液体キセノンTPC検出器による XENON,ZEPLINなどの実験のまとめ

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TIPP09

Non Accelerator Session II での
液体キセノンTPC関連の発表
(各20分+質疑応答5分)

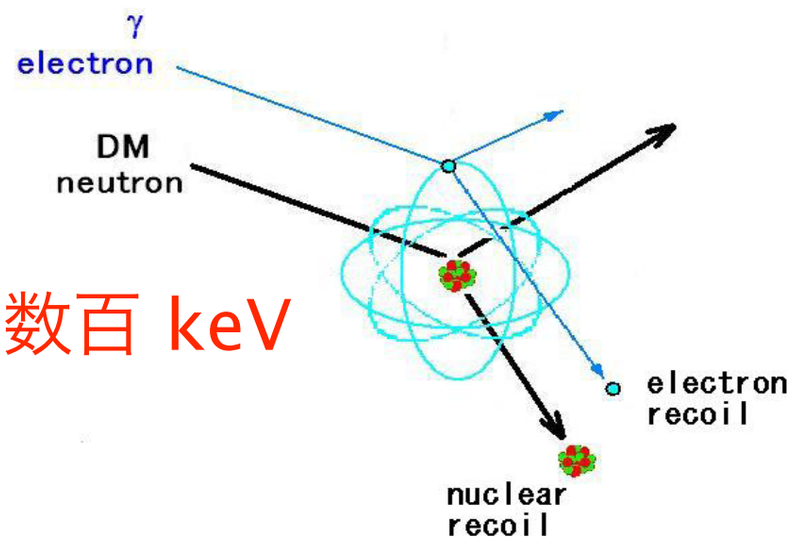
- ZEPLIN III　D.Yu.Akimov (ITEP)
- ZENON 100 Karl-Ludwig Giboni (コロンビア)

暗黒物質の直接検出

暗黒物質の正体が

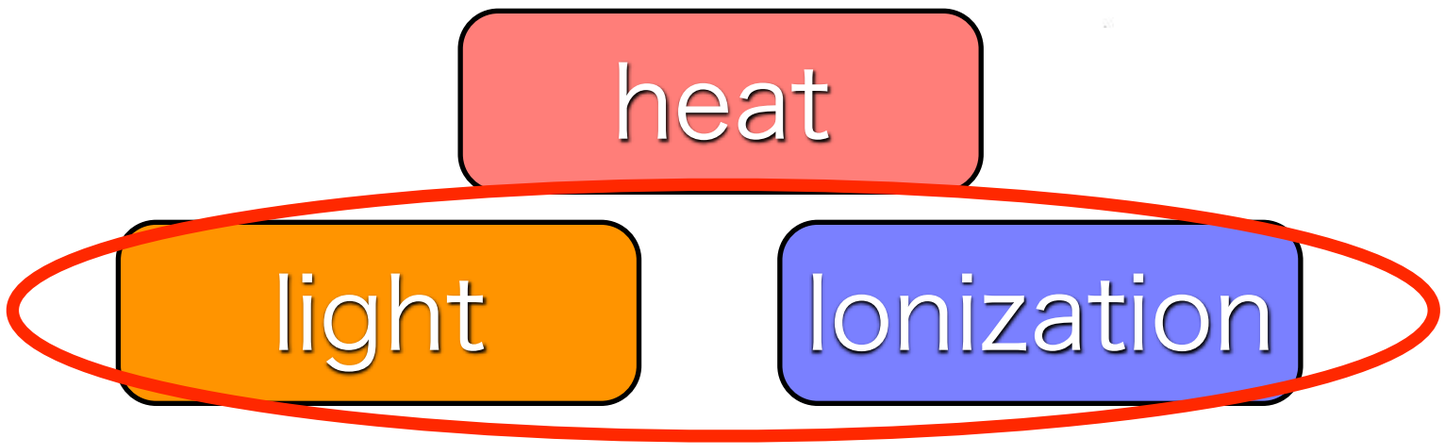
まだ発見されていない素粒子ならば？

- WIMP, アクシオン　etc



WIMPによる反跳原子核

のエネルギー検出　数十〜数百 keV



＋ 飛跡？

なぜ液体キセノンか？

Particle detection with LXe

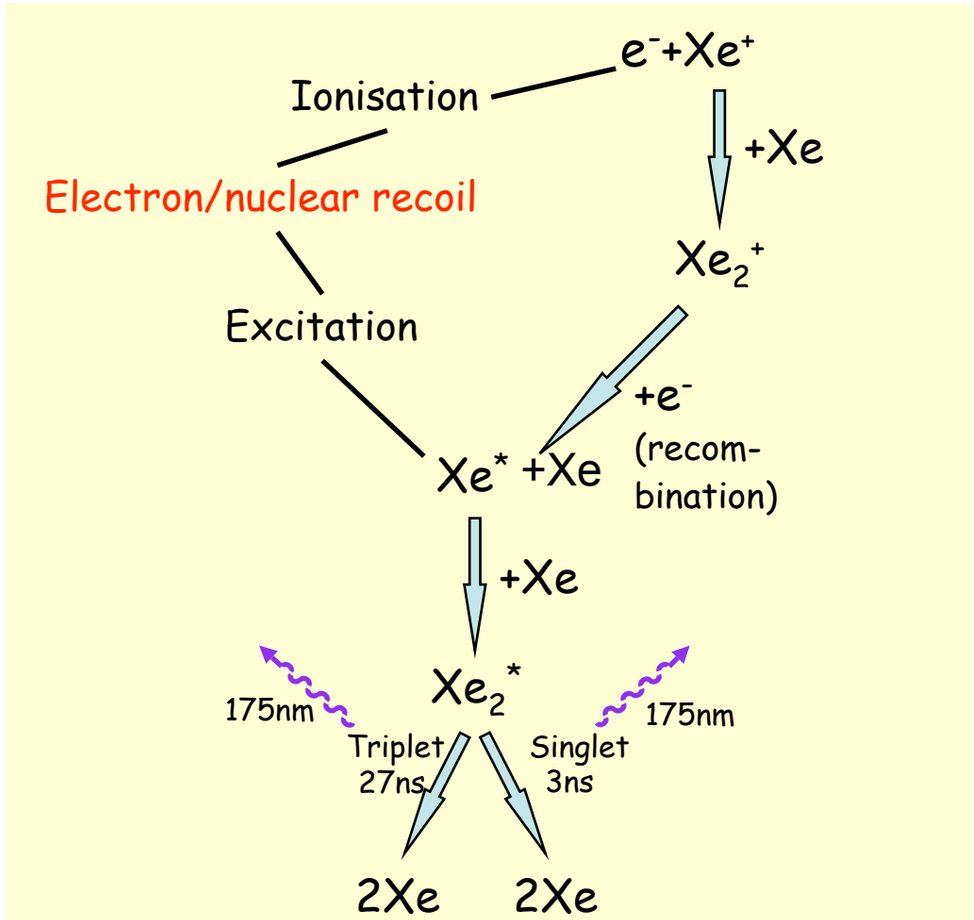
LXe properties,
WHY LXe?

- high density
- high Z
- SC - high light yield
- high radio purity
- possibility of discrimination by simultaneous measurements of scintillation and ionization signals

The main obstacle so far for the wide use was

- VUV region of SC,
- cryogenics

Scintillation and ionisation in LXe:

