First SPES School on Experimental Techniques with Radioactive Beams

INFN LNS Catania – November 2011

Experimental Challenges
Lecture 2: Detector Systems

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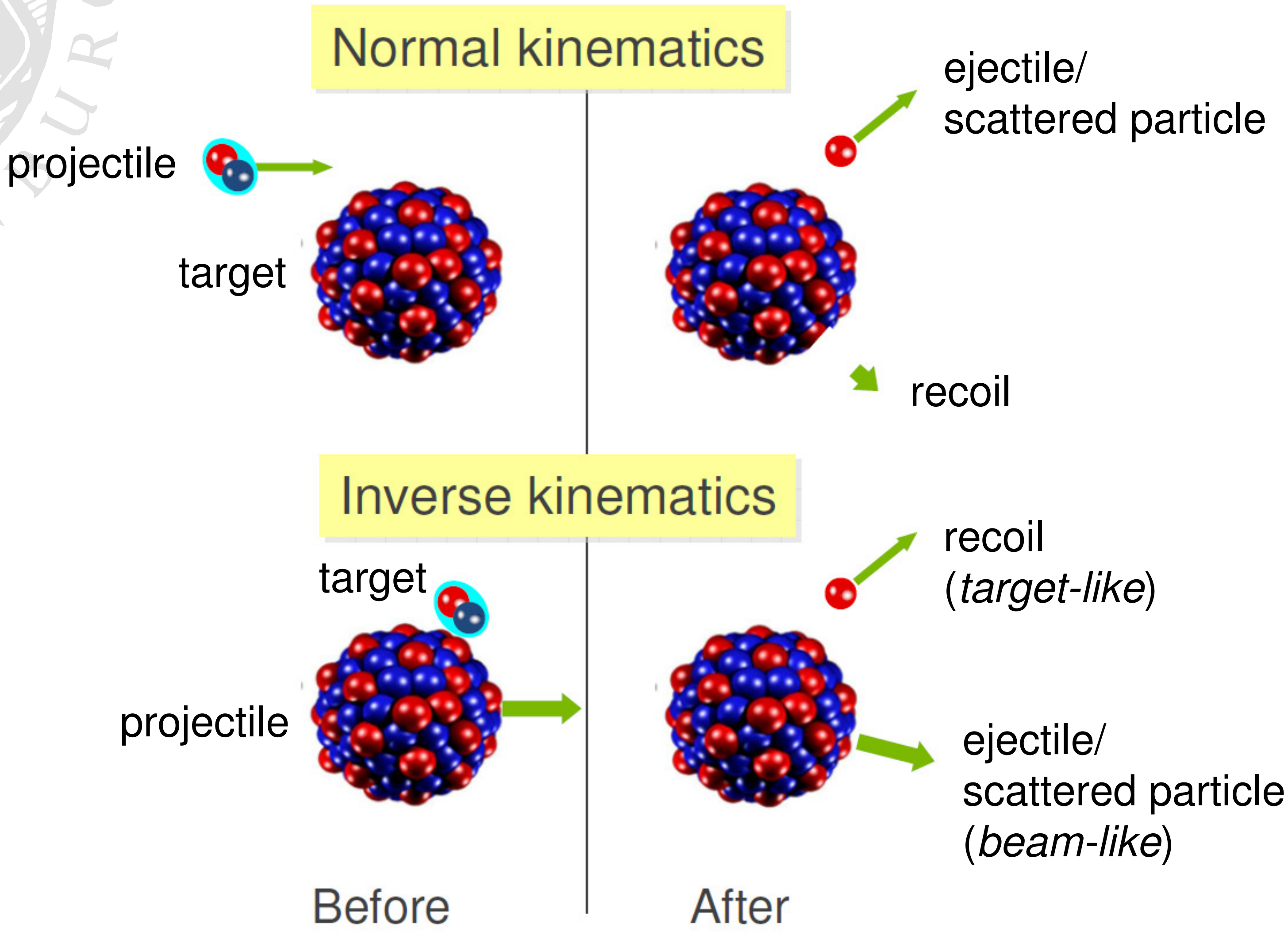
Outline

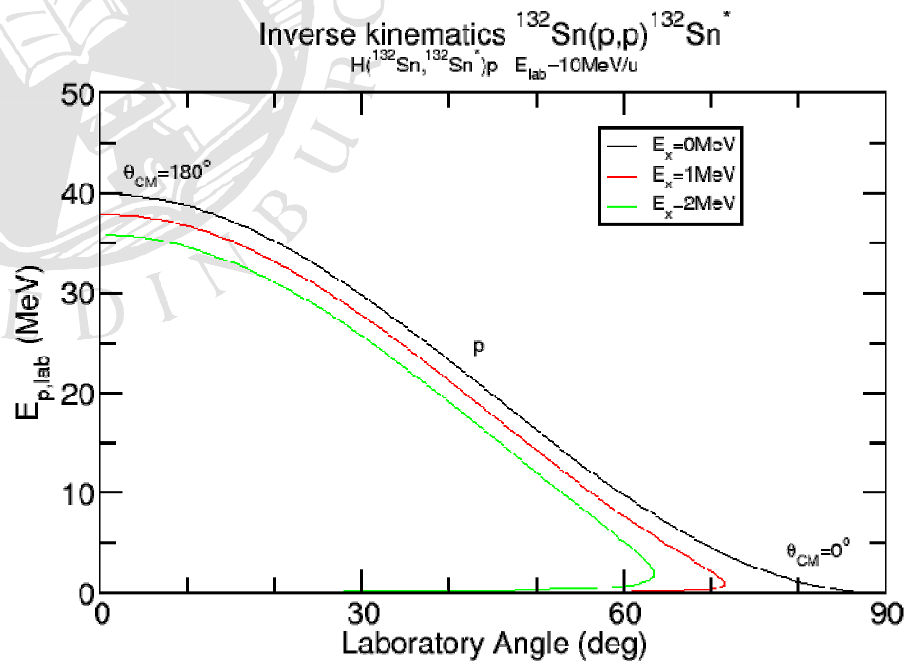
- Inverse kinematics
- Early examples
- First generation systems
  - LEDA – CD – TUDA – TECSA
  - SIDAR
- Second generation systems
  - TIARA – SHARC – ORRUBA – T-REX
  - ANASEN
- Future systems (Lecture 3)
  - HELIOS
  - MUST-II
  - AIDA

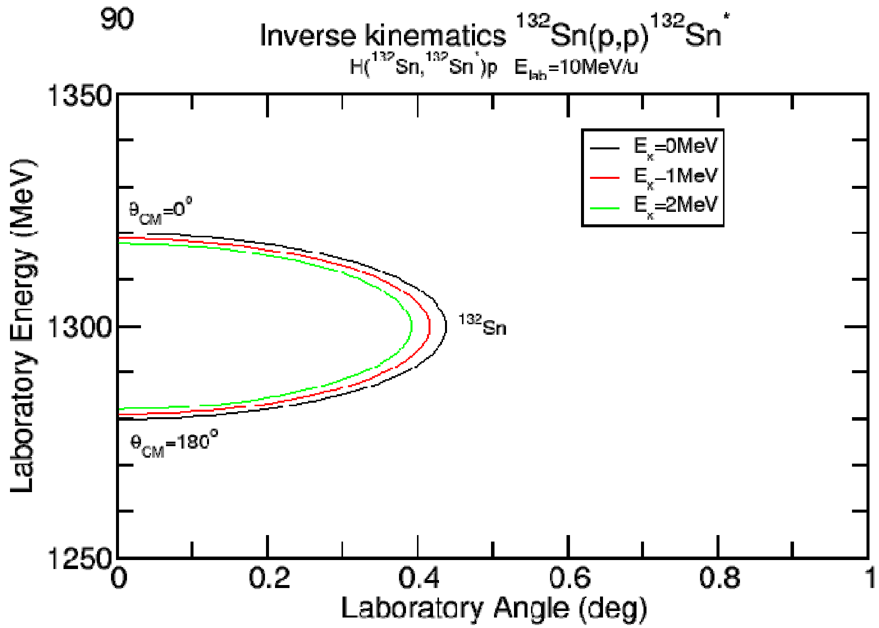
Inverse Kinematics



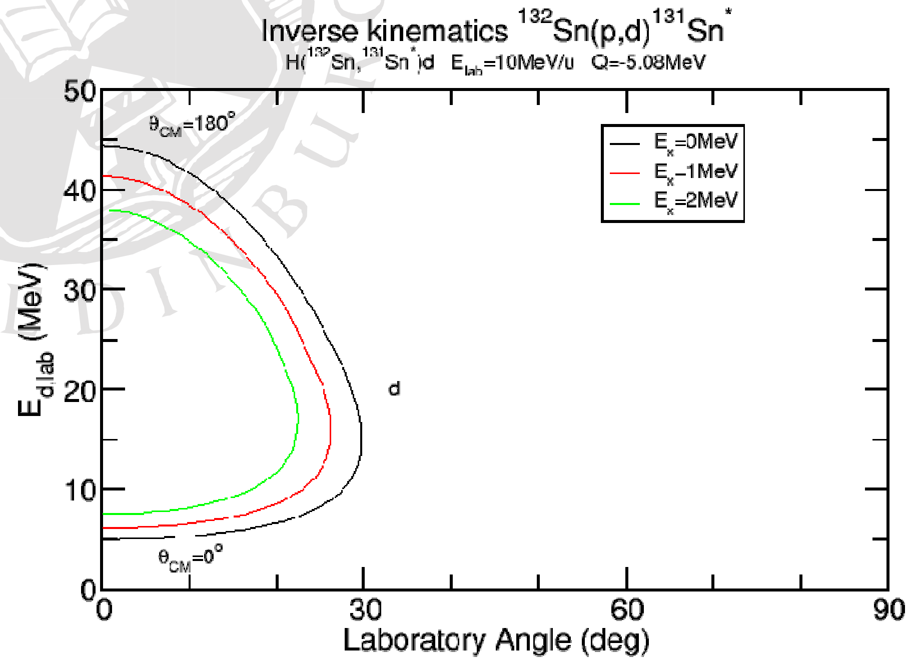
from B.B.Back, ANL
http://www.phy.anl.gov/atlas/helios/index.html

