A new focal plane detector for the K600

R Neveling, P Adsley, T. Khumalo, P Papka,
L Pellegri, FD Smit

iThemba Laboratory for Accelerator Based Sciences
University of the Witwatersrand
University of Zululand
Stellenbosch University

Conference on Neutrino and Nuclear Physics 2020

(CNNP2020)
Cape Town (South Africa)
24-28 February 2020

Scientific topics

Nuclear double beta decays
Nuclear structure in connection with neutrino physics
Nuclear reactions as a probe for weak decays
Neutrino-nucleus interaction at low and high energy
Supernova models and detection of supernova neutrinos
Solar models and detection of solar neutrinos
Direct and indirect dark-matter searches
Rare beta decays of nuclei for neutrino-mass measurements
Neutrino oscillations and matter effects
Anomalies in reactor neutrinos
New related detection technologies

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https://indico.tlabs.ac.za/event/85/
cnnp2020@tlabs.ac.za

CNNP2020

...to promote collaboration between scientists from the fields of nuclear, neutrino, astro and dark-matter physics...

24 – 28 February

Where:
In the vicinity of Cape Town

See poster at conference office

Website: **https://indico.tlabs.ac.za/event/85/**
Email: **cnnp2020@tlabs.ac.za**

The K600: a kinematically corrected** QDD magnetic spectrometer for light ions

BaGeL run: December 2018

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** Not to the level of a Q3D though

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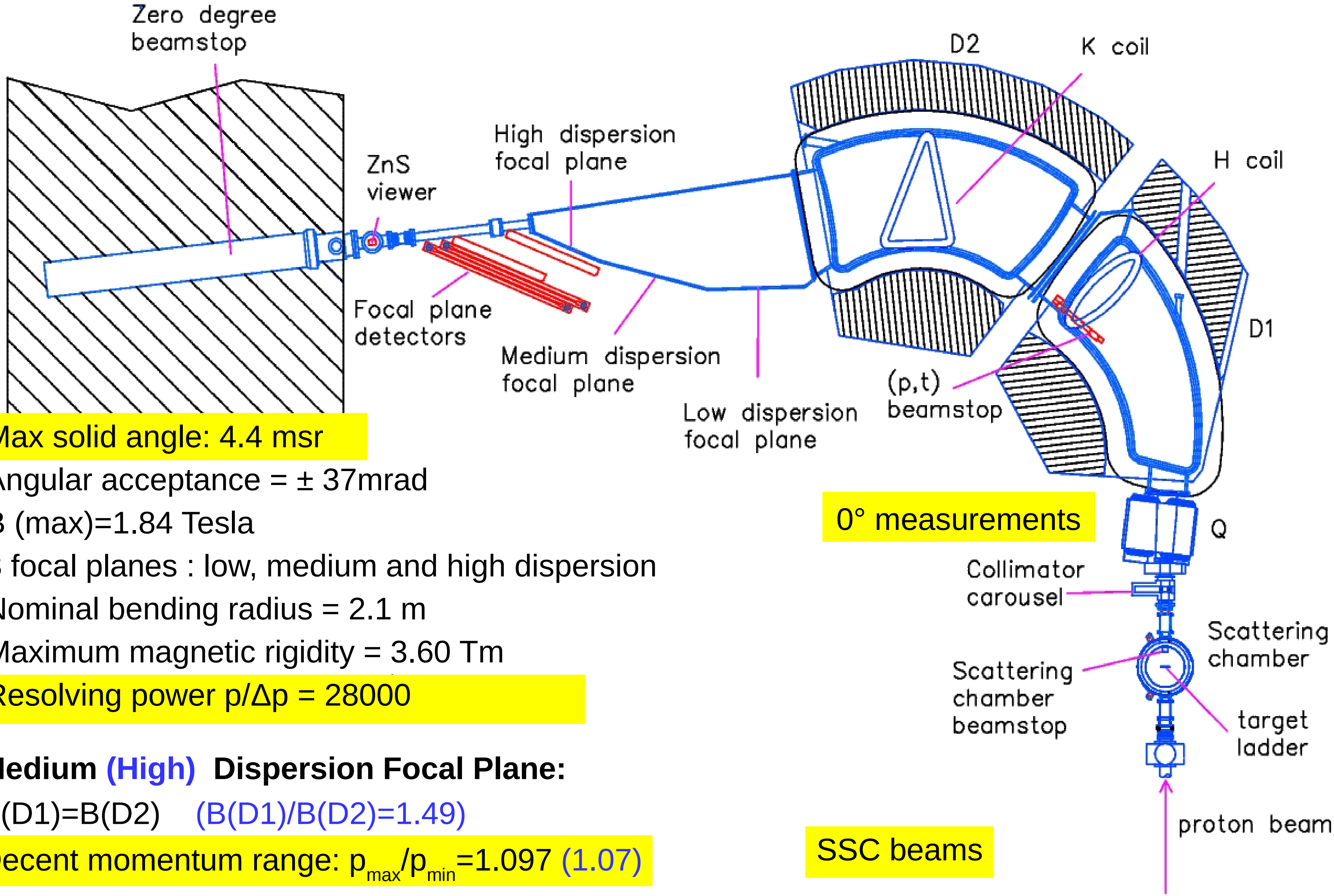
The K600: defining characteristics



0° measurements

SSC beams

Max solid angle: 4.4 msr

Angular acceptance = ± 37mrad

B (max)=1.84 Tesla

3 focal planes : low, medium and high dispersion

Nominal bending radius = 2.1 m

Maximum magnetic rigidity = 3.60 Tm

Resolving power p/Δp = 28000

Medium (High) Dispersion Focal Plane:

B(D1)=B(D2) (B(D1)/B(D2)=1.49)

Decent momentum range: p_{max}/p_{min}=1.097 (1.07)

Horizontal magnification M_x =-0.52 (-0.74)

Vertical magnification M_y =-5.5 (-7.05)

Dispersion: 8.4 cm/% (10.9 cm/%)

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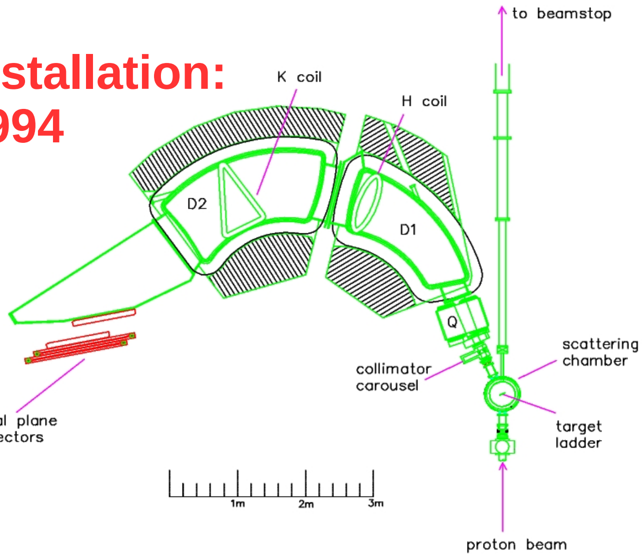
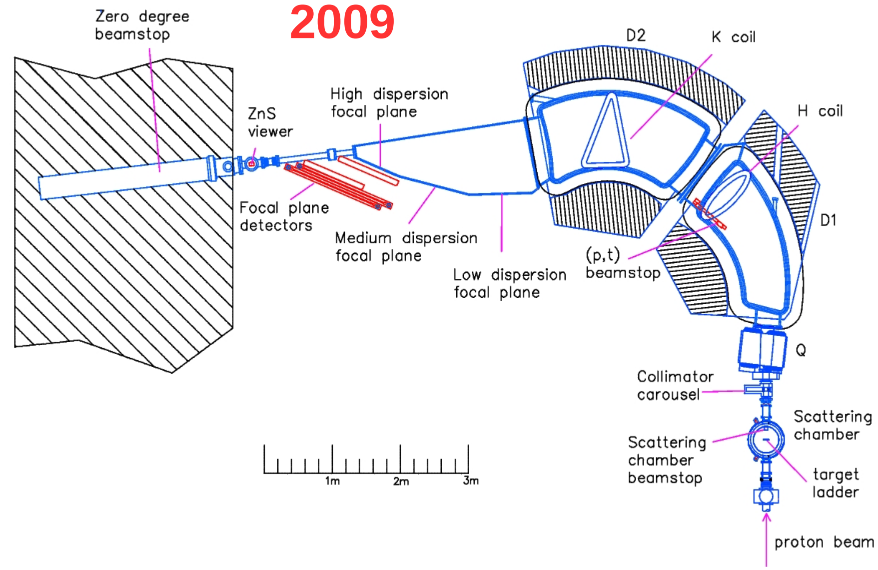
The evolution of the K600

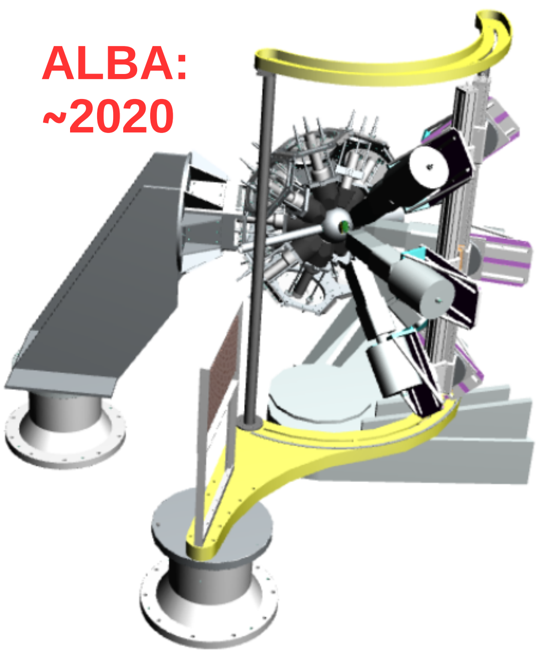
Installation: 1994



Zero degrees: 2009

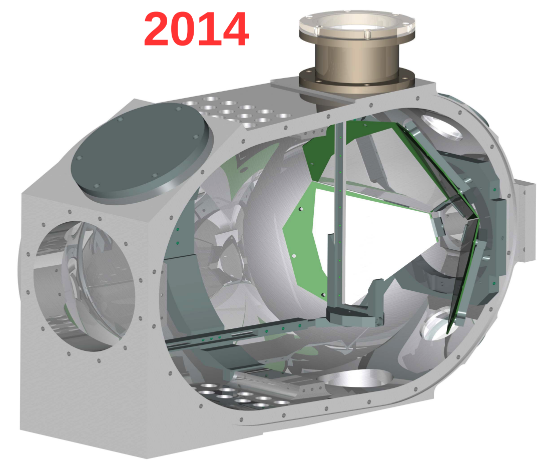


ALBA: ~2020



BaGeL: 2016

CAKE: 2014



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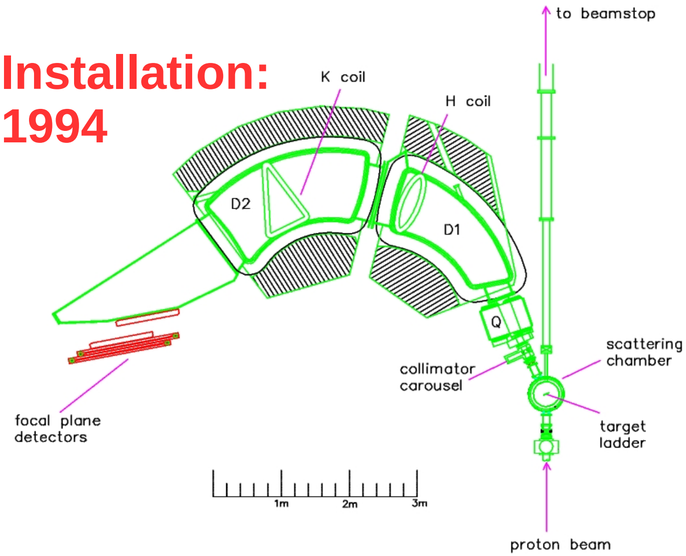

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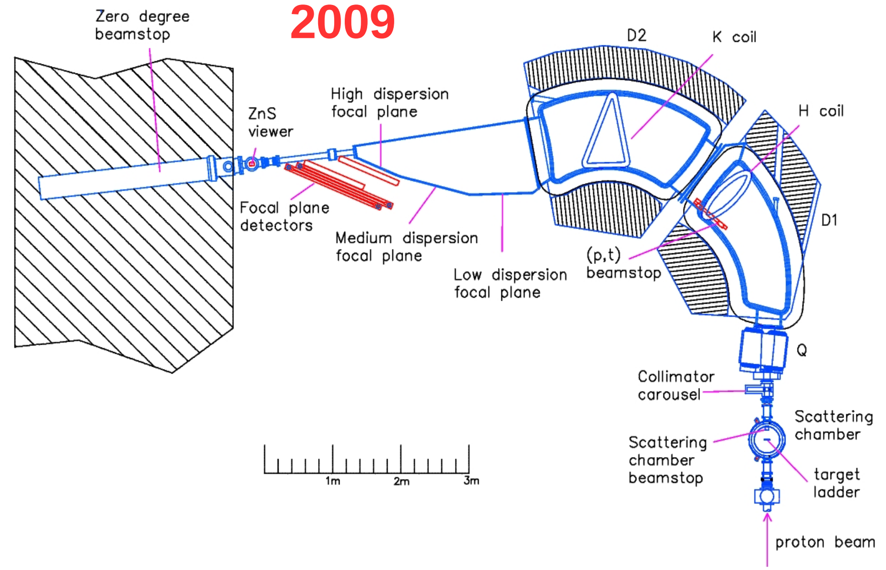

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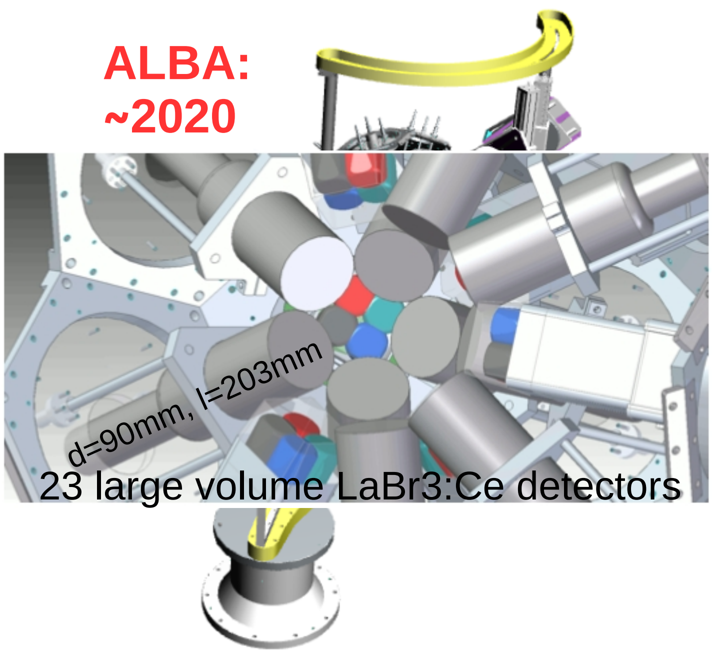

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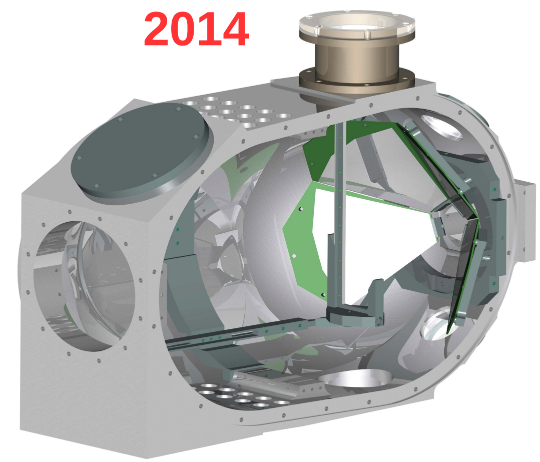

A low E Focal Plane Detector: 20??

