Weak interaction studies via beta-delayed proton emission

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on behalf of
the WISArD collaboration

Outline

- Weak Interaction studies in the LHC era
- Beta-neutrino correlation with proton emission
- Kinematic shift measurements
- WISArD setup - upgrades
- Beamtime Request

Weak Interaction – Standard Model

- **Vector-Axial Vector interaction** $C_V \equiv 1; \quad C_A = -1.27$ **(C_A/C_V from n-decay)**
- **Maximal parity violation** $C_V' = C_V \quad \& \quad C_A' = C_A$
- **No Scalar (S) or Tensor (T)** $C_S = C_S' = C_T = C_T' = C_P = C_P' \equiv 0$
- **No time reversal violation** **all C's are real**

(except for the CP-violation included in the CKM matrix)

Weak Interaction – New Physics

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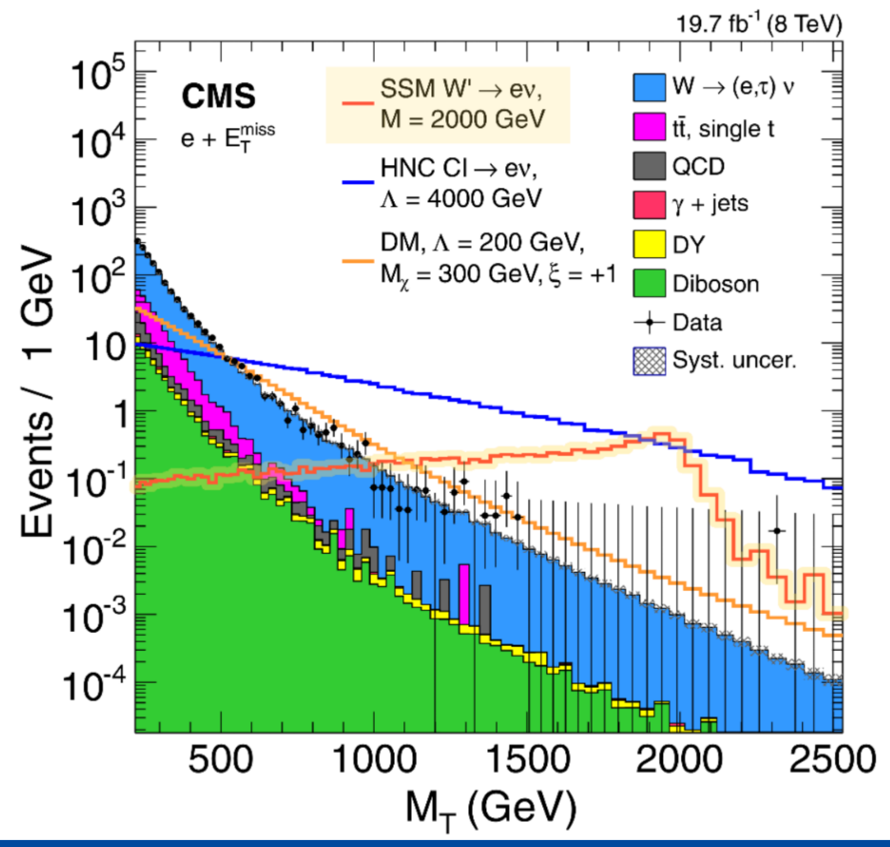
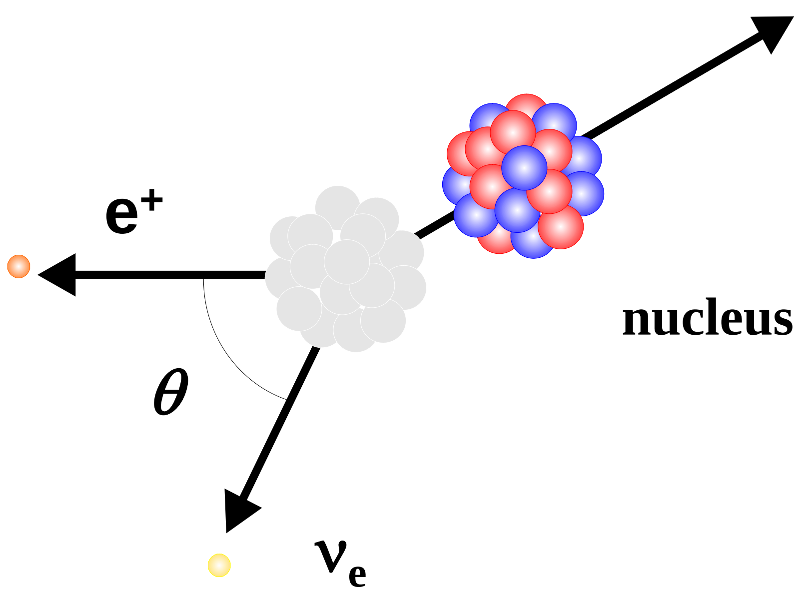
I) Energy frontier, i.e LHC experiments



II) Precision frontier, i.e correlation measurements



Beta decay observables

$$dW \sim dW_0 \left(1 + a \frac{\boldsymbol{p}.\boldsymbol{q}}{E_e E_\upsilon} + b \frac{\gamma m_e}{E_e}\right)$$

phase-space factor

beta-neutrino angular correlation coefficient

Fierz interference term

Pure Fermi transitions

SM: Vector current
- **Preferred emission angle: θ = 0°**
- **Maximum recoil energy**

Correlation Parameters

$$a_F = 1$$

$$b_F = 0$$

Beta decay observables

$$dW \sim dW_0\left(1 + a\frac{\boldsymbol{p}.\boldsymbol{q}}{E_e E_\upsilon} + b\frac{\gamma m_e}{E_e}\right)$$

