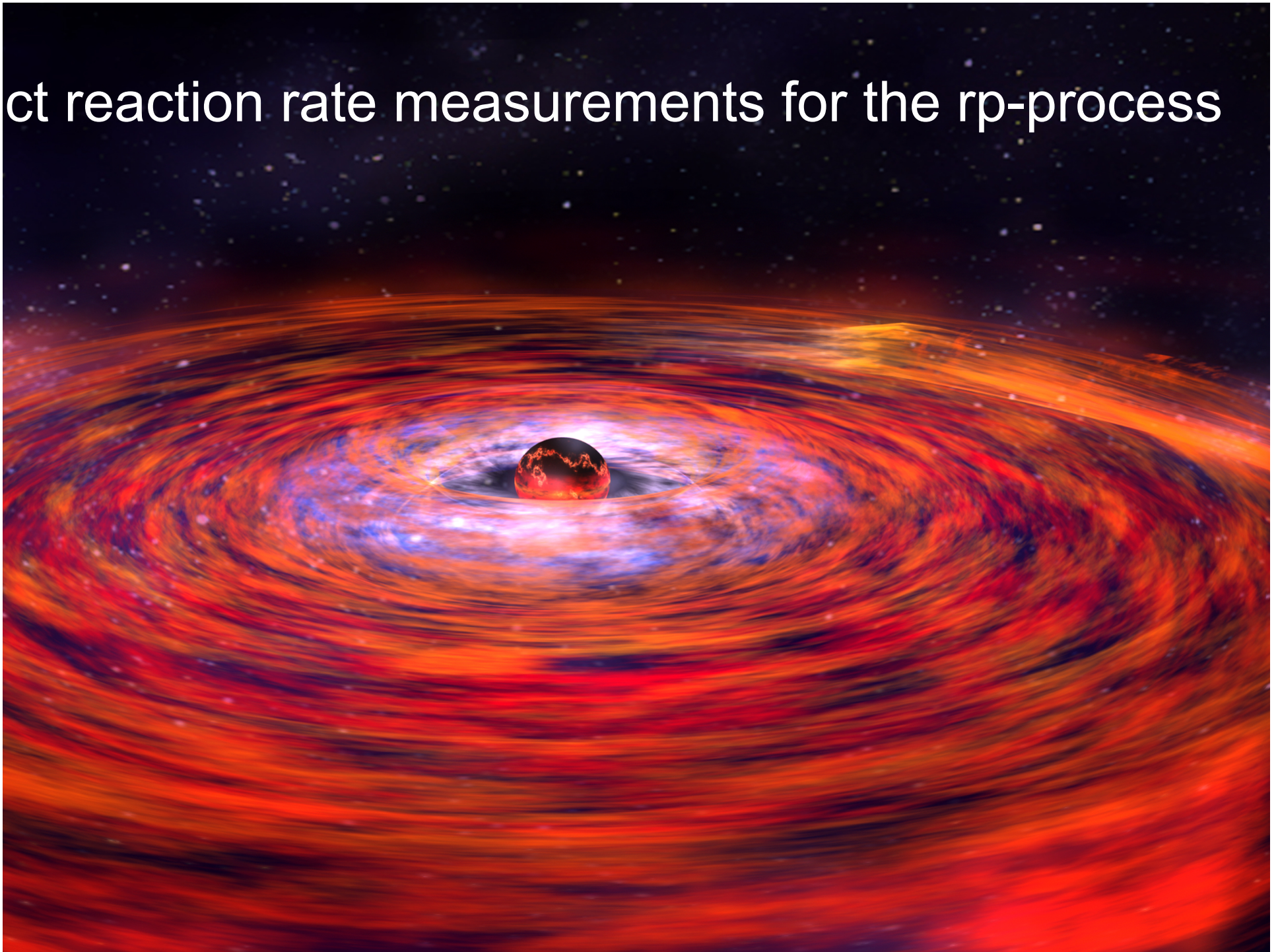
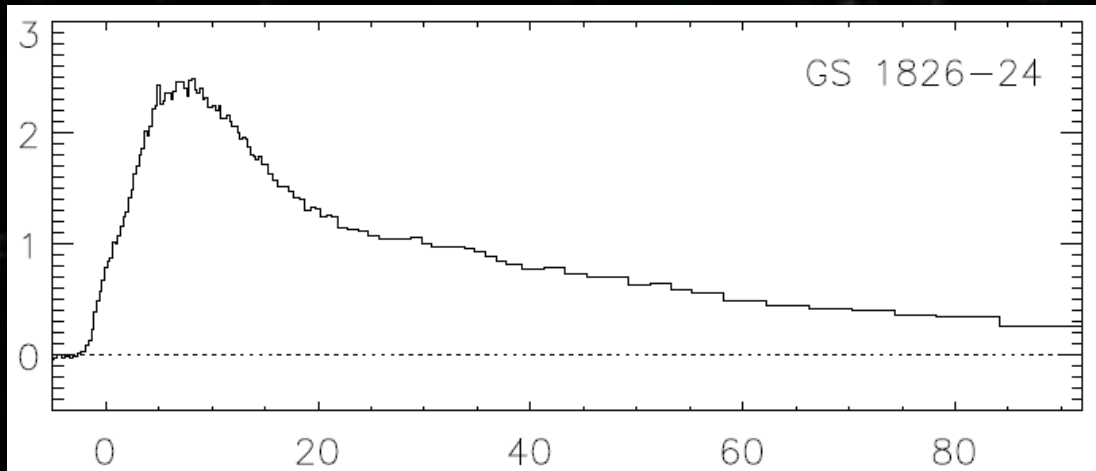
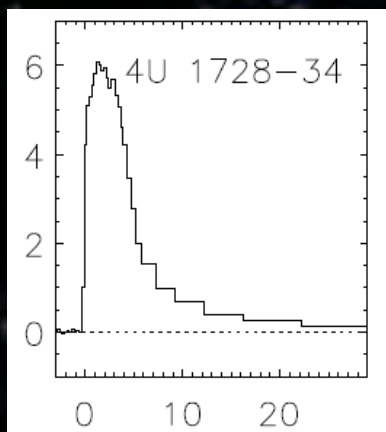


