The XENON1T Experiment

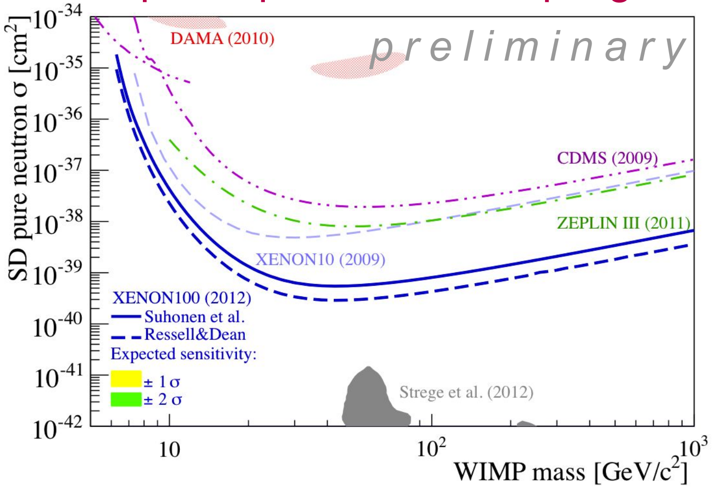
Ranny Budnik
Columbia University

On behalf of the XENON1T collaboration

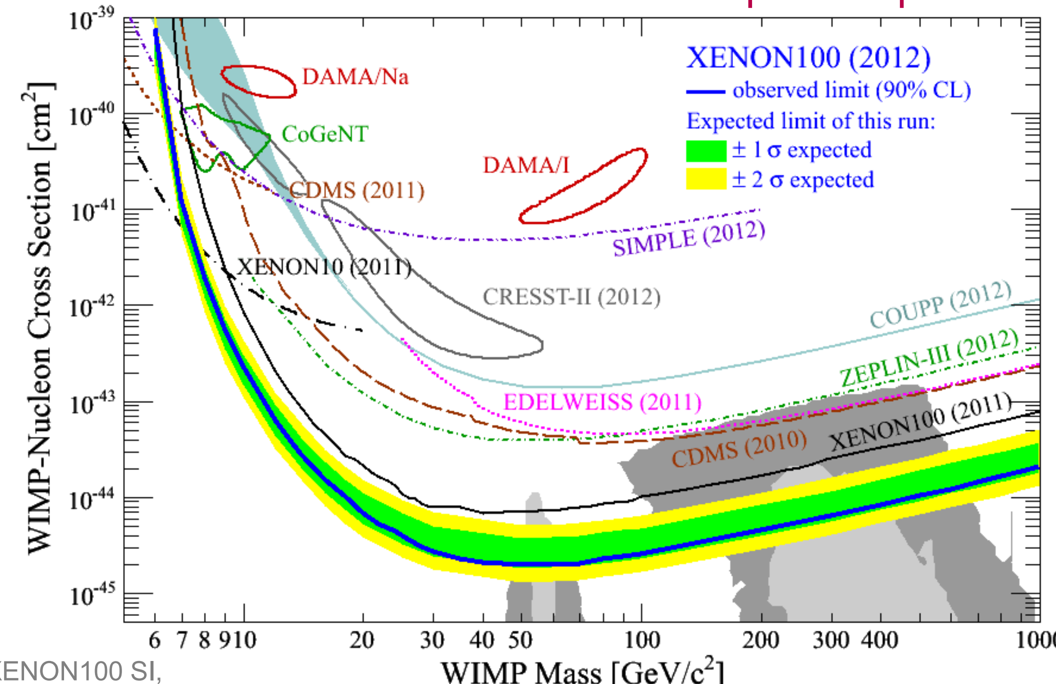
Xe
XENON
Dark Matter Project

Status in WIMP DM Sensitivities (2012)

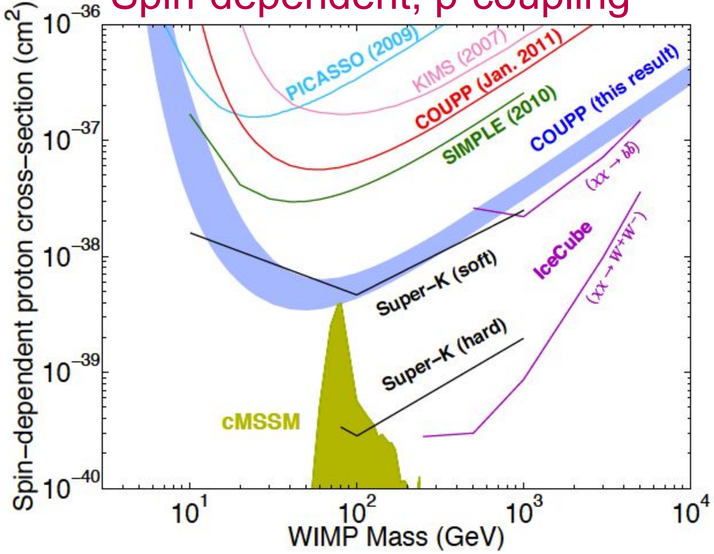
Spin-dependent, n-coupling



Spin-independent



Spin-dependent, p-coupling



XENON100 SI,
2010 PRL 105, 131302
2011 PRL 107, 131302

CDMS-II SI, 2010
Science 327, 1619

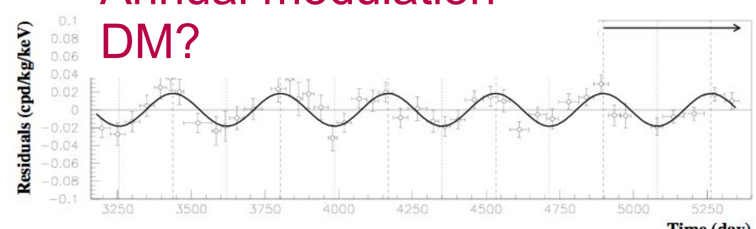
EDELWEISS-II SI, 2011
Phys. Lett. B 702, 329

CoGeNT SI,
PRL 106 (2011) 131301
2011b: arxiv:1106.0650

COUPP SD:
2012: arXiv:1204.3094

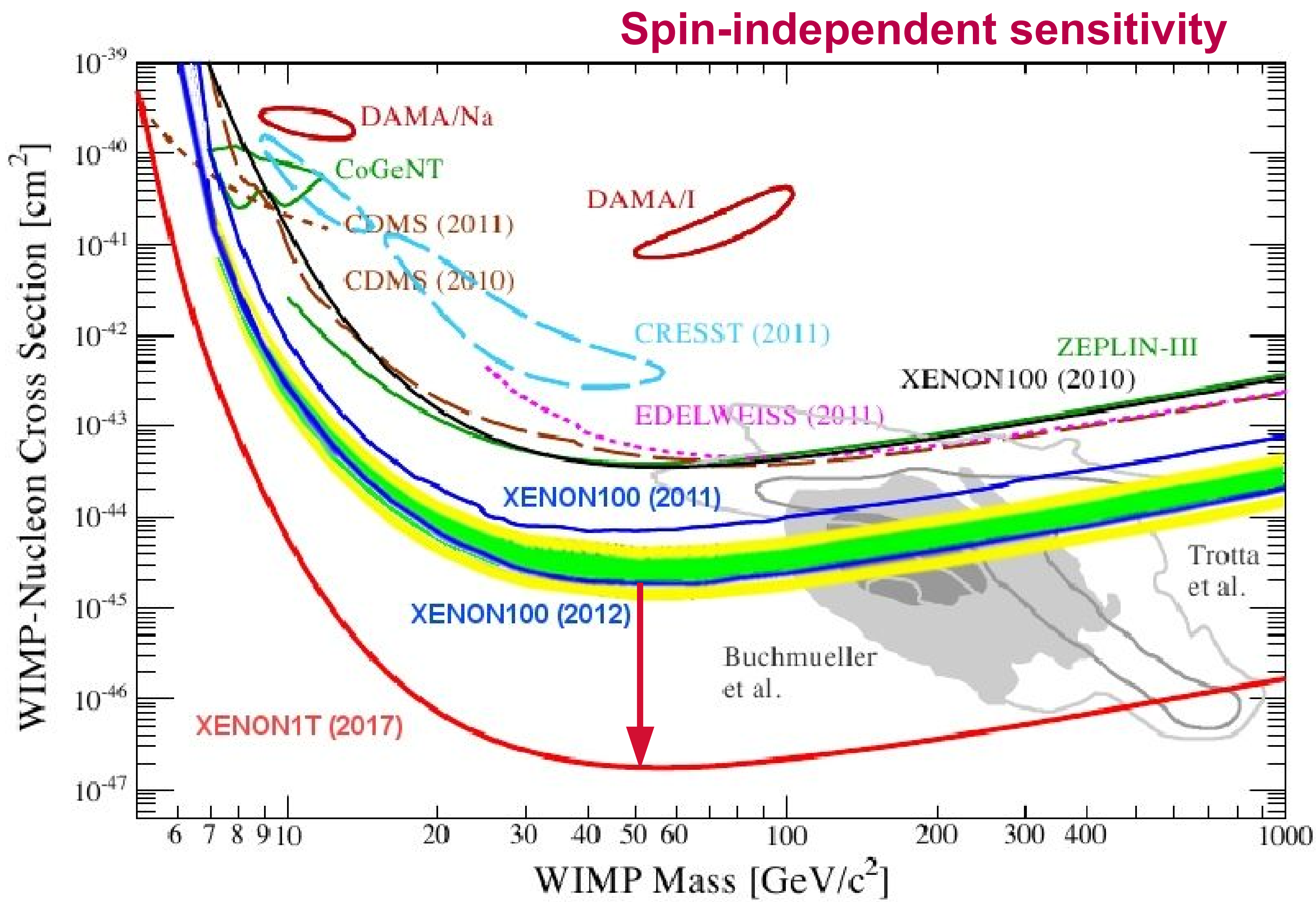
PICASSO SD, 2012
arxiv:1202.1240

Annual modulation – DM?



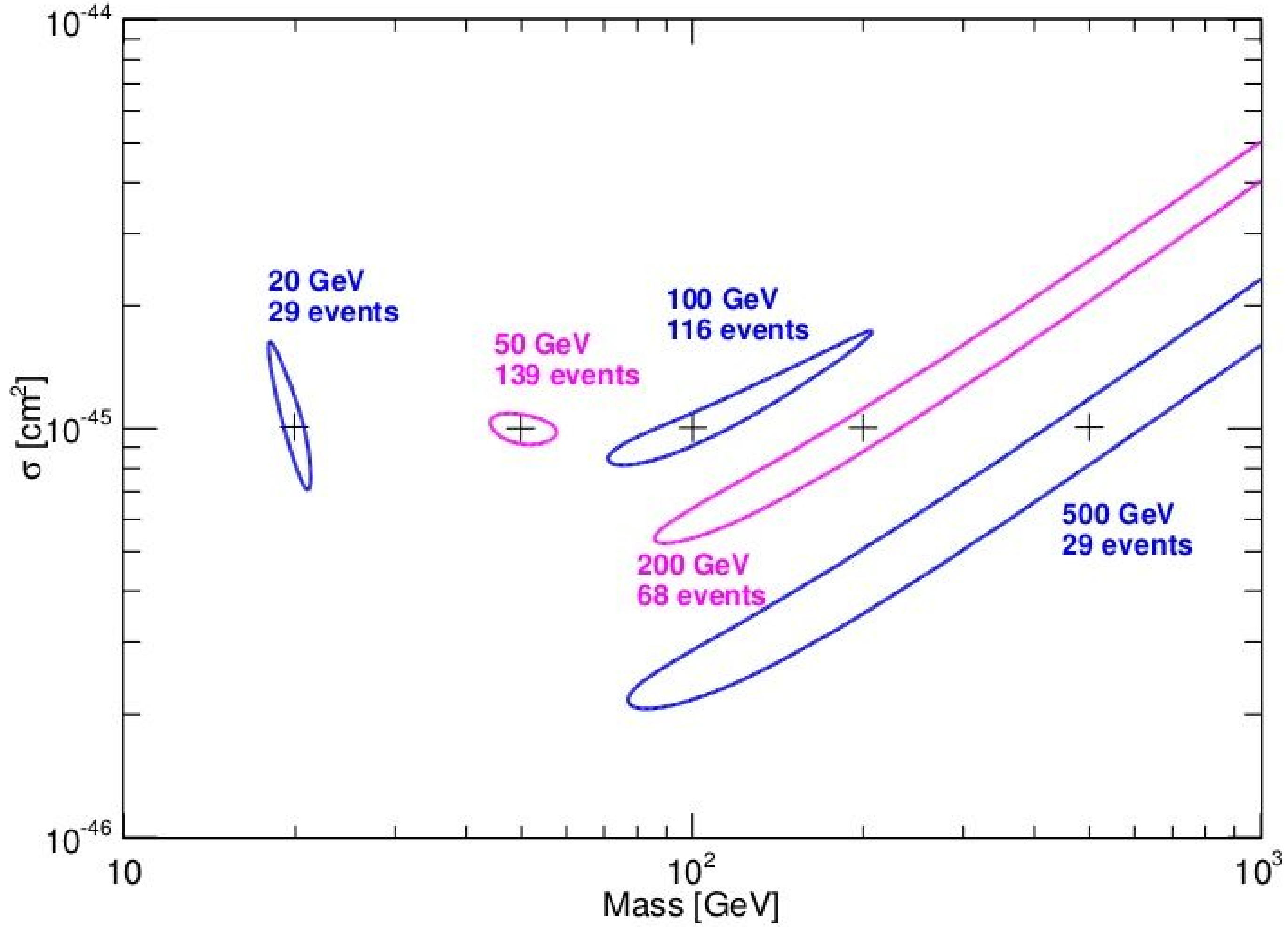
DAMA/LIBRA, 2010
arxiv:1002.1028

The Future of Direct Dark Matter Searches
(next ~5 years)



