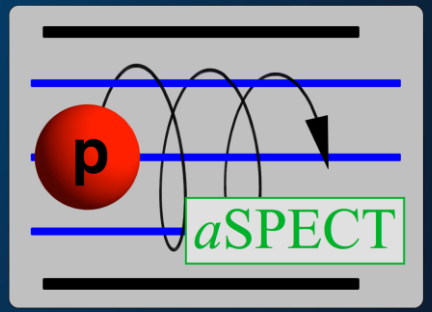
U. Schmidt

Reanalysis of the β-$\bar{\nu}_e$e angular correlation measurement of aSPECT with (new) constraints on Fierz interference

OUTLINE

- Introduction and Motivation
- aSPECT spectrometer/measurement principle
- results published 2020 and reanalysis
- Outlook



Weak interaction parameters

$$M \propto G_F V_{ud} \left(\bar{\psi}_p \gamma_\mu (1 + \lambda \gamma_5)\, \psi_n\right) \cdot \left(\bar{\psi}_e \gamma_\mu (1 - \gamma_5)\, \psi_{\bar{\nu}_e}\right)$$

Fermi constant

Cabibbo-Kobayashi-Maskawa (CKM) Matrixelement

Ratio of axial-vector (A) to vector (V) coupling constant

$$\lambda = \left|\frac{g_A}{g_V}\right| e^{i\phi}$$

Neutron decay observables

- Neutron lifetime $\rightarrow \tau_n(V_{ud}, \lambda)$
- Correlation coefficients $\rightarrow \lambda$

$$dW \propto 1 + a \frac{\vec{p}_e \vec{p}_{\bar{\nu}_e}}{E_e E_{\bar{\nu}_e}} + b \frac{m_e}{E_e} + \frac{\vec{\sigma}_n}{\sigma_n}\left(A \frac{\vec{p}_e}{E_e} + B \frac{\vec{p}_{\bar{\nu}_e}}{E_{\bar{\nu}_e}} + \cdots\right)$$

$$\frac{dA}{d\lambda} \approx 0.37$$

$$\frac{da}{d\lambda} \approx 0.30$$

Test of the standard model

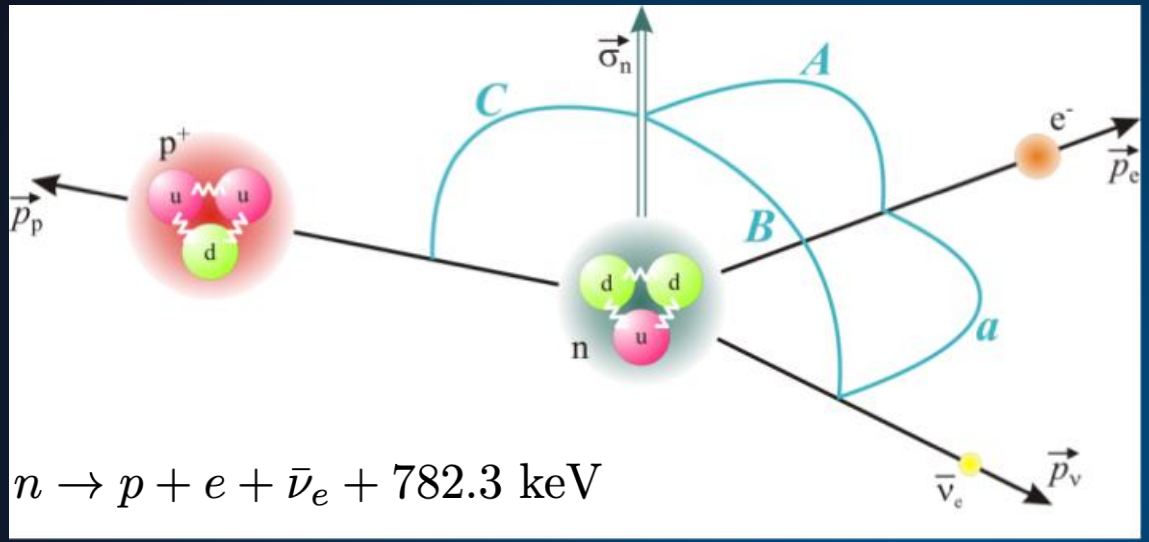
SM: $\lambda = {}^{L_A}/_{L_V}$, $L_V = 1, L_A = \lambda$, $L_S = L_T = R_V = R_A = R_S = R_T = 0$

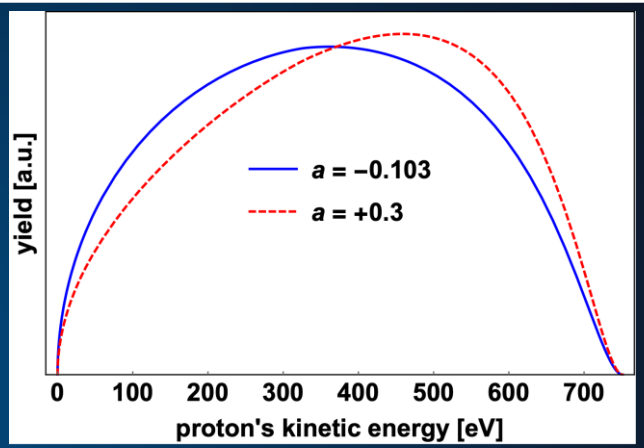
$$a = \frac{1}{\xi}(|L_V|^2 - |L_A|^2 - |L_S|^2 + |L_T|^2 + |R_V|^2 - |R_A|^2 - |R_S|^2 + |R_T|^2)$$

$$A = \frac{2}{\xi}\Re(-|L_V|^2 - L_V L_A^* + |L_T|^2 + L_S L_T^* + |R_A|^2 + R_V R_A^* - |R_T|^2 - R_S R_T^*)$$

SM: $a = \frac{1-|\lambda|^2}{1+3|\lambda|^2}$, $A = -2\frac{|\lambda|^2 - Re(\lambda)}{1+3|\lambda|^2}$

