A Large Acceptance Spectrometer
for Deep-Inelastic Scattering with Reaccelerated Radioactive Beams

George A. Souliotis

Laboratory of Physical Chemistry, Department of Chemistry, National and Kapodistrian University of Athens, Athens, Greece
and
Cyclotron Institute, Texas A&M University, College Station, Texas, USA

2nd IRIS Workshop , GSI, Darmstadt, Germany, Nov. 19, 2010

ΕΘΝΙΚΟ ΚΑΙ
ΚΑΠΟΔΙΣΤΡΙΑΚΟ
ΠΑΝΕΠΙΣΤΗΜΙΟ
ΑΘΗΝΩΝ

CYCLOTRON
INSTITUTE
Texas A&M University

A Large Acceptance Spectrometer* for DIC with RIBs at E/A ~6-15 MeV:

Research objectives:

- **structure studies** of neutron-rich nuclei (at high spin states) around the projectile
- **reaction dynamics (e.g.** peripheral collisions, N/Z equilibration, symmetry energy, EOS)

Present work:

- Preliminary design of a large acceptance spectrometer for above-barrier energies: E/A=6-15MeV/u

Requirements :

- design specific for binary reactions
- large angular acceptance ($\Delta\Omega$>20msr) and high momentum resolving power (>1000) via trajectory reconstruction [“Raytracing spectrometer”]
- Z, A identification of projectile residues up to Z~60, A~150
- flexibility in target and focal plane detector setups:
  target location: accommodate a 4π Gamma Array (and charged particle array)
  focal plane: accommodate a decay setup
- spectrograph and associated detectors must be rotatable (θ= -20-120degrees)

*G. A. Souliotis, Nucl. Instrum. Methods B 266 (2008) 4213

Large Acceptance Spectrometers in Europe:

VAMOS: RNBs from SPIRAL,
combined with
EXOGAM and TIARA

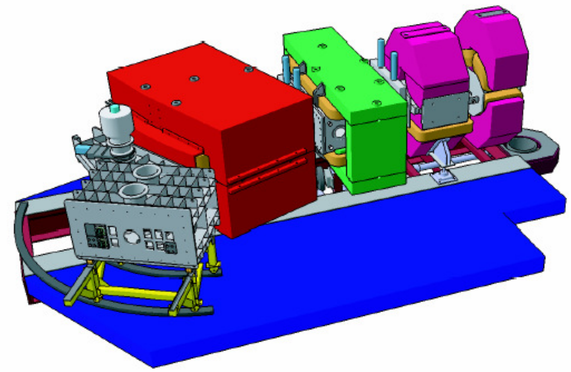


Fig. 6.5: Three-dimensional drawing of the VAMOS spectrometer at GANIL.

E-71

PRISMA (combined with CLARA)

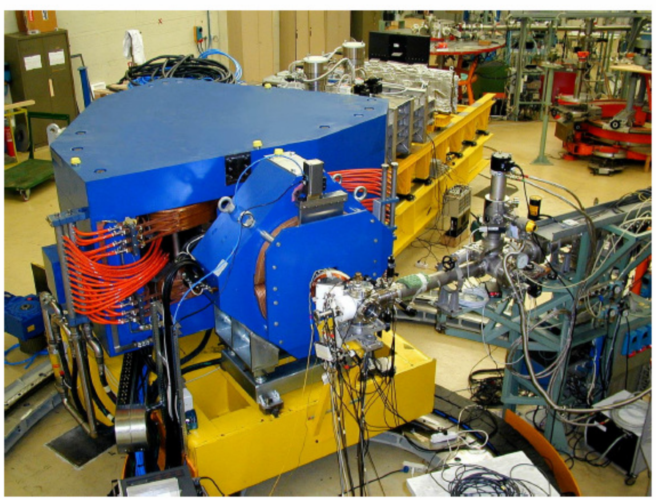
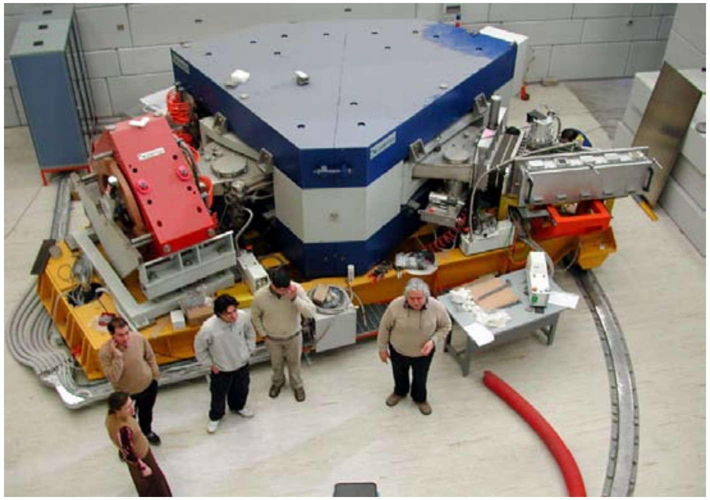


Fig. 6.6: The PRISMA spectrometer at LNL, Legnaro, in Italy.

MAGNEX (RNBs from EXCYT or FRIBs)



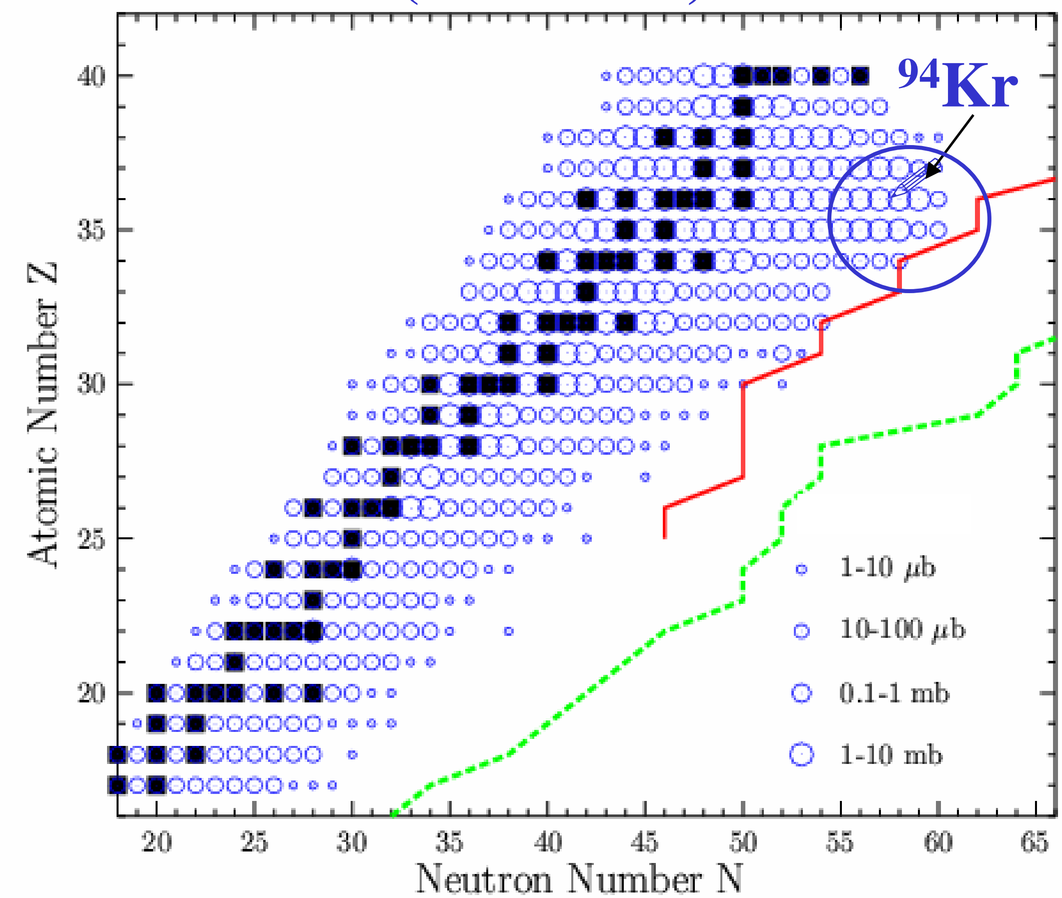
Example of nuclide production in DIC with RIBs:

Calculated nuclide cross sections:

Very important:

Neutron-pickup channels !!! along with proton stripping

^{94}Kr (15 MeV/u) + ^{64}Ni



❍ Calculations*:

