Crystal R&D(IHEP) for direct DM Search

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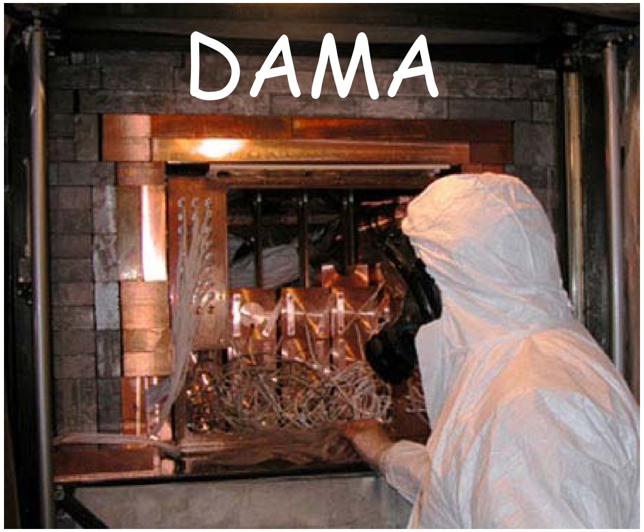
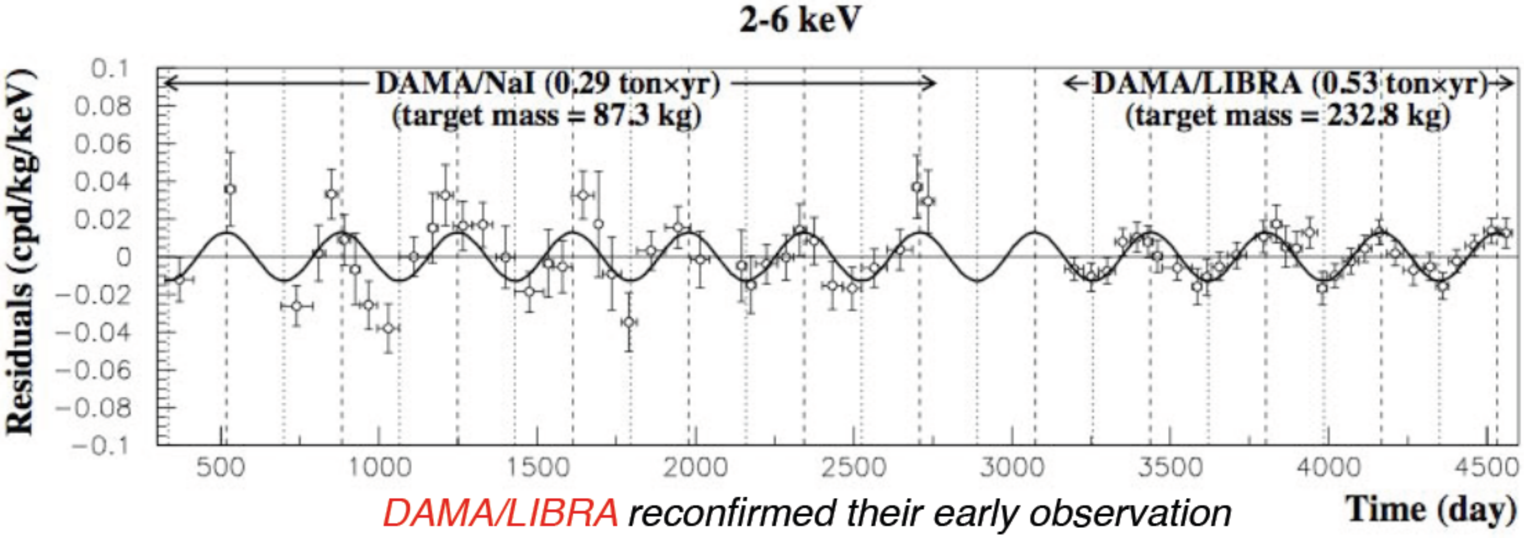
2011/3/24

The First Darkmatter Direct Search Detector (Crystal)



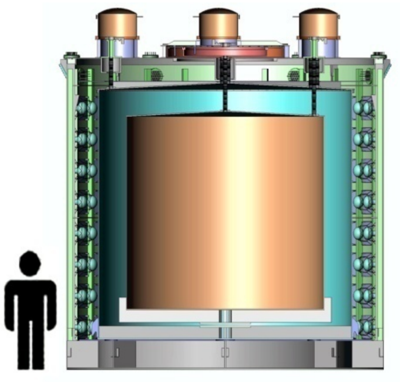


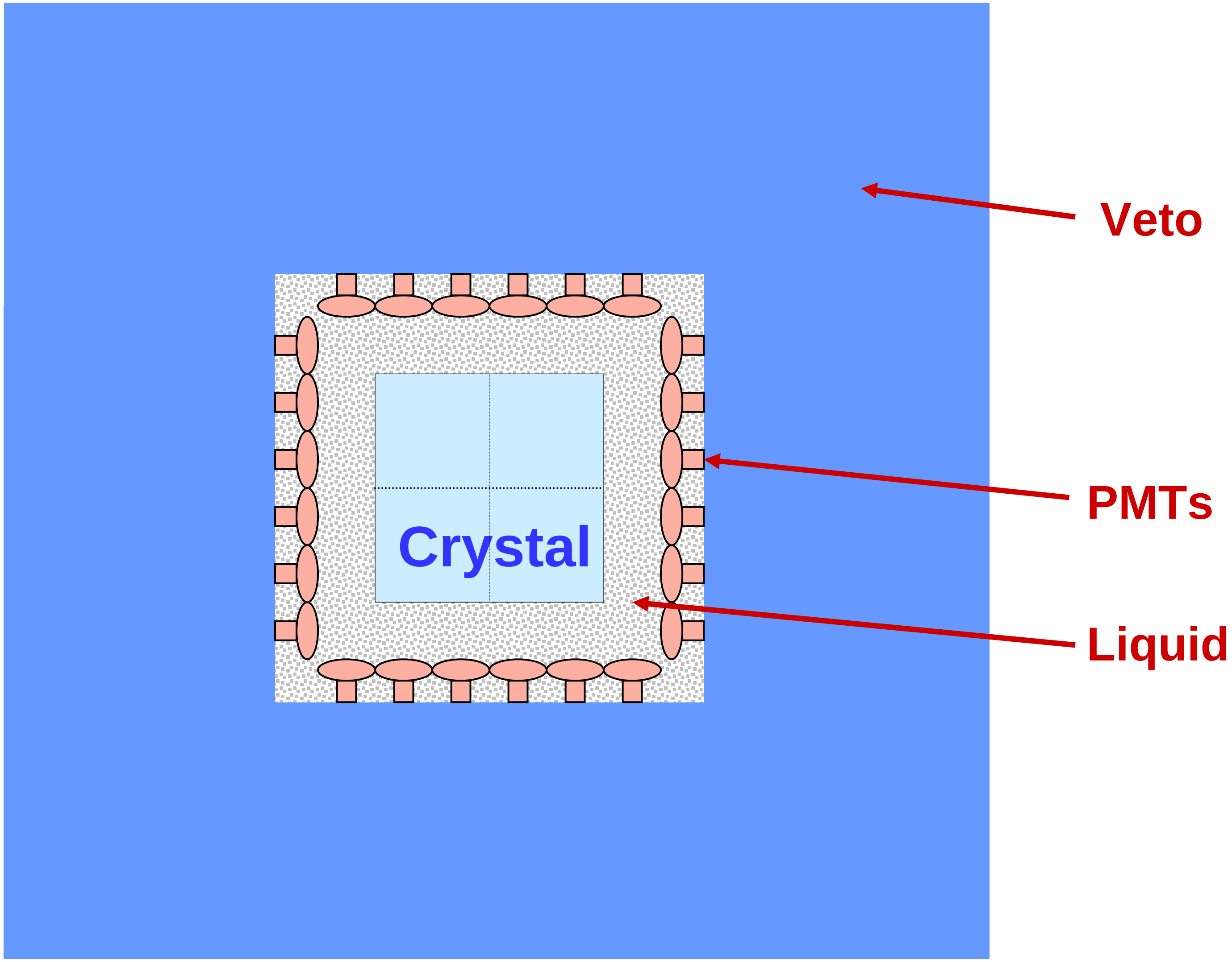
*DAMA/LIBRA reconfirmed their early observation of annual modulation signal [*arXiv:0804.2741*]*

