The Cyclotron Institute Upgrade at Texas A&M

and

Polarized correlation studies with ^{37}K at ISAC/TRIUMF

Dan Melconian

June 2, 2009

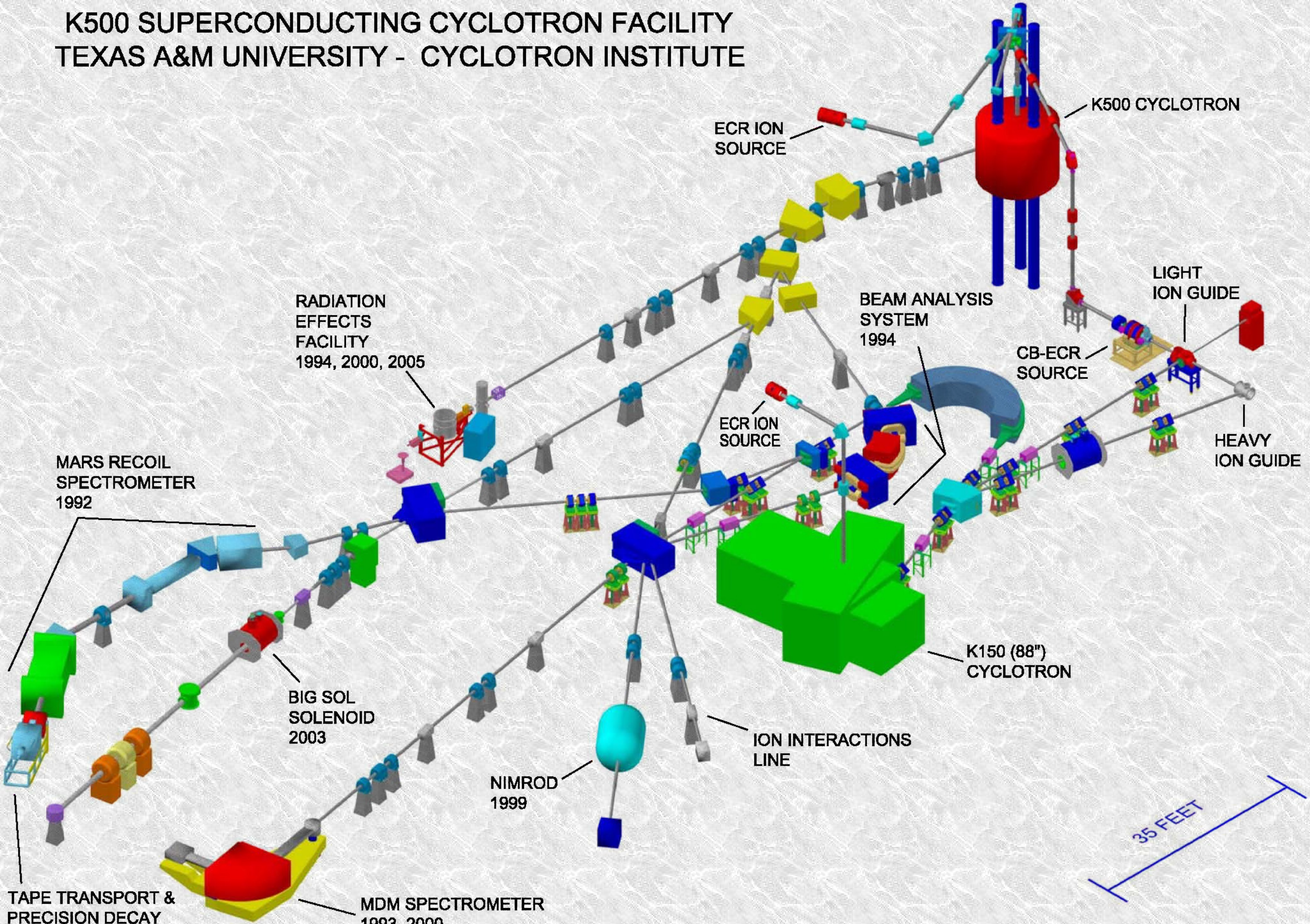
The CI upgrade: what we're doing

- Recommisioning the K150 (88”) cyclotron
- Constructing light- & heavy-ion guides to catch RIs
- Will charge boost and inject into K500

Project deliverables:

- high-intensity beams from stand-alone K150
- use K150 as driver for secondary RIBs accelerated with K500 cyclotron

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



Dan Melconian

Cyclotron Institute

Expected 88" Beam Intensities

Isotope	Max Energy [MeV/u]	Max Intensity [pμA]
p	55	27
d	33	21
^{3}He	45	11
^{4}He	33	10
^{6}Li	33	7
^{7}Li	24	7
^{10}B	33	3
^{11}B	27	3
^{16}O	33	2.3

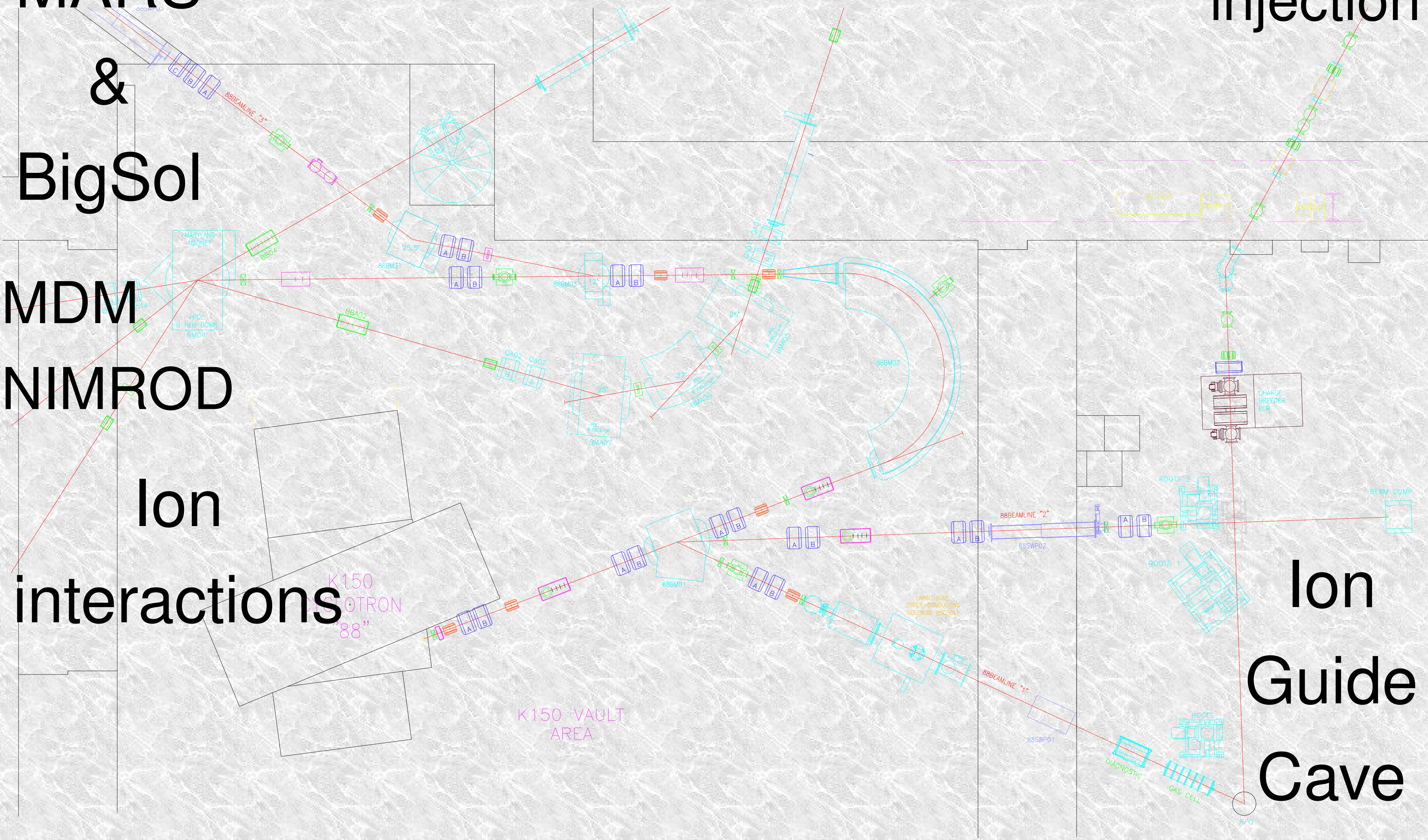
Isotope	Max Energy [MeV/u]	Max Intensity [pμA]
^{20}Ne	26	3.0
^{22}Ne	27	0.5
^{34}S	19	0.7
^{40}Ar	16	1.4
^{40}Ca	16	1.5
^{59}Co	11	0.9
^{78}Kr	9.5	0.6
^{86}Kr	7.8	0.6
^{129}Xe	5.3	0.5

