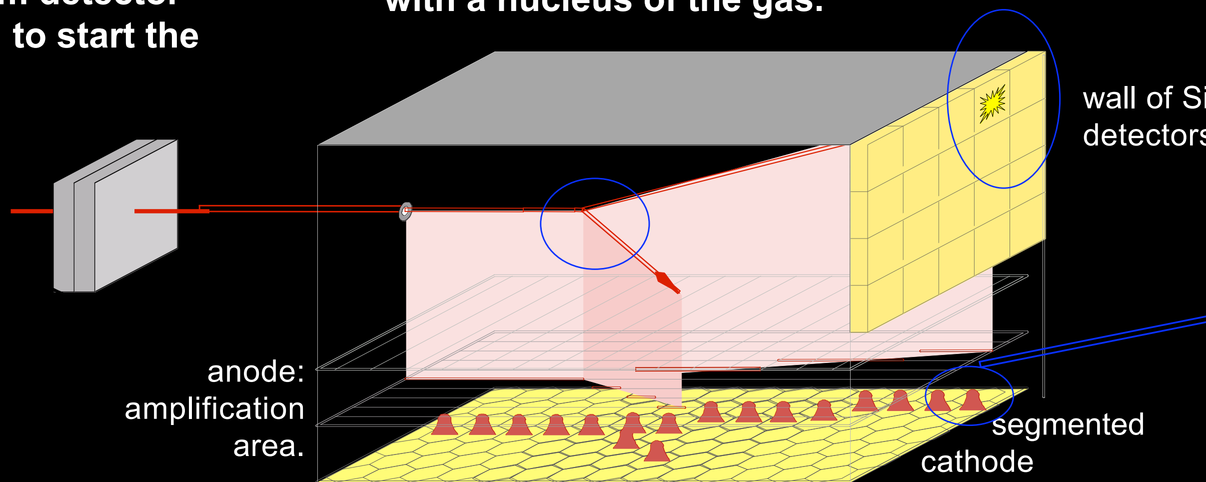
MAYA target-detector

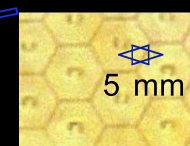
MAYA principle

there is a beam detector before MAYA, to start the DAQ.

the projectile makes reaction with a nucleus of the gas.

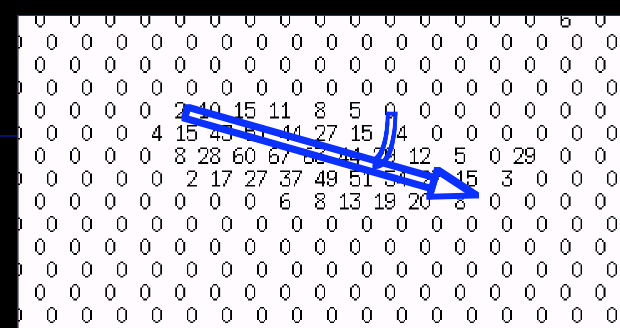
the light scattered particles do not stop inside, and go forward to a wall made of 20 Si detectors, where they are stopped, and identified.



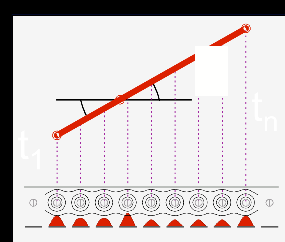


COG over 3 axes

the product leaves enough energy to induce an image of its trajectory in the plane of the segmented cathode.

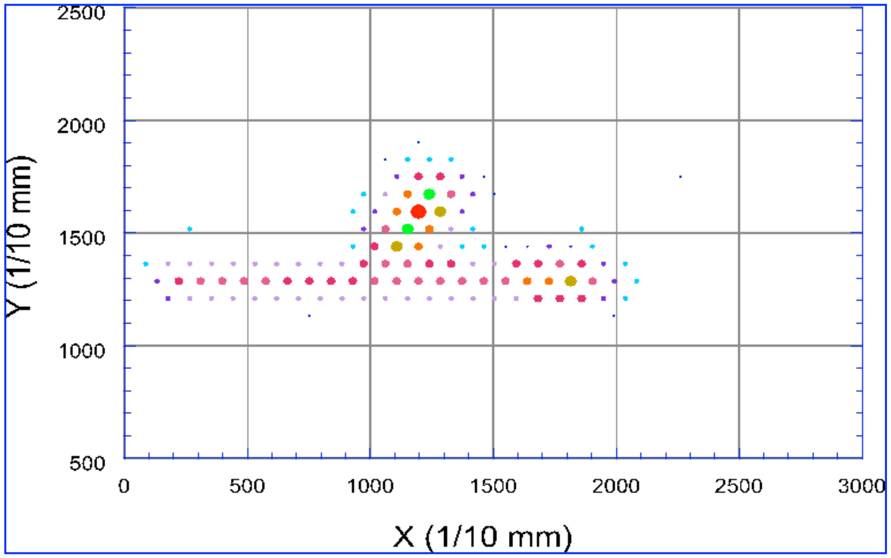


we measure the drift time up to each amplification wire. The angle of the reaction plane is calculated with these times.

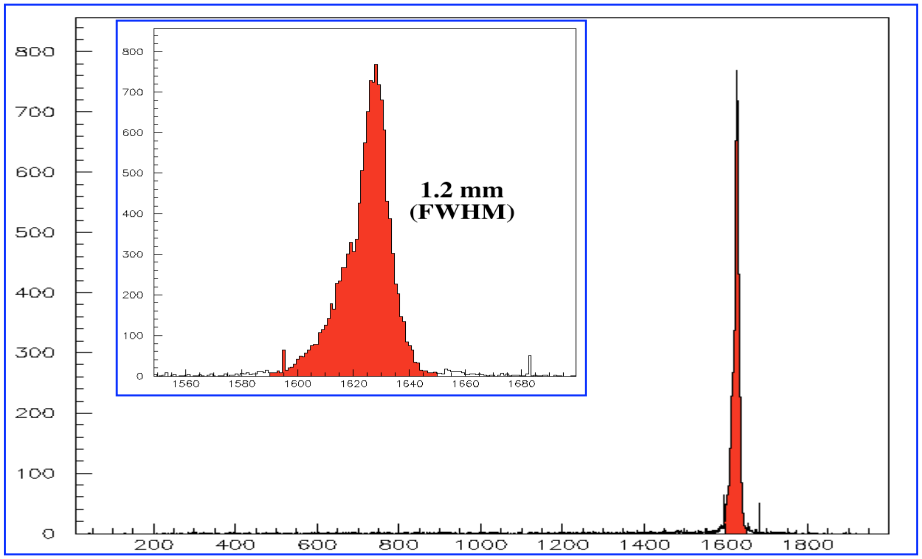


MAYA resolution

Projected trajectories



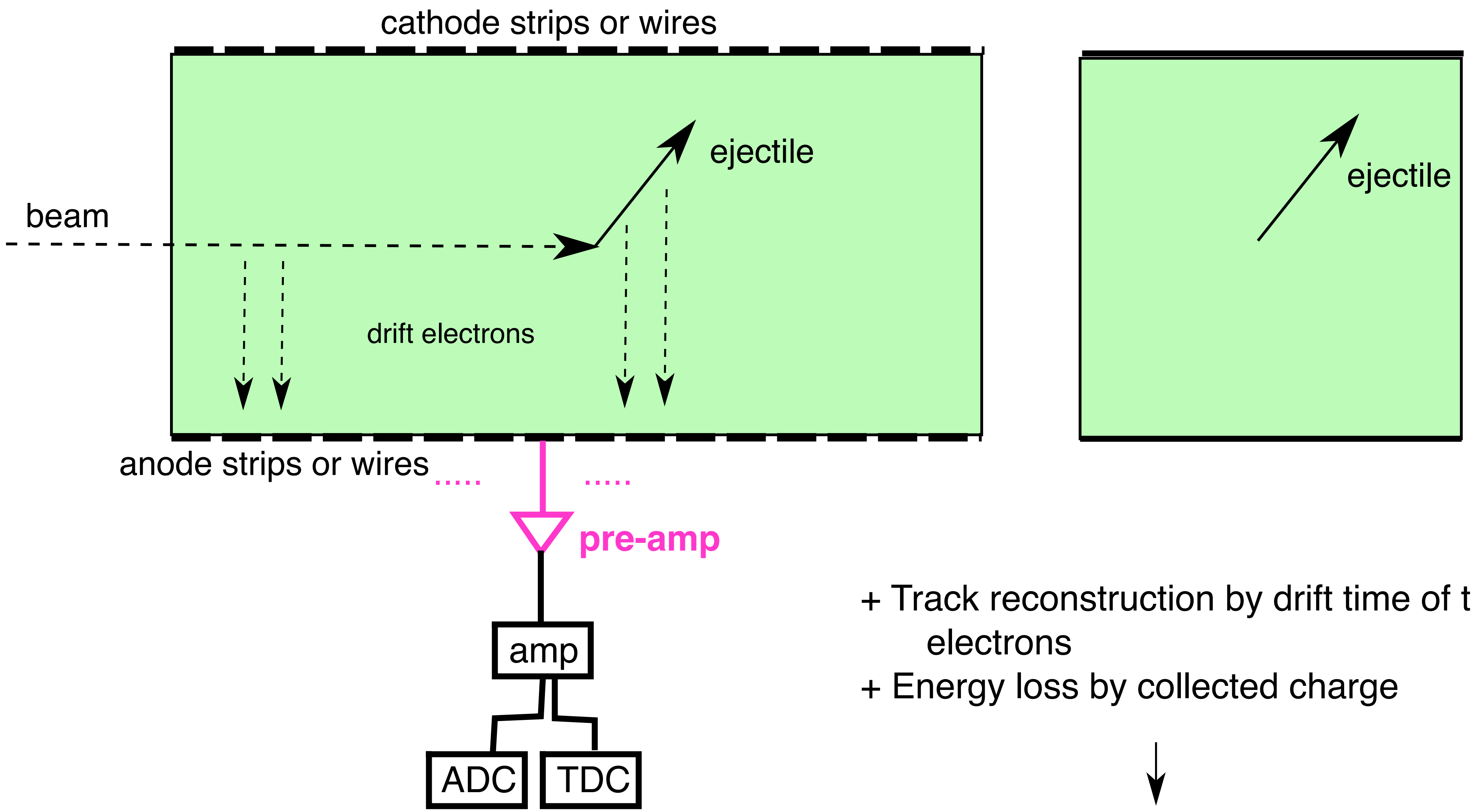
Range measurement



Range resolution ~ 1 %
Angular resolution ~ 0.7 deg
vertex resolution ~ 3 mm

Position resolution ~ 1 mm
Charge resolution ~ 10 %

Schematic and simplified view of a tracking chamber for nuclear reactions



+ Track reconstruction by drift time of the electrons
+ Energy loss by collected charge

↓

Particle identification

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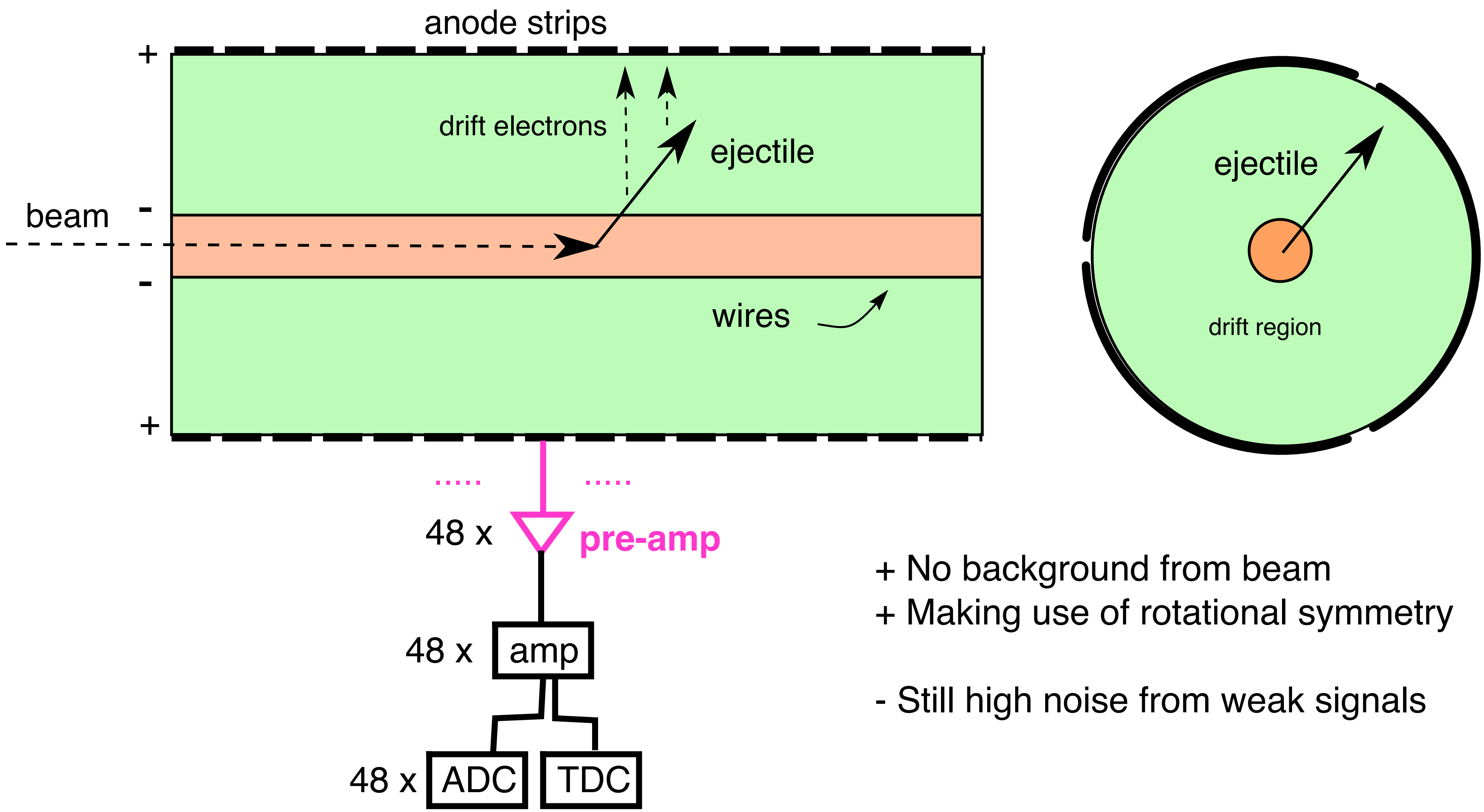
Cylindrical chamber