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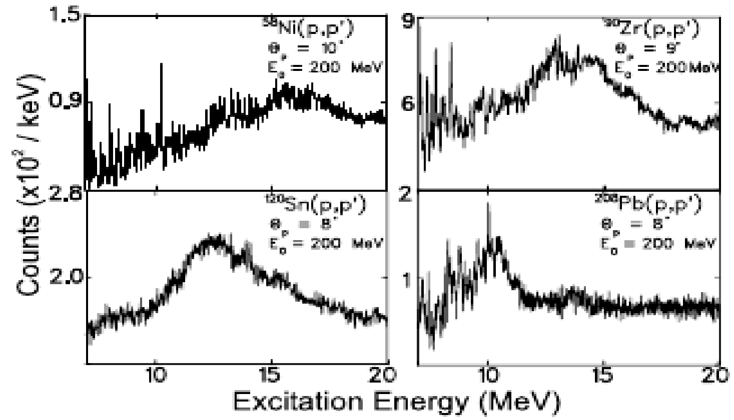
K600 physics program

High resolution **giant resonance** studies e.g.

- IVGDR: (p,p') with E_p = 200 MeV at 0°, ΔE ~ 45 keV (FWHM)
- ISGQR: (p,p') with E_p = 200 MeV at 7°, ΔE ~ 30-45 keV (FWHM)
- ISGMR: (α,α') with E_α = 200 MeV at 0°,4°, ΔE ~ 70 keV (FWHM)

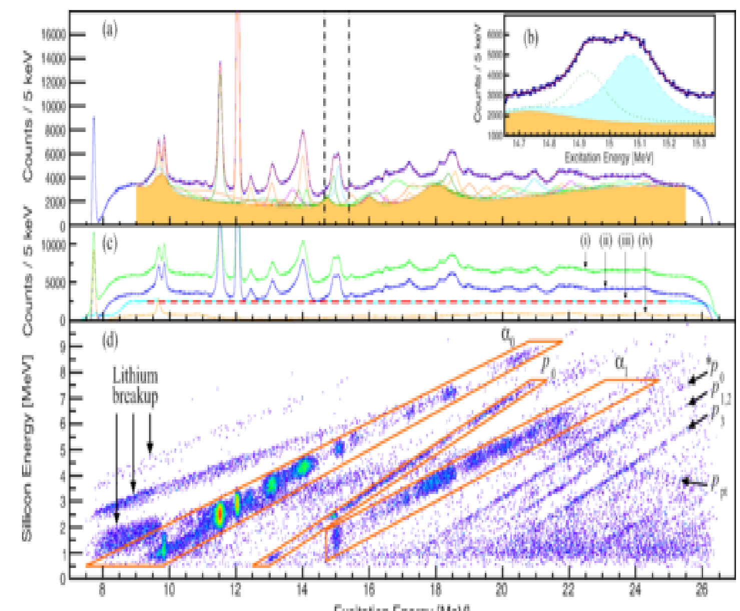


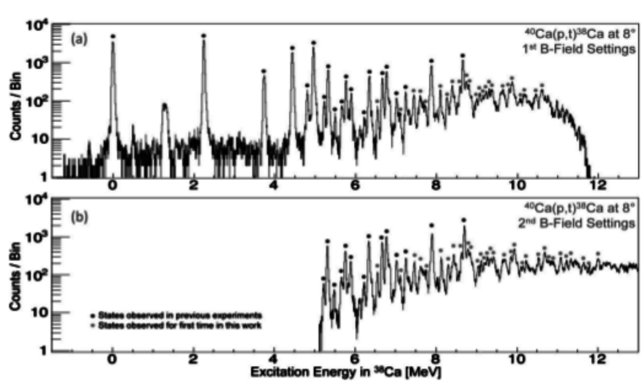
Nuclear reaction mechanism studies e.g. α knockout (p,pα) studies at E_p= 100 MeV, or proton knockout (p,2p) at 200 MeV

Searching for **cluster states, their collective excitations and particle decay** through CAKE coincidences using e.g. high resolution (p,p’) at 66 MeV, (α,α') = 200 MeV, (p,t) at 66 MeV

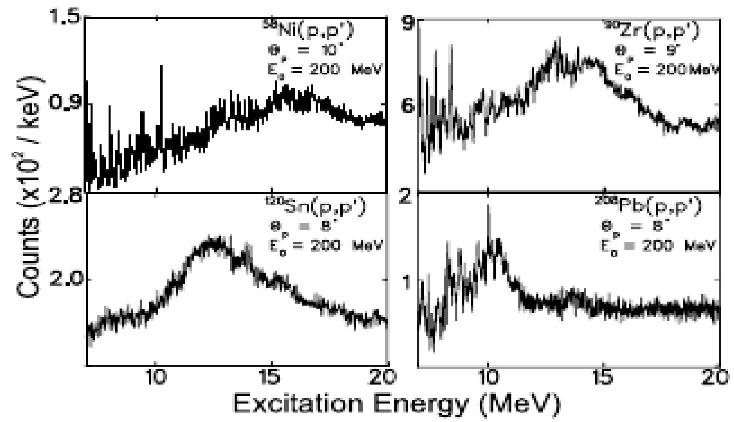
High resolution nuclear structure studies of nuclei for **astrophysical interest**: (p.t) at 100 MeV and 0°

PDR studies in coincidence with the BaGeL gamma detector array: (α,α') with E_α = 120 MeV at 0°





K600 physics program



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- ISGMR: (α,α') with E_α = 200 MeV at 0°,4°, ΔE ~ 70 keV (FWHM)

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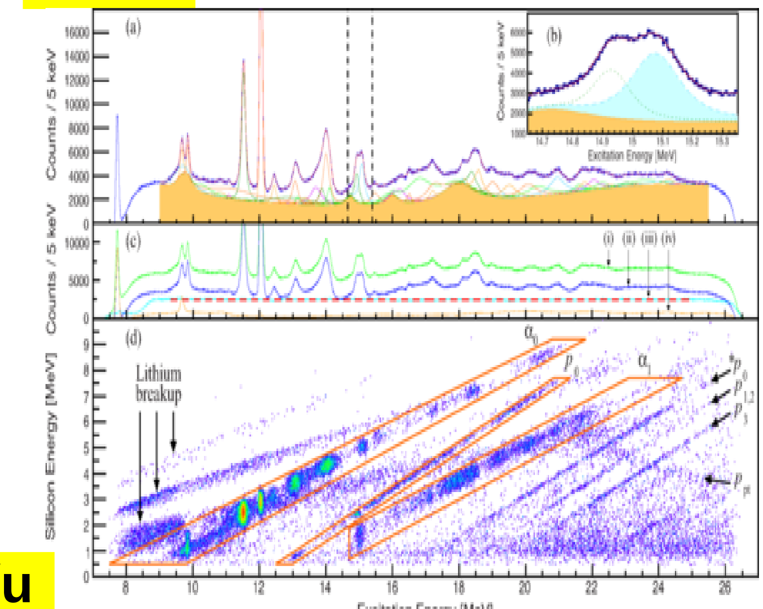

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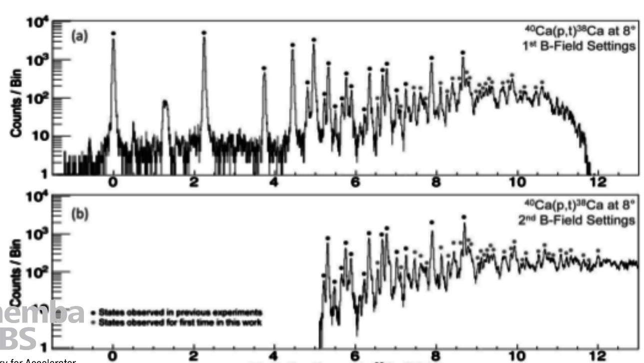


Z = 1,2

30-200 MeV/u

high energy resolution

Topics for research requiring new FPD

Low energy scattering

- low-spin modes for topics in clustering *Phil Adsley*
- shape co-existence studies (coincident conversion electron spectroscopy) *Pete Jones*

Alpha-cluster transfer using the (d,6Li) reaction *Phil Adsley*

Two-neutron transfer using (p,t) for pairing studies

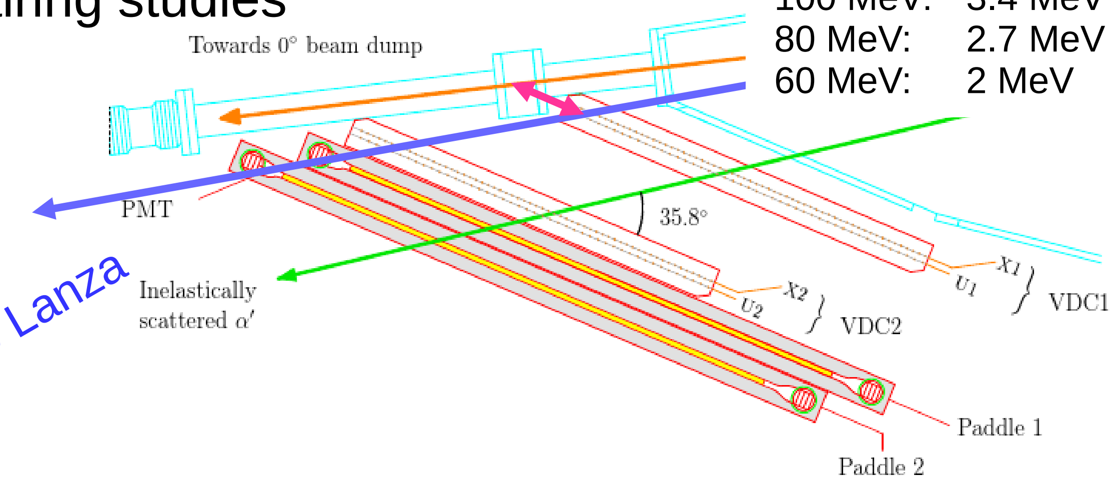
Also e.g. (4He,6He)

Single-nucleon transfer

- to high-L orbitals (d,3He)
- for PDR studies (d,p) and (p,d) *Edoardo Lanza*

Coulomb excitation studies

Ebeam	Ex
120 MeV:	4 MeV
100 MeV:	3.4 MeV
80 MeV:	2.7 MeV
60 MeV:	2 MeV



Particles in the focal plane:

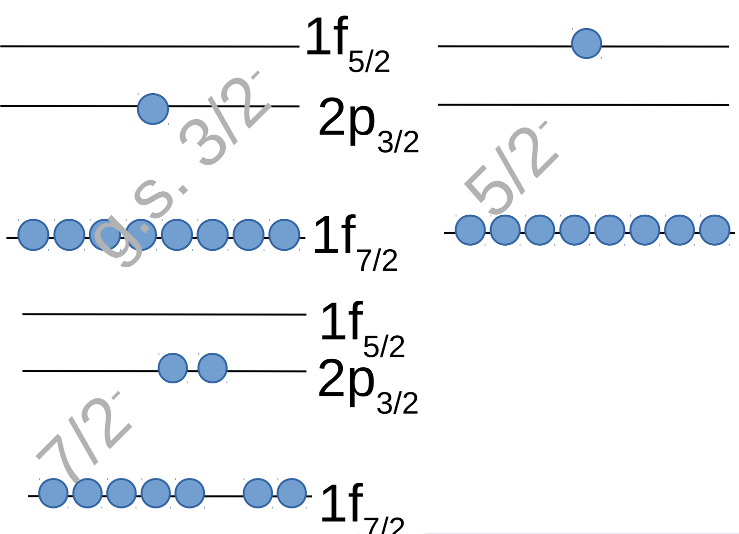
Protons	20 MeV
Tritons	10 MeV/u
3He	10-25 MeV/u
4He	10-15 MeV/u
6Li	8-12 MeV/u
12C	4 MeV/u
18O	4 MeV/u

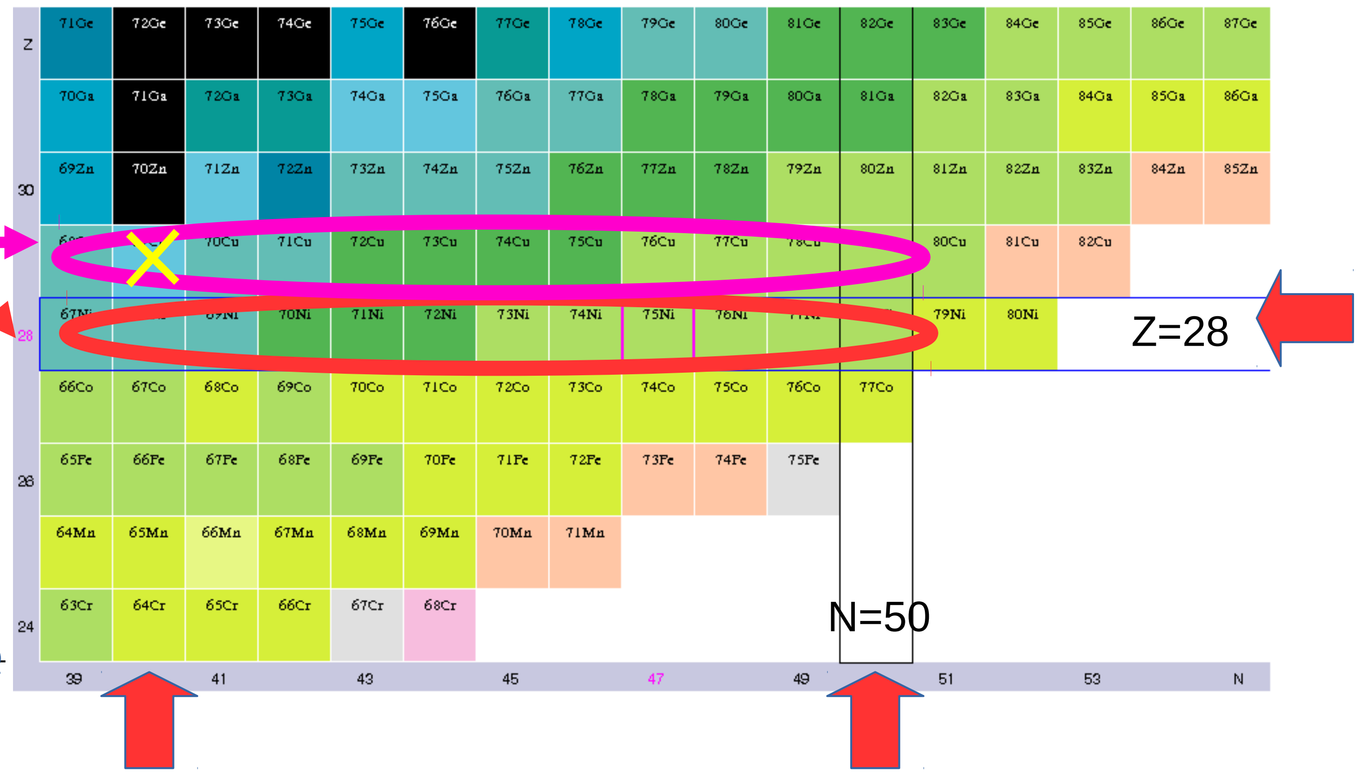
Probing the proton gap: behavior of $\pi f_{7/2}$

Understand evolution of Z=28 proton gap

Cu isotopes, Z=29
1 p outside Ni core

Looking for E differences between orbitals





Start filling $\nu g_{9/2}$ orbital

^{78}Ni: β decay half-life suggest sizable magicity
(PRL 113 (2014) 032505)

Orbitals behaviour will constrain the πf -νg 9/2 proton-neutron interaction
allow test of strength of the tensor interaction and determine the spin-orbit splitting in this region.

