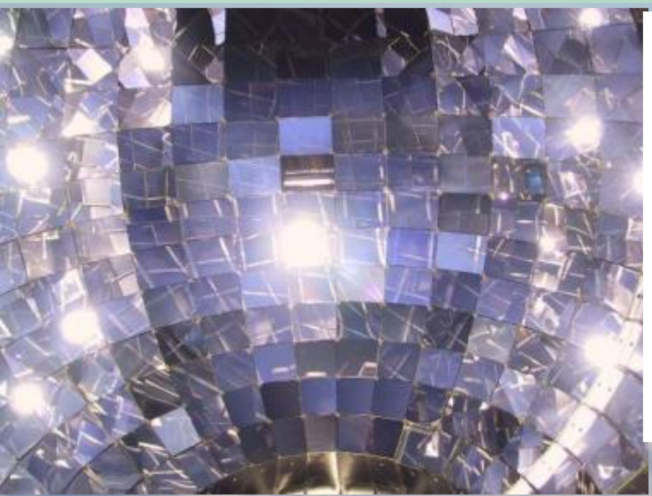
Present possibility and status of In Flight exotic beam(FRIBs) at LNS



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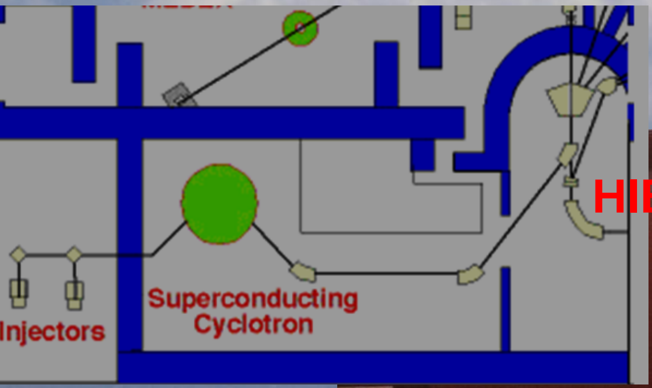
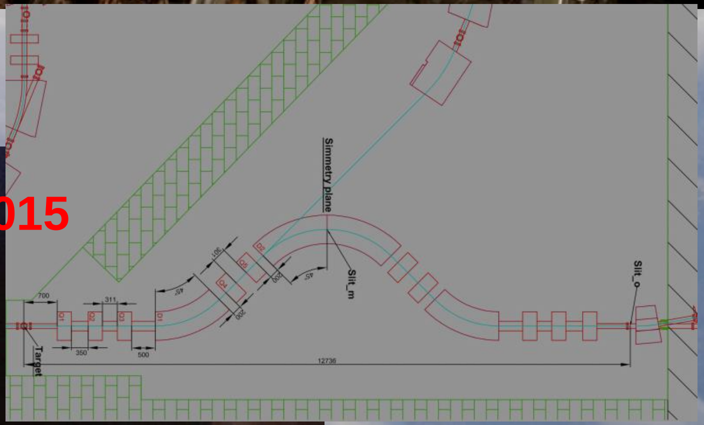
INFN CT



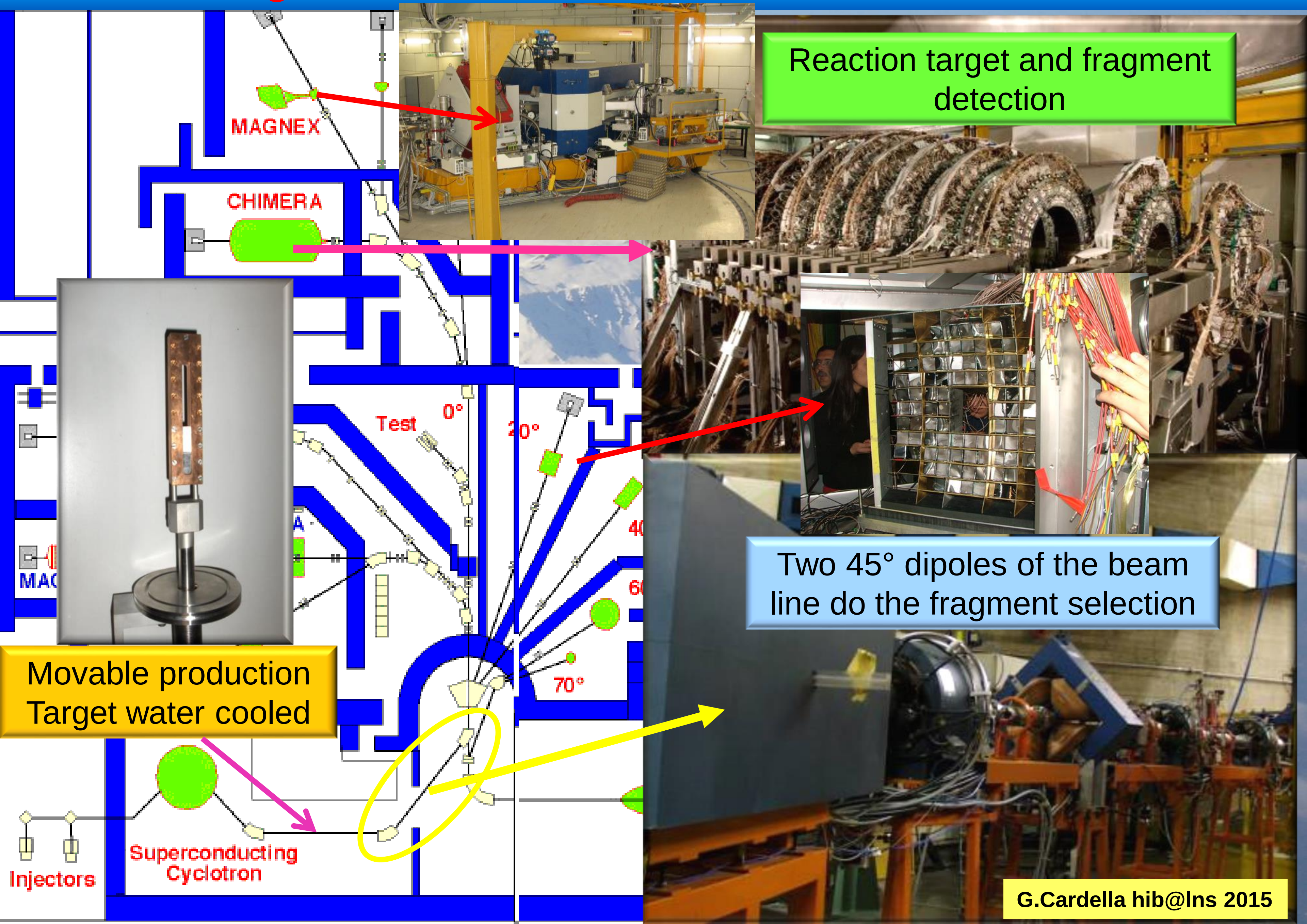


HIB@LNS December 15, 2015

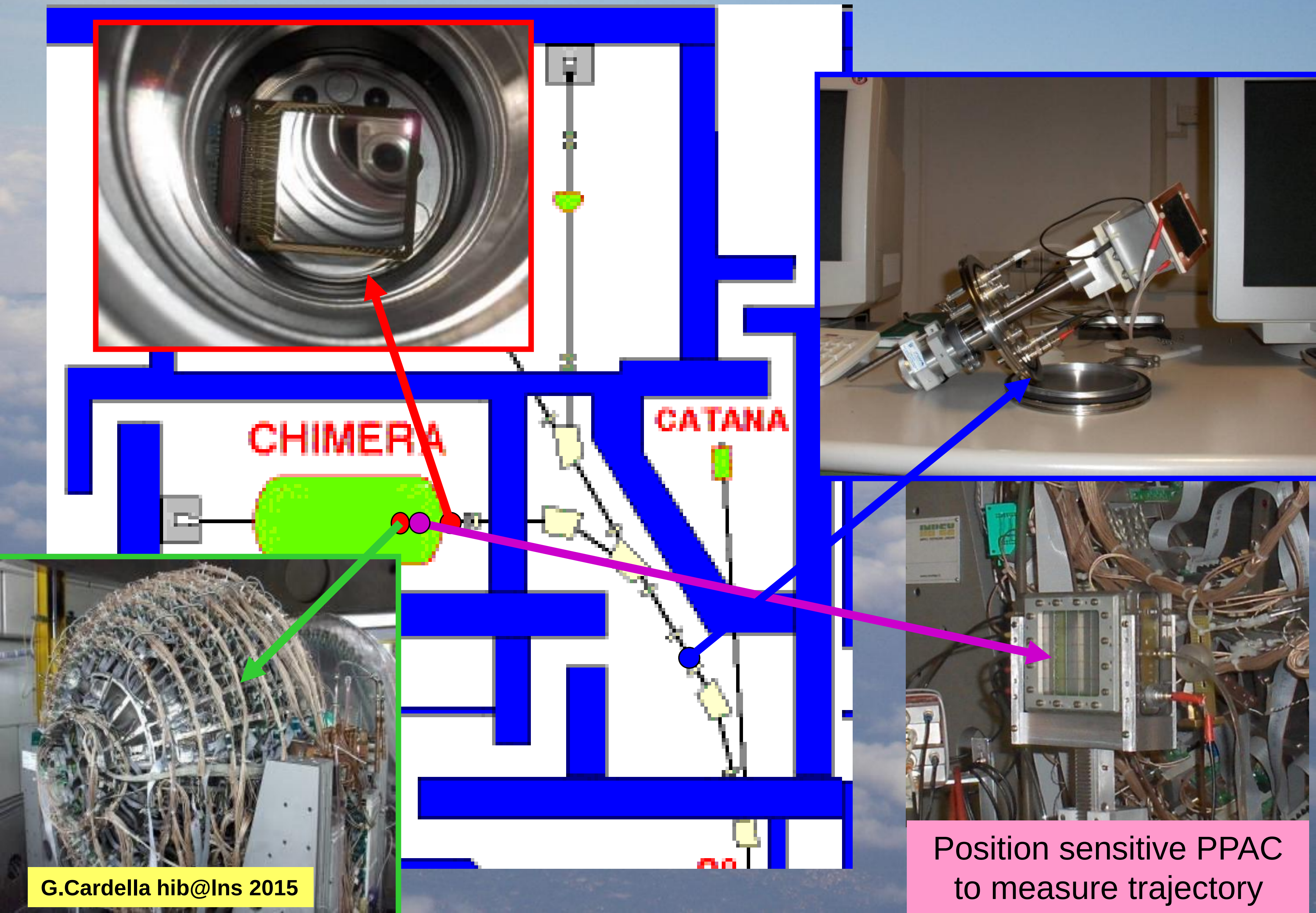
Outline

- ➢ The LNS Fragment separator (present)
- ➢The CHIMERA tagging system performances
- ➢ Some results
- ➢ perspectives and new needs
- ➢Conclusions

Fragmentation beams at INFN-LNS - Catania



Tagging system: layout of the CHIMERA case



Position sensitive PPAC to measure trajectory

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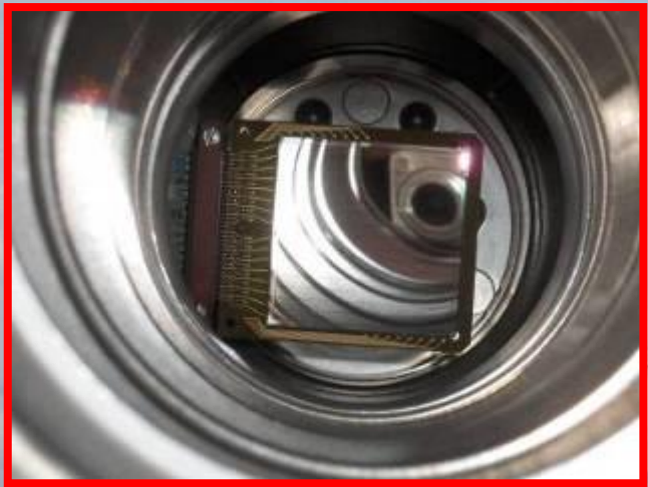
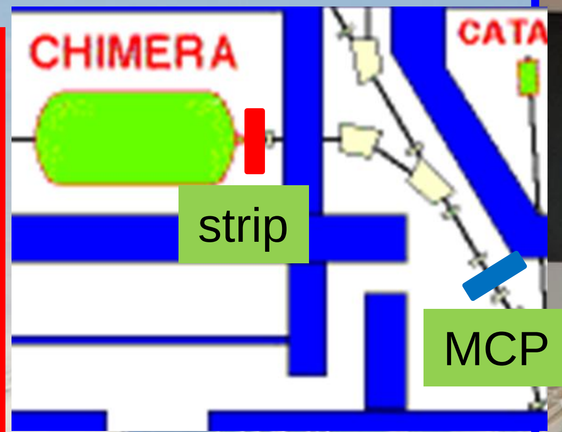
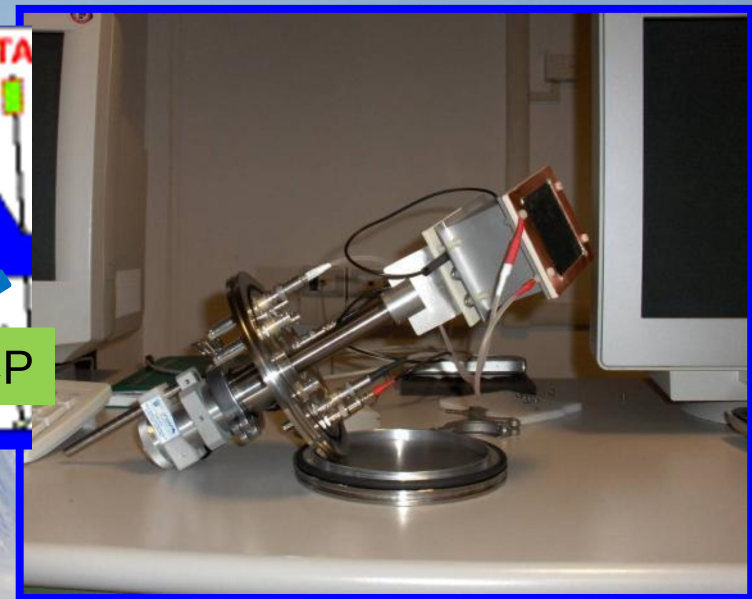
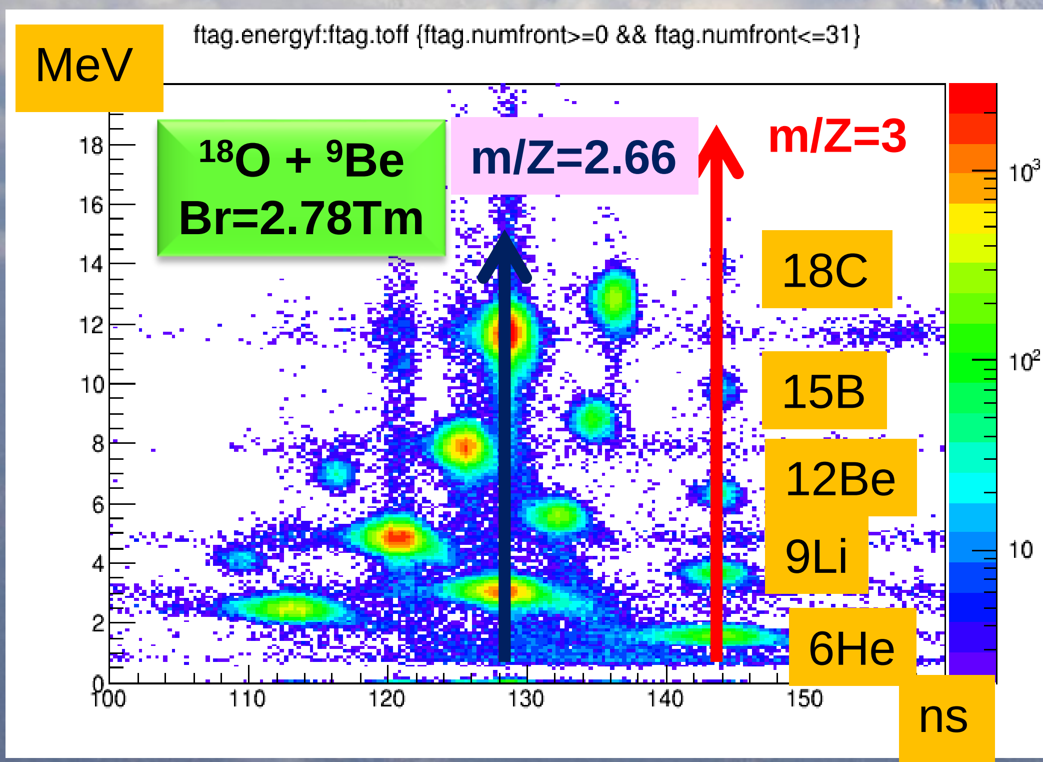
Tagging system: particle identification









