TEXAS A&M UNIVERSITY

JINR FLNR Dubna

Super Heavy Nuclei International Symposium

Texas A&M University, College Station
Texas, USA

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On-line separators for SHE Factory

Andrey Popeko
FLNR JINR

Bottom lines:

Universal Gas-filled & Air-free separator:

- complete fusion reactions;
- multi-nucleon transfer reactions;
- nuclear spectroscopy @ target & focal plane.

Preseparator & gas-catcher, RPC-chamber:

- chemistry;
- fusion and multi-nucleon transfer reactions;
- mass-spectrometry and nuclear spectroscopy;
- laser spectroscopy of heavy atoms.

The goal: high production rate of SHE

- High beam current;
- High transmission;
- Reduction of background.

What from what?

- **SHE;**
- **Primary beam;**
- **Target (transfer target-like) products;**
- **Neutrons;**
- **High-energy protons or alphas;**
- **Scattered beam.**

Charge systematics

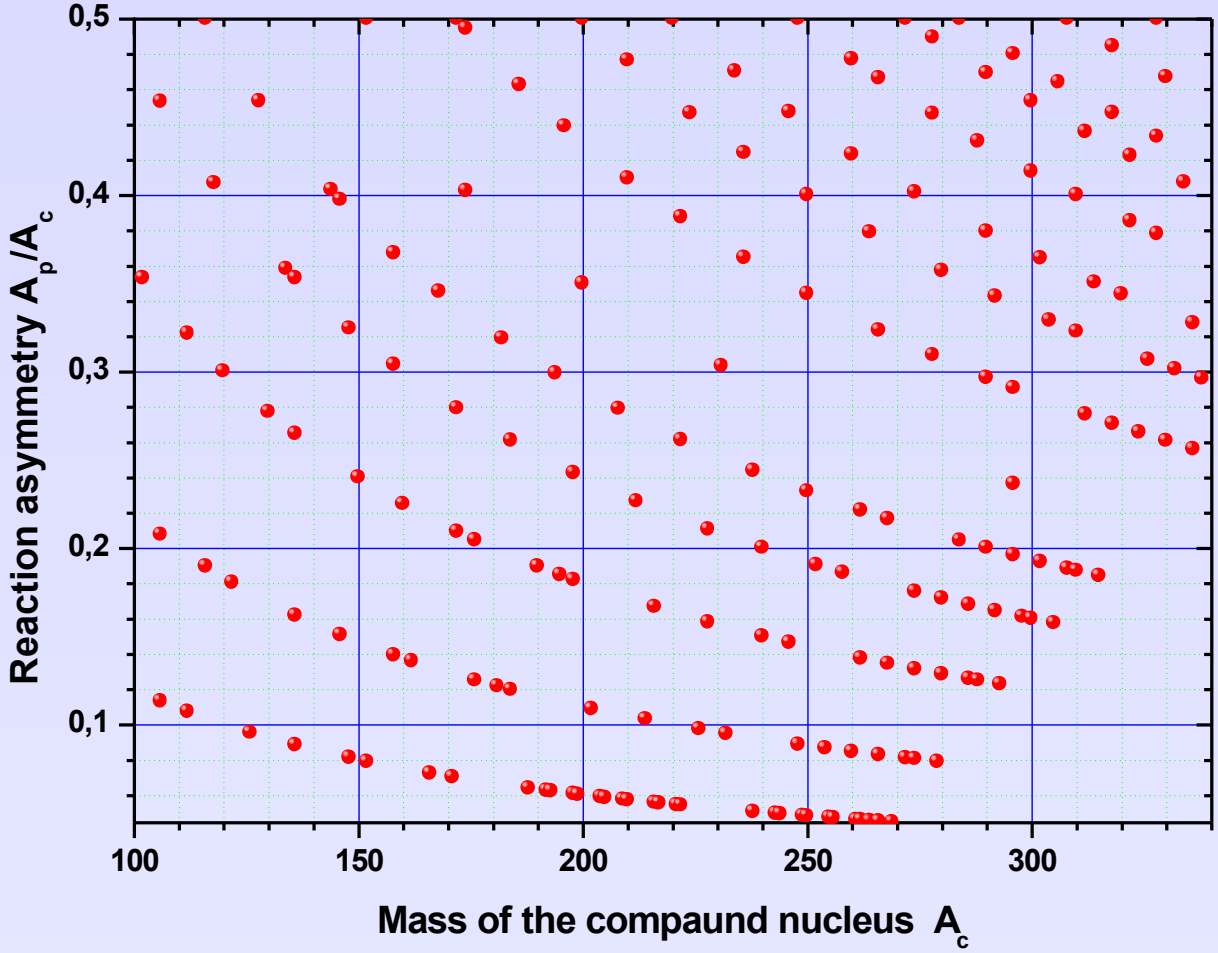
- V.S. Nikolaev & I.S. Dmitriev, Phys. Lett., 28A(1968)277;
- K. Shima, T. Ishihara & T. Mikumo Nucl. Instr. & Meth., 200(1982)605;

- Yu.Ts. Oganessian *et al.*, Z. Phys. D., 21(1991)357.
- A. Ghiorso *et al.*, Nucl. Inst. & Meth., A269(1988)192.
- Y. Baudinet-Robinet *et al.*, J. Phys. B11(1978)1291.

Scattering and solving down

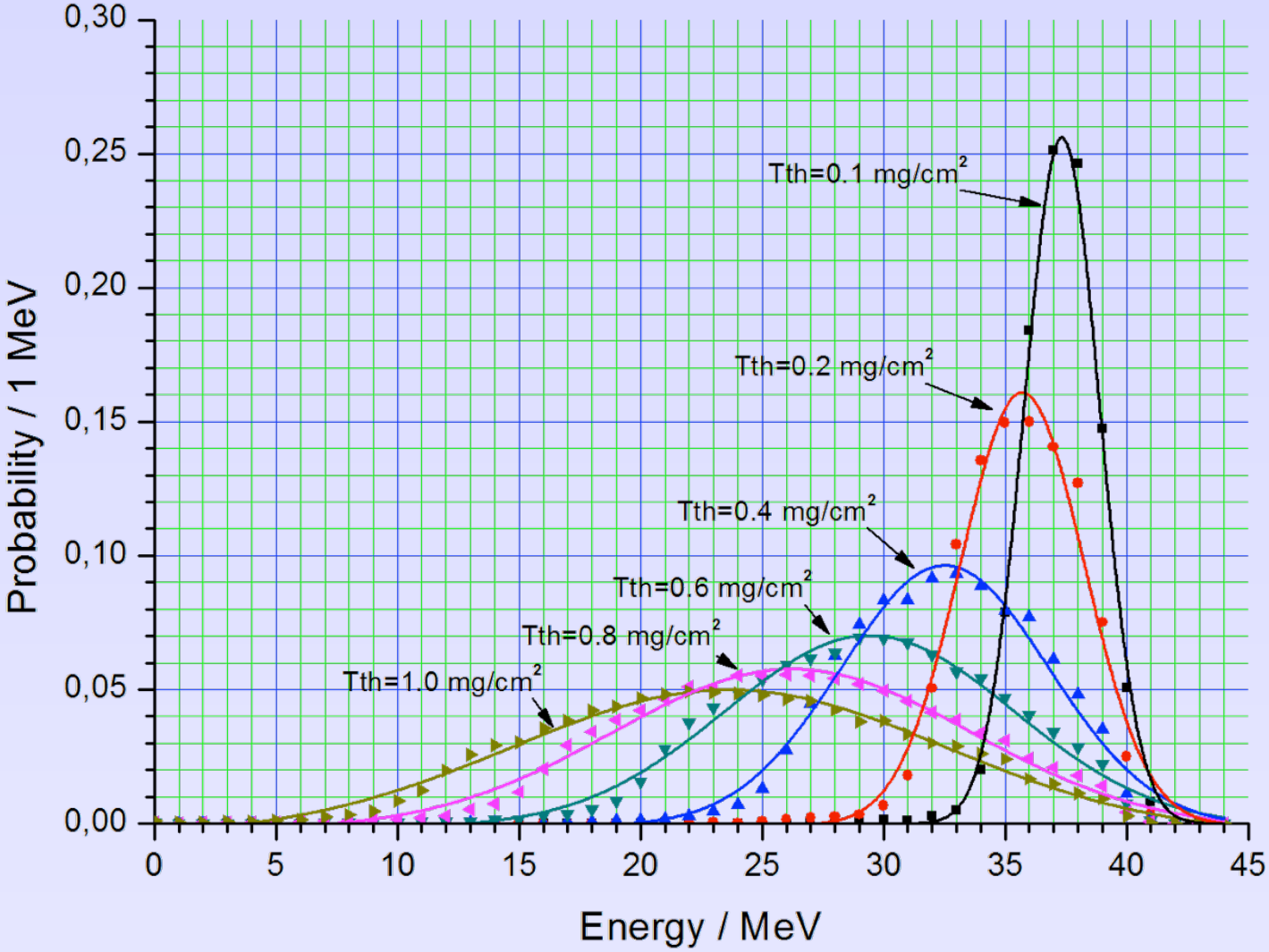
- J.F. Ziegler, J.P. Biersack, U. Littmark. *The stopping and range of ions in solids.* V. 1, Pergamon press, 1985.

Analyzed reactions



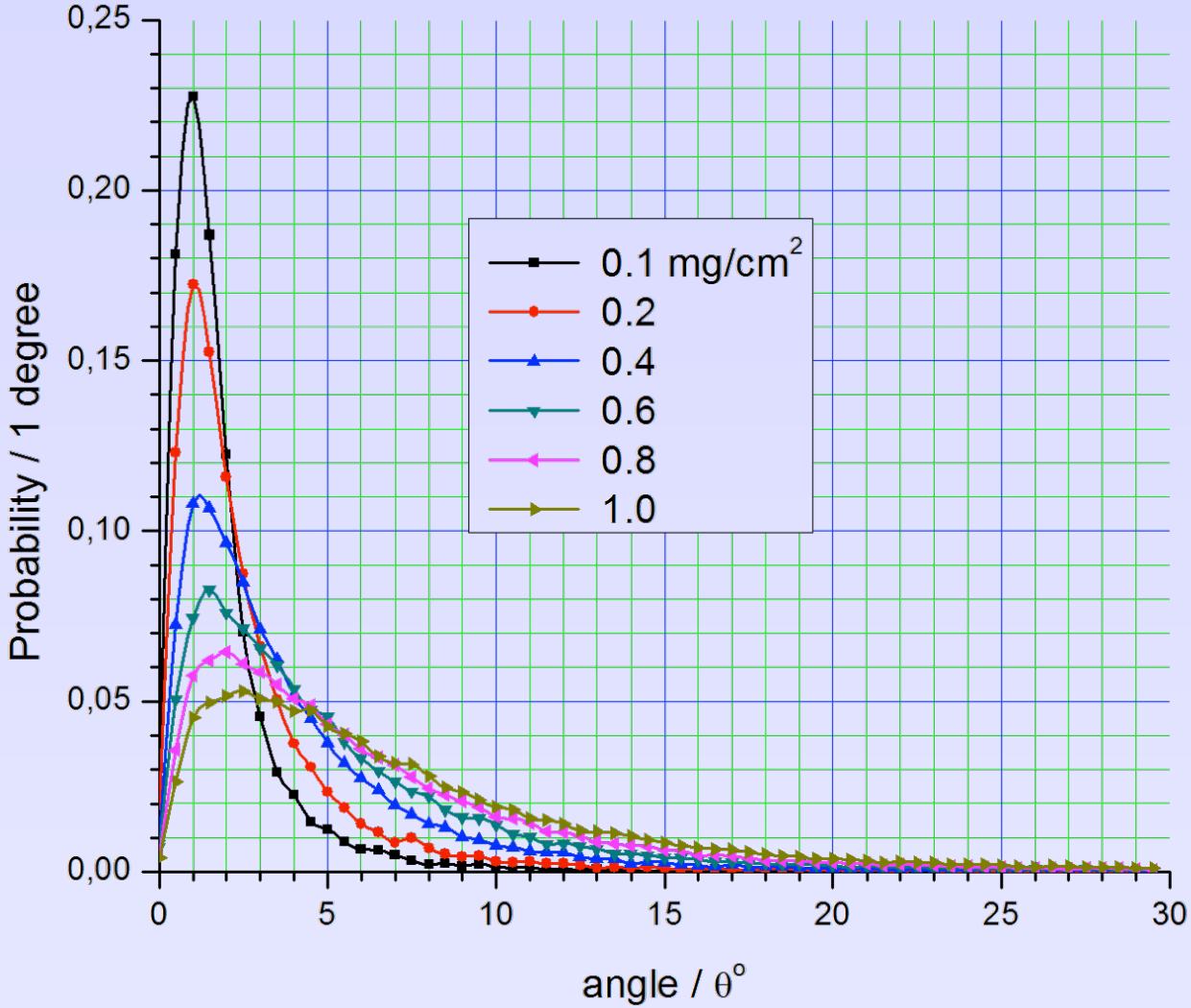
Energy distributions for different target thicknesses