DIT: (interaction, nucleon exchange)
GEMINI : de-excitation

■ stable nuclides

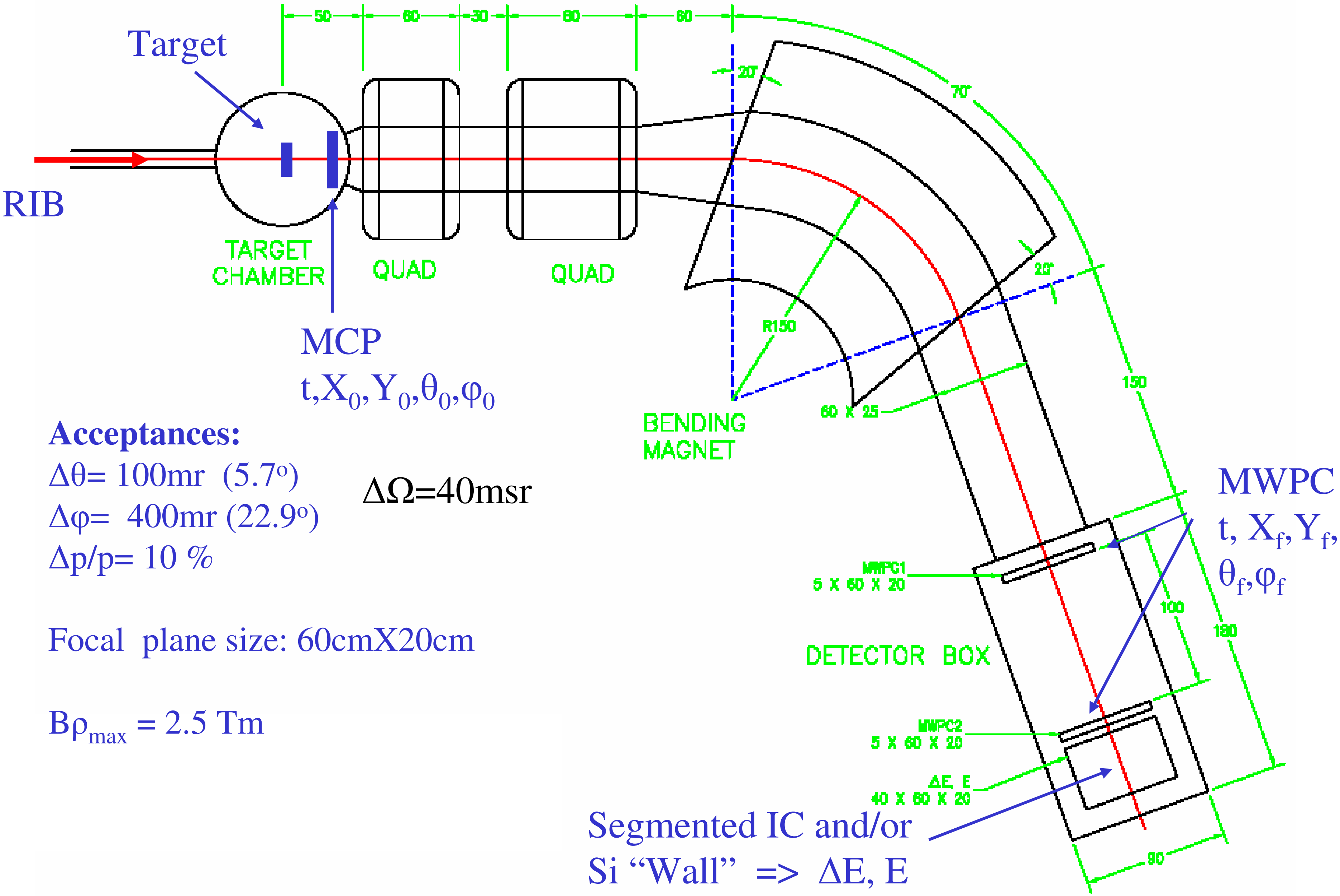
---- r-process
----- n-drip line

Work in progress to improve DIT code and make it appropriate for very low cross sections with very n-rich projectiles

Rate estimate: ^{94}Kr from "FRIB" at ~10^8 pps, ^{64}Ni (20mg/cm^2) :
1mb => 200 pps

*References: **DIT**: L. Tassan-Got and C. Stephan, Nucl. Phys. A524 121 (1991)
GEMINI: R. Charity et al., Nucl. Phys. A483 391 (1988)

Large Acceptance Spectrograph : preliminary layout



Acceptances:

$\Delta\theta$= 100mr (5.7°)

$\Delta\varphi$= 400mr (22.9°)

$\Delta p/p$= 10 %

$\Delta\Omega$=40msr

Focal plane size: 60cmX20cm

$B\rho_{max}$ = 2.5 Tm

LAS prelim. specifications: QQD type, $B\rho_{max}$=2.5Tm

Large Bore Quadrupoles (30-40cm diameter). Large Gap Dipole magnet (20-25cm)
Room temperature vs superconducting magnets (either option possible)

Target - Q1 distance: 30-120cm. "Nominal": 50cm

Quadrupole Q1: aperture: 30cm, length 60cm, $B_{max,tip}$ = 1.5T (Y focusing)
Quadrupole Q2: aperture: 40cm, length 80cm, $B_{max,tip}$ = 0.5T (X focusing).
Collins type (elliptical aperture) can also be used (e.g.VAMOS)
Superposition of higher multipoles is also considered

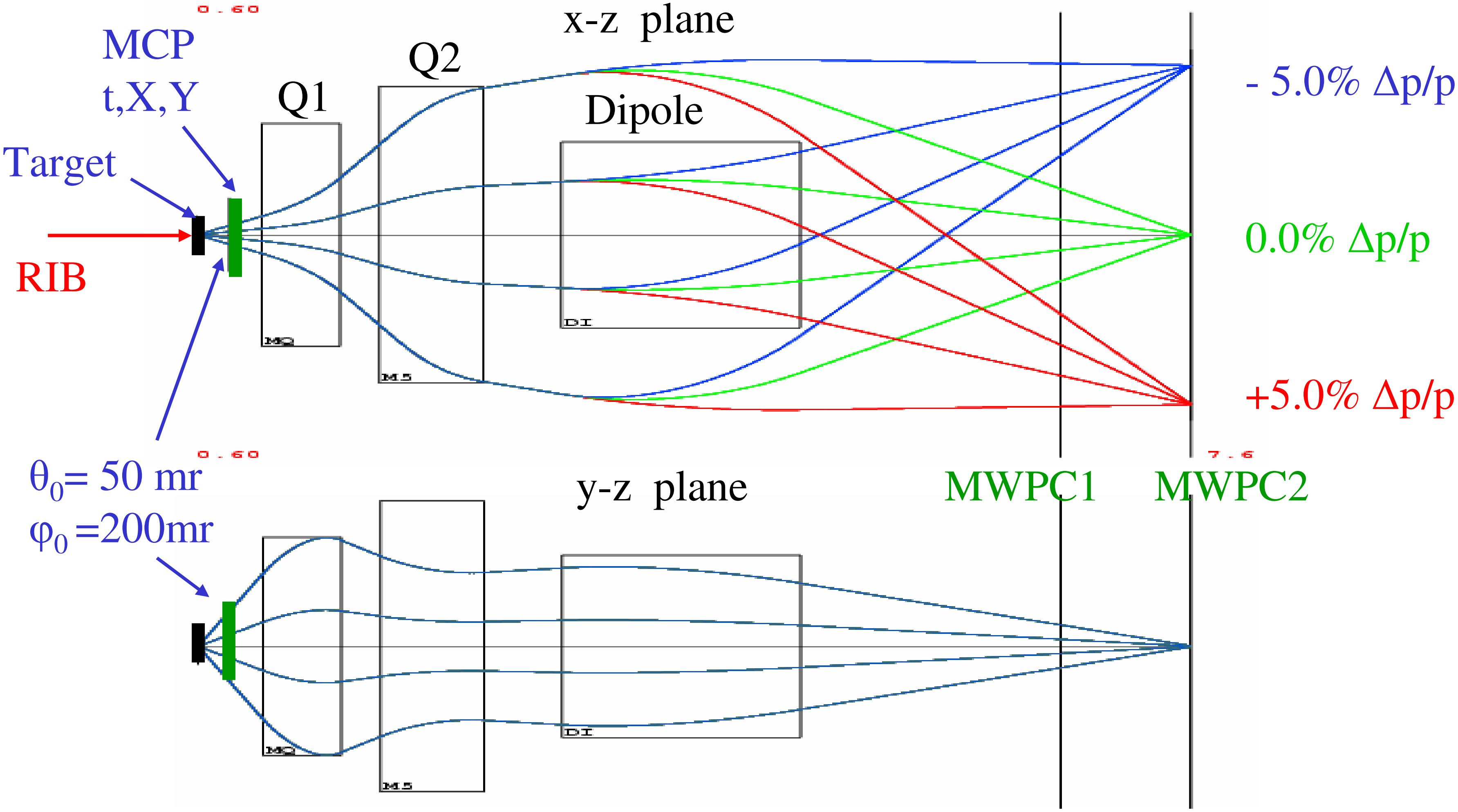
Dipole: bending radius: 150cm, bending angle: 70^o, gap: 25cm, B_{max} = 1.7T
Entrance and exit pole face rotation: +20^o (Y-focusing)
Entrance and exit pole face curvatures ($1/R_1$=0.2, $1/R_2$=0.0) to be optimized
(along with inclusion of possible higher-order profiling etc.)

Dipole - MWPC1: 2.0m, MWPC 1- MWPC2: 1.0m (this version, can be shorter also)

Length of **central trajectory**: 7.6 m
Appropriate for mass A determination via TOF: 130ns at 15MeV/u,
160ns at 10MeV/u, 210ns at 6 MeV/u

