$\beta-\nu$ correlations in ^{6}He decay using an electrostatic trap an "In-House" experiment at the WI

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Collaboration between the Nuclear Structure and the molecular and Atomic Physics groups. Also scientists from the Hebrew University, Soreq NRC center, MPIK – Heidelberg and LBL

Ph.D. Thesis of **<u>Sergey Vaintraub</u>**
<u>Tsviki Hirsh</u>

- Good News…
- Bad News…..

Goal

A high precision measurement of the β-ν correlation coefficient, "*a*", from radioactive decay of $^6He \rightarrow {}^6Li + e^- + \nu$ in an Electrostatic ion trap

$$H_\beta^{^6He} = \sum_{i=S,P,V,A,T} \overline{(^6Li)}\hat{O}_i(^6He)[\bar{e}\hat{O}_i(C_i + C_i'\gamma_5)\upsilon_e] + h.c.$$

$$dW \propto \xi\left(1 + a_{e\nu}\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m}{E_e} + \ldots\right)$$

$$a_{e\nu} = a_{GT} = -\frac{1}{3}$$

J. D. Jackson, S. B. Treiman, and H. W. Wyld, Jr., Nucl. Phys. 4, 206 (1957).

β DECAY 101

Possible observables in nuclei

$$\frac{d\Gamma}{dE_\beta d\Omega_\beta d\Omega_\nu} \propto \xi \left\{ 1 + a\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m}{E_e} + c\left[\frac{1}{3}\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} - \frac{(\vec{p}_e \cdot \vec{j})(\vec{p}_\nu \cdot \vec{j})}{E_e E_\nu}\right] \left[\frac{J(J+1) - 3 < (\vec{J} \cdot \vec{j})^2 >}{J(2J-1)}\right] + \frac{<\vec{J}>}{J} \cdot \left[A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu}\right] \right\}$$

Parameter	Observable	Sensitivity	SM Prediction
a	β-ν (recoil) correlation	Tensor & Scalar terms	1 for pure Fermi -1/3 for pure GT or combination
b (Fierz term)	Comparison of β^+ to EC rate	SV/T/A interference	0
A	β asymmetry for polarized nuclei	Tensor, ST/VA Parity	Nucleus dependent
B	ν asymmetry (recoil) for polarized nuclei	Tensor,TA/ST/VA/SA/VT Parity	Nucleus dependent
D	Triple product	ST/VA Interference TRI	0

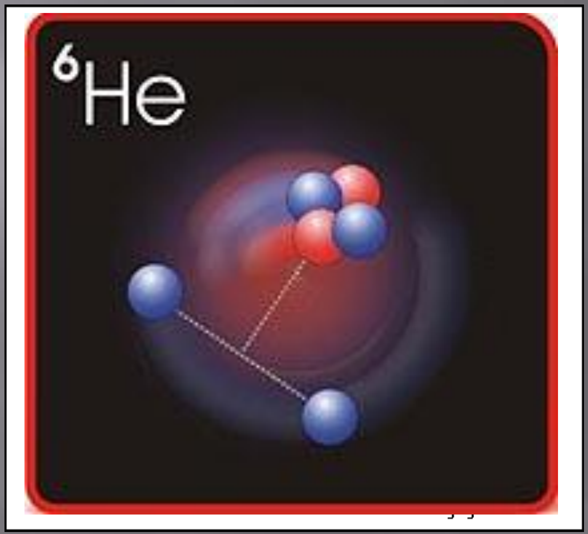
Example: ^{6}He beta decay
See, e.g, Flechard et al, PRL (2008)

^{6}Li
daughter nucleus

e⁻ Electron

$$dW \propto a\xi\left(\frac{p_e}{E_e}\cos\theta\right)$$

$$dW_{SM}(^6He) \propto -\frac{1}{3}\left(\frac{p_e}{E_e}\cos\theta\right)$$



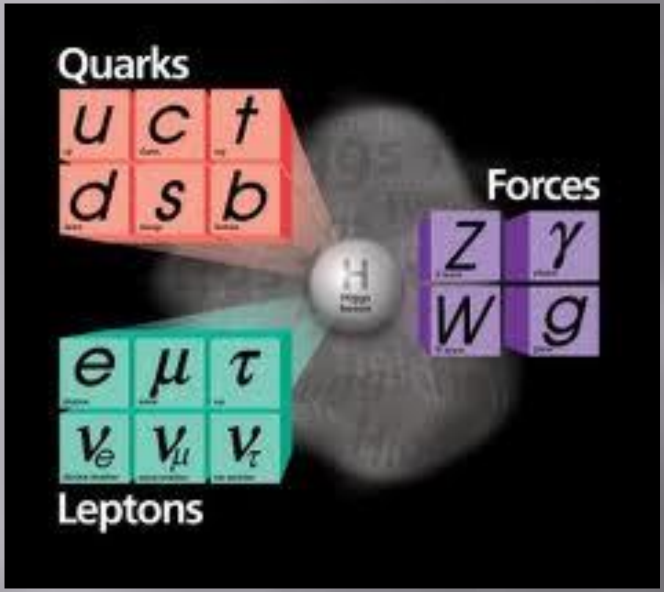
θ

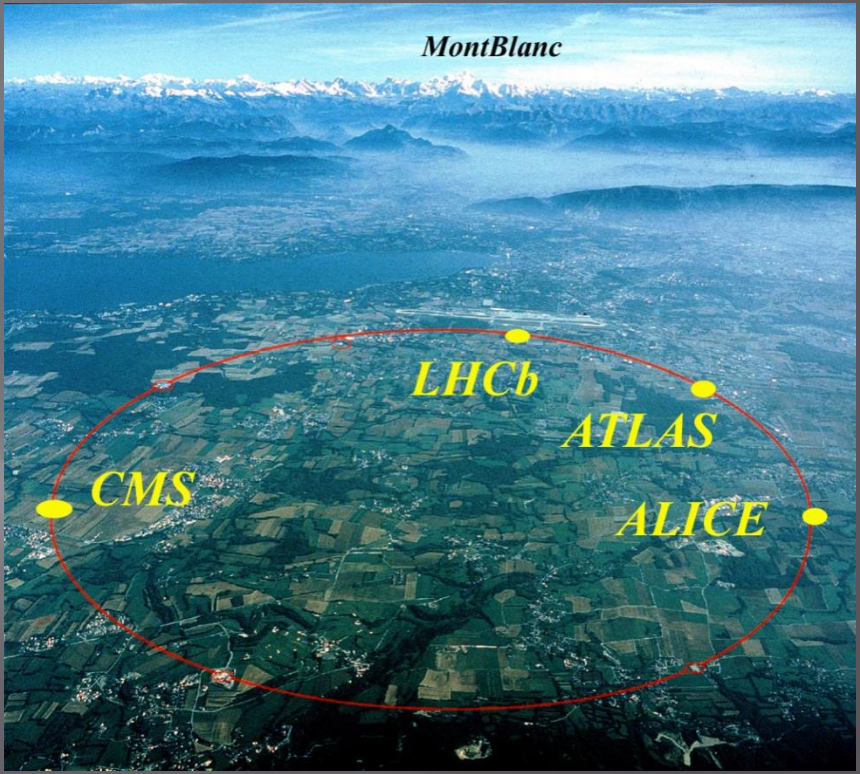
$\overline{\nu}_e$ Electron
anti-neutrino

$$^6He \rightarrow {}^6Li + e^- + \overline{\upsilon}_e$$

- New physics beyond the Standard Model's V-A structure
  "LHC-type" physics at the low energy frontier!

The Standard Model of Particles and Forces





BUT…
Also "Physics Beyond the Standard Model"

Why RNB's in Traps?

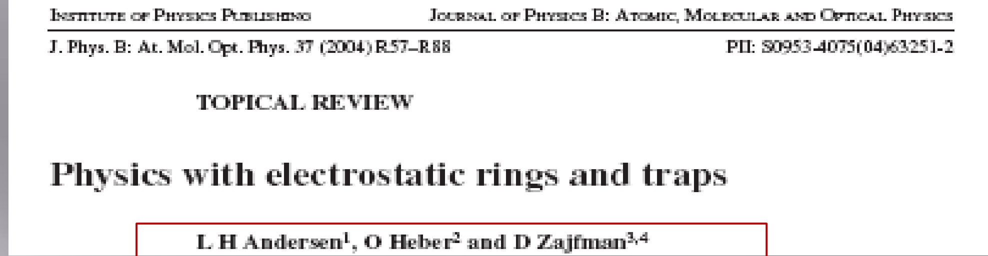
- No possibility for detection of neutrinos
- Small effects - low energy of ions, multiple scattering, angle resolution
- "Single" Atom/Ion in a trap

World-wide activity (MOT, Penning, Paul)

Berkeley
TRIUMF
GANIL
ISOLDE
Argonne
Seattle
WI (commissioning) – **Electrostatic Trap**
Jerusalem - MOT (initialization phase)

Beta Decay Studies World Wide
(Partial List)

