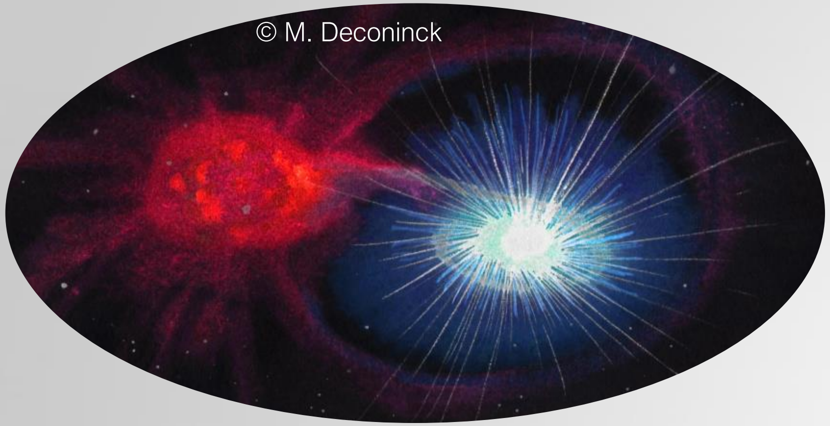


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# Understanding $^{22}$Na cosmic abundance by measuring lifetimes in $^{23}$Mg

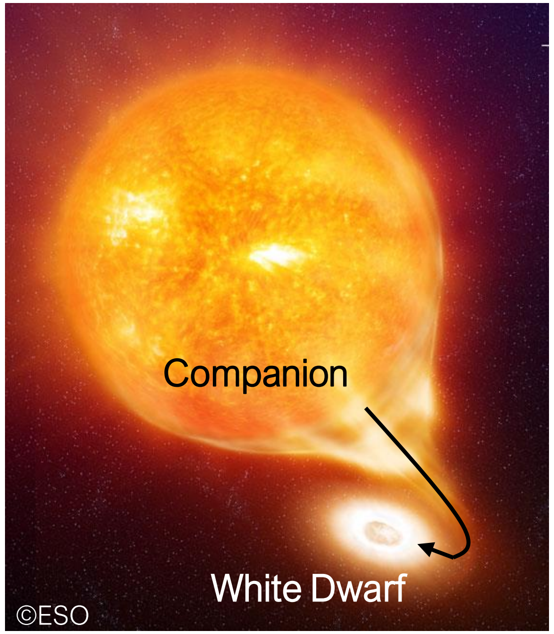

C. Fougères[1], F. de Oliveira Santos[1] et al.

[1]GANIL CEA/DRF-CNRS/IN2P3, Caen (France)

laboratoire commun CEA/DRF CNRS/IN2P3

# Astrophysics motivations

# Stellar objects of interest



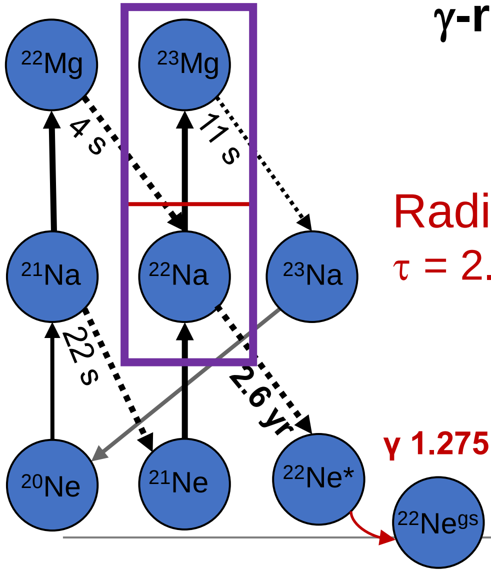

Binary system {Red Giant RG + White dwarf WD}
Matter accretion → explosive hydrogen burning at surface

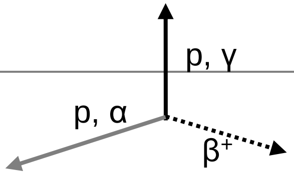
## Impacts

- Abundances of nuclei
- Isotopic composition of meteoritic presolar grains *Black (1972)*
- Test of Nova models
- Number of supernovae SNIa (dark energy)