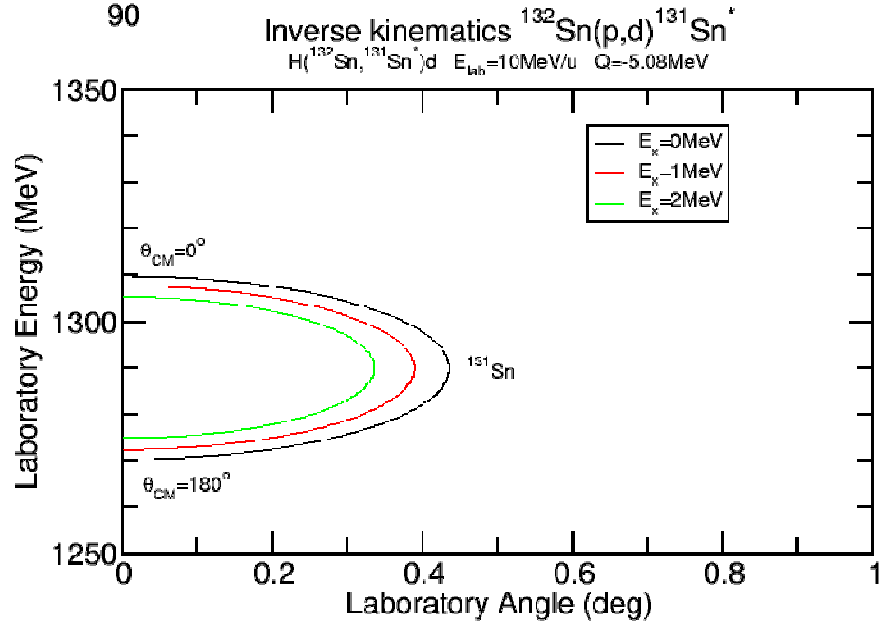
Inverse Kinematics – elastic scattering



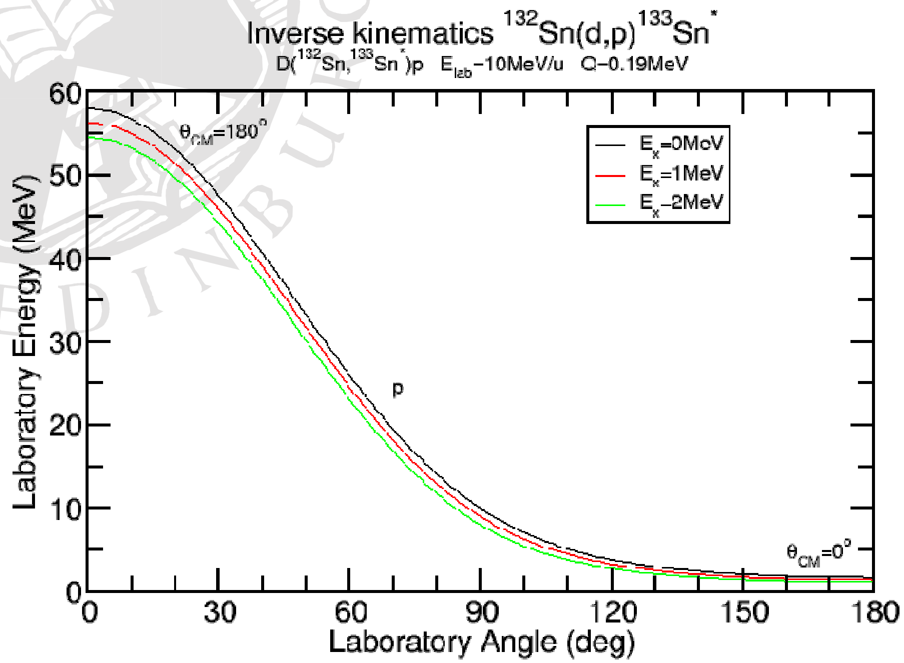


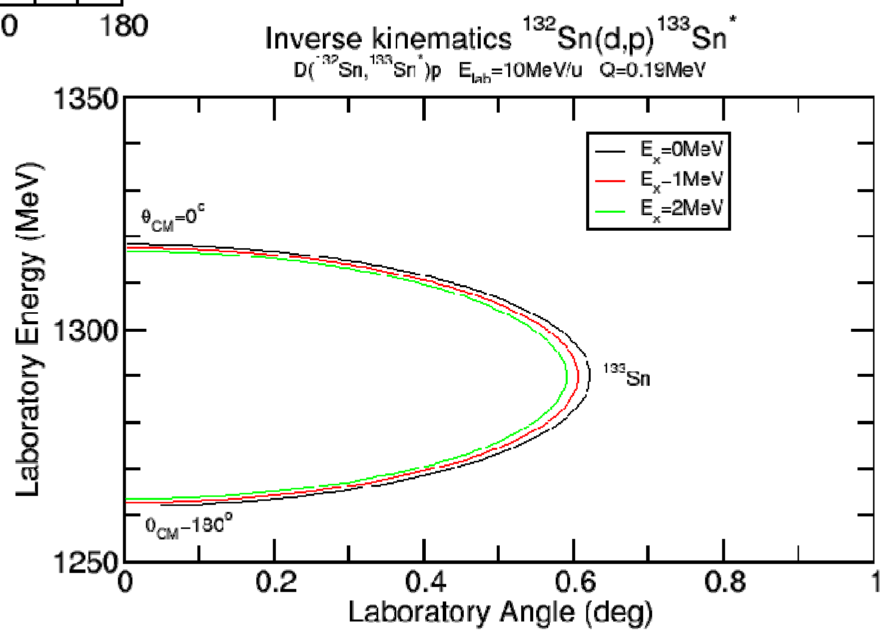
Inverse Kinematics – pickup reactions





Inverse Kinematics – stripping reactions





Inverse Kinematics: Summary

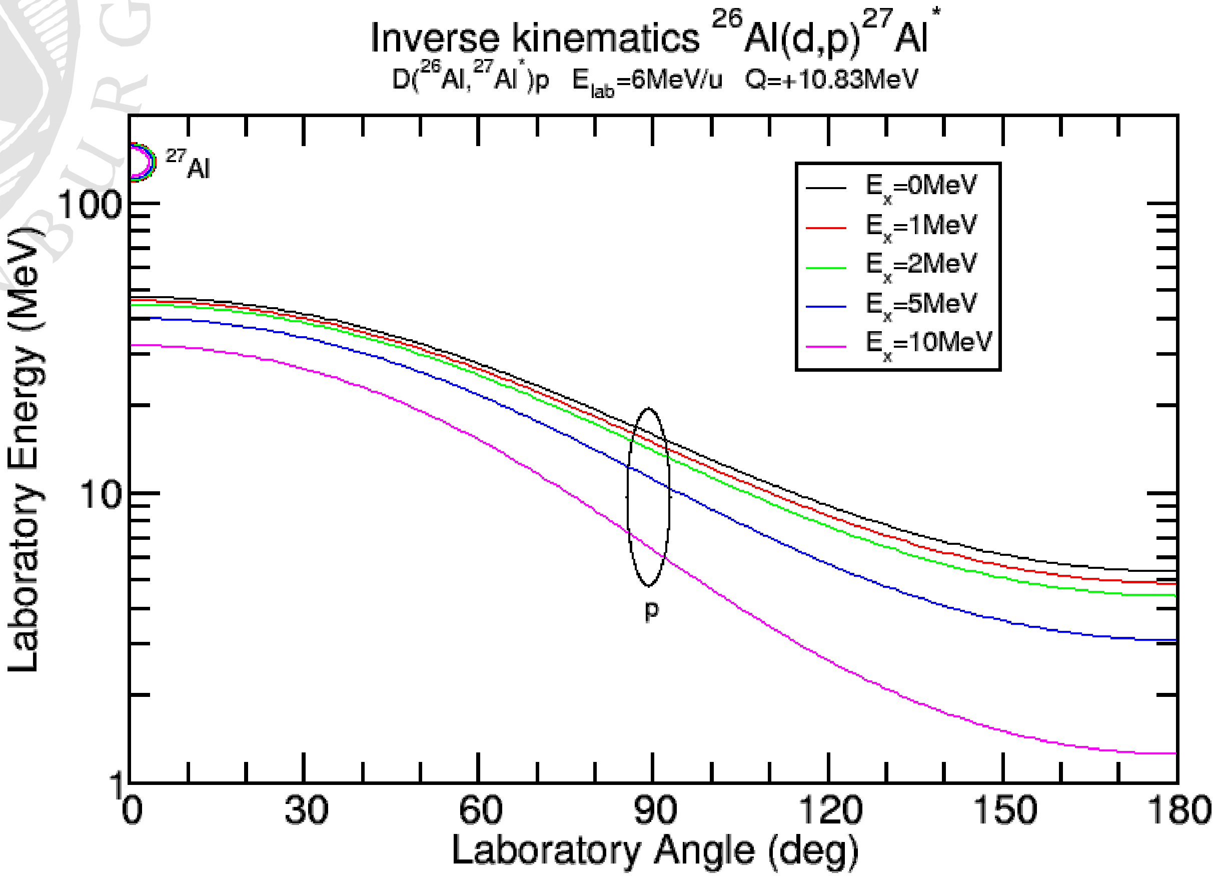
- distinct types of kinematics

  elastic – recoils $\theta < 90^{o}$
  pickup – recoils at forward angle
  stripping – recoils $0^{o} < \theta < 180^{o}$
  scattered/ejectile particle – very forward laboratory angles

