

# CHAMPs a sprawę litową

Czy długожyciowe masywne cząstki naładowane były zamieszane w aferę litową?



Kobieta z wazonem (1903)

T. Axentowicz (lit. barwna)



pegmatyt

# $\alpha\beta\gamma$ papier

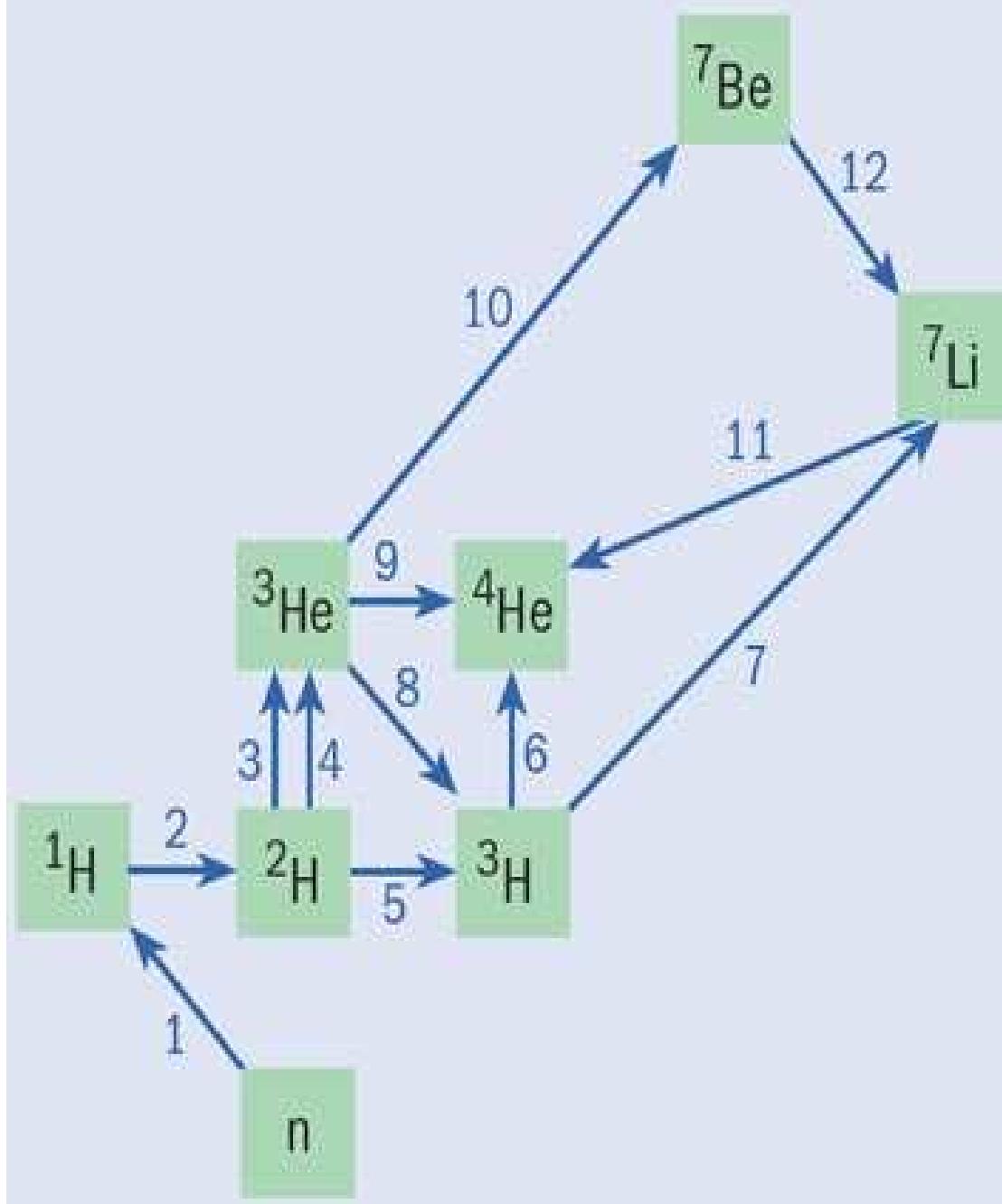


Pionierzy idei pierwotnej nukleosyntezy

R. A. Alpher, H. Bethe and G. Gamow.

*The Origin of Chemical Elements,*  
Physical Review, 73 (1948), 803.

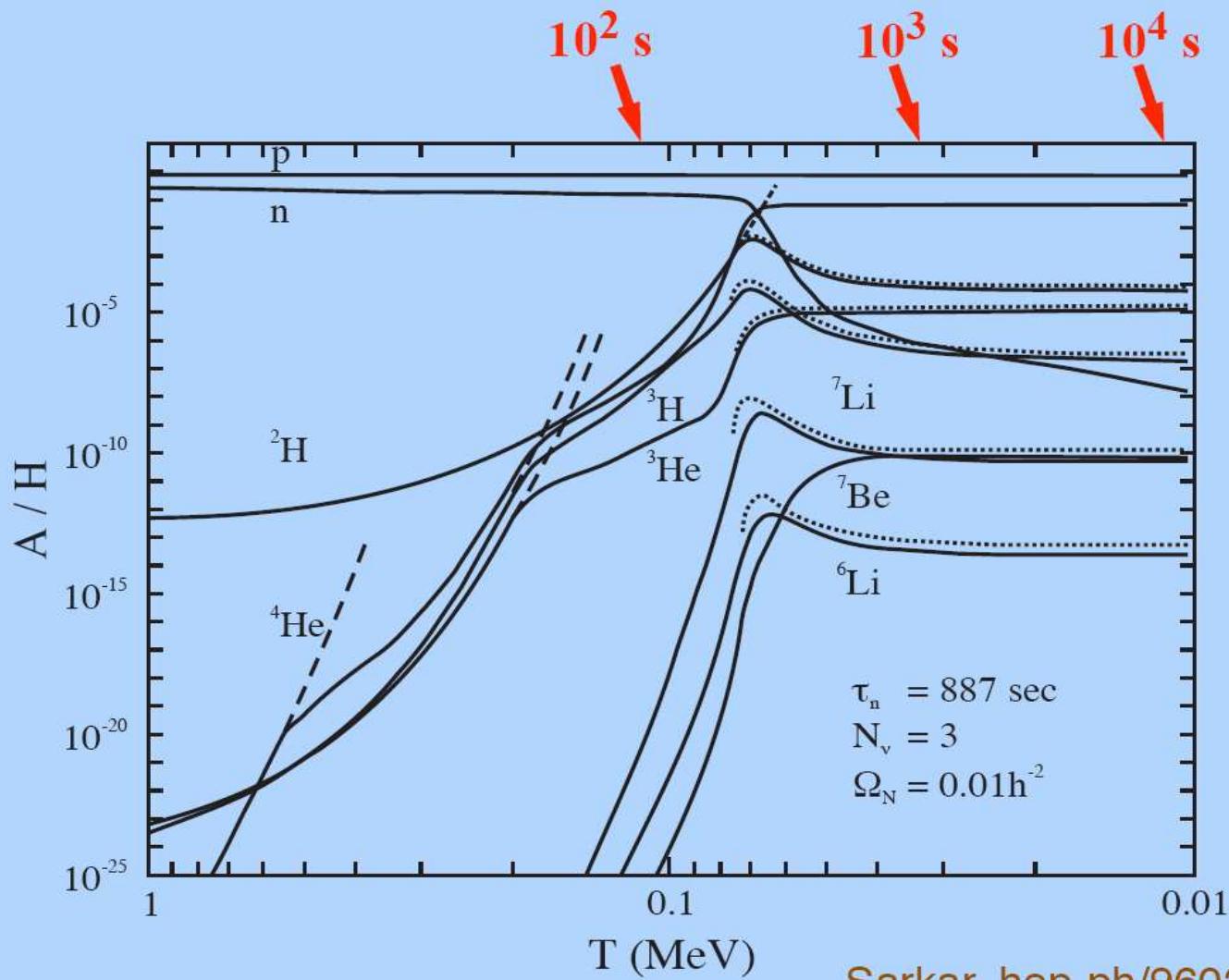
# reakcje pierwotnej nukleosyntezy



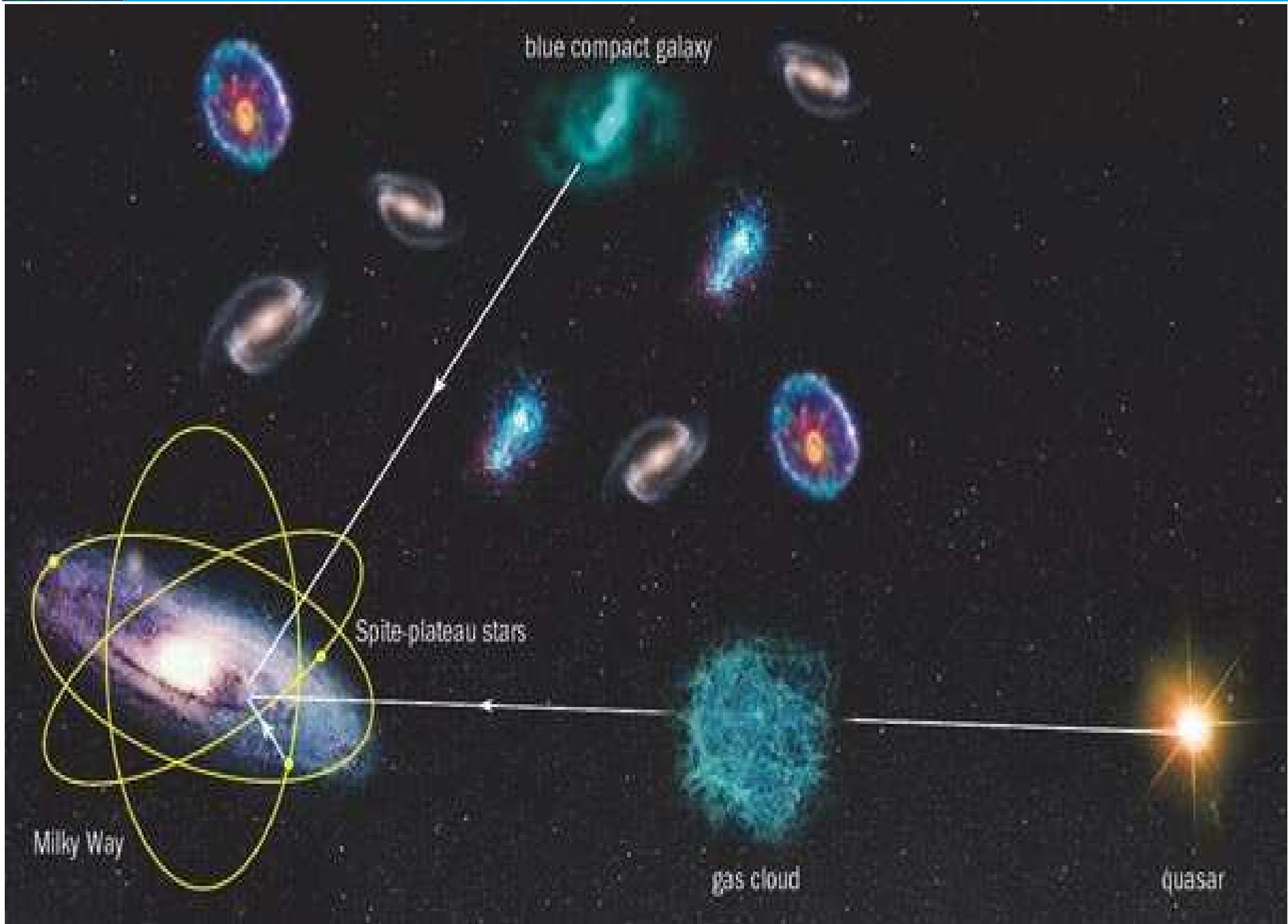
- 1  $n \rightarrow {}^1H + e^- + \bar{\nu}$
- 2  ${}^1H + n \rightarrow {}^2H + \gamma$
- 3  ${}^2H + {}^1H \rightarrow {}^3He + \gamma$
- 4  ${}^2H + {}^2H \rightarrow {}^3He + n$
- 5  ${}^2H + {}^2H \rightarrow {}^3H + {}^1H$
- 6  ${}^2H + {}^3H \rightarrow {}^4He + n$
- 7  ${}^3H + {}^4He \rightarrow {}^7Li + \gamma$
- 8  ${}^3He + n \rightarrow {}^3H + {}^1H$
- 9  ${}^3He + {}^2H \rightarrow {}^4He + {}^1H$
- 10  ${}^3He + {}^4He \rightarrow {}^7Be + \gamma$
- 11  ${}^7Li + {}^1H \rightarrow {}^4He + {}^4He$
- 12  ${}^7Be + n \rightarrow {}^7Li + {}^1H$