Ion guide configurations

1. Light Ion Guide: like JYFL, mainly (p,n) reactions; also fission fragments using very heavy targets.

2. Heavy Ion Guide: like ANL, use a gas-catcher to collect deep-inelastic reactions of heavy ions on targets

K150 Beamlines

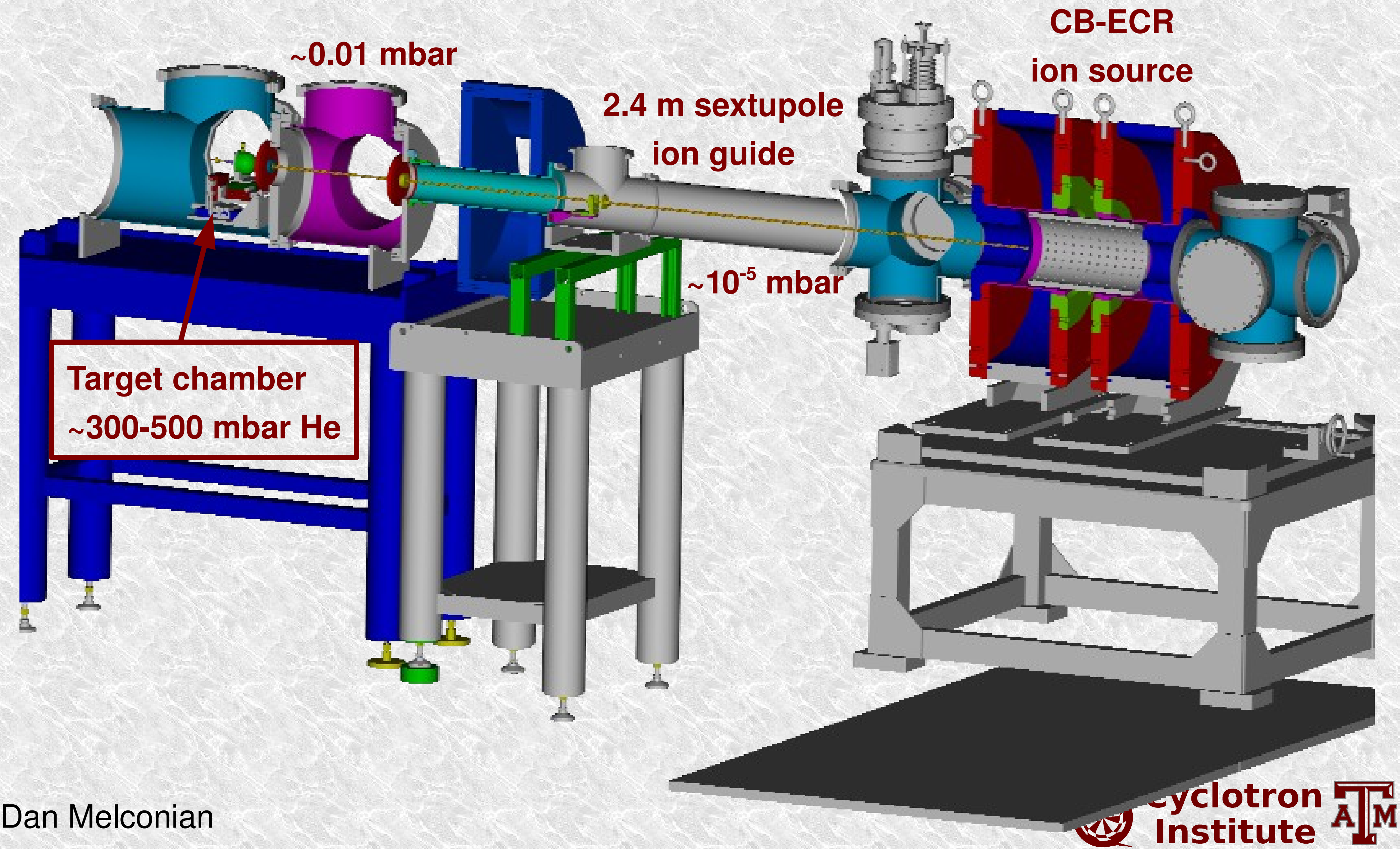


Dan Melconian

Cyclotron Institute

1. Light Ion Guide System

in collaboration with J. Ärje – Jyväskylä



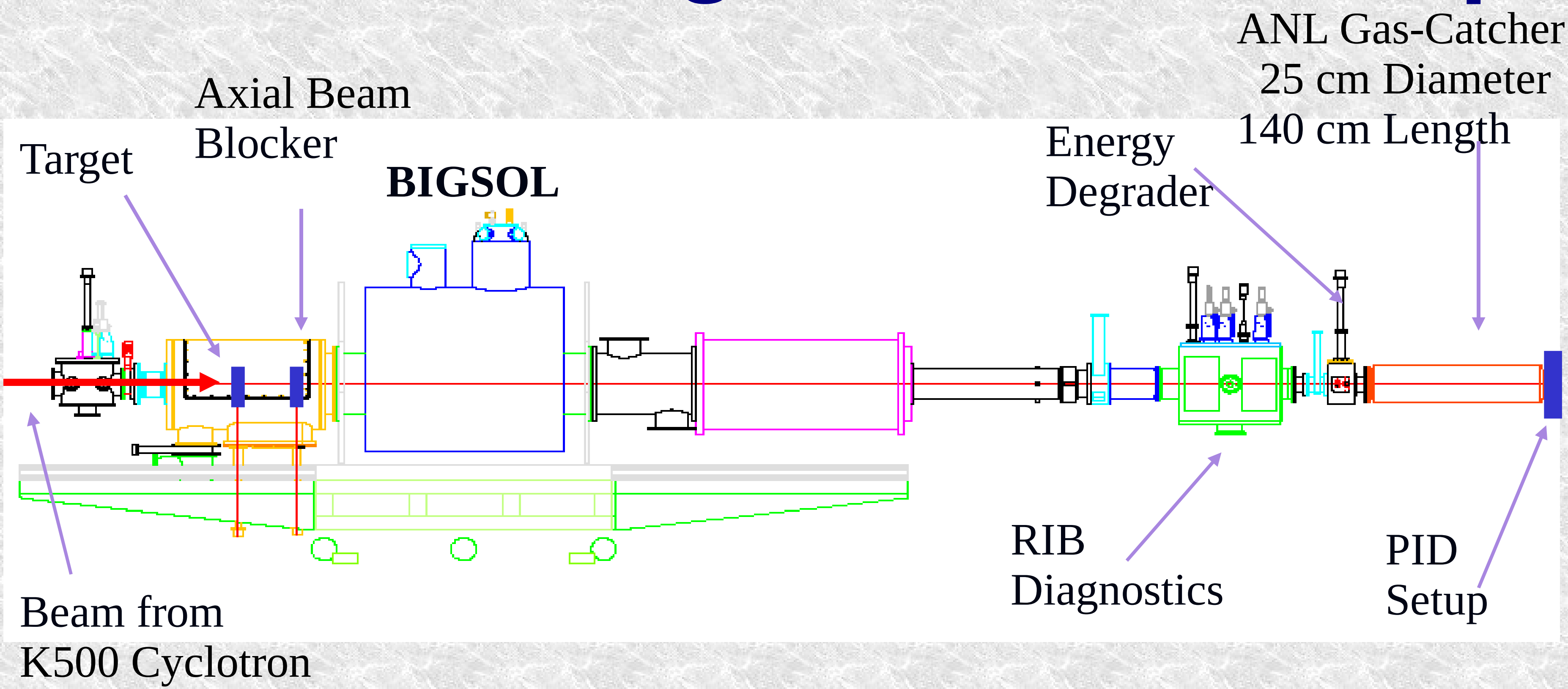
Expected Intensities from LIG

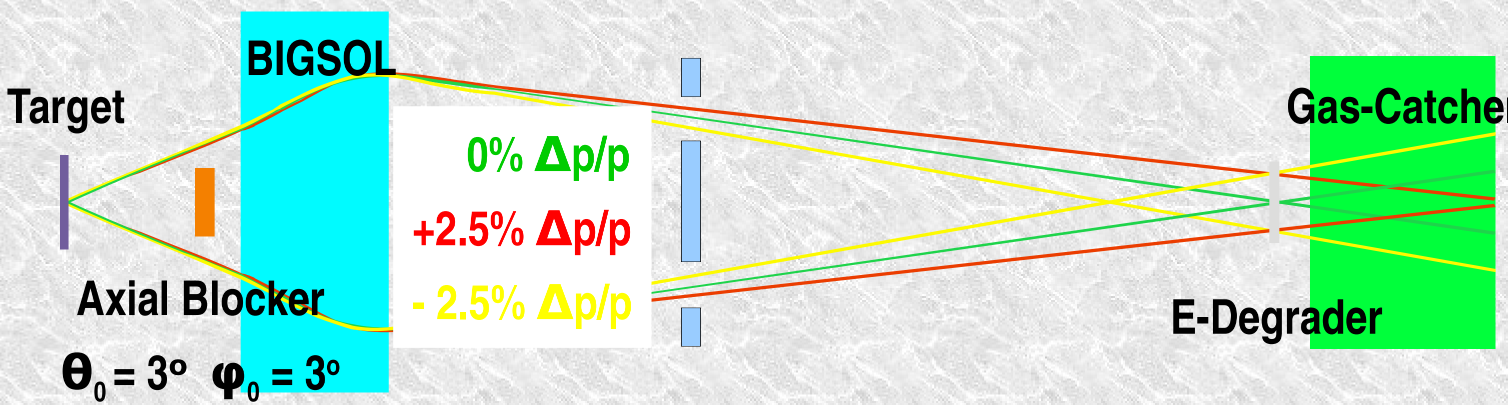
(p,n) reaction product	max energy [MeV/u]	intensity (pps)
^{27}Si	57	5.4×10^{3}
^{50}Mn	45	2.1×10^{4}
^{54}Co	45	5.4×10^{3}
^{64}Ga	45	3.5×10^{4}
^{92}Tc	35	3.5×10^{4}
^{106}In	28	5.4×10^{4}
^{108}In	28	2.7×10^{4}
^{110}In	26	5.4×10^{4}

Expected Intensities from LIG (cont)

fission fragment	max energy [MeV/u]	intensity (pps) (20% IG eff)
^{26}Sr	31	4.3x10^{4}
^{98}Y	30	3.9x10^{5}
^{100}Zr	29	3.6x10^{4}
^{103}Nb	27	3.2x10^{5}
^{105}Mo	26	2.6x10^{5}
^{107}Tc	25	1.1x10^{5}
^{110}Ru	24	1.1x10^{5}
^{112}Rh	23	0.9x10^{4}
^{115}Pd	22	1.4x10^{5}
^{117}Ag	21	1.1x10^{5}
^{120}Cd	20	1.0x10^{5}

