The $p\left({}^{11}_{5}\mathrm{B},\alpha\right)2\alpha$ Reaction and the Perspectives for Application

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on behalf of p11B project team of

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Introductory Personal Remarks:

Not (directly) related to the scientific topic of the presentation

Background

$$p\left({}^{11}_{5}\mathrm{B},\alpha\right)2\alpha$$

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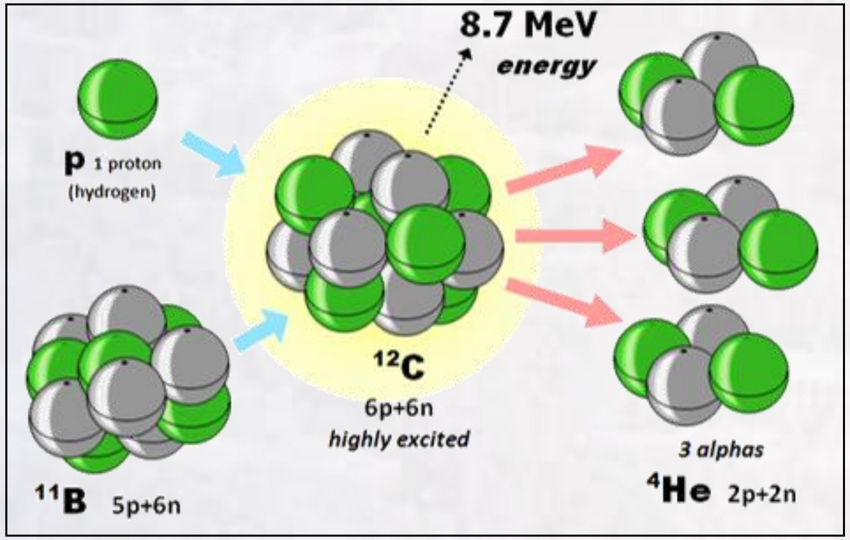
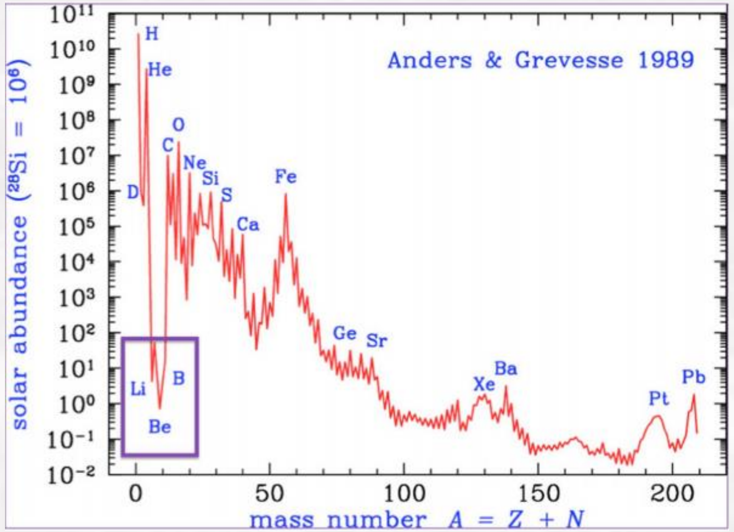
Advanced fusion schemes



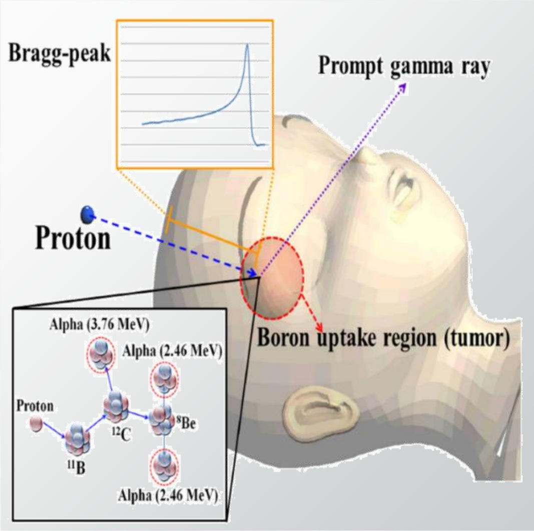
Nature Communications 4, 2506 (2013)

Element abundance in solar system



The Astrophysical Journal 943,40 (2013)

Proton Boron Capture Therapy (PBFT)



Journal of Instrumentation 12, C03049 (2017)

Programme


[Haw]

I*ntr*oduction for the benefit of students and non-experts

a)Remarks on the current status of Fusion (Energy)

b) My Opinion

c) The Proton Boron Reaction

d) Our Experiments

Conclusion and Outlook

Current Status of DT-Fusion

Motivation and Introductory Remarks: Magnetic Confinement Fusion

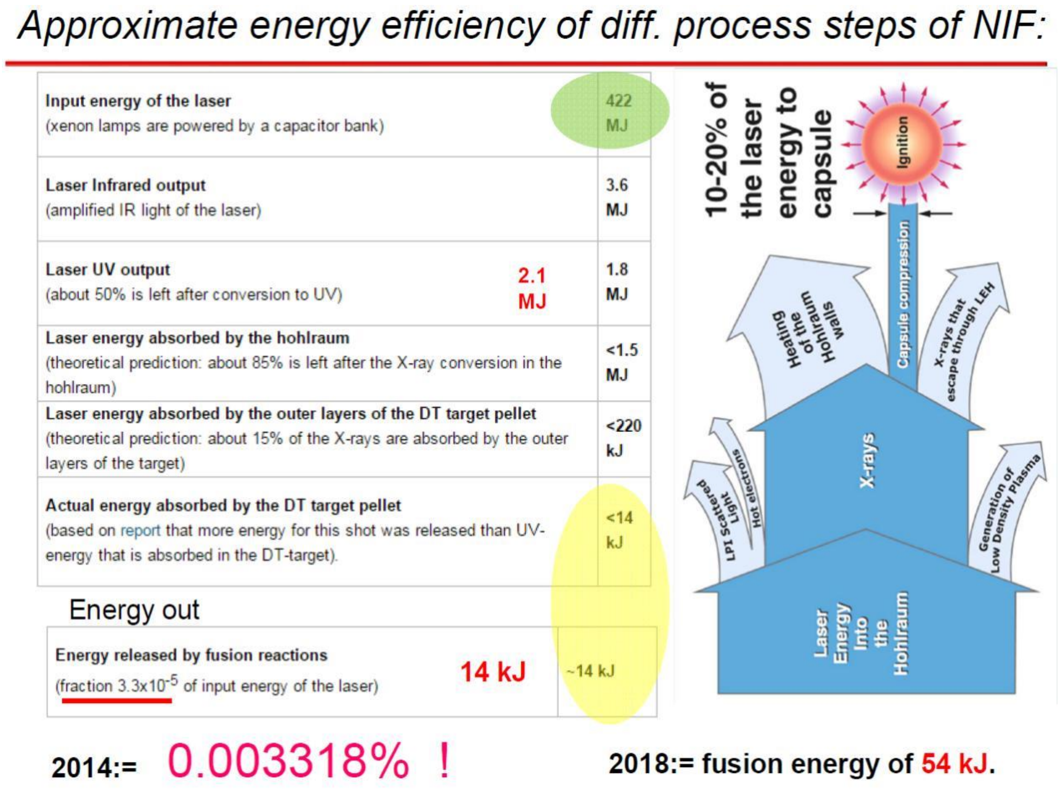
May 28, 2021: The Experimental Advanced Superconducting Tokamak achieved a world record for Temperature $T_e$and confinement time τ

Another remarkable achievement (59 MJ)is reported From JET in a DT experiment in 2021

$T_e = 100\ Million\ K \qquad \tau = 101\ s \quad ; \qquad T_e = 160\ Million\ K \qquad \tau = \ 20s$

Inertial Fusion Breakthrough at NIF, Livermore

2.8 MJ in 2022 and > 3MJ recently



Approximate energy efficiency of diff. process steps of NIF:

Input energy of the laser (xenon lamps are powered by a capacitor bank)		422 MJ
Laser Infrared output (amplified IR light of the laser)		3.6 MJ
Laser UV output (about 50% is left after conversion to UV)	2.1 MJ	1.8 MJ
Laser energy absorbed by the hohlraum (theoretical prediction: about 85% is left after the X-ray conversion in the hohlraum)		<1.5 MJ
Laser energy absorbed by the outer layers of the DT target pellet (theoretical prediction: about 15% of the X-rays are absorbed by the outer layers of the target)		<220 kJ
Actual energy absorbed by the DT target pellet (based on report that more energy for this shot was released than UV-energy that is absorbed in the DT-target).		<14 kJ

Energy out

Energy released by fusion reactions (fraction 3.3x10^{-5} of input energy of the laser)	14 kJ	~14 kJ

2014:= 0.003318% !

2018:= fusion energy of 54 kJ.

