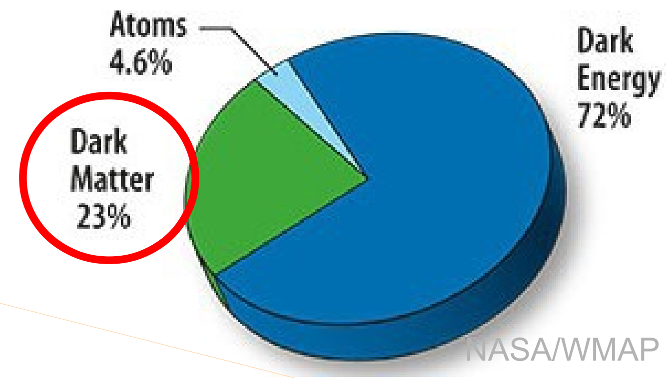
Prospects for WIMP Dark Matter Direct Searches with
XENON1T and DARWIN



8th Patras Workshop on
Axions, WIMPs, and WISPs

Chicago, 21-July-2012

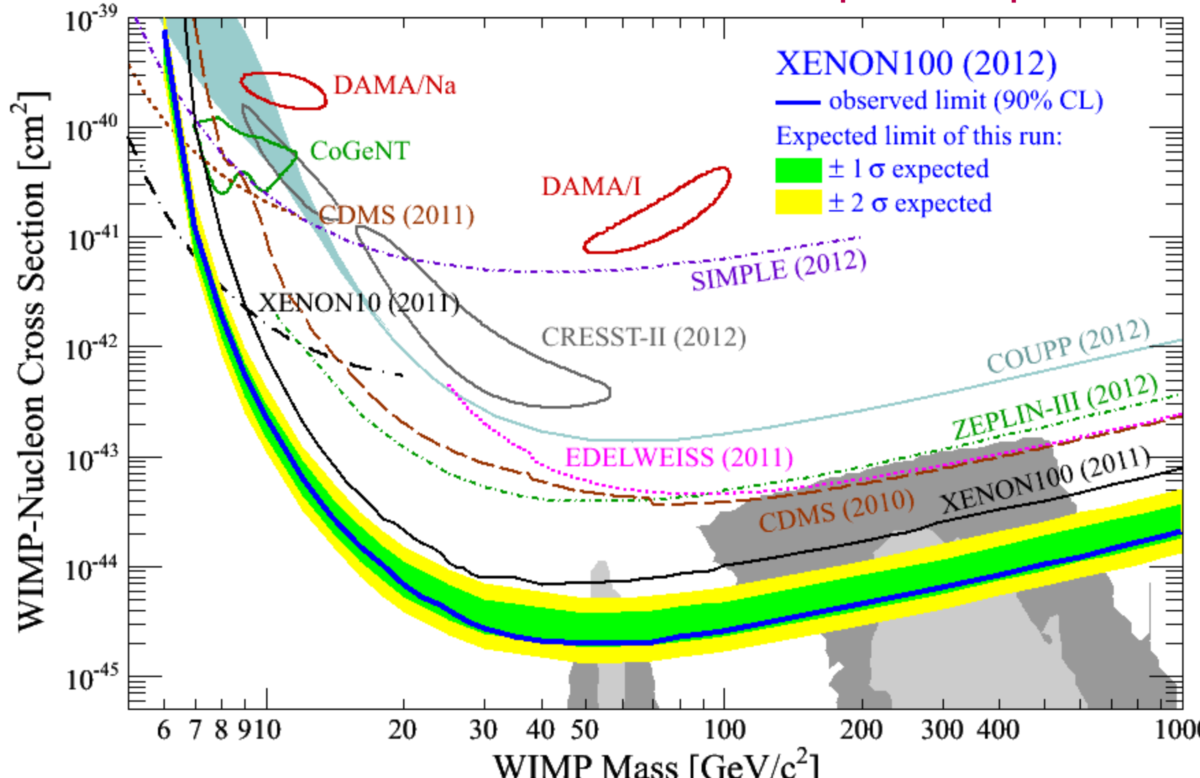
Uwe Oberlack

http://xenon.physik.uni-mainz.de

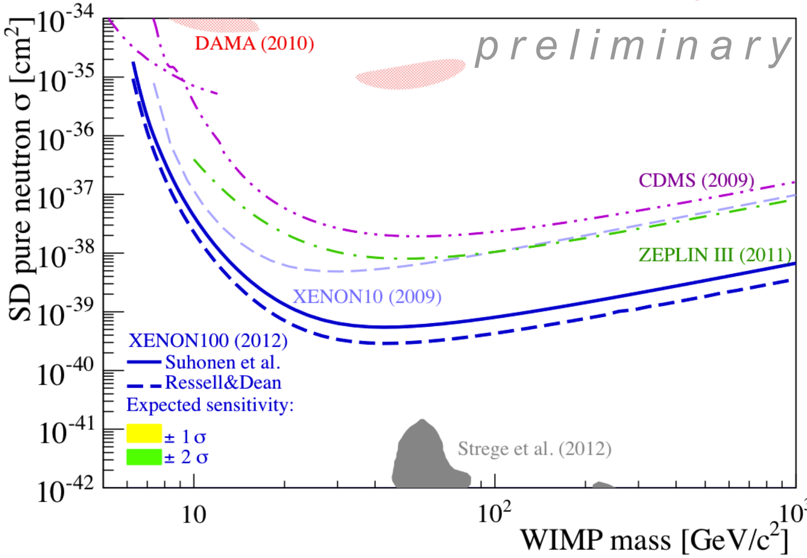
JOHANNES GUTENBERG
UNIVERSITÄT MAINZ

Status in WIMP DM Sensitivities (2012)

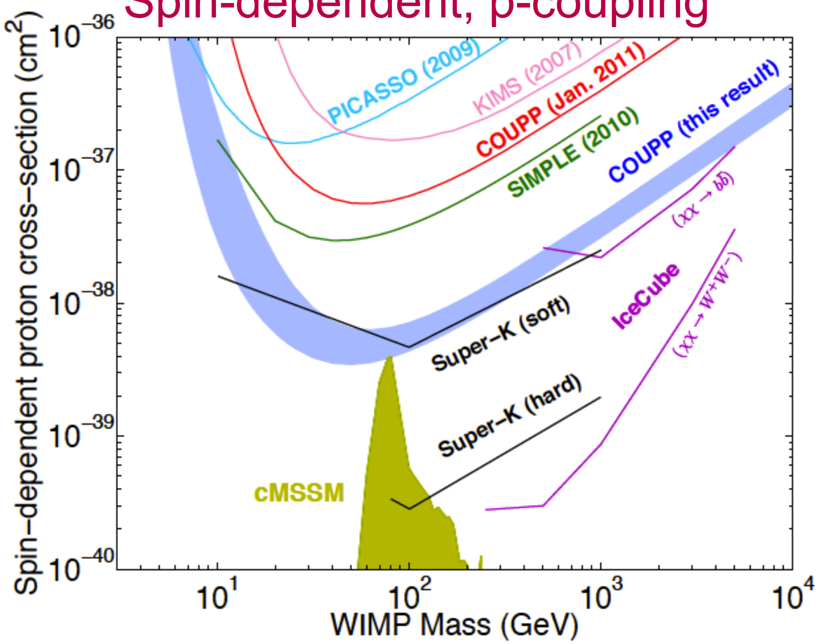
Spin-independent



Spin-dependent, n-coupling



Spin-dependent, p-coupling



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

CDMS-II SI, 2010
Science 327, 1619

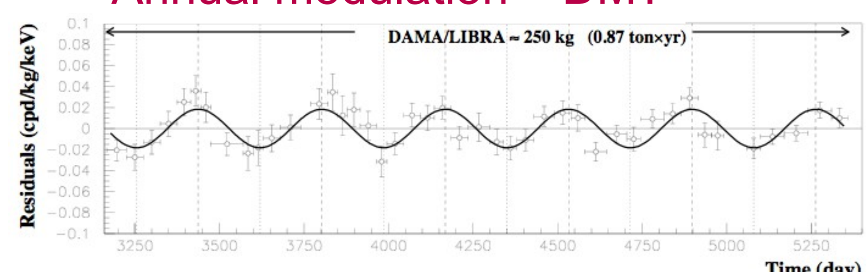
EDELWEISS-II SI, 2011
Phys. Lett. B 702, 329

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

COUPP SD:
2012: arXiv:1204.3094

PICASSO SD, 2012
arxiv:1202.1240

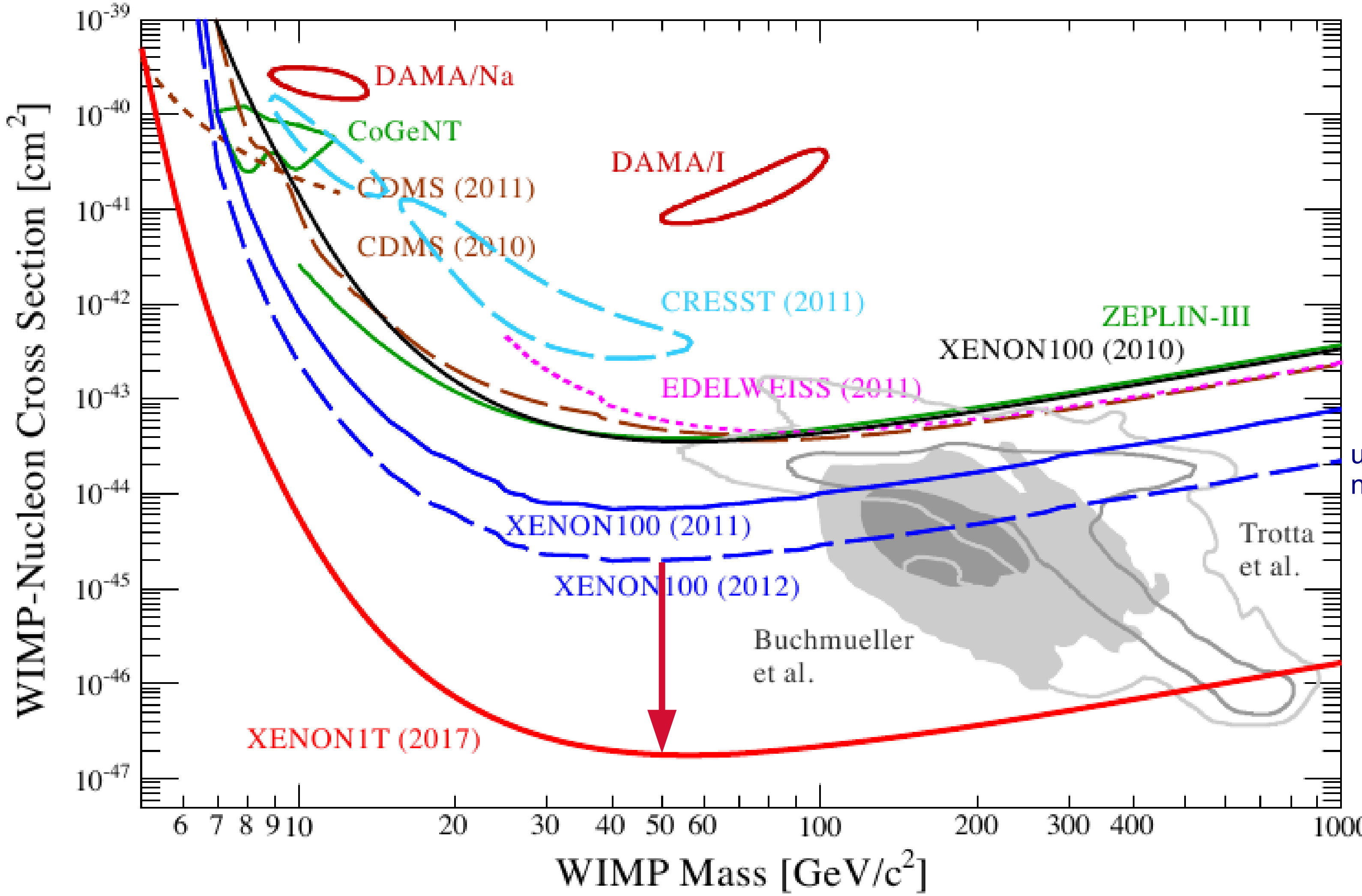
Annual modulation – DM?



