HIDDeν
Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

UNIVERSITAT DE BARCELONA

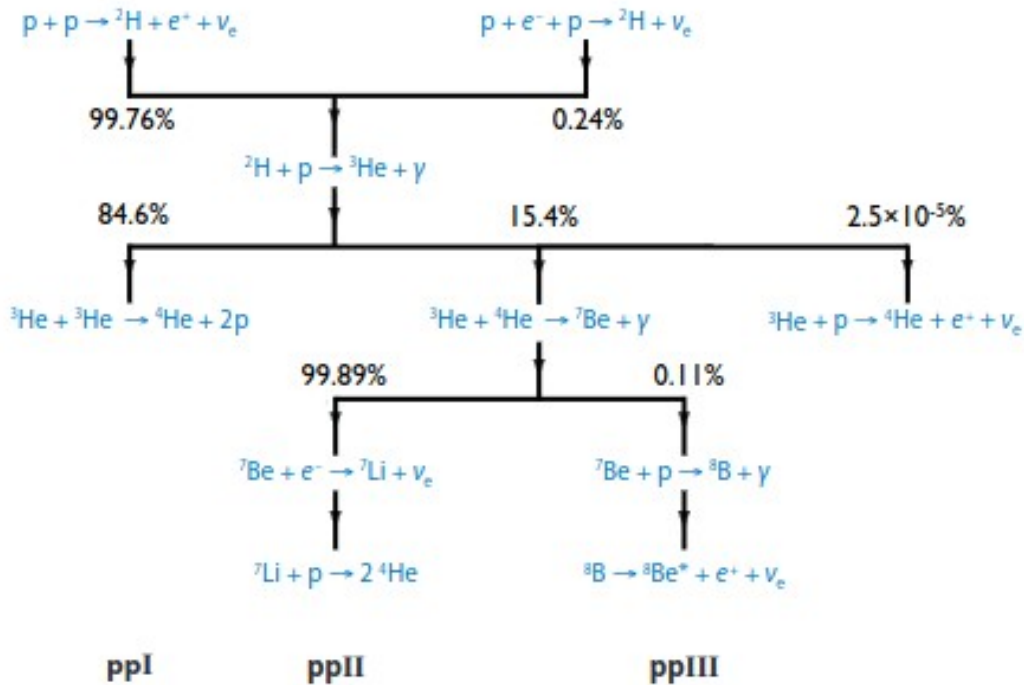# Examining the Standard Solar Models in face of new Solar neutrino data

M. C. Gonzalez-Garcia, Michele Maltoni, Joao Paulo Pinheiro*, Aldo Serenelli

Departament de Física Quántica i Astrofísica and Institut de Ciencies del Cosmos, Universitat de Barcelona, Diagonal 647, E-08028 Barcelona, Spain
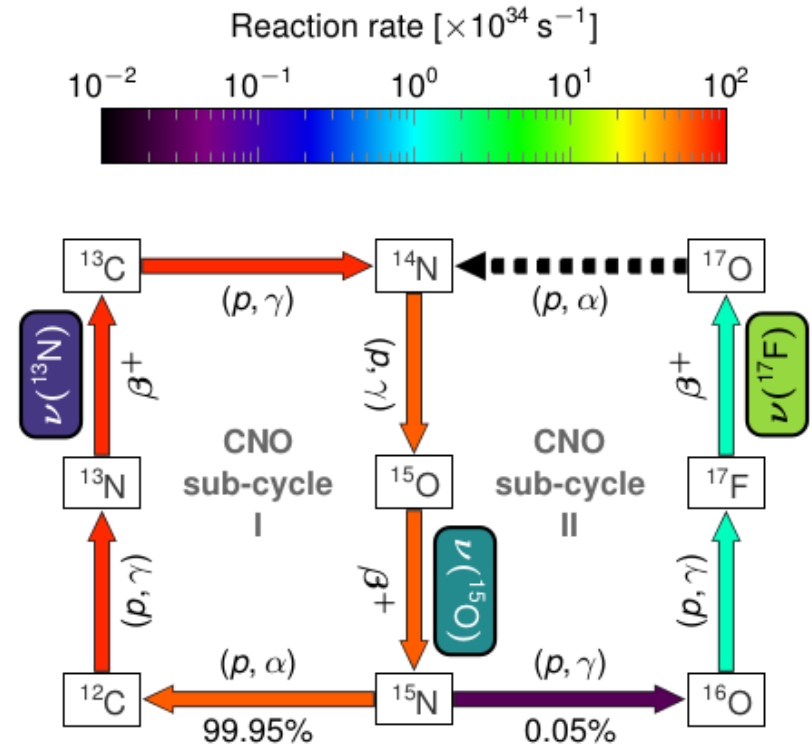
*joaopaulo.pinheiro@fqa.ub.edu
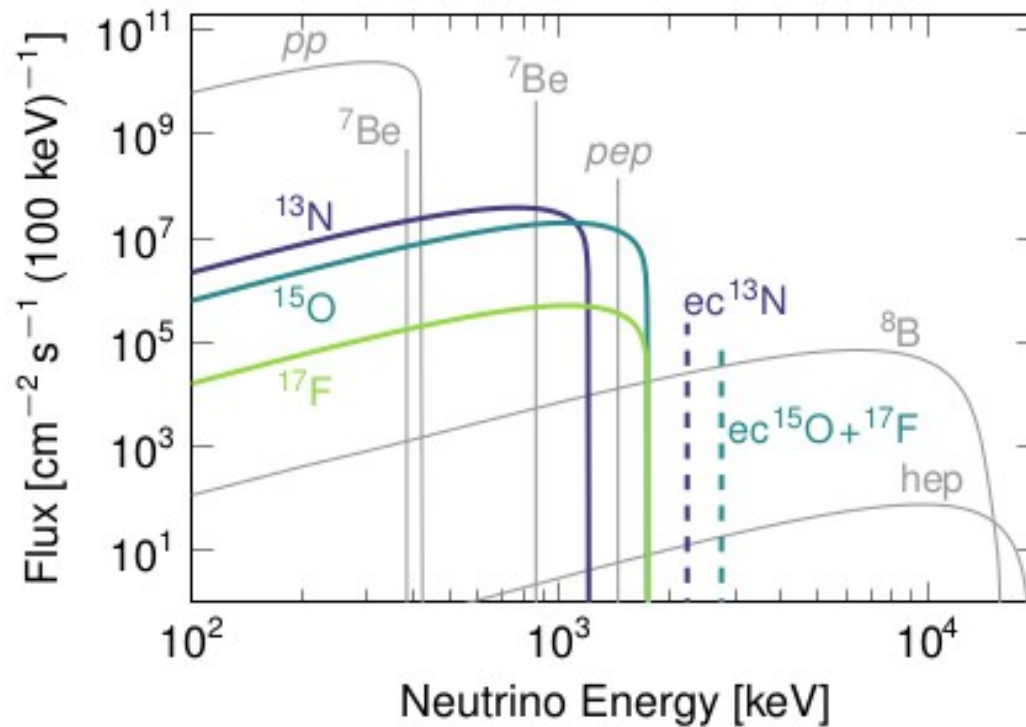
pp-chain vs CNO cycle

