STELar LAboratory Experiment : Designed to measure nuclear Astrophysics cross sections

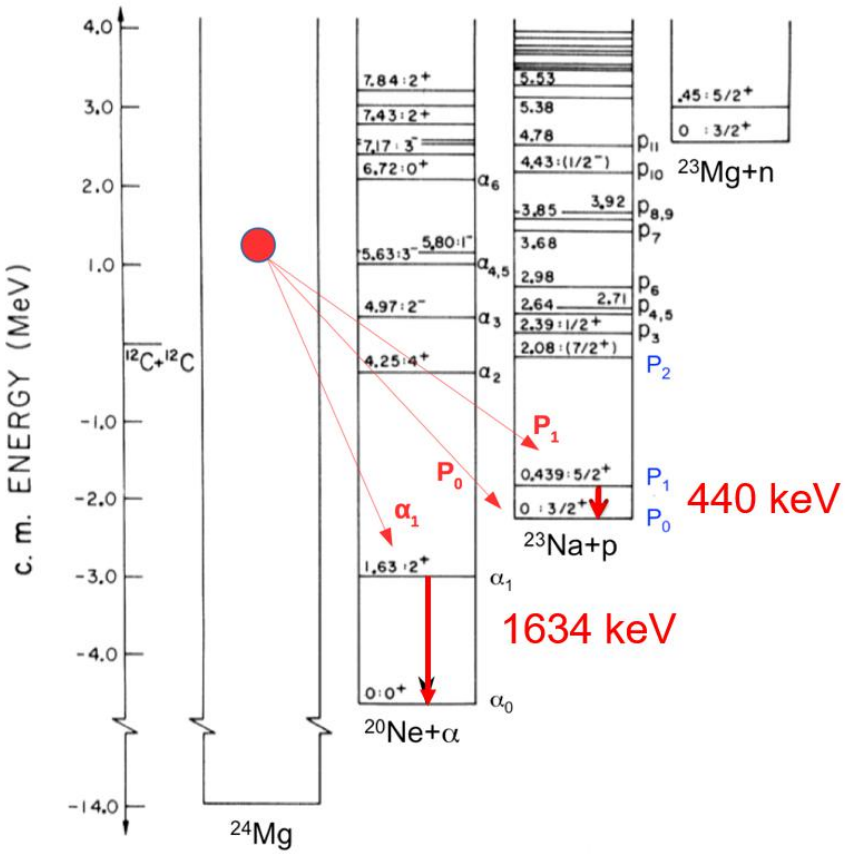
Jean Nippert

IPHC

Content :

- $^{12}C + {}^{12}C$ fusion reaction :
  - Measuring picobarn cross sections
  - Experimental setup
- Results and perspectives
  - Coincidences
  - Results (Sfactor)
- Conclusion

Reaction $^{12}C + {}^{12}C$:



- Carbon Burning
  - $^{12}C + {}^{12}C \rightarrow {}^{24}Mg^*$
    - $^{24}Mg^* \rightarrow {}^{23}Na^* + p$
      - Q = 2,24 MeV
    - $\rightarrow {}^{20}Ne^* + \alpha$
      - Q = 4,62 MeV

Cross section of the order of picobarn
Hindrance additional suppression
$^{12}C + {}^{12}C$ symmetries resonnances

The (incomplete yet) complex story of ^{12}C fusion

ex D.A. Bromley *et al.*, **PRL** 4, 365, (1960)
ex E. Almqvist *et al.*, **PRL** 4, 515, (1960)
th B. IMANISHI *et al.*, **PLB** 27, 267, (1968)
ex J.R. Patterson *et al.*, **APJ** 157, 367, (1969)
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ex P.R. Christensen *et al.*, **NP A** 280, 189, (1977)
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ex J. Zickefoose *et al.*, **PRC** 97, 065806 (2018)
th K. Godbey *et al.*, **PRC** 100, 024619 (2019)
ex A.M. Mukhamedzhanov *et al.*, **PRC** 99, 064618 (2019)
ex C. Beck *et al.*, **EPJA** 56, 87 (2020)
th A. Bonasera, J.B. Natowitz **PRC** 102, 061602, (2020)
ex G. Fruet *et al.*, **PRL** 124, 192701 (2020)
ex Y.J. Li *et al.*, **CPC** 44, 115001 (2020)
ex W.P. Tan *et al.*, **PRL** 124, 192702 (2020)
ex N.T. Zhang *et al.*, **PLB** 801, 135170 (2020)
th Y. Taniguchi, M. Kimura, **arXiv**, 2106.04321v1 (2021)

- Tons of publications the last 5 years
  - 11 experimental
- 3 STELLA publications in the 4 first years of existence

The (incomplete yet) complex story of ^{12}C fusion

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ex W.P. Tan *et al.*, **PRL** 124, 192702 (2020)
ex N.T. Zhang *et al.*, **PLB** 801, 135170 (2020)
th Y. Taniguchi, M. Kimura, **arXiv**, 2106.04321v1 (2021)

University of Strasbourg and IPHC (France):

S.C, D. Curien, G. Fruet, L. Gross, M. Heine, E. Monpribat, J. Nippert, M. Richer

IPN Orsay (France):
S. Della Negra, F. Hammache, N. de Séreville, P. Adsley, A. Meyer et al.