DAMA/LIBRA, 2010 arxiv:1002.1028

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

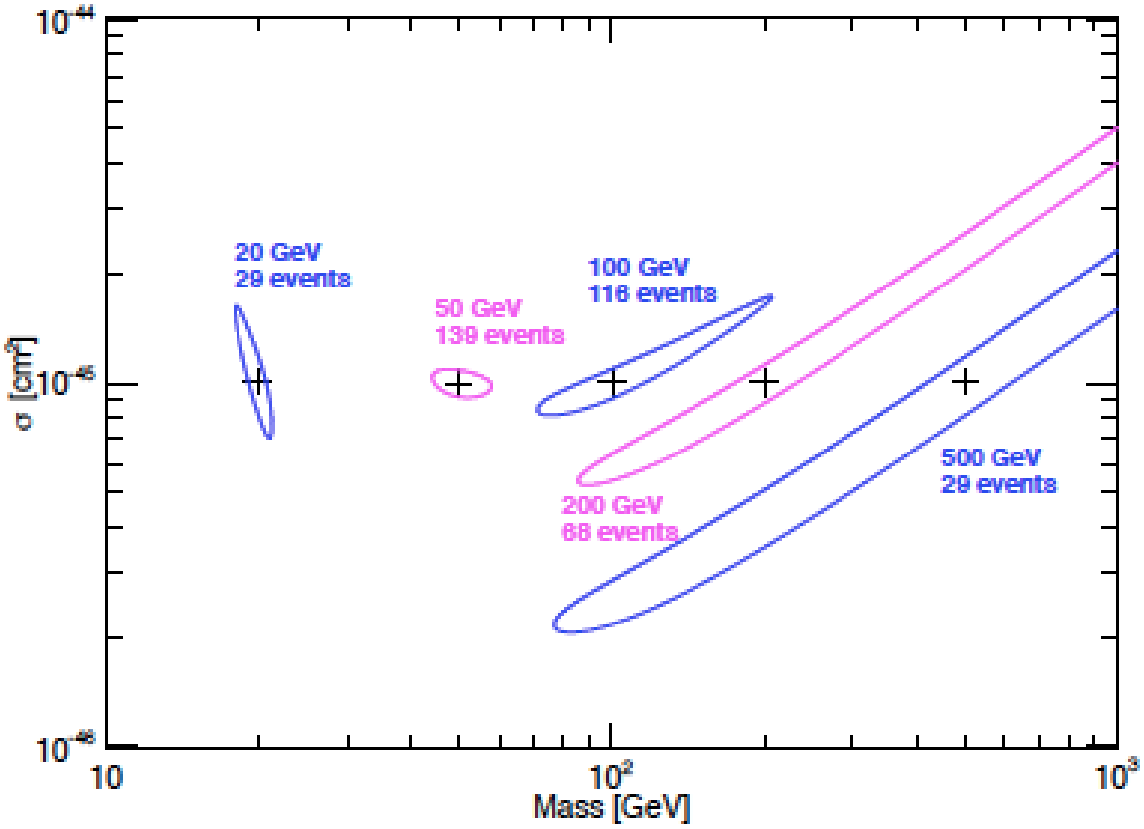
Spin-independent sensitivity



update with new limit

… but we hope for a detection

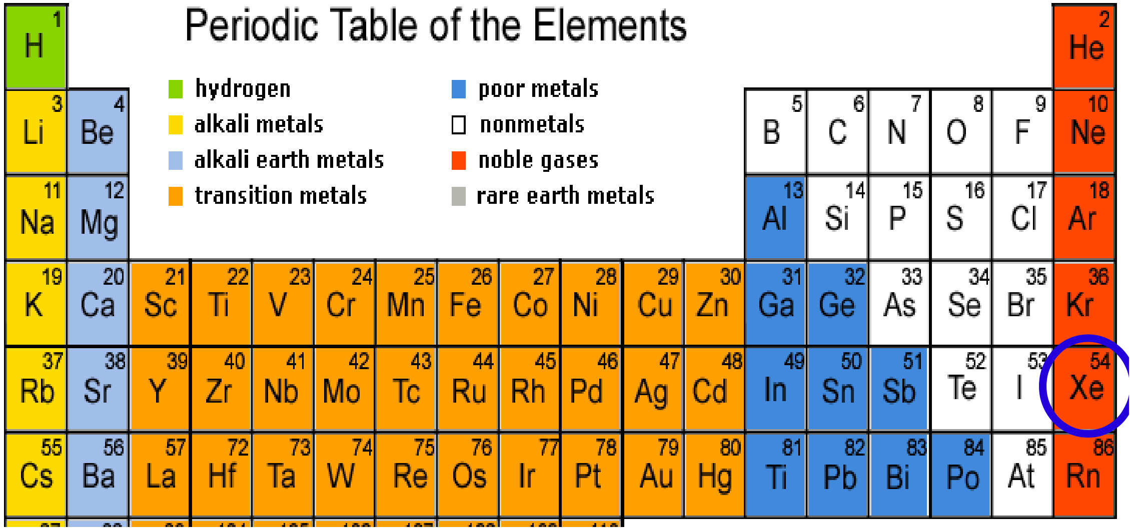
For a WIMP with 10^{-45} cm^2
~100 events

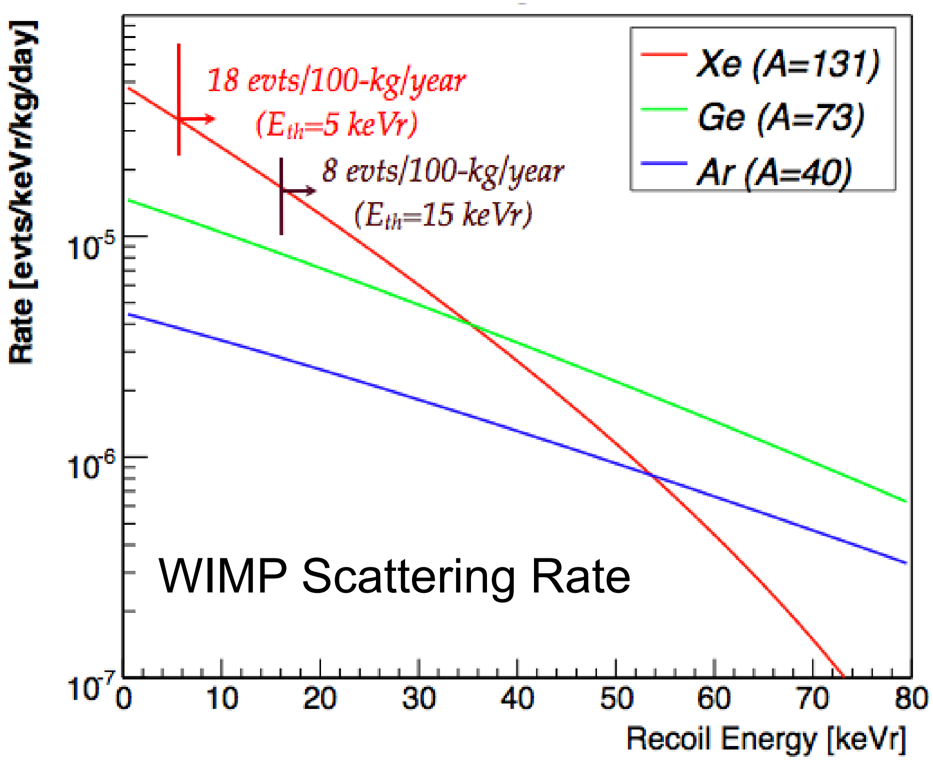


Reminder:

Liquid Xenon for Dark Matter Search

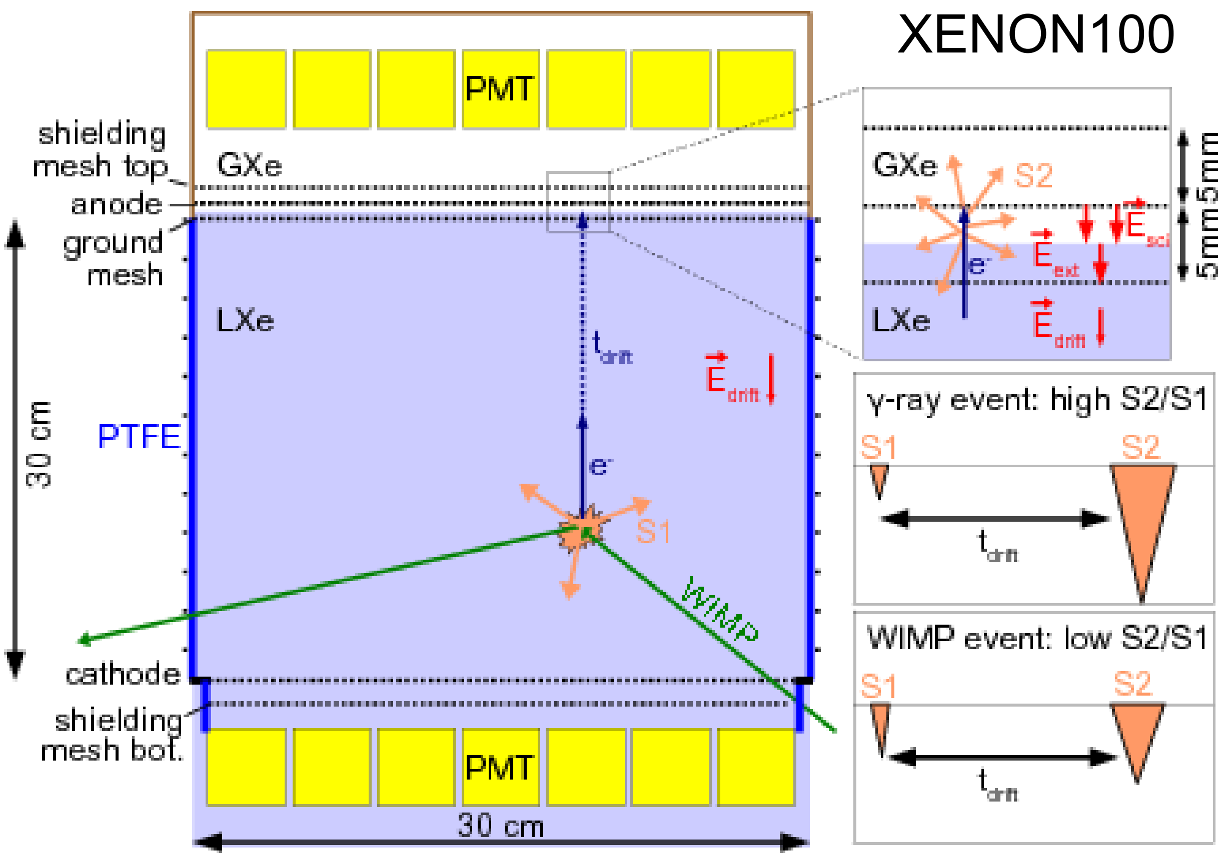
- Large atomic number A~131 best for SI interactions (σ~A²).
  Need low threshold.
- ~50% odd isotopes: SD interactions
  If DM detected: probe physics with the same detector using isotopically enriched media.
- No# long-lived Xe isotopes.
  But control Kr-85, Rn-222. #Xe-136 2νββ
- High Z (54) and density:
  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

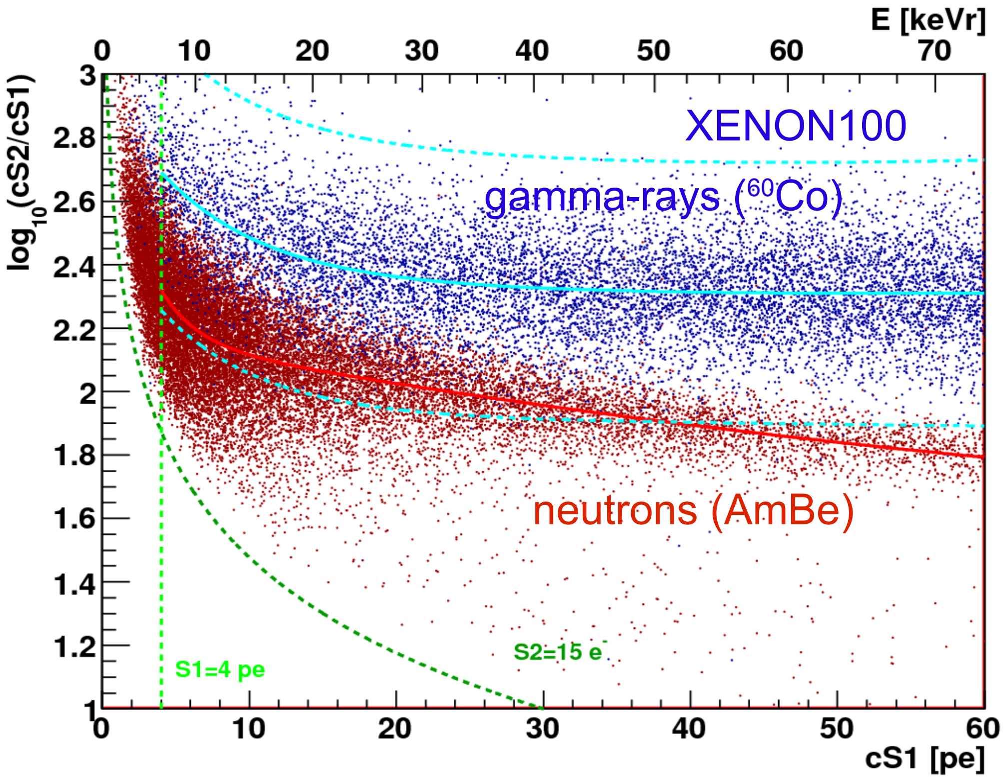
- WIMP recoil on Xe nucleus in dense liquid (2.9 g/cm^3)
  → Ionization + UV Scintillation
- Detection of primary scintillation light (S1) with PMTs.
- Charge drift towards liquid/gas interface.
- Charge extraction liquid/gas at high field between ground mesh (liquid) and anode (gas)
- Charge produces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



