Technical Specifications and Requirements on Direct detection for Dark Matter Searches

Jin Li
THU/IHEP

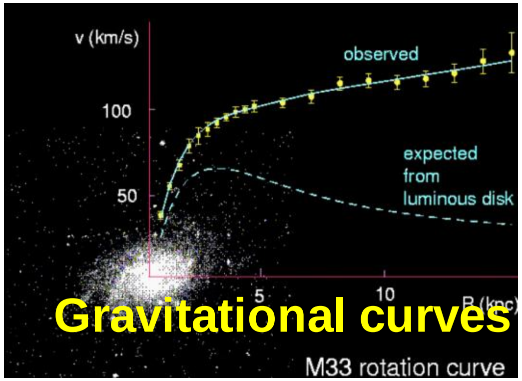
中国锦屏地下实验室
CJPL China Jinping Underground Laboratory

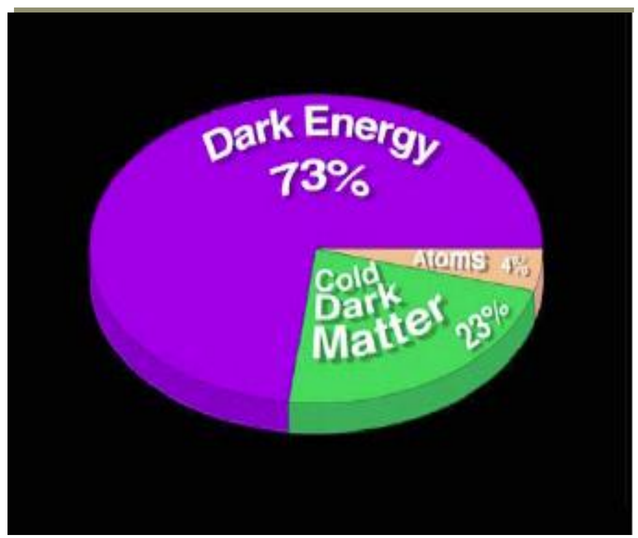
Symposium of the Sino-German GDT Cooperation
04/08/2013 Tübingen

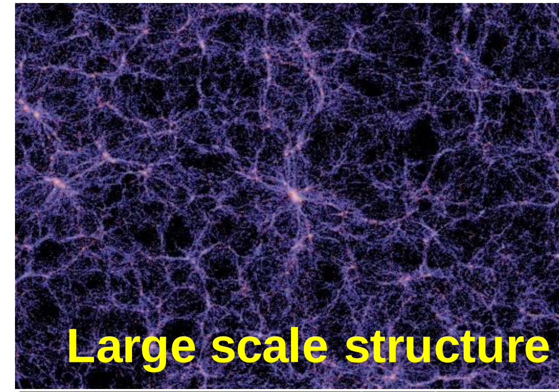
Outline

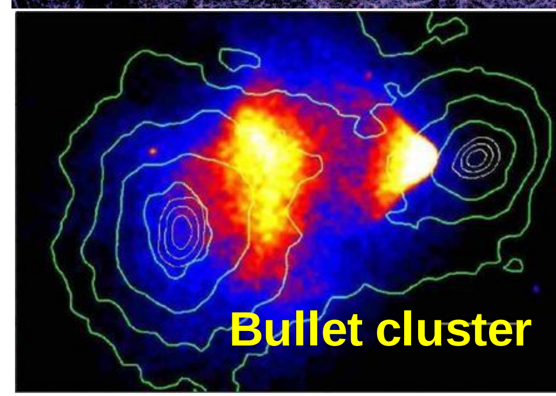
- Introduction
- Direct detection of dark matter particle WIMPs
- Requirements on detectors & experiment sites
- Typical direct detection
- Detection technology in the future

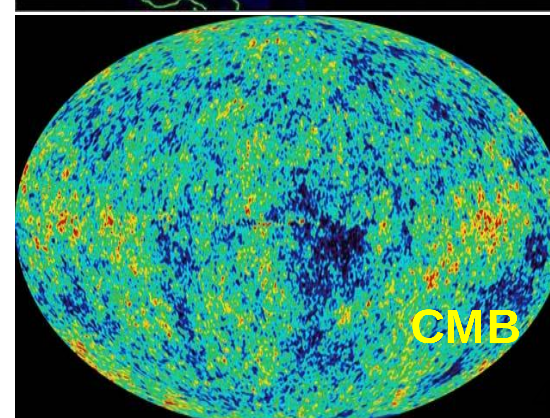
Evidences of DM from gravitational effects











Dark Matter

Can not be detected with any kind light

But it is in existence

With gravitational effects

And main part of universe

Questions

Is there interaction between DM & SM

What is the interaction

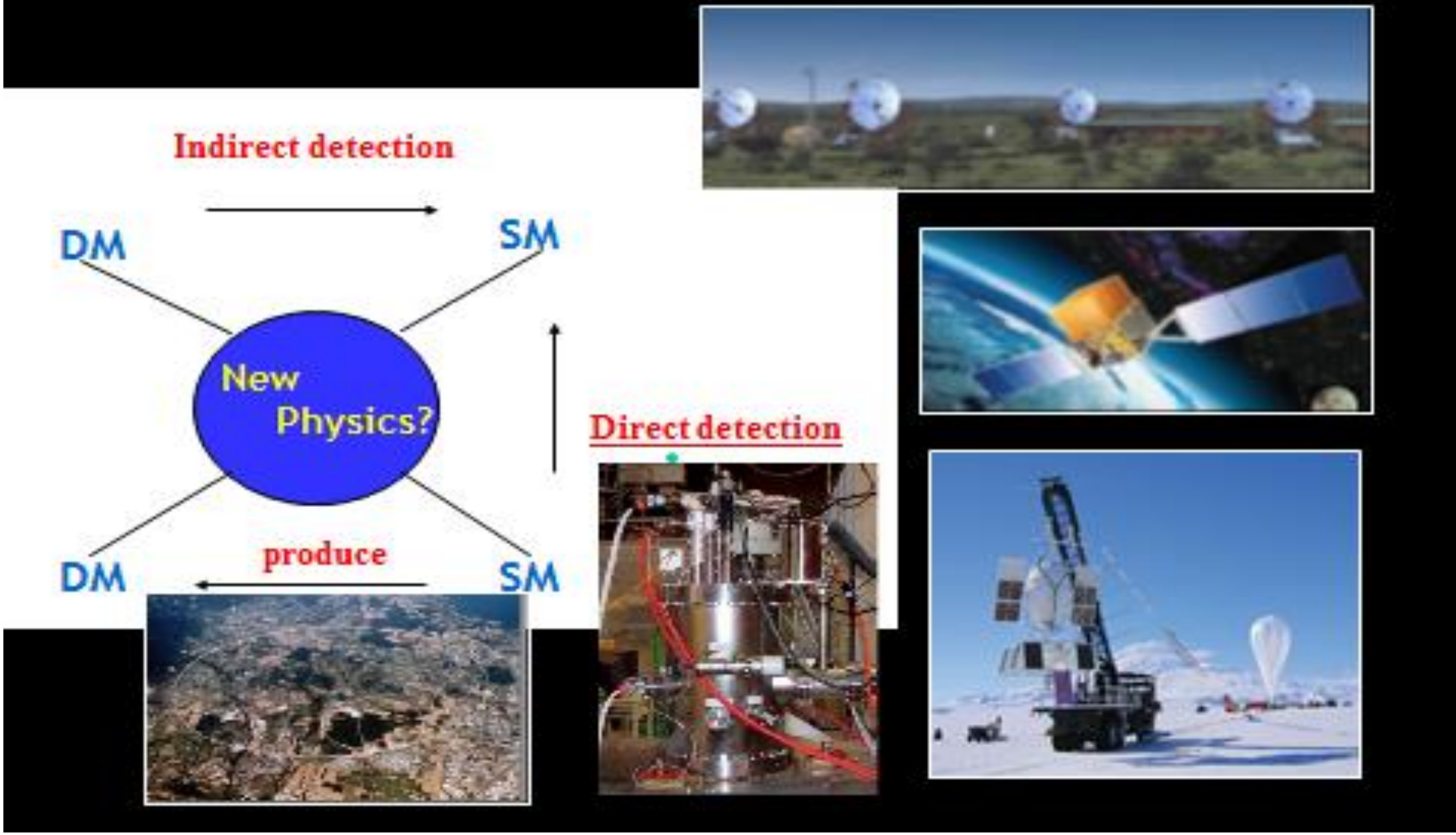
What is the mass of DM

…….

The direct detection could be answer the question !

There are many Candidates , we focus on the WIMPs

Detection of dark matter particle WIMPs



A, DM+ DM' → SM + SM'