2021/22 fusion energy ≈ 1.8 MJ/ >3MJ recently

A few remarks on my opinion on current status of DT-fusion

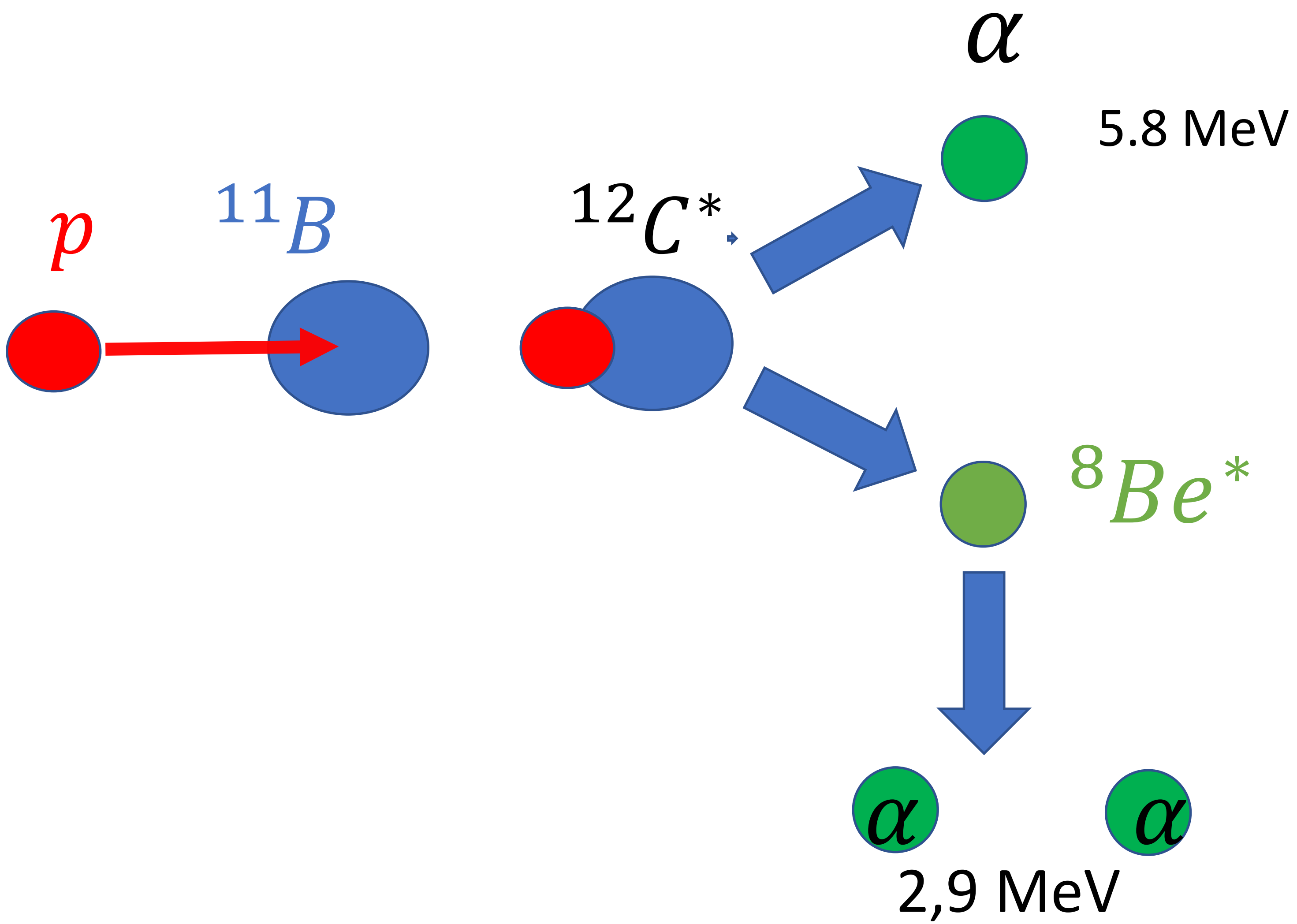
Issues on the path to Fusion Energy with DT reaction

Probably a number of issues (incomplete list):

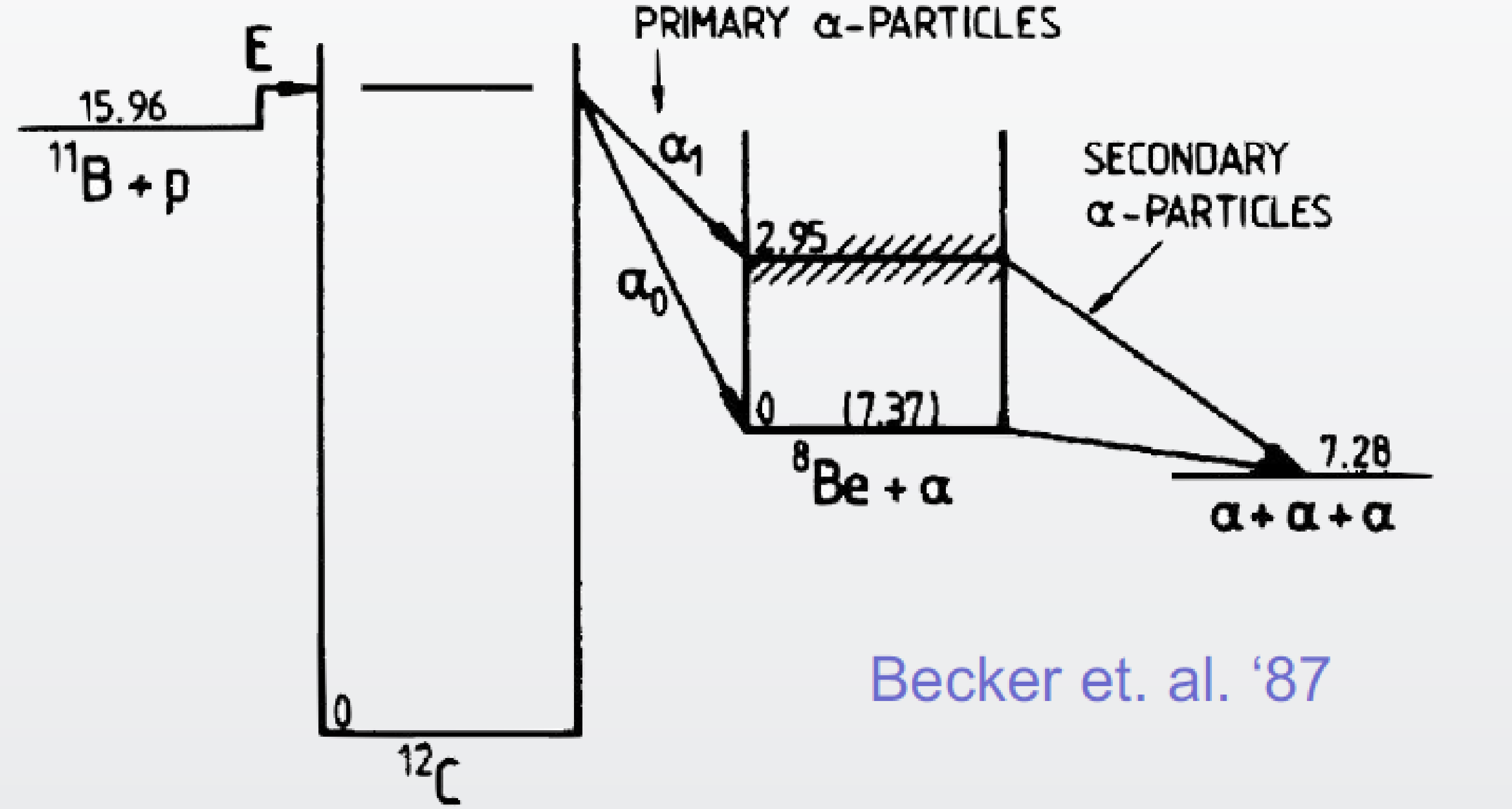
Target issues
Tritium problem (abundance and production from Li
Neutron issues (Damage to final optics)
Superconducting magnets

From the scientific and technology point of view the NIF program is a success story