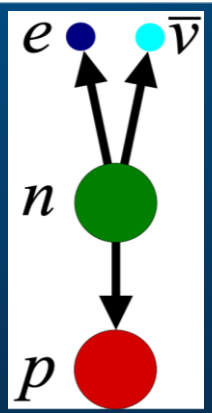
Differential proton spectrum



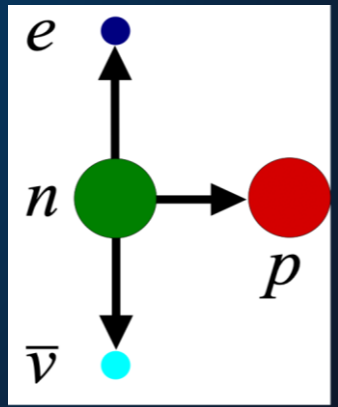


$$dW \propto 1 + a\frac{\vec{p}_e \vec{p}_{\bar{\nu}_e}}{E_e E_{\bar{\nu}_e}}$$

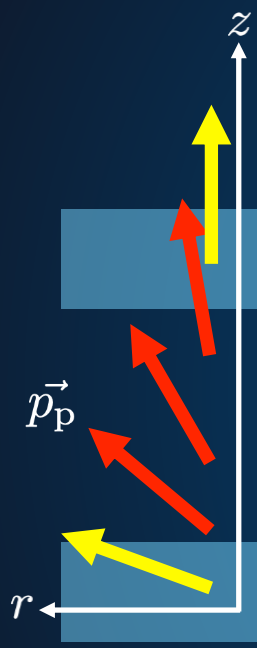
$a > 0$



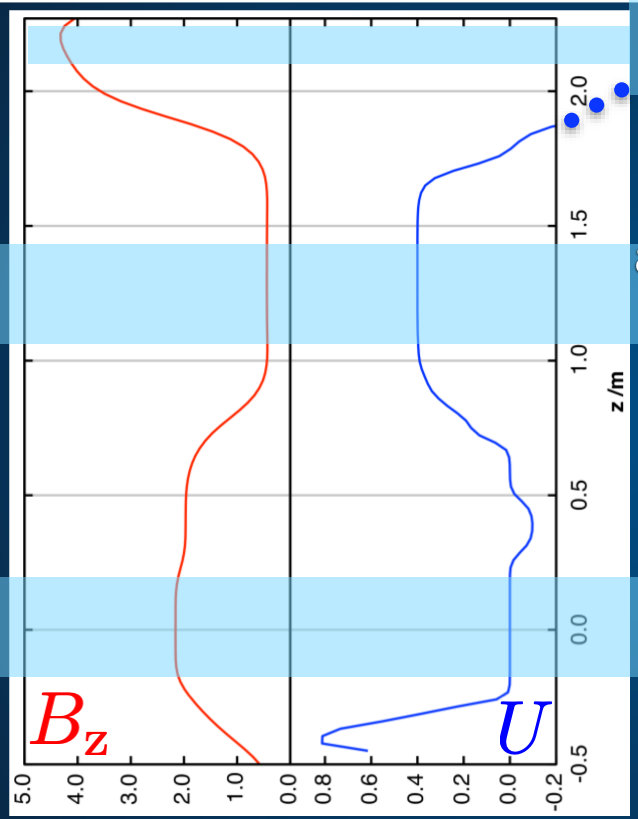
$a < 0$



*a*SPECT - measurement principle



MAC-E type spectrometer

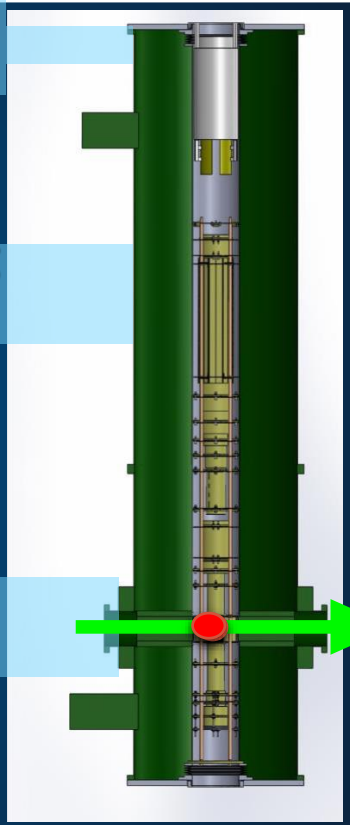


mag. flux density [T] *retardation voltage [kV]*

detector -15keV

analysing plane

decay volume

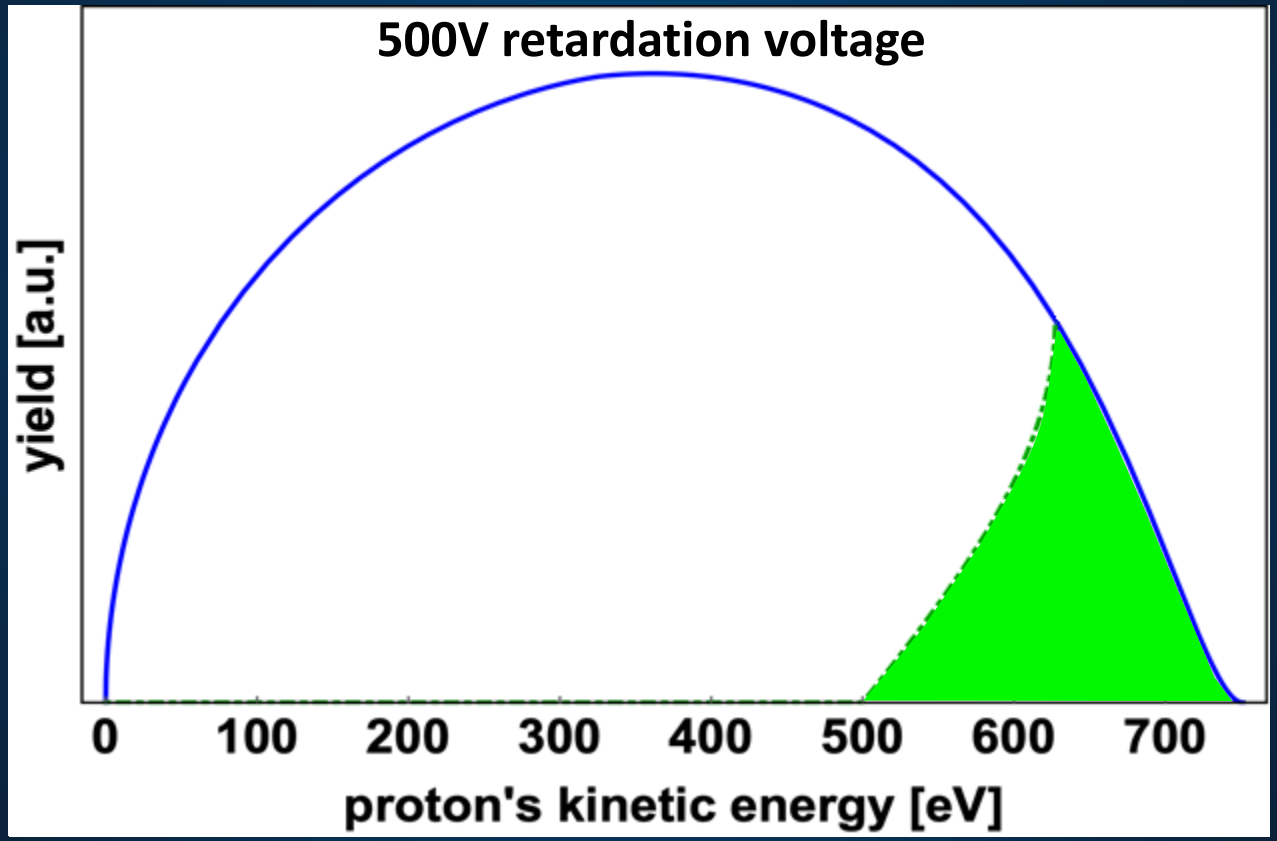


neutron beam

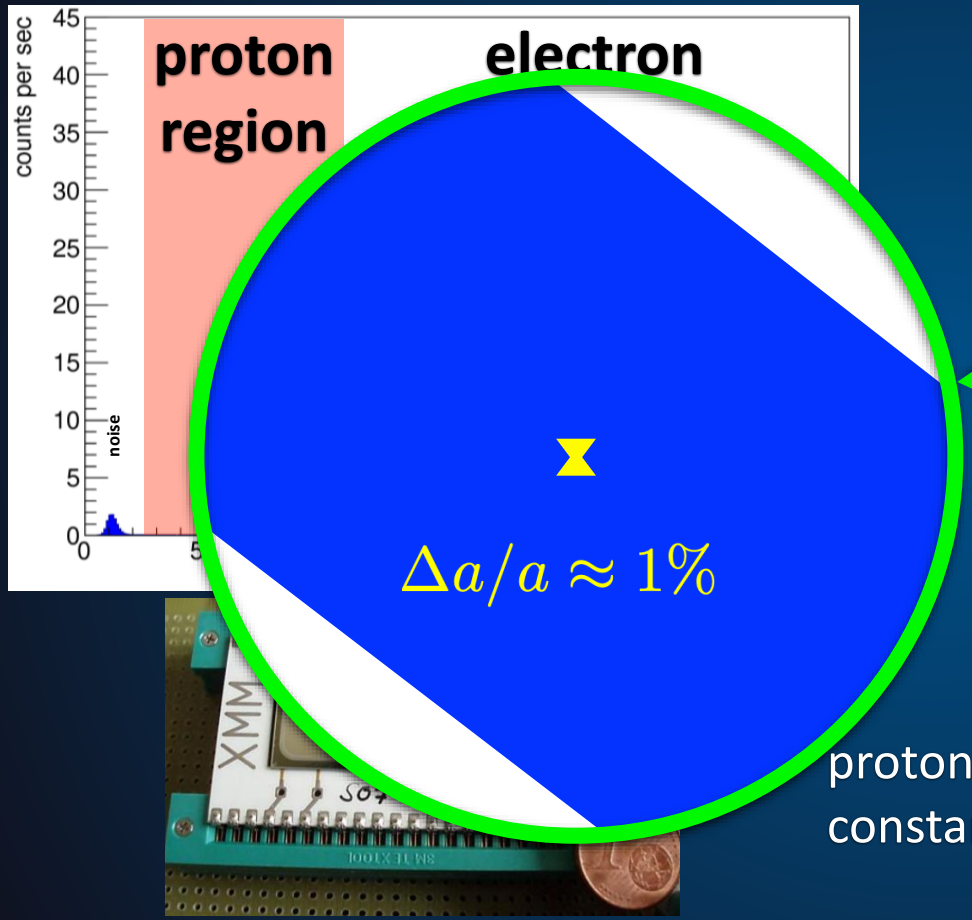
cut through aSPECT cryostat

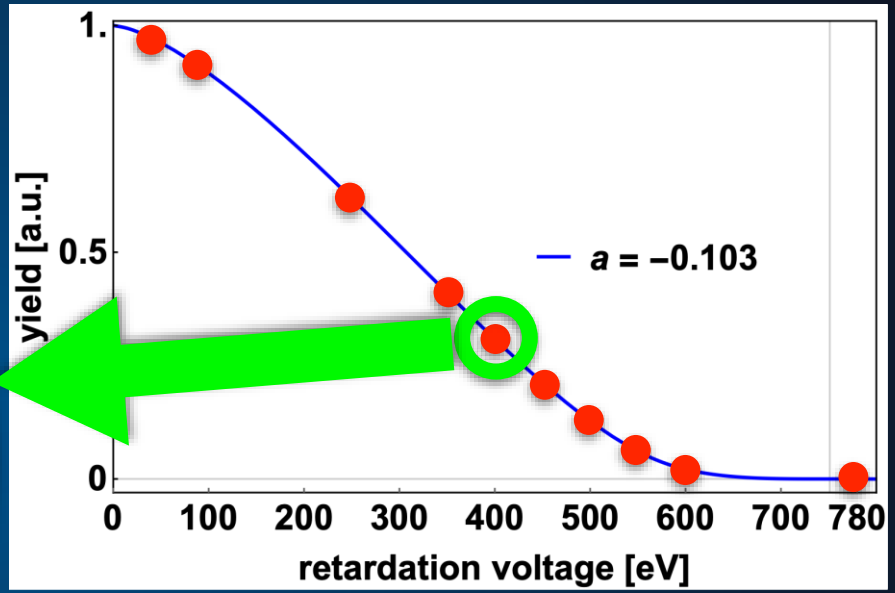
*a*SPECT – Transmission measurement

$f_{trans}(T, U_{AP}, r = B_{AP}/B_{DV})$

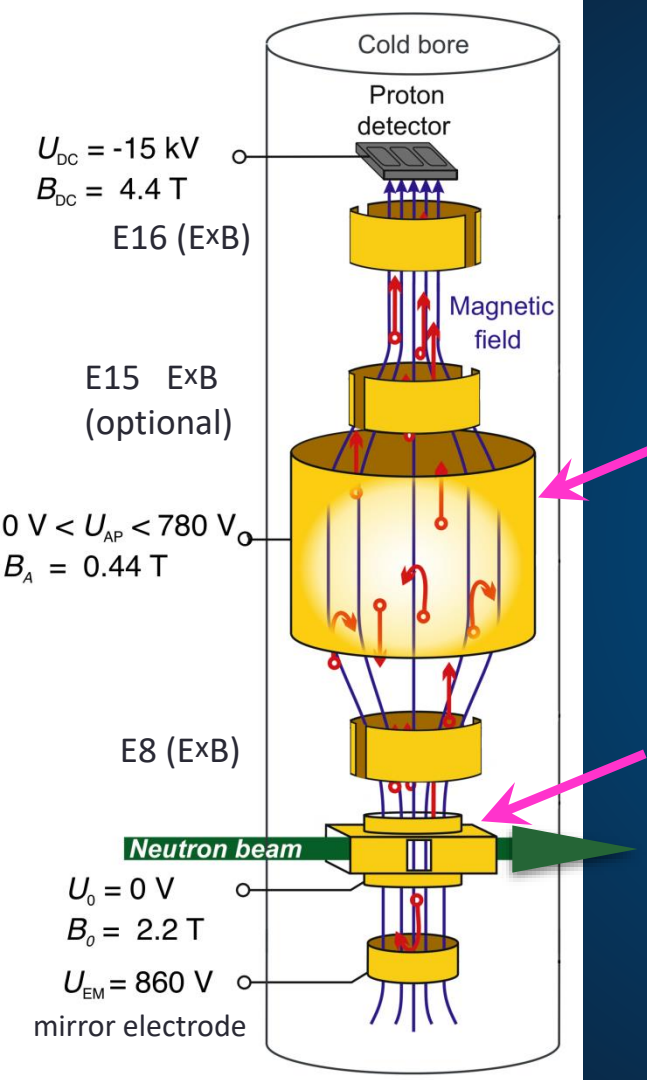


Integral proton spectrum

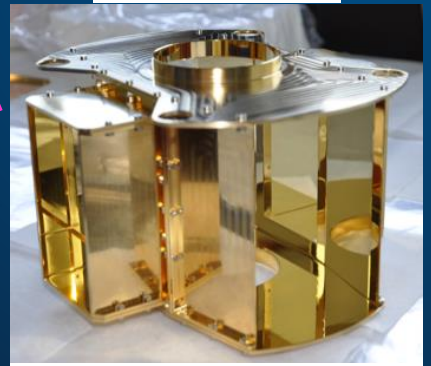




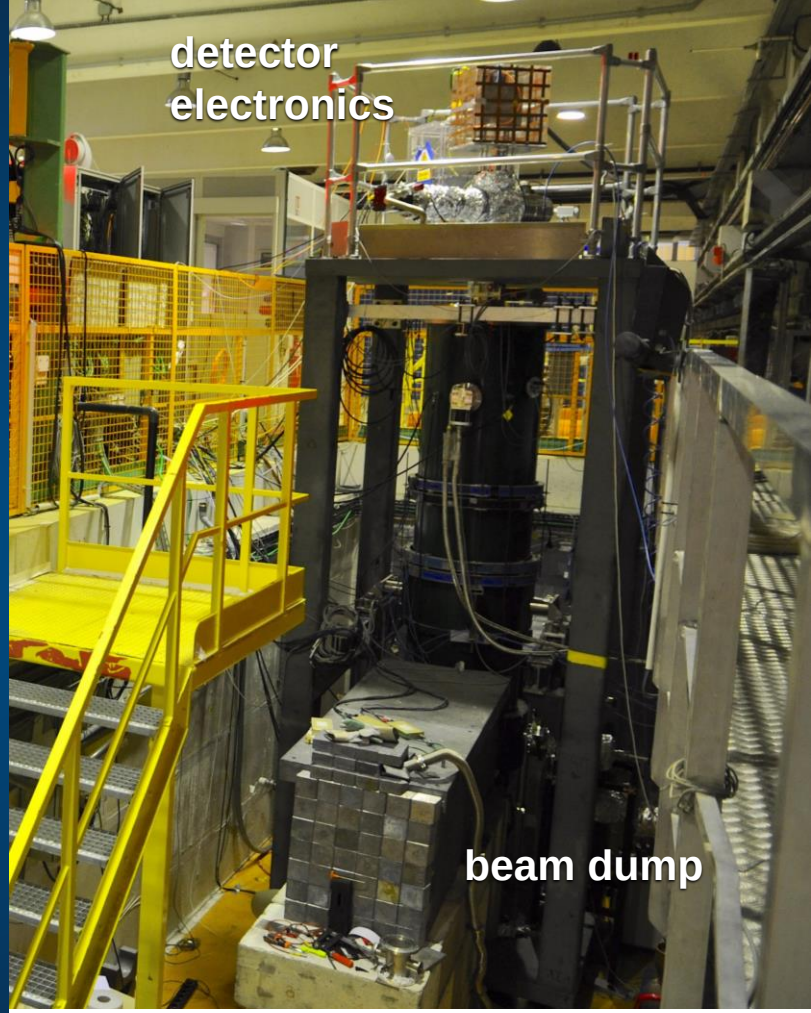
proton countrate per pad ~440Hz @ 50V
constant background ~ 6Hz(decay electrons)