^{70}Zn(d,^{3}He)^{69}Cu
Recent study at Orsay
with the SplitPole @ 27 MeV
Pierre Morfouace et al. PRC **93** 064308 (2016)

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Probing the proton gap: behavior of $\pi f_{7/2}$

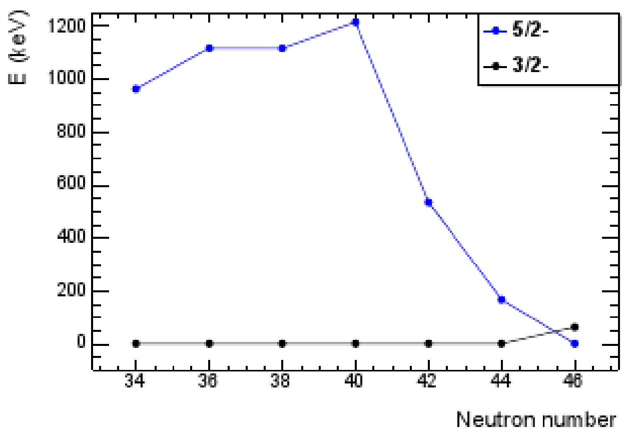
Probing the Z=28 proton gap: behavior of πf7/2 orbital

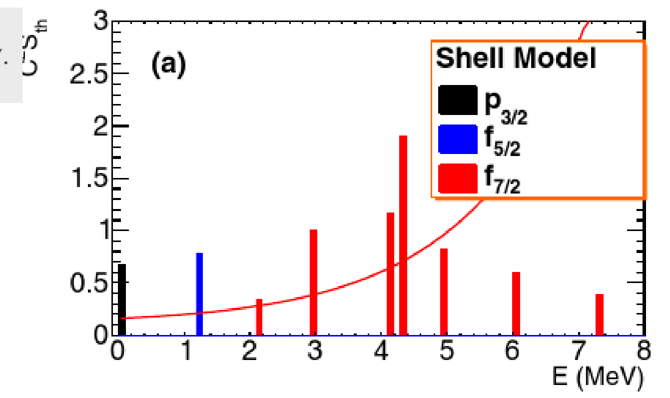
Orsay Enge split pole at 6°,9°,12°,15, 18°,21°,24°
27 MeV deuteron beam
42 keV (FWHM) resolution
Angular distributions of states below 7 MeV to determine jπ

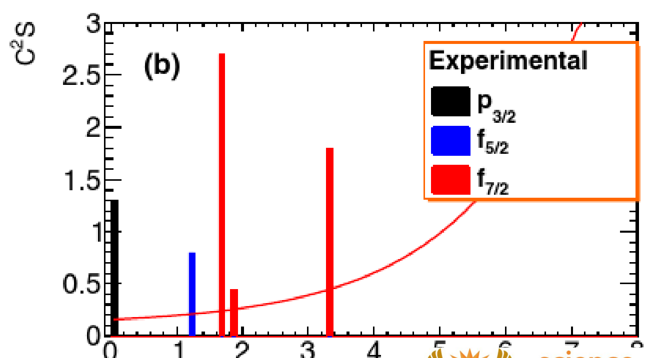
Missing strength, no proper momentum matching for L=3
Lower limit of $7/2^-$ centroid established

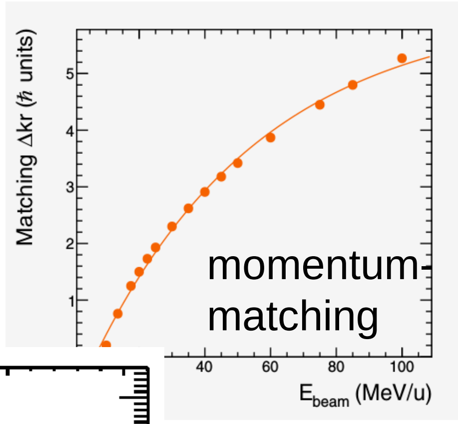
$$E(f_{7/2}) = \sum \frac{C^2S(7/2^-)E(7/2^-)}{C^2S(7/2^-)} = 2.45\ \text{MeV}.$$

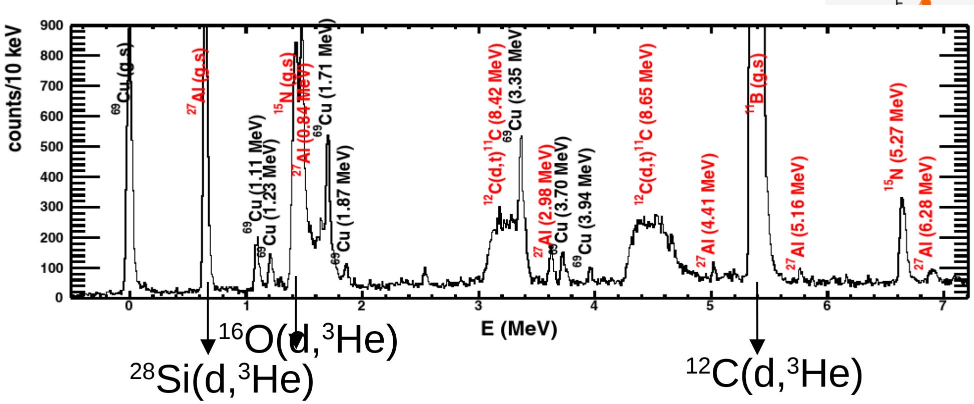
Need higher E beam from cyclotron
(75-90 MeV deuterons)











Why new detectors?

1. Material budget **limits particles species and energies** we can look at

2. For Z=1,2 particles we can go down fairly low, but we **lose energy resolution** due to **loss of tracking capability**

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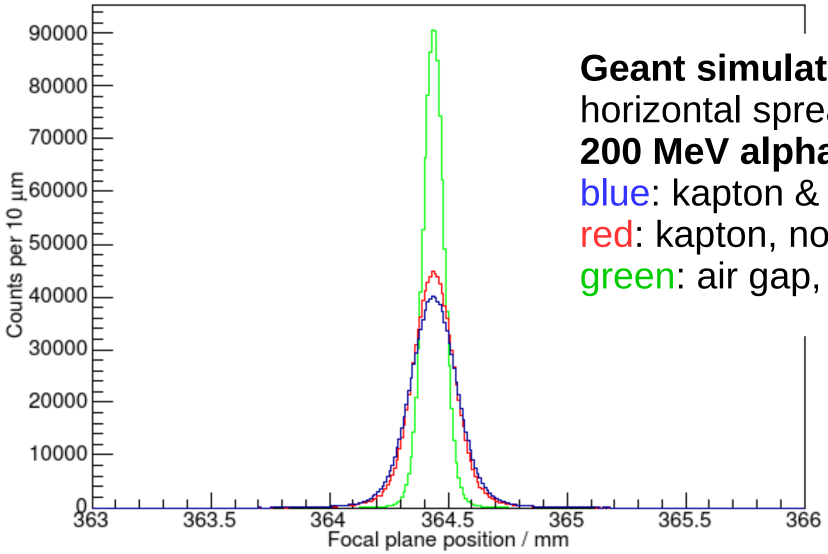
2. For Z=1,2 particles we can go down fairly low, but we **lose energy resolution** due to **loss of tracking capability**

but also

3. Energy resolution affected by **straggling due to thick Kapton window** improve the energy resolution of high E (α,α‘) measurements

(Resolution of (α,α‘) at 200 MeV:
~ 70 - 80 keV (FWHM)
as opposed to 30 - 35 keV for p)

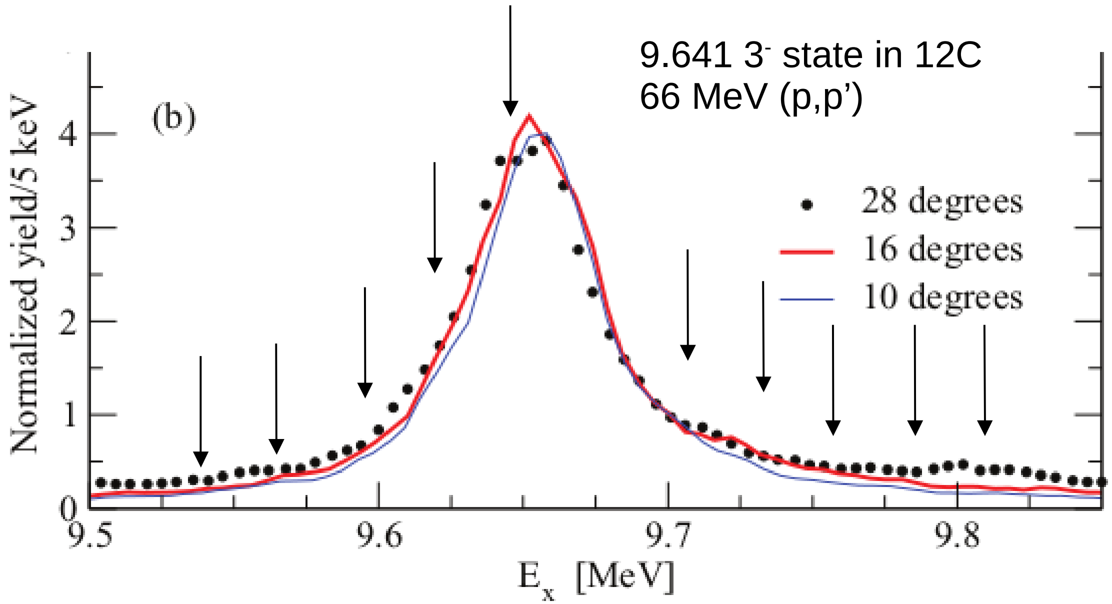


and

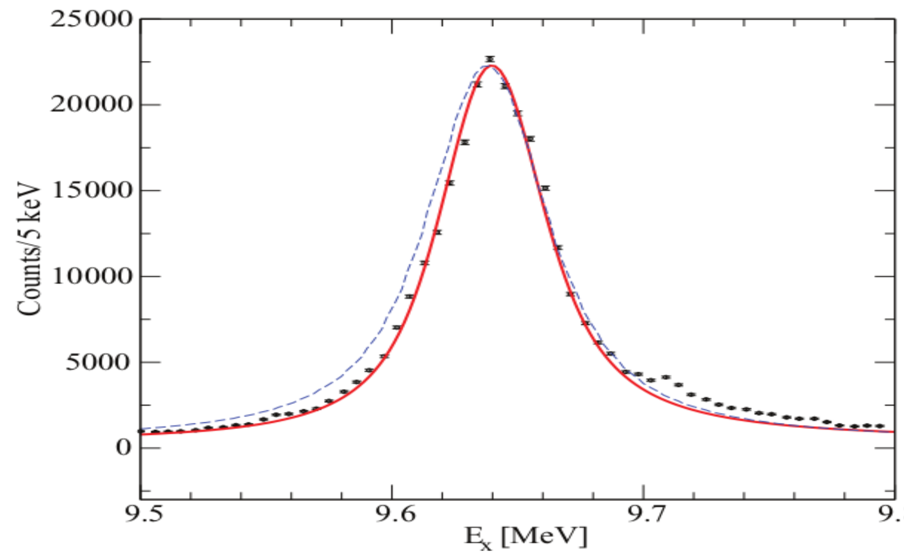
4. Improve **periodicity problems** in short runs

Periodicity in position spectrum

4mm substructure sometimes seen...

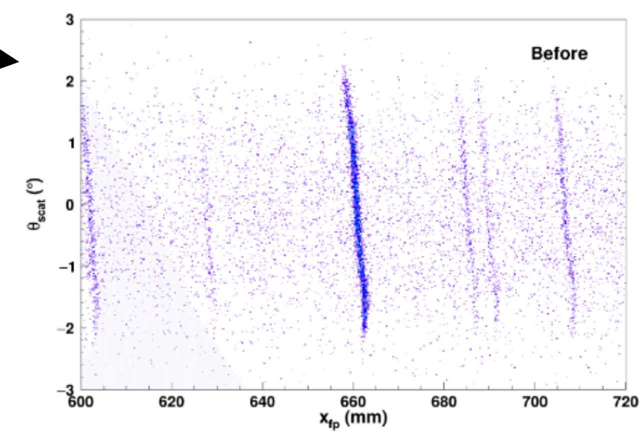


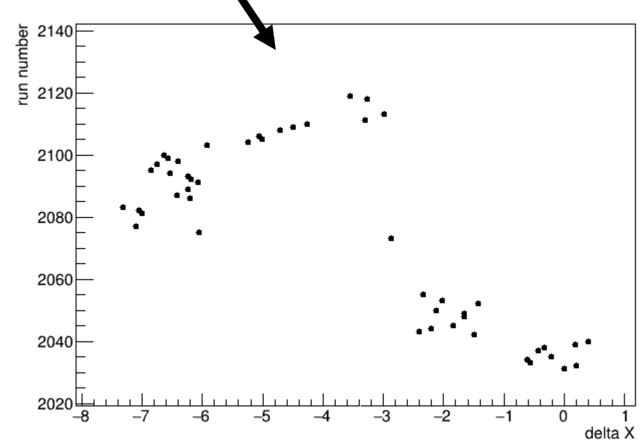
But most of the times not...