The $^{11}B(p,\alpha)2\alpha$ Reaction at $E_o = 612\ keV$

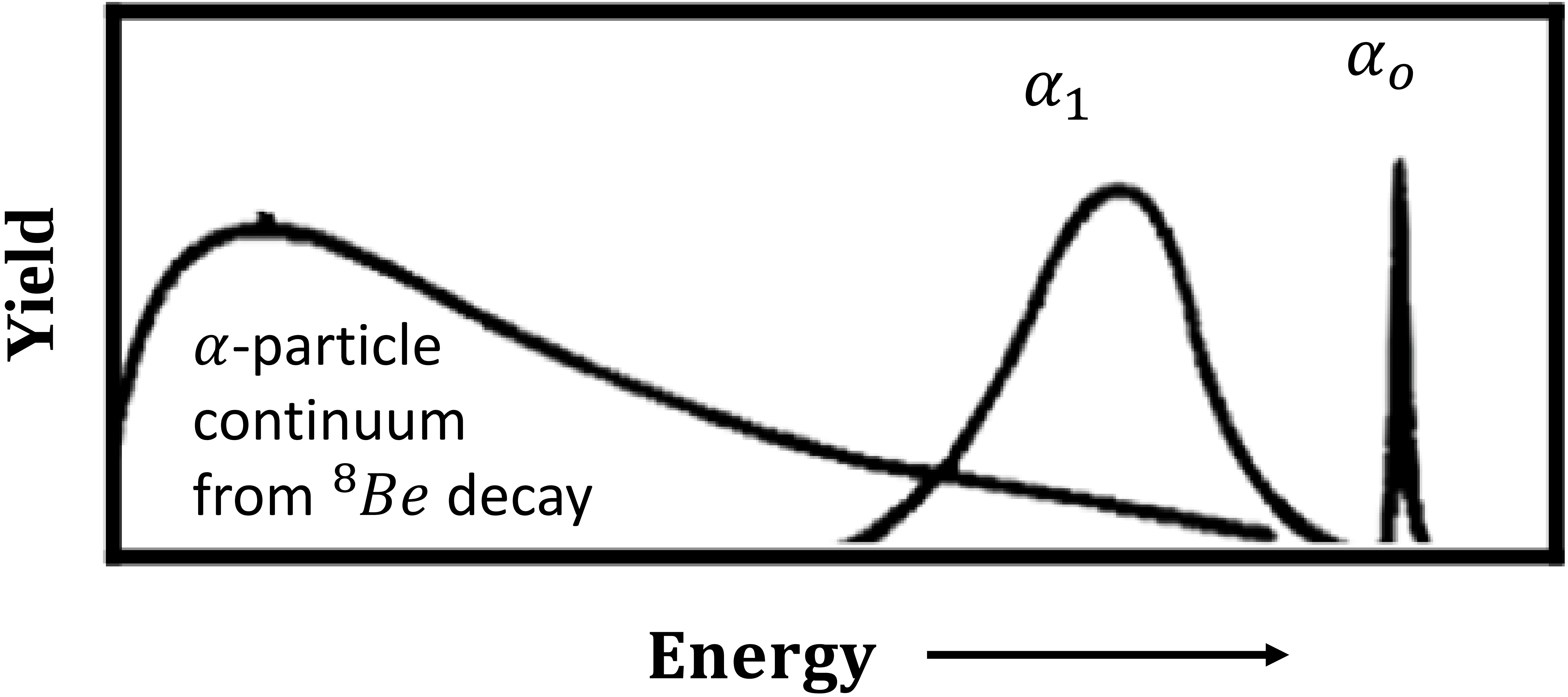


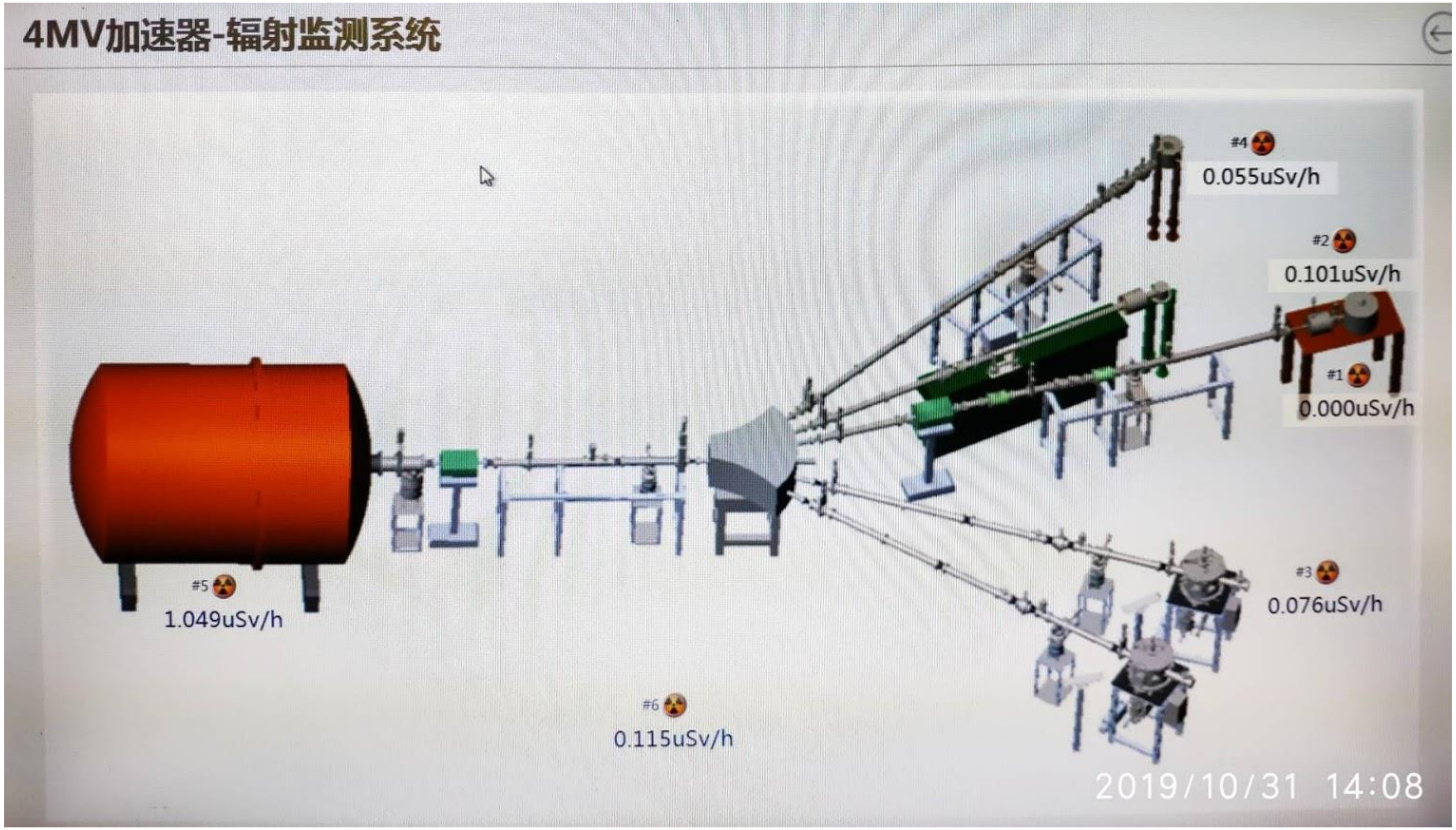
Nuclear Level Scheme of the $^{11}B(p,\alpha)2\alpha$ Reaction



