

PRISMA-FIDES 2013-2016

Heavy-ion reactions from grazing collisions to complete fusion

<u>G.Montagnoli (100%), D.Montanari (100%), F.Scarlassara (50%)</u> (Univ. and INFN - Padova)	2.5 FTE
A.M. Stefanini (100%), L. Corradi (80%), E.Fioretto (100%), Huiming Jia (100%) (INFN - LNL)	3.8 FTE
G.Pollarolo (50%) (Univ. and INFN - Torino)	0.5 FTE
Total	6.8 FTE

→ → Joint work with the experiments **EXOTIC** and **GAMMA**

→ → Collaborations with GSI (D.Ackermann), Zagreb (S.Szilner, T.Mijatovic), Dubna (N.Kondratiev, R.Sagaidak), Strasbourg (F.Haas, S.Courtin), Cracow (J.Grebosz)

PRISMA-FIDES

- Study of nucleon-nucleon correlations (particle-vibration couplings, pairing vibrations, sub-barrier transfer) in binary reactions near the barrier
- Couplings effects and fusion hindrance far below the barrier - fusion cross sections in light heavy-ion systems
- Developments for Prisma: the new scattering chamber with a second TOF arm for kinematic coincidences, better tracking of ion trajectories for higher A resolution (very useful for weak channels/beams)
- Test of the EXOTIC set-up for very low fusion x-sects. measurements with stable beams
- All this will allow us to use the future exotic SPES beams with great efficiency and versatility.

Fraction of the beam-time TANDEM-PIAVE-ALPI allocated to PRISMA-PISOLO (+ γ -arrays)

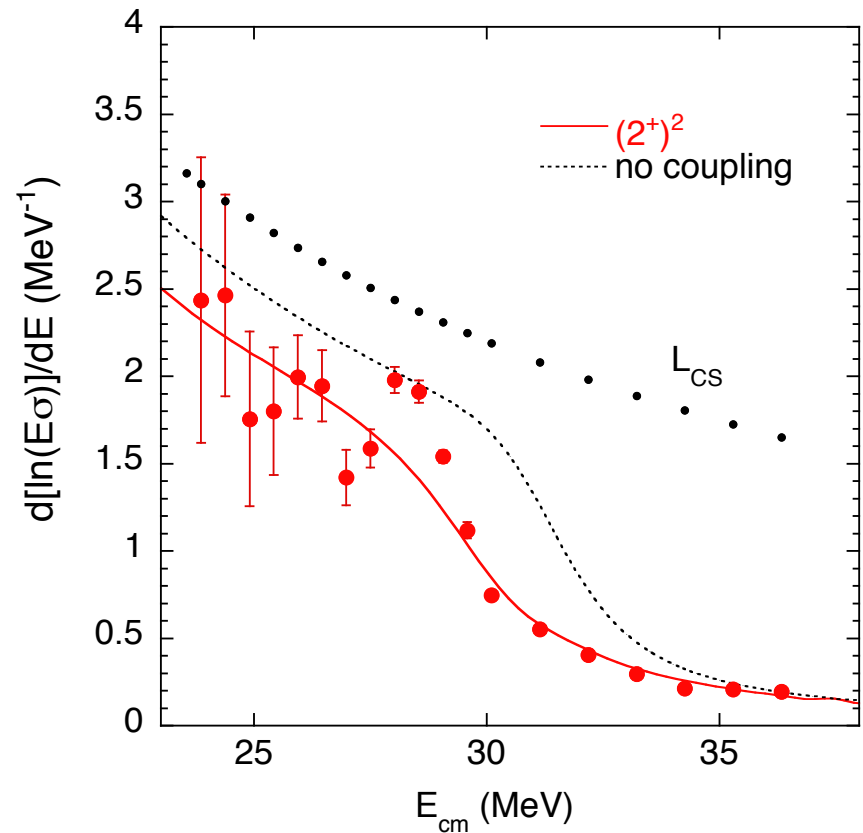
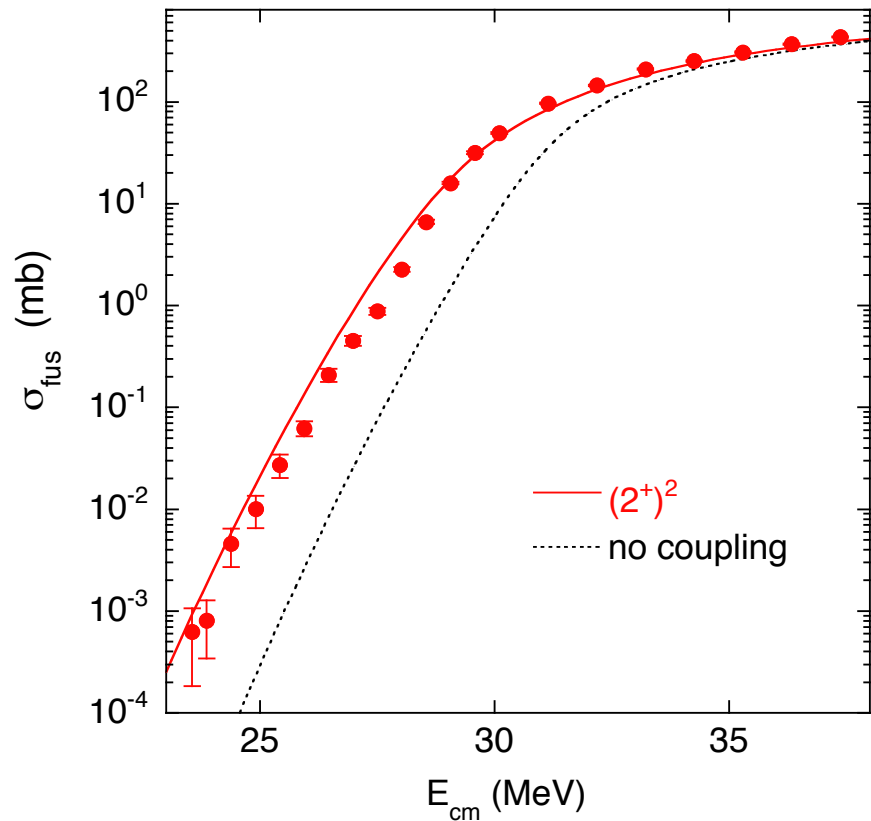
2005	40 %	}	CLARA
2006	58 %		
2007	47 %		
2008	31 %		
2009	35 %	}	AGATA
2010	38 %		
2011	47 %		
2012	32 %		