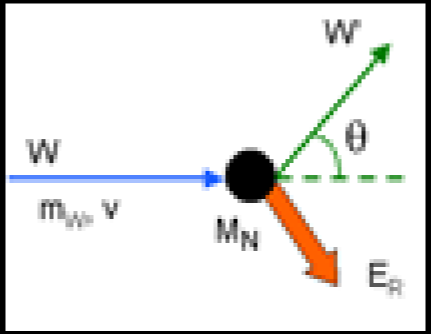
B, DM + SM → DM + SM

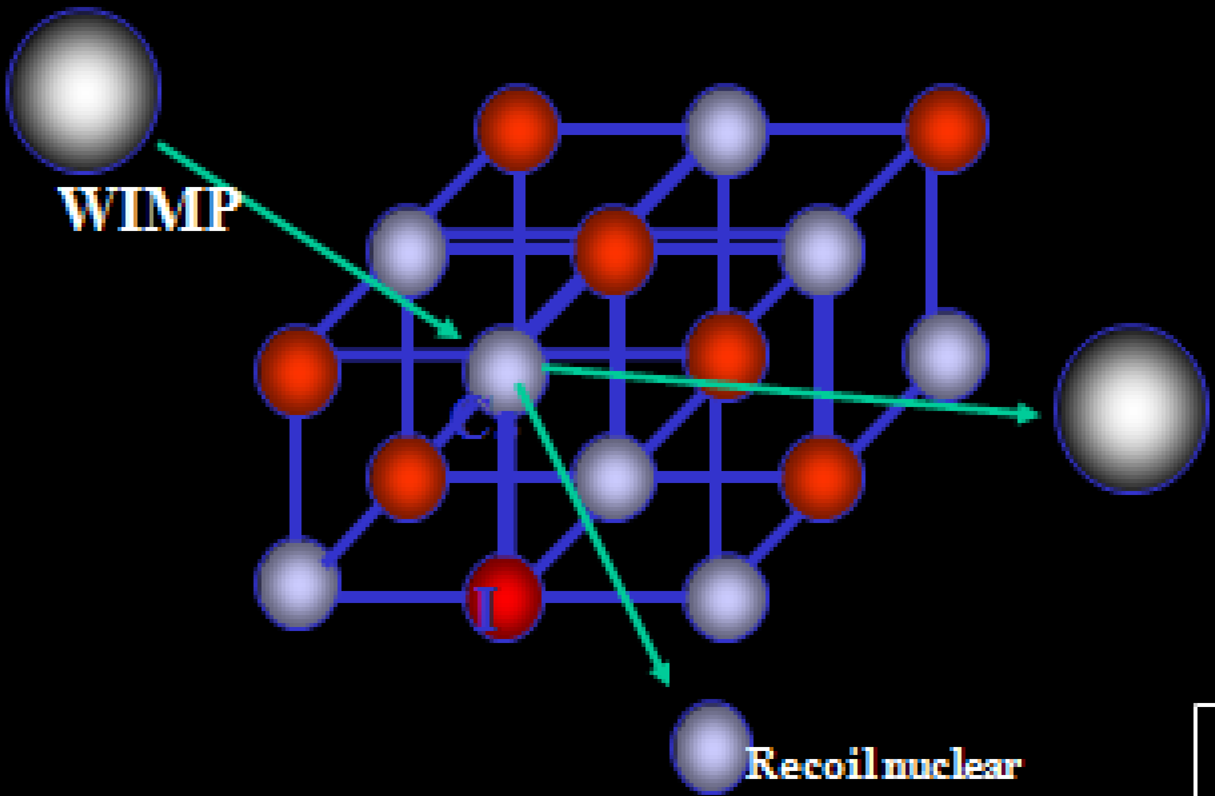
C, SM + SM→ DM + DM

We focus on the direct detection of WIMPs

Direct detection of dark matter particle WIMPs

WIMP nuclear elastic scattering





< 1/kg/day

Detector / Target

Deduce the WIMPs from detection of recoil nuclear

Properties of WIMPs

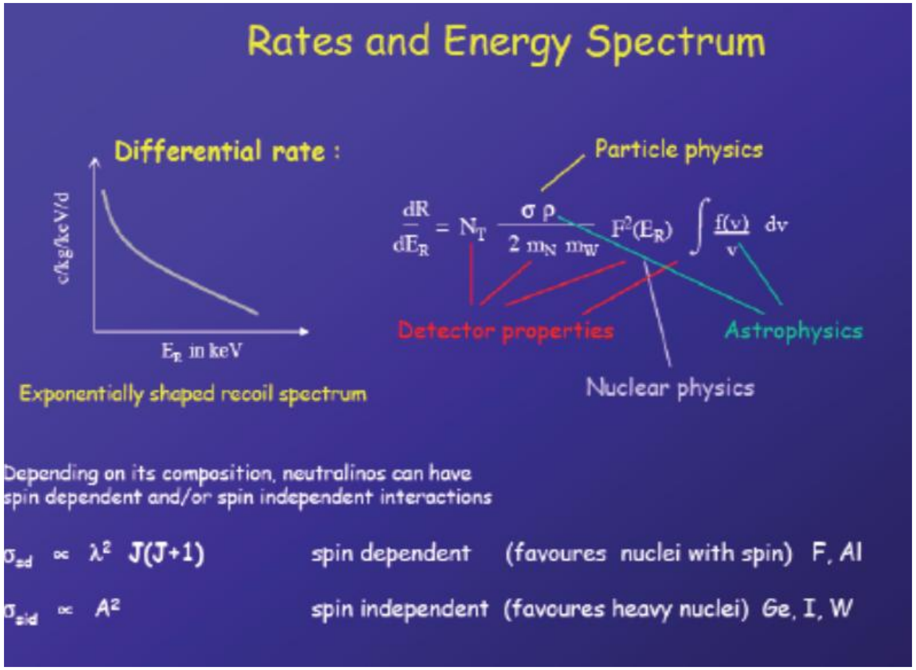
Suppose : Element particle

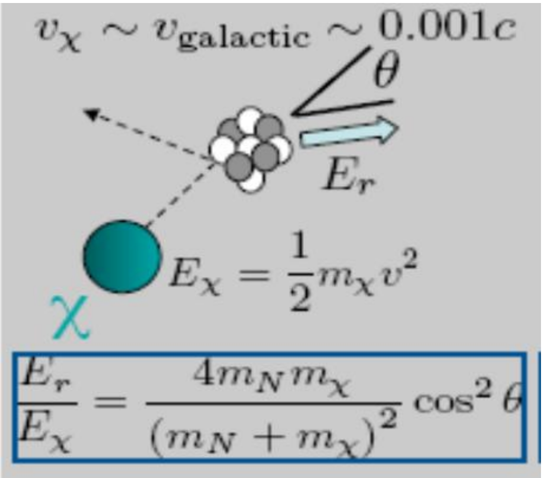
- stable, came from BB
- massive
- neutral
- speed very low
- <u>weak interaction ?</u>

WIMP mass : 10~100 GeV (or smaller)

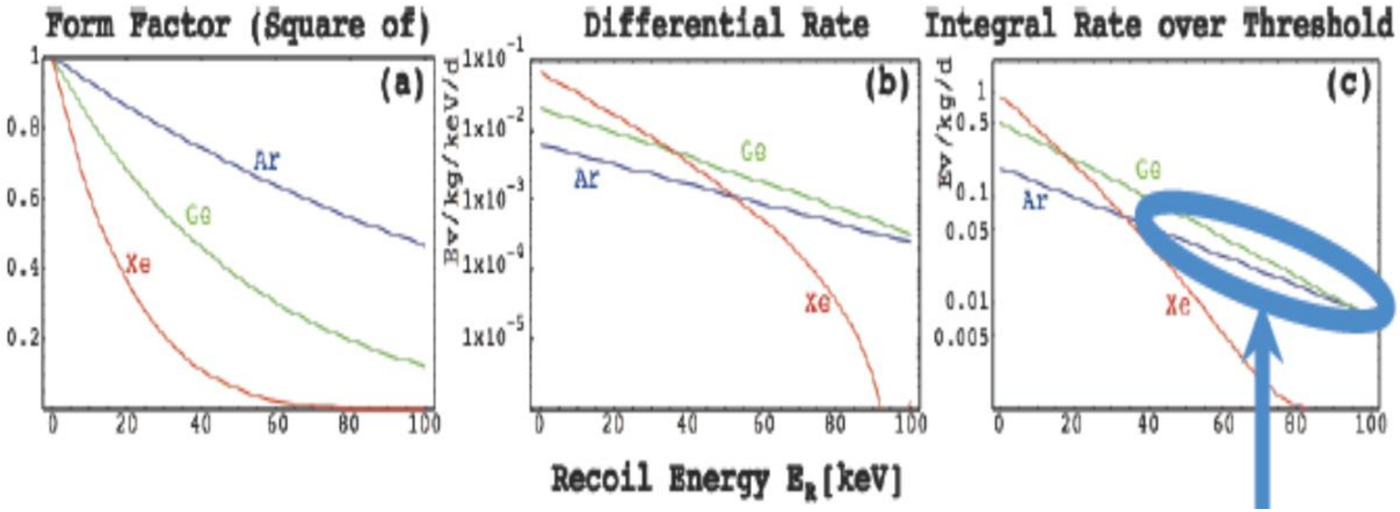
flux: 100,000/cm^2/s

Characteristic of WIMP nuclear elastic scattering





1, recoil energy very low
2, recoil energy depends on nuclear mass
3, exponential distribution of recoil energy
4, probability of collision (event rate) very low
5, recoil nuclear is charged ion and can be detected

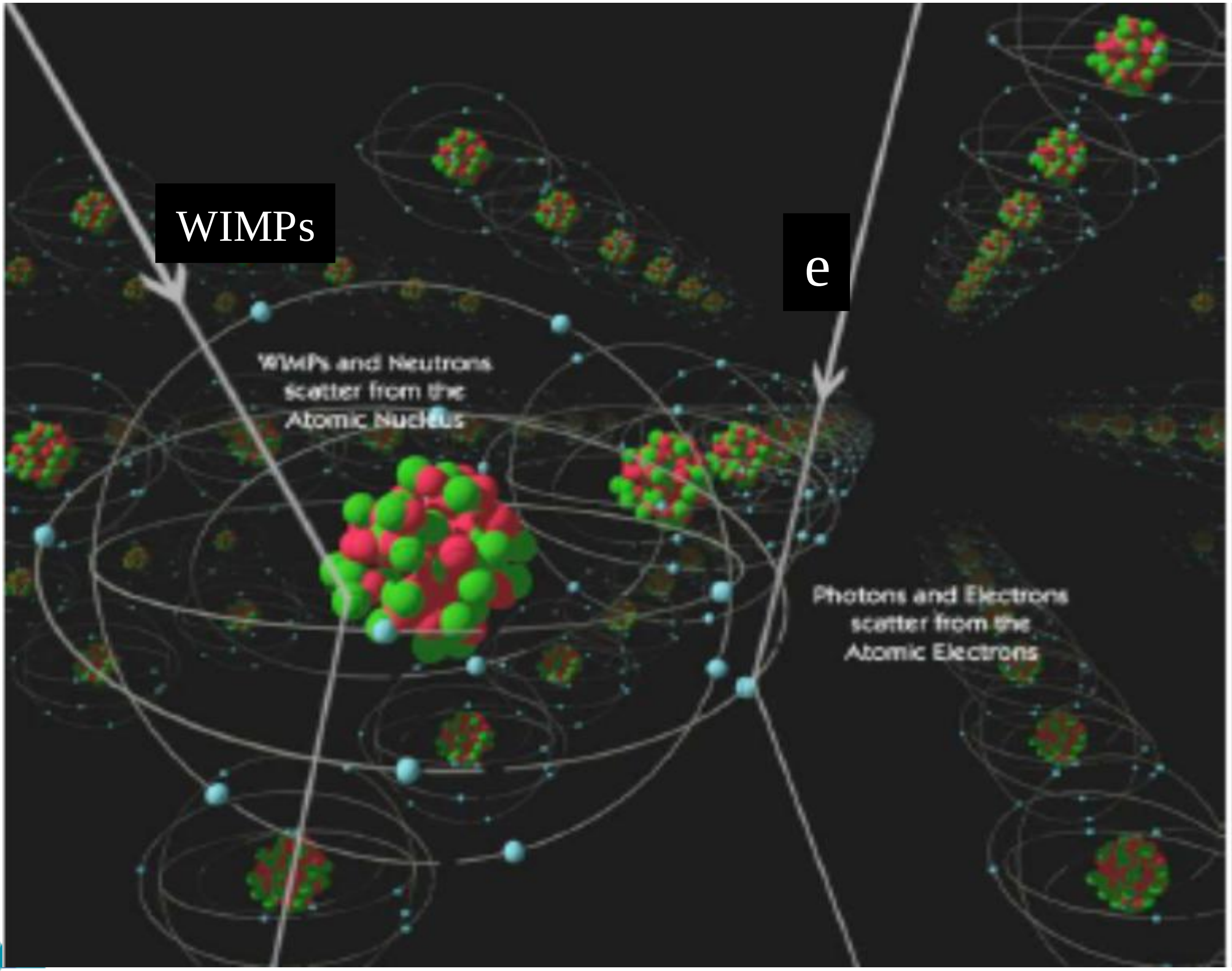


- Comparison of different detector (target) Ge, Xe, Ar
- WIMP 100GeV in mass
- 10e-6pb in cross section
- Background gamma ,neutron much high

CJPL

Most background are recoil electron

Very bad background are neutron



Requirements on detectors

- 1, detector must be target
- 2, large mass
- 3, high atomic number
- 4, high density
- 5, small ratio of surface/volume
- 6, low radioactivity
- 7, low noise
- 8, low threshold
- 9, ability to identify radioactivity background
- 10, long term stability

Big challenges

CJPL

Requirements on experiment sites

- Cosmic ray flux
- Low radiation environment
- Radon concentration
- Work condition
- Living condition