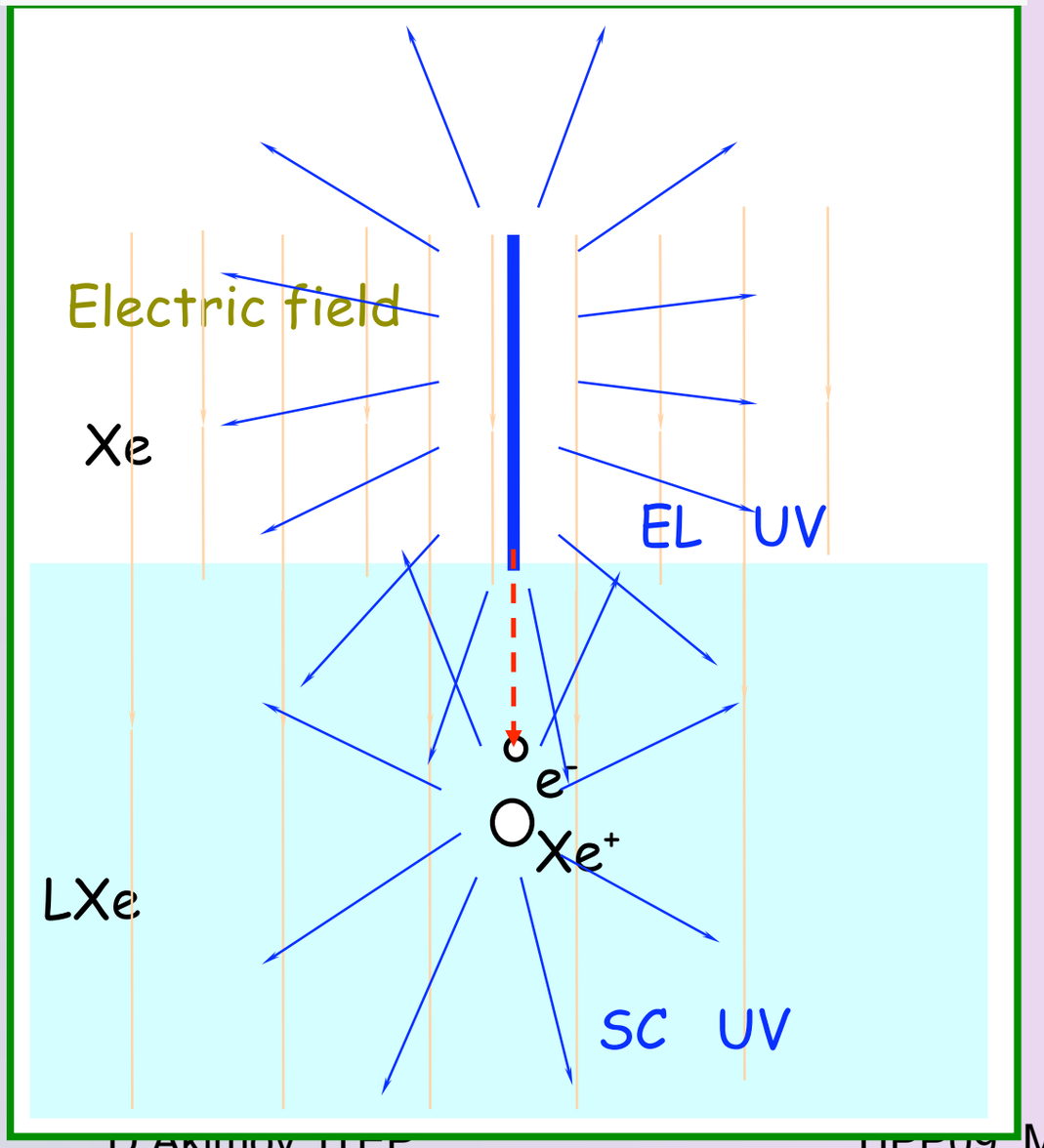


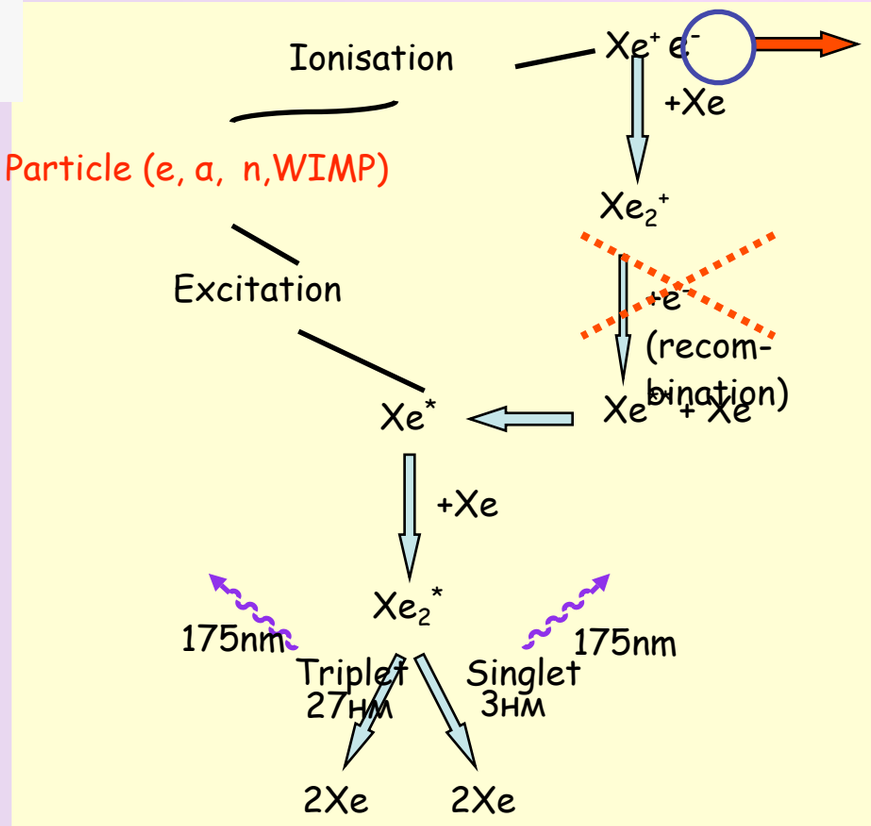
Particle detection with LXe

Discrimination of particles in a two-phase detector (Xe)

B.A. Dolgoshein, V.N. Lebedenko, B.U. Rodionov, JETF Letters (in Russian), 1970, v. 11, p. 513

For the Dark Matter search:
A.S. Barabash and A.I. Bolozdynya, JETF Letters (in Russian), 1989, v.49, p. 359

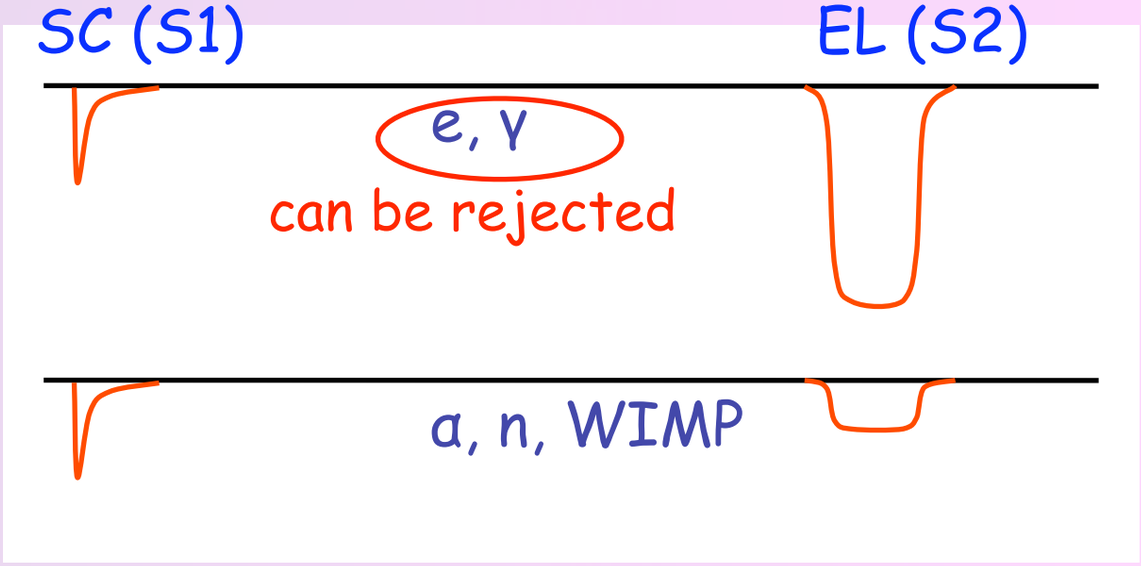




Electrons are partly extracted from the track: recombination is suppressed

Suppression depends on dE/dX

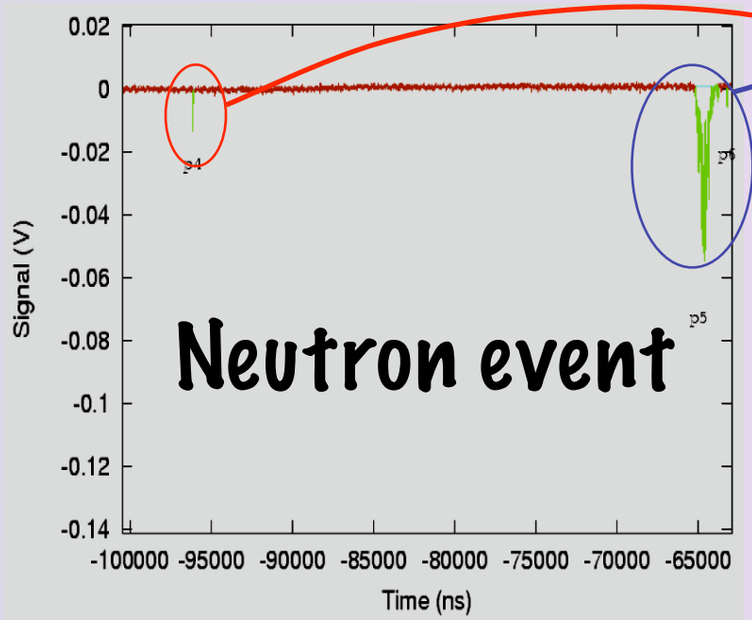
Ratio of SC/EL is different for different kind of particles

