Cross-section measurements by means of laser beams

(and future experiments @ ELI-NP?)

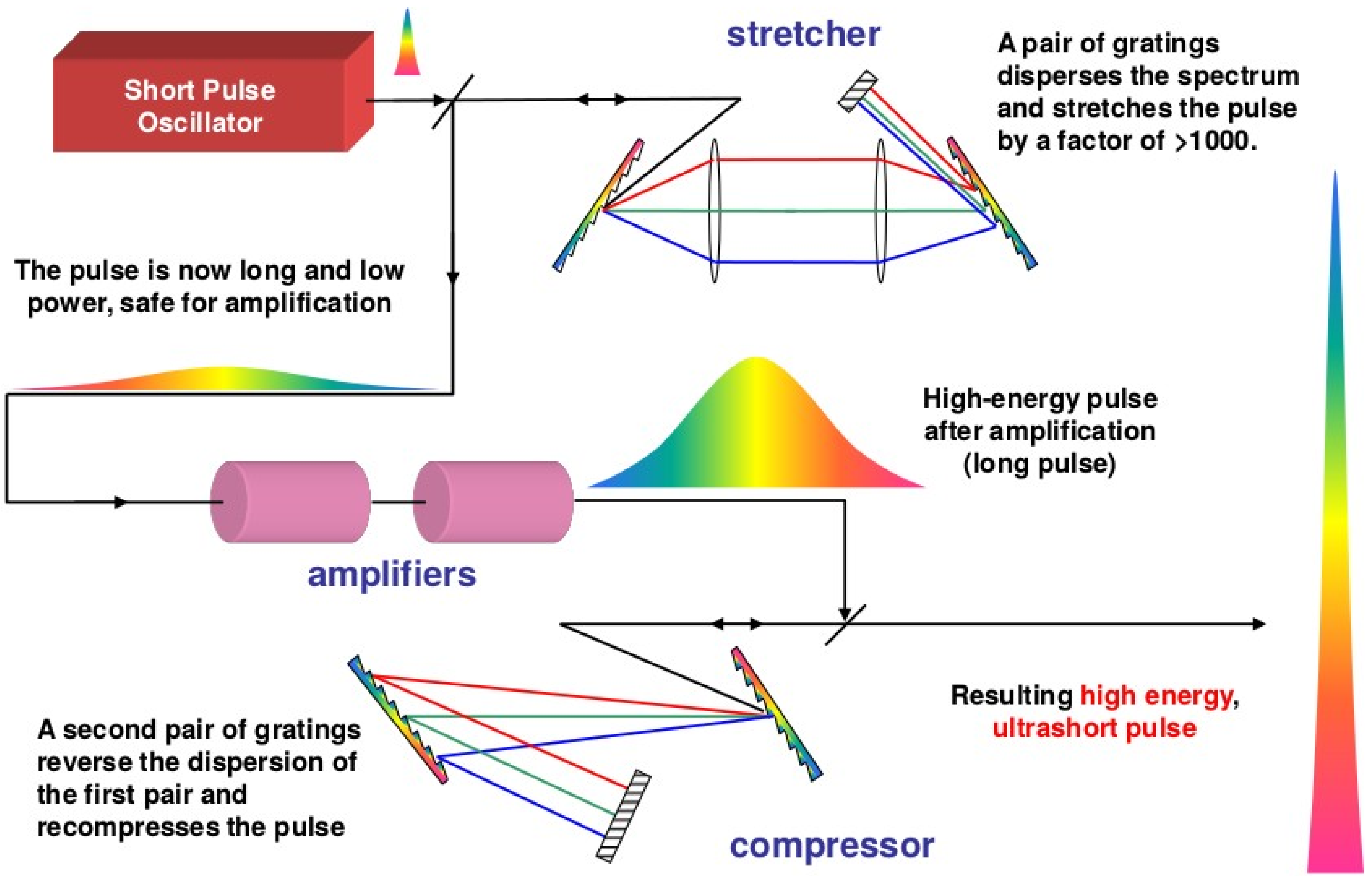
Dario Lattuada
ELI-NP, LNS

IX GIANTS Conference,
Bologna, 5-6 October 2017

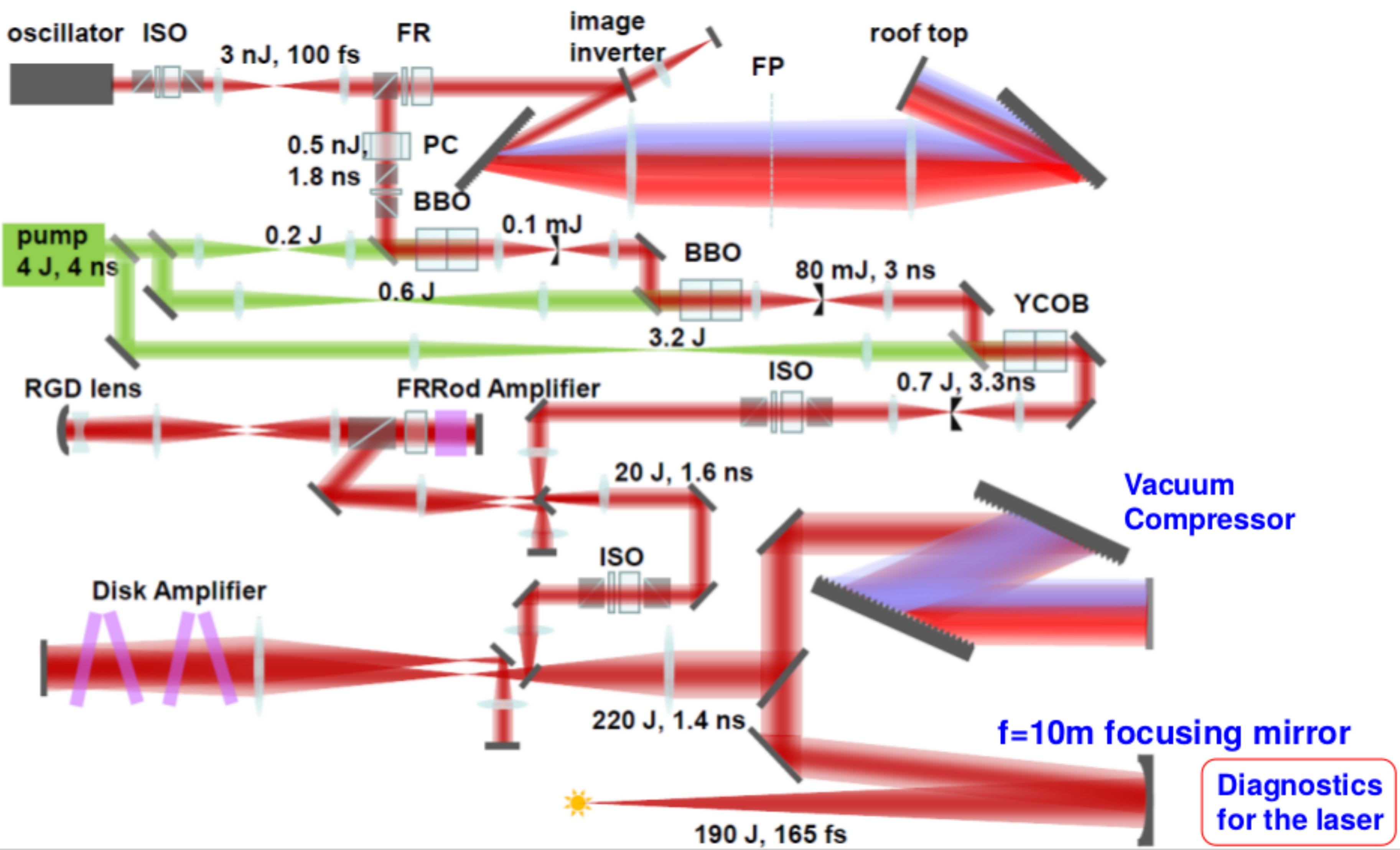
Outlines

- Laser-cluster experiment @ UT PW Laser
- Cross-section measurements (results)
- Future experiments: UT and ELI-NP
- Photonuclear reactions
- ELI-NP and the GBS
- ELISSA

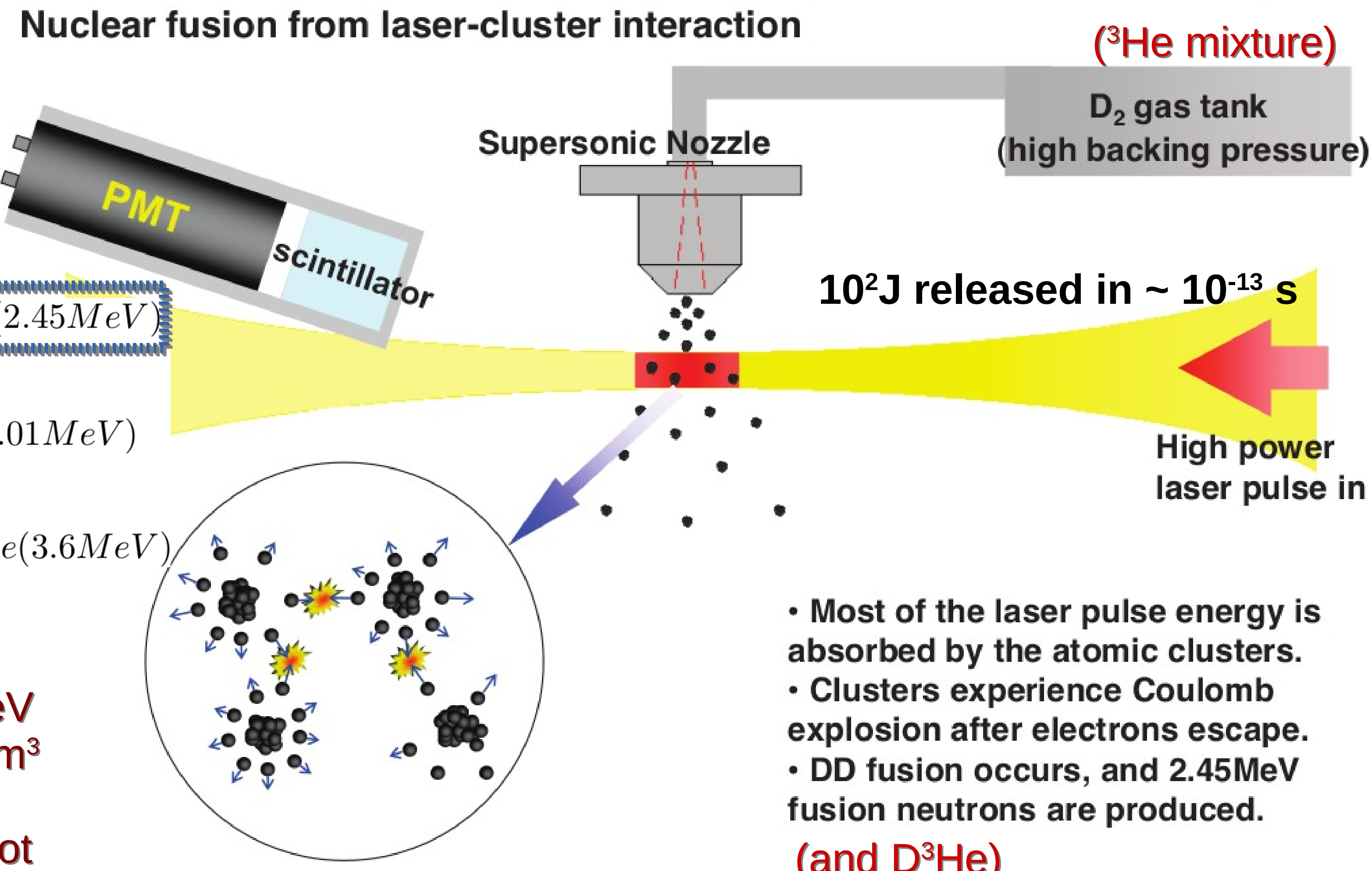
Chirped Pulse Amplification (CPA) is the basic technique for modern ultra-intense, ultrafast lasers