AP electrode



DV electrode

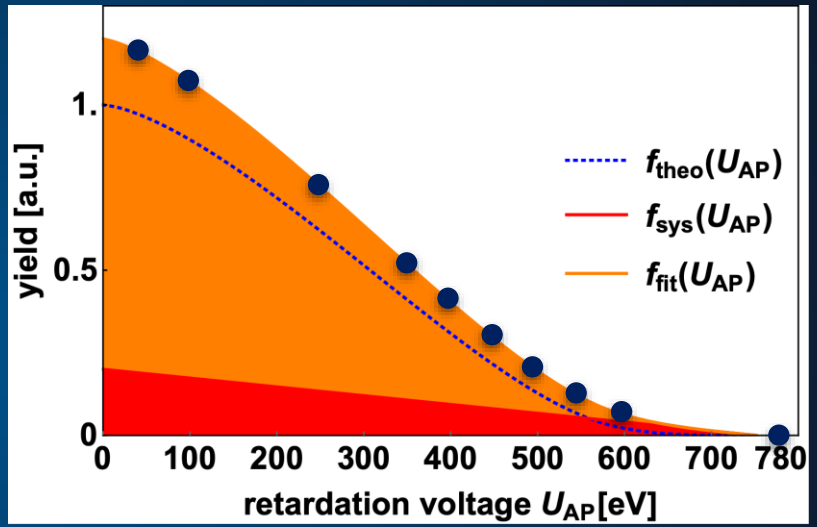


full setup at PF1B, ILL

Analysis

Systematic effects

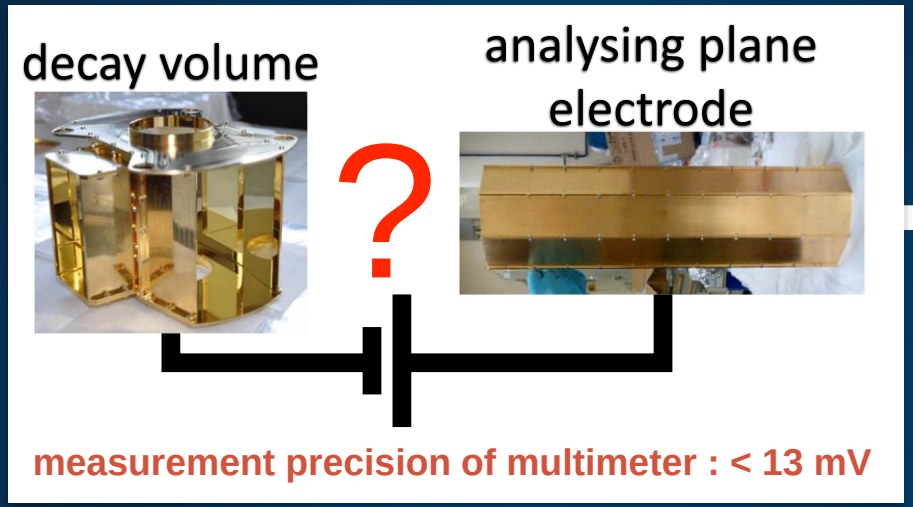
A. Temporal stability and normalization
B. Magnetic field ratio <rB>
C. Retardation voltage <UAP>
D. Background
E. Edge effect
F. Backscattering and below-threshold losses
G. Dead time and pile-up
H. Proton traps in the DV region

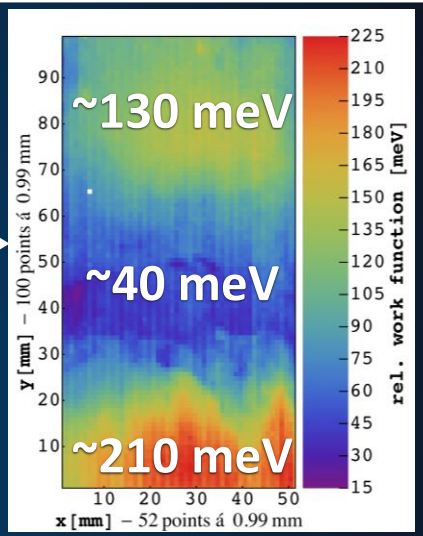


$$f_{fit}(U_{AP}) = f_{theo}(U_{AP}, a) + \sum_i f_{sys_i}(U_{AP})$$

Retardation voltage - WF measurements

$$\Delta U_{\mathrm{AP}} = 10\ \mathrm{mV}$$
$$\cong$$
$$\Delta\, a/a \approx\ 0.1\ \%$$



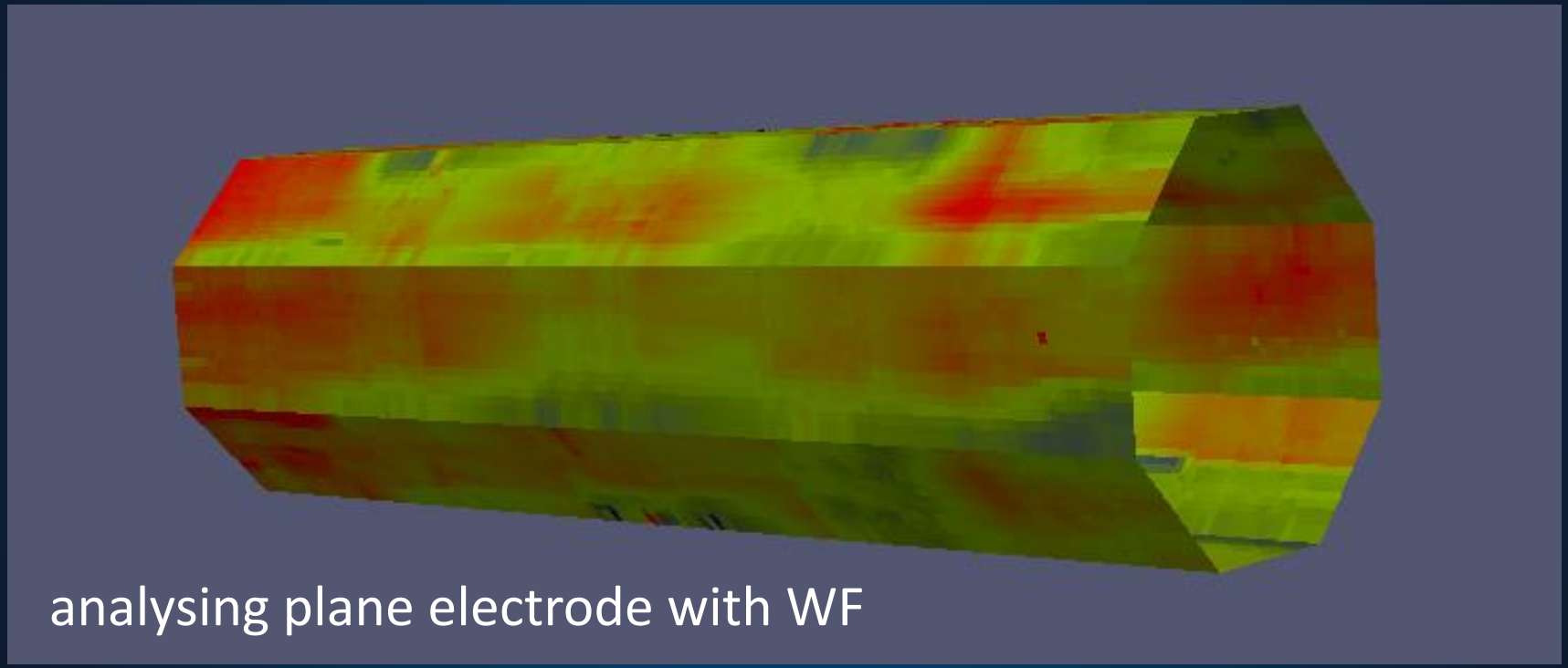


Production run
***a*SPECT**
2013
~120 K
≤ 10^{-9} mbar

WF measurements with Kelvin probe under ambient and HV conditions
until 2017

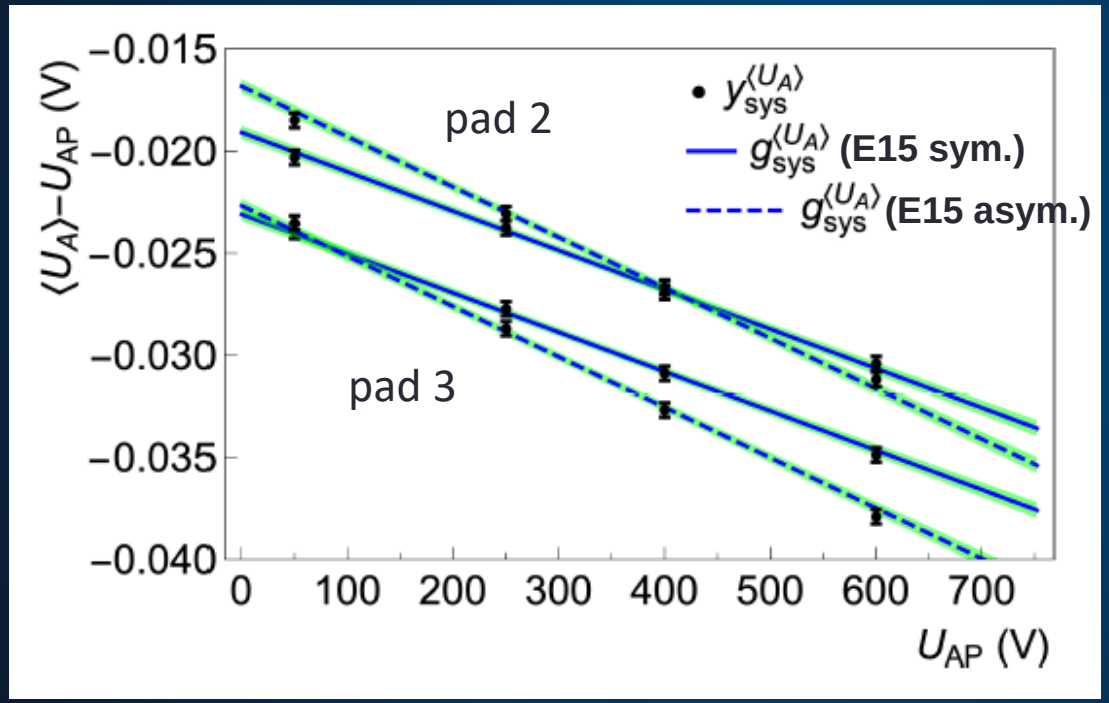
- ✓ **Aging effects < 20 meV**
- ✓ **Temperature effects < 10 meV**
- ✓ **Air-vacuum difference < 11 meV**

