

Radioactive ^{30}S Beam to Study XRBs

D. Kahl^a, A. A. Chen^a, J. Chen^a, S. Hayakawa^b, A. Kim^c, S. Kubono^b,
S. Michimasa^b, K. Setoodehnia^a, Y. Wakabayashi^b, H. Yamaguchi^b.

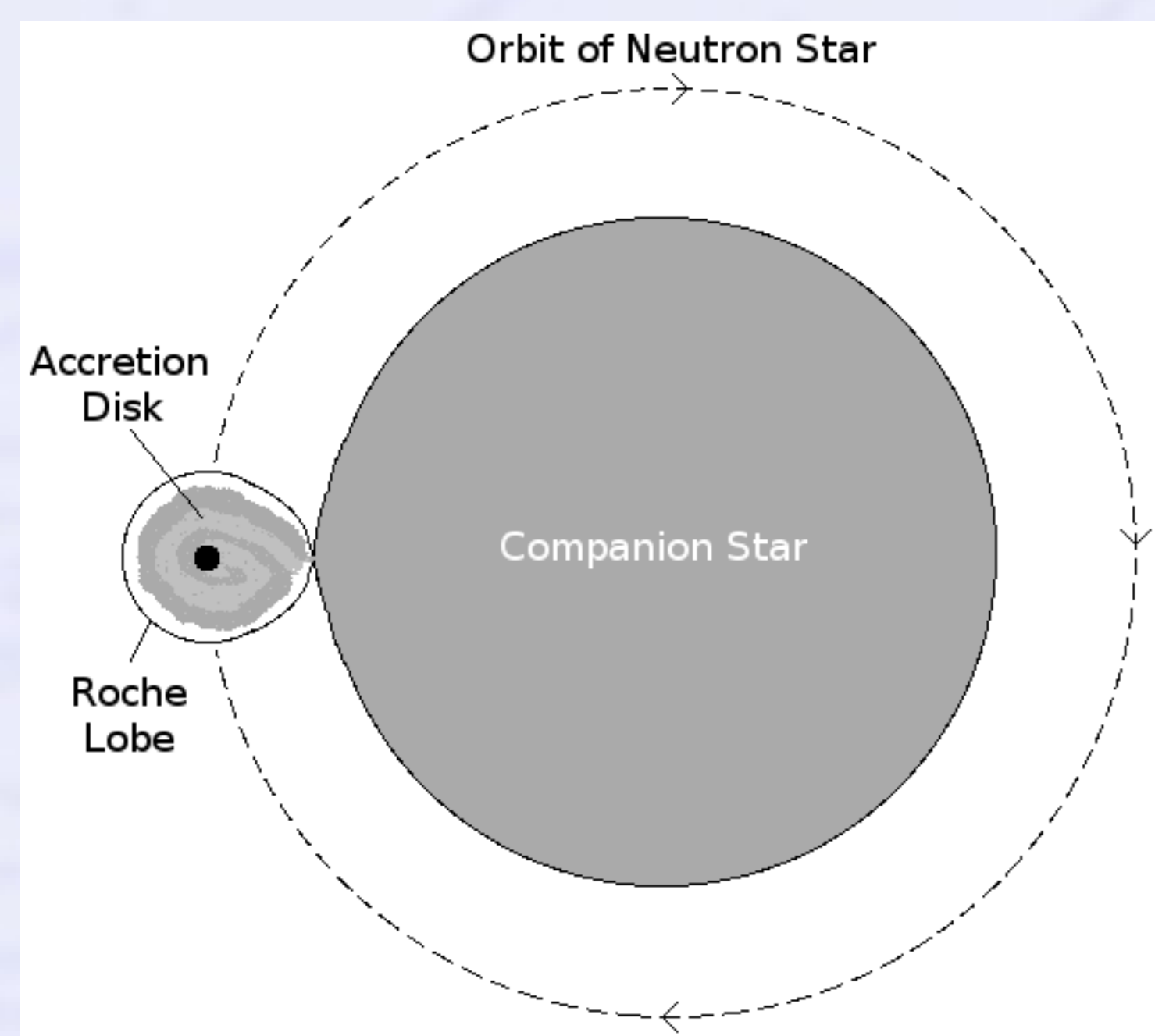
^aDepartment of Physics & Astronomy, McMaster University (Canada)