*G. A. Souliotis, Nucl. Instrum. Methods B 266 (2008) 4213

RIA Large Acceptance Spectrograph: 1st order optics



Rays through LAS: **$^{94}Kr^{34+}$(15 MeV/u)** Bρ=1.54 Tm

Ion Optics calculations with COSY-Infinity

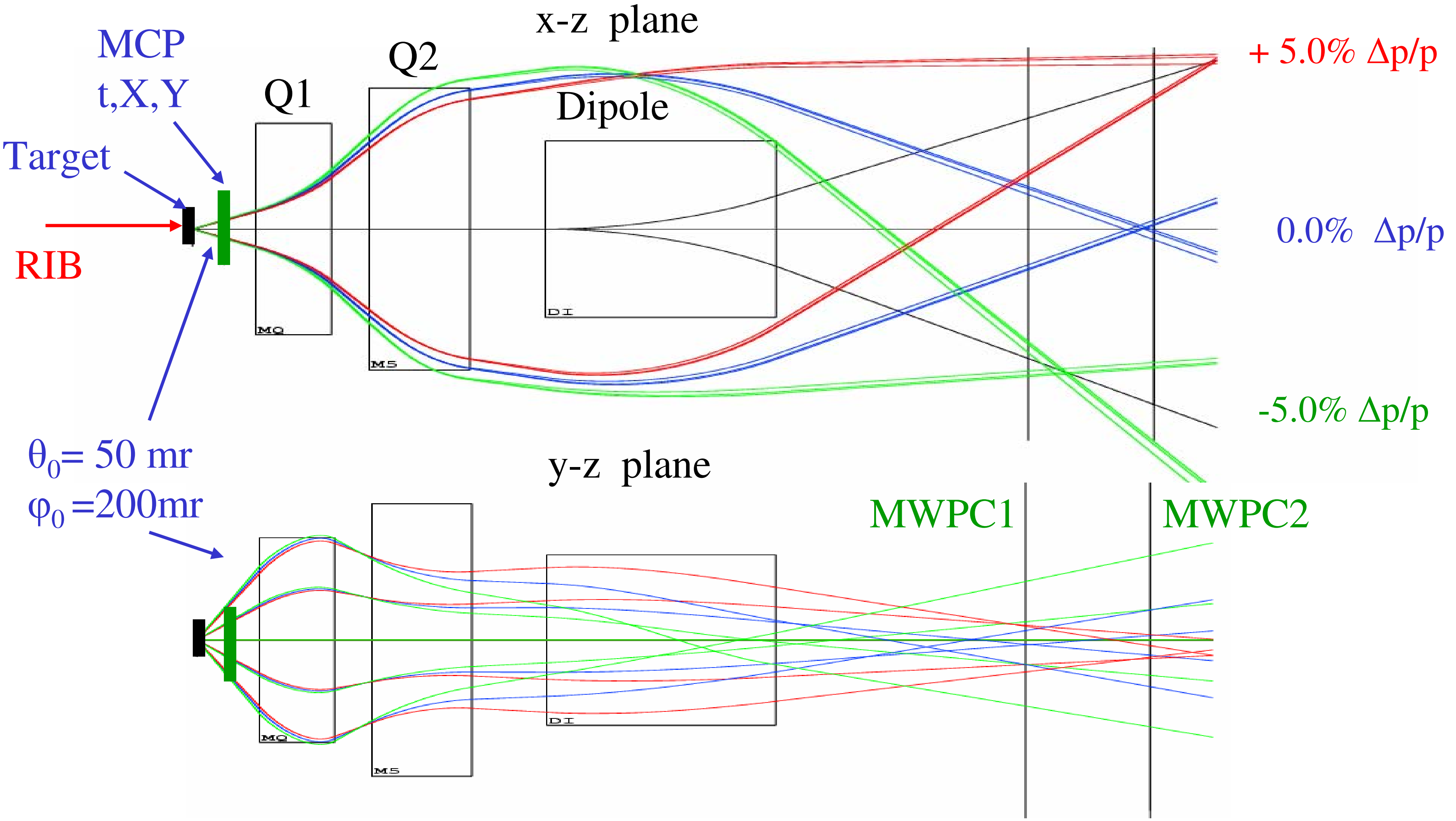
Large Acceptance Spectrograph : optics summary:

First-order optics (point-to-point focusing in x,y at MWPC2)**:**
Dispesions: (x/δ)= 4.6cm/%, (θ/δ)= 12 mr/%
Magnifications: $M_x=(x/x)= -0.80$, $M_y=(y/y)= -7.0$
$M_\theta=(\theta/\theta)= 1.24$, $M_\varphi=(\varphi/\varphi)= -0.14$
Path length dependences: (l/δ) = 3.5cm/%, (l/θ)= –0.3cm/mr

The most important higher-order aberrations in x,y (cm)
at full acceptable phace space: $\Delta\theta = \pm 50$mr, $\Delta\varphi = \pm 200$mr, $\Delta p/p = \pm 5$ %

Horizontal (X)	Vertical(Y)
2nd order:	
$(x/\theta\delta)$=> 4.5cm	$(y/\theta\varphi)$=> -2.2cm
(x/δ^2) => -2.1cm	$(y/\varphi\delta)$=> 6.8cm
3d order:	
(x/θ^3) => 1.5cm	(y/φ^3) => -4.0cm
$(x/\theta\delta^2)$=> -0.8cm	$(y/\theta^2\varphi)$ => 0.6cm
	$(y/\theta\varphi\delta)$=> -0.5cm

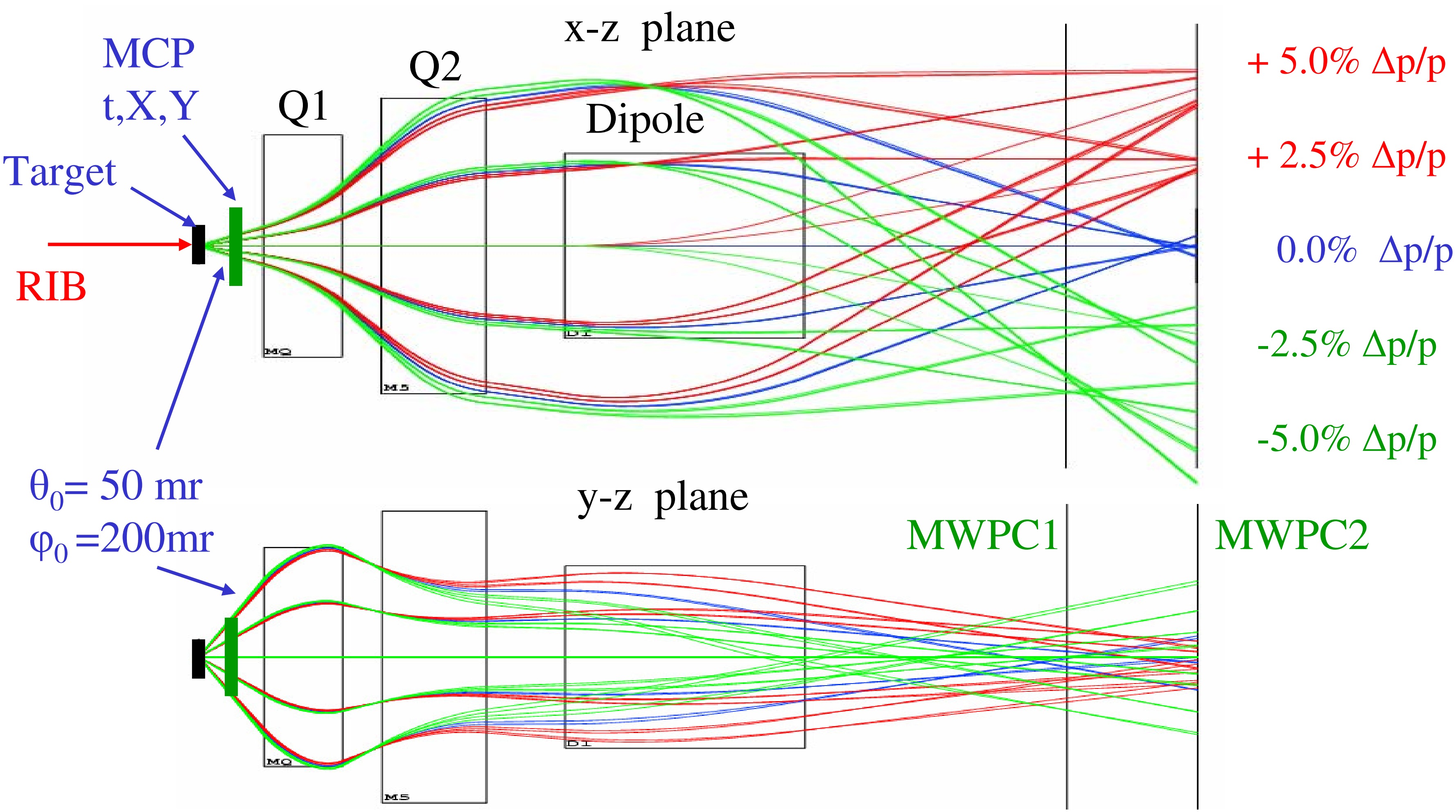
Large Acceptance Spectrograph: 5th order optics



Rays through LAS: **$^{94}Kr^{34+}$(15 MeV/u)** Bρ=1.54 Tm

Ion Optics calculations with COSY-Infinity

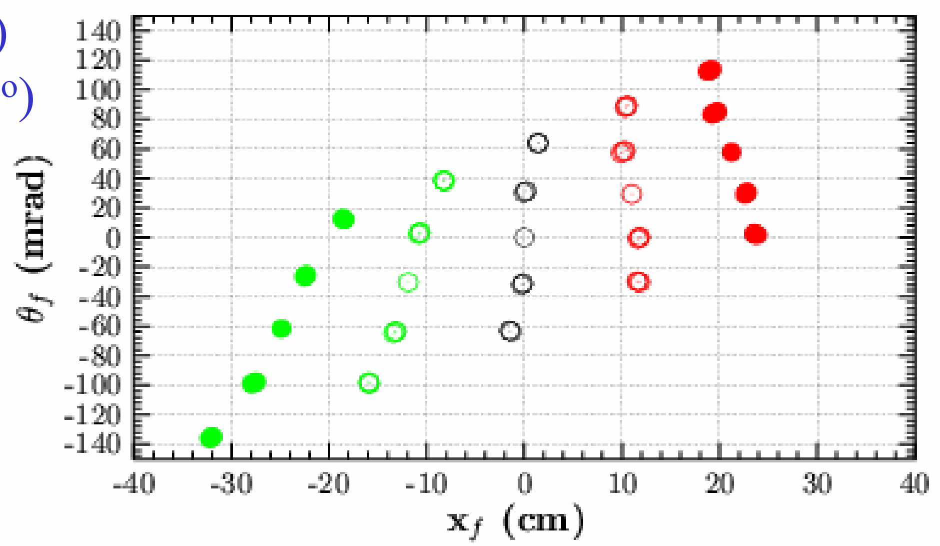
LAS: 5th order optics, multipoles (H,O,D,DD) included



