Fragmentation beams at LNS: recent results

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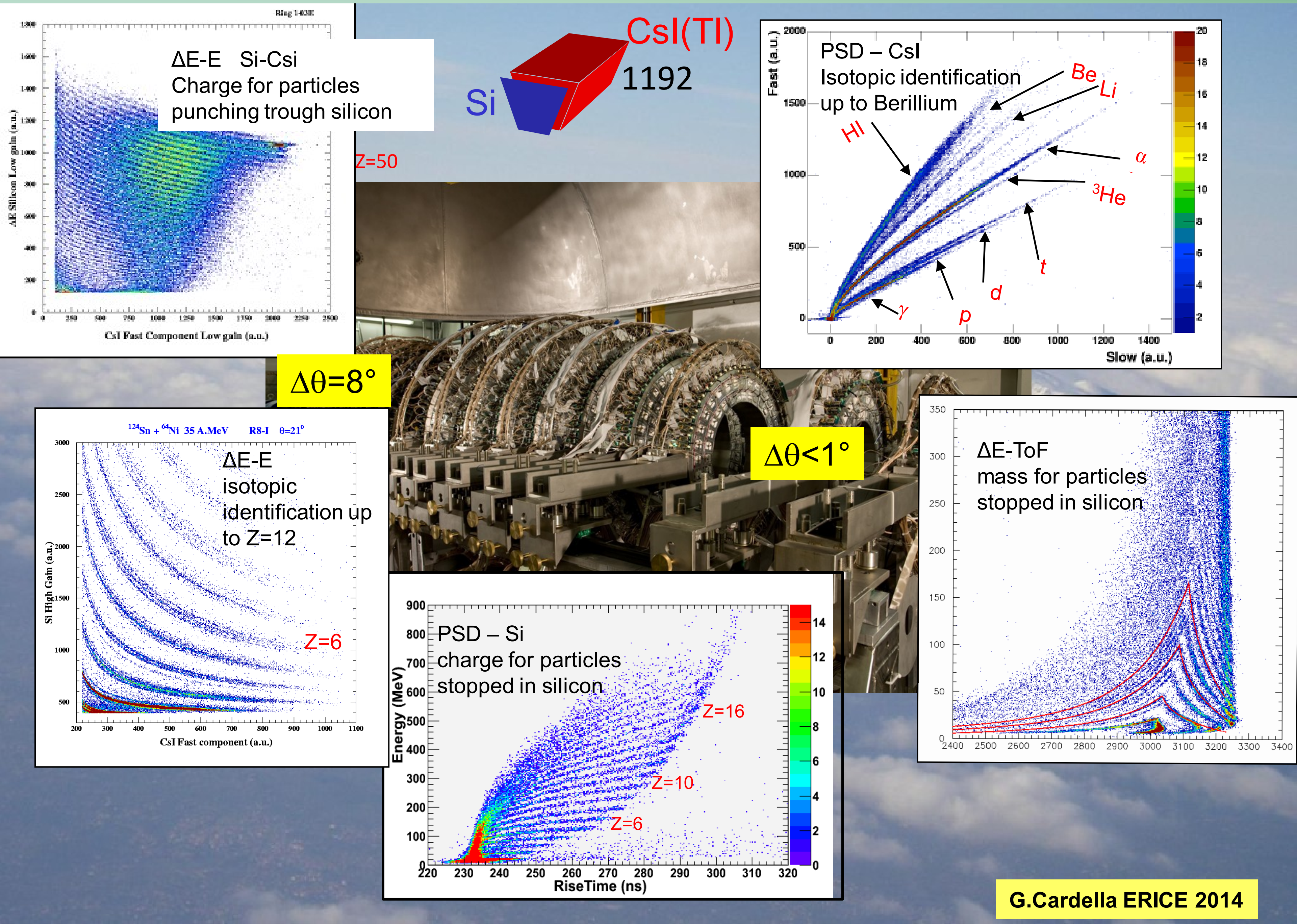
for the
EXOCHIM collaboration

International School of Nuclear Physics
36th Course
Nuclei in the Laboratory and in the Cosmos
Erice-Sicily
September 16-24, 2014

Outline

- Short presentation of the CHIMERA detector and LNS fragmentation beams
- Some results on transfer and break-up
- Possibility to measure in coincidence particles, γ-rays and neutrons
- Next measurements on Pigmy resonances and symmetry energy
- Conclusions and perspectives

The CHIMERA detector : particle identification methods

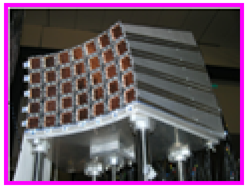


The most recent result we have obtained on symmetry energy

ASY-EOS S394 experiment @ GSI Darmstadt (May 2011)

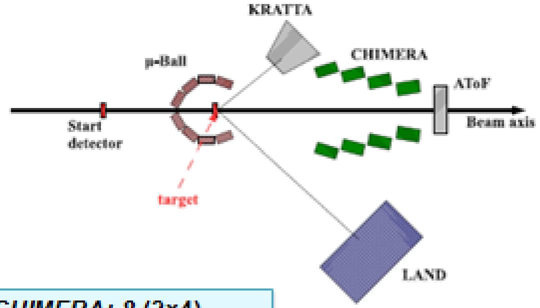
Au+Au, ^{96}Zr+^{96}Zr , ^{96}Ru+^{96}Ru @ 400 AMev

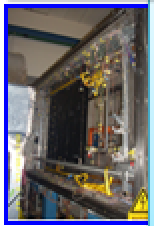
uBall: 4 rings CsI(Tl), Θ>60°. Discriminate real target vs. air interactions at backward angles. Multiplicity measurements.



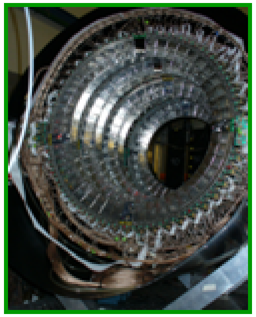
Kracow array: 35 (5x7) triple telescopes (Si-CsI-CsI) placed at 21°<Θ<60° with digital readout . Light particles and IMFs emitted at midrapidity

Shadow bar: evaluation of background neutrons in LAND

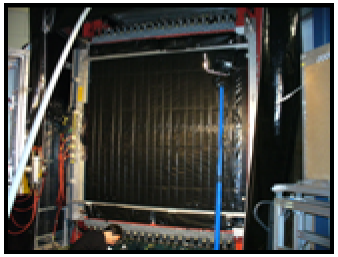




TOFWALL: 96 plastic bars Tof, Energy X-Y position. Trigger, impact parameter and reaction plane determination



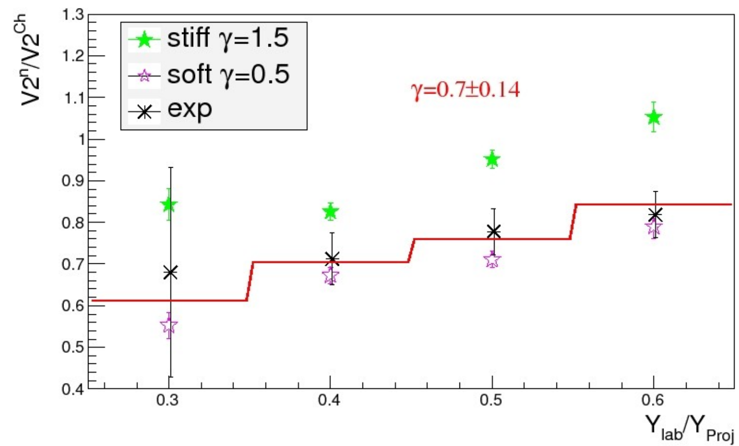
CHIMERA: 8 (2x4) rings, high granularity CsI(Tl), 352 detectors 7°<Θ<20° + 16x2 pads silicon detectors. Light charged particle identification by PSD. Multiplicity, Z, A, Energy measurement , Reaction plane determi-nation



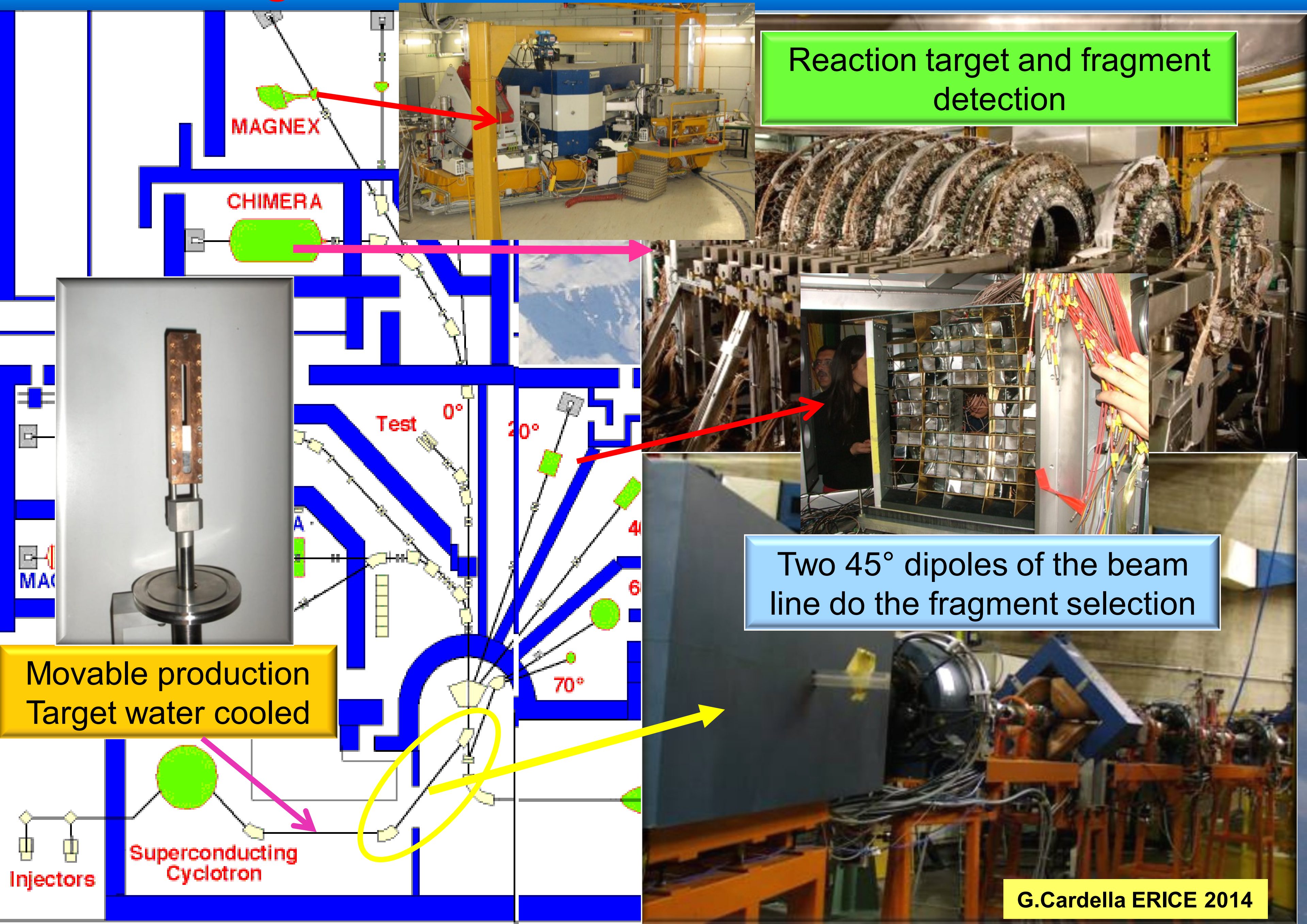
LAND: Large Area Neutron Detector . Plastic scintillators sandwiched with Fe 2x2x1 m^3 plus plastic veto wall. New Taquila front-end electronics. Neut and Hydrogen detection. Flow measurements

