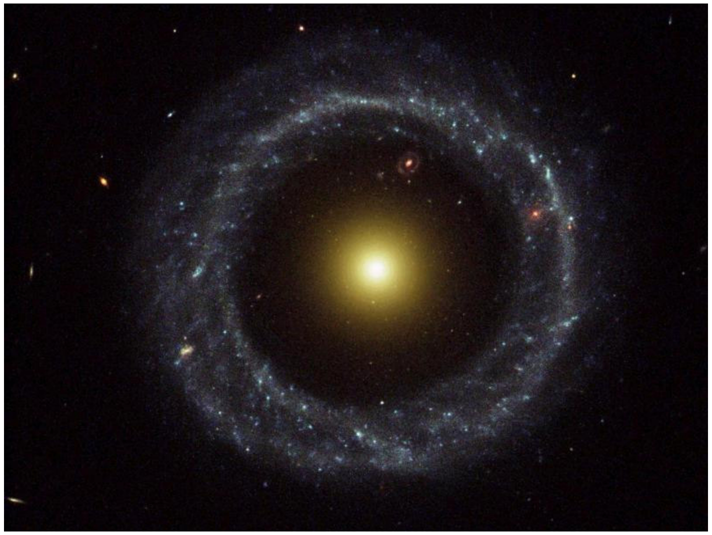
Indirect Technique in Nuclear Astrophysics: ANC



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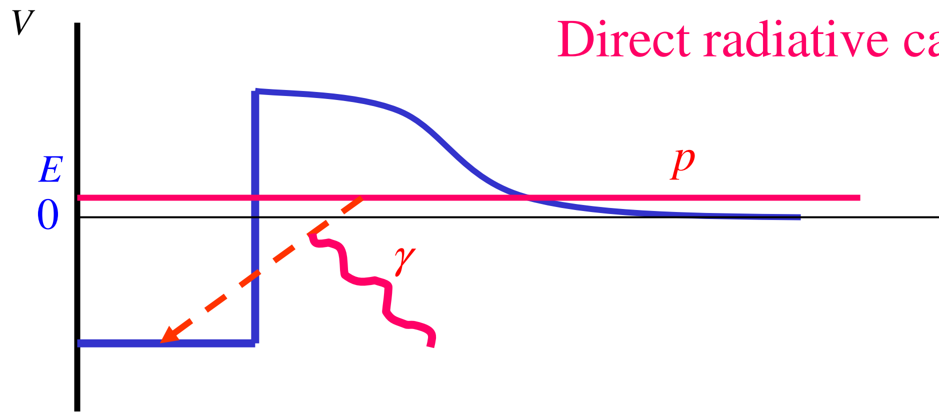
JINA-ANL 2007

Techniques to obtain reaction rates in Nuclear Astrophysics

- **Direct Measurements** (LUNA, LENA, DRAGON, . . .)
- **Radiative widths** for resonance rates
  - populate resonance state and measure decay
- **Coulomb dissociation**
  - applications with radioactive beams
- **Trojan Horse**
  - unique way to understand screening
- **A**symptotic **N**ormalization **C**oefficients
  - stable and radioactive beams

Direct radiative capture



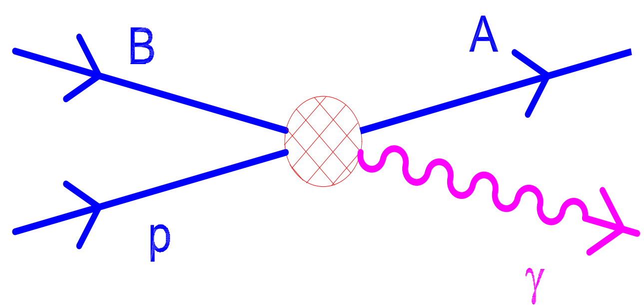
Transition Amplitude: $M = \left\langle I_{Bp}^{A}(r_{Bp}) \middle| \hat{O}(r_{Bp}) \middle| \psi_i^{(+)}(r_{Bp}) \right\rangle$