$^{48}Ca + ^{238}U(UF_4) \rightarrow ^{283}Cn + 3n$



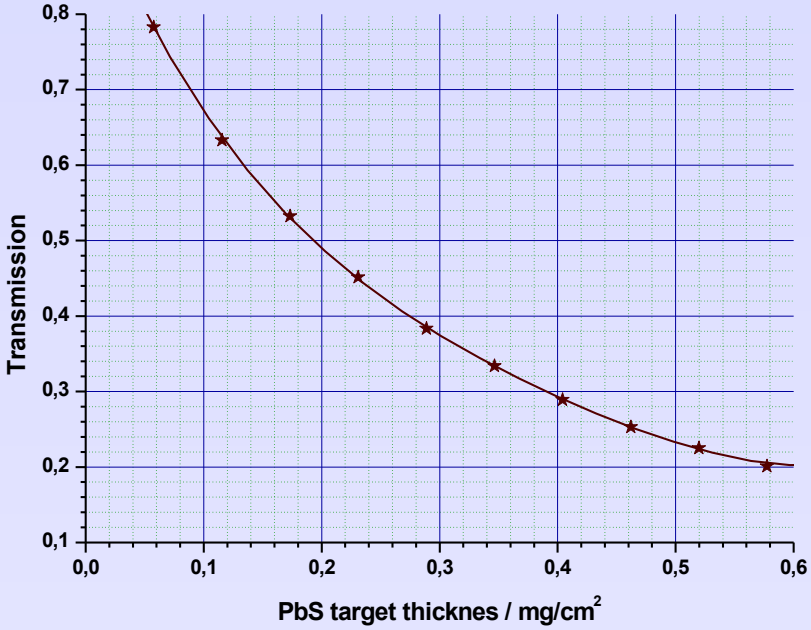
Angular distributions for different target thicknesses

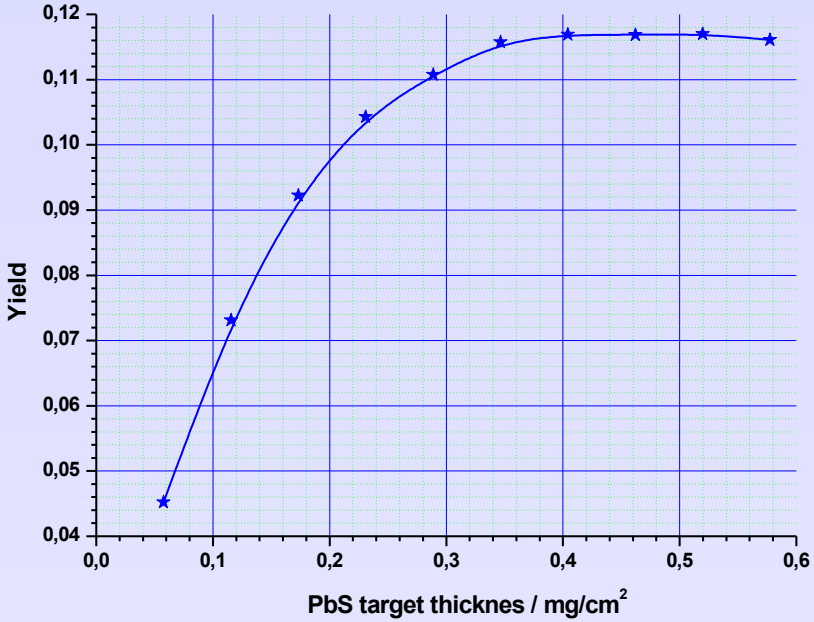
$^{48}Ca + ^{238}U(UF_4) \rightarrow ^{283}112 + 3n$



Transmission & yield of ^{254}No

^{208}Pb(^{48}Ca,2n)^{254}No (FWHM=10.0 MeV→1.37 mg/cm^2, σ =0.583 mg/cm^2)



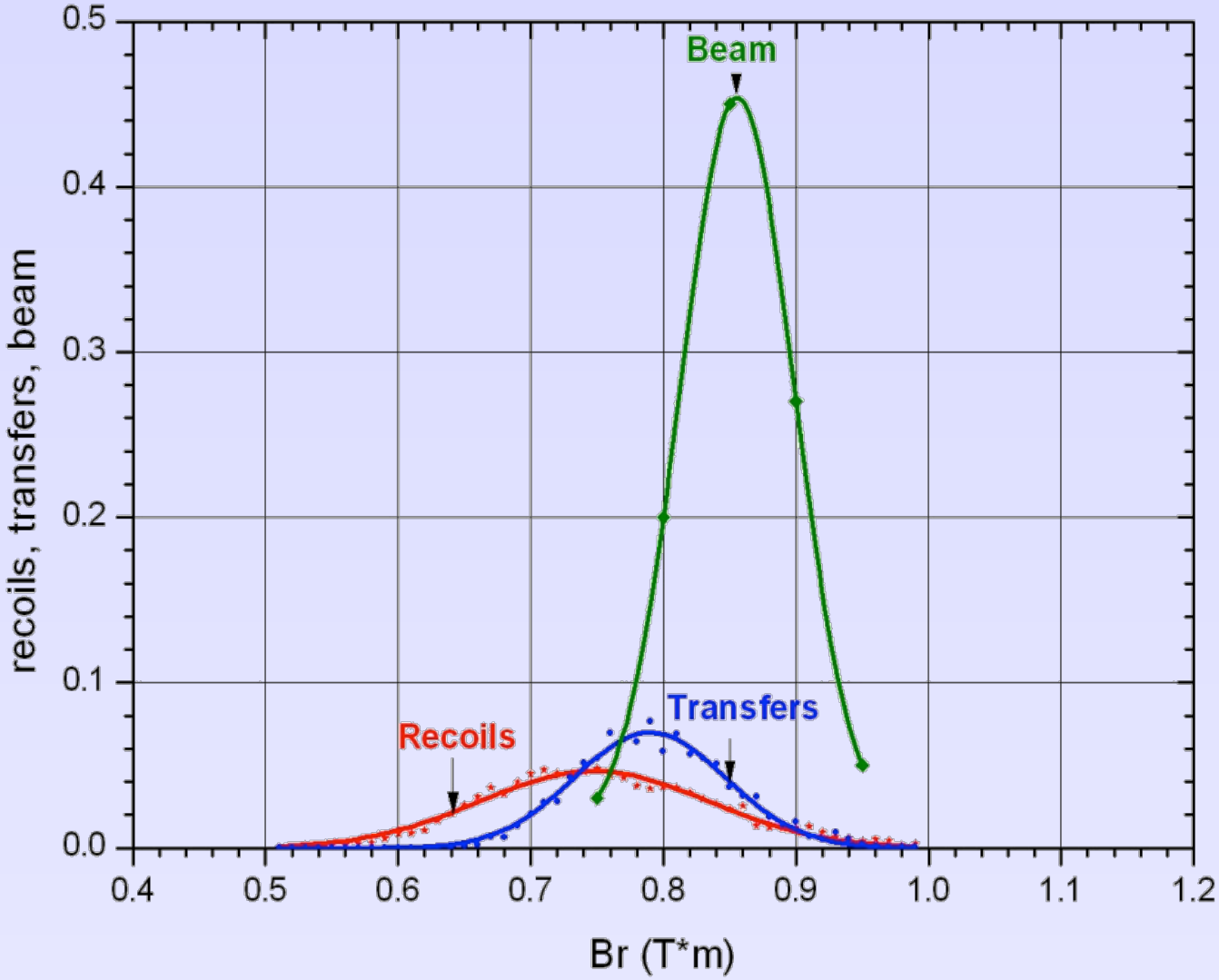


$$^{48}Ca + ^{244}Pu \longrightarrow ^{292}114^*$$

Nucl.	E(MeV)	Bρ (vac. T·m)	Bρ (He. T·м)	Bρ (H_2. T·м)	V (cm/ns)	E/q_{vac} (MV)
^{48}Ca	236	0.88	0.94	0.94	3.1	13.0
$^{292}114$	38.8	0.79	2.0	2.18	0.51	2.0
^{244}Pu	129.7	0.83	1.65	1.49	1.0	4.2
^{4}He	67		1.2		5.7	
$^{1}H_2$	18.8			0.62	6.02	