Symmetry energy at High density 2 ρ_0

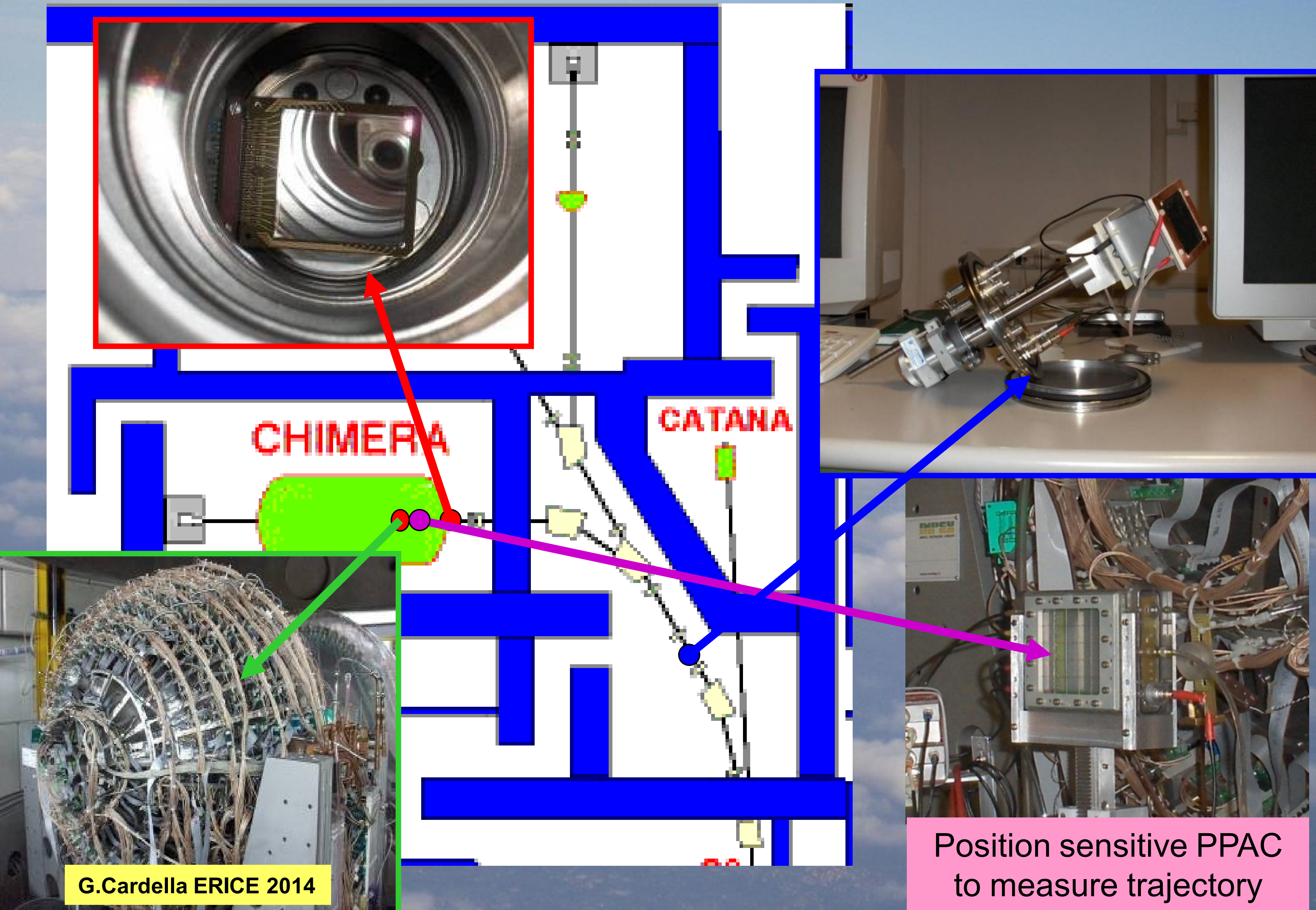
Au+Au @ 400 AMeV
b< 7.5 fm



Fragmentation beams at INFN-LNS - Catania



Tagging system: layout



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

New beams to be used during 2014/2015

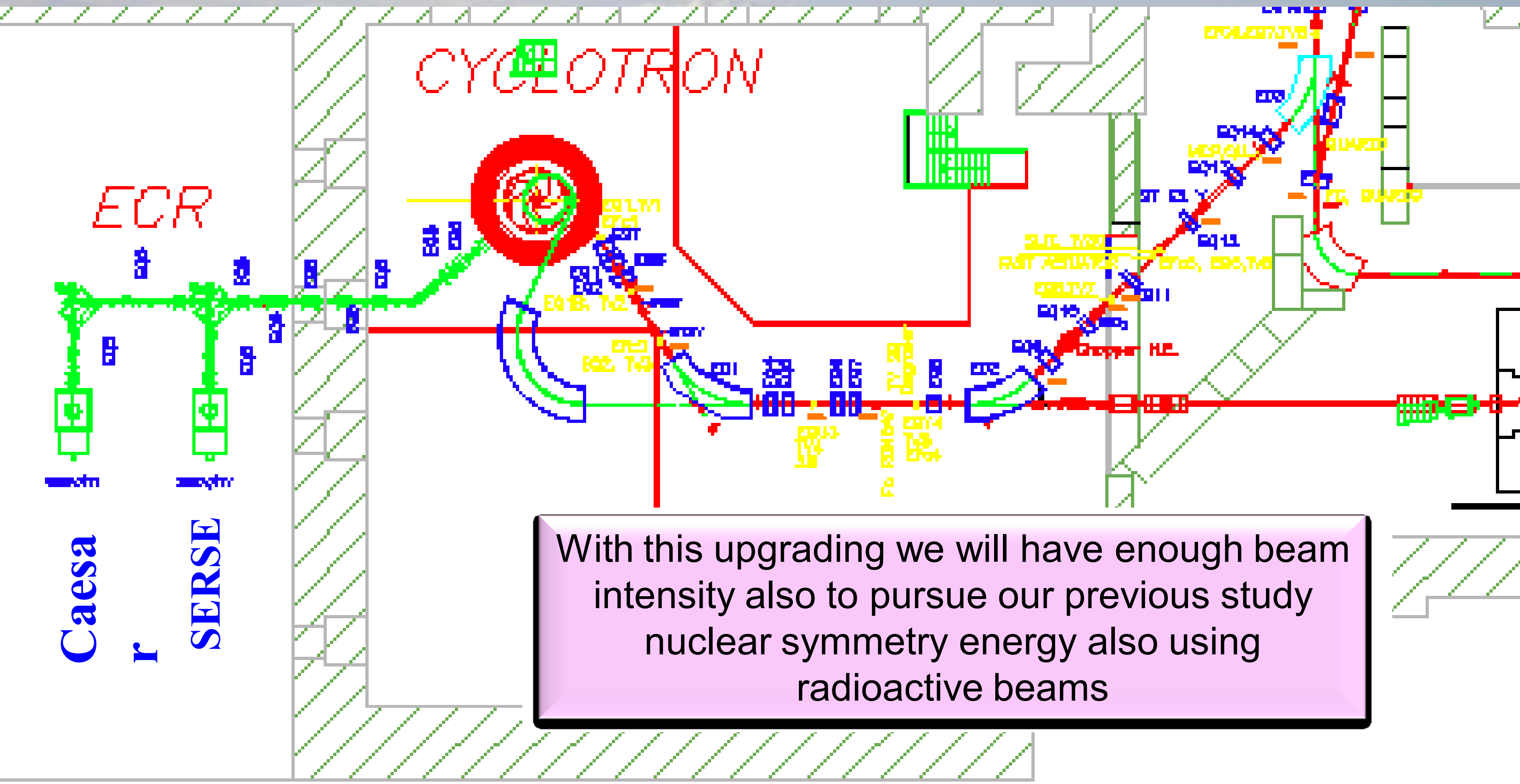
^{8}He (CHIMERA)

^{14}Be (test experiment) collaboration with Leuven

^{38}S (Magnex)

Possible upgrading

New cryostat and coils for the CS – possibility to extract beam trough stripping – the acceleration of beams with lower charge status will allow an increase of intensity from 20 to 100 – This will be a fantastic perspective for the fragmentation beam



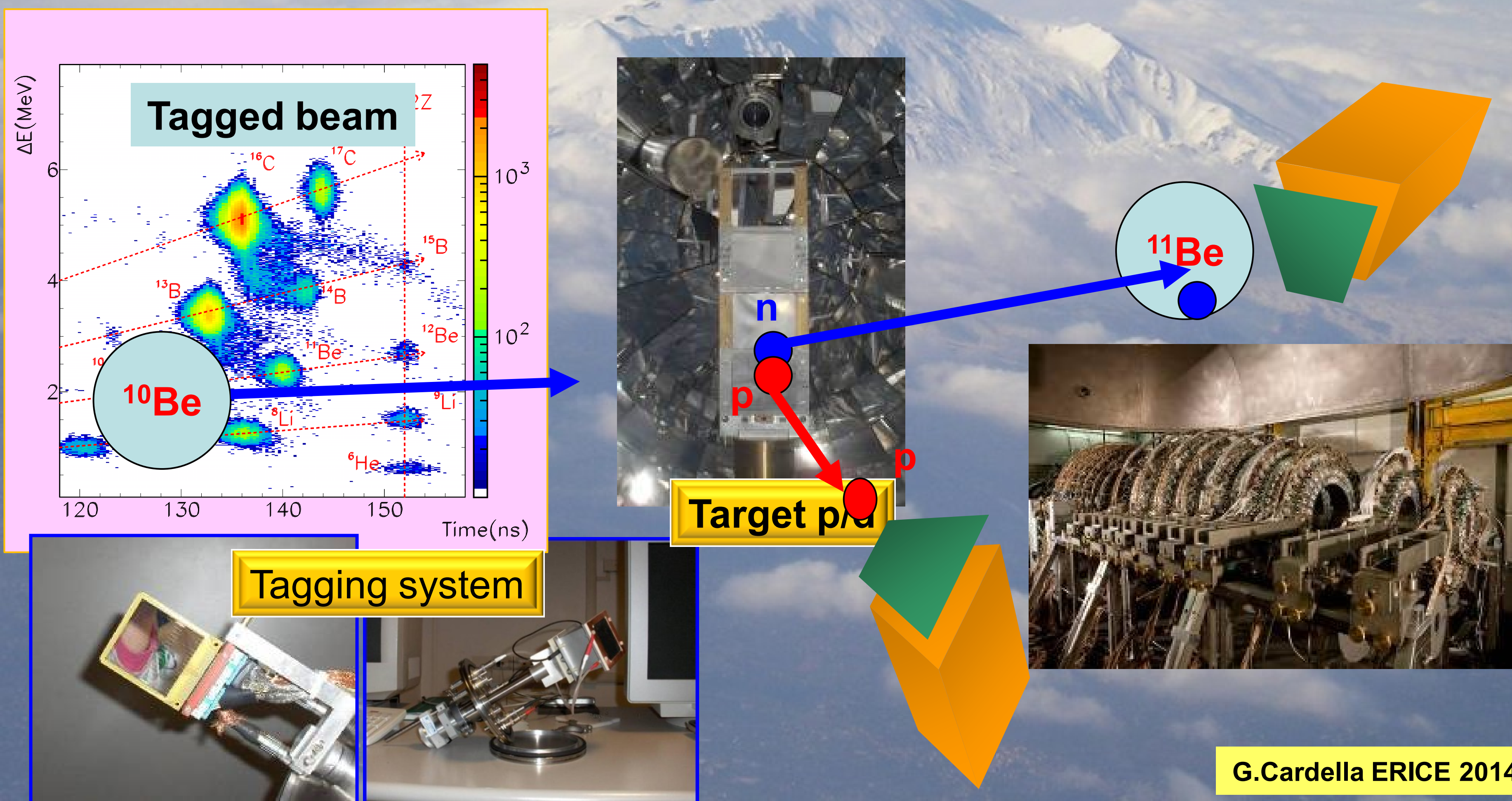
With this upgrading we will have enough beam intensity also to pursue our previous study nuclear symmetry energy also using radioactive beams

Slide from L.Calabretta

-Neutron transfer reactions near halo nuclei -

In this experiment we studied direct reactions using light exotic nuclei impinging on p, d targets useful to investigate on various structure effects

EVENT SELECTION performed with kinematic coincidences – measuring in binary/ternary reactions all reaction partners we clean the events



