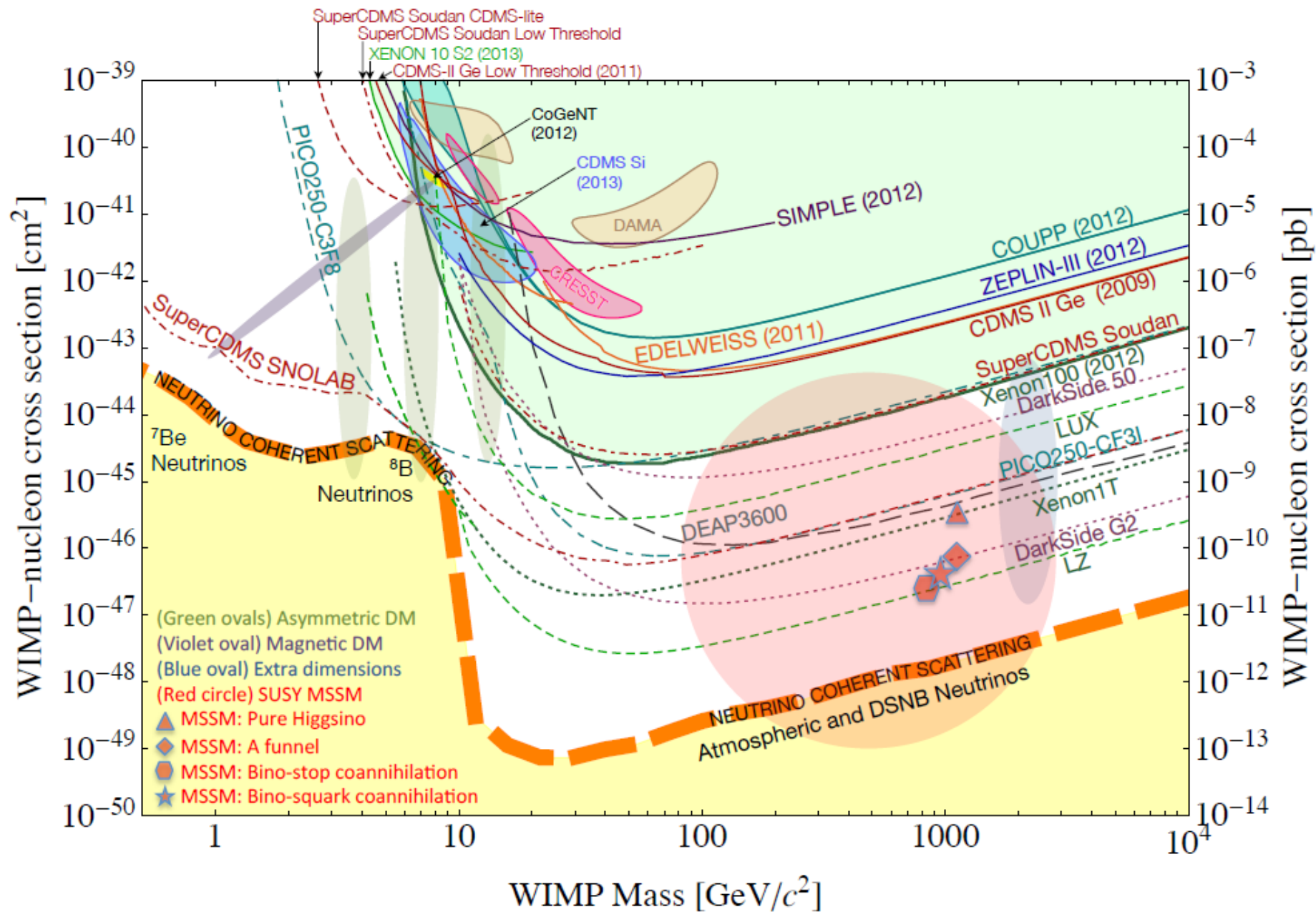


# PICO-LON high purity NaI(Tl) crystal for dark matter search

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for  
KamLAND-PICO

1. PICO-LON for dark matter search
2. Purification of NaI(Tl) crystal
3. Future prospects





**The DAMA/LIBRA set-up ~250 kg NaI(Tl)**  
**(Large sodium Iodide Bulk for RARE processes)**

As a result of a second generation R&D for more radiopure NaI(Tl)  
by exploiting new chemical/physical radiopurification techniques  
(all operations involving crystals and PMTs - including photos - in HP Nitrogen atmosphere)

Residual contaminations in the new DAMA/  
LIBRA NaI(Tl) detectors:  
 $^{232}\text{Th}$ ,  $^{238}\text{U}$  and  $^{40}\text{K}$  at level of  $10^{-12}$  g/g

- *Radiopurity, performances, procedures, etc.:* NIMA592(2008)297, JINST 7 (2012) 03009
- *Results on DM particles: Annual Modulation Signature:* EPJC56(2008)333, EPJC67(2010)39  
*related results:* PRD84(2011)055014, EPJC72(2012)2064, IJMPA28(2013)1330022
- *Results on rare processes: PEP violation in Na, I:* EPJC62(2009)327, *CNC in I:* EPJC72(2012)1920,  
*IPP in  $^{241}\text{Am}$ :* EPJA49(2013)64

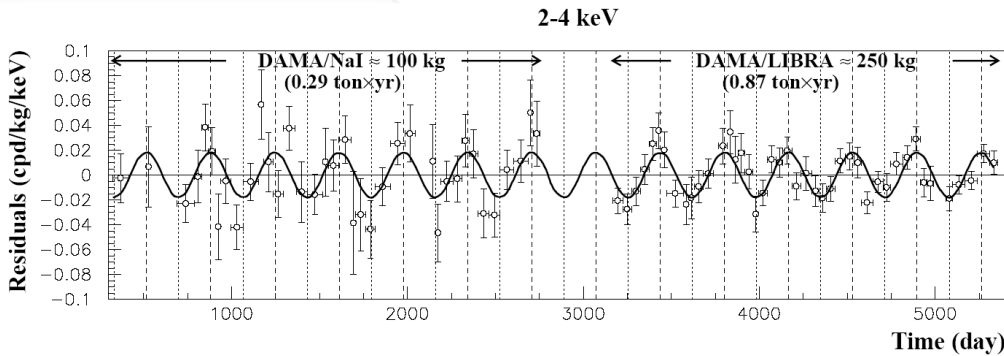
# Model Independent Annual Modulation Result