Can be avoided

- if you dont do magnetic kinematic correction
- during slightly longer experiments the SSC E changes wipe out 4mm structures





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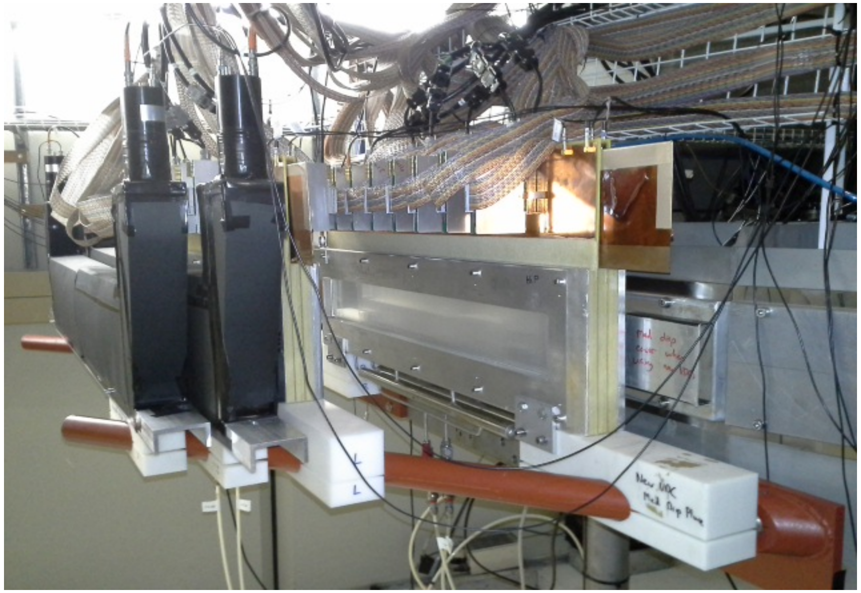
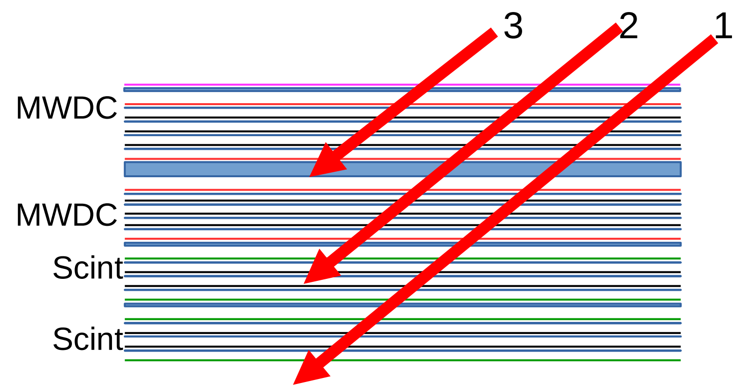
Focal plane detector change

Low energy detection threshold determined by material budget



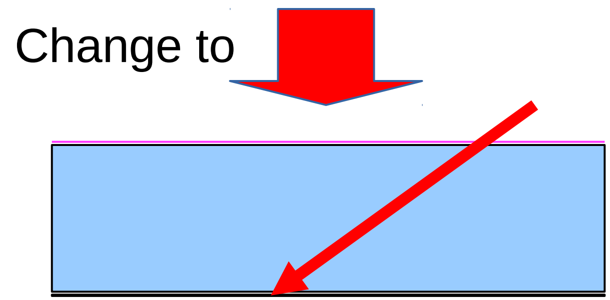


TRIM estimations

1. p: 43-200 MeV
   t: 68-200 MeV
   α: 170-200 MeV

2. p: 21- 43 MeV
   t: 30 - 68 MeV
   α: 78 - 170 MeV
   ^{7}Li: above 165 MeV

3. p: above 14 MeV
   t: above 23 MeV
   α: above 57 MeV
   ^{7}Li: above 110 MeV



New detectors: Proportional Drift Chambers

⇒ gas filled

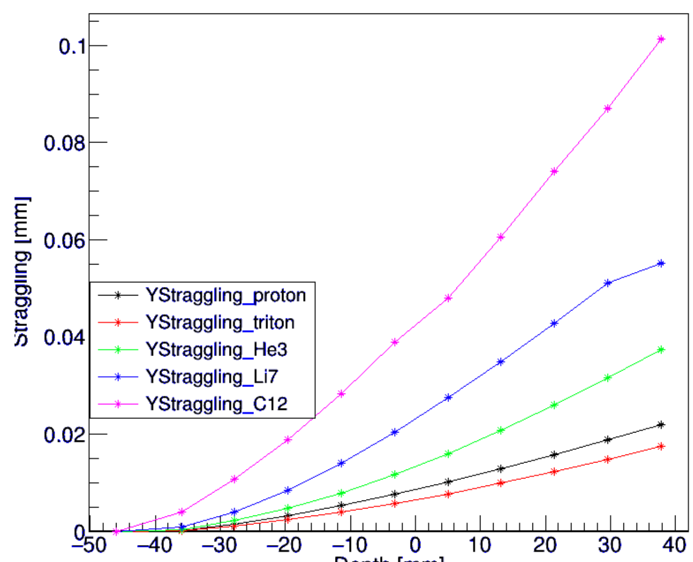
⇒ operates at low pressure (~20 mbar)

⇒ entrance window: few um thick Mylar

⇒ no wires, HV plane at the top

⇒ electrons drift vertically ⇒ TPC-like

⇒ position determined from cathode pads



New detector:
Straggling calculations

for 50 MeV
p,t,^{3}He,^{7}Li,^{12}C

in 100 mbar Ar gas and
1.5 um Mylar window

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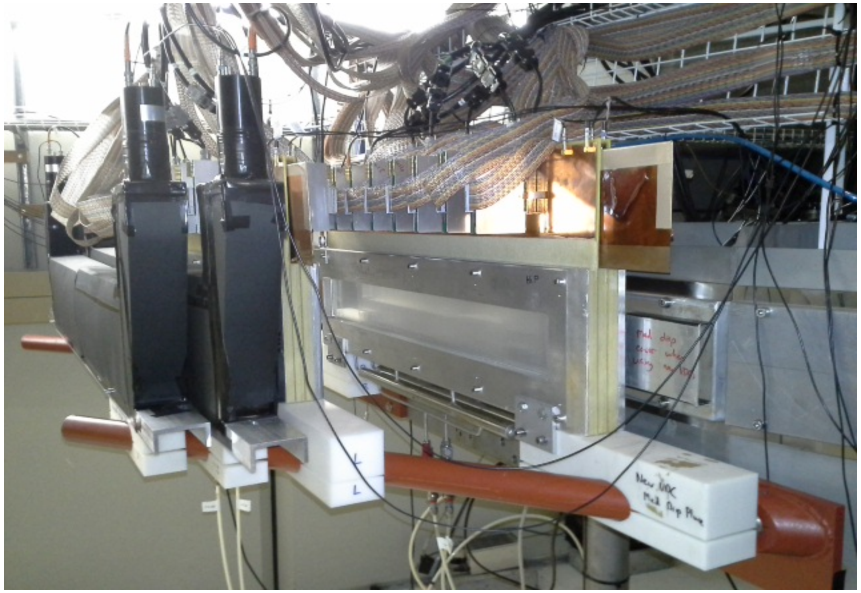
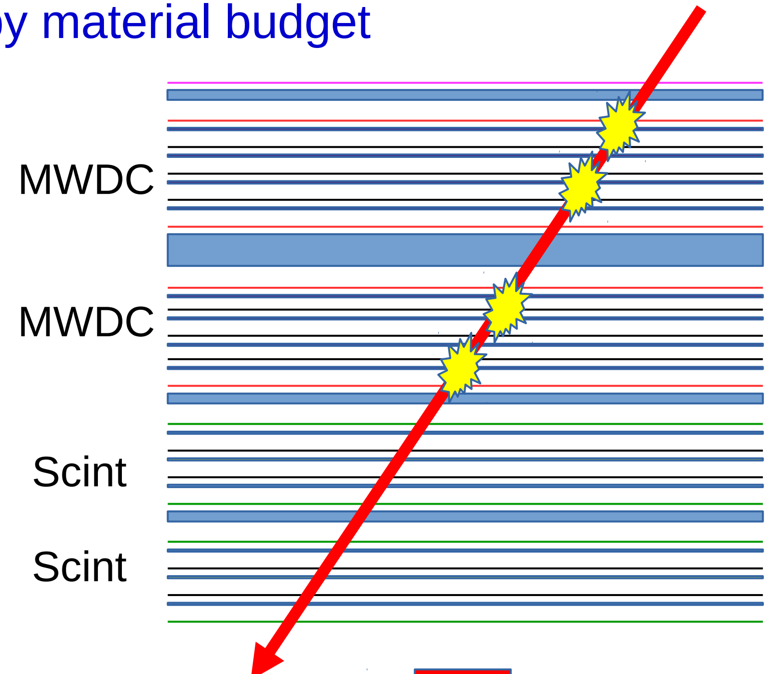
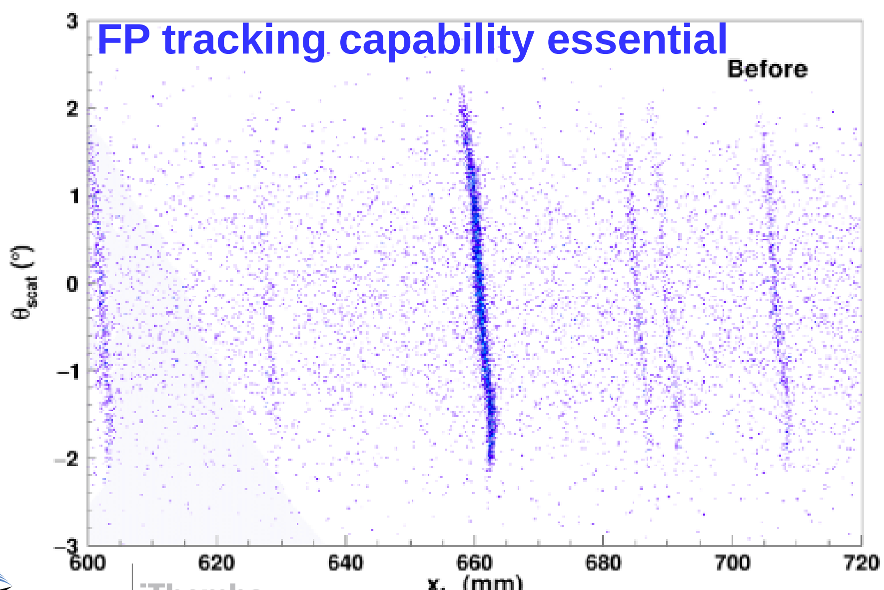
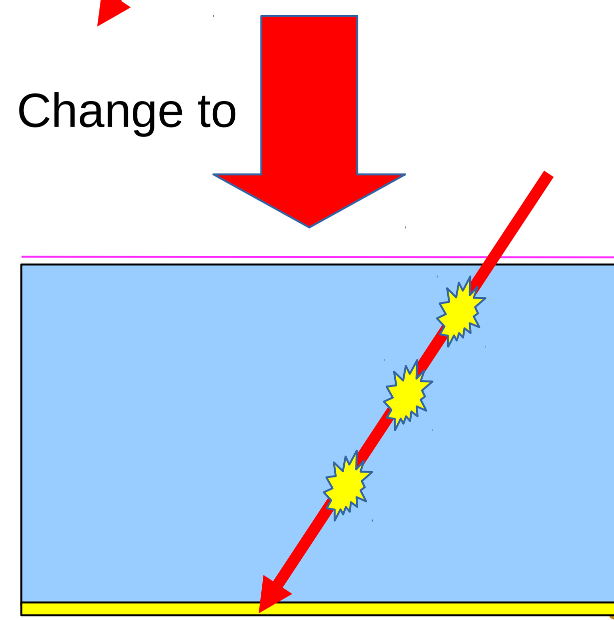




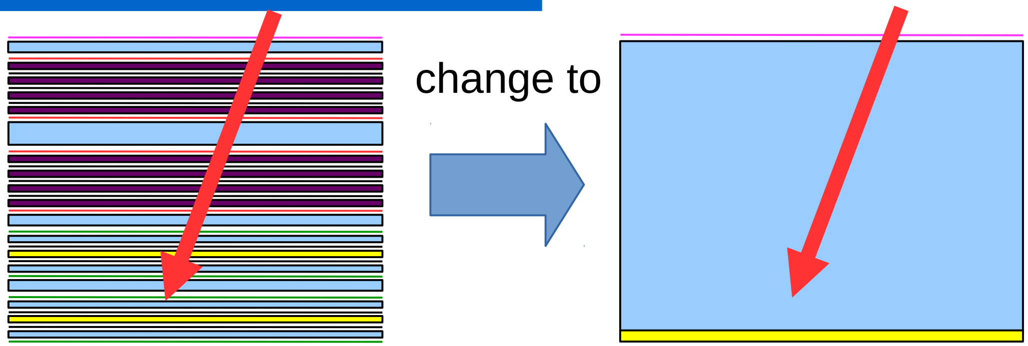




Which new FPD system to use?

Lower detectable E range for Z=1,2
& make Z>2 options available
reduce material budget
Accurate position determination necessary
Accurate angle determination necessary

ΔX: 0.35 mm	Δθ: 2 VDCs: ~1 mrad
ΔY 0.8 mm	1 VDC: ~ 15 mrad



⇒ gas filled
⇒ operates at low pressure (~20 mbar)
⇒ no wires, HV plane at the top/bottom
⇒ electrons drift vertically ⇒ TPC-like
⇒ position determined from cathode pads

Low pressure focal plane detectors:

VAMOS @ GANIL — drift chambers with amplification wires and anode pads, **T_{126} = 0**
dX = 270 micron, dY = 350 micron

horizontal chromatic abberation

MAGNEX @ Catania — drift chambers with amplification wires and anode pads,
dX = dY = 0.6 mm, dθ = 5 mr **(test detector dX = 0.26 mm, only 12° to beam angle)**

PRISMA @ Legnaro — Parallel Plates Avalanche Counters of Multi-Wire type (MWPPAC) , **T_{126} = 0**
dX = 1 mm, dY=2mm

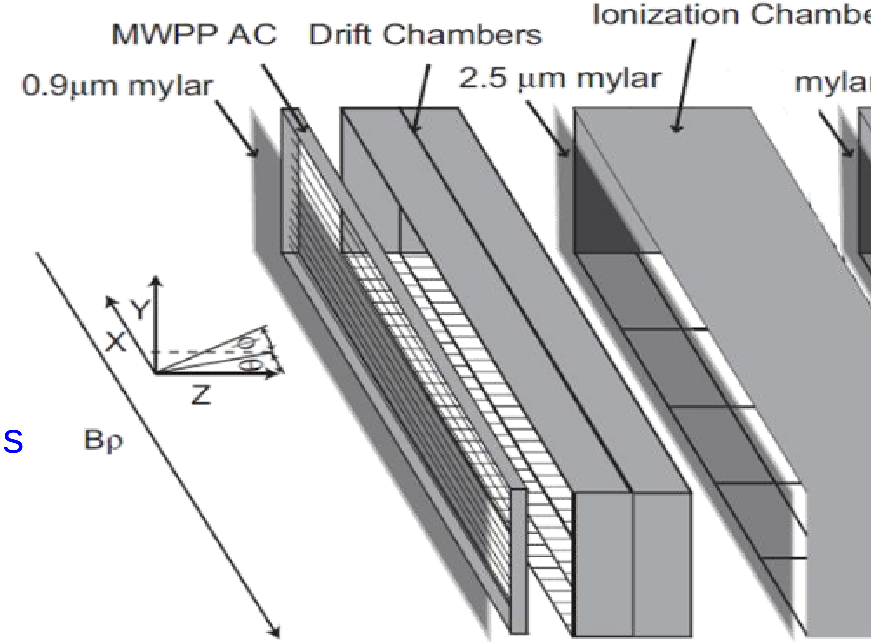
MDM @ Texas A&M — resistive wire ionization chamber, **dX = 1 mm, T_{126} = 0**

Q3D @ Munich — cathode strip detector, for p,d,t,alpha , **dX = 0.1**, **no FP angle info**

Enge Split-pole @ TUNL — similar to Q3D at Munich, **no FP angle info**

VAMOS and MAGNEX FPD systems

Drift chambers, drift region, amplification region, Amplification wires, induced signal on shaped pads



VAMOS:

- energy resolution δE/E = 10 −3
- momentum dispersion of 2 cm/%.