Under Ground Dark Matter Search Experiment

Experiment	Target	Type	Status	Site	Nation
ANAIS	NaI	annual modulation	construction	Canfranc	Spain
DAMA/NaI	NaI	annual modulation	concluded	LNGS	INFN-ITALY
DAMA/LIBRA	NaI	annual modulation	running	LNGS	INFN-ITALY
DAMA/1 ton	NaI	annual modulation	R&D	LNGS	INFN-ITALY
NAIAD	NaI	PSD	concluded	Boulby	UK
HDMS	Ge	ionization	concluded	LNGS	INFN-ITALY
KIMS	CsI	PSD	R&D	Y2L	Korea
Caf_2-Kamioka	CaF_2	PSD	running	Kamioka	Japan
DAMA/Lxe	**LXe**	**PSD**	**running**	**LNGS**	**INFN-ITALY**
WARP	**LAr**	**2 phase**	**running**	**LNGS**	**INFN-ITALY**
XENON 10	**LXe**	**2 phase**	**running**	**LNGS**	**INFN-ITALY**
Zeplin II	**LXe**	**2 phase**	**running**	**Boulby**	**UK**
Zeplin III	**LXe**	**2 phase**	**installation**	**Boulby**	**UK**
ArDM	**LAr**	**2 phase**	**R&D**	**Canfranc**	**Spain**
LUX	**LXe**	**2 phase**	**R&D**	**Dusel**	**USA**
CLEAN	**LNe**	**PSD**	**R&D**		**USA**
DEAP	**LAr**	**PSD**	**R&D**	**SNOLAB(CANADA)**	**USA**
XMASS	**LXe**	**PSD**	**construction**	**Kamioka**	**Japan**
CDMS	Ge	bolometer	running	Soudan	USA
CRESST	$CaWO_4$	bolometer	running	LNGS	INFN-ITALY-Italy
EDELWEISS	Ge	bolometer	running	Frejus	France
ROSEBUD	Ge, sap,tung	bolometer	R&D	Canfranc	Spain
COUPP	F	SH droplet	R&D	Fermilab	USA
PICASSO	F	SH droplet	running+R&D	SNOLAB	CANADA
SIMPLE	F	SH droplet	running+R&D	Bas Bruit	France
Drift	CS_2 gas	TPC	R&D	Boulby	UK
MIMAC	^{3}He gas	TPC	R&D		

A Sketch of design





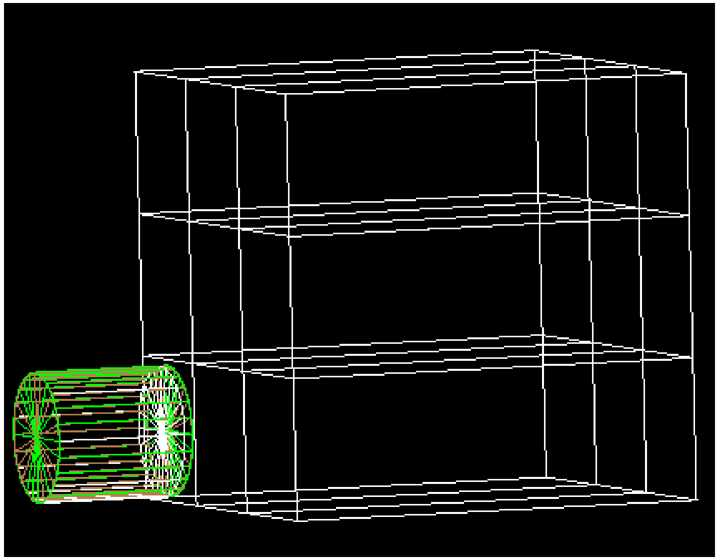
Proper Optical Coupling

CsI(Na)
- Desity 4.51 g/cm^3
- Radiation length 1.85cm
- Peak wave length 420 nm
- decay time 630 ns
- **Refractive index 1.7876**
- Photon 39000 /MeV

Methylene iodide 分子量 267.87，
density：**3.3254g/m^3，**
Refractive index：1.7425，
Boiling point：180 ℃，
Melting point： 5～6℃，
Stability：steady
MYCRO LTD.

Properties	LAr	LXe	NaI(Tl)	CsI(Tl)	BGO
Density	1.4	3.1	3.67	4.51	7.1
Z(effective)	18	54	51	58	74
τ (ns)	10/1500	3/27	230	1000	300
Photo/MeV	4×10^4	$2.5\text{-}7.8\times10^4$	4.3×10^4	6.5×10^4	2.8×10^4
R index (5893Å)			1.85	1.78	2.15
λ (nm)	125	178	415	565	480

Simulation



Single Scintillator (CsI (Na)) :
30cm*10cm*10cm

Total: 9

Gap:0.2mm

PMT: cylinder

Sensitivity radius: 4.5cm

Total : 9*6=54

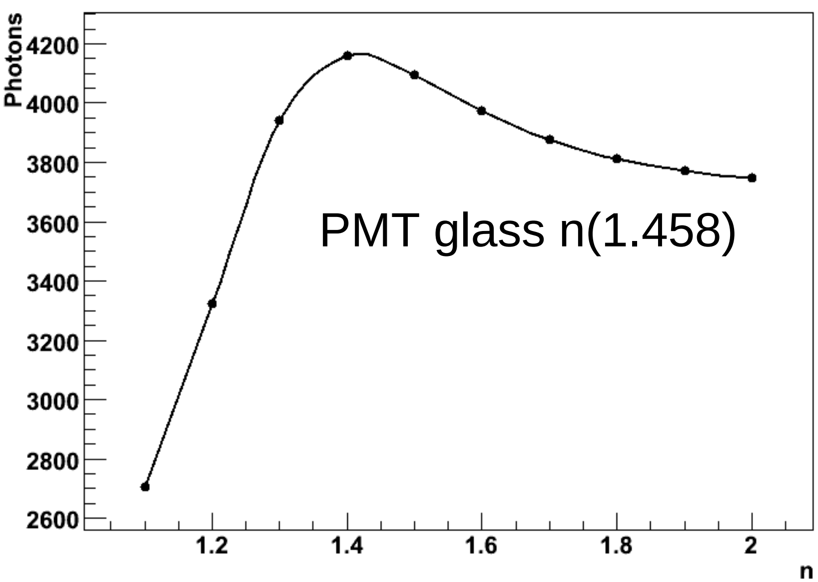
PMT Coverage: 63.4%

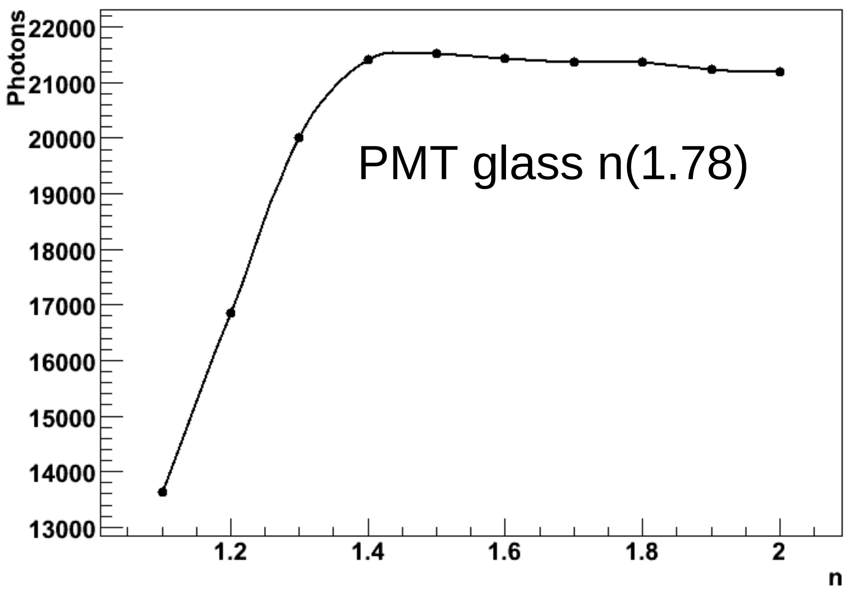
Gap: 0.1mm

Fill all of the gaps with the CH2I2 .

