Unbound states of the drip-line nucleus ^{24}O from (p,p′) scattering

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de l'Univers

Light neutron-rich nuclei

Observations

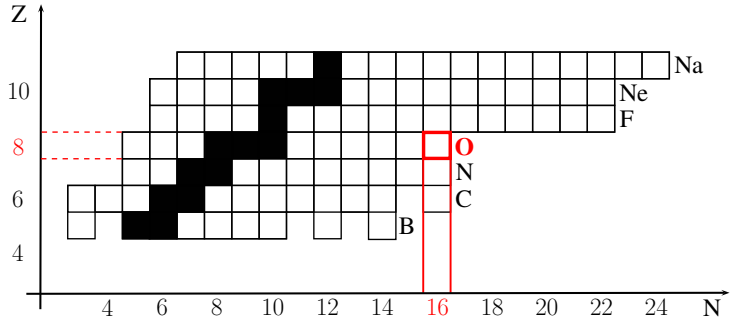
- **Drip-line** (known up to ^{24}O)

  ^{28}O unbound, ^{31}F bound
  Tarasov *et al.*, PLB **409** 64 (1997)
  Sakurai *et al.*, PLB **448** 180 (1999)

- **Isospin dependence** and **magic number**

  Disappearance of N=20
  Motobayashi *et al.*, PLB **346** 9 (1995)

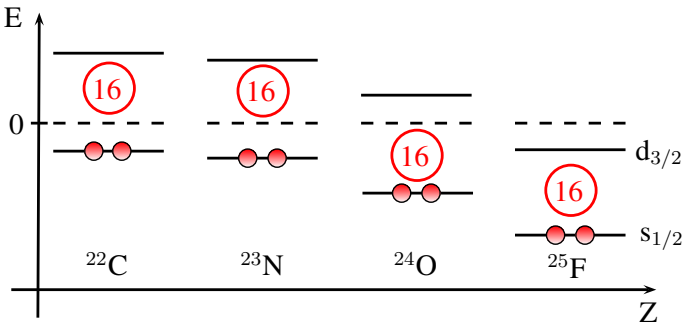
  S_n trend for a given T_z
  Ozawa *et al.*, PRL **84** 24 (2000)



Interpretations

→ Spin-isospin term
Otsuka *et al.*, PRL **87** 082502 (2001)

→ 3-body forces
Hagen *et al.*, PRC **80** 021306 (2009)



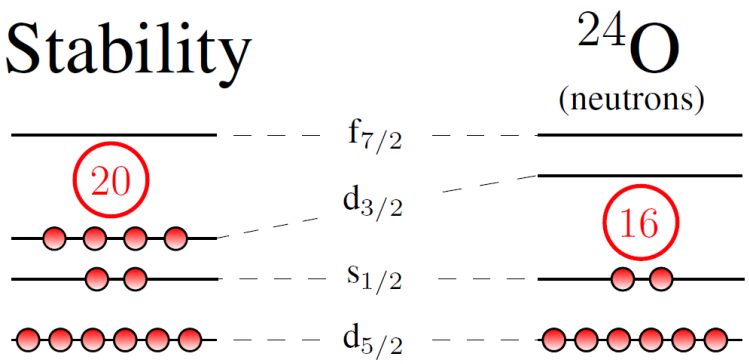
^{24}O doubly-magic nucleus

N=16 magic number at the *drip-line*

- Spectroscopic factor of $s_{1/2}$ shell
  Kanungo *et al.*, PRL **102** 152501 (2009)
- ^{24}O : **no bound** excited state ($> S_n$)
  Stanoiu *et al.*, PRC **69** 034312 (2004)
  Hoffman *et al.*, PLB **672** 17 (2009)

Invariant mass E_{exc} 4.72(11) et 5.33(12) MeV

→ Continuum coupling effect



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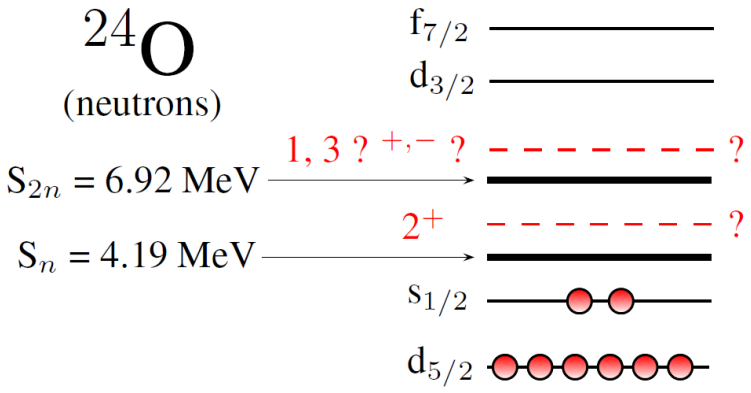

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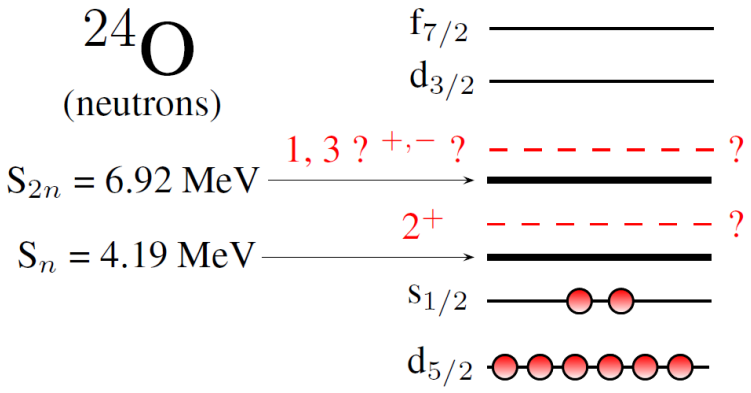


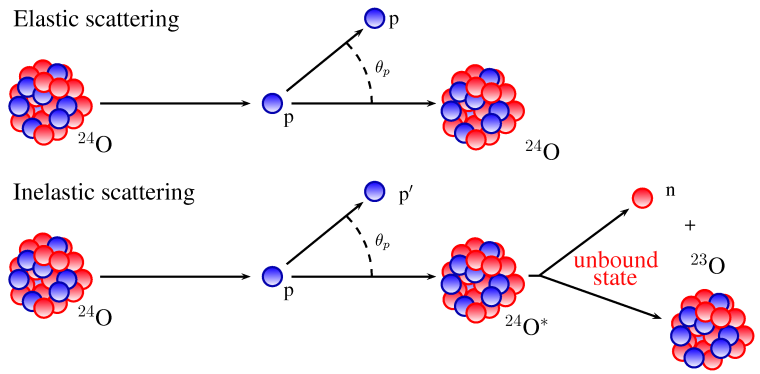
Experiment goals (proposed in 2008)

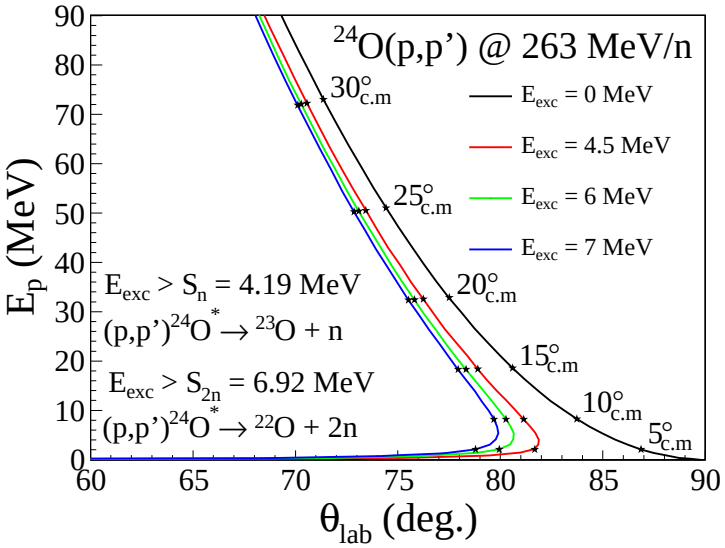
- **Direct measurement of E_x via (p,p′) reaction and particle spectroscopy**

+ **Elastic angular distribution**

→ Performed in 2010 at RIKEN

Experimental method for ^{24}O(p,p′)^{24}O*

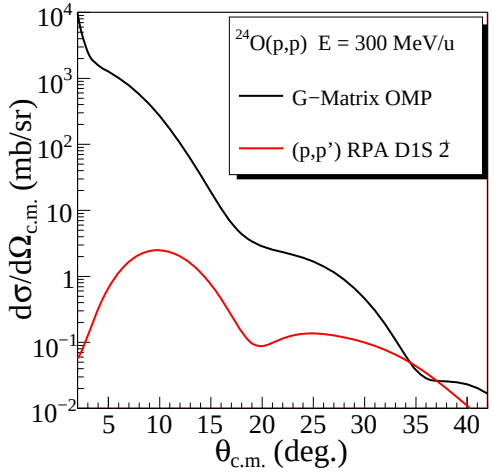




Missing mass method

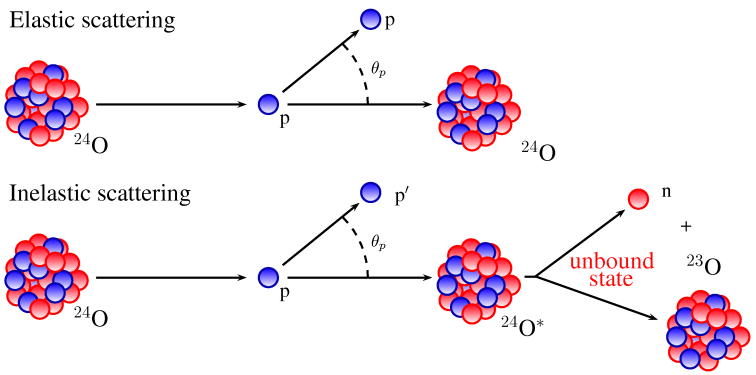
$(\mathrm{E_p}, \theta_{\mathrm{lab}})$ of the scattered proton

$$\begin{aligned} \mathrm{E_{exc}} &= (m_{\mathrm{rec}} - m_0)c^2 \\ m_{\mathrm{rec}}^2 c^4 &= m_0^2 c^4 + 2 p_i p_{\mathrm{p}} c^2 \cos\theta_{\mathrm{lab}} \\ &\quad -2T_{\mathrm{p}}(\mathrm{E}_i + m_{\mathrm{p}} c^2) \end{aligned}$$