# Przewidywania pierwotnej nukleosyntezy

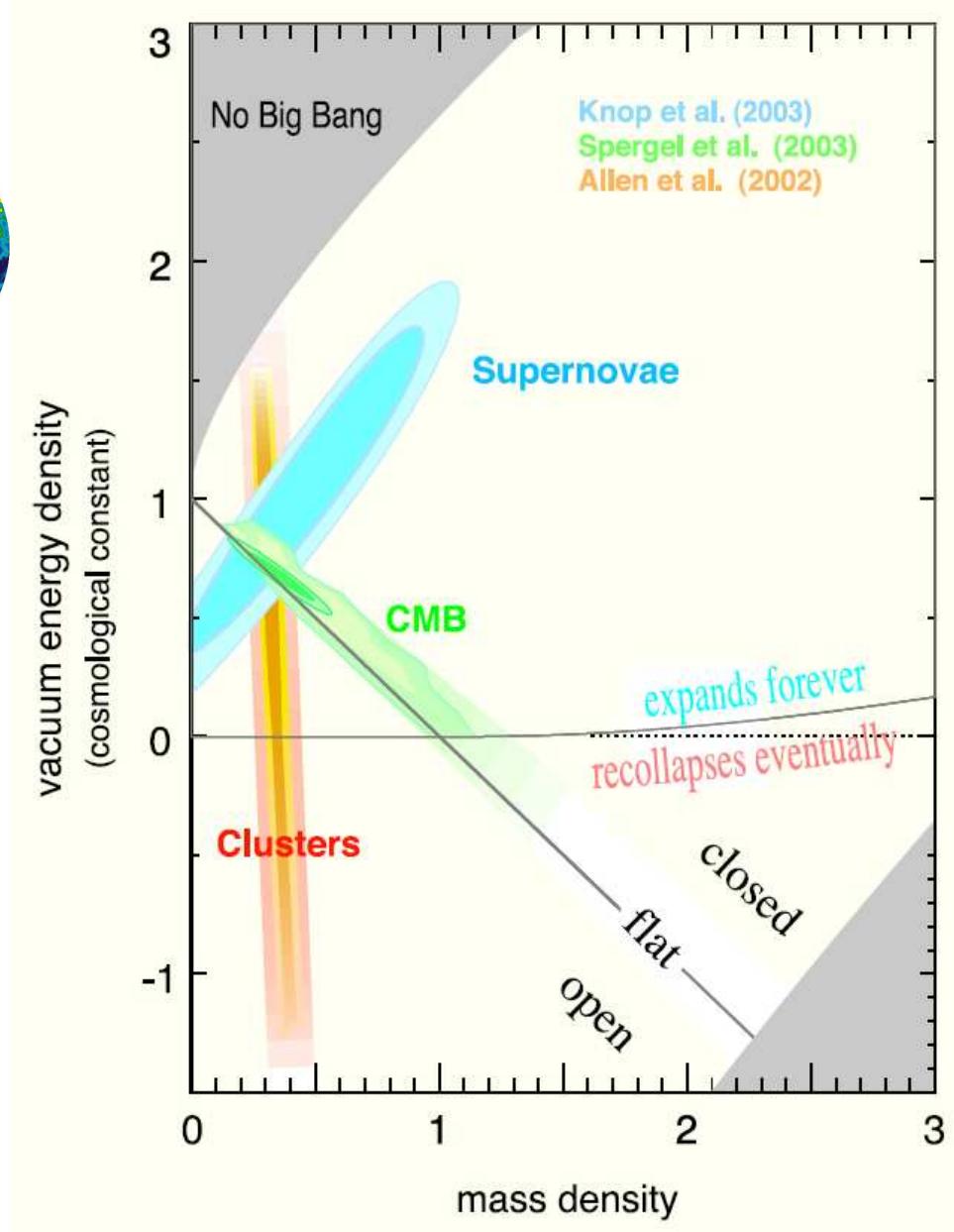
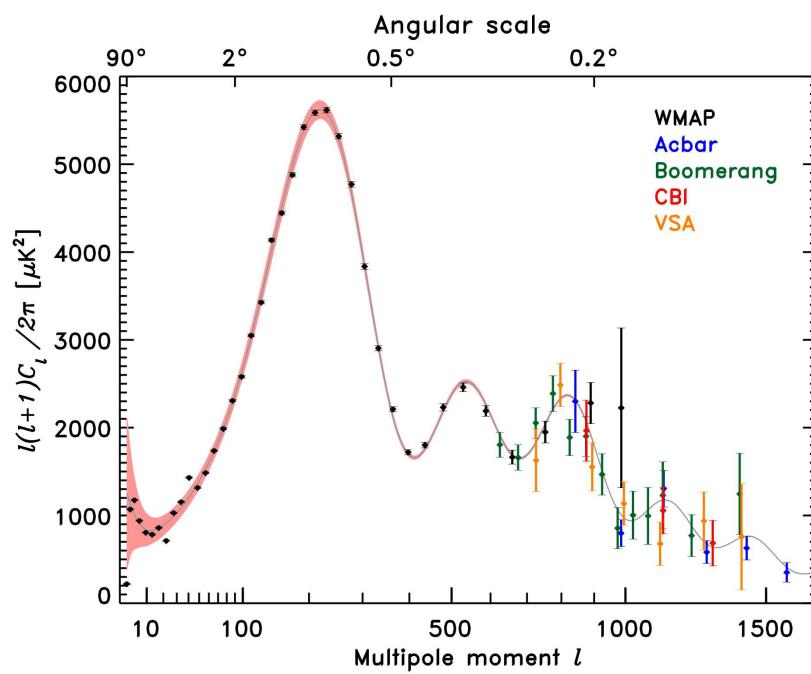
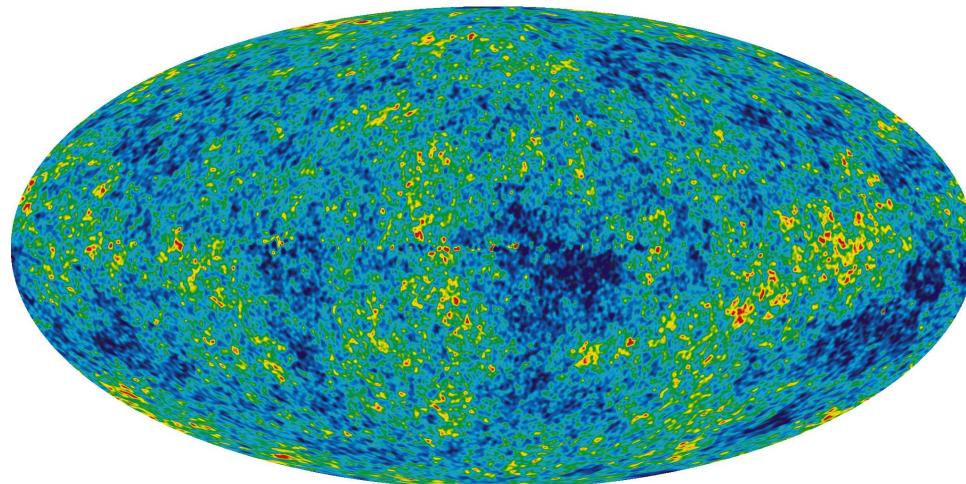
## *Light elements production*



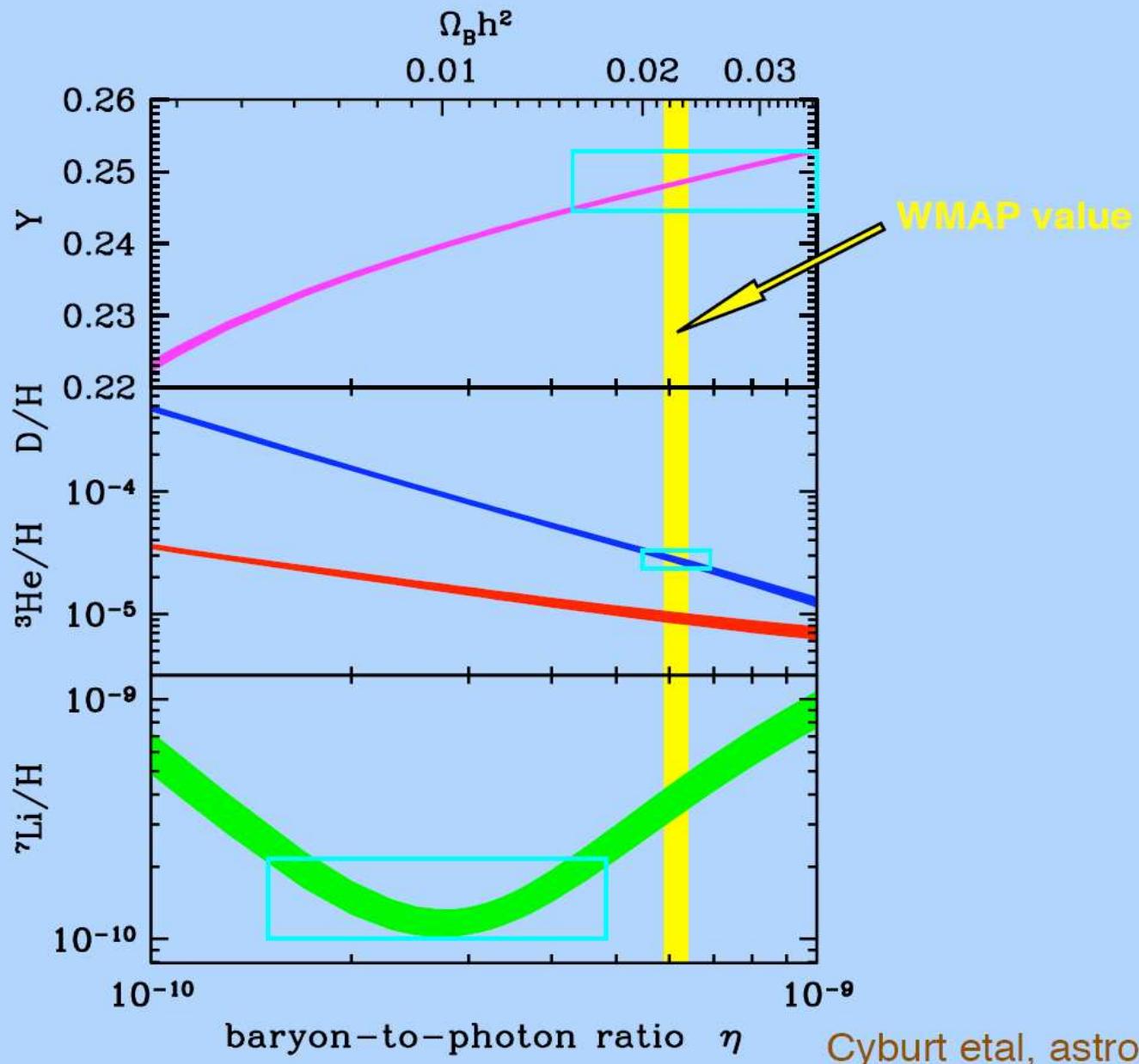
# Jak to się mierzy?



