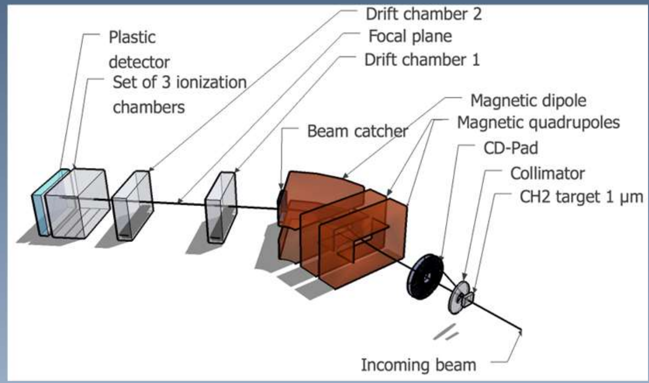
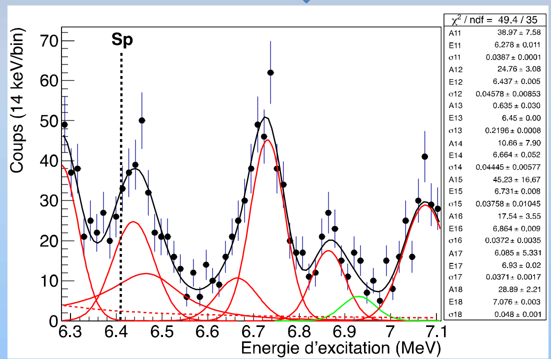
Spectroscopy of ^{19}Ne via a new method of inelastic scattering. Application to the ^{18}F(p,α)^{15}O reaction rate calculation of astrophysical interest.

Florent Boulay GANIL, Caen France

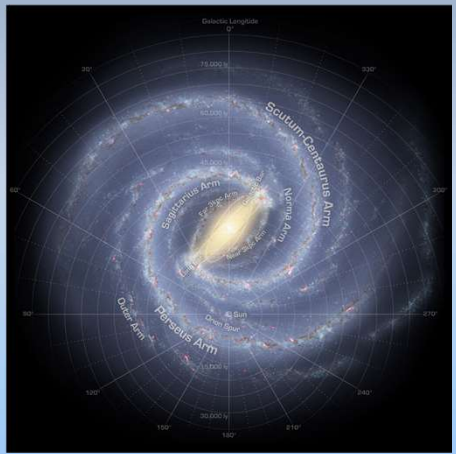
I) Astrophysical context : The nova phenomenon



II) The experimental setup

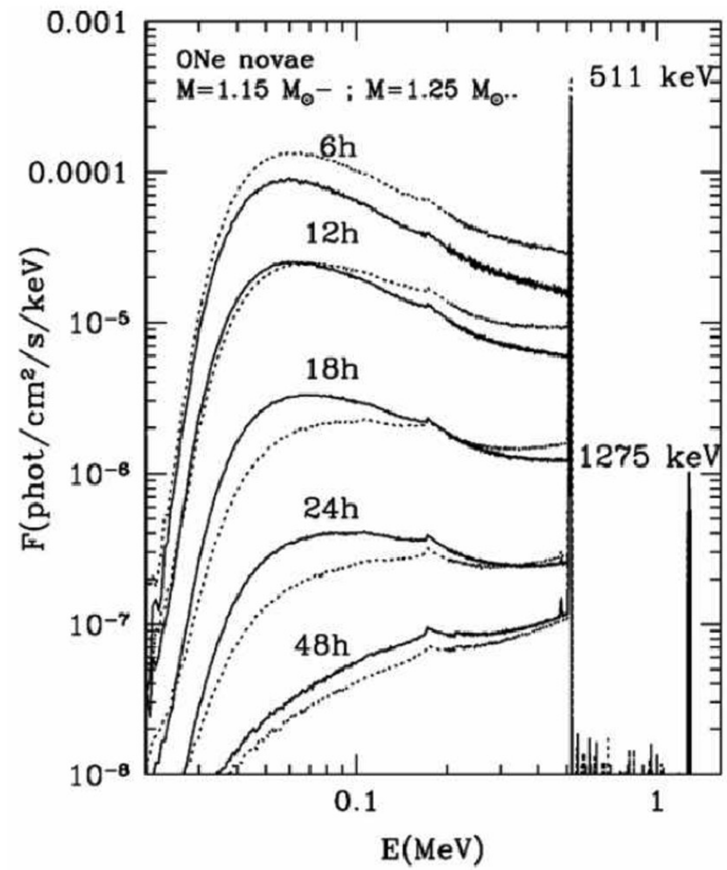


III) The results



IV) Interpretations of the results

Conclusion & Outlooks



Predictions at 1 kpc J. José M. Hernanz J. Phys. G 2007

- A key observable: Gamma rays at 511 keV + continuum
- One of the main β+ emitters: ^{18}F
- 2 main reactions constrain the abundance of ^{18}F
- $^{18}F(p,\alpha)^{15}O$ et $^{18}F(p,\gamma)^{19}Ne$.

1)Astrophysical context

To constrain the $^{18}F(p,\alpha)^{15}O$ reaction rate

Direct measurements

Cross section of ^{18}F +p (inverse kinematics)
- Low beam intensity
- Beam impurities (^{18}O...)
- Low cross section (coulomb barrier...)

C. E. Beer et al. Phys. Rev. C, 83 :042801, Apr 2011.
D. J. Mountford, et al. Phys. Rev. C, 85 :022801, Feb 2012.
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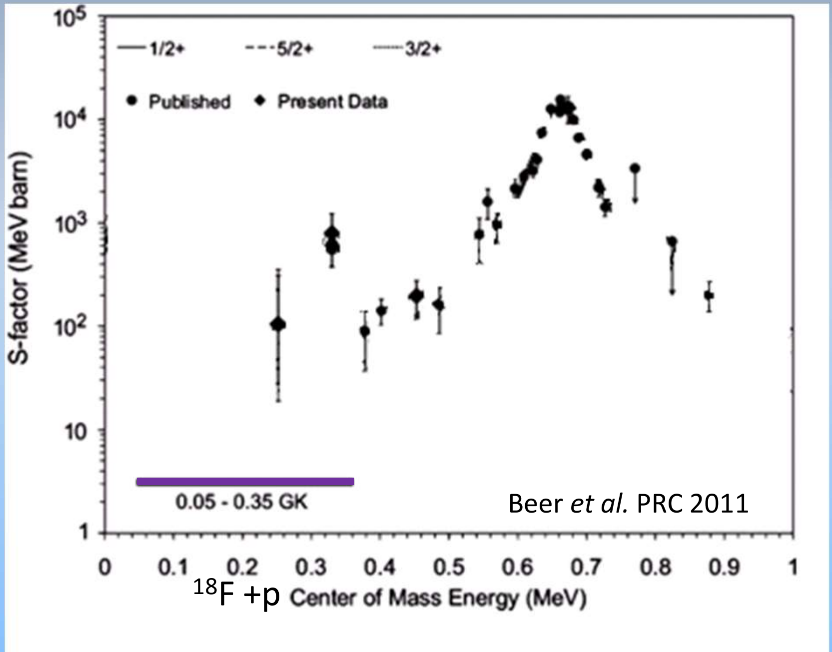

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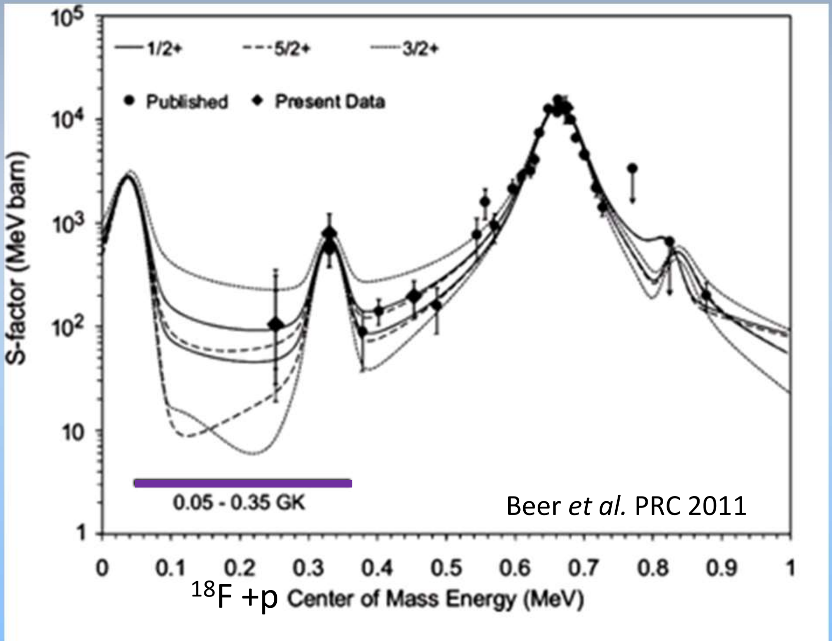

Indirect measurements

Study of the ^{19}Ne properties (Energy, spin, widths) around the proton threshold or the mirror nucleus ^{19}F

Selectivity on the state populated depending on the reaction mechanism (transfer...)

Most of the time, angular momentum is not assigned independently of the model.

S. Adekola, et al. Phys. Rev. C, 84 :054611, Nov 2011.
M. Laird et al. Phys. Rev. Lett., 110 :032502, Jan 2013.
St. J. Murphy, et al. Phys. Rev. C, 79 :058801, May 2009
S Utku,et al. Physical Review C, 57(5) :2731, 1998.
N. de Séréville et al., Nucl. Phys. A (2007).
D. W. Bardayan, et al. Phys. Rev. C, 63 :065802, May 2001.
etc

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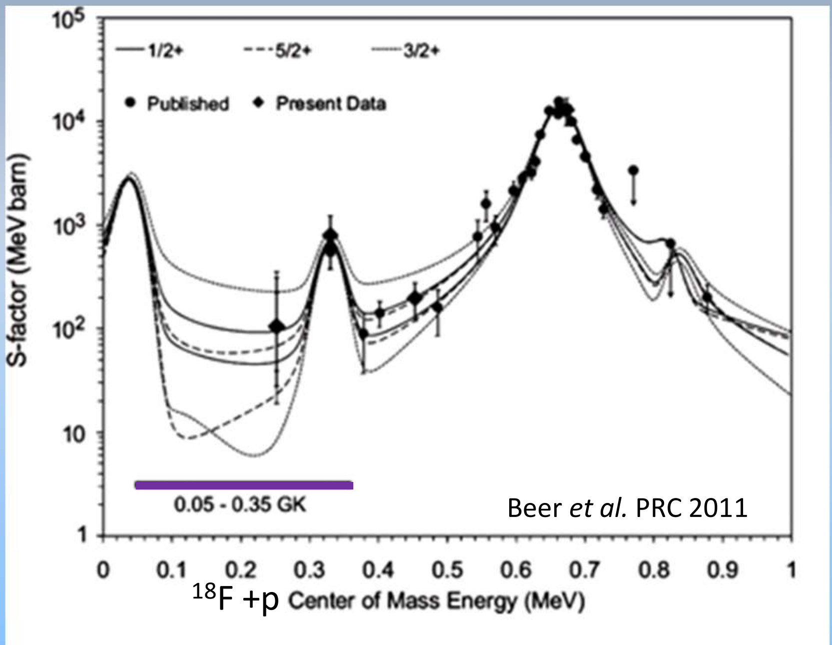

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S. Ad
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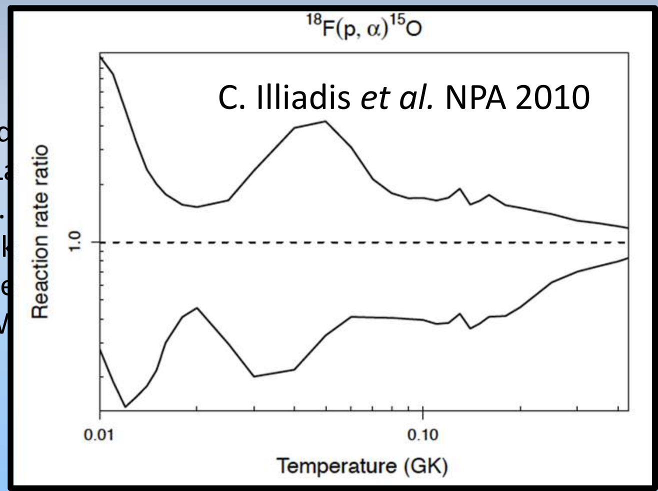
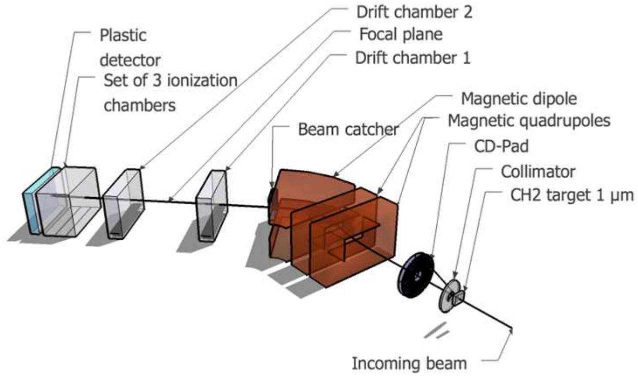
D. W 01.
etc



II) The experimental setup

How do we measure the ^{19}Ne spectroscopic properties (Energy, Spin, Width) ?

I) Astrophysical context : The nova phenomenon



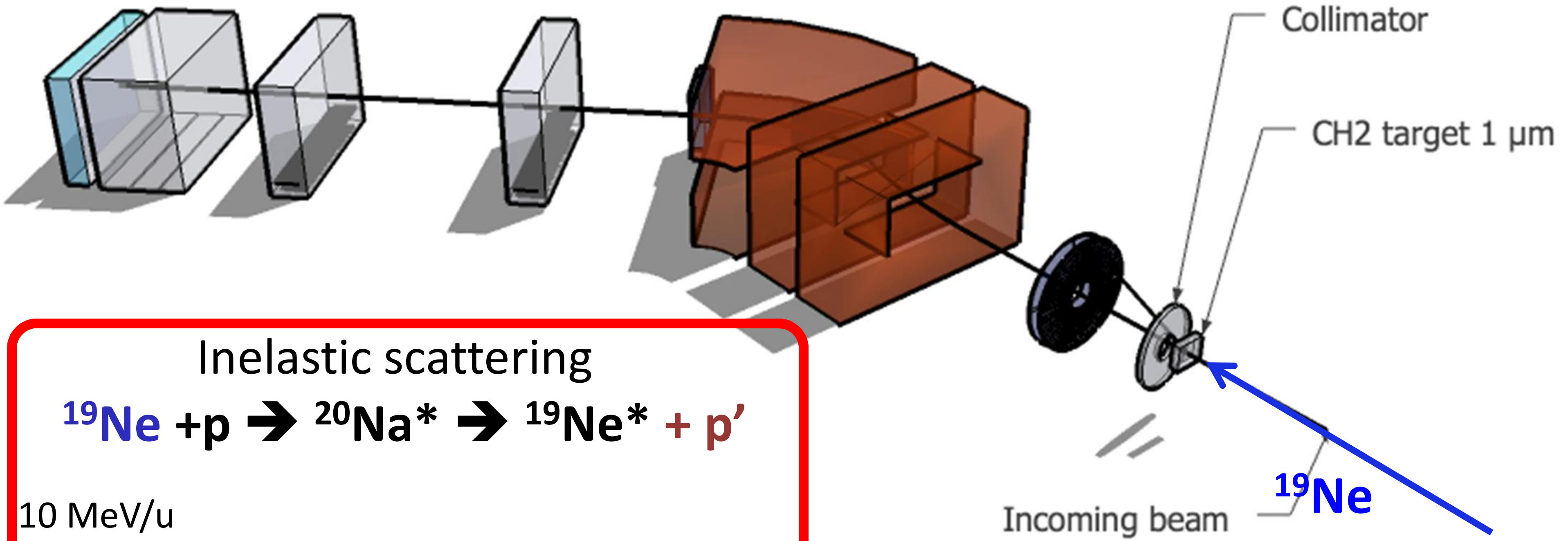
II) The experimental setup

III) The results

IV) Interpretations of the results

Conclusion & Outlooks

how populate the ^{19}Ne excited state?
Using inelastic scattering mecanism
Same reaction as Dalouzy et al. PRL (2009) with new experimental setup



Inelastic scattering

^{19}Ne +p ➔ ^{20}Na* ➔ ^{19}Ne* + p'

10 MeV/u

Compound nucleus

=> less selectivity in the states populated

SPIRAL 1 beam up to 2.10^8pps
purity 100 %
$i=2.10^7$ pps ($i_{max}=2.10^8$ pps)

how populate the ^{19}Ne excited state?
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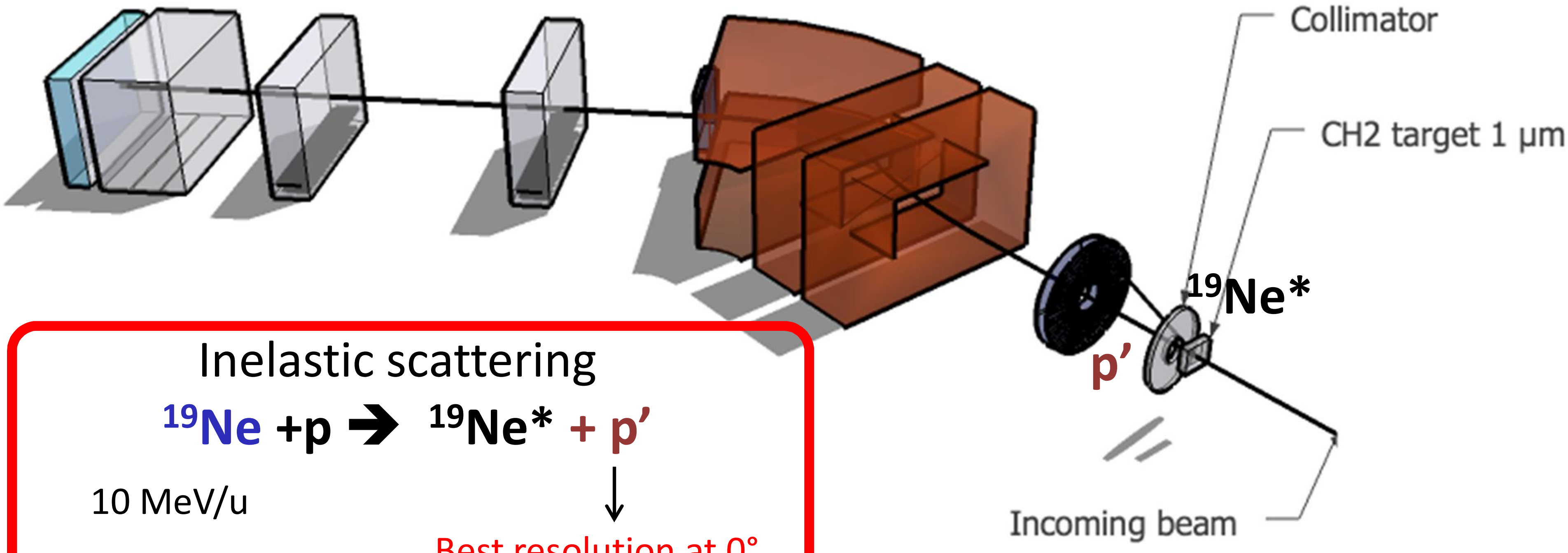