Texas Petawatt laser uses three OPCPA and two Nd:glass amplifier stages and delivers a 190J laser pulse



UT Petawatt Laser



$$d + d \rightarrow {}^3\mathrm{He}(0.82MeV) + n(2.45MeV)$$

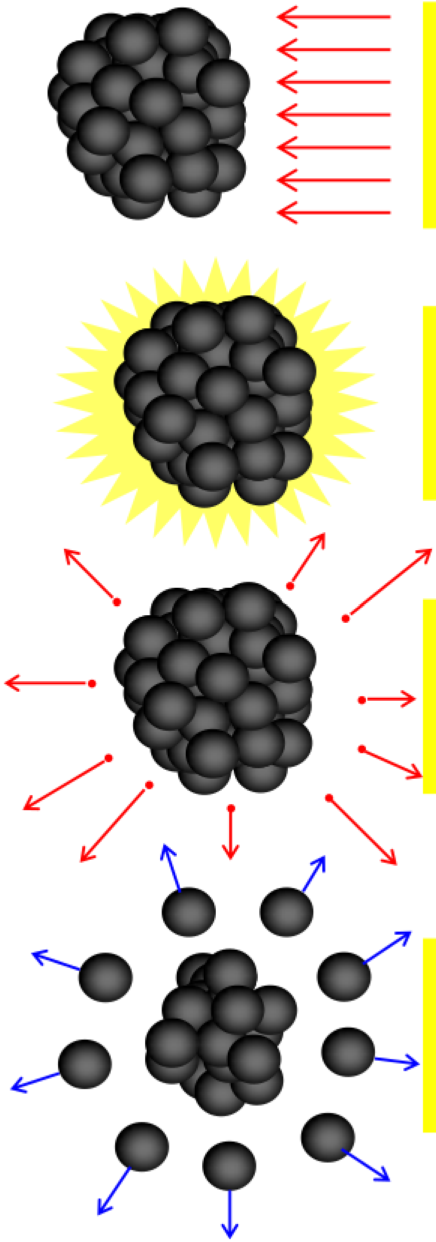
$$d + d \rightarrow p(3.02MeV) + t(1.01MeV)$$

$$d + {}^3\mathrm{He} \rightarrow p(14.7MeV) + {}^4\mathrm{He}(3.6MeV)$$

deuterium ions
Kinetic Energy < 10^2 keV
Density ~ 10^{18} atoms/cm^3

10^5-10^7 neutrons per shot

Coulomb Explosion



Step 1

Clusters are irradiated by high intensity laser pulse ($\sim 10^{16} \sim 10^{18}$ W/cm^2).

Step 2

Laser pulse energy is first absorbed by electrons via heating mechanisms such as rapid collisional heating.

Step 3

Electrons escape from the cluster and leave positive charge build-up on the cluster.

Step 4

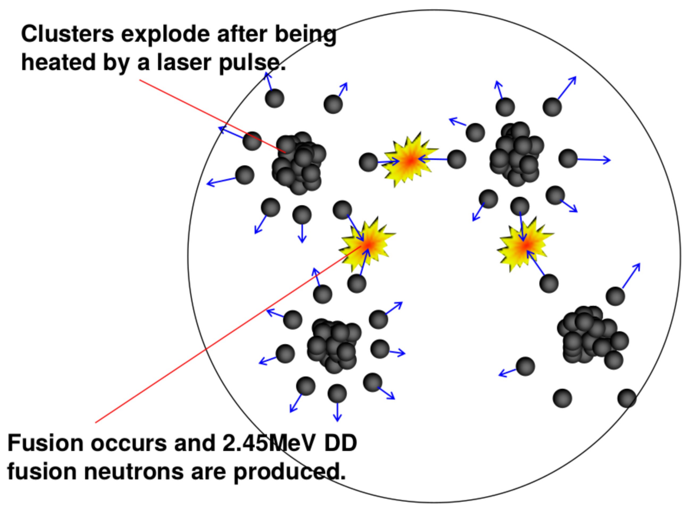
The cluster "explodes" and deuterons acquire multi-keV kinetic energy.

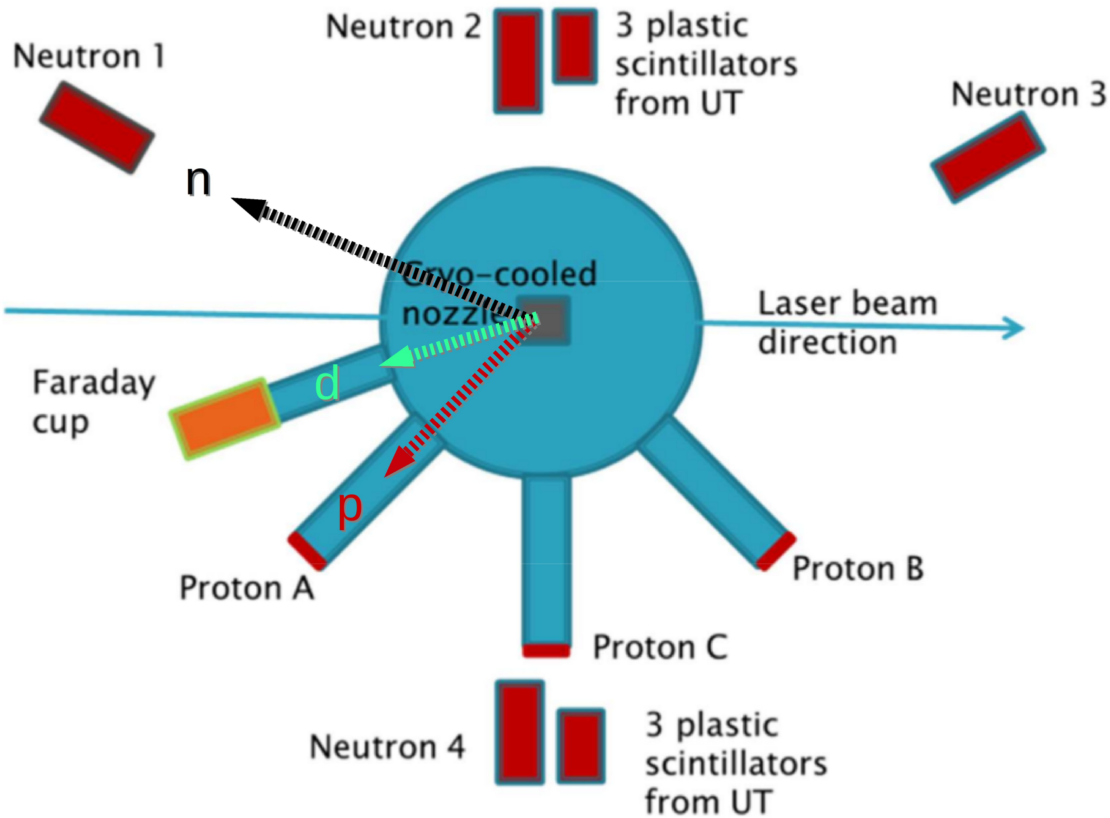
The 2011 experiment

$$d + d \rightarrow {}^3\mathrm{He}(0.82MeV) + n(2.45MeV)$$

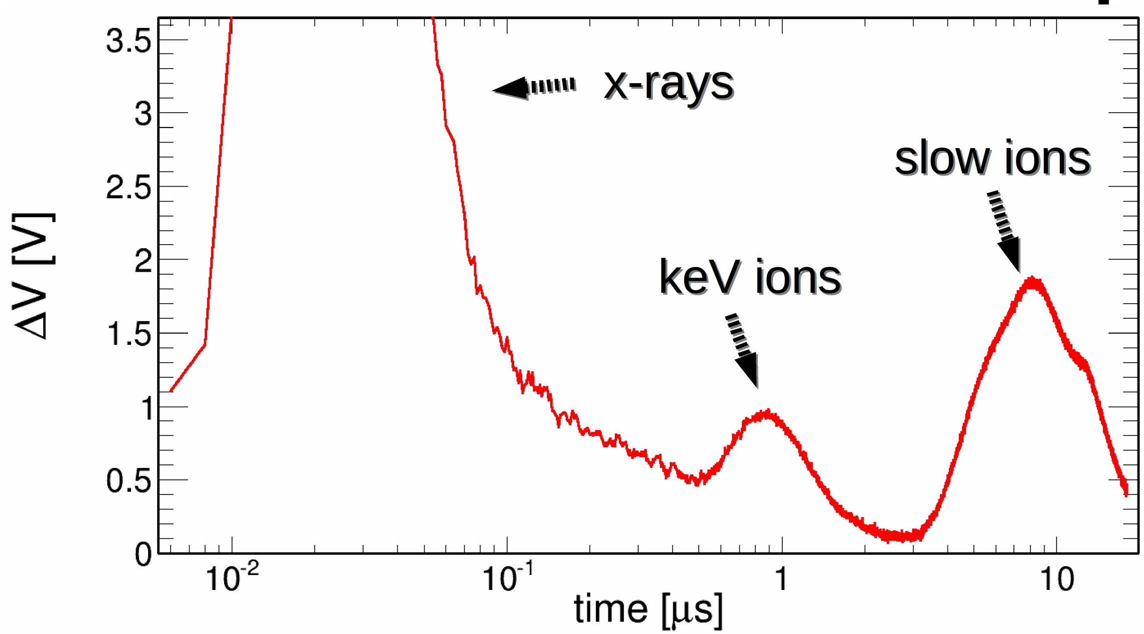
$$d + {}^3\mathrm{He} \rightarrow p(14.7MeV) + {}^4\mathrm{He}(3.6MeV)$$

$$Y_{n,BB} = l\rho_D \int \frac{dN}{dE} \sigma_{BB}(E)dE$$

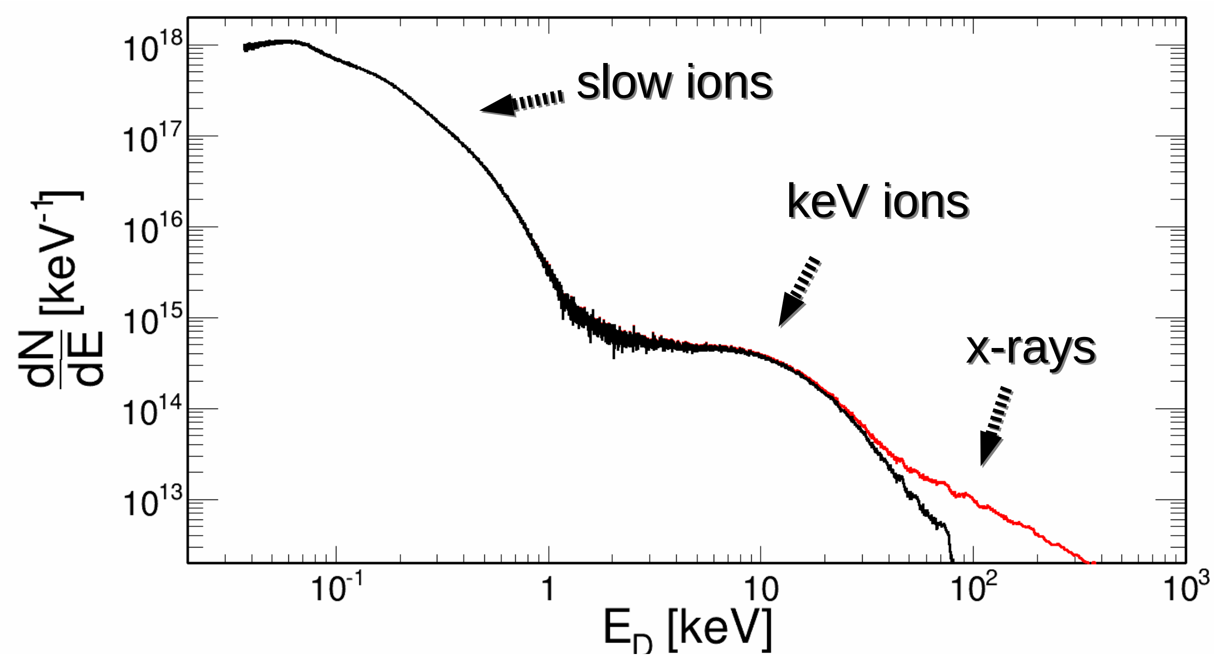




The 2011 experiment



$$\frac{d^2N}{dt\,d\Omega} = \frac{\Delta V}{qeR_\Omega \Delta\Omega}$$



$$\frac{d^2N}{dE\,d\Omega} = \frac{s^3}{m_D v_D^3 \pi r_F^2} \frac{\Delta V}{qeR_\Omega}$$

