暗物质实验研究进展

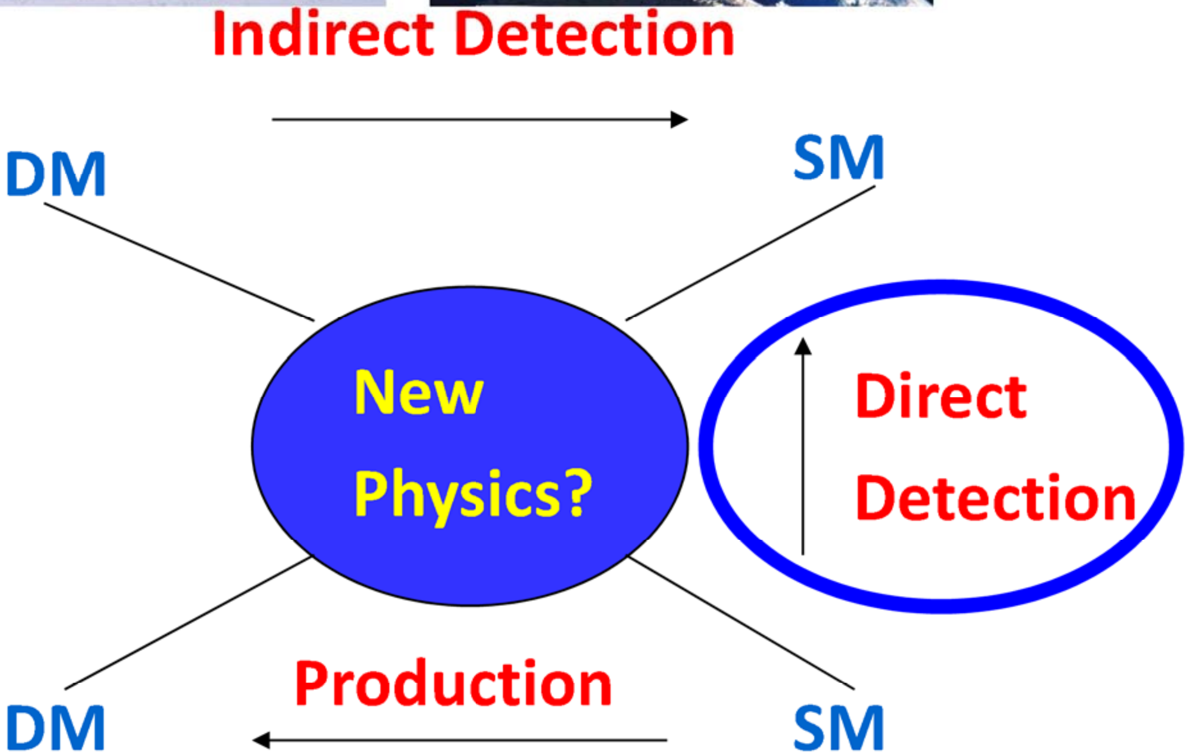
岳骞
清华大学
2011年12月21日

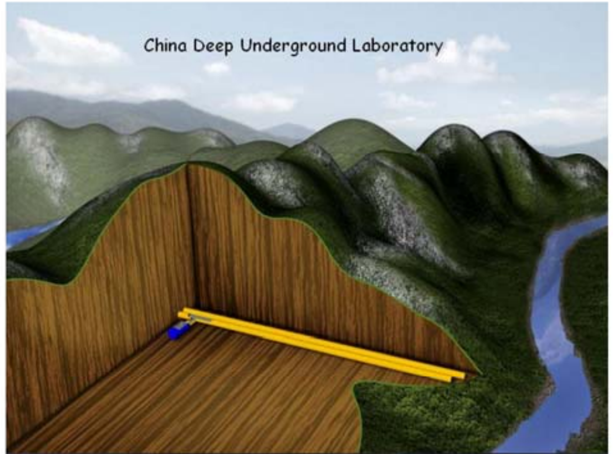
中国锦屏地下实验室
CJPL China Jinping Underground Laboratory

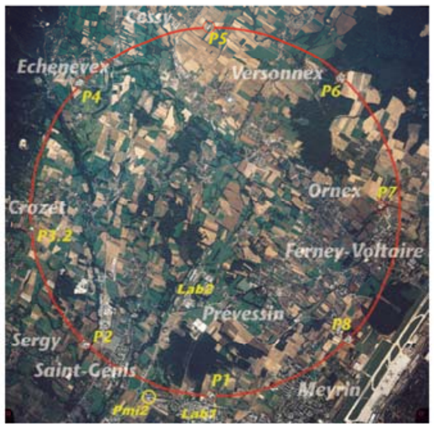
SKLTP

2011年研究工作进展

- 国际暗物质直接探测实验进展
- CDEX暗物质实验研究进展；
- CJPL参数研究和通风系统改造；
- 总结


Indirect Detection
DM
SM
New
Physics?
Direct
Detection
Production
DM
SM


China Deep Underground Laboratory


Cessy
P5
Echenevex
P4
Versonnex
P6
Ornex
P7
Crozet
Ferney-Voltaire
Prevessin
Sergy
Saint-Genis
P8
P2
P1
Meyrin

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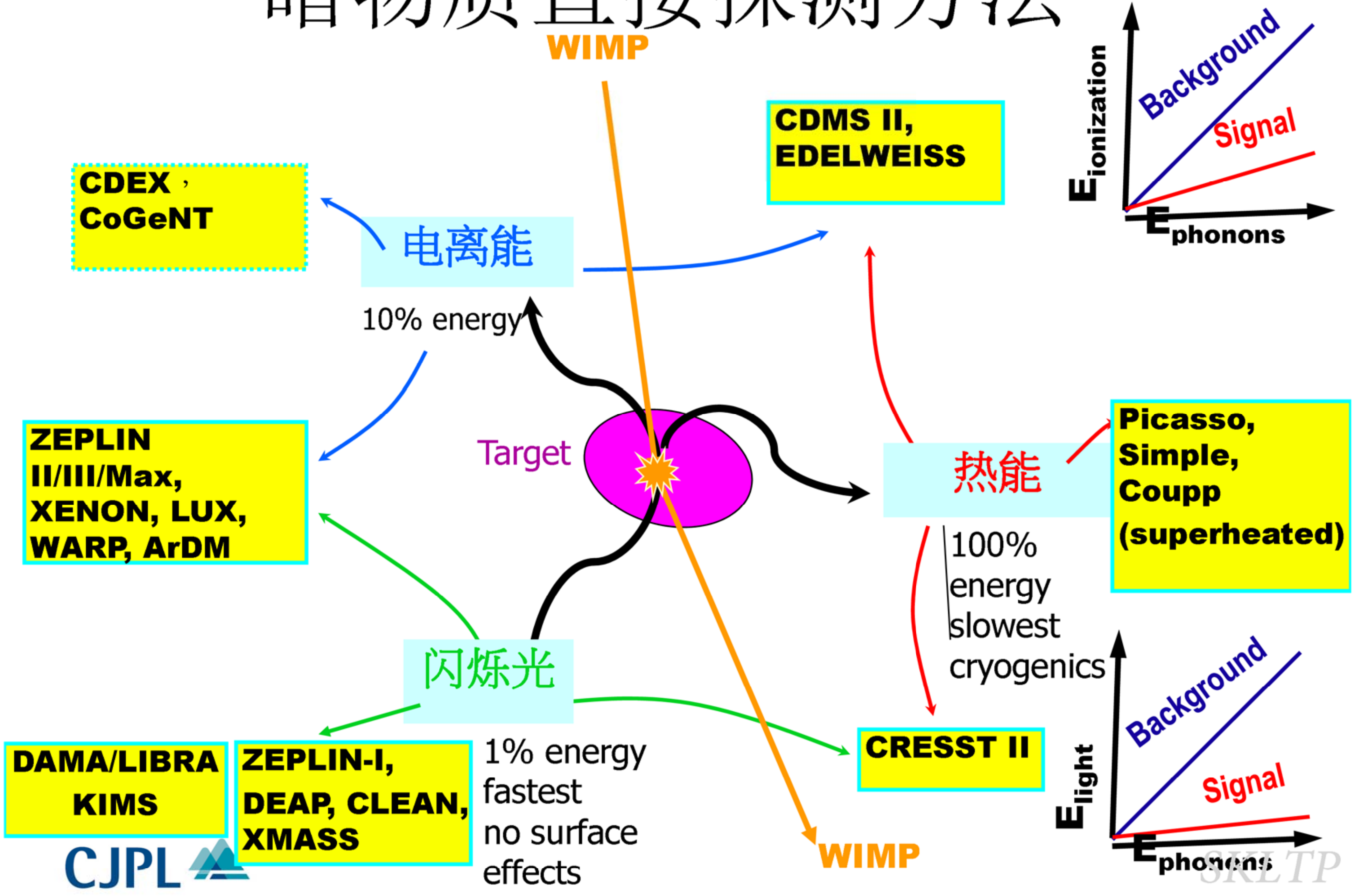
暗物质直接探测方法



WIMP
CDEX，
CoGeNT
电离能
10% energy
CDMS II,
EDELWEISS
Background
Signal
$E_{ionization}$
$E_{phonons}$
ZEPLIN
II/III/Max,
XENON, LUX,
WARP, ArDM
Target
热能
Picasso,
Simple,
Coupp
(superheated)
100%
energy
slowest
cryogenics
闪烁光
DAMA/LIBRA
KIMS
ZEPLIN-I,
DEAP, CLEAN,
XMASS
1% energy
fastest
no surface
effects
CRESST II
WIMP
Background
Signal
E_{light}
$E_{phonons}$
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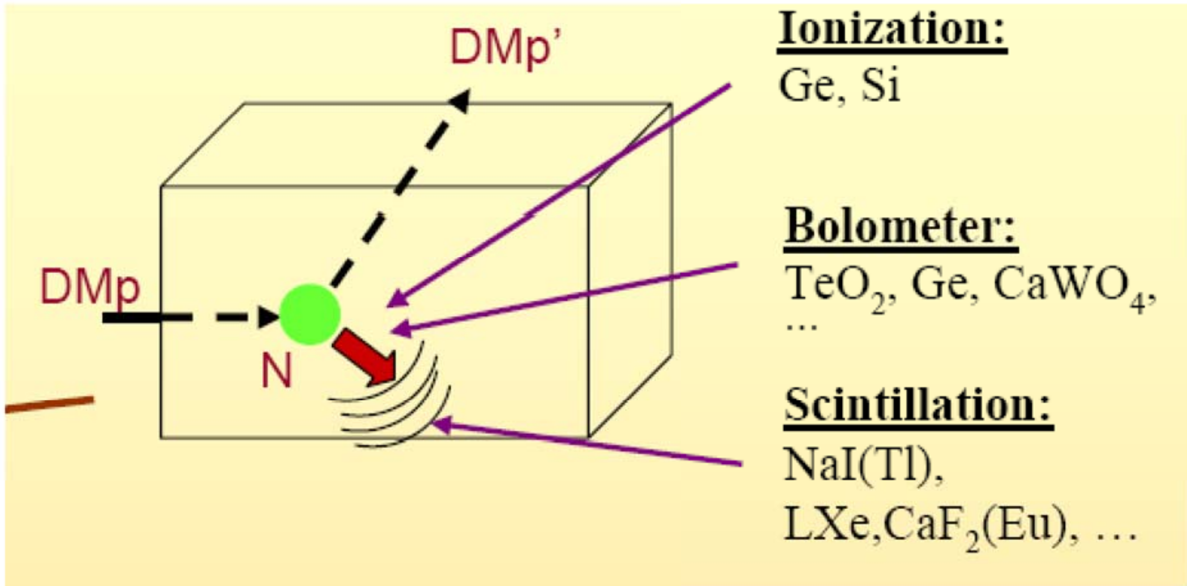
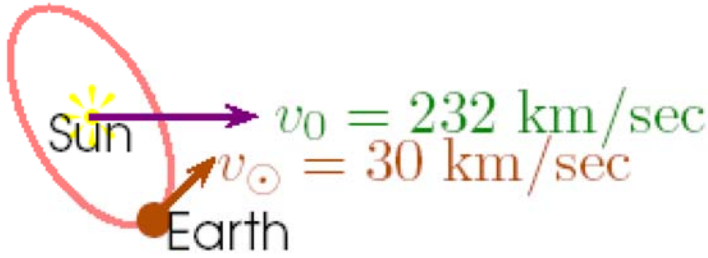
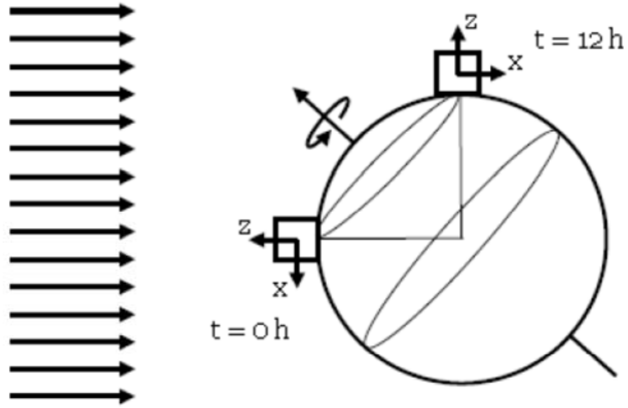
暗物质直接探测方法



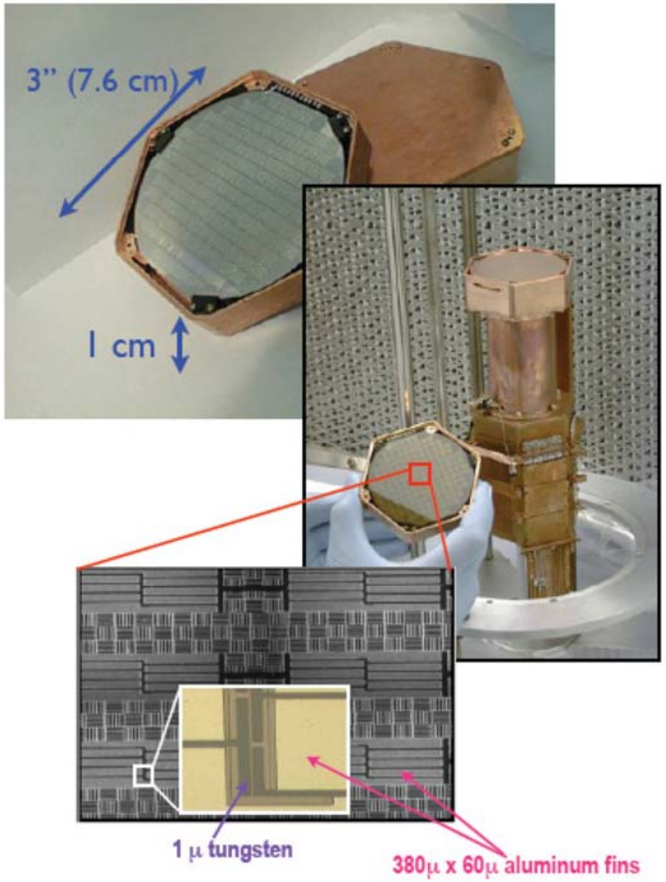


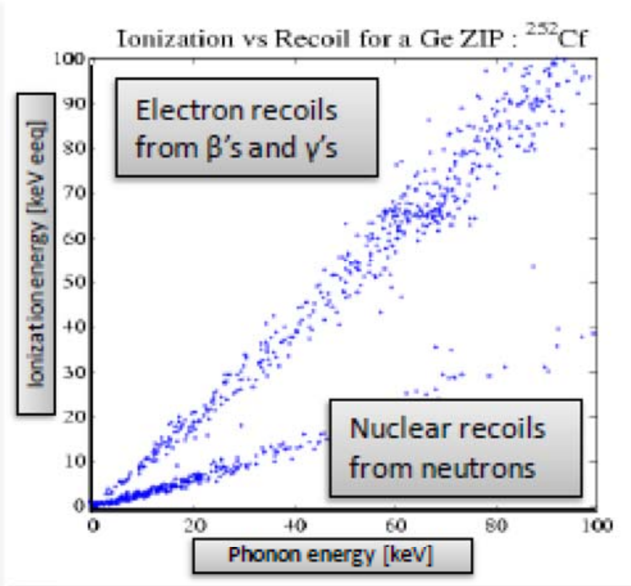


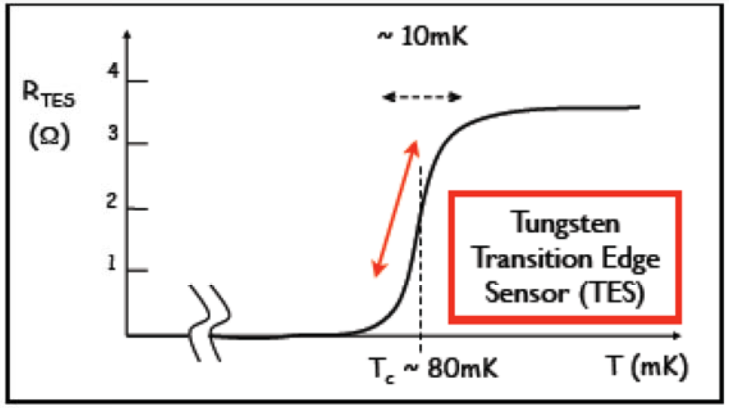
- WIMP与靶核的弹性散射；
- 自旋相关(J/J+1)和自旋无关(A^2)相互作用；
- 反冲核的能量小于10keV，随能量降低事例率指数增加；
- 特征性信号：年度调制效应
- 方向特性：日调制效应，

CDMS-II ZIP Detectors

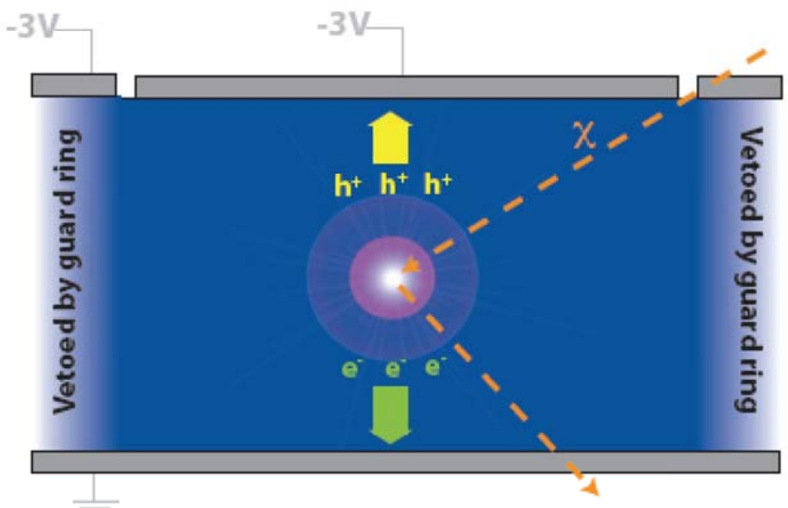
- **Z**-sensitive **I**onization and **P**honon mediated
- **230 g Ge** or **100 g Si** crystals (1 cm thick, 7.5 cm diameter)
- Photolithographically patterned to **collect athermal phonons** and **ionization signals**
  - xy-position imaging
  - Surface (z) event rejection from pulse shapes and timing
- **30 detectors** stacked into **5 towers** of 6 detectors