Direct Radiative proton capture $\quad \sigma \propto \left| M \right|^2$

Low B.E.: $I_{Bp}^{A}(r_{Bp}) \overset{r_B > R_N}{\approx} C_{Bp}^{A} \dfrac{W_{-\eta_A, l+\frac{1}{2}}(2\kappa_{Bp} r_{Bp})}{r_{Bp}}$

ANC ⇒ amplitude for tail of overlap function

Find: $\sigma_{\text{capture}} \propto (C_{Bp}^{A})^2$

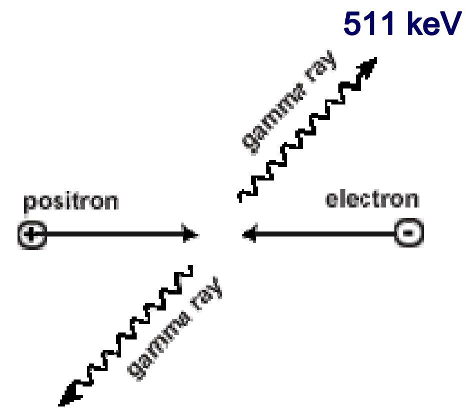


For Example !

* Major sources of γ-ray lines:

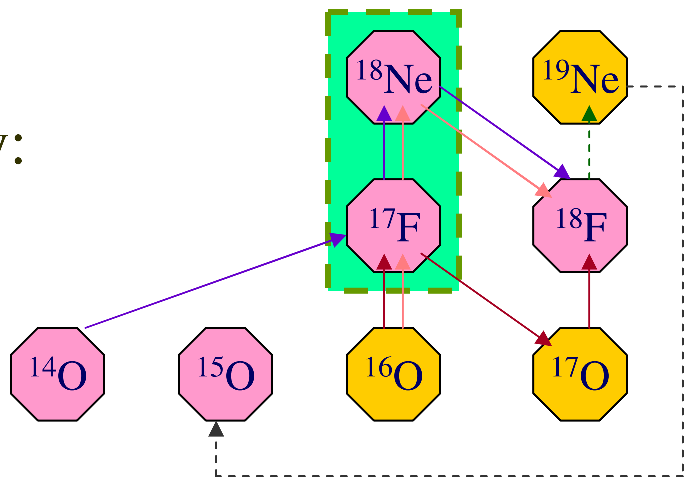
  1- Following β-decays
  2- electron-positron annihilation.

* ^{18}F emits positron ($T_{1/2}$ = 158 min).