phase-space factor

beta-neutrino angular correlation coefficient

Fierz interference term

Sensitivity to NP

$$\tilde{a} = \frac{a}{1 + \alpha \boldsymbol{b}}$$

Pure Fermi transitions

SM: Vector current

- **Preferred emission angle: θ = 0°**
- **Maximum recoil energy**

NP: Scalar current

- **Preferred emission angle: θ = 180°**
- **Minimum recoil energy**

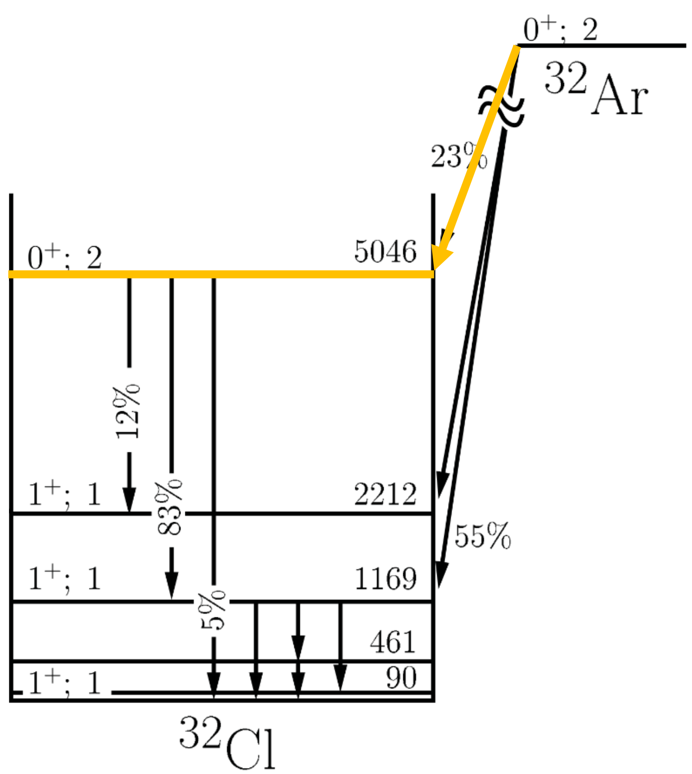
Correlation Parameters

$$a_F \cong 1 - \frac{|C_S|^2 + |C_S'|^2}{|C_V|^2}$$

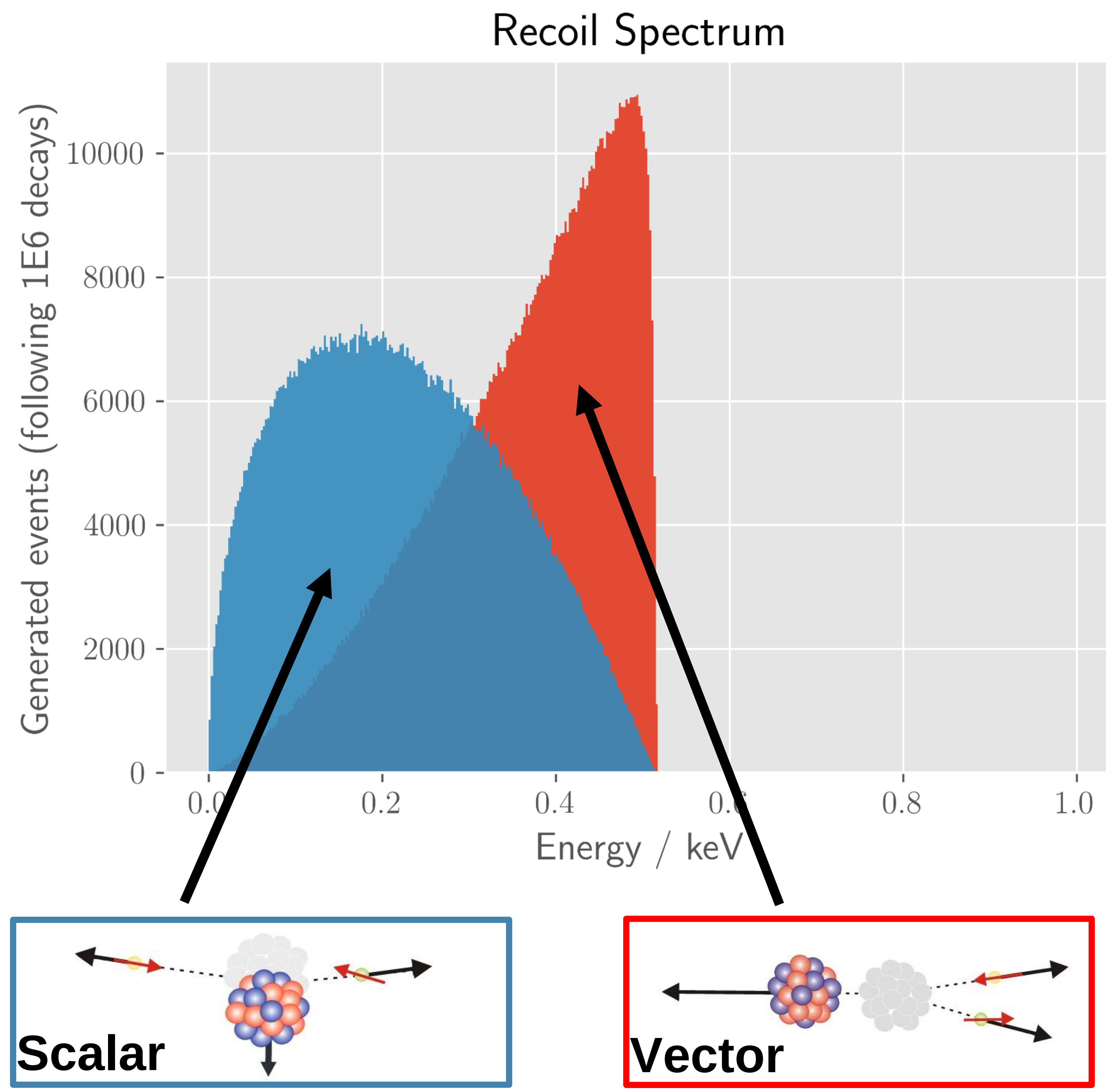
$$b_F \cong \pm Re\left(\frac{C_S + C_S'}{C_V}\right)$$