Becker et. al. '87

Schematic Decomposition of the $p(^{11}B,\alpha)2\alpha$ Particle Spectrum




4MV加速器-辐射监测系统

#4 0.055uSv/h

#2 0.101uSv/h

#1 0.000uSv/h

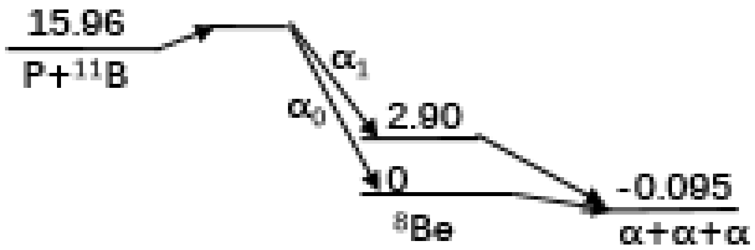
#5 1.049uSv/h

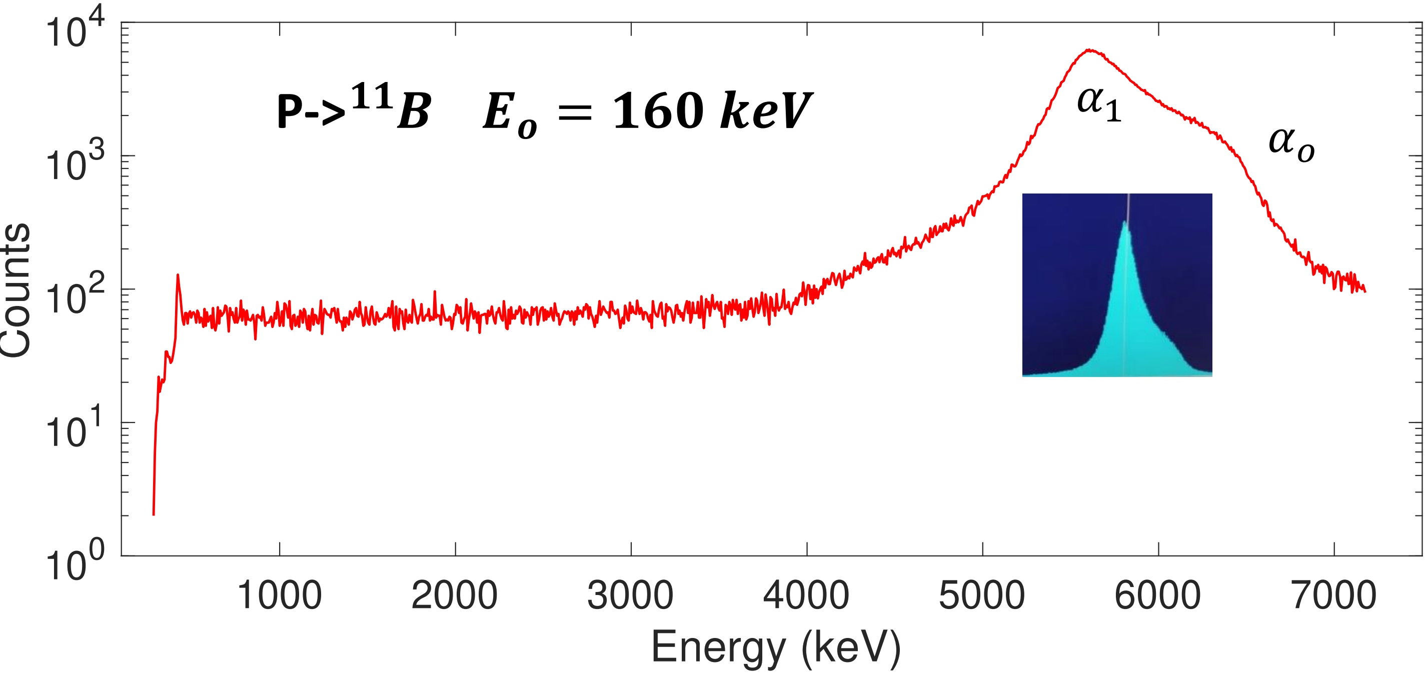
#3 0.076uSv/h

#6 0.115uSv/h

2019/10/31 14:08

The $p(^{11}B,\alpha)2\alpha$ Reaction





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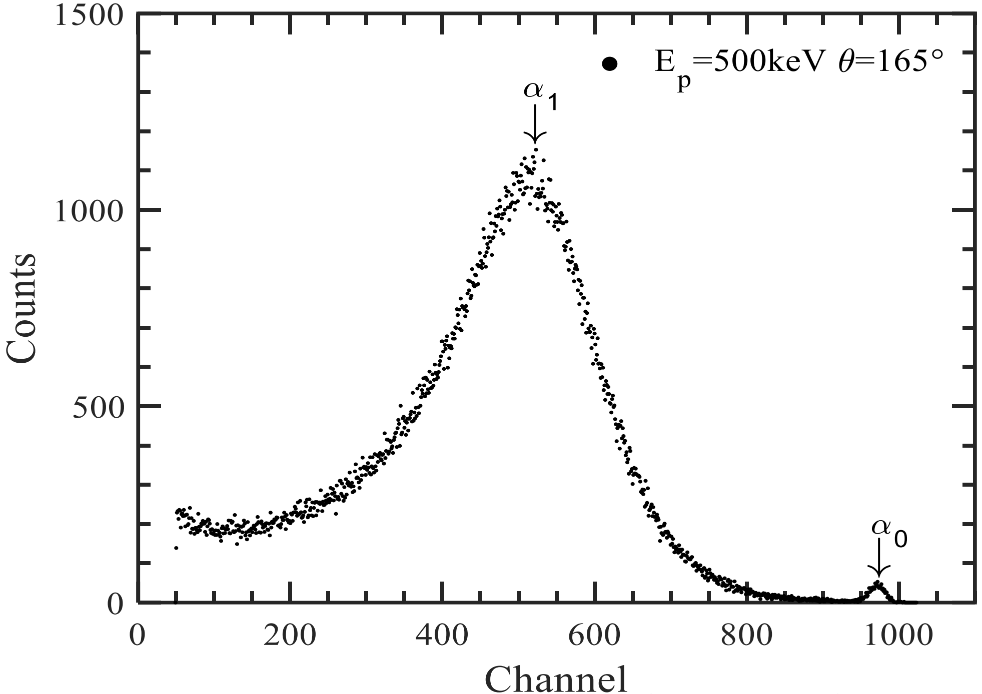
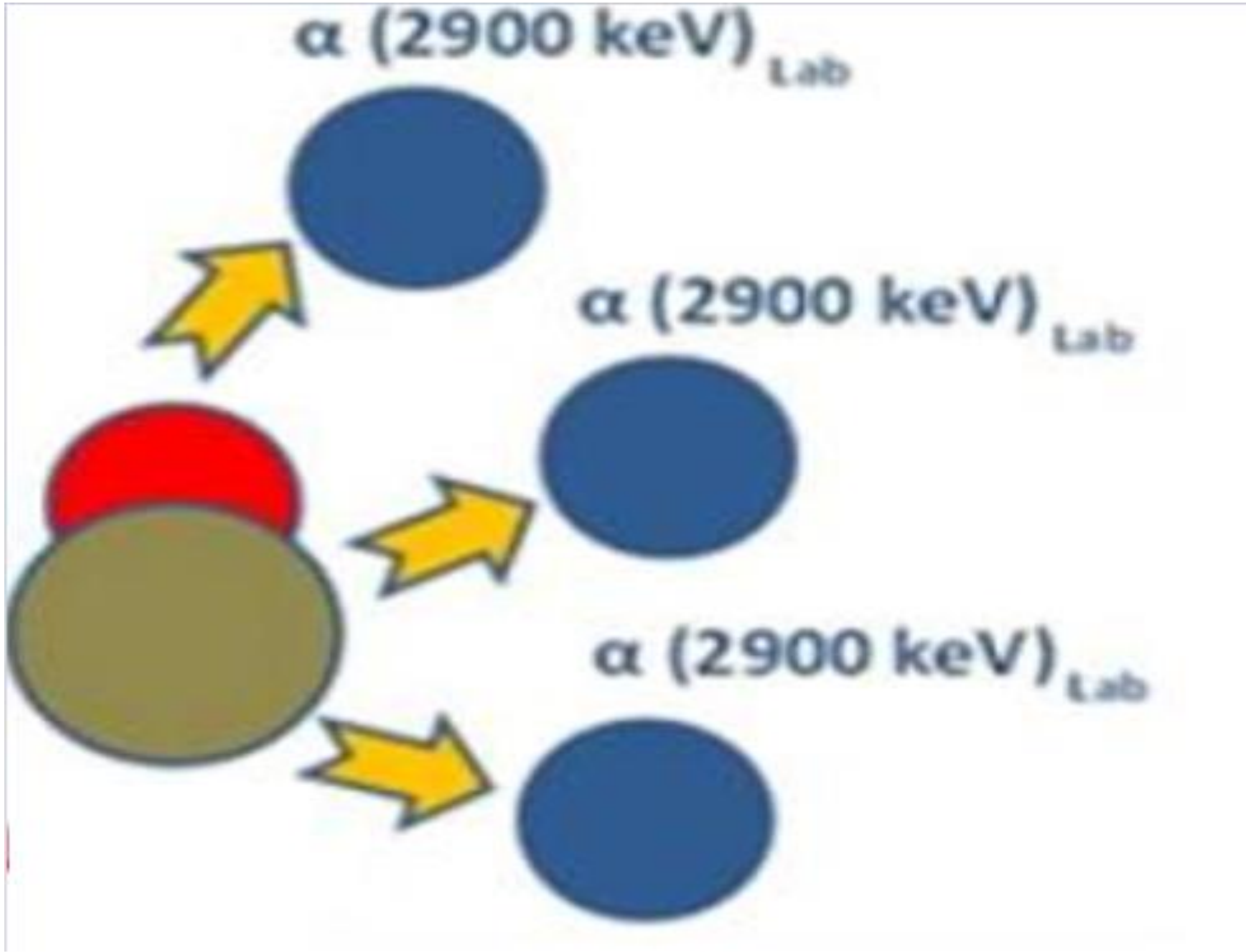
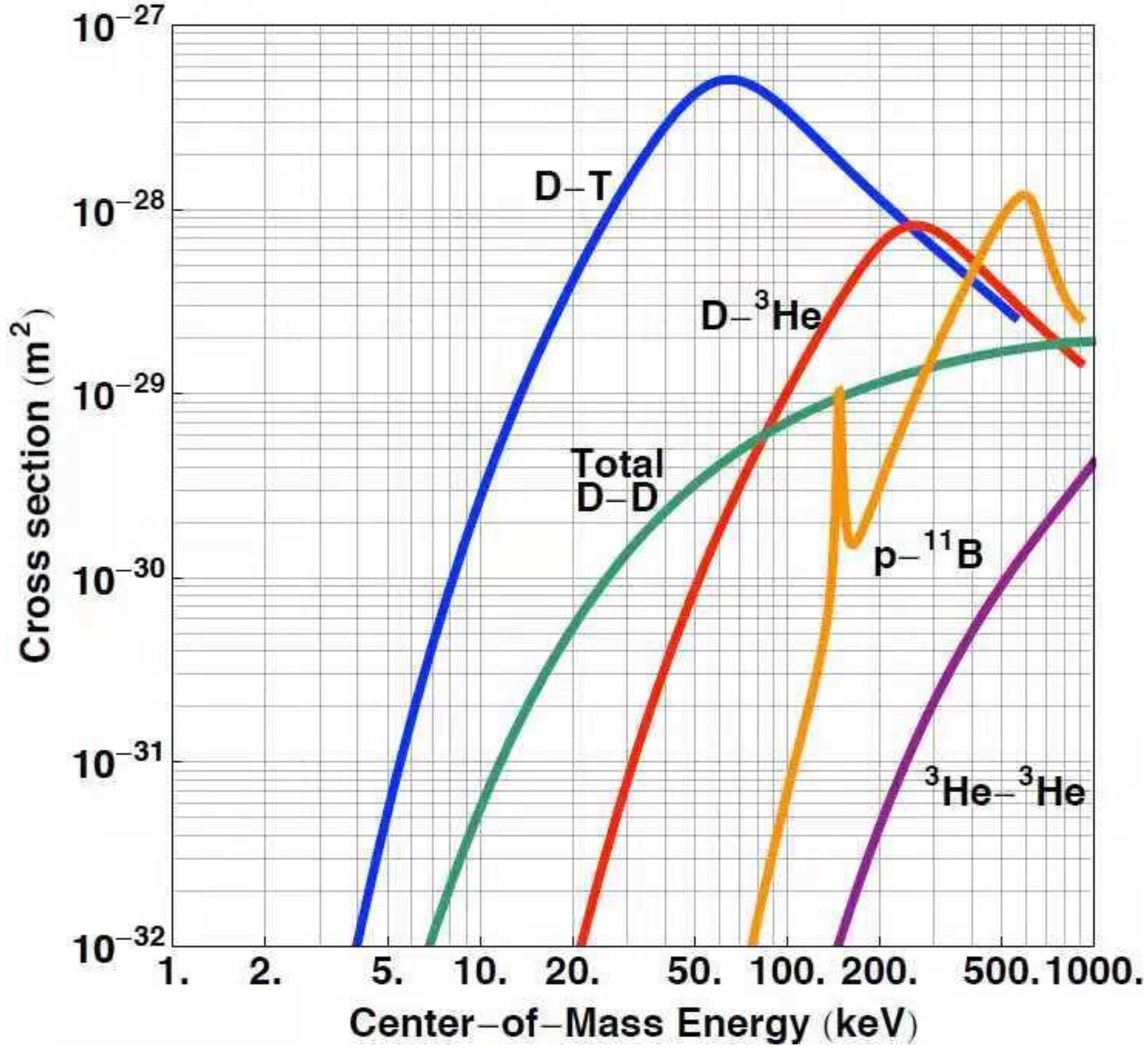