Isotope	Technique	Group
^{6}He	Electrostatic Trap	WI (Hass) + HUJI (Ron) + LBL (Kolomensky)
^{6}He	MOT	ANL (Mueller) + UW (Garcia)
^{8}Li	Paul Trap	ANL (Savard)
^{38m}K / ^{87}Rb	MOT	TRIUMF (Behr)
$^{17/25}$Ne	MOT	HUJI (Ron)
^{26m}Al / ^{35}Ar / ^{46}V	Penning Trap	Leuven / WITCH (Severijns)
^{6}He / ^{35}Ar	Paul Trap	LPC CAEN (Fléchard)
neutron	Many	Many
^{21}Na	MOT	LBL (Freedman - deceased)
^{16}N	Electrostatic Trap	WI (Hass)
^{21}Na	MOT	KVI (Jungmann)



INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS B: ATOMIC, MOLECULAR AND OPTICAL PHYSICS

J. Phys. B: At. Mol. Opt. Phys. 37 (2004) R57–R88 PII: S0953-4075(04)63251-2

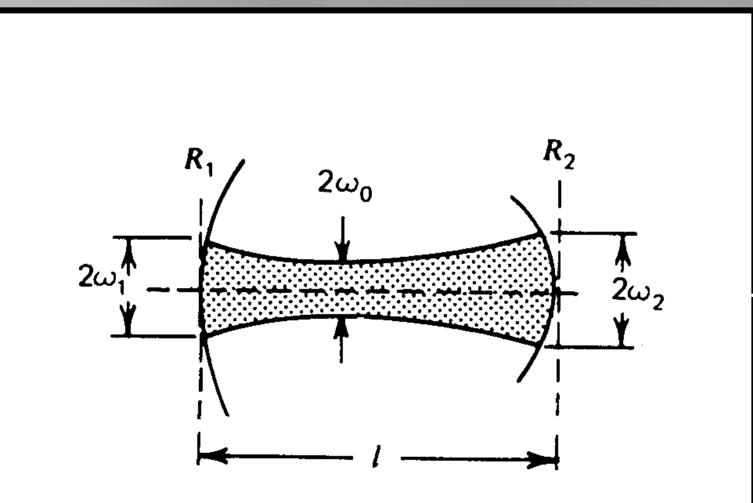
TOPICAL REVIEW

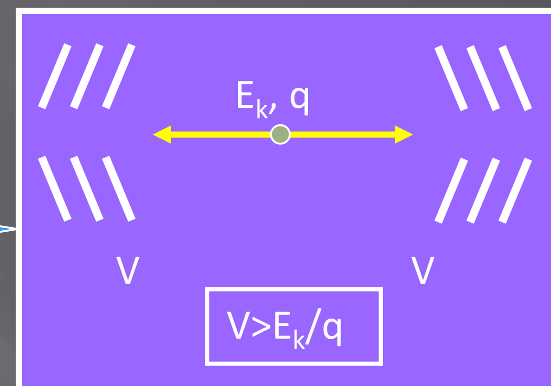
Physics with electrostatic rings and traps

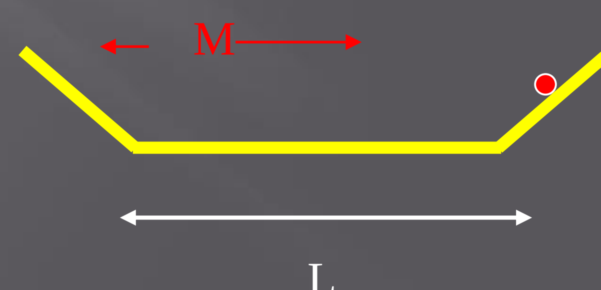
L H Andersen[1], O Heber[2] and D Zajfman[3,4]

Optical resonator

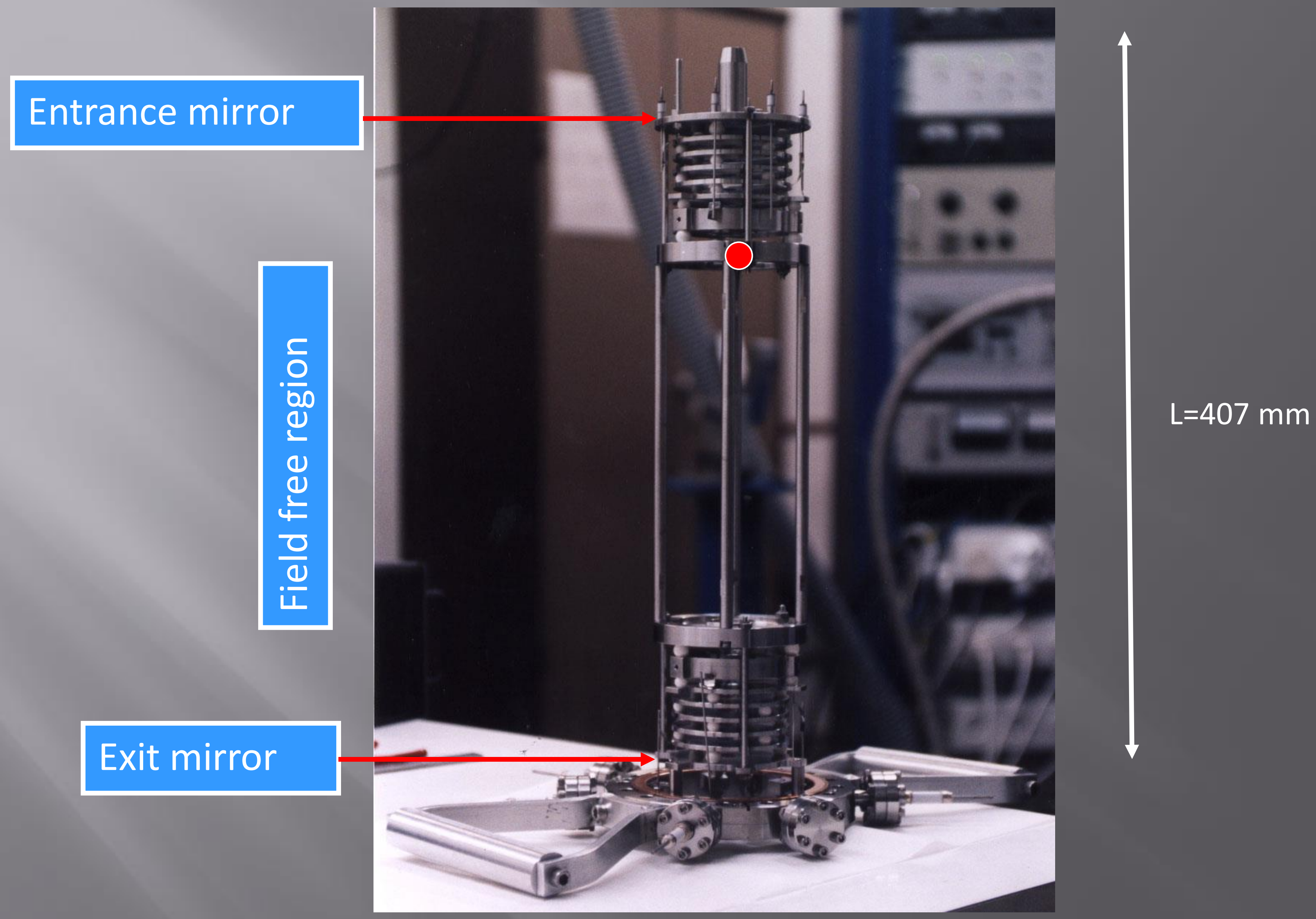
Particle resonator







Trapping of fast ion beams using electrostatic field


Entrance mirror
Field free region
Exit mirror
L=407 mm

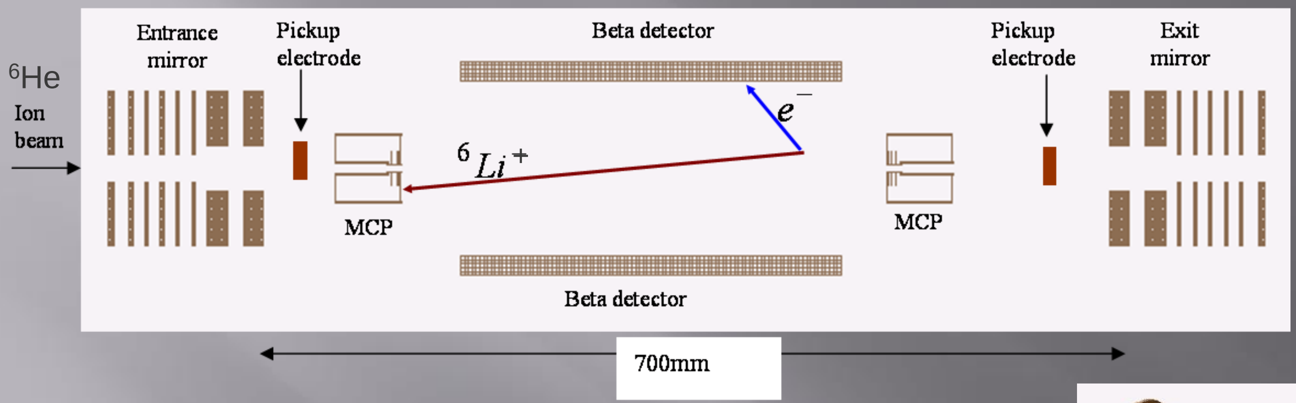
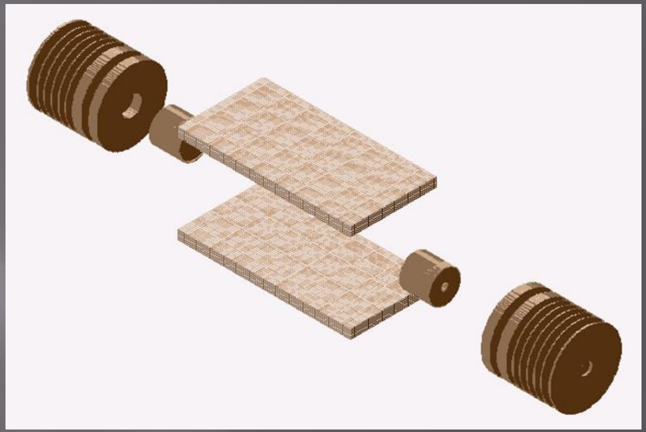


Fig. 2 A schematic view of the EST for β-decay studies. The radioactive ion, like ^{6}He, moves with E_k-4.2 keV between the reflecting electrodes. The β electrons are detected in position sensitive counters while the recoiling ions, due to kinematic focusing, are detected with very high efficiency in either one (determined by the instantaneous direction) of the annular MCP counters.



