Fasci esotici: facilities e strumentazione

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INFN Istituto Nazionale di Fisica Nucleare

Incontro di Fisica Nucleare 12-14 November 2012 INFN-LNS

Summary

- **Exotic beam facilities: a brief survey worldwide (subset !)**
- **Exotic beam facilities: the European situation (subset !)**
- **The facilities in Italy at the INFN laboratories**
- **Instrumentation:**
  - **Present status and developments**

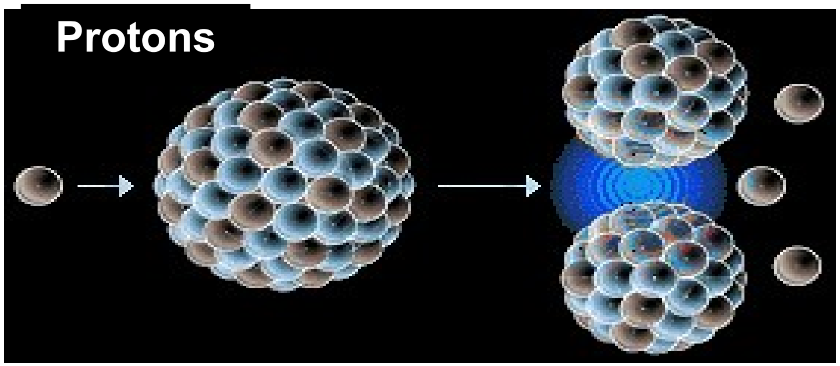
NOTE: Contributions by all groups involved in the CSN3 "low-energy" branch. No specific citation to papers in the slides

Geography of exotic nuclei

A world chart of Rib facilities

On RIB Production methods

1. Isotope Separator On-Line (ISOL) Method



ENERGY → High energy beams
NUCLEAR PHYSICS

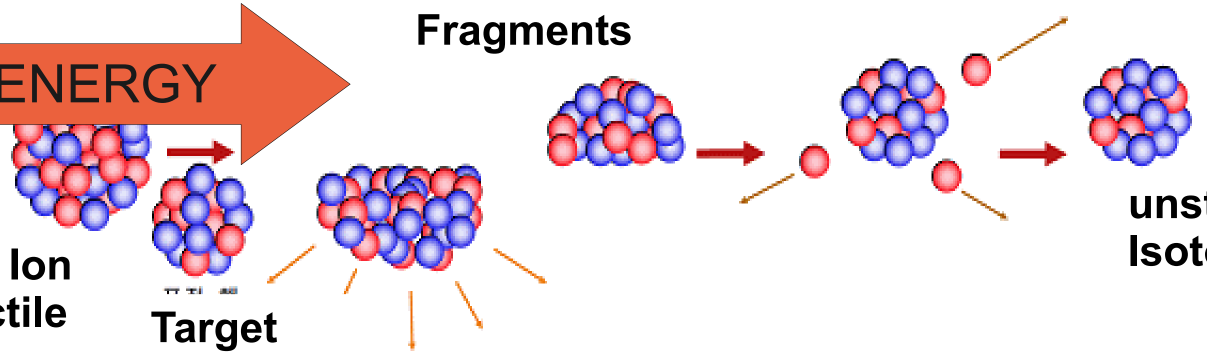
Low energy extraction
eV to keV:
ATOMIC PHYSICS

breeding,separation,
reacceleration,
purification,transport

2. In-Flight Fragmentation (IFF) method

Advantages and disadvantages are somewhat complementary....

ENERGY



Fragments

Heavy Ion Projectile

Target Nucleus

unstable Isotopes

High energy beams
NUCLEAR PHYSICS

FRIB and the Low-Energy facilities around US

ATLAS at ARGONNE
Fission of 252Cf (1Ci) source
Reacceleration up to 15MeV/u via a SC LINAC
Intensity upgrading on progress

Nuclear Science LAB @Notre-Dame
3 small Accelerators for low-energy experiments
10MV Tandem
Mass Separator StGeorge
TwinSol

FRIB @ MSU NSCL (ready 2019)
BIG SCALE!
Linac+ production + Fragment Separator
Fast beam <100MeV/u
Reacceleration 0.2-20MeV/u

Active Target TPC
Up to 400kW U 200MeV/u

FOX Accelerator LAB@FLORIDA State.Univ.
TandemVdG+SC linac
Reacceleration up to 18MV
RIB A<40 E=5-8MeV/u
Production of RIB in rev.kinematics via transfer

^{7}Li(d,^{3}He)^{6}He	20-30 MeV	~4 · 10^4 pps (90% pure)
^{18}O(d,p)^{19}O	95 MeV	~5 · 10^4 pps (90% pure)

T-Rex @TAMU
Medium-size facility
First RIB in 2012
Q3 spectrometer

Asian and African facilities, emerging societies

source: H.Sahkai, Riken 2011

Rare Isotope Beam(RIB) Facilities

ASIA

1. RIBF (RIKEN, Wako, Japan), In-flight RIB
2. HIRLF-CSR (IMP, Lanzhou, China), In-flight RIB
3. BRIF2 (CIAE, Beijing, China), ISOL RIB
4. VECC RIB (Calcutta, India), ISOL RIB
5. KoRIA (Daejun, Korea), In-flight+ISOL RIB

Since 2010, ANPHA: **Asian Nuclear Physics Association** (2700 people)

→ ANPHA : NUPECC = ASIA : EUROPE

KORIA South Korea ....something like FAIR in ASIA.

Both ISOL & In-Flight Fragmentation (IFF) methods for RI production

Technical Design Report (by Jun. 2013)

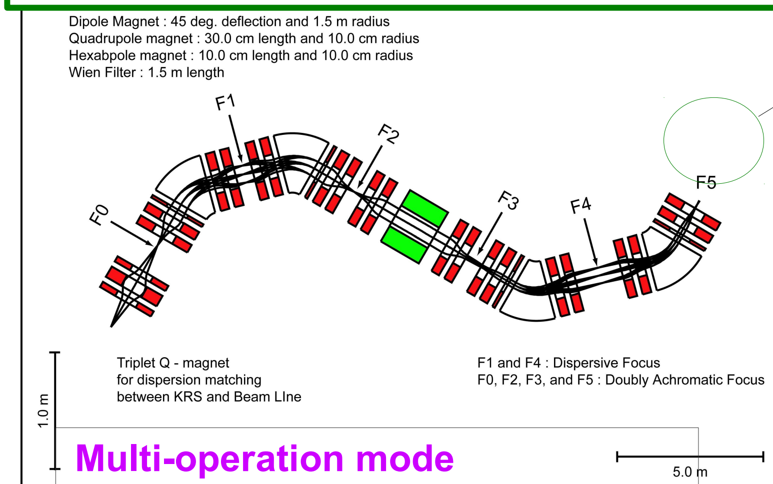
ITHEMBA South Africa, Separated-Sector Cyclotron

65MeV proton 350μA, fundamental studies and applications

Impressive KORIA, SouthKorea

3 B$ initiative *corresponding to about 50 SPES!*

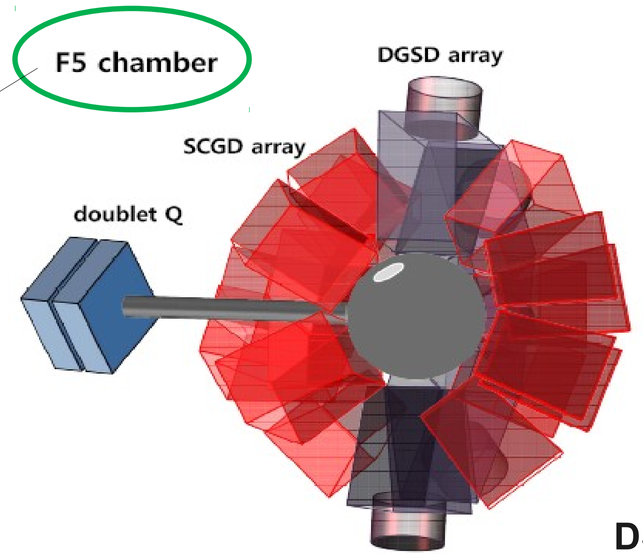
Recoil Spectrometer (KRS)



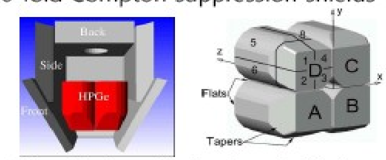
Multi-operation mode

1) Recoil mass separator (RMS)
2) In-flight RI beam separator (IRIS)
3) Beam transportation (BT)

FIRST CLASS INSTRUMENTATION



- Segmented clover Ge (SCGD) array
  A total of 22 SCGDs
  Crystal dimension: 8x8 cm², 10 cm (length)
  Position resolution: < 1mm
  20-fold Compton suppression shields



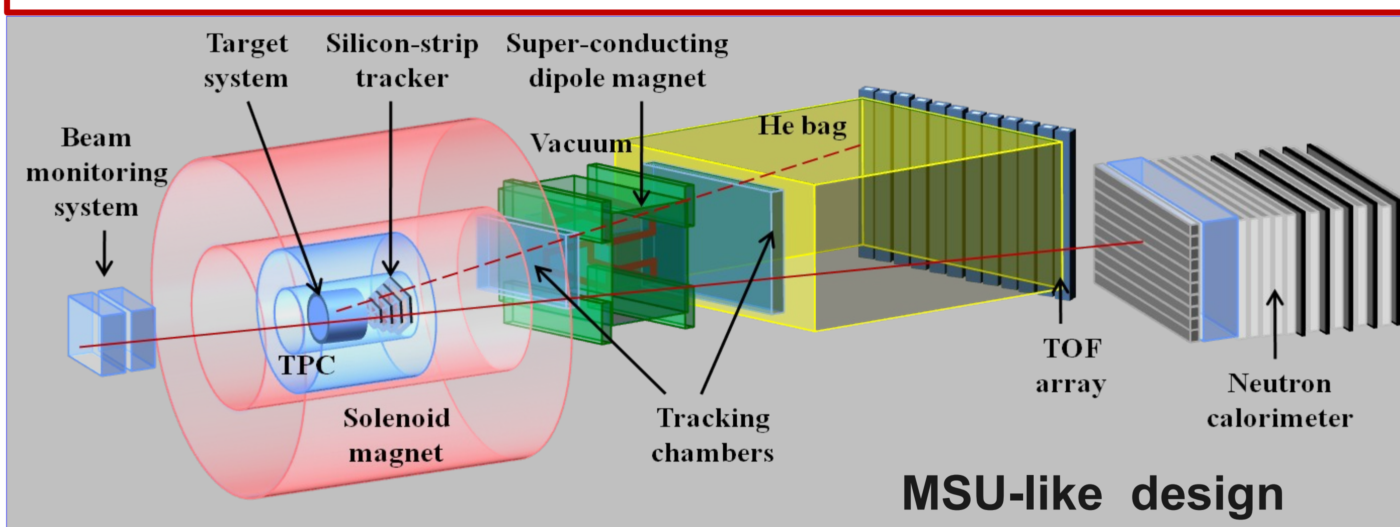
Schematic views of a clover-type Ge detector of TIGRESS at TRIUMF

- DGSD array
  A total of 8 DGSDs
  Crystal dimension: 9x9 cm², 2 cm (thick.)
  Segment size: 3 x 3 mm²

DSGD=Double-side Ge Strip Det.

Large Acceptance Multi-Purpose Spectrometer (LAMPS)

Large acceptance
Combination of solenoid and dipole spectrometers
Movable arms
Keep the flexibility for other physics topics in the future

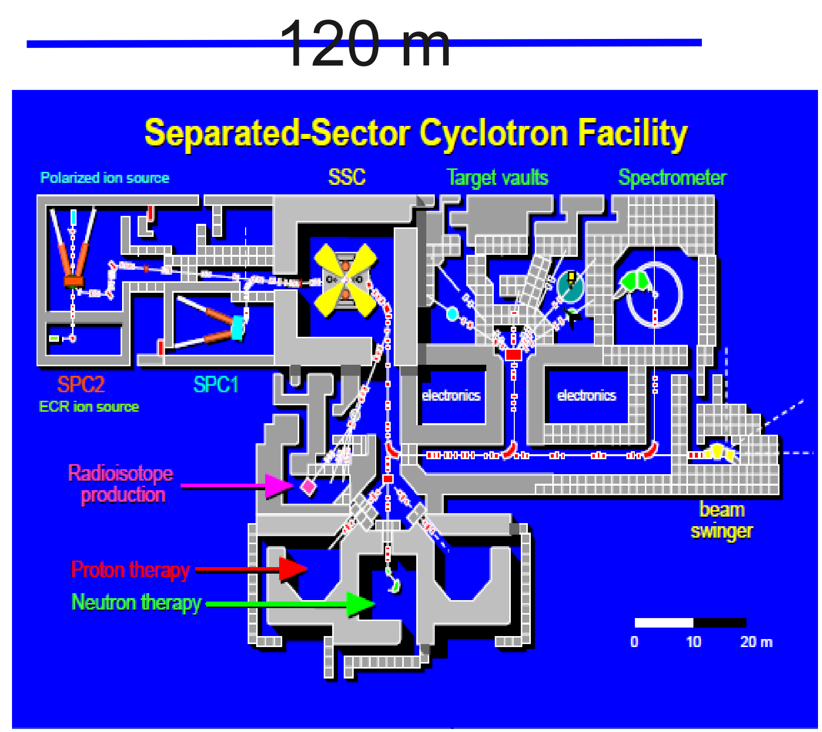


ITHEMBA LAB, SouthAfrica

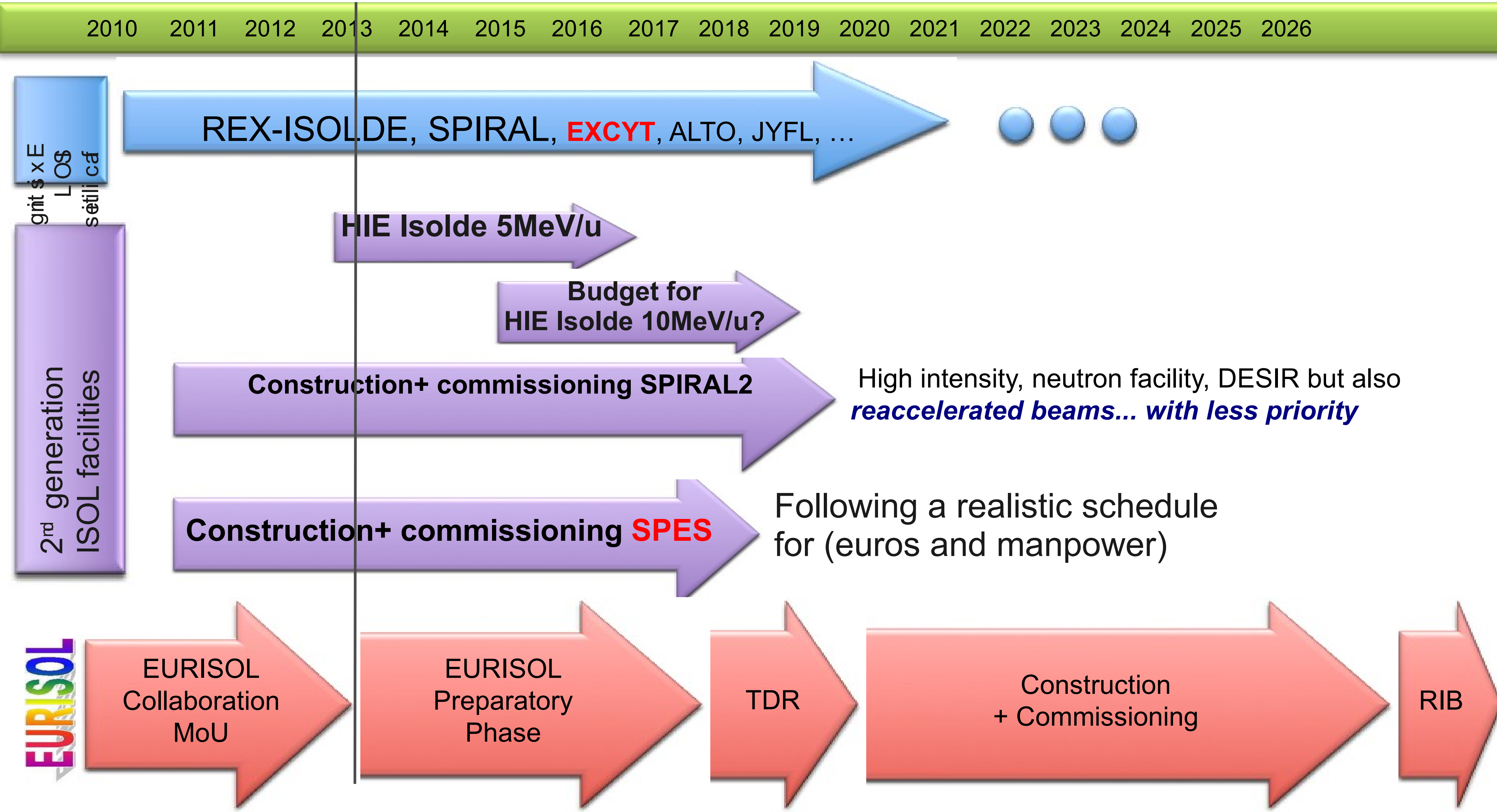
List of subjects to be discussed at iTHEMBA for new RIB facility

- Light n-rich RIBs
- An active Target
- Coulex and Proton-rich beams
- Large Acceptance Spectrometer/n-rich beams
- Desired Beams

FACILITY	132Sn intensity pps (accelerated beam on target)
SPES (Italy)	10^8
SPIRAL II (France)	10^9
HRIBF (USA)	~~10^8~~ ? CLOSED!
HIE ISOLDE (CERN)	10^8
ITHEMBA LABS	10^8 ?
BRIF (China)	10^7
KORIA (Korea)	10^9



Timeline for European ISOL RIB facilities (adapted from NupeCC)

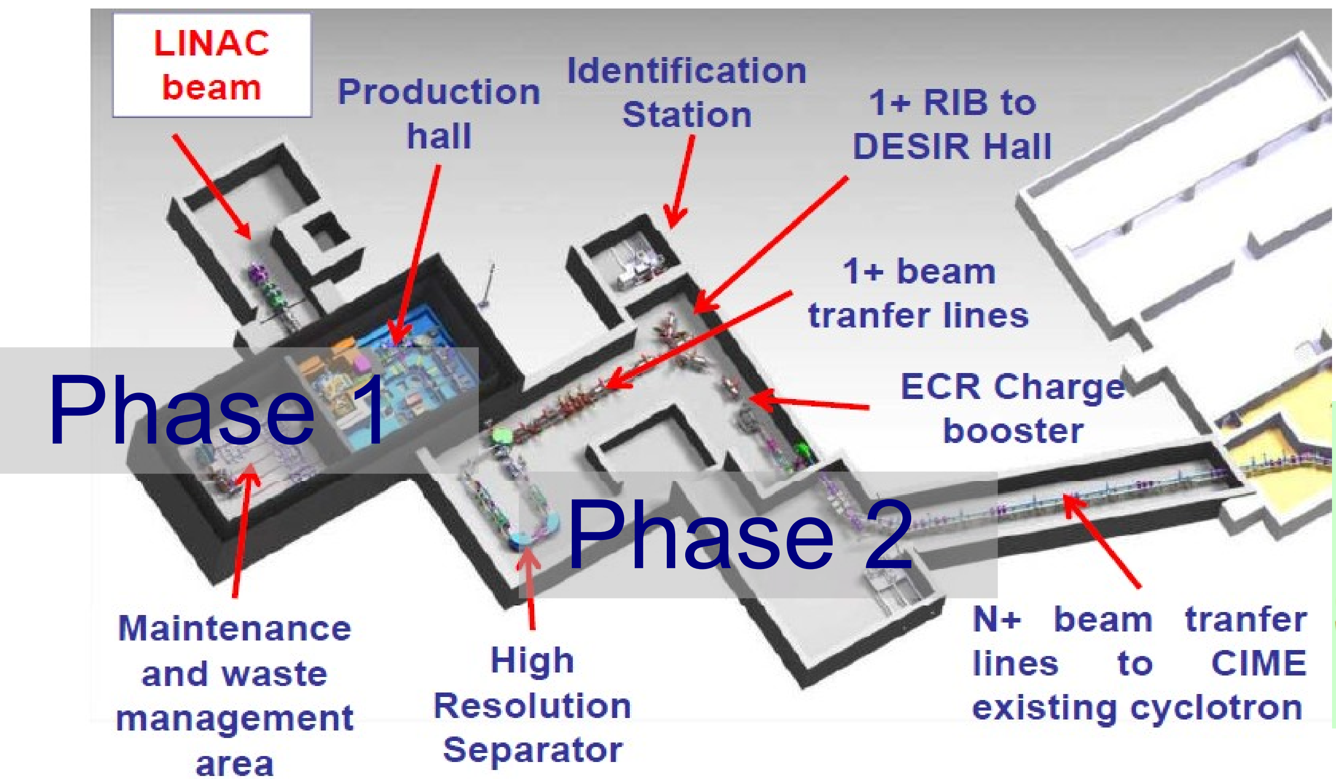


NOTE: neglected in this context the **FAIR** facility at GSI

Spiral2 @GANIL: ISOL Facility … and more

- **Phase 1** C-Wave superconducting LINAC , 5mA deuteron beam 40MeV → 200kW power. Big France collaboration GANIL, ORSAY, GRENOBLE, SACLAY
  NFS Neutron for Science facility

- **Phase 2** Production Building
C converter+ U target to about 10000 billion fissions/s. Masses 60-140
DESIR facility



PHASE 2: STARTING 2014

First trimester 2014

- Starting buildings construction

Second semester 2015

- Starting assembly of the equipments into the buildings

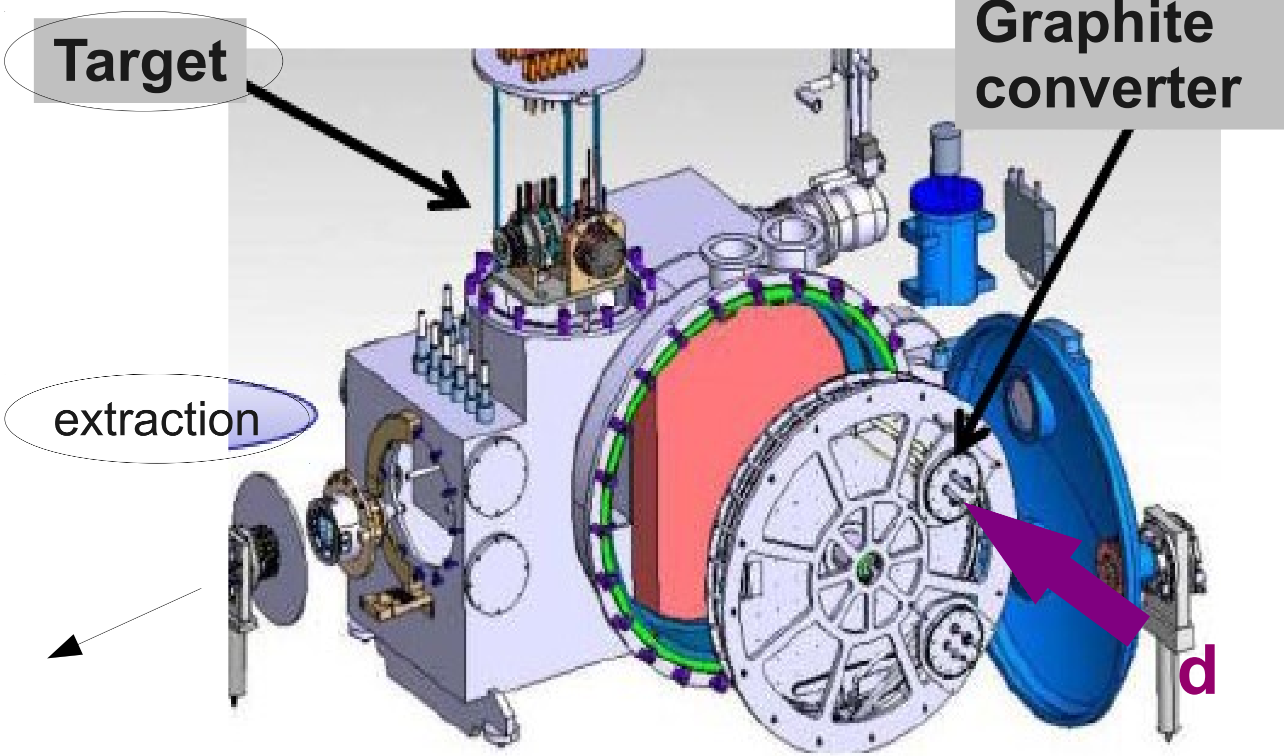
Spiral2 @GANIL ISOL Facility

Phase 2

Cooperation with INFN Istituto Nazionale di Fisica Nucleare

C converter+ U target to about 10^{13} fissions/s. Nuclear masses A=60-140

d intense Beam → Graphite converter → neutron → Uranium core → fission → exotics



Final 200kW

Converter :

The first complete prototype of the 50kW : under construction at INFN-LNL.

