PandaX: Direct Dark Matter Search Experiment in China Jinping Underground Lab

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University of Maryland

SJTU, 2013, 6, 5

Outline

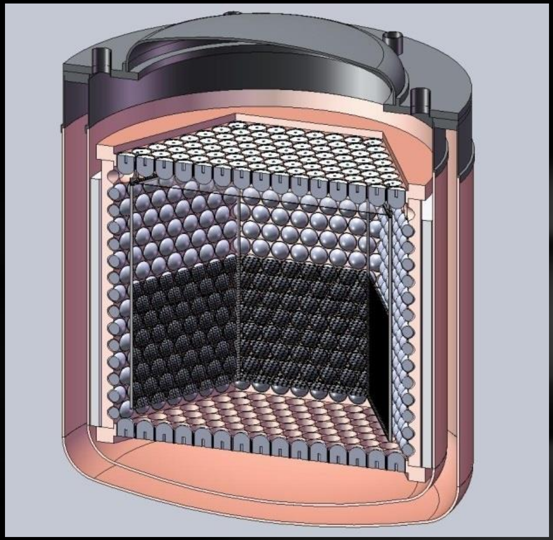
- WHY DARK MATTER?
- DARKMATTER RUSH
  - FERMI & AMS-2
  - LHC
  - Direct Detection (DAMA, CoGeNT, CRESST, XENON100, CDMS)
- PandaX
- Summary

Why Dark Matter?

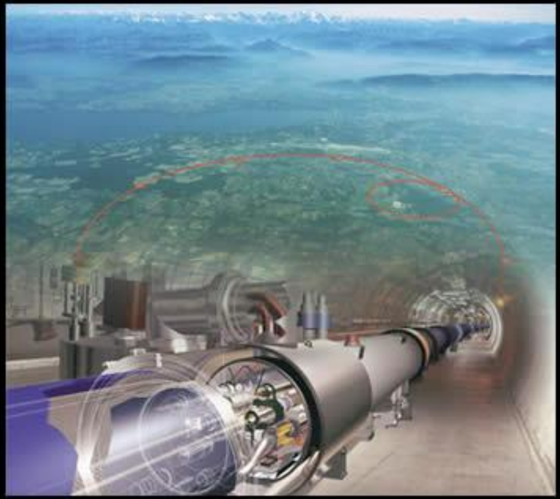
- There are plenty of astrophysical and cosmological evidence for DM,
  - All gravitational effects
  - Galaxy rotation curve, hot X-ray, gravitational lensing, bullet cluster….
  - Large scale structure, CMB fluctuation….
- There are plenty of DM candidates in theories
  - Color and electric neutral, long-lived
  - Might have weak-scale interactions (WIMPs)
  - SUSY, extra dimension, …

WIMPs Detection

Direct Detection



Accelerator

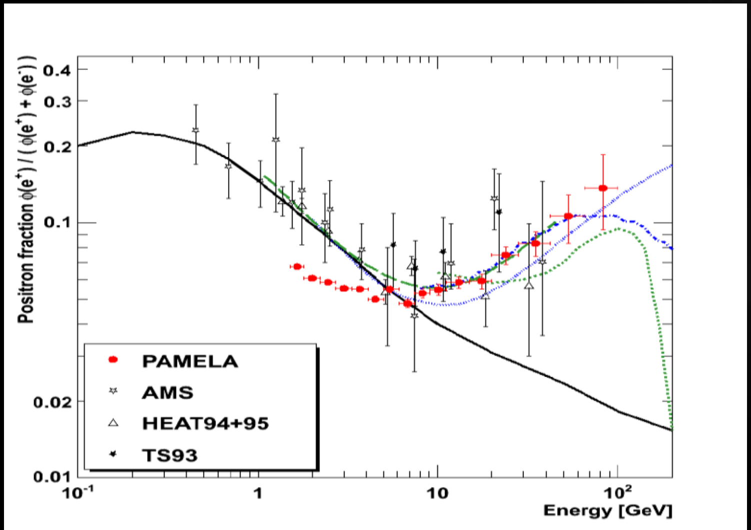


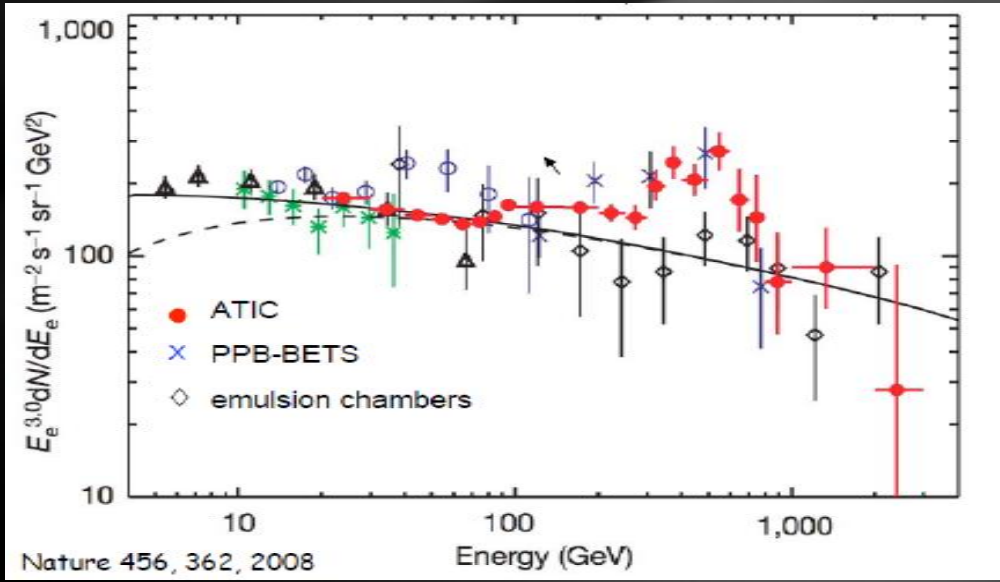
Indirect Detection

Dark matter rush…

Indirect signals

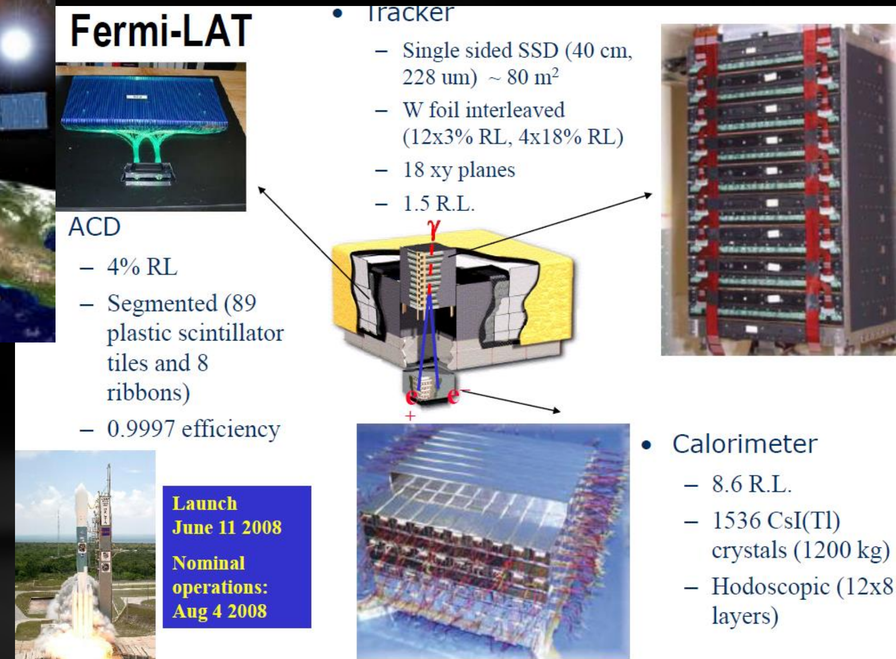
- Sources of standard model particles from dark matter annihilations in our galaxy
- Gamma ray
- Electrons and positions, neutrinos…