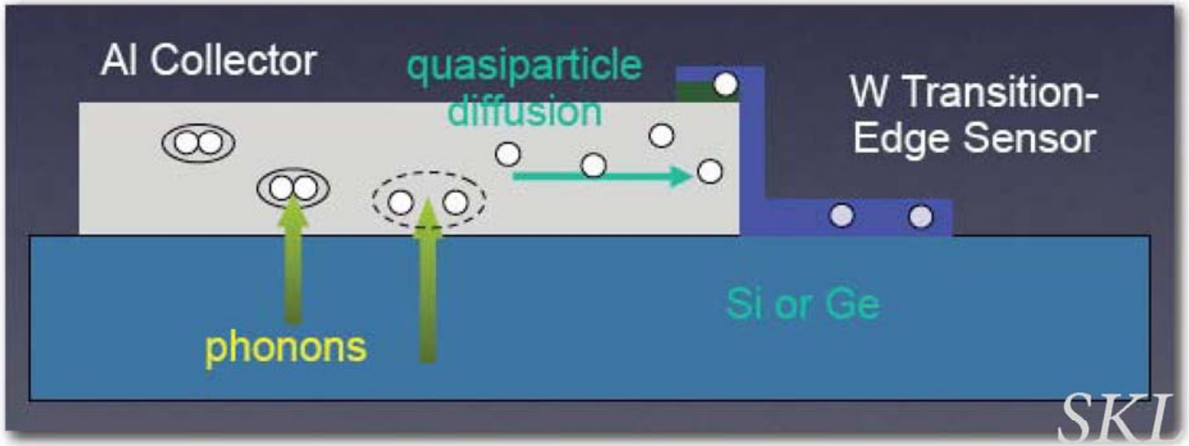


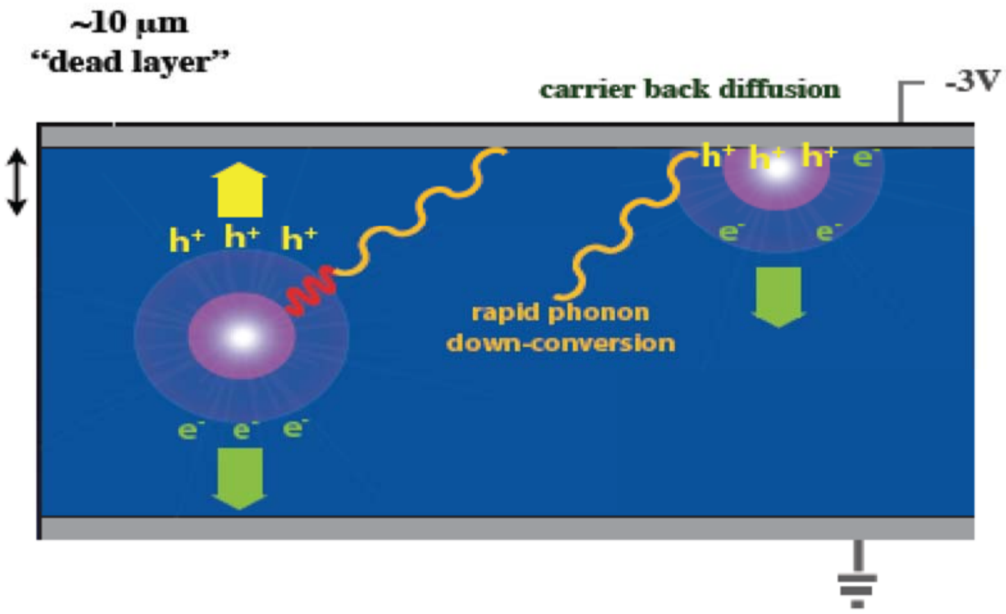




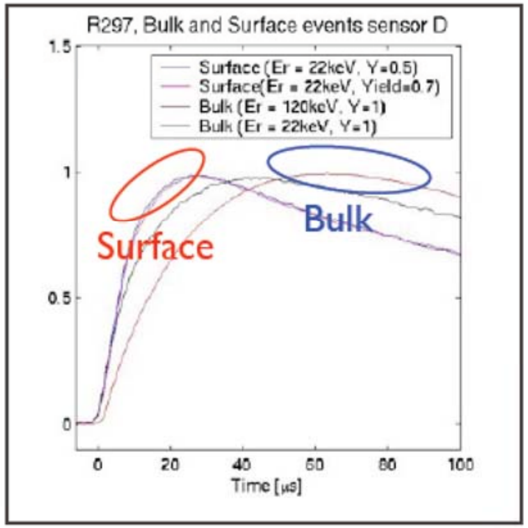
SLAC. Dec. 17. 2009



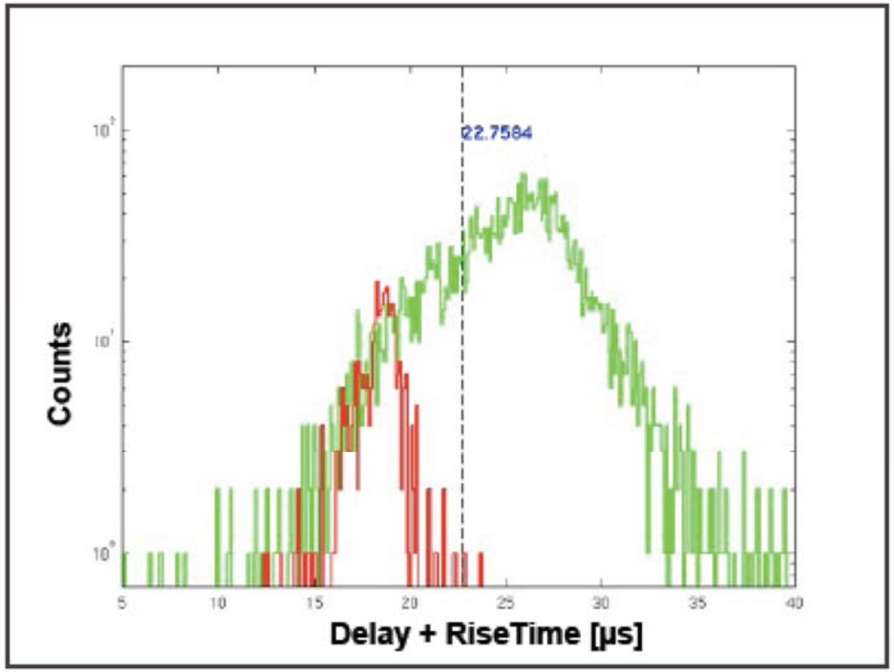




- Reduced charge yield is due to carrier back diffusion in surface events.
- "Dead layer" is within ~10μm of the surface.



Phonons near surface travel faster, resulting in shorter risetimes of phonon pulse.



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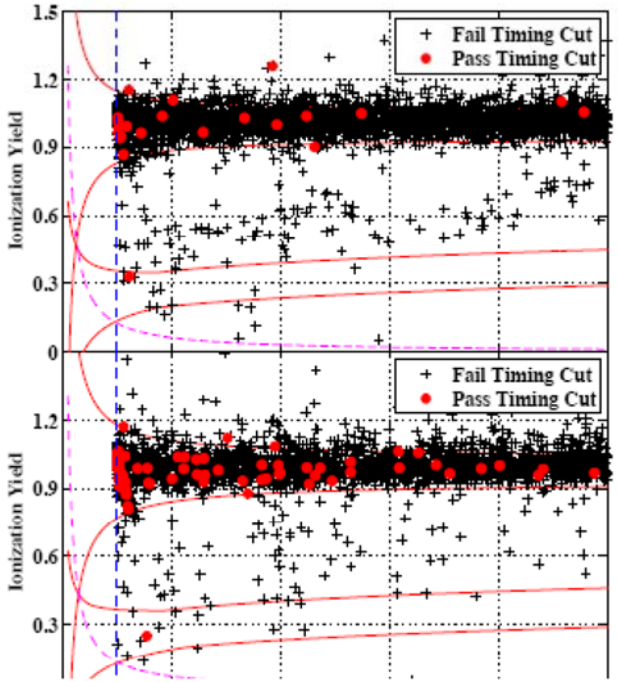
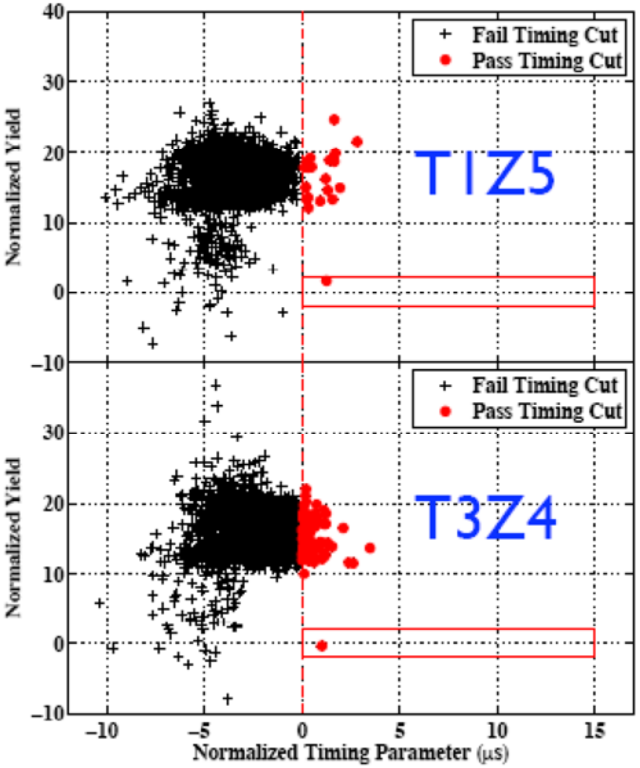
Opening the Box

Box opened November 5 , 2009 for 14 Ge ZIP detectors



arXiv: 0912.3320



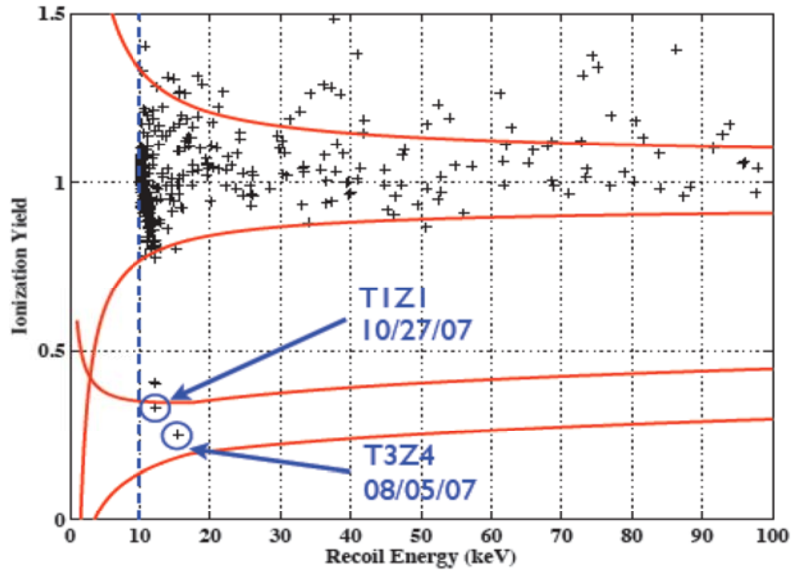
3σ region masked

☑ Hide unvetoed singles

Lift mask, see 150 singles failing timing cut

Apply the timing cut ...

2 EVENTS OBSERVED!



A refined calculation of the surface background taking into account larger errors in the timing estimate a low energy produced a post-unblinding leakage estimate of

$$0.8 \pm 0.1(\mathrm{stat.}) \pm 0.2(\mathrm{syst.})$$

Based on this revised estimate the **probability of observing 2 or more events is 23%** (includes neutron + surface event background).

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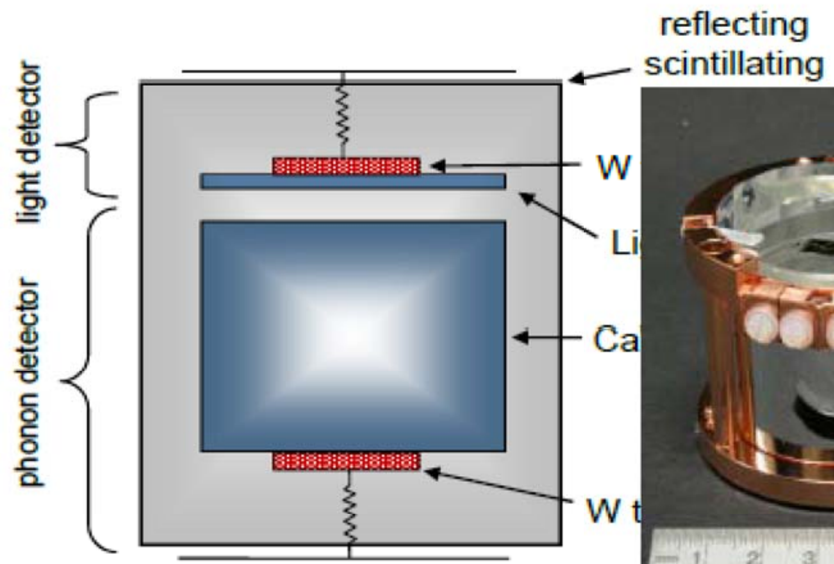
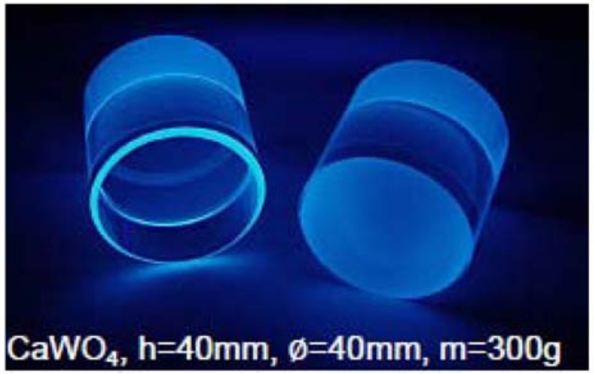
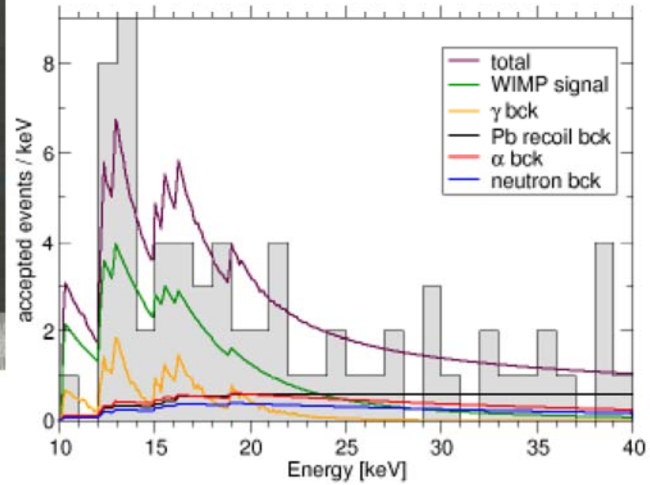
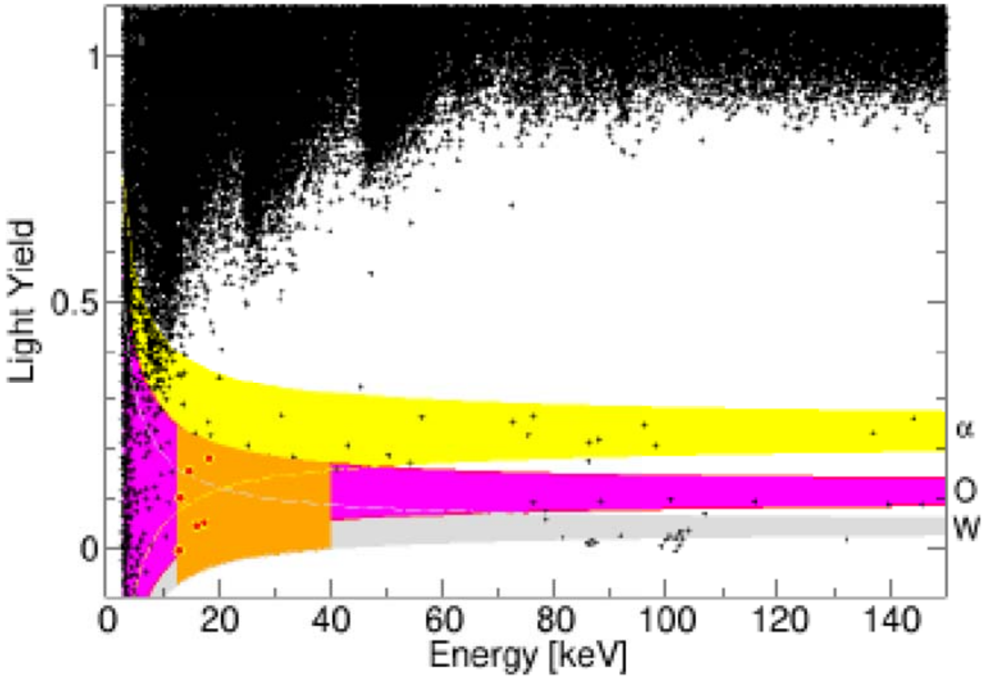
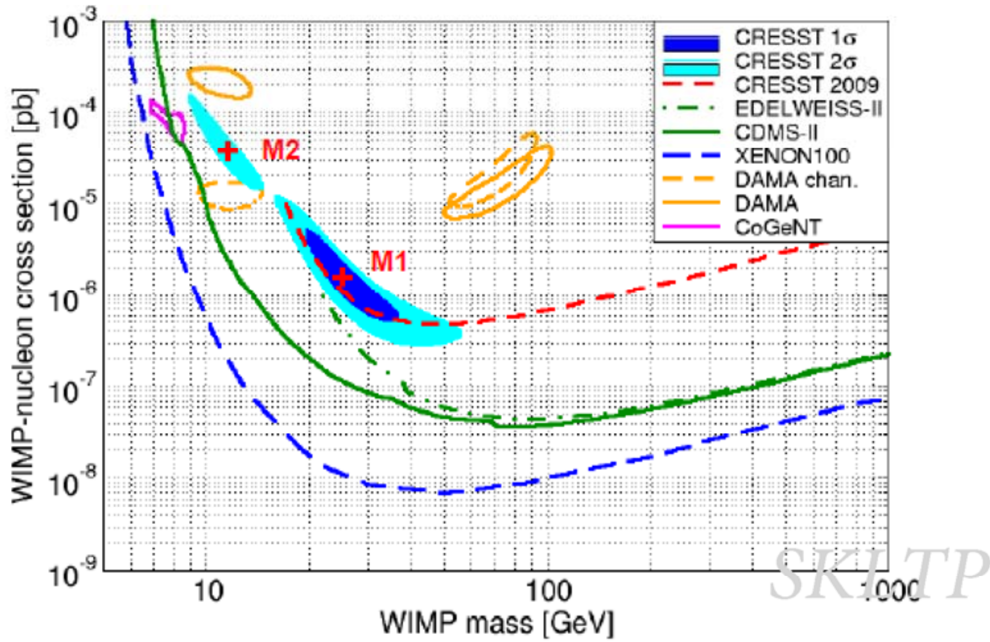
CRESST-II Dark Matter Search