DAMA/NaI (7 years) + DAMA/LIBRA (6 years)

EPJC67(2010)39; see also refs therein

$$\text{Acos}[W(t-t_0)] \ddagger$$

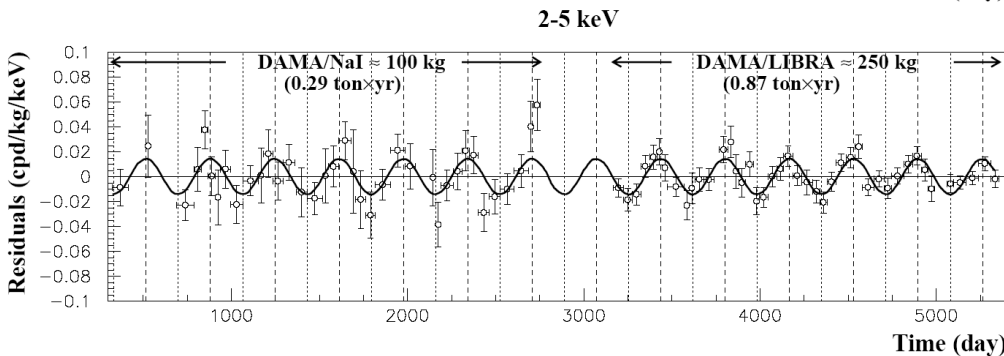
continuous lines:  $t_0 = 152.5$  d,  $T = 1.00$  y!



2-4 keV!

Absence of modulation? No

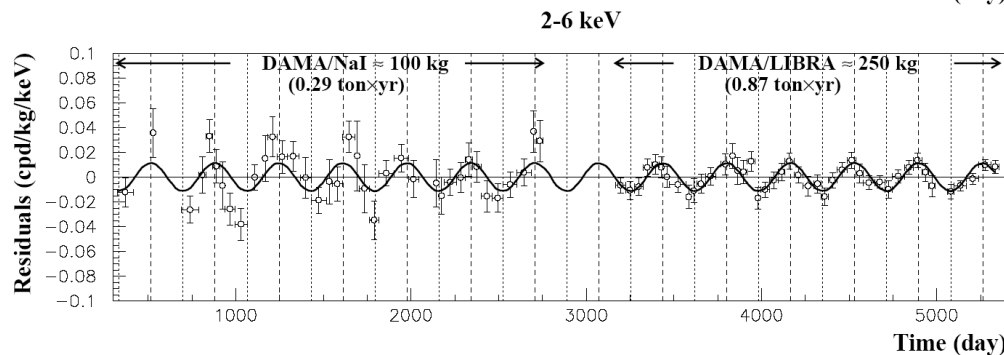
$$c^2/\text{dof}=147/80 \supset P(A=0) = 7 \cdot 10^{-6}$$



2-5 keV!

Absence of modulation? No

$$c^2/\text{dof}=135/80 \supset P(A=0) = 1.1 \cdot 10^{-4}$$



2-6 keV!

Absence of modulation? No

$$c^2/\text{dof}=140/80 \supset P(A=0) = 4.3 \cdot 10^{-5}$$

The data favor the presence of a modulated behavior with proper features at  $8.8\sigma$  C.L.

# Other groups to check DAMA/LIBRA

- Limited number of NaI(Tl) maker

- BICRON

- 

- HARSHOW



Saint Gobain



DAMA/LIBRA

- Horiba

I.S.C.Lab.



PICO-LON

- Fragmented set-up
- etc.

ULB NaI(Tl) also allows the study of several rare processes



**High benefits/cost**

To develop ULB NaI(Tl): many years of work, specific experience in the specific detector, suitable raw materials selections, developments of purification strategies and of growing/handling protocols, long dedicated time and efforts, etc. etc. **The developments themselves are difficult and uncertain experiments.**



**ULB NaI(Tl) - as whatever ULB detector - cannot be simply bought or made by another researcher for you ...**

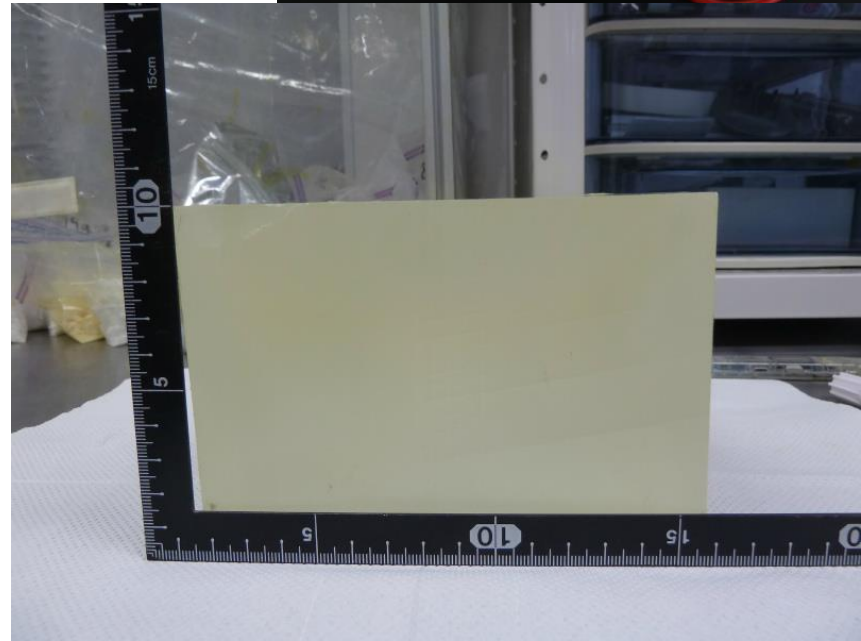


# PICO-LON for WIMPs search

- **P**ure
  - **I**norganic
  - **C**rystal
  - **O**bservatory for
  - **L**ow-background
  - **N**eutr(al)ino
- High selectivity
  - Background reduction
  - Sensitive to
  - Elastic scattering (SI+SD)
  - Inelastic scattering (SD)
  - Study the interaction type of WIMPs

