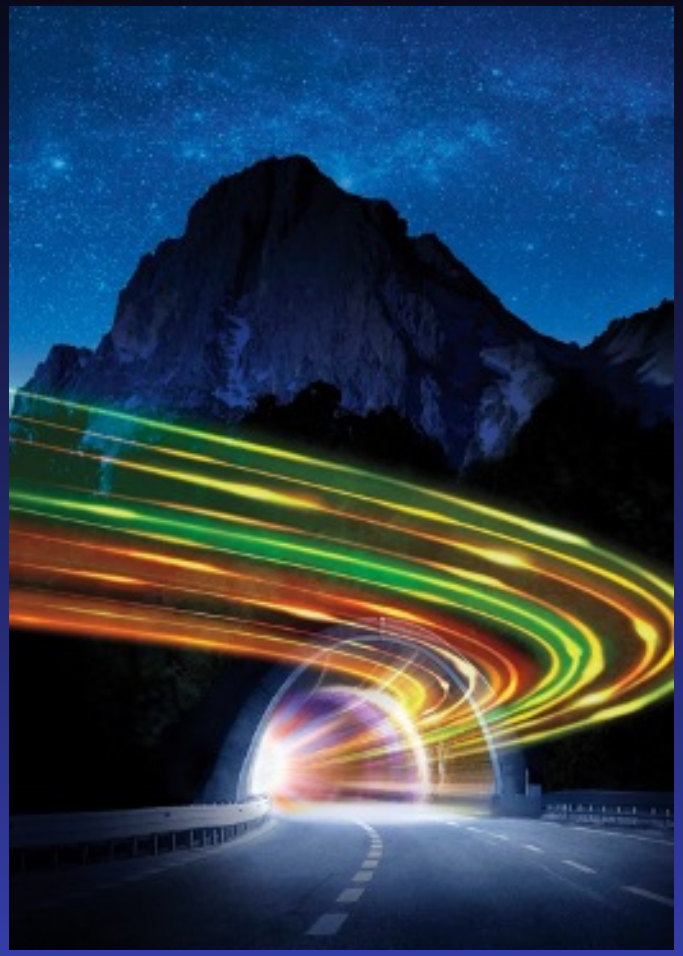
Once upon a time…
LUNA turns 35

P. Corvisiero
Genova University and INFN (Italy)

"some people are so crazy that they actually venture into deep mines to observe the stars in the sky".



Naturalis Historia
Plinio, 23-79 a.C.

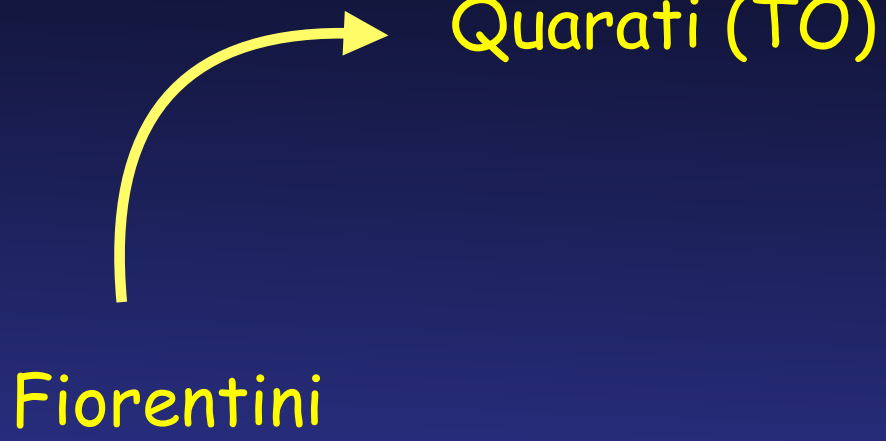
the initial spark…

Nuclei in the Cosmos I, 1990 Baden/Vienna

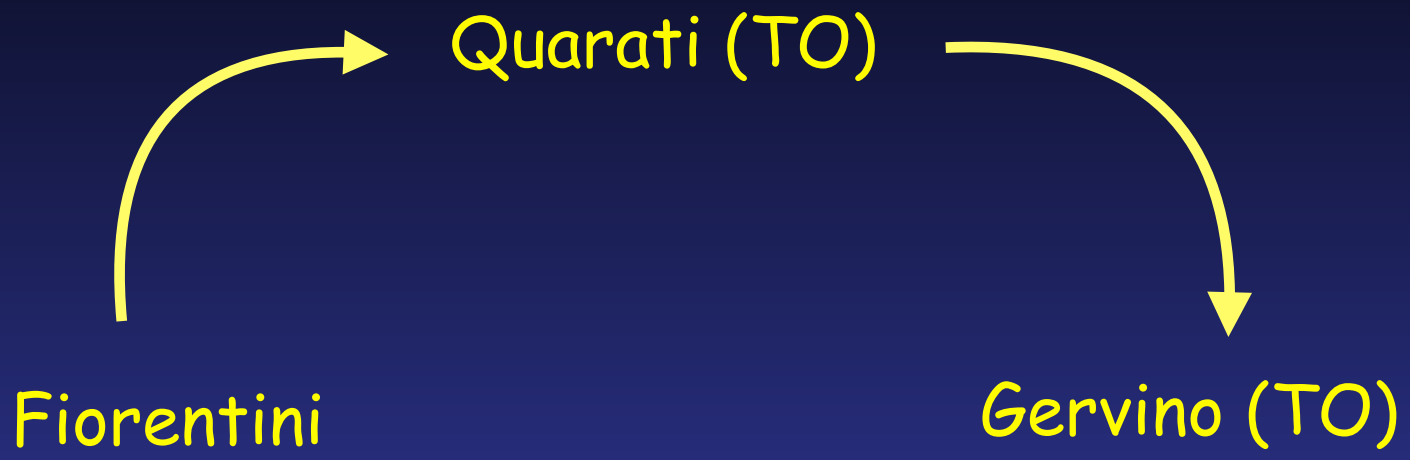
courtesy: Marialuisa Aliotta

but an Italian experimental physicist was needed

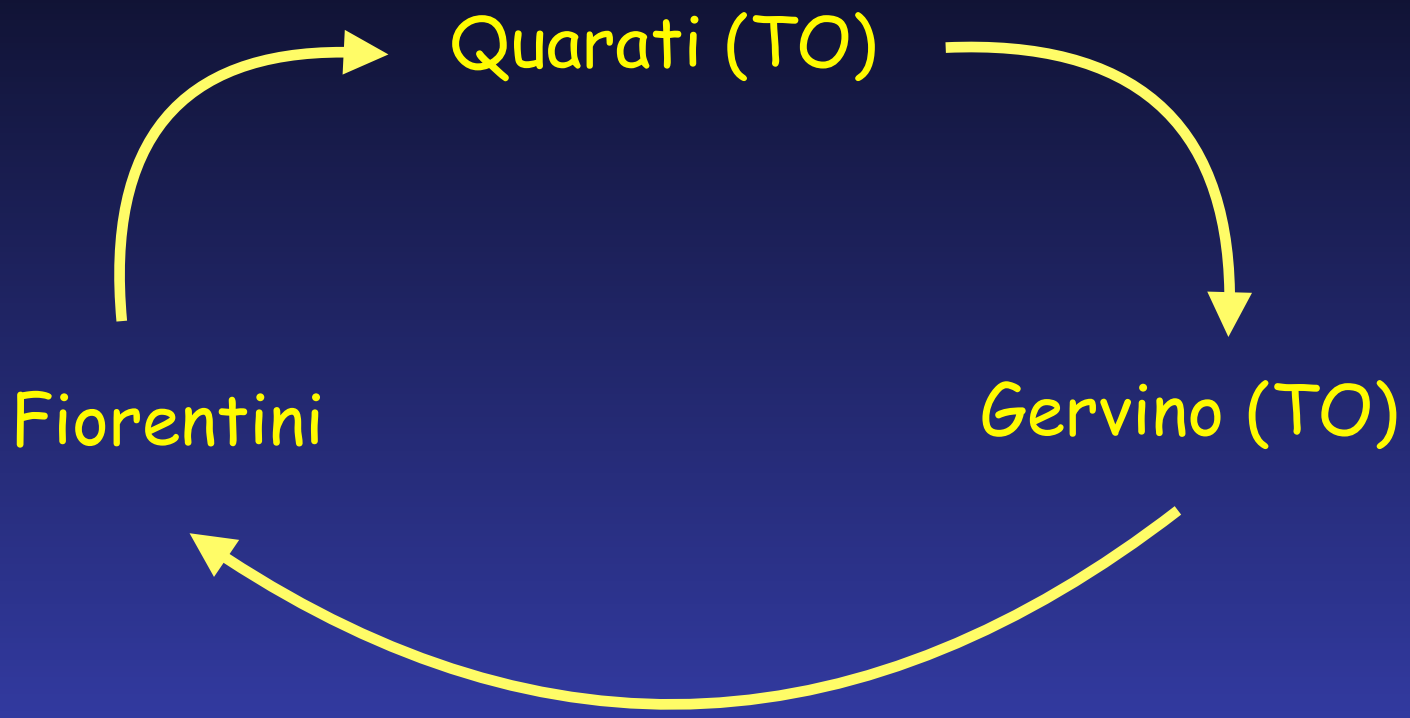
but an Italian experimental physicist was needed



but an experimental physicist was needed



but an experimental physicist was needed



Gianni came to Genova

Gianni came to Genova

I tried to get involved Gruppo III

Gianni came to Genova

I tried to get involved Gruppo III

INFN Genova Director "sent me to hell"…

Gianni came to Genova

I tried to get involved Gruppo III

INFN Genova Director sent me to hell…

I broke away and only Paolo followed me

Gianni came to Genova

I tried to get involved Gruppo III

INFN Genova Director sent me to hell…

I broke away and only Paolo followed me

We started with;
no money;
no mechanical workshop support;
against Director's wishes

summarising….


NEVER GIVE UP!

Milano: Puccio Bellotti

Milano: Puccio Bellotti

LNGS:

Cristina Arpesella;

Carlo Broggini;

Carlo Gustavino

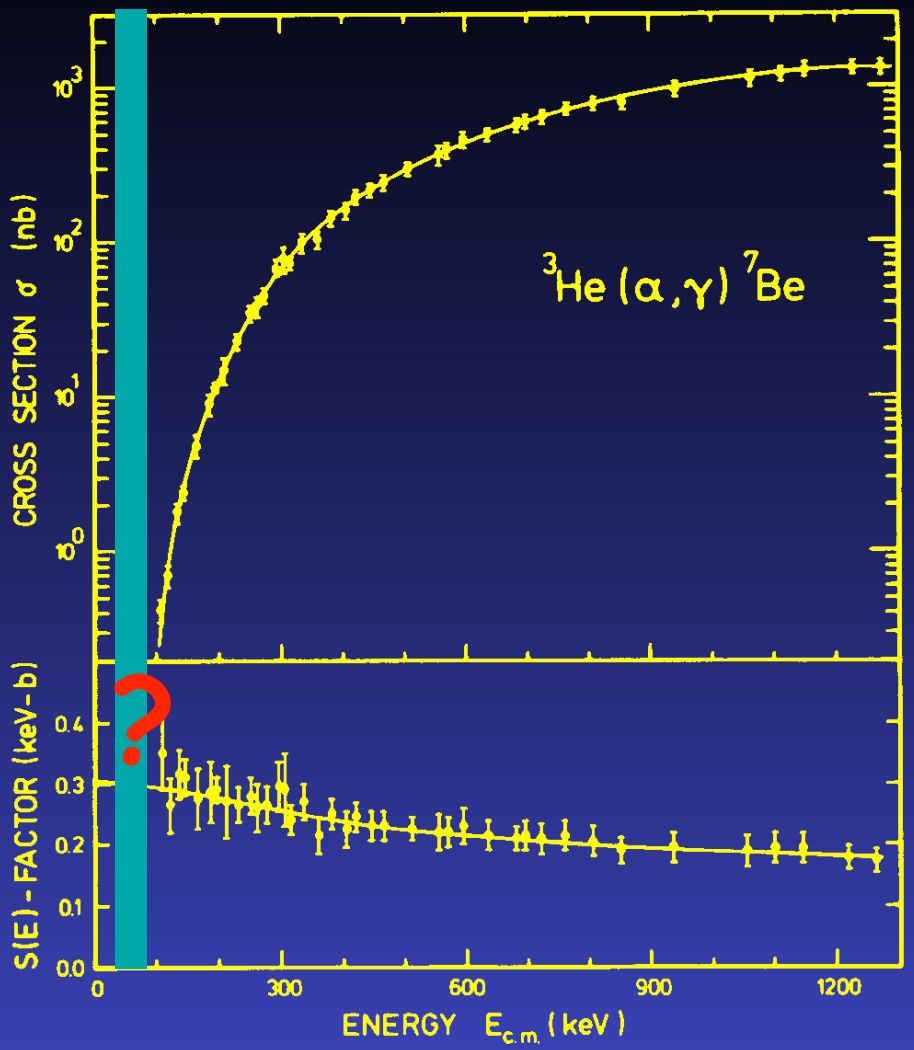
Milano: Puccio Bellotti

LNGS:

- Cristina Arpesella;
- Carlo Broggini;
- Carlo Gustavino

Roma:

- INFN President;
- INFN Executive Board (Sandro Bettini)



$$\sigma(E) = S(E)\cdot\exp(-2\pi\eta)\,/E$$

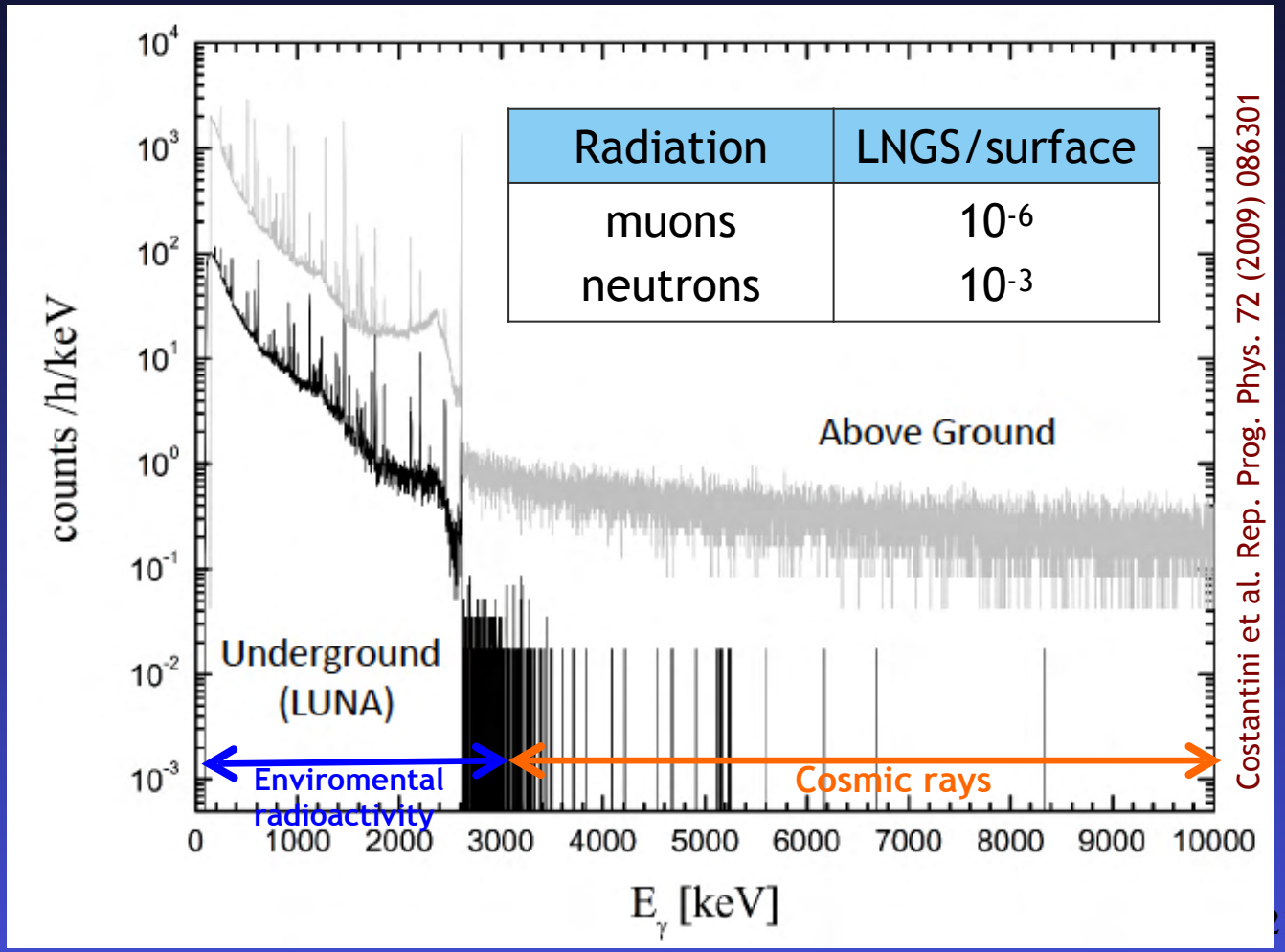
$$S(E) = E\cdot\sigma(E)\cdot\exp(2\pi\eta)$$

$$2\pi\eta = 31.29\, Z_1 Z_2 (\mu/E)^{0.5}$$

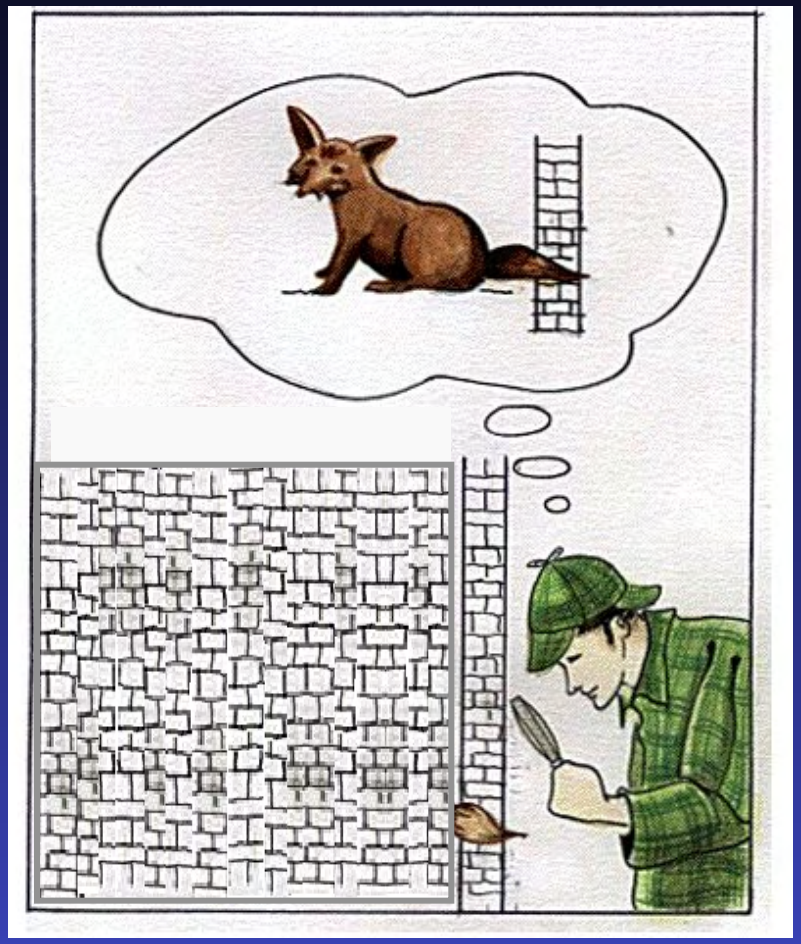
extrapolation in mandatory....

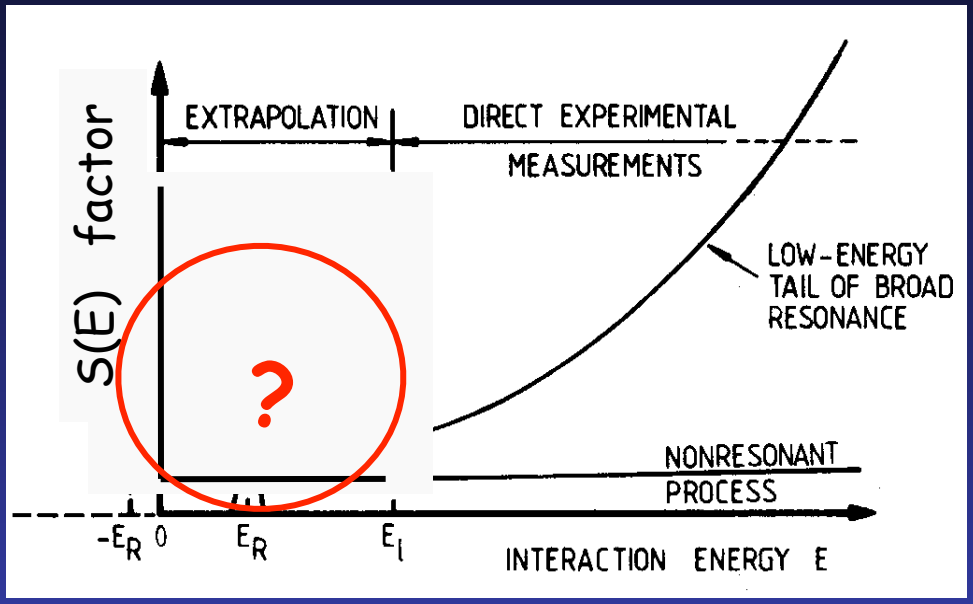
Gamma-ray background: underground vs overground comparison

1.4 km rock overburden: million-fold reduction in cosmic background



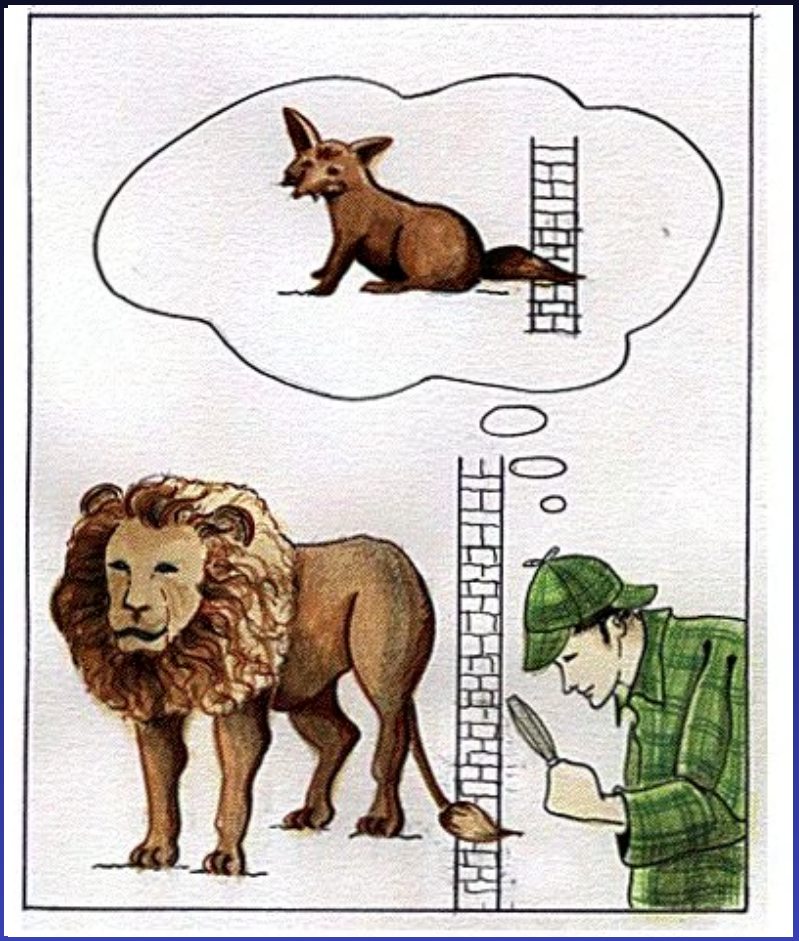
Radiation	LNGS/surface
muons	10^{-6}
neutrons	10^{-3}

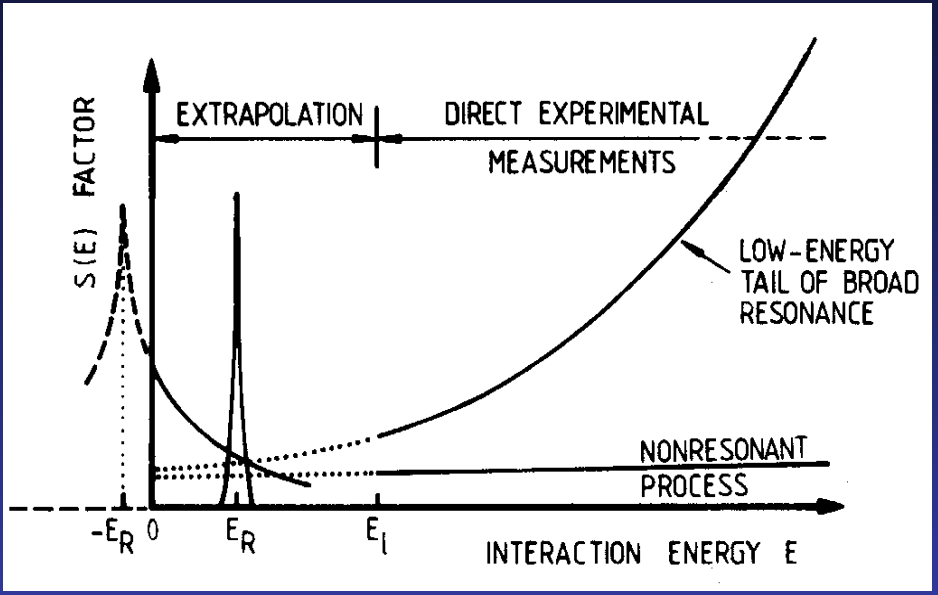




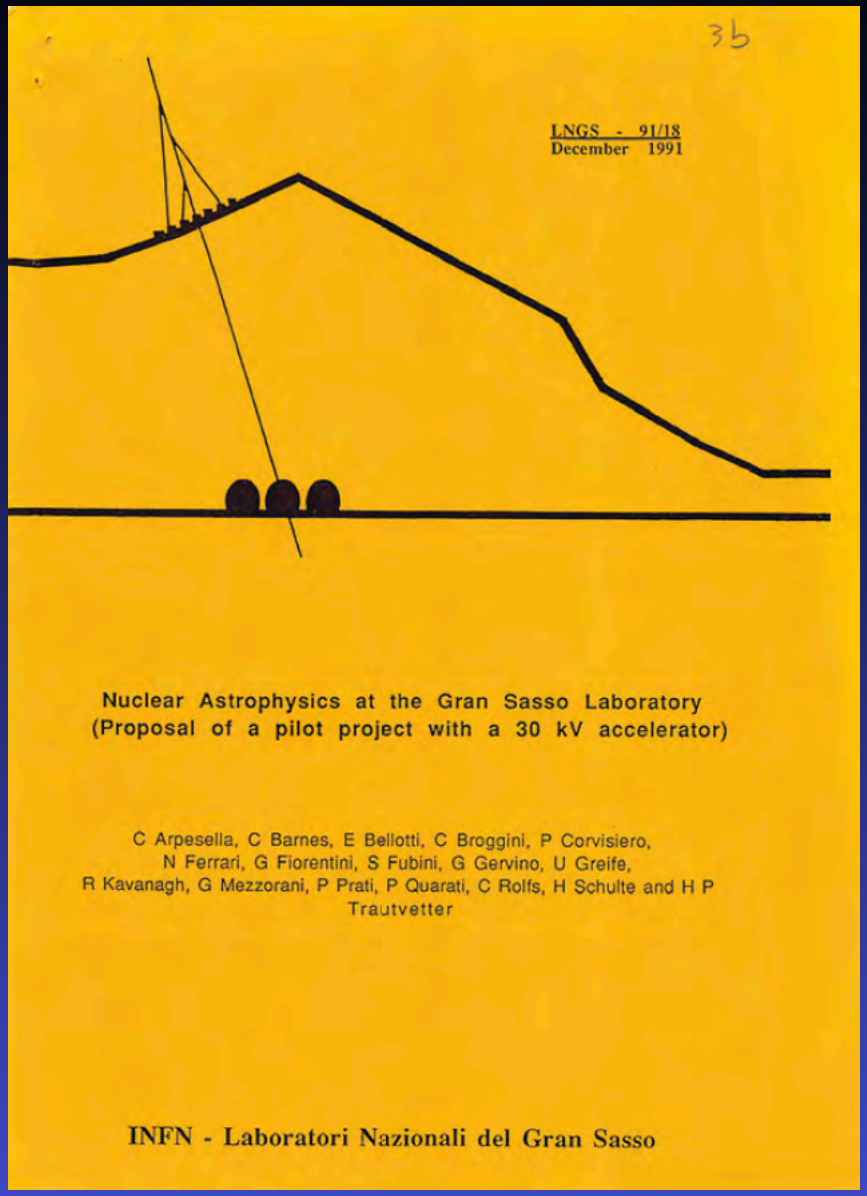
extrapolation is necessary

But….





sometimes extrapolation fails !!