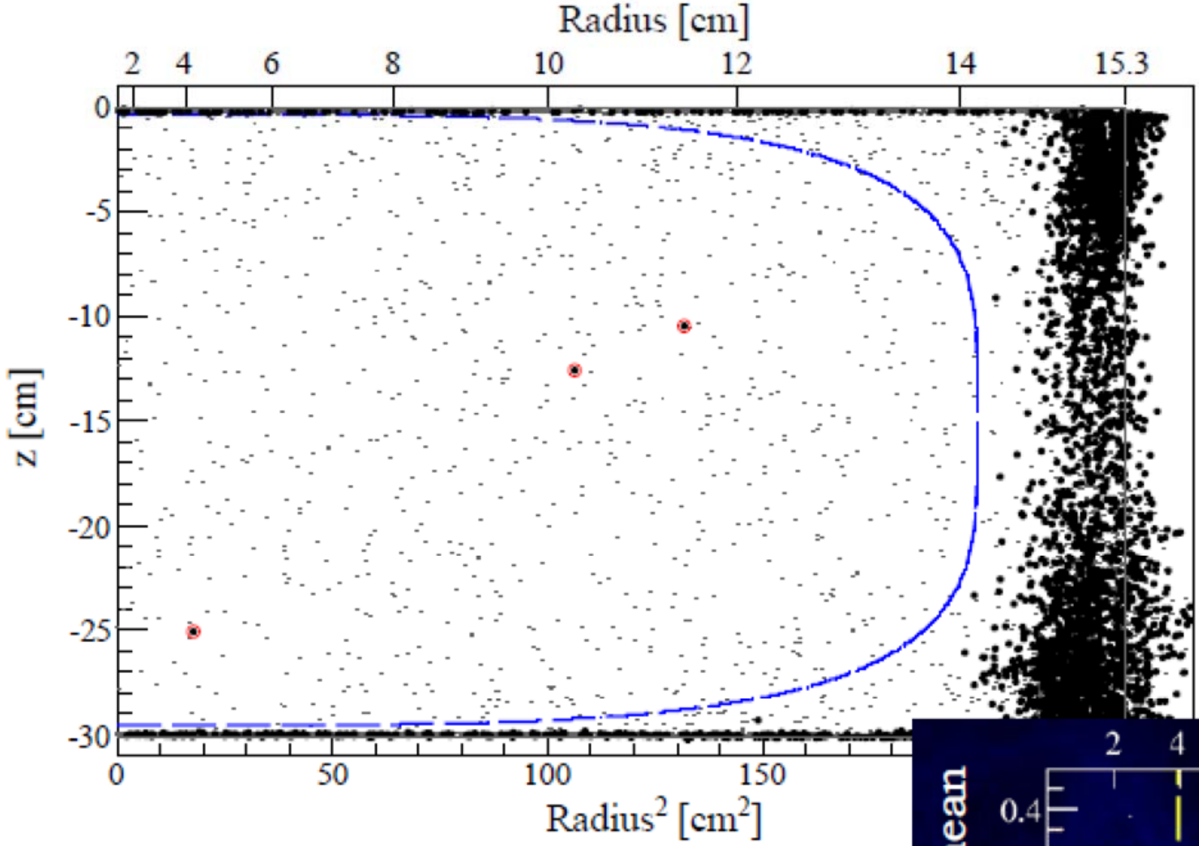






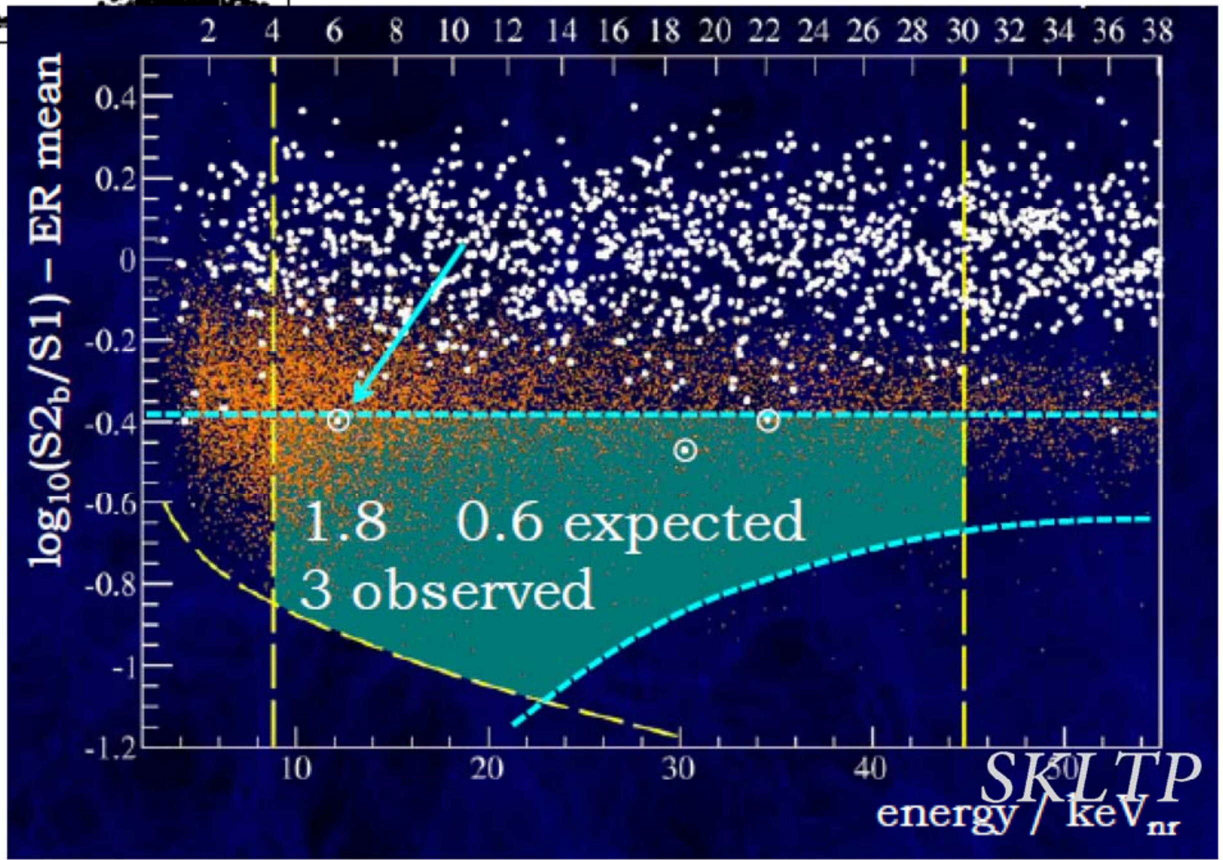






Radius [cm]
2 4 6 8 10 12 14 15.3
0 -5 -10 -15 -20 -25 -30
z [cm]
0 50 100 150
Radius^2 [cm^2]

EXNON100



2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
0.4 0.2 0 -0.2 -0.4 -0.6 -0.8 -1 -1.2
$\log_{10}(S2_b/S1)$ – ER mean
1.8 0.6 expected
3 observed
10 20 30 40 50
energy / keV$_{nr}$
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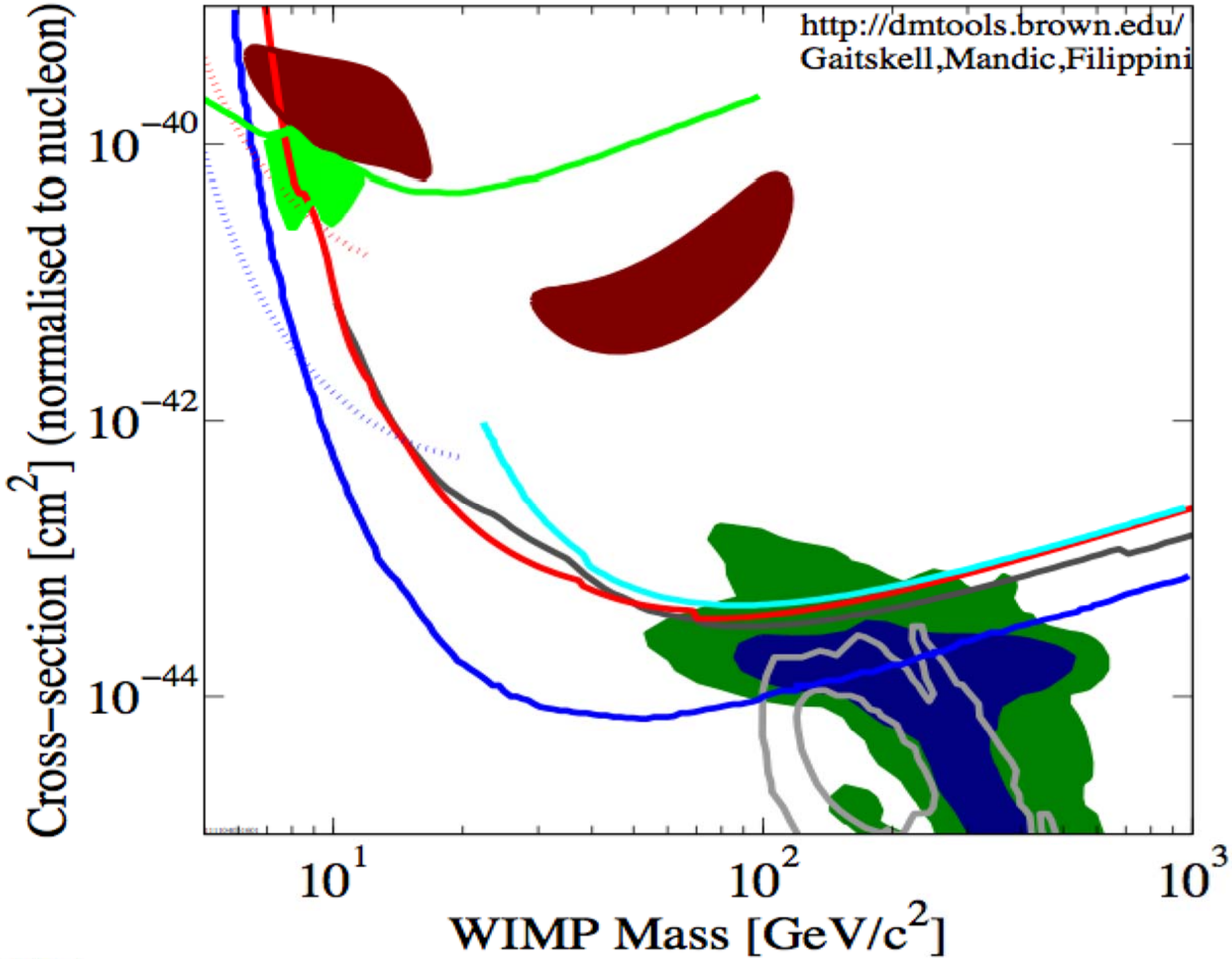
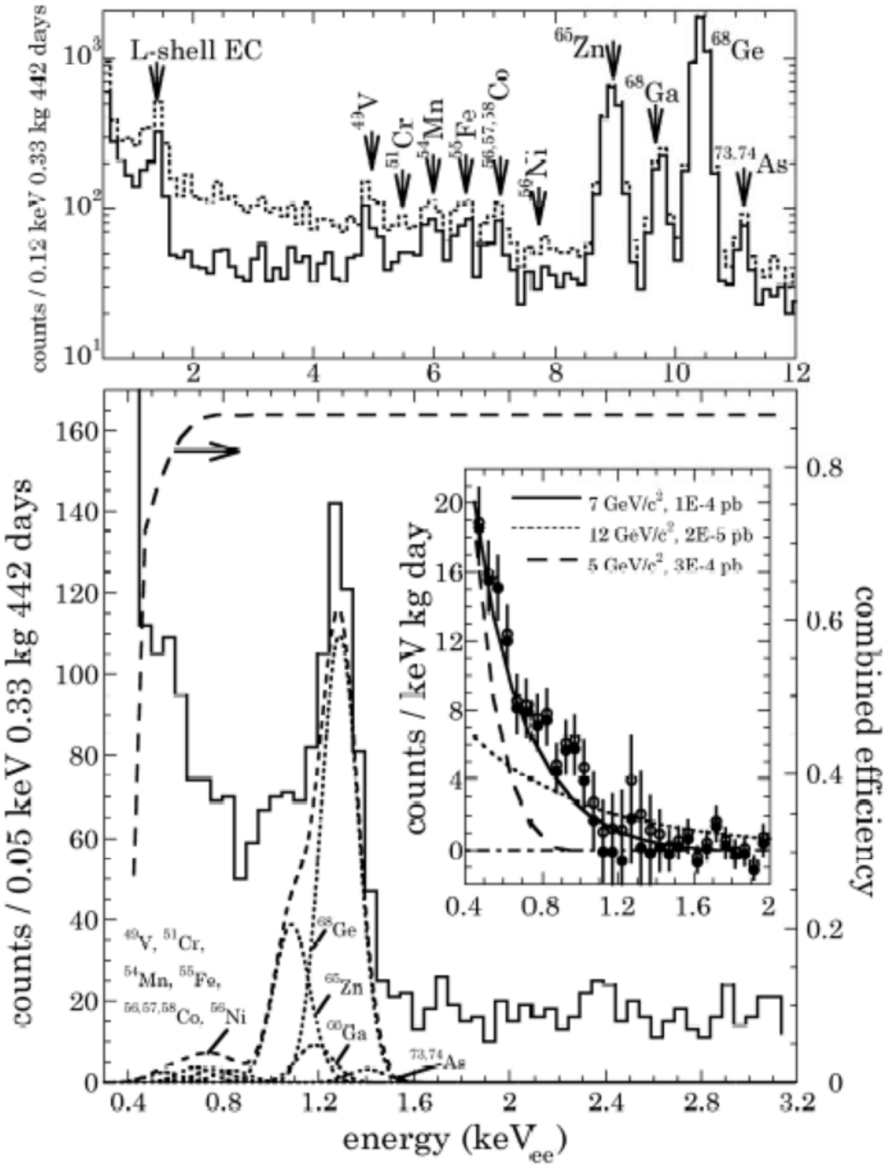
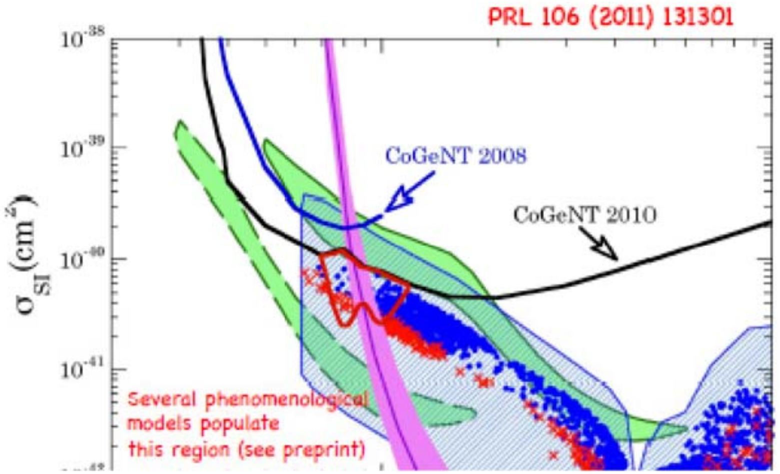
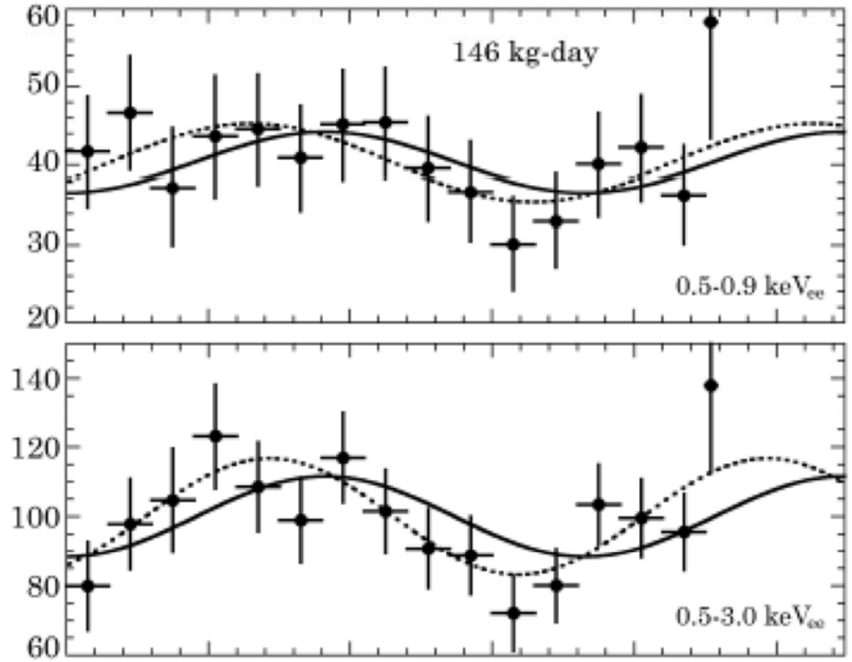
EXNON100



http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini
Cross-section [cm^2] (normalised to nucleon)
10^{-40}
10^{-42}
10^{-44}
10^1
10^2
10^3
WIMP Mass [GeV/c^2]