Retardation voltage - WF measurements



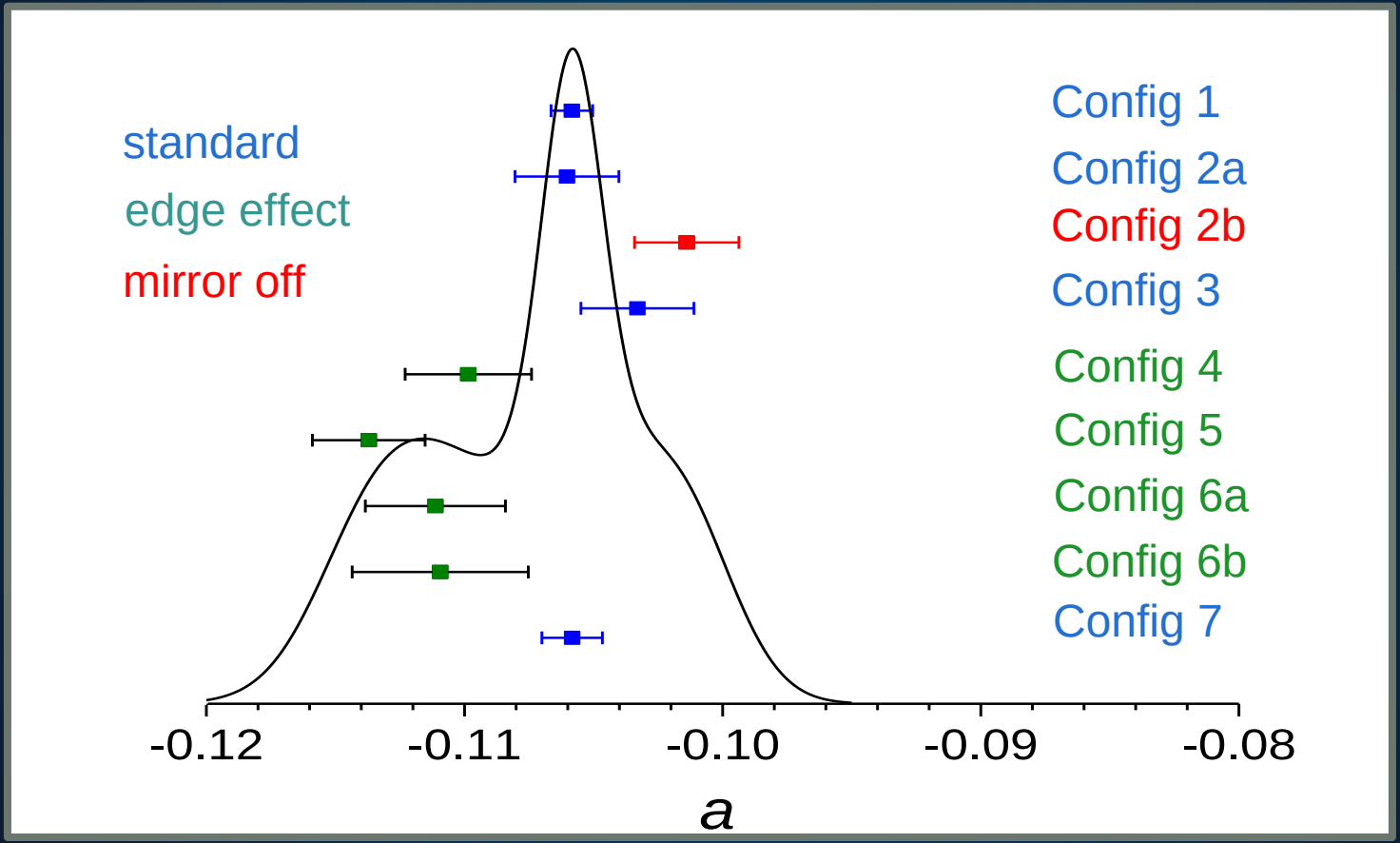
Retardation voltage - WF measurements

Shift of the effective retardation voltage from particle tracking simulations

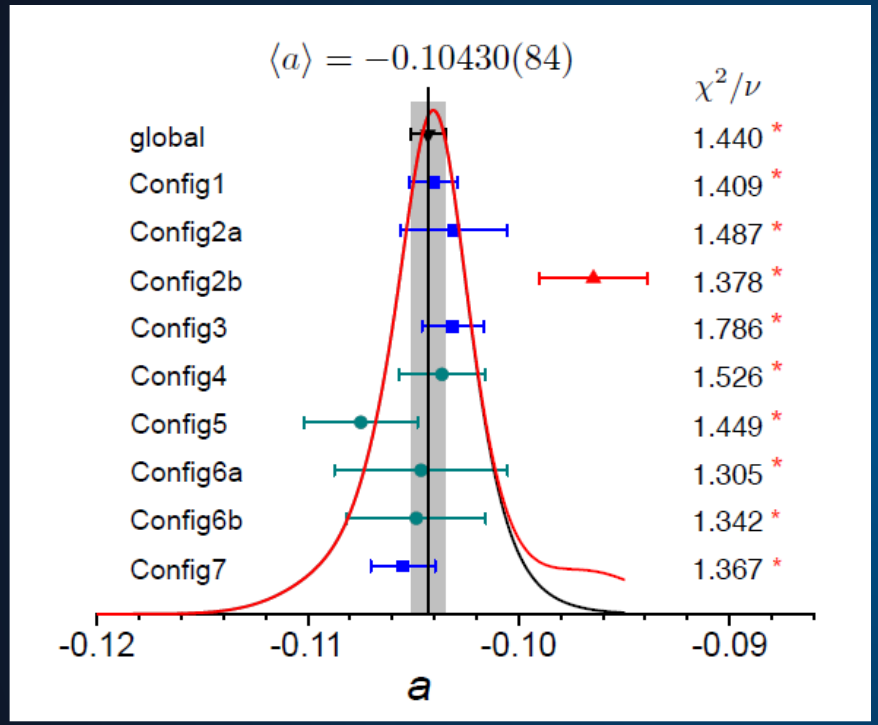


Uncertainties from WF measurements and UAP reading: $\pm$ 30 mV (offset)

Raw data


standard
edge effect
mirror off
Config 1
Config 2a
Config 2b
Config 3
Config 4
Config 5
Config 6a
Config 6b
Config 7
-0.12
-0.11
-0.10
-0.09
-0.08
a

Global fit results with systematic corrections



Error scaling data of integral proton spectra	Error scaling systematic corrections	χ^2_G/ν	p value	a
1.00	1.00	1.44	3.1×10^{-6}	−0.104 30(84)*
1.20	1.00	1.17	0.029	−0.104 30(84)*
1.00	1.20	1.27	0.0018	−0.104 33(82)*
1.20	1.20	1.00	0.49	−0.104 32(80)

144 datapoints int. proton spectrum
192 auxiliar measurements & Monte Carlo results
68 fit parameter $\nu = 268$ (degree of freedom)

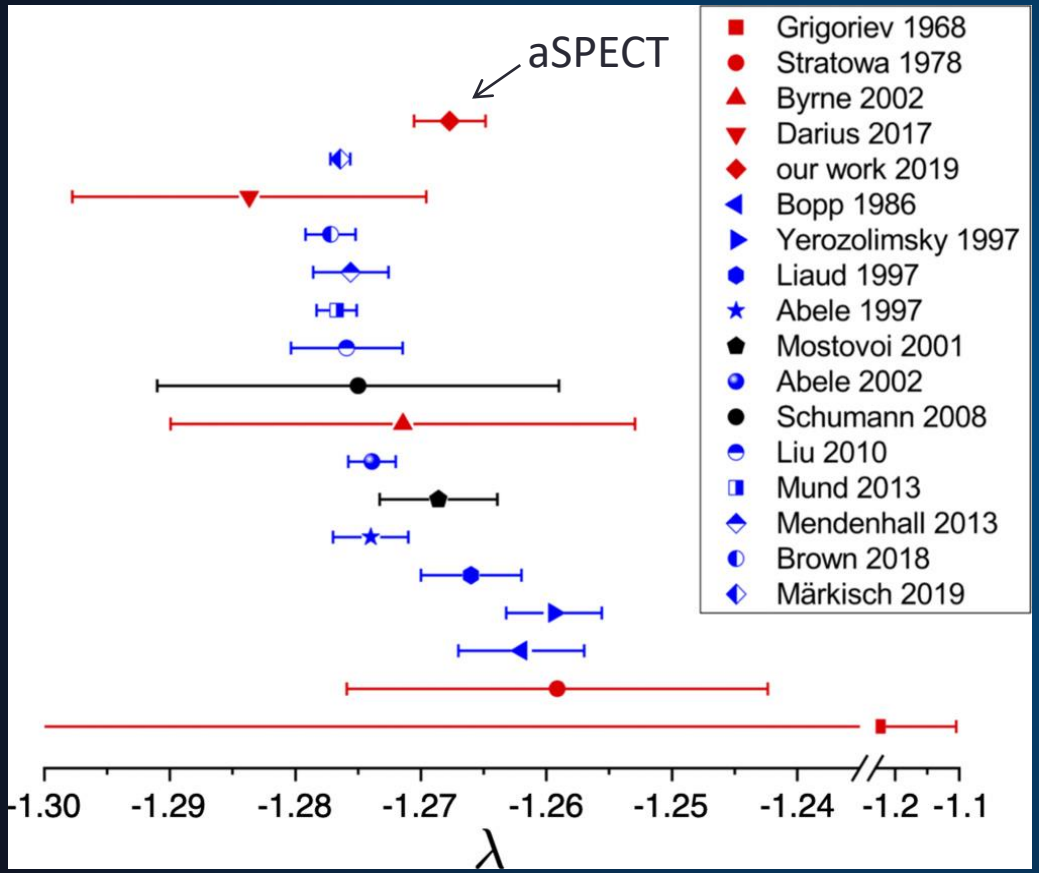
$$\frac{\chi^2}{\nu} = 1.440, \quad p\ value: 3.0 \cdot 10^{-6}$$

$$\sigma_{nd}^2 = 6.8 \cdot 10^{-6}$$

$$(< 10^{-4} \rightarrow near\ normal\ distributed)$$

$$a = -0.10430(84), \Delta a/a = 0.8\%$$

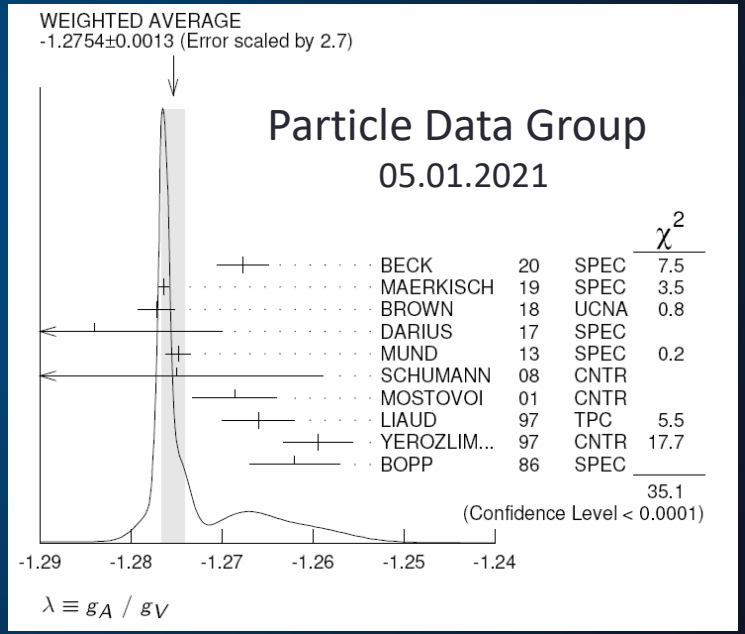
Global fit result λ



$aSPECT\ result$:

$\lambda = -1.2677 \pm 0.0028$

Phys.Rev. C 101, 055506 (2020)



Reanalysis

Went something wrong?

