MEASUREMENT OF THE β ASYMMETRY PARAMETER IN ^{35}Ar DECAY WITH A LASER POLARIZED BEAM

Status of the project

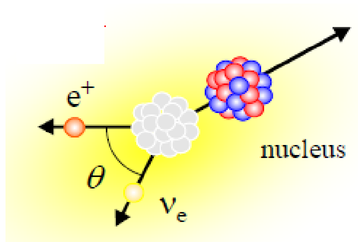
IKS-LPCCaen Collaboration Meeting
LPCCaen, 15th December 2015

Philippe Velten

V_{ud} quark mixing matrix element from with correlation measurements of mirror β transitions

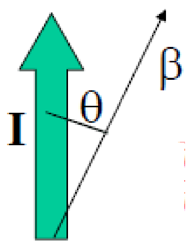
- β-ν correlation:

$$a = \frac{(1-\rho^2/3)}{(1+\rho^2)}$$



- β asymmetry:

$$A = \frac{\rho^2 - 2\rho\sqrt{J(J+1)}}{(1+\rho^2)(J+1)}$$



ΔV_{ud} for relative precision of 0.5% on $a_{\beta\nu}$ or A_β

	a			A		
Parent nucleus	ΔV_{ud}	$(\Delta V_{ud})^{\text{limit}}$	Factor $\Delta\mathcal{F}t$	ΔV_{ud}	$(\Delta V_{ud})^{\text{limit}}$	Factor $\Delta\mathcal{F}t$
^{3}H	0.0011	0.0010	2.1	0.0011	0.0009	2.3
^{11}C	0.0025	0.0016	4.0	0.0207	0.0207	0.3
^{13}N	0.0017	0.0017	1.0	0.0123	0.0123	0.1
^{15}O	0.0020	0.0016	2.4	0.0023	0.0020	1.9
^{17}F	0.0019	0.0013	3.1	0.0341	0.0341	0.1
^{19}Ne	0.0011	0.0010	1.5	0.0011	0.0011	1.5
^{21}Na	0.0022	0.0017	2.7	0.0036	0.0034	1.3
^{23}Mg	0.0025	0.0018	3.1	0.0034	0.0030	1.9
^{25}Al	0.0019	0.0018	1.7	0.0056	0.0056	0.5
^{27}Si	0.0029	0.0018	4.1	0.0068	0.0066	1.1
^{29}P	0.0026	0.0018	3.4	0.0024	0.0014	4.3
^{31}S	0.0038	0.0018	5.9	0.0068	0.0061	1.8
^{33}Cl	0.0021	0.0018	2.0	0.0013	0.0006	6.0
^{35}Ar	0.0019	0.0018	1.1	0.0007	0.0004	4.8
^{37}K	0.0034	0.0017	5.8	0.0050	0.0041	2.3
^{39}Ca	0.0024	0.0016	3.5	0.0032	0.0027	2.2
^{41}Sc	0.0029	0.0022	2.7	0.0299	0.0299	0.2
^{43}Ti	0.0076	0.0018	13.2	0.0167	0.0151	1.6
^{45}V	0.0112	0.0020	17.7	0.0115	0.0032	11.2

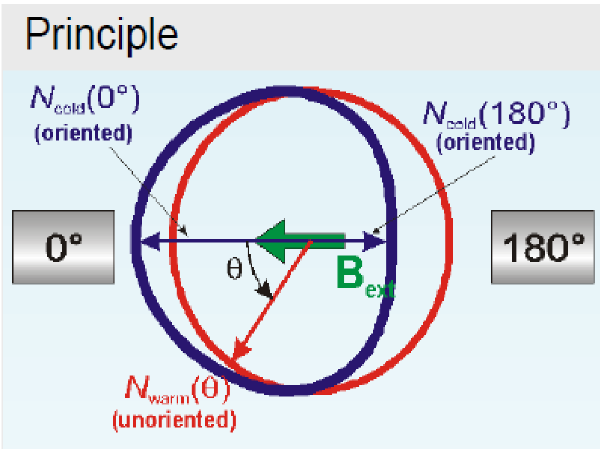
N.Severijns & O. Naviliat-Cuncic, Physica Scripta T152 (2013) 014018