Measurement at SINAS (Shanghai) by ENN-XJTU- IMP collaboration

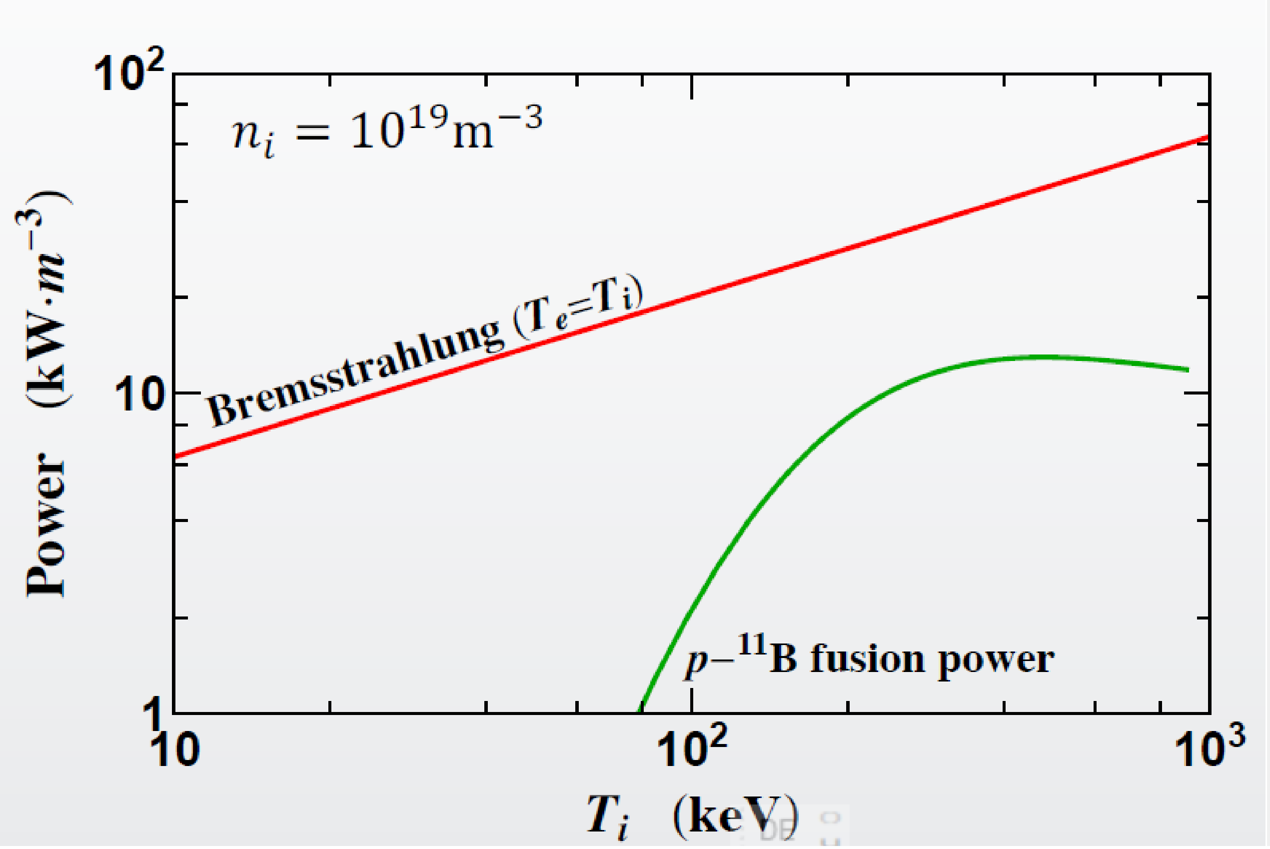
This ends The Fairy Tale of 3 Alphas at 2.9 MeV



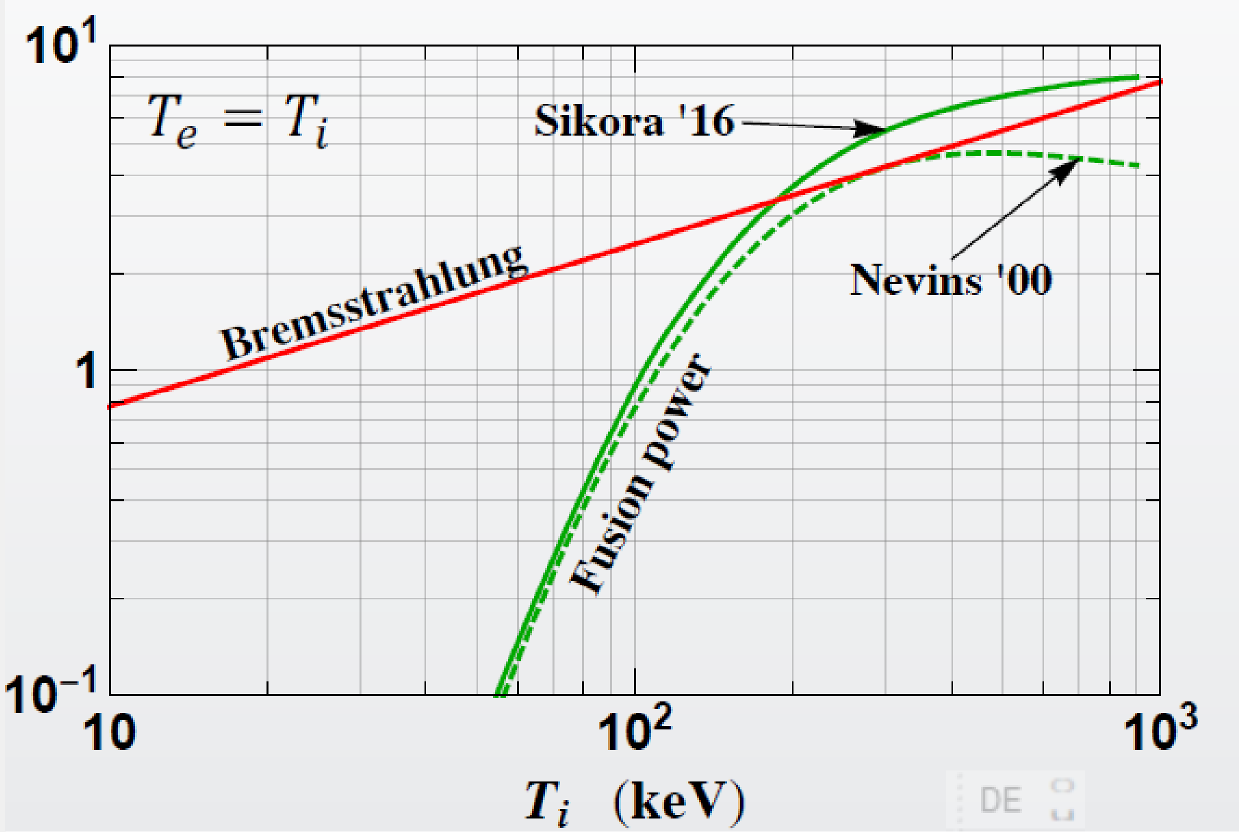
Challenges of the $^{11}B(p,\alpha)2\alpha$ Reaction

