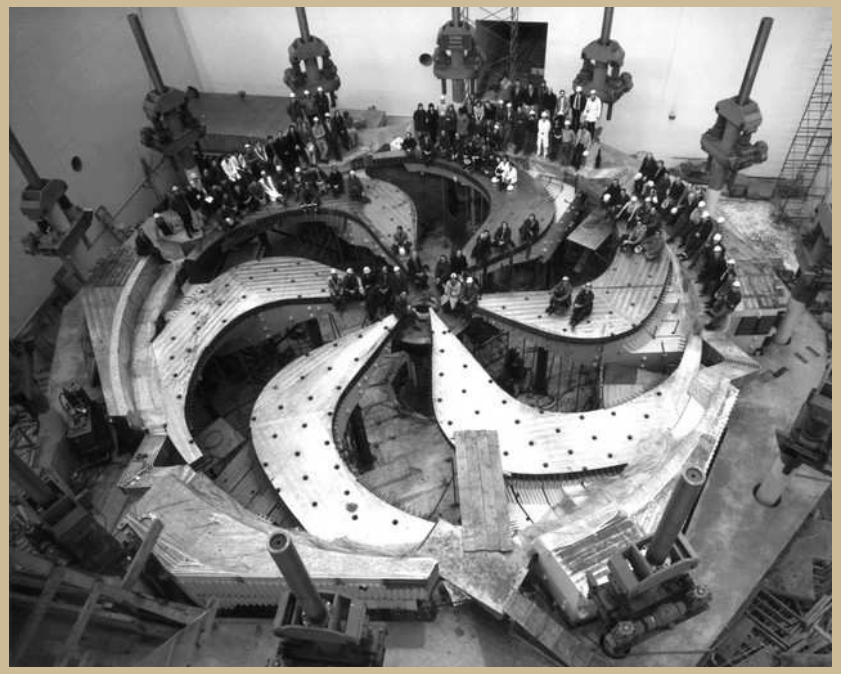
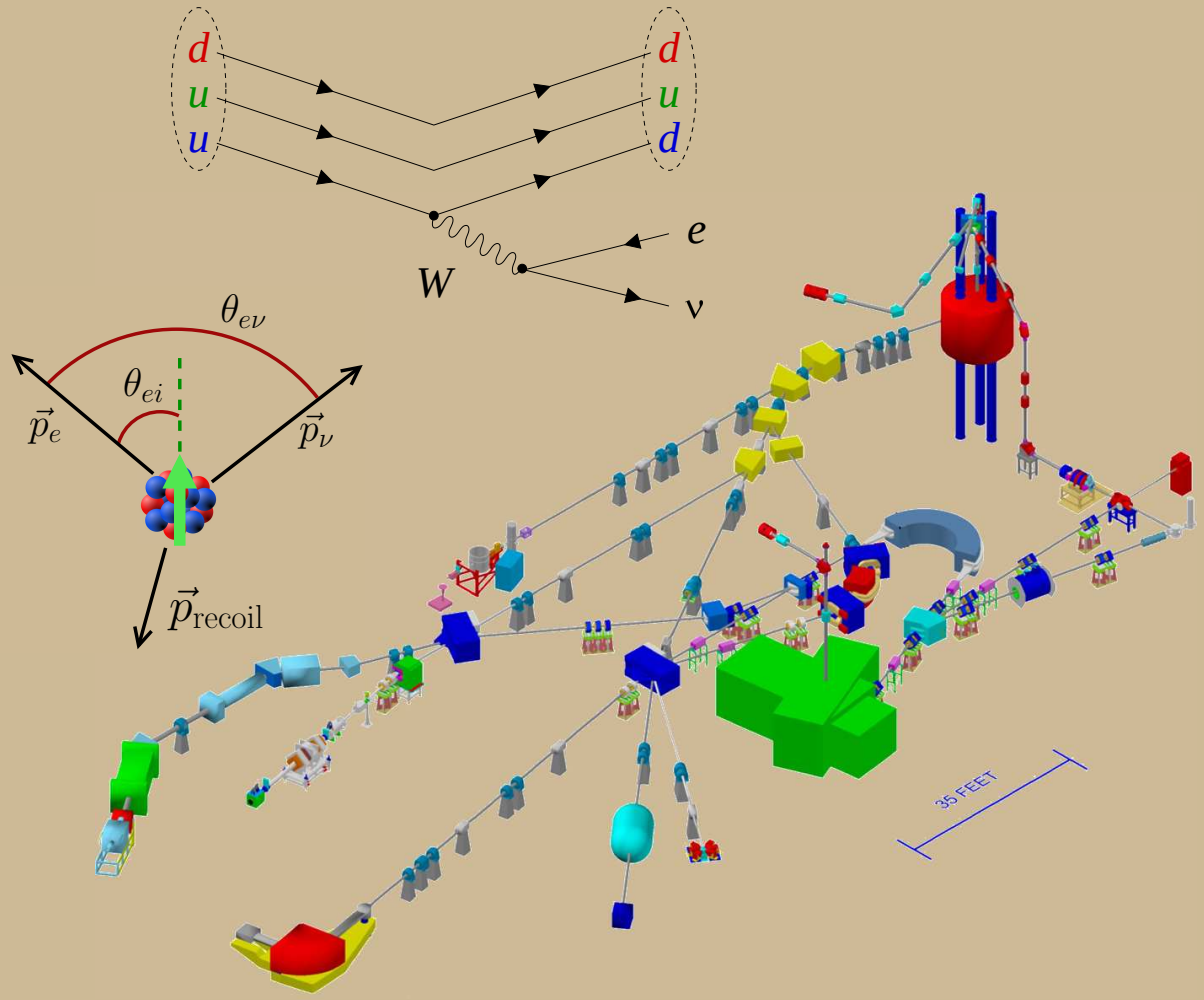
A new correlation Penning trap for fundamental physics at Texas A&M





Dan Melconian

Dec 5, 2014

Overview

1. Fundamental symmetries

- brief **motivation**
- **game plan** for testing the SM

2. Cyclotron Institute upgrade project

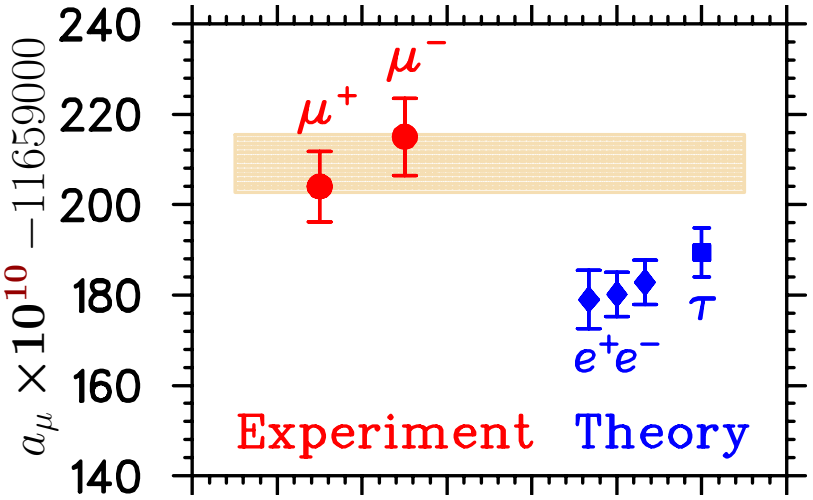
- overview
- expected **RIB production**

3. TAMU Penning Trap (being built)

- **physics** of superallowed β decay
- **ion trapping** of proton-rich nuclei at T-REX

We all know the SM works stubbornly well

- ✔ it **predicted** the existence of the $W^{\pm}$, $Z_{\circ}$, g, c and t
  $\rightsquigarrow$ and now **the Higgs!**
- ✔ is a **renormalizable** theory
- ✔ GSW $\Rightarrow$ **unified** the **weak** force with **electromagnetism**
- ✔ QCD **explains** quark confinement



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$$\Delta a_\mu = 288(80)\times 10^{-11}\text{!!}$$

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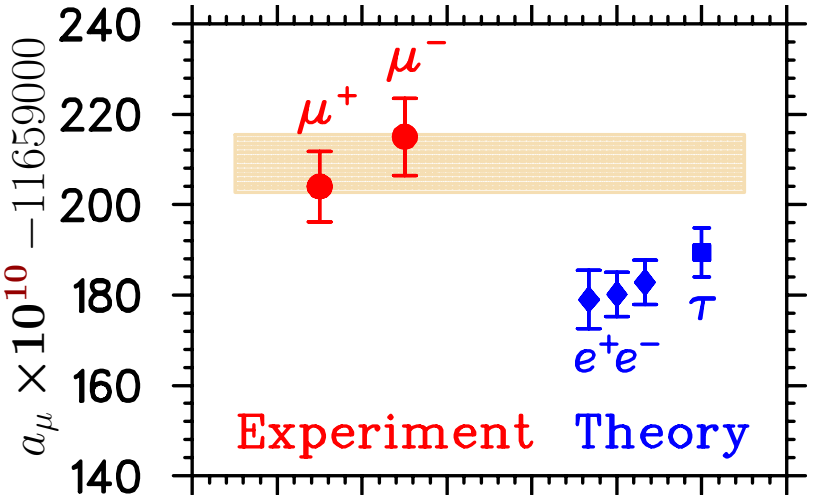

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$$\Delta a_\mu = 288(80)\times 10^{-11}\text{!!}$$

(PDG 2013)

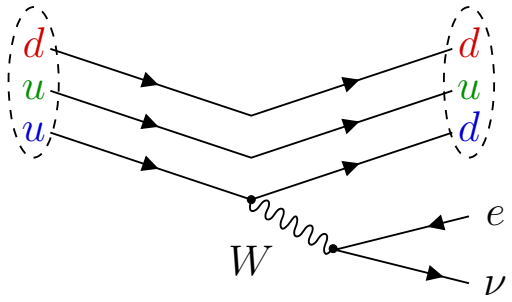
Wow . . . this is

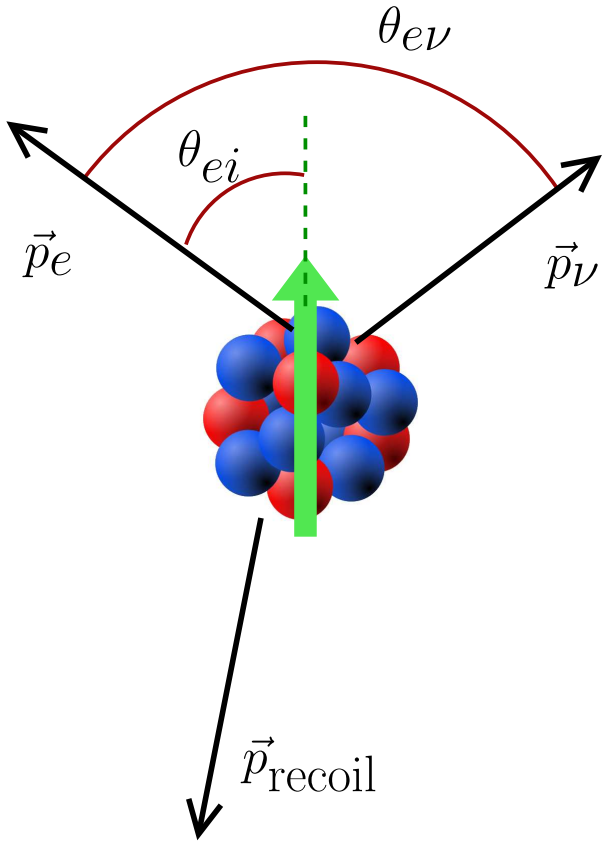
the most precisely tested theory ever conceived!

But we also know there's more to discover

- **parameters values**: does our "ultimate" theory *really* need **25** arbitrary constants? Do they **change** with time?
- **dark matter**: SM physics makes up **only 4%** of the energy-matter of the universe!
- **baryon asymmetry**: why more **matter** than **anti-matter**?
- **strong *CP***: do **axions** exist? **Fine-tuning**?
- **neutrinos**: **Dirac** or **Majorana**? Mass **hierarchy**?
- **fermion generations**: why **three** families?
- **weak mixing**: Is the CKM matrix **unitary**?
- **parity violation**: is parity **maximally** violated in the weak interaction? No **right-handed** currents?
- **gravity**: of course can't forget about a **quantum** description of **gravity**!

How do many of us plan to test the SM?





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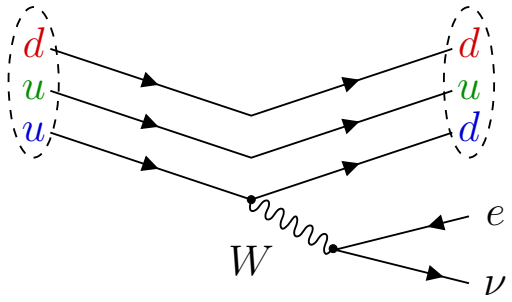

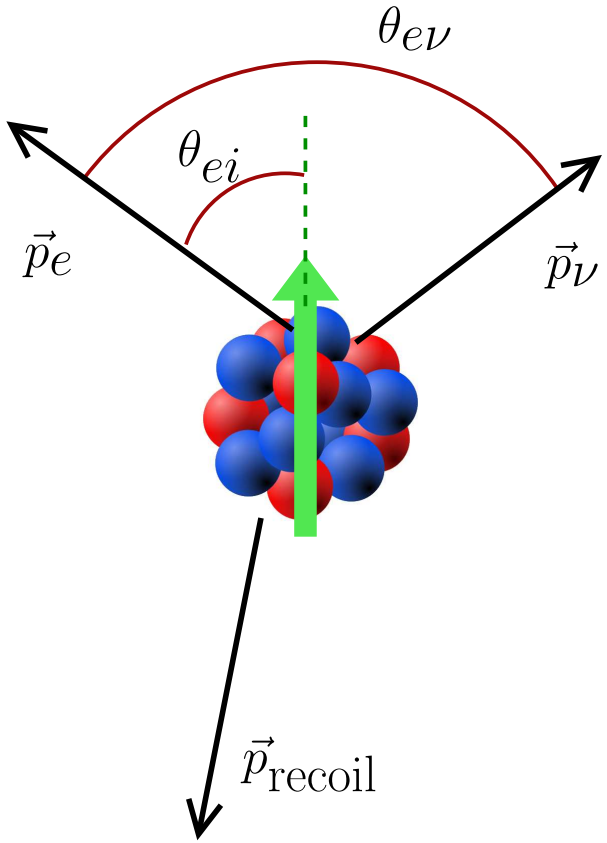

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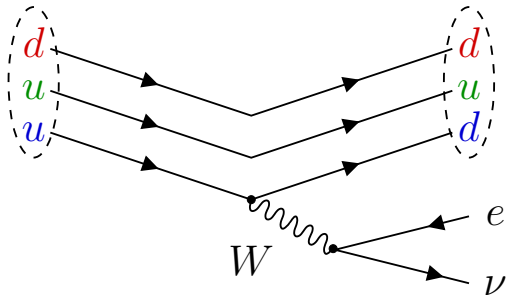

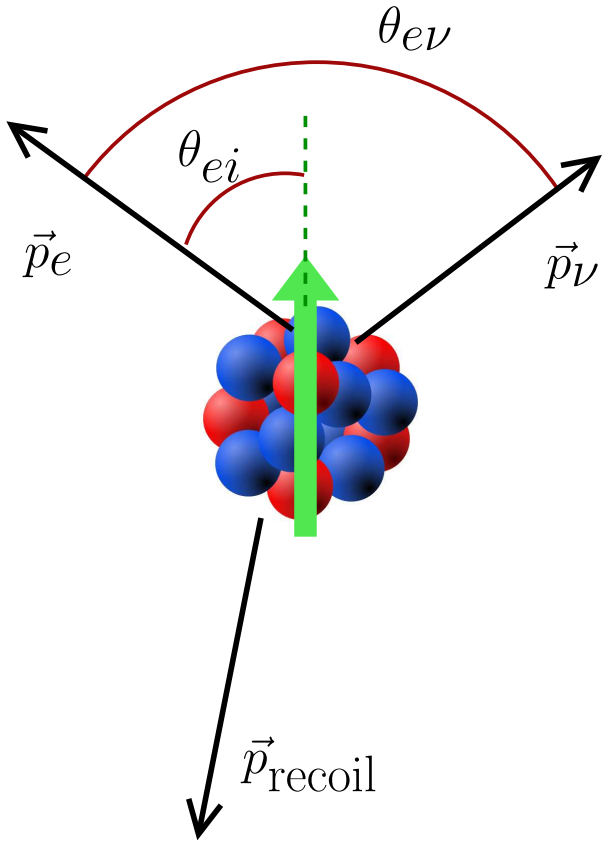

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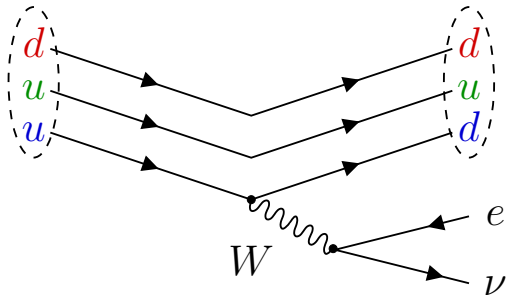

