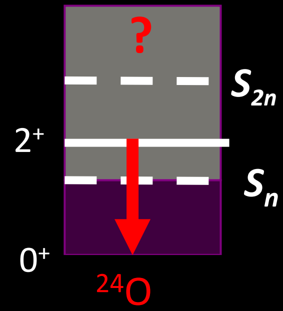
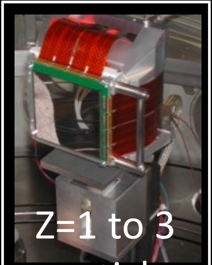
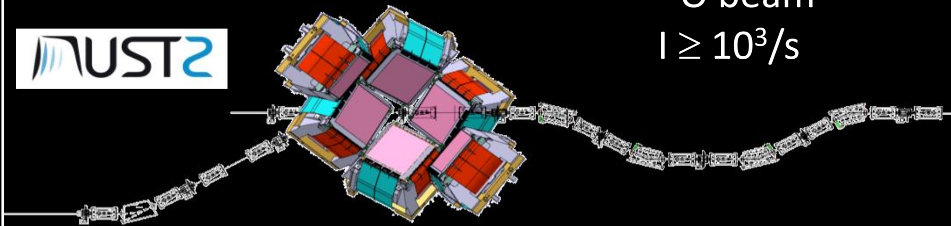
ESNT
31st March -11 April 2014



Resonances of ^{24}O and proton-nucleus interaction potentials of $^{21\text{-}24}O$ via (p,p') scattering at RIBF using the MUST2 array



Z=1 to 3 particle array



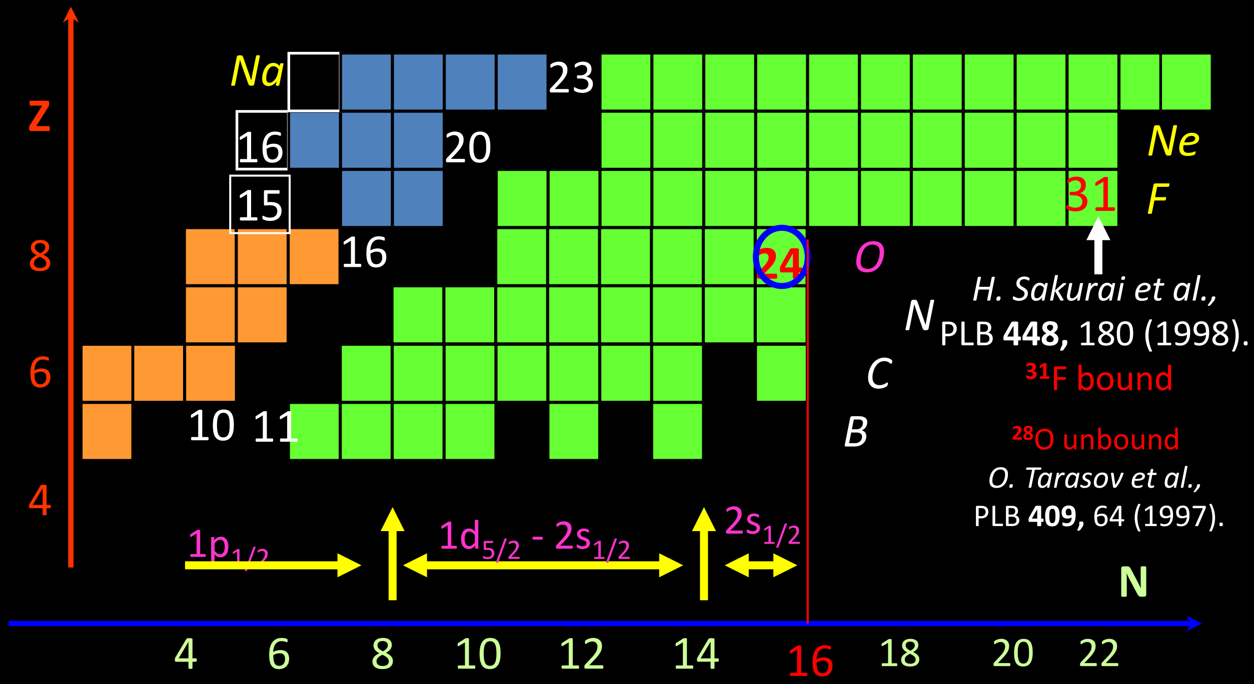
The Japanese –French RIBF57 collaboration *MUST2 campaign at RIKEN in 2010*
>> combination of unique worldwide array and RIBF intensities

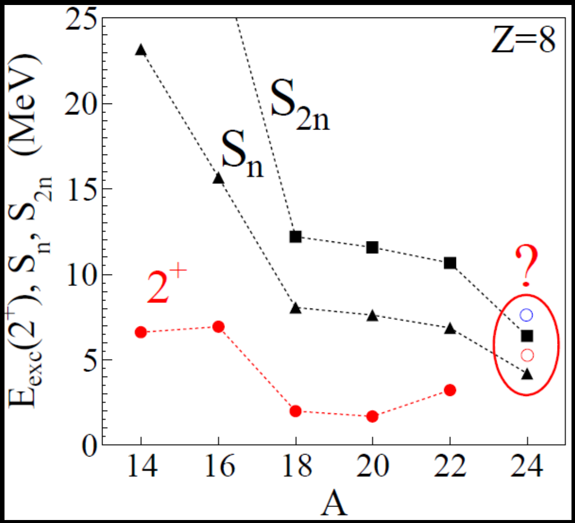
vlapoux@cea.fr

doubly-magic A/Z=3
$T_{1/2}$=65 ms N=16
possible n-skin

^{24}O: a long story of a nuclear problem for French-Japanese teams!

Last bound N = 16





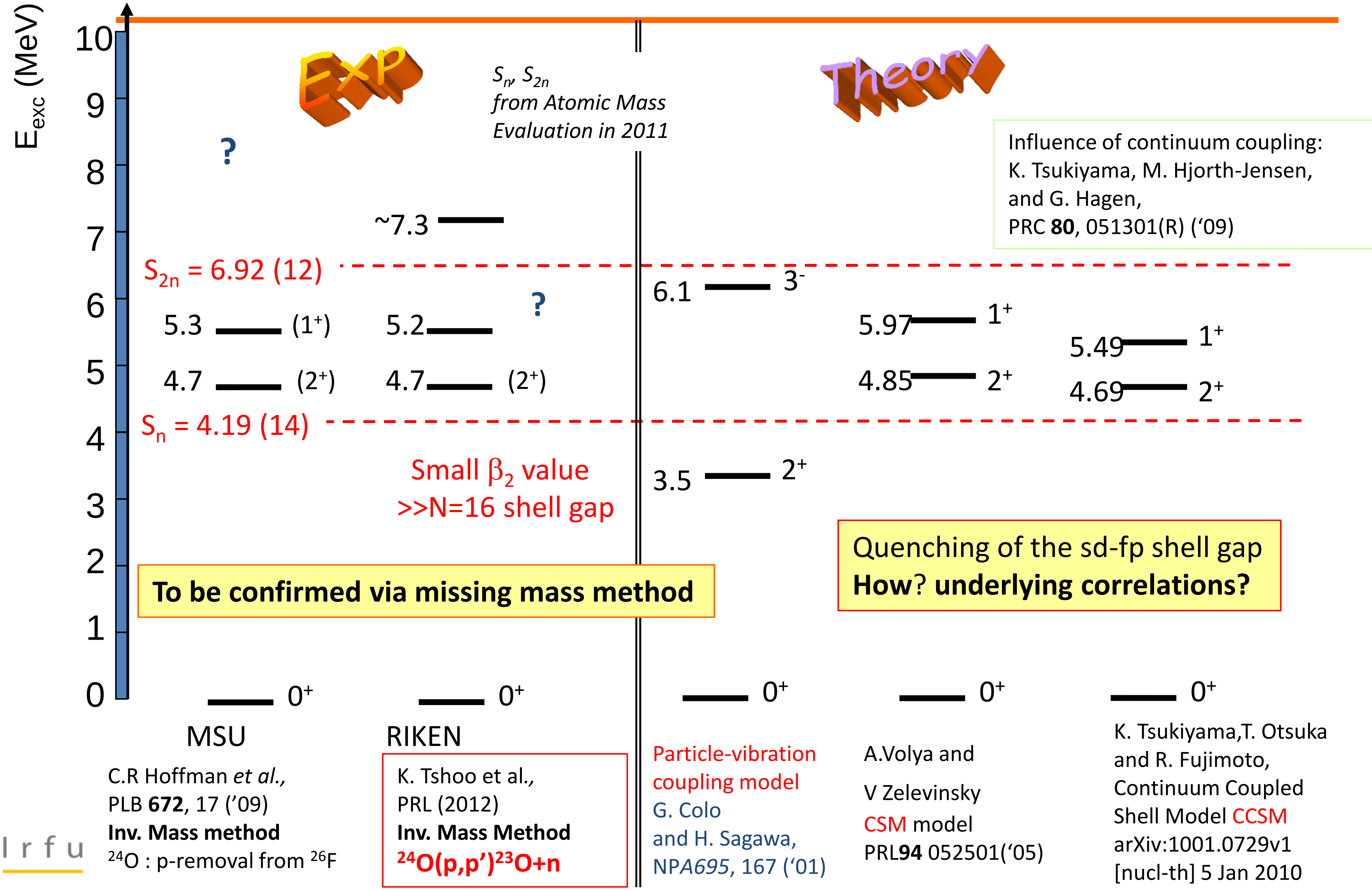
Location of the drip line for light nuclei influenced by the 3-nucleon forces
ab-initio calculations by G. Hagen et al., PRC **80**, 021306 ('09).
T. Otsuka et al., PRL **105**, 032501, (2010).