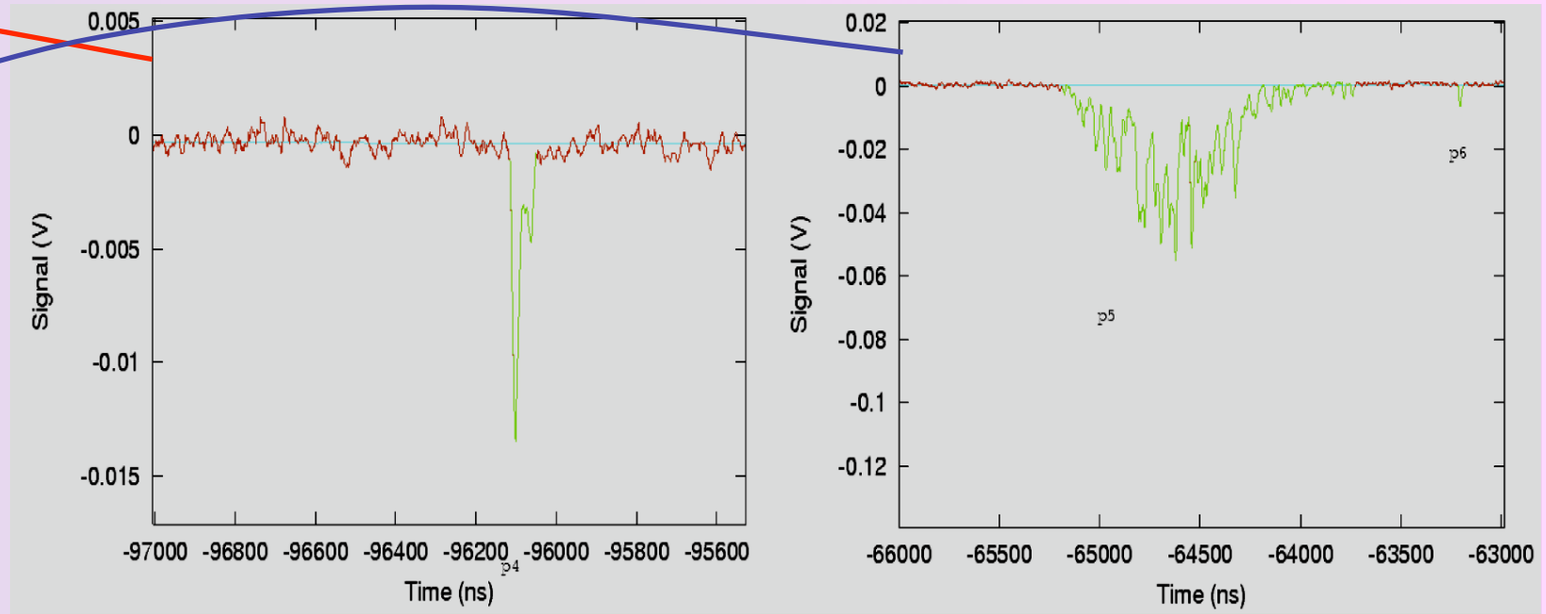


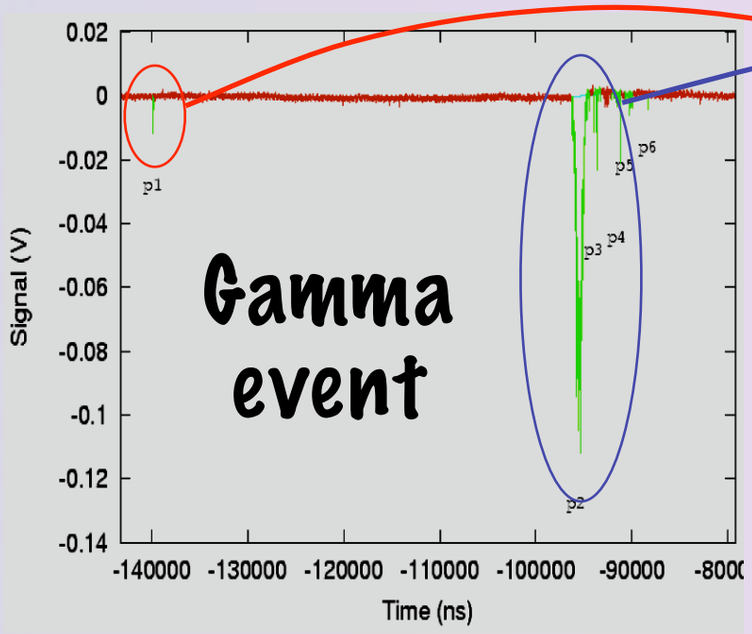
Neutron/Gamma pulses

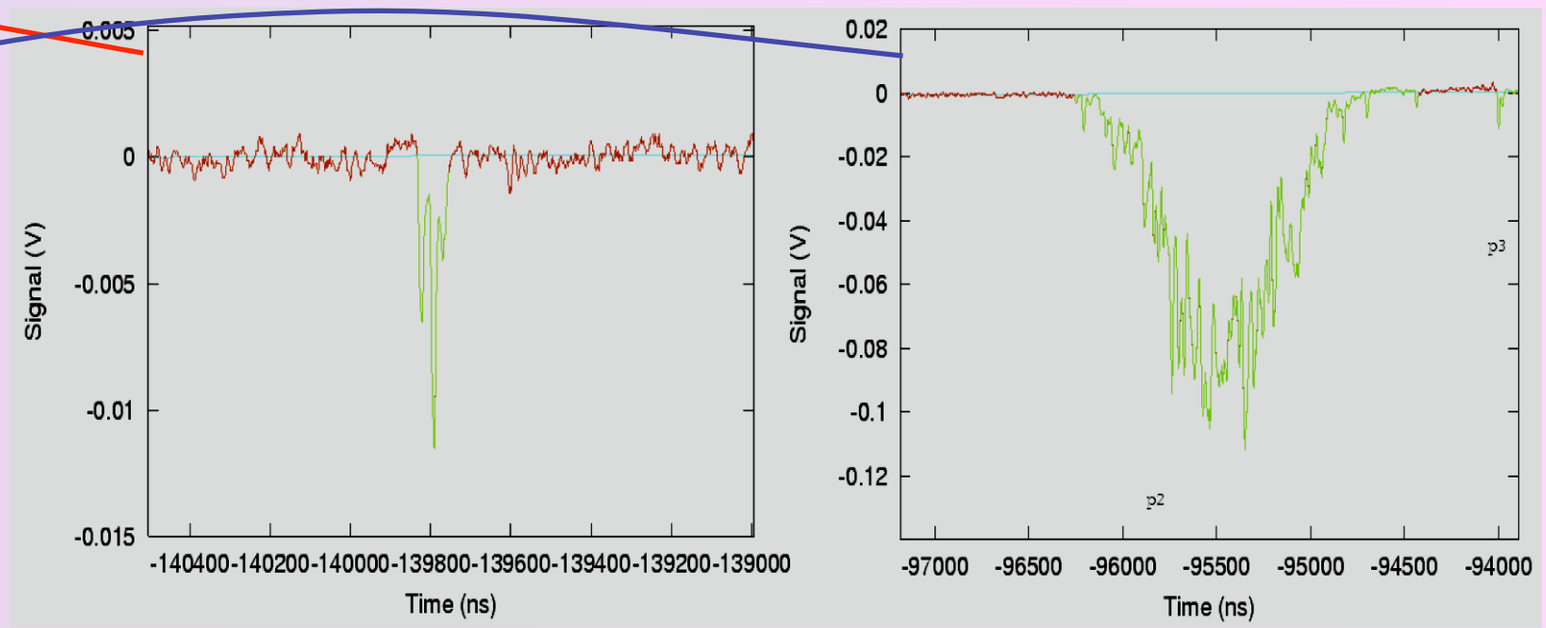
Before closing the shield, calibration by AmBe neutron source has been done