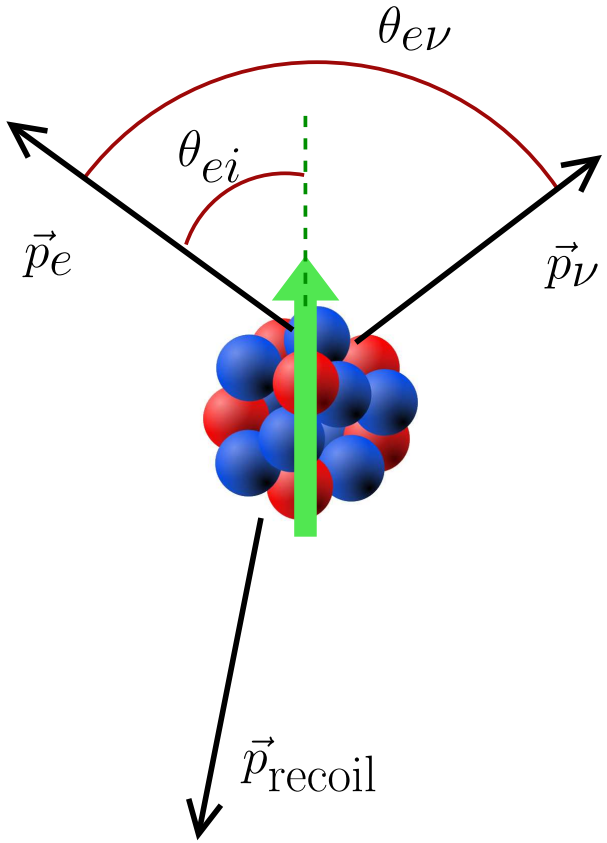

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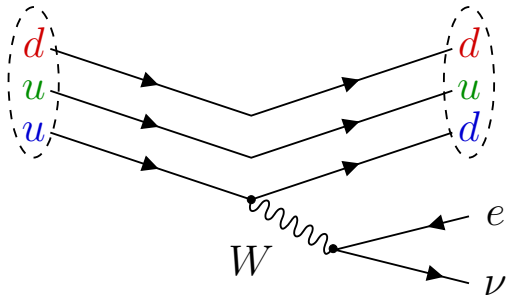
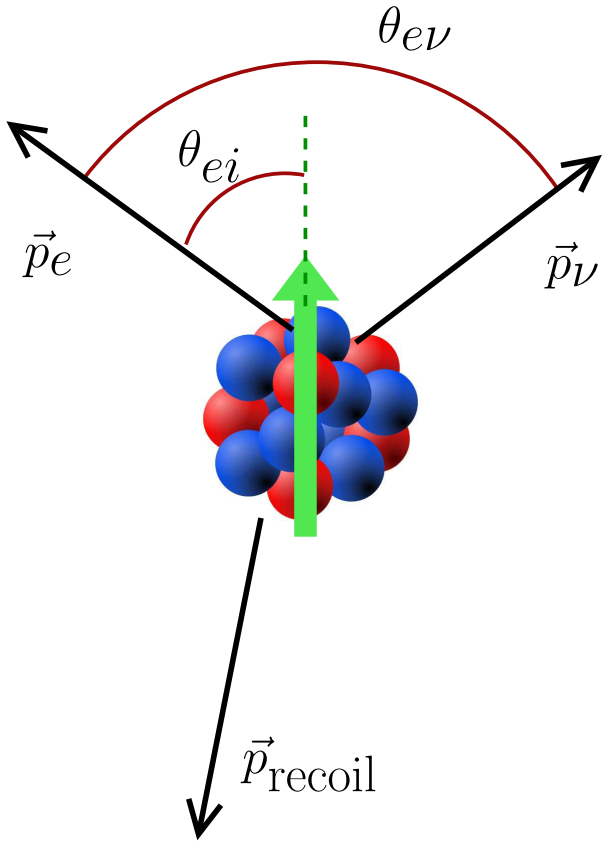


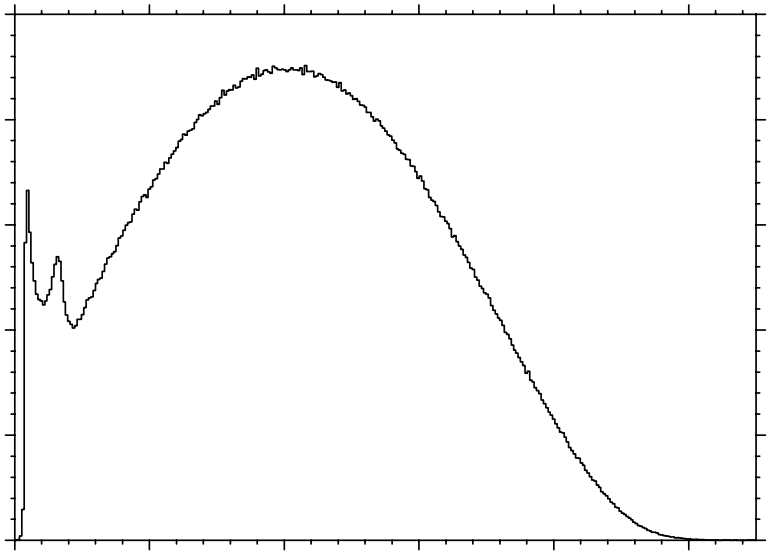


- perform a β decay experiment on **short-lived** isotopes
- make a **precision measurement** of the angular correlation parameters
- **compare** the SM predictions to observations
- look for **deviations** as an indication of **new physics**
- try to convince HEP community when you see something!

A little more specifically…

Test SM via the **angular distribution** of β decay: the often-quoted Jackson, Treiman and Wyld (Phys Rev **106** and Nucl Phys **4**, 1957)

$$\frac{d^5W}{dE_e d\Omega_e d\Omega_{\nu_e}} = \overbrace{\frac{G_F^2 |V_{ud}|^2}{(2\pi)^5} p_e E_e (A_\circ - E_e)^2 \xi}^{\text{basic decay rate}} \left(1 + \overbrace{b \frac{\Gamma m_e}{E_e}}^{\text{Fierz term}} \right)$$



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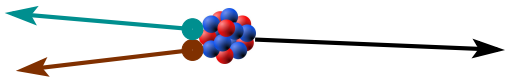

$$a_{\beta\nu} = \frac{|C_V|^2 + |C'_V|^2}{|C_V|^2 + |C'_V|^2}$$

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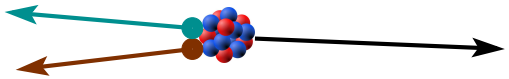
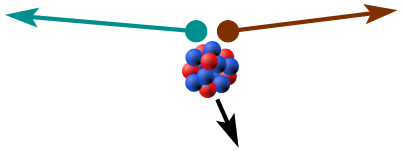


scalar



$$a_{\beta\nu} = \frac{|C_V|^2 + |C'_V|^2}{|C_V|^2 + |C'_V|^2} \qquad a_{\beta\nu} = \frac{-|C_S|^2 - |C'_S|^2}{|C_S|^2 + |C'_S|^2}$$

$$a_{\beta\nu} = \frac{|C_V|^2 + |C'_V|^2 - |C_S|^2 - |C'_S|^2}{|C_V|^2 + |C'_V|^2 + |C_S|^2 + |C'_S|^2}$$

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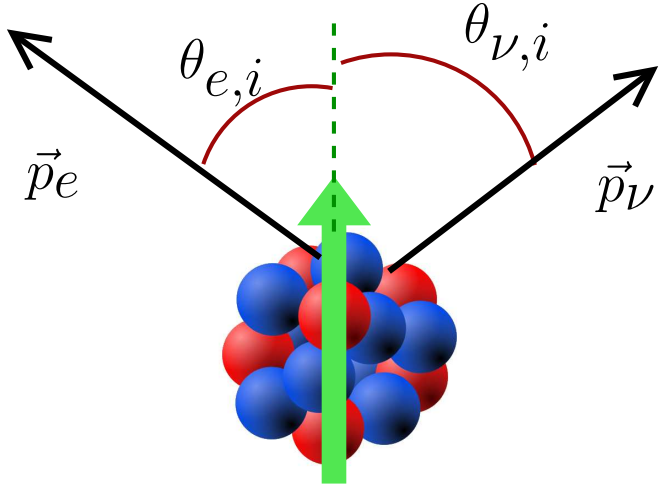

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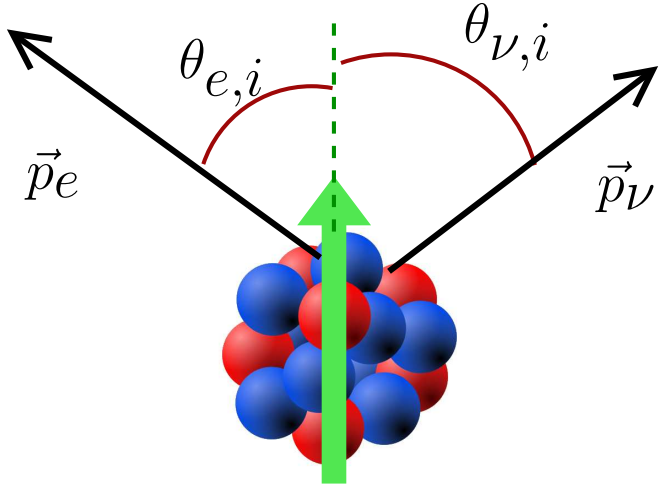

$$A_\beta = \frac{-2\rho}{1+\rho^2} \left[(1-xy) \sqrt{\frac{3(1+x^2)}{5(1+y^2)}} - \frac{\rho(1-y^2)}{5(1+y^2)} \right]$$

where $x \approx (M_L/M_R)^2 - \zeta$

and $y \approx (M_L/M_R)^2 + \zeta$

are right-handed current parameters that are zero in the SM

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$$\left. + \frac{\langle \vec{I} \rangle}{I} \left[A \frac{\vec{p}_e}{E_e} + B \frac{\vec{p}_\nu}{E_{\nu_e}} + D \frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_{\nu_e}} \right] \right) + \ldots$$

$\vec{p}_e$

β-decay parameters depend on the currents mediating the weak interaction

$\Rightarrow$ sensitive to **new physics** $\Leftarrow$

Goal must be **0.1%** to complement LHC

see Profumo, Ramsey-Musolf and Tulin, PRD **75** (2007) and Cirigliano, González-Alonso and Graesser, JHEP **1302** (2013)

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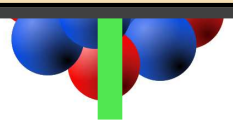

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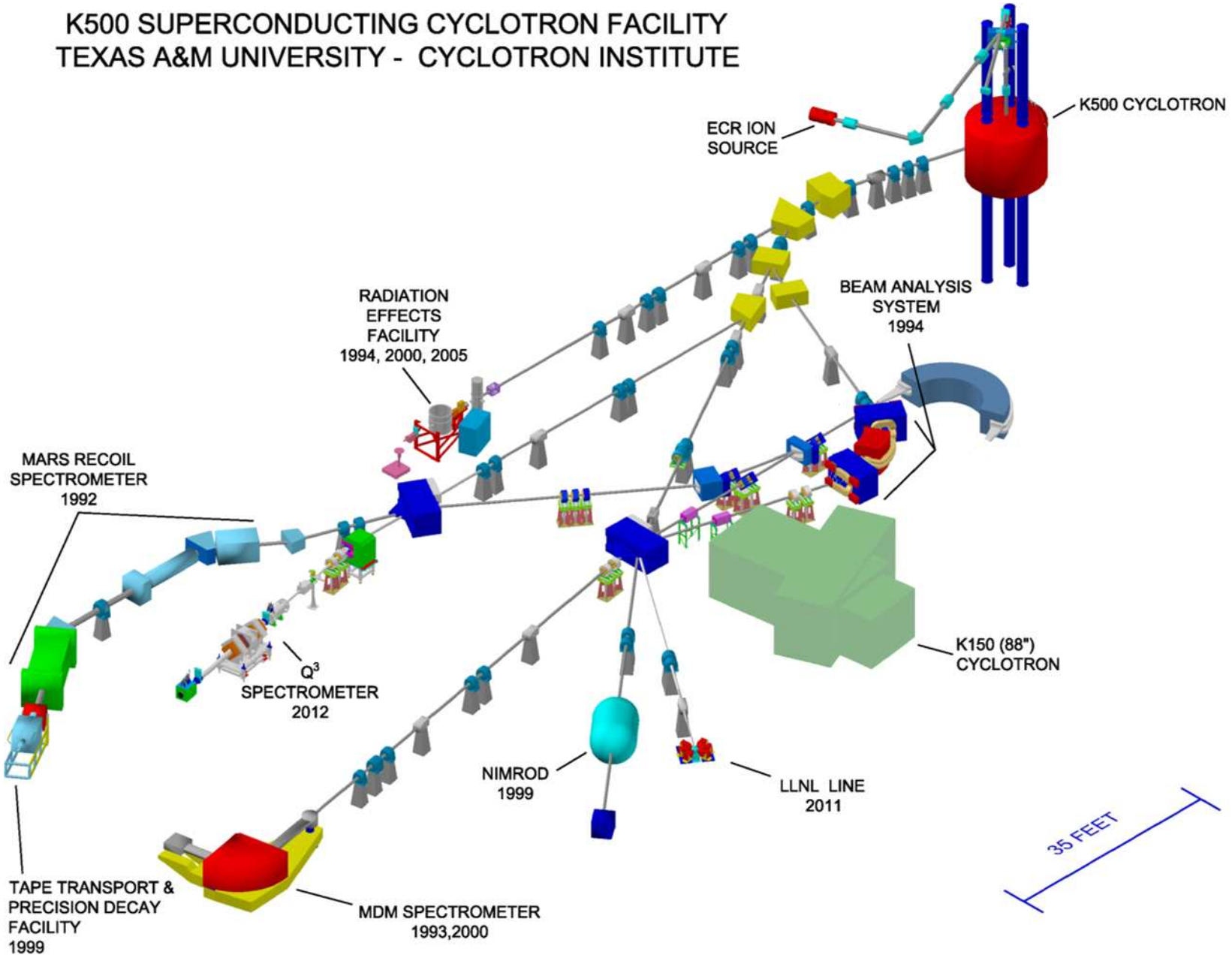
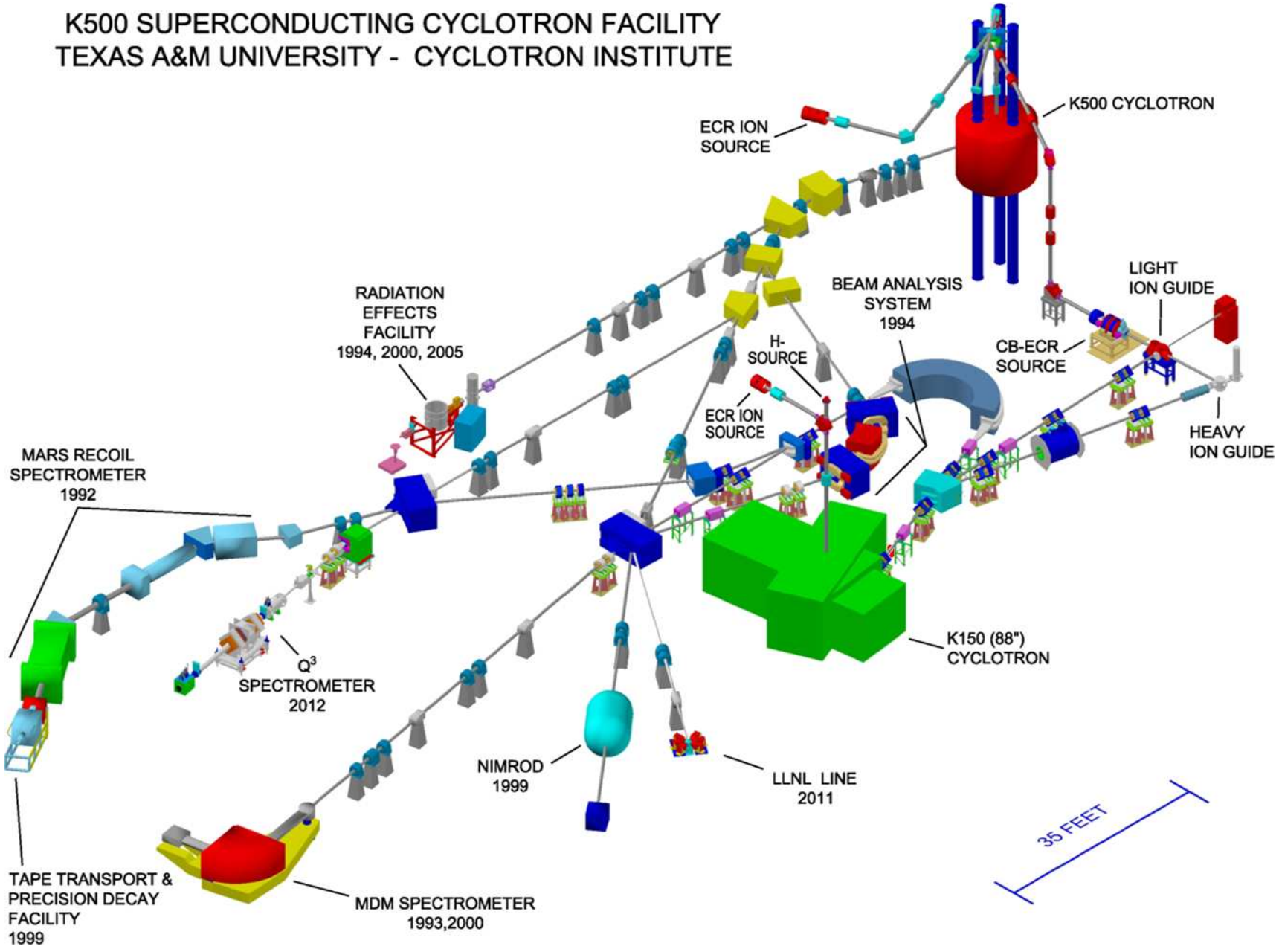