The FPD system of VAMOS, designed for

- light (A ≤15) fast particles (~2-20 MeV/u) from direct reactions
- heavy slow particles (≥ 2 MeV/u) from fusion reactions

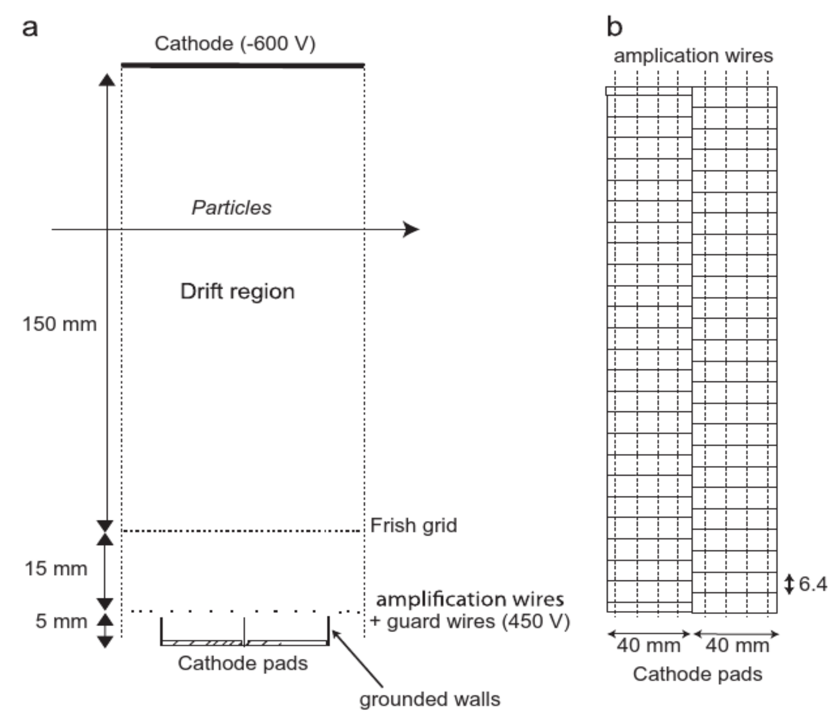
Size: 1000mm x 100mm x 150mm
Rate: less than 10kHz
dX=270 micron, **dY=**350 micron
isobutane @ 6 mbar

MAGNEX:

- energy resolution δP/P = 1/5400
- momentum dispersion of 4 cm/%.

The FPD system of VAMOS, designed for ions 0.2 – 40 MeV/u

Size: 1360mm x 200mm x 96mm
Rate: less than 5 kHz
DX=0.6 mm, **dY=0.6 mm**
isobutane @ 7-30 mbar



VAMOS and MAGNEX FPD systems

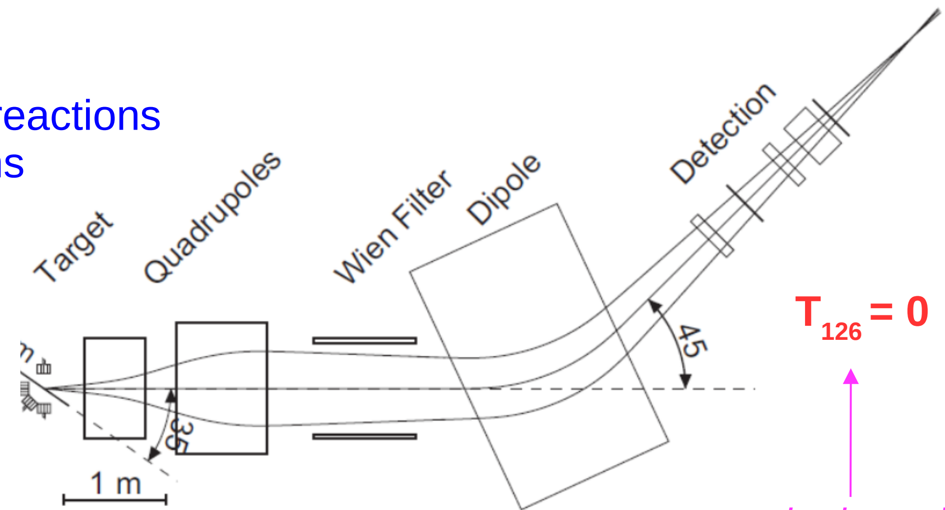
VAMOS:

- energy resolution $\delta E/E = 10 -3$
- momentum dispersion of 2 cm/%.

The FPD system of VAMOS, designed for

- light (A ≤15) fast particles (~2-20 MeV/u) from direct reactions
- heavy slow particles (≥ 2 MeV/u) from fusion reactions

Size: 1000mm x 100mm x 150mm
Rate: less than 10kHz
dX=270 micron, **dY=**350 micron
isobutane @ 6 mbar



$T_{126} = 0$

horizontal chromatic abberation

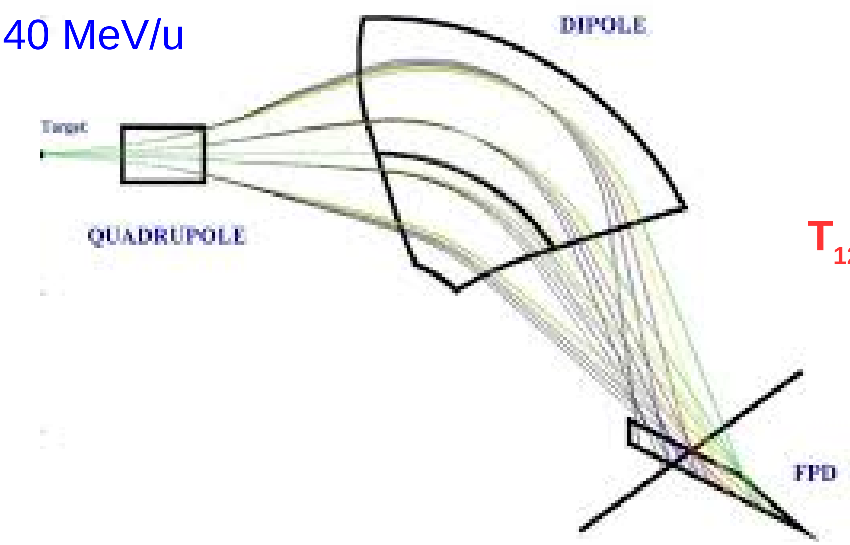
$T_{126} \neq 0$

MAGNEX:

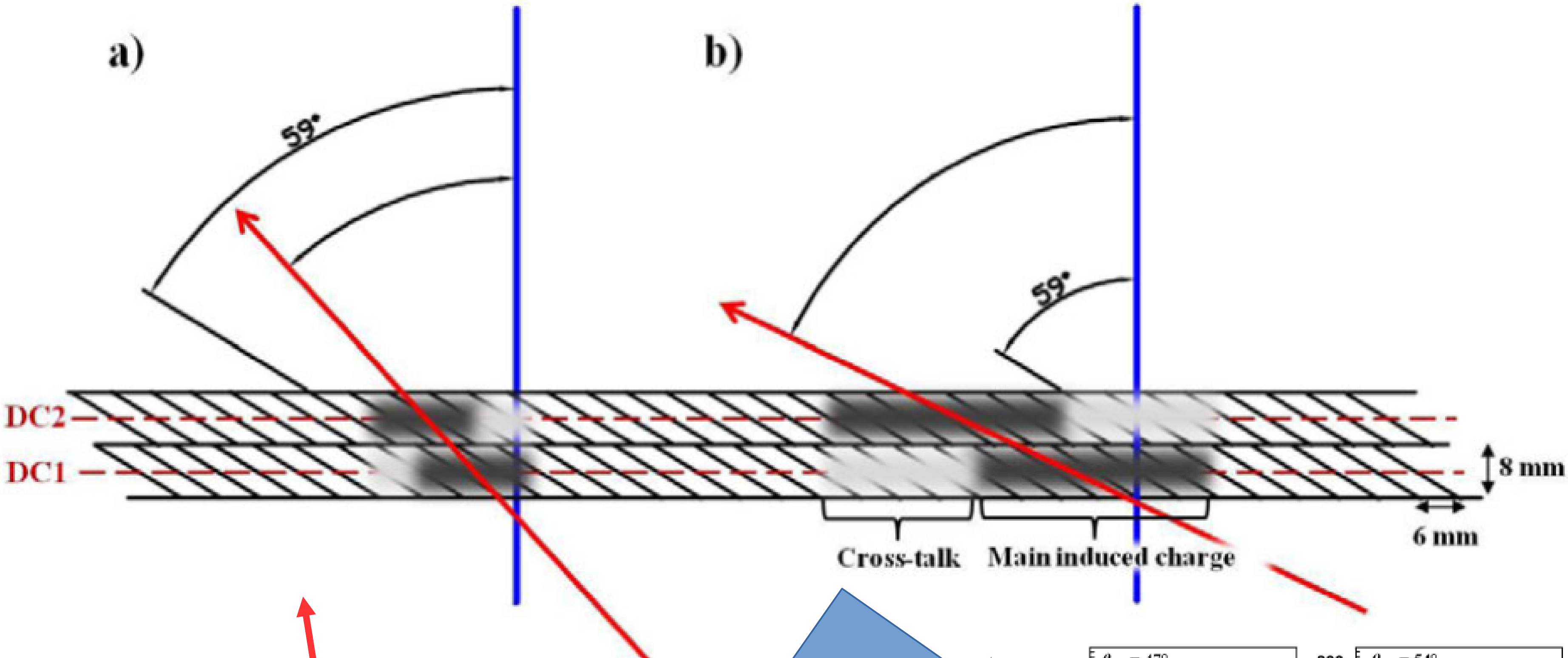
- energy resolution $\delta P/P = 1/5400$
- momentum dispersion of 4 cm/%.

The FPD system of VAMOS, designed for ions 0.2 – 40 MeV/u

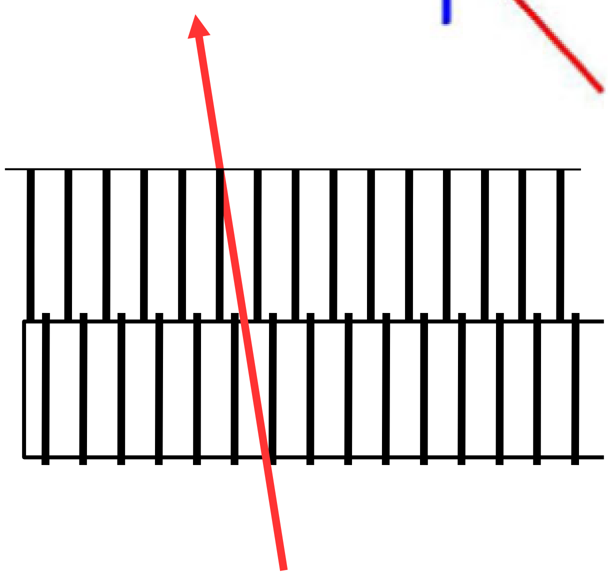
Size: 1360mm x 200mm x 96mm
Rate: less than 5 kHz
DX=0.6 mm, **dY=0.6 mm**
isobutane @ 7-30 mbar