sampled at 500 MS/s by 8-bit AQIRIS digitizers





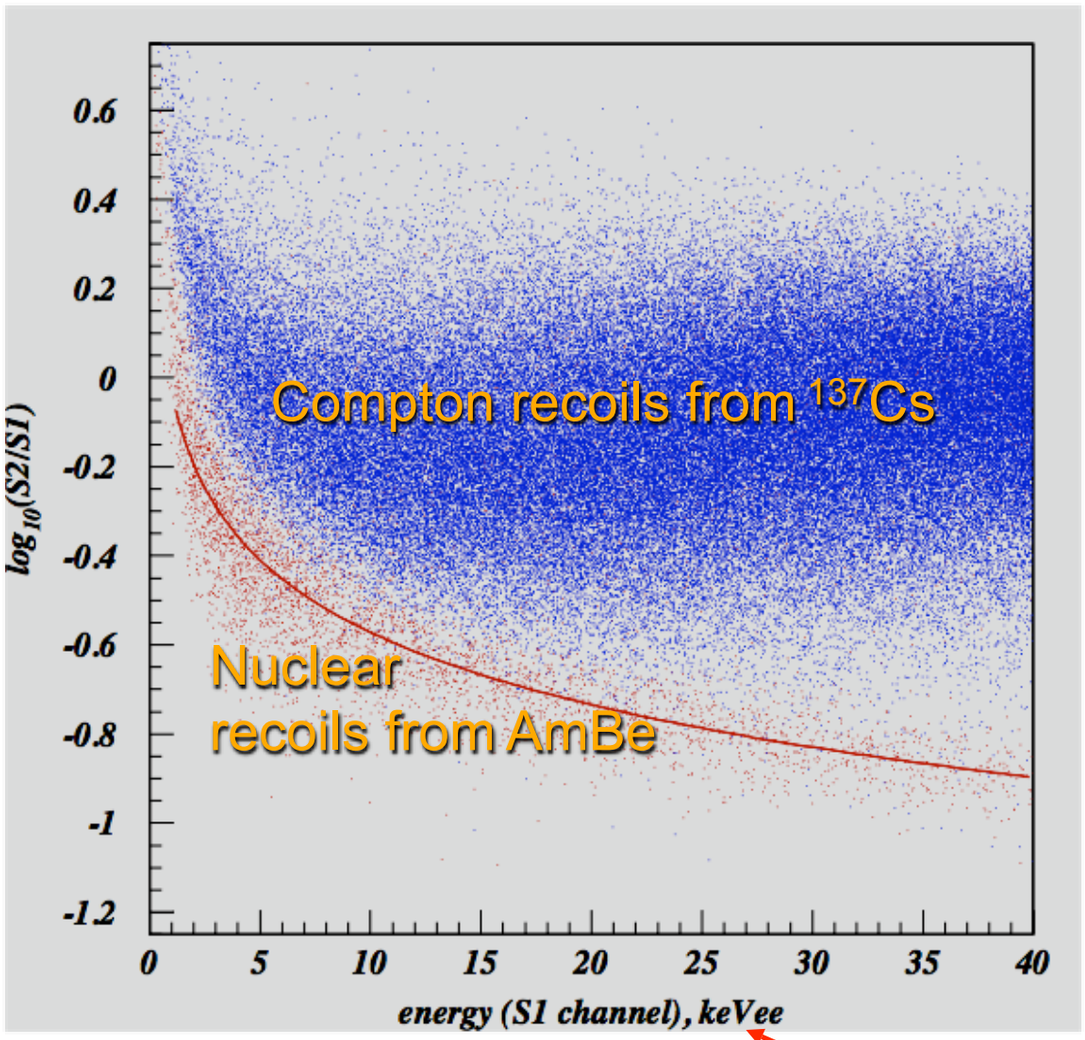


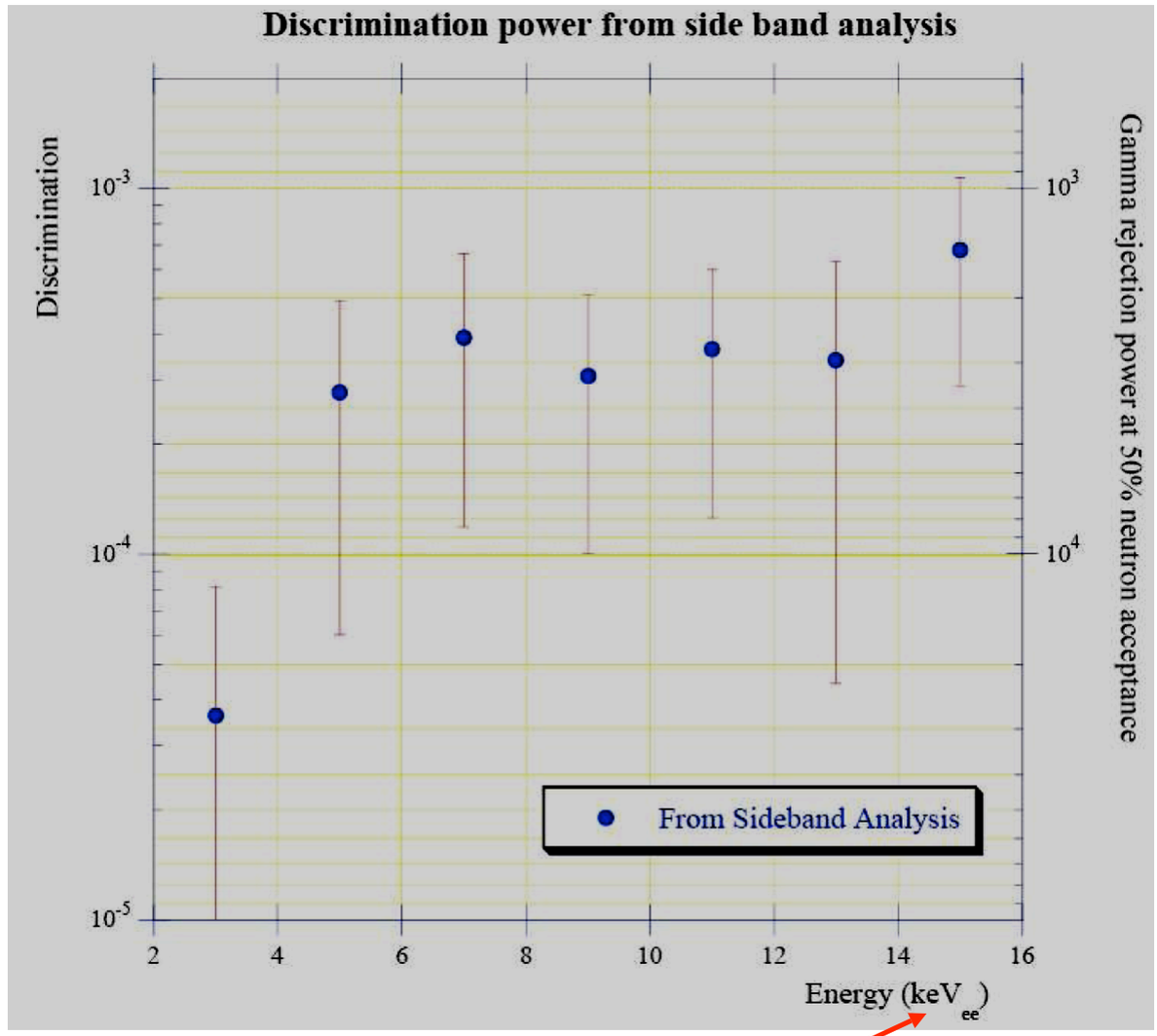


n/γ discrimination power

Discrimination is defined as leakage of gammas below 50% nuclear recoil line is > 10^3

AmBe and ^{137}Cs data





! Here and below, keVee – electron equivalent energy scale

Motivation

ZEPLIN III

Rotation curves of spiral galaxies

Large-scale structure of the Universe

Brilliant agreement of the CMB and SN Ia data

Astrophysical motivations

Gravitational lensing for galaxy clusters

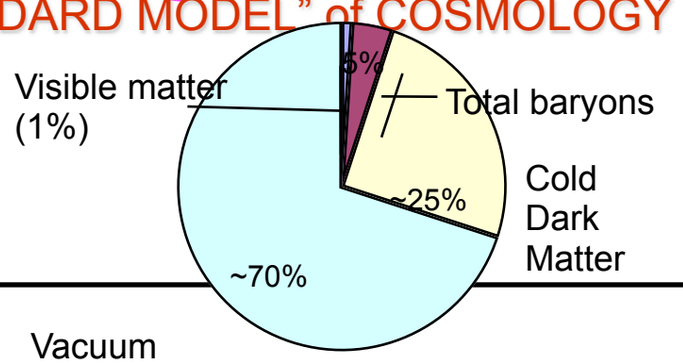
Cosmological motivations

Anisotropy of cosmic microwave background (CMB)