Dupuis *et al.*, PLB **665** 152 (2008)

Experimental method for $^{24}O(p,p')^{24}O^*$



Missing mass method

(E_p, θ_{lab}) of the scattered proton

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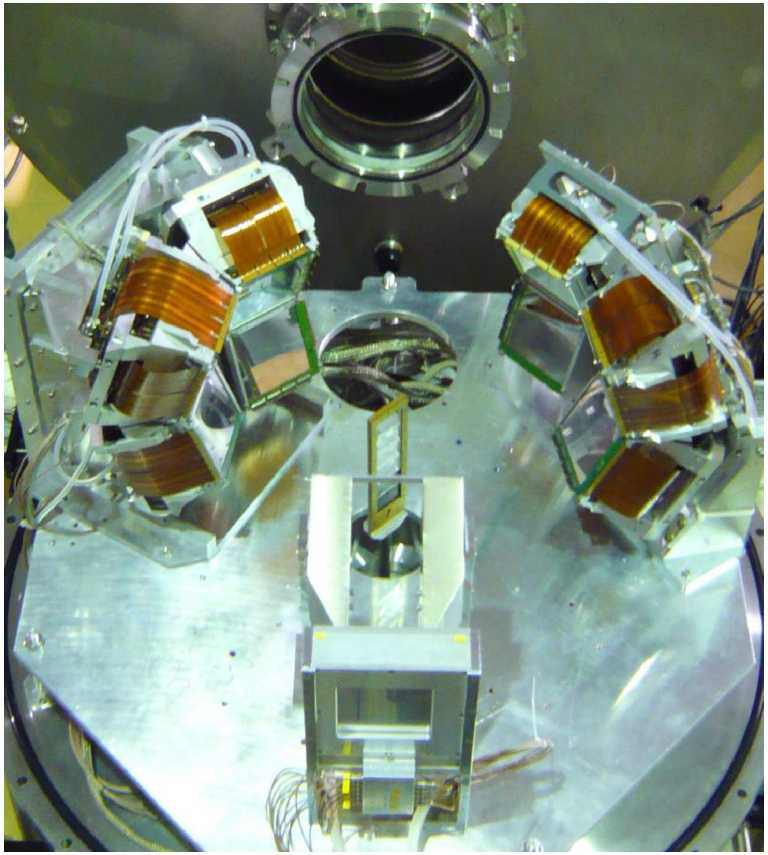
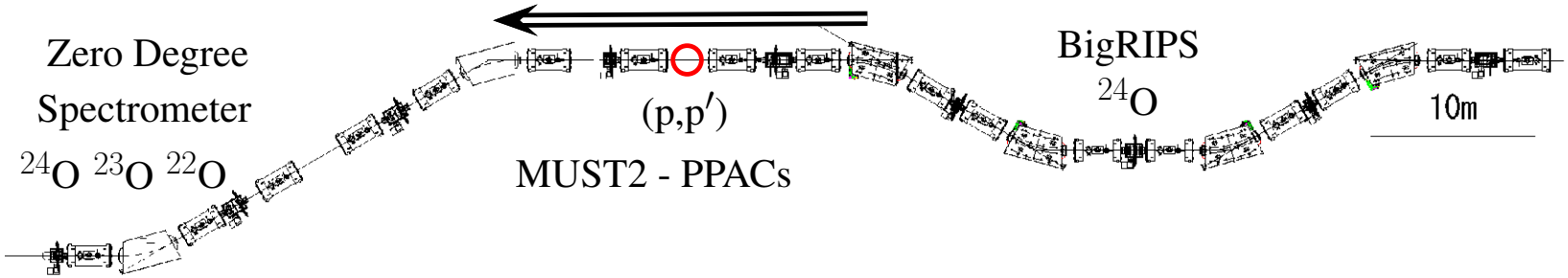
$$



Target CH_2 2.7 mg/cm^2 (30 μm)

Experimental setup and data analysis



ZDS

- Large acceptance mode $\Delta p/p = 6\%$
- **3 different Bρ settings**

(X,Y,T) PPAC F9

(E,T) plastics F9 - F11

F8 area

- MUST2 scattered proton (E_p, θ_p)
- PPAC F8 Target (X,Y)

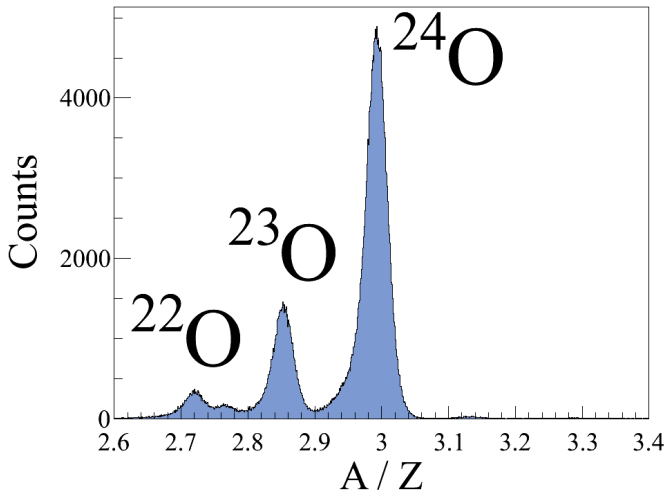
BigRIPS

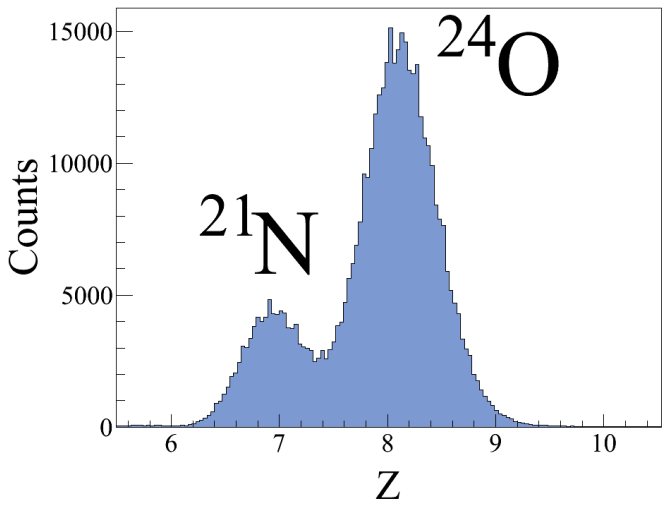
- ^{48}Ca @ 345 MeV/n
- ^{9}Be (15 mm) target
- ^{24}O @ 263 MeV/n 1000/s on average