The 50kW prototype is going to be produced

ISOLDE @CERN

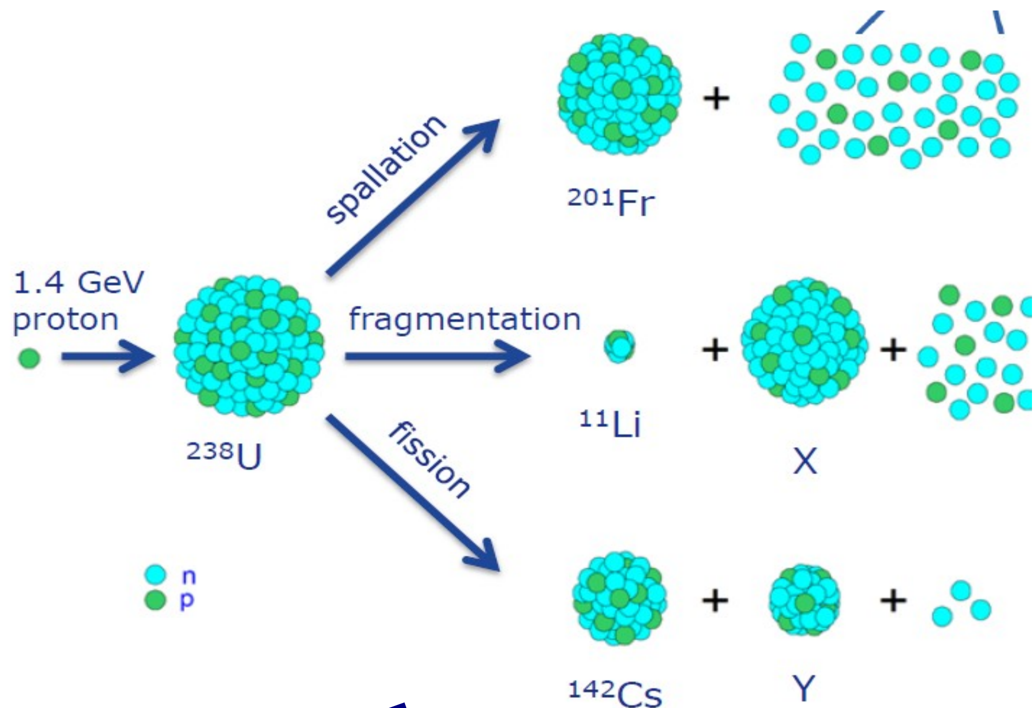
Adapted from M.Huyse talk, 2012

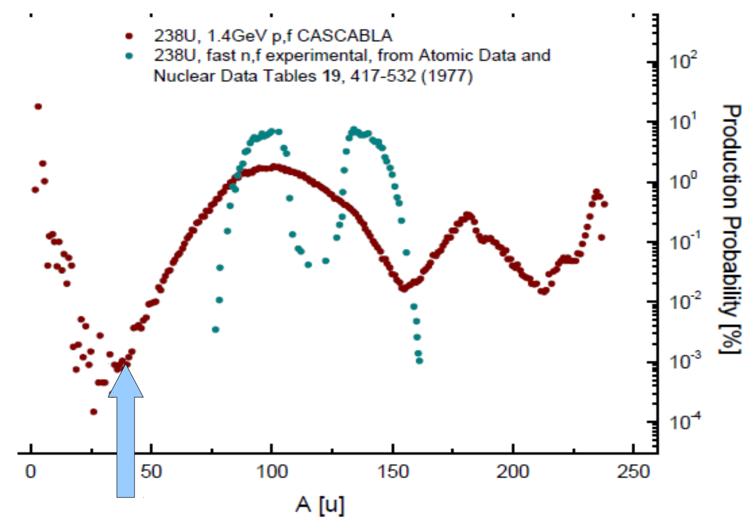
ISOL Facility since many years.
Impressive table of available exotic species
>600 nuclei from 70 elements produced at ISOLDE

Mass	Element	Mass	Element	Mass	Element	Mass	Element	Mass	Element	Mass	Element	Mass	Element
6	He	35	Ar	68	Ni	95	Rb	139	Nd	180	Hg		
8	He	36	Ar	69	Ge	96	Kr	139	Pr	180	Tl		
8	Li	40	Cl	69	Ni	98	Rb	139	Sm	180	Yb		
8	LiO	42	K	70	As	101	Ag	140	Cs	181	Tl	205	Fr
9	Li	43	Ar	70	Ga	103	Cd	140	La	182	Tl	205	Rn
10	C	45	K	71	As	104	Cd	140	Nd	183	Tl	206	Fr
10	CO	45	Ti	71	Kr	106	Rh	140	Pr	184	Tl	206	Hg
11	CO	46	Sc	71	Ni	107	Cd	140	Sm	186	Pb	206	Tl
13	NO2	47	K	71	Zn	110	Ag	141	Nd	186	Tl	207	Fr
15	CO	48	Cr	72	Kr	111	Ag	141	Sm	188	Hg	208	Fr
16	NO	49	K	72	Ni	111	Cd	142	Cs	188	Pb	208	Hg
16	CO	49	Ti	72	Se	111	In	142	Dy	188	Tl	208	Rn
17	NO	50	K	72	Zn	112	Pd	142	Pr	189	Hg	208	Tl
19	Ne	50	Sc	73	As	113	Ag	142	Sm	190	Pb	209	At
20	Mg	51	K	73	Ga	114	Ag	143	Sm	190	Tl	214	Fr
20	Na	51	Ti	73	Kr	114	Cd	147	Nd	191	Hg	217	At
21	Mg	52	Fe	74	As	115	Ag	149	Tb	192	Hg	218	At
21	Na	52	Ti	74	Kr	117	Ag	151	Dy	193	At	220	At
22	Mg	53	Fe	74	Zn	118	Cd	152	Dy	193	Hg	220	Fr
22	MgO	55	Co	76	Zn	118	In	152	Nd	194	At	220	Rn
23	Mg	55	Cr	77	Br	124	In	152	Tb	194	Pb	222	At
24	Al	56	Cr	77	Zn	126	Cd	157	Dy	195	Hg	222	Fr
24	Na	57	Co	78	Zn	128	Cd	157	Eu	195	Tl	222	Rn
25	Al	57	Cr	79	Zn	128	Cs	165	Dy	196	At	223	Fr
25	Na	58	Cu	80	As	129	Te	167	Dy	196	Pb	224	Fr
26	Na	60	Co	80	Rb	130	Cs	168	Dy	197	Hg	226	Fr
27	Mg	61	Fe	80	Zn	131	Cs	168	DyO	198	Ir	227	Fr
27	Na	61	Cu	81	Rb	131	Xe	169	Yb	199	At	228	Fr
28	Mg	61	Mn	81	Zn	132	Cs	172	Er	199	Hg	229	Fr
30	Mg	62	Co	82	Rb	135	Pr	176	Yb	200	Fr	230	Fr
30	Na	63	Co	82	Zn	136	Cs	178	Hg	200	Pb	231	Fr
31	Al	63	Ni	83	Br	136	Pr	178	Tl	201	Fr	232	Fr
31	Mg	65	Ni	83	Zn	137	Cs	178	Yb	202	Fr	232	Th
32	Ar	66	Ga	84	Kr	137	Pr	179	Lu	202	Tl	233	Fr
33	Ar	66	Ni	86	Kr	138	Cs	179	Tl	204	At	233	Ra
33	Cl	67	Cu	91	Kr	138	Nd	179	Yb	204	Tl	234	Ra
34	Ar	67	Ni	93	Rb	138	Pr	180	Hf	205	At	238	U

Almost all nuclei can potentially be charge-bred and accelerated to 3MeV/u

Low-Energy: mainly CoulEX experiments and transfer reactions for the lightest systems





Development on CaO target to fill this valley
R&D on new materials and new structures for best ion effusion

EVEN MORE

HIE Upgrading: a step to **High intensity and Energy**

HIE ISOLDE CERN

Adapted from M.Huyse, 2012

HIE Upgrading

HIE-ISOLDE aims at increasing the range of elements, the purity of the beams, the intensity by a factor 10 and their energy up to 10 AMeV.

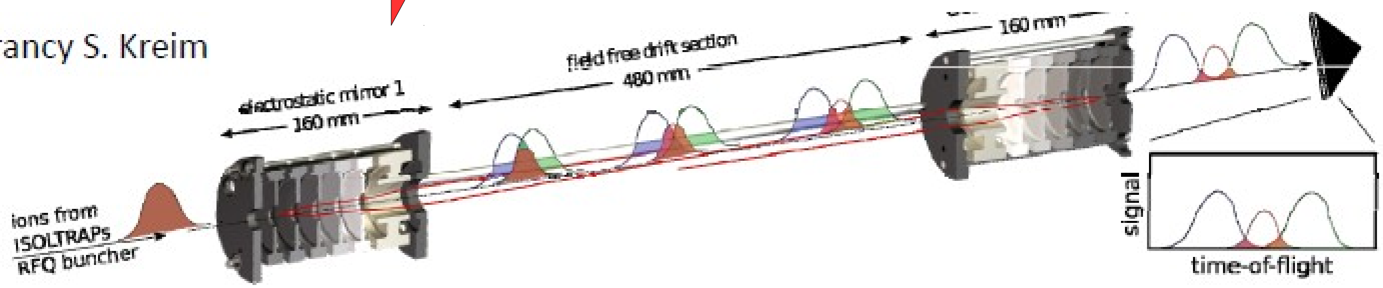
A three step process

Beam optical properties and quality → ISCOOL : RFQ cooler buncher

Beam purity → HRS higher mass resolving power

to exploit the larger RIB production, need of a better mass separation (nuclear S/N ratio)

Transparancy S. Kreim



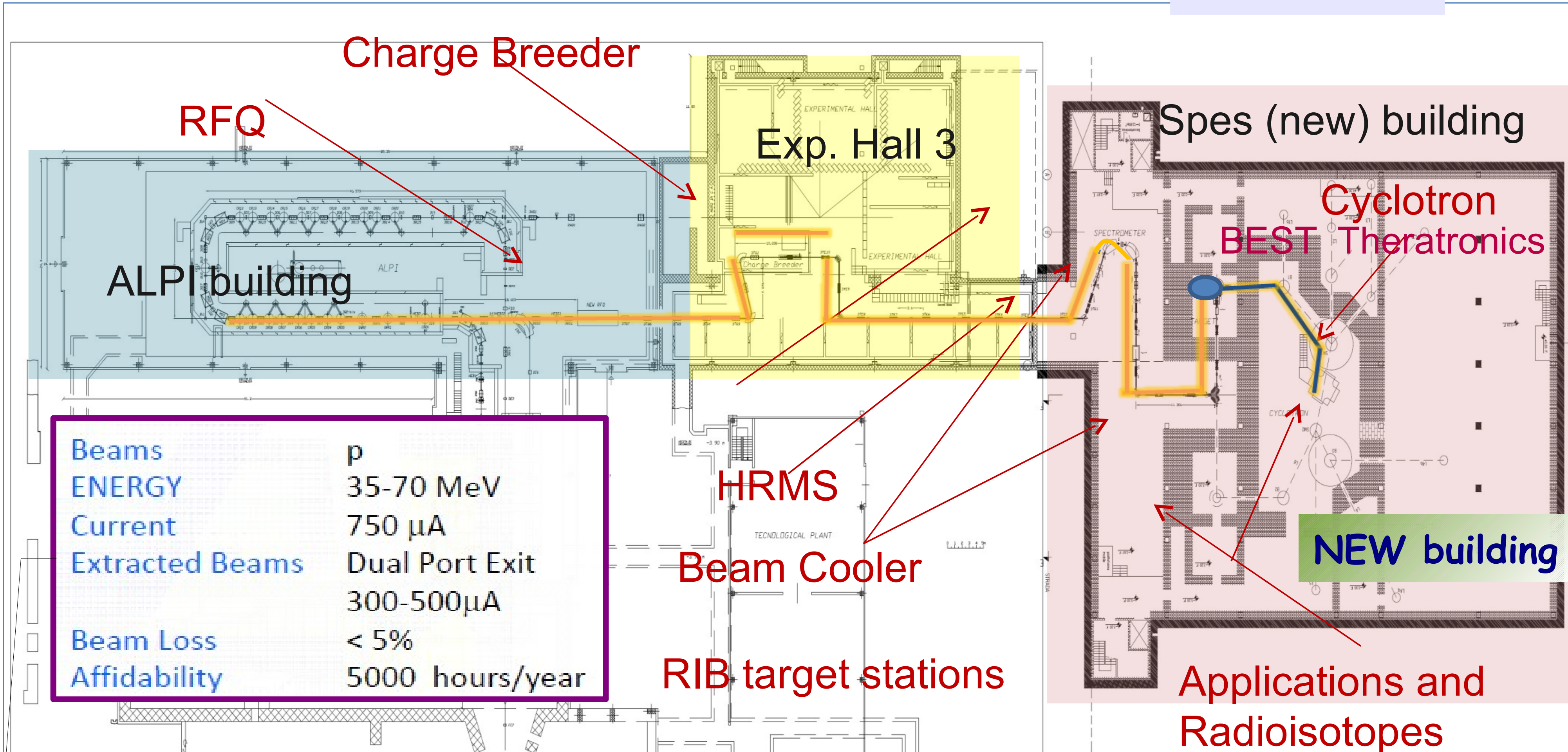
Increased proton beam E and I LINAC-4 project
4x BEAM POWER
Upgrading infrastructures (target,chamber, walls....)

→ From present 2.8kW to 10kW :
E from1.4 to 2GeV,
Cycle duration from 1.2 to 0.9 s,
proton current from 2 to 4microA

Strong competitor/collaborator of SPES!

The SPES initiative: Layout

Adapted from G.Prete



CYCLOTRON

First factory test at Best in Canada: sept 2013.
Cyclotron at LNL: installation and commissioning in 2014

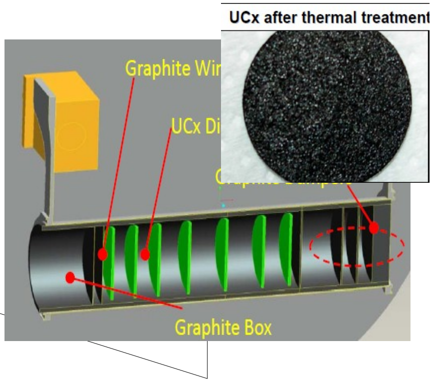
8Meuro basis funding. Committed the building firm.
Construction starts on january 2013 (prediction)

BUILDING

SPES cooperation

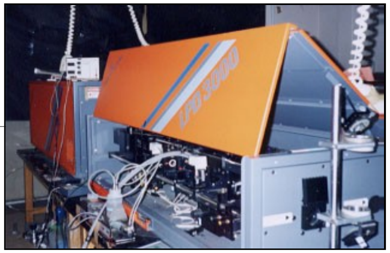
Core UCx target
(and other rafractaries)

ISOL target, six years activity at **LNL**: prototype developed, tested also at OakRidge ORNL and now under operation at Legnaro. Radioprotection issues...**LNS**



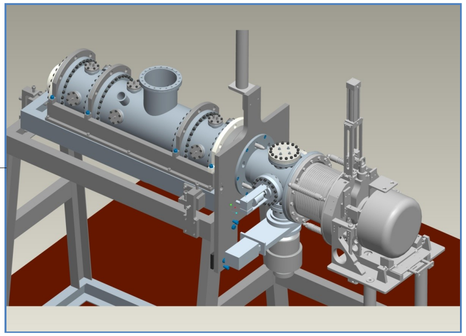
LASER set-up at **PAVIA** to optimize exotic beam selection through selective photoionization (Nd:YAG 300mJ, 10Hz)

Resonance ionization Laser ion Source



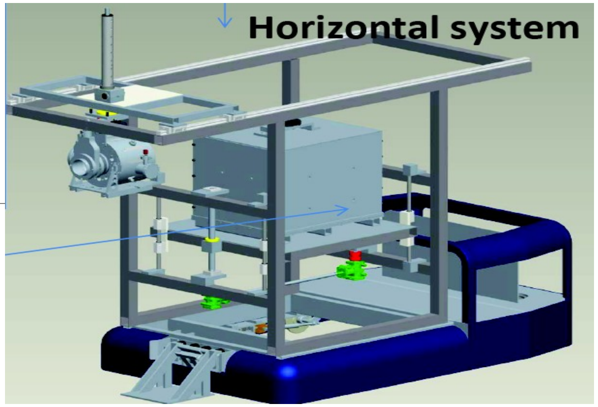
nuclide selection

Test-bench for production target tests at **LNS** with Protons from CS 40MeV 50nA . Support made in **Bologna**



Beam production

Remote support and moving system of the HOT target region



An integrated design and structure done at **Bo,Mi, Pd**

SPES: the on-line Front End at LNS

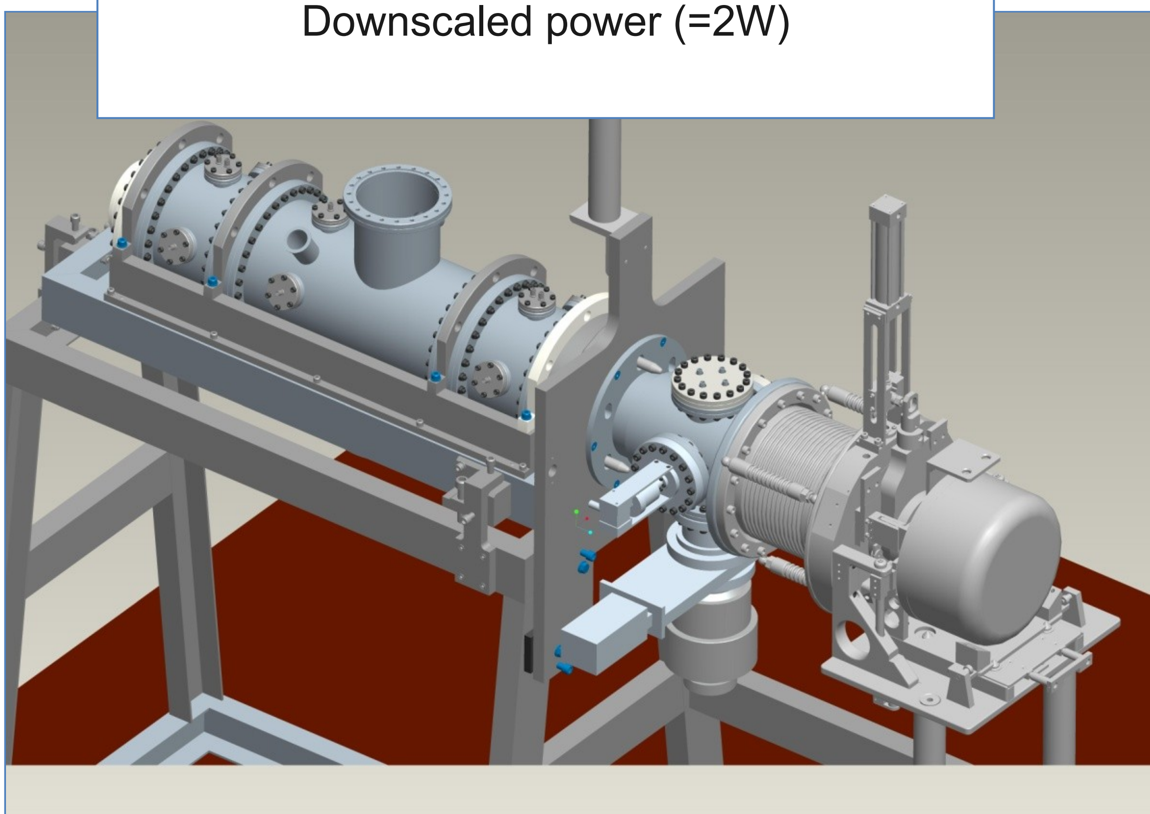
It is extremely important to have a test-bench in Italy!

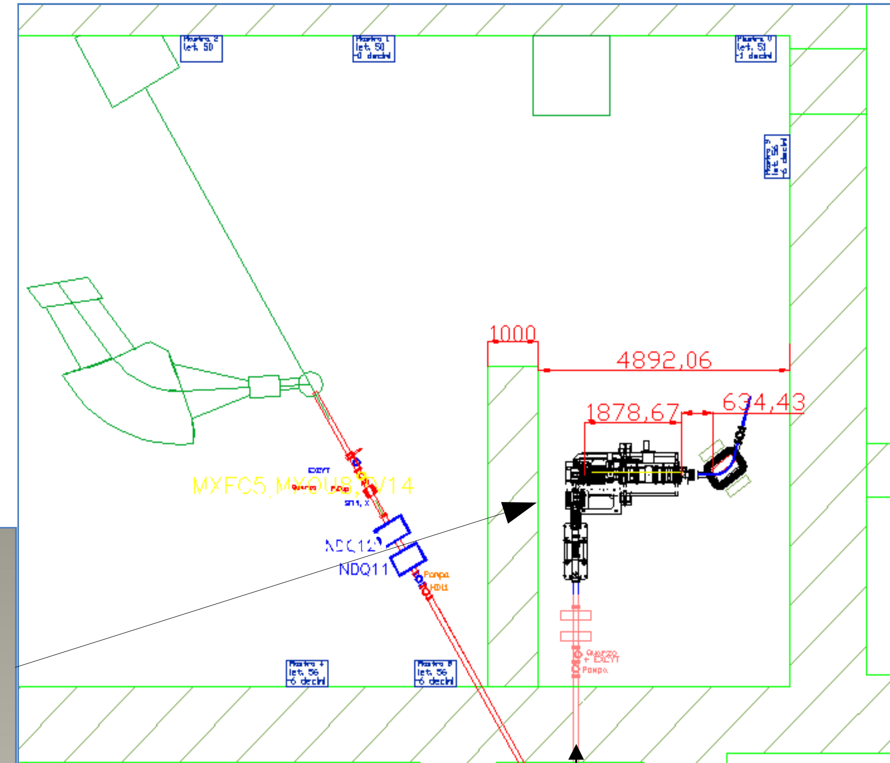
For RIB production test using LNS Cyclotron

Proton; E= 40 MeV

I = 50 nA

Downscaled power (=2W)





Proton from K800 Cyclotron

SPES costs and funding steps

Collaboration with G.Prete

Total cost of the project: ~55Meuro
Including TD personnel and consumables next 5 years

Already used and/or obtained: ~26Meuro

- INFN old funding 17Me
- PROGETTO PREMIALE 2011 5.6 Meuro
- INFN special funding for SPES building ~3Meuro

Major expenses Cyclotron ~10.5Meuro

Buinding and infrastructures ~8Meuro (basis)

Still needed ~30-35Meuro (for RIB production and Reaccelearation)

Five-year plan, spread over several funding sources:

- Progetti premiali next years
- Regione Veneto and local institutions
- UE
- INFN

big expense: beam cooler and HRMS, 3.5Meuro

2^{nd} GEN ISOL facilities in Eu (UCx target)

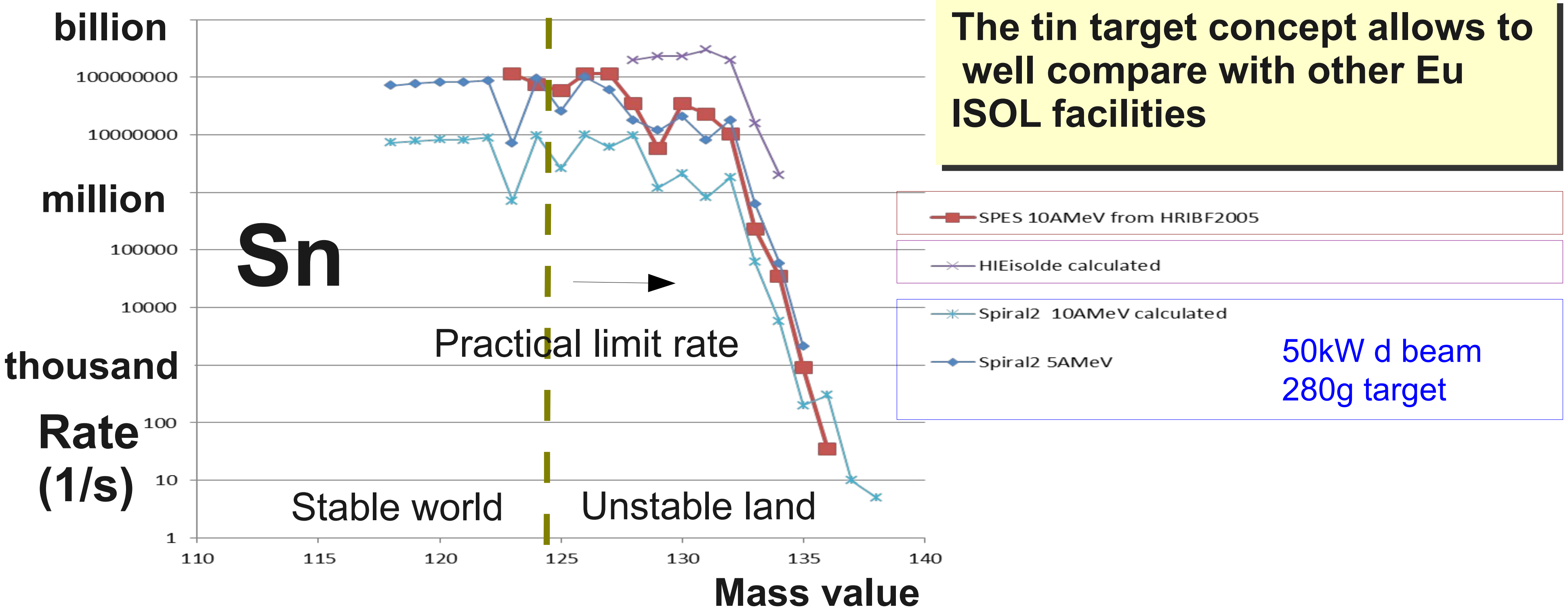
Adapted from G.Prete

Facility	Primary beam	Power on target	UCx target	Fission s^{-1}	Reaccelerator	Nominal energy AMeV A=130
HIE ISOLDE upgrade	p 1-1.4 GeV - 2 μA p 2GeV - 4 μA	2 kW 4kW ?	Direct (150g)	**$4\cdot10^{12}$** **10^{13} ?**	SC Linac	5-10
SPIRAL2	d 40 MeV 5mA	200 kW	Converter (4000g)	**10^{13}** 10^{14}	CIME Cyclotron	5-6
SPES	p 40 MeV 200 μA	8 kW	Direct (30g)	**10^{13}**	ALPI SC Linac	10

Synergy & complementarity

- European nuclear community will have up-to-date facilities to improve the knowledge of nuclei
- Towards *HORIZON2020*: Interdisciplinary and applyied sciences (neutron irradiation, radioisotopes for medicine, nuclear waste incineration)

SPES: the game in the exotic Sn region...



