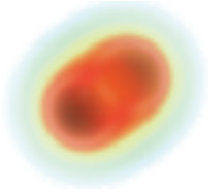
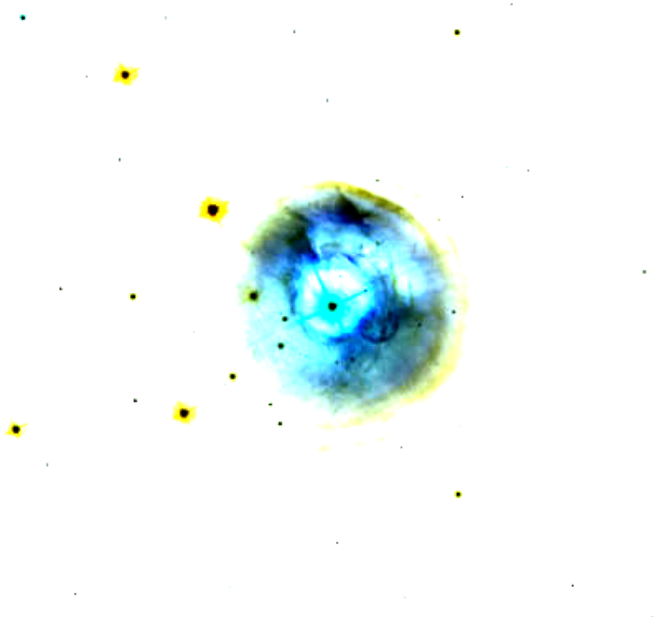
Sub-barrier fusion cross section measurements with gamma-particle-coincidences with STELLA