Nucleosynthesis theory

N-body simulations

"STANDARD MODEL" of COSMOLOGY



$\rho \approx \rho_{cr}$ =>

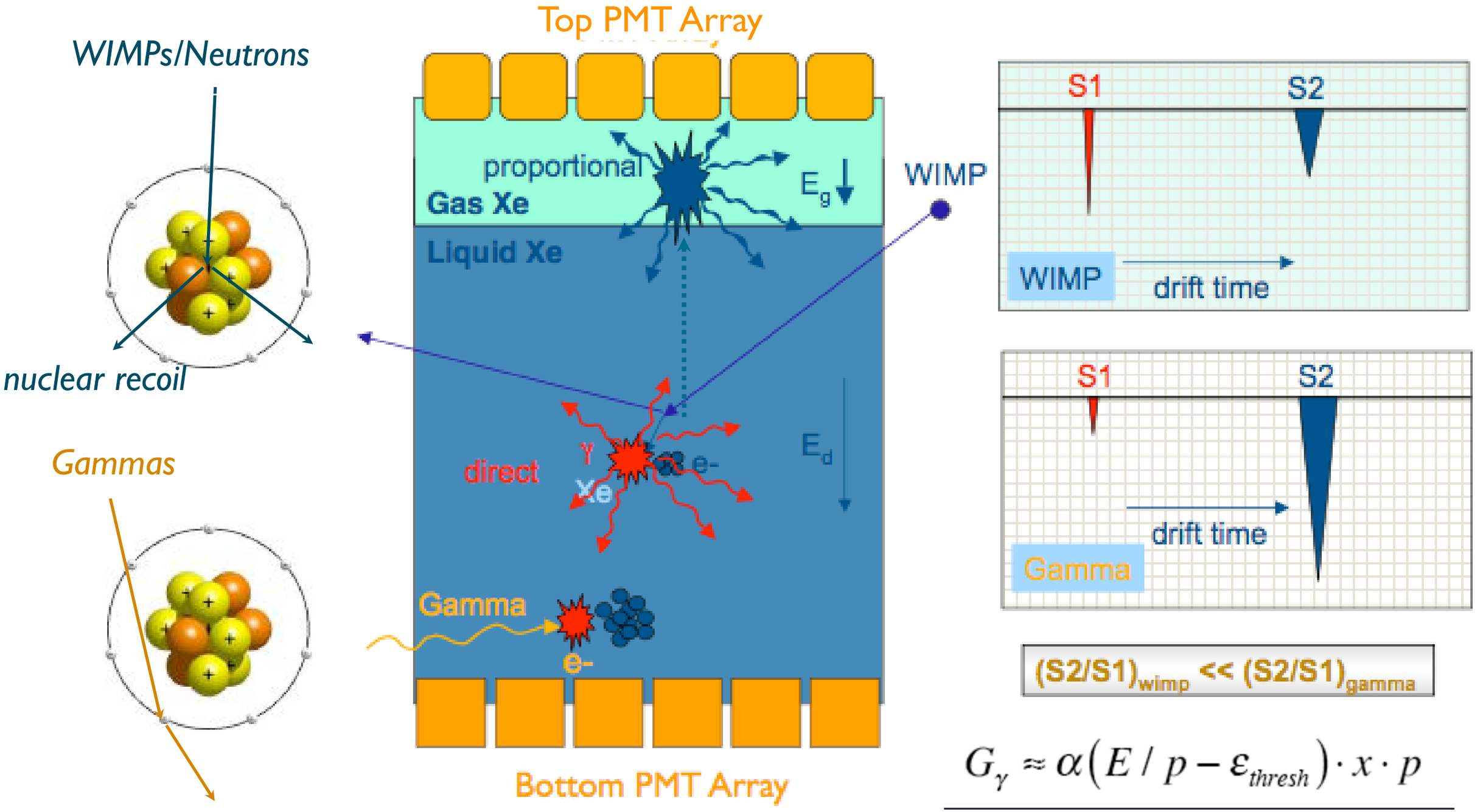
$\Omega = \rho / \rho_{cr} \approx 1$

XENON100

暗黒物質探索用

今回は、
冷凍機システムについての
発表であるため明確なモチベーションは示されていない。

The XENON two-phase TPC concept

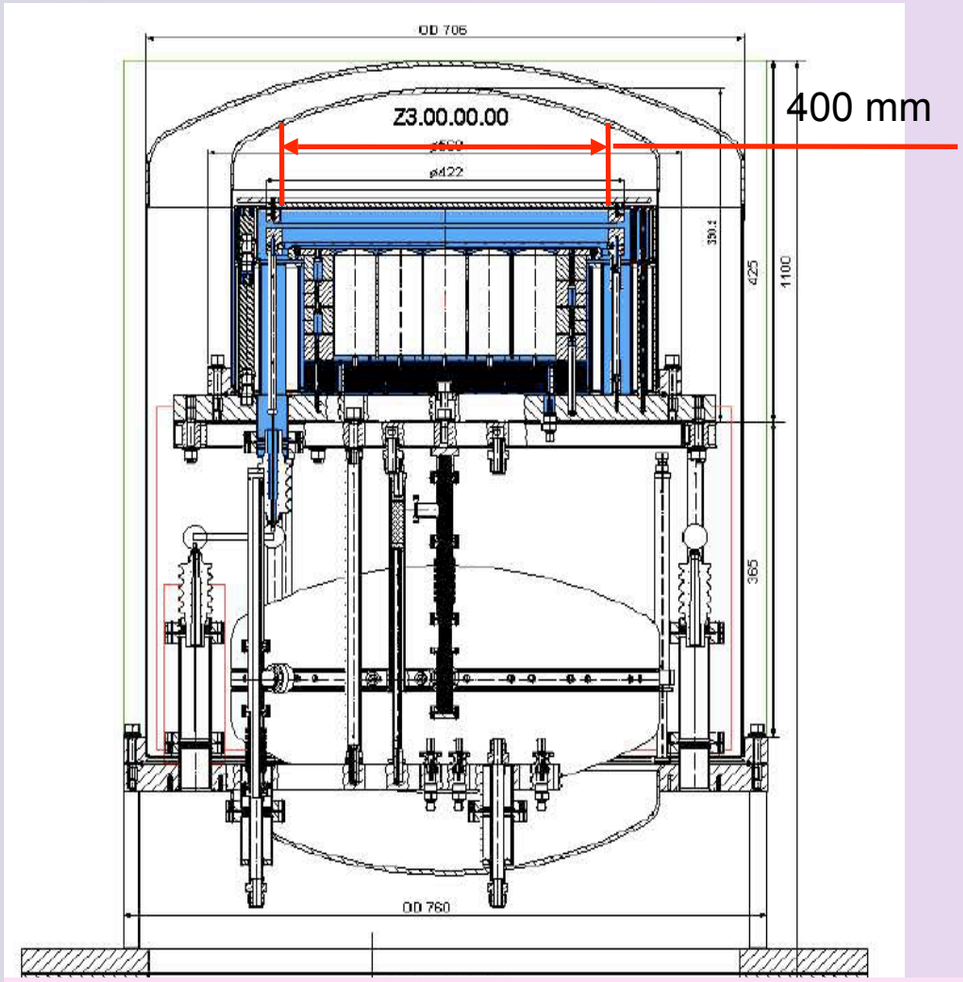


$(S2/S1)_{wimp} << (S2/S1)_{gamma}$

$$G_\gamma \approx \alpha\left(E / p - \varepsilon_{thresh}\right) \cdot x \cdot p$$

$$\alpha_{LXe} = 70\ \gamma / kV \qquad \varepsilon_{thresh}^{LXe} = 1.3 kV / cm / atm$$