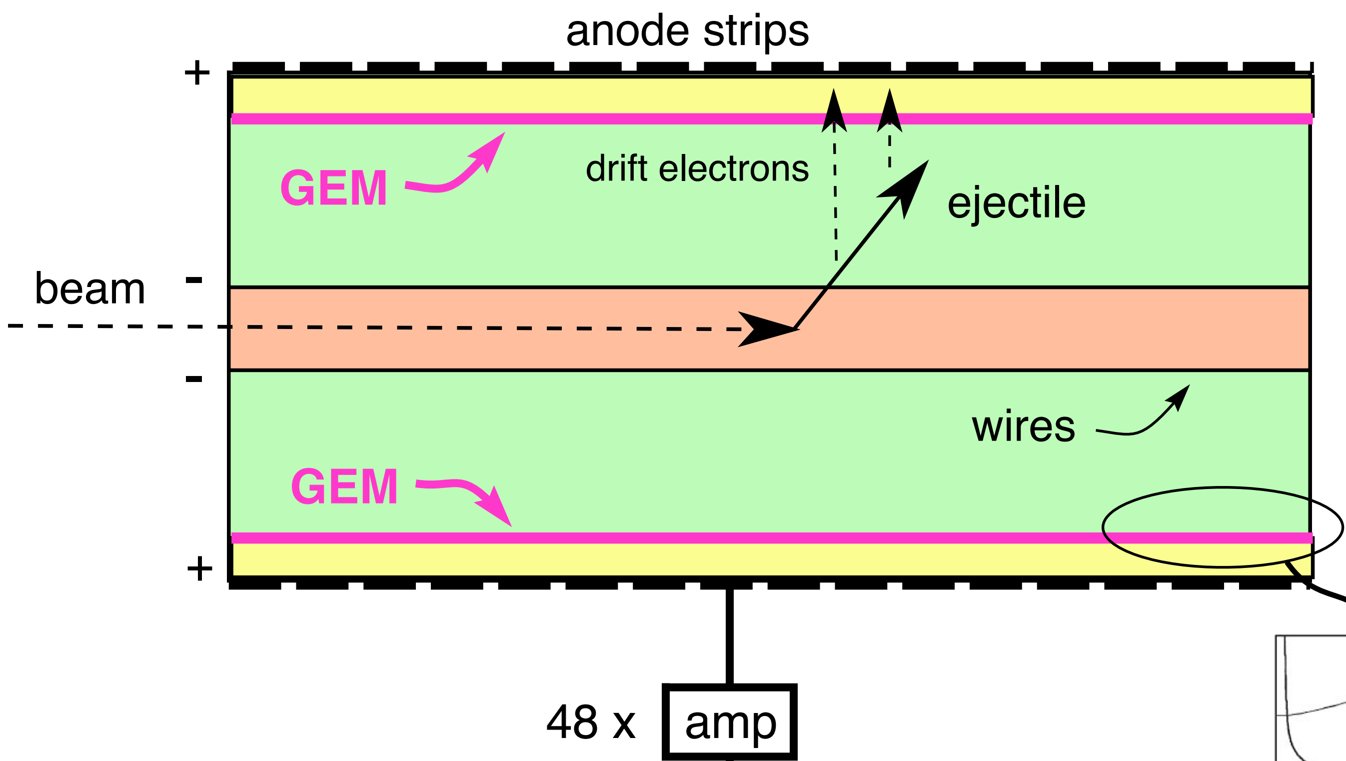


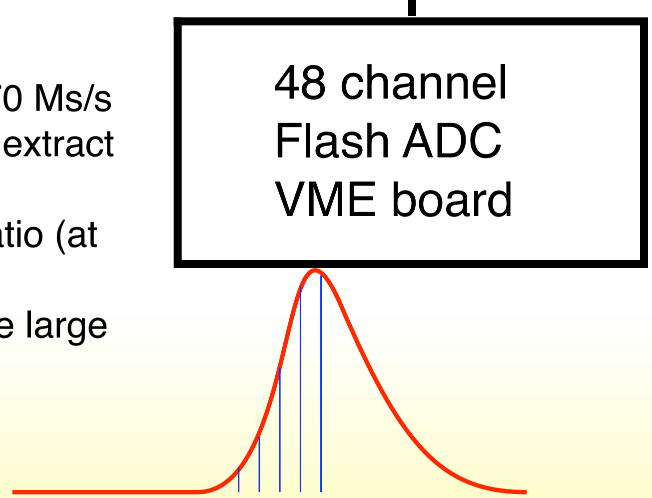
+ No background from beam
+ Making use of rotational symmetry

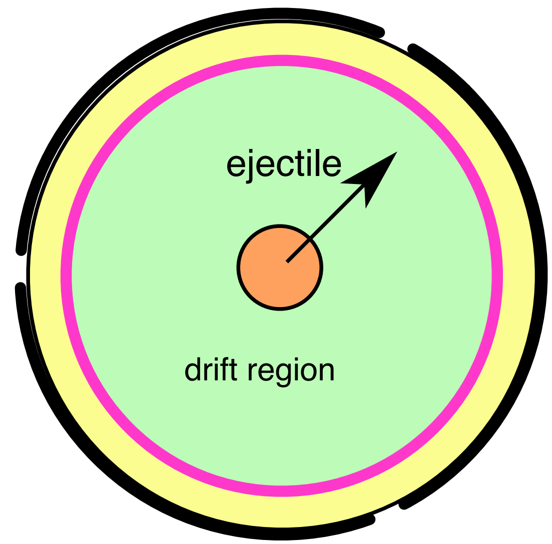
- Still high noise from weak signals

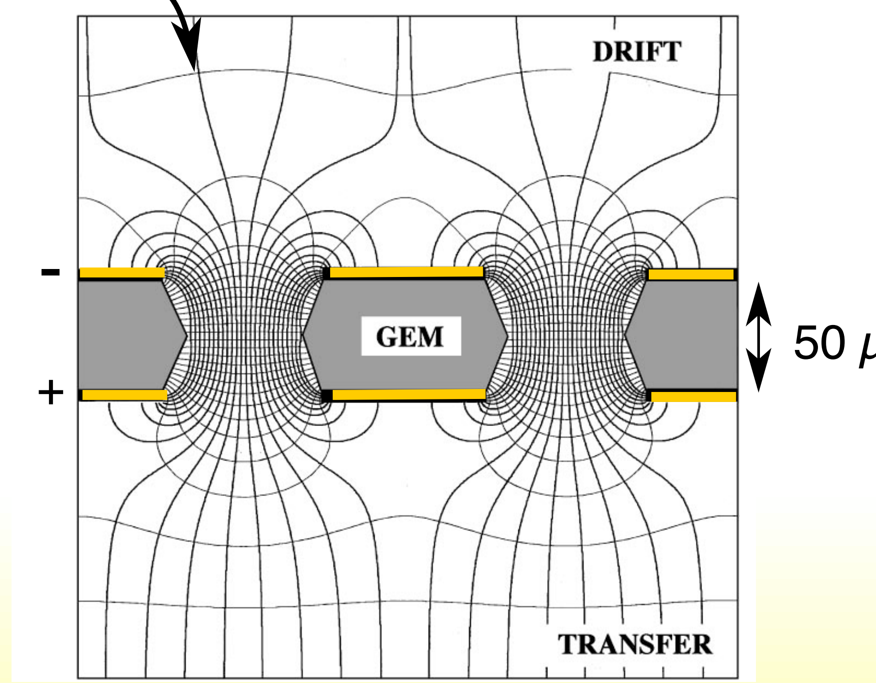
TACTIC

TRIUMF Annular Chamber for Trackingand Identification of Charged particles

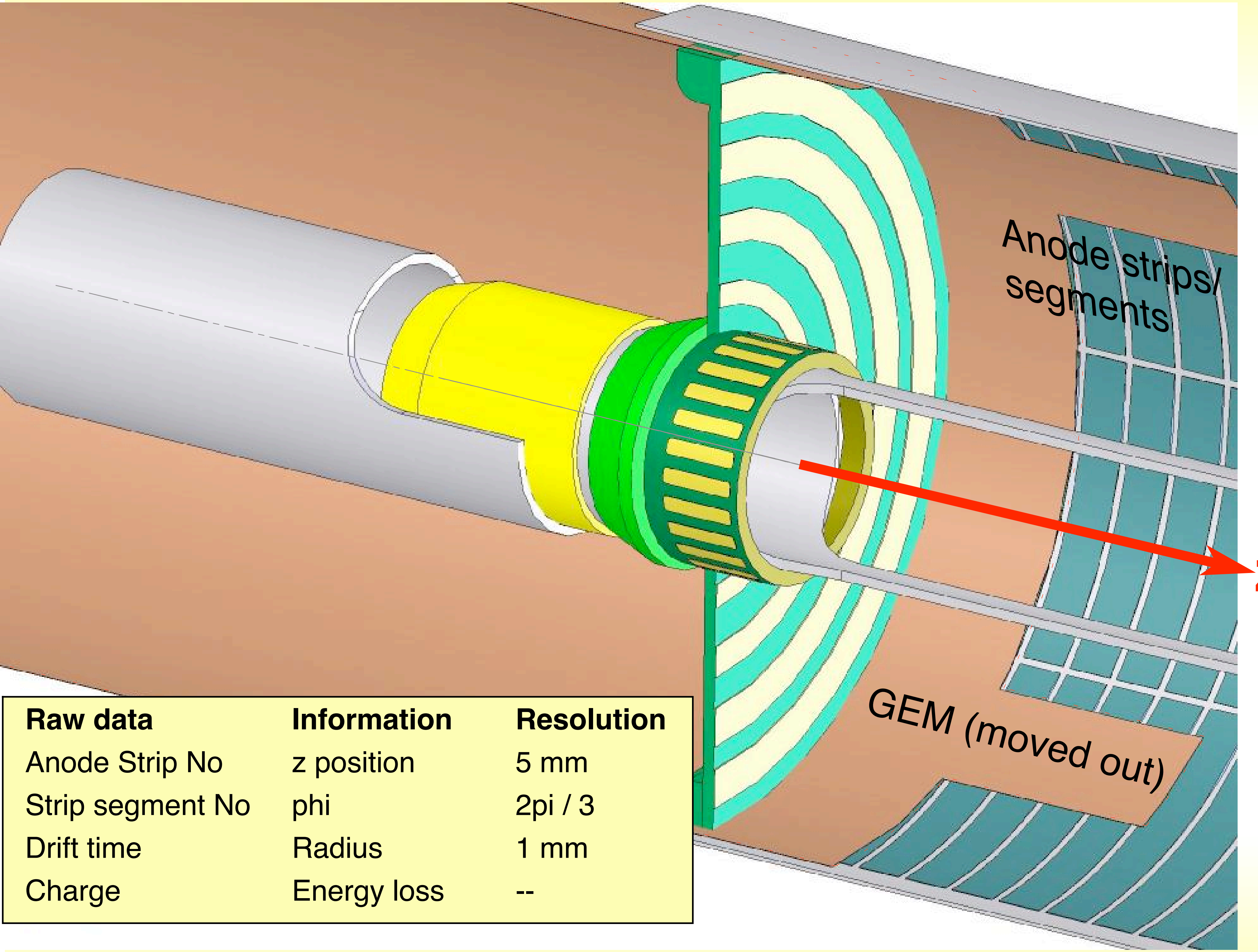




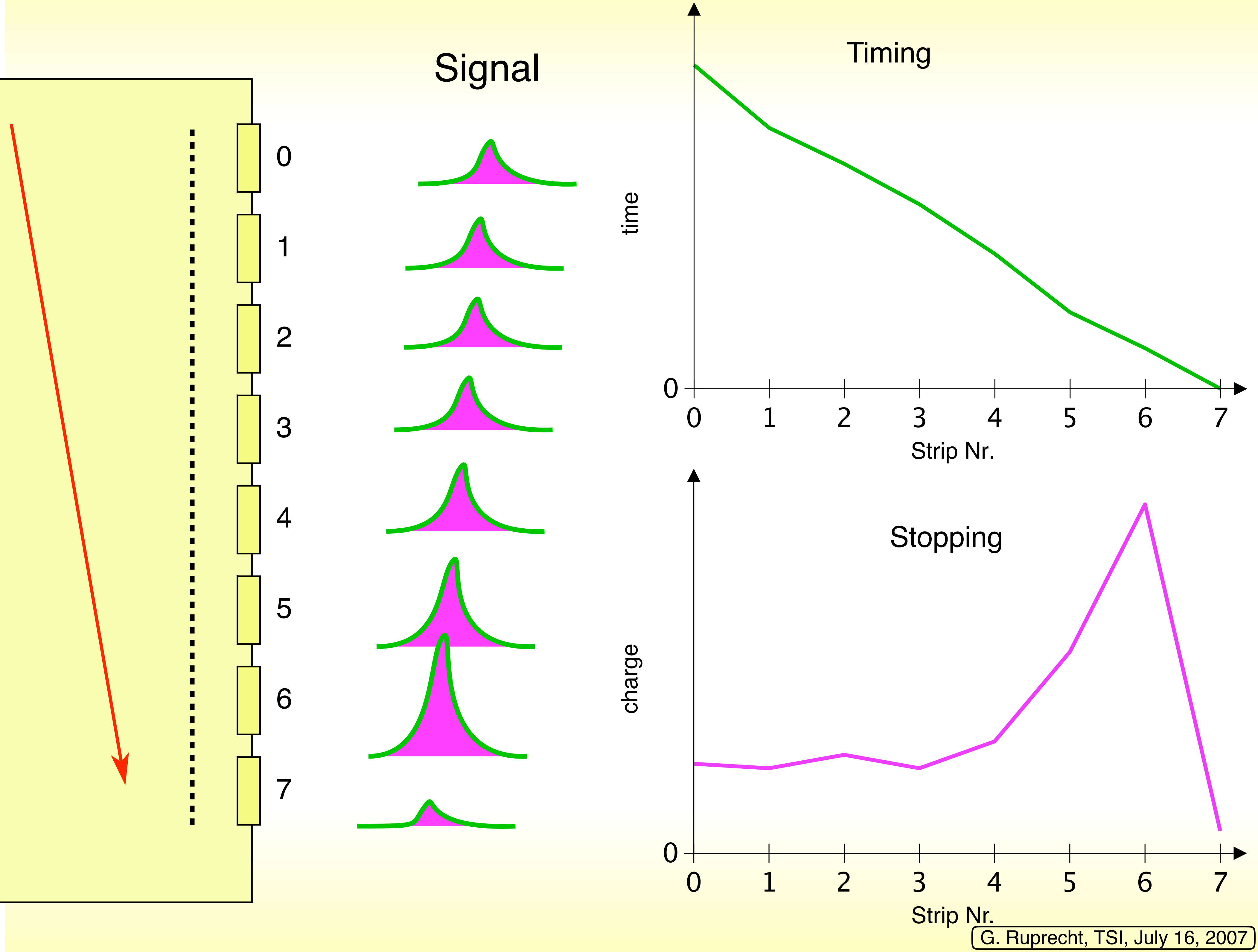




Sampling rate 50-70 Ms/s
FPGA algorithm to extract time and charge
Needs good S/N ratio (at least 10)
Rise time should be large enough



Raw data	Information	Resolution
Anode Strip No	z position	5 mm
Strip segment No	phi	2pi / 3
Drift time	Radius	1 mm
Charge	Energy loss	--


Signal
0
1
2
3
4
5
6
7
Timing
time
0
0 1 2 3 4 5 6 7
Strip Nr.
Stopping
charge
0
0 1 2 3 4 5 6 7
Strip Nr.
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Problems

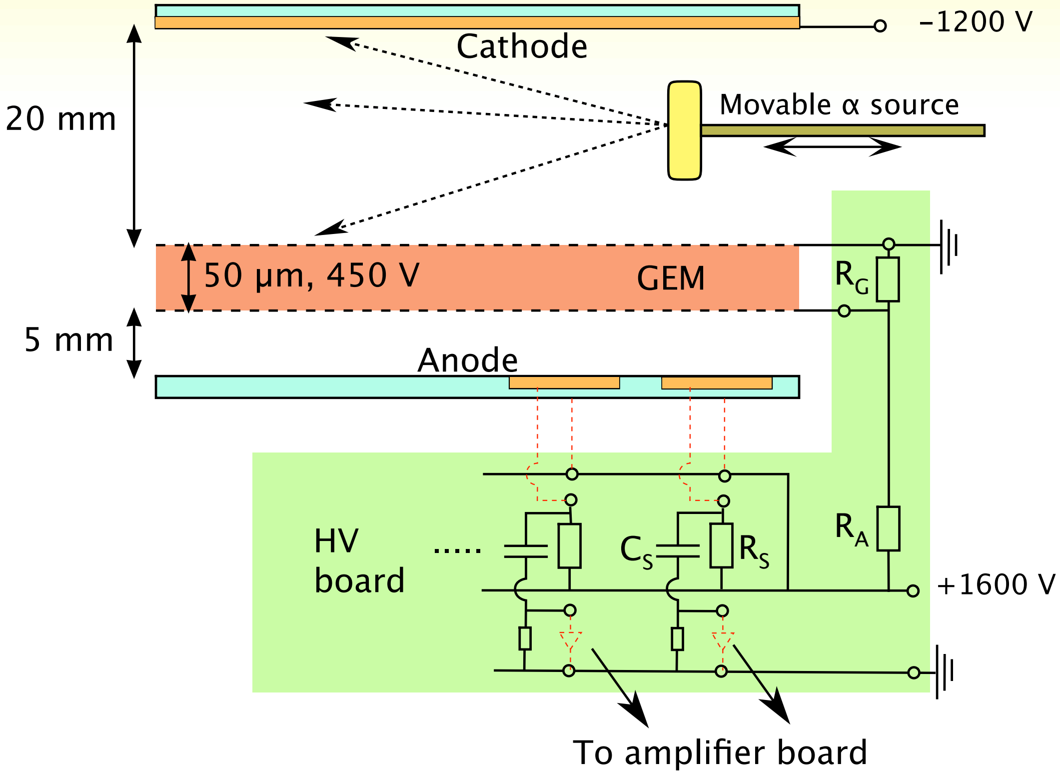
1. How is the GEM working with Helium?