The T-REX Upgrade Project



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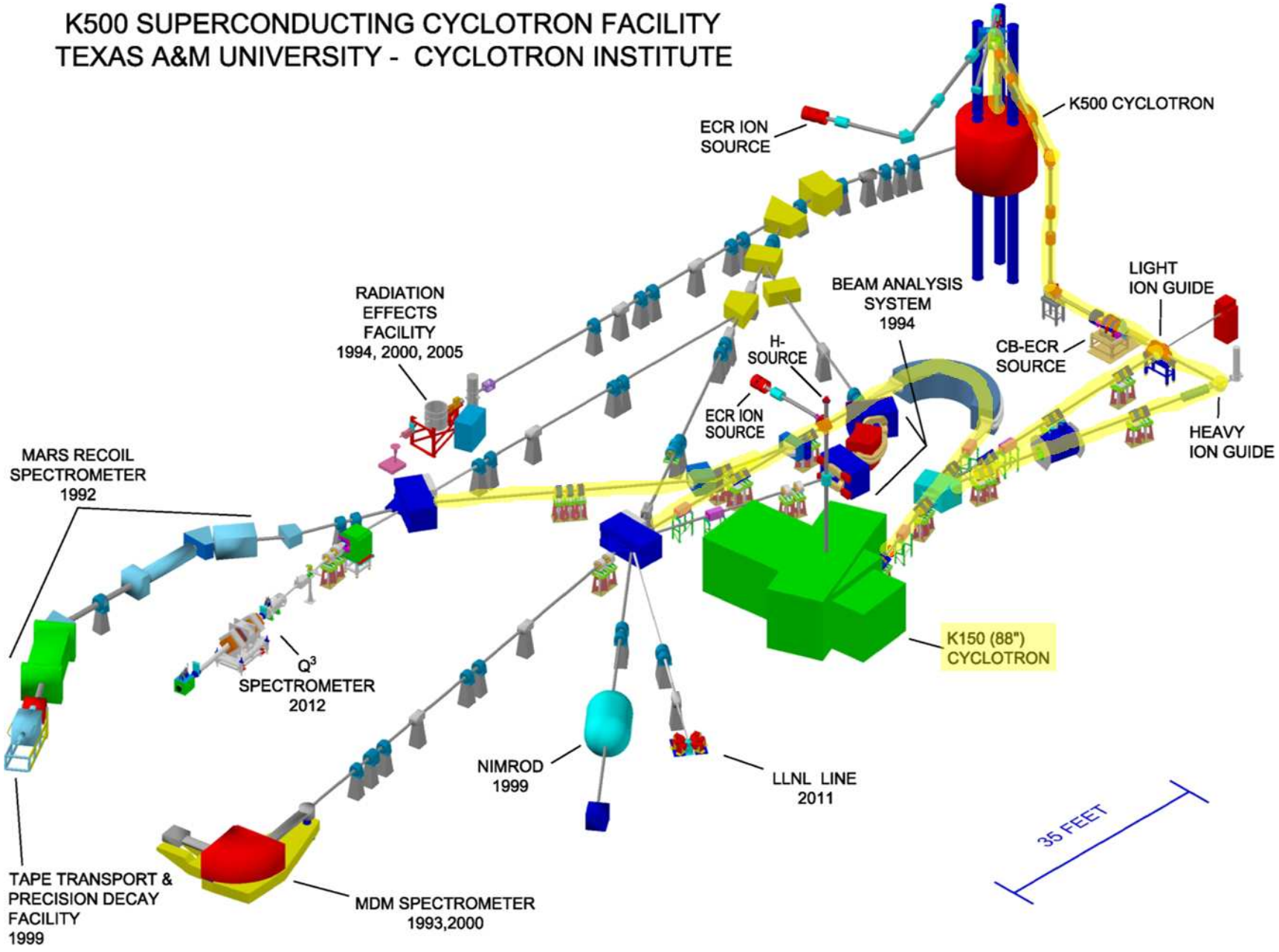
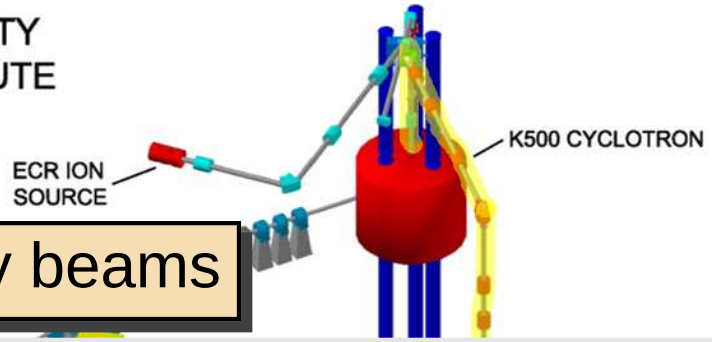


The T-REX Upgrade Project

K500 SUPERCONDUCTING CYCLOTRON FACILITY
TEXAS A&M UNIVERSITY - CYCLOTRON INSTITUTE

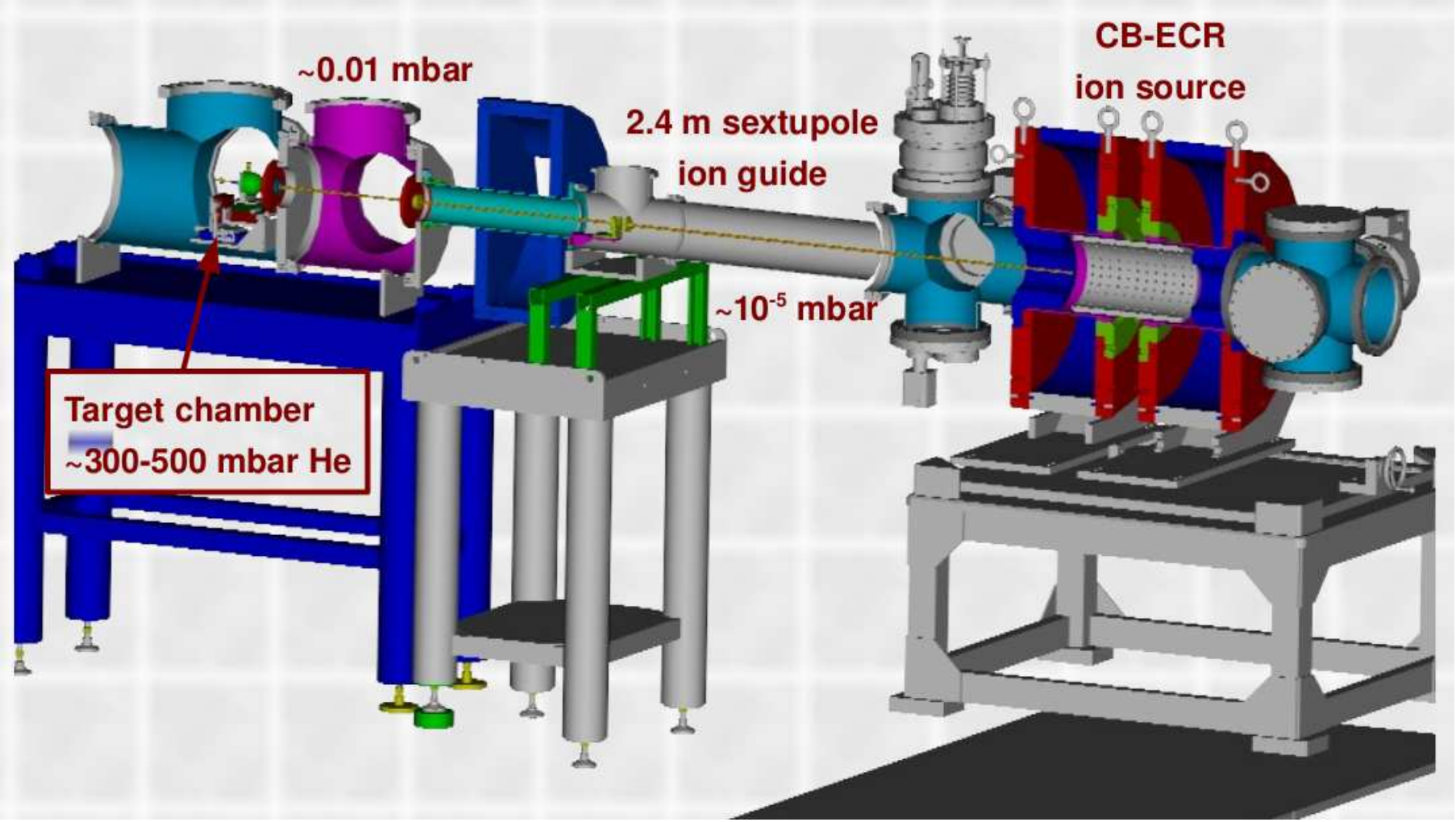


K500 primary beams

Isotope	Energy [MeV/u]	Intensity $[p\mu A]$	Isotope	Energy [MeV/u]	Intensity $[p\mu A]$
p	55	27	^{20}Ne	28	3.0
d	35	21	^{22}Ne	29	0.5
^{3}He	45	11	^{34}S	20	0.7
^{4}He	35	10	^{40}Ar	17	1.4
^{6}Li	35	7	^{40}Ca	17	1.5
^{7}Li	25	7	^{59}Co	11	0.9
^{10}B	35	4	^{78}Kr	10	0.6
^{11}B	29	4.7	^{86}Kr	8.3	0.6
^{16}O	35	2.3	^{129}Xe	5.6	0.5

The Light Ion Guide

- mainly (p, n), (d, p) and (α, n) reactions, based on JYFL design
- also light-ion induced fission with heavy targets



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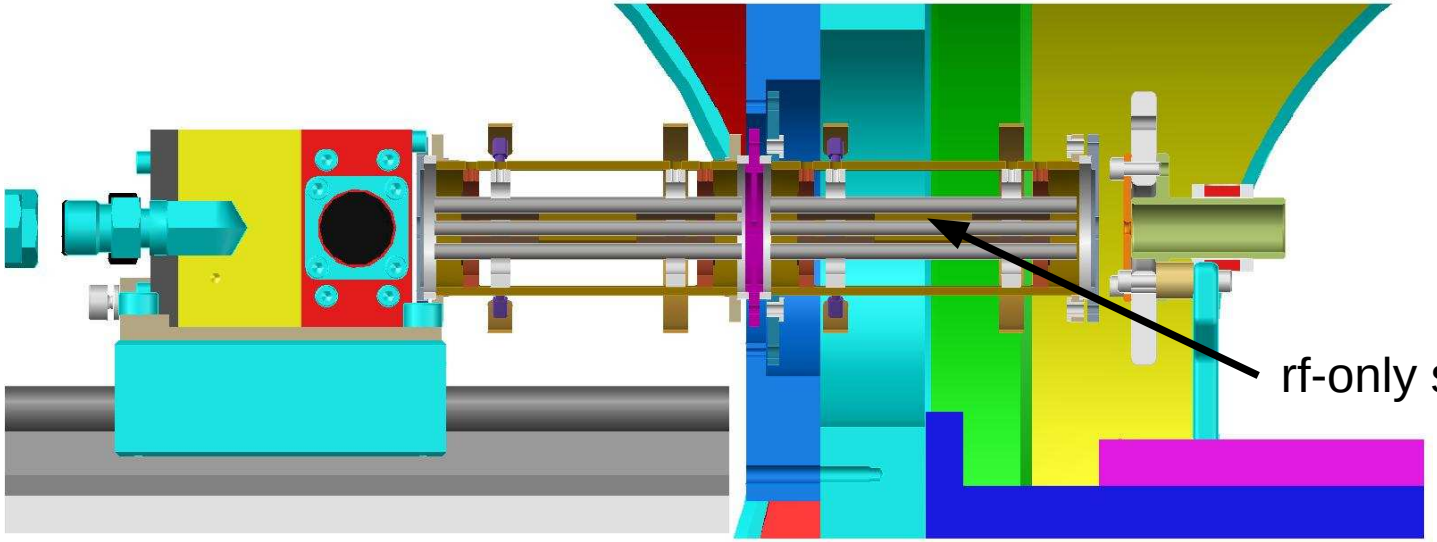
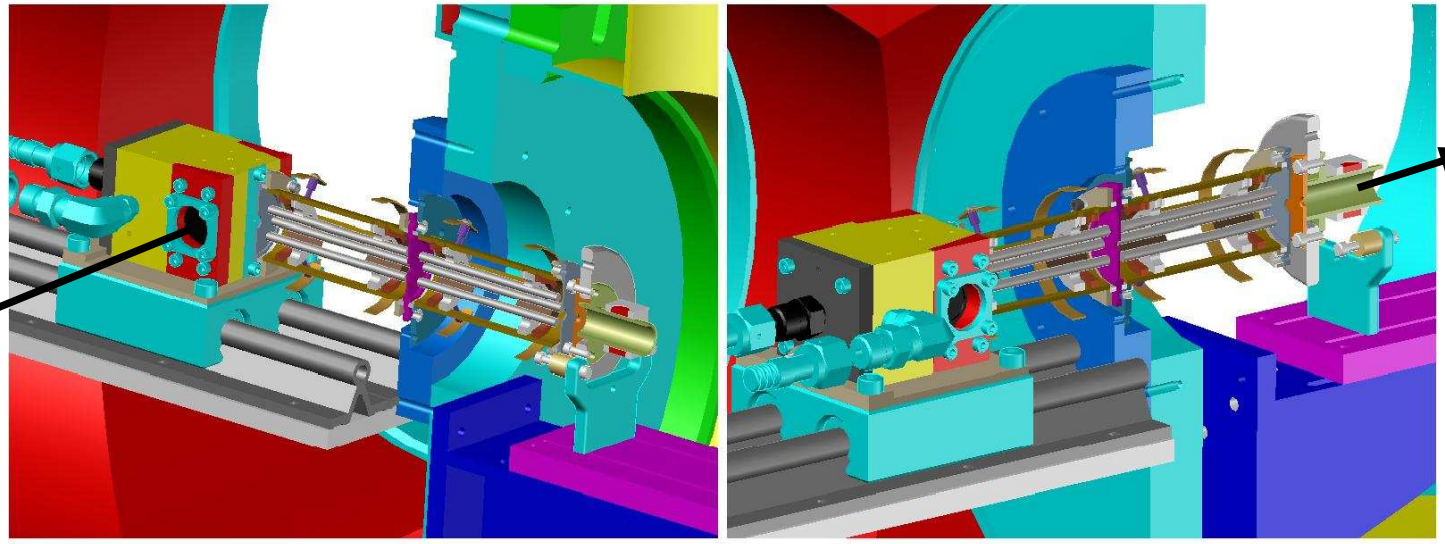
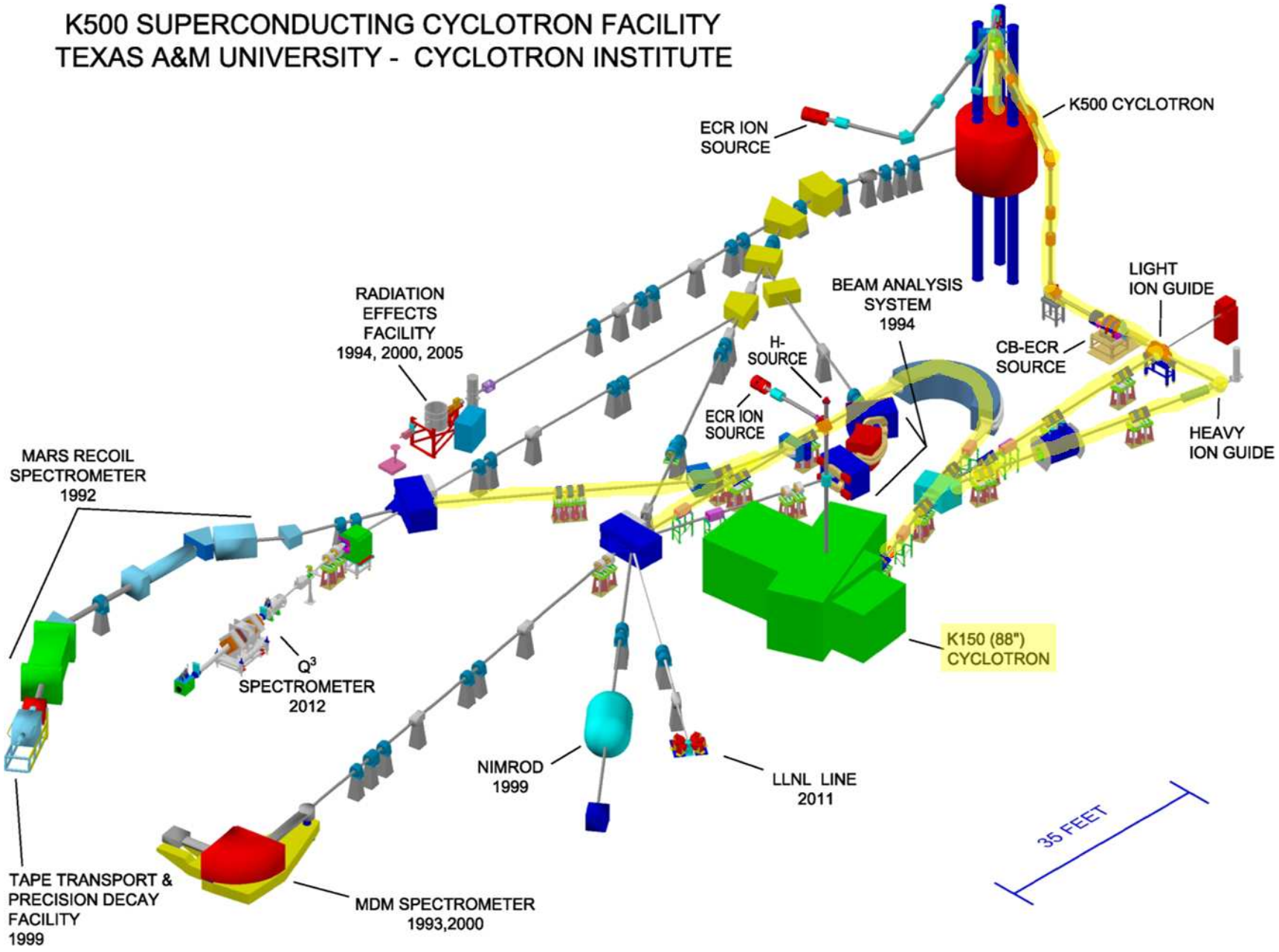




The Heavy Ion Guide



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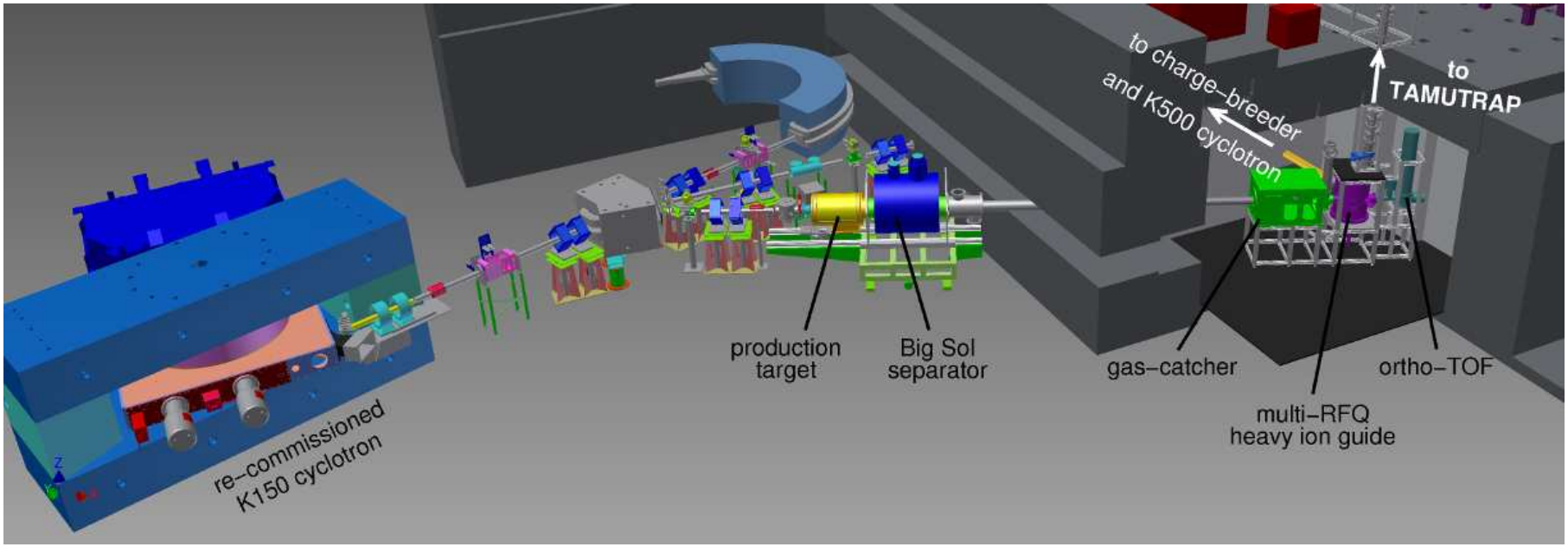
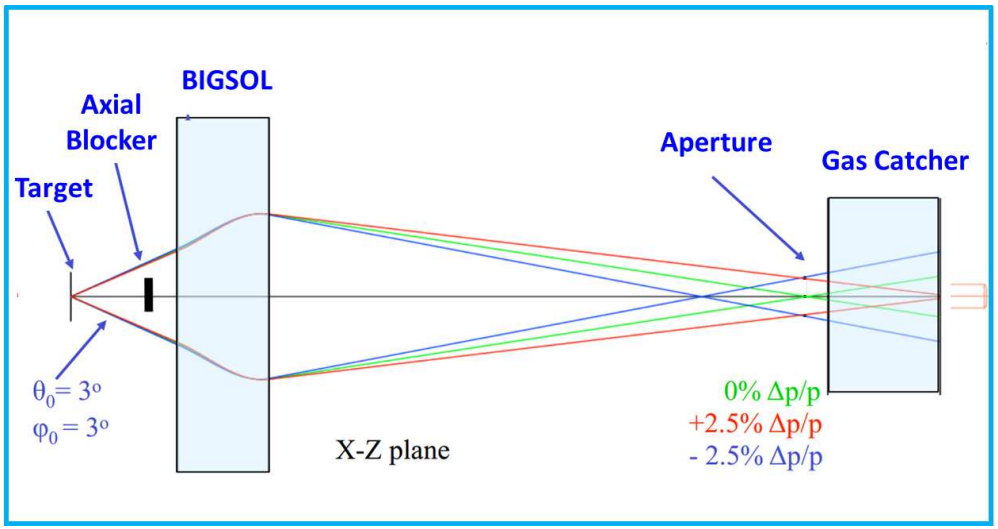