Marcel Heine for the STELLA Collaboration

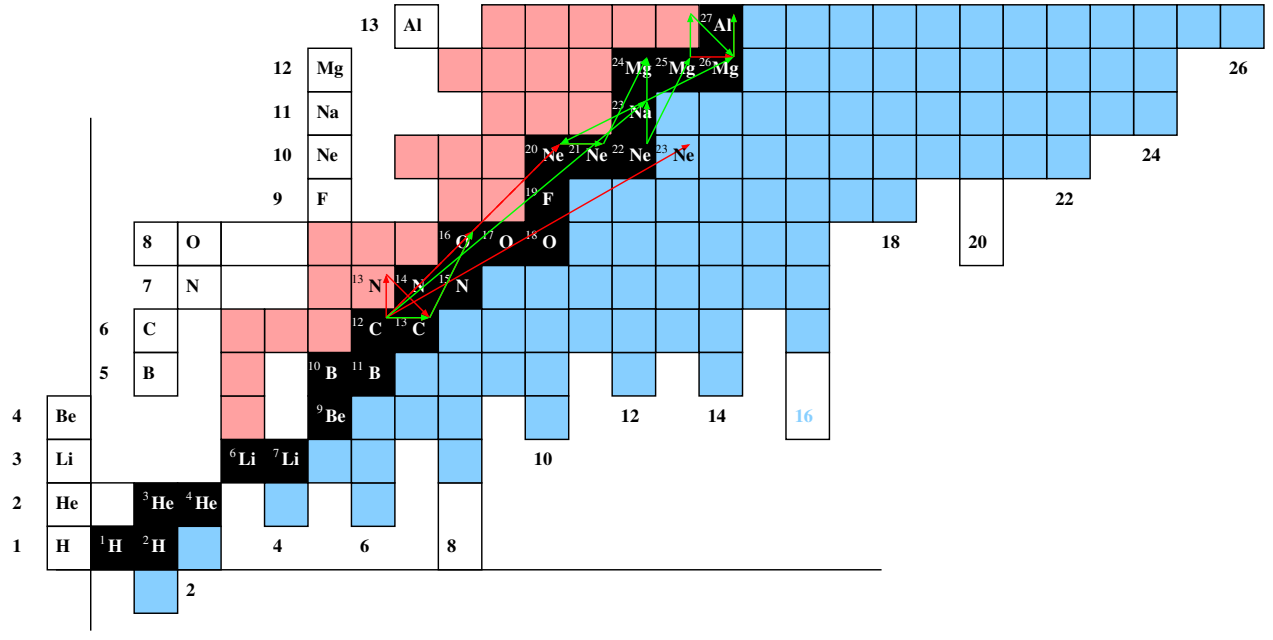
IPHC/CNRS Strasbourg

6/28/2017



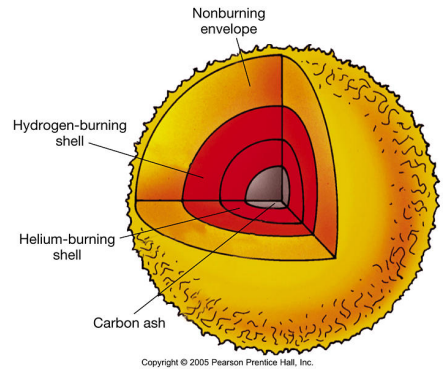


Network Reaction Flow during Carbon Burning

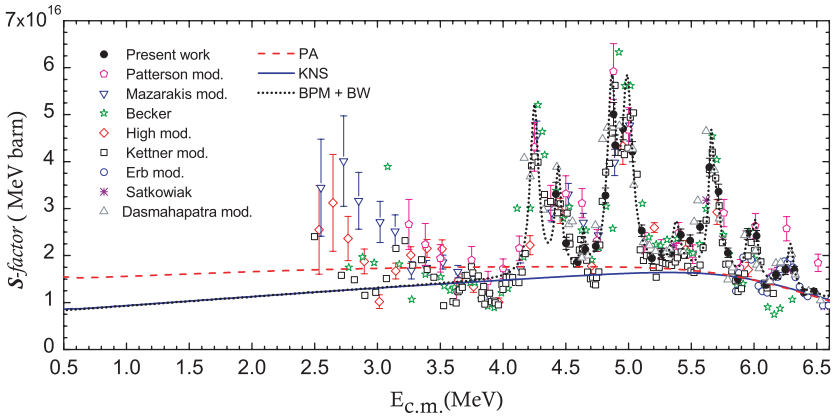


A. Chieffi *et al.*, APJ**502**, 737, (1998)

$$^{12}\mathrm{C} + ^{12}\mathrm{C} \rightarrow ^{24}\mathrm{Mg}^{*} \rightarrow ^{24}\mathrm{Mg} + \gamma;\ Q = 13.93\ \mathrm{MeV}$$
$$\rightarrow ^{20}\mathrm{Ne} + \alpha;\ Q = 4.62\ \mathrm{MeV}$$
$$\rightarrow ^{23}\mathrm{Na} + \mathrm{p};\ Q = 2.24\ \mathrm{MeV}$$
$$\rightarrow ^{23}\mathrm{Mg} + \mathrm{n};\ Q = -2.60\ \mathrm{MeV}$$



Measurement below the Coulomb barrier:



E.F.Aguilera *et al.*, PRC**73**, 064601, (2006)

J.-P.Ebran *et al.*, PRC**90**, 054329, (2014)

- γ Aquilera *et al.*, High *et al.*, Kettner *et al.*, Erb *et al.*, Satkowiak *et al.*, Dasmahapatra *et al.*
- p/α Patterson *et al.*, Mazarakis *et al.*, Becker *et al.*
- $\rightarrow$ 'unified' data sets

$$S = E\sigma(E)\exp(2\pi\eta)$$

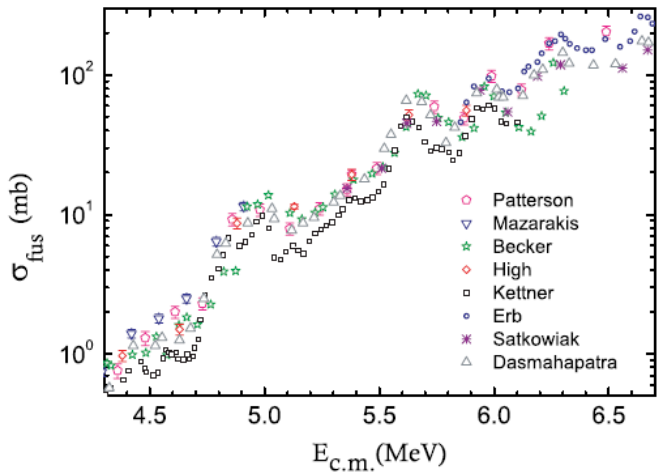
cluster states in ^{24}Mg

- branching into ^{20}Ne, ^{23}Na

The (Incomplete) Story of Sub-barrier ^{12}C Fusion

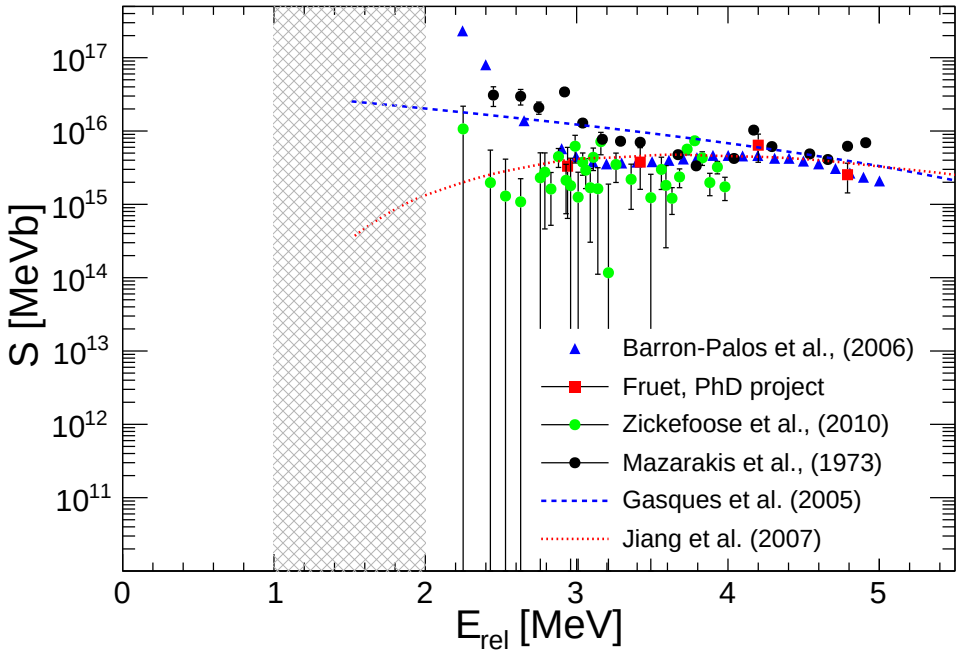
+ J.R. Patterson *et al.*, APJ 157, 367, (1969)
- G.J. Michaud and E.W. Vogt, PRC 5, 350, (1972)
+ M.G. Mazarakis and W.E. Stephens, PRC 7, 1280, (1973)
- R.G. Stokstad *et al.*, PRL 37, 888, (1976)
+ P.R. Christensen *et al.*, Nucl. Phys. A 280, 189, (1977)
+ M.D. High and B. Čujec, NIM A 282, 181, (1977)
+ K.-U. Kettner *et al.*, PRL 38, 377, (1977)
+ K.A. Erb *et al.*, PRC 22, 507, (1980)
+ H.W. Becker *et al.*, Z. Phys. A 303, 305, (1981)
- Y. Suzuki and K.T. Hecht, Nucl. Phys. A 388, 102. (1982)
+ B. Čujec *et al.*, PRC 39, 1326, (1989)
- L.R. Gasques *et al.*, PRC 72, 025806, (2005)
+ E.F. Aguilera *et al.*, PRC 73, 064601, (2006)
+ L. Barrón-Palos *et al*, Nucl. Phys. A 779, 318, (2006)
+ D. Jenkins *et al.*, PRC 76, 044310, (2007)
+ C.L. Jiang *et al.*, PRC 75, 015803, (2007)
+ T. Spillane *et al.*, PRL 98, 122501, (2007)
+ J. Zickefoose, Ph.D. thesis, U. of Connecticut (2010)
+ C.L. Jiang *et al.*, NIM A 682, 12, (2012)
+ X. Fang *et al.*, Jour. Phys. 420, 012151, (2013)
+ C.L. Jiang *et al.*, PRL 110, 072701, (2013)
- A.A. Aziz *et al.*, PRC 91, 015811, (2015)
+ B. Bucher *et al.*, PRL 114, 251102, (2015)
+ A. Tumino *et al.*, EPJ Conf. 117, 09004, (2016)