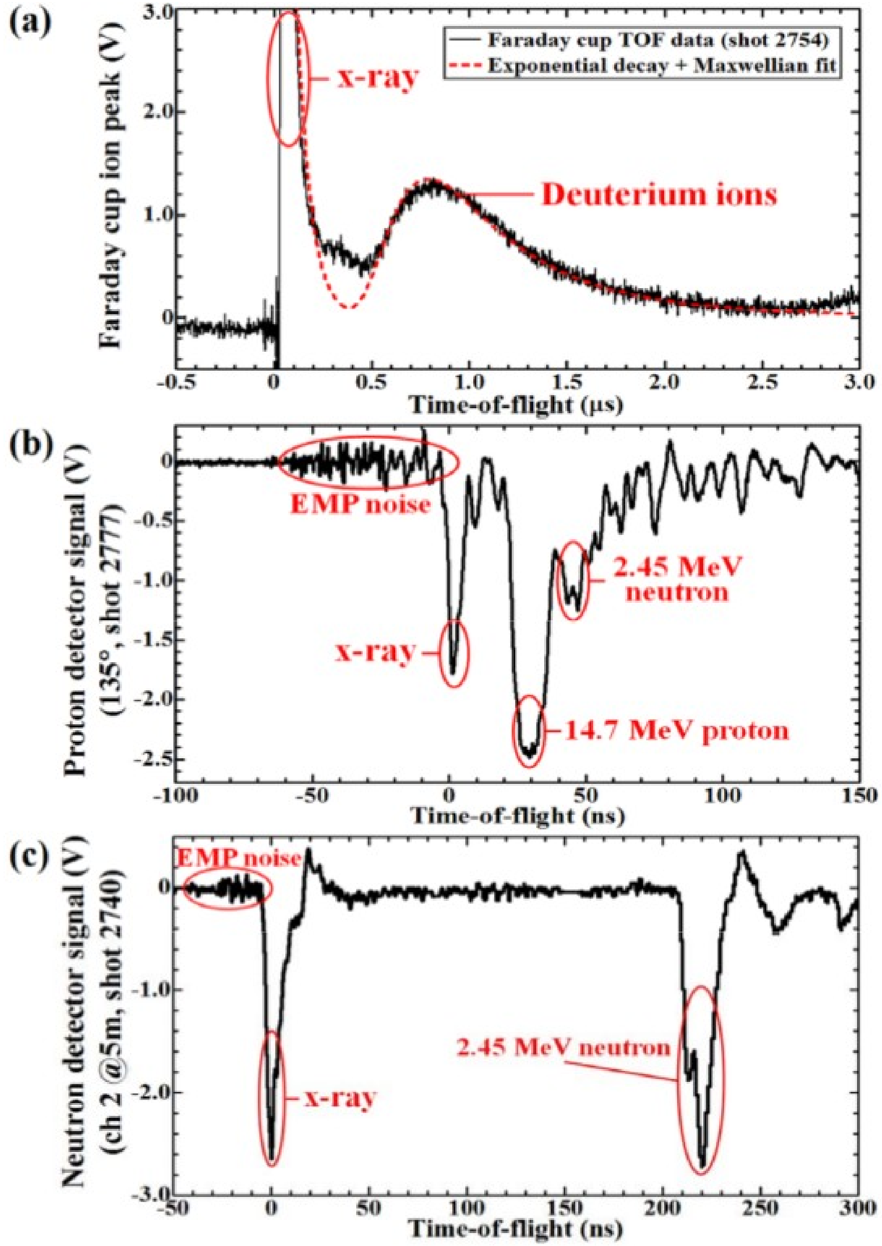
The 2011 experiment

$$Y_{n,BB} = l\rho_D \int \frac{dN}{dE}\sigma_{BB}(E)dE$$

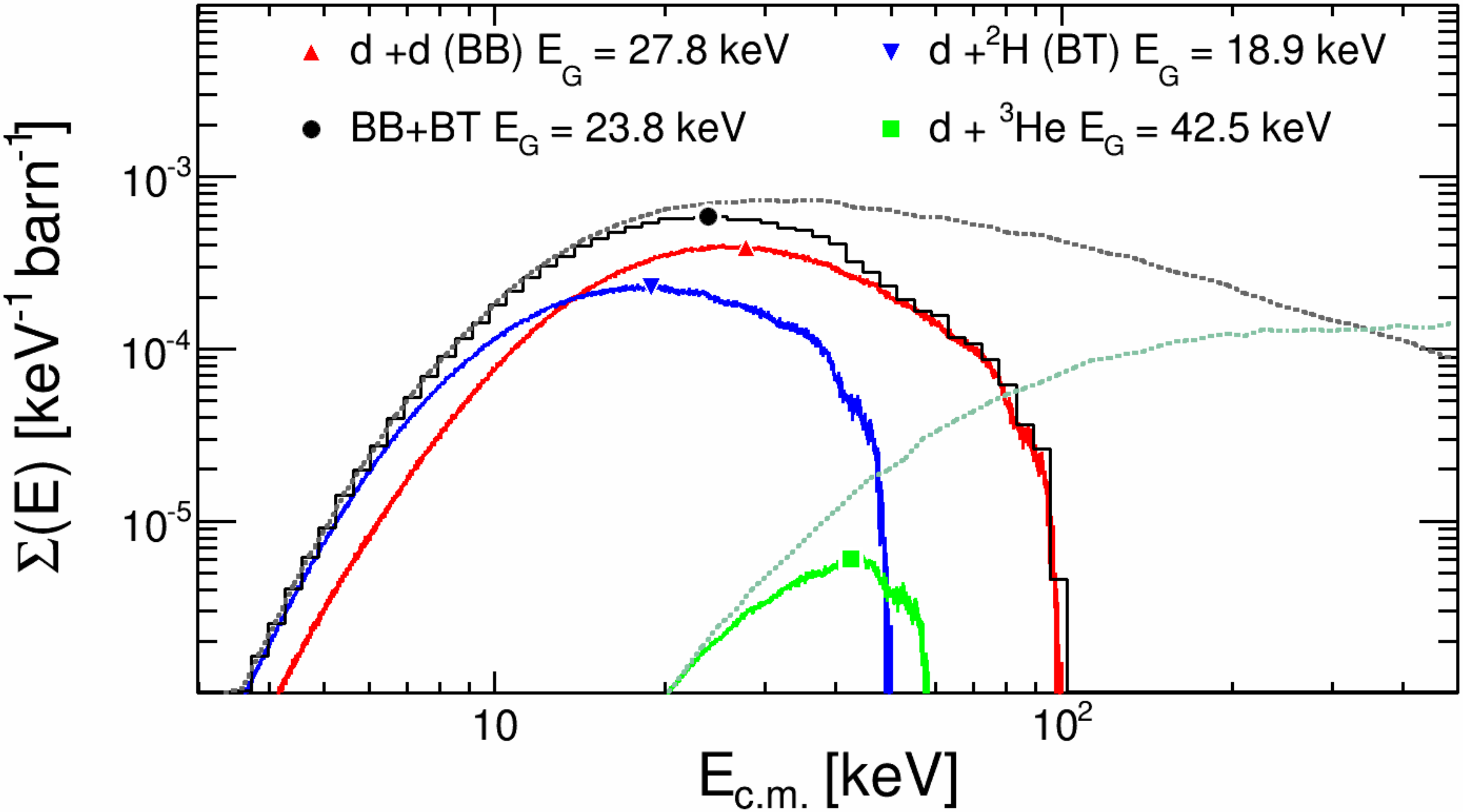
$$\sigma(E) = \frac{S(E)}{E}\exp(-2\pi\eta(E))$$

$$2\pi\eta = b/\sqrt{E}$$

$$b = 0.9898 Z_i Z_j \sqrt{A}\ \mathrm{MeV}^{1/2}$$



The 2011 experiment



PHYSICAL REVIEW C

covering nuclear physics

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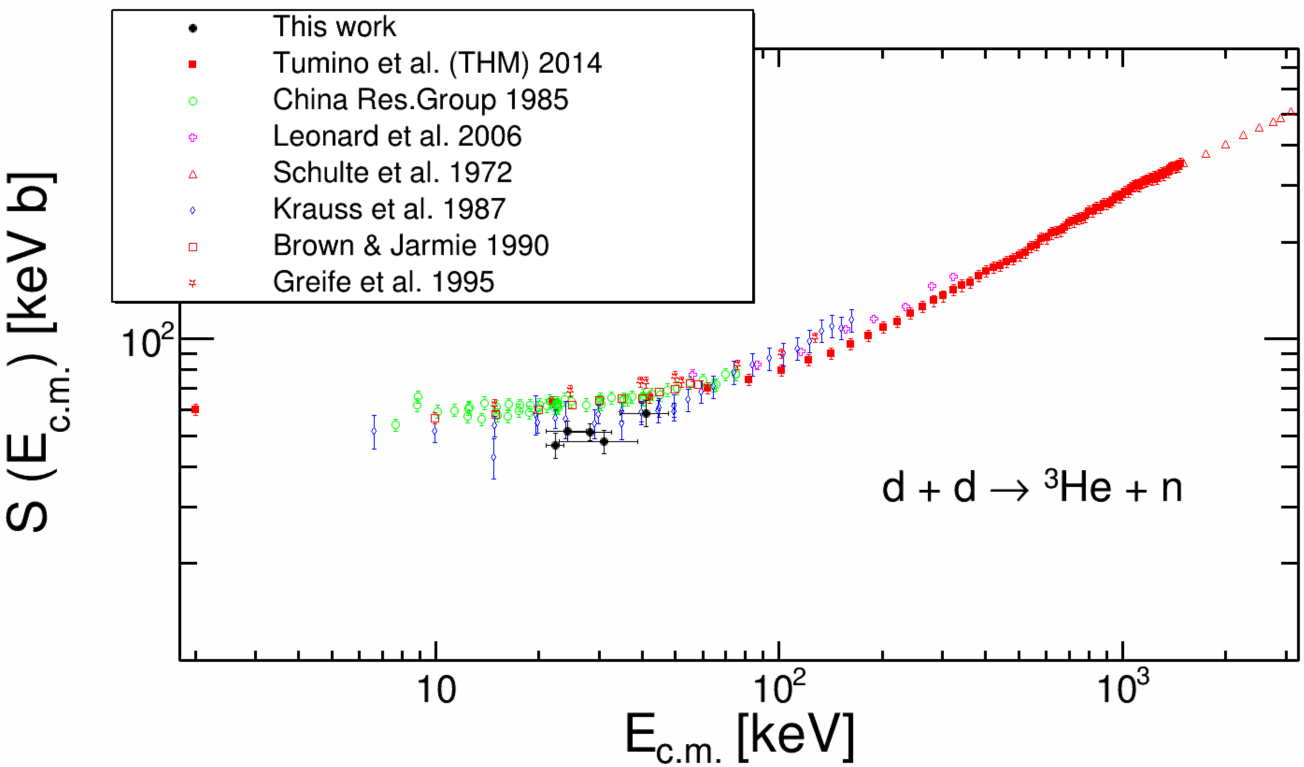
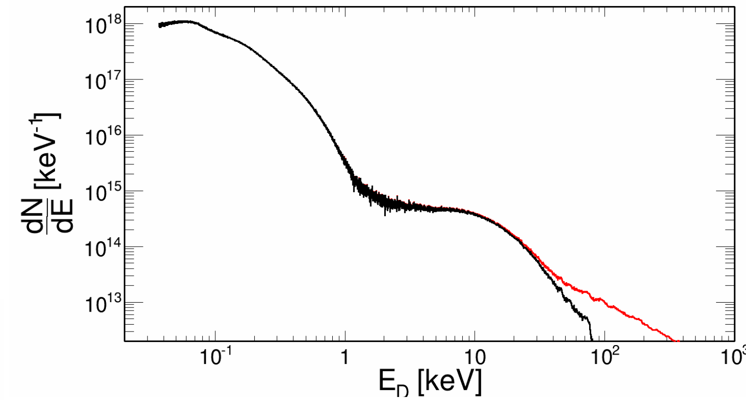
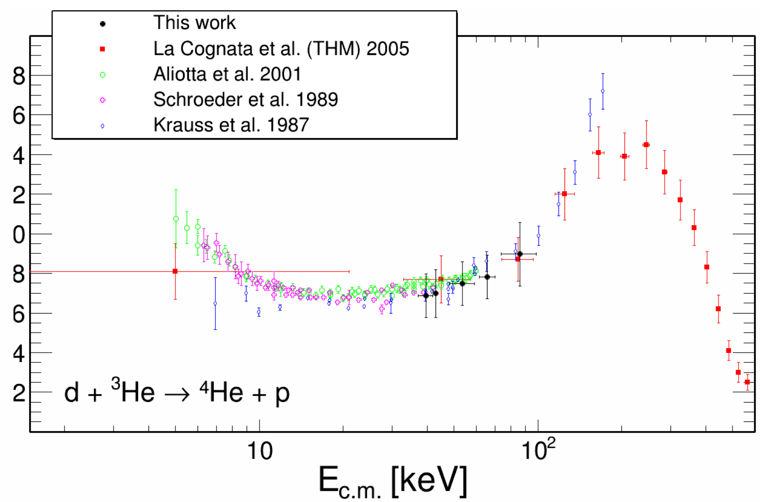
Model-independent determination of the astrophysical *S* factor in laser-induced fusion plasmas