- ✓ **CH2I2 index: 1.74; attenuation length:1m;**
- ✓ **Wavelength range :200nm ~ 800nm.**

Refractive Index





photons V.S n_{liquid}

Maximum light output at n=1.4

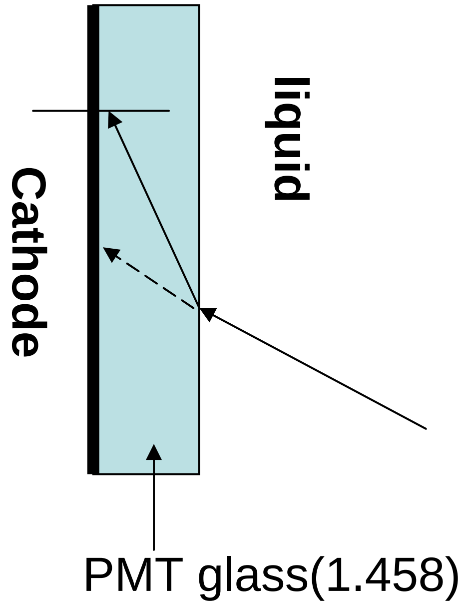
Refractive Index n_{glass}=1.458

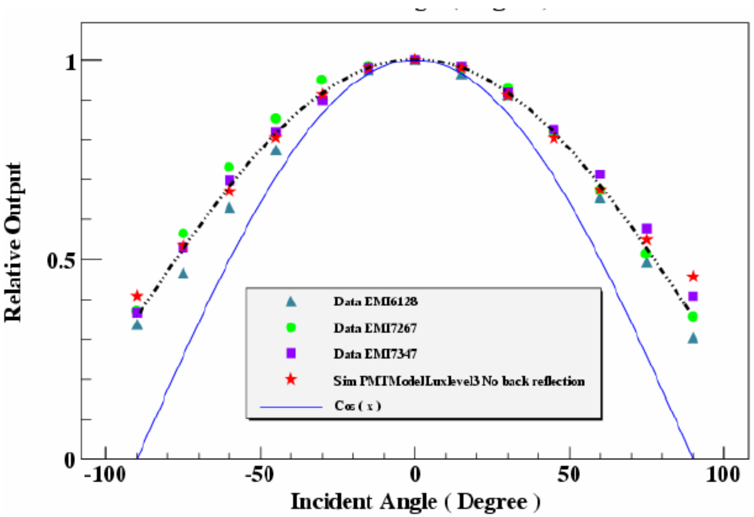
Change refractive index of PMT glass to 1.78，

Maximum value also at n=1.4, but keep flat with increasing n_{liquid}

Will $n_{liquid} > n_{glass}$ efficiency of photon collection decrease。

PMT refraction

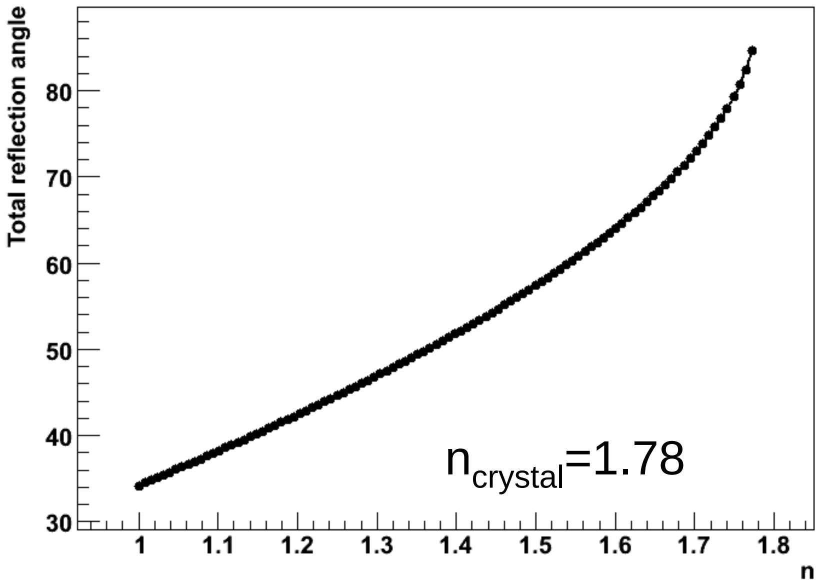




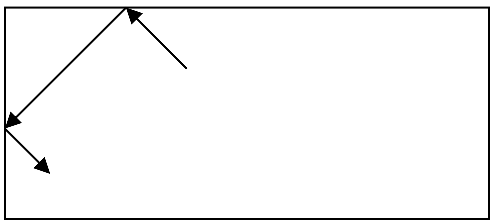
PMT response decrease while incident angle increase, While $n_{liquid} > n_{glass}$, incident angle will increase after refraction, this effect become more important while difference of n increase.

If the n of PMT glass is at it is, light collection efficiency is fine as long as liquid refractive index nliquid> 1.4

(Refractive Index<1.4)



Total reflection Critical angle n_c



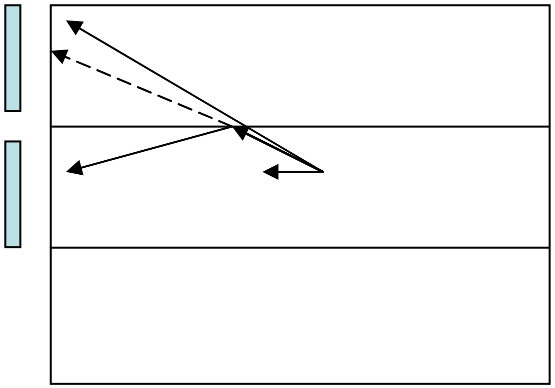
Optical propagation in crystal

- **While n_{liquid} < 1.3, Critical angle less than 45 degree, light between n_c~90-n_c will always propagate inside square crystal.**
- **While n_{liquid} > 1.5, n_c> 55degree, all light could propagate out crystal.**

Other non-uniformity

- Crystal geometry +PMT incident angle effect；

While n_{liquid} is far less than $n_{crystal}$： for some particular angle,photon will likely reflect on the top and bottom surface of crystal， photon will centralize toward center of crystal，photon distribution will be non-uniform 。



While n_{liquid} near $n_{crystal}$, photon distribution will be much more uniform。

Globular will be the best shape

Non-uniformity for event at different position

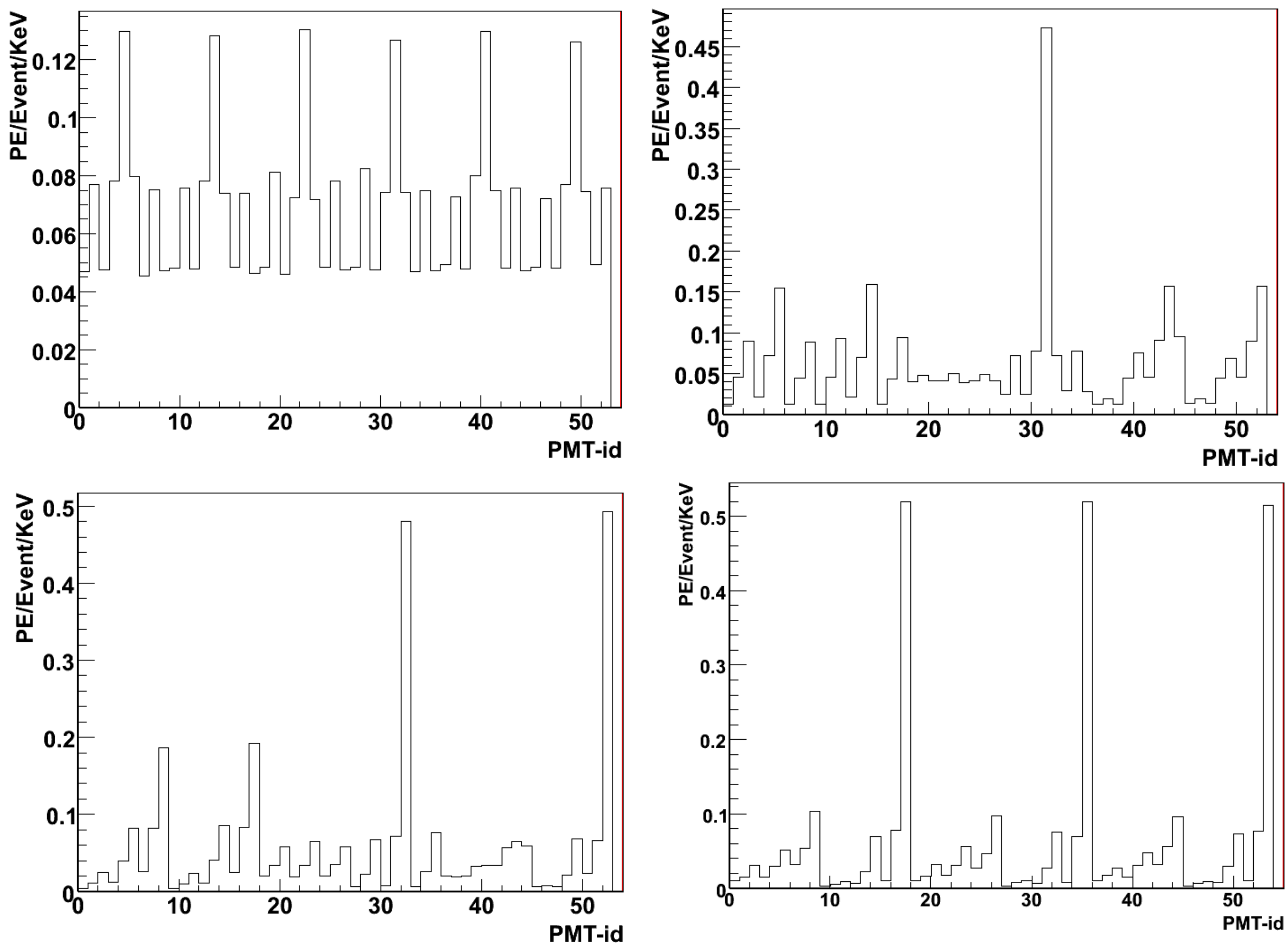
- We choose several positions to check response of the detector。
- position（0,0,0）Center of detector；