1991

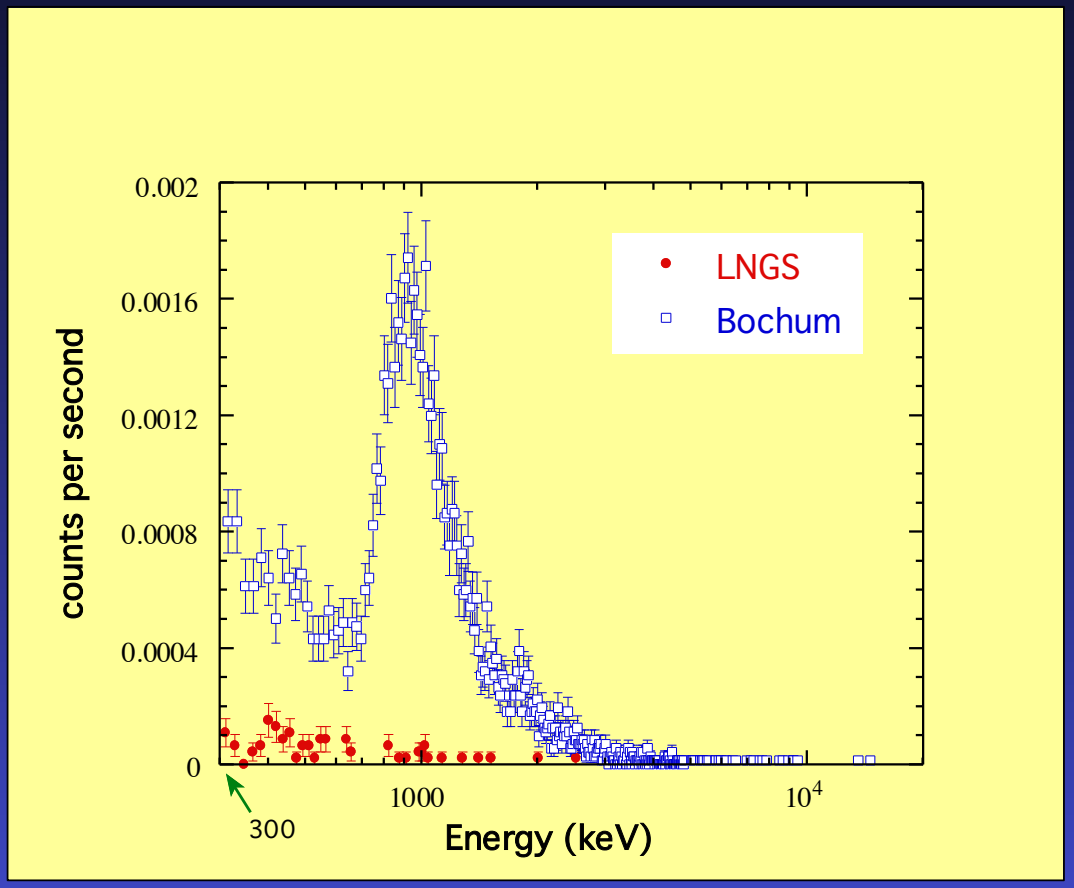
proposal to INFN Executive Board

pilot project

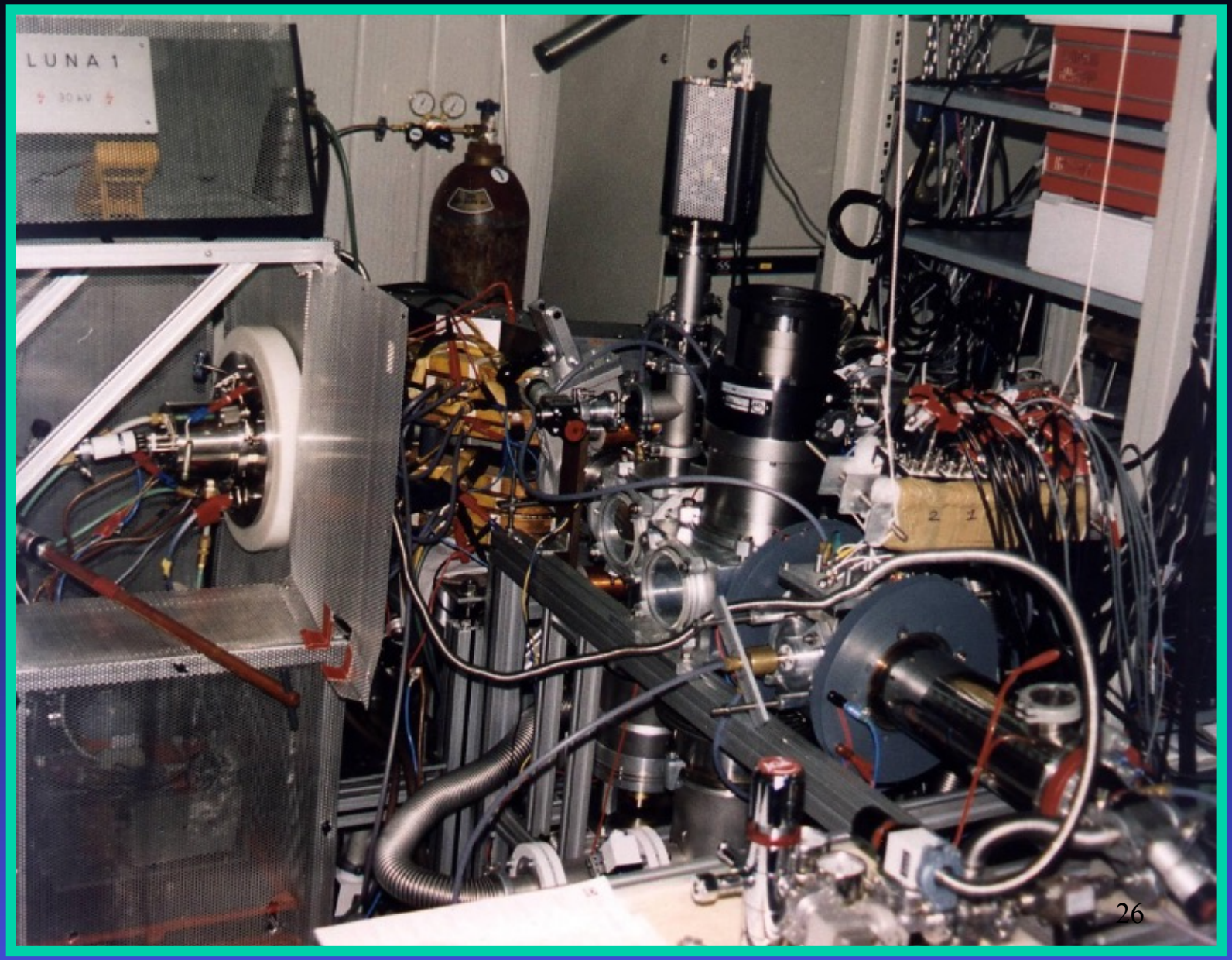
courtesy: Carlo Broggini

1991: First Background Test in LNGS

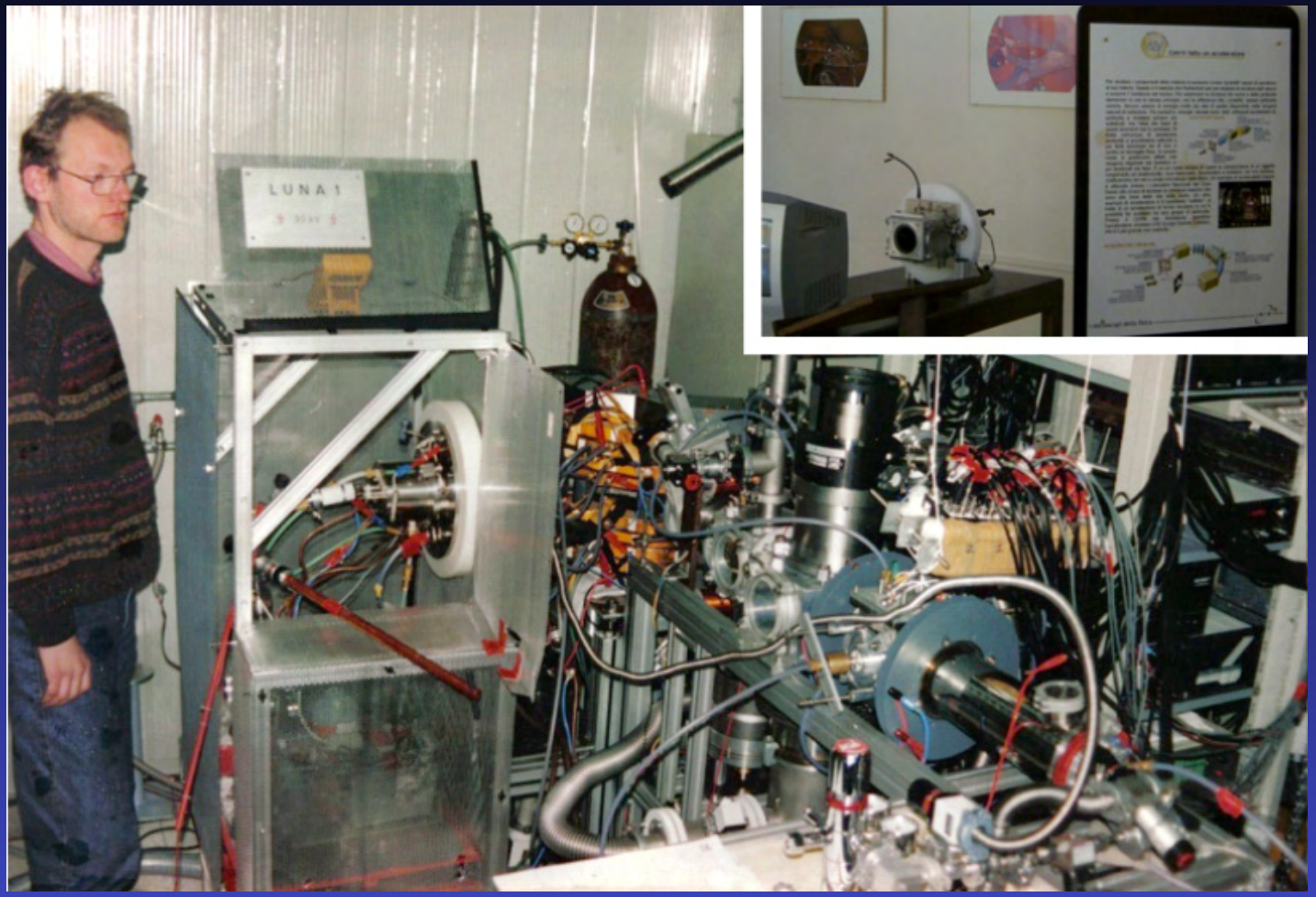
2 mm surface-barrier silicon detector

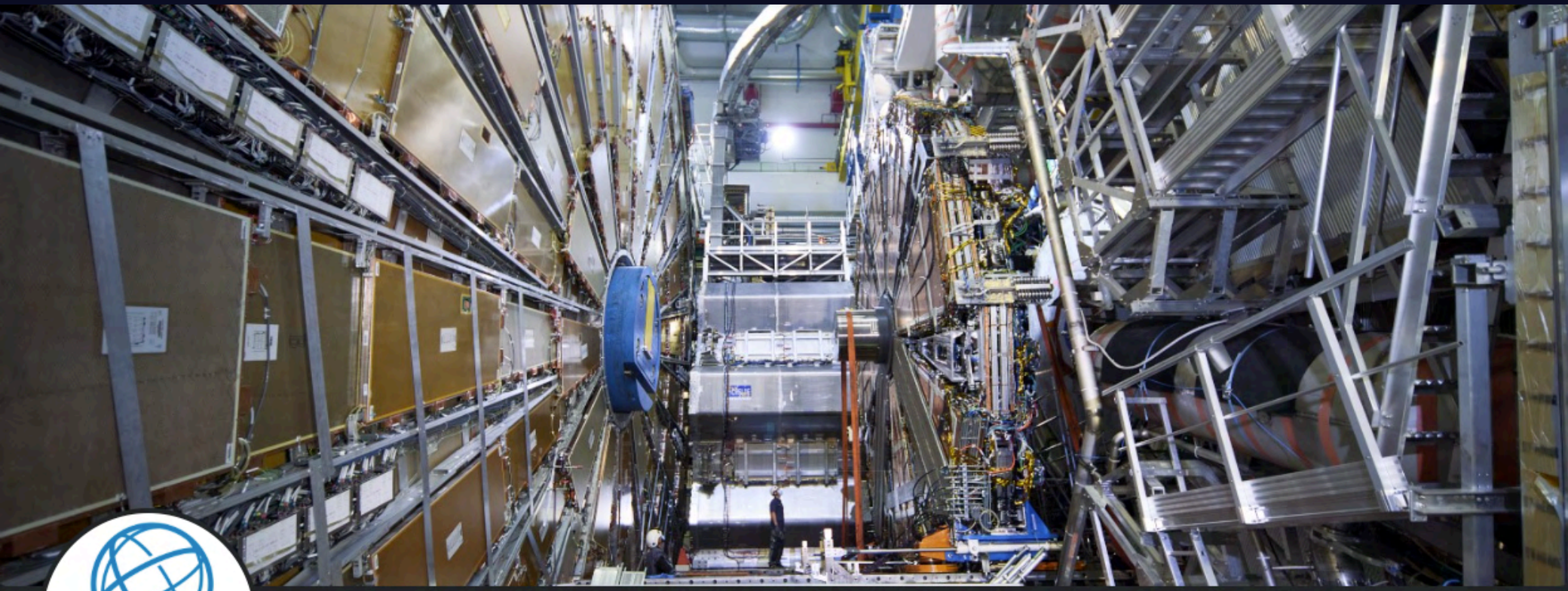


The first 50 kV accelerator



LUNA 50 kV accelerator

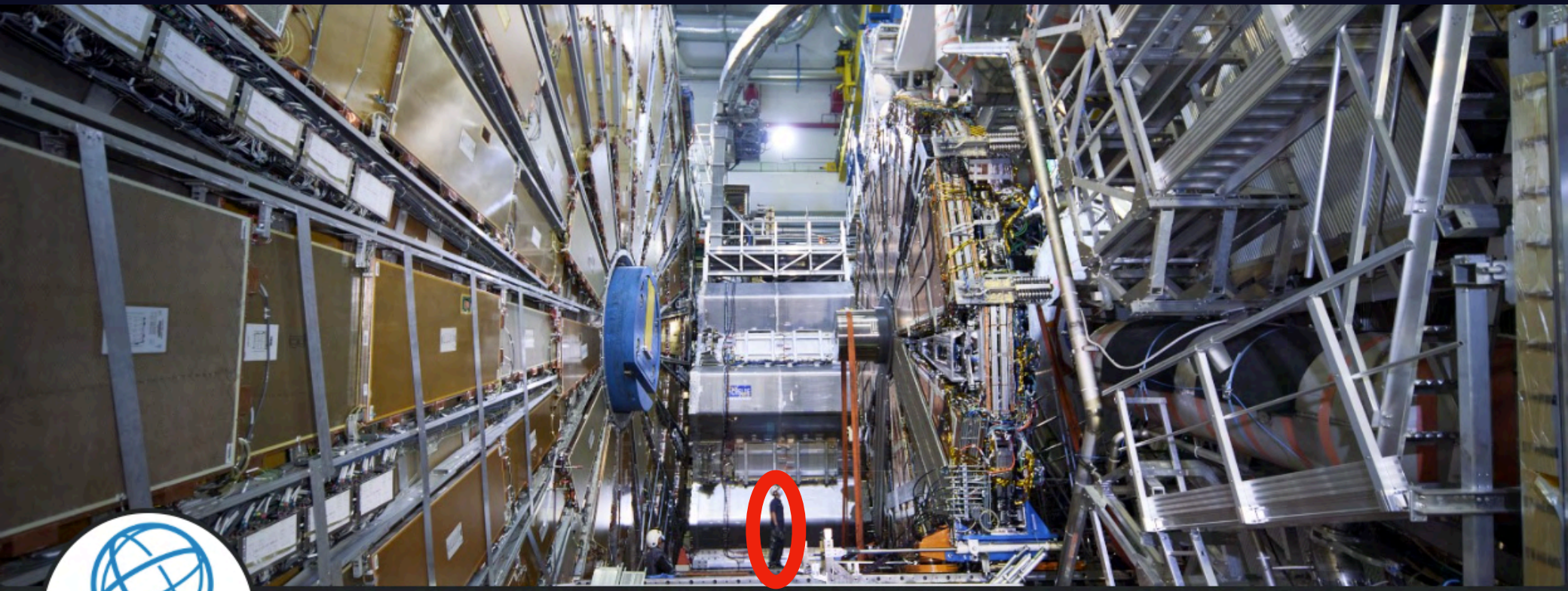




ATLAS EXPERIMENT

ATLAS Experiment at CERN

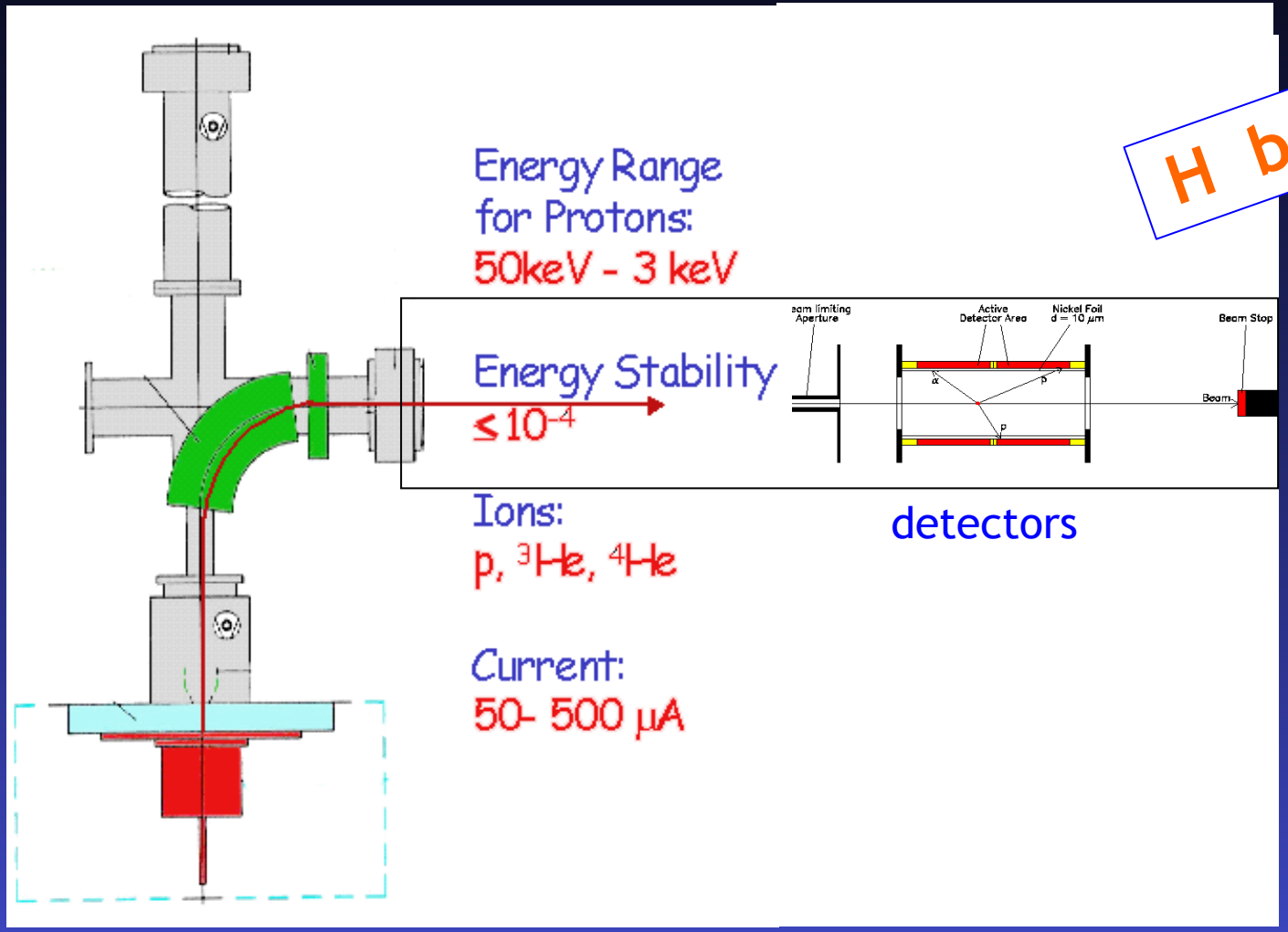
Follower: 44.426 · Seguiti: 14



ATLAS Experiment at CERN

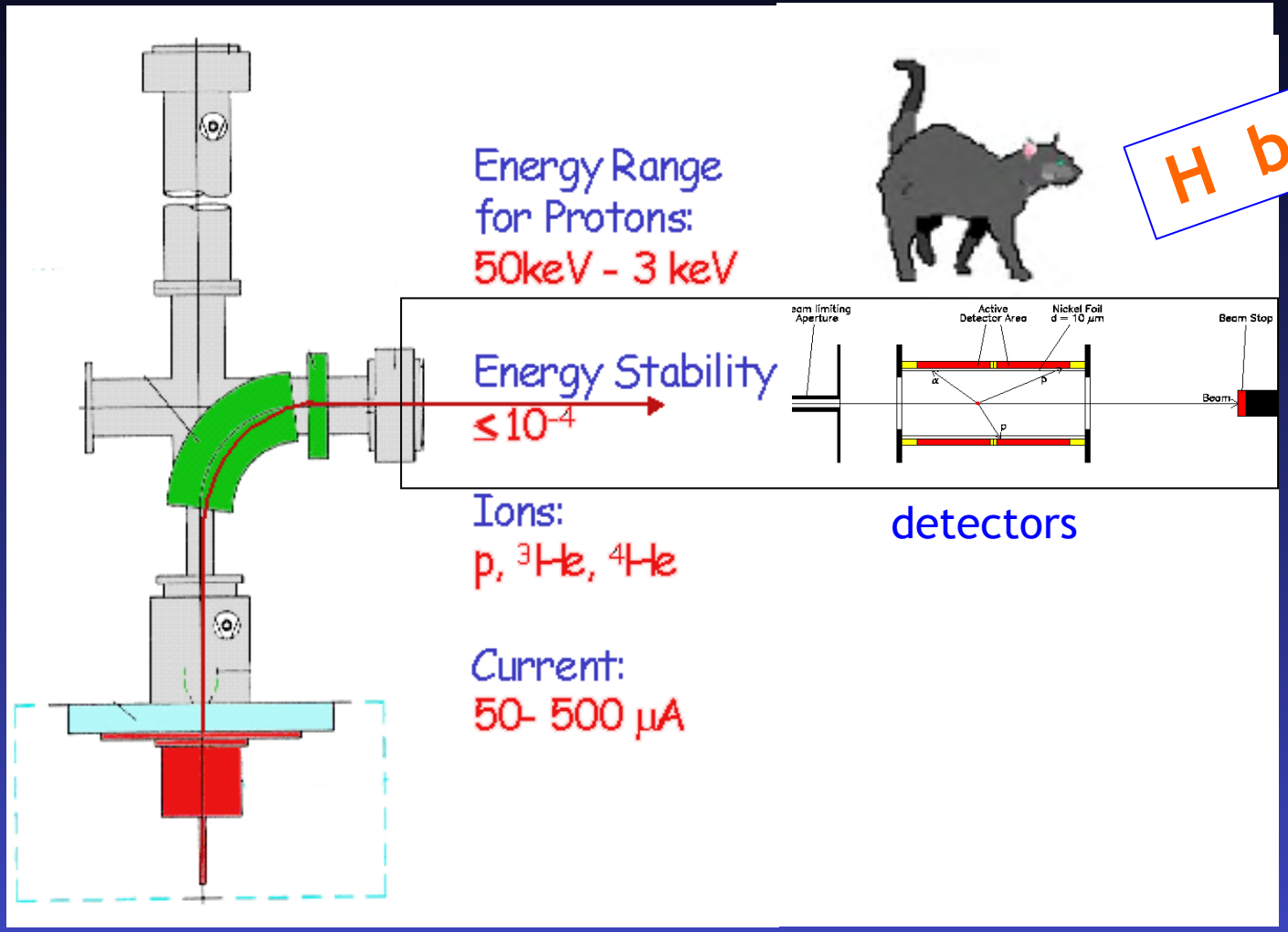
Follower: 44.426 · Seguiti: 14

LUNA 50 kV accelerator



H burning

LUNA 50 kV accelerator



good wine comes in small barrels !!

courtesy: Carlo Broggini

courtesy: Carlo Broggini

courtesy: Carlo Broggini

courtesy: Carlo Broggini

$$^{3}He + {}^{3}He \rightarrow {}^{4}He + 2p$$

for 30 years
all neutrino detection efforts consistently
measured **1/3 of expected neutrinos flux**
based on **Standard Solar Model**

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solar neutrino puzzle

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solar neutrino problem

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poor understanding of neutrino properties ?