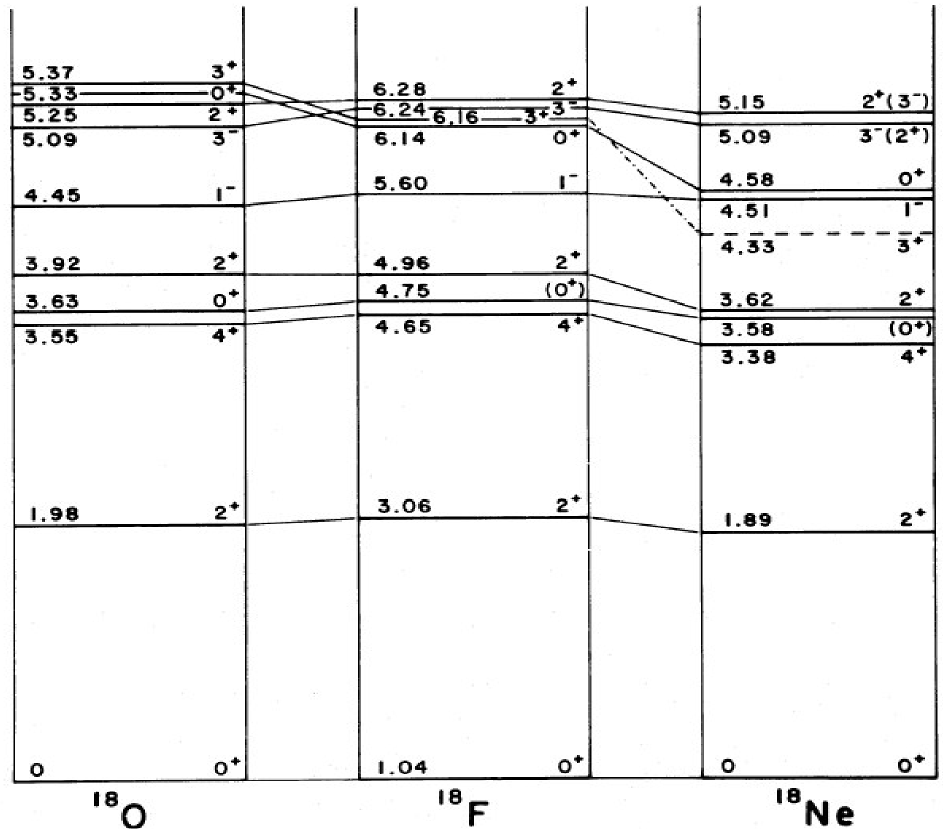


* ^{18}F production may be influenced by:

$^{17}F(p,\gamma)^{18}Ne$?

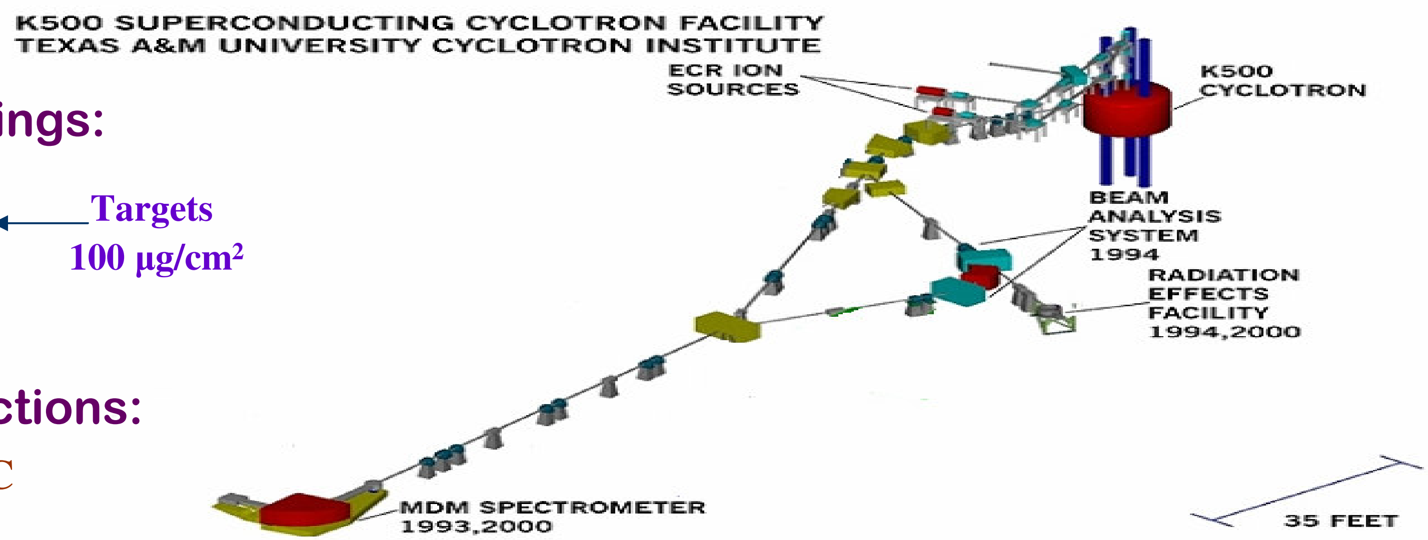


Mirror Nuclei
^{18}Ne & ^{18}O



- The nuclear structure for ^{18}O & ^{18}Ne are similar.
- The ANCs for ^{18}O will be obtained from $^{13}C(^{17}O,^{18}O)^{12}C$ reaction.
- Stable beam (^{17}O) enables the ability to separate between interesting levels in ^{18}O.