BIGSOL-ANL gas catcher setup

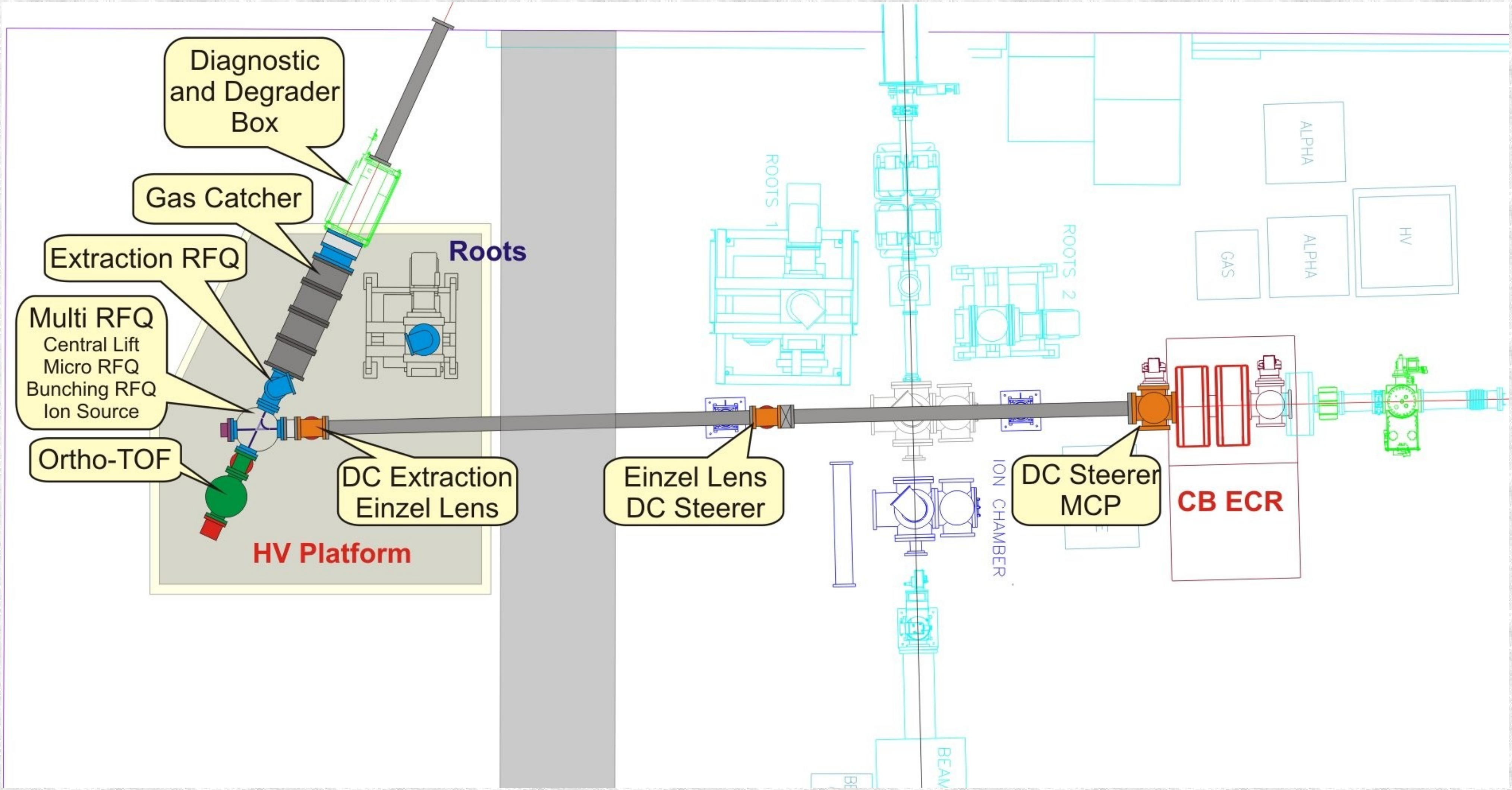




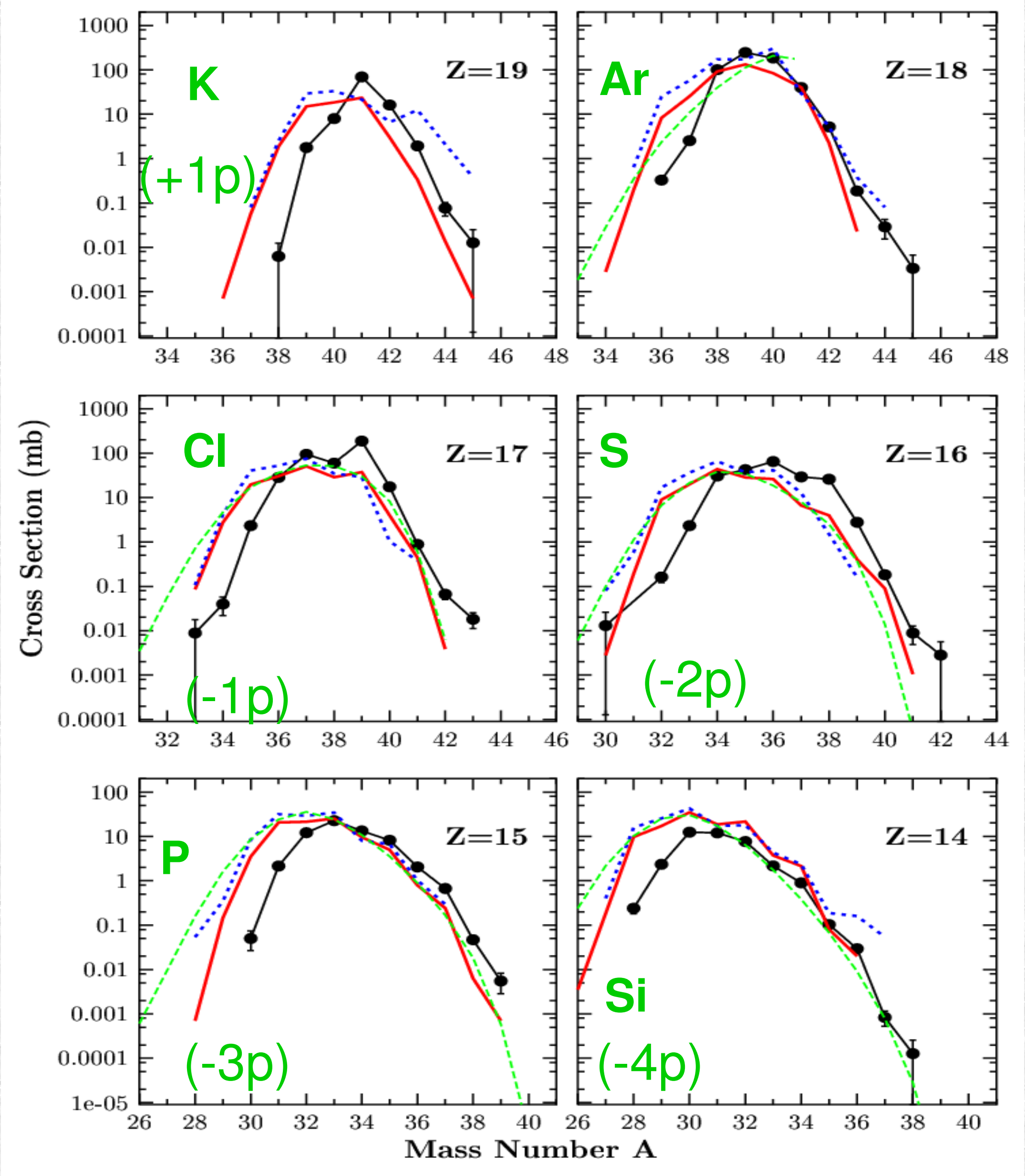
Rays through BIGSOL: $^{48}Ca_{20}$+ (15 MeV/A) Bρ=1.344 Tm, $B_{z,0}$ =3.305 T, I_{BIGSOL}=87.1A

2. Heavy Ion Guide System

in collaboration with G. Savard – ANL



Comparison: ^{40}Ar(15 MeV/u) + ^{64}Ni



- MARS data
- DIT/GEMINI
- CoMD/GEMINI
- EPAX

Data show enhanced cross sections of *n*-rich nuclides close to the projectile *

Model Calculations underestimate the cross sections on the neutron-rich side

DIT: Deep Inelastic Transfer:
L. Tassan-Got, Nucl. Phys. A 524, 121 (1991)

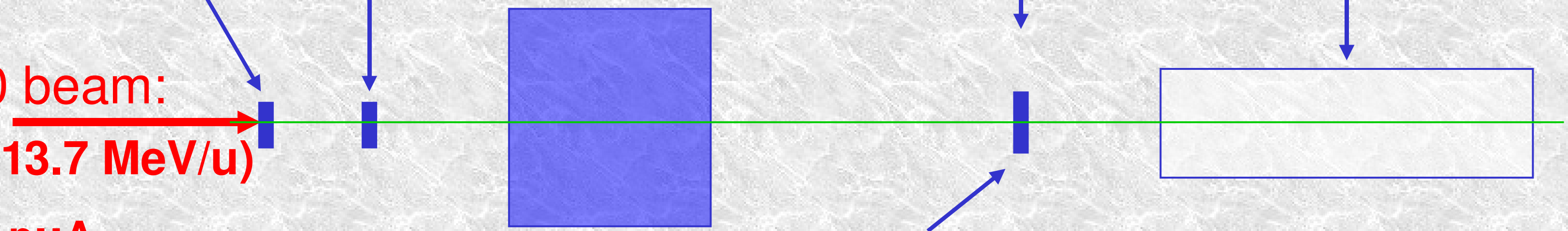
CoMD: Constraint Molecular Dynamics:
M. Papa et al., Phys. Rev. C 64, 024612 (2001)

GEMINI: Binary decay code:
R. Charity, Nucl. Phys. A483 391 (1988)

EPAX: Cross Section parametrization (high-energy)
K. Suemmerer et al, Phys. Rev. C 61, 034607 (2000)

* G.A. Souliotis et al., Phys. Rev. Lett. 91 022701 (2003)

E.g. ^{38}S from ^{40}Ar (13.7MeV/u) + ^{64}Ni



^{38}S energy : ~2.0 MeV/u (0.0-5.0 MeV/u)

Range in the gas cell (SRIM-2003)
^{38}S at 2.0 MeV/u: 35 cm
at 5.0 MeV/u: 100 cm

^{38}S cross section: 20 mb (6.0 mb)

Energy: 11.0 MeV/u (8-13 MeV/u)

Total production rate: 5.3×10^7 pps (1.6×10^7 pps)

Rate after BigSol (30% eff): 1.6×10^7 pps (0.5×10^7 pps)

Rate after gas-catcher (25% eff): 4.0×10^6 pps (1.3×10^6 pps)

Charge boosting: ~4%
Reacceleration: ~11%

Final re-accelerated rate: 1.8×10^4 pps
(was expected to be 5.3×10^3 pps)

(calculation courtesy of G. Souliotis)

Cyclotron Institute

Project progress/schedule

TASK #	Level	Milestone	Original Baseline	Updated Baseline	Forecast / Actual	Completed Yes / No
	1	Start Project	Q2 05		Q2 05	Yes
1	2	Bid Award for K150 Coil Power Supplies	Q3 05	Q3 05	Q3 05	Yes
2	2	Light Ion Guide & SPIG Design Complete - Phase 1	Q3 05	Q3 05	Q3 05	Yes
1	2	K150 Vacuum System Design Complete	Q4 05	Q4 05	Q4 05	Yes
1	2	K150 Initial Vacuum System Equipment Procured	Q1 06	Q1 06	Q1 06	Yes
1	2	K150 ECR & Injection Line Design Complete	Q1 06	Q1 06	Q1 06	Yes
2	2	Light Ion Guide & SPIG Materials Procured - Phase 1	Q1 06	Q2 06	Q3 06	Yes
1	1	K150 Initial Vacuum System Commissioned	Q2 06	Q4 06	Q4 06	Yes
2	1	Light Ion Guide & SPIG Assembly & Testing Complete - Phase 1	Q3 06	Q4 06	Q3 06	Yes
3	2	n+ Transport System Design Complete	Q1 07	Q1 07	Q1 07	Yes
1	1	K150 Start-up Sub-Systems Restored	Q3 06	Q2 07	Q2 07	Yes
1	1	K150 Coil Power Supplies Commissioned	Q4 07	Q2 07	Q2 07	Yes
2	1	1+ Ions Transferred Through SPIG - Phase 1 Complete	Q1 07	Q2 07	Q2 07	Yes
1	1	K150 RF System Commissioned	Q3 06	Q3 07	Q3 07	Yes
1	1	K150 ECR & Injection Line Commissioned	Q3 07	Q4 07	Q3 07	Yes
1	1	Extract First Beam From K150	Q3 07	Q1 08	Q4 07	Yes
1	2	K150 Beam Line Materials Procured	Q2 07	Q1 08	Q2 08	Yes
2	2	Heavy Ion Guide Development Complete	Q2 08	Q2 08	Q2 08	Yes
3	2	CBECR-IS Installed		Q4 08	Q4 08	Yes
2	2	Heavy Ion Guide Design Complete	Q1 09		Q1 09	Yes
1	1	K150 Beam Lines Assembled	Q2 08	Q2 09	Q2 09	
1	1	K150 Beams Transported to Ion Guide Cave & K500 Beam Lines	Q2 08	Q2 09	Q2 09	
2	1	Light Ion Guide & SPIG Assembled - Phase 2	Q1 09	Q4 09		
2	2	LIG Target Handling System Design Complete	Q4 09			
3	1	CBECR-IS Commissioned	Q3 09	Q4 09		
1	1	Extract 14 mircoA 30 MeV Protons	Q2 09	Q1 10		
2	2	Beam Dump & Shielding Materials Procured	Q1 09	Q2 10		
2	2	Heavy Ion Guide Materials Procured	Q2 10			
3	2	n+ Transport System Installed	Q4 08	Q2 10		
3	1	n+ Transport System Commissioned	Q3 09	Q4 10		
3	1	Accelerate Stable Ions Through K500	Q3 09	Q4 10		
2	1	Beam Dump & Shielding Materials Commissioned	Q3 09	Q1 11		
2	1	Beam Induced 1+ Ions To CBECR-IS - Phase 2 Complete	Q3 09	Q1 11		
2	2	LIG Target Handling System Installed	Q1 11			
1	1	0.9 pmicroA 13.7 microA MeV/u Ar on target	Q1 11	Q3 11		
2	1	Heavy Ion Guide Commissioned	Q1 11	Q3 11		
3	1	Reaccelerate LIG RIBs in K500	Q2 10	Q3 11		
3	1	Reaccelerate HIG RIBs in K500	Q1 11	Q3 11		
	1	Project Complete	Q1 11	Q3 11		

FY09

FY10

FY11

June 2011

Cyclotron Institute

Scientific Program

- Nuclear astrophysics: ANC by transfer reactions
- Nuclear structure: Giant monopole resonances, α–cluster structures
- Fundamental interactions: V_{ud} / CKM unitarity, lifetimes, BRs, EC rates, correlations, ...