Papers on International Journals 2002-2012

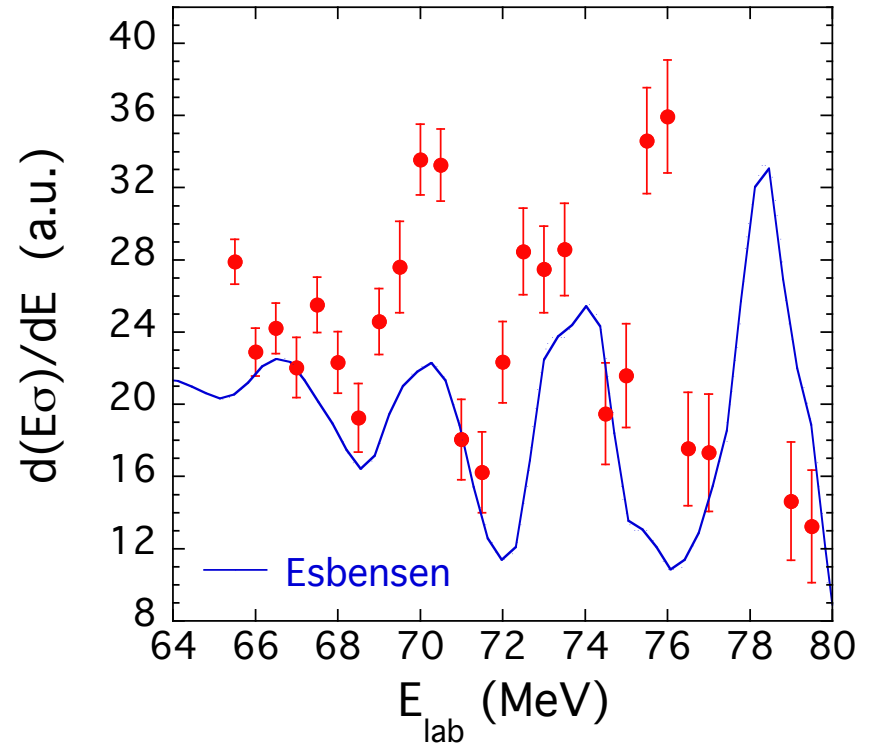
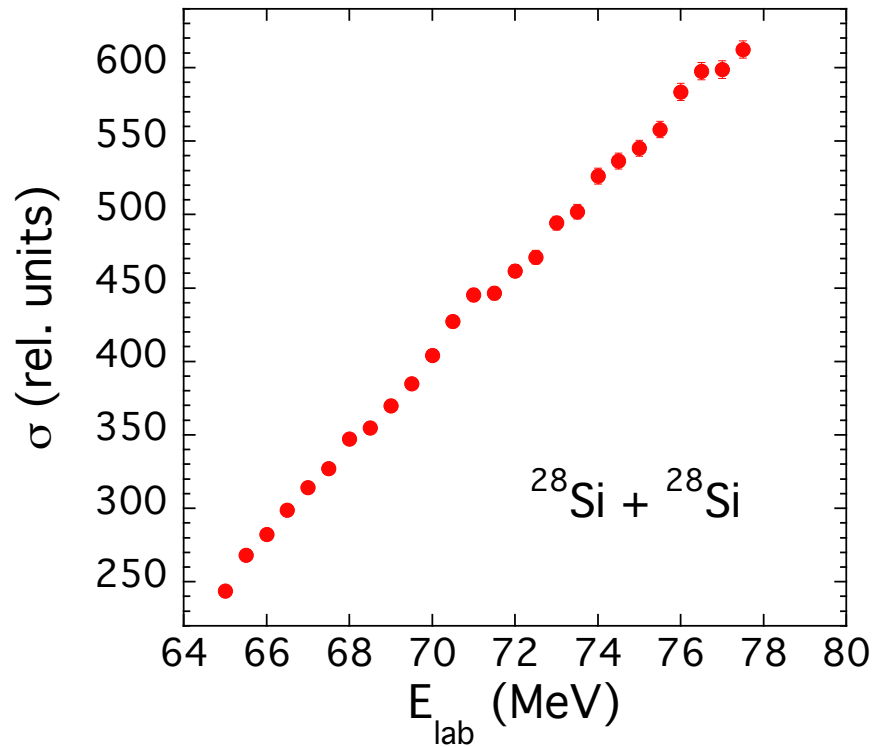
44 Physical Review C
13 Nuclear Physics A
3 Physical Review Letters
5 Physics Letters B
11 European Physics Journal A
4 Nuclear Instruments and Methods
4 Journal of Physics G
13 other

Sub-barrier fusion: $^{28}\text{Si}+^{28}\text{Si}$

CC analysis of the excitation function, using a Woods-Saxon potential with $a=0.63$ fm, $r_0=1.04$ fm, $V_0=73.6$ MeV (adjusted to fit the data in the barrier region)



Fusion cross sections of $^{28}\text{Si}+^{28}\text{Si}$ and energy-weighted derivative of the excitation function above the barrier



H.Esbensen, PRC 85, 064611 (2012)

L-dependent fusion barriers:
$$V_B(L) = V_{CB} + \frac{\hbar^2 L(L+1)}{2\mu R_{CB}^2}$$

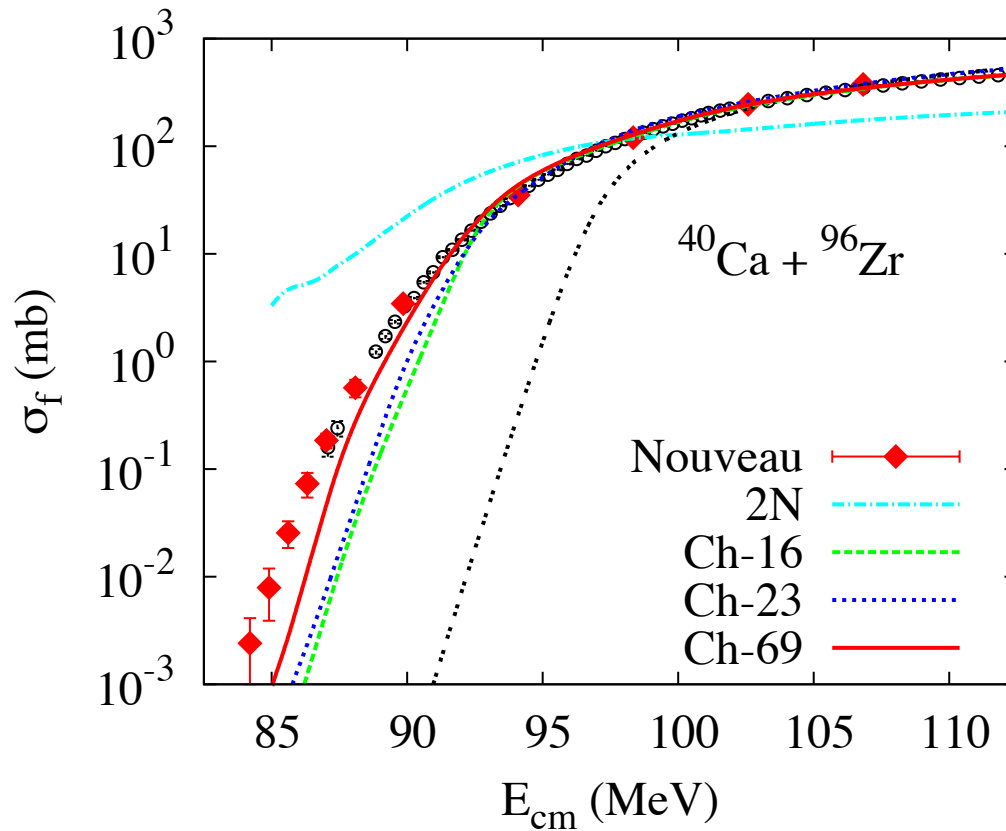
The energy difference between successive barriers:

$$\Delta V_B = V_B(L+1) - V_B(L) \approx \frac{\hbar^2 2(L+1)}{2\mu R_{CB}^2}$$

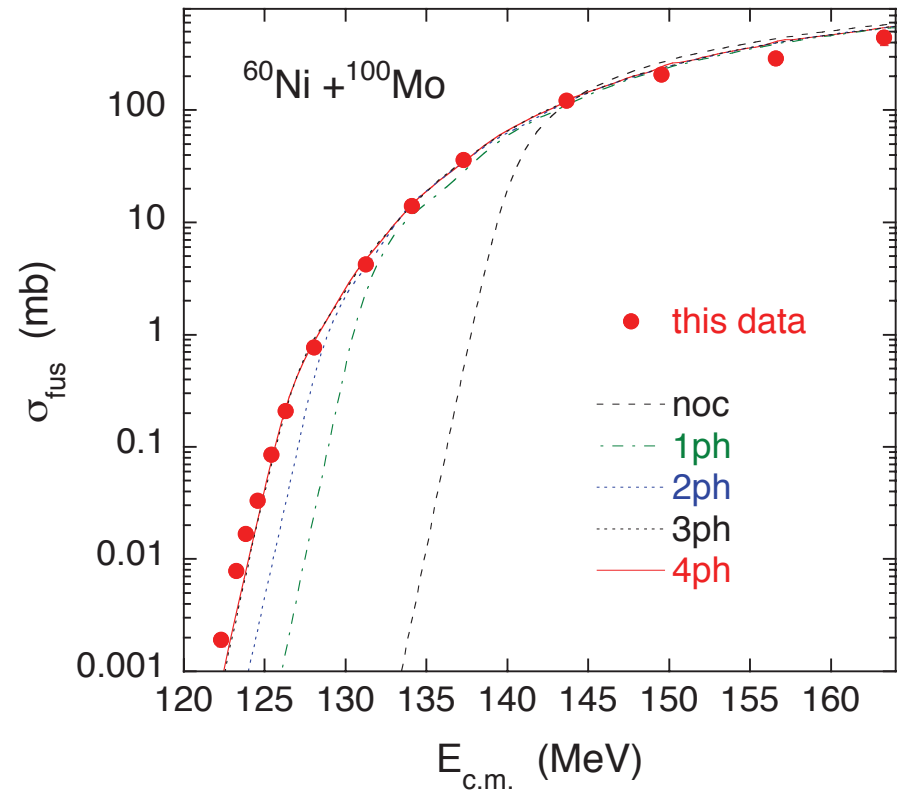
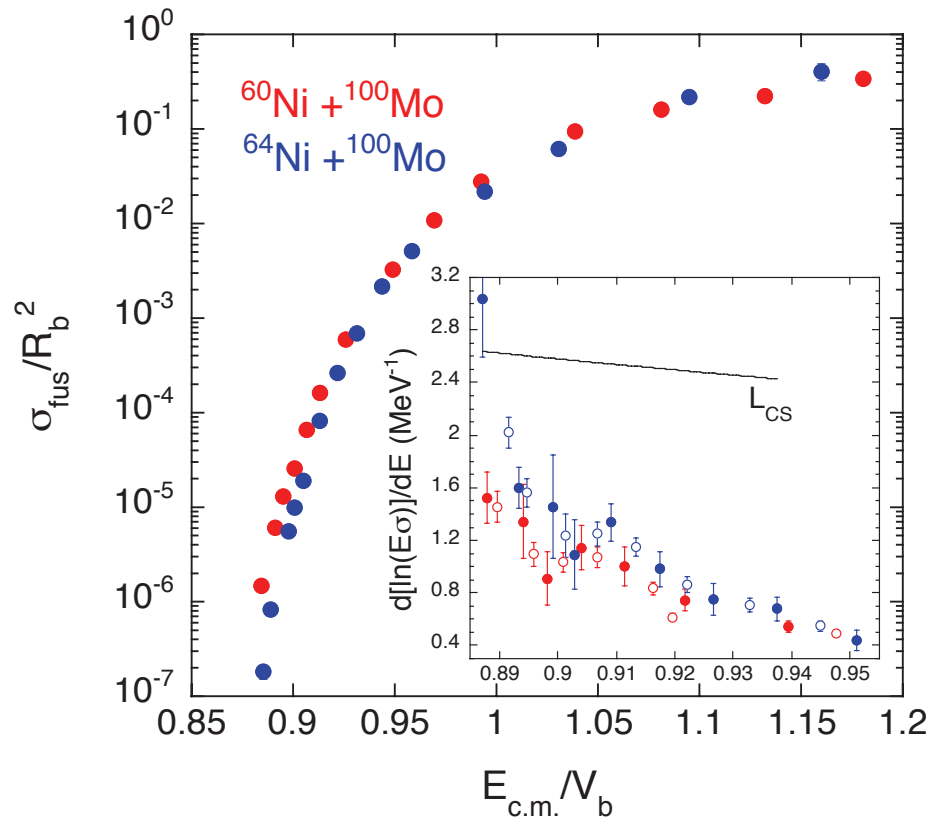
(twice as that for a symmetric system like $^{28}\text{Si} + ^{28}\text{Si}$, i.e. ≈ 1.52 MeV)

$^{40}\text{Ca} + ^{90,96}\text{Zr}$ fusion

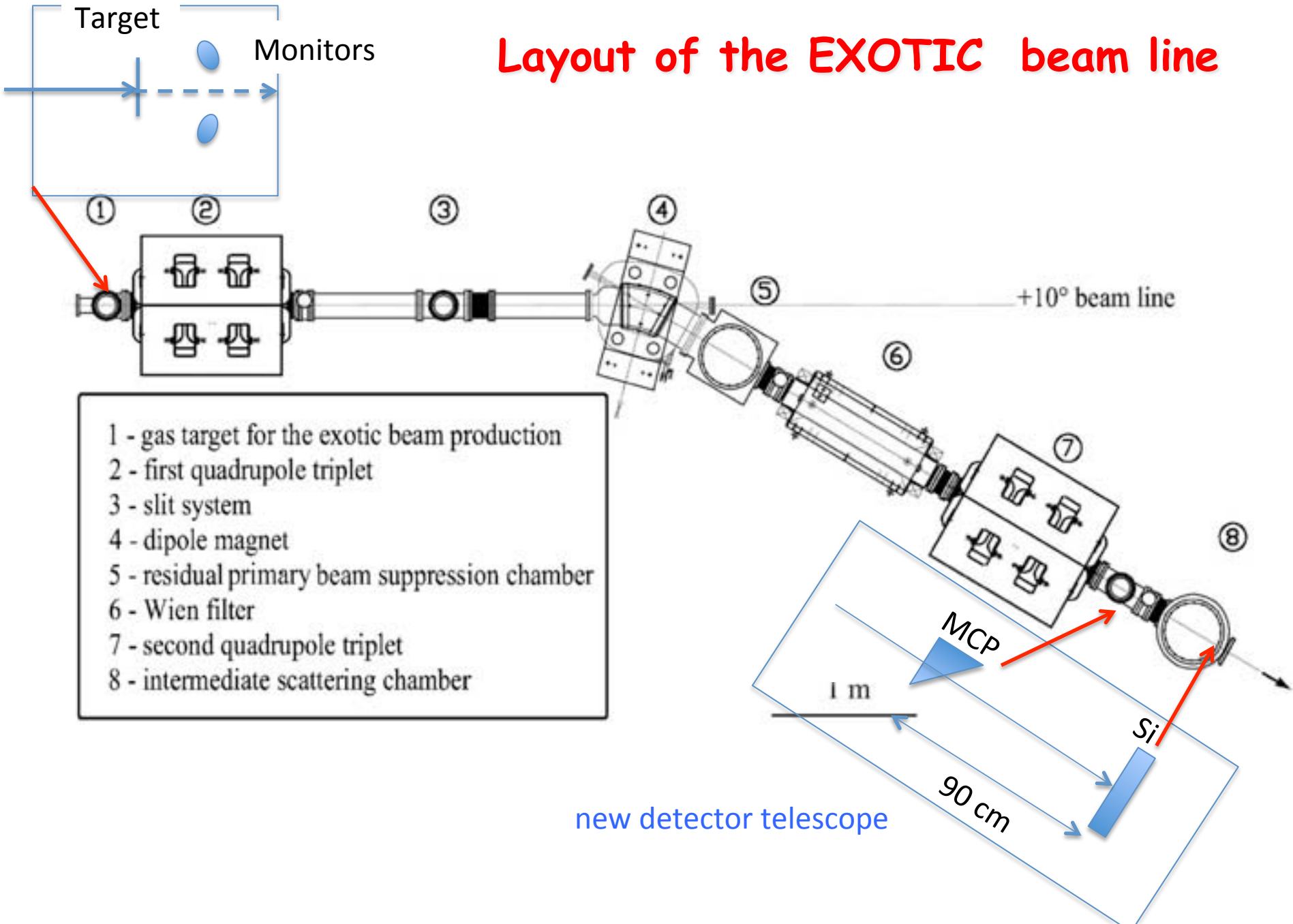
new data and a detailed analysis using WS potentials