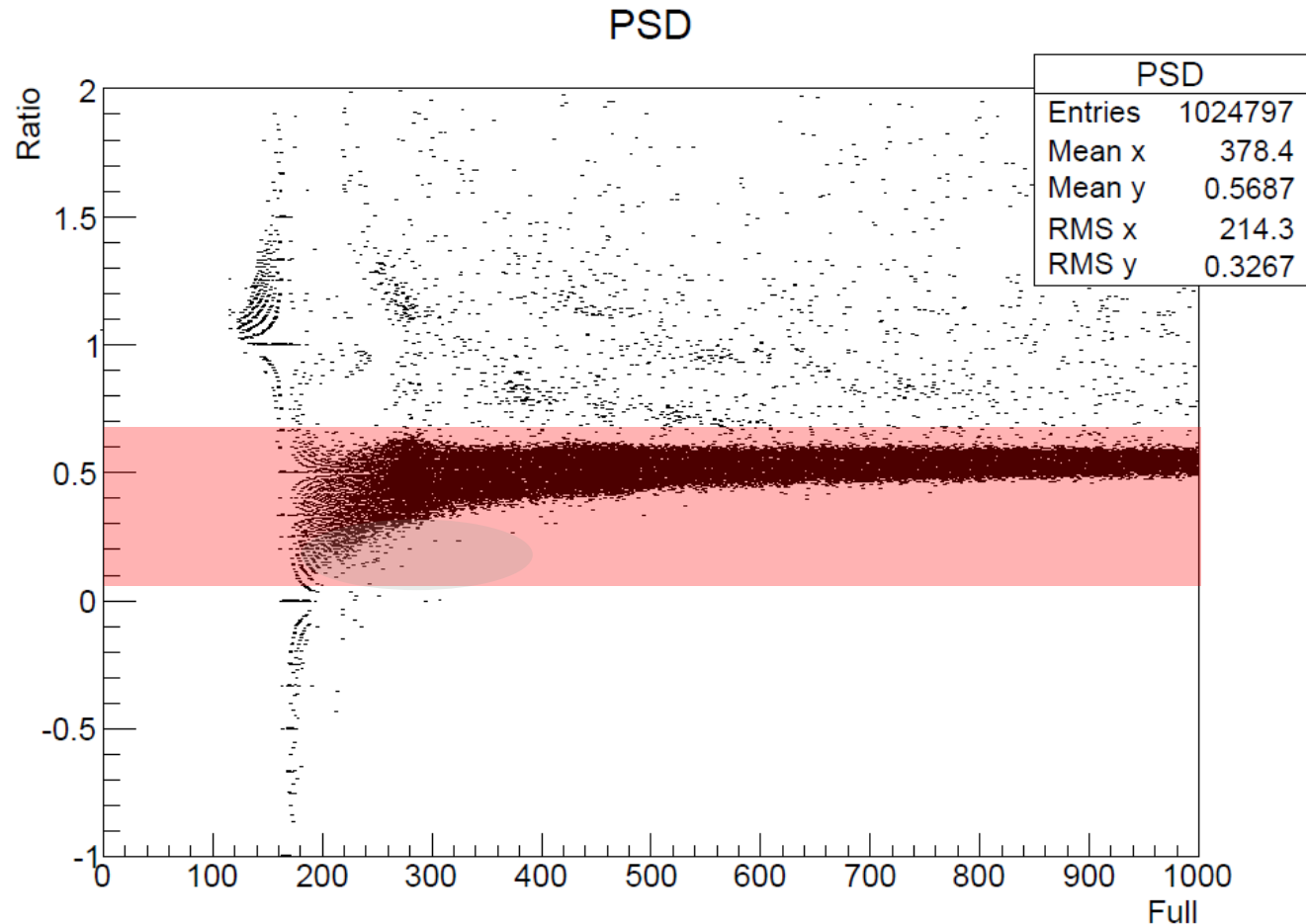
# R&D for pure NaI(Tl) production

- Development in collaboration with I.S.C. Lab.
- Selection of
  - Crucible
  - NaI powder
  - Chemical process
  - Surrounding environment
- 3.0"  $\phi$  X 3.0" NaI(Tl)
- Improvement step by step
- **Low E threshold**
- **High purity**



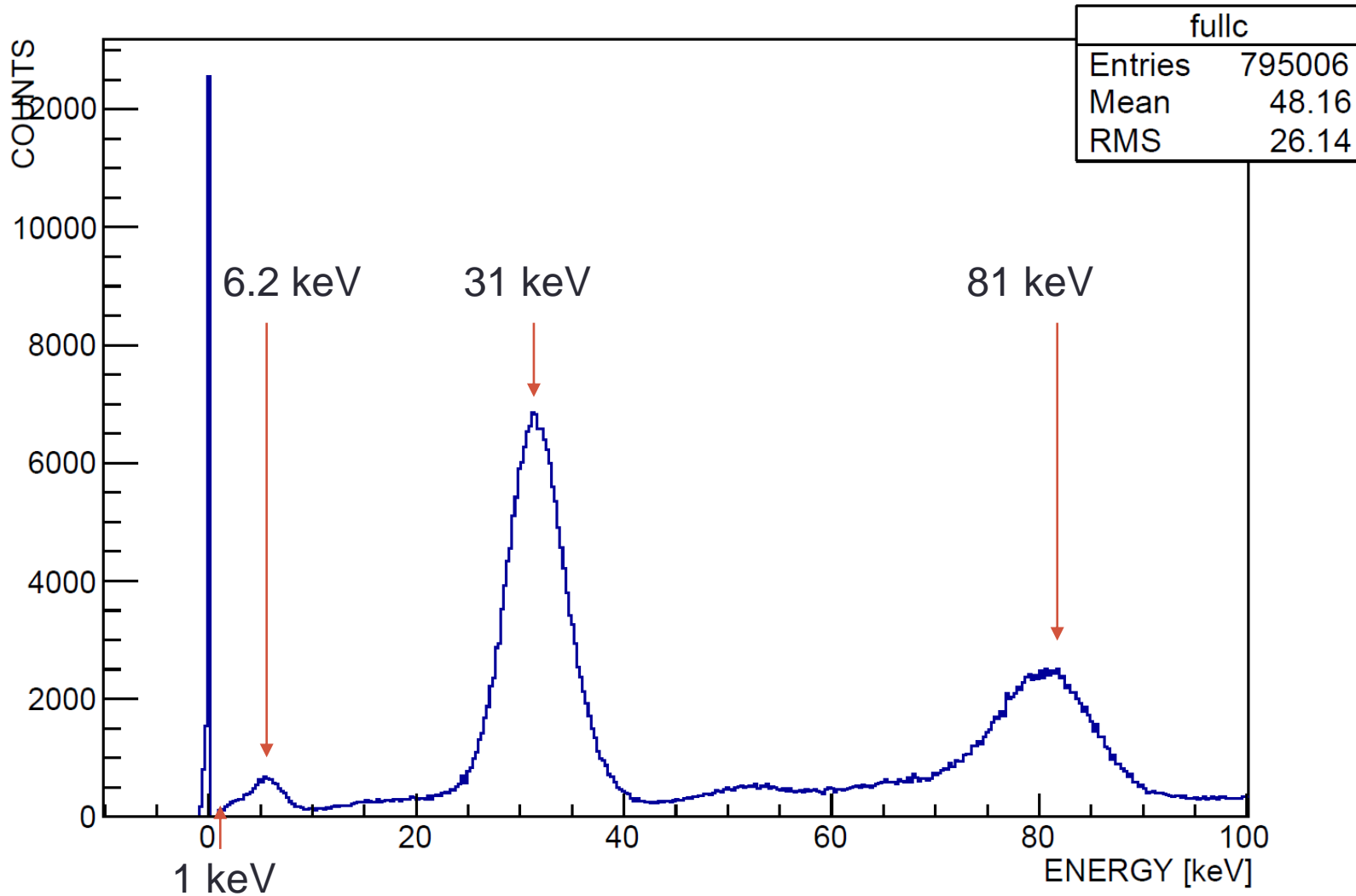
# Low energy threshold (Noise reduction)