pp-chain(reaction A<8)

Haxton,Robertson, Serenelli astro-ph:1208.5723

CNO-cycle(catalyst)

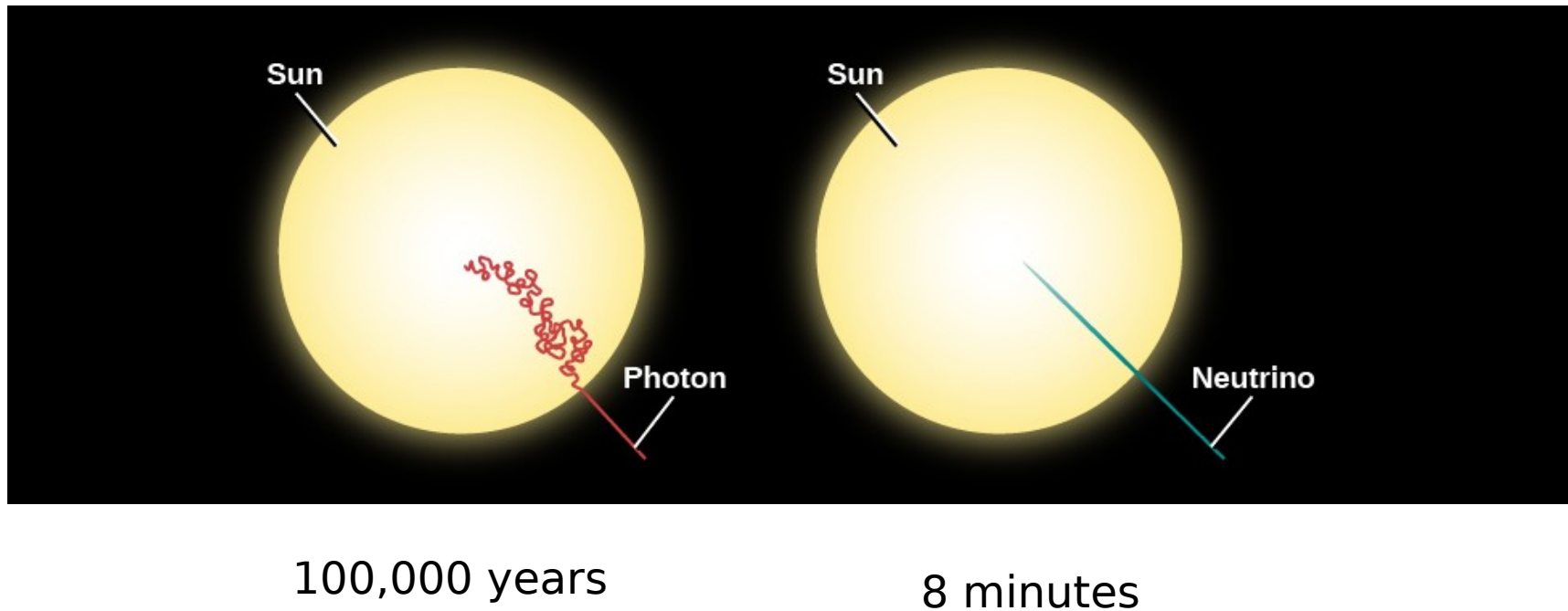Borexino col., hep-exp:2006.15115

João Paulo Pinheiro(UB)

Borexino col., hep-exp:2006.15115

Solar Neutrinos vs Solar photons

From philschatz.com

100,000 years   8 minutes

João Paulo Pinheiro(UB)

-Give information about the atomic composition of the Sun;

