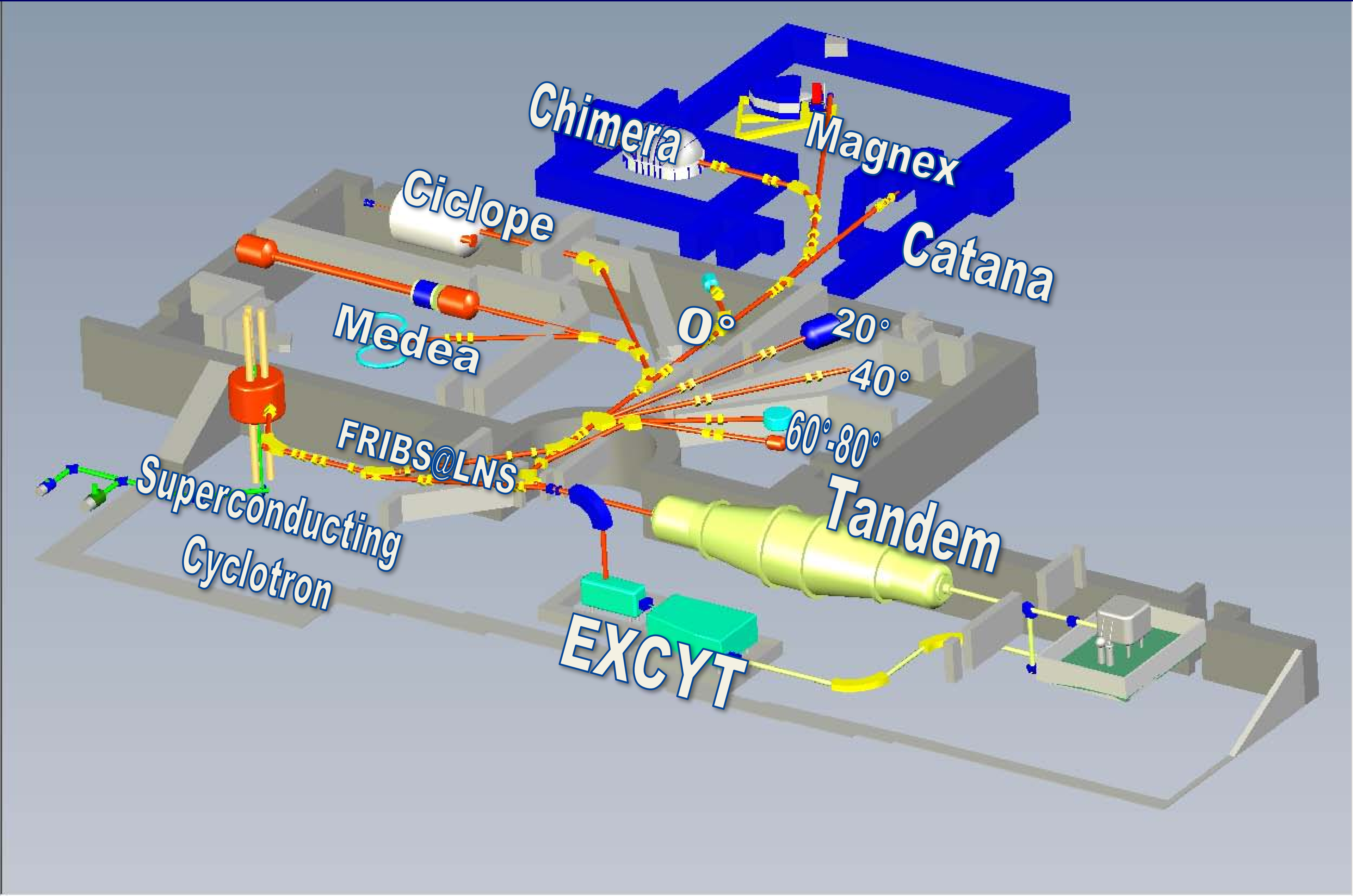
Status of the LNS accelerators

Danilo Rifuggiato

LNS Users Meeting

LNS, Catania, December 6, 2013

LNS lay-out: accelerators and experimental halls



Accelerator equipment for ion beam production

450 KV injector
2 sputtering
sources

Normal conducting
ECR source
CAESAR

Superconducting
ECR source SERSE

Upgrade of parts of the accelerators through the Project LNS Nuclear Astrophysics

Upgrade of the Tandem

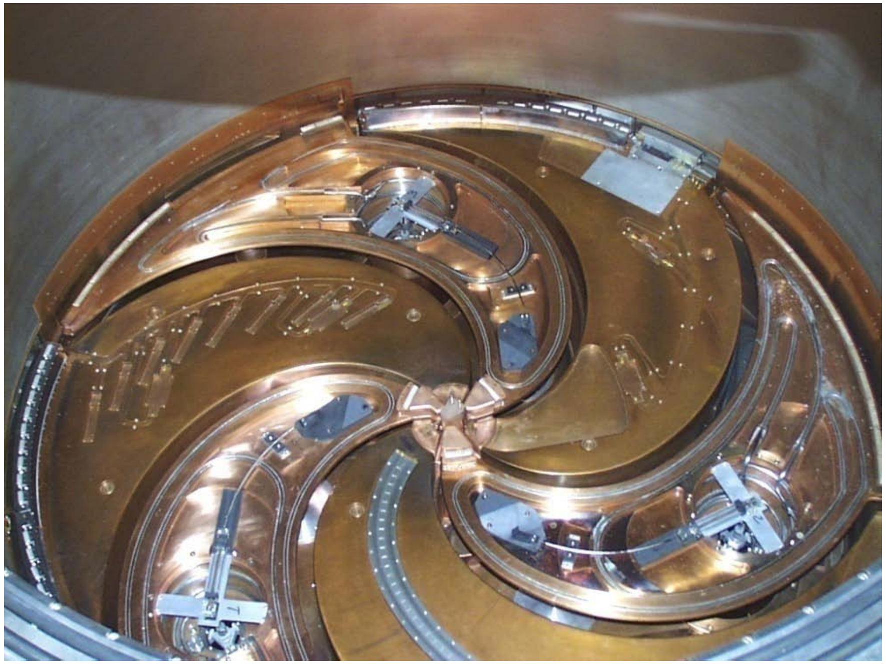
- **Replacement of 2 out of 8 accelerating tubes**
  € 237.000,00

- **Replacement of the belt charging system with the NEC pelletron system**
  US$ 598.845,50

Upgrade of parts of the accelerators through the Project LNS Nuclear Astrophysics

Contribution to the revamping of the helium liquefier

€ 155.000,00



Upgrade of parts of the accelerators through the Project LNS Nuclear Astrophysics

New cryogenic system for the superconducting ECR source SERSE

€ 300.000,00

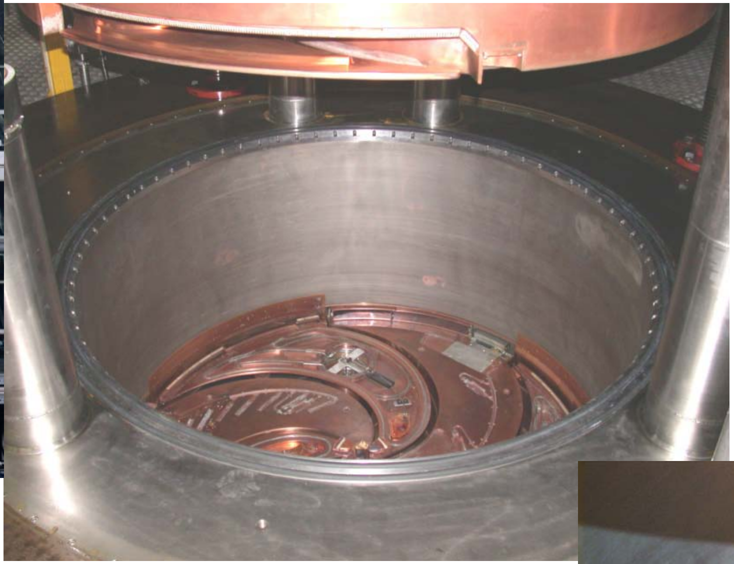
Superconducting ECR source SERSE

Normal conducting ECR source CAESAR

The LNS Superconducting Cyclotron

$(T/A)_{max} = K_{bending}\,(Q/A)^2 \sim$ 25 AMeV Au36+

$(T/A)_{max} = K_{focusing}\,(Q/A)$ ~100 AMeV fully stripped



Bending limit	K=800
Focusing limit	Kfoc=200
Pole radius	90 cm
Yoke outer radius	190.3 cm
Yoke full height	286 cm
Min-Max field	2.2-4.8 T
Sectors	3
RF range	15-48 MHz