# Niezależny pomiar: WMAP et all



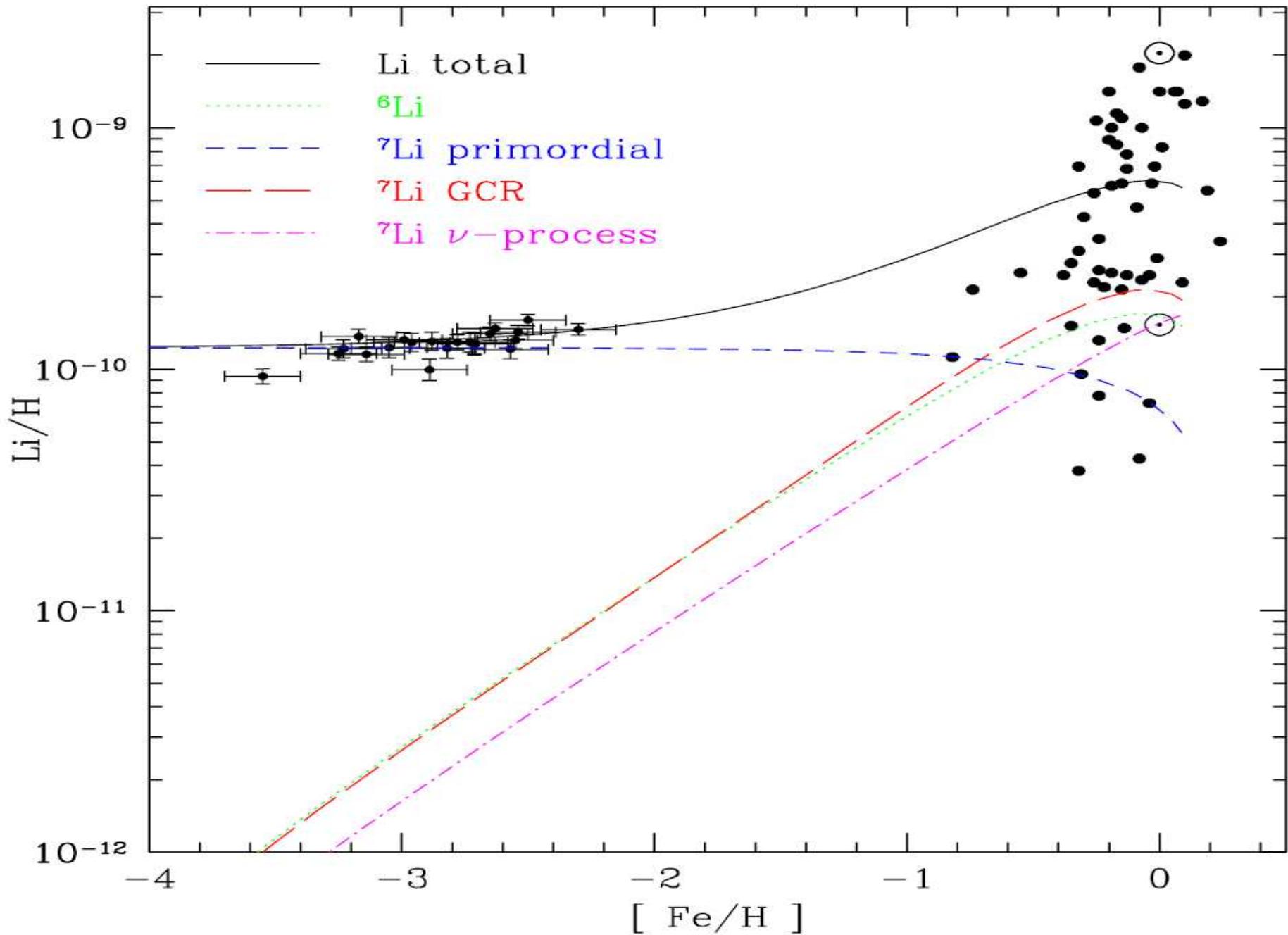
# Porównanie



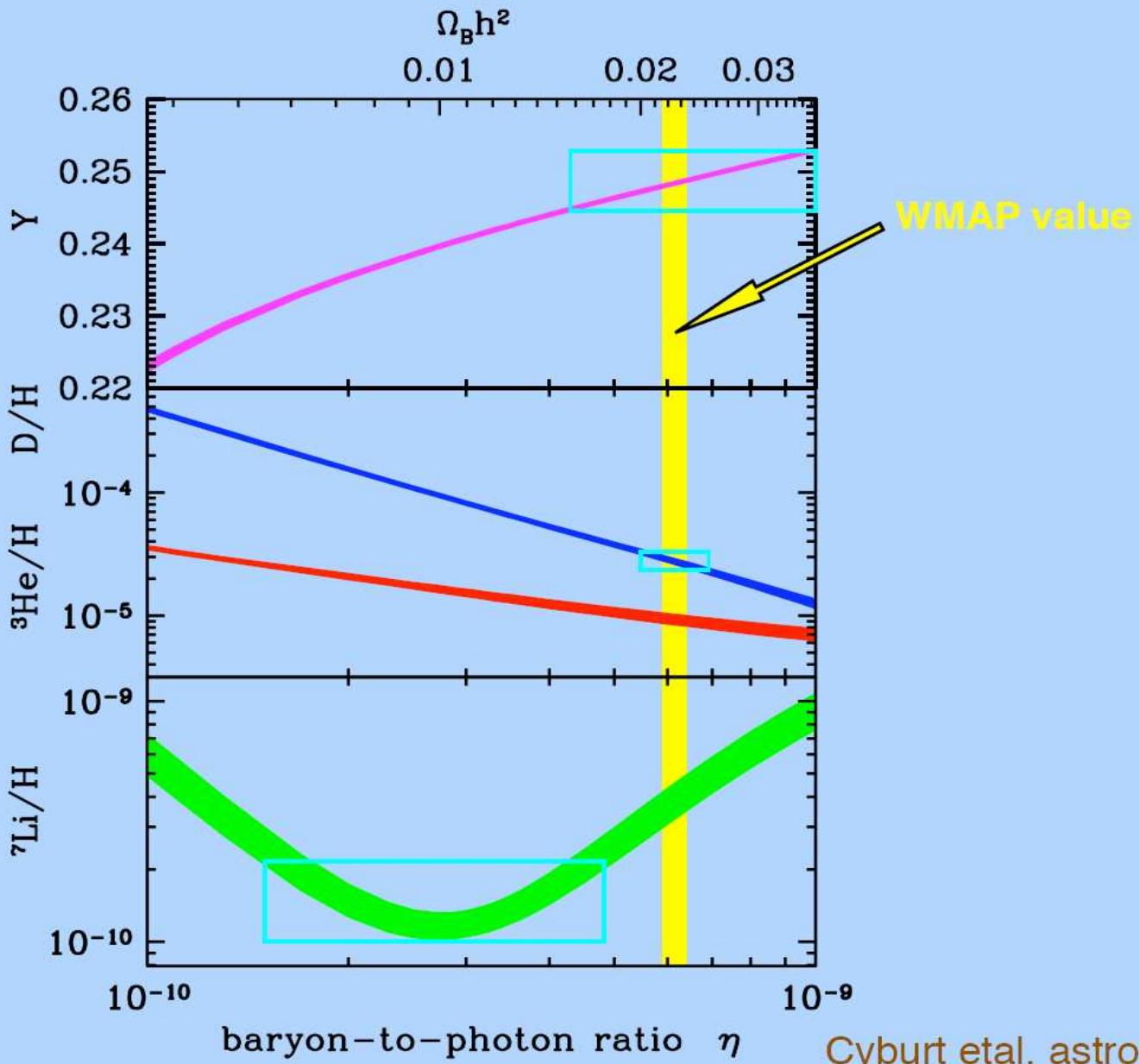
# Sprawa litu - M80



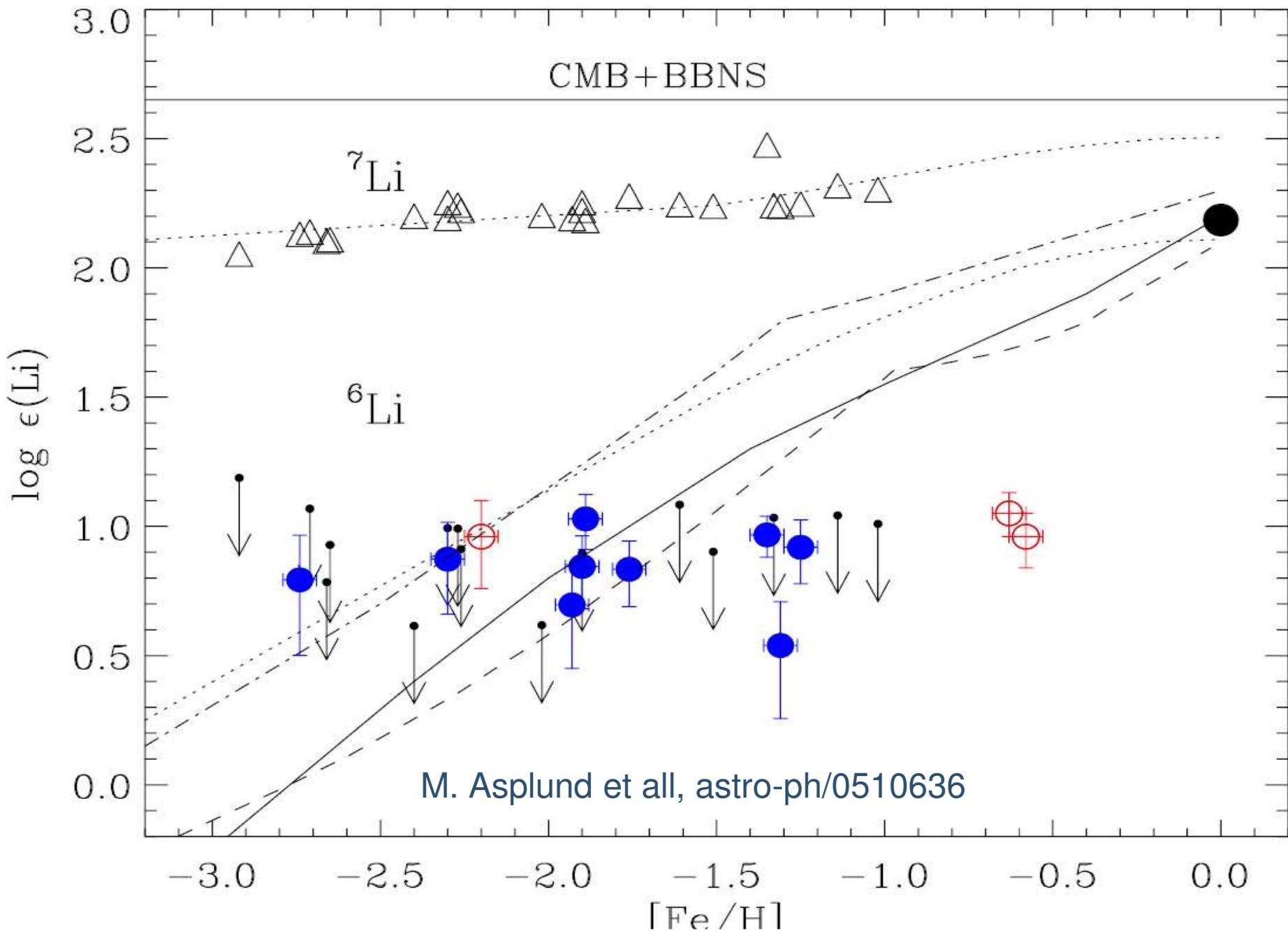
# Sprawa litu - plato Spite'ów



# Sprawa litu - brak litu 7



# Sprawa litu - nadmiar litu 6

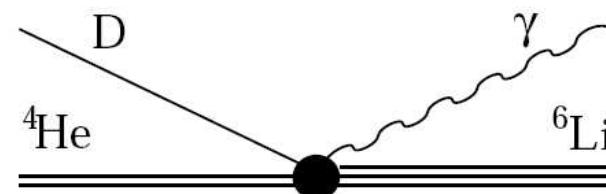


# kataliza za pomocą CHAMPs

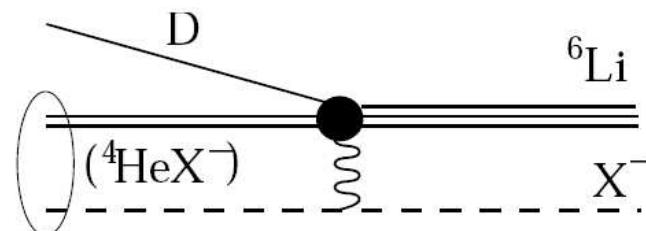
## Catalyzed BBN

- bound-state formation of  $X^-$  with light elements opens up new reaction channels
- most significant for production of  ${}^6\text{Li}$  [Pospelov, 2006]

standard BBN:  
 $\rightarrow \langle \sigma v \rangle$



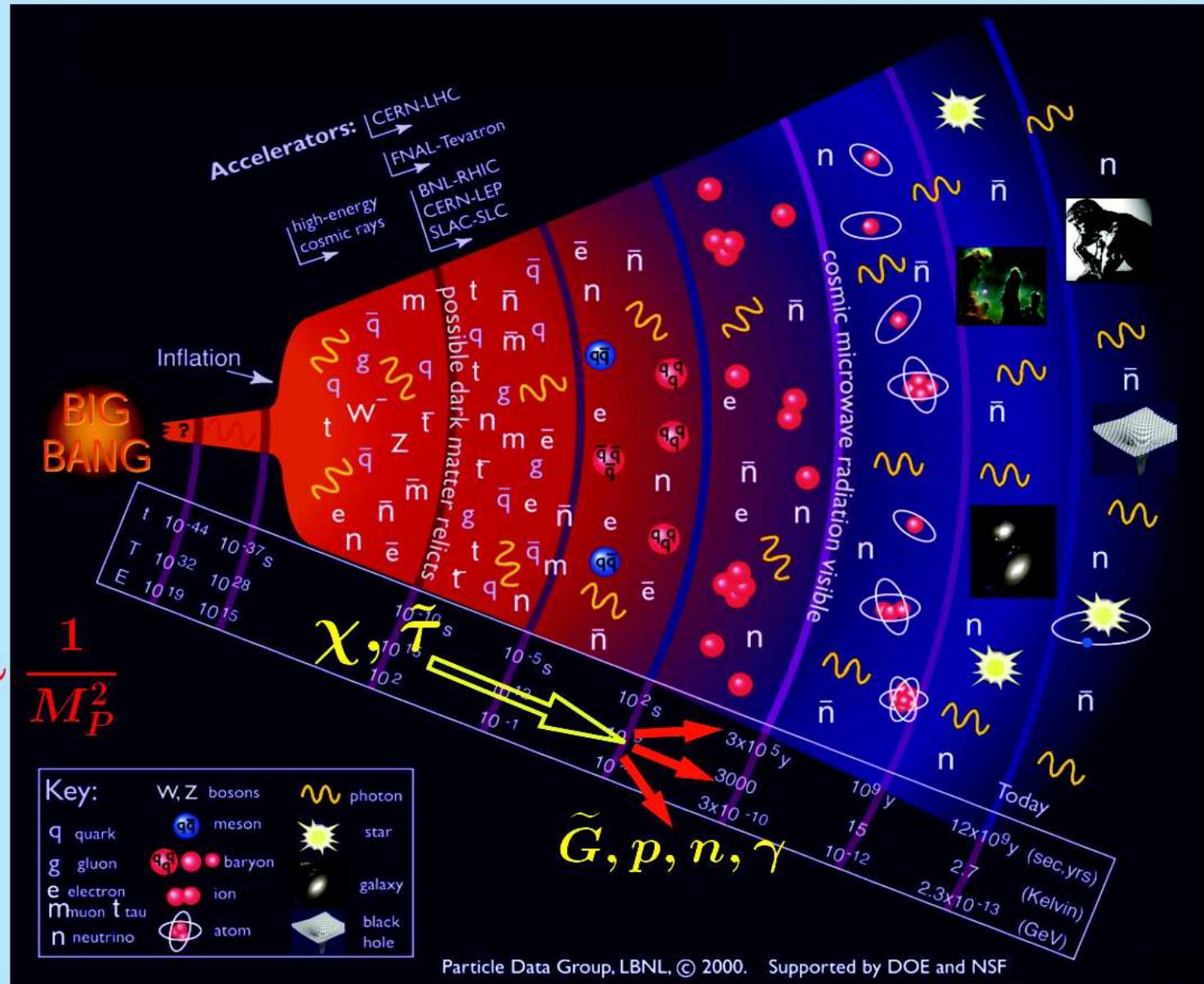
catalyzed BBN:  
 $\rightarrow \langle \sigma_C v \rangle$



cross-section enhanced by 7 orders of magnitude

# Historia Wszechświata

.. if gravitino is the LSP

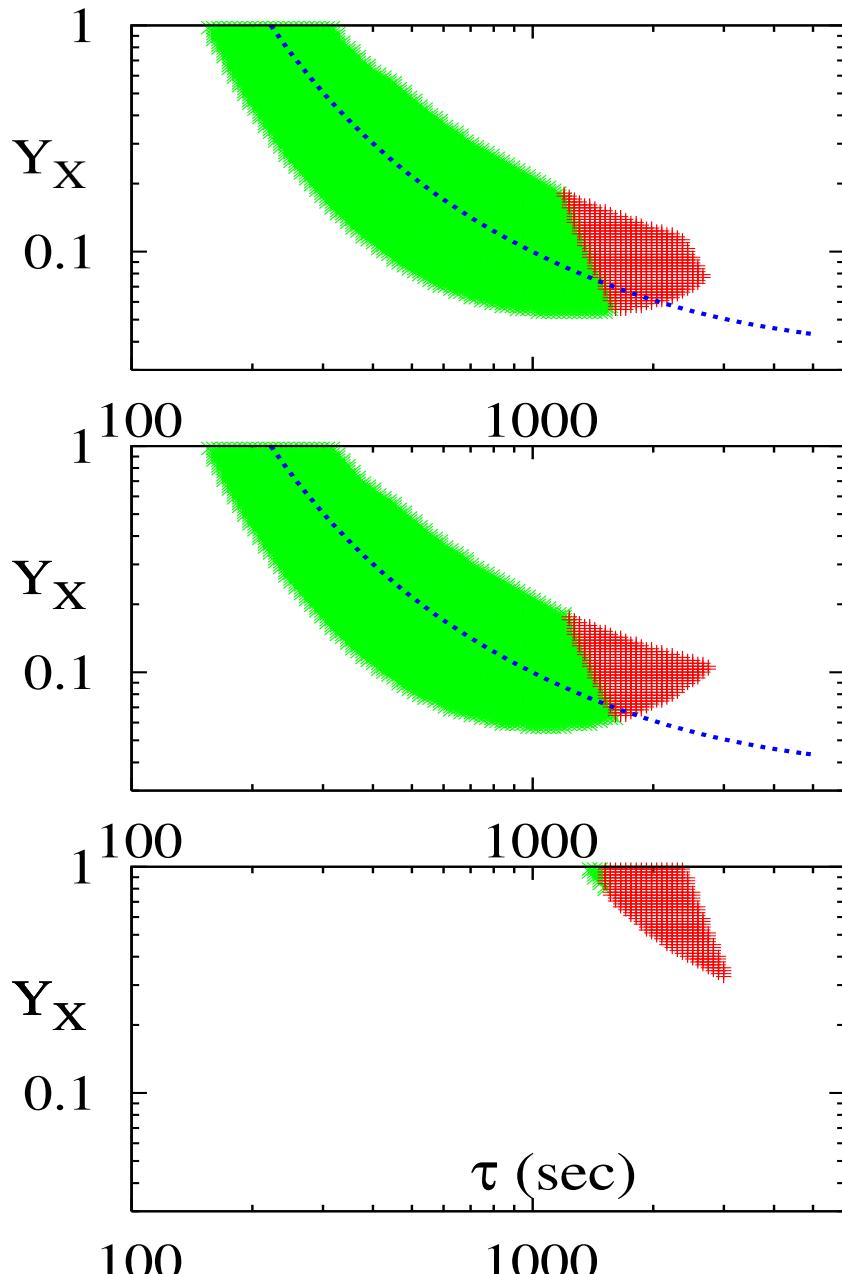


# referencje (z tegorocznego lata)

## Catalyzed BBN

- bound-state formation of  $X^-$  with light elements opens up new reaction channels
- most significant for production of  ${}^6\text{Li}$  [Pospelov, 2006]
- recent result for  ${}^6\text{Li}$  production cross section  $\langle \sigma_C v \rangle$  [Hamaguchi et al., 2007]
- For additional constraints on  ${}^4\text{He}$ ,  ${}^3\text{He}/\text{D}$ ,  $\text{D}$ ,  ${}^7\text{Li}$  and  ${}^6\text{Li}/{}^7\text{Li}$  see e.g. [Sigl et al., 1995; Jedamzik, 2000, 2004, 2006; Kawasaki et al. 2005; Cyburt et al., 2006; Kawasaki et al., 2007]  
→ talk by Vassilis Spanos
- → only D bound can be more severe than  ${}^6\text{Li}|_{\text{CBBN}}$  bound
- ${}^6\text{Li}|_{\text{CBBN}}$  bound might vanish for  $\tau_{\tilde{\tau}} \gtrsim 10^7$  s [Jedamzik, 2007]