The tin target concept allows to well compare with other Eu ISOL facilities

… and in promotion and formation

- International Workshop LNL for the LoI presentations (22 letters arrived), 2010
- Partnership in the Eurorib12 organization, 2012
- 5 one-day short WorkShops all around Italy on LoI upgrading (2 already done, 2012)
- First SPES school on experimental techniques with RIB, LNS, 44 participants

ISOL beams: not only uranium...

Adapted from A.Andrighetto, 2012

Strong efforts done by the LNL SPES Target Group

An intedisciplinary field: chemistry, material sciences and nuclear physics, are involved altogether

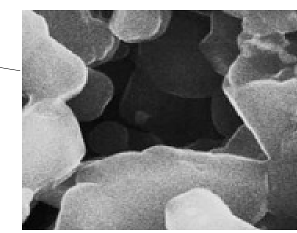
Need of effective cooperation between target/source developments and nuclear physics inputs

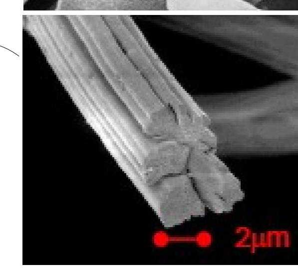
Also within the Acti-LAB Eu-FP7 Ensar

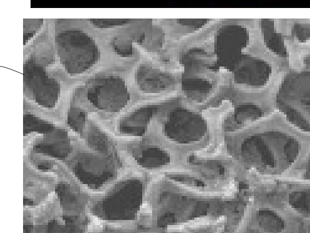
1) Target with high working temperature -> refractory carbides/oxides

2) Material with good characteristics in terms of release (grain and porosity) -> carefully R&D is mandatory!

proton-rich isotope	$T_{1/2}$	Ion Source	Yield (1/s)	Target material
^{7}Be	53 d	LIS-PIS	~10^9	B_4C
^{17}F	65 s	PIS	~10^9	HfO2 – ZrO2
^{18}F	110 m	PIS	~10^8	HfO2 – ZrO2
^{25}Al	7 s	LIS-PIS	~10^6	SiC
^{26}Al	6 s	LIS-PIS	~10^8	SiC
^{27}Si	4 s	LIS-PIS	~10^5	SiC
^{34}Cl	32 m	PIS	~10^6	CeS







Other RIB initiatives: EXOTIC at LNL

INFN-Na, Pd @LNL

The production mechanism employs **inverse kinematics reactions** with heavy ion beams impinging on light **gas targets**.

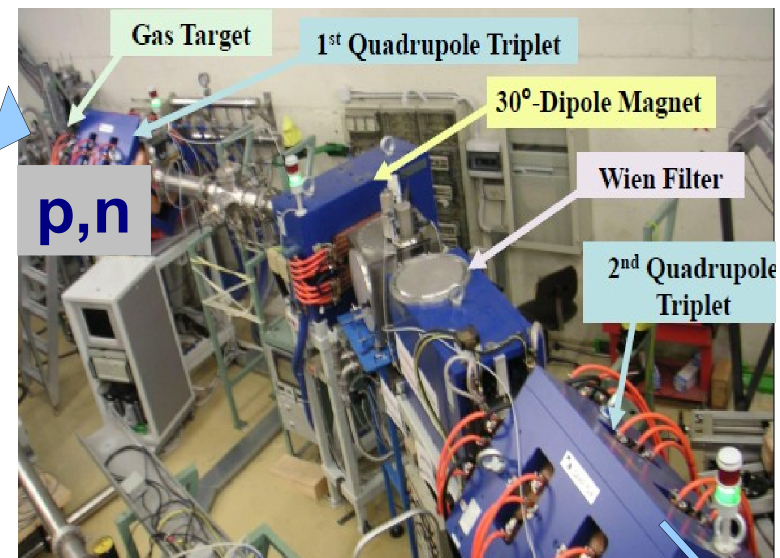
^{17}F (S_p = 600 keV): **$^1H(^{17}O,^{17}F)n$** Q_{value} = -3.54 MeV;
^8B (S_p = 137.5 keV): **$^3He(^6Li,^8B)n$** Q_{value} = -1.97 MeV;
^7Be (S_α = 1.586 MeV): **$^1H(^7Li,^7Be)n$** Q_{value} = -1.64 MeV.

Primary Beam: $^{17}O^{6+}$
E_{lab} = 100 MeV
i ~ 90-100 pnA on target

Target: H_2 Gas
p_1 = 750/950 mbar,
T_1 = 90/300 K

Secondary Beam: $^{17}F^{9+}$
E_{1-2} = (54.1/58.5 ± 1.1) MeV
$I_1 \sim I_2 \sim 10^5$ pps
$Purity_{1-2}$ = 93/96 %

^{17}O



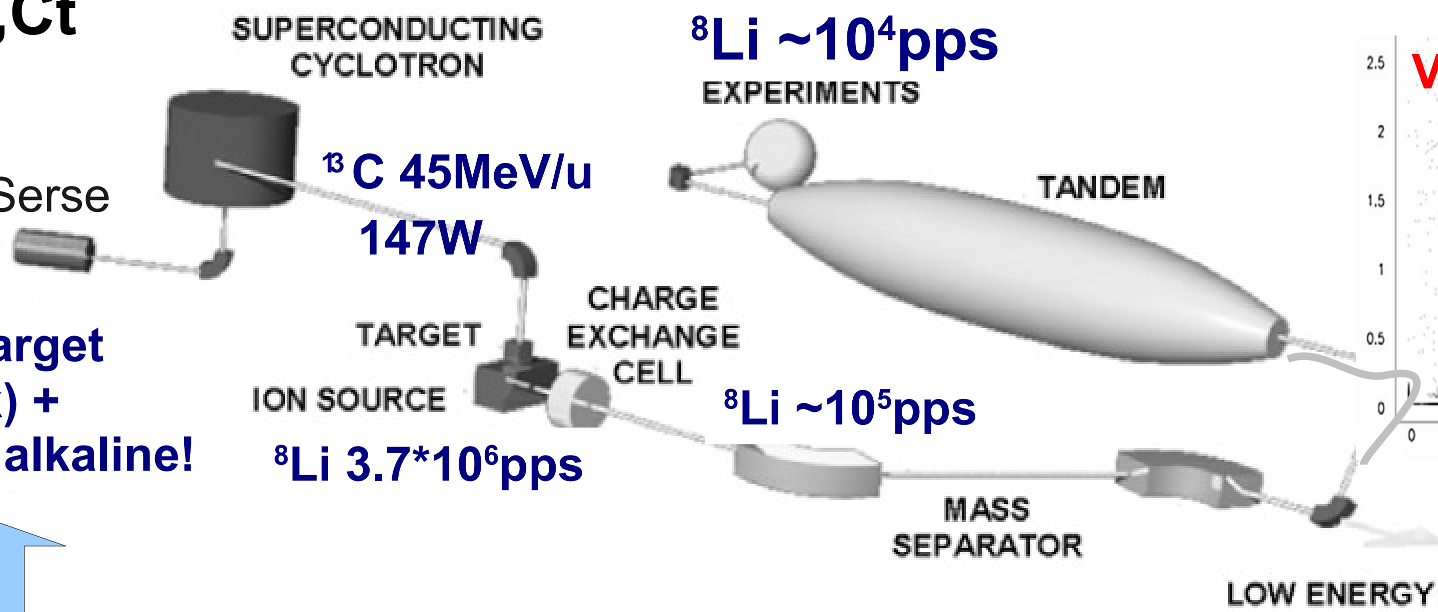
^{17}F

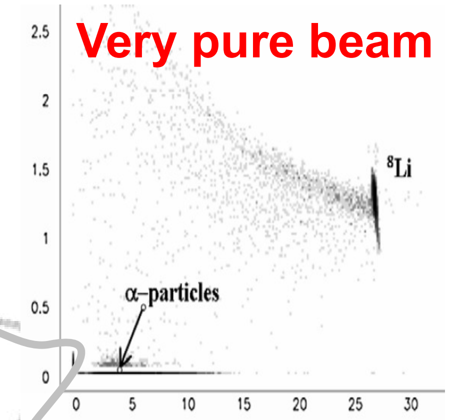
^{17}F	E = 3–5 MeV/u	Purity: **93-96 %**	Intensity: **~ 10^5 pps**
^8B	E = 3 MeV/u	Purity: **~ 30 %**	Intensity: ~ **10^3 pps**
^7Be	E = 3 MeV/u	Purity: **99 %**	Intensity: **2-3*10^5 pps**

(Very) high purity light proton rich beams

INFN-LNS,Ct

EXCYT an ISOL facility in Catania





graphite target (8.5mm thick) + SIS, fine for alkaline!

Beam crew

Beam user

An ISOL facility where INFN groups learnt a lot about RIB: production, monitoring, transport and use for the final experiment and also radioprotection issues and laws. **A valuable bkg for SPES-LNL-LNS collaboration, both from the production side and the final-user side**

First EXPERIMENT / COMMISSIONING

Commissioning experiment with the **8Li** beam: **8Li+4He → 11B+n**
Inclusive reaction cross section at Ecm=1.05MeV for astrophysical interest (heavy nuclei formation at BigBang and in SN Type II)

Helium Gas target + neutron 4p Polycube counter

R&D to increase the final current and to produce other light beams

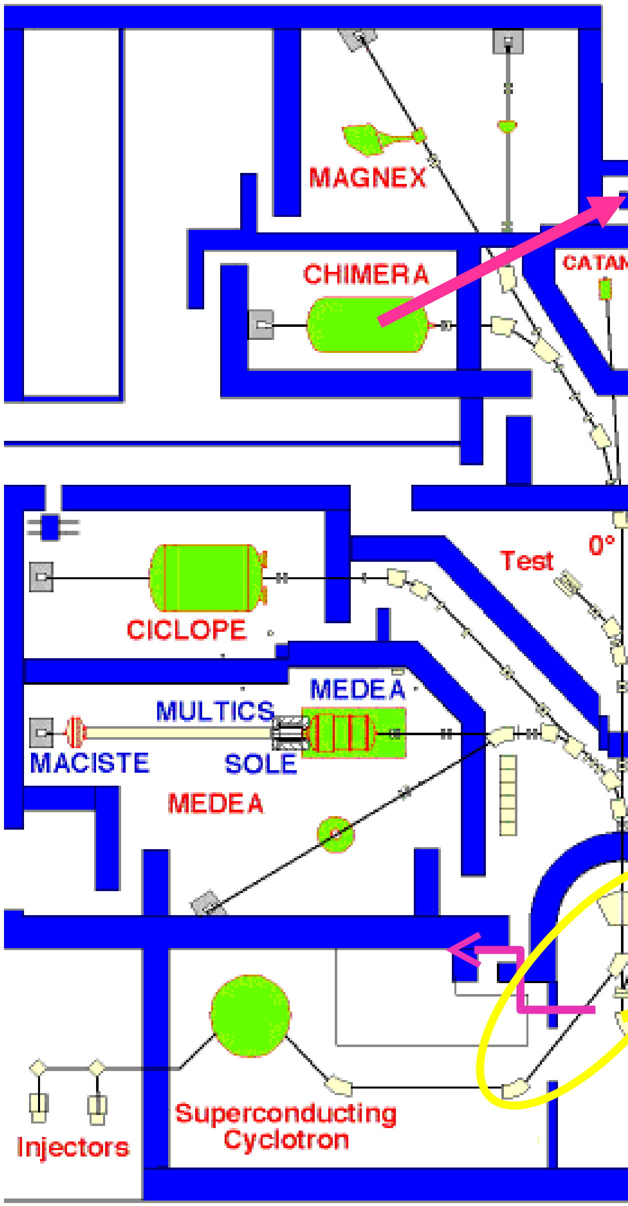
FRIBs: Fragmentation beams at INFN-LNS

From an idea by ***G.Raciti***

A special facility for fragmentation beams

CS Beams from 15 to 50MeV/u

Power up 100W (~10^{11} pps)

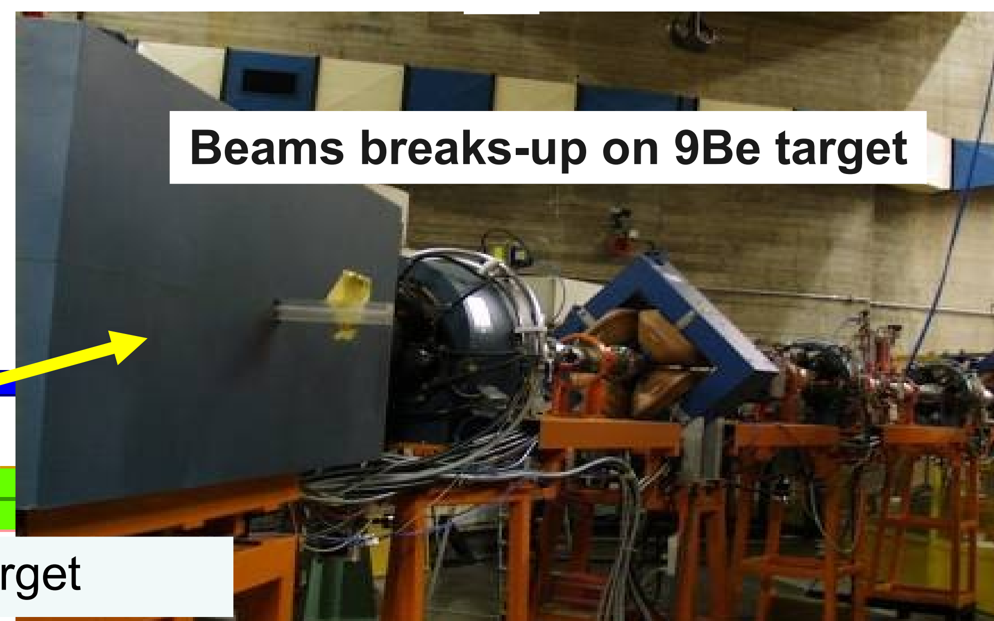


CHIMERA

EXAMPLES

36Ar 25MeV/u→ 34K, 37Ar 20MeV/u 2-20kHz

18O 55MeV/u→ 13B,16C,12Be,9Li 50MeV/u 2-60kHz



FRIBs: beam developments

100 Watt, 0.25mm 9Be production target

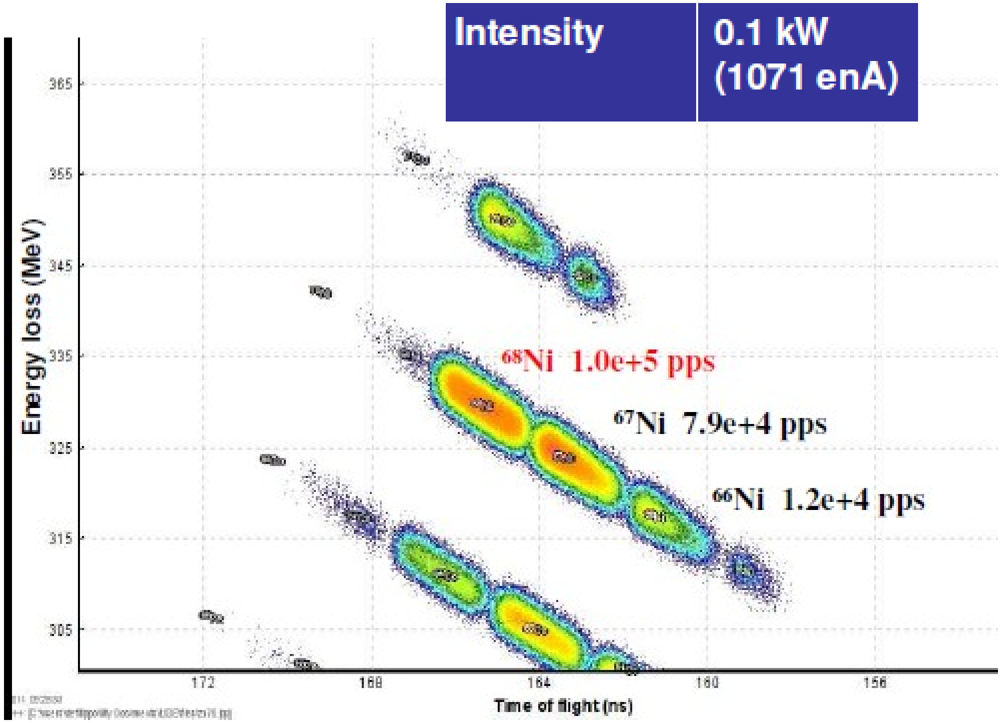
^{68}Ni from ^{70}Zn beam; currents up to 10^5pps (LISE calc.), obtained so far $2*10^4$

Issues: radiation damage in the TAGGING detectors

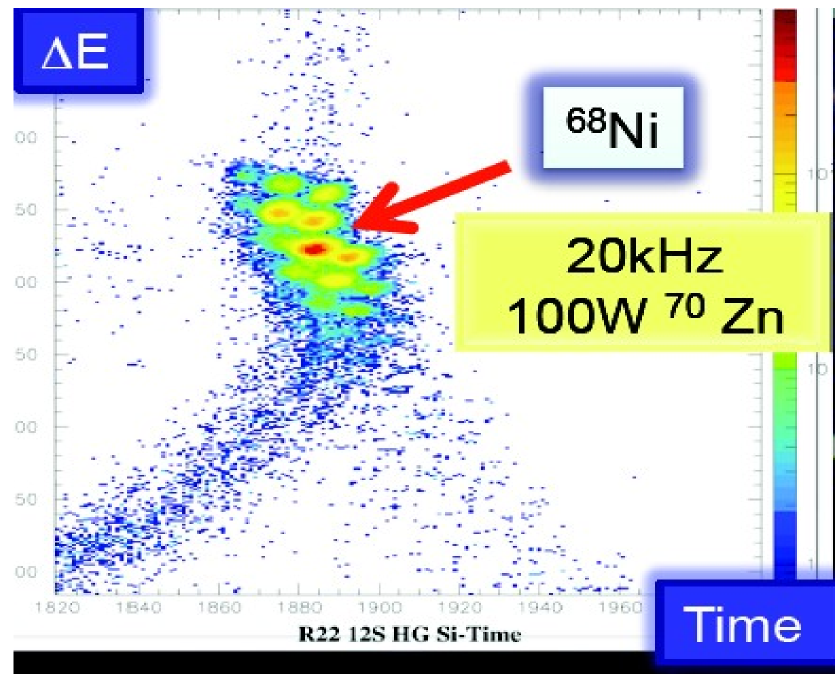
^{8}He from ^{11}B beams; currents about 2000pps

Issues: plastic instead of MCP due to low efficiency

Another beam request is to improve the production of ^{8}He using as primary beam ^{11}B Lise predictions - quite reliable for this ion with ^{18}O - give a rate of about 2kHz enough for some interesting experiments



Calculated



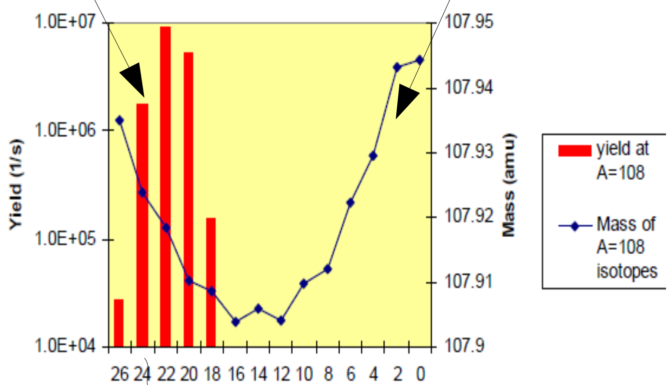
Obtained

Beam purity and isobaric separation

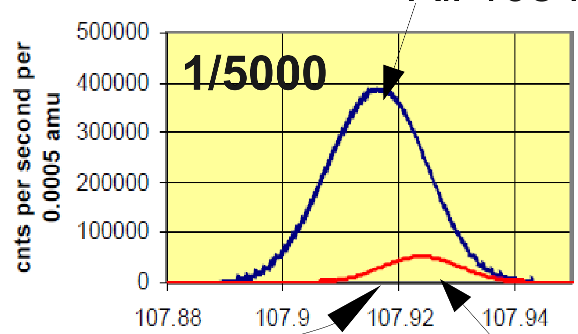
RIB production

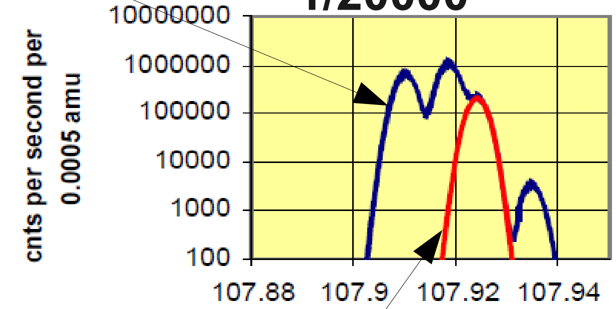
Mass values

EXAMPLE CASE OF A=108



All 108 isobars





N-Z

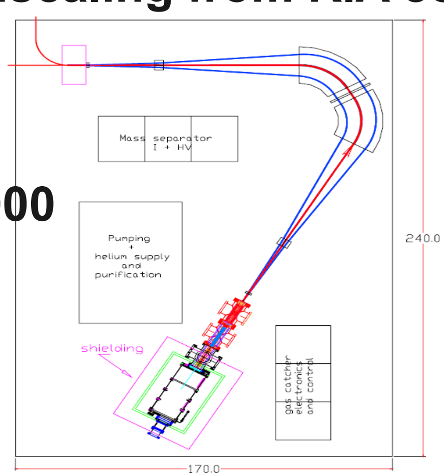
Let's take 108Mo

Molibdenum 108

Resolving power <u>at least</u> 1/20000 needed !