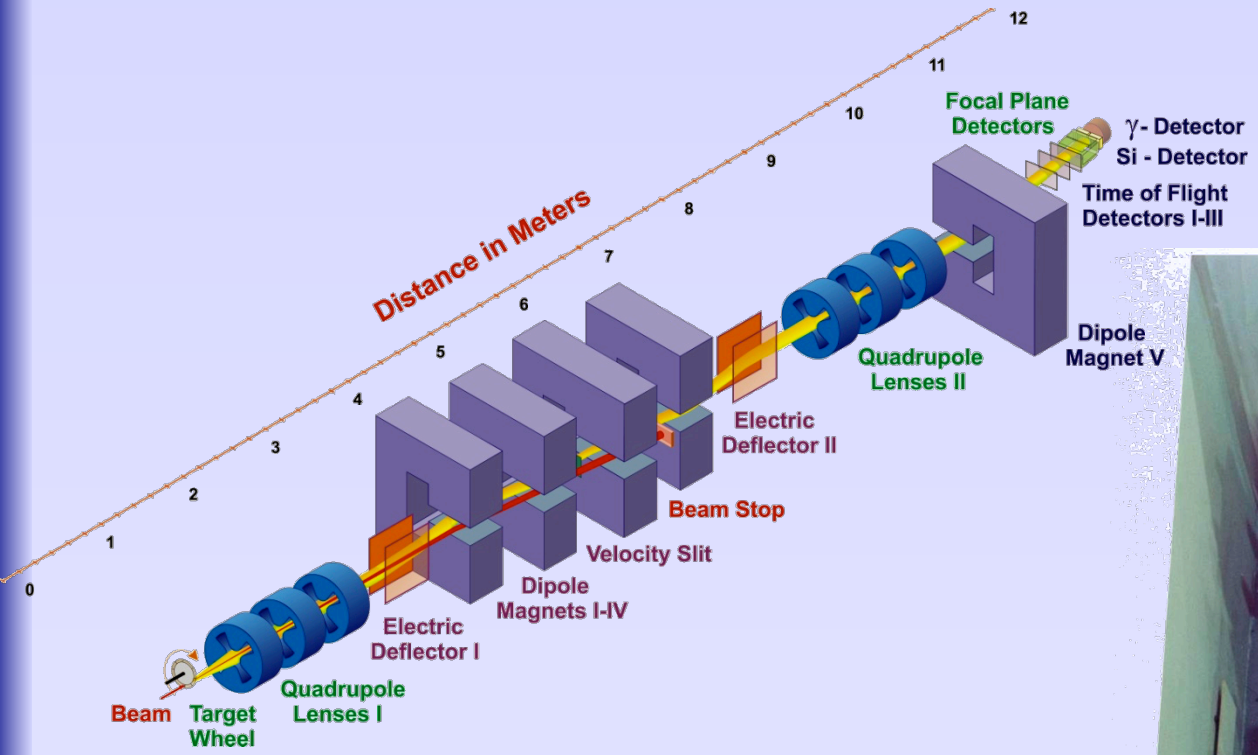
Magnetic rigidities

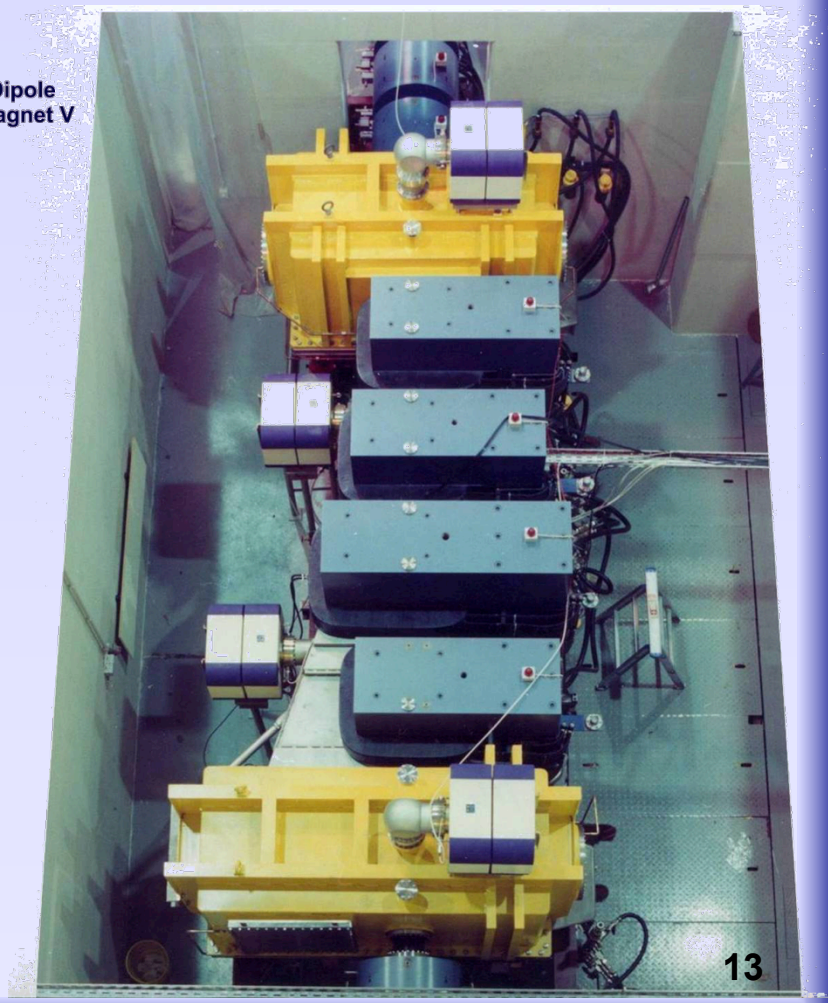
$^{48}Ca(E_{1/2}= 236MeV) + ^{248}Cm(300mg/cm^2, CmO_2) \rightarrow ^{296}116^*$



Air-free separator

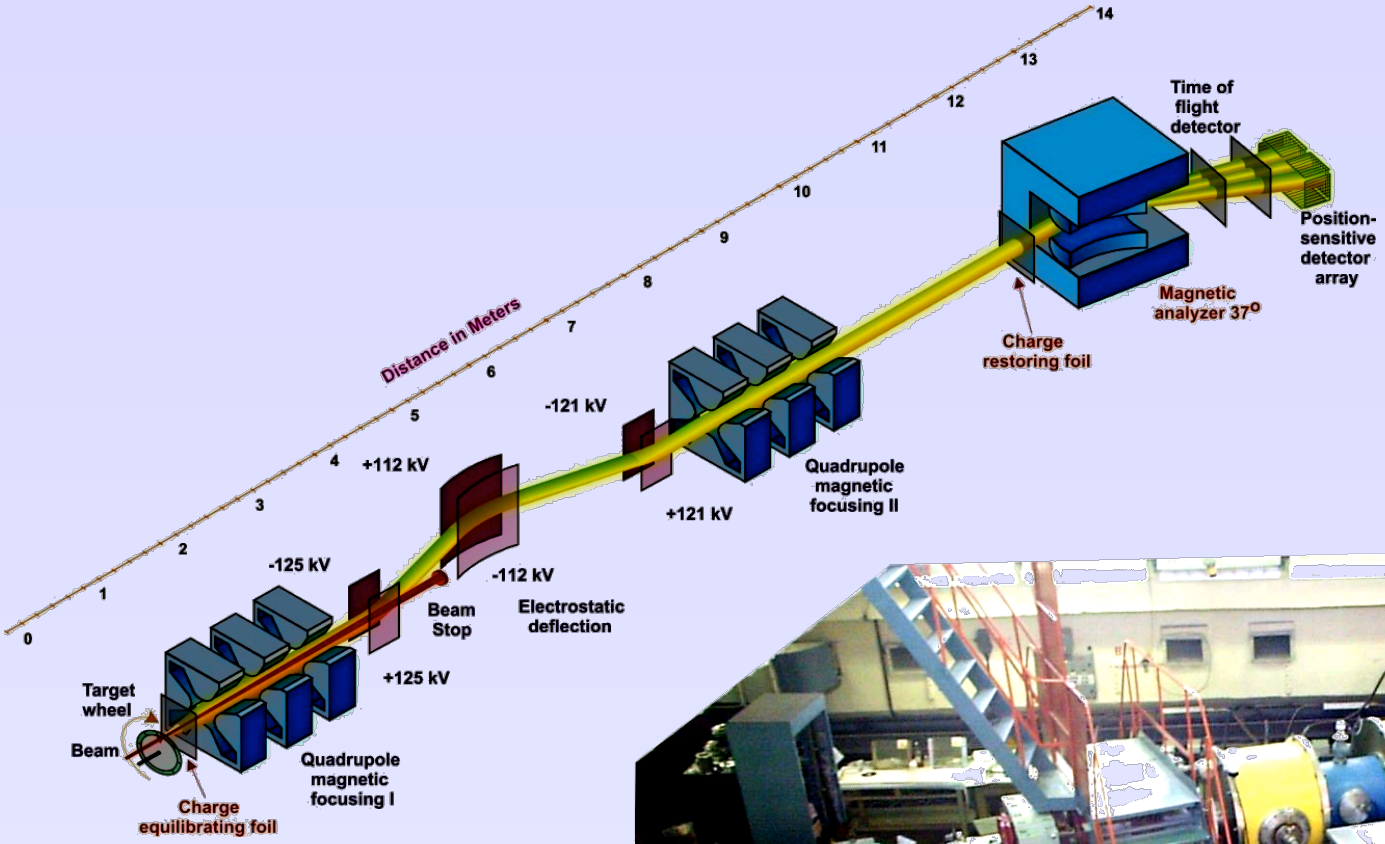
Velocity Filter "SHIP"