D. Lattuada, M. Barbarino, A. Bonasera, W. Bang, H. J. Quevedo, M. Warren, F. Consoli, R. De Angelis, P. Andreoli, S. Kimura, G. Dyer, A. C. Bernstein, K. Hagel, M. Barbui, K. Schmidt, E. Gaul, M. E. Donovan, J. B. Natowitz, and T. Ditmire

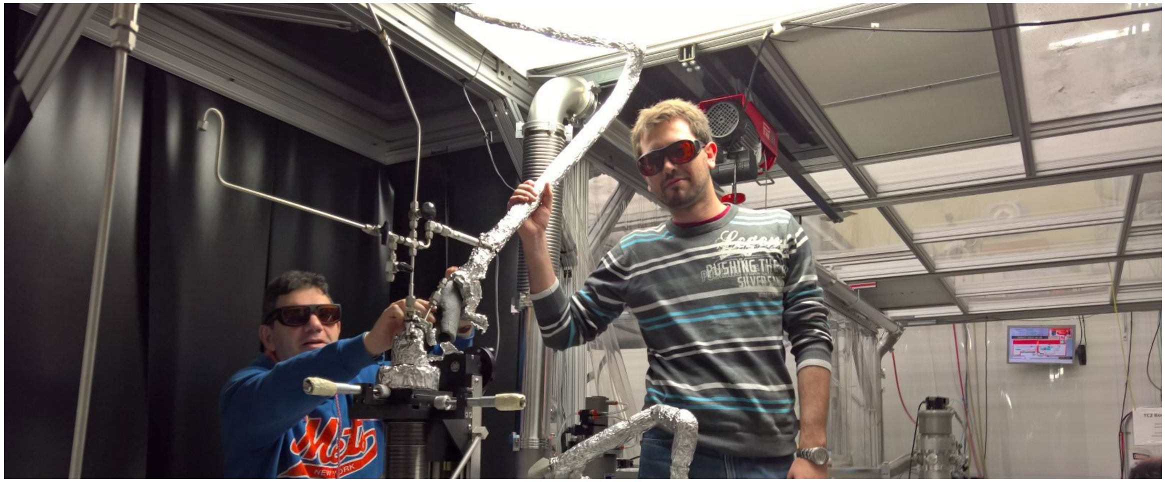
Phys. Rev. C **93**, 045808 – Published 19 April 2016