  （0,10,0）Center of one side，

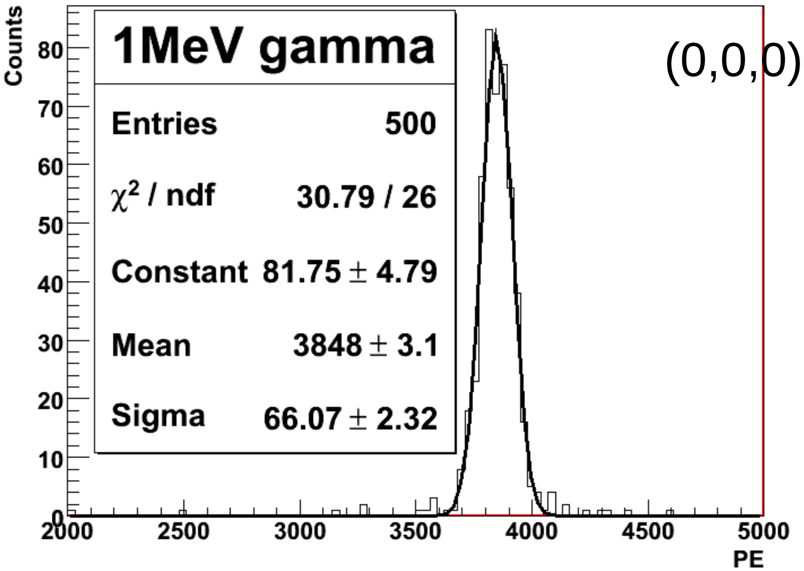
  （0,10,10）,

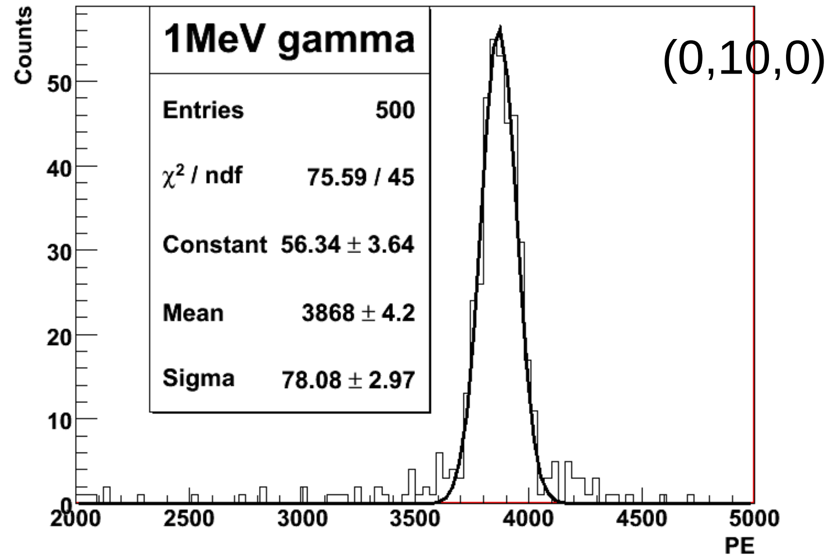
  （10,10,10）。

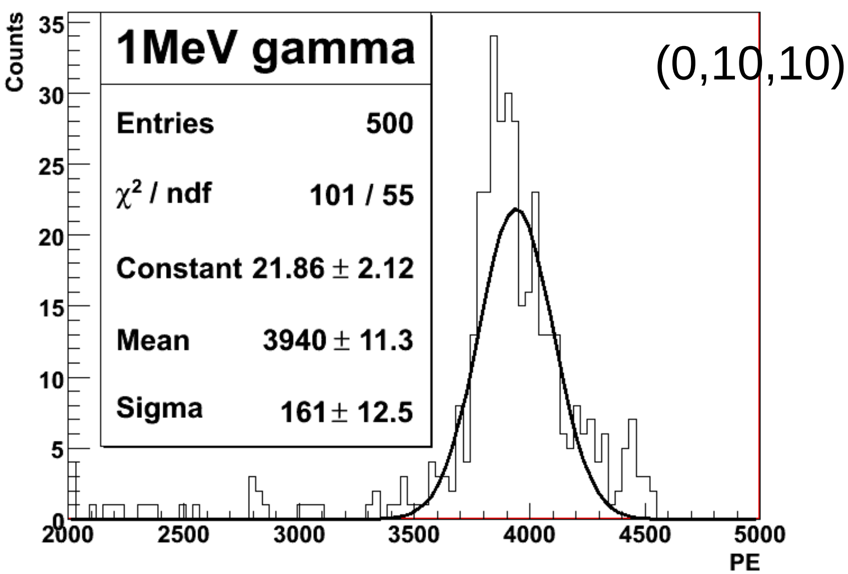
Single PMT response is quite non-uniform

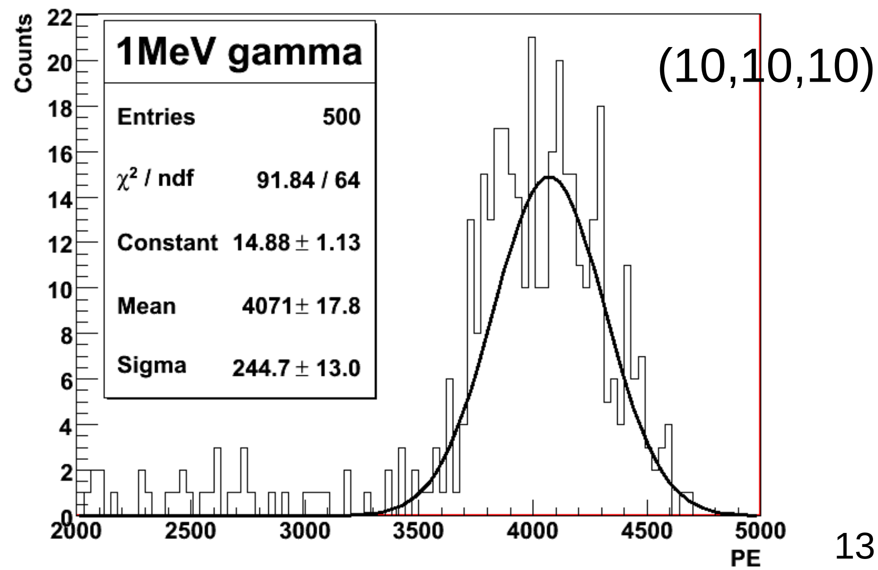


Total response is uniform (~6%)









Couple high reflective material (tyvek) for PMT uncovered area

- Geometry：3 X 3 crystals = (10 x 10 x 30 cm)
- No tyvek V.S 98% reflectance
- Event position: （0,0,0),(10,0,0),(10,10,0),(10,10,10)

- **Monte Carlo: 20% more photon could be collected with tyvek；better uniformity could be get with high reflective material**

Backgroud Shielding V.S thickness of liquid

KE=all

cm	0	10	20
Oil	14970	1452	442
CH2I2	14320	325	29

1KeV<KE<100KeV

cm	0	10	20
Oil	6385	24	10
CH2I2	4910	4	0

- **Simulation events:100000**
- **Oil density: 0.86g/cm^3;   CH2I2 density:3.325g/cm^3;**
- **For shielding，CH2I2 is clearly better than Oil。**