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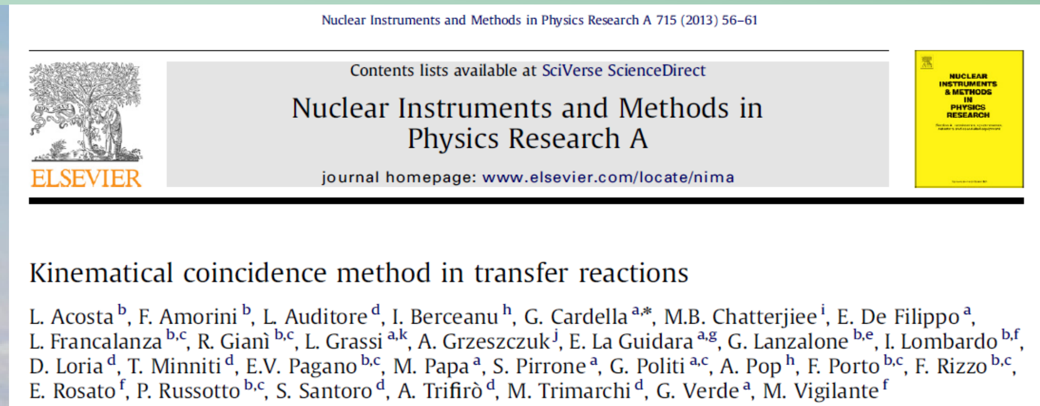
– Advantages of binary kinematics : the $^{10}Be+p \rightarrow {}^{9}Be+d$ case -



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Kinematical coincidence method in transfer reactions

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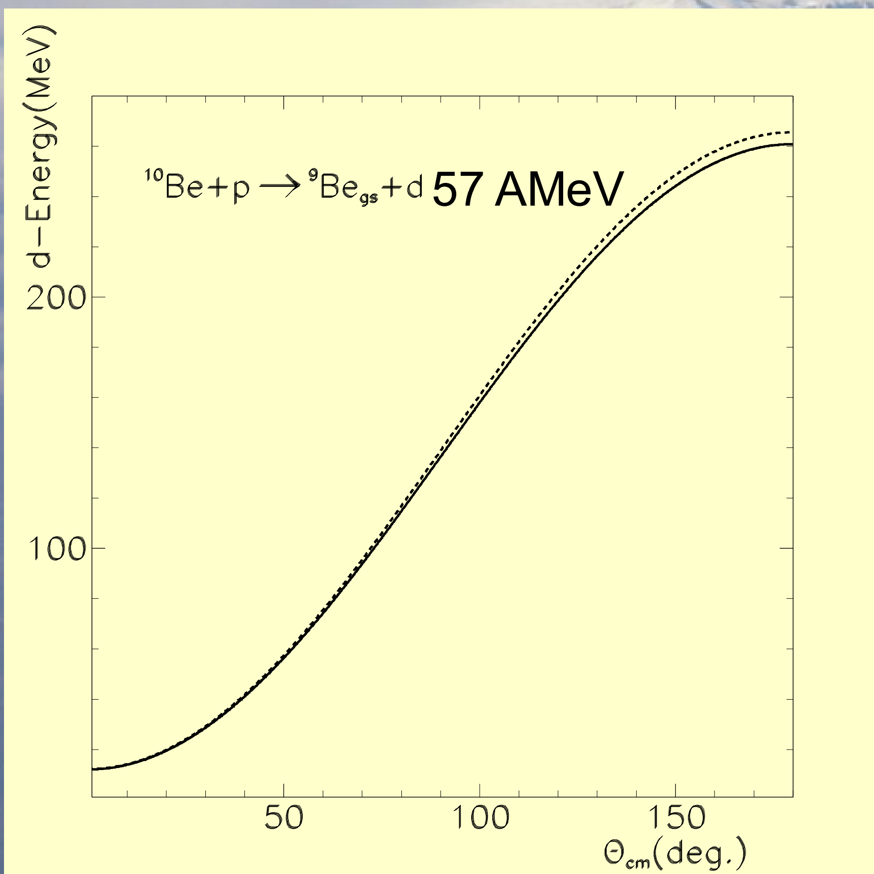


The lab energy of the detected particle determines the CM emission angle

Due to the relatively good energy resolution we can obtain an angular distribution with much better resolution than the one determined by the size of the detectors

– STEPS of the analysis $^{10}Be+p \rightarrow {}^{9}Be+d$

We select only complete events with two detected particles and with total detected charge Ztot=Zbeam+1

We can plot the Δϕ angle between the two coincidence detectors – due to momentum conservation Δϕ must be 180°

Δϕ width due to the finite opening of the detectors

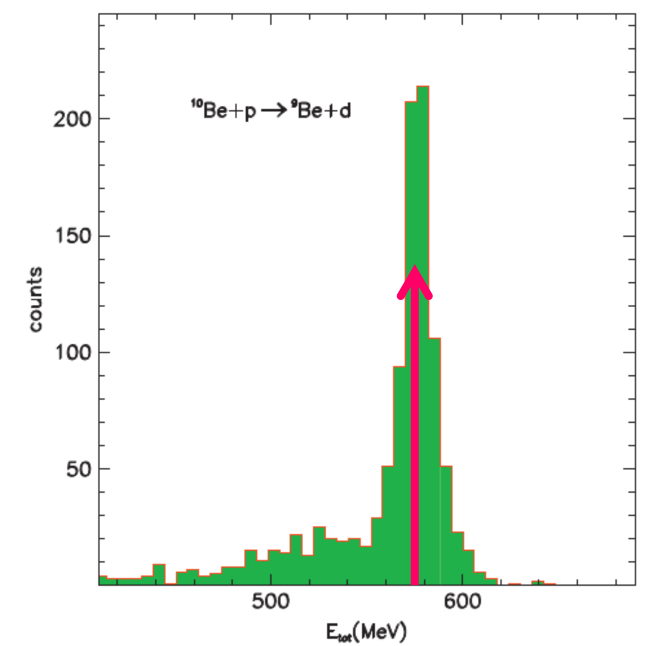
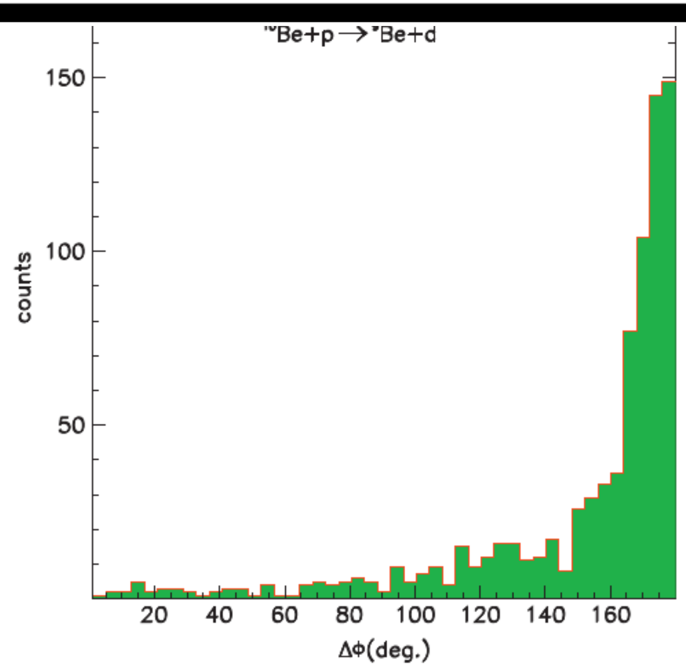


Fig. 6. Total kinetic energy detected in the reaction $^{10}Be+p \rightarrow {}^{9}Be+d$.



...elescopes selected in coincidence in the ...30° is due to kinematical coincidences.

We also clean the events putting constraints on the total detected energy must be equal to the beam energy 580 MeV + Q_{value} (-4.58 MeV)

Notwithstanding the scarce total energy resolution we see only GS events
$^{9}Be^{*} \rightarrow n+\alpha+\alpha$
S_n=1.66 MeV

– The $^{10}Be+p \rightarrow {}^{9}Be_{g.s.}+d$ angular distribution -

From the analysis we get the deuteron energy spectrum

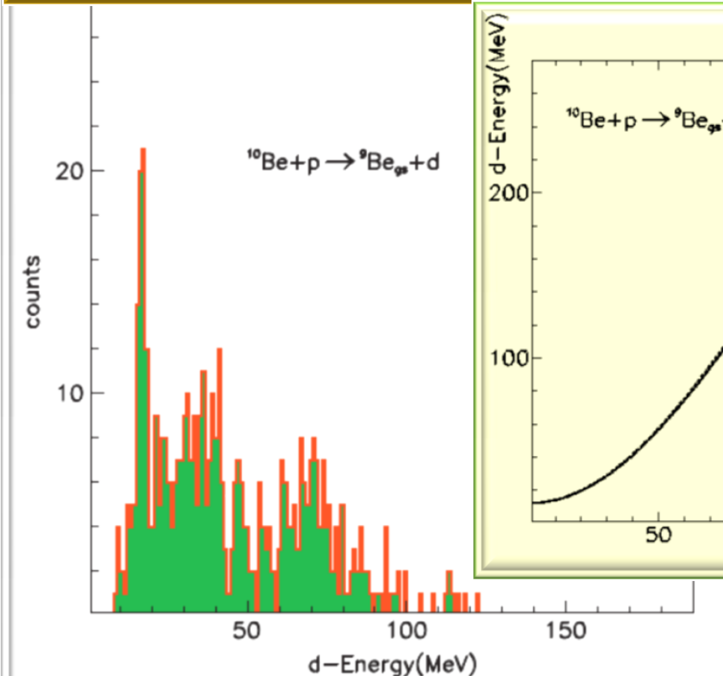
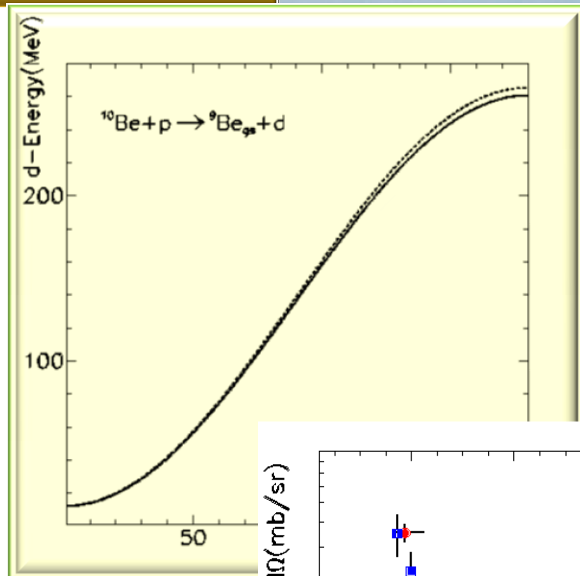
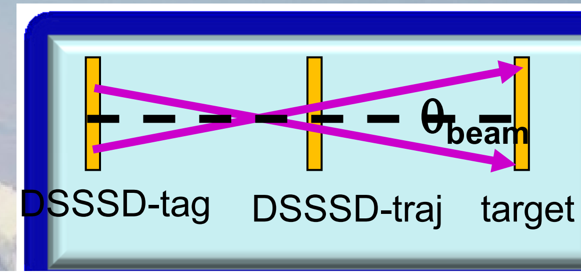
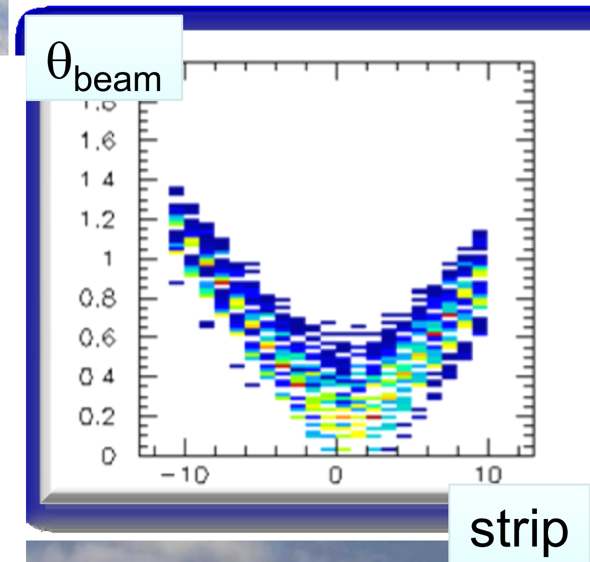


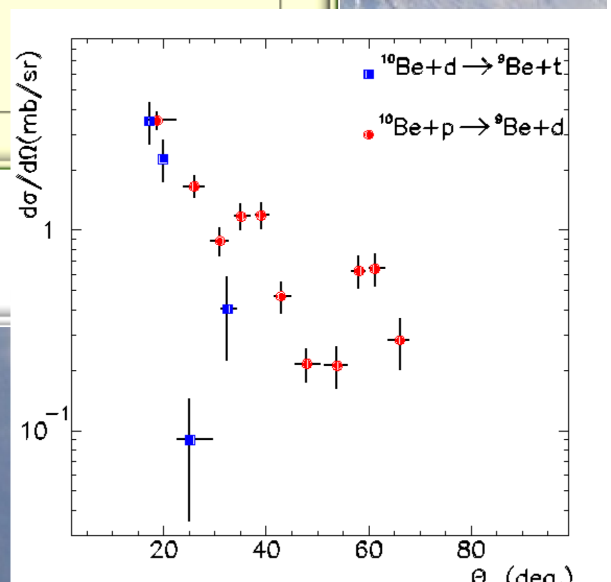
Fig. 7. Deuteron energy spectrum from the reaction $^{10}Be+p \rightarrow {}^{9}Be_{gs}+d$.