A(^{35}Ar) is the best candidate:

- *ΔA/A=0.5%* → ΔV_{ud} = 0.0007 with present Ft value
- *ΔA/A=0.5%* → ΔV_{ud} = 0.0004 if Ft value is improved by factor 4.8 (requires Q_{EC}, $T_{1/2}$ and BR)

(<u>Note</u>: ΔV_{ud} (0+ → 0+) = 0.00022)

Measuring the β asymmetry parameter in nuclear β decay



- Transition rate of polarized nuclei:

$$W(\theta) = W_0 \left(1 + \frac{v}{c} J A cos(\theta)\right)$$

- Experimental asymmetry:

$$\mathcal{A} = \left\langle \frac{v}{c} \cos(\theta) \right\rangle J A = \frac{R-1}{R+1}$$

- Spin-flip:

$$R = \sqrt{\frac{N(0,+J)N(\pi,-J)}{N(0,-J)N(\pi,+J)}}$$

- High precision measurement:

Poorly known

$$\mathcal{A} = \left\langle \frac{v}{c} \cos(\theta) \right\rangle J A = \frac{R-1}{R+1}$$

Accumulate statistics

requires adv. MC calculations
-> 1-2% pres. at best

Goal:
0.5% precision

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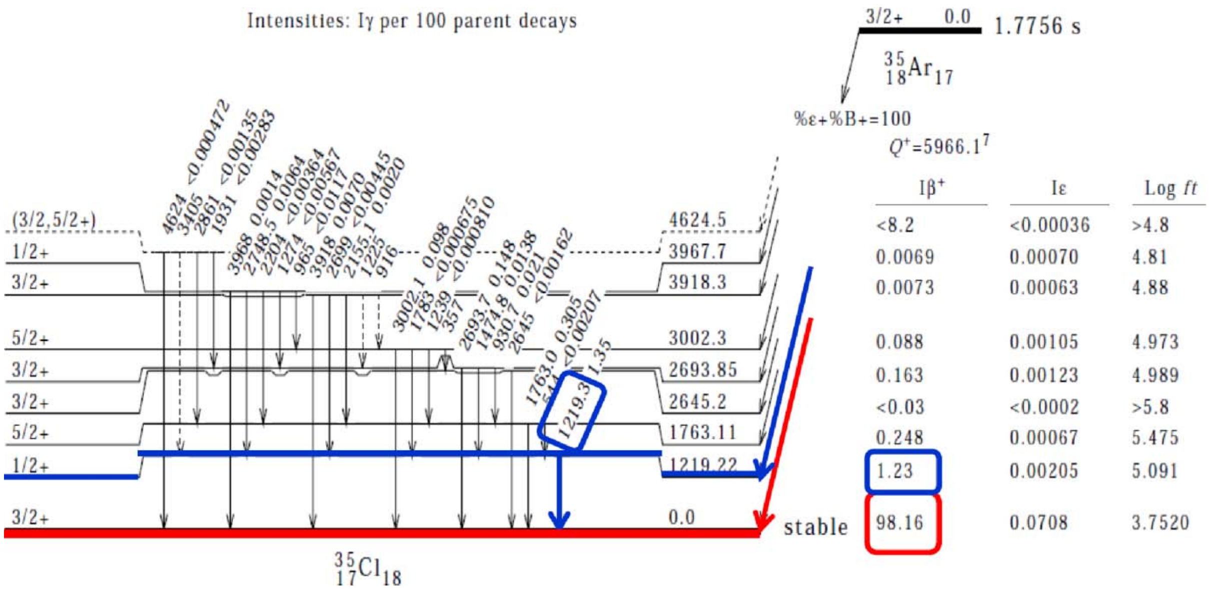
Using the 1st excited state of 35Ar transition to reach high precision level

- Measurement of both ground & **first excited state** of ^{35}Ar:



$$\frac{A_{gs}}{A_{ex}} = \frac{\left\langle \frac{v}{c}\cos(\theta) \right\rangle_{ex}}{\left\langle \frac{v}{c}\cos(\theta) \right\rangle_{gs}} \frac{A_{gs}}{A_{ex}}$$

=1 (pure GT)

measured

0.5% prec. should be ok (study in progress)