Design Advantage

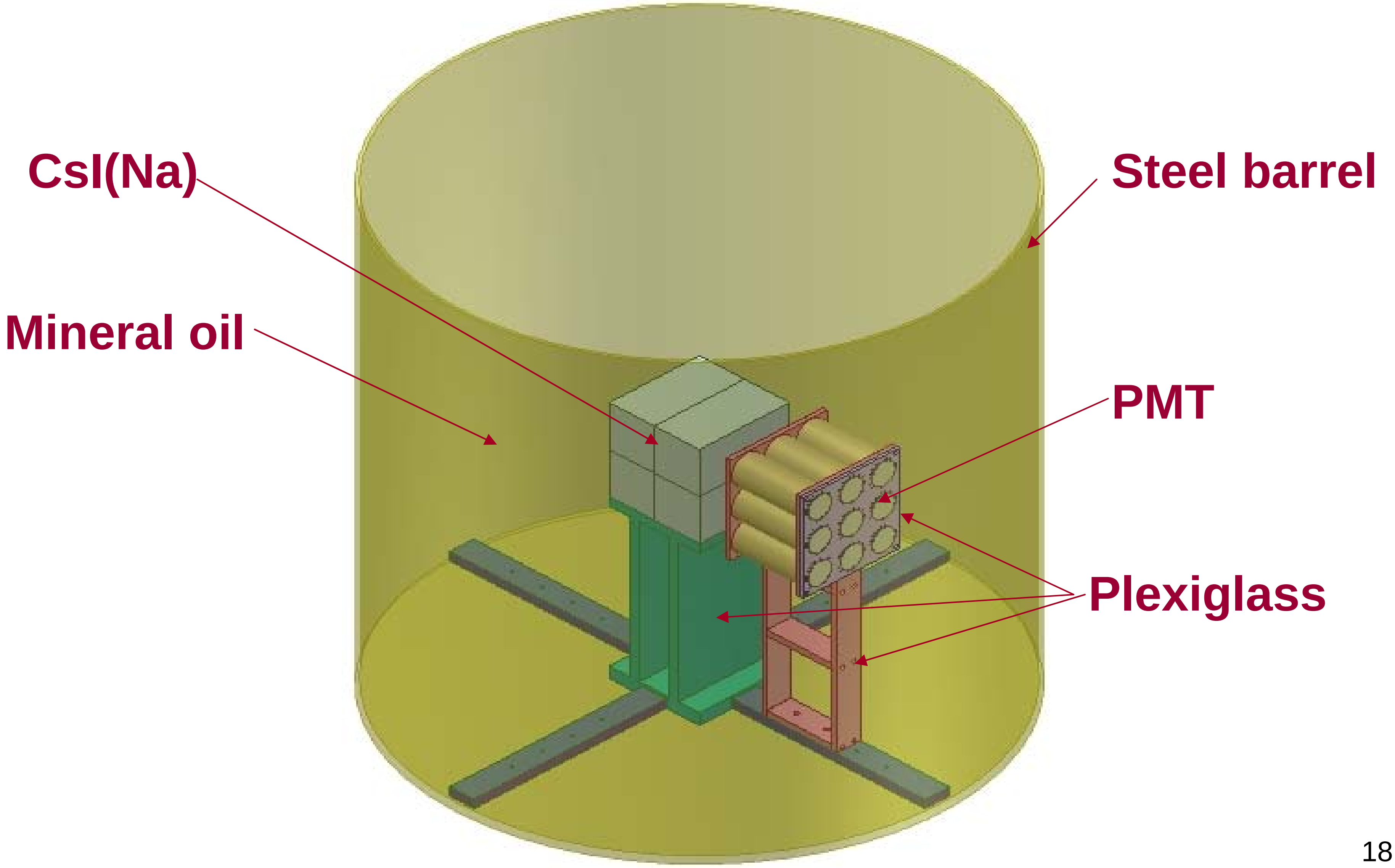
1. The mass of detector could be large by piling up several crystals （~ton 60x60x60cm^3）；
2. Thick enough liquid shielding can reduce outside background including PMT background;
3. Trigger by coincident of several PMTs could reduce PMT noise；
4. Main background will be radioactivity of crystal itself；
5. Higher reflector for PMT uncovered area;
6. More photon could be possible collected by 4π PMT coverage (compared with DAMA），lower threshold and better energy resolution would expected ；
7. Possible replace different crystal。

Exp. with different crystal

CsI(Na)/CsI(Tl)/CaF_2

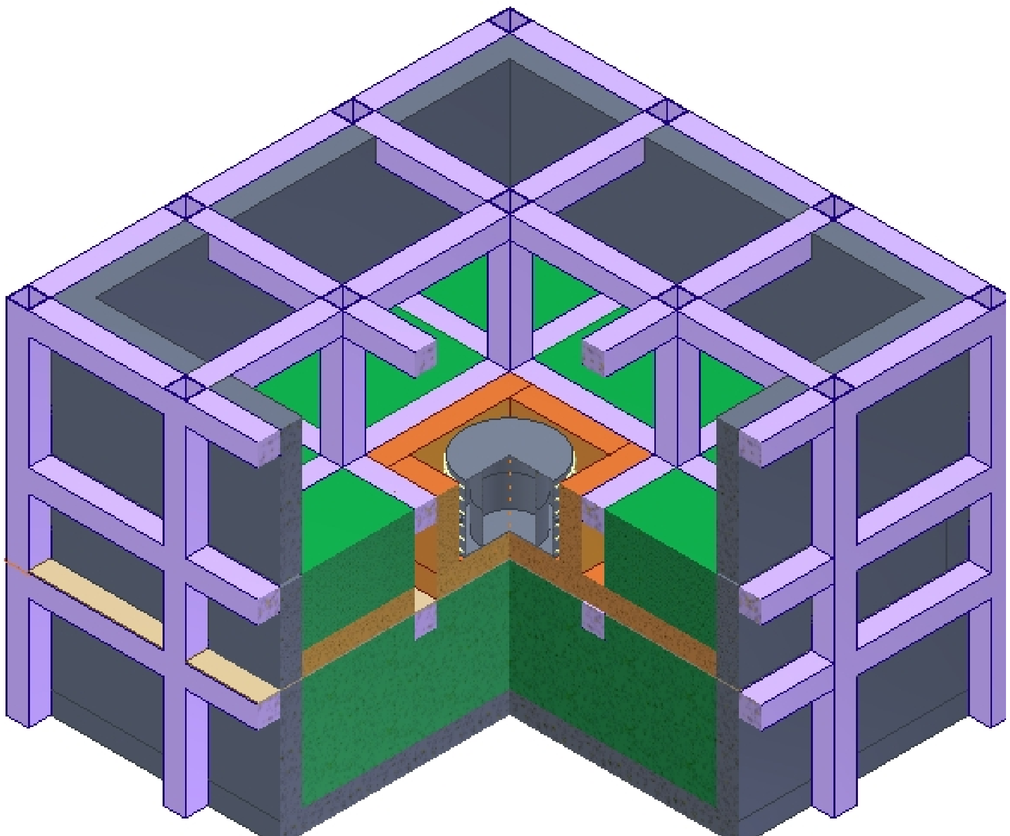
- **Using different crystal to measure spin dependent or spin independent property of dark matter**
- **Once dark matter is found, could be possible to measure the mass of dark matter by using different crystals for detection.**

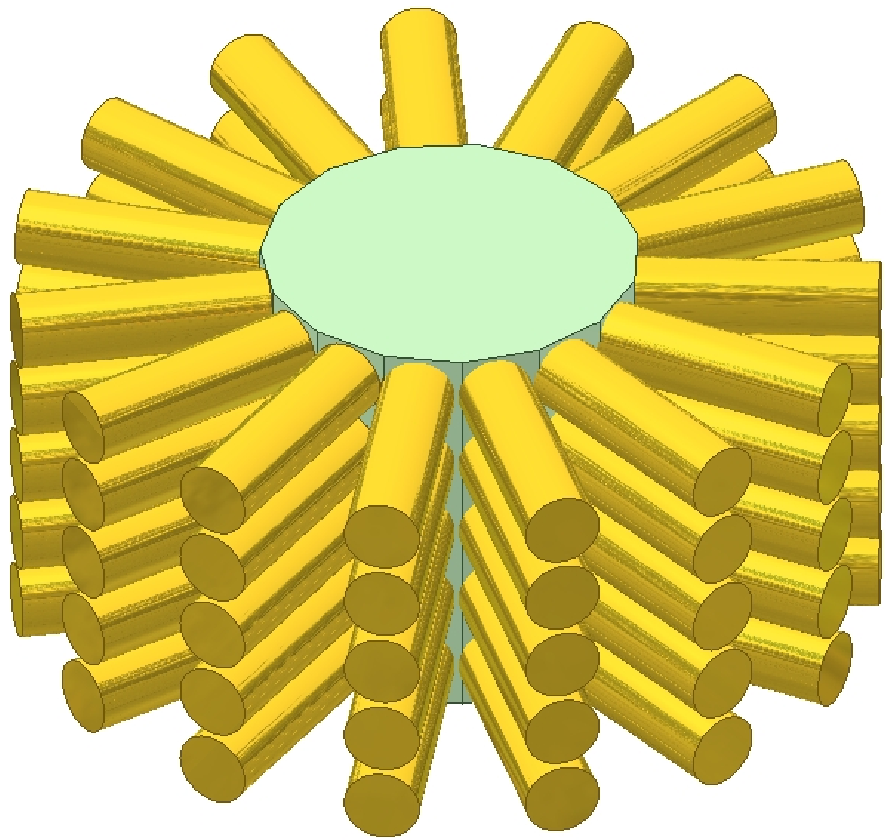
A Prototype in IHEP



整体装置和晶体探测单元

从外到内:
机械架,铅墙(20cm),含硼石蜡(50cm),无氧铜(10cm),
低温箱,晶体探测器.