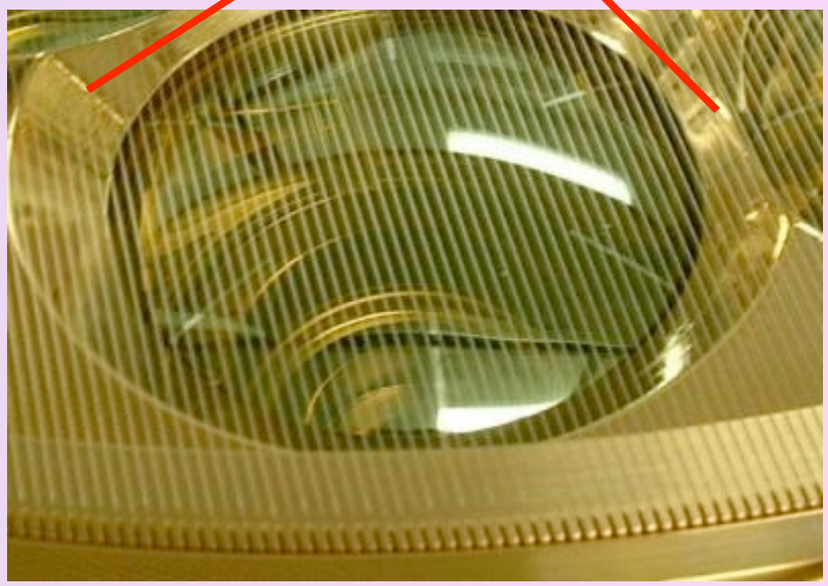
ZEPLIN III Experiment



- PMTs in liquid to improve light collection
- 31 2” PMTs for fine position sensitivity
- 12 kg target mass, 50 kg total
- 3.5 cm drift depth – high E-field (3.9kV/cm)
- provides better n/γ discrimination
- 0.5 cm electroluminescent gap
- open plan – no surfaces - reduced feedback
- Low-background xenon (40 yr old - low Kr)
- All-copper construction - electron beam welded

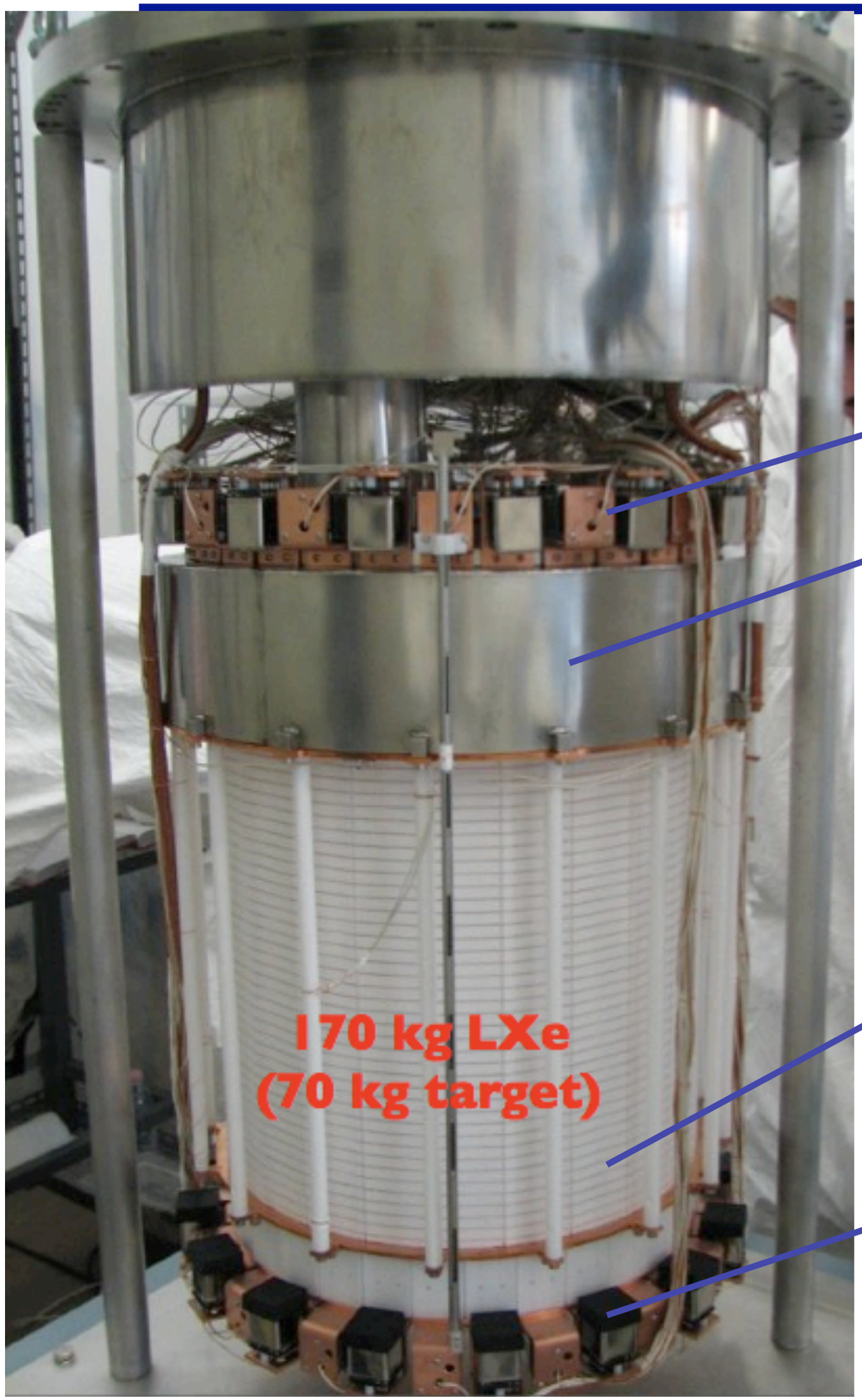
31 PMTs

31 PMTs with grid



100 μm ss wires, 1 mm pitch

Status of XENON100: the TPC Assembly



Top Shield PMTs

'Bell' with Top PMT Array inside

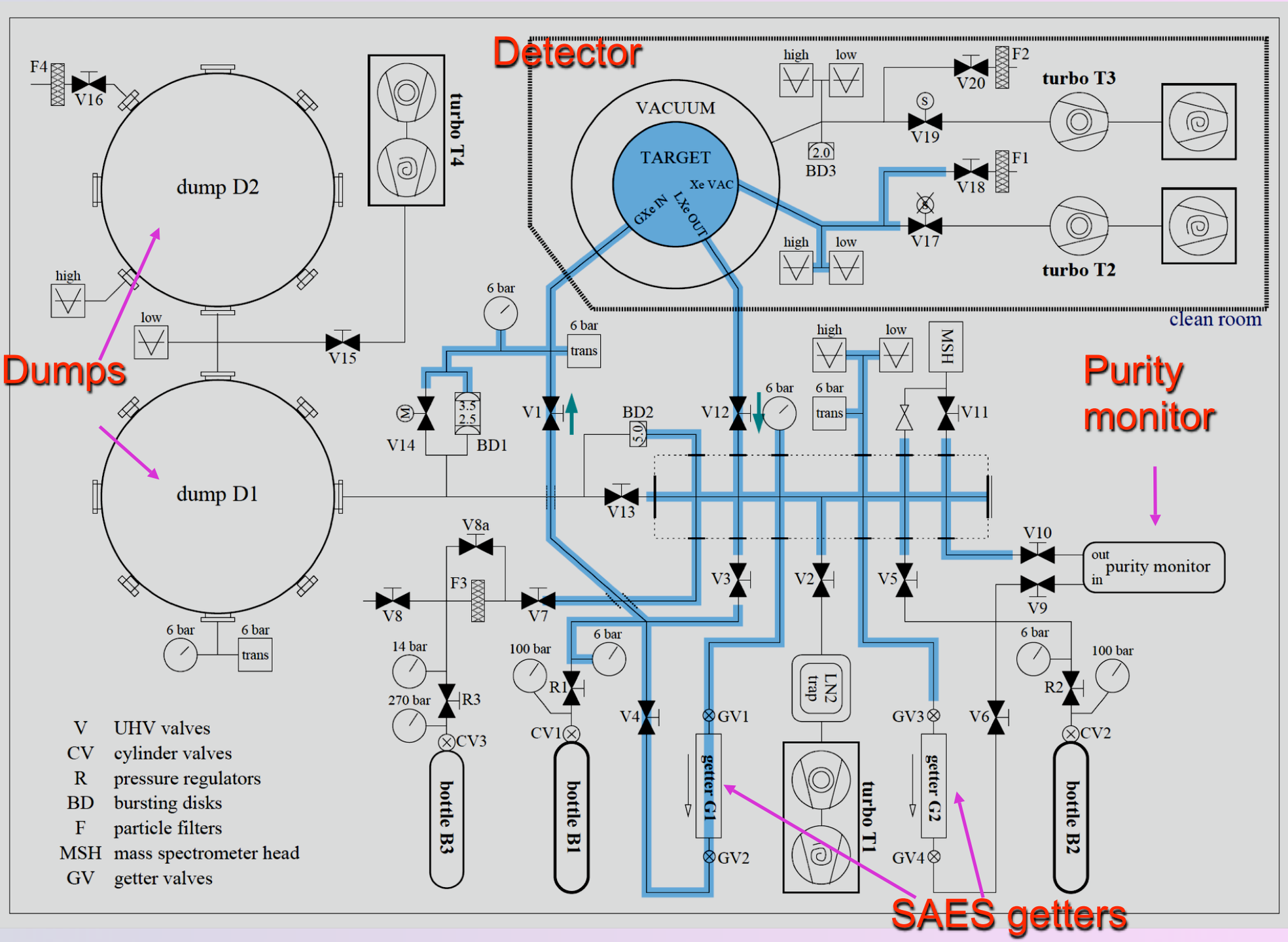
Teflon Cylinder
(Field shaping Ring Support,
Separation of Target and Shield)