CJPL

Detection has to be in deep underground

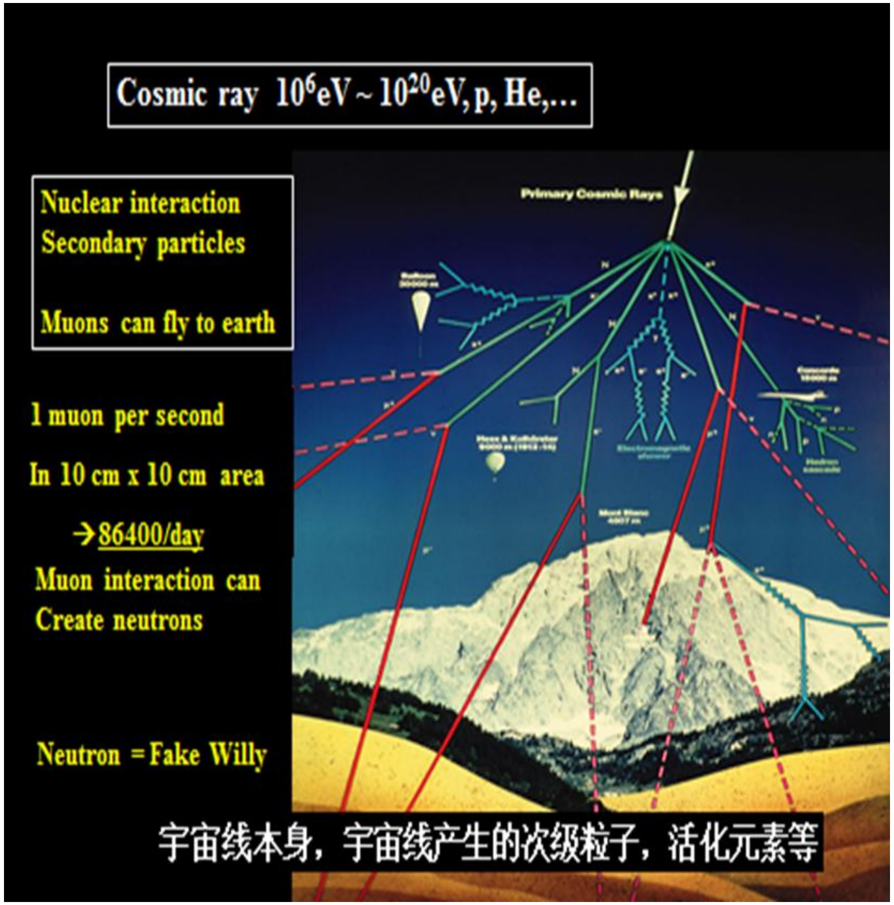
1, Cosmic ray: muon, proton

2, second particles produced
on the environment

3, second particles produced
on the shielding

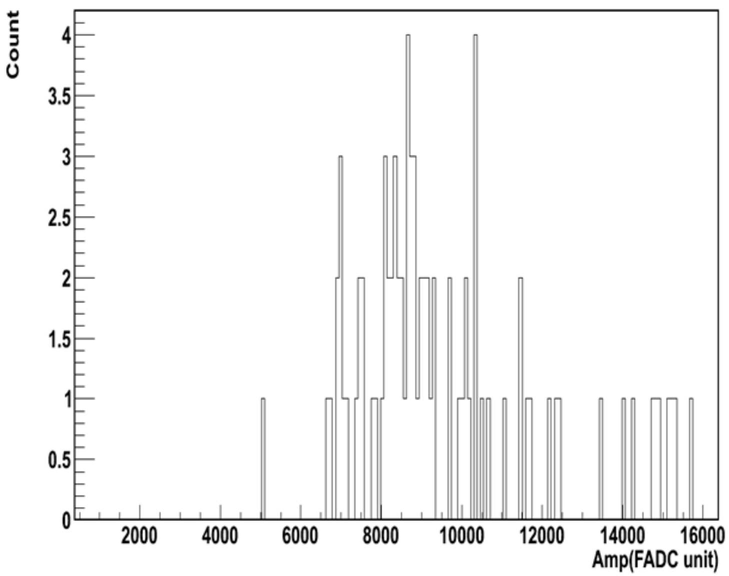
4, background produced
on the detector

5, neutron and Gamma

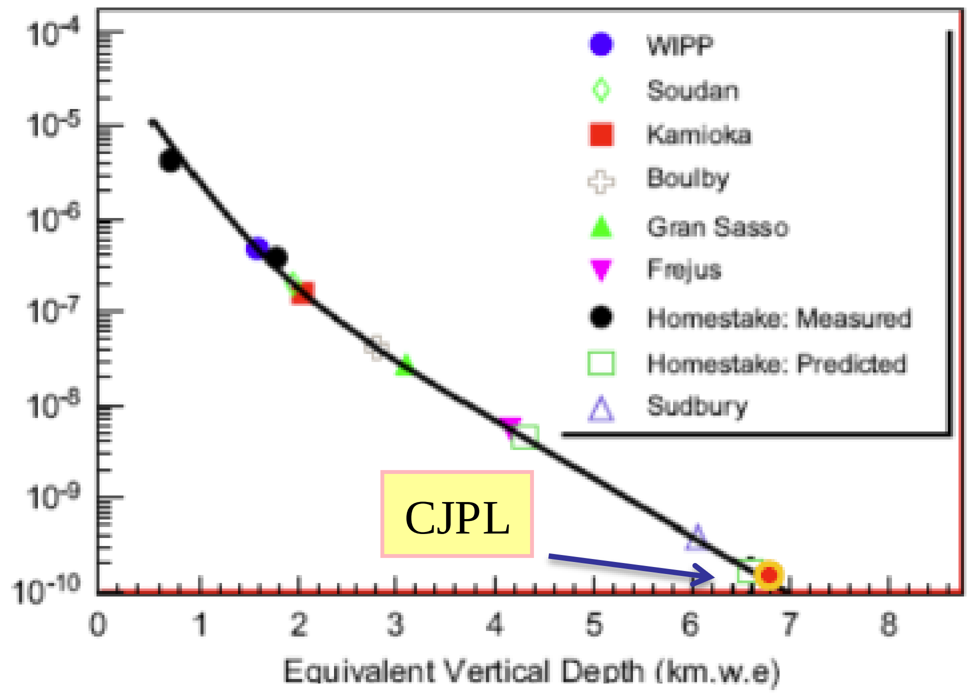


CJPL

Muon Flux in underground Labs



F.E. Gray, et al., NIMA638 (2011)

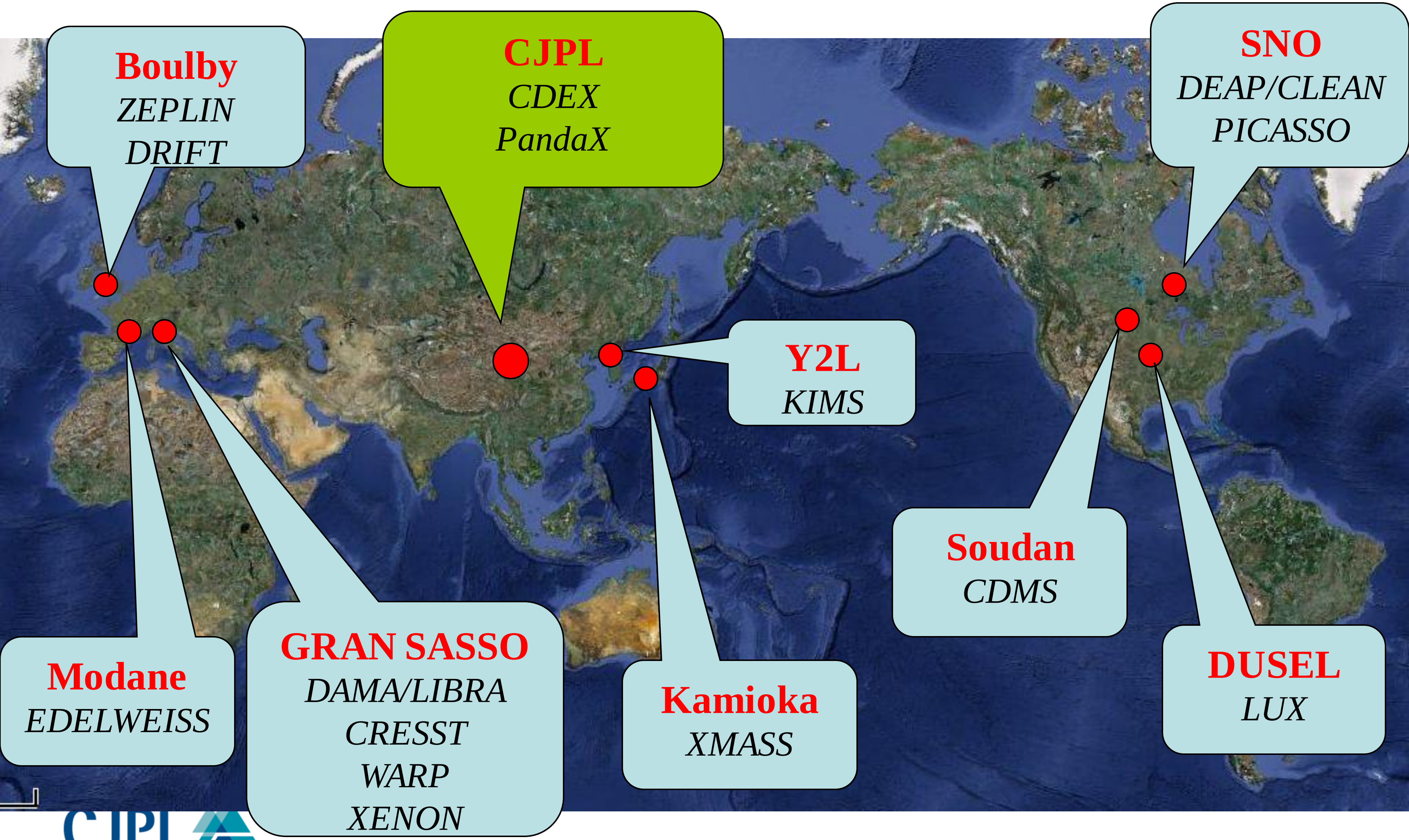


2 groups of 3-fold coincident Plastic Scintillators.

- 28 Cosmic Ray Events within 178 days.
- CR flux is ~ $2 \times 10^{-10} cm^{-2} s^{-1}$, ~ 10^{-8} of ground level.