CsI(Na)/CsI(Tl) internal background ?

n/gamma separation

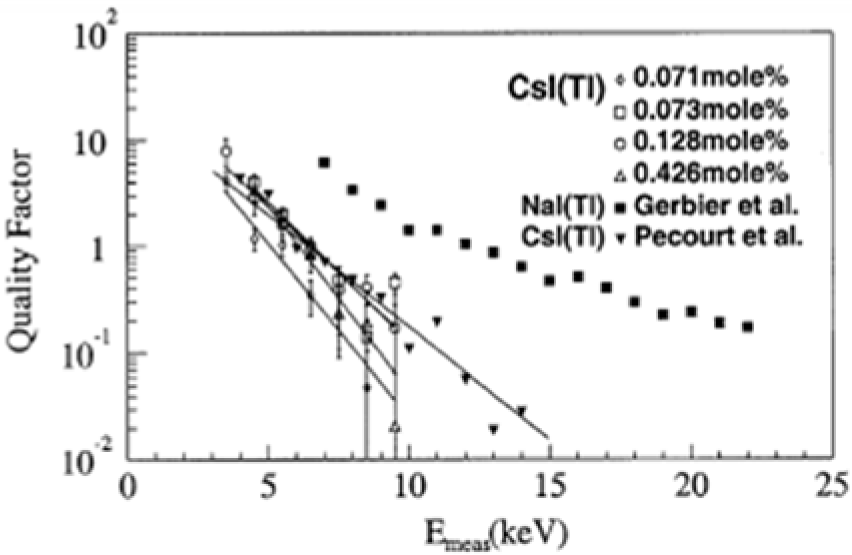


Fig. 10. Quality factors for various CsI(Tl). The errors are only statistical. The present results (open markers) are compared to the data of Pécourt et al. [10] and of Gerbier et al. [19].

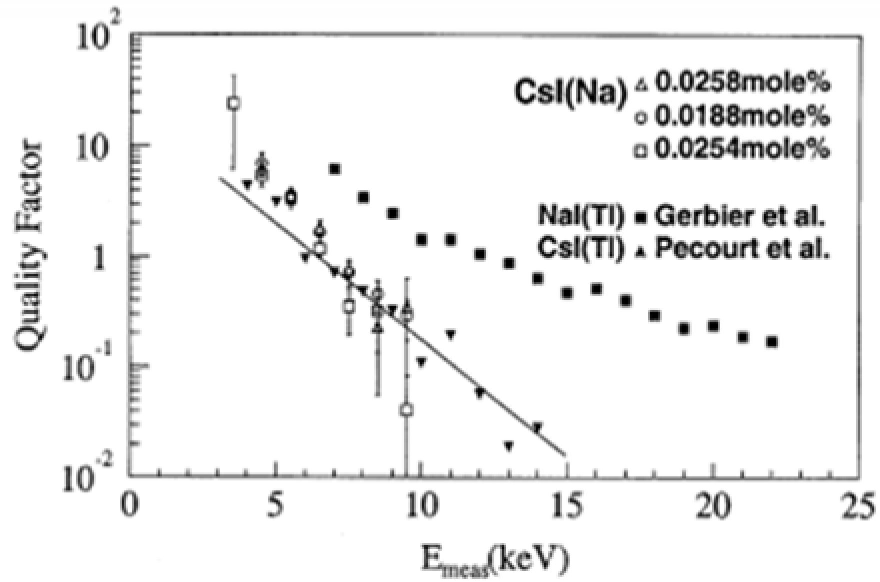


Fig. 11. Quality factors for various CsI(Na). The errors are only statistical.

Xilei Sun et al

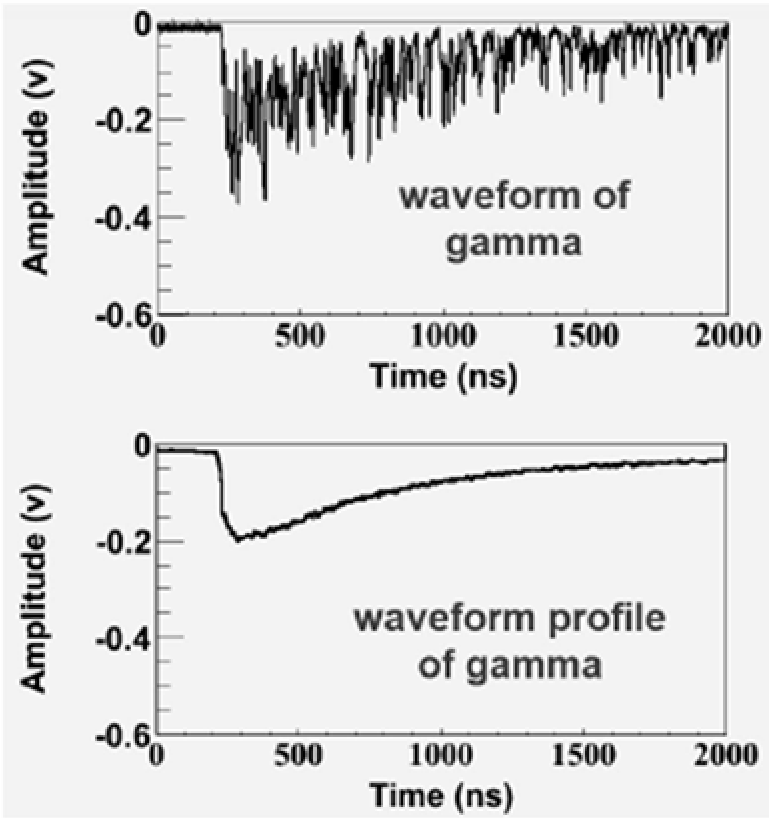


Fig. 7 A typical waveform of pure γ-ray (59.5 keVee) from (50-60 keVee).

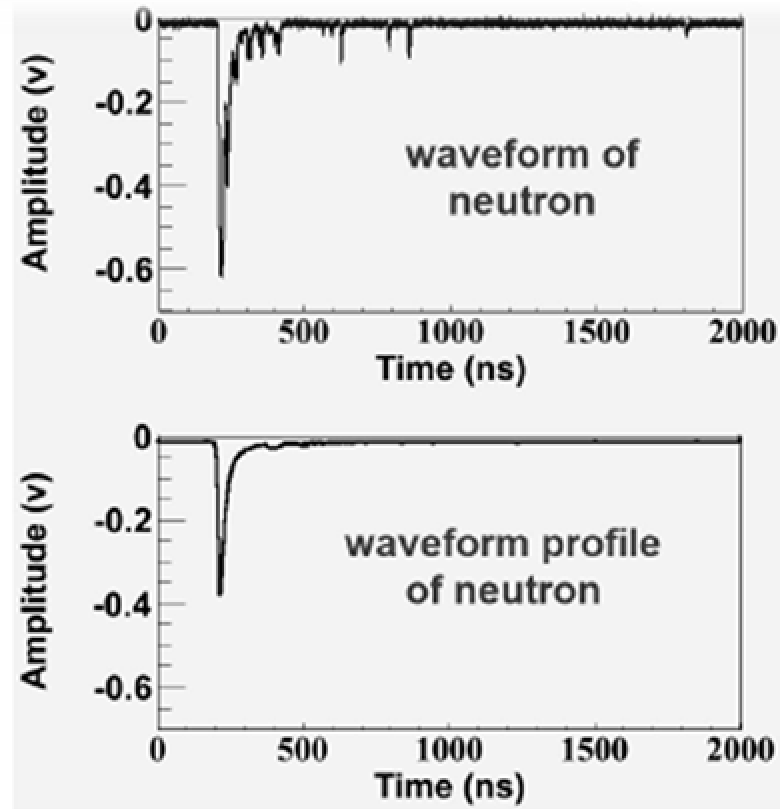


Fig. 8 A typical waveform of neutron (10 keVee) from (5-10 keVee).

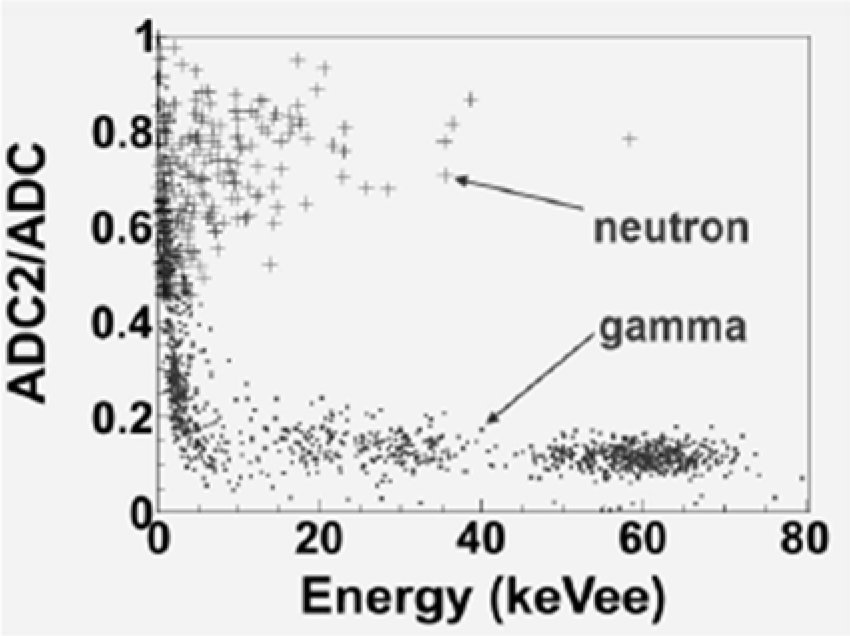


Fig. 9. Scatter plot of ADC2/ADC versus energy fo
neutron at a scattering angle of 50°.