^bCenter for Nuclear Study, Graduate School of Science, University of Tokyo (Japan)

^cDepartment of Physics, Ewha Womans University (Korea)

Astrophysical Motivation

X-Ray Bursts with multiple peaks in their bolometric luminosity are explained by Fisker *et al.* as multiple releases of nuclear energy, separated by a nuclear waiting point.¹



- Low mass accreting neutron star binaries
- Accreted material assumed to be solar²
 - 90.99% H, 8.87% He
 - .03% C, .01% N, .08% O
- β -limited hot CNO pre-burst
 - ($T_9 = .1 - .2$ K)
- Thermal instabilities \rightarrow explosion
 - rp -process ($T_9 = 1 - 2$ K)
 - CNO seed nuclei
- Recurrent bursts, ~ 100 known XRBs

Figure 1: Schematic drawing of accreting neutron star binary where the companion has filled the Roche lobe.

- 4 observed multi-peaked bursts^{3,4,5,6}
 - These constrain XRB models
 - Many proposed explanations
- Fisker *et al.* propose nuclear waiting point
 - Explains peaks with only nuclear physics
 - Infer bottleneck at ^{30}S
 - β^+ -decay on order of burst rise-times
 - Burning inhibited by photodisintegration
- $^{30}\text{S}(\alpha,p)^{33}\text{Cl}$ cross section affects light curve
 - By changing *theoretical reaction rate* by factor of 100, the model by Fisker *et al.* shows a different profile shape.
- We will experimentally measure $^{30}\text{S}(\alpha,p)^{33}\text{Cl}$
 - To do this, we need a radioactive ^{30}S beam