# Rozwiązań dla $\tau_X \sim 1000\text{s}$



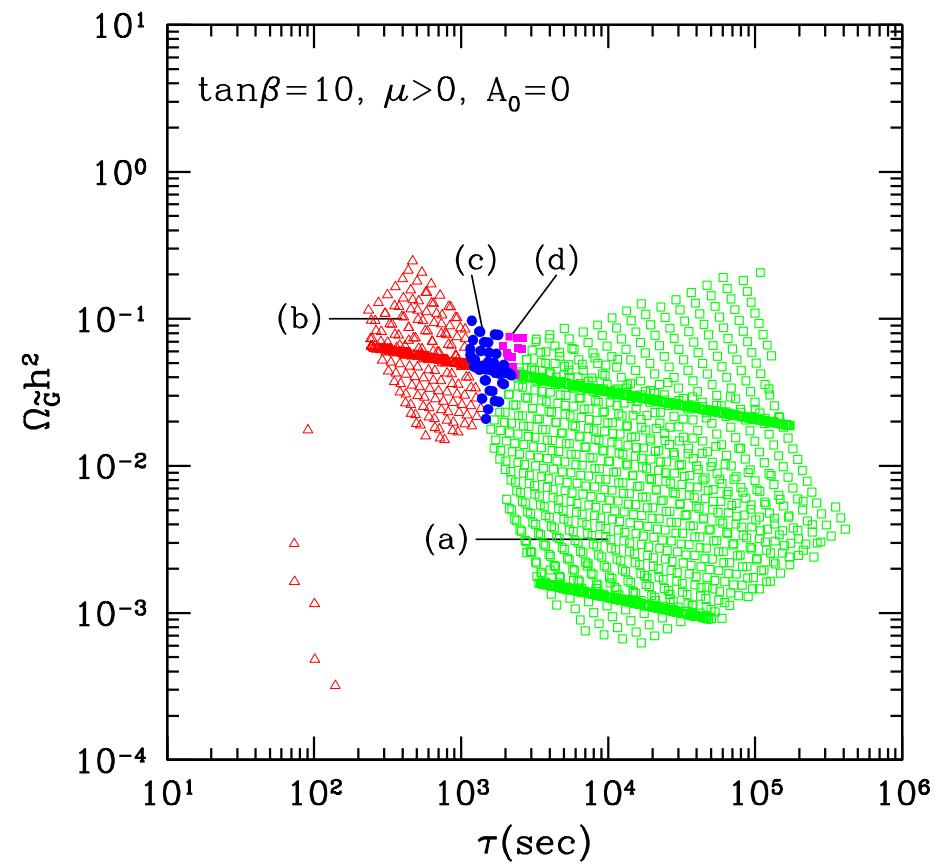
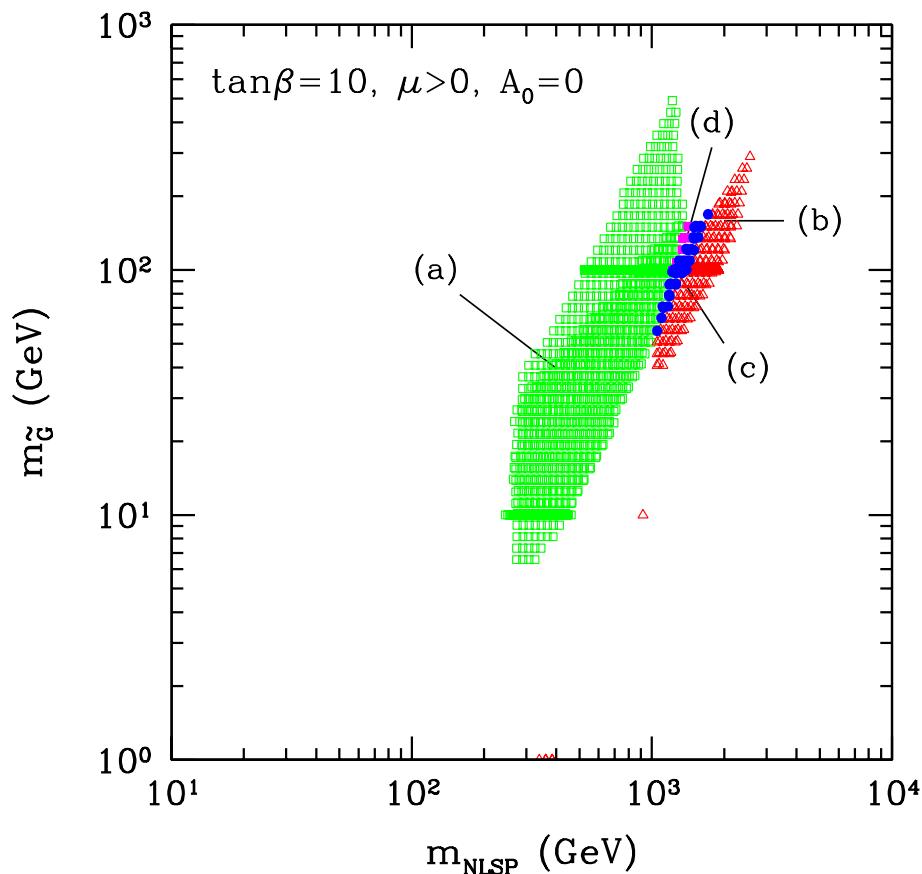
Parameter space in the relic particle-to-baryon ratio  $Y_X$  and relic particle decay time  $\tau_X$  which may resolve either the  $^7\text{Li}$  problem (green) or both, the  $^7\text{Li}$  and  $^6\text{Li}$  problems (red).

The panels show, from top to bottom:  
 a charged relic with  $B_h = 10^{-4}$ ,  
 a neutral relic with  $B_h = 10^{-4}$ , and a charged relic with  $B_h = 0$ .

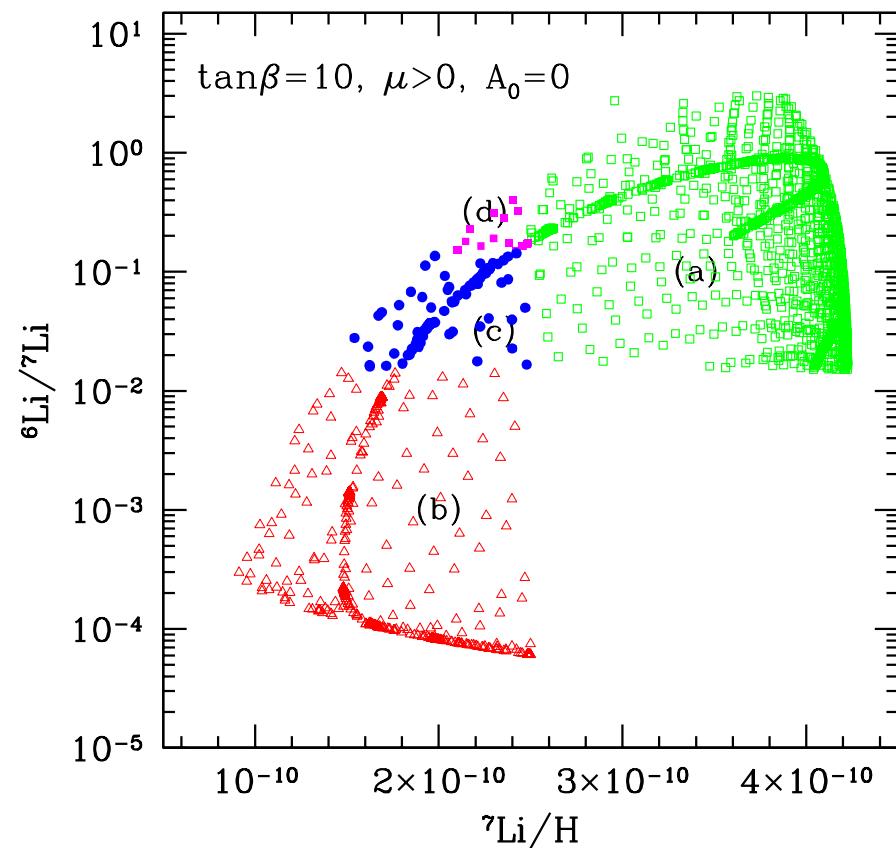
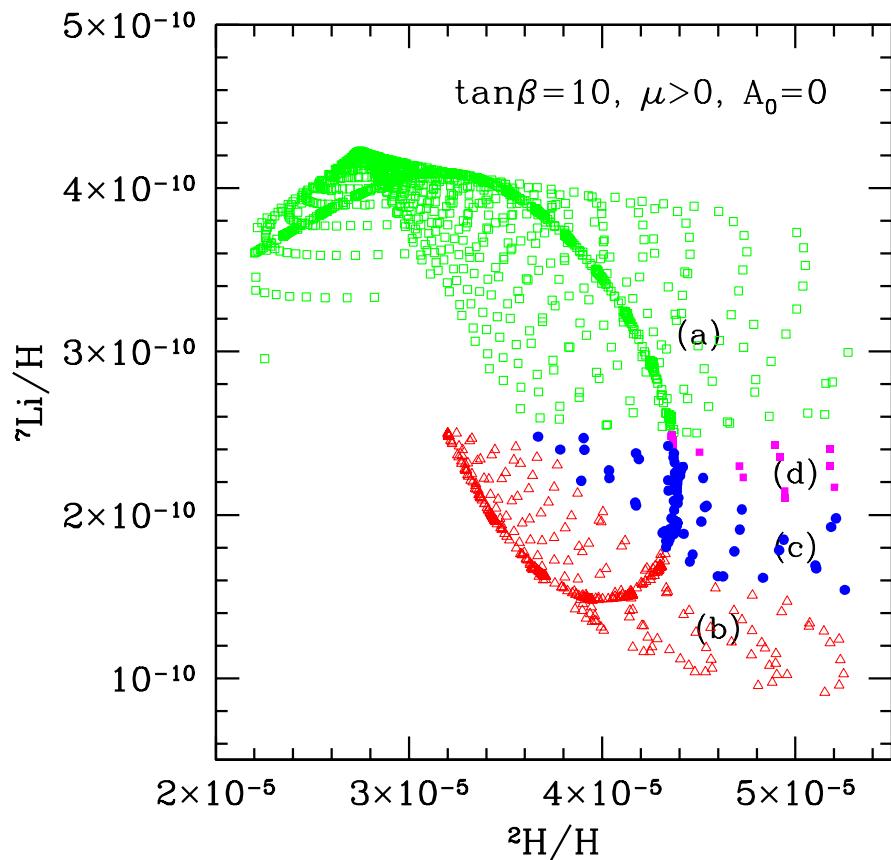
All three panels assume a mass  $M_x = 1\text{ TeV}$  for the relic.  
 Above the dotted lines the  $^2\text{H}/^1\text{H}$  ratio exceeds a value of  $4 \times 10^{-5}$ .

K. Jedamzik astro-ph:07072070v3

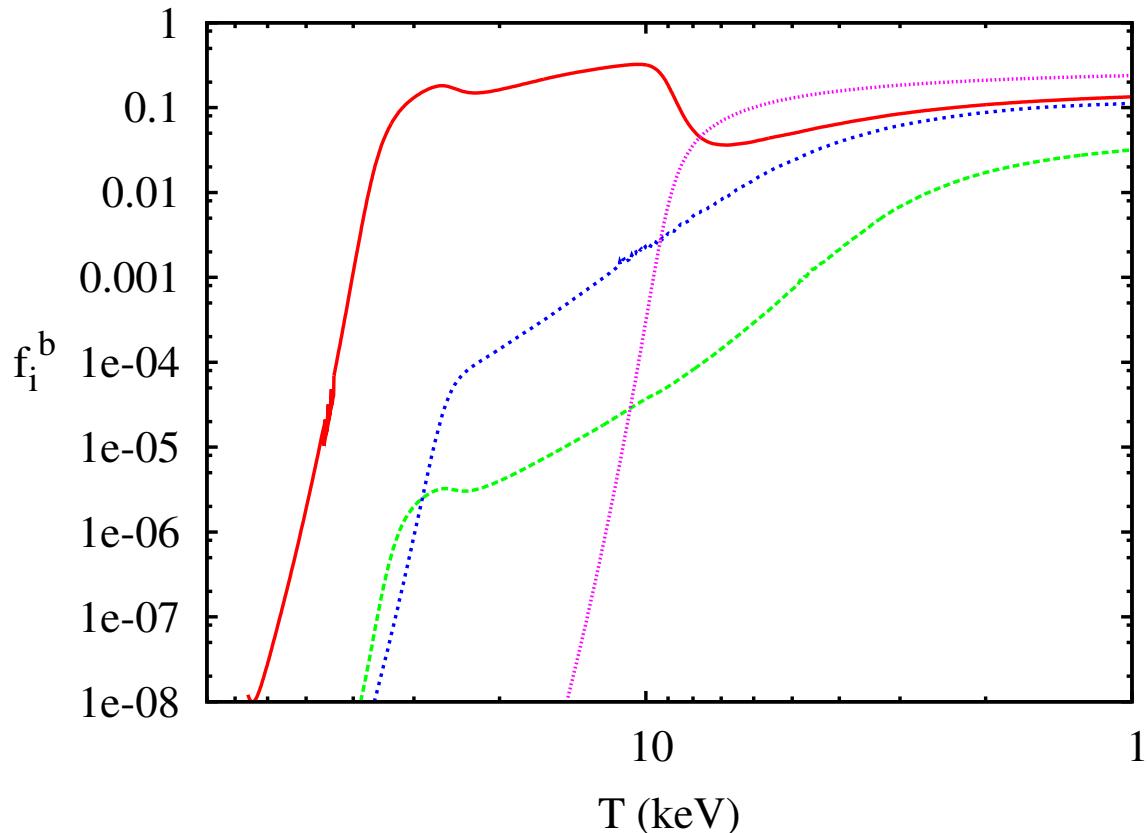
hep-ph/0512044



hep-ph/0512044



# Frakcje stanów związanych



Bound state fractions

$f_i^b \equiv n_{(N_i X^-)} / n_{N_i}^{tot}$  of nuclei  $N_i$  bound to CHAMP  $X^-$  as a function of temperature  $T$ , for a model with  $M_X = 100$  GeV and  $\Omega_X h^2 = 0.1$  (corresponding to a CHAMP-to-baryon ratio  $Y_{X^-} = 4.26 \times 10^{-2}/2$ ). Shown are  $f_i^b$  for  ${}^7\text{Be}$  (red),  ${}^7\text{Li}$  (green),  ${}^6\text{Li}$  (blue) and  ${}^4\text{He}$  (purple).