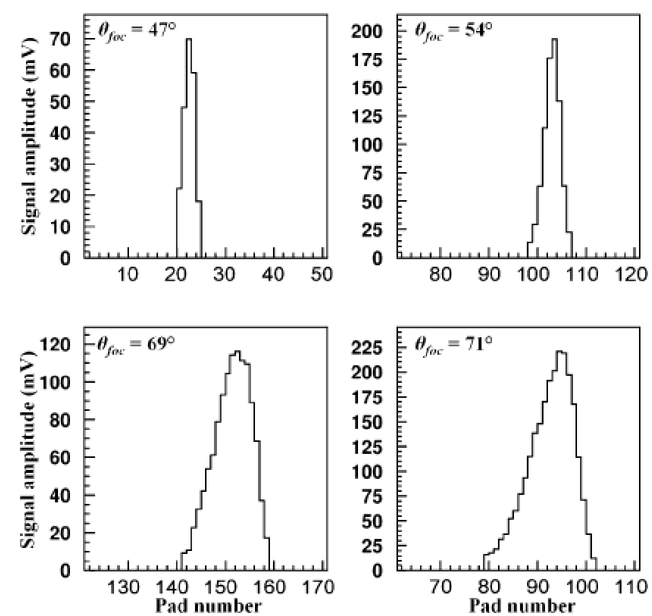


FPD induction pad shape

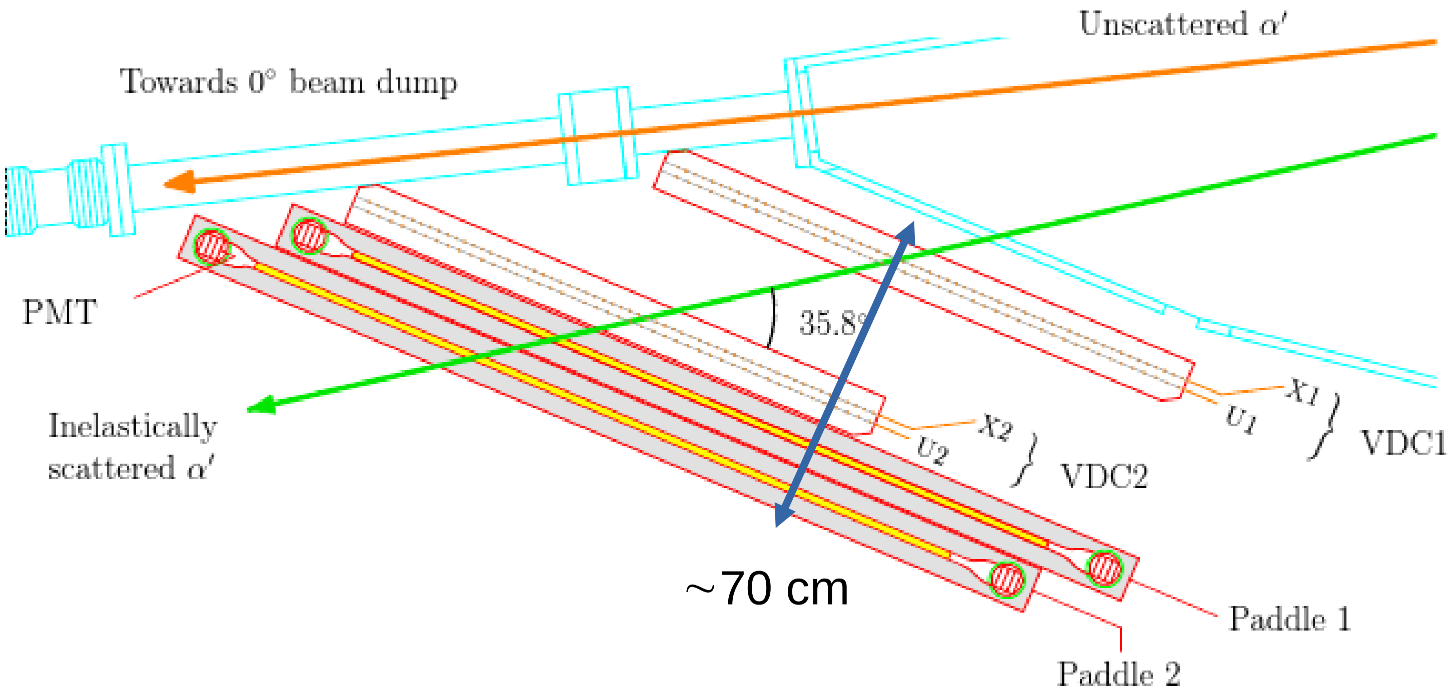


vs

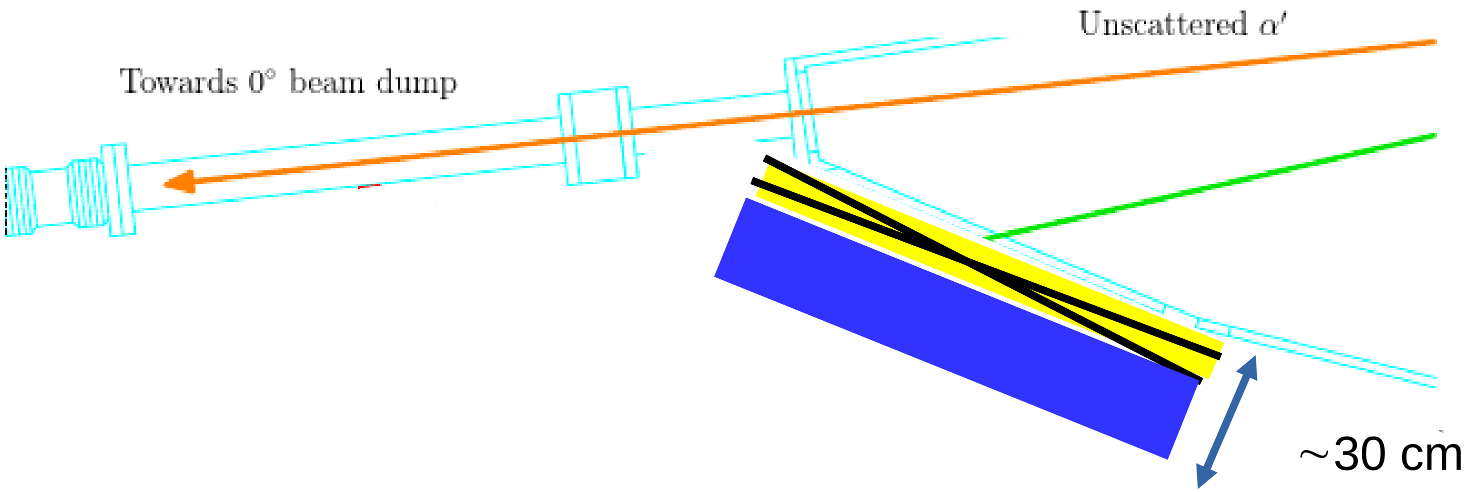


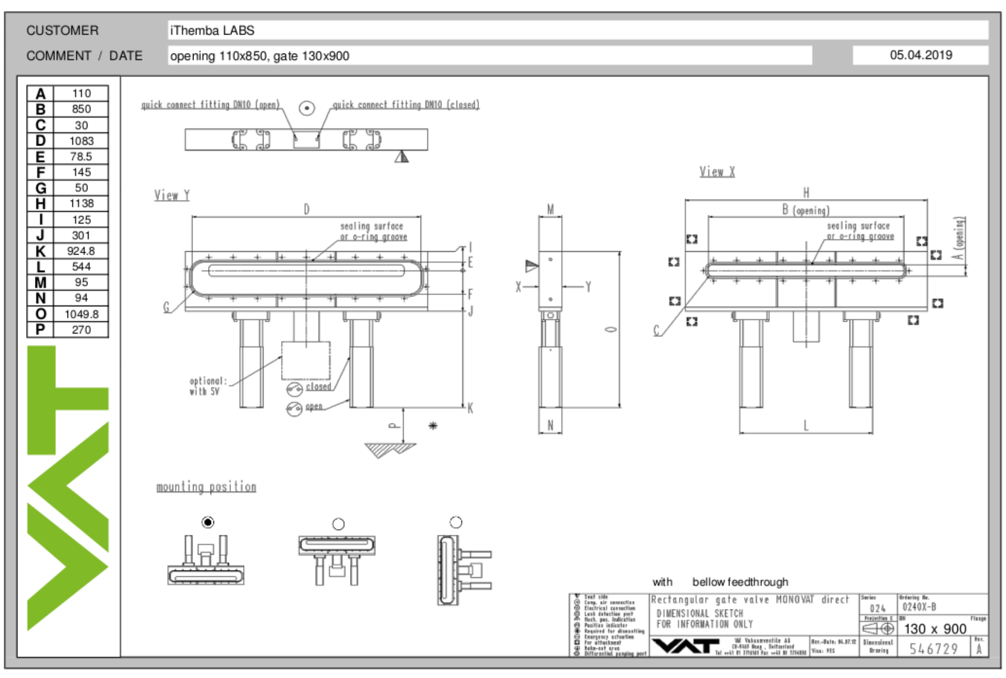


Focal plane detector change

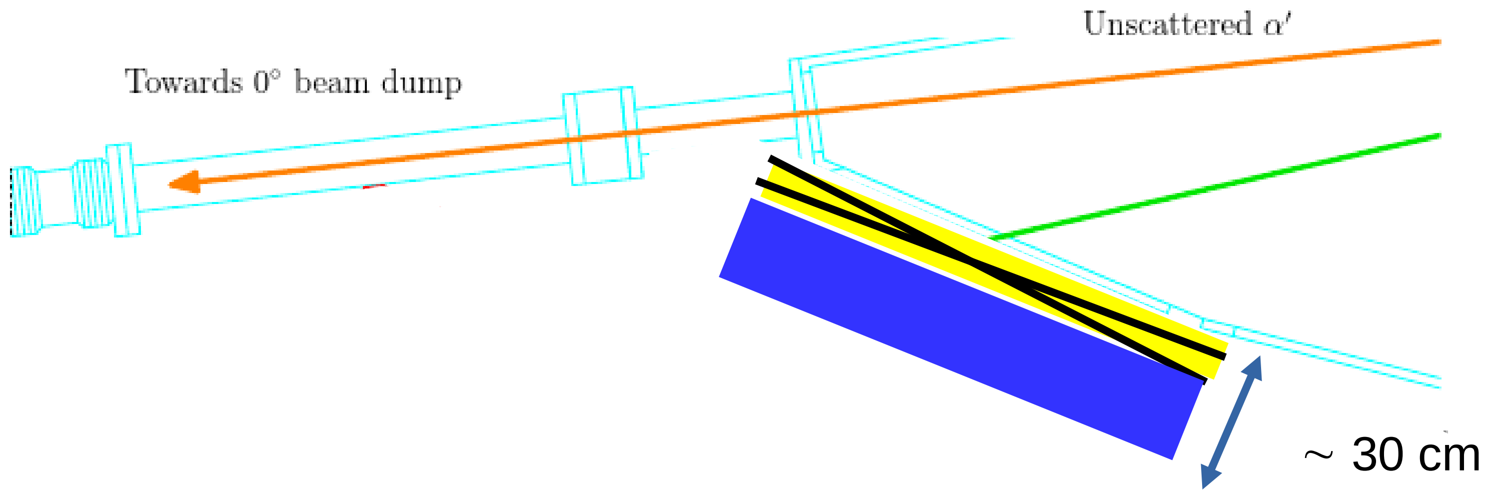


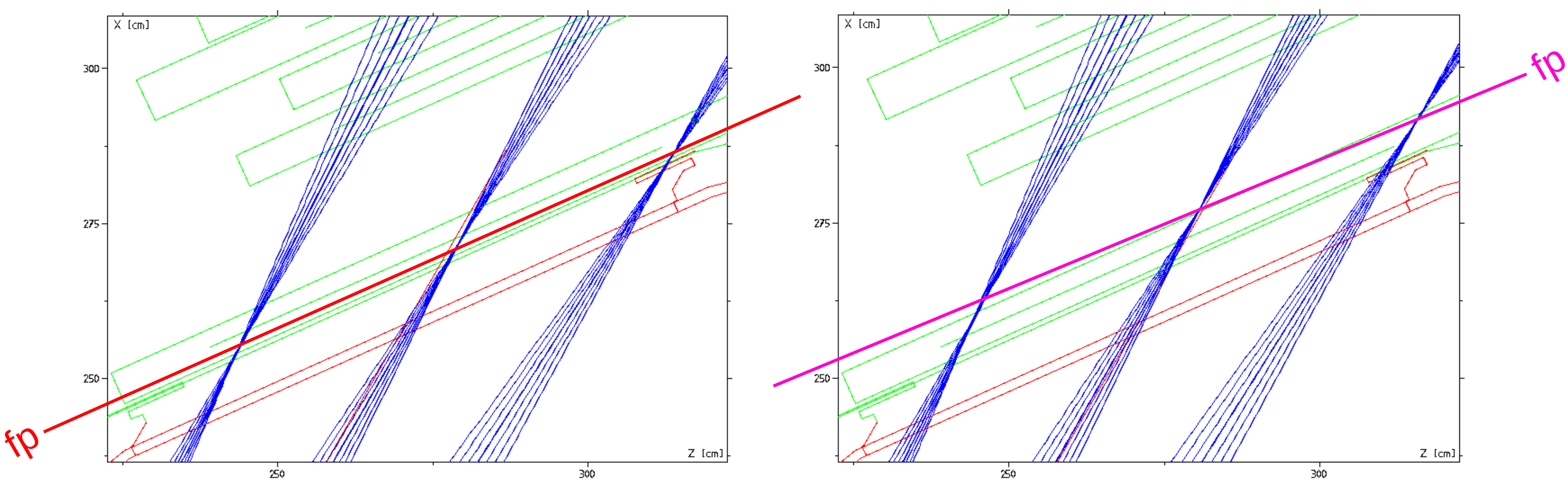
Focal plane detector change





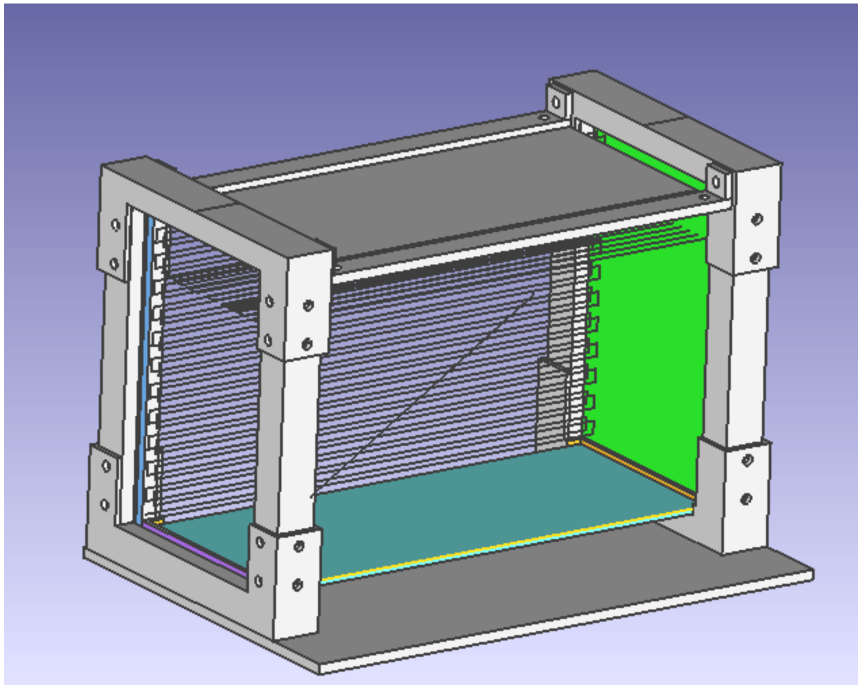
Focal plane detector change



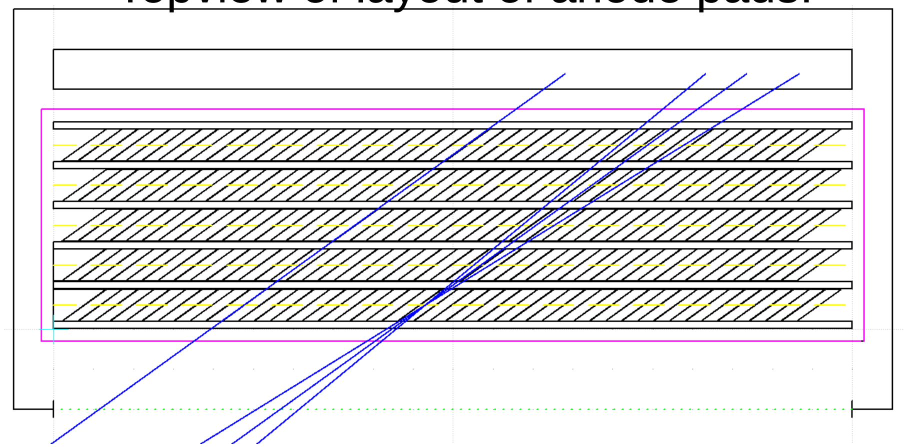


Must push focal plane downstream with K-coil
Question: do we have enough dynamic range with K-coil?