- heavy ion deep inelastic collisions and fragmentation
- fusion evapouration reaction



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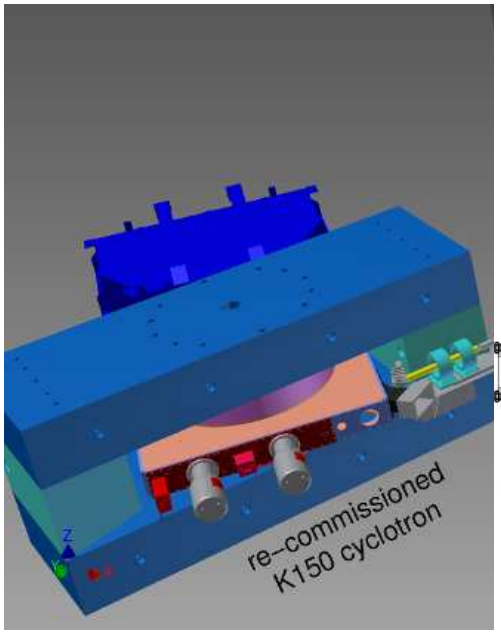

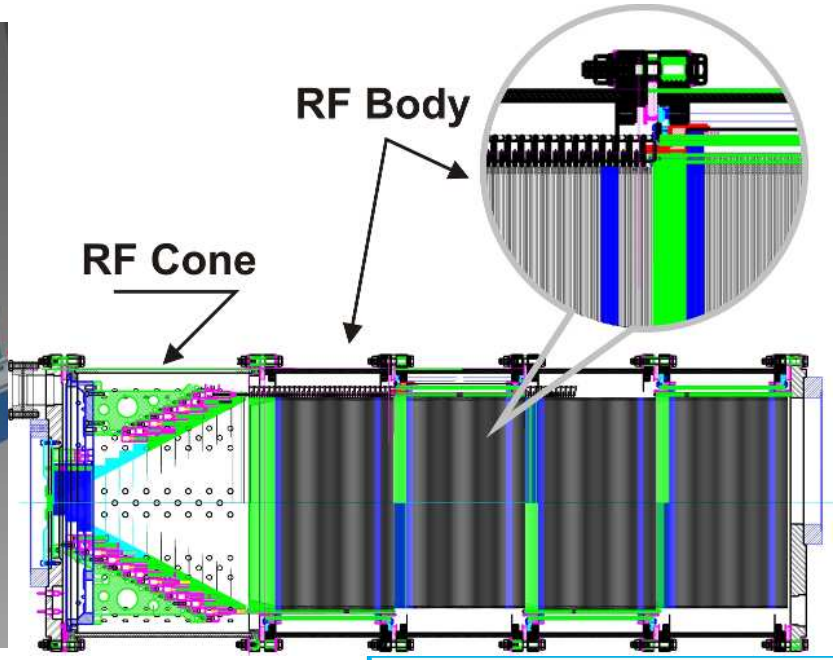

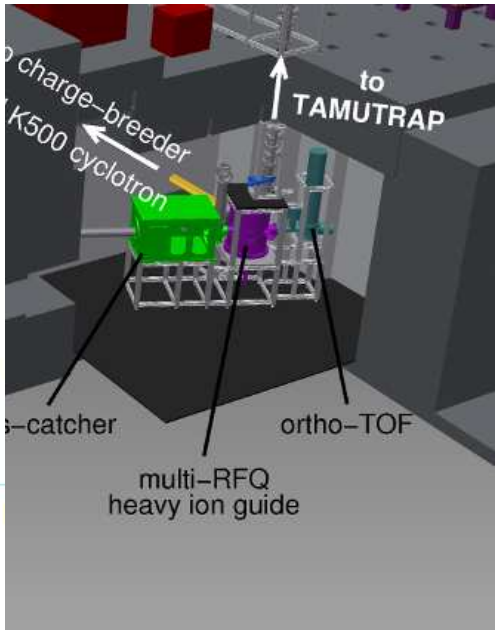

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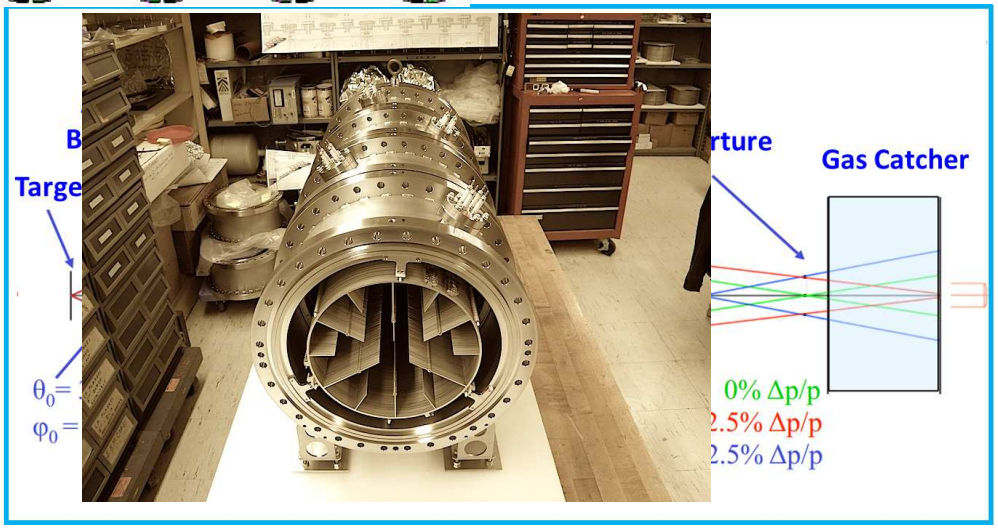


Expected RIB Production – LIG

Projected intensities after K500 (based on JYFL experience)

(p,n) product	Max energy [MeV/u]	Intensity [pps]
^{27}Si	57	6×10^3
^{50}Mn	45	2×10^4
^{54}Co	45	6×10^3
^{64}Ga	45	4×10^4
^{92}Tc	35	4×10^4
^{106}In	28	4×10^4
^{108}In	28	3×10^4
^{110}In	26	6×10^4

Expected RIB Production – HIG

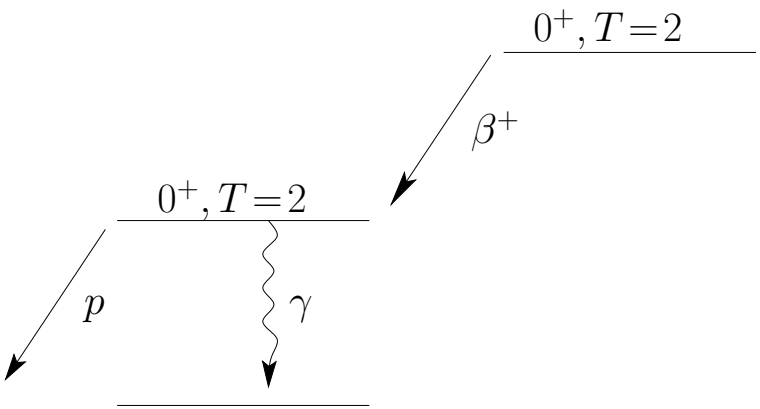
Projected intensities after K500 (calc by G. Souliotis)

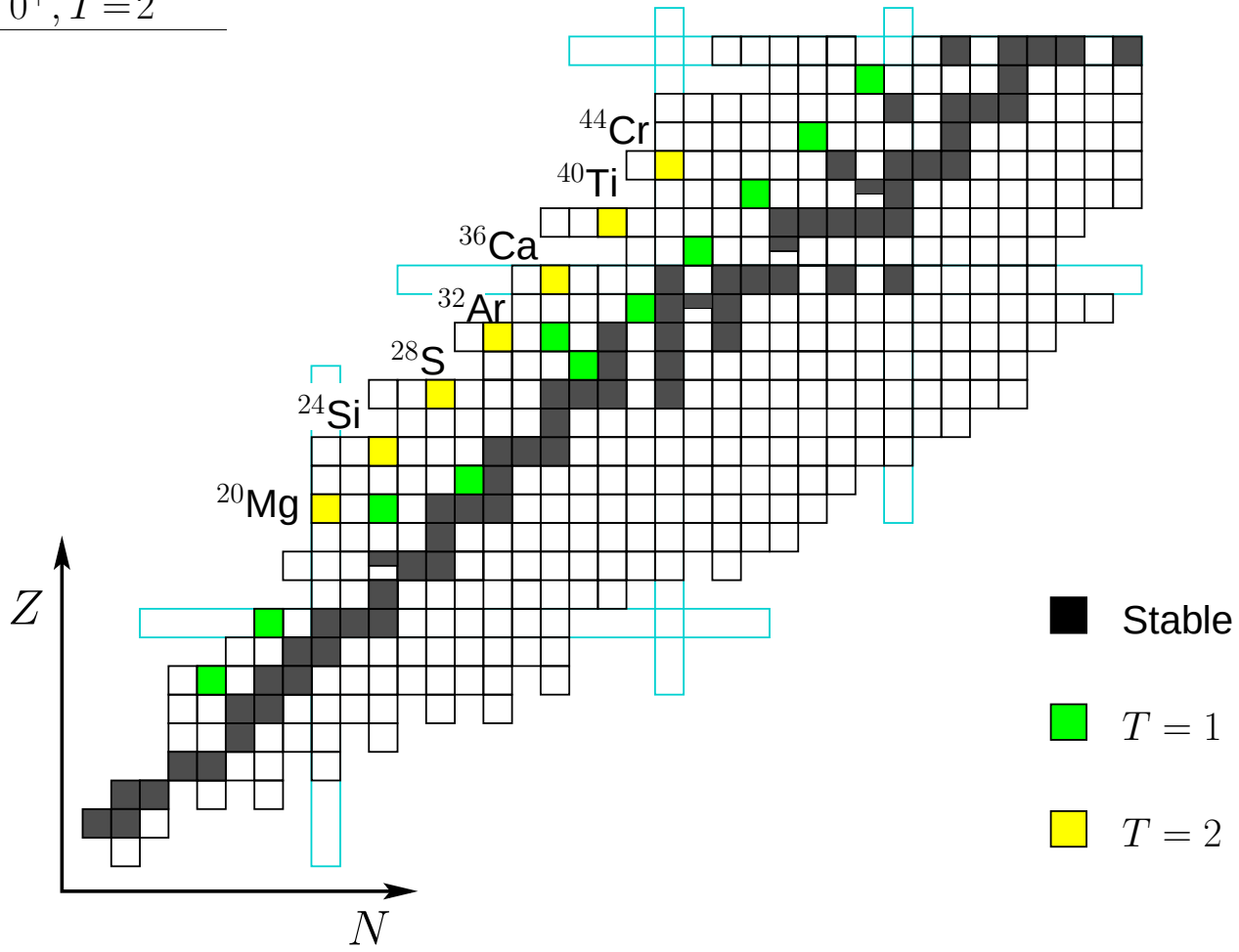
Isotope	Max energy [MeV/u]	Intensity [pps]	Isotope	Max energy [MeV/u]	Intensity [pps]
^{9}Li	45	3×10^6	^{7}Li	60	1×10^6
^{11}Be	45	1×10^6	^{8}Be	70	2×10^6
^{22}O	40	4×10^4	^{11}O	63	2×10^6
^{24}Ne	40	1×10^4	^{14}Ne	70	1×10^5
^{32}Mg	40	2×10^4	^{22}Mg	57	5×10^4
^{38}S	36	4×10^5	^{23}S	60	2×10^3
^{42}Ar	39	5×10^5	^{27}Ar	62	2×10^3
^{62}Fe	38	3×10^4	^{62}Fe	47	3×10^2
^{60}Cr	32	1×10^3	^{65}Ga	45	1×10^4

Overview

1. **Fundamental symmetries**
   - brief **motivation**
   - **game plan** for testing the SM
2. **Cyclotron Institute upgrade project**
   - overview
   - expected **RIB production**
3. **TAMU Penning Trap (being built)**
   - **physics** of superallowed β decay
   - **ion trapping** of proton-rich nuclei at T-REX

$T = 2$ superallowed decays





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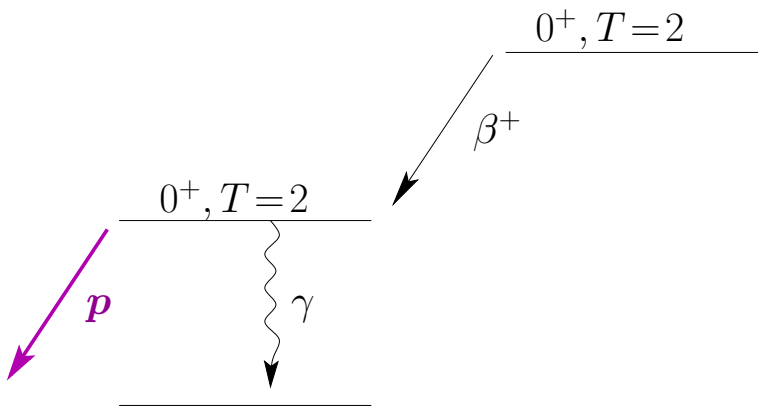

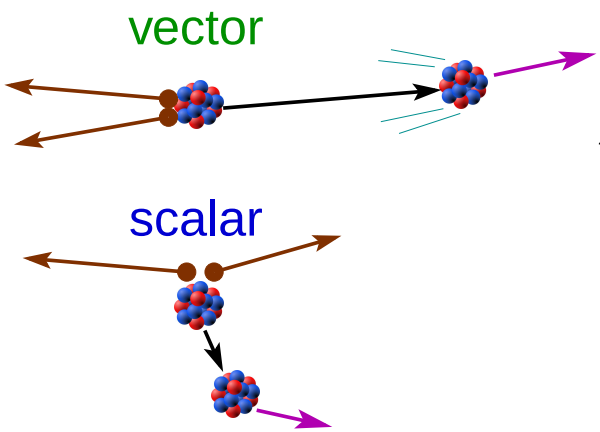

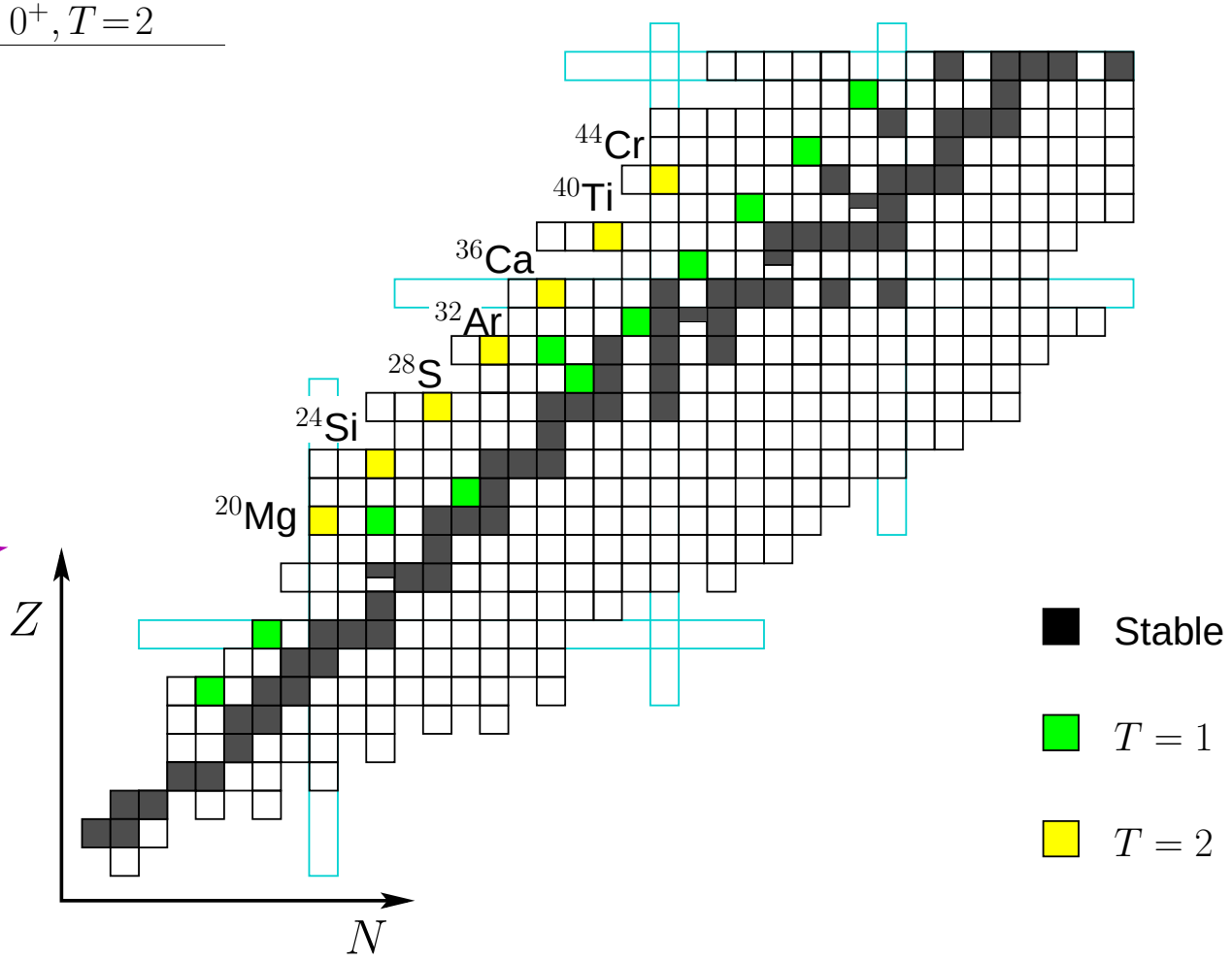

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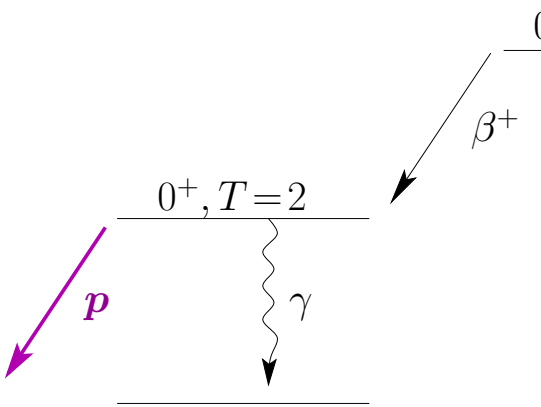

pure Fermi decay $\Leftrightarrow$ minimal structure effects; decay rate simply given by:

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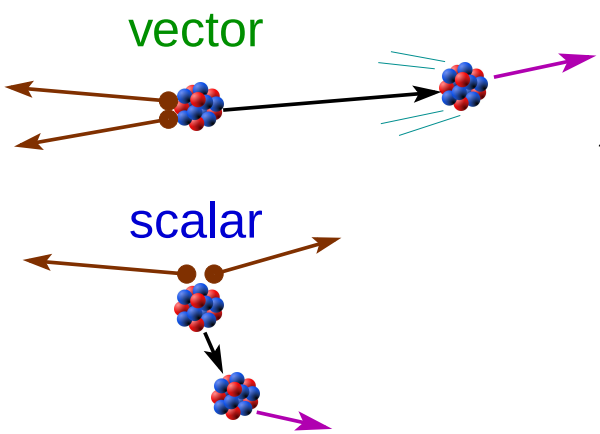

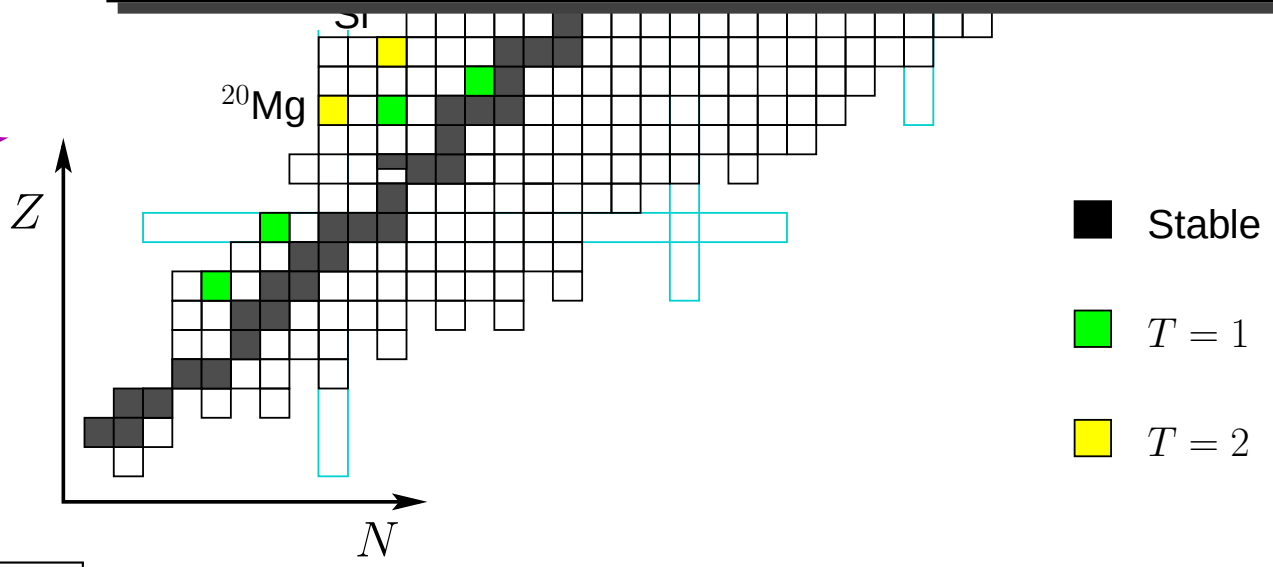

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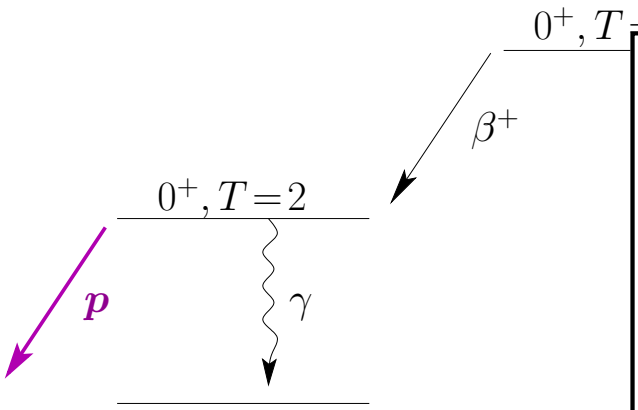

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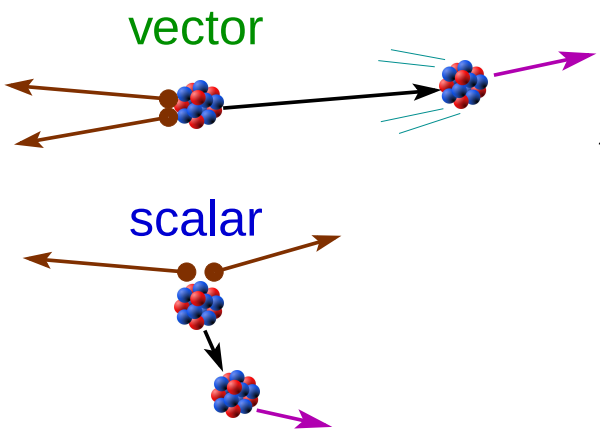

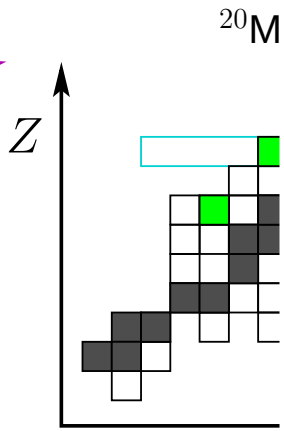

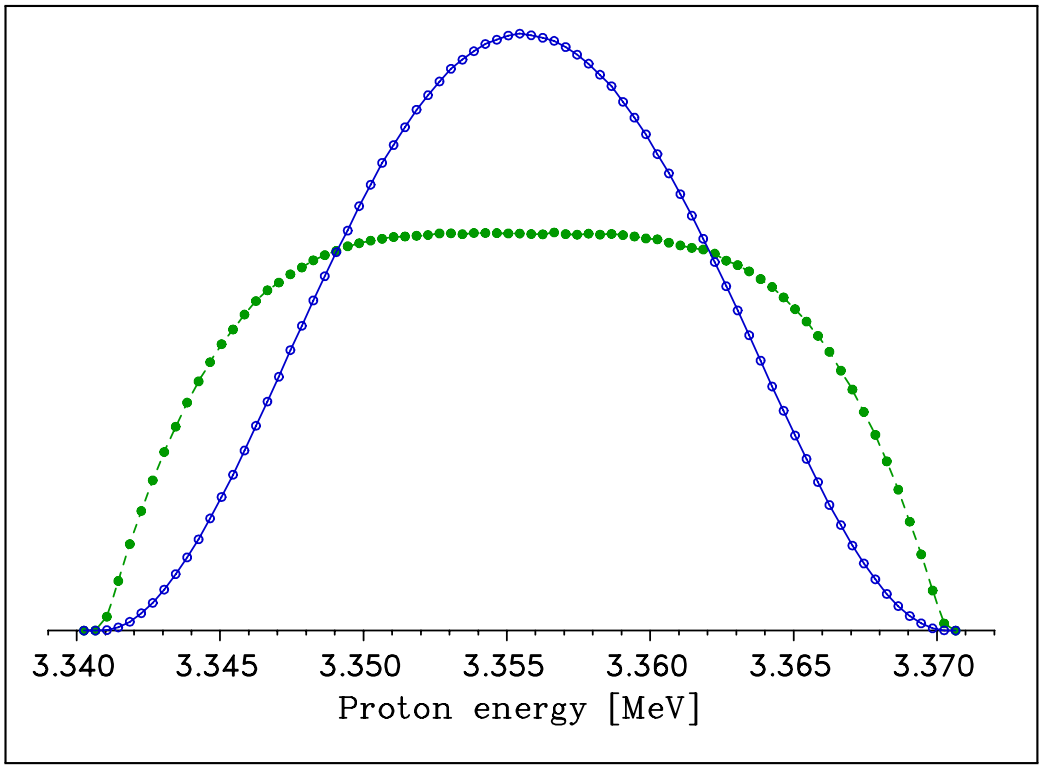

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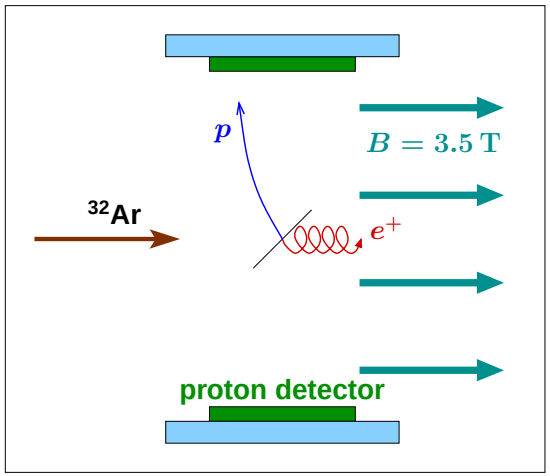

VOLUME 83, NUMBER 7 PHYSICAL REVIEW LETTERS 16 AUGUST 1999

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[1]*Department of Physics, University of Washington, Seattle, Washington 98195-1560*
[2]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556*
[3]*Instituto de Estructura de la Materia, CSIC, E-28006 Madrid, Spain*
[4]*EP Division, CERN, Geneva, Switzerland CH-1211*

(Received 24 February 1999)

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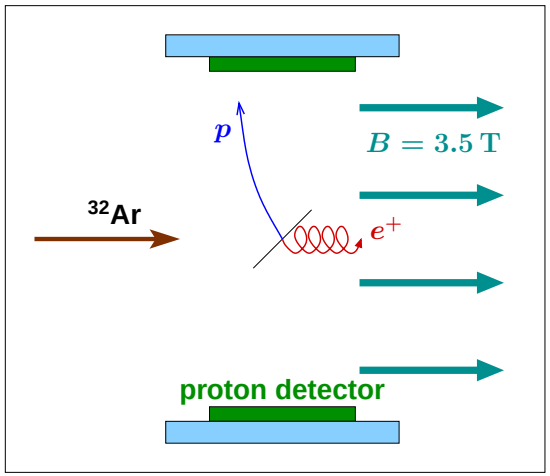

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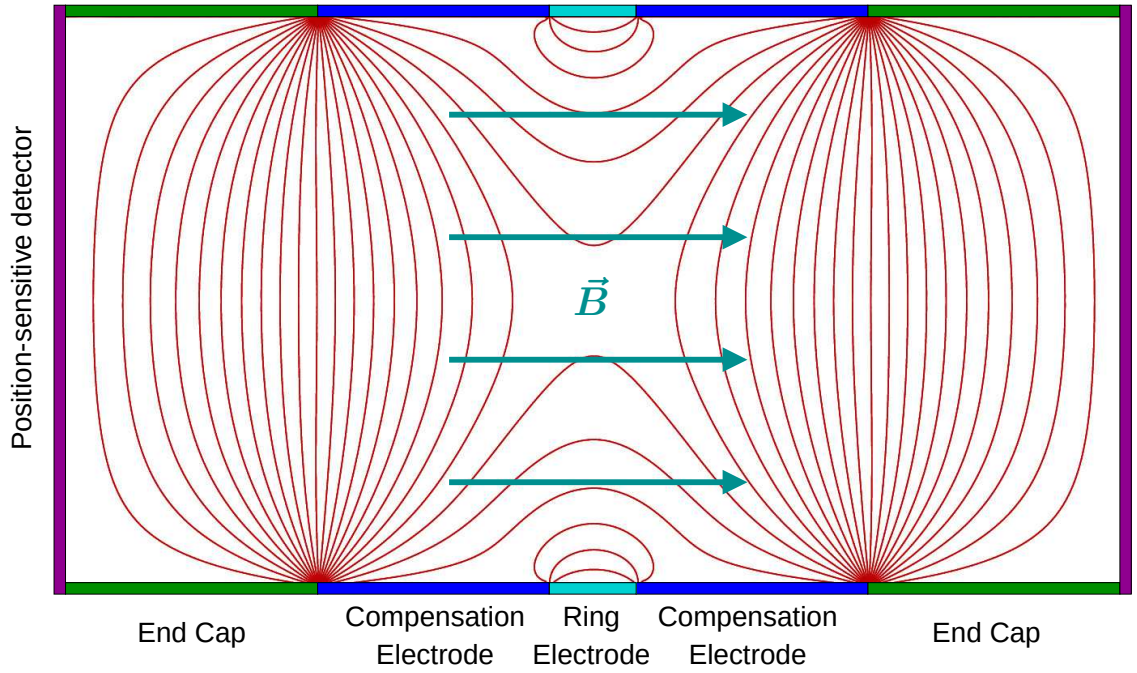
Mehlman *et al.*, NIM **A712**, 9 (2013)



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$\rightsquigarrow$ increase sensitivity and solid angle using a Penning trap to observe $e - p$ coincidences!

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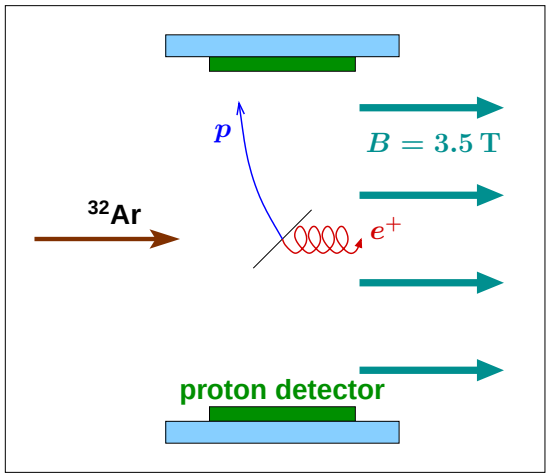

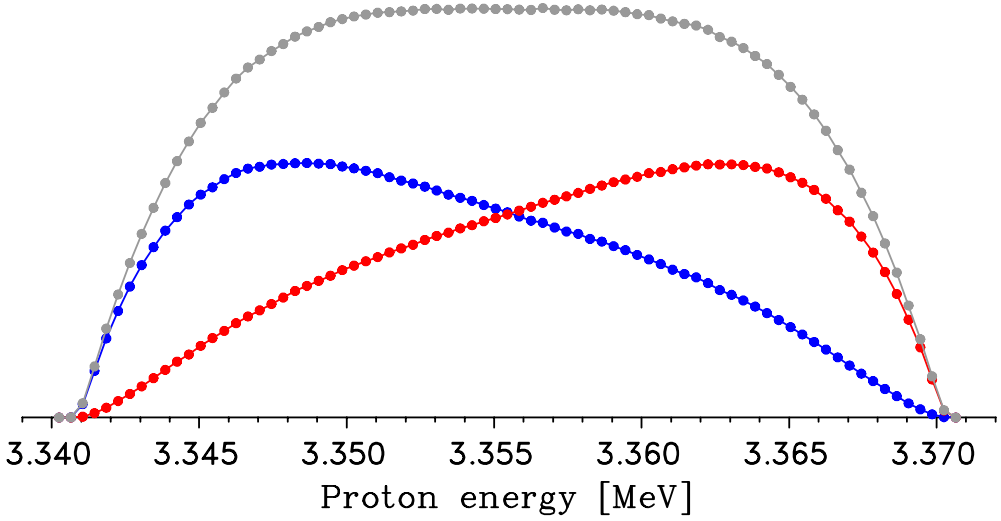

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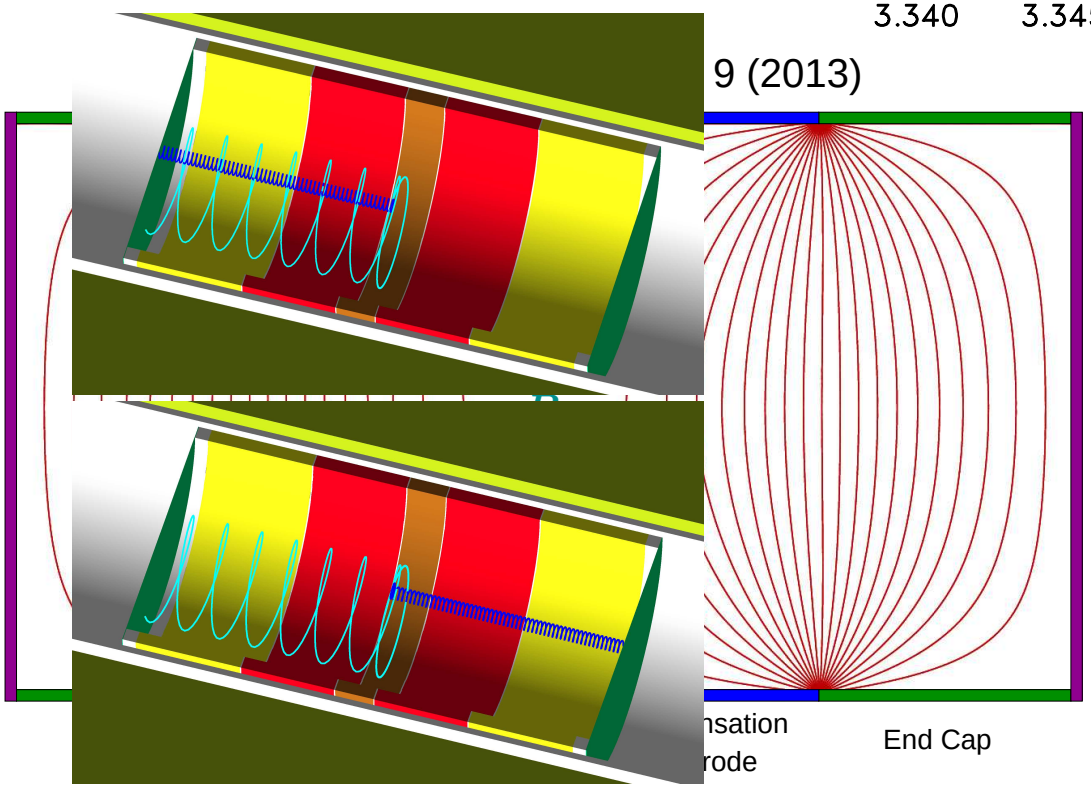