Inelastic scattering

^{19}**Ne +p ➔ ^{19}Ne* + p'**

10 MeV/u

↓

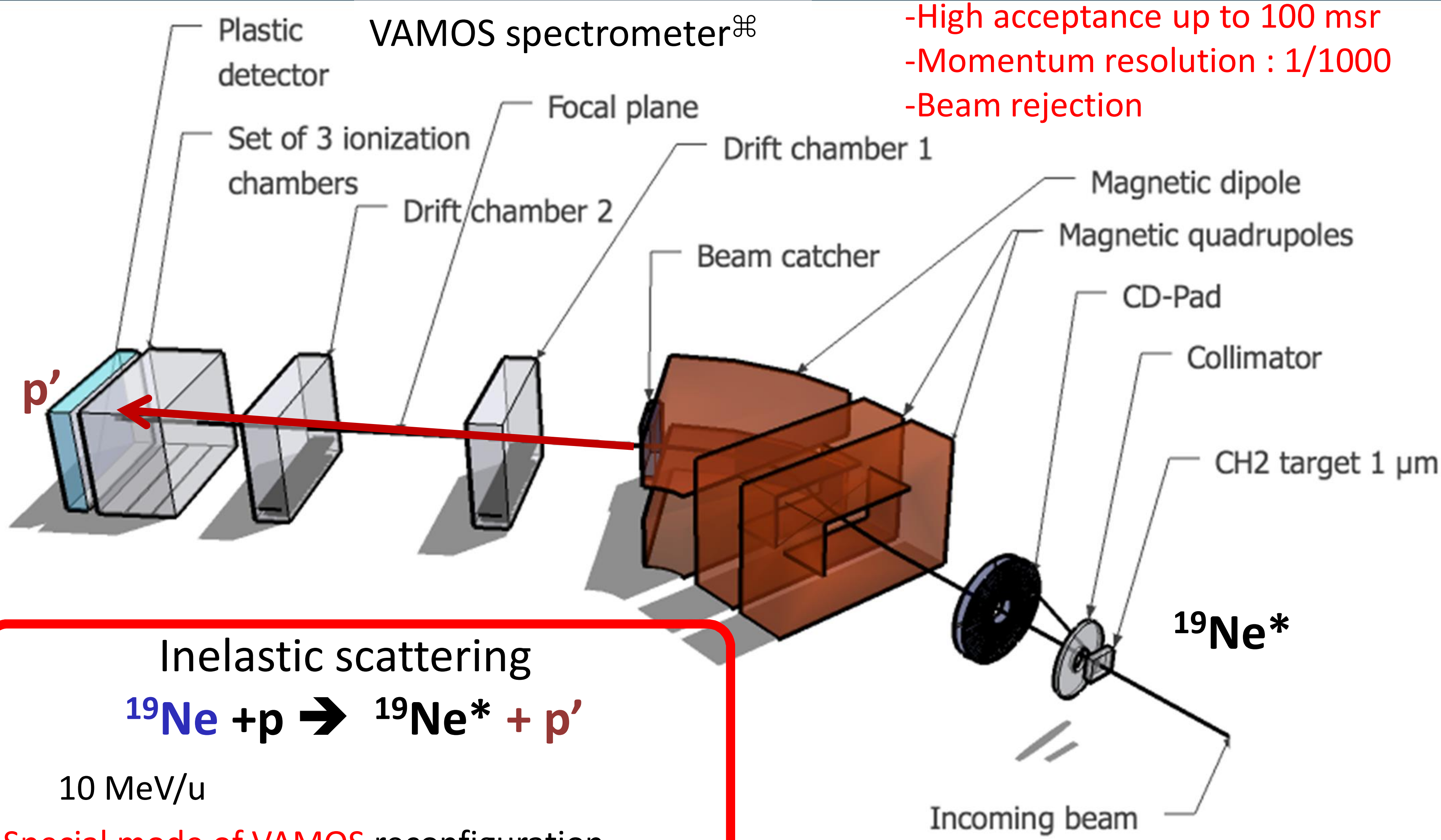
Best resolution at 0°

=> protons p' kinematics allow us to reconstruct $^{19}Ne^*$ energy spectra (Ex)

$i=2.10^7$ pps ($i_{max}=2.10^8$ pps)

VAMOS spectrometer⌘

-High acceptance up to 100 msr
-Momentum resolution : 1/1000
-Beam rejection



Inelastic scattering

^{19}Ne +p → ^{19}Ne* + p'

10 MeV/u

Special mode of VAMOS reconfiguration (pressure, voltages) of the drift chambers =>Proof of principle with an experiment in Rez Czech Rep. F. Boulay Internal report

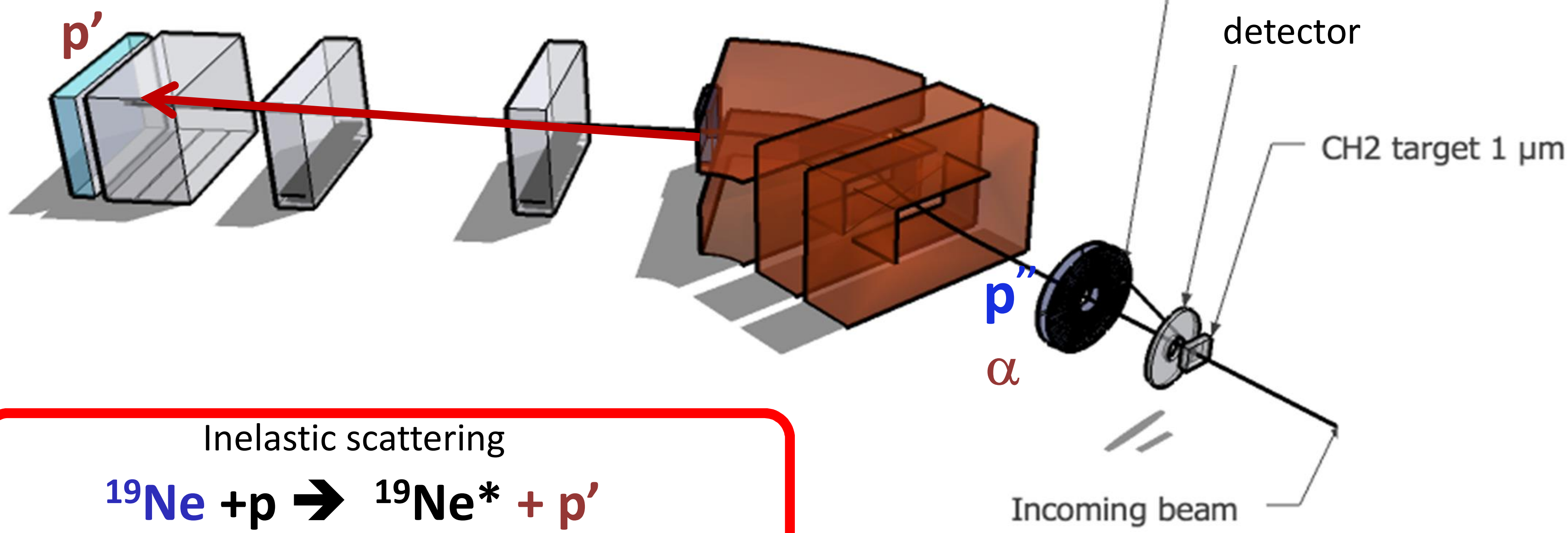
i=2.10^7 pps (i_{max}=2.10^8 pps)

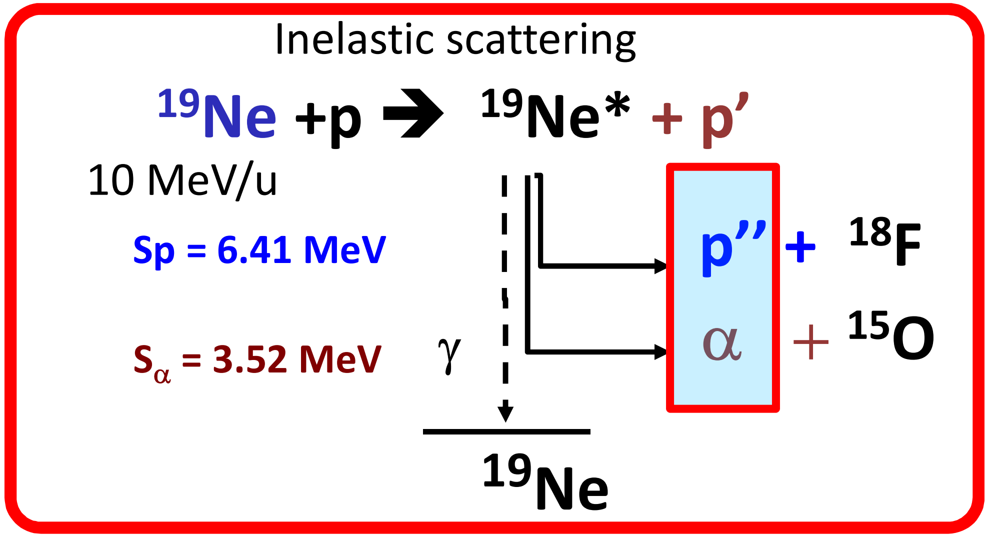
⌘M. Rejmund *et al.* NIMA (2011)

2)The experiment

How do we measure the angular distribution and branching ratio ?

The angular distribution of p''α contain the information concerning the spin of $^{19}Ne^*$ decaying :
method independant of the model





⌘T. Davinson *et al.* NIMA 454(2000)

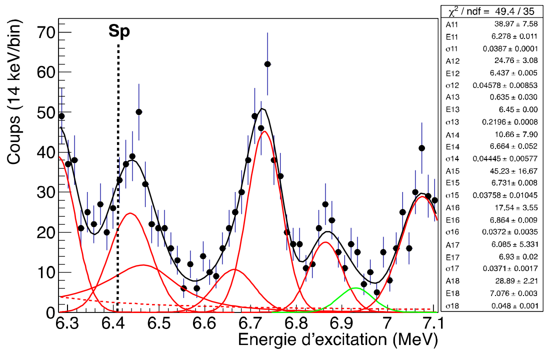
III) The results

I) Astrophysical context : The nova phenomenon

II) The experimental setup

Conclusion
& Outlooks

IV) Interpretations of the results



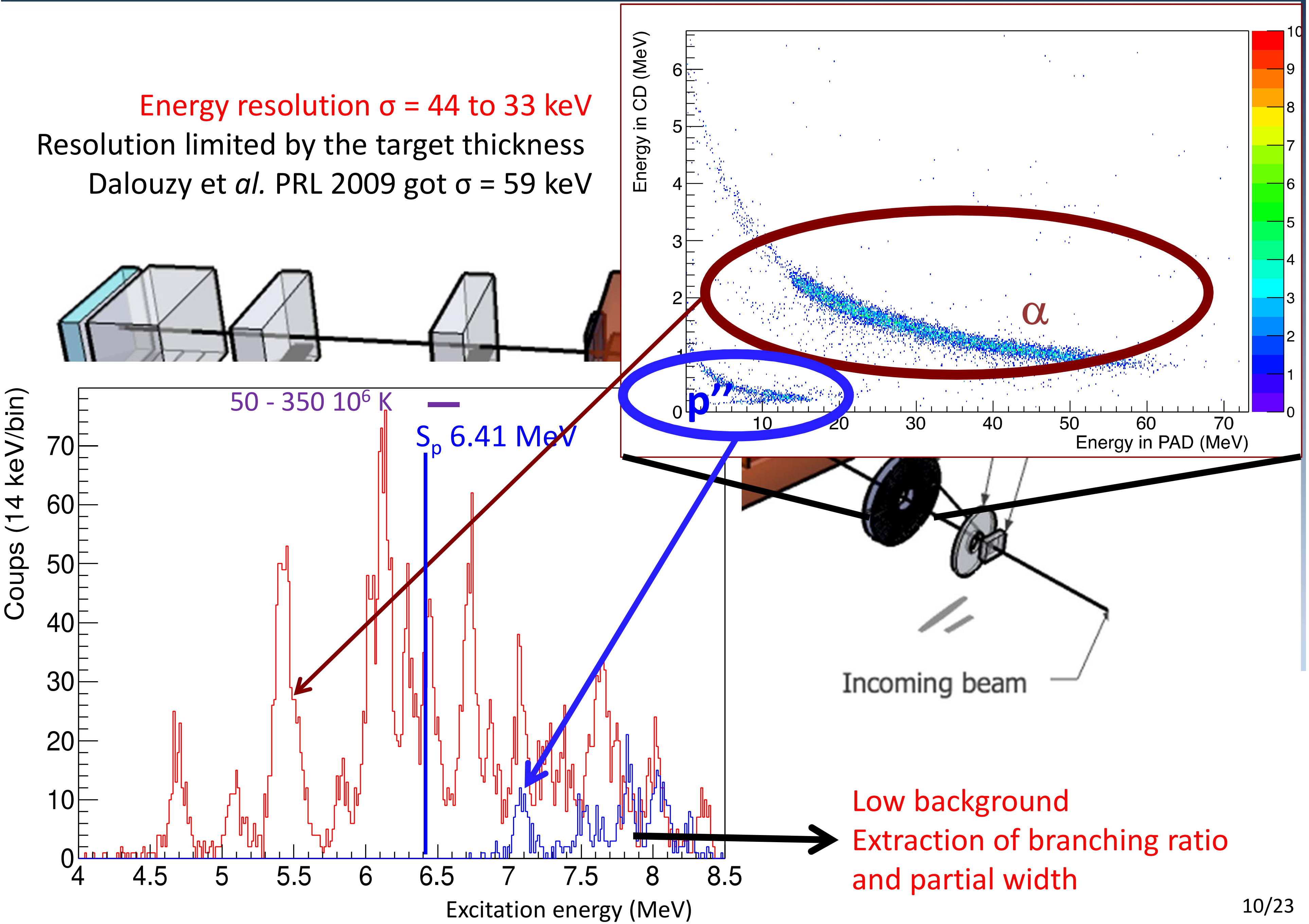
III) The results

Excitation energy, width and branching ratio

Energy resolution σ = 44 to 33 keV

Resolution limited by the target thickness

Dalouzy et *al.* PRL 2009 got σ = 59 keV

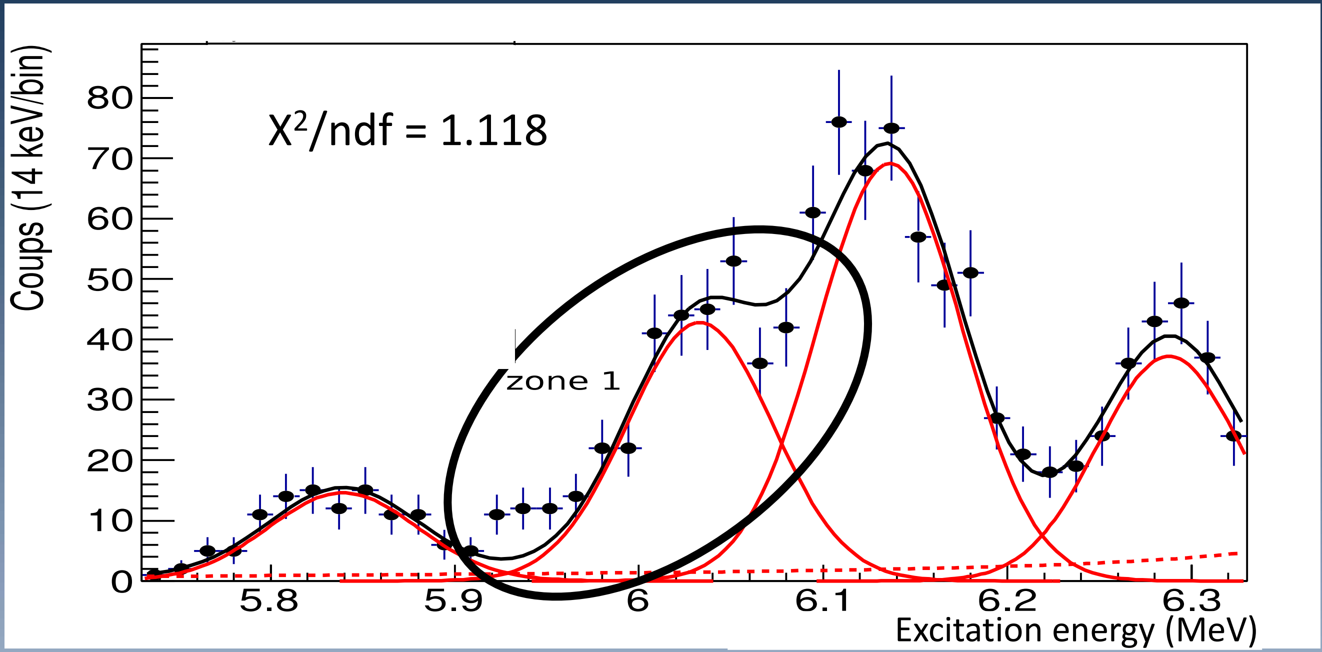


Low background

Extraction of branching ratio and partial width

3)The results

Analysis of key states



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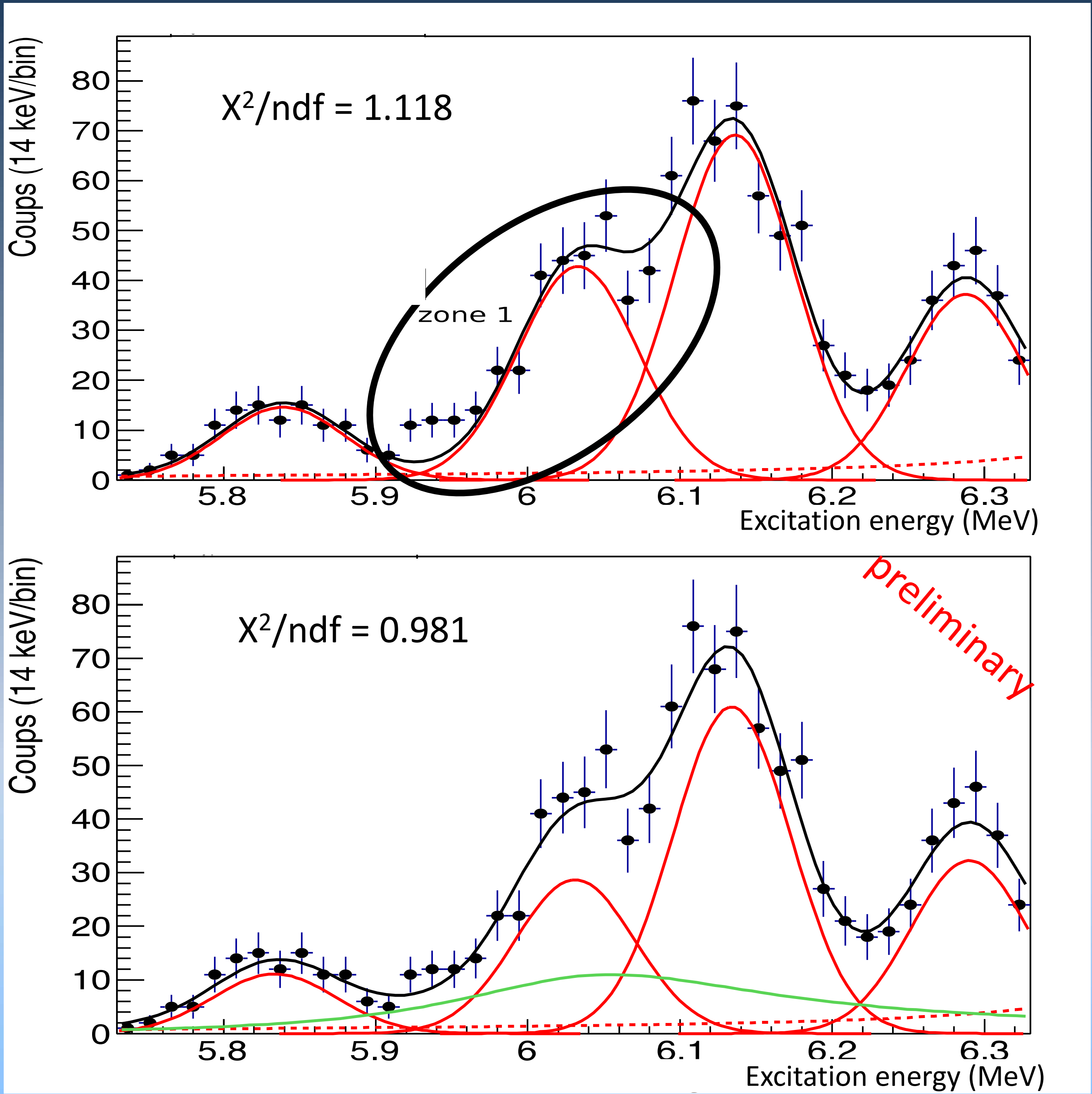
Analysis of key states