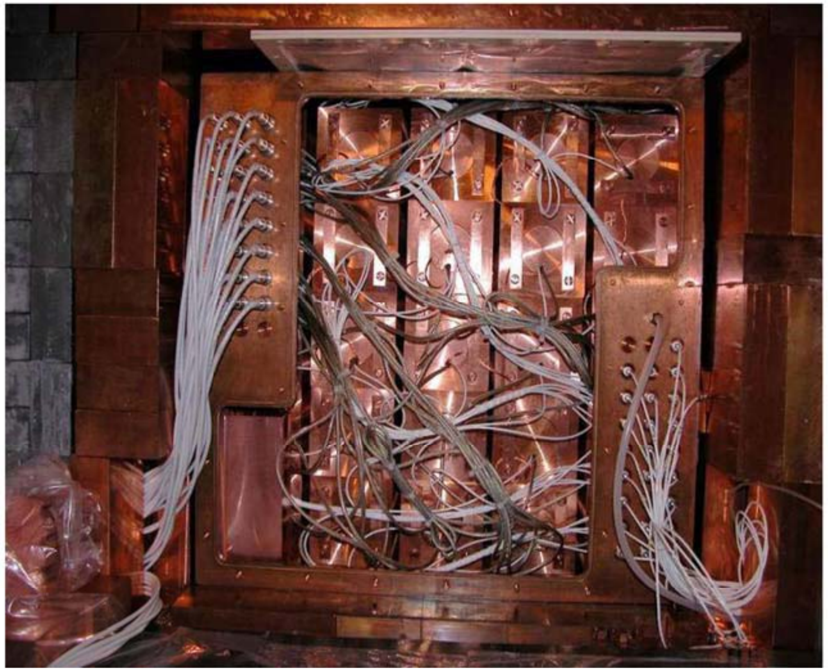


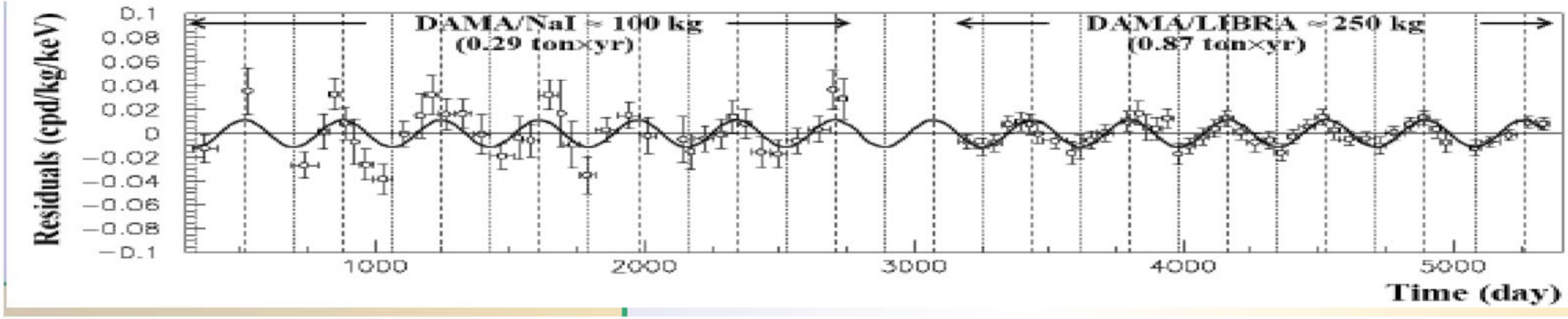


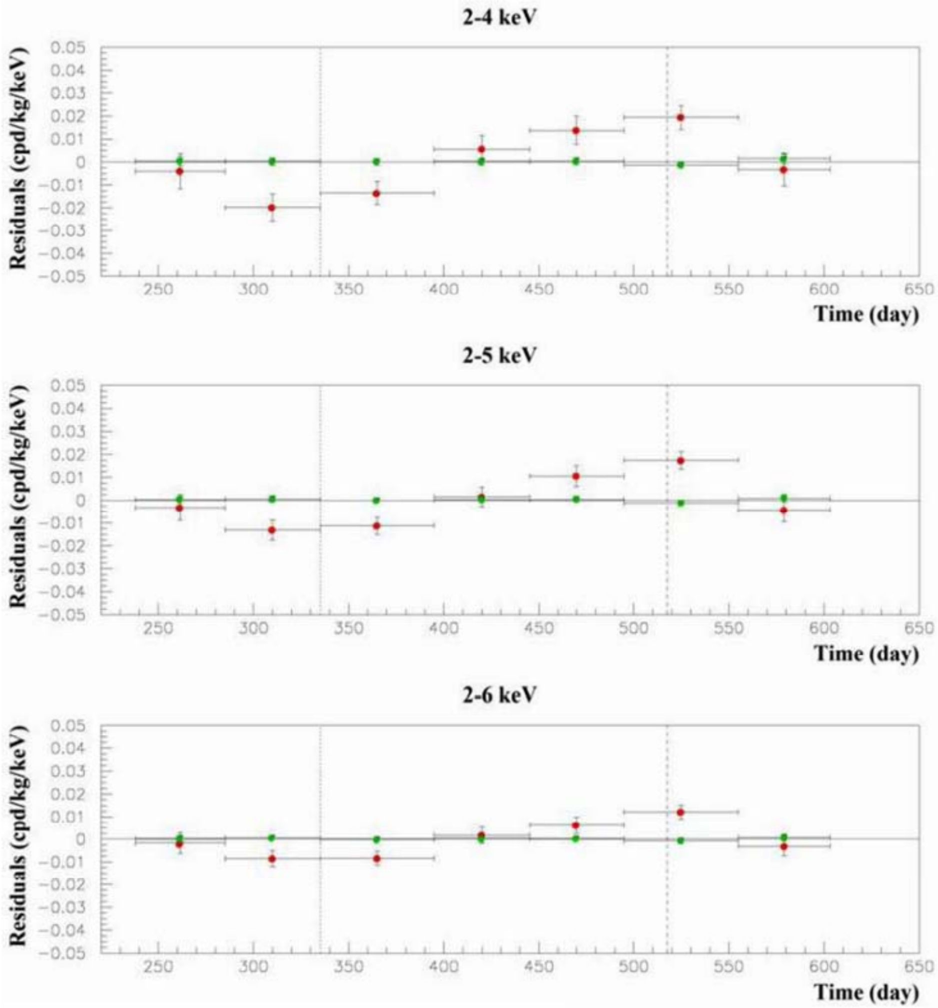
$$\left.\frac{dR}{dE}\right|_{\text{observed}} = \alpha \cdot \left.\frac{dR}{dE}\right|_{\text{DM\_Theory}} + \beta \cdot \left.\frac{dR}{dE}\right|_{\text{Noise}} + \gamma \cdot \left.\frac{dR}{dE}\right|_{\text{residual\_Bkg}}$$

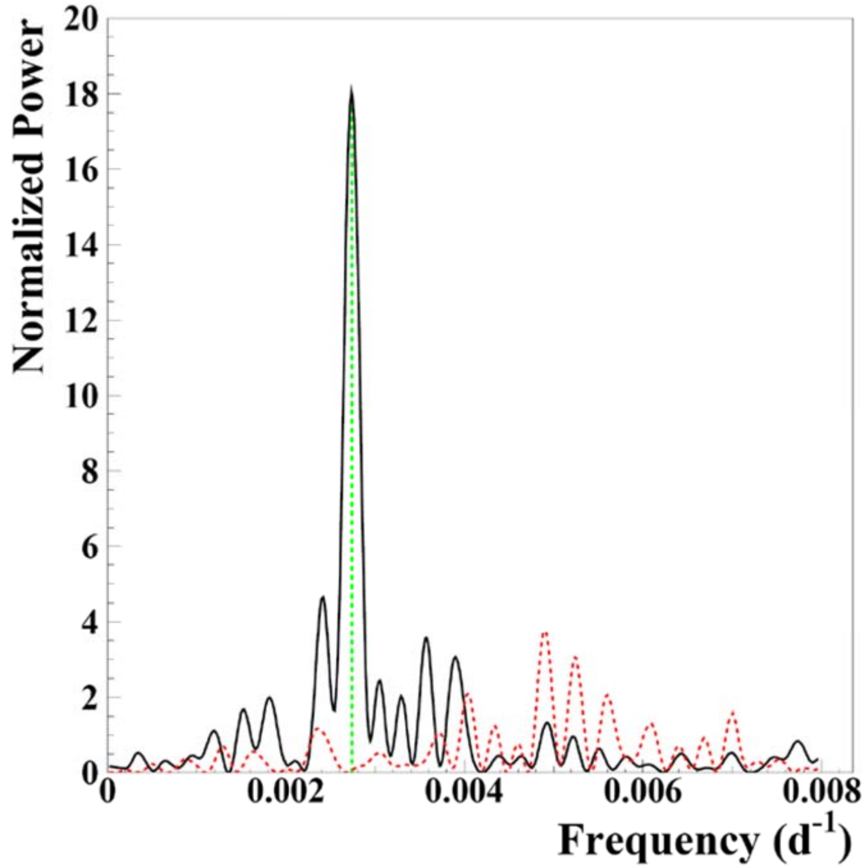
DAMA/LIBRA：

- NaI(Tl) Scintillator at Gran Sasso : total 0.29+0.87 ton-year data
- Observe annual modulation in the 2-6 keV single-hit signal band, total 11 cycles, > 8σ
- No modulations at higher energy & for multiple-hits









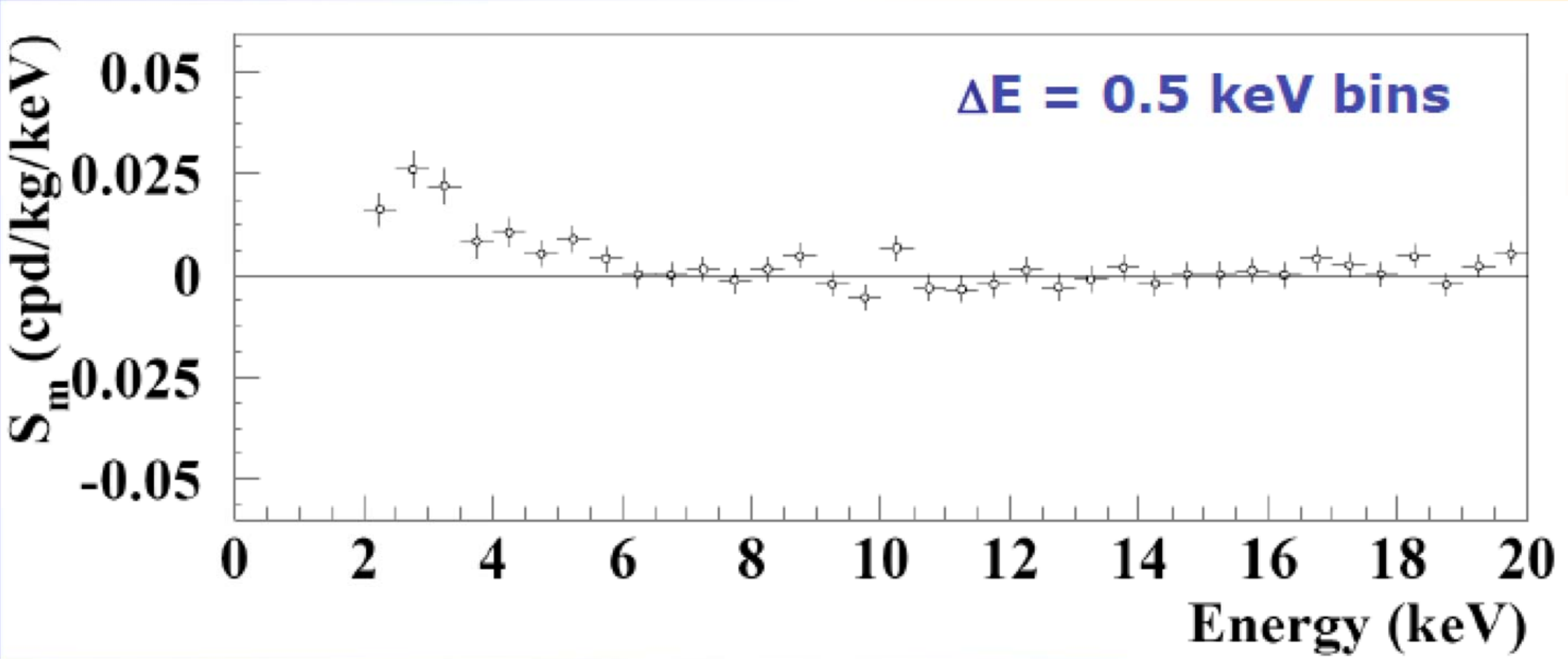
- **Annual Modulation in single hit at 2-6 keV**
- **No Modulation for multiple hits at 2-6 keV**
- **No Modulation for single hit above 6 keV**

Energy distribution of the modulation amplitudes

$$R(t) = S_0 + S_m \cos[\omega(t - t_0)]$$

here $T=2\pi/\omega=1$ yr and $t_0 = 152.5$ day

DAMA/NaI (7 years) + DAMA/LIBRA (6 years)
total exposure: 425428 kg×day ≈1.17 ton×yr



A clear modulation is present in the (2-6) keV energy interval, while S_m values compatible with zero are present just above

The DAMA: modulation amplitude 10^{-2} cpd/kg/keV, in 2-6 keV energy range for single hit events; phase:

May 26 ± 7 days

(stable over 13 years)

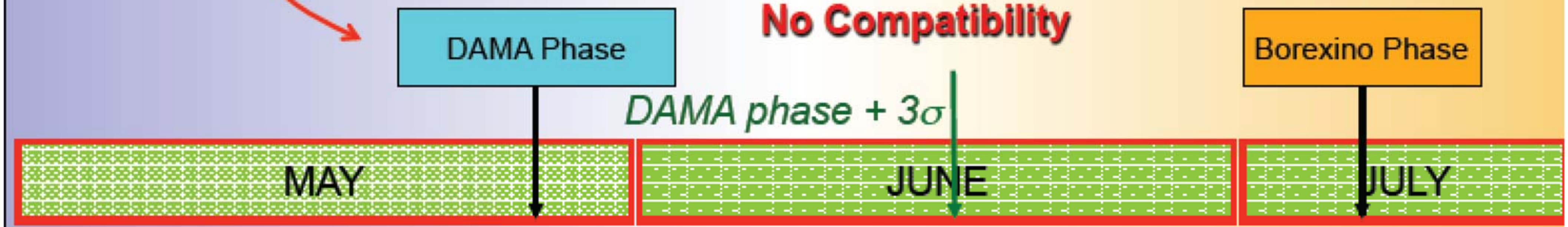
μ flux @ LNGS (MACRO, LVD, BOREXINO) $\approx 3 \cdot 10^{-4}\ m^{-2}s^{-1}$; modulation amplitude 1.5%; phase:

July 6 ± 6 days (BOREXINO, CSN2 sept. 2010)

but

the muon phase differs from year to year (error no purely statistical); LVD/BOREXINO phase value is a "mean" of the muon phase of each year

No Compatibility



The DAMA phase is 5.7σ far from the LVD/BOREXINO phases of muons (7.3 σ far from MACRO measured phase)

1) if we assume for a while that the real value of the DAMA phase is June 16th (that is 3σ fluctuation from the measured value), it is well far from all the measured phases of muons by LVD, MACRO and BOREXINO, in all the years

2) Moreover, considering the seasonal weather condition in Gran Sasso, it is quite impossible that the maximum temperature of the outer atmosphere (on which μ flux modulation is dependent) is observed in the middle of June

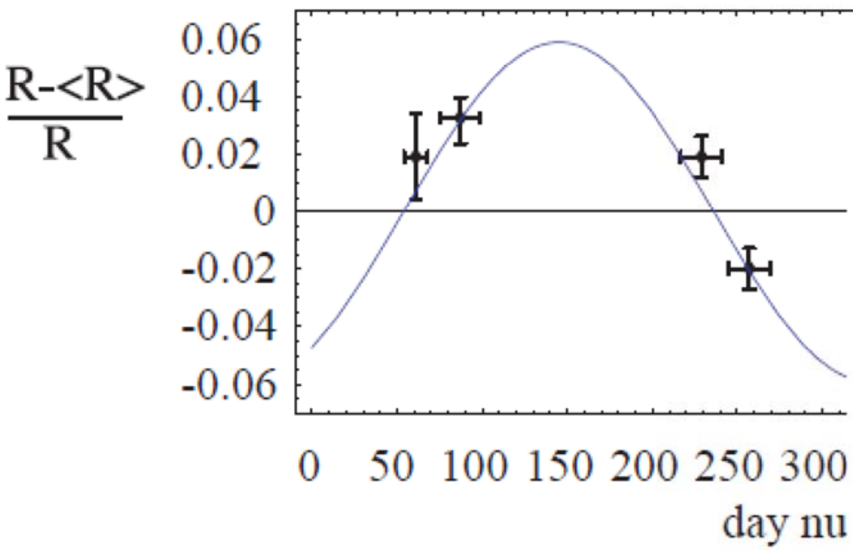
Inconsistency of the phase between DAMA signal and μ modulation

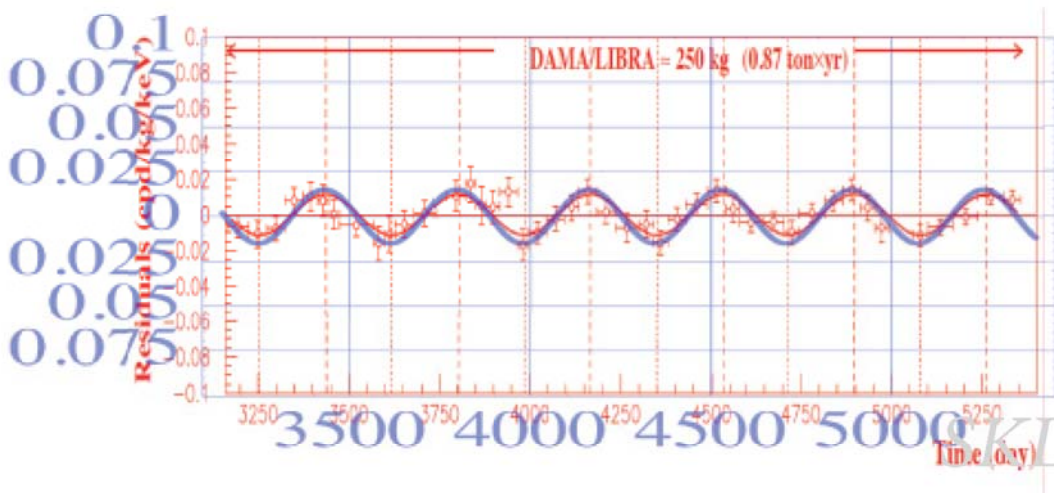
One Model Explains DAMA/LIBRA, CoGENT, CDMS, and XENON