Rays through LAS: **$^{94}Kr^{34+}$(15 MeV/u)** Bρ=1.54 Tm
Multipoles (O,D,DD) superimposed on Q2,
Entrance pole face of dipole curved with R=+5m (convex)

LAS: Relations at the Focal Plane

$\Delta\theta_0$= 100 mr (5.7°)
$\Delta\varphi_0$ =400 mr (22.9°)

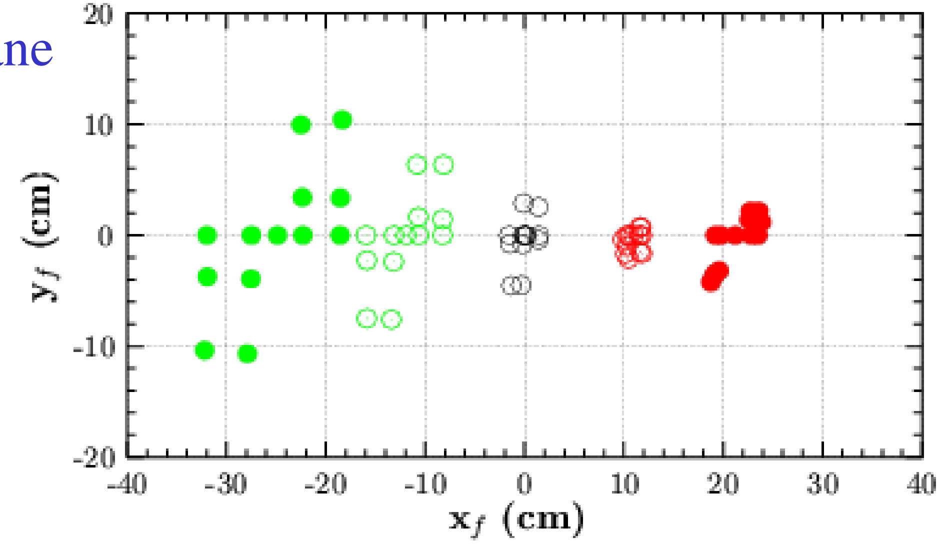


θ_0 (mr)
-50
-25
0
25
50

$\Delta p/p$ range: -5.0% -2.5% 0.0% +2.5% +5.0%

Effective Focal Plane and **Detector size**:

60cm x 25cm



φ_0 (mr)
-200
-100
0
100
200

5th order ion optics calculations with COSY-I

Details of Experimental Procedures:

Momentum (=>Bρ) reconstruction:

Measured quantities: after target: (MCP): θ_0,φ_0
At the focal plane detectors: (MWPC1,2): $x_f, y_f, \theta_f, \varphi_f$

Assuming 1.5mm beam spot on target, x,y position resolutions of 1mm,
and final angle resolution of 2mrad:
momentum can be reconstructed with **resolution 1/2000**
using calculated inverse **transfer maps** (determined to 5th order or higher with COSY)
and accurate description of the fields of the magnets.

Summary of measured and extracted quantities:

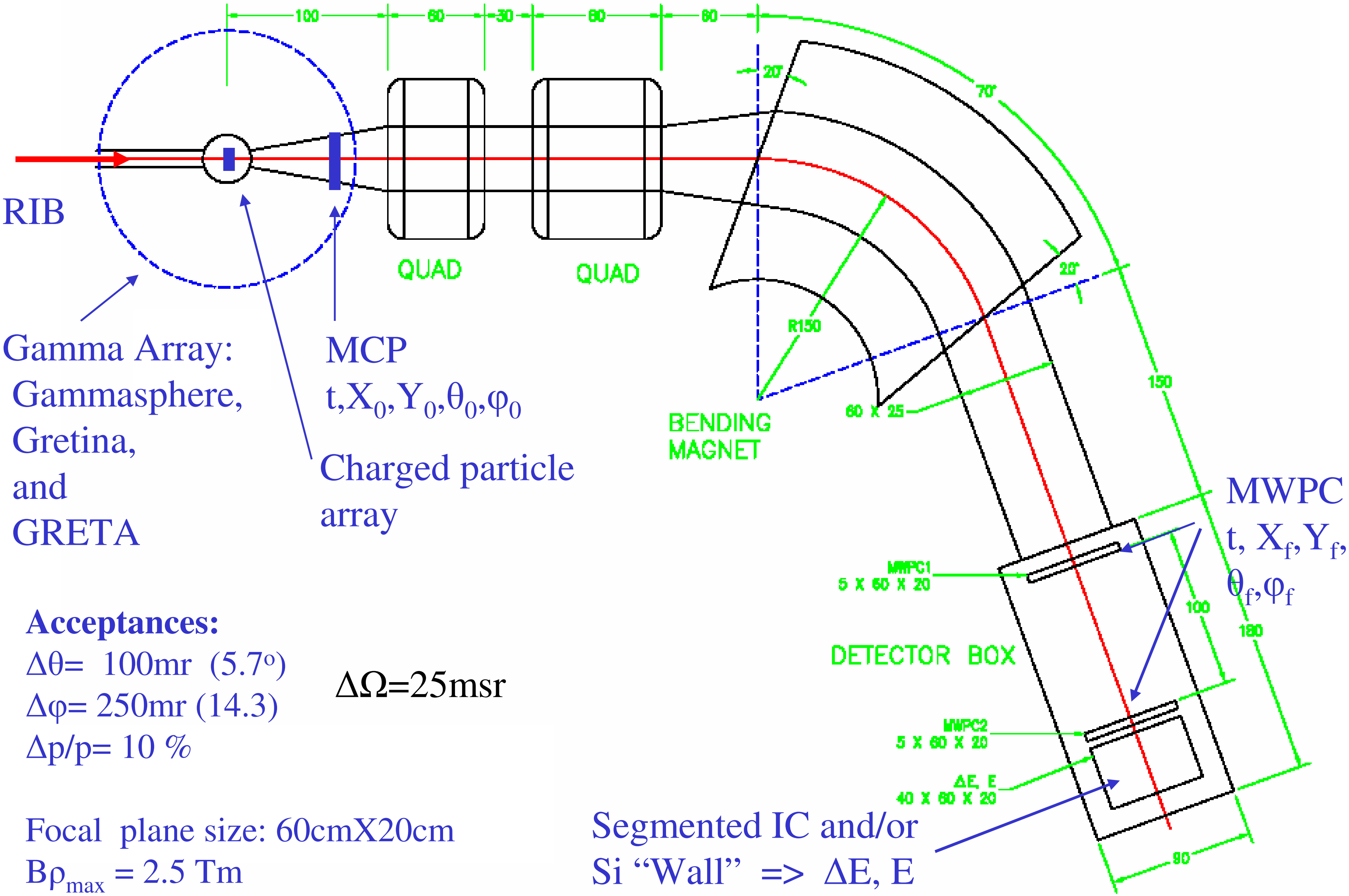
Velocity (from TOF), Energy loss (from IC), Total Energy (IC+Si wall)

Mass-to-charge ratio: A/Q	$B\rho \sim A/Q \times \upsilon$
Atomic Number Z	$Z \sim \upsilon \ \Delta E^{1/2}$
Ionic charge Q	$Q \sim f(E, \upsilon, B\rho)$
Mass number A	$A = Q_{int} \times A/Q$

Complete Identification of heavy residues in Z,Q,A,υ,θ_r

Residue yield distributios in Z,A,υ and θ_r can be obtained

Layout of “LAS” + Gamma and Charged Particle Arrays:



Acceptances:

$\Delta\theta$= 100mr (5.7°)

$\Delta\varphi$= 250mr (14.3)