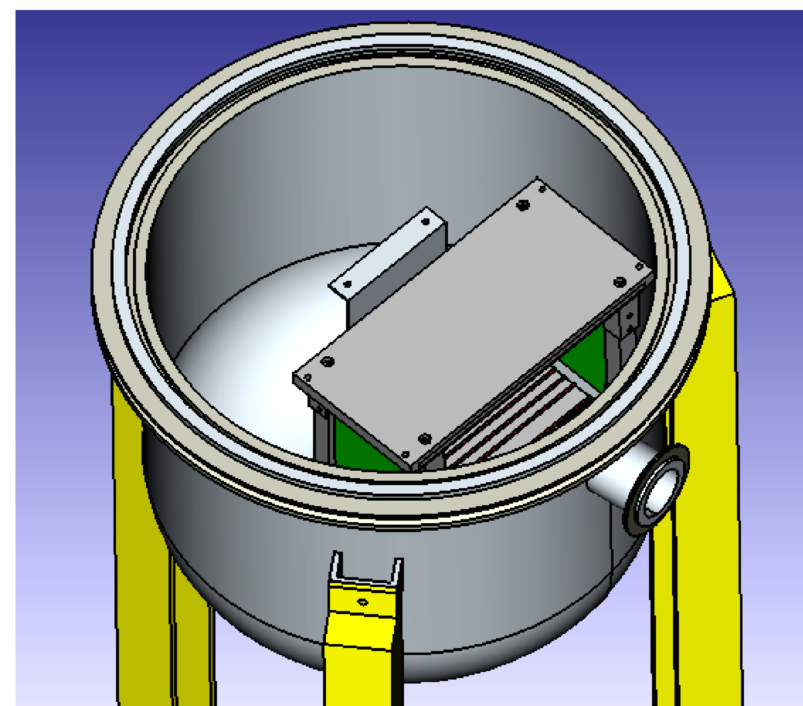
FPD prototype



Topview of layout of anode pads:



Build fieldcage: Drift region + amplification region:
220 x 100 x 100 (W x H x D)

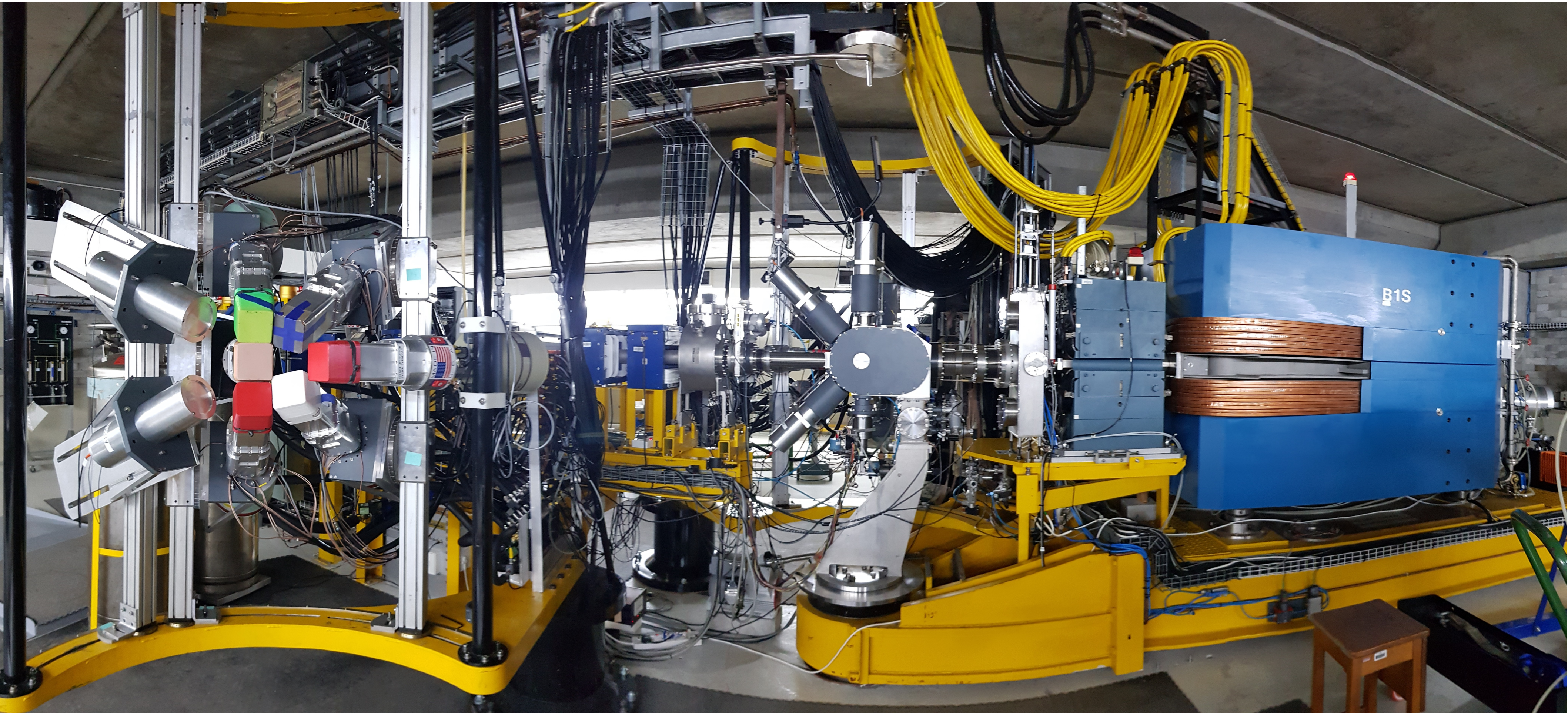


- Anode PCB with 5x46 channels: (θ range: 34°-38° compared to Magnex: 21°-43°)
- 1.5 um entrance mylar window
- Bronkhorst pressure control system and Ar/CO2 gas mixture
- DAQ and electronics

- Initial tests: Mesytec preamplifiers, amplifiers and CAEN ADCs
- Final system still undediced (old: GASSIPLEX, new: CAEN Weeroc ASICs)

- Initial tests at Tandetron: 6 MeV p, 9 MeV 4He (2.25 MeV/u), 12 MeV 16O (0.75 MeV/u)
- Also try ThGEM and integrated pads (higher signal amplification at lowest gas pressures)

Thank you



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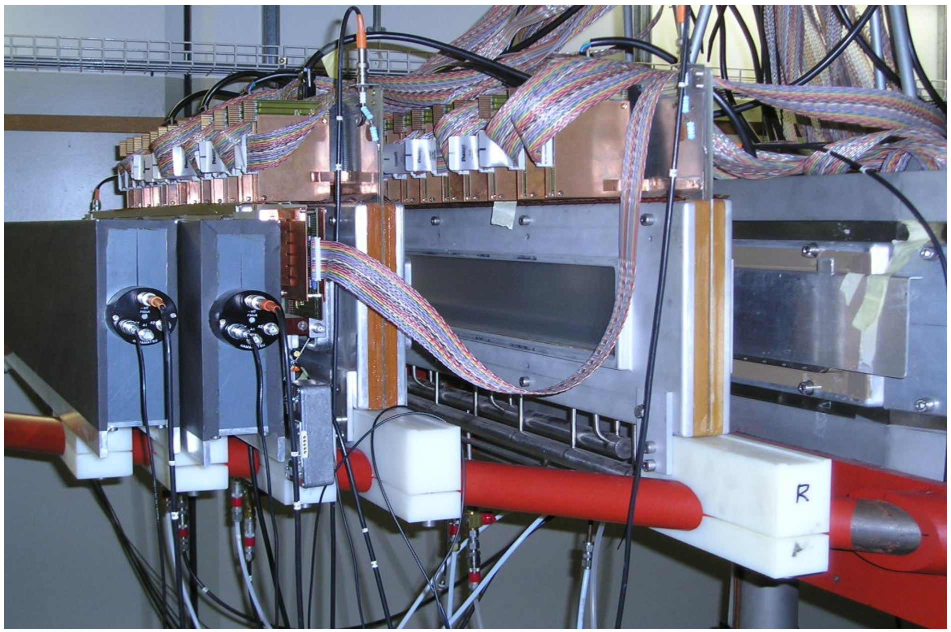
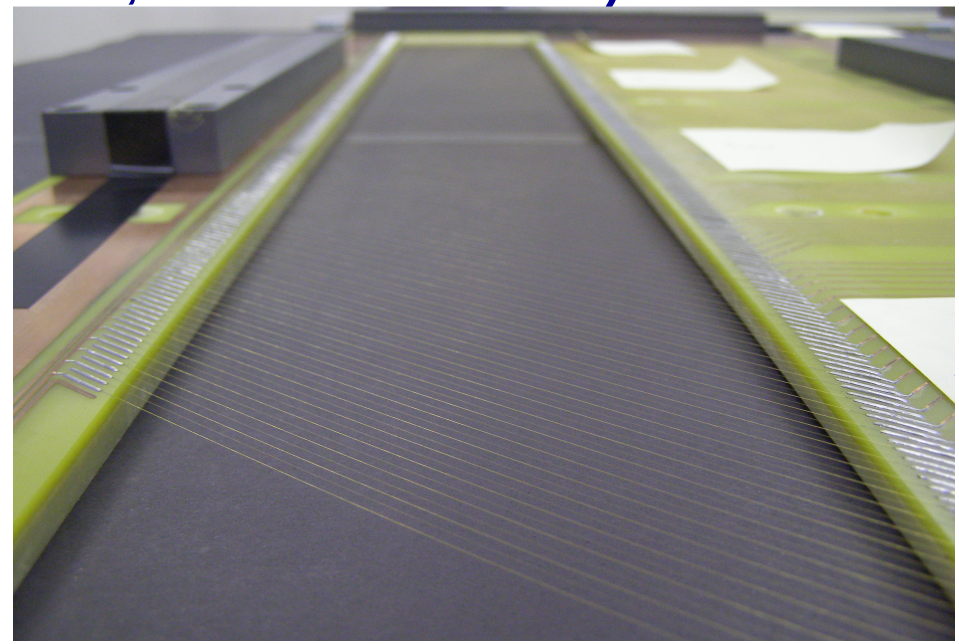
Department: Science and Technology
REPUBLIC OF SOUTH AFRICA

Existing focal plane detectors

PROUDLY SOUTH AFRICAN

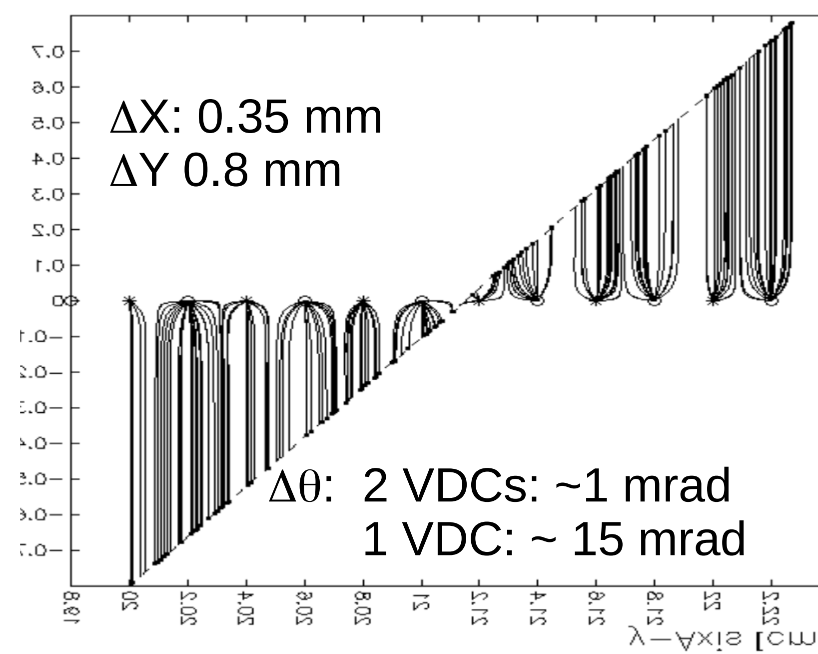
2 MWDC + 2 scintillators **(2 generations available, built 1995 and 2008)**



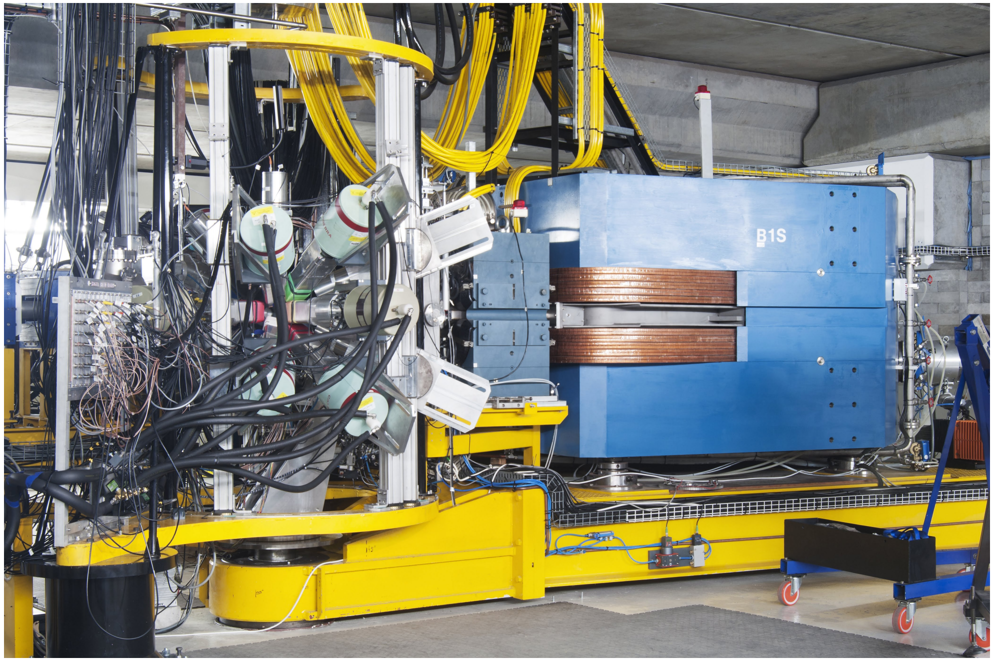


2nd generation:

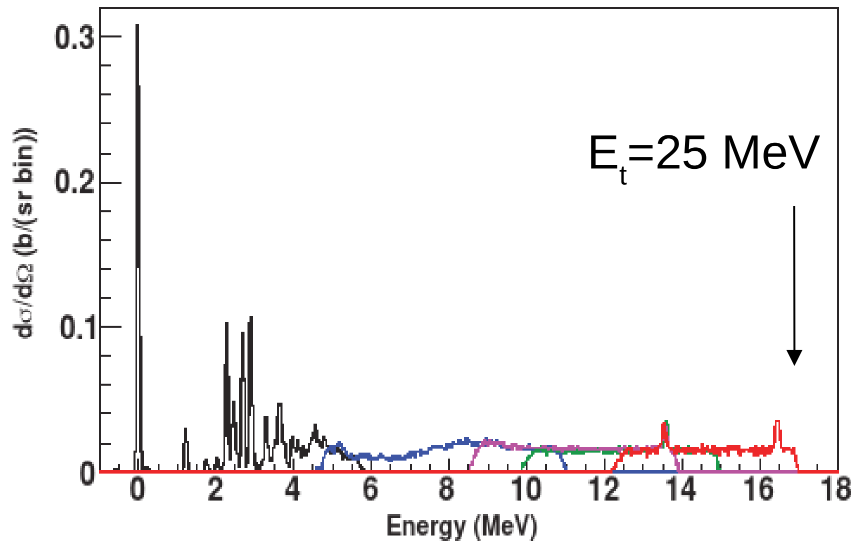
- 2 wireplanes (vertical and 50°), sandwiched between 3x Al 20μm HV planes (16 mm separation)
- 198 (X) + 143 (U) active wires per detector (682 signal wires in total)
- 20 μm diameter Au plated W signal wires
- 50 μm diameter Au plated W field shaping wires
- 90% Ar 10% CO_2 gas mixture