- gammas/particles
- thin/thick target

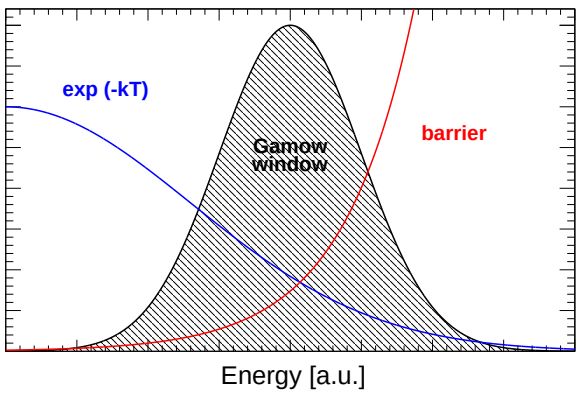


E.F. Aguilera *et al.*, PRC**73**, 064601, (2006)

- resonances
- extrapolations



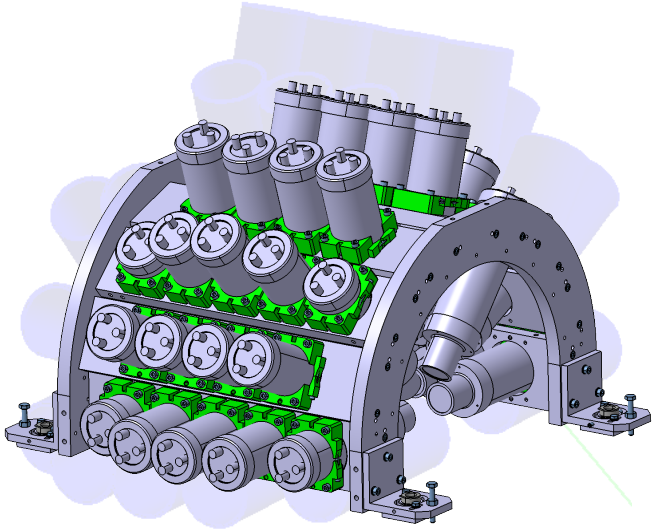
Gamow window

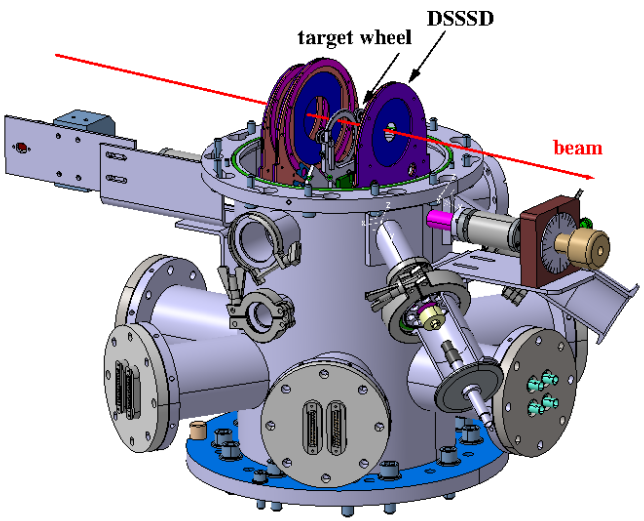


$$S = E\sigma(E)\exp(2\pi\eta)$$

- Gamow window: fusion cross sections in the nbarn range
- extremely sensitive to background contributions