- Fast PMT dark noise was rejected by Timing filter AMP.
- Pulse shape discrimination → Rejects pile-up events



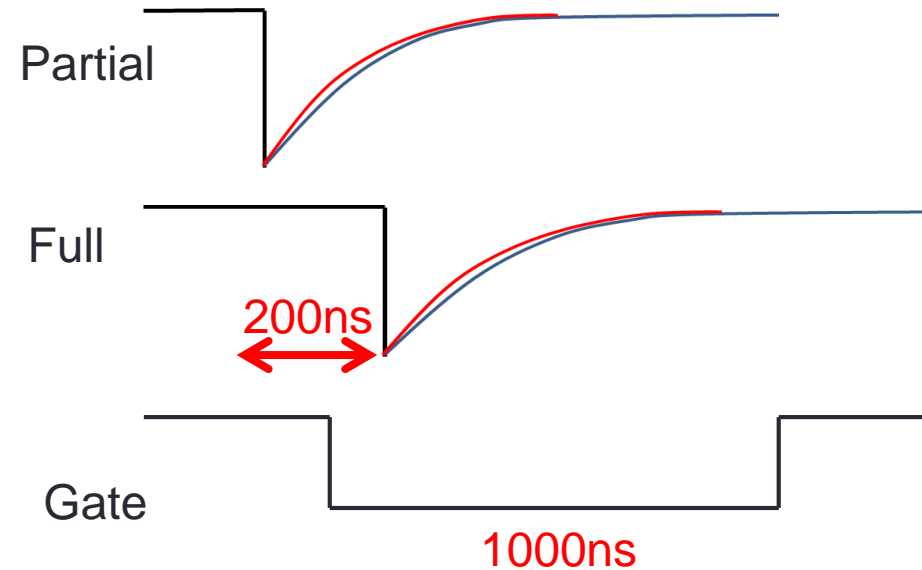


- 1 keV Energy threshold has been established

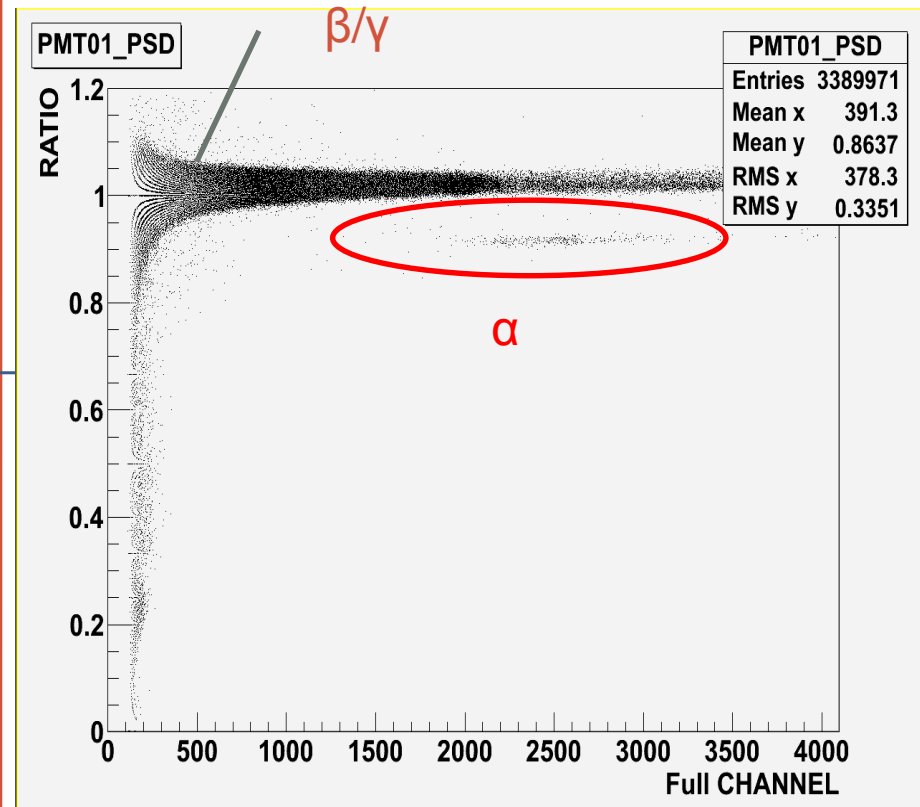