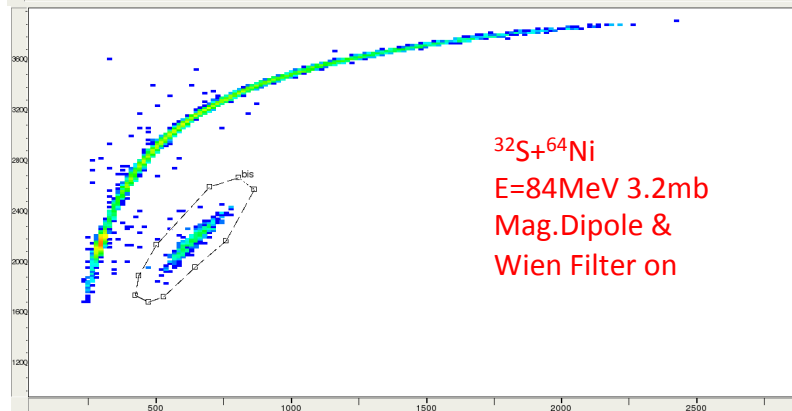
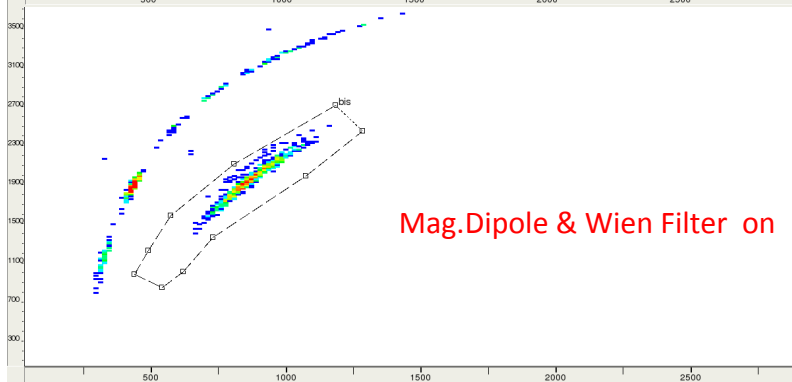
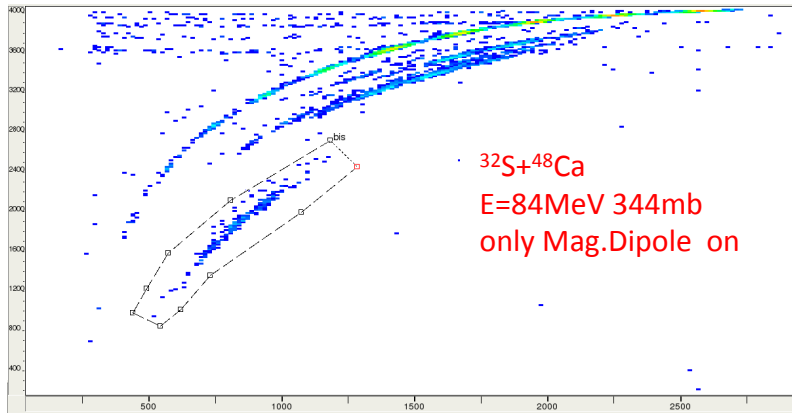
Fusion of $^{60}\text{Ni} + ^{100}\text{Mo}$ (experiment performed at ANL)



Layout of the EXOTIC beam line



TOF (channels)

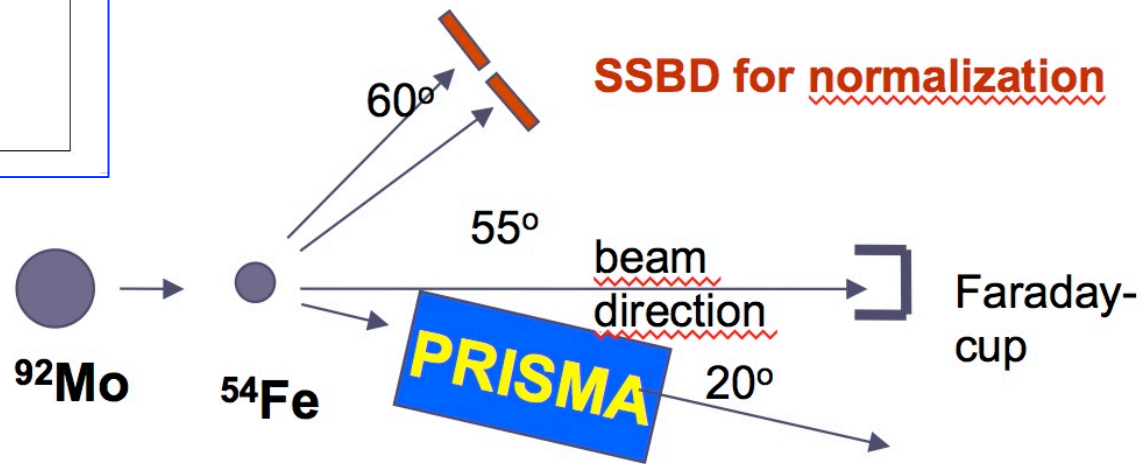
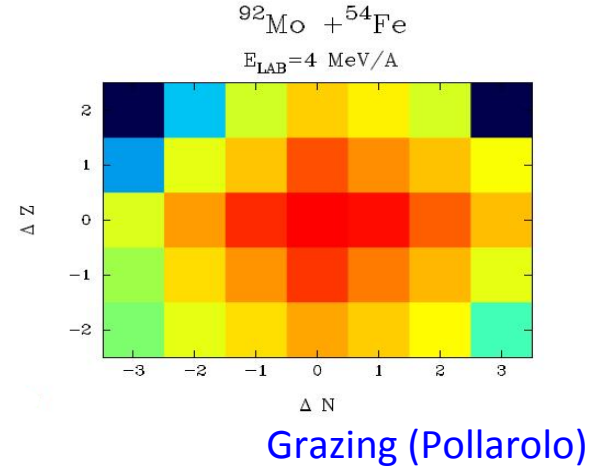
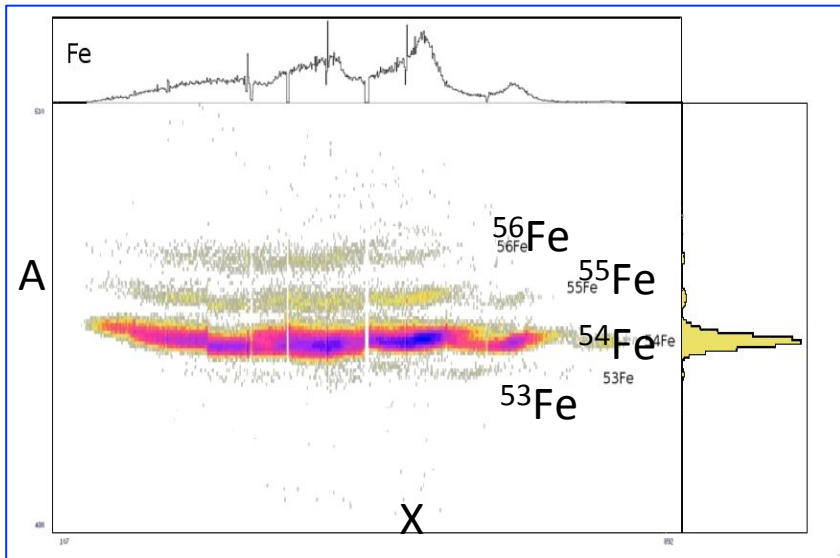


Energy (channels)