Same time = same v

Br=mv/q → same m/q
or for fully stripped ions
Same m/Z

Smaller time
larger v → smaller m

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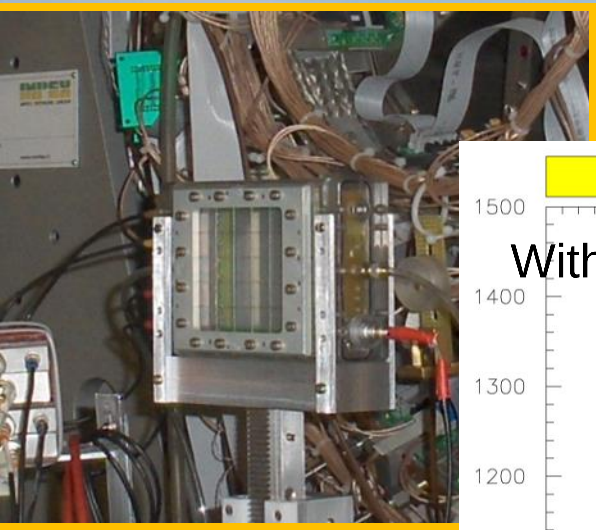
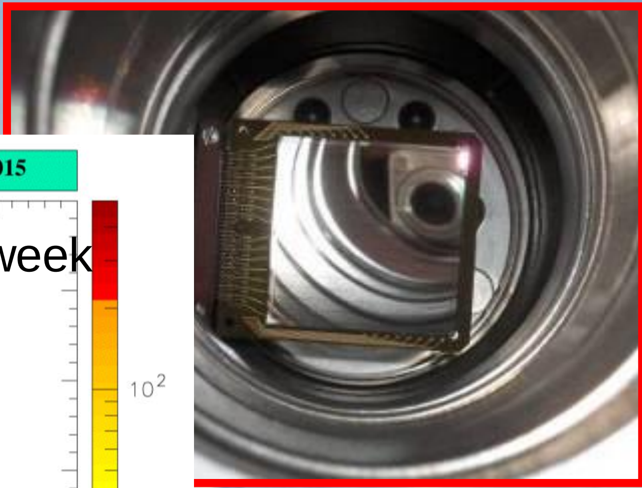
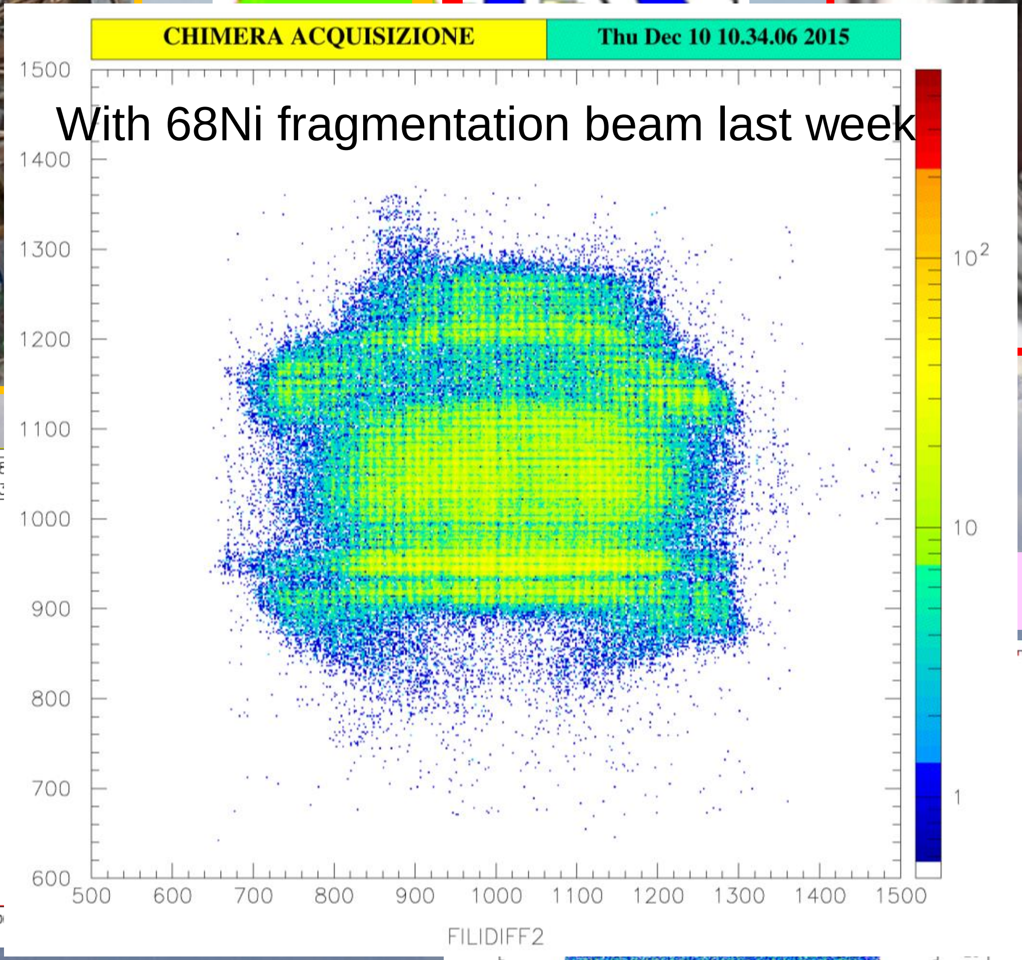
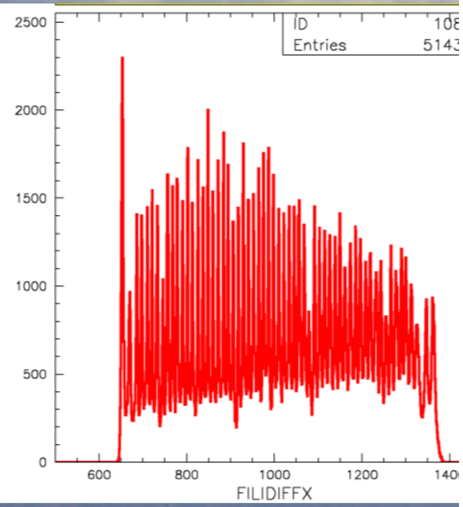
Tagging system: tracking capabilities

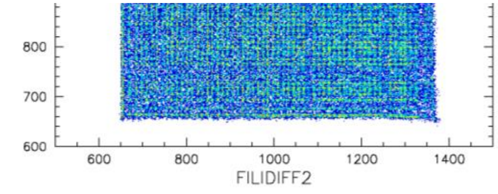


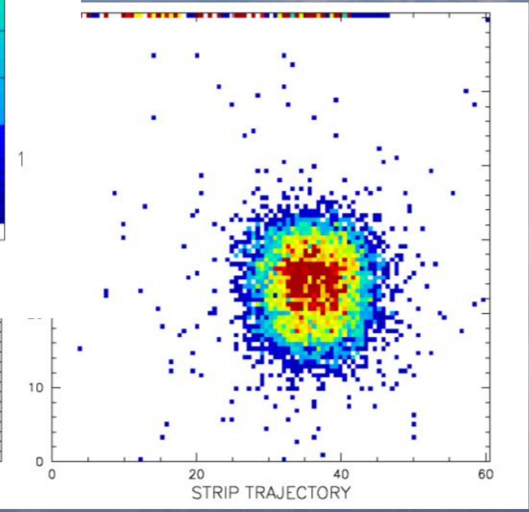


image









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Intensities available from the most recent beams produced

primary beam	beam	intensity (kHz/100W)
18O 55MeV/A	16C	120
setting 11Be	17C	12
	13B	80
	11Be	20
	10Be	60
	8Li	20
18O 55MeV/A	14B	3
setting 12Be	12Be	5
	9Li	6
	6He	12
13C 55 MeV	11be	50
setting 11Be	12B	100
36Ar 42 MeV	37K	100
setting 34Ar	35Ar	70
	36Ar	100
	37Ar	25
	33Cl	10
	34Cl	50
	35Cl	50
20Ne 35 MeV	18Ne	50
setting ne18	17F	20
	21Na	100
70Zn 42MeV		
setting 68Ni	68Ni	20

Some improvement for 16C/11Be as I will show

But it is not straightforward get 100 W

Intensities available from the most recent produced beams

^{16}C-$^{10-11}Be$ production with ^{18}O+^{9}Be 1.5 mm thick 55AMeV

experiment	UNSTABLE	UNSTABLE	CLIR
year	2009	2011	2015
beam current FC5	520	510	240 30W
MCP(kHz)	26	100	148
strip (kHz)	15	97	169

Source intensity problems with CESAR - SERSE not available

New quadrupole triplets and beam line upgrading

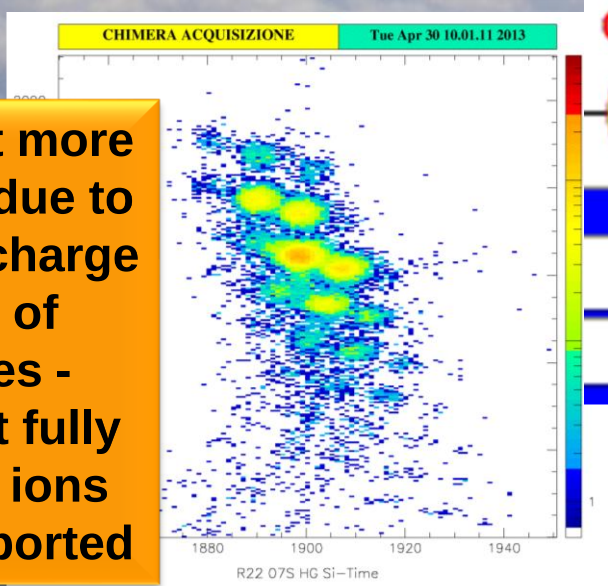
Replacement of old radioprotection faraday cups with collimators and optimized transport using available diagnostic (see cosentino) + larger size strip detector

Intensities available from the most recent produced beams

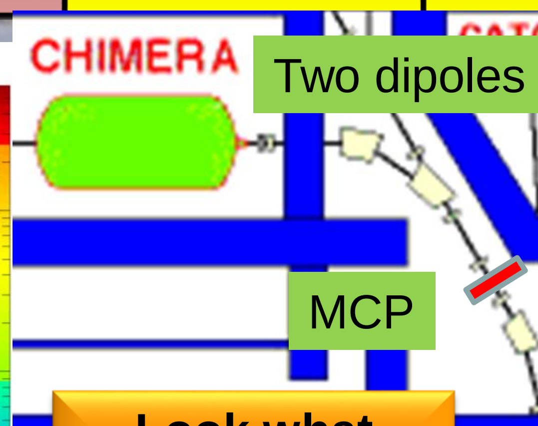
^{68}Ni production with ^{70}Zn+^{9}Be 0.25 mm thick 40 AMeV

experiment	Timescalezn	Pygmy
year	2012	2015
beam current FC5 nA	280	310
MCP(kHz)	187	225
strip (kHz)	25	33

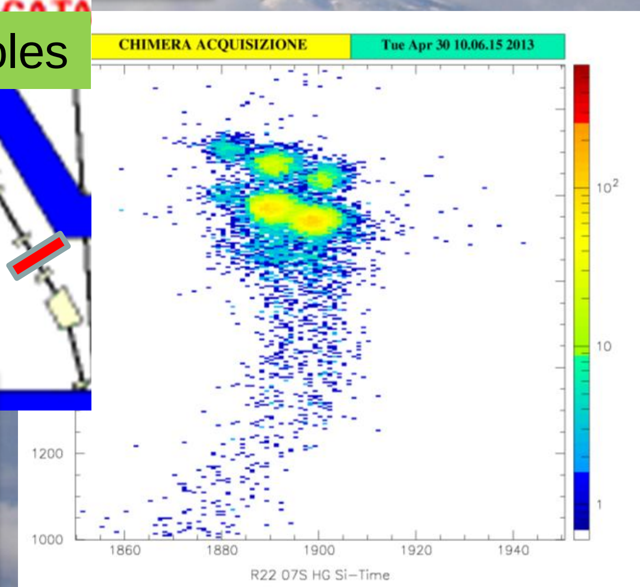
Serse source not well equipped for metals with low temperature fusion point



Transport more complex due to different charge status of isotopes - many not fully stripped ions are transported



Look what happens after MCP stripping of particles with charge $27^{+} \rightarrow 28^{+}$



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Beam diagnostic

The EXCYT diagnostic was essential to improve the beam transport efficiency respect to previous transports based on Pilot beams **A.Amato,..G.Cosentino et al LNS report 2009**