... but we hope for a detection

For a WIMP with 10^{-45} cm^2 ~100 events

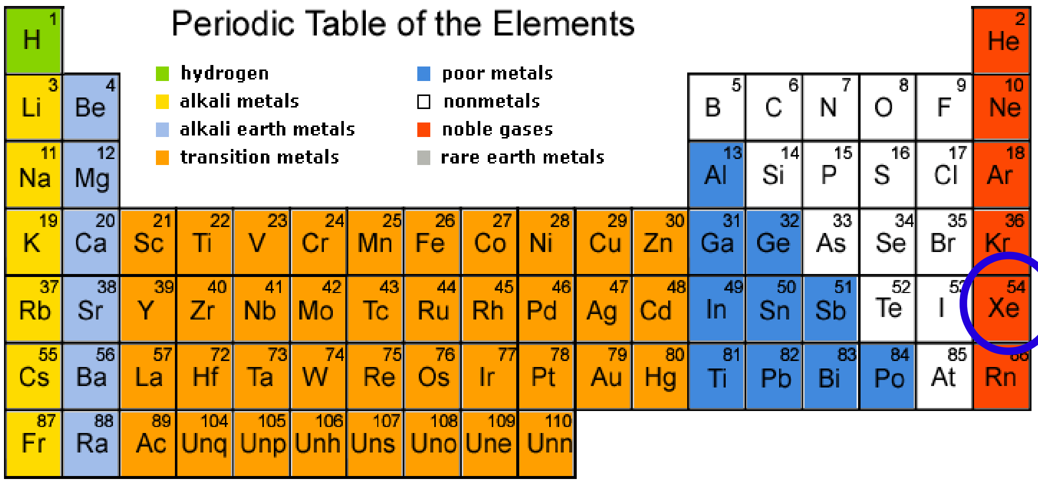


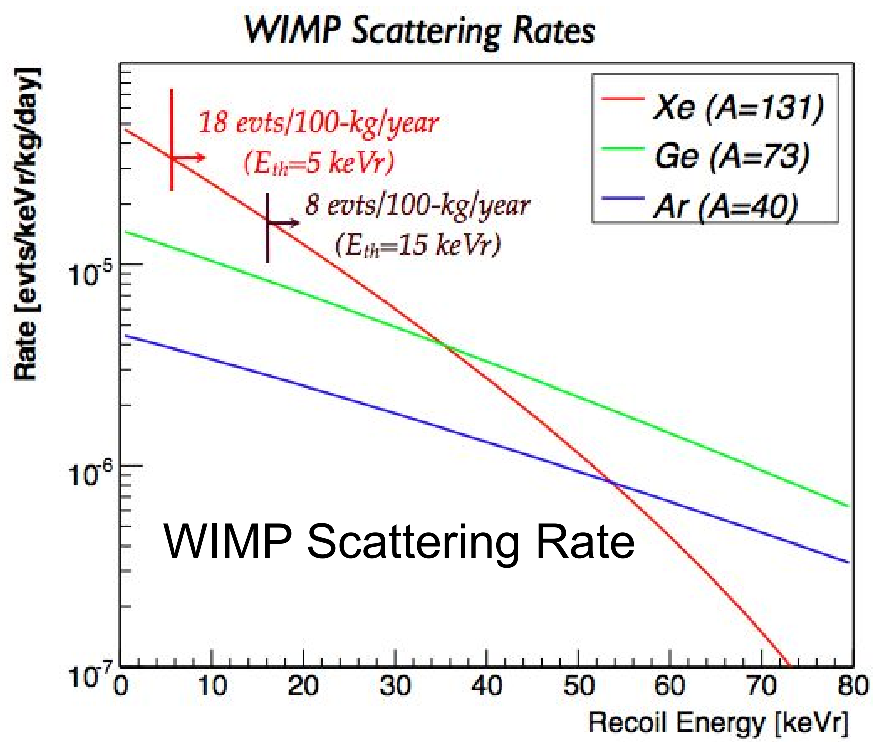
(Assuming standard isothermal halo, 220 km/s, escape vel. 540 km/s)

Reminder:

Liquid Xenon for Dark Matter Search

- Large atomic number A~131 best for SI interactions ($\sigma \sim A^2$).
  Need low threshold.
- ~50% odd isotopes: SD interactions
  If DM detected: probe physics with the same detector using isotopically enriched media.
- No# long-lived Xe isotopes.
  But control Kr-85, Rn-222. #Xe-136 $2\nu\beta\beta$
- High Z (54) and density:
  compact & self-shielding
- Scalability to large mass.
- "Easy" cryogenics (-100°C).
- Efficient and fast scintillator.
- Good ionization medium, long drift.
- Background discrimination in TPC.
  - Ionization/Scintillation
  - 3D imaging of TPC

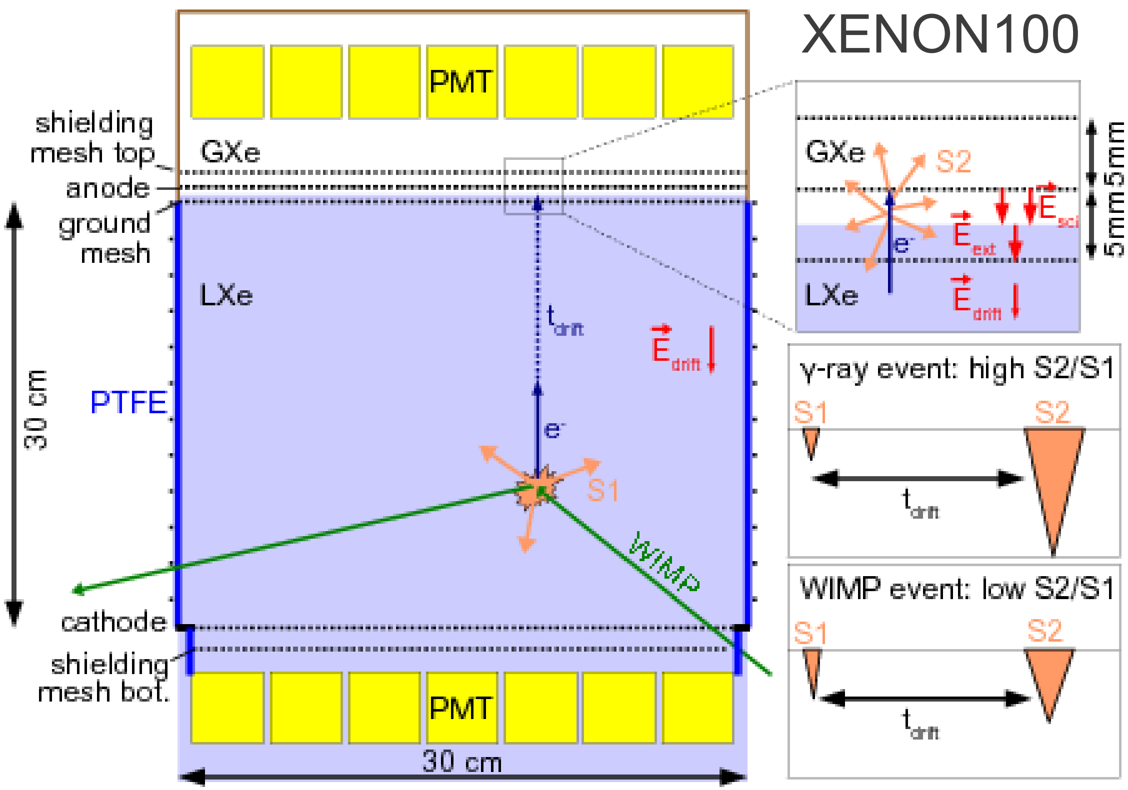




The Liquid Xenon Dual Phase TPC

Ionization + Scintillation

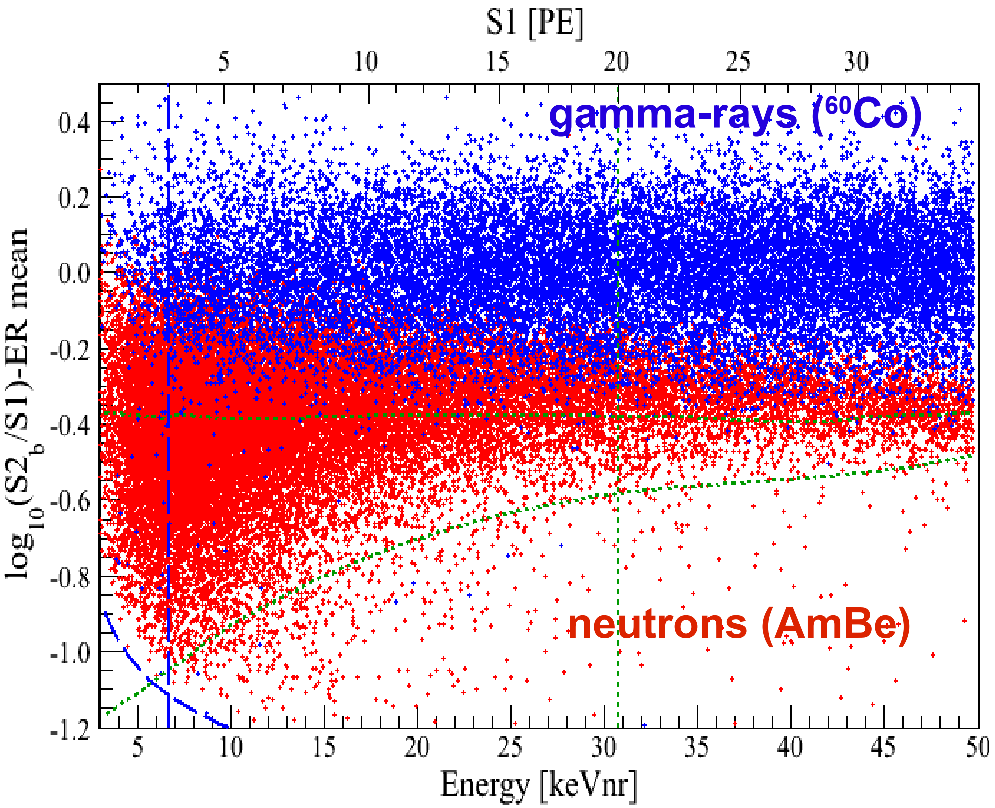
- WIMP recoil on Xe nucleus in dense liquid (2.9 g/cm^3)
  → Ionization + UV Scintillation
- Detection of primary scintillation light (S1) with PMTs.
- Charge drift towards liquid/gas interface.
- Charge extraction liquid/gas at high field between ground mesh (liquid) and anode (gas)
- Charge produces proportional scintillation signal (S2) in the gas phase (12 kV/cm)



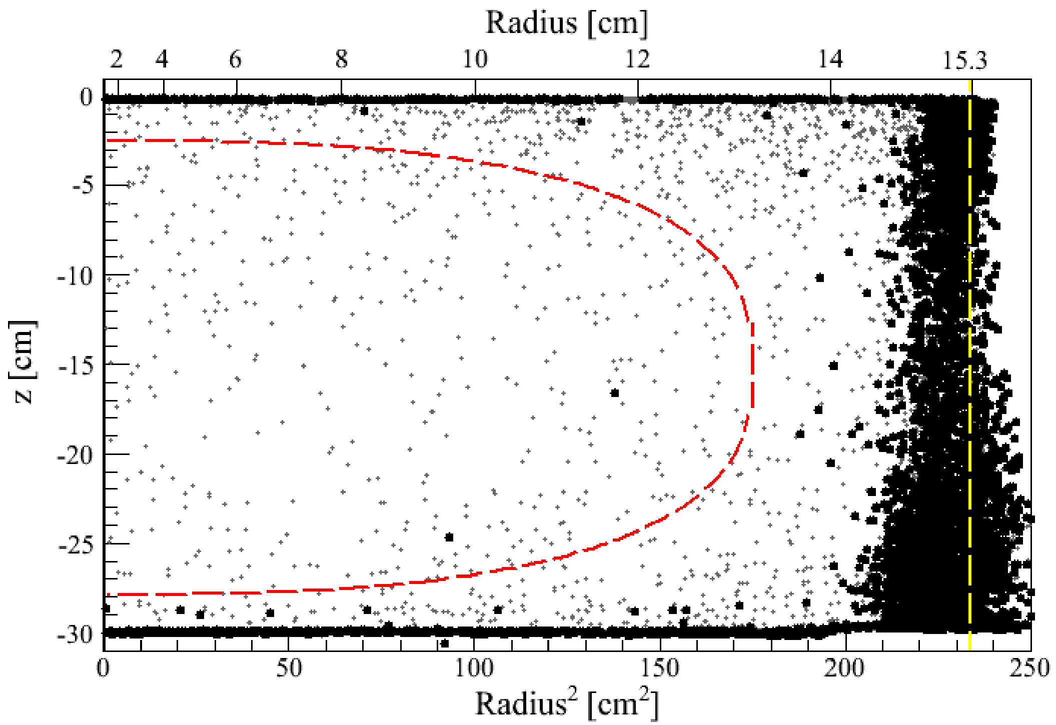
- **3D position measurement**
  - X/Y from S2 signal. Resolution few mm.
  - Z from electron drift time (~0.3 mm).