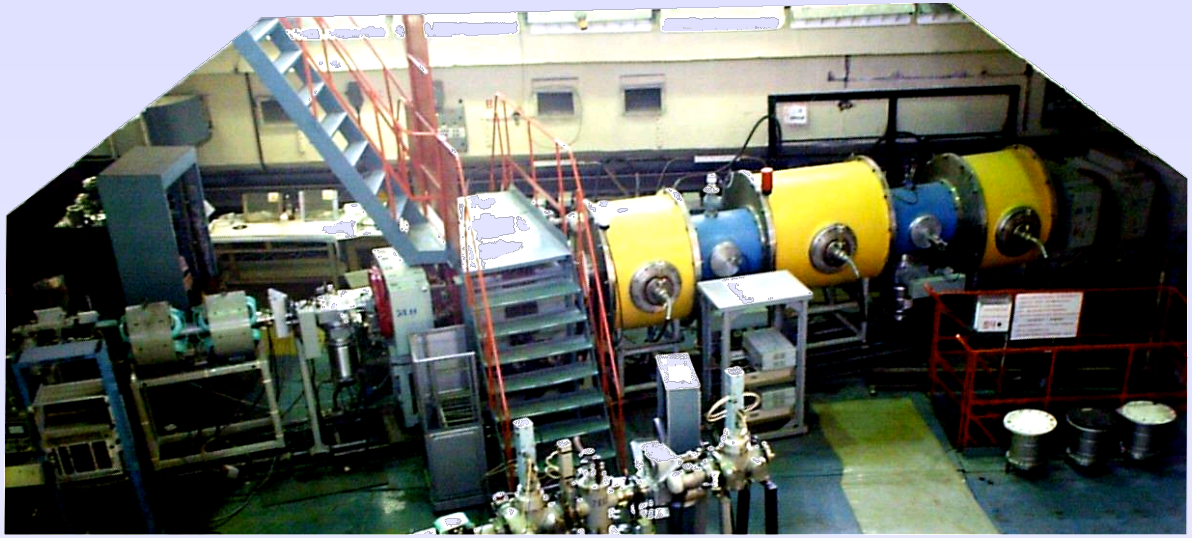


Electrostatic separator VASSILISSA

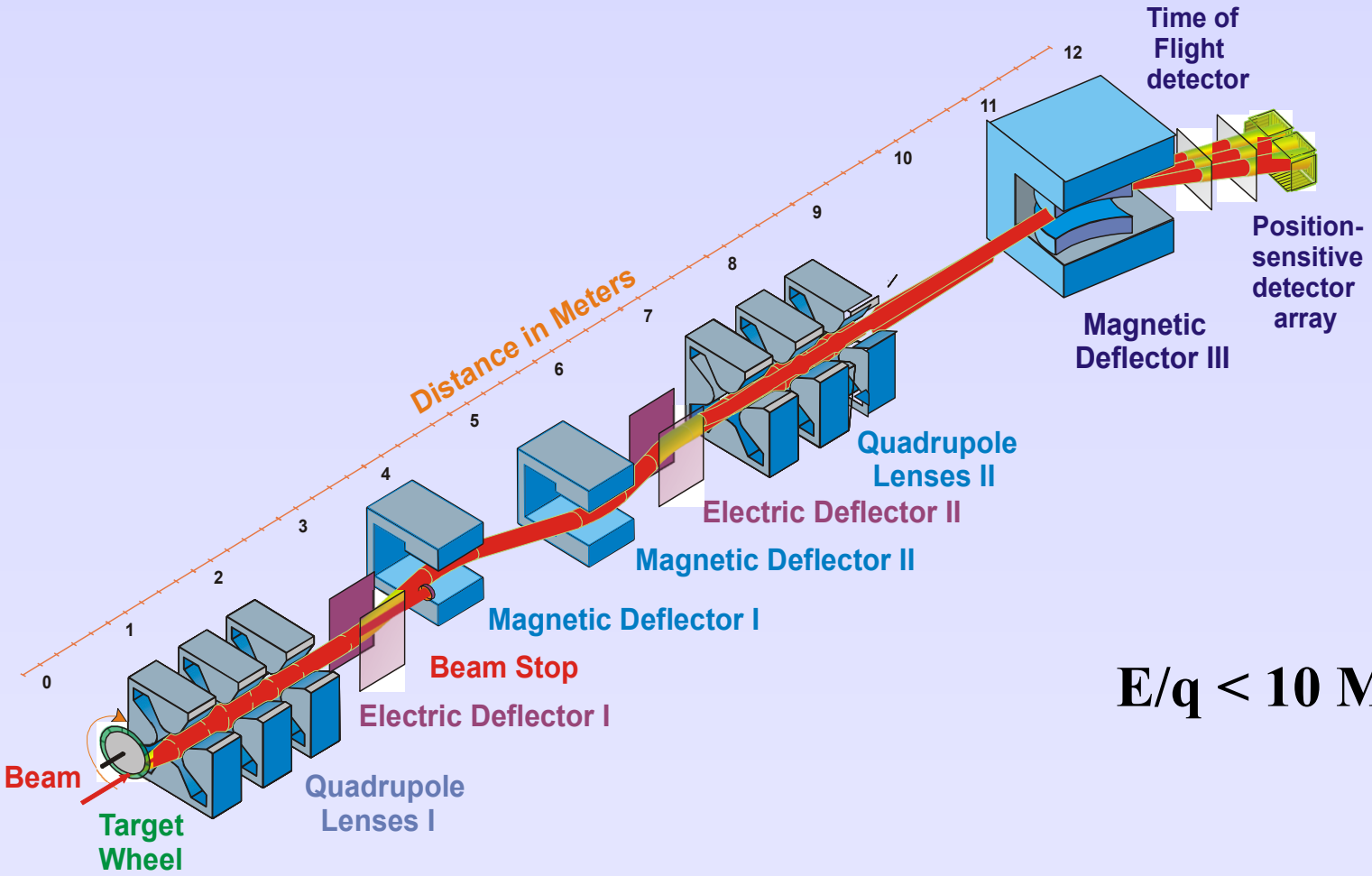
1987 – 2004 – 2012



E/q < 2 MV



Velocity filter SHELS
(Separator for Heavy ELement Spectroscopy)



E/q < 10 MV

Movable plates of electrostatic deflectors

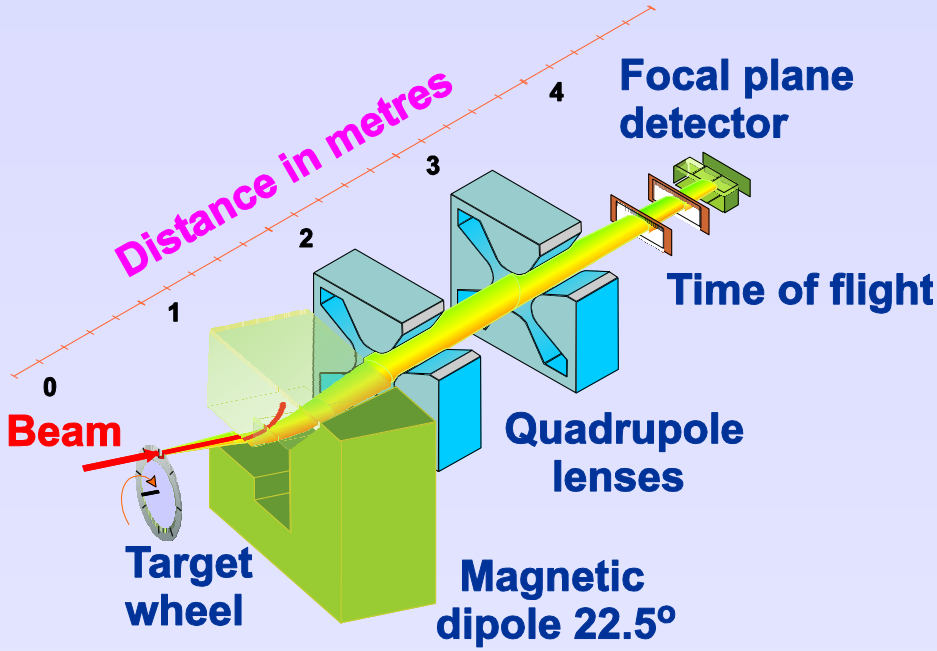
SHELS + GABRIELA

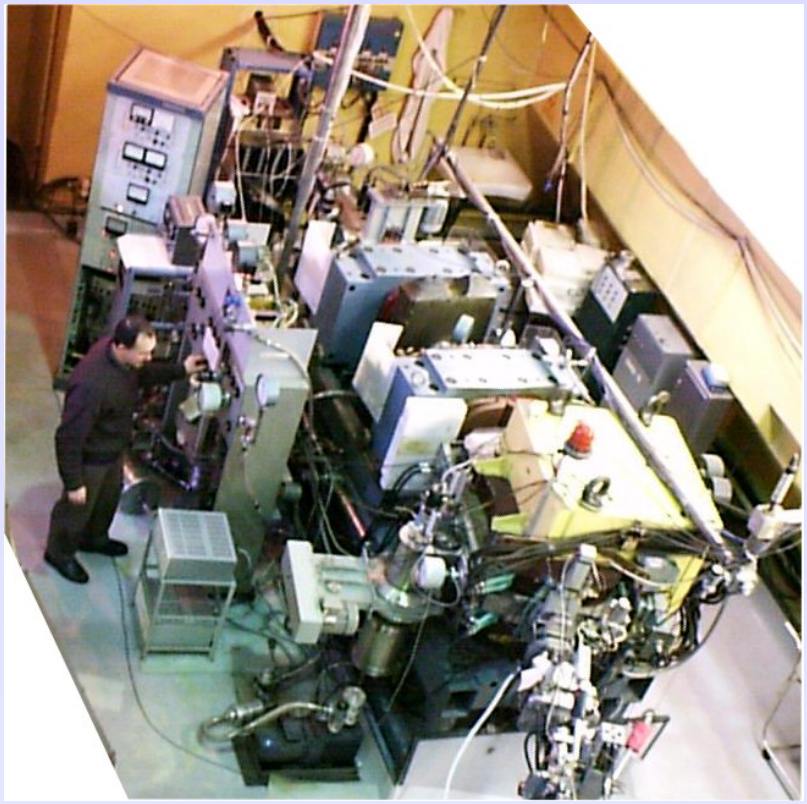
Gas-filled separator

GF-separators

Separator	DGFRS	GARIS	RITU	BGS	TASCA
Configuration	DQ_hQ_v	DQ_hQ_vD	$Q_vDQ_hQ_v$	Q_vD_hD	DQ_hQ_v
Deflection angle (^{o})	23	45+10	25	70	30
Bρ (max/T·m)	3.1	2.15	2.2	2.5	2.4
Length (m)	4.0	5.75	4.7	4.6	3.5
Dispersion (mm/% Bρ)	7.5	9.7	10.0	20.0	9.0