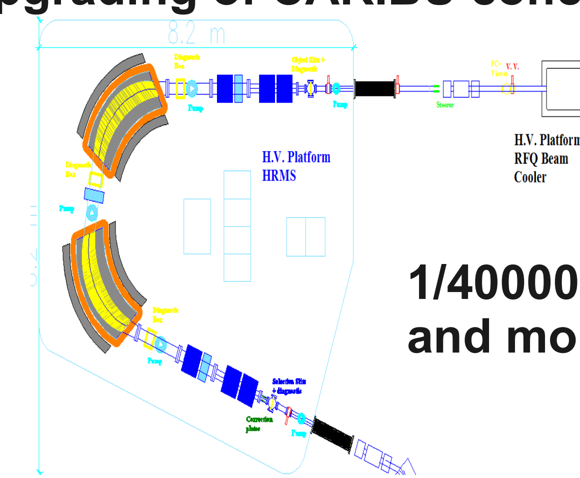
CARIBU HRMS at Argonne
(downscaling from RIA concept)

1/20000



LNS-LNL collaboration

SPES HRMS at LNL
(upgrading of CARIBU concept)



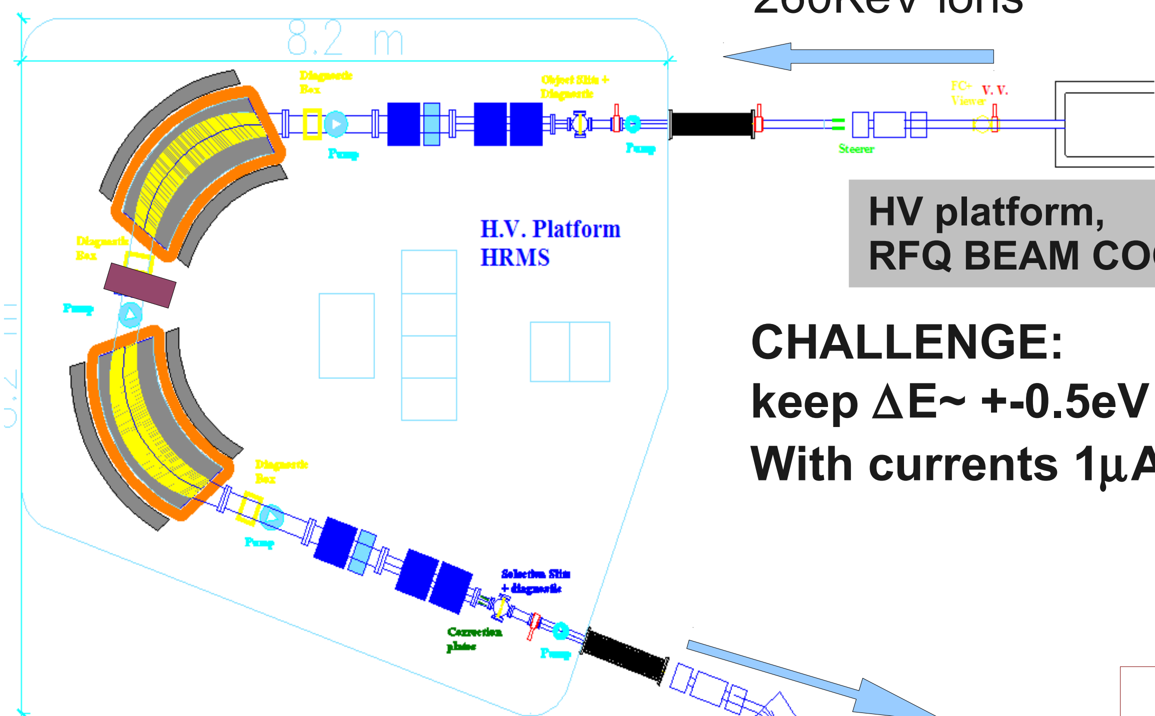
1/40000
and more?

SPES: high resolution mass separator HRMS

Collaboration with L.Calabretta, 2012

LNS-LNL collaboration

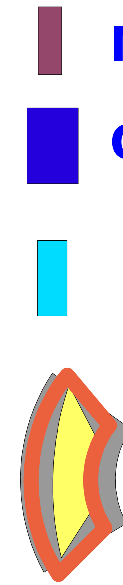
260KeV ions



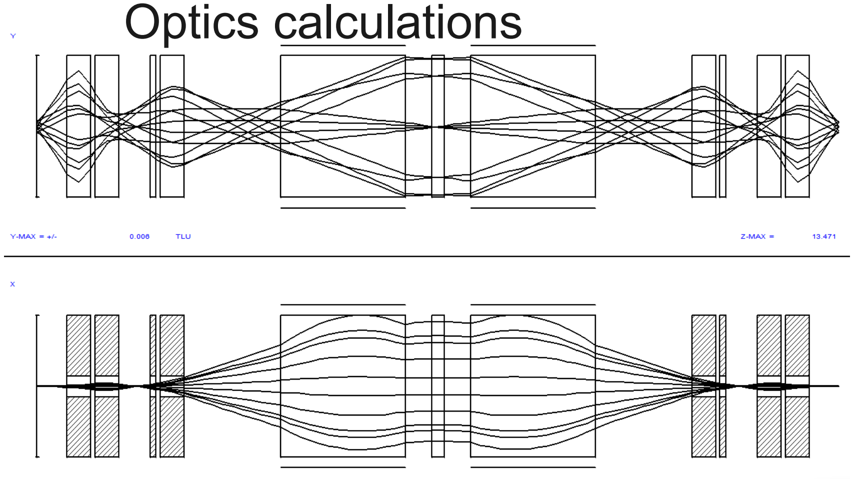
HV platform, RFQ BEAM COOLER

CHALLENGE:
keep ΔE~ +-0.5eV
With currents 1μA !

legenda



Optics calculations

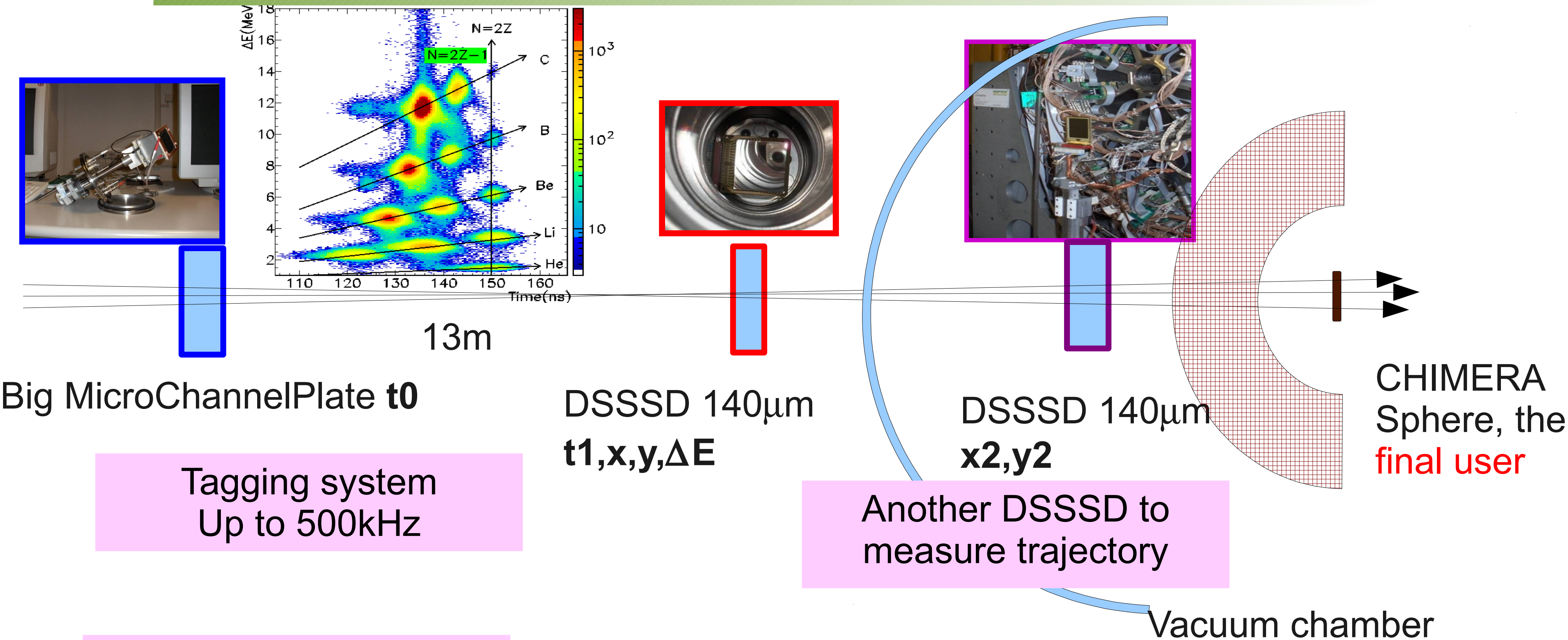


CHARACTERISTICS

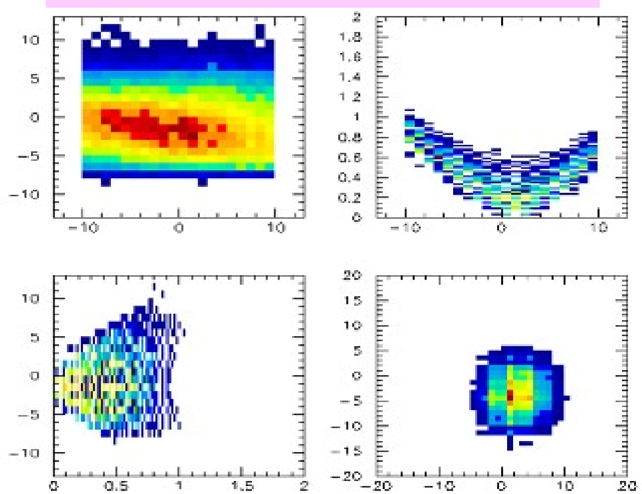
- Energy 260 kV
- Bend=80° ρ=1.5 m, Bmax=0.9 T
- Dipole Edge=28°
- (X,X') emittance=3 π mm*mrad
- (Y,Y') emittance=4 π mm*mrad
- Entrance/Exit slits 1 mm
- M/Dm ~ 40.000

Coupling with a good BEAM COOLER

Fribs at LNS : Tagging and profiling beams



Beam profiling



It is possible select part of the beam on target – with very small divergence - but loosing many particles –
next experiment: a new DSSSD 32X32 strips 6.4x6.4cm2

Instrumentation: conceptual map

Impact parameter

LOW ENERGY 4 to 12 MeV/u
ISOL Facilities:
Heavy n-rich beams from fissile nuclei
Slightly neutron deficient light- medium mass beams

Main reaction-exit channels

Coulomb Excitation → gamma spectrometry, simple particle array

Direct reactions → gamma spectrometry, segmented particle array

Multinucleon Transfer (MNT) and deep inelastic collisions → spectrometers, HI-detectors, gamma arrays

Fusion reactions → spectrometers, gamma arrays, fission fragment detectors

INTERMEDIATE ENERGY from 15 to 40 MeV/u
IFF Facilities:
Medium size exotic beams both slightly neutron deficient or rich

Main reaction channels

Direct, fast reactions →particle correlators, gamma arrays, multidetectors

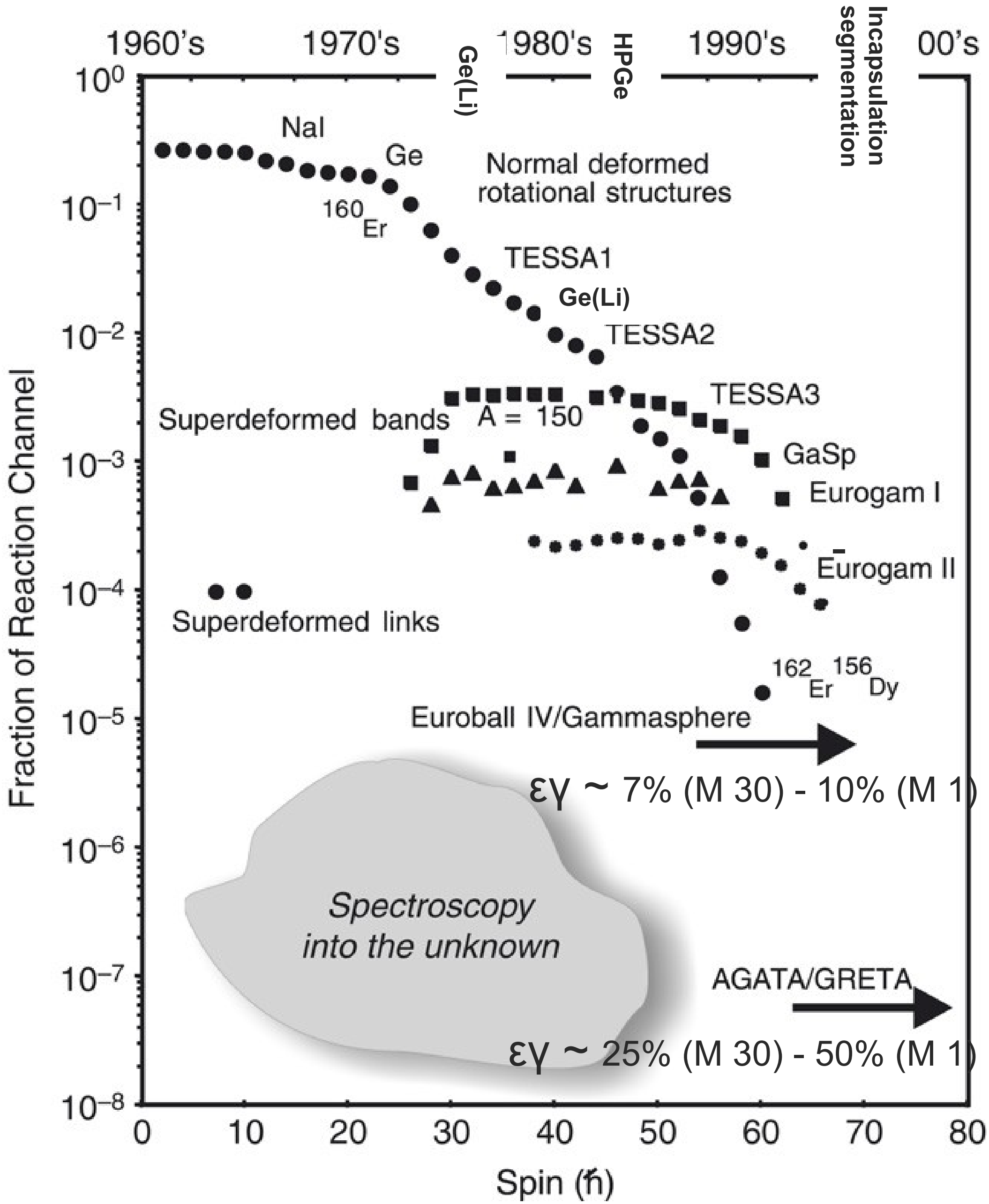
Deep inelastic collisions + fast emission/fission → HI-detectors, high energy gamma arrays, correlators

Central collisions with incomplete fusion, multifragmentation → fission fragment detectors, correlators, high energy gamma array, large acceptance multidetectors

Neutron arrays:
Efficient n-counters and precise spectrometres useful in several cases.
R&D on materials and software are on progress

γ–ray arrays: impact on high spin physics

Adapted from D.R. Napoli - LNL



HPGe detectors still are fundamental tool in nuclear gamma spectroscopy

Our goal is to extract valuable information on the **nuclear structure through the γ-rays** emitted following nuclear reactions.

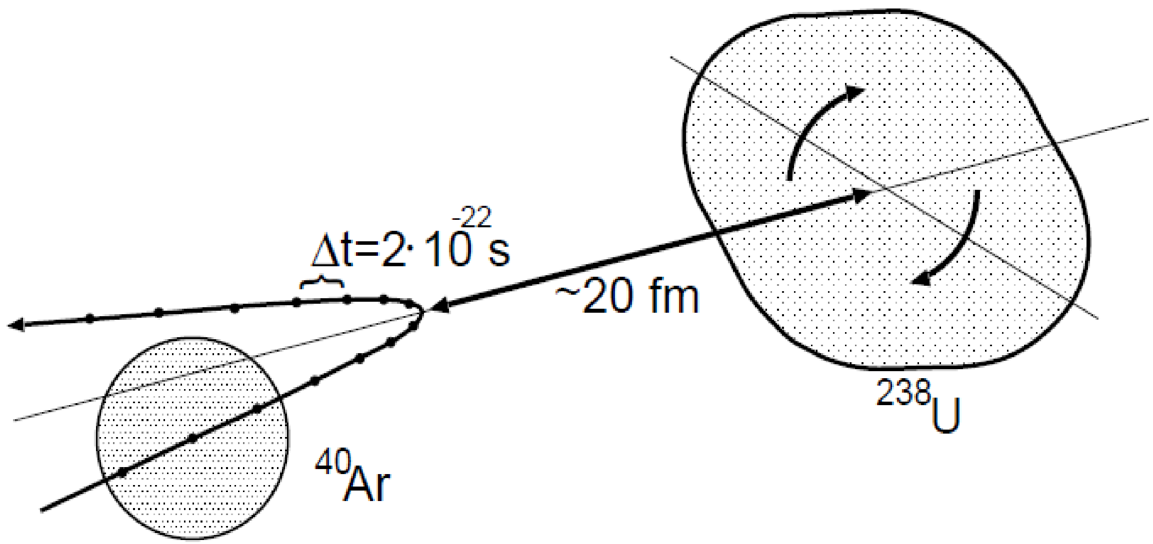
- Complex spectra, many dense energy lines and low cross sections.
- The effective energy resolution is necessary also at "extreme" v/c values.
- Higher segmentation of the HPGe is not sustentable (electronics density!)

Coulomb Excitation: a door to RIB experiments

- **low-lying single-particle levels can be studied**
- **Subjects: nuclear shapes, collectivity towards n-drip and close to magic nuclei**
- **One of the "easiest" experiment to be done:** **gamma detectors + particle recoil detector**

A gentle interaction of nuclear systems

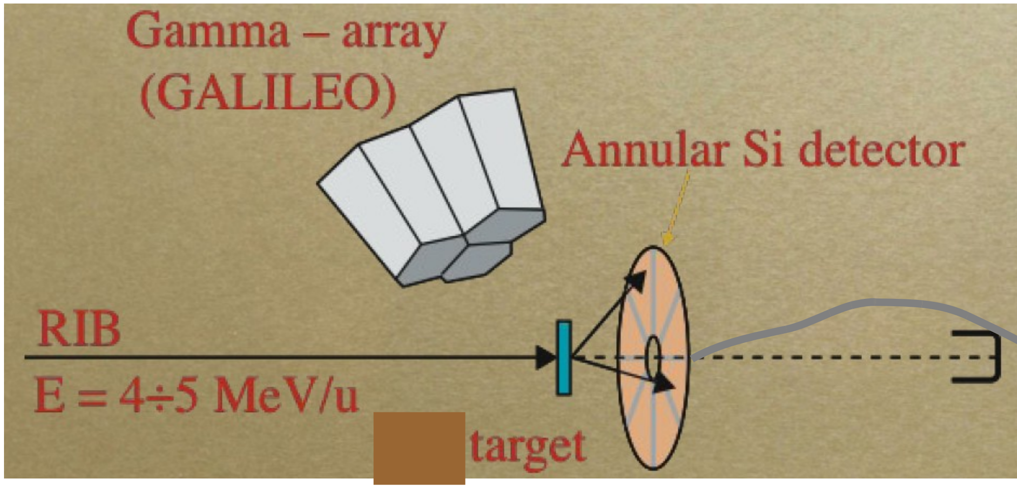
Only nuclear structure almost nothing about nuclear effects (distance larger than 5-6fm)



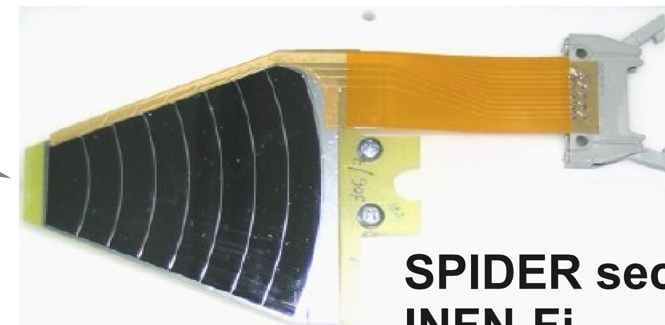
Gamma+ recoils with stable beams (time ago...)

- Projectile recoil measured at several angles to scan excited levels
- Particle-gamma correlations possible with high stastistics
- Doppler corrections

Coulomb Excitation: a door to RIB experiments



The high cross section helps: technique suitable also with currents as low as 100000pps (large Cross-sections



SPIDER sector, INFN-Fi

Several physics cases presented in the SPES letters of intents

Particle segmented detectors. Why?

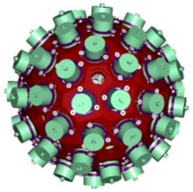
- projectile and target detection
- Reduction of high BKG of beta-decay
- Doppler correction
- Forward mounting (low currents)

...also Spectrometres (A,Z of scattered projectile) could be used!

With RIBs problems with (stable) contaminants: Purtity is an issue
Low currents → particle detector at forward angles

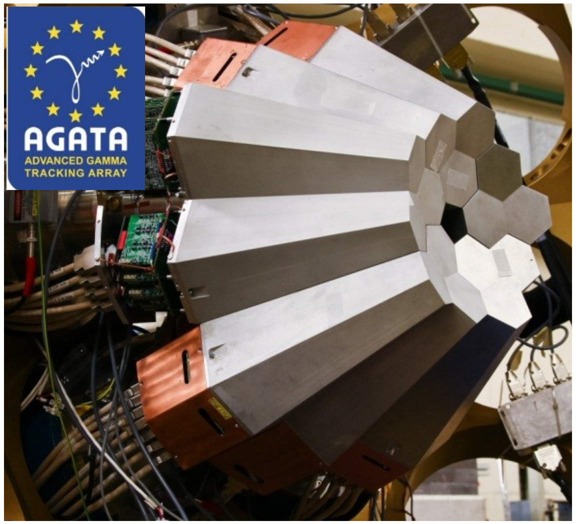
Look at HIE-ISOLDE!

Relevant point: high energy of the SPES beams allows multiple CoulEx and population of high-lying states



AGATA (Advanced GAmma Tracking Array)

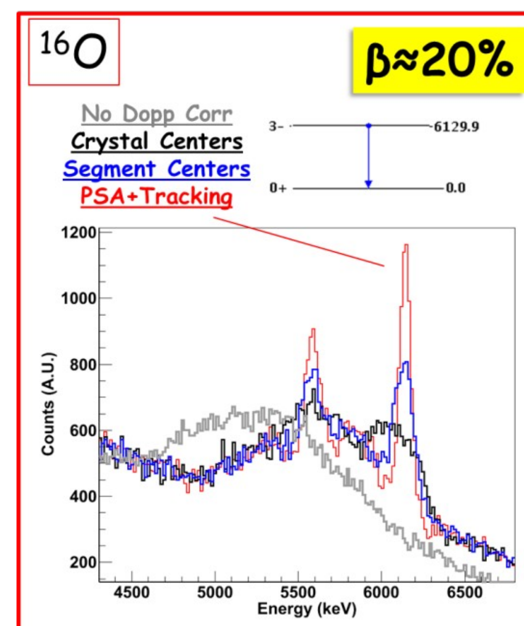
Adapted from E.Farnea, 2012



European collaborative project to ultimately build an array of HPGe detectors with photopeak efficiency >40%, through the innovative use of detectors in position-sensitive mode (combining digital DAQ, pulse shape analysis, γ-ray tracking), making AGATA the ideal device for spectroscopic studies of weak channels.

- **Capability to stand high rates (> 50kHz per crystal)**
- **Outstanding quality of Doppler correction**

Charge-particle arrays for detection of big residue **(TRACE, DANTE)**



Campaigns at several labs:

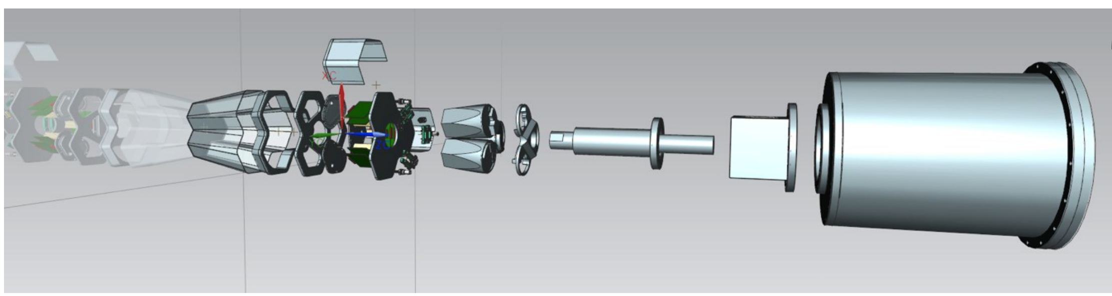
- **LNL (2010-11)**
- GSI (2012-13)
- GANIL (2014-15)

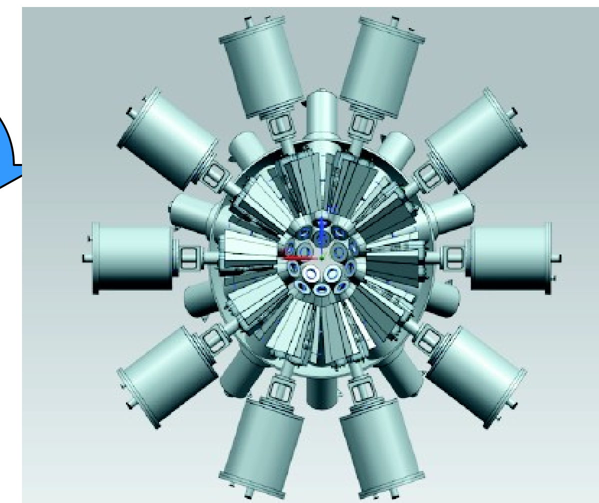
Future campaigns **to be discussed**!