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The Texas A&M University Penning Trap

- ID = 180 mm: **very open-geometry** ion trap for RIBs!
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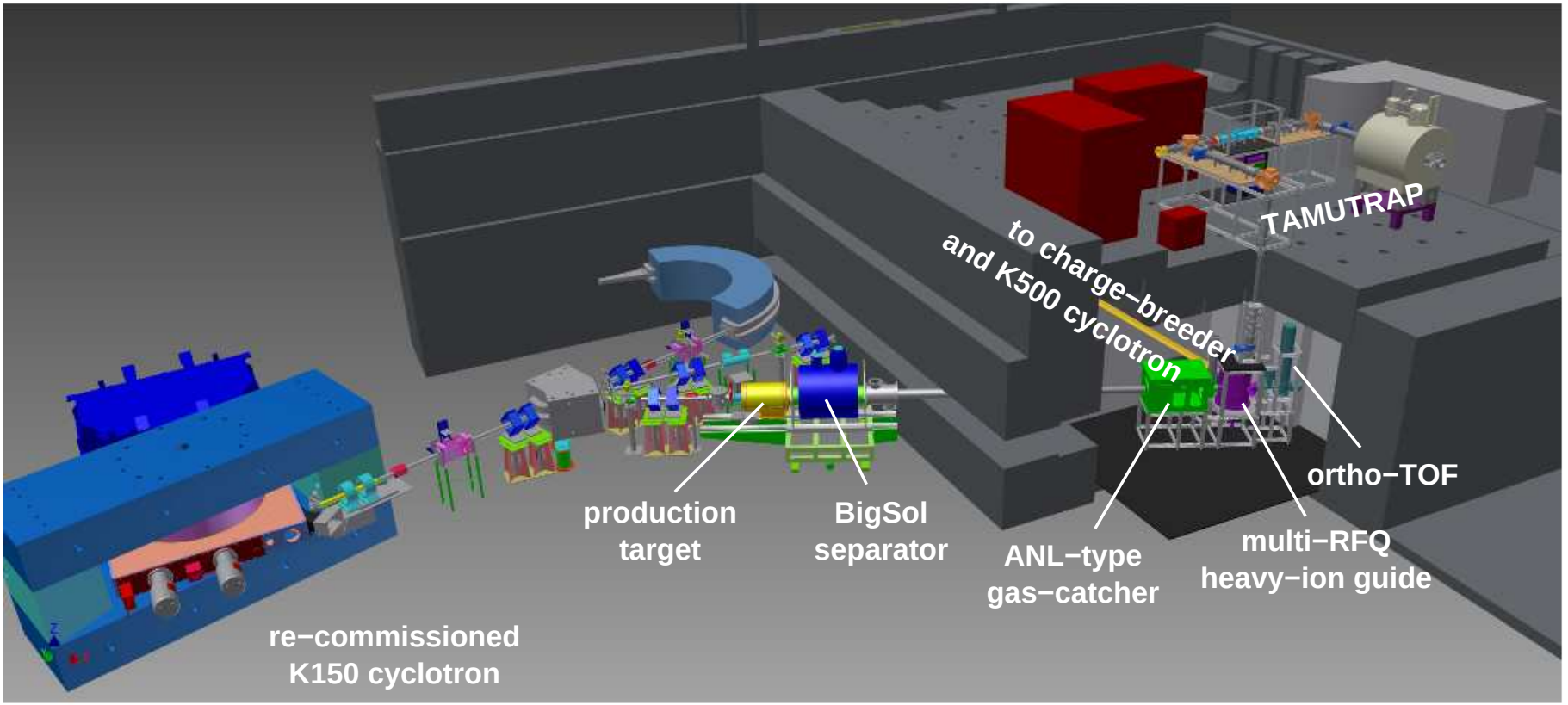

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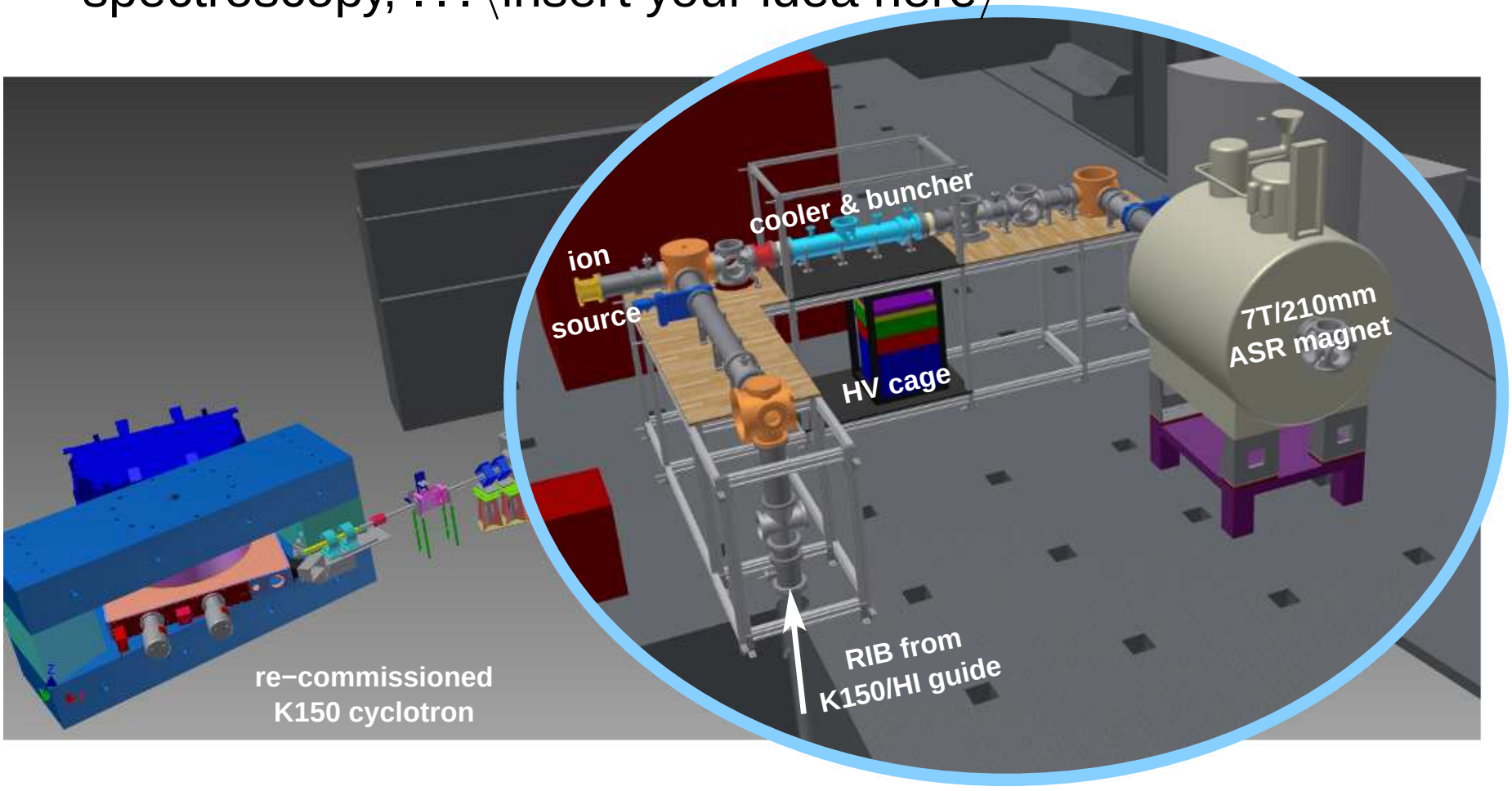
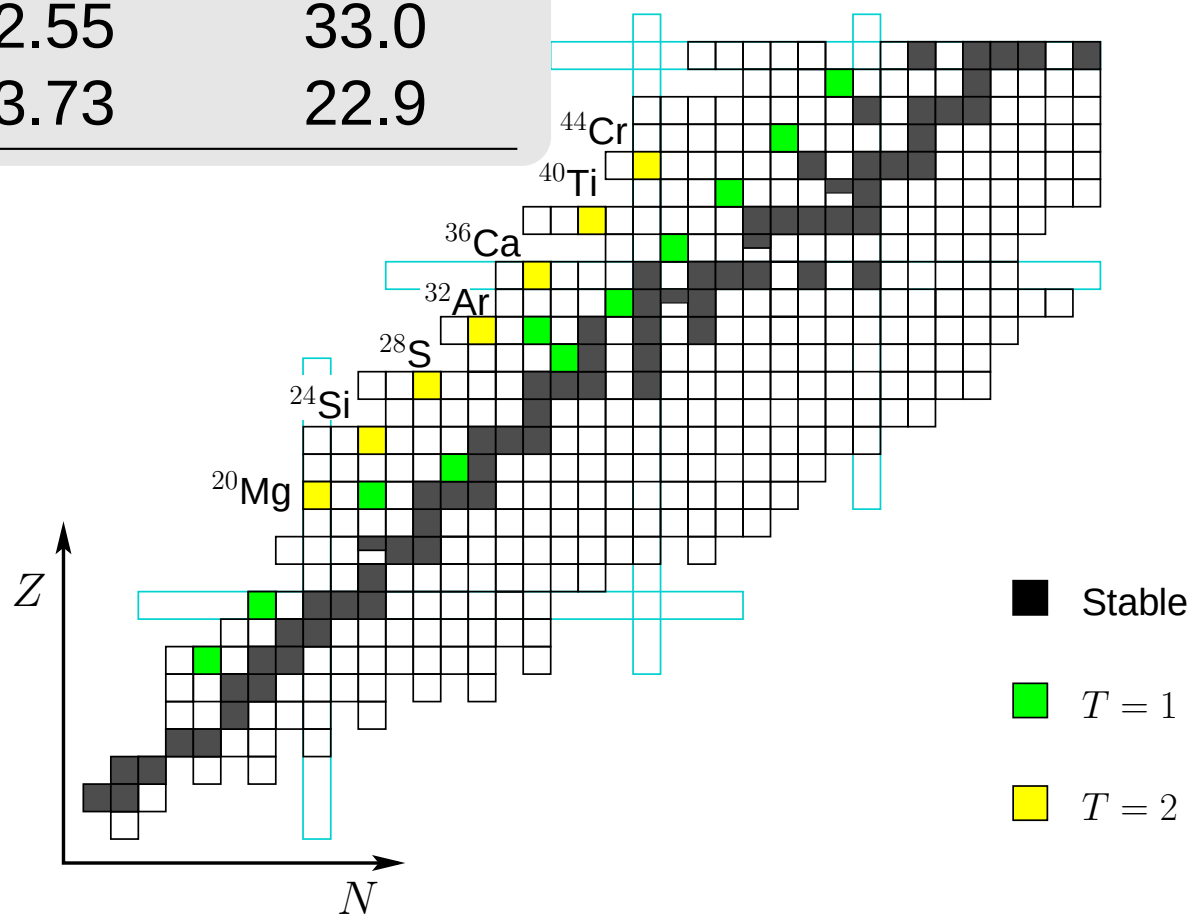


K500 production of $T = 2$ nuclei

Isotope	Intensity	E_p [MeV]	R_L [mm]
^{20}Mg	1×10^4	4.28	42.7
^{24}Si	6×10^5	3.91	40.8
^{28}S	1×10^5	3.70	39.7
^{32}Ar	1×10^5	3.36	37.8
^{36}Ca	2×10^4	2.55	33.0
^{40}Ti	7×10^5	3.73	22.9



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Biggest hits/worries:

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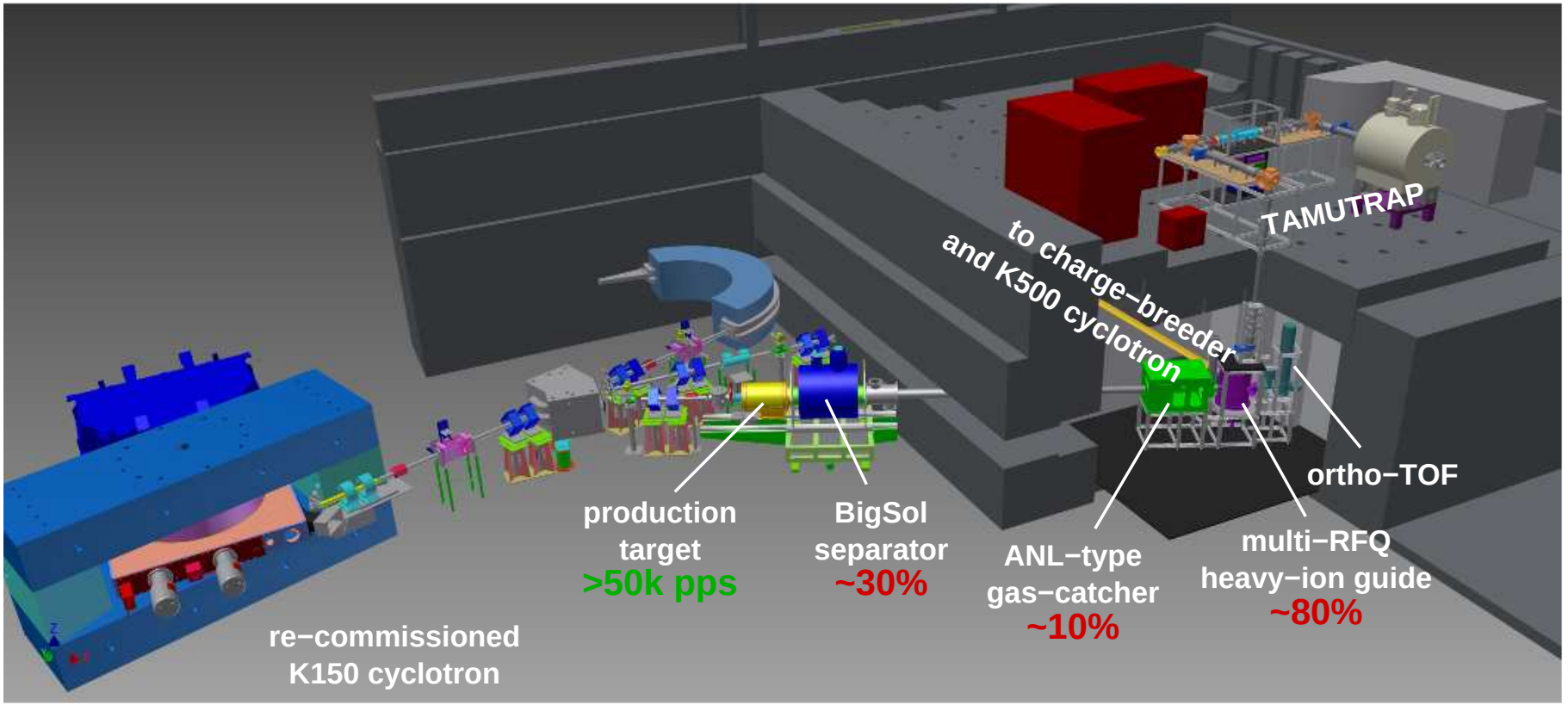

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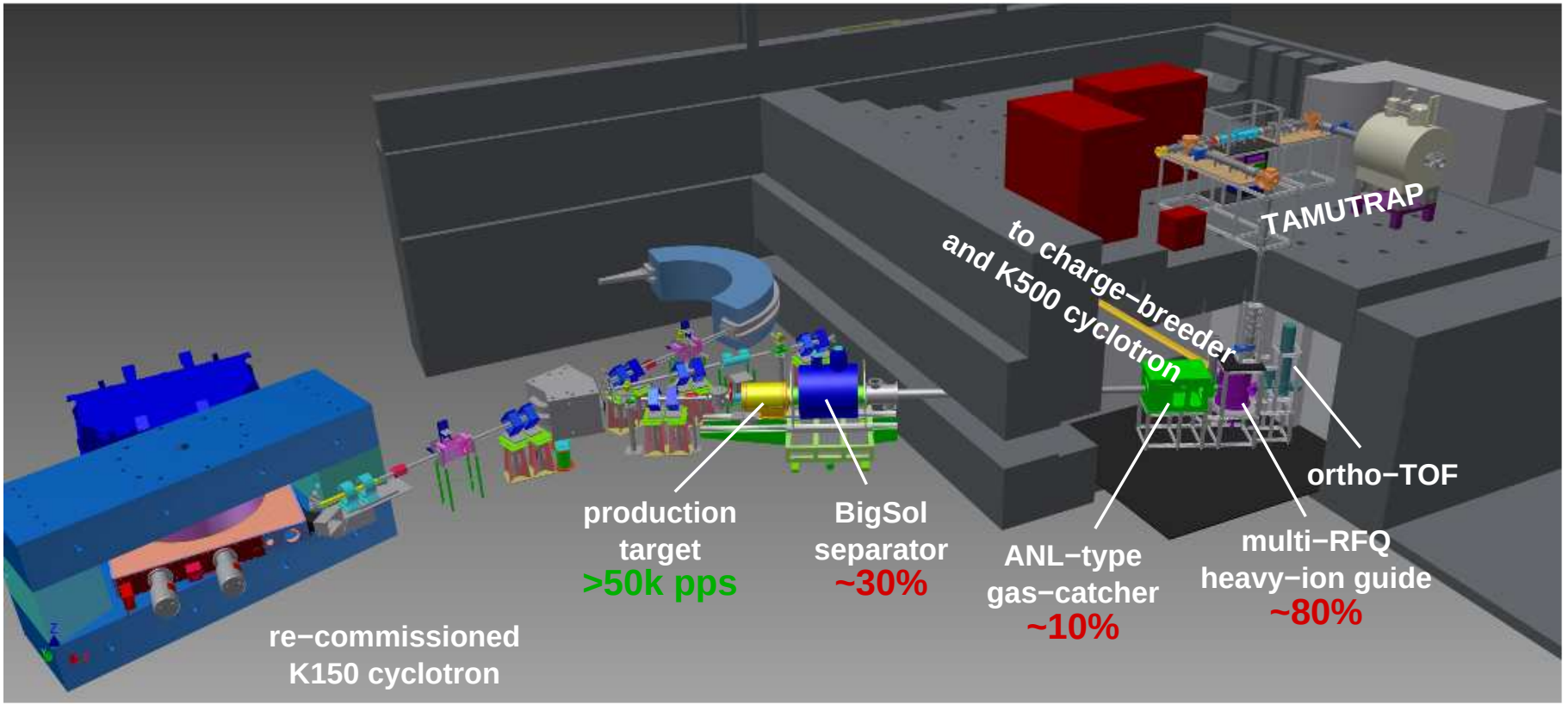