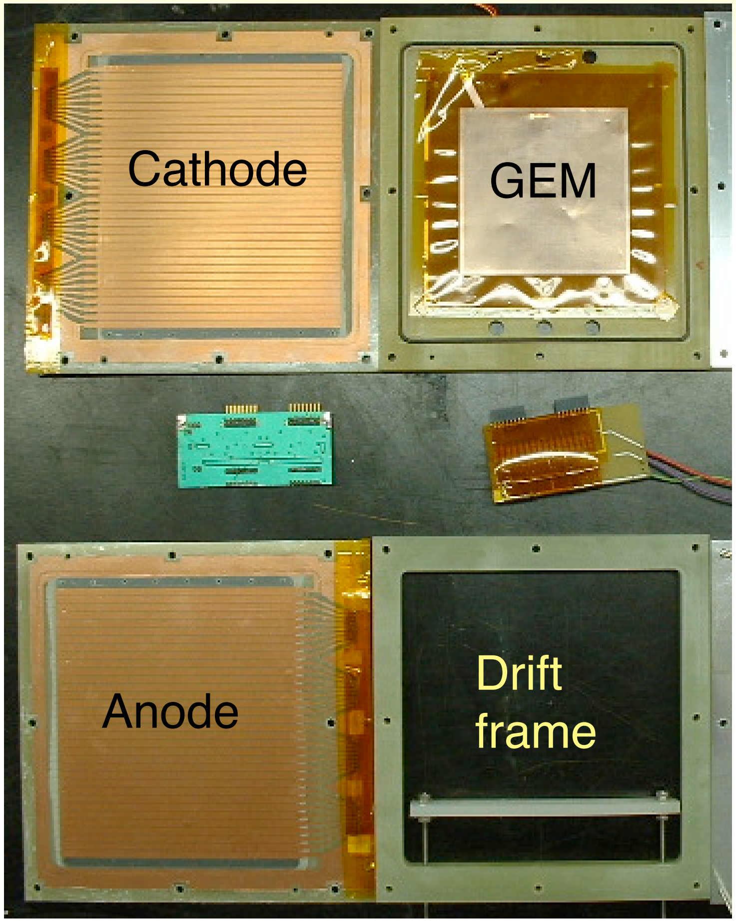
2. What is the optimal geometry?
   Length, diameter vs. pressure, kinematics

3. Pulse shapes, signal/noise ratio vs. pressure

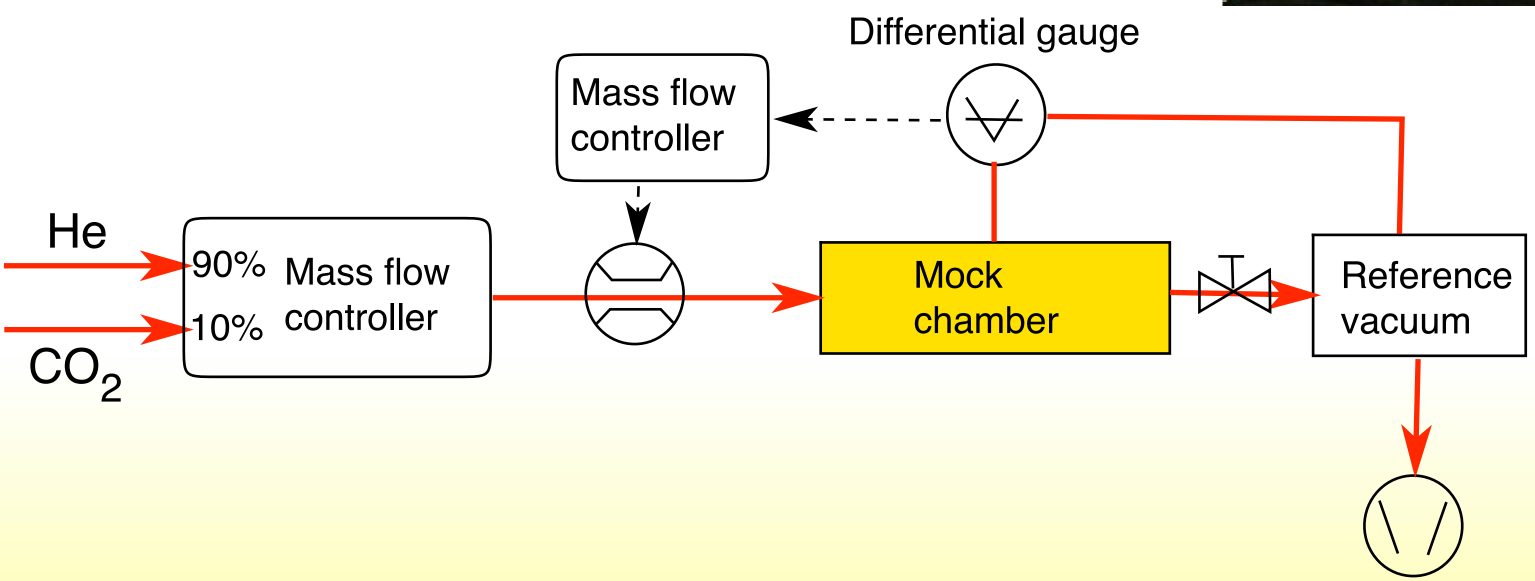
4. How to suppress beam electrons?

Testchamber





The Gas Handling System



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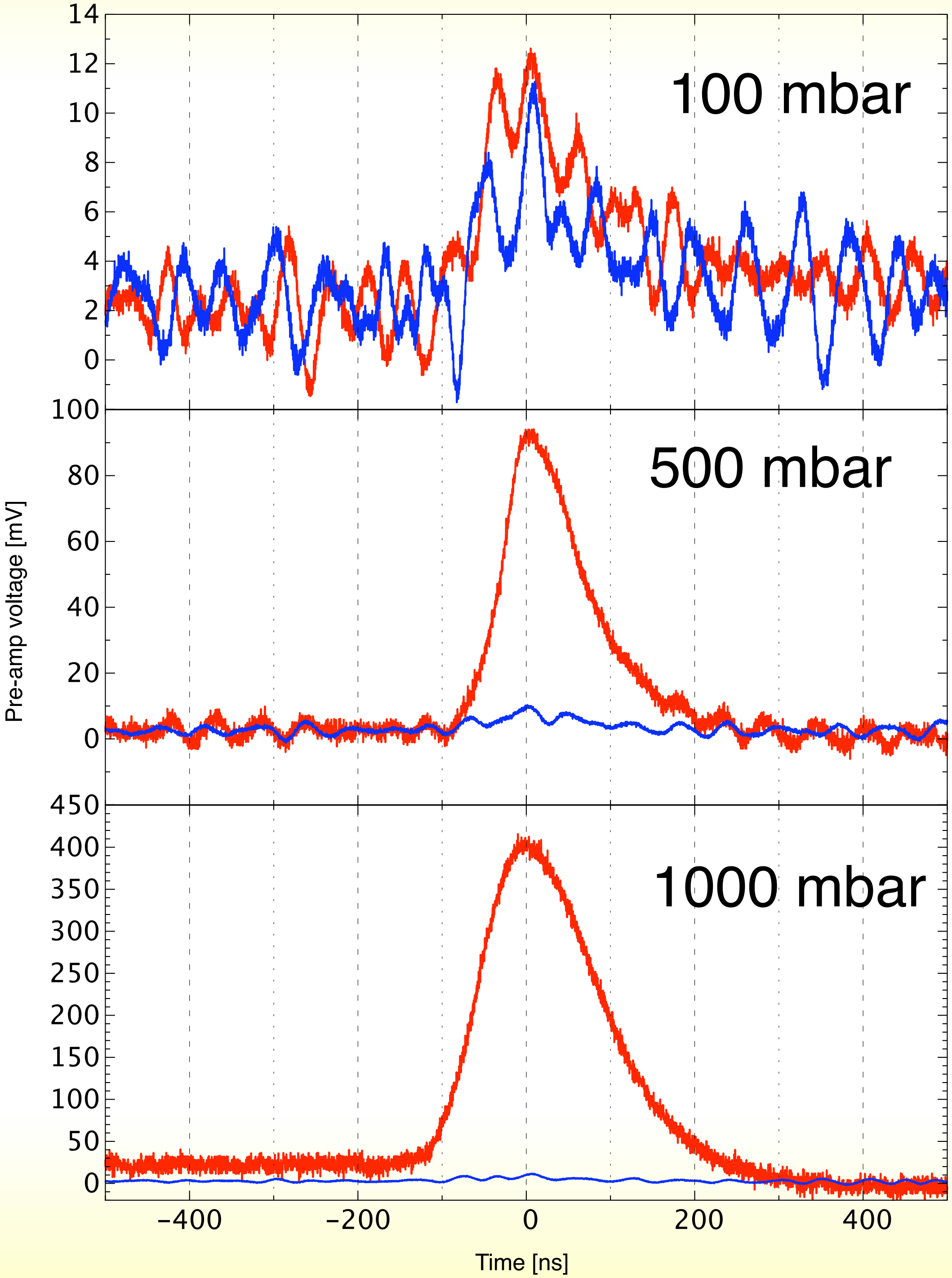
Pressure dependence



Note: With the pressure, the follwing quantities change:

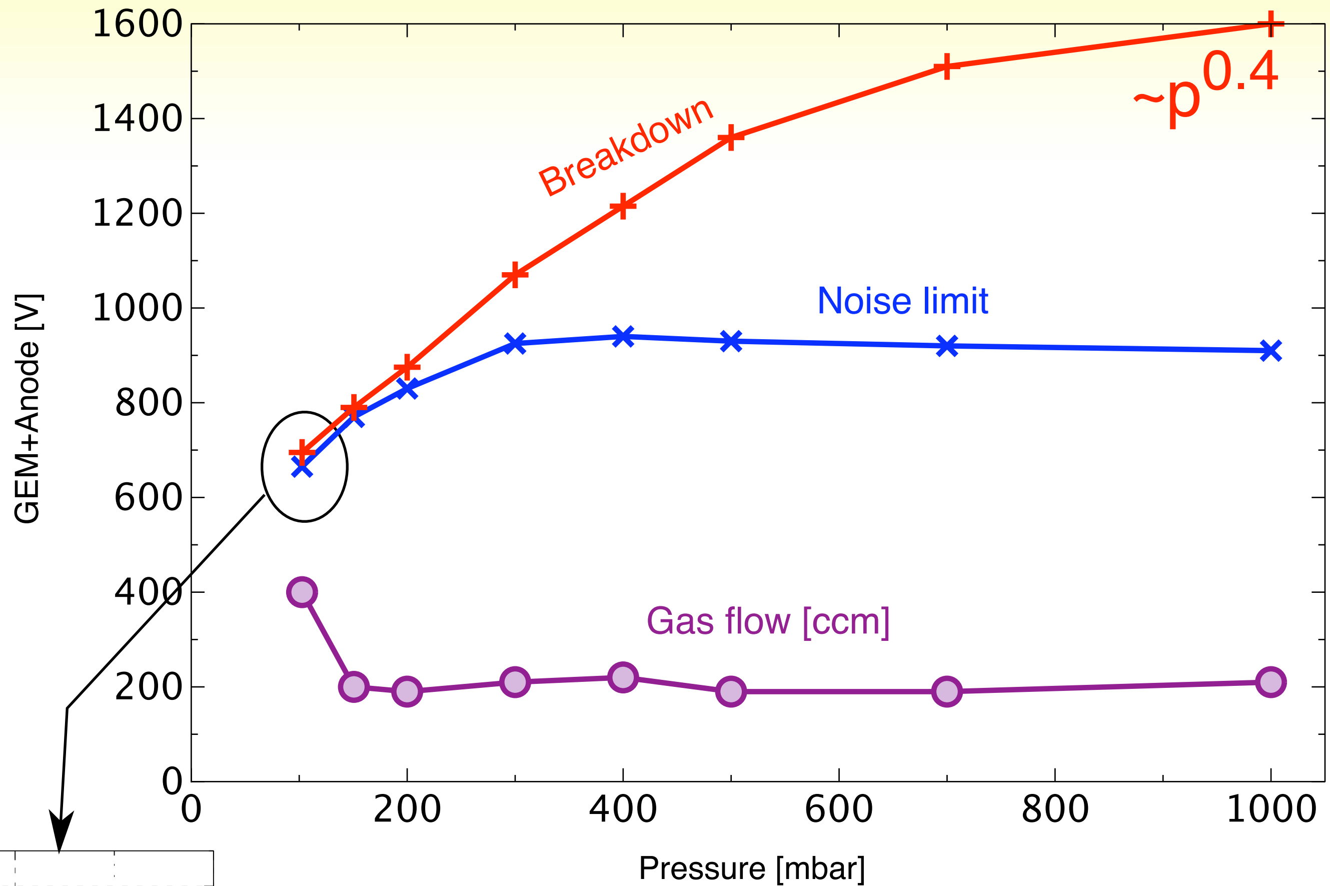
- Primary ionization per strip
- Track length
- Drift time
- Gain

The primary ionization or track length is known

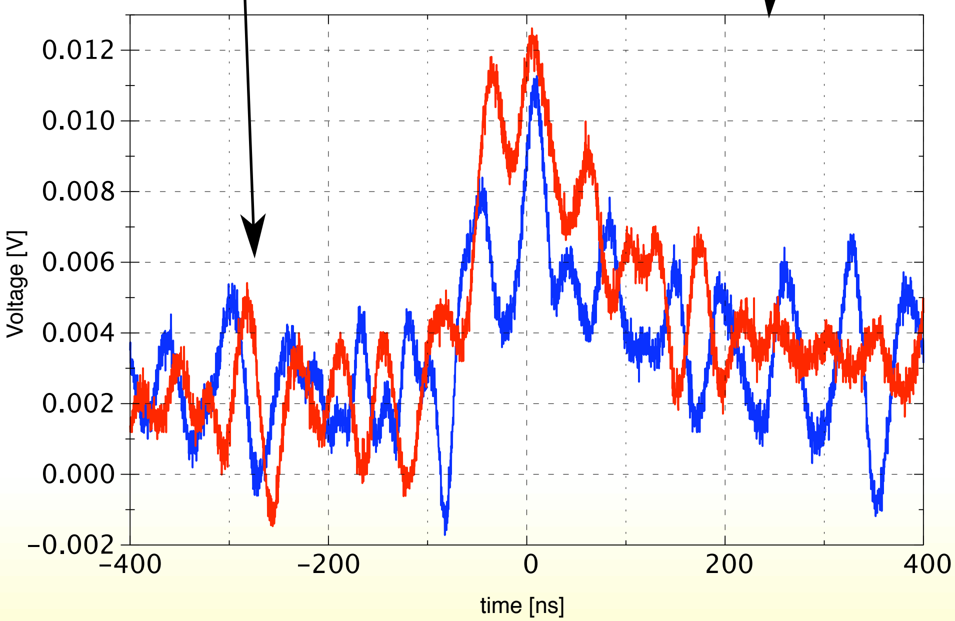
The drift time is known to depend on E/p