Good timing 1 ns (4π detectors)

Reliability (protontherapy)

High intensity (radioactive beams)

Increasing the Cyclotron beam intensity

$^{13}C^{4+}$ @ 45 AMeV (EXCYT primary beam)
Pextr = 150 watt I=1020 enA= 1.5×10^{12} pps

Septum: directly cooled
New septum material: W vs. Ta
Bigger thickness: 0.3 vs. 0.15 mm
⇨extraction efficiency 63% vs. 50%

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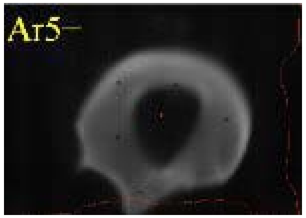

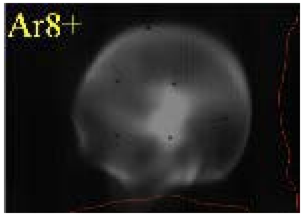

The source-cyclotron matching needs to be improved

Beam transport along the injection line is now being considered, following the MSU, JYFL, KVI methods

Superconducting Cyclotron status: Cryogenic problems in 2013

- **January 1st 2013 Breakdown of the helium liquefier: turbine found broken due to impurities (Air Liquide diagnosis) – restart on January 15 - Cyclotron operating on January 25**
- **May 2nd 2013 a new failure! Air Liquide inspection: again problems at the turbine - extraordinary maintenance and upgrade (revamping) needed to restore the reliability grade of the past 20 years**

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- **July 8th 2013 Economical offer for the revamping operation produced by Air Liquide after a heavy interaction (around 2 months)**
  Cost: 599.800 € taxes excluded
  Estimated time: 6 months from the order
  - **Reduced electrical expense (in advance from INFN) € 450.000**
  - **Budget of the Accelerator Division € 92.000**
  - **LNS Nuclear Astrophysics project € 190.000**

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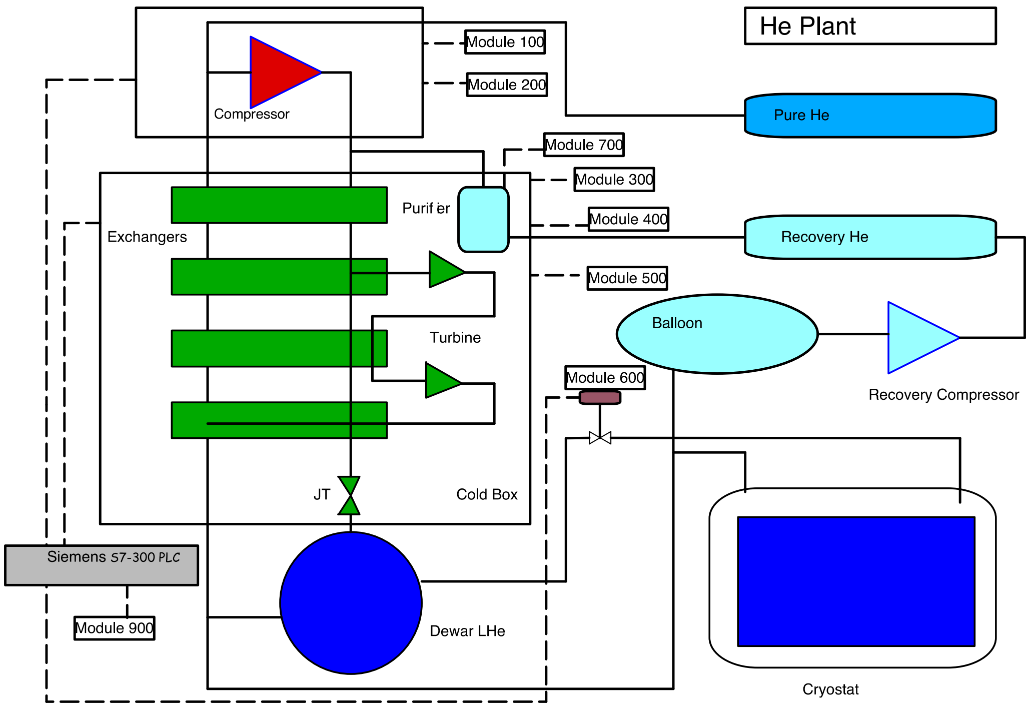
- **October 15th 2013 order issued**

Superconducting Cyclotron status: Cryogenic problems in 2013

Helial 4011 Revamping Planning : end on March 14th 2014

At the same time revision of the LN2 lines and the compressor maintenance € 130.000



Improvements on ECR sources: cryogenics of Serse and new injection system of Caesar

Limited availability of SERSE due to cryogenic problems

Autonomous system based on Helium recondensation

1) **Dimensioned and designed - cost defined to be around 300 k€ : project LNS Nuclear Astrophysics**
2) **Realization : a) purchase of cryocoolers just done 128 k€ b) assembling of cryocoolers and high TC current leads → second half of 2014**

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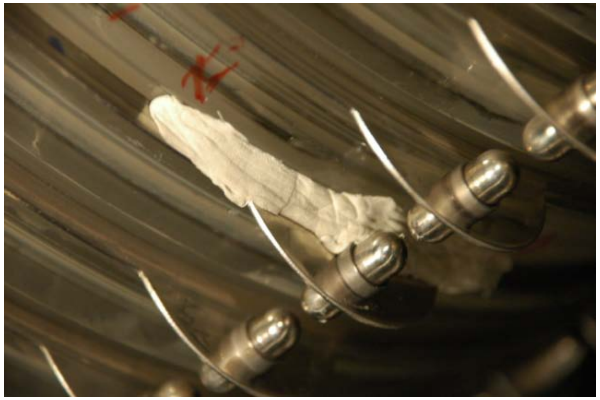
New beams with CAESAR new injection system

- **metallic species through the installation of an oven: in 2014 after the implementation of the new control system**
- **MIVOC technique for production of “difficult beams”, for instance ^{11}B for production of ^{8}He with FRIBS@LNS tests done – feasibility demonstrated**

Tandem status

Vacuum losses in the first accelerating tube

- difficult to be located $<5 \cdot 10^{-5}$ mbar•lt/s (limited access)
- high residual pressure in the Low Energy section: $4 \cdot 10^{-6}$ mbar
- once roughly located, fixed by means of a vacuum sealant
- done three times - after few months the problem appears again



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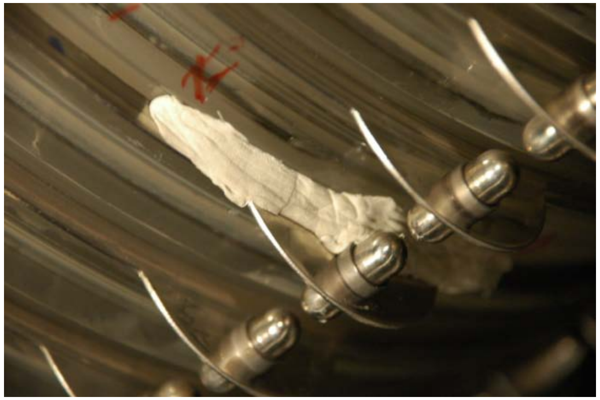


The replacement of the first accelerating tube is mandatory – the eighth tube looks damaged in several regions so it was decided to replace it too

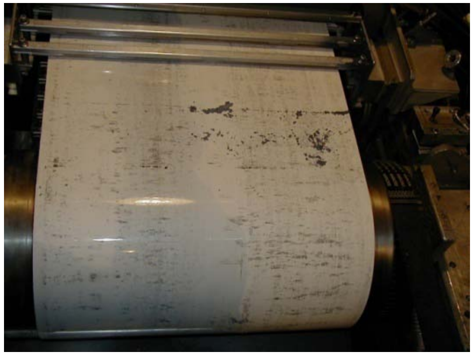
Cost 237.000 € project LNS Nuclear Astrophysics – supplied by VIVIRAD (France) – contract approved by the INFN Executive Board – waiting for documents - expected delivery in May 2014