*No Gamma: M. Stanoiu et al., PRC **69**, 034312 (2004)*
A. Ozawa et al. PRL 84, 24 (2000)
Sn trend with Tz
→ possible change at N=16
→ T. Otsuka et al., PRL 2001-2010

Challenges for nuclear models:
treatment and interplay between correlations, tensor, 3-body forces, continuum coupling effects

Evolution of the structure at large isospin ?
→ structure
→ unbound excited states

Low-lying excited states of ^{24}O, experiments and calculations

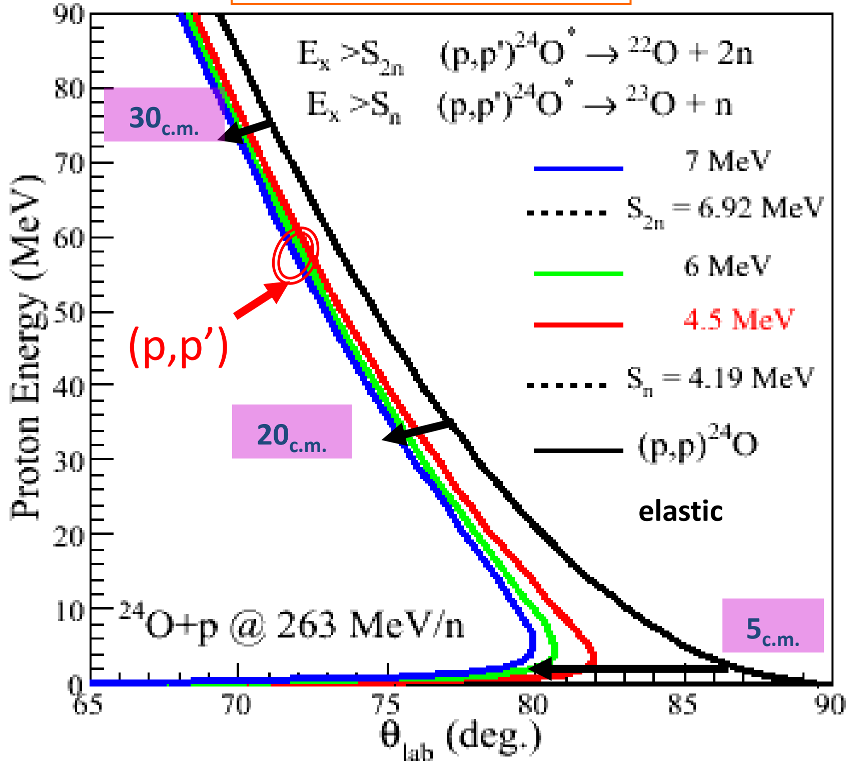


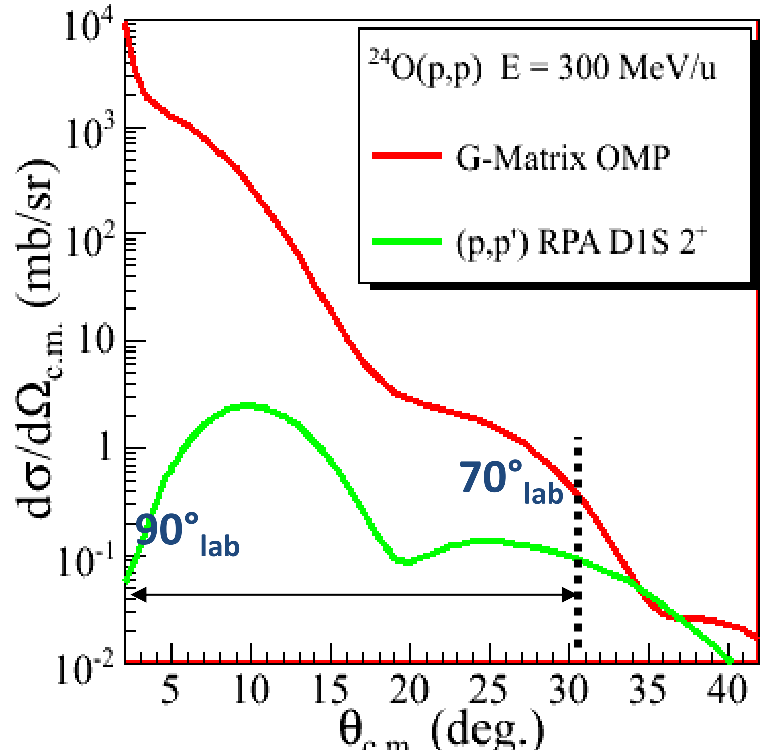
Kinematics and possible angular distributions

(depending on transition densities, transition strength)

^{24}O has no bound excited state ; S_n = *4.19 (10) MeV from Mass Eval. in 2011)*
>> unbound states via (p,p') & particle spectroscopy >> missing mass method