The gain is not known so far

Pulse shapes, signal/noise ratio vs. pressure

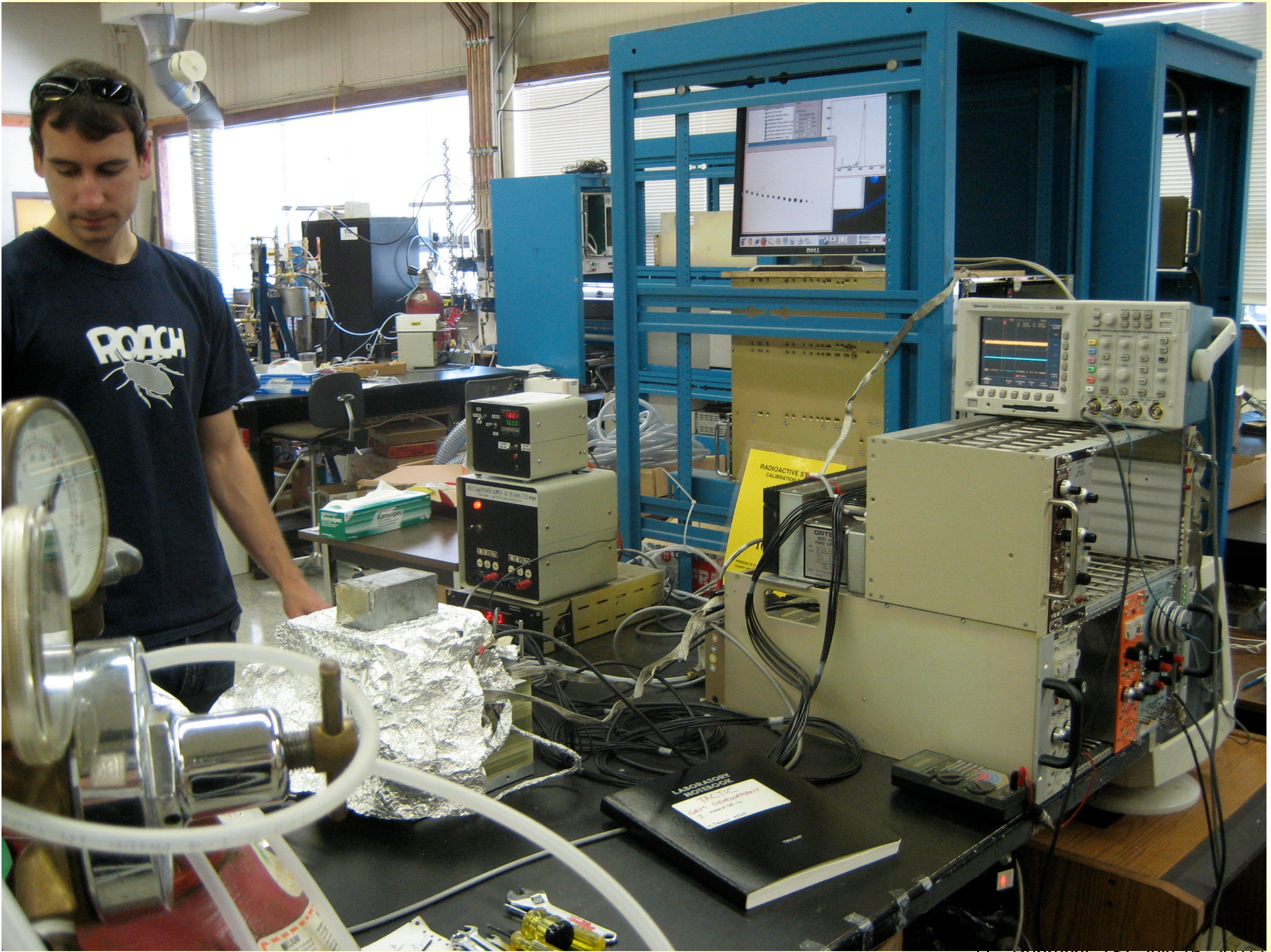


Laboratory noise from unshielded electronics



5.5 MeV a particles with 18 μm Mylar foil

For the real case, the ^{11}B stopping is much higher



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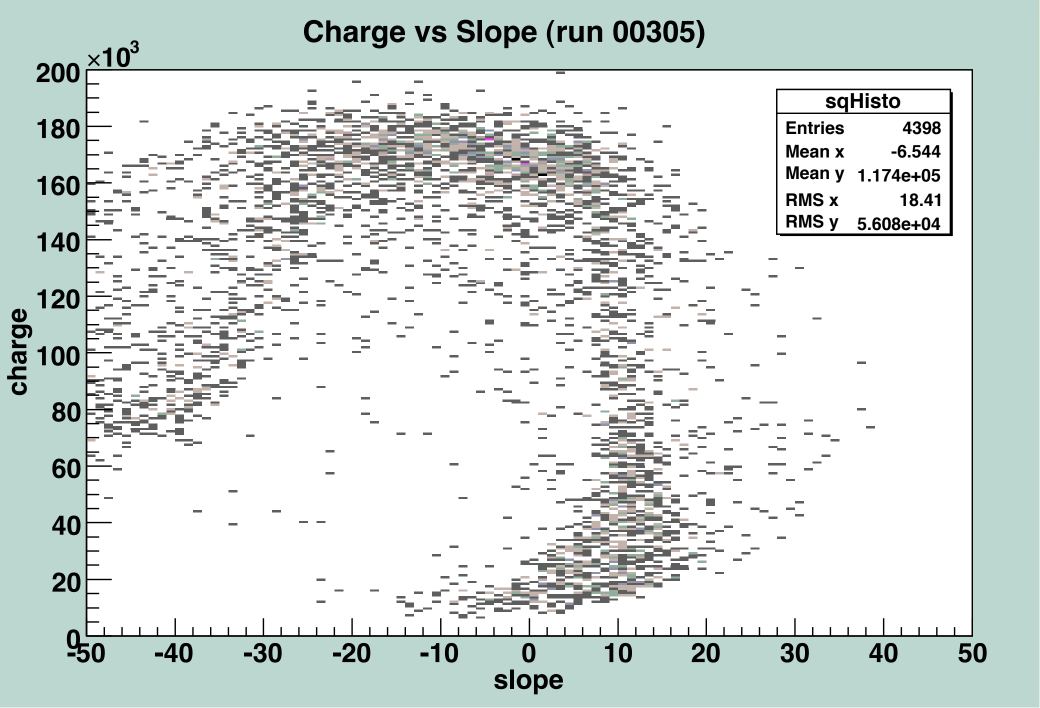
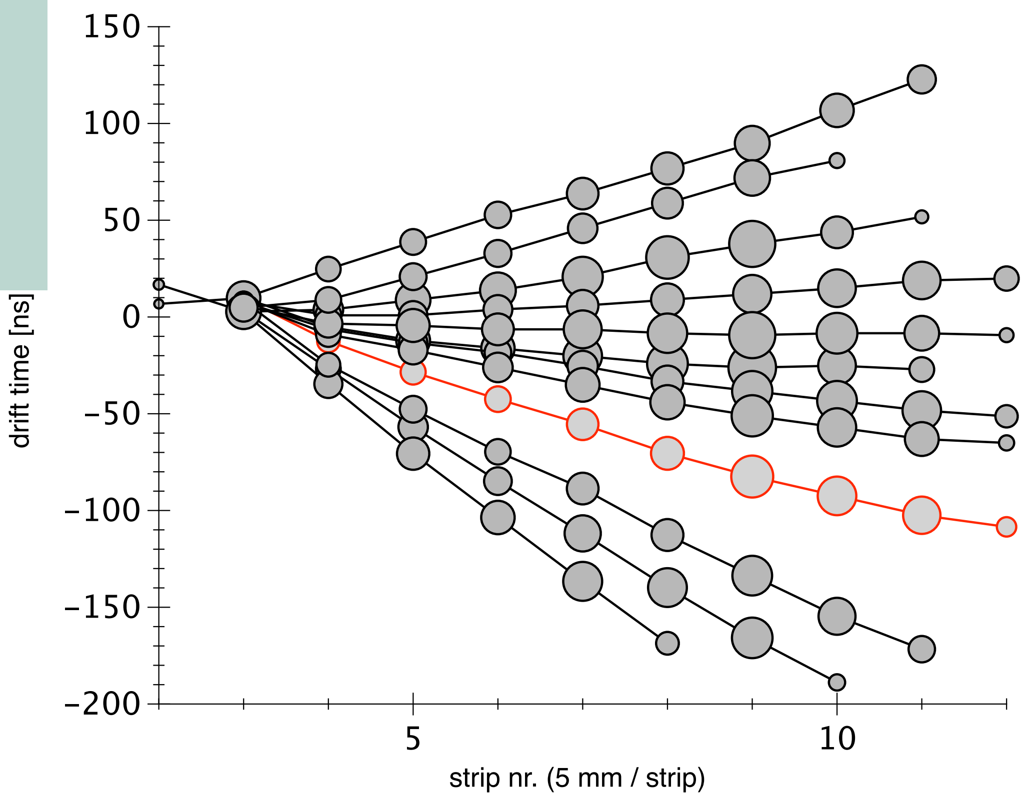
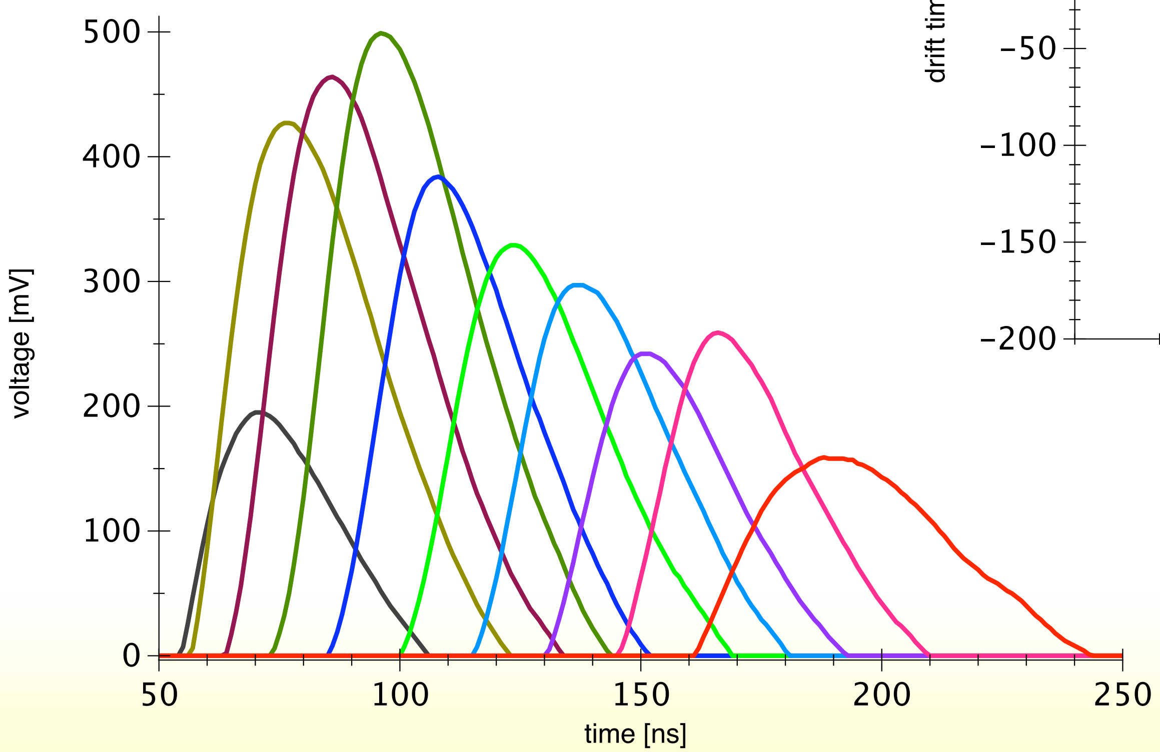
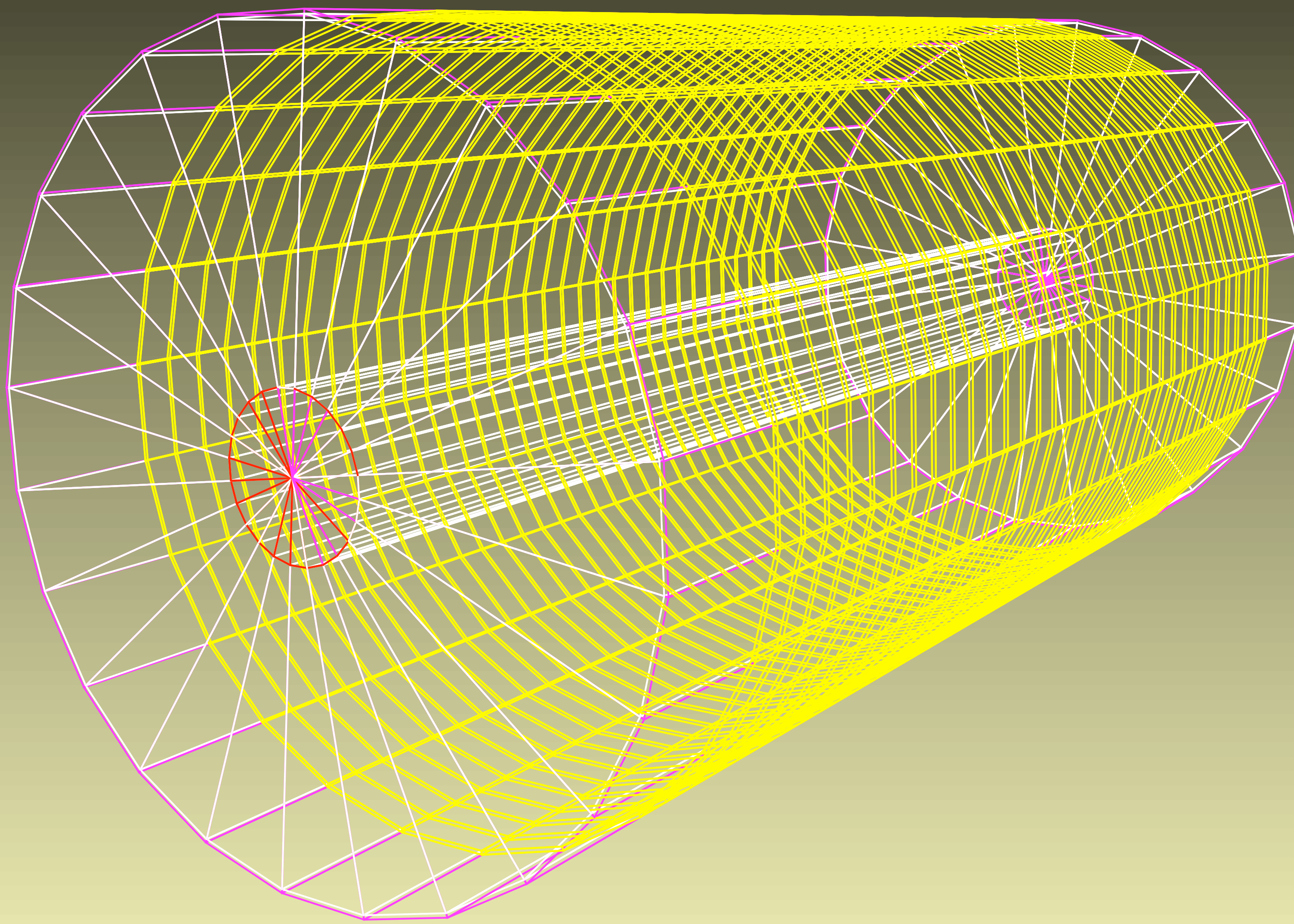
Signals and trajectories