Tandem status

Charging system

Original (HVEC) belts are not any longer available

Several attempts with belts produced by different companies



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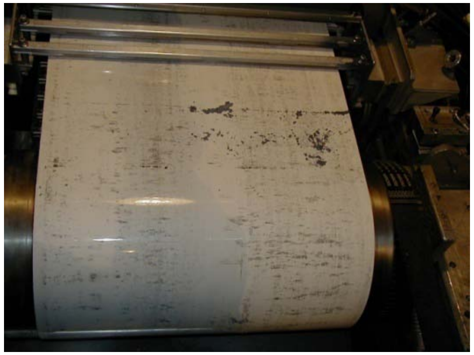


Another attempt ………… after only few weeks

Tandem status

Charging system

The insulating material does not resist to temperature and discharges

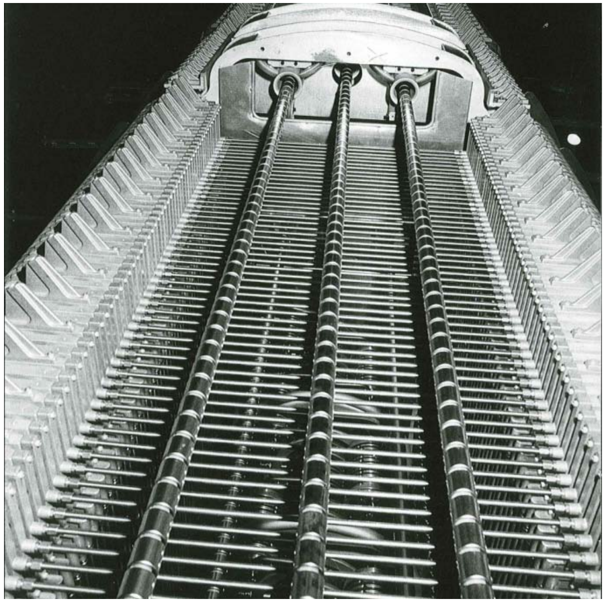
The belt must have good mechanical and electrical characteristics -no company available to improve them

Alternative to the belt : Pelletron by NEC

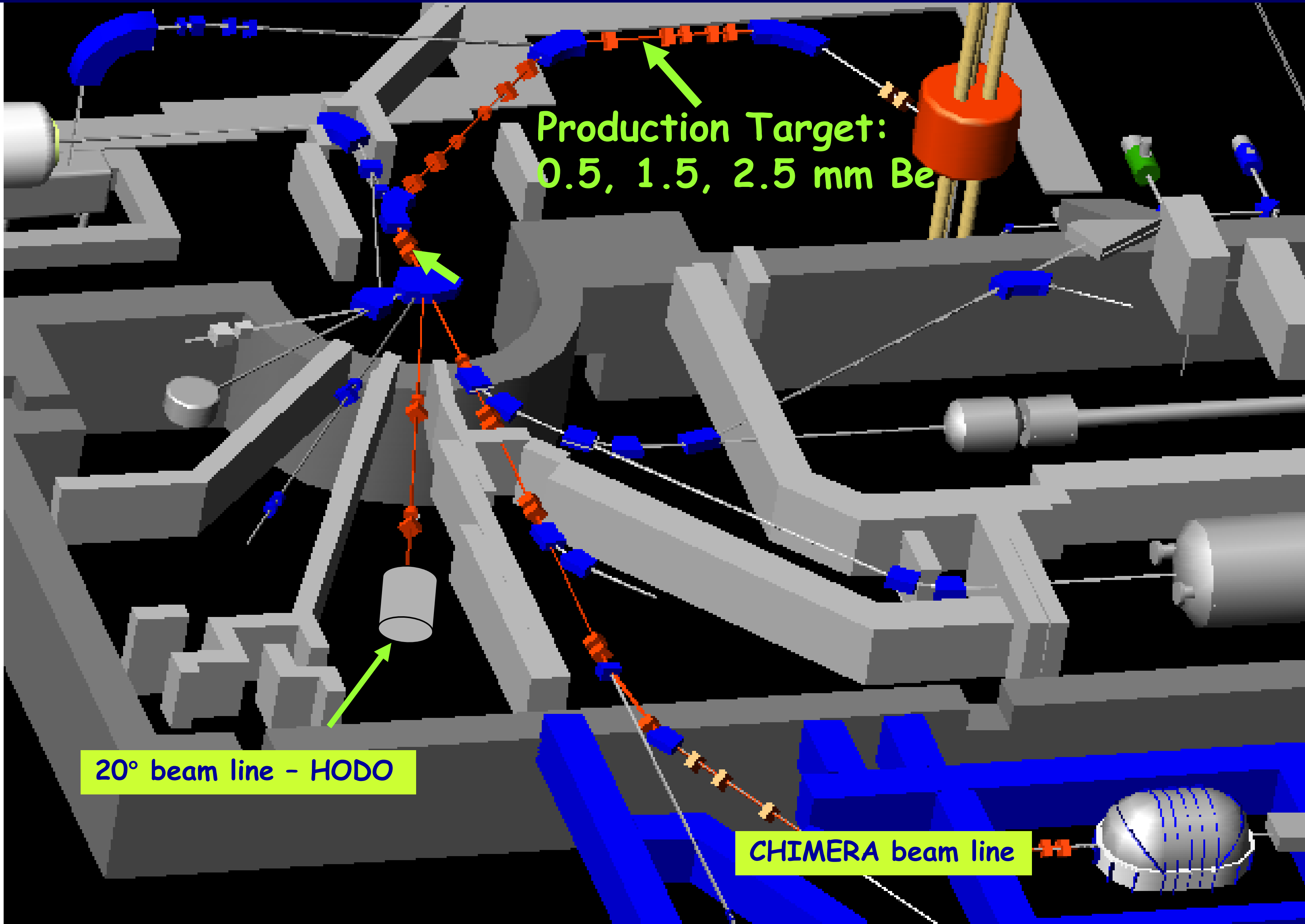
Order to NEC dated July 25 2013: 598.845,50 $ project LNS Nuclear Astrophysics - Time needed for installation: 2 months - Delivery in or before December 2014