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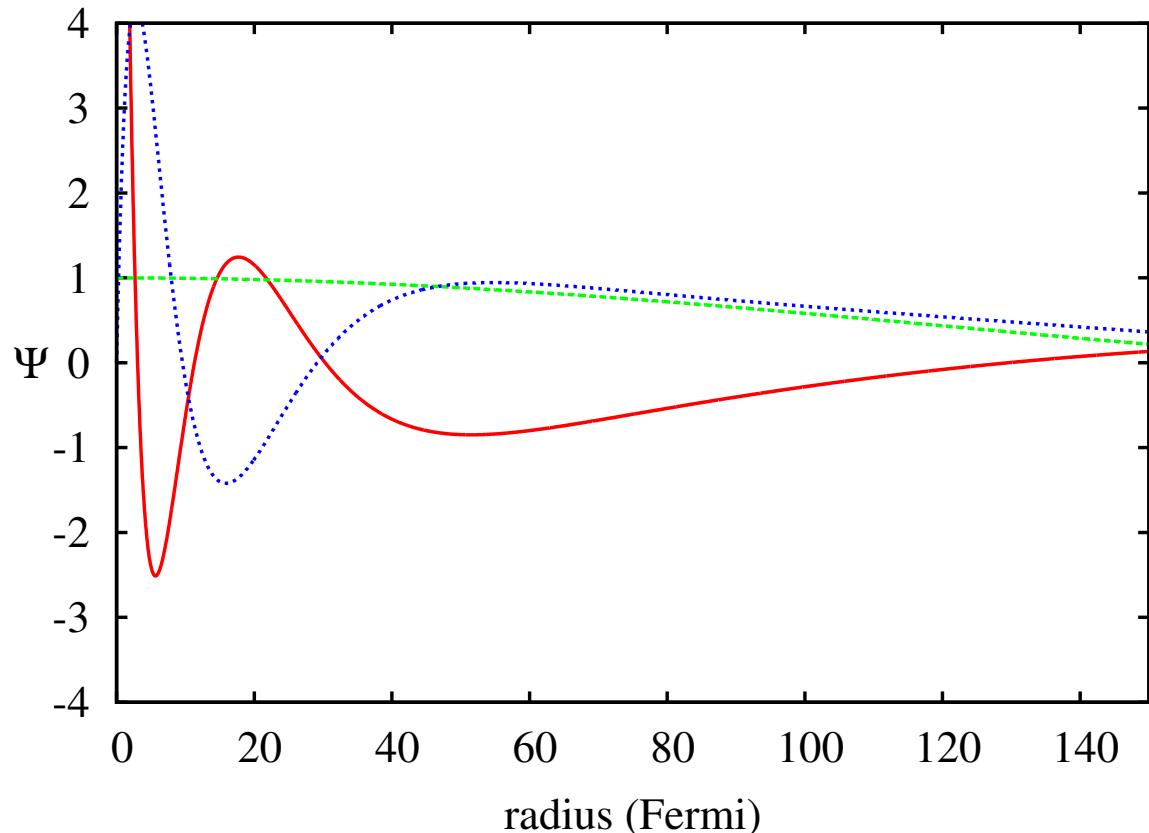
# Własności stanów związanych

nucleus	$E_b$ (keV)	$\approx a_B$ (fm)	$\langle r^2 \rangle_c^{1/2}$ (fm)
$^1\text{H}$	24.97	28.8	0.895
$^2\text{H}$	49.5	14.4	1.3
$^3\text{H}$	72.6	9.6	1.7
$^3\text{He}$	269	5.2	1.951
$^4\text{He}$	349.6	4.8	1.673
$^6\text{Li}$	842.5	2.1	2.37
$^7\text{Li}$	897.6	1.9	2.50
$^7\text{Be}$	1385	1.5	2.50

Nucleus, energy of bound state, approximative Bohr radius of bound state  $a_B$ , and adopted root-mean-square charge radius for nucleus

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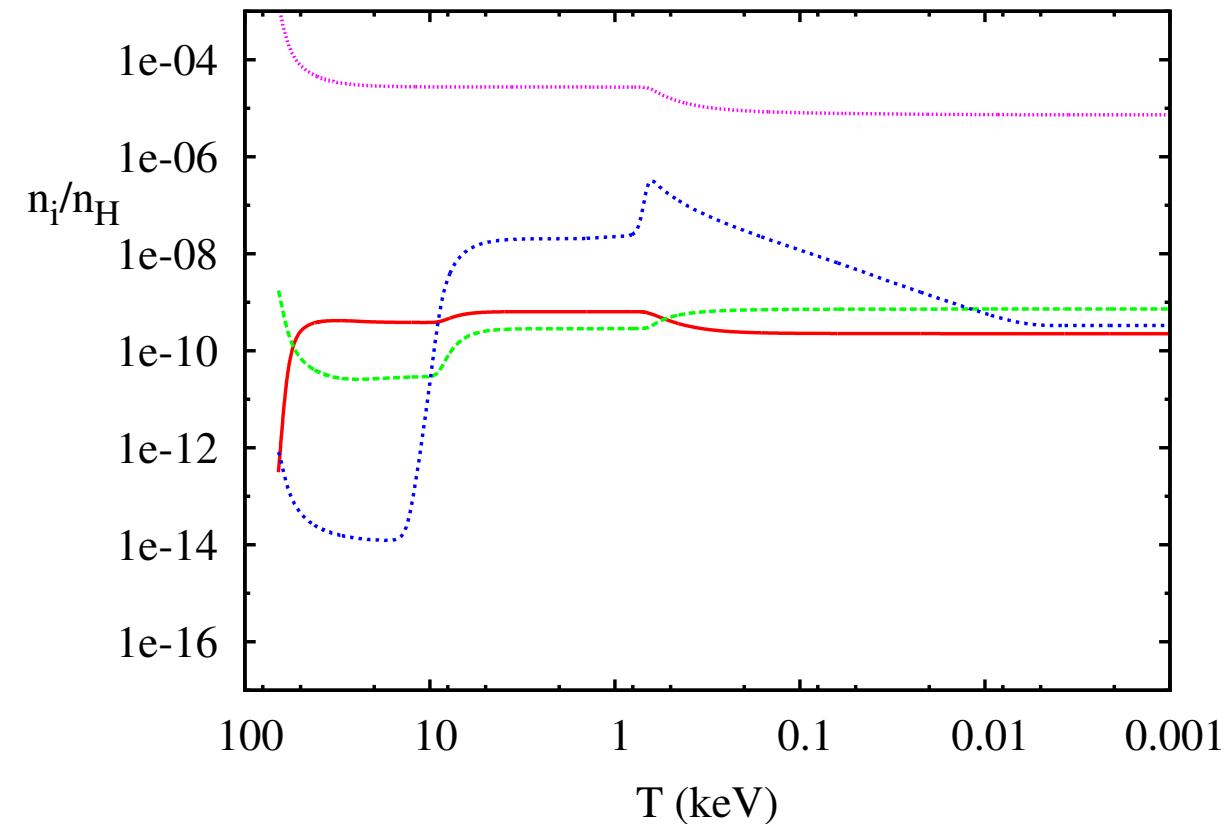
# Funkcje falowe



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Spherical Coulomb wave functions of a  ${}^6\text{Li}$  nuclei with energy  $E = 1 \text{ keV}$  in the electric field of the  ${}^1\text{H}-X^-$  bound state, for  
**s-wave  $l = 0$  (red)** and  
**p-wave  $l = 1$  (blue)**  
where  $X^-$  is at radius  $r = 0$ .  
For comparison the spherical wave function **without any Coulomb barrier**, i.e.  $V_C = 0$ , for s-wave, is also shown (in green).

# Ewolucja stosunków



Evolution of light-element number ratios

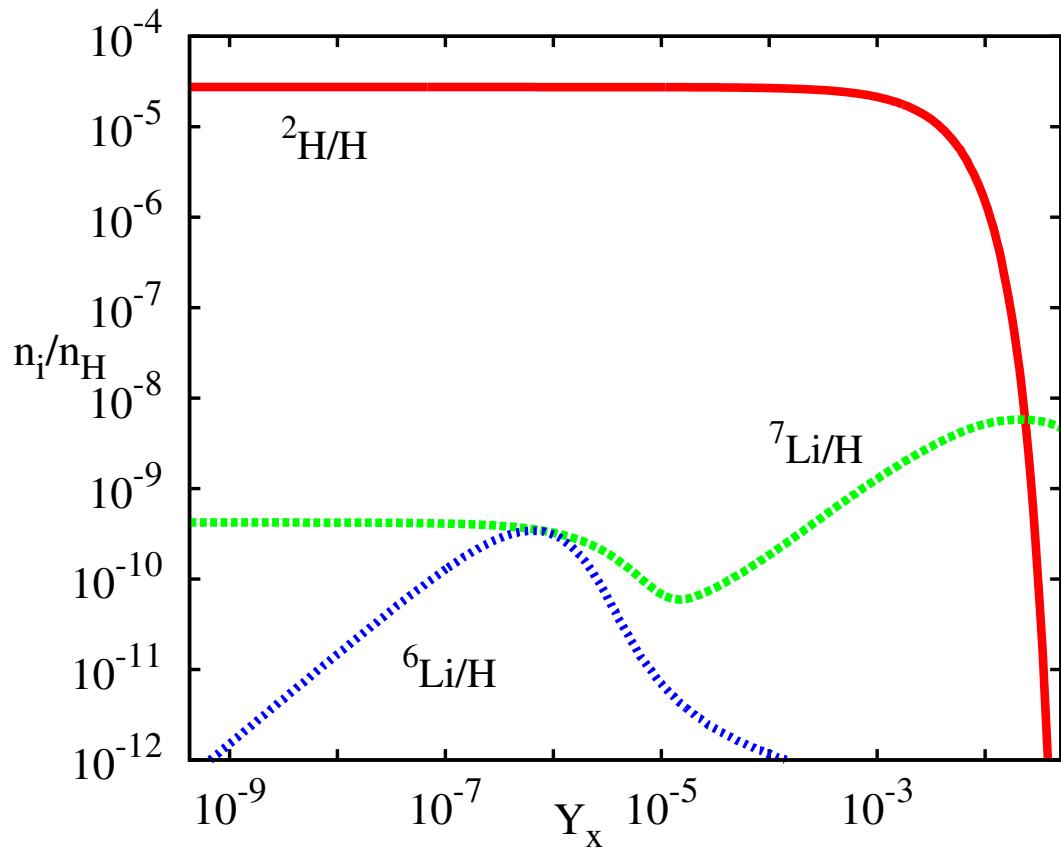
${}^7\text{Be}/{}^1\text{H}$  (red),  
 ${}^7\text{Li}/{}^1\text{H}$  (green),  
 ${}^6\text{Li}/{}^1\text{H}$  (blue) and  
 ${}^2\text{H}/{}^1\text{H}$  (purple),

for a CHAMP model with  
 $M_X = 100 \text{ GeV}$ ,  $\Omega_X h^2 = 0.01$ , and  
 $\tau_X = 10^{10} \text{ s}$ .

It is seen that large amounts of  ${}^6\text{Li}$  and  ${}^7\text{Be}$  synthesized at  $T \approx 10 \text{ keV}$  will be again destroyed at  $T \approx 1 \text{ keV}$ .

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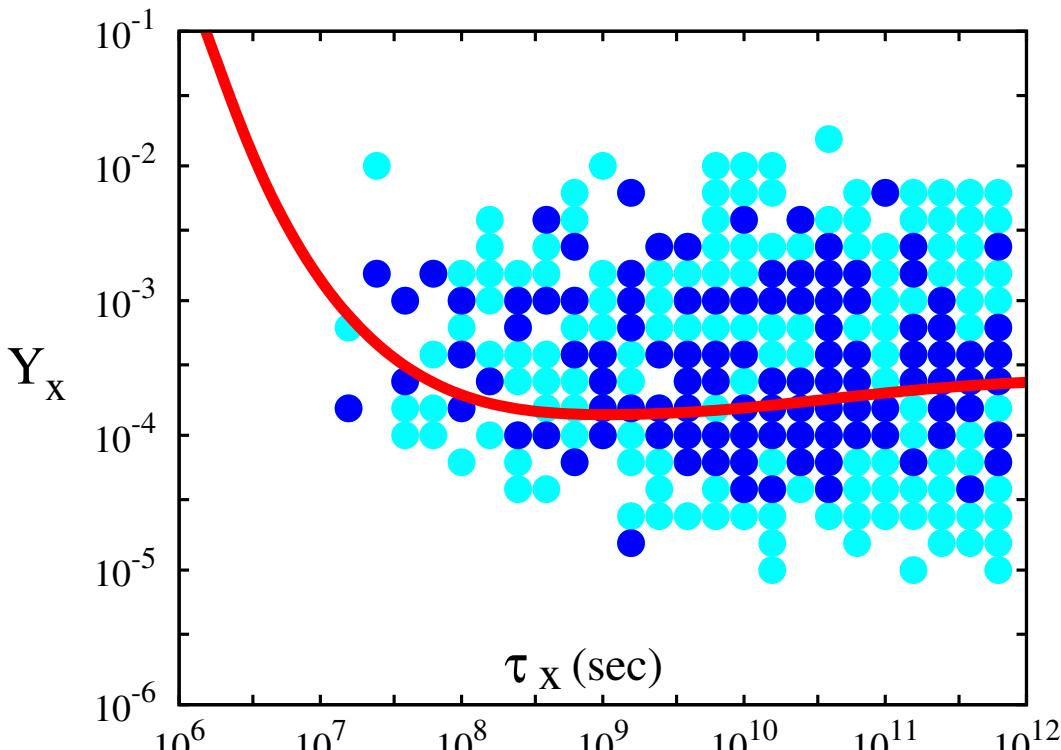
# Rozpowszechnienie dla jednego z modeli



Abundance yields of  
 $^2\text{H}/\text{H}$  (red)  
 $^7\text{Li}/\text{H}$  (green) and  
 $^6\text{Li}/\text{H}$  (blue)  
as a function of CHAMP-to-baryon  
ratio  $Y_x$  for a model with  
 $\tau_x = 10^{12}$  sec.

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# Rozwiązania dla dużych czasów życia



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Probability in the CHAMP-to-baryon  $Y_x$  - CHAMP life time  $\tau_x$  parameter space at large  $\tau_x$  that simultaneous solutions to the  ${}^7\text{Li}$  and  ${}^6\text{Li}$  (blue) or only  ${}^7\text{Li}$  (light-blue) problems exist. The points indicate 1 – 5% probability to find solution among of all randomly chosen reaction rates in the Monte-Carlo analysis. **Areas above the red line would be ruled out due to EM cascade nucleosynthesis** (under the assumption that  $f_{EM} = 3 \times 10^{-2}$ ).

# Podsumowanie K. Jedamzik

The detailed study reveals that bound-state BBN proceeds very differently than initially forecasted (Pospelov,Kohri). At low temperatures  $T \lesssim 1 \text{ keV}$ , a large number  $\sim 20$  of Coulomb-barrier unsupressed nuclear reactions and charge exchange reactions become operative and are capable, in most of the parameter space, to change  ${}^6\text{Li}$ ,  ${}^7\text{Li}$ , and  ${}^2\text{H}$  abundances by orders of magnitude. Unfortunately, reaction rates for these processes are not well approximated by the Born approximation, such that for CHAMP life times  $\tau_x \gtrsim 10^5 \text{ sec}$  one has to resort to a Monte-Carlo analysis.

It is shown, that a priorly proposed simultaneous solution of the  ${}^6\text{Li}$  and  ${}^7\text{Li}$  problems with a relic particle decaying at  $\tau_x \approx 1000 \text{ sec}$  is not very dependent on the decaying relic being charged or not, unless its hadronic branching ratio is well below  $B_h \lesssim 10^{-4}$ .