Kinematic shift: $^{32}Ar \rightarrow {}^{32}Cl$

- **^{32}Ar decays by β-decay to ^{32}Cl**

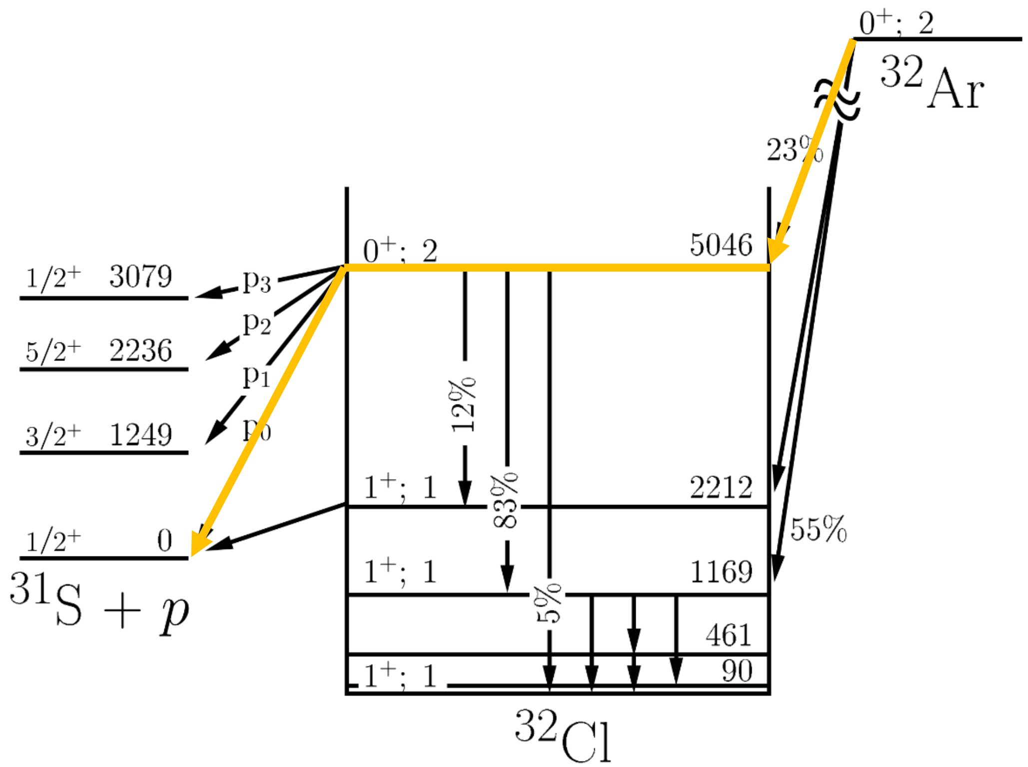


- **Recoil energy ~ hundreds eV**

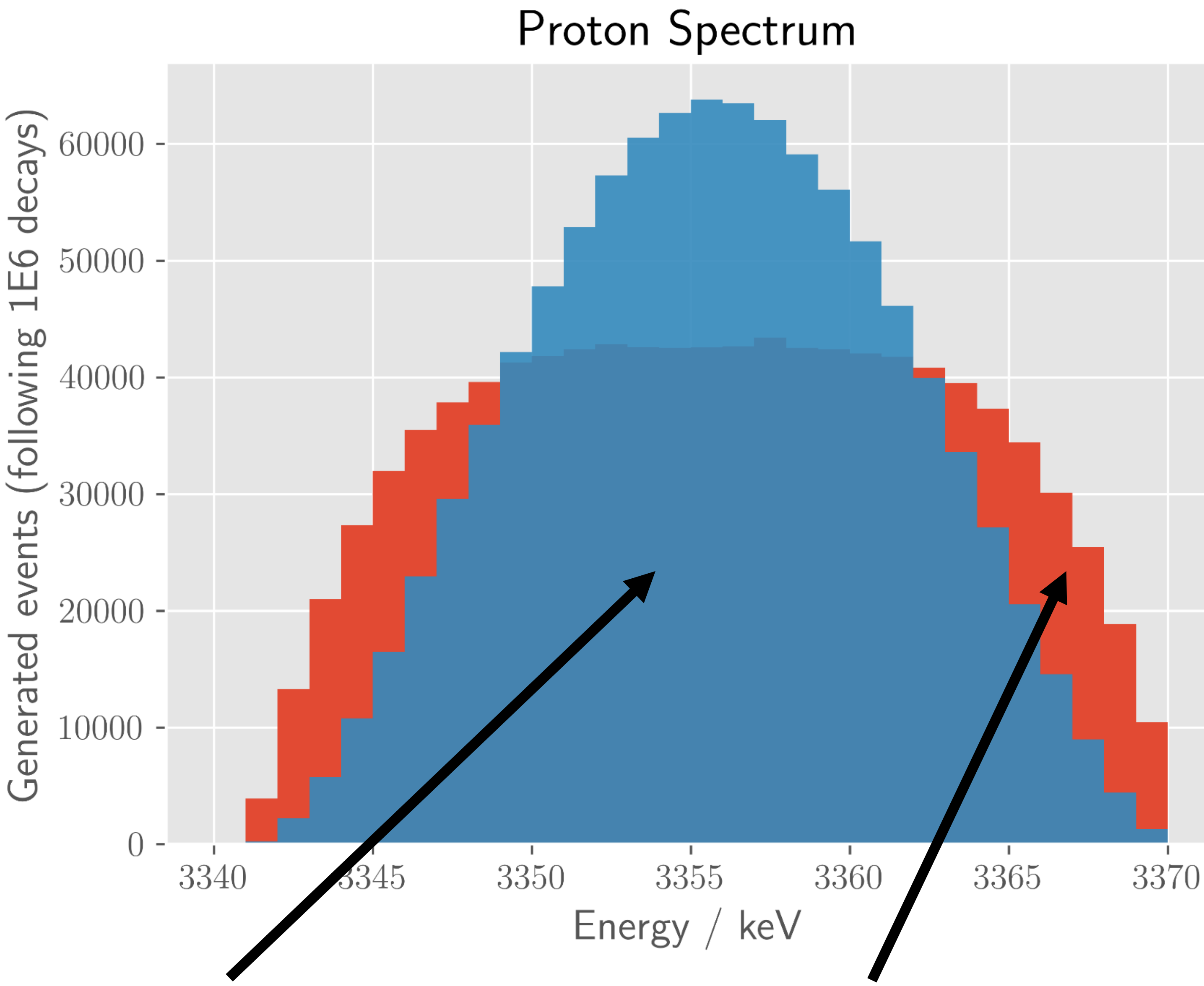


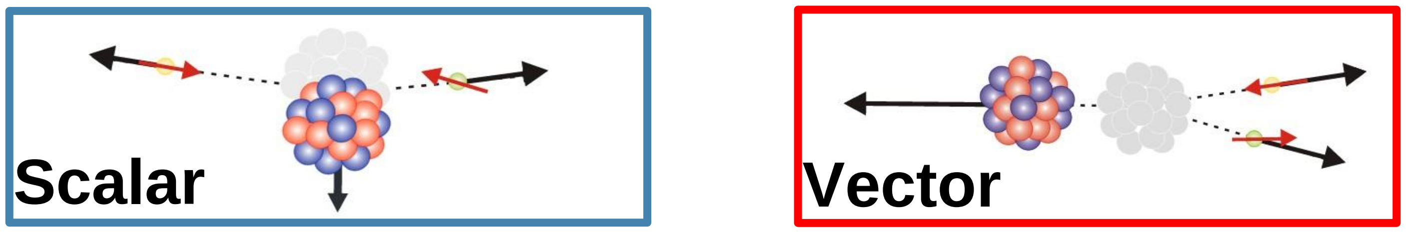
Kinematic shift: $^{32}Ar \rightarrow {}^{31}S+p$

- **^{32}Ar decays by β-decay to ^{32}Cl which subsequently decays by proton emission to ^{31}S**