Using kinematics we can convert it from dN/dE → dN/dθ







After efficiency correction taking into account few rings missing for a GSI experiment we get the angular distributions

Note that angular distributions are automatically corrected for the fragmentation beam angular spread

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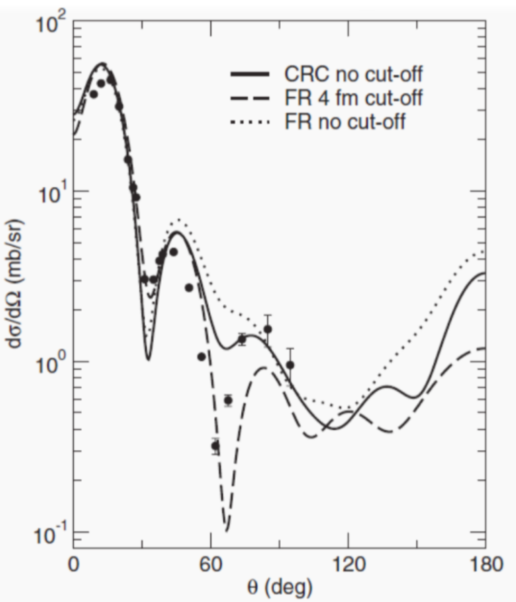
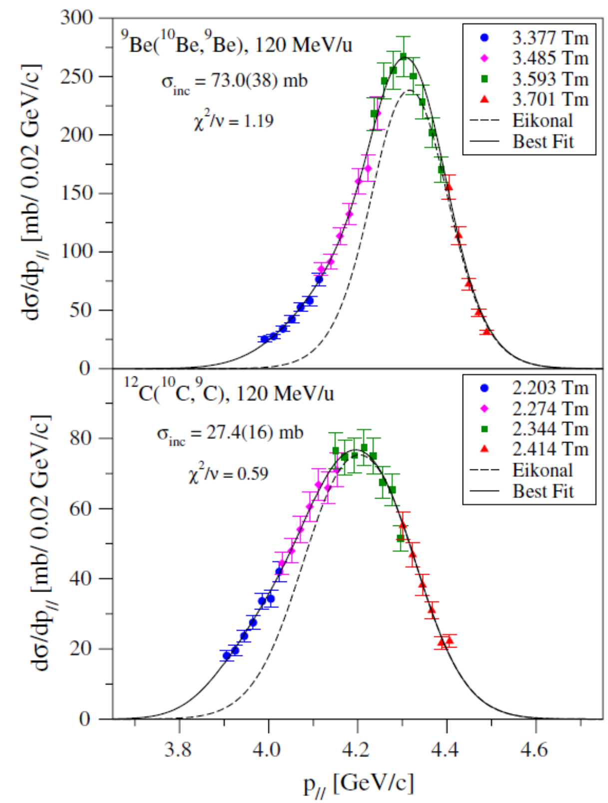
– Preliminary results from CRC calculations -

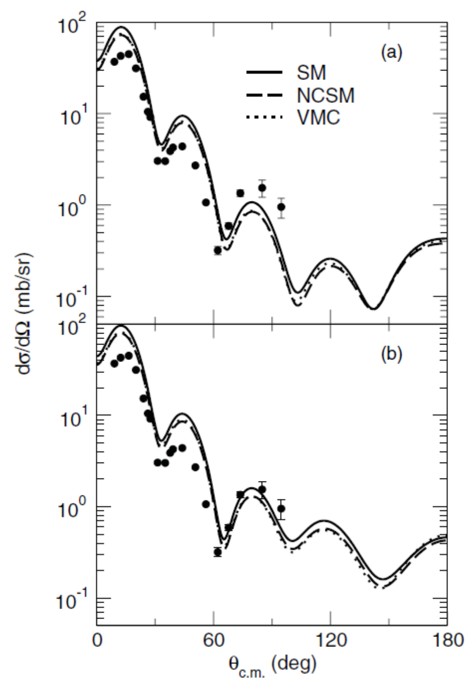


It is very interesting a comparison with previous d,t data with 16 MeV deuteron beam direct kinematics from Auton *Nuclear Physics A157 (I970) 305*



And also see if transfer reactions get same spectroscopic results as knockout reactions

N.Keeley et al PRC86,014619(2012)



G.F.Grinyer et al PRL106,162502(2011)

In the Keeley work one see that using the same <10Be|9Be + n> bound-state form factors from the knockout analysis one overestimate transfer cross section of about 30-40%

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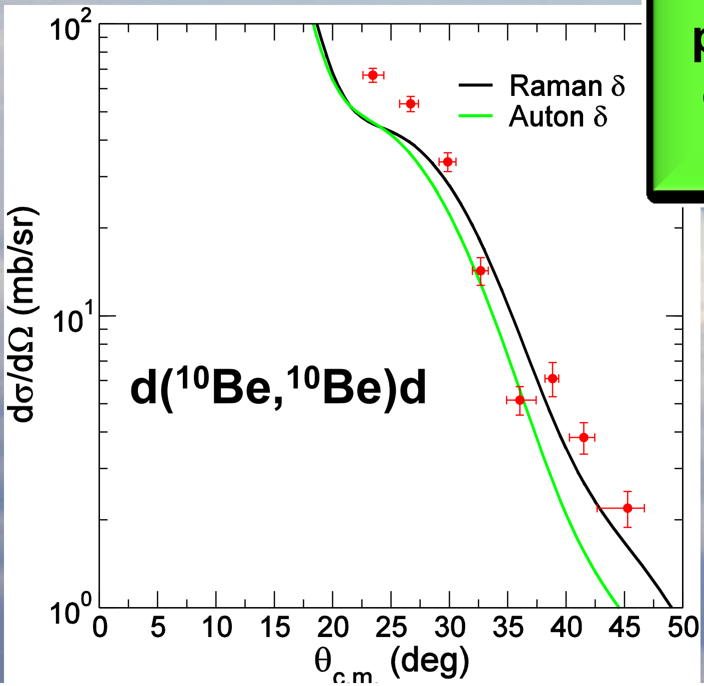
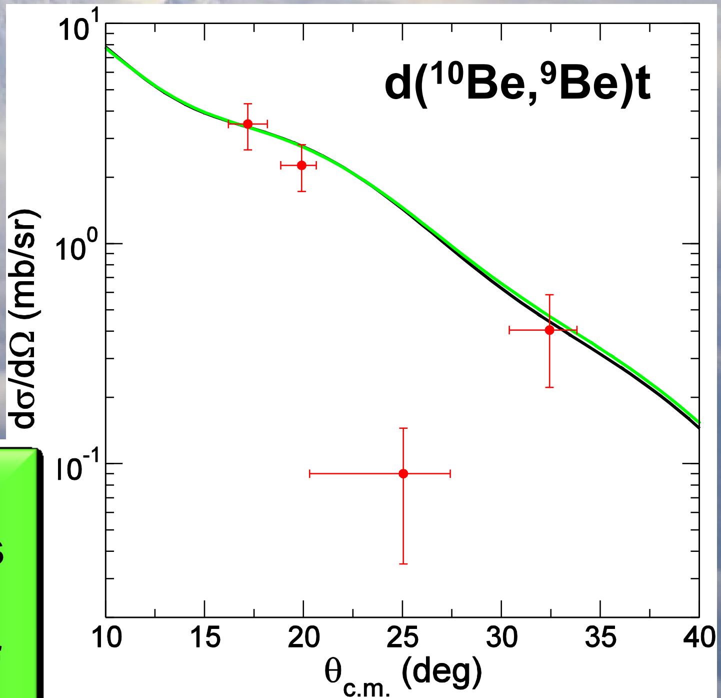
– Preliminary results from CRC calculations -

Our data at around 50 MeV/A could be useful to verify if part of the problem is due to the quite different beam energy (15 for transfer and 120 for knockout)

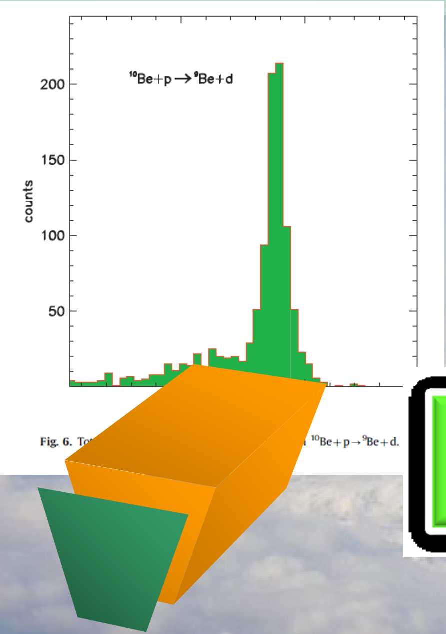
using elastic and quasi-elastic channels to fix other parameters in CRC calculations (first excited state of ^{10}Be has been included in calculations with two different assumptions for BE2 transition)





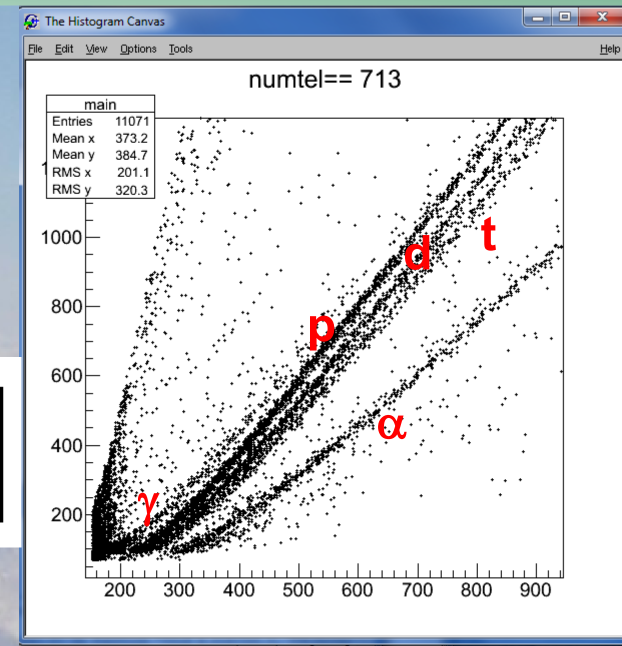
the normalization problem using knockout form factors persists - we had to normalize calculations again using a factor around 0.7 - however more work is necessary also from experimental point of view to improve data quality – Moreover one should investigate if non relativistic calculations are correct enough at 50 MeV/A

– Excited levels - γ-ray tagging? -

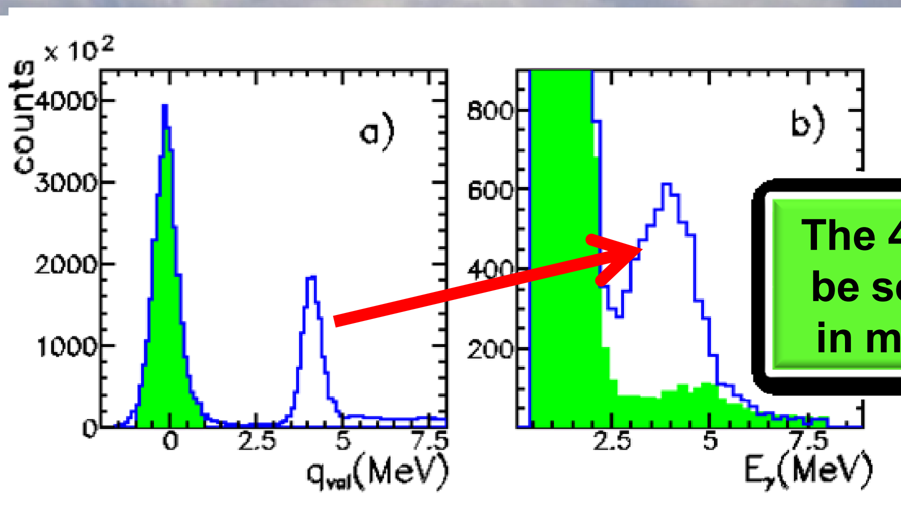


γ-ray tagging could be a solution to extend the method in case of excited levels - How to combine efficient γ-ray detectors and CHIMERA?