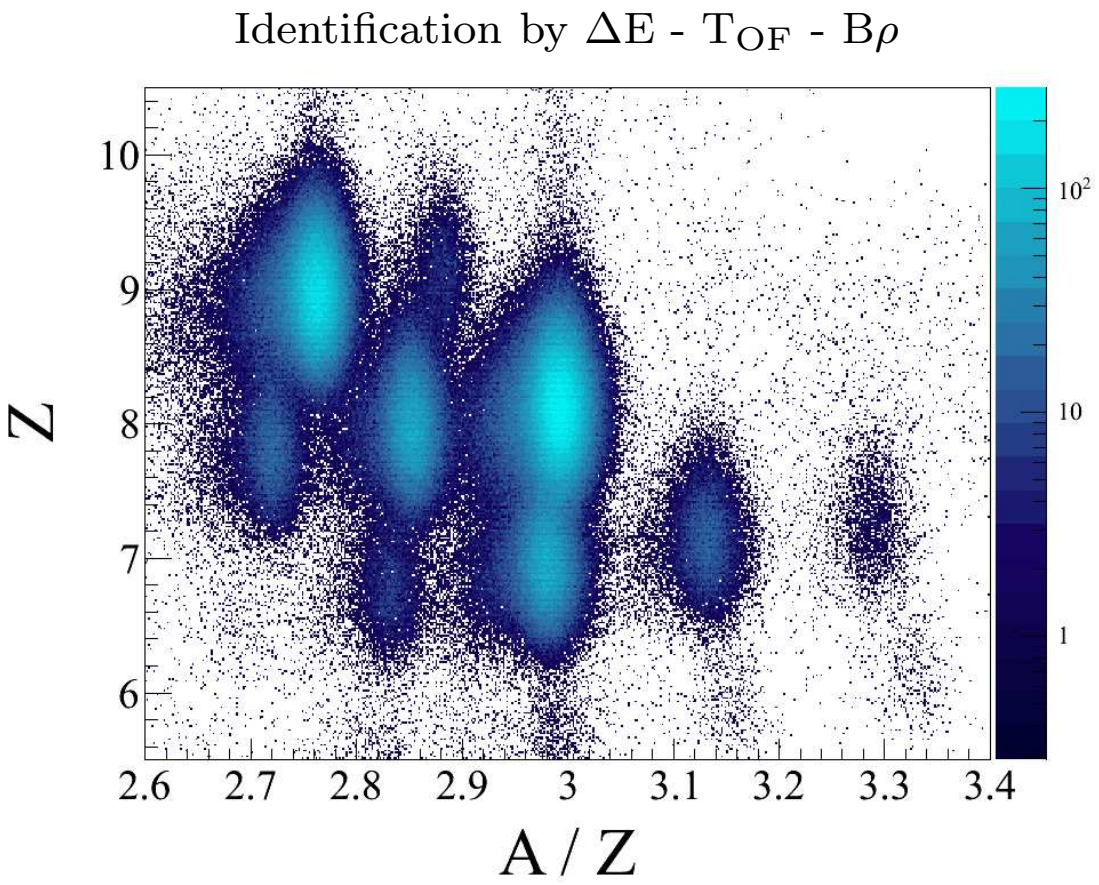
(X,Y,T) PPAC F5

(E,T) plastics F3 - F7

BigRIPS


^{24}O
^{23}O
^{22}O
Counts
A / Z

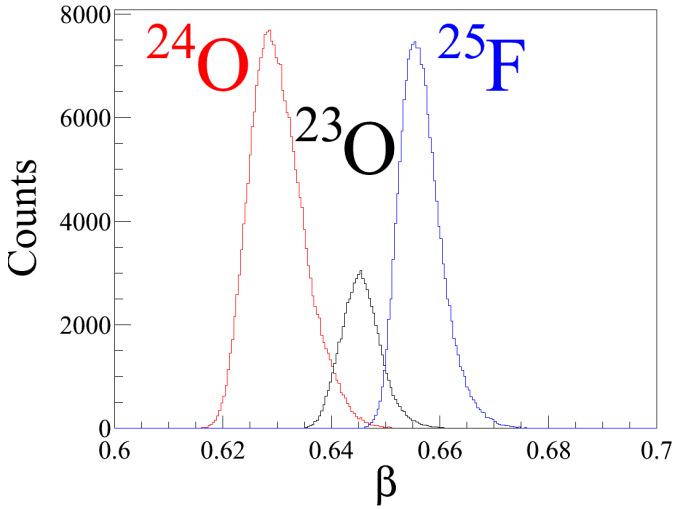

^{24}O
^{21}N
Counts
Z


Identification by ΔE - T_{OF} - Bρ
Z
A / Z

BigRIPS

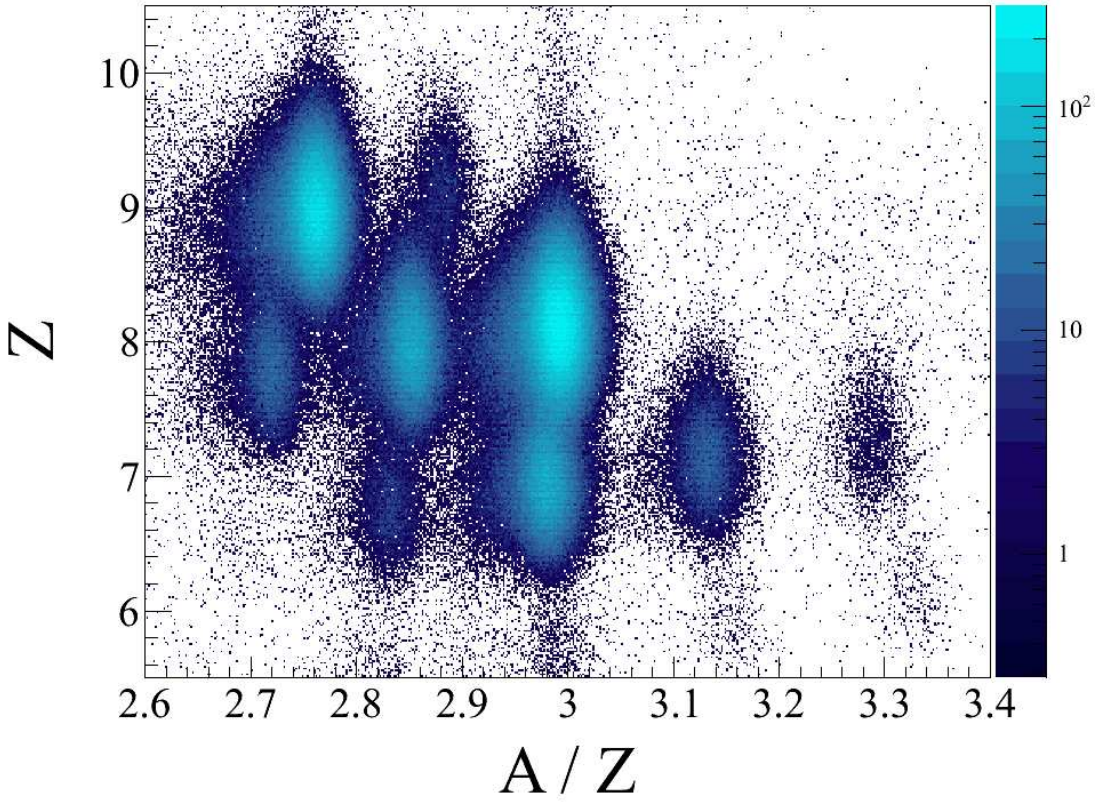
Nuclei	Rate (%)
^{24}O	35
^{23}O	9.7
^{25}F	23
^{21}N	9.6

PPACs normalization



Incident energy resolution ≈ 9%

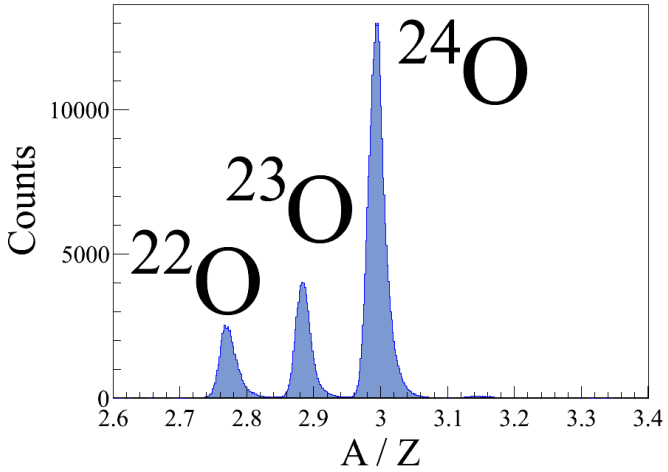
Identification by ΔE - T_{OF} - Bρ

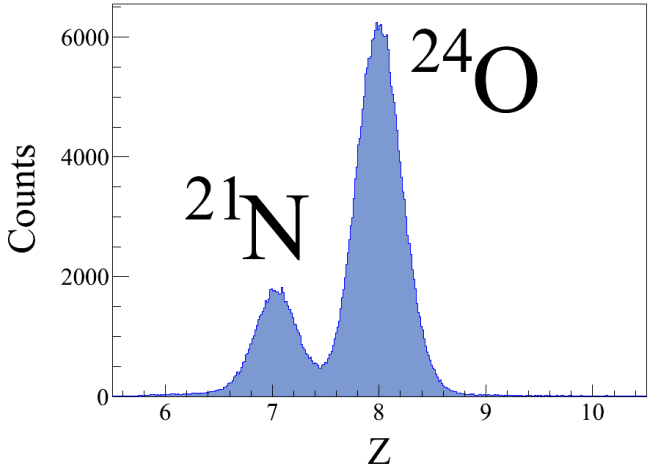


^{24}O ≈ 4% of total beam (triton)