**Need of astronomical observables**

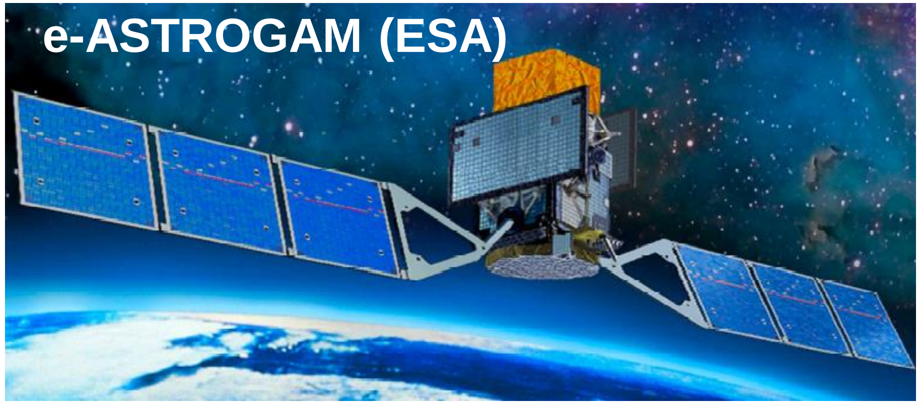
## ONe novae




**γ-ray observation campaigns**
(INTEGRAL, COMPTEL…)
$E_\gamma$ = 1.275 MeV never seen

Radiotracer $^{22}$Na
$\tau$ = 2.6 yr, $E_\gamma$ = 1.275 MeV




Sensitivity improved by x30
*De Angelis, Tatischeff et al. (2017)*

## Uncertainties

*Accretion dynamics, initial WD temp.*

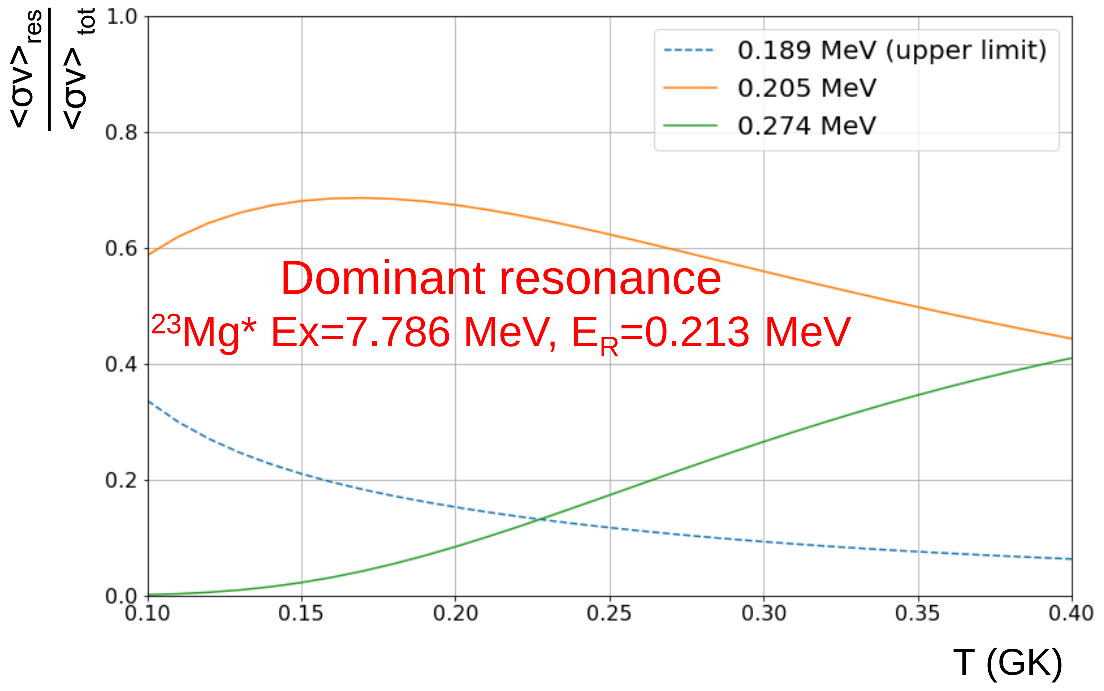
*Sensitivity on $^{22}$Na from nova*

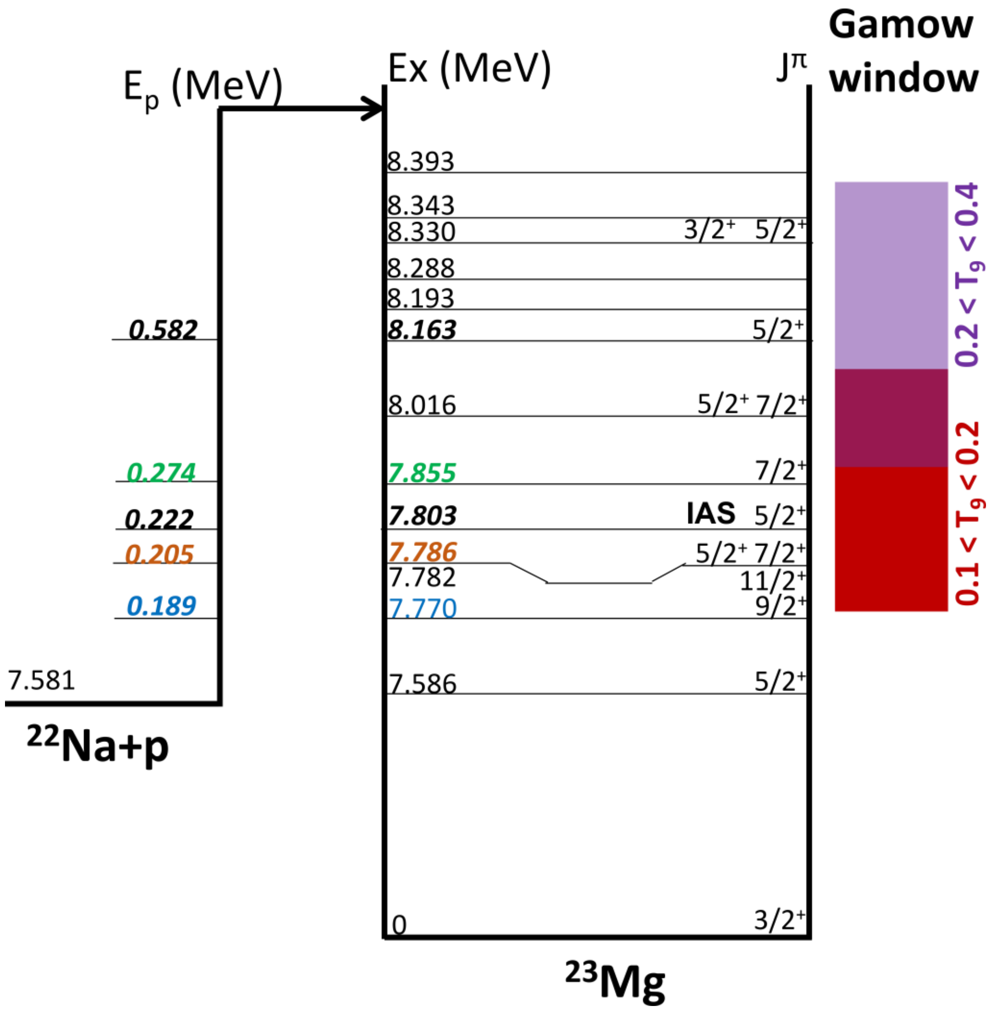
*$^{22}$Na(p, γ)$^{23}$Mg* rate*

# Destruction $^{22}$Na(p, γ)$^{23}$Mg

$^{22}$Na(p, γ)$^{23}$Mg rate = Σ (∝ resonant ωγ)

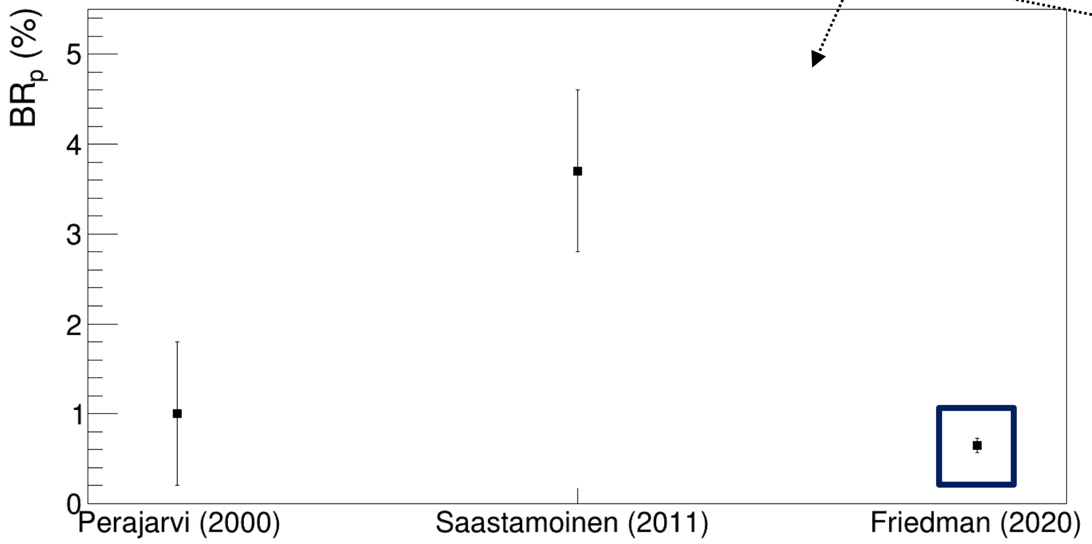
Direct ωγ measurements, TRIUMF $^{22}$Na(p, γ)$^{23}$Mg *Sallaska et al. (2011)*

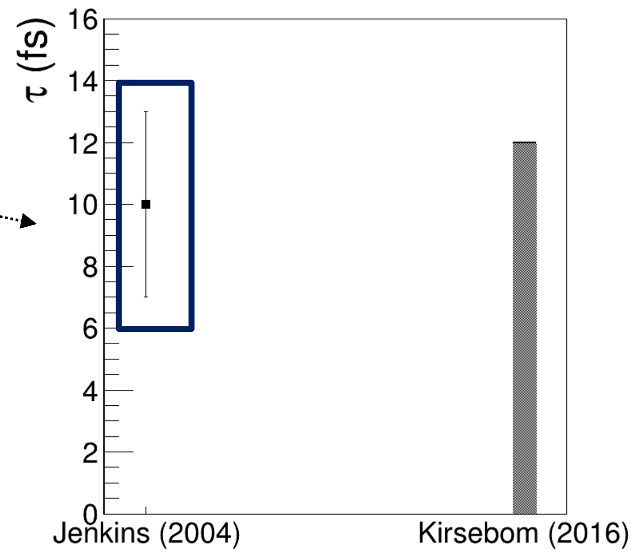


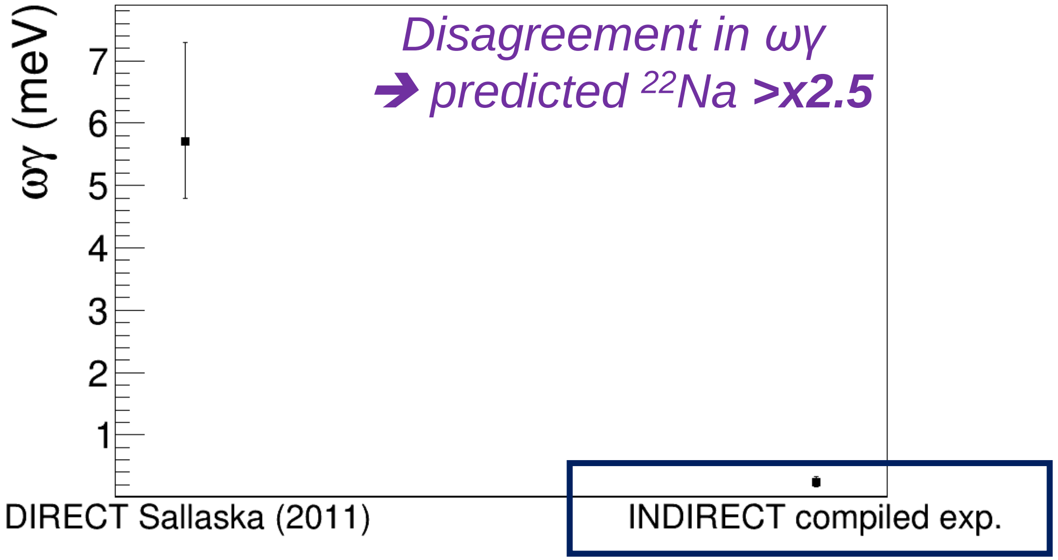



# Indirect access of ωγ at $E_R$ = 0.213 MeV

$$\omega\gamma = \frac{2J_{^{23}Mg}+1}{(2J_{^{22}Na}+1)(2J_{p+1})} \times \frac{\hbar}{\tau} \times BR_p(1-BR_p)$$