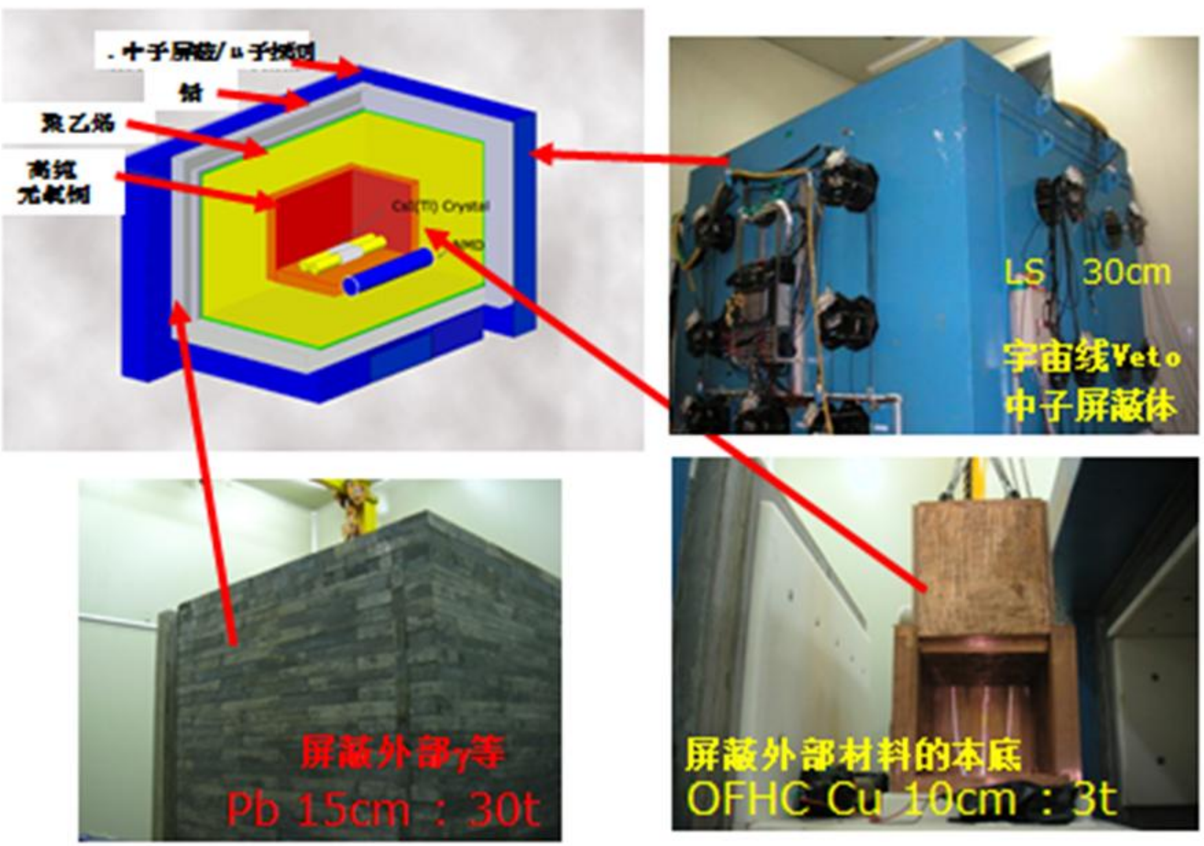
CJPL

International Main Undergound Laboratories



Detection needs passive shielding & active shielding

中韩合作Y2L地下实验室KIMS实验屏蔽体和VETO



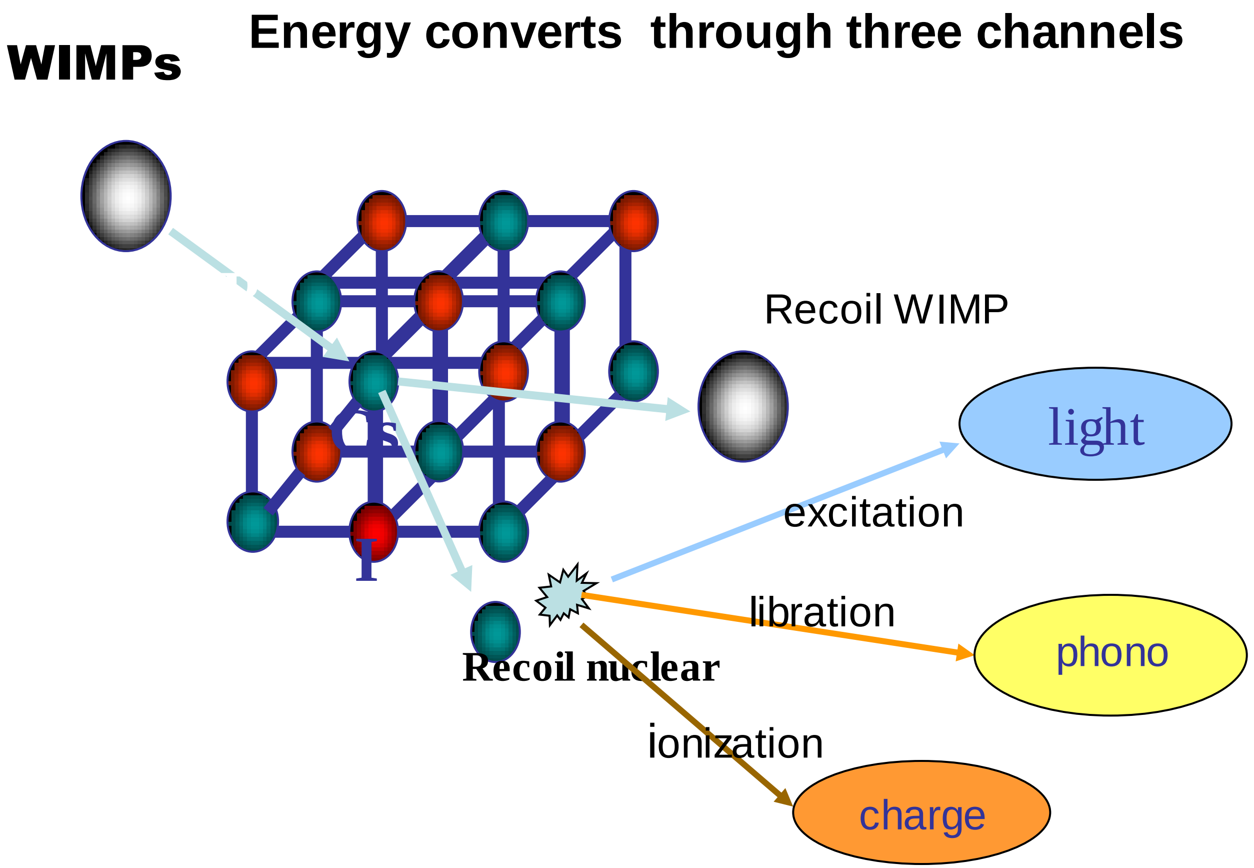
1, Active veto

2,Shielding

Lead
Polyethylene(PE)
Boron +PE
Cu

3, Blow gas

Principle of direct detection of WIMPs



Recoil nuclear is charged particle which can be detected

Events rate 0.01cpd. Energy : 1-100KeV

Background: cosmic ray ; gamma , neutron, surface contamination

Experiment has to be in undergroungd

CJPL

Technical Specifications on typical detectors

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

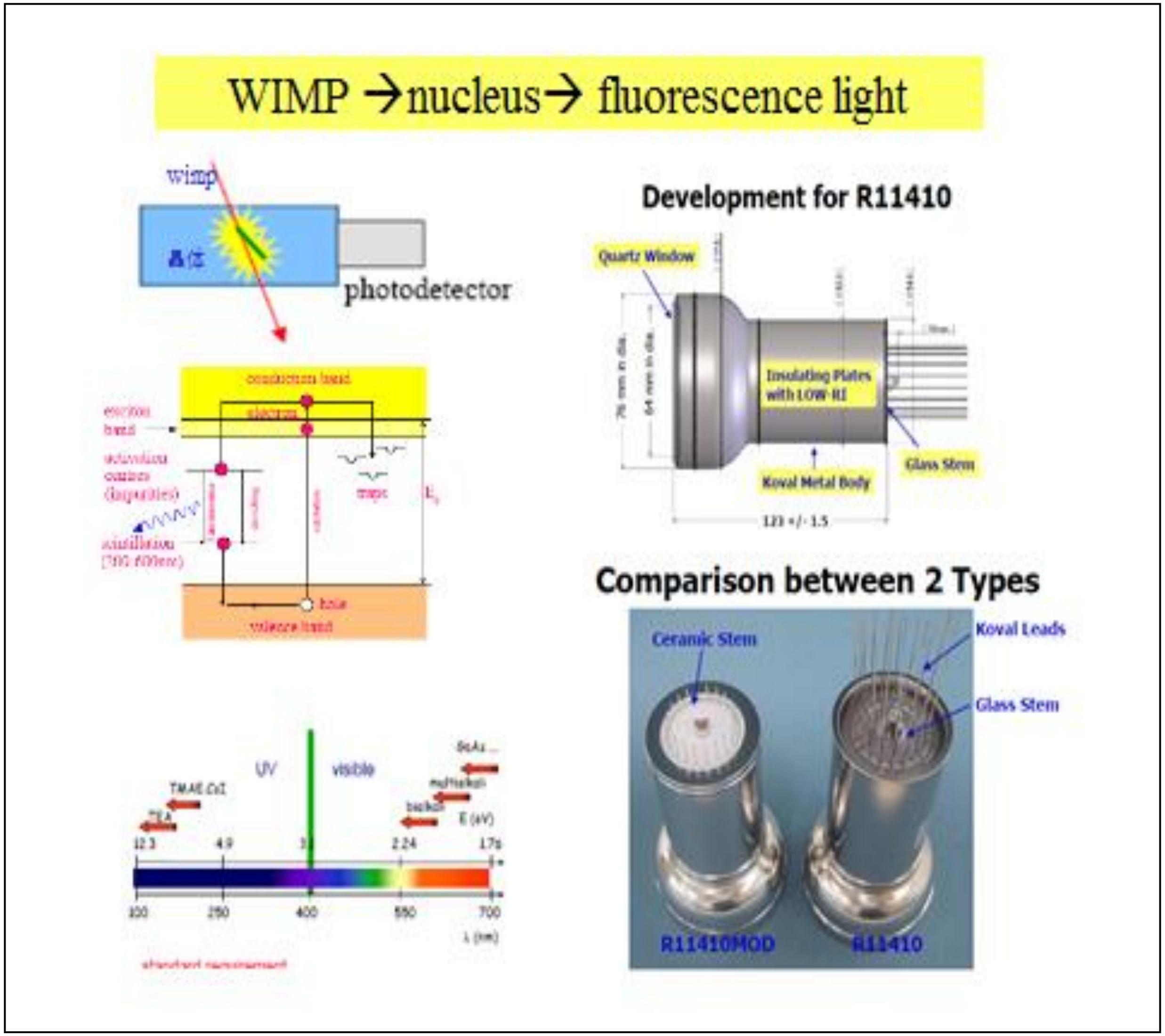
Symposium of the Sino-German GDT Cooperation
04/08/2013 Tübingen

1, Scintillation Crystal Detector

Detect light only

- Large mass
- high density
- Convenience
- Simple & easy
- PSD

- internal radiation
- Quenching factor
- Channeling



CJPL

Pulse Shape Discrimination & internal radiation

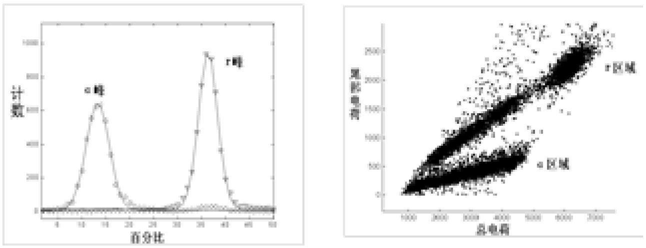
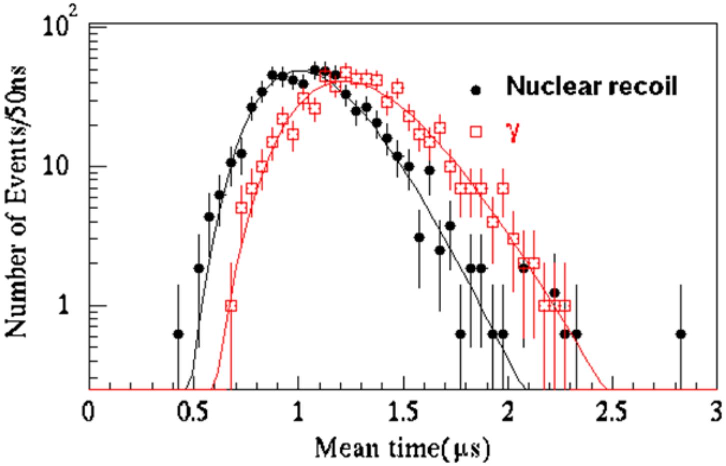
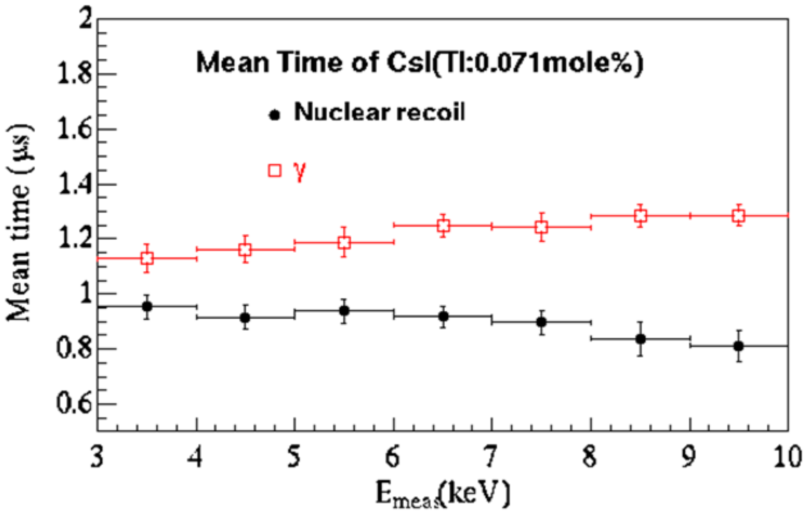
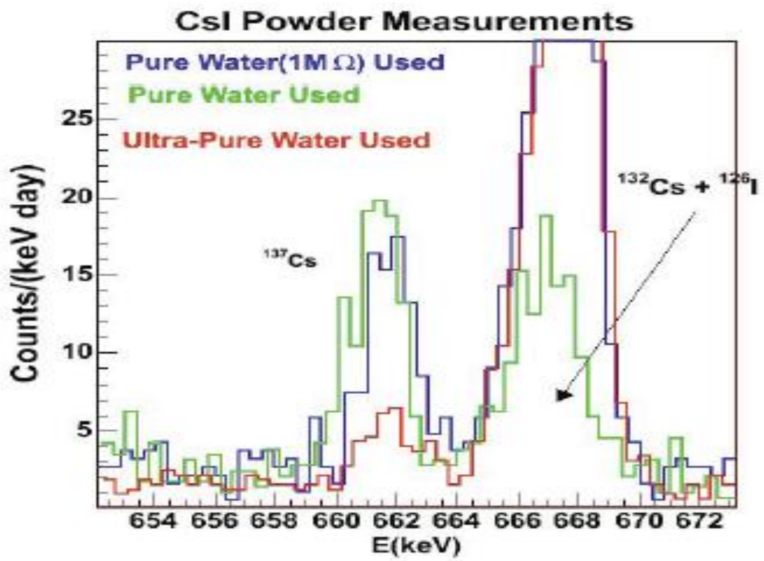


图 5.2.3 一个实测甄别谱形，采用电荷比较法.　　左图是甄别谱，此图计算出的优质因子 FOM=2.21

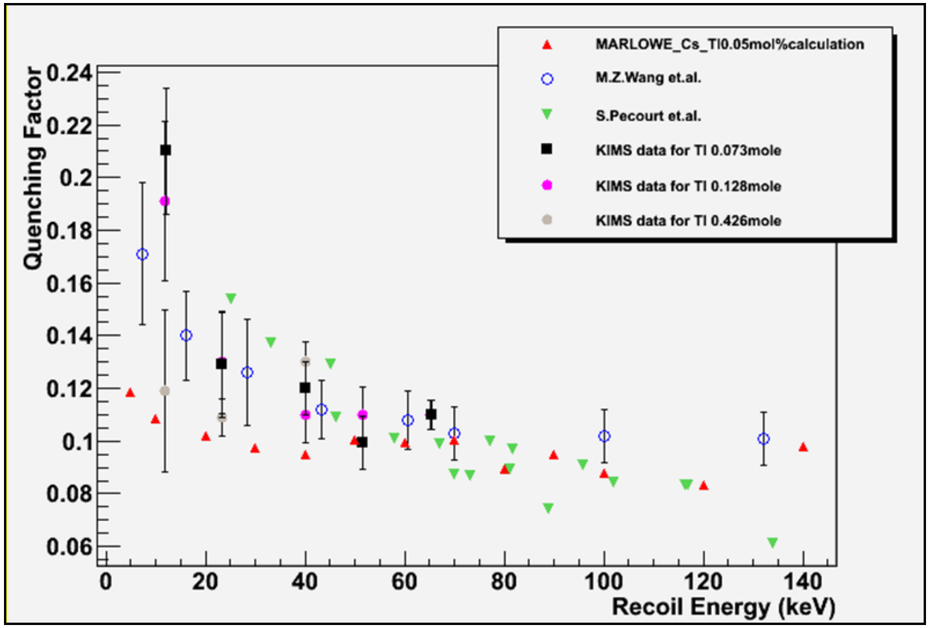




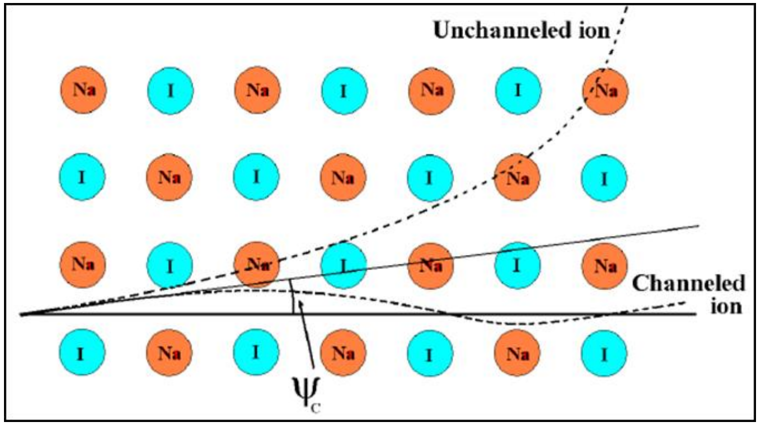


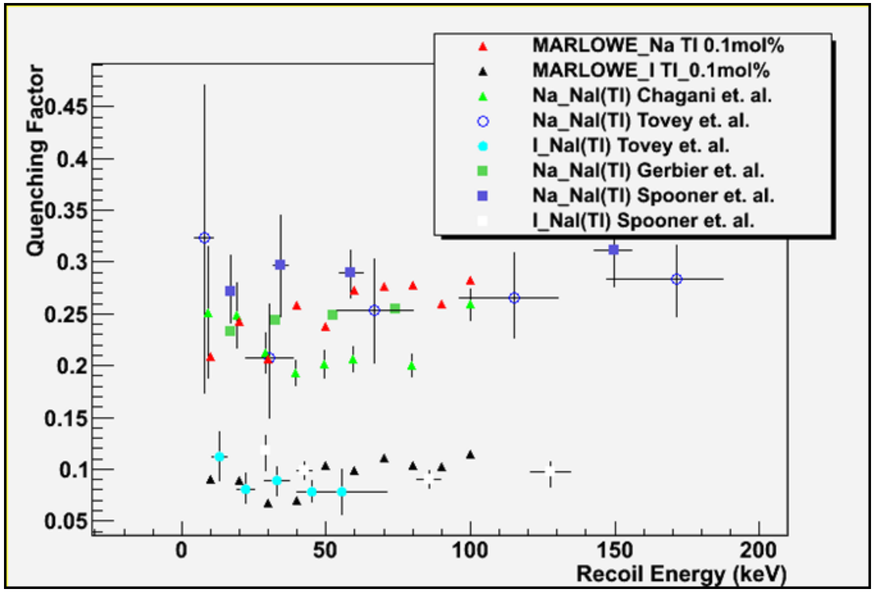
CJPL

Quenching factor & Channeling



$$\alpha_R = \left.\left(\frac{L_R}{L_{e-}}\right)\right|_E = \left.\left(\frac{\varepsilon_R L_R^{output}}{\varepsilon_{e-} L_{e-}^{output}}\right)\right|_E = \frac{E_R^{ee}}{E_R^{th}}$$