From the belt

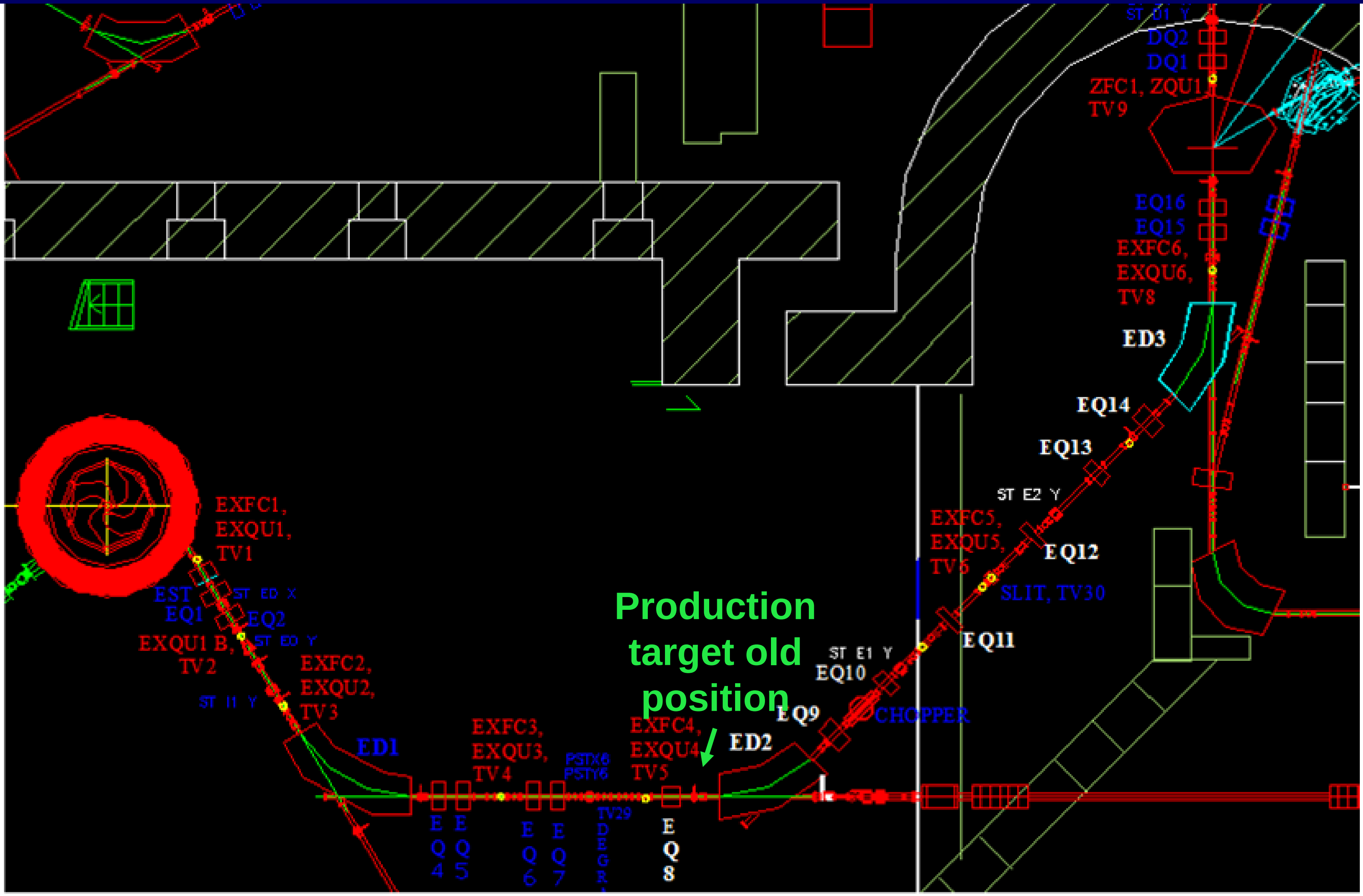
to the Pelletron



FRIBS@LNS: in Flight Radioactive Ion BeamS

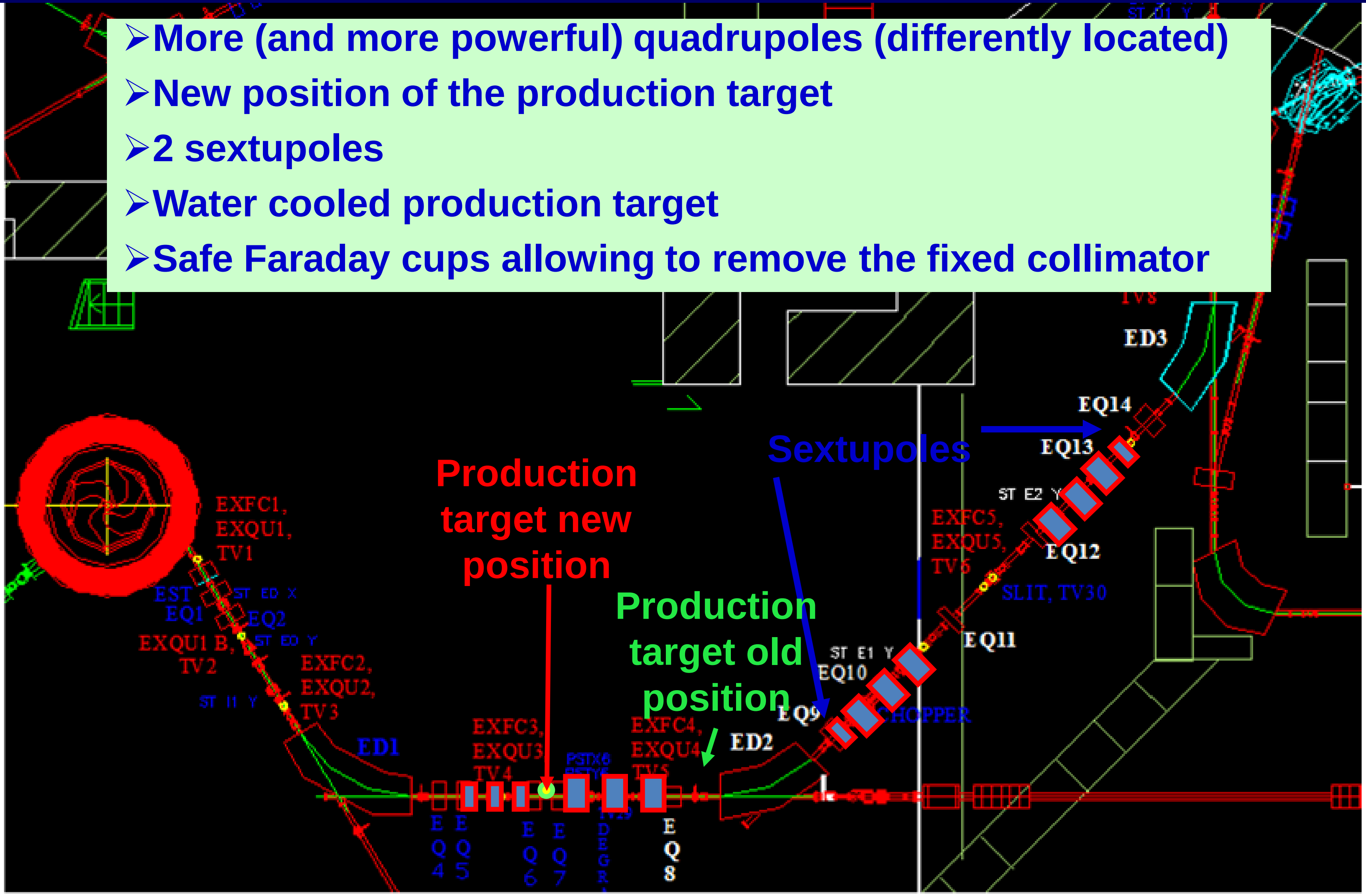


Improvements of FRIBS@LNS

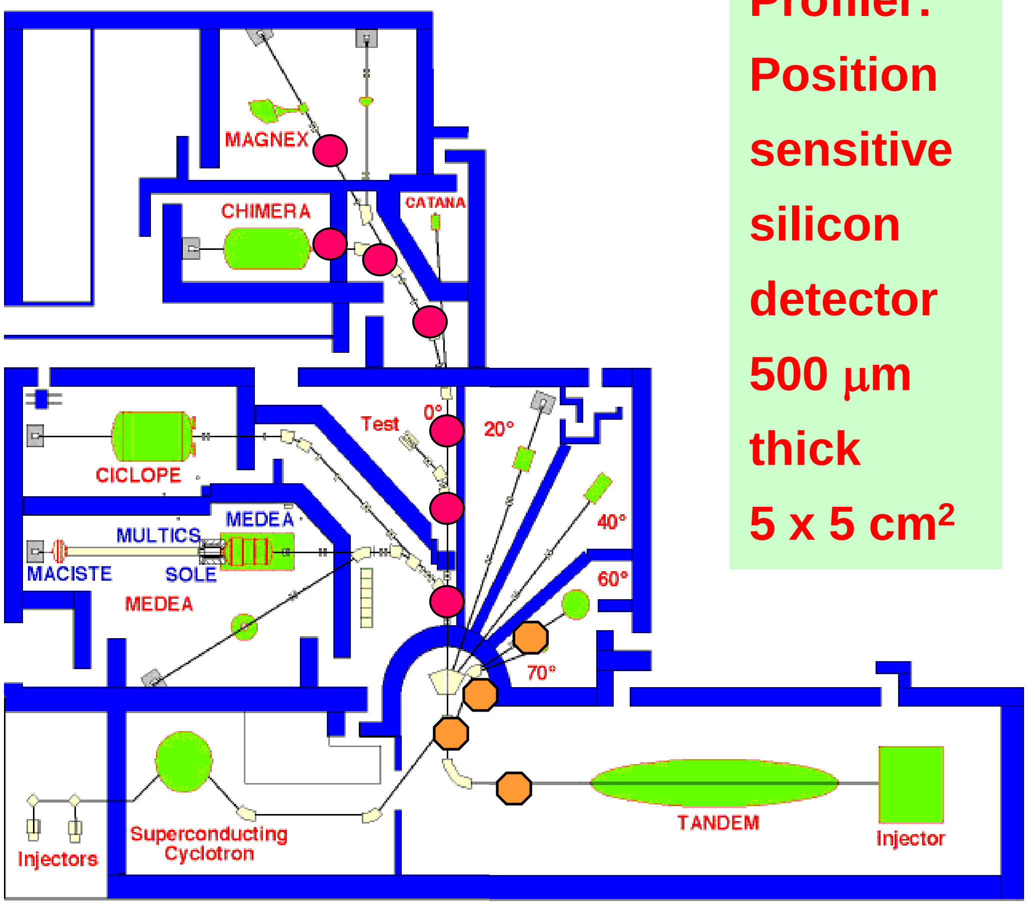


Improvements of FRIBS@LNS

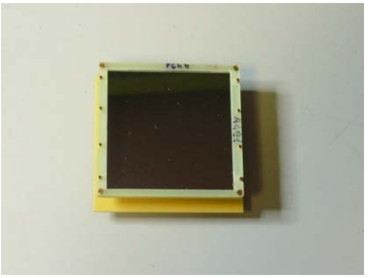
- More (and more powerful) quadrupoles (differently located)
- New position of the production target
- 2 sextupoles
- Water cooled production target
- Safe Faraday cups allowing to remove the fixed collimator