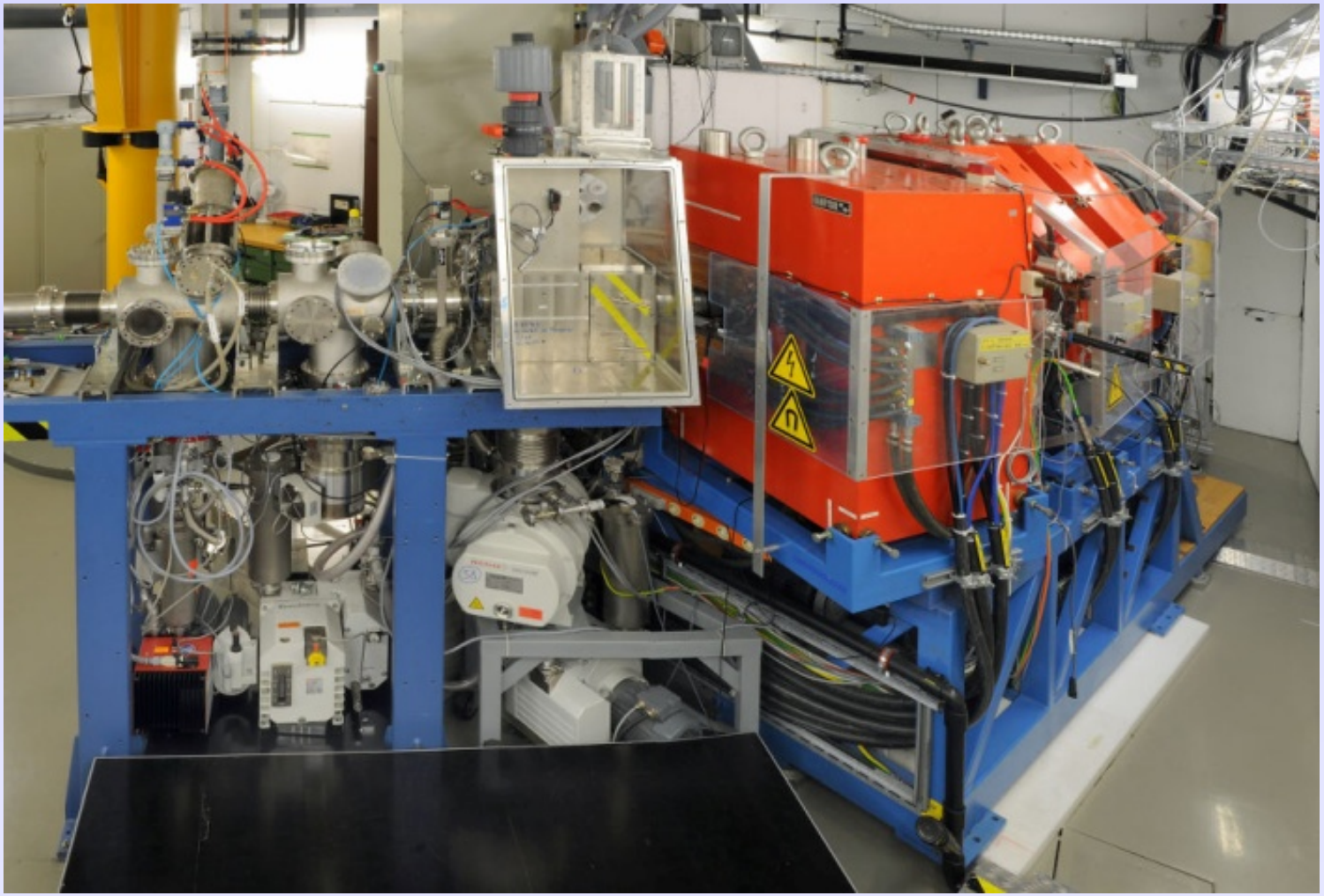
Dubna Gas Filled Recoil Separator



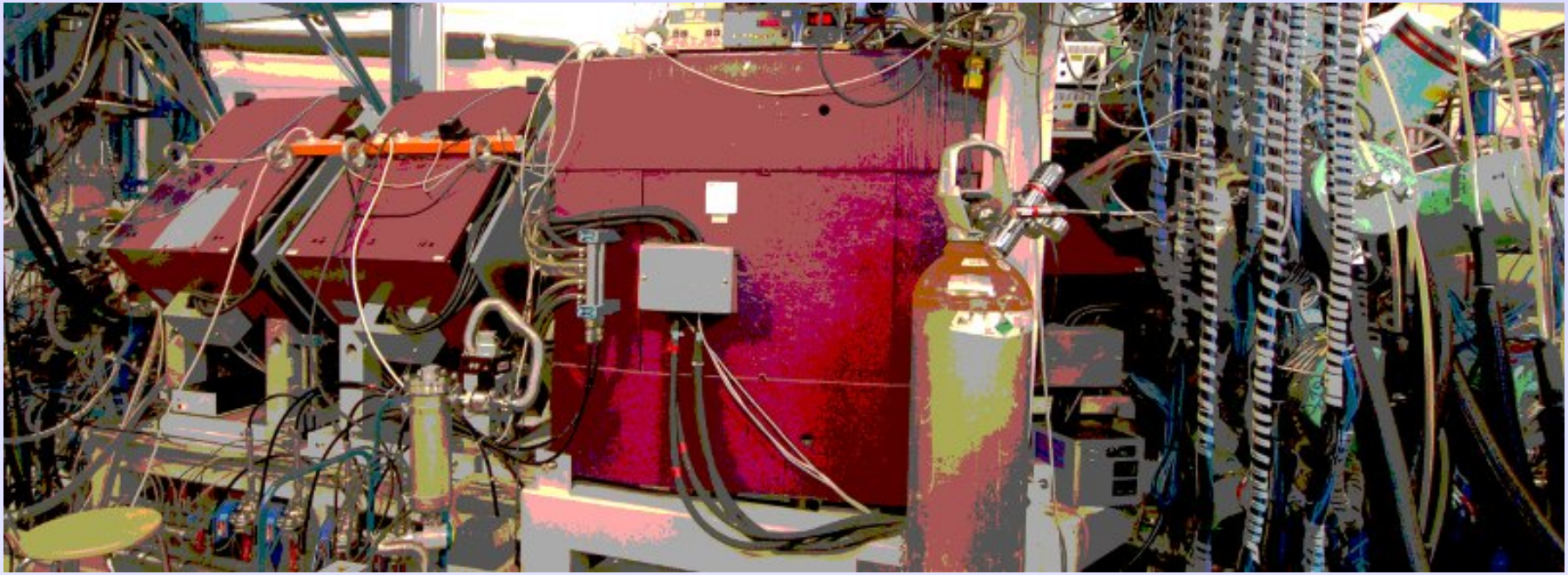


Gas-filled Recoil Separator
(RIKEN)

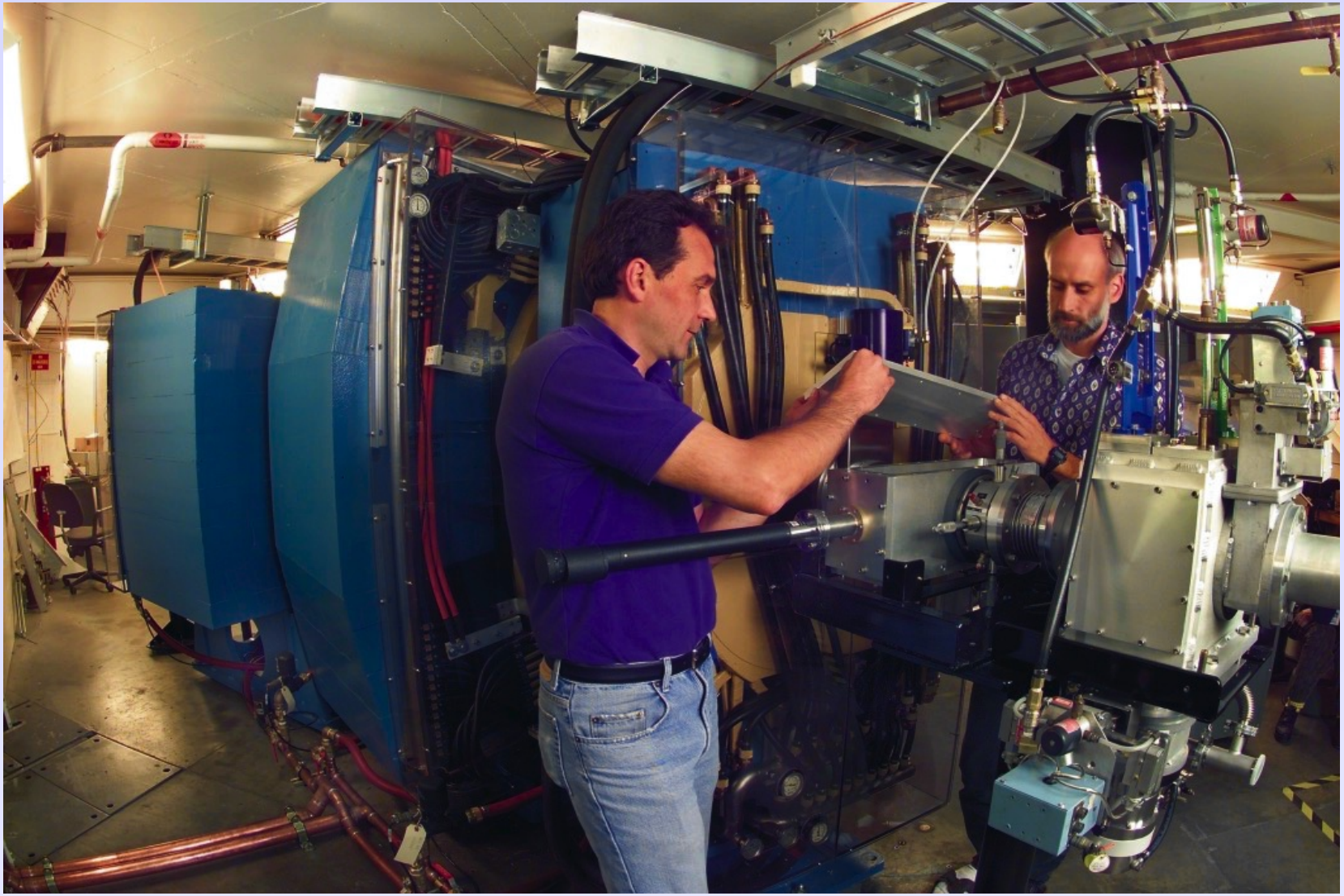
TransActiniden Separator und Chemie Apparatur (TASCA) (GSI, Darmstadt)



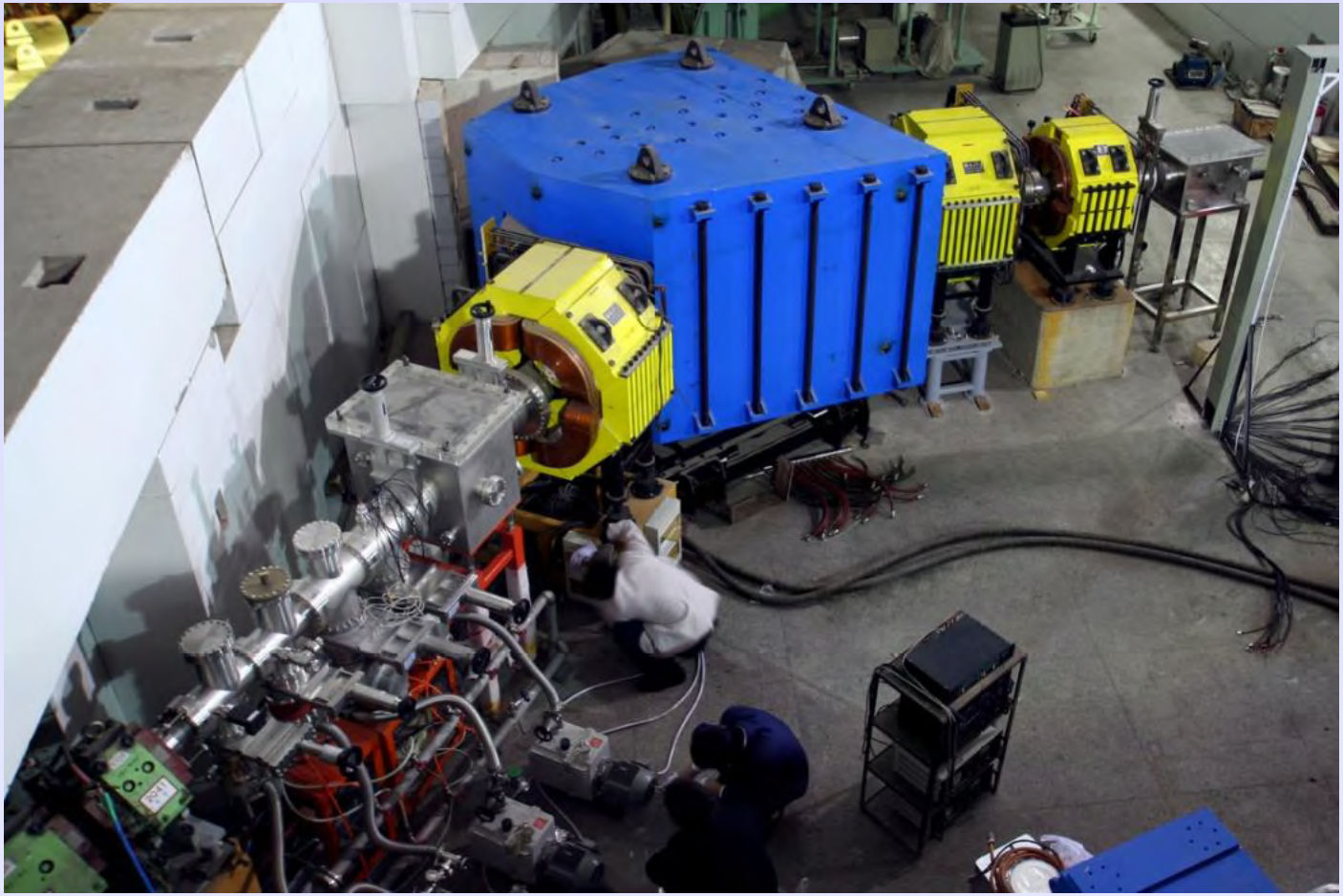
Recoil Ion Transport Unit (RITU)
(Jyväskylä, Finland)



Berkeley Gas-filled Separator



Spectrometer for Heavy Atom and Nuclear Structure (SHANS) (IMP, Lanzhou)

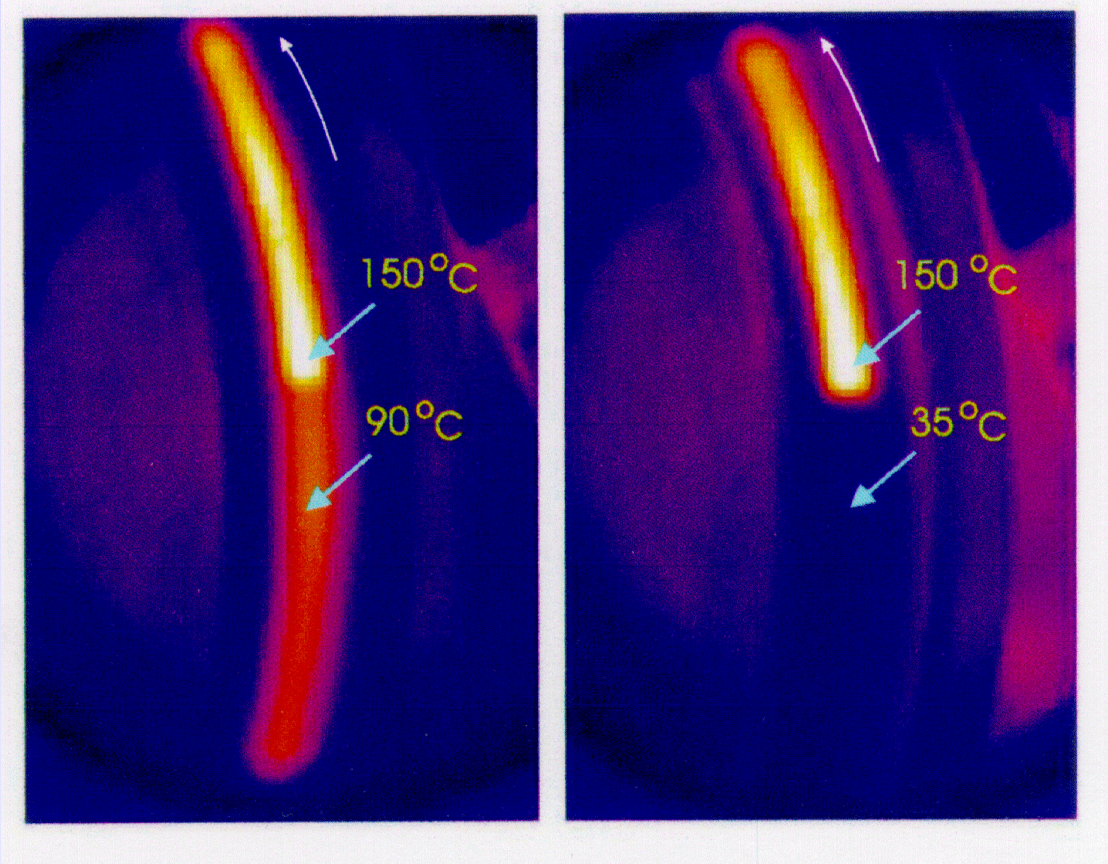


Gas-filled separator Advantages:

- presence of a gas – H_2, He;
- ✓ high energy and charge acceptances;
- ✓ additional target cooling through convection;
- low number of elements;
- no high voltage;
- “low” price.