ct reaction rate measurements for the rp-process





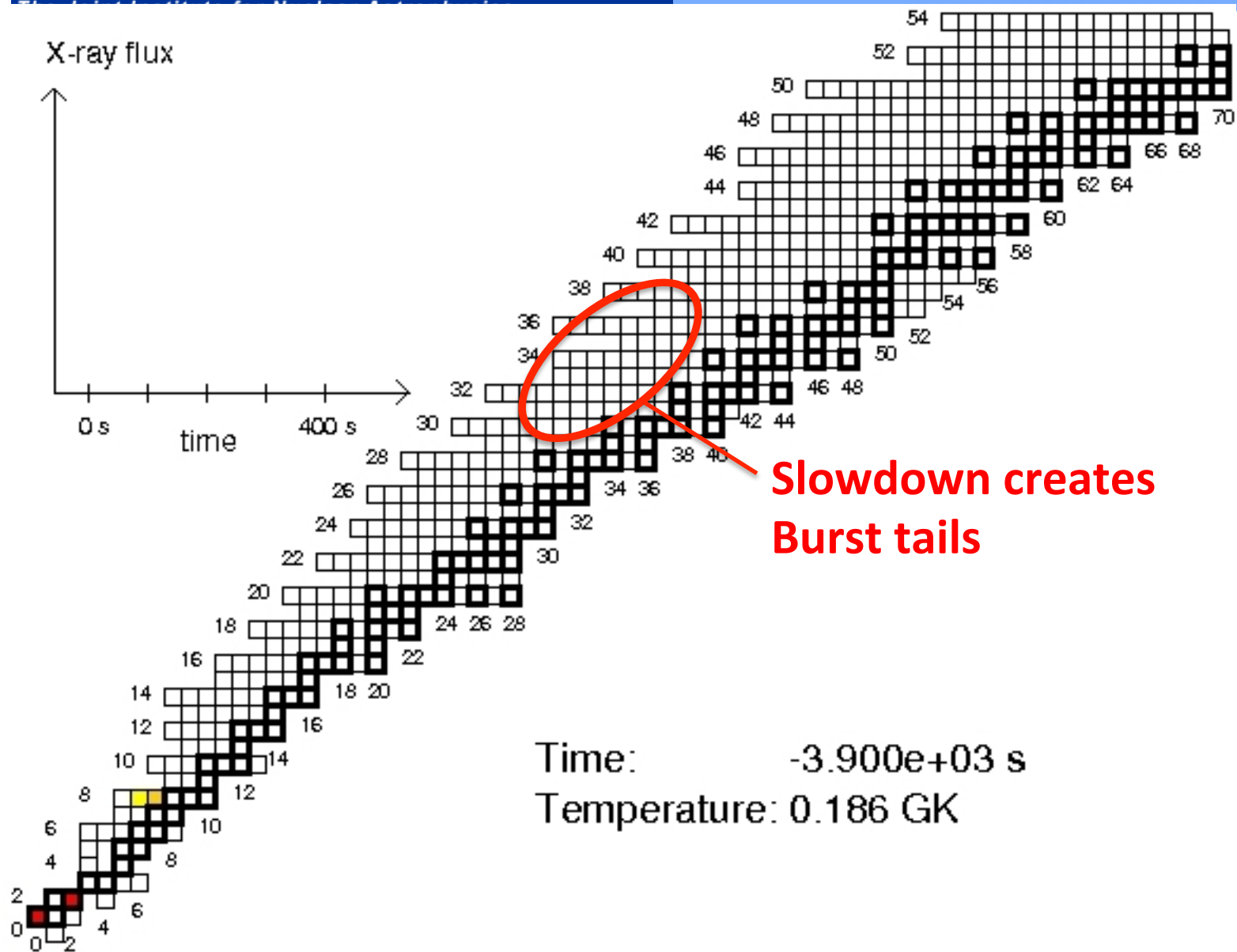
Long bursts



**Short
bursts**

Goals:

- Understand phenomena
 - Learn about neutron stars
- Its nuclear physics!