CsI(Tl) have a large efficiency for γ-ray detection



We have calibrated the γ-ray signals from CsI(tl) using proton beam on carbon target and looking at excitation and decay of the 4.44 MeV ^{12}C first excited state



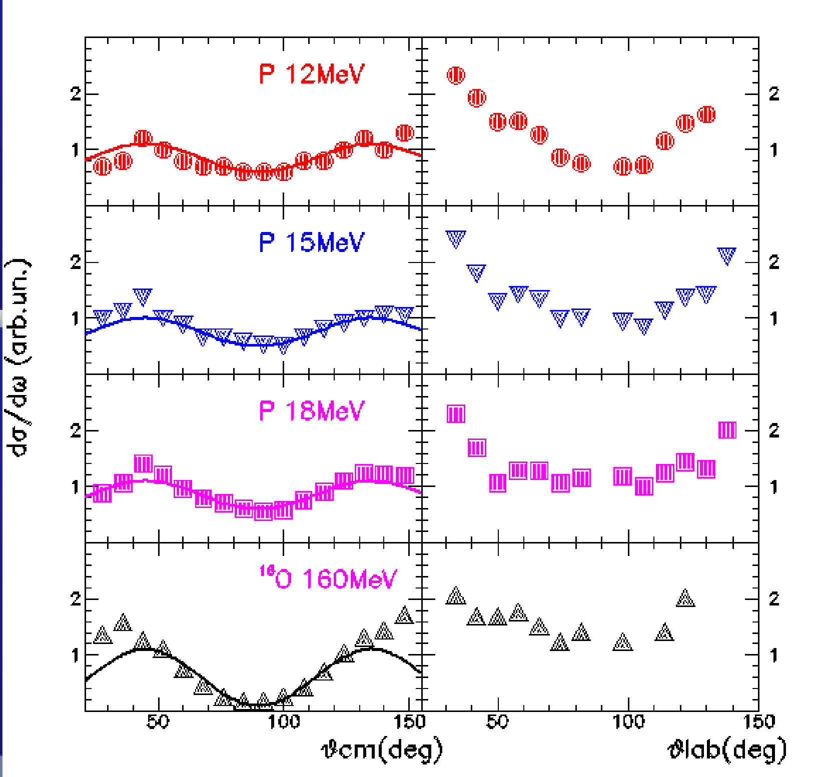
The 4.44 MeV γ can be seen quite well in most detectors

CHIMERA and γ-rays: angular distribution

We have a large efficiency (around 30-40% at 4 MeV) and we can extract accurate angular distributions both in Lab and in the frame of recoiling excited $^{12}C^{4.44}$ with our data taken at various proton energies

In the CM we can reproduce data as P+^{12}C → E2+cost. similar results for all energies

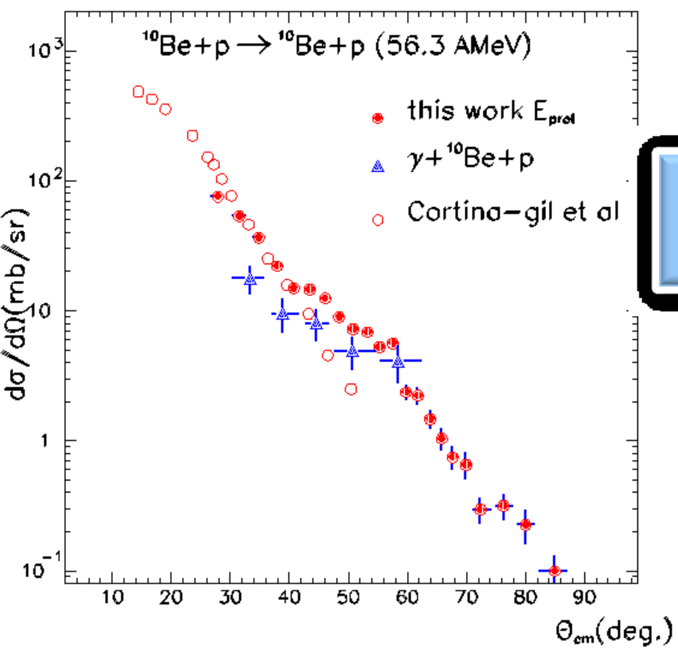
Comparing proton beam with ^{16}O beam we get much stronger polarization effect and we can reproduce data with pure E2 $^{16}O + ^{12}C$ → E2



The symmetry around 90° in the LAB ensure us of the quality of efficiency reconstruction

This difference is due to proton spin flip allowing population of M=±1 magnetic substates non populated with the zero spin ^{16}O beam – This method can be used to complement information on spin orbit interaction with radioactive beams

– Using the γ-ray tagging: the ^{10}Be+p elastic channel -



The angular distribution we measure for this channel shows a slope change around 40°

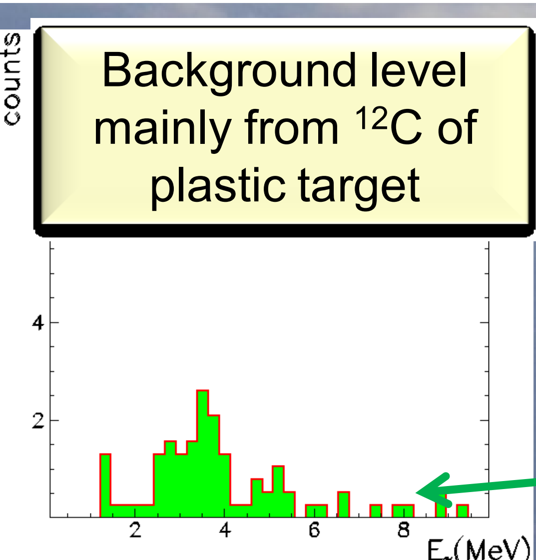
This change of slope is not seen in previous data measured by Cortina-Gil et al Phys.Lett.b 401(1997)9

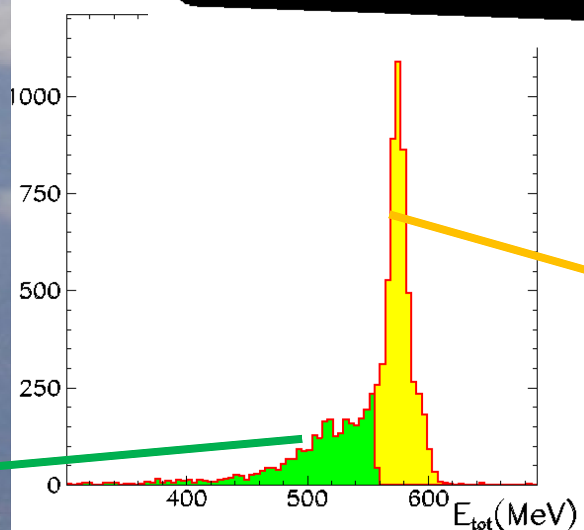
The proton angular distribution measured in coincidence with γ-rays explains the change of slope and the deviation from Cortina-Gil data