^{24}O(p,p') @ 263 MeV/n





Reaction energy conservation – **Ex from (Ep, *p*)**

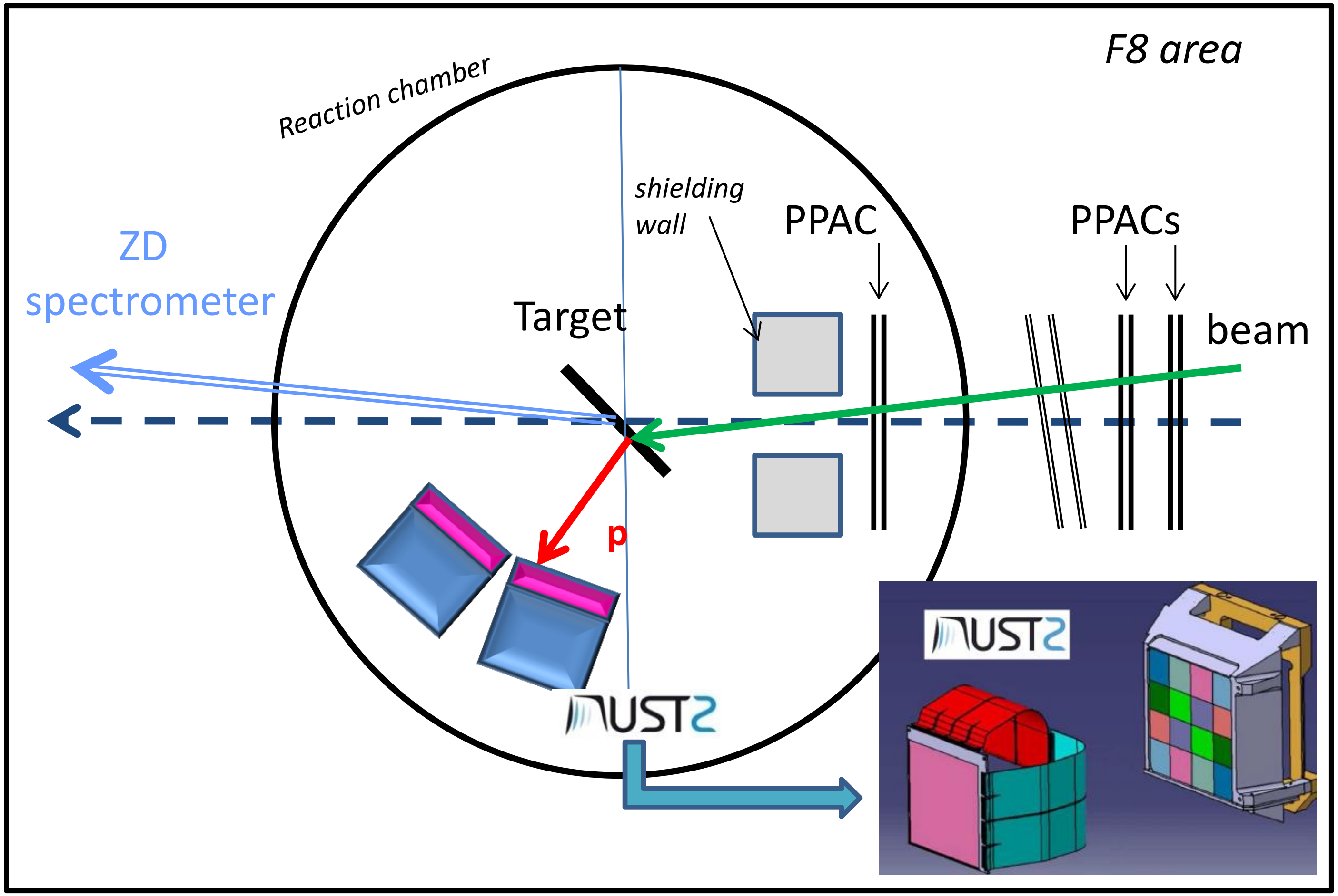
$(M_{recoil} c^2)^2 = (E_0)^2 + 2(p_{inc}c^2)(p_p c^2)(\cos \Theta_p) - 2T_p(E_{inc}+m_p c^2)$

$E_{ex} = M_{recoil} c^2 - E_0$

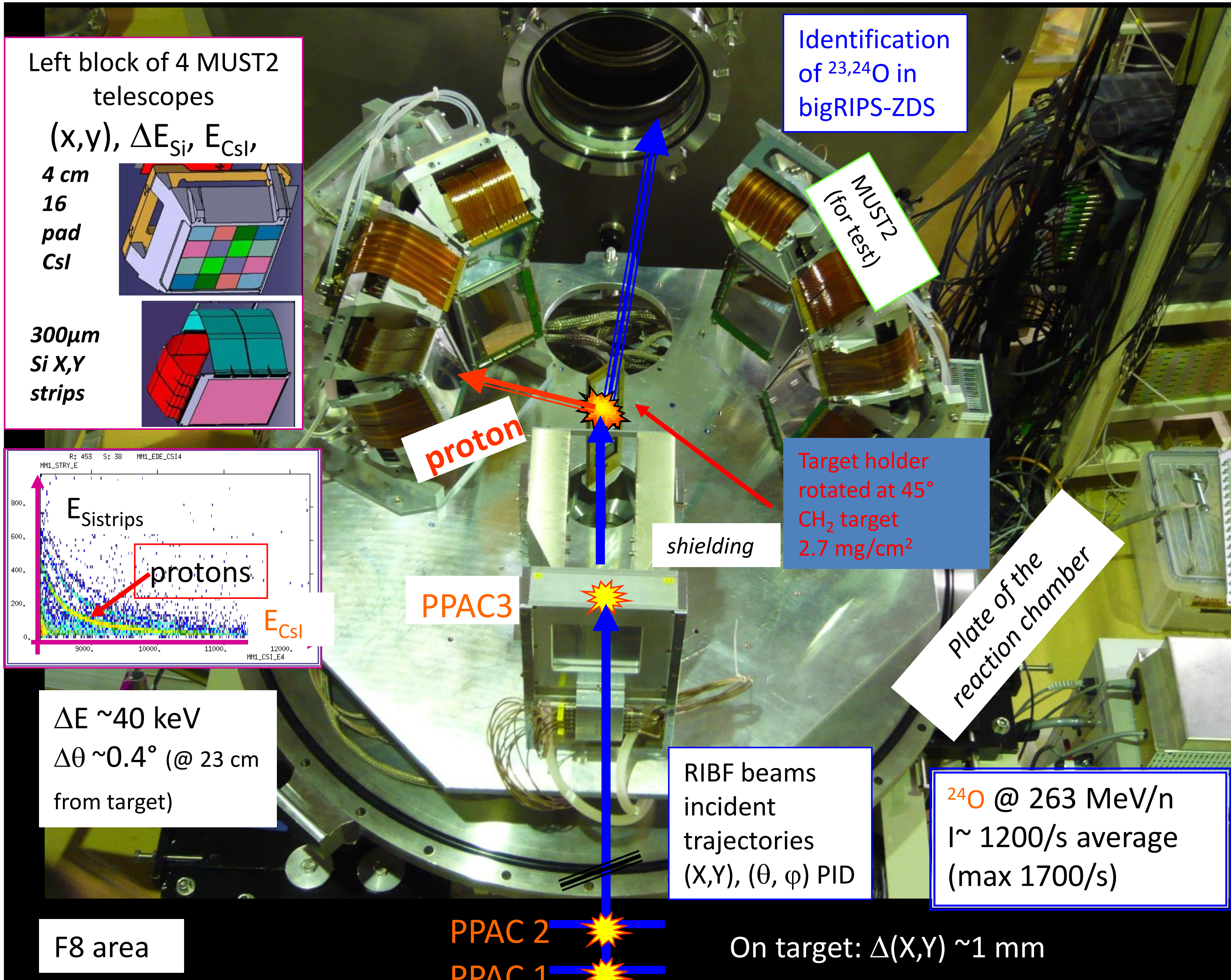
Non-local g-matrix potential approach
*(p,p) M. Dupuis et al. PRC**73**, 014605 ('06)*
*(p,p') ; PLB **665**, 152 ('08) RPA+D1S*

ASSETS: Ex up to 35 MeV, exclusive, angular distributions

RIBF57 Experimental set-up



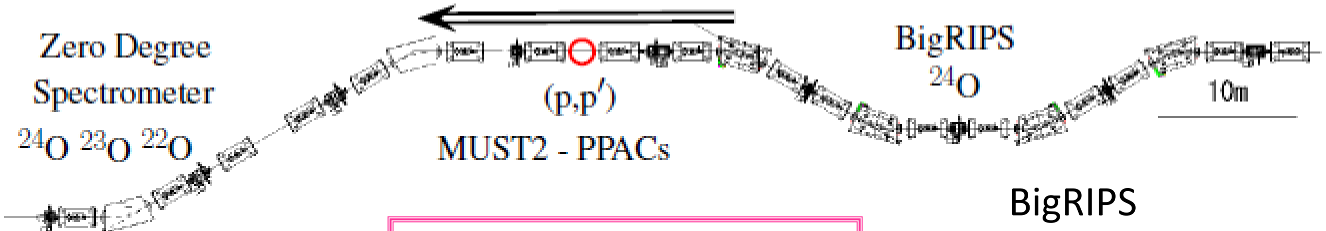
TOP VIEW: MUST2 telescopes in F8 reaction chamber, PPAC and target holder