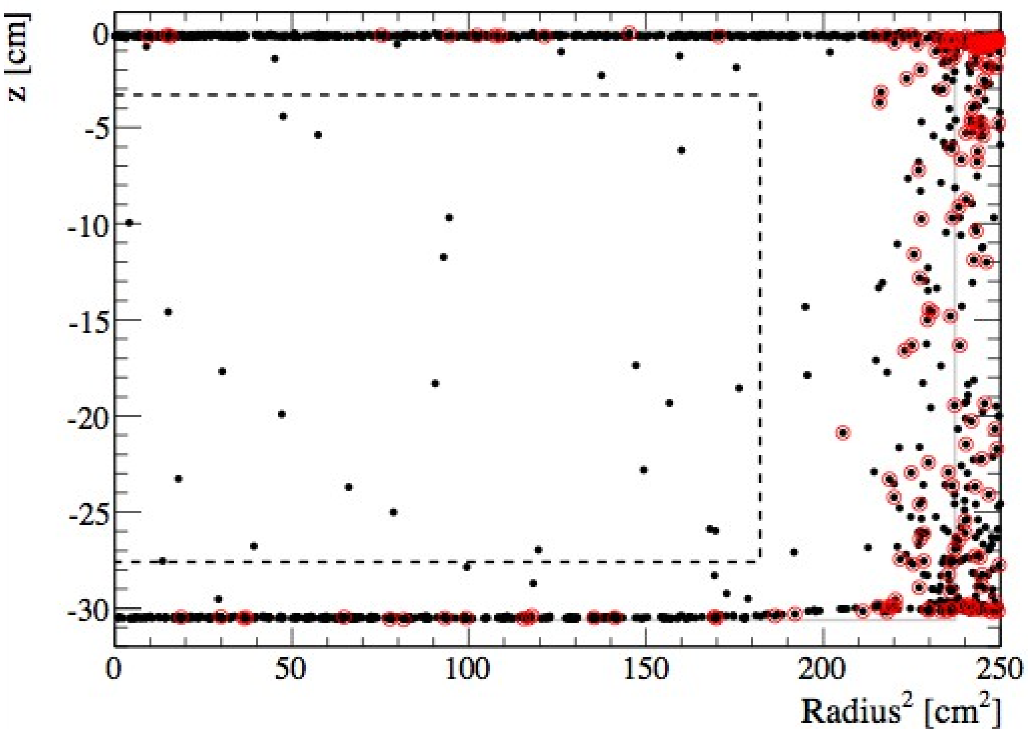
- **3D position measurement**
  →X/Y from S2 signal. Resolution few mm.
  →Z from electron drift time (~0.3 mm).

Background Discrimination in Dual Phase Liquid Xenon TPC's

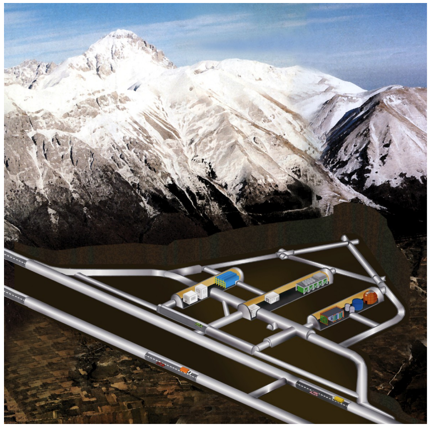
Ionization / Scintillation Ratio S2/S1



3D Position Resolution: fiducial cut, singles/multiples



The XENON Program



GOAL: Explore WIMP Dark Matter with a sensitivity of σ_{SI}~10^{-47} cm^2.

→Requires ton-scale fiducial volume with extremely low background.

CONCEPT:

- Target LXe: excellent for DM WIMPs scattering.
  →Sensitive to both axial and scalar coupling.
- Detector: two-phase LXeTPC: 3D position sensitive, self-shielding.
- Background discrimination: simultaneous charge & light detection.
- PMT readout with >3 pe/keV.
  Low energy threshold for nuclear recoils (~6-8 keV).

PHASES:

R&D	XENON10	XENON100	XENON1T
Start: 2002	2005-2007	2007 → ...	2011 → DM search 2015
	Proof of concept. Total mass: 14 kg 15 cm drift. Best limit in '07: σ_{SI}~10^{-43} cm^2	Ongoing DM search. Total mass: 170 kg 30 cm drift. Best limit in '11, '12: 2012: σ_{SI}~ 2 x 10^{-45} cm^2	Technical design studies. Total mass: ~ 3 t 1 m drift. Goal: σ_{SI} ~ 2 x 10^{-47} cm^2

The XENON Collaboration

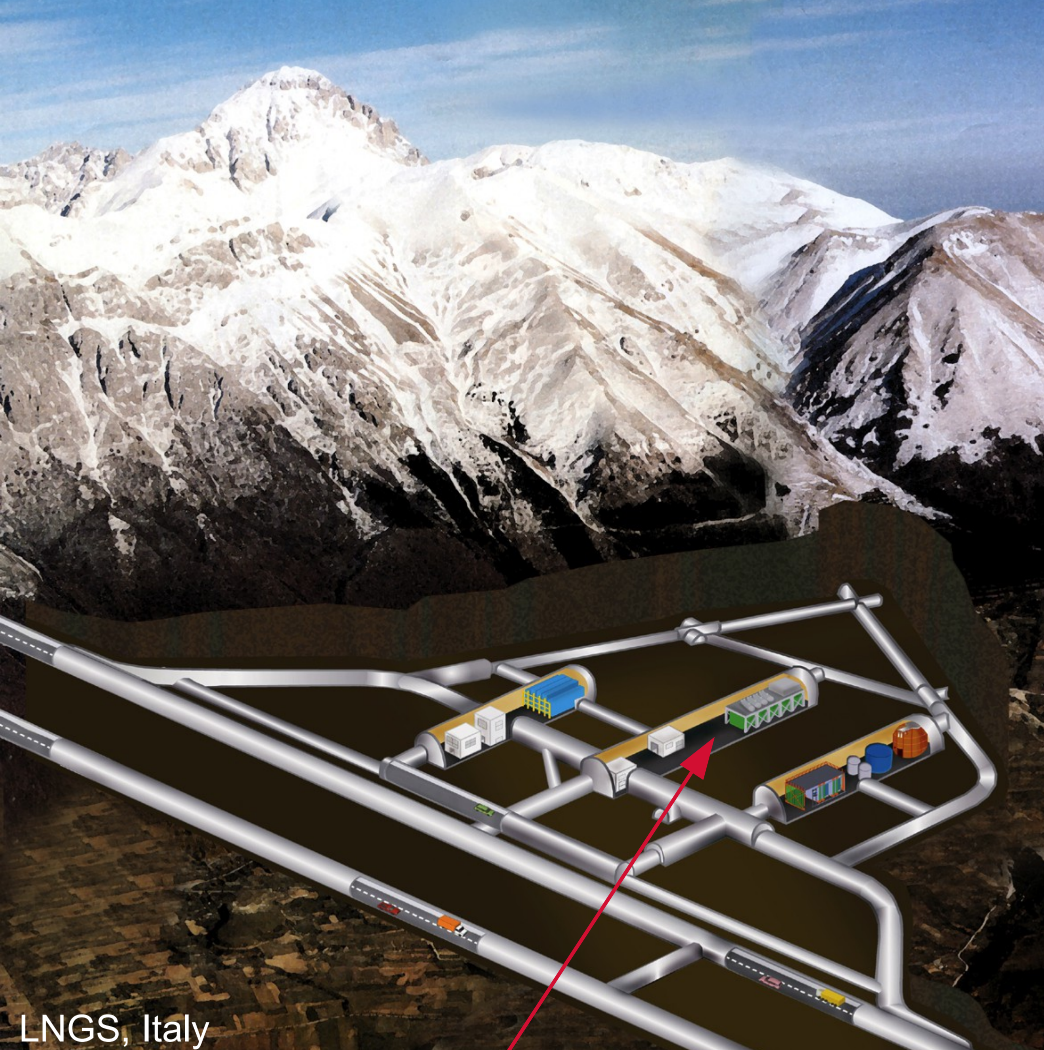
USA, Switzerland, Portugal, Italy, France, Germany, Israel, Netherlands, China (XENON100)

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

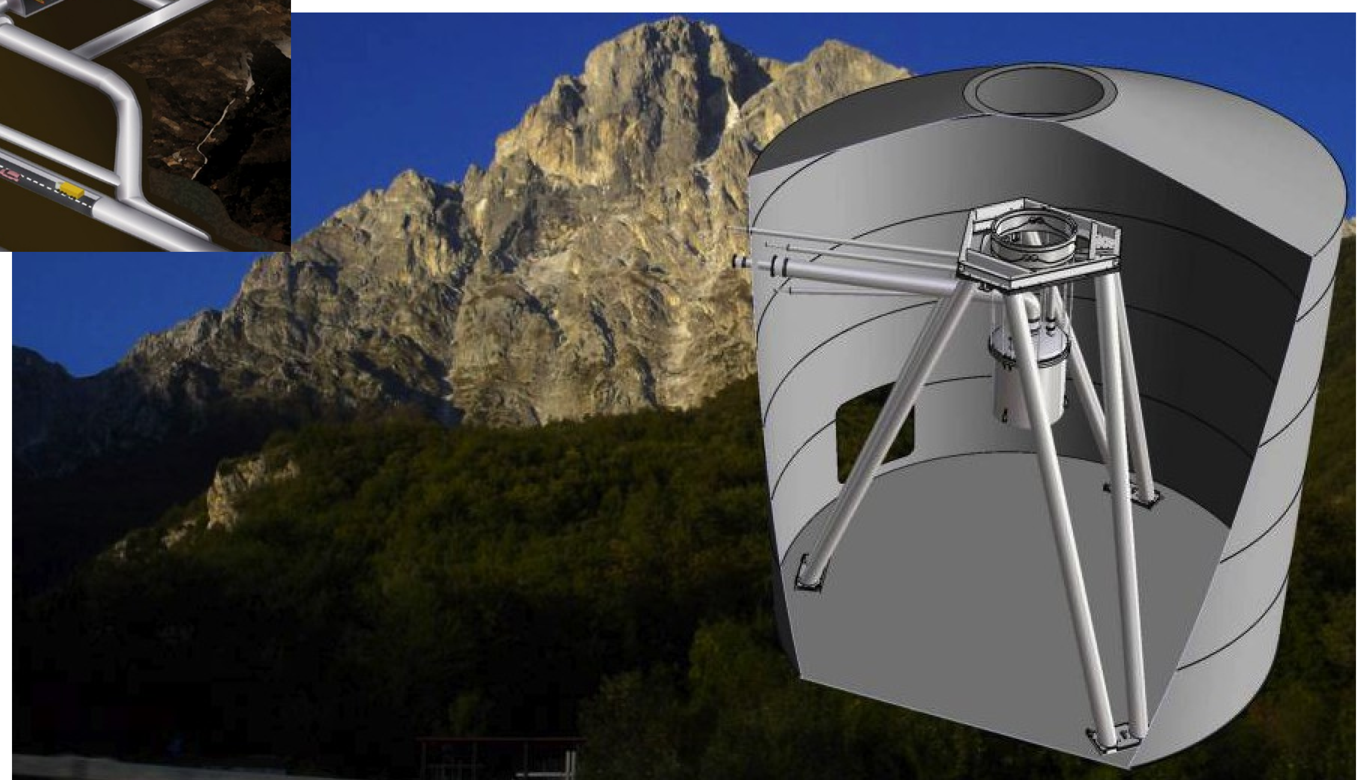
Mainz | Bologna | Subatech | Münster | Nikhef | MPI-K | Weizman

XENON1T
(2011-2015)

- Liquid xenon TPC to explore σ ~ 2×10^{-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.