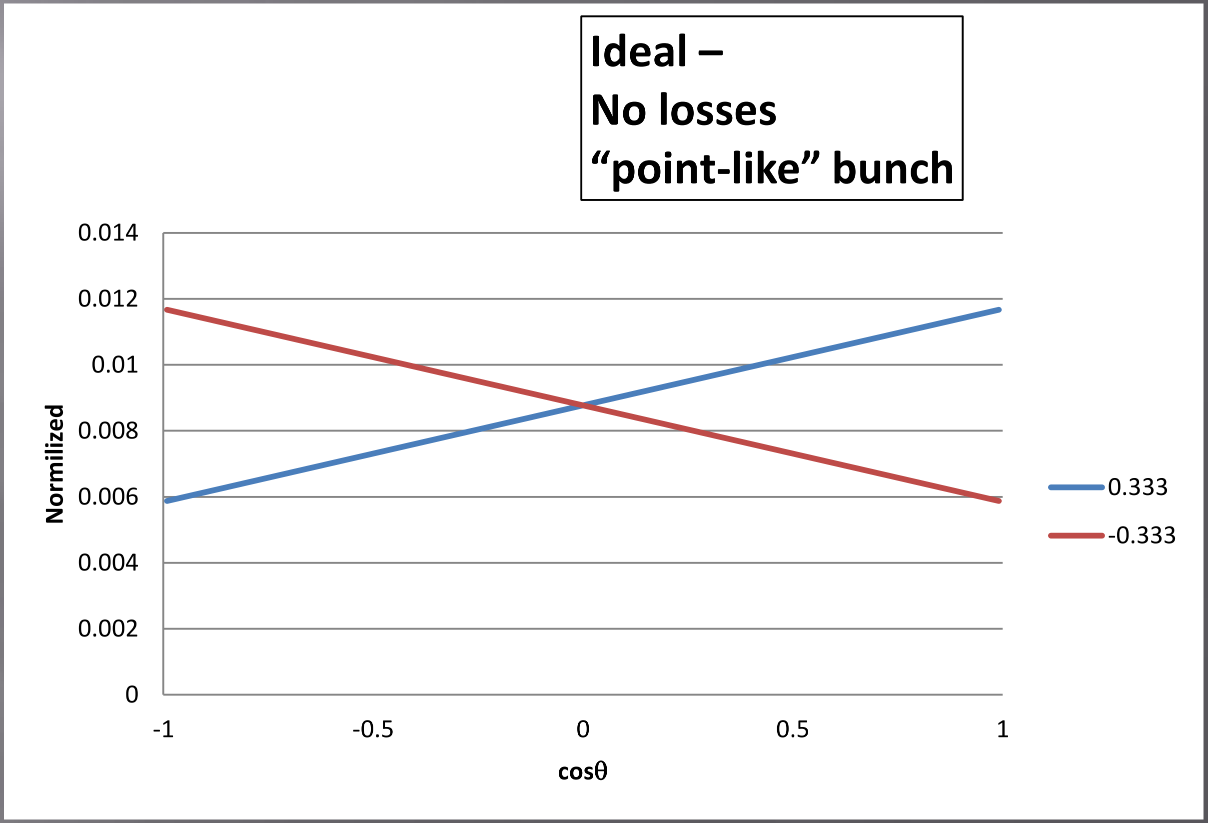
Apparent advantages:

- Large solid angles (for BOTH ion recoil and electrons
- Field-free and "equipment-free" inner region
- Simplicity, portability
- Complementary to other method (different systematic errors)
- Full reconstruction of event-by-event - <u>actually measure cos(θ)!</u>