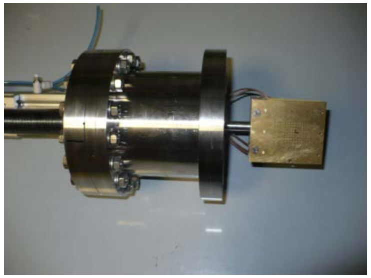


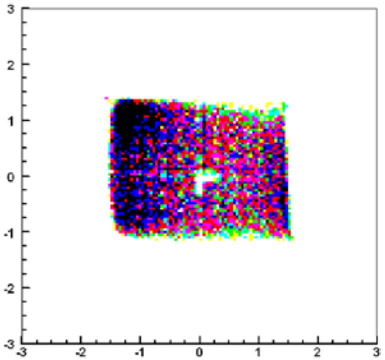
Low intensity diagnostics in the Chimera and Magnex beam lines



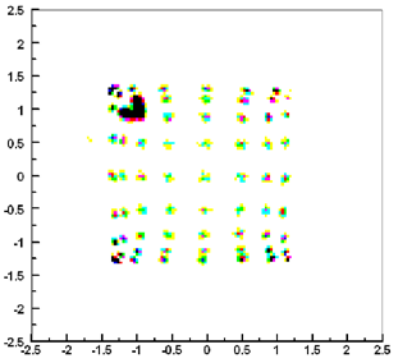
Profiler:
Position sensitive silicon detector
500 μm thick
5 x 5 cm^2





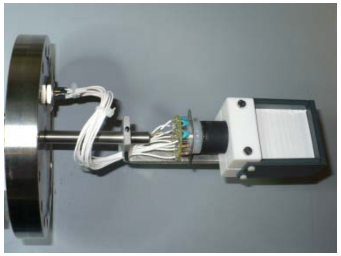


Cyclotron beam

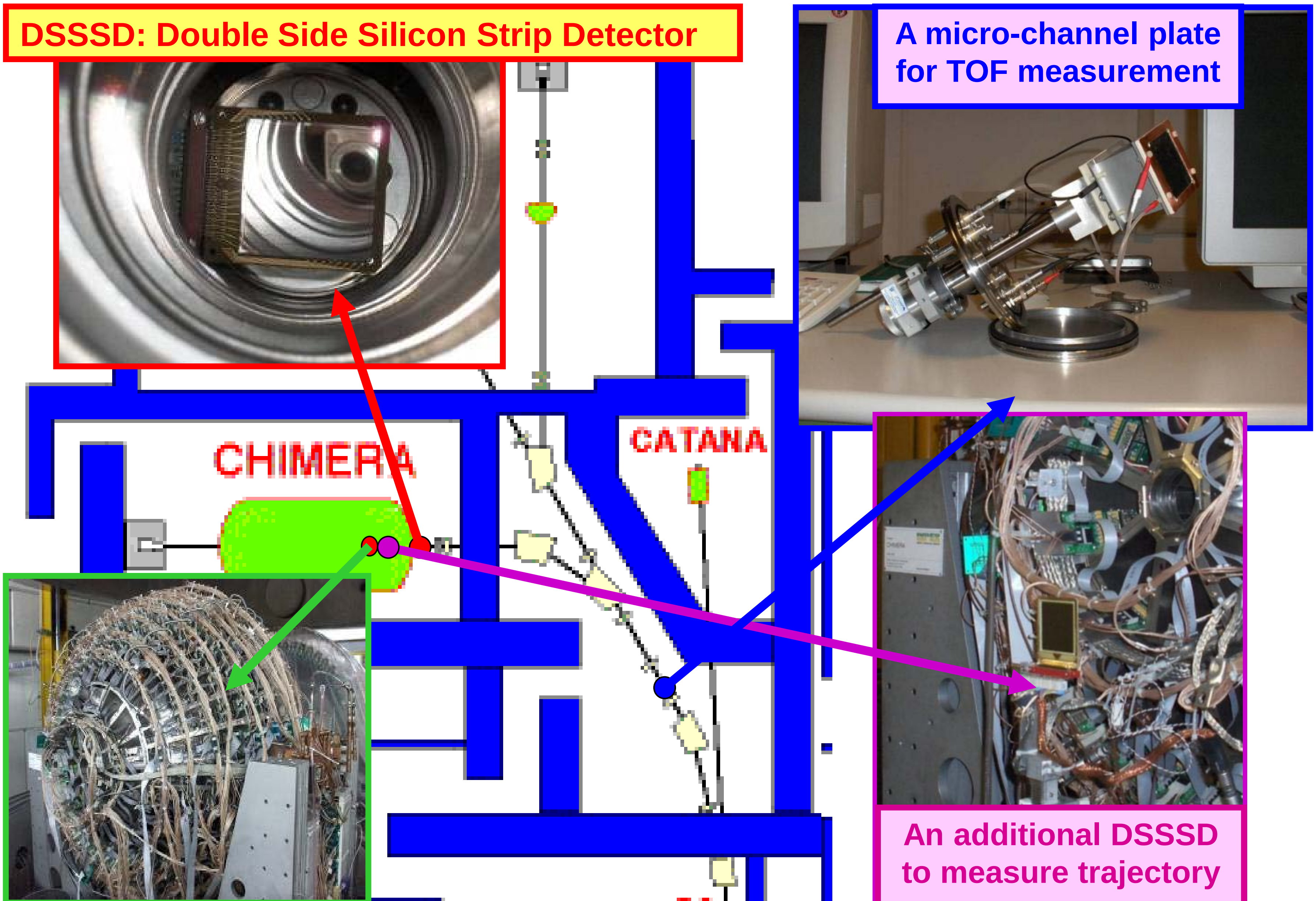


Tandem beam

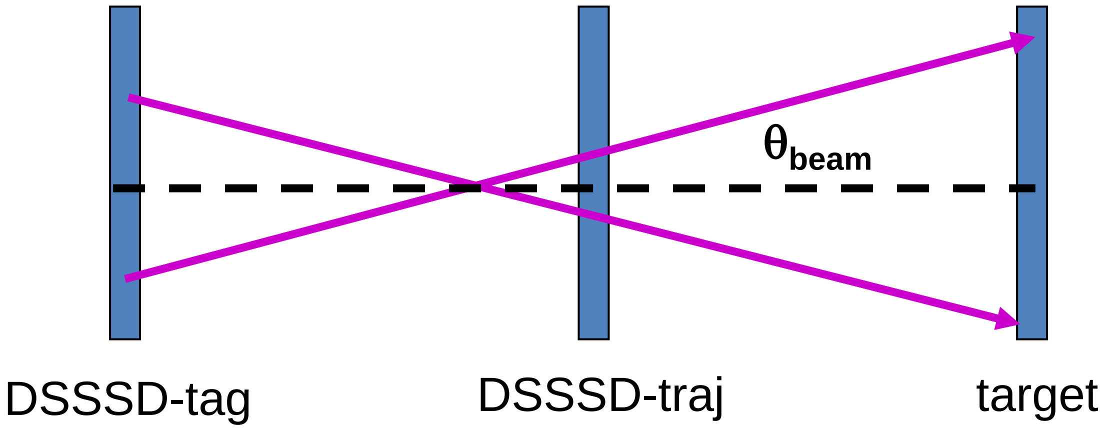
Counter: plastic scintillator BC408 + PM