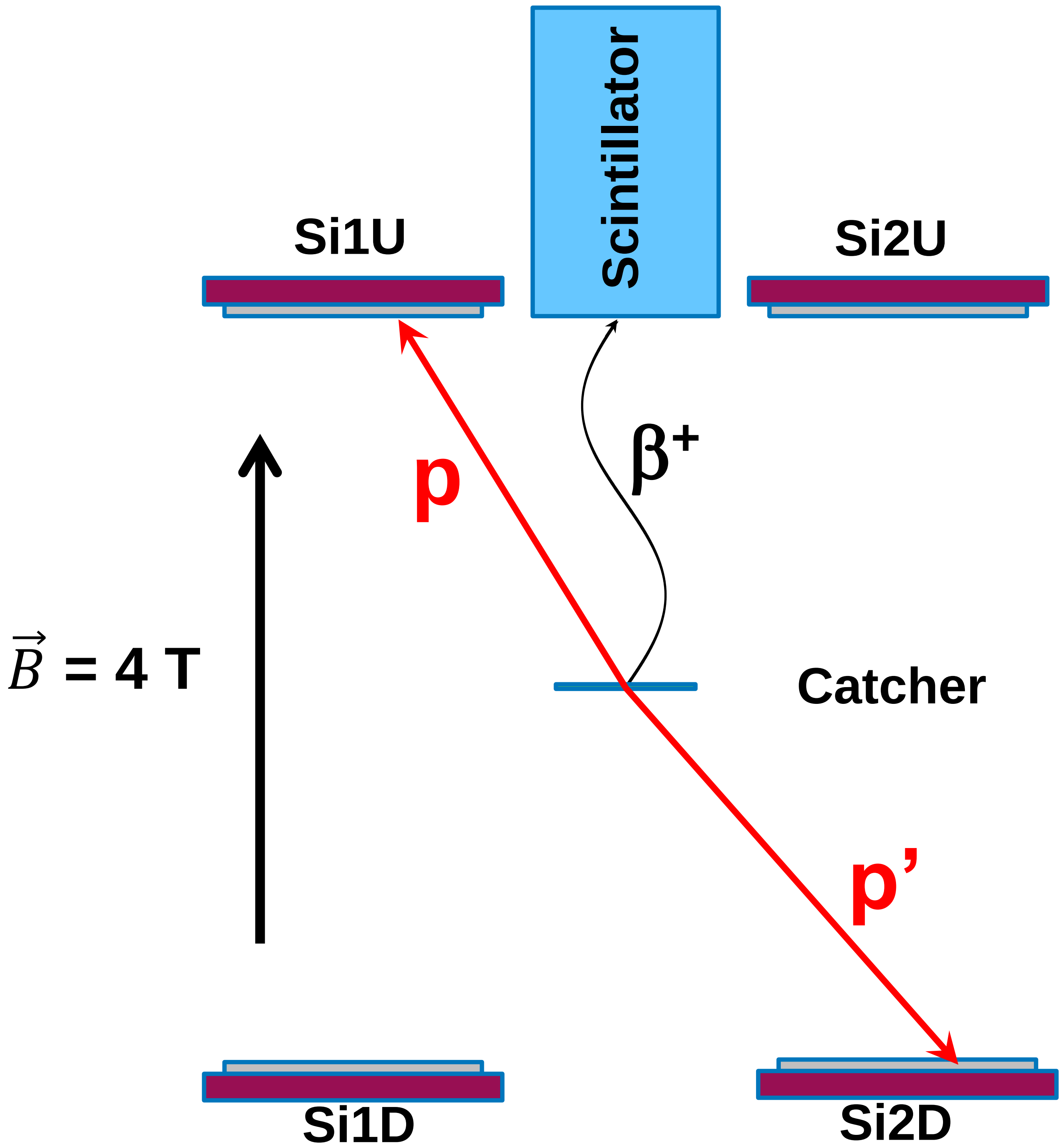
- **Recoil energy ~ hundreds eV**
- **Protons energies ~ several MeV**
- **The energy of the emitted protons is subject to kinematic shift due to the recoiling daughter nucleus**