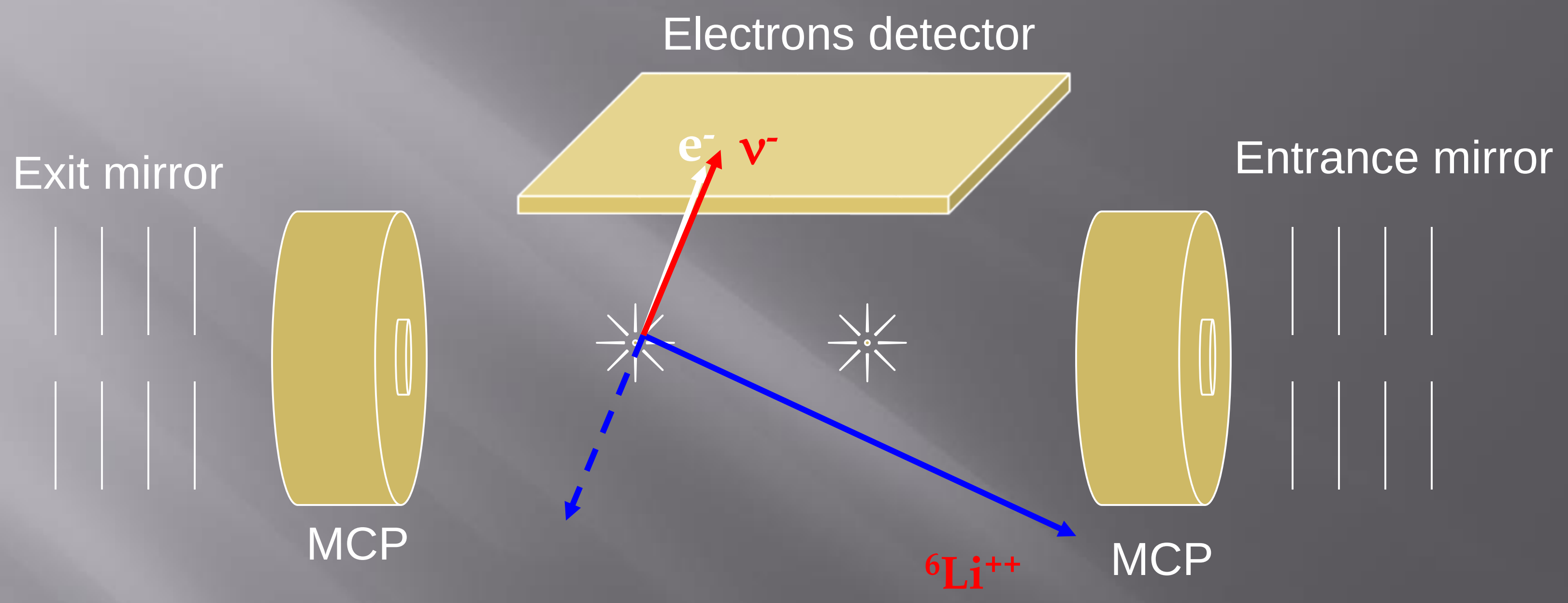
Ideal Case

$$dW \propto a\xi\left(\frac{p_e}{E_e}\cos\theta\right)$$

$$dW_{SM}(^6He) \propto -\frac{1}{3}\left(\frac{p_e}{E_e}\cos\theta\right)$$

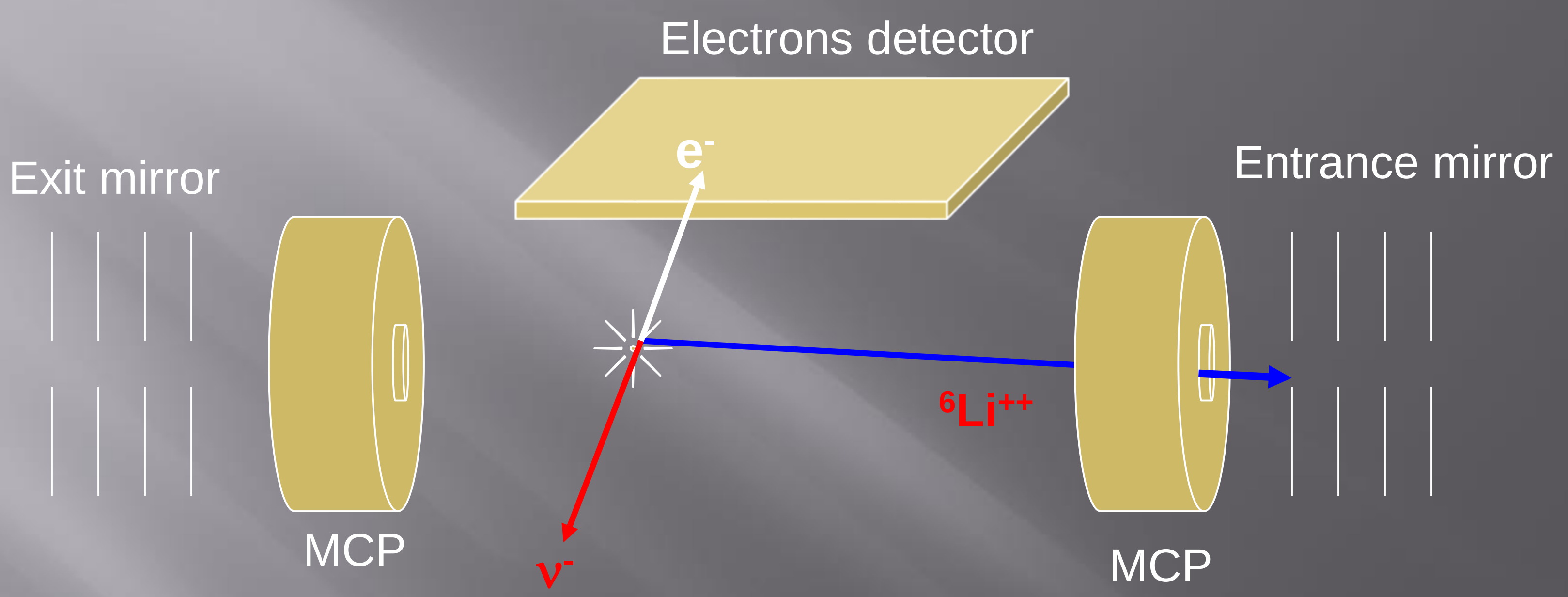


Cosθ ~ 1



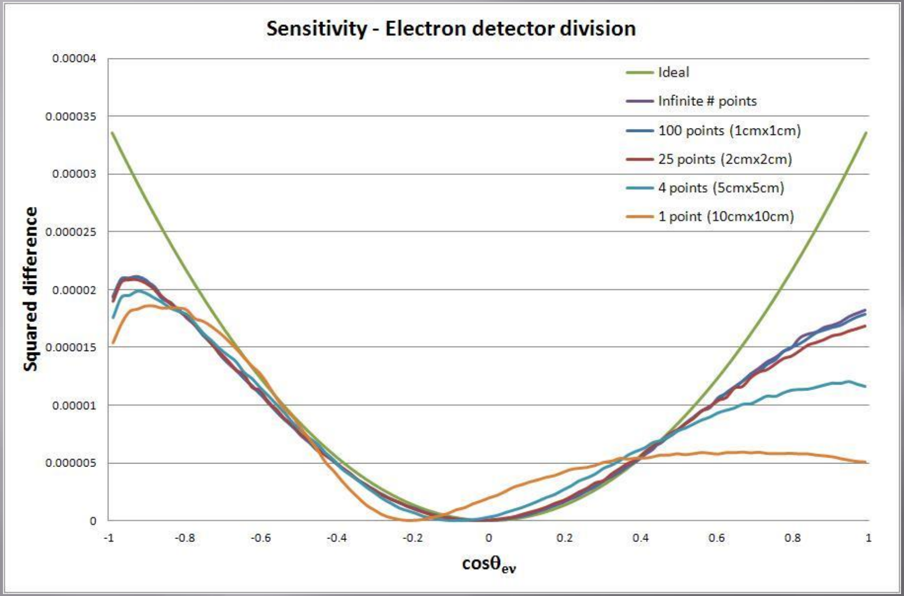
Some of the ^{6}Li ions will miss the MCP at its periphery

$\text{Cos}\theta \sim -1$

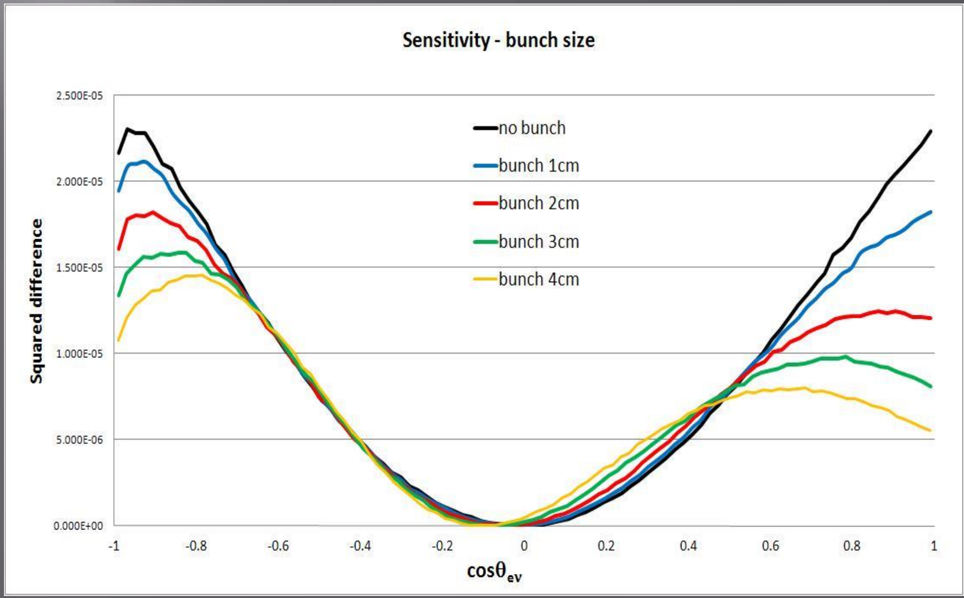


Some of the ^{6}Li ions will go though the MCP hole

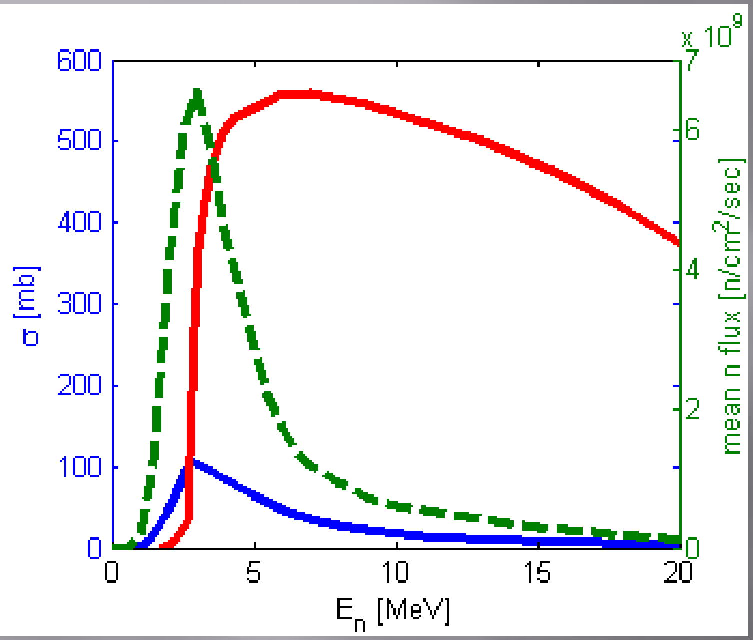
Sensitivity of measurement to various parametrs

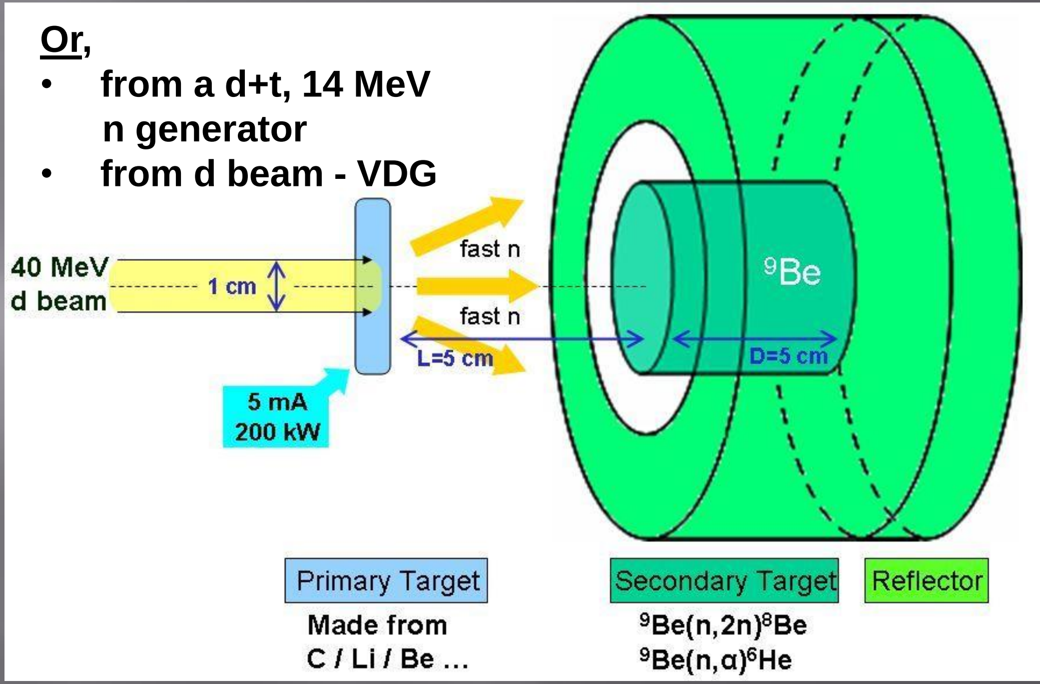


"Sensitivity" =
$\Sigma\,[(a{=}1/3) - (a{=}{-1/3})]^2$



^{6}He Production





Hass et al., J. Phys. G: Nucl. Part. Phys., 014042 (2008)