E710 indirect method on $^{23}$Mg* Ex=7.786MeV

**(τ, $BR_p$)**

Use of AGATA → fs resolution by DSAM on $^{15}$O*

*Michelagnoli Ph.D. thesis (2013)*

# Experimental approach

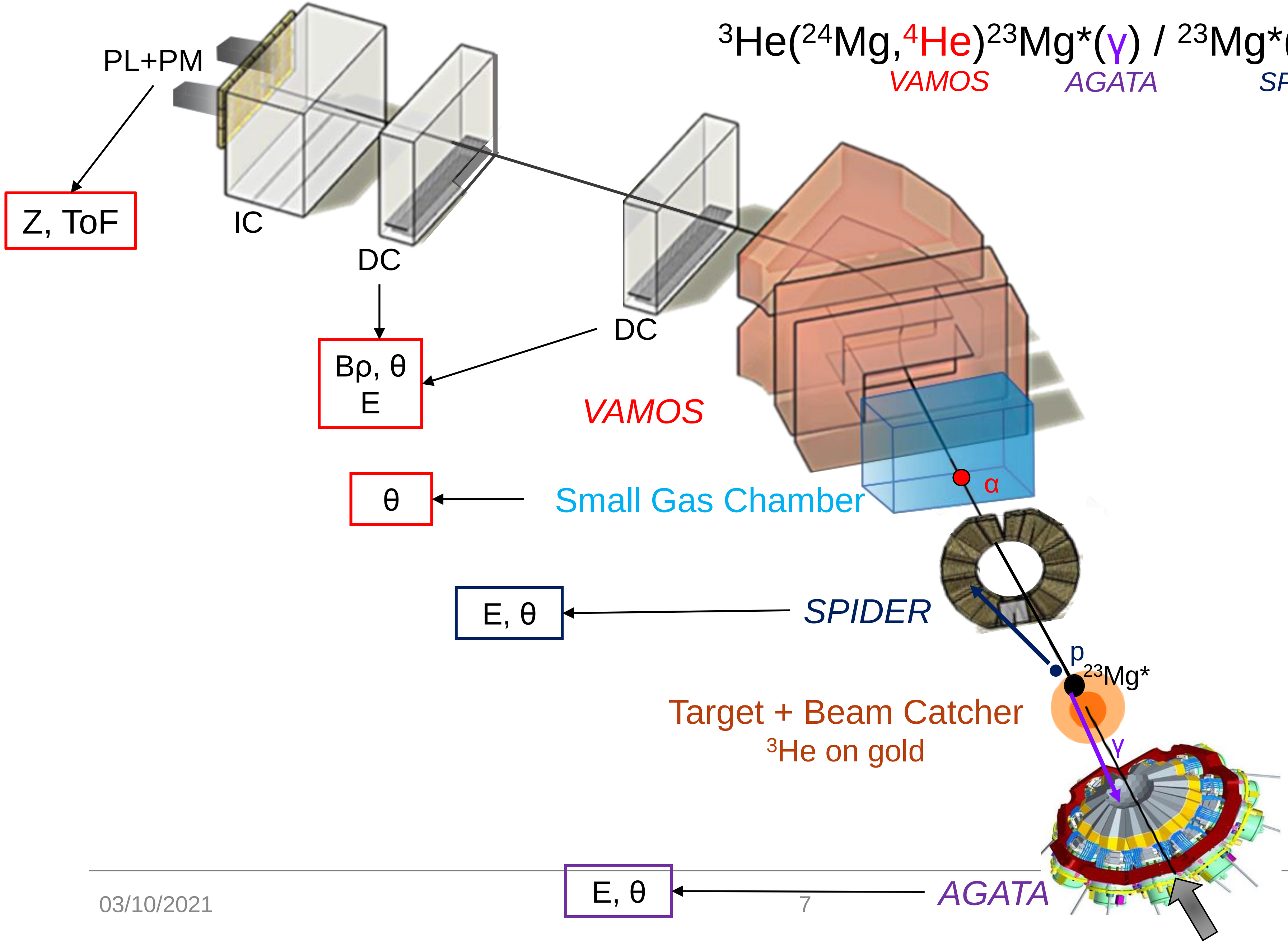
Indirect E710@GANIL

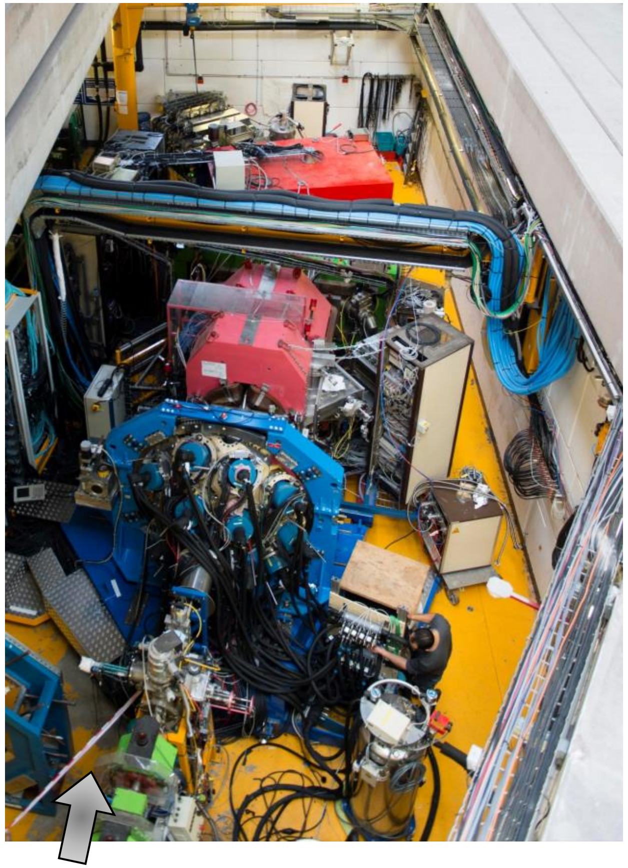
# Set-up

**E710** *C. Michelagnoli et al. (2016)*

$^{3}He(^{24}Mg,^{4}He)^{23}Mg^{*}(\gamma)$ / $^{23}Mg^{*}(p)$

*VAMOS* *AGATA* *SPIDER*

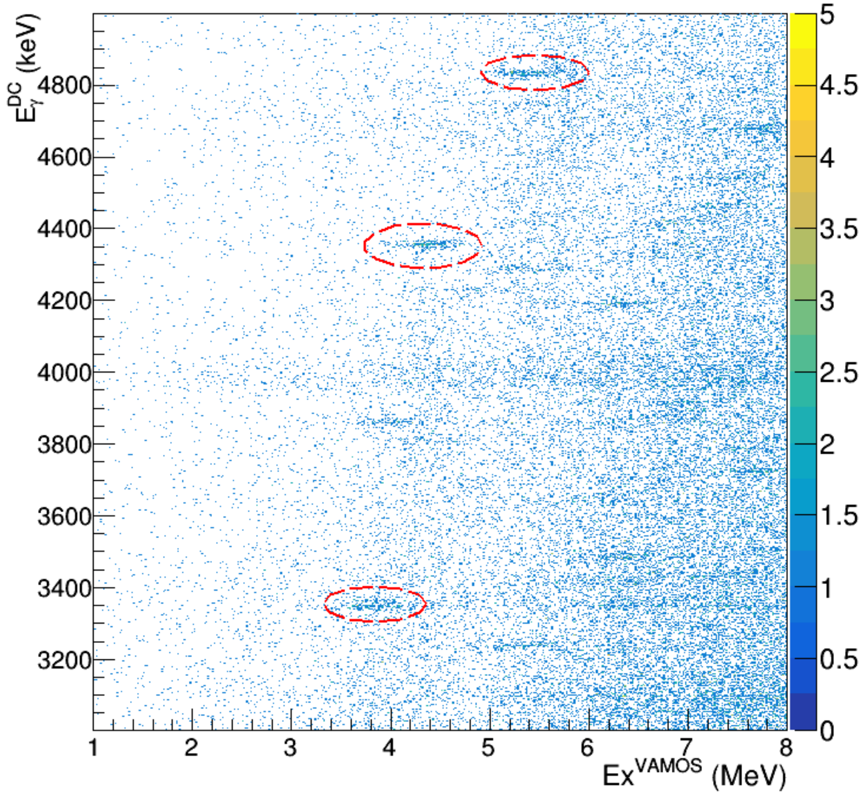


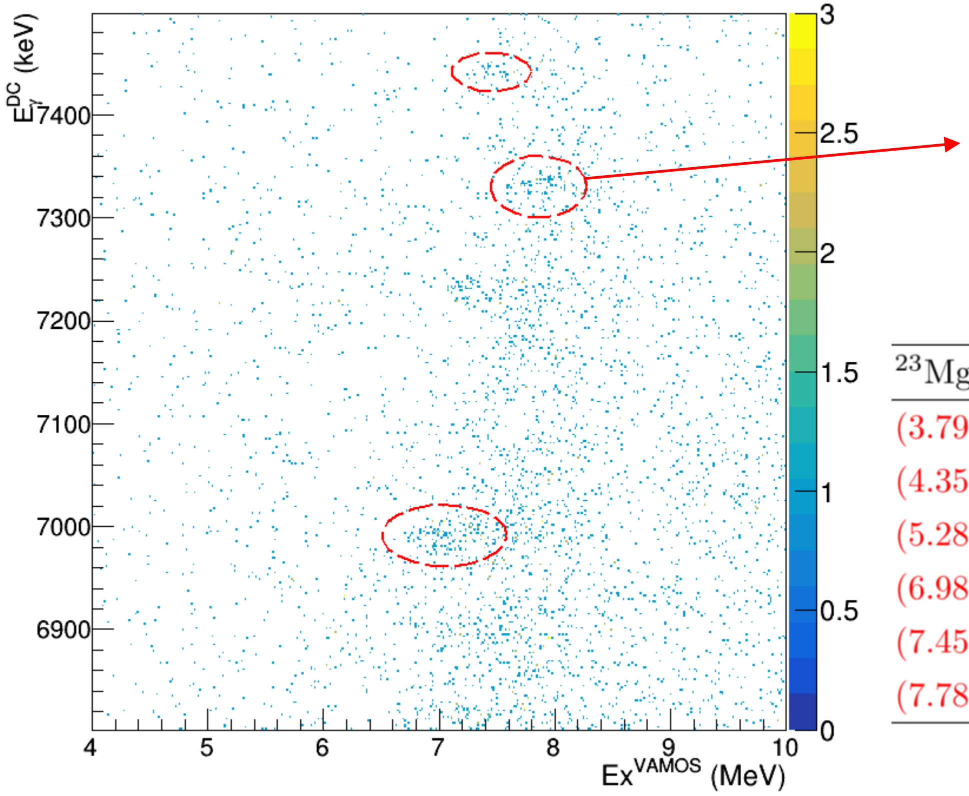



BEAM

$^{24}Mg$ at 4.6 MeV/u

# Population of $^{23}$Mg* states

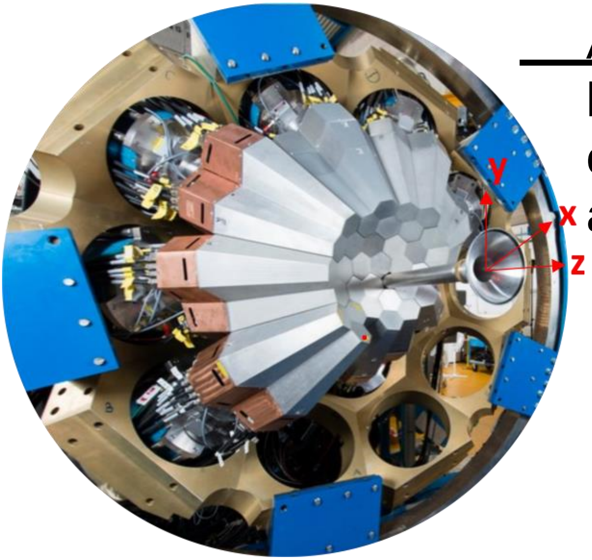