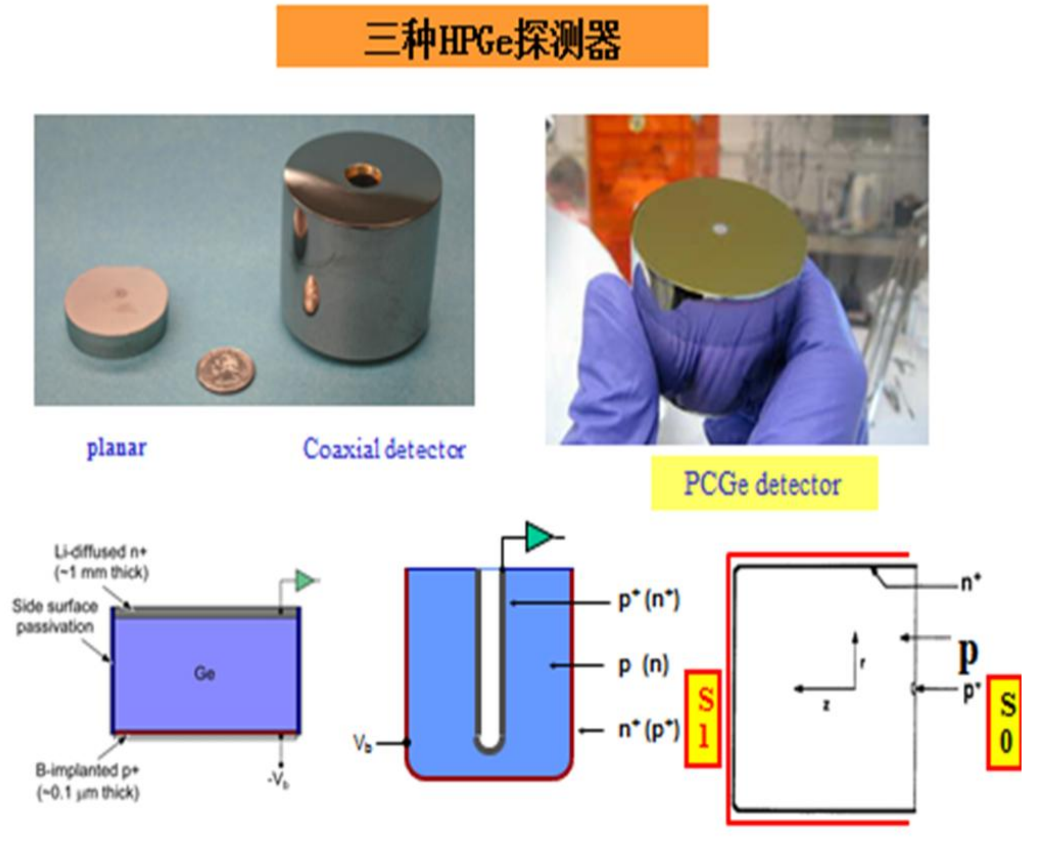


2, HP Ge detector / PC Ge detector

Detect charge only

High efficiency
High resolution
High density ,
Large mass
Pure material(internal radiation
Low noise/ Low threshold
PSD

Low temperature(77K)
Background suppress

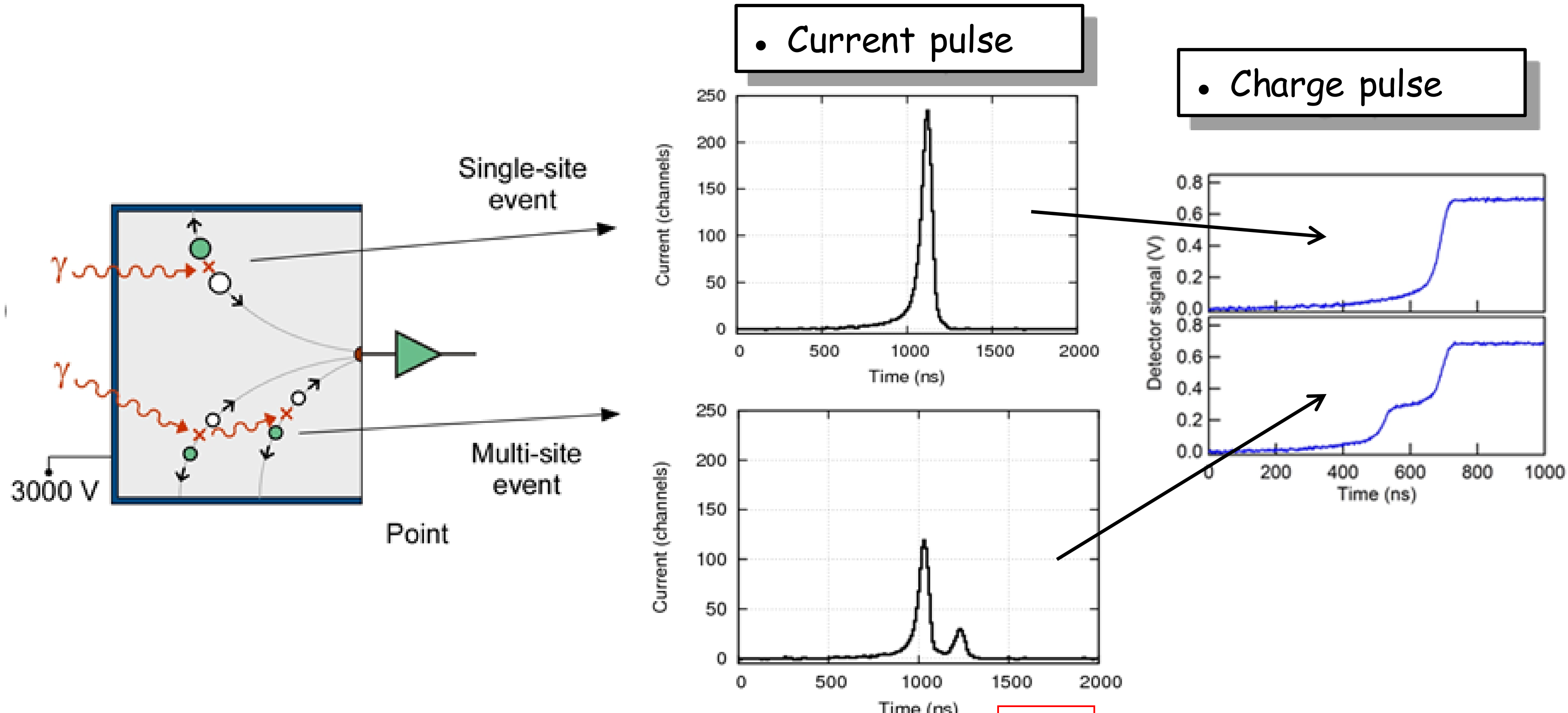


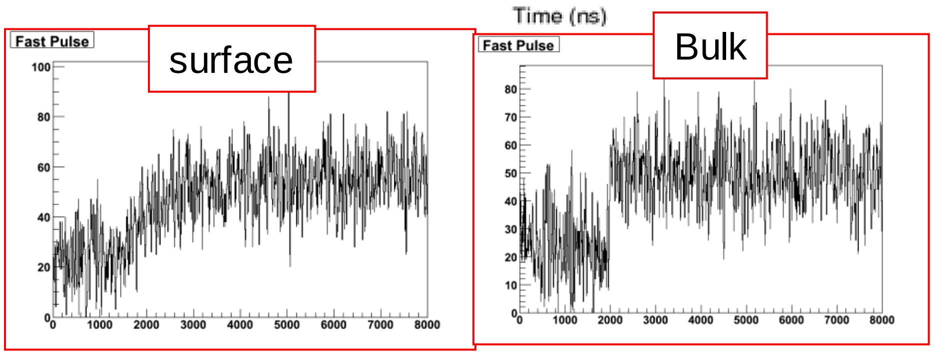
Typical Performance : Summary

Measurement	ULEGe	PCGe
Detector Mass	4 X 5 g	500 g
Pulser FWHM	80 eV	160 eV *[expect ~130 eV in next detector]*
Noise Edge	200-300 eV	~500 eV
50% Trigger Efficiency @ Discriminator Threshold	~80 eV @ 4.3 σ	~ 180 eV @ 3.1 σ
50% Selection Efficiency	~200 eV	~300 eV

CJPL

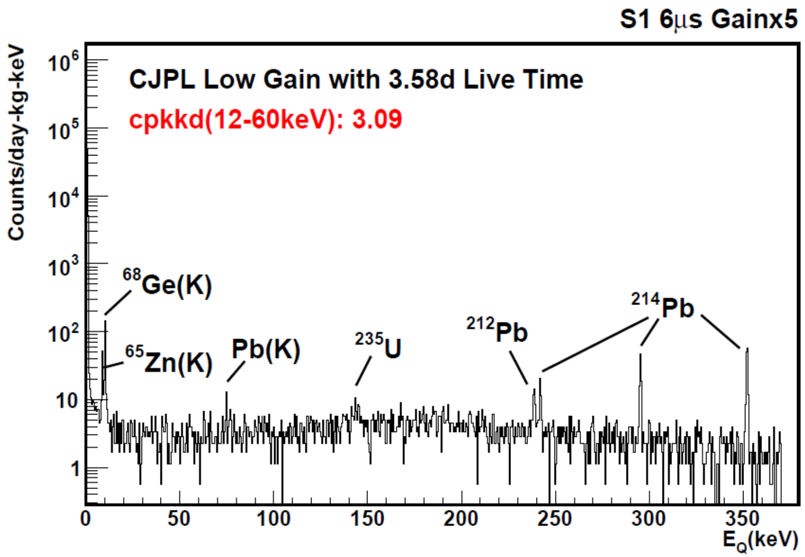
Pulse Shape of PCGe

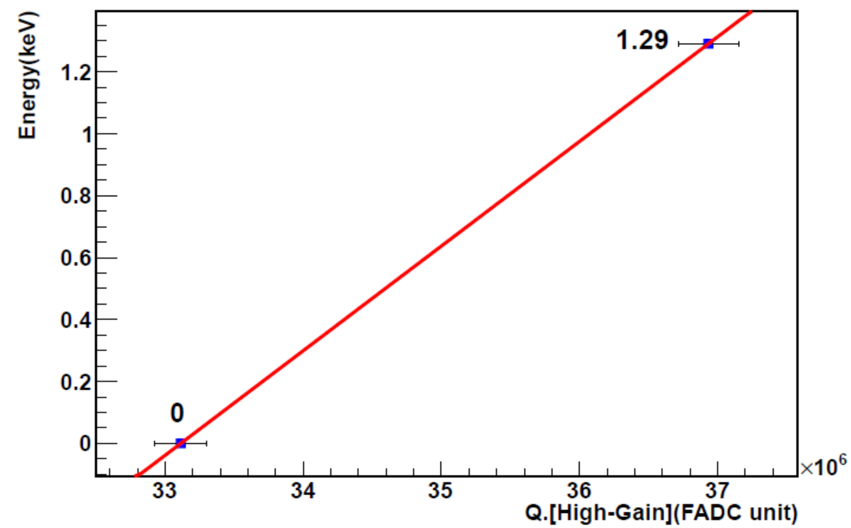


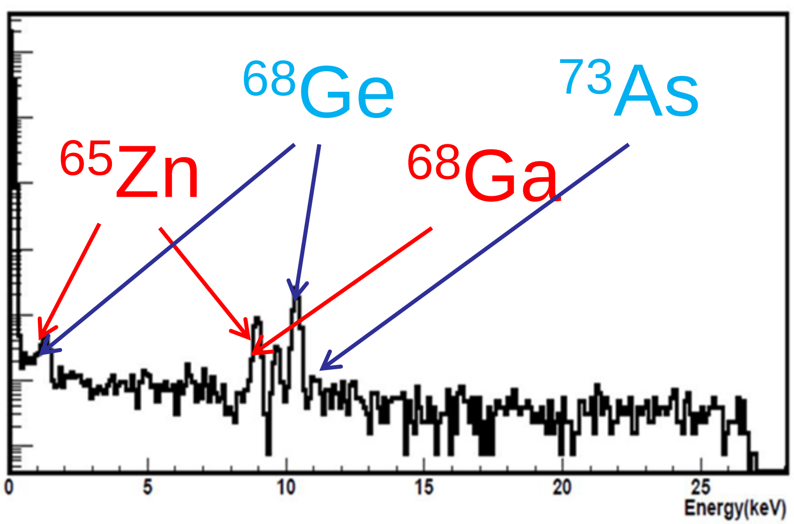


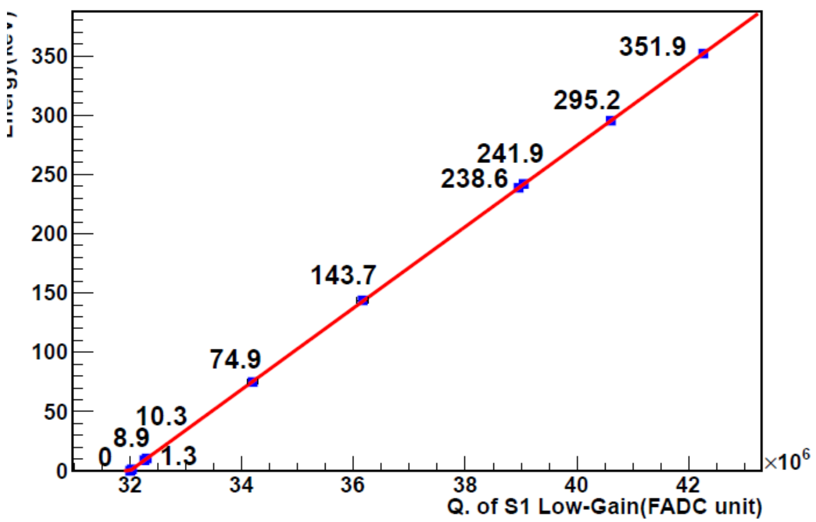
CJPL

Internal radiation of HPGe









CJPL

Radiation isotopes produced by cosmic ray

Cu

产物(Cu)	半衰期	Gamma
Sc46	83.788d	2
Co60	5.27y	2
Co58	70.83d	1
Co57	271.8d	3
Mn54	312.13d	1
Co56	77.236d	12
Fe59	44.495d	3
V48	无	
Zn65	244.01d	1