University of Surrey (UK):

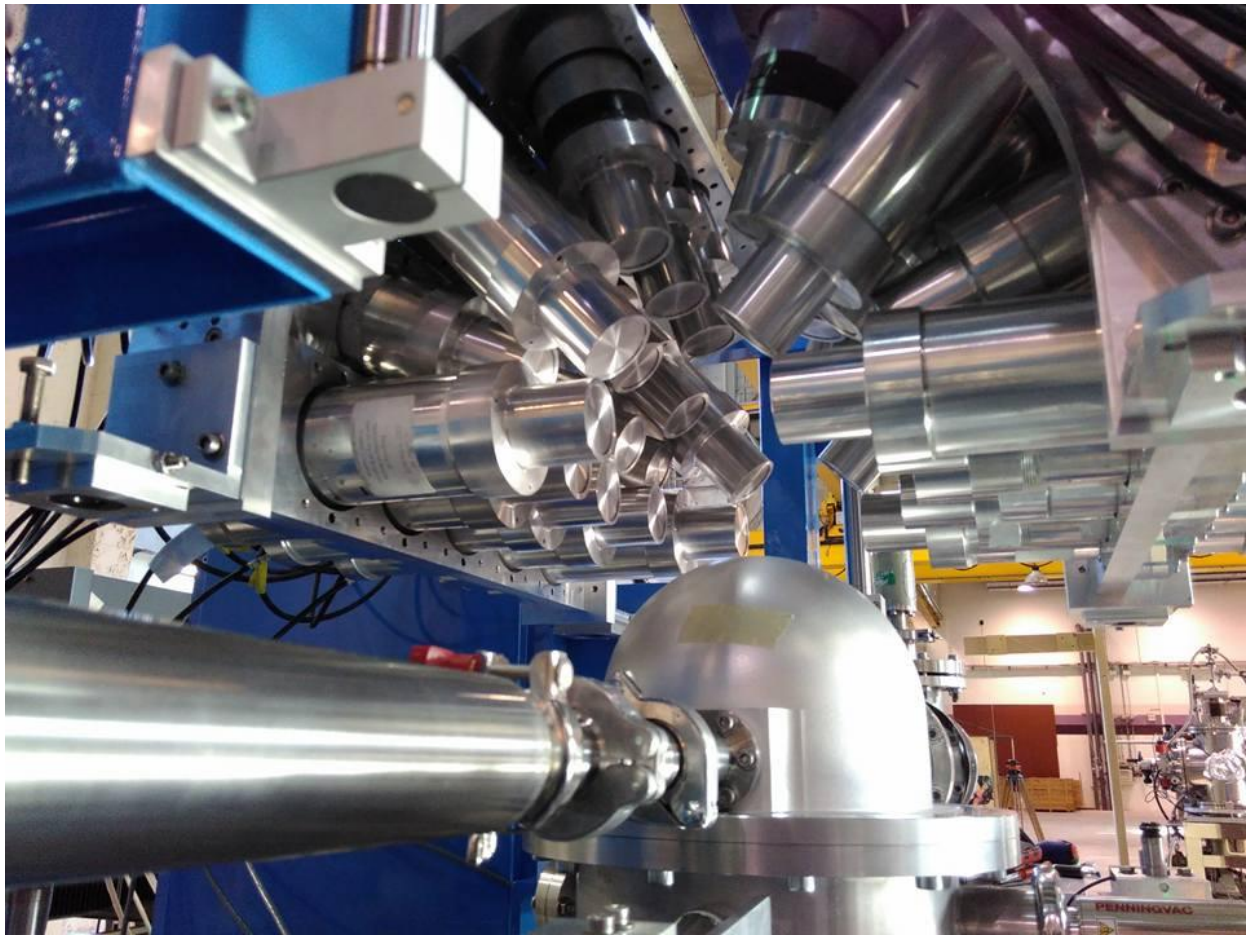
P.H. Regan, M. Rudigier, Zs. Podolyak et al.

GANIL (Caen, France):

C. Stodel et al.

University of York (UK):
D.Jenkins , L.Morris, G. Vega et al.