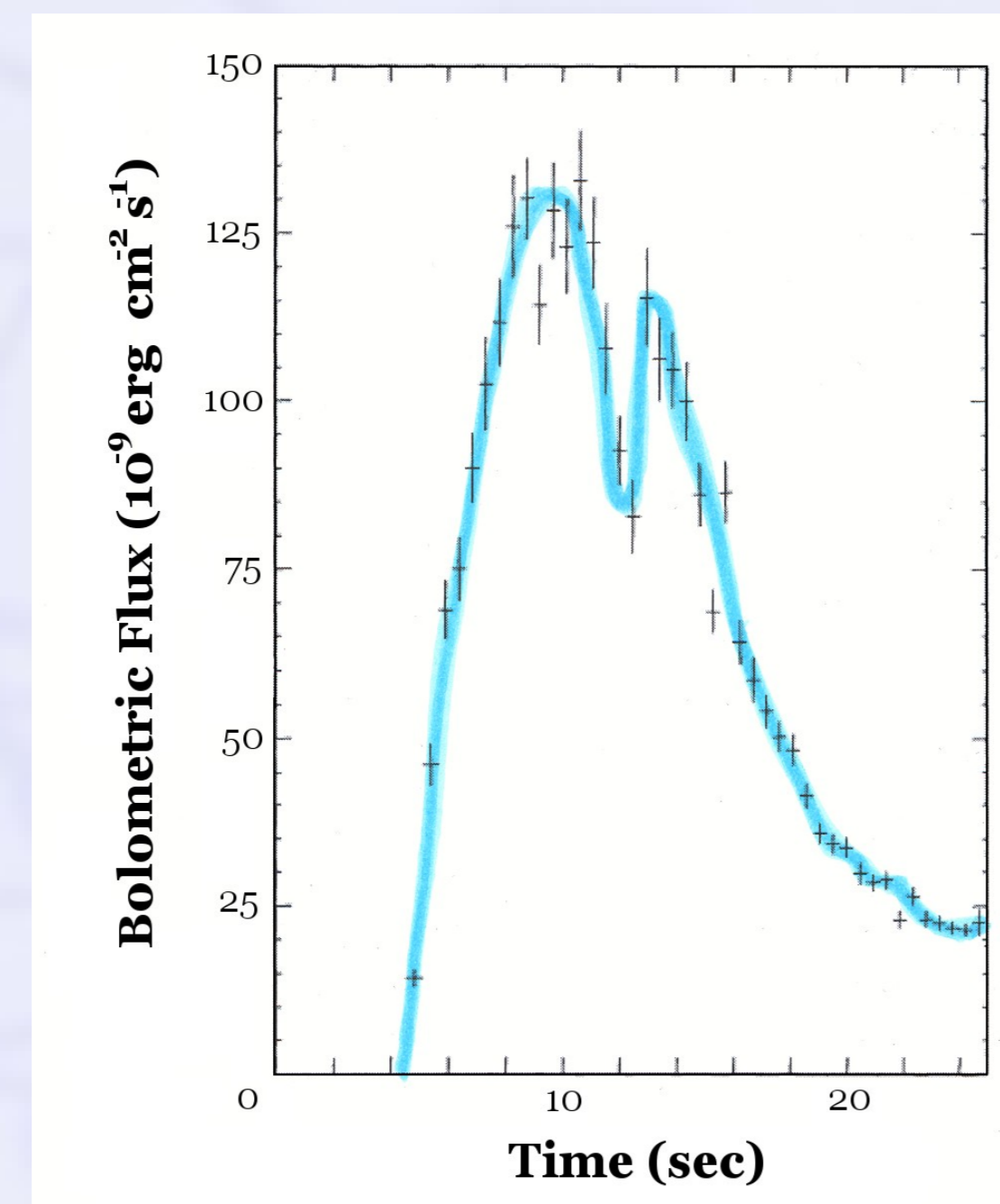


Figure 2: Double-peaked XRB 4U 1608-52 spectrum, plotted as time versus bolometric flux (10^{-9} in cgs). Notice 25% decrease in luminosity after first peak.⁶