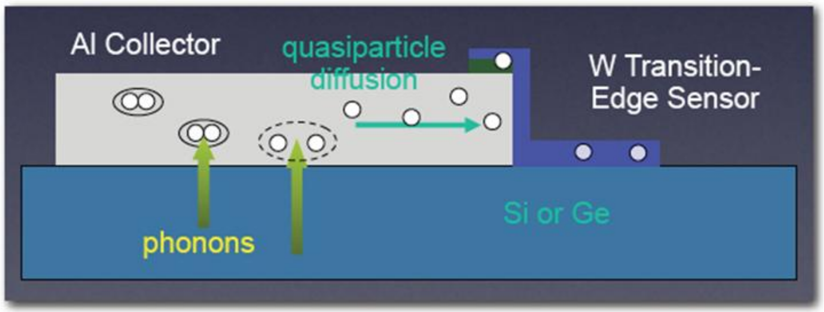
Ge

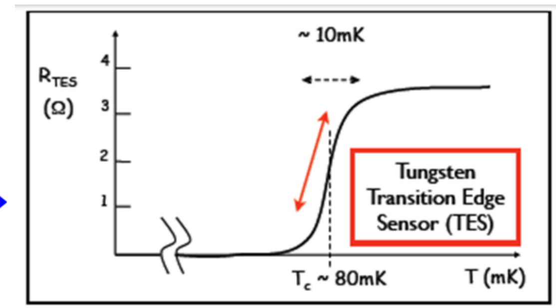
产物(Ge)	半衰期	gamma
Ge68	288 d	0
Co60	5.27 y	2
Mn54	312.2 d	1
Co57	276.3 d	3
Zn65	244.3 d	1
Fe55	2.73 y	0
Co58	70.83 d	1
Ni63	100.1 y	0
V49	330 d	0
Ga68	1.128 h	2

CJPL

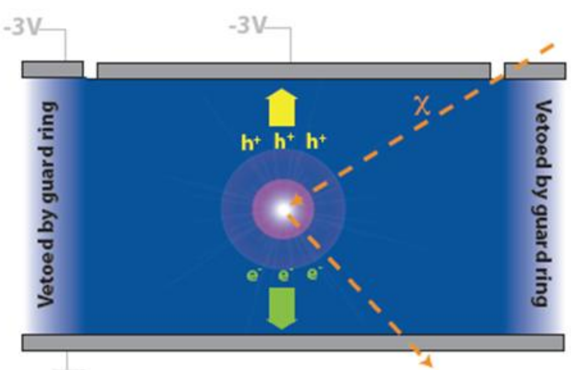
3, Ge (Si)+ Phonon detector

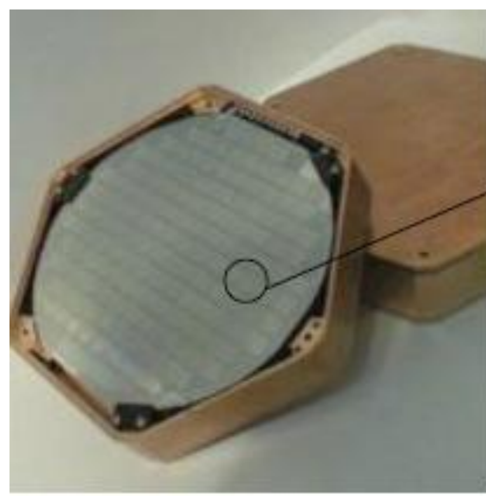
Phonon detector

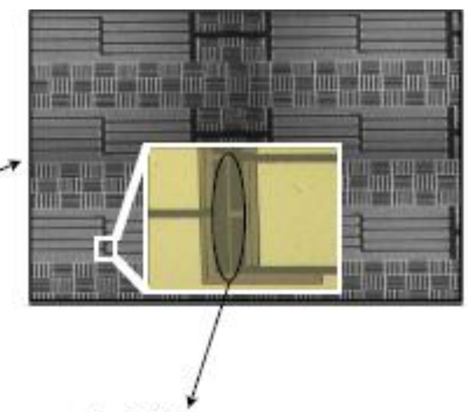




Ionization detector







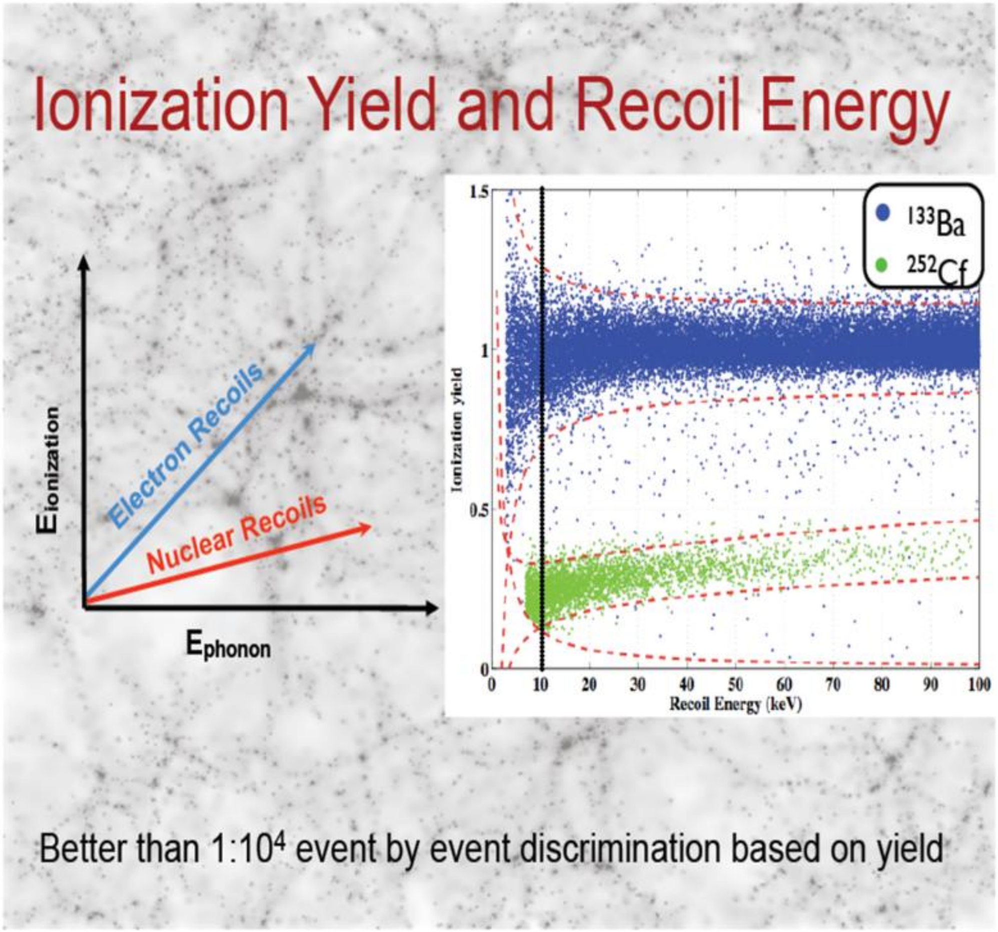
1x250 μm
Transition Edge Sensor

Ge (Si)+ Phonon detector

detect charge and phonon

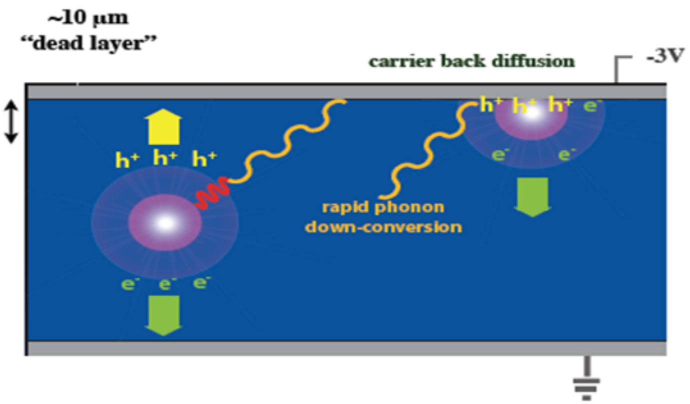
high efficiency
good resolution
high density ,
good background suppressior

cryogenic system (mK)
small mass
threshold high
S/B

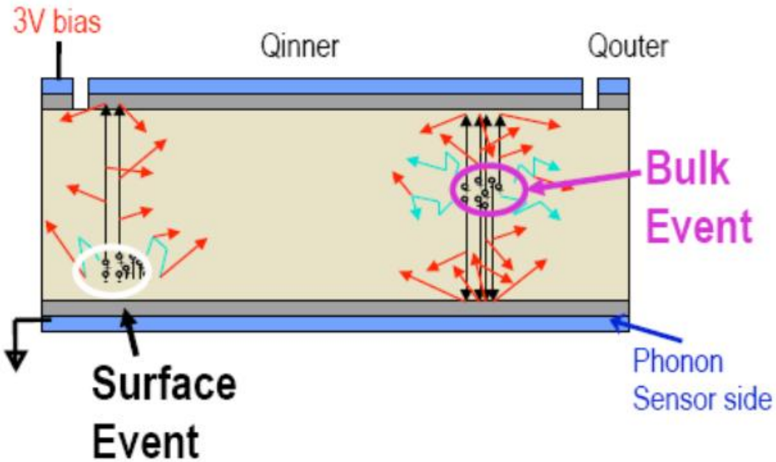


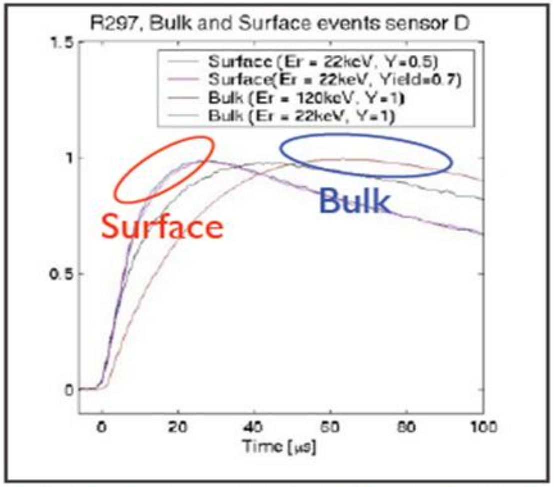
CJPL

Surface and bulk event



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





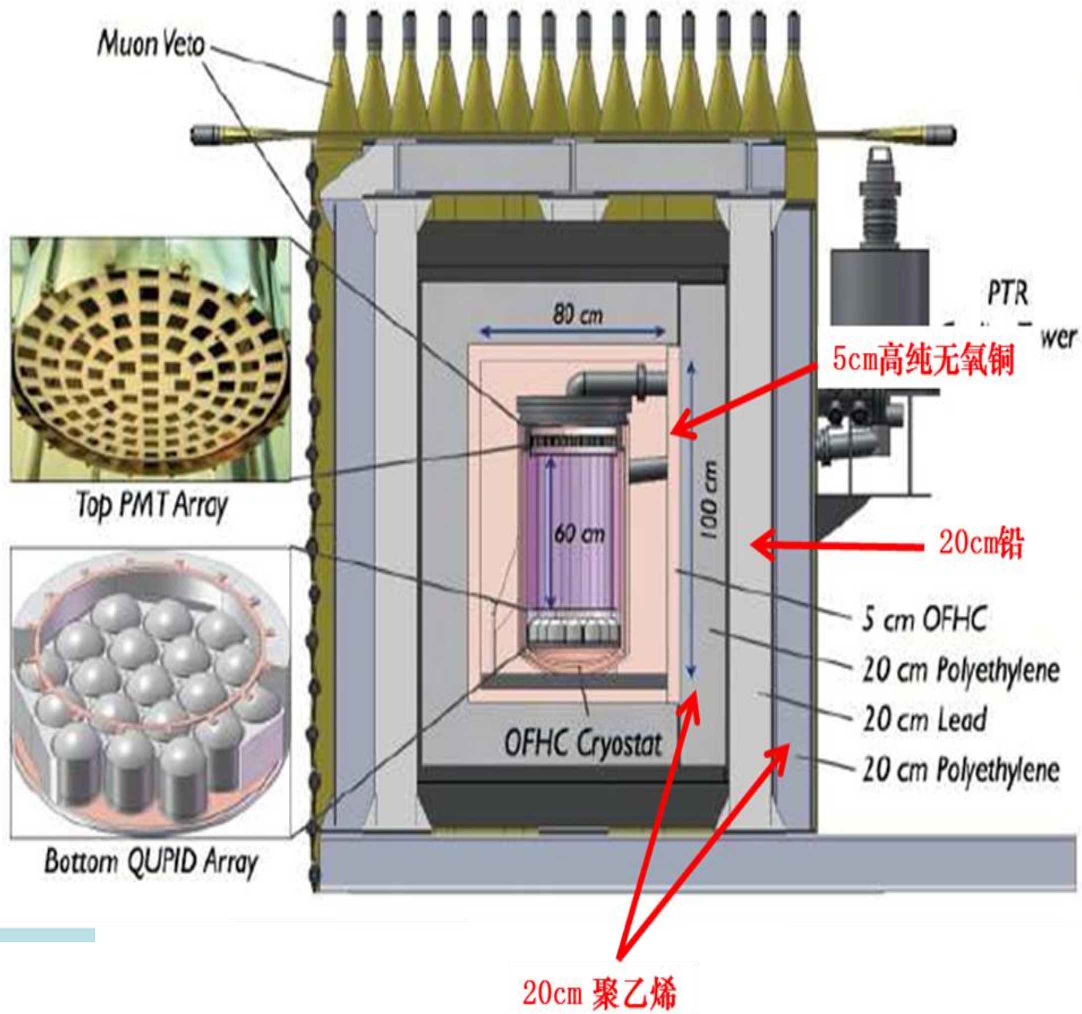
Phonons near surface travel faster, resulting in shorter risetimes of phonon pulse.