STELlar LAboratory

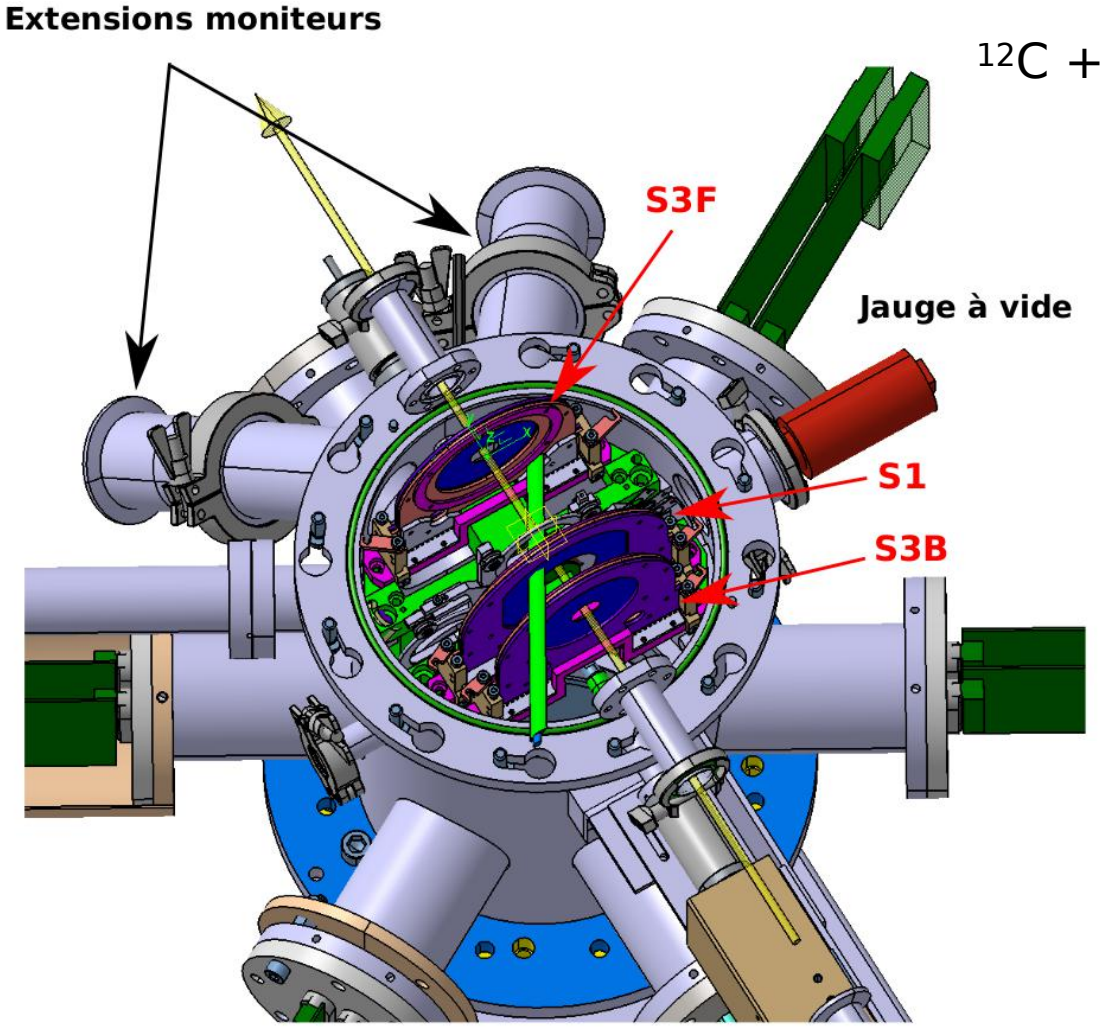


- Challenges :
  - Background supression
  - Intense Beam
    - Andromède : Stable and intense beam
  - Long measurement time (weeks)

$$^{12}C + {}^{12}C \rightarrow {}^{23}Na + p + \gamma$$
$$\rightarrow {}^{20}Ne + \alpha + \gamma$$

- Coincidence technique
  - Background reduction
  - Gamma : New generation scintillators $LaBr_3$(CE)
    - Good energy resolution and very good detection efficiency
    - Timing resolution lower than nanosecond
    - Cylindrical configuration