中子本底？

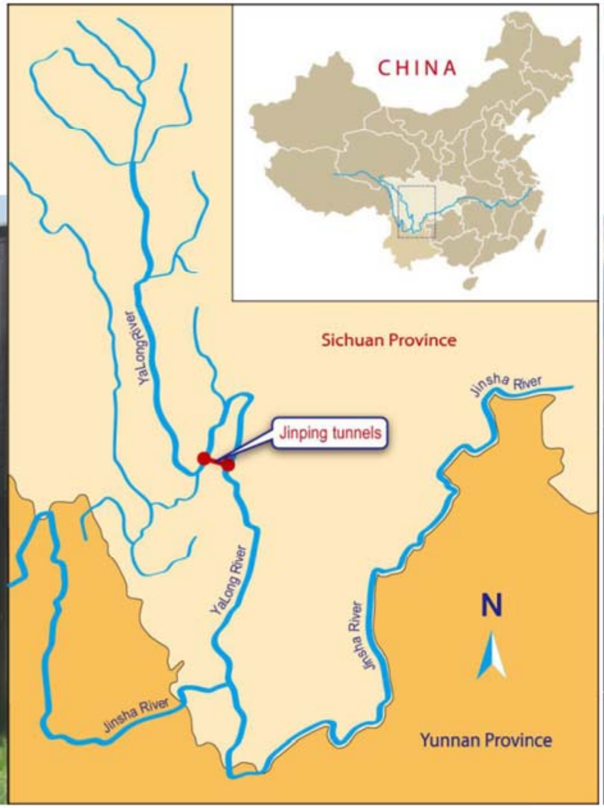
John P. Ralston
Department of Physics & Astronomy,
The University of Kansas, Lawrence, KS 66045

Many experiments seek dark matter by detecting relatively low energy nuclear recoils. Yet since events from ordinary physics with energies in the 1-100 KeV range are commonplace, all claims of signals or their absence hinge on exhaustive calibrations and background rejection. We document many curious and consistent discrepancies between the backgrounds which neutrons can produce versus the picture of neutrons and claims of neutron calibration found in dark matter literature. Much of the actual physics of neutrons is either under-recognized or under-reported, opening up new interpretations of current data. All signals seen so far, including those presented tentatively such as CoGENT, or the bold claims and time dependence of DAMA/LIBRA, appear to be consistent with neutron-induced backgrounds. At the same time it is the burden of proof of experimental groups to support their claims no possible background could matter, not ours. The existing hypotheses ... face value and as published, make possible





CDEX



✓研究团队：

—— 清华大学
—— 四川大学
—— 中国原子能科学研究院
—— 南开大学
—— 二滩水电公司

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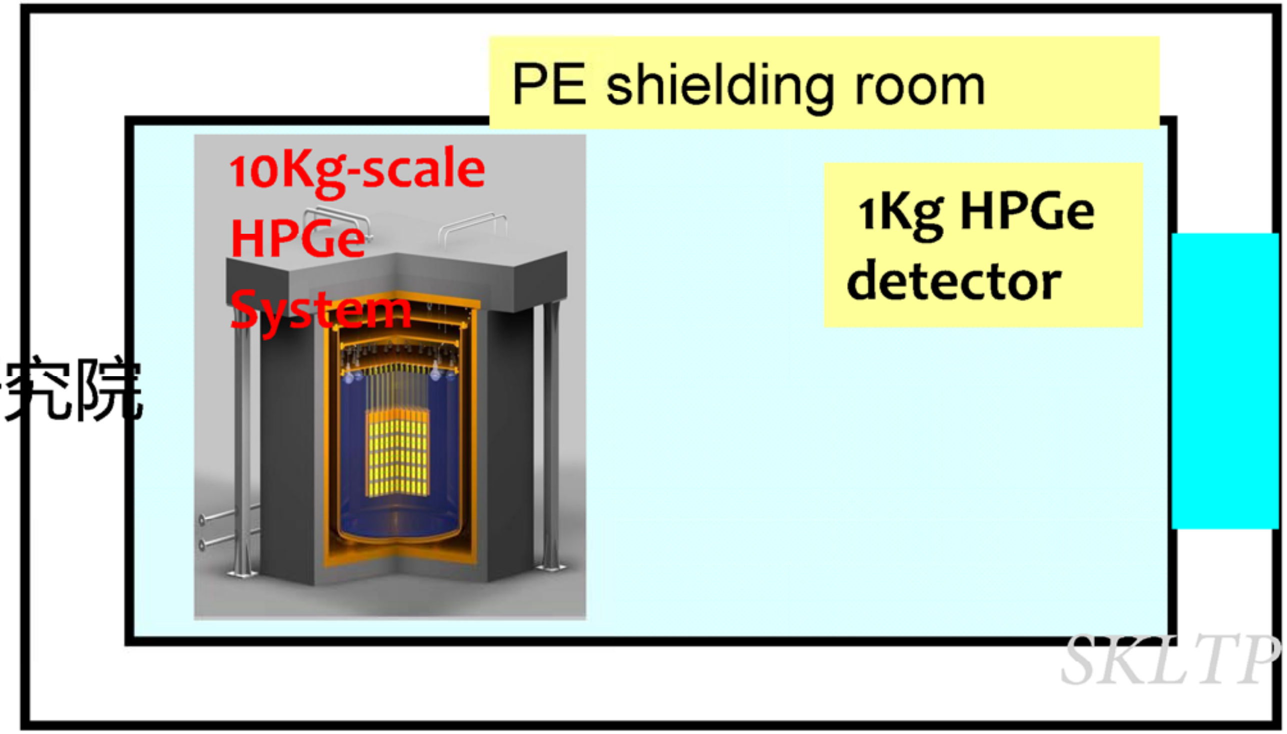


CDEX-1   1kg探测器
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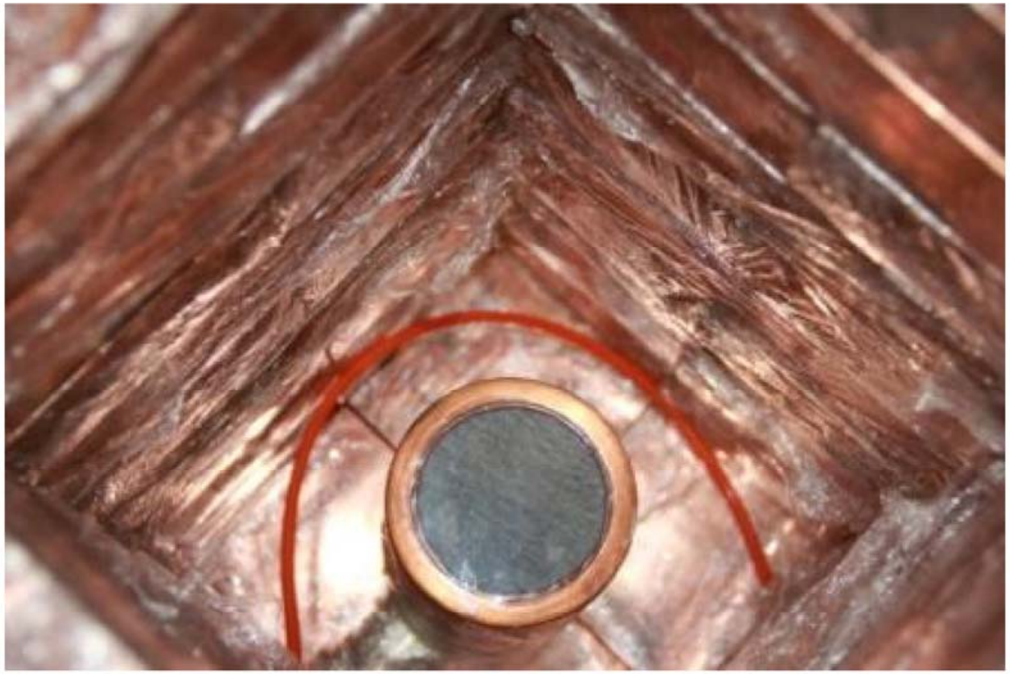
CDEX-1实验研究

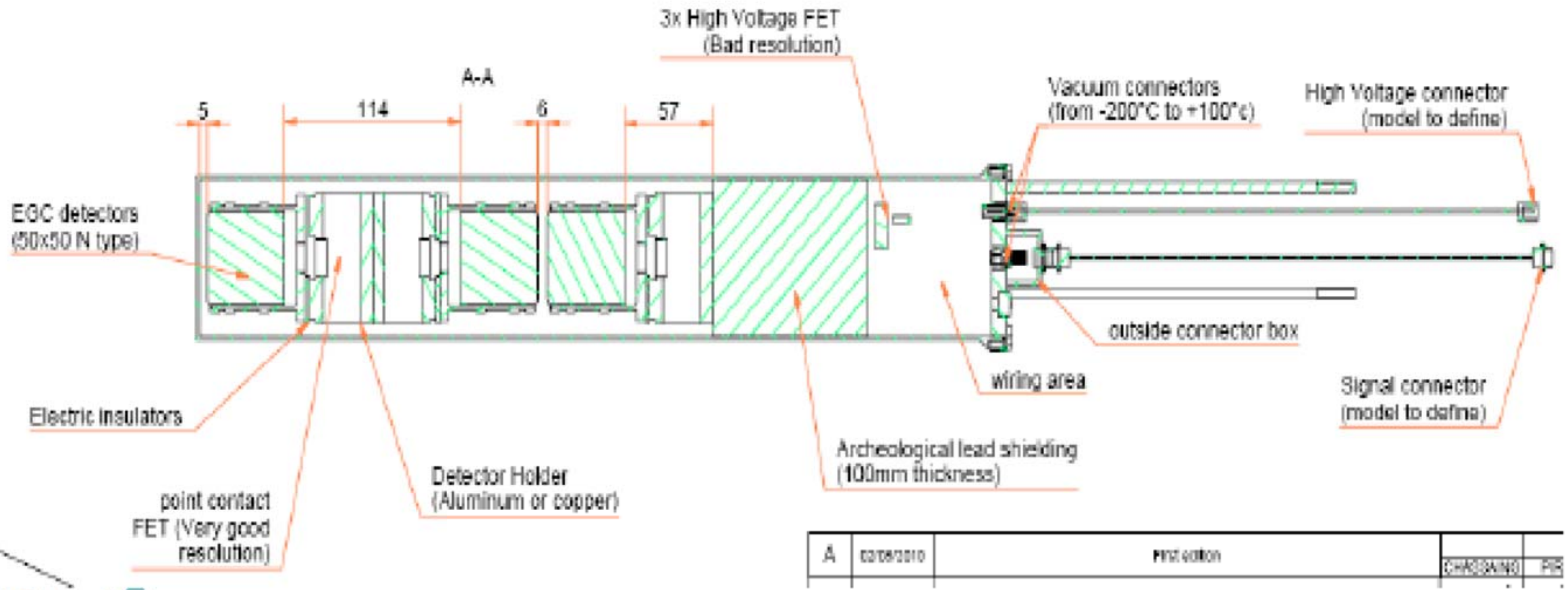


- 20g高纯锗探测器一期实验已经运行结束，正在分析数据；
- 1kg高纯锗探测器已经完成初步测试和预运行。

CDEX-10 探测器系统设计工作

高纯锗探测器——

- 三单元高纯锗探测器系统；
- 已经定制，500gN-PCGe + 2*1kg PPCGe；
- 2012年4月完成。



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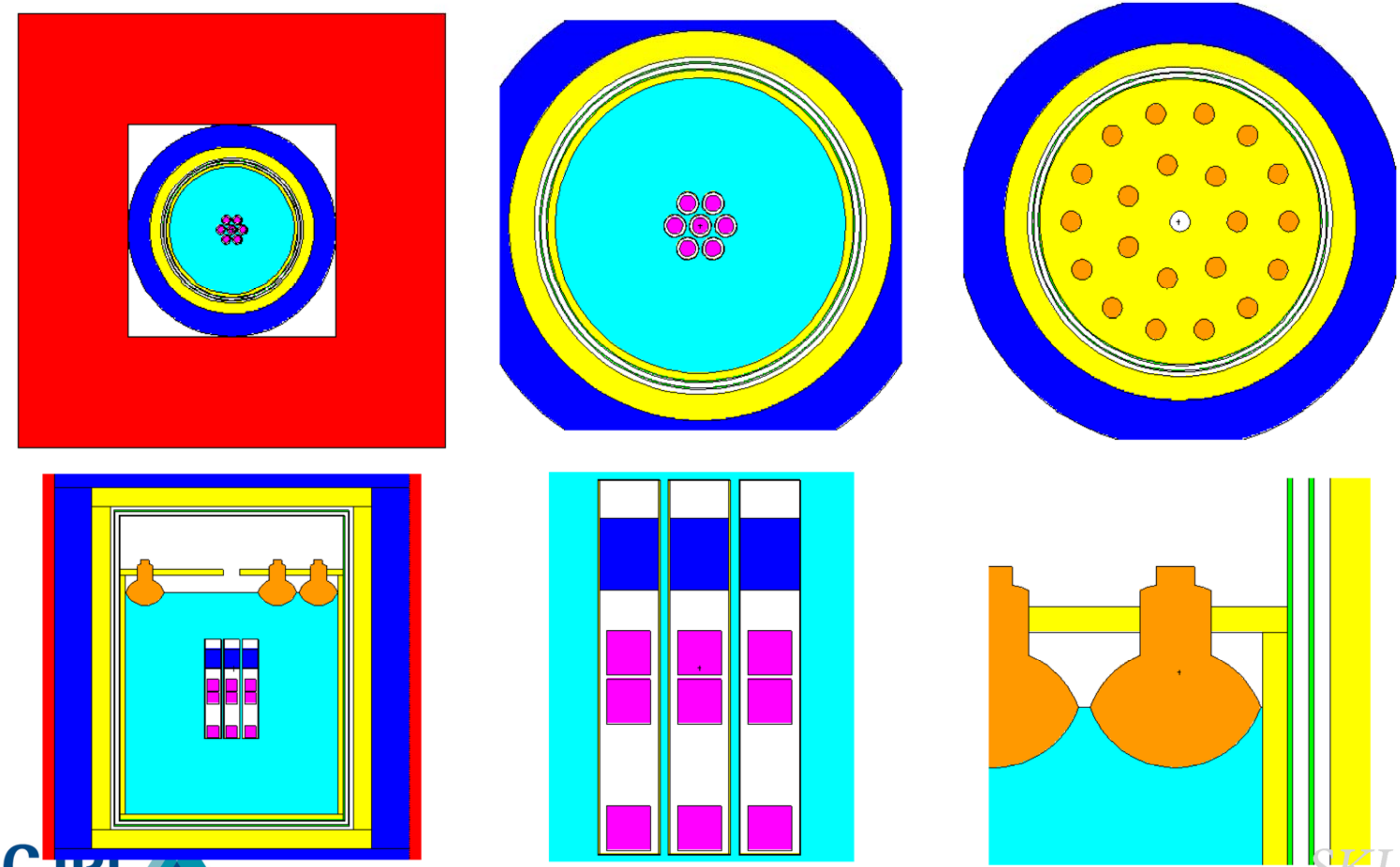
CDEX-10 探测系统模拟



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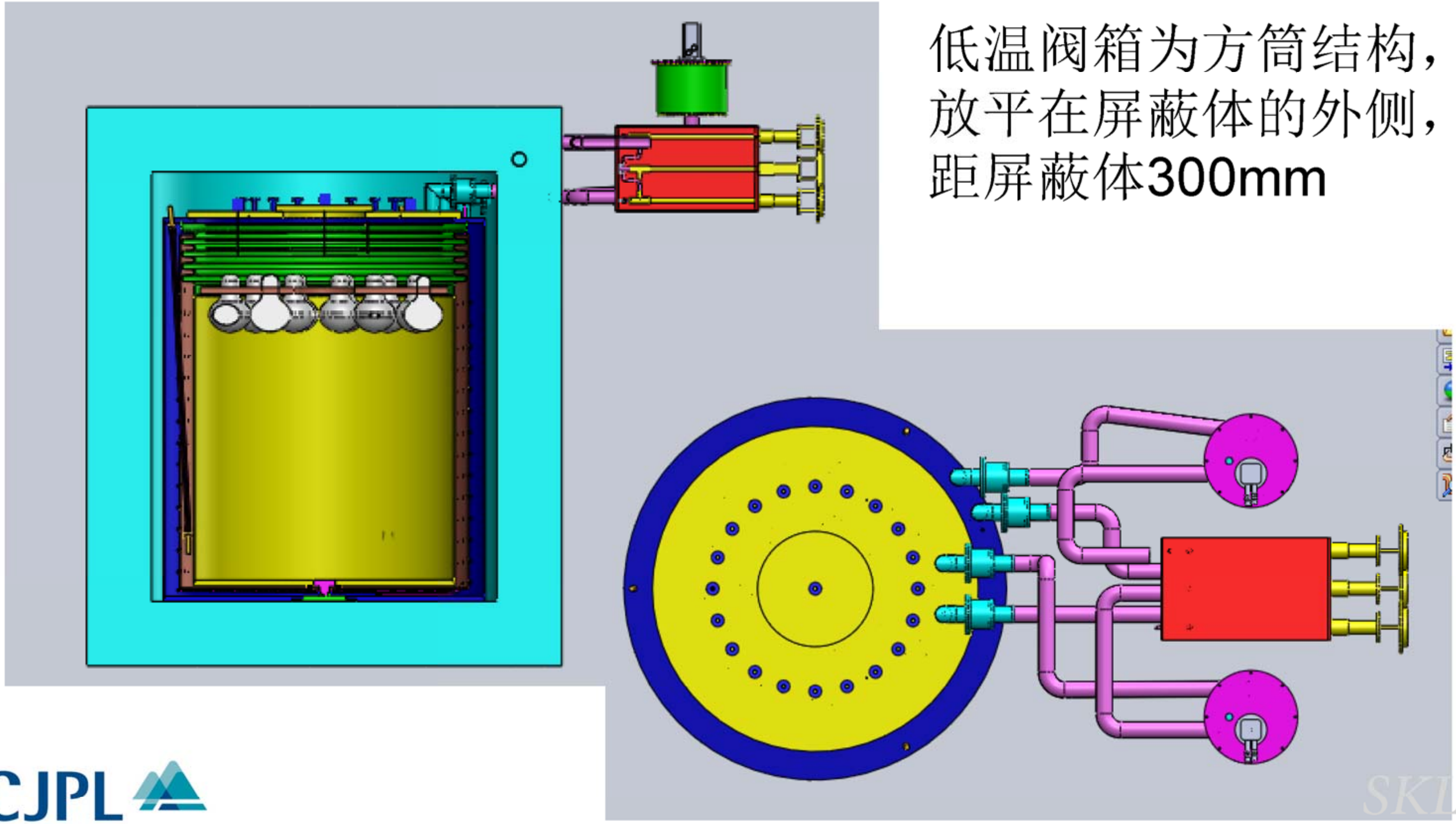
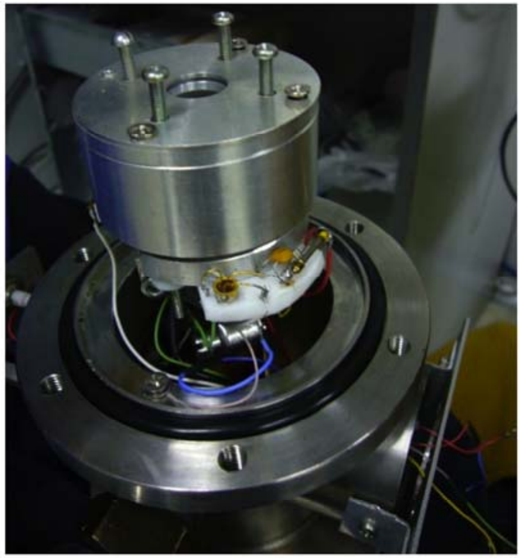
CDEX-10 低温反符合系统设计