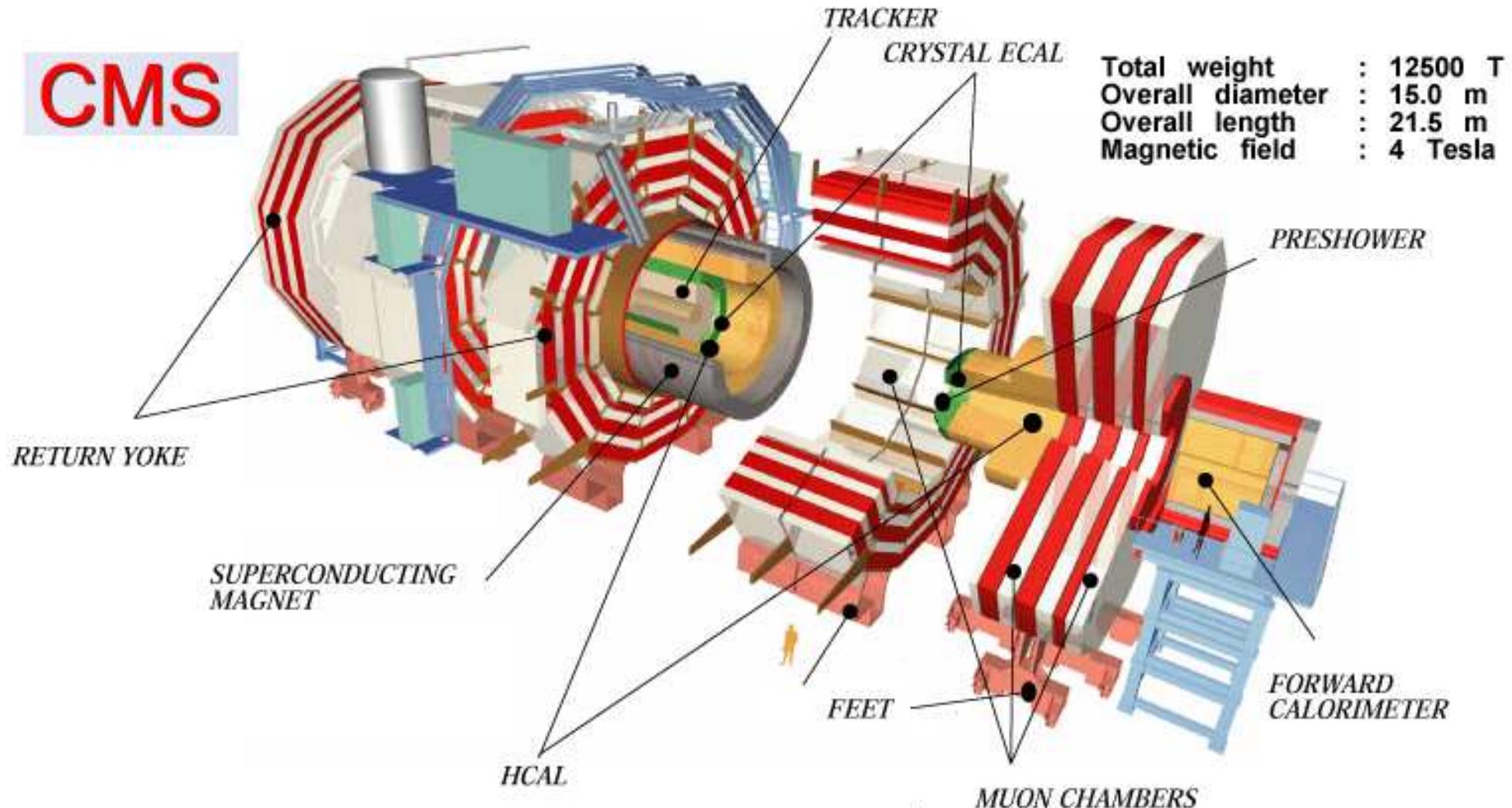
Since  ${}^6\text{Li}$  and  ${}^7\text{Li}$  may be rapidly destroyed at late times one generically expects further simultaneous solutions of the  ${}^6\text{Li}$  and  ${}^7\text{Li}$  problems for  $\tau_x \gtrsim 10^6 \text{ sec}$ .

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# Large Hadron Collider



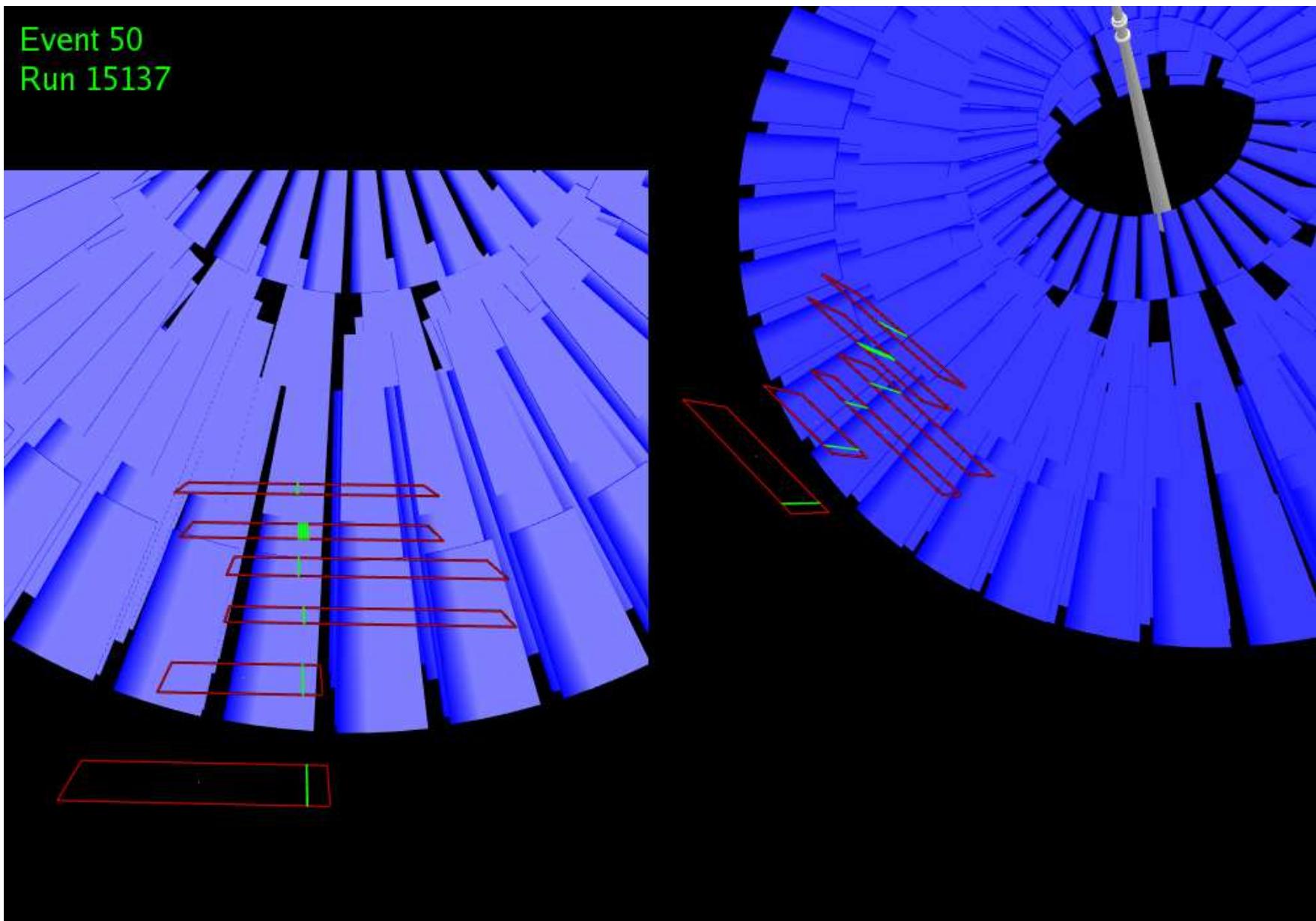
# Schemat Detektora CMS



# aktualny widok detektora



# to już działa: mion kosmiczny

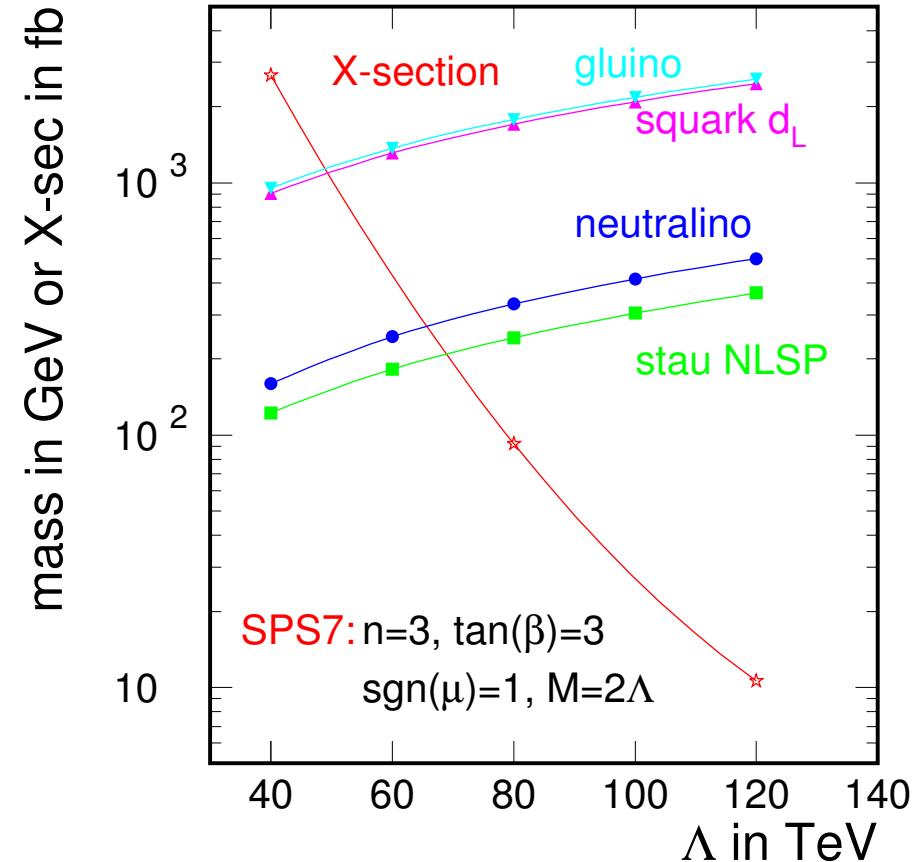


# $\tilde{\tau}_1$ NLSP: signal characteristics

Signal:  $\Lambda = 50\text{TeV}$   
and  $\Lambda = 80\text{TeV}$  points  
from the GMSB SPS7 line

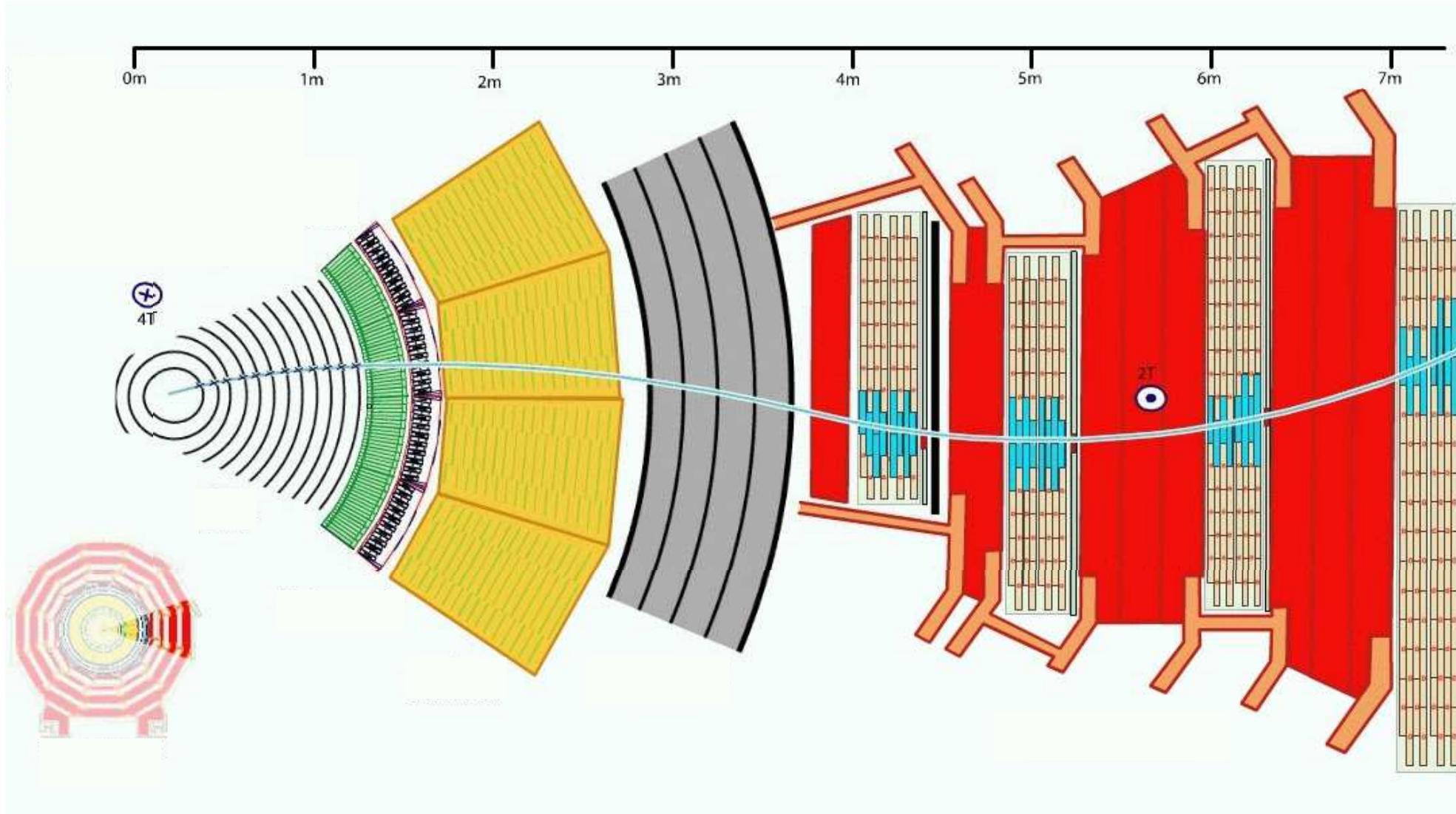
Signal characteristics:

- at least two energetic muon candidates;
- large mass of the pair of muon candidates;
- many hard jets (cascade decays);
- missing transverse momentum (stable massive staus).