$\Delta p/p$= 10 %

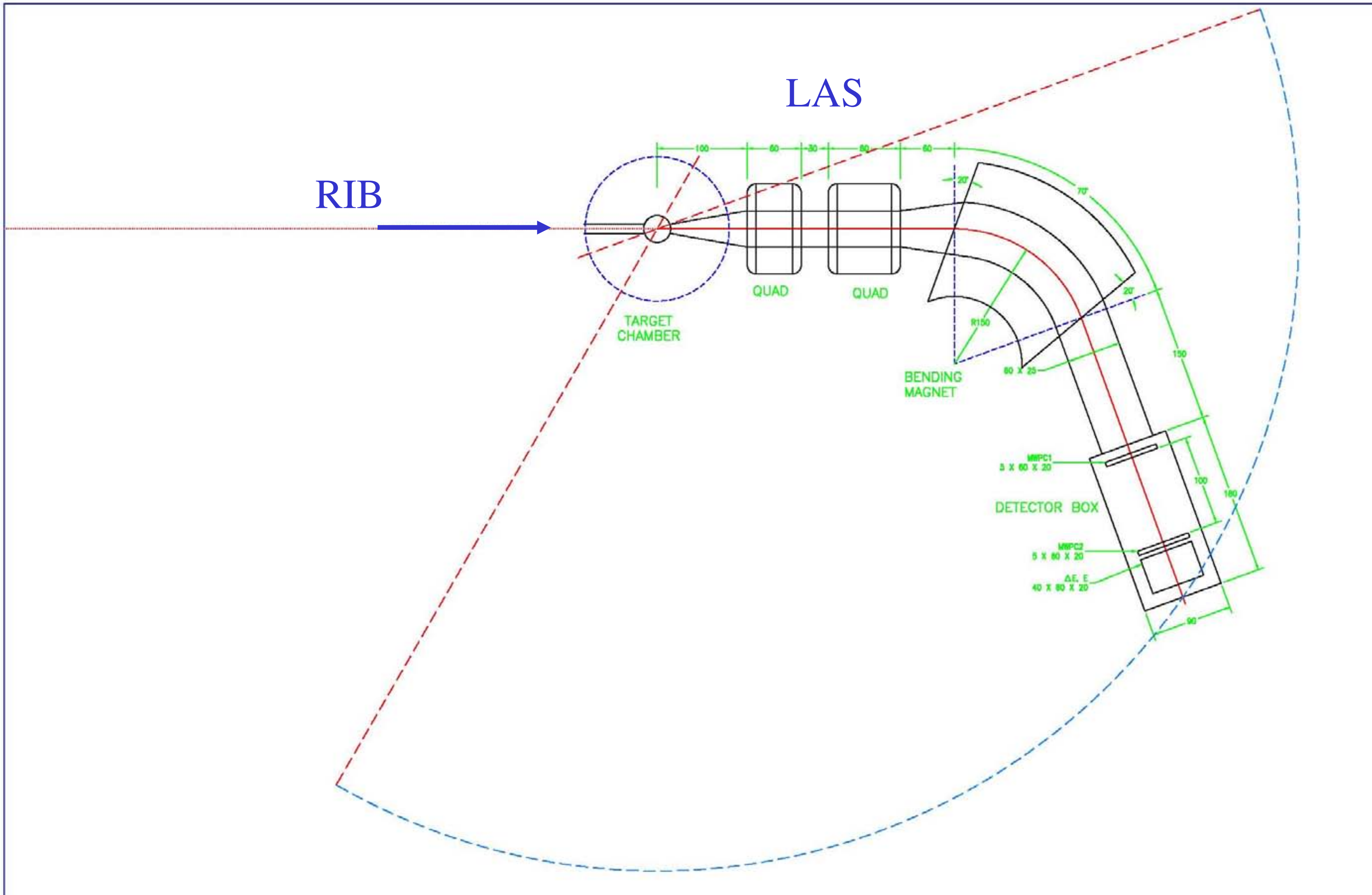
$\Delta\Omega$=25msr

Focal plane size: 60cmX20cm

$B\rho_{max}$ = 2.5 Tm

LAS : preliminary layout of experimental room:

The room dimensions are: ~10m x 15 m, arc is ~7m radius; angular range -20 to 120 degrees



Overview of "LAS" tasks (partial list) :

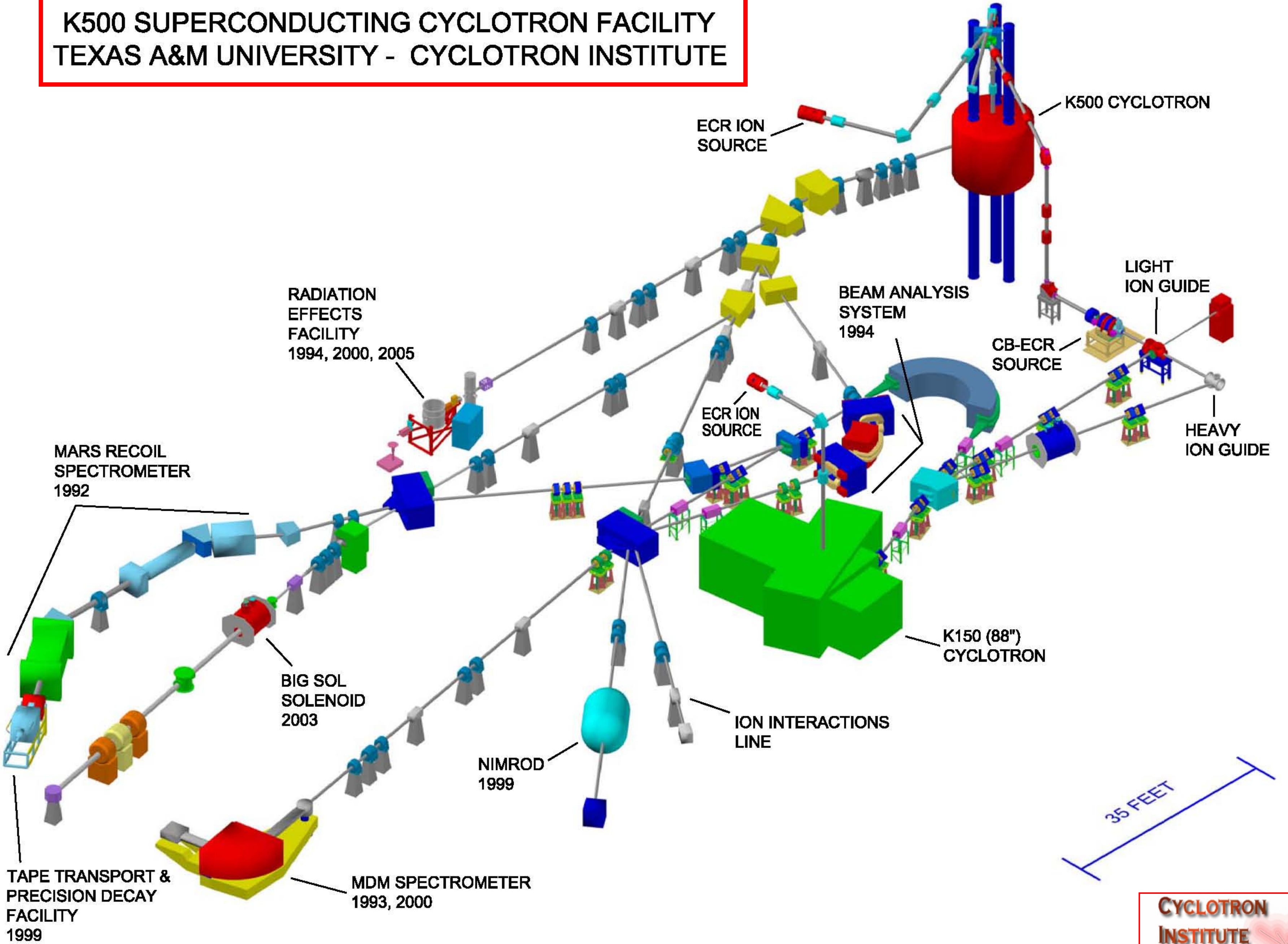
- Detailed definition of the spectrograph specifications
- Detailed design of the spectrograph according to these specifications
- Magnets (superconducting ?)
- Detectors: need state of the art detector systems:
  - tracking-MCP, MWPC/drift chambers
  - segmented IC
  - large area (+high uniformity) Si detectors for E ("Si walls")
- Target chamber (s)
- Electronics, data acquisition

Representative results from recent cross section measurements of neutron-rich products at 15MeV/nucleon with ^{40}Ar and ^{86}Kr beams at Texas A&M with the MARS recoil separator:

ΕΘΝΙΚΟ ΚΑΙ ΚΑΠΟΔΙΣΤΡΙΑΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ

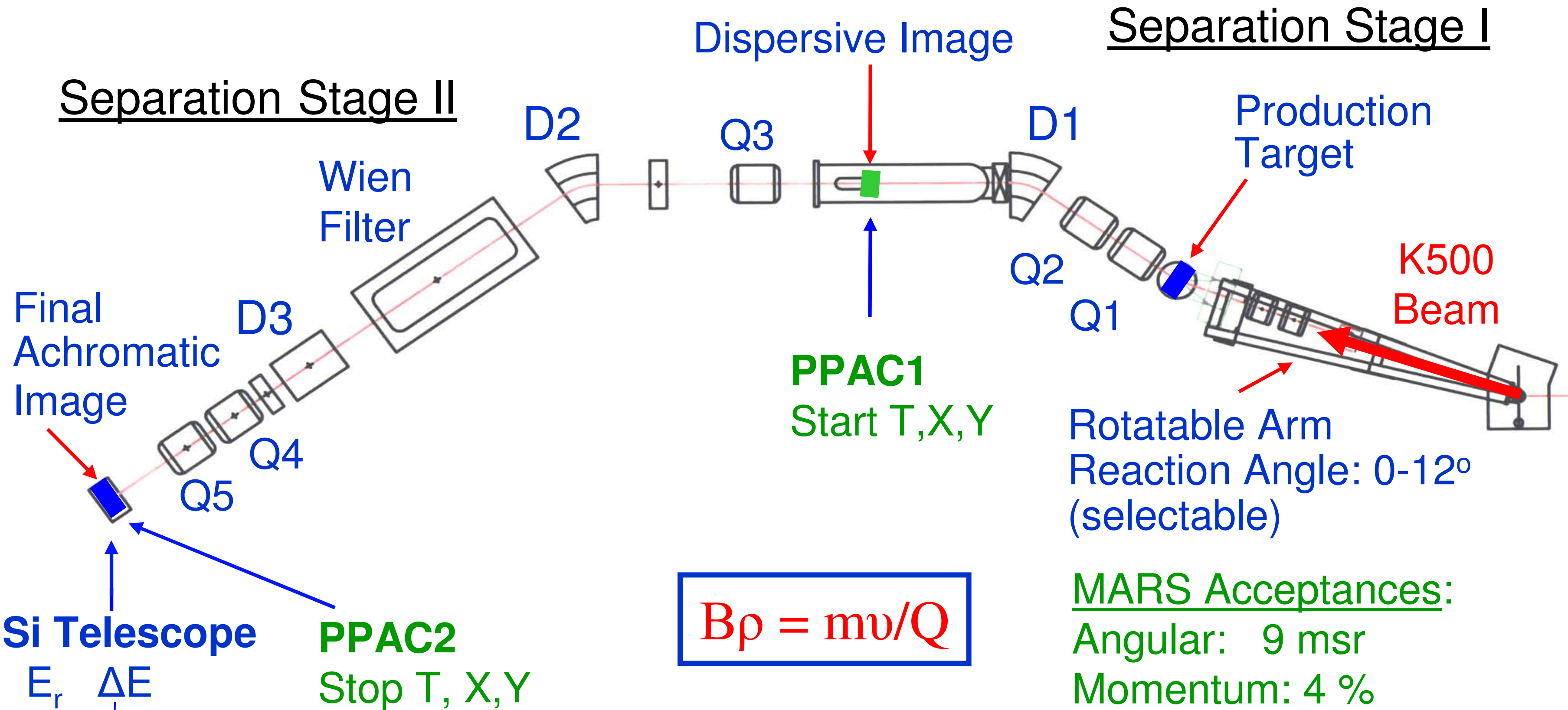
CYCLOTRON INSTITUTE
Texas A&M University