$\rightarrow$ normalization of the errors of the independent variables (x-errors)
after proper normalisation:
χ^2/ν $= 1.440$ $\rightarrow$ χ^2/ν $= 1.2$
value of a shift by $1/2\sigma_a$
error σ_a stayes the same

Revised Systematic effects

F. Backscattering and below-threshold losses: effects from channeling?

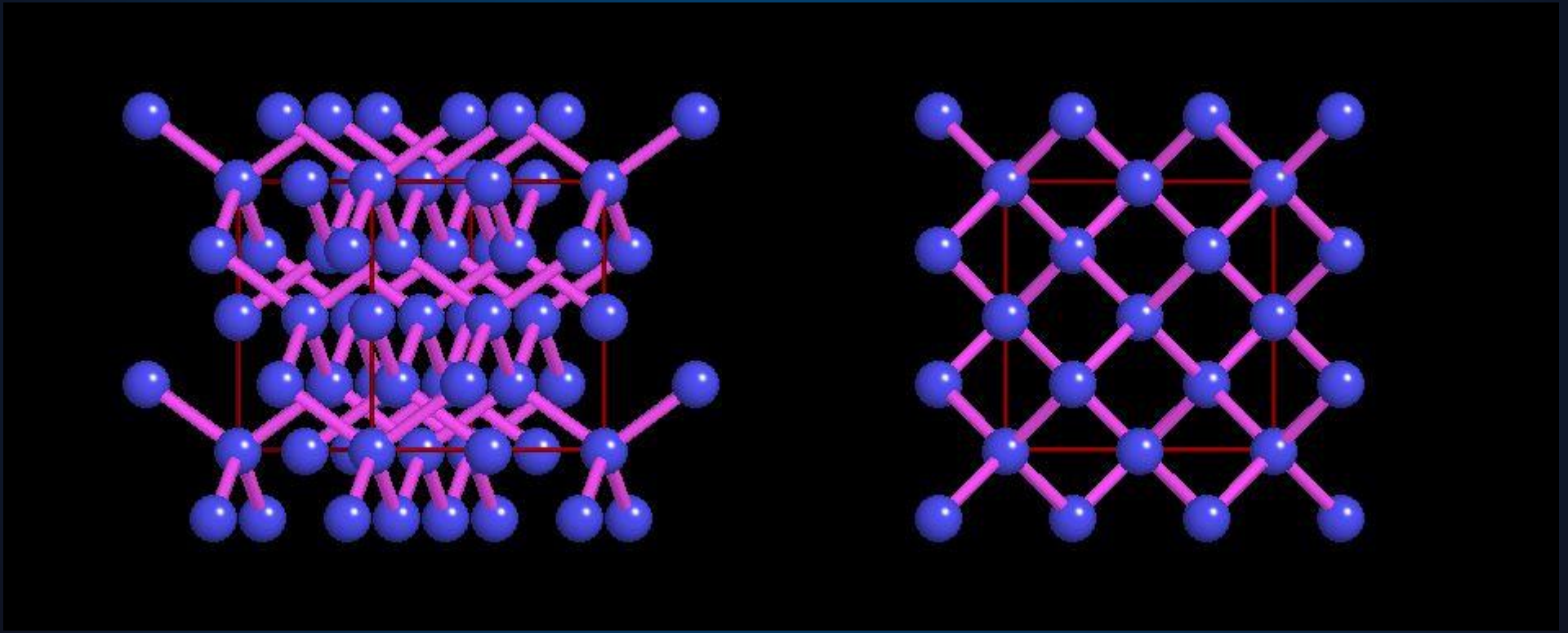
Coulomb and radiative Correction:

Ferenc Glück is a collaboration member so we aware of the 4 body kinematic in case of Bremsstrahlung:

Radiative corrections to neutron and nuclear β-decays: a
serious kinematics problem in the literature
arXiv:2205.05042v1 [hep-ph] 10 May 2022

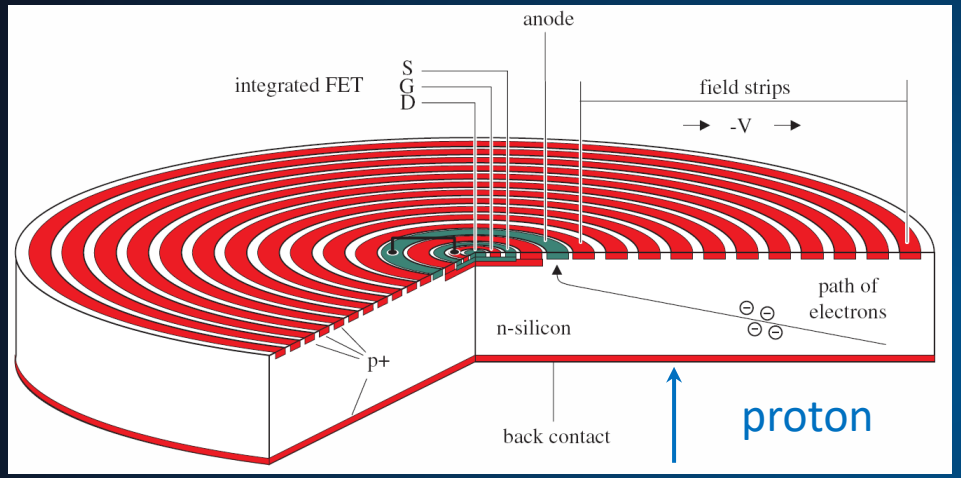
What is Channeling?

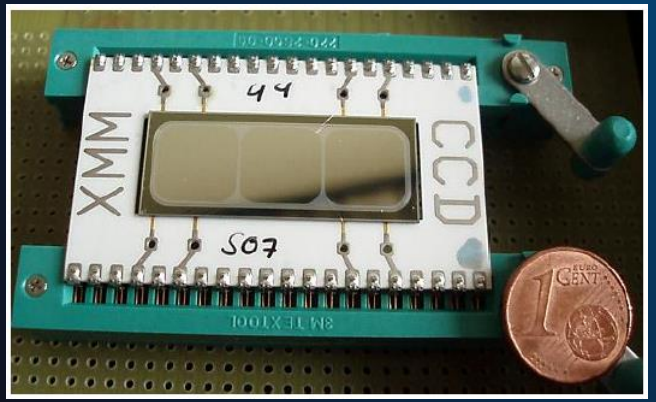
Lock on the same diamond crystal from to different direction i.e. different angles



Backscattering and below-threshold losses

Silicon Drift Detector





max. penetration depth 200nm for 15 keV protons

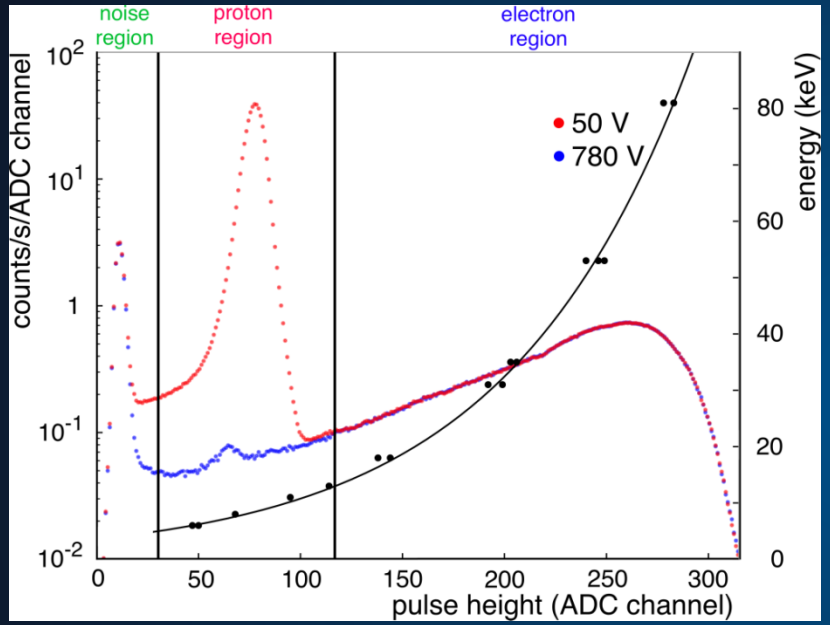
dead layer (back contact) $\Delta z \approx 30$ nm of aluminum

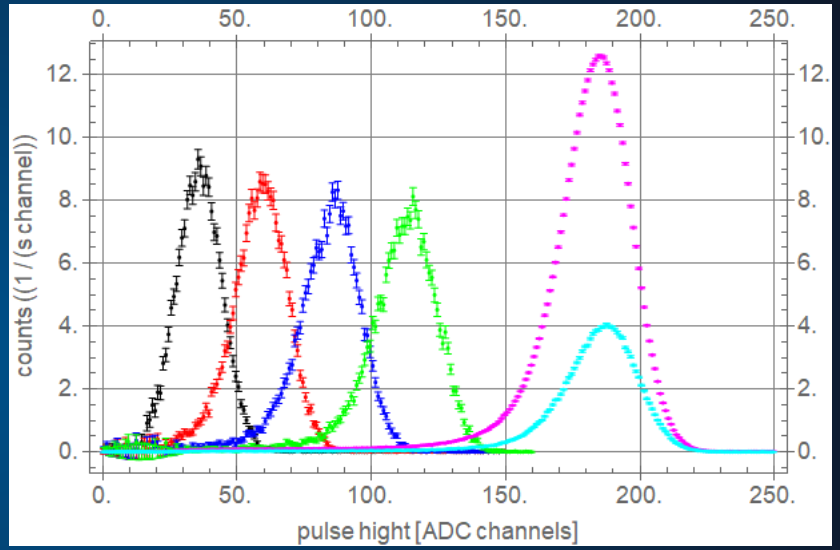
charge collection efficiency for electrons inside the n-silicon

$$f_{CCE}(z) = \begin{cases} 0 & \text{for } z' = z - \Delta z \\ S + B\left(z'/L\right)^c & \text{for } 0 \le z' \le L \\ 1 - Ae^{-\frac{z'-L}{\tau}} & \text{for } L \le z' \le D \end{cases}$$

$$A = (1-S)\frac{\tau c}{L + \tau c}, \qquad B = (1-S)\left(1 - \frac{\tau c}{L + \tau c}\right)$$