Expected Yields for a BeO target:

^{9}Be(n,α)^{6}He

SARAF (40 MeV, 2 mA): $8 \cdot 10^{12}$/sec

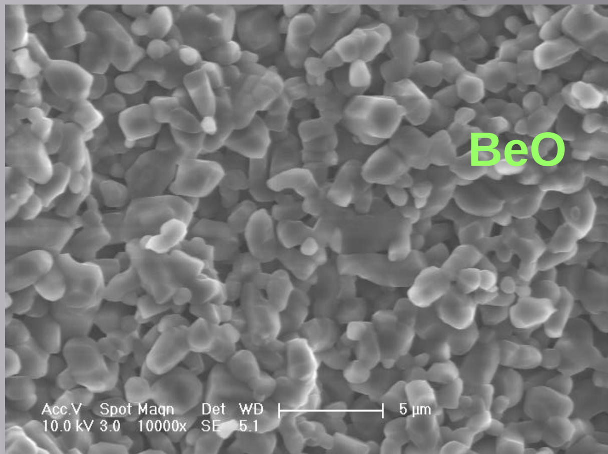
SPIRAL2 (40 MeV, 5 mA): $2 \cdot 10^{13}$/sec

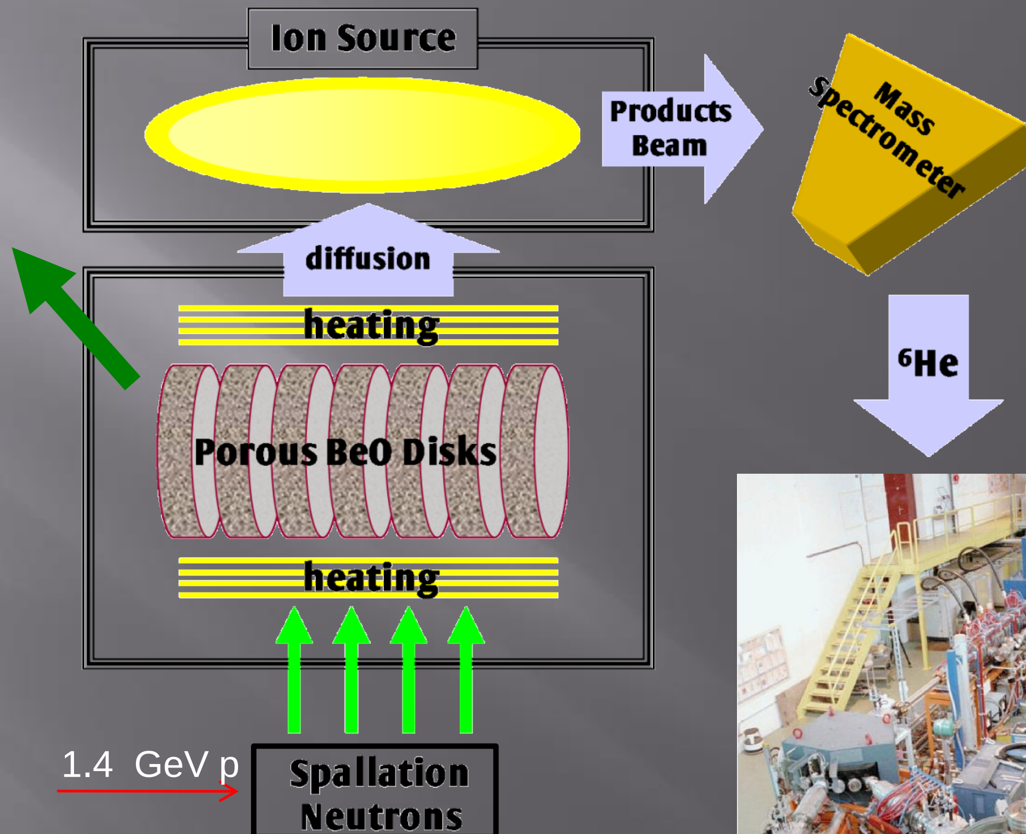
Expected Yields for a BN target:

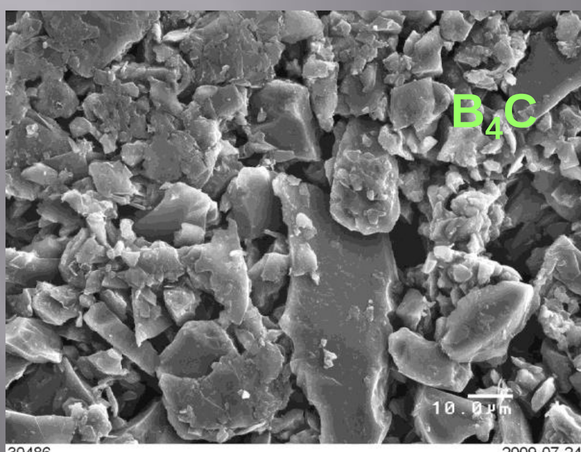
^{11}B(n,α)^{8}Li

SARAF (40 MeV, 2 mA): $2 \cdot 10^{12}$/sec

^{6}He production at ISOLDE (CERN)