Background Discrimination in Dual Phase Liquid Xenon TPC's

Ionization / Scintillation Ratio S2/S1



3D Position Resolution: fiducial cut, singles/multiples



XENON100

XENON Dark Matter Project

USA, Switzerland, Portugal, Italy, France, Germany, Israel, Netherlands

The XENON1T Collaboration

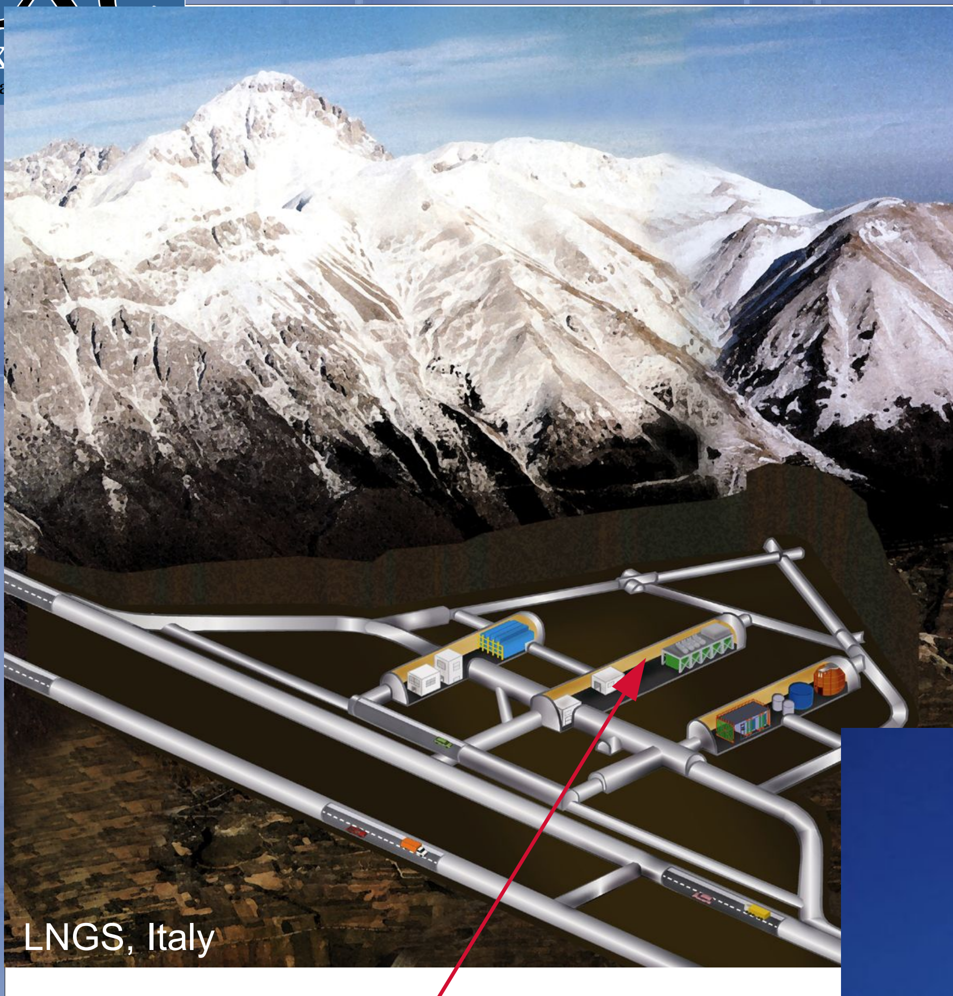
Columbia | Rice | UCLA | Zürich | Coimbra | LNGS | Purdue

Mainz | Bologna | Subatech | Münster | Nikhef | Heidelberg MPI-K | Weizmann

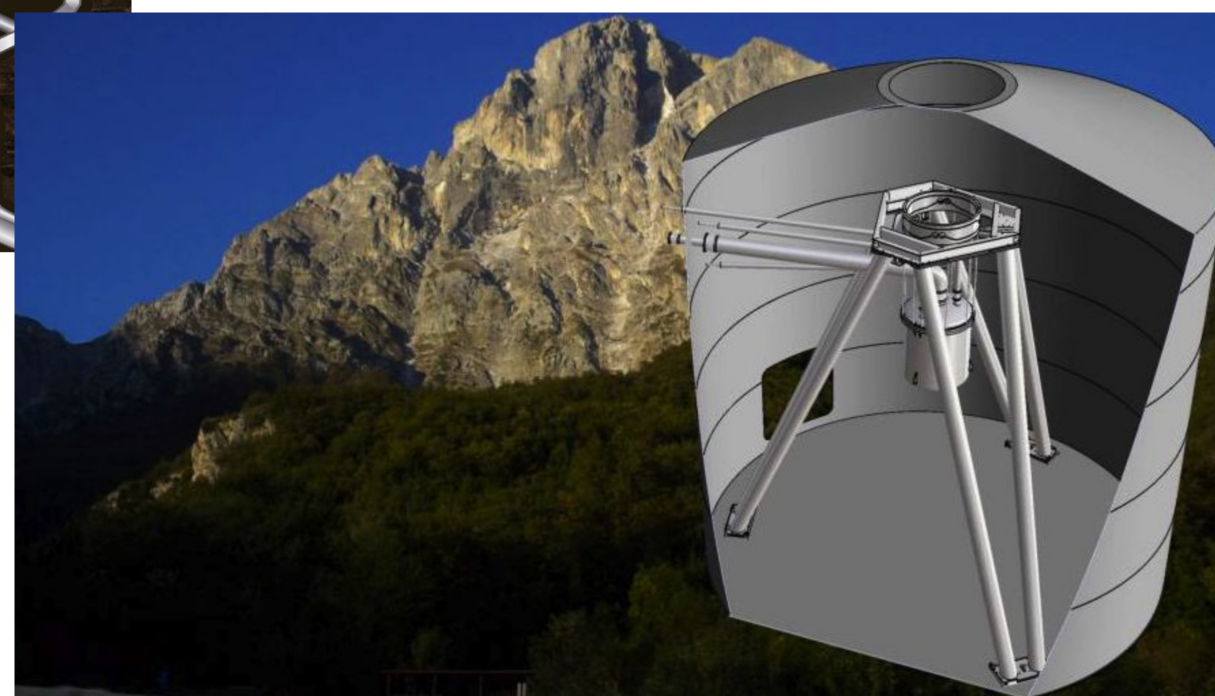
XENON1T

(2011-2015)

- Liquid xenon TPC to explore $\sigma \sim 2\times10^{-47}$ cm^2
- Detector size:
  ~ 1 m^3, ~ 3 t LXe, ~ 1 t fiducial mass
- Water Cherenkov Muon Veto
- Approved by INFN.
- Funded.
- Construction start: fall 2012.



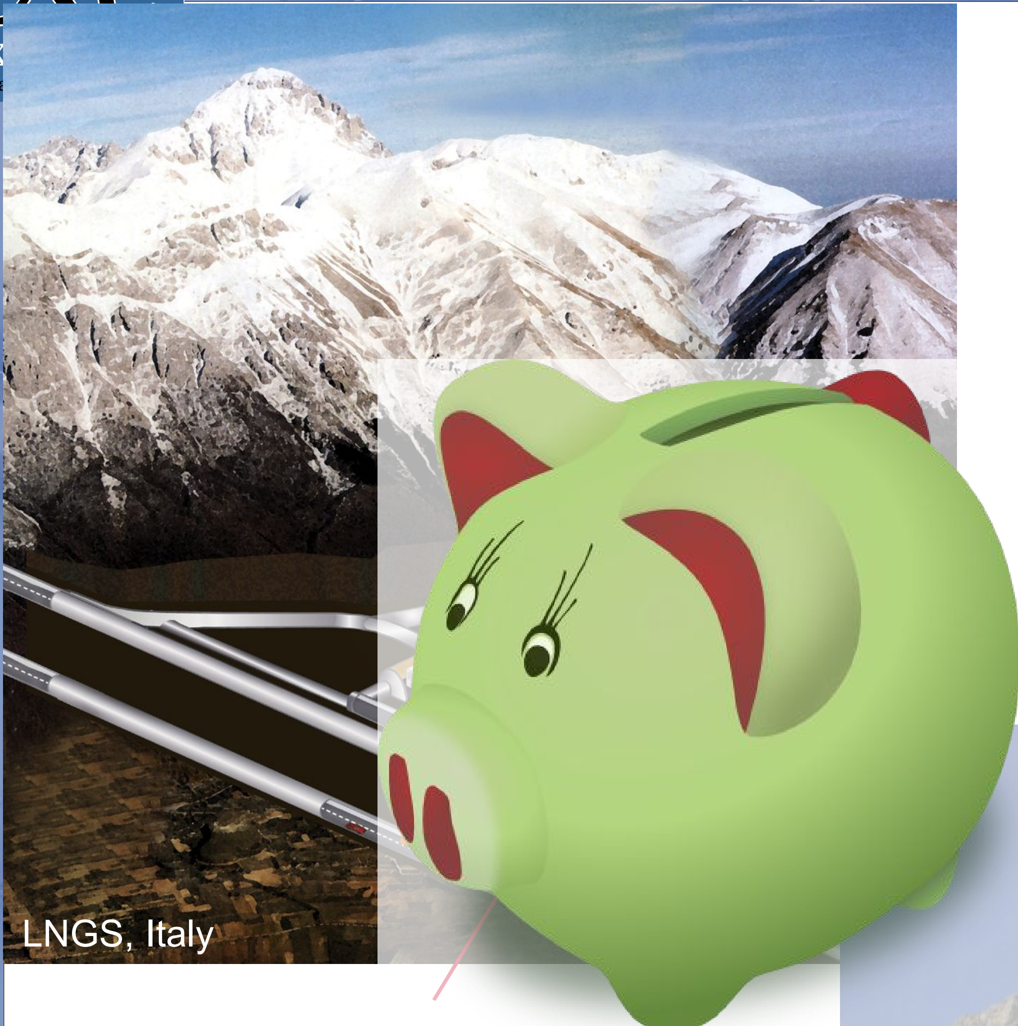
XENON1T in Hall B
(next to Icarus) @ LNGS

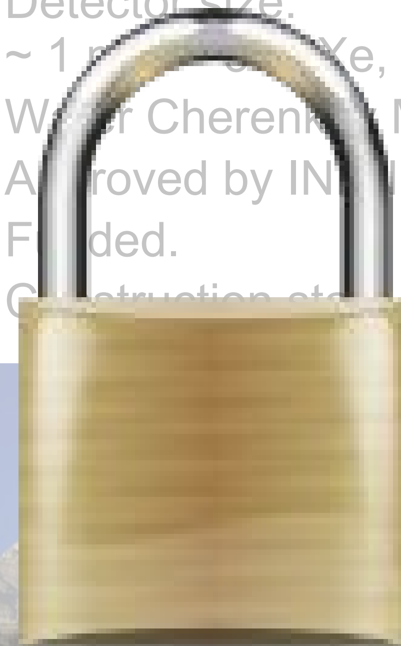


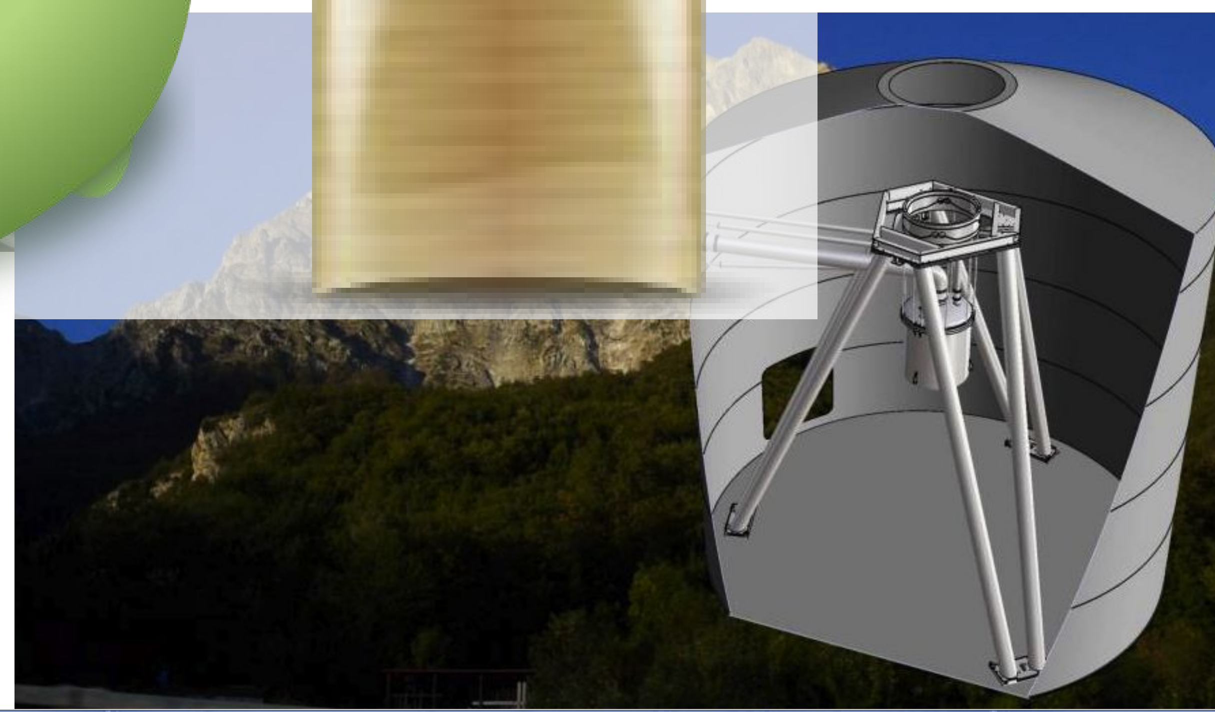
XENON1T

(2011-2015)

- Liquid xenon TPC to explore σ ~ 2×10^{-47} cm^2
- Detector size:
  ~ 1 … Xe, ~ 1 t fiducial mass
- W… Cheren… Muon Veto
- A…roved by IN…
- F…ded.
- C… fall 2012.