-Information can be extracted from the atmosphere of the Sun(photons) or from the nucleus of the Sun(neutrinos);

https://physics.aps.org/articles/v15/190

João Paulo Pinheiro(UB)
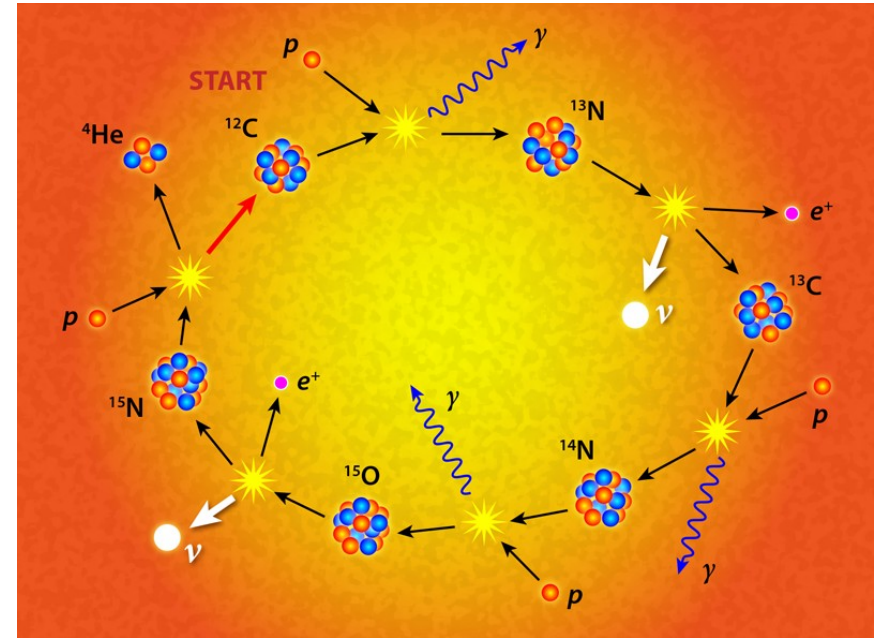
Solar composition problem!
## Garay and Serenelli:astro-ph/0811.2424

AGS models (Asplund, Grevesse and Sauval 0909.0948)

-Solar surface composition using spectroscopic technics;
-3D hydrodynamic models of solar atmosphere;
-**Low Z** in the solar interior;
-**Fail** to reproduce all helioseismic probes;

GS models (Grevesse, N., Sauval, Space Science Reviews 85, 161–174 (1998), Garay and Serenelli 1211.6740)

-Helioseismology measurements such as the radial distributions of sound speed and density
-Determination of nuclear reaction rates affecting energy and neutrino production in the Sun;
-**High Z**;
-**Fail** to modulate the **atmosphere** of the Sun;

João Paulo Pinheiro(UB)

Borexino phase III
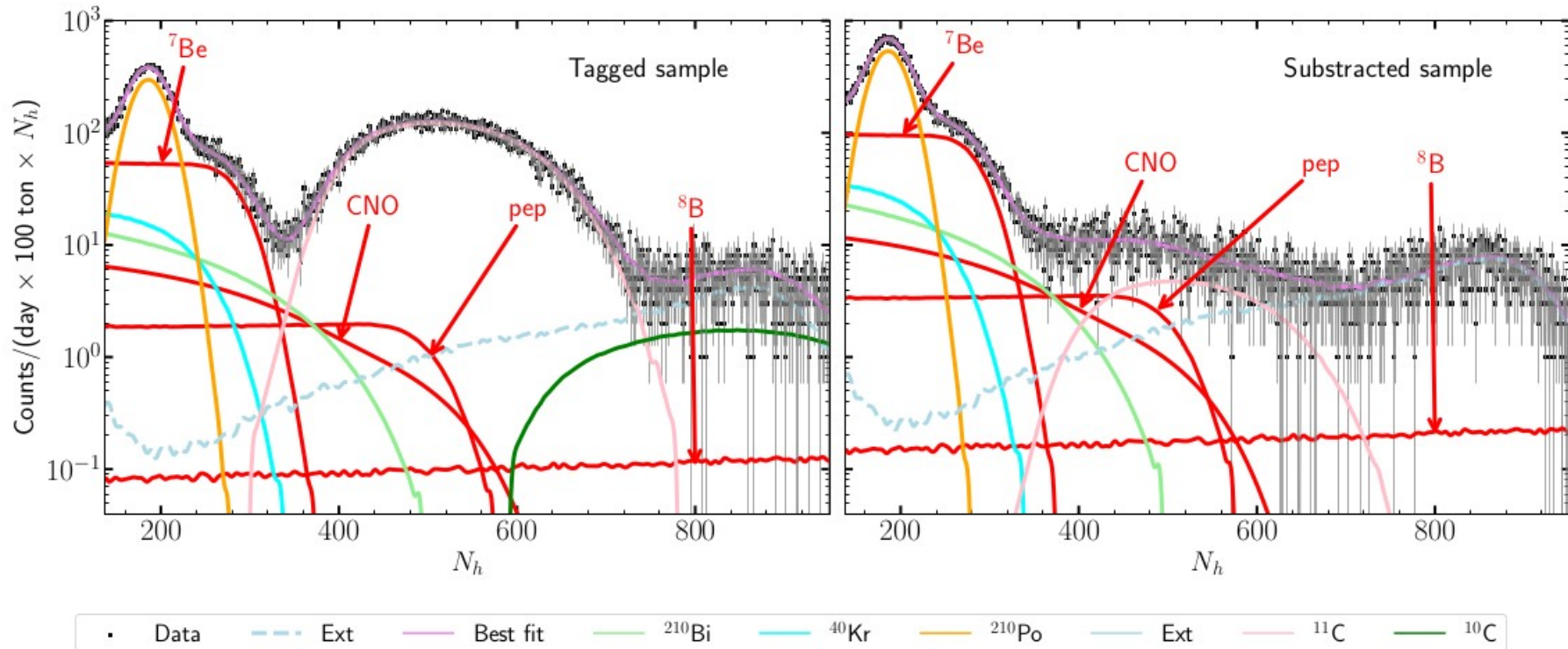
Our reproduction of BXIII