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all neutrino detection efforts consistently
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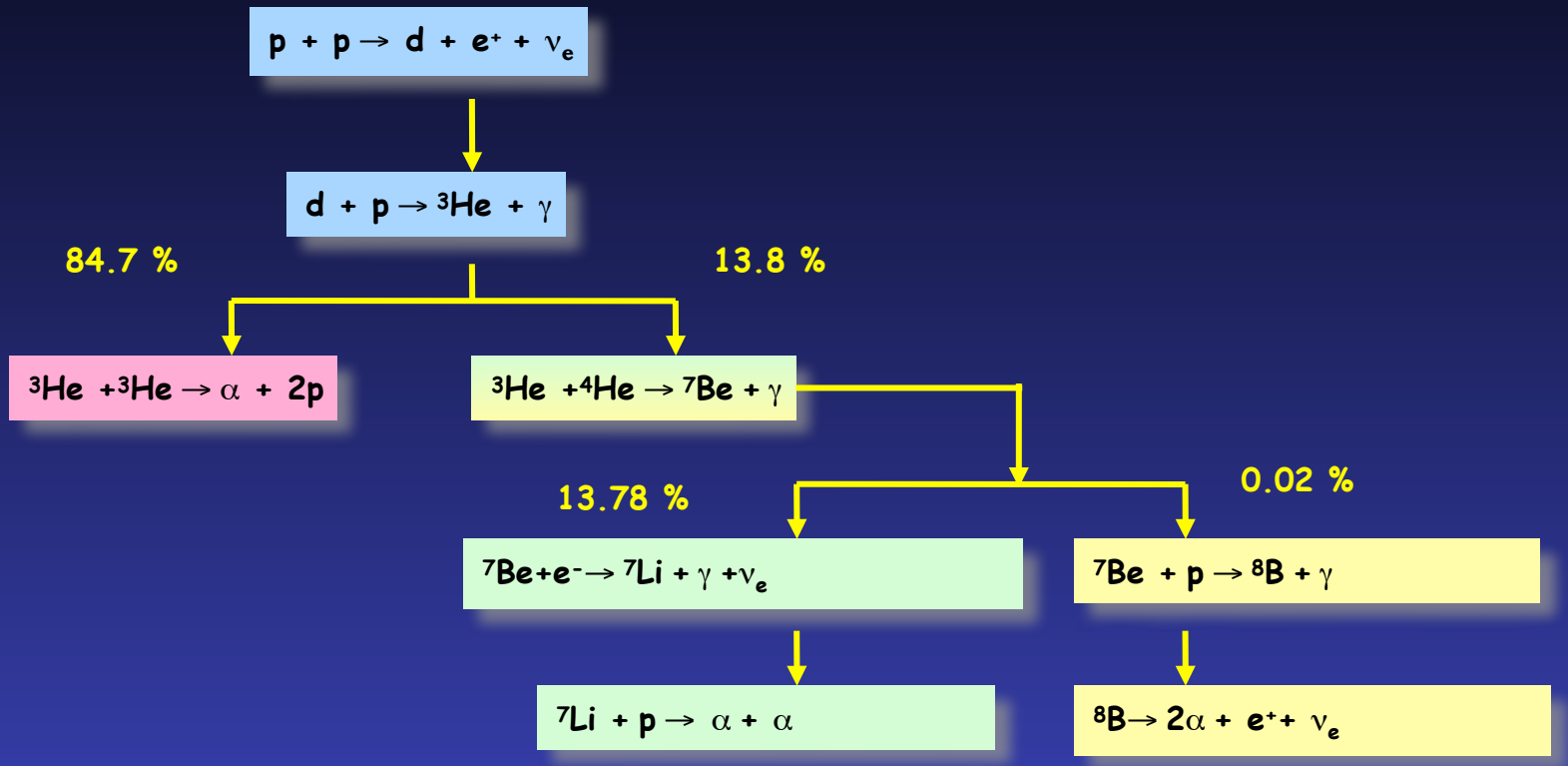
solar neutrino problem

wrong assumption of SSM ?

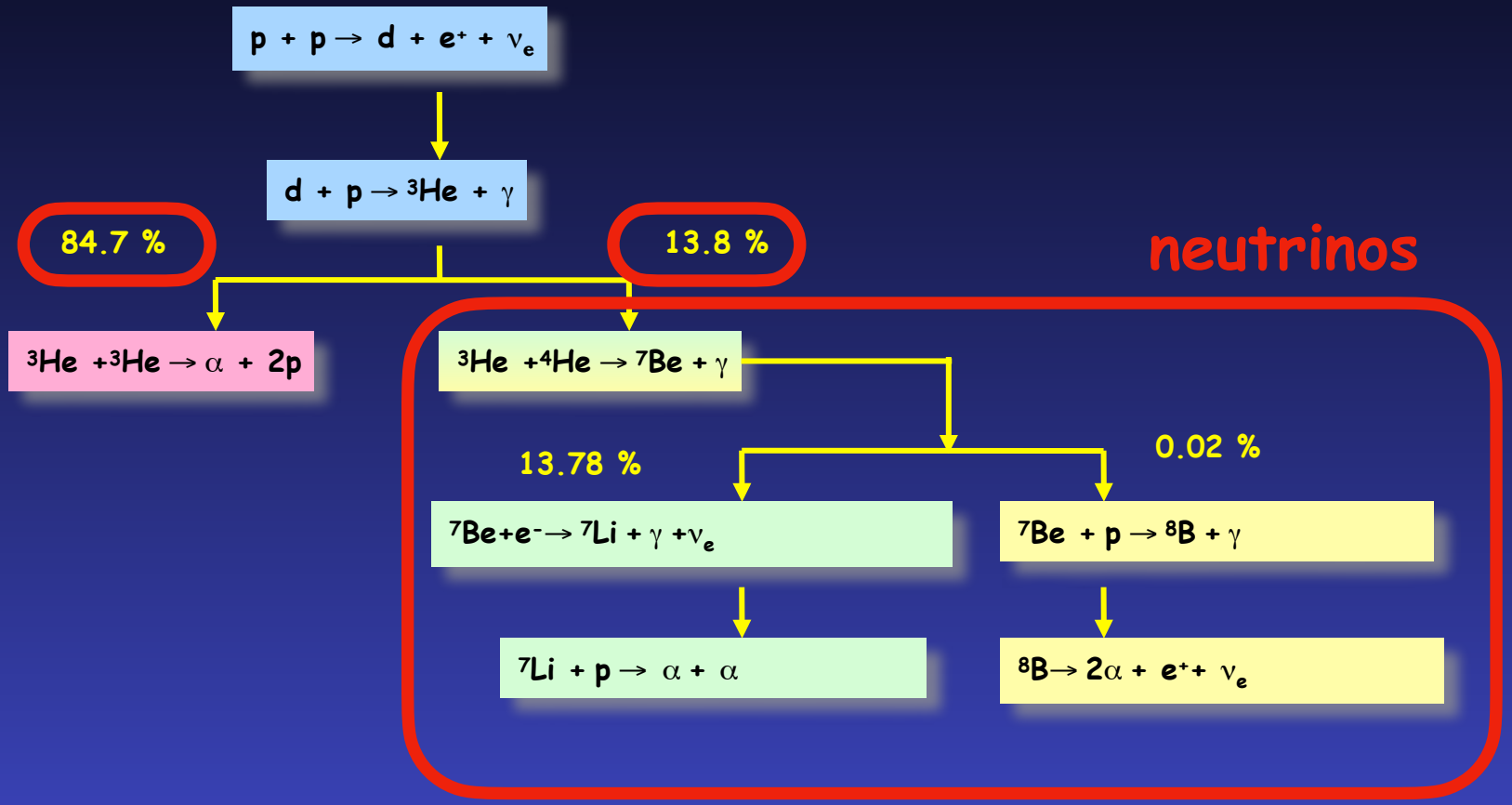
poor understanding of neutrino properties ?

unclear nuclear inputs ?



$$4p \rightarrow {}^4He + 2e^+ + 2\nu_e + 26.73\ MeV$$

a resonance in $^3He + ^3He$ channel ??



$4p \rightarrow {}^4He + 2e^+ + 2\nu_e + 26.73\ MeV$

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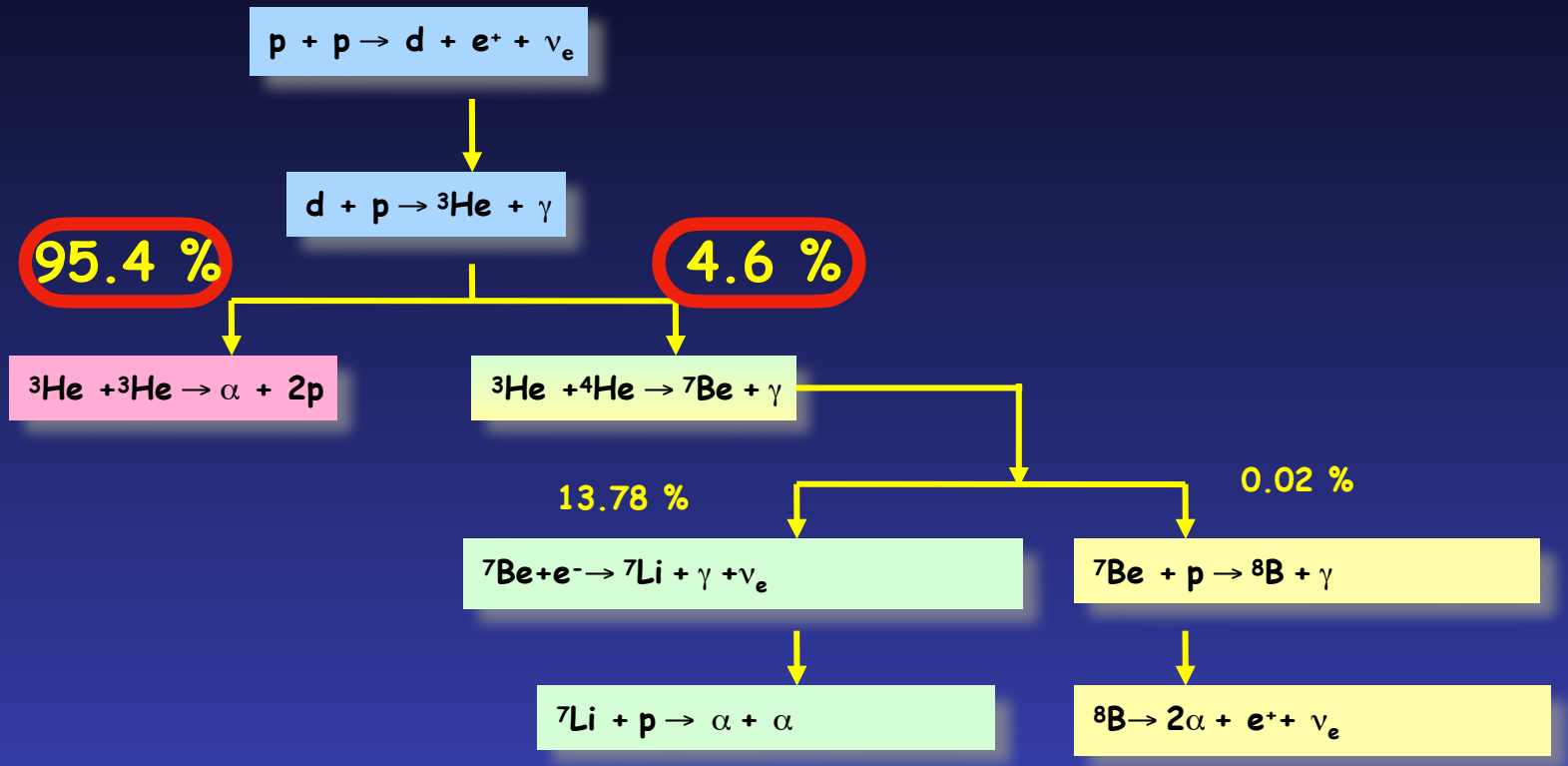
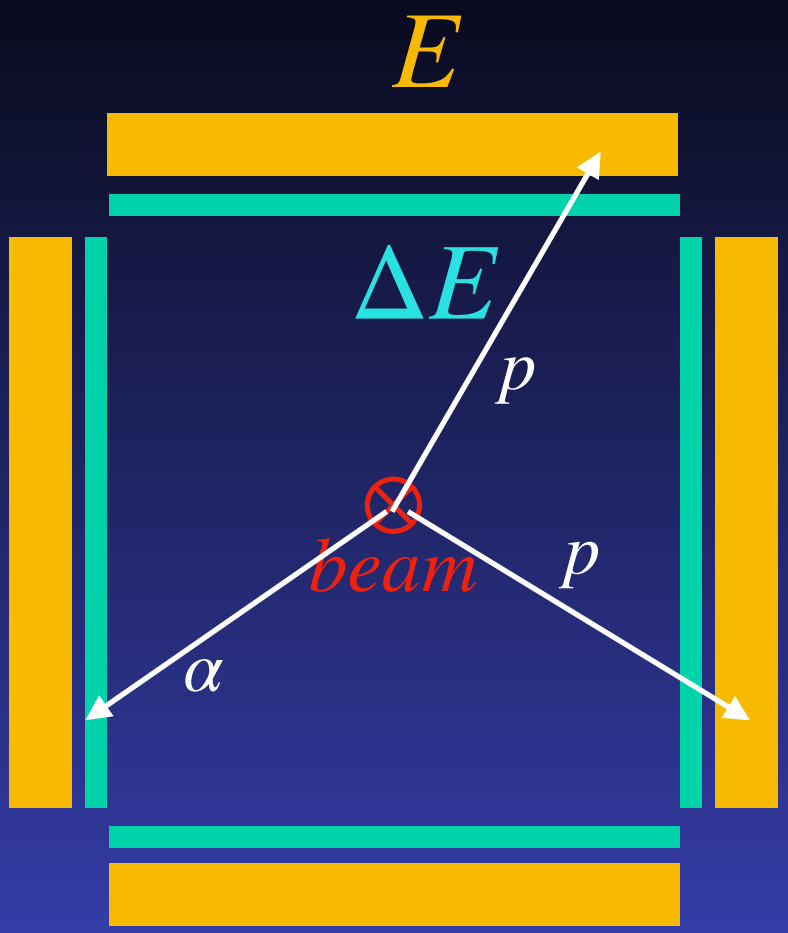


would solve the problem !!



beam: ^3He

gas target: ^3He

$E - \Delta E$ telescopes inside gas target

against the opinion of the "Germans" (rough people, suspicious of "Italians" and suspicious of new things!), Genova:

against the opinion of the "Germans"
(rough people, suspicious of "Italians"
and suspicious of new things!), Genova:

proposed and realised (Sandra) a
Monte Carlo code Geant3 based

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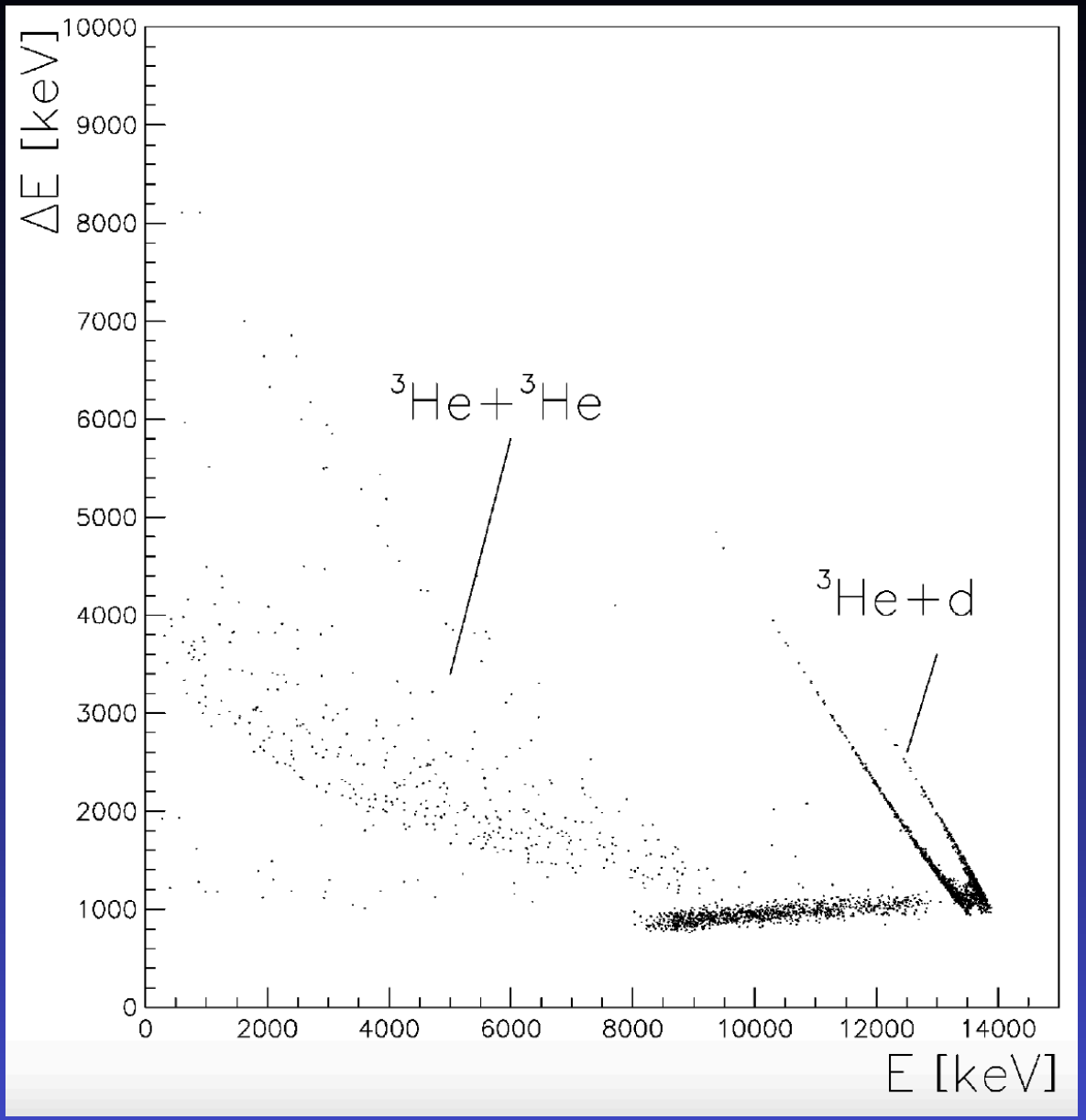
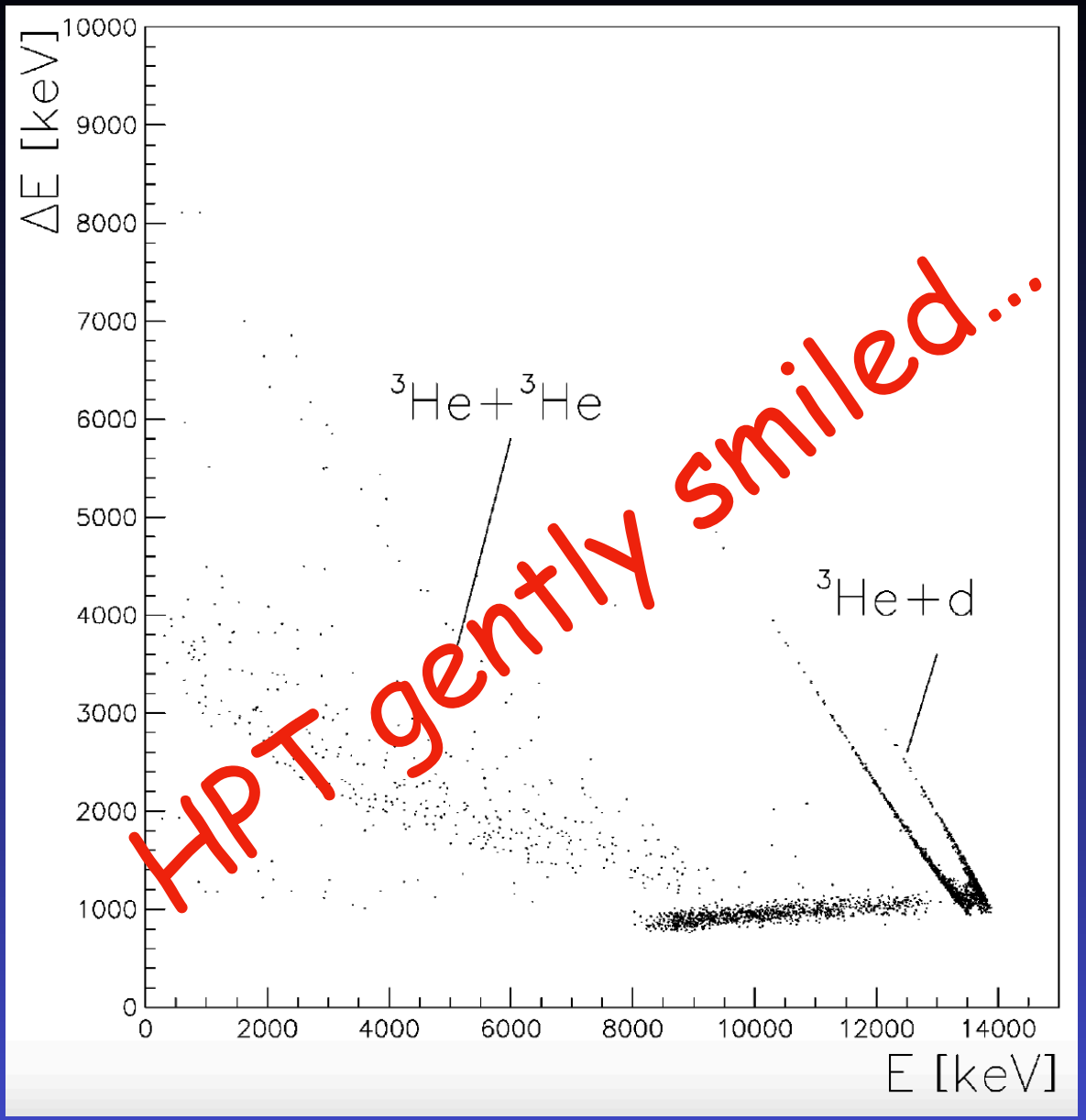
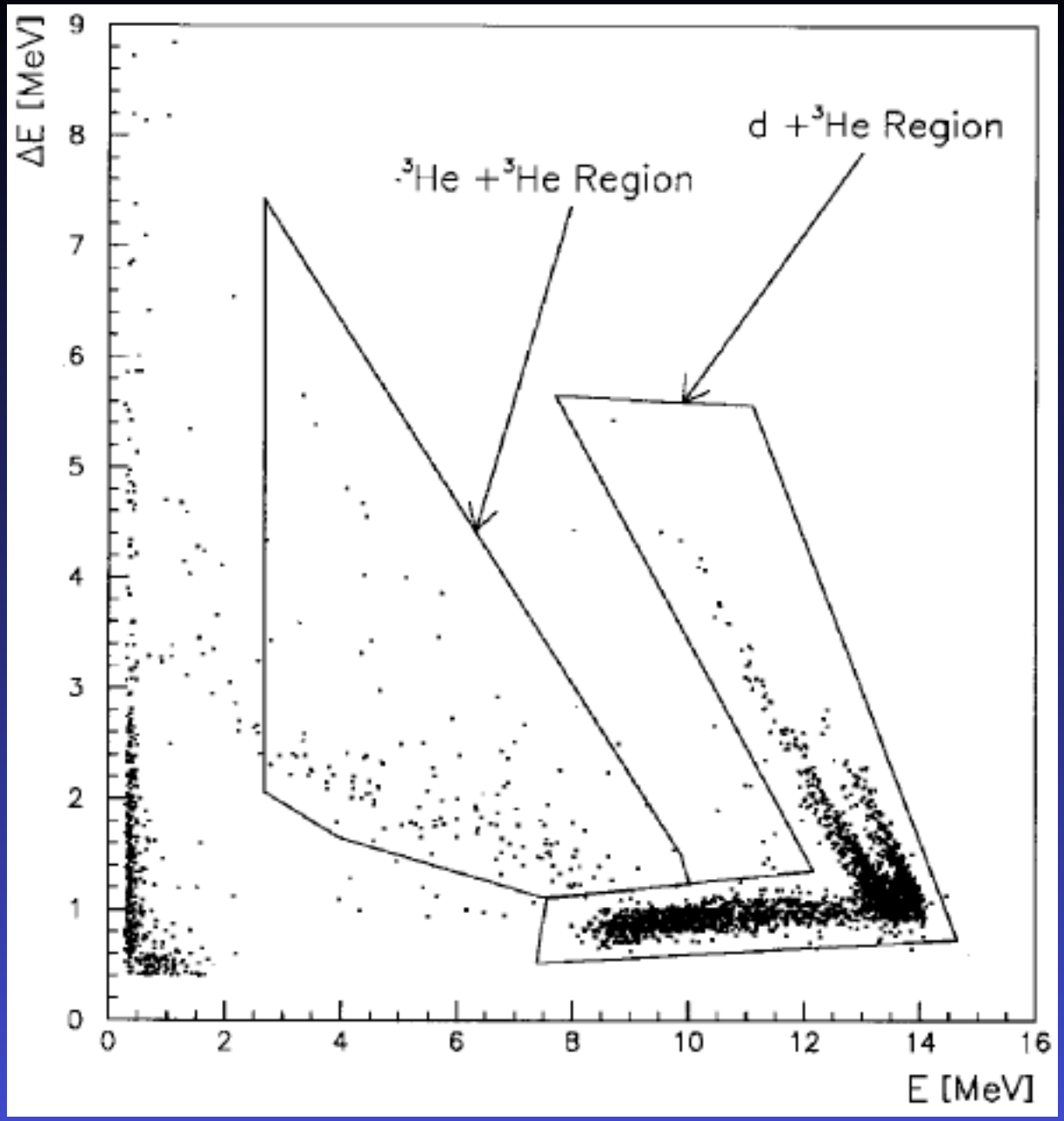
(rough people, suspicious of "Italians"
and suspicious of new things), Genova:

proposed and realised (Sandra) a
Monte Carlo code Geant3 based

proposed and realised (Andrea) a
new DAQ based on "modern" Camac

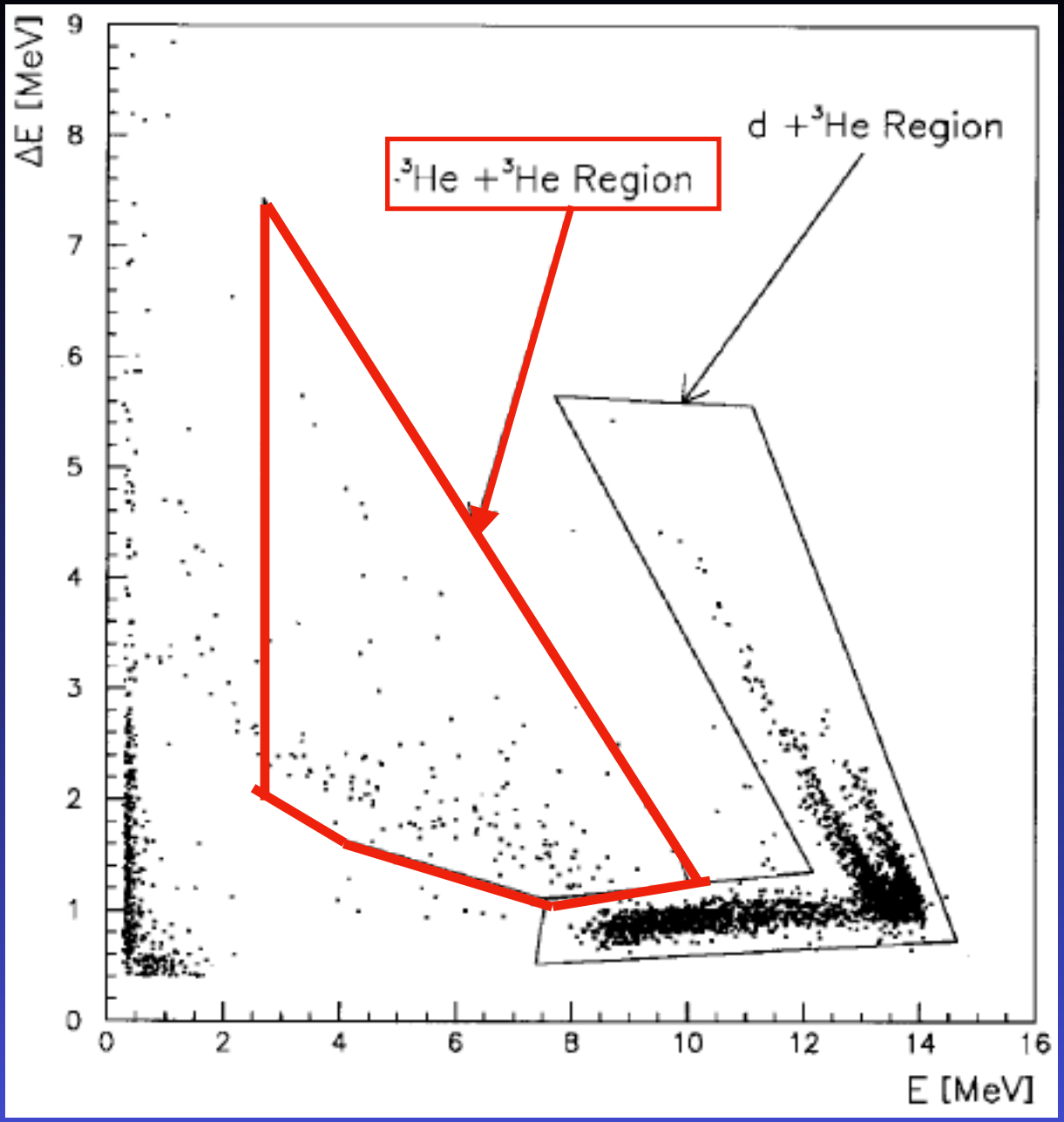

ΔE [keV]
E [keV]
^{3}He+^{3}He
^{3}He+d
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
2000
4000
6000
8000
10000
12000
14000

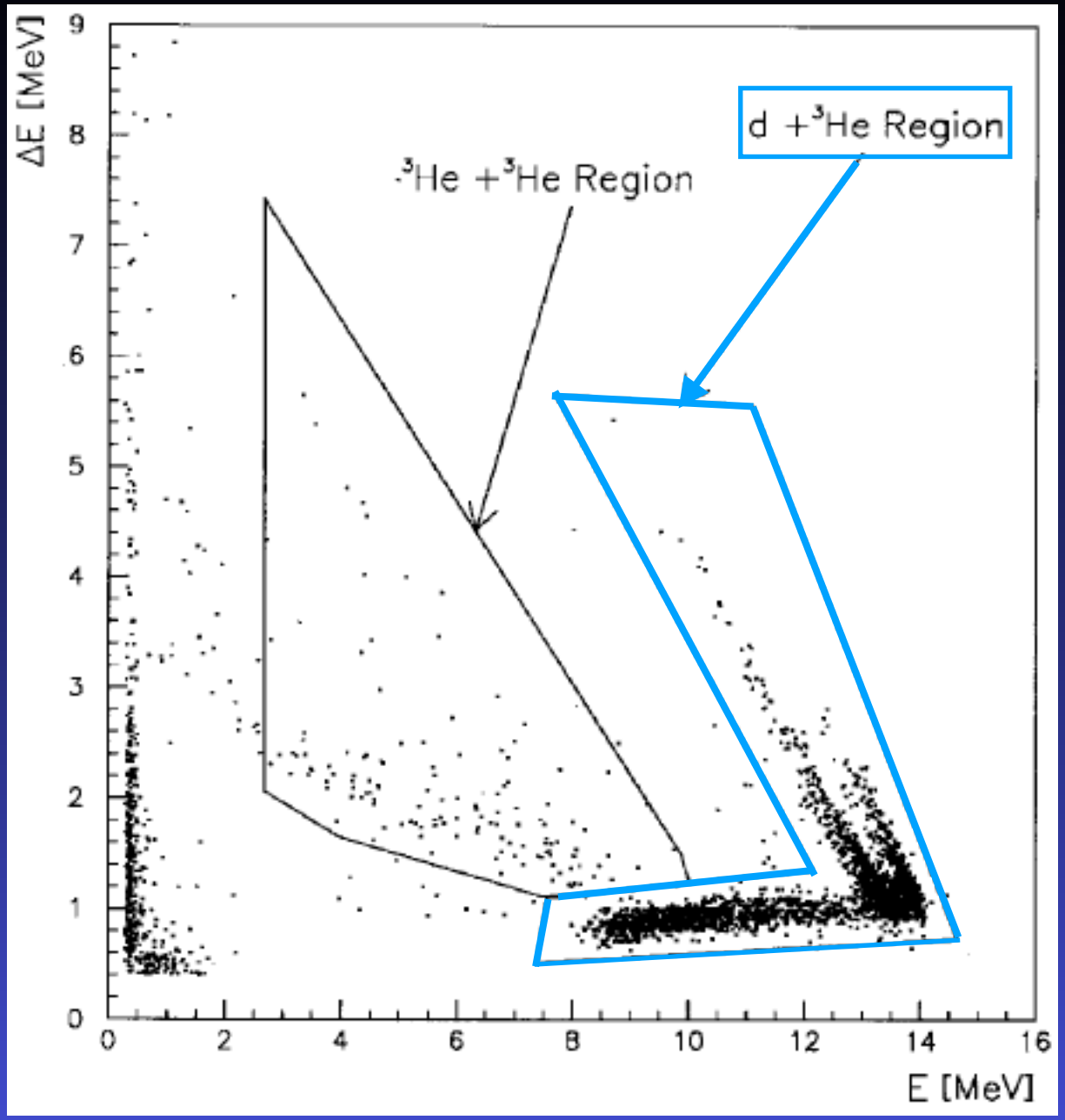

ΔE [keV]
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2000
4000
6000
8000
10000
12000
14000
E [keV]
^{3}He+^{3}He
^{3}He+d
HPT gently smiled...


ΔE [MeV]
E [MeV]
d +³He Region
³He +³He Region
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12
14
16

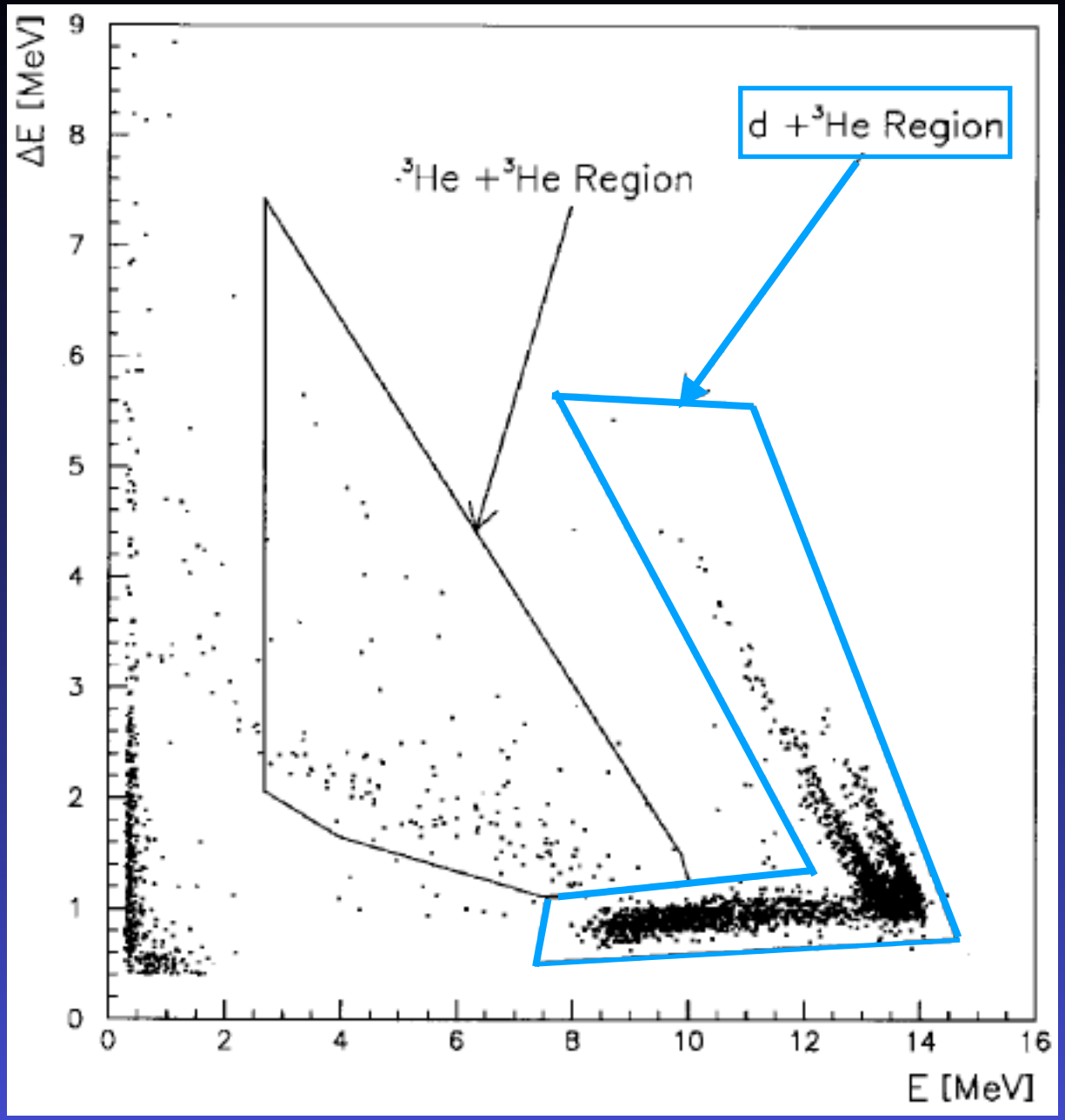
GenGS (the ancestor of SimLUNA) was used to determine the efficiency of the setup

(and in the future for the simulation of many other experiments)


ΔE [MeV]
E [MeV]
^{3}He +^{3}He Region
d +^{3}He Region
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12
14
16


ΔE [MeV]
E [MeV]
d +³He Region
³He +³He Region
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12
14
16

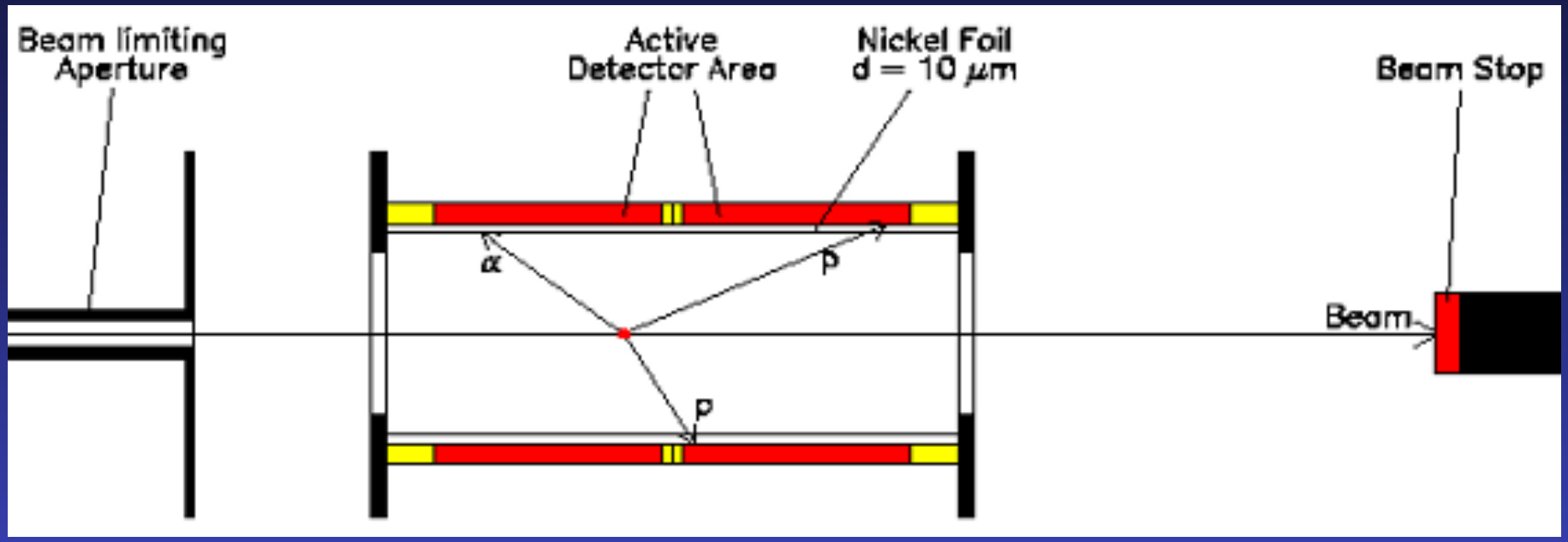
?