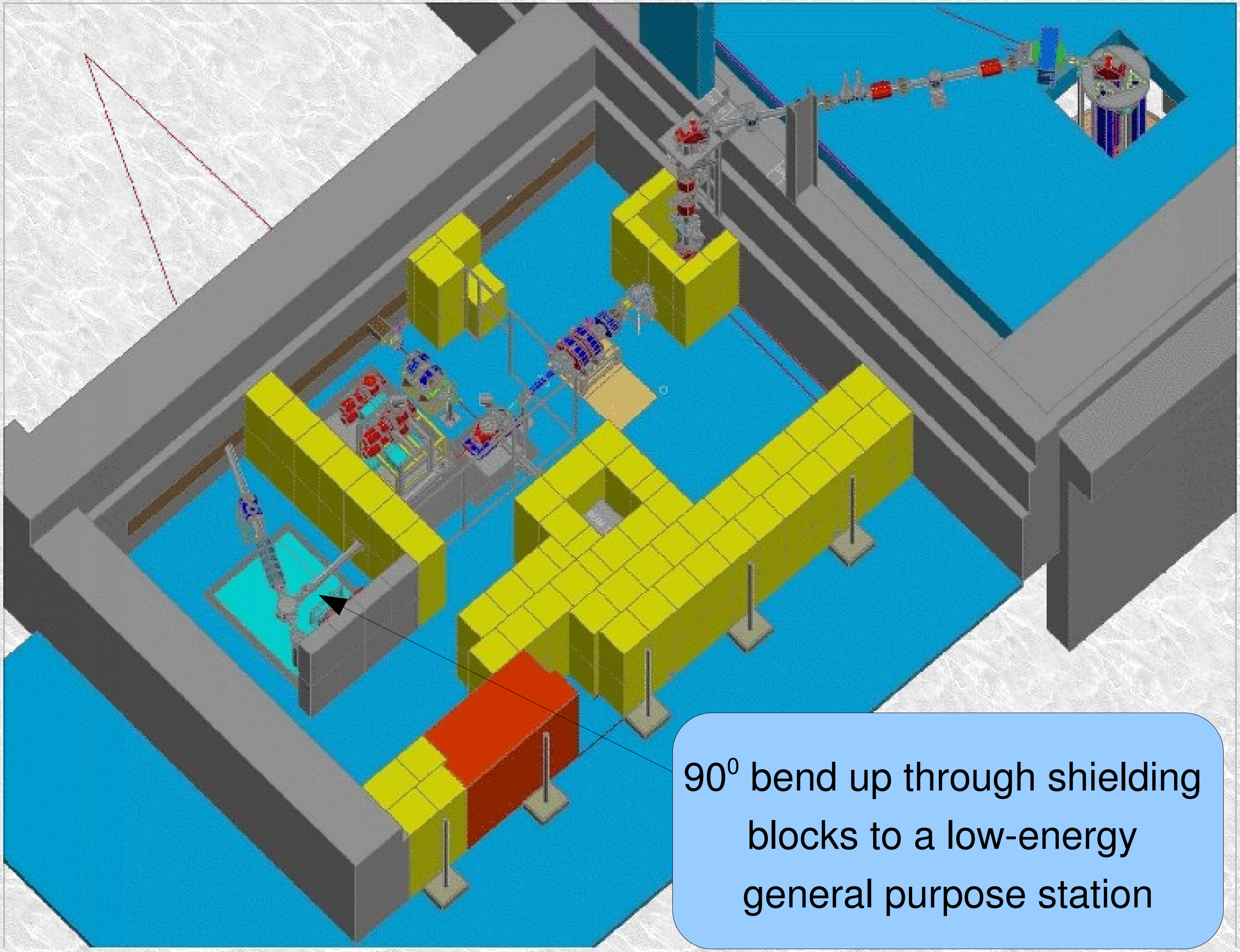
⇒ *add your ideas here!* ⇐

- Nuclear dynamics: isospin and the nuclear EoS
- Radiation line: te$ting microchip$

What else would we want?

- A source of a clean, low-energy, low-emittance RIBs! Why lose 10^2-10^3 in re-accelerating ...?
  - Correlation studies
  - Separate daughters in β-delayed proton decays (T=2 proton-rich nuclei, e.g. ^{32}Ar
    ⇒ large bore, strong solenoid)
- Atom trap? RFQ cooler buncher? Penning trap? Collinear beamline?

Where would it fit in the upgrade?



90^{0} bend up through shielding blocks to a low-energy general purpose station

Cyclotron Institute
A&M

Polarized correlation studies at ISAC

TRIUMF's Neutral Atom Trap (TRINAT) collaboration:

TRIUMF
ISAC

S. Behling

D. Melconian

(**Graduate student** *Research associate*)

J.A. Behr M.R. Pearson M. Dombsky *C. Höhr*

A. Gorelov K.P. Jackson P. Bricault *J. Holt*

TEL AVIV UNIVERSITY

O. Aviv

D. Ashery I. Cohen

UBC

R. Pitcairn

D. Roberge

T. Kong

UNIVERSITY OF MANITOBA

G. Gwinner

Undergrads:

B. Lee, A. Gaudin, B. Dej, T. Wiebe,

A. Chatwin-Davies, A. Berman

NC STATE UNIVERSITY

A. Young

Polarized correlation studies with trapped atoms

Lifetime:

$$\frac{\mathcal{F}t^{0^+\rightarrow\,0^+}}{ft} = \frac{1+\boldsymbol{\lambda}^2}{2}, \qquad \boldsymbol{\lambda} \equiv G_A M_{GT}/G_V M_F$$

Angular distribution of the decay:

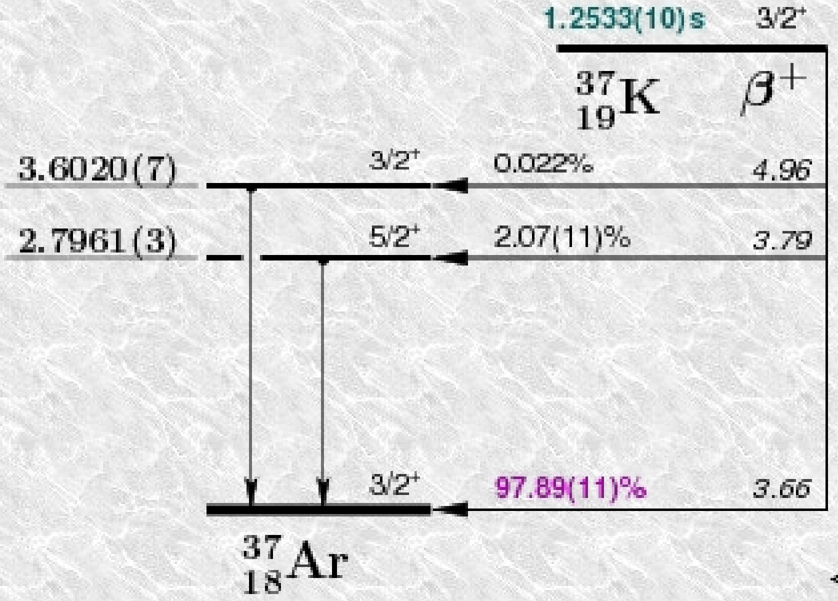
$$dW \sim 1 + a\frac{\boldsymbol{p}_e\cdot\boldsymbol{p}_\nu}{E_e E_\nu} + b\Gamma\frac{m}{E_e} + \frac{\boldsymbol{I}}{I}\cdot\left[\boldsymbol{A_\beta}\frac{\boldsymbol{p}_e}{E_e} + \boldsymbol{B_\nu}\frac{\boldsymbol{p}_\nu}{E_\nu} + \boldsymbol{D}\frac{\boldsymbol{p}_e\times\boldsymbol{p}_\nu}{E_e E_\nu}\right]$$

$$+\, c_{\text{align}}\left[\frac{\boldsymbol{p}_e\cdot\boldsymbol{p}_\nu}{3E_e E_\nu} - \frac{(\boldsymbol{p}_e\cdot\hat{i})(\boldsymbol{p}_\nu\cdot\hat{i})}{E_e E_\nu}\right]\left[\frac{I(I+1)-3\langle(\boldsymbol{I}\cdot\hat{i})^2\rangle}{I(2I-1)}\right]$$

The correlation parameters are sensitive to the form of the weak interaction

$$\text{E.g.}: \qquad A_\beta(^{60}\text{Co}) = \begin{cases} -1 & \text{axial vector} \\ +1 & \text{tensor} \end{cases}$$

Beta decay observables



Q(^{37}K) = 5.1265(15) MeV

$B.R.$ = 0.9789(11)

and $t_{1/2}$ = 1.2533(10) s

$\Rightarrow \mathcal{F}t/ft$ = 0.6655(9)

$\Leftrightarrow |G_A M_{GT}/G_V M_F|$ = 0.5754(16)

$$\frac{d^5W}{dE_\beta\, d\Omega_\beta\, d\Omega_\nu} \sim \cdots + \frac{\langle \boldsymbol{I} \rangle}{I} \cdot \left[\boldsymbol{A_\beta} \frac{\boldsymbol{p}_\beta}{E_\beta} + \boldsymbol{B_\nu} \frac{\boldsymbol{p}_\nu}{E_\nu} + \boldsymbol{D} \frac{\boldsymbol{p}_\beta \times \boldsymbol{p}_\nu}{E_\beta E_\nu} \right] + \cdots$$

<u>$\mathcal{F}t/ft$ + SM</u>

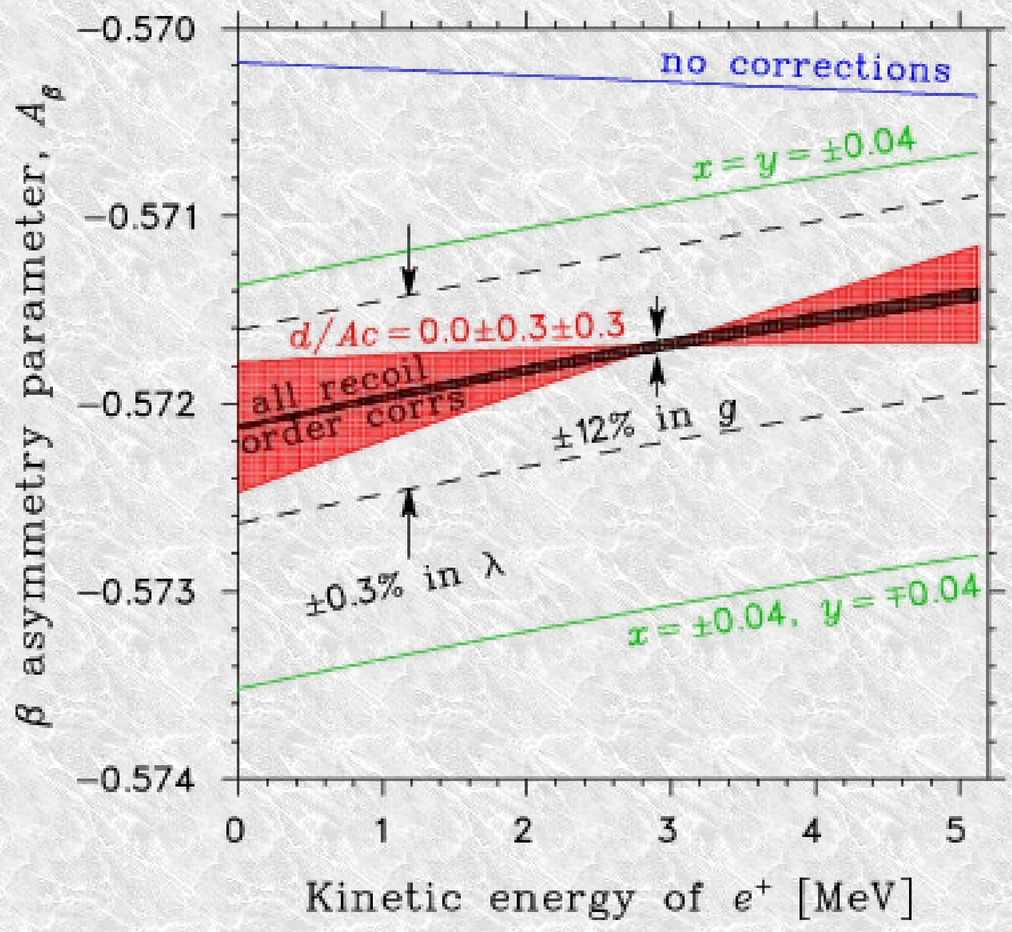
$$\Rightarrow \begin{cases} \boldsymbol{A_\beta} = -0.5702(6) \\ \boldsymbol{B_\nu} = -0.7692(15) \end{cases}$$