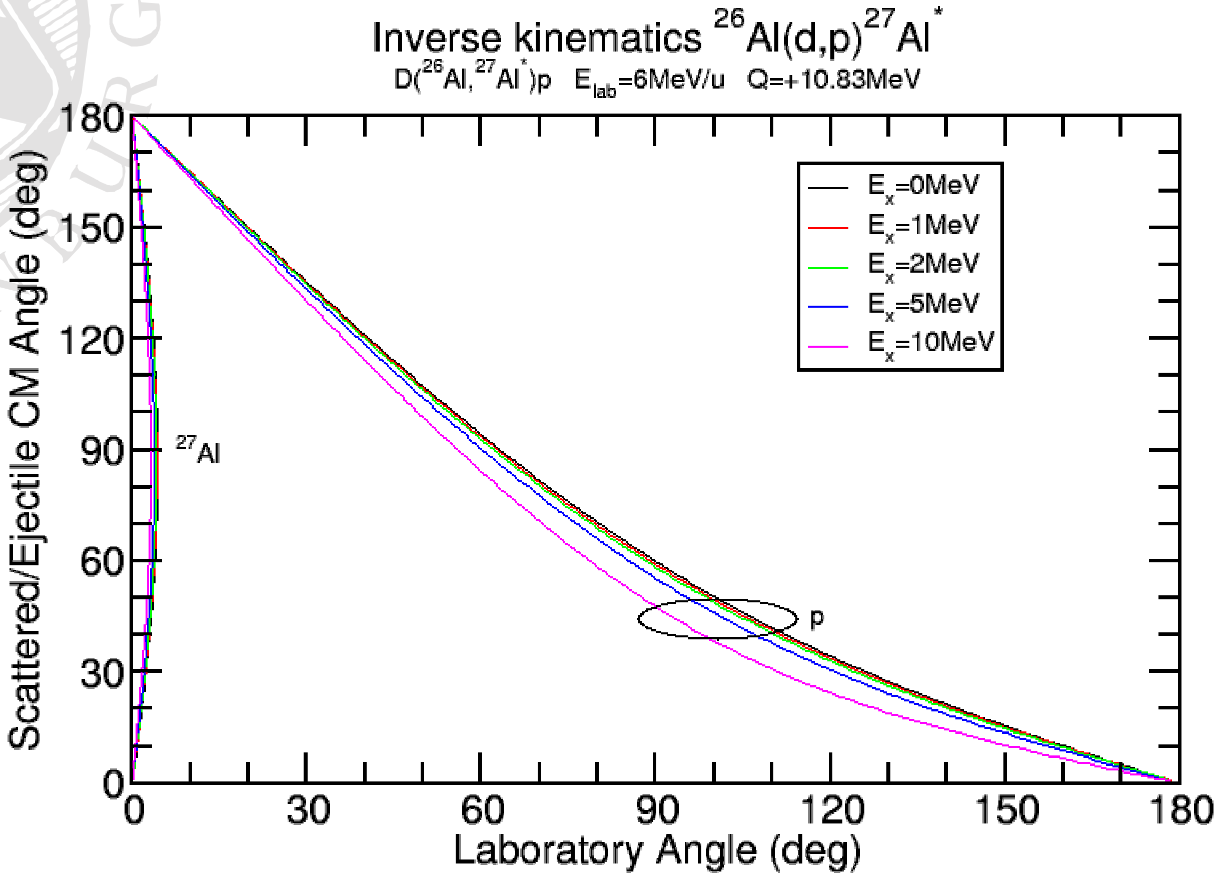
- detection options (*see Further Reading*)

scattered/ejectile	spectrometer kinematically focussed difficult to achieve good E_x resolution
recoil	silicon detector large angular coverage resolution limited by target *dE/dx*(beam) & *dE/dx*(ejectile) – 'thin' targets
recoil + γ-rays	silicon & HPGe high efficiency γ-ray array required 'thick' targets

A Specific Example

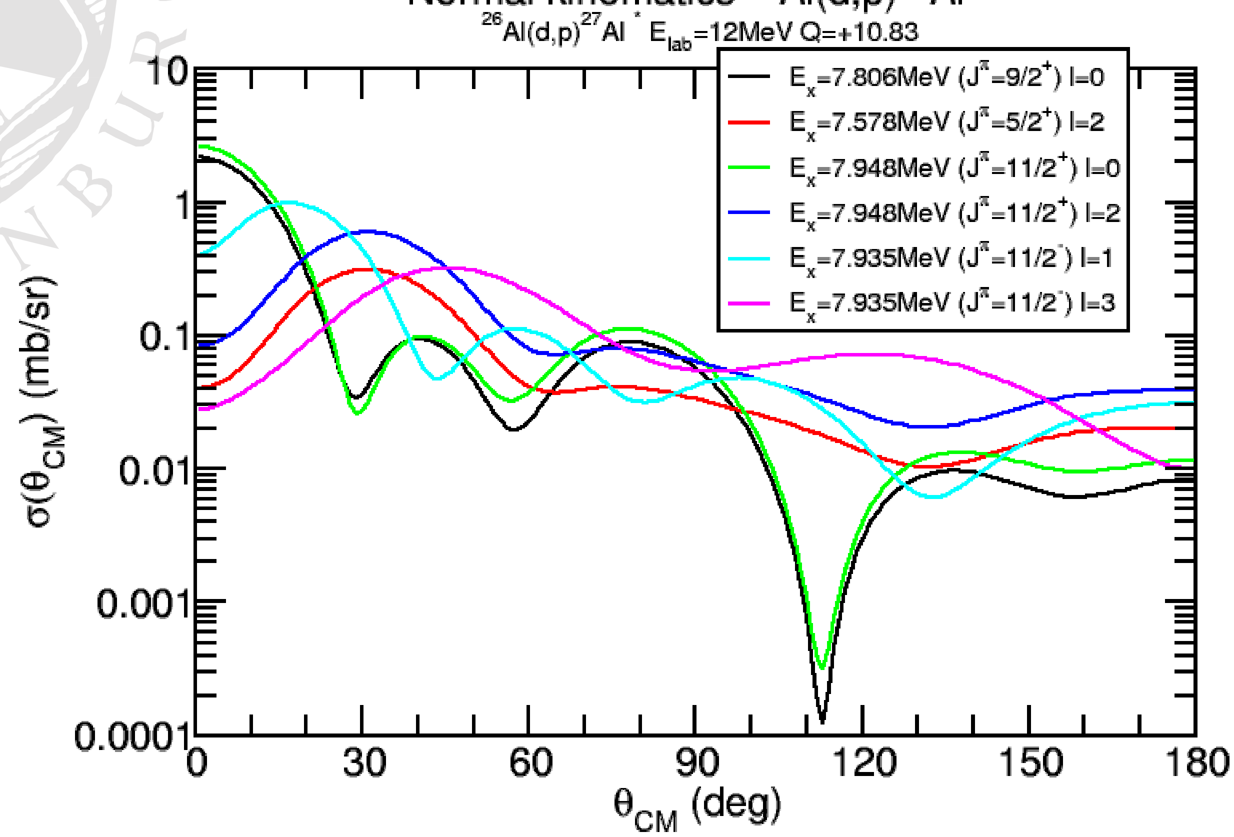


Relationship Between θ_{CM} and θ_{LAB}



Angular Distributions

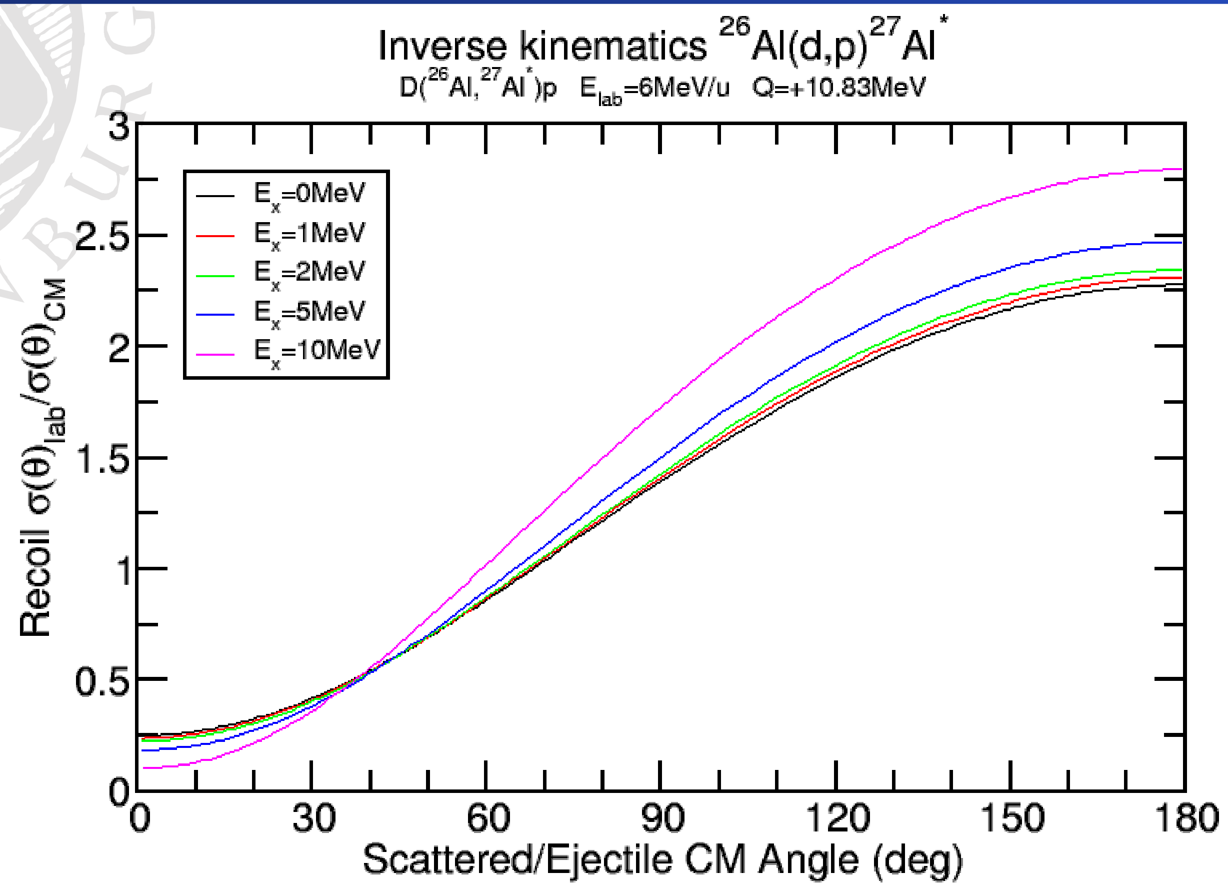
Normal kinematics $^{26}Al(d,p)^{27}Al^*$