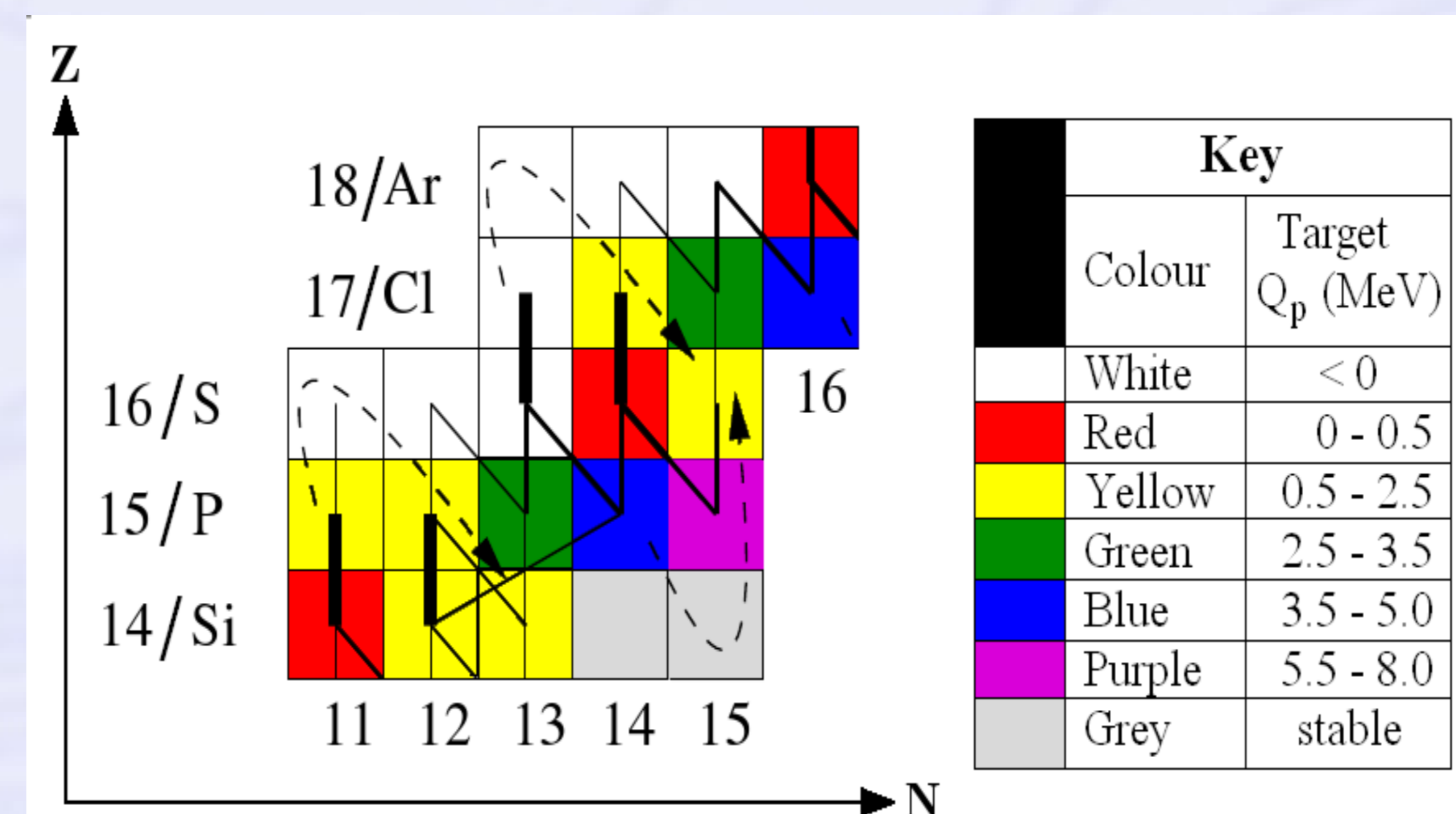


Figure 3: N vs. Z diagram near ^{30}S ($Z=16$, $N=14$). Colour indicates energy released during proton-capture (Q_p). Black lines indicate strength of the reaction path for (p,γ) , β^+ , (α,p) , except for thick vertical lines indicating (p,γ) - (γ,p) equilibrium. XRB nucleosynthesis must pass through ^{30}S ($t_{1/2}=1.178$ s). $^{30}\text{S}(\alpha,p)$ not shown – no experimental data.¹

^{30}S Beam Development

We successfully separated out the proton-rich isotope ^{30}S , after bombarding a ^3He gas cell with a stable ^{28}Si beam using the $^3\text{He}(^{28}\text{Si},n)^{30}\text{S}$ reaction.⁷

- 2 days of ^{30}S beam development in December 2006
- Work performed at CRIB⁸
 - CRIB is operated by the University of Tokyo and located at the RIKEN laboratory (Wako, Japan).