| $^{23}$Mg (Ex, $E_{\gamma,0}$) MeV | $Ex^{VAMOS}$ (MeV) $\pm\sigma$ |
|---|---|
| (3.794, 3.344) | 3.79±0.27(1) |
| (4.356, 4.356) | 4.35±0.19(1) |
| (5.287, 4.836) | 5.25±0.16(2) |
| (6.984, 6.984) | 6.99±0.17(1) |
| (7.450, 7443) | 7.44±0.31(8) |
| (7.786, 7.333) | 7.78 ±0.15(1) |

→ 22 states in $^{23}$Mg* identified and isolated at Ex +/- 0.3 MeV

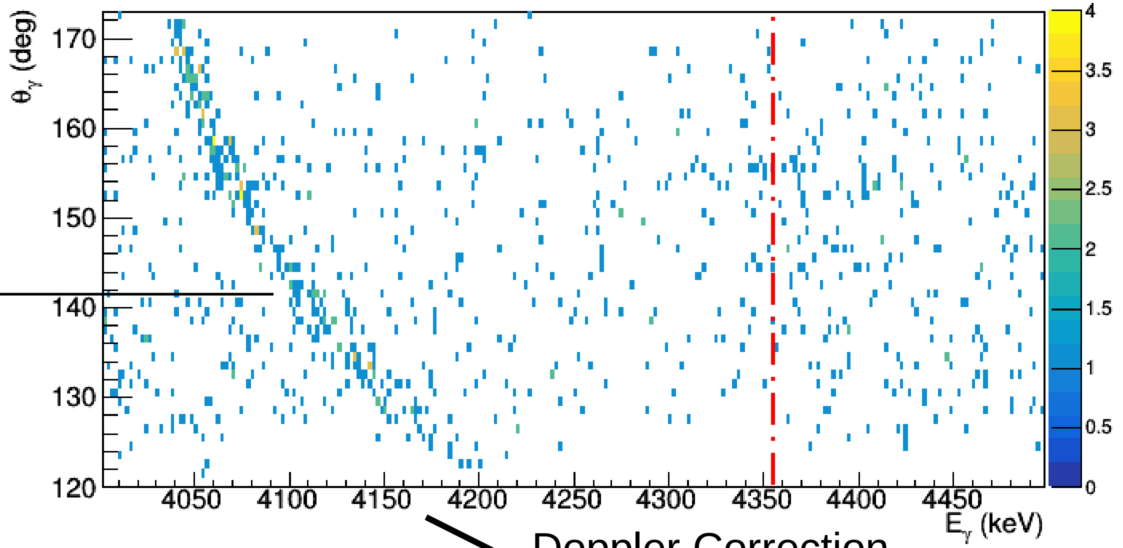
# Accessing γ–ray transition with AGATA

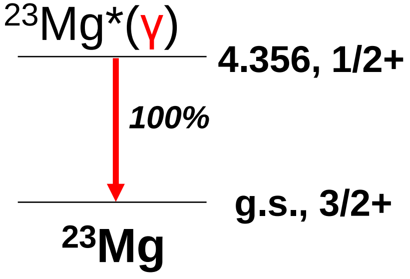



AGATA
high resolution
continuous
angular coverage

Transition observed in 2-dimensions ($E_\gamma$, $\theta_\gamma$)
$Ex^{VAMOS}$ = 4.35 +/-0.2 MeV