4, two phase Liquid scintillation detector

Charge and light

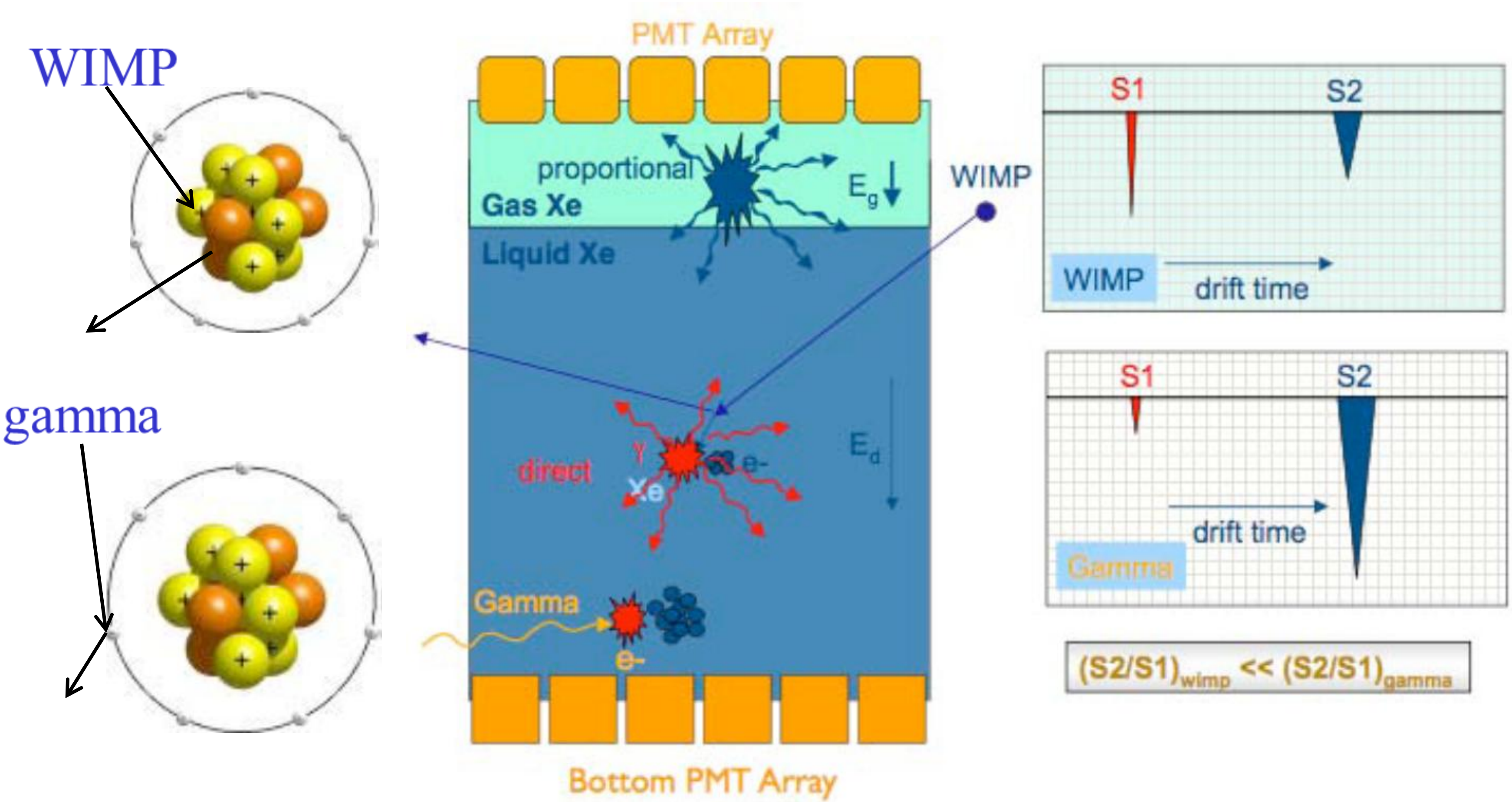
Background suppression
Large mass
High density
Low temperature