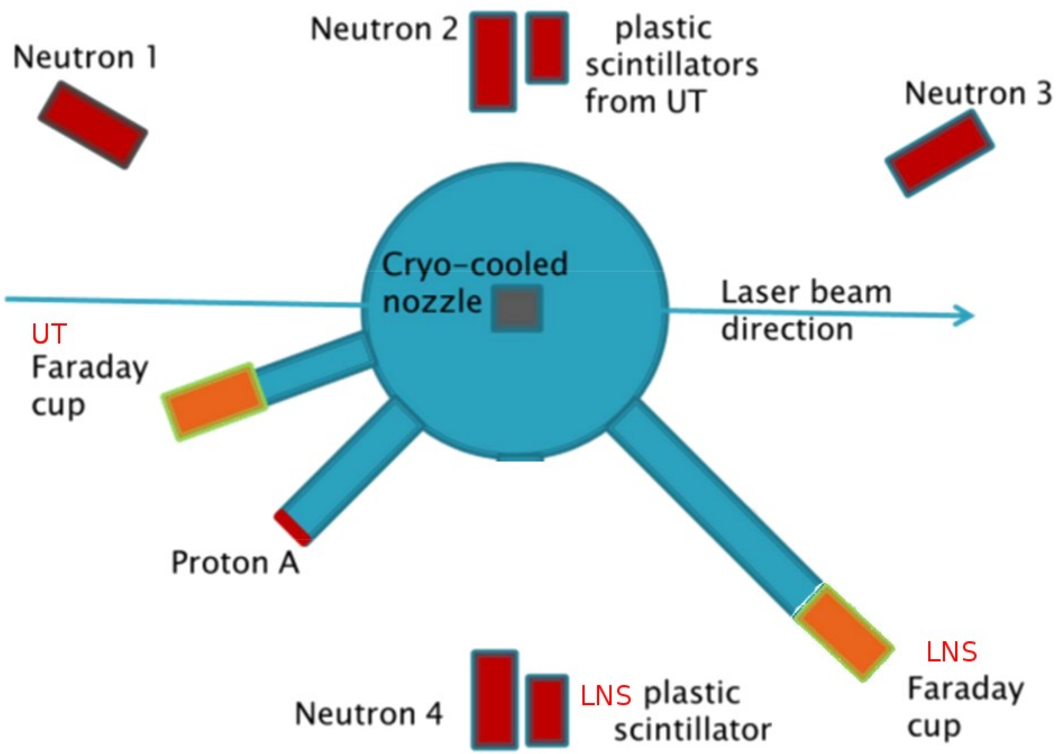






The 2016 experiment





ELSEVIER

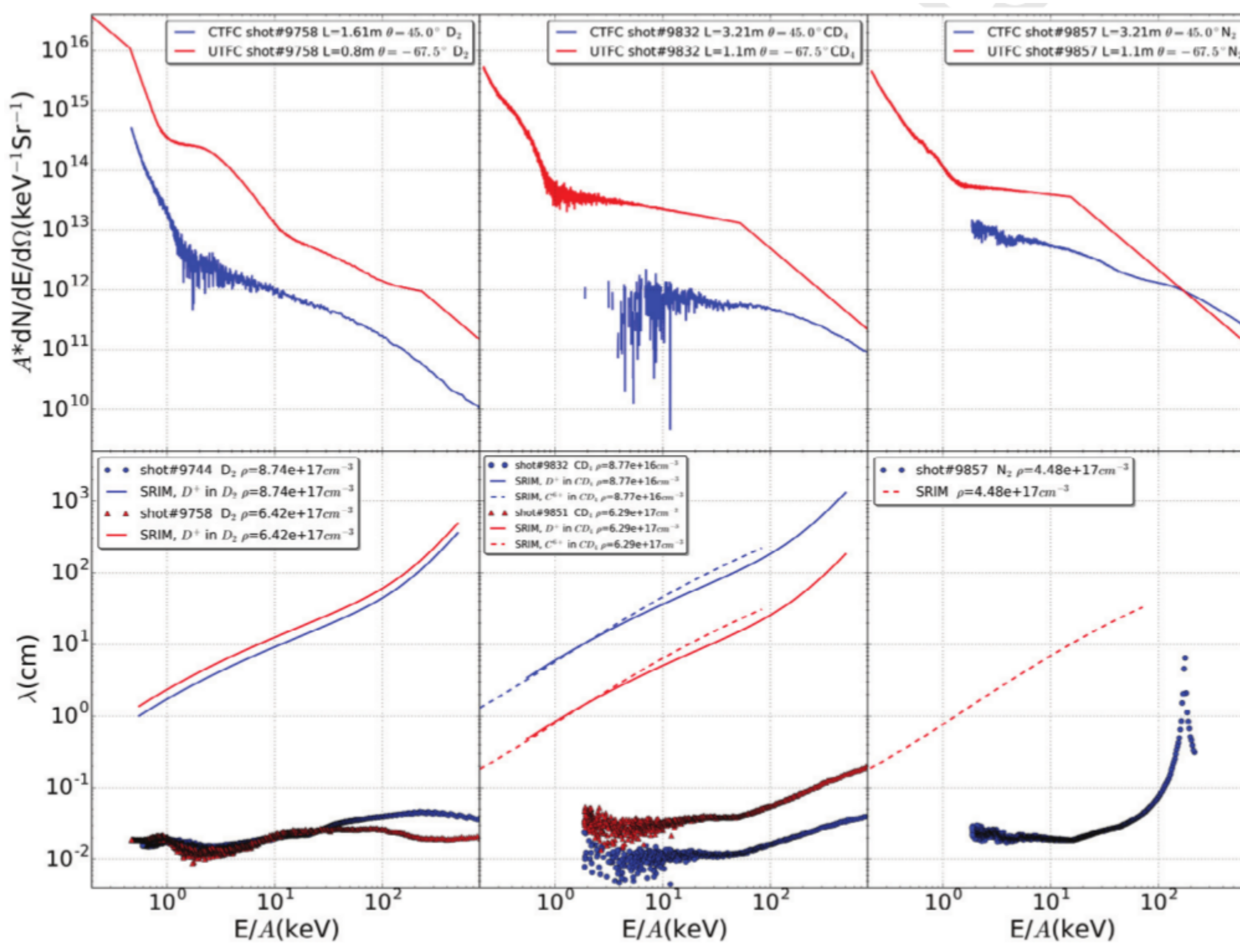
Physics Letters A

Volume 381, Issue 19, 18 May 2017, Pages 1682–1686

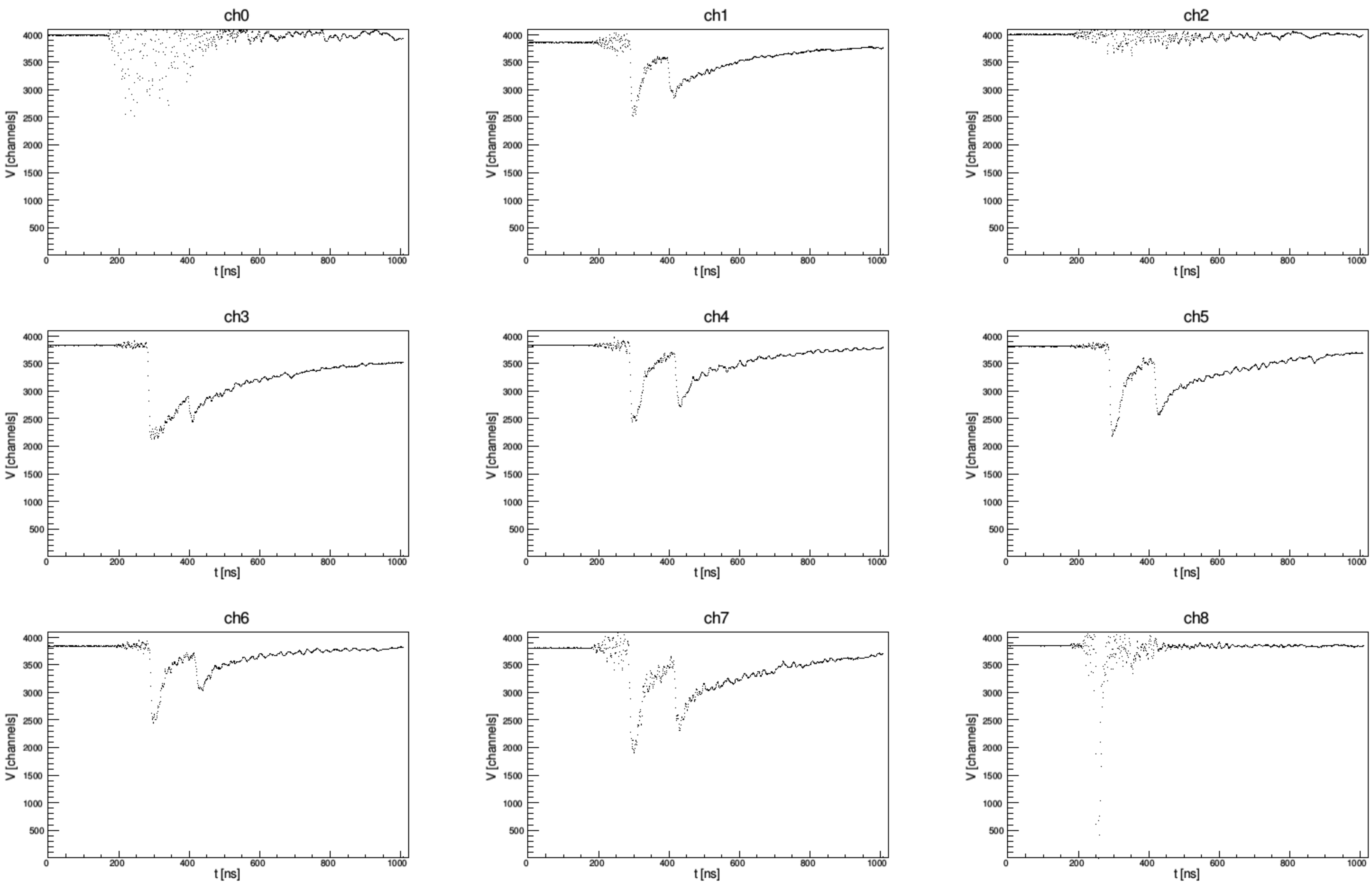
Range of plasma ions in cold cluster gases near the critical point

G. Zhang[a, 1], H.J. Quevedo[b], A. Bonasera[a, c], M. Donovan[b], G. Dyer[b], E. Gaul[b], G.L. Guardo[c], M. Gulino[c, d], M. La Cognata[c], D. Lattuada[c], S. Palmerini[e, f], R.G. Pizzone[c], S. Romano[c], H. Smith[b], O. Trippella[e, f], A. Anzalone[c], C. Spitaleri[c], T. Ditmire[b]

- Measurement of the ion range in cold gases
- It strongly depends on initial gas T and P
- “SRIM + homogenous gases” fails to reproduce
- Range increase when near the critical point gas/liquid..