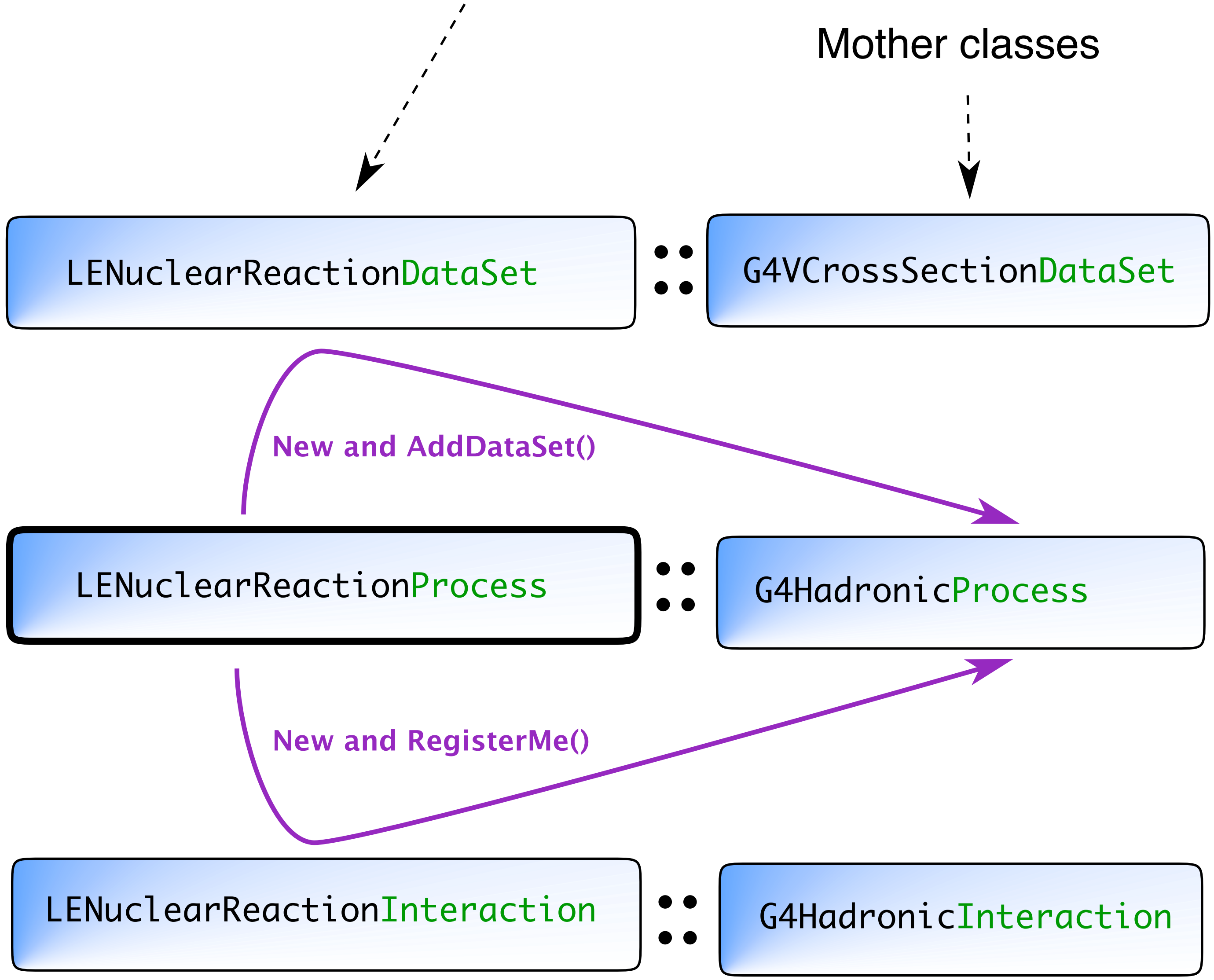




GEANT4



3 new classes to define the GEANT4 low energy nuclear reaction process



Provides the total cross-section in order to sample the occurence of the process

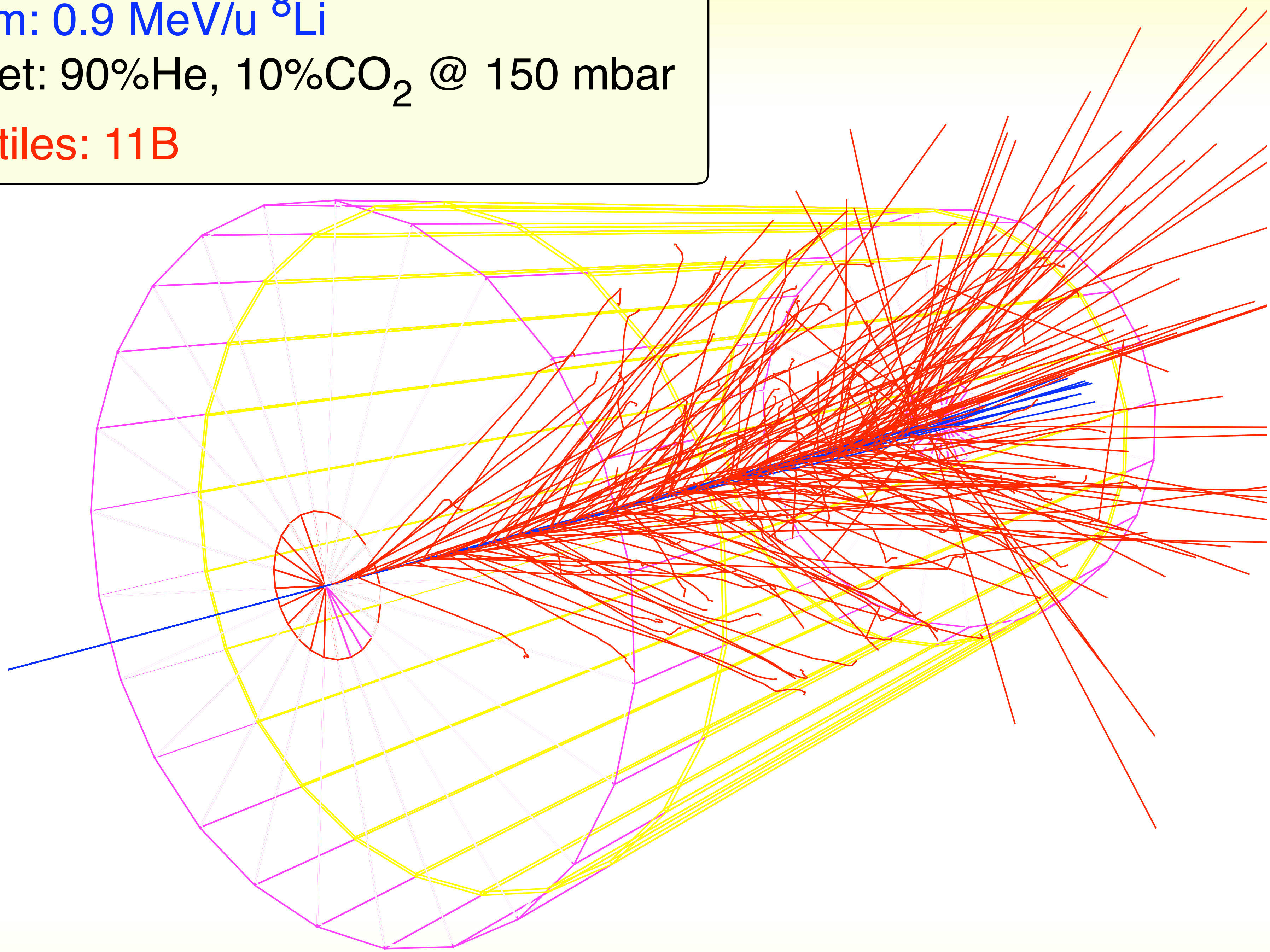
Defines the process to be associated with low energy heavy ions

Samples the direction of the ejectiles if the process has been selected to occur.

Beam: 0.9 MeV/u ^{8}Li

Target: 90%He, 10%CO_2 @ 150 mbar

Ejectiles: 11B



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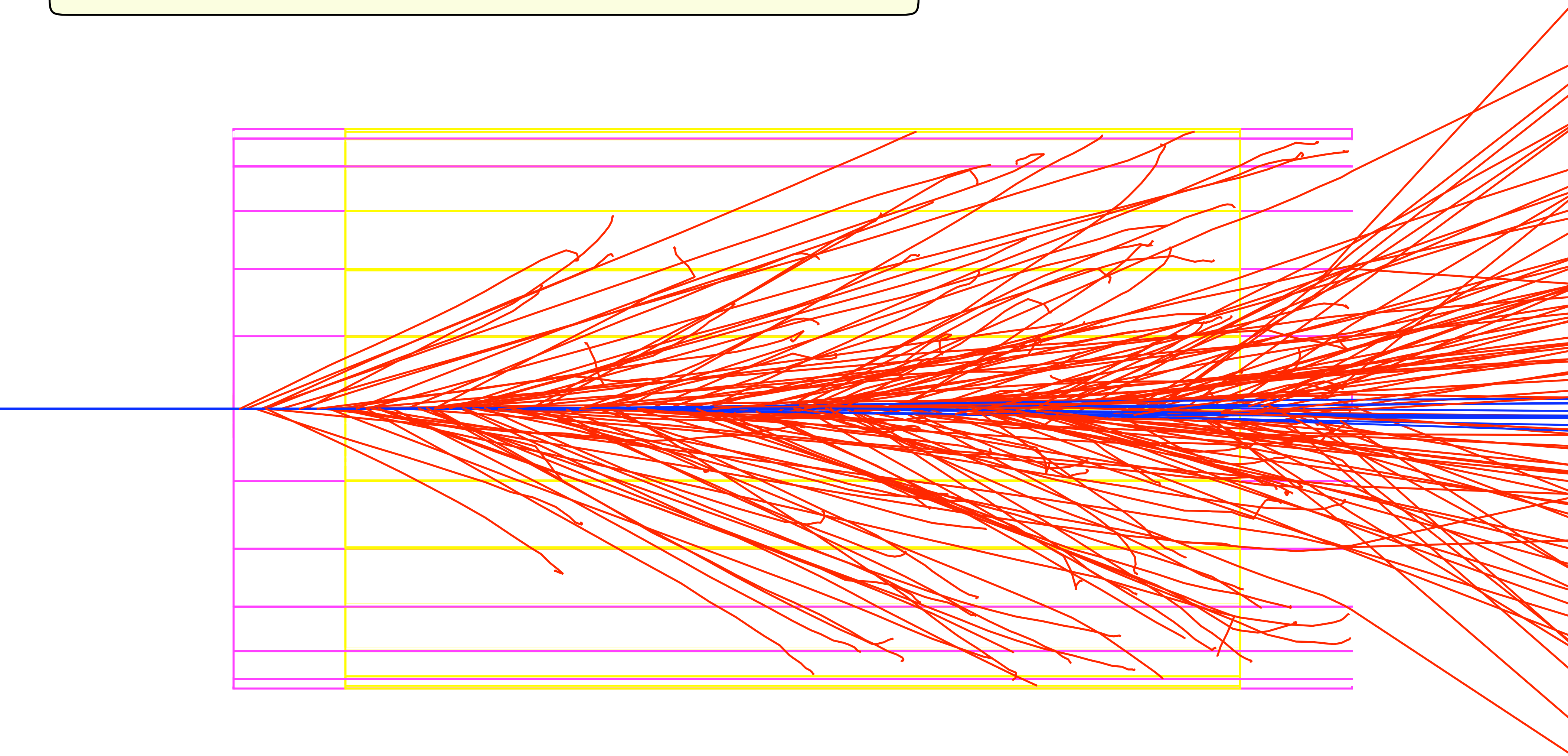

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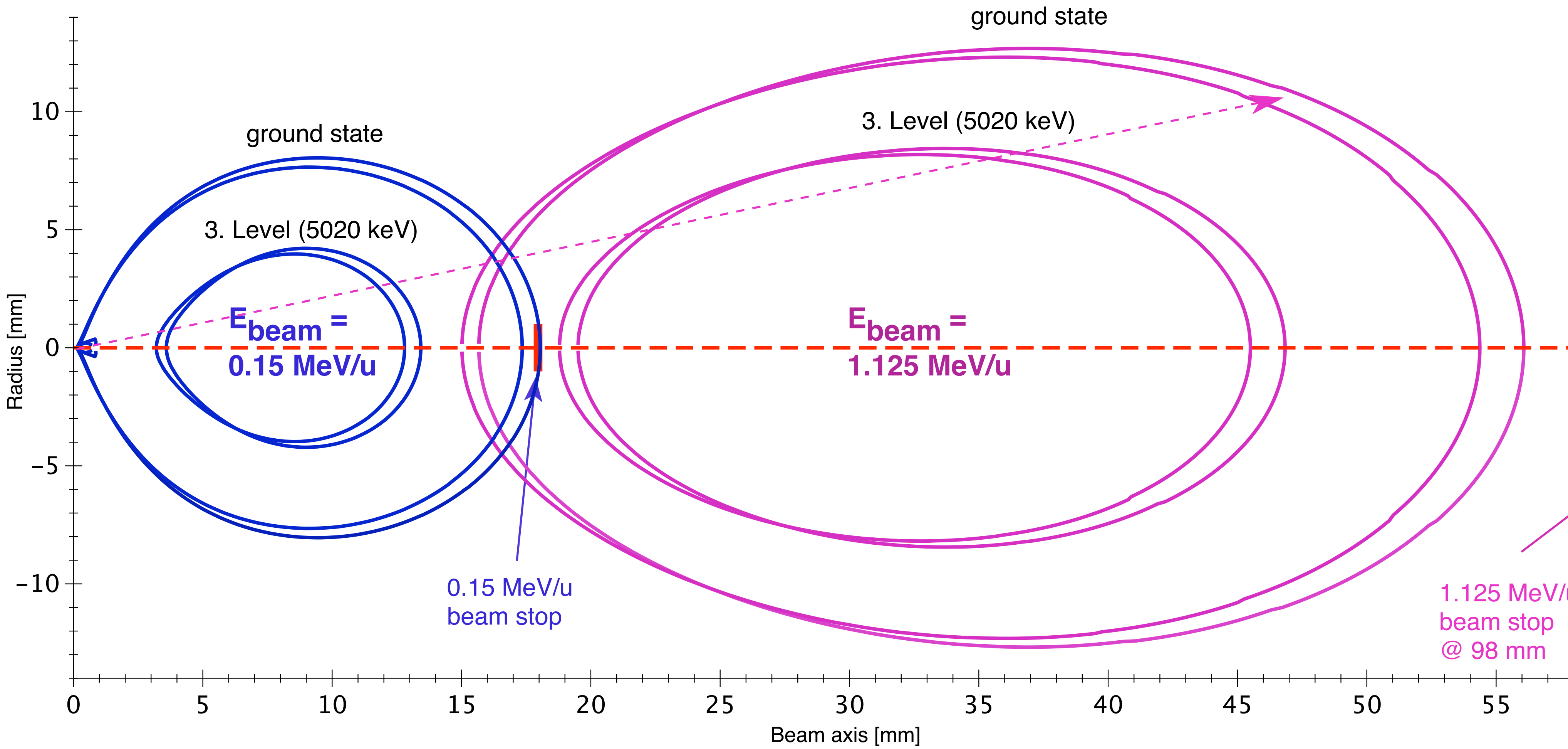
Range of ^{11}B from $\alpha(^{8}Li,^{11}B)n$ in 90% He 10% CO_2 gas mixture at STP

What is the optimal geometry?