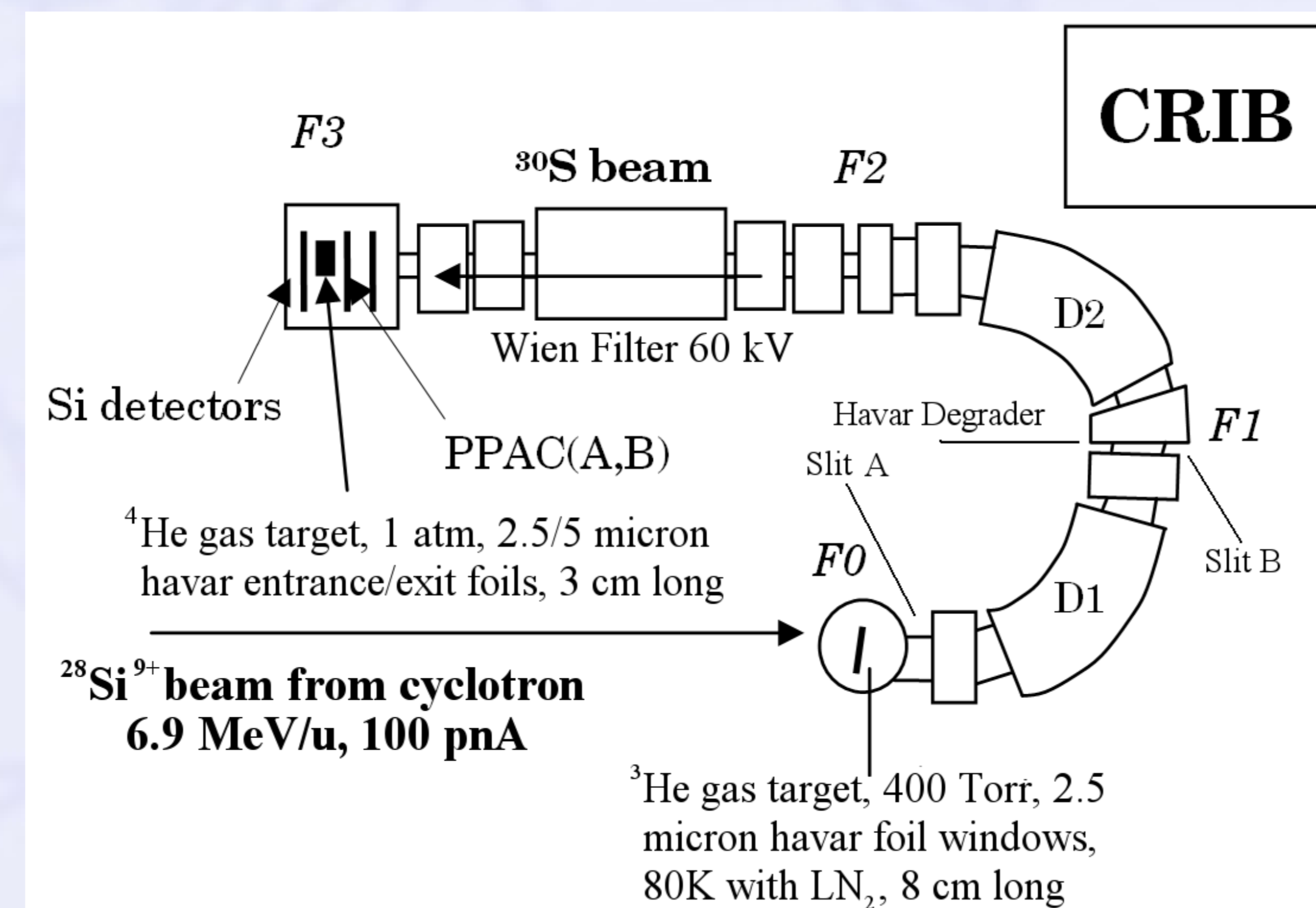


Figure 4: Schematic of CNS radioactive ion beam separator (CRIB) facility, showing experimental parameters of interest for ^{30}S beam development run.

Experimental Setup

To measure the $^{30}\text{S}(\alpha,p)^{33}\text{Cl}$ cross section, we will bombard a He gas cell with ^{30}S , looking for reaction protons in coincidence with incident ^{30}S beam particles.⁹

- Scan Gamow window for $T_9 = 1 - 2$ K
 - Equivalent $E_{\text{beam}} = 12 - 33$ MeV
- Thick target method to scan Gamow window
 - Set He pressure based on $\langle E_{\text{beam}} \rangle$
 - Expected to be ~ 1 atmosphere