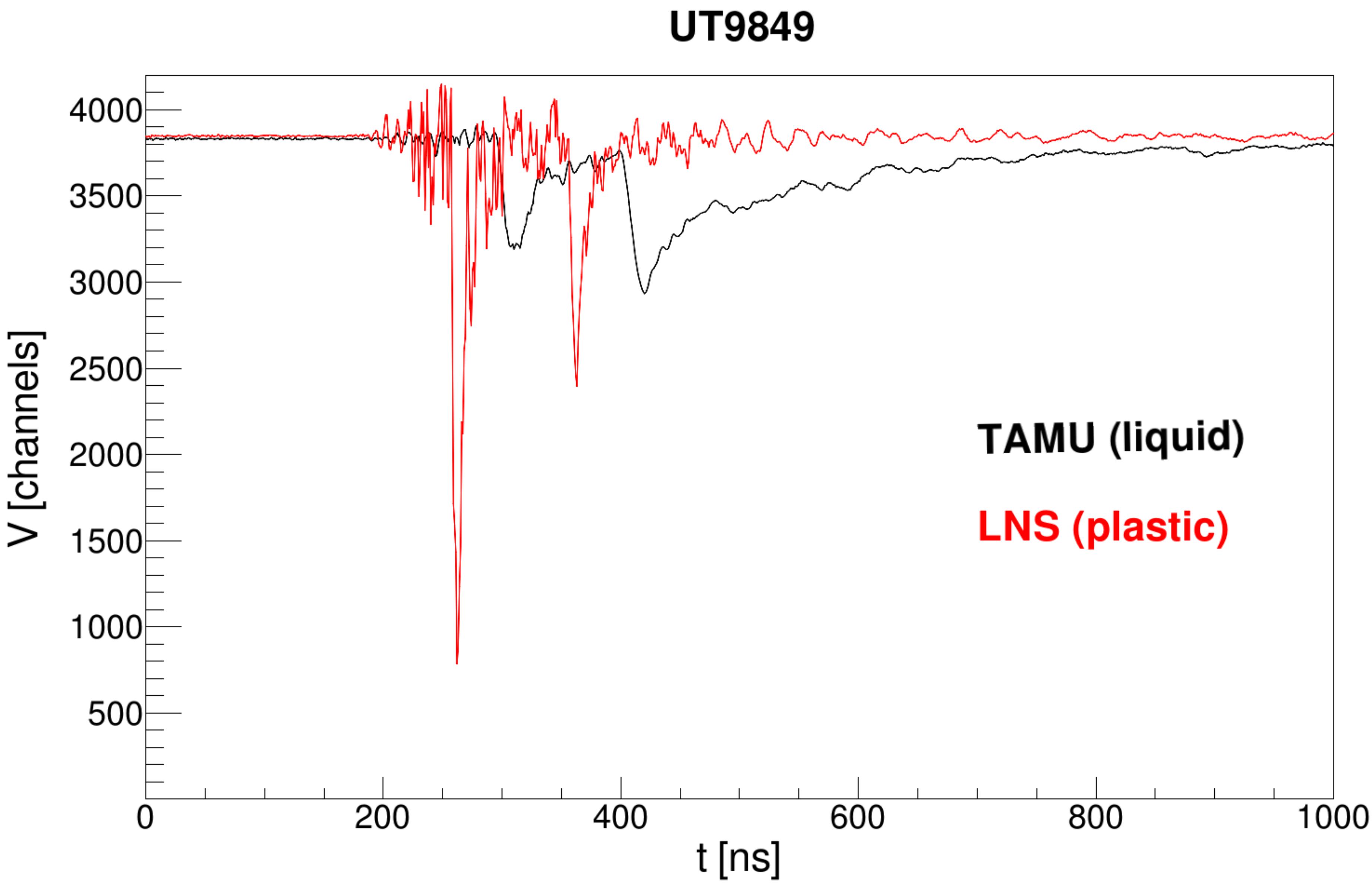


The 2016 experiment



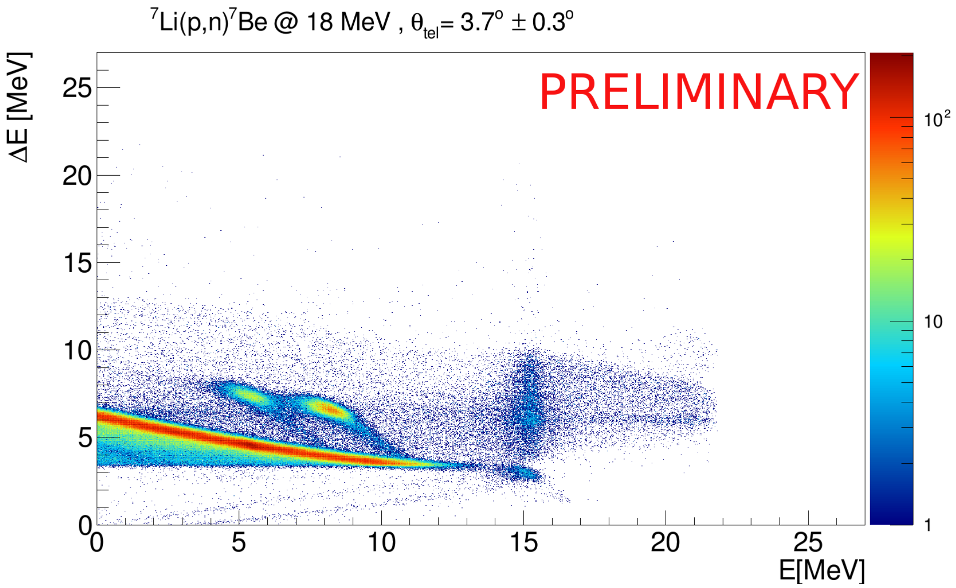
The 2016 experiment

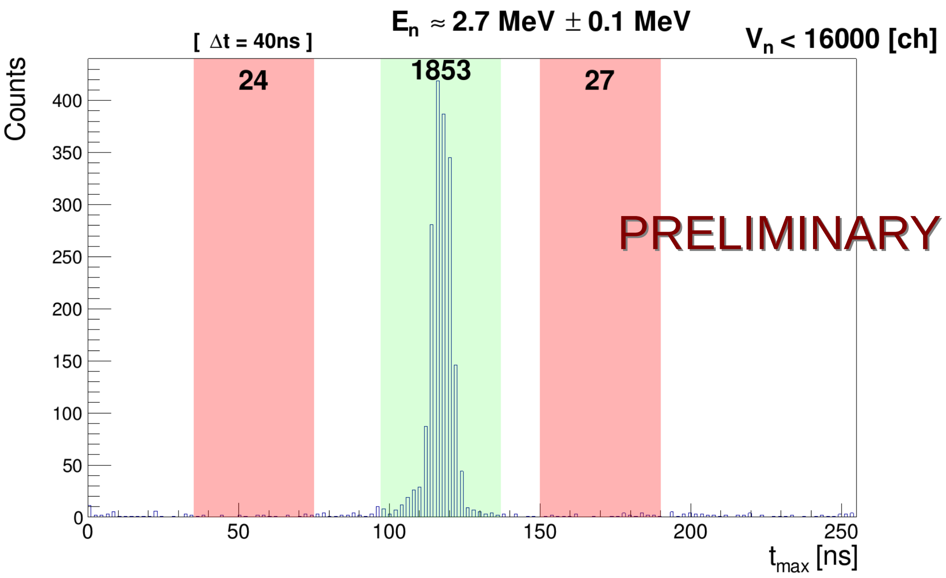
Ongoing analysis

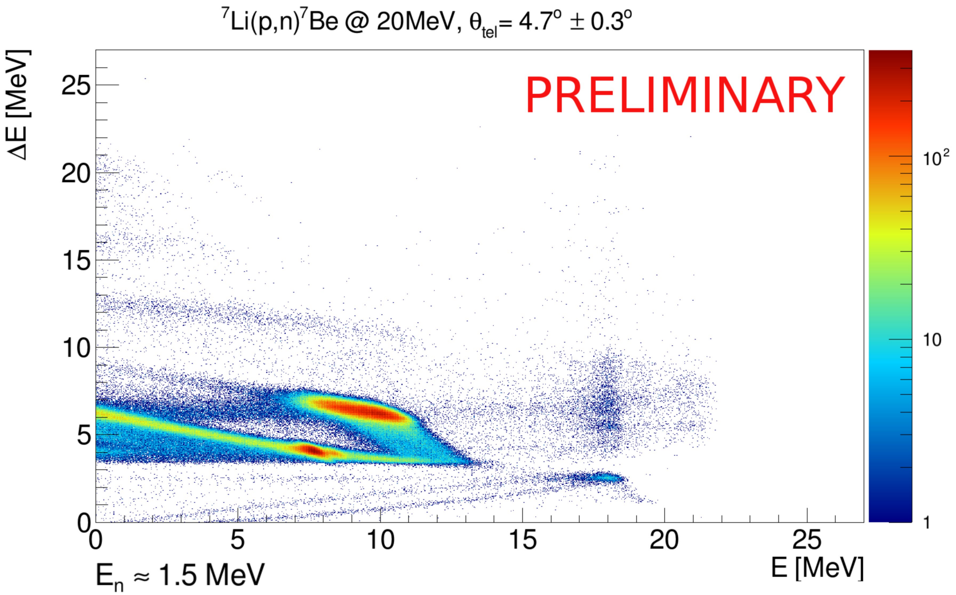


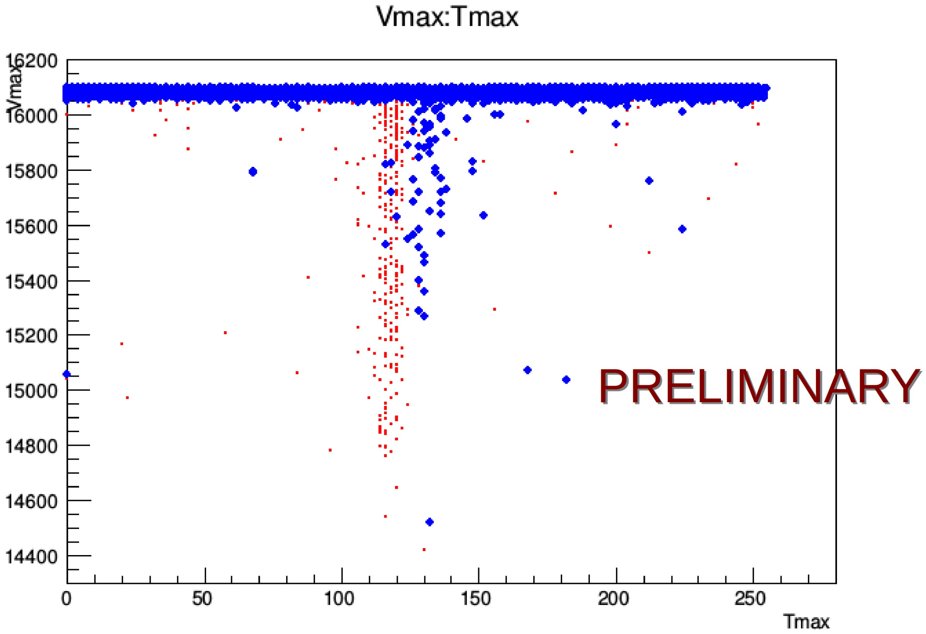
efficiency tests @LNS

Ongoing analysis









Conclusions & 2018+ experiments?

- It is possible to accelerate ions to multi-keV energies using ultrashort laser pulses in laser-cluster experiments
- It is possible to calculate S(E) without assuming thermal equilibrium (and MB)
- It is possible to extend the measurements to higher and lower energies by tuning the nozzle T and P .
- Ion range is not reproduced by SRIM, with 2-3 orders of magnitude discrepancy
- Critical point… (preliminary, submitted)

- Proposal UT 2018 ?

- ELI-NP 2020 ? Laser-cluster interaction (RA3) photonuclear reactions with SD (ELISSA in RA4)

Thank you

UT2016 experiment:
A. Anzalone[1], A. Bonasera[1,2], T. Ditmire[3], M. Donovan[3], G. Dyer[3], E. Gaul[3], G. L. Guardo[4], M. Gulino[1,5], M. La Cognata[1], D. Lattuada[4], S. Palmerini[6,7], R. G. Pizzone[1], H. J. Quevedo[3], S. Romano[1], H. Smith[3], O. Trippella[6,7], C. Spitaleri[1], G. Zhang[2]

1) Laboratori Nazionali del Sud-INFN, via S. Sofia 64, 95123 Catania, Italy.
2) Cyclotron Institute, Texas A&M University, 77843 College Station, TX.
3) Center for High Energy Density Science, C1510, University of Texas at Austin, Austin, Texas 78712, USA
4) Extreme Light Infrastructure – Nuclear Physics, Magurele, Bucharest, Romania.
5) Libera Universita' Kore, 94100 Enna, Italy
6) Department of Physics and Geology, University of Perugia, Via A. Pascoli, 06123 Perugia, Italy
7) Istituto Nazionale di Fisica Nucleare, Section of Perugia, Via A. Pascoli, 06123 Perugia, Italy

ELI-NP laser and GBS

Extreme Light Infrastructure - Nuclear Physics

10 PW Laser & Gamma Beam System ..

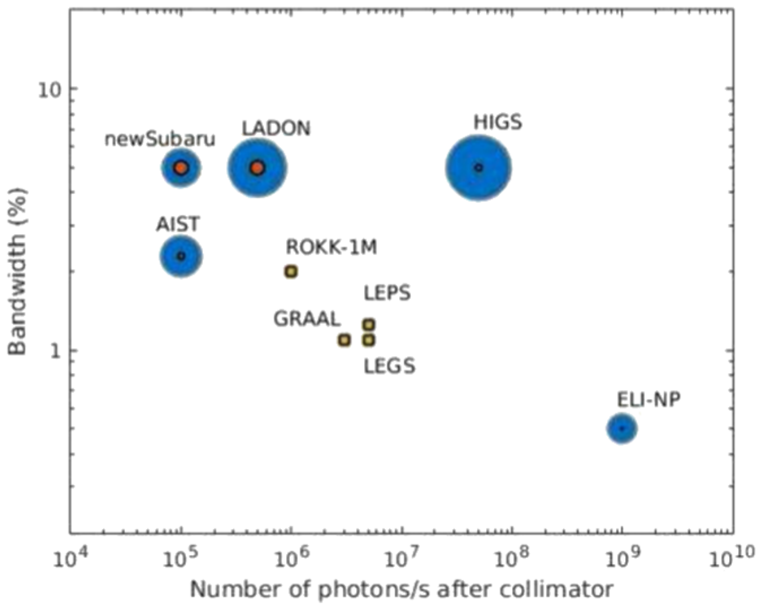


Table 1. The parameters of the gamma beams at ELI-NP Gamma Beam System (GBS).

Gamma beam parameters	Value
Energy [MeV]	0.2-19.5
Spectral density [photons/s/eV]	$>0.5 \cdot 10^3$
Bandwidth [%]	$\leqslant 0.5$
Peak brilliance [photons/s·mm^2·mrad^2·0.1% bdw]	10^{20}–10^{23}
Pulse length rms [ps]	0.7-1.5
Linear polarization [%]	>95
Macro repetition rate [Hz]	100
Number of pulses/macropulse	32
Pulse-to-pulse separation [ns]	16

ELI-NP & Nuclear Astrophysics

- **Big Bang Nucleosinthesys and Li-problem**

  $^{7}Li(\gamma,t)^{4}He$ reaction

- **Si-burning in stars and presupernova phase**

  $^{24}Mg(\gamma,\alpha)^{20}Ne$ reaction

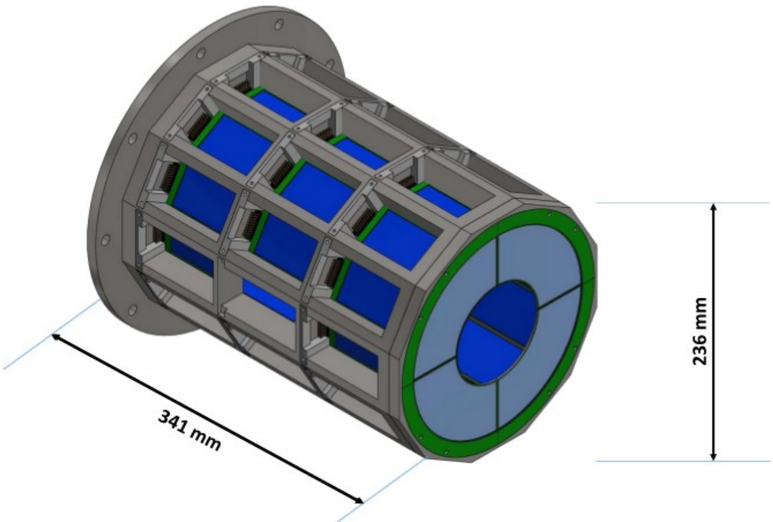
  $^{28}Si(\gamma,p)^{27}Al$ reaction

- **p-process (production of proton rich nuclei)**

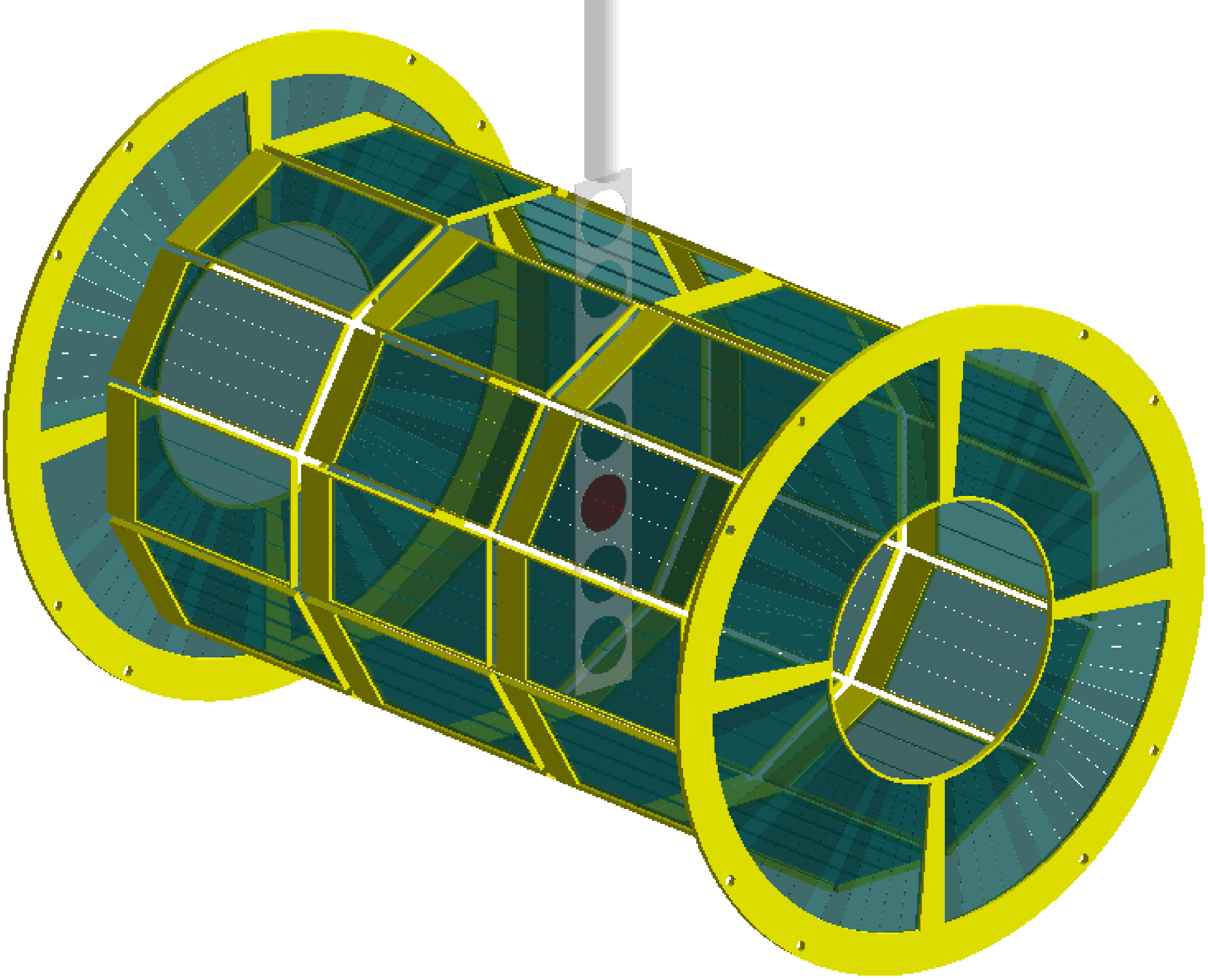
  $^{96}Ru(\gamma,\alpha)^{92}Mo$ reaction