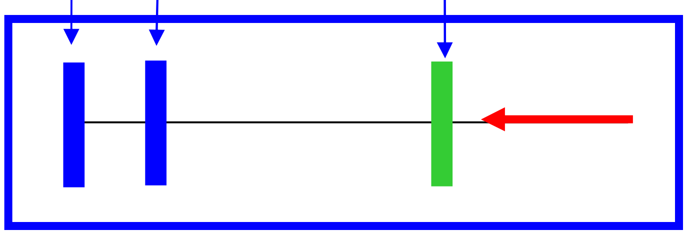
K500 SUPERCONDUCTING CYCLOTRON FACILITY
TEXAS A&M UNIVERSITY - CYCLOTRON INSTITUTE



CYCLOTRON INSTITUTE
Texas A&M University

MARS Recoil Separator and Setup for Heavy Rare Isotope Studies*





$$B\rho = m\upsilon/Q$$

MARS Acceptances:

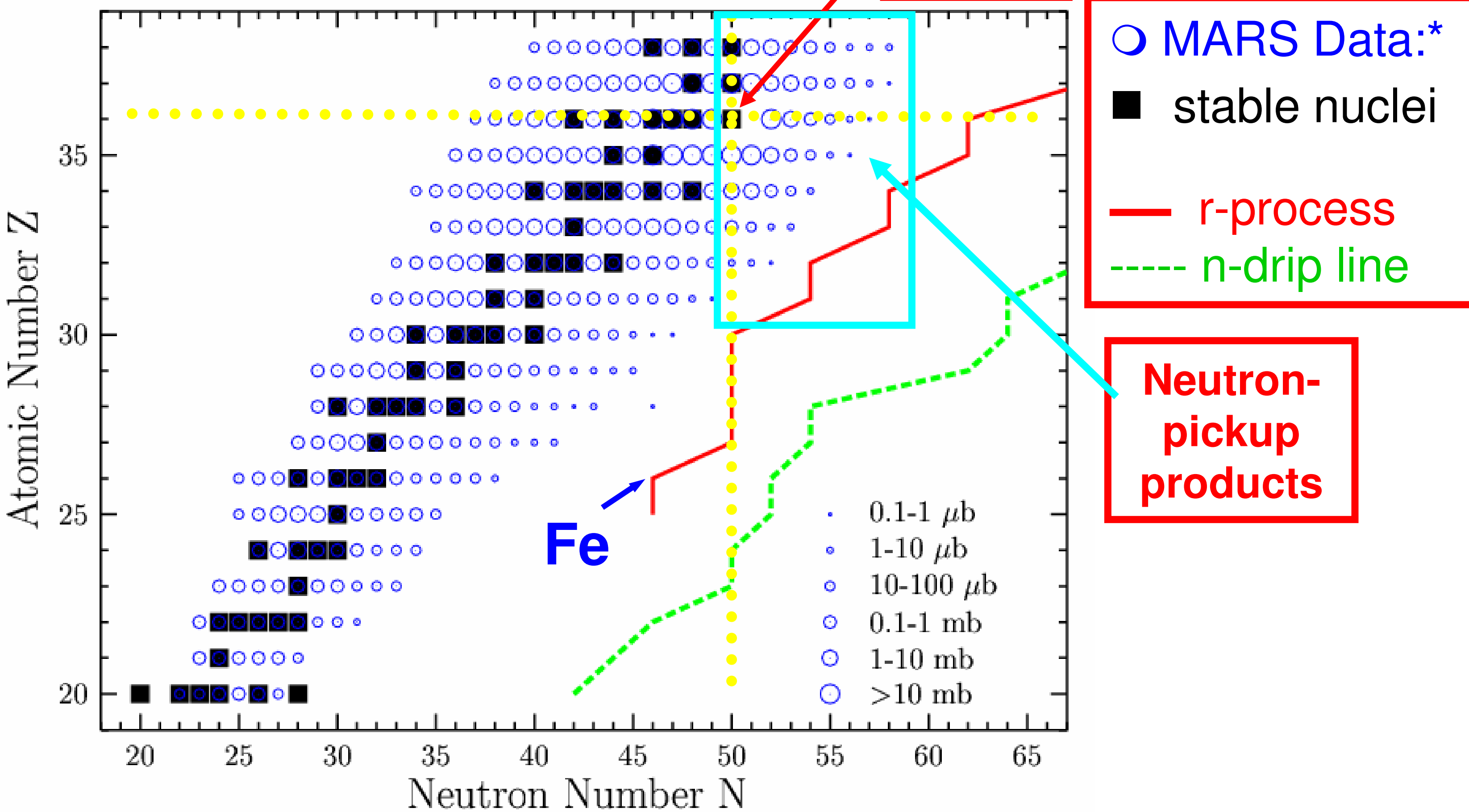
Angular: 9 msr

Momentum: 4 %

*G. A. Souliotis et al.,
Nucl. Instr. Methods B, 266, 4692 (2008)
and references therein

Rare Isotope Production at 15MeV/nucleon :

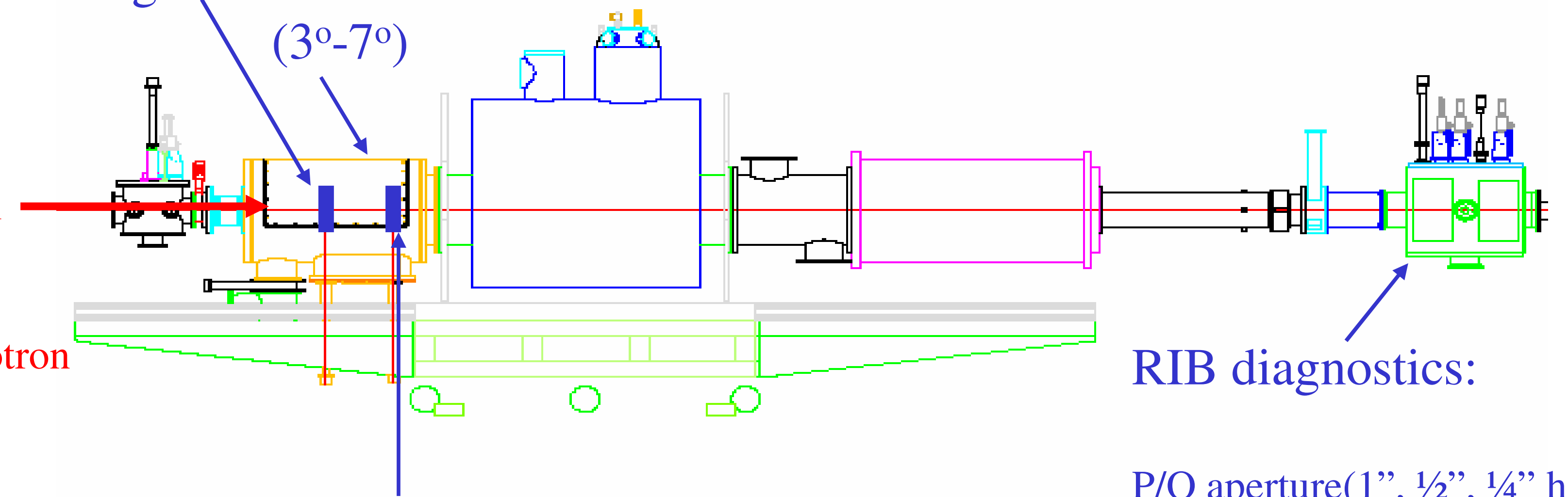
^{86}Kr (15 MeV/nucleon) + ^{64}Ni



Neutron-Rich Rare Isotopes near and above the **Fe-Ni region**

*G. A. Souliotis et al., in preparation

BigSol Setup for RIB production



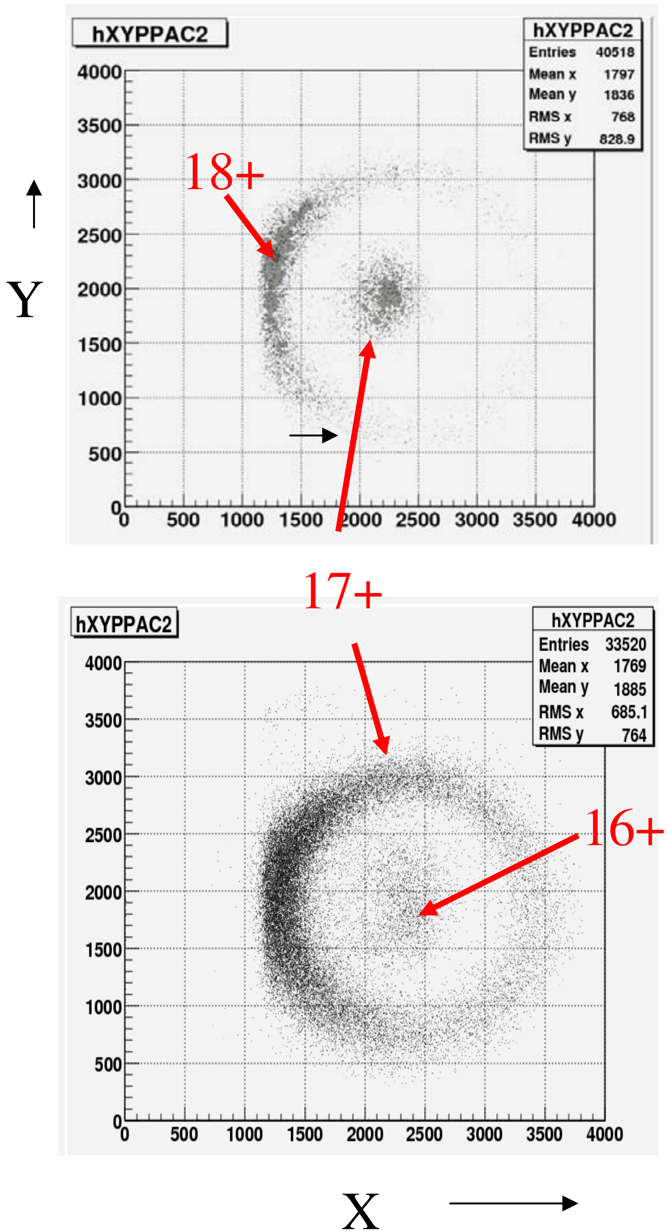
PPAC1 (“start”, X,Y)