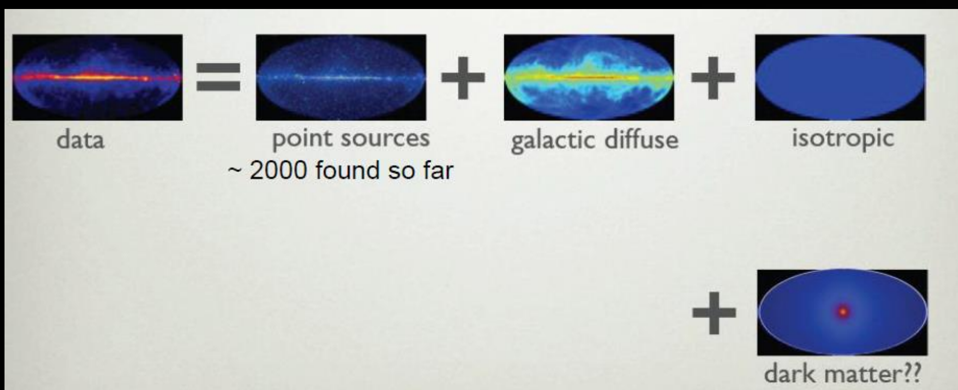


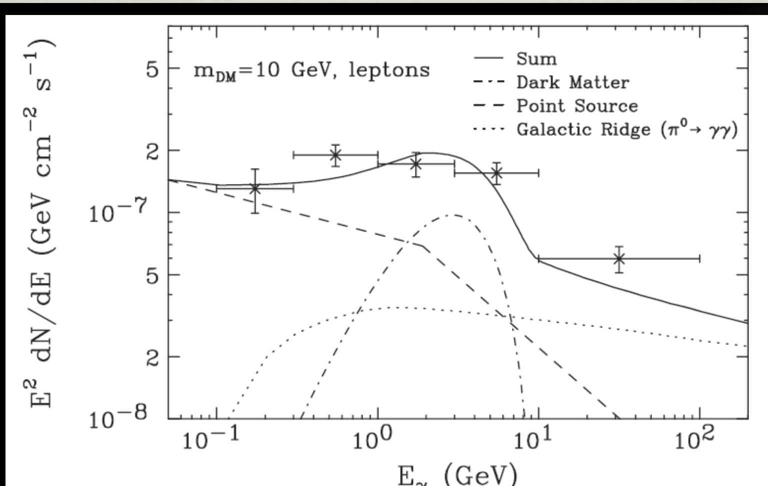


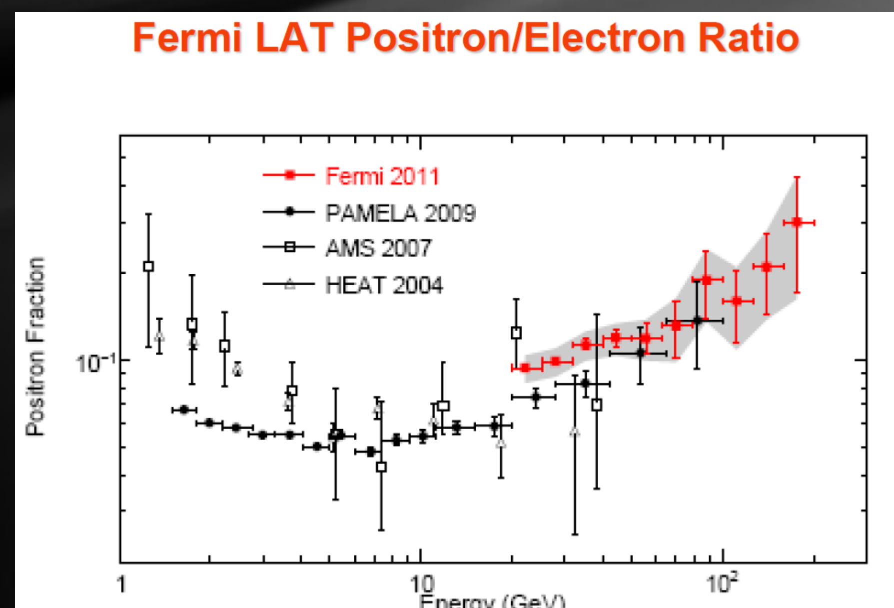
Fermi Satellite

- Lunched June 11, 2008
- Gamma Ray detector



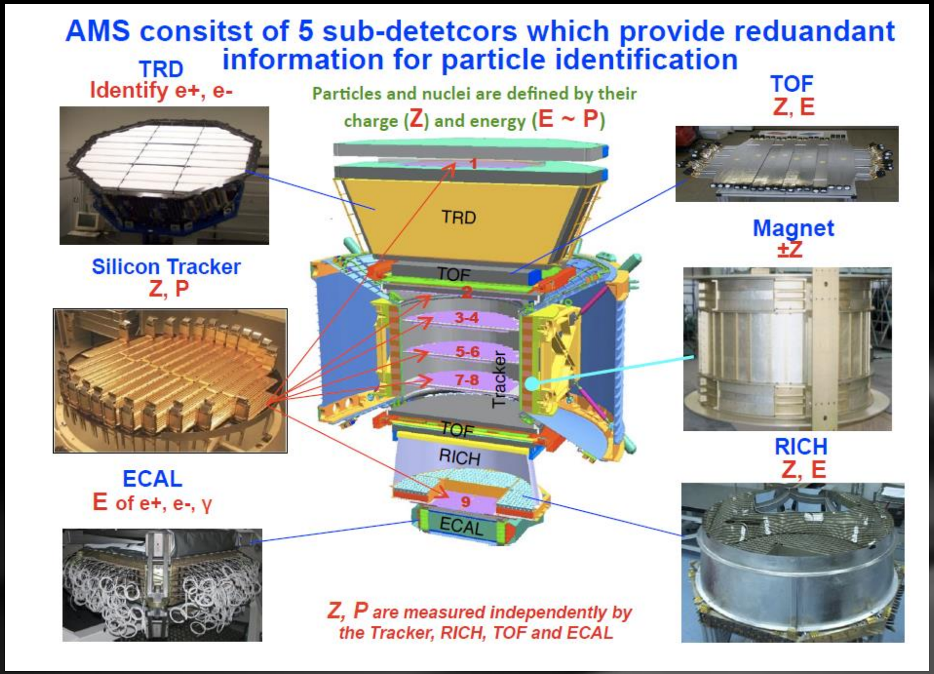


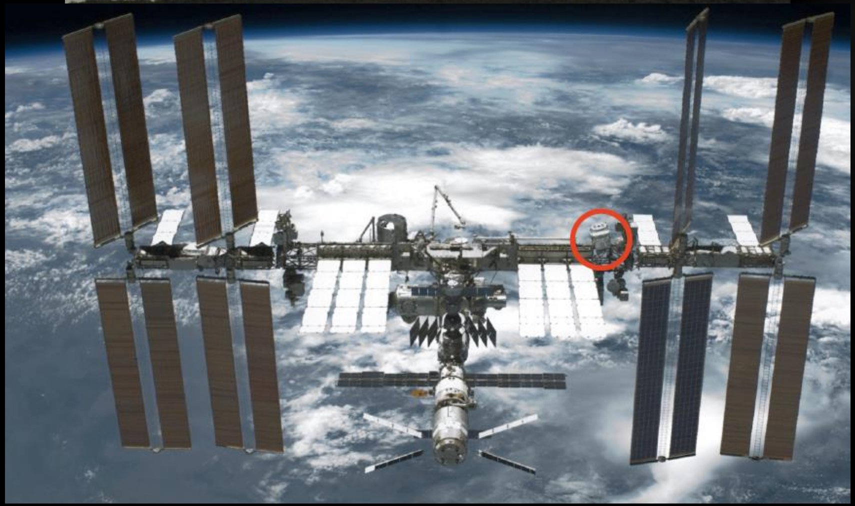




AMS-2

- Lunched May 16, 2011

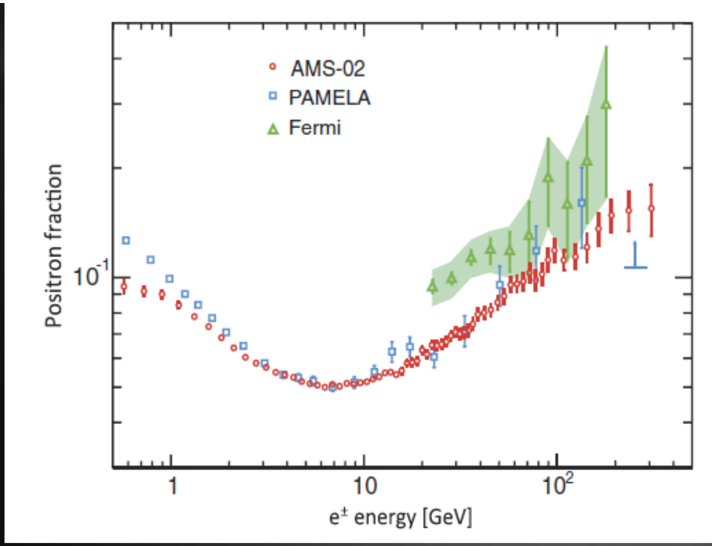




Selected for a Viewpoint in *Physics*

PRL **110,** 141102 (2013) PHYSICAL REVIEW LETTERS week ending 5 APRIL 2013

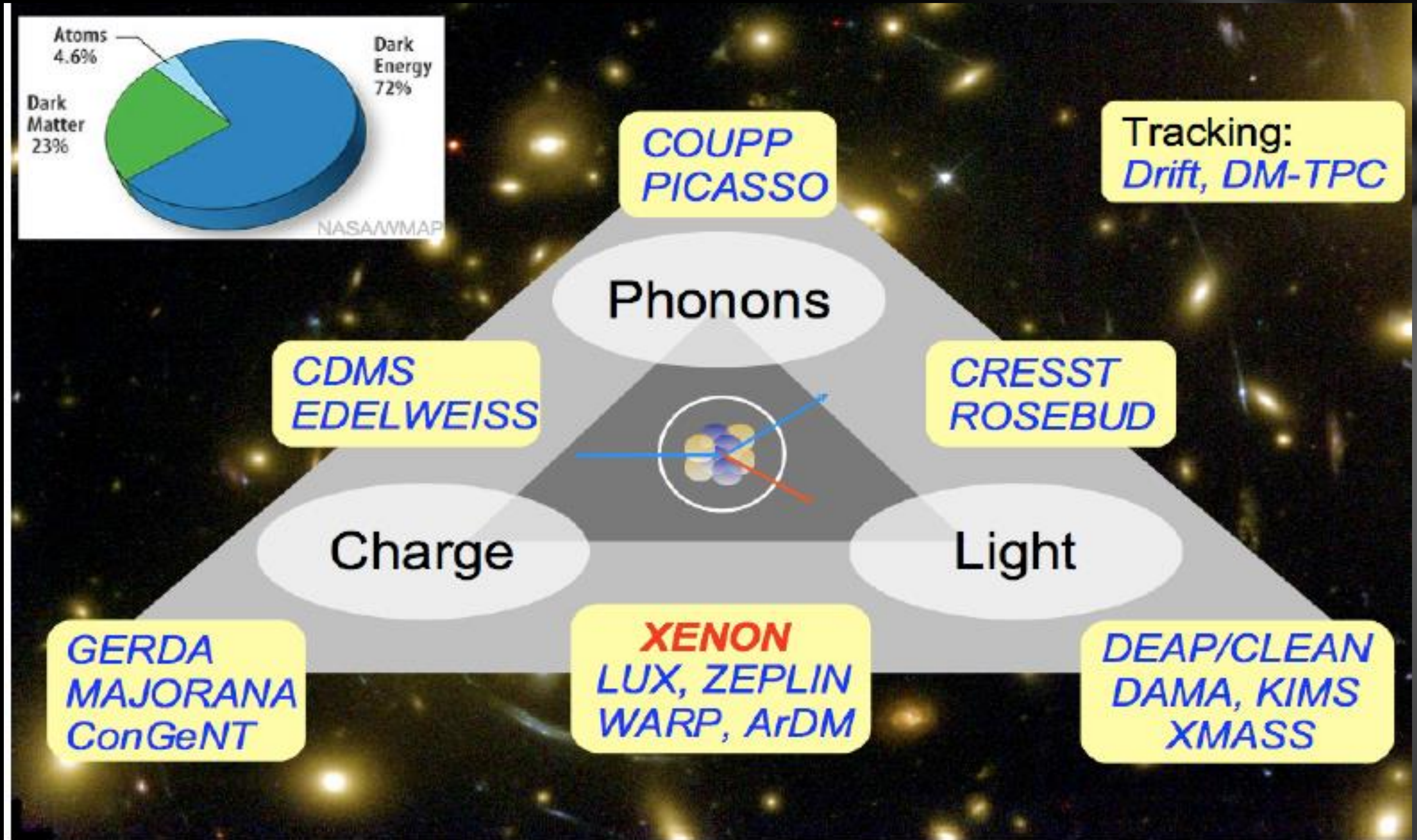
First Result from the Alpha Magnetic Spectrometer on the International Space Station: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV



Direct searches

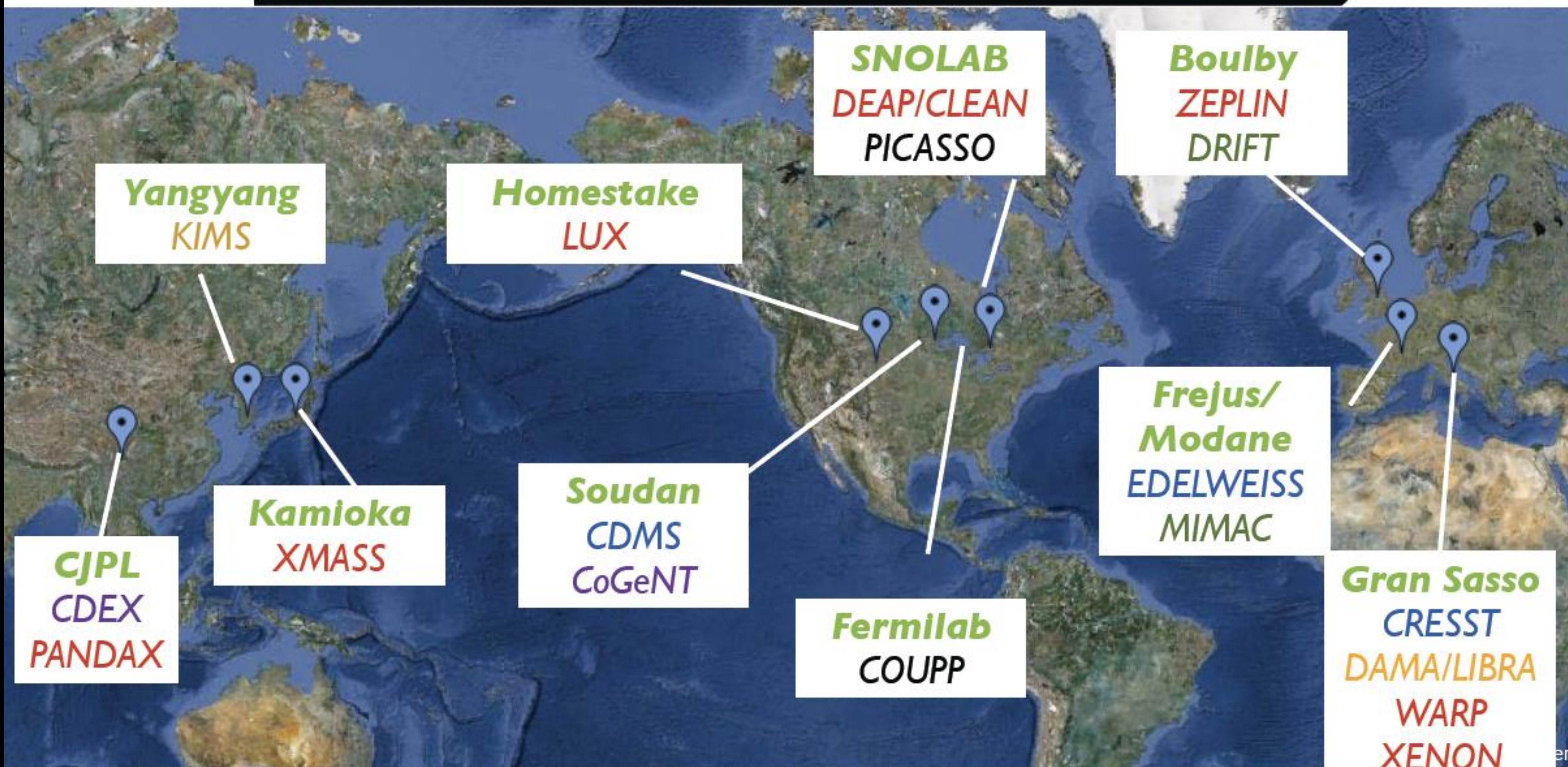
- **Dark matter forms a giant sea, enclosing the milky way. The earth and solar system like a small fish, swimming in it.**
- **Dark Matter particle has a small probability hitting the atomic nuclei (<1 time/ 100kg day), producing nuclei recoil**
- **Direct detection is to detect the atomic excitations due to nuclear recoil**

Three types of signals



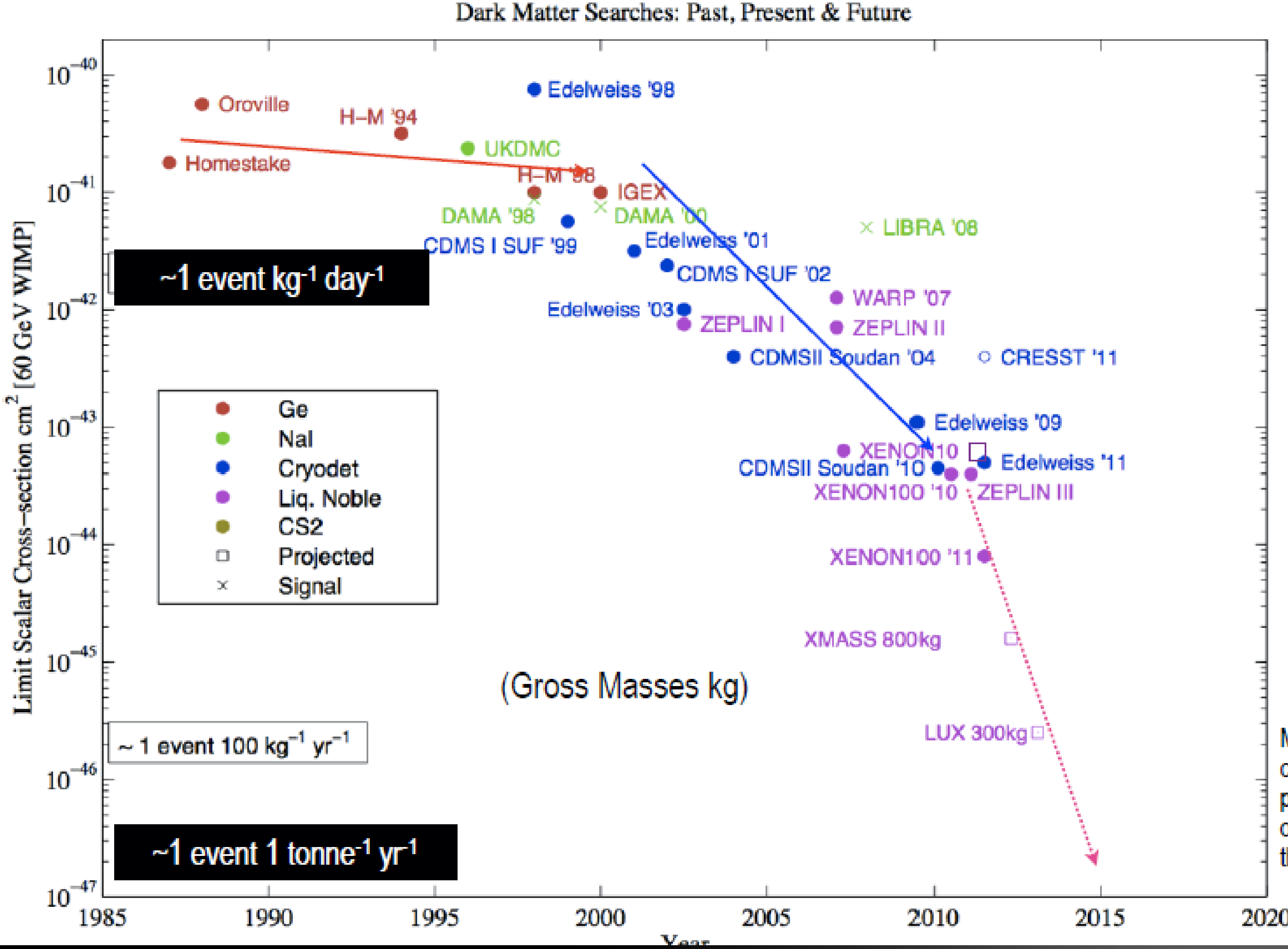
Direct detection experiments around the world

Cryogenic Bolometer (Ge, Si etc.)
Solid Scintillator (NaI, CsI)
Noble Liquids (LXe, LAr)
Directional / Ultra-low threshold / Bubble chamber



DM Direct Search Progress Over Time (2012)

Plot does not track low mass WIMPs 10 GeV



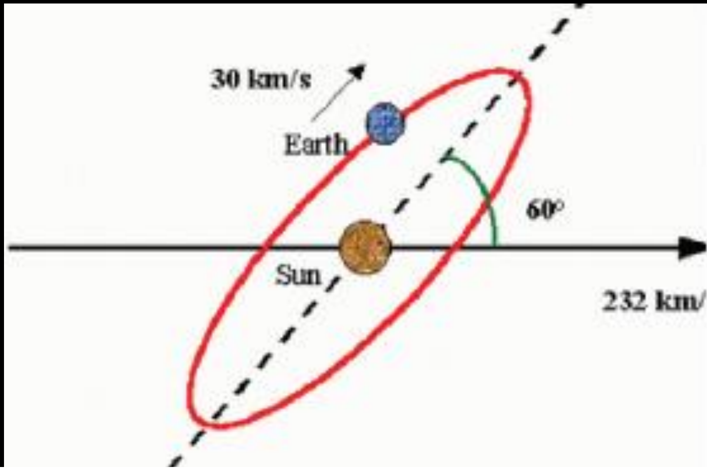
Many of current projections omitted fro[m] this plot