  $^{74}Se(\gamma,p)^{73}As$ reaction

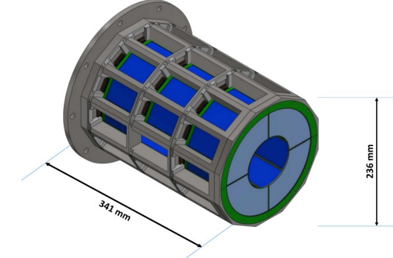
Extreme Light Infrastructure Silicon Strip Array

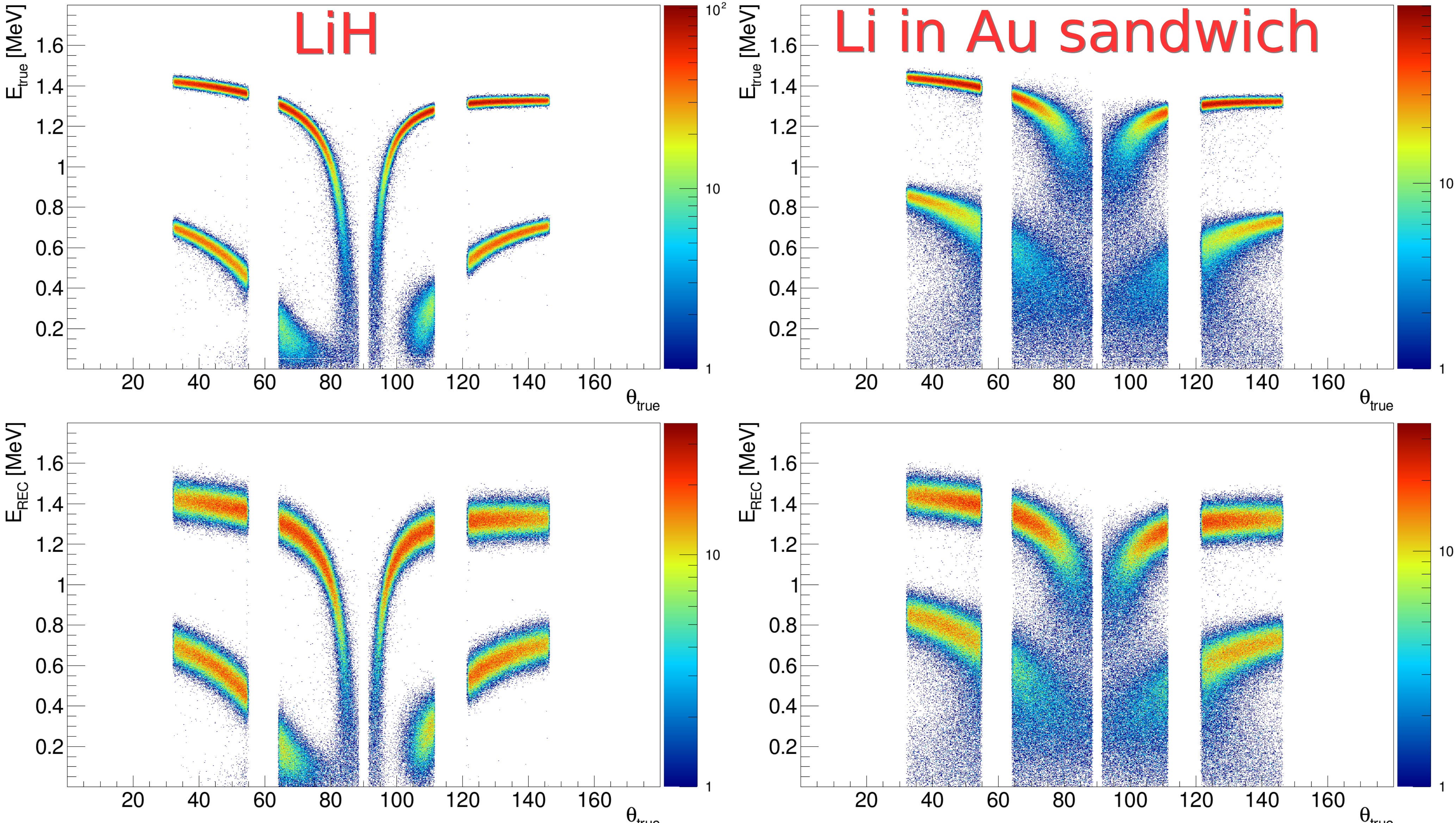


- 3 rings of 12 position-sensitive X3 silicon-strip detectors (minus 1)
  Energy resolution (FWHM) ~ 0.3%
  Angular resolution 1 mm or ~ 0.4 deg
- 2 end cap detectors made up of 4 QQQ3 DSSSD
  Energy resolution (FWHM) ~ 0.3%
  Angular resolution 3 mm or ~ 0.8 deg



$^{7}Li(\gamma,t)^{4}He$ @ 5MeV





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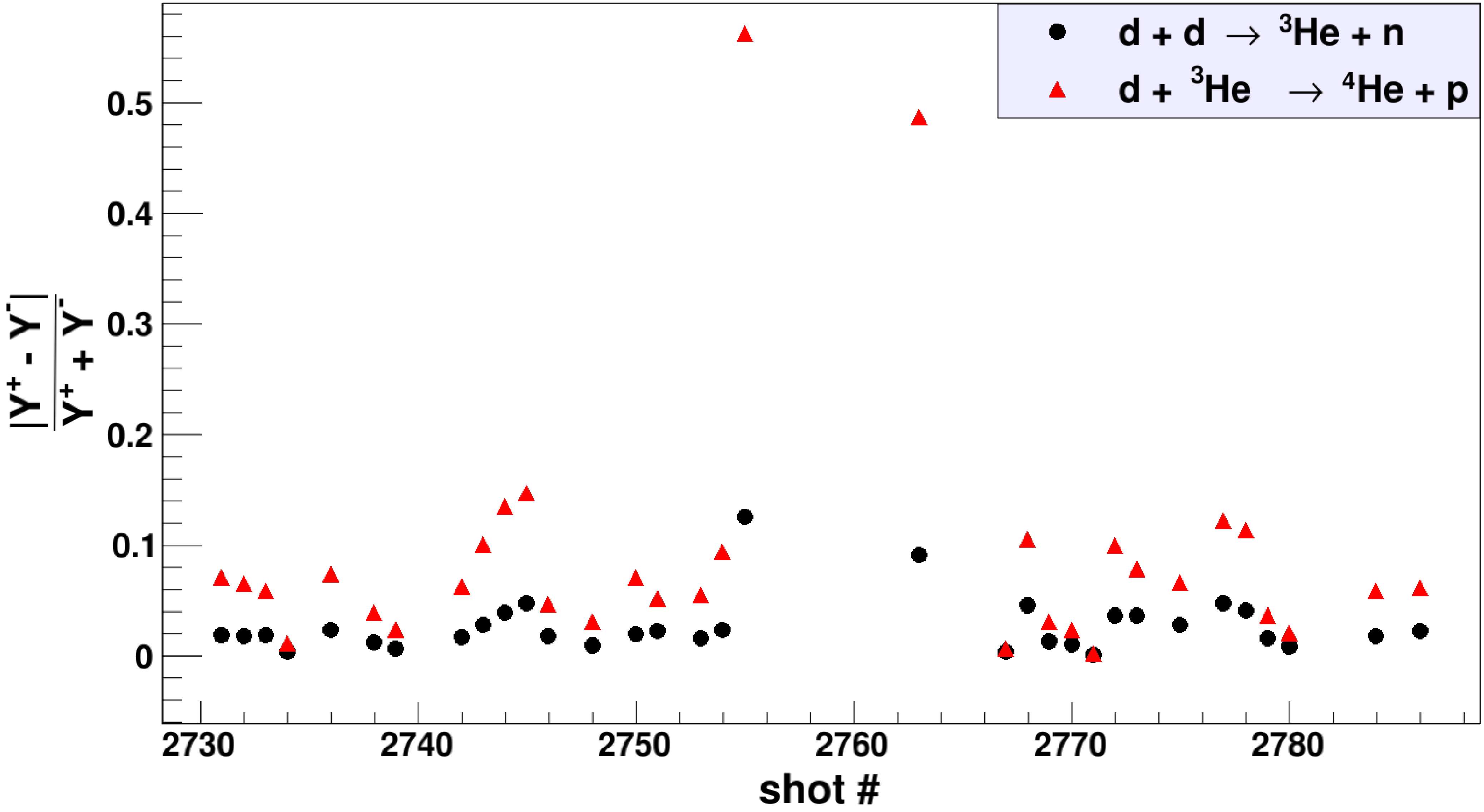
Bologna, 5-6 October 2017

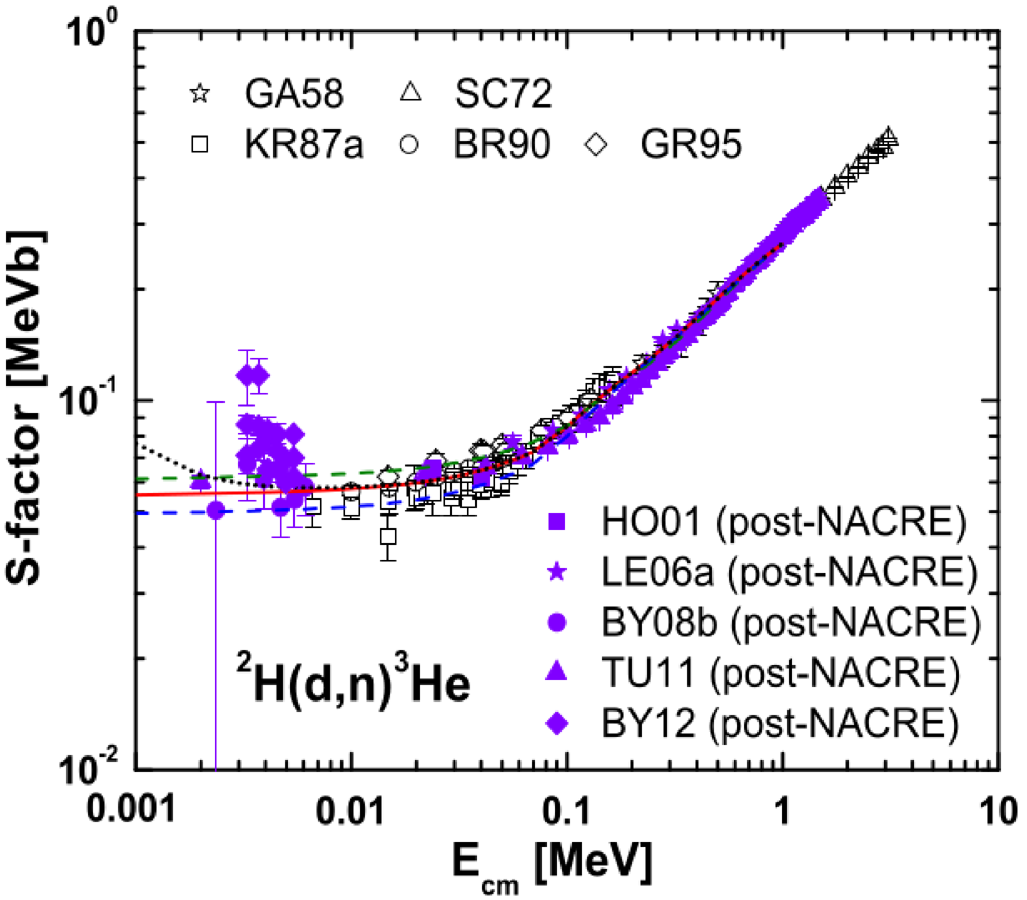
Conclusions

Backup slides?