XENON1T in Hall B
(next to Icarus) @ LNGS

LNGS Underground Laboratory – Hall B

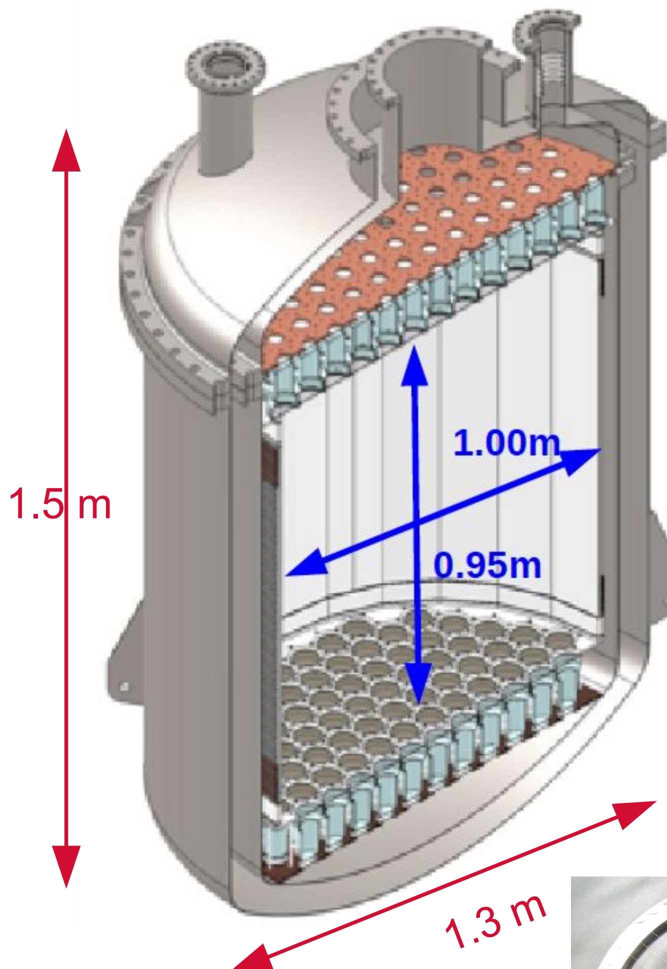
LNGS Underground Laboratory – Hall B

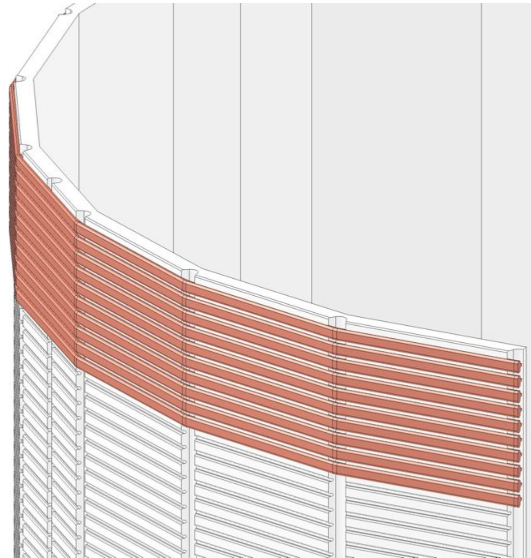
XENON1T design challenges

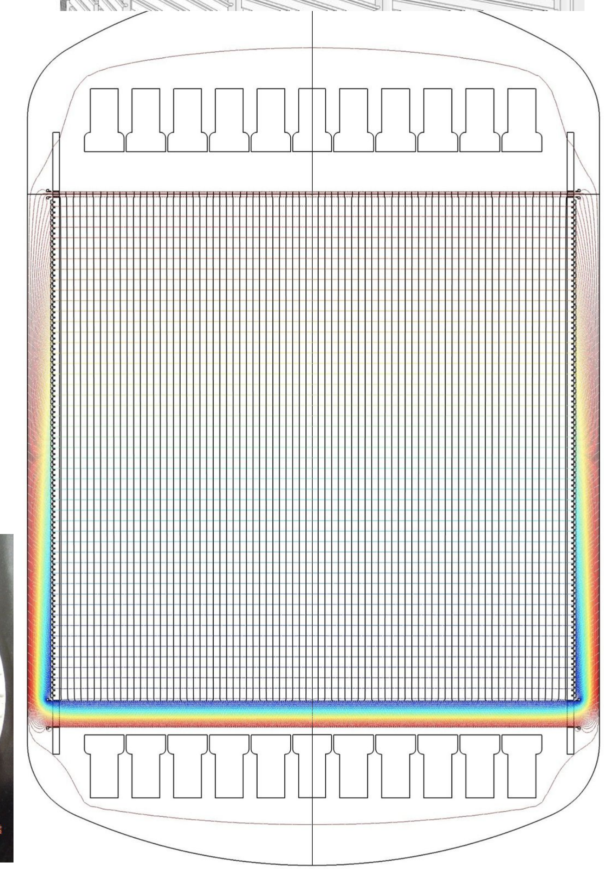
	Background*		Xe purity (e^- lifetime)	HV
	Total	Rn/Kr		
XENON100	~$5\cdot10^{-3}$ dru (events/kg/keV/day)	Kr: ~20 ppt Rn ~65 μBq/kg	160 kg @ ~400 μs In several months	30 cm @0.53 kV/cm
XENON1T essentials	~$5\cdot10^{-5}$ dru (Events/kg/keV/day)	Kr: 0.5 ppt Rn: ~1 μBq/kg	~3 tons @ ~1000 μs In ~2 months	100 cm @ 1 kv/cm
By how much should we improve?	X 100	Kr: X 40 Rn: X 50	X 3 (purity) X 50 (purification speed)	X 6

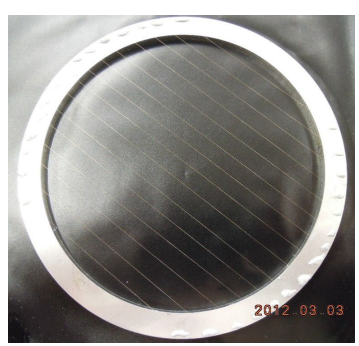
* In FV, including Veto, before discrimination

TPC





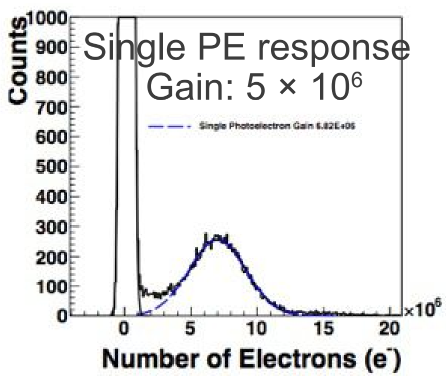


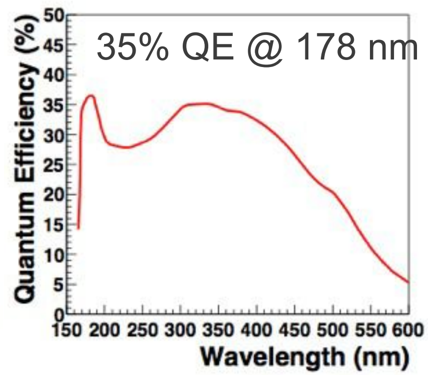


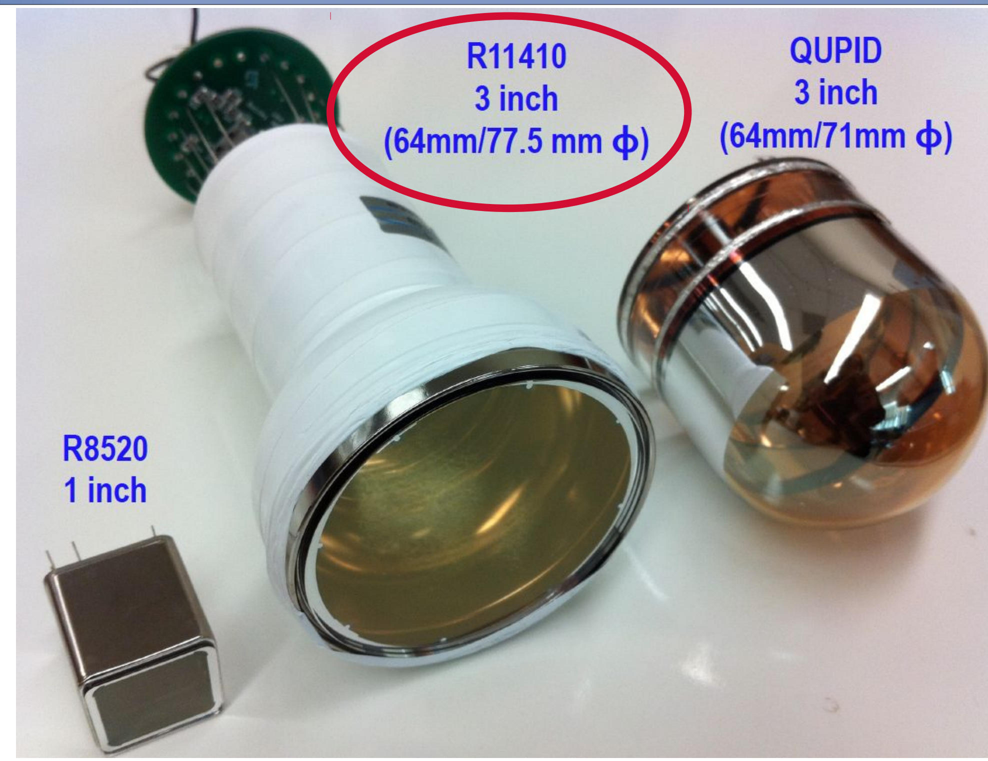
Columbia-Rice-UCLA-Zurich

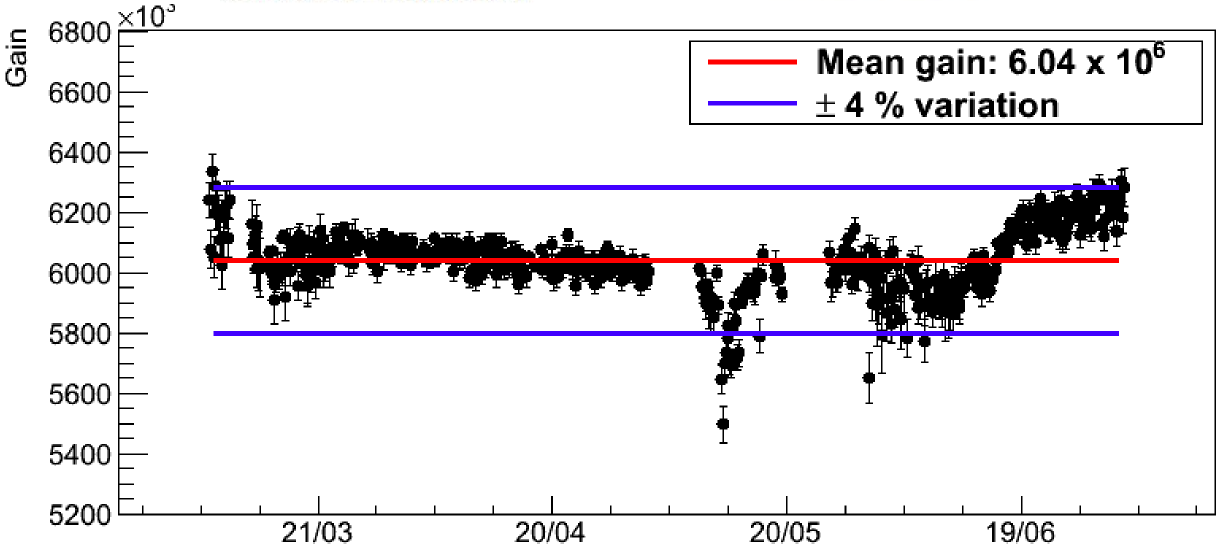
PMTs

- 2 × 121 3” PMTs by Hamamatsu
- QE: 30% min., >35% achieved
- Ongoing screening program
  to further reduce radioactivity

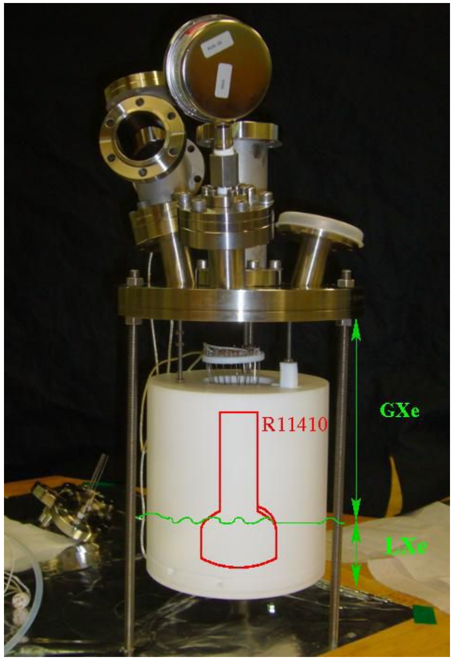








Performance and stability tests (Also T dependence)

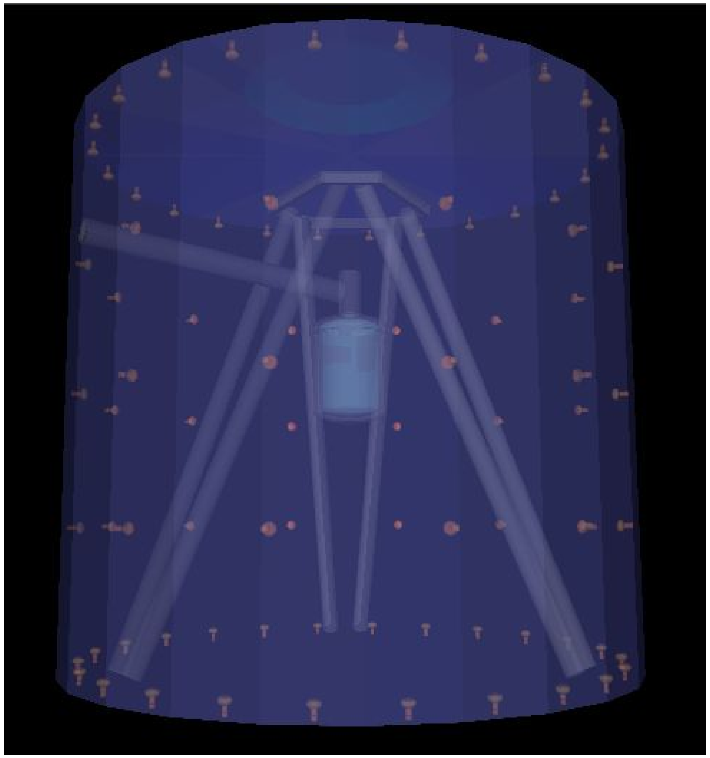


UCLA – Columbia – MPIK – Zurich

Water Cerenkov Muon Veto

Concept:

- Water tank: ~10 m high and 9.6 m in diameter
- 84 high QE 8” PMTs Hamamatsu R5912 with water-tight base
- Specular Reflector: foil DF2000MA by 3M



Bologna – Mainz – Torino

Trigger requirements:

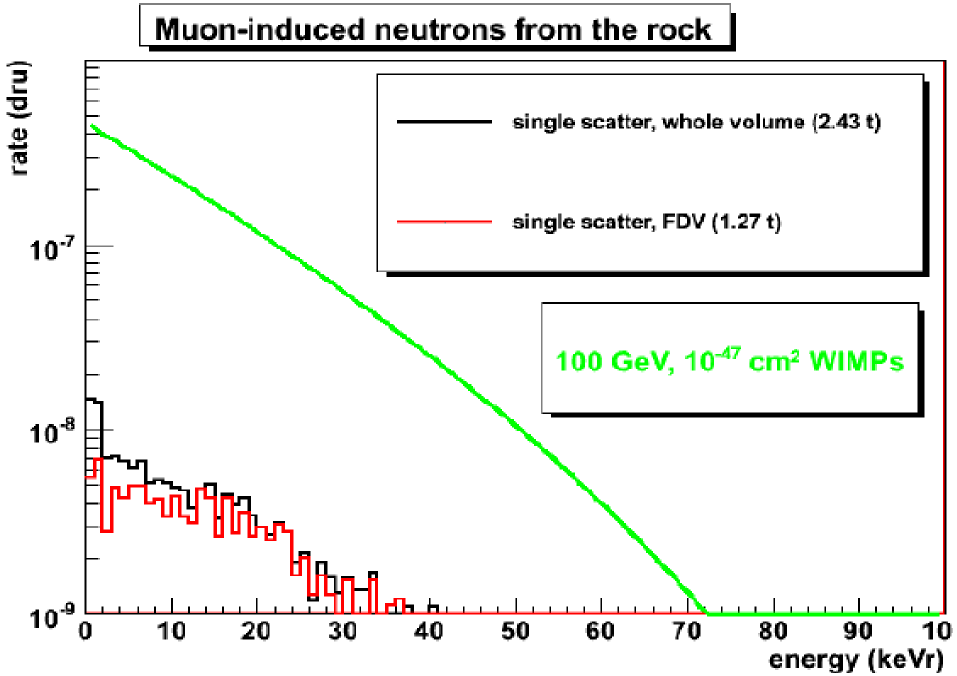
- single photoelectron
- 4 fold coincidence
- time window: 300 ns

Trigger efficiency

- > 99.5% for neutrons with muons in WT
- ~ 78% for neutrons with μ's outside WT

μ-induced neutron background

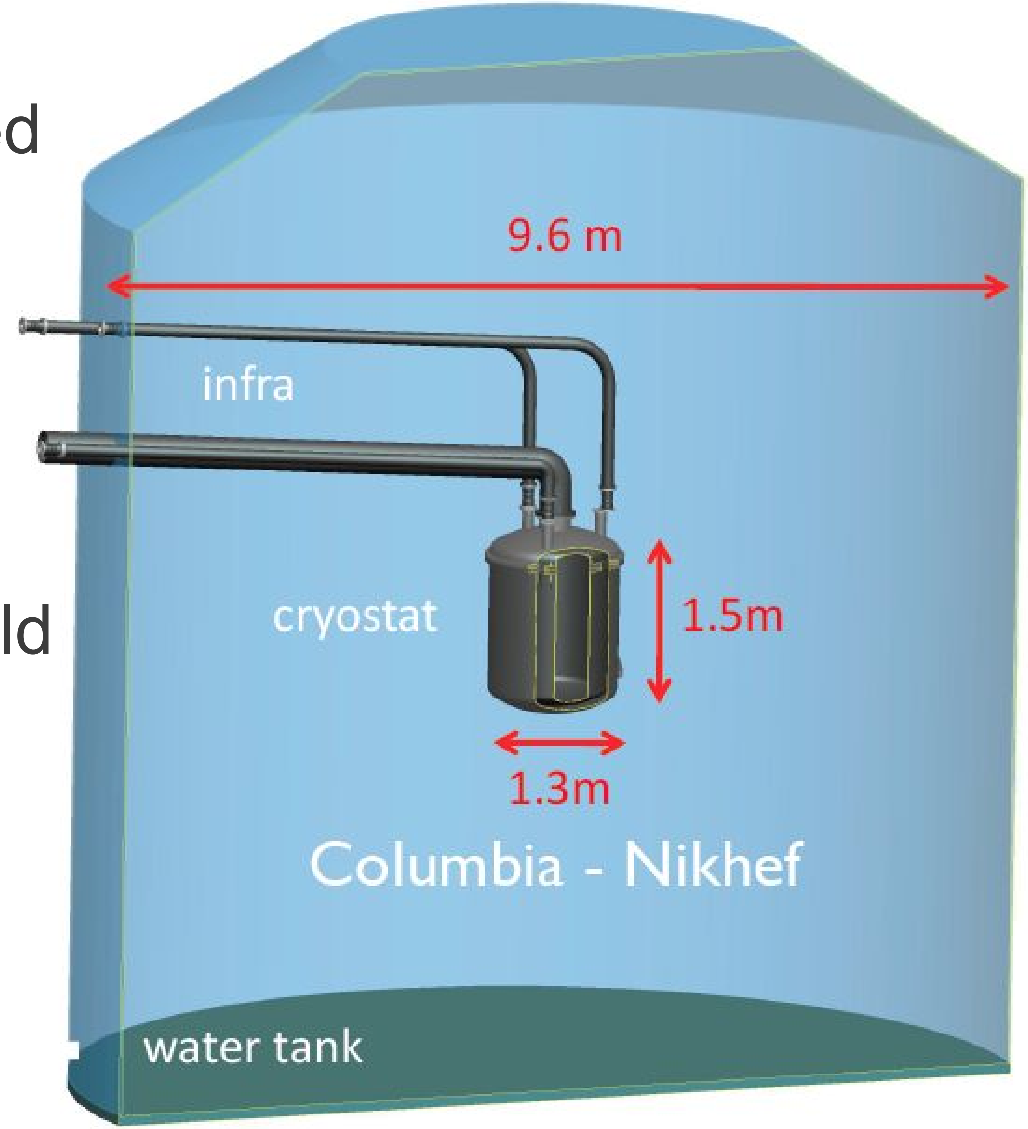
- 0.01 per year
- ≪ WIMP signal



Cryostat

Baseline design

- Ti grade 1 double-walled cryostat
- UHV compatible, low outgas rate
- Heat load < 50 W
- Immersed in water shield
- Buoyancy load
- LNGS seismic environment
- Safety review currently ongoing