Experimental Setup



Elastic Scatterings:

Beams 12 MeV/u

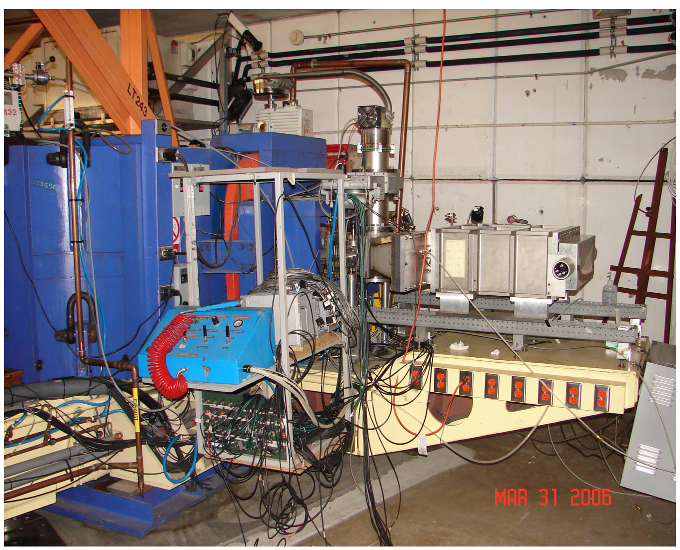
$^{17}O + ^{13}C$

$^{18}O + ^{12}C$

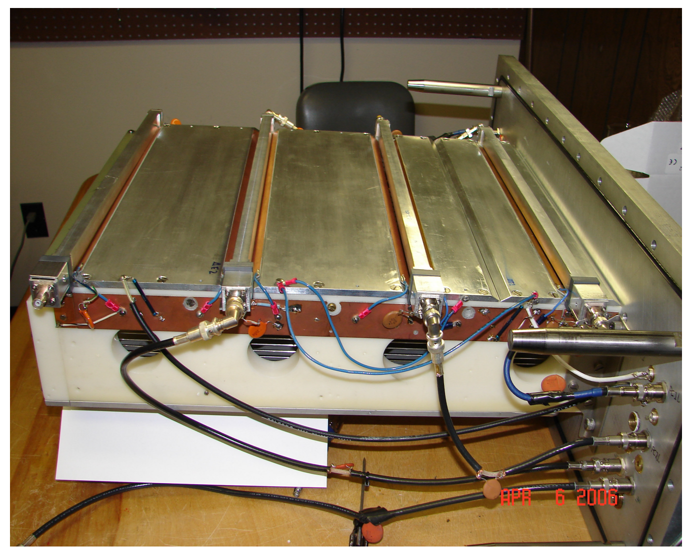
Targets 100 µg/cm²

Transfer Reactions:

$^{13}C(^{17}O,^{18}O)^{12}C$



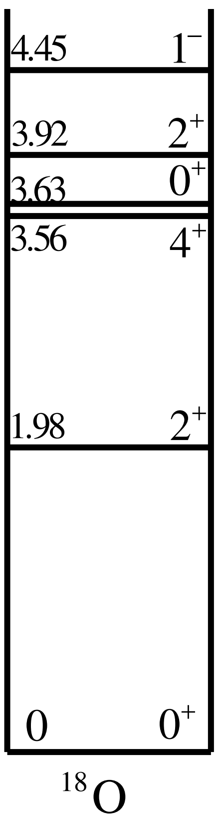
MDM Spectrometer

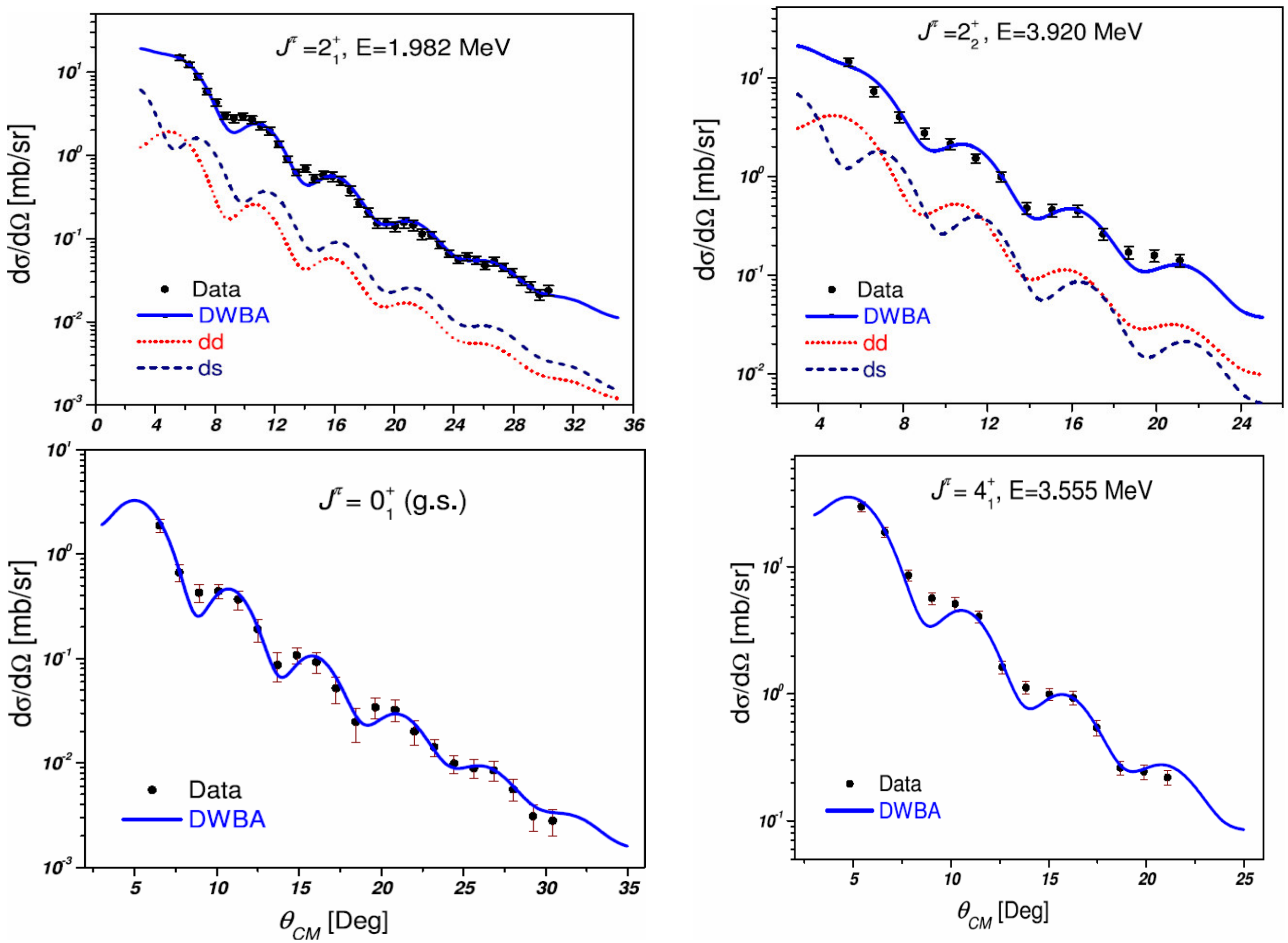


Oxford Detector

$^{13}C(^{17}O,^{18}O)^{12}C$

- $J^{\pi} = \left(0_1^+, 2_1^+, 4_1^+, 2_2^+\right)$
- 2^+ states are combinations of $(d_{5/2})^2$ & $(d_{5/2}s_{1/2})$, T. Dehnhard, *et al*, PRC **13** (1976) 55.
- 4^+ & 0^+ have pure $(d_{5/2})^2$ configuration.