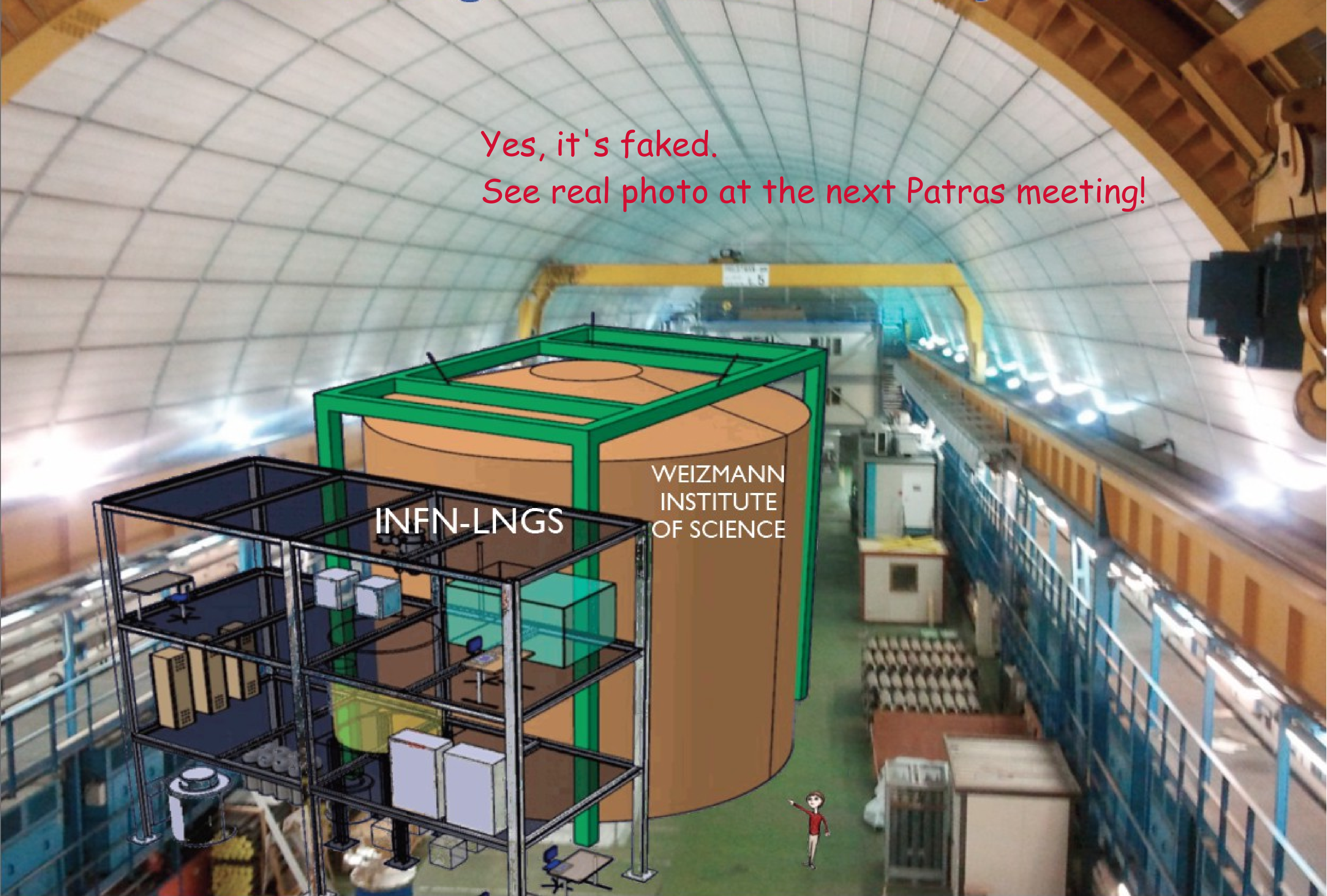


XENON1T in Hall B
(next to Icarus) @ LNGS



LNGS Underground Laboratory – Hall B

LNGS Underground Laboratory – Hall B



Water Cherenkov 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

Trigger requirements:

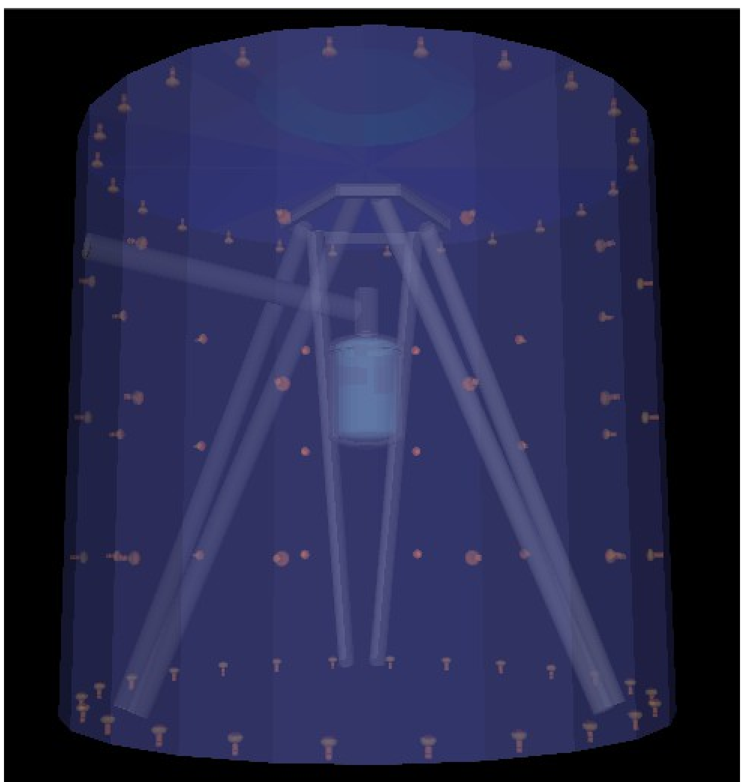
- single photoelectron
- 4 fold coincidence
- time window: 300 ns

Trigger efficiency

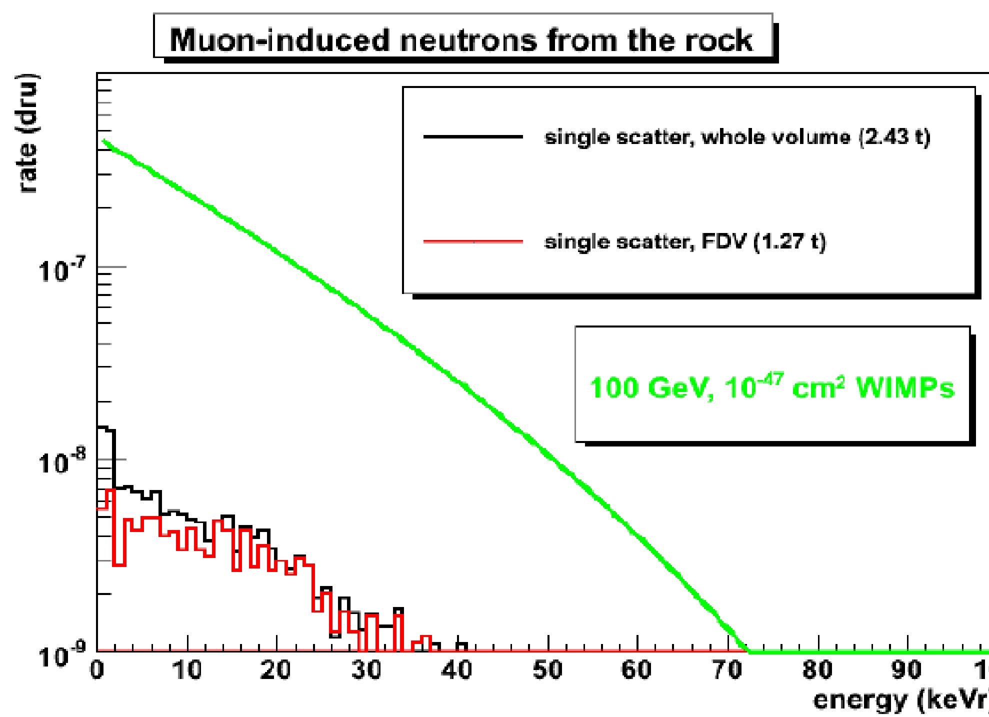
- > 99.5% for neutrons with muons in WT
- ~ 78% for neutrons with μ's outside WT

μ-induced neutron background

- 0.01 per year
- ≪ WIMP signal



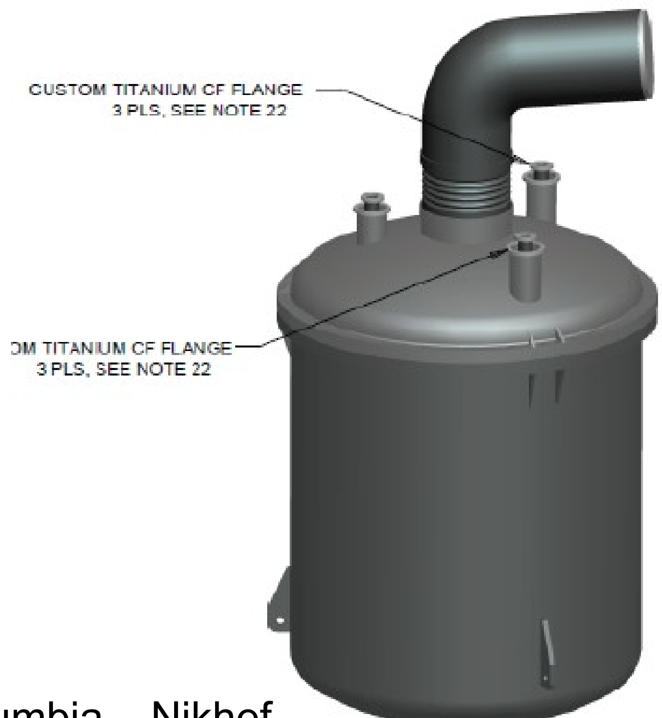
Bologna – Mainz – Torino

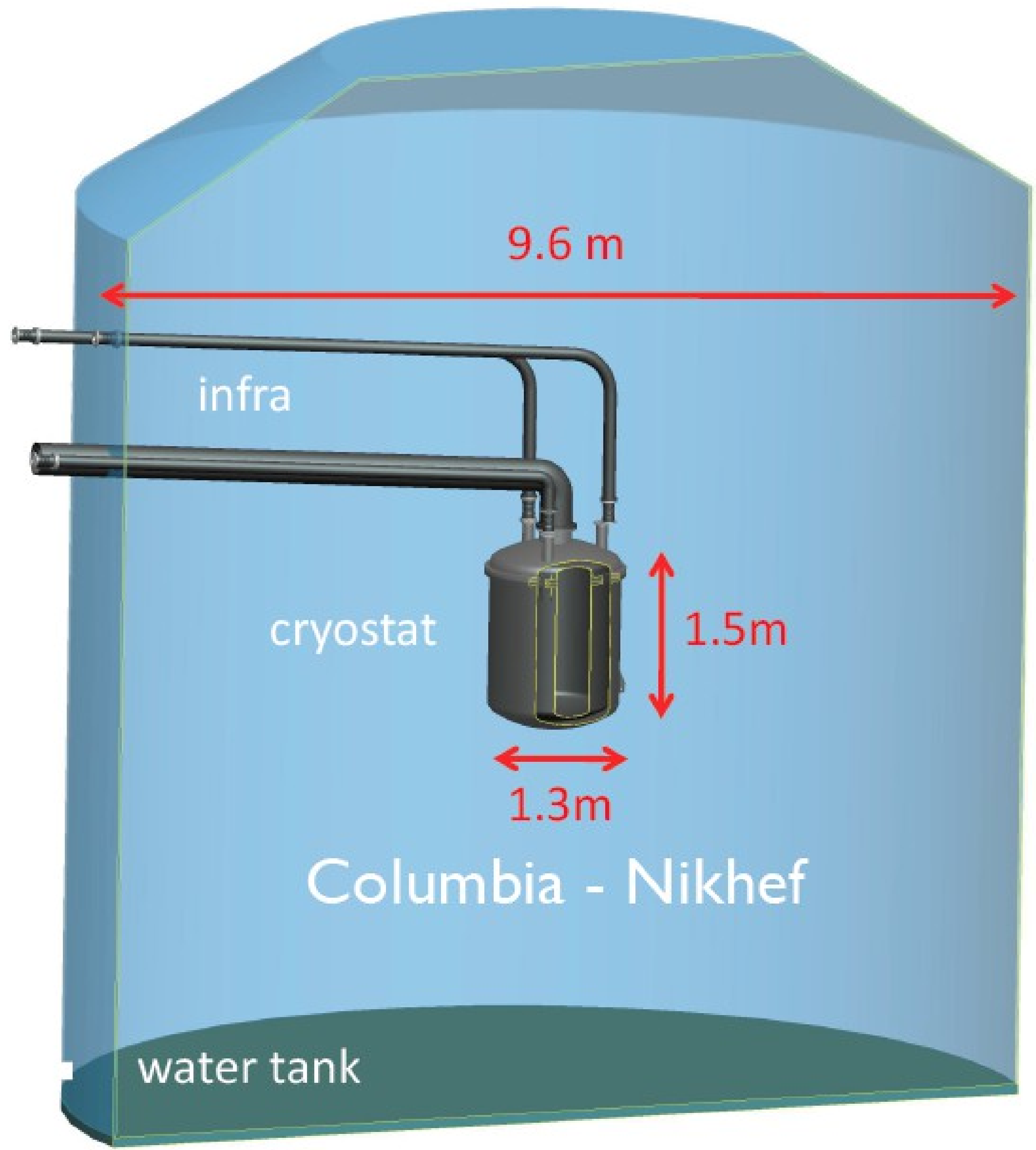


Cryostat

Baseline design

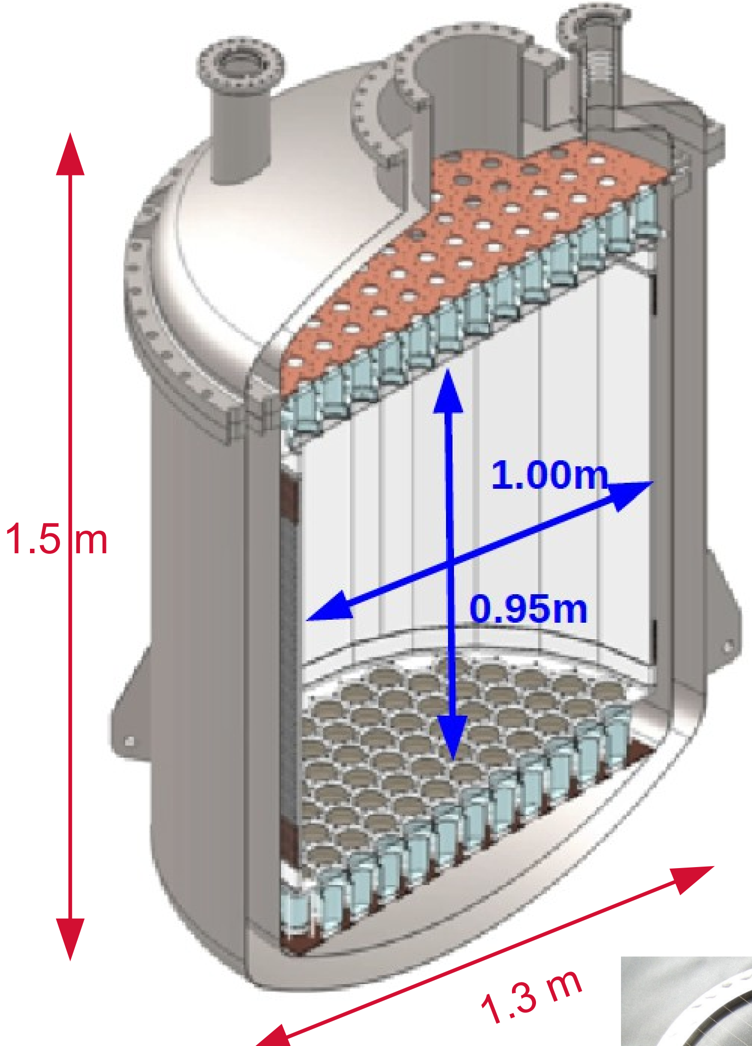
- Ti grade 1 double-walled cryostat
- UHV compatible, low outgas rate
- Heat load < 50 W
- Immersed in water shield
- Buoyancy load
- LNGS seismic environment
- Safety review currently ongoing