$^{3}He(^{24}Mg,^{4}He)^{23}Mg^{*}(\gamma)$

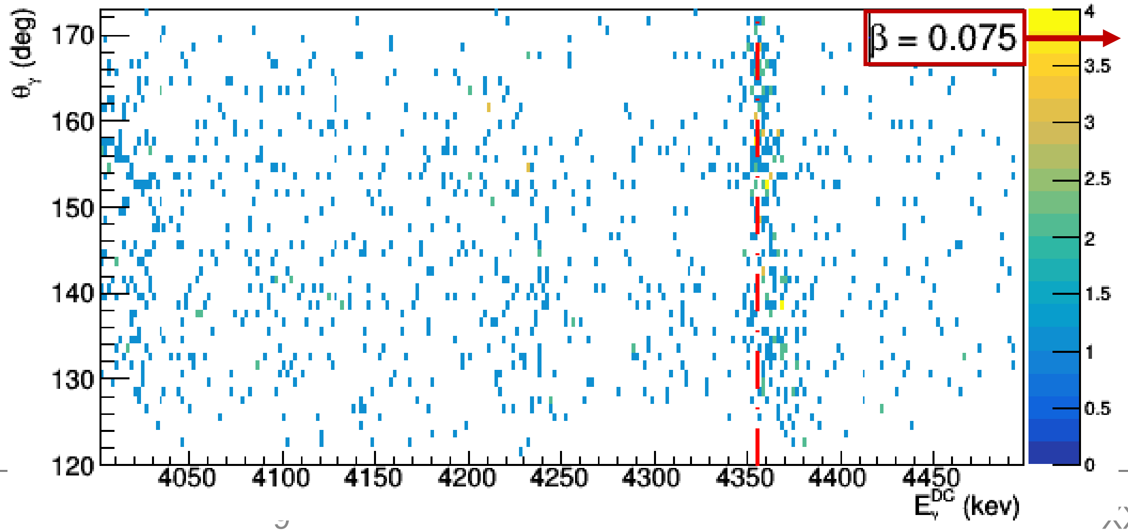



Doppler shift

Doppler Correction

Reconstruct **(β, $E_\gamma^{DC}$)**
**on event basis**




**mean β=0.075(1)**

# Preliminary results

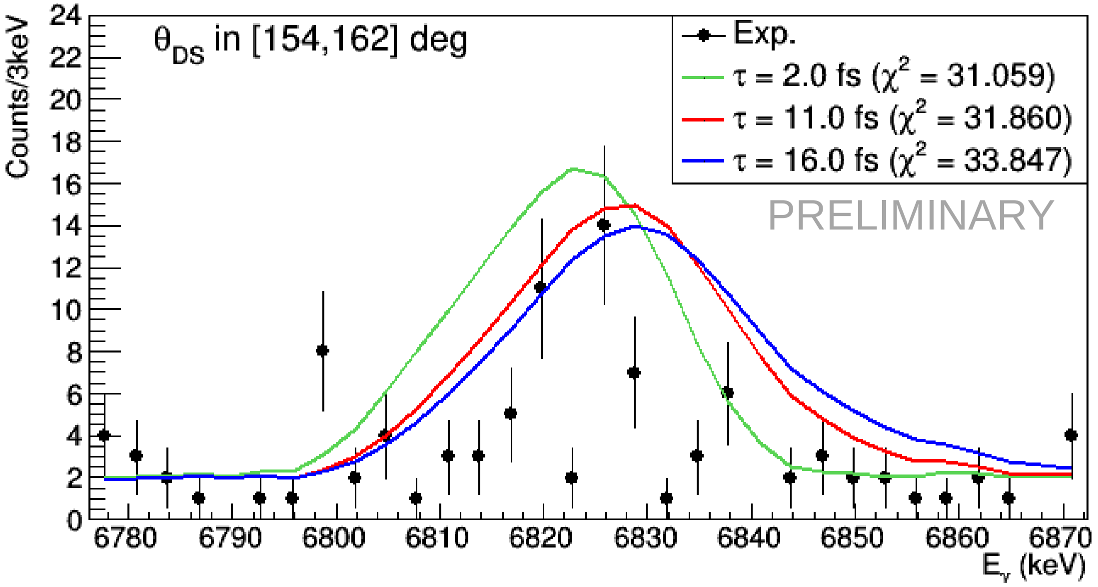
Spectroscopy of the Ex=7.786 MeV excited state in $^{23}Mg^*$

# Accessing lifetimes (1)

Based on lineshape analysis where experiment compared with simulations (EVASIONS code built for E710)

**Method N°1: DSAM** ***classical***

$E_\gamma$ projected on angle slices

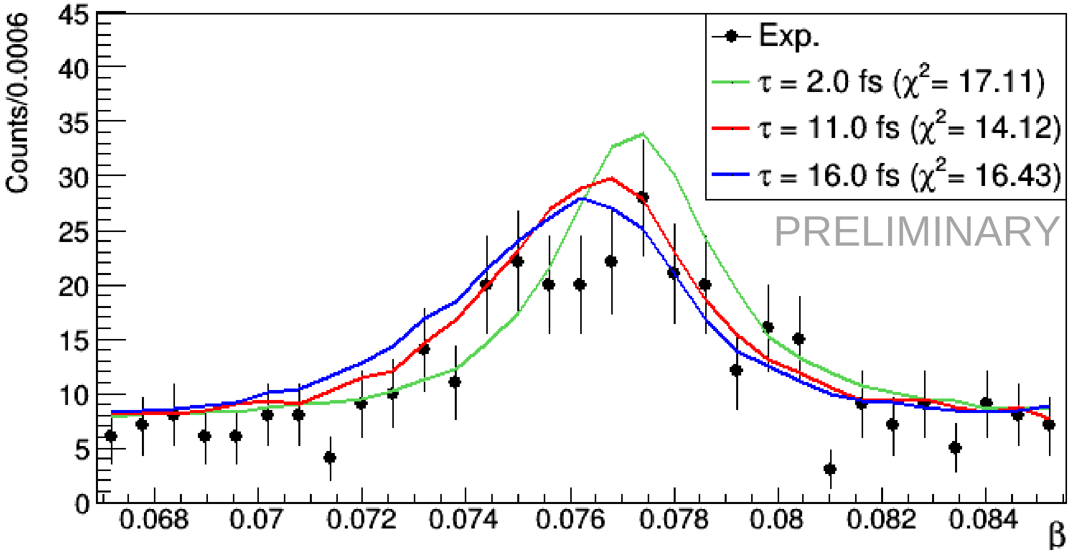



→ Upper limit obtained

# Accessing lifetimes (2)

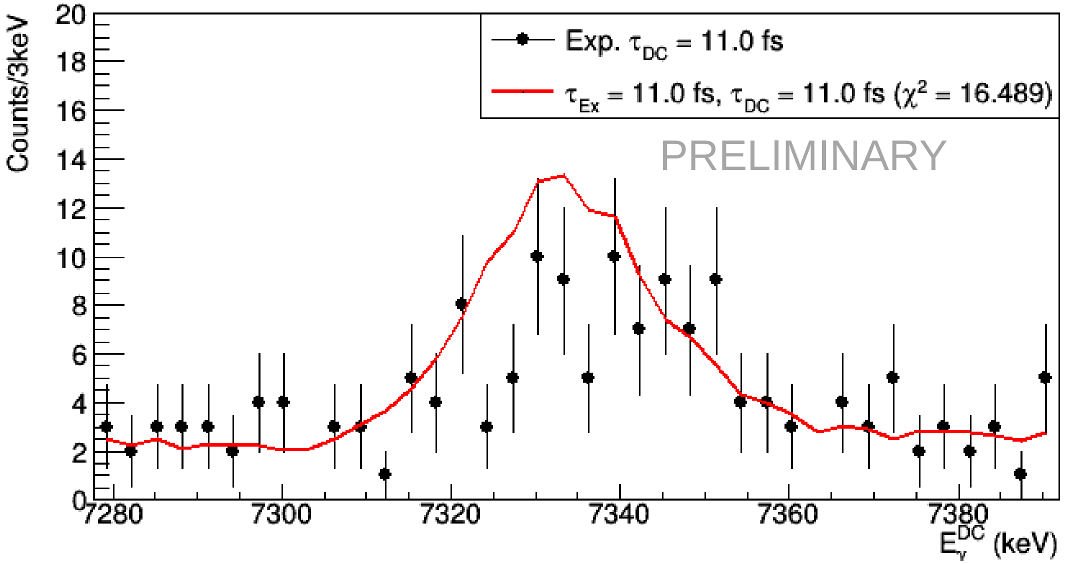
**Method N°2: β distribution** ***new***