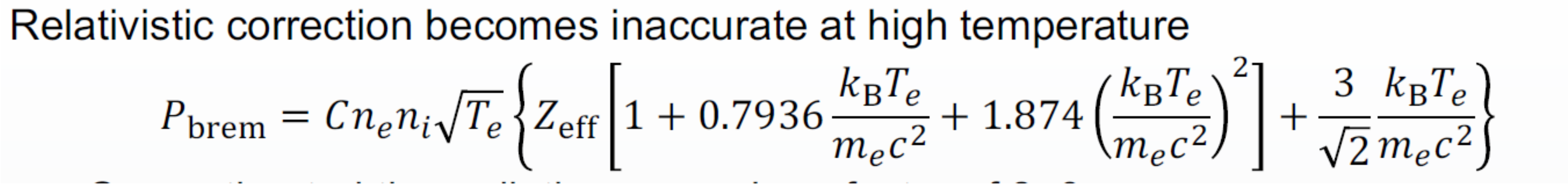


Challenges of the $^{11}B(p,\alpha)2\alpha$ Reaction



Reducing Bremsstrahlung by Changing the Fuel Mix Ratio





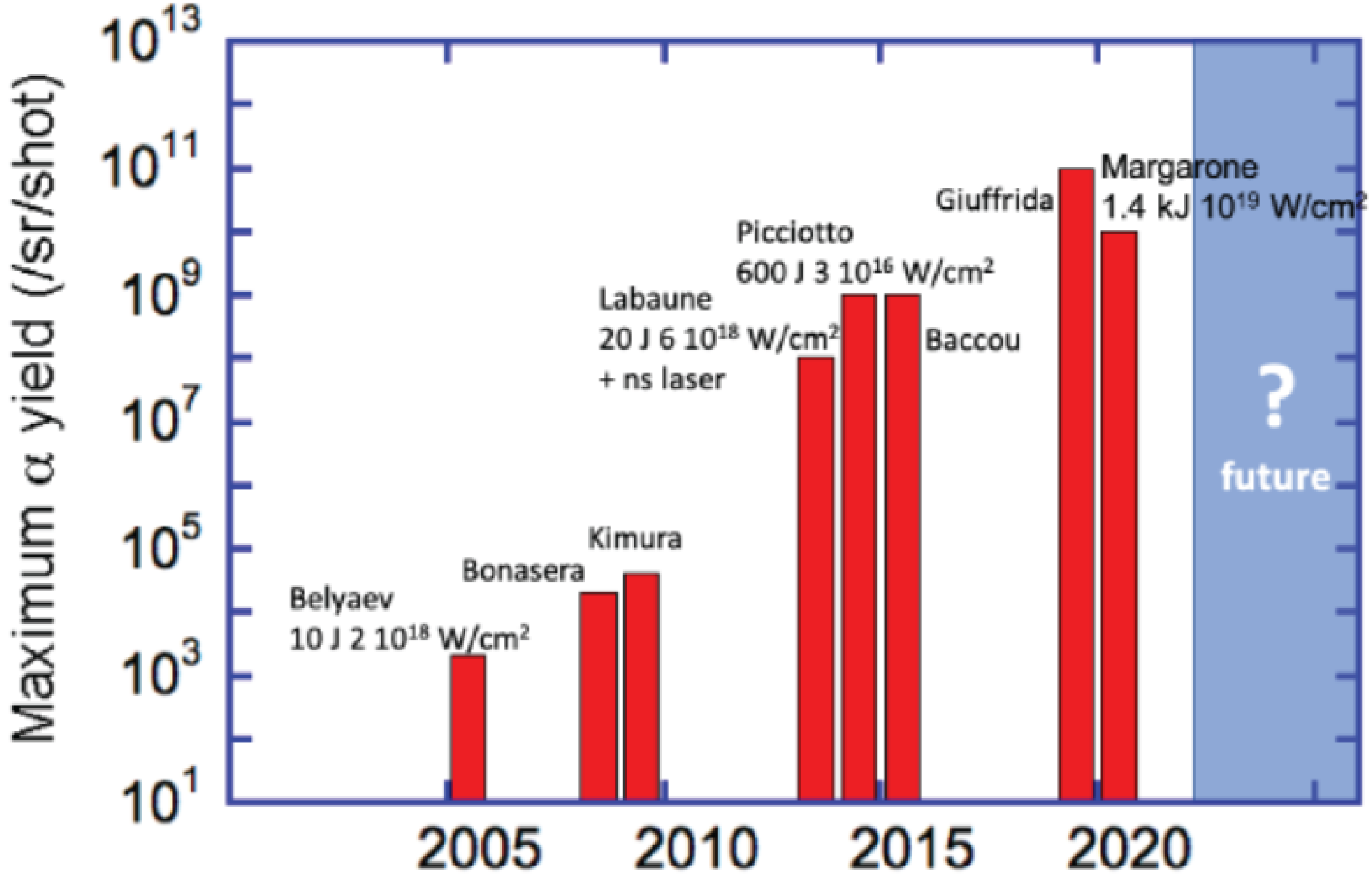
Relativistic correction becomes inaccurate at high temperature

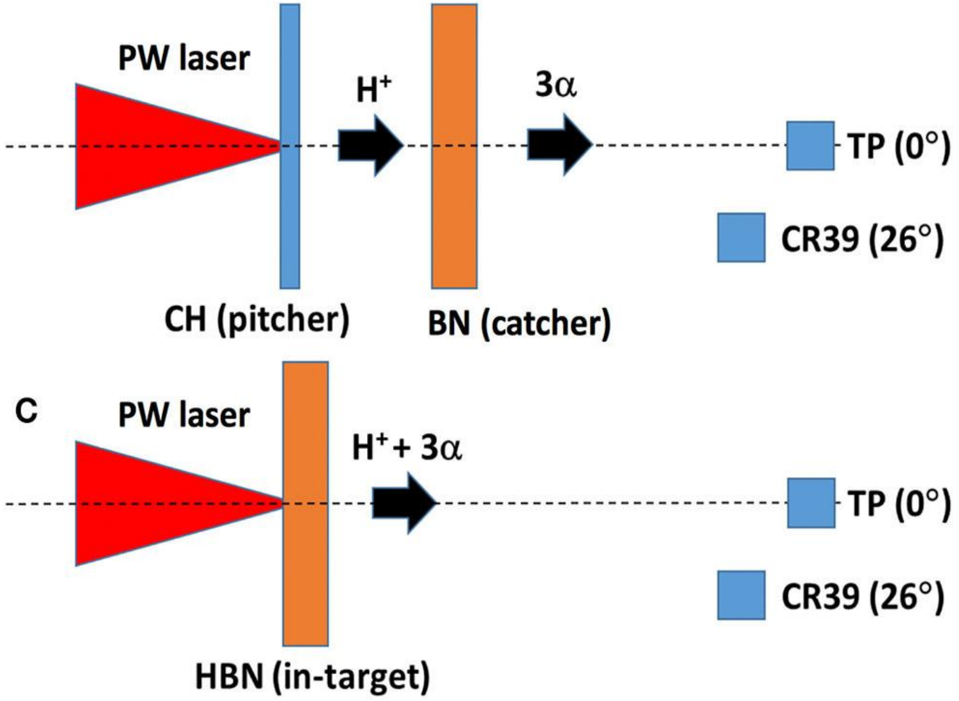
$$P_{\mathrm{brem}} = C n_e n_i \sqrt{T_e}\left\{Z_{\mathrm{eff}}\left[1 + 0.7936\frac{k_{\mathrm{B}}T_e}{m_e c^2} + 1.874\left(\frac{k_{\mathrm{B}}T_e}{m_e c^2}\right)^2\right] + \frac{3}{\sqrt{2}}\frac{k_{\mathrm{B}}T_e}{m_e c^2}\right\}$$

Beam Fusion Experiments

研究背景与意义

- □ 激光驱动的氢硼聚变产额不断刷新纪录，2020年达到了1E10-1E11/sr/shot（kJ）.