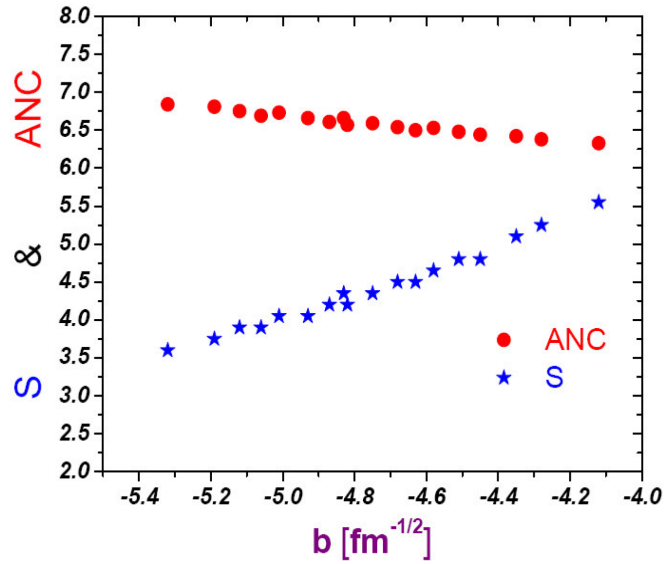


$^{13}C(^{17}O,^{18}O)^{12}C$

* Comparison ANC vs S: The reaction is *peripheral*

* The ANCs are obtained using:

* Charge Symmetry implies: $\frac{C_{\ell j}^2}{b_{\ell j}^2}\left(^{18}\mathrm{O}\right) = \frac{C_{\ell j}^2}{b_{\ell j}^2}\left(^{18}\mathrm{Ne}\right)$



J^π	Proton Orbital	^{18}O B.E. [MeV]	^{18}O $C_{\ell j}^2$ [fm^{-1}]	^{18}Ne B.E. [MeV]	^{18}Ne $C_{\ell j}^2$ [fm^{-1}]
0_1^+	$d_{5/2}$	8.04	7.33 ± 0.73	3.92	10.76 ± 0.97
2_1^+	$d_{5/2}$	6.06	2.06 ± 0.21	2.04	2.17 ± 0.24
	$s_{1/2}$		6.55 ± 0.69		14.29 ± 1.71
4_1^+	$d_{5/2}$	4.48	1.05 ± 0.11	0.54	2.17 ± 0.22
2_2^+	$d_{5/2}$	4.12	0.49 ± 0.06	0.31	2.69 ± 0.32
	$s_{1/2}$		4.47 ± 0.54		127 ± 17