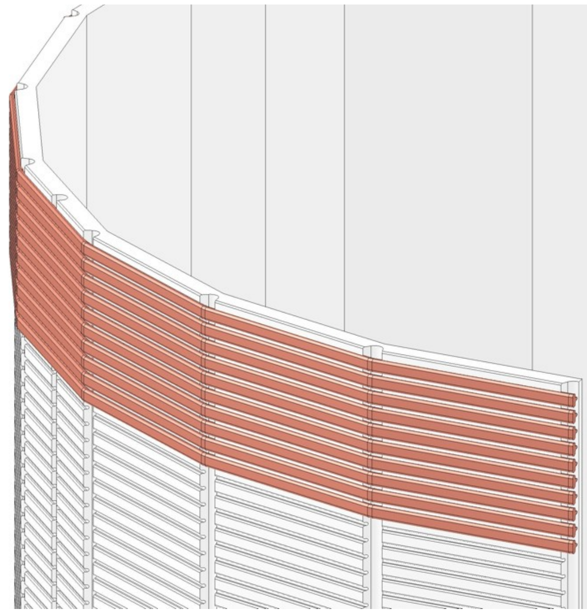


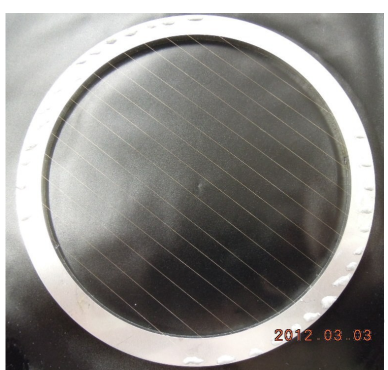


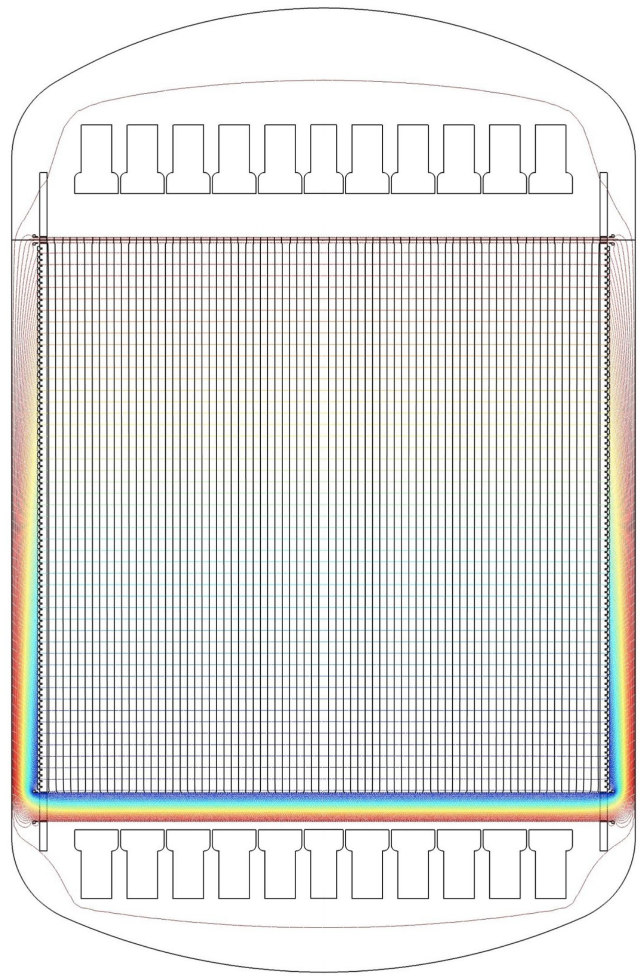
Columbia – Nikhef

TPC







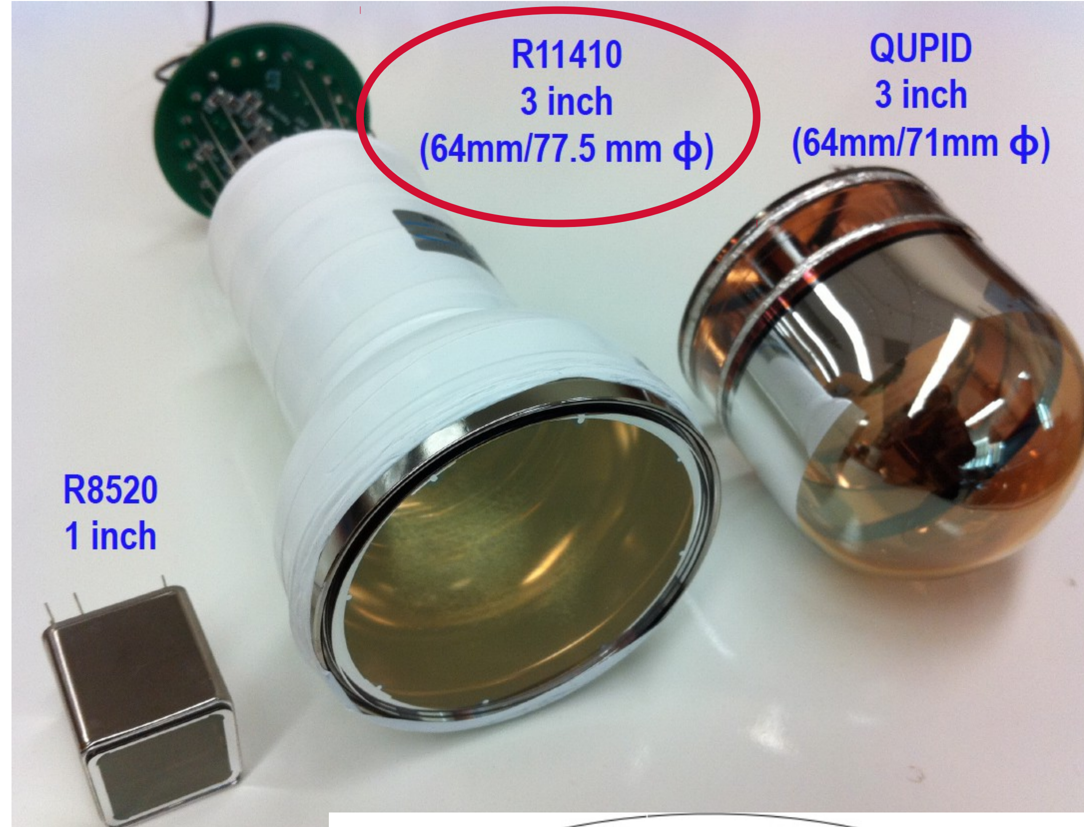


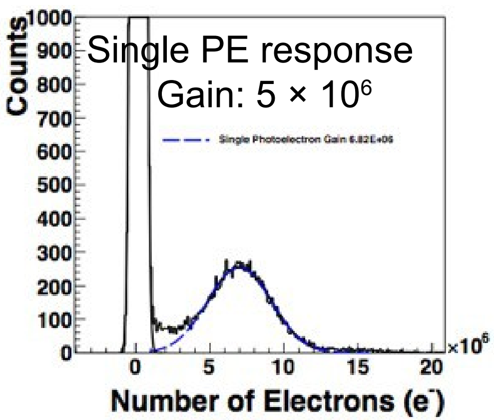
Columbia-Rice-UCLA-Zurich

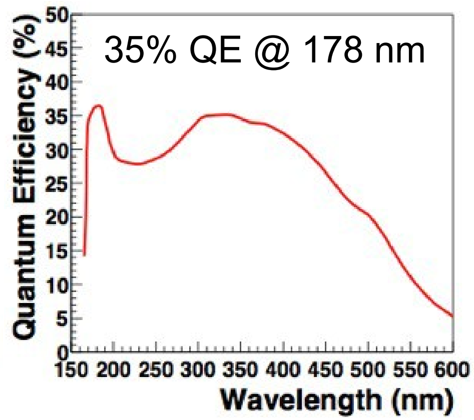
Uwe Oberlack

PMTs

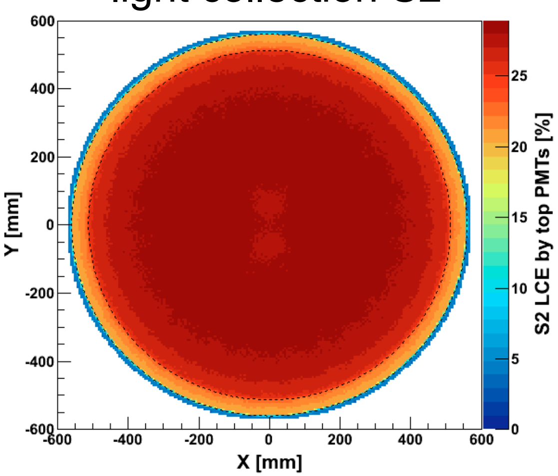
- 2 × 121 3” PMTs by Hamamatsu
- QE: 30% min., >35% achieved
- Ongoing screening program to further reduce radioactivity