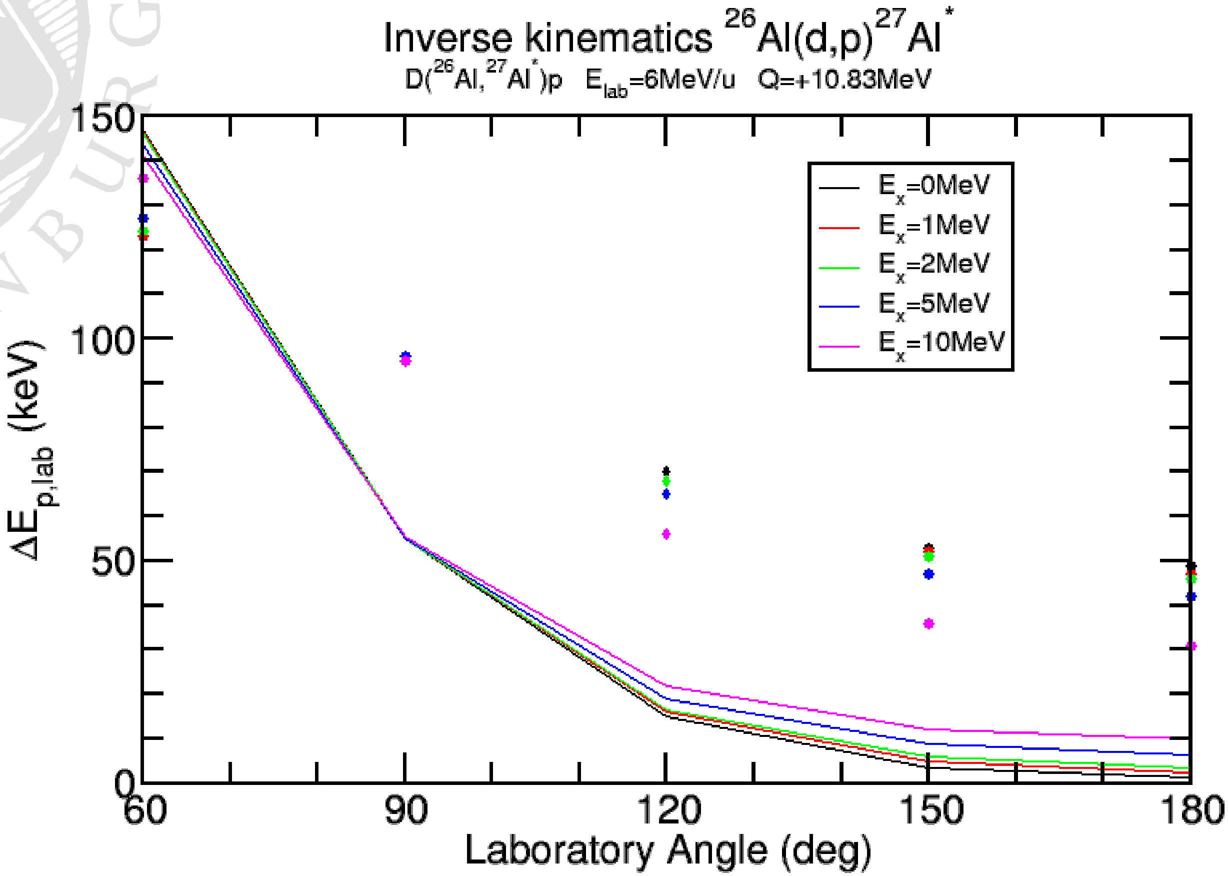
θ_{max} ~ const × l

e.g. for l=0 $\theta_{max} = 0^o$ (inverse kinematics – recoil (p) lab angle 180^o)

Recoil Jacobian



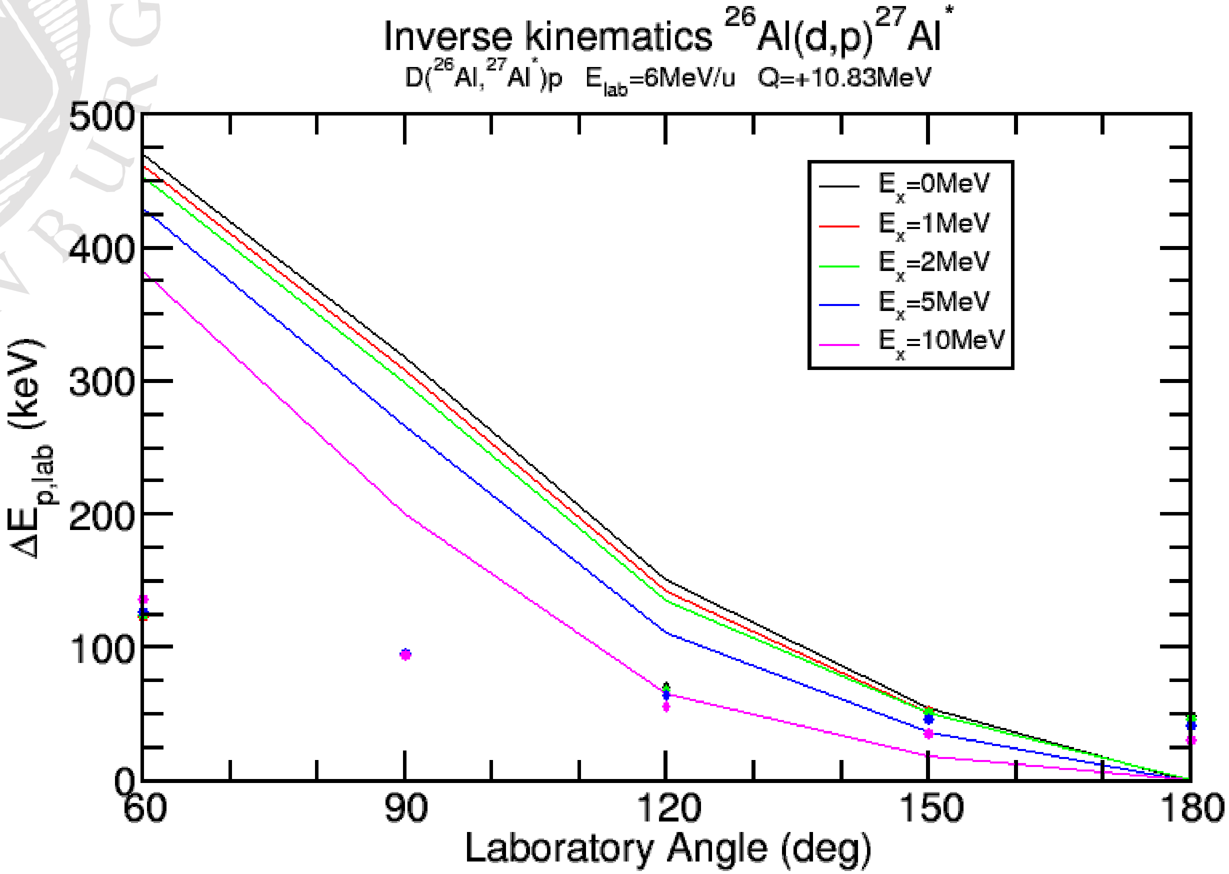
Does Beam Energy Resolution Matter?



Solid lines - variation of proton lab energy for 1% change in beam lab energy
Solid dots - variation of proton lab energy for ΔE_x=100keV (for comparison)

from Lecture 1 ISAC-II beam energy resolution 0.2% FWHM

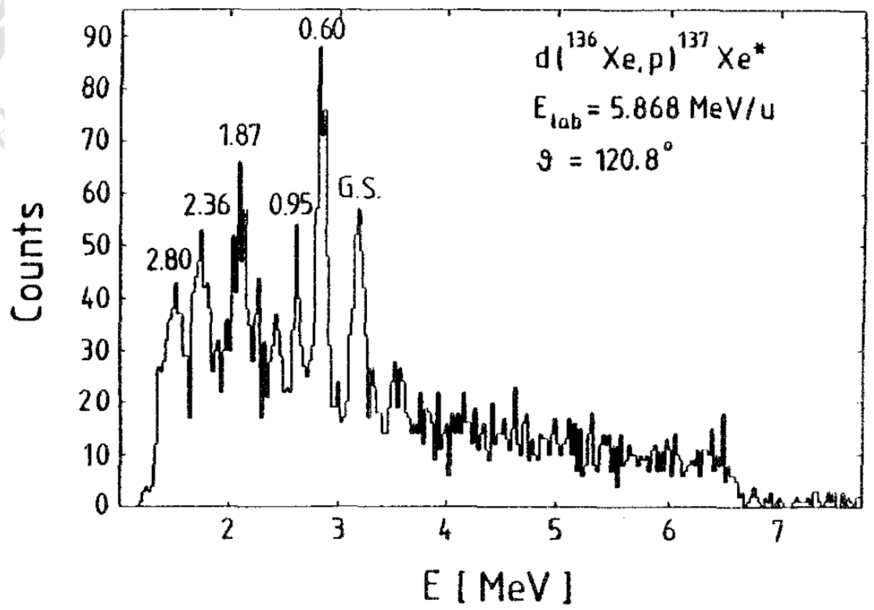
Does Beam Angular Resolution (ε_{xy}) Matter?

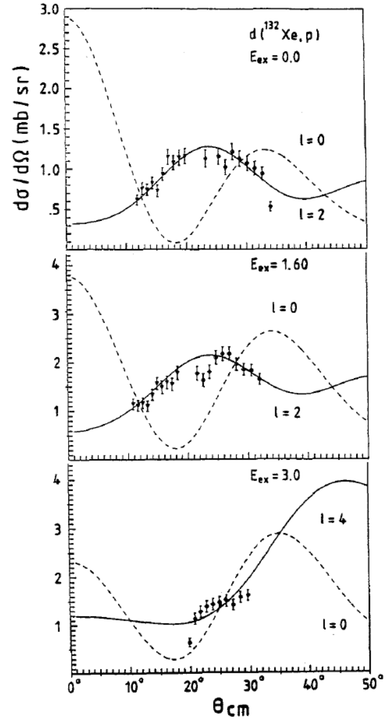


Solid lines - variation of proton lab energy for 1° change in lab angle
Solid dots - variation of proton lab energy for ΔE_x=100keV (for comparison)

from Lecture 1 optimum angular resolutions (@ optimum beam spot size)
~ 2.3 - 7.3 mrad (0.13 - 0.42°)