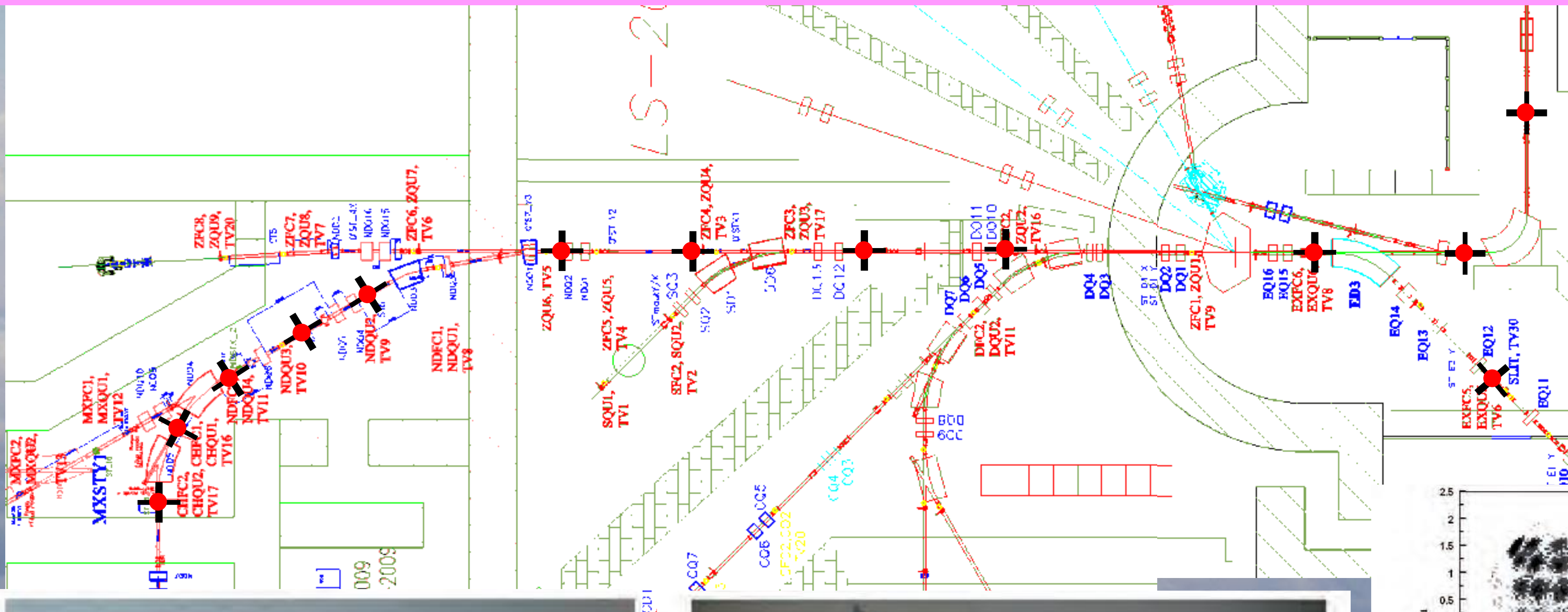
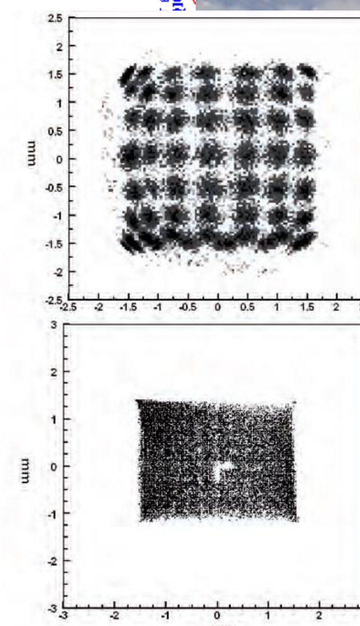


Fig. 2. Beam particle counter, based on a plastic scintillator coupled to a photomultiplier.

Fig. 3. PSSD mounted in a pneumatic actuator. The mask made by brass is 2mm thick.



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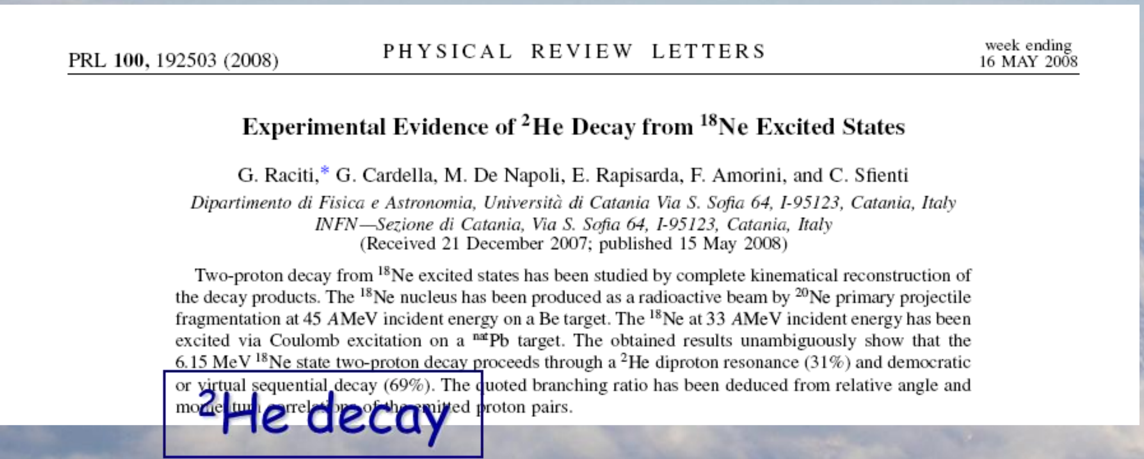
SOME RESULTS: Di-proton

Using ^{18}Ne beam we have studied the excitation and decay of a special state that can decay emitting a diproton



PRL **100**, 192503 (2008) PHYSICAL REVIEW LETTERS week ending 16 MAY 2008

Experimental Evidence of ^{2}He Decay from ^{18}Ne Excited States

G. Raciti,* G. Cardella, M. De Napoli, E. Rapisarda, F. Amorini, and C. Sfienti

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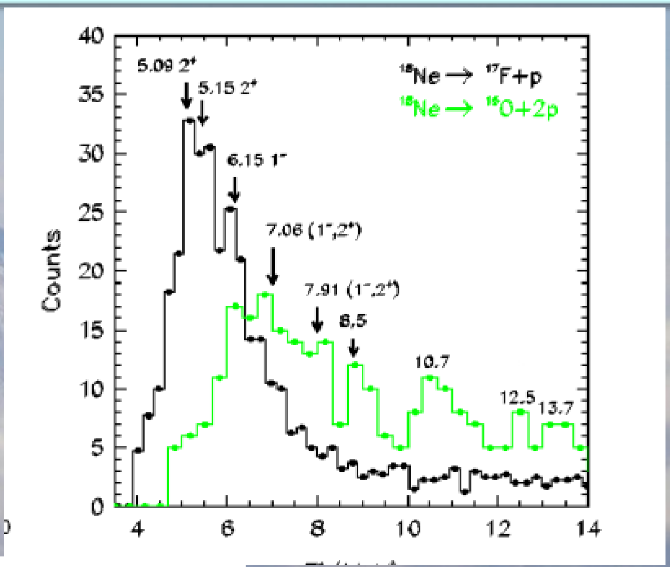
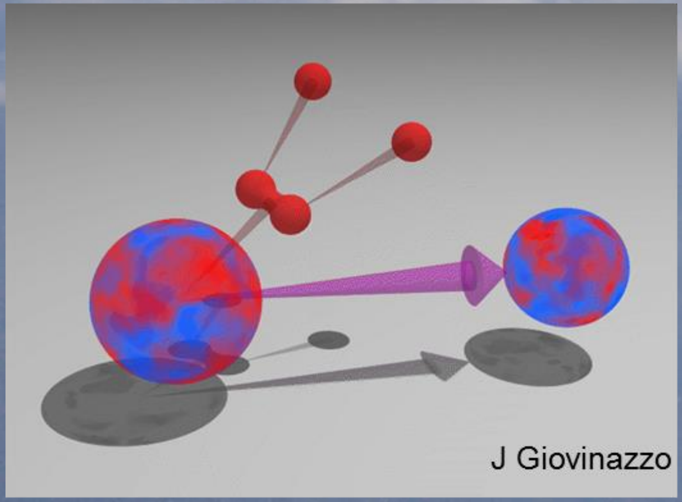
INFN—Sezione di Catania, Via S. Sofia 64, I-95123, Catania, Italy
(Received 21 December 2007; published 15 May 2008)

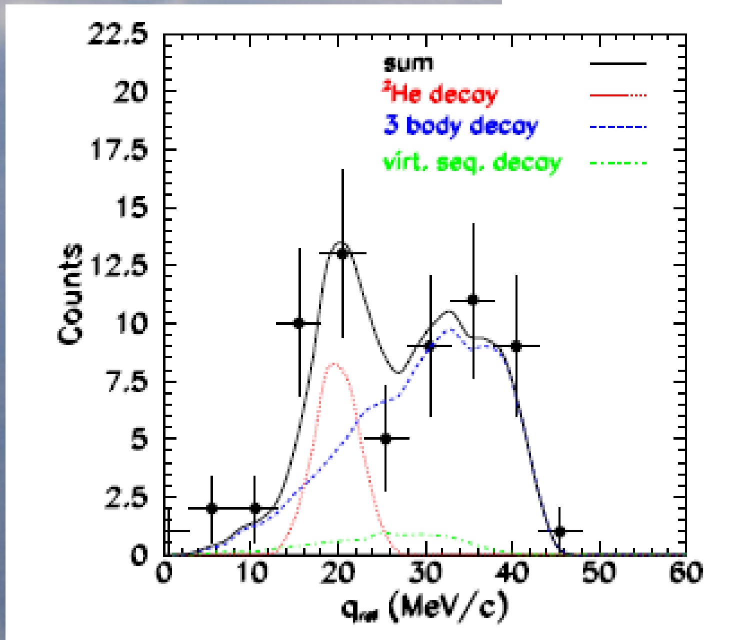
Two-proton decay from ^{18}Ne excited states has been studied by complete kinematical reconstruction of the decay products. The ^{18}Ne nucleus has been produced as a radioactive beam by ^{20}Ne primary projectile fragmentation at 45 AMeV incident energy on a Be target. The ^{18}Ne at 33 AMeV incident energy has been excited via Coulomb excitation on a ^{nat}Pb target. The obtained results unambiguously show that the 6.15 MeV ^{18}Ne state two-proton decay proceeds through a ^{2}He diproton resonance (31%) and democratic or virtual sequential decay (69%). The quoted branching ratio has been deduced from relative angle and momentum correlations of the emitted proton pairs.

^{2}He decay





V. I. Goldansky, *Nucl. Phys.* 19 (1960) 482



Other experiments Performed with hodo-CT: FLUBBER (F17 break-up)

Some results : UNSTABLE

Nuclear Instruments and Methods in Physics Research A 715 (2013) 56–61

Contents lists available at SciVerse ScienceDirect

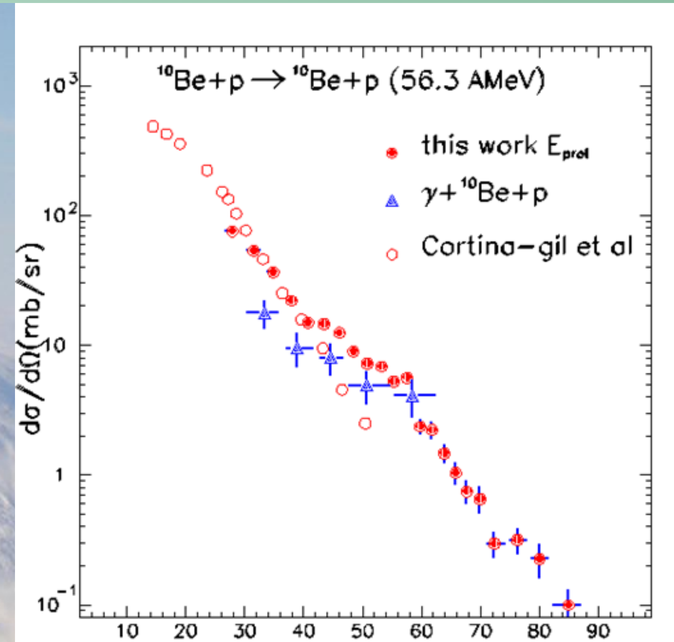
Nuclear Instruments and Methods in Physics Research A

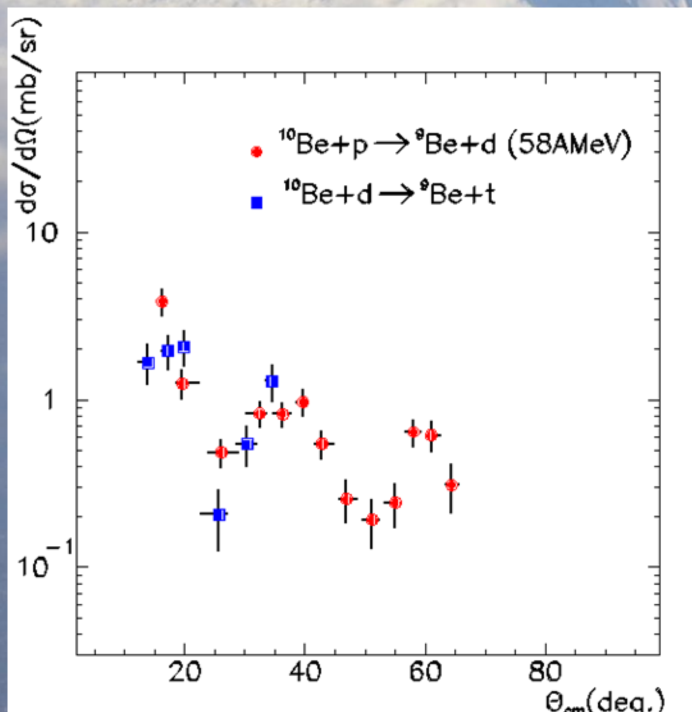
journal homepage: www.elsevier.com/locate/nima

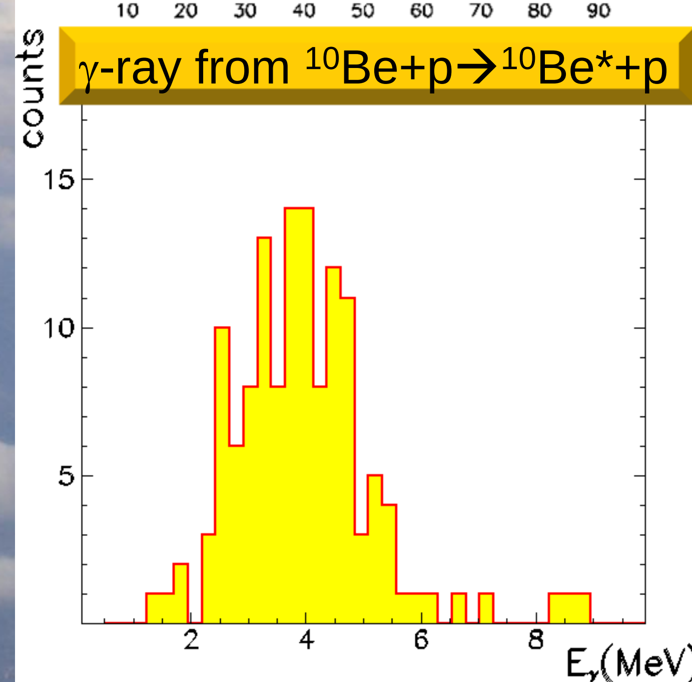
ELSEVIER

Kinematical coincidence method in transfer reactions

L. Acosta [b], F. Amorini [b], L. Auditore [d], I. Berceanu [h], G. Cardella [a,*], M.B. Chatterjee [i], E. De Filippo [a], L. Francalanza [b,c], R. Gianì [b,c], L. Grassi [a,k], A. Grzeszczuk [j], E. La Guidara [a,g], G. Lanzalone [b,e], I. Lombardo [b,f], D. Loria [d], T. Minniti [d], E.V. Pagano [b,c], M. Papa [a], S. Pirrone [a], G. Politi [a,c], A. Pop [h], F. Porto [b,c], F. Rizzo [b,c], E. Rosato [f], P. Russotto [b,c], S. Santoro [d], A. Trifirò [d], M. Trimarchi [d], G. Verde [a], M. Vigilante [f]