First test (May 2013) of sub-barrier fusion measurements with the Exotic set-up

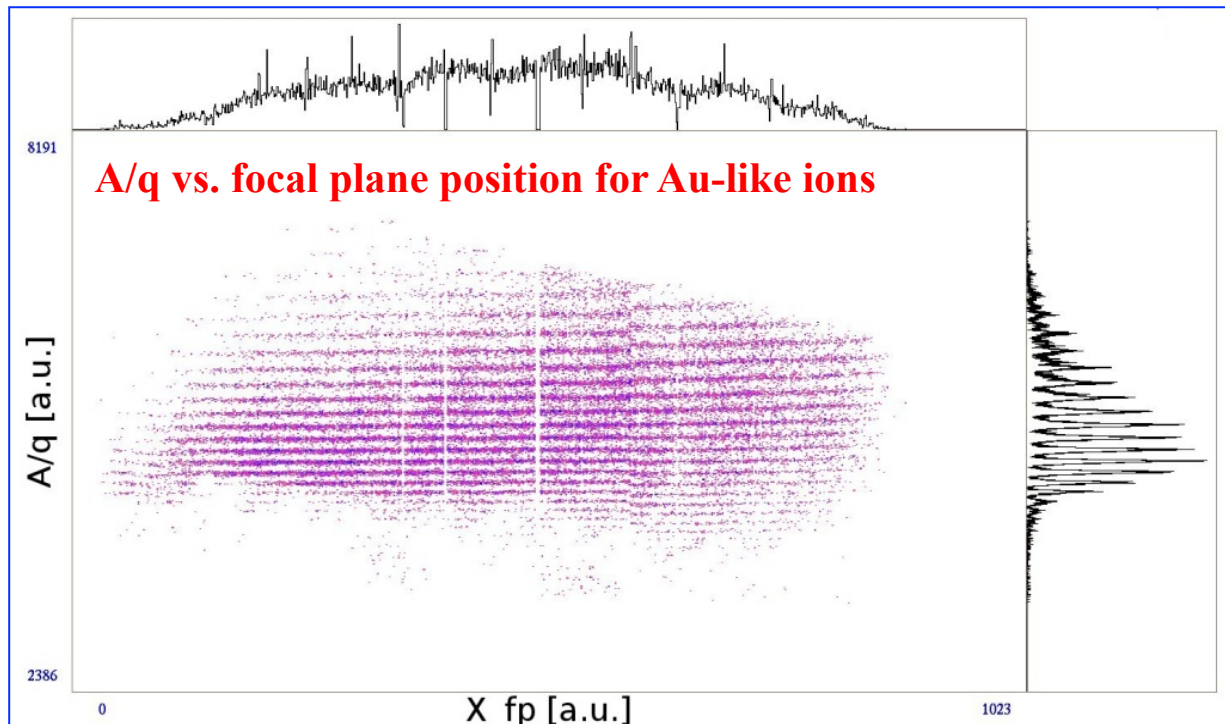
- Very good beam rejection factor $\approx 10^{11}$
- Transmission not yet optimized

Probing nucleon-nucleon correlations via transfer of (nn), (pp) and (np) pairs at sub-barrier energies in $^{92}\text{Mo} + ^{54}\text{Fe}$

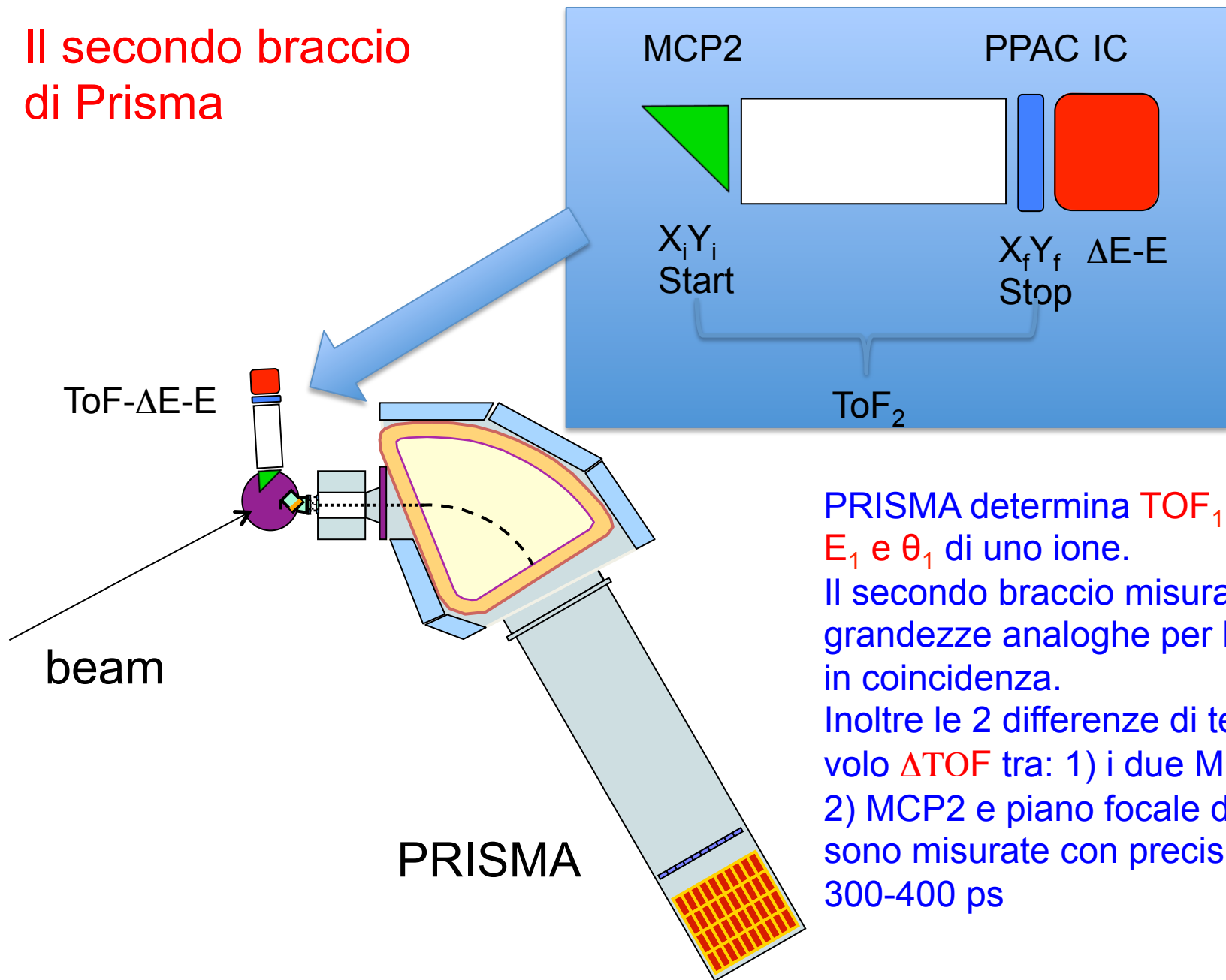


Neutron rich nuclei populated via multinucleon transfer reactions: the $^{197}\text{Au}+^{130}\text{Te}$ system as a benchmark

$E_L = 1070 \text{ MeV}$, $\theta_L = 37^\circ$ and $E_L = 1300 \text{ MeV}$, $\theta_L = 27^\circ$
Detected both Te- and Au-like transfer products