$^{17}F(p,\gamma)^{18}Ne$

*** Direct Capture Reaction Rate (RADCAP) :**

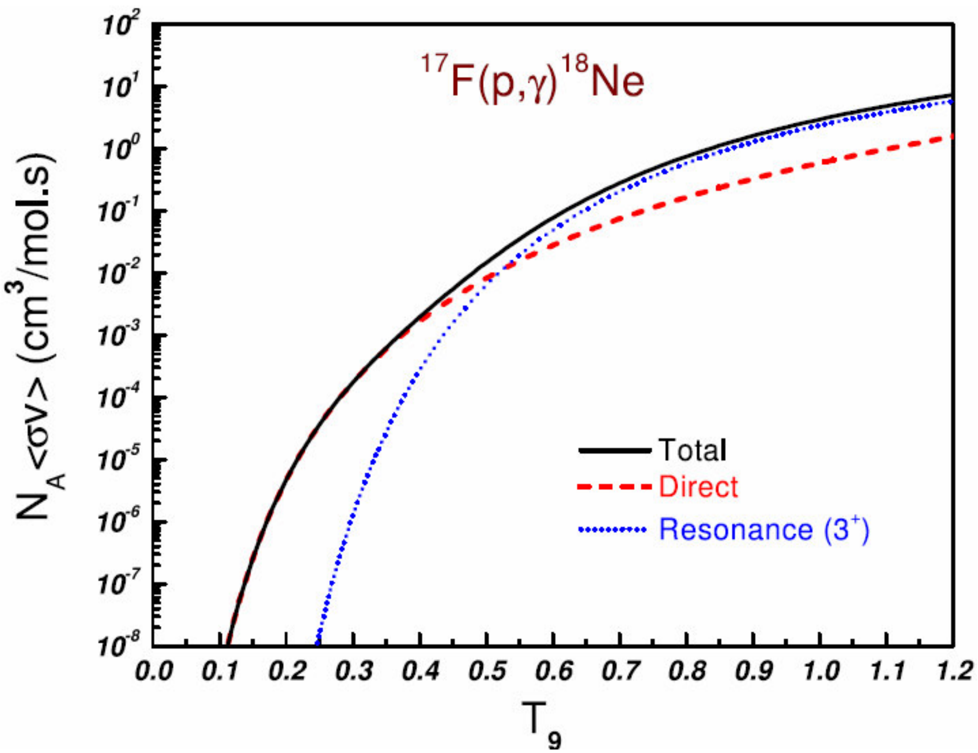
$$N_A\langle\sigma v\rangle = 51\tau^2 S_{eff}(T_9)e^{-\tau}\left[\frac{\mathrm{cm}^3}{\mathrm{mole.s}}\right]$$

*** Resonant Capture reaction rate:**

D. W. Bardayan, PRC 62, 055804(2000)

*** DC >> RS for $T_9 \leq 0.4$**
➔ DC dominates in ONe novae

*** The uncertainty of DC rate is <u>±20%</u>**



S. Parete-Koon AJ 598, 1239 (2003)

* Astrophysical Implications:

- Our rate is comparable with Bardayan & Garcia. *(Considered SLOW)*
- If nova M = 1.25 $M_\odot$, more ^{18}F & ^{18}O.
- If M ≥ 1.35 $M_\odot$, less ^{18}F.

"Thank You"

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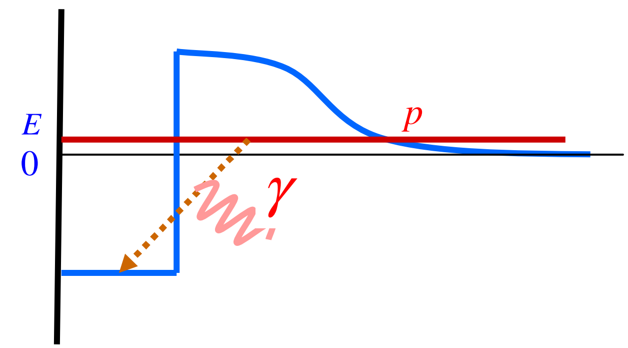
Asymptotic Normalization Coefficients (ANC)

**A.Mukhamedzhanov et al., PRC 56,1302(1997)

Direct Capture Reactions for charged particles:

- The binding energy of the captured particle is low.
- The capture occurs through the tail of the overlap function.
- The Amplitude of the tail is given by the ANCs.



For a Transfer reaction (X+A→Y+B):

- The DWBA amplitude:

$$M(E) = \langle \chi_f^{(-)} I_{A,p}^{B}(r_{A,p}) \left| \Delta V \right| I_{Y,p}^{X}(r_{Y,p}) \chi_i^{(+)} \rangle$$

- The reaction cross section is related to the DWBA by:

$$\frac{d\sigma}{d\Omega} = \sum_{l_B j_B l_X j_X} S_{A a l_B j_B} S_{y a l_X j_X} \sigma_{l_B j_B l_X j_X}^{DWBA}$$

- For a peripheral reaction r > R_N,

$$I_{A,p}^{B}(r) = \sqrt{S_{A,p}}\,\varphi(r) \Longrightarrow S = \frac{C^2}{b^2}$$