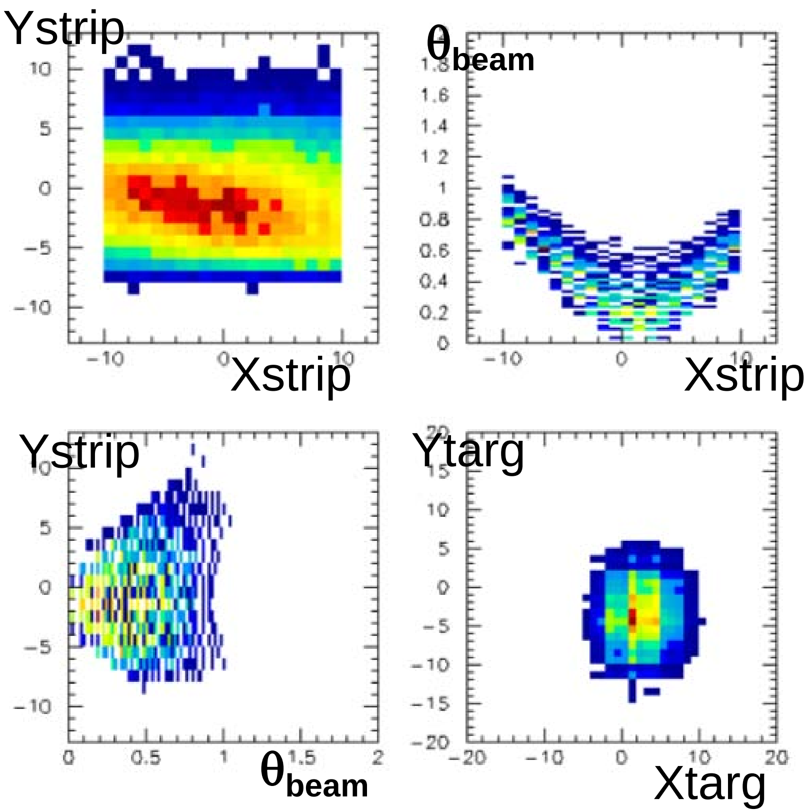


FRIBS@LNS tagging system



FRIBS@LNS beam on target

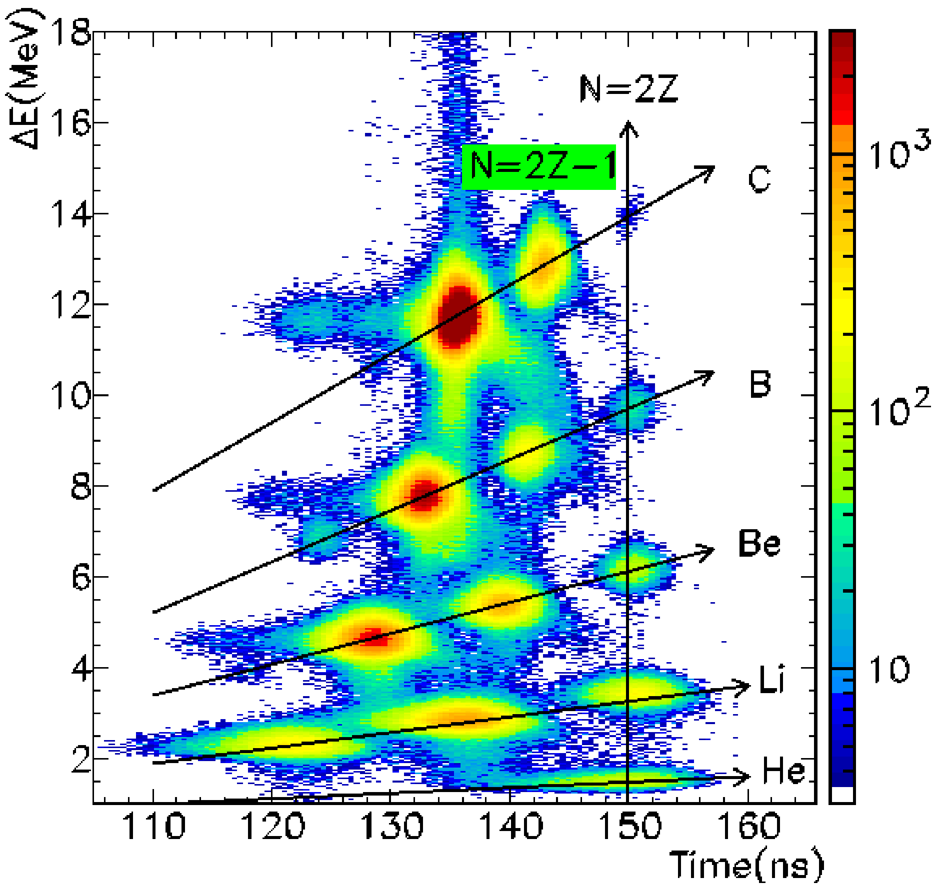


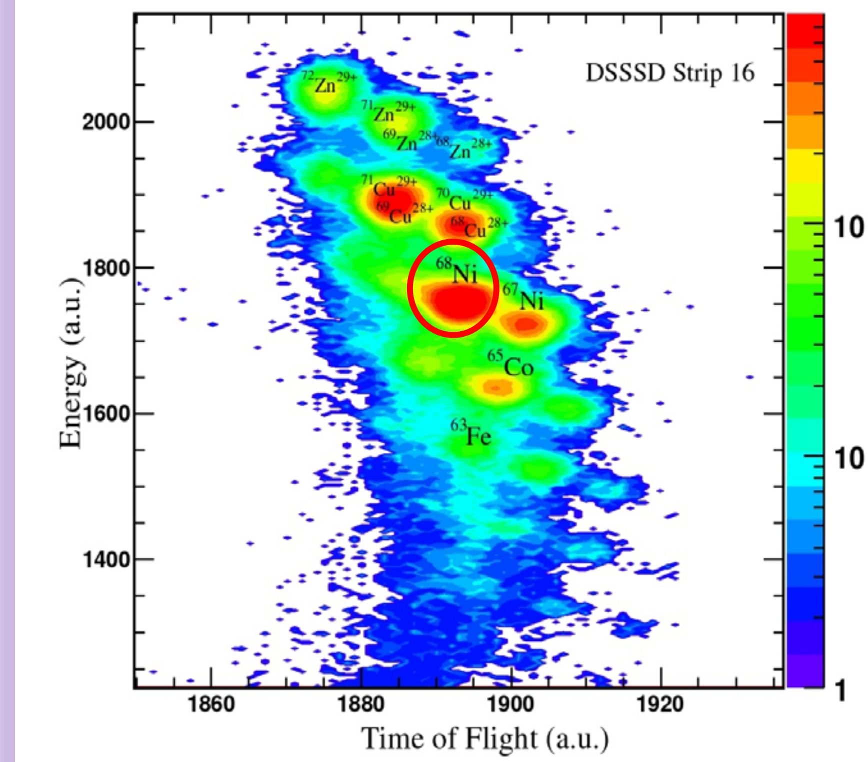


It is possible to produce a focused beam on target – with a very small divergence

Courtesy of G. Cardella

FRIBS@LNS beam identification





Production of a ≈45 AMeV ^{16}C beam by means of a $^{18}O^{7+}$ 55 AMeV primary beam impinging on a 500 μm ^{9}Be target

Production of a ≈30 AMeV ^{68}Ni beam by means of a $^{70}Zn^{19+}$ 40 AMeV primary beam impinging on a 250 μm ^{9}Be target