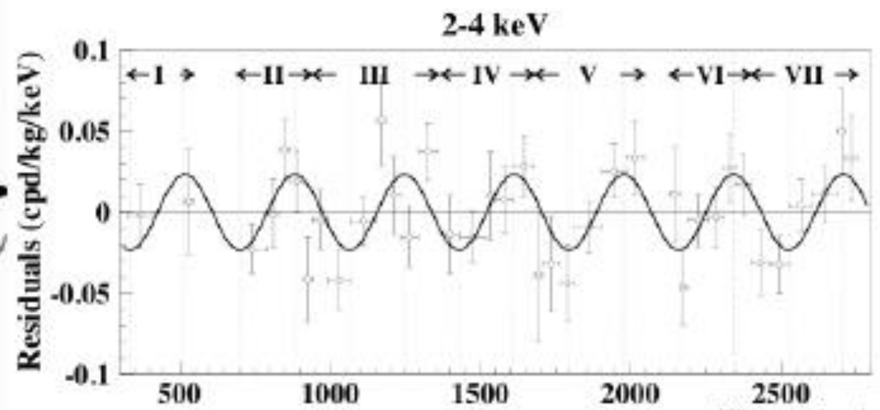
Some high-lights

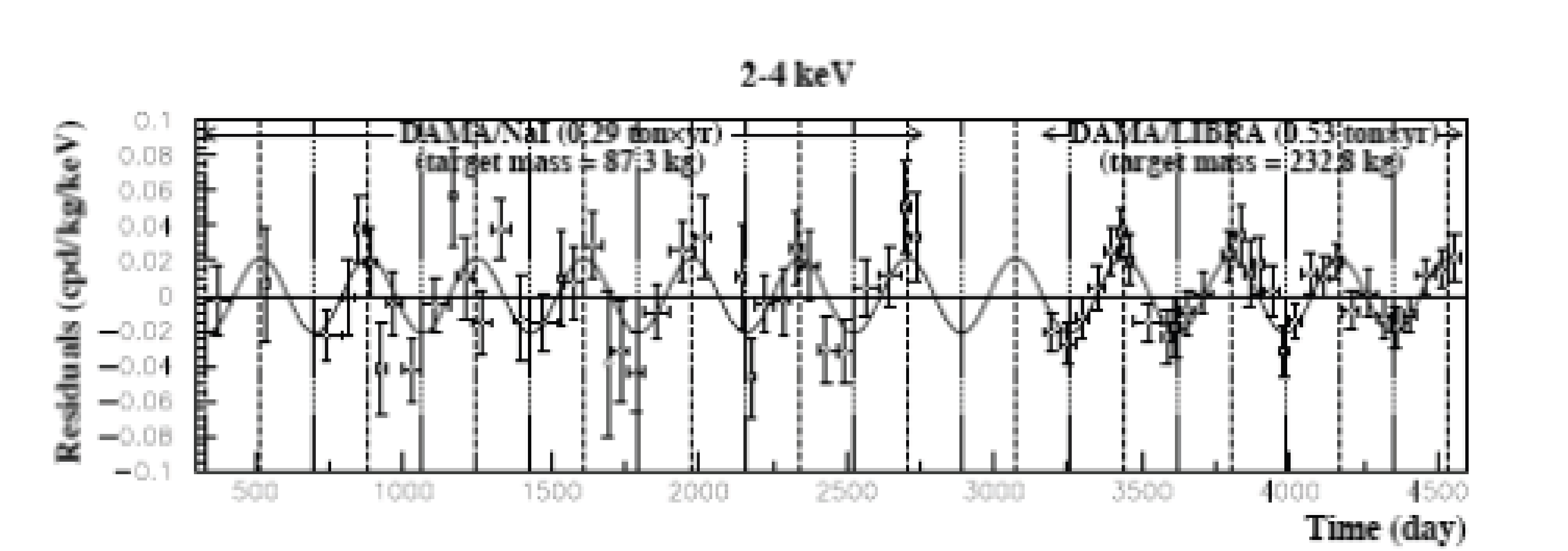
- DAMA/LIBRA (NaI crystal)
- CoGeNT (Ge)
- CRESST (crystal)
- XENON100 (Xe)
- CDMS
- .....

DAMA/LIBRA

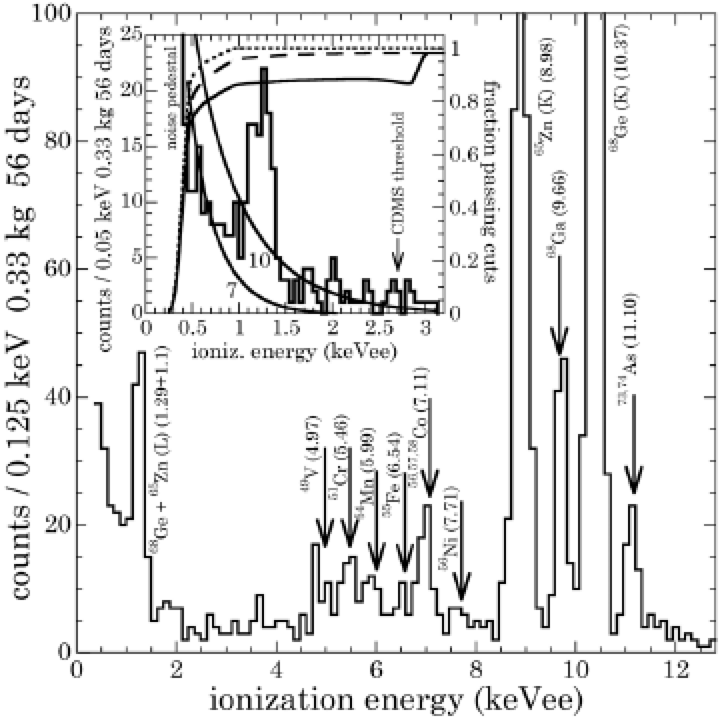
- Annual Modulation
  - Significance is 8.9σ
  - 1-2% effect in bin count rate
  - Appears in lowest energy bins
  - Can another experiment observe this effect?







Direct detection status: CoGeNT



σ_{SI} (cm^2)

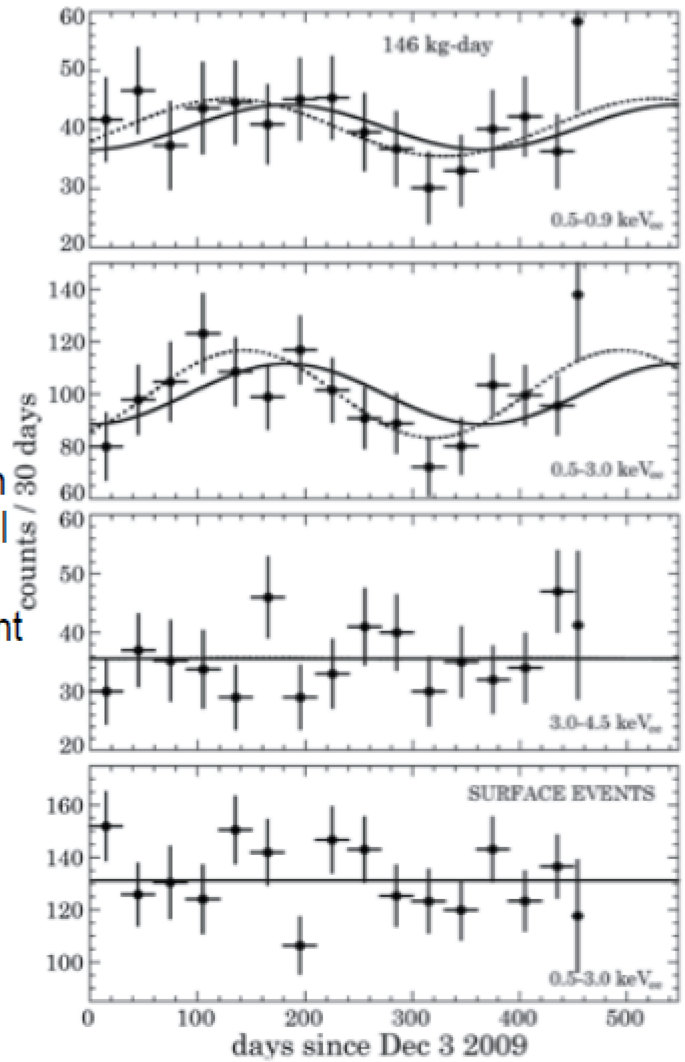
period: 347±29 d

mod. amplitude: 16.6±3.8%

minimum: Oct. 16±12 d

2.8σ better fit with mod than with null

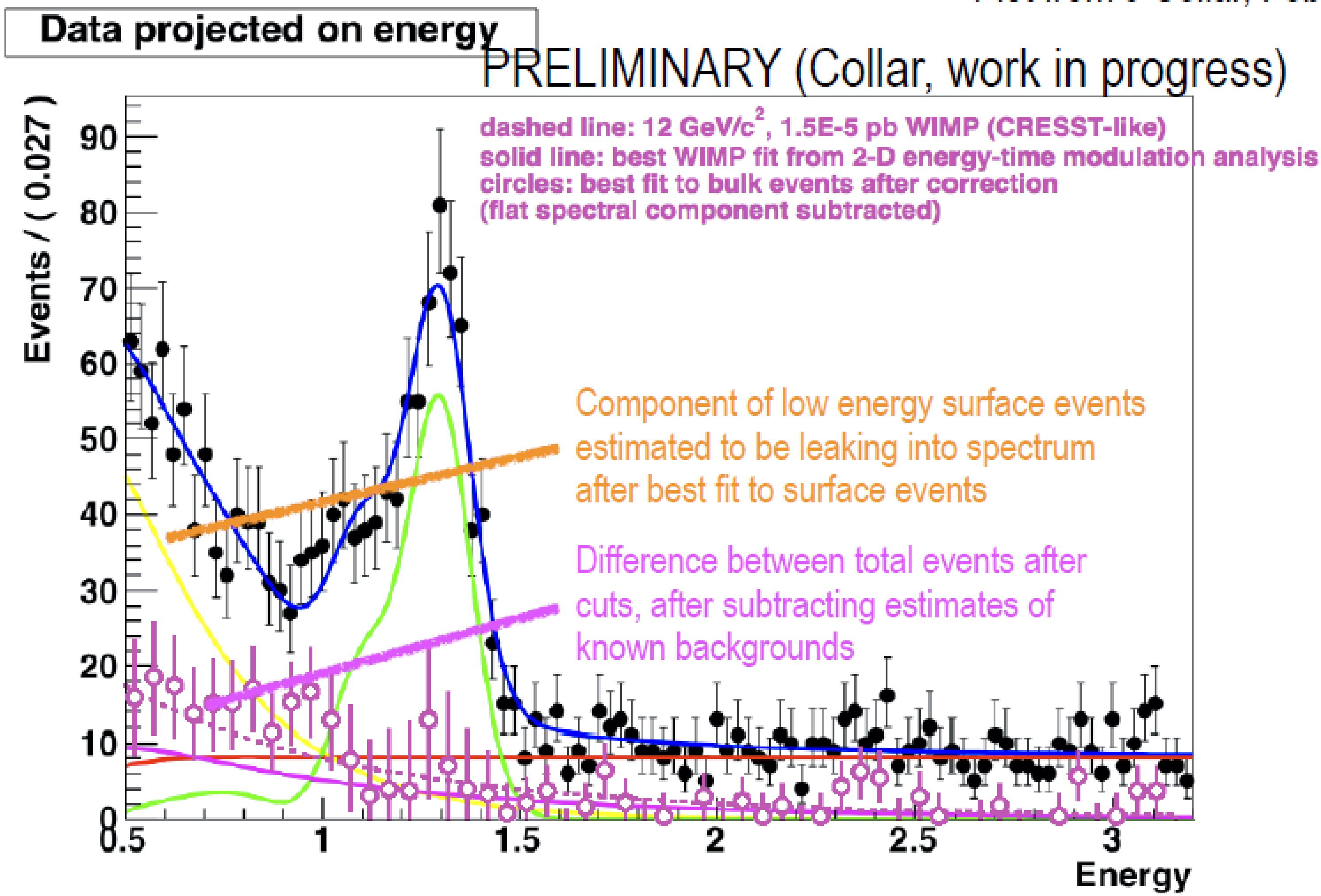
but 16% consistent with null



arXiv: 100

Recent GoGeNT Analysis

Plot from J Collar, Feb 2012



Spectral and modulation analysis in CoGeNT seem to point to a similar WIMP mass & coupling,
BUT then modulated amplitude is definitely not what you would expect from a vanilla halo (way too large).

CRESST

An experiment in Gran Sasso

Using 10x300g $CaWO_4$ crystals

Measure both light and heat (phonon)

Different element has different sensitivity on the different WIMP mass

CRESST

W. Seidel[1,a], G. Angloher[a], M. Bauer[c], I. Bavykina[a], A. Brown[e], C. Bucci[d], C.Ciemniak[b], G. Deuter[c], F. von Feilitzsch[b], D. Hauff[a], S. Henry[e], P. Huff[a], C.Isaila[b], J. Jochum[c] M. Kiefer[a], M. Kimmerle[c], R. Kleindienst[a], H. Kraus[e], Q. Kronseder[a], J.C.Lanfranchi[b], V. B. Mikhailik[e], F. Petricca[a], S. Pfister[b], W. Potzel[b], F. Pröbst[a], S.Roth[b], K. Rottler[c], C. Sailer[b], K. Schäffner[a], J. Schmaler[a], S. Scholl[c], M.vonSivers[b], L. Stodolsky[a], C. Strandhagen[c], R. Strauß[b], I. Usherov[c]

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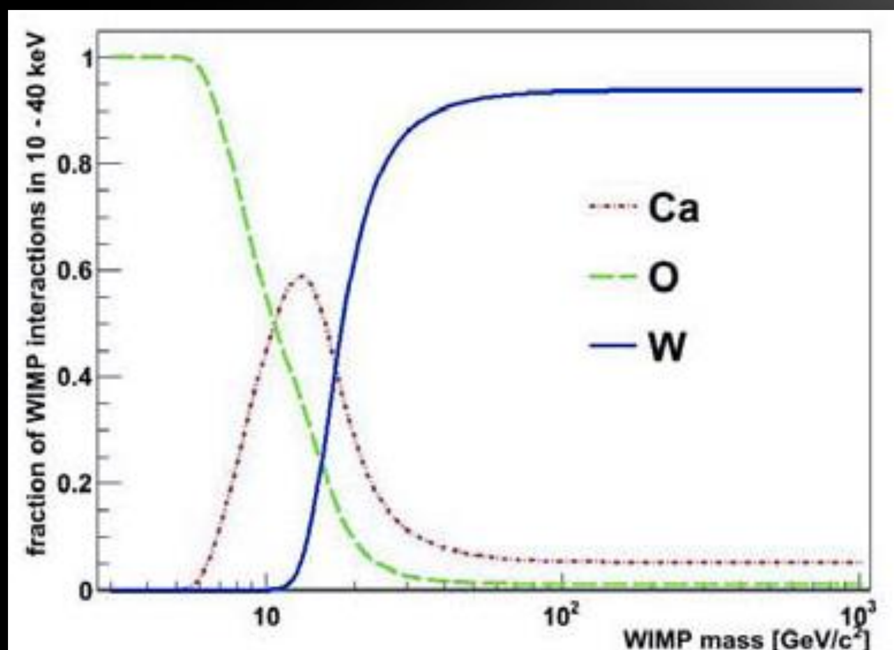
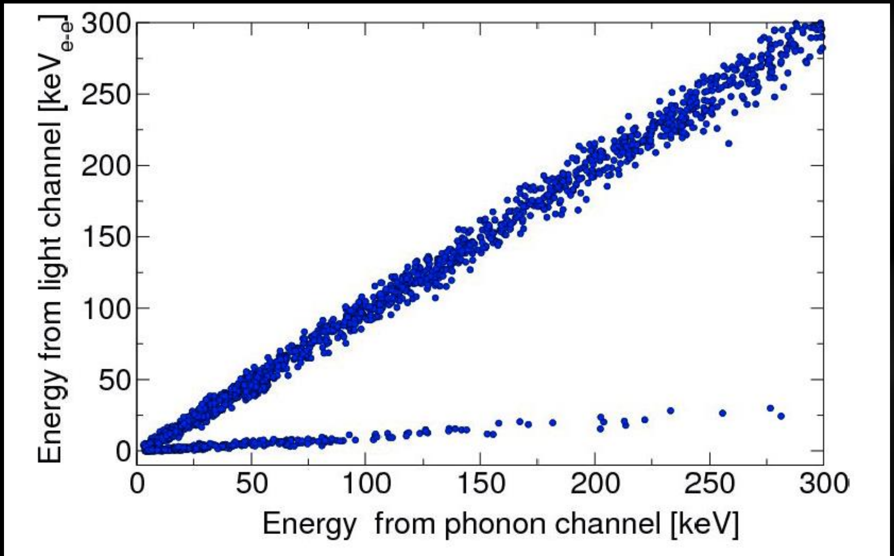
E-mail: `seidel@mppmu.mpg.de`