1 evidence for a new state

E_r = 6.08(9) MeV

Γ_{tot} = 230(5) keV

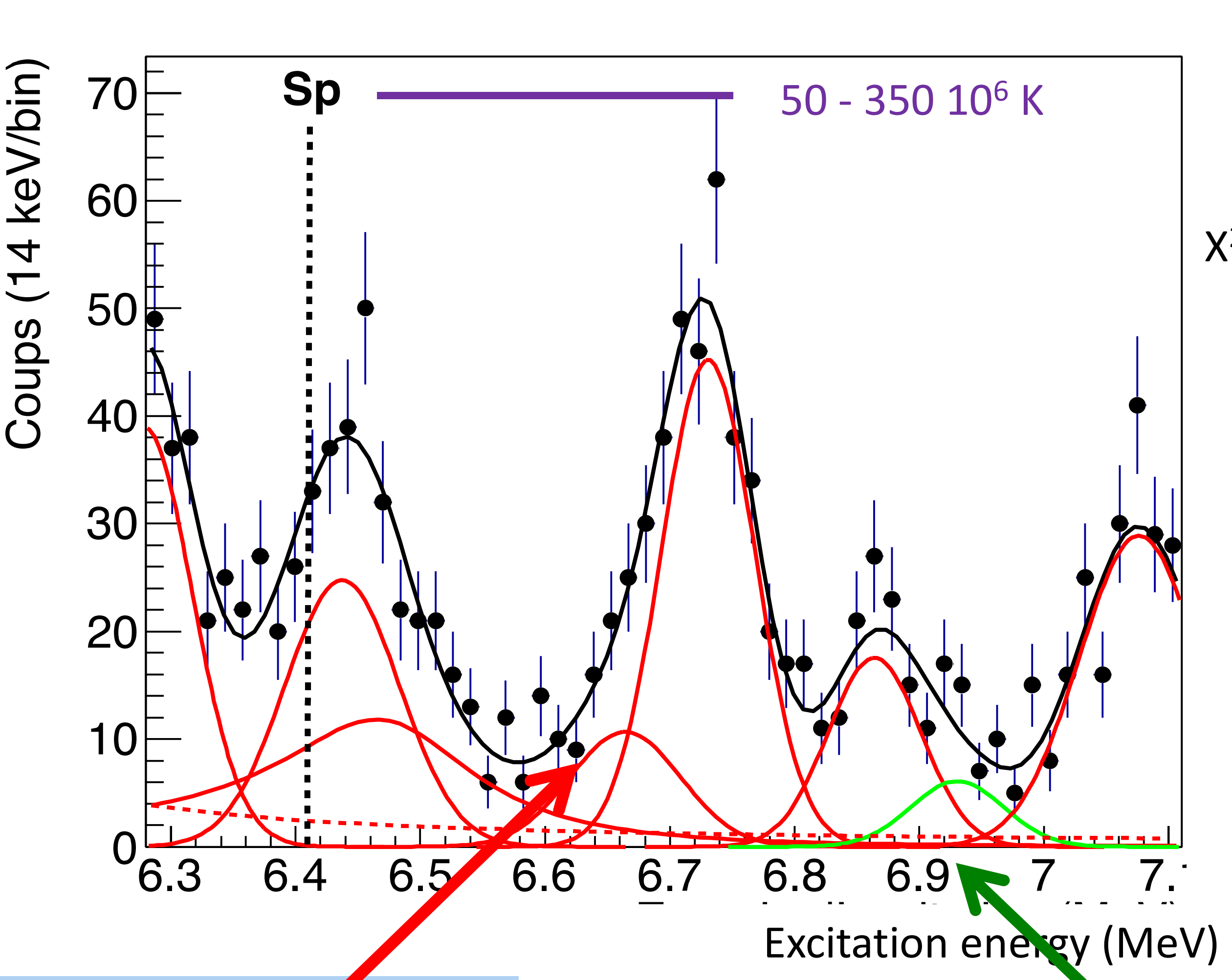
Result compatible with Descouvemont & Dufour theoritical prediction

E_r = 6 MeV

Γ_{tot} = 231 keV

J^{π} = 1/2 +

Analysis of key states

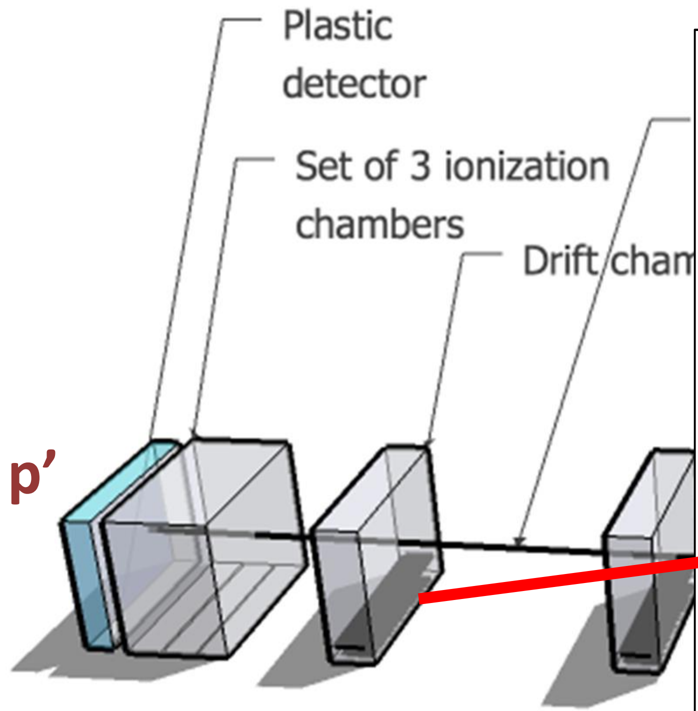


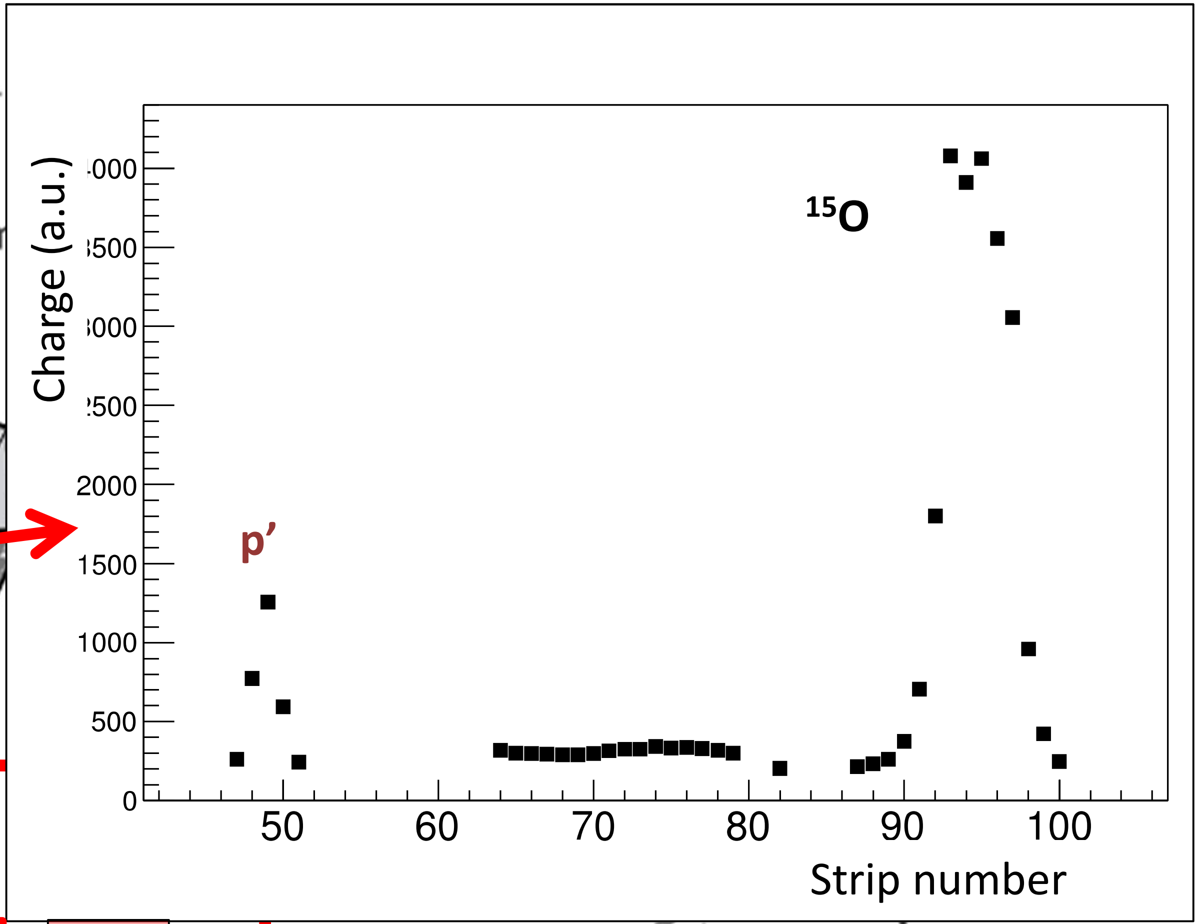
$X^2/ndf = 1.41$

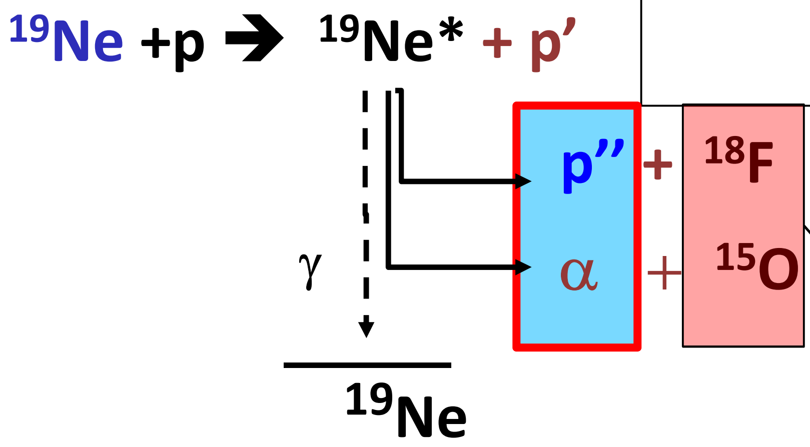
29 keV broad or 2 states ?

At least 1 new state at 6.941 MeV possible

3)The results Contamination effect







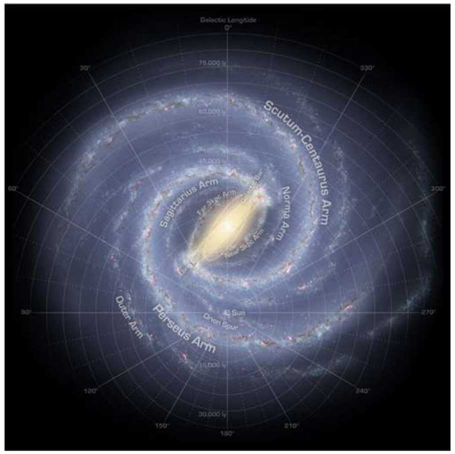
Enter in VAMOS with the proton p' prevent angular distribution measurement

IV) Interpretations of the results

Which consequences for the gamma detection from ^{18}F e^{-} - e^{+} annihilation ?

I) Astrophysical context : The nova phenomenon

II) The experimental setup



IV) Interpretations of the results

III) The results

Conclusion
& Outlooks

4) Interpretations

E^{*19}Ne (MeV)	E_r (keV)	J^π	Γ_{tot} (keV)	$\frac{\Gamma_p}{\Gamma_\alpha}$	Γ_α (keV)	Γ_p (keV)
6.031(5)	-379	$\frac{7}{2}^{b(+)}$				
*6.08(9)	-330	$(\frac{1}{2}^+)^g$	230(1)		230(1)	
6.134(3)	-276	$\frac{3}{2}^{(-)b}$				
6.290(4)	-120	$\frac{7}{2}^{be(-)}$	(0.013)		(0.013)	
		$\frac{7}{2}^{b(+)}$	(3.64)		(3.64)	
		$(\frac{3}{2}^+)$	($\leq$0.55)		($\leq$0.55)	($1.59\text{x}10^{-15}$)
*6.437(8)	27	$(\frac{11}{2}^+)$	($\geq 4.1\text{x}10^{-3}$)		($\geq 4.1\text{x}10^{-3}$)	($3.58\text{x}10^{-23}$)
		$(\frac{3}{2}^+)$	(1.25)		(1.25)	($1.59\text{x}10^{-15}$)
*6.450(5)	40	$(\frac{1}{2}^-)$	220(40)		220(40)	($1.10\text{x}10^{-15}$)
*6.664(52)	254	$(\frac{3}{2}^-)$	29(8)		29(8)	($0.35\text{x}10^{-3}$)
*6.731(8)	321	$\frac{3}{2}^{-cdfjh}$	(5.07)		(5.07)	($2.12\text{x}10^{-3}$)
*6.864(6)	454	$\frac{7}{2}^{-fj}$	(1.16)		(1.16)	($1.57\text{x}10^{-5}$)
*6.93(2)	520	$(\frac{1}{2}^-)$	14.25(2)		14(2)	(0.25)
		$(\frac{5}{2}^+)$	14(2)		14(2)	($2.24\text{x}10^{-3}$)
*7.076(3)	666	$\frac{3}{2}^{+k}$	35(4)	0.68(9)	20.6(2.6)	14.2(1.7)
*7.19(1)	780	$\frac{3}{2}^{lno(+)}$	($\leq$9.85(21))	0.67(9)	($\leq$5.9)	($\leq$3.95(21))
*7.258(16)	848	$\frac{1}{2}^{+\ o}$	16(6)		16(6)	0.9(9)^o
7.36(1)	950			0.25(3)		
7.43(2)	1020					
7.504(10)	1094	$\frac{5}{2}^{+lmn}$	21(4)	4.24(58)	4.0(9)	17.0(8.6)
7.555(11)	1145					
7.638(7)	1228			0.45(6)		
7.735(11)	1325			1.43(24)		
7.821(10)	1411			1.60(32)		
*7.938(30)	1528	$\frac{1}{2}^{+hlng}$	340(42)	1.31(23)	110(10)	230(41)
7.995(19)	1585			5.68(36)		

50 - 350 10^6 K

Measured for the first time

Measured in this experiment

Deduced from mirror nuclei

4) Interpretations

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*6.437(8)	27	$(\frac{11}{2}^+)$	($>4.1\text{x}10^{-3}$)		($>4.1\text{x}10^{-3}$)	($3.58\text{x}10^{-23}$)
[illegible]	[illegible]			[illegible]		
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7.995(19)	1585			5.68(36)		