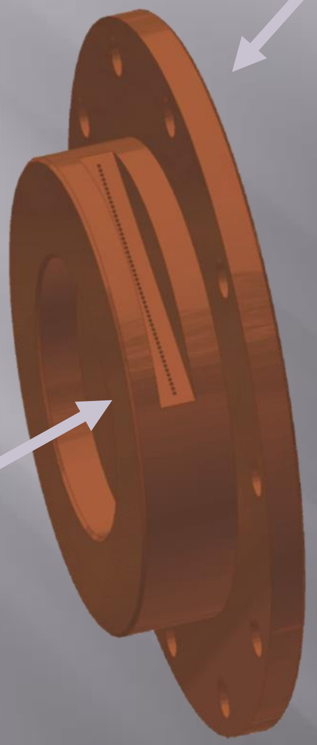




Similar possibilities
With $^{11}B(n,\alpha)^{8}Li$

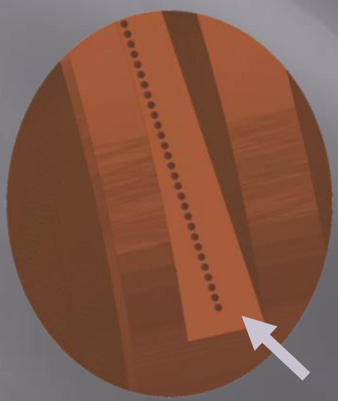
ISOLDE Exp.
17.4.2009

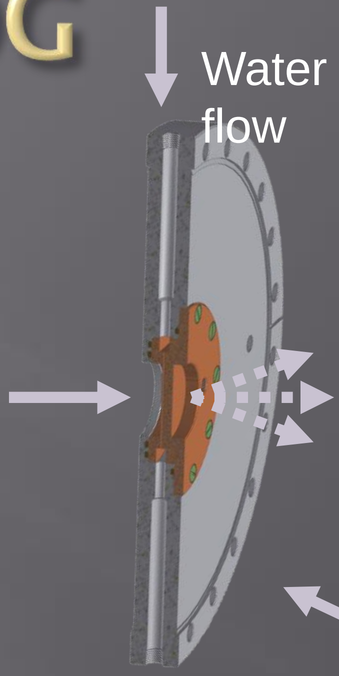
LiFTiT & 3 MV VDG



2.5 MeV 10-50 μA

d beam





D. Petrich et al., “A neutron production target for FRANZ”, (2009)

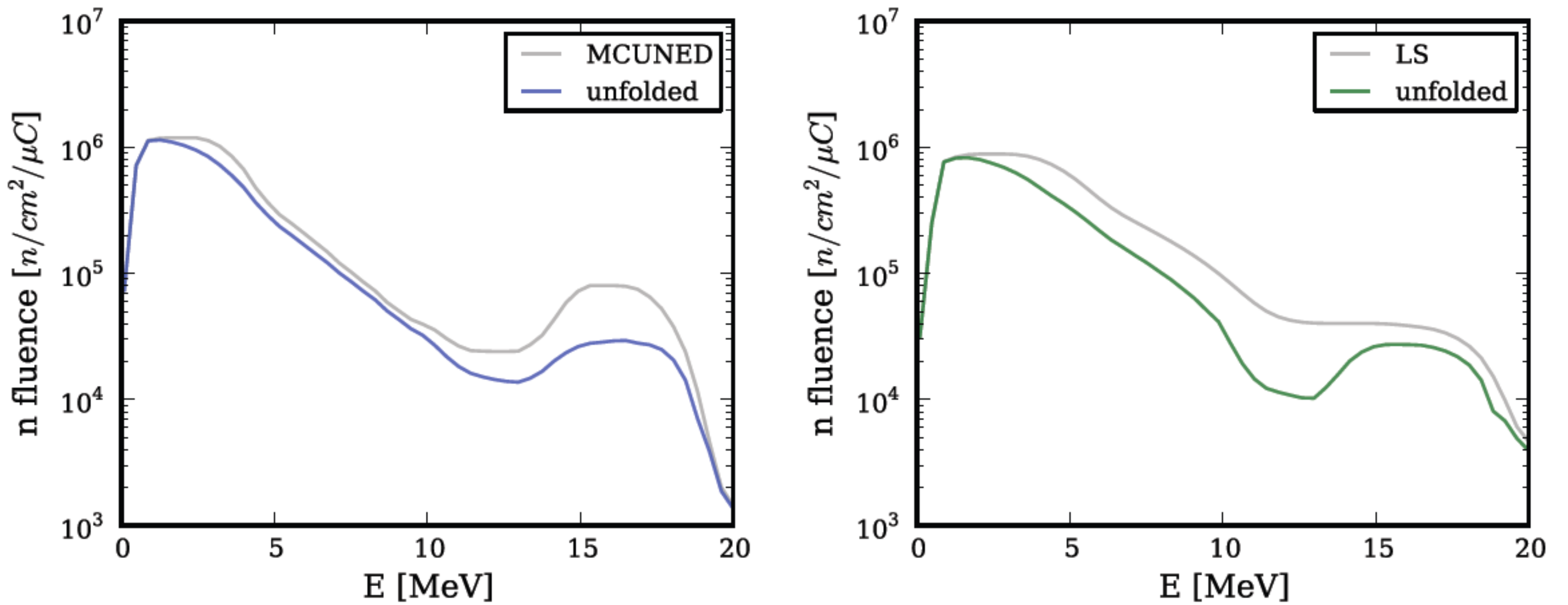
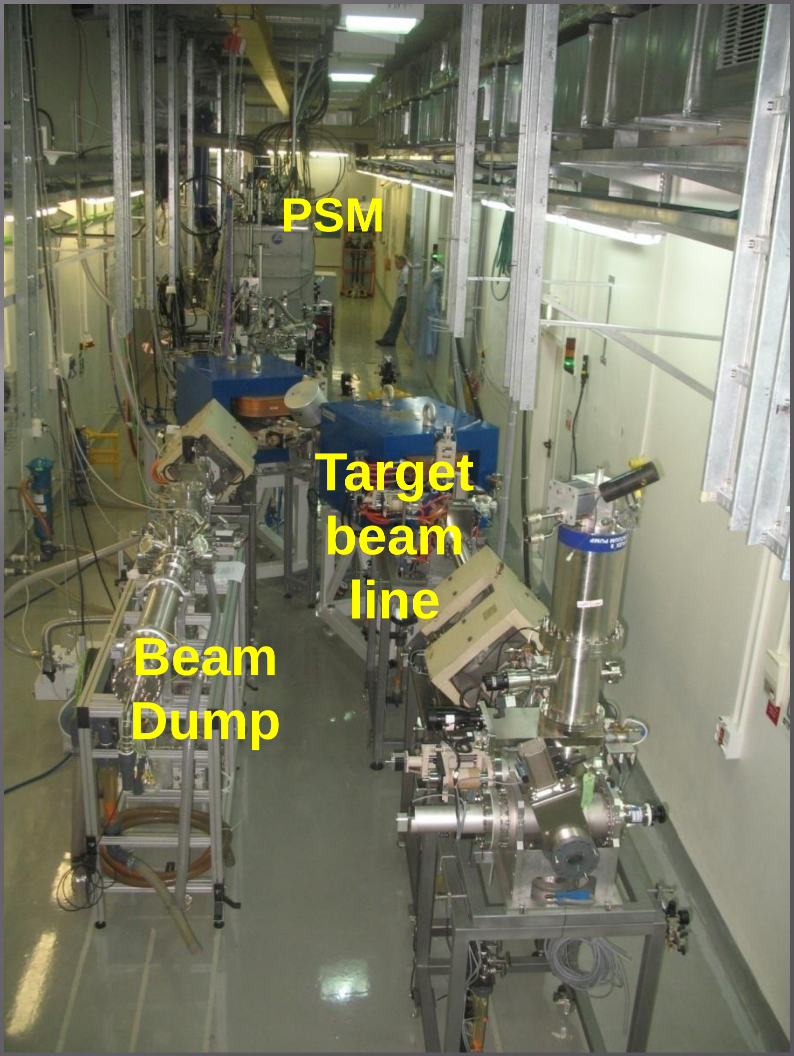


Figure 3.20: Unfolded spectrum of *LiFTiT* by using *MCUNED* (left) and Liquid Scintillator (right) initial guess spectra.

SARAF Phase I
@
Soreq Center - Israel

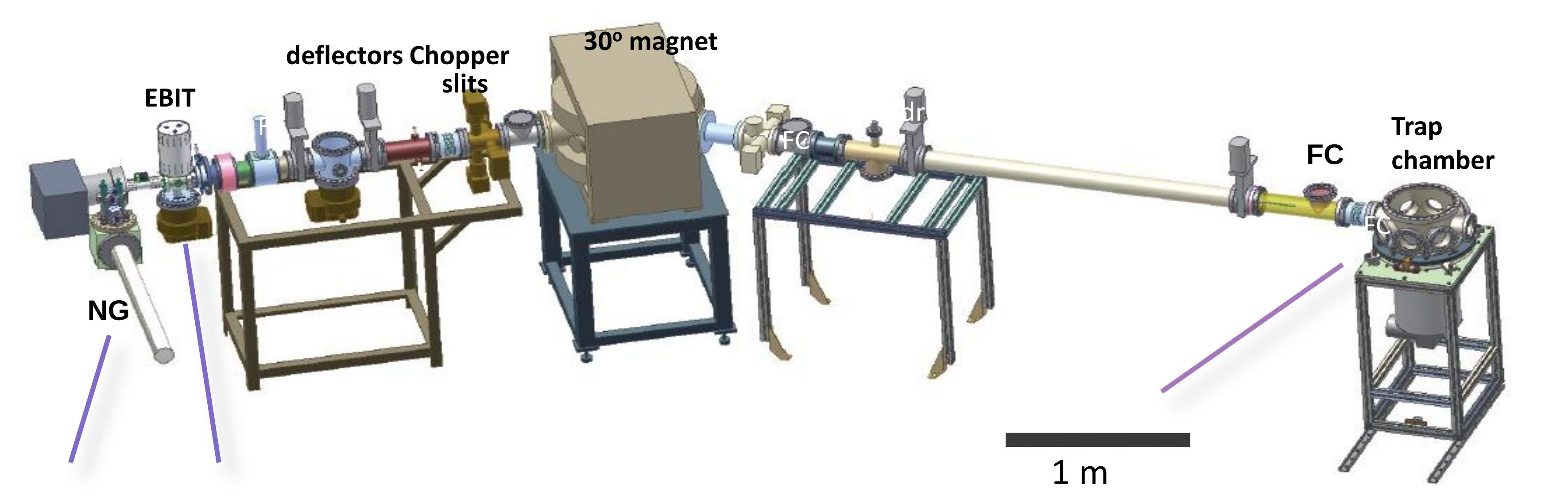
- Commissioning of Phase-I is approaching finalization
- 1 mA CW proton beam has been accelerated up to an energy of 3.7 MeV
- Low duty cycle (~0.2 mA) deuteron beam has been accelerated up to an energy of 4.3 MeV
- Phase-II – up to 40 MeV (2015)



WIRED

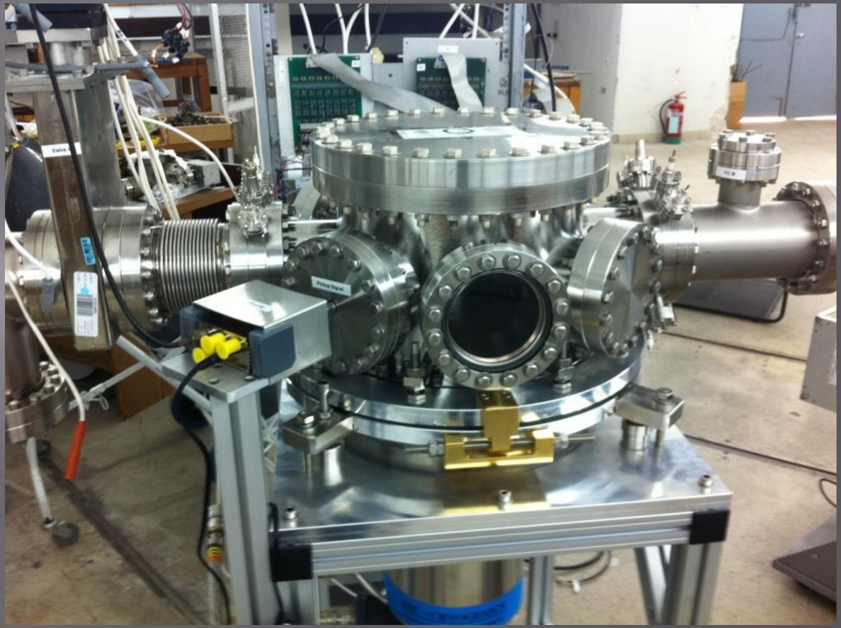
Weizmann Institute Radioactive Electrostatic Device