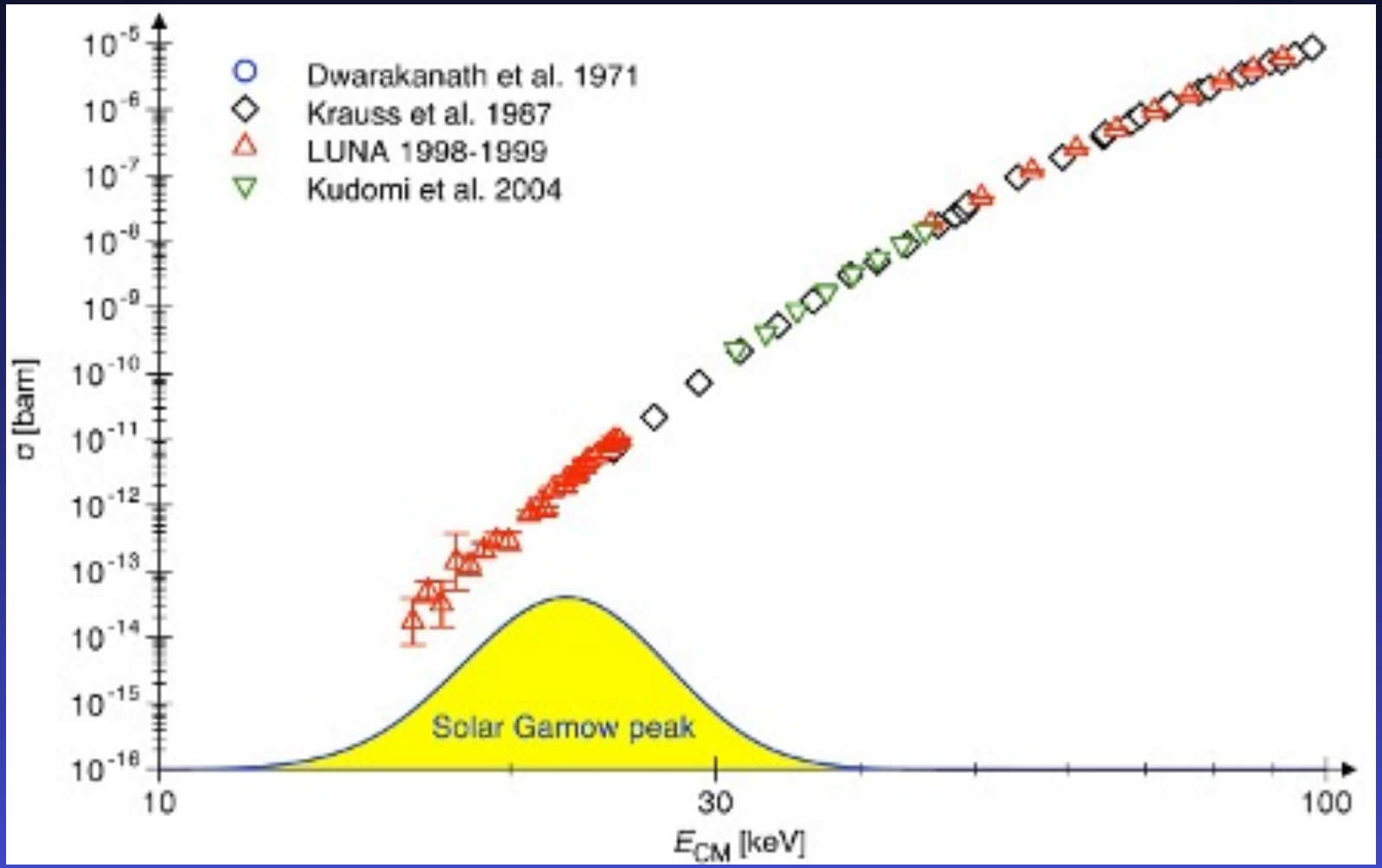


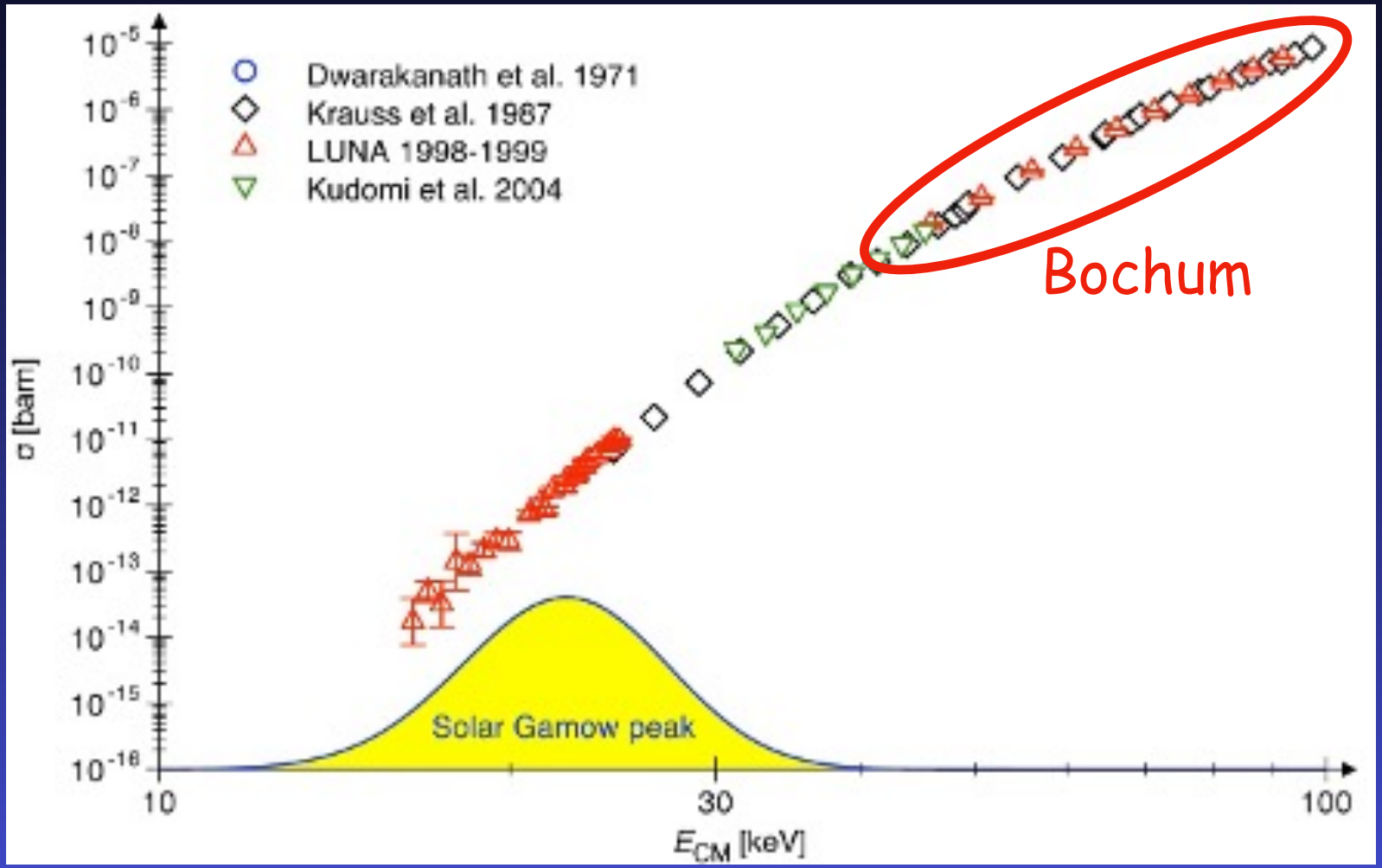
$^3He^+ \equiv HD^+$

$^3He(d,p)^4He$

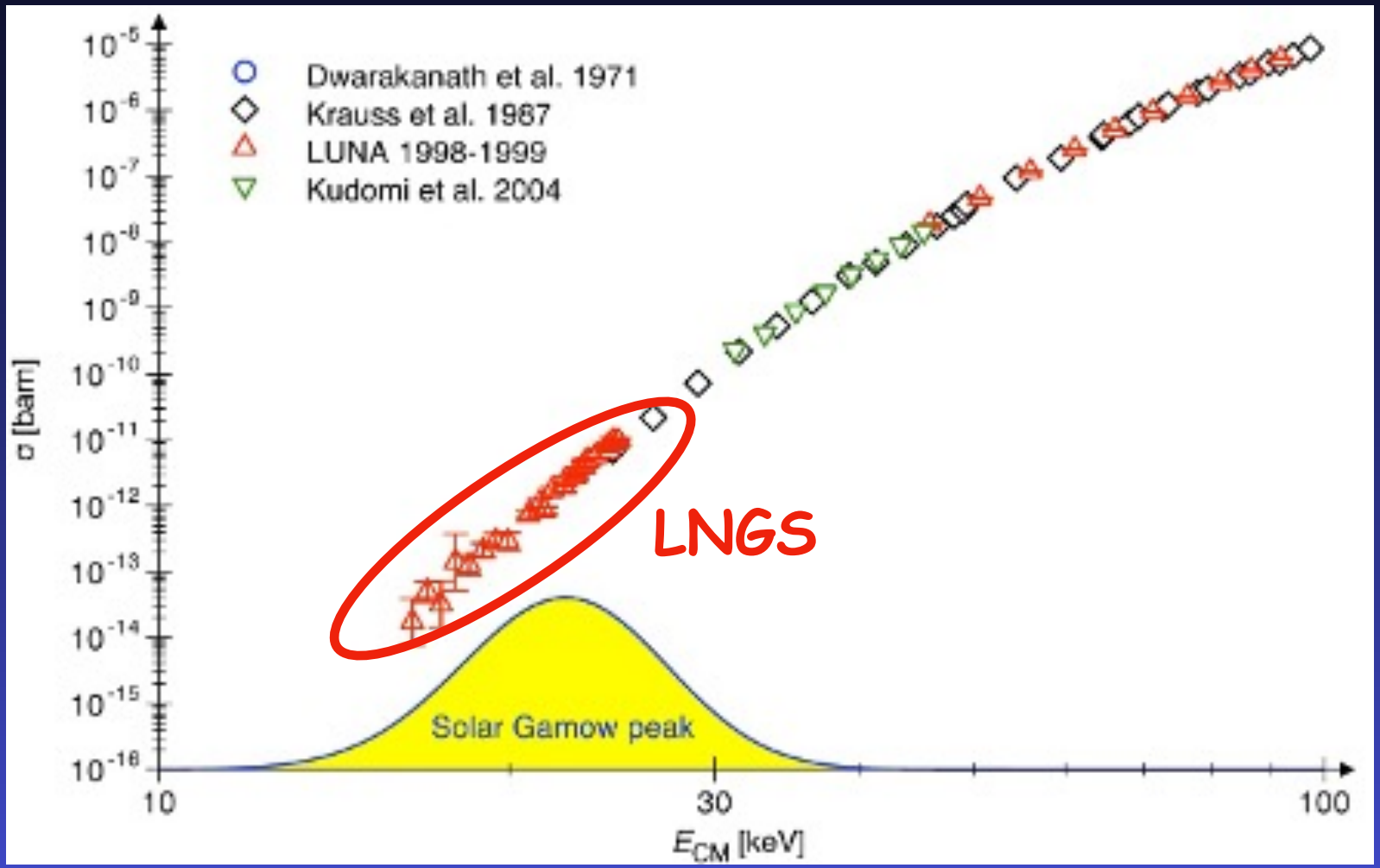
looking at $p - p$ coincidences

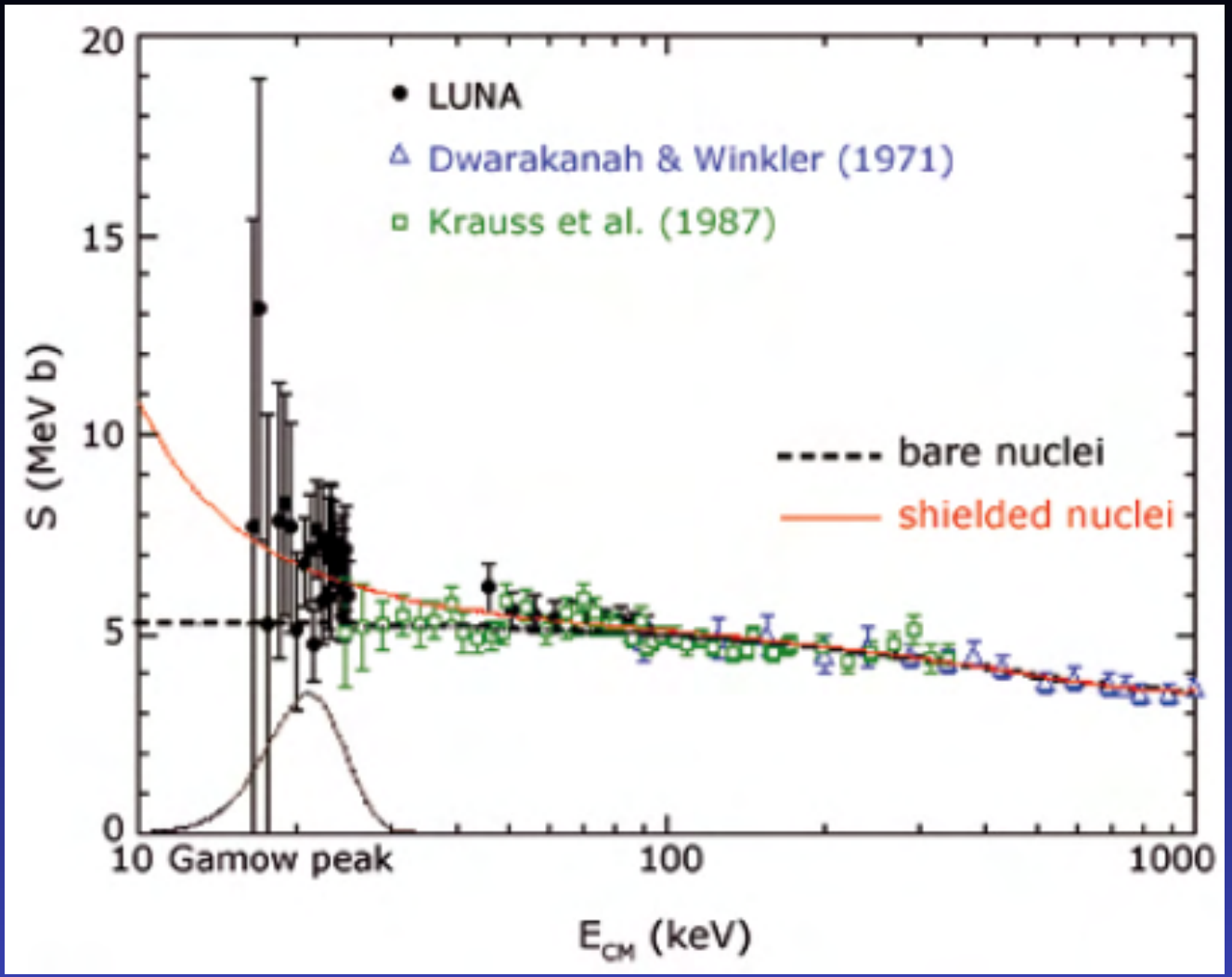



Dwarakanath et al. 1971
Krauss et al. 1987
LUNA 1998-1999
Kudomi et al. 2004
σ [barn]
Solar Gamow peak
10
30
100
E_{CM} [keV]


Dwarakanath et al. 1971
Krauss et al. 1987
LUNA 1998-1999
Kudomi et al. 2004
Bochum
Solar Gamow peak
σ [barn]
E_{CM} [keV]
10
30
100

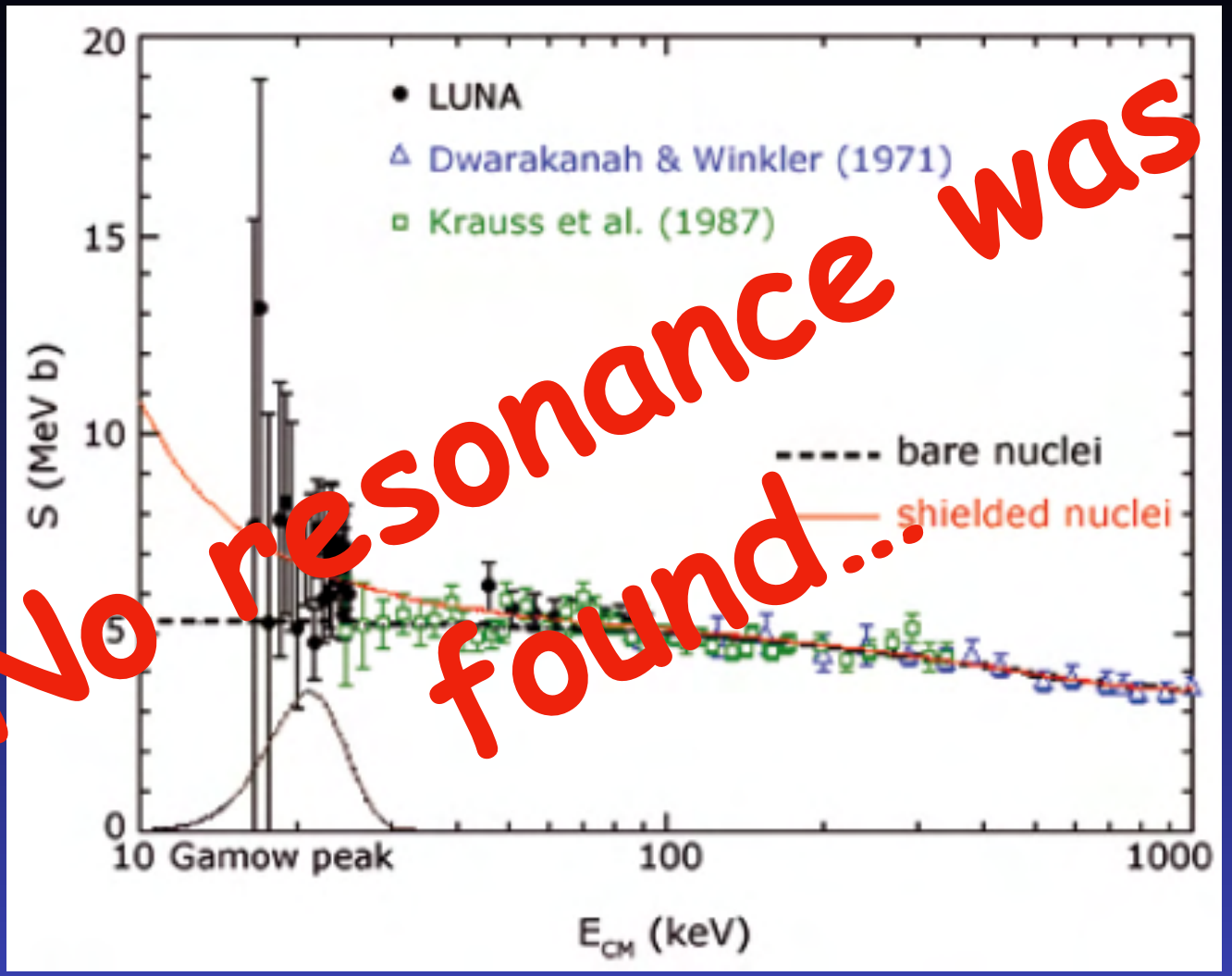
for the first time inside Gamow peak !!





at lowest measured energy:

$\sigma \approx 20\, fb$ (2 counts/month)



at lowest measured energy:

$\sigma \approx 20\, fb$ (2 counts/month)

THE INSTITUTE FOR ADVANCED STUDY

PRINCETON, NEW JERSEY 08540

E-mail: jnb@sns.ias.edu FAX: (609)924-7592

SCHOOL OF NATURAL SCIENCES JOHN N. BAHCALL

28 May 1997

Professor P. Corvisiero
Professor C. Rolfs
Spokesmen for the LUNA-Collaboration

Dear Professors Corvisiero and Rolfs:

I am writing to you about a historic opportunity of which I first became aware at the recent meeting on Solar Fusion Reactions at the Institute of Nuclear Theory, Washington University. At this meeting, I had the opportunity to see for the first time the results of the LUNA measurements of the important $3He - 3He$ reaction in a region that covers a significant part of the Gamow energy peak for solar fusion. This was a thrill that I had never believed possible. These measurements signal the most important advance in nuclear astrophysics in three decades.

I have had some experience in helping to set priorities for research in physics and in astronomy, most recently as Chair of the Decade Survey for Astronomy and Astrophysics of the National Academy of the United States and as President (now emeritus) of the American Astronomical Society. I can say, with the perspective provided by these previous assignments, that the work of the LUNA collaboration is unique and essential for further progress in solar neutrino studies and for understanding how main sequence stars evolve. I personally would rank the LUNA project among the highest priorities internationally for research in nuclear astrophysics, in stellar evolution, in solar neutrinos, and in particle phenomenology.

Sincerely yours,

John N. Bahcall
Professor of Natural Science

JNB:jnb

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JNB:jnb

VOLUME 82, NUMBER 26 PHYSICAL REVIEW LETTERS 28 JUNE 1999

First Measurement of the $^3He(^3He, 2p)^4He$ Cross Section down to the Lower Edge of the Solar Gamow Peak

R. Bonetti,[1] C. Broggini,[2,*] L. Campajola,[3] P. Corvisiero,[4] A. D'Alessandro,[5] M. Dessalvi,[4] A. D'Onofrio,[6] A. Fubini,[7] G. Gervino,[8] L. Gialanella,[9] U. Greife,[9] A. Guglielmetti,[1] C. Gustavino,[5] G. Imbriani,[3] M. Junker,[5] P. Prati,[4] V. Roca,[3] C. Rolfs,[9] M. Romano,[3] F. Schuemann,[9] F. Strieder,[9] F. Terrasi,[3] H.P. Trautvetter,[9] and S. Zavatarelli[4]
(LUNA Collaboration)

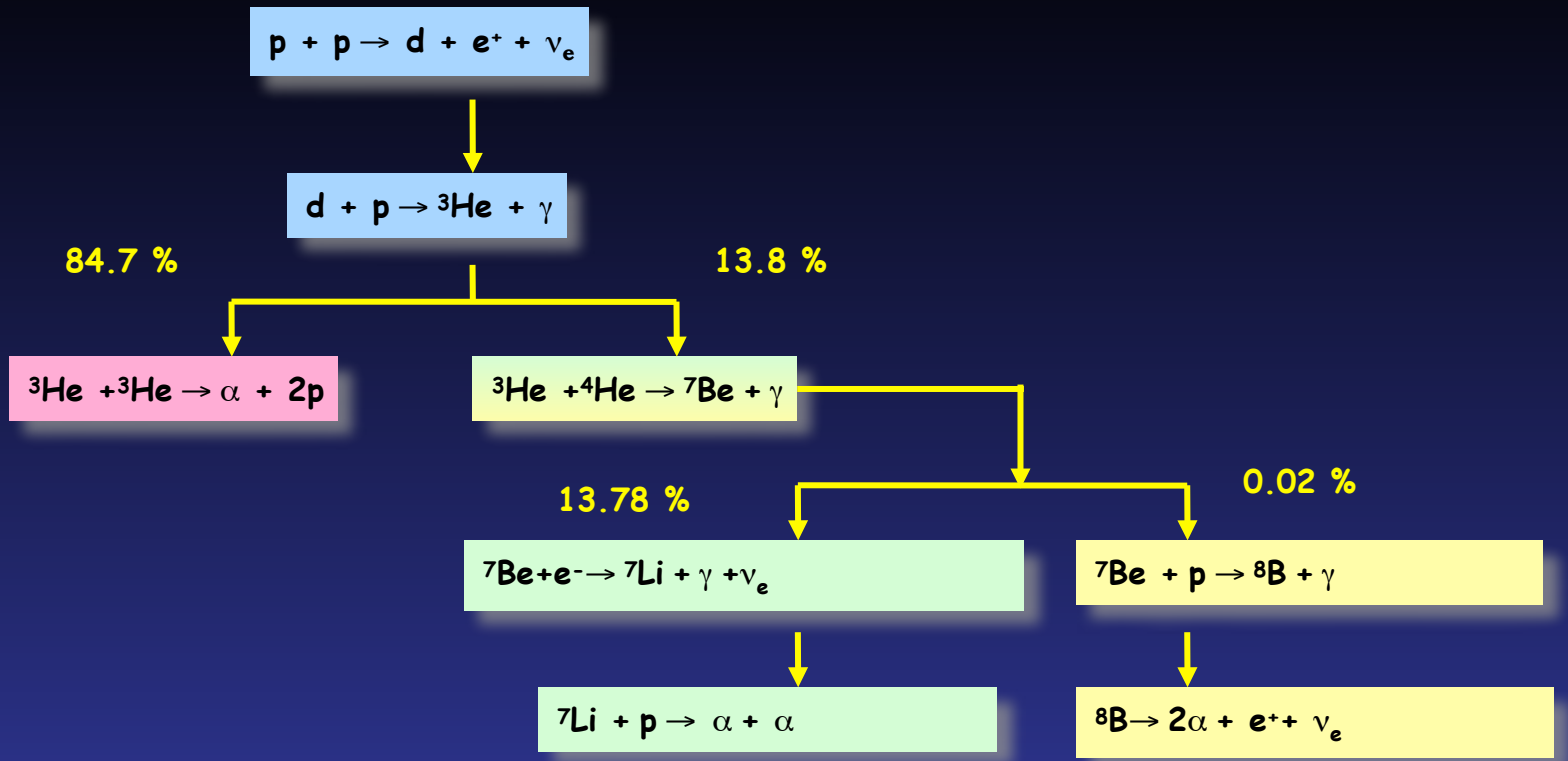
excluded a "nuclear solution" to the missing neutrino problem

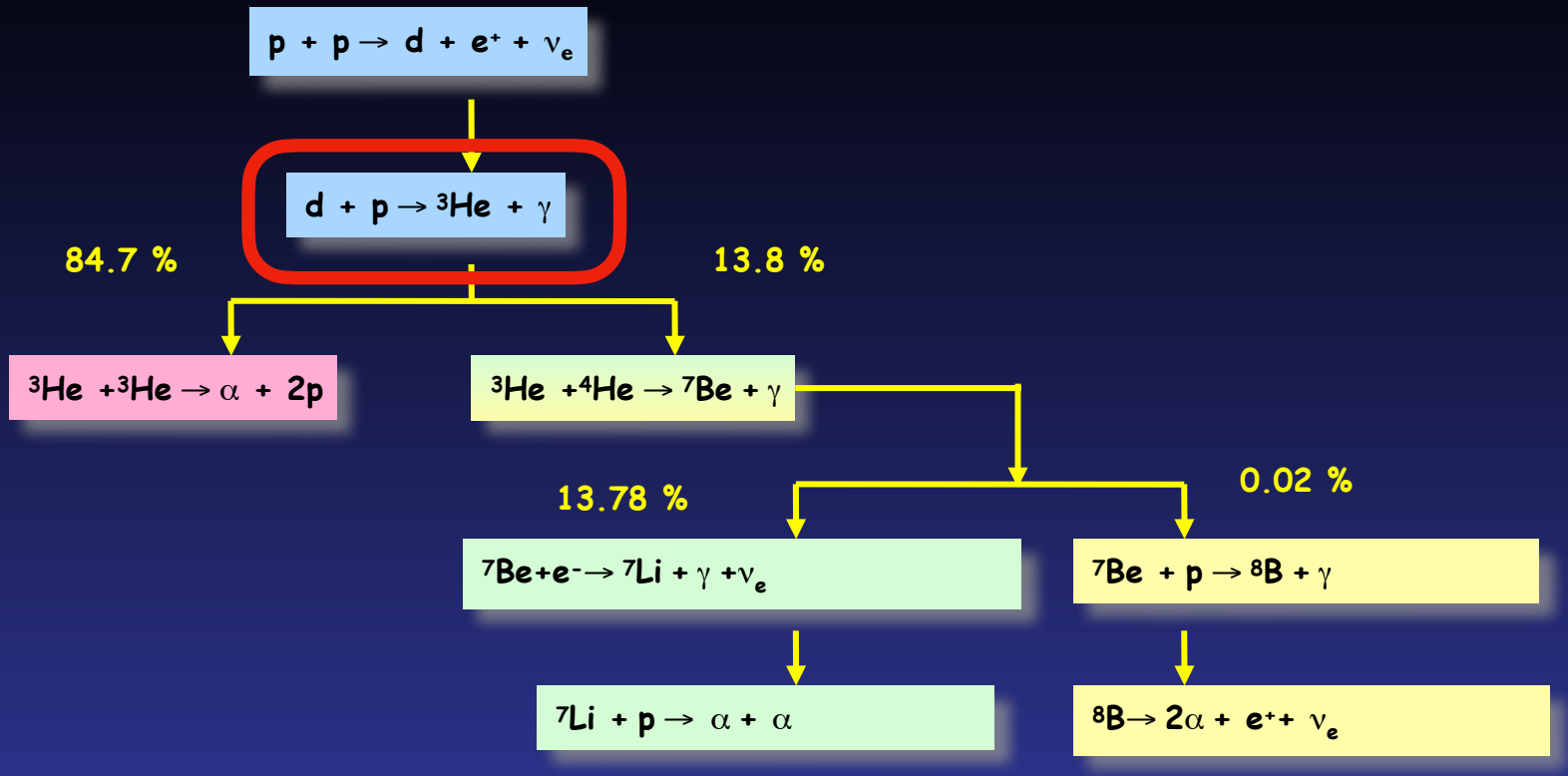
T. Kajita

A. McDonald

2015 Nobel Prize in Physics
Discovery of Neutrinos Oscillations

$$p + d \rightarrow {}^{3}He + \gamma$$

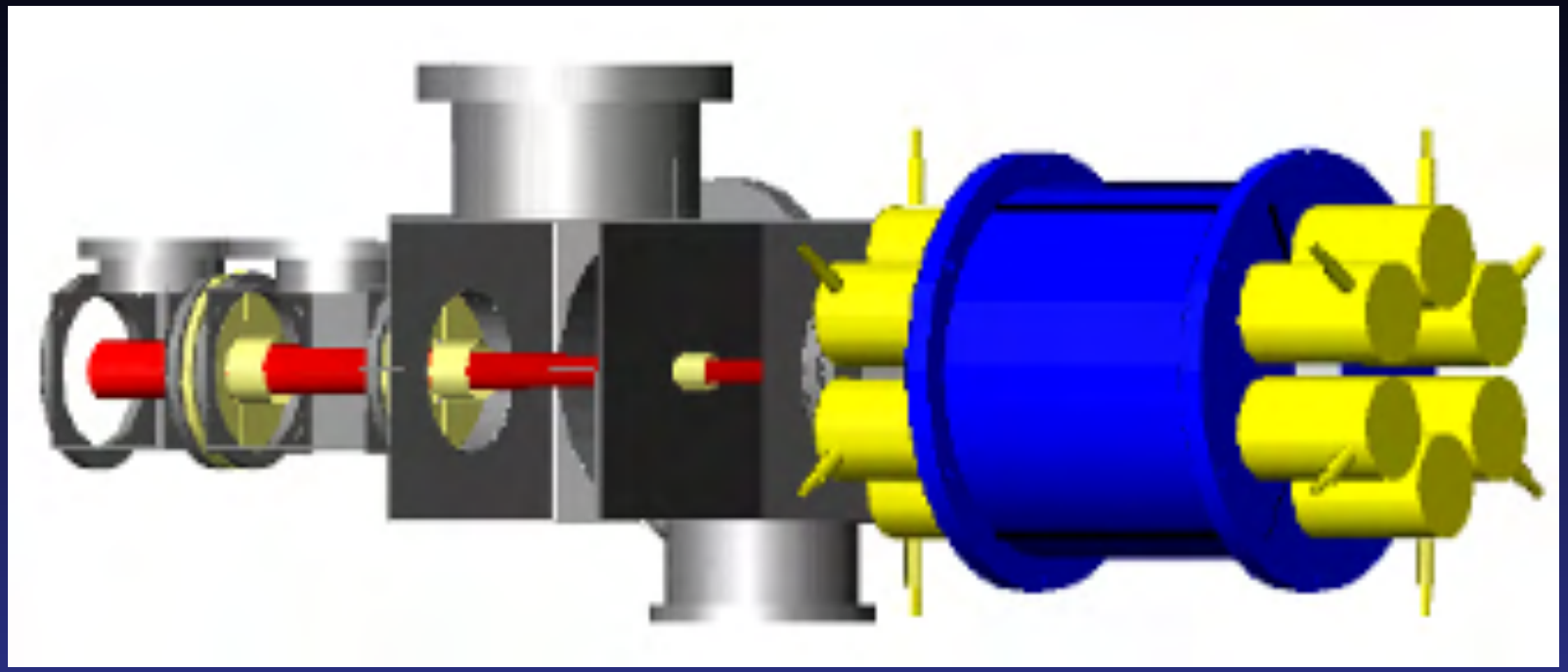

p + p → d + e⁺ + νe
d + p → 3He + γ
84.7 %
13.8 %
3He +3He → α + 2p
3He +4He → 7Be + γ
13.78 %
0.02 %
7Be+e⁻ → 7Li + γ +νe
7Be + p → 8B + γ
7Li + p → α + α
8B → 2α + e⁺ + νe



not so important for Sun and stars physics

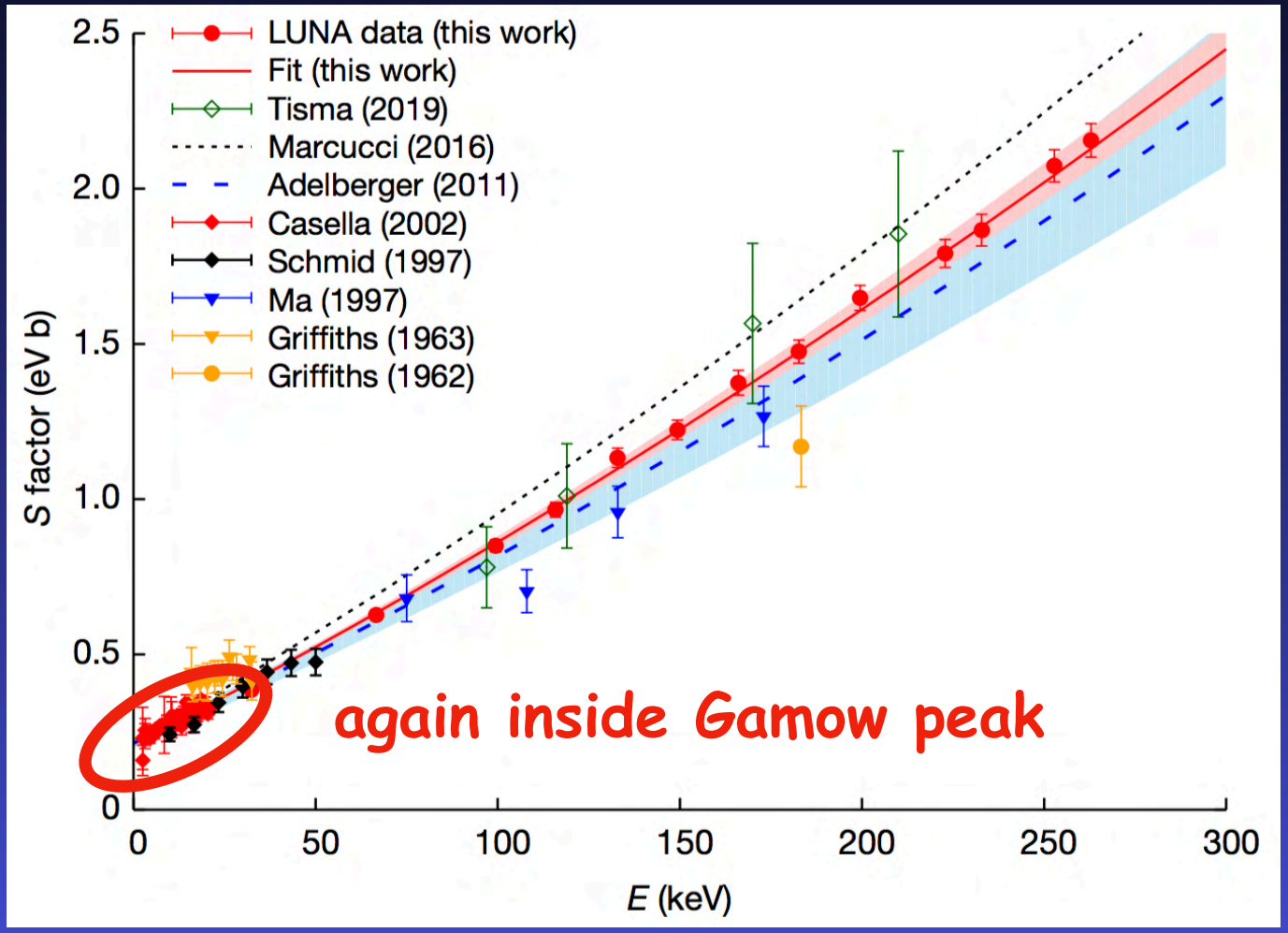
very important for BBN physics and cosmology