Flight path : 5.5 m (PPAC1-PPAC2)

P/Q aperture(1”, ½”, ¼” holes)
PPAC2(“stop”, X,Y)
DE,E Si telescope (5cmx5cm)

Optics: object/image ~ 3 / 1

Results of BigSol test run: Charge State Distributions



Charge state distribution at PPAC2 of ^{40}Ar (15MeV/u) thru PPAC1 (acting as a stripper).

Angular acceptance: 3.0-4.0 deg. (set by the blocker system)

$B\rho = 1.244$ Tm, $I_{BigSol} = 81.6$ A

$B\rho = 1.320$ Tm, $I_{BigSol} = 86.6$ A

Results of BigSol Line tests: Rare Isotope Production

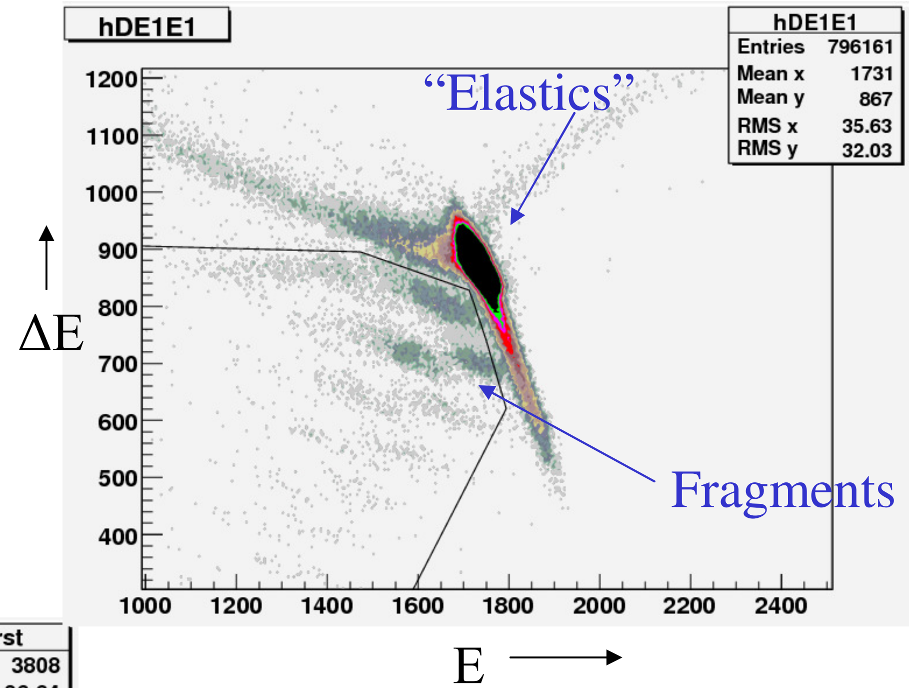
Example of nueutron-rich fragment production :

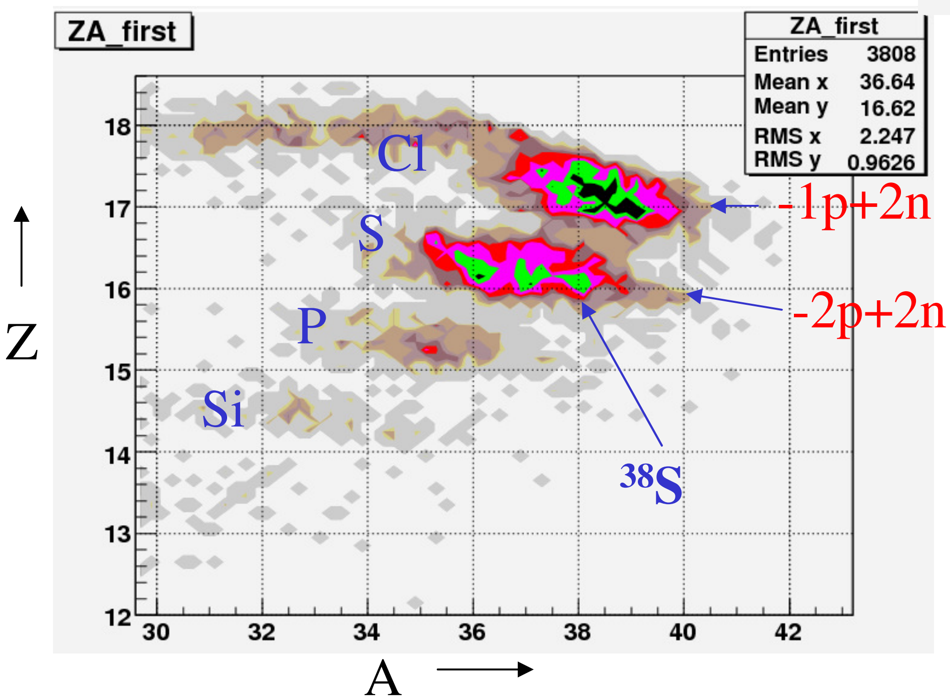
$^{40}Ar(15MeV/u)+^{64}Ni$

$B\rho = 1.282$ Tm,

$I_{BigSol}=84.1$ A

Angular acceptance: 3.0-4.0 deg.