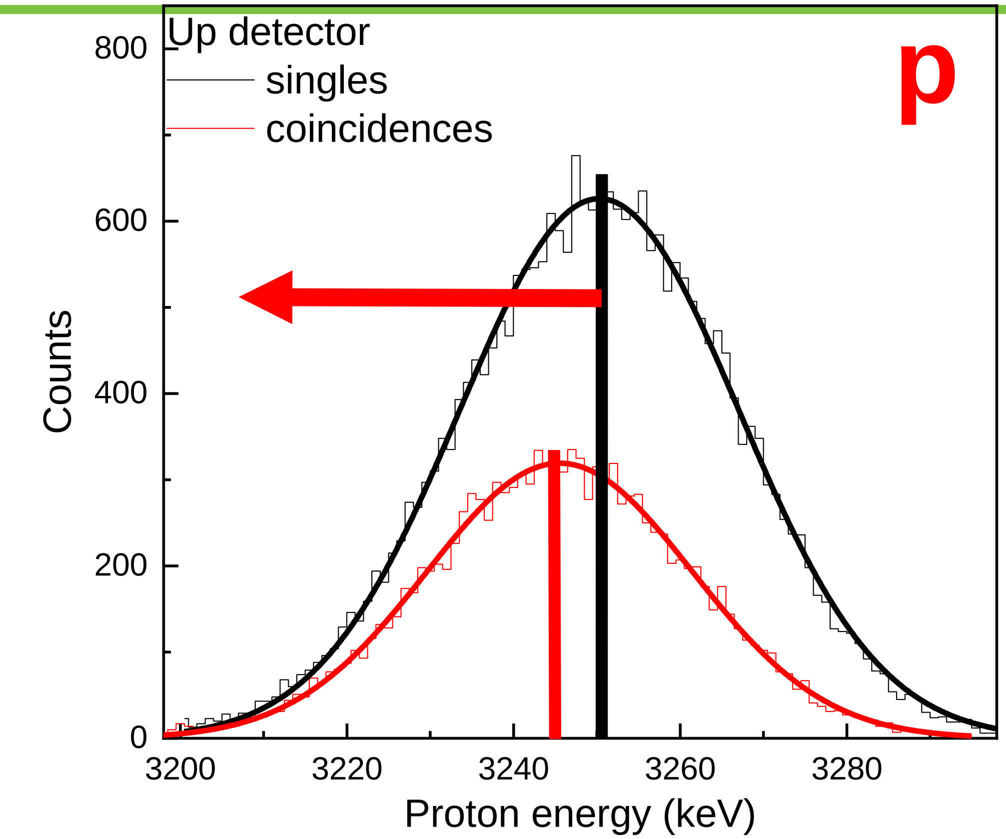


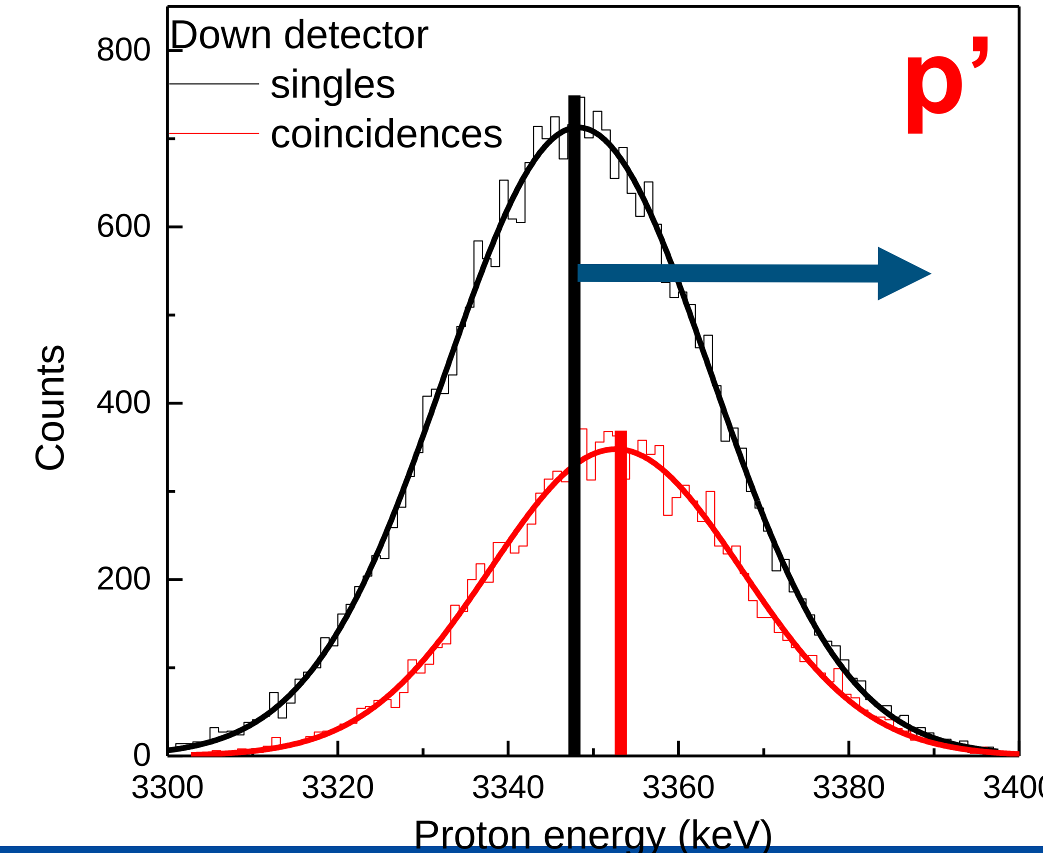


Kinematic shift with β - p coinc.

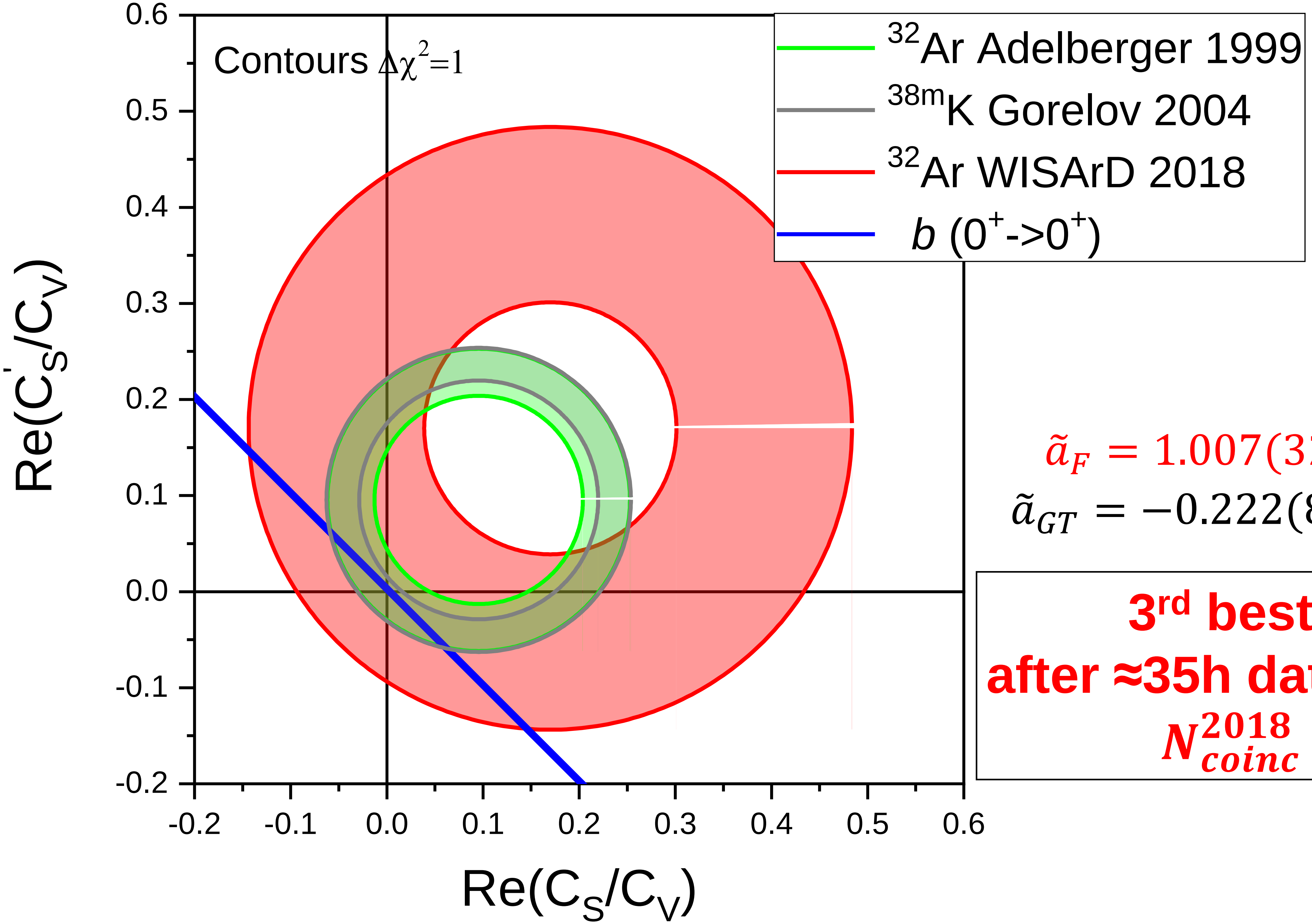
Example energy shift of one detector (IAS)