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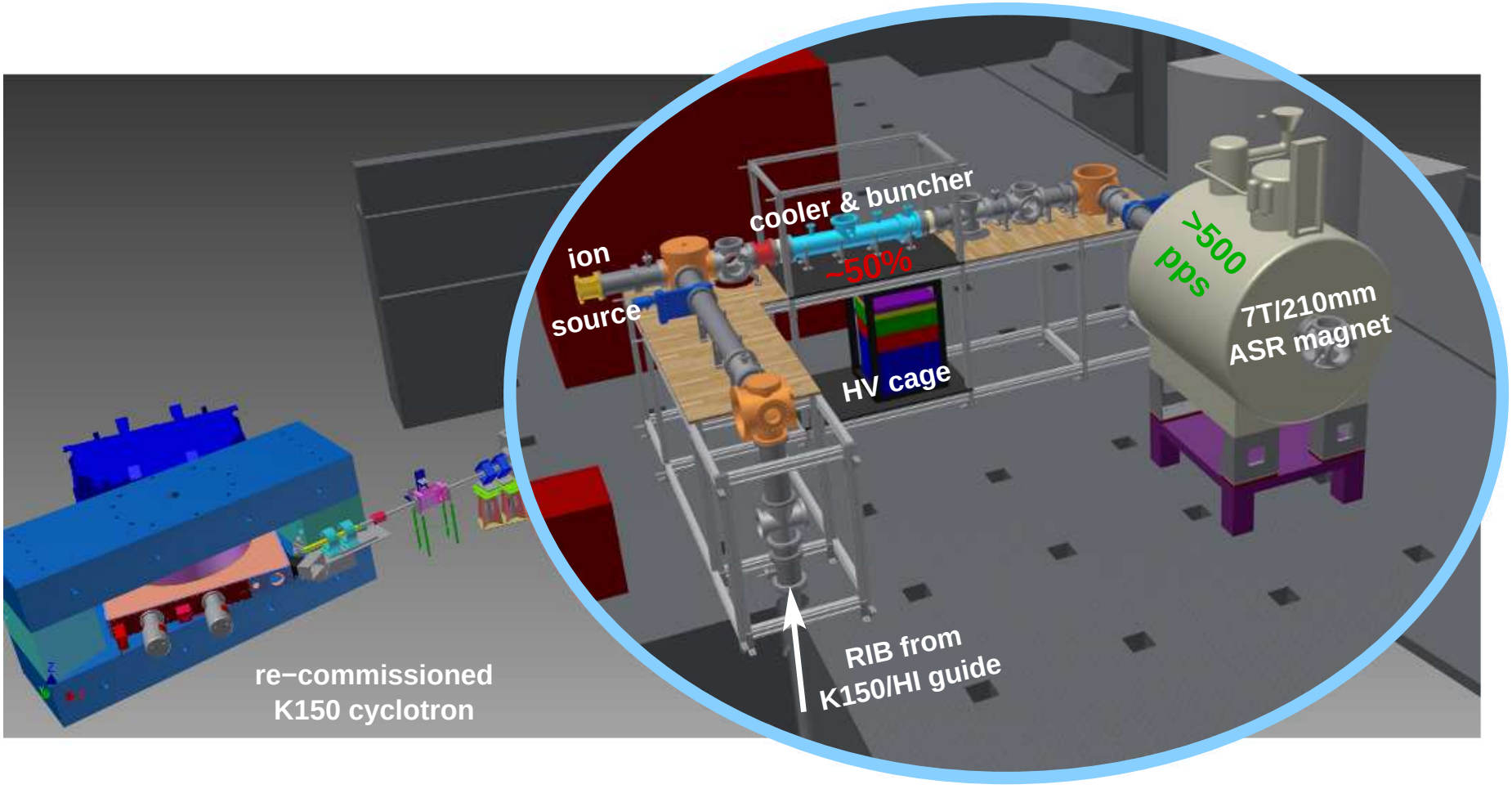

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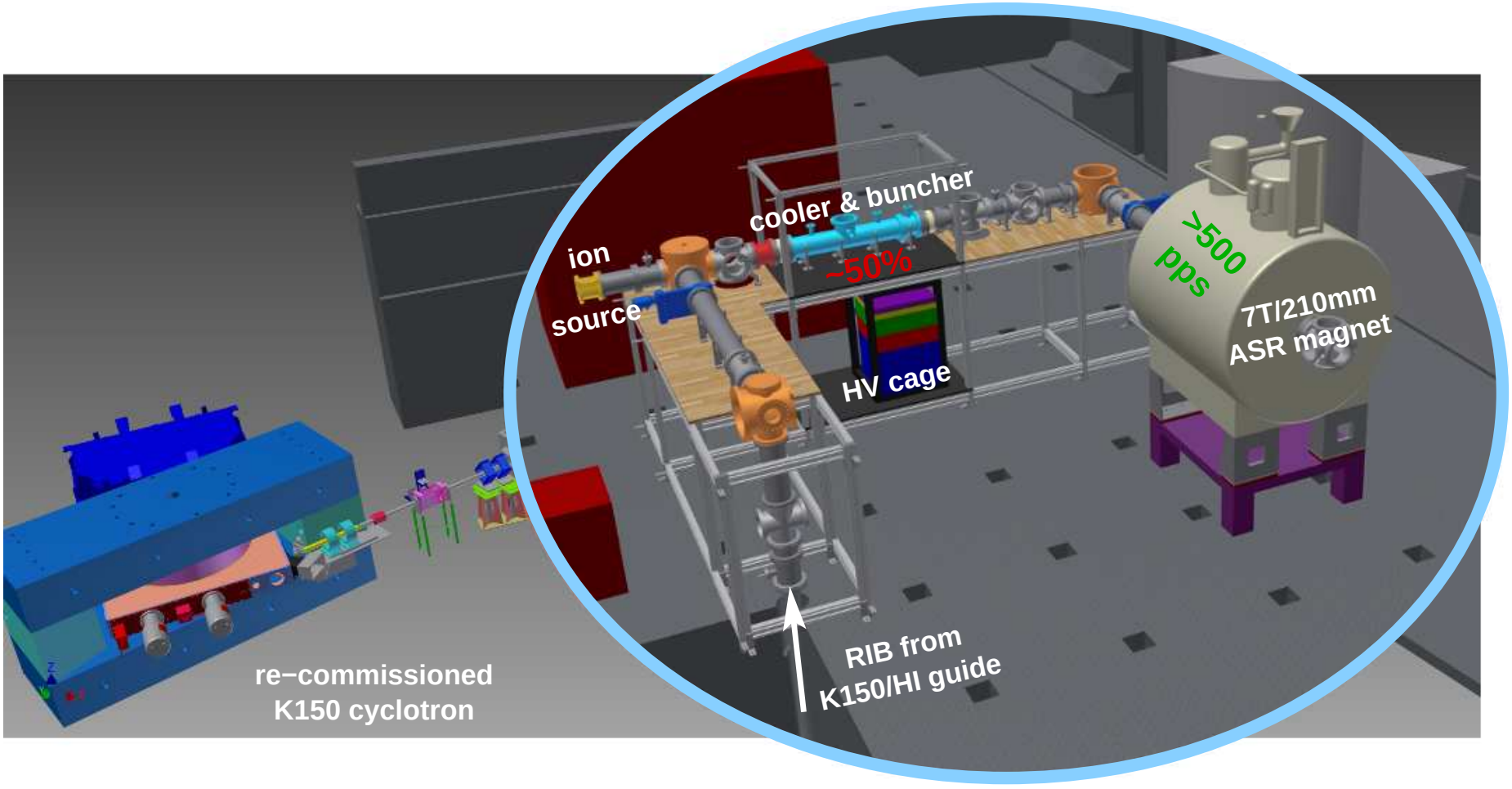

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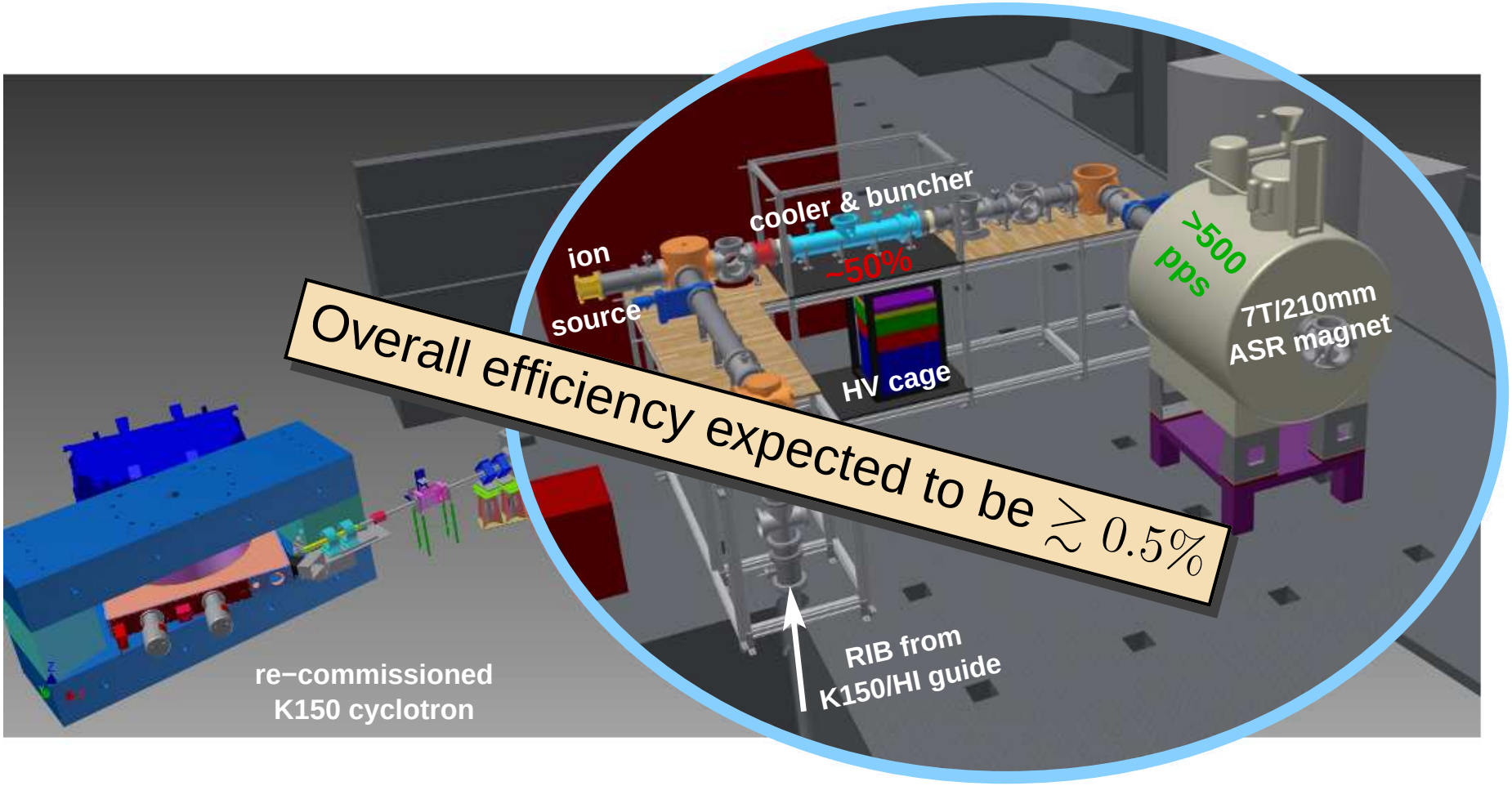

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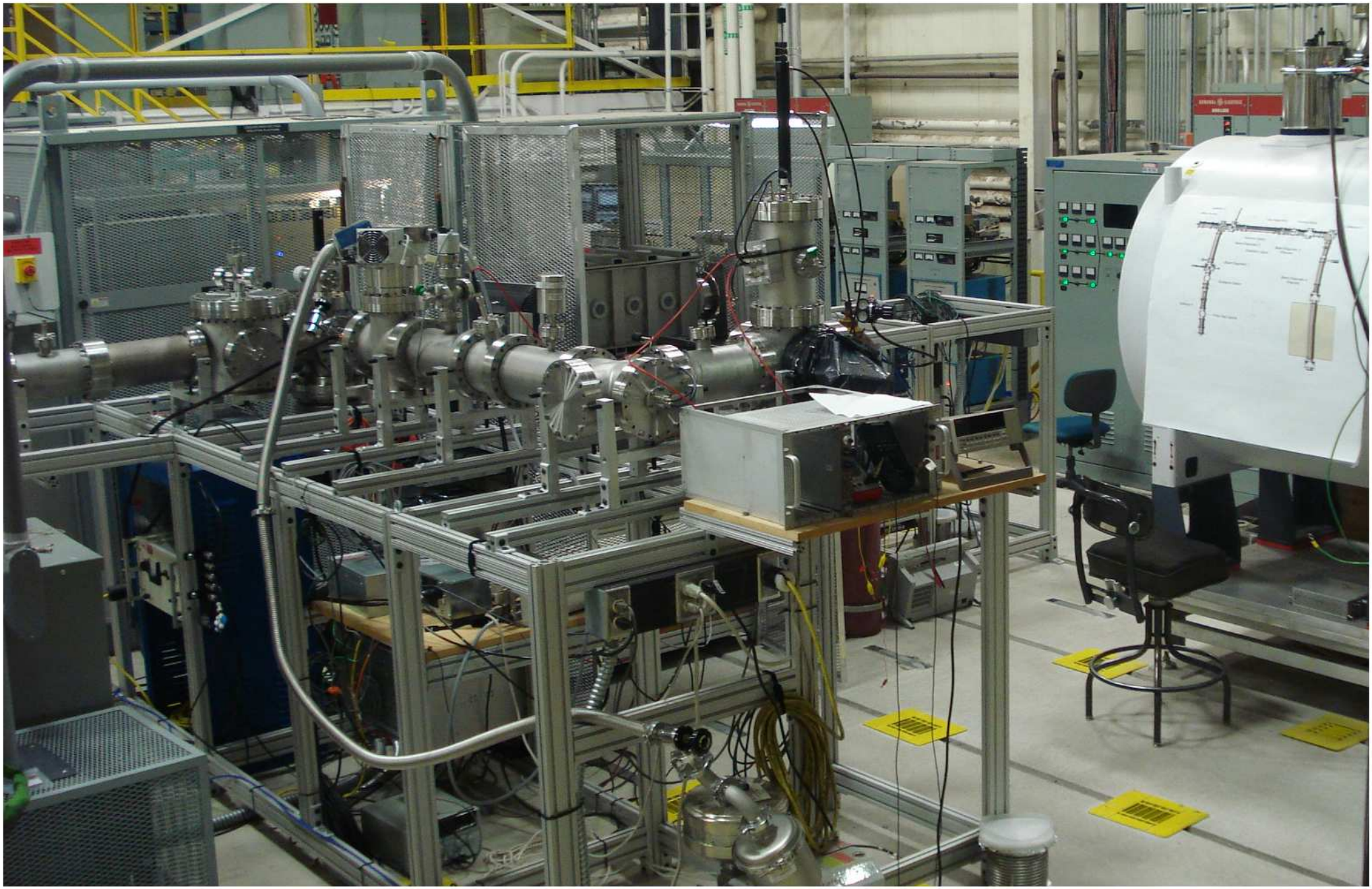

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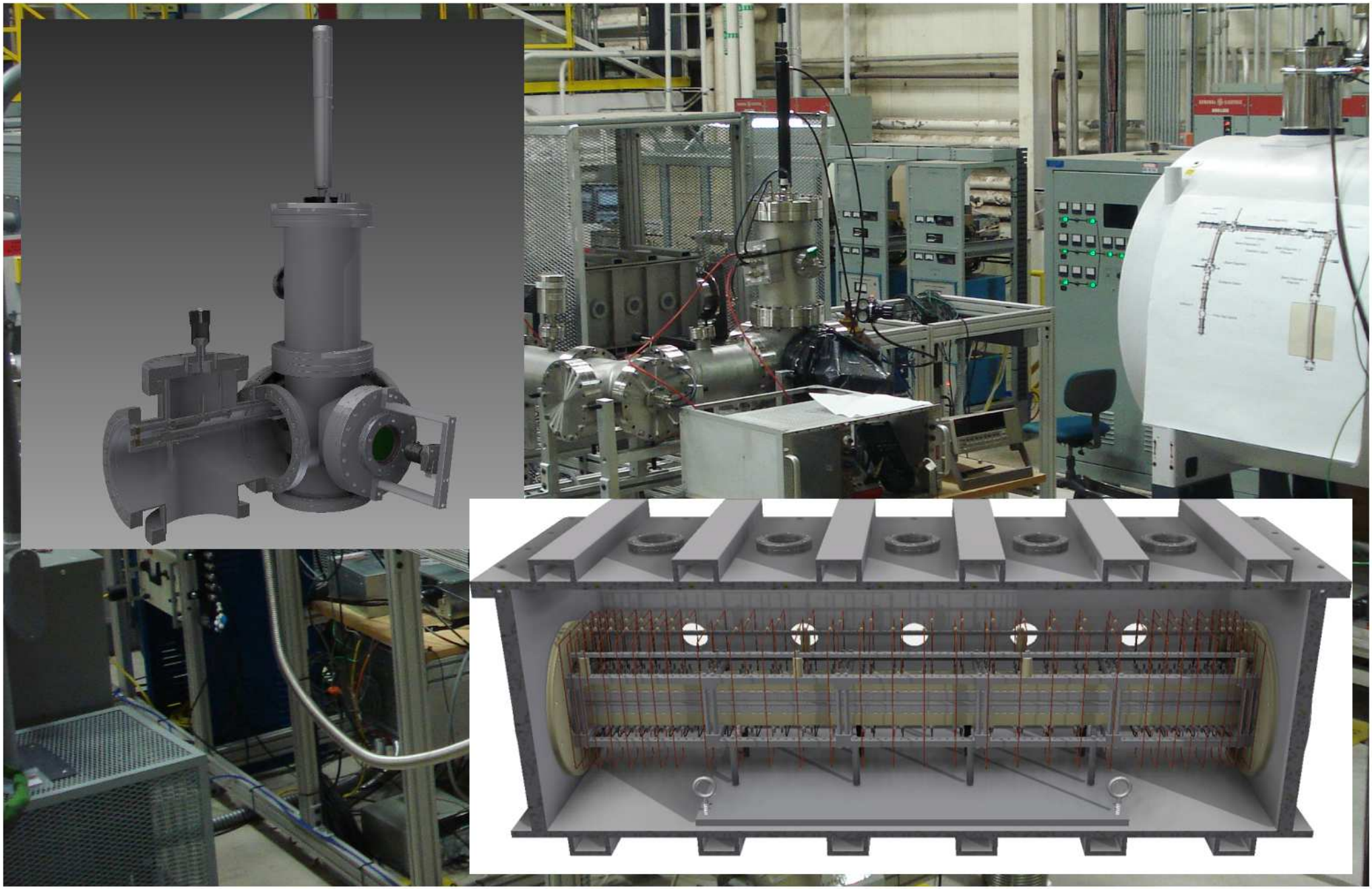