^{19}Ne spectroscopic properties

-> ^{18}F(p,α)^{15}O reaction rate obtained with AZURE2

-> ^{18}F mass fraction produced during a nova obtained with cococubed

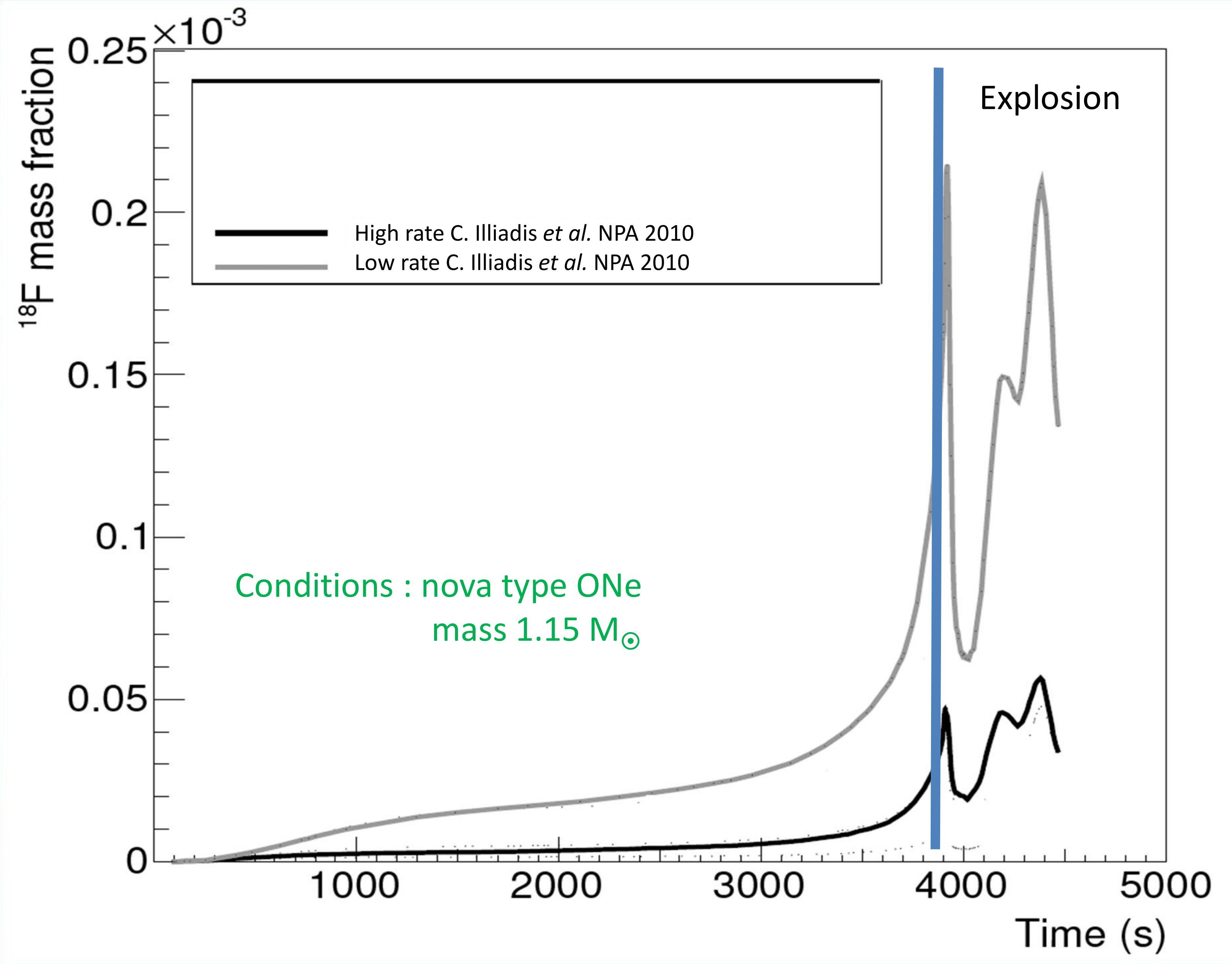
Measured for the first time

Measured in this experiment

Deduced from mirror nuclei

4) Interpretations

Results from Cococubed code



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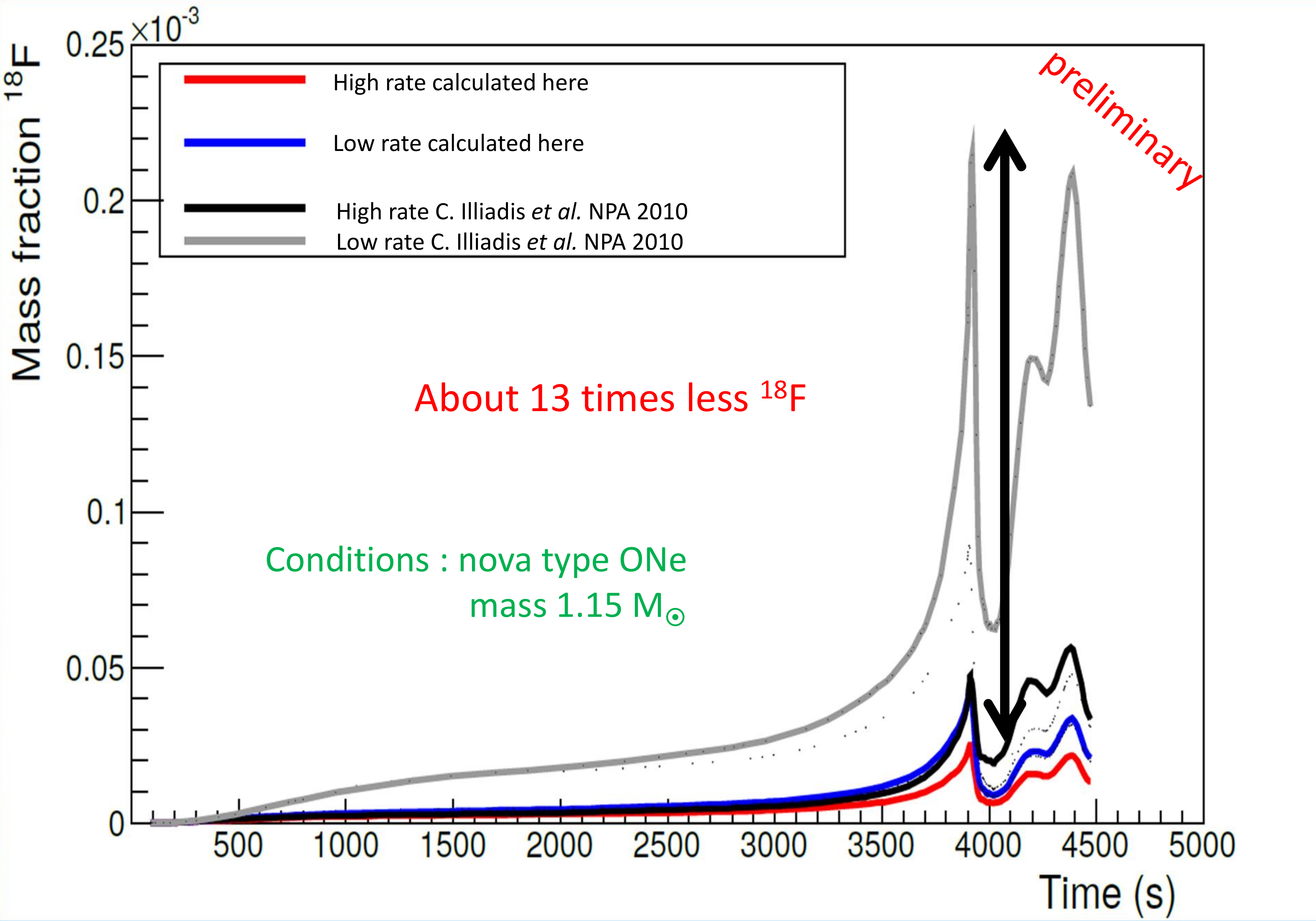
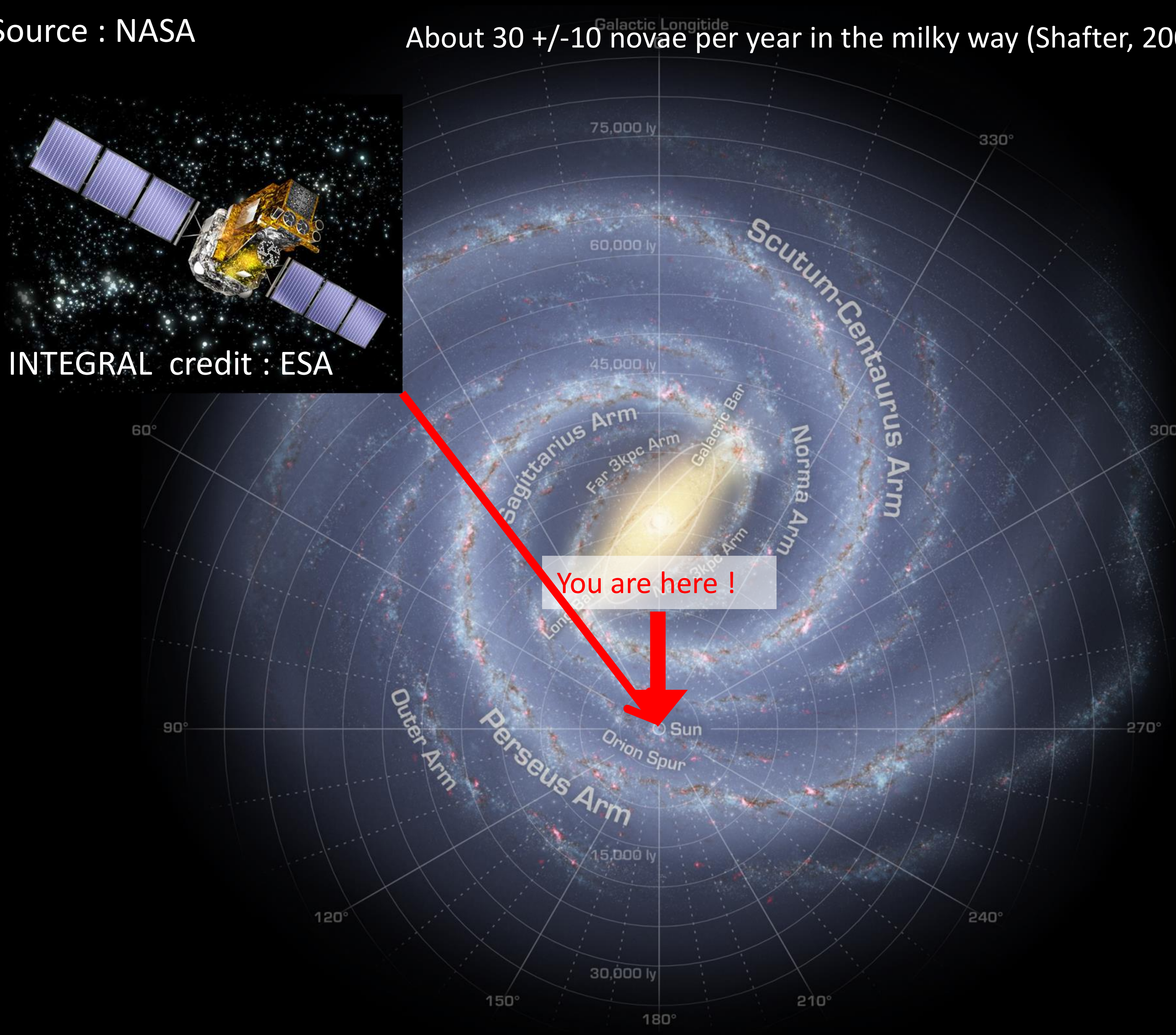


Source : NASA

About 30 +/-10 novae per year in the milky way (Shafter, 2002)

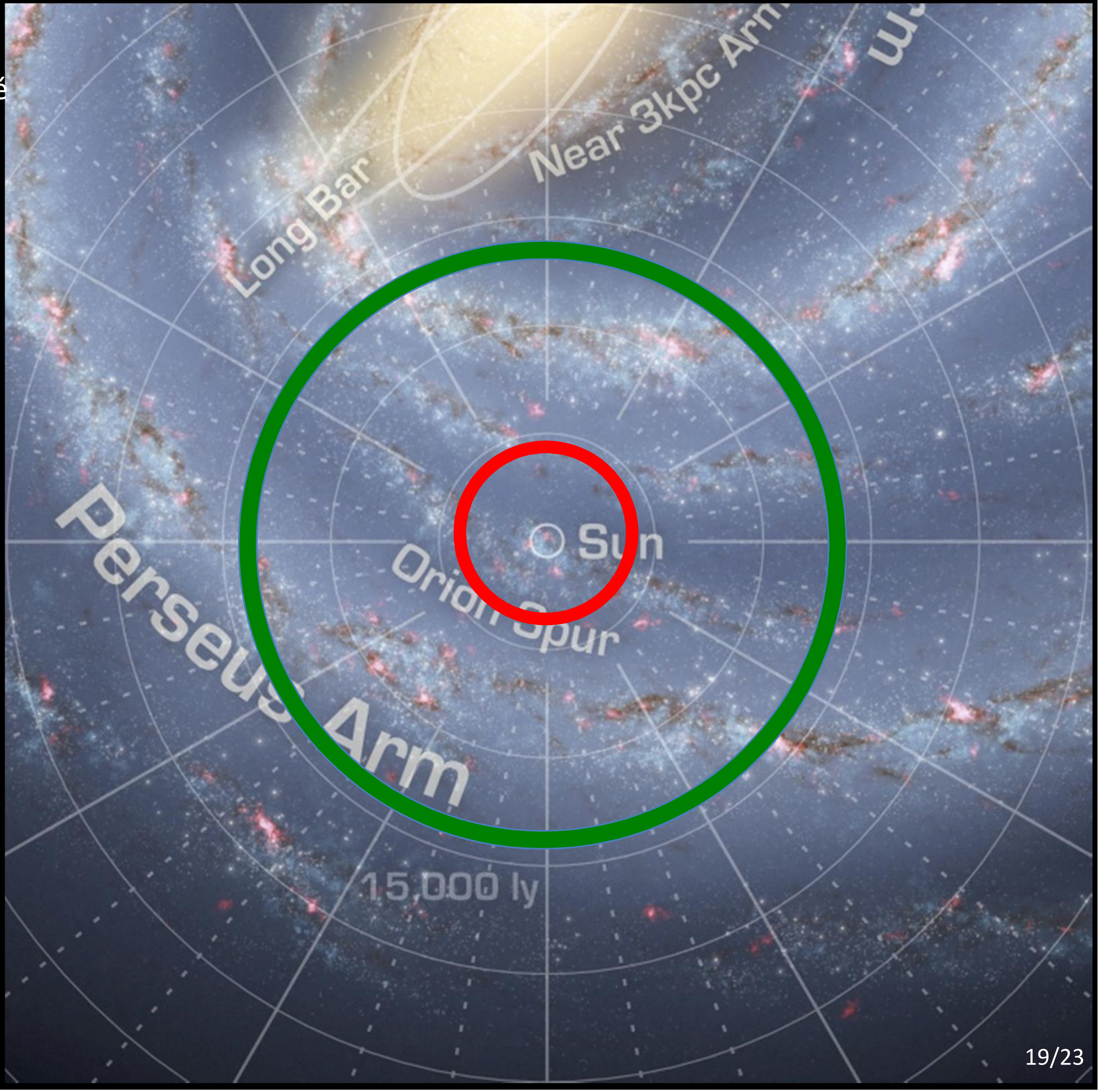


4) Interpretations

Hernanz Gomez-Gomar José Coc (2001)
Limit detection ^{18}F for
ONe 1.15 $M_\odot$ is 3.7 kpc

With N times less ^{18}F limit radius of detectability reduces by $N^{1/2}$

All galaxy 30 novae per year



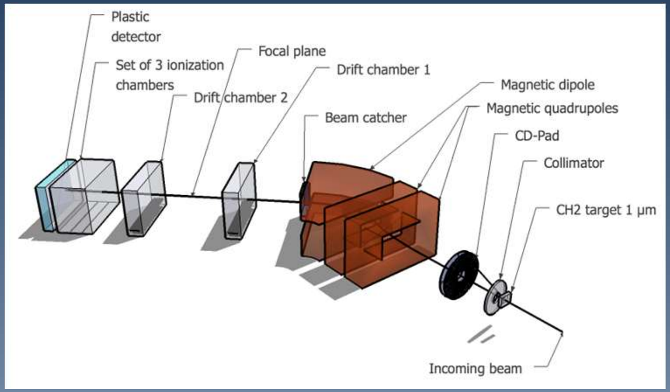
2 novae per year

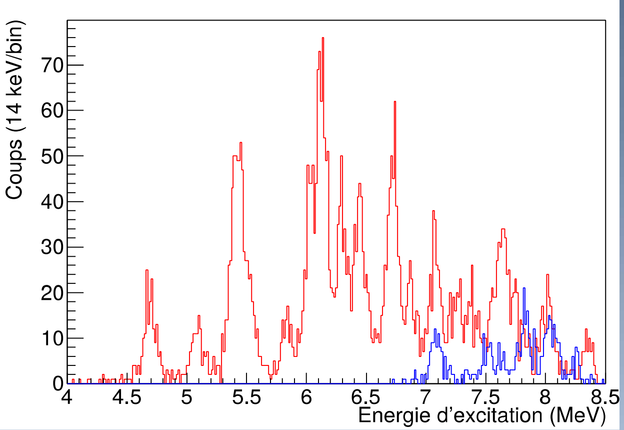
1 nova per decade

Conclusions & Outlooks

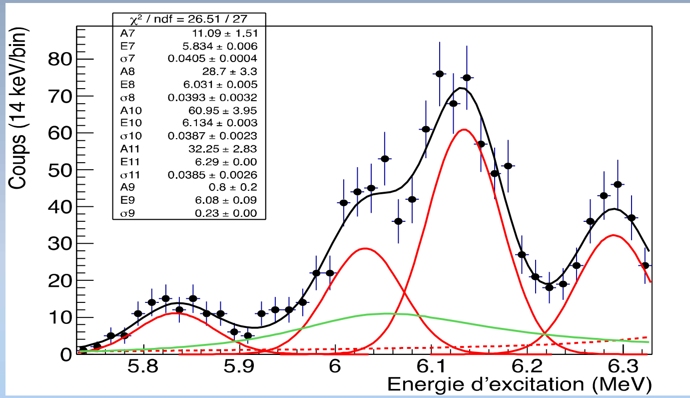
Conclusions

New experimental setup.
VAMOS used for the first time to detect protons

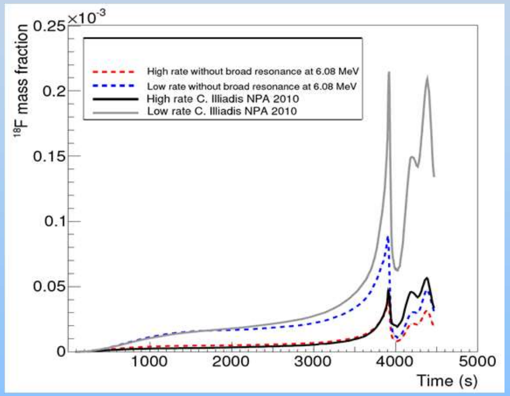




Best energy resolution reach for this type of experiment.



Clues for a new resonance of astrophysical interest



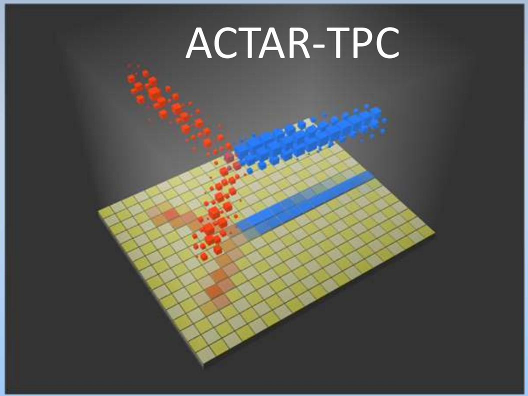
New reaction rate $^{18}F(p,\alpha)^{15}O$ is much higher

INTEGRAL has less chance to detect gamma rays from the beginning of the explosion

Outlooks

Concerning the novae

- **We need a confirmation of the 6.0 MeV broad resonance**
- **Constrain the reaction rates associated to ^{22}Na and ^{26}Al**
- **To study the nova phenomenon with others observables**
  ^{7}Be detected optically Nature A. Tajitsu et *al.*



Concerning the method

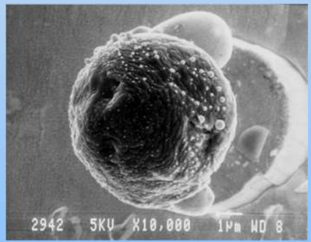
- Remove the contamination that destroys the angular distribution measurement

- To improve the energy resolution of this method : active target

-This new method could be applied, in the future, for the reaction rates such as :

$^{30}P(p,g)^{31}S$ ✪

✪ Defined as **key reactions** by the **NuPECC long range plan 2010**



micrometeorite

Thank you for your attention

GANIL (France) : F. Boulay, B. Bastin, F. De Oliveira, A. Lemasson, M. Rejmund, C. Schmitt, B. Jacquot, O. Kamalou, A.M. Sanchez-Benitez, E. Traykov, C. Rodriguez, J. Grinyer, O. Sorlin, J.-C. Thomas and P. Delahaye.
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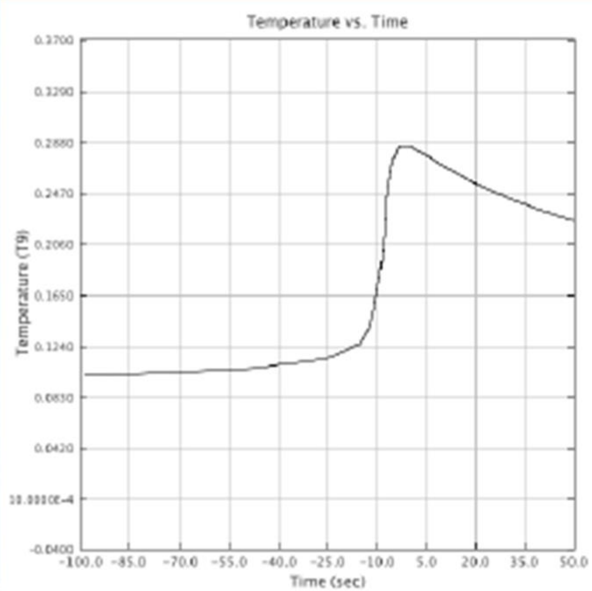
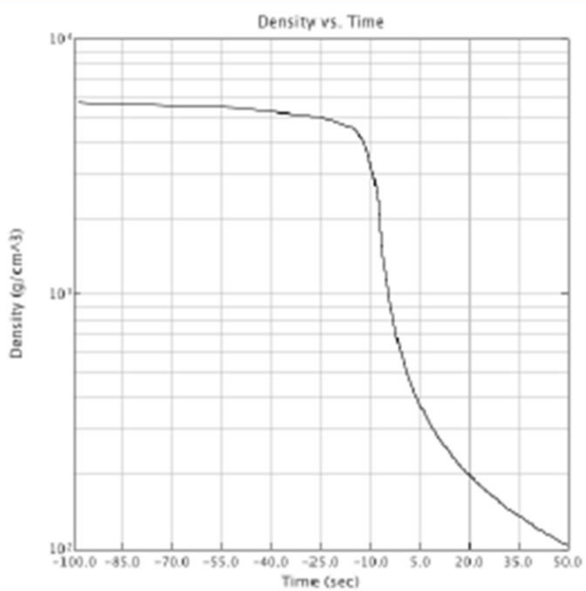
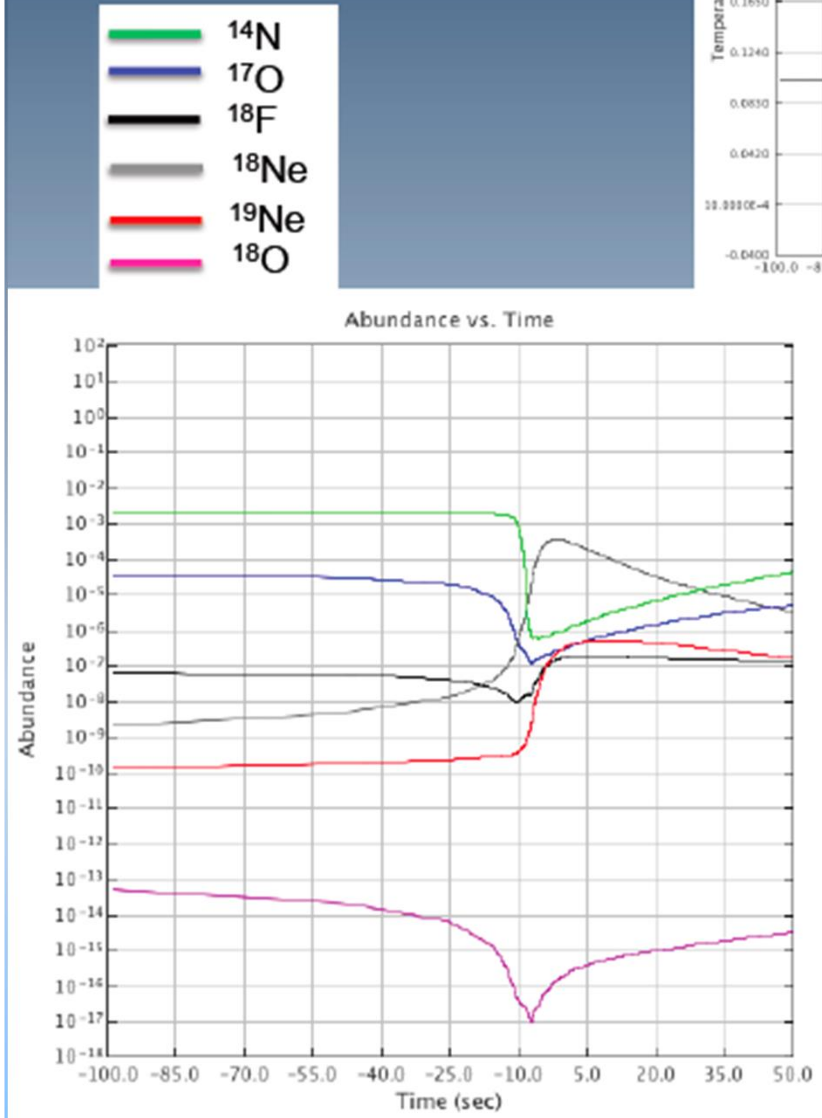
University of Santiago de Compostel (Spain) : D. Ramos.
University of York (England) : A. Laird.
IPN Orsay (France) : N. de Séréville.
University of Huelva (Spain) : G. Marquinez Duran and L. A. Acosta Sanchez.
LPC Caen (France) : L. Achouri.
Vinca Institute (Serbia) : P. Ujic.
Rez (Czech Republic) : J. Mrazek.
IFIN/HH (Romania) : F. Negoita, F. Rotaru, M. Stanoiu and C. Borcea .
Niewodniczanski Institute of Nuclear Physics (Poland) : M. Ciemala.