1.14 10^9 ^{24}O on CH_2 (30μm) target

Zero Degree Spectrometer





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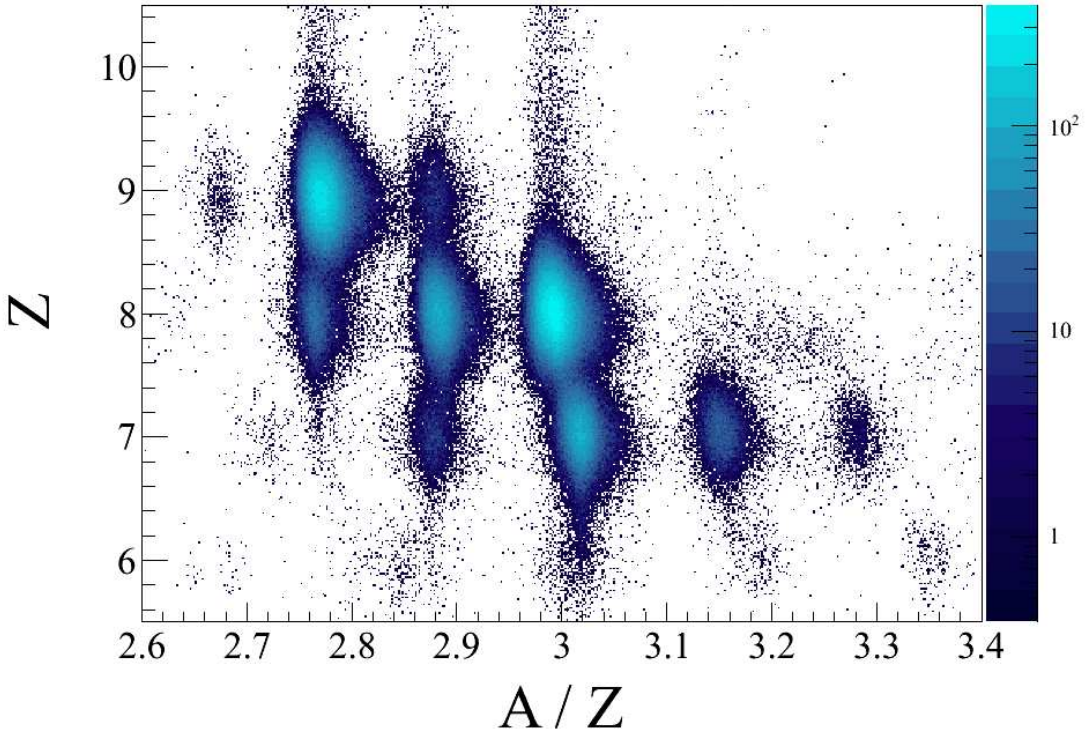
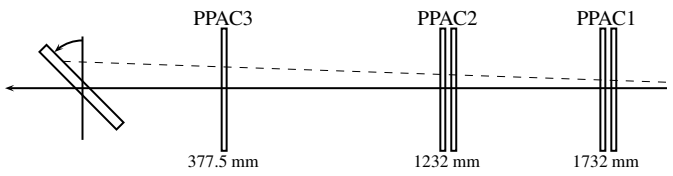
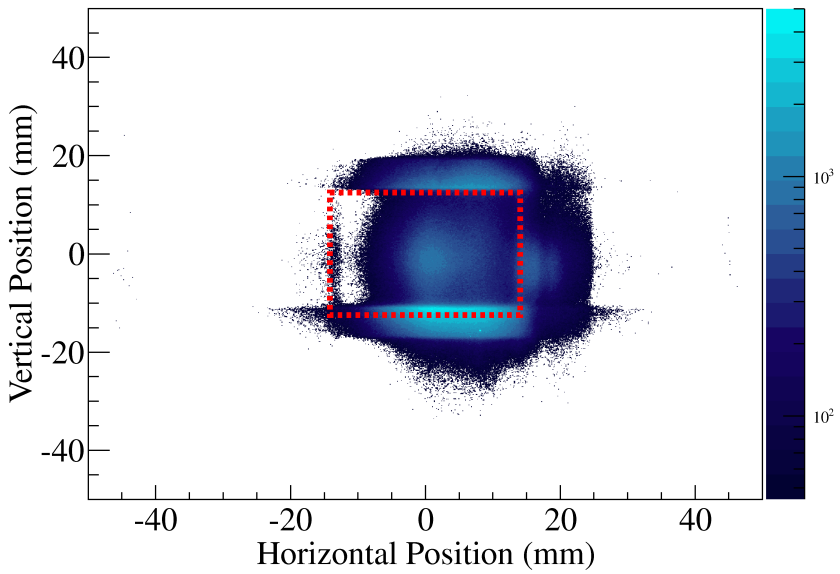
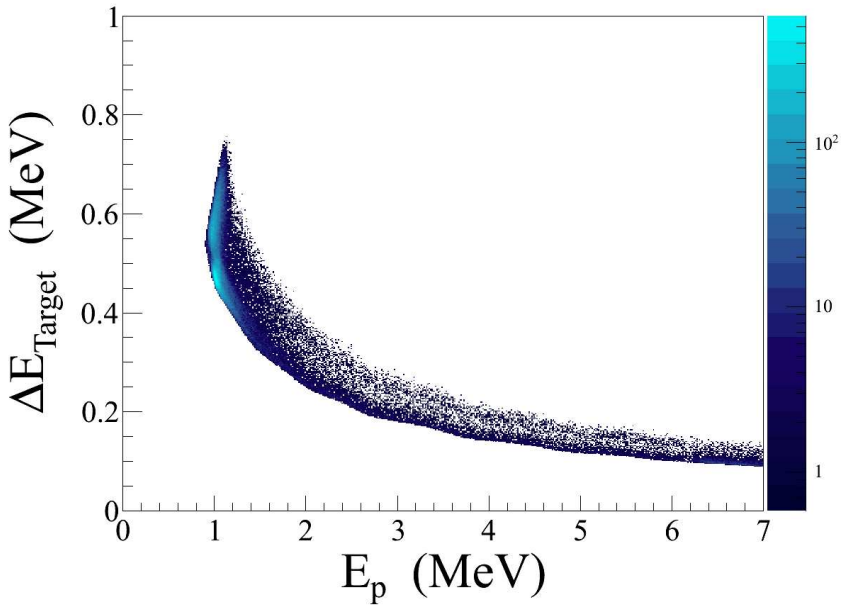


PPAC F8 : reconstruction of incident trajectory

- (X,Y) $\delta \approx 1$ mm
- Position on target rotated @ 45°, vertex taken at mid-target



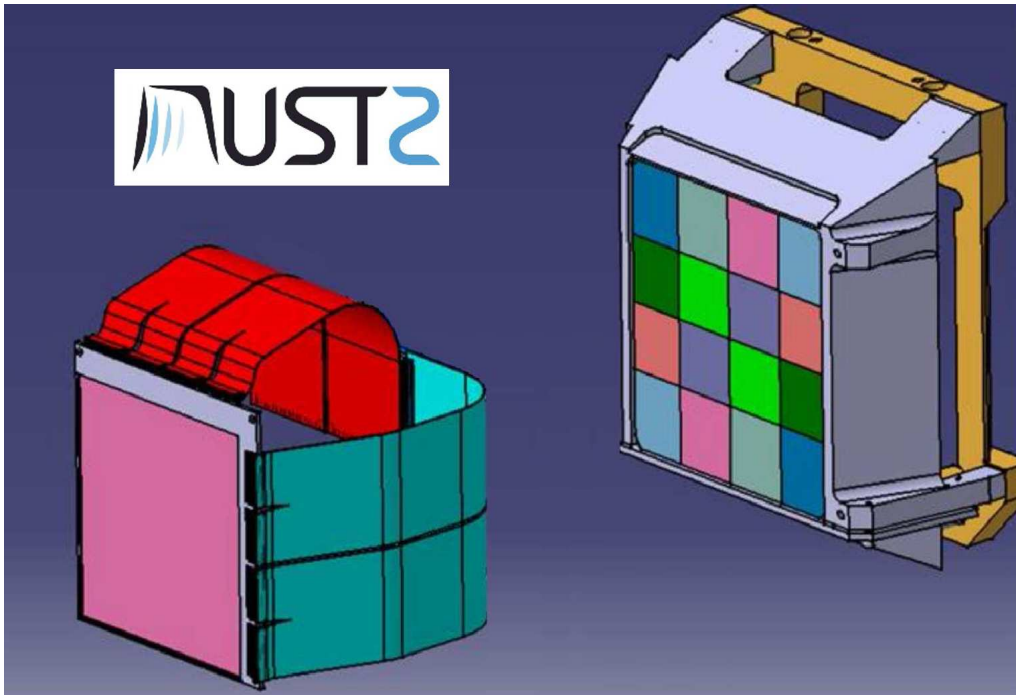




5% of total energy for 4 MeV proton

MUST2 : light charged particle detection

- Identification of p, d, t, ^{3,4}He
- Energy and angle of the scattered particle