Il secondo braccio di Prisma

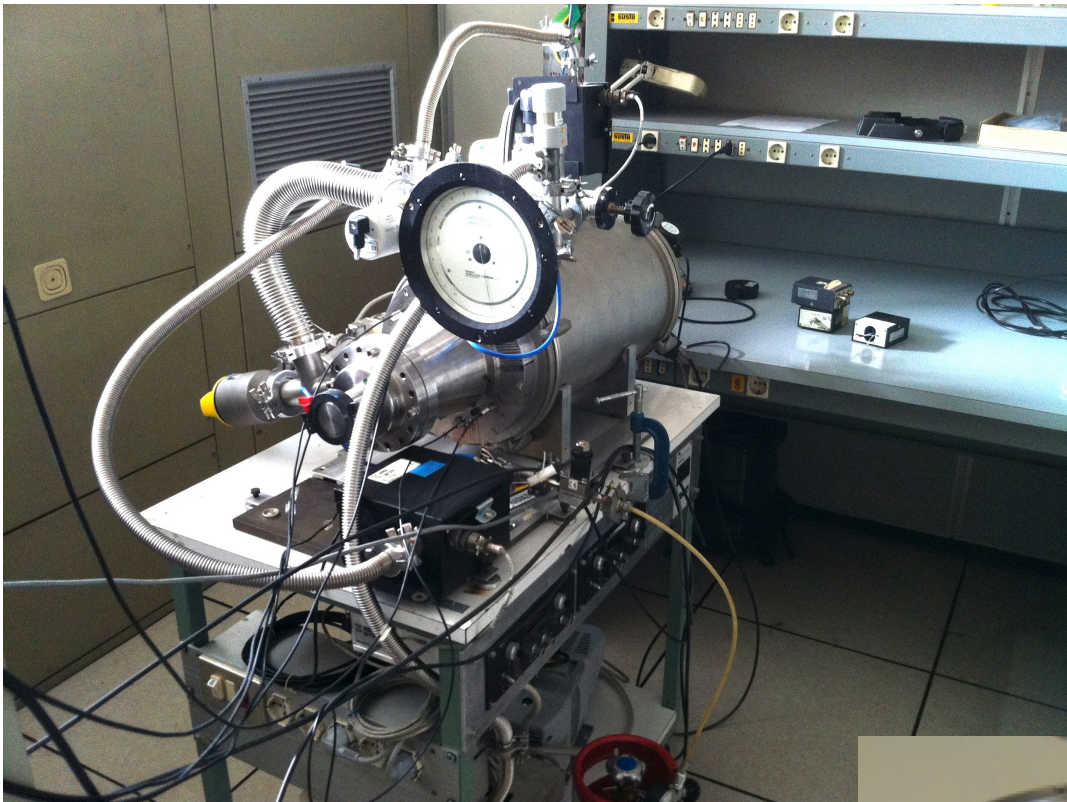


PRISMA determina TOF_1 , ΔE_1 , E_1 e θ_1 di uno ione.

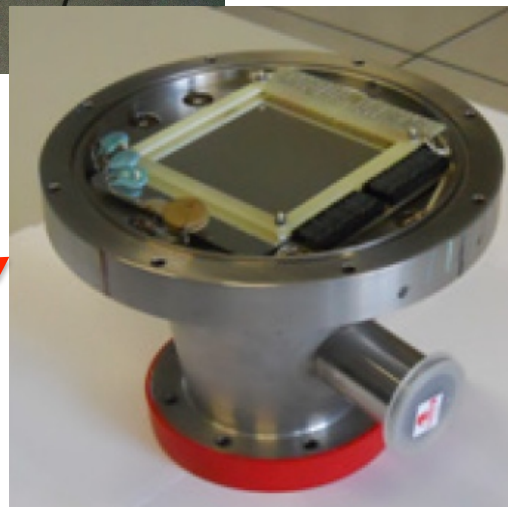
Il secondo braccio misura le grandezze analoghe per lo ione in coincidenza.

Inoltre le 2 differenze di tempo di volo ΔTOF tra: 1) i due MCP e 2) MCP2 e piano focale di PRISMA sono misurate con precisioni di 300-400 ps

The Bragg chamber for the 2nd arm of Prisma, during the laboratory tests



Inner side of the axial chamber with the guard rings



Position sensitive PPAC mounted in front of the axial ionization chamber

Results of the tests with α -particles

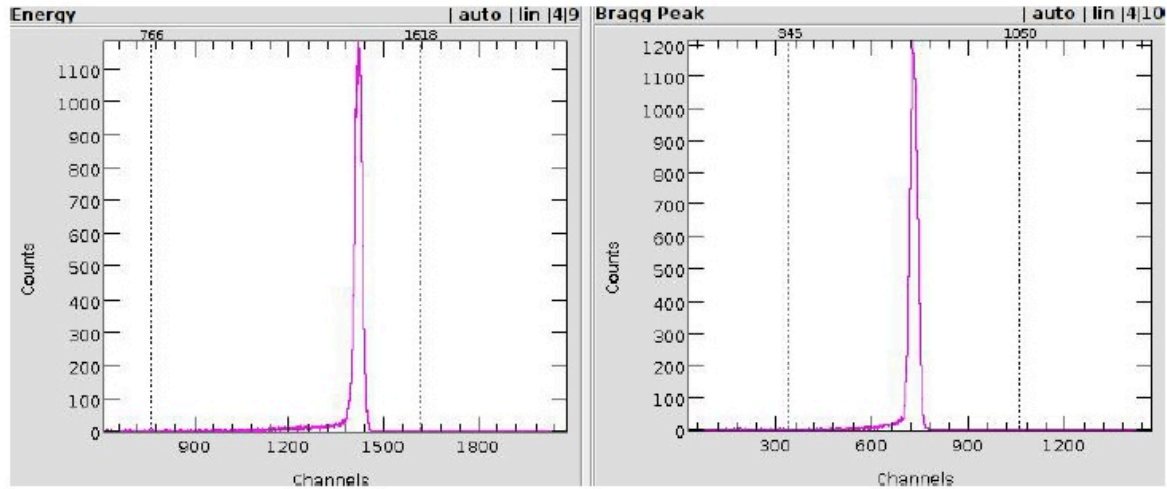


FIG. 2: Energy and Bragg peak spectra obtained with shaping times of $4 \mu\text{s}$ and $0.5 \mu\text{s}$.

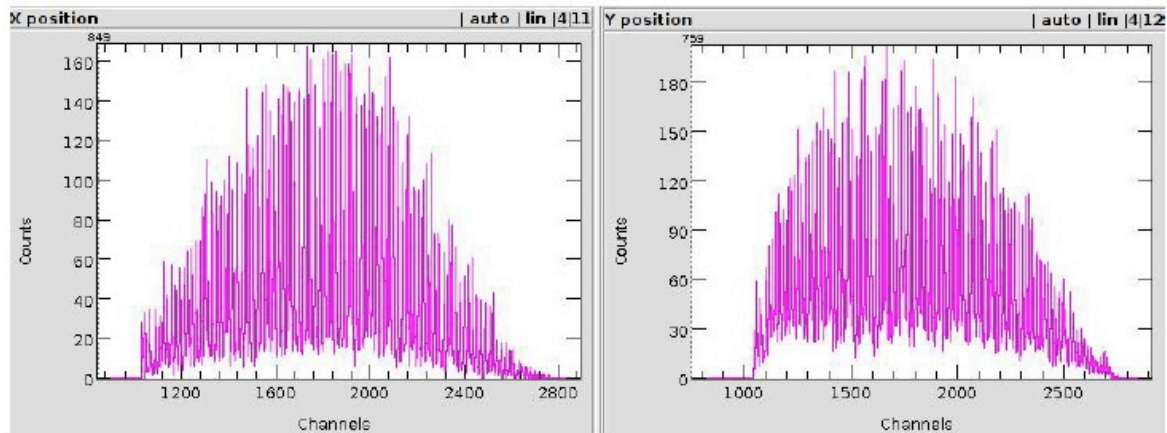


FIG. 3: X and Y position spectra measured with 5.486 MeV α particles.