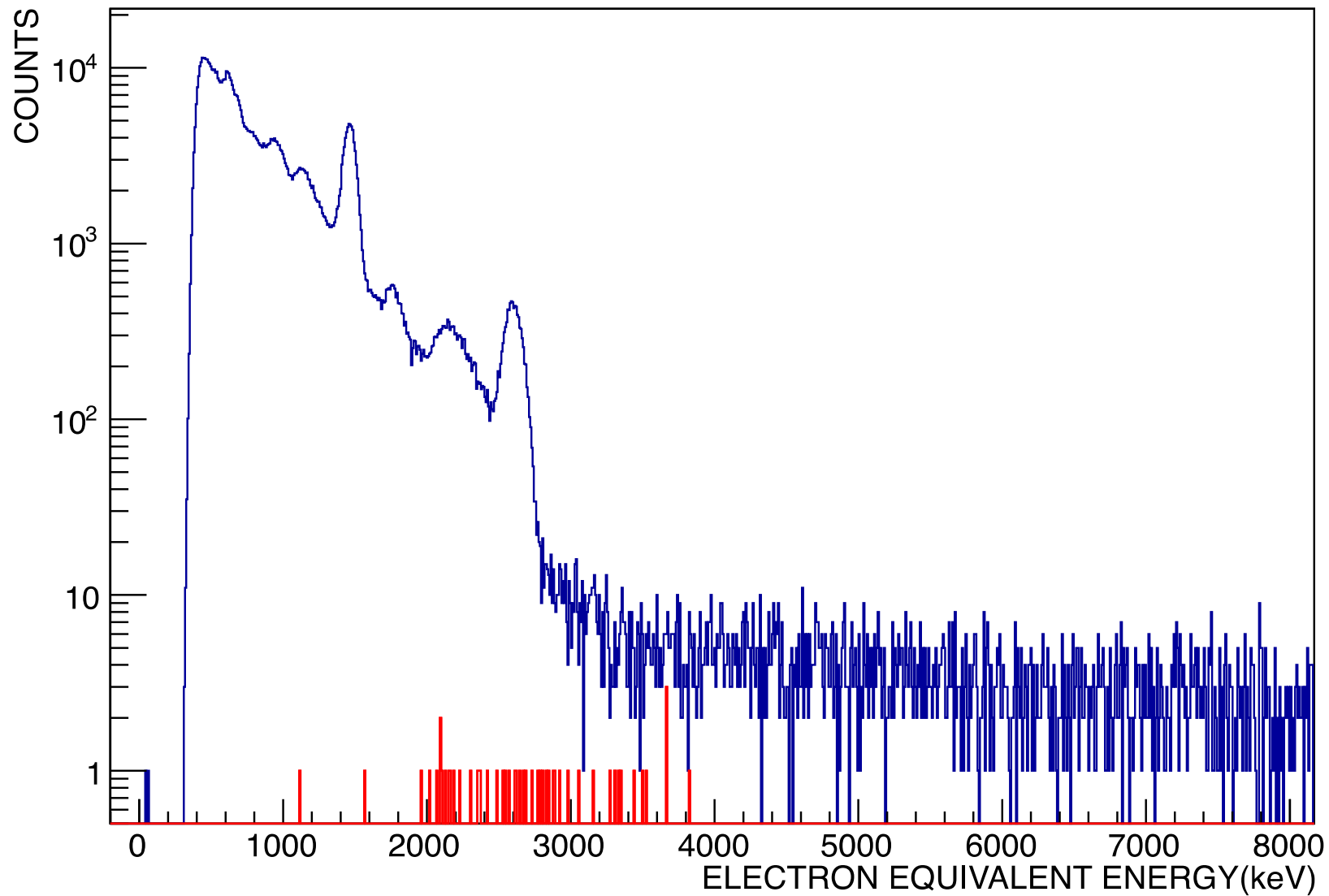
# Pulse shape discrimination for alpha/beta selection

Small difference of pulse shape



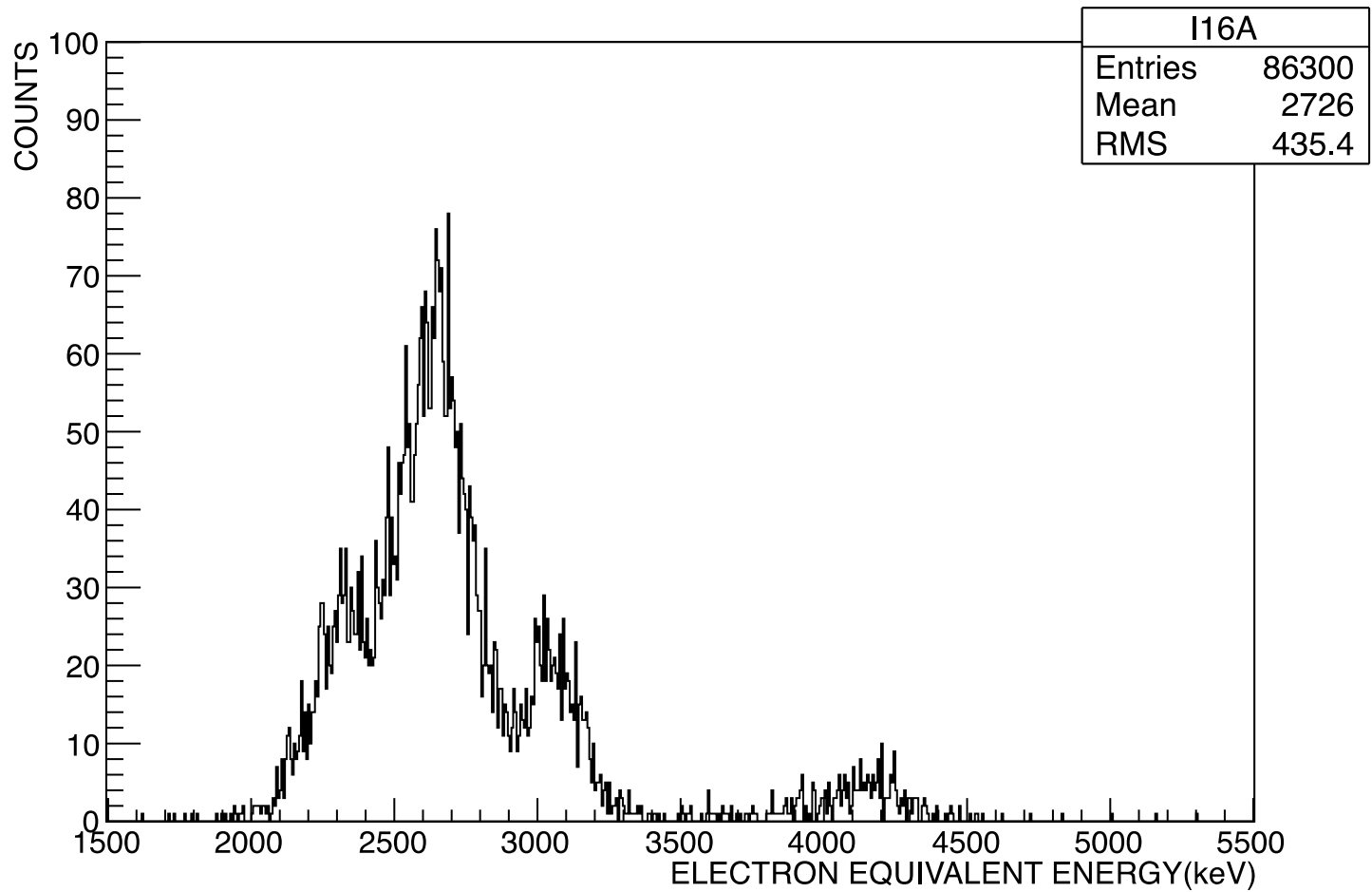
	Decay time	
$\alpha$	190ns	—
$\beta/\gamma$	230ns	—