GALILEO: a gamma detector at LNL

Basic idea: perform future gamma spectroscopy studies **at LNL** by re-using existing HPGe crystals (GASP, EUROBALL) equipped with state-of-the-art digital electronics and DAQ systems:

- R&D on electronics (in close synergy with AGATA)
- R&D on cryostats





30 detectors from GASP and 10 triple-Ge from Euroball

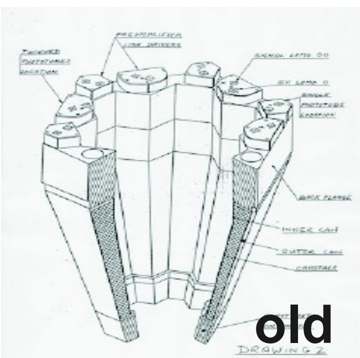
Expected photopeak efficiency ~8%, P/T~50%

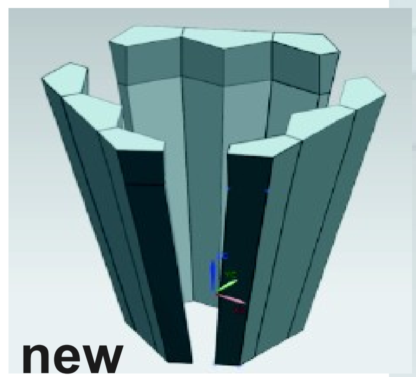
Start of measurements 1st half of 2013

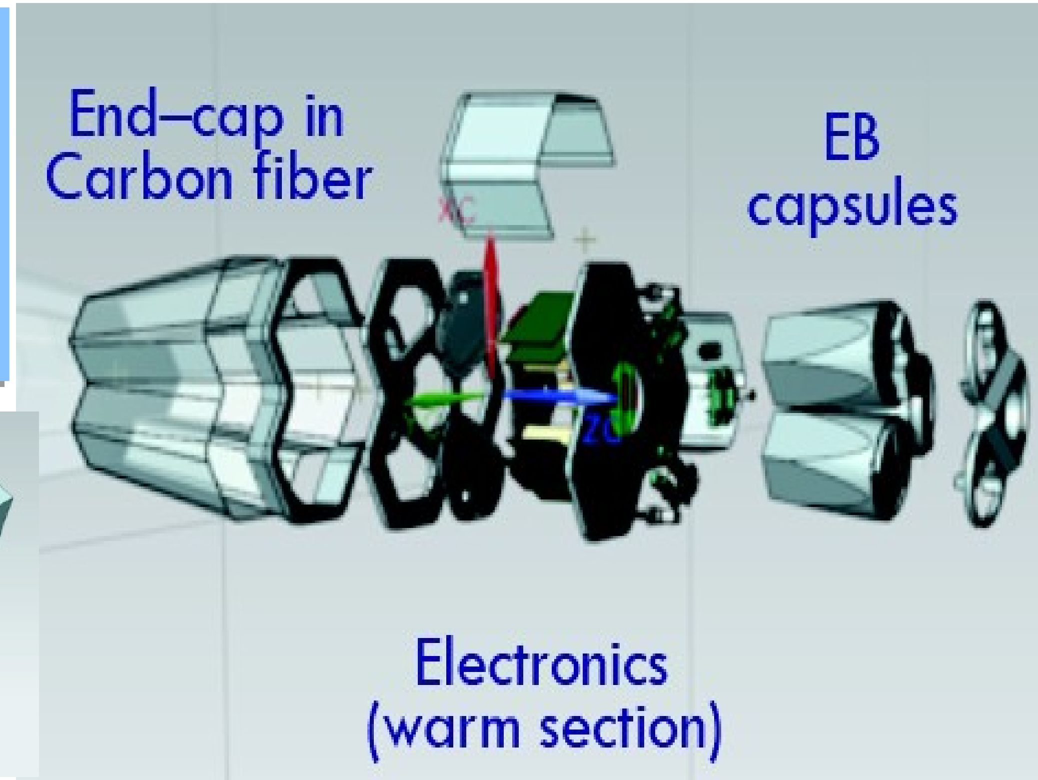
Adapted from D.R.Napoli, 2012

GALILEO: a gamma detector at LNL

Re-using:
- Triple-cluster Ge from Euroball (EB) with new end-cups in carbon fiber
- AntiCompton from EB: dismount and transform them







Integration of ancillary detectors

- **RFD and N–Wall in advanced stage**
- **others – EUCLIDES, TRACE, SPIDER, LUSIA**

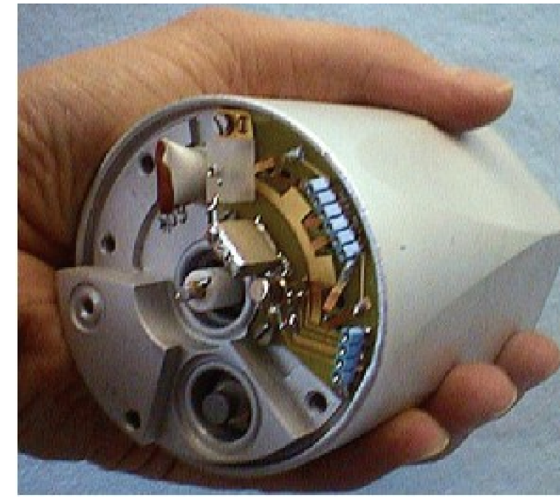
On progress idea: first “training” experiments at Legnaro on CoulEx?

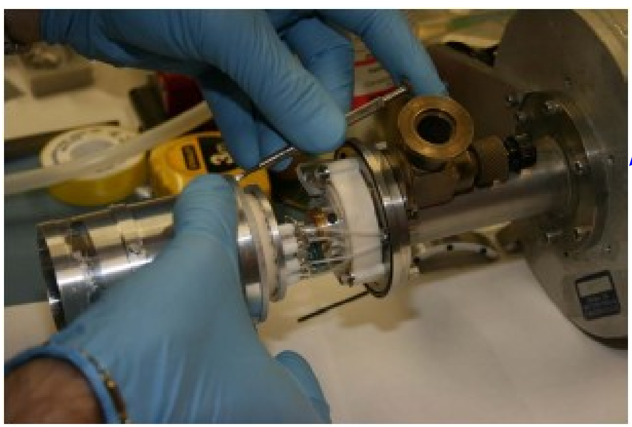
Self-production/repair of HPGe detectors

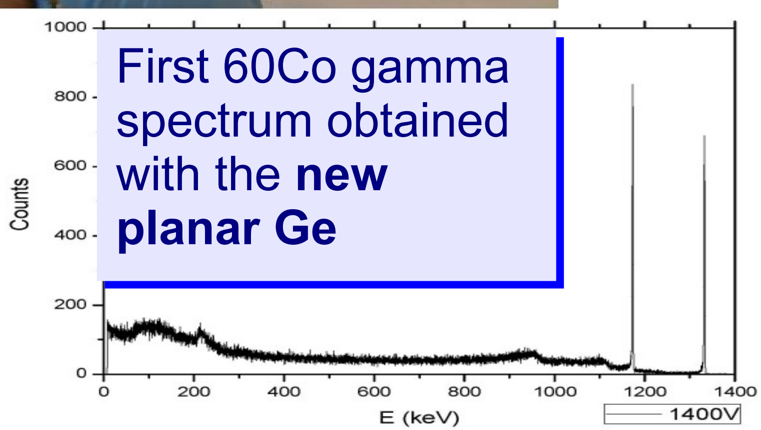
Adapted from D.Napoli, 2012

An R&D activity to develop new technologies for HPGe detectors is in progress at LNL

New surface treatments are under study and one of them is being patented by INFN. The techniques are tested on self-produced planar detectors







First 60Co gamma spectrum obtained with the **new planar Ge**

COATING
Easy Germanium recovery with the new coating.

Ge-PRODUCTION
Since 2011 R&D on planar-Ge.
Coax-Ge (segmented?) will start in 2013

know-how essential to repair existing complex HPGe detectors. Also, one hopes on a self-production of such detectors, provided that the **whole international community** supports the effort (with funds and manpower).

Spectrometers with RIB

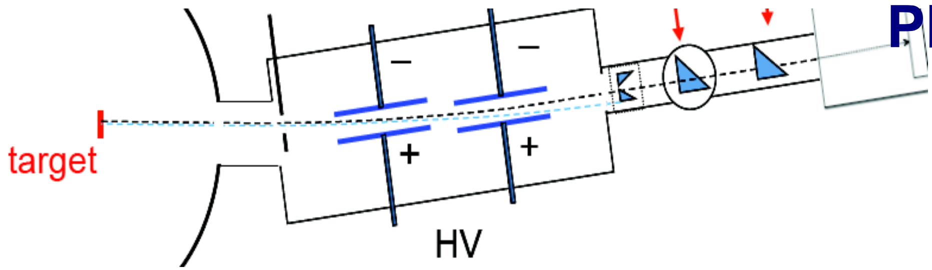
Worldwide Rib facilities have SPECTROMETERS as fundamental instrumentation

- **Coupling with powerful detectors for Gamma, Neutrons or Charged particles**
- **Identification of heavy ions (even slow) at forward angles**
- **Possibility to reject the beam (zero degree experiments)**
- **Energy resolution to achieve precise energy spectra**

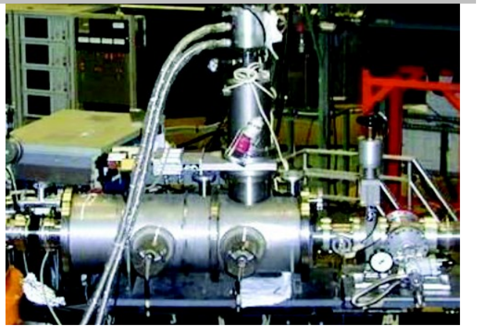
INFN LNL Pd

Spectrometers at Legnaro

PISOLO



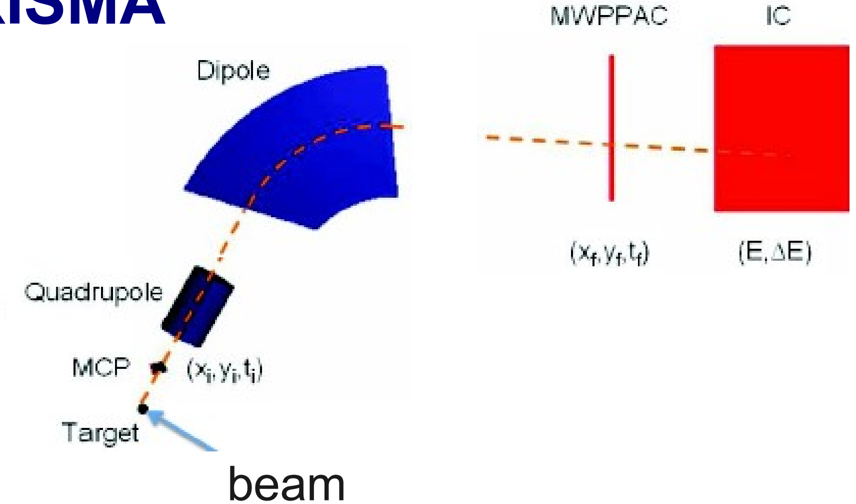
Electrostatic beam separator



Fusion at and below the Coulomb Barrier

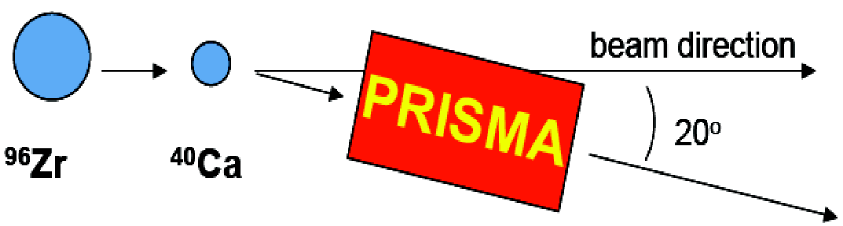
PRISMA

magnetic SPECTROMETER



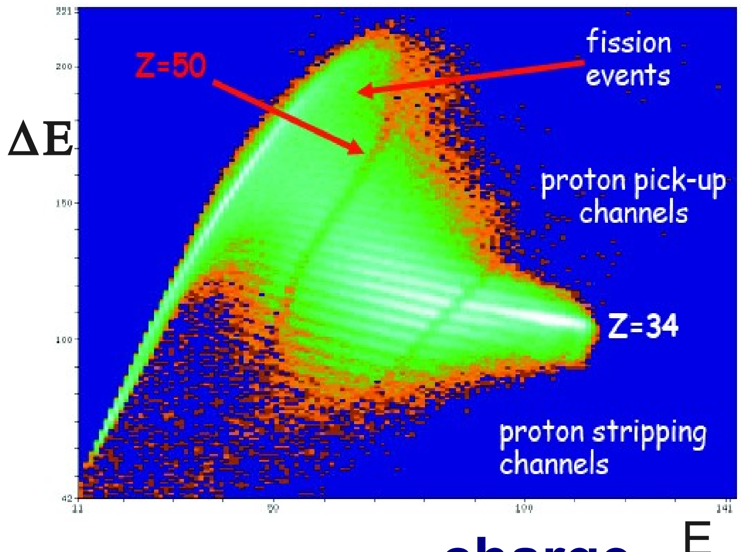
Binary reactions with formation of nuclei far from beta-stability via Multi NucleonTransfer, MNT
Scientific impact enhanced when coupled with big Gamma Arrays

Recently Prisma also used for target-like at forward angles in reverse kinematics (sub barrier neutron transfer)



Spectrometers at Legnaro: PRISMA

Adapted from G.Montagnoli, 2012



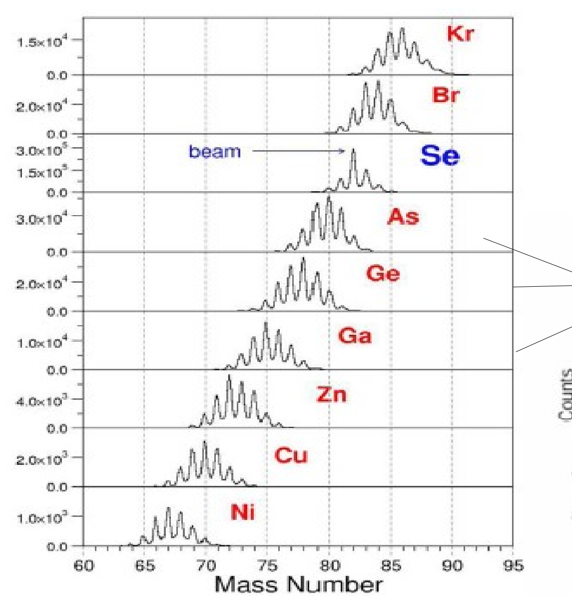
charge

Z,A identification

Mass resolution $\frac{\Delta m}{m} \simeq \frac{1}{270}$

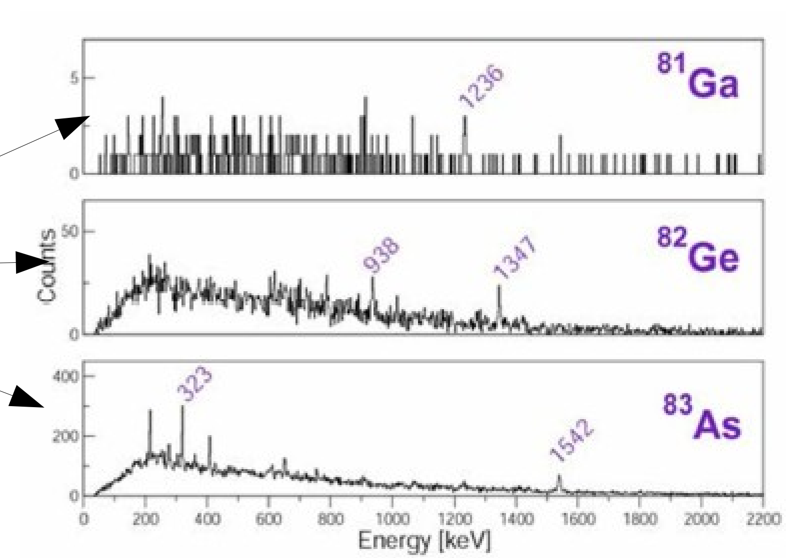
Charge and mass identification in PRISMA allows for precise tagging of species in a wide domain. Coupling with Gamma arrays permits accurate structure studies

505 MeV $^{82}Se+^{238}U$



Mass (heavy nuclei)

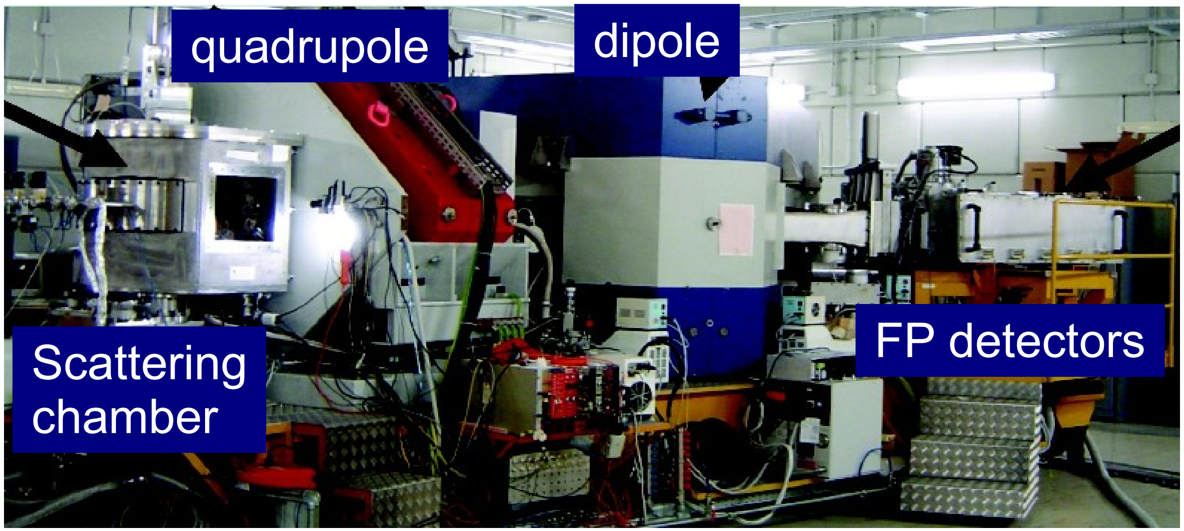
PRISMA
CLARA



Spectrometres at LNS, Catania

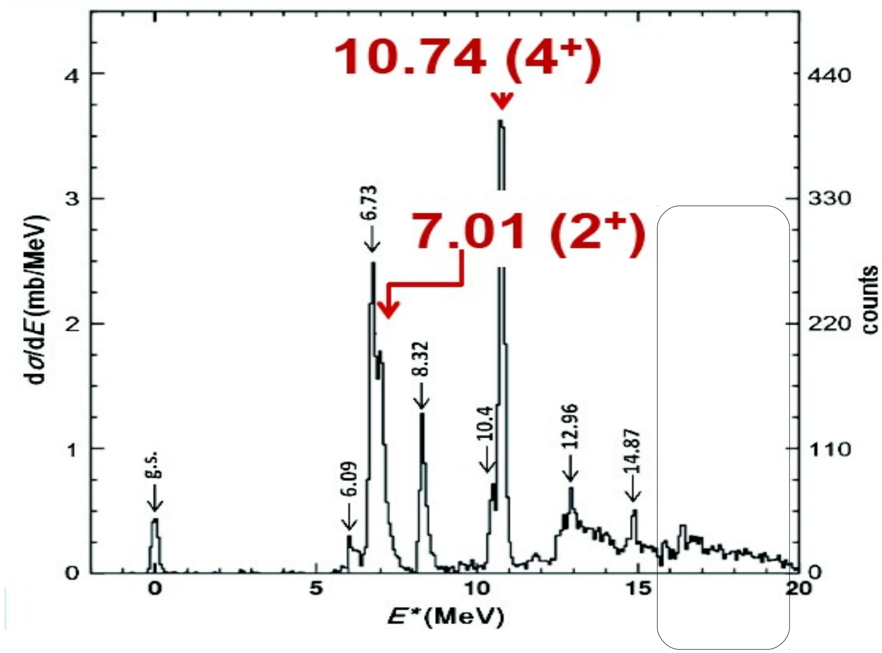
Magnex is a big rotating spectrometre with large acceptance (**+-6deg, 50msr**) capable of very high energy resolution (precise track reconstruction)

Magnex used for stable species beams such as oxygen isotopes from Tandem and CS. In the future also fragmentation beams (Fribs) and Excyt beams (if enough currents)



Achieved resolution

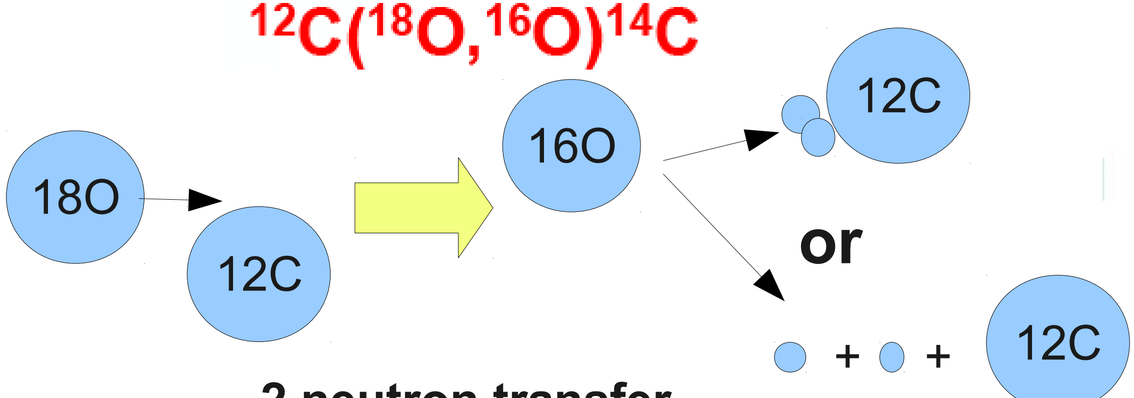
Energy $\Delta E/E \sim 1/1000$
Angle $\Delta\theta \sim 0.3°$
Mass $\Delta m/m \sim 1/160$



GPV predictions

Transfer of correlated pairs

$^{12}C(^{18}O,^{16}O)^{14}C$



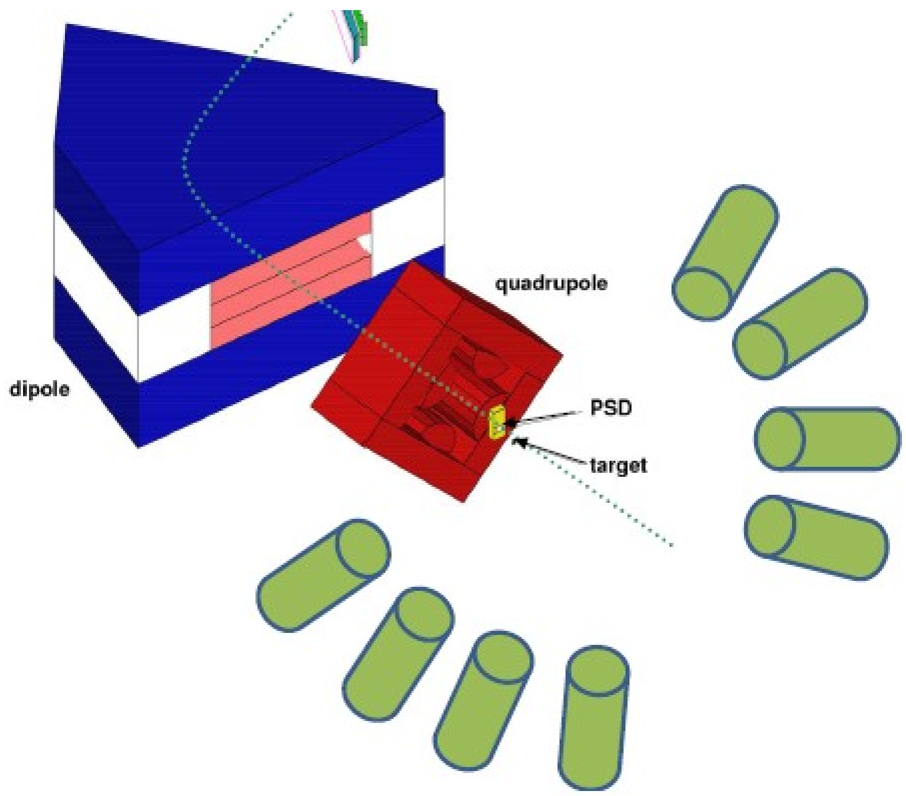
2 neutron transfer

Spectrometres at LNS, Catania

Magnex is now coupled with the EDEN neutron array

- 40 liquid scintillator detectors (NE213)