1st stage : DSSD

- 300 μm silicium
  128 *strips* in X and Y
  100×100 mm

  δE ≈ 40 keV
  $\delta\theta \approx 0.2°$
  $\delta T \approx$1.5 ns

  400 keV < E_p < 6.2 MeV

2nd stage : CsI

- 40 mm scintillators
  16 *pads*
  3×3 cm

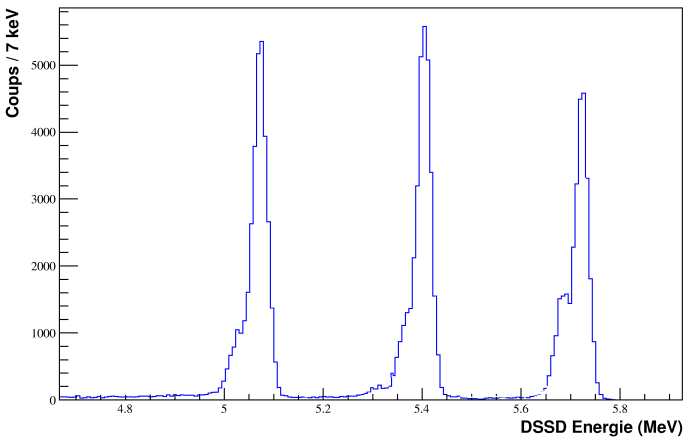
  ΔE/E ≈ 8% @ 5 MeV

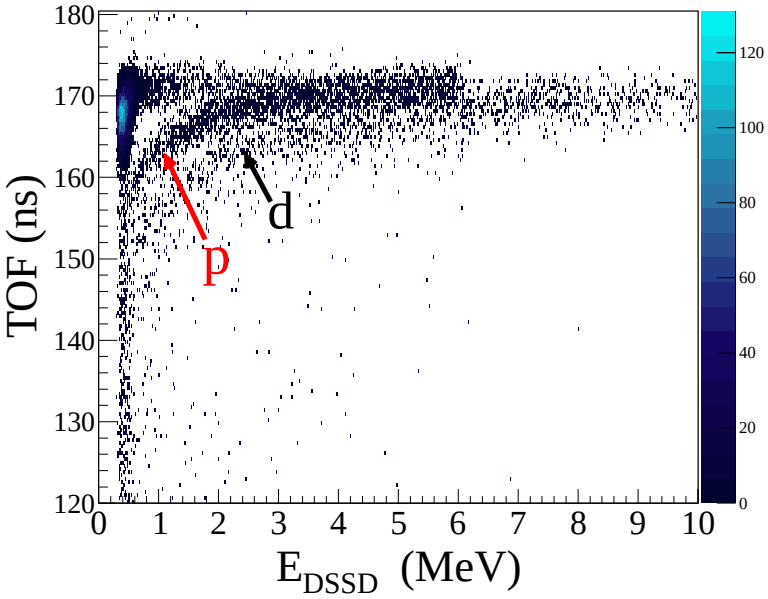
  1 MeV < E_{CsI} < 90 MeV

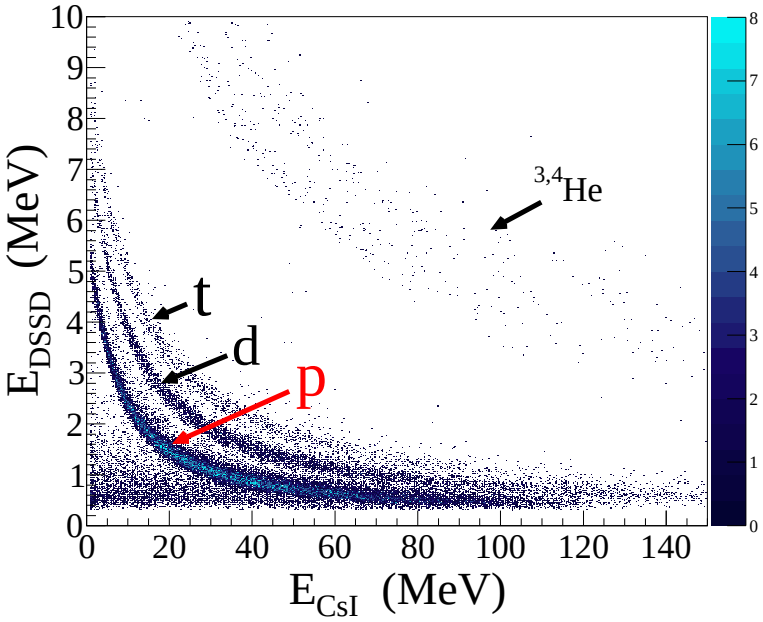
Calibration of MUST2 telescopes

- DSSD source 3-α
  (5.15, 5.48, 5.80 MeV)
- CsI via ΔE_{DSSD}

Resolution ≈ 38 keV on average



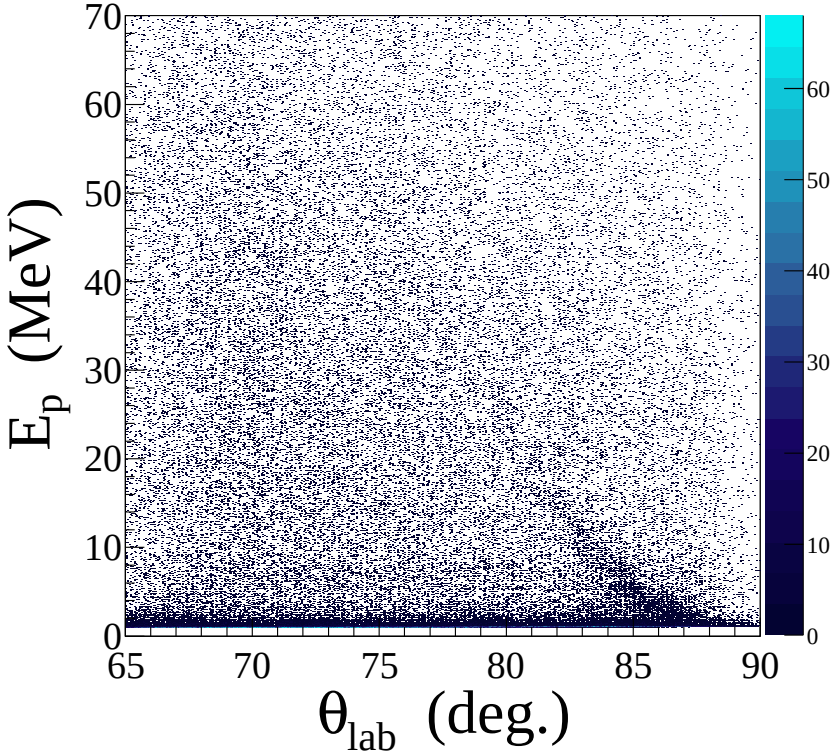


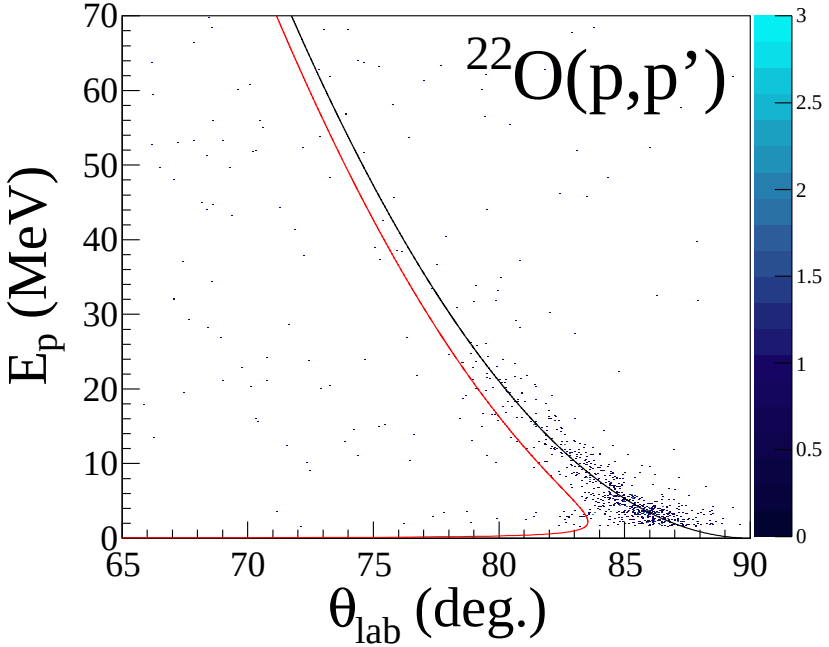


Reconstructed kinematics with MUST2 - T1 & T4

Conditions : Multiplicity 1, proton, $E_p > 1.6$ MeV

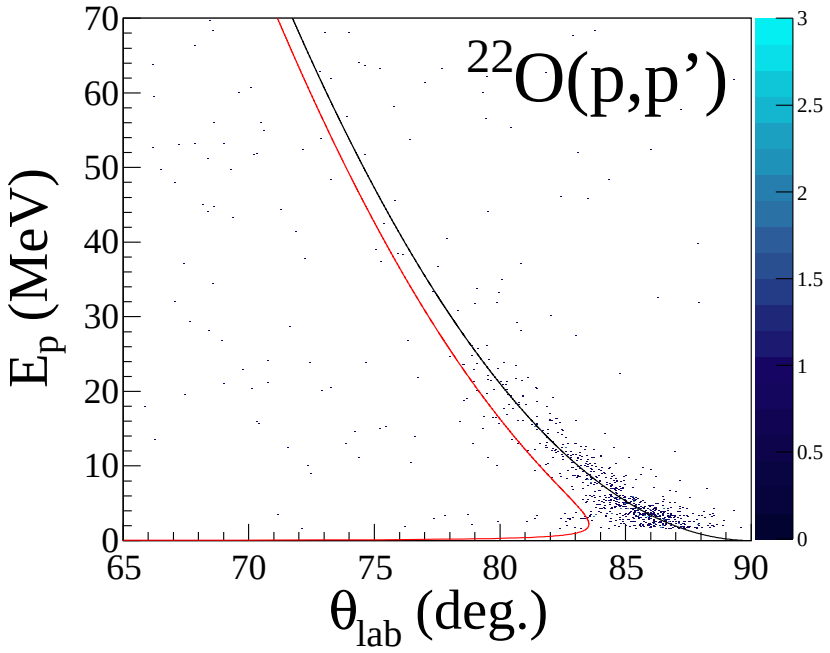
Coverage : **(67, 90) $^{\circ}_{\mathbf{lab}}$ - (1.6, 90) MeV**