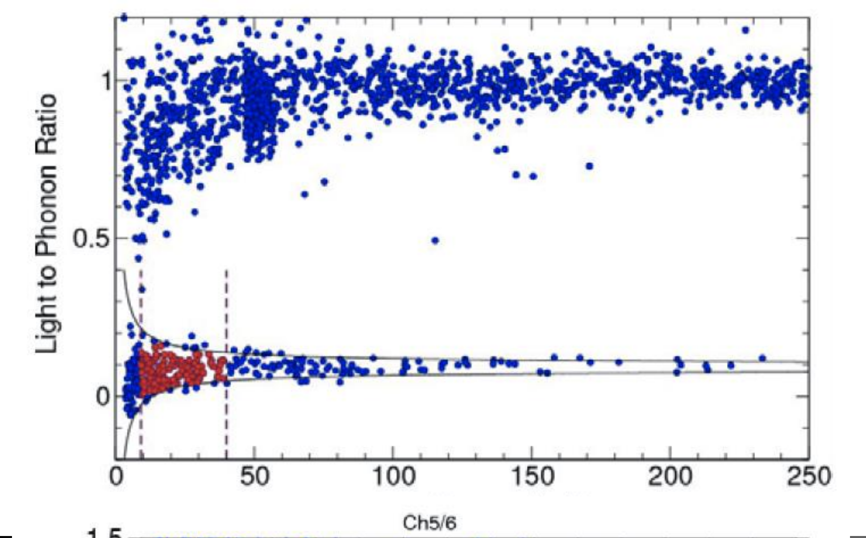


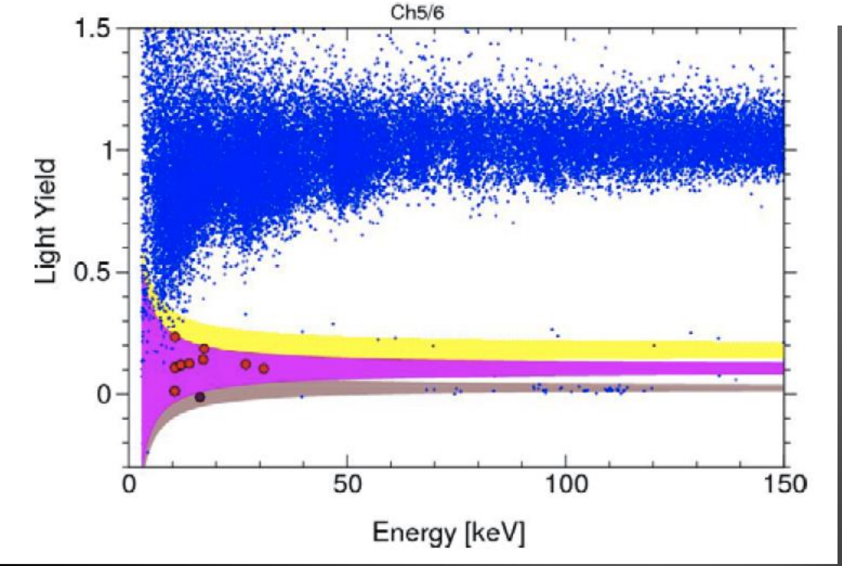
Recent results

Nuclear recoil vs.

Electron recoil







CRESST-II New Analysis

- Florian Reindel (MPI/TUM) - Diploma Thesis
  - Improved energy calib / new pulse shape cut - adaptive for noise changes / improved coincidence window-cut / new analysis allowed fully blind cuts
  - New analysis total 52 events in 572 kg d compared to 67 events in 730 kg d
  - Reduced significance of WIMP signal component
    - 1.9σ for lowest mass, 13 GeV WIMP, hypothesis
    - 2.5σ for 29 GeV WIMP hypothesis

	Analysis of this Work		Analysis of [1]	
	M1	M2	M1	M2
e/γ-Events	8.0	8.0	8.0	8.0
α-Events	9.8	9.6	11.5	11.2
Neutron Events	7.7	9.1	7.5	9.7
Pb Recoils	11.1	12.5	15.0	18.7
Signal Events	13.0	10.2	29.4	24.2
m_χ [GeV]	28.9	13.0	25.3	11.6
σ_{WN} [pb]	$7.6 \cdot 10^{-7}$	$1.6 \cdot 10^{-5}$	$1.6 \cdot 10^{-6}$	$3.7 \cdot 10^{-5}$
Significance	2.5σ	1.9σ	4.7σ	4.2σ

XE100 latest

PRL 109, 181301 (2012) PHYSICAL REVIEW LETTERS week ending 2 NOVEMBER 2012

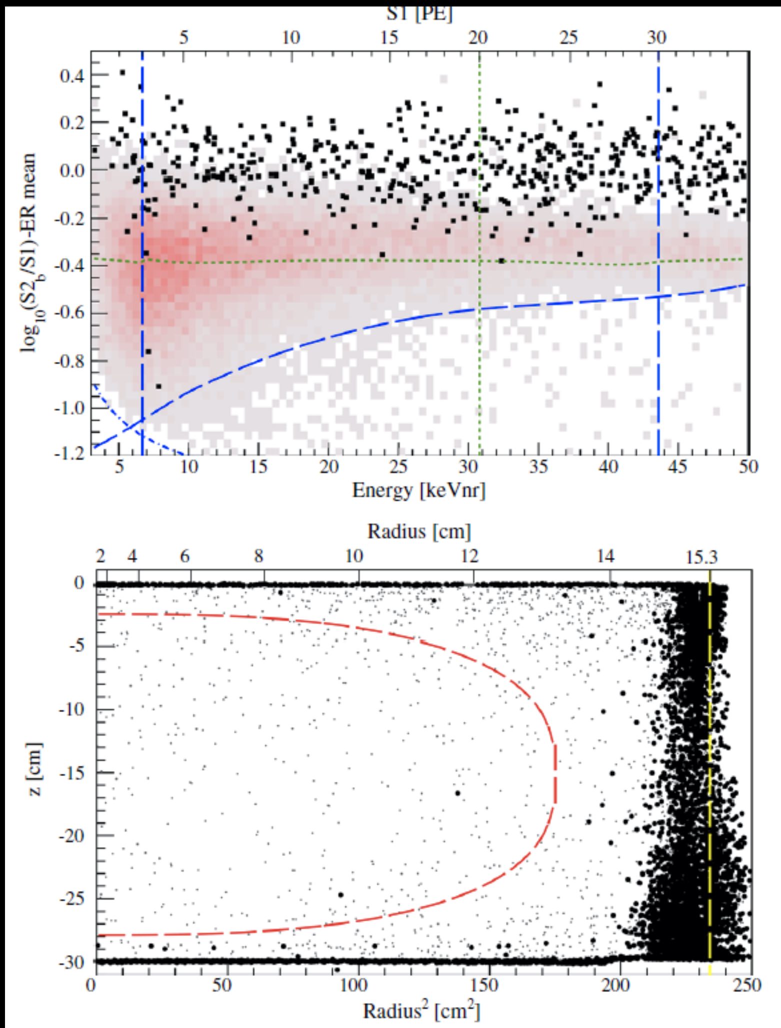
Dark Matter Results from 225 Live Days of XENON100 Data

E. Aprile,[1] M. Alfonsi,[2] K. Arisaka,[3] F. Arneodo,[4] C. Balan,[5] L. Baudis,[6] B. Bauermeister,[7] A. Behrens,[6] P. Beltrame,[3] K. Bokeloh,[8] E. Brown,[8] G. Bruno,[4] R. Budnik,[1] J. M. R. Cardoso,[5] W.-T. Chen,[9] B. Choi,[1] D. Cline,[3] A. P. Colijn,[2] H. Contreras,[1] J. P. Cussonneau,[9] M. P. Decowski,[2] E. Duchovni,[10] S. Fattori,[7] A. D. Ferella,[6] W. Fulgione,[11] F. Gao,[12] M. Garbini,[13] C. Ghag,[3] K.-L. Giboni,[1] L. W. Goetzke,[1] C. Grignon,[7] E. Gross,[10] W. Hampel,[14] F. Kaether,[14] A. Kish,[6] J. Lamblin,[9] H. Landsman,[10] R. F. Lang,[15,1] M. Le Calloch,[9] C. Levy,[8] K. E. Lim,[1] Q. Lin,[12] S. Lindemann,[14] M. Lindner,[14] J. A. M. Lopes,[5] K. Lung,[3] T. Marrodán Undagoitia,[6] F. V. Massoli,[13] A. J. Melgarejo Fernandez,[1,*] Y. Meng,[3] A. Molinario,[11] E. Nativ,[10] K. Ni,[12] U. Oberlack,[7,16] S. E. A. Orrigo,[5] E. Pantic,[3] R. Persiani,[13] G. Plante,[1] N. Priel,[10] A. Rizzo,[1] S. Rosendahl,[8] J. M. F. dos Santos,[5] G. Sartorelli,[13] J. Schreiner,[14] M. Schumann,[6,†] L. Scotto Lavina,[9] P. R. Scovell,[3] M. Selvi,[13] P. Shagin,[16] H. Simgen,[14] A. Teymourian,[3] D. Thers,[9] O. Vitells,[10] H. Wang,[3] M. Weber,[14] and C. Weinheimer[8]

(XENON100 Collaboration)

We report on a search for particle dark matter with the XENON100 experiment, operated at the Laboratori Nazionali del Gran Sasso for 13 months during 2011 and 2012. XENON100 features an ultralow electromagnetic background of $(5.3 \pm 0.6) \times 10^{-3}$ events/(keV$_{ee}$ $\times$ kg $\times$ day) in the energy region of interest. A blind analysis of 224.6 live days $\times$ 34 kg exposure has yielded no evidence for dark matter interactions. The two candidate events observed in the predefined nuclear recoil energy range of 6.6–30.5 keV$_{nr}$ are consistent with the background expectation of (1.0 ± 0.2) events. A profile likelihood analysis using a 6.6–43.3 keV$_{nr}$ energy range sets the most stringent limit on the spin-independent elastic weakly interacting massive particle–nucleon scattering cross section for weakly interacting massive particle masses above 8 GeV$/c^2$, with a minimum of 2×10^{-45} cm^2 at 55 GeV$/c^2$ and 90% confidence level.

XENON100 bound



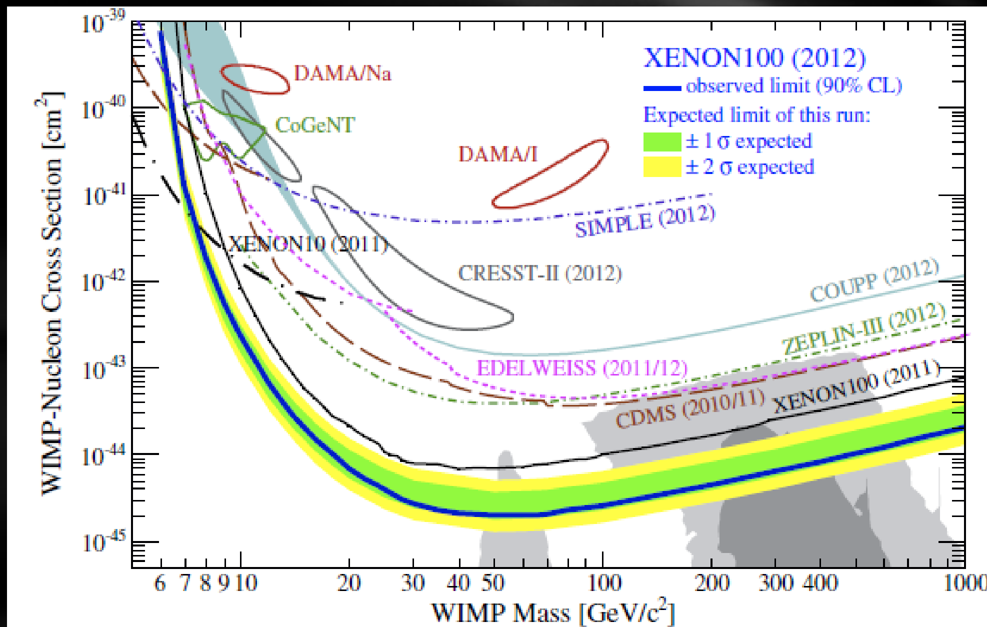
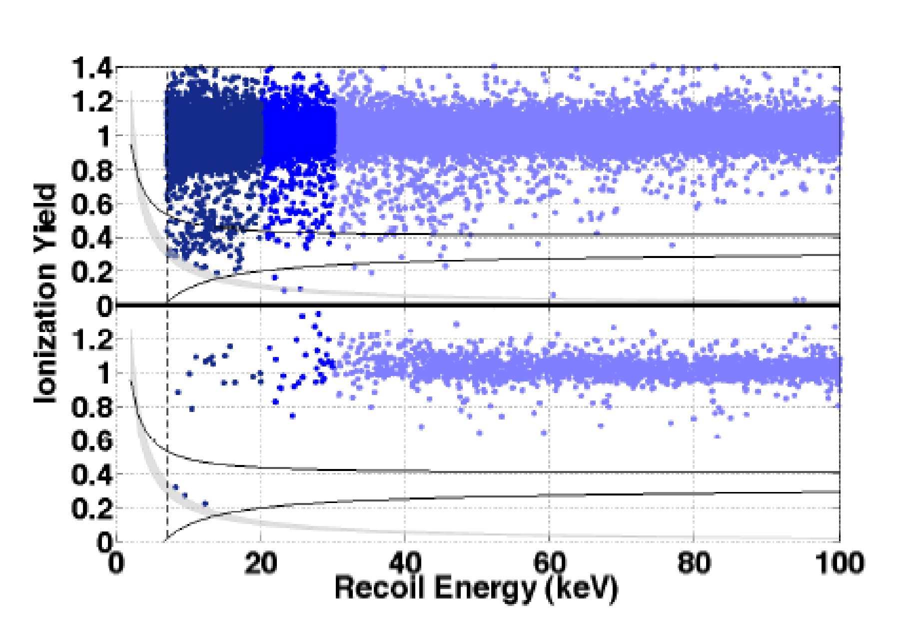


FIG. 3 (color online). Result on spin-independent WIMP-nucleon scattering from XENON100: The expected sensitivity of this run is shown by the dark (green) and light (yellow) band [1σ (2σ)] and the resulting exclusion limit (90% C.L.) by the solid blue line. For comparison, other experimental limits (90% C.L.) and detection claims (2σ) are also shown [19–22], together with the regions ($1\sigma/2\sigma$) preferred by supersymmetric models [18].