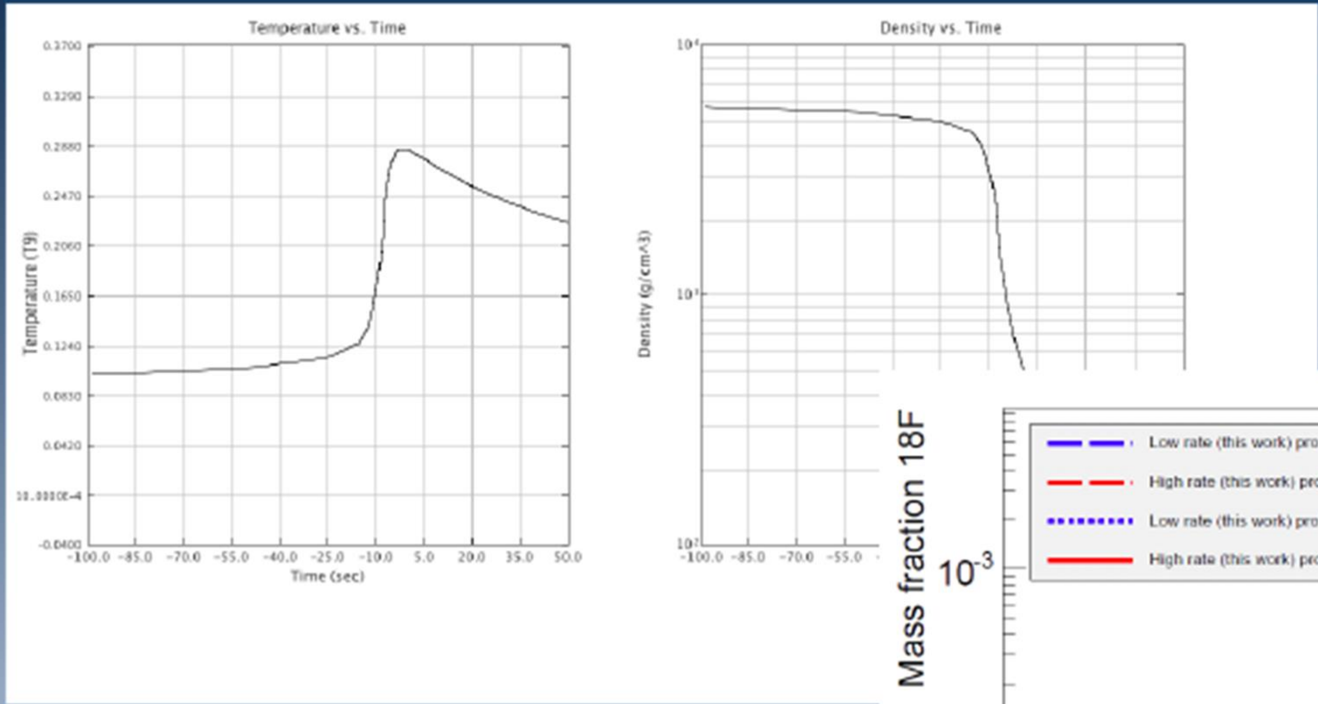
Backup slides

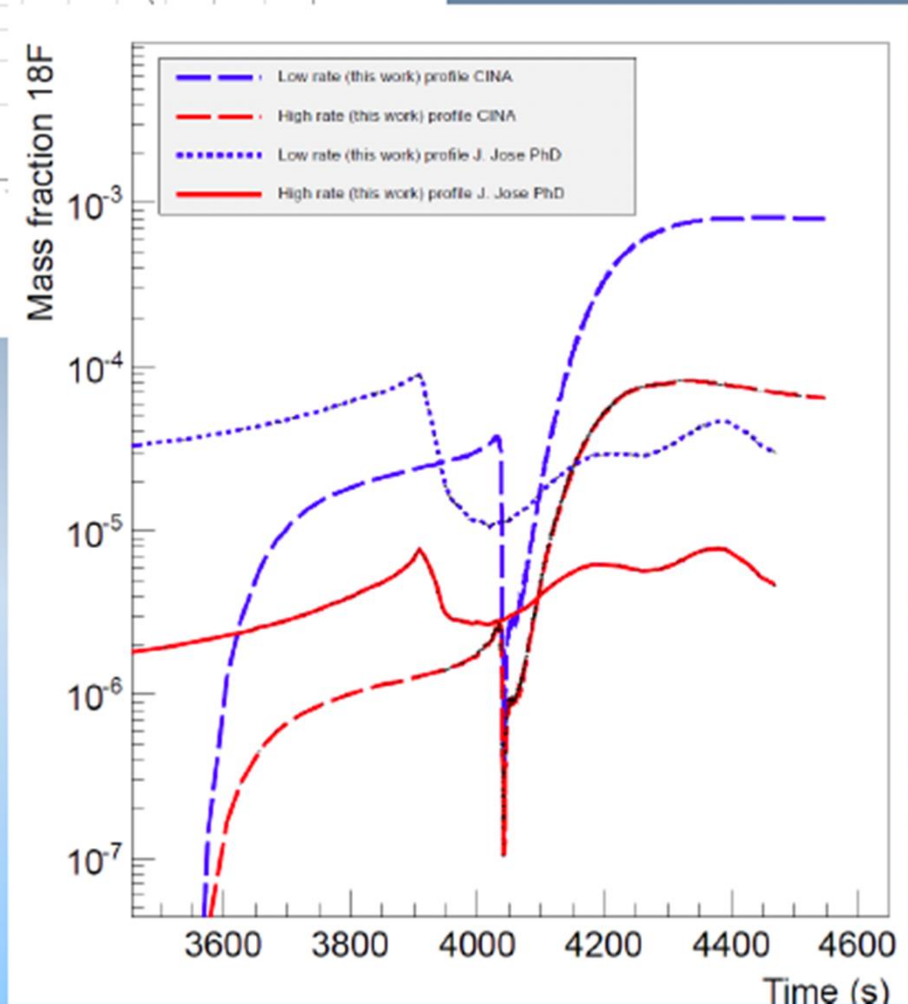






Results from CINA calculation code

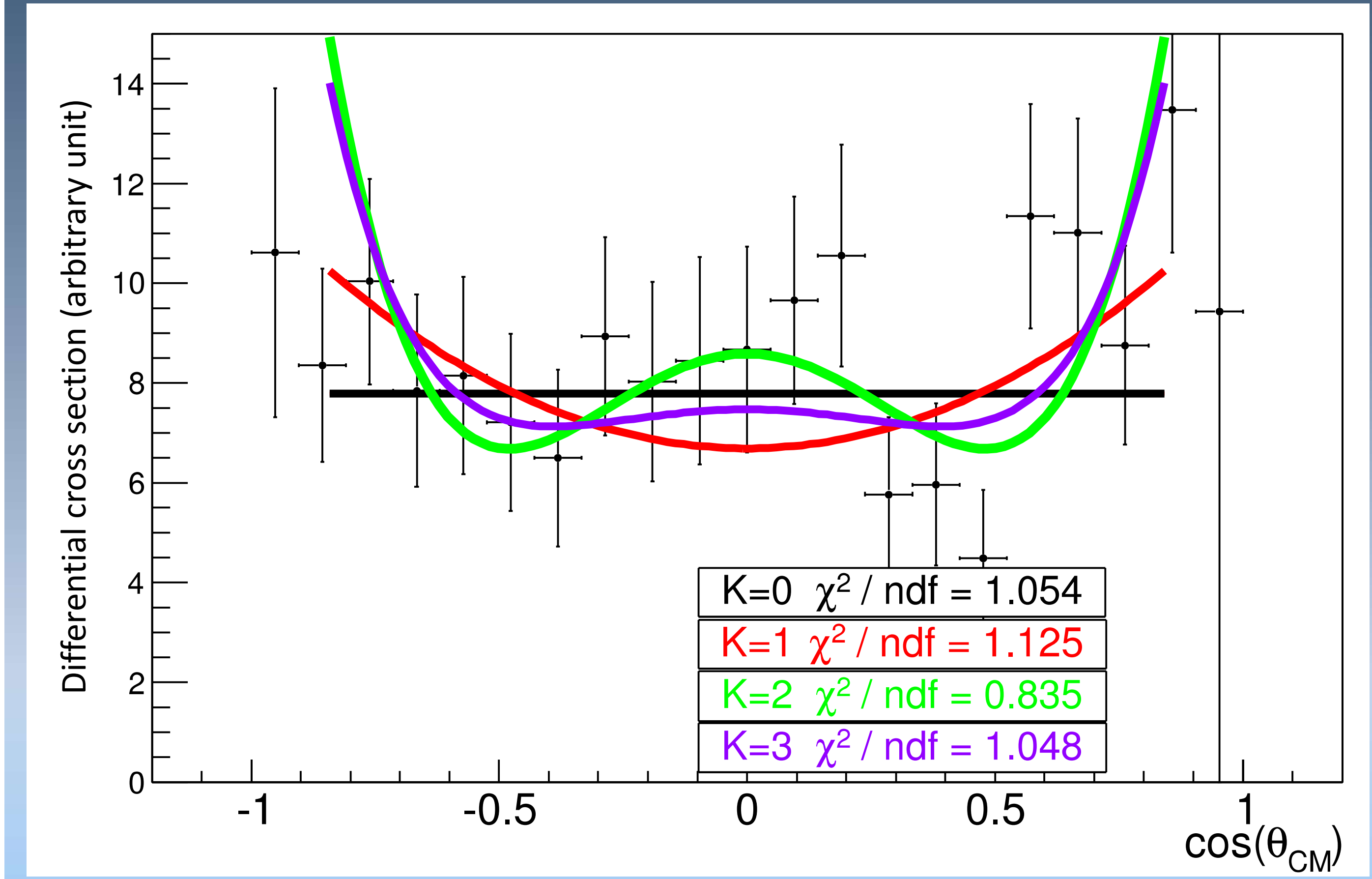




Shape of ^{18}F production depends on the profiles

3) The results Angular distribution

State at 7.075 MeV well known 3/2+ => second degree Legendre polynomial



No discrimination possible according to X^2/ndf argument

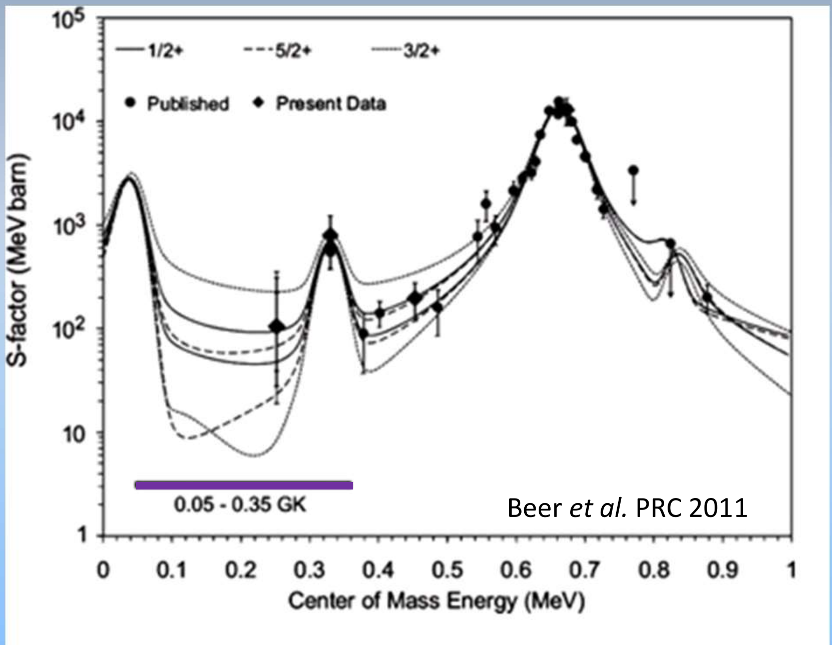
Contamination with ^{18}F and ^{15}O in VAMOS -> we need quadrant per quadrant correction
->low statistics does not allow this correction

To constrain the $^{18}F(p,\alpha)^{15}O$ reaction rate

Direct measurements

Cross section of ^{18}F +p (inverse kinematics)
- Low beam intensity
- Beam impurities (^{18}O...)
- Low cross section (coulomb barrier...)

C. E. Beer et al. Phys. Rev. C, 83 :042801, Apr 2011.
D. J. Mountford, et al. Phys. Rev. C, 85 :022801, Feb 2012.
N. de Séréville et al., Phys. Rev. C **79**, 015801 2009.
D.W. Bardayan et al. Nucl Phy. A (2003)



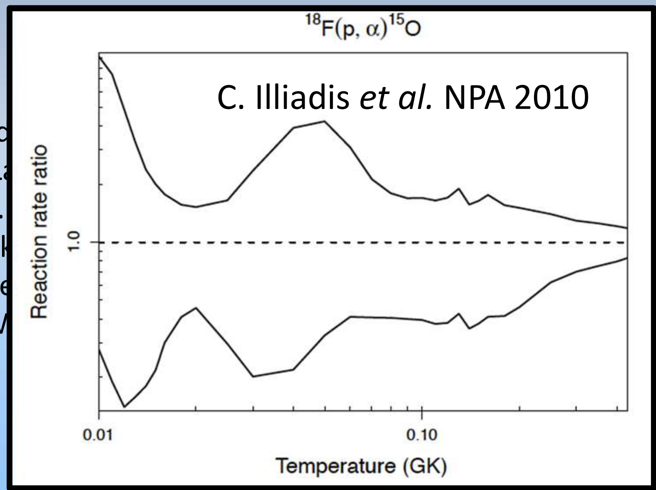
Indirect measurements

Study of the ^{19}Ne properties (Energy, spin, widths) around the proton threshold or the mirror nucleus ^{19}F

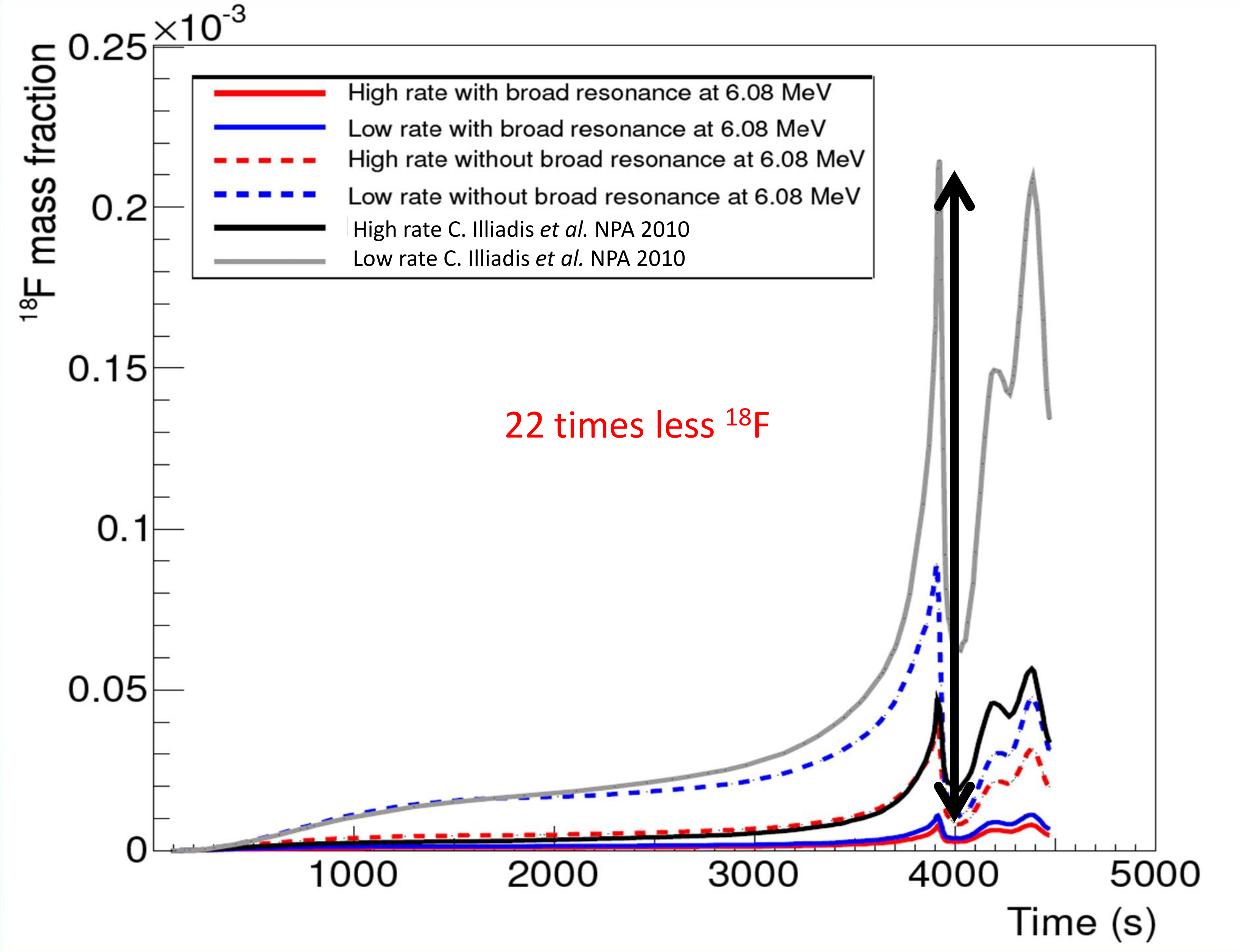
Selectivity on the state populated depending on the reaction mechanism (transfer...)

Most of the time, angular momentum is not assigned independently of the model.