<u>**cold neutrons**</u>

$$\Rightarrow \boldsymbol{D} = (-4 \pm 6) \times 10^{-4}$$

Soldner et al.,
PhysLett **B581** (2004)

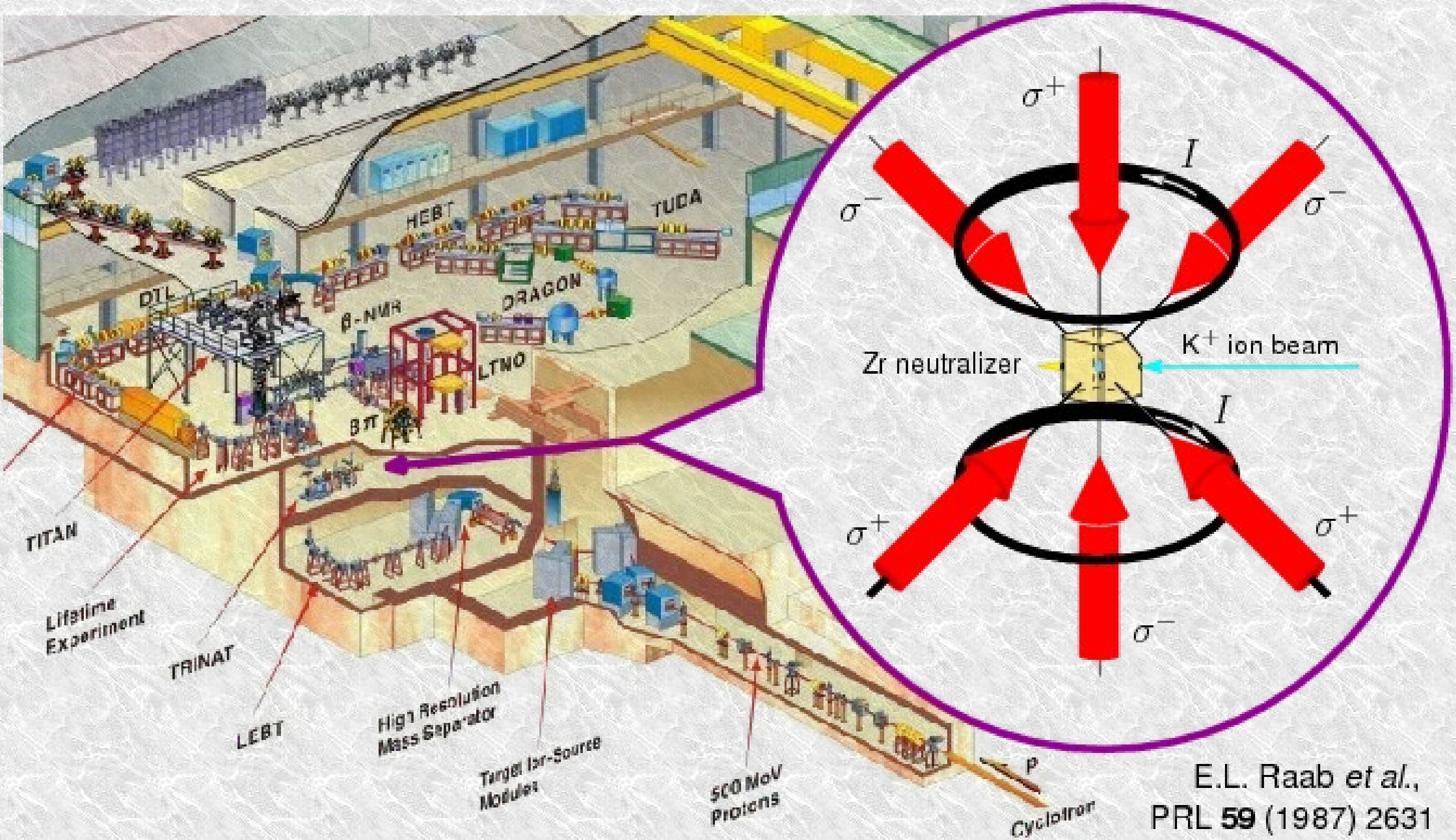
E.g. The beta asymmetry parameter



$$A_\beta = \frac{-2\lambda\left(\sqrt{3/5} - \lambda/5\right)}{1 + \lambda^2}$$

- recoil order corrections under control
- measure V_{ud} (^{37}K = "heavy neutron")
- sensitive to RHCs and SCCs

TRINAT at ISAC/TRIUMF



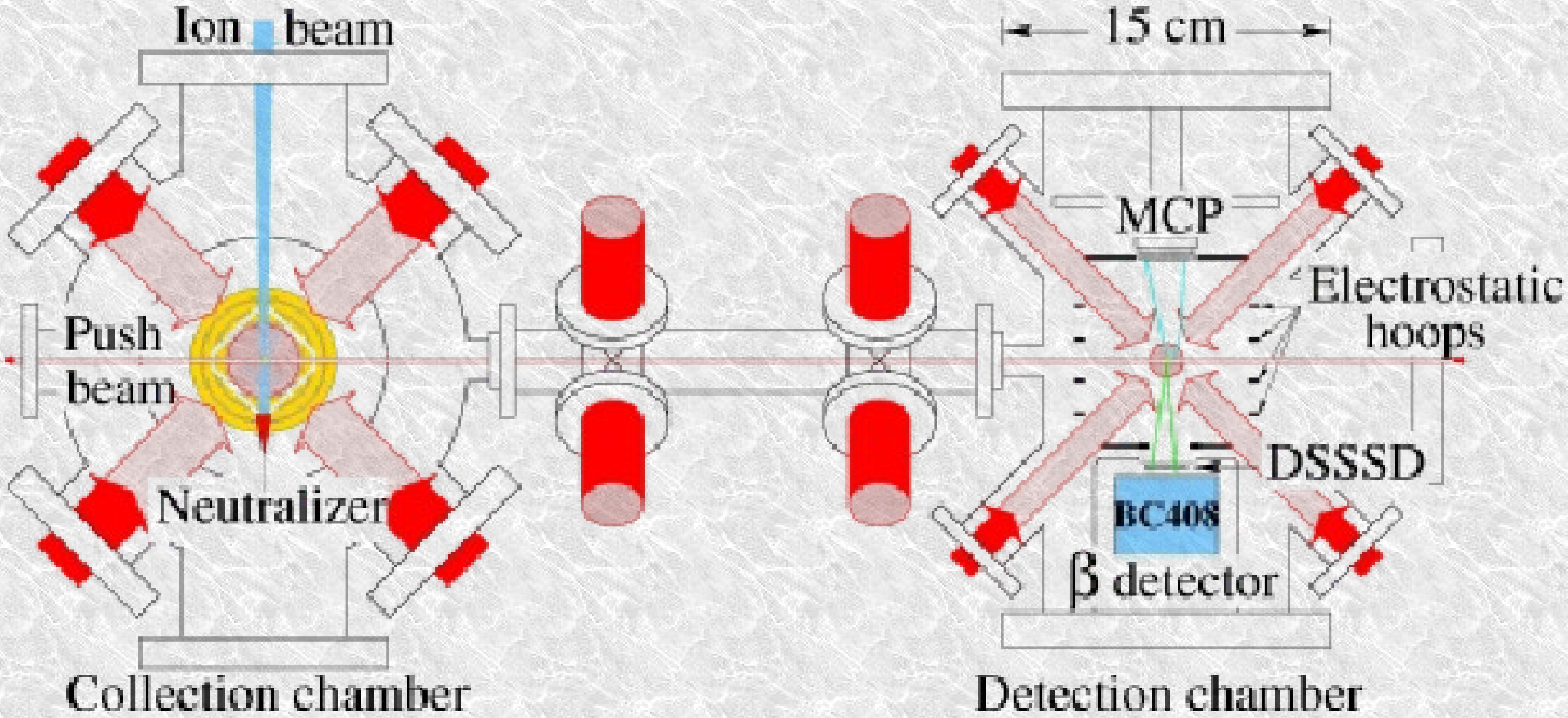
E.L. Raab *et al.*, PRL **59** (1987) 2631

^{37}K yield with 40 μA on TiC #1: 6×10^7/s

Dan Melconian

Cyclotron Institute

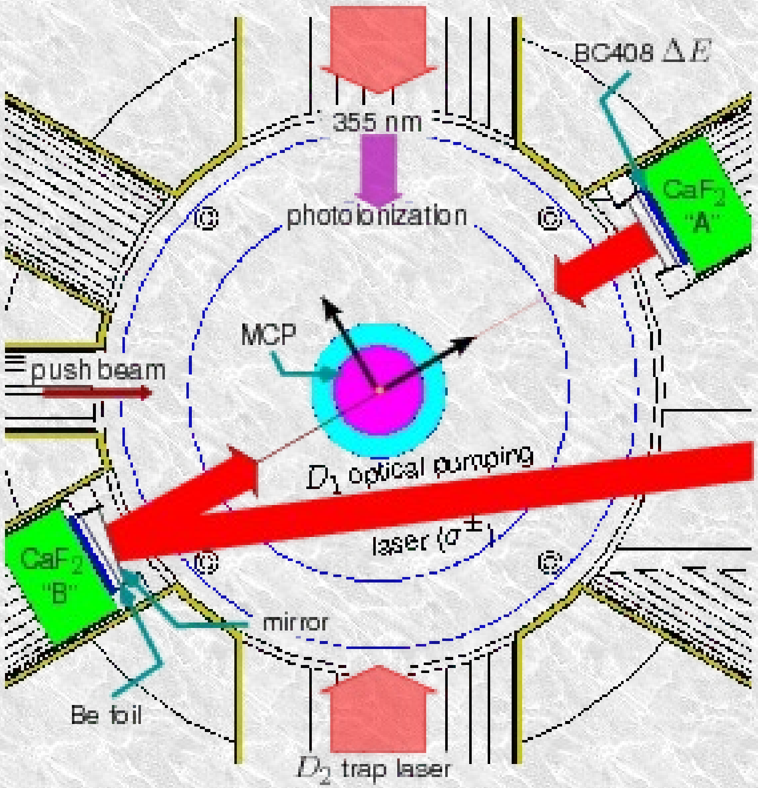
Double-MOT system



- Isomerically selective
- $\lesssim 1$ mm^3 cloud size
- $\approx 10^{-3}$ K cloud temperature
- recoils escape unperturbed

decay from rest, observe $\boldsymbol{p}_\beta$ and $\boldsymbol{p}_{\mathrm{recoil}}$
$\Rightarrow$ infer $\boldsymbol{p}_\nu$, *event-by-event*!