Bottom Shield PMTs

冷凍機・
ガス循環システム

Purification/gas-filling system

The main aim: to remove electronegative contaminants which suppress S2 signal down to the ppb level



The base vacuum attainable in the system is ~10^{-8} torr, dominated by H_2;
a partial H_2O pressure of ~10^{-10} torr was achieved prior to the xenon filling

The XENON Dark Matter Search Project

Dual Phase Liquid Xenon TPC

Phased program to explore successively lower cross sections

In each phase we also establish the technologies for the next phase.

Name	Size {kg of xenon) Fiducial	Total	Status
XENON3		< 3	Lab tests only, completed
XENON10	5	25	Experiment, Data published
XENON100	50	170	Experiment, final commissioning
XENON100 Upgrade	100	350	Design, 2010 - 2012
XENON1T	1000	3000	Planning, 2012 - 2014

What will be different for XENON1T

(for Cryogenic System only!)

Much larger Xenon Volume, but we also want even lower Radioactivity.

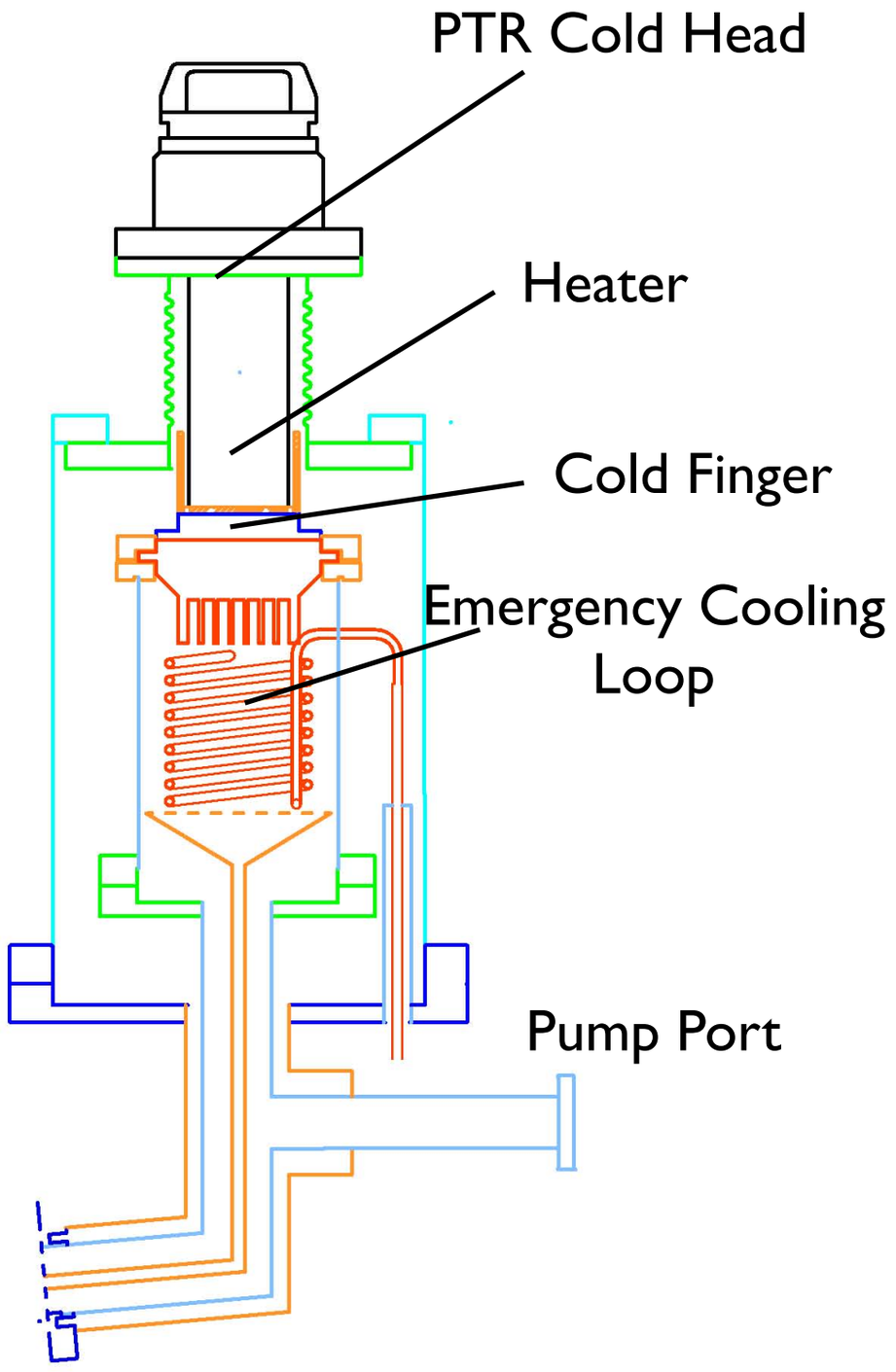
Cooling with Iwatani Pulse Tube Refrigerator

Detector	Cryo Cooler	Compressor Power	Cooling Power
XENON10	PC090	3.5 kW	100 W
XENON100	PC150	6.5 kW	200 W
XENON1T	2x PC150	2x 6.5 kW	400 W

Cooling power sufficient to counteract heat entering detector, and either fill or re-circulate with 10 SLPM
Recirculation can be more efficient with Heat exchanger

Control of cooling power with Temperature Controller (Lakeshore)

Emergency cooling with LN2 coil. Regulated with pressure in chamber.
Two completely independent systems.