GSI

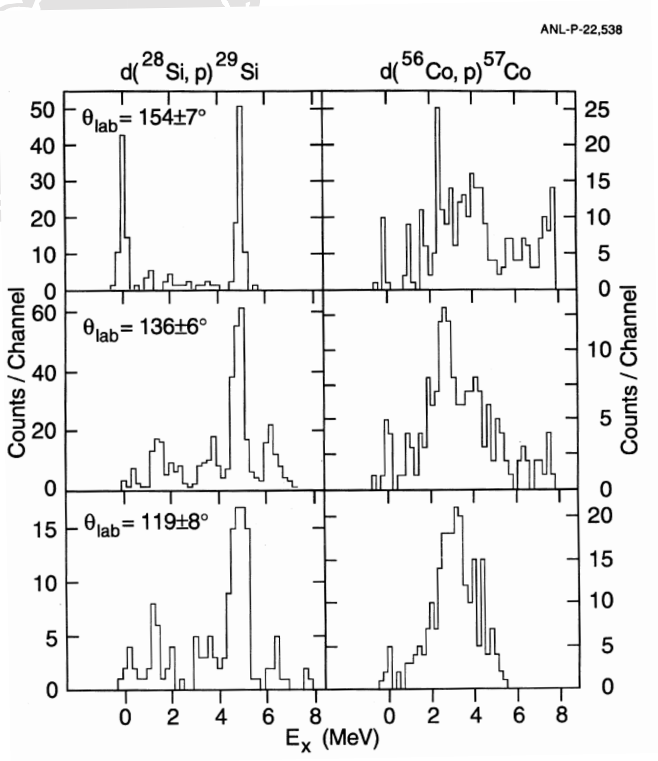


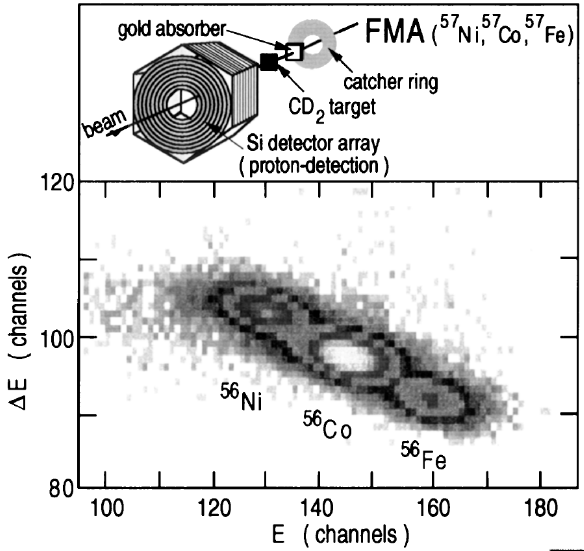


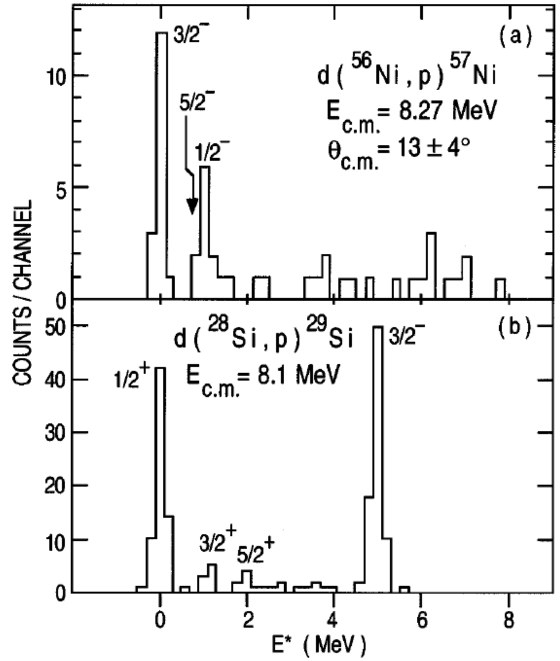
10x10 array of 10mm x 10mm x 320µm PIN photodiodes
100µg/cm² Ti:D + 200µg/cm² Al backing
energy resolution ~ 80keV FWHM
dominated by angular resolution ~ 1.5 deg

G.Kraus *et al.*, Z. Phys. A 340 (1991) 339-340

ANL



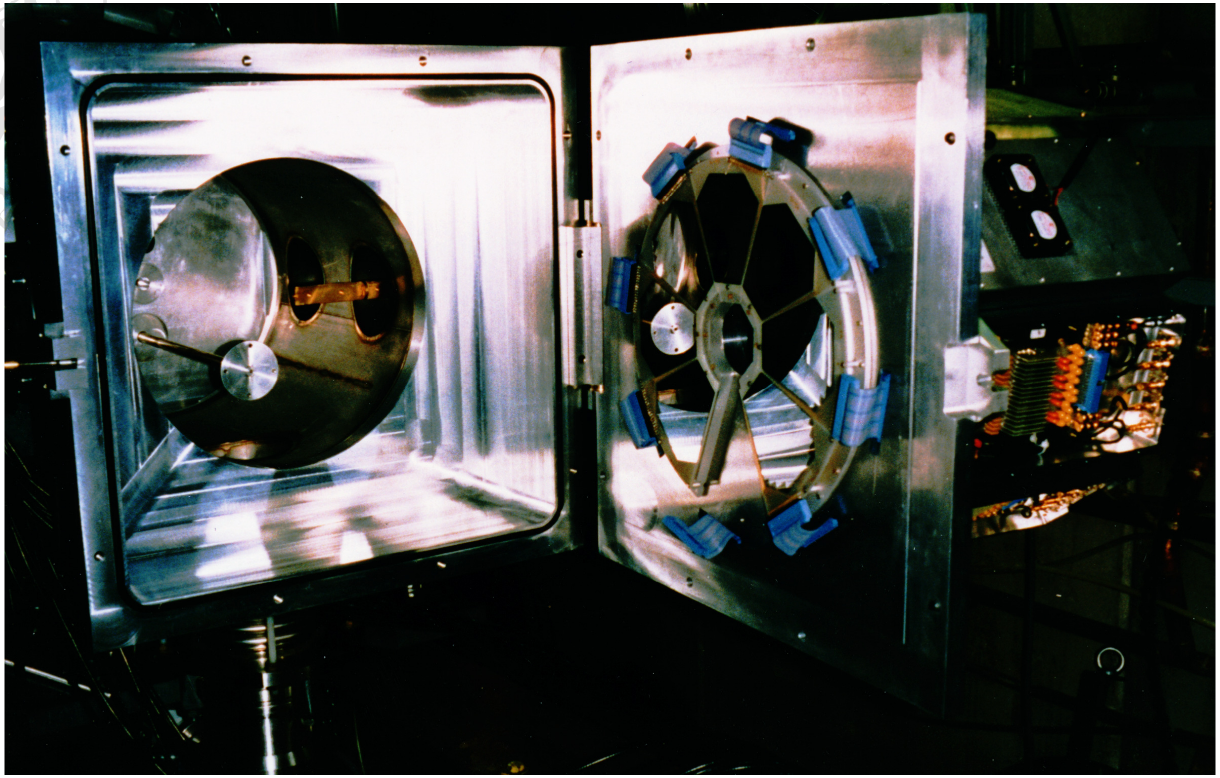




2.5x10^4/s 250MeV ^{56}Ni + 500µg/cm^2 $(CD_2)_n$
protons - annular DSSSD 147-161°, barrel 111-141°
^{57}Ni – FMA focal plane

K.E.Rehm *et al.*, Phys. Rev. Lett. 80 (1998) 676
K.E.Rehm *et al.*, NIM A 449 (2000) 208

Louvain Edinburgh Detector Array (LEDA)



CYCLONE RIB Facility, Louvain-la-Neuve, Belgium (c. 1989-2008)

- CYCLONE30 (IBA) + CYCLONE110
- ~10^9/s ^{13}N and ^{19}Ne plus ≥ 10^5/s ^{6}He, ^{7}Be, ^{11}C, ^{15}O, ^{18}F, ^{18}Ne etc.

Beam spot ~ 5mm x 8mm

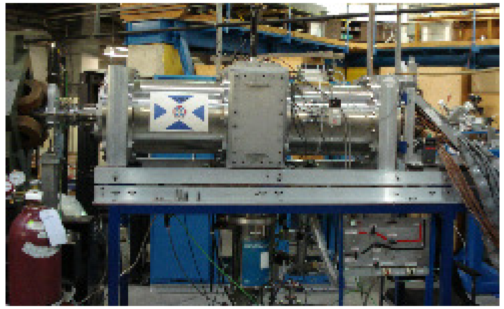
MSL type YY1 annular silicon strip detector (see Lecture 1)

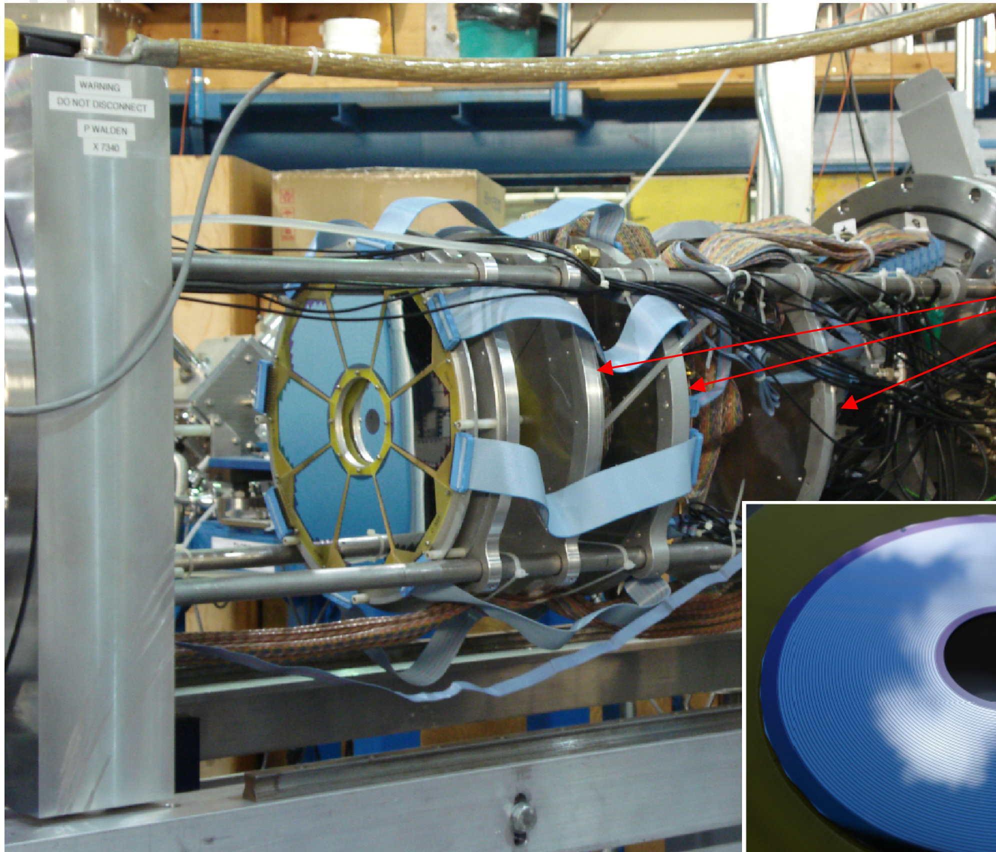
Configurable strip detector system ≤ 320 channels