Polarizing the laser-cooled atoms



$\hat{z}$ = MCP–β-telescope axis

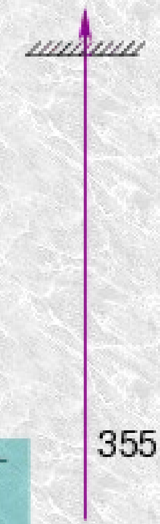
$\hat{x}$ = phoswich detector axis

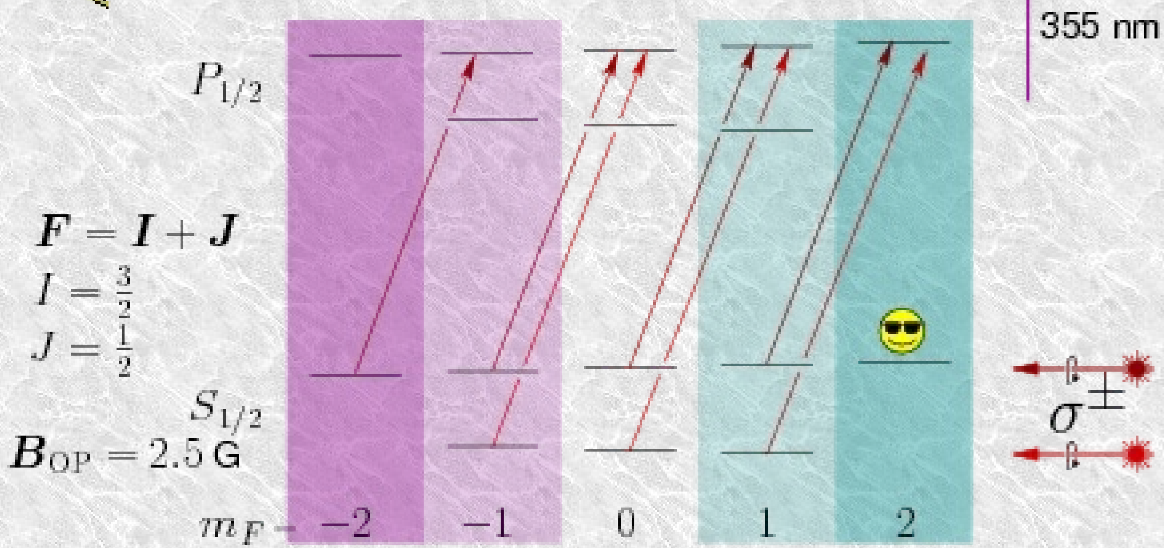
= polarization axis

can monitor

atomic fluorescence ⇒

via photoions

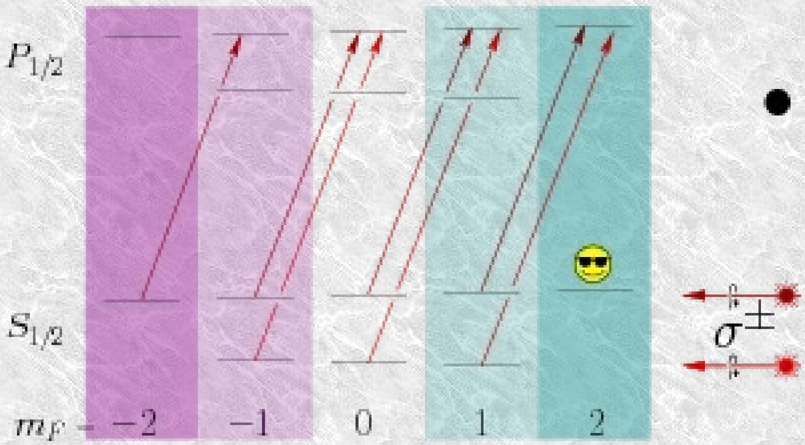




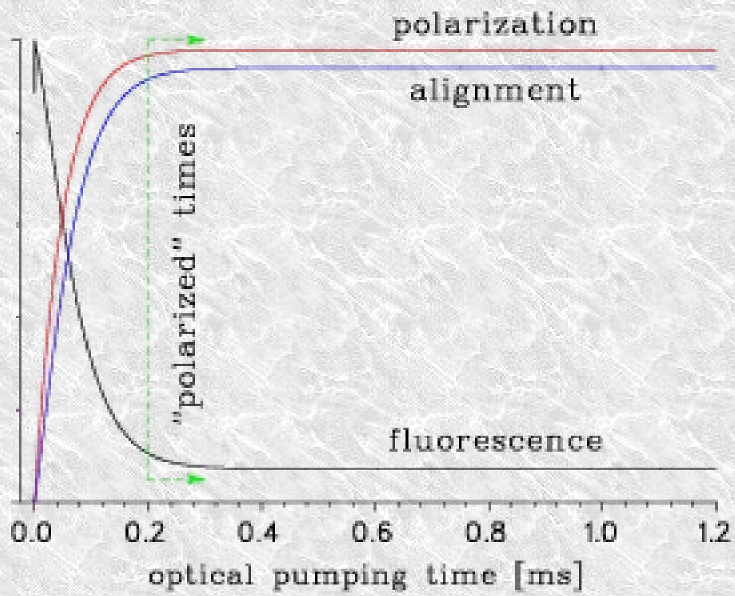
Dan Melconian

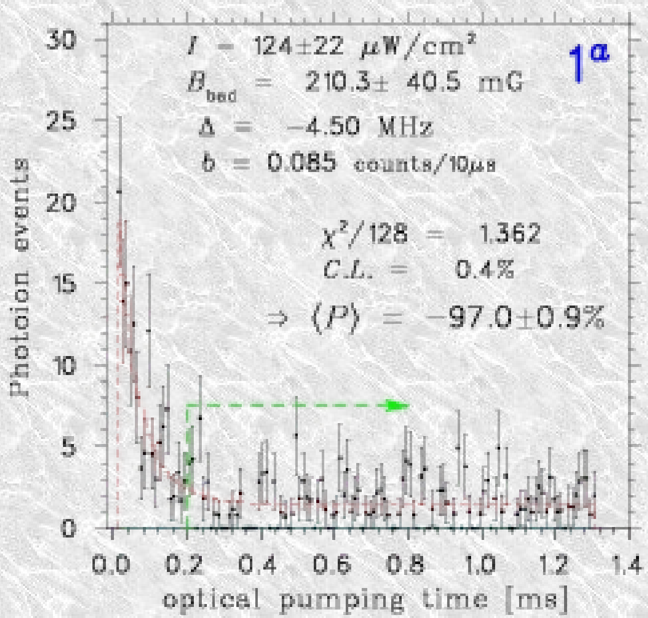
Cyclotron Institute

Optical pumping ⇒ high polarization!



- deduce P based on a model of the excited state populations:



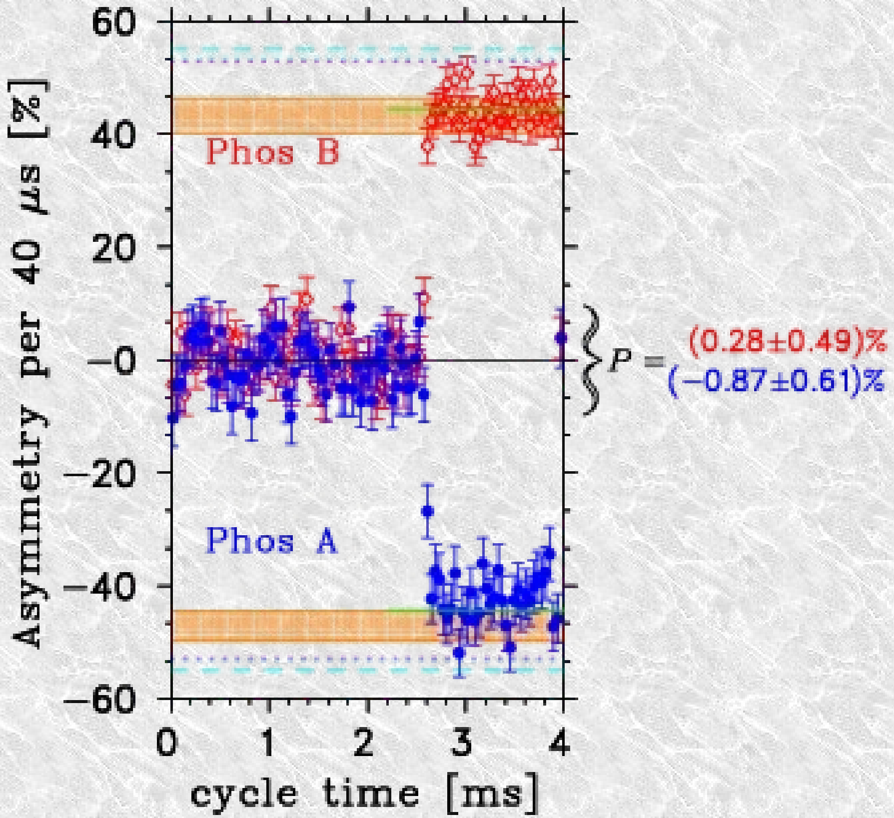


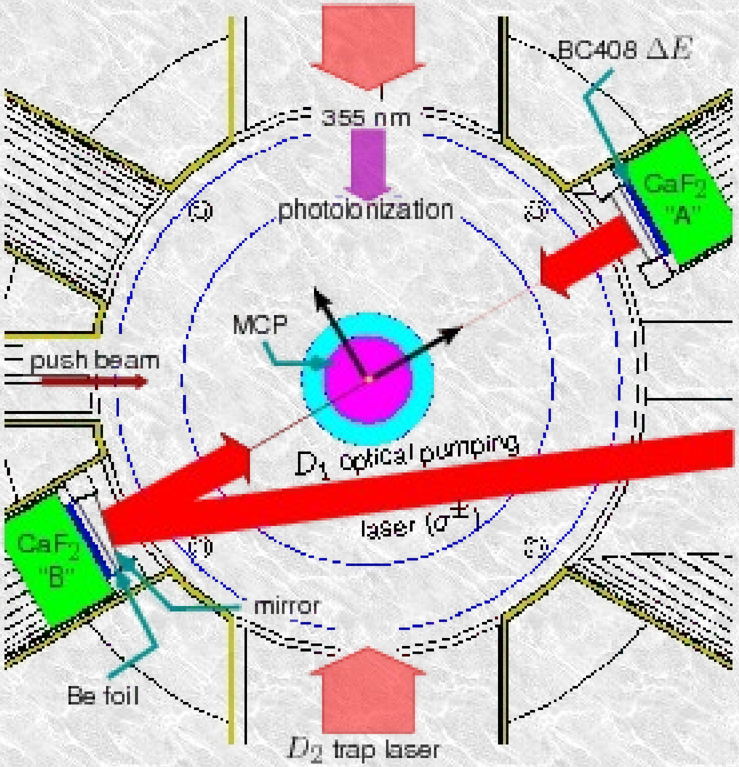
$$\Rightarrow P_{\mathrm{nucl}} = 96.74 \pm 0.53^{+0.19}_{-0.73}$$

Cyclotron Institute A|M

1st attempt at the β asymmetry

$$\text{Asymmetry} = \frac{N(\sigma^+) - N(\sigma^-)}{N(\sigma^+) + N(\sigma^-)}$$
$$\sim P A_\beta \left\langle \frac{p_e}{E_e} \right\rangle$$