Reaction chamber



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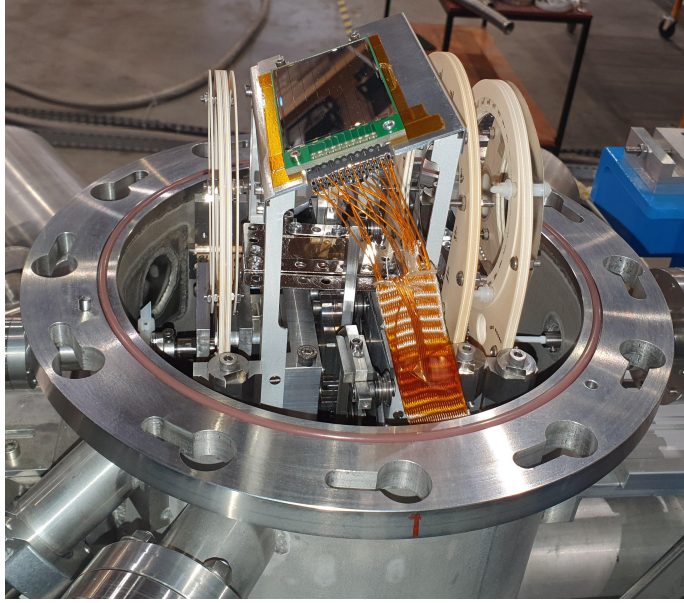
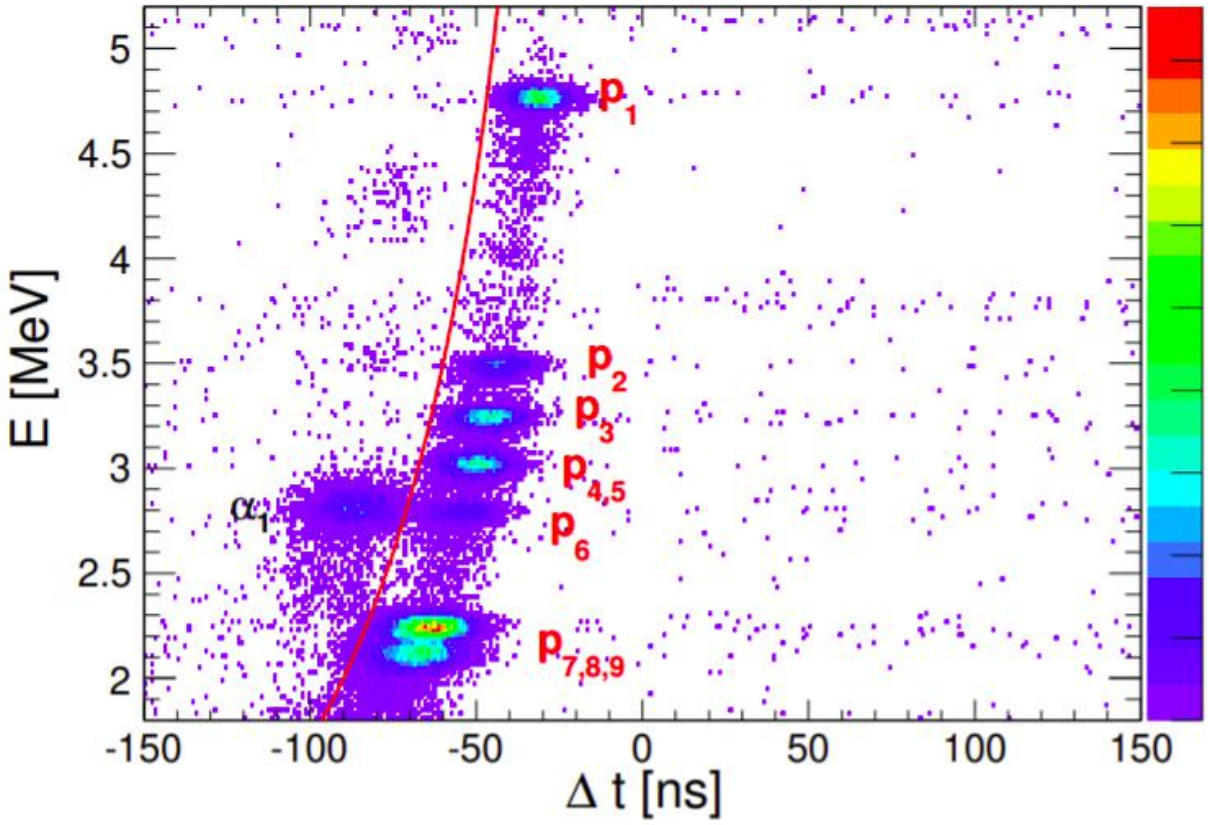


Reaction chamber

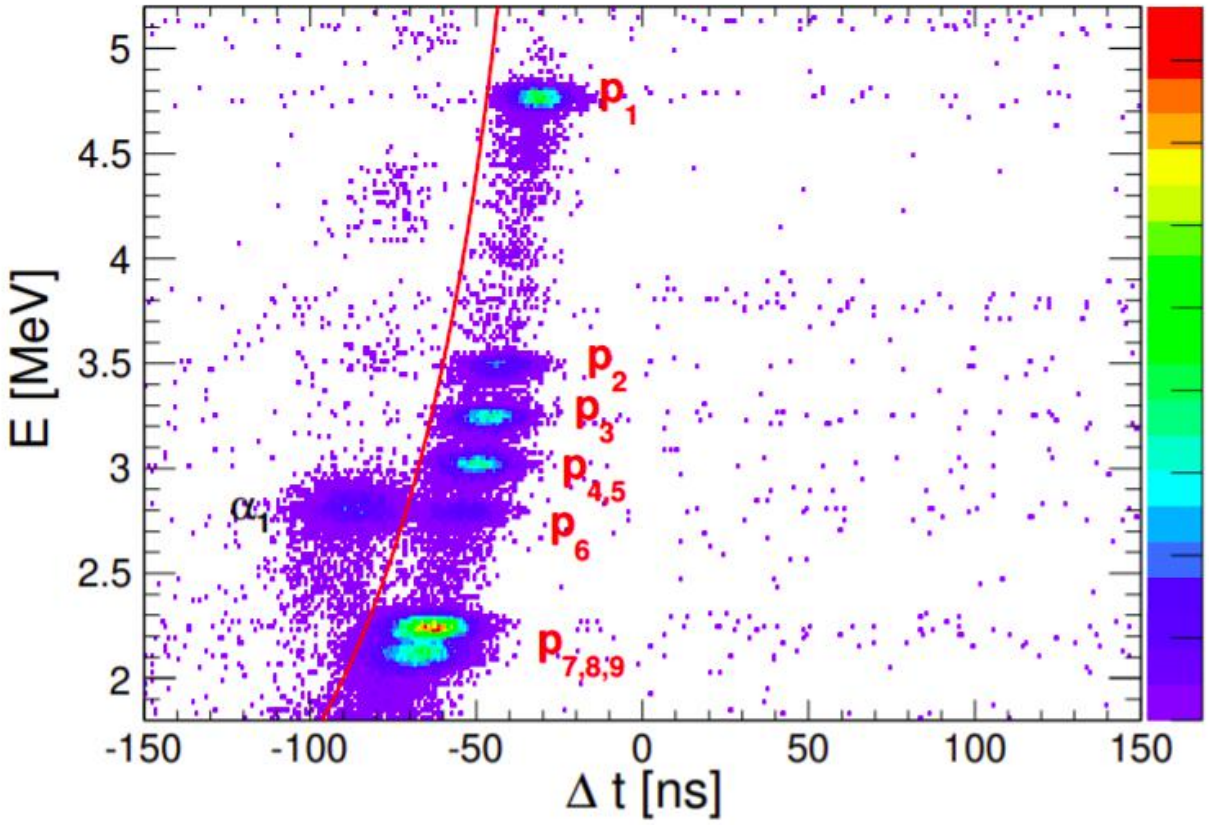
- Aluminum cup 1,5 mm thick
- Self supporting thin rotating target foils (1000rpm)
  - **Heat dissipation**
- DSSSD S3 and S1
  - granularity allows angular distributions measurement
- Pixel : BB10 and SUPER X3
- Monitor detectors
- cryogenic pump
  - Vacuum down to 10^{-8}mbar