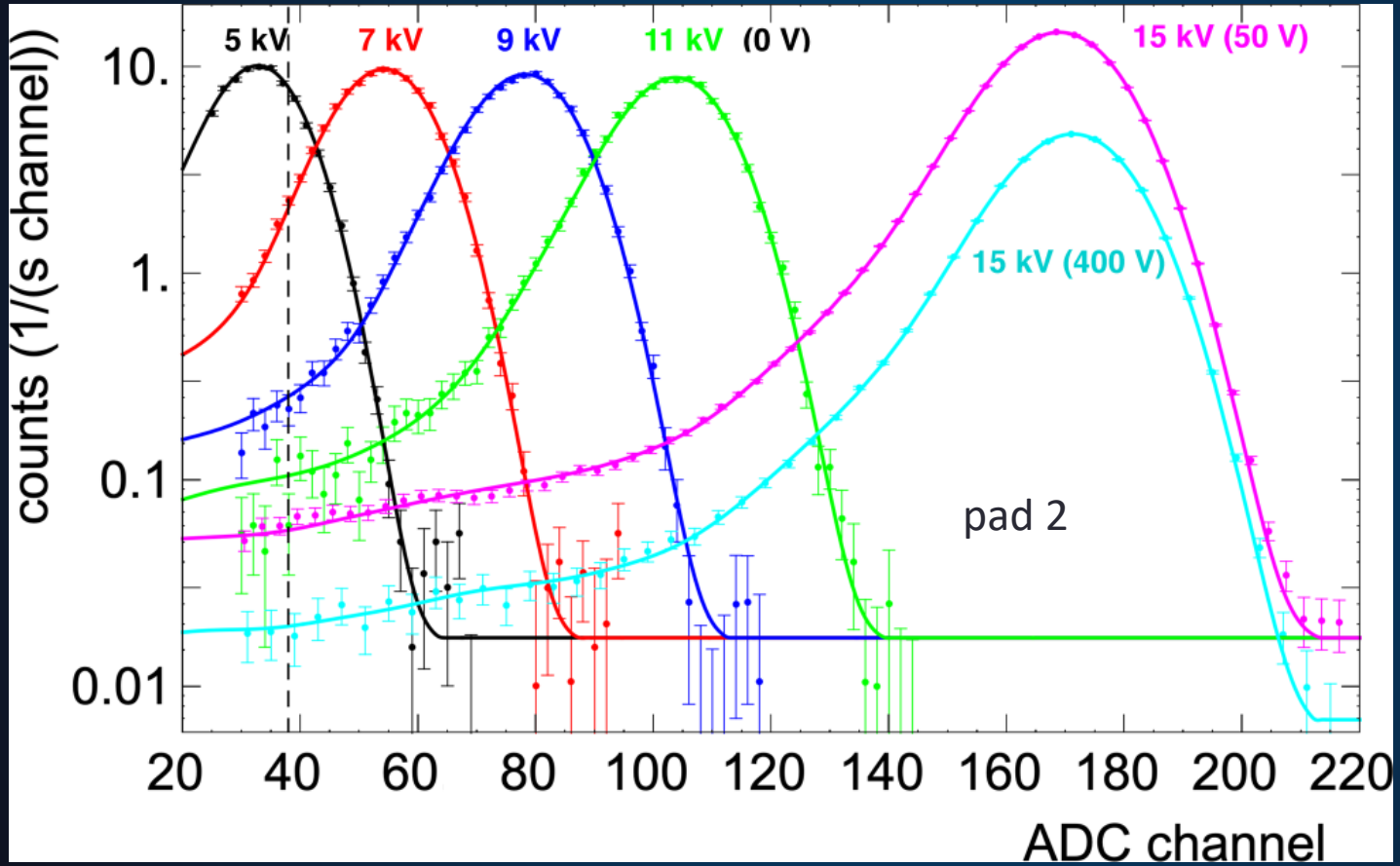
Backscattering and below-threshold losses





SRIM-2012.03 Monte Carlo code for calculating the transport of ions in matter
With SRIM we calculate the ionization energy deposited in 3nm thick slabs of the detectormaterial, multiply the values with the f_{CCE} and sum up.

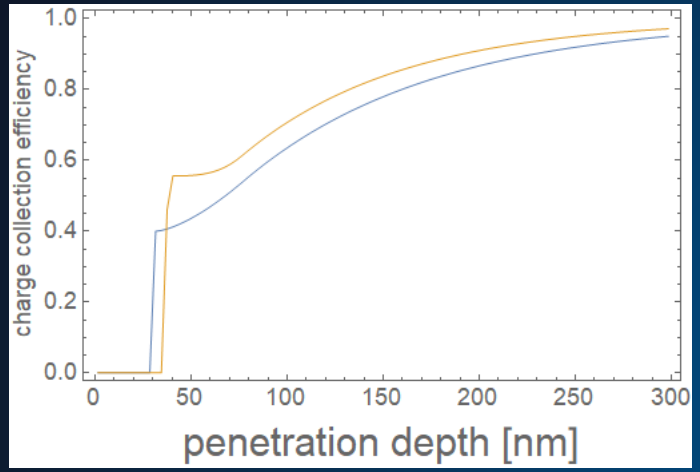
Backscattering and below-threshold losses

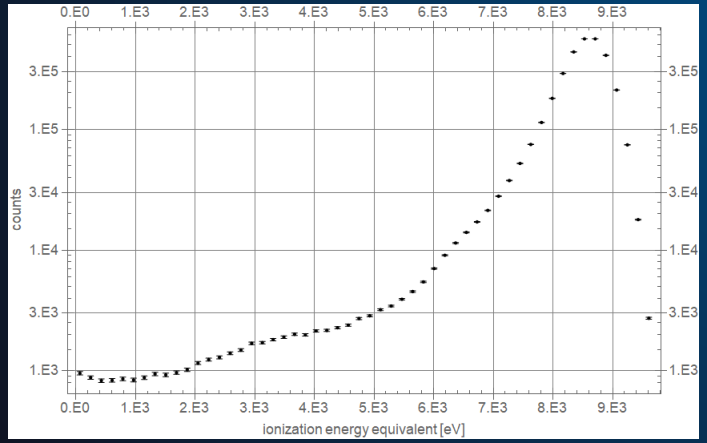


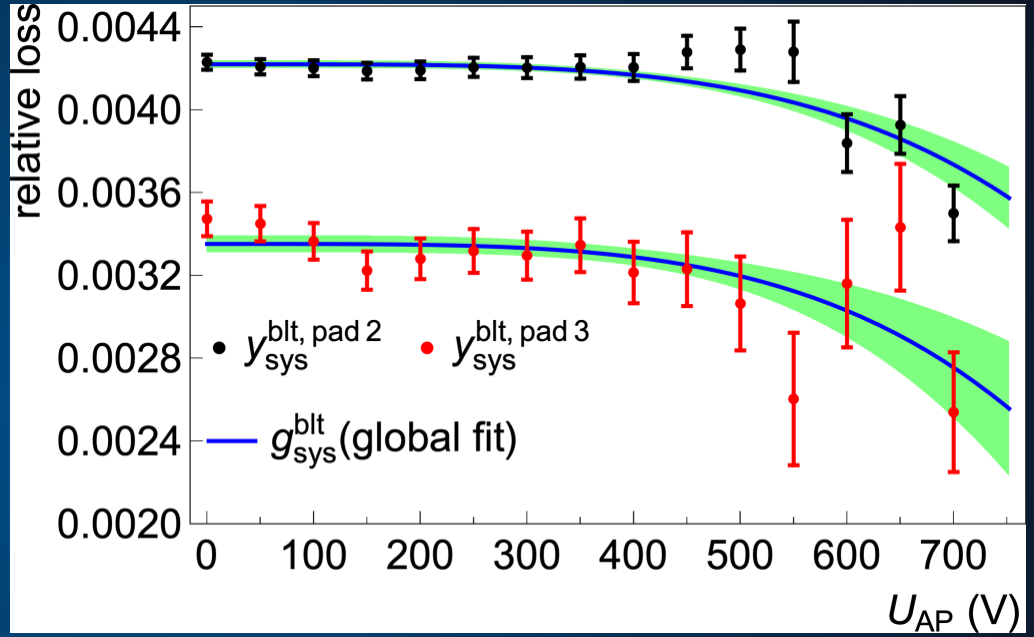
Simultaneous Fit to all pulse height spectra reveals f_{CCE} parameter

$norm.\chi^2 = 0.85$
$deg.free = 820$
$S = 0.5562(10)$
$L = 38.01(27)\text{nm}$
$c = 3.171(23)$
$\tau = 84.39(37)$
$\Delta z = 6.54(4)\text{nm}$
$d_{dead} = 36.54(4)$
threshold= 37.6