恒温杜瓦结构示意图

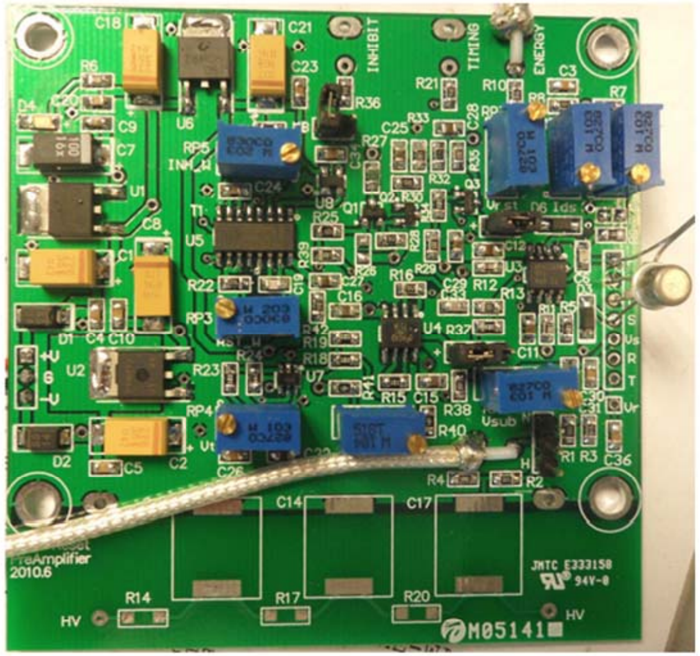


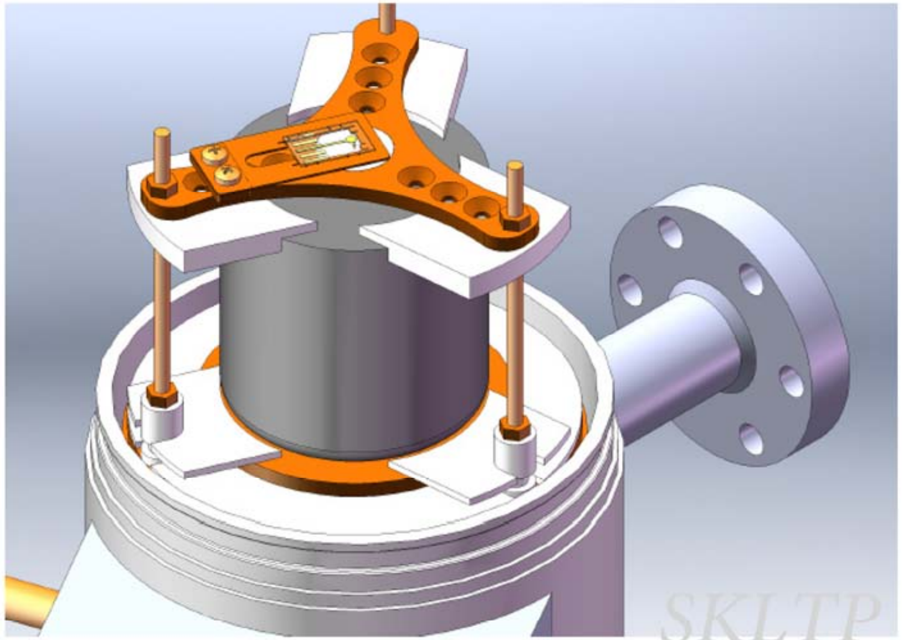
低温阀箱为方筒结构，
放平在屏蔽体的外侧，
距屏蔽体300mm

高纯锗探测器自主研制



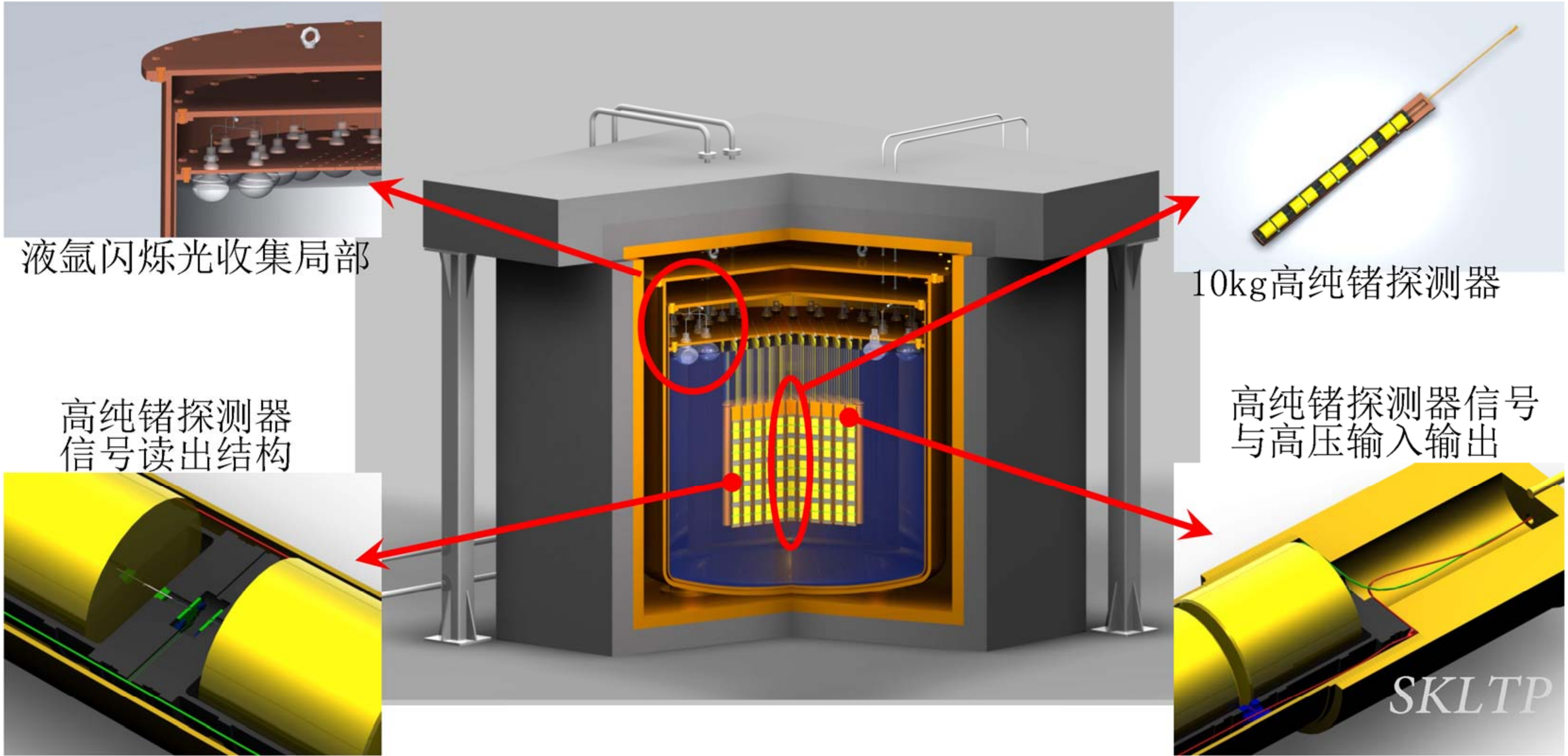
高纯锗探测器及其前放研制



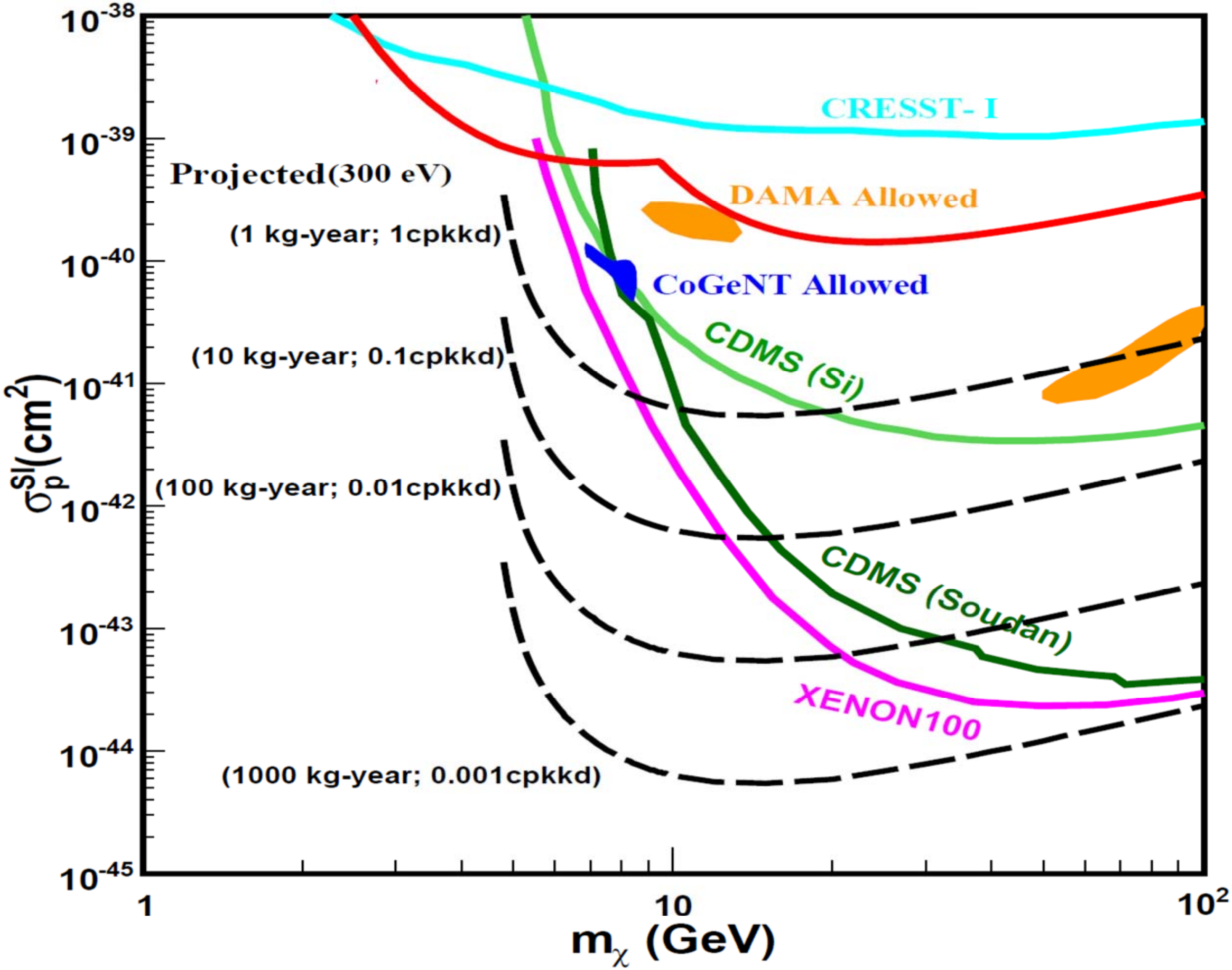


CDEX-1T实验探测器系统

- ✓ 10个1kg高纯锗探测器单元模块构成一个探测器真空封装结构；
- ✓ 将其浸泡在液氩中，液氩不仅作为低温介质，还是反符合探测器系统；
- ✓ 液氩中的闪烁光通过低温低本底大口径光电倍增管读出；



CDEX预期物理结果



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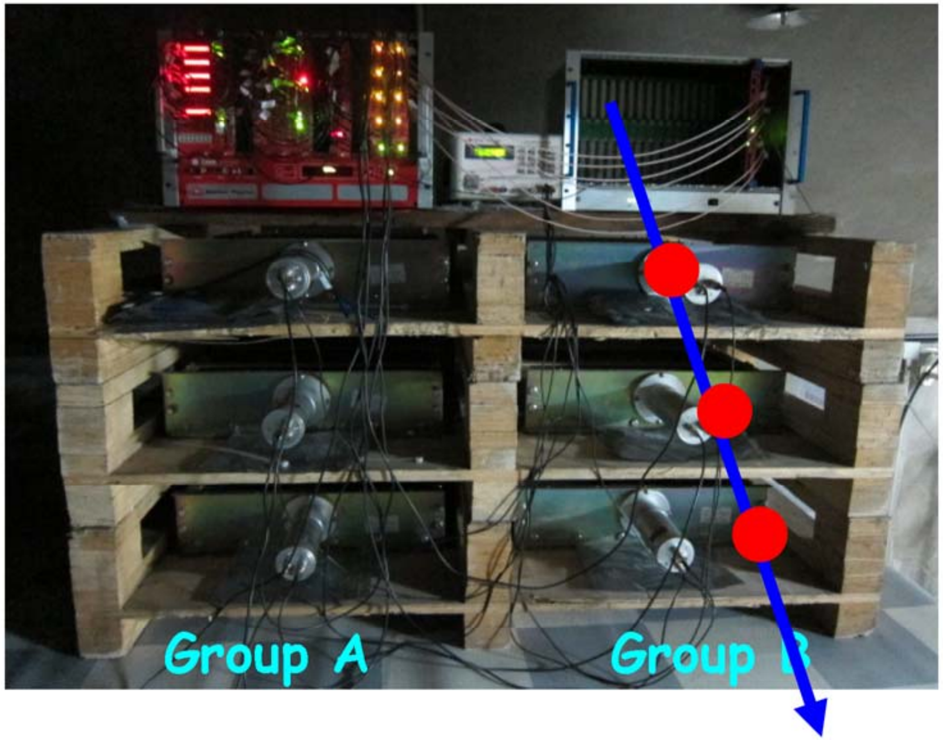
CJPL重要实验性能参数研究

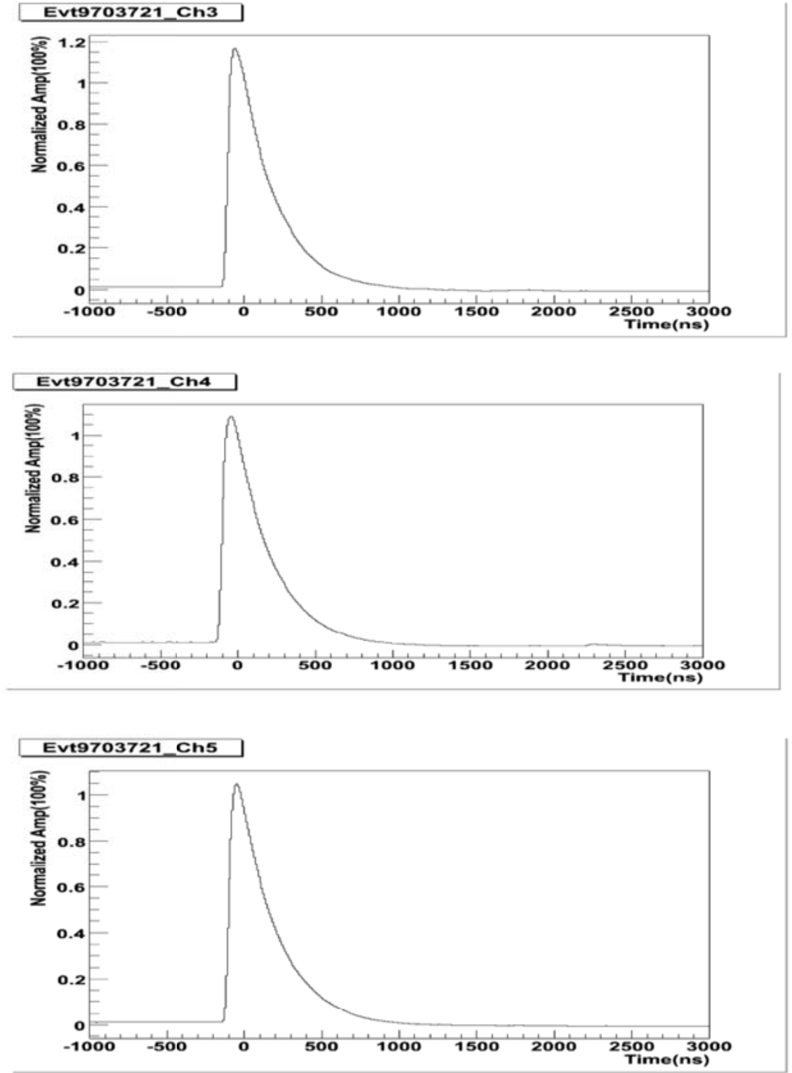
- 宇宙线通量测量；
- 本底伽马通量测量；
- 氡气含量测量；
- 热中子测量；
- 快中子测量；
- 低本底测量装置。

宇宙线通量测量

- 宇宙线通量是CJPL实验室最为重要的参数，是地下实验室性能的重要标志。
- 由于宇宙线通量极低，有效事例率极低，测量较为困难。
- 2011年研究工作取得了重要进展，得到了世界上最低的宇宙线通量值。
- 正在继续积累实验数据，准备正式的物理文章。