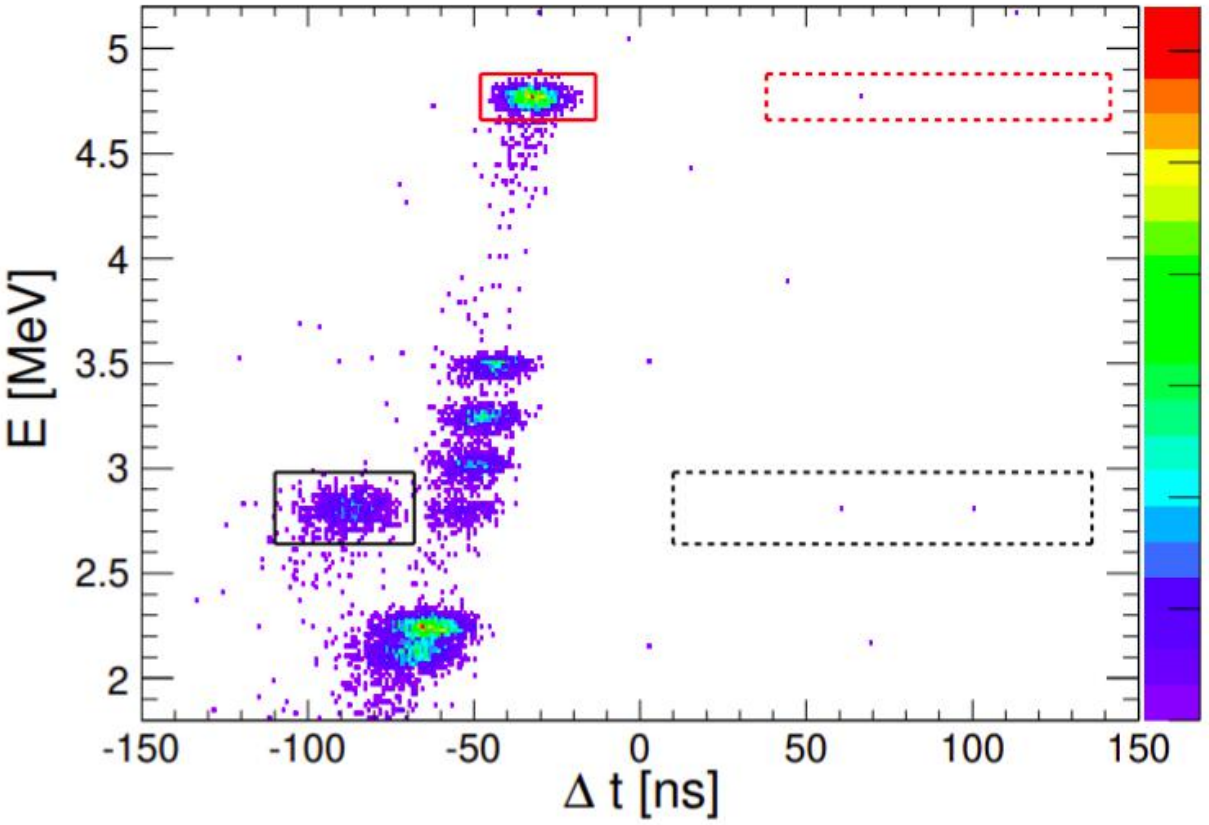
Background Supression : Coincidences with Nanosecond timing with UK FATIMA