T.Davinson *et al.*, NIM A454 (2000) 350

TRIUMF UK Detector Array (TUDA)

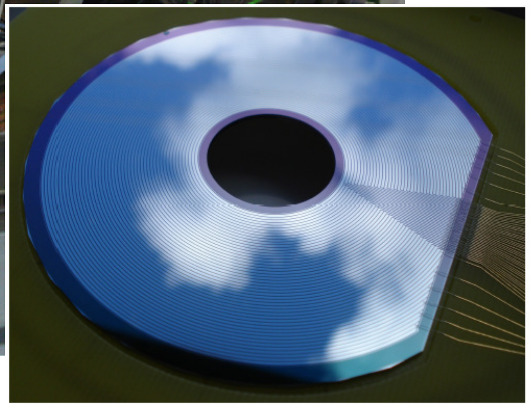
ISAC-I (~0.15-1.5MeV/u) & ISAC-II (<6.5MeV/u)
Direct & indirect nuclear astrophysics measurements
Configurable strip detector system ≤ 512 channels
- strip pitches 0.39mm – 5mm

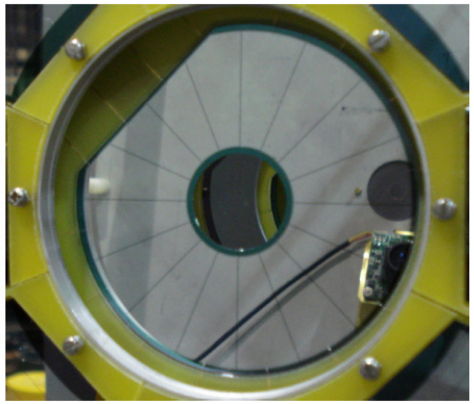




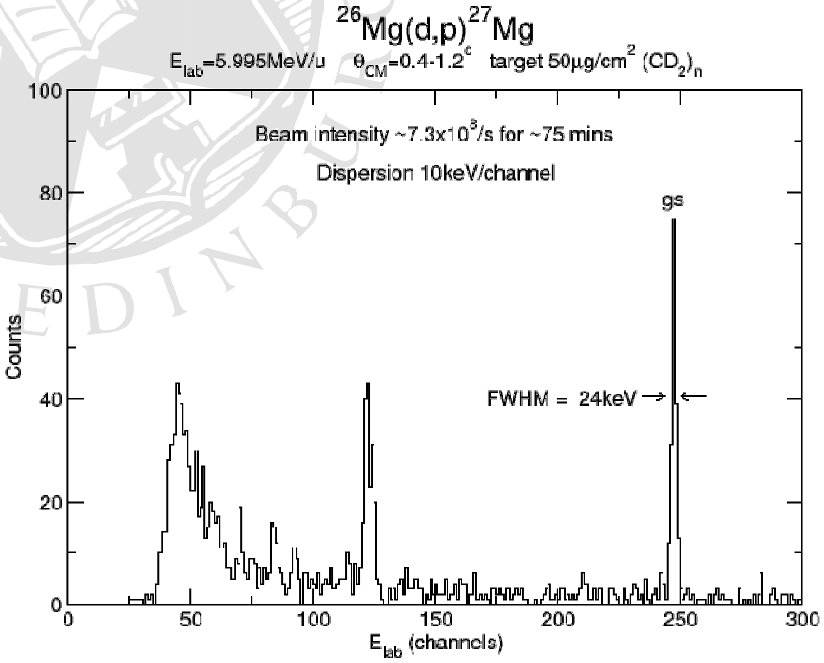
(cooled) preamps within vacuum chamber

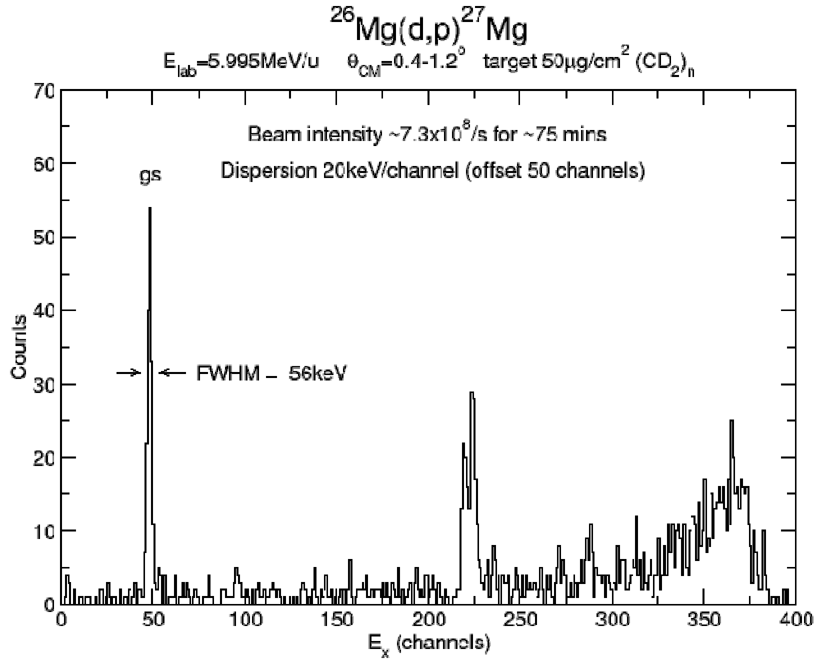
MSL type S2 DSSSD





Example of TUDA Performance





- 3x MSL type S2 annular DSSSDs + 1x MSL YY1 annular SSD
- *online* calibration
  - path dependent energy losses, kinematics – negligible for low θ_{CM}
  - ϕ dependence – alignment of DSSSD to beam axis
- angular resolution limited by transverse beam emittance
- energy resolution dominated by target thickness effects and detector

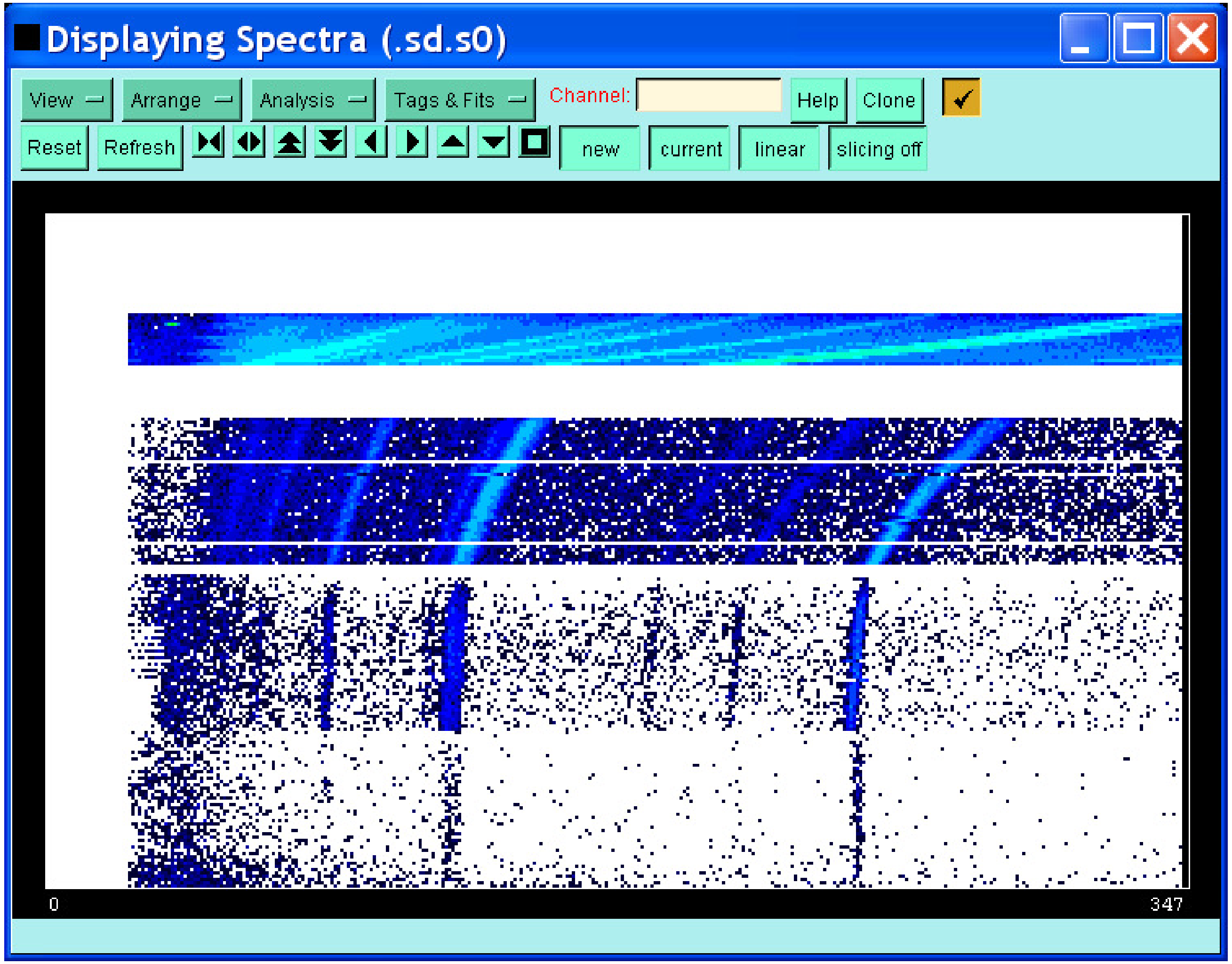
Example of TUDA Performance contd.