Deepest zone of first burst (model zM of Woosley et al. 2007)

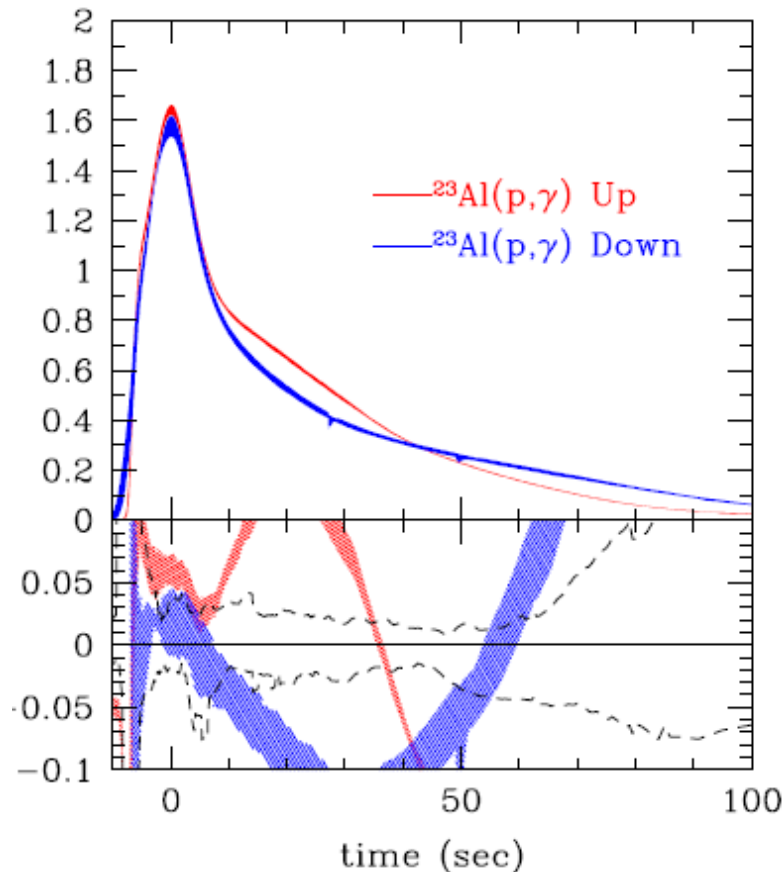
Model by Heger, Woosley et al.; Similar to other groups: Fisker et al. and Jordi et al.

Reaction rates in X-ray bursts

Sensitivity study with full 1D burst model from Heger (Cyburt, Amthor, et al.)

→ Rates do matter too (not full equilibrium at all times)

Burst X-ray light curve



Multi-institutional
Multi-disciplinary
NSF Physics Frontiers Center



The JINA reaclib database

(Richard Cyburt)

- Continuously updated
- Snapshots available
- <http://www.jinaweb.org> → Tools&Data

(see also BRUSLIB effort)

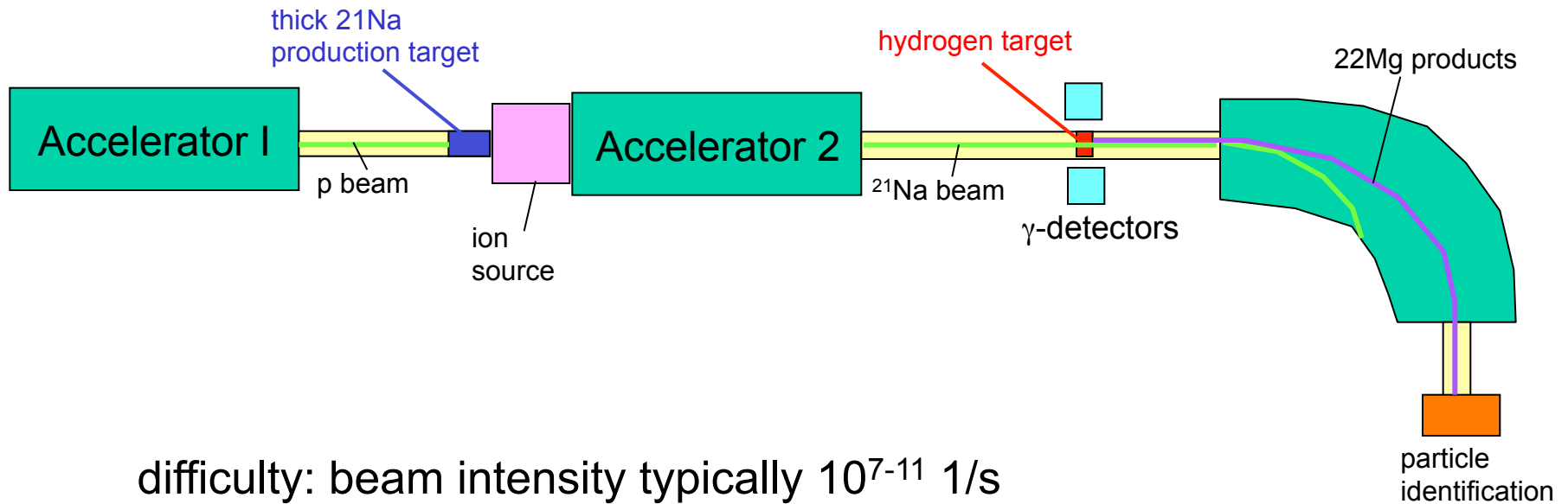
(see also post-processing but full Monte Carlo study by Parikh et al. 2008

--> only minor effect from correlations - single rate variation ok)

Example for direct measurement: $^{21}\text{Na}(p,\gamma)^{22}\text{Mg}$

problem: ^{21}Na is unstable (half-life 22.5 s)