Experimental set-up:BigRIPS, MUST2 and ZDS, production and PID of ^{24}O

ZDS PID via DE-TOF-Bρ

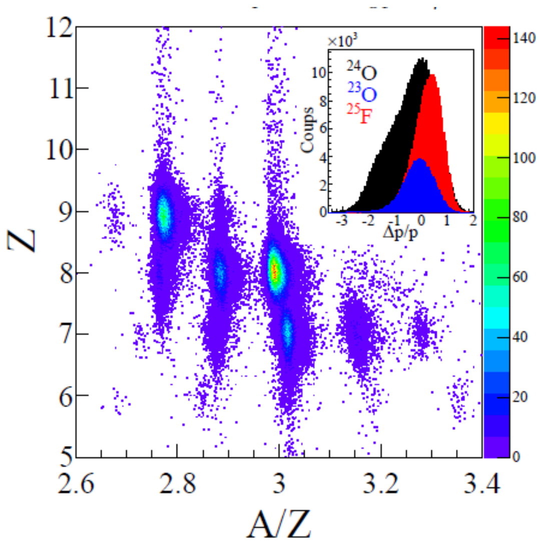
BigRIPS PID via DE-TOF-Bρ



ZDS
dp/p = 6% large acceptance mode
X,Y,T PPAC F9 (E,T) plastics F9-F11 (3.1mm)
3 settings Brho=7.49T.m,
- ^{23}O : -4.17 %; - ^{22}O : -4.34 %

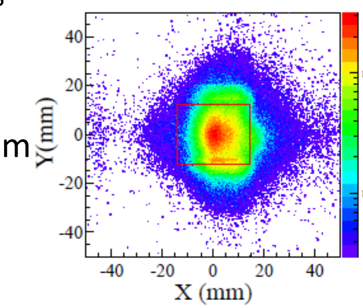
MUST2
PID proton (E_p, Θ_p)
PPACs F8 → target (X,Y, Θ_{inc})

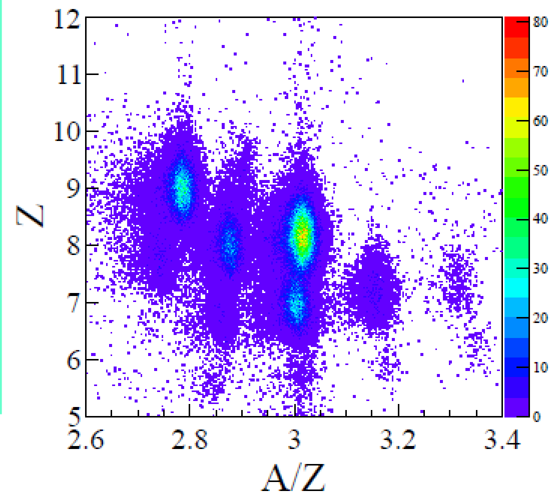
BigRIPS
^{48}Ca @ 345 MeV/n
^{9}Be 15mm thick Target
(X,Y,T) PPAC F5
(E,T) plastics F3-F7 (1.1mm)



PPACs in F8 beam reconstruction on target
(FWHM) in X: 9; Y : 12mm
Angle 0.77°; total <2°

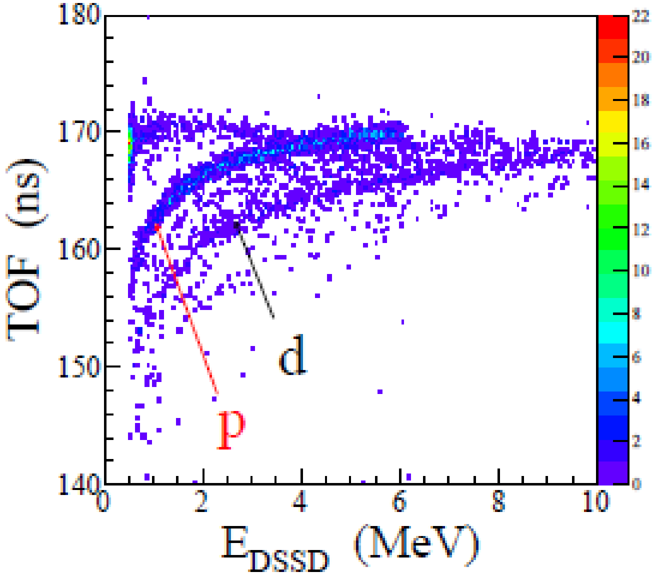
resolution
σ_X = 1.2 ; σ_Y = 1.3 mm
σ (θ) = 0.04 deg
Efficiency: 92%

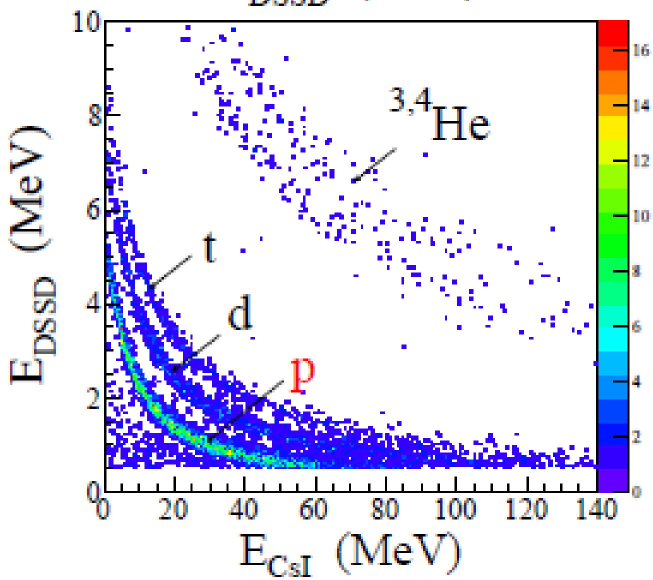




PhD analysis by S. Boissinot, SPhN

Total (^{24}O) = 1.05 10^9 in 7 days (1760/s) for 1^{ary} beam @ 180 pnA
Purity 2.5% of the beam (including A/Z =3 particles) DE/E (beam) = 9%



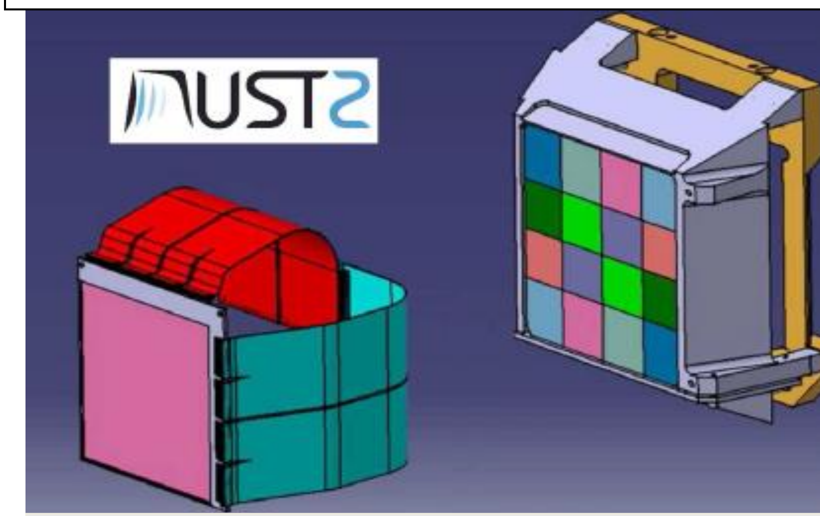


- collaboration IRFU, IPN Orsay, GANIL
- 8 telescopes 10×10 cm² Si-strips/(SiLi 4.5 mm)/CsI
- high granularity 128 (X,Y)

ASIC electronics 'MATE' Time and Energy for each channel developed by DAPNIA/SEDI

- Compact geometry - 1400 channels (E,T)

E. Pollacco *et al.*, EPJA **25**, s01, 287 (2005).



Si 300 µm 128(X,Y) Resolutions:

ΔE ~ 45keV at 5.5 MeV; Δx, Δy ~ 0.53mm

$\Delta\theta_{lab}$ ~ 0.2° at 15cm ΔT~1.5 ns

CsI 40 mm ; 16 pads 3×3 cm² $\Delta E/E$ ~ 8% @ 5 MeV

Conditions for RIBF57:

θ_{lab} ~0.17° at 23cm ; $\sigma(E_X)$= 34 keV; $\sigma(E_Y)$=38 keV

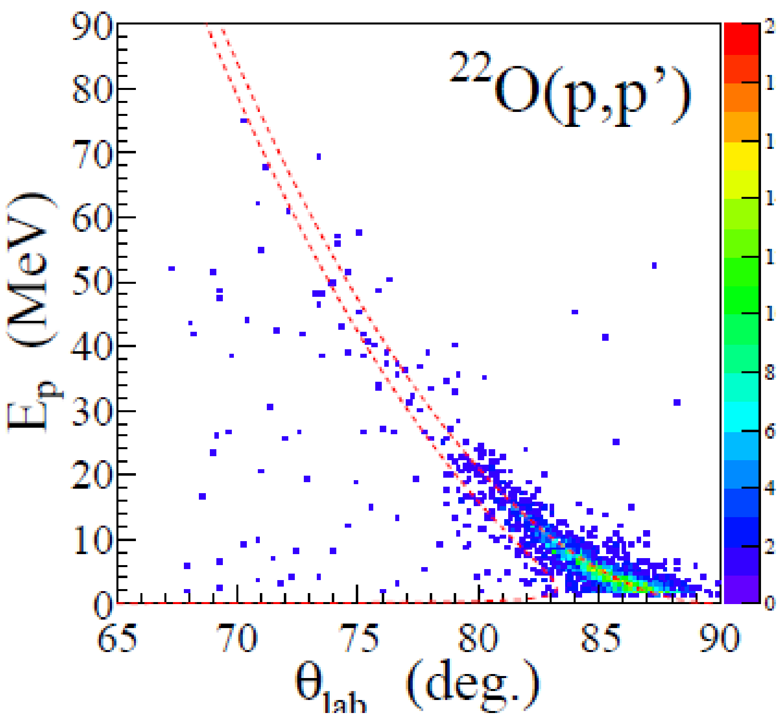
Si Threshold 400 keV 400 keV <Ep < 6.2 MeV

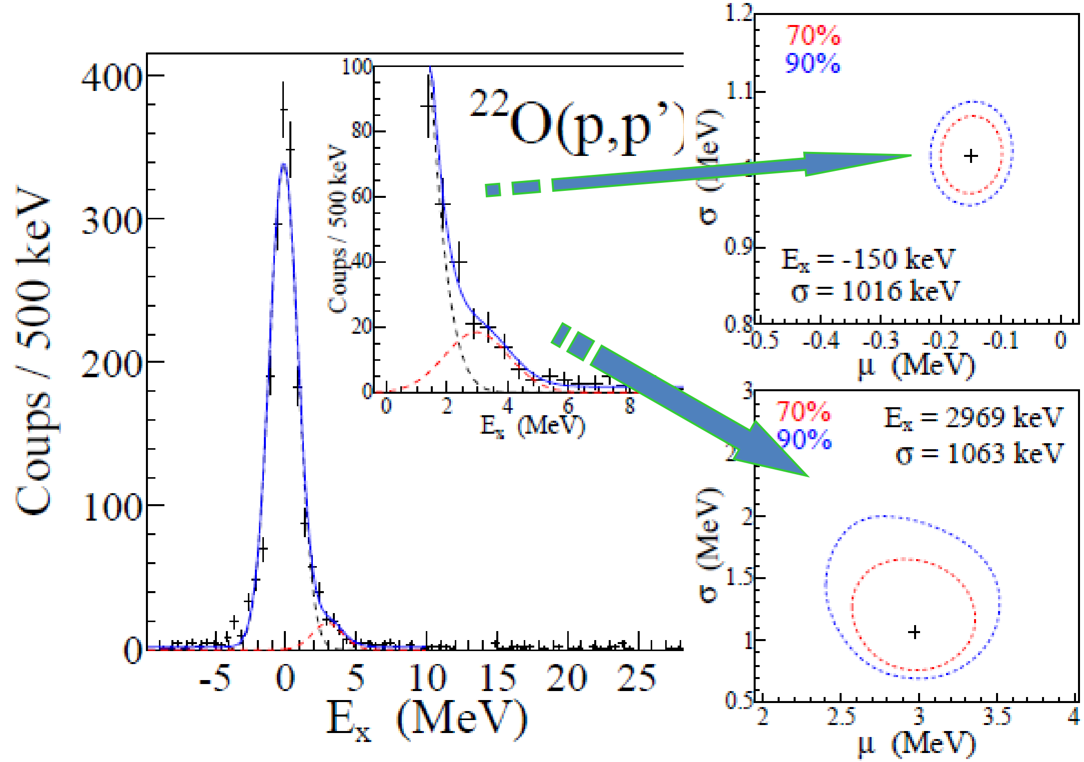
1 MeV < E_{CsI} < 90 MeV

Analysis for the reference experiment: $^{22}O(p,p')$

One day statistics ^{22}O ; intensity ~1.4 10^4/s; E = 262.5 MeV/u ; CH_2 2.7 mg/cm^2 at 45deg

All conditions: Target cut selection +PID BigRIPS , ZDS MUST2 kinematics for 1.6 < Ep< 90 MeV ; 67 <th<90° lab	Whole statistics of the elastic and inelastic data $^{22}O(p,p')$ 1936 counts





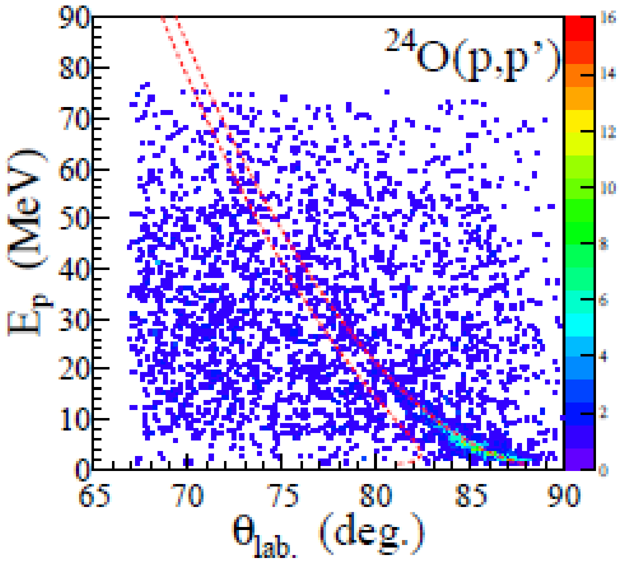
gamma-spectroscopy 3.199 (8) MeV
*M. Stanoiu et al., PRC **69**, 034312 (2004)*

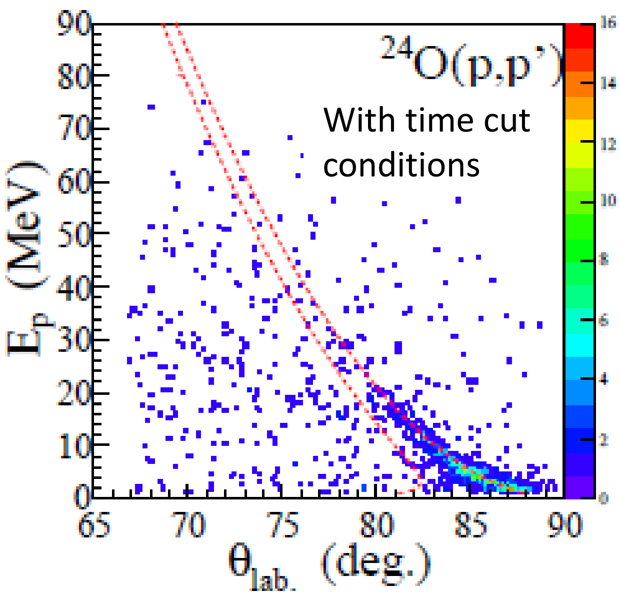
Here: Ex = 3.0 ±0.5 MeV ;
Ex resolution ~ 1.2 to 1.5 MeV