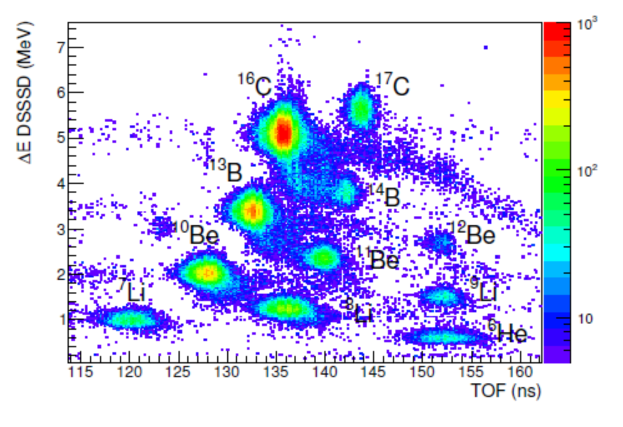


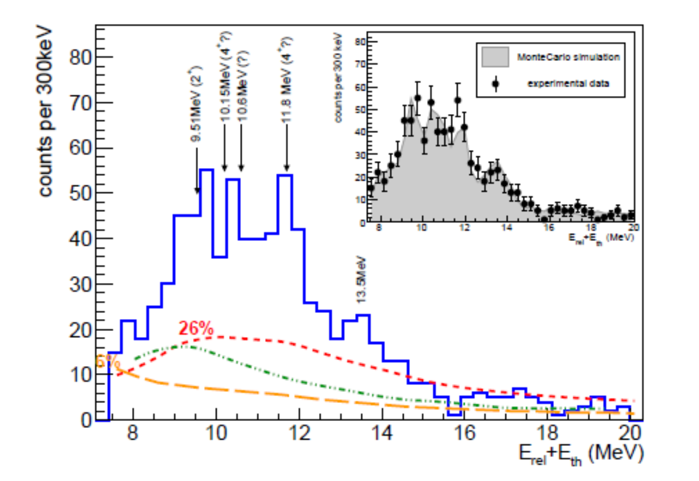


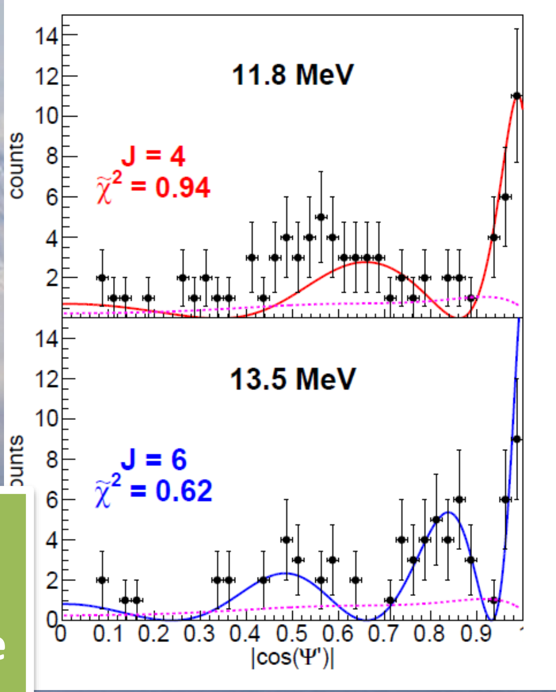


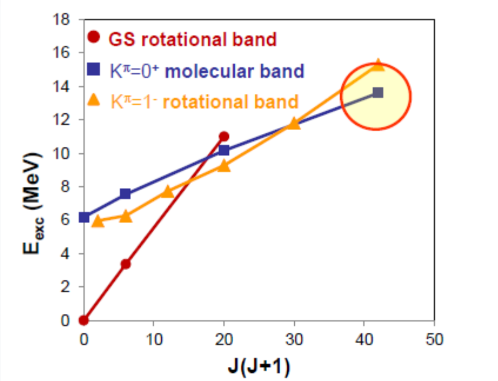
Some results : Unstable going to CLIR

New experimental investigation of ^{10}Be and ^{16}C structure by means of intermediate energy sequential break-up









Possible 6^+ further member of the $K=0^+$ molecular band → low statistics → new experiments are needed.

Analyzing break-up events of ^{10}Be (produced with FRIBS) on plastic target we have evidence of a possible new state at 13.5 MeV – the angular distribution is compatible with a $j^\pi=6^+$ missing level of a molecular band

D.Dell'Aquila et al submitted to PRC

Some results (last week experiment): PYGMY

Search for iso-scalar excitation of the PIGMY resonance in ^{68}Ni nuclei

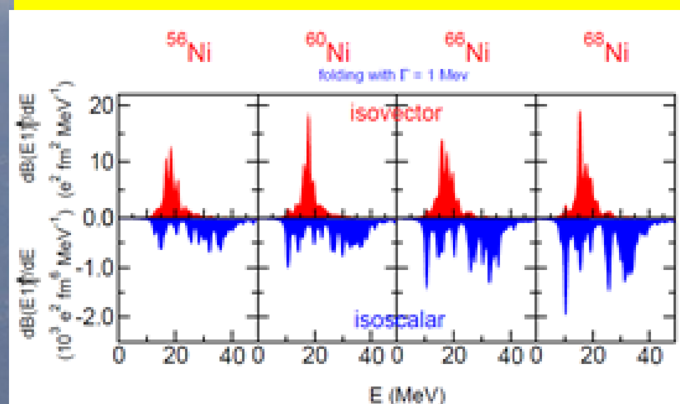
Spokes: G.Cardella, E.G.Lanza
for the
EXOCHIM collaboration

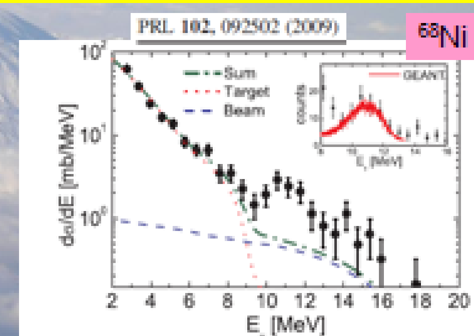
INFN Istituto Nazionale di Fisica Nucleare
Sezione di Catania

The Pigmy resonance

The search for population and decay of the Pigmy resonance was particular stressed in the last years especially due to the results obtained with neutron rich nuclei at GSI. The interest was high also because its sensitivity to the symmetry term of the nuclear equation of state - A recent revue can be found in Progress in Particle and Nuclear Physics 70 (2013) 210 by D. Savran , T. Aumann, A. Zilges

Experiments at GSI were performed using ^{132}Sn and ^{68}Ni – The resonance was excited by virtual photons generated by the Coulomb field of heavy target nuclei, so probing its isovector response function

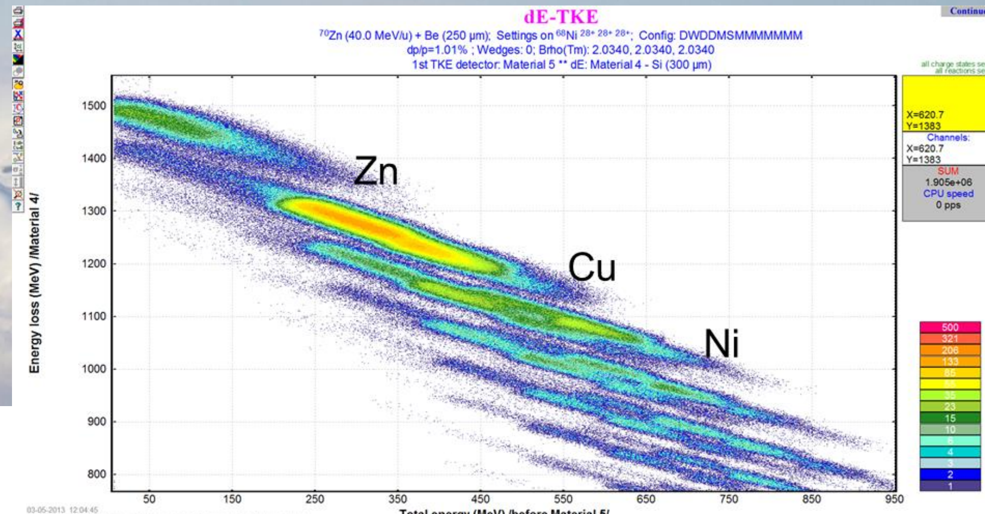


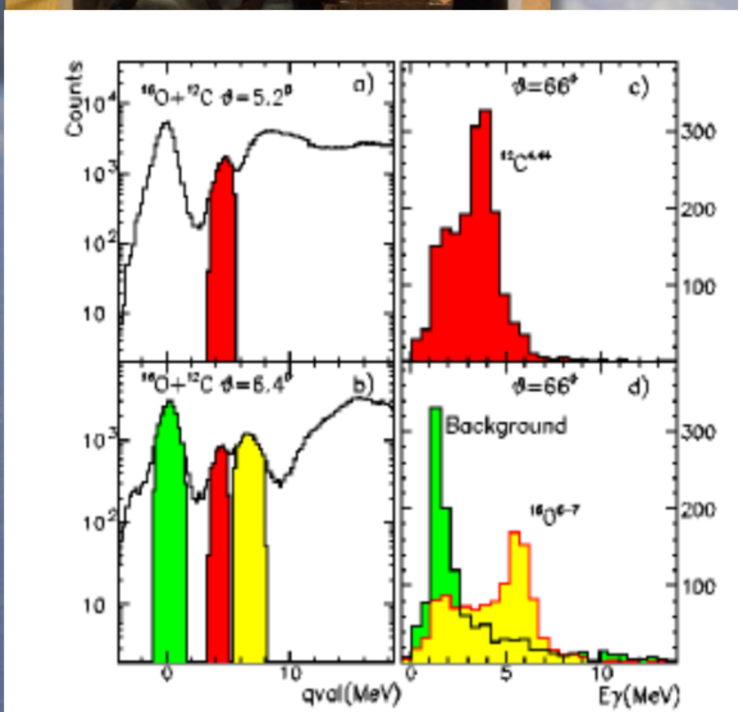


However various calculations show that this resonance can be excited also using isoscalar probes

Detection system for the Pygmy experiment

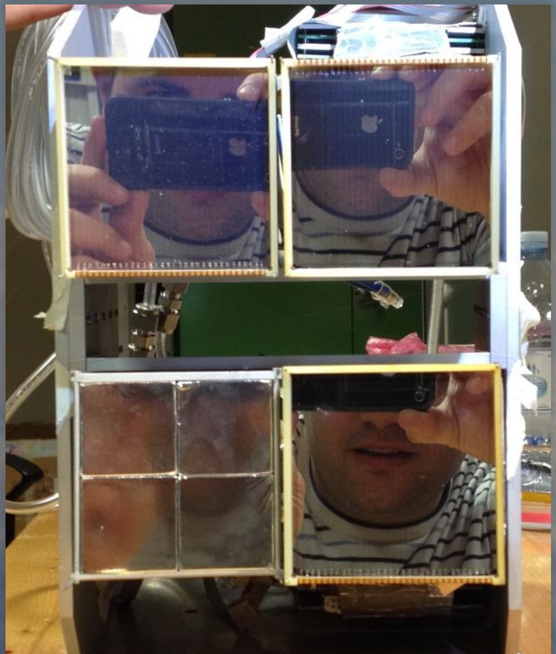
FARCOS detect and identify ^{68}Ni with good energy resolution (stopped in the two silicon stages of the telescopes)



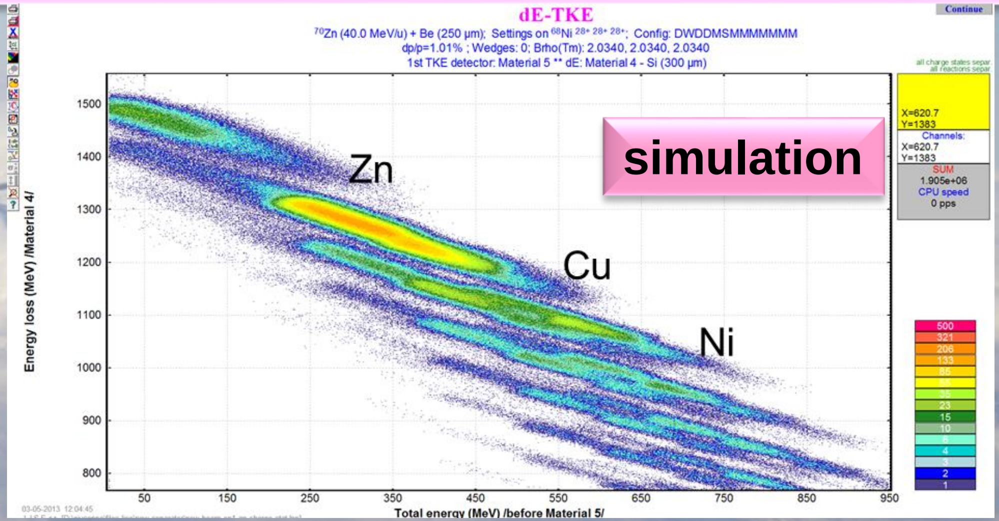


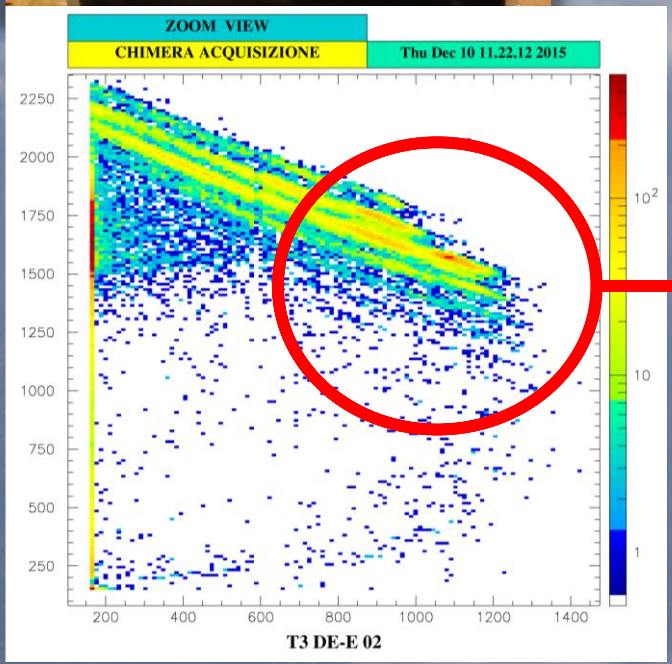
The Sphere CsI provide γ detection

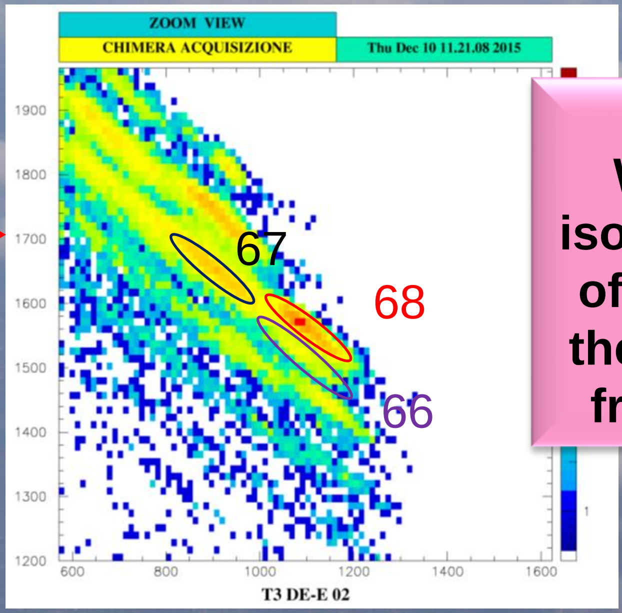
Detection system for the Pigmy experiment