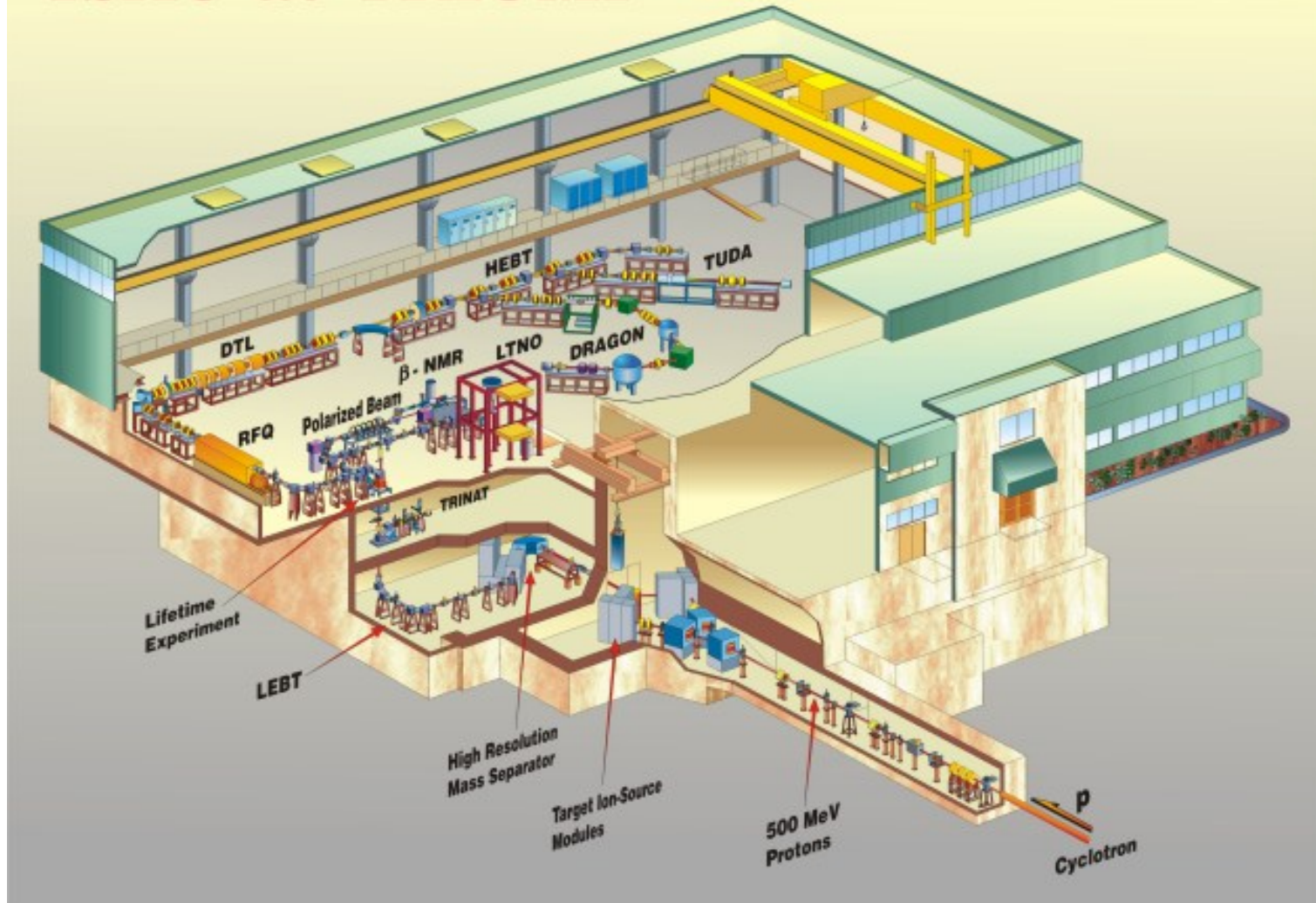
solution: radioactive beam experiment in inverse kinematics:



difficulty: beam intensity typically 10^{7-11} 1/s

(compare with $100 \mu\text{A}$ protons = $6 \times 10^{14}/\text{s}$)