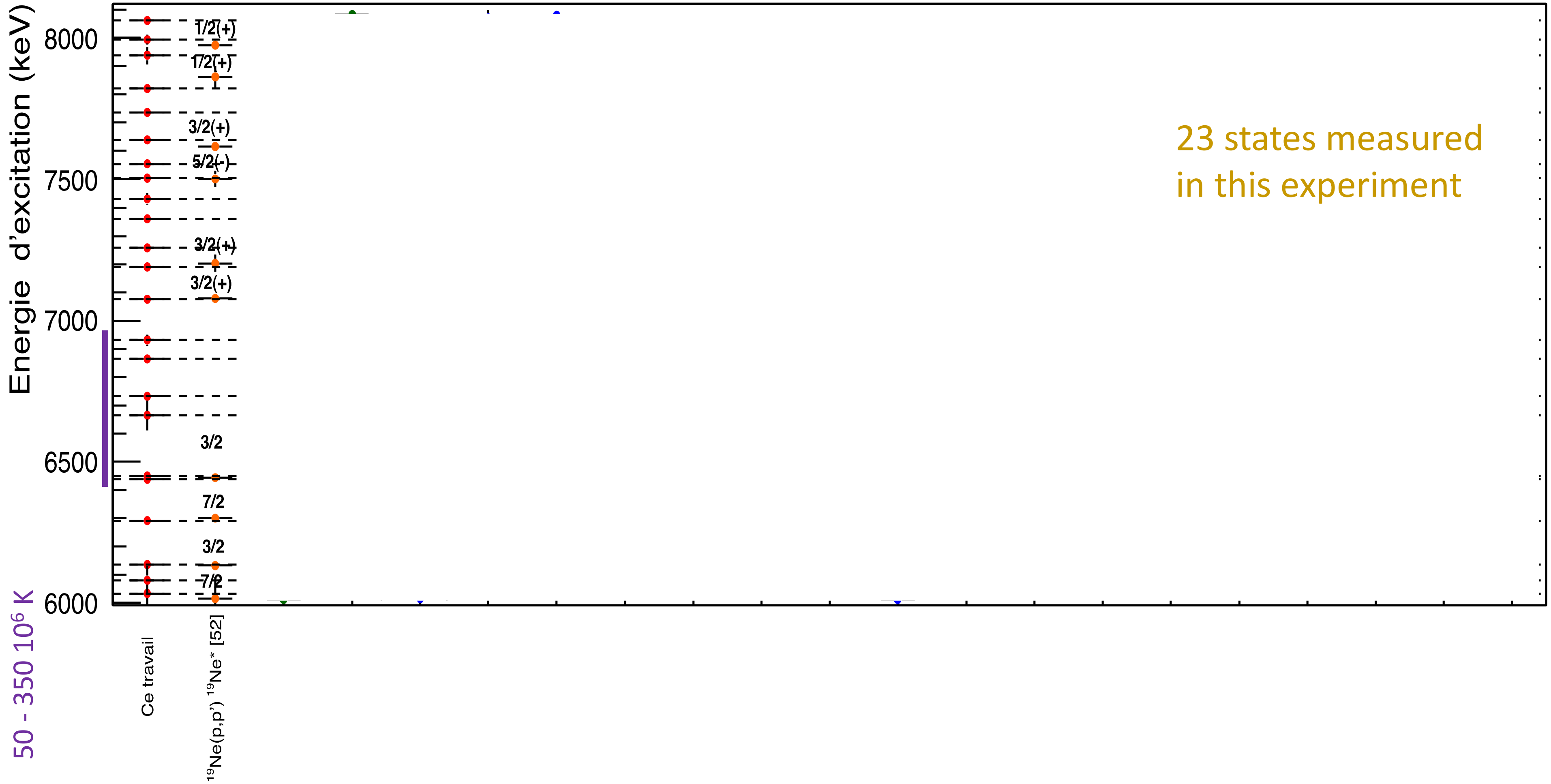
S. Ad
M. La
St. J.
S Utk
N. de
D. W ... 01.
etc



Results from Cococubed code



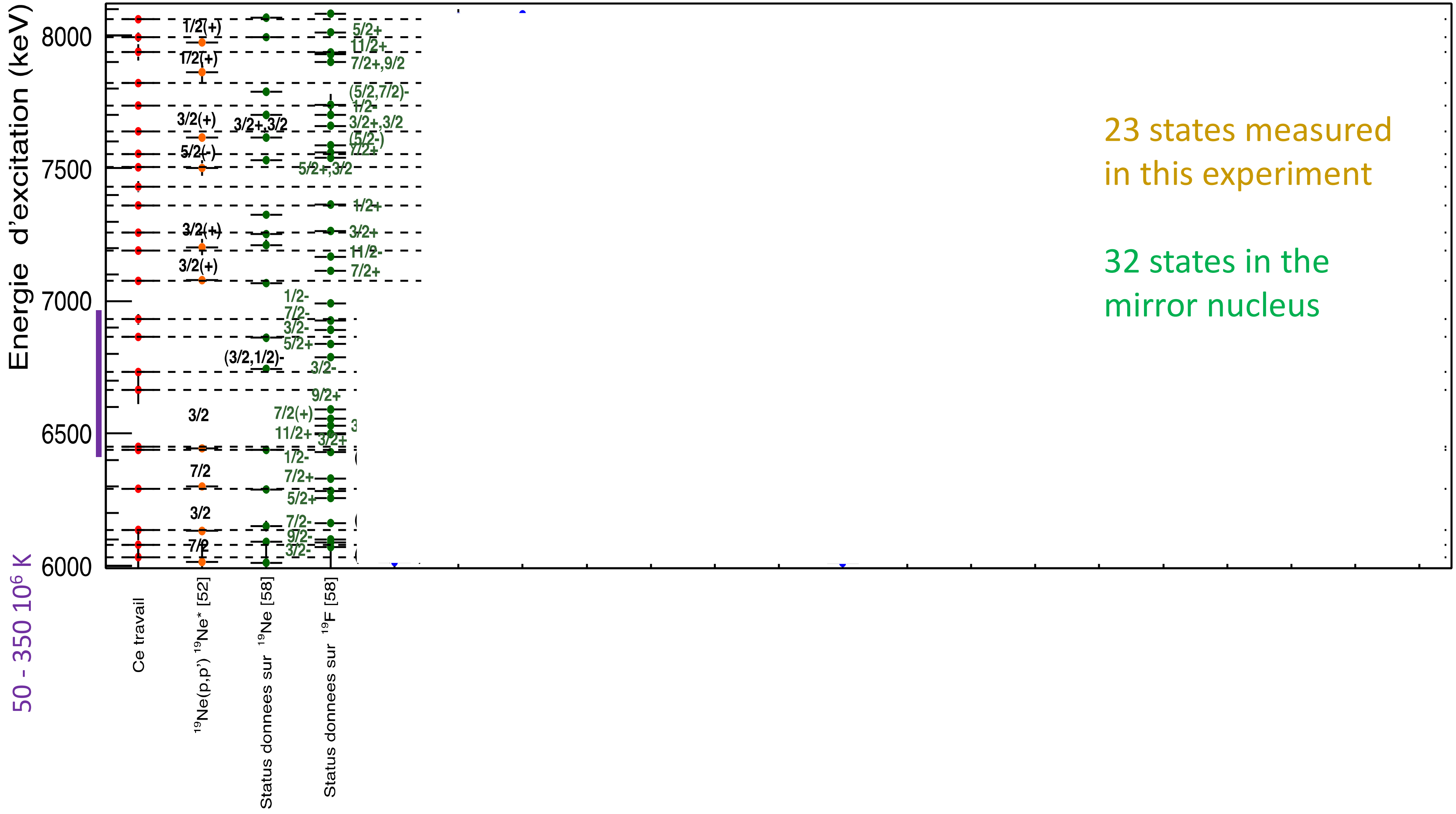
4) Interpretations



23 states measured
in this experiment

DIFFUSION INELASTIQUE

[52] J.C. Dalouzy PhD thesis



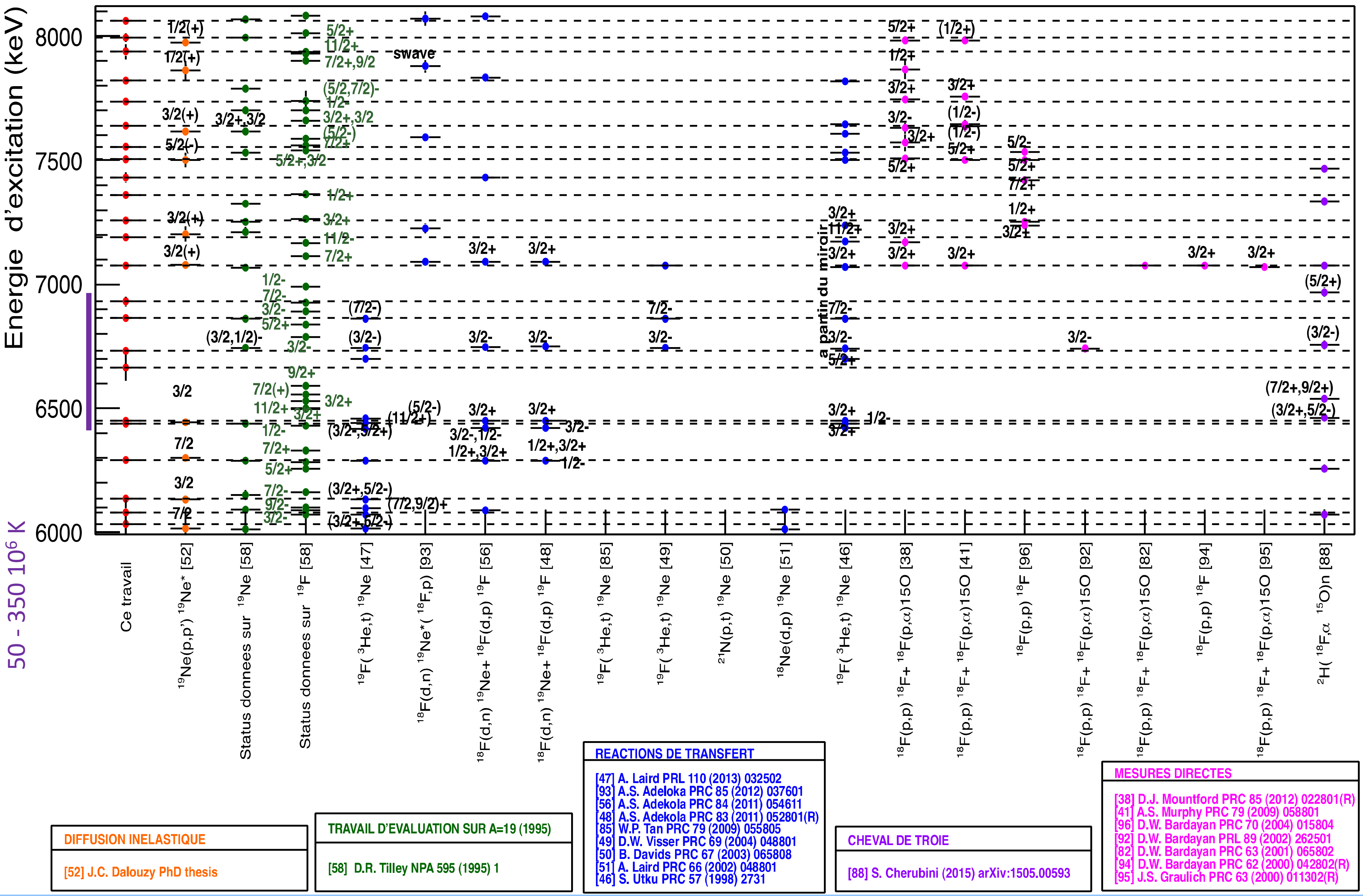
23 states measured in this experiment

32 states in the mirror nucleus

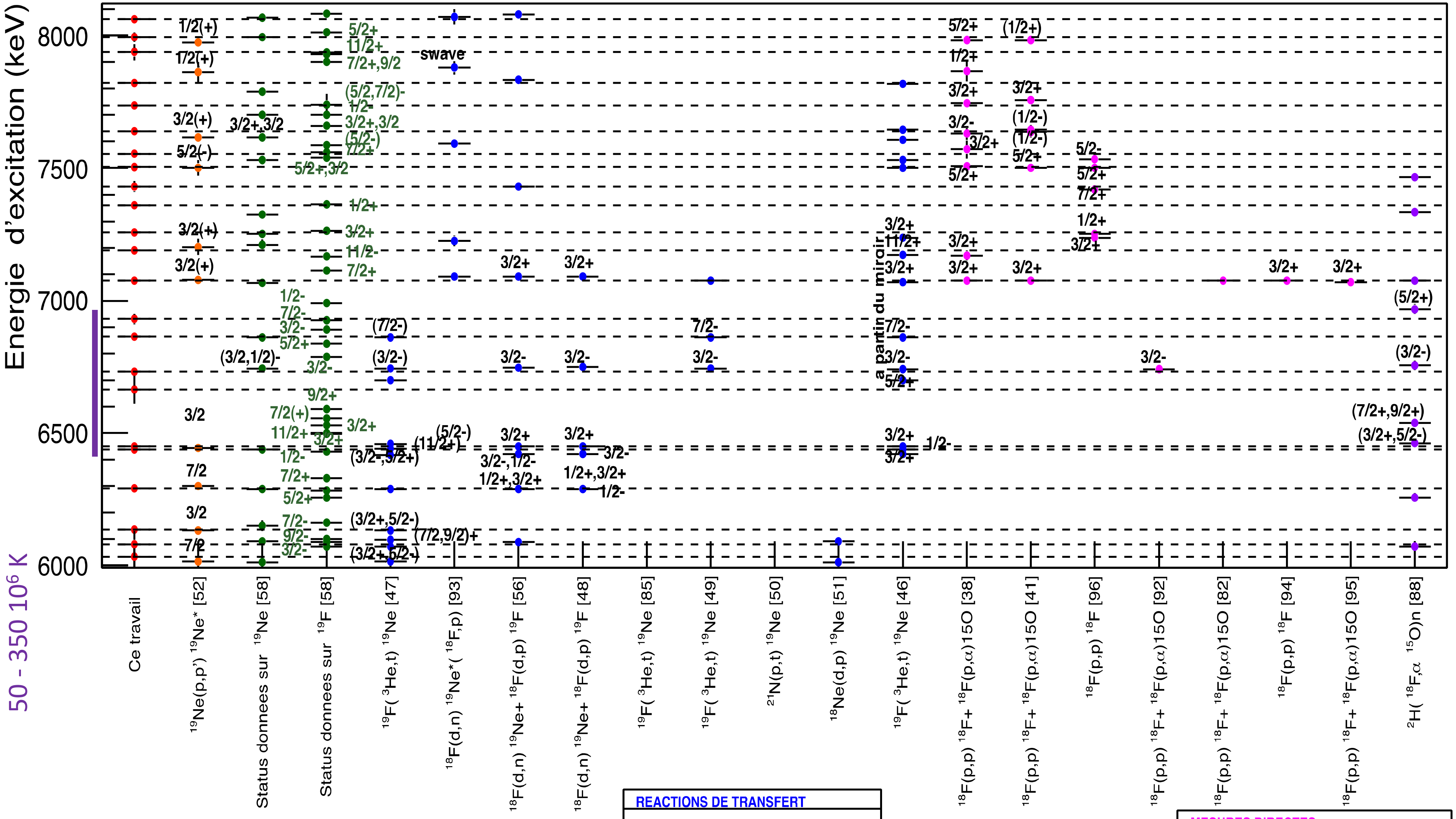
DIFFUSION INELASTIQUE
[52] J.C. Dalouzy PhD thesis

TRAVAIL D'EVALUATION SUR A=19 (1995)
[58] D.R. Tilley NPA 595 (1995) 1

4) Interpretations



4) Interpretations



REACTIONS DE TRANSFERT

[47] A. Laird PRL 110 (2013) 032502
[93] A.S. Adeloka PRC 85 (2012) 037601
[56] A.S. Adekola PRC 84 (2011) 054611
[48] A.S. Adekola PRC 83 (2011) 052802(R)
[85] W.P. Tan PRC 79 (2009) 055805
[49] D.W. Visser PRC 69 (2004) 048801
[50] B. Davids PRC 67 (2003) 065808
[51] A. Laird PRC 66 (2002) 048801
[46] S. Utku PRC 57 (1998) 2731

MESURES DIRECTES

[38] D.J. Mountford PRC 85 (2012) 022801(R)
[41] A.S. Murphy PRC 79 (2009) 058801
[96] D.W. Bardayan PRC 70 (2004) 015804
[92] D.W. Bardayan PRL 89 (2002) 262501
[82] D.W. Bardayan PRC 63 (2001) 065802
[94] D.W. Bardayan PRC 62 (2000) 042802(R)
[95] J.S. Graulich PRC 63 (2000) 011302(R)

DIFFUSION INELASTIQUE

[52] J.C. Dalouzy PhD thesis

TRAVAIL D'EVALUATION SUR A=19 (1995)

[58] D.R. Tilley NPA 595 (1995) 1

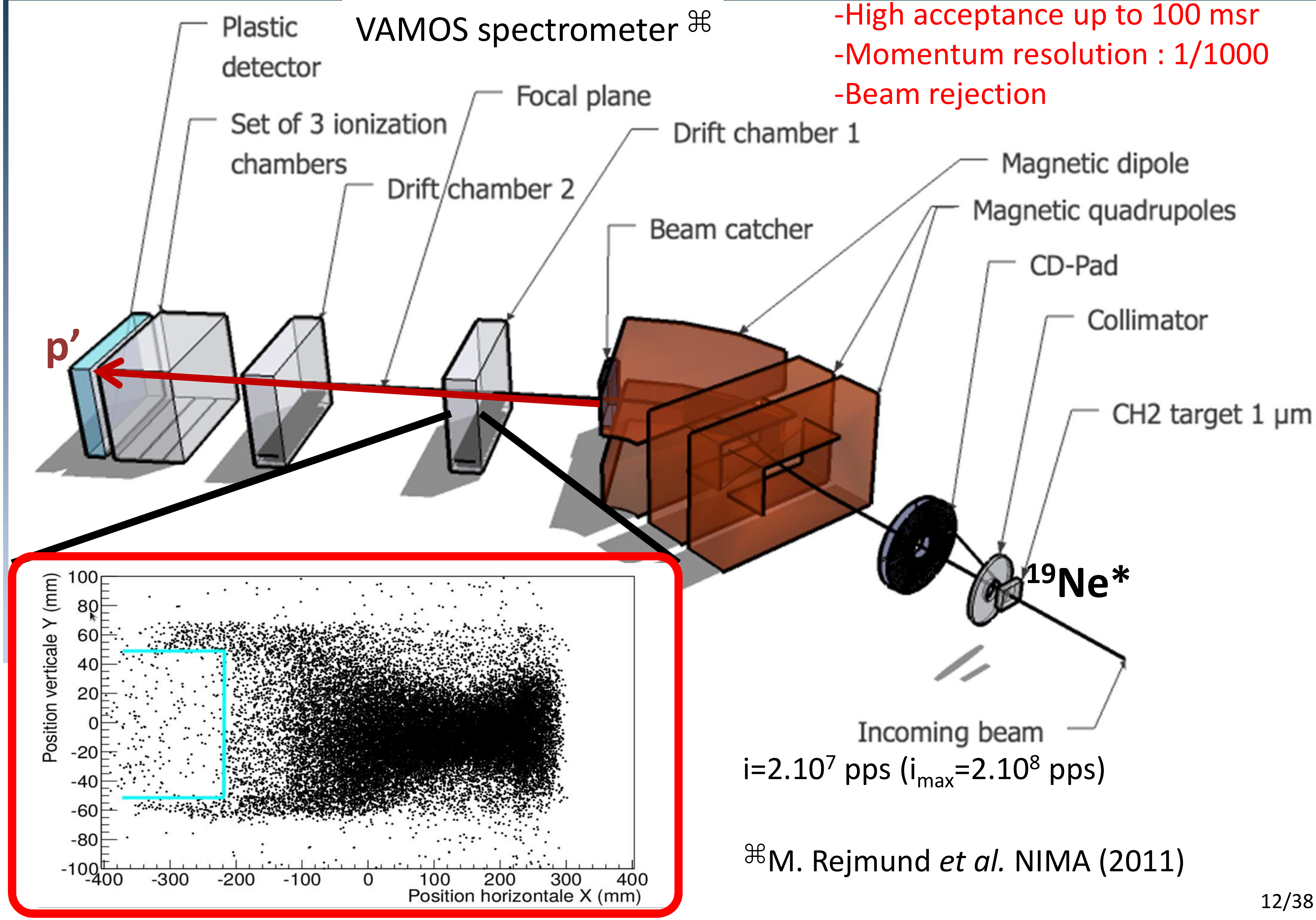
CHEVAL DE TROIE

[88] S. Cherubini (2015) arXiv:1505.00593

2)The experiment

VAMOS spectrometer ⌘

- -High acceptance up to 100 msr
- -Momentum resolution : 1/1000
- -Beam rejection



i=2.10^7 pps (i_{max}=2.10^8 pps)

⌘M. Rejmund *et al.* NIMA (2011)

What is a nova ?