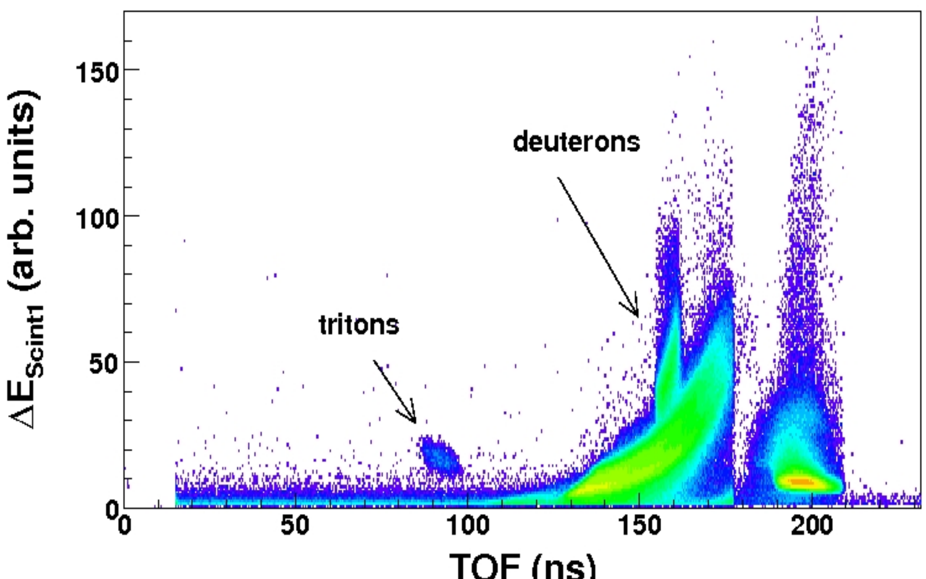


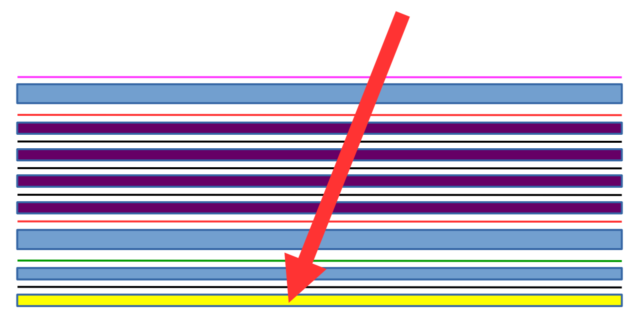
GPV: too high E at iTL



^{120}Sn(p,t) at 50 MeV at 0° → GPV search







TRIM estimations

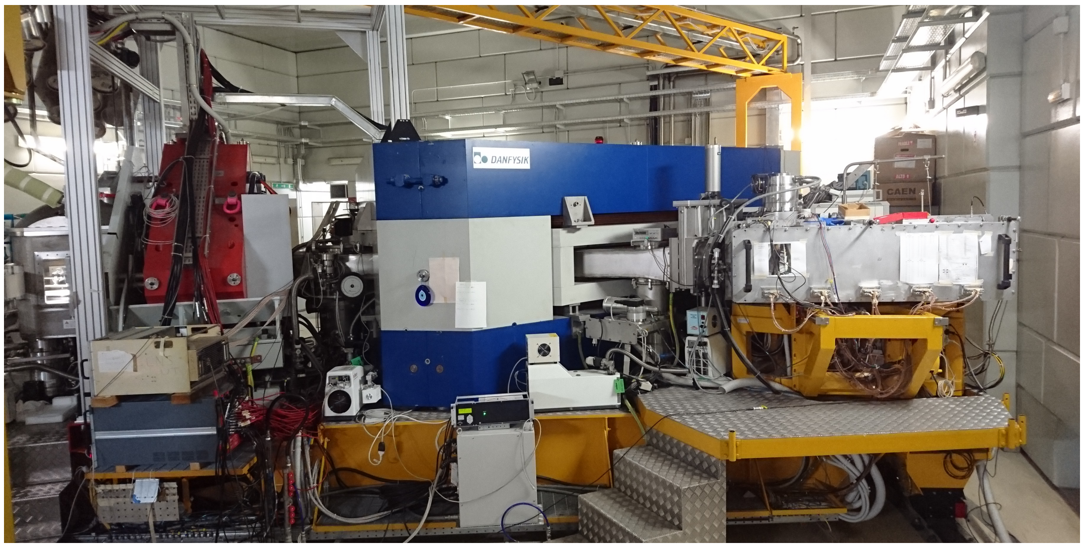
p: above 14 MeV

t: above 23 MeV

α: above 57 MeV

^{7}Li: above 110 MeV

GPV: signatures found at INFN-LNS



^{120}Sn(p,t) at 50 MeV at 0° → GPV search

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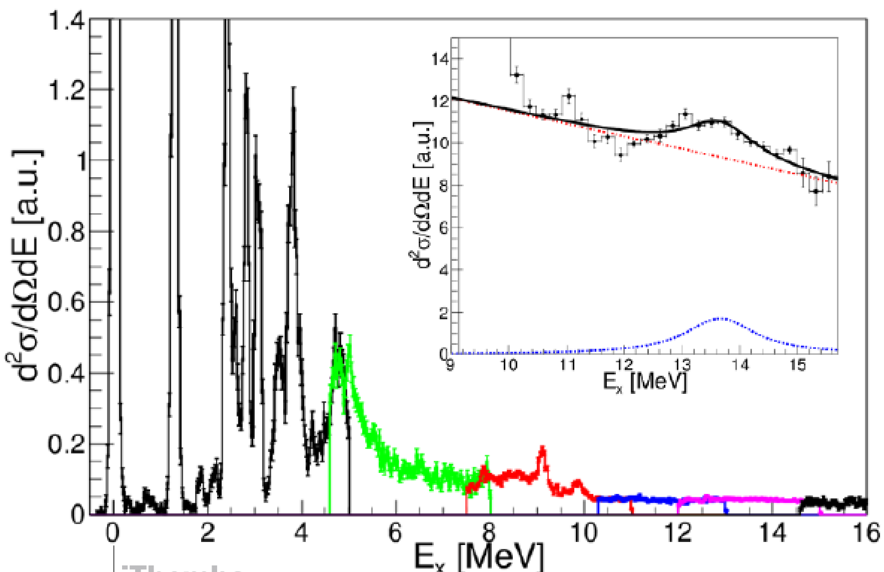
B. Mouginot *et al.* PRC 8**3** 037302 (2011)

No signature found



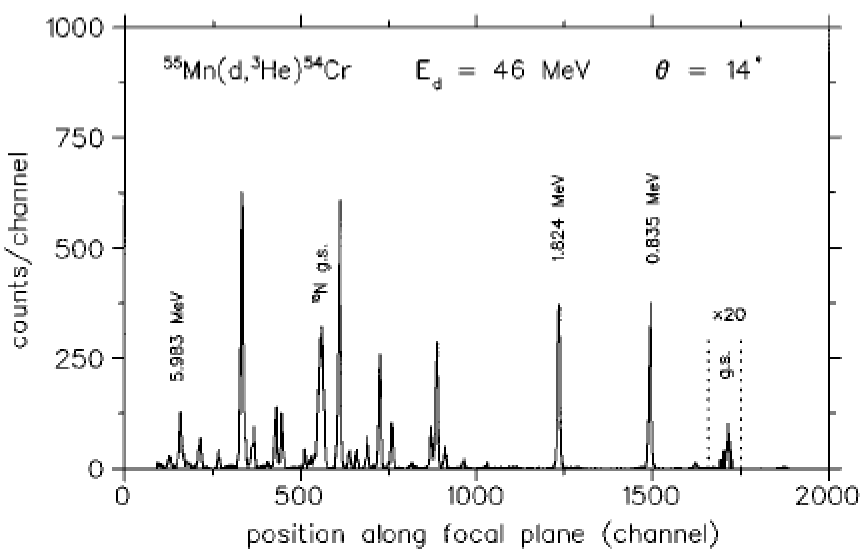
Search for the GPV with MAGNEX

(p,t) measurement at: E_{beam} = 35 MeV

Also see INFN-LNS study with (^{18}O,^{16}O) reaction @ 84 MeV

Existing focal plane: MWDC's + scintillators

PRC 54 (1996) p1773 R.T Newman *et al.*

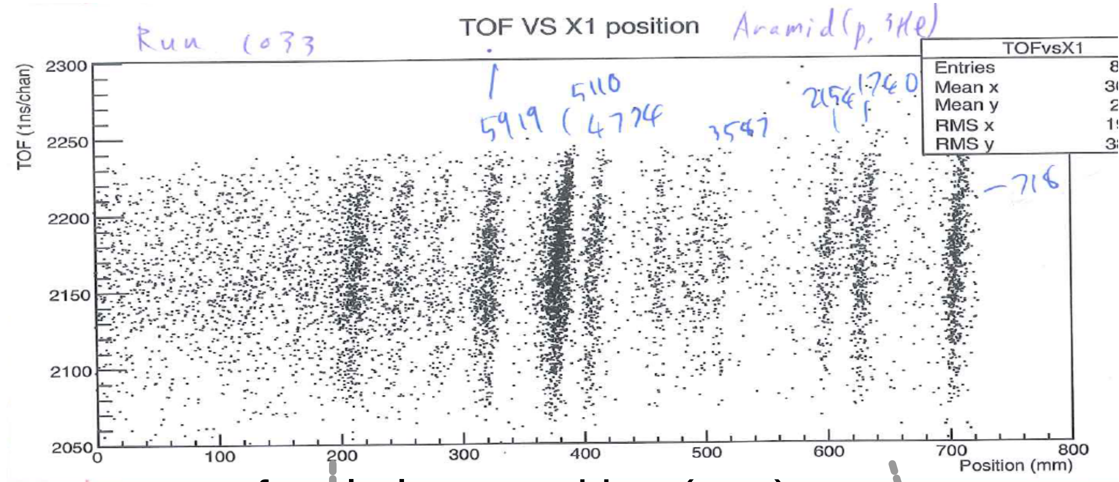


E_{3He}: 37 – 43 MeV

40 keV FWHM:

ΔX=4.65 mm position resolution

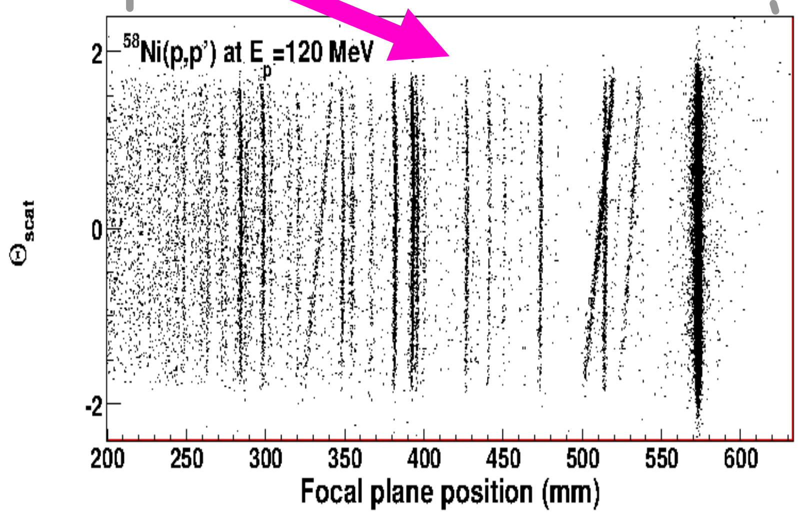
aramid target: 0.7 mg/cm^2



focal plane position (mm) ~ 62-72 MeV

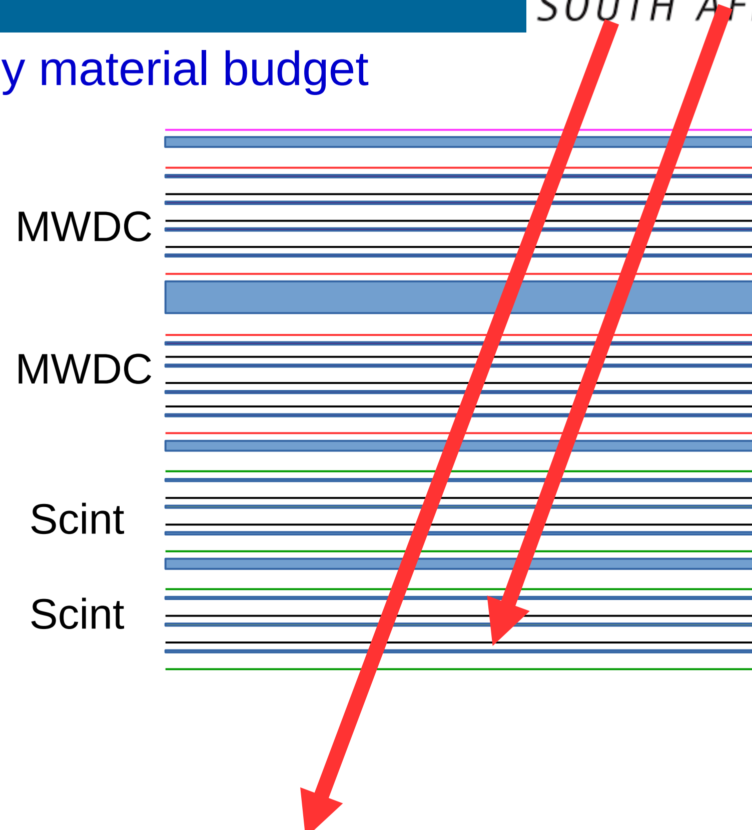
Not good!

This is what you want!

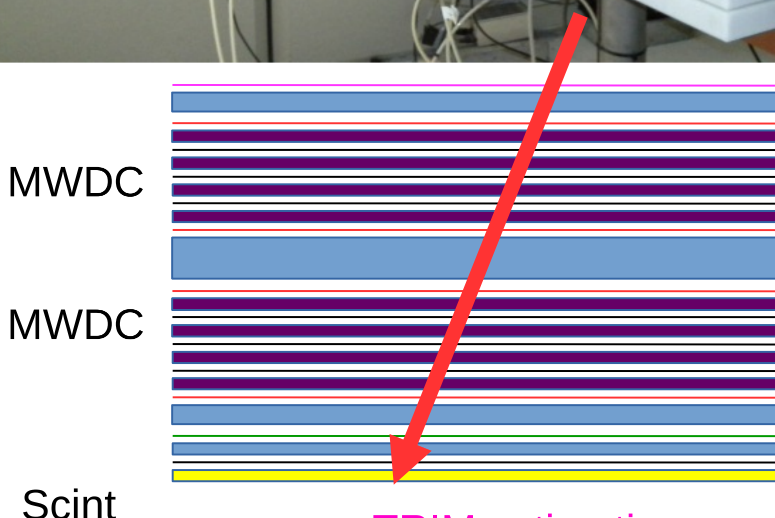


Existing focal plane detectors

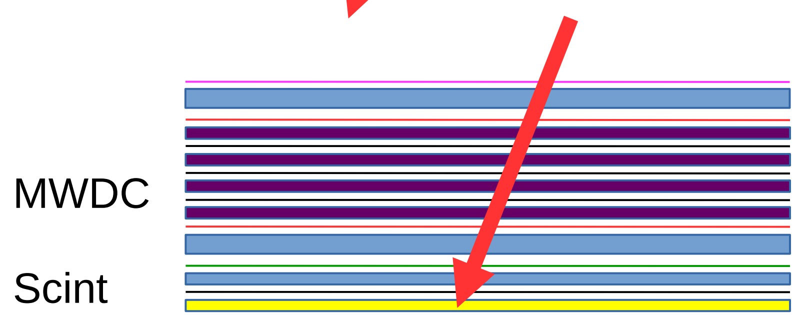
Low energy detection threshold determined by material budget



TRIM estimations
p: 43-200 MeV
t: 68-200 MeV
α: 170-200 MeV



TRIM estimations
p: 21- 43 MeV
t: 30 - 68 MeV
α: 78 - 170 MeV
^{7}Li: above 165 MeV



TRIM estimations
p: above 14 MeV
t: above 23 MeV
α: above 57 MeV
^{7}Li: above 110 MeV