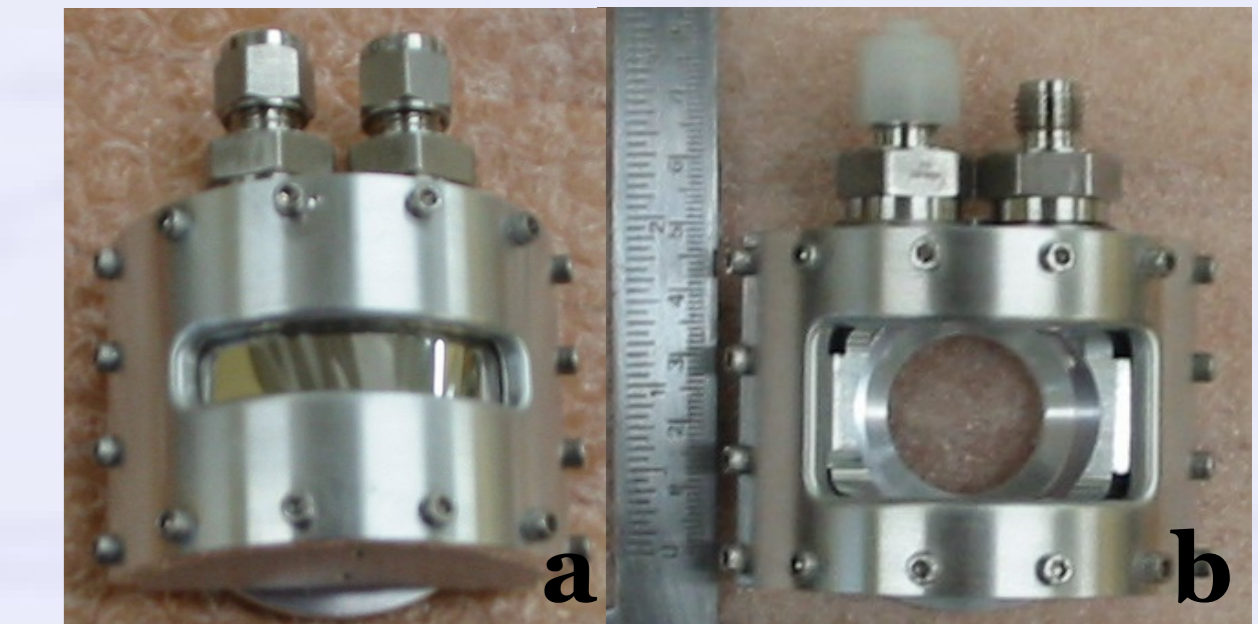


Figure 5: (a) Gas cell with havar window with 1 cm windows and (b) modified gas cell (foil windows absent) with 2 cm windows. Picture shows rear perspective of gas cell. ^{30}S beam diameter found to be ~ 1.5 cm.