A step towars RIB experiments



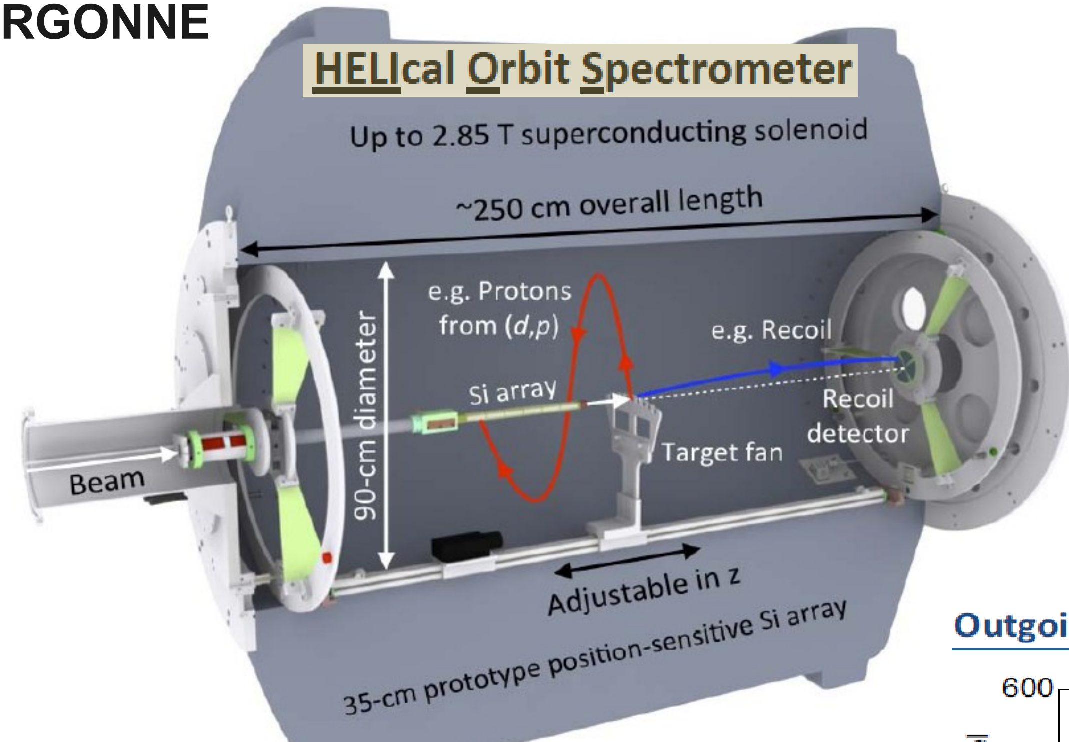
Resonants states of n-rich nuclei
(With low binding energy)

Excitation of well identified reaction products with MAGNEX.
Detect with EDEN the coincident neutrons with enough efficiency and E-resolution

a Spectrometer for direct reactions

A superconducting solenoid for Reverse kinematics reactions

ARGONNE

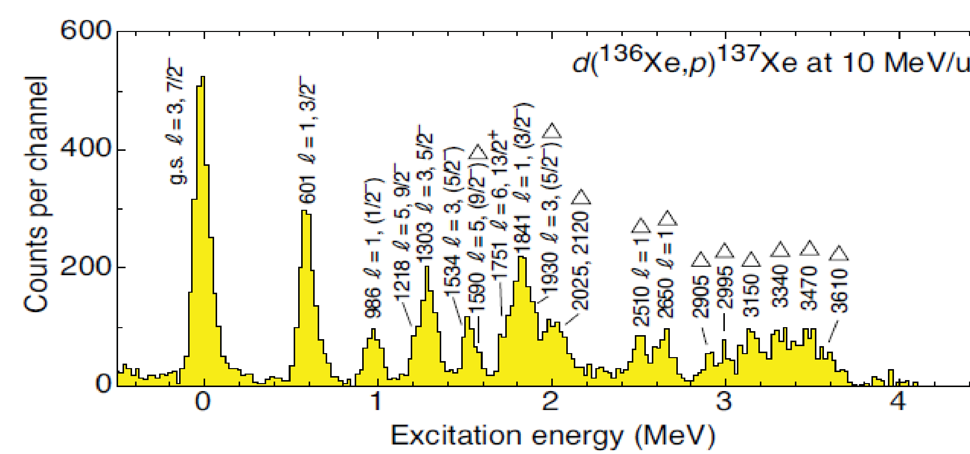


Measured quantities	
Flight time:	$T_{flight}=T_{cyc}$
Position:	z
Energy:	E_{lab}

Derived quantities	
Part. ID:	m/q
Energy:	E_{cm}
Angle:	θ_{cm}

The target and detector are both on the solenoid axis. The reaction products are bent back to the axis.

Outgoing proton spectrum: ^{137}Xe



Something similar also in ITALY?

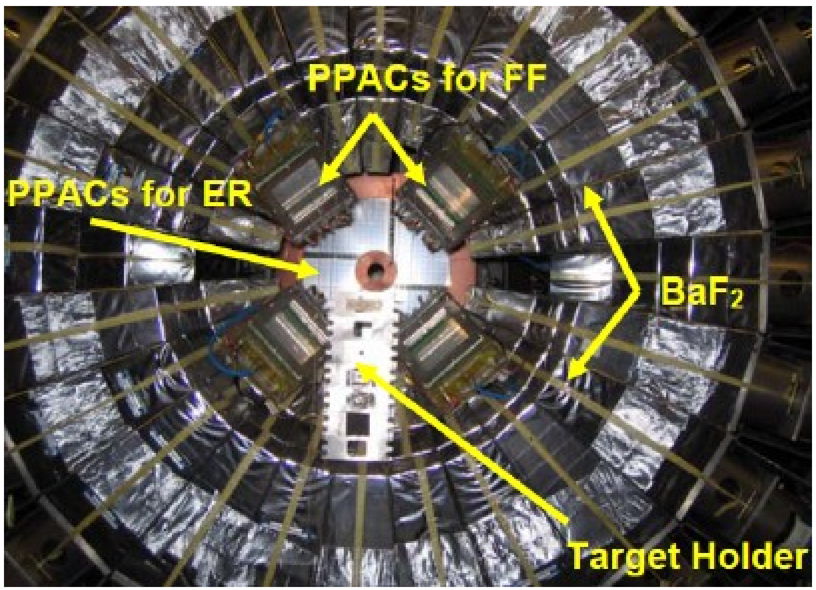
Attempts are on progress to consider SOLE at LNS for this purpose

$^{136}Xe(d,p)^{137}Xe$ 10MeV/u

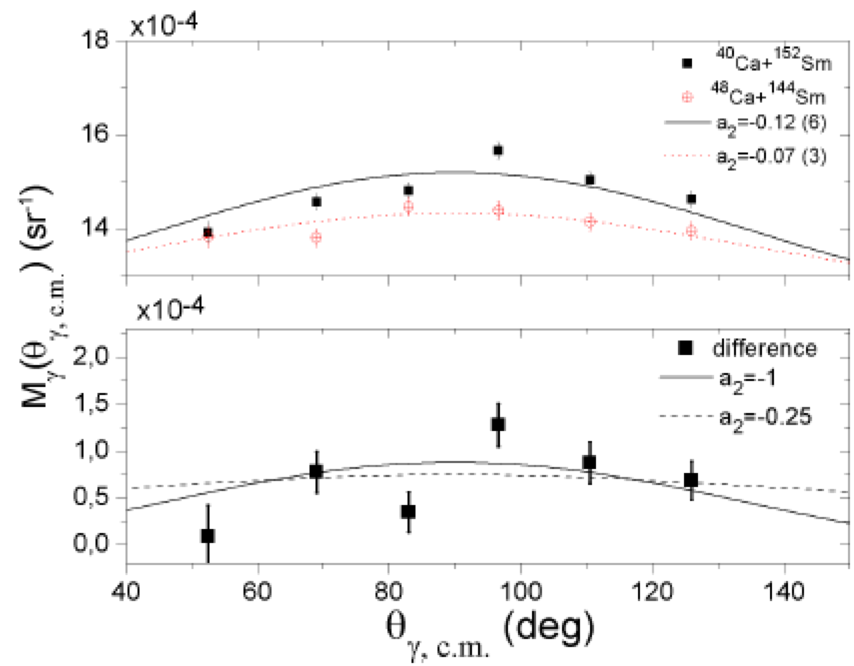
A detector for collective emission

The puzzle of Dynamical Dipole Emission

Dipolar nature revealed by specific angular emission: weak signal!



$$M(\vartheta_\gamma) = M_0[1 + a_2 P_2(\cos\vartheta_\gamma)]$$

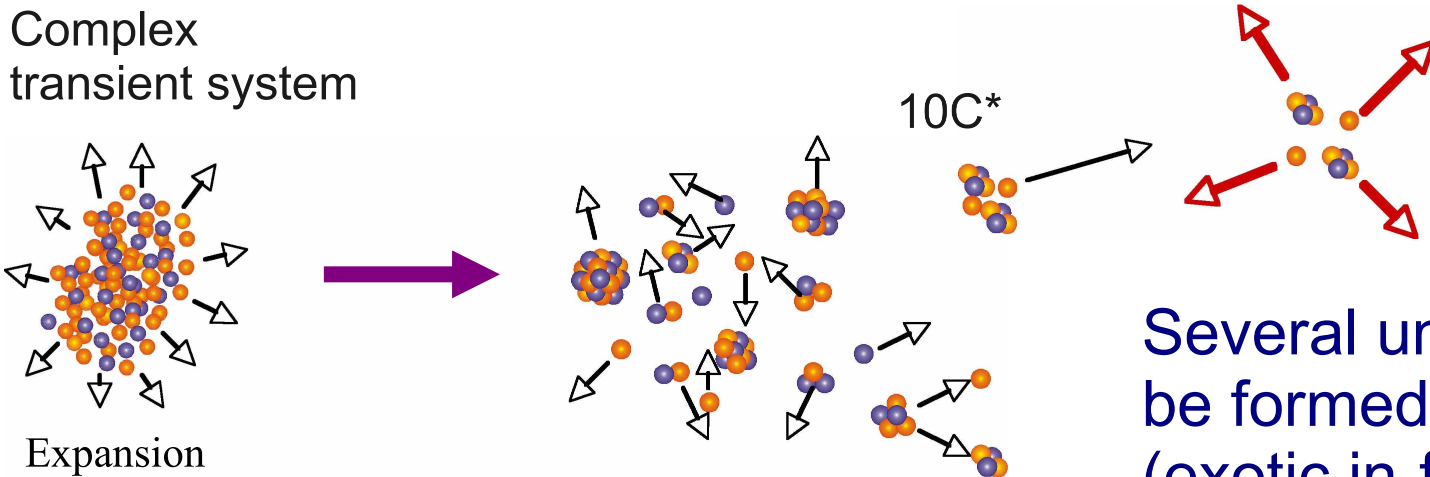


MEDEA at LNS
BaF2 array HECTOR Milan Group
PARIS European collaboration

But other specific developments are needed in our community

Multi-Particle Correlation Spectroscopy

collaboration with G.Verde, 2012



Several unbound species can be formed which then decay (exotic in-flight studies)

Correlations as a spectroscopic tool

- Cluster states in stable and exotic nuclei
- Bose Einstein Condensate and Hoyle states
- Backtrace the decay chain to recover 'hot sources'

Experimental needs

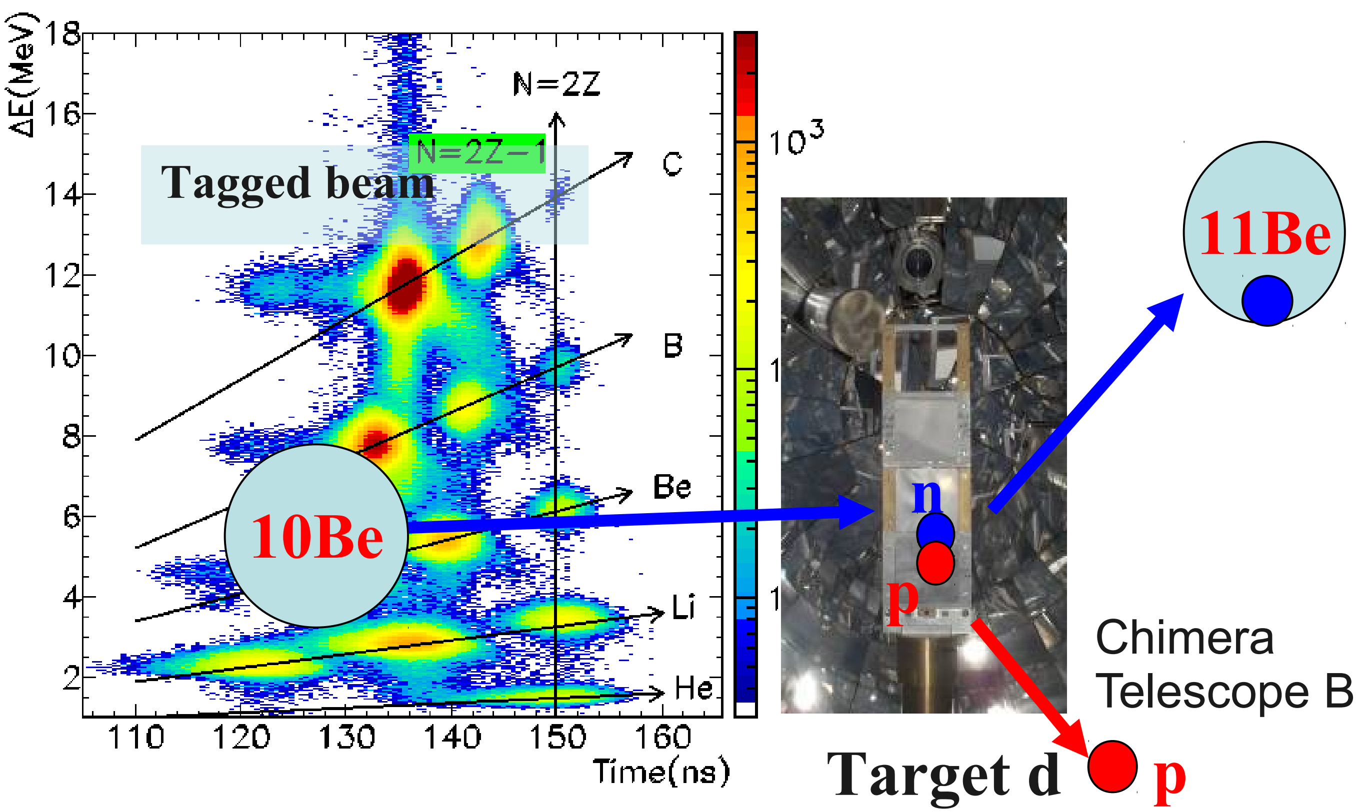
- Large acceptance
- High position and energy resolution

Multidetectors at the interface between structure and reactions

Adapted from G.Cardella, 2012

neutron transfer reactions and halo nuclei

Elastic scattering and transfer reactions of light nuclei on p, d targets --> halo or other nuclear structure effects



CHIMERA MULTIDETECTOR

kinematic coincidences –> binary reactions where both reaction partners are detected

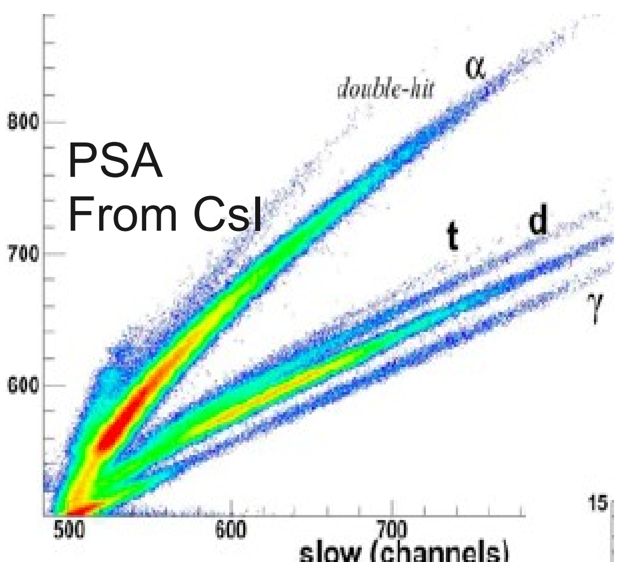
Multidetectors at the interface between structure and reactions

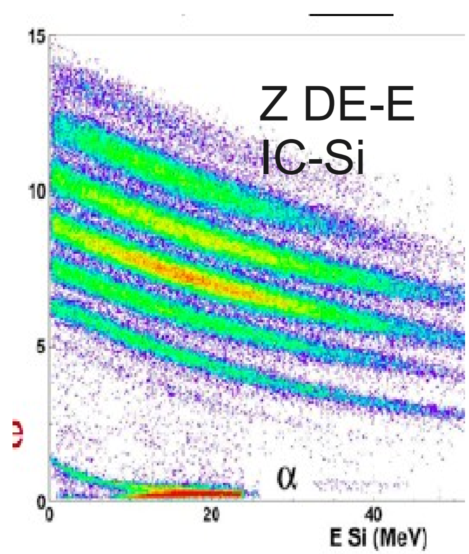
Digital and digital signal processing techniques

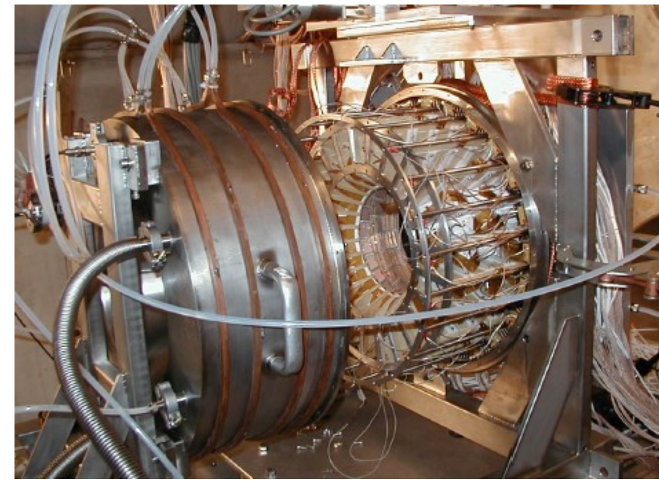
GARFIELD + RingCounter
LNL,Bo, Fi

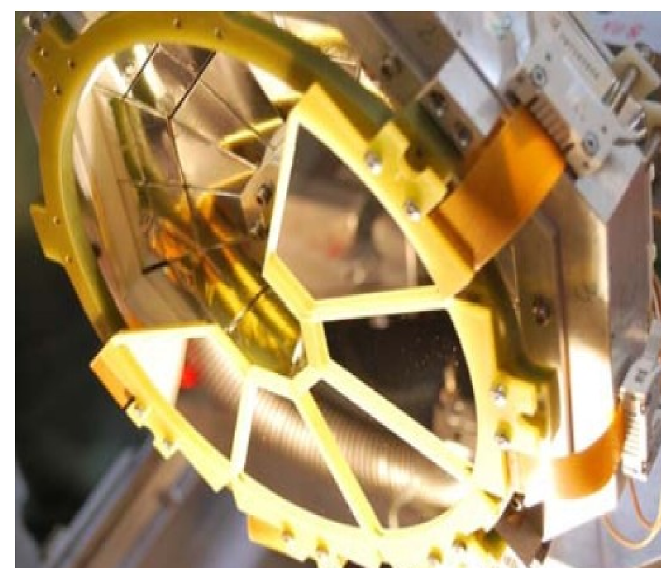
First fully digitized equipment
125MS/s 12bit + DSP
Specific algorithms for parameter evaluation

- 64 nTD Silicon pads reverse mounted
- 8 gas ionization chamber
- 228 CsI(Tl) detector









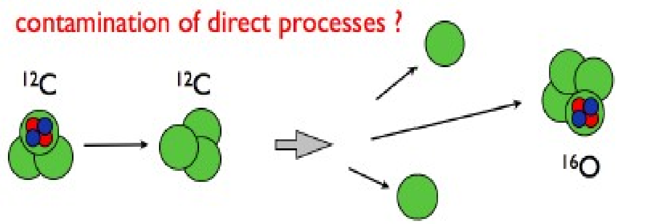
Multidetectors at the interface between structure and reactions

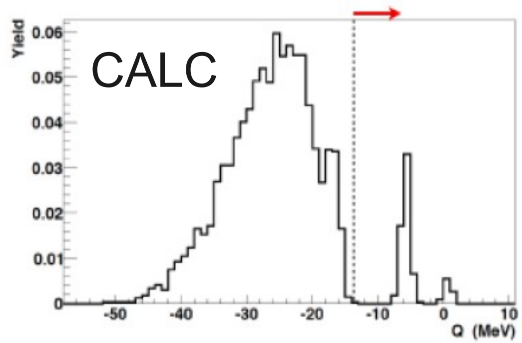
1 Complete reconstruction of decay channels in ligth systems

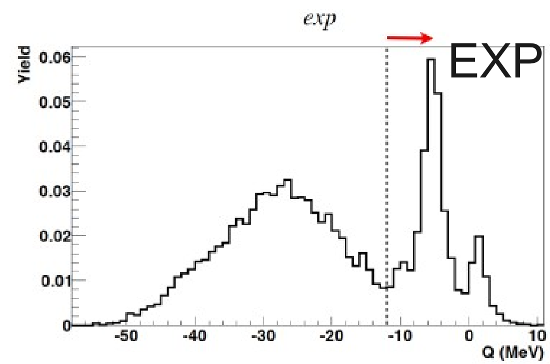
Complete charge balance

C+C reactions

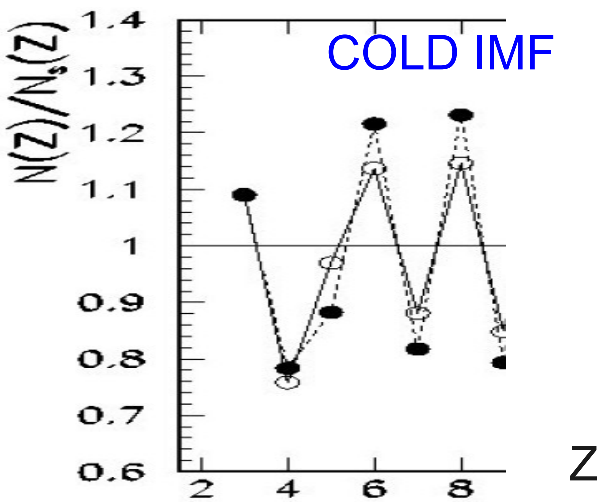
Dynamical processes observed beyond fusion-evaporation