Pros:

- **J cancels out**
- **Higher precision on kinematic & geometrical factor**

Con:

- **requires β-γ coincident detection**
- **statistical precision limited by excited state asymmetry since br = 1.23%**

Requirements to reach the 0.5% precision on A(^{35}Ar)

- Highly efficient β-γ coincident detection setup

  → Development in progress at IKS - KU Leuven

- Intense decay source of highly polarized ^{35}Ar

→ **VITO beamline at CERN-ISOLDE**

expected performance for the 35Ar beam:
- production rate: **I = ~1e6 ^{35}Ar/s**
- polarization: **P = 0.2 – 0.4**

→ **Implant 35Ar in a host lattice + magnetic field to maintain polarization**

Which crystal is the best suitable to implant ^{35}Ar and maintain polarization long enough to measure the β asymmetry (λ=1.8s) ?

→ Answering this question is the goal of the "crystal test" runs

- Preliminary estimation: 0.5% statistical precision is achievable within few days of data taking time

  → Depends strongly on the polarization level of the decay source:

  Ex: if J= 0.4 → 0.2, the data taking time to reach a given stat. precision is **multiplied by 5**

Polarization and crystal tests at ~~COLLAPS~~ VITO

- **Selection of host candidates:**
  - o **KBr**:
    - Used as implant host in ^{35}Ar magnetic moment measurement with β-NMR
    - Cooled at 20K

    Matsuta K, et al. Nuc. Phys. A 701 383c (2002)
  - o **NaF & CaF**:
    - NaF Used as catcher for β-NMR study of ^{23}Ne noble gas
    - Cooled at 15K
    - CaF: mass closer to Ar

    Ohtsubo T, et al. Hyp. Int. 180 85 (2007)
  - o **NaCl & Si**:
    - Good implantation hosts for several elements

    Minamisono T, et al. Hyp. Int. 35 979 (1987), Borremans D, et al. Phys. Rev. C 72 044309 (2005)

Current Status of the crystal test run preparations

- **Run of November 2015 on COLLAPS has been cancelled due to other priorities (Ca run with new ROC setup)**
- **ROC setup will most probably stay mounted on COLLAPS all next year**
- **Decision has been taken to move to VITO directly**
  - **Run planned late summer next year**

- **First organizational meeting happened at ISOLDE workshop early December**
  - **Local coordination has been decided and tasks have been assigned**
  - **Biweekly meeting have been proposed to follow advancements**

- **The main effort consists of building the beamline and installing the laser**
  - **Mainly the task of Gerda's people and CERN locals (Magda, Frank, Mark)**
  - **Involvement of IKS WI's group to be clarified at a later stage**

Current Status of the crystal test run preparations

- Summary of advancement concerning the detection setup:

  - Old NMR COLLAPS chamber is contaminated & damaged!
    - Need to design and build a new chamber

  - Design will be constrained by the NMR magnet that will be used:
    - COLLAPS magnet: need to measure max field -> does it reach 0.5T?
    - LEUVEN magnet: stronger magnet (B~1T) but more tricky to use
      - Need of a precise 3D field mapping to design beam guiding coils to ensure correct adiabatic rotation -> should be performed by CERN field mapping service
      - Need to check available space around VITO

  - COLLAPS cold head has been tested and is working correctly
    - 26K reached in about 1h. Warming up in vacuum requires more than 10h
    - Some upgrades are planned to enhance performance and reduce warming up
  - New cold finger (direct LHe cooling) has arrived at IKS
    - Performance needs to be tested
  - Attempt to use both systems in the new chamber:
    - Independent crystal cooling + cooling shield

Current Status of the crystal test run preparations

- Summary of advancement concerning the detection setup:
  - Old NMR COLLAPS chamber is contaminated & damaged!
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b275 has been locked by RP because of the contamination issue

- Radioactivity checks are being performed since 2 months
  - Radioactive parts are being moved in special storage
- Access to building is currently very difficult:
  - for now, magnet test is not feasible
  - location and status of cold head unknown

    - Some upgrades are planned to enhance performance and reduce warming up
  - New cold finger (direct LHe cooling) has arrived at IKS
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Data taking time estimation