Borexino III and the CNO-cycle

Borexino col., hep-exp:2307.14636
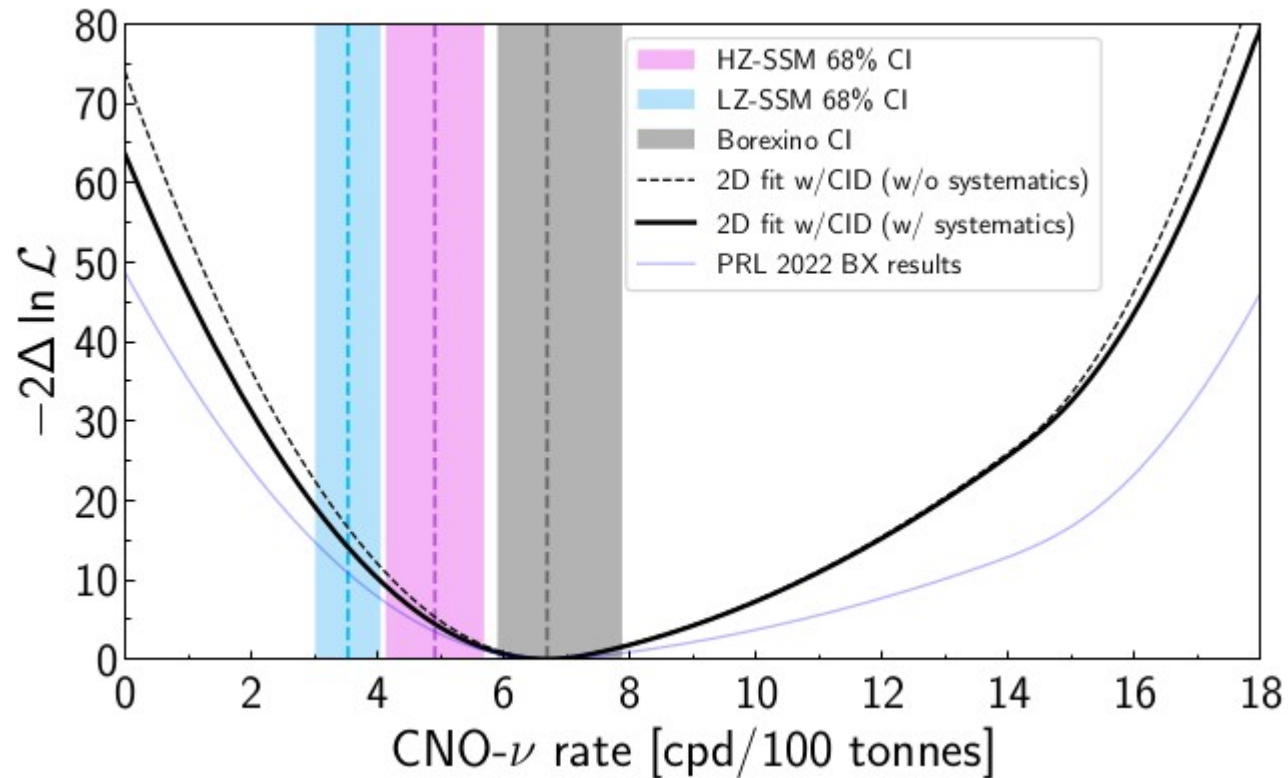
Discovery of the CNO-cycle with more than **7σ**!!
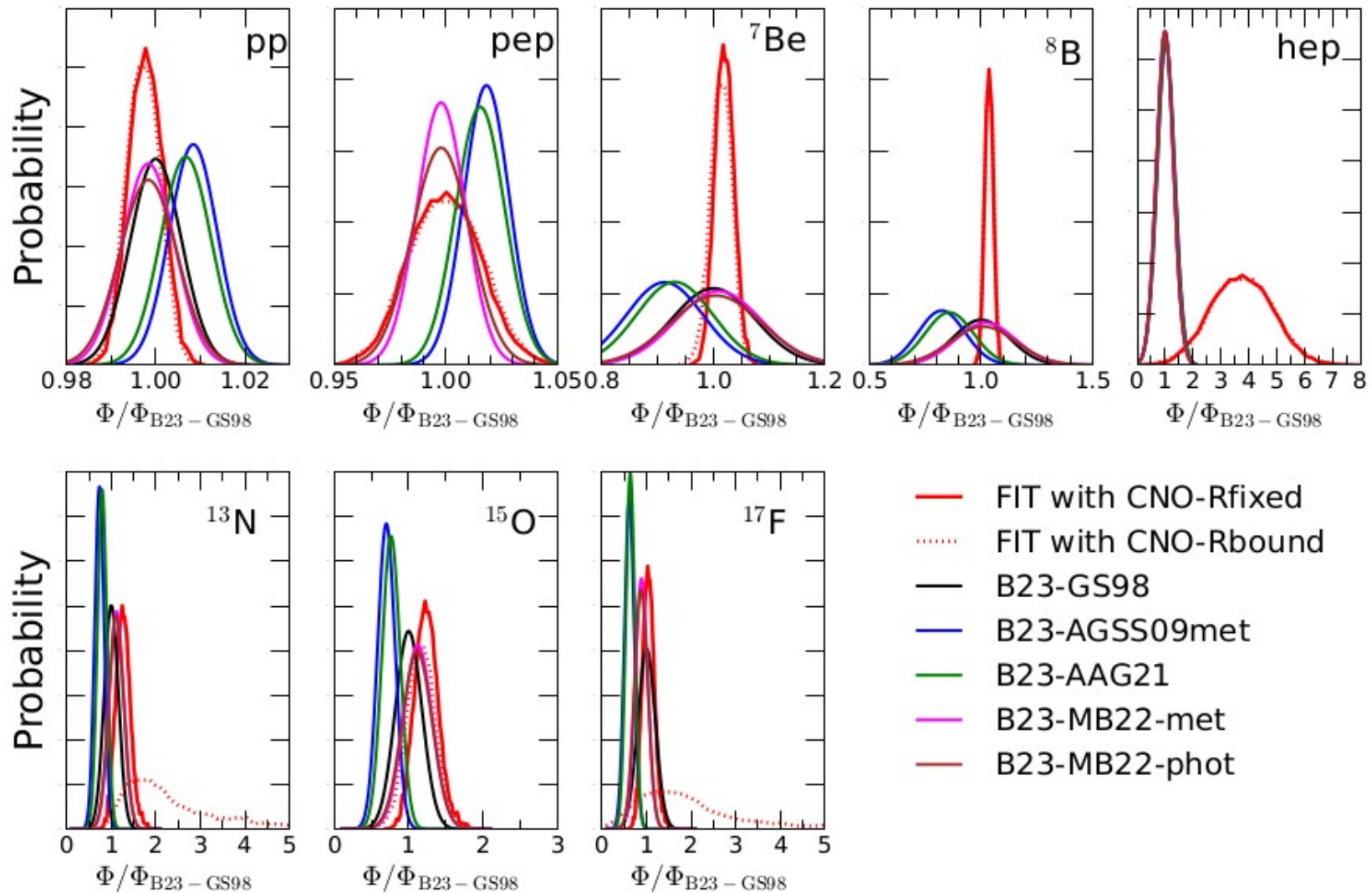
Preference for High Metallicity!