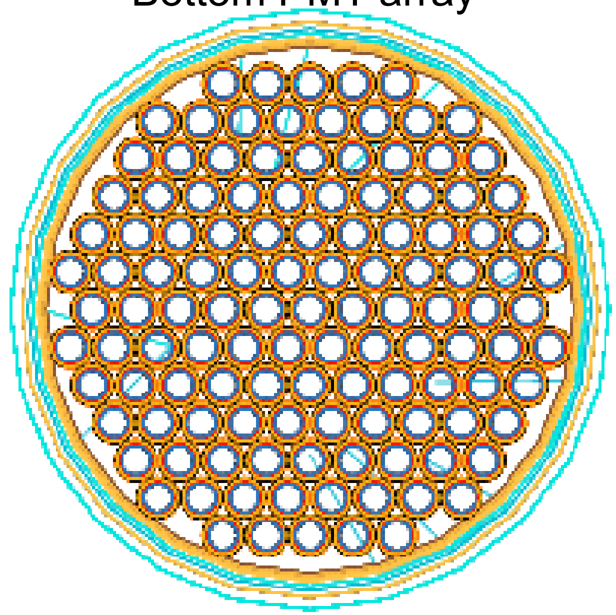


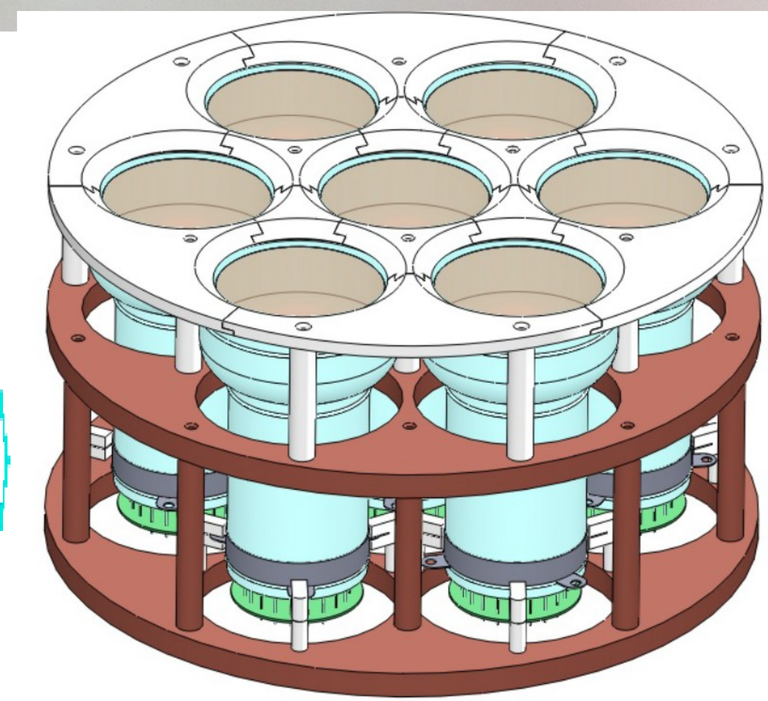
light collection S2



UCLA – Columbia – MPIK – Zurich

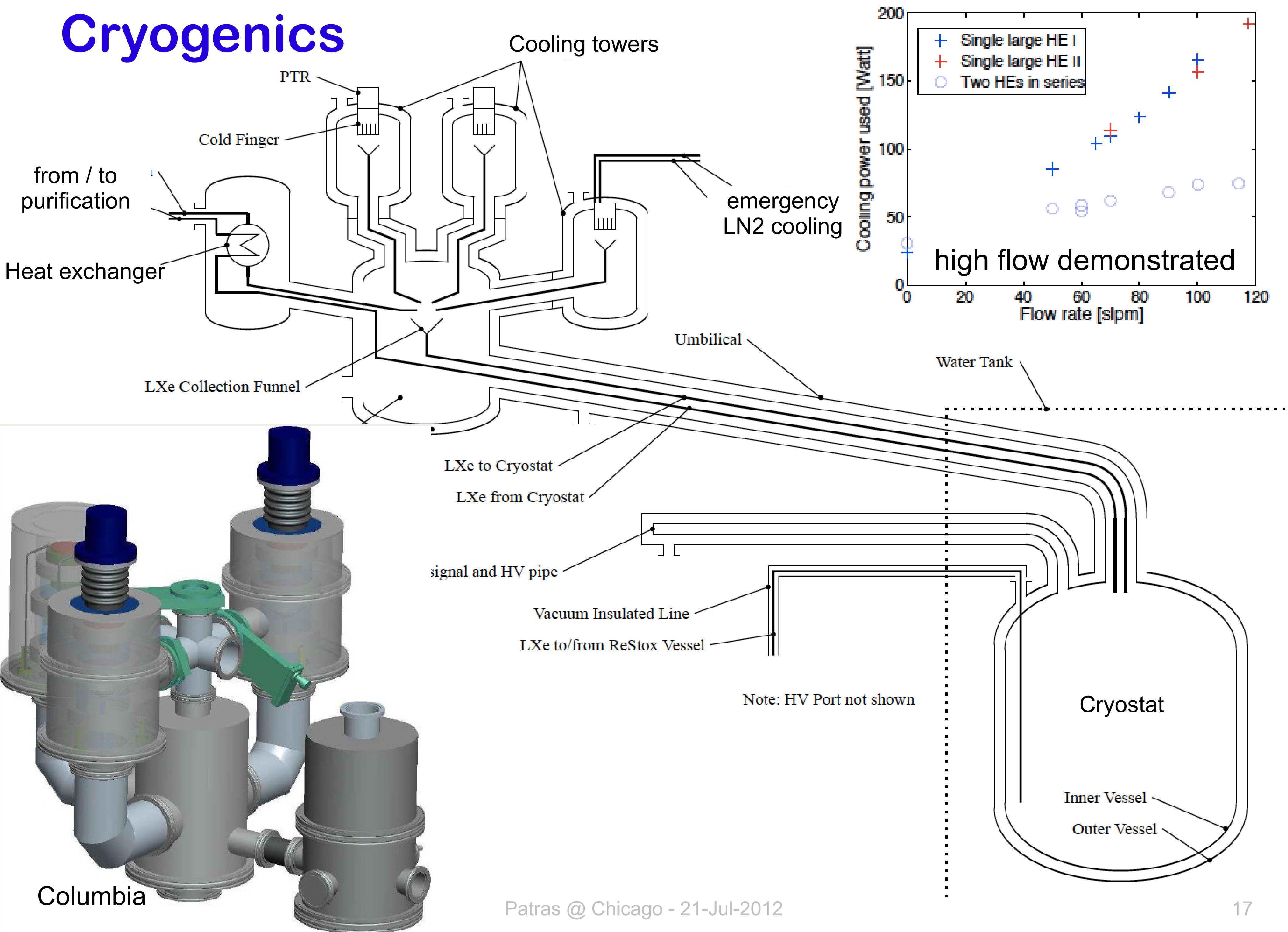
Bottom PMT array





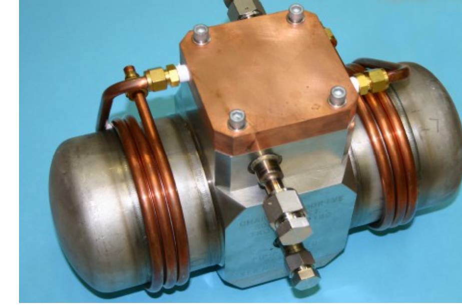
Prototype PMT mounting

Cryogenics



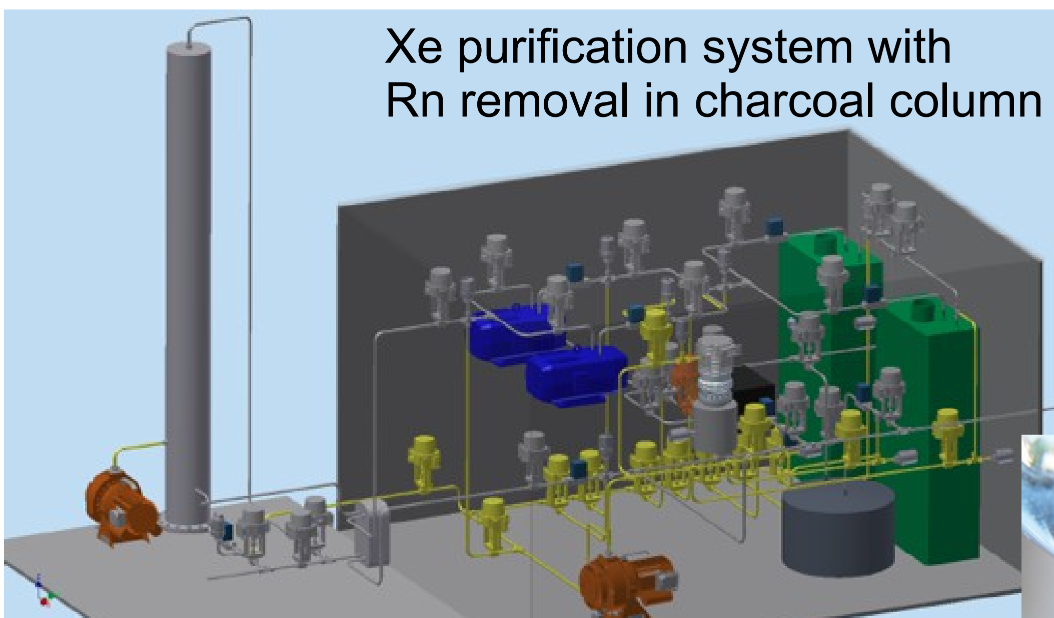
Cooling towers
PTR
Cold Finger
from / to purification
Heat exchanger
emergency LN2 cooling
Umbilical
Water Tank
LXe Collection Funnel
LXe to Cryostat
LXe from Cryostat
signal and HV pipe
Vacuum Insulated Line
LXe to/from ReStox Vessel
Note: HV Port not shown
Cryostat
Inner Vessel
Outer Vessel
Single large HE I
Single large HE II
Two HEs in series
Cooling power used [Watt]
Flow rate [slpm]
0
50
100
150
200
0
20
40
60
80
100
120
high flow demonstrated
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

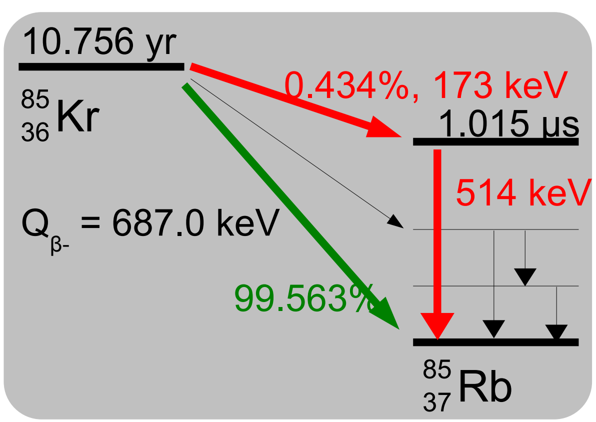
Münster (Xe purification) – MPIK (Rn column)

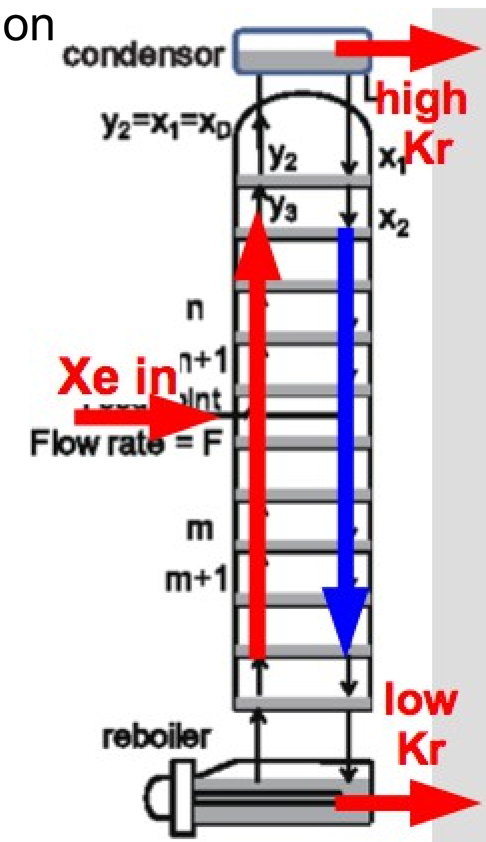
Krypton Removal

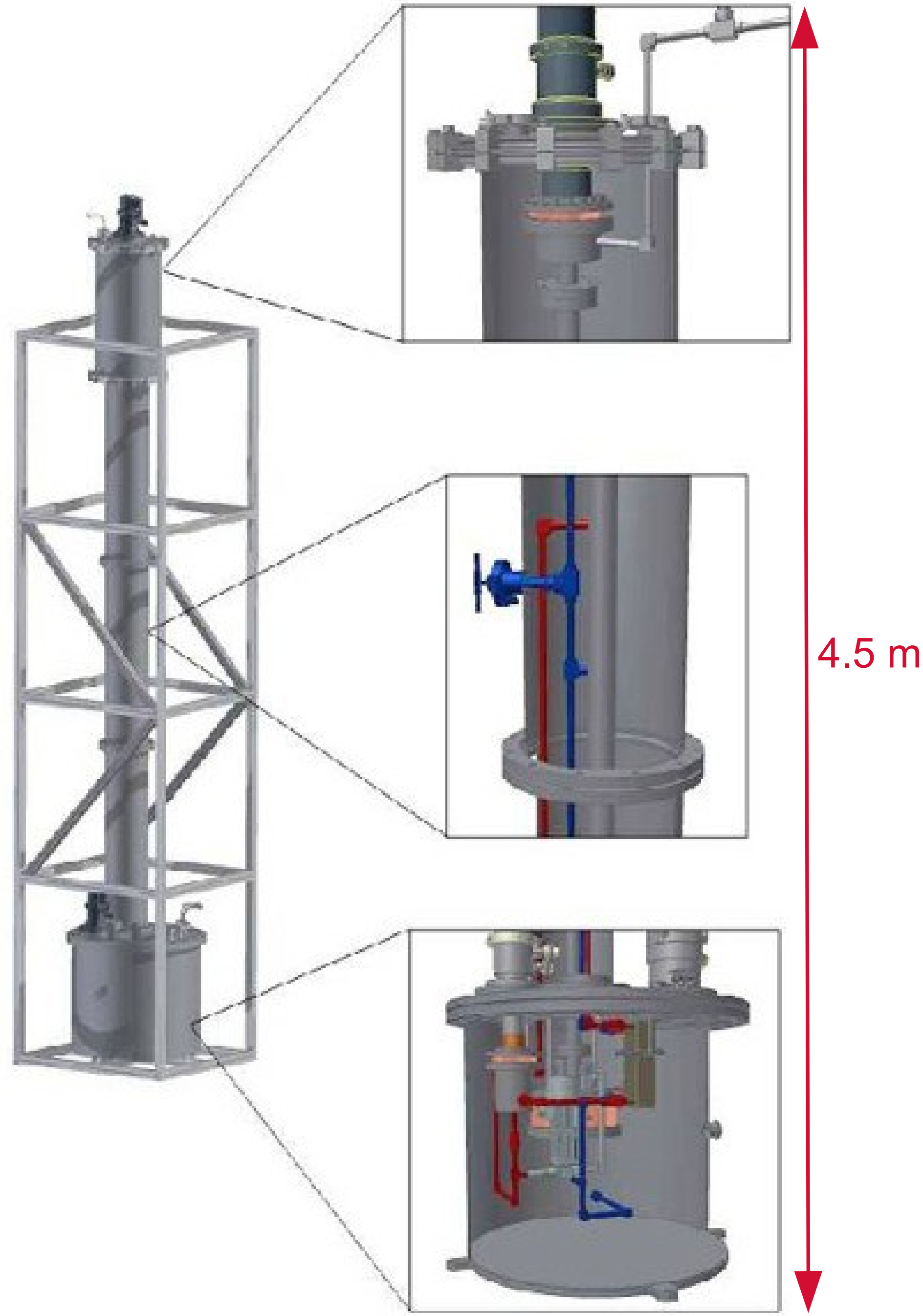
- Cryogenic distillation
- Reduce ppb Kr traces in Xe gas to ppt
- proven technique,
  achieved (19 +- 1) ppt in XENON100