Threshold high

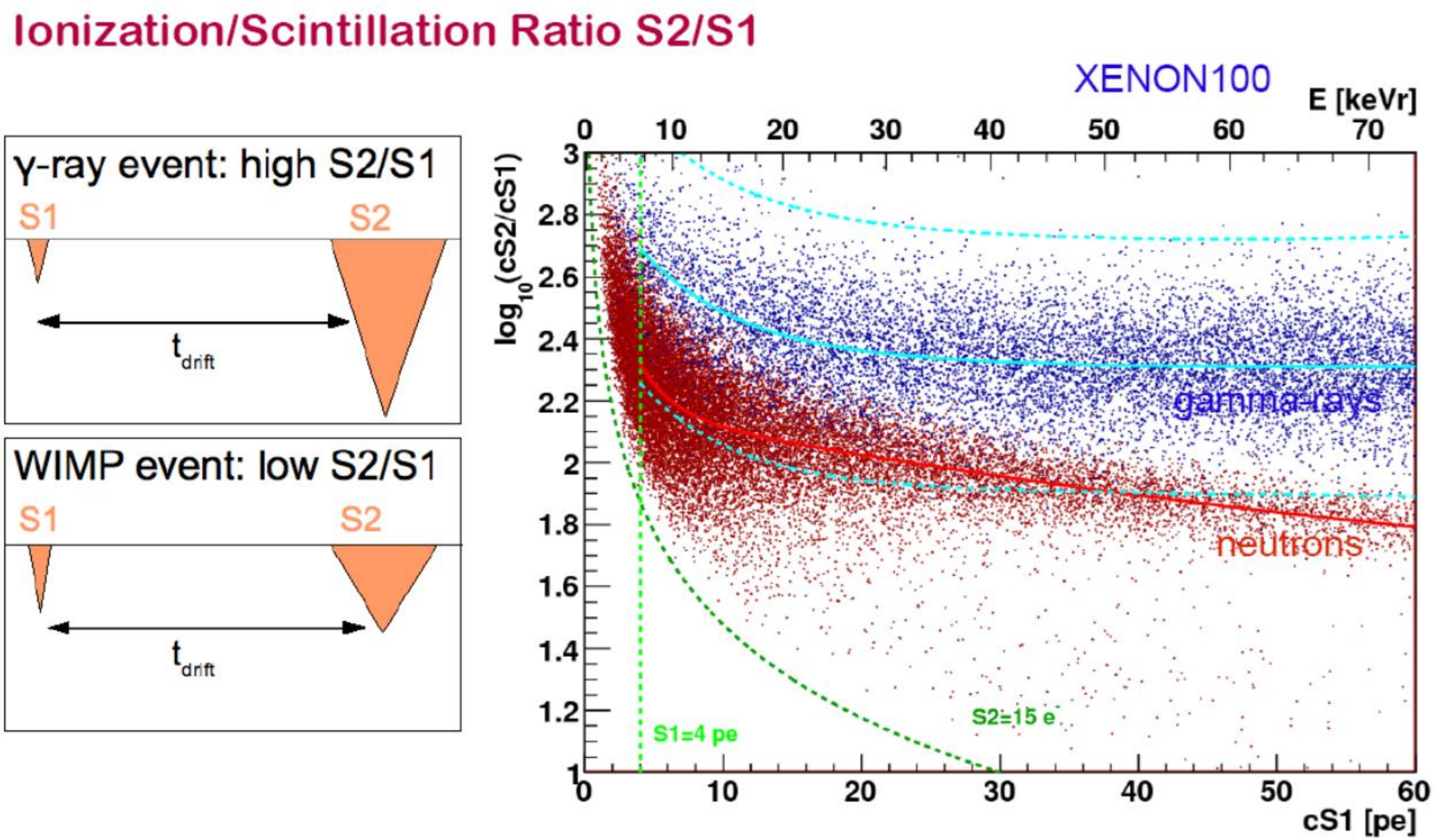


CJPL

Liquid scintillation detector



Background suppress



5, New scheme
Track detector & others

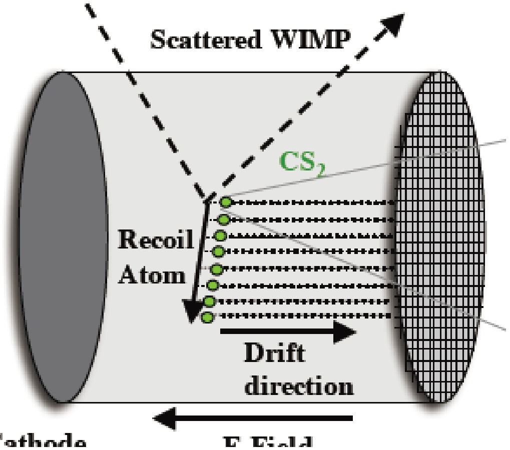
Liquid TPC

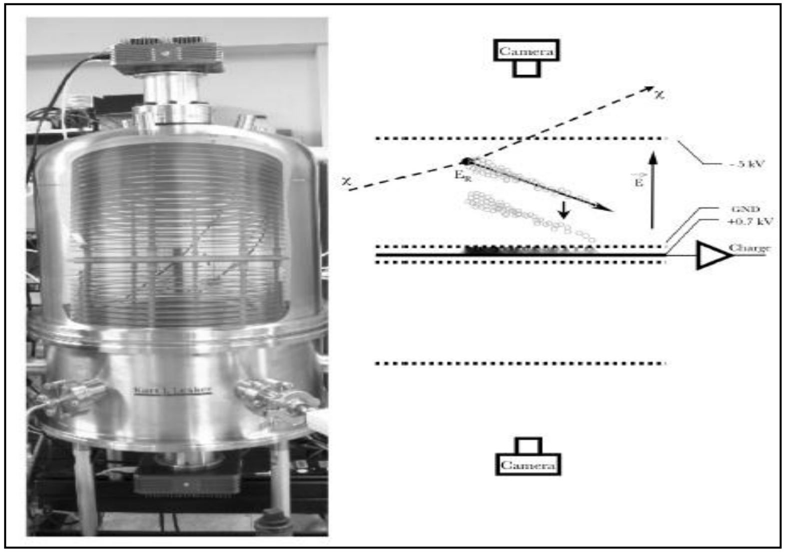
Emulsion nuclear-track

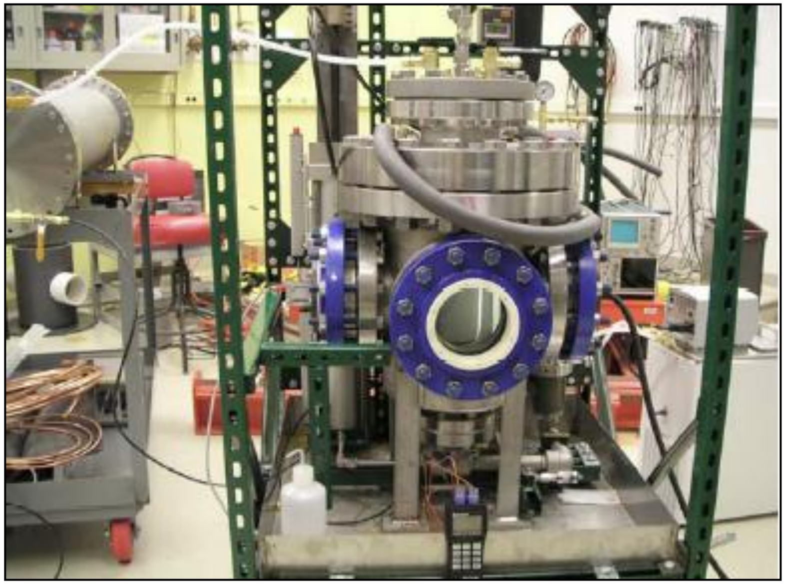
Bubble chamber

Bolometer

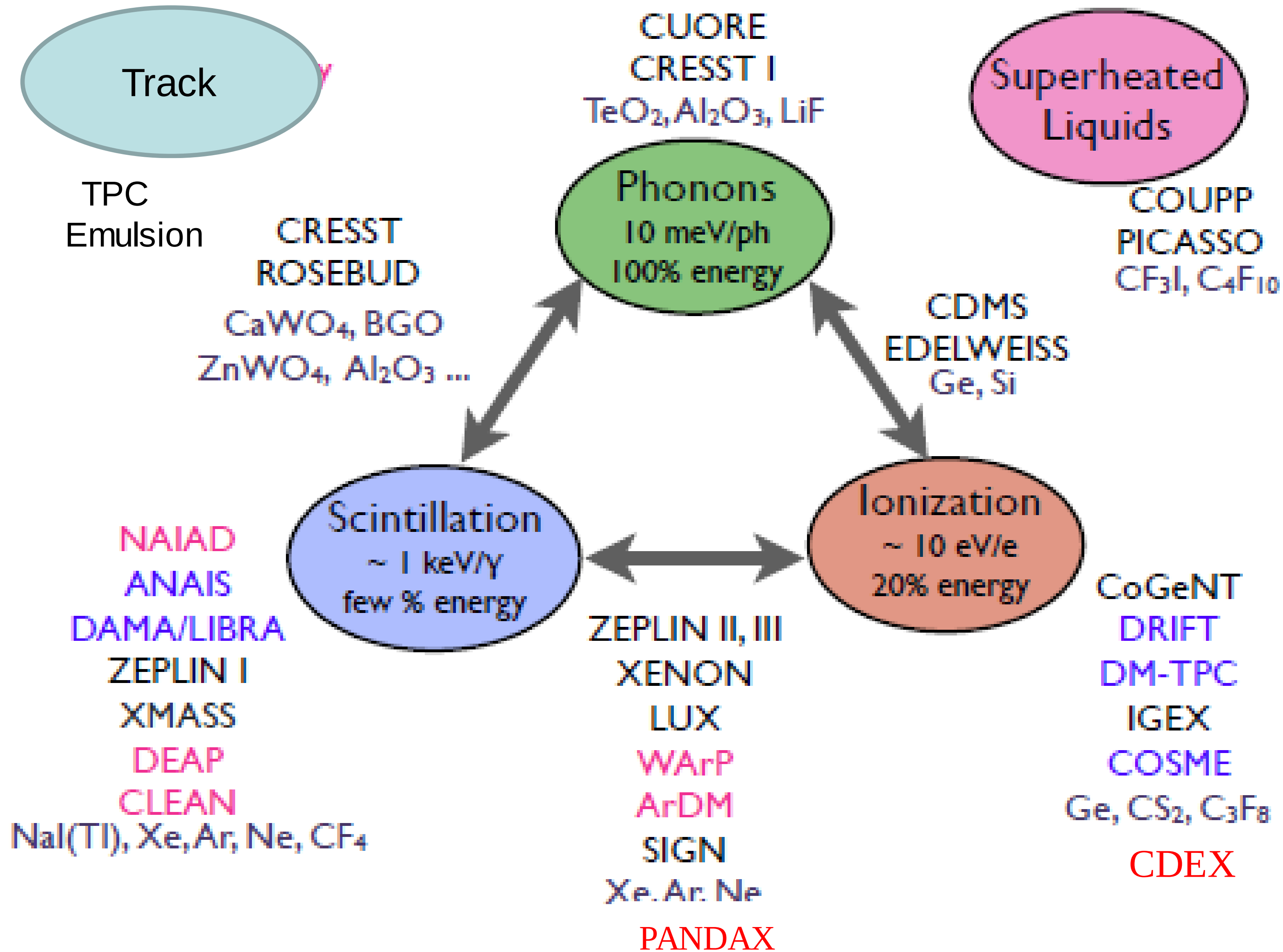
……







Experiments for direct detection of WIMPs

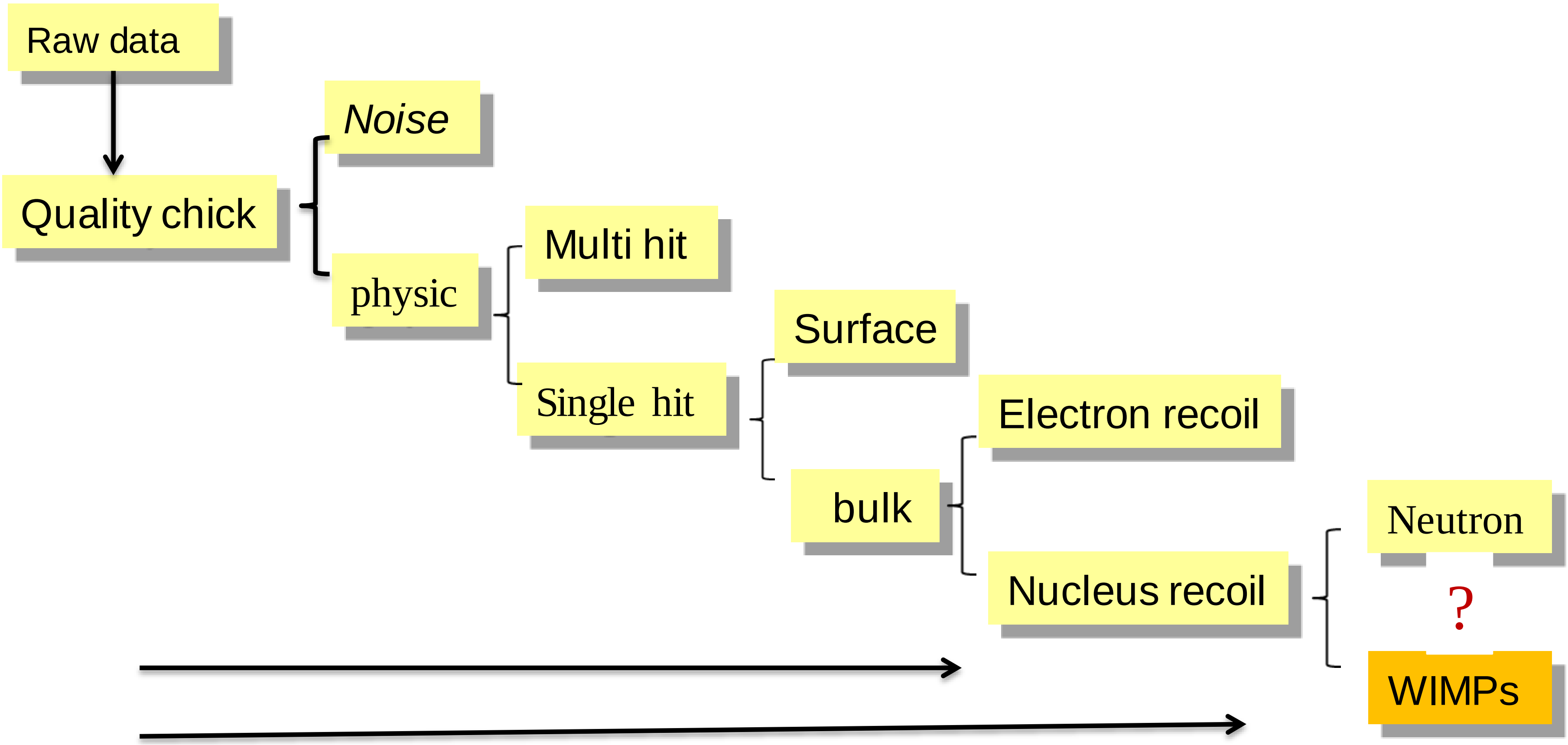


CJPL

Experiments for direct detection of WIMPs

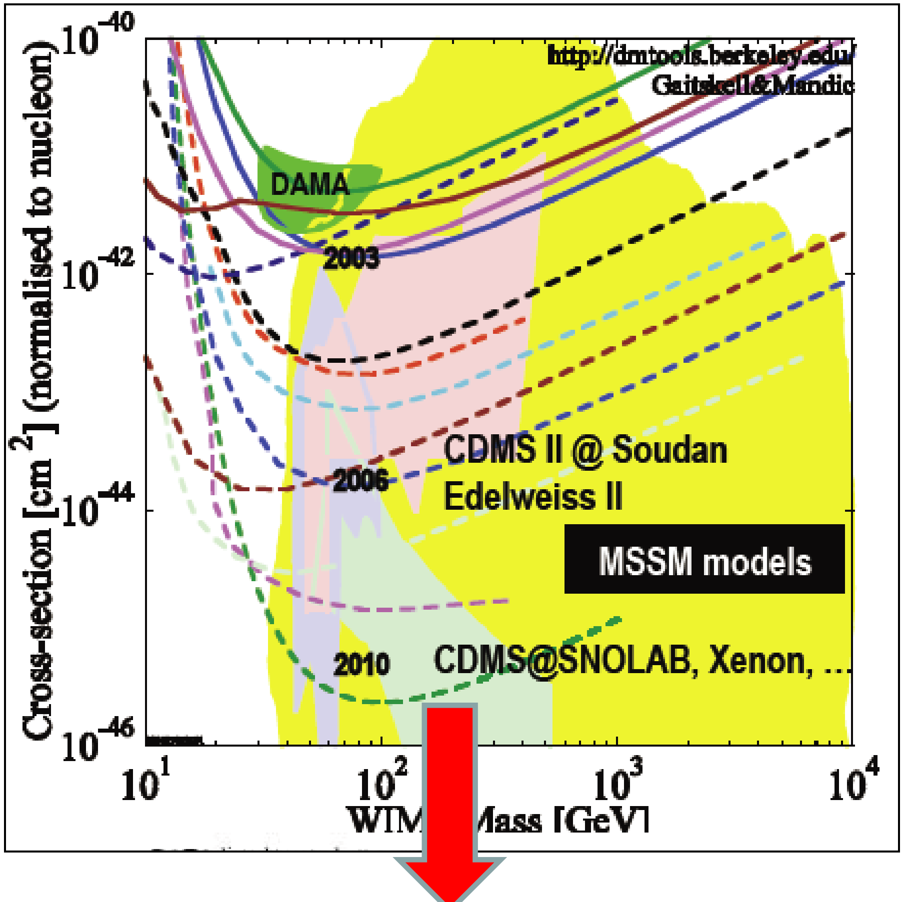
Experimen	Target	Type	Status	Site	Nation
ANAIS	NaI	annual modulation	construction	Canfranc	Spain
DAMA/NaI	NaI	annual modulation	concluded	LNGS	INFN-ITALY
DAMA/LIBRA	NaI	annual modulation	running	LNGS	INFN-ITALY
DAMA/1 ton	NaI	annual modulation	R&D	LNGS	INFN-ITALY
NAIAD	NaI	PSD	concluded	Boulby	UK
HDMS	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		
CDEX	Ge	ionization	running	CJPL	China
Pandax	LXe	2phase	installation	CJPL	China

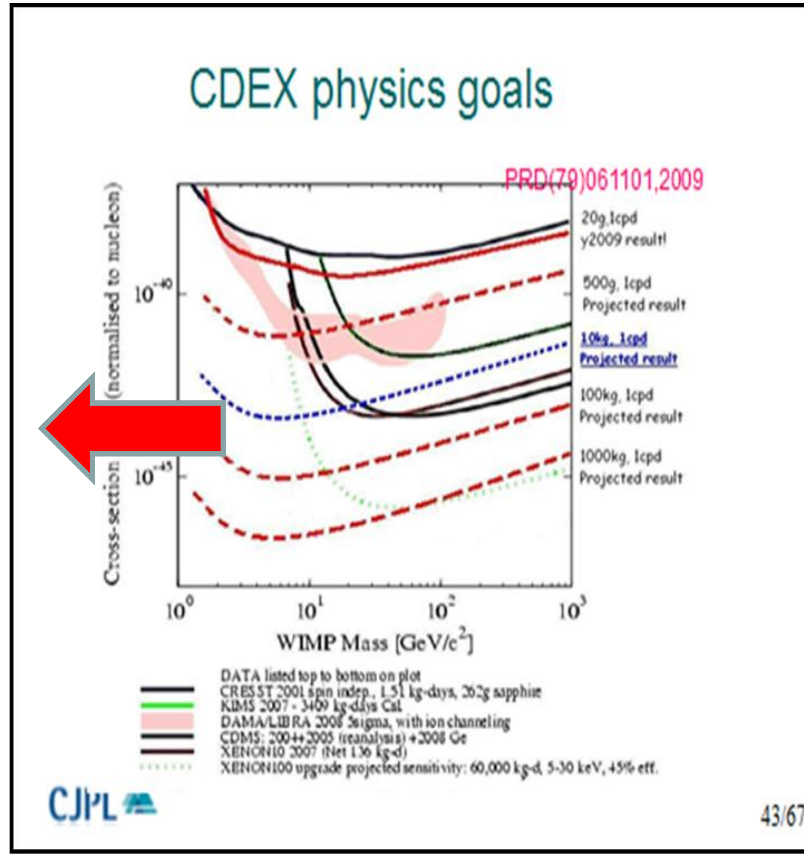
Events select procedure



?? Threshold to high

Status and future of DM search





Detection technology in the future

- Larger mass

  1kg → 1ookg → 1t
- Lower backgrounds

  deep sites; low contamination & radon concentration;

  low internal radiation; high efficiency Veto;
- Lower threshold

  5 keV → 500 eV →100eV
- Good background suppression

  high rejection ability of detector
- Longer stable exposures

  low statistics fluctuate

CJPL


Thanks
Symposium of the Sino-German GDT Cooperation
04/08/2013 Tübingen