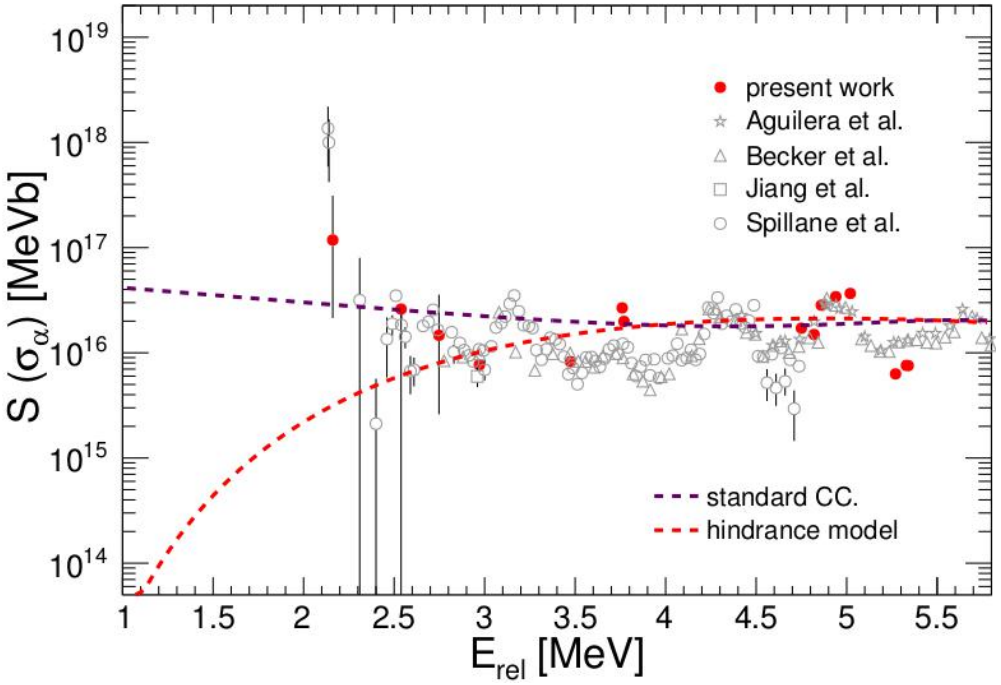
- Synchronization of 1 GHz gamma DAQ and 125 MHz particle DAQ
- Energy-deposition dynamics in silicon substrate: triggering on pulse shapes
  - Timing gates σ ~15 ns
  - Proton-α separation