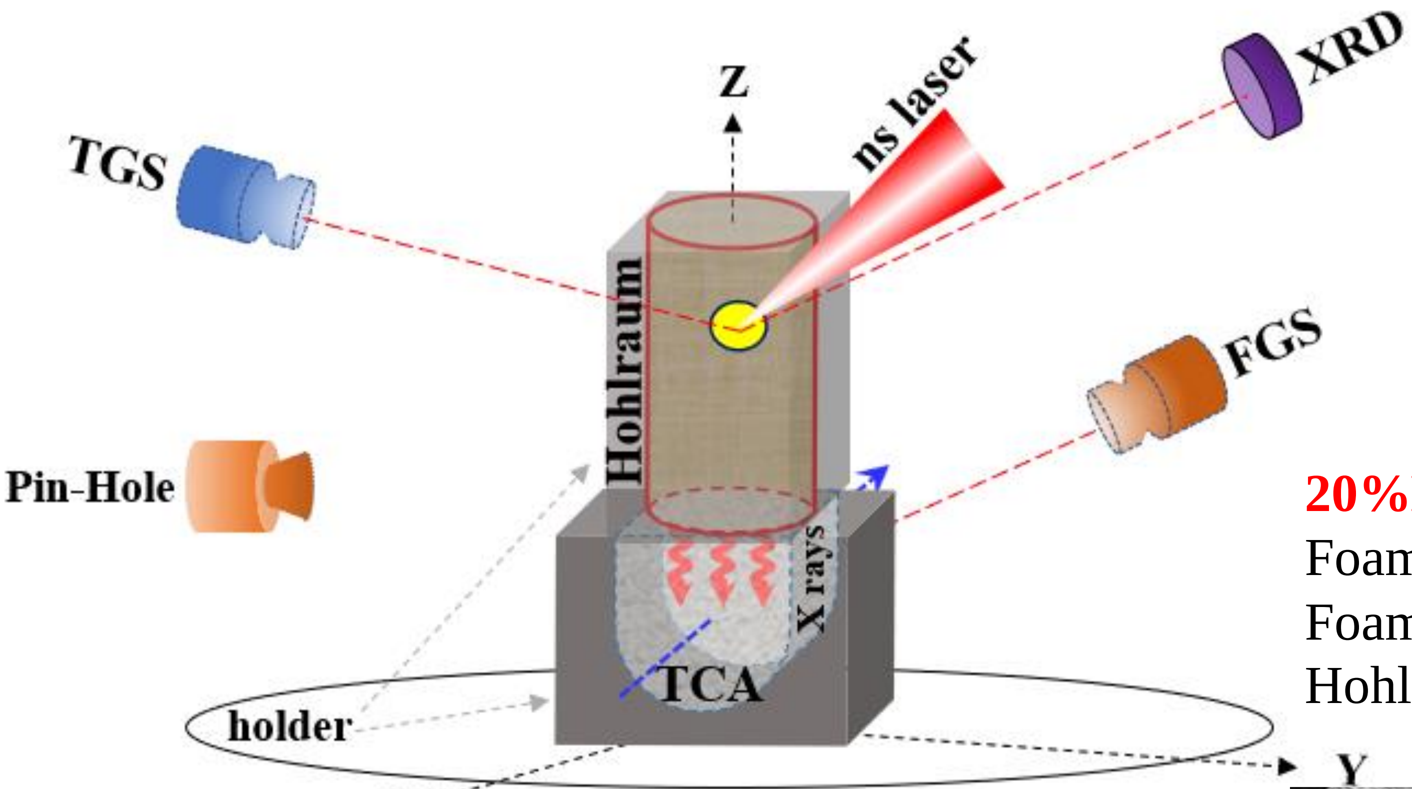




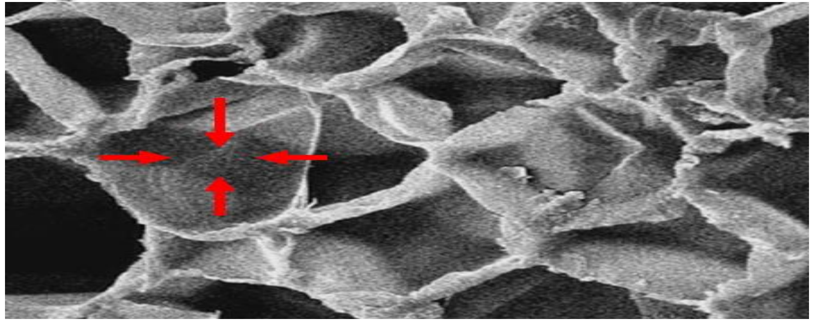
稠密等离子体环境和强流条件下氢硼聚变产额远远高出预期，相关物理机制仍有待深入。

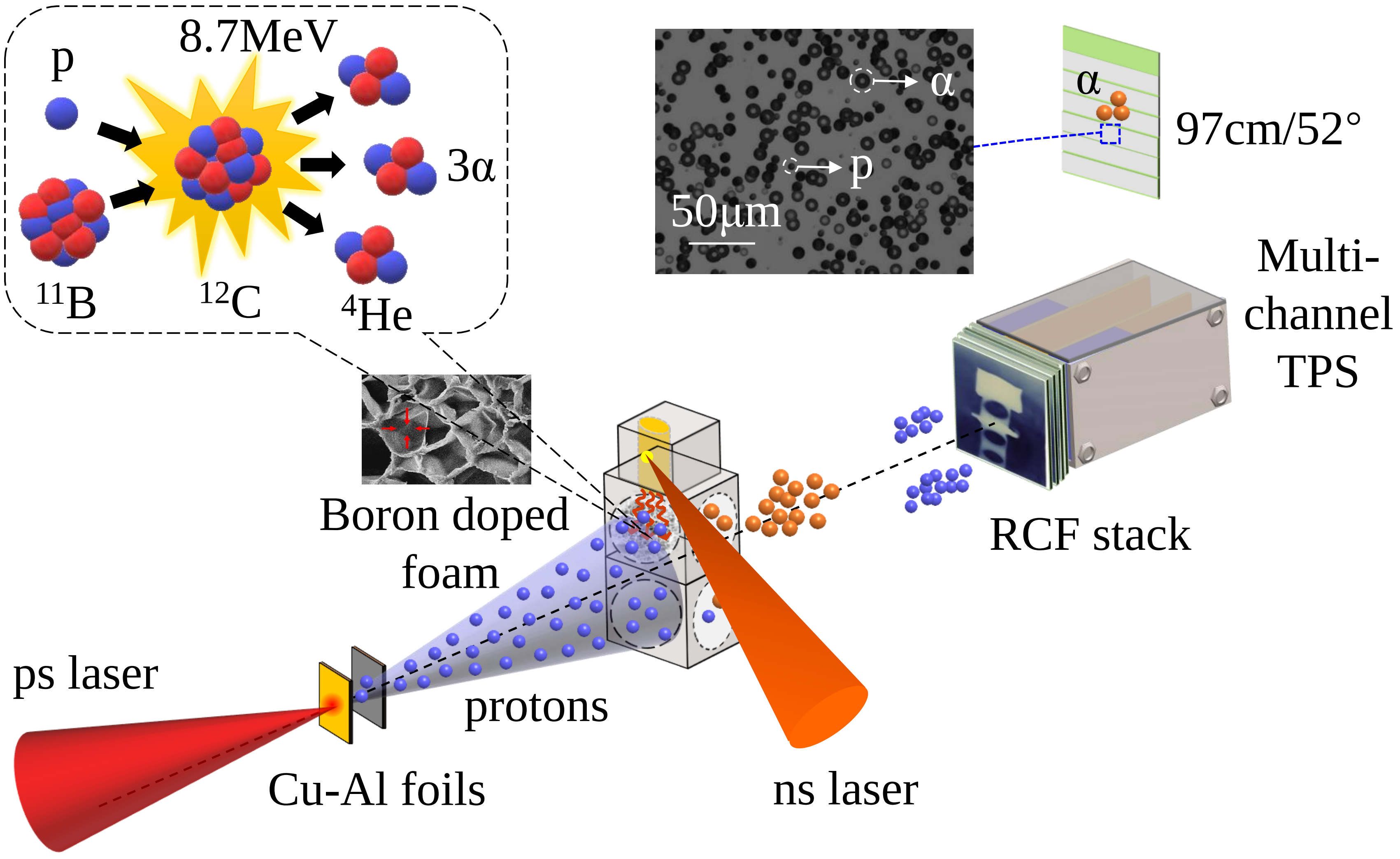
Experiments

Experiments at Laser Fusion Center in Mianyang



20%B-doped TCA foam ($C_9H_{16}O_8$)
Foam density: 2mg/cc
Foam thickness： 1mm
Hohlraum diameter: 1mm