$\rightarrow$ gamma-particle (coincidence) technique



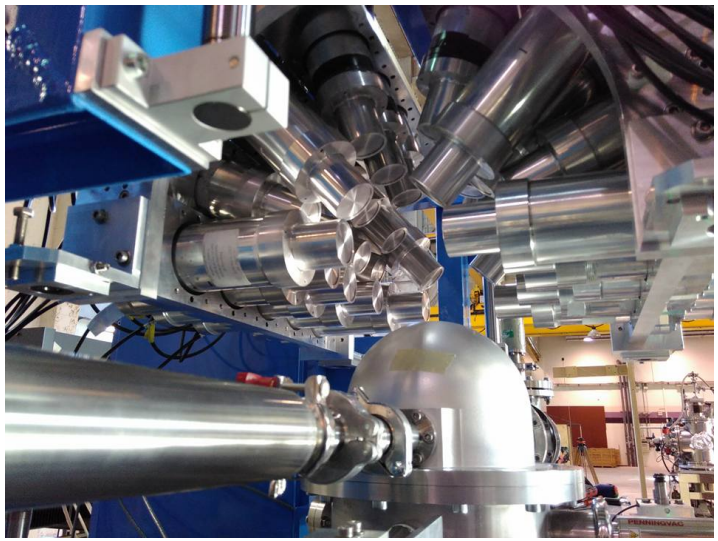


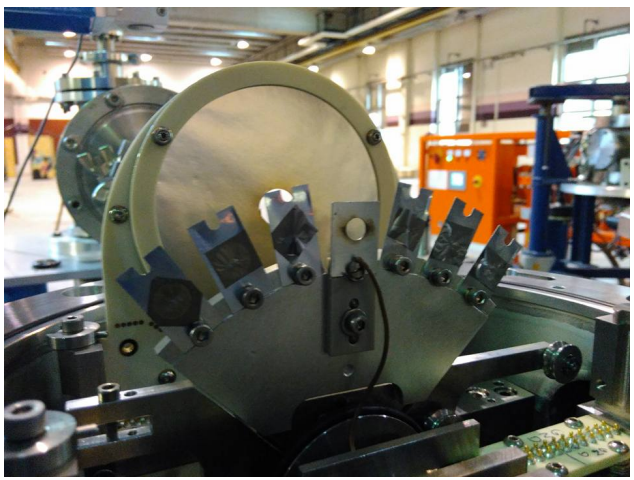
M. Krauth, G, Heitz, P. Dené

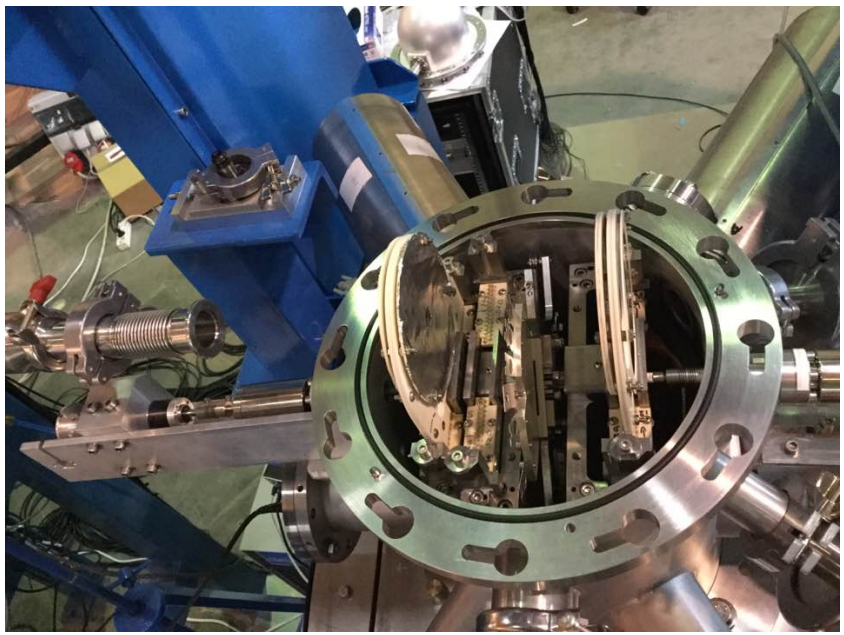
- 36 $LaBr_3$ with the **UK FATIMA** collaboration
- three annular DSSSD
- trigger less time stamped data streams
- high intensity stable beam: **Andromède** at IPN (Orsay)
- rotating target mechanism
- ultra-high vacuum: 10^{-8} mbar (carbon build-up)
- monitor detectors: normalization

\+ Faraday cup: beam current

STELLA at Andromède at IPN (Orsay)