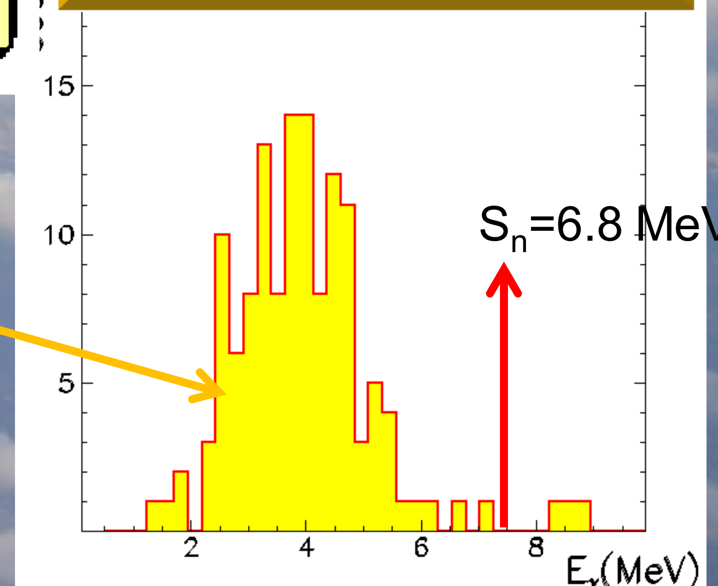
^{10}Be + p → ^{10}Be + p

γ-ray from ^{10}Be+p→^{10}Be*+p

Background level mainly from ^{12}C of plastic target







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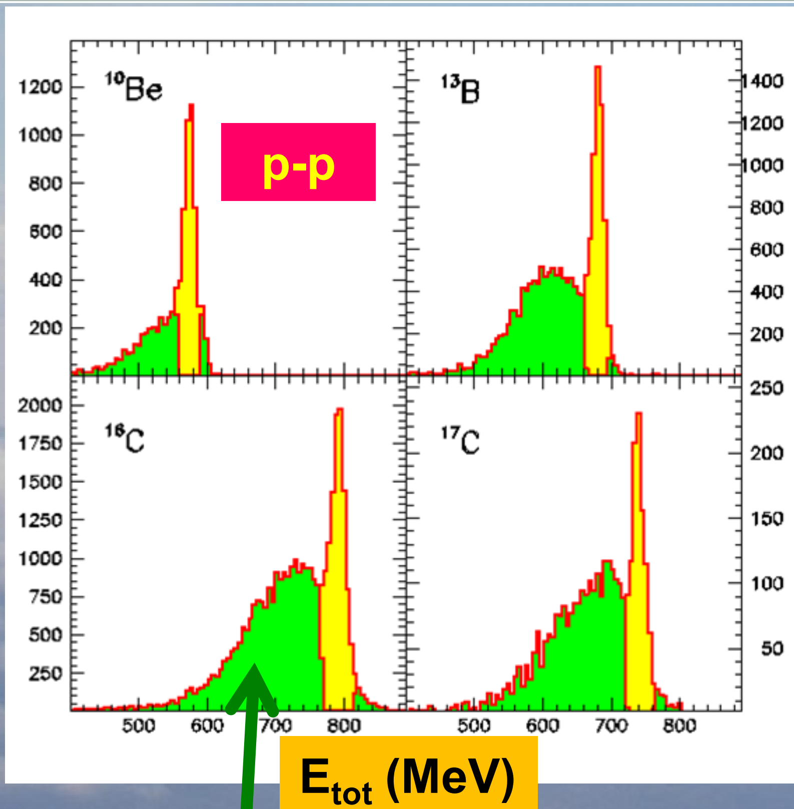
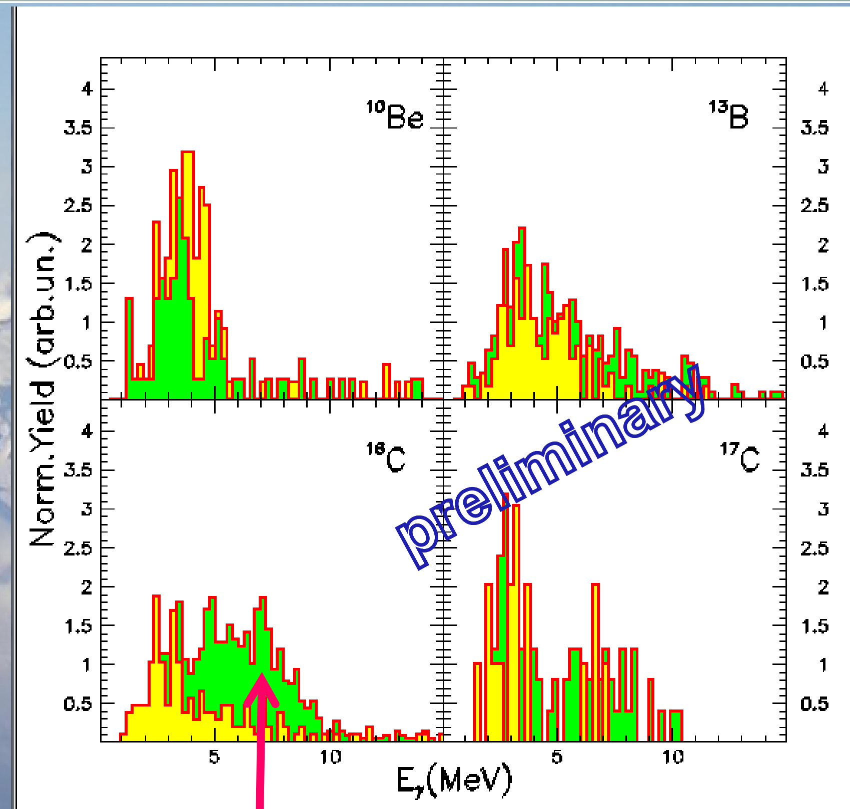
CHIMERA and γ-rays: normalized energy γ-spectra



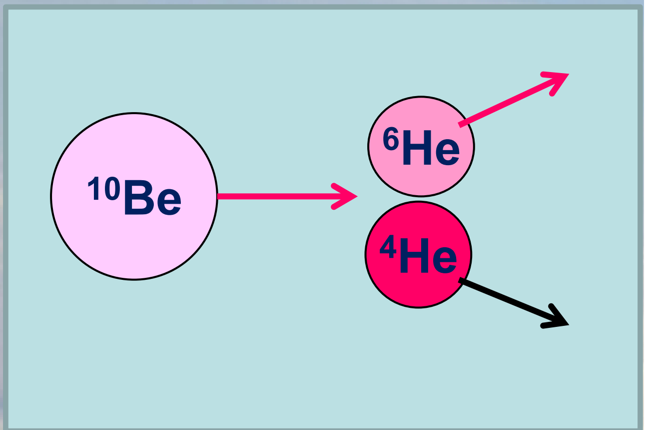


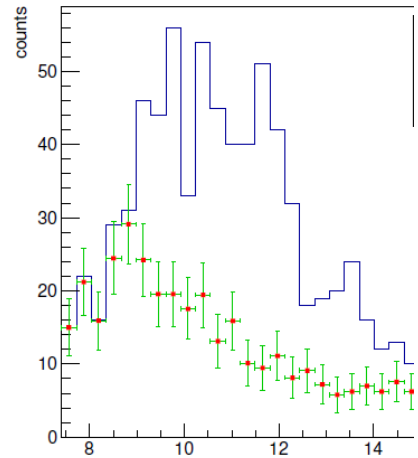
xn channel

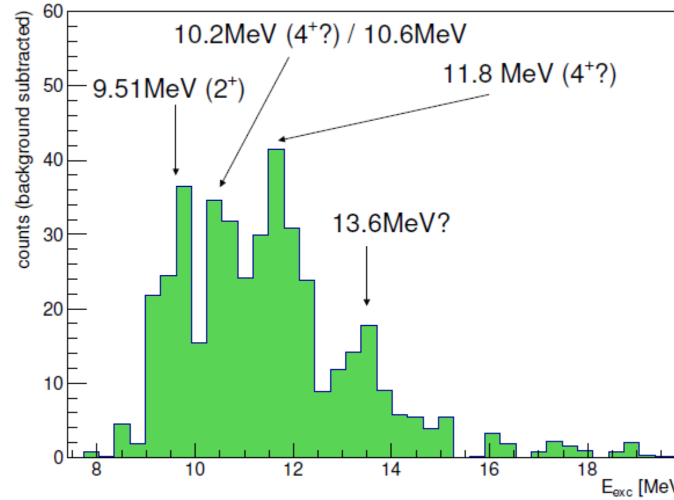
7 MeV 2n-channel? (^{14}C)

We are going to extract angular distributions of events tagged with γ-rays and also to look to γ-ray angular distributions to check spin and parities

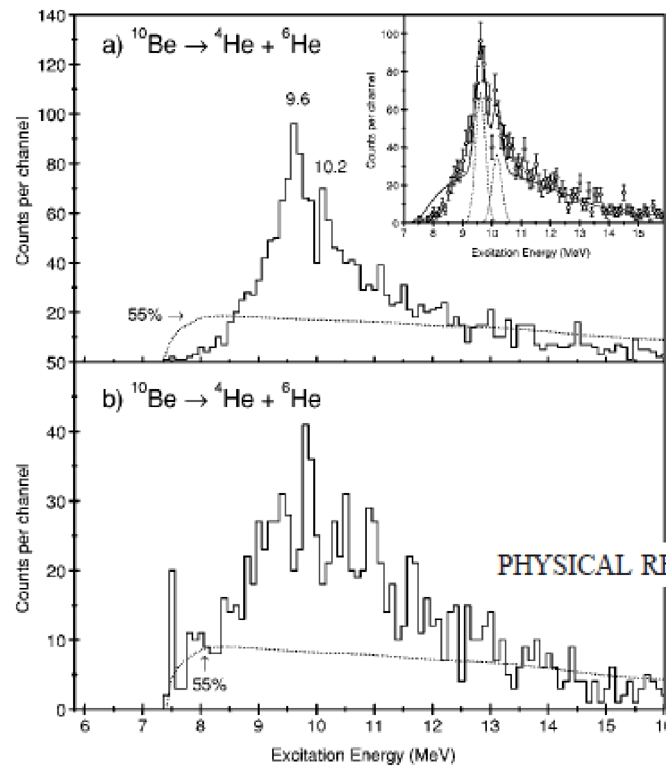
Not only transfer: Break-up at 56 MeV/A







We are doing a check with published data measured around 30 MeV/A to verify calibrations and efficiency



PHYSICAL REVIEW C 69, 024303 (2004)

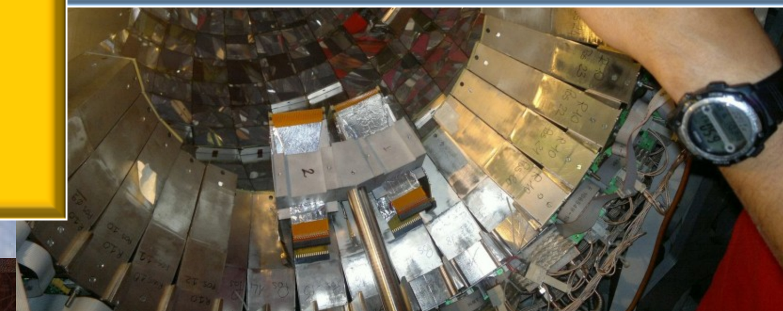
Subtracting uncorrelated background we see also 11.8 and perhaps 13.6 MeV excited levels

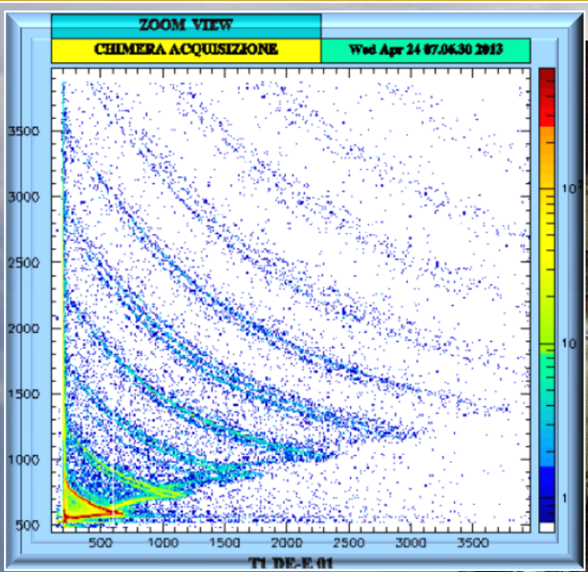
A new dedicated experiment with more complete angular coverage and better resolution to look for such exotic states in ^{10}Be but also in ^{16}C and all the other beams produced will be performed at the end of this year

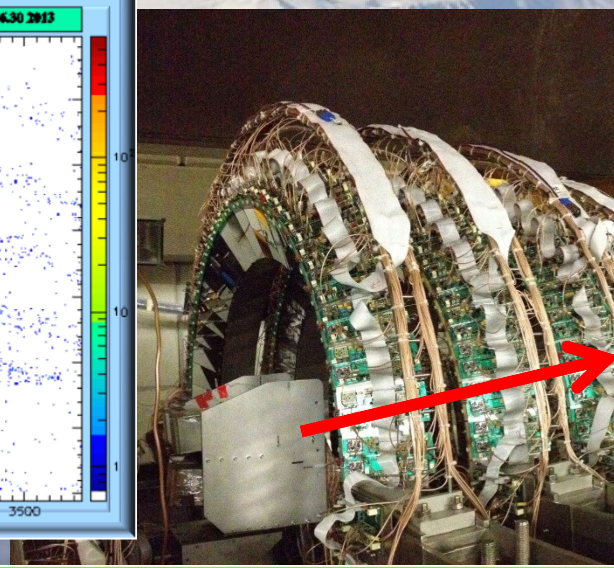
Next measurements : FARCOS prototye as forward angle spectrometer

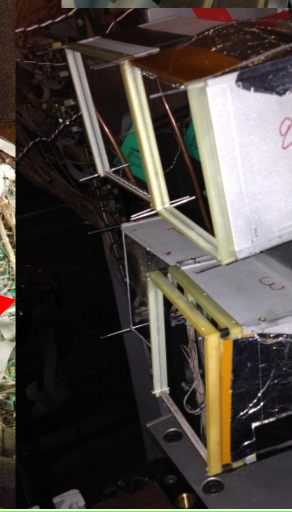
New triple telescopes Si-Si-CsI
First stage 32x32 strip 6.2x6.2cm^2 300 μm DSSSD
Second stage 32x32 strip 1500 6.2x6.2cm^2 μm DSSSD
Third stage 4 CsI(tl) 3.1x3.1 cm^2 photodiode readout 6 cm thick

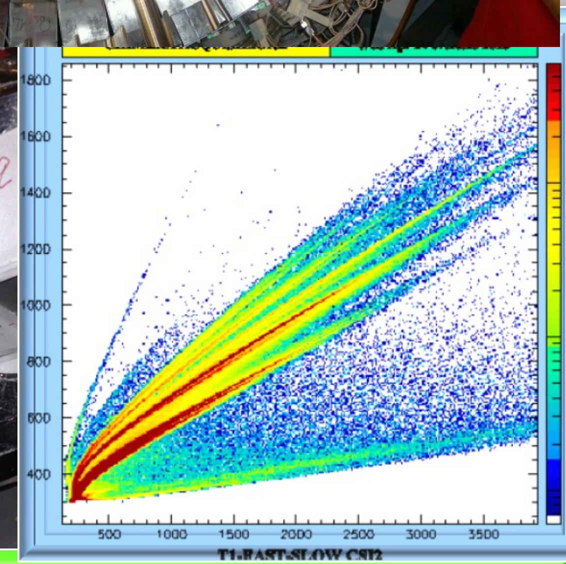
First test-experiment coupled with Chimera
April 2013