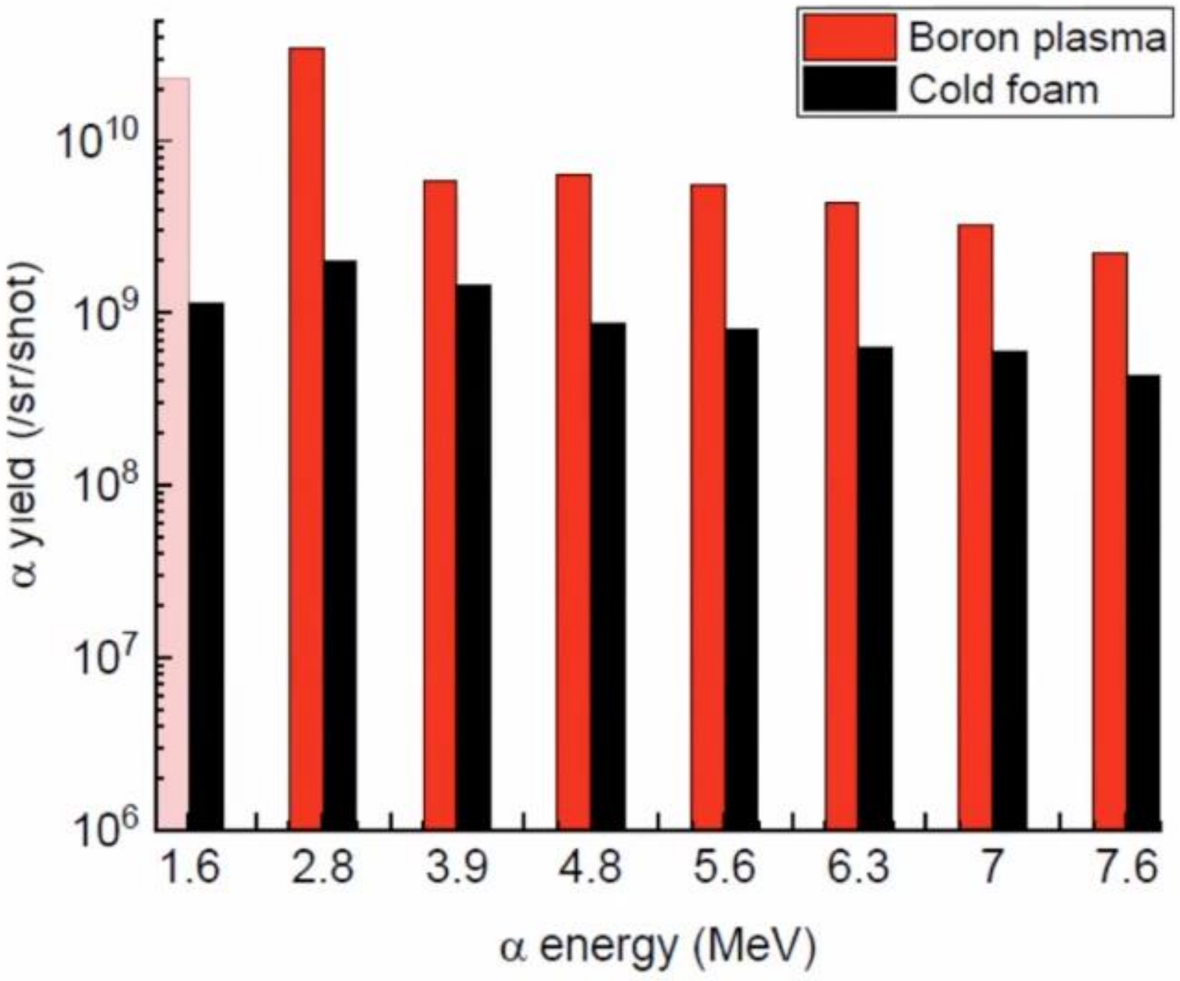

p
8.7MeV
3α
^{11}B
^{12}C
^{4}He
α
p
50μm
α
97cm/52°
Multi-
channel
TPS
Boron doped
foam
RCF stack
ps laser
protons
Cu-Al foils
ns laser

alpha yield normalized by beam intensity for plasma and cold foam

In this experiment we observe orders of magnitude more alphas than expected from p11B reactions with the beam protons. We attribute this to electric field similar to those that are responsible for the high degree of stopping in this experiment:

Jieru Ren, Zhigang Deng, Wei Qi, et al. Observation of a high degree of stopping for laser-accelerated intense proton beams in dense ionized matter. Nature Communications, 11(1):5157, 2020.

Additional protons from the target are set in motion and do p11B reactions. We have to finalize the analysis. Compared to the 250 Joule laser energy we get 0.28J alpha energy 0.1%. Taking only the beam power and only the energy necessary to heat the target numbers are in the % range. Still far away from scientific 1, but not bad for a beginning



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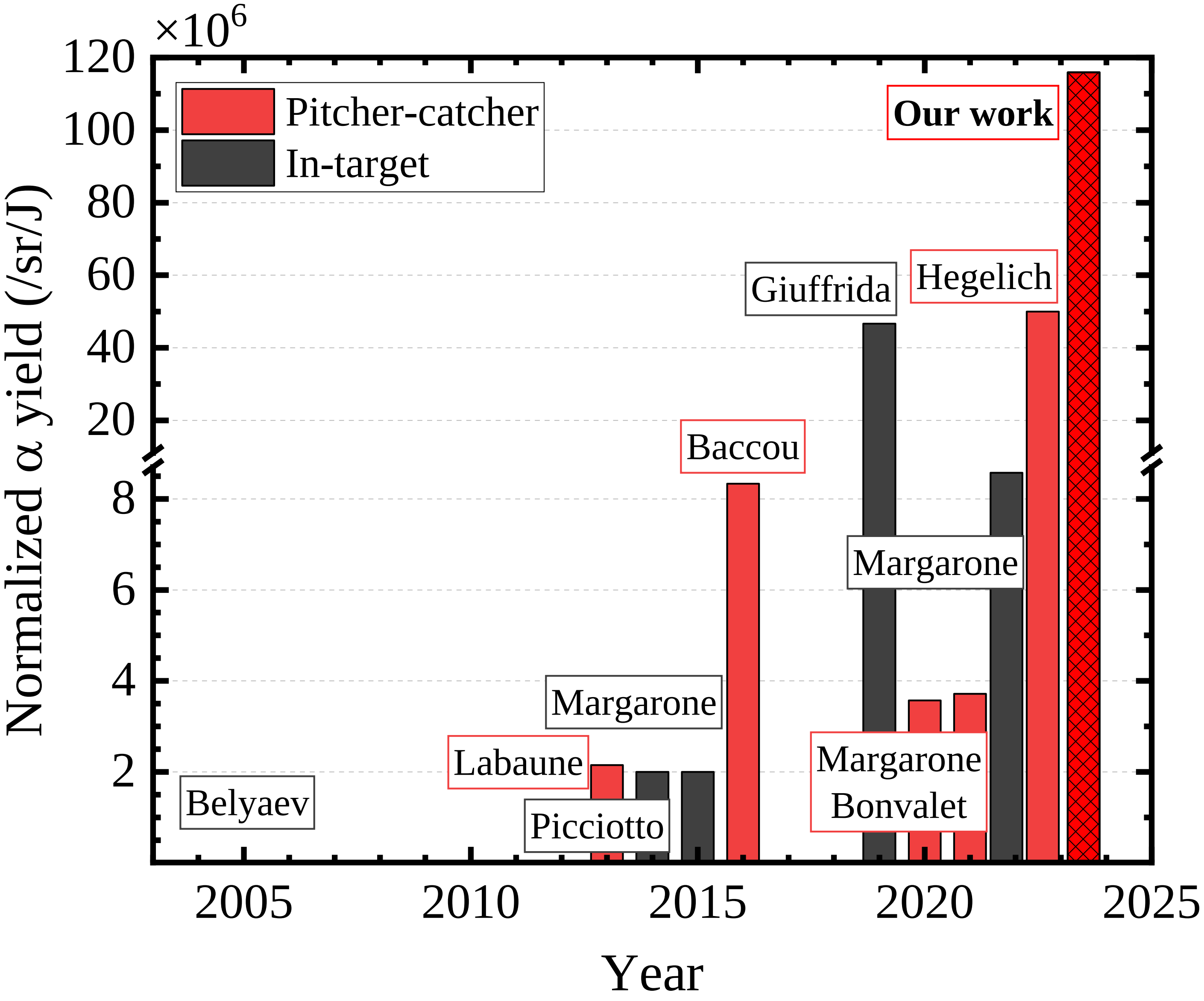
×10^6
120
100
80
60
40
20
8
6
4
2
Pitcher-catcher
In-target
Our work
Hegelich
Giuffrida
Baccou
Margarone
Margarone
Labaune
Margarone
Bonvalet
Belyaev
Picciotto
2005
2010
2015
2020
2025
Year
Normalized α yield (/sr/J)

Summary and Outlook

The α yield from plasma is generally 1~2 orders higher than that from the cold foam.

Nonlinear increase of alpha particle yield with proton beam intensity

Alpha spectra depend on proton energy

Alpha yield depends on Hydrogen Boron ratio of the target

All of this needs further verification

To Do List:

1:Remeasure the fusion cross section up to about 10 MeV
2: If possible measure under plasma conditions
3: Study the influence of magnetic fields
4:Opacity measurements on p11B plasma
5: Experimental and theoretical data on EOS
6: make better Boron Targets and Boron Hydrogen Targets

Problems for p11B energy production

p11B in the Inertial Confinement scheme
needs **extremely high compression** to about
$10^5\, {}^{g}/_{cm^3}$ (Weaver et al. LLNL 1973)

It will be extremely difficult to produce a Boron pellet with the required surface roughness

We need an efficient driver to do the compression work or is there a possibility to get away without compresion?