Distribution of β reconstructed from ($E_\gamma$, $\theta_{DS}$)



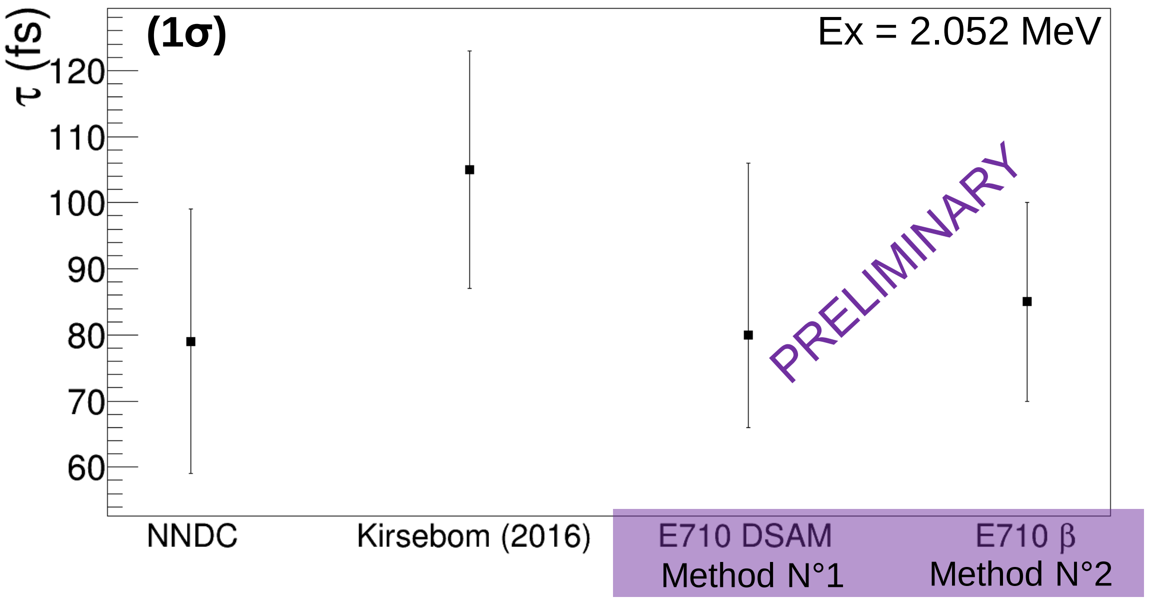

**Method N°3: DCM** ***recent***

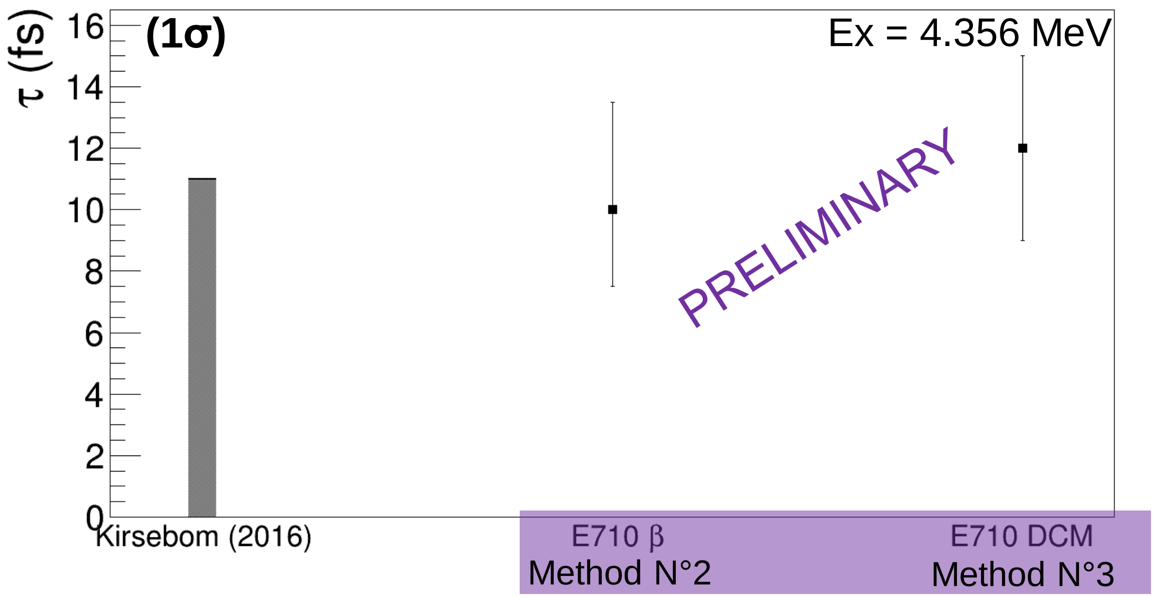
Doppler Corrected Method ($E_\gamma^{DC}$ projected on all angles)