Beams developed at FRIBS@LNS

primary beam	beam	intensity (kHz/100W)
18O 55 AMeV	16C	120
setting 11Be	17C	12
	13B	80
	11Be	20
	10Be	60
	8Li	20
18O 55 AMeV	14B	3
setting 12Be	12Be	5
	9Li	6
	6He	12
13C 55 AMeV	11Be	50
setting 11Be	12B	100
36Ar 42 AMeV	37K	100
setting 34Ar	35Ar	70
	36Ar	100
	37Ar	25
	33Cl	10
	34Cl	50
	35Cl	50
20Ne 35 AMeV	18Ne	50
setting ne18	17F	20
	21Na	100
70Zn 40 AMeV		
setting 68Ni	68Ni	20

Beams to be delivered in 2014-2015 to approved experiments

^{16}C (CHIMERA)

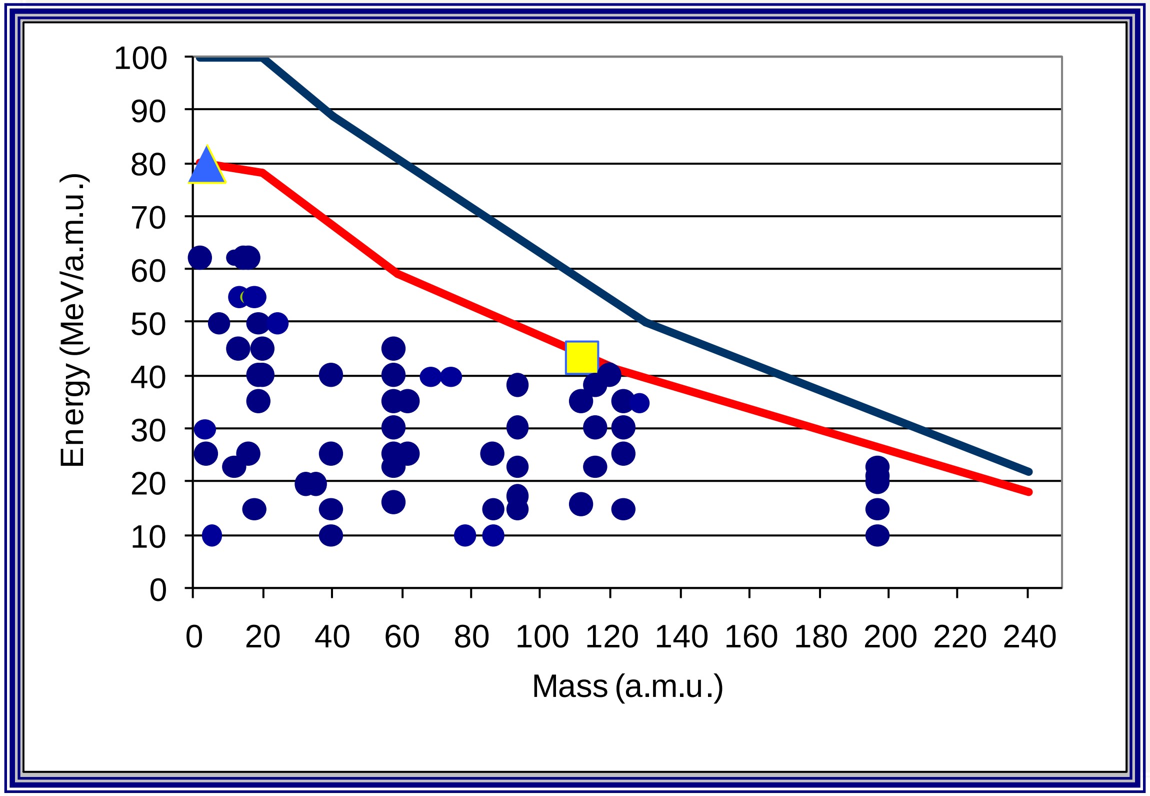
^{68}Ni (CHIMERA)

^{8}He (CHIMERA) new

^{14}Be (test experiment) new

^{38}S (MAGNEX) new

Superconducting Cyclotron beams developed



^{4}He 80 AMeV

^{112}Sn 43.5 AMeV

In red beams with intensity 10^{12} pps

^{A}X	E (AMeV)
H_2^+	62,80
H_3^+	30,35,45
$^{2}D^+$	35,62,80
^{4}He	25,62,80
He-H	10, 21
^{9}Be	45
^{11}B	55
^{12}C	23,62,80
^{13}C	45,55
^{14}N	62,80
^{16}O	21,25,55,62,80
^{18}O	15,55
^{19}F	35,40,50
^{20}Ne	20,40,45,62
^{24}Mg	50
^{27}Al	40
^{36}Ar	16,38
^{40}Ar	15,20,40
^{40}Ca	10,25,40,45
^{48}Ca	10,45
^{58}Ni	16,23,25,30,35,40,45
^{62,64}Ni	25,35
^{68,70}Zn	40
^{74}Ge	40
^{78,86}Kr	10
^{84}Kr	10,15,20,25
^{93}Nb	15,17,23,30,38
^{107}Ag	40
^{112}Sn	15.5,35,43.5
^{116}Sn	23,30,38
^{124}Sn	15,25,30,35
^{129}Xe	20,21,23,35
^{197}Au	10,15,20,21,23
^{208}Pb	10

Beams developed at the Tandem source

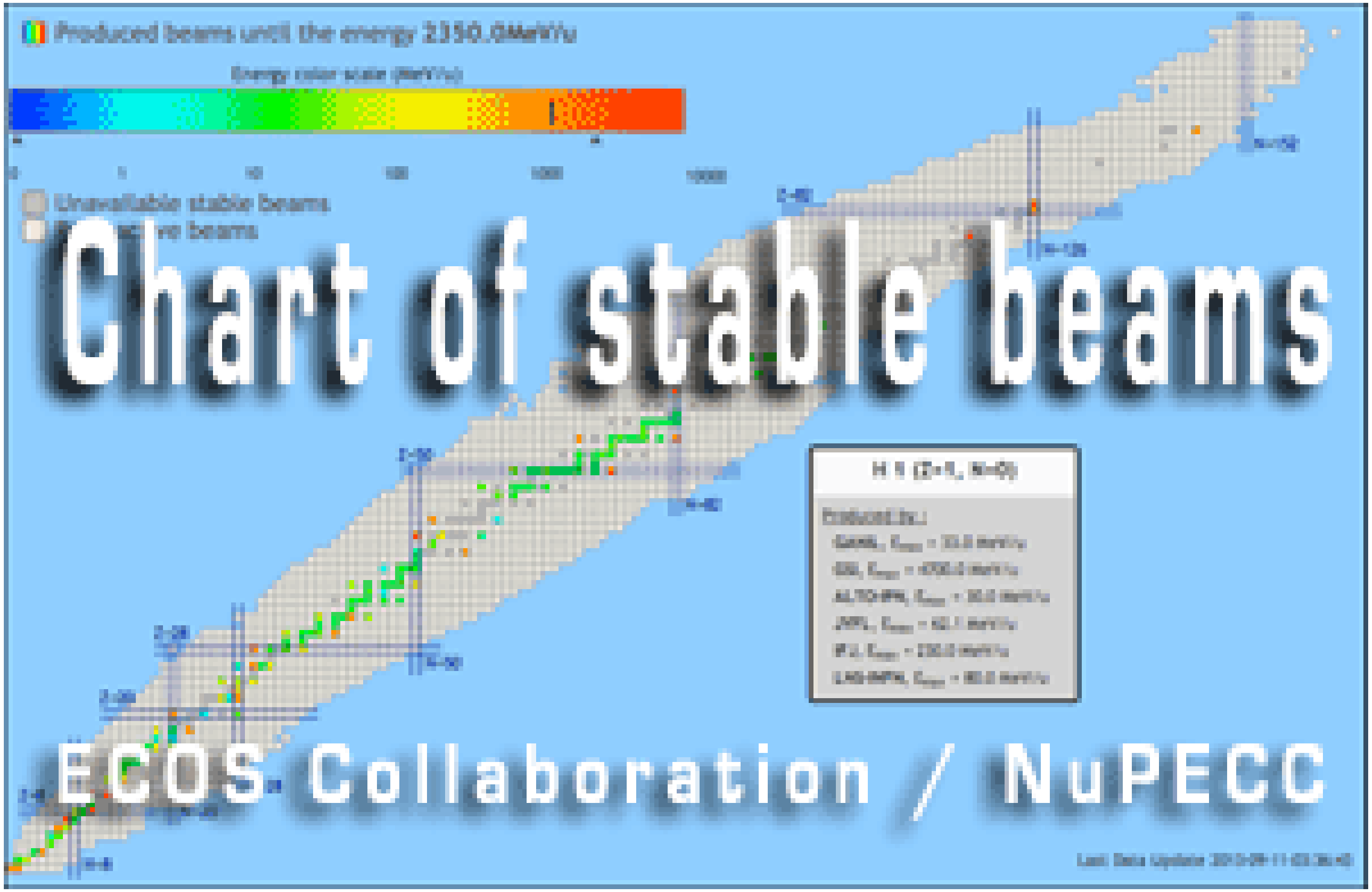
Negative ions	Intensity (nA)
^{1}H	1500
^{2}D	1500
^{6}Li	250
^{7}Li	250
^{9}Be (as BeO)	200
^{10}B	300
^{11}B	300
^{12}C	700
^{13}C	150
^{14}N (as CN)	400
^{16}O	700
^{17}O	700
^{18}O	700
^{19}F	700
^{27}Al	200
^{28}Si	400
^{29}Si	300
^{32}S	400
^{34}S	200
^{35}Cl	400
^{37}Cl	300
^{40}Ca (as CaH_3)	150
^{58}Ni	700
^{60}Ni	300
^{63}Cu	400
^{65}Cu	400
^{70}Ge	500
^{79}Br	200
^{93}Nb (as NbC)	200
^{116}Sn	200
^{120}Sn	250
^{127}I	300
^{197}Au	700