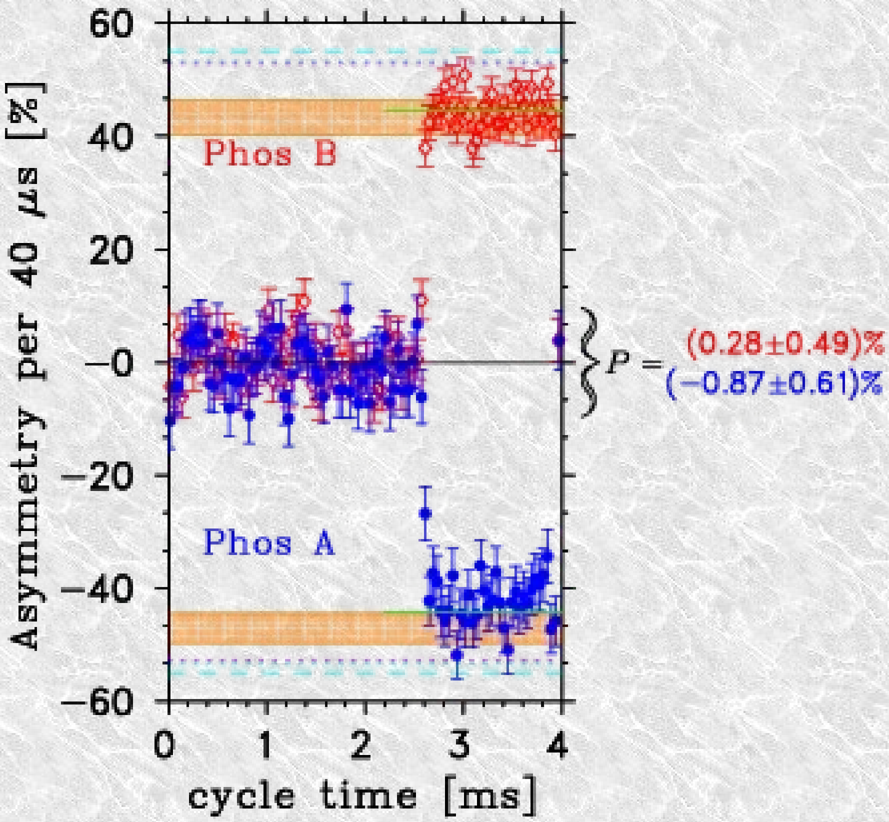
Dan Melconian

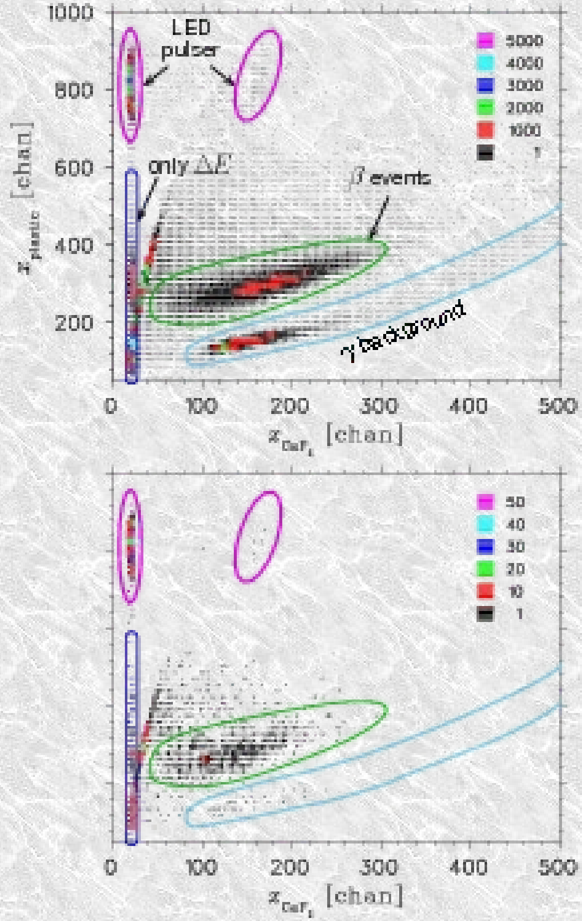
Cyclotron Institute

Phoswich detectors *are* okay ...

$$\text{Asymmetry} \equiv \frac{N(\sigma^+) - N(\sigma^-)}{N(\sigma^+) + N(\sigma^-)}$$

$$\sim P A_\beta \left\langle \frac{p_e}{E_e} \right\rangle$$



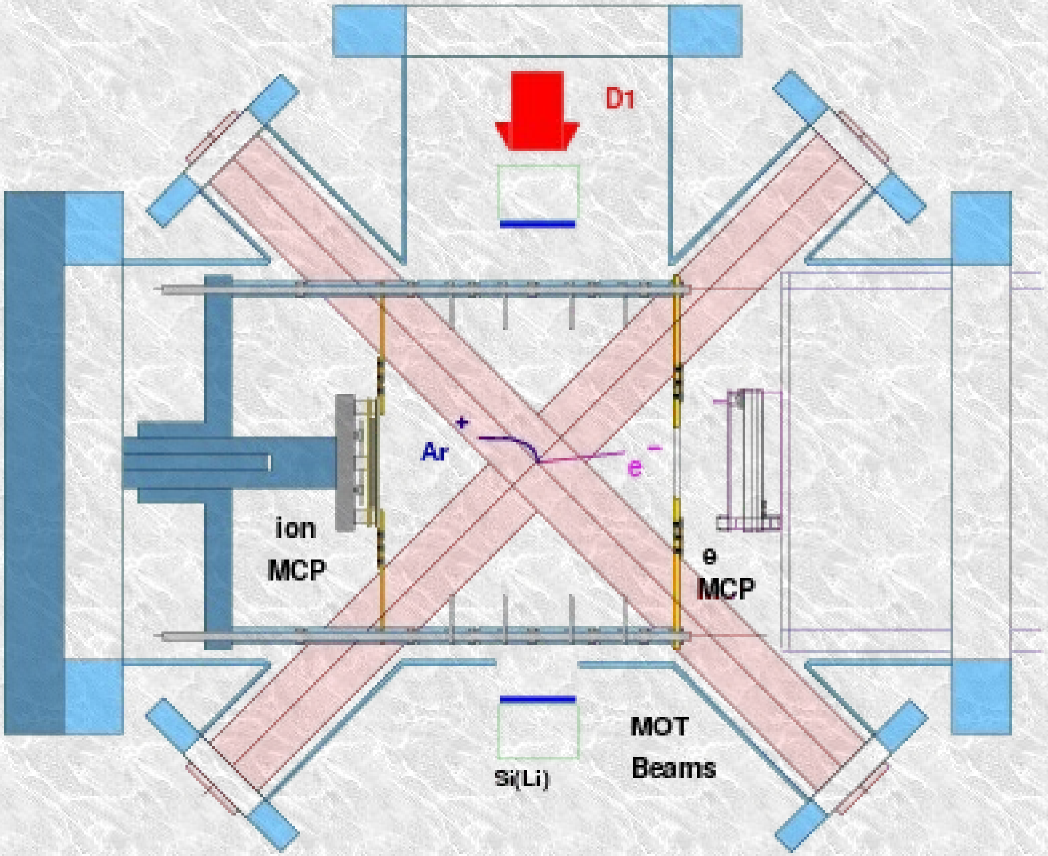


atoms can get sprayed onto the thin mirrors and walls . . .

recoil coincidences cleaner!

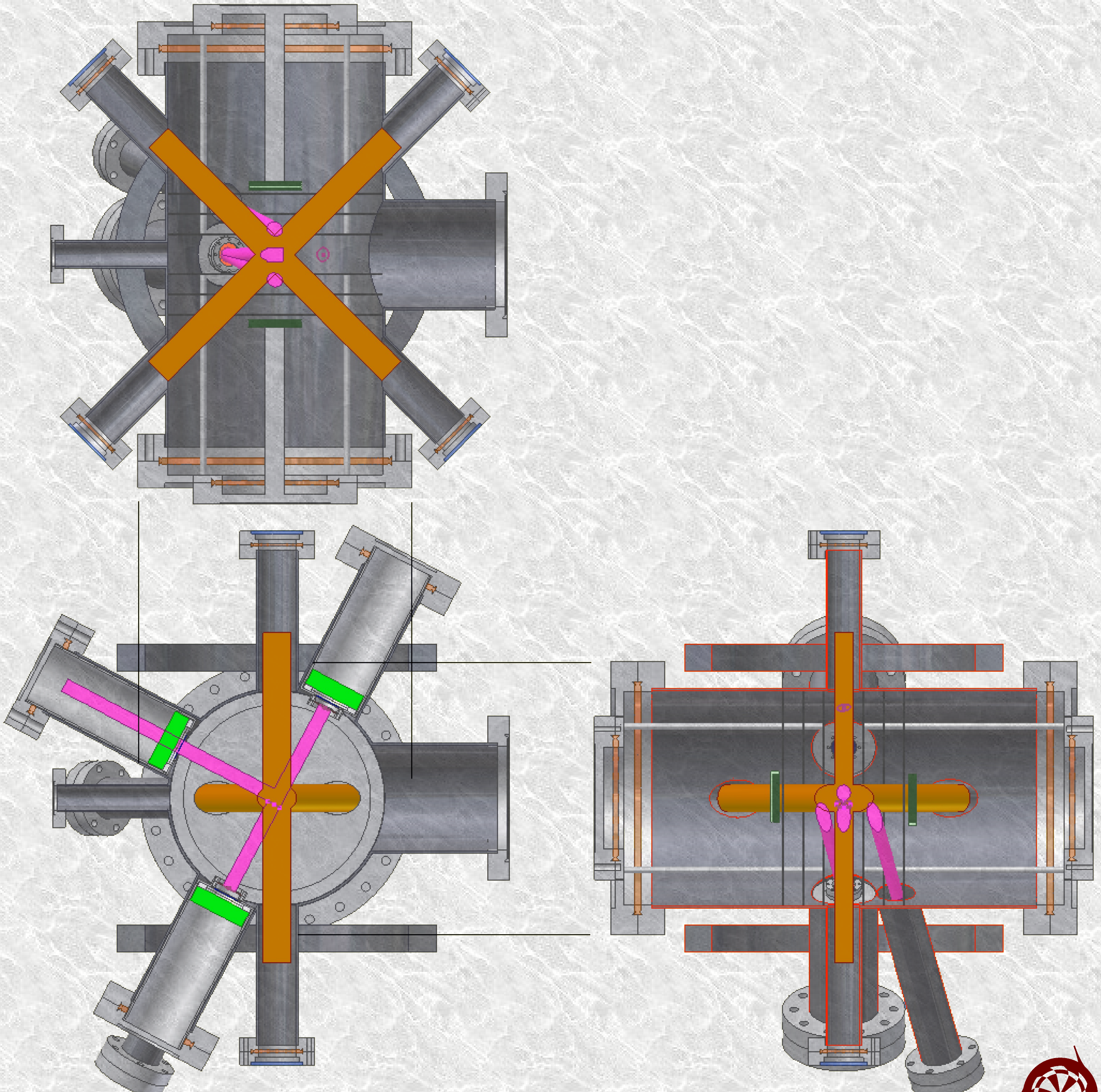
Cyclotron Institute

Shake-off electron detection



- high-statistics!
- *know* decay occured from trap!
- S1188 approved with high priority
- goal is 0.1% in A_β

New chamber design (in progress)