- Level of polarization impact greatly the data taking duration:

$$\Delta t = \frac{4}{\epsilon_{br}} \times \frac{1}{I_{dcy}} \times \frac{1}{\epsilon_\gamma} \times \frac{1}{\epsilon_\beta^{>E_{\rm th}}} \times (1 + 2/\mathrm{SB}) \times \frac{R}{(R-1)^2} \times \left(\frac{\Delta\mathcal{A}}{\mathcal{A}}\right)^{-2}$$

Decay source intensity

Particle detection efficiencies

S/B ratio

G(A, J, θ) = Asymmetry setting factor

Statistical precision on exp. asymmetry

Data taking time estimation

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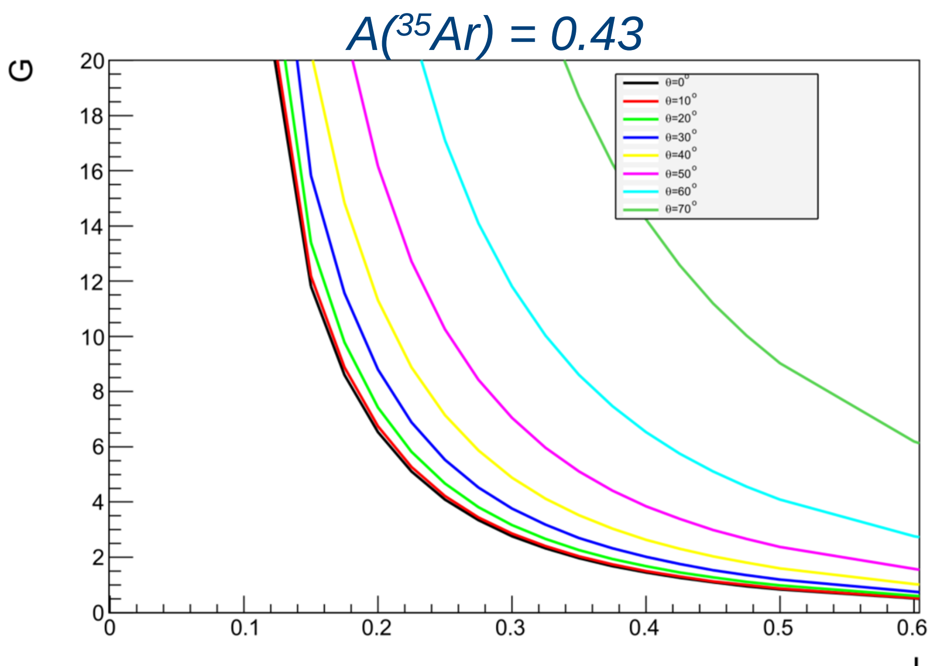
Statistical precision on exp. asymmetry

G(A, J, θ) = Asymmetry setting factor

A: asymmetry parameter
J: polarization of the source
θ: position of the detectors



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Polarization enhancement by reionization at VITO & CRIS

- Level of polarization impact greatly the data taking duration:

$$\Delta t = \frac{4}{\epsilon_{br}} \times \frac{1}{I_{dcy}} \times \frac{1}{\epsilon_\gamma} \times \frac{1}{\epsilon_\beta^{>E_{\rm th}}} \times (1 + 2/\mathrm{SB}) \times \frac{R}{(R-1)^2} \times \left(\frac{\Delta\mathcal{A}}{\mathcal{A}}\right)^{-2}$$