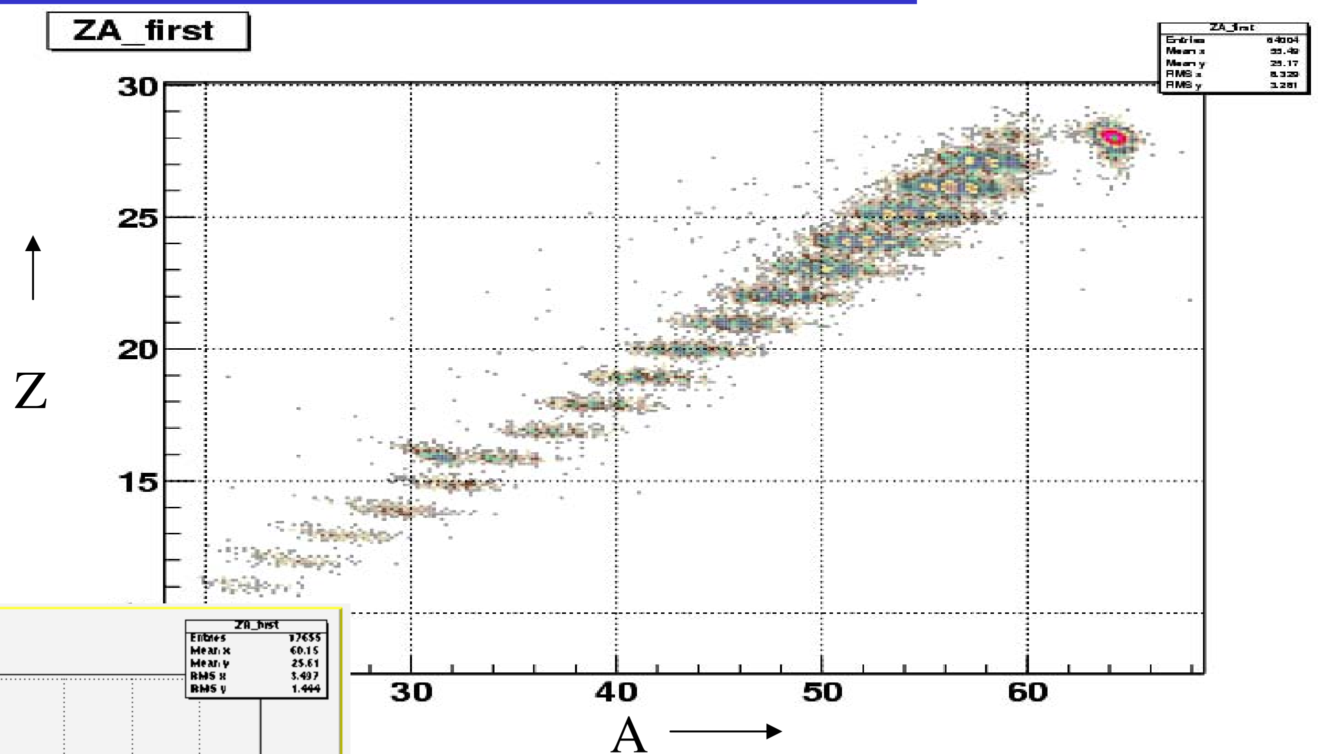


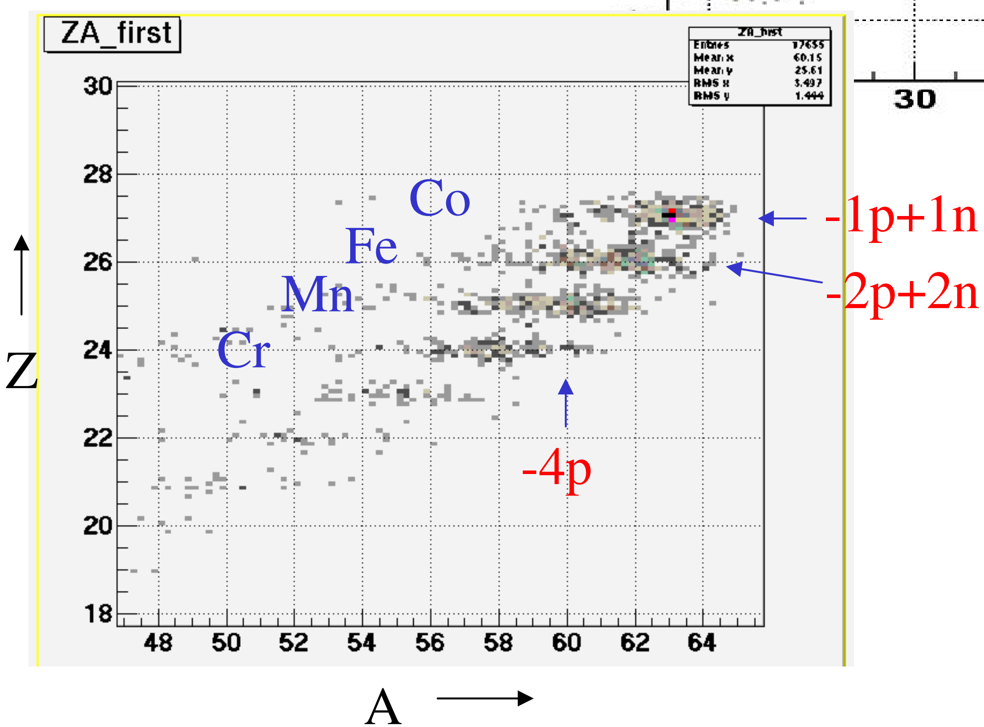


Cyclotron Institute
Texas A&M University

BigSol Line Data: Rare Isotope Production

Example of Z-A distribution of fragments from ^{64}Ni(25MeV/u)+^{64}Ni
B ρ =1.473,
I_{BigSol}=79.3 A
Angular acceptance: 1.5-3.0 deg.



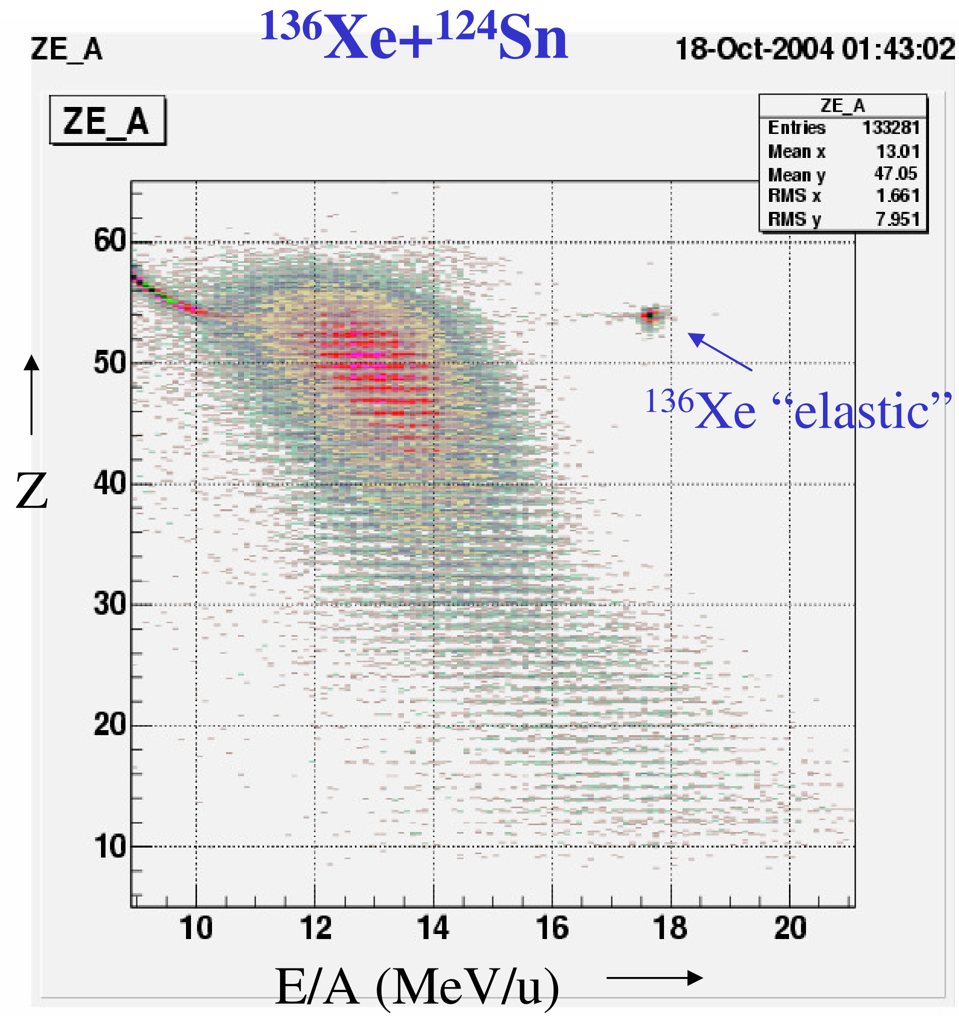


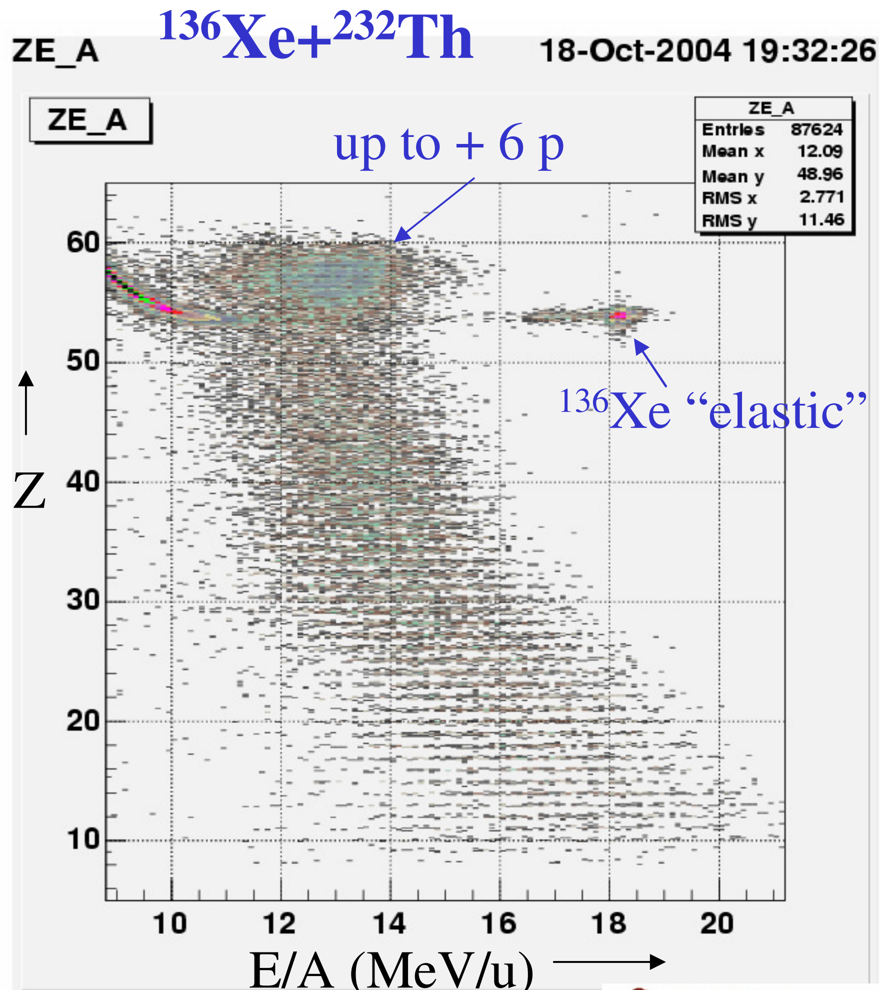
Neutron-Rich fragments from
^{64}Ni (25MeV/u) + ^{64}Ni (4.0mg/cm^2)
B ρ =1.900 Tm, I_{BigSol}=102.5 A
i_{beam} = 1 pnA, 4 hour run
Angular acceptance: 1.5-3.0 deg.

Cyclotron Institute
Texas A&M University

BigSol Line: analysis of test DIC data

Example of Z-E/A distribution of fragments from ^{136}Xe (20 MeV/u) data:
(ΔE-E-TOF techniques, use of large area Si and PPACs) :





B ρ =1.325 Tm, Angular acceptance: 1.5-3.0 deg.

Acknowledgements:

Special thanks to:

Robert Janssens, Jerry Nolen, Ernst Rehm and Alan Wuosmaa
for discussions and support of the LAS effort

Work on DIC at TAMU:

M. Veselsky, S. Galanopoulos, M. Jandel,
A. Keksis, D.V. Shetty, B. Stein, S.J. Yennello

This work was supported in part by:

The Department of Energy: Grant Number DE-FG03-93ER40773,
The Robert A. Welch Foundation: Grant Number A-1266

ΕΘΝΙΚΟ ΚΑΙ
ΚΑΠΟΔΙΣΤΡΙΑΚΟ
ΠΑΝΕΠΙΣΤΗΜΙΟ
ΑΘΗΝΩΝ

CYCLOTRON
INSTITUTE
Texas A&M University