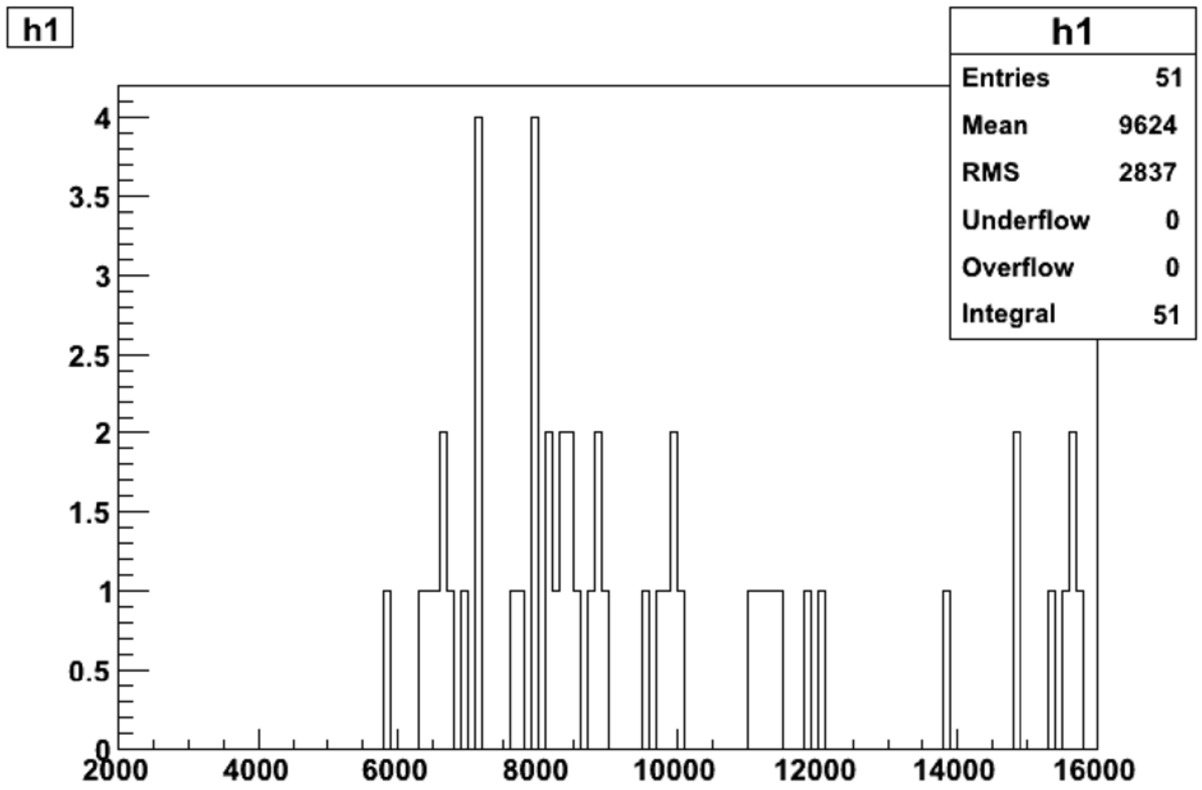
宇宙线通量测量





- 已经测量得到30多个可能事例！

宇宙线通量测量



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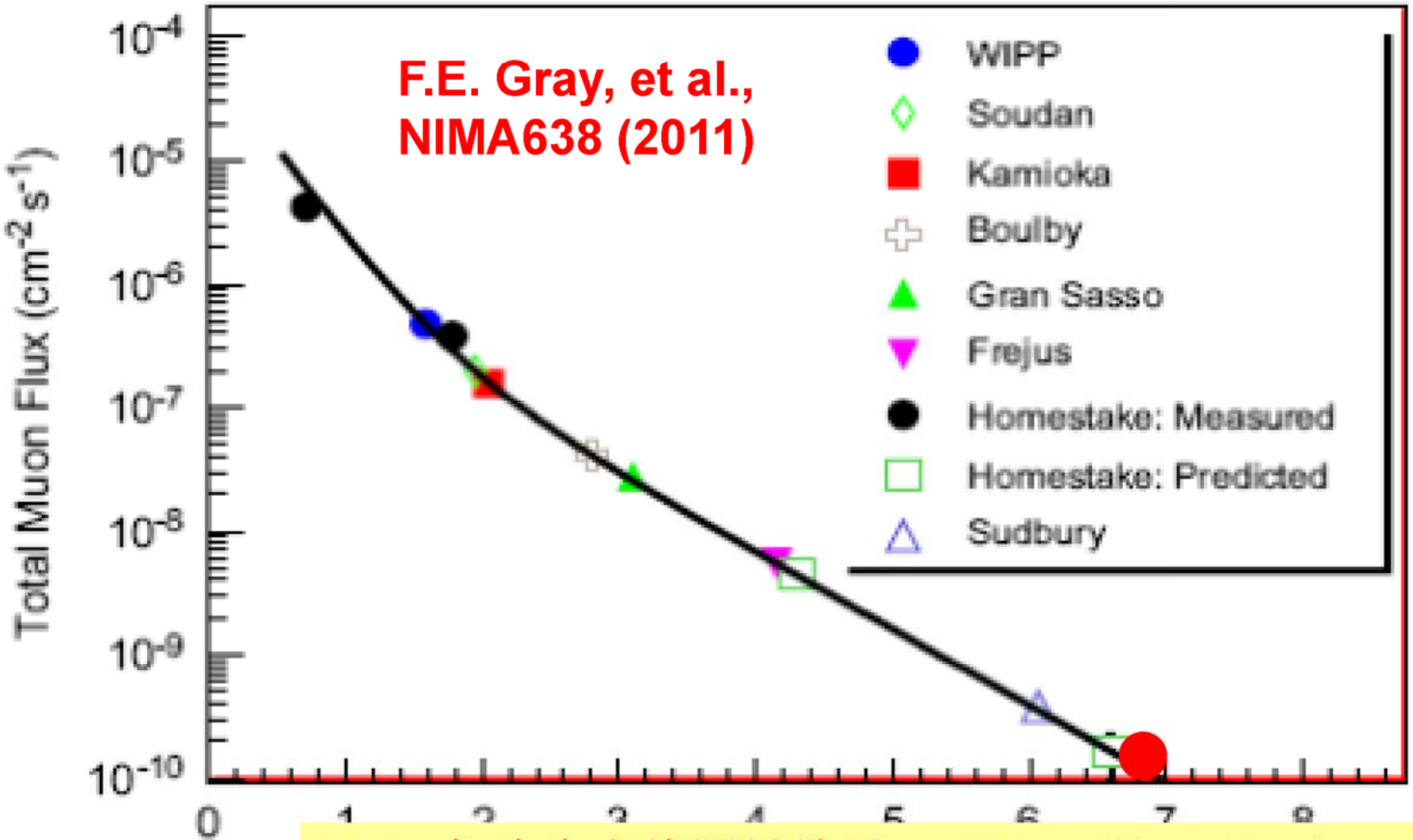
CJPL 宇宙线通量初步结果

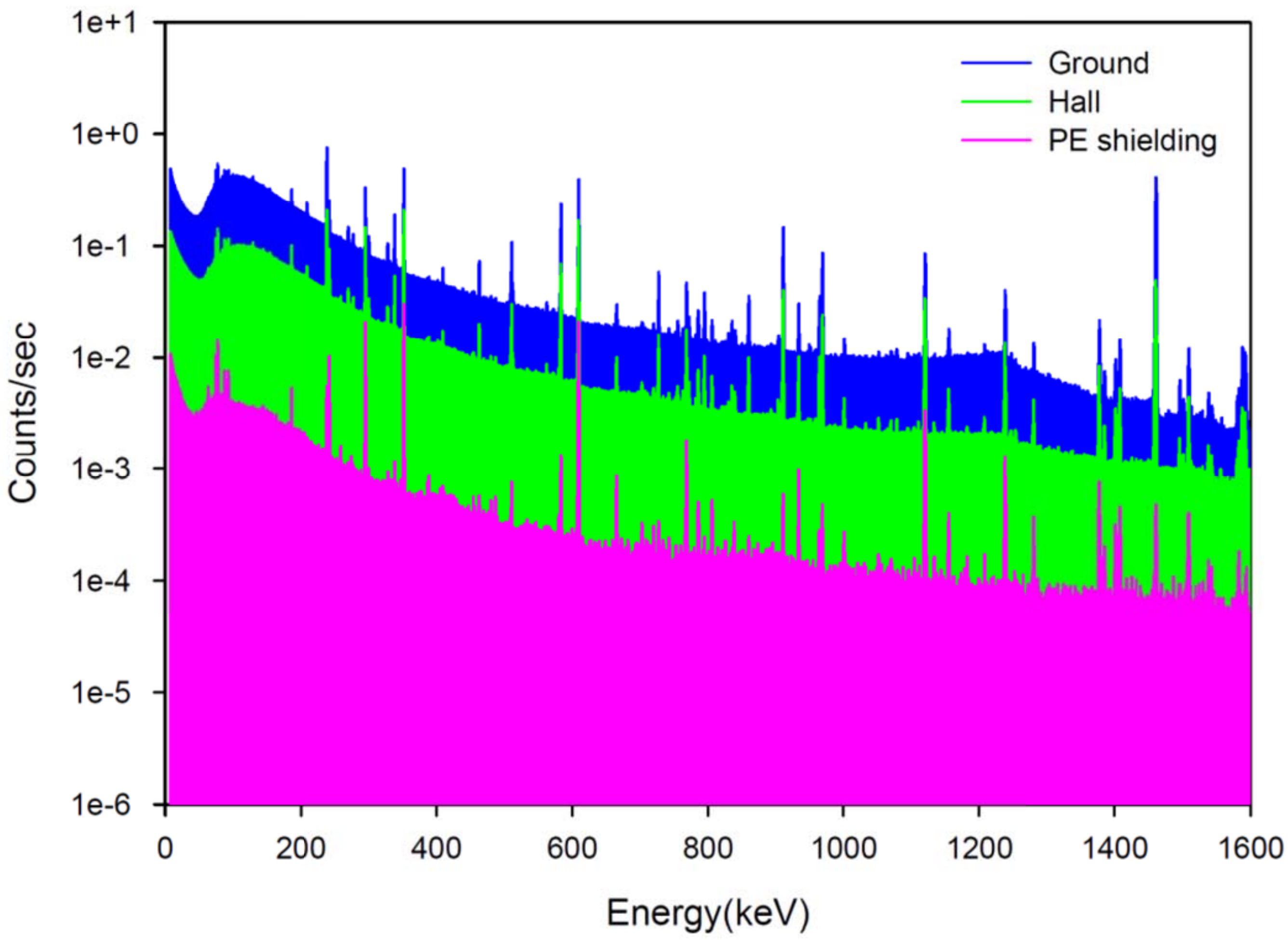
- 连续81天，测量得到17个宇宙线事例。深度数据分析正在开展。



CJPL初步宇宙线测量结果：~2×10^{-10} cm^{-2} s^{-1}
或 约每年每平方米70个， 是地面宇宙线通量的约亿分之一

实验室环境伽马本底测量

- 环境伽马来自周围岩石，混凝土，钢材等实验室建设和屏蔽材料。



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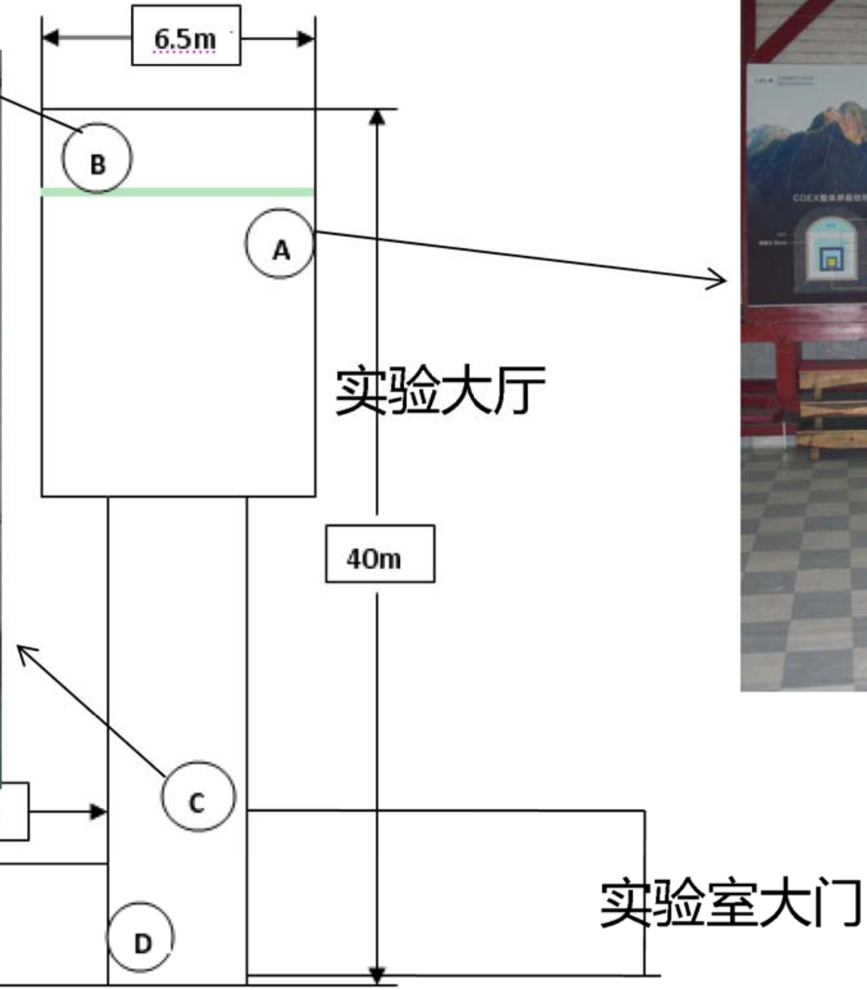
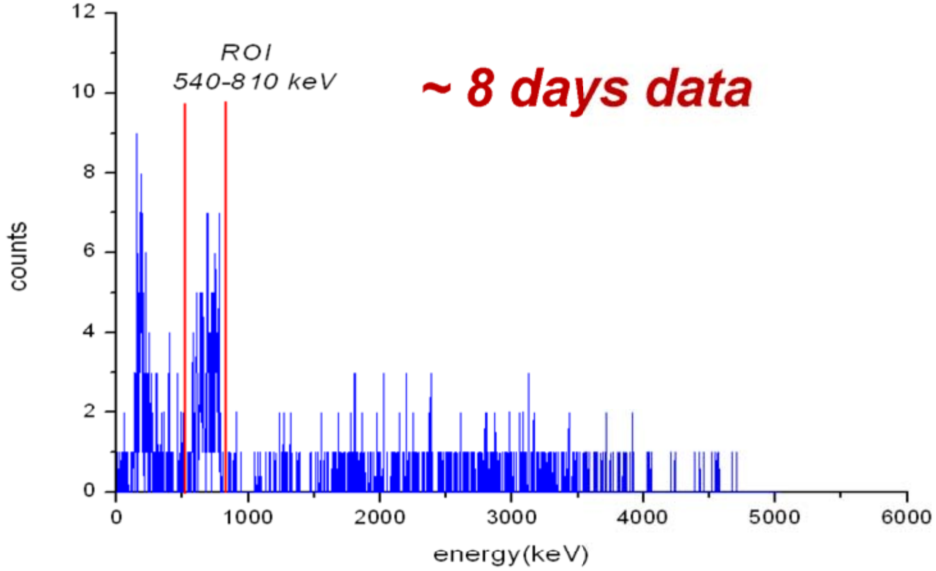
便携式高纯锗的实验点示意

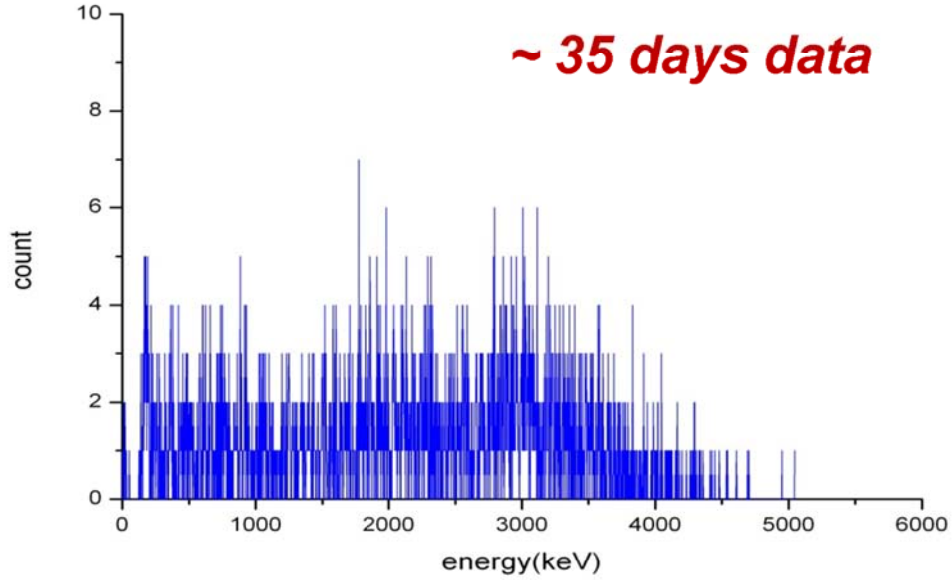


CJPL热中子通量测量

- 自行研制低本底He-3管测量热中子通量，需要定制；
  - 高纯无氧铜管壁减小本底；
  - 双端读出定位入射粒子位置；
  - 直径25.4mm*1m有效长度。

CJPL热中子通量测量初步结果





	大厅	屏蔽体内
ROI内计数率	34.11 cpd	3.71 cpd
α在ROI内的计数率	4 cpd	4.4 cpd
热中子的计数率	~30 cpd	< 1 cpd
热中子通量	4.34 x10^{-6} n/cm^2/s	< 1.45 x10^{-7} n/cm^2/s