CDMSII Silicon

- Total exposure 140 kg.day
- 3 events with background < 0.2
- Fit: WIMP mass 8.6 GeV

  cross section 1.9 x 10^{-44} cm



arXiv:1304.4279, April 15 2013

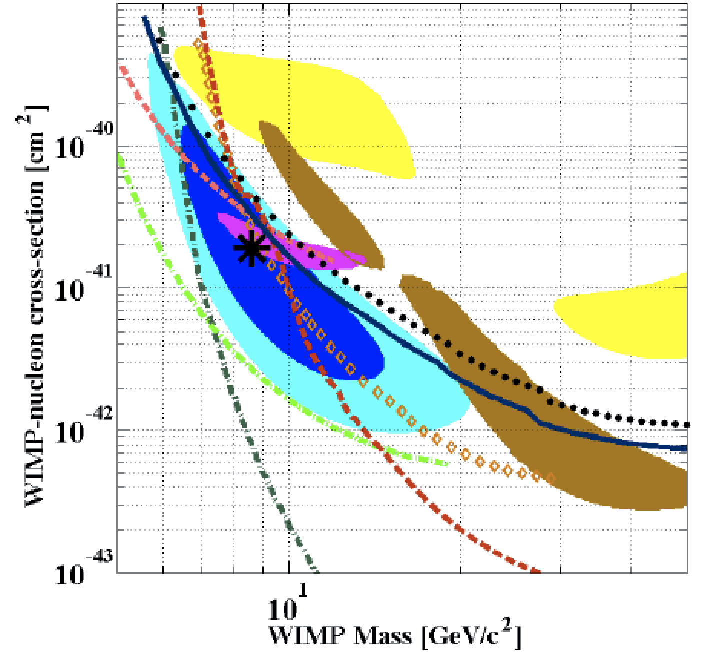
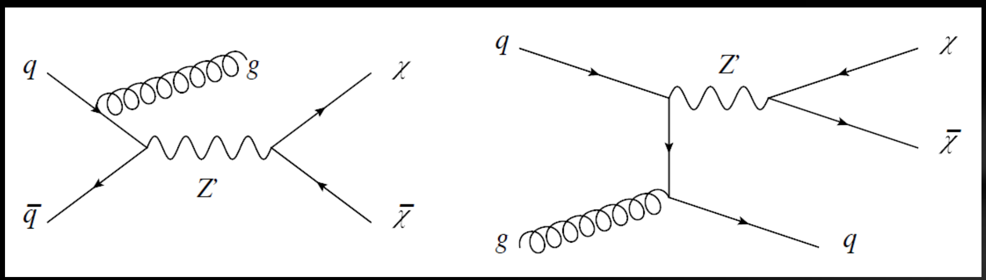
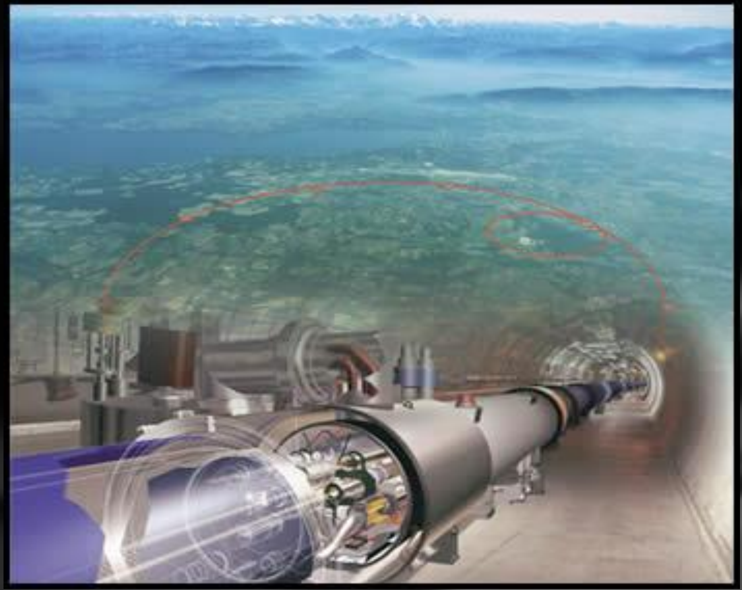


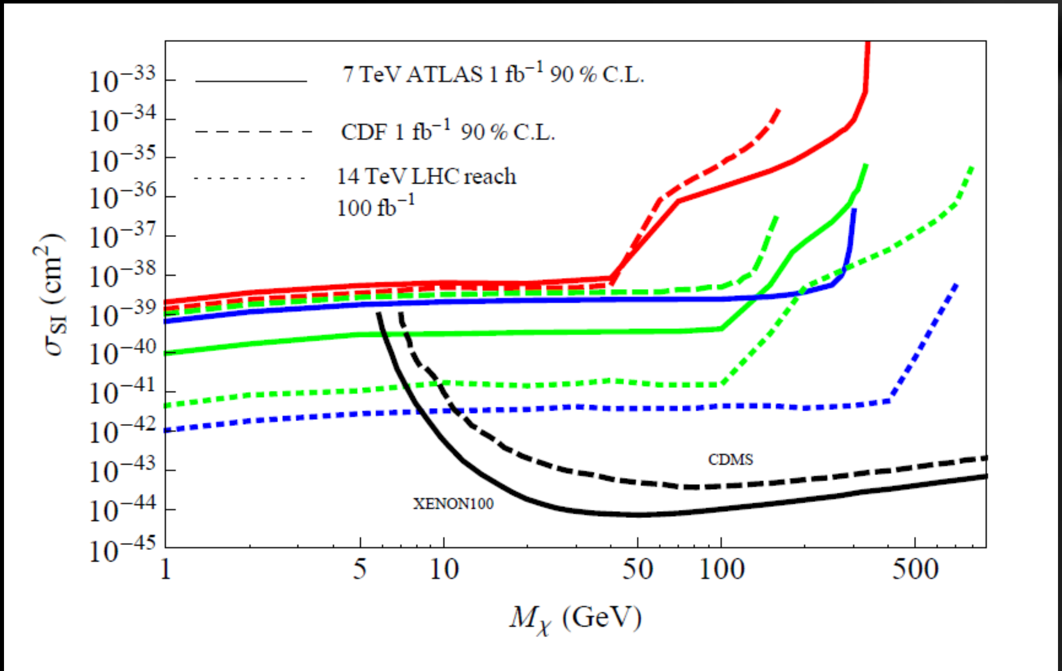
FIG. 4. Experimental upper limits (90% confidence level) for the WIMP-nucleon spin-independent cross section as a function of WIMP mass. We show the limit obtained from the exposure analyzed in this work alone (*black dots*), and combined with the CDMS II Si data set reported in [22] (*blue solid line*). Also shown are limits from the CDMS II Ge standard [11] and low-threshold [27] analysis (*dark and light dashed red*), EDELWEISS low-threshold [28] (*orange diamonds*), XENON10 S2-only [29] (*light dash-dotted green*), and XENON100 [30] (*dark dash-dotted green*). The filled regions identify possible signal regions associated with data from CoGeNT [31] (*magenta*, 90% C.L., as interpreted by Kelso *et al.* including the effect of a residual surface event contamination described in [32]), DAMA/LIBRA [16, 33] (*yellow*, 99.7% C.L.), and CRESST [18] (*brown*, 95.45% C.L.) experiments. 68% and 90% C.L. contours for a possible signal from these data are shown in blue and cyan, respectively. The asterisk shows the maximum likelihood point at (8.6 GeV/c^2, 1.9×10^{-41} cm^2).

Collider search

- Associated production







An, Ji, and Wang,
arXiv:1202.2894 [hep-ph]

PandaX

PandaX collaboration

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PandaX goal

- PandaX: Particle AND Astrophysical

  Xenon TPC

- Build a state-of-art large-size xenon dual-phase TPC detector working at the lowest background possible
  - Used for both dark matter search and
  - 136Xe double beta decay search
- **Two important features:**
  - Emphasize light collection efficiency so as to enhance the sensitivity to low-mass WIMPs (stage 1)
  - Accommodate a ton-scale experiment (stage 2)

Why Xe?

- Liquid Xe is an excellent liquid scintillator (S1)
- Free charges In LXe drift under an electric field and can be collected/detected through a proportional chamber (gas phase) (S2).
- With S1 and S2 signals, one can construct the location of events and veto gamma rays.
- Xenon does not have long-lived radioactive isotopes, can be purified relatively easily.
- Xenon is not terribly expensive and the cost for ton scale experiment is manageable.

PandaX Design Concept

PandaX will progress through three stages.

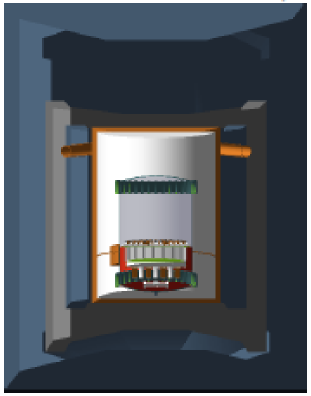
Built for Stage II
from the Start

No change to:
Shield,
Outer Vessel,
Cryogenics,
Purification,
General Infrastructure

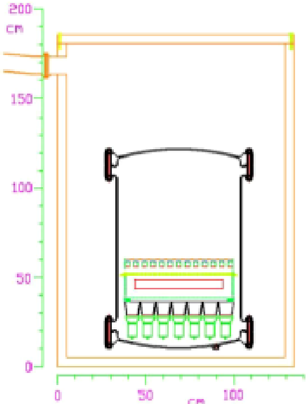
Cryostat: Two Versions

TPC: Three Versions

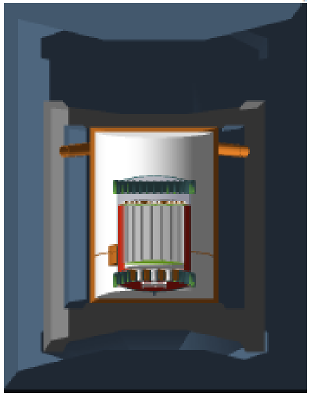
Stage Ia: 25kg (fid)



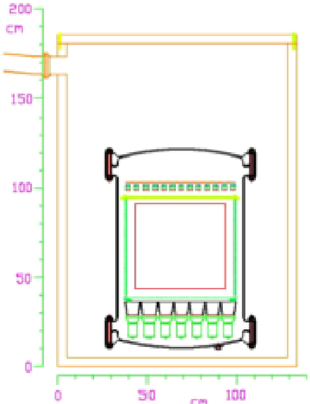
Low threshold
High light collection



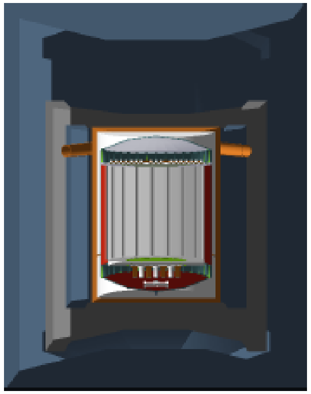
Stage Ib: 300kg (fid)



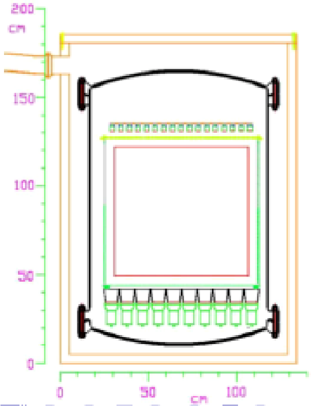
Same inner vessel
Quick to implement



Stage II: 1Ton (fid)



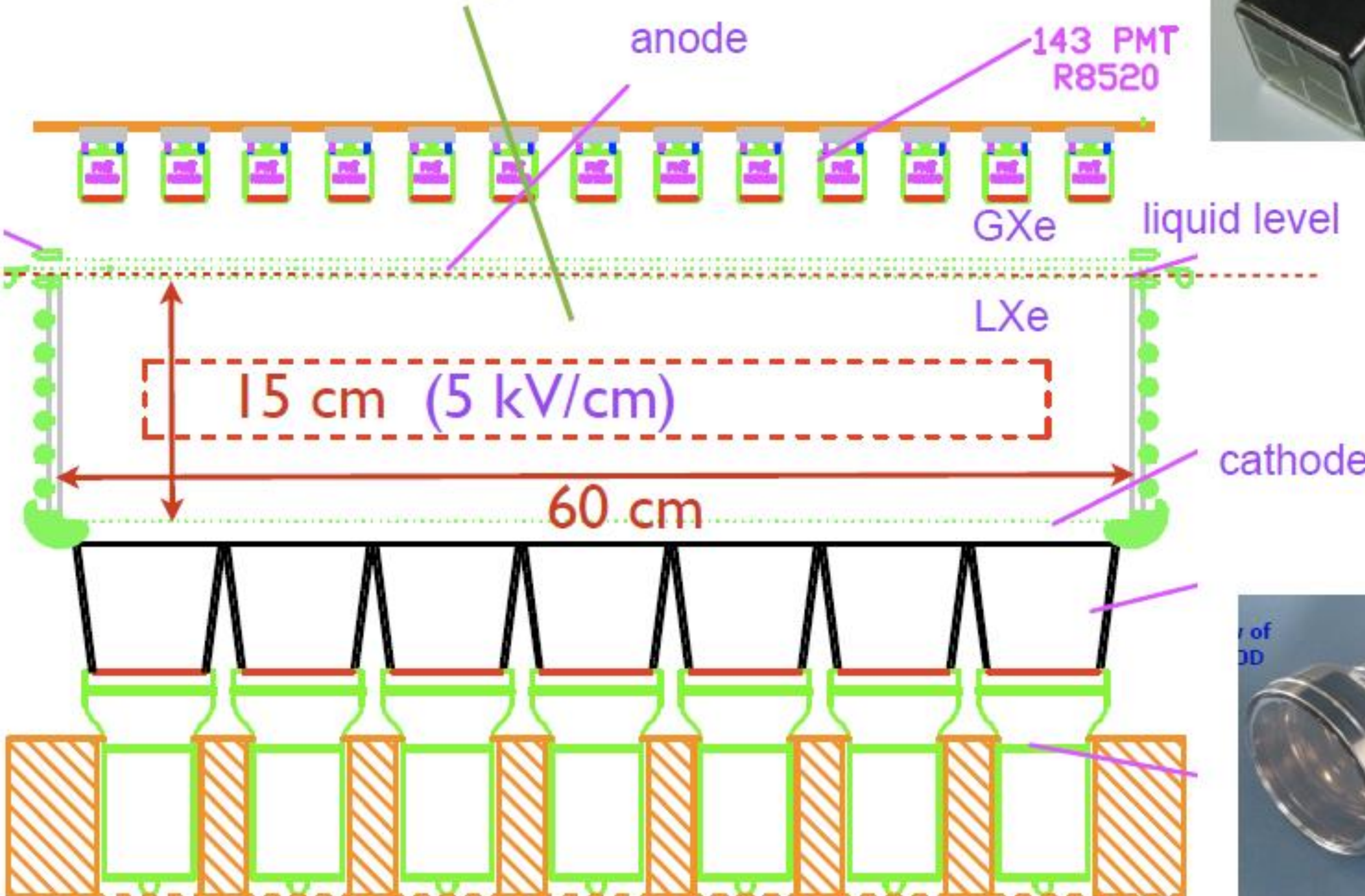
Same shield/OV/cooling/+
New inner vessel

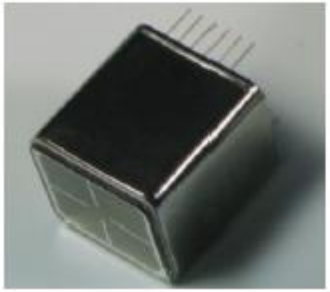


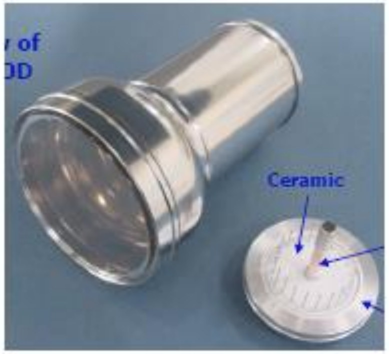
PANDAX: a LXe detector with high field & high light yield