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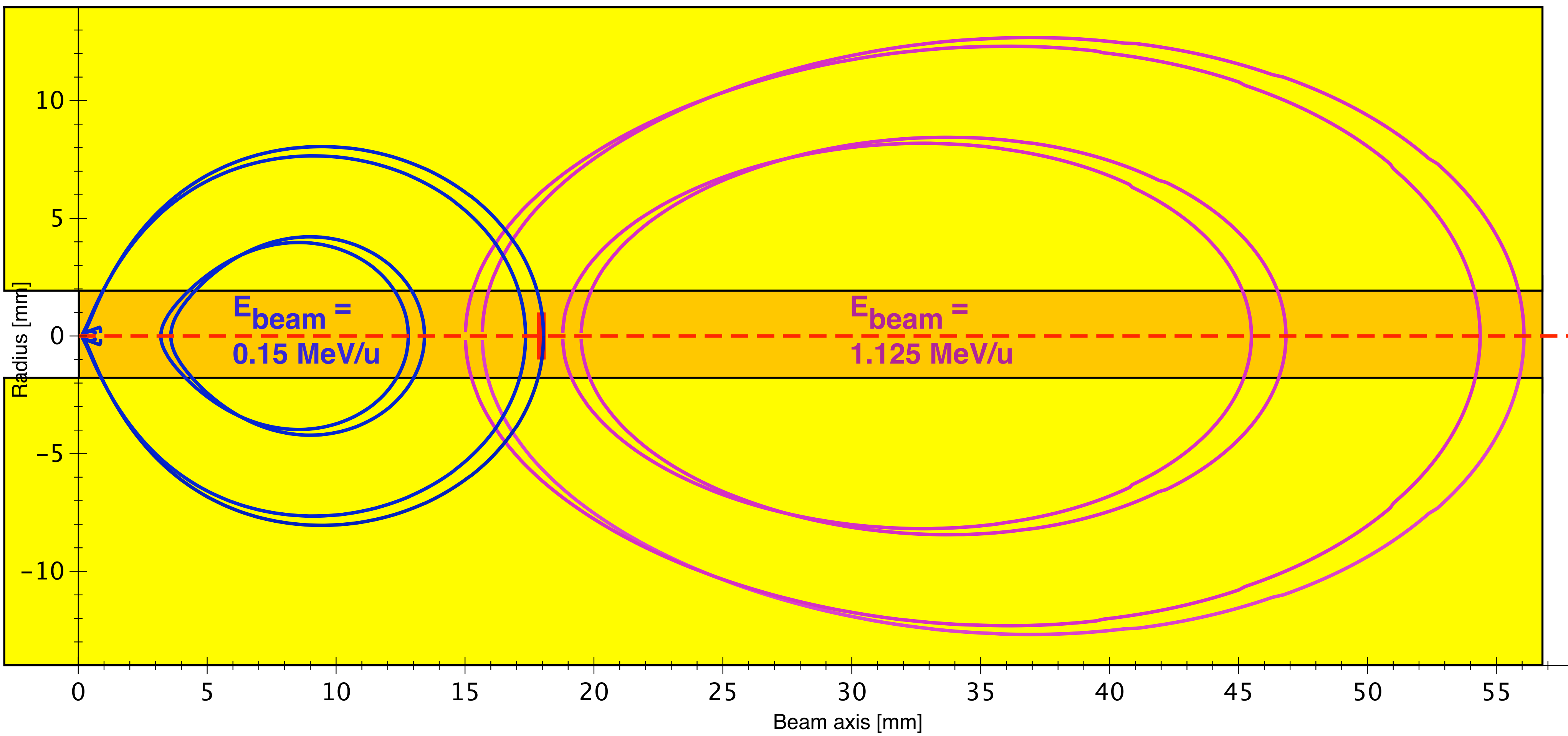
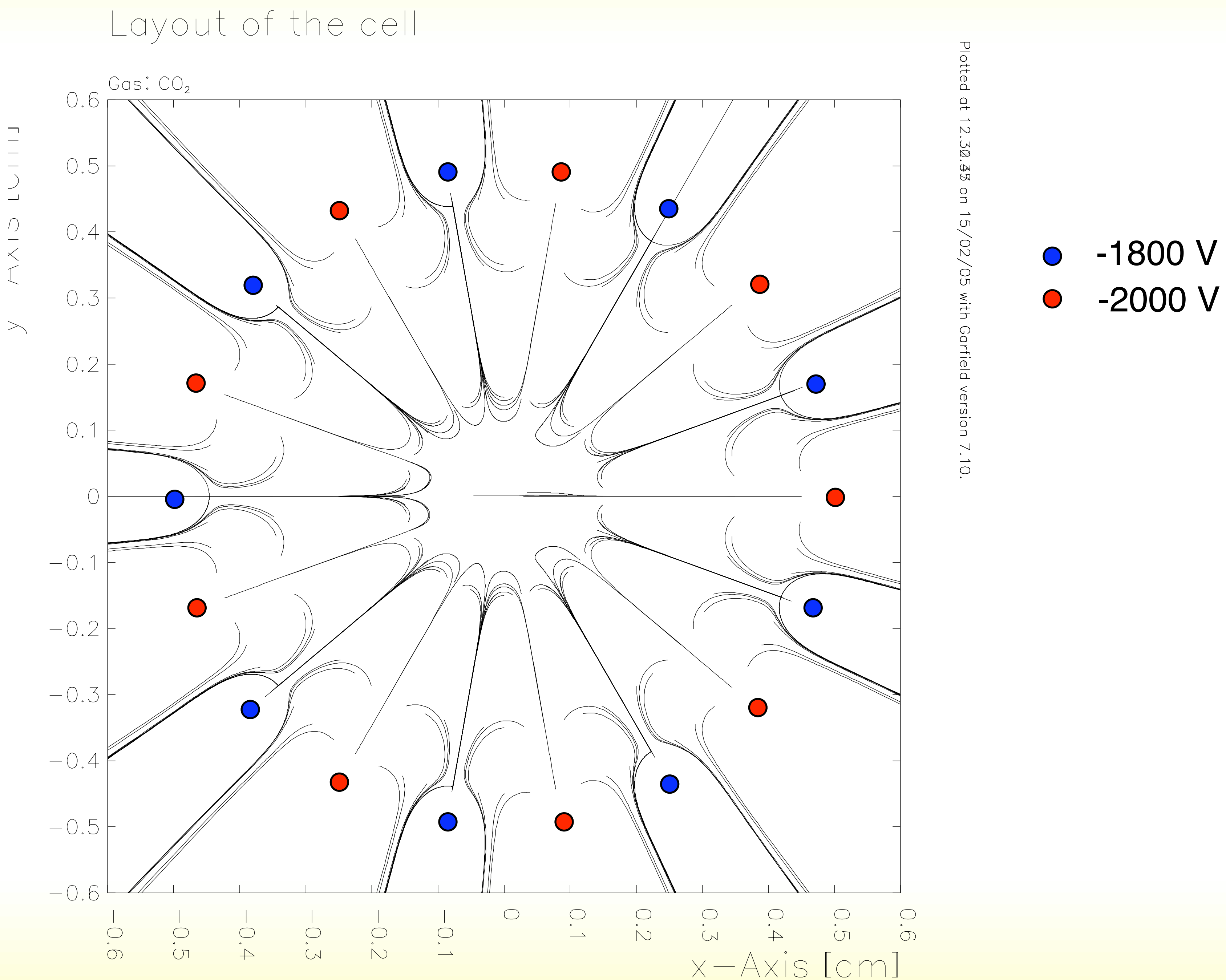
Range of ^{11}B from $\alpha(^{8}Li,^{11}B)n$ in 90% He 10% CO_2 gas mixture at STP

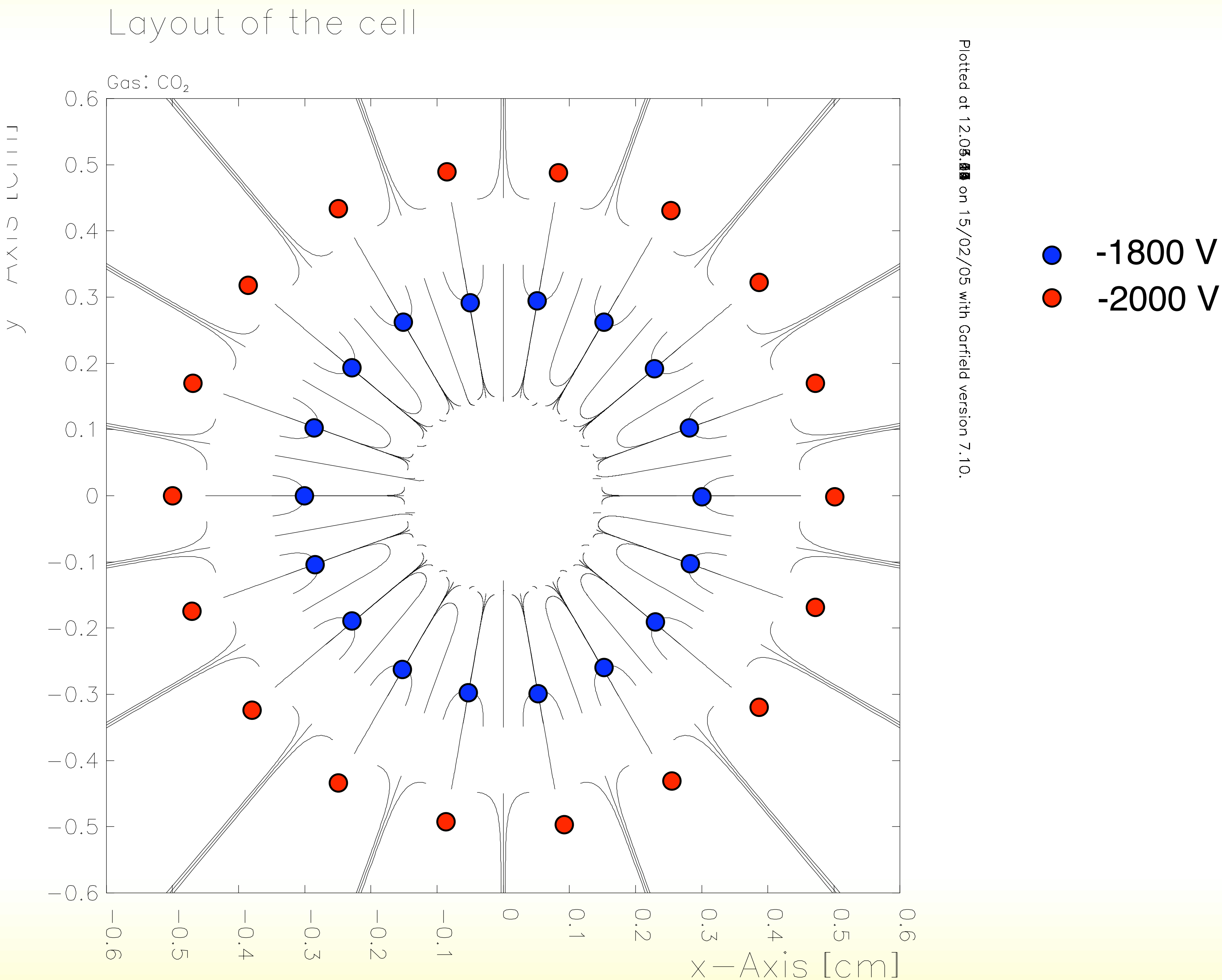
What is the optimal geometry?