credits: François de Oliveira

1)Astrophysical context

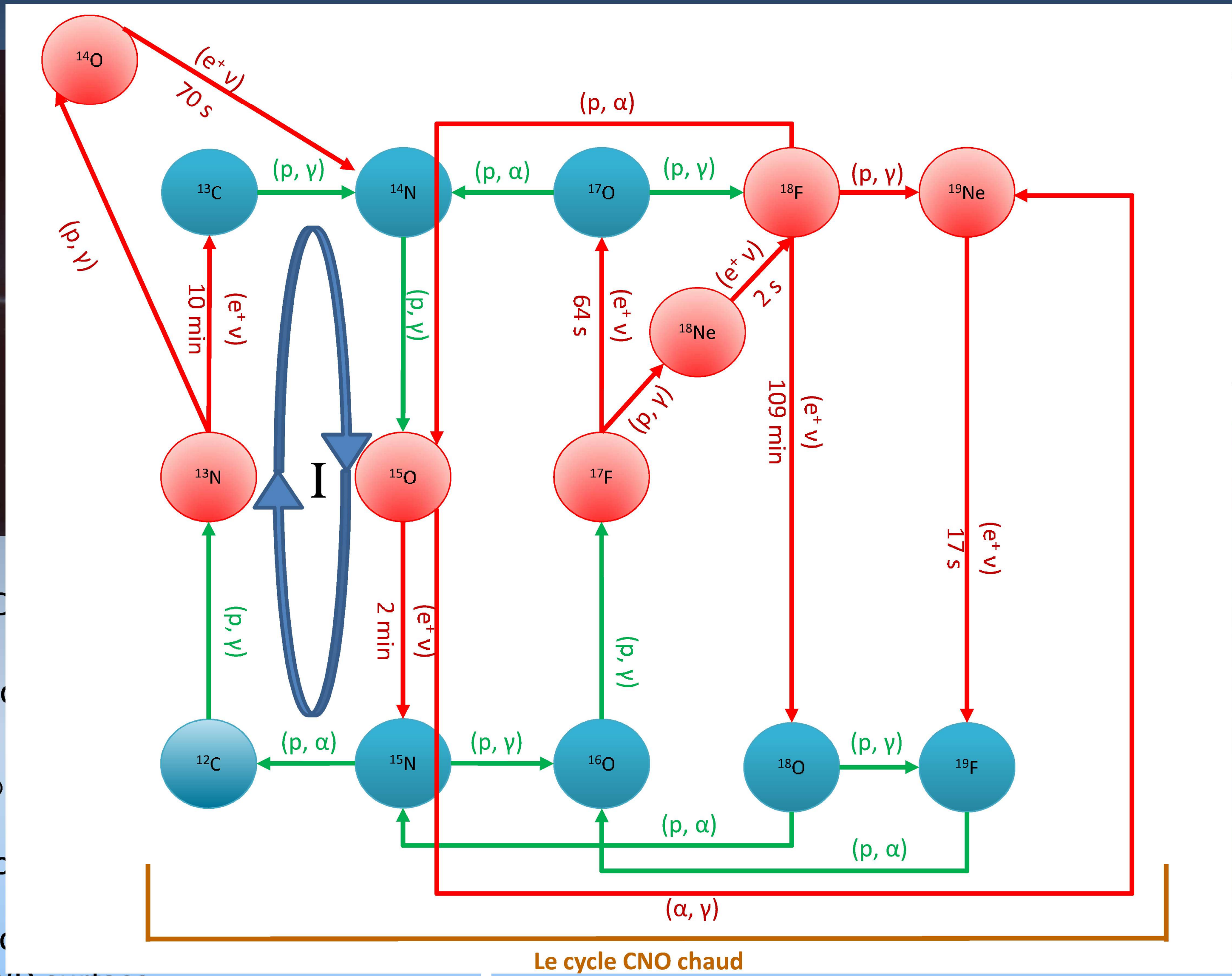
What is a nova ?

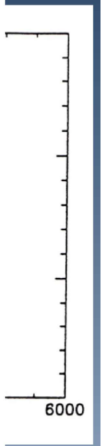
credits: François de Oliveira

1)Astrophysical context

Scenario of the explosion

A nova is an exlosion that occurs in binary system of stars (Walker 1954)





Two types of White D

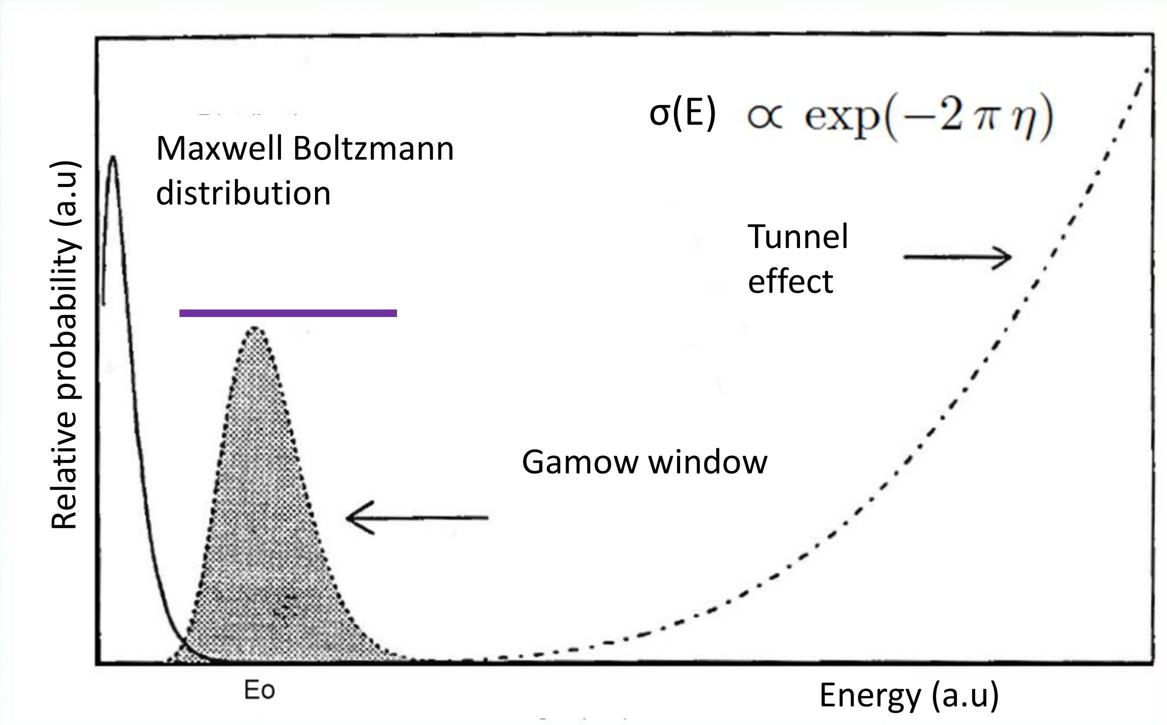
What's make a classi

Accretion < 10^{-9} $M_\odot$

Time between explo

Electronic degenerac
$>10^2$ $g.cm^{-3}$ on the WD surface
=> pressure quasi-independant of the temperature

For example, this reaction : p + ^{18}F->^{19}Ne ->^{15}O + α
In a gas at the thermodynamical equilibrium
(possible electronic degeneracy but no nuclei degeneracy)



T = 50 to 350 10^6 K
Gamow window
E_{Gamow} = 30 to 360 keV

General expression of the reaction rate *(mole.s^{-1}.cm^{-3})*

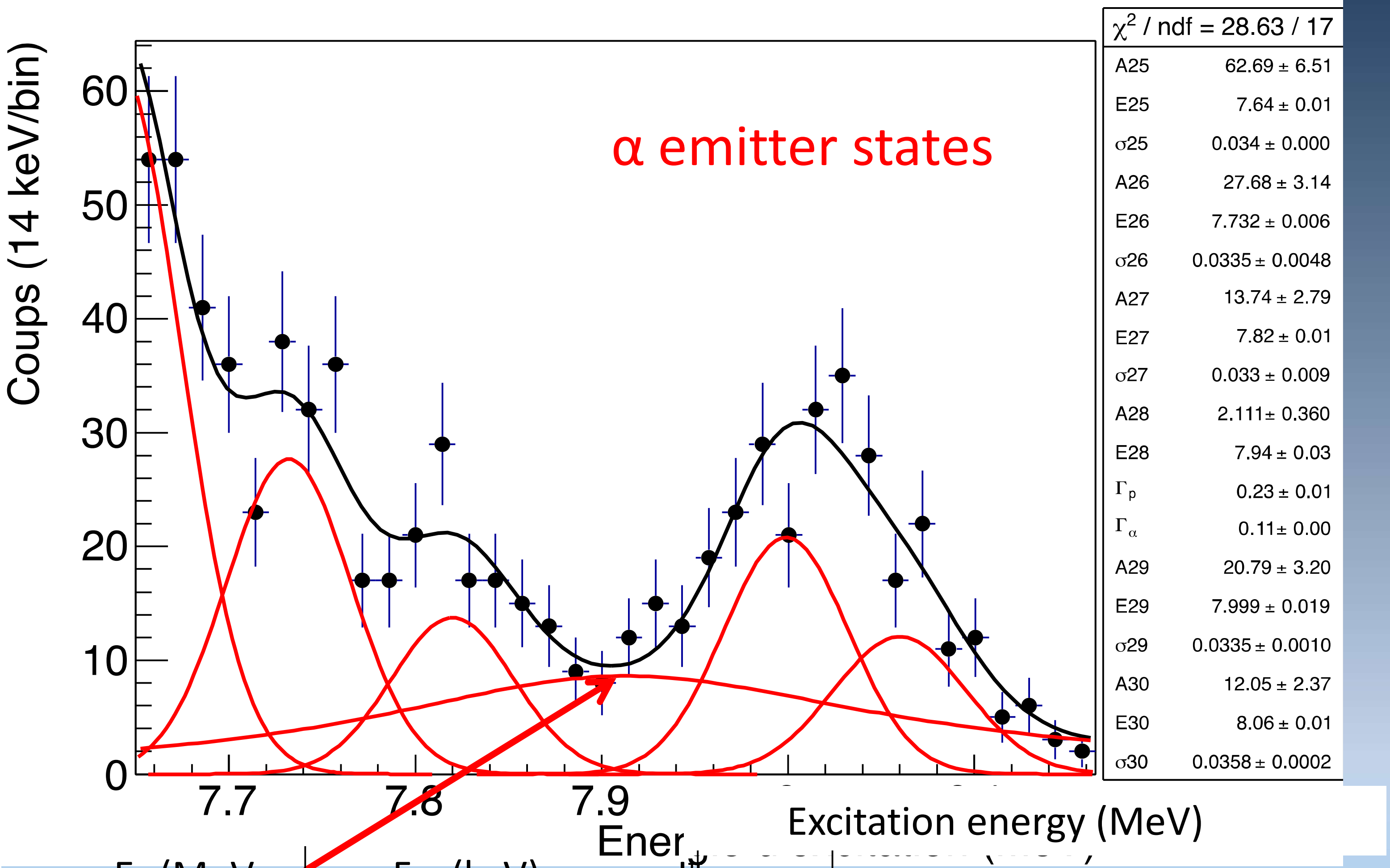
$$< \sigma v >_G = \sqrt{\frac{8}{\pi\mu}} (k_b T)^{\frac{-3}{2}} \int_0^{+\infty} E\,\sigma(E)\,\exp\left(\frac{-E}{k_b T}\right) \mathrm{d}E$$

Astrophysical factor S(E) *(MeV.barn)*

$$\sigma(E) = \frac{S(E)}{E} \exp(-2\pi\eta)$$

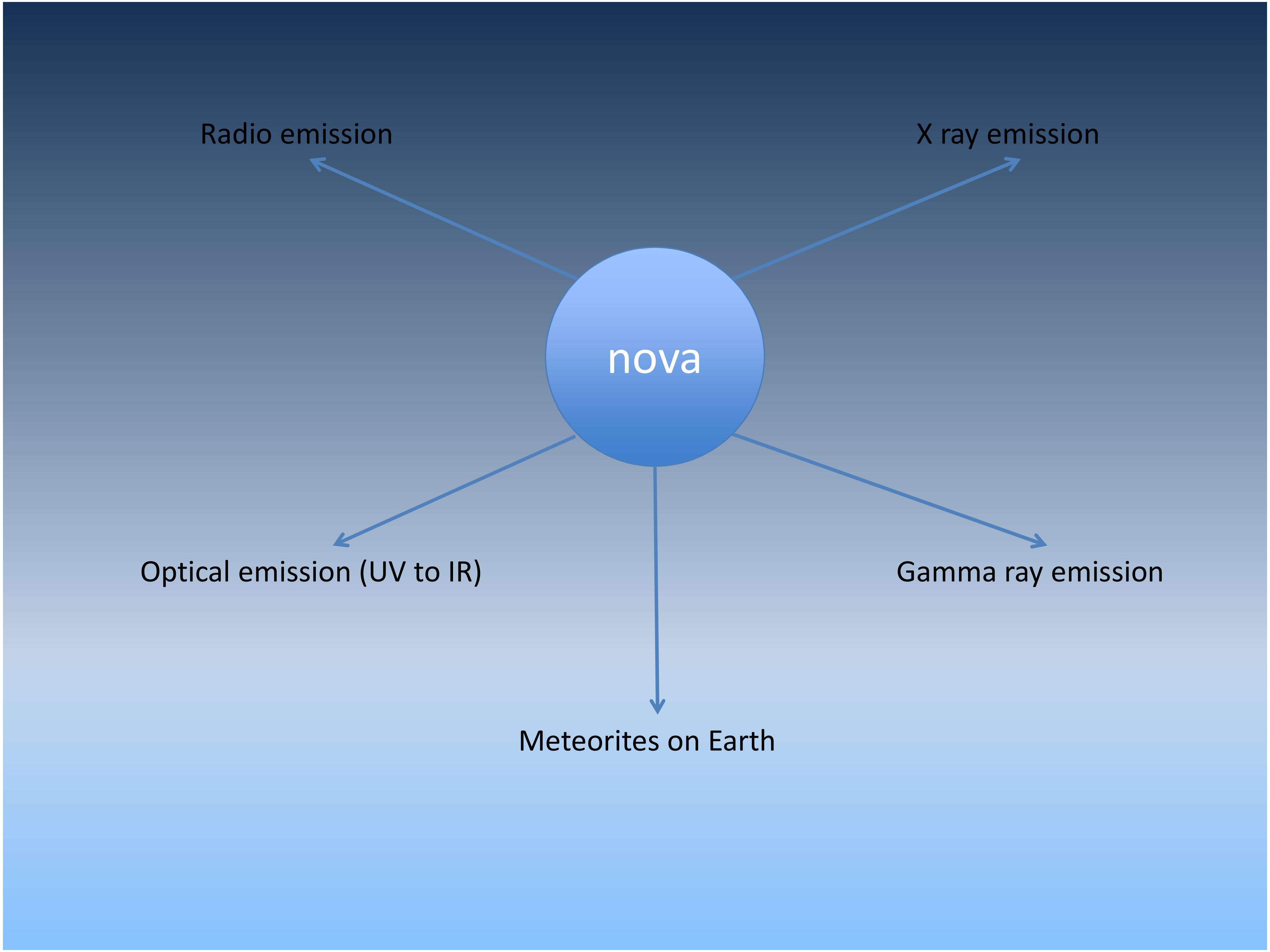
3)The results

c) Analyze of key states

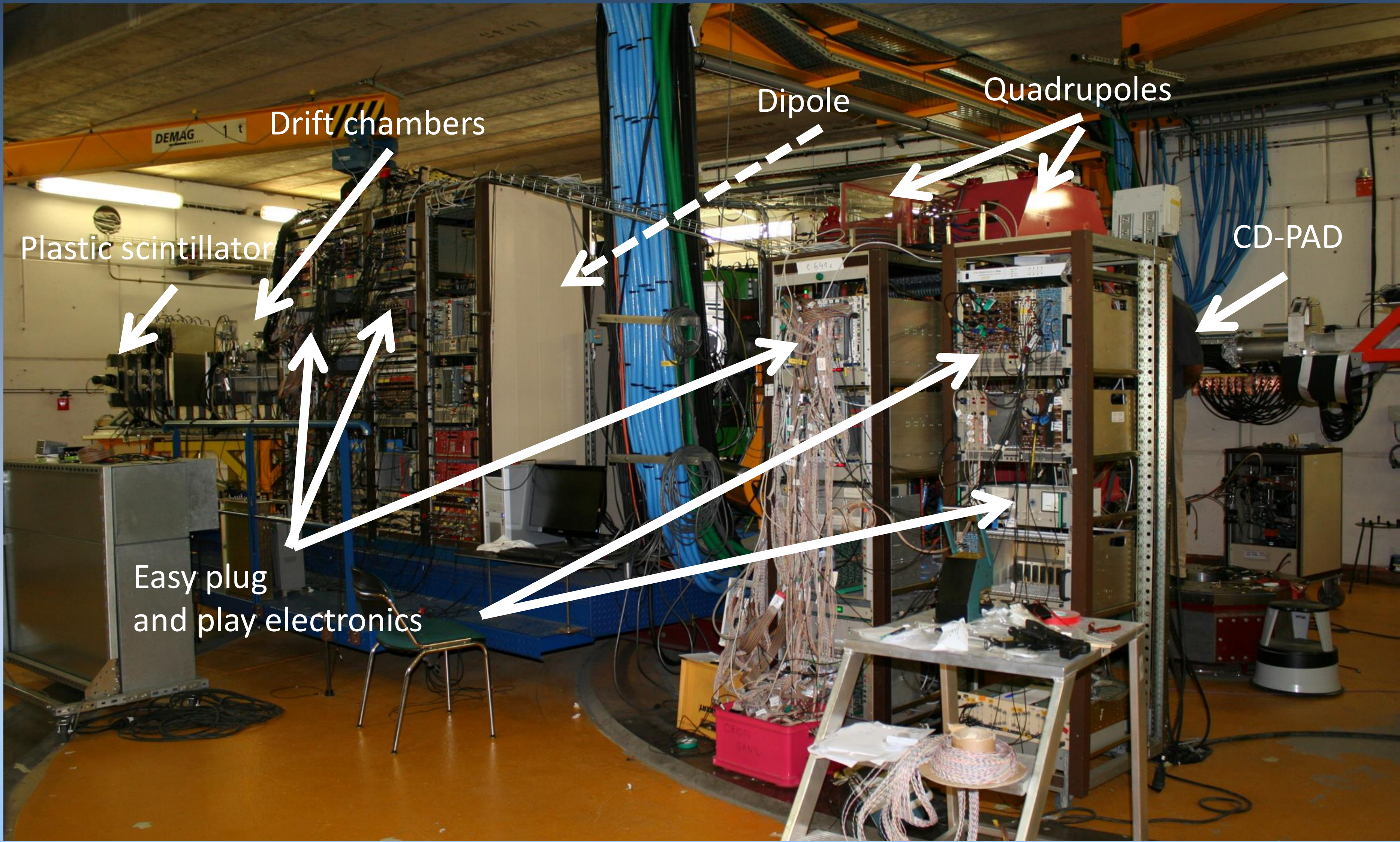


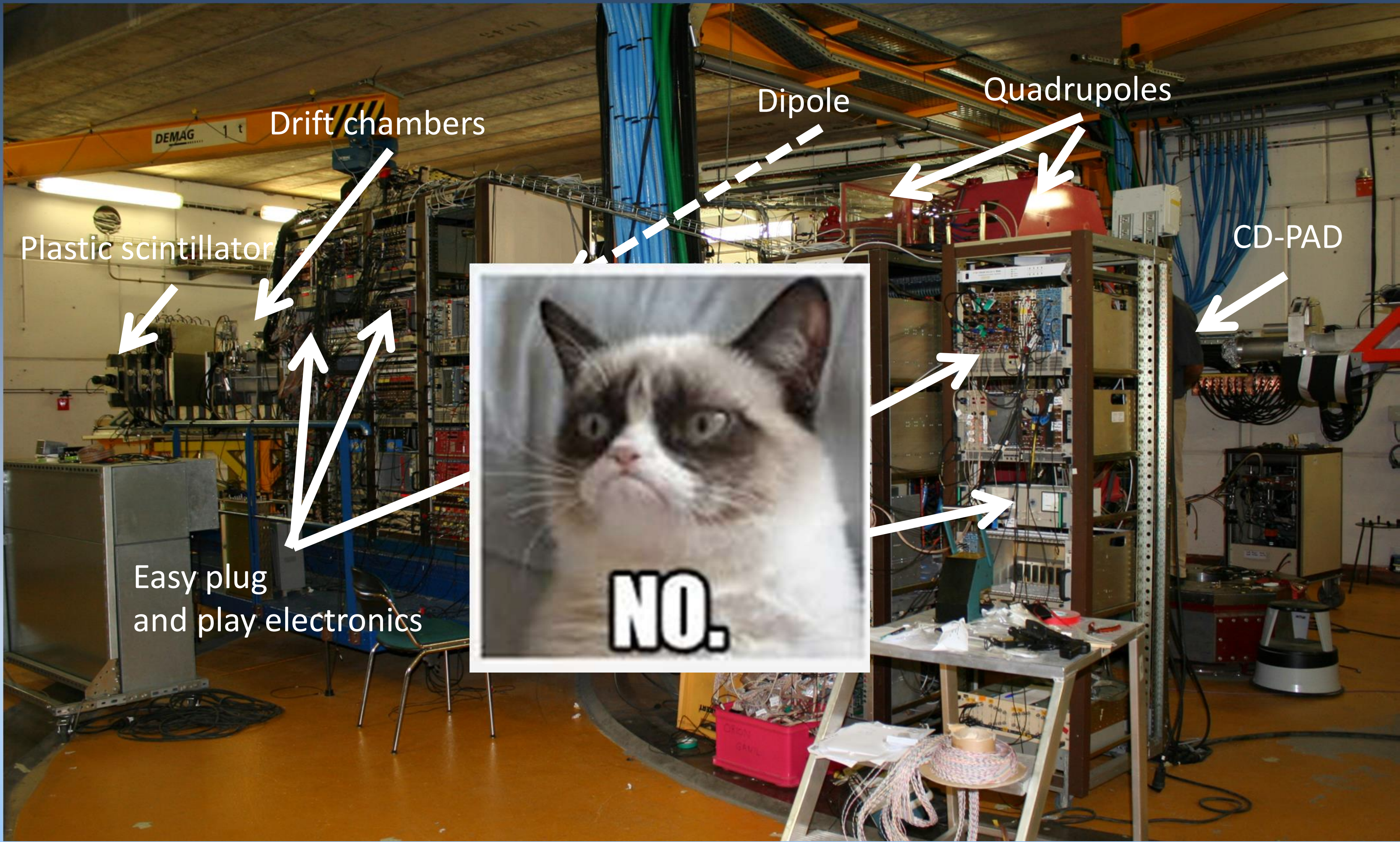
X^2/ndf = 1.86

Er (MeV	Γ_{tot} (keV)	J^π	
7.94(3)	230(10)		This work
7,879(26)	358(57)		Adekola et al PRC
7,865(38)	402(93)		Mountford et al PRC
7,863(39)	292(107)	1/2	Dalouzy et al PRL
7.9	296	1/2 +	Descouvemont & Dufour (theoritical prediction)