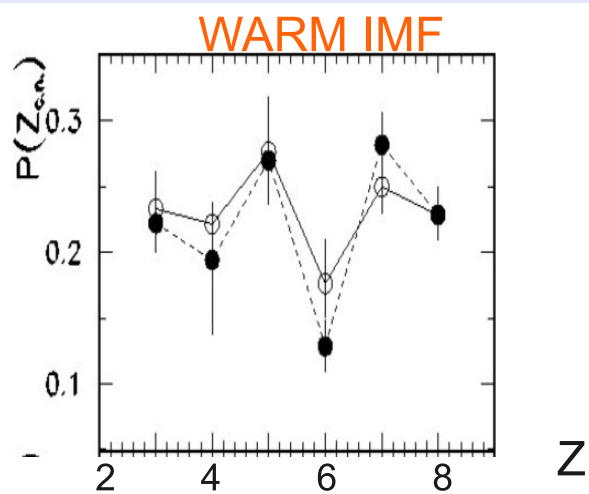






2 Backtracing fragment composition to approach source formation

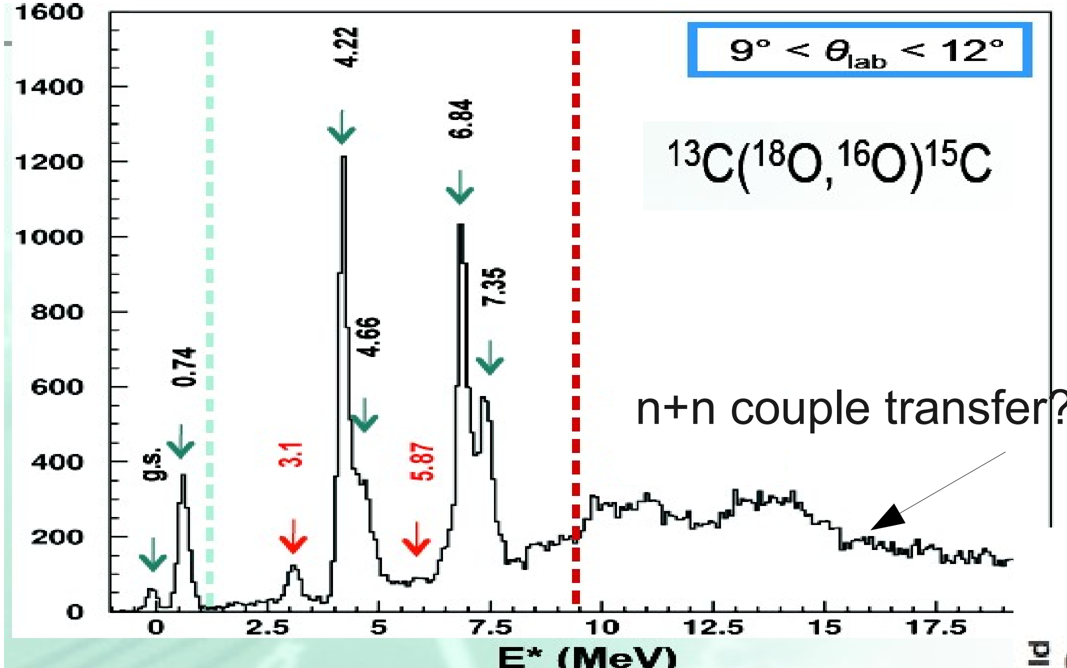




QuasiProjectile DECAY

S+58,64Ni

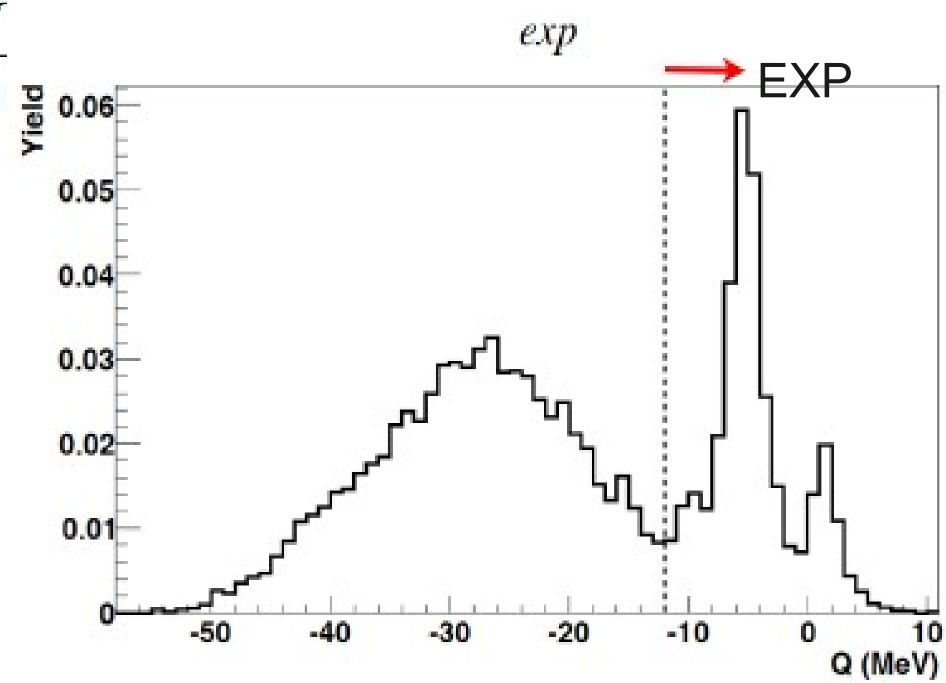
Excitation energy spectra without gammas



n+n couple transfer?

Continuum Structures populated by neutron transfers

MAGNEX DATA



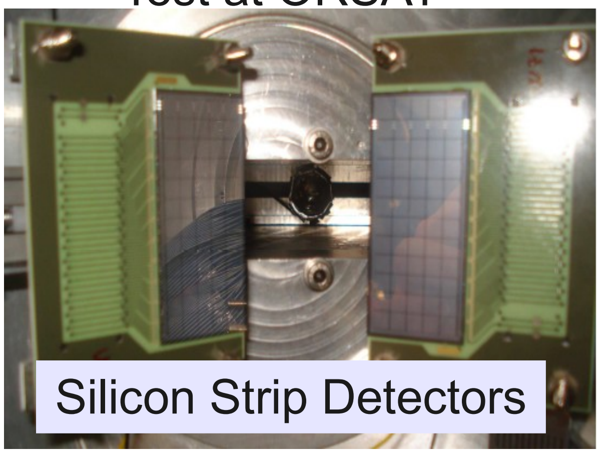
Relative abundance of states reveals entrance-channel effect

GARFIELD DATA

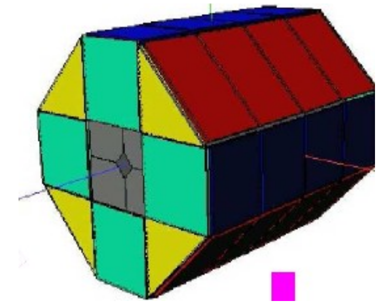
Detectors for light systems as ancillary for gamma arrays

@LNL

Test at ORSAY



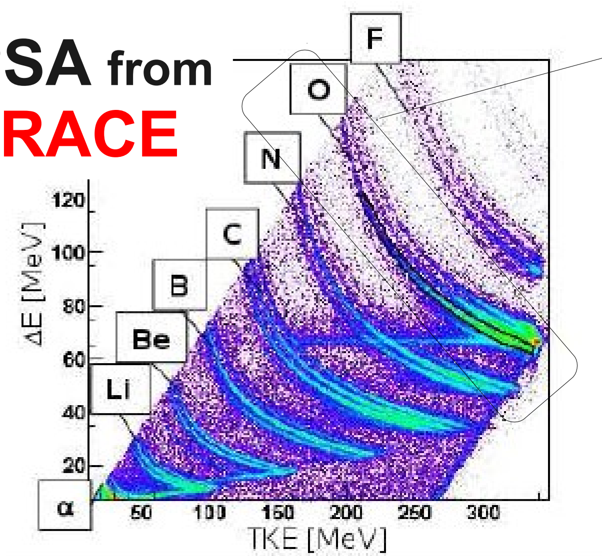
The **TRACE** strip-array
32 telescopes of DSSD for light particles and fragments.
Trigger-Selector for AGATA/GALILEO arrays

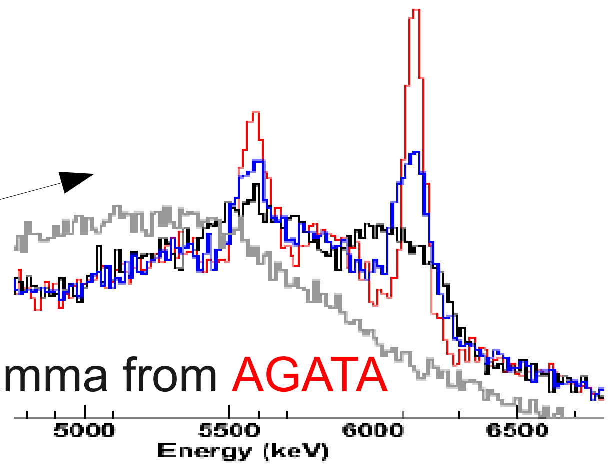


TRACE
Concept drawing

Three experiments done at LNL with TRACE strip-prototypes and AGATA crystals

PSA from TRACE

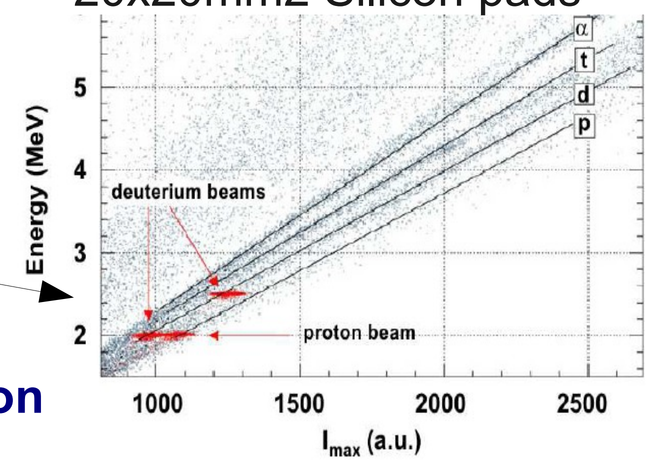




Gamma from AGATA

Use of nTD special **FAZIA** 20x20mm2 Silicon pads

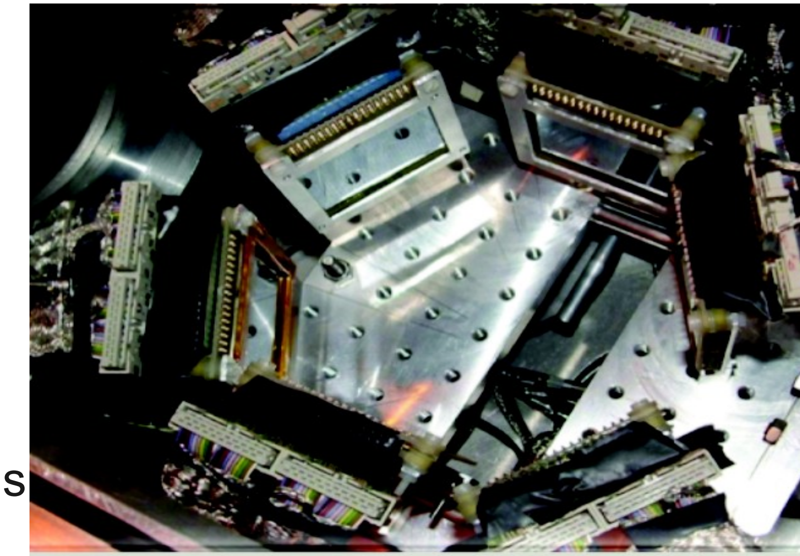
R&D for Light particle identification at low energies via DPSA



Separation p,d,t down to 2-3 MeV in Silicon

Strip Detectors for Light systems @LNS

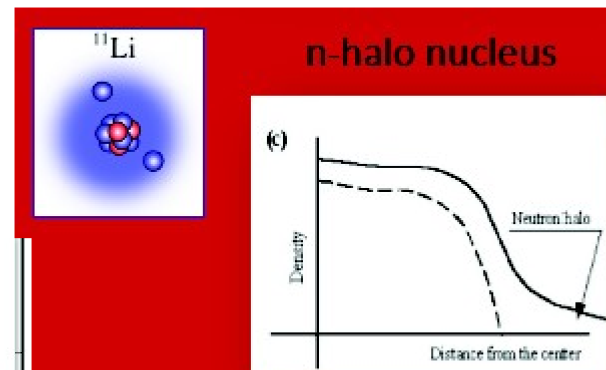
LNS-Structure and Reaction Mechanisms



Light Nuclei: a "quantum laboratory" where structure (clusters in n-rich and neutron or proton halos) play an essential role in reactions

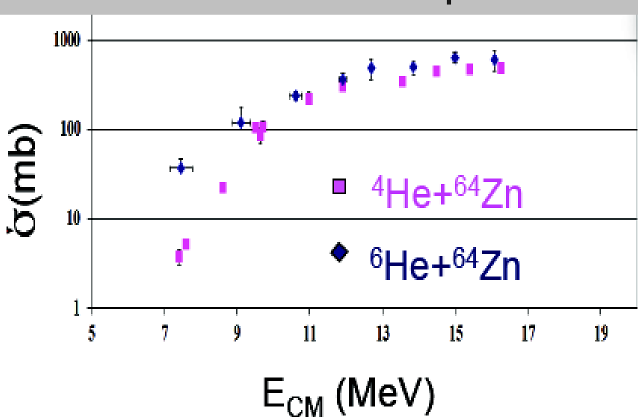
CLAD (cluster approaching dripline) **set-up**
High acceptance and fine energy and position resolutions
High granularity for particle coincidences

ΔE 50μm E 500 (or 1000)μm, 16+16 orthogonal strips
For light particles and light fragments

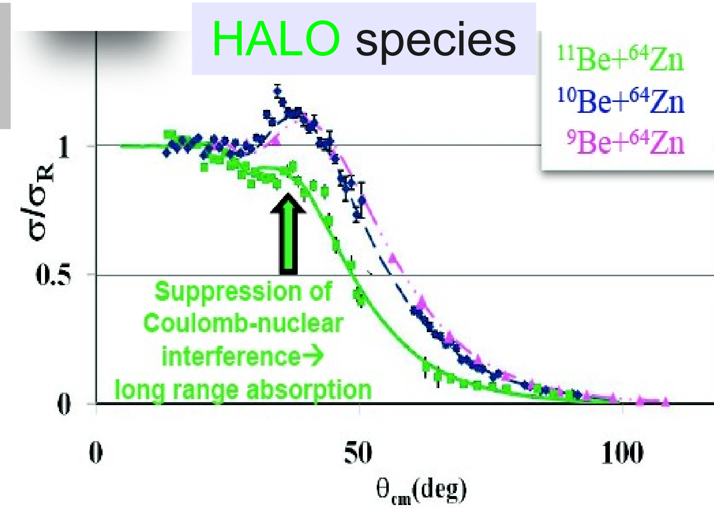


Weak binding → long tails

Larger fusion cross section due to n-halo with He isotopes

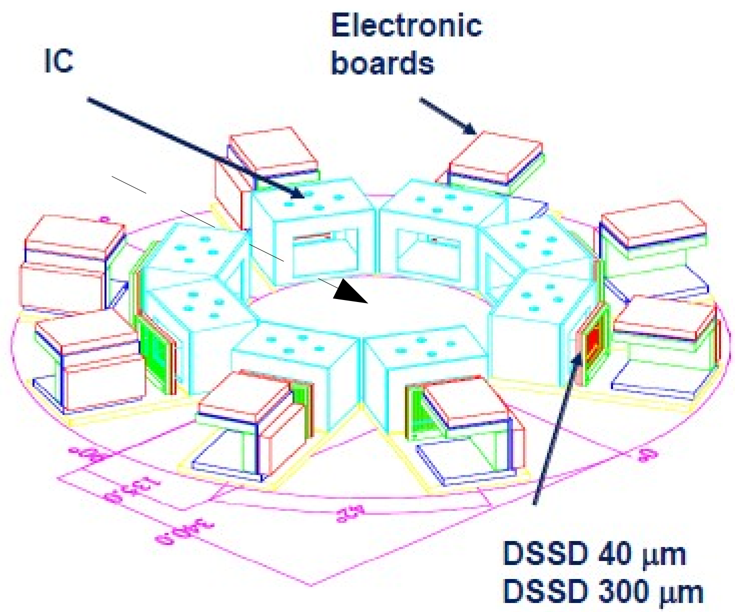


HALO species

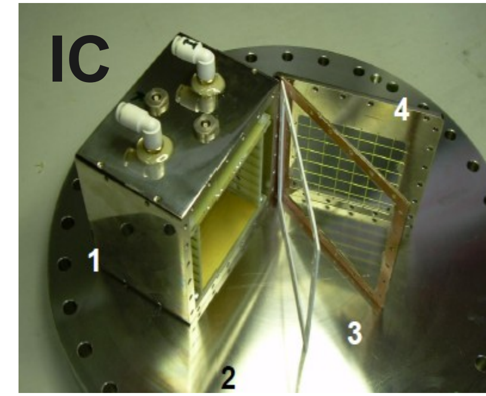


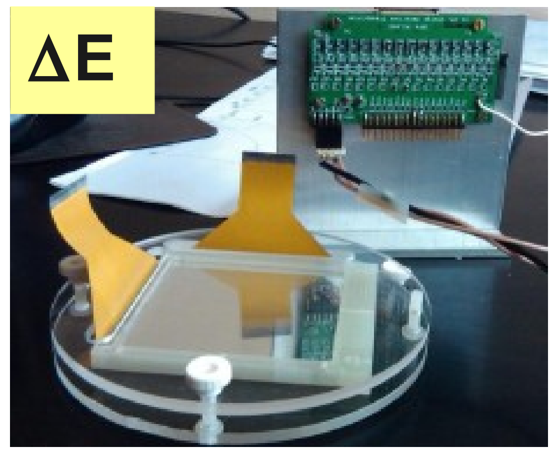
Strip Detectors for Light systems

INFN- Na,Pd @LNL



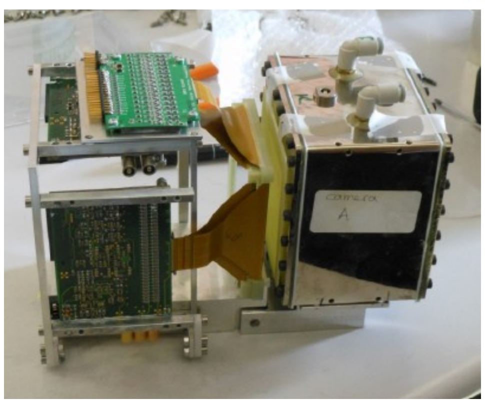
EXPADES: 8 telescopes
ΔE gas ioniz. chamber
ΔE 40μm E 300μm DSSD
32+32 orthogonal strips
62.5x62.5 mm2 active area





readout traditional electronics
ΔE (FWHM): **45 keV**
Δt (FWHM): **0.9 ns**

In the case of the 300μm
Innovative readout electronics by means of an **ASIC** chip.
Resolution achieved: **80 keV**.



Readout electronics of the E stage based on ASIC chips manufactured by IDEAS-GM (Norway):

Timing and Energy outputs from an ASIC

PHYSICS
Inelastic scattering 17F+p
7Be + Ni,Si inclusive and exclusive BreakUp
7Be on Bi, Pb

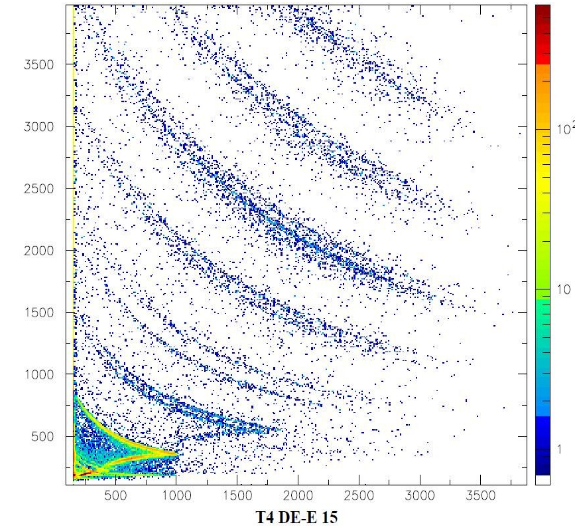
Cooling system with Peltier cells and water

Nuclear Spectroscopy with particles

Cocktail neutron-rich beams from FRIB at LNS
Extract angular distributions for various reaction channels searching for halo or other structure effects

Large acceptance for extensive use of the kinematical coincidence technique (so far with CHIMERA)

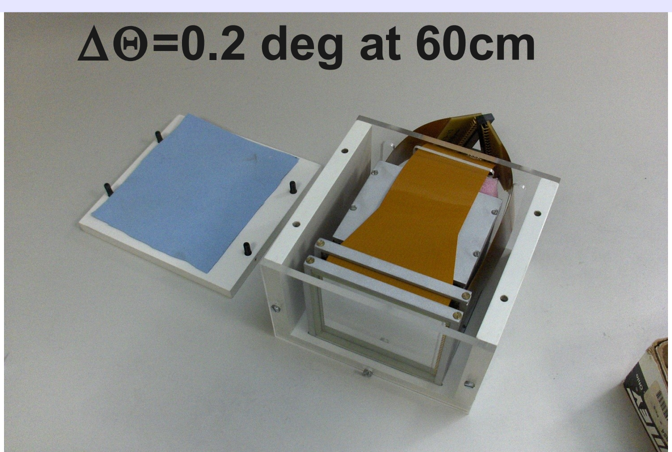
In future: improving detection capabilities with special strip-correlator (FARCOS) and/or with some neutron detectors



First tests with FARCOS modules

ΔEstrip-ΔEstrip-E CsI
Strip 32x32 double side
300 μm + 1500 μm + 6cm

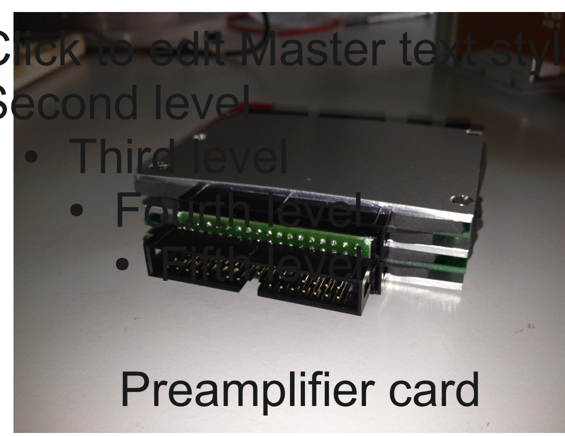
ΔΘ=0.2 deg at 60cm



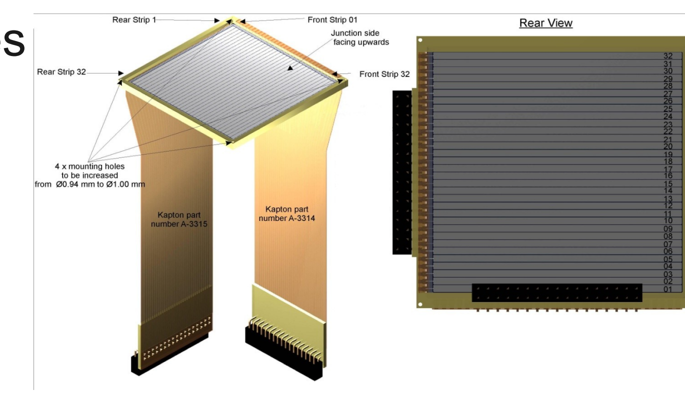
FARCOS

High resolution light particle and fragment-fragment correlations, on light systems and heavy nuclei

Click to edit Master text styles
Second level
- Third level
  - Fourth level
    - Fifth level



Preamplifier card



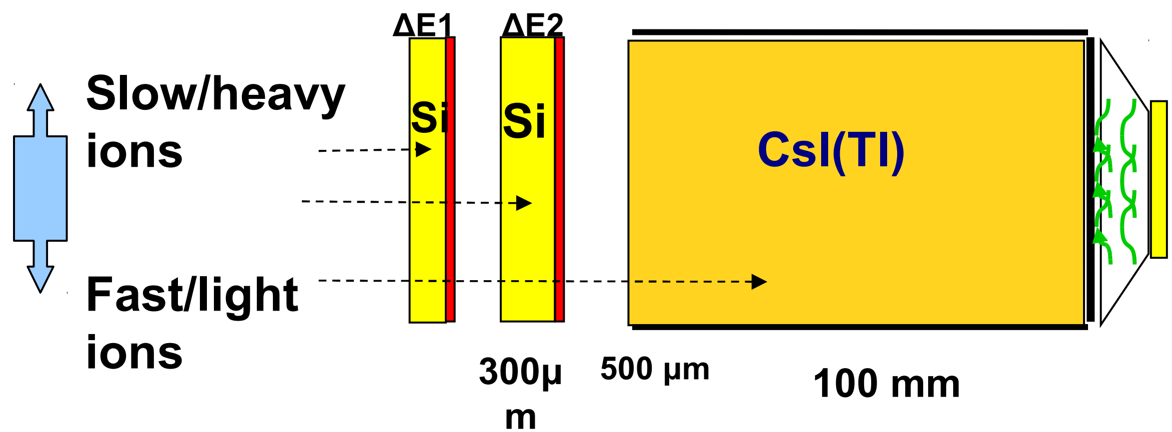
Efforts towards densely spaced electronic channels

Advances in detectors performances

A,Z ion identification, down to low-energy is a challenge in HI physics with RIB.
Different groups are playing with detectors to push at maximum the performances