Target gas cooling
(infra red snap-shots)

10^{-6} mB
P=1.3 W
T=90-150°C



0.6 mB He
P=2.7 W
T=35-150°C

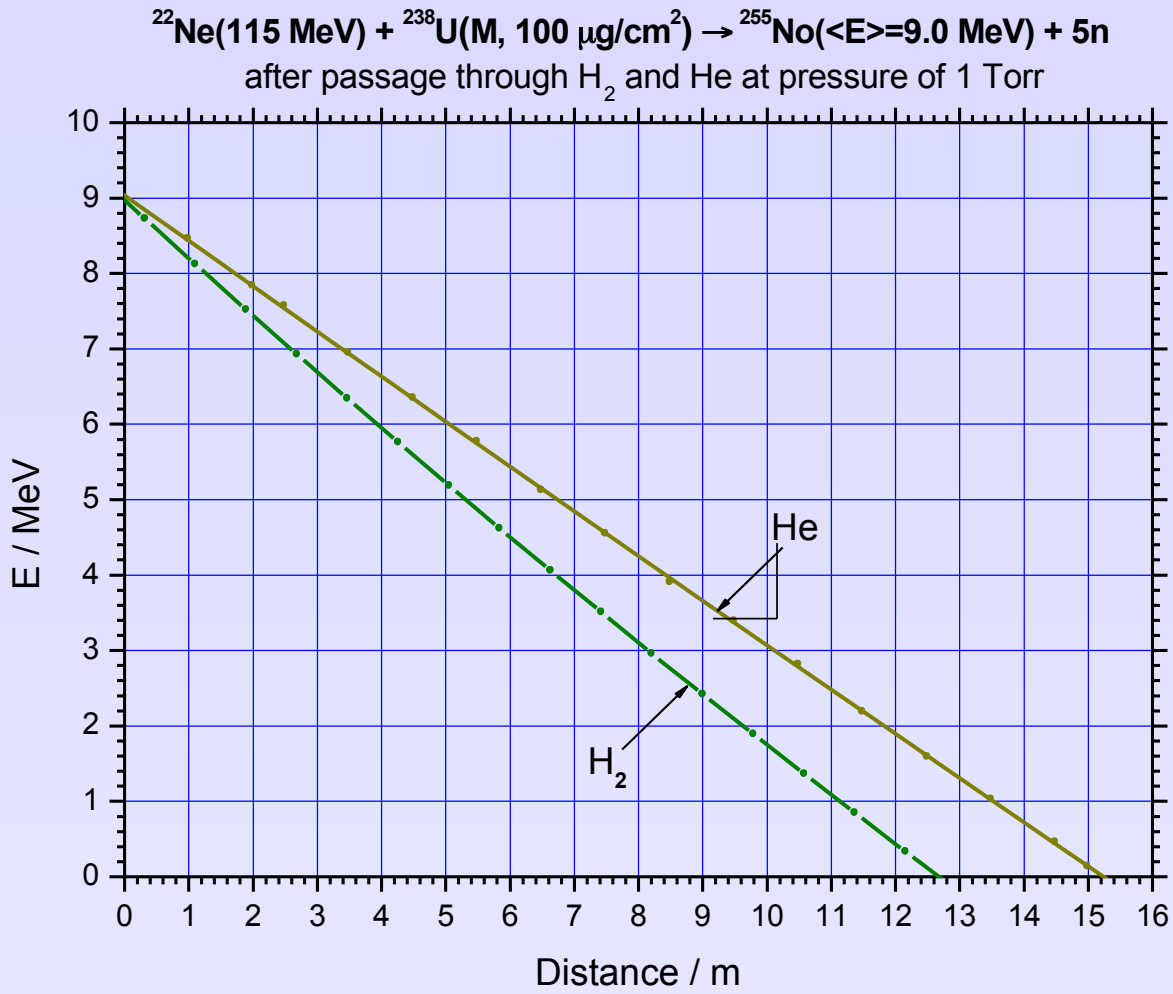
Gas-filled separator Disadvantages:

- presence of gas – H_2, He;
- ✓ background from high energetic (15 – 60 MeV) light particles;
- ✓ must be short (< 5 m) → difficult to organize shielding;
- ✓ difficult (or impossible) to organize "coming from outside" mark;
- not suitable for very asymmetric reactions;
- not applicable for symmetric reactions;

$$^{22}Ne + ^{238}U \longrightarrow ^{260}No^*$$

Nucl	E(MeV)	Bρ (vac. T·m)	Bρ (He, T·m)	Bρ (H_2. T·m)	V (cm/ns)	E/q_{vac} (MV)
^{22}Ne	112.4	0.76	0.76	0.76	3.14	11.7
^{260}No	9.5	0.74	1.82	2.45	0.26	0.99
^{238}U	34.8	0.72	1.89	2.01	0.53	1.93
^{4}He	58.5		1.1		5.3	
$^{1}H_2$	18.7			0.62	6.0	

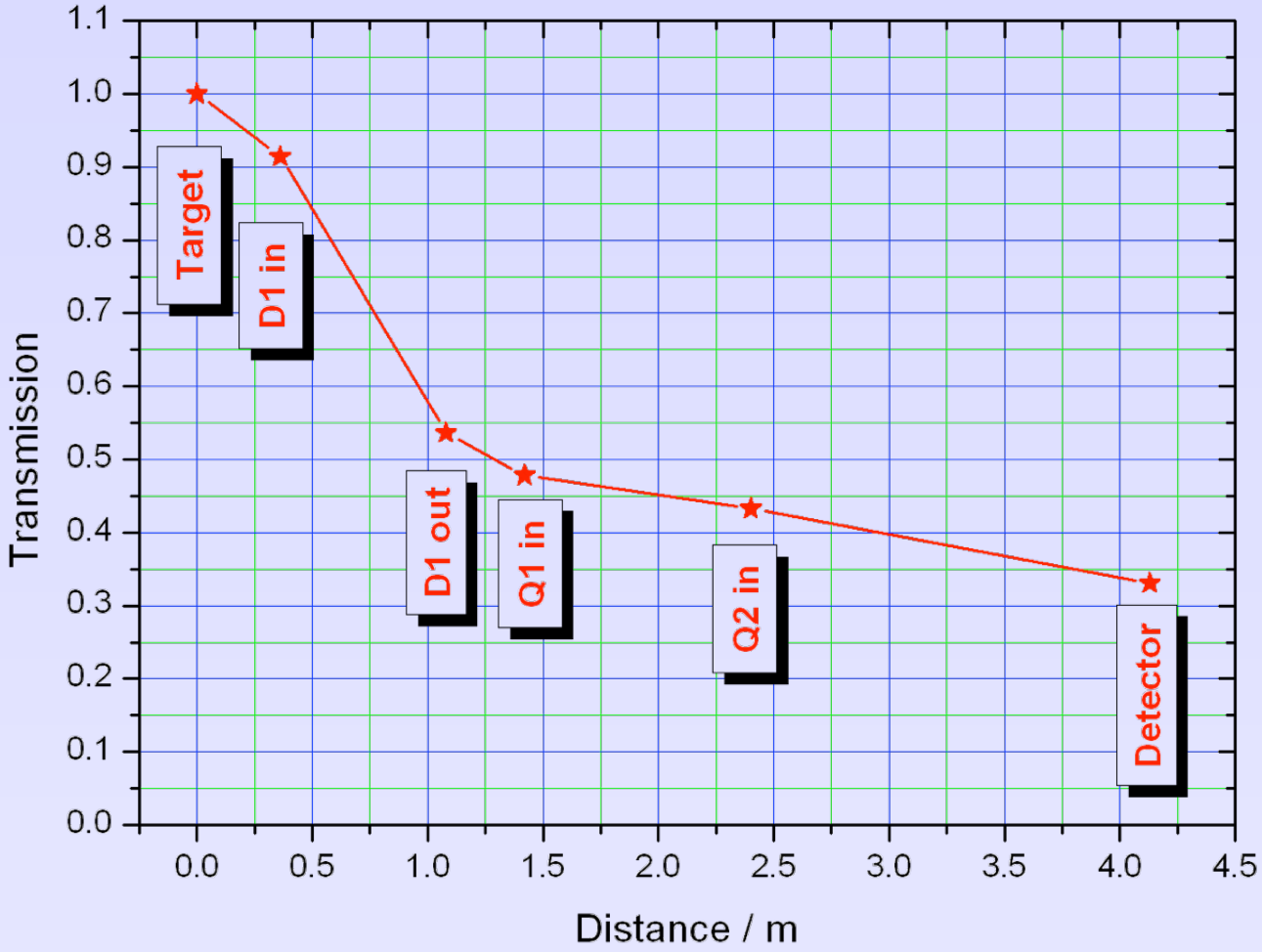
Gas filled separators for asymmetric combinations