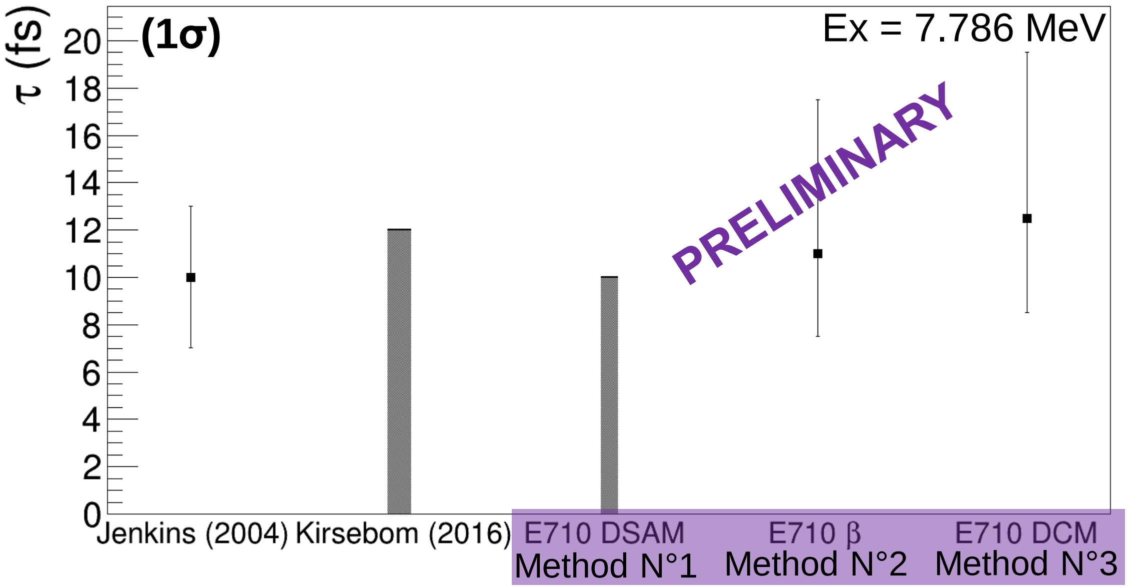
# Results in lifetimes of $^{23}Mg^*$

Preliminary tests




Key state




**Present work**

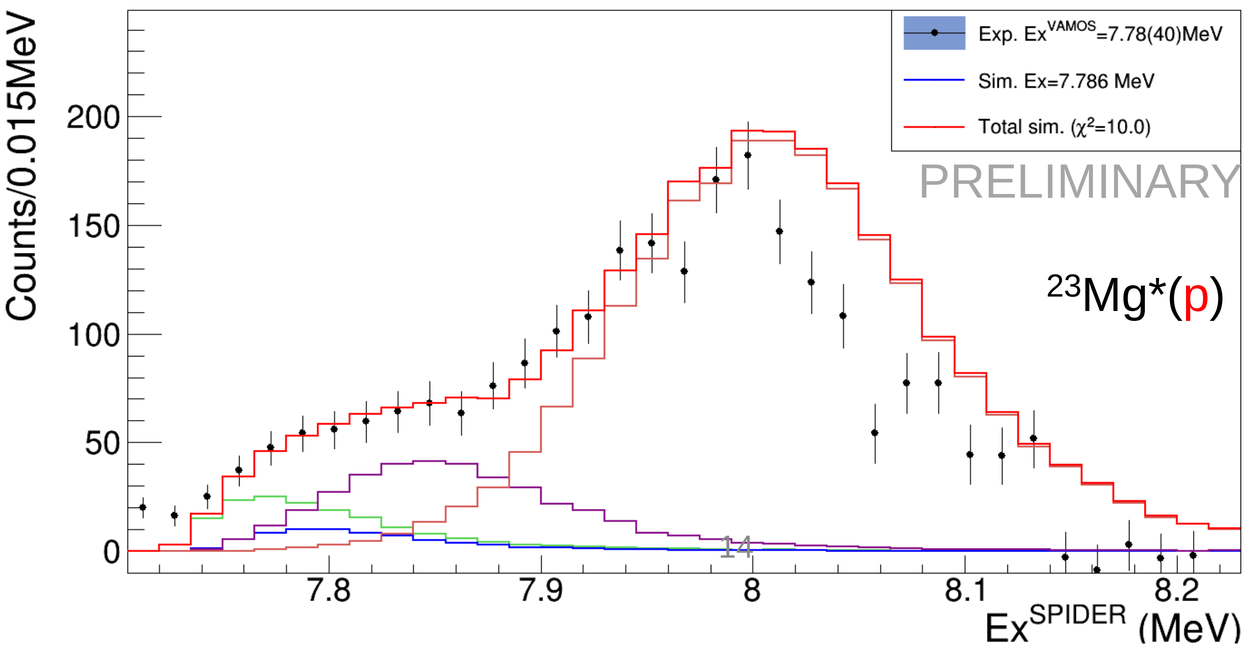
*C. Fougères et al.*
*Results to be submitted,*

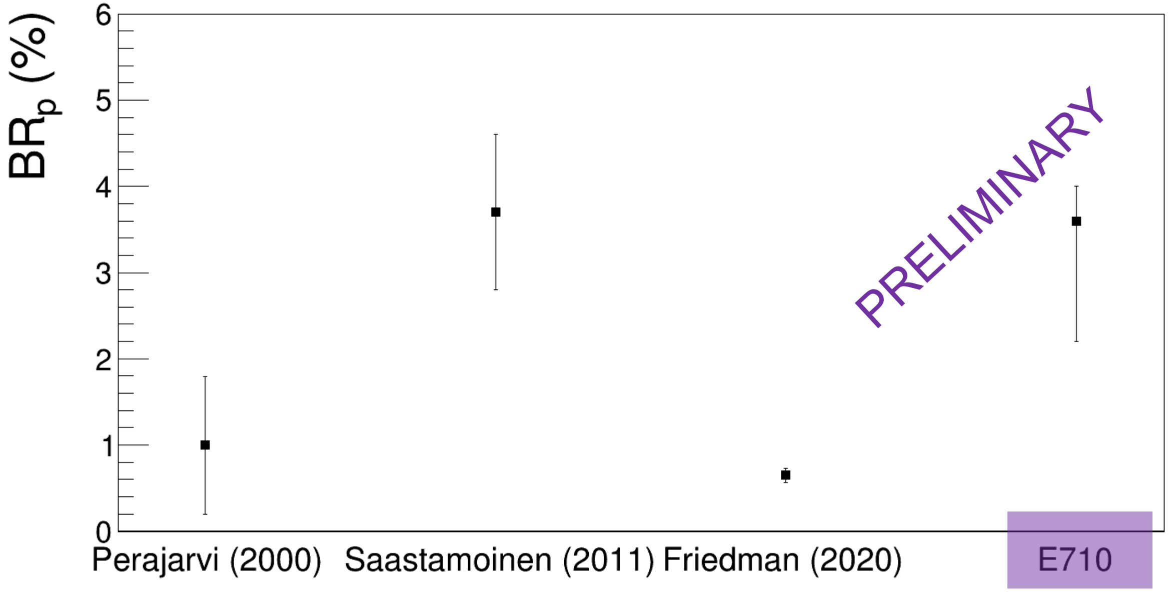
# Accessing $BR_p$



**Present work**

$Ex^{VAMOS}$ = 7.78 +/-0.4 MeV



# Astrophysical impacts

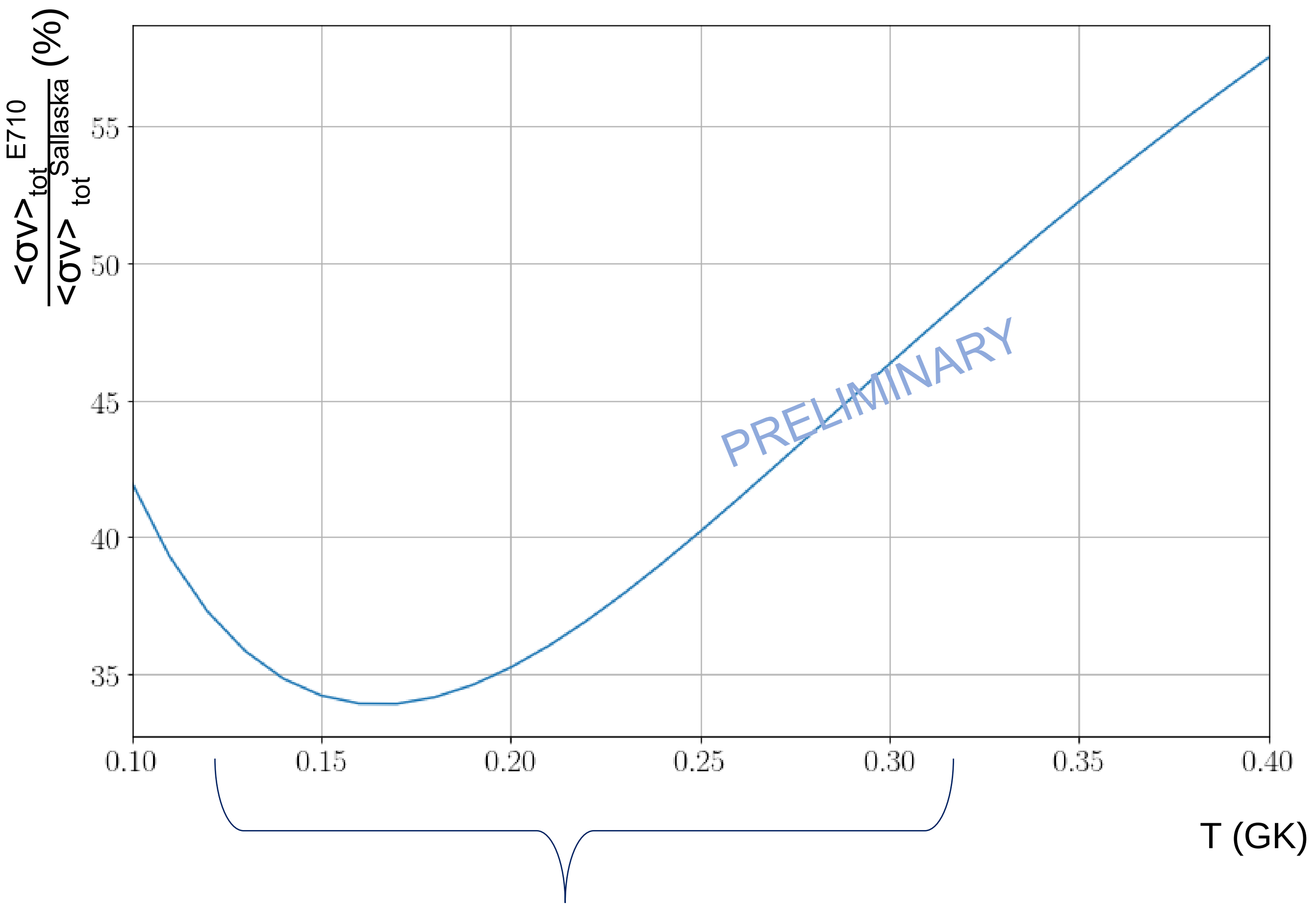
Predictions in $^{22}$Na flux

# New rate $^{22}Na(p, \gamma)^{23}Mg$

Analytic calculations, with **$\omega\gamma_{0.213MeV}$ = 0.21(7) meV** PRELIMINARY