Available stable beams at LNS

Isotope		Acceleration energy (MeV/A)		Corresponding intensities (PPS)		Observation	Accelerator	
Element	A	Minimum	Maximum	Minimum	Maximum		Min.energy	Max. energy
Hydrogen	1	4	80	1,00E+03	1,00E+11		Tandem	Cyclotron
Deuterium	2	2	80	1,00E+03	1,00E+11		Tandem	Cyclotron
Helium	4	10	80	1,00E+03	1,00E+12		Cyclotron	Cyclotron
Lithium	6	1,5	8,7	1,00E+03	1,00E+11		Tandem	Tandem
Lithium	7	1,3	7,4	1,00E+03	1,00E+11		Tandem	Tandem
Beryllium	9	1,6	55	1,00E+03	1,00E+10		Tandem	Cyclotron
Boron	10	1,2	6,5	1,00E+03	1,00E+11		Tandem	Tandem
Boron	11	1,3	55	1,00E+03	1,00E+12		Tandem	Cyclotron
Carbon	12	1	80	1,00E+03	1,00E+12		Tandem	Cyclotron
Carbon	13	1	55	1,00E+03	1,00E+12		Tandem	Cyclotron
Nitrogen	14	0,8	80	1,00E+03	1,00E+12		Tandem	Cyclotron
Nitrogen	15	0,8	6	1,00E+03	1,00E+11		Tandem	Tandem
Oxygen	16	0,7	80	1,00E+03	1,00E+12		Tandem	Cyclotron
Oxygen	17	0,7	6,9	1,00E+03	1,00E+11		Tandem	Tandem
Oxygen	18	0,7	55	1,00E+03	1,00E+12		Tandem	Cyclotron
Fluorine	19	0,6	50	1,00E+03	1,00E+11		Tandem	Cyclotron
Neon	20	10	62	1,00E+03	1,00E+12		Cyclotron	Cyclotron
Magnesium	24	10	50	1,00E+03	1,00E+10		Cyclotron	Cyclotron
Aluminum	27	0,9	50	1,00E+03	1,00E+10		Tandem	Cyclotron
Silicon	28	0,9	6,9	1,00E+03	5,00E+10		Tandem	Tandem
Silicon	29	0,9	6,7	1,00E+03	5,00E+10		Tandem	Tandem
Sulphur	32	0,9	50	1,00E+03	5,00E+10		Tandem	Cyclotron
Sulphur	34	0,9	6,5	1,00E+03	5,00E+10		Tandem	Tandem
Chlorine	35	0,9	6,9	1,00E+03	5,00E+10		Tandem	Tandem
Chlorine	37	0,9	6,7	1,00E+03	5,00E+10		Tandem	Tandem
Argon	36	10	50	1,00E+03	1,00E+12		Cyclotron	Cyclotron
Argon	40	10	50	1,00E+03	1,00E+12		Cyclotron	Cyclotron
Calcium	40	0,9	45	1,00E+03	2,00E+10		Tandem	Cyclotron
Calcium	48	10	45	1,00E+03	2,00E+10		Cyclotron	Cyclotron
Nickel	58	0,7	45	1,00E+03	2,00E+10		Tandem	Cyclotron
Nickel	60	0,7	45	1,00E+03	2,00E+10		Tandem	Cyclotron
Nickel	62	10	45	1,00E+03	2,00E+10		Cyclotron	Cyclotron
Nickel	64	10	45	1,00E+03	2,00E+10		Cyclotron	Cyclotron
Copper	63	0,7	5	1,00E+03	3,00E+10		Tandem	Tandem
Copper	65	0,7	4,8	1,00E+03	3,00E+10		Tandem	Tandem
Zinc	68	10	45	1,00E+03	5,00E+11		Cyclotron	Cyclotron
Zinc	70	10	45	1,00E+03	5,00E+11		Cyclotron	Cyclotron
Germanium	74	0,7	45	1,00E+03	3,00E+10		Tandem	Cyclotron
Bromine	79	0,7	45	1,00E+03	1,00E+10		Tandem	Cyclotron
Krypton	78	10	45	1,00E+03	1,00E+11		Cyclotron	Cyclotron
Krypton	84	10	45	1,00E+03	1,00E+11		Cyclotron	Cyclotron
Krypton	86	10	45	1,00E+03	1,00E+11		Cyclotron	Cyclotron
Niobium	93	0,6	45	1,00E+03	1,00E+10		Tandem	Cyclotron
Silver	107	10	43,5	1,00E+03	2,00E+10		Cyclotron	Cyclotron
Tin	112	10	43,5	1,00E+03	2,00E+10		Cyclotron	Cyclotron
Tin	116	0,5	40	1,00E+03	2,00E+10		Tandem	Cyclotron
Tin	120	0,5	40	1,00E+03	2,00E+10		Tandem	Cyclotron
Tin	124	10	40	1,00E+03	2,00E+10		Cyclotron	Cyclotron
Iodine	127	0,5	2,6	1,00E+03	1,00E+10		Tandem	Tandem
Xenon	124	10	40	1,00E+03	5,00E+10		Cyclotron	Cyclotron
Xenon	129	10	35	1,00E+03	5,00E+10		Cyclotron	Cyclotron
Erbium	168	10	30	1,00E+03	1,00E+10		Cyclotron	Cyclotron
Gold	197	0,3	25	1,00E+03	1,00E+10		Tandem	Cyclotron
Lead	208	10	25	1,00E+03	5,00E+09		Cyclotron	Cyclotron

Chart of stable beams

Chart of stable beams is now available on GANIL-SPIRAL2 utilities web site:
http://u.ganil-spiral2.eu/chart-ecos



Beam availability at LNS

Superconducting Cyclotron (including FRIBS@LNS beams)

expected to be operating in April 2014 after the liquefier revamping

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- **Proposals submitted to the PAC once per year – ENSAR TNA support available**
- **last PAC meeting in June 2013 270 BTU assigned to experiments to be performed until July 2015 due to the liquefier revamping**

Beam availability at LNS

Tandem

- until April 2014 working with an old belt to allow for experiments running with **7-10 MV**
- Upgrade program: in **May-June 2014** the accelerating tubes will be replaced, at the **end of 2014** the pelletron will be installed
- After the upgrade: available beam time of the order of **450 BTU** - up to now the beam demand has been **300 BTU on the average**
- Proposals submitted to the PAC once per year – ENSAR TNA support available

Thank you for your attention