FARCOS will detect and identify ^{68}Ni with good energy resolution (stopped in the two silicon stages of the telescopes)



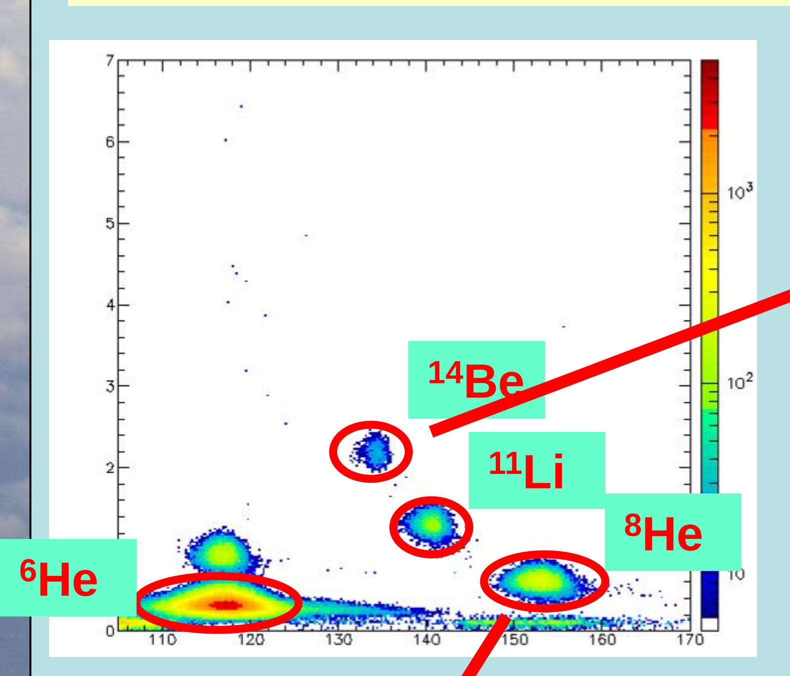




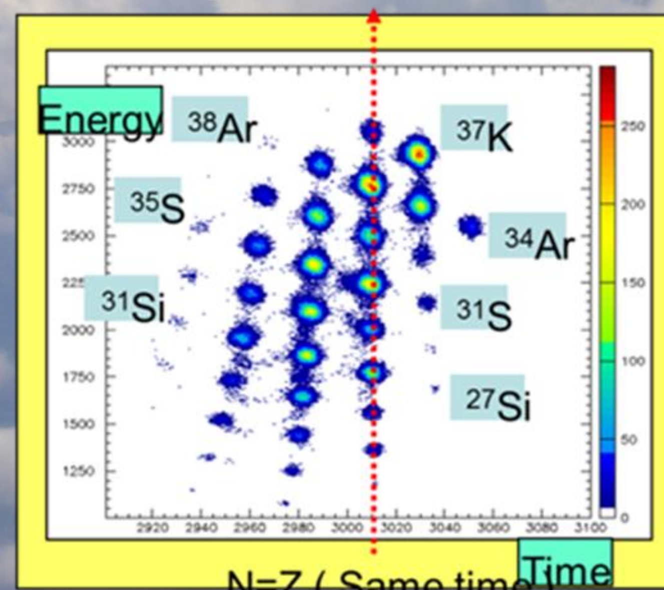
Reality
We mass identify isotopes in the region of nickel also due to the cleaning effect of fragment separator

Other possibilities

Another experiment was in program approved by the PAC - but now canceled by the collaboration is the ^{8}He production by using a ^{11}B primary beam – while with ^{18}O primary beam there is a request for the ^{14}Be study



Implantation and beta delayed decay study of ^{14}Be
By Leuven group
R. Raabe and G.Randisi



^{8}He+d - study of ^{9}He resonance with CHIMERA+FARCOS

The GREEN Experiment

LNS- PAC response: Priority A-
ALL the 52 BTU assigned !

Spokespersons: M. De Napoli, C. Agodi, F.Cappuzzello

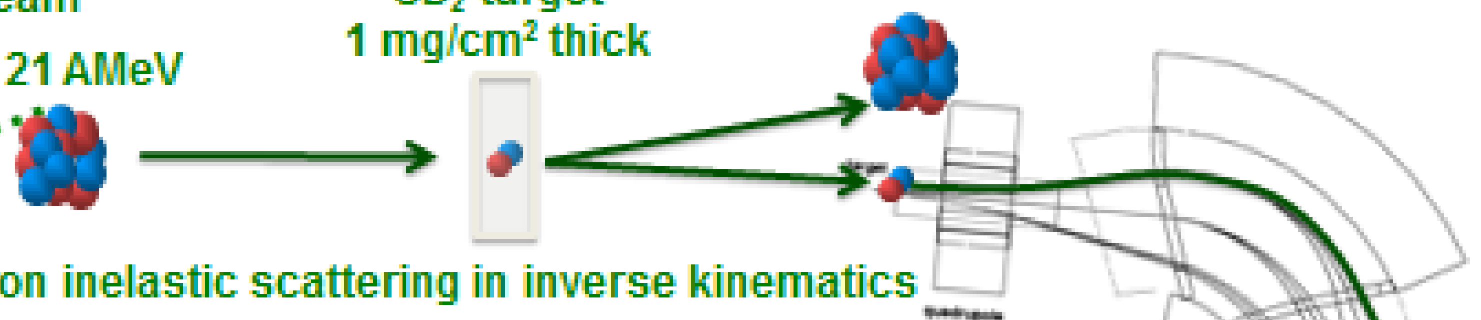
Measure of the ISGMR in the ^{38}S exotic nucleus

FRIBS@LNS
Beam

^{38}S @ 21 AMeV

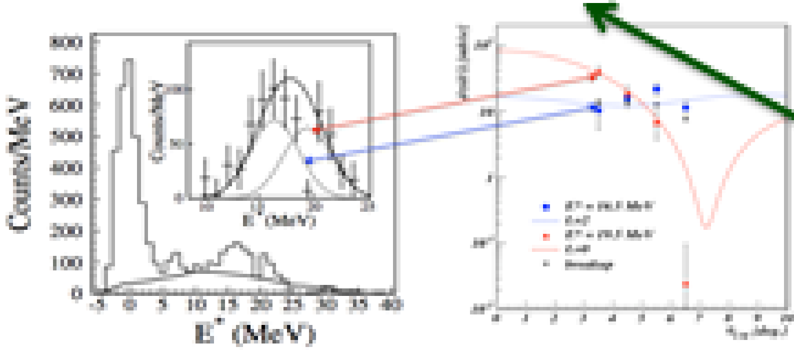
How…

CD_2 target
1 mg/cm^2 thick



Deuteron inelastic scattering in inverse kinematics

^{38}S excitation energy spectrum
and angular distributions



The recoiling deuteron is measured at small angles around 0° in MAGNEX

Complete reconstruction of the deuteron momentum vetor

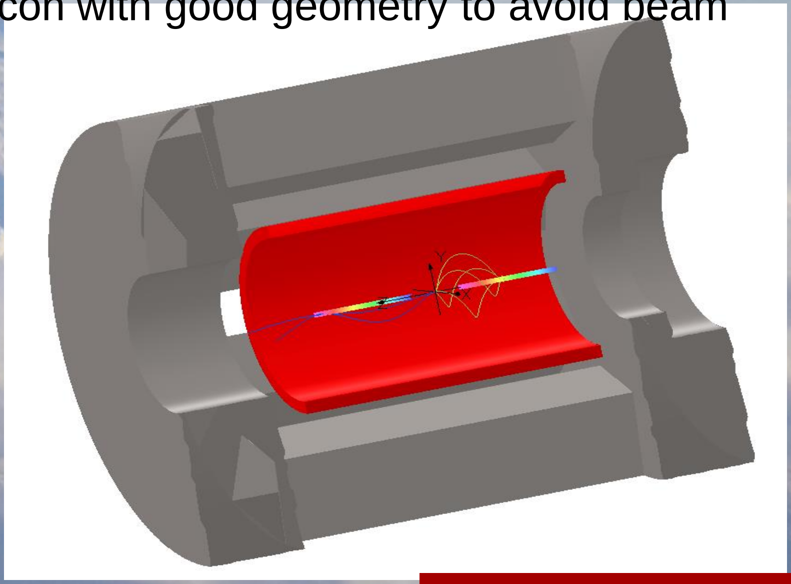
Future opportunities - SOLE

Use SOLE (the solenoid after MEDEA) like HELIOS (Argonne)

- TARGET on the axis of the solenoid (Bmax = 5 tesla)
- Particles emitted follow an elicoidal motion and are focussed on the solenoid axis:

$T_{cyc} = 2\pi m/Bqe \quad z = v_{par} T_{cyc}$

- Detection with an array of position sensitive silicon with good geometry to avoid beam and recoil



HELIOS SCHEME

We need to measure :

- Impact point **z** (Δx = 1 mm)
- $\mathbf{E_{lab}}$
- **Particle ToF** (~ 1 ns)

Homogeneous field ToF = T_{cycl}

We can extract:

- Particle m/q
- $\mathbf{E_{cm}}$
- Θ_{cm}

$$\frac{m}{q} = \frac{eB}{2\pi} \times T_{flight}$$

$$E_{cm} = E_{lab} + \tfrac{1}{2} m V_{cm}^2 - \frac{V_{cm} qeB}{2\pi} z$$

$$\theta_{cm} = \arccos\left(\frac{1}{2\pi} \frac{qeBz - 2\pi m V_{cm}}{\sqrt{2mE_{lab} + m^2 V_{cm}^2 - m V_{cm} qeBz/\pi}} \right)$$

T_{cycl} = 65.6 * A/qB (ns) (A amu, B Tesla)

	B= 2 Tesla	B = 3 Tesla
Proton	32.8 (ns)	21.9 (ns)
d, Alpha^{2+}	65.6 (ns)	43.7 (ns)
tritium	98.4 (ns)	65.6 (ns)

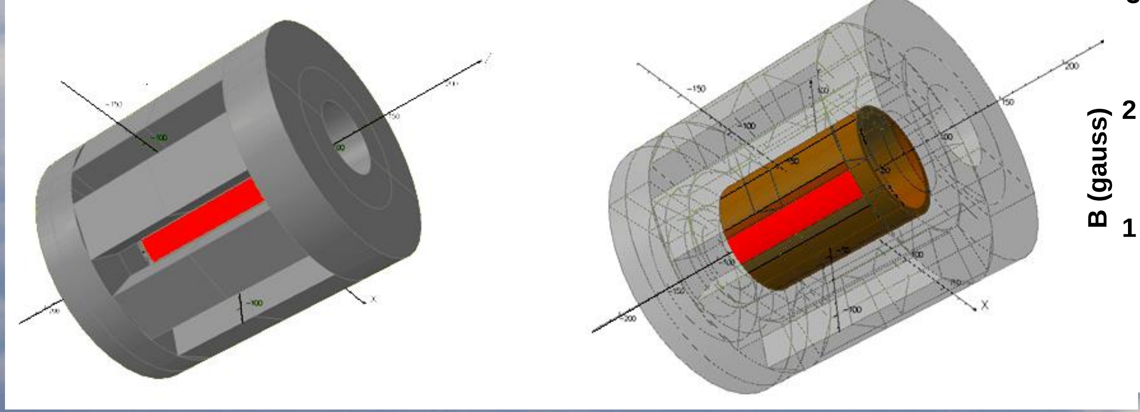
Future possibilities - SOLE

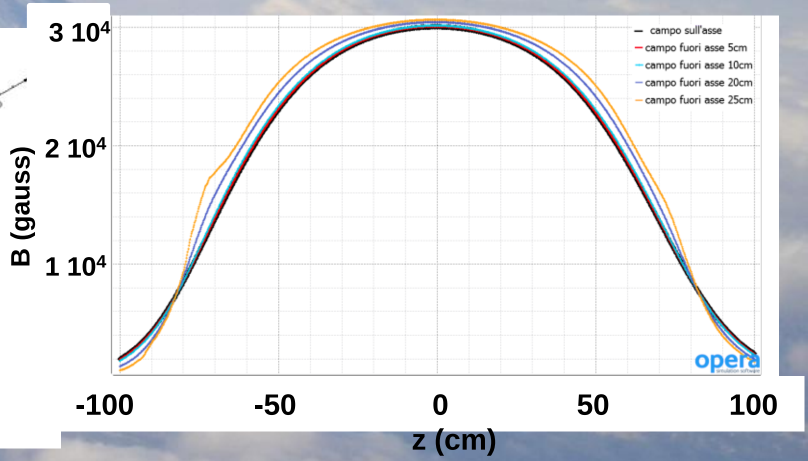
What can be studied depend on:
- kinematics
- Maximum field
- Magnet size

Quality depends on:
- Precision of field measurements
- Precision of detection array

Very well suited for direct reactions

Sole model in OPERA



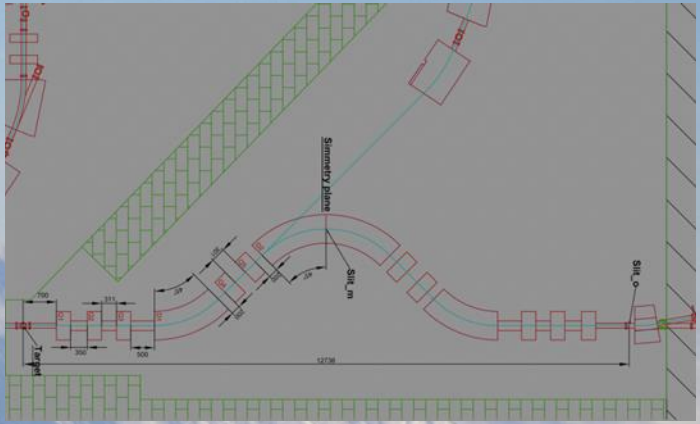


Study done with some assumtion:
- One proton emitted from target in the center of magnet (various angles and energies)

Studied:
- z detection point on the axis
- ToF to reach detection point
- Maximum radious of the proton trajectory as a funtion of E and Θ_{lab}