(see later)



proton beam - D_2 gas target 10 cm long inside BGO

Astrophysical S(E) factor



encouraged by this success, with a strong tailwind

We asked INFN for a new accelerator

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Commissione III enthusiastically approved but in 1998 INFN was under an infringement procedure

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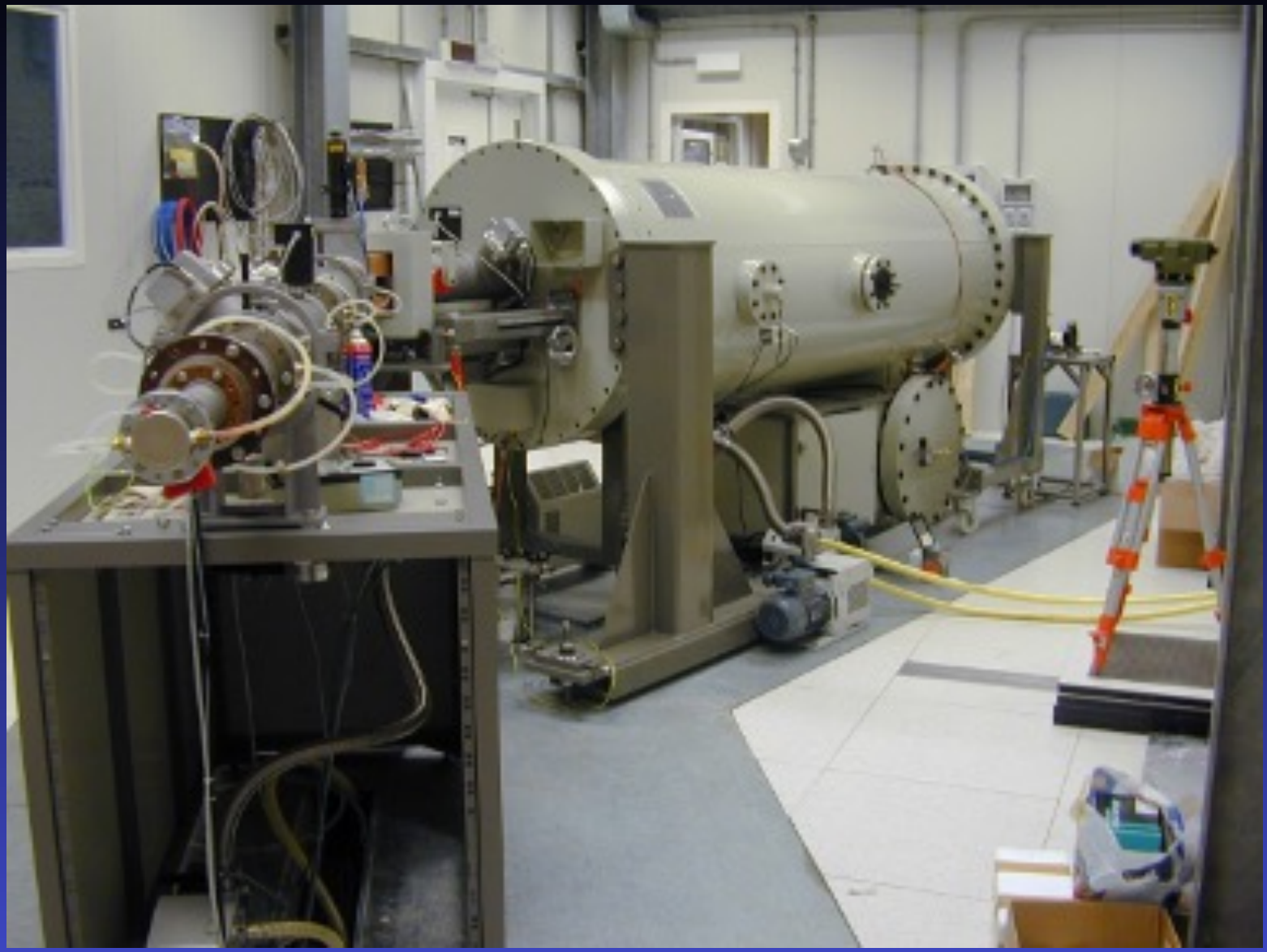
We asked INFN for a new accelerator

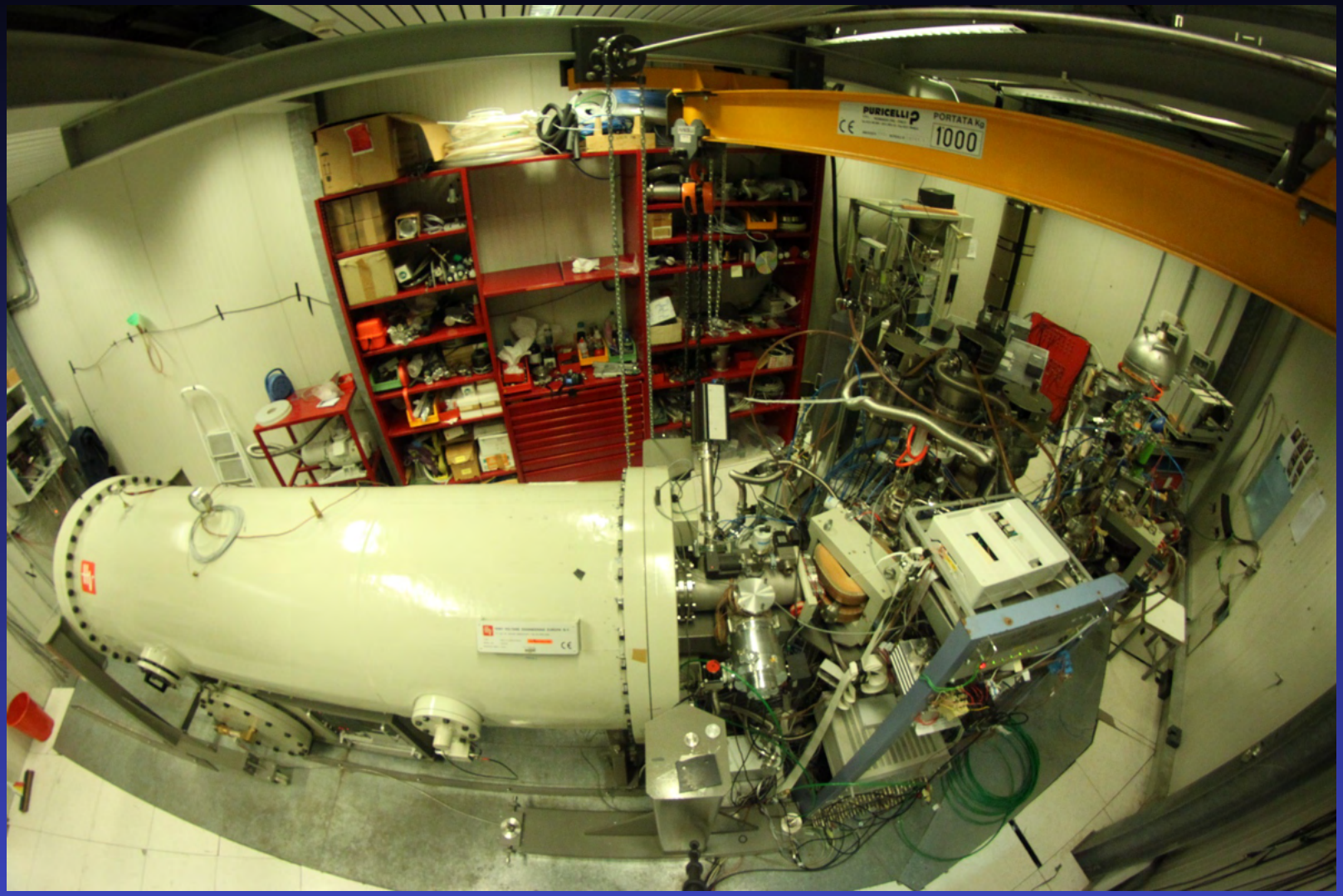
Commissione III enthusiastically approved but in 1998 INFN was under an infringement procedure

we had to wait for an extra year
in the summer of 2000

LUNA 400



as it was..



and as it is..

PHYSICAL REVIEW LETTERS

28 JUNE 1999

First Measurement of the $^3He(^3He, 2p)^4He$ Cross Section down to the Lower Edge of the Solar Gamow Peak

R. Bonetti,[1] C. Broggini,[2,*] L. Campajola,[3] P. Corvisiero,[4] A. D'Alessandro,[5] M. Dessalvi,[4] A. D'Oss... A. Fubini,[7] ... Roca,[3] G. Gervino,[8] L. Gialanella,[9] U. Greife,[9] A. Guglielmetti,[1] C. Gustavino,[5] G. Imbriani,[3] M. Junker,[5] F. C. Rolfs,[9] M. Romano,[3] F. Schmetzann,[9] F. Strieder,[9] F. Terrasi,[3] H.P. Trautvetter,[9] and S. (LUNA Collaboration)

PRL 109, 202501

PHYSICAL REVIEW LETTERS

First Direct ...measurement of the $^{17}O(p,\gamma)^{18}F$ Reaction Cross Section at Gamow Energies for Cl... Novae

D. A. Scott,[1] A. Caciolli,[2,3] M. Campeggio,[2] ... week ending 16 NOVEMBER 2012

PRL 115, 252501 (2015)

PHYSICAL REVIEW LETTERS

Three New Low-Energy Reso...

Cavanna,[1] R. Depalo,[2] M. Aliotta,[3] M. Anders,[4,5] ... P. Corvisiero,[1] T. Davinson,[3] A. di Le... C. Gustavino,[14] Gy. Gyürky,[15] ... Scott,[3] E. Somorjai,[15] O. S...

nature astronomy

LETTERS

PUBLISHED: 30 JANUARY 2017 | VOLUME: 1 | ARTICLE NUMBER: 0027

Origin of meteoritic stardust unveiled by a revised proton-capture rate of ^{17}O

M. Lugaro[1,2*], A. I. Karakas[3,4], C. G. Bruno[1], M. Aliotta[1], L. R. Nittler[5], D. Bemmerer[7], A. Best[8], A. Boeltzig[6], C. Broggini[10], A. Caciolli[7], F. Cavanna[11], G. F. Ciani[6], P. Corvisiero[12], T. Davinson[1], R. Depalo[7], A. Di Leva[8], Z. Elekes[13], F. Ferraro[12], A. Formicola[14], Zs. Fülöp[13], G. Gervino[15], A. Guglielmetti[16], C. Gustavino[17], Gy. Gyürky[13], G. Imbriani[8], M. Junker[14], R. Menegazzo[10], V. Mossa[18], F. R. Pantaleo[18], D. Piatti[19], P. Prati[12], D. A. Scott[1,4], O. Straniero[14,19], F. Strieder[20], T. Szücs[13], M. P. Takács[7] and D. Trezzi[16]

Astronomy & Astrophysics

LUNA has pioneered underground studies in Nuclear Astrophysics for ~~two~~ three decades

ELSEVIER

Available online at www.sciencedirect.com

SCIENCE DIRECT

PHYSICS LETTERS B

First measurement of the $^{14}N(p,\gamma)^{15}O$ cross section dow...

LUNA Collaboration

A. Lemut[a], D. Bemmerer[b], F. Confortola[a], R. Bonetti[c], C. Broggini[b,*], P. ... H. Costantini[a], J. Cruz[d], A. Formicola[e], Zs. Fülöp[f], G. Gervino[g], A. Guglielmet... Gy. Gyürky[f], G. Imbriani[h], A.P. Jesus[d], M. Junker[e], B. Limata[h], R. Menega... V. Roca[h], D. Rogalla[i], C. Rolfs[j], M. Romano[h], C. Rossi Alvarez[b], F. Schuman... O. Straniero[k], F. Strieder[j], F. Terrasi[l], H.P. Trautvetter[j]

The bottleneck of CNO burning and the age of Globular Clusters

G. Imbriani[1,2,3], H. Costantini[4], A. Formicola[5,6], D. Bemmerer[7], R. Bonetti[8], C. Broggini[9], P. Corvisiero[4], J. Cruz[10], Z. Fülöp[11], G. Gervino[12], A. Guglielmetti[8], C. Gustavino[6], G. Gyürky[11], A. P. Jesus[10], M. Junker[6], A. Lemut[4], R. Menegazzo[9], P. Prati[4], V. Roca[2,3], C. Rolfs[5], M. Romano[2,3], C. Rossi Alvarez[9], F. Schümann[5], E. Somorjai[11], ... F. Terrasi[2,13], H. P. Trautvetter[5], A. Vomiero[14], and S. Zavatarelli[4]

PRL 117, 142502 (2016)

PHYSICAL REVIEW LETTERS

week ending 30 SEPTEMBER 2016

Improved Direct Measurement of the 64.5 keV Resonance Strength in the $^{17}O(p,\alpha)^{14}N$ Reaction at LUNA

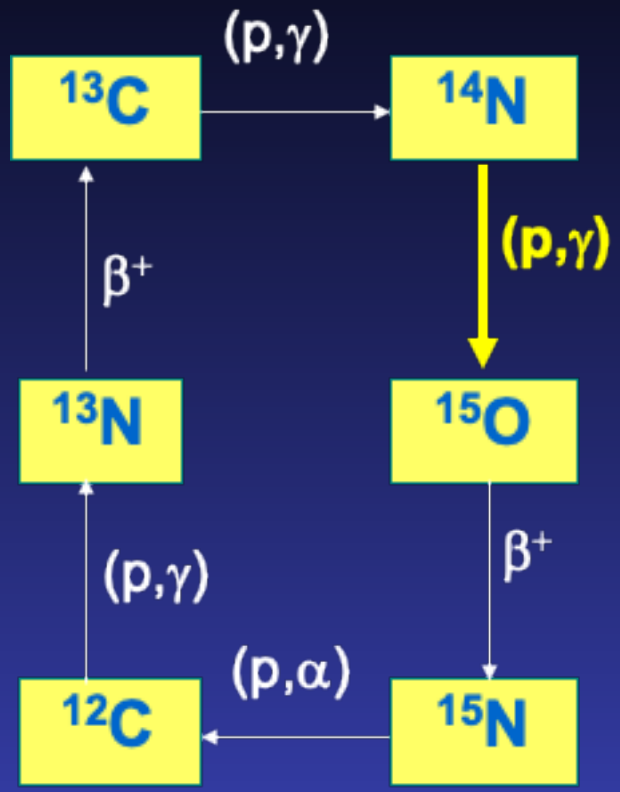
C. G. Bruno,[1,*] D. A. Scott,[1] M. Aliotta,[1,†] A. Formicola,[2] A. Best,[3] A. Boeltzig,[4] D. Bemmerer,[5] C. Broggini,[6] A. Caciolli,[7] F. Cavanna,[8] G. F. Ciani,[4] P. Corvisiero,[8] T. Davinson,[1] R. Depalo,[7] A. Di Leva,[3] Z. Elekes,[9] F. Ferraro,[8] Zs. Fülöp,[9] G. Gervino,[10] A. Guglielmetti,[11] C. Gustavino,[12] Gy. Gyürky,[9] G. Imbriani,[3] M. Junker,[2] R. Menegazzo,[6] V. Mossa,[13] F. R. Pantaleo,[13] D. Piatti,[7] P. Prati,[8] E. Somorjai,[9] O. Straniero,[14] F. Strieder,[15] T. Szücs,[5] M. P. Takács,[5] and D. Trezzi[11]