Experimental scheme



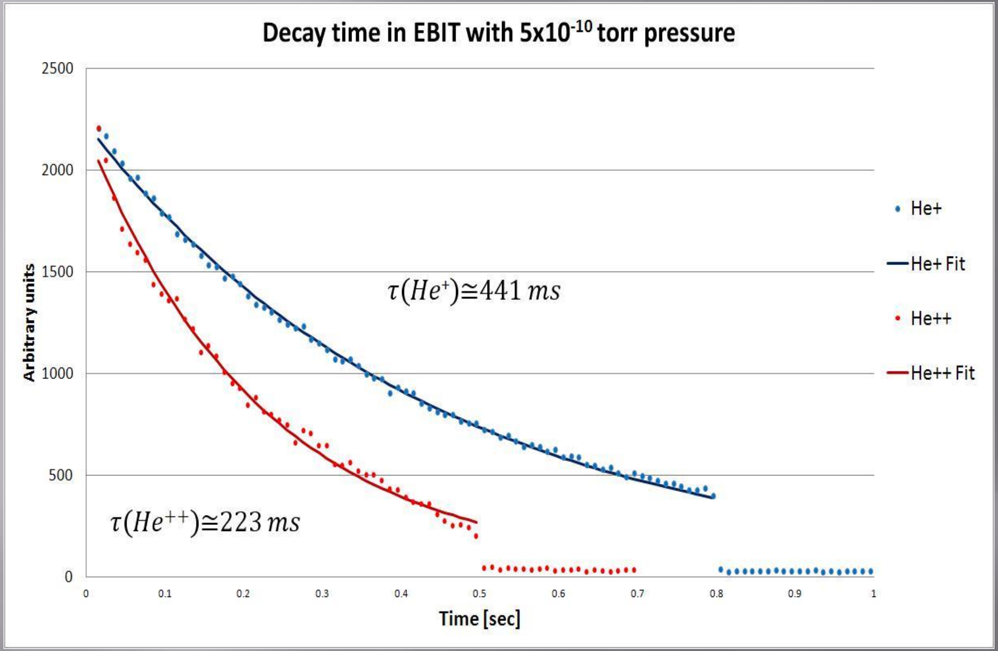
A) High energy (14 MeV) neutrons from a d+t NG hit a hot BeO target; ^{6}He nuclei are produced.
B) ^{6}He atroms are transferred to an EBIT where they get ionized, accumulated, and bunched and guided
C) The ion bunch is injected into the EIBT for beta-decay studies.
D) Data acquisition: signals from detectors are processed, recorded, and analyzed.

"In- House" Research!
R&D steps at the WI

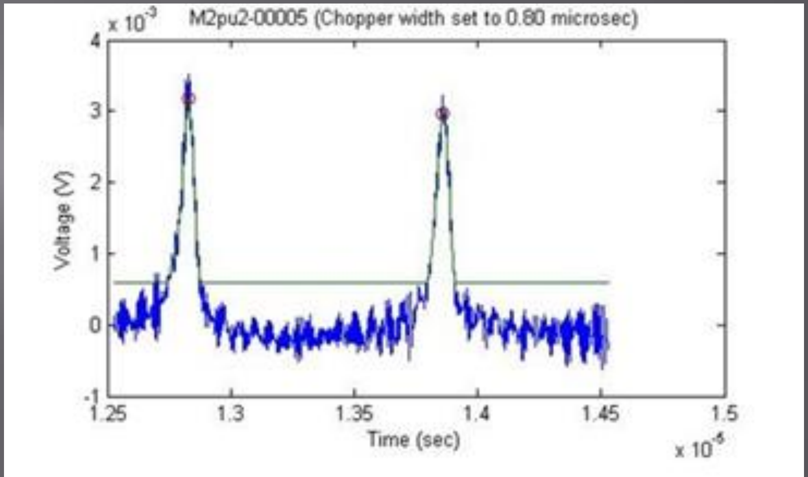


Use infrastructure (Shielding, radiation protection, equipment) from de-commissioned 14 MV Koffler accelerator

Most Recent Results and R&D



Trapping and bunching of stable $^4He^+$ and $^4He^{++}$. As expected, the trapping time of $^4He^{++}$ is shorter than that of $^4He^+$.



- Bunching R&D with ^4He
- Algorithm and tests of a position-sensitive e-detector
- R&D into specialized design of Electron Beam Ion source

Experimental tests and control of systematic errors

- Using stable 4He that undergo collisions in the residual gas to test the acceptance of the MCP. In particular, this will allow probing any position-dependent efficiency variation of the MCP and possible “edge detection effects” of the MCP on its periphery and around its annular hole.

- Varying trapping voltages (hence, kinetic energy of 6He ions and resulting 6Li recoils) and/or 6He charge state (singly or doubly ionized).

- Varying the bunch length arrangement with respect to the two identical MCP detectors at both ends.

- Using various cuts in the analysis such as those of the electron energy and decay position in the trap.

- Using different strategies of analysis, from event-by-event reconstruction of the □□□ angle to the use of distributions such as the 6Li time of flight and position distribution on the MCP’s.

Full E_e determination + position information

Thick plastic scintillator

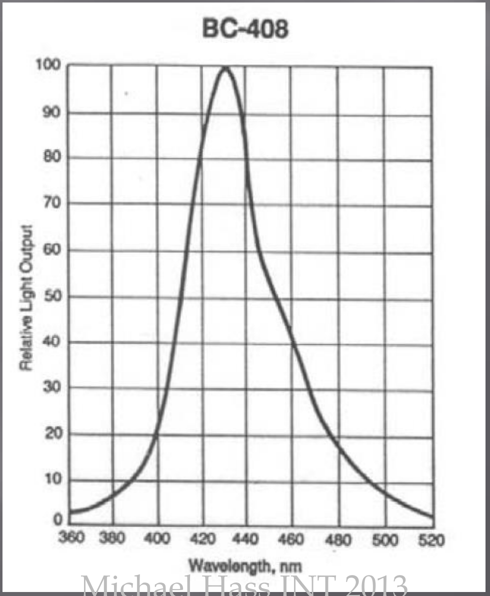
Individual
photomultipliers

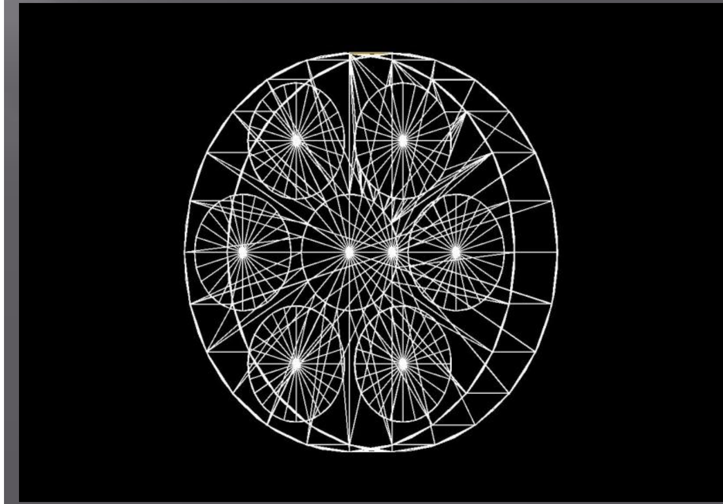
Detector – BC-408

- 65 cm radius circular Plastic Scintillator
- Cover – VIKUITI (3M) >99% Reflectivity
- 7 PMT 1.9 cm Radius
- Scintillation Parameters