To be evaluated the effect of the angular spread of fragmentation beam

Perspectives

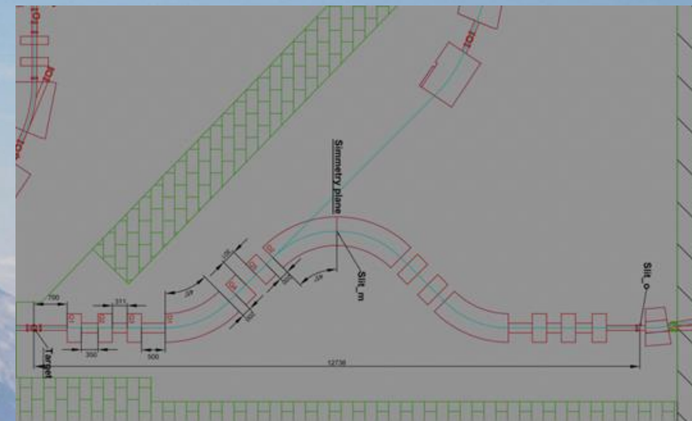


The cyclotron intensity upgrade and the installation of a new fragment separator open very interesting perspectives for the use of fragmentation beams at LNS

Up to now we limited our self to nuclei relatively near the stability line – a variety of beams could be produced profiting of the larger primary beam intensity using ^{11}B, ^{12,13}C, ^{16,18}O, ^{20,22}Ne and hopefully ^{36,40}Ar

Larger mass beams cannot profit of the higher intensity - but will profit of the bigger efficiency of the new spectrometer, the smallest distance to the detection system, the improved sources and beam injection systems in the CS

New needs



For extremely rare isotopes the tagging system up to now available could be performant enough – however for all the other beams we should improve its capabilities as time resolution, and maximum count rate

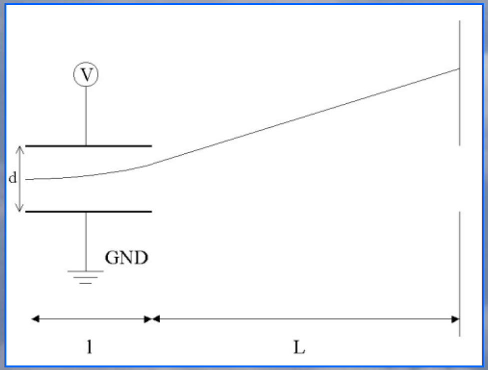
We should improve our beam selection capabilities in order to reduce the total rate to a level that can be handled by the tagging system using degraders and possibly Wien filters

Next improvement

Chopper - 500

The production of consecutive accelerated bunches with a separation time of up to 200 ns and a width of 500 ps FWHM, is the goal of this new chopping beam system. The chopper 500 should cut the present length of the accelerated beam bunches, delivered from the superconducting cyclotron, from 1.5÷2 ns to 0.5 ns.

From separation time 20-66 ns
Width of single bunch 1.6-5 ns



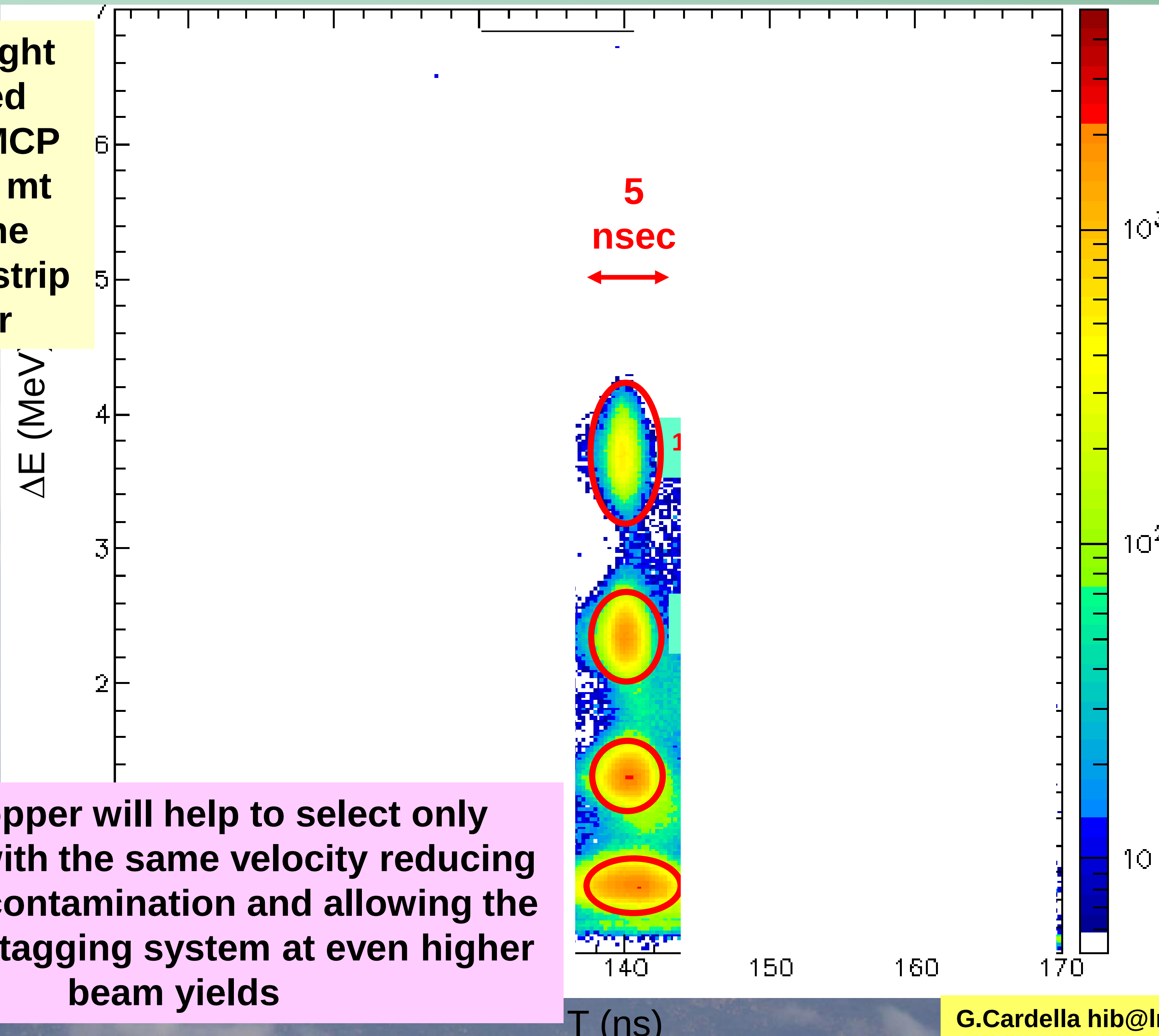
To separation time ≤ 200 ns
Width of single bunch 500 ps

Chopper-500 cavity

From L.Calabretta

Next Improvements

Time of flight measured between MCP placed 13 mt before the CHIMERA strip detector



The chopper will help to select only particles with the same velocity reducing the beam contamination and allowing the use of the tagging system at even higher beam yields

Conclusions

Fragmentation beams at LNS is a beautiful opportunity

To fully exploit the opportunities of the CS intensity upgrade we need to invest on a second generation fragment separator – effort must be done to allow the use of fragmentation beam on different beam lines

Investment in man power should be done on the maintenance and upgrading of the diagnostic systems and of the ion sources

Efforts to improve performances of tagging systems are necessary

I wish to thank all my collaborators

L.Acosta[1,8], L.Auditore[4], C.Boiano[5], G.Cardella[1], A.Castoldi[5], M.D'Andrea[1], E. De Filippo[1],D.Dell'Aquila[6], S. De Luca[4], F.Fichera[1], L.Francalanza[6], N.Giudice[1], B.Gnoffo[1], A.Grimaldi[1], C.Guazzoni[5], G.Lanzalone[2,7], F.Librizzi[1], I.Lombardo[6], C.Maiolino[2], S.Maffesanti[5], N.Martorana[2], S.Norella[4], A.Pagano[1], E.V.Pagano[2,3], M.Papa[1], T.Parsani[5], G.Passaro[2], S.Pirrone[1], G.Politi[1,3], F.Previdi[5], L.Quattrocchi[4], F.Rizzo[2,3], P.Russotto[1], G.Saccà[1], G.Salemi[1], D.Sciliberto[1], A.Trifirò[4], M.Trimarchì[4], M.Vigilante[6]

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3-Dipartimento di Fisica e Astronomia Università di Catania

4-INFN_gr. Coll. Messina and Dipartimento di Fisica Università Messina

5-INFN- Sezione di Milano and Politecnico di Milano

6-INFN-Sez. di Napoli and Dipartimento di Fisica Università di Napoli Federico II

7-Università Kore Enna

8-Instituto de Física Universidad Nacional Autónoma de México Apartado Postal 20-364, México D. F. 01000

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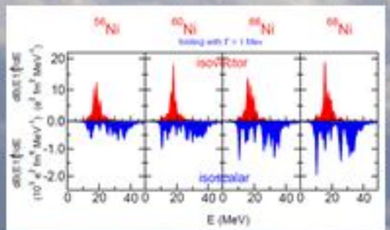
D.Santonocito – EXPERA group - Magnex group

L.Calabretta , G.Cosentino, A.Russo, D.Rifuggiato

Experiments to be done – PIGMY with CHIMERA/FARCOS

Search for iso-scalar excitation of the PIGMY resonance in ^{68}Ni nuclei

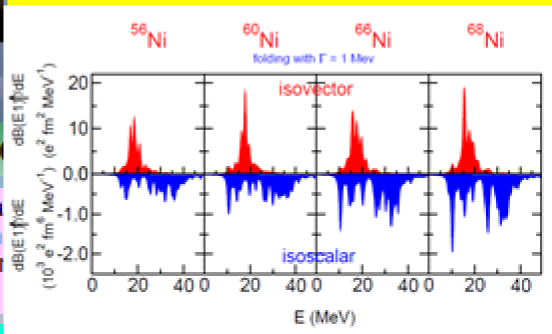
Spokes: G.Cardella, E.G.Lanza
for the
EXOCHIM collaboration

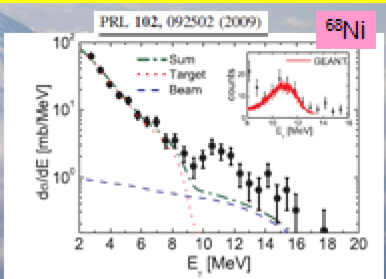


The Pigmy resonance

The search for population and decay of the Pigmy resonance was particular stressed in the last years especially due to the results obtained with neutron rich nuclei at GSI. The interest was high also because its sensitivity to the symmetry term of the nuclear equation of state - A recent revue can be found in Progress in Particle and Nuclear Physics 70 (2013) 210 by D. Savran , T. Aumann, A. Zilges

Experiments at GSI were performed using ^{132}Sn and ^{68}Ni – The resonance was excited by virtual photons generated by the Coulomb field of heavy target nuclei, so probing its isovector response function





However various calculations show that this resonance can be excited also using isoscalar probes

The Pigmy resonance: Beam chara

The need of new investigations of the isoscalar response of the pigmy resonance well match with the recent production at LNS of ^{68}Ni beams in the framework of the TIMESCALEZN experiment

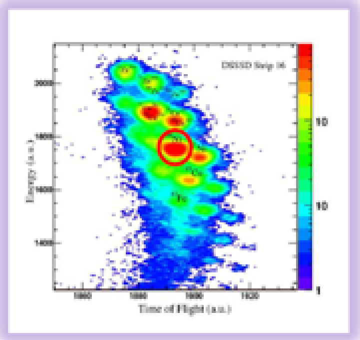
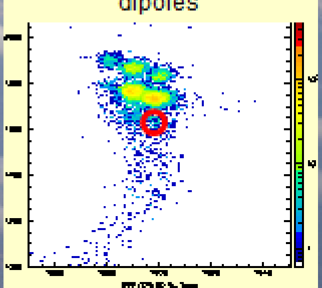


Fig.4 Identification scatter plot of ^{68}Ni fragmentation beam

The bea
via fragm
a 0.25 mr

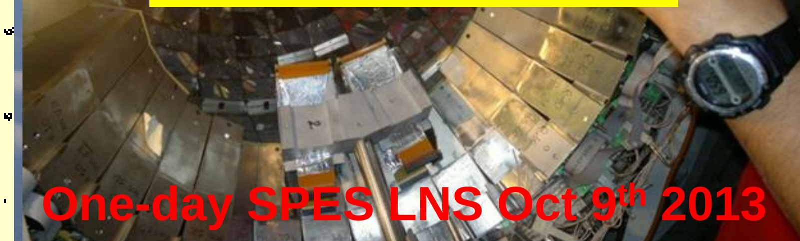
A beam intensity of about $2x10^4$ part/sec/ 100 W primary beam was obtained

Examples of Ions 27+ stripped to 28+ by the MCP mylar foil observed changing the field of last dipoles



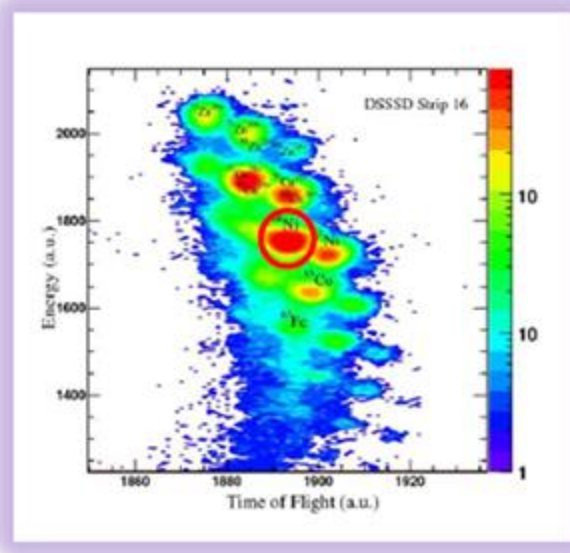
^{68}Ni is the most intense beam transported In our system we can in fact clean quite well not fully stripped ions that could be a source of intense background
The mylar foil of the tagging MCP is a stripper foil cleaning most of such contaminants

Reaction ^{68}Ni+^{12}C To evidence the isoscalar character of pigmy resonance



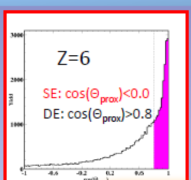
Future Experiments : symmetry energy

We are waiting for the intensity upgrading to perform new measurements - using radioactive beams - also on reaction dynamics to get information on symmetry energy



Identification scatter plot of ^{68}Ni fragmentation

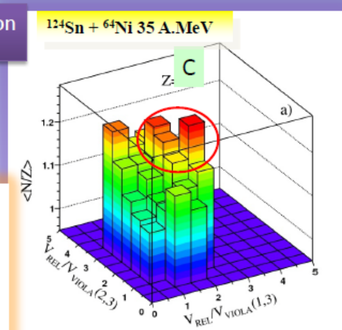
Neck neutron enrichment; reduction of "staggering" odd-even effects

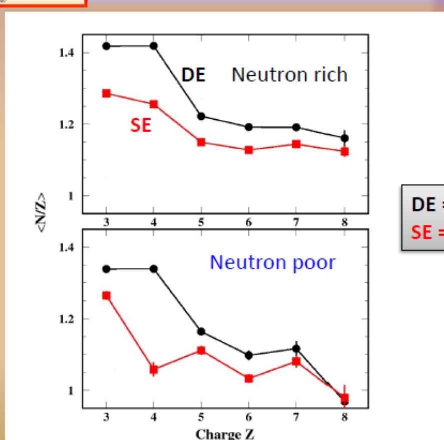


(1) Condition on cos(Θ_{prox})

+

(2) Condition on V_{rel} plot



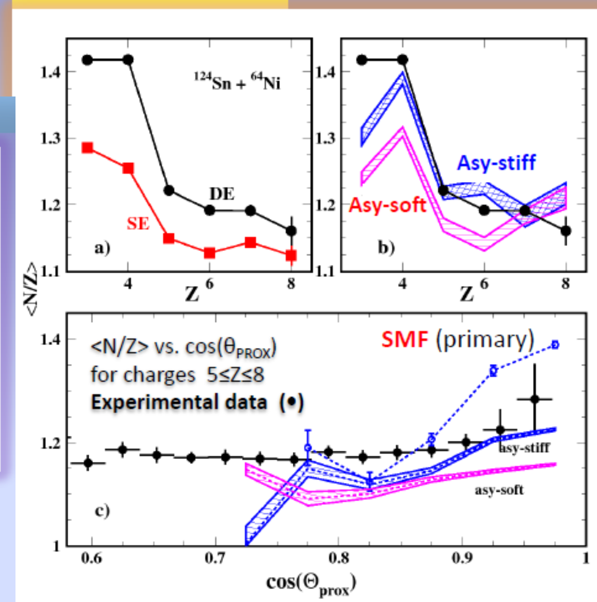


DE = Dynamical emitted
SE = Statistical emitted

The correlation shows that the greatest neutron enrichment is linked to the largest deviations from Viola systematics.