Backscattering and below-threshold losses

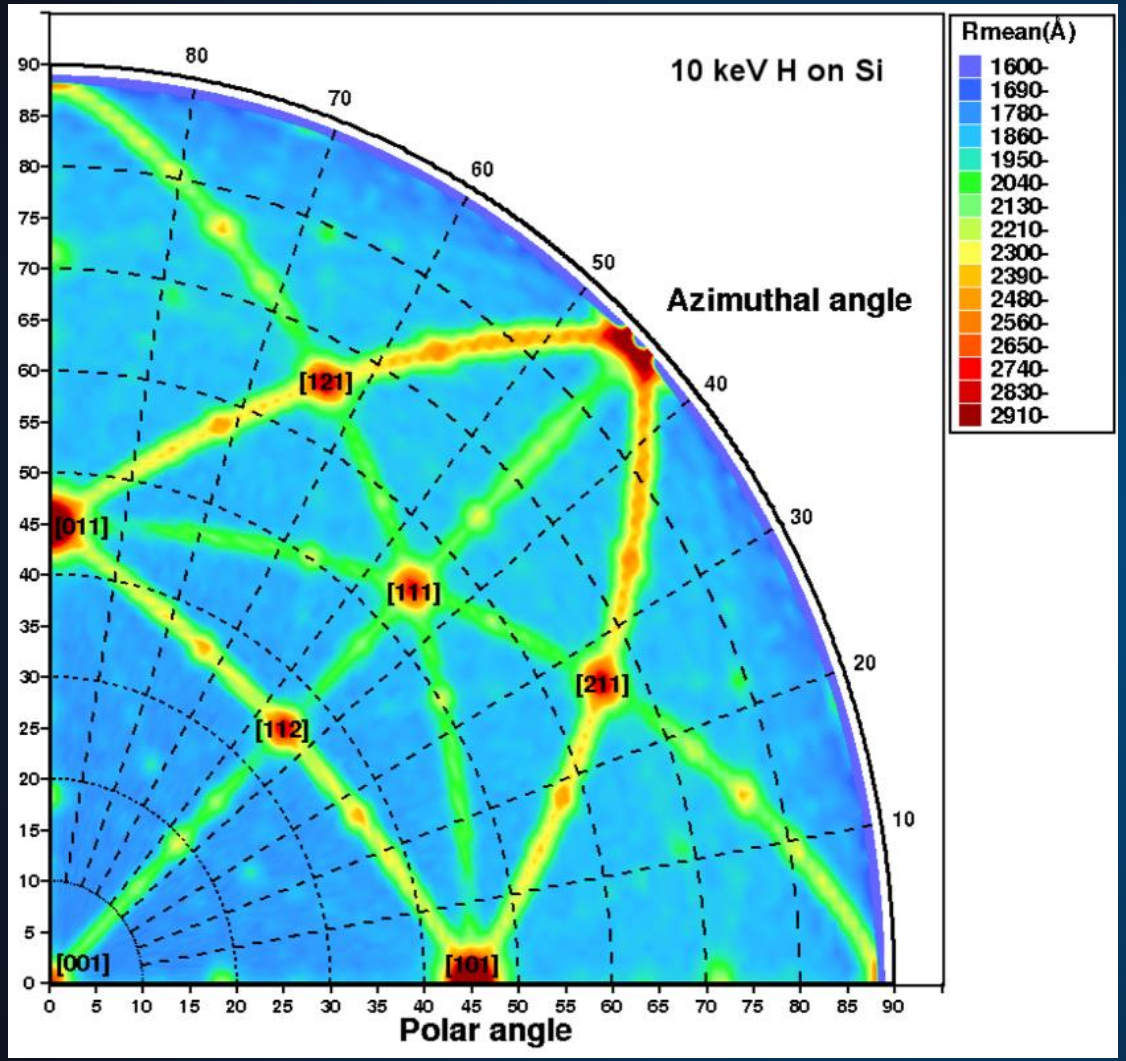






$3.2 \cdot 10^6$ simulated protons, properties from tracking Monte Carlos

backscattering probability $(1.23 \pm 0.02) \cdot 10^{-2}$



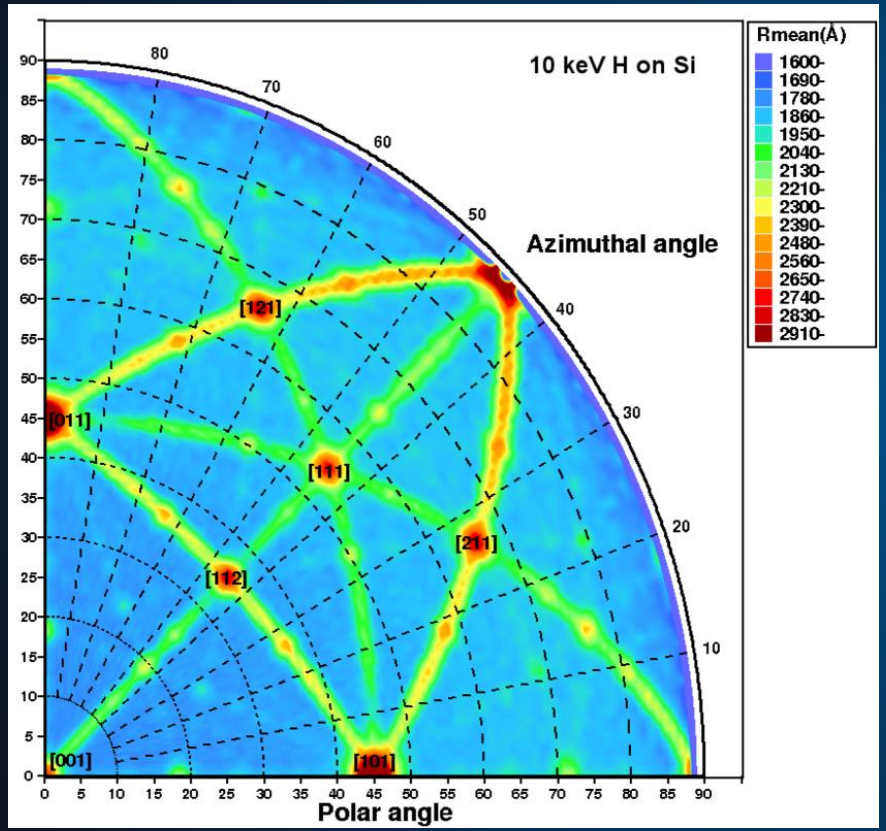
Channeling: Average penetration depth [Å] calculated with MDRANGE

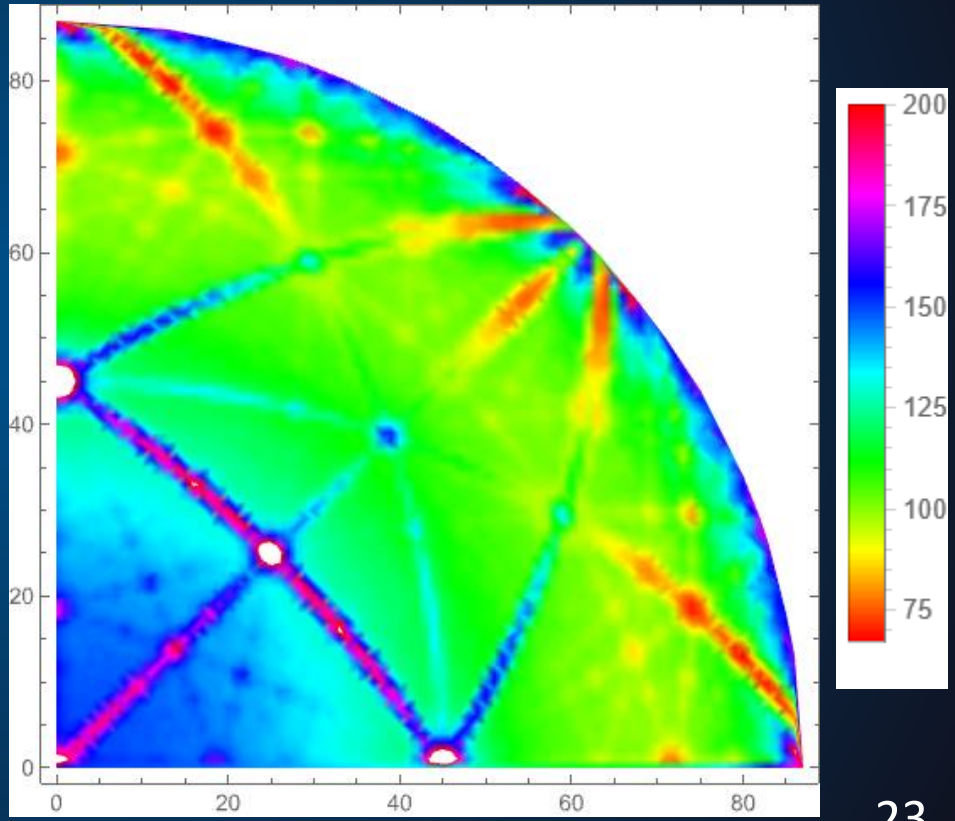
Picture from
"Large fraction of crystal directions leads to ion channeling"
K. Nordlund, F. Djurabekova and G. Hobler

PHYSICAL REVIEW B 94, 214109 (2016)

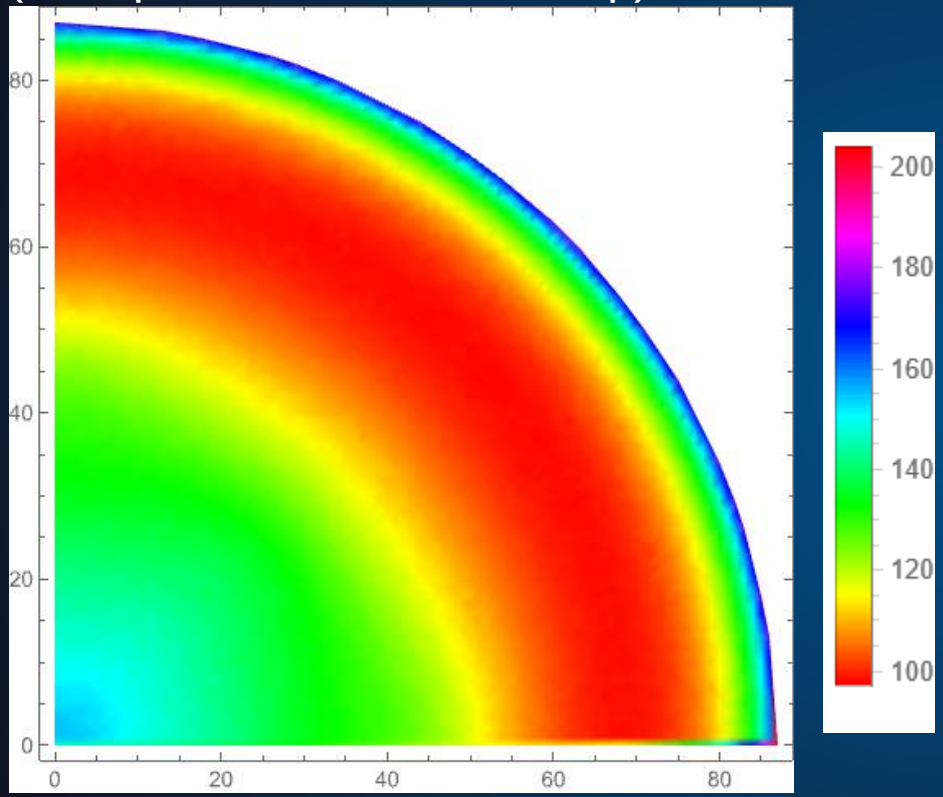
Average penetration depth [Å] calculated with MDRANGE

Average penetration depth [nm] calculated with Crystal-Trim, only small angles are comparable due to different scatting geometry

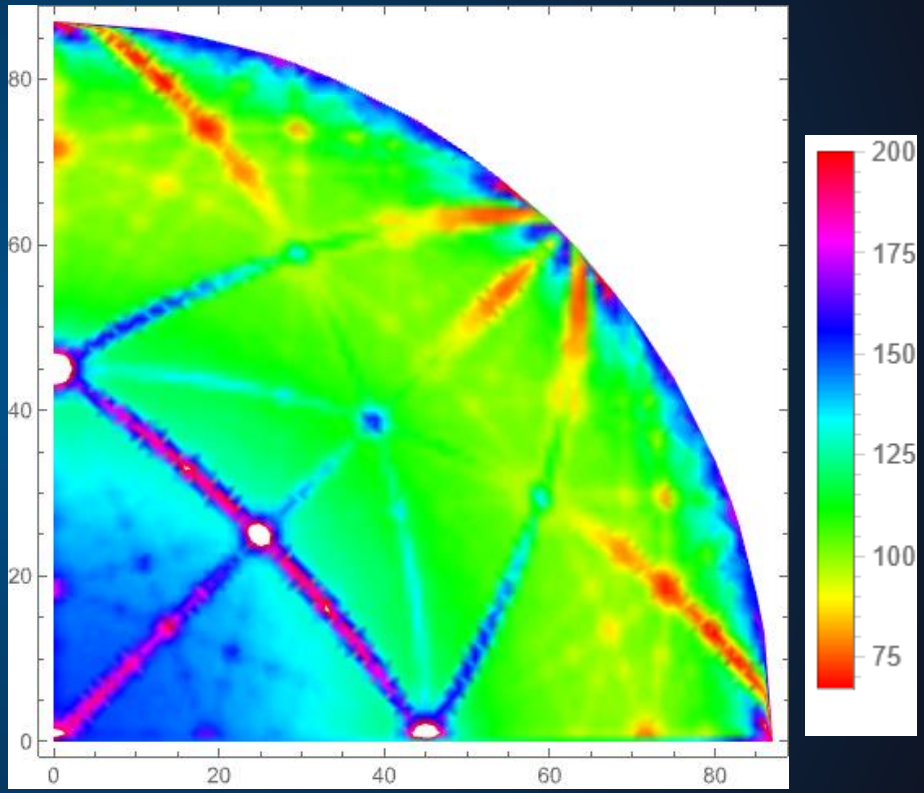




Average penetration depth [nm] of 15.2keV protons on <100> Si with a 30nm Layer of (amorphous Aluminum on top)