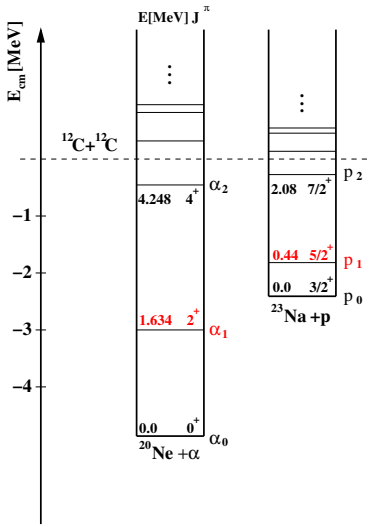


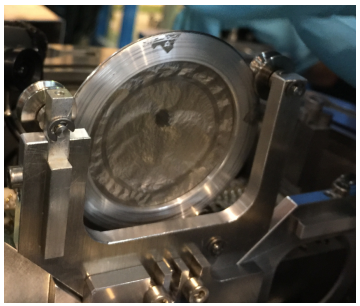
Focus of the First Campaign

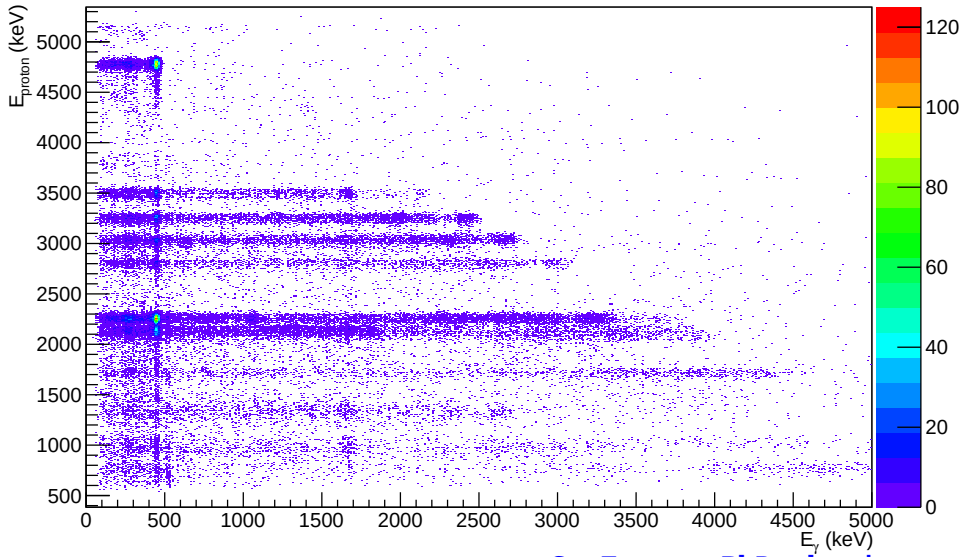
- $^{12}C+^{12}C$ at $E_{beam} = 5.6 \leftarrow 11.1$ MeV
  first excited states in ^{20}Ne, ^{23}Na:
- Q-value, cascading

$\rightarrow$ detect 0.440 MeV, 1.634 MeV gammas
fixed target experiment:

- $^{12}C^{2,3+}$ beam, $I = 100 \rightarrow 800$ pnA
- $\Delta t = 1/2\text{h} \rightarrow 1\ 1/2\text{weeks}$