sensitive mass：123 kg

fiducial mass: 25 kg

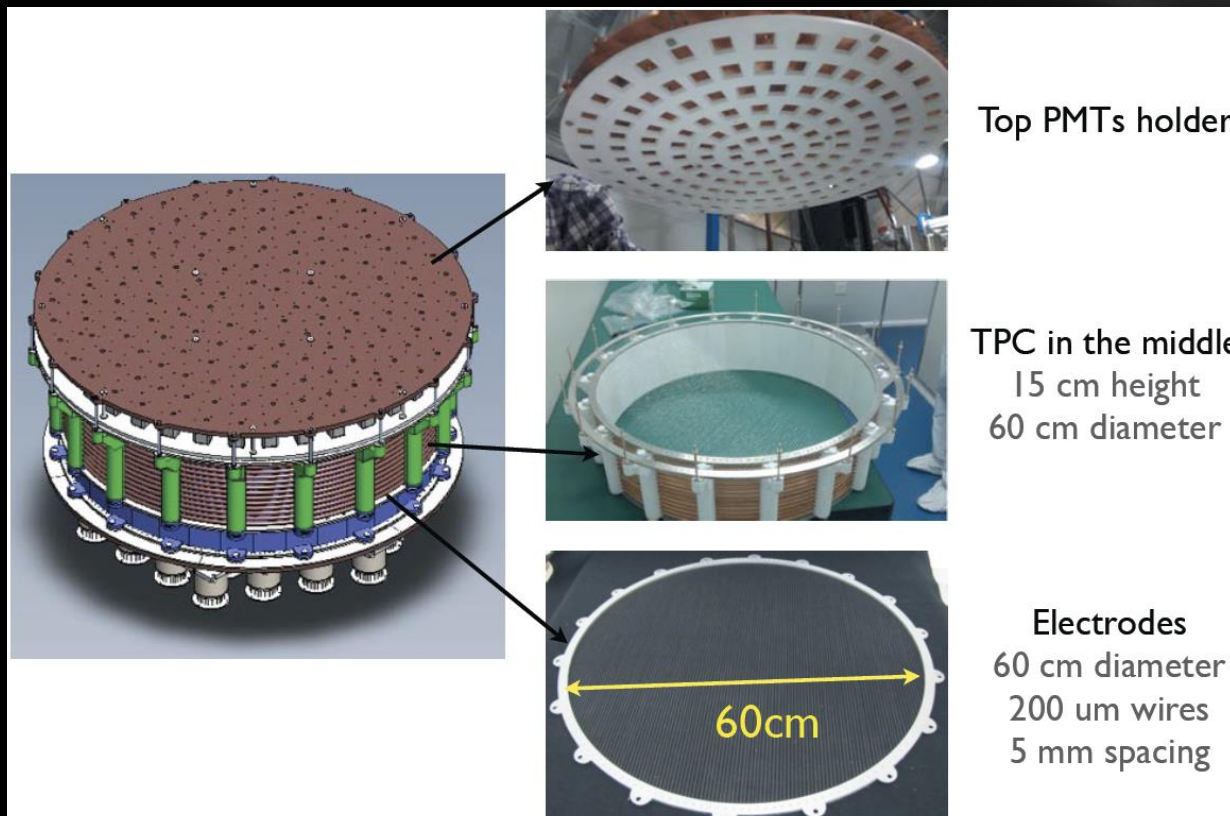


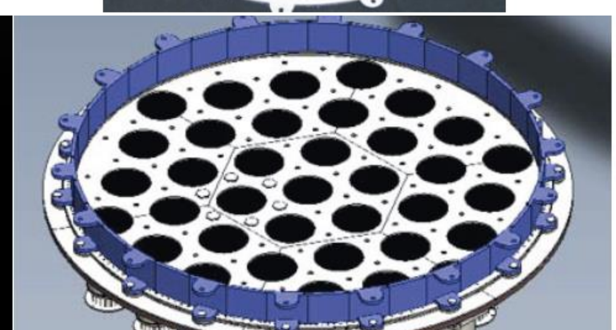




37 R11410 PMT

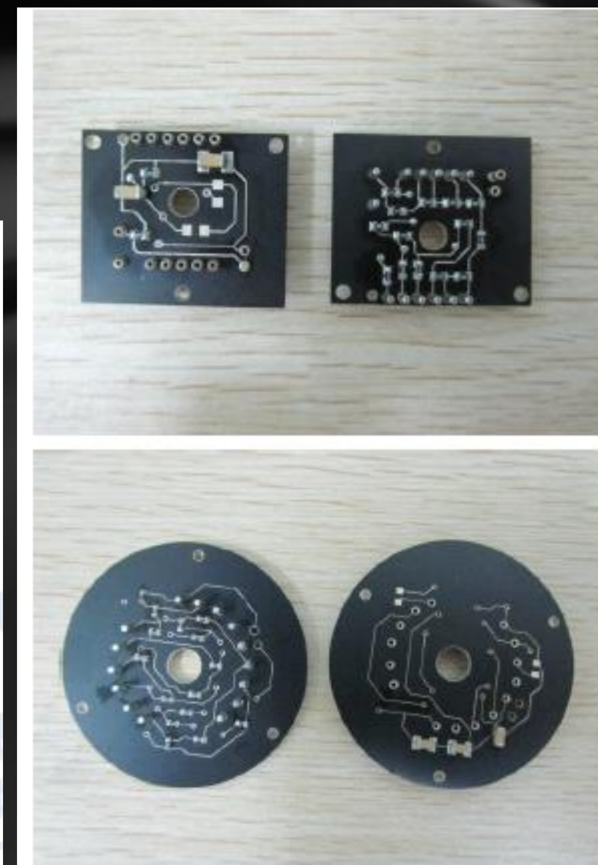
TPC construction





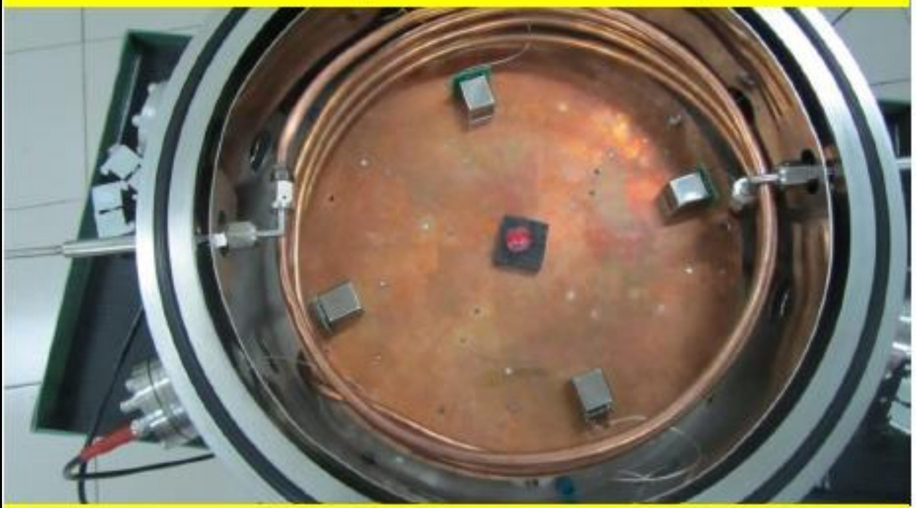
PMTs

- 150 1-in R8520-406 PMT, bases and decoupler designed and constructed. PMT's tested . A data base has been established.
- 50 3-in PMT for the bottom TPC.



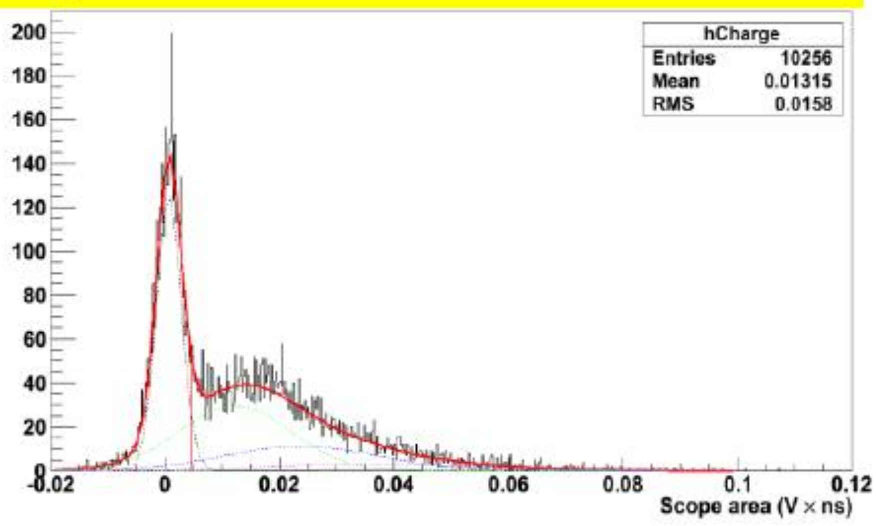
PMT Testing

Dark chamber design to be 0 to 2 atm, -100 C



Full test setup

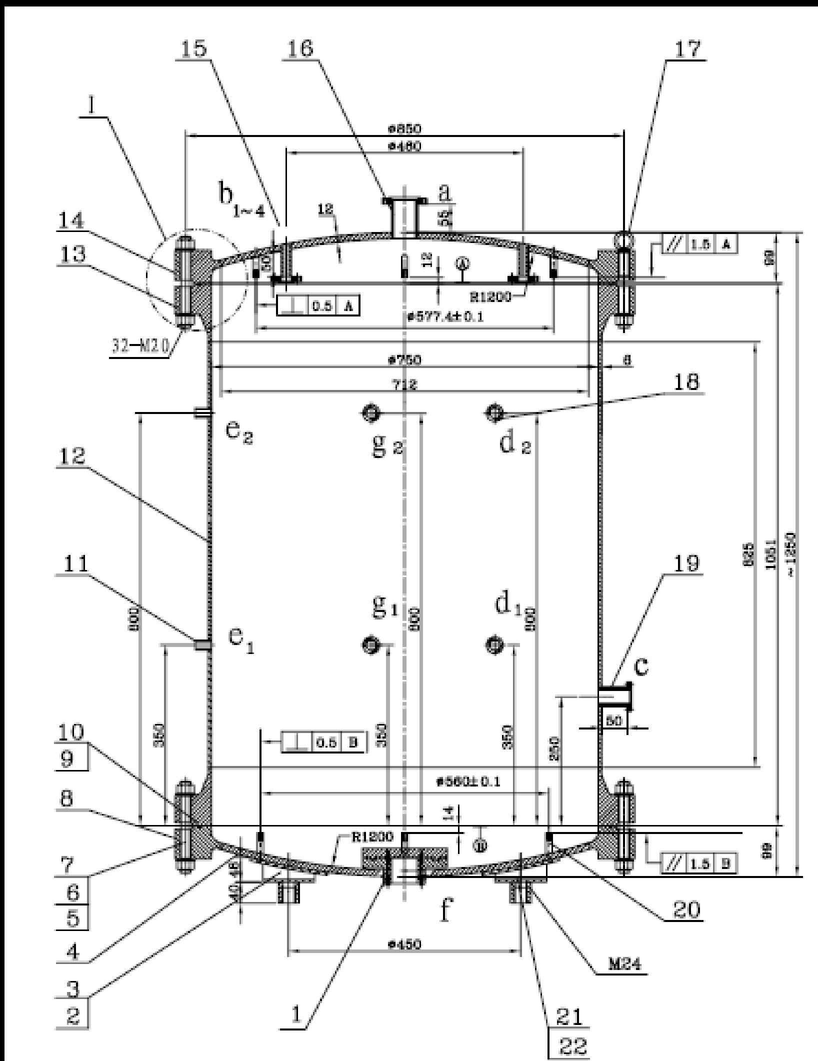
SPE spectrum



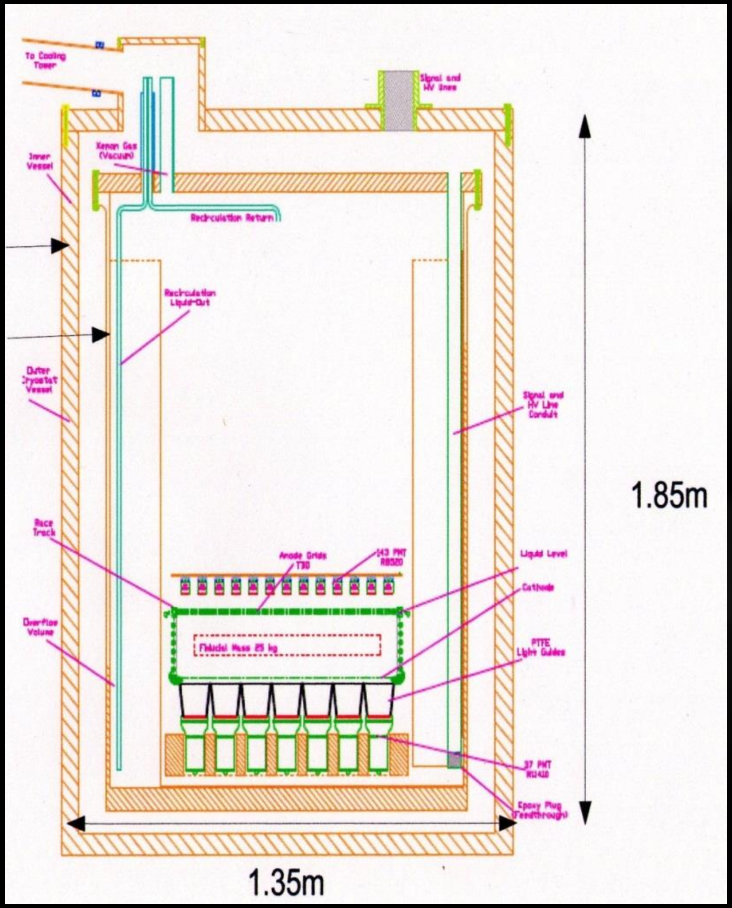
Under testing:

- PMT properties under realistic experimental conditions (vs temperature)
- Signal processing and electronics performance (full chain test)

InnerVessel



Cryogenic system



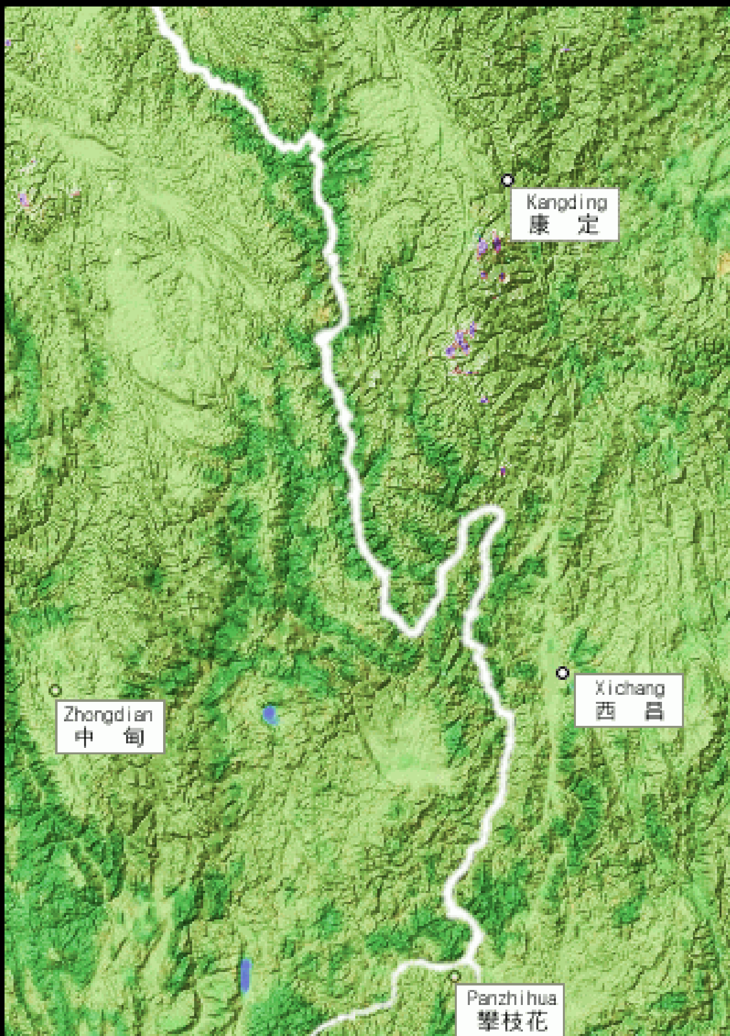
- Outer Vessel (vacuum) part of shield 5 cm OFHC copper
- All auxillary structures removed to outside of shield
- ‘Weir’ structure instead of ‘Bell’
- Minimize PTFE use. Neutron production on Fluorine
- Reduced cabling in xenon. Less outgassing