Borexino col., hep-exp:2205.15975
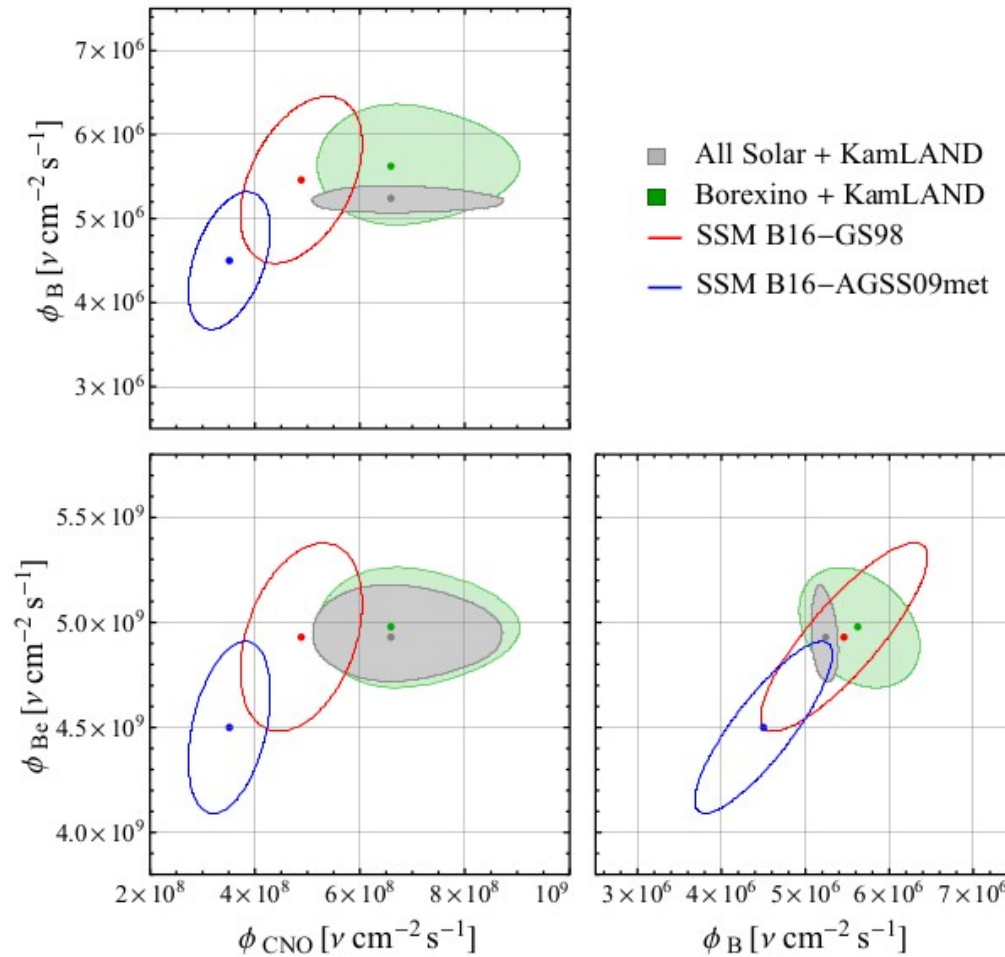
- They were not precise enough to provide a significant discrimination;