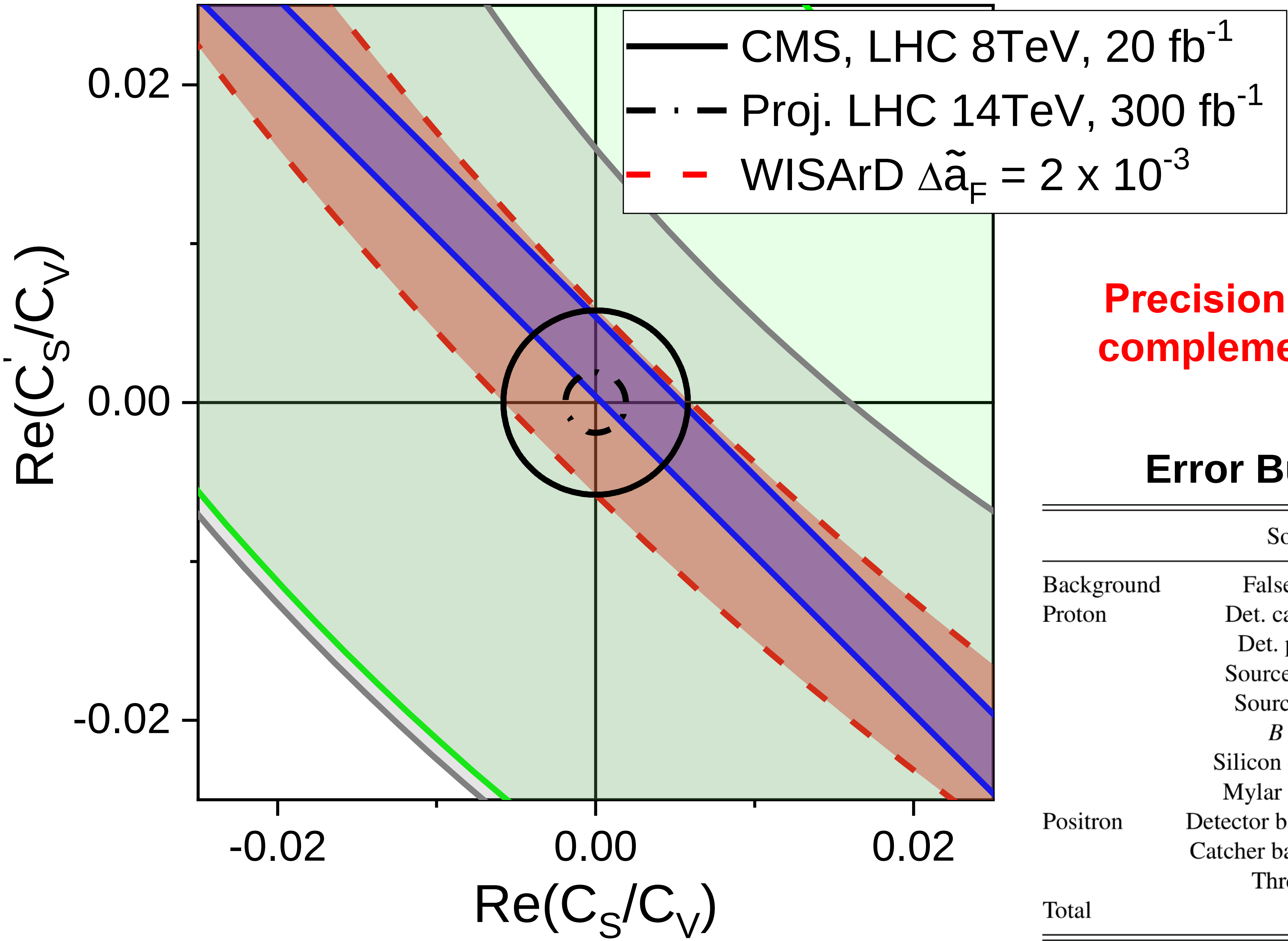
Scalar couplings - present



$$\tilde{a}_F = 1.007(32)_{stat}(25)_{syst}$$
$$\tilde{a}_{GT} = -0.222(86)_{stat}(16)_{syst}$$

3rd best result
after ≈35h data collection
N^{2018}_{coinc} ≈ 1E5

Scalar couplings - future



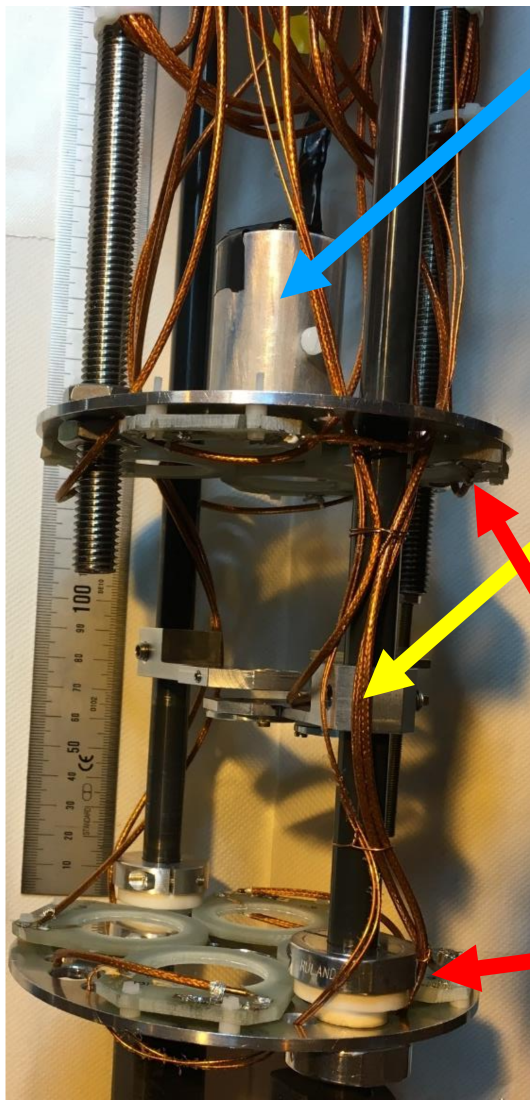
Precision ≤ 0.1% needed to complement LHC searches!

Error Budget NOV2018

	Source	Uncertainty	$\Delta\tilde{a}_F$ x1E-3
Background	False coinc.	8%	<1
Proton	Det. calibration	0.2%	9
	Det. position	1 mm	<1
	Source position	3 mm	3
	Source radius	3 mm	1
	B field	1%	<1
	Silicon dead layer	0.3 μm	5
	Mylar thickness	0.15 μm	2
Positron	Detector backscattering	15%	2
	Catcher backscattering	15%	21
	Threshold	12 keV	8
Total			25