European collaboration

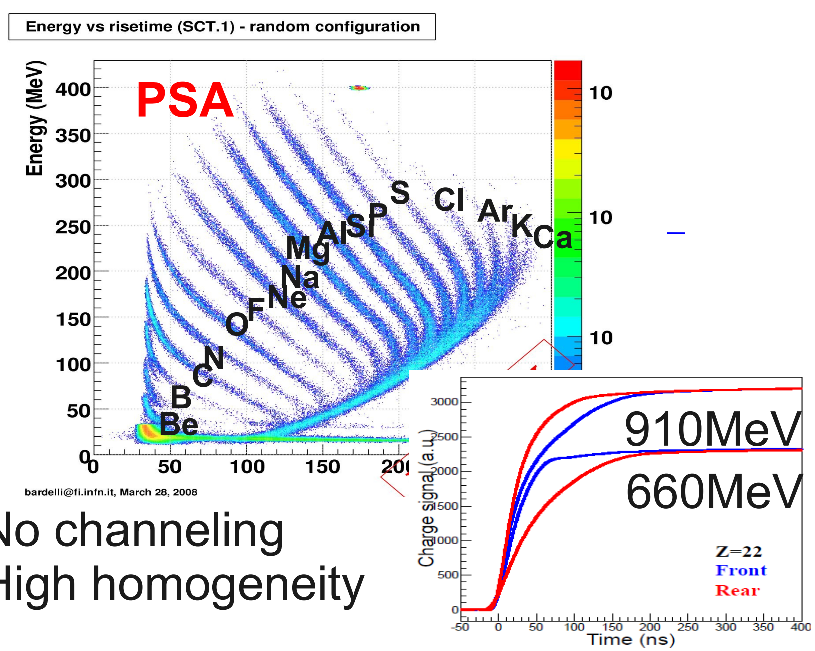
FAZIA



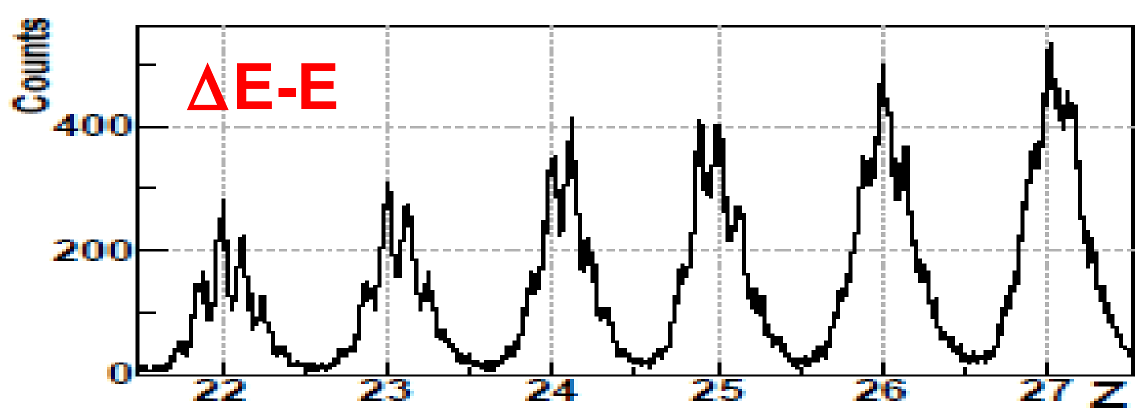
Telescopes ΔE-ΔE-E CsI
20x20mm2 reverse mounting
300 μm + 500 μm + 10cm

Efforts in Digital techniques for pulse shape analysis PSA , from detectors to software

- Avoiding channeling (crystalline symmetric)
- highly homogenous Si-detectors (nTD)
- Evaluating the optimum electronics
- Software algorithms



No channeling
High homogeneity

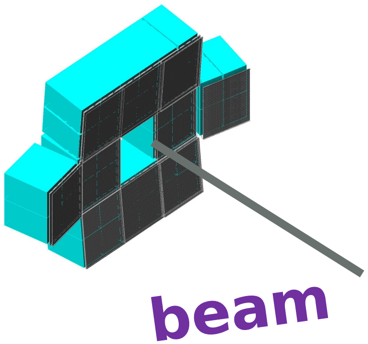


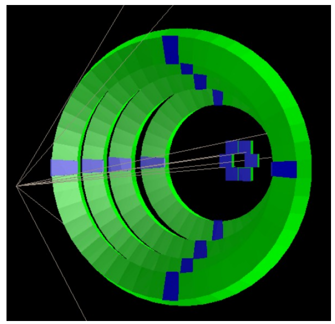
Mounting flexibility: a premium

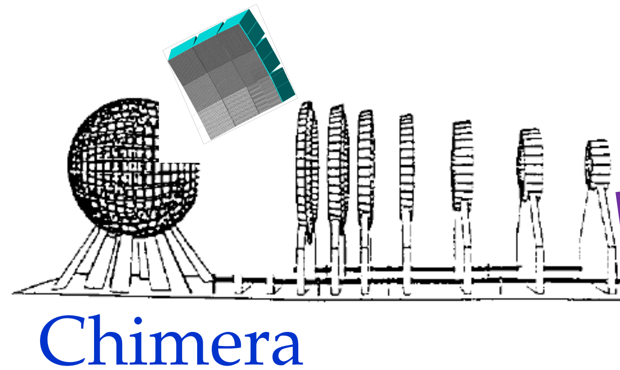
Cross geometry centered on the beam axis (10 clusters)

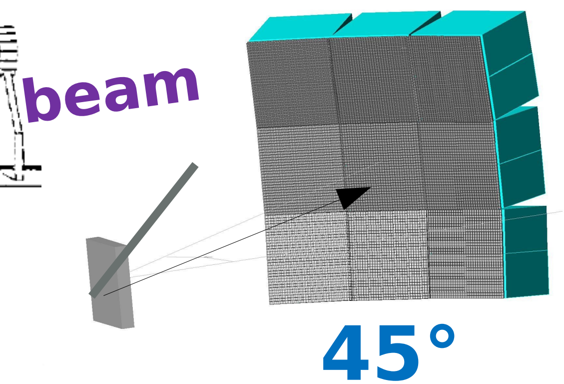
FARCOS

Wall geometry placed at 45° from beam axis (9 clusters)



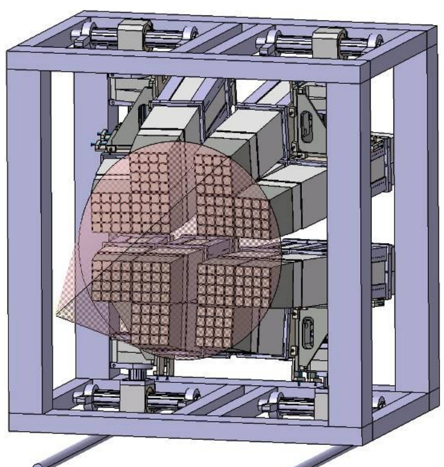




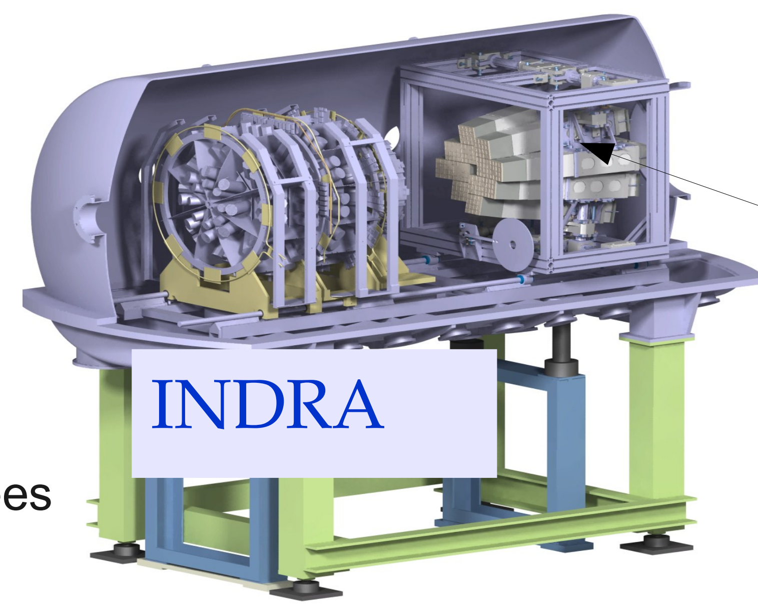


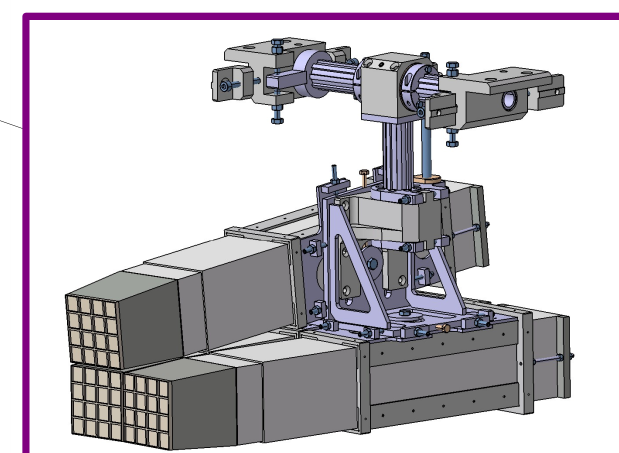
FAZIA

192 telescopes



100cm distance, 3 to 14 degrees



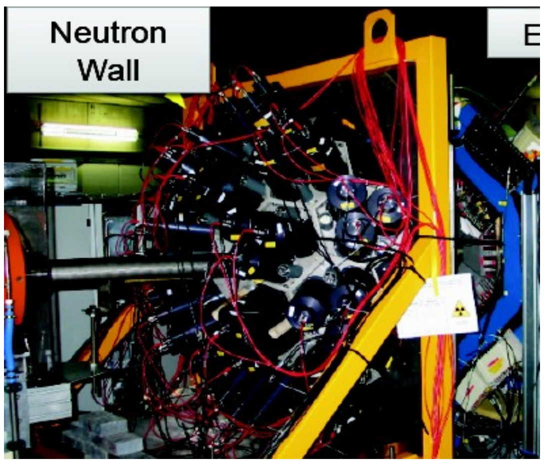


R&D on neutron detectors

n-counters

Detecting neutrons to proceed towards the p-drip line

Coupling with GAMMA ARRAYS



N=Z-2

N=Z

$^{24}Mg(^{32}S,2n)^{54}Ni$

Fusion reactions

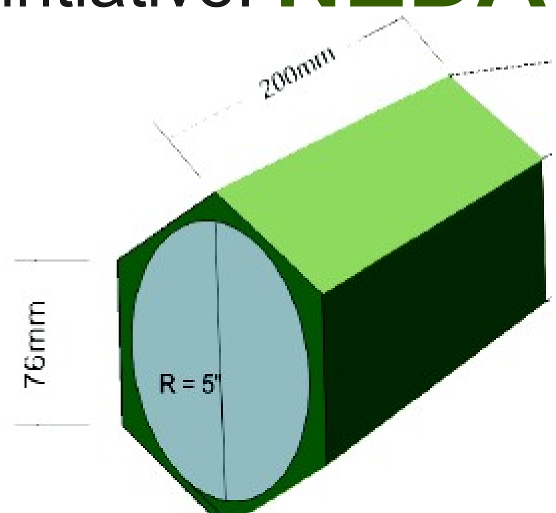
$^{28}Si(^{28}Si,2n\alpha)^{50}Fe$

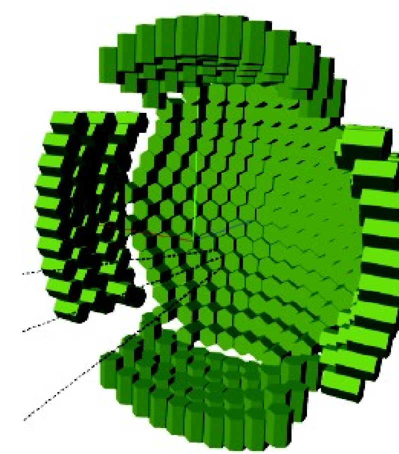
PROBLEM
Cross-talk between adjacent modules → use of subset of them → reduced efficiency to 1-2%

On progress Eu-intiative: **NEDA**

355 BC-501 cells

- **Excellent neutron—gamma separation**
- **Efficiency up to 6%, special geometry**
- **High count rate operation**
- **Coupling with GALILEO, TRACE, AGATA**
- **Fast digitizing electronics (algorithms)**
- **R&D beyond liquid scintillators**





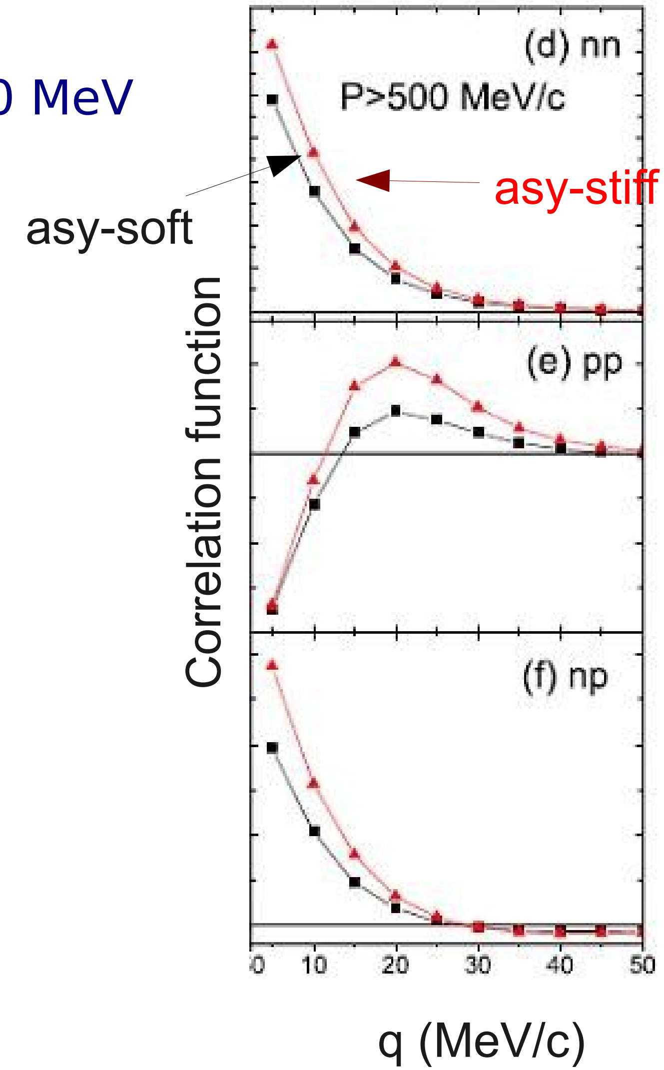
R&D on neutron detectors

n-spectrometers

In some cases it is important to detect neutron energy and position

particle-particle correlations for symmetry energy

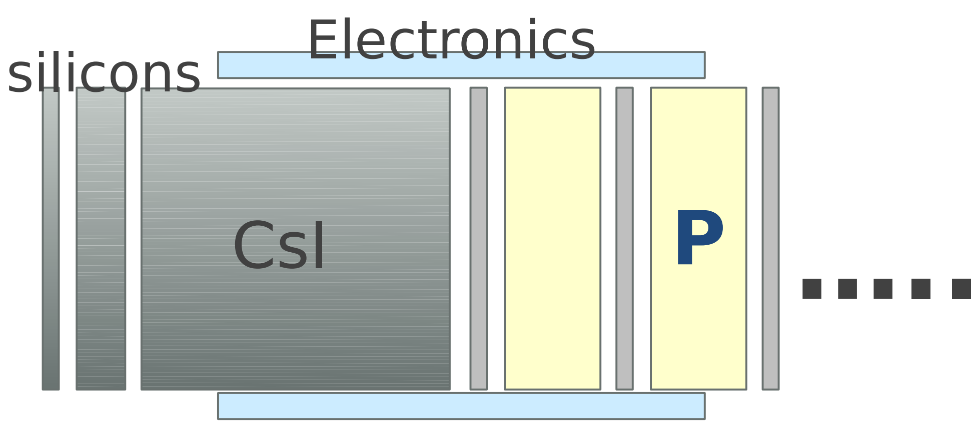
IBUU simulations
$^{52}Ca+^{48}Ca$ E/A=80 MeV
Central collisions



Other possibility: neutron detectors under vacuum

"Transparency" of materials and electronics boards to neutrons

final stages for neutron detection (new Silicon scintillators (LNL,LNS), proton converter (LNS)



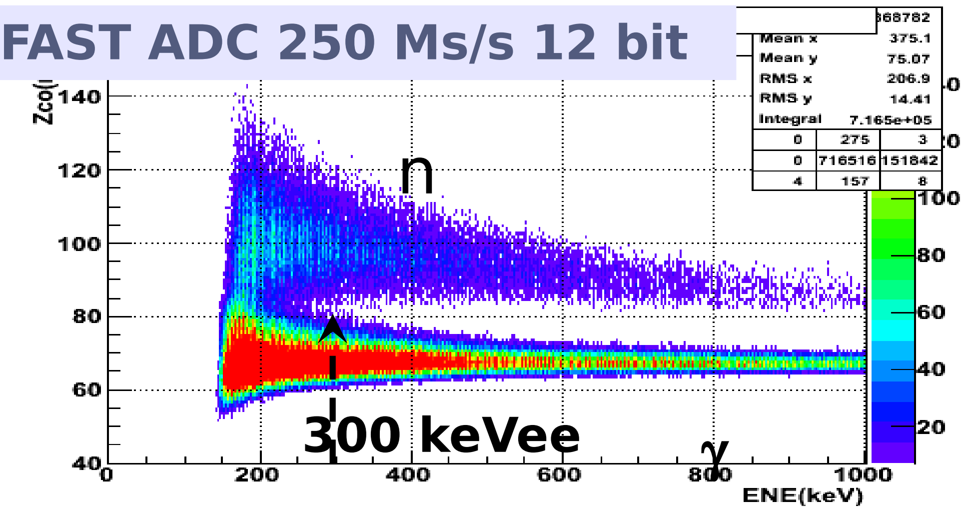
R&D on neutron detectors

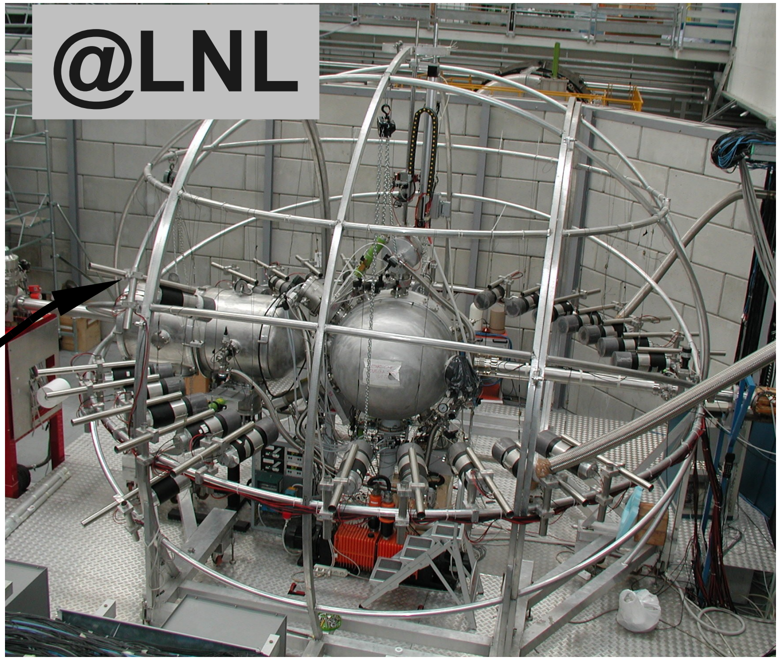
n-spectrometers

- **24 BC501 cylindrical Liquid Scintillators**
- **Fully digital electronics (hardware and software)**

Modular thin structure for detector mounting

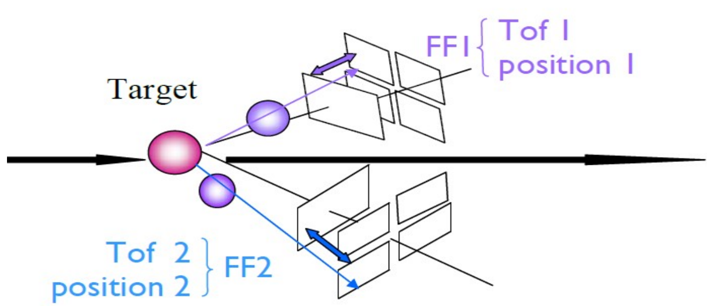
FAST ADC 250 Ms/s 12 bit



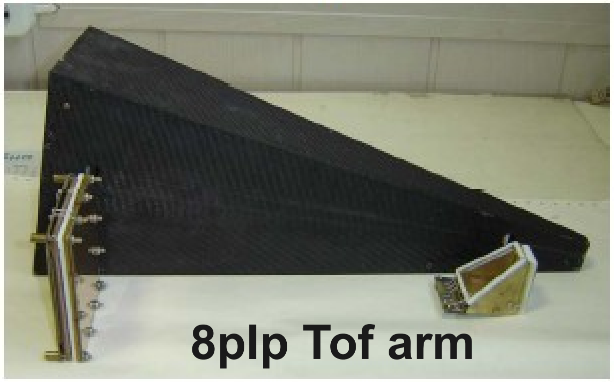


THE **RIPEN** ARRAY

Experiments fusion-fission with neutrons



CORSET MCP system for 8πLP



Electronics challenges towards RIBs

Fast low-noise 'dense' pre-amplifiers (small dimensions)

multiple gains and large dynamic range (MeV to GeV, protons to Z>50)

Configurability, low power dissipation

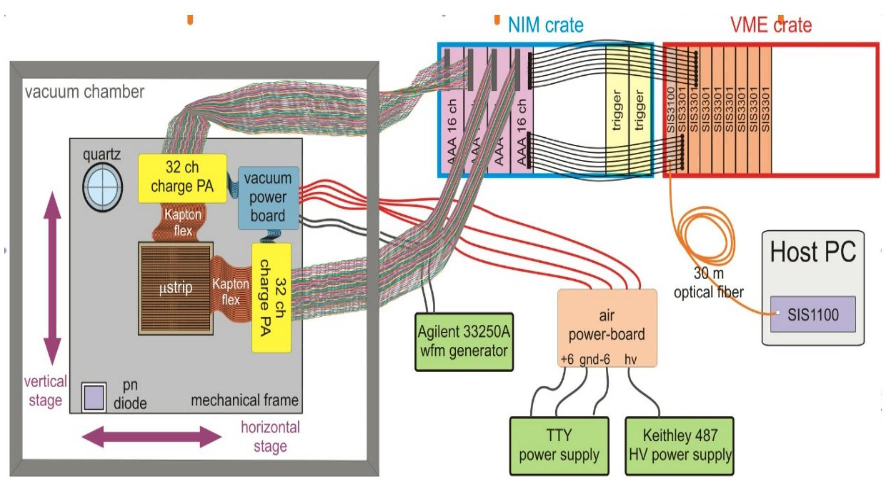
Pulse-shape capabilities

Low identification thresholds for low energy experiments

Digitalizing all signal shapes (Silicon, Germanium, AntiCompton, CsI(Tl), LaBr.....)

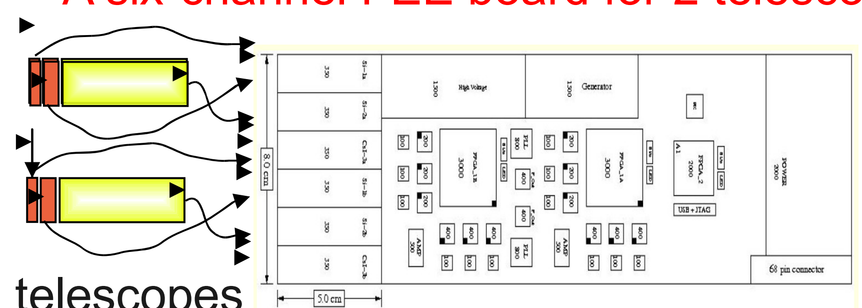
Coupling to different detectors (in different laboratories)

Subjects common to many arrays under development



FARCOS development layout

A six-channel FEE board for 2 telescopes



25W /board: **cooling** is an issue!

FAZIA multifunction 6ch FrontEnd CARD

Concluding remarks

- Interest worldwide about RIB facilities of different sizes from 0.1 to 400 kW
- Fundamental science and Technical applications can be done with RIBS
- SPES is well positioned within the European scenario, even more when considering the period of severe shortage (low cost/benefit ratio)
- The LINAC post acceleration allows to reach 10-11MeV/u for A>100 isotopic species. This is a crucial and unique feature of mid-range RIB facility.
- Italian nuclear groups are variously partecipating at the SPES initiative, developments on the different probes (gamma, neutrons, charge particles, fragments)
- Challenges concern both beam production, selection, and tagging and all aspects of detectors behaviour (from materials to electronics)
- Links with other laboratories and complementarity are and will be important