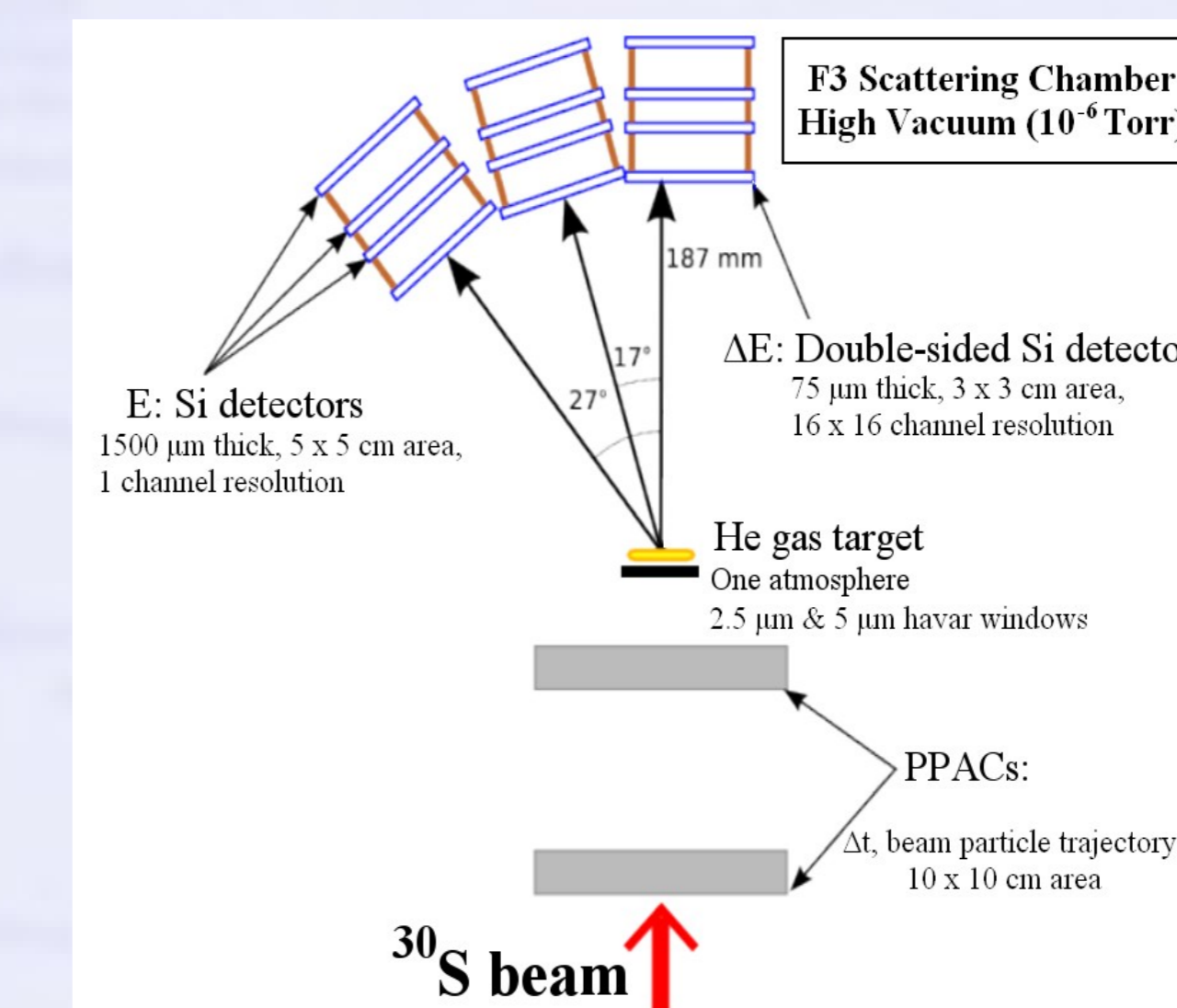


Figure 6: Schematic view of scattering chamber (F3 on Figure 4) detector setup.

- Detect protons at three angles
 - ΔE -E Silicon telescopes
 - Distinguish scattered α 's from protons
- Parallel plate avalanche counters (PPAC)
 - Correlate beam particles with protons¹⁰
- Find efficiency using known (α,p) reaction¹¹
 - Use ^{28}Si beam, like RIB production
 - $\alpha(^{28}\text{Si},p)^{32}\text{S}$ previously measured^{12,13}

Results

We developed a number of ^{30}S beams optimized to different parameters: one with 56% purity, another with 11.3 ± 1.8 MeV, and a third with 3×10^3 particles per second (pps).¹⁴