WISArD Detection setup

2018

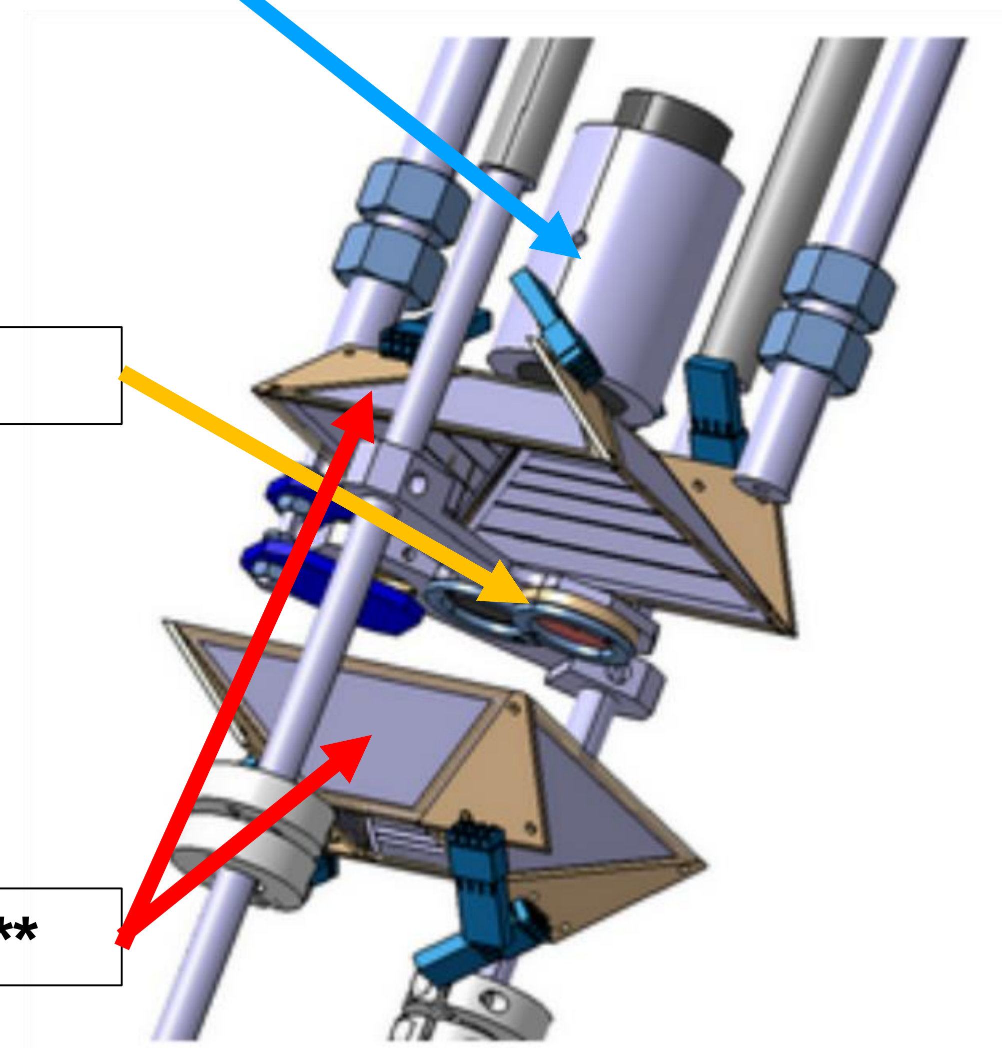


Beta detector* + SiPM

Catcher***

proton detectors planes**

2021



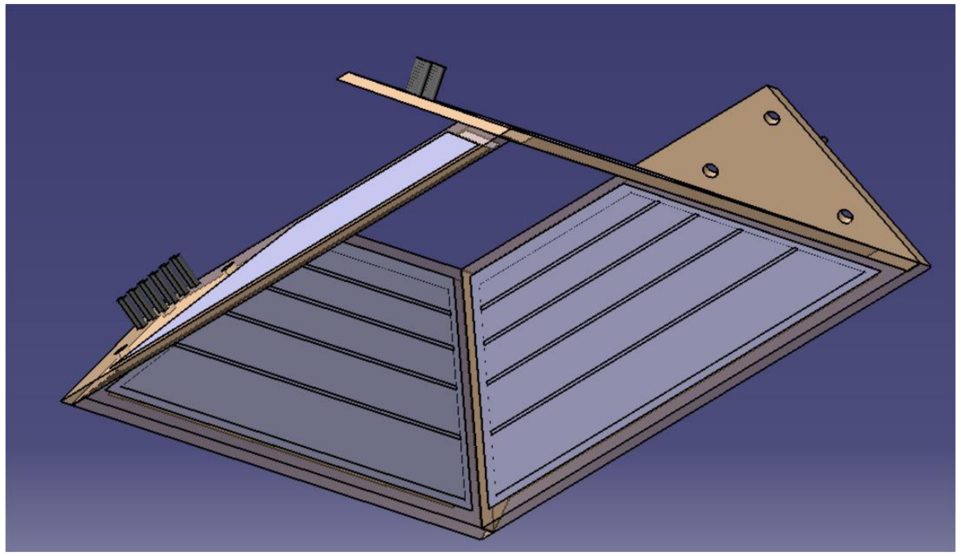
*** Plastic scintillator;**
**** Silicon surface-barrier (thickness = 300 µm);**
***** Aluminized Mylar (thickness = 6.7 µm)**

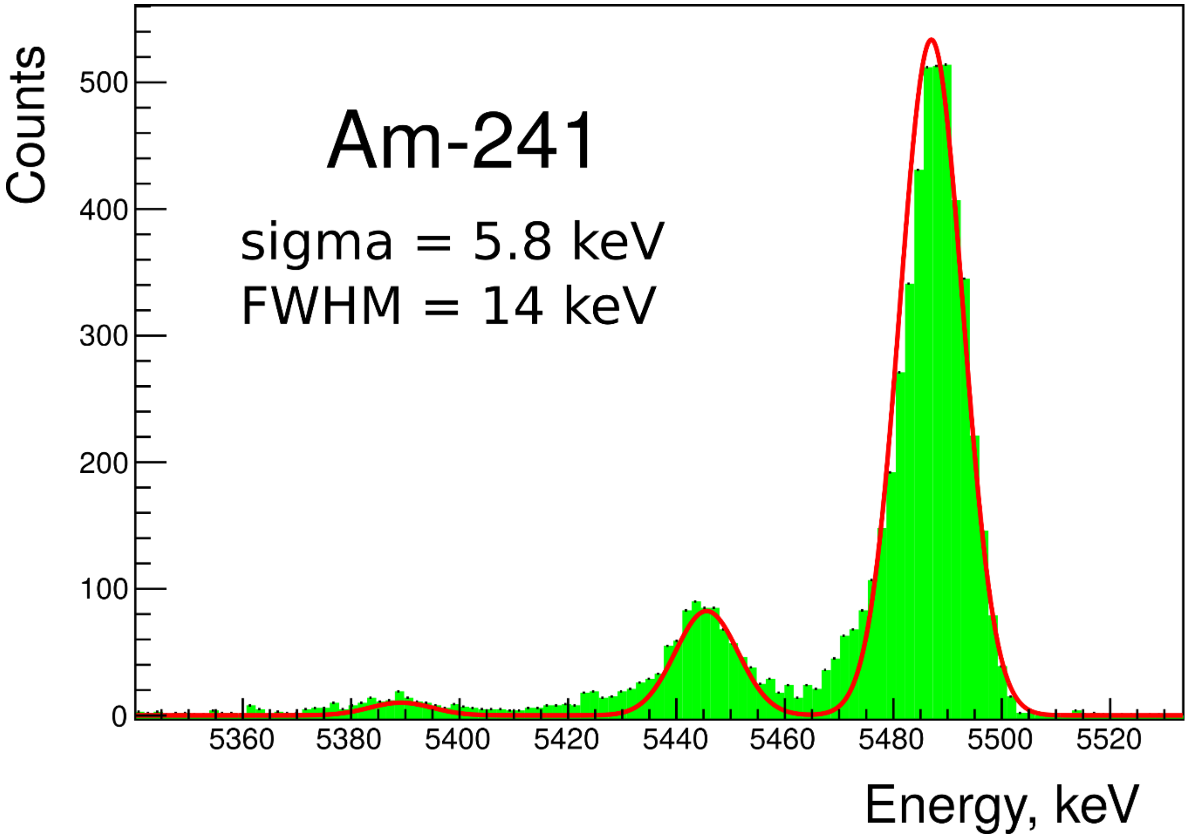
*** Plastic scintillator – EJ200;**
**** MICRON single-sided silicon-strip (thickness = 300 µm);**
***** Aluminized Mylar (thickness = 0.5 µm)**

WISArD Detection setup

Ongoing Upgrades (2019-2021):

- **WISArD beamline instrumentation – improvements in ion-beam transport ~ 98% (SIMION)**
- **Proton detectors resolution 10 keV (FWHM)** ***(8 segmented quadrants with 5 strips each)***
- **Improved geometry – solid angle 40% + reduction of proton energy loss due to dead layer**