FIT	B23-SSM	FULL			Be+B+CNO			CNO		
		n=6			n=3			n=1		
		$\Delta\chi^2$	p_{GF}	CL $[\sigma]$	$\Delta\chi^2$	p_{GF}	CL $[\sigma]$	$\Delta\chi^2$	p_{GF}	CL $[\sigma]$
CNO-Rfixed	AGSS09-met	14.5	0.024	2.3	9.8	0.020	2.3	7.2	0.0073	2.7
	GS98	8.1	0.24	1.2	3.0	0.39	0.86	2.4	0.12	1.5
	AAG21	12.5	0.052	1.9	7.8	0.05	2.0	6.2	0.013	2.5
	MB22-met/phot	7.1	0.31	1.0	2.2	0.53	0.62	2.0	0.16	1.4
		n=8			n=5			n=3		
		$\Delta\chi^2$	p_{GF}	CL $[\sigma]$	$\Delta\chi^2$	p_{GF}	CL $[\sigma]$	$\Delta\chi^2$	p_{GF}	CL $[\sigma]$
CNO-Rbound	AGSS09-met	14.4	0.072	1.8	9.5	0.091	1.7	7.5	0.057	1.9
	GS98	6.8	0.56	0.58	1.9	0.86	0.17	1.6	0.66	0.44
	AAG21	11.9	0.15	1.4	7.0	0.22	1.2	6.1	0.11	1.6
	MB22-met/phot	6.1	0.64	0.47	1.2	0.94	0.07	1.1	0.78	0.28

Possible solution:

Phase 1: high-Z accretion (Time t_A)
1.90 $R_\odot$
disk winds   dust   **a**
proto-Sun   disk

Phase 2: low-Z accretion (Time t_B)
1.20 $R_\odot$
protoplanets

Present-day Sun (Time $t_\odot$)

Increased opacity compatible with **helioseismic** observations

Low-Z solar surface compatible with **spectroscopic** observations

High-Z solar core compatible with **neutrino** observations

1.0 $R_\odot$
Metallicity, Z
0.015   0.016   0.017
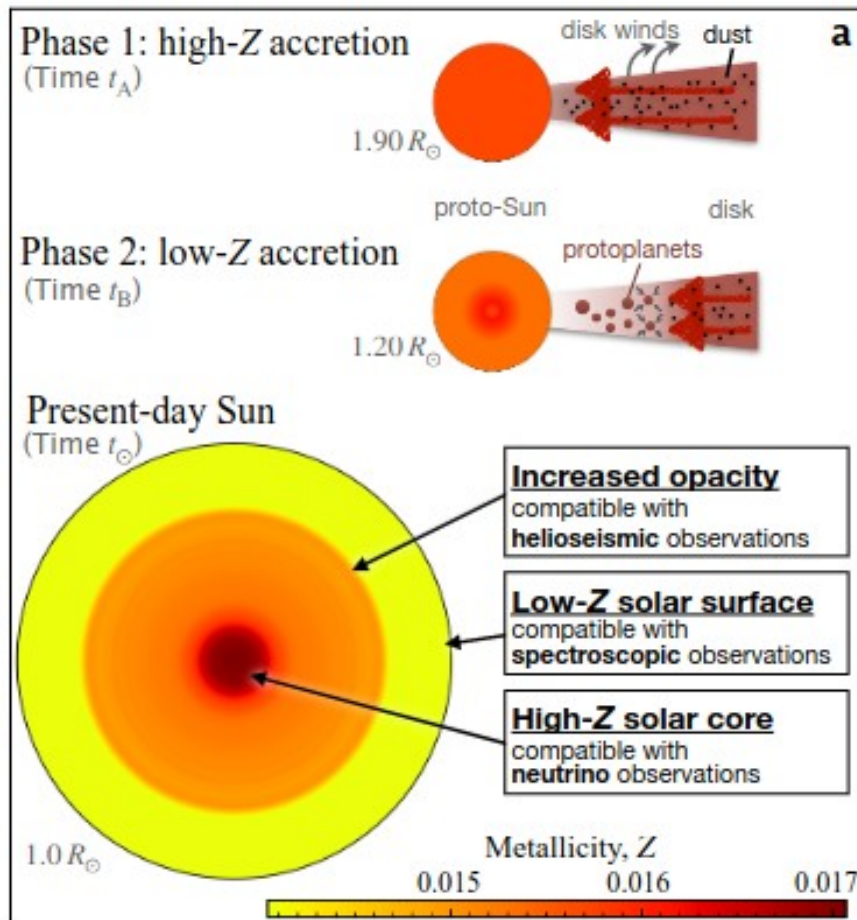
Sun's chemical composition varies with depth:

The Sun having formed in an inhomogeneous environment, or by the Sun's outer layers having been enriched in certain elements by accretion of planetary material

Serenelli, Haxton and Pena-Garay: astro-ph:1104.1639

Kunitomo, Guillot and Buldgen: astro-ph:2210.06900

Thank you!