Statistical precision on exp. asymmetry

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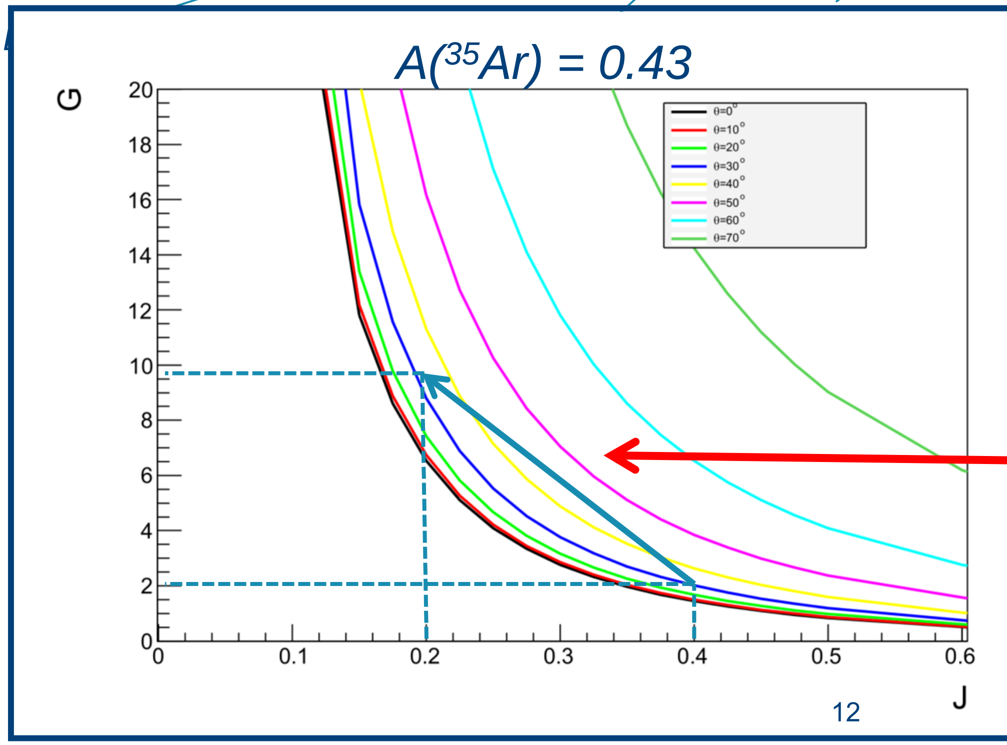


J: 0.4 → 0.2
→ Δt x5

Data taking time estimation

$$\Delta t = \frac{4}{\epsilon_{br}} \times \frac{1}{I_{dcy}} \times \frac{1}{\epsilon_\gamma} \times \frac{1}{\epsilon_\beta^{>E_{\rm th}}} \times (1 + 2/\mathrm{SB}) \times \frac{R}{(R-1)^2} \times \left(\frac{\Delta\mathcal{A}}{\mathcal{A}}\right)^{-2}$$

Parameter	Nominal	Pessimistic scenario
$\frac{\Delta\mathcal{A}}{\mathcal{A}}$	0.5%	idem
v/c	0.96	idem
θ (degree)	35	idem
$E_{\rm th}$ (MeV)	1.4	idem
$\epsilon_\beta^{>E_{\rm th}}$ (count/decay)	2×10^{-2}	idem
ϵ_γ (count/decay)	4.7×10^{-2}	idem
$\epsilon^{\rm coinc}$ (count/decay)	1.16×10^{-5}	idem
S/B	4.7	idem
Q	1.43	idem
J	0.3	0.2
$\mathcal{A}_{ex}$	0.24	0.16
R	1.62	1.37
G	4.24	9.86
$N_2^{\rm tot}$	7.4×10^5	1.89×10^6
I (decays/s)	10^6	0.5×10^6
$\frac{dN_{\rm det\beta}}{dt}$ (counts/s)	3.7×10^4	1.85×10^5
$< \frac{dN_{\rm CsI\ block}}{dt} >$ (counts/s)	2.3×10^4	1.15×10^4
Δt (s)	83680	388888

Nominal -> Pessimistic:

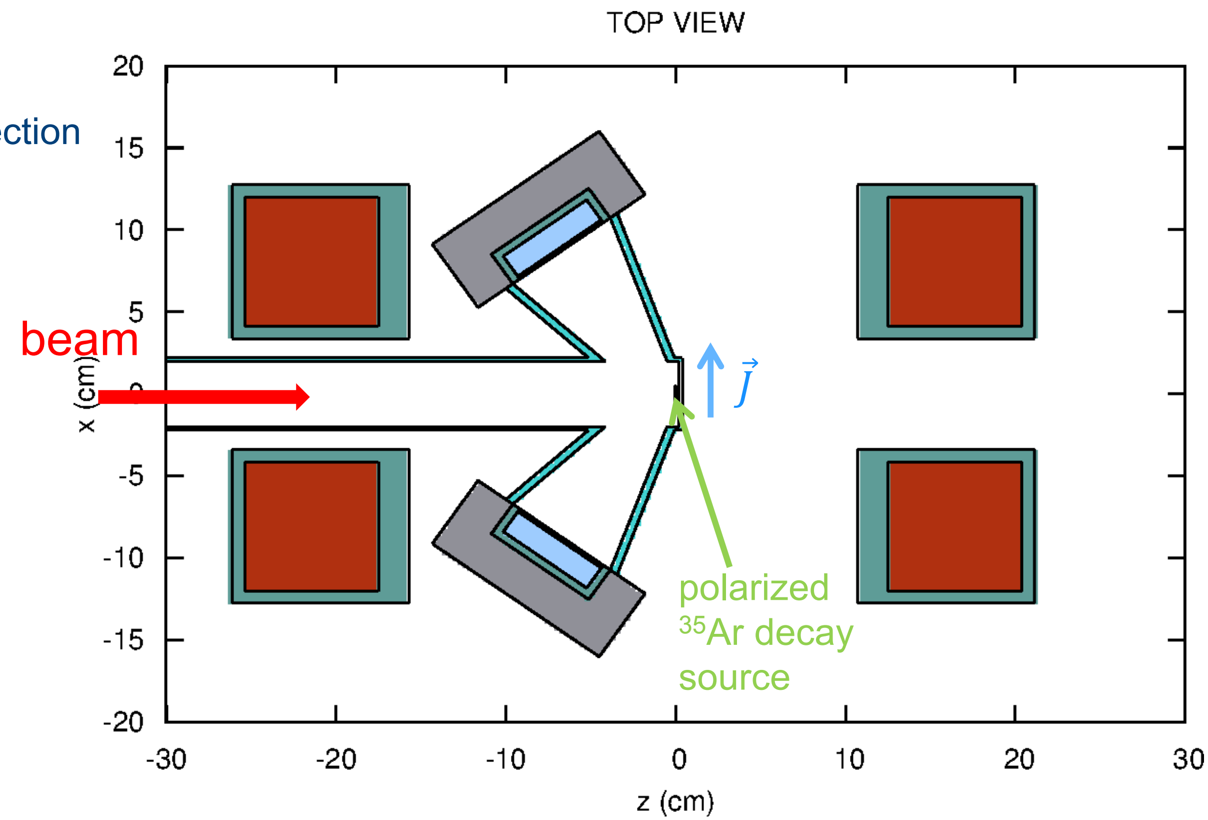
- 50% reduction in decay source
- Polarization: J= 0.2 instead of 0.3