Stochastic Mean Field (SMF) + GEMINI calculation

^{124}Sn+^{64}Ni 35 A.MeV



Phys. Rev. C **86** *014610 (2012)*

Experimental <N/Z> distribution of IMFs as a function of their atomic number compared with results SMF+GEMINI calculations (hatchad area) for two different parametrizations of the symmetry potential (asy-soft and asy-stiff)

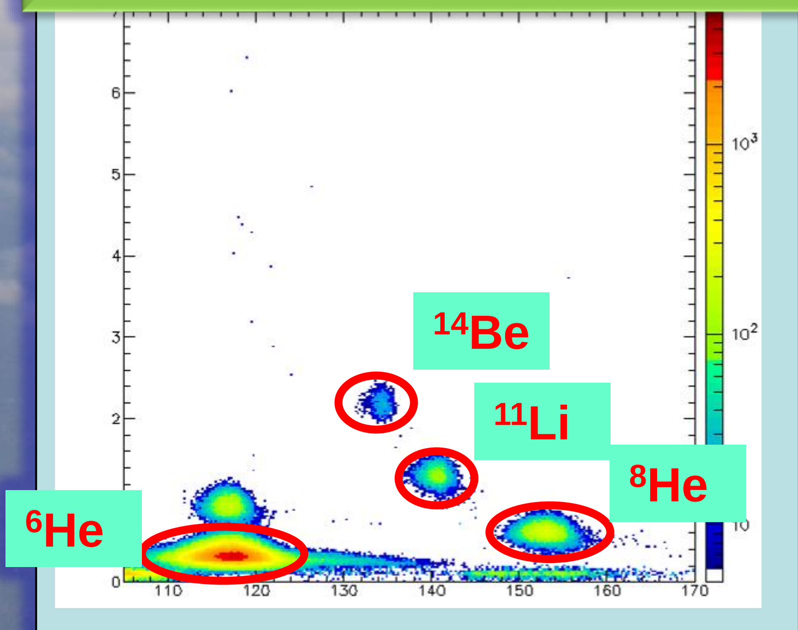
- Dynamically emitted particles
- Statistically emitted particles

See also: S. Hudan et al., PRC **86** 021603(R).
K. Brown et al., arXiv:1305.1320 (2013)

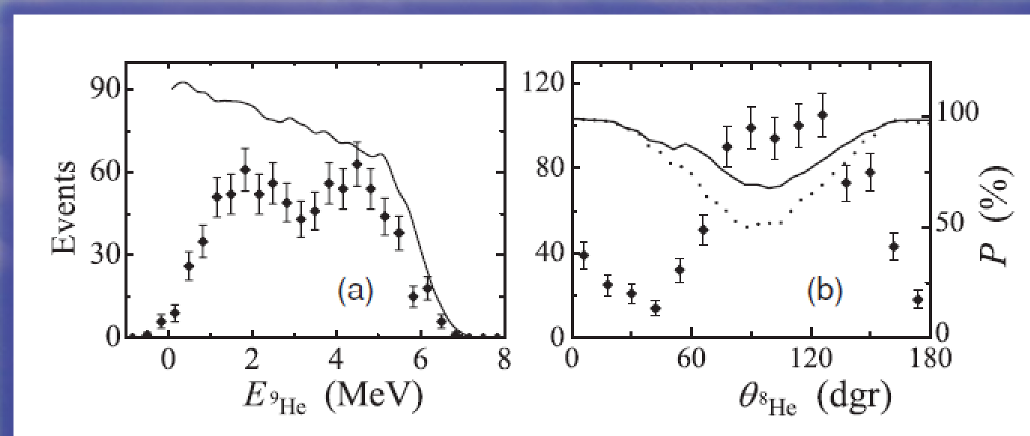
Coming Experiments : Neutron transfer on ^{8}He

One programmed experiment is the ^{8}He+d reaction performed to study the ^{9}He resonance - production will by done using a ^{11}B primary beam – We expect around 2000 particles/sec of beam intensity

Preliminary production test performed with ^{18}O primary beam



Reaction studied at Dubna at 25 AMeV We will increase the beam energy searching for higher excitation energy structures



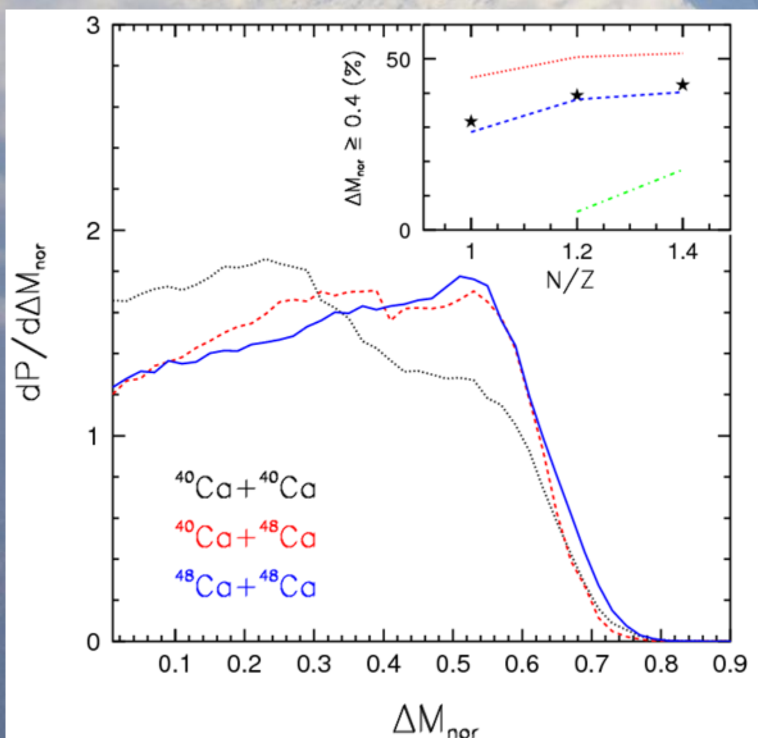
M. S. Golovkov et al PHYSICAL REVIEW C 76, 021605(R) (2007)

Isospin physics

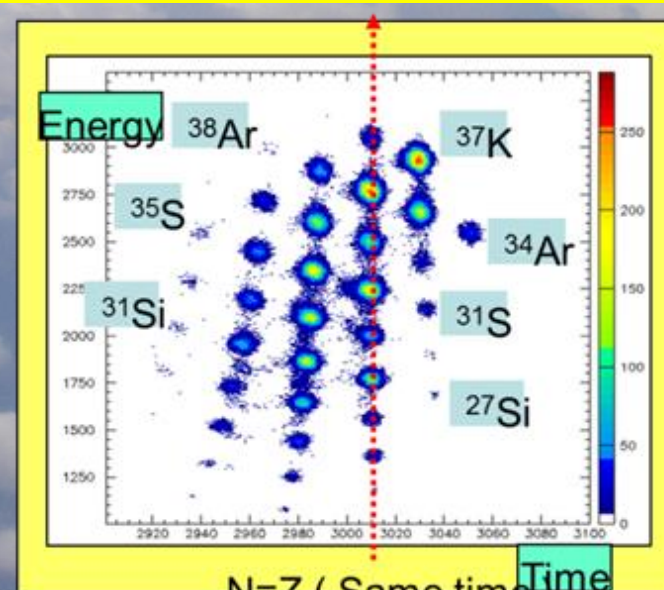
PHYSICAL REVIEW C **00**, 004600 (2012)

Effects of neutron richness on the behavior of nuclear systems at intermediate energies

G. Cardella,[2] G. Giuliani,[2,3] I. Lombardo,[4,*] M. Papa,[2] L. Acosta,[1] C. Agodi,[1] F. Amorini,[1] A. Anzalone,[1] L. Auditore,[5] I. Berceanu,[8] S. Cavallaro,[1,3] M. B. Chatterjee,[9] E. De Filippo,[2] E. Geraci,[2,3] L. Grassi,[2,3] J. Han,[1] E. La Guidara,[2,7] D. Loria,[5] G. Lanzalone,[1,6] C. Maiolino,[1] T. Minniti,[5] A. Pagano,[2] S. Pirrone,[2] G. Politi,[2,3] F. Porto,[1,3] F. Rizzo,[1,3] P. Russotto,[1,3] S. Santoro,[5] A. Trifirò,[5] M. Trimarchi,[5] G. Verde,[2] and M. Vigilante[4]



Competition between fusion and binary-like reactions as a function of N/Z using beams in the region of Ar



Coming Experiments : Break-up study - CLIR

(Clusters in Light Ion Reactions)

Cl

Break-up of RIBs: coincidences

Self-conjugated nuclei → cluster effect in GS

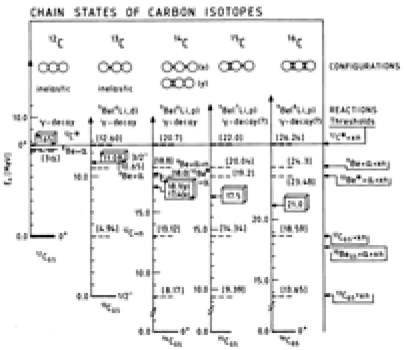
→ role of *quartetting* in nuclei → unveiled from the existence of *rotational bands*

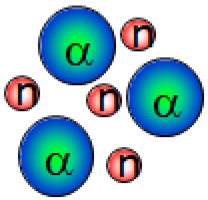
ith RIBs

INFN –LNS and Sezione di Napoli

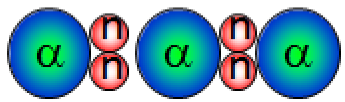
Neutron-rich light isotopes → cluster effect leading to *nuclear molecules* → *covalence bonding* due to neutrons

Light isotopes approaching *n-drip line* → *exotic clustering* effects → also influence of *pairing* in covalent neutrons





^{16}C



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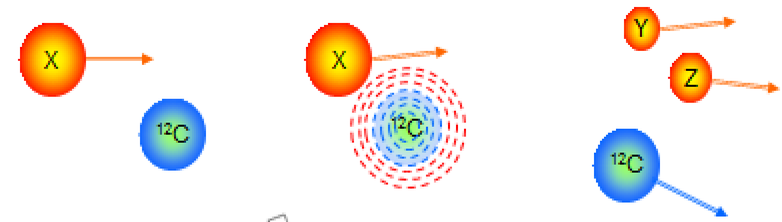
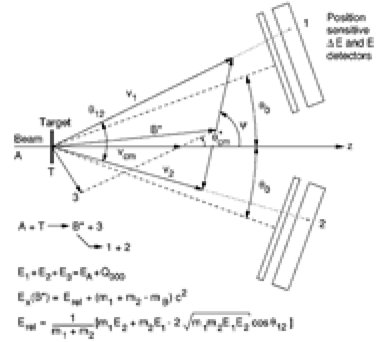
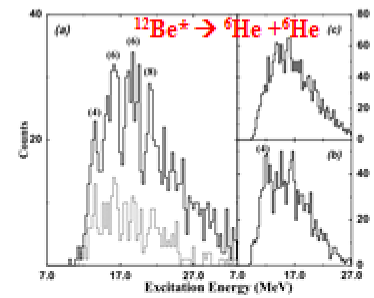
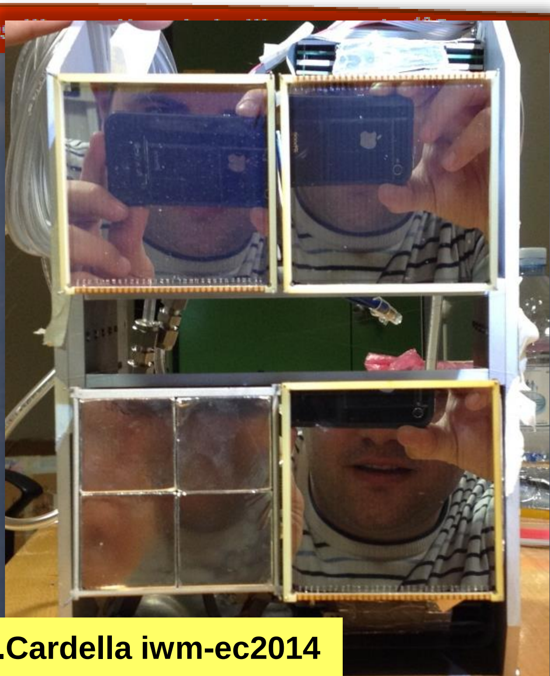






Ga

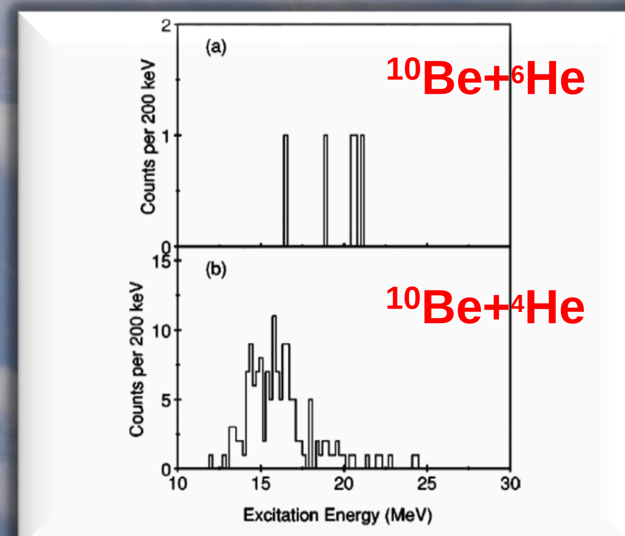
Low statistics & high resolution



$^{16}C+^{12}C$

Search for exotic decay of ^{16}C

(and the other available beams $^{10,11}Be$ ^{13}B …..)