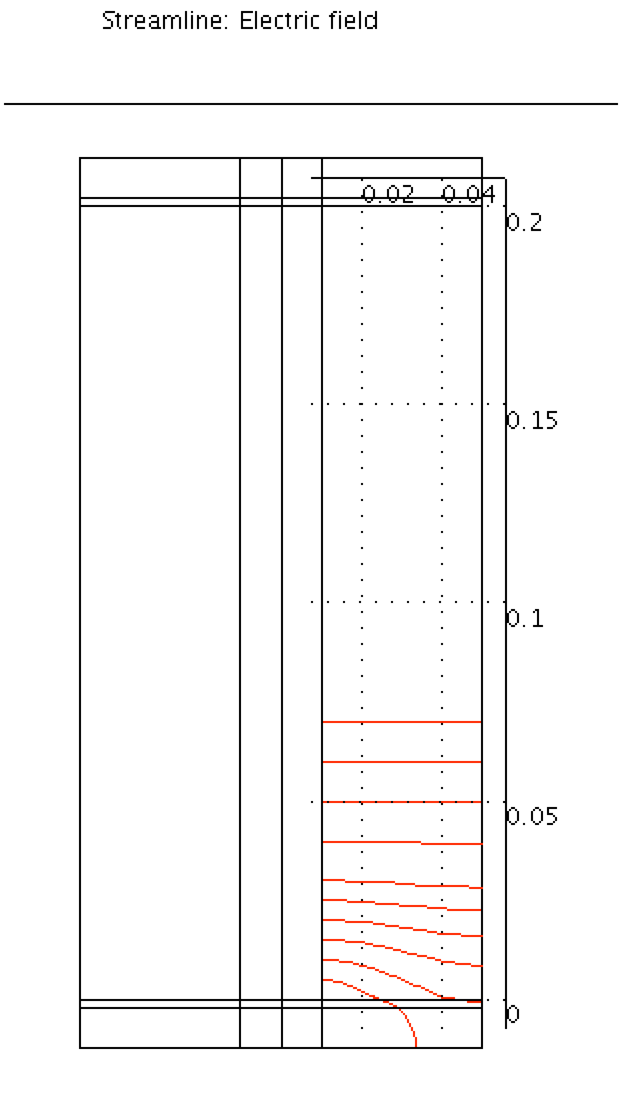
Suppression of Beam Induced Electrons

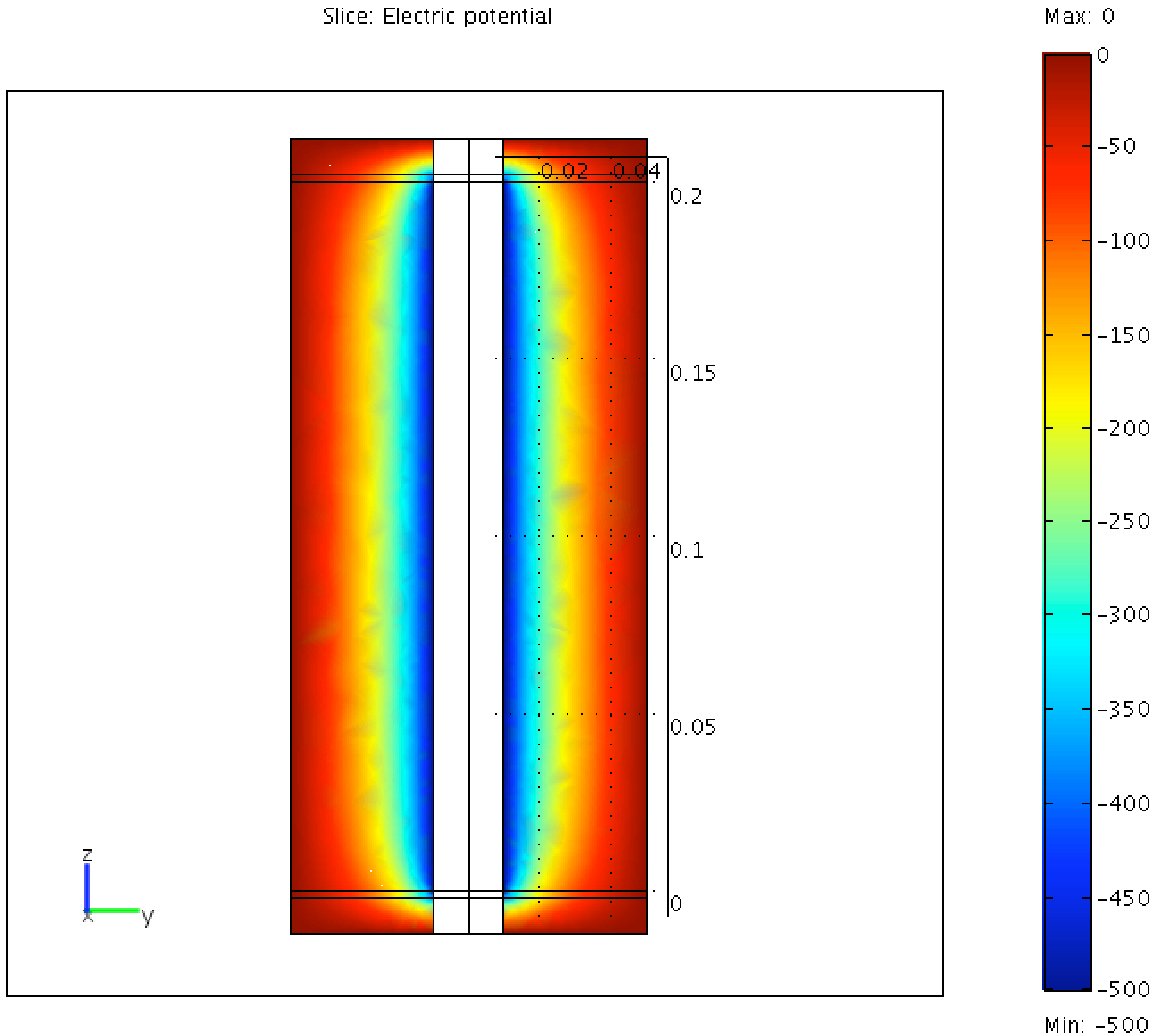


Suppression of Beam Induced Electrons

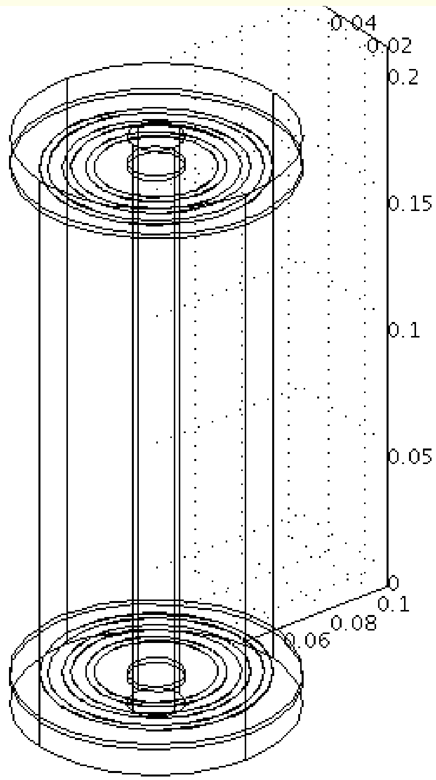


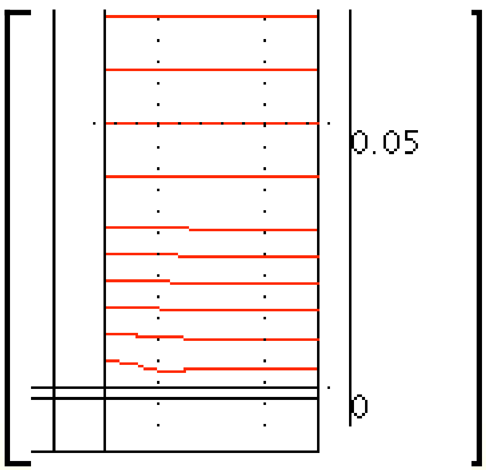
Drift field potential w/o pads

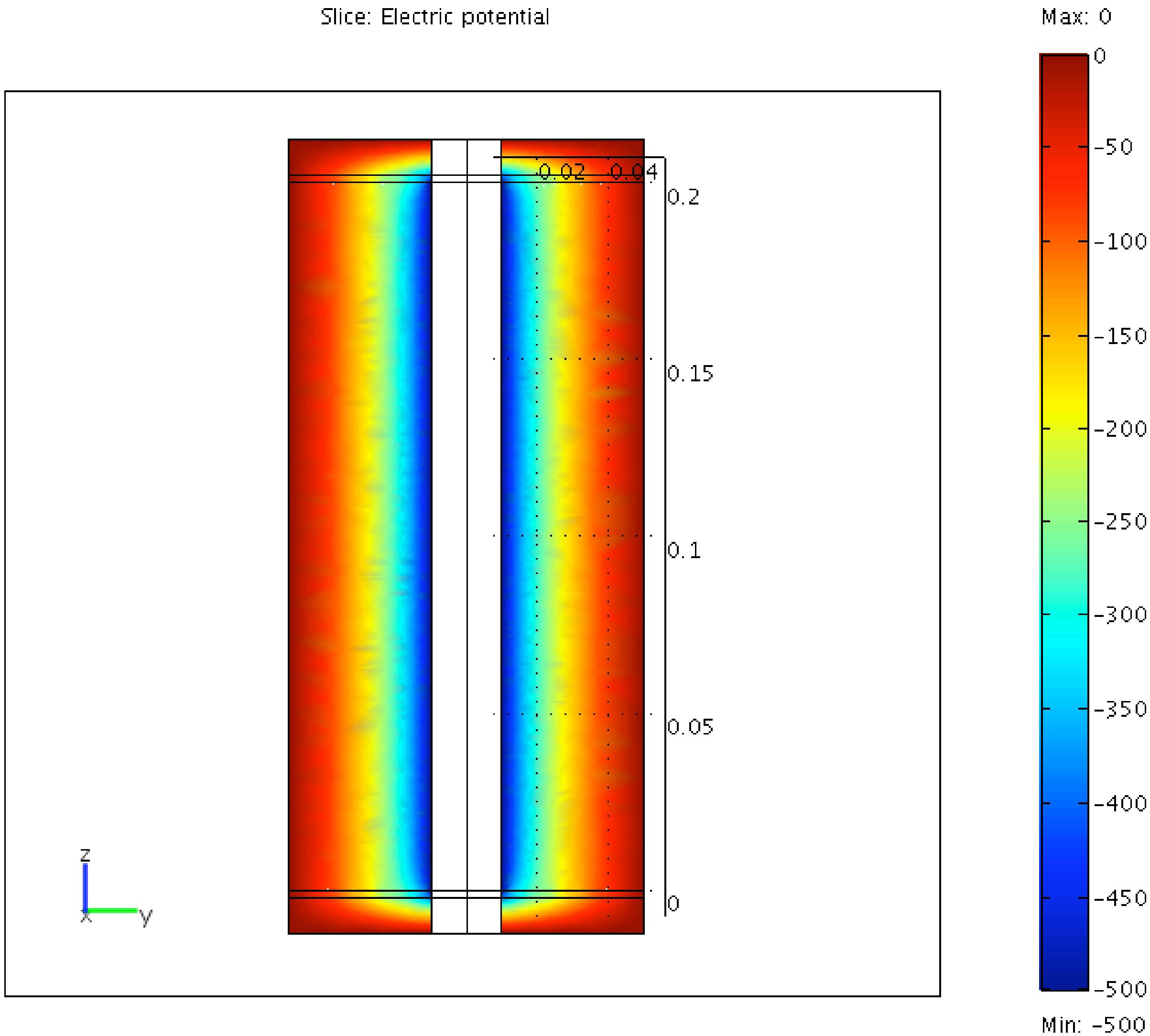




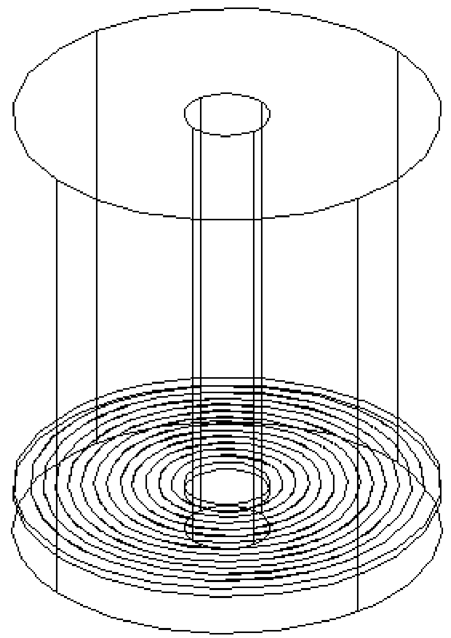
Drift field supported by 3 rings

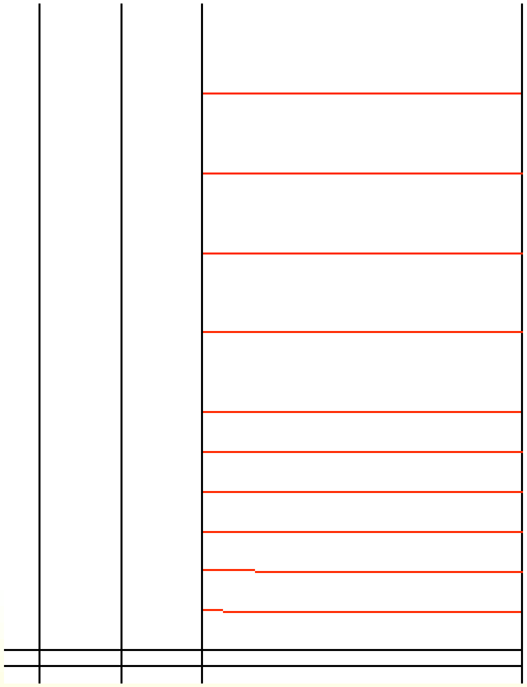


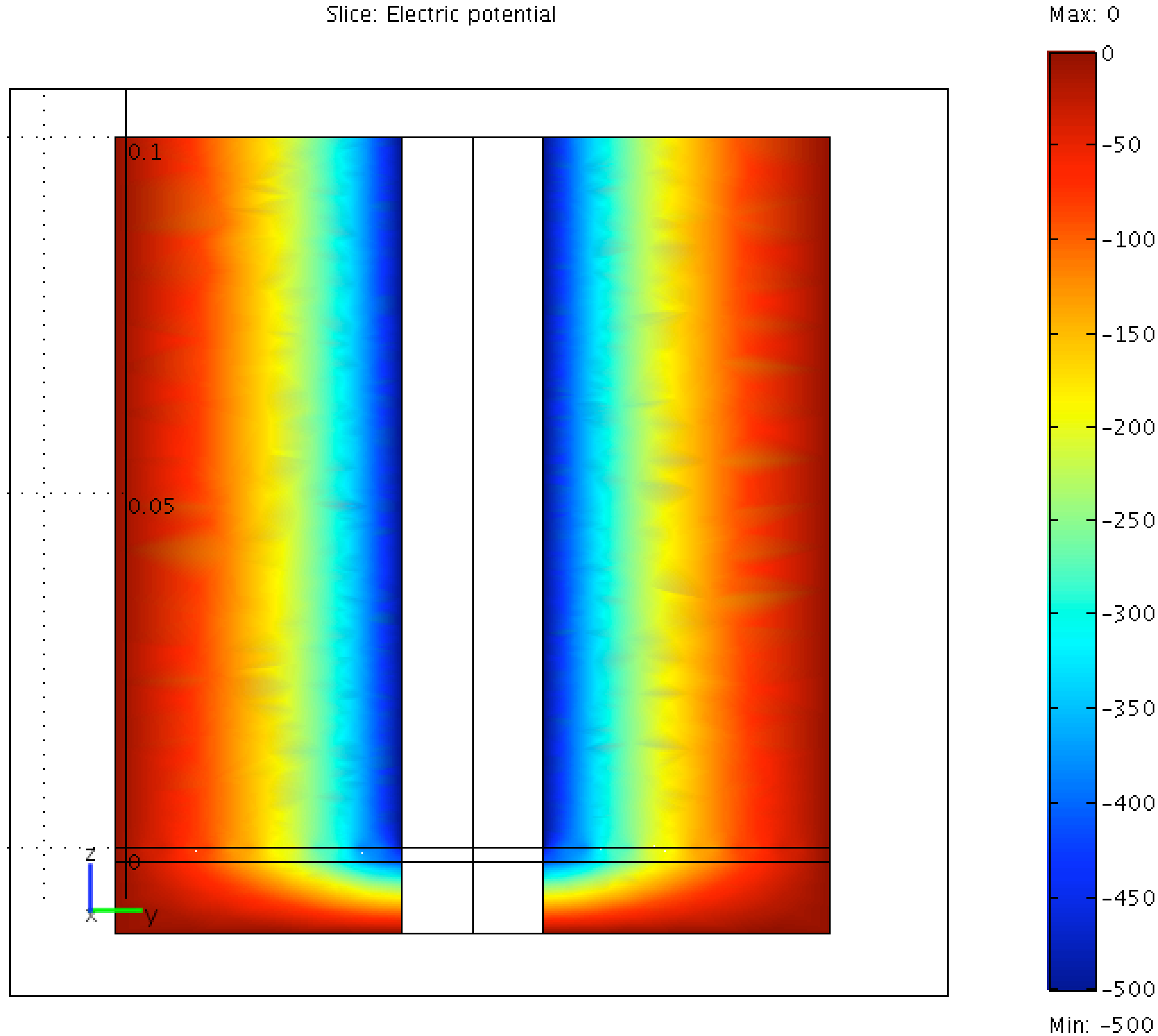




Drift field supported by 6 rings



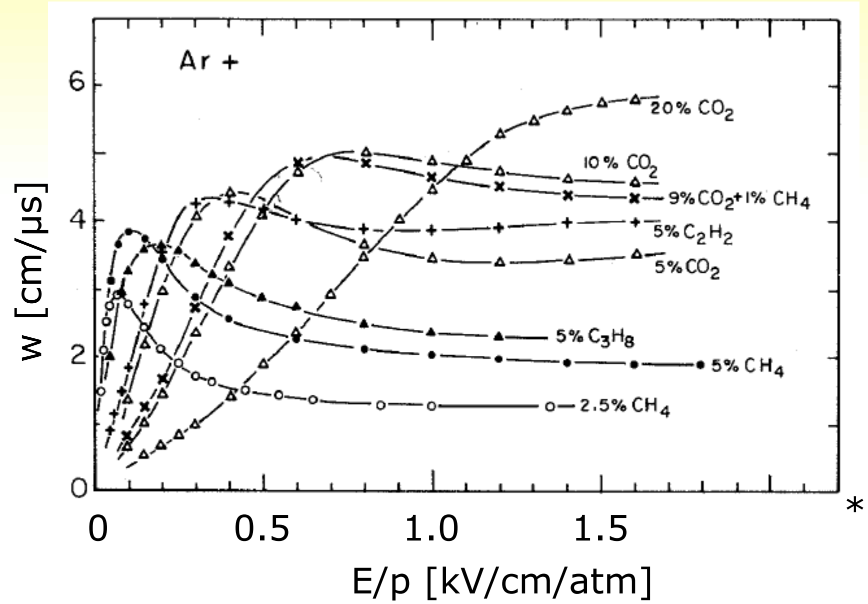


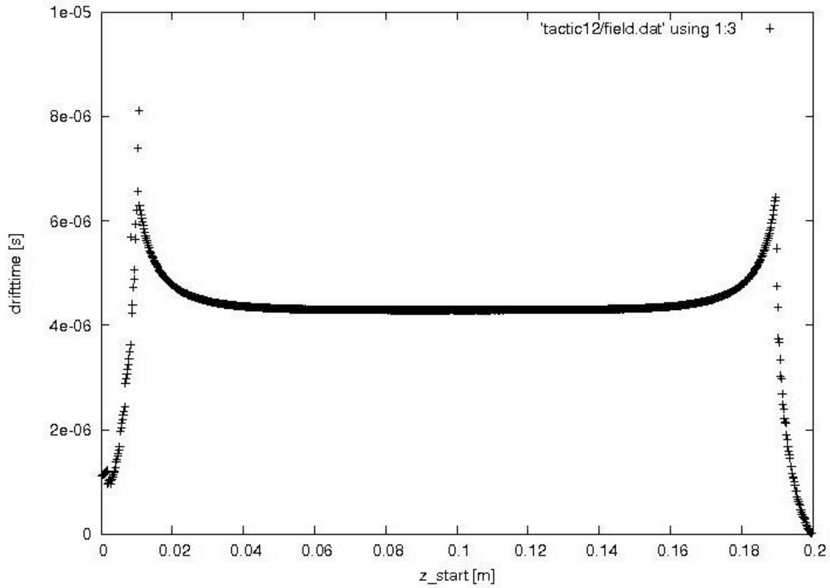


e⁻ drift time

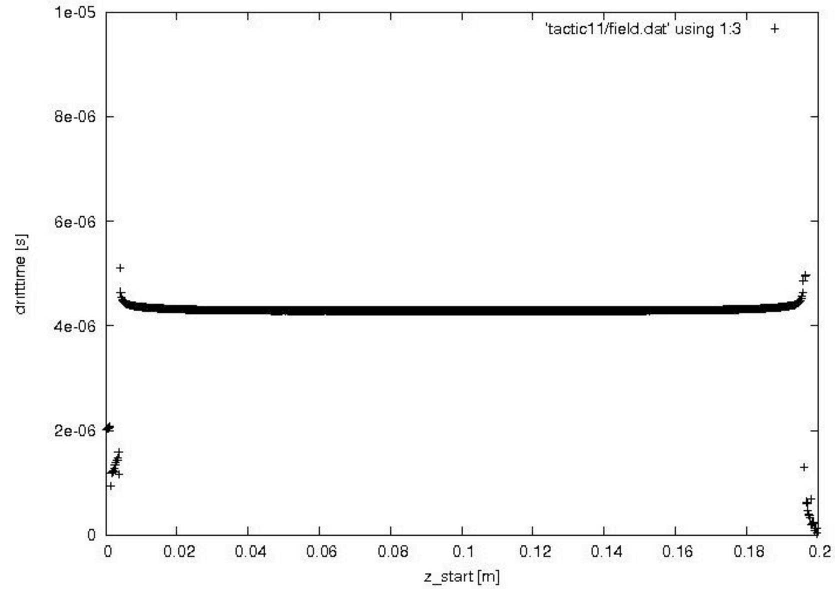