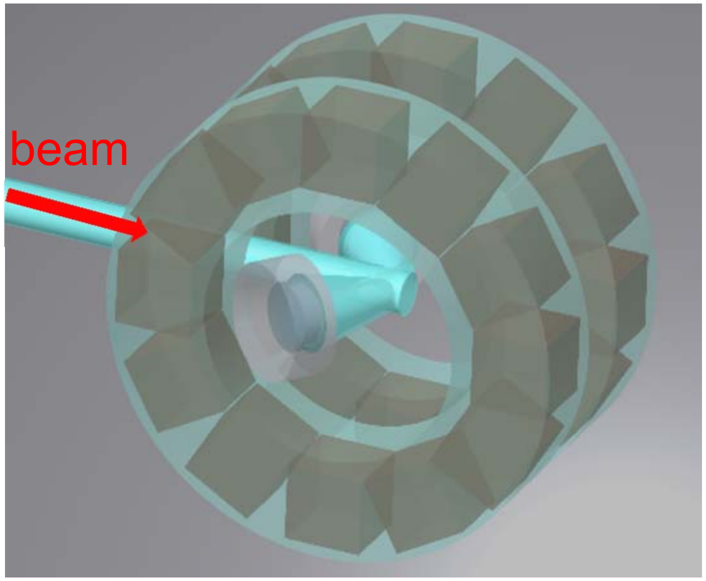
← 4.5 days instead of 24h

(Possible) detection setup for the A(^{35}Ar) measurement

2x ΔE-E telescopes for β+ detection
2x CsI rings for γ-ray @1.219 MeV detection

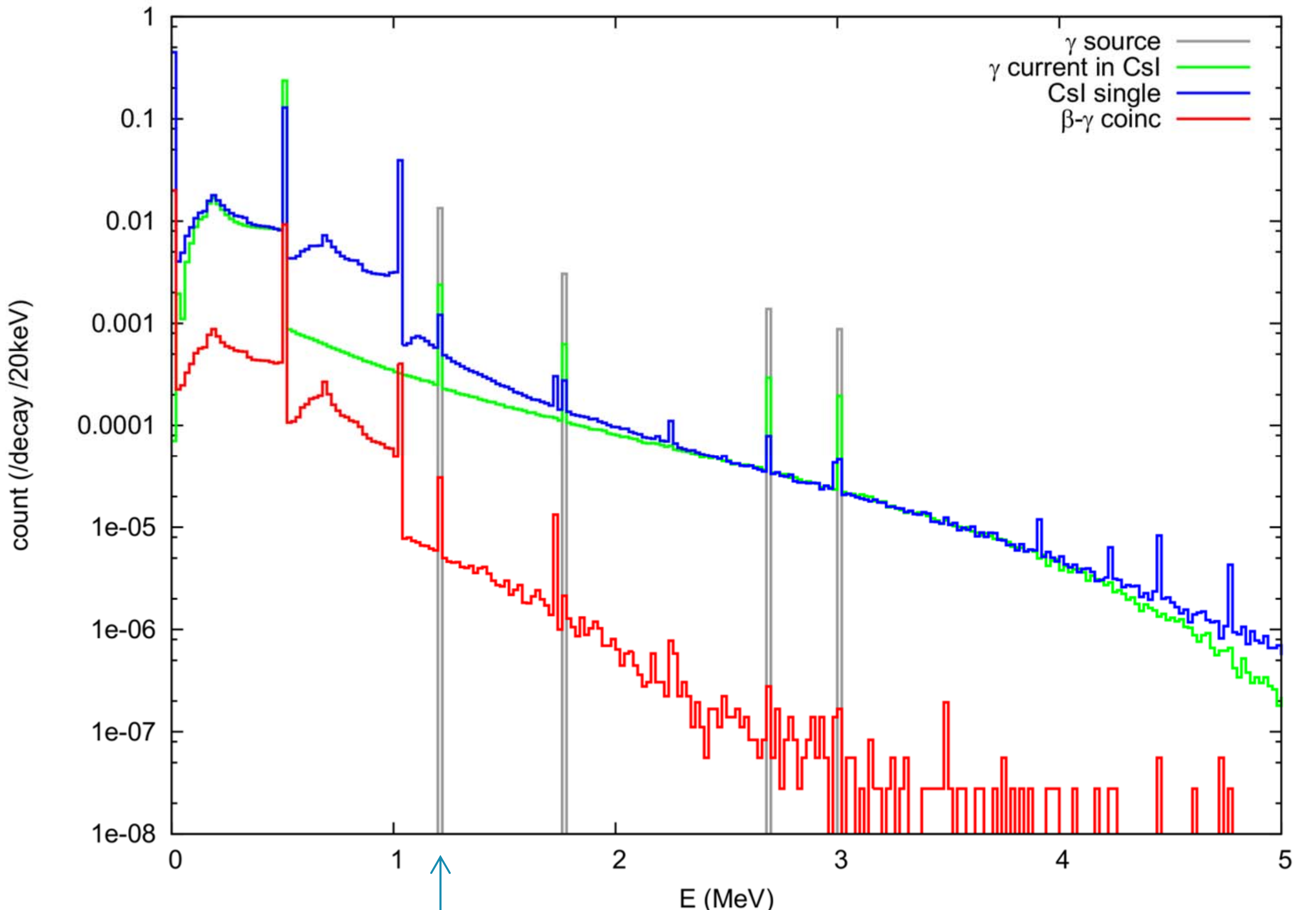
Main features:
- Left-Right symmetric layout
- Maximize detection solid angle





MC simulations has been initiated to
- Optimize detection efficiency
- Study systematic effects (β scattering, etc.)

Gamma detection



1st excited state γ-ray