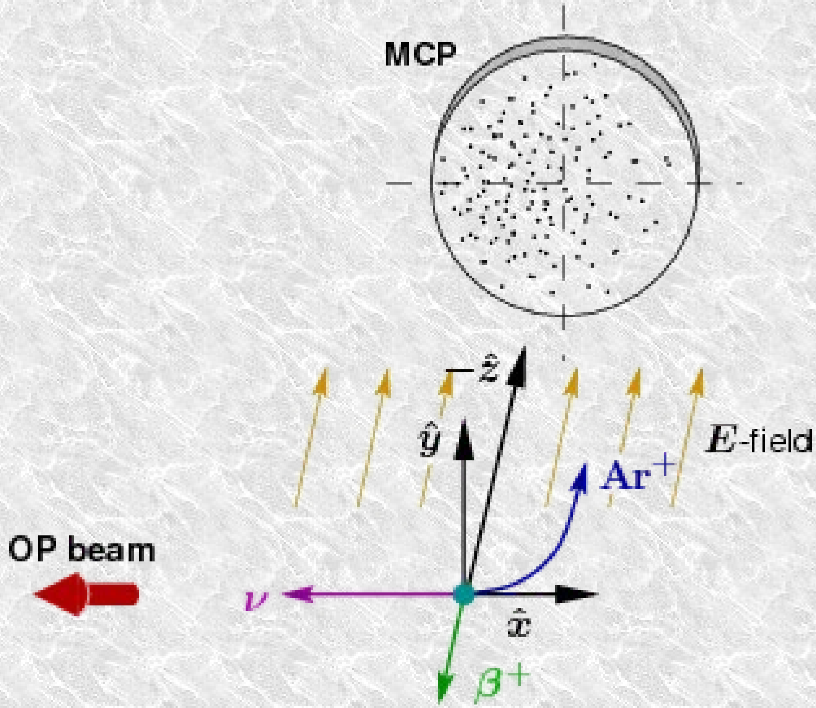


Dan Melconian

Cyclotron Institute

Measuring the neutrino asymmetry

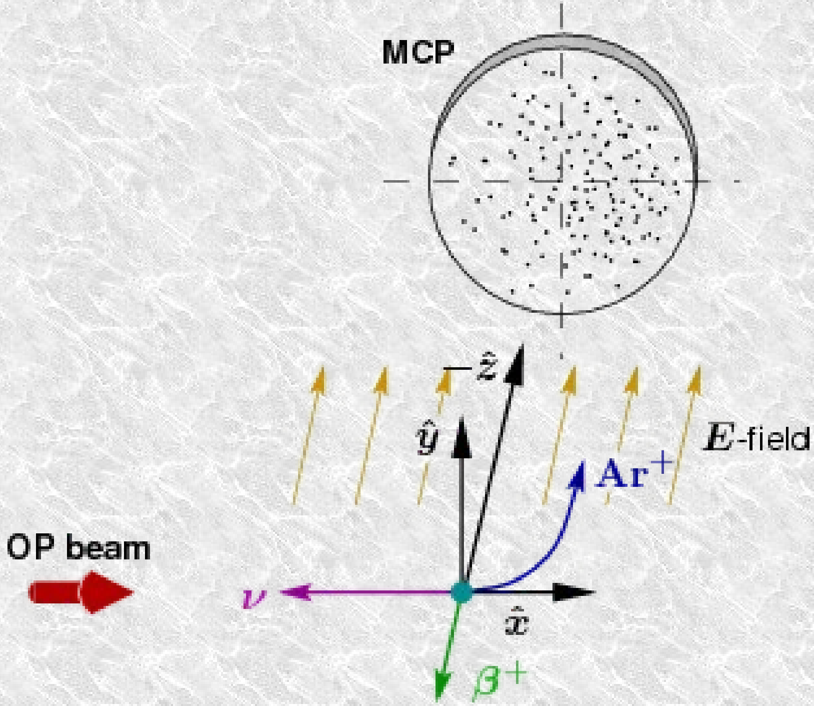
$$dW \sim \boldsymbol{P}\boldsymbol{B_\nu}\hat{p}_\nu \cdot \hat{i} + \boldsymbol{P}\boldsymbol{D}\frac{\hat{i}\cdot(\boldsymbol{p}_\beta \times \hat{p}_\nu)}{E_\beta}$$



$$\hat{p}_\beta \approx \hat{z} \quad \Rightarrow \boldsymbol{p}_\nu \approx -\boldsymbol{p}_{\mathrm{Ar}}$$

Measuring the neutrino asymmetry

$$dW \sim PB_\nu \hat{p}_\nu \cdot \hat{i} + PD\frac{\hat{i}\cdot(\boldsymbol{p}_\beta \times \hat{p}_\nu)}{E_\beta}$$



$$\hat{p}_\beta \approx \hat{z} \quad \Rightarrow \boldsymbol{p}_\nu \approx -\boldsymbol{p}_{\mathrm{Ar}}$$

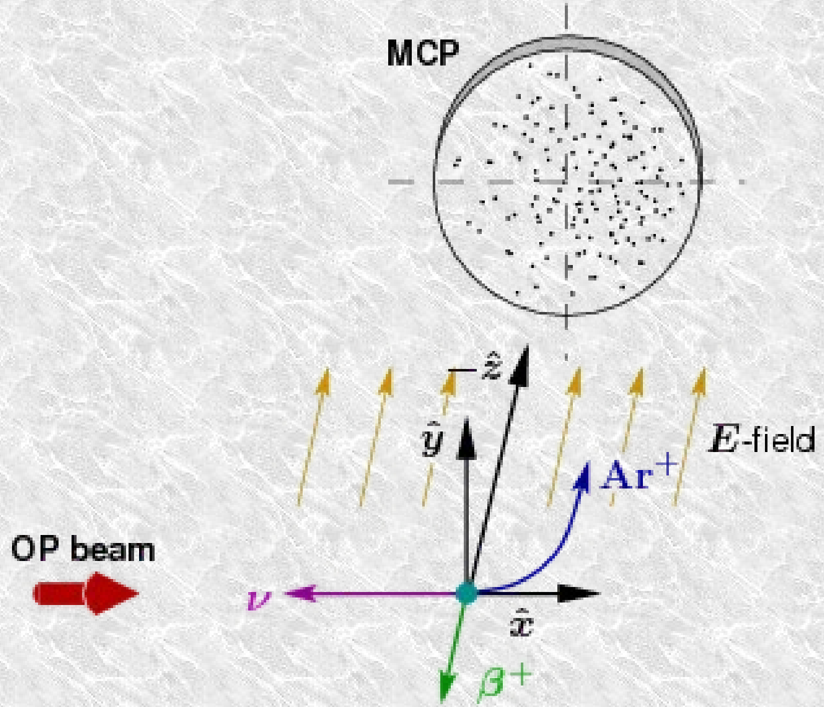
$\hat{x}$ asymmetry $\sim PB_\nu$

$\hat{y}$ asymmetry $\sim PD$

Cyclotron Institute

Measuring the neutrino asymmetry

$$dW \sim PB_\nu \hat{p}_\nu \cdot \hat{i} + PD \frac{\hat{i} \cdot (\boldsymbol{p}_\beta \times \hat{p}_\nu)}{E_\beta}$$



$$\hat{p}_\beta \approx \hat{z} \quad \Rightarrow \boldsymbol{p}_\nu \approx -\boldsymbol{p}_{\mathrm{Ar}}$$

$\hat{\boldsymbol{x}}$ asymmetry $\sim PB_\nu$

$\hat{\boldsymbol{y}}$ asymmetry $\sim PD$

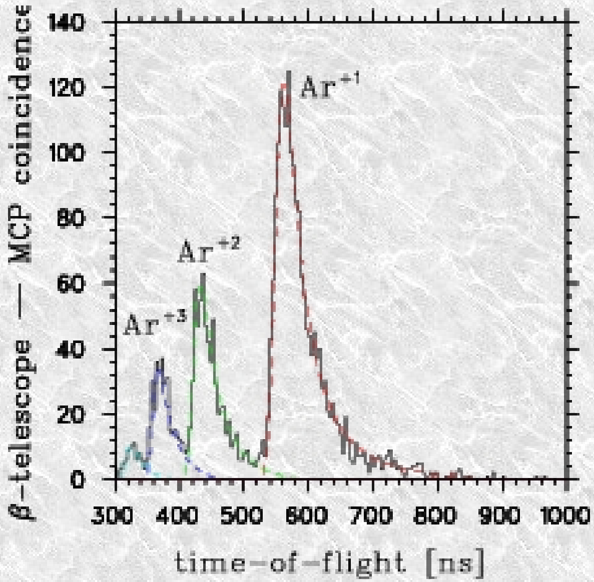
— **negligible** backgrounds
— detectors **well characterized**
— asym meas $\Rightarrow$ **reduced systs**
⋮

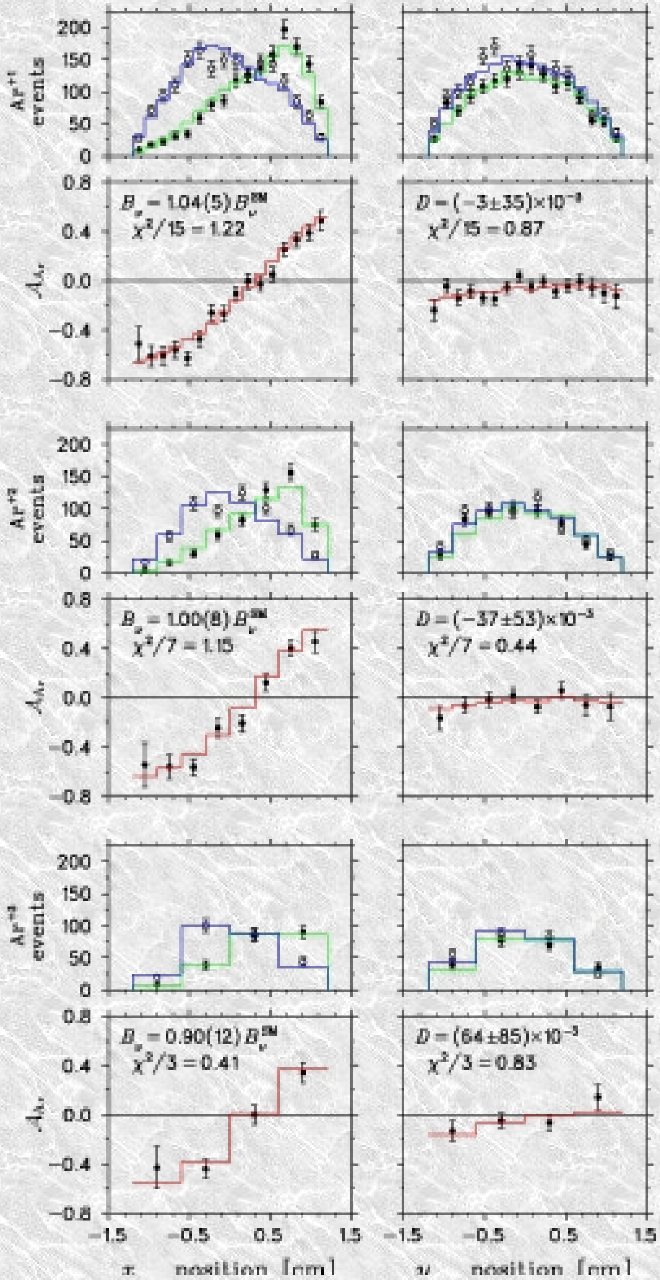
— MCP position **(in)efficiency**
— dependence on cloud **position**, **velocity** (**size**, **temperature**)
⋮

Dan Melconian

Cyclotron Institute

1st Result measuring B_ν





$$B_\nu^{\text{exp}} = -0.755 \pm \underset{\text{(stat)}}{0.020} \pm \underset{\text{(syst)}}{0.013}$$

$$B_\nu^{\text{SM}} = -0.7692 \pm 0.0015$$

agrees to statistics-limited 3%

DM *et al.*, PLB **649**, 370 (2007)

Dan Melconian

Cyclotron Institute

“Conclusions”

- Exciting upgrade at Cyclotron Institute
  - RIB beams without a PAC!
  - Opportunity for new directions/collaborations
- *Cool* physics with atom traps
  - Rich program with polarized correlations
  - Happy to expand collaboration list

Systematics

Source	$\langle \Delta B_\nu \rangle / B_\nu^{SM}$ [%] Phys Lett B		$\langle \Delta B_\nu \rangle / B_\nu^{SM}$ [%] future
Asymmetry fit	± 2.5		± 0.3
Polarization (stat)	± 0.8		± 0.1
	± 2.6	$\rightarrow$	± 0.3
Polarization (syst)	± 0.4		$\leq \pm 0.2$
cloud position/velocity	± 1.2		$\leq \pm 0.4$
cloud size/temperature	± 0.3		$\leq \pm 0.1$
binning	± 0.3		$-$
MCP calibration	± 1.0		± 0.1
efficiency	± 0.5		$-$
$\hat{x}_{\rm MCP}$—OP align	± 0.3		± 0.1
	± 1.8	$\rightarrow$	$\leq \pm 0.5$