ISAC at TRIUMF

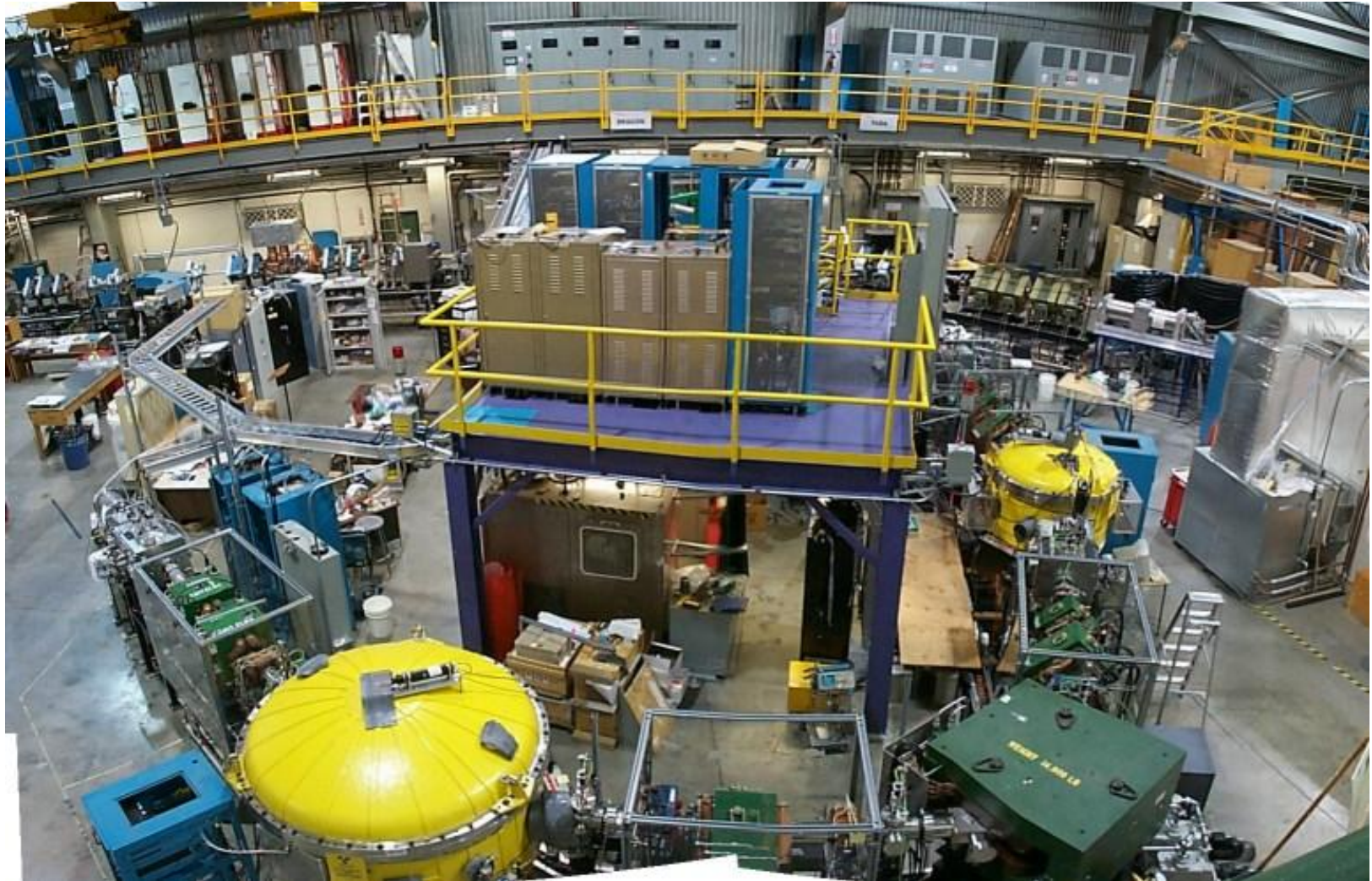


DRAGON

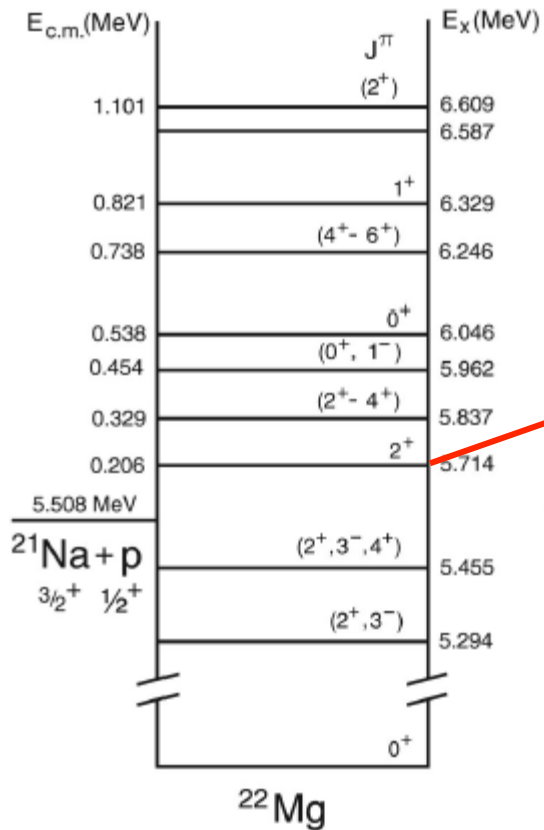
*Detector of Recoils And
Gammas Of Nuclear reactions*



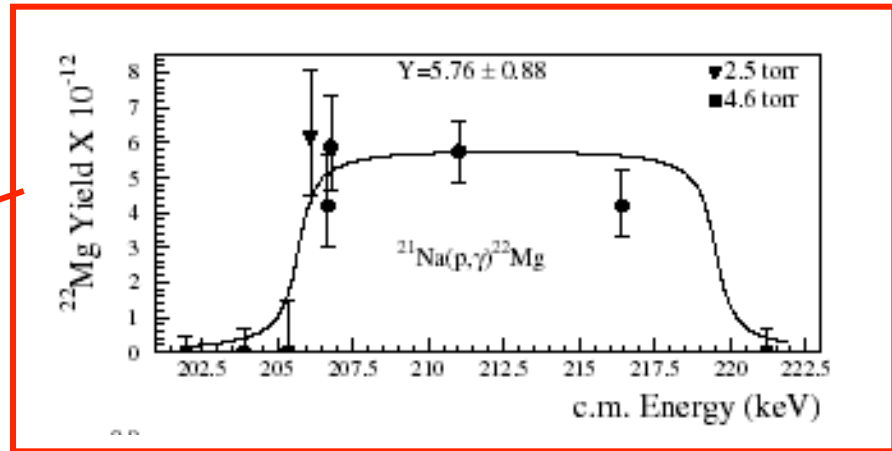
DRAGON @ TRIUMF



Results



Result for 206 keV resonance:



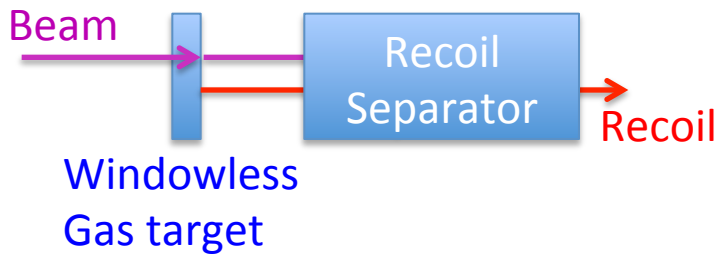
S. Bishop et al. Phys. Rev. Lett. 90 (2003) 2501

rp-process reaction rate measurements

Reaction rate measurements:

p, γ and α, p reaction rates

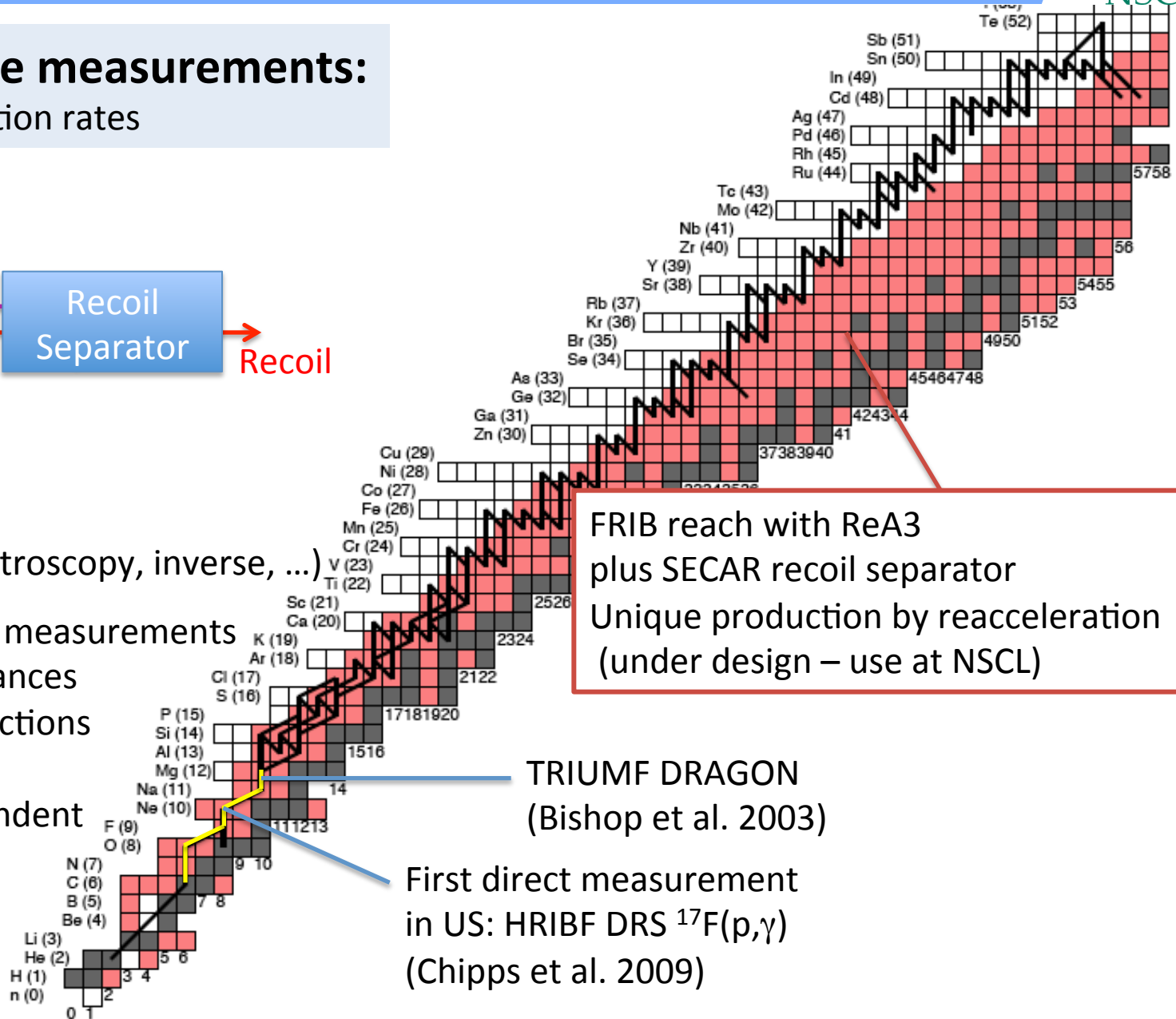
1) Directly



2) Indirectly

(transfer, γ -spectroscopy, inverse, ...)

- Guide direct measurements
 - Weak resonances
 - Low cross sections
- BUT
- Model dependent
 - Ambiguities
 - Incomplete