Design Parameters for XENON1T

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

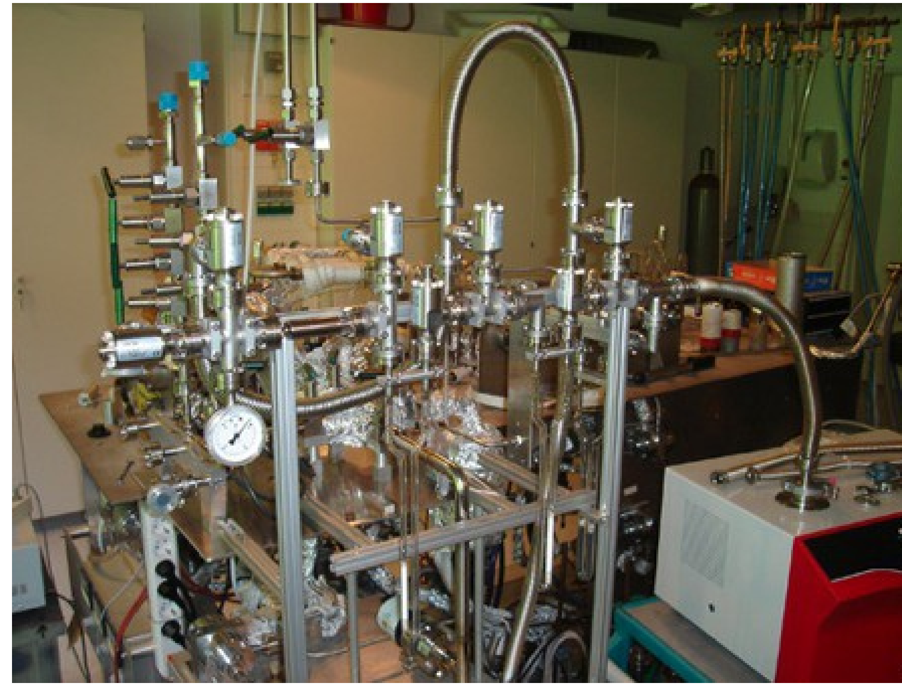




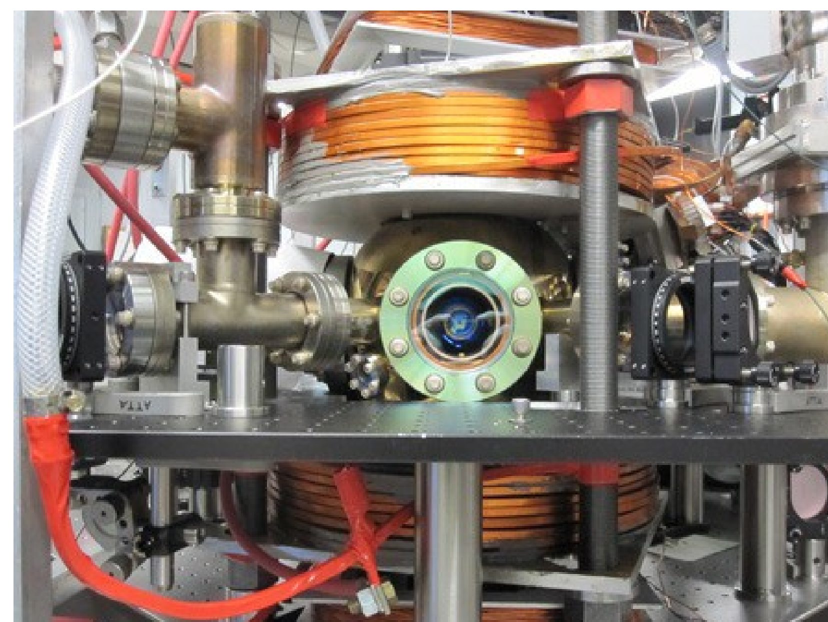


Münster

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

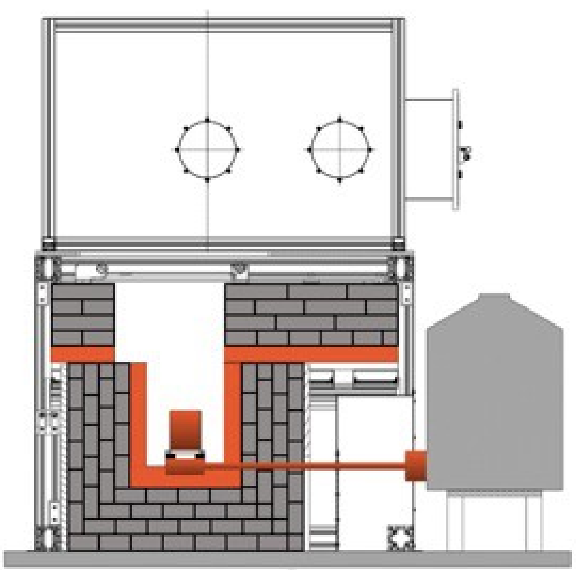


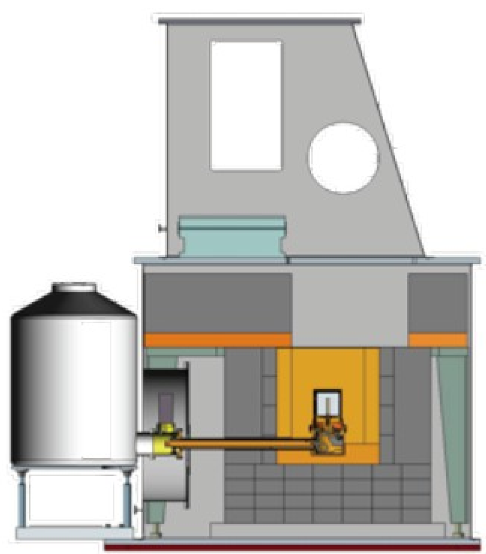
- ^{84}Kr measurement with atomic trap ATTA
  - →measurement of ^{84}Kr to ppt level
  - →extrapolation to ^{85}Kr from atmospheric abundance
  - →Atom trap operational and efficient for Ar*
  - →First Kr/Xe measurements for XENON100 by Fall 2012

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

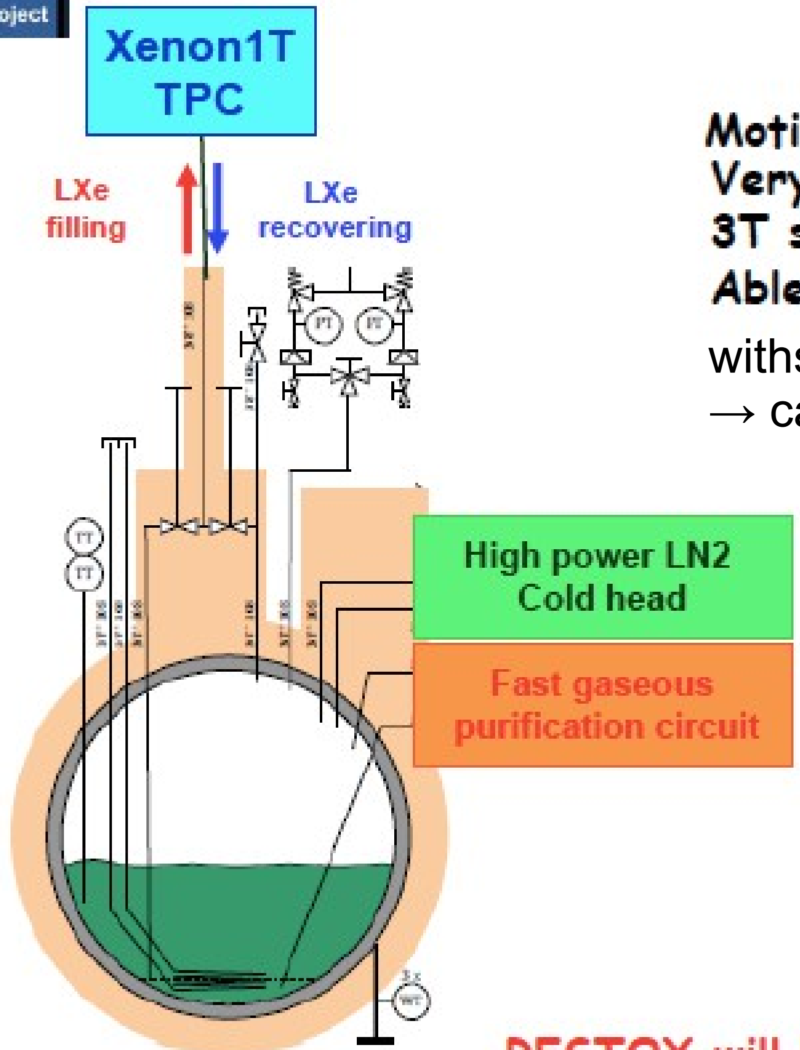




MPIK – Zurich

Xenon Storage

RESTOX : A Liquid Xenon station
(REcovering and STOrage system of Xenon1T)



Motivations :
Very compact station
3T storage capacity from 20°to -108°C
Able to keep high purity all the time

withstands 65 bar
→ can also keep Xe at room temperature

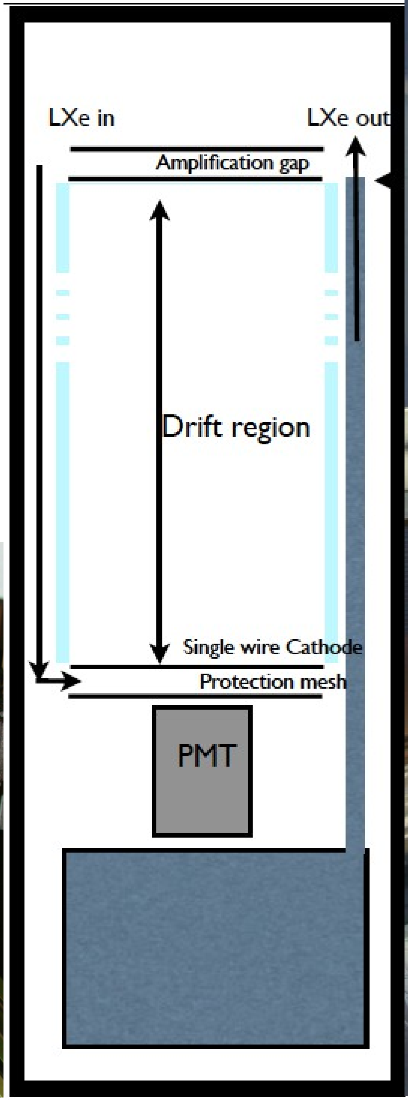
Time schedule:
Construction will start in summer 2012
Installation for end of 2013

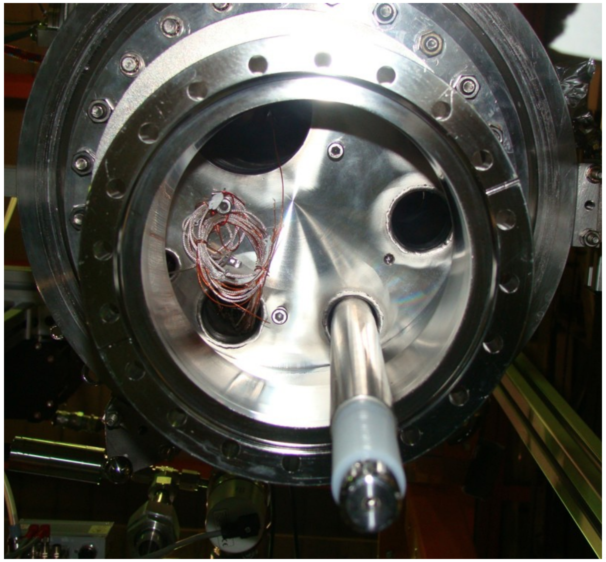
RESTOX will be easily scalable to larger sizes

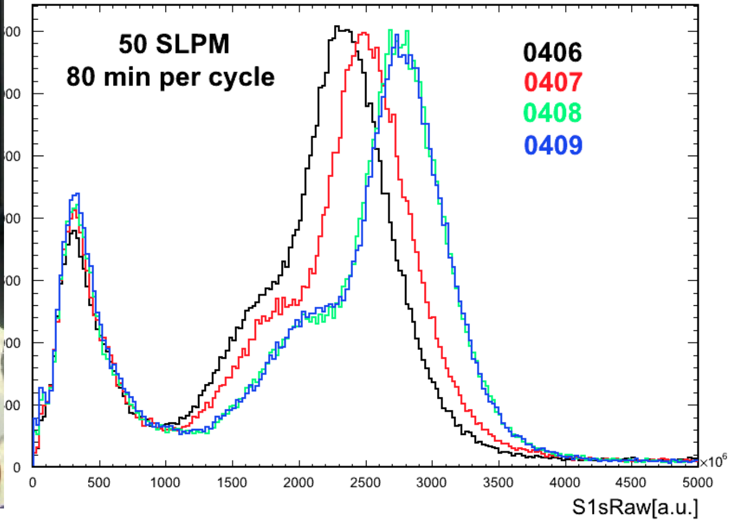
Subatech

XENON1T Demonstrator

- XENON purification and heat exchange at 100 slpm
- Verification of cooling concept
- Cathode HV tests: grid+feed-through goal: -100 kV
- Electron lifetime demonstrated. Next: 1 m drift