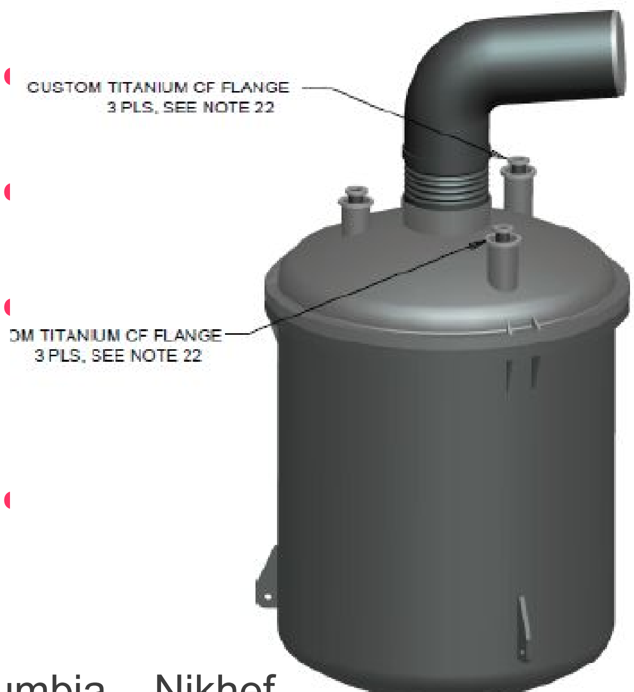


Columbia – Nikhef

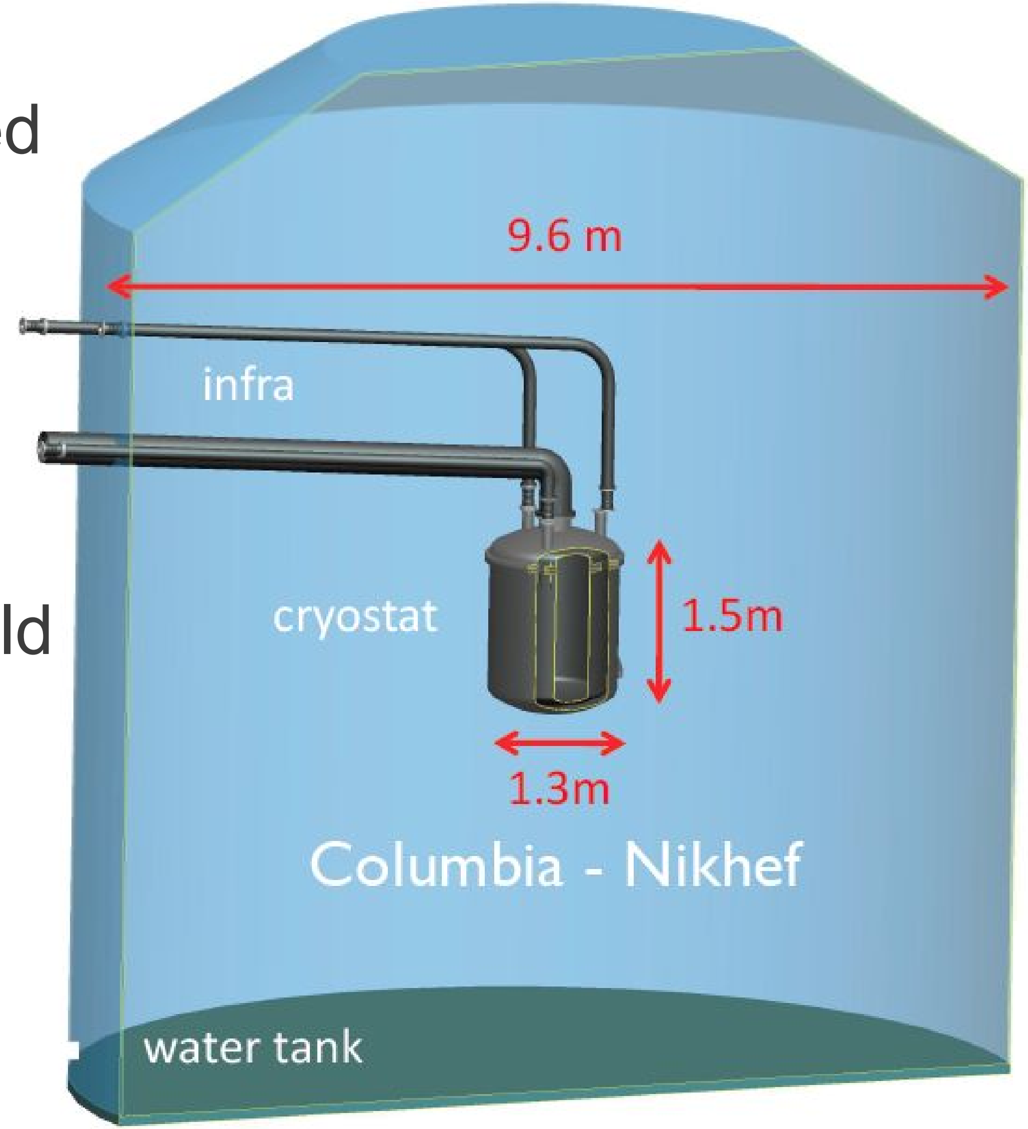
Cryostat

Baseline design

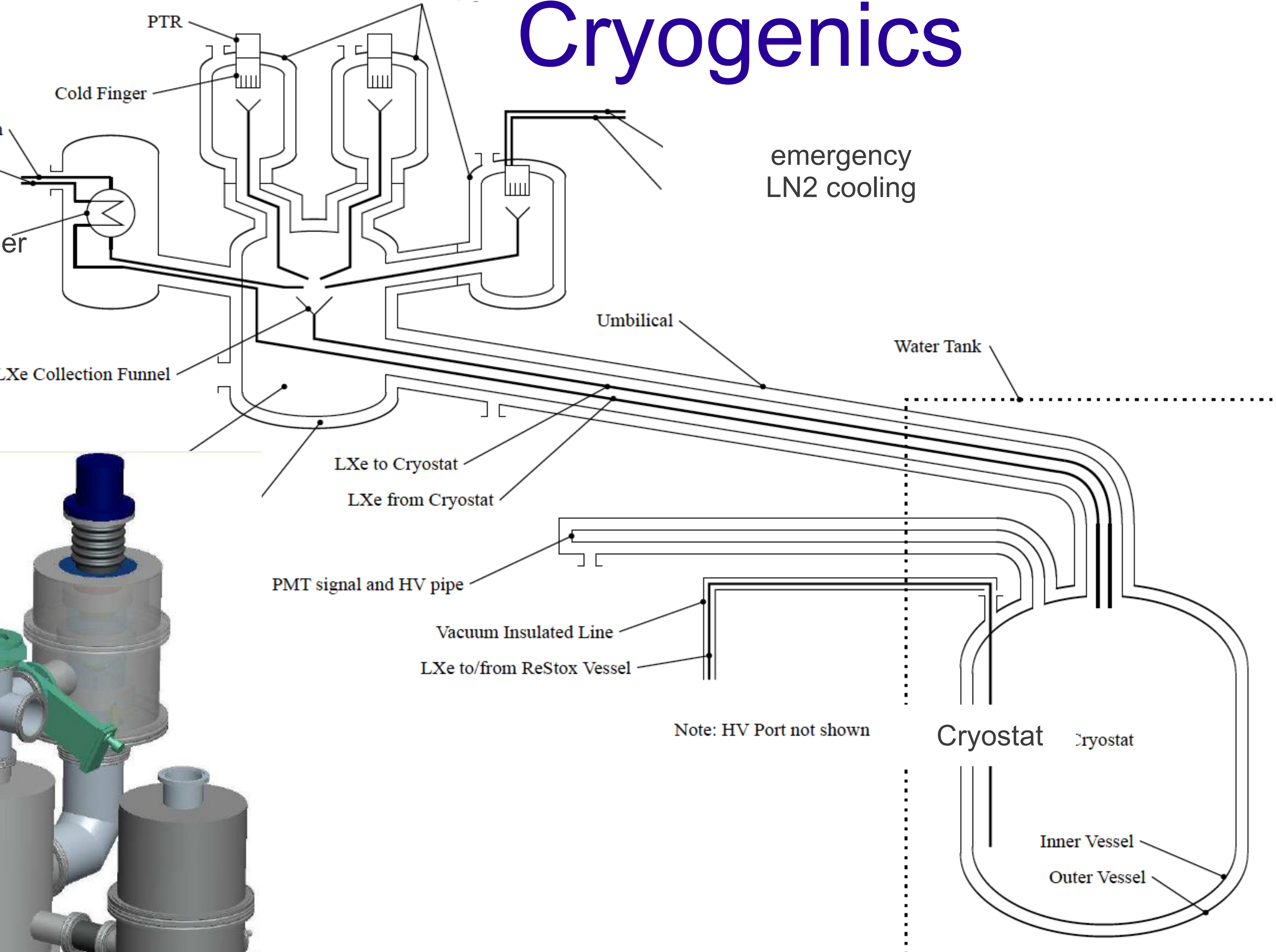
- Ti grade 1 double-walled cryostat
- UHV compatible, low outgas rate
- Heat load < 50 W
- shield
- ntly

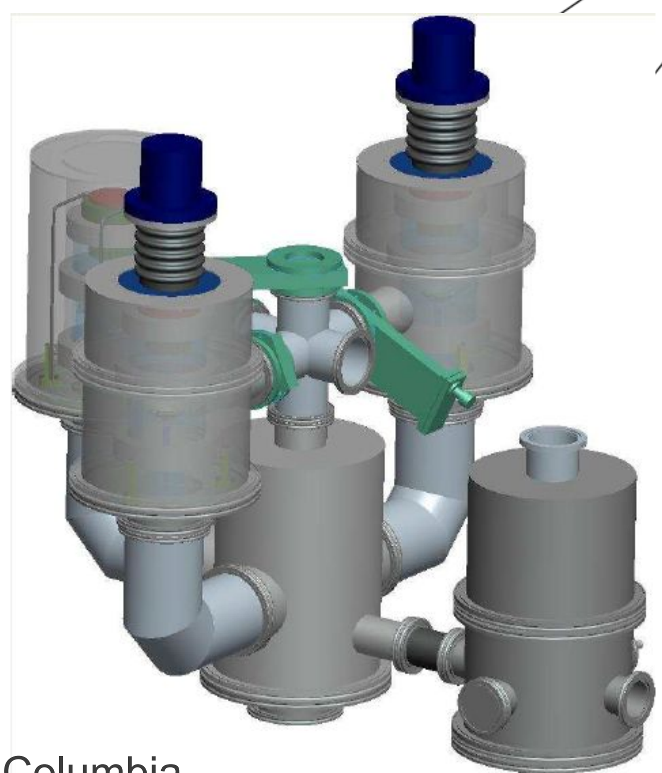


Columbia – Nikhef



Cryogenics





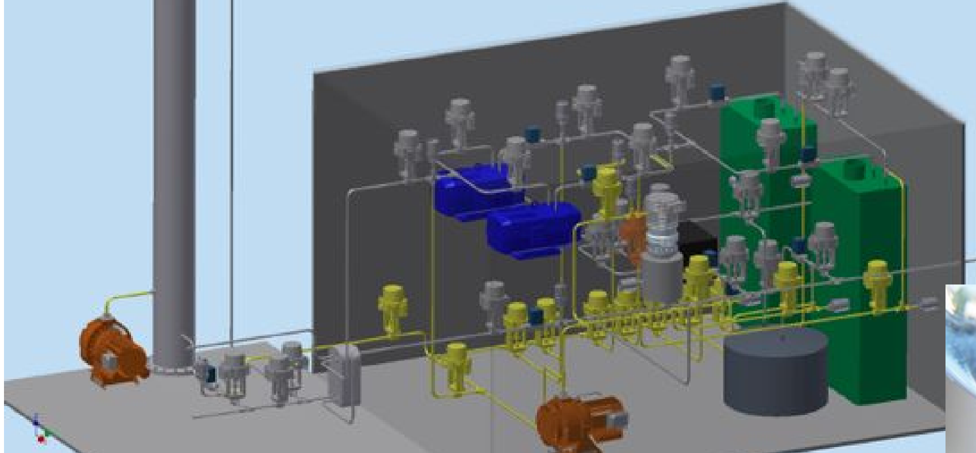
Columbia

Xenon Purification & Rn-Removal

- ½ inch gas lines, VCR connections
- Orbitally welded
- Pneumatic valves
- SAES PS4-MT50 getter
- QDrive and KNF pumps
- Dedicated monitors for ppb-level impurities (H_2O, O_2, Kr)

Xe purification system

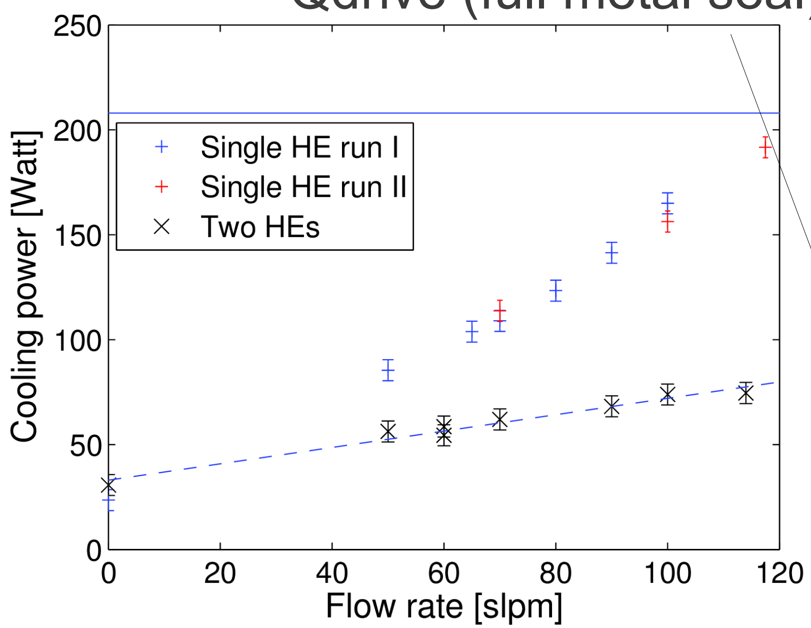
Xe purification system with Rn removal in charcoal column



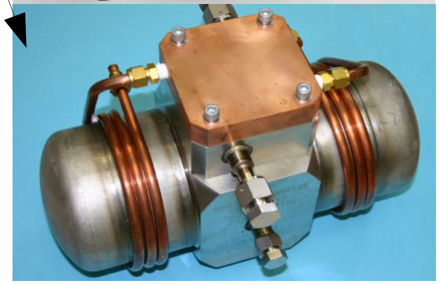
Münster (Xe purification) – MPIK (Rn column)

Ongoing R&D: XENON1T Demonstrator

- Demonstrated high speed circulation >800 kg/day
- Cryogenics full prototype
  >130 W spare cooling power
- Circulation pumps:
  - KNF (diaphragm)
  - Qdrive (full metal seal)



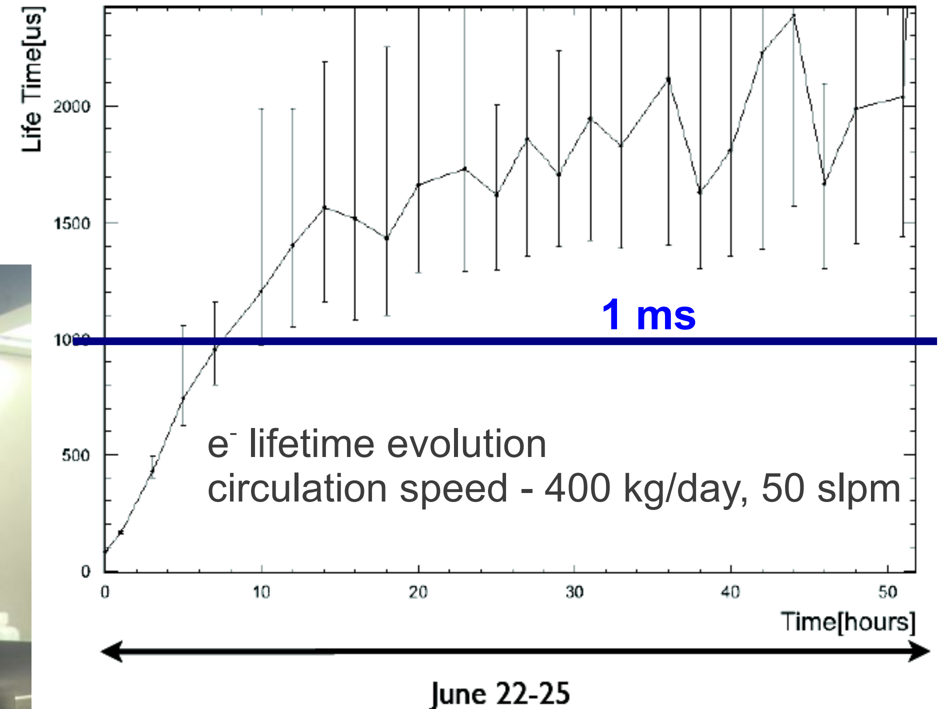
Columbia, Rice, UCLA

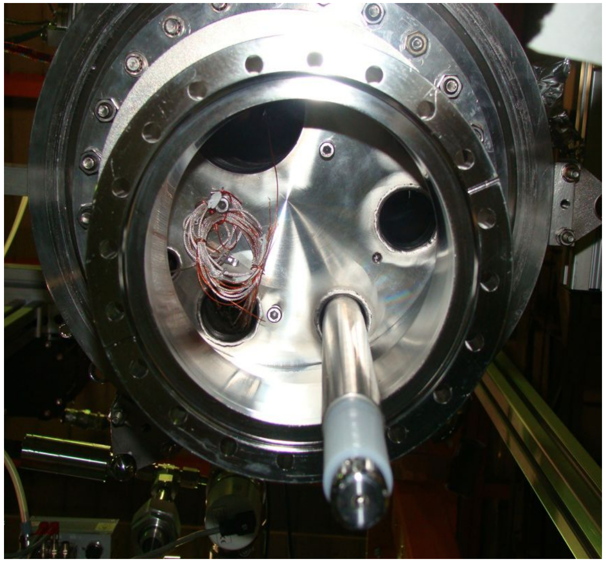


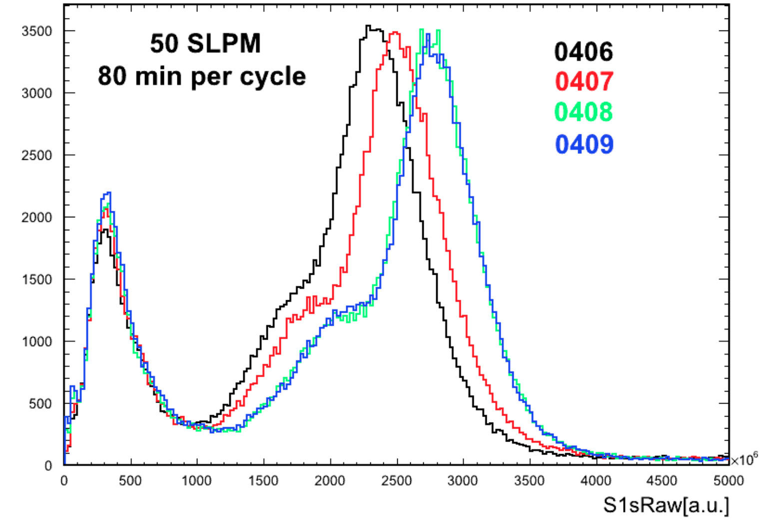
Built at Nevis Labs, Columbia

Ongoing R&D: XENON1T Demonstrator

- Fast Purification: 1ms lifetime in ~12h (25 kg)
- 30 cm drift TPC, R11410 and R8520 PMTs
- HV FT @ 100 kV in Lxe
- 1m Full HV TPC in a month