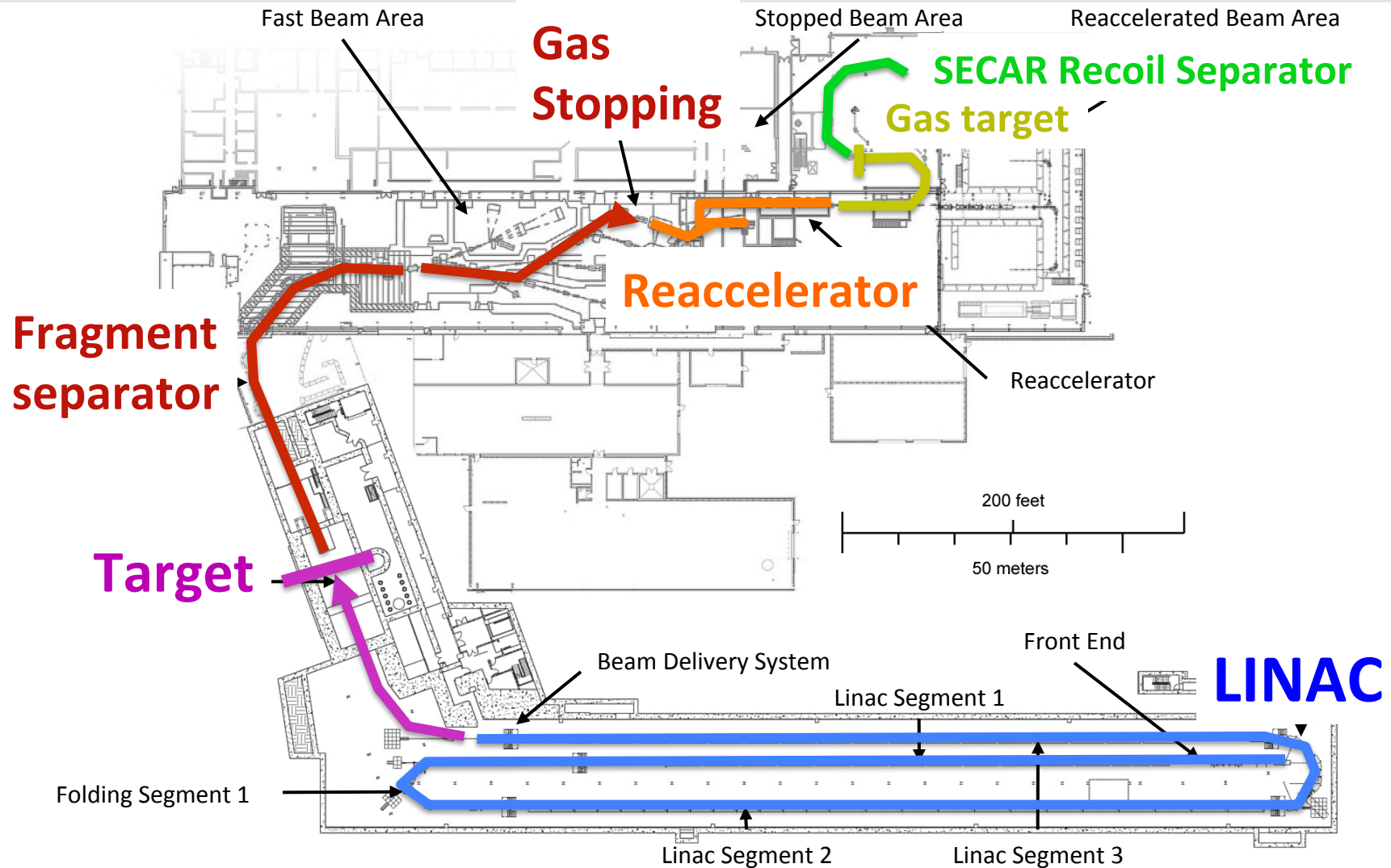
FRIB reach with ReA3
plus SECAR recoil separator
Unique production by reacceleration
(under design – use at NSCL)

TRIUMF DRAGON
(Bishop et al. 2003)

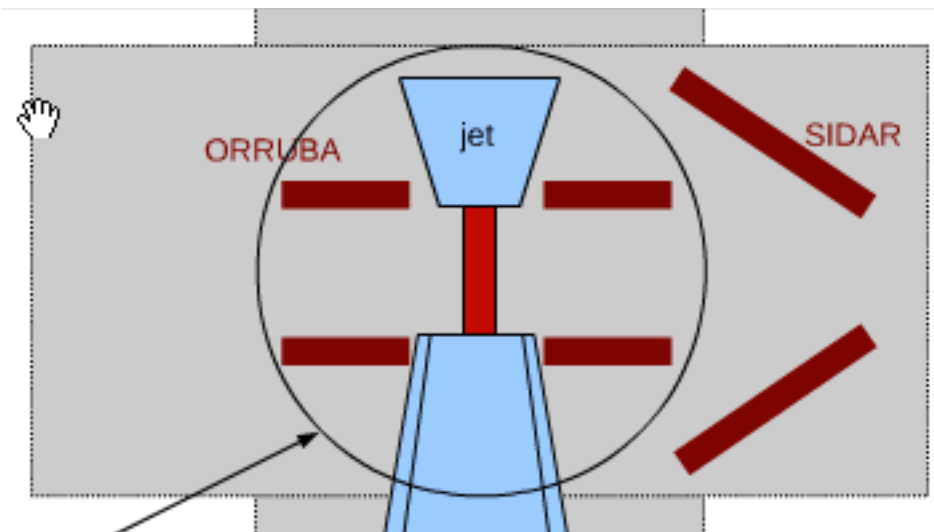
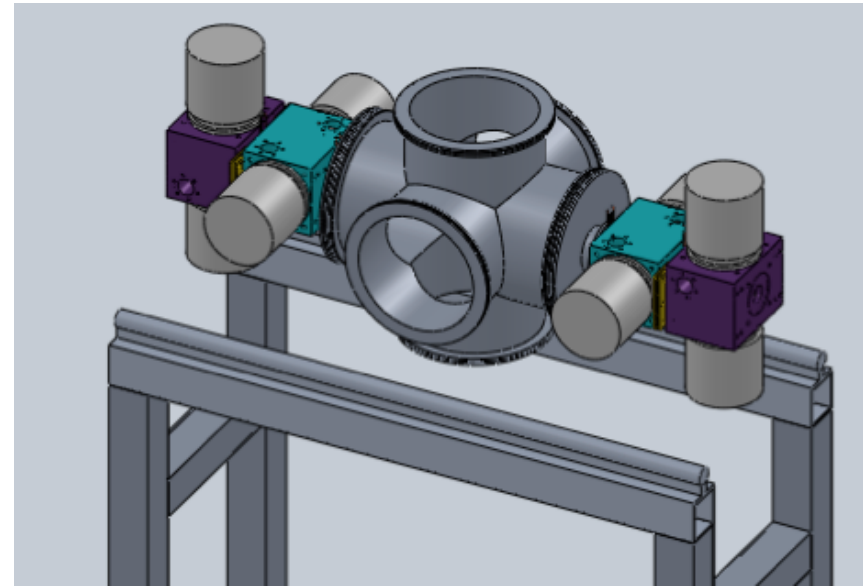
First direct measurement
in US: HRIBF DRS $^{17}\text{F}(p, \gamma)$
(Chipps et al. 2009)