极低的热中子通量！

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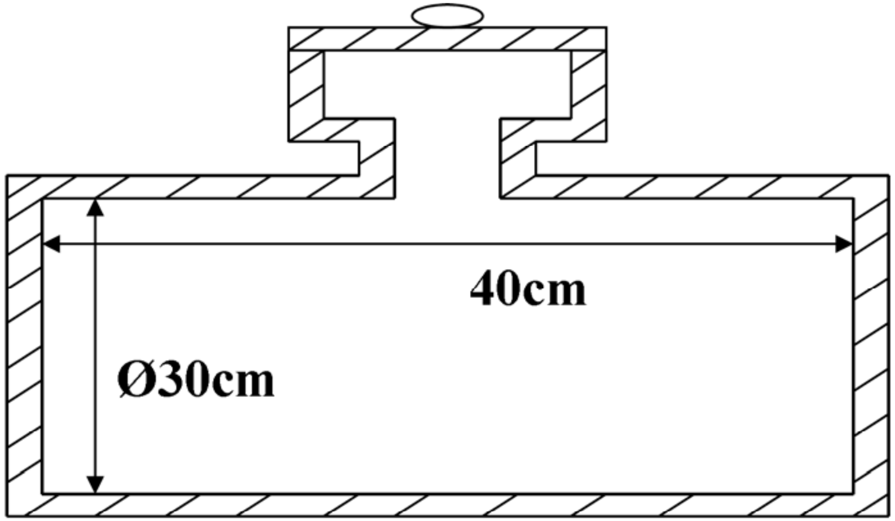
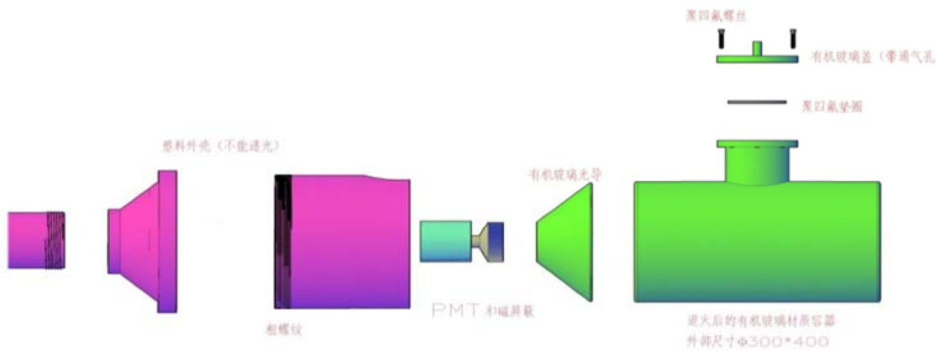
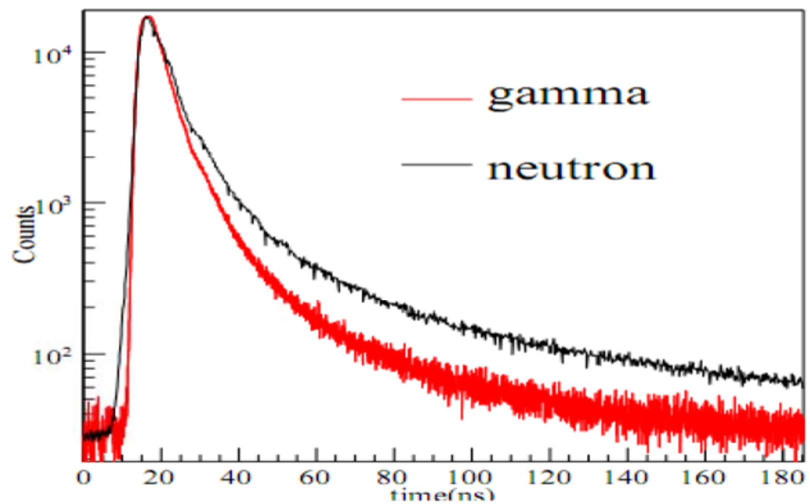
CJPL快中子通量测量

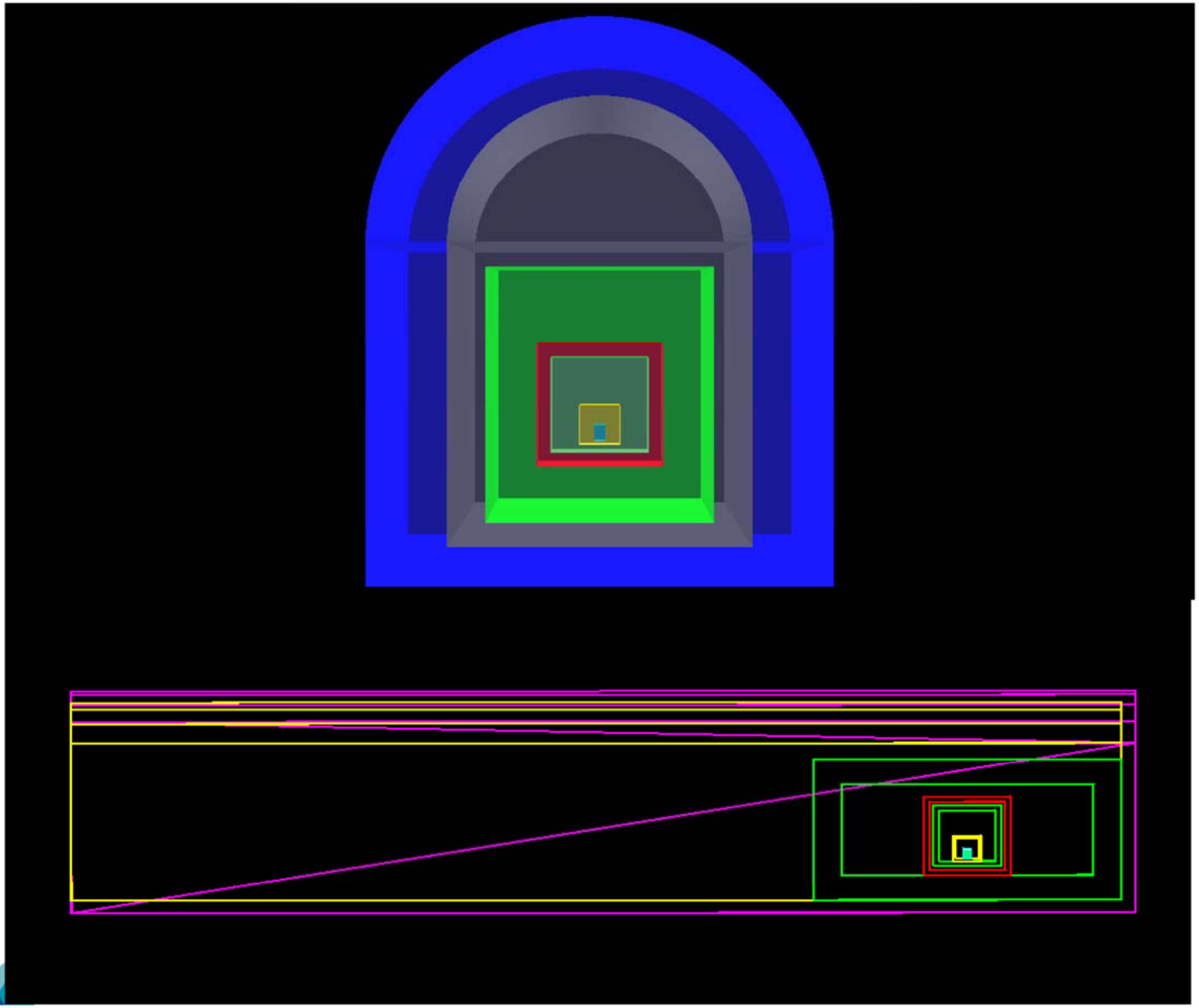
载钆液闪探测器，正在川大和原子能院开展地面实验室研究和刻度，2012上半年在CJPL开展研究工作。







CJPL快中子模拟研究



低本底测量装置的建立

GeTHU-0,
第一个探测器

↓

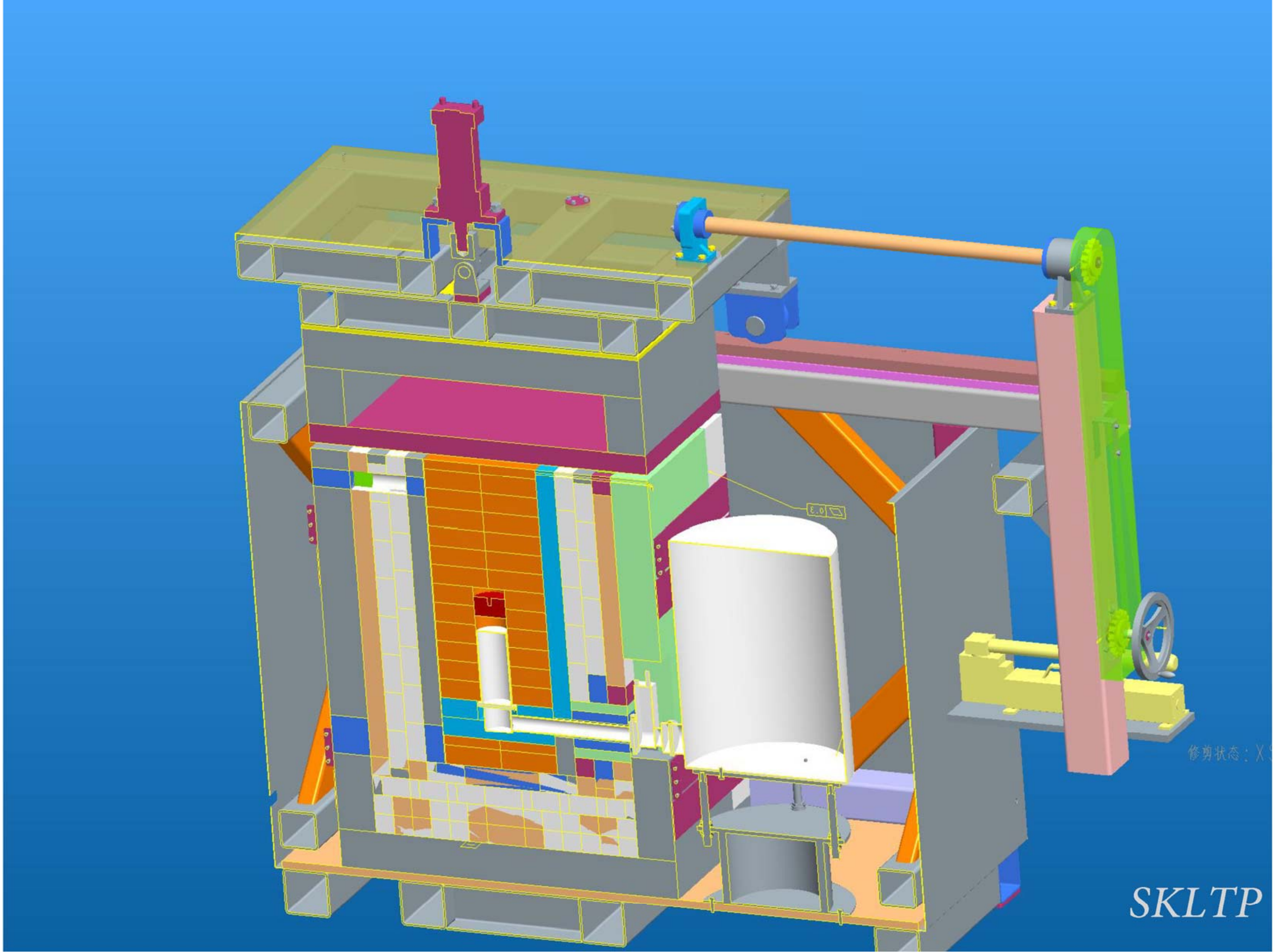
GeTHU-I, <1mBq/kg

↓

GeTHU-II,
~1μBq/kg

目的：

- 环境本底测量；
- 暗物质屏蔽材料选择；


修剪状态：X
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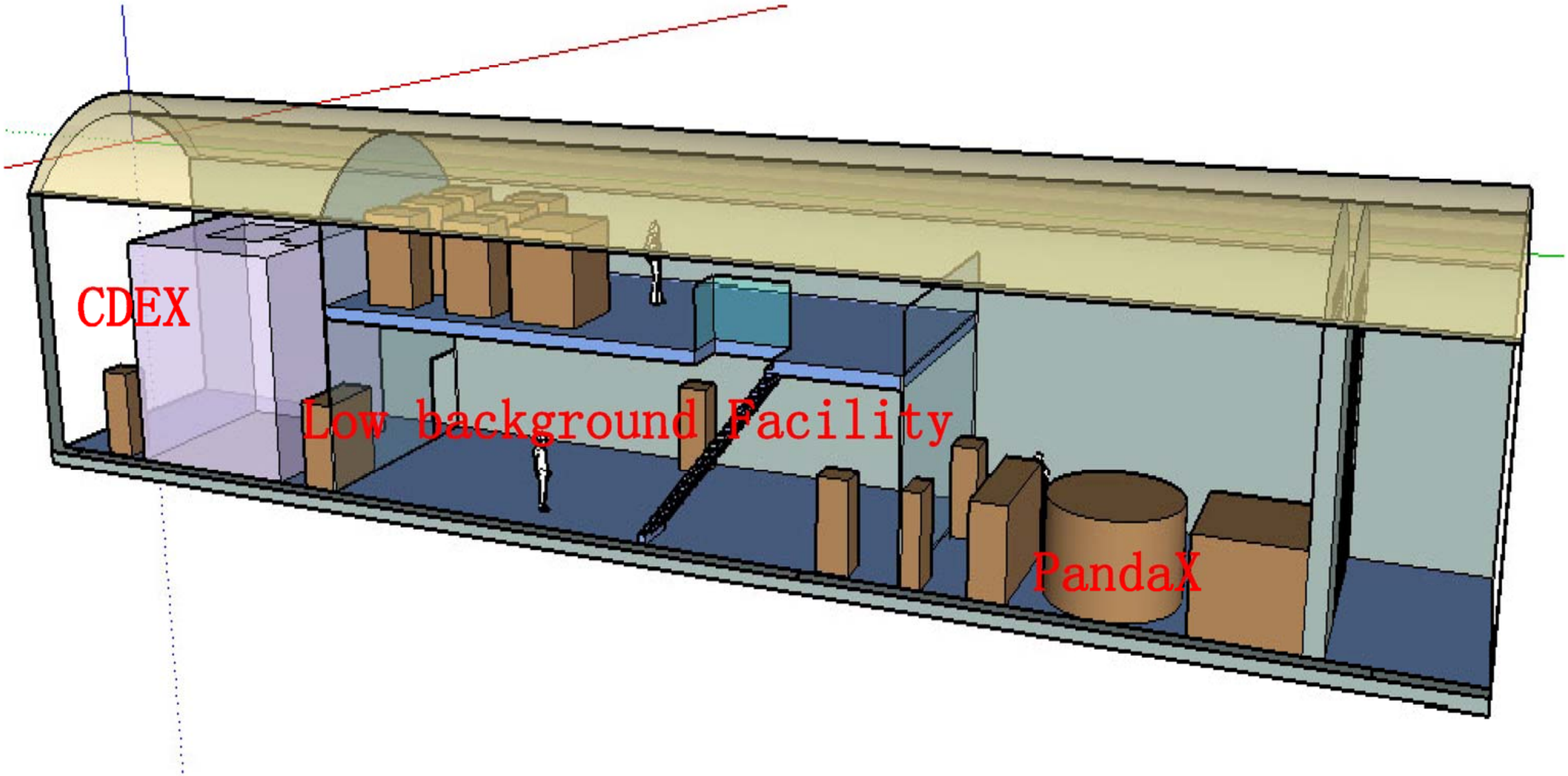
CJPL内部空间使用



通风系统改造

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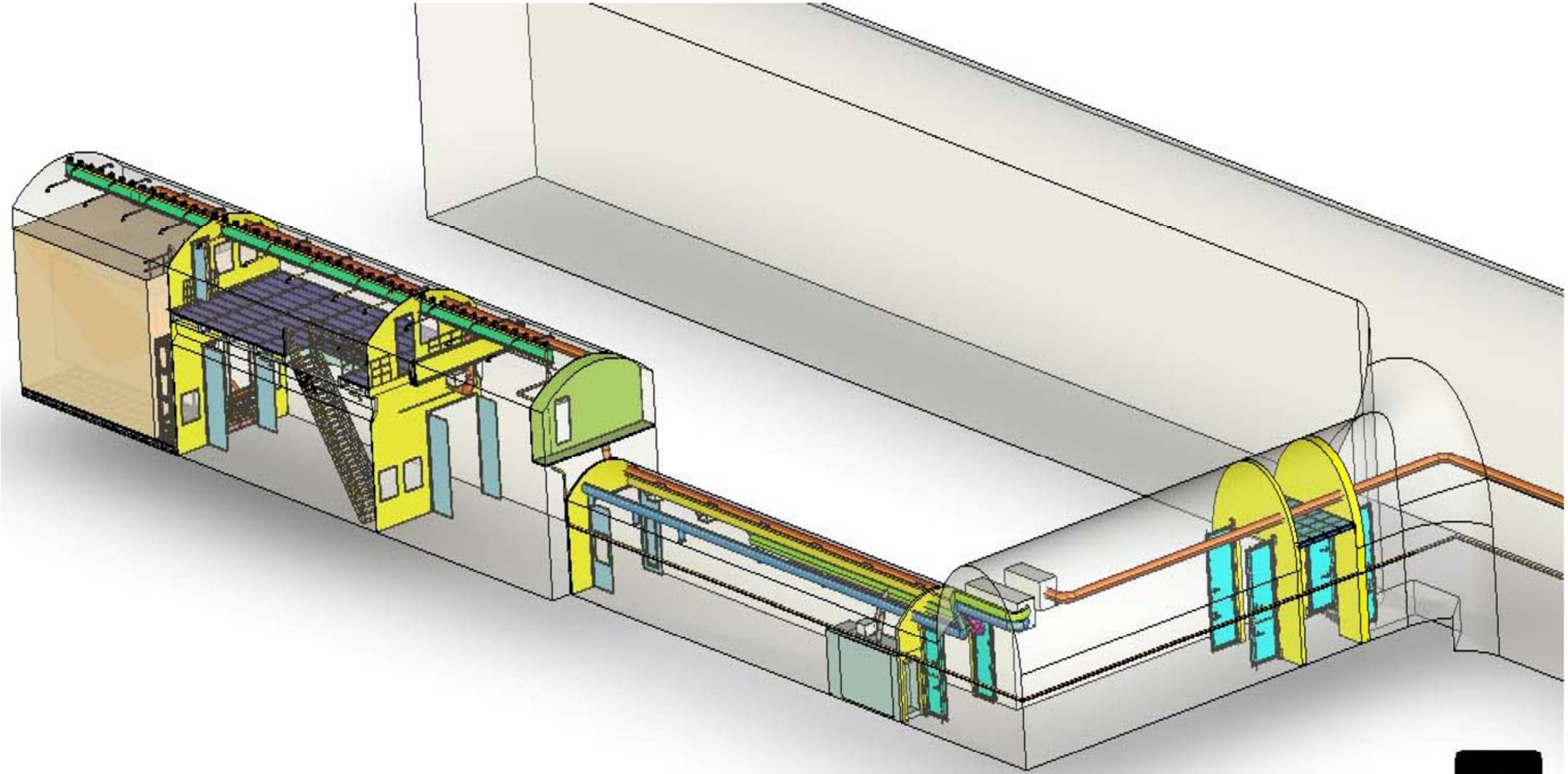

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总结

- 国际上暗物质研究在低质量区间竞争很激烈；
- CDEX合作组率先在CJPL中开展暗物质实验研究，CDEX-1的两个探测器应经开始数据获取，现正在数据分析；
- CDEX-10开始工程设计，LAr+PCGe是技术创新；
- CJPL宇宙线和热中子通量测量得到初步结果；
- CJPL通风系统改造完成，为下一步实验的开展提供了良好的实验环境和低本底环境。

CJPL China Jinping Underground Laboratory

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