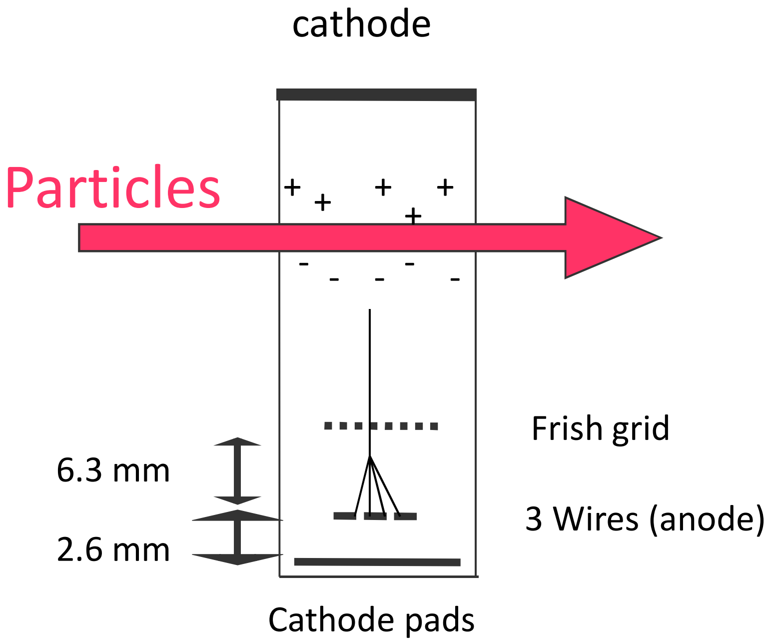
Radio emission
X ray emission
nova
Optical emission (UV to IR)
Gamma ray emission
Meteorites on Earth

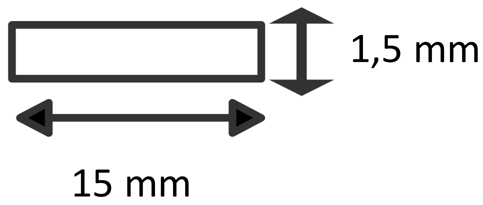

Drift chambers
Dipole
Quadrupoles
Plastic scintillator
CD-PAD
DEMAG
Easy plug
and play electronics


Drift chambers
Dipole
Quadrupoles
Plastic scintillator
CD-PAD
Easy plug
and play electronics
NO.

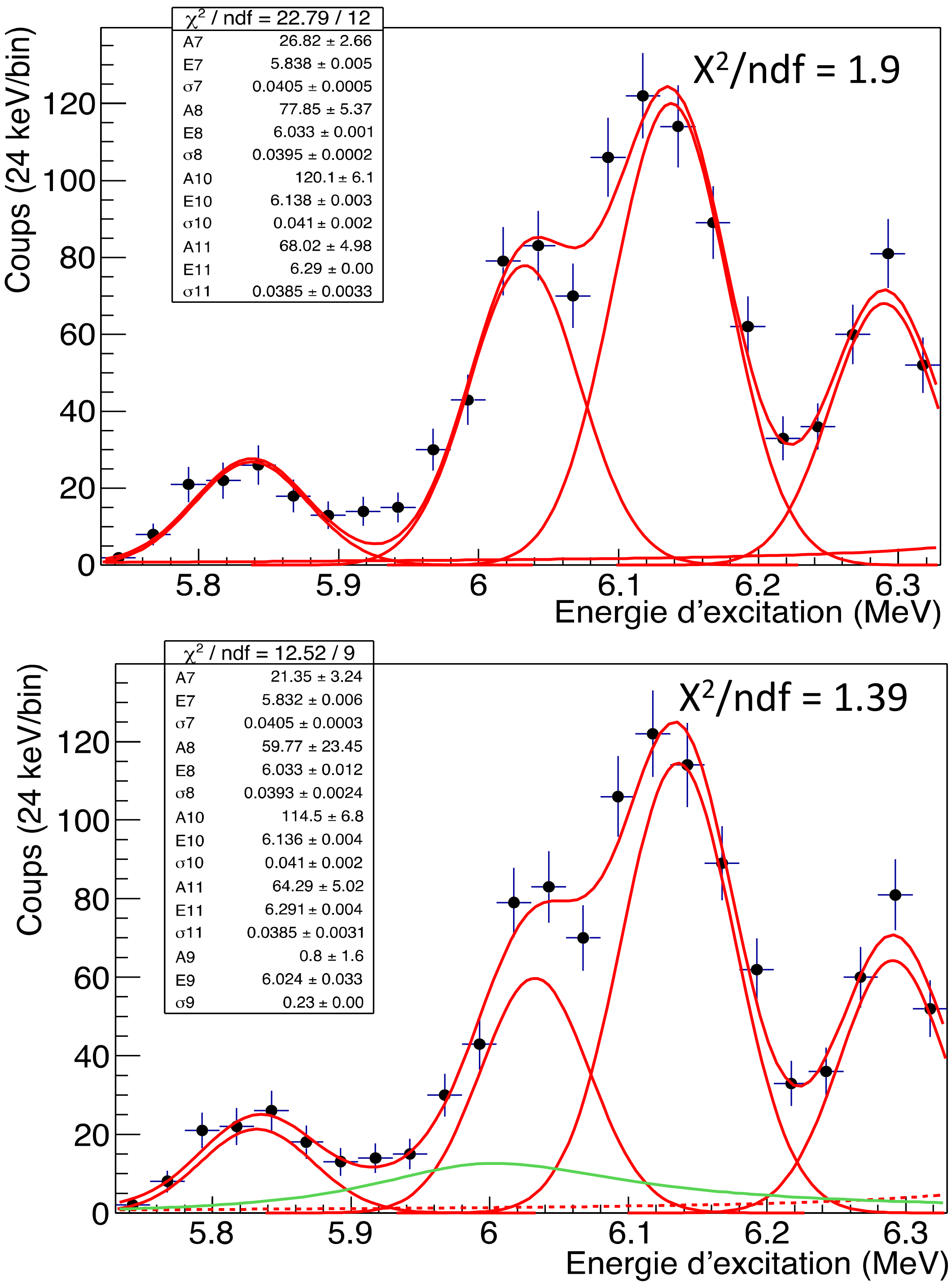
Using the prototype Mayaito

<u>Aim</u> : Which parameters of voltage (anode and cathode) and pressure of isobutane inside the drift chambers of VAMOS will optimize the detection of protons?

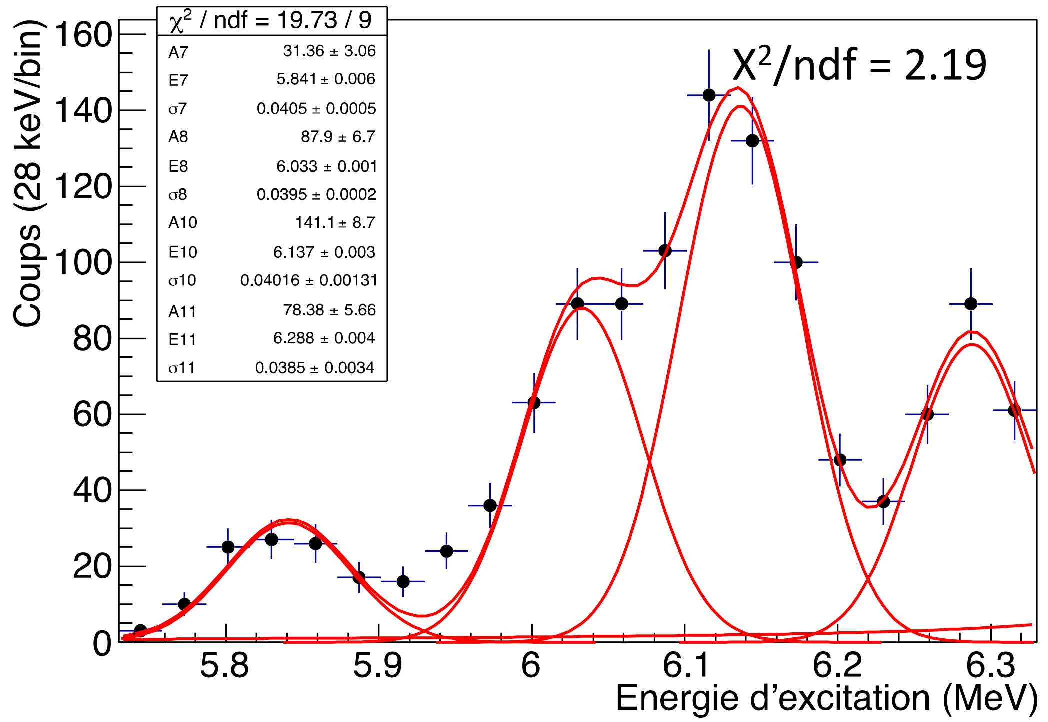


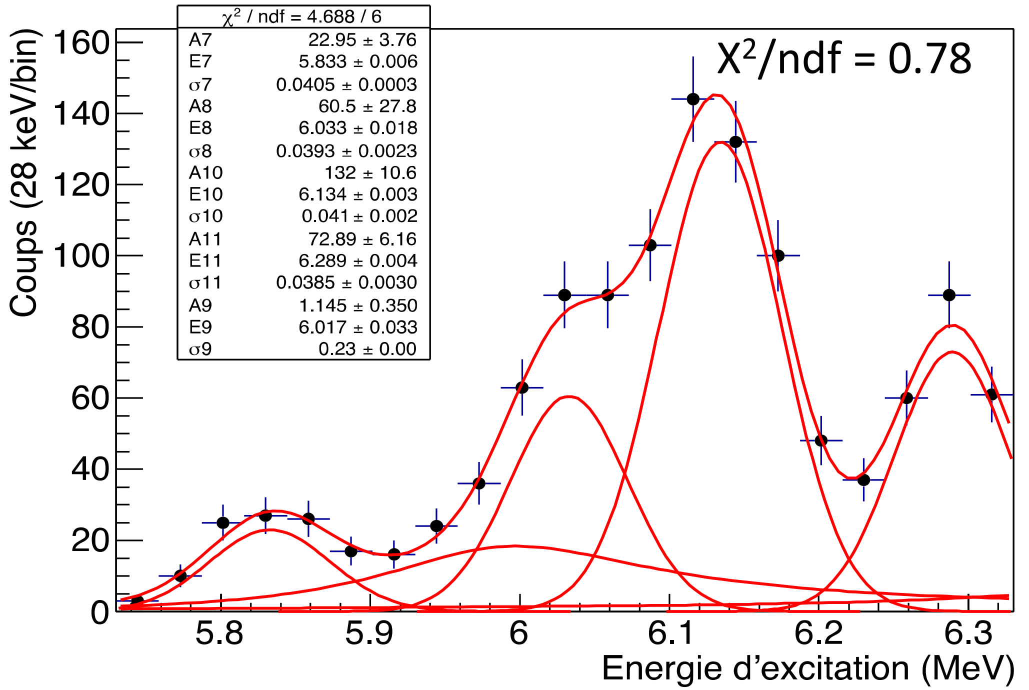


Size of one detection pad
(there are 128 inside)

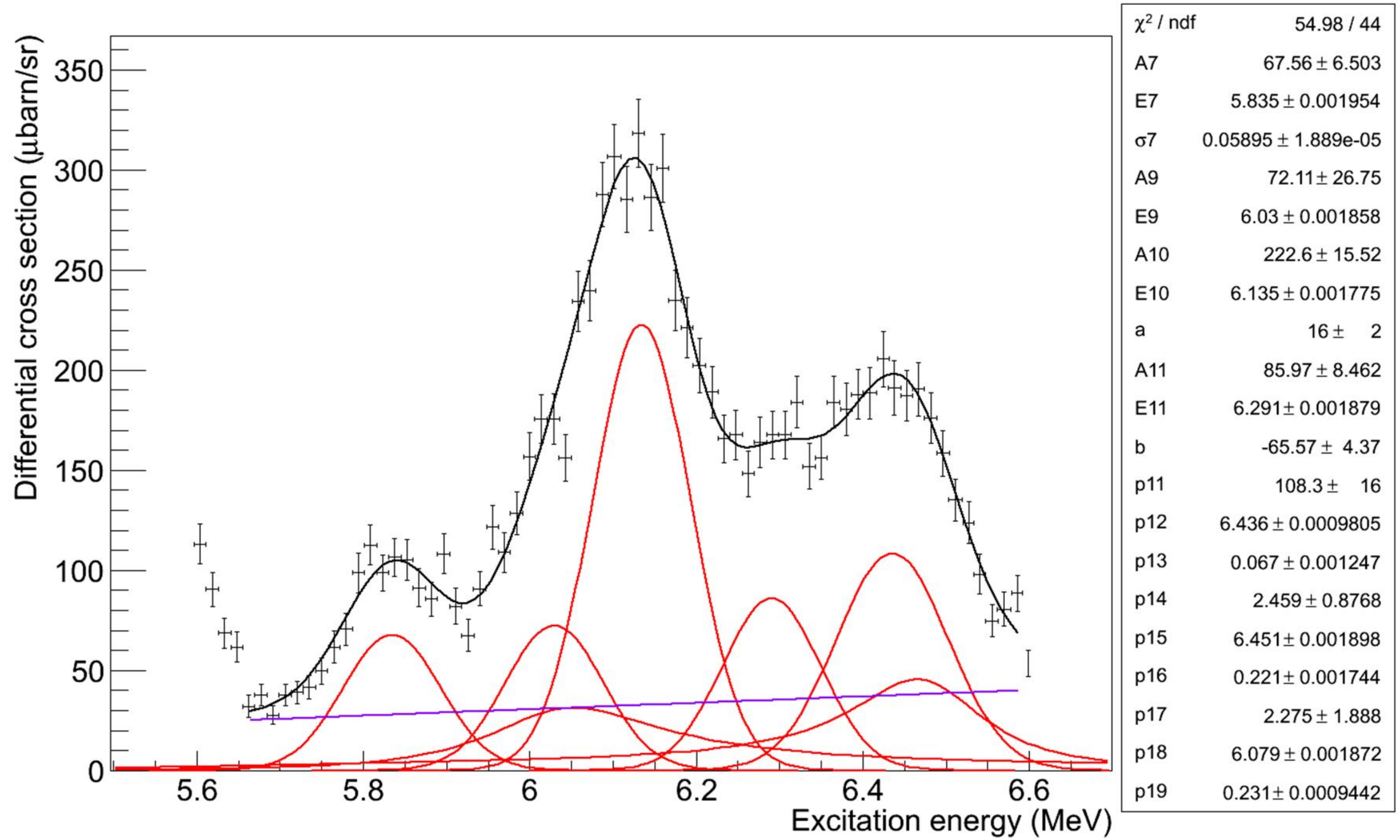


χ² / ndf = 22.79 / 12
A7 26.82 ± 2.66
E7 5.838 ± 0.005
σ7 0.0405 ± 0.0005
A8 77.85 ± 5.37
E8 6.033 ± 0.001
σ8 0.0395 ± 0.0002
A10 120.1 ± 6.1
E10 6.138 ± 0.003
σ10 0.041 ± 0.002
A11 68.02 ± 4.98
E11 6.29 ± 0.00
σ11 0.0385 ± 0.0033
X²/ndf = 1.9
Coups (24 keV/bin)
Energie d'excitation (MeV)
χ² / ndf = 12.52 / 9
A7 21.35 ± 3.24
E7 5.832 ± 0.006
σ7 0.0405 ± 0.0003
A8 59.77 ± 23.45
E8 6.033 ± 0.012
σ8 0.0393 ± 0.0024
A10 114.5 ± 6.8
E10 6.136 ± 0.004
σ10 0.041 ± 0.002
A11 64.29 ± 5.02
E11 6.291 ± 0.004
σ11 0.0385 ± 0.0031
A9 0.8 ± 1.6
E9 6.024 ± 0.033
σ9 0.23 ± 0.00
X²/ndf = 1.39
Coups (24 keV/bin)
Energie d'excitation (MeV)


χ2 / ndf = 19.73 / 9
A7 31.36 ± 3.06
E7 5.841 ± 0.006
σ7 0.0405 ± 0.0005
A8 87.9 ± 6.7
E8 6.033 ± 0.001
σ8 0.0395 ± 0.0002
A10 141.1 ± 8.7
E10 6.137 ± 0.003
σ10 0.04016 ± 0.00131
A11 78.38 ± 5.66
E11 6.288 ± 0.004
σ11 0.0385 ± 0.0034
X2/ndf = 2.19
Coups (28 keV/bin)
0
20
40
60
80
100
120
140
160
5.8
5.9
6
6.1
6.2
6.3
Energie d'excitation (MeV)


χ2 / ndf = 4.688 / 6
A7 22.95 ± 3.76
E7 5.833 ± 0.006
σ7 0.0405 ± 0.0003
A8 60.5 ± 27.8
E8 6.033 ± 0.018
σ8 0.0393 ± 0.0023
A10 132 ± 10.6
E10 6.134 ± 0.003
σ10 0.041 ± 0.002
A11 72.89 ± 6.16
E11 6.289 ± 0.004
σ11 0.0385 ± 0.0030
A9 1.145 ± 0.350
E9 6.017 ± 0.033
σ9 0.23 ± 0.00
X2/ndf = 0.78
Coups (28 keV/bin)
0
20
40
60
80
100
120
140
160
5.8
5.9
6
6.1
6.2
6.3
Energie d'excitation (MeV)

With J.C. Dalouzy (PhD thesis) data



- Calcul Talys à ajouter