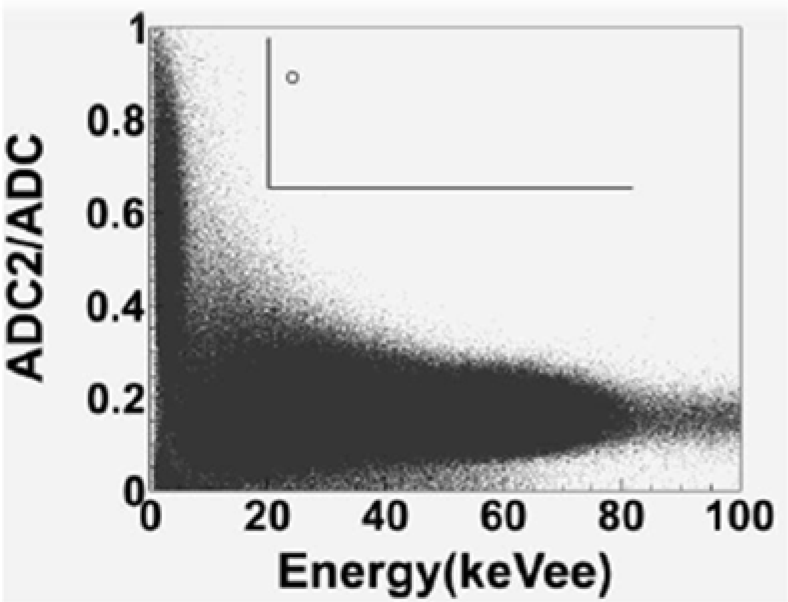
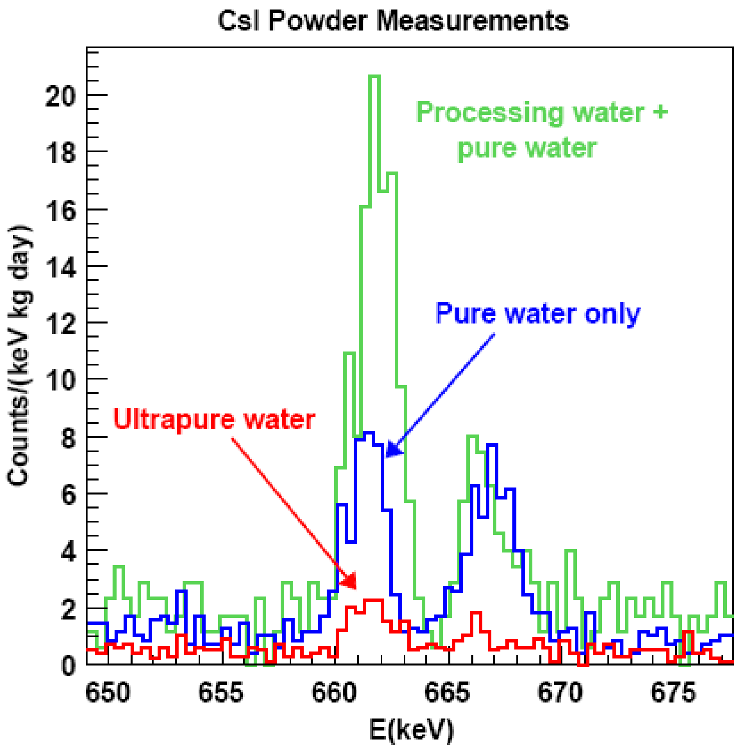
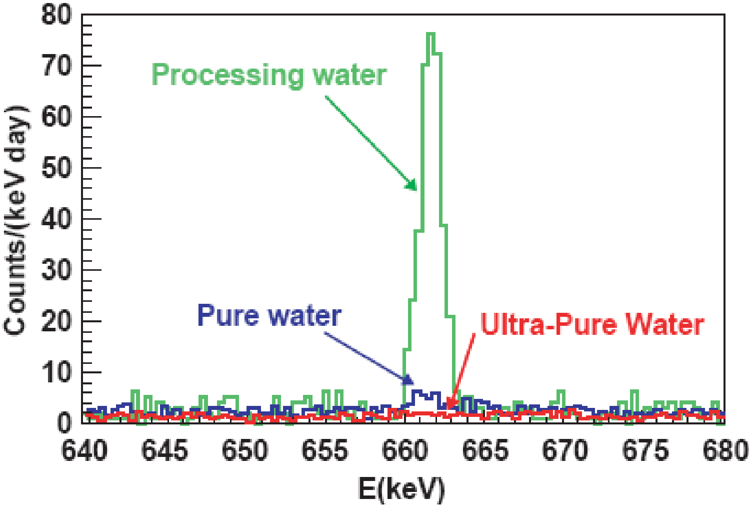


Fig. 10. Scatter plot of ADC2/ADC as a function of energy for γ-ray events. Only one event (in the small round circle) was seen in the region of ADC2/ADC > 0.65 and energy >20 keVee.

Radioactivity of CsI



CsI Powder



CsI crystal

- How much n radioactivity in CsI?
- The n/gamma separation technique can not distinguish the n background from inside of the crystal …
- Crystal to do modulation only (?) …