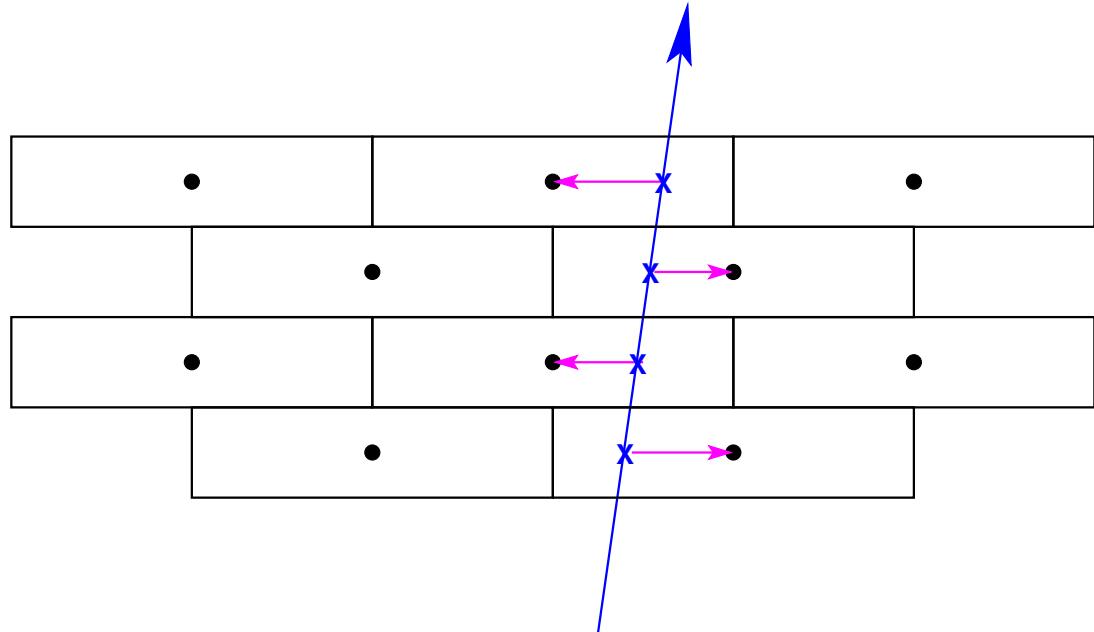


GMSB SPS7 line

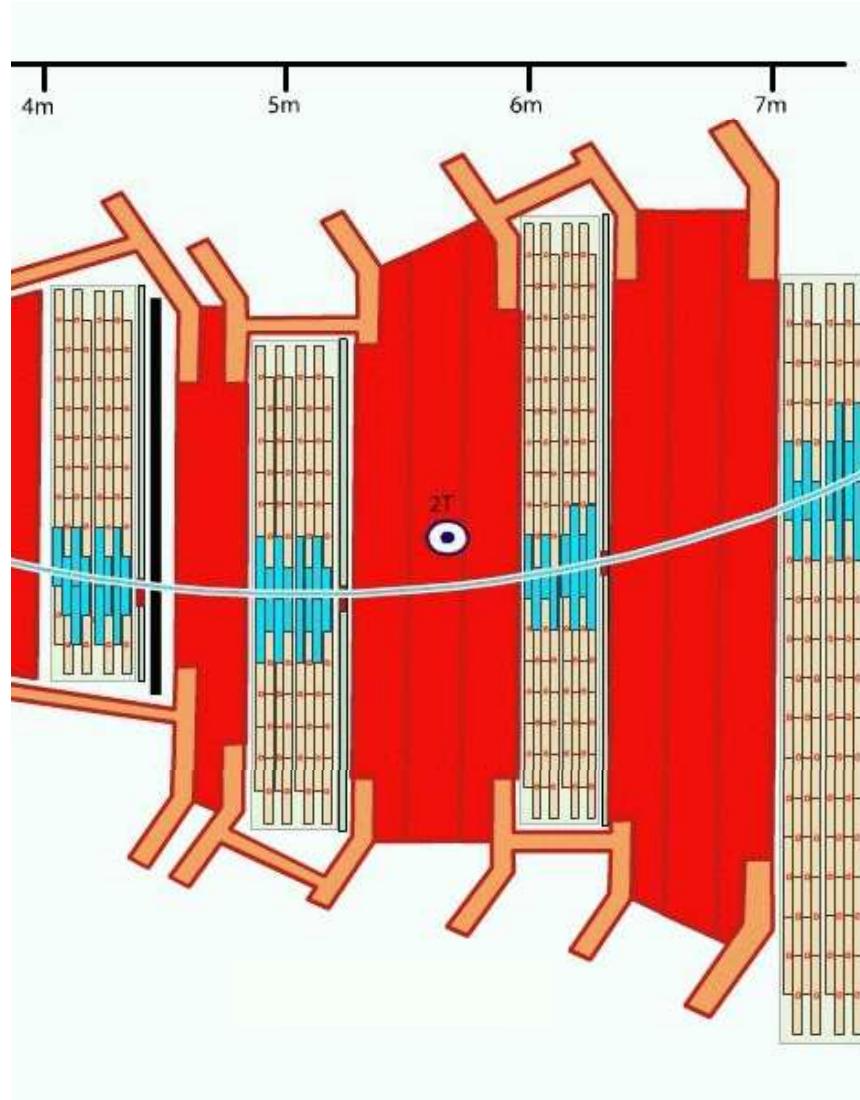
# CMS: $\tilde{\tau}_1$ NLSP: long-lived charged



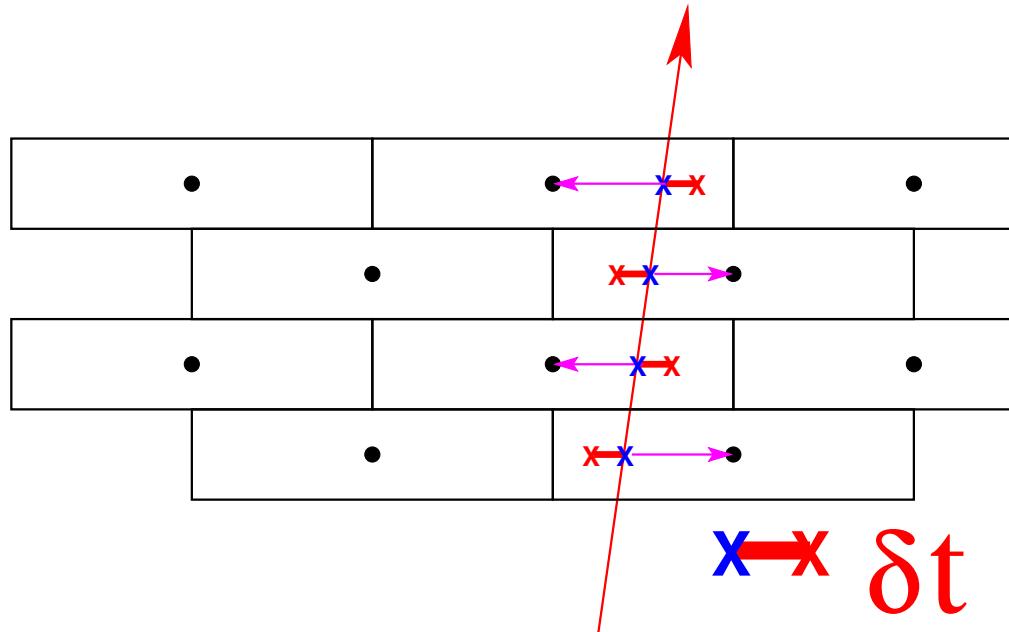
# CMS: $\tilde{\tau}_1$ NLSP: long-lived charged



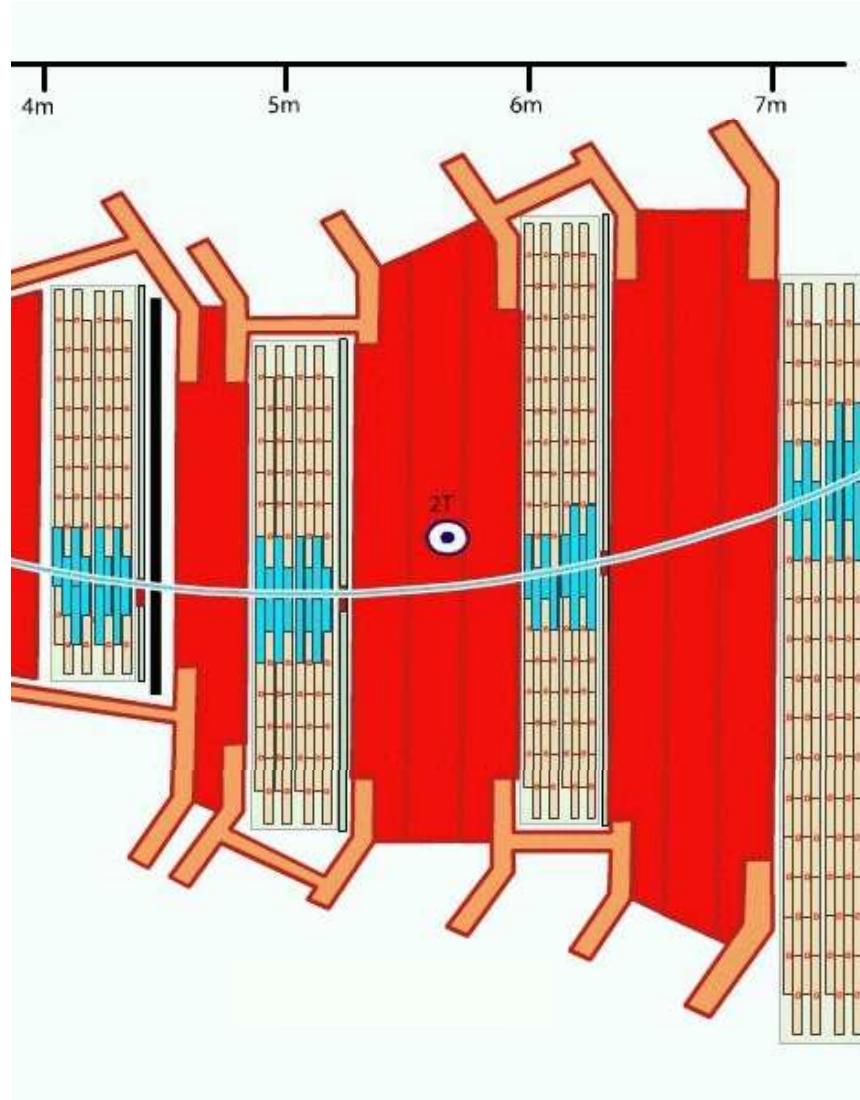
in a given super-layer hits due to muon should align if timing is correct



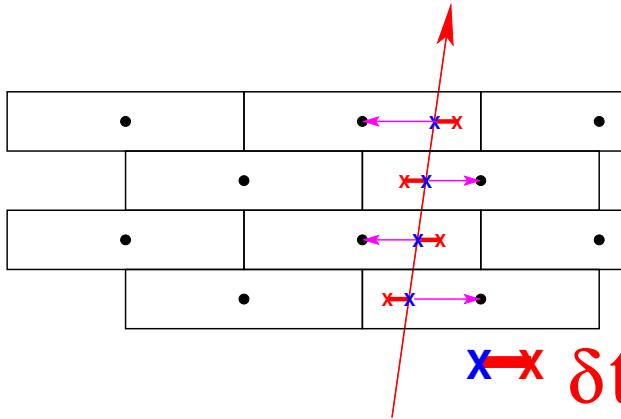
# CMS: $\tilde{\tau}_1$ NLSP: long-lived charged



hits due to delayed particle do not align,  
they are shifted backward from the wire



# CMS: $\tilde{\tau}_1$ NLSP: long-lived charged



$$\frac{\delta_x}{v_{\text{drift}}} = \delta_t = t_{\beta < 1} - t_c = \frac{L}{c} \left( \frac{1}{\beta} - 1 \right)$$

and hence

$$\frac{1}{\beta} = 1 + \frac{\delta_x}{L} \frac{c}{v_{\text{drift}}}$$

and finally

$$\frac{1}{\beta} = 1 + \frac{c}{v_{\text{drift}}} \frac{1}{N} \sum_{i=1}^N \frac{\delta_x^i}{L_i}$$

where  $L$  is the flight distance,  $v_{\text{drift}}$  is the drift velocity and  $\delta_x^i = |x_i^{\text{hit}} - x_i^{\text{wire}}| - |x_i^{\text{reco}} - x_i^{\text{wire}}|$

# CMS: $\tilde{\tau}_1$ NLSP: full simulation

## Preselection

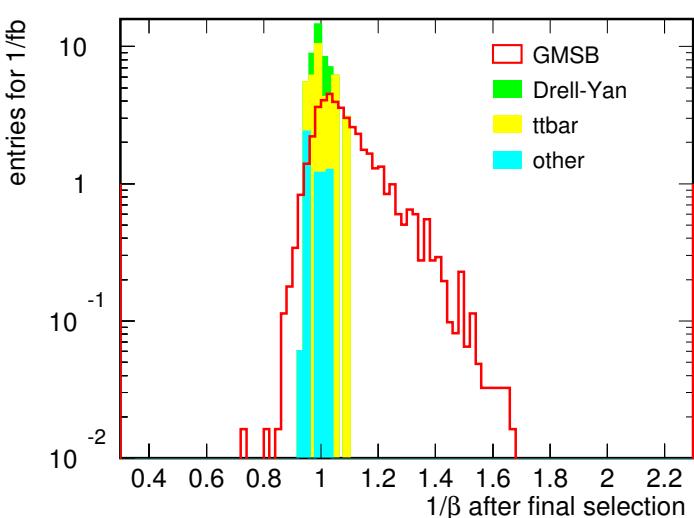
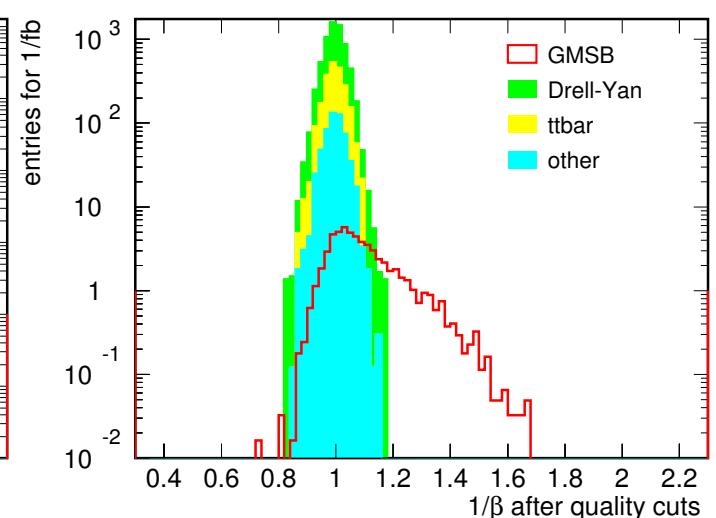
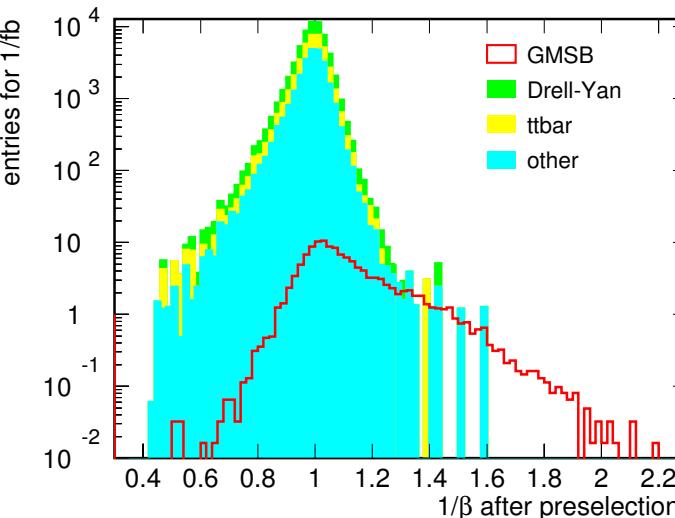
- Single muon HLT trigger;
- Momentum greater than 80 GeV;

## Quality requirements

- left & right hits in each super-layer
- $\phi \& \eta$  in each station
- at least 15 hits per candidate
- $\text{RMS}(\beta^{-1}) < 0.06$

## Selection

- At least two energetic muon candidates  $p_T^{2\mu} > 60 \text{ GeV}$ ;
- Mass of the pair of muon candidates:  $M_{\mu\mu} > 110 \text{ GeV}$ ;
- Effective event mass:  $M_{\text{eff}} > 360 \text{ GeV}$ ;