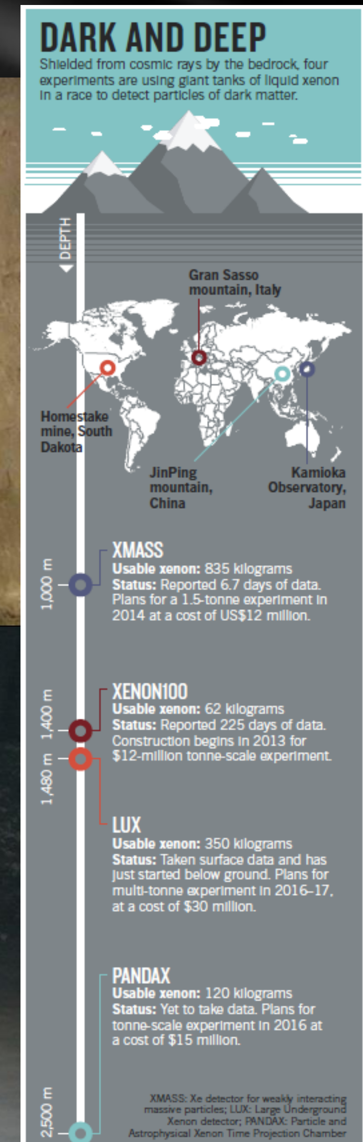
Testing Vessel and gas handling

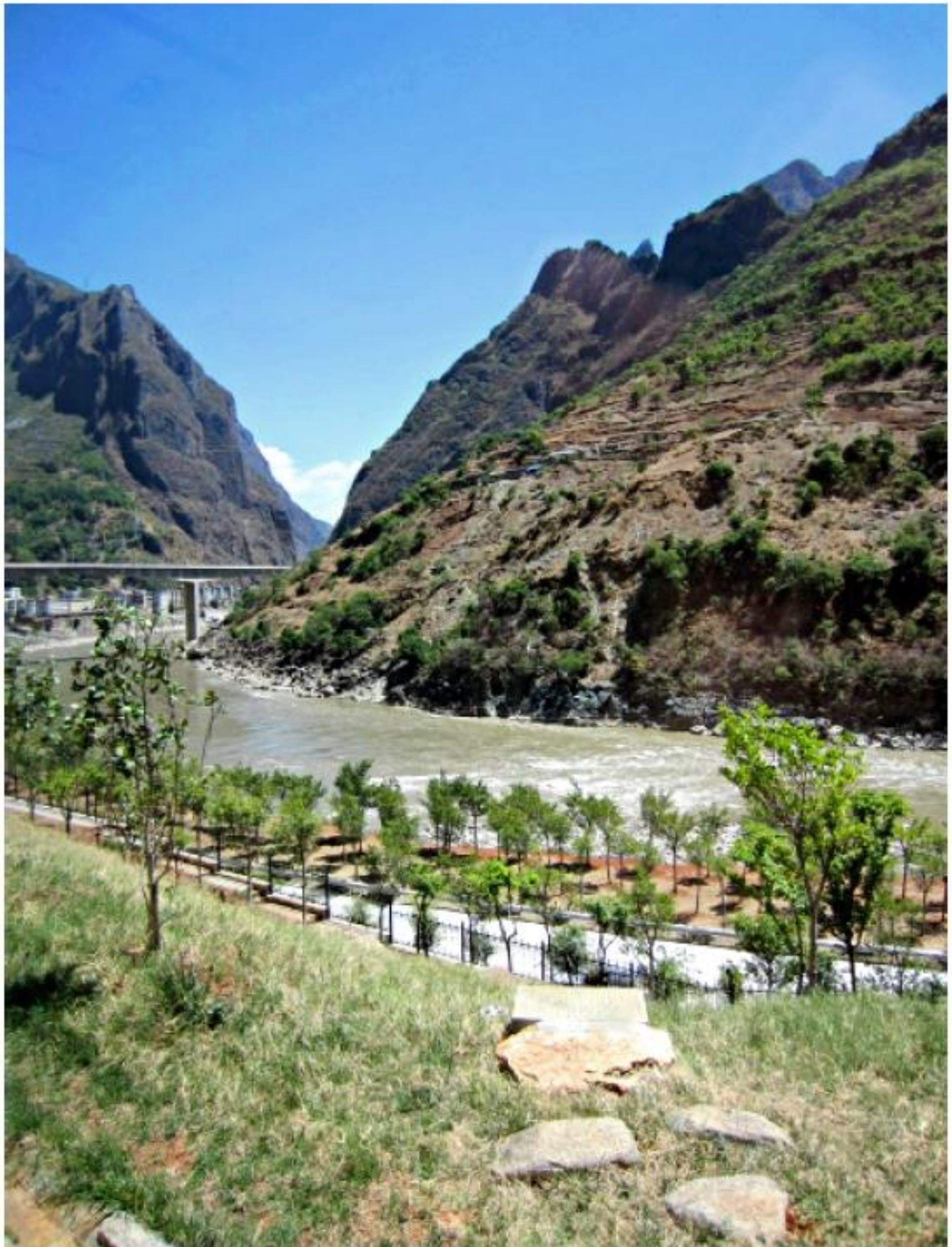
Cooling bus

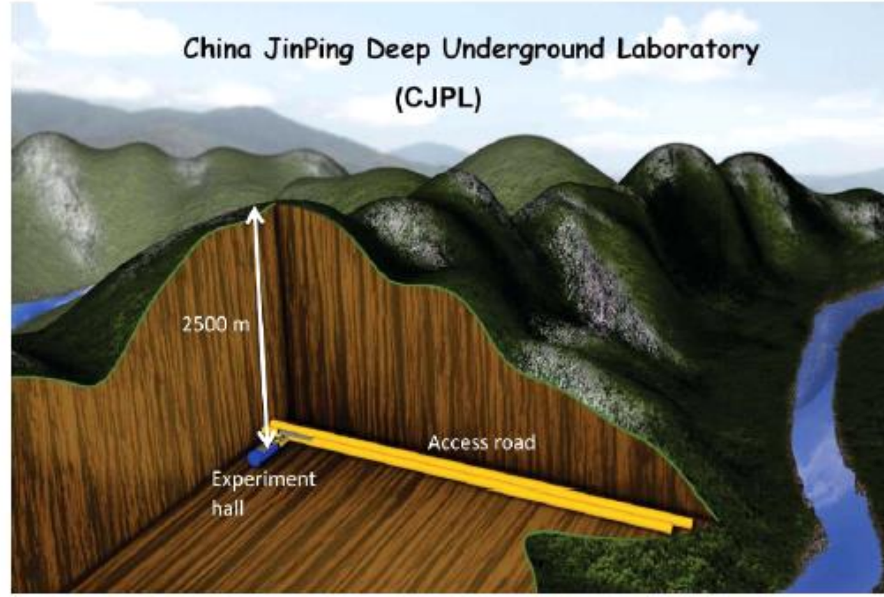
with Heat Exchanger ,
with speed up to 100 SLPM.

Jinping lab in Sichuan, China



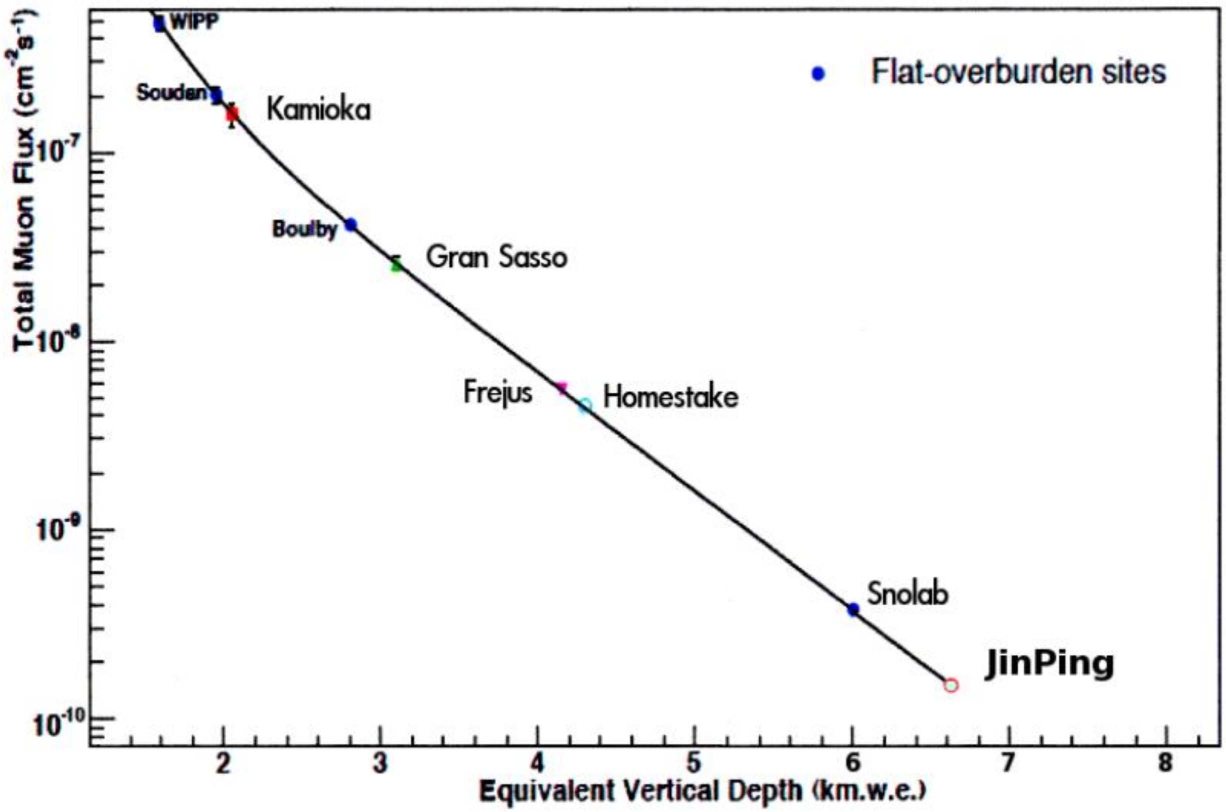





China JinPing Deep Underground Laboratory
(CJPL)
2500 m
Access road
Experiment
hall

JinPing Lab: A Low Background Facility

Low cosmic muon background



Low radioactivity from rock

Facility	Depth [m.w.e.]	μ Flux [events / ($m^2 \cdot$year)]	Rock	^{238}U [Bq/kg]	^{232}Th [Bq/kg]	^{40}K [Bq/kg]
Jinping (PandaX)	6,600	66	marble	1.8 ± 0.2	< 0.27	< 1.1
Homestake	4,500	950	rhyolite	100	45	900
Grand Sasso – Hall B	3,500	8,030	dolomite	5.2	0.25	4.9

The 66 muons/m^2/year is an estimate based on 33 days of measurement, less uncertainty soon

PHYSICS

Dark-matter hunt gets deep

China launches world's deepest particle-physics experiment — but it joins a crowded field.

BY EUGENIE SAMUEL REICH

WOLFGANG LORENZON

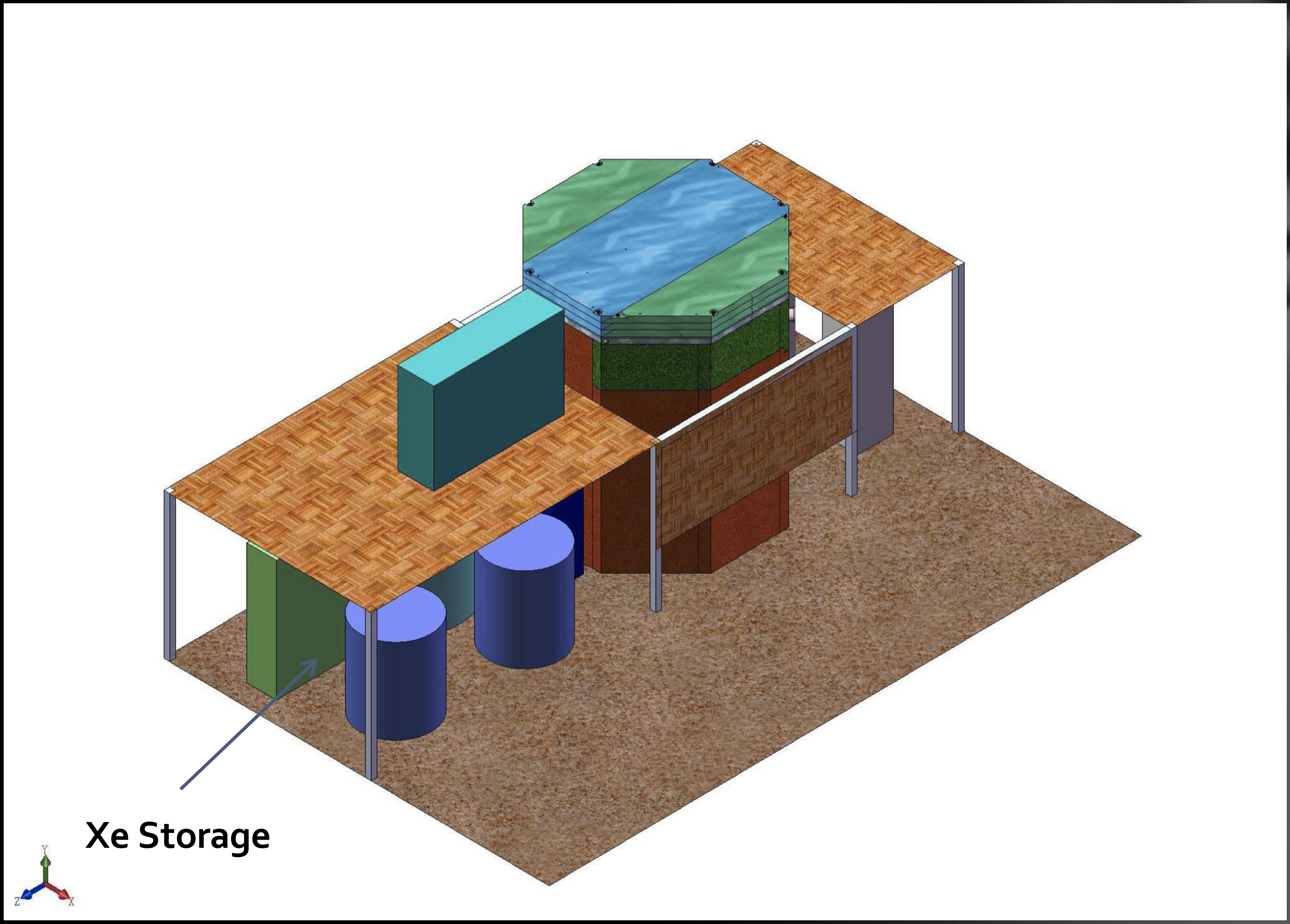
A conveyor belt removes rock from JinPing laboratory, a 2,500-metre-deep dark-matter experiment site.

More than 1,000 metres underground, physicists have set traps of liquid xenon to catch their prey: hypothetical particles of dark matter that might very rarely interact with ordinary matter as they drift through Earth. With construction costs on the order of US$10 million each, such experiments are a relatively cheap way to work out the composition of 85% of the matter in the Universe. But does the world really need four of them?

Ongoing experiments in Italy, the United States and Japan are now being joined by a fourth in China, called PandaX (see 'Dark and deep'). Installed in the deepest laboratory in the world, 2,500 metres under the marble mountain of JinPing in Sichuan province, PandaX will this year begin monitoring 120 kilograms of xenon. The team hopes to scale the tank up to 1 tonne by 2016, which would mean that the experiment had developed more quickly than any other dark-matter search. "We want to demonstrate that world-class research in dark matter is possible in China," says Xiangdong Ji, a physicist at Shanghai Jiao Tong University in China and a spokesman for PandaX.