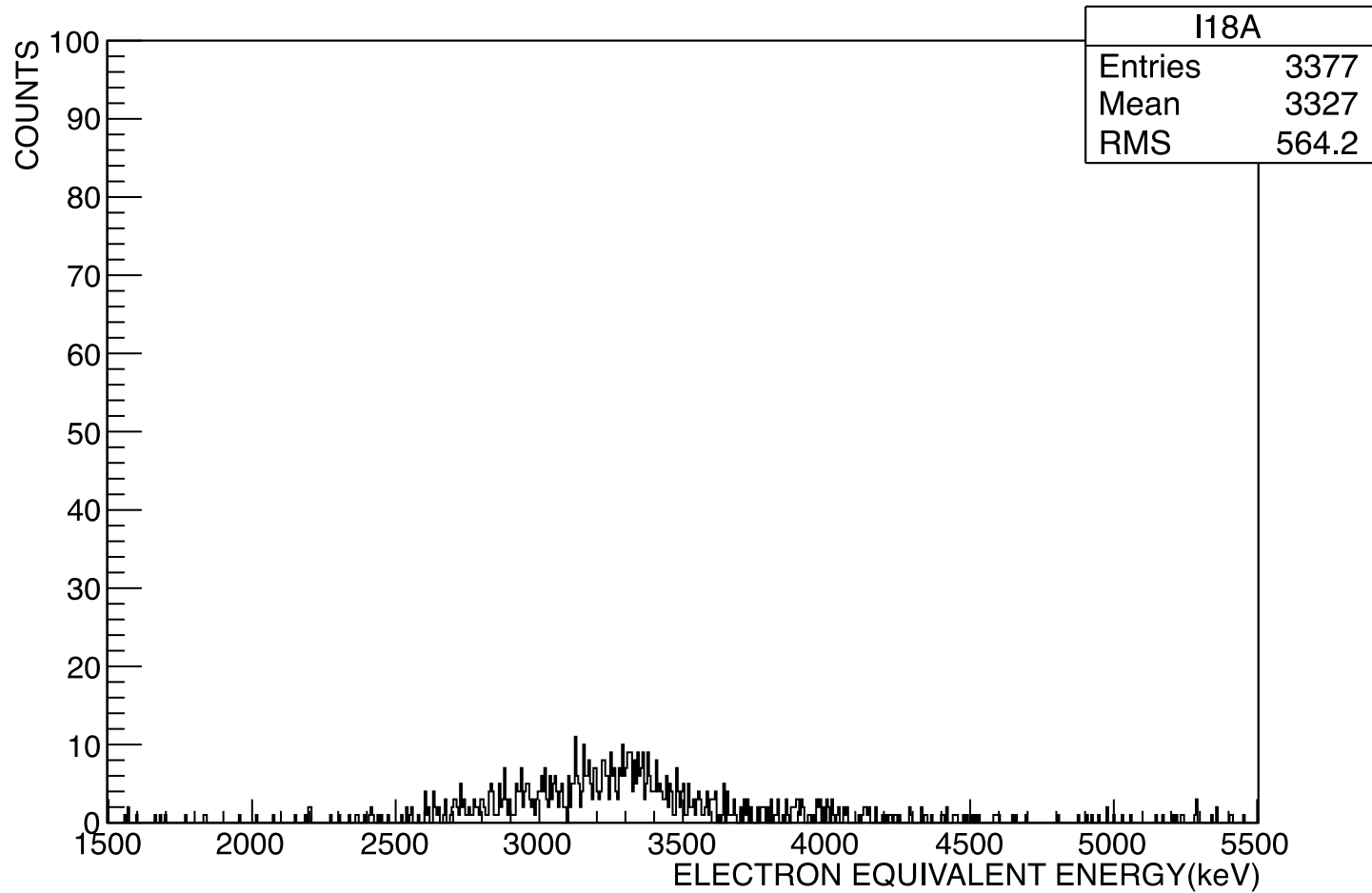
# Normal NaI(Tl)