courtesy: Marialuisa Aliotta

$$p + {}^{14}N \rightarrow {}^{15}O + \gamma$$

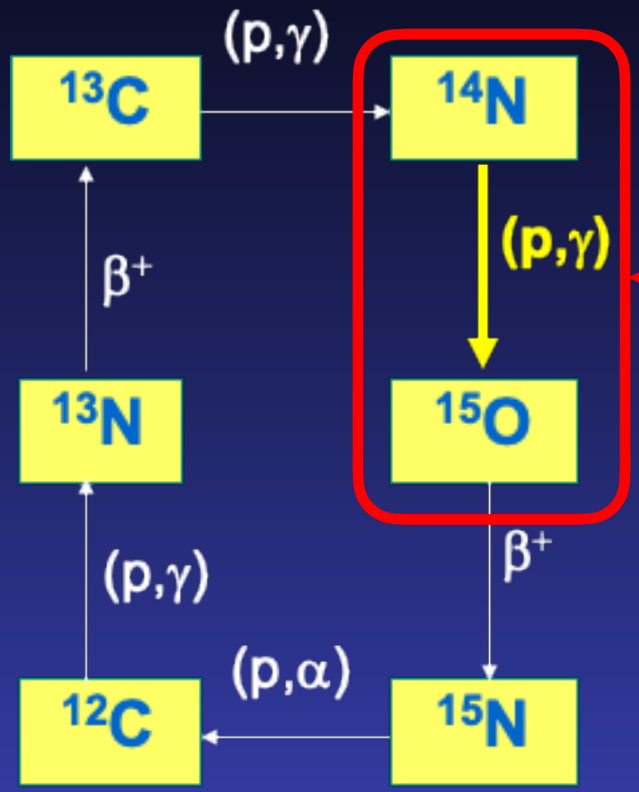
$$p + d \rightarrow {}^{3}He + \gamma$$

$$p + {}^{14}N \rightarrow {}^{15}O + \gamma$$



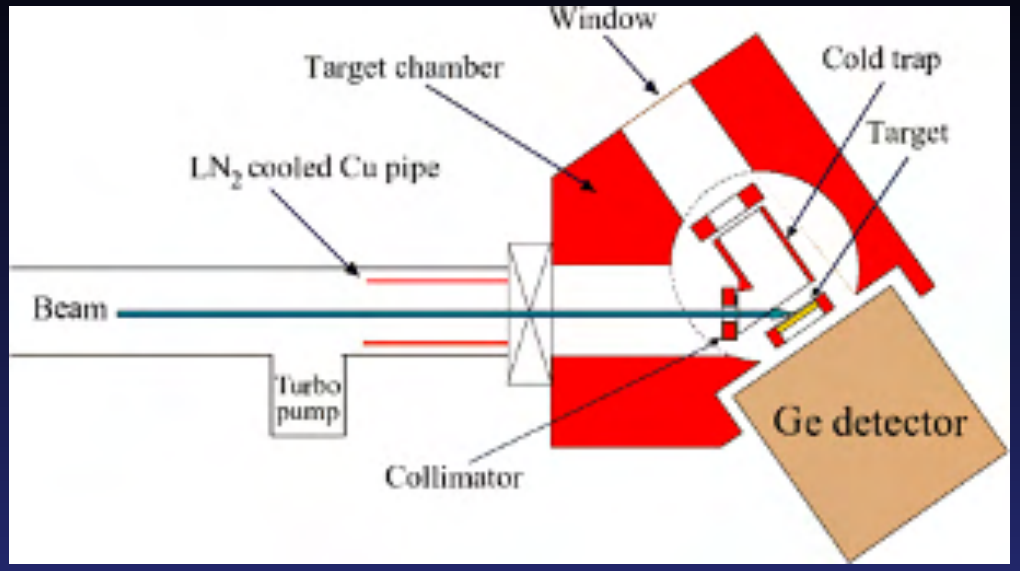
CNO cycle

Solar neutrino physics



bottleneck reaction

regulates flux of CNO neutrinos from the Sun



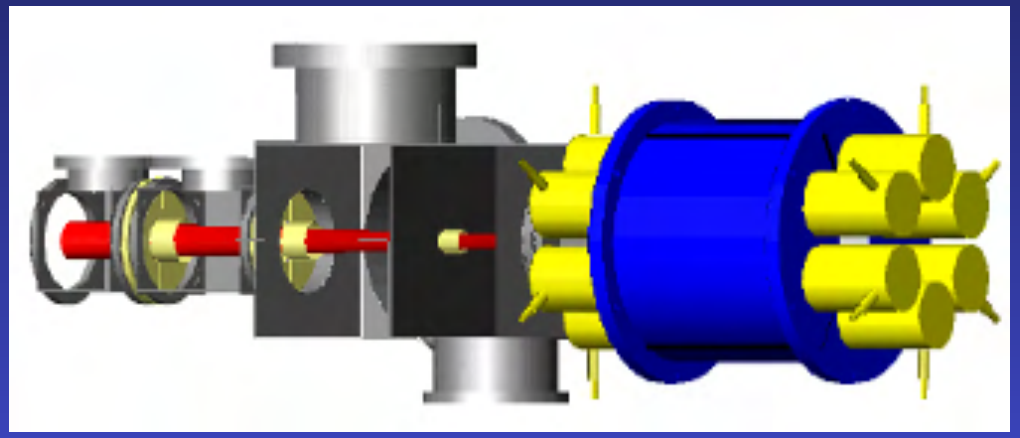
solid target + HpGe detector

high energy resolution

single γ transitions

branching ratios

En. range: $119 \div 367\ keV$

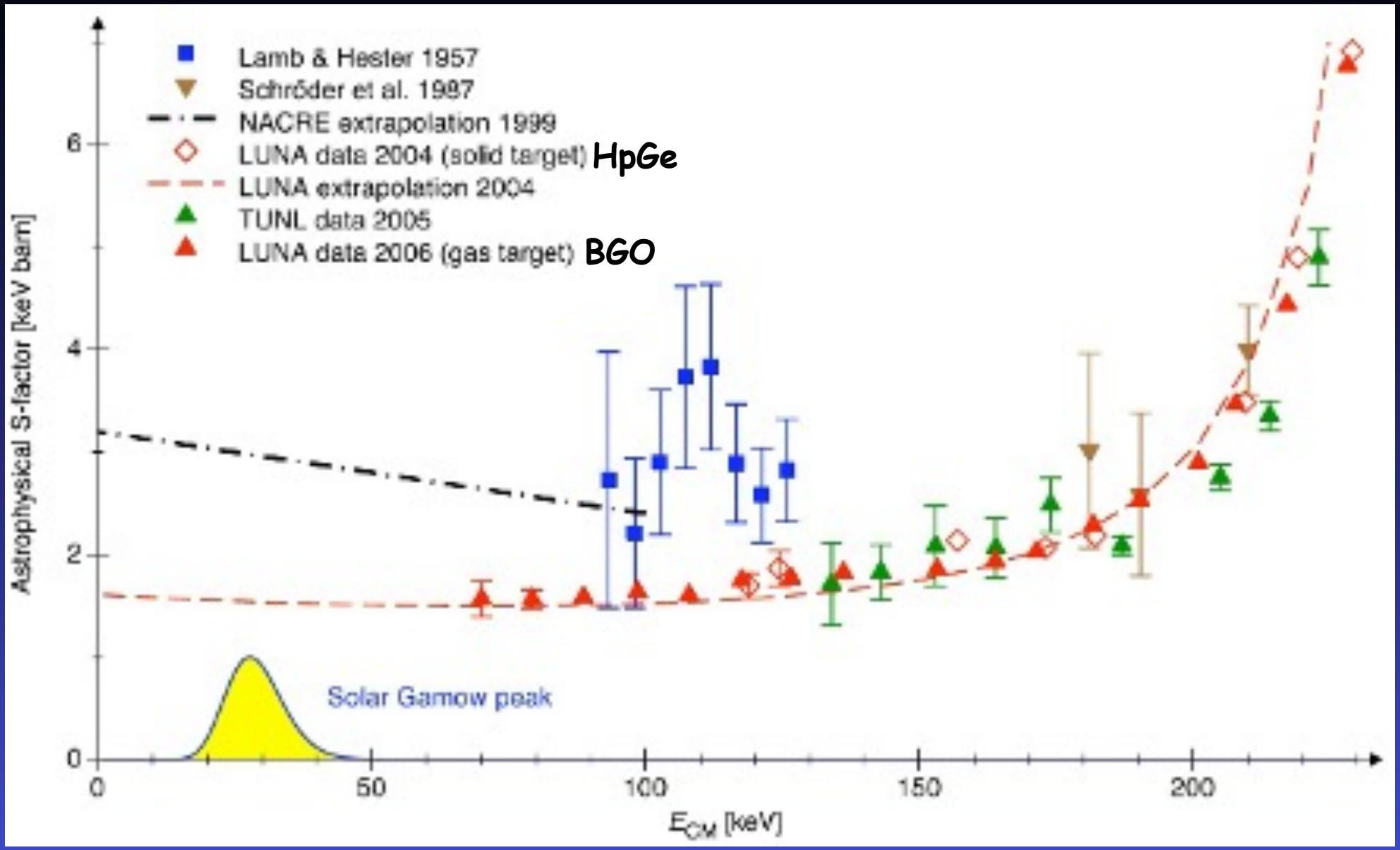


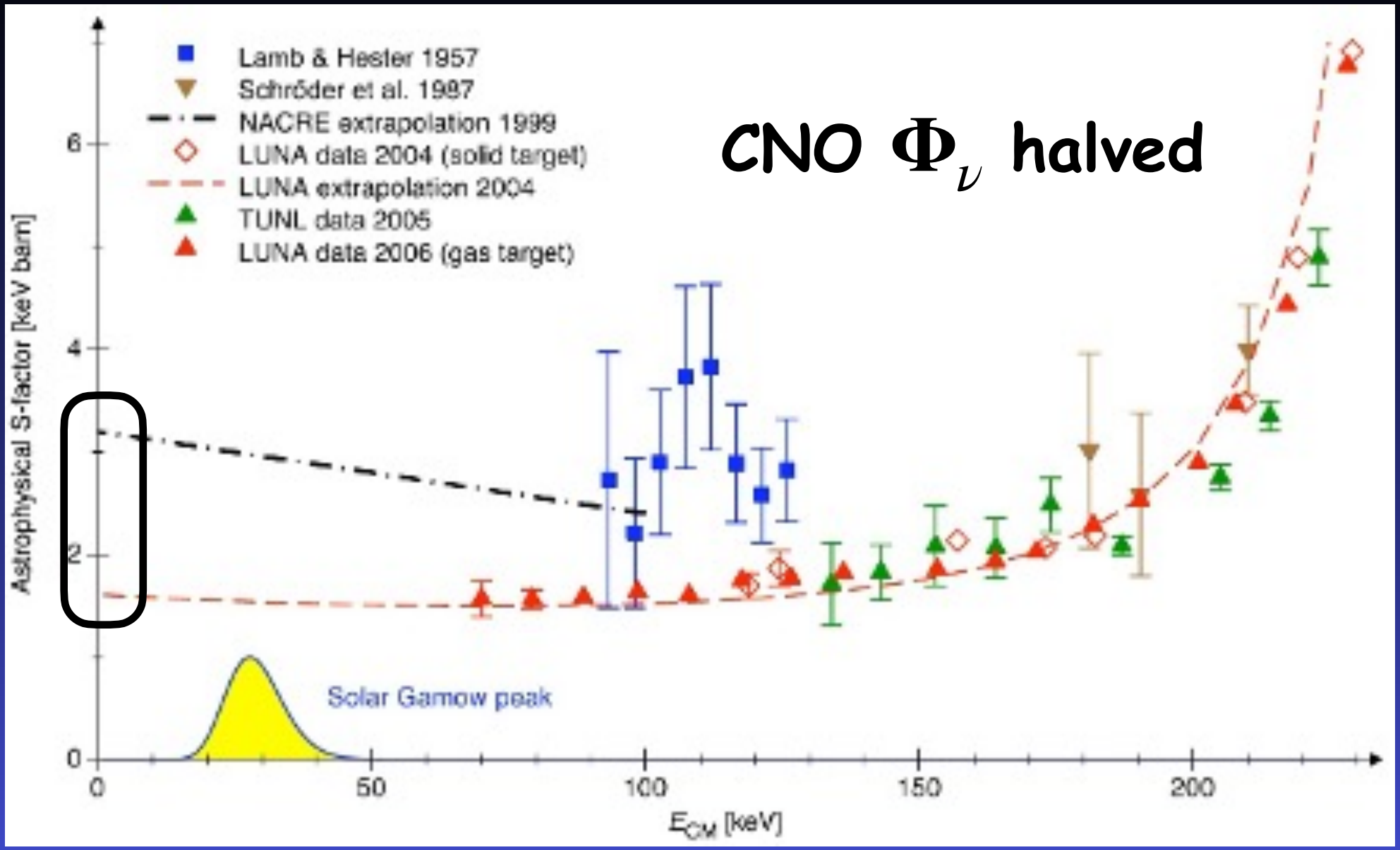
gas target + BGO detector

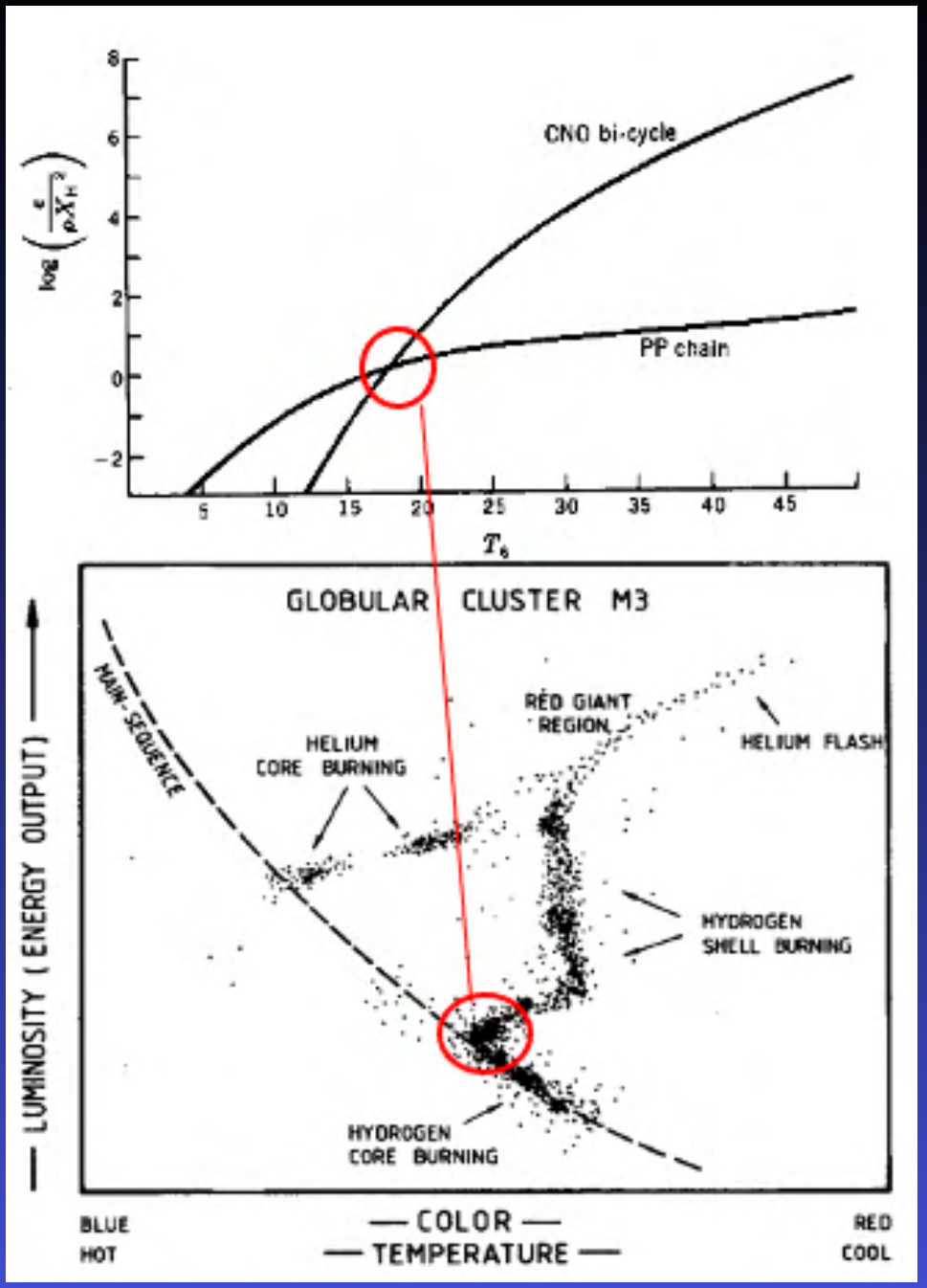
low energy resolution

total cross section $\rightarrow$ S_{14}

En. range: $70 \div 230\ keV$

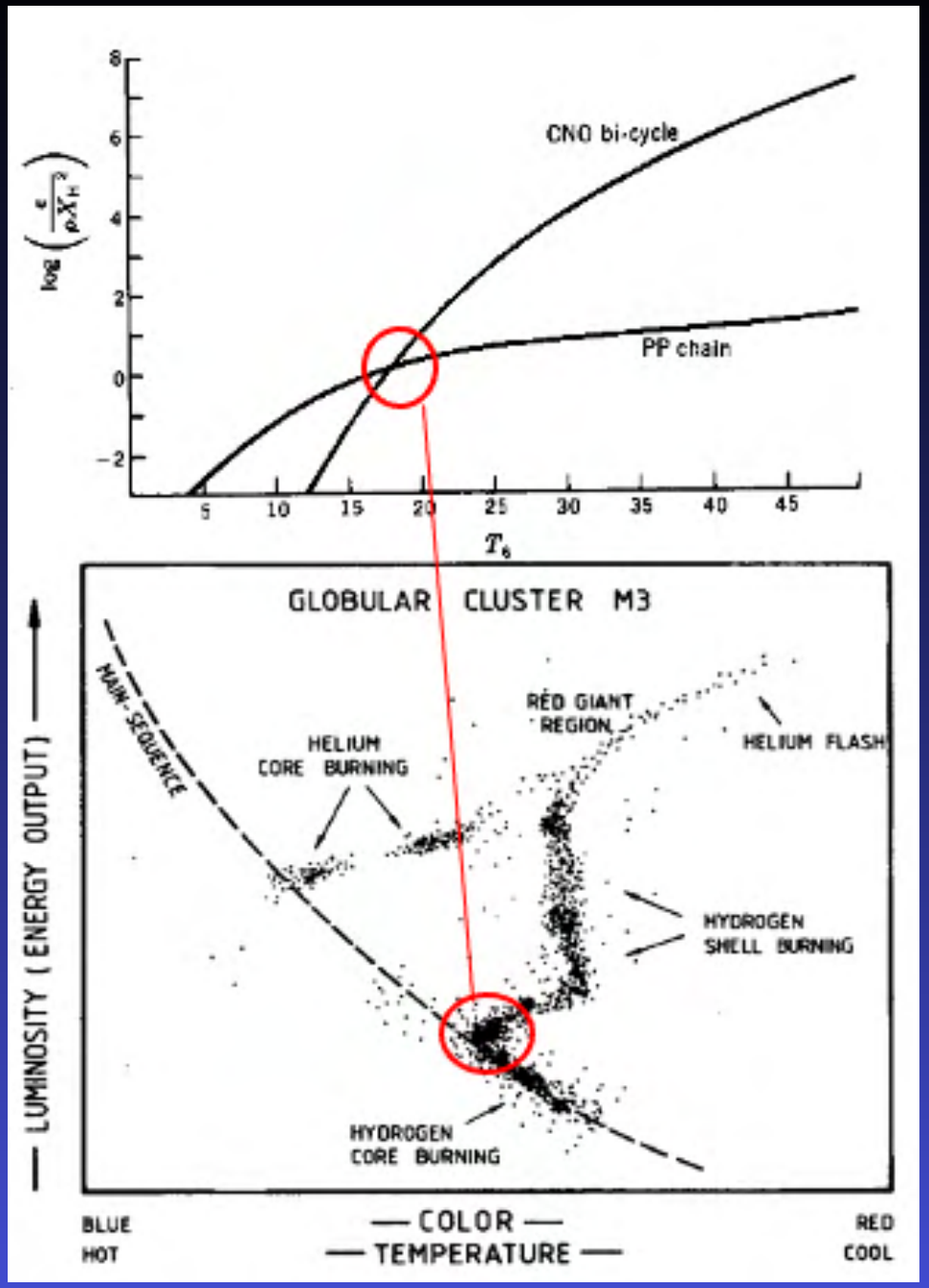

Lamb & Hester 1957
Schröder et al. 1997
NACRE extrapolation 1999
LUNA data 2004 (solid target) HpGe
LUNA extrapolation 2004
TUNL data 2005
LUNA data 2006 (gas target) BGO
Solar Gamow peak
Astrophysical S-factor [keV barn]
E_{CM} [keV]
0
2
4
6
0
50
100
150
200


Lamb & Hester 1957
Schröder et al. 1987
NACRE extrapolation 1999
LUNA data 2004 (solid target)
LUNA extrapolation 2004
TUNL data 2005
LUNA data 2006 (gas target)
CNO Φ_ν halved
Astrophysical S-factor [keV barn]
Solar Gamow peak
0
2
4
6
0
50
100
150
200
E_{CM} [keV]

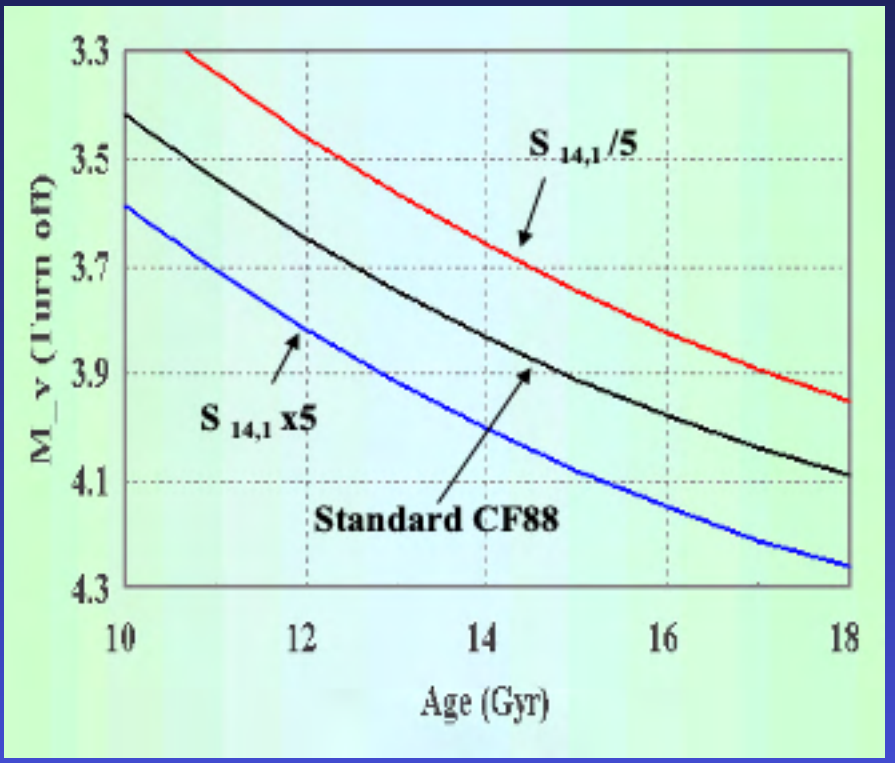


Gobular clusters are the oldest stars in our Galaxy

turnoff point is very sensitive to S_{14} (now halved)

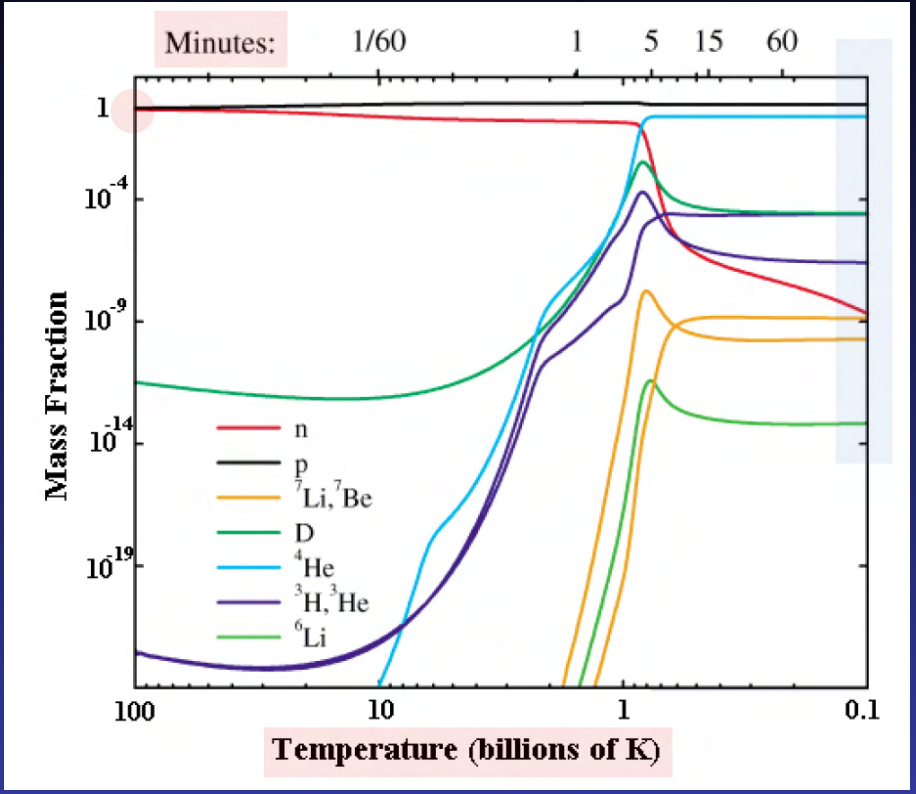


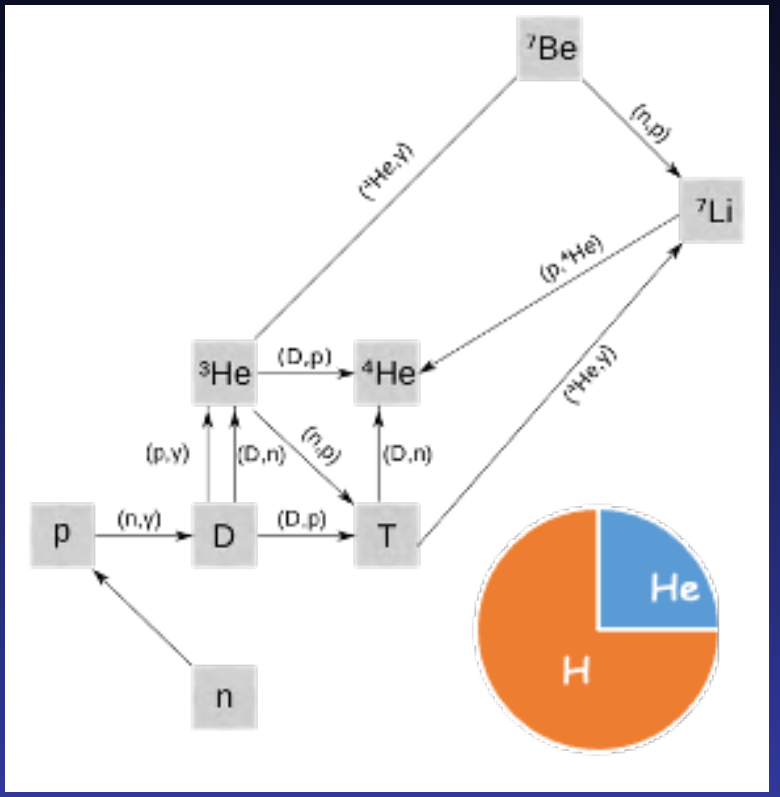
Globular Clusters (and our Galaxy) are 0.7 Gy older !!



$$p + d \rightarrow {}^{3}He + \gamma$$

Big Bang Nucleosynthesis





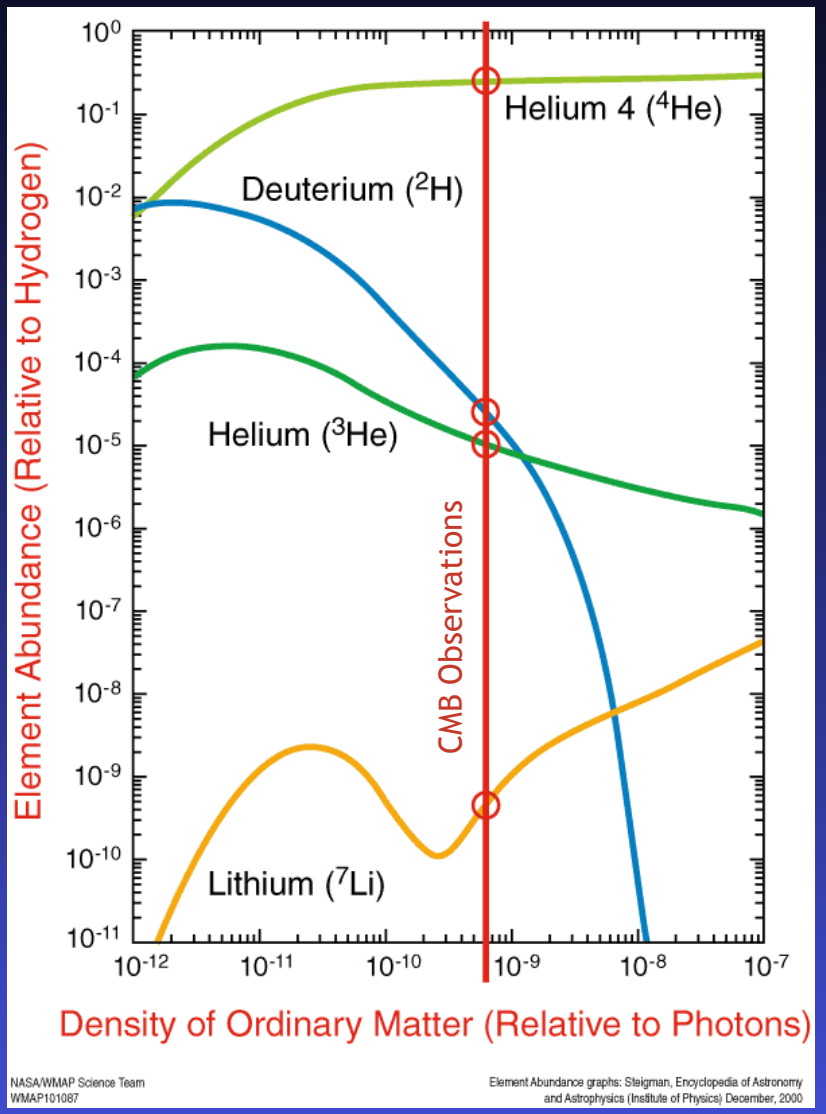
BBN occurs 3 minutes after Big Bang

After BBN mainly H and ^{4}He plus small amounts of D, ^{3}He, ^{6}Li and ^{7}Li

Primordial Nucleosynthesis (BBN)

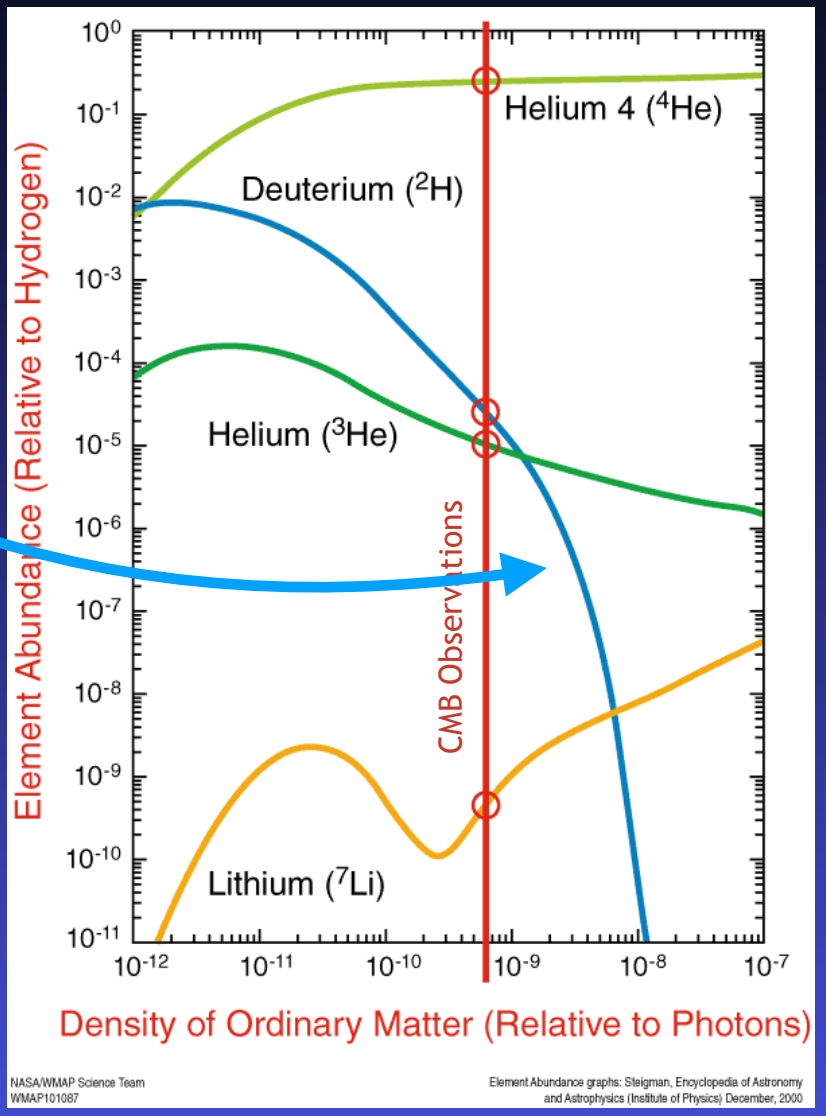
observation of $D, {}^3He, {}^4He$ an Li in very old (metal poor) stars provide stringent test of BBN

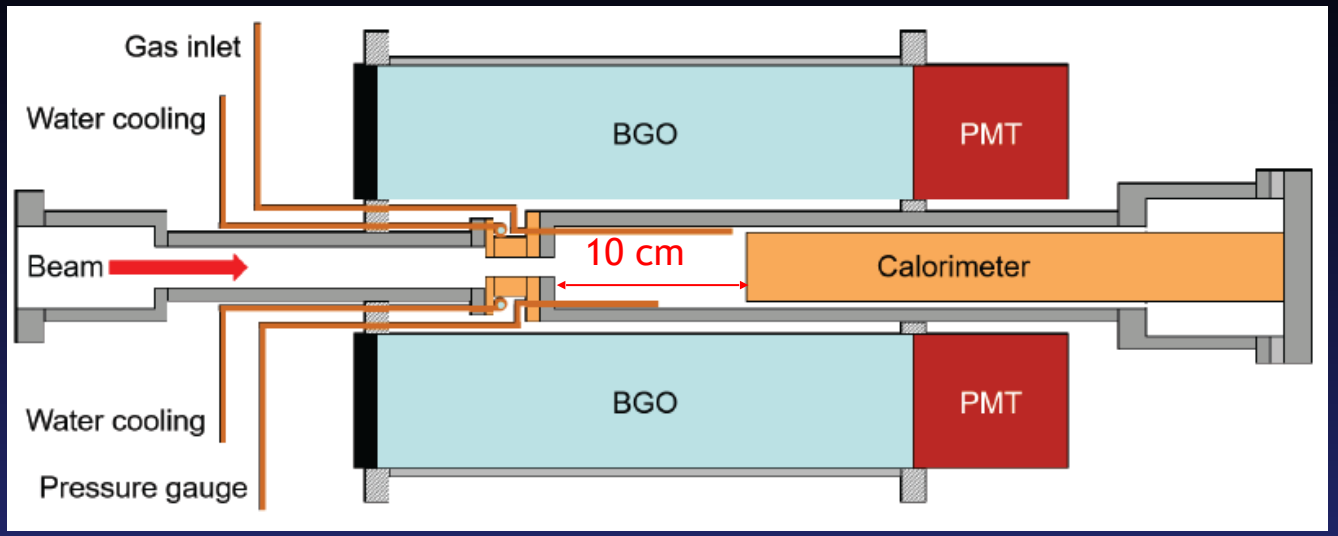
- ${}^4He$: emission lines in low-metallicity extragalactic regions HII. Probe for n/p ratio and N_{eff}
- D: light spectra of quasars crossing H gas clouds at high redshift. Consumed during stellar evolution: if observed, it's primordial.
- ${}^3He$: both produced and destroyed by stars, difficult to extract primordial sample.
- ${}^7Li$: absorption line in low metallicity stars in the galactic halo. ${}^6Li$: thermal broadening in the stellar atmospheres exceeds the isotope separation. Disputed measurements: if true, **"second Lithium problem"**.