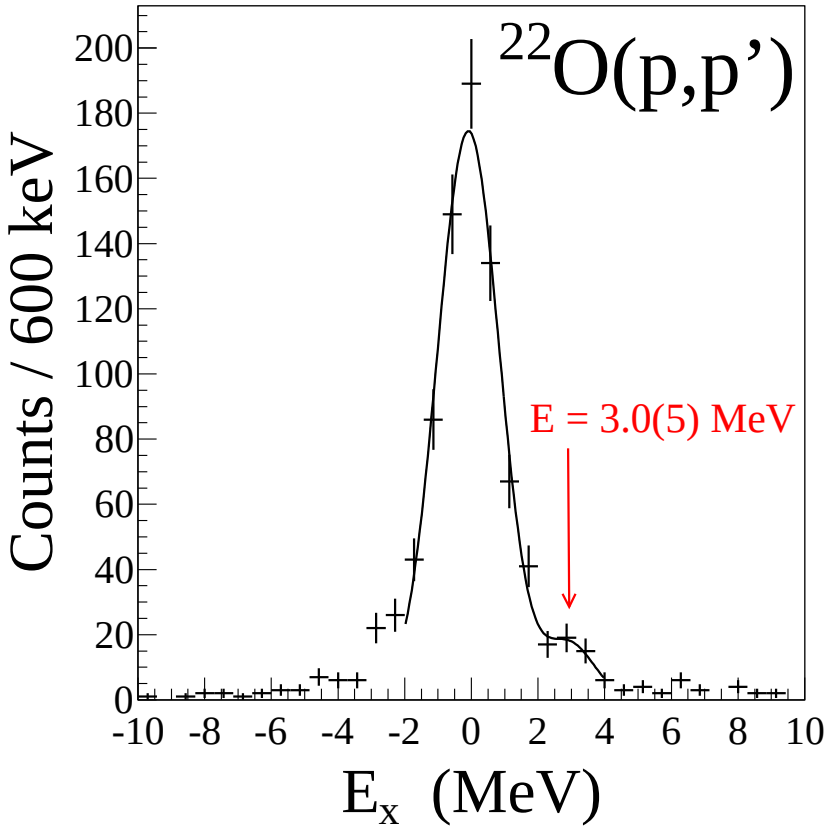
Reference measurement ^{22}O

Exclusive kinematics



3.2 MeV Belleguic *et al.*, NPA **682** 136 (2001)
3.199(8) MeV Stanoiu *et al.*, PRC **69** 034312 (2004)

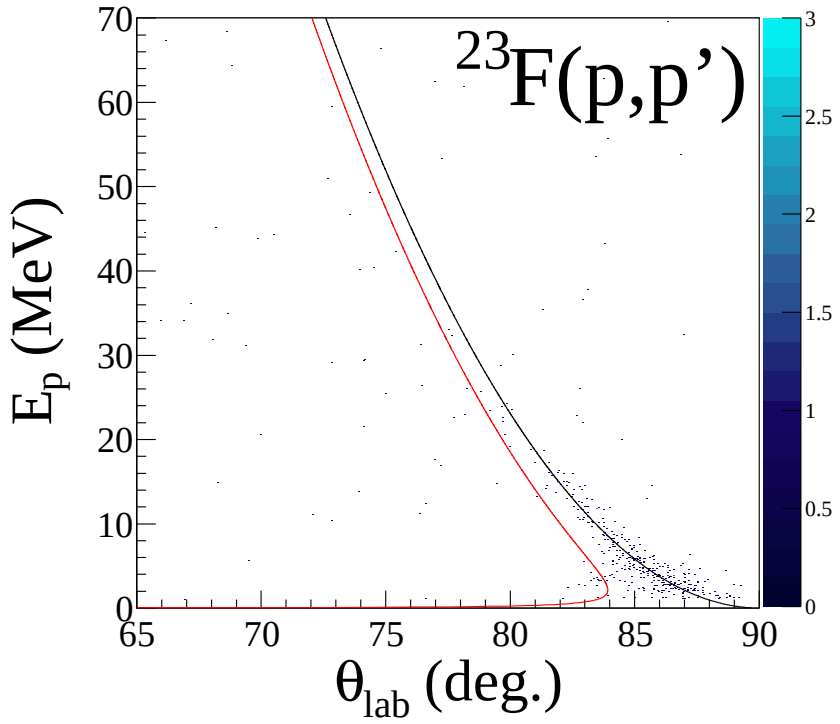
Exclusive spectrum



E_x resolution $\approx$ 1.2 MeV

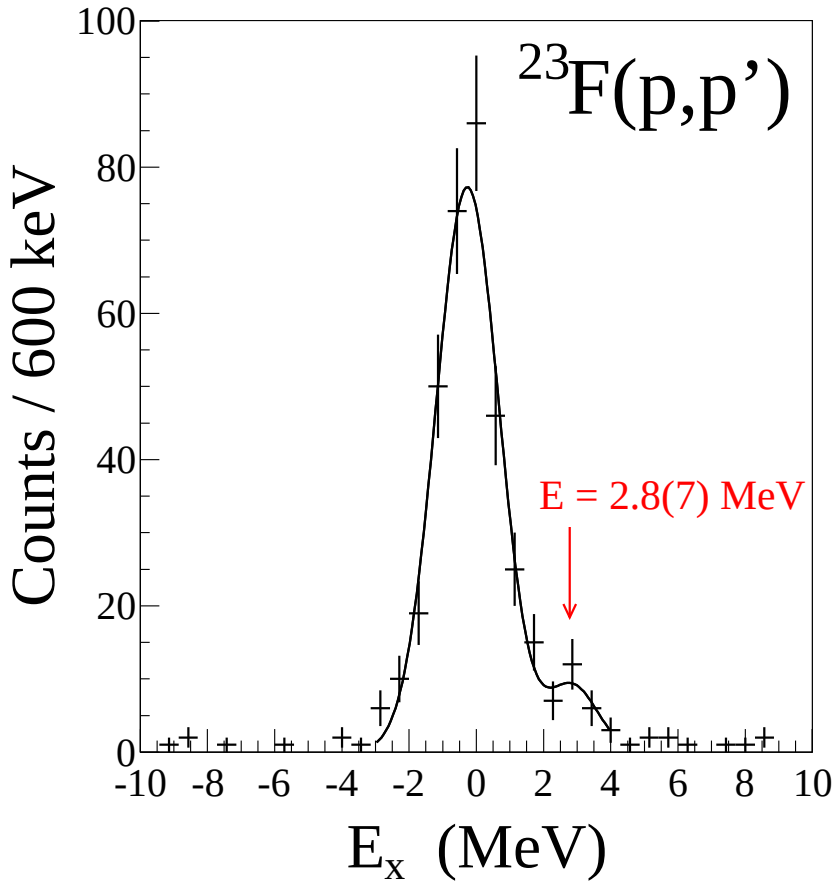
Contaminant ^{23}F

Exclusive kinematics

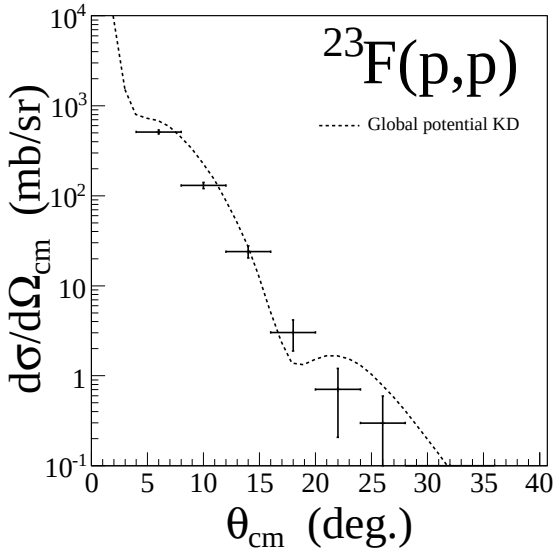


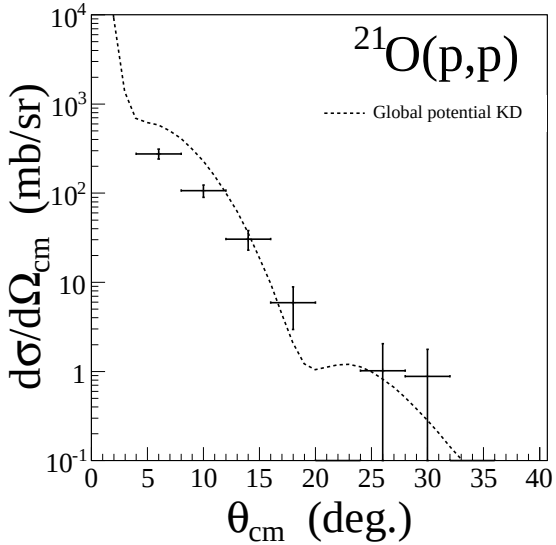
E_x = 2.383(17), 2.920(1), 3.385(10) MeV