I16 Alpha



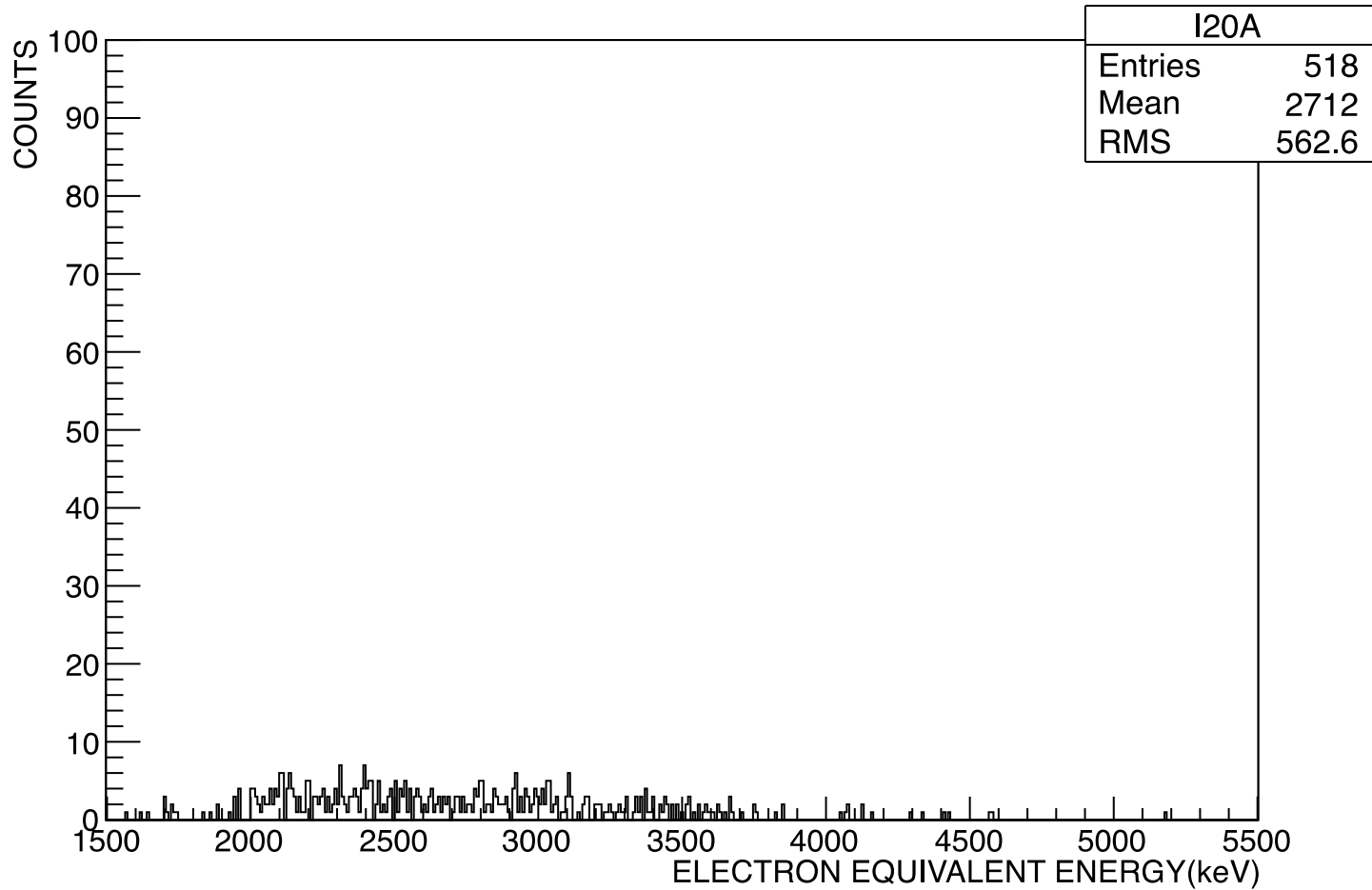
# High purity crucible

I18 Alpha



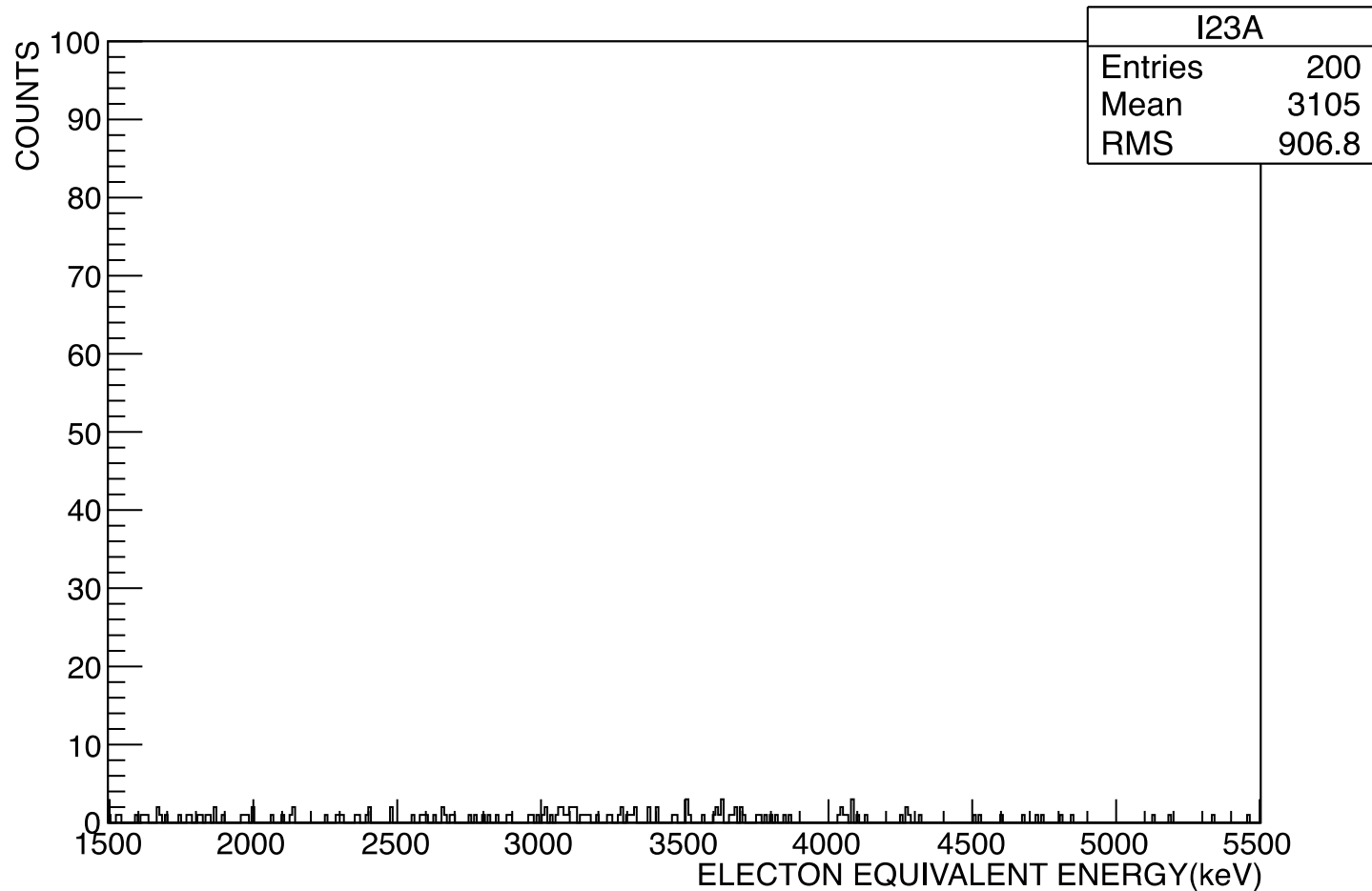
# More highly pure crucible

I20 Alpha

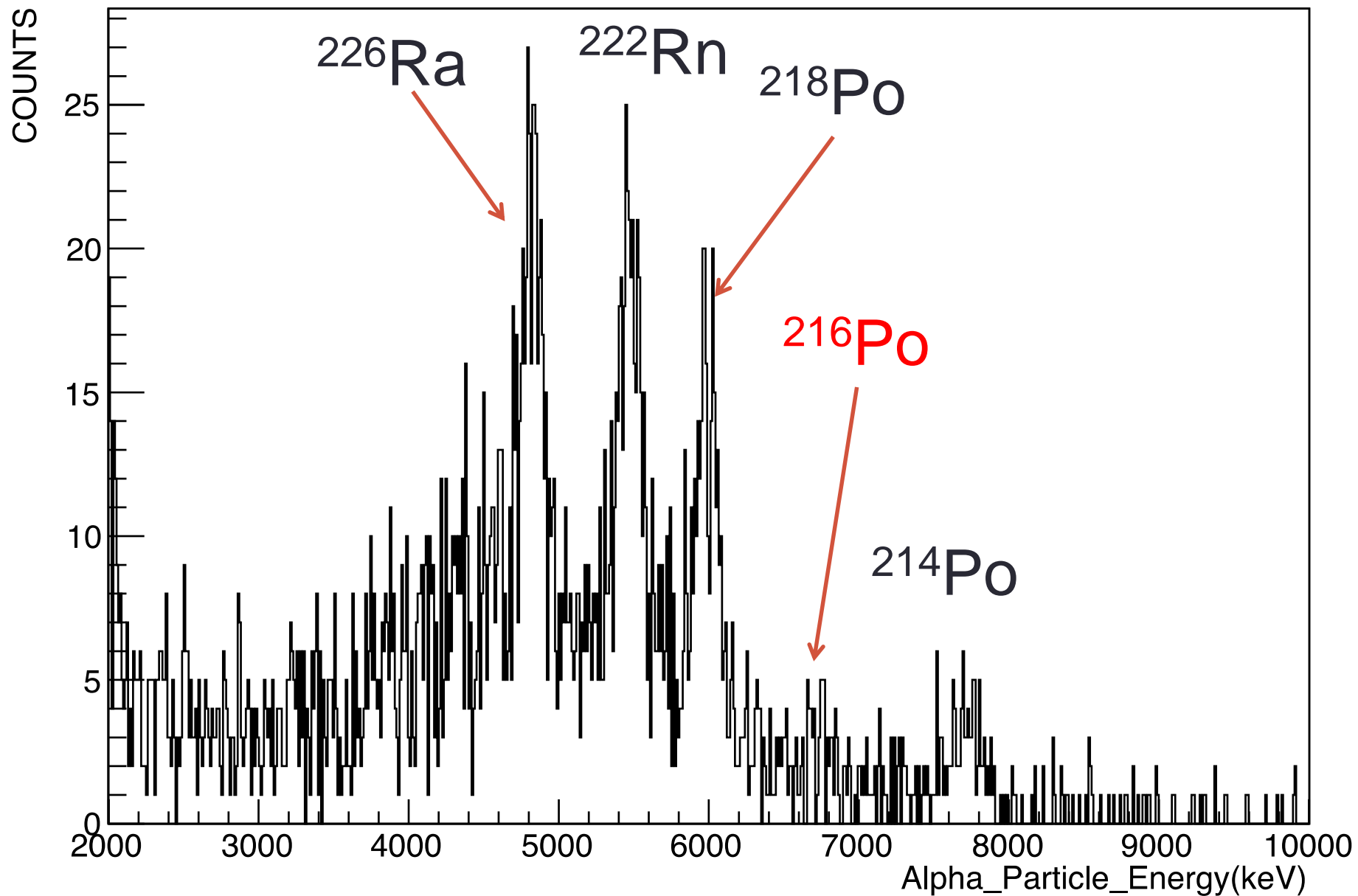


# Chemical process

I23 Alpha



# Ingots 23 results (26 days live time)





# Improvement of U, Th concentration ( $\mu\text{Bq/kg}$ )

$\alpha$ source		Ingot 16	Ingot 18	Ingot 20	Ingot 23
U chain	$^{210}\text{Po}$	$9600 \pm 100$	$1825 \pm 45$	$440 \pm 22$	60
	$^{226}\text{Ra}$	$4510 \pm 60$	$308 \pm 26$	$81 \pm 11$	66
	$^{234}\text{U} + ^{230}\text{Th}$	$520 \pm 73$	$1161 \pm 38$	$372 \pm 23$	<100
Th chain	$^{228}\text{Th}$	$243 \pm 11$	$255 \pm 12$	$60 \pm 14$	13

# Present result

	DAMA	DM-Ice	<b>Ingot 23</b>	Goal of PICO-LON
$^{nat}\text{K}$ (ppb)	<20	660	Not yet (<100)	<20
$^{232}\text{Th}$ (ppt)	0.5-0.7	2.5	<b><math>3.3 \pm 2.0</math></b>	<4
$^{238}\text{U}$ (ppt)	0.7-10	1.4	<b><math>5.4 \pm 0.9</math></b>	<10
$^{210}\text{Pb}$ ( $\mu\text{Bq/kg}$ )	5-30	1470	<b><math>58 \pm 26</math></b>	< 5

- U-chain: 1ppt= 12.3 $\mu\text{Bq/kg}$
- Th-chain: 1ppt= 4.0 $\mu\text{Bq/kg}$
- $^{210}\text{Pb}$ : 1ppt=2.5kBq/kg

# Summary

- Low energy threshold
  - 1 keV electron equivalent
- Purification of NaI(Tl) crystal
  - R&D undergoing
  - $^{210}\text{Pb}$  → The same level DAMA/LIBRA
  - $^{40}\text{K}$  → To be measured

We are now ready to check DAMA/LIBRA!