PhD analysis by S. Boissinot, SPhN

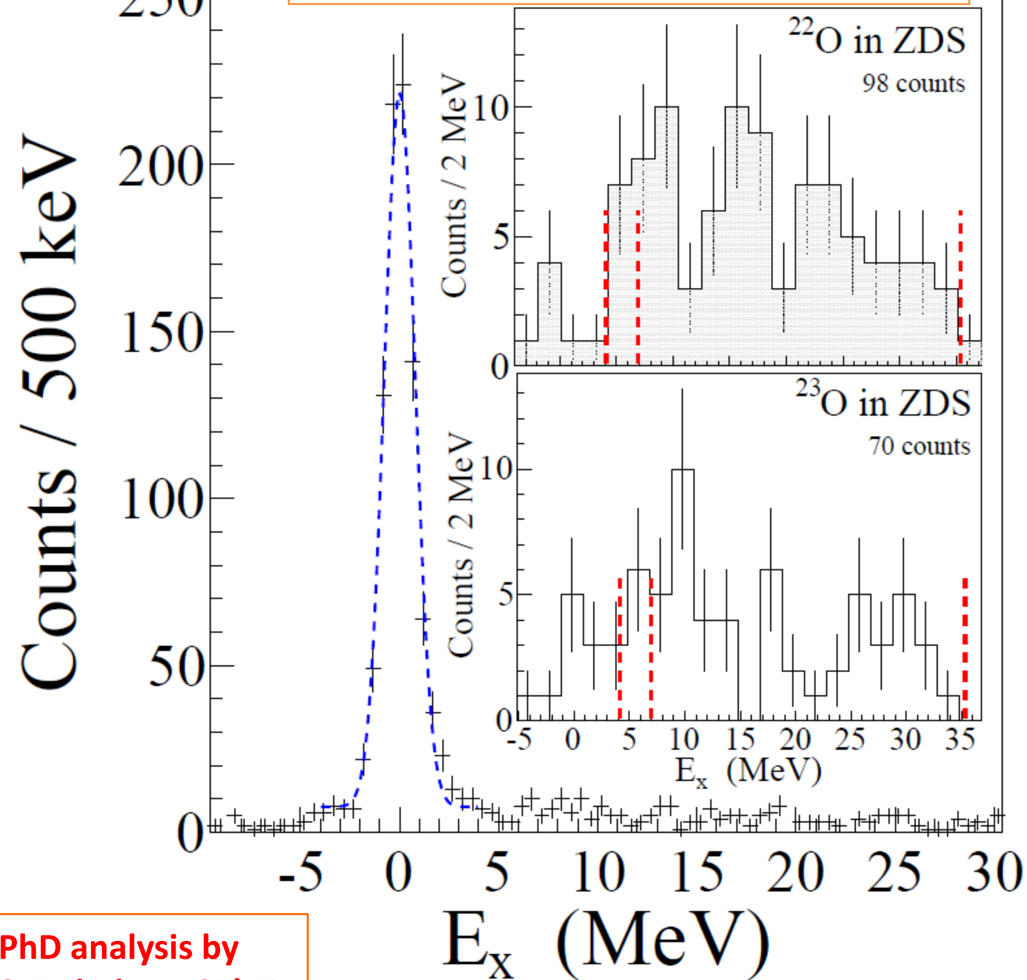
Elastic % (p,p') orders of magnitude
>> in agreement with calculations at 262.5 MeV/n

Kinematics and Ex spectra $^{24}O(p,p')$ @ 263 A.MeV



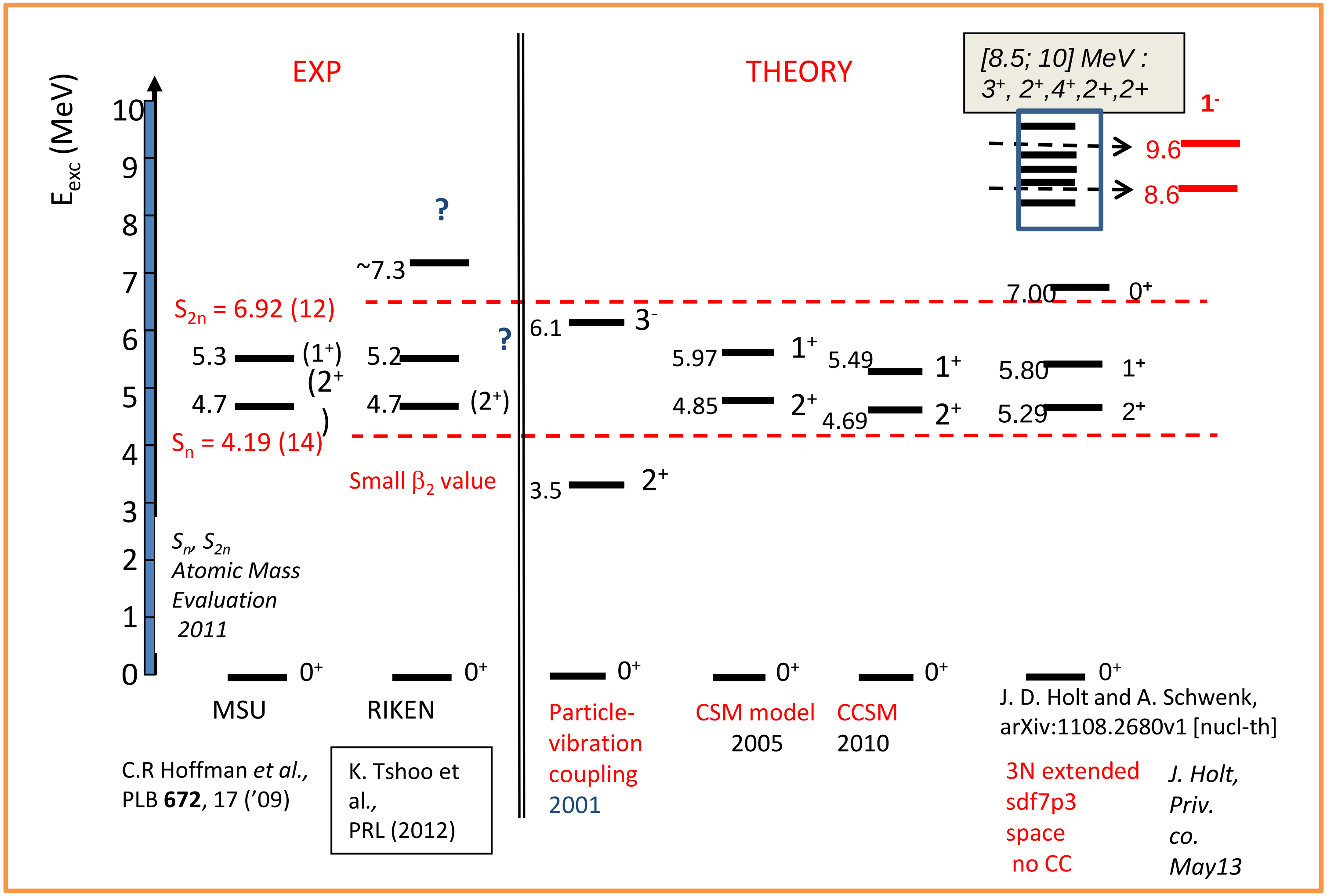


Quintessence…
Whole statistics of the elastic
& inelastic data $^{24}O(p,p')$ 1300 counts



PhD analysis by
S. Boissinot, SPhN

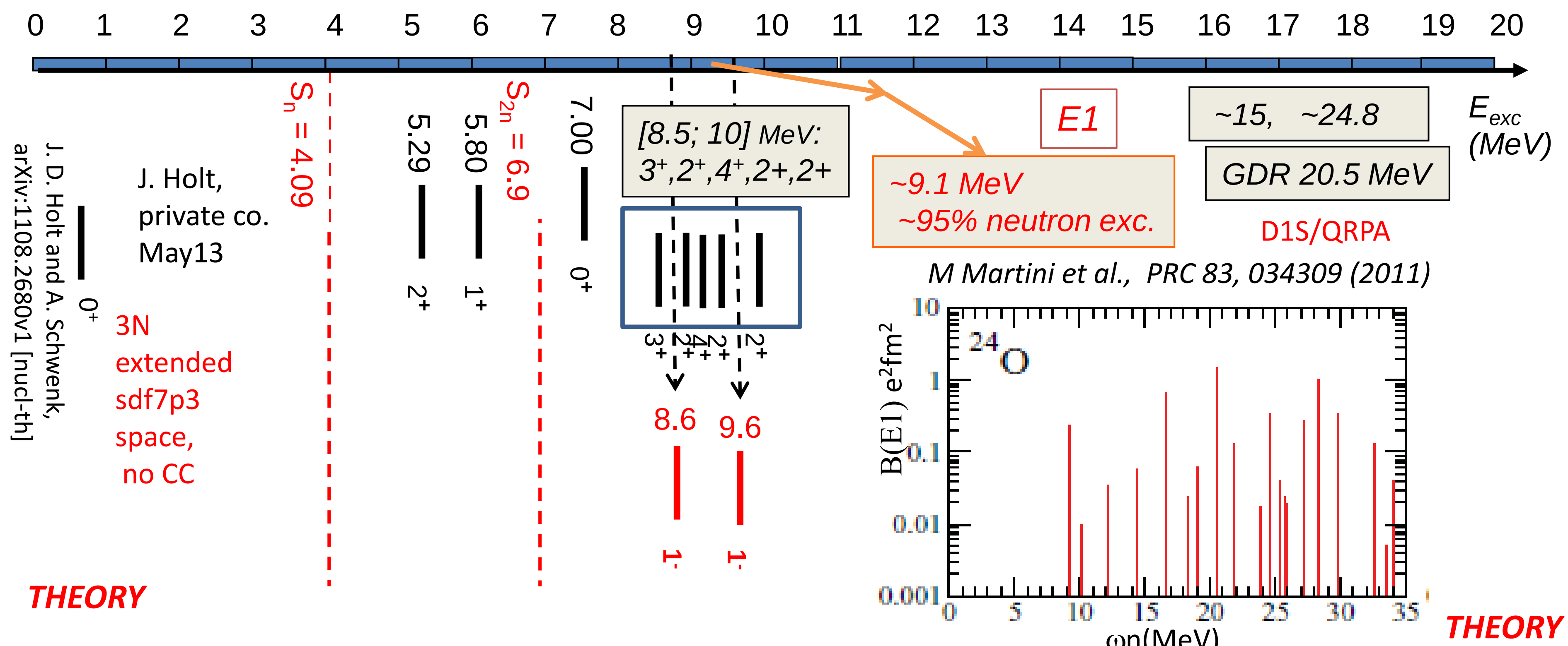
Theoretical calculations for the spectroscopy of ^{24}O, cases of large valence space