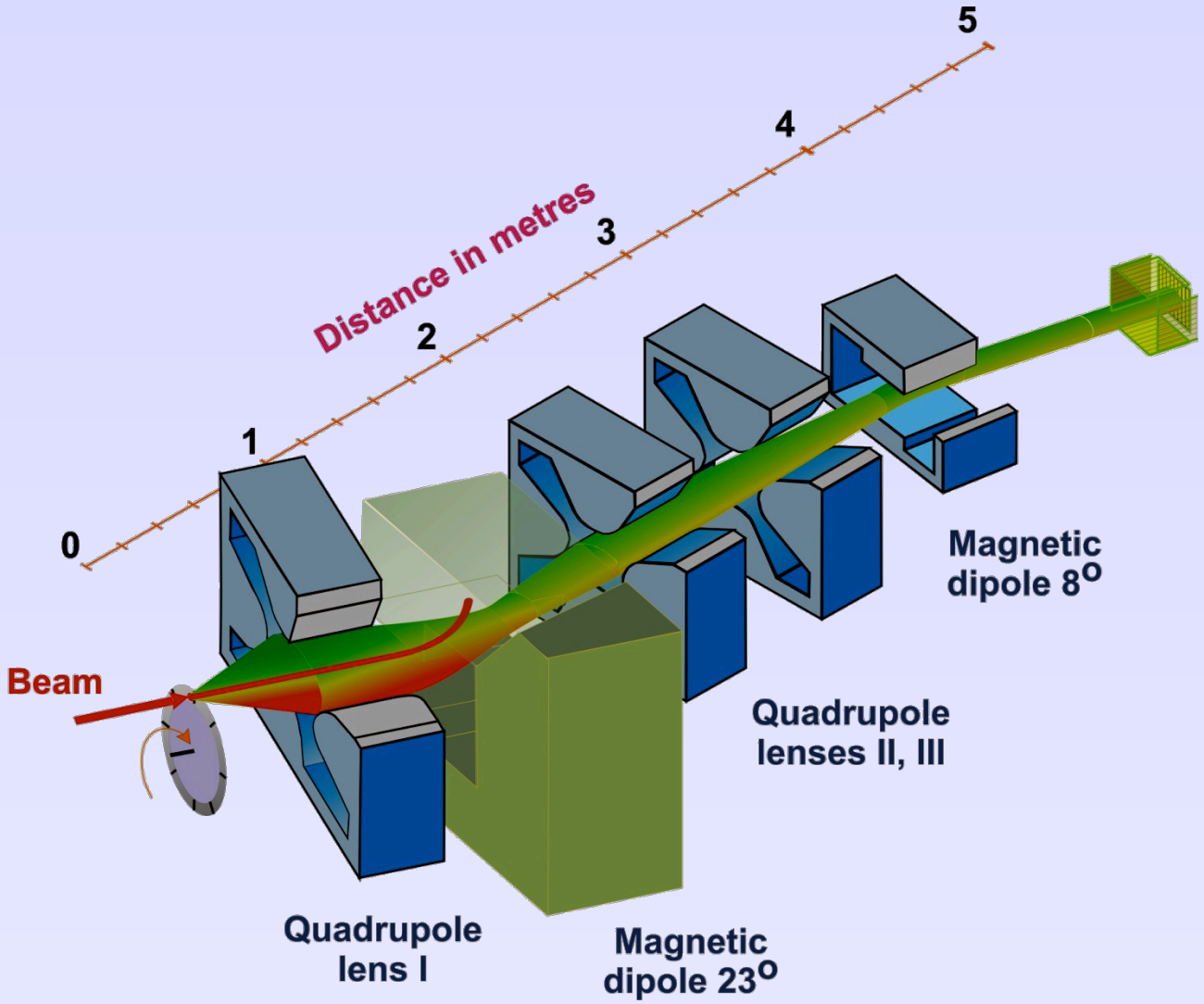
$$^{136}Xe + ^{136}Xe \longrightarrow ^{272}Hs^*$$

Nucl.	E(MeV)	Bρ (vac. T·m)	Bρ (He. T·m)	Bρ (H_2. T·m)	V (cm/ns)	E/q_{vac} (MV)
^{136}Xe	600	1.1	1.38	1.38	3.0	15.7
^{272}Hs	300	0.95	1.39	1.21	1.46	6.85
^{136}Xe	600	1.1	1.38	1.38	3.0	15.7
^{4}He	66.6		1.2		5.7	
$^{1}H_2$	17.4			0.6	6.0	

Transmission losses in the DGFRS ($^{243}Am(^{48}Ca,4n)^{286}115$; DQ_hQ_v)

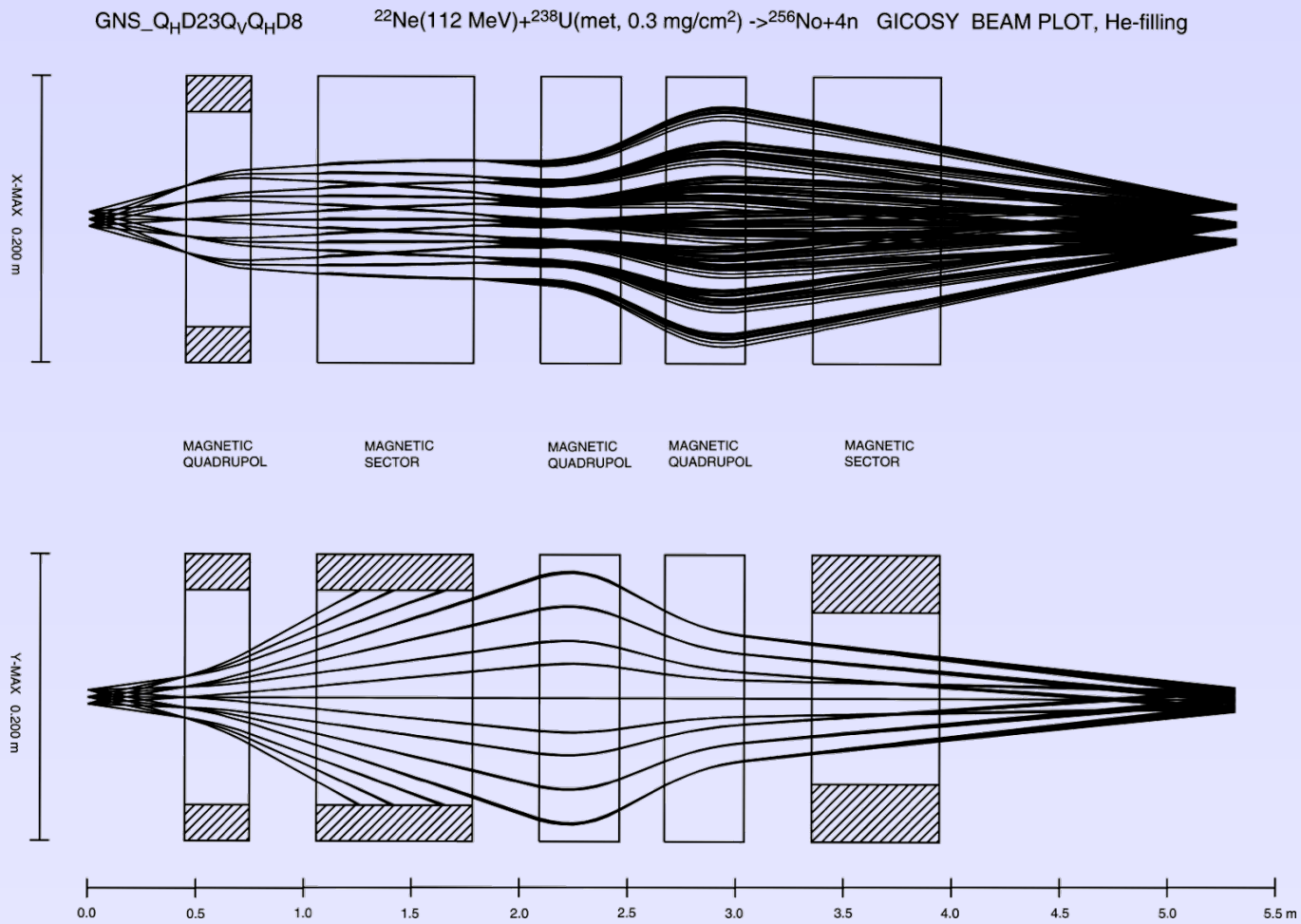


Universal QDQQD-gas-filled separator



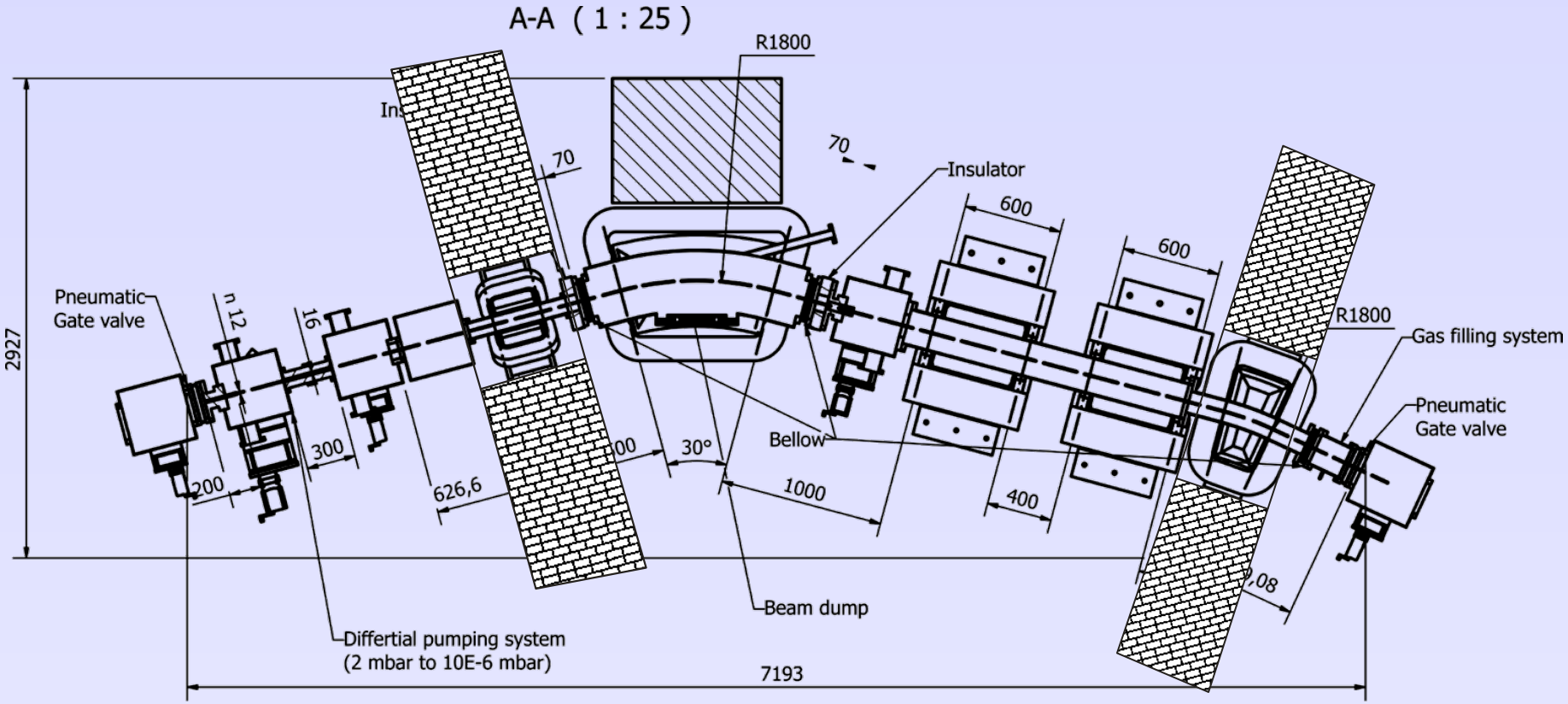
GICOSY beam plot for $Q_vDQ_hQ_vD$

$^{22}Ne(112\ MeV) + {}^{238}U(met, 0.3\ mg/cm^2) \rightarrow {}^{256}No + 4n$



New Gas-Filled Separator

(DANFYSIKs technical drawing, 1.5 years, 1.5 M€)



Main optical elements of the QDQQD-GFS

Magnetic quadrupole 1

Effective length	370
Bore diameter	150 mm
Maximum field gradient	15 T/m

Magnetic quadrupole 2 & 3

Effective length	520
Bore diameter	220 mm
Maximum field gradient	10 T/m

Magnetic dipole 1

Gap	120 mm
Deflection angle	30^0
Radius of curvature	1.8 m
Maximum field	1.7 T
Face pole rotation angle	10^0
Rear pole rotation angle	55^0