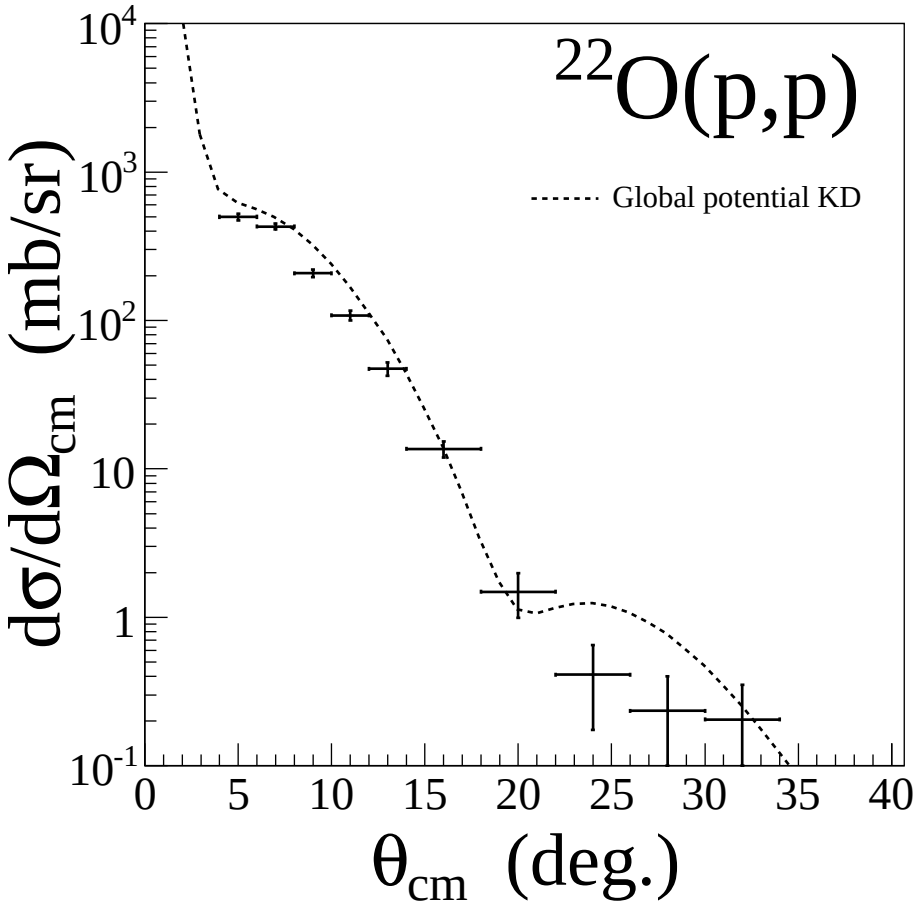
Exclusive spectrum



Exclusive cross sections ^{22}O, ^{23}F and ^{21}O

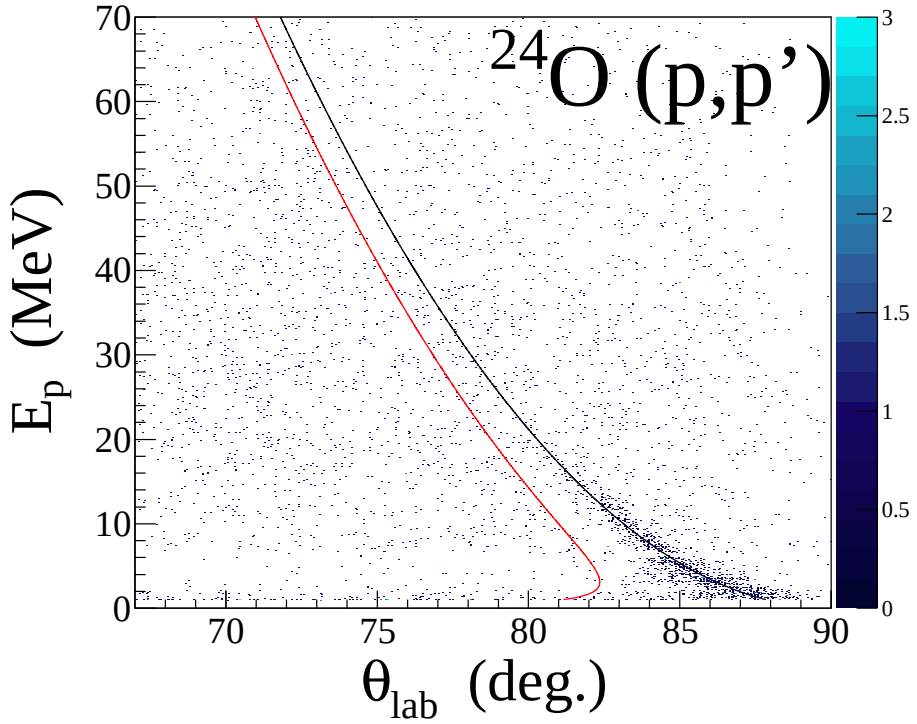




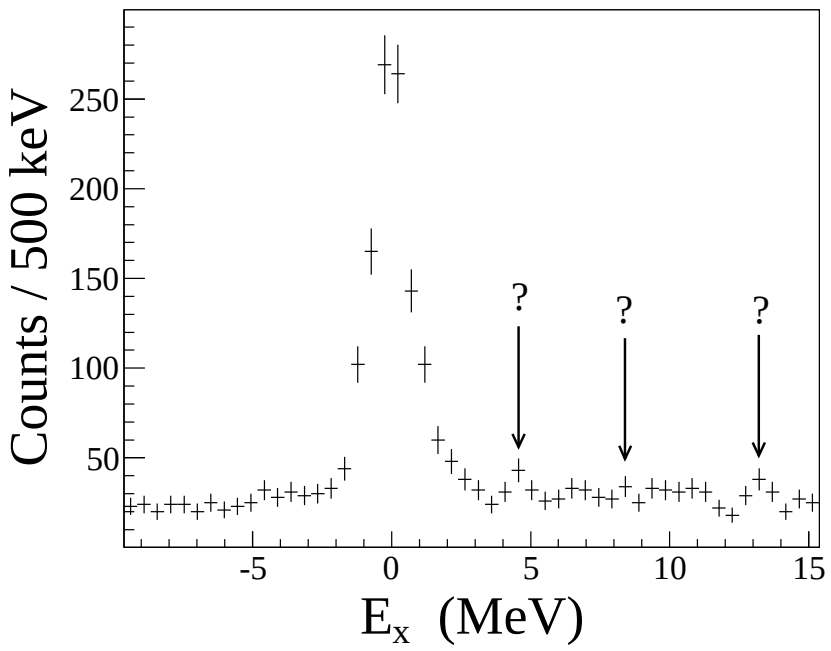


Exclusive kinematics and spectra ^{24}O

Elastic and inelastic ZDS ^{24}O and ^{23,22}O



Elastic and inelastic ZDS ^{24}O and ^{23,22}O

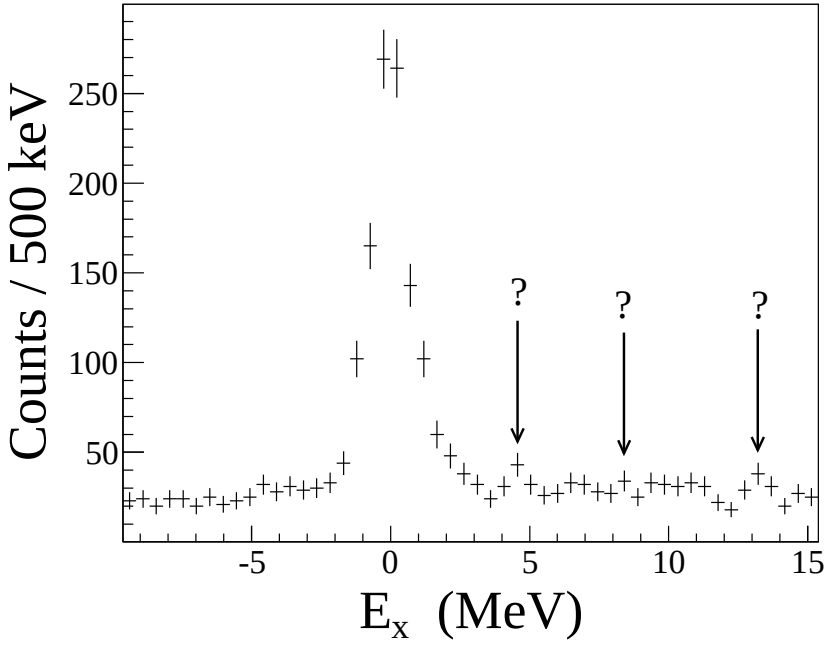


S_n = 4.19(14) MeV (AME2011)