Particle-vibration coupling model
G. Colo and H. Sagawa,
NP*A695*, 167 ('01)

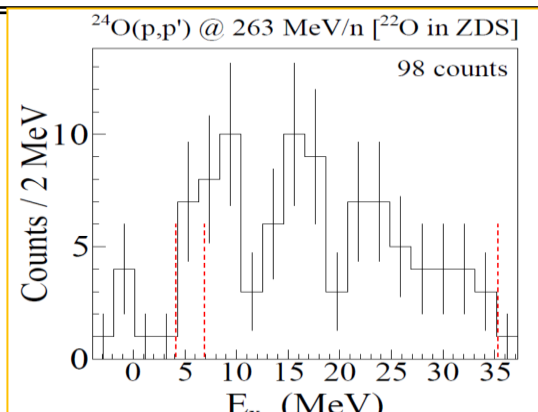
Inclusion of f7/2 p3/2
J.D Holt, J.Menendez, A.Schwenk,
EPJA **49**, 39 (2013).

Unbound excited states of ^{24}O above S_{2n}, experiment and calculations



~9, 16, 22 MeV

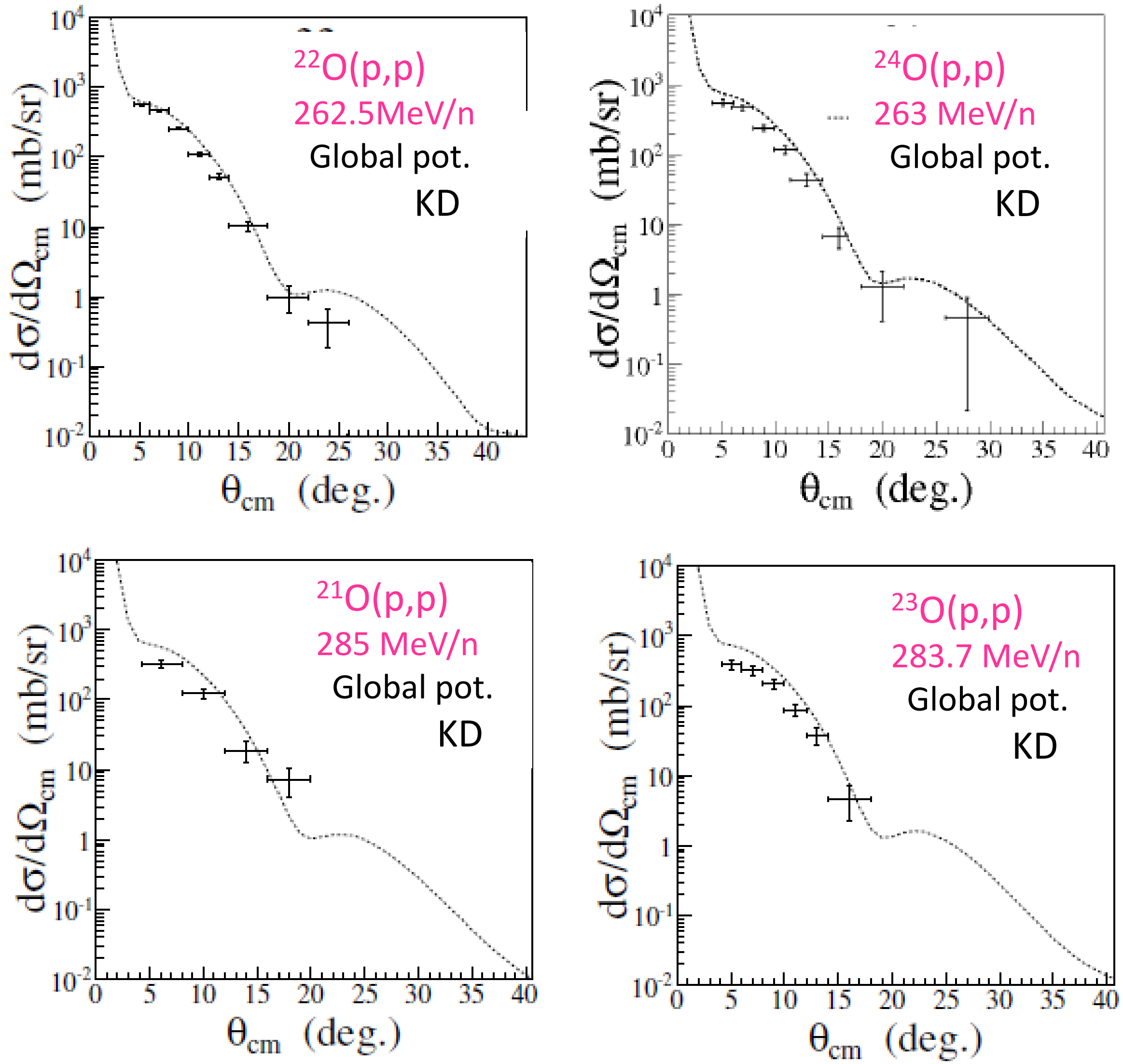
THIS WORK



Eexc (E1)? last neutron-rich N=16 nucleus known :
^{26}Ne (N/Z =1.6) Ex ~ 9 MeV
*J Gibelin et al, PRL **101**, 212503(2008)*

E1 and Pygmy due to n-skin? WB10 psdpf shell
^{24}O (N/Z =2) Ex ~ 9 MeV
*H. Sagawa and T. Suzuki , PRC **59**, 3118 (1999)*

Exclusive cross sections for $^{21,22,23,24}O(p,p)$



OMP Calculations
ECIS 06 code
(J Raynal CEA-SPhT)
+ Koning-Delaroche (KD)
global nucleus-nucleon
P otential
NPA*713*, 231(2003)