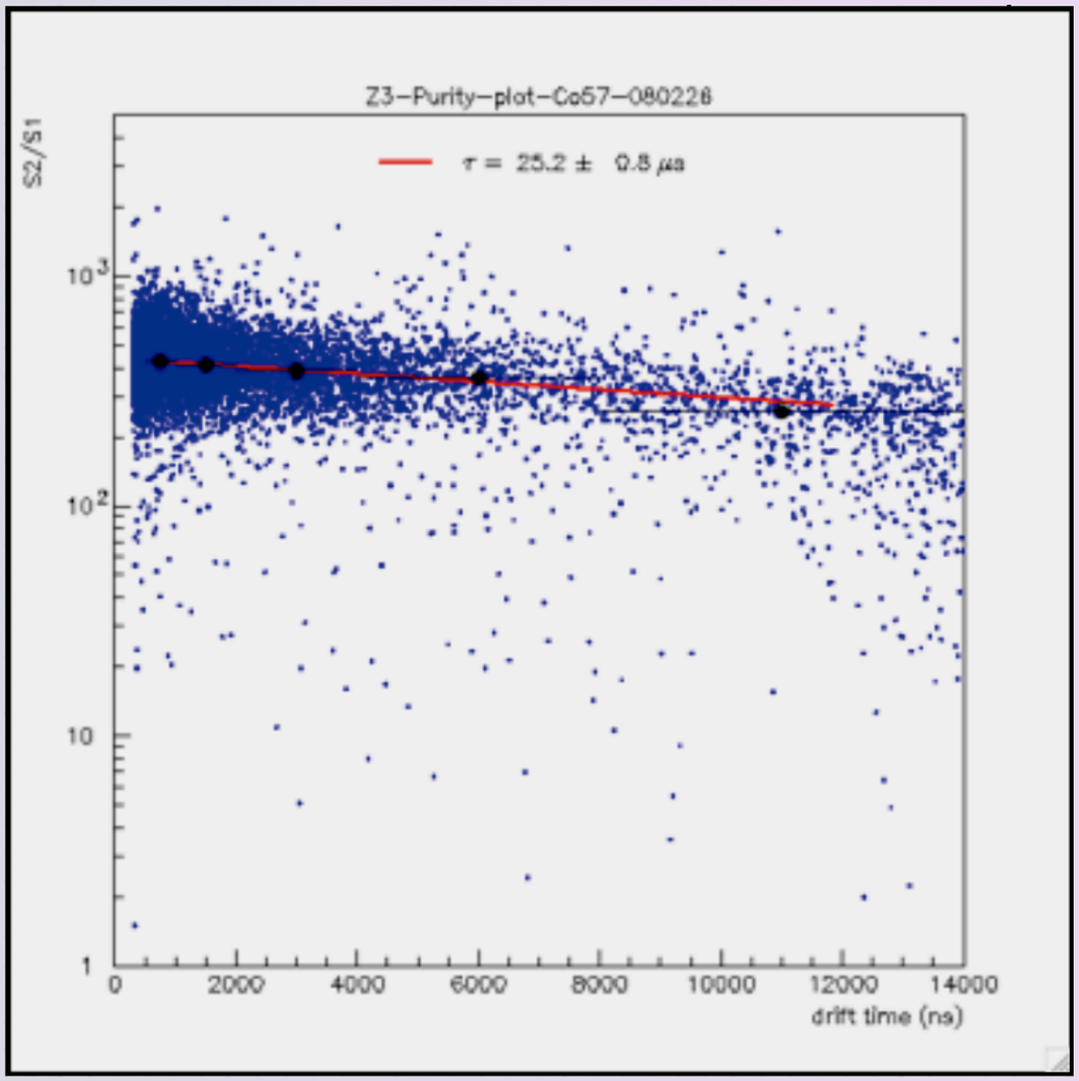
純度(purity)

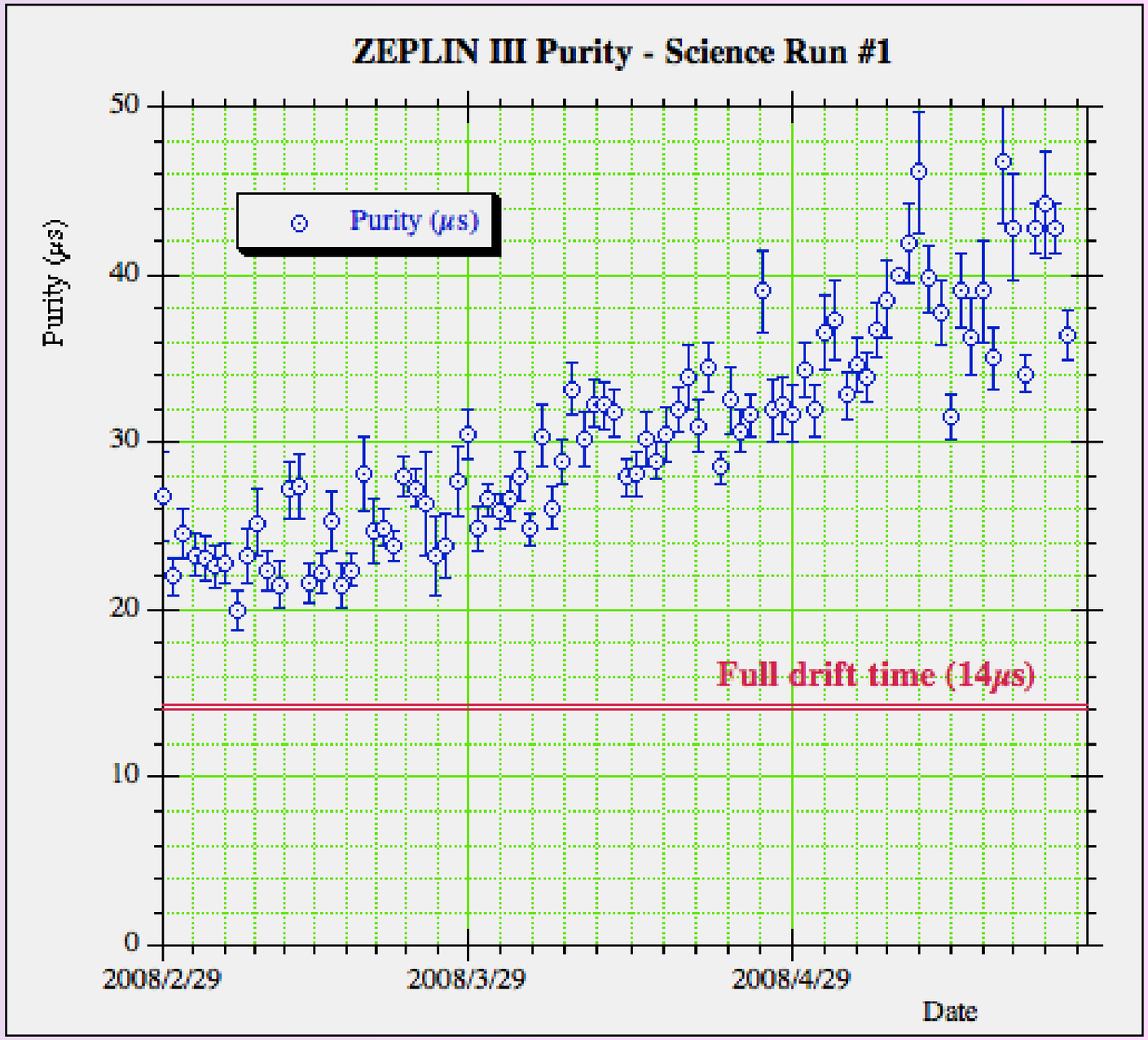
Purity Evolution

- Daily monitor with ^{57}Co source for stability measurement
- S2/S1 as a function of depth
- Cross check against FSR & ^{137}Cs

Knowledge of purity is necessary for S2 correction

Note that in the 1st run there was no recirculation through the getters. "Self cleaning"





Purification

Main impurities, but there are others:
Purity for light is determined by water.
Purity for charge is also determined by oxygen.

Purification of Gas with continuous re-circulation
and passage of gas through hot getter (SAES)

We monitor:
Initially: light yield (S1)
Then: Charge yield vs. drift time (S2)

Xenon10
Recirculation speed 5 SLPM
Maximum drift time: >2msec
Duration of cleaning: 2 months

Xenon100
Recirculation speed 10 SLPM
Light yield still increasing

XENON100: Kr Removal

Kr85 (Beta, Emax = 687 keV, t = 10.8 y, br = 99.563%) -> Rb85

Kr85 (Beta, Emax = 173 keV, t = 10.8 y, br = 0.434%)
-> Rb85m (Gamma, E = 514 keV, t = 2.43 us) -> Rb85

XENON100 science goal requires Kr contamination
~ 50 ppt

We use cryogenic distillation from Taiyo Nissan Sanso to separate Kr from Xe:

1) Spectra Gas Xe < 10 ppb Kr
verified by delayed coincidences (**7+-2 ppb**)

2) distilled on site
Design Value: Reduction by **10^3** in single Pass at **0.6 kg/hr**

Column parameters have been fine tuned in first commissioning run Sep 08.

3)Next run of column around April.

Summary

- ZEPLIN-III successfully deployed in first stage configuration
- Detector operated stably during 2008
- First science run completed
- 847 kg.days total exposure, 453.6 fidcual,126.7 kg.days exposure after all cuts
- Full analysis completed

90% c.l. Limit at 7.8 x10^{-8} pb @ 60GeV WIMP mass

- Upgrades planned this year

PMT upgrade - lower background

Veto - tag background, provide diagnostics

Xe recirculation

What will be different for XENON1T
(for Cryogenic System only!)

Much larger Xenon Volume, but we also want even lower Radioactivity.

Copper Vessel	Better insulation needed Copper- Stainless Couplings
Fill time much longer	Store and fill in liquid state
Increase Cooling Power	2 PTRs for 400 W for filling Use heat exchanger for more efficient recirculation
Purification Still Undecided	Liquid or gas?

付録

暗黒物質ニュートラリーノの性質

- 電気的に中性
- 質量 30GeV（アルミ原子程度）以上
- 平均速度およそ220km /秒（おそい）
- 銀河系の中で等方的に飛行
- 物質とはまれにしか衝突しない
- ほとんどすり抜ける