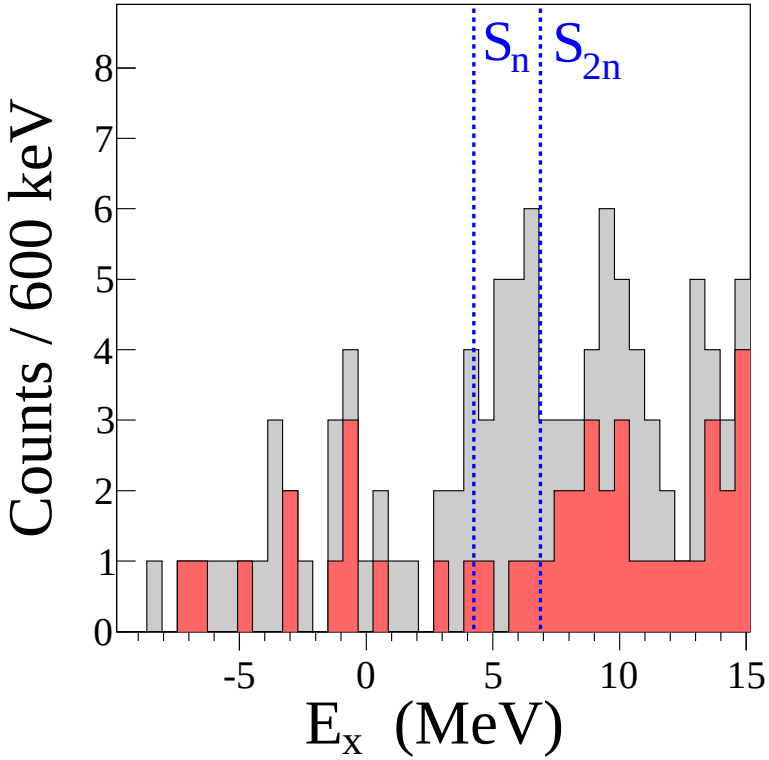
S_{2n} = 6.92(12) MeV

Exclusive kinematics and spectra ^{24}O

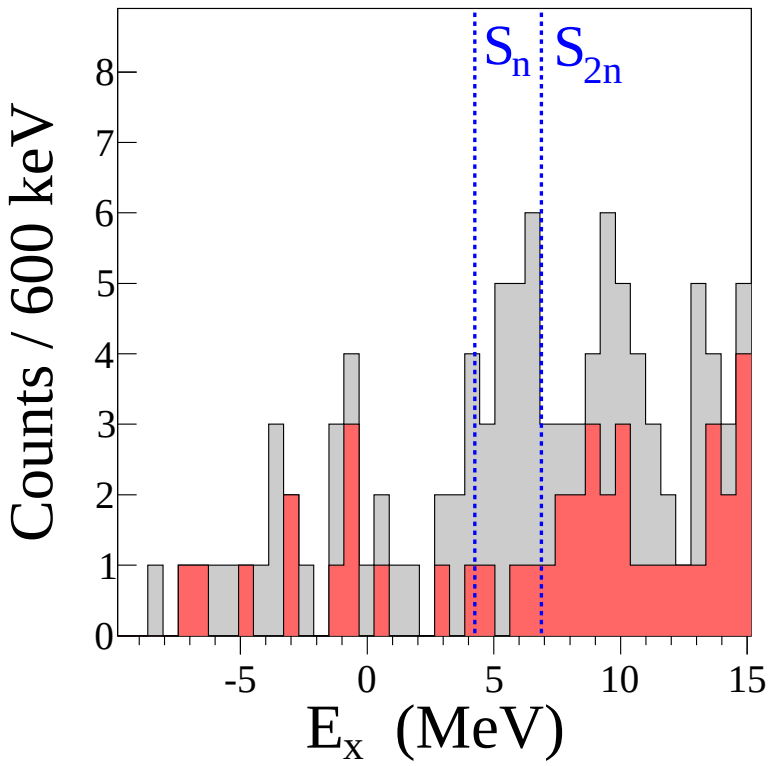
Elastic and inelastic ZDS ^{24}O and ^{23,22}O

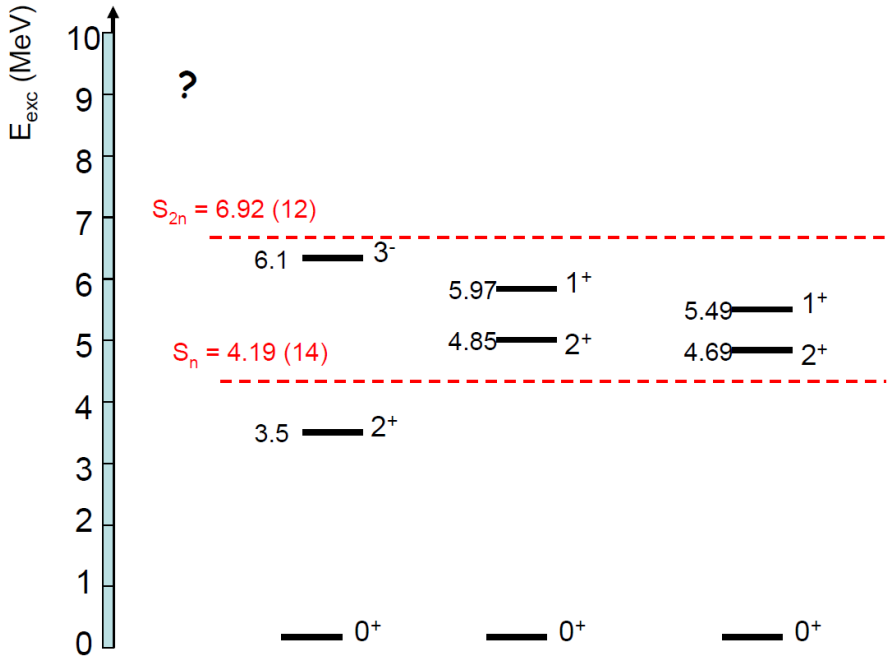


Inelastic ZDS ^{23}O and ^{22}O



Theoretical calculation ^{24}O





PVC, Colo and Sagawa, NPA **A695** 167(2001)

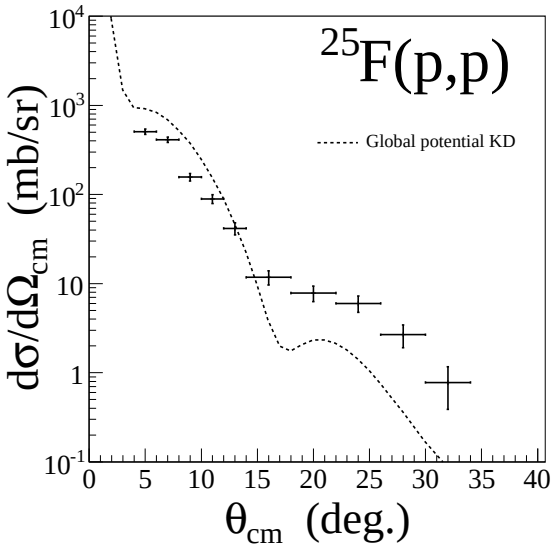
CSM, Volya and Zelevinsky, PRL **94** 052501(2005)

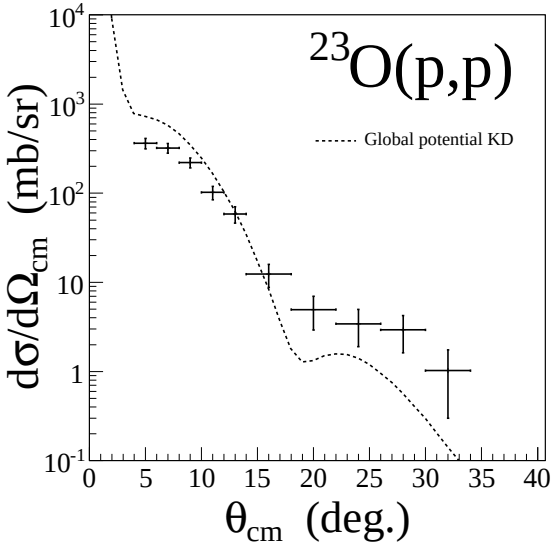
CCSM, Tsukiyama, Otsuka and Fujimoto, arXiv :1001.0729 (2010)

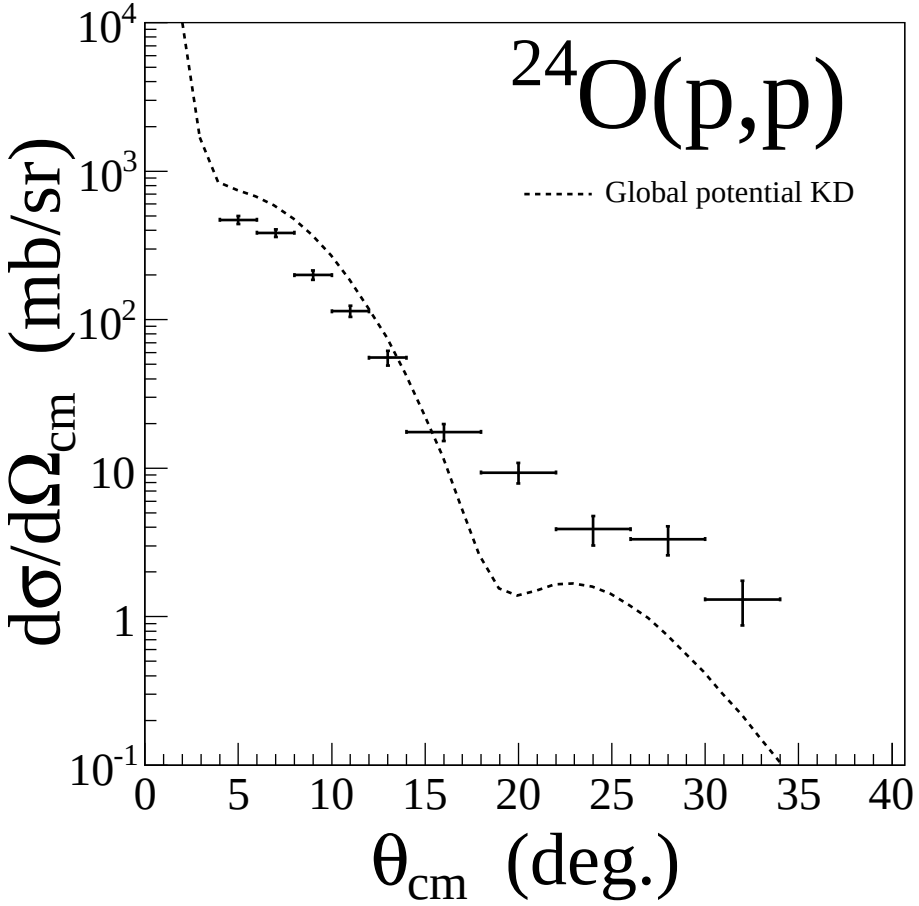
→ Importance of configuration space

Holt *et al.*, ArXiv :1108.2680 (2011)

Exclusive cross sections ^{24}O, ^{23}O and ^{25}F







Conclusions

- Intensity 1000 ^{24}O/s on target at RIKEN
  1 day $N_{inc}^{22O} = 5.13 \cdot 10^8$ - 9 days $N_{inc}^{24O} = 1.14 \cdot 10^9$
- Low statistics but high exclusivity
- First angular distribution @ 263 MeV/n

Perspectives

- Fitting of excited states positions of $^{24}O^*$ (low statistics analysis)
- Study of $E_{exc} > 9$ MeV states
- Analysis of contaminants ^{23}O and ^{25}F
- Extraction of the exclusive cross sections ^{24,23,22,21}O(p,p)

Collaboration

Spokespersons : V. Lapoux (CEA Saclay) and H. Otsu (RIBF)

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