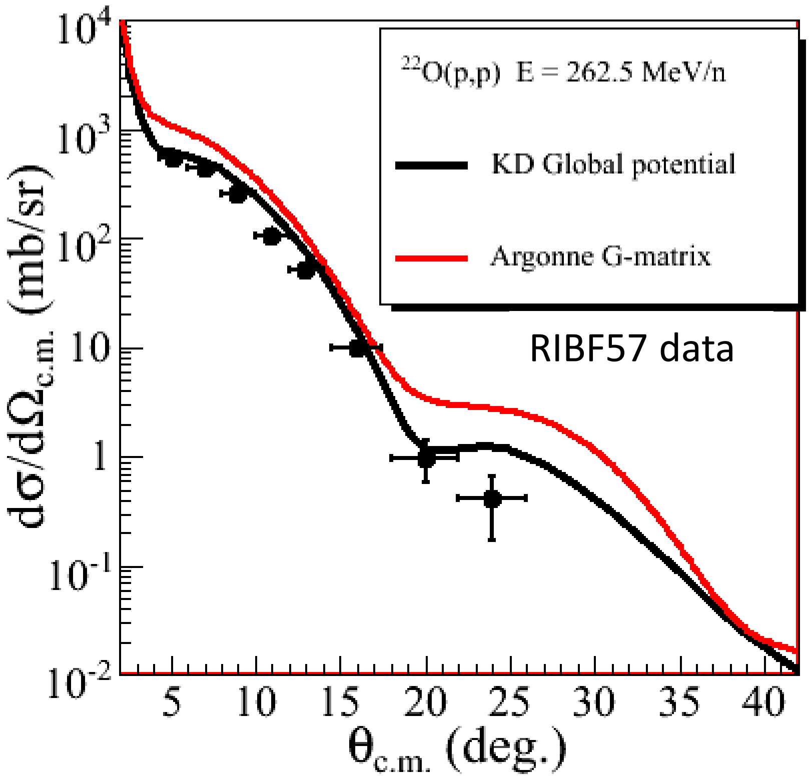
Full statistics
on target (all runs)

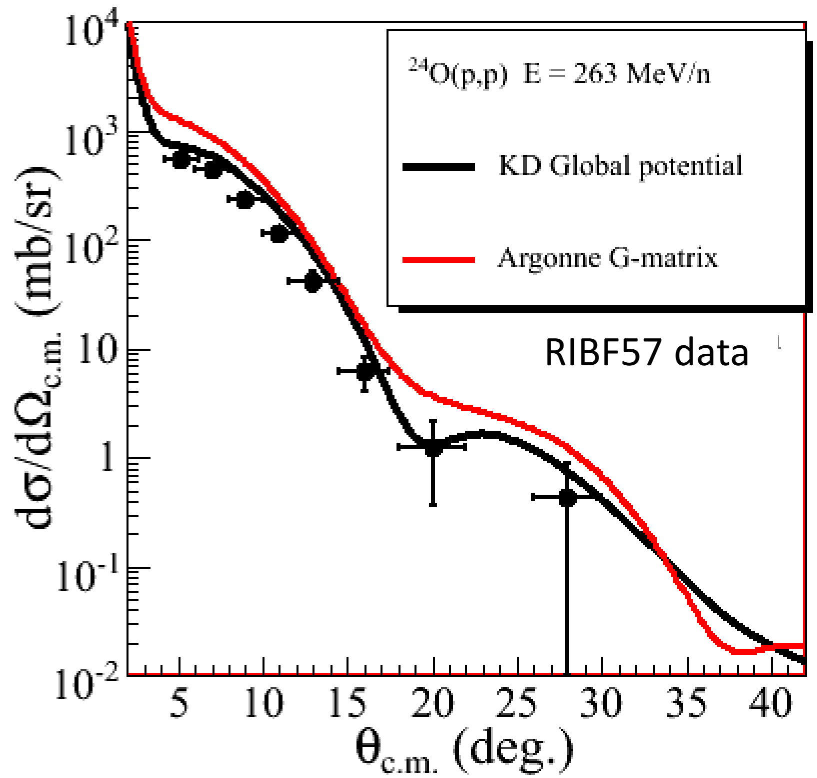
N(^{22}O) = 1.09 E+09
(1day)

N(^{24}O) = 1.05 E+09
(7 days)

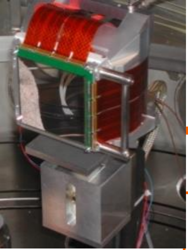
OMP G –matrix calculations for $^{22}O(p,p)$ and $^{24}O(p,p)$

Microscopic potentials OMP: H Arellano Univ of Chile,
Densities CEA-DAM HFB D1S Gogny; ^{22}O *(rms)$_m$ =3.0 fm;* **^{24}O** *(rms)$_m$ = 3.3 fm.*
*Cf H. F. Arellano and M. Girod PRC **76**, 034602 (2007)*
Scattering based on Argonne18 bare potential.
Same for Melbourne G-matrix interaction: M Dupuis et al CEA BIII.





Global potentials (KD)
(Vlx) OMP with ECIS 06



Conclusions and perspectives

+ Doing (p,p') particle spectroscopy for ^{24}O : to have 1000/s at RIBF we worked at 263. A.MeV

→ low cross sections, triton contamination due to A/Z=3

Difficult path (9,4m^3 + heavy 1852kg of MUST2 equipments !)

but unique way to obtain (p,p) up to now: I ~ 1700/s @RIBF

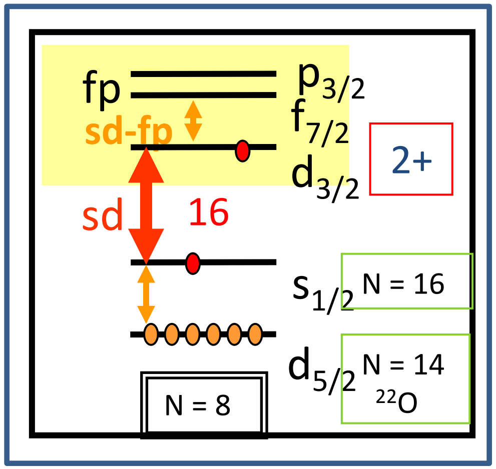
+Combination of state-of-the-art particle detector array MUST2 and BigRIPS

+ **unique worldwide RIBF intensities** >>> Rare data but very **exclusive**

+ Analysis of Ex spectrum UP TO 35 MeV → E1 window !!

Indication of structures at ~ 9 MeV, 16 and 22 (2) MeV

E1 window



Low integrated (p,p') yields for states below S_{2n}, **σ(2+) <0.4 mb**

→ low transition strength,

within microscopic reaction models σ(2+) =0.53 mb

→ consistent with the N=16 shell gap from Tshoo et al.

Further: study of states > S_{2n},

possible probes for the sd-fp shell gap at N = 16 studied within models including 3-body interaction and extended sd-fp space.

+ First (p,p) elastic cross sections at RIBF energies E~260 -290MeV/n

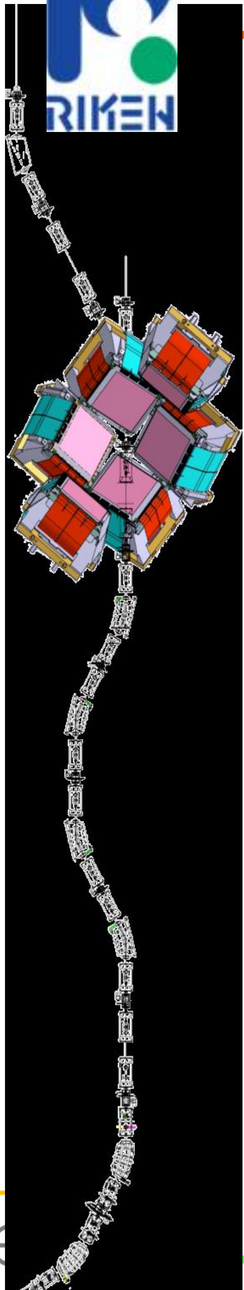
Systems: **^{24}O(p,p)** ^{23}O also for ^{23}F + reference ^{22}O(p,p) + ^{21}O also for ^{25}F (Chen, Otsu et al.)

→ Whole set of (p,p) for $^{21,22,23,24}O$: comparison to OMP microscopic calculations

Further: **Extend the reaction models to include (p,pX) knock-out contributions**

→ Extract the range for the **matter rms radii**, - smaller rms from σ_I measurements

*Values consistent with the (p,p) data are: ^{22}O (rms)$_m$ =3.0 fm; **^{24}O** (rms)$_m$ = 3.3 fm.(within +/-0.15 fm)*



Collaboration of the ^{24}O(p,p') RIBF 57 experiment

Spokespersons:

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RIKEN RIBF

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CNRS IN2P3 IPN-Orsay: Adrien MATTA, Serge FRANCHOO, Fairouz HAMMACHE, Yorick BLUMENFELD

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(Electronics, Data acquisition) Ch. HOUARNER, Frédéric SAILLANT

Mechanics, drawings IPN Orsay Emmanuel RINDEL, Philippe ROSIER