"This project has received funding /support from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska -Curie grant agreement No 860881- HIDDeN"

João Paulo Pinheiro(UB)
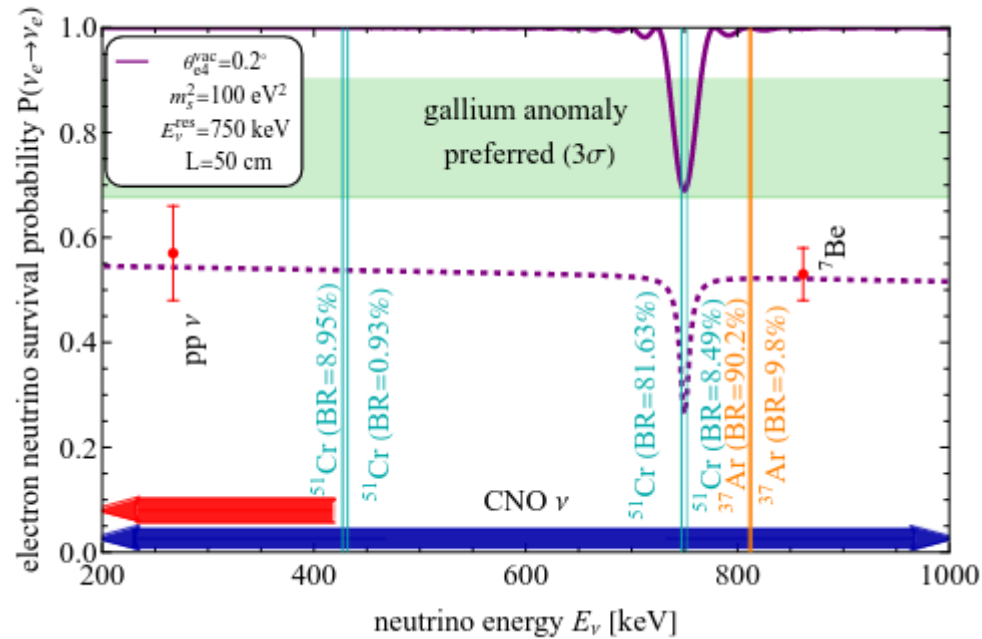
BACKUP SLIDES

Gallium experiment

Gallium based solar-neutrinos were designed to detect pp neutrinos from the Sun.

-**Excess** of electron – neutrino events;
-**Tension** with other Solar neutrino experiments;
-Problems to calculate the Matrix elements of the amplitude – **tension can be reduced**;

João Paulo Pinheiro(UB)

HIDDe
Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

UNIVERSITAT de BARCELONA
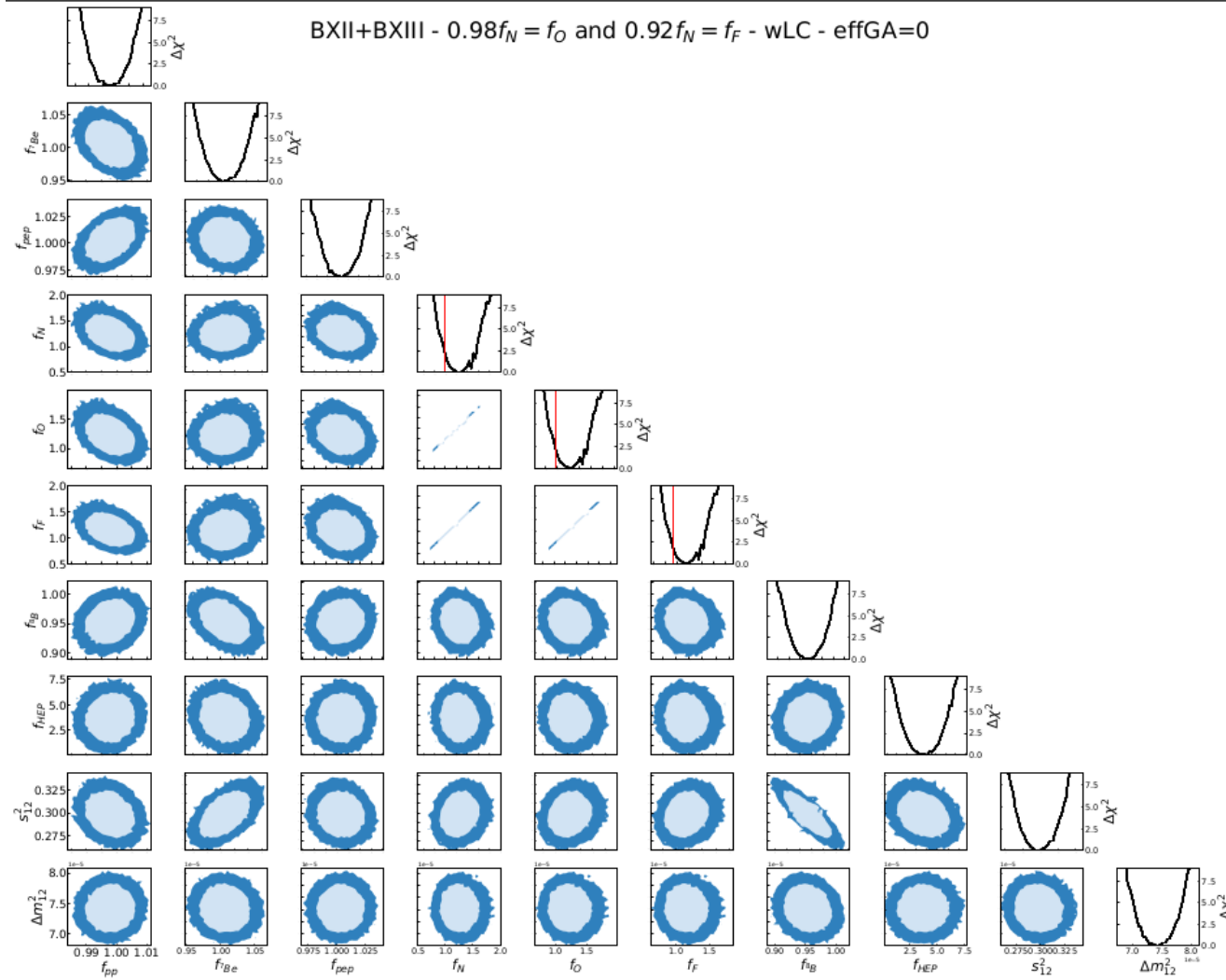
Kopp at al, hep-ph:2303.05528