Light Yield evolution

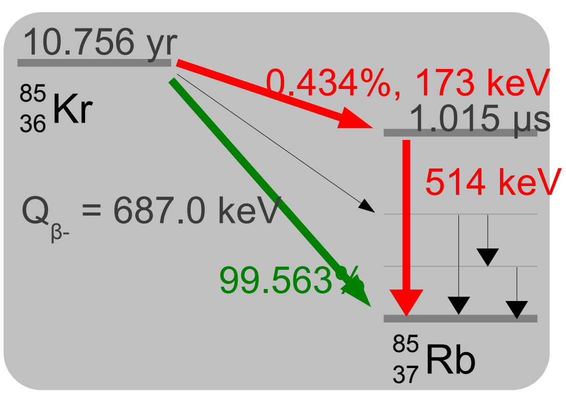
Columbia, Rice, UCLA

Krypton Removal

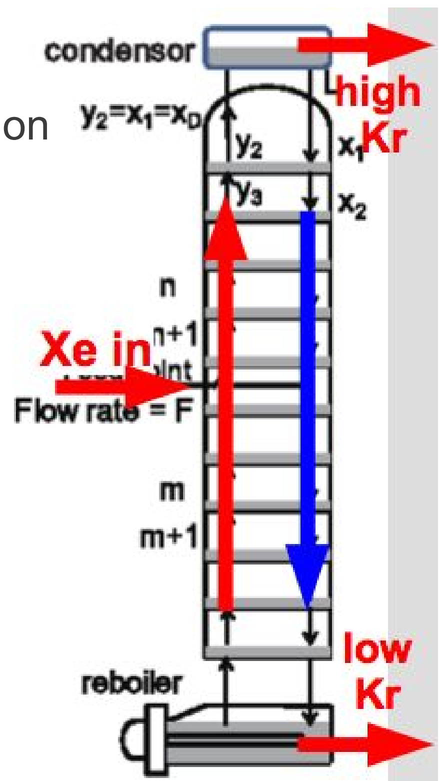
- Cryogenic distillation
- Reduce ppb Kr traces in Xe gas to ppt
- proven technique,
  achieved (19 +- 1) ppt in XENON100

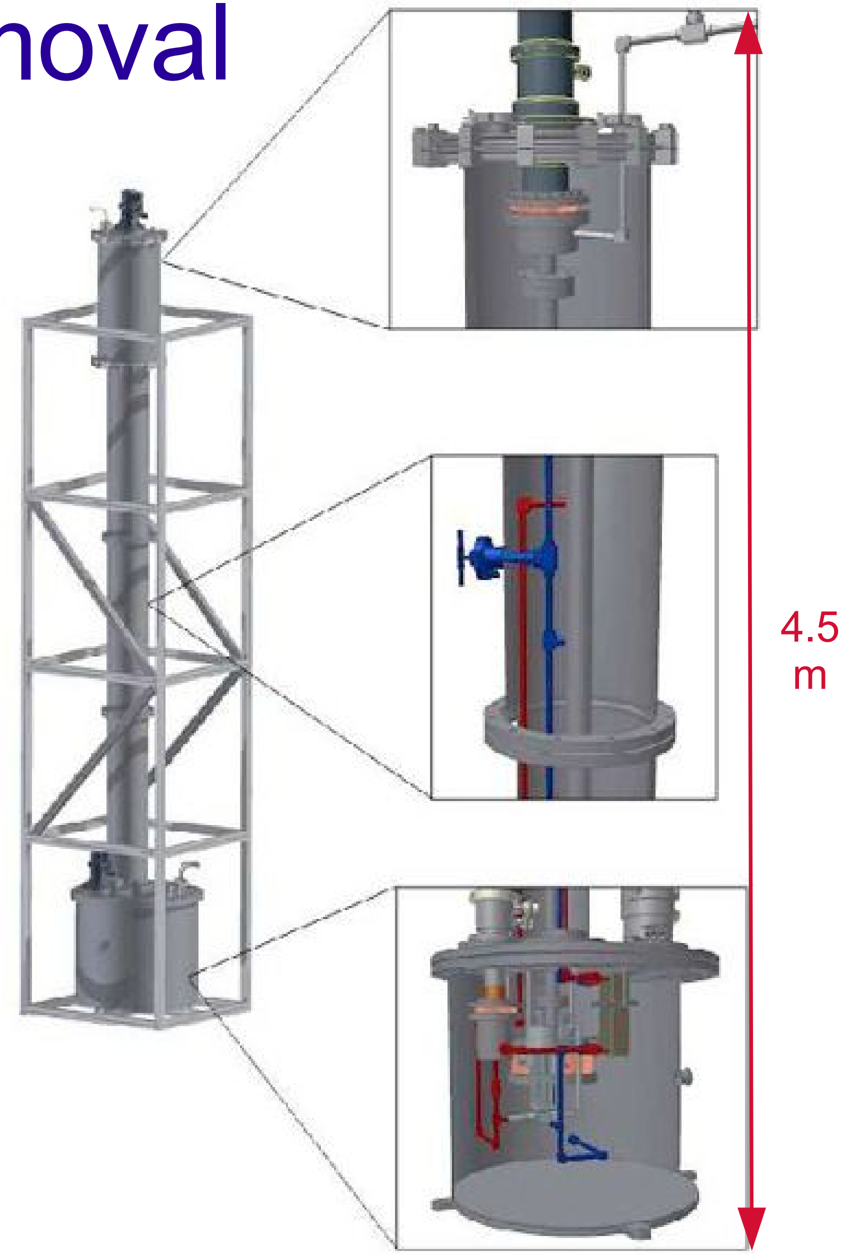
Design Parameters for XENON1T

- through-put: 3 kg/hr
- factor of 10^4-10^5 separation
- final Kr/Xe < 1 ppt



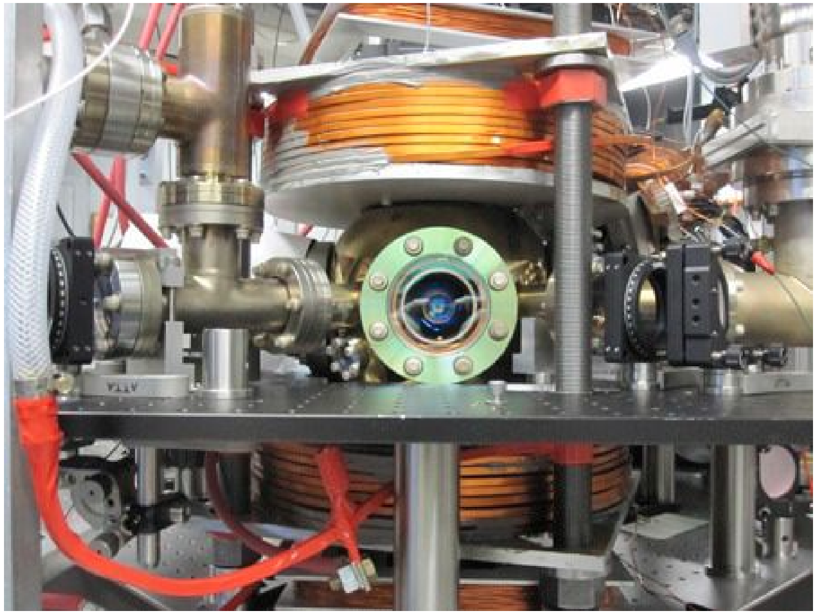
Münster





Krypton Analysis

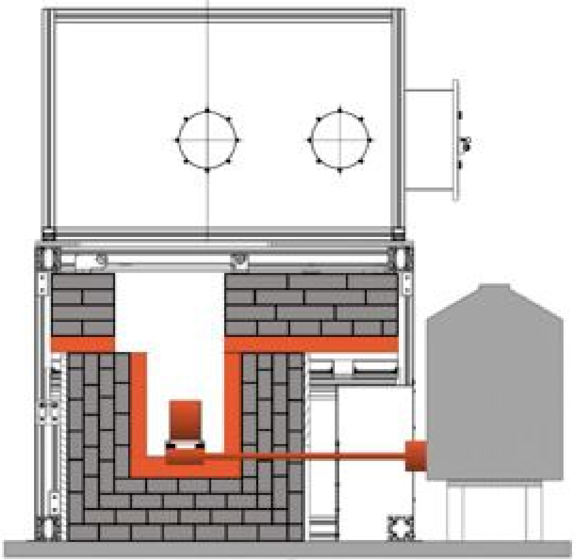
- Kr measurements with gas chromatography plus Rare Gas Mass Spectroscopy RGMS
  - measurement of ^{nat}Kr to ppt level
  - extrapolation to ^{85}Kr from atmospheric abundance
  - gas chromatography: Xe separation
  - demonstrated for XENON100
- ^{84}Kr measurement with atomic trap ATTA
  - measurement of ^{84}Kr to ppt level
  - extrapolation to ^{85}Kr from atmospheric abundance
  - Atom trap operational and efficient for Ar*
  - First Kr/Xe measurements for XENON100 by Fall 2012

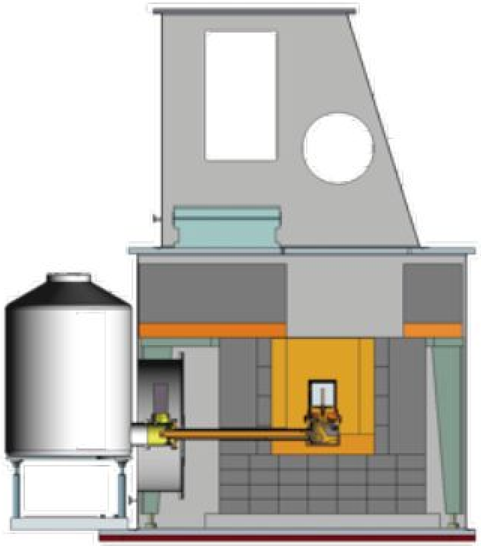


MPIK (RGMS) –
Columbia (ATTA)

Material Screening

- Gamma-ray screening with sensitivity ~10 µBq/kg with GeMPIs and Gator, located at LNGS
- Gas counting systems, located at LNGS and MPIK, for ^{222}Rn measurements at few atoms sensitivity
- ICPMS @ LNGS, UCLA
  Inductively coupled plasma mass spectrometry
- Neutron activation analysis @ PSI, Mainz

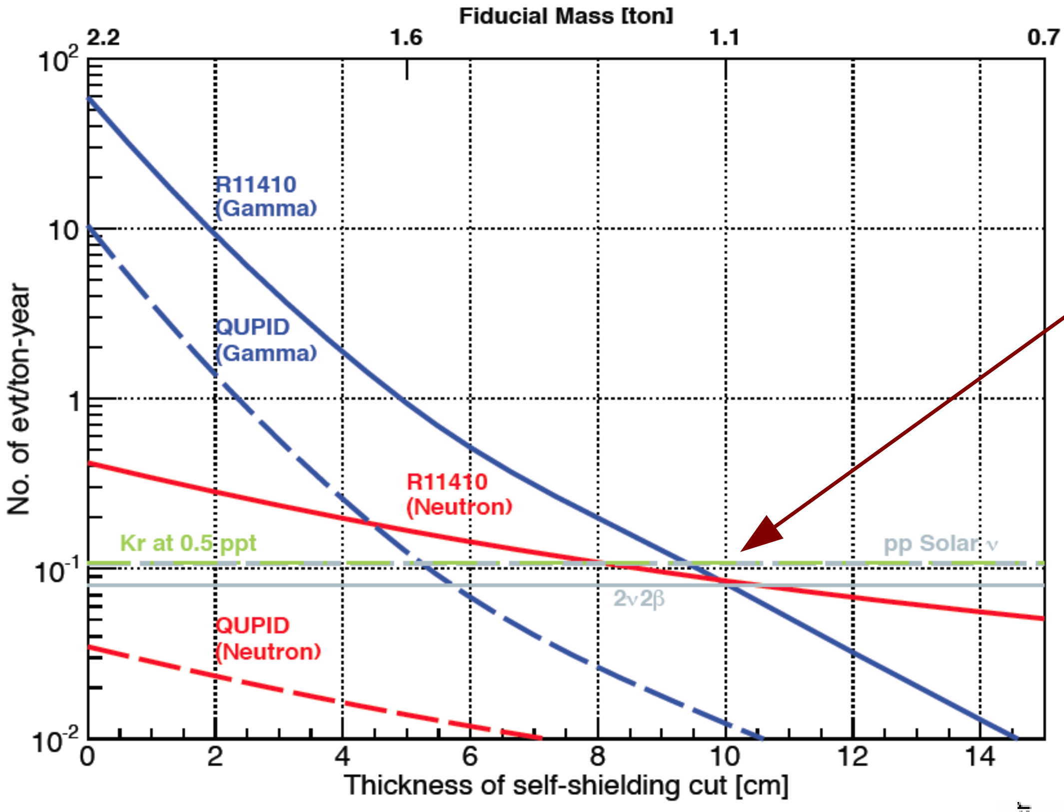




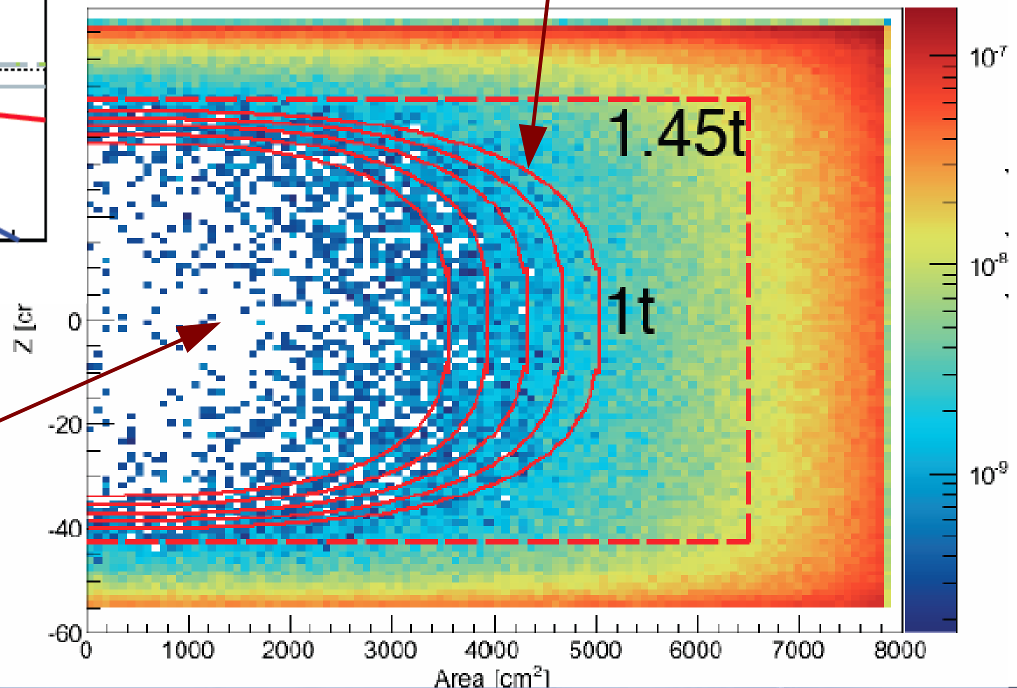
MPIK – Zurich

L. Baudis, et al. JINST 6 P08010, 2011

XENON1T Background Simulations



Choosing the perfect cut...