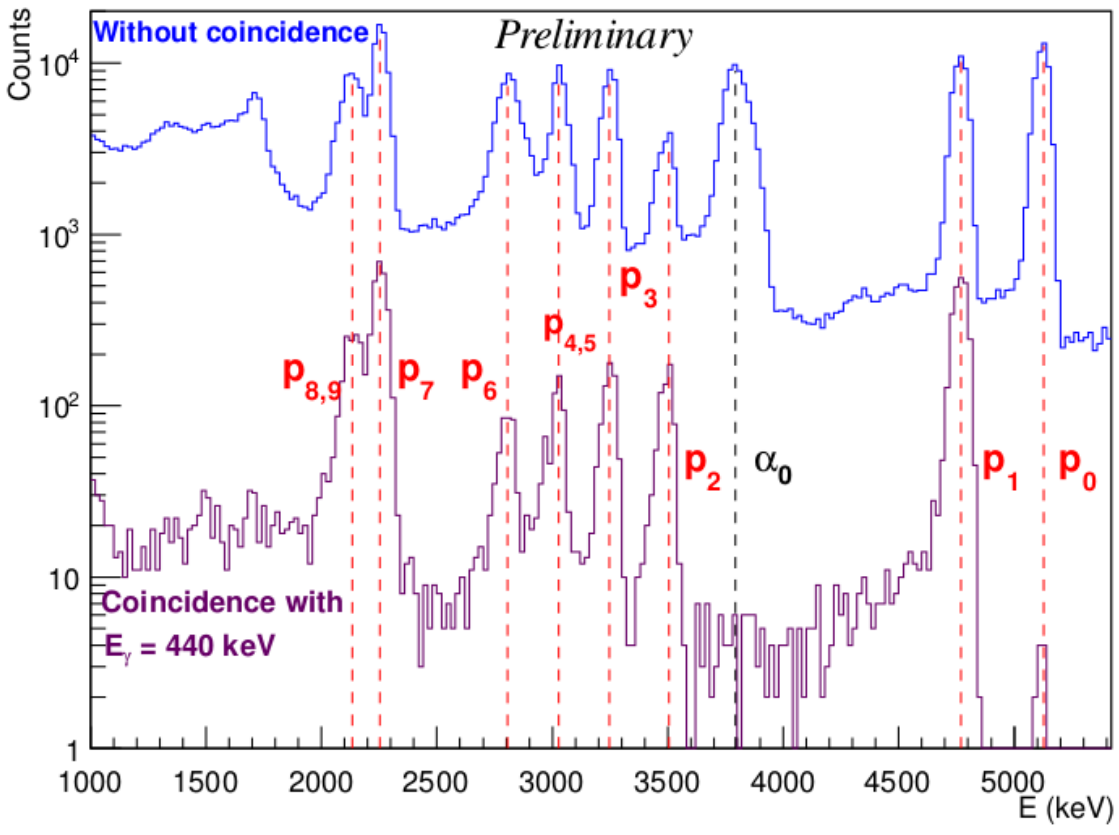




G. Fruet, PhD thesis

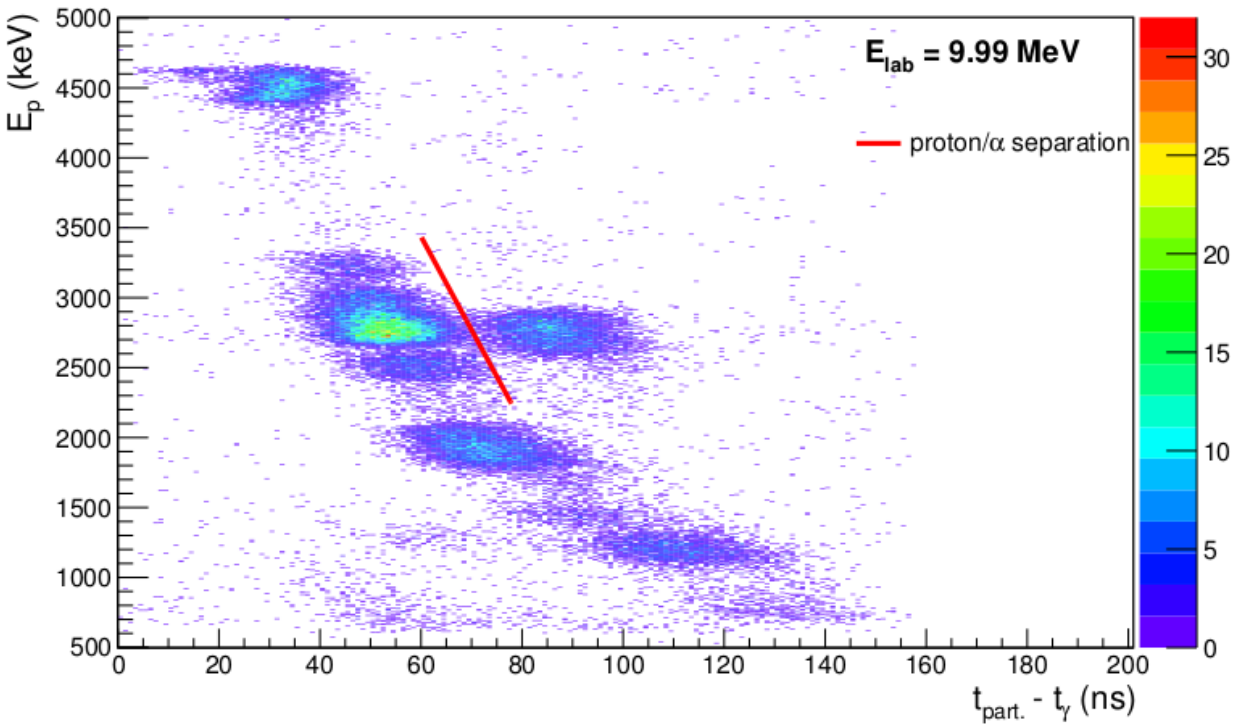
Background Reduction from Coincidence Condition

- particle detector spectrum in backward direction, 150ns gate
- coincidence suppresses background by two orders of magnitude
- full-energy detection efficiency at 0.44MeV: 6%



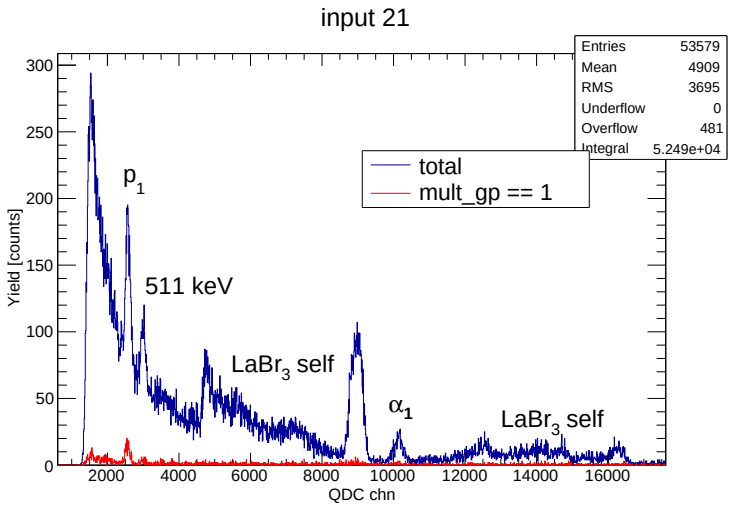
G. Fruet *et al.*, submitted to EPJ Web of Conference

- synchronization of 1GHz γ DAQ and 125MHz particle DAQ
- insufficient timing to resolve ToF gap between protons and alphas
- pulse form difference impacts timing though