θ_{lab}=133.6-111.4º
$d\Omega$=233msr

θ_{lab}=168.9-149.9º
$d\Omega$=552msr

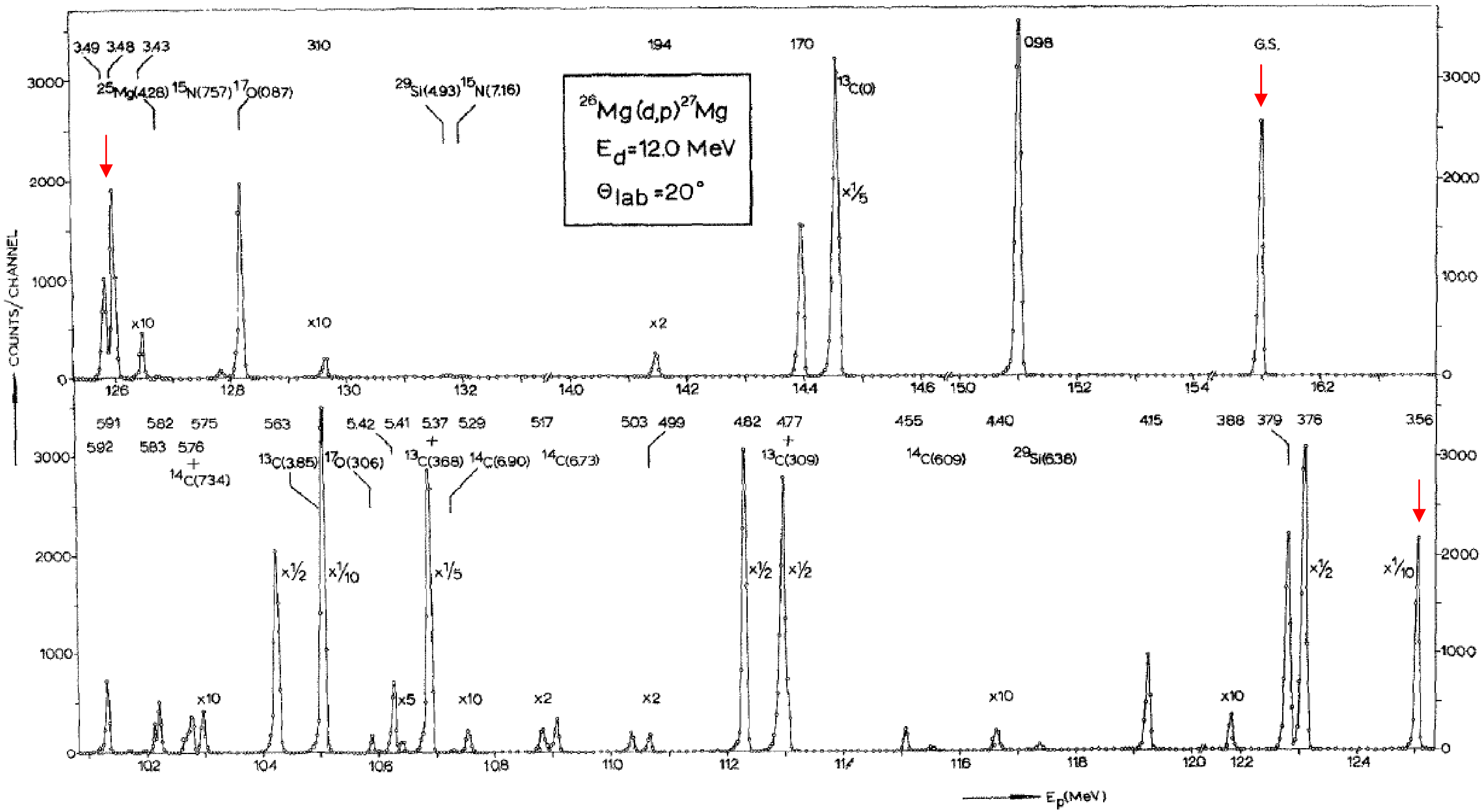
θ_{lab}=176.8-170.6º
$d\Omega$=56msr

θ_{lab}=179.1-177.3º
$d\Omega$=4.5msr



$E_{lab}\rightarrow$

Enge Split Poles *and all that …*

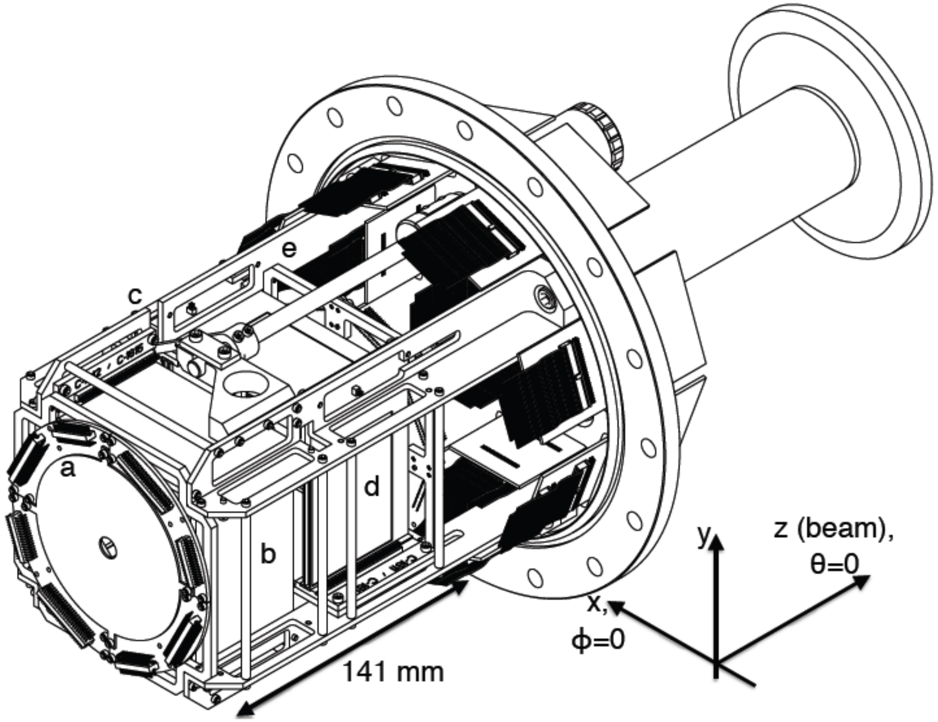


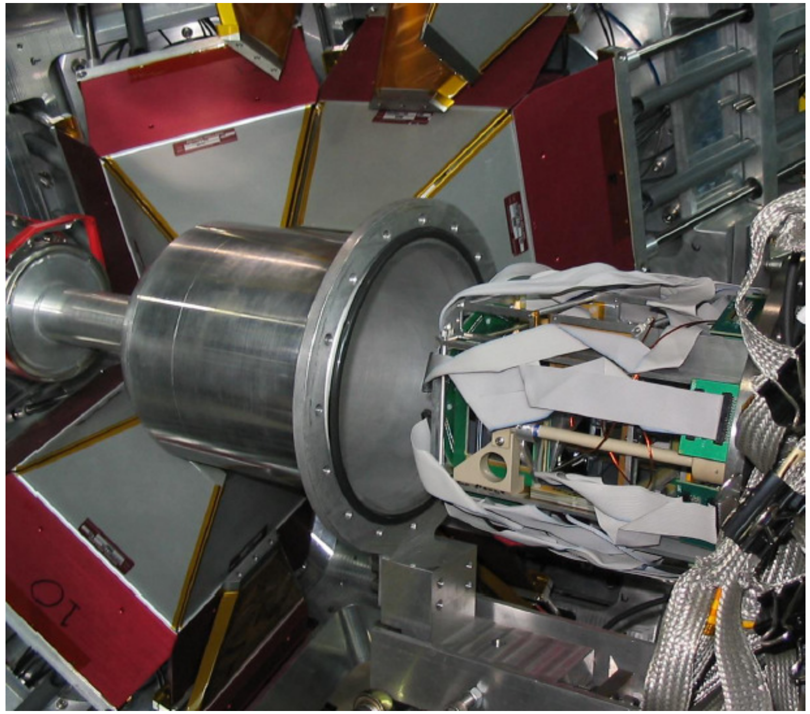
Energy resolution ~ 5keV FWHM

F.Meurders & A.Van der Steld, Nucl. Phys. A230 (1974) 317

SHARC/TIGRESS @ ISAC-II

Primary application - transfer reactions and Coulex
Compact Si detector system ~1000 channels (within sphere of radius ~11cm)
- (square) barrel + annular end caps
ΔE-E particle ID
TIGRESS high efficiency, high segmentation HPGe array

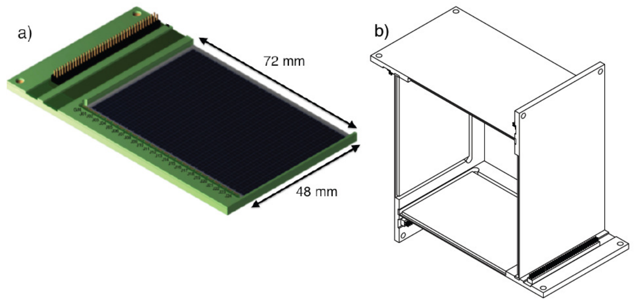




C.A.Diget *et al.*, J. Inst. 6 (2011) P02005

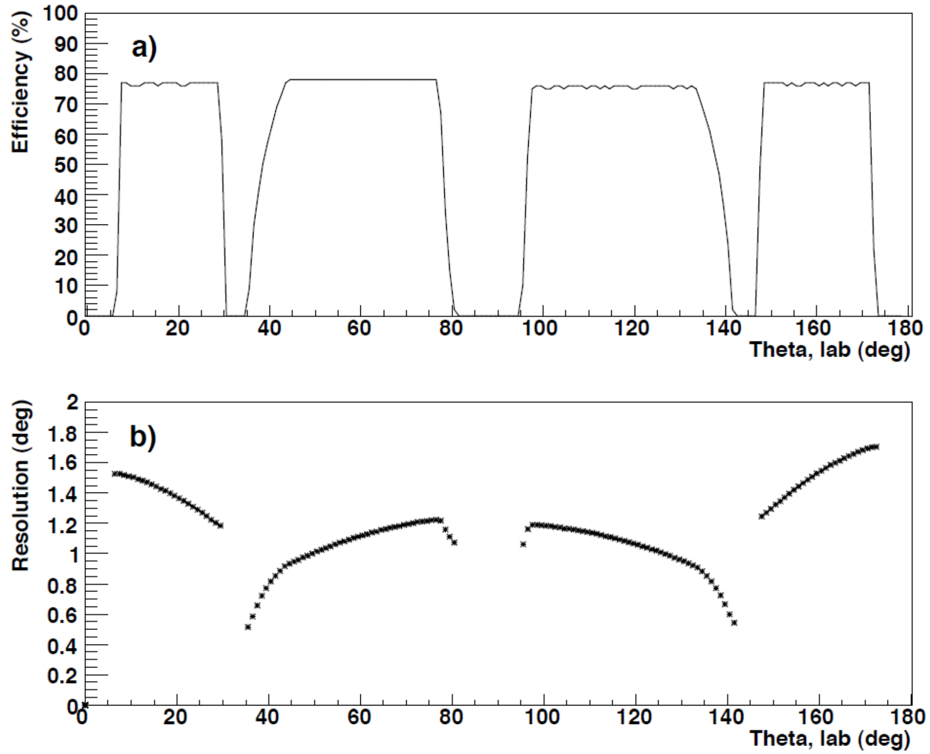
SHARC contd.