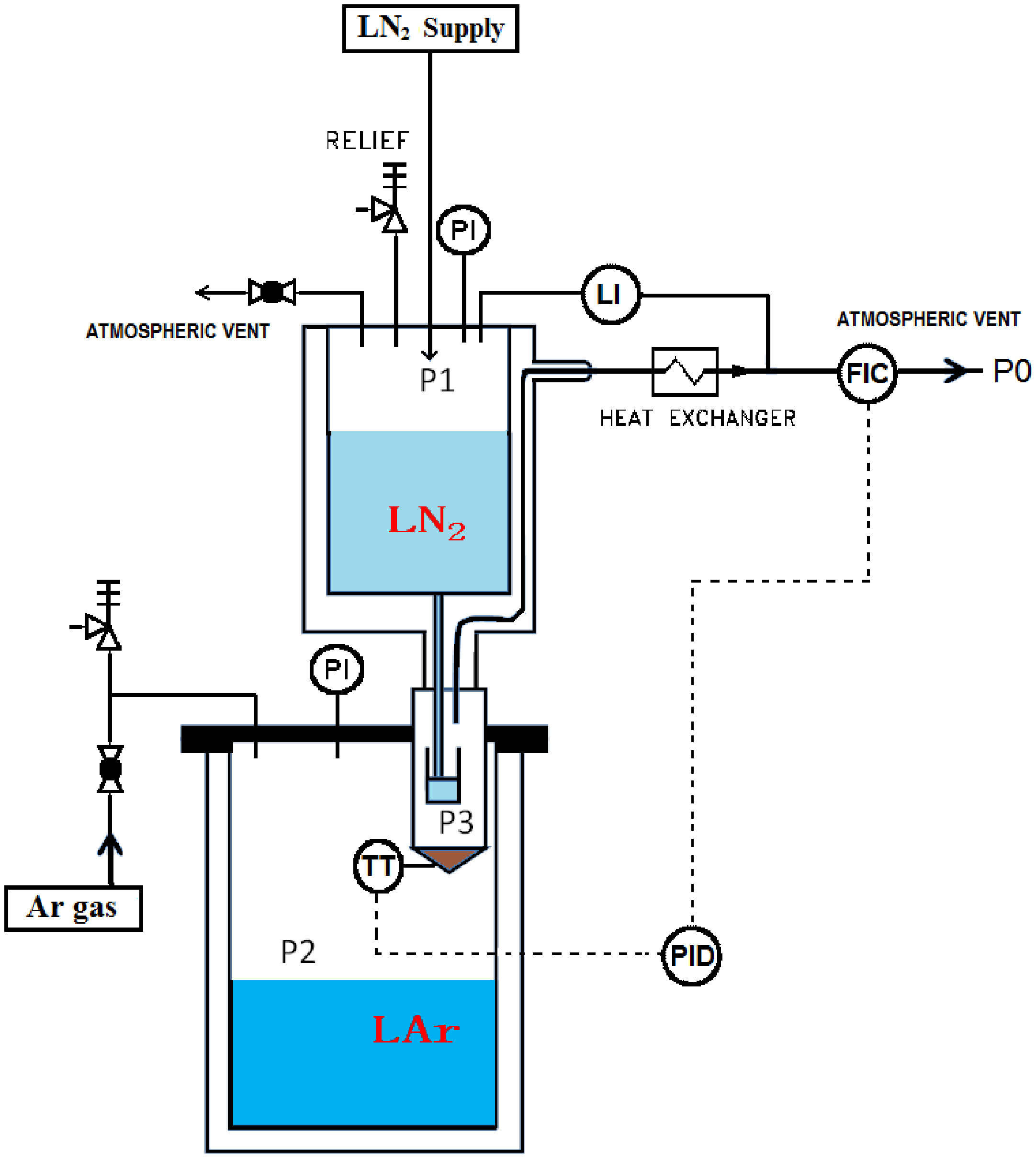
DarkSide

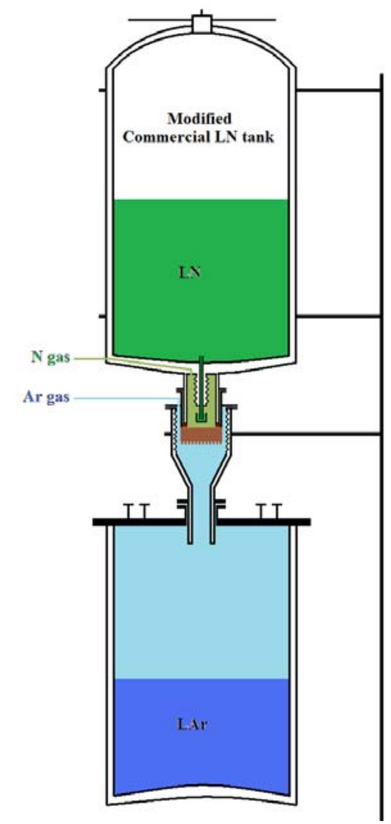
Augustana College – SD, USA
Black Hills State University – SD, USA
Fermilab – Il, USA
IHEP – Beijing, China
INFN Laboratori Nazionali del Gran Sasso – Assergi, Italy
INFN and Università degli Studi Genova, Italy
INFN and Università degli Studi Milano, Italy
INFN and Università degli Studi Napoli, Italy
INFN and Università degli Studi Perugia, Italy
Joint Institute for Nuclear Research – Dubna, Russia
Princeton University, USA
RRC Kurchatov Institute – Moscow, Russia
St. Petersburg Nuclear Physics Institute – Gatchina, Russia
Temple University – PA, USA
University of California, Los Angeles, USA
University of Houston, USA
University of Massachusetts at Amherst, USA

The DarkSide Program

- DS-10
  - 2011
- DS-50
  - 2012
- Ton-Scale Detector: DS-1k
  - 2014
- Ten-ton Scale Detector: DS-20k (DS-50k?)
  - 2017-9
  - Requires much deeper Lab. Jinping?

高能所：一个液氩探测小模型正在构建中





Thanks!

Internal background

Radioisotopes in the crystal

^{137}**Cs** : $\tau_{1/2}$= 30.07 year (**Artificial**) **0.35 cpd/mBq/kg @ 10 keV**

β decay to ^{137}Ba* (Q = 1175.6 keV)

→ 2 min life time, emitting 661.6 keV gamma

Hard to reject

^{137}Cs : 10 mBq/kg
^{134}Cs : 20 mBq/kg
^{87}Rb : 10 ppb

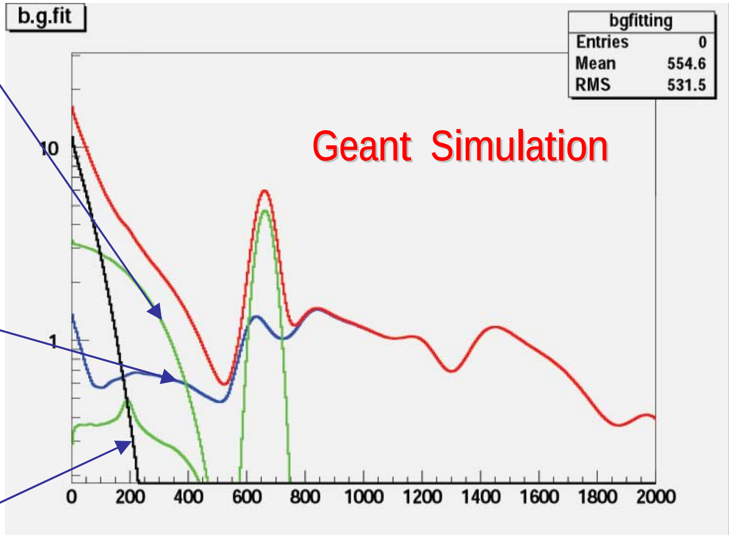
0.07 cpd/mBq
0.005 cpd/mBq

^{134}**Cs** : $\tau_{1/2}$ = 2.065 year : **Artificial+** ^{133}**Cs(n, γ)**

β to ^{134}Ba* (Q=2058.7 keV)

→ prompt γ emission

Can be rejected easily : not a problem



^{87}**Rb** : $\tau_{1/2}$ = 4.75 x 10^{10} year (**27.8% nat. abun.**)

β Beta deacy to ^{87}Sr (Q=282.3 keV)

→ no γ emission

Hard to reject

→ **reduction technique in material is known**

1.07 cpd/ppb

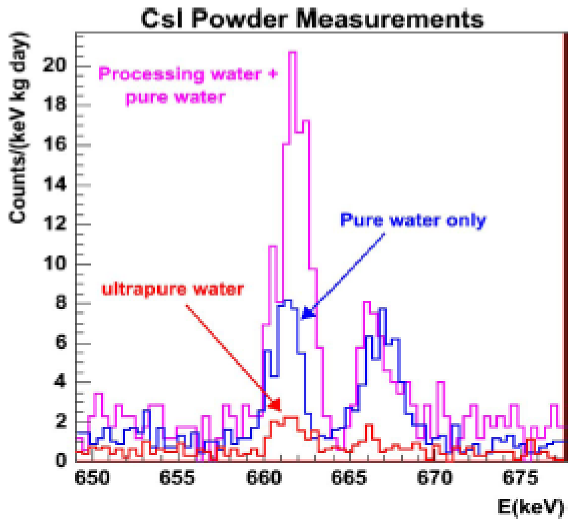


Fig. 5. The measured spectra of three different CsI powder samples with the HPGe detector. The peak near 665 keV is caused by gs from ^{132}Cs and ^{126}I.

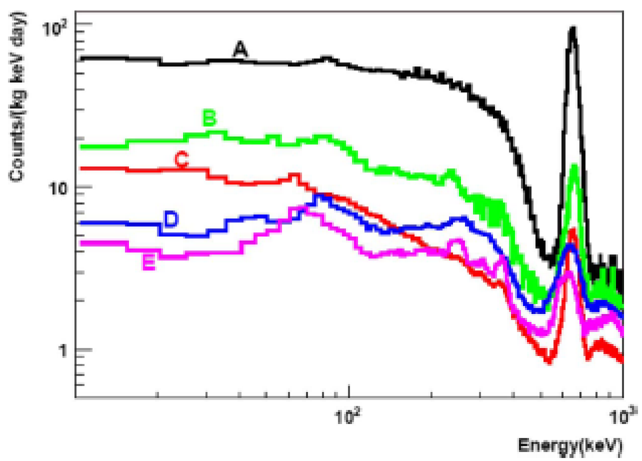


Fig. 6. Background spectra of various crystals; A: Best crystal in the market, B: Crystal was made by careful powder selection, C: Crystal was made by powder with "pure" water, D: Crystal was made by powder with recrystallization and "pure" water, E: Crystal was made by powder with recrystallization and "ultra-pure" water.

在IEEE2008年的文章中：

- 左图显示了在采用pure water、recrystallization等办法后137Cs、87Rb可减少，但仍存在很大影响，由图在10keV处为5counts/keV/day/kg，在<10keV处是多少？
  - 137Cs: 1.9mBq/kg
  - 87Rb: <1ppb

U,Th,K

Table 2
ICP-Mass analysis of CsI(Tℓ) crystals (in ppb)

Element	CsI crystal			
	A	B	C	D
Li	<1.7	<1.7	<1.7	10.6
Na	1646	<120	<120	21290
Mg	33.5	28.3	27.4	661.6
Al	50.5	78.6	139.8	503.5
K	<327	<327	<327	—
Cr	0.8	2.0	2.5	121.3
Fe	218.3	488.0	253.4	705.8
Rb	816.0	3.2	205.1	202.8
Sr	<0.08	<0.08	<0.08	298.9
Ba	1052.7	1062.4	1042.7	654.4
La	18.7	18.8	18.6	12.2
Sm	2.2	2.3	2.5	1.3
Lu	0.015	0.0097	0.0076	2.5
Tl	269500	554600	216400	265500
Th	<0.02	<0.02	<0.02	0.5
U	0.05	0.0086	0.0066	<0.002

NIM 2003

NIM 2007

Table 3
ICP-Mass analysis of CsI(Tℓ) crystals (ppb)

Element	Rb	Th	U	Tl	Li	Mg	Al	Fe	Ba
Crystal(A)	12.57	<0.02	0.038	255 600	154	379	284	84	846
Crystal(B)	2.77	<0.02	0.08	176 600	55	269	2898	234	949