~ 11000 #Ph/MeV

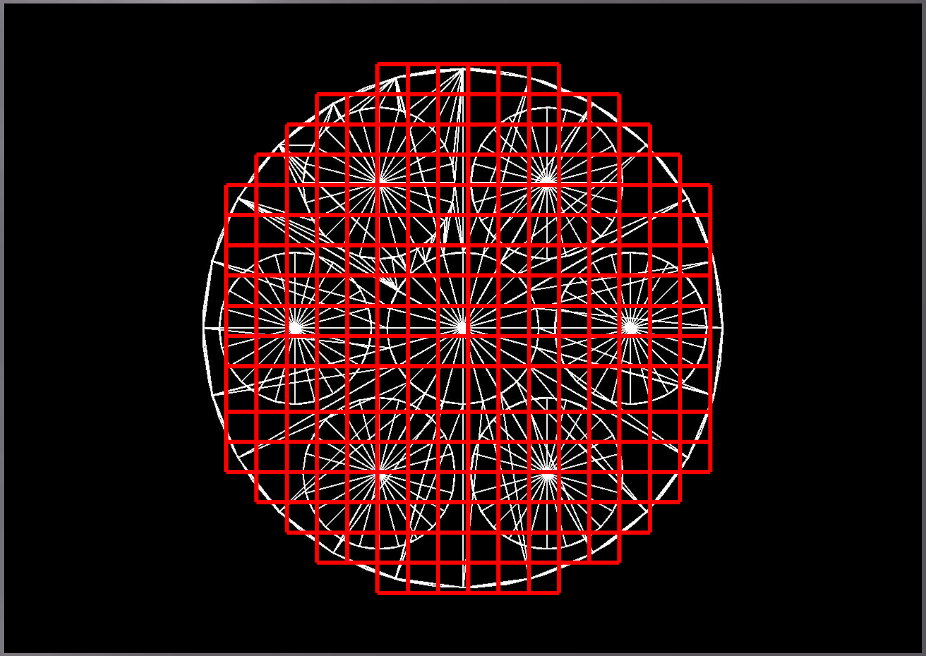
- λ_{max} = 425 nm
- l_{abs} = 210 cm



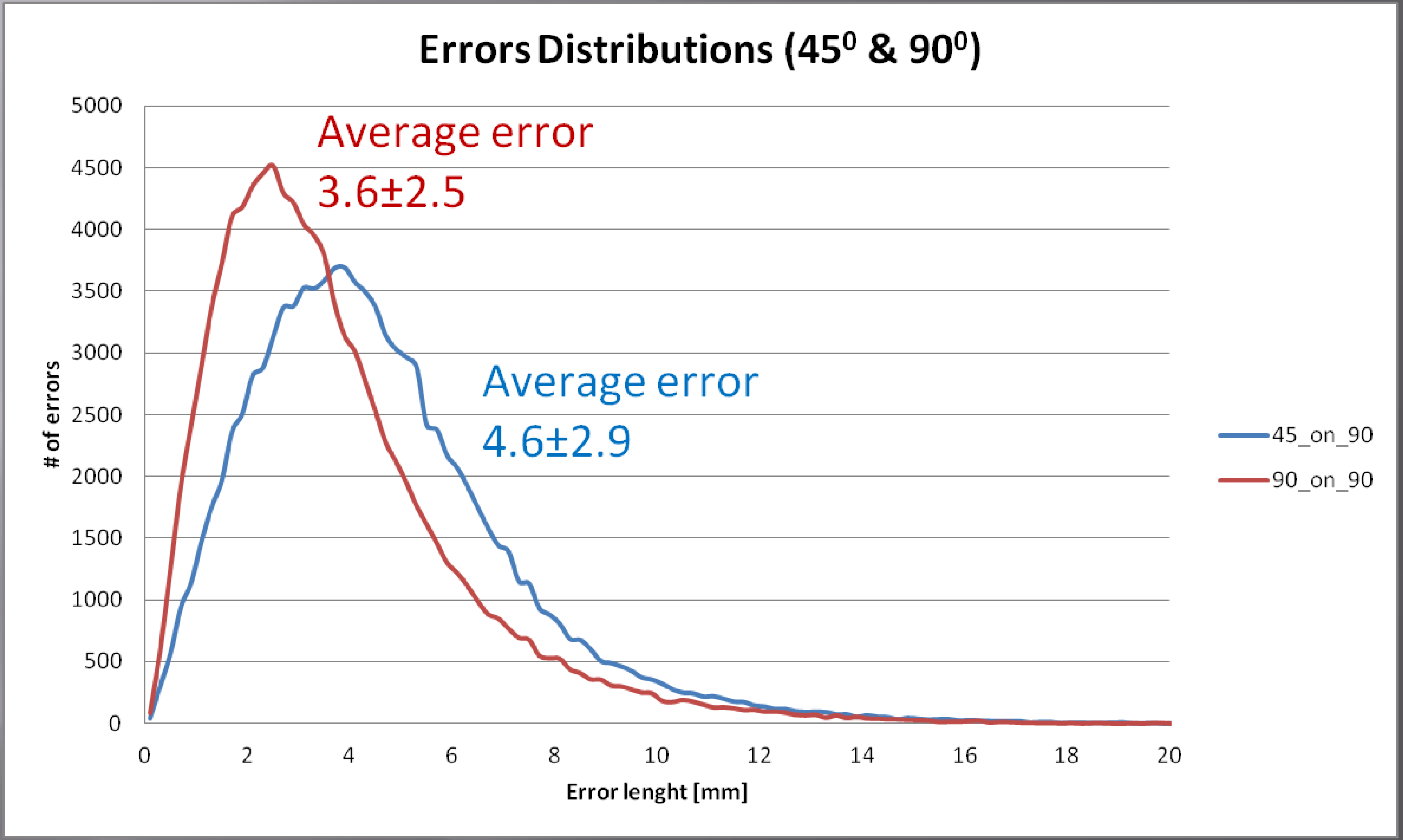


Geant4 Simulation

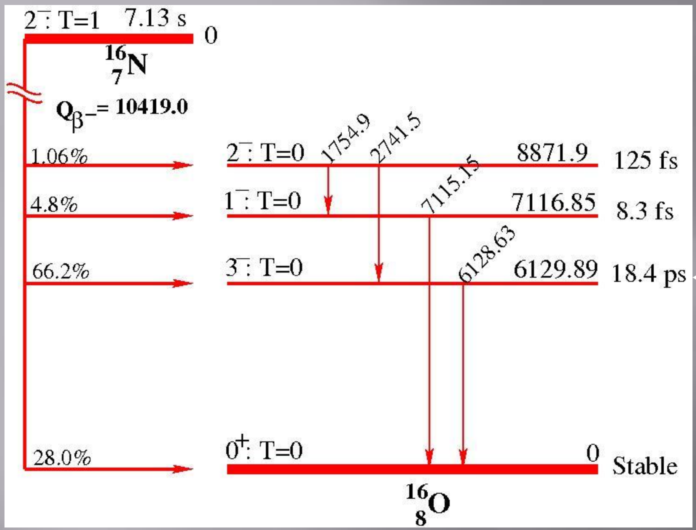
- Dividing area of Detector to squares
- Distribution of Photons in PMTs per square
- Statistical Map



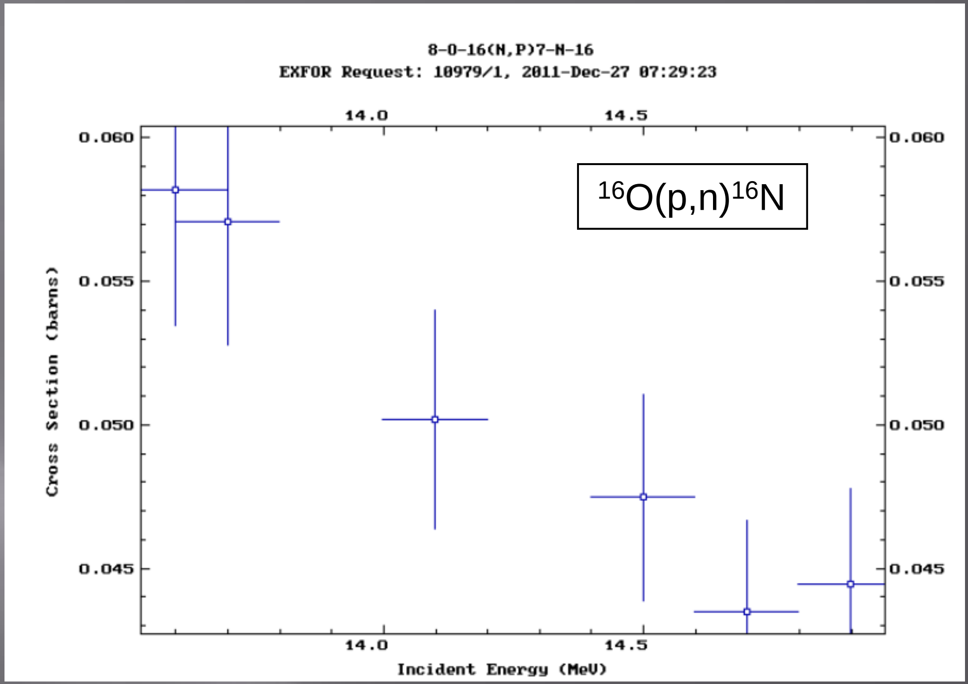
Comparison - Error



The case of ^{16}N



GT

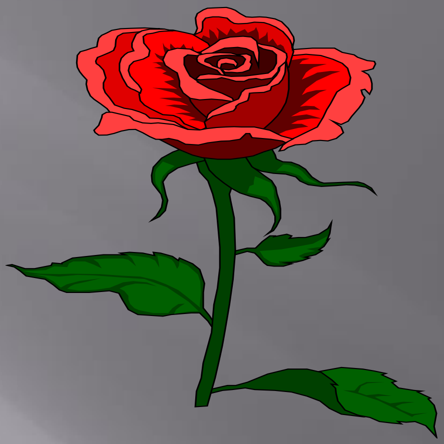


^{16}N is produced simultaneously with ^{6}He, and with a comparable yield, in the BeO target

Theoretical work on the β–ν correlation coefficient for the forbidden 2^{-} -> 0^{+} transition. DG

Summary

- A novel application of the electrostatic trap concept
- Potential for a significant contribution to the β–ν correlation field
- Experiment “almost” ready to start taking data
- “The proof of the pudding is in the eating….



Many thanks to all my colleagues