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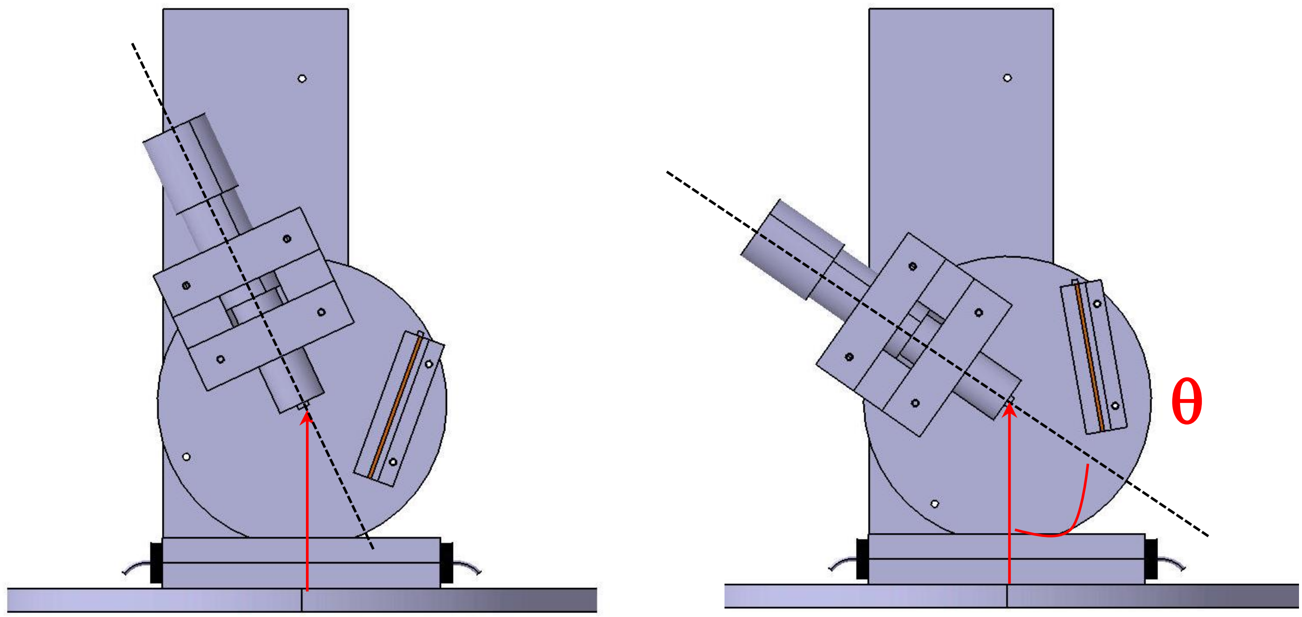
- **Backscattering of beta particles** ***(detection threshold as function of E and θ validation + constraints for GEANT4)***



Beamtime Request - summary

$\tilde{a}_F = 1.007(32)_{stat}(25)_{syst}$ N_{coinc}^{2021} ~ 290 x N_{coinc}^{2018} = 2.9E7

	2018	2021	Gain	Shifts (8h)
Resolution (keV)	35	10	2.1	-
Yield (pps)	~1700	~4000	2.35	-
Transport efficiency (%)	12	70	5.8	-
Detector geometry (%)	8	40	5	-
Beamtime Duration (h)	35	144	4.1	18
Calibration ^{33}Ar				3
Stable beam + TISD				3
TOTAL				24

Thank you

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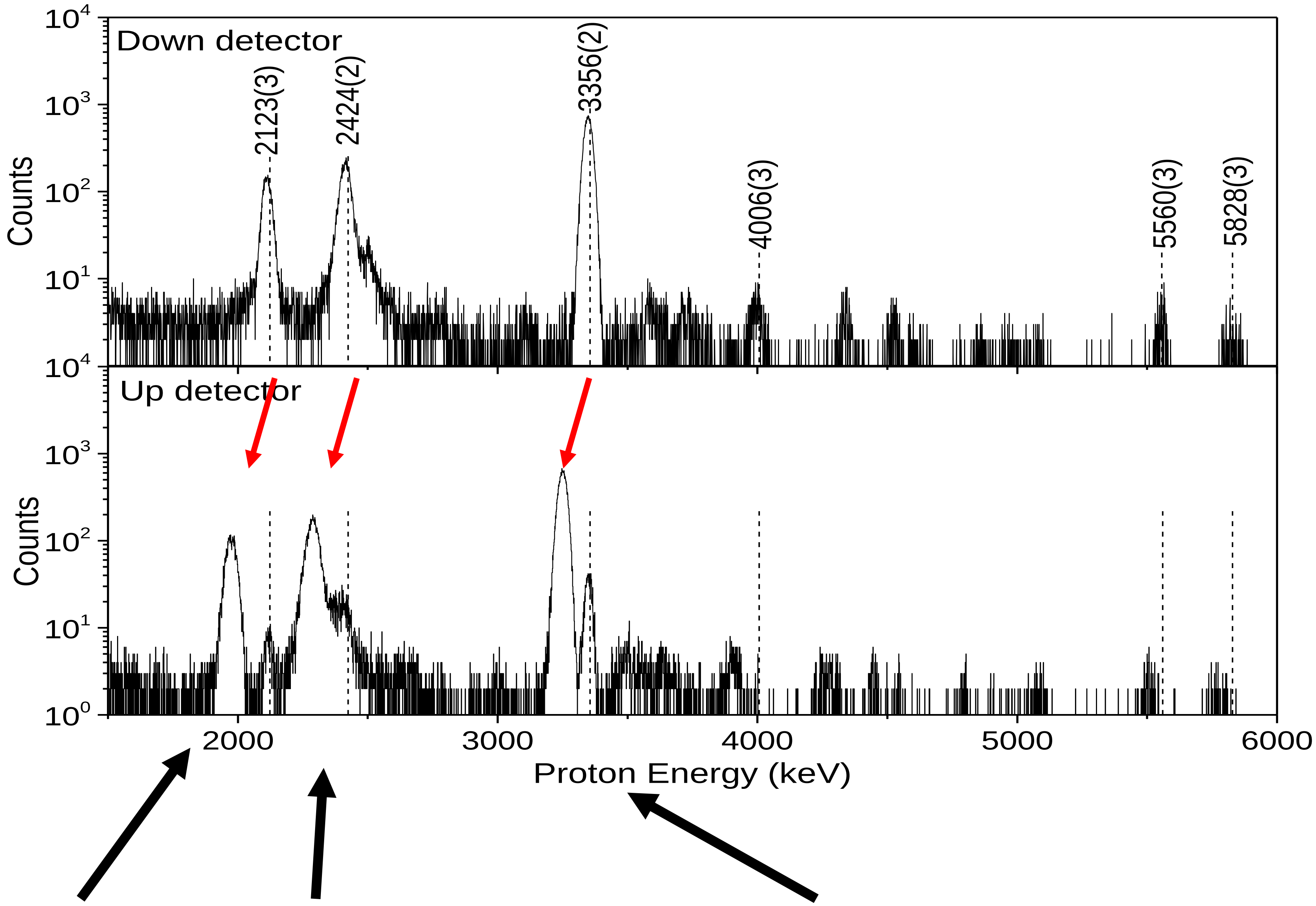
Example spectra



Gamow-Teller

IAS: Fermi transition

Results – NOV2018

Weighted average energy shifts:

$$\Delta E = \left|\bar{E}_{coinc} - \bar{E}_{single}\right|$$

$$\Delta E_F = 4.49(3)\ keV$$

$$\Delta E_{GT} = 3.05(9)\ keV$$