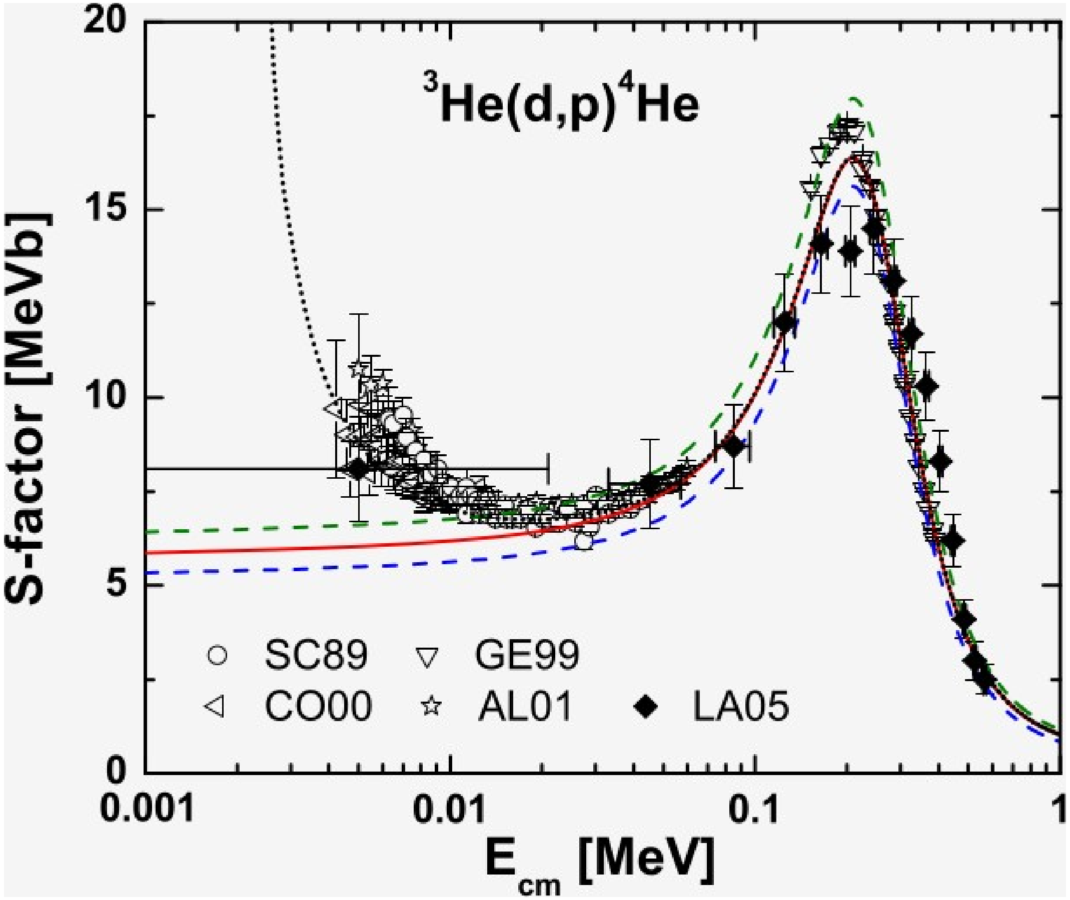


d + d → ^{3}He + n
d + ^{3}He → ^{4}He + p
0.5
0.4
0.3
0.2
0.1
0
$\frac{|Y^+ - Y^-|}{Y^+ + Y^-}$
2730
2740
2750
2760
2770
2780
shot #

NACRE - II



S-factor [MeVb]
10^0
10^{-1}
10^{-2}
GA58
SC72
KR87a
BR90
GR95
HO01 (post-NACRE)
LE06a (post-NACRE)
BY08b (post-NACRE)
TU11 (post-NACRE)
BY12 (post-NACRE)
$^2H(d,n)^3He$
0.001
0.01
0.1
1
10
E_{cm} [MeV]



S-factor [MeVb]
20
15
10
5
0
$^3He(d,p)^4He$
SC89
GE99
CO00
AL01
LA05
0.001
0.01
0.1
1
E_{cm} [MeV]

$$Y = \frac{\rho_1 \int \frac{dN}{dE} S(E) \exp(-2\pi\eta(E)) \upsilon\tau dE}{1 + \delta_{12}}$$

ncyclopedia Air Liquide | Air Liquide - Mozilla Firefox

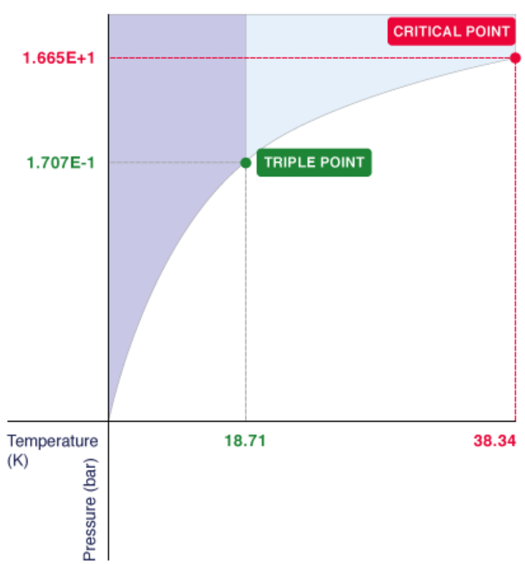
https://encyclopedia.airliquide.com/deuterium

Physical Properties

Under solid (grey), liquid (blue) and vapor states (white) along the equilibrium curves

GENERAL PROPERTIES | SOLID PHASE | LIQUID PHASE | GAS PHASE

(P) log(P) DOWNLOAD



Molecular weight	4.028 g/mol
Content in air	/

Critical Point

Temperature	- 234.81 °C
Pressure	16.653 bar
Density	69.797 kg/m³

Triple Point

Temperature	- 254.44 °C

D_2

Deuterium

$^2H - {}^2H$

CAS Number 7782-39-0

UN1957 (gas)

Molecule

Properties

Liquid / Gas Volum

Applications

Safety

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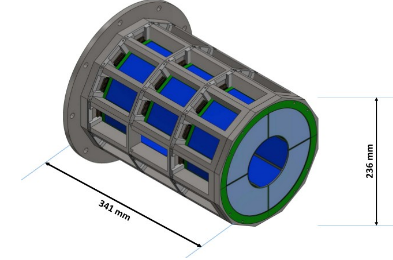
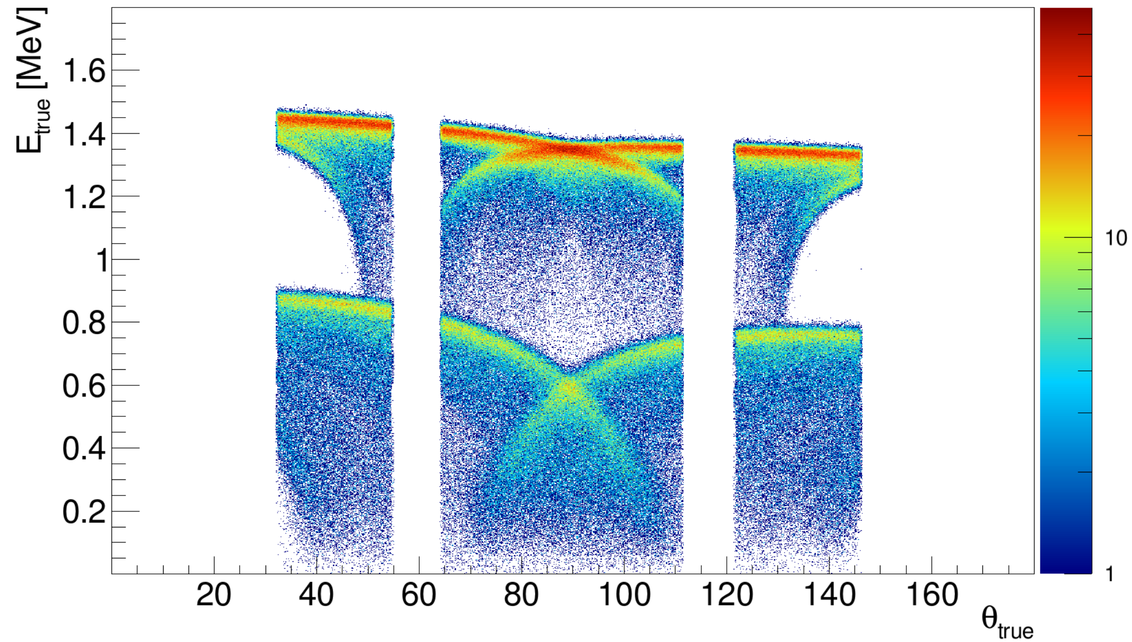
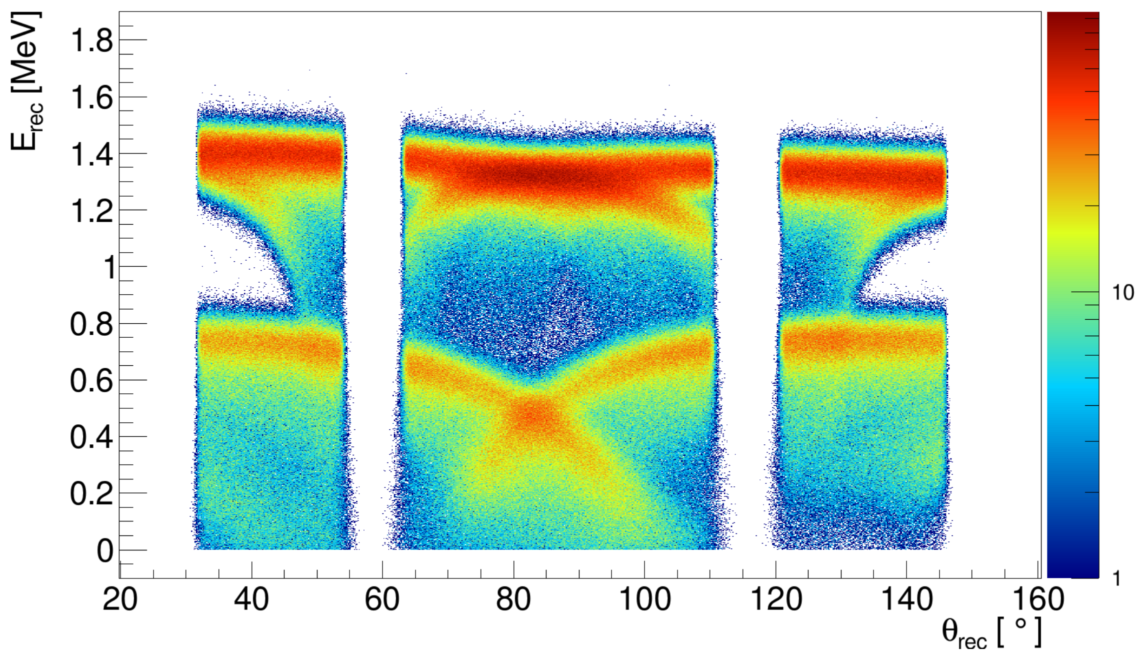
Highlight All Match Case Whole Words 1 of 1 match Reached end of page, continued from top







By rotating the target (35° here) we can minimize (remove) the effect of blind kinematics due to the straggling of ejectiles inside target

Analysis ongoing.