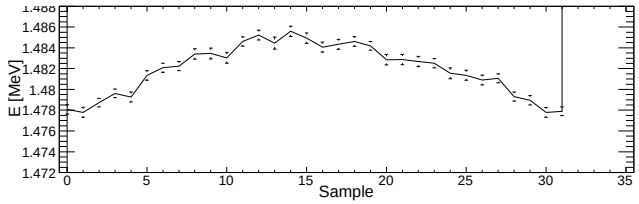


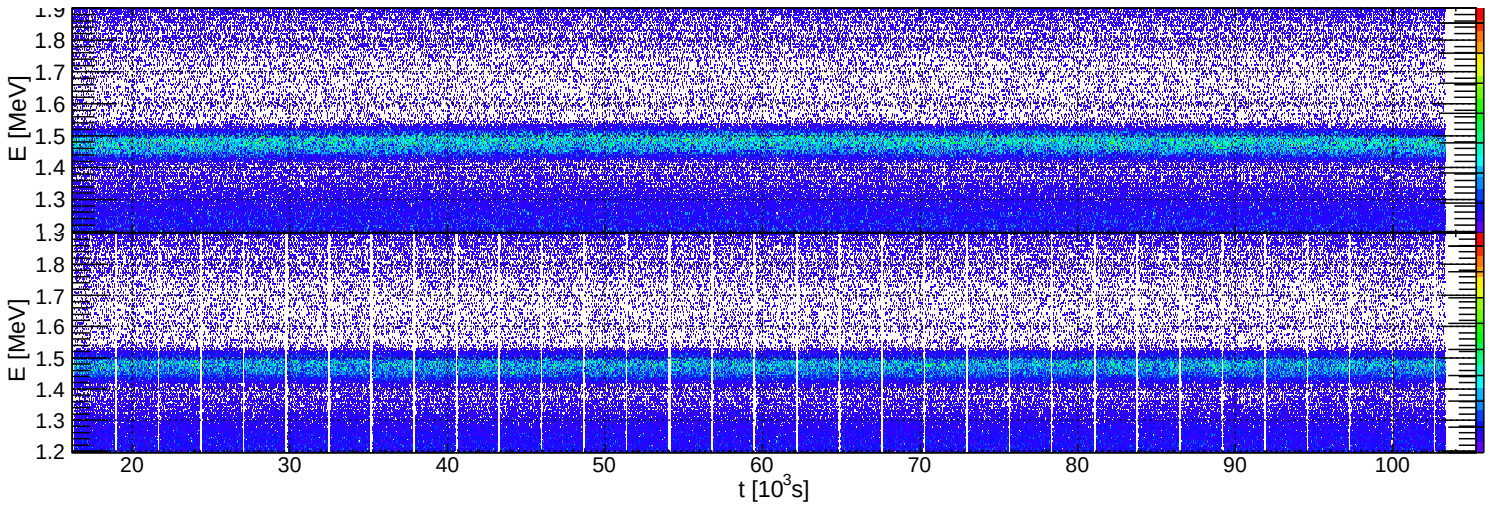
G. Fruet, PhD thesis

Drift of the Gamma Detectors with Temperature Difference

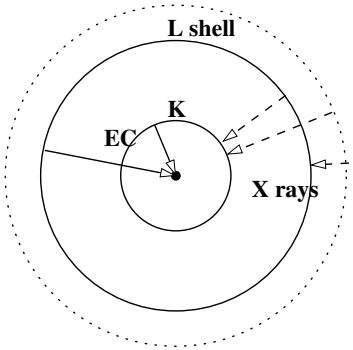


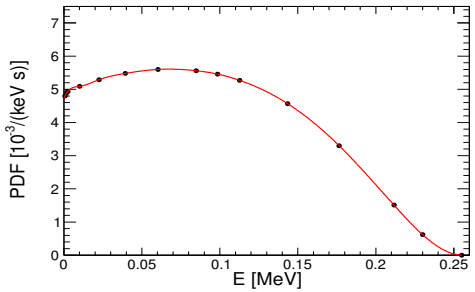
- 24h run, blocks of 45min
- drift of 1.47MeV line: 5keV
- ? options for correction

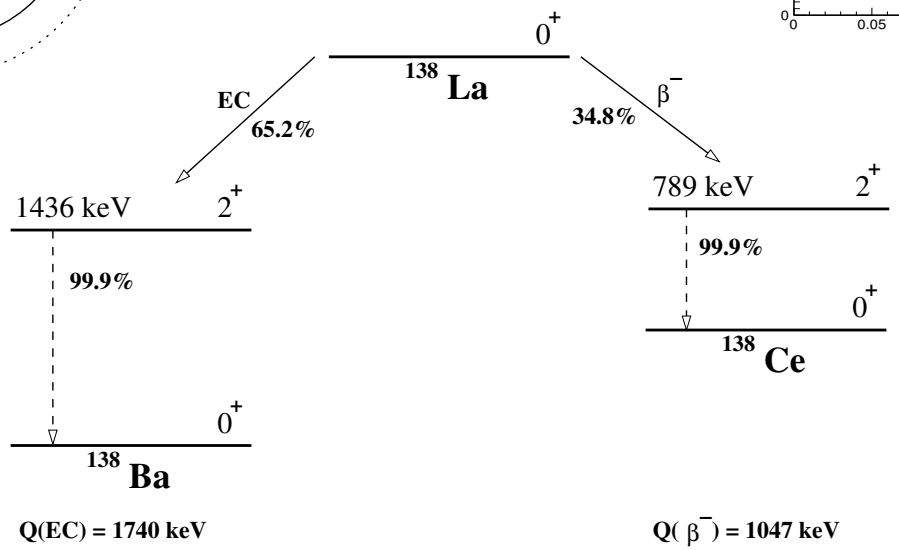




$T_{1/2} = 1.05 \cdot 10^{11}$ a, nat. ab. = 0.090% $\Rightarrow A = 90$ Bq

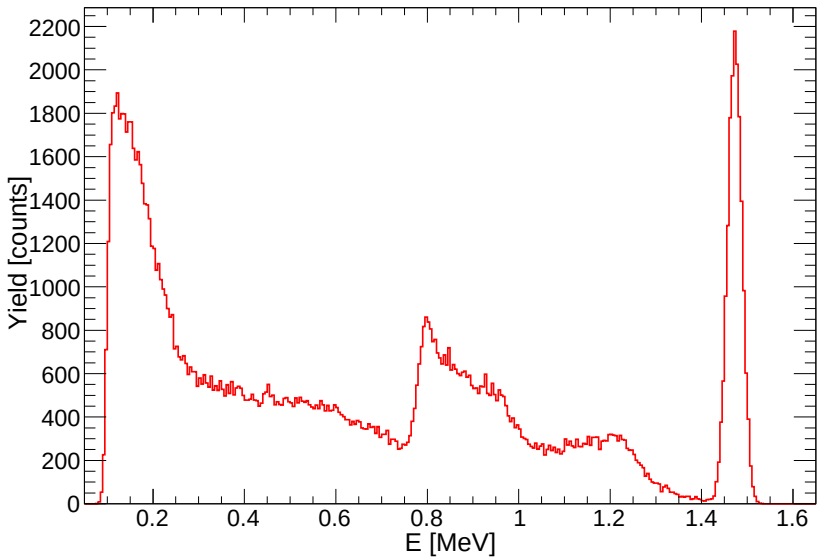






→ Simulate decay pattern of crystals placed in the gamma array and fit experimental data to the values of the nominal energy depositions.