(J=7/2+, τ = 11.7 fs), $BR_p$ = 0.65% *Friedman et al (2020)*

*$^{22}Na(p, \gamma)^{23}Mg^{*}$ rate*




*Impact on emitted nova $^{22}Na$ ?*

*C. Fougères et al.*
*Results to be submitted*

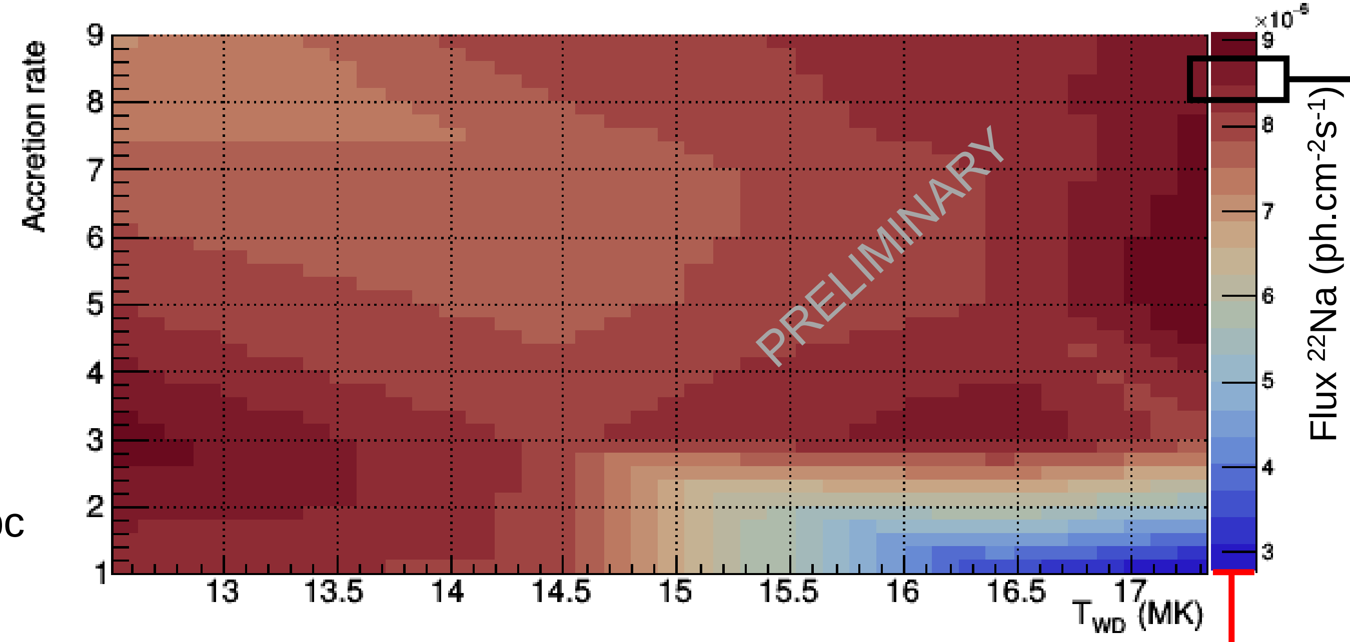
# Predictions in $^{22}$Na flux

Simulations of novae

MESA

*(Paxton et al, 2013)*

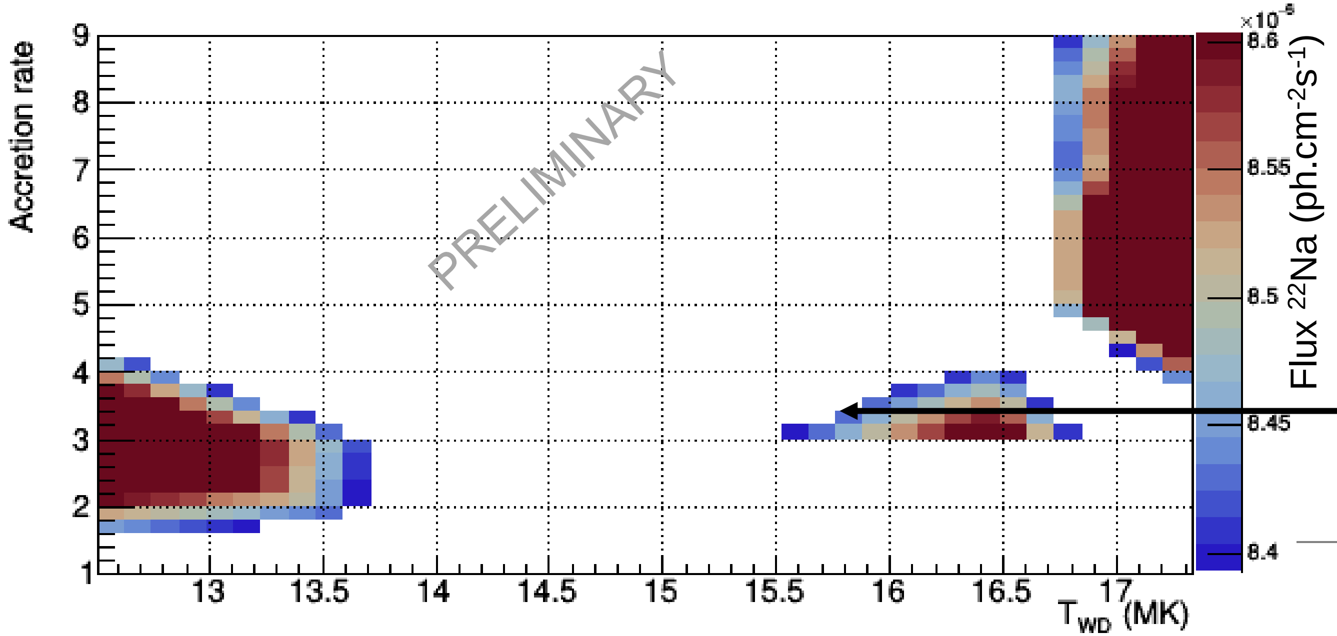
Nova at 0.5 kpc
$M_{WD} = 1.2\ M_\odot$



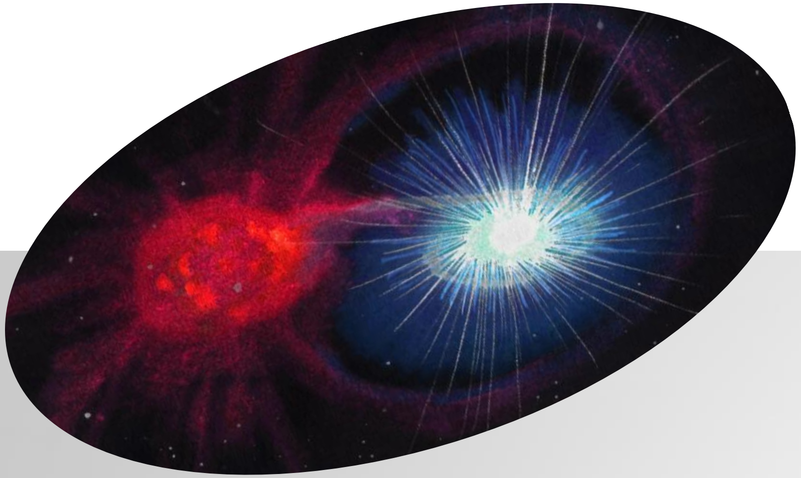

*Accretion dynamics, initial WD temp.?*

*Sensitivity on $^{22}$Na from nova ?*

e-ASTROGAM limit




Constrain novae parameters with observed flux



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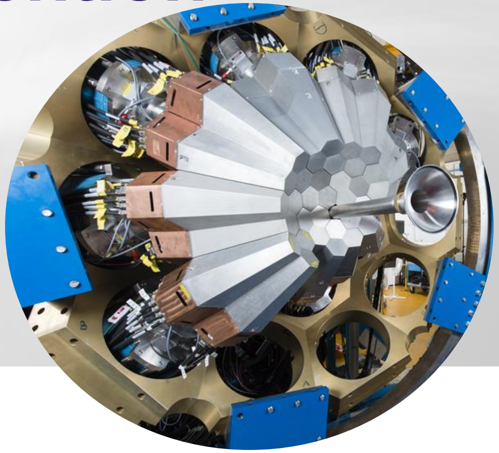
# Outlooks

Final results in ($BR_p$, J)

Calculations of Monte Carlo reaction rate *Meyer Ph.D. thesis (2020)*

Nova simulations with SHIVA *J.José et al, (1998, 2021)* + other free parameters (composition of thermonuclear medium)

## THANKS
## to E710 collaboration and to you for the attention



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