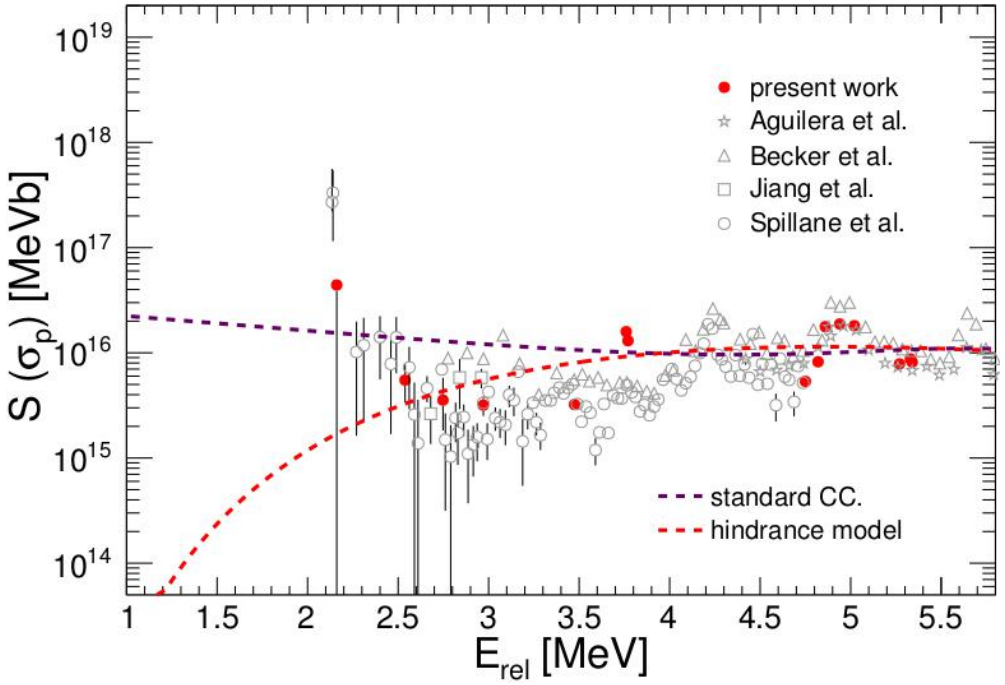
Coincidence





Results



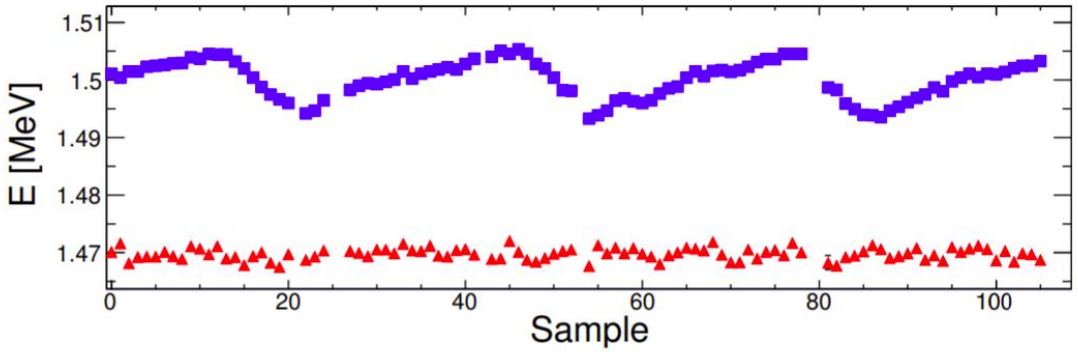


- G. Fruet et al.Phys. Rev. Lett. 124, 192701
  - suspection of hindrance
  - Current analysis in progress
  - New experiment in progress

$$\sigma(E) = \frac{1}{E}\exp\left(-2\pi\eta\right)S(E)$$

η : Sommerfeld parameter (energy dependent)

Conclusion



- STELLA is capable of measuring picobarn cross sections with reasonable data taking time (weeks)
  - 200h for the lowest point (1 count) on alpha channel
  - Stable high intensity [pμA] beam required

- Possible identification of hindrance phenomenon
- Possible identification of a resonance at low energy
- Impact on astrophysics studied and published by Monpribat & al.
- STELLA :
  - 3 major publications (NIM, PRL, Astronomy & Astrophysics)
  - 25 oral communications (12 invited)
  - 1 Defended Thesis and 3 in progress
  - 2 Post-doc : Eleonora Gregor, Gurpreet Kaur

Thank you for your attention

PHYSICAL REVIEW LETTERS 124, 192701 (2020)

Advances in the Direct Study of Carbon Burning in Massive Stars

G. Fruet,[1,2] S. Courtin,[1,2,3,*] M. Heine,[1,2,†] D. G. Jenkins,[4] P. Adsley,[5] A. Brown,[4] R. Canavan,[6,7] W. N. Catford,[6] E. Charon,[8] D. Curien,[1,2] S. Della Negra,[5] J. Duprat,[9] F. Hammache,[5] J. Lesrel,[5] G. Lotay,[6] A. Meyer,[5] D. Montanari,[1,2,3] L. Morris,[4] M. Moukaddam,[6] J. Nippert,[1,2] Zs. Podolyák,[6] P. H. Regan,[6,7] I. Ribaud,[5] M. Richer,[1,2] M. Rudigier,[6] R. Shearman,[6,7] N. de Séréville,[5] and C. Stodel[10]

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The STELLA apparatus for particle-Gamma coincidence fusion measurements with nanosecond timing

M. Heine [a,b,*], S. Courtin [a,b,c], G. Fruet [a,b], D.G. Jenkins [d], L. Morris [d], D. Montanari [a,b,c], M. Rudigier [f], P. Adsley [e], D. Curien [a,b], S. Della Negra [e], J. Lesrel [e], C. Beck [a,b], L. Charles [a,b], P. Dené [a,b], F. Haas [a,b], F. Hammache [e], G. Heitz [a,b], M. Krauth [a,b], A. Meyer [e], Zs. Podolyák [f], P.H. Regan [f,g], M. Richer [a,b], N. de Séréville [e], C. Stodel [h]