fit: bin content and energy value

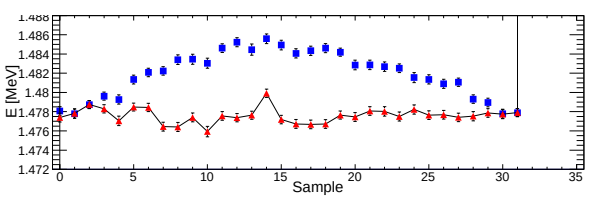


- red: simulation
- blue: experiment
- black: some exponential
- green: fit - exponential

^{152}Eu run:

- linear energy response
- energy resolution. . . in ROI

- marginal effect/correction (dotted blue) in current data ($\Delta T \approx 10°C$)
- promising option for runs of several weeks



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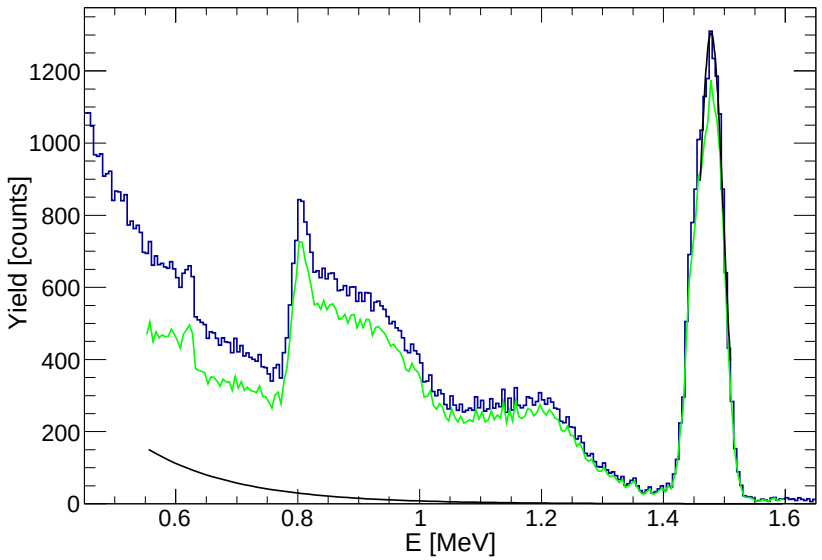

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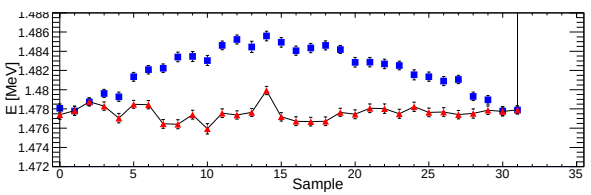

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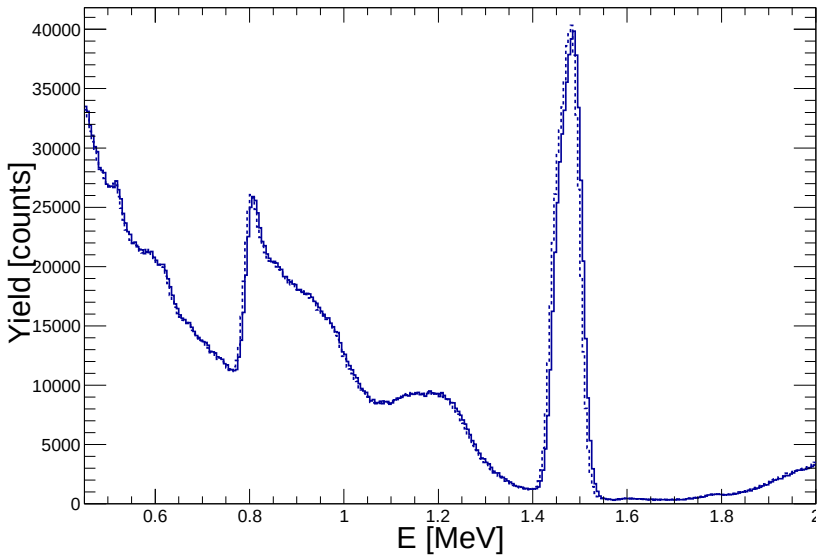

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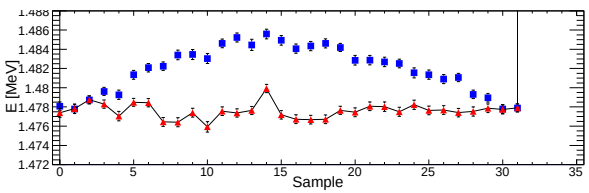

- STELLA project
  1. astrophysics motivation for fusion cross sections
  2. relevance for nuclear physics models
  3. experimental technique and reduction gates
- UK FATIMA detectors
  1. experimental arrangement and features
  2. instant calibration routine

six weeks of beam time starting September:

- increase beam energy with rotating target in place
- measurement station for target thickness

Thank You For Listening!!

P. Adsley[1,2], F. Agnese[3], C. Beck[3], L. Charles[3], O. Clausse[3], S. Courtin[3,4], E. Dangelser[3], P. Dené[3], S. Della Negra[2], G. Fruet[3], L. Gross[3], F. Haas[3], F. Hammache[2], M. Heine[3], G. Heitz[3], M. Imhoff[3], D.G. Jenkins[1], O. Kirsebom[5], H. Kocher[3], M. Krauth[3], J. Lesrel[2], M. Loriggiola[6], C. Mathieu[3], A. Meyer[2], D. Montanari[3,4], L. Morris[1], M. Richer[3], P.H. Regan[7,8], M. Rudigier[7], C. Ruescas[3], N. de Séréville[2], C. Stodel[9], D. Thomas[3] and C. Wabnit[3]

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