FRIB Layout

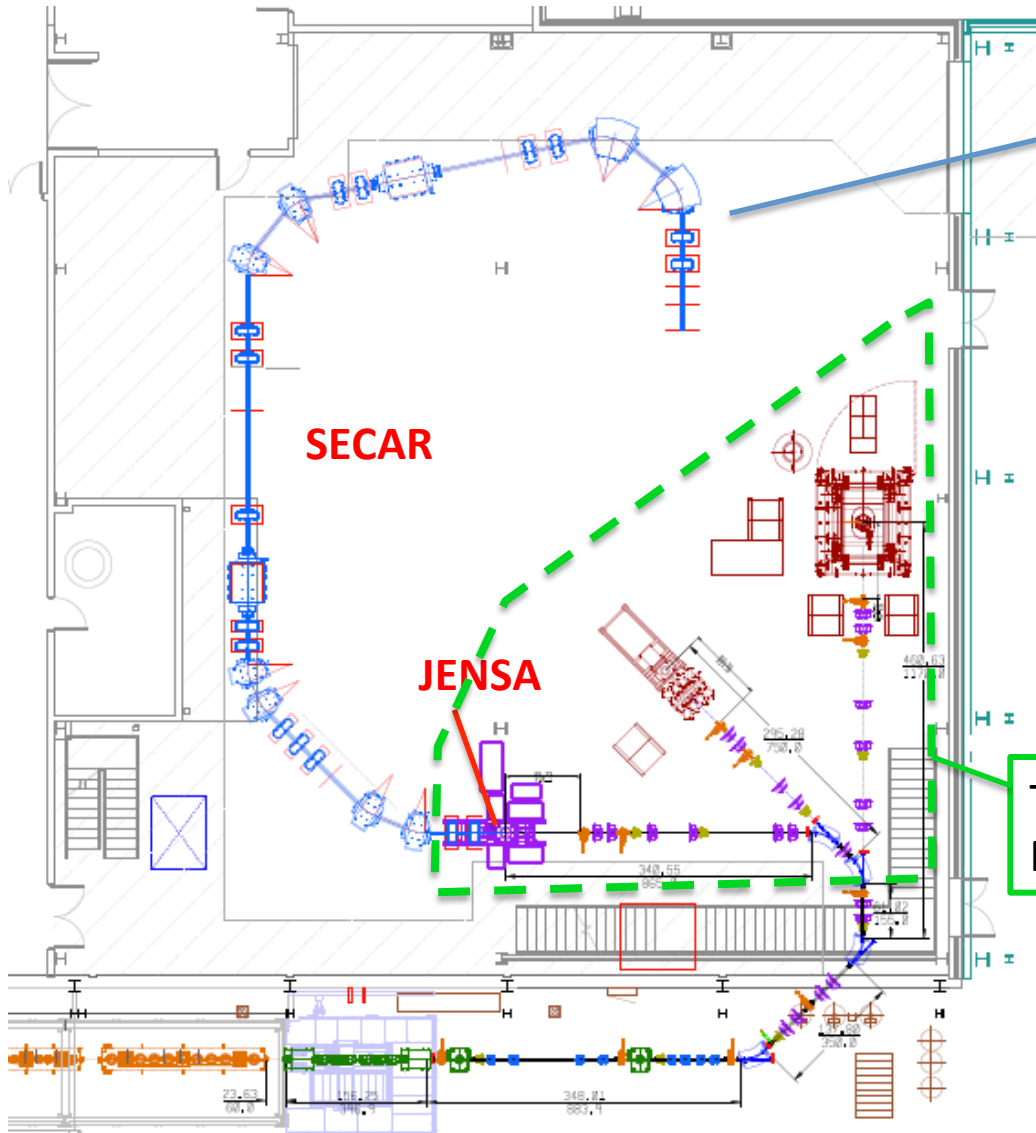
example: nuclear astrophysics experiment



The JENSA gas target



SECAR Recoil Separator at NSCL/FRIB at MSU



SECAR under design
(G. Berg, M. Couder)
(DOE Office of Science)

Inspired by



To be completed
Fall 2013

Large multi-institutional collaboration:
(ANL, CSM, JINA, LSU, McMaster,
MSU, ND, ORNL, PNNL)

- Direct reaction rate measurements with radioactive beams become feasible at FRIB in many cases
- The measurements of p,γ rates require:
 - Intense radioactive beams
 - A hydrogen gas target
 - A recoil separator optimized for such measurements
- Need compilation of reaction rates to ensure experimental data are used in astrophysics
 - accomplished by JINA reaclib database
<https://groups.nslc.msu.edu/jina/reaclib/db/>
(or via jinaweb.org – Tools&Data – reaclib database)