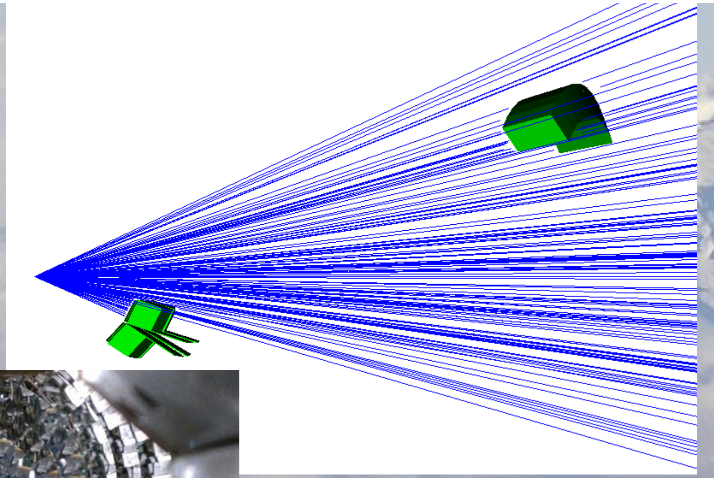


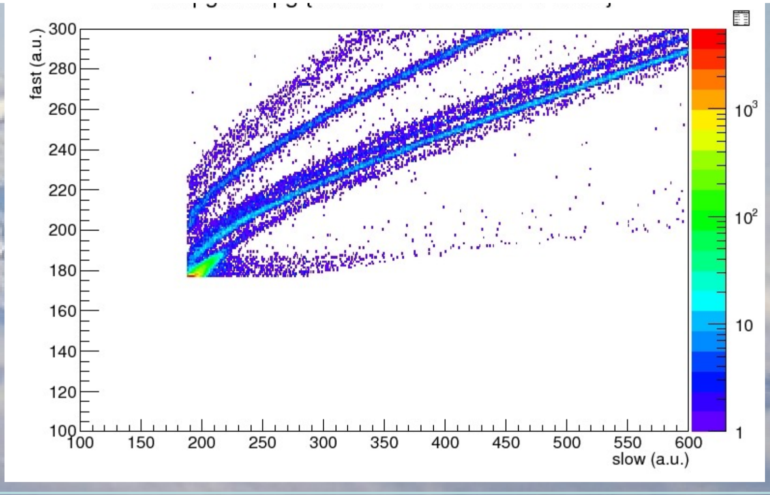
- ➢**Improved CsI(TI) energy resolution due to corrections for the particle detection position**
- ➢**Improved energy calibrations/resolution also due to the two stages of silicon detectors**
- ➢**Improved θ/ϕ granularity and isotopic identification**

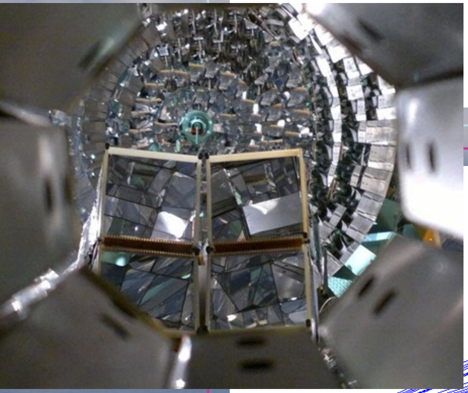
CHIMERA & Neutrons

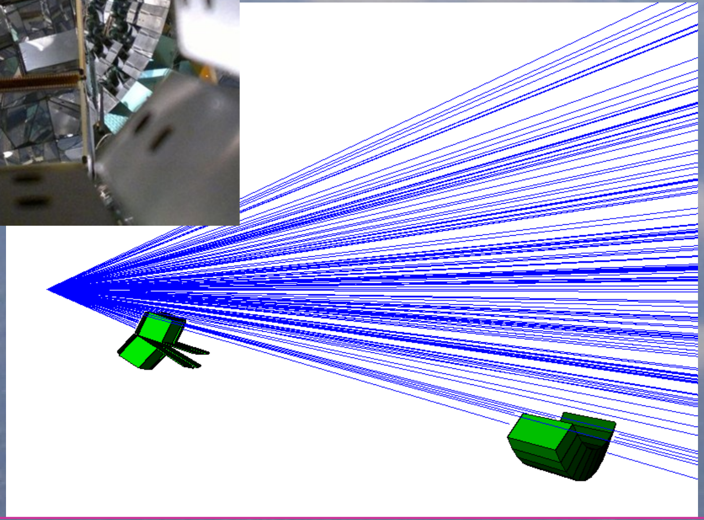
Experiment **INKIISSY** @LNS: $^{124}Xe+^{64}Zn$@35AMeV

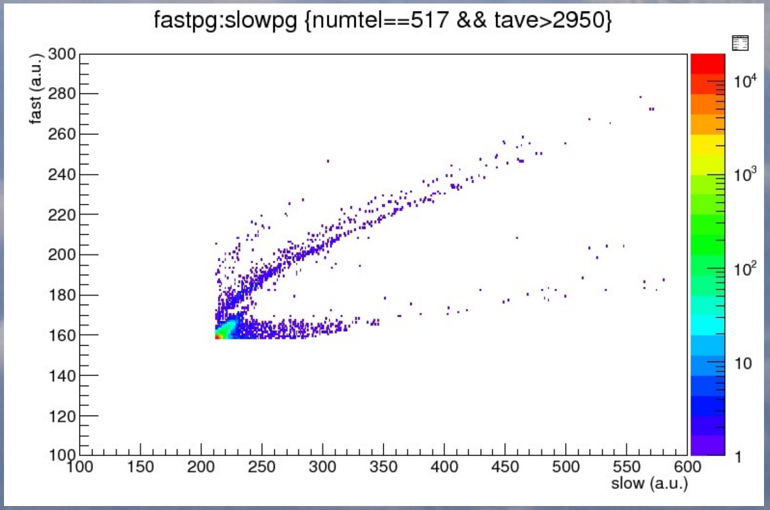
Some of the CHIMERA RINGS were covered by FARCOS – in such telescopes we can identify neutrons trough the particles produced in CsI











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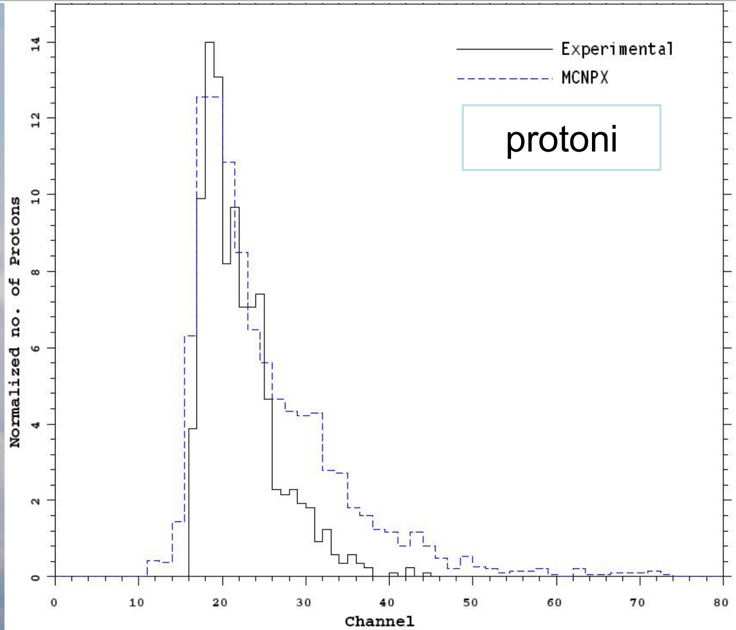
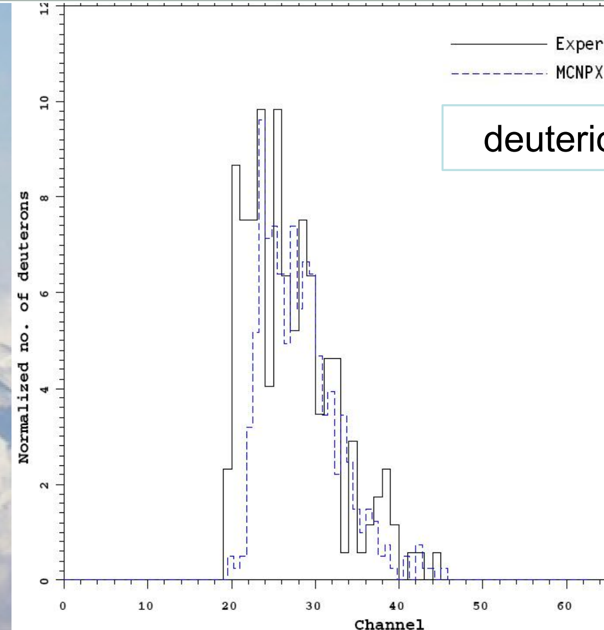
CHIMERA & Neutrons





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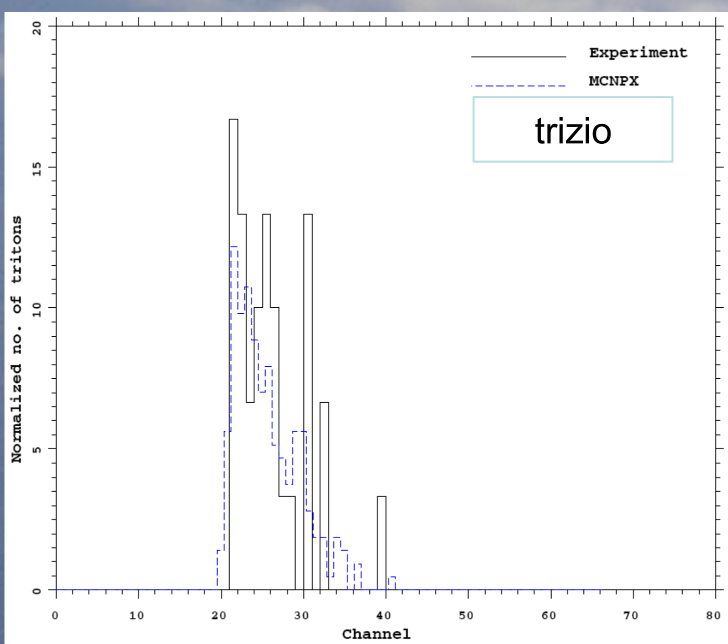

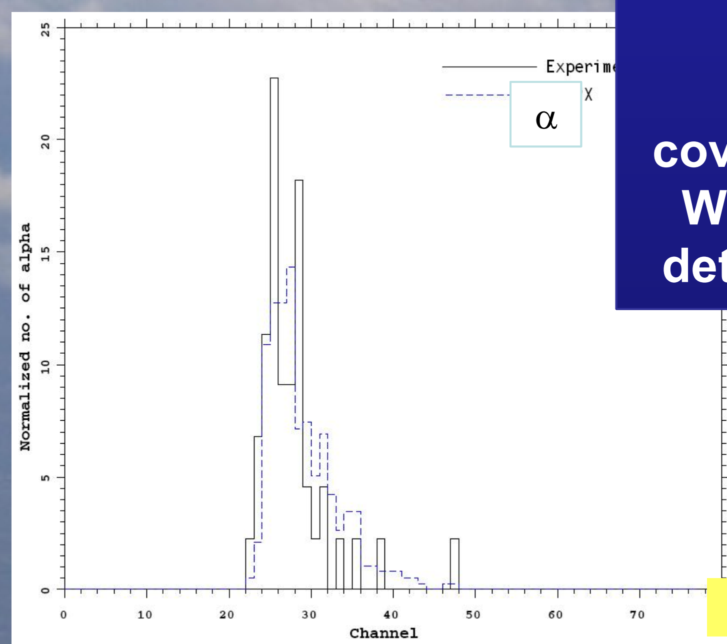

Simulations relatively well reproduce data - We assume a neutron energy distribution similar (apart Coulomb effects) to the one of proton measured in detectors not covered by FARCOS We are evaluating detection efficiency