(Square) barrel ~7.5cm x 7.5cm
- 8x DSSSDs (ΔE) 1mm x 3mm strip pitch
- 8x PAD (E)



End caps
- 2x annular DSSSD (8 sectors)
- strip pitch (ΔE) 2mm x 3.5°

Silicon & HPGe readout
sampling ADC / DSP
(see lecture 4)



Relatively poor ΔE_x (from Si)
but …
efficient (~50% Si, >20% HPGe)
large angular coverage
ΔE_x recovered with γ-rays

C.A.Diget et al., J. Inst. 6 (2011) P02005

ORRUBA

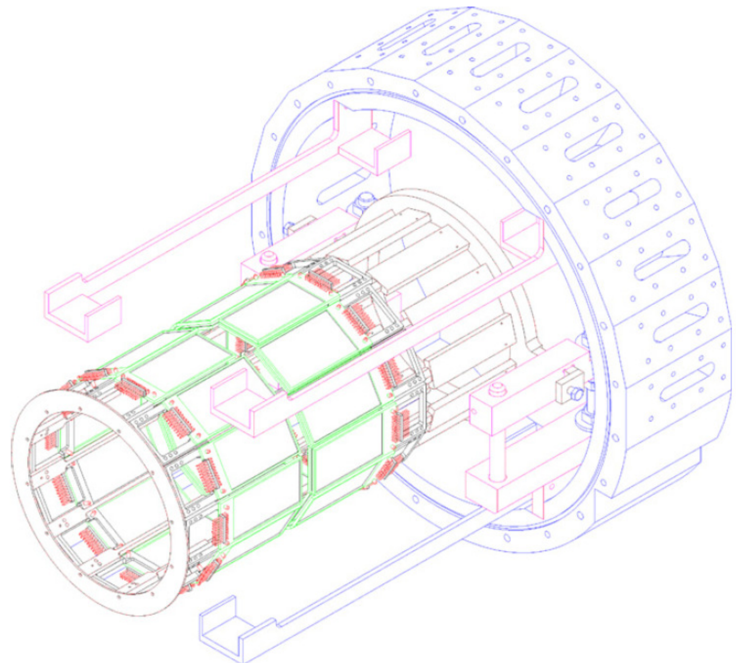
An evolving composite barrel-type array at HRIBF, ORNL

Primary application - (d,p) reactions with heavy nuclei e.g. ^{132}Sn
- low intensity beams
- high beam energy loss in targets

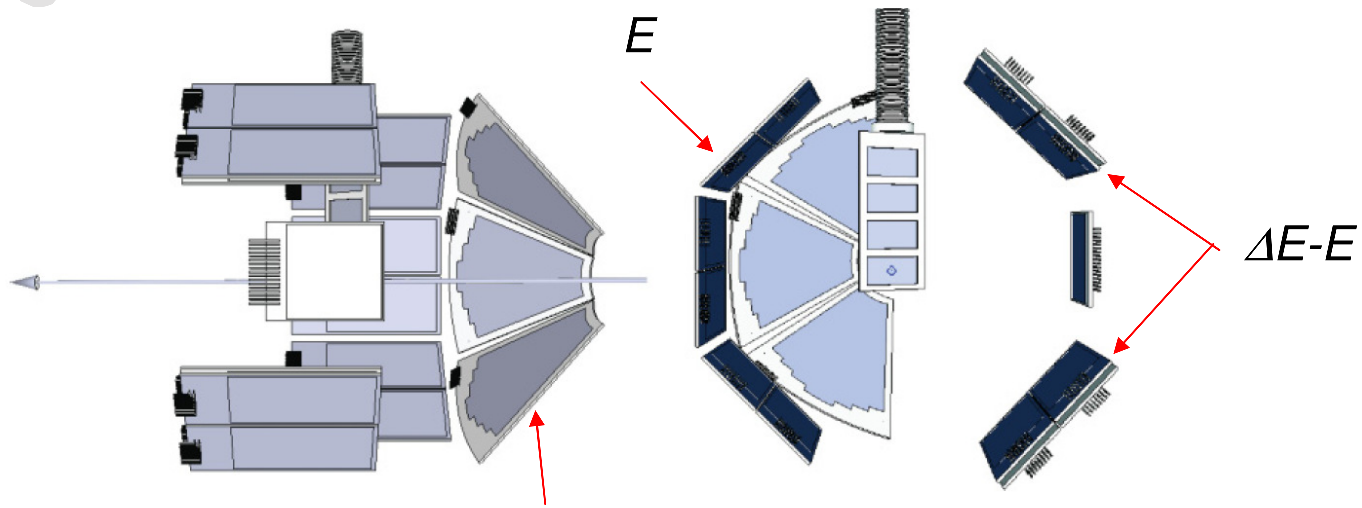
Silicon detector energy/angular resolution sufficient not to dominate overall resolution

SSD (ΔE) + PSSSD (E) forward
PSSSD (E) backward

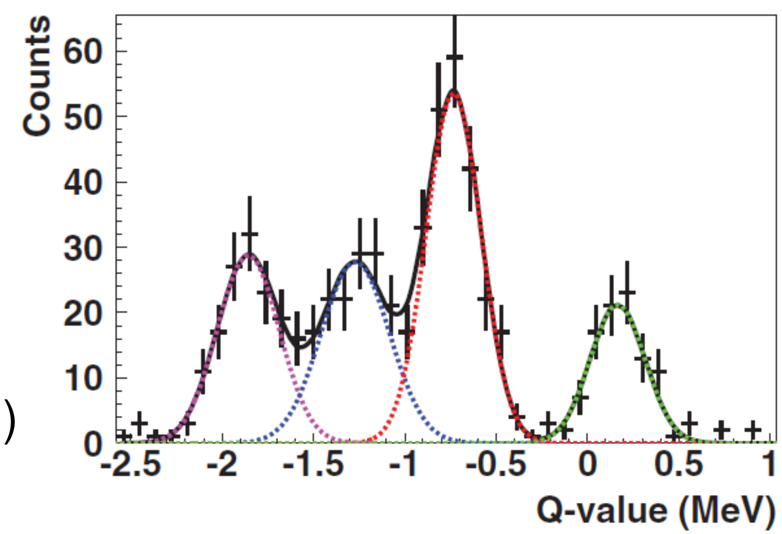
S.D.Pain *et al.*, NIM B261 (2007) 1122



ORRUBA



SIDAR (installed but not useful in this case)



D(^{132}Sn,p)
80µg/cm2 $(CD_2)_n$ target (@ 30^o to beam)
ΔQ ~ 300keV FWHM

K.L.Jones *et al.*, Phys. Rev. C84 (2011) 034601

Compare & Contrast

TUDA	TIARA-SHARC-T-REX-(ORRUBA)
• nuclear astrophysics	• nuclear structure
• low l (typically 0 & 1) - weakly populated states	• $0 \leq l \leq 6$ (say) - strongly populated states
• backward lab angles	• wide range of lab angles
• high intensity beams $>10^6$/s	• low intensity beams $\sim 10^3$-10^6/s
• thin targets	• thicker targets
• good E_x resolution	• low/moderate E_x resolution - possible recovery by γ-ray

… some fairly major generalisations … interpret with caution!

Design Guidelines … *discuss!*

- Understand your science requirements
  - distinguish what you **need** from what you **want** (… *not easy!*)
- DSSSDs not PSSSD/SSSD
  - better resolution (cf. PSSSD)
  - rejection of inter-strip events
- Single layer
  - simpler, cheaper, better energy (& time) resolution, lower min. threshold
  - PID requires good time reference (beam or tagging)
- Co-locate instrumentation (preamplifiers) if possible
  - if not, do not improvise detector – preamplifier interconnect
- Design, implement and control grounding scheme
- Diagnostics, diagnostics, diagnostics …

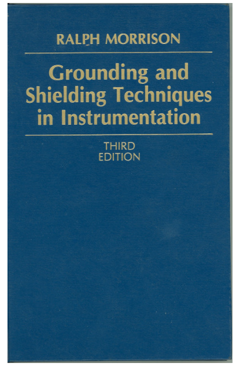
Design Guidelines … *discuss!* contd.

- *The best is the enemy of the good*

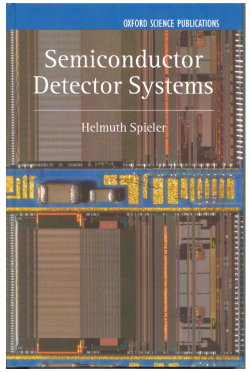
  keep it simple – faster, cheaper and (arguably) better

Further Reading

Grounding and Shielding Techniques in Instrumentation,
Ralph Morrison, Wiley, 1986_



Semiconductor Detector Systems,
Helmuth Spieler, Oxford, 2005
http://www-physics.lbl.gov/~spieler/



Transfer Reactions with Radioactive Ion Beams,
W.Catford, Euroschool on Exotic Beams, Leuven, Belgium, 2009
http://www.euroschoolonexoticbeams.be/site/files/2009_catford-euroschool2009.ppt

Neutron Transfer Reactions with Radioactive Beams,
J.S.Winfield *et al.*, NIM A396 (1997) 147