G.Cardella iwm-ec2014

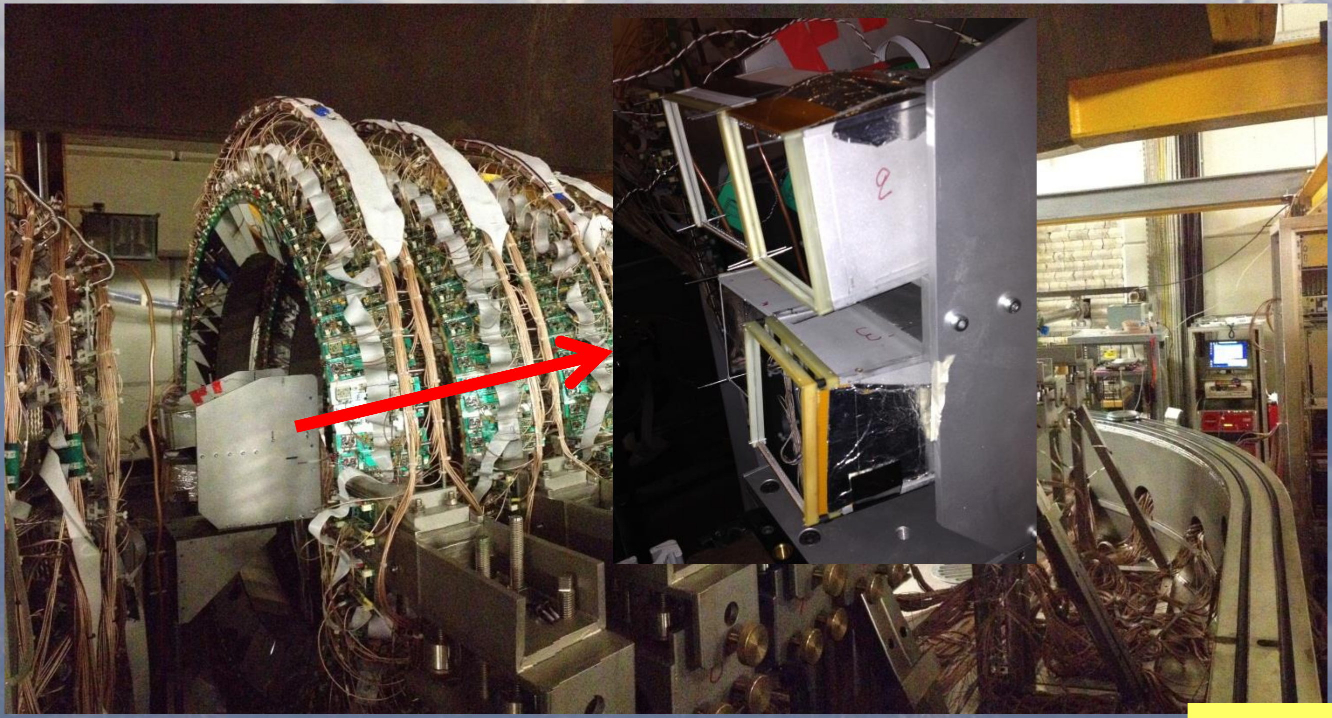
N. I. Ashwood et al Pl

G.Cardella hib@lns 2015

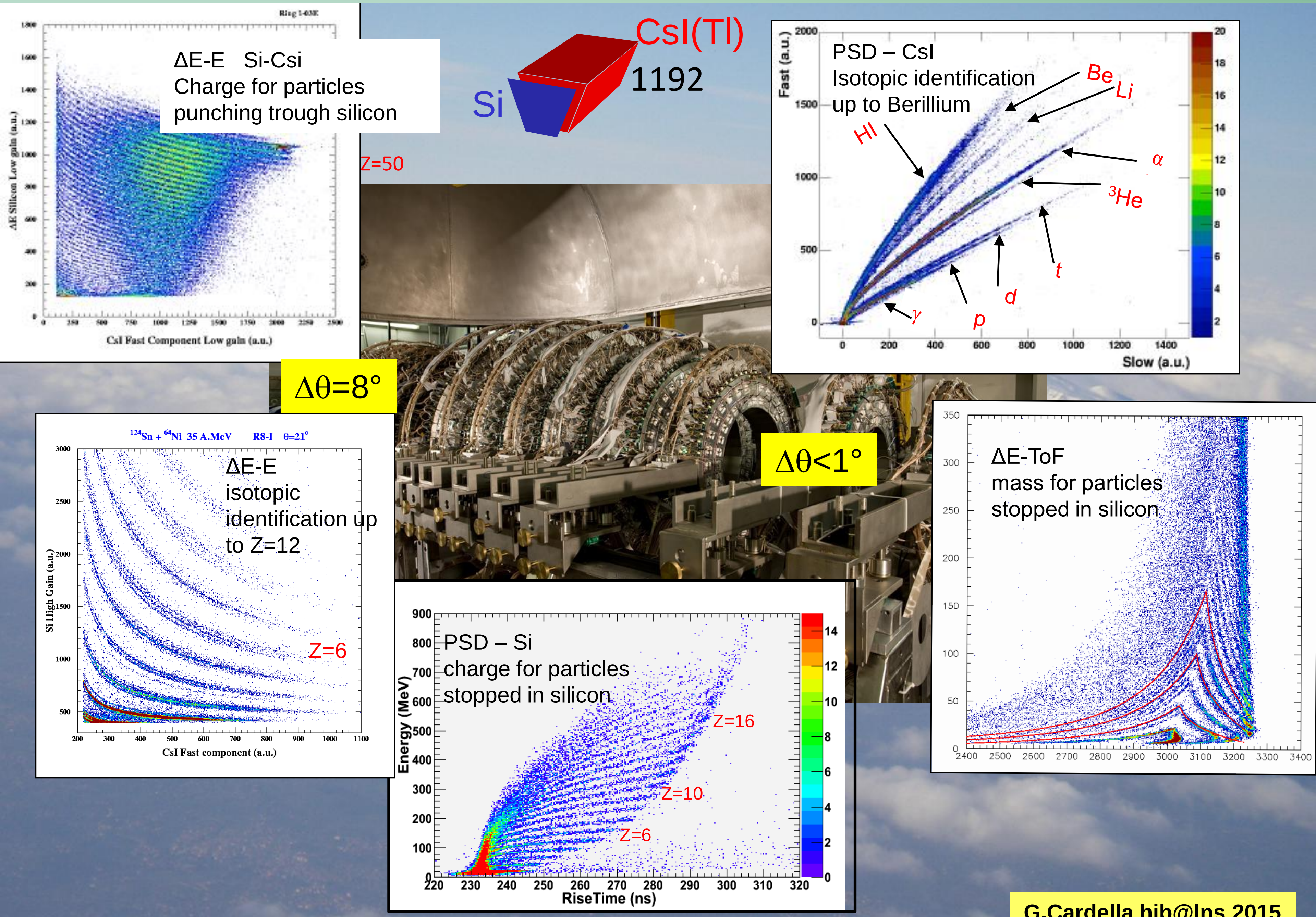
Improvement of the detection system

FARCOS 0°

For next experiments we will use FARCOS in configuration around 0° in order to have a kind of spectrometer to measure the quasi-projectile – light particles will be detected with CHIMERA using kinematical coincidence and beam trajectory measurement we will clean from background and extract more accurate excitation energies and CM angular distributions

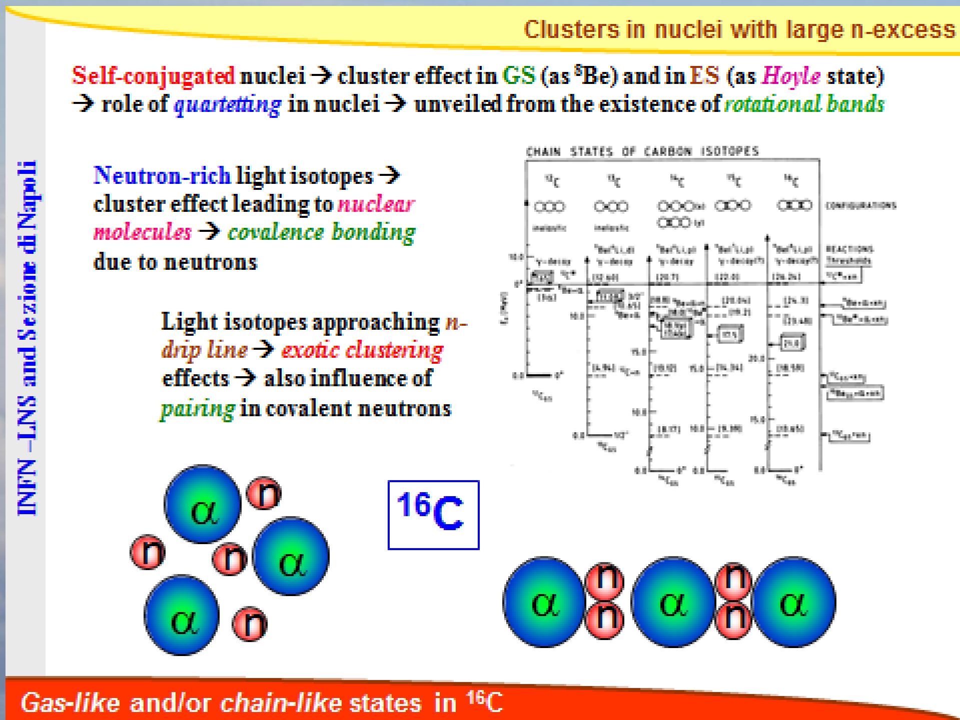


The CHIMERA detector : particle identification methods

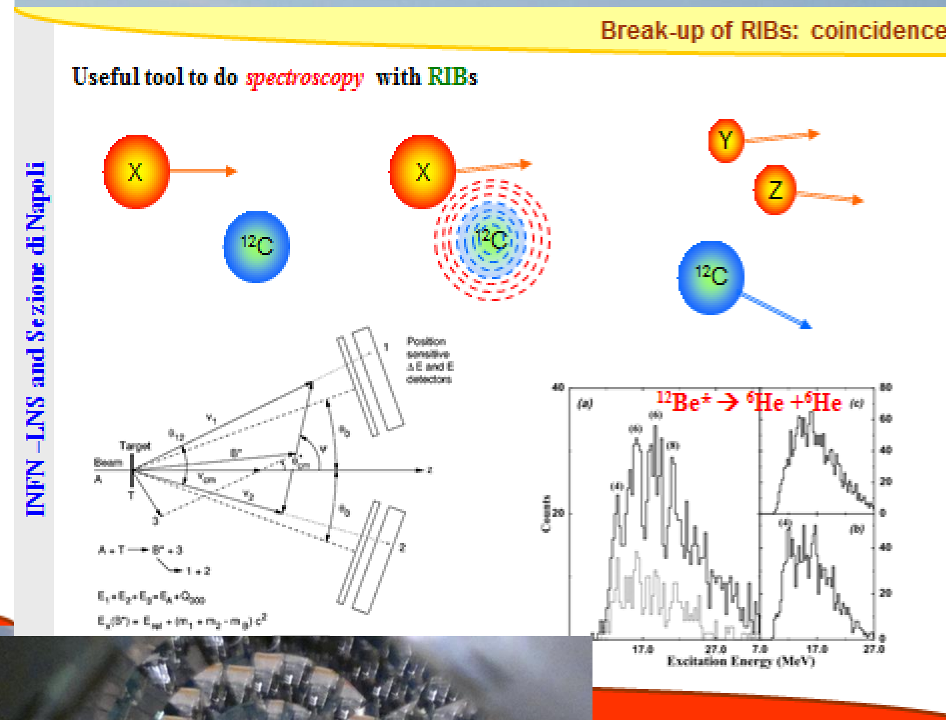


G.Cardella hib@lns 2015

Experiments to be done – CLIR with CHIMERA/FARCOS

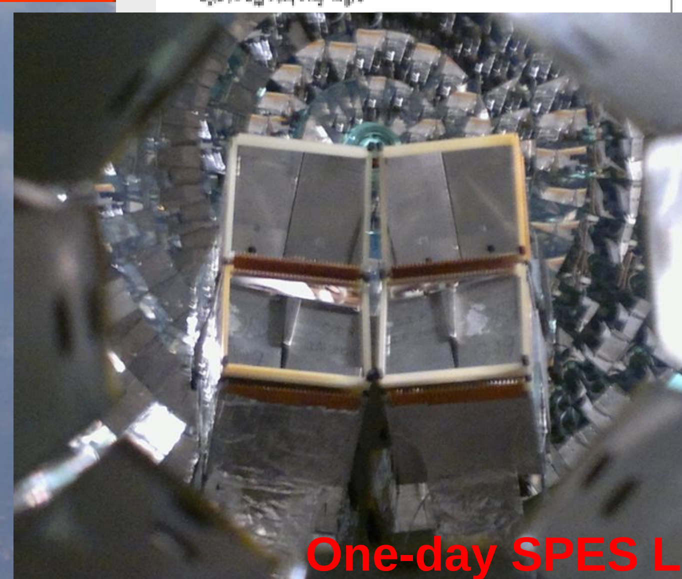


(Custers in Light Ion Reactions)



$^{16}C + ^{12}C$

Search for exotic decay of ^{16}C
(and the other available beams $^{10,11}Be$ ^{13}B …..)



One-day SPES LNS Oct 9th 2013

^{68}Ni Beam for the Pigmy experiment

^{68}Ni beam was recently produced at LNS in the framework of the TIMESCALEZN experiment

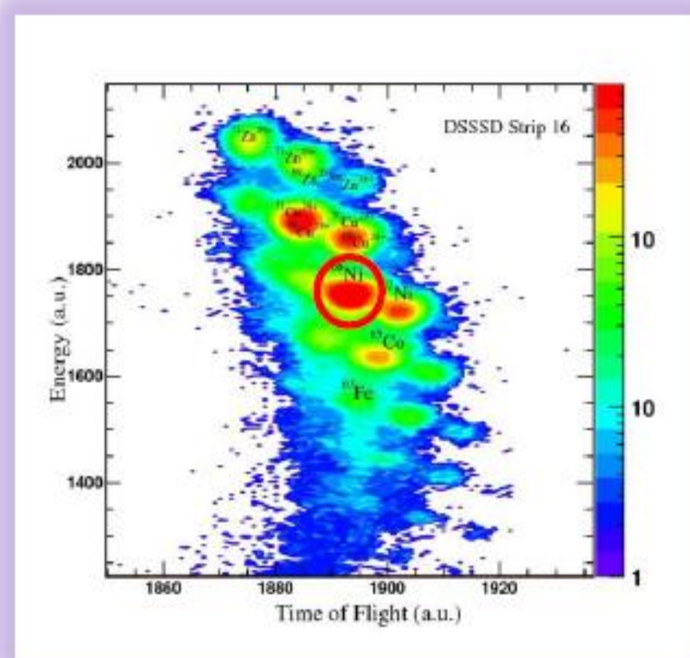


Fig.4 Identification scatter plot of ^{68}Ni fragmentation beam

The beam was produced via fragmentation of ^{70}Zn on a 0.25 mm ^{9}Be target at 40 MeV/A

A beam intensity of about $2x10^4$ part/sec/ 100 W primary beam was obtained

We also demonstrated that we can clean our beam from not fully stripped ions - The mylar foil of the tagging MCP is a stripper foil cleaning most of such contaminants – thank to this ^{68}Ni is the most intense beam transported