Letting the GA cross section and the pp flux free changes something?

Answer: No!

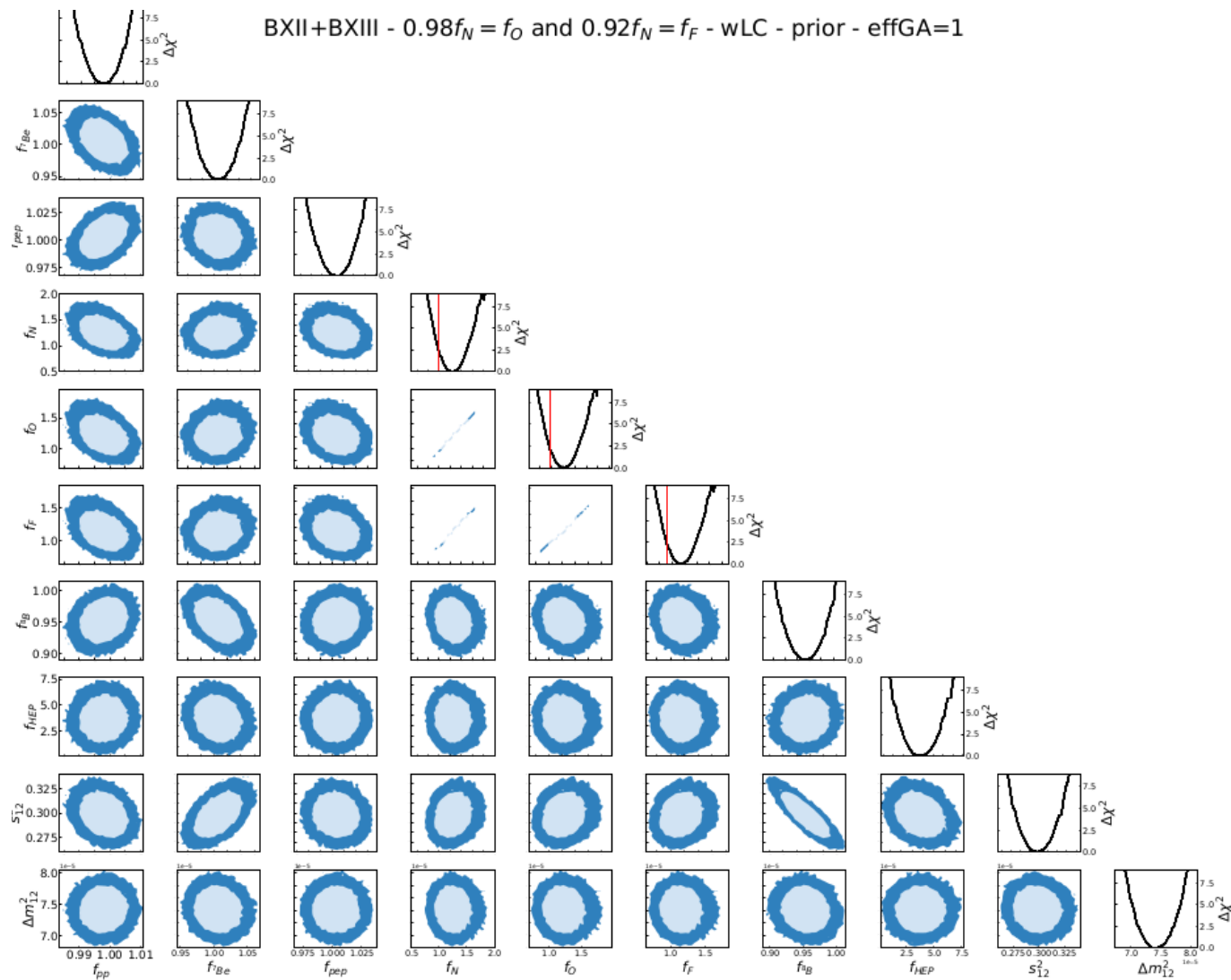Details in the backup slides...

The tension continues...

BXII+BXIII - $0.98 f_N = f_O$ and $0.92 f_N = f_F$ - wLC - effGA=0

BXII+BXIII - $0.98f_N = f_O$ and $0.92f_N = f_F$ - wLC - prior - effGA=1

BXII+BXIII - $0.98f_N = f_O$ and $0.92f_N = f_F$ - wLC - effGA=free wo prior