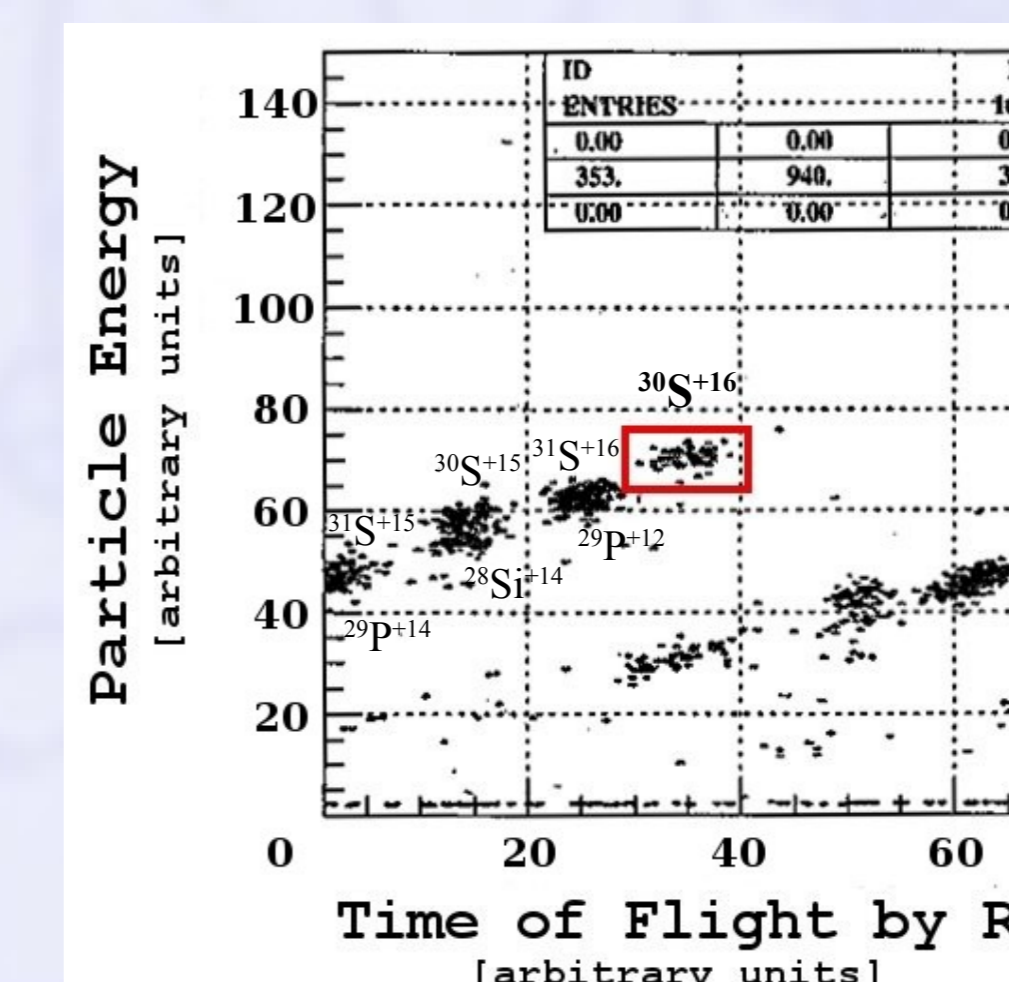


Figure 7: Sample on-line particle identification spectrum. Red box encloses $^{30}\text{S}^{16+}$ ions. Notice charge state contamination of ^{30}S ions with similar A/Q values to other reaction products.

- Fully ionized ^{30}S yielded the best results
 - $^{30}\text{S}^{16+}$, $E_{\text{beam}} = 14 \pm 1.5$ MeV
 - 3×10^3 pps / 100 pNA
 - 4.3% purity for lower intensities
- Second beam development run planned
 - Early 2008
 - 10^5 pps needed based on theoretical rate
 - Increase E_{beam} to Gamow window
- Measure $^{30}\text{S}(\alpha,p)$ cross section spring 2008
 - Worst case: set lower limit
 - If rate is 10^2 above theoretical value, it's inconsistent with Fisker's waiting point theory, which we can measure with 10^3 pps.

References and Works Cited

- [1] J. L. Fisker, F.-K. Thielemann, M. Wiescher, *ApJ* **608** (2004) L61.
- [2] E. Anders & M. Grevesse, *Geochim. Cosmochim. Acta* **53** (1989) 197.
- [3] E. Kuulkers *et al.*, *A&A* **382** (2002) 947
- [4] M. Sztajno *et al.*, *ApJ* **299** (1985) 487.
- [5] J. van Paradijs *et al.*, *MNRAS* **221** (1986) 617.
- [6] W. Penninx *et al.*, *A&A* **208** (1989) 146.
- [7] W. Bohne *et al.*, *Nucl. Phys. A* **378** (1982) 525.
- [8] S. Kubono *et al.*, *Eur. Phys. J. A* **13** (2002) 217.
- [9] W. Bradfield-Smith *et al.*, *Nuc. Inst. and Meth. A* **425** (1999) 1.
- [10] H. Kumagai *et al.*, *Nuc. Inst. and Meth. A* **470** (2001) 562.
- [11] C. Wrede, private communication (2007).
- [12] M. A. Buckby & J. D. King, *Can. J. Phys.* **62** (1984) 134.
- [13] S. K. Das *et al.*, *Phys. Rev. C* **62** (2000) 054606.
- [14] D. Kahl *et al.*, CNS Annual Report 2006.