Bilancio complessivo PRISMA-FIDES 2014

	Padova		LNL		Torino
Missioni	Interne	5	Interne	4	2
	Estere	6	Estere	8	2
Consumo	Rinnovo Pre PPAC	2	Isotopi arricch. (^{54}Cr , ^{58}Fe , ^{30}Si)	10	
	Si e monitor x Pisolo ed Exotic	10	Ricambi alim. magneti Prisma	9	
	Coppia MCP Pisolo 43x63 mm ²	4	Cons. vario, gas, cavi, manutenz.	5	
	Flange attrezzate x cam. scatt.	2	mov. Pisolo e flange su Exotic		
Inventario	Oscillosc. Digitale Lecroy	6	Ricambi mis. vuoto Prisma	9	
	Controllo turbo $\Phi=150$ Pisolo	4	TDC x misura tempo drift (pos. Y)	5	
	Pompa turbo $\Phi=63$ Pisolo	6	Flash ADC per II braccio	12	
	Pompa a secco x Pisolo	5			
Totali		50		62	4

Richieste ai servizi Padova per il 2014

Servizio	Lavoro richiesto	Tempo (mesi uomo)
Ufficio Tecnico	Alloggiamento rivelatori LaBr_3 su coperchio cam. sliding seal dedicato	2
Officina Meccanica	Costruzione parti per il sistema di rotazione del II braccio su camera sliding seal, installazione e allineamenti	6
Laboratorio Elettronica	Ottimizzazione fast ampl. + HV per i due PPAC	2

Richieste ai servizi LNL per il 2014

Servizio	Lavoro richiesto	Tempo (mesi uomo)
Officina meccanica	Installazione II braccio di Prisma (con rivelatori, meccanica, allineamenti)	6
Servizio Utenti (Supporto App. Sperim.)	Controllo PLC del vuoto Pisolo Upgrading controllo x II braccio	3 1
STIE (Servizio Tecnologie Informatiche ed Elettroniche)	Assistenza durante gli esperimenti Prisma e Pisolo, sviluppi per nuovo DAQ per Prisma	3

Milestones PRISMA-FIDES 2014

- 1) **July 30, 2014** to complete the installation and the in-beam commissioning of the 2nd arm of PRISMA, including the Flash ADC for the read-out of the Bragg chamber
- 2) **July 30, 2014** to complete the in-beam tests for the use of the Exotic set-up for the measurement of sub-barrier fusion with stable beams
- 3) **July 30, 2014** to perform the approved experiments on deep sub-barrier fusion with medium-mass and light systems
- 4) **Nov. 30, 2014** to perform a sub-barrier transfer experiment with a $A \approx 200$ Piave-ALPI beam in inverse kinematics, using PRISMA with its 2nd arm
- 5) **Dec. 20, 2014** to install and test the TDC for the Y read-out from the IC of PRISMA (better tracking)

Considerazioni finali

Le prospettive per la sperimentazione con PRISMA per lo studio dei meccanismi di reazione e per la spettroscopia gamma sono di sicuro interesse internazionale, mediante l' utilizzo sia di fasci stabili che dei fasci radioattivi prodotti da SPES

L'obiettivo a medio-lungo termine e' di rendere PRISMA uno strumento piu' versatile, per l'uso con i futuri fasci di qualita' prodotti dagli acceleratori dei LNL, stabili e instabili, con un uso combinato con set-up complementari come Exotic e futuri array γ

La prosecuzione degli esperimenti e gli sviluppi degli apparati, in vista anche di SPES, sono basati sul supporto tecnico della Sez. di Padova e dei LNL (finora eccellenti), anche per mantenere e migliorare la qualita' dei fasci stabili forniti dagli acceleratori Tandem, ALPI e Piave

End

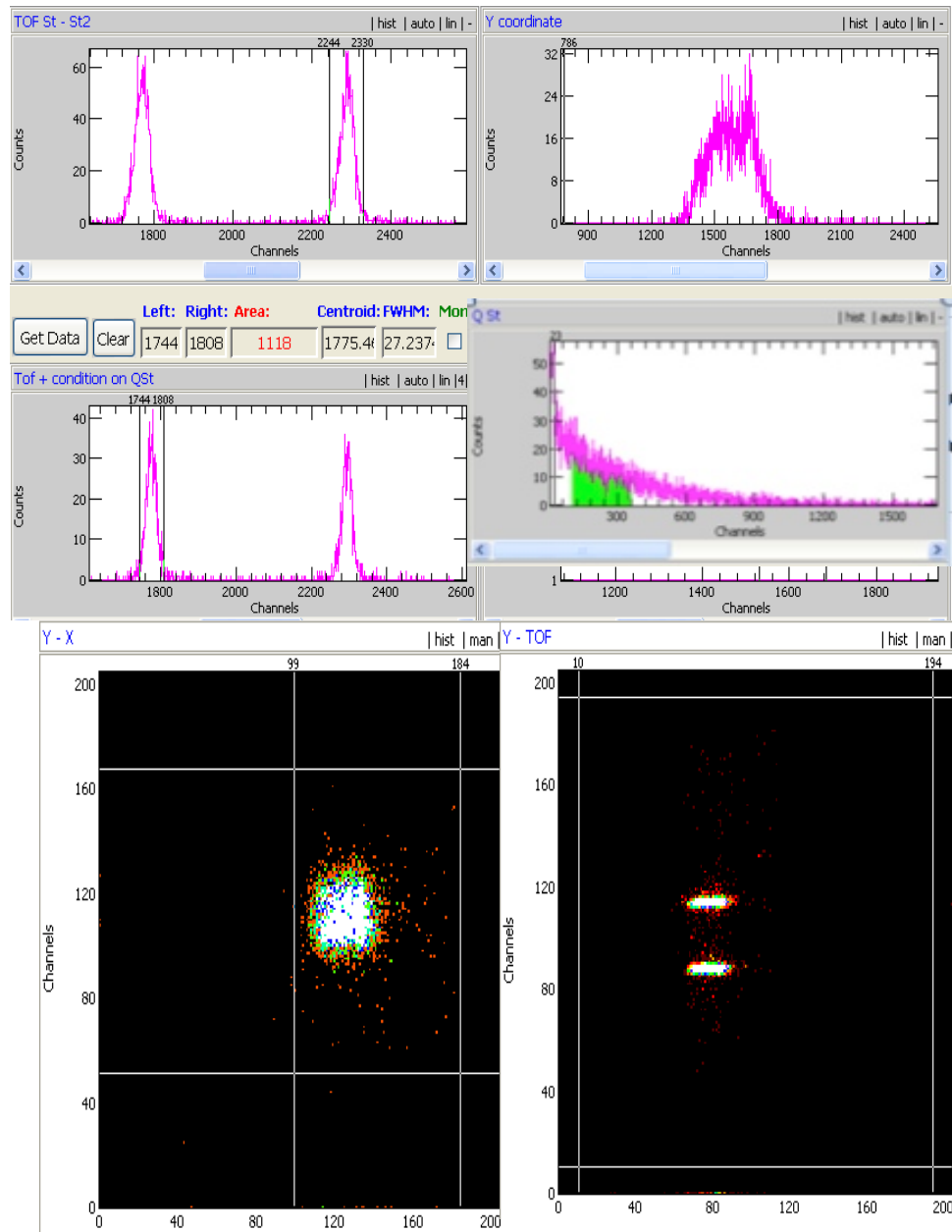
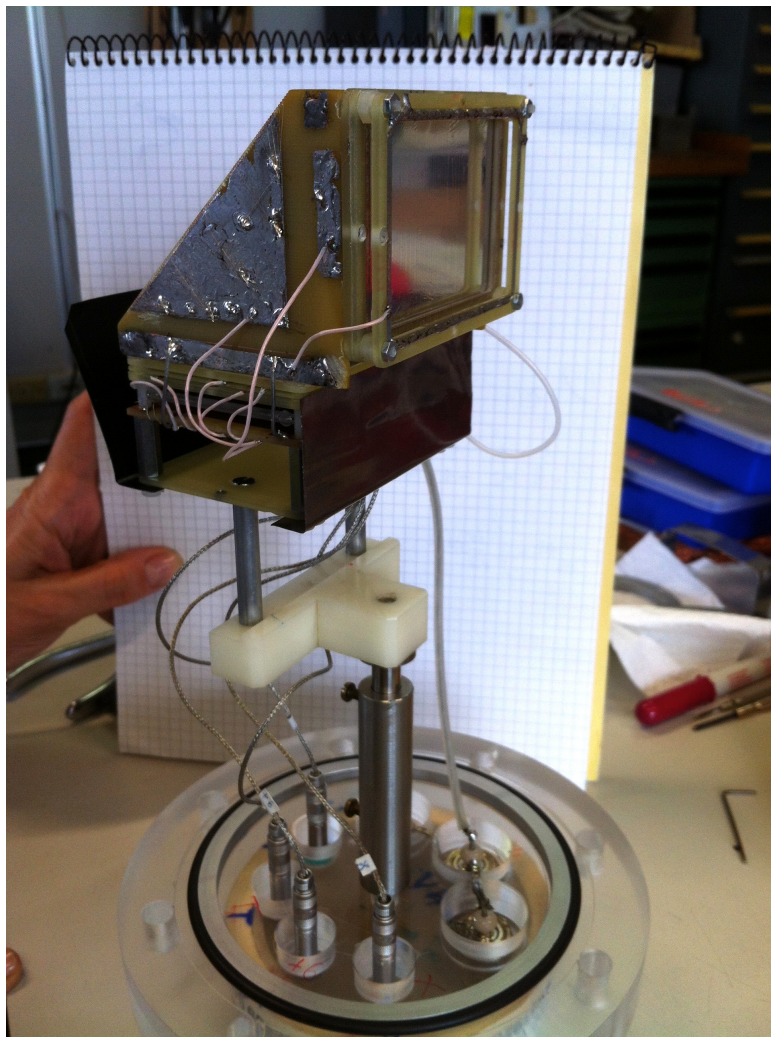
Milestones PRISMA-FIDES 2013