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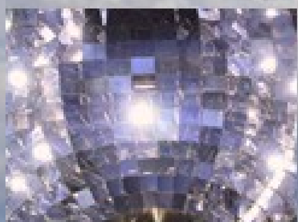
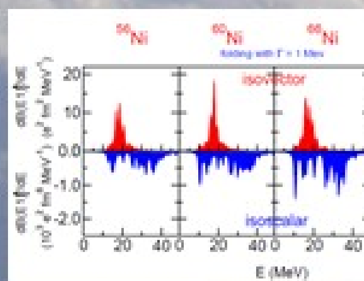
Coming Experiments : PIGMY

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

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





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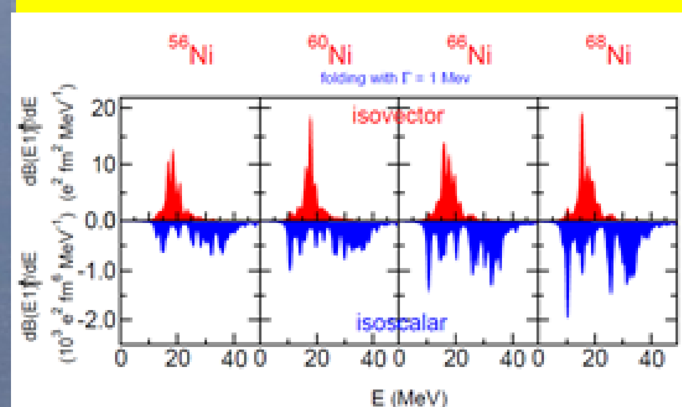
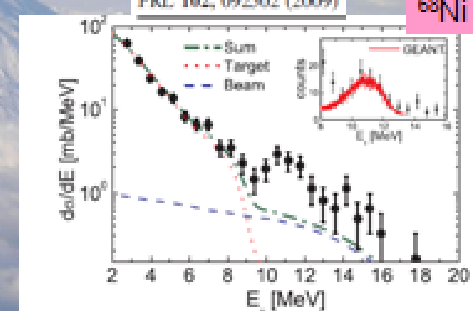
The Pigmy resonance

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



PRL 102, 092502 (2009)



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

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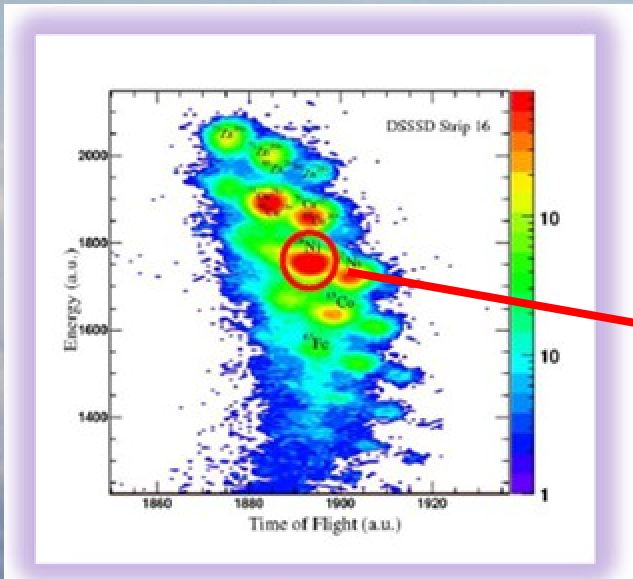
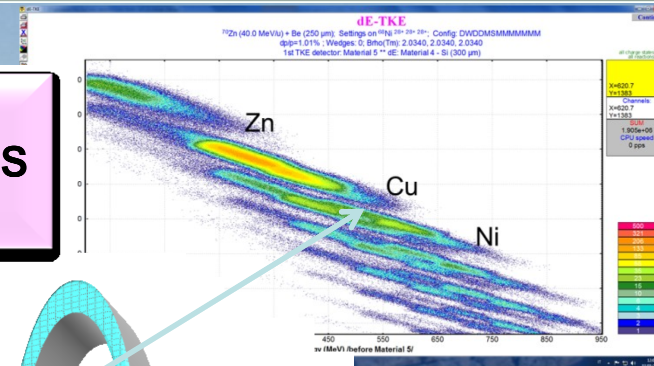
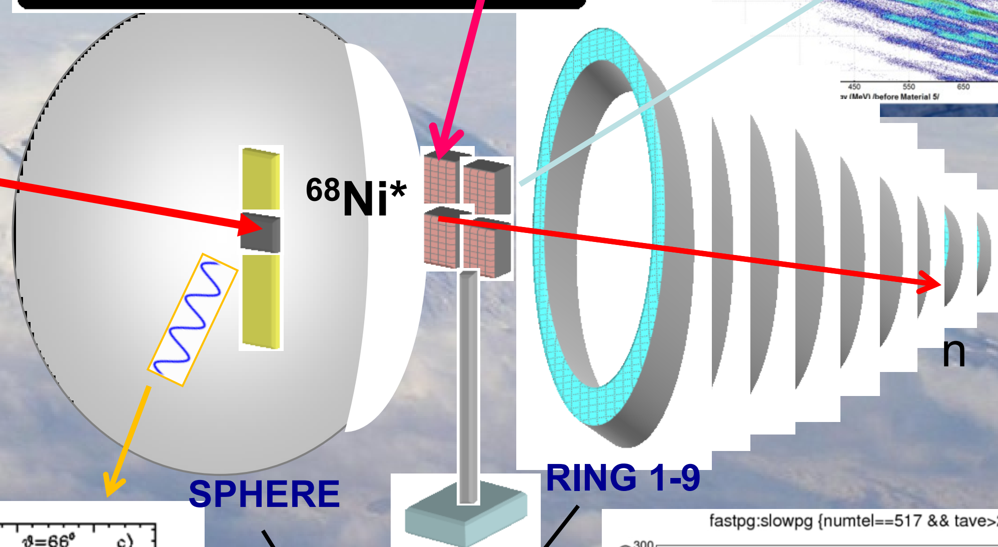
Future perspectives: the Pygmy resonance measurement

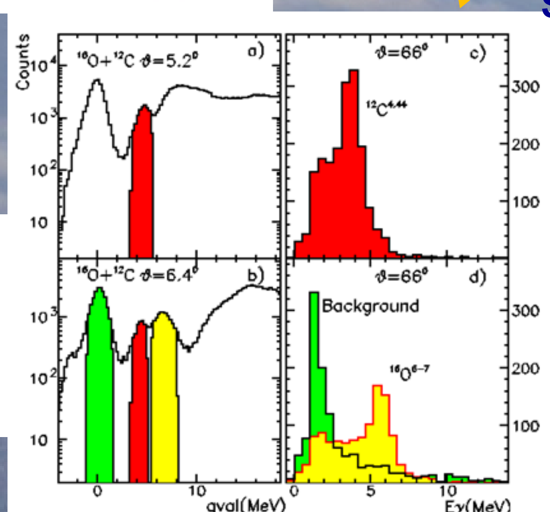


Identification scatter plot of ^{68}Ni fragmentation beam

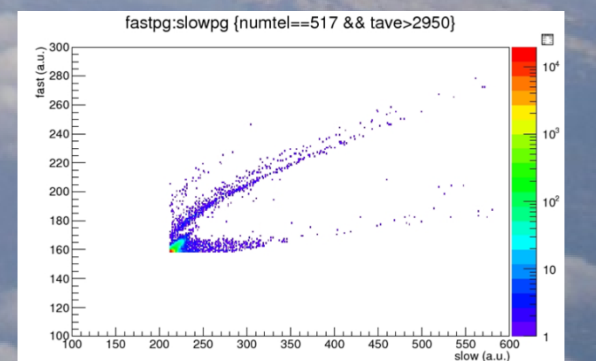
Expected ^{68}Ni identification in FARCOS silicon detectors





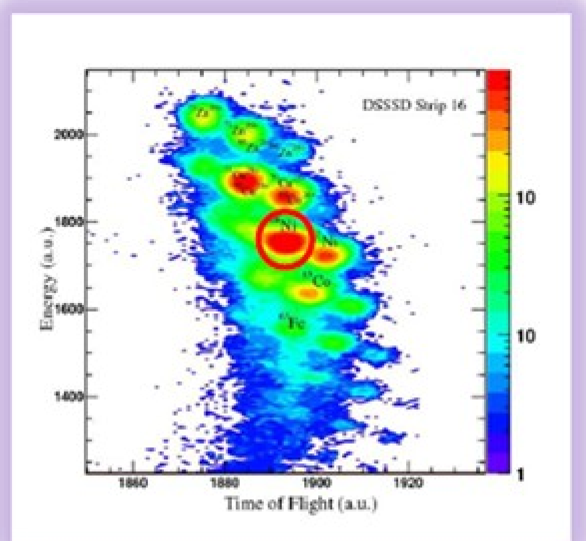


γ-rays on the CsI(Tl) of the sphere



Neutrons on the CsI(Tl) of CHIMERA rings covered by FARCOS

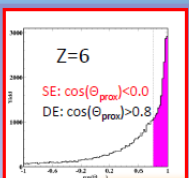
Future Experiments : symmetry energy



Identification scatter plot of ^{68}Ni fragmentation

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

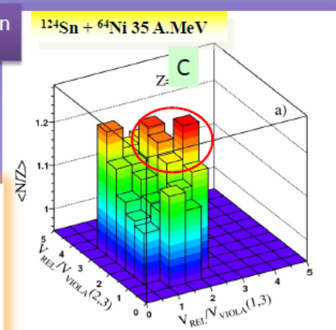
Neck neutron enrichment; reduction of "staggering" odd-even effects

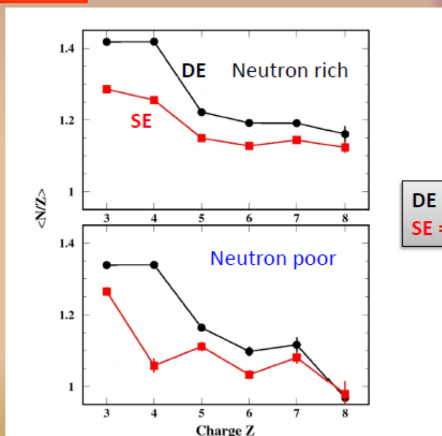


(1) Condition on $\cos(\Theta_{prox})$

+

(2) Condition on V_{rel} plot



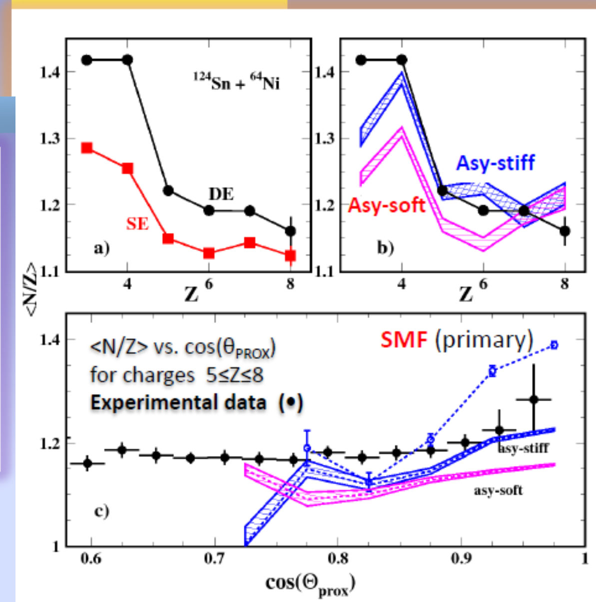


DE = Dynamical emitted
SE = Statistical emitted

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



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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)

Conclusions and perspectives

Using cocktail of neutron rich beams with the CHIMERA detector we are able to extract angular distributions for many reaction channels searching for structure effects on cross sections

The 4π detection efficiency is very useful and allows extensive use of the kinematical coincidence technique

We can also measure and identify γ-rays and neutrons with our CsI(Tl) detectors in order to tag excited levels or particular decay channels

Break-up reactions can be also very well seen –

New measurements will be performed to look for pigmy resonance - We plan also to use radioactive beams to better investigate on symmetry energy profiting of the higher beam intensity that should be available in next years

I wish to thank all my collaborators

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