A new $^{12}C + ^{12}C$ nuclear reaction rate: impact on stellar evolution

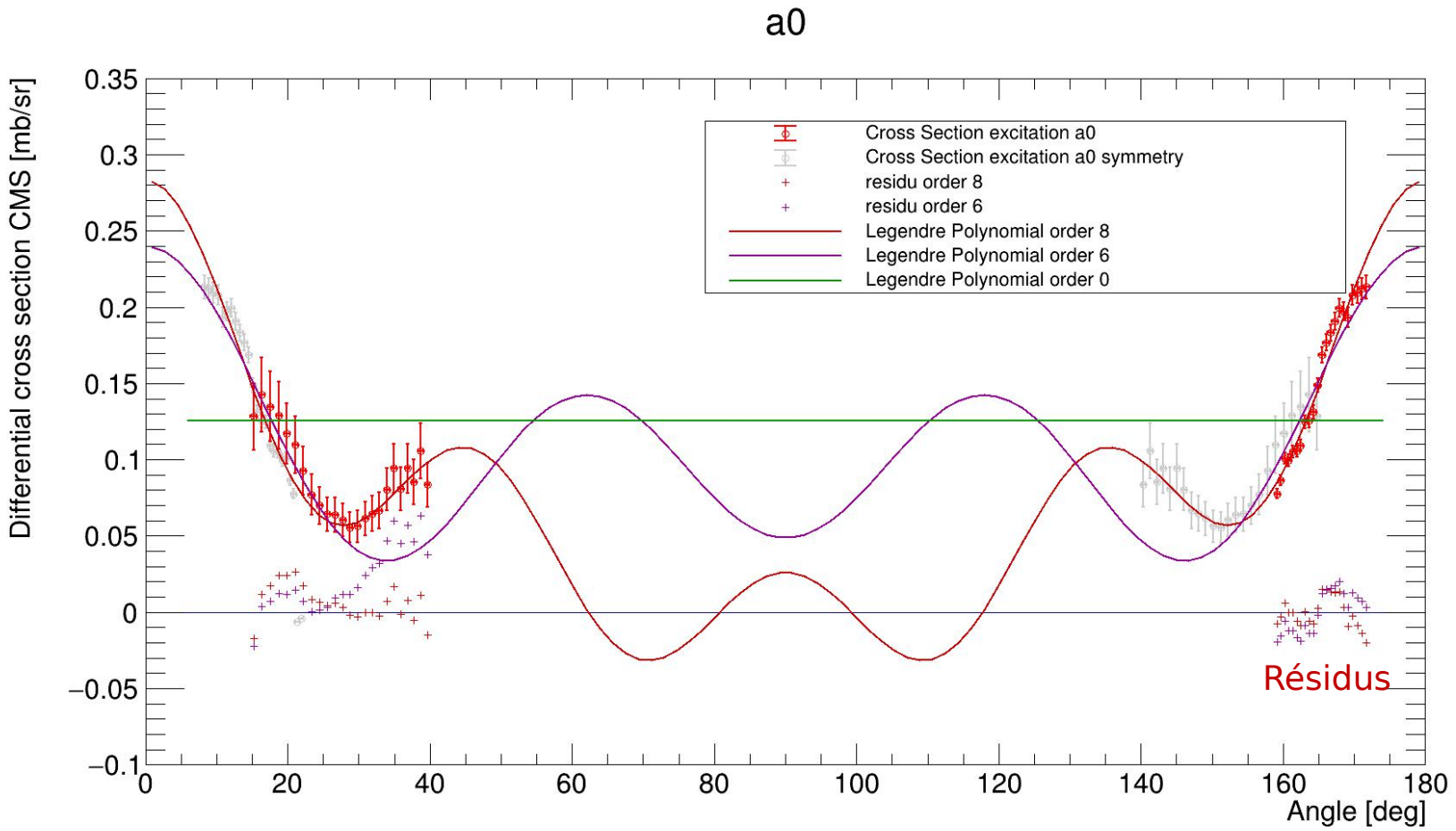
E. Monpribat[1], S. Martinet[2], S. Courtin[1,3], M. Heine[1], S. Ekström[2], D. G. Jenkins[3,4], A. Choplin[5], P. Adsley[6,7], D. Curien[1], M. Moukaddam[1], J. Nippert[1], S. Tsiatsiou[2], and G. Meynet[2]

Collaboration with University and Observatory of Geneva (Switzerland): *G. Meynet, S. Martinet, S. Ekström*

Stagiaires et doctorants :

- Guillaume Fruet (université de Strasbourg, M2 2015), sections efficaces
- Marina Begun (université de Strasbourg, M1 2016), coïncidences
- Philippe Cotte (université de Strasbourg, M1 2016), coïncidences
- Guillaume Fruet (université de Strasbourg, doctorat 2018), sections efficaces
- Jean Nippert (université de Strasbourg, M1 2018), calibration DSSSD
- Alexandre Ohier (université de Strasbourg, M1 2018), calibration DSSSD
- Hugo Nartz (université de Pari Sued, apprentissage hors murs en L3 2019), calibration du faisceau
- Jean Nippert (université de Strasbourg, M2 2019), sections efficaces
- Jean Nippert (université de Strasbourg, doctorat 2023), sections efficaces
- Emma Monpribat (université de Strasbourg, M1 2019), taux de réaction
- Emma Monpribat (université de Strasbourg, M2 2020), taux de réaction
- Mykalin Jones (université de Strasbourg, M2 2021), développement PIXEL
- Emma Monpribat (université de Strasbourg, doctorat 2023), taux de réaction
- Gustavo Vega (université de York, doctorat 2023). sections efficaces
- Cathy Gellenoncourt (université de Strasbourg, EX2 2022), stabilité des mesures,
- Louis Lemair (université de Strasbourg, EX2 2022), stabilité des mesures,
- Guillaume Harmant (université de Strasbourg, M1 2022), mesures de la voie neutron,
- Emeline Oliviera (université de Strasbourg, M2 2022), focalisation du faisceau.

Section efficace différentielle



- Section efficace différentielle à E_{cm} = 5,38 MeV
  - a0
  - polynome d'ordre 8
  - paramètres d'ordres inférieurs plus libres
    - nécessite plus grande couverture angulaire
  - IDEX Pixel M.Heine
    - ajout détecteur à 90°
    - meilleure couverture angulaire
    - augmentation de l'angle solide