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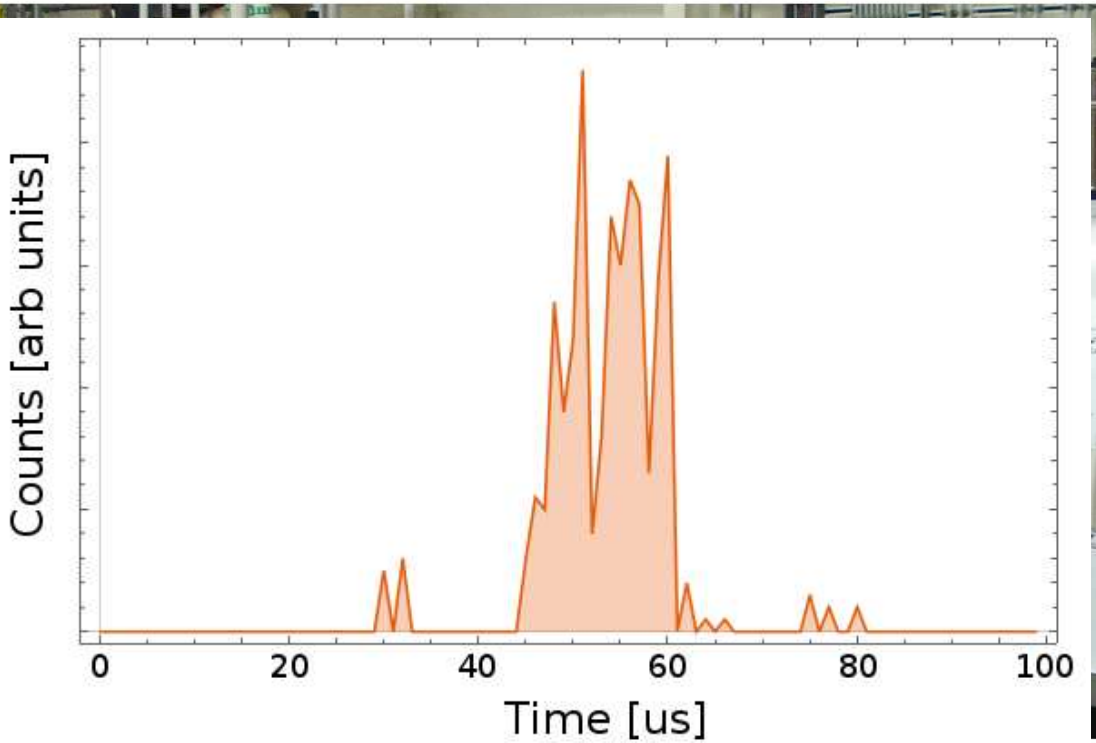

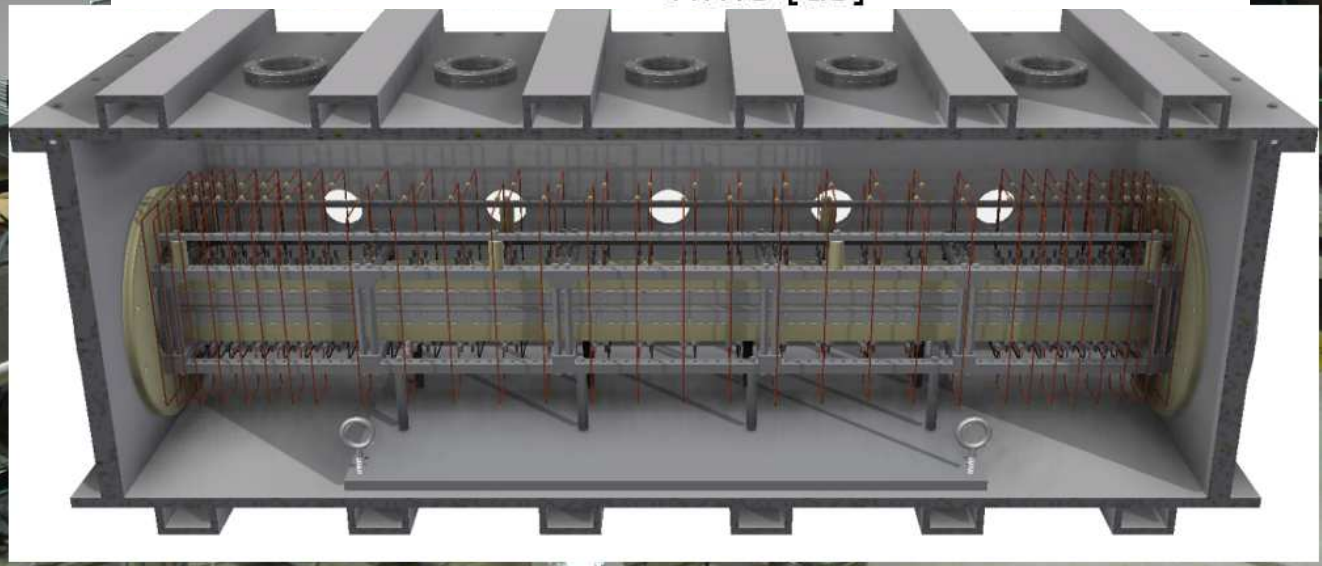

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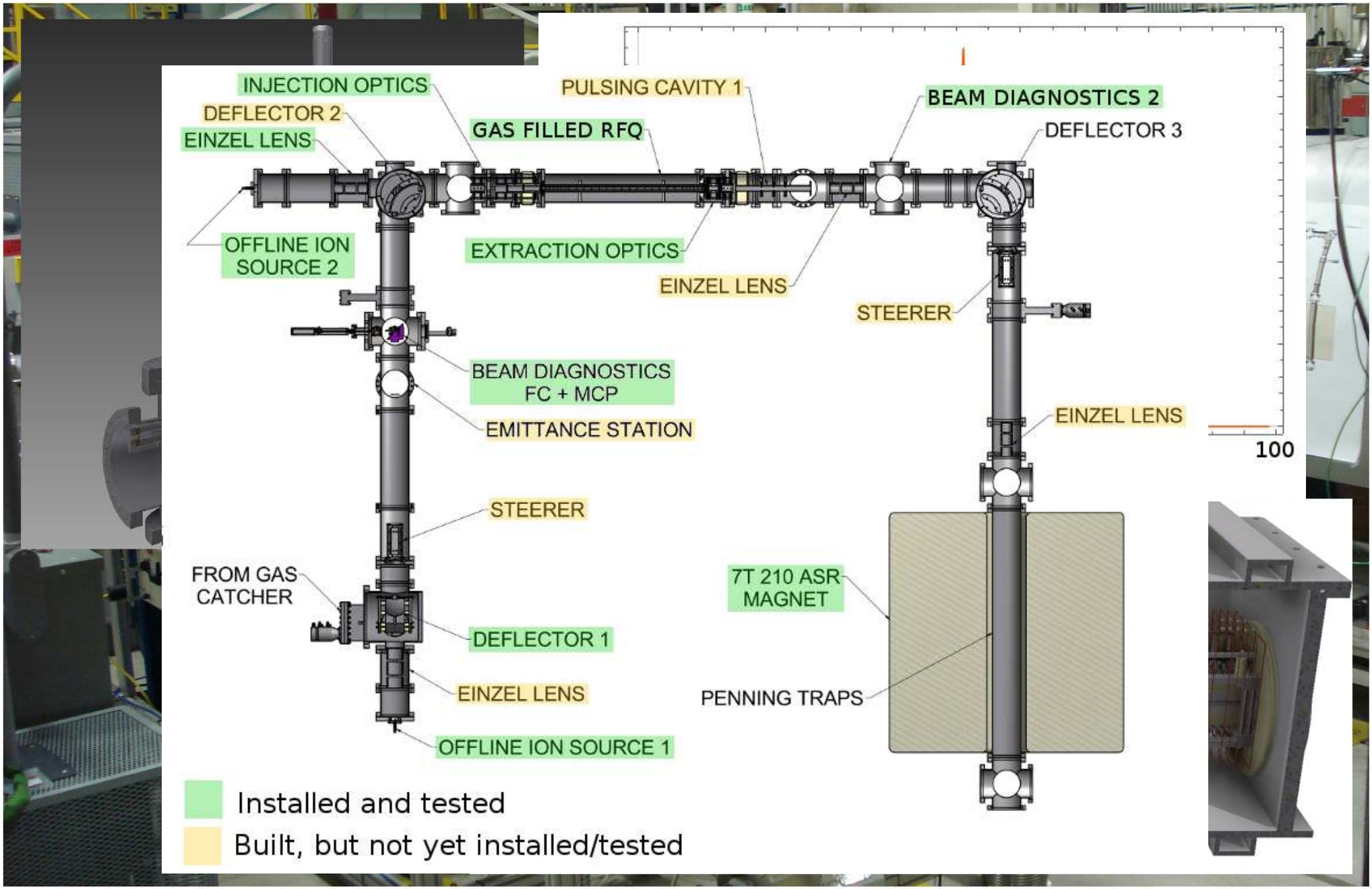

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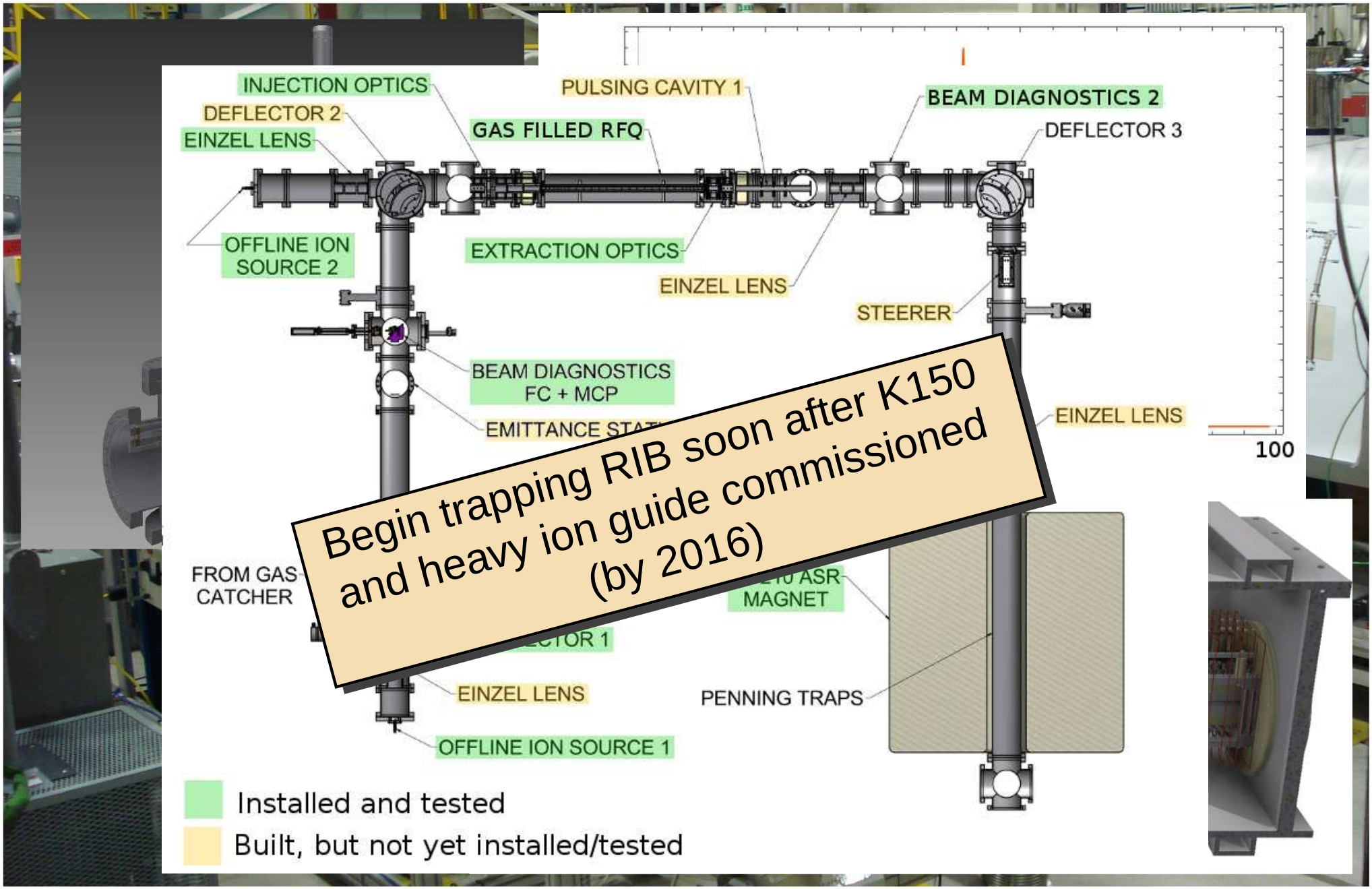

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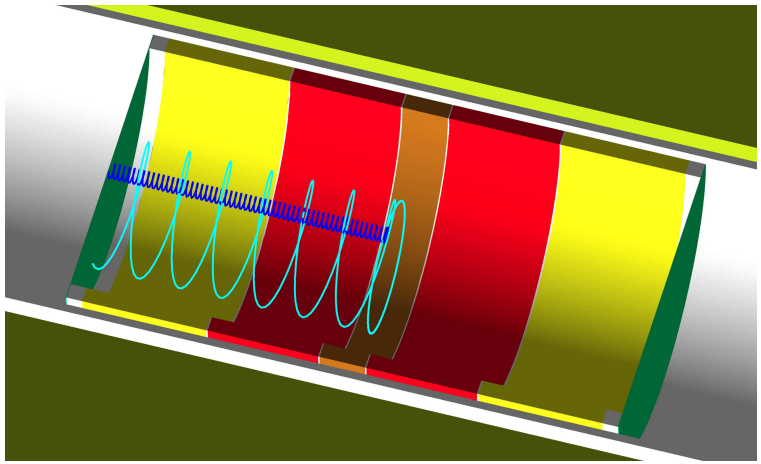

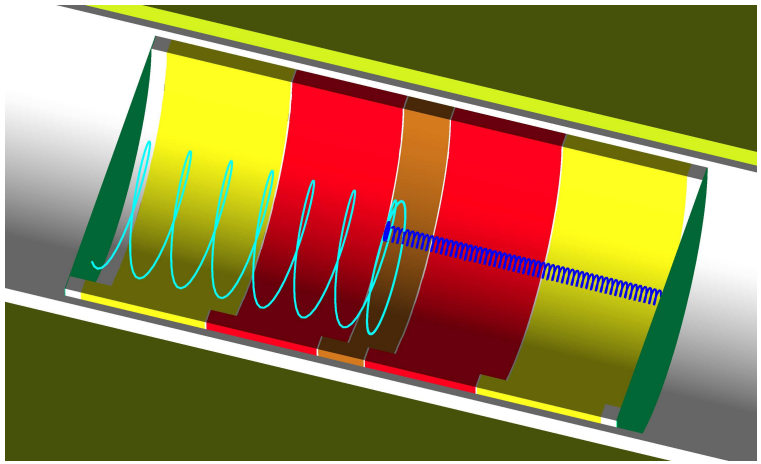

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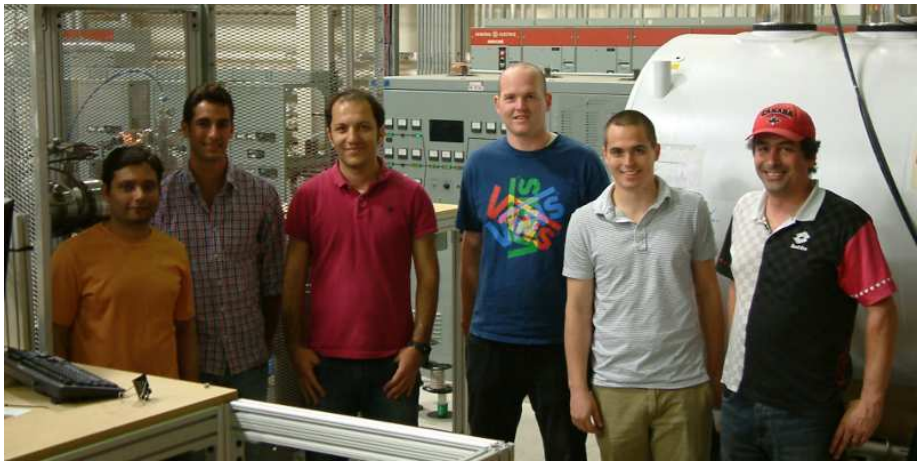
Arigatou Gozaimasu

TAMU members:
Mike Mehlman, Praveen Shidling, Yakup Boran; Eames Bennett



This community must be the **friendliest** in all of science. . . !
Many thanks to all who have helped:

- Sage advice/drawings from TITAN (Dilling, Kwiatkowski, Good), CPT (Savard, Clark), LEBIT (Ringle, Bollen)
- Local support from the Cyclotron Institute (Tabacaru, Chubaryan, . . .)

Also, thank$ to

DOE DE-FG02-93ER40773, Early Career ER41747

TAMU/Cyclotron Institute

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Happy to collaborate — let's trade beamtime for expertise!