Magnetic dipole 2

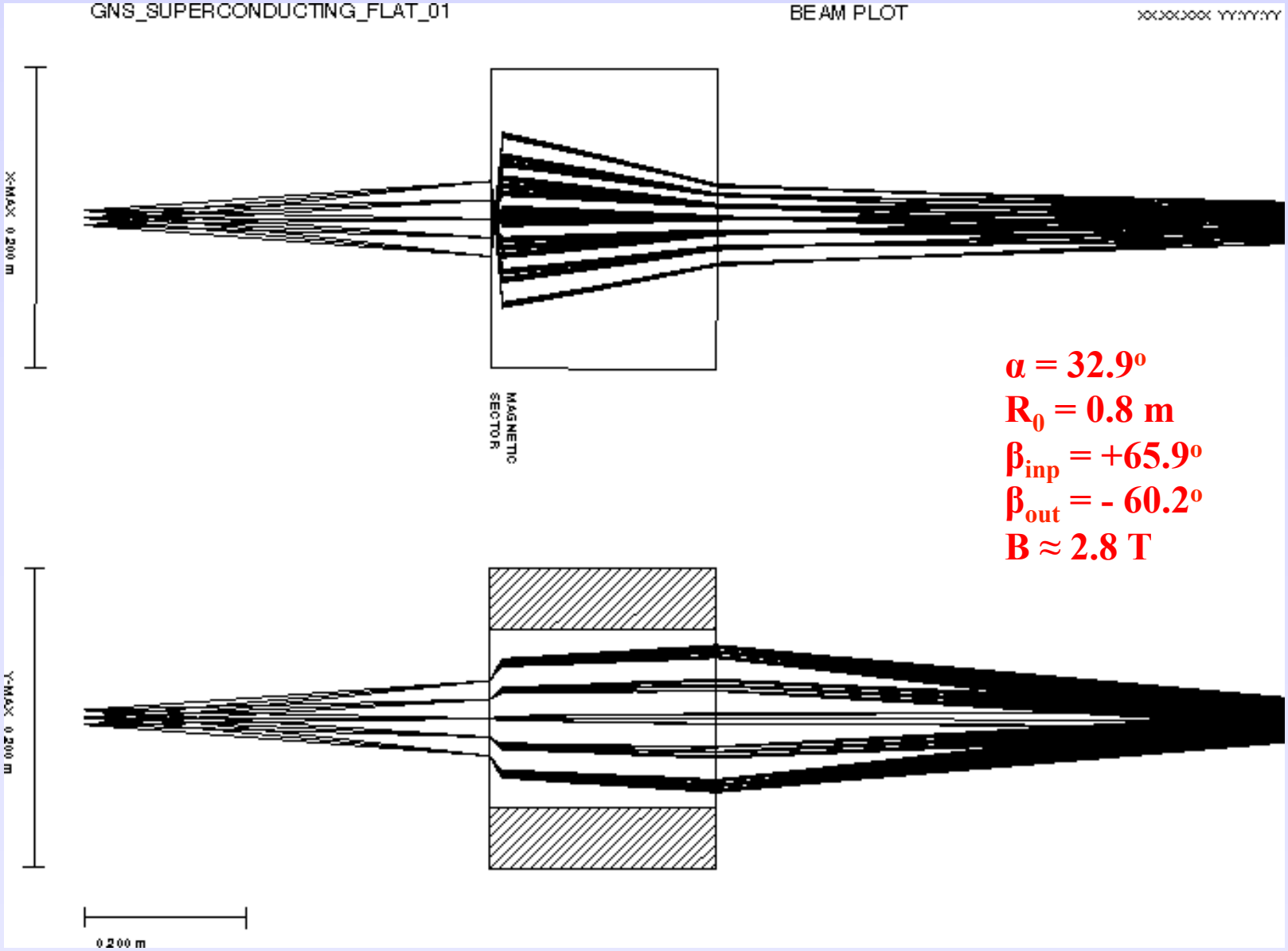
Gap	120 mm
Deflection angle	10^0
Radius of curvature	1.8 m
Maximum field	1.7 T
Face pole rotation angle	0^0
Rear pole rotation angle	10^0

Transmissions of the QDQQD

Reaction	Asymmetry $A_p/(A_p+A_t)$	Transmission %
$^{244}Pu(^{22}Ne,3n)^{263}Rf$	0.083	7.5
$^{244}Pu(^{48}Ca,3n)^{289}114$	0.164	35
$^{244}Pu(^{58}Fe,4n)^{298}120$	0.192	50
$^{70}Zn(^{208}Pb,1n)^{277}Cn$	0.252	60
$^{93}Kr(^{226}Ra,1n)^{318}124$	0.291	70

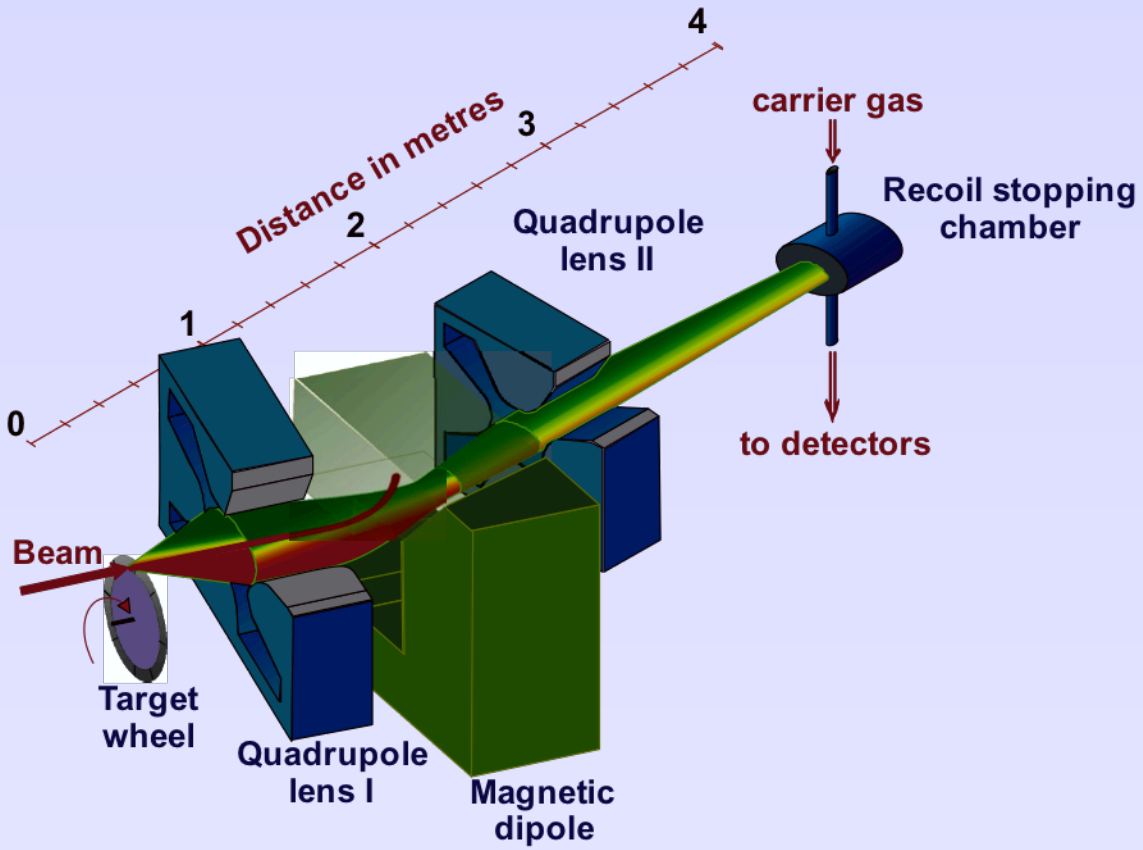
Preseparator

GFS superconducting

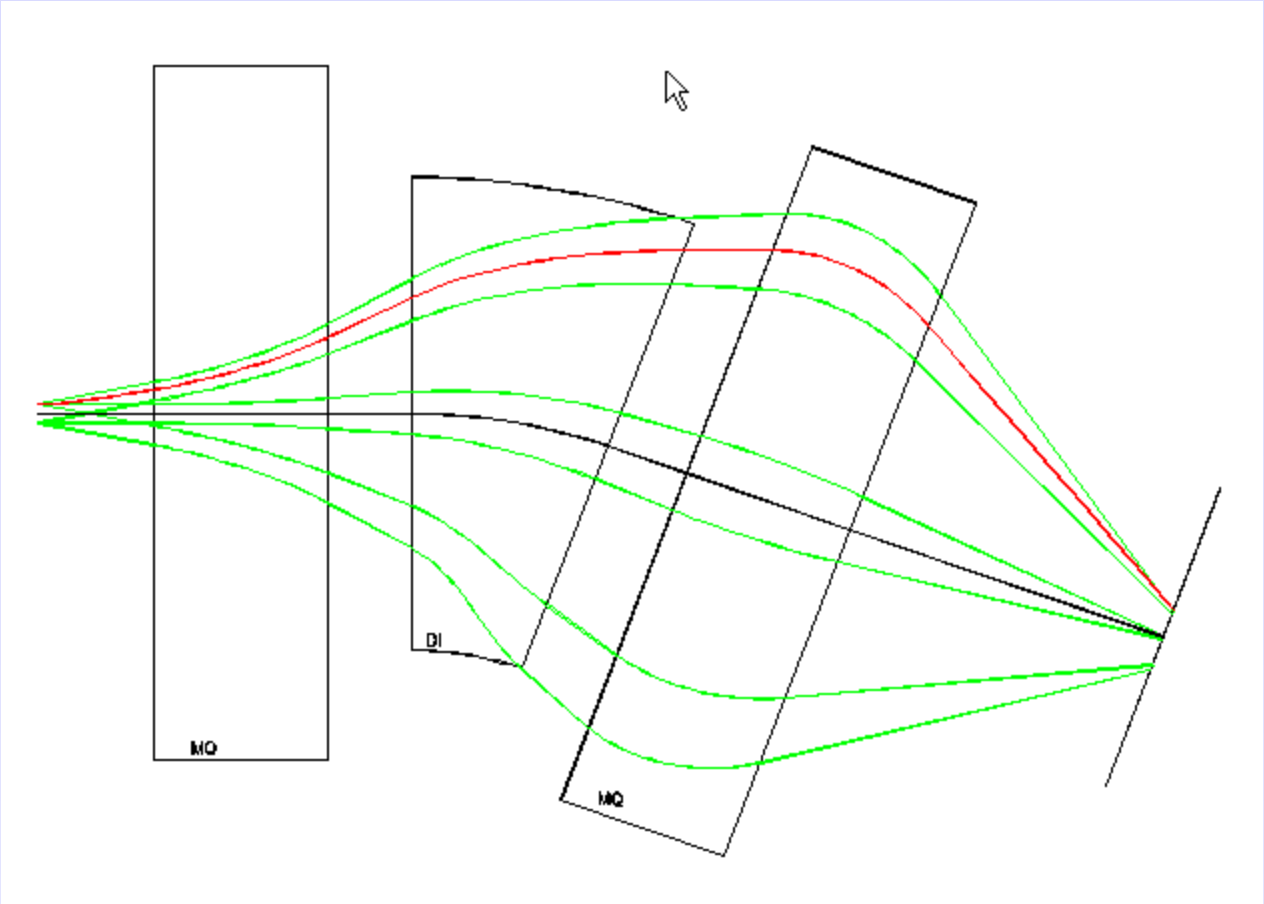


$\alpha = 32.9^o$
$R_0 = 0.8$ m
$\beta_{inp} = +65.9^o$
$\beta_{out} = -60.2^o$
$B \approx 2.8$ T

Q_vDQ_h-gas-filled "chemical" pre-separator



GFS - Q_vDQ_h



Summary & Proposals:

- Velocity selector SHELS
- Universal gas-filled separator $Q_vDQ_hQ_vD$
- Gas-filled pre-separator Q_vDQ_h


THANK YOU
FOR YOUR
ATTENTION !
Flerov Laboratory of Nuclear Reactions (JINR)