- 1) **July 30, 2013** to propose at the LNL PAC an experiment on sub barrier fusion in medium-light systems \longrightarrow 100 %
- 2) **July 30, 2013** to propose at the LNL PAC an experiment on nucleon transfer channel in $^{48}\text{Ca}+^{48}\text{Ca}$ $^{197}\text{Au}+^{130}\text{Te}$ \longrightarrow 100%
- 3) **July 30, 2013** to perform the approved experiment ($^{92}\text{Mo}+^{54}\text{Fe}$, proton-rich) about sub-barrier transfer \longrightarrow 100 %
- 4) **July 30, 2013** to complete the installation of the new scattering chamber for PRISMA \longrightarrow by October
- 5) **Dec. 20, 2013** to test the new detectors and perform the DAQ upgrading for the second arm of PRISMA \longrightarrow will be done

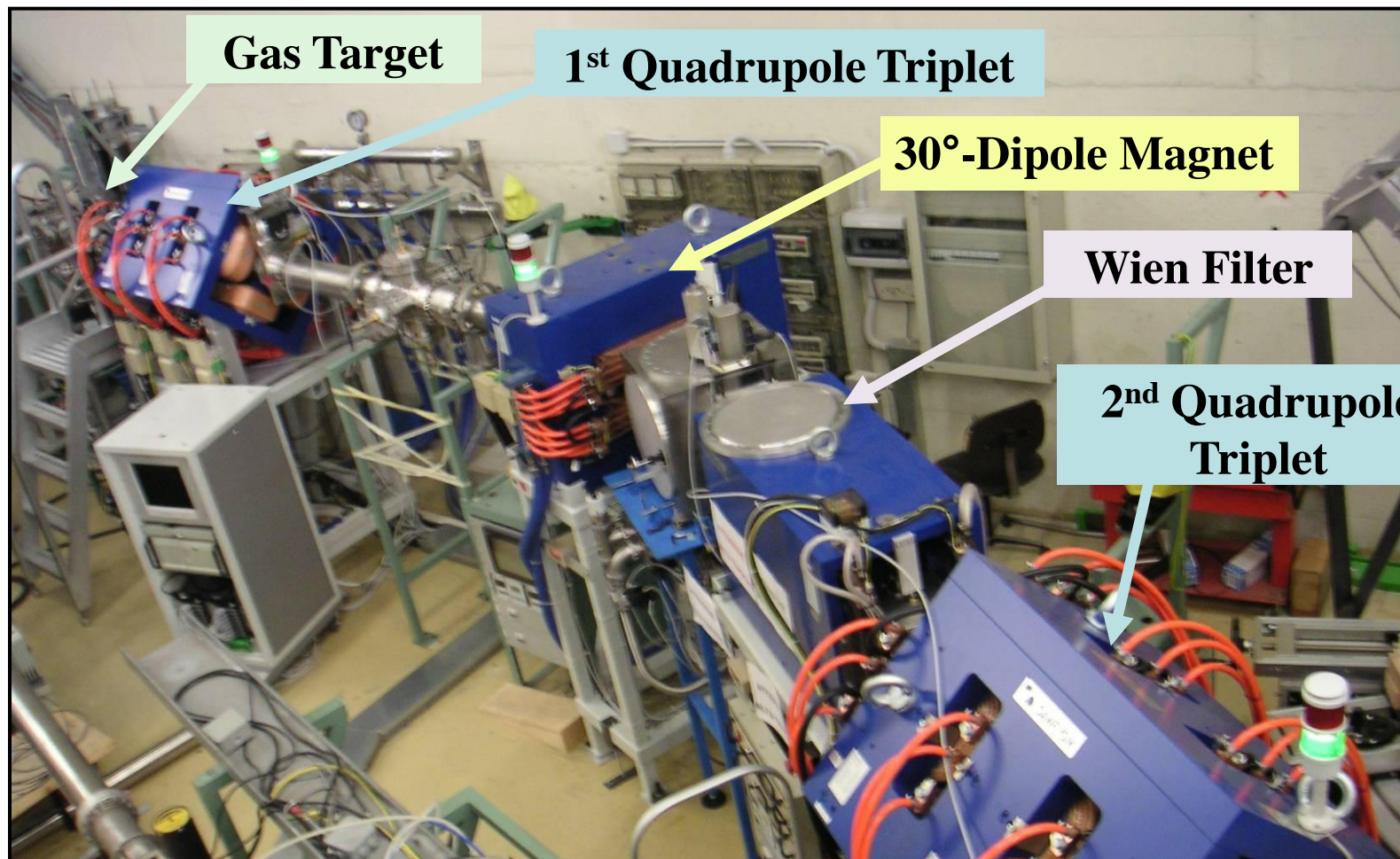
Secondo braccio: si tratta di un telescopio TOF- ΔE -E flangiato alla camera di scattering con angolo variabile rispetto a PRISMA

- **coincidenze** tra ioni tipo fascio di massa media identificati in PRISMA e ioni **target-like** pesanti rivelati dal secondo braccio: questo permette di determinarne la "**survival probability**" verso la fissione, in funzione dell'energia, della reazione e del numero di nucleoni trasferiti \longrightarrow produzione di **nuclei pesanti** con l'uso di reaz. di trasferimento
- coincidenze cinematiche **ad alta risoluzione** in reazioni tra ioni di massa media ($A \approx 100$ o meno); il piu' pesante e' identificato da PRISMA, l'altro dal secondo braccio: \longrightarrow informazioni sull'**evaporazione** di particelle leggere (neutroni) dai due frammenti primari in reazioni di trasferimento multiplo
-

The MCP detector for the 2nd arm of Prisma, used also during the Exotic test



The EXOTIC beamline at LNL



L-dependent fusion barriers can be parametrized as

$$V_B(L) = V_{CB} + \frac{\hbar^2 L(L + 1)}{2\mu R_{CB}^2}$$

The **energy difference** between the heights of successive barriers is

$$\Delta V_B = V_B(L + 1) - V_B(L) \approx \frac{\hbar^2 2(L + 1)}{2\mu R_{CB}^2}$$

and \approx twice as that for symmetric systems, i.e. **1.52 MeV** for $^{28}\text{Si} + ^{28}\text{Si}$.

The **width** of the individual barriers is $\varepsilon_0 = \hbar\omega/2\pi$ where $\hbar\omega$ is the curvature of the Coulomb barrier, in the parabolic approximation

$$2\varepsilon_0 = \mathbf{1.13\ MeV} \text{ for } ^{28}\text{Si} + ^{28}\text{Si}$$