- assume $w_{drift}(E) = 0.9 \frac{\text{m}}{\text{s}} / \frac{\text{V}}{\text{m}} \cdot E$

  (approx. for 90% Ar + 10% CO_2)





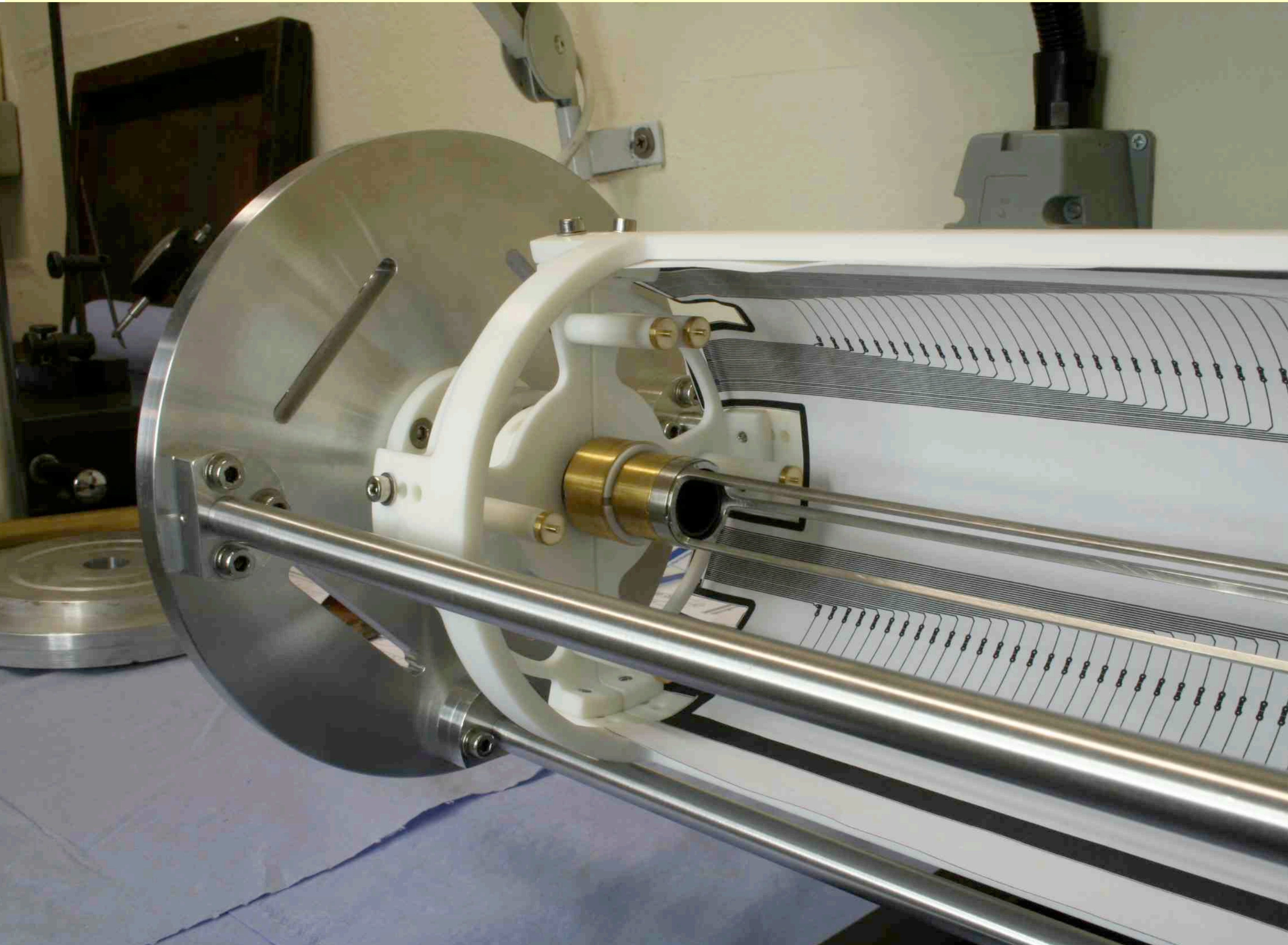
no pads

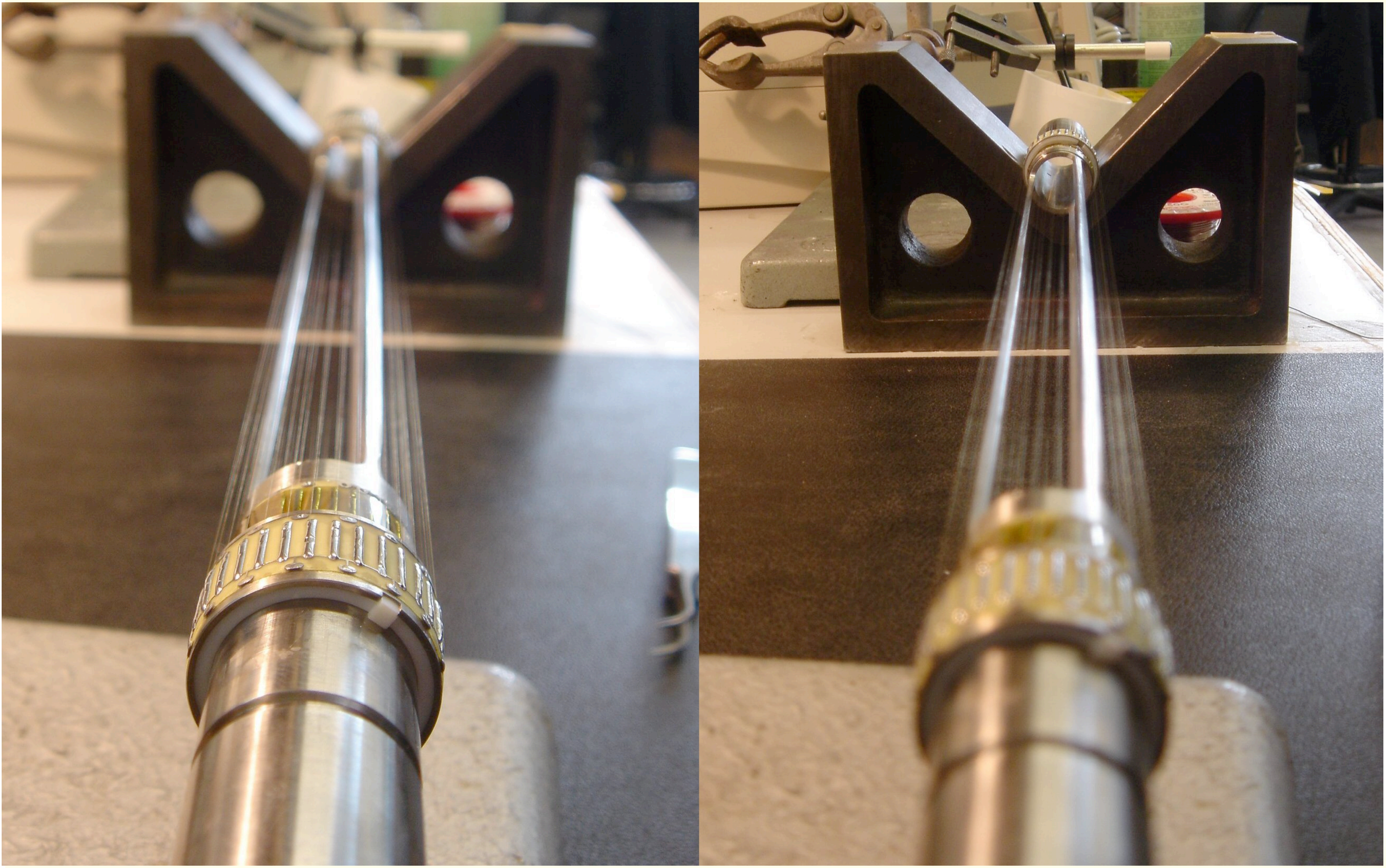


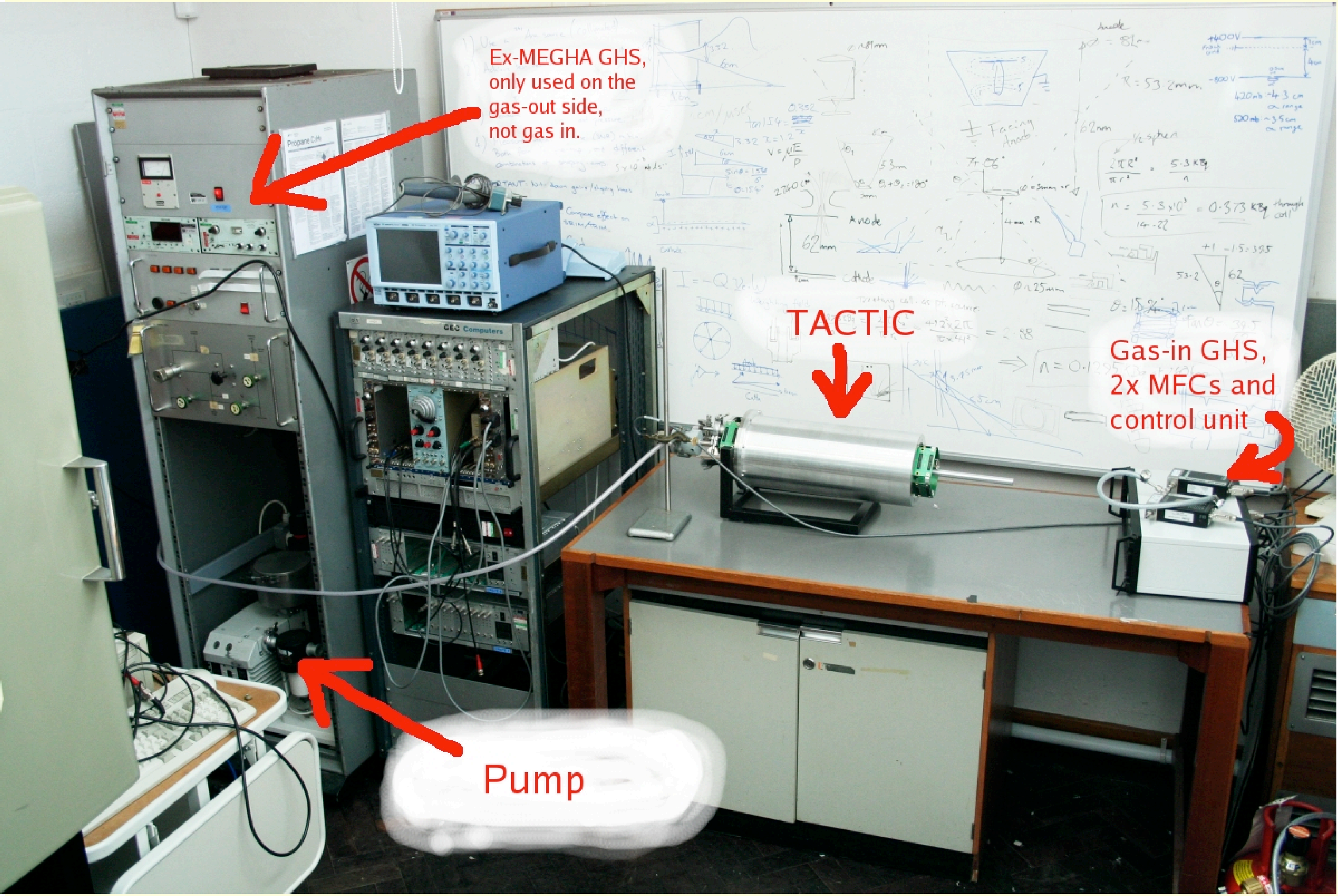
3 pads

*) from A. Peisert, F. Sauli: Drift and Diffusion of Electrons in Gases, Fig. 63, CERN, 1984


2nd board mounted
on mandrel, about
to be glued






Ex-MEGHA GHS,
only used on the
gas-out side,
not gas in.
TACTIC
Gas-in GHS,
2x MFCs and
control unit
Pump

Future detectors

GANIL (AC) / DAPNIA / CENBG
CCLRC DARESBURY (FC)
U. LIVERPOOL (AC) / U. BIRMINGHAM *
U. SANTIAGO DE COMPOSTELA (AC) / GSI / INP CRACOW *
(associated participant)*