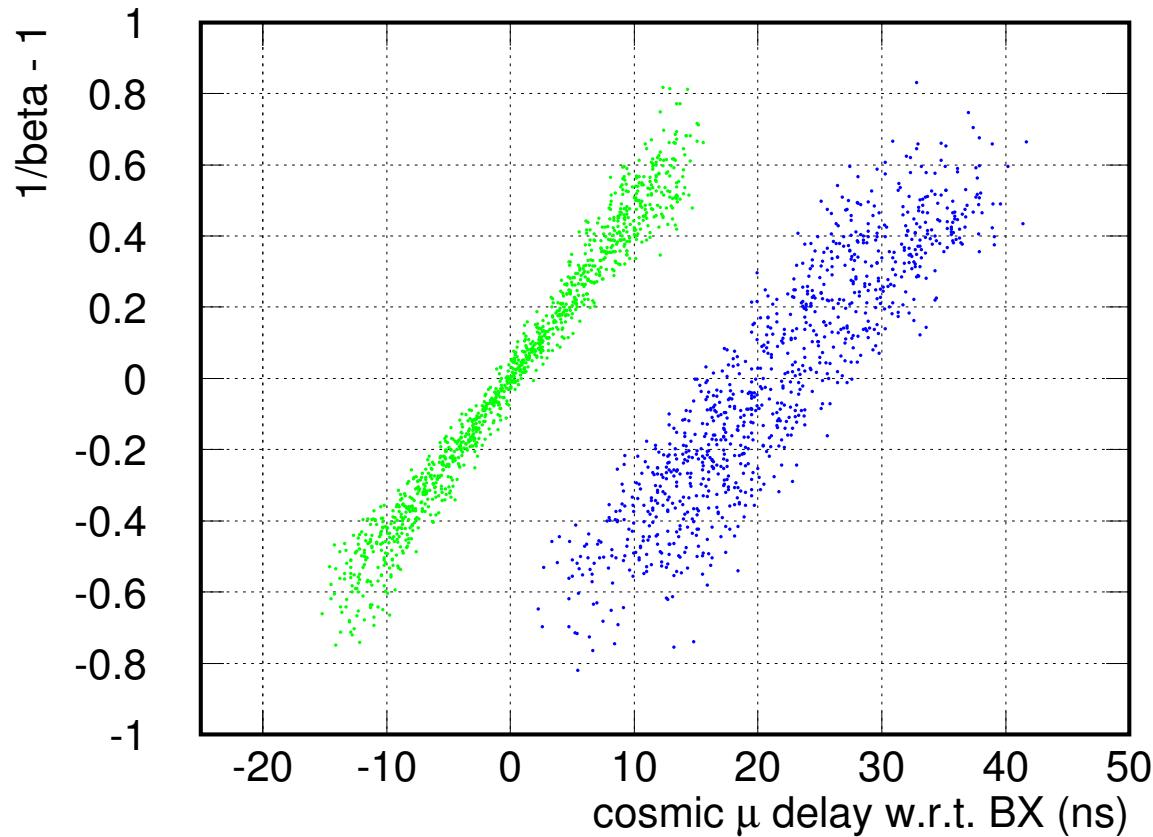
$\Lambda = 80 \text{ TeV}; \mathcal{L} = 1/\text{fb}$

Drell-Yan;

$t\bar{t}2\mu$ ;

all other bkg.

# Cosmic muon background



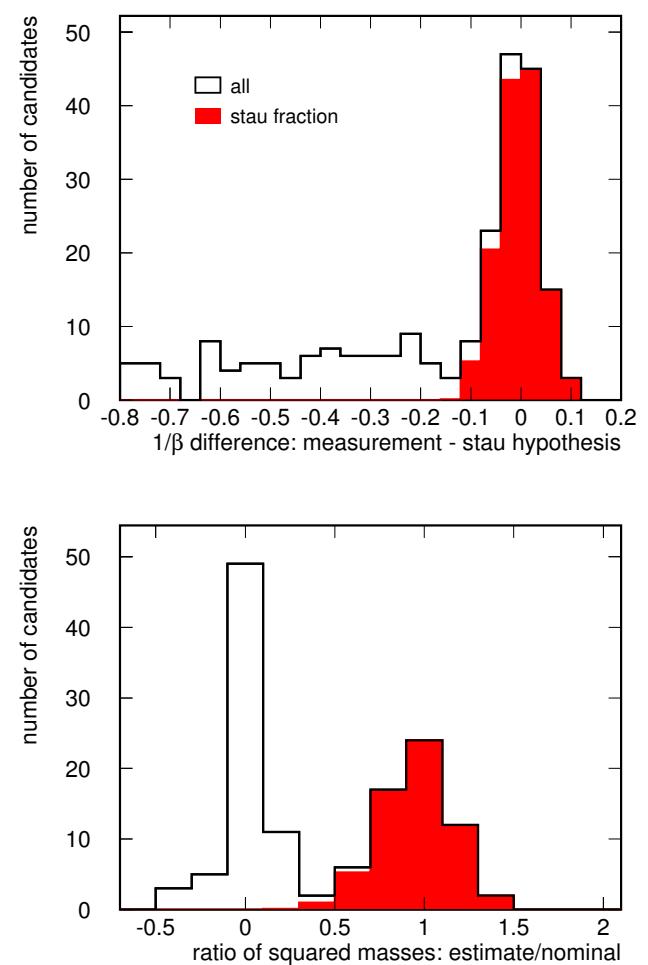
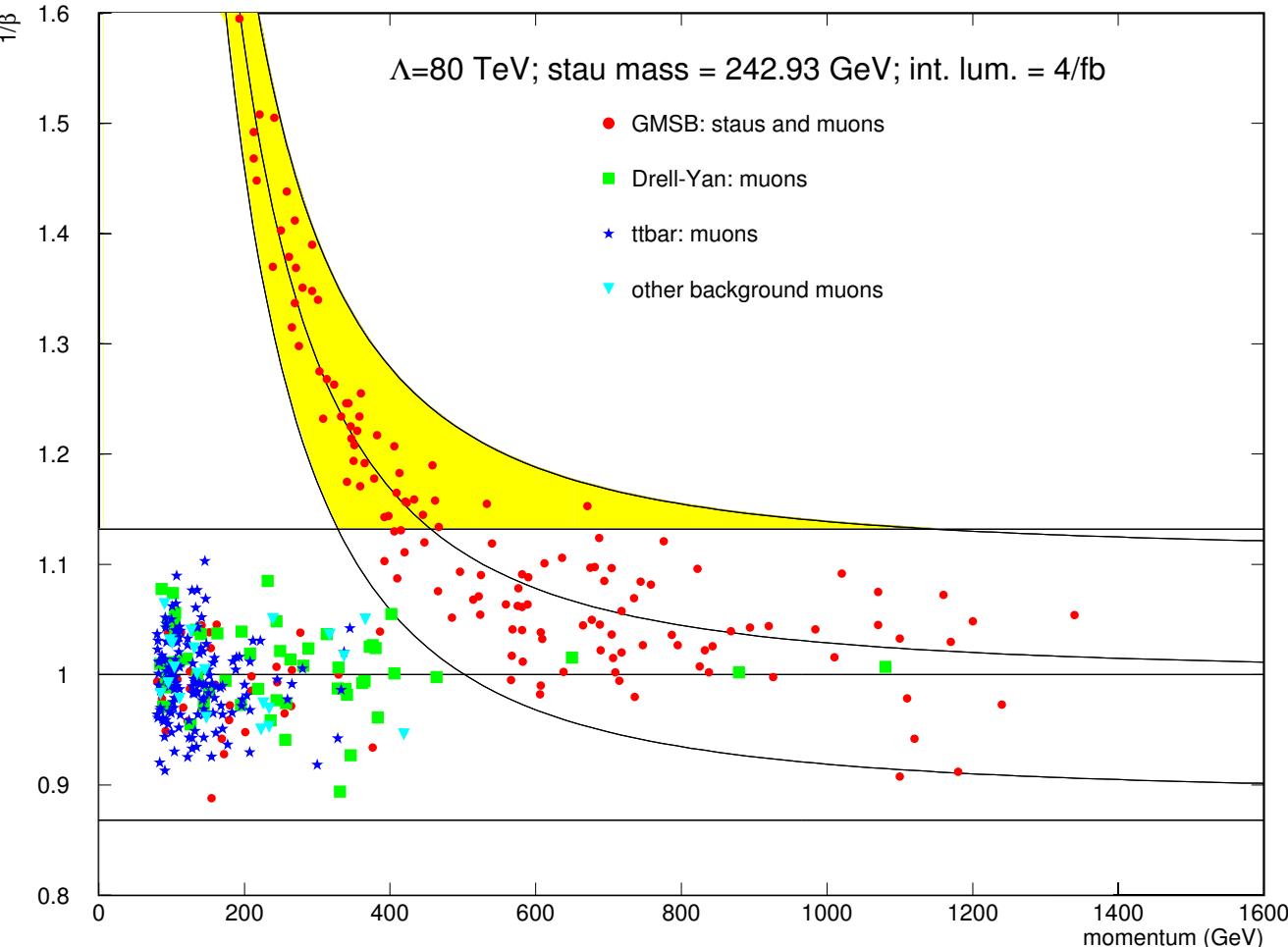
Cosmic muons are a natural source of background in a search for delayed particles.

$1/\beta - 1$  measurement for pseudo-cosmic muons in function of their time delay at the CMS origin.

Green: outward going muons.

Blue: inward going muons.

# CMS: $\tilde{\tau}_1$ NLSP: $\Lambda = 80\text{TeV}$ results



# CMS: $\tilde{\tau}_1$ NLSP: significance

Number of background events at different stages of the selection for 1/fb

dataset	preselection	quality	selection	“yellow”
signal $\Lambda = 50\text{TeV}$	1714.1	956.4	666.4	155.054
signal $\Lambda = 80\text{TeV}$	108.8	59.8	45.0	12.019
Drell-Yan 2mu $\hat{s} > 115\text{GeV}$	8105.6	4422.6	13.6	0.012
tt 2mu	2686.0	1624.4	33.7	0.029
WW 2mu	573.7	327.7	6.0	0.005
ZZ 2mu	202.0	110.1	0.1	0.000
ZW 2mu	231.6	121.3	0.0	0.000
$\Sigma$	11798.9	6606.1	53.4	0.046

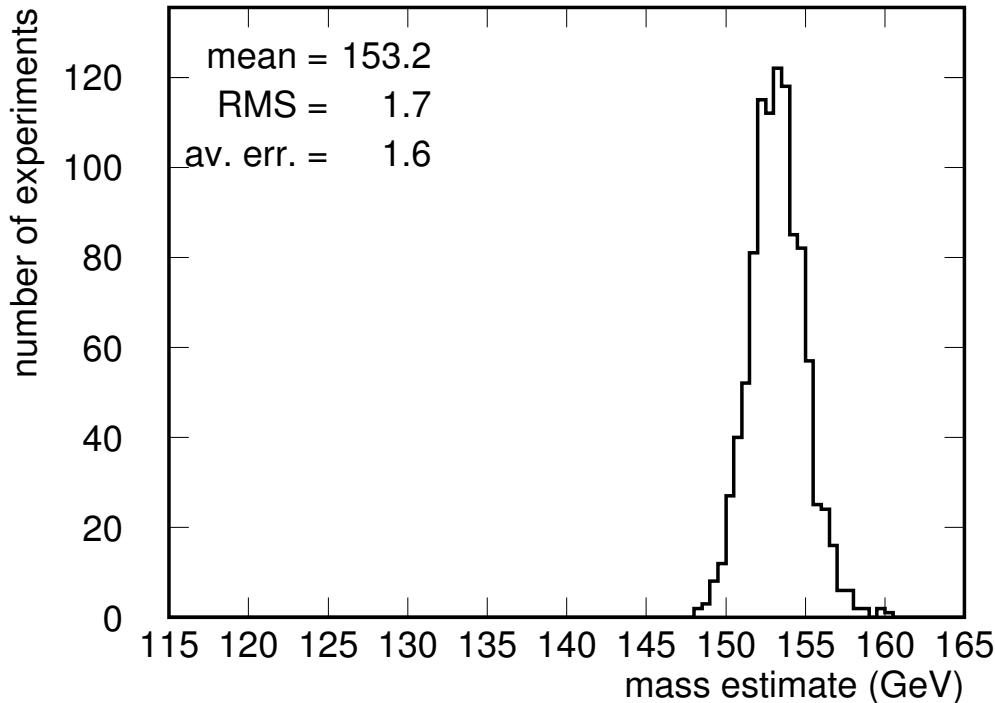
The upper limit for number of expected background events in the “yellow” signal region was evaluated to be 0.05 events for 1/fb.

Using  $S_{c12} = 2(\sqrt{s+b} - \sqrt{b})$  the  $5\sigma$  is obtained with 8 signal events.

This correspond to

$\mathcal{L} = 52/\text{pb}$  for  $\Lambda = 50\text{TeV}$  and  $\mathcal{L} = 667/\text{pb}$  for  $\Lambda = 80\text{TeV}$ .

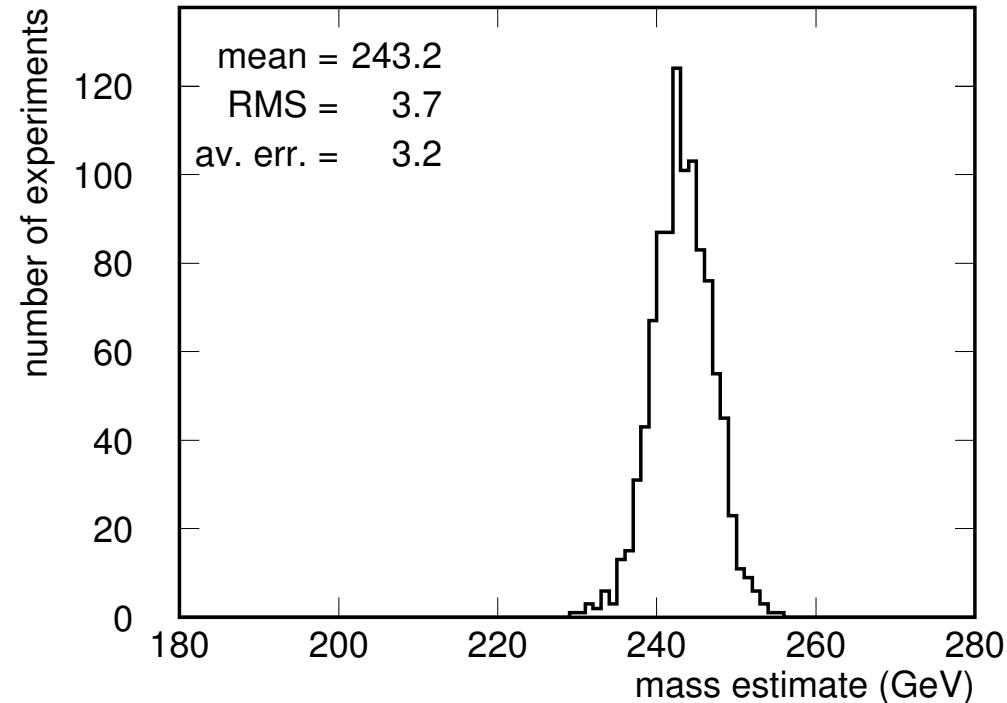
# CMS: $\tilde{\tau}_1$ NLSP: mass estimate



1000 pseudo-experiments for  $\mathcal{L} = 0.5/\text{fb}$

$$M_{\tilde{\tau}_1}^{\text{gener.}} = 152.31 \text{ GeV}$$

$$M_{\tilde{\tau}_1}^{\text{est.}} = \{153.2 \pm 1.6(\text{stat.}) \pm 0.9(\text{syst.})\} \text{ GeV}$$



1000 pseudo-experiments for  $\mathcal{L} = 4/\text{fb}$

$$M_{\tilde{\tau}_1}^{\text{gener.}} = 242.93 \text{ GeV}$$

$$M_{\tilde{\tau}_1}^{\text{est.}} = \{243.2 \pm 3.2(\text{stat.}) \pm 1.4(\text{syst.})\} \text{ GeV}$$

# Mowa końcowa



# Mowa końcowa



# Mowa końcowa