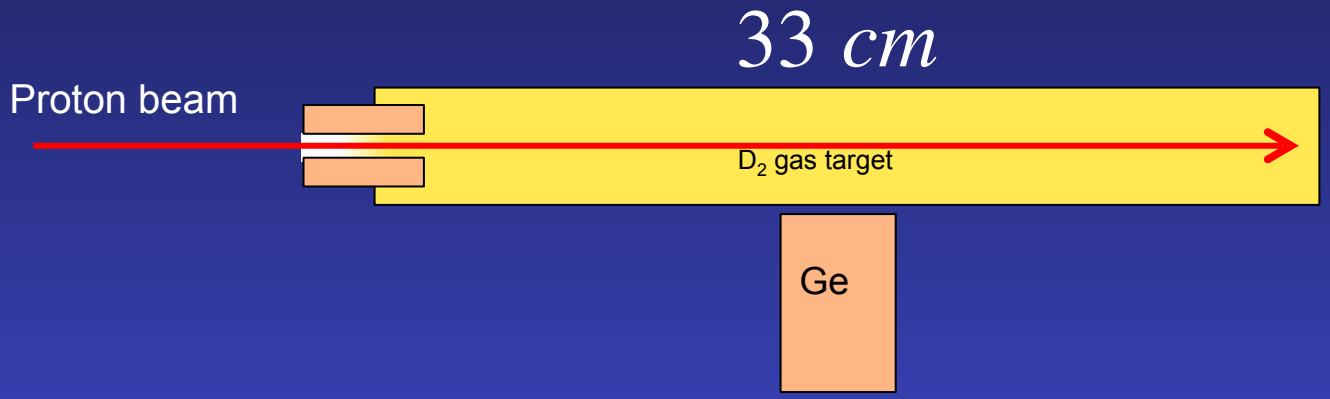


Primordial Nucleosynthesis (BBN)

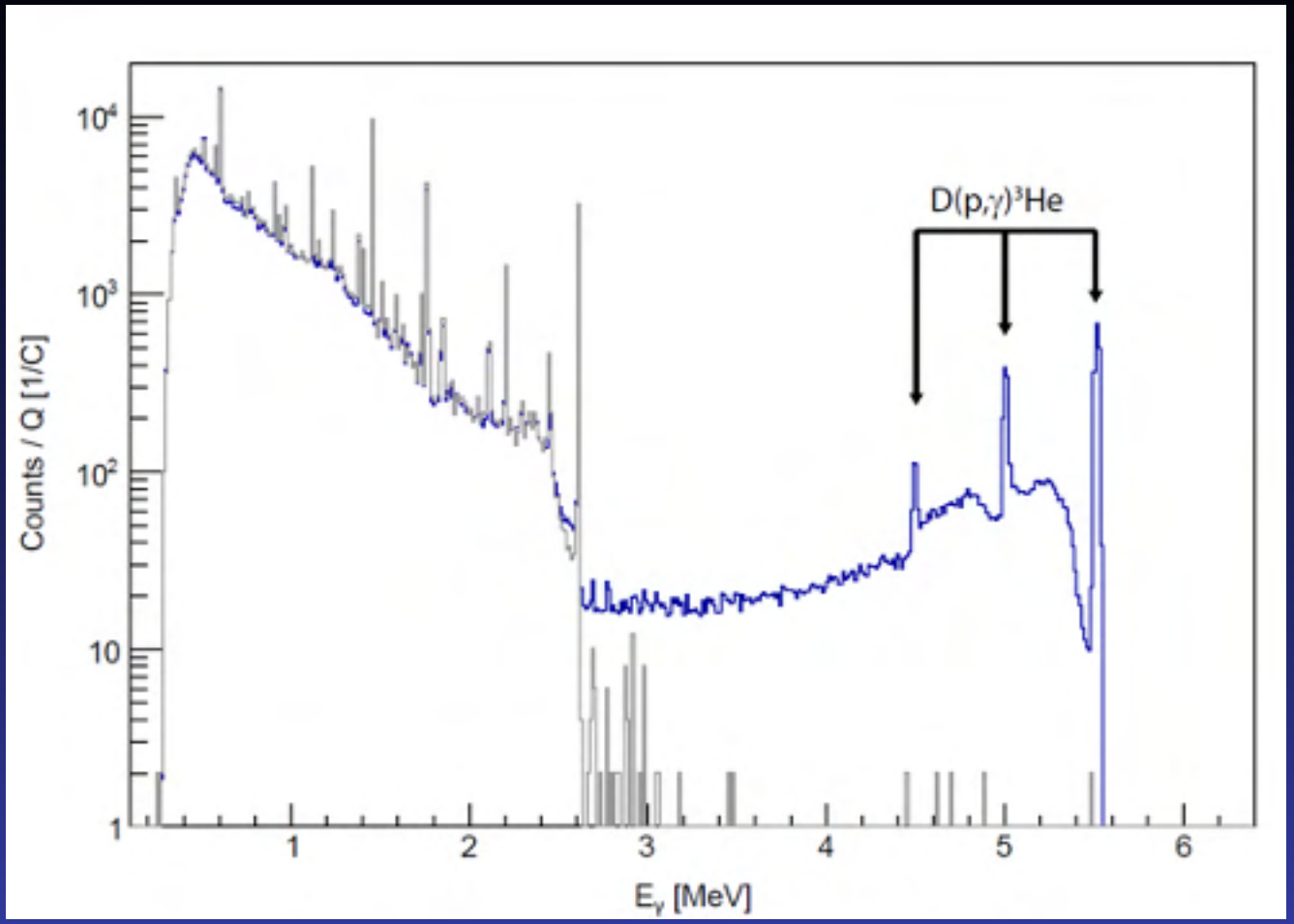
Deuterium is a bariometer




Gas inlet
Water cooling
BGO
PMT
Beam
10 cm
Calorimeter
BGO
PMT
Water cooling
Pressure gauge

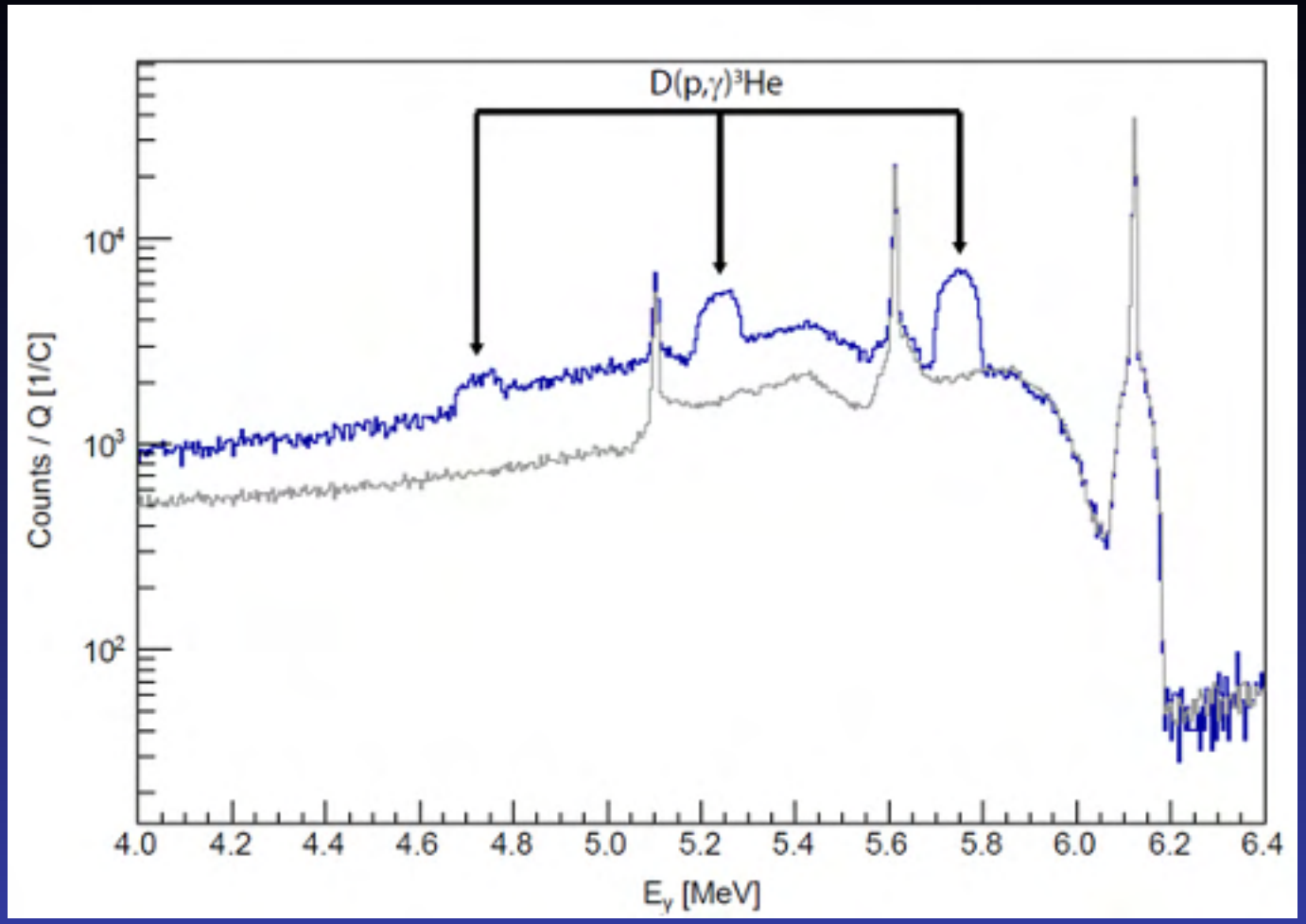

33 cm
Proton beam
D_2 gas target
Ge

Hp-Ge setup



Spectrum obtained @ E_p = 50 keV with D_2 gas target (P=0.3 mbar)

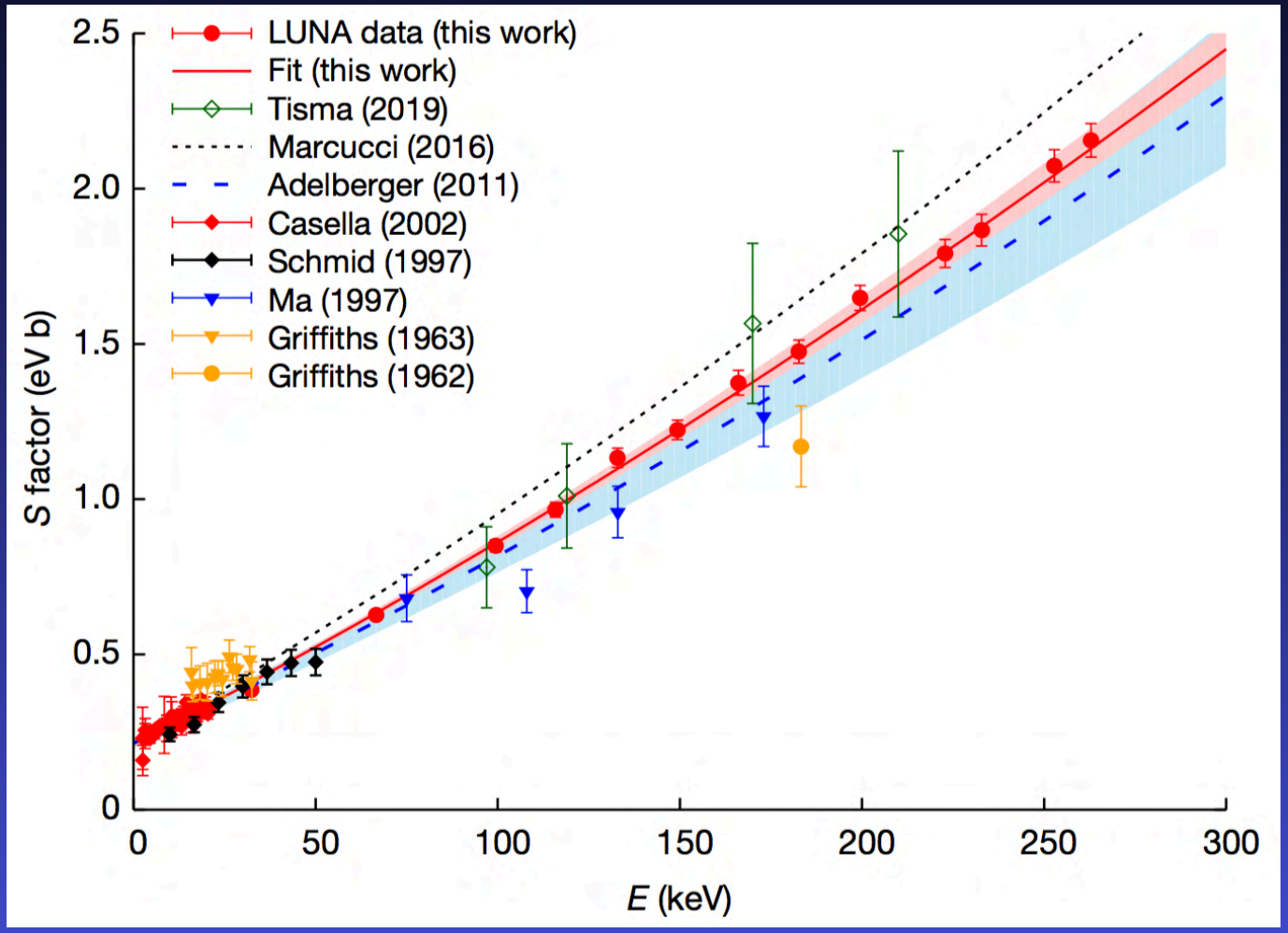
Spectrum obtained @ E_p = 50 keV with ^4He gas target (P=0.4 mbar)



Spectrum obtained @ E_p = 395 keV with D_2 gas target (P=0.3 mbar)

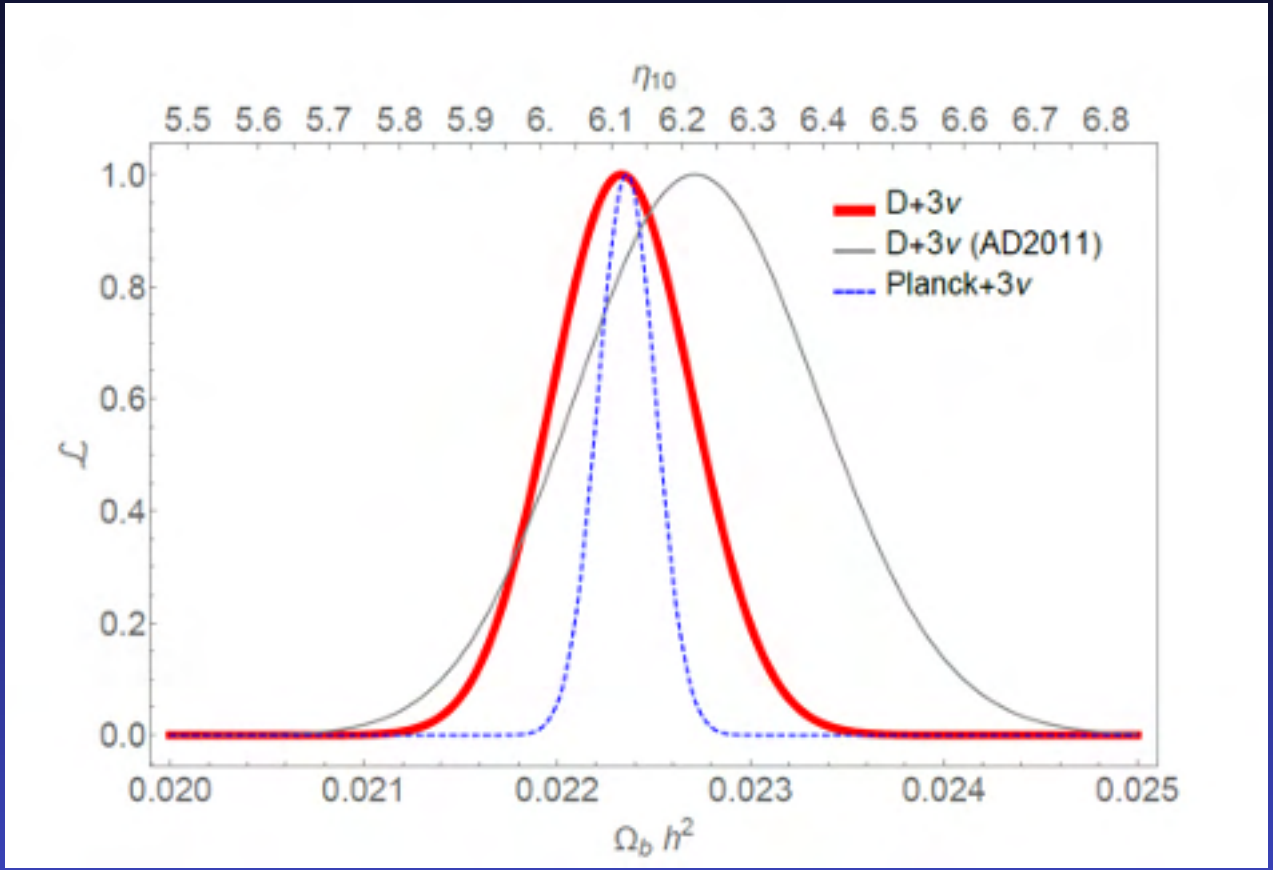
Spectrum obtained @ E_p = 395 keV with ^4He gas target (P=0.4 mbar)

Astrophysical S(E) factor



Baryon density obtained with PARTHENOPE code by comparing $[D/H]_{OBS}$ and $[D/H]_{BBN}$ $N_{eff} = 3.045$, fixed

Comparison with Planck results

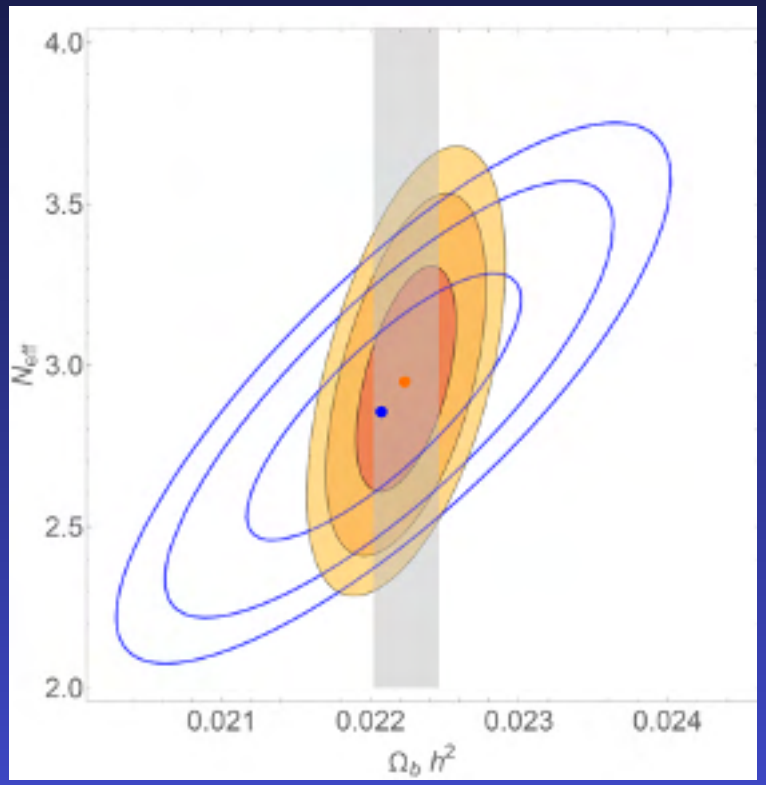


Analysis performed by Ofelia Pisanti and Gianpiero Mangano

Likelihood analysis, both $\Omega_b h^2$ and N_{eff} left as free parameters

D+CMB case with $(D/H)_{obs}$ and $(D/H)_{BBN}$ combined with the CMB baryon density from Plank

D+CMB case with observed and predicted values of both deuterium abundance and the ^4He mass fraction, Y_p



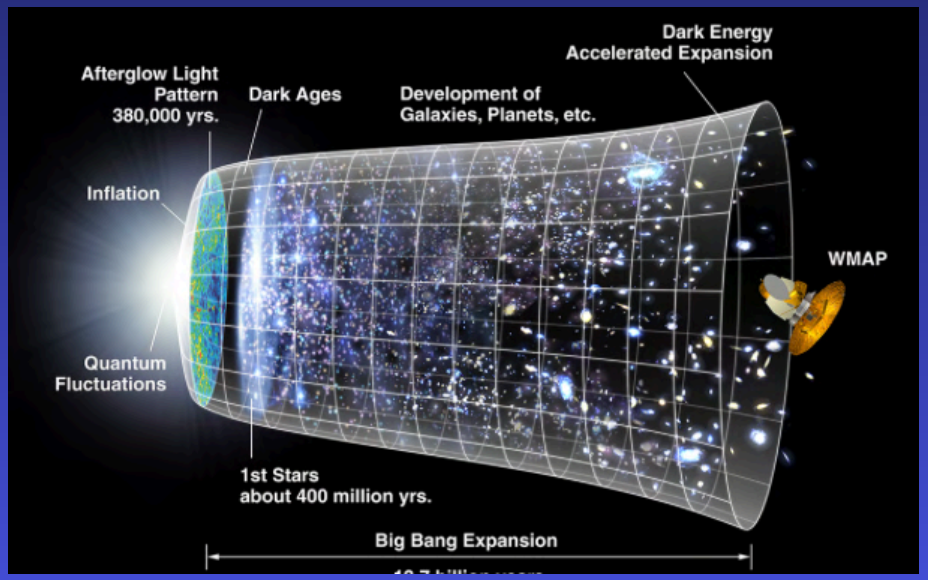
$$N_{eff} = 2.95^{+0.61}_{-0.57}$$

$$N_{eff} = 2.86^{+0.75}_{-0.67}$$

Our largest value of N_{eff} deviates by at most 20% from $N_{eff} = 3.045$

Summary:

- BBN + $(D/H)_{obs}$ very good agreement on the baryon density with cosmic microwave background (Planck):
- no tension between few minutes and 380000 years after Big Bang, no need for new physics
- We confirm $N_{eff} = 3$ (by excluding $> 3\sigma$ $N_{eff} = 2,4$)
- Direct observation, BBN and CMB do agrees on D abundance!
- Standard cosmological model is supported



What's next ?

Luna MV ⇒ Bellotti Ion Beam Facility

single ended da 3.5 MV linear accelerator

now under LNGS management
scientific programs approved by PAC

18/10/2023 inaugurazione Bellotti Ion Beam Facility

...but this is your task !!

Courtesy: H.P. Trautvetter


thank you all !!
I wish you
all the best!
per aspera ad astra !

Before starting, I want to explain the reason for this seminar, which will be more a chat among friends than a scientific seminar.

Well, you must know that, due to age restrictions, the INFN has not allowed me to attend this meeting as a simple spectator, but only if my presence makes a significant scientific contribution to the meeting .

Honestly, I'm almost eighty years old, I retired ten years ago, and I can't expect the INFN to continue spending money on my travel expenses.

So I was about to give up, when Sandra and a group of friends spoke together and found a trick: Zsolt, as a convener of this meeting, with an official invitation letter to give a prestigious seminar, convinced the director of the Genoa section (who many and many years ago was a student of mine and now is going to retire…).

So I asked myself: why not to take advantage of this opportunity to tell, like a grandfather, the tale of LUNA to the young people who weren't even born when this fantastic adventure stared ? And that is what I'll try to do..