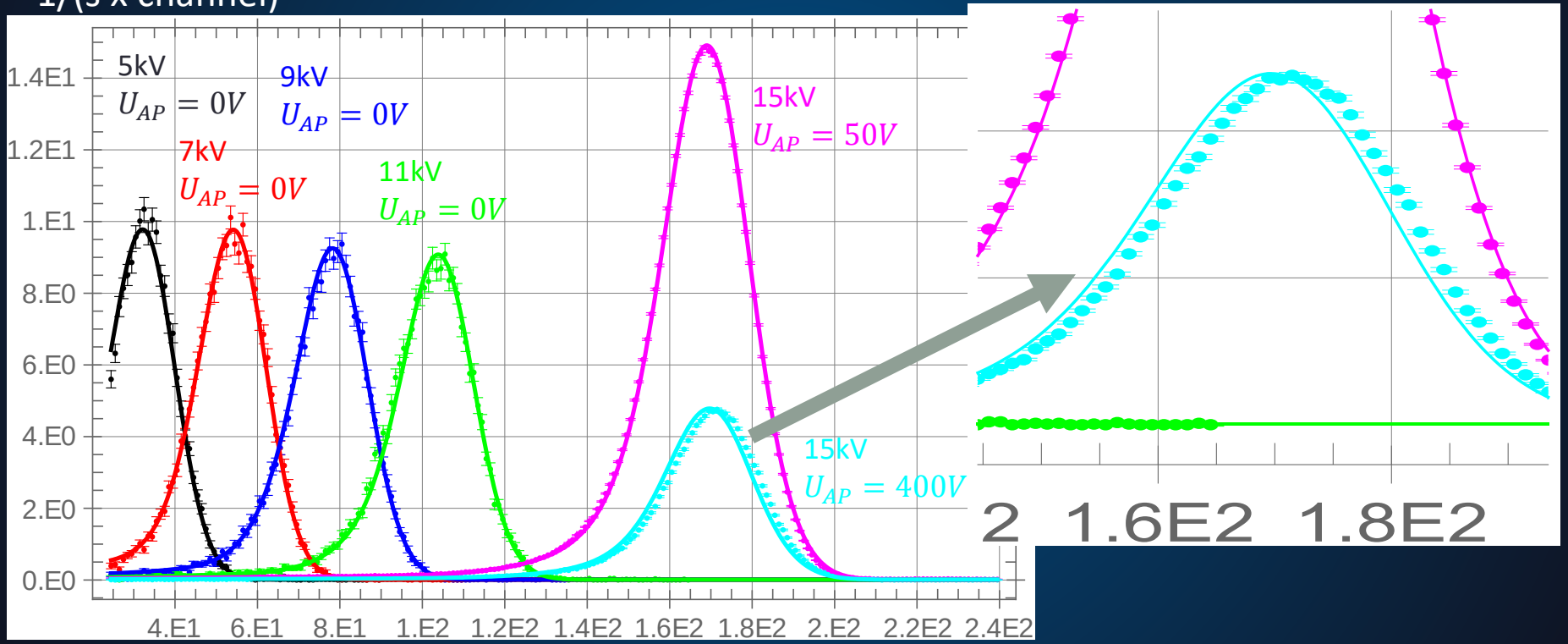
Average penetration depth [nm] of 10keV protons on <100> Si



CRYSTAL-TRIM AND ITS APPLICATION TO INVESTIGATIONS ON CHANNELING EFFECTS DURING ION IMPLANTATION, M. POSSELT, ***Radiation Effects and defects in Solids,1994, Vol. 130-131, pp 97-119***

Channeling with aluminium cover layer: 0.3 % shift of Peak with 400V Retardation potential compared to no channeling (amorphous silicon)

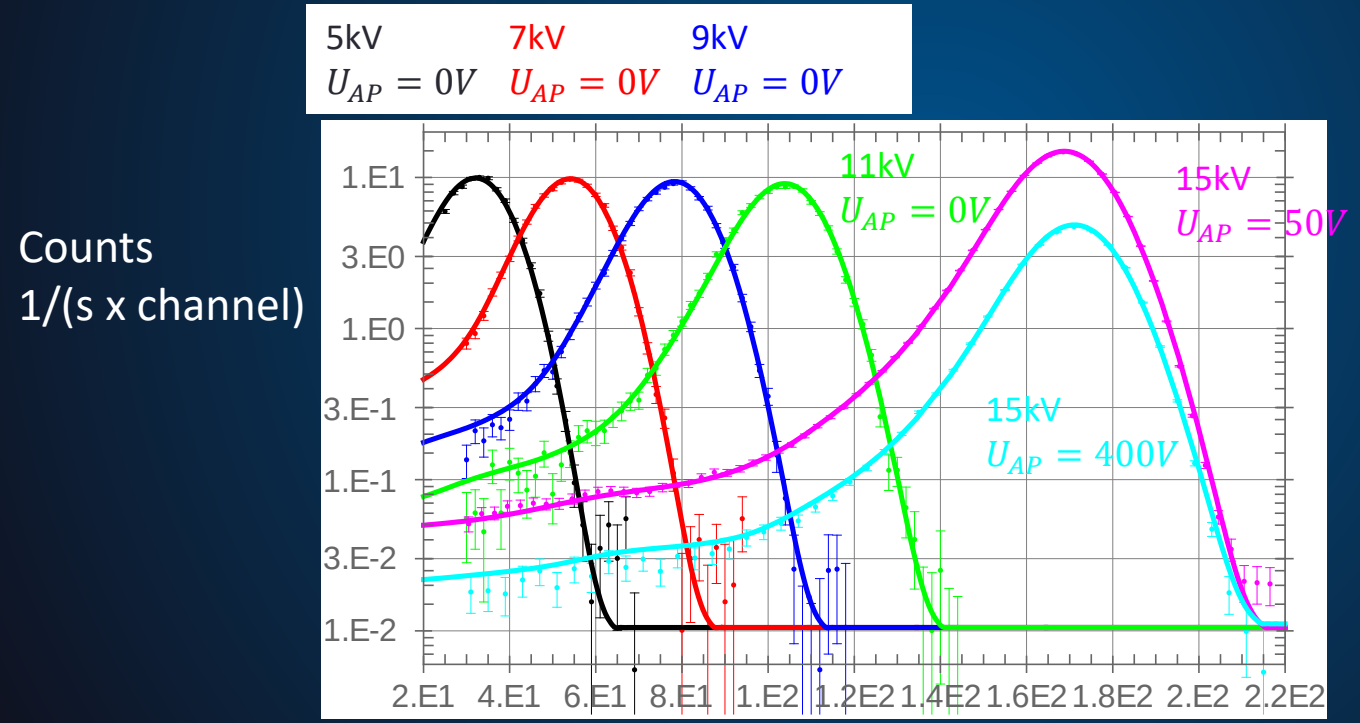
Counts
1/(s x channel)



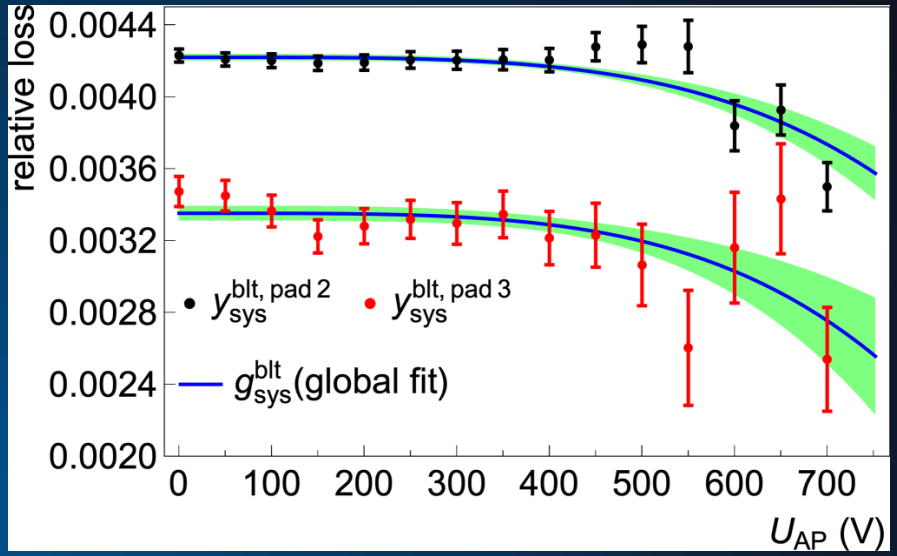
ADC Channel

Channeling predicts a shift of the Peak with 400V Retardation voltage relative to the other peaks, but we don't see it in the data?

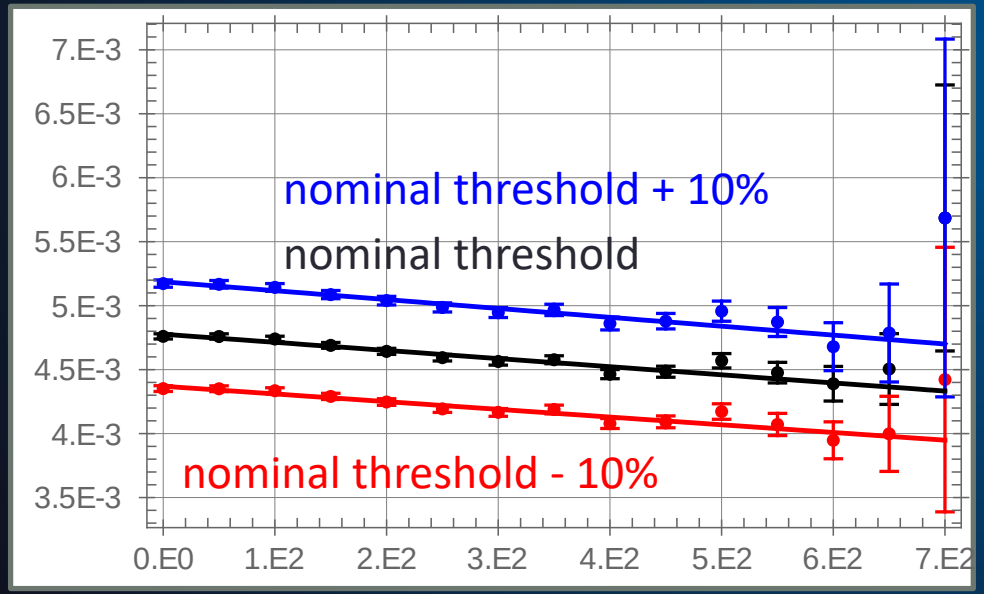
Shift is canceled due to misalignment between surface normal and magnetic field by a few degrees.



Without channeling only 4th order term
→ Very small shift (correlation) on a



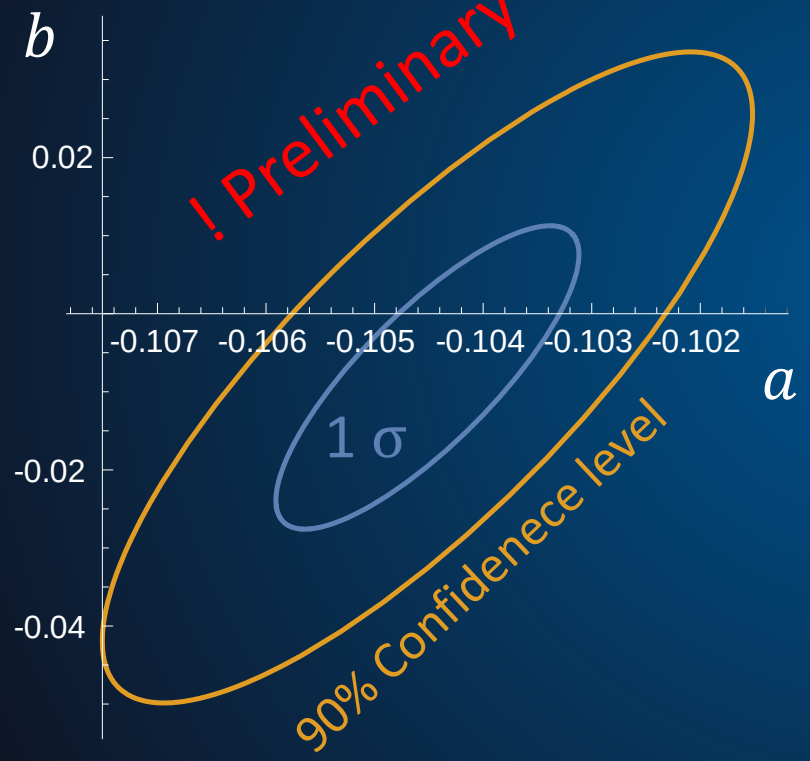
relative loss



With channeling linear term
→ $\frac{1}{2}\sigma$ shift on a (preliminary!)

4th order term ? (more statistic is needed)

Physics beyond the Standard Model: Fierz term b



! Preliminary !

Result (1σ Error)

$$a = -0.1045 \pm 0.0014$$

$$b = -0.008 \pm 0.019$$

! Preliminary a will shift!

Outlook

- A few month of running Monte-Carlo-Code will likely fix the unknown misalignment angel and the resulting shift in the a value
- Combining our result with PEKEO III in λ-b-plane
- Extract a new limit on right handed tensor currents

Thank You