But watching for irreducible background!

Bologna-UCLA-Zurich

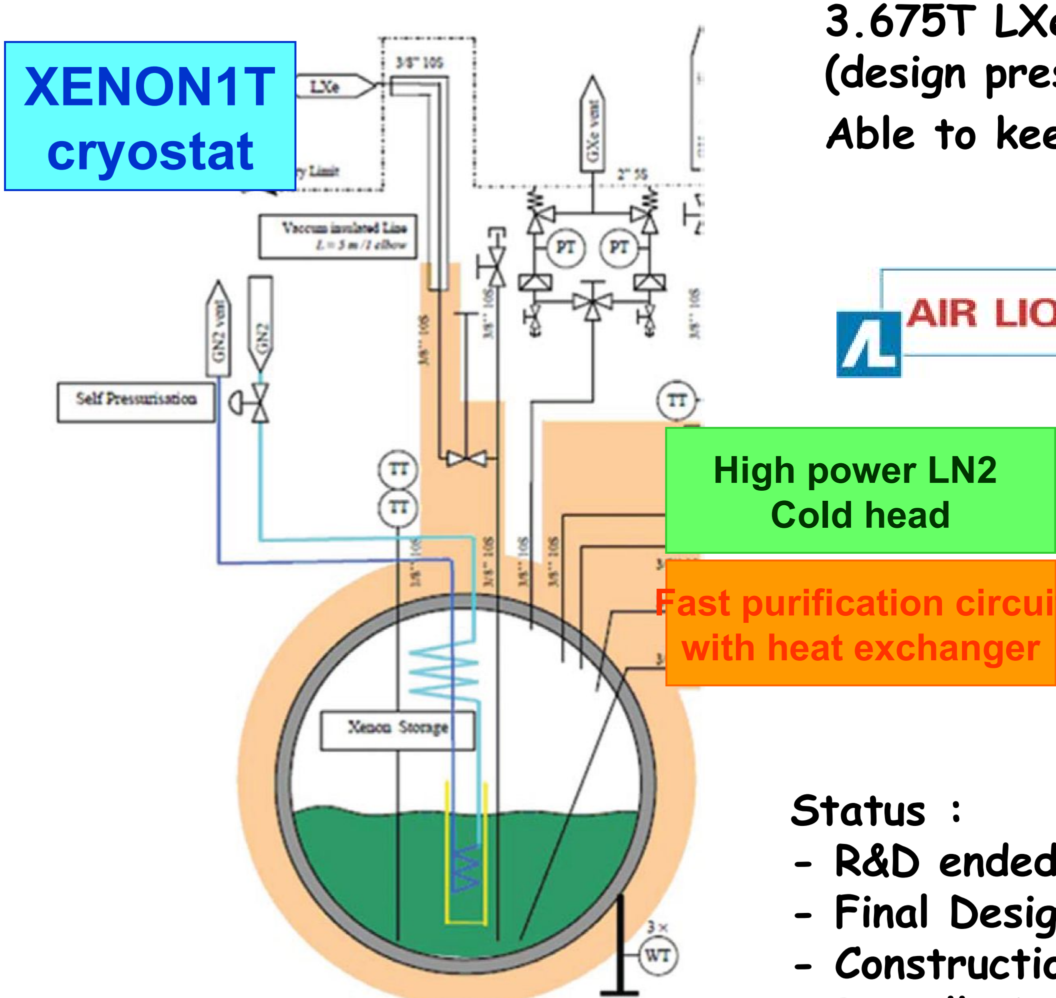
Xenon Storage

ReStoX : Recuperation and Storage system of XENON1T

Very compact station
3.675T LXe storage from 16°C
(design pressure P_d: 65 atm) to -108°C (1.15 atm)
Able to keep high purity all the time

AIR LIQUIDE

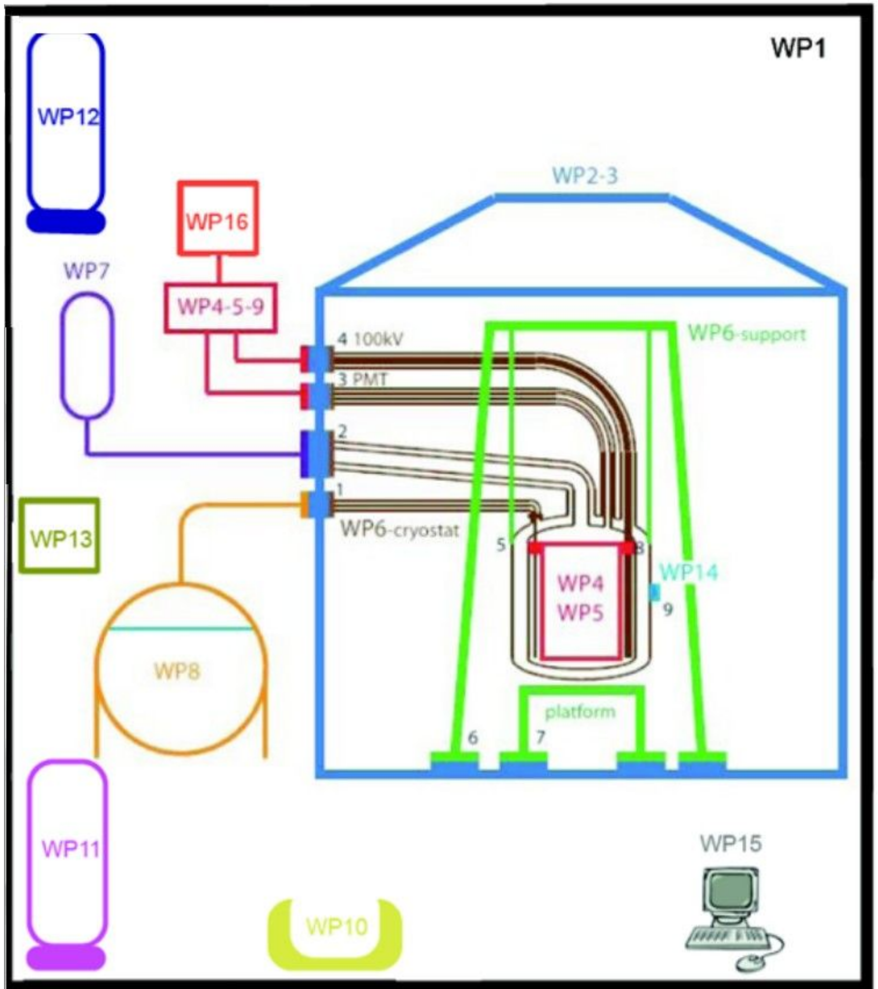
Subatech



Status :
- R&D ended (result presented at ICEC24-ICMC2012)
- Final Design for the end of 2012
- Construction in 2013
- Installation at LNGS for the end of 2013

Can be easily scalable to larger sizes

Organizing

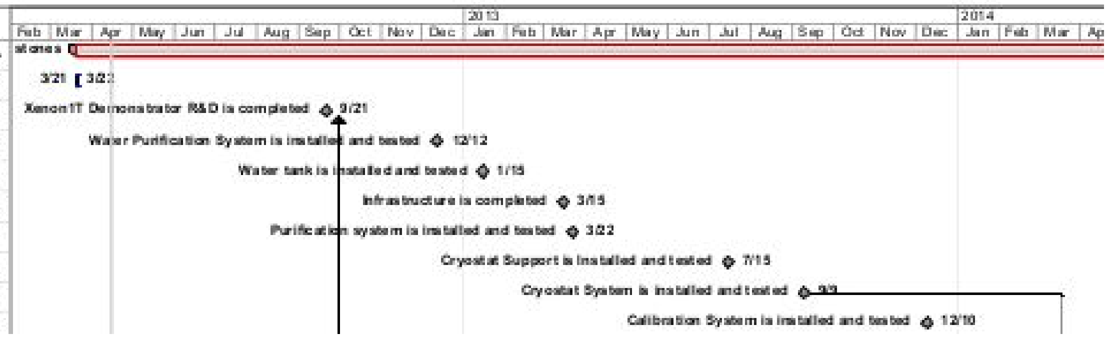


1. Infrastructure
   F. Arneodo (LNGS)
2. Muon veto
   W. Fulgione (INFN-Torino), S. Fattori (Mainz)
3. Water tank
   H. Landsman (Weizmann)
4. Detector: TPC, Grids, HV
   M. Messina (Columbia), M. Schumann (Zurich)
5. PMTs
   K.Arisaka (UCLA)
6. Cryostat & Support Platform)
   G. Tajiri (Columbia), A. Colijn (Nikhef)
7. Cryogenics
   G. Plante , R. Budnik (Columbia)
8. Cryogenic storage vessel
   L. Scotto Lavina (Subatech)
9. Slow control
   J. Cardoso (Coimbra)
10. Material screening and selection
    A. D. Ferella (Zurich), J.Schreider (MPIK)
11. Distillation column
    C. Weinheimer (Munster)
12. Xe Purification
    E. Brown (Munster), A. Malgarejo (Columbia)
13. Gas purity and analytics
    H. Simgen (MPKI)
14. Calibration
    A. Kish (Zurich), R. Lang (Purdue)
15. Monte Carlo simulation
    C. Cham (UCLA), M. Selvi (Bologna)
16. DAQ and Trigger
    M. Schumann (UZH), P. Decowski (Nikhef)

And now...

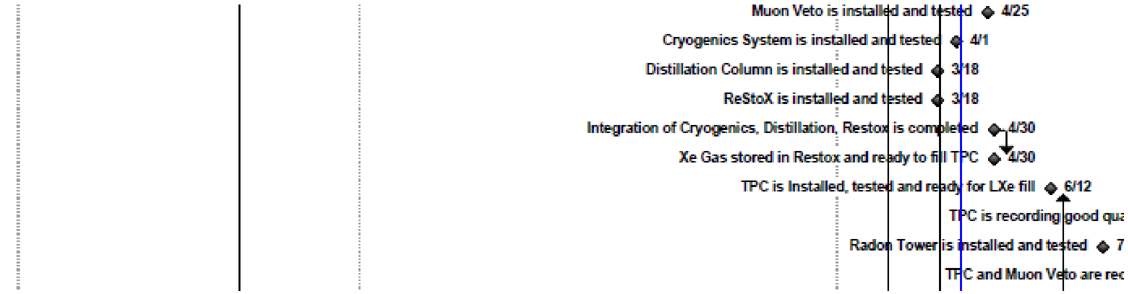
Xenon1T_Master schedule_04152012 v3

ID		Task Name	Duration	Start	Finish
1		XENON1T Major Milestones	720 days	Mar 21 '12	Dec 23 '14
2	✓	XENON1T NSF Review at Columbia	2 days	Mar 21 '12	Mar 22 '12
3		Xenon1T Demonstrator R&D is completed	0 days	Sep 21 '12	Sep 21 '12
4		Water Purification System is installed and teste	0 days	Dec 12 '12	Dec 12 '12
5		Water tank is installed and tested	0 days	Jan 15 '13	Jan 15 '13
6		Infrastructure is completed	0 days	Mar 15 '13	Mar 15 '13
7		Purification system is installed and tested	0 days	Mar 22 '13	Mar 22 '13
8		Cryostat Support is Installed and tested	0 days	Jul 15 '13	Jul 15 '13
9		Cryostat System is installed and tested	0 days	Sep 9 '13	Sep 9 '13
10		Calibration System is installed and tested	0 days	Dec 10 '13	Dec 10 '13



To work!

Muon Veto is installed and tested	0 days	Apr 25 '14	Apr 25 '14
Cryogenics System is installed and tested	0 days	Apr 1 '14	Apr 1 '14
Distillation Column is installed and tested	0 days	Mar 18 '14	Mar 18 '14
ReStoX is installed and tested	0 days	Mar 18 '14	Mar 18 '14
Integration of Cryogenics, Distillation, Restox i	0 days	Apr 30 '14	Apr 30 '14
Xe Gas stored in Restox and ready to fill TPC	0 days	Apr 30 '14	Apr 30 '14
TPC is Installed, tested and ready for LXe fill	0 days	Jun 12 '14	Jun 12 '14
TPC is recording good quality data	0 days	Sep 30 '14	Sep 30 '14
Radon Tower is installed and tested	0 days	Jul 22 '14	Jul 22 '14
TPC and Muon Veto are recording good quality	0 days	Dec 23 '14	Dec 23 '14



Jul 22 '14	Jul 22 '14
Dec 23 '14	Dec 23 '14

XENON
Dark Matter Project

Summary

- XENON1T is funded and on schedule
- Sensitivity goal for SI cross section of 10^{-47} cm^2 expected by 2017
- All challenges are addressed:
  - Background
  - Purity
  - High Voltage
- Construction on site starts this fall
- Getting exciting...

XENON1T Background Simulations

Neutron production in materials