Dark-matter researchers in the West are excited by the ambition of the project, but some question the duplication of effort. "Spending all our money on different direct-detection ▶

Layout of the exp in Jinping lab



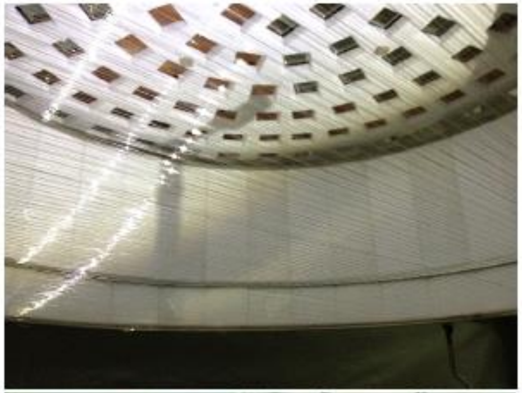
Before moving in


2012 04 16


2012 03 11


2012 04 20

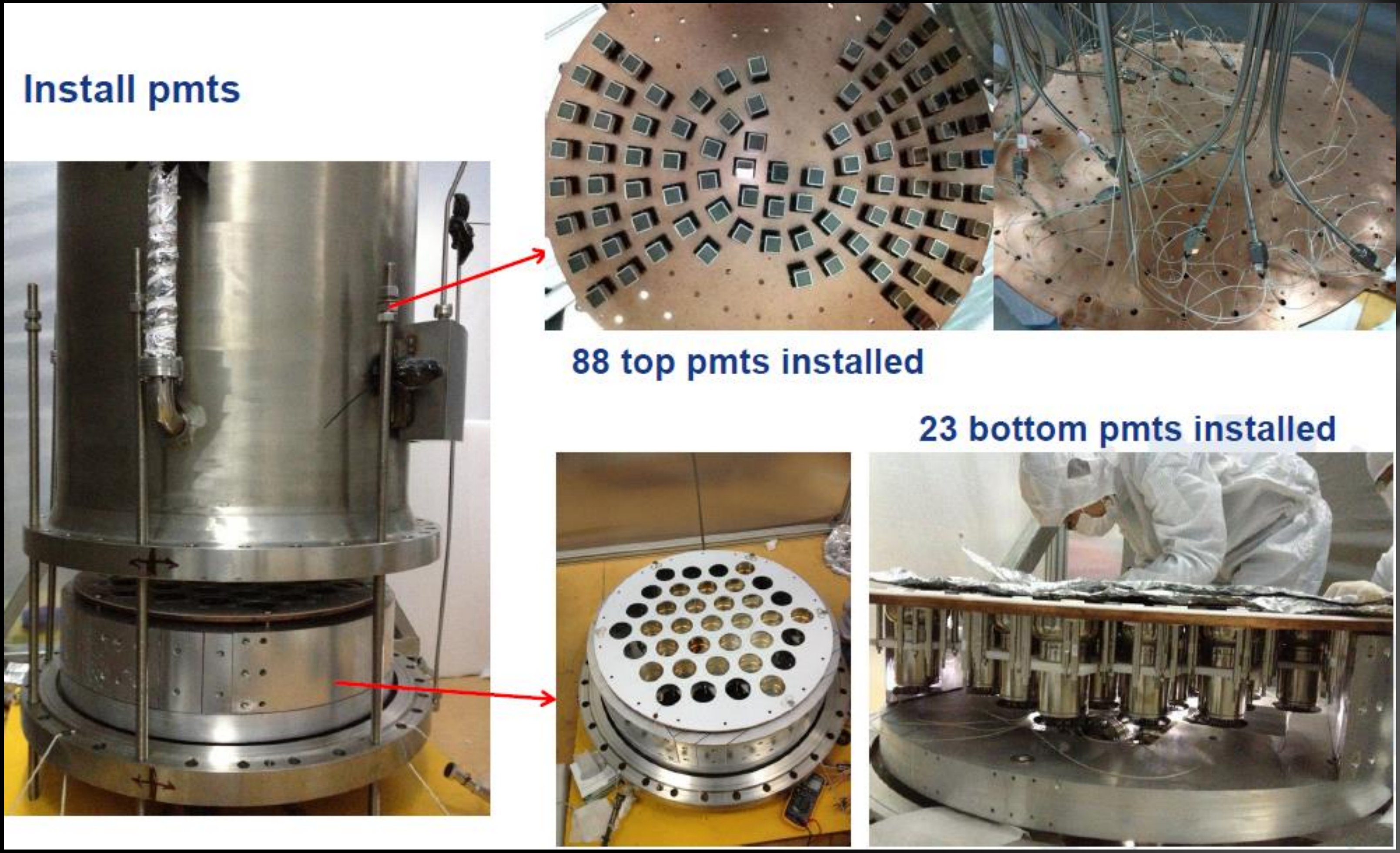
Current Status - Stage Ia



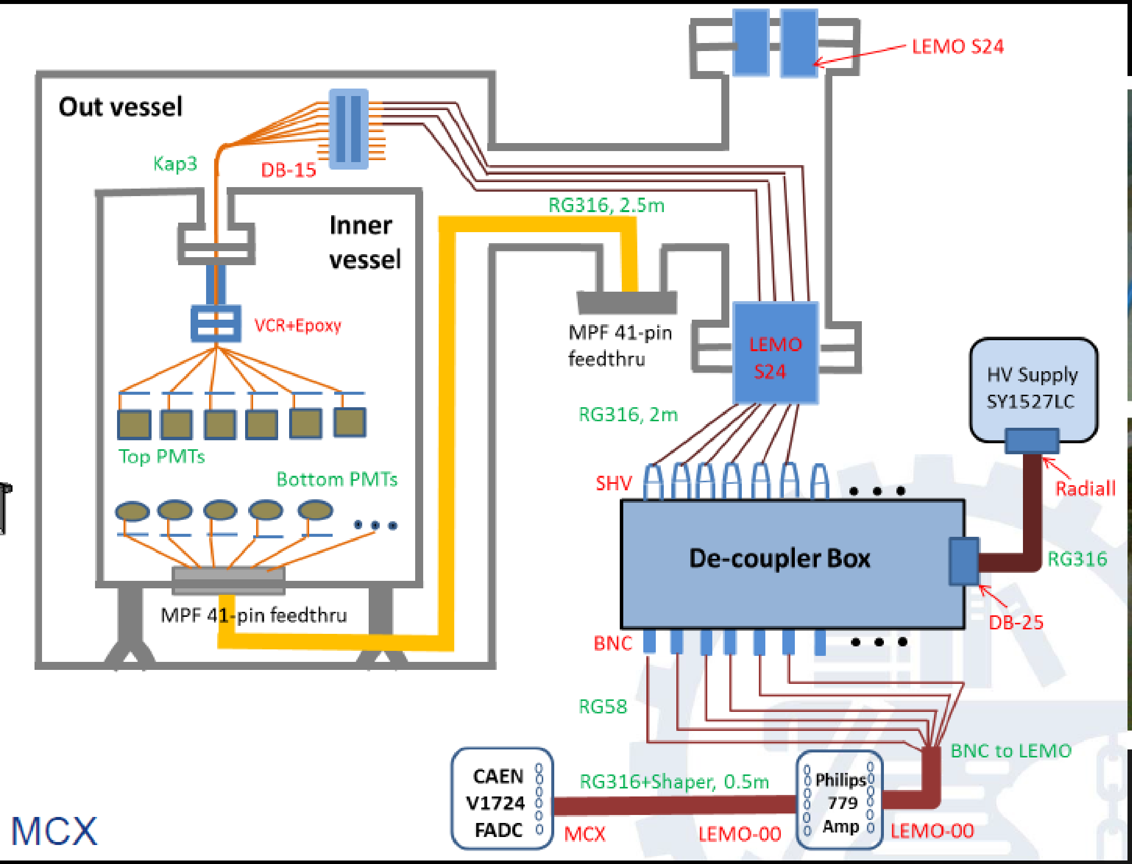
PandaX Stage Ia:
Currently undergoing commissioning:

- Major components at CJPL
- Clean room environment: TPC assembled
- Slow control in place
- Cryogenic system operating
- Xenon on site
- Small xenon fill and liquefaction so far
- DAQ installed
- Personnel on site daily

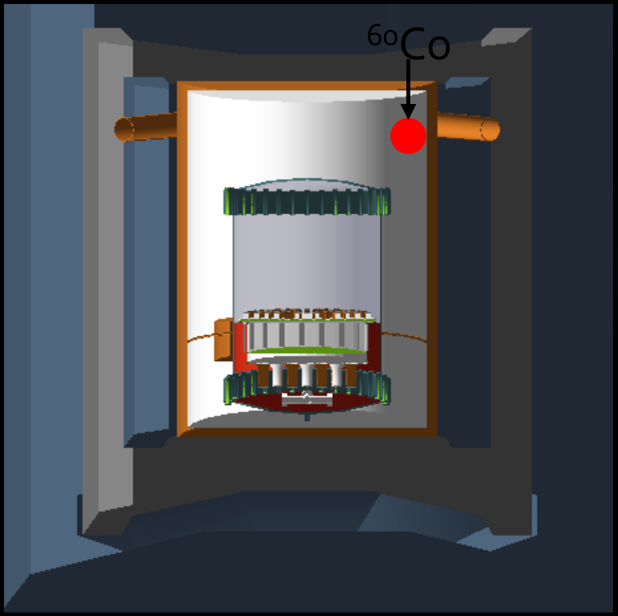
TPC & PMT at Jinping

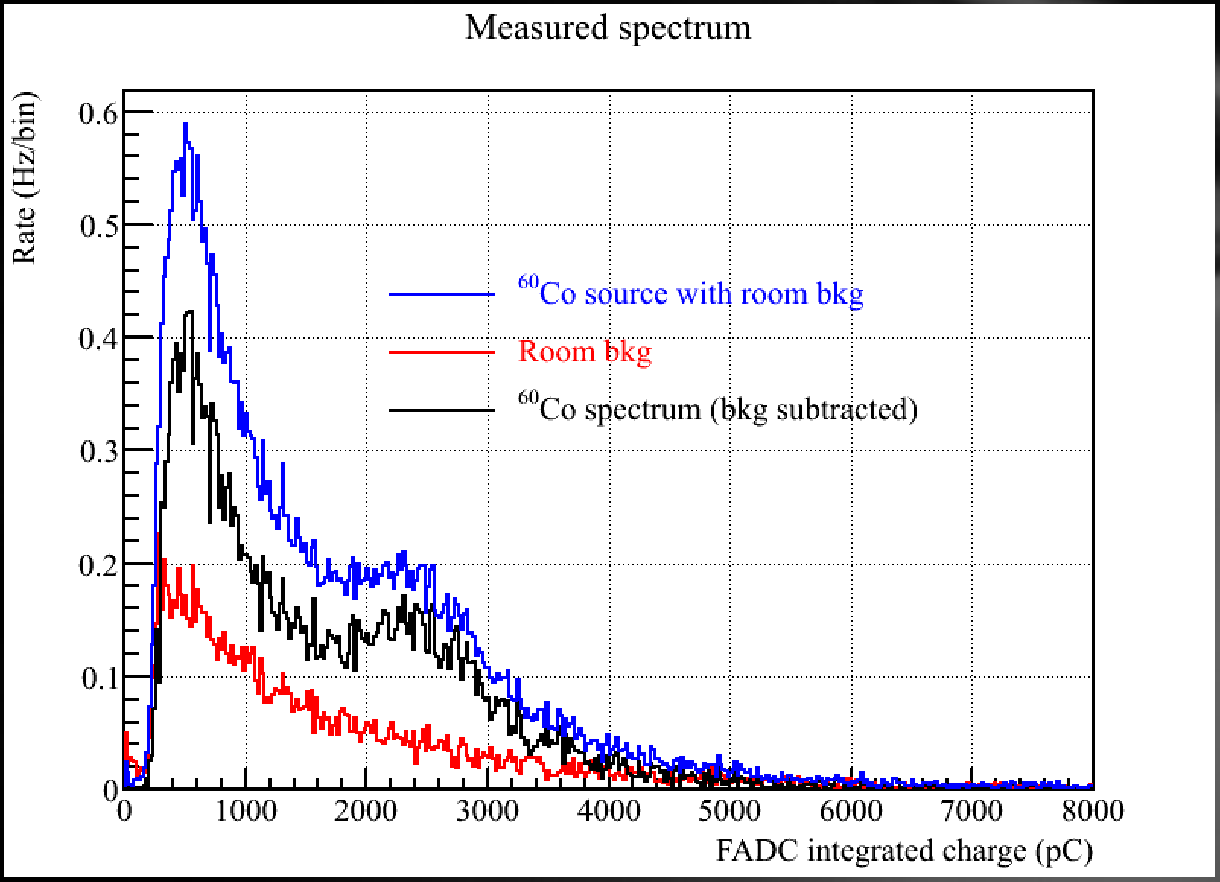


Cabling, decouplers, DAQ at jinping



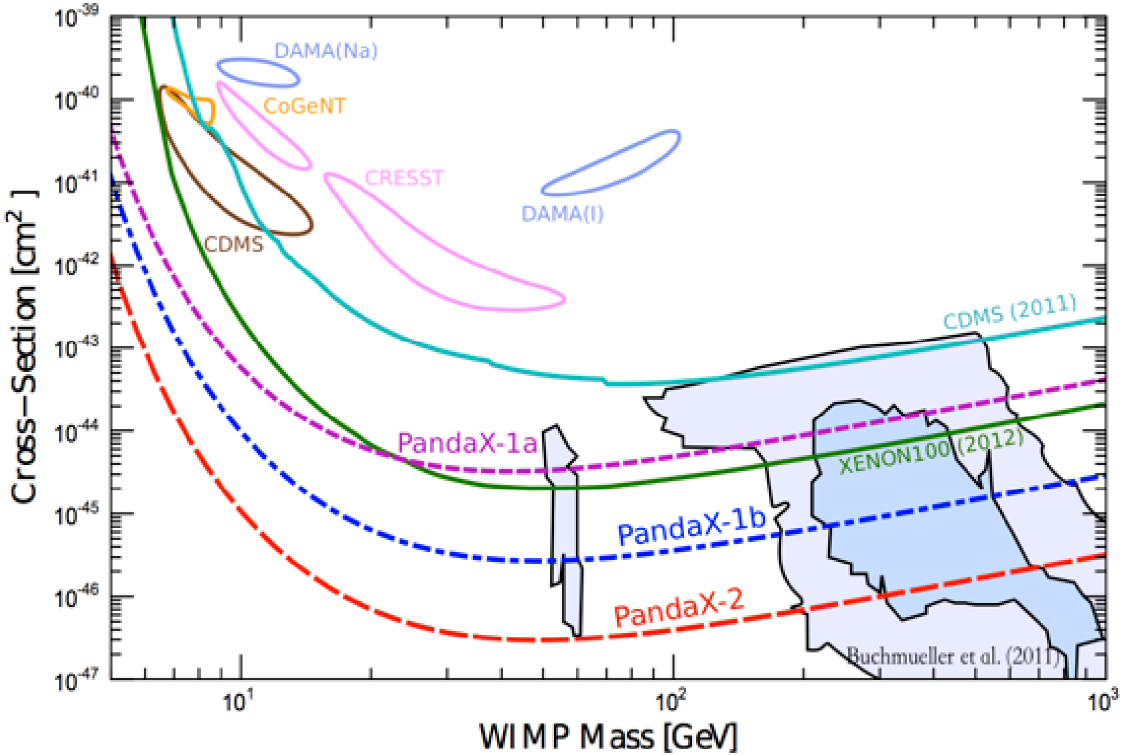
First LXe Test Run (450kg Xe)

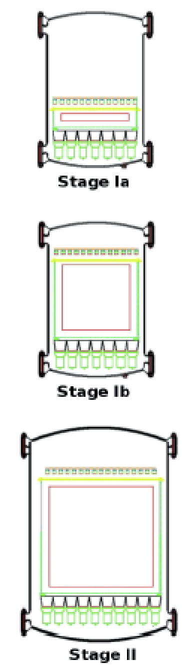




Light signals only (bottom PMT array only): functional cryogenic liquid scintillator

PandaX sensitivity





Stage Ia

- light yield: 4-5 pe/keV$_{ee}$
- S1 energy range: 3-30 pe
- exposure: 25 kg x 60 days
- NR acceptance: 0.35
- estimated bkg events: 0.3

Stage Ib

- light yield: 2.5 pe/keV$_{ee}$
- S1 energy range: 3-30 pe
- exposure: 300 kg x 180 days
- NR acceptance: 0.35
- estimated bkg events: 0.5

Stage II

- light yield: 2.5 pe/keV$_{ee}$
- S1 energy range: 3-30 pe
- exposure: 1000 kg x 600 days
- NR acceptance: 0.35
- estimated bkg events: 1.3

Summary

- There are multiple evidences indicating that the dark matter might be found just around the corner.
- PandaX is a first large scale experiment in China aiming to: 1) detect low-mass WIMPs with unprecedented sensitivity 2) enhance the detection threshold for WIMPs by a ton-scale target.
- PandaX is on its way to prepare a first stage running.