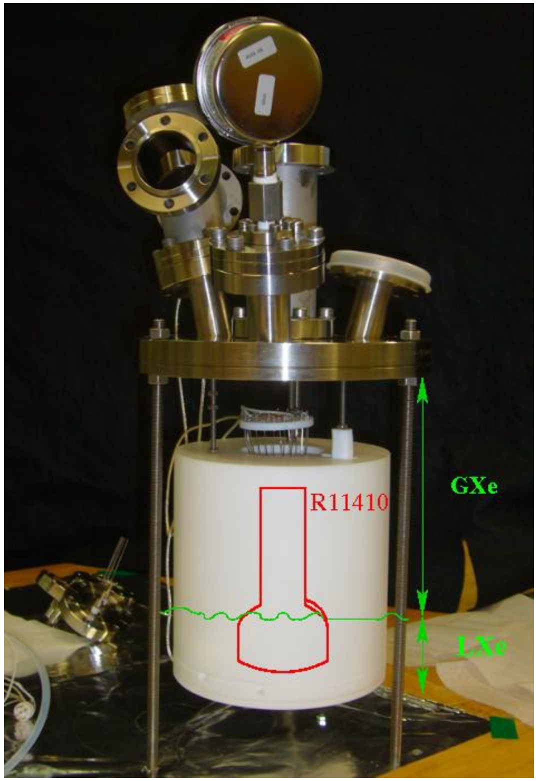


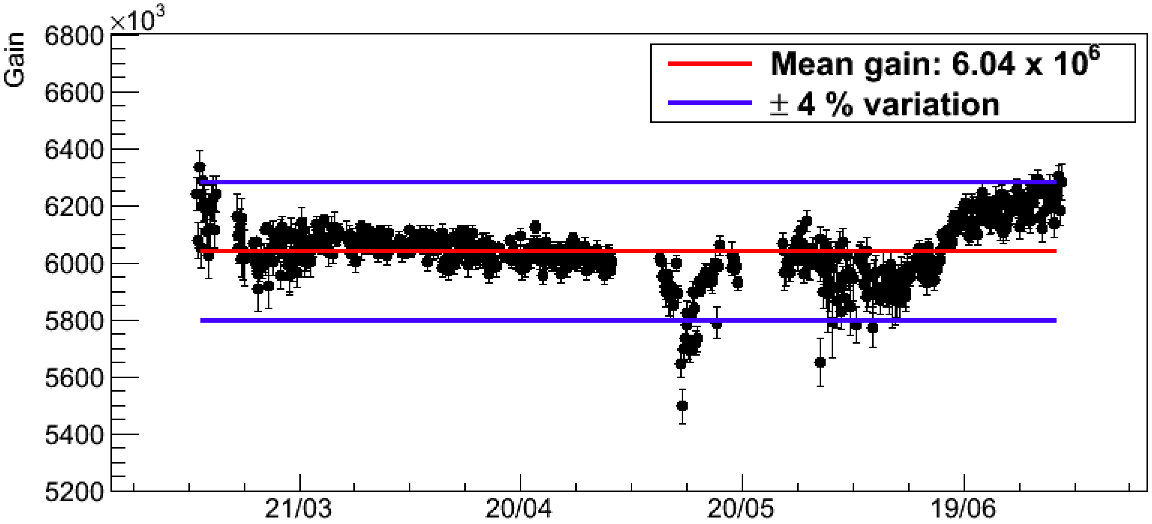




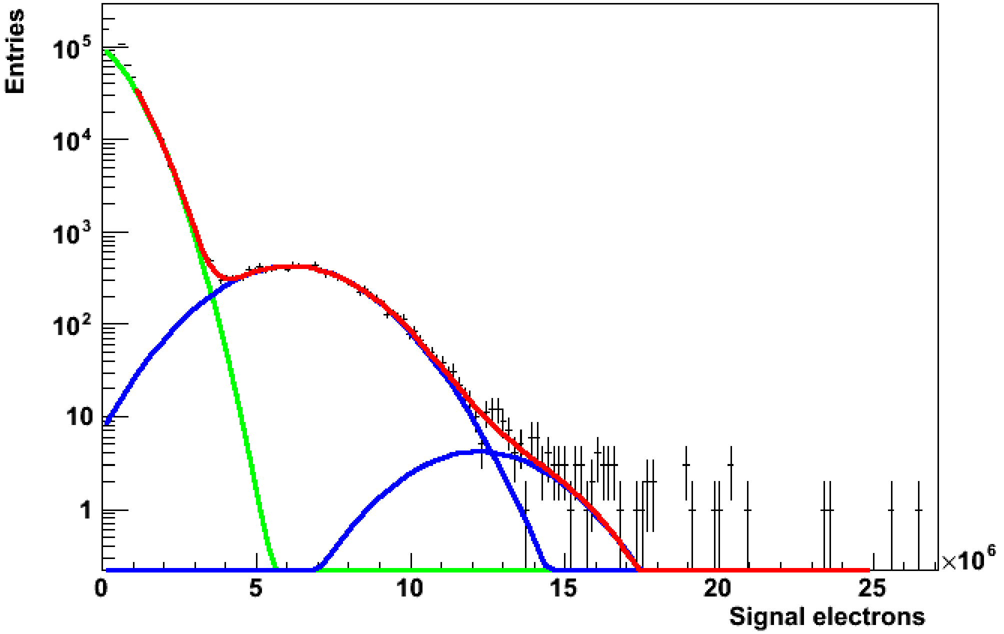
PMT Stability Tests

- Stable operation in liquid and gaseous Xe over 5 months
  - →Blue LED for SPE
  - →PMT @ –1 600V
  - →T = 171 K
  - →P = 1.4 bar





Single PE response



Zurich

DARWIN

Dark Matter WIMP Search with Noble Liquids

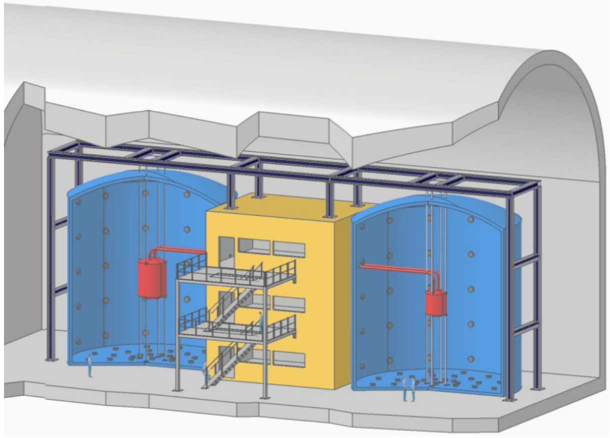
R&D and design study for a next-generation noble liquid facility in Europe

25 groups from ArDM, DarkSide, WARP, XENON

Europe: UZH, INFN, ETHZ, Subatech, Mainz, MPIK, Münster, Nikhef, KIT, TU Dresden, Israel: WIS, USA: Columbia, Princeton, UCLA, Arizona SU

similar effort in the US: MAX

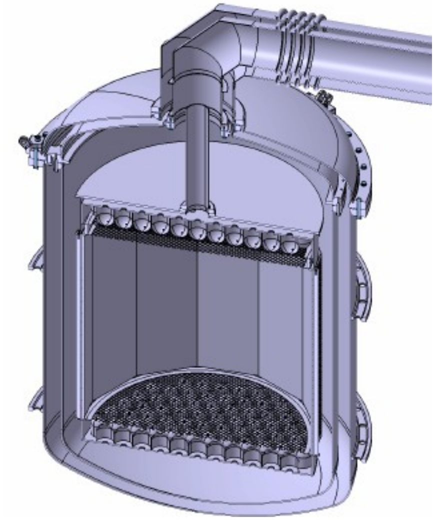
Evolution LAr / LXe TPC's



XENON10:
14 kg (5.4 f d)

XENON100:
161 kg (62 f d.)

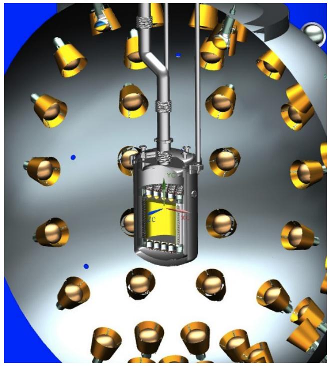
XENON1t:
2.4 t (1 t f d)



DARWIN:
20 tons LXe/LAr (10 t f d)
(indicative masses*)

WARP: 2.3 l

WARP:
140 kg



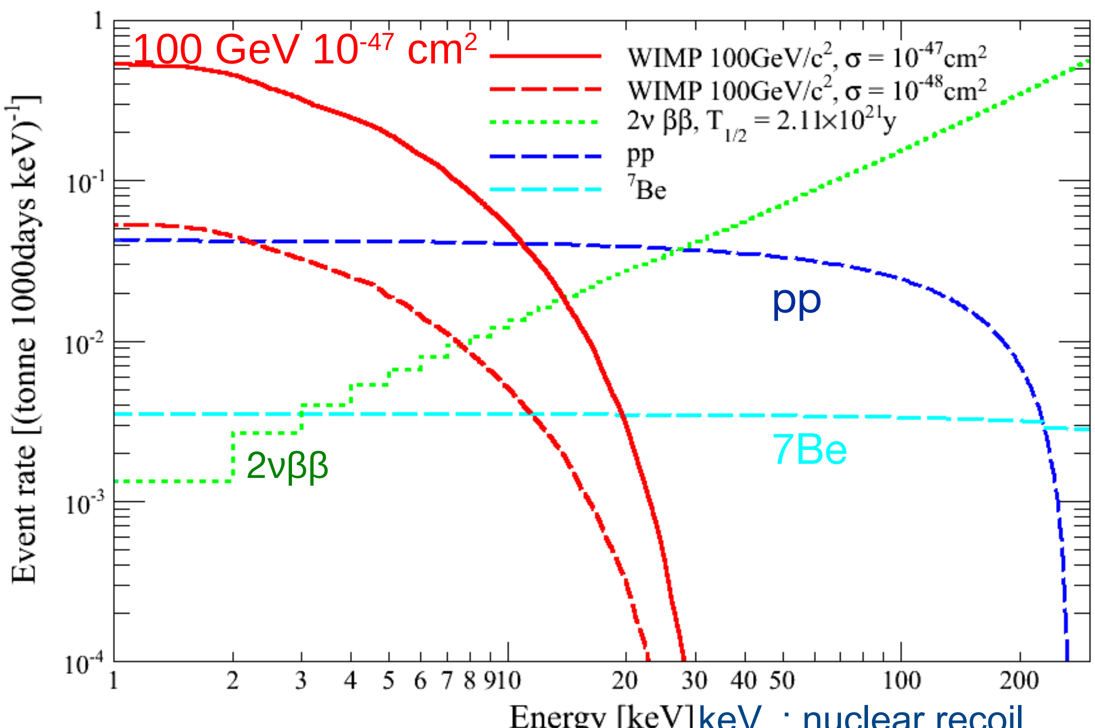
DarkSide:
55 kg (33 f d.)

ArDM: 850 kg

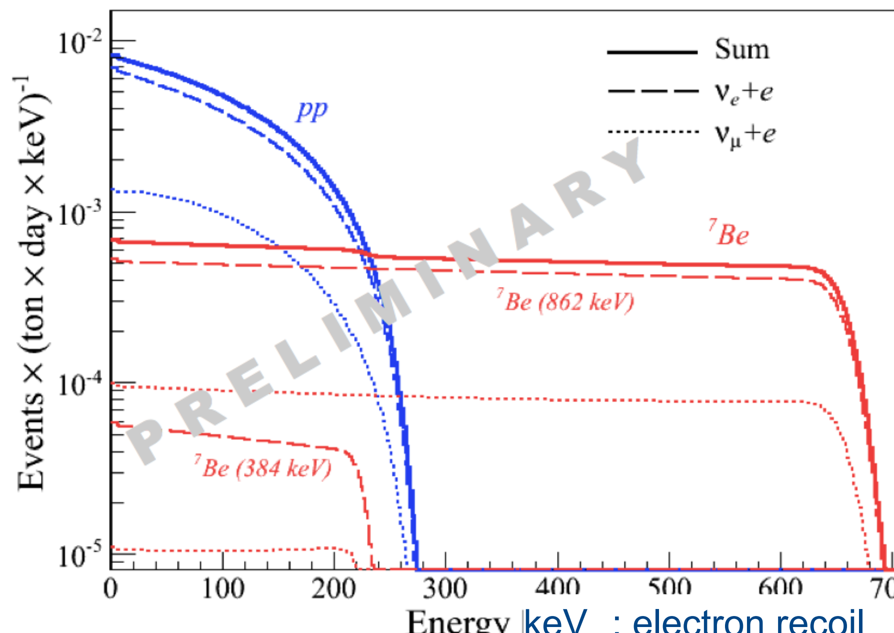
(*optimal masses for LAr/LXe to be determined in the study;
here MC sketch)

DARWIN physics

- Measurement of dark matter properties
  → ultimate WIMP limit around 10^{-48} cm^2
- Measurement of pp-neutrinos
  → with 10 t of LXe about 4000 neutrinos per year
- ^{85}Kr (^{nat}Kr < 0.1 ppt) and ^{222}Rn < 0.1 µBq/kg required



keV$_{nr}$: nuclear recoil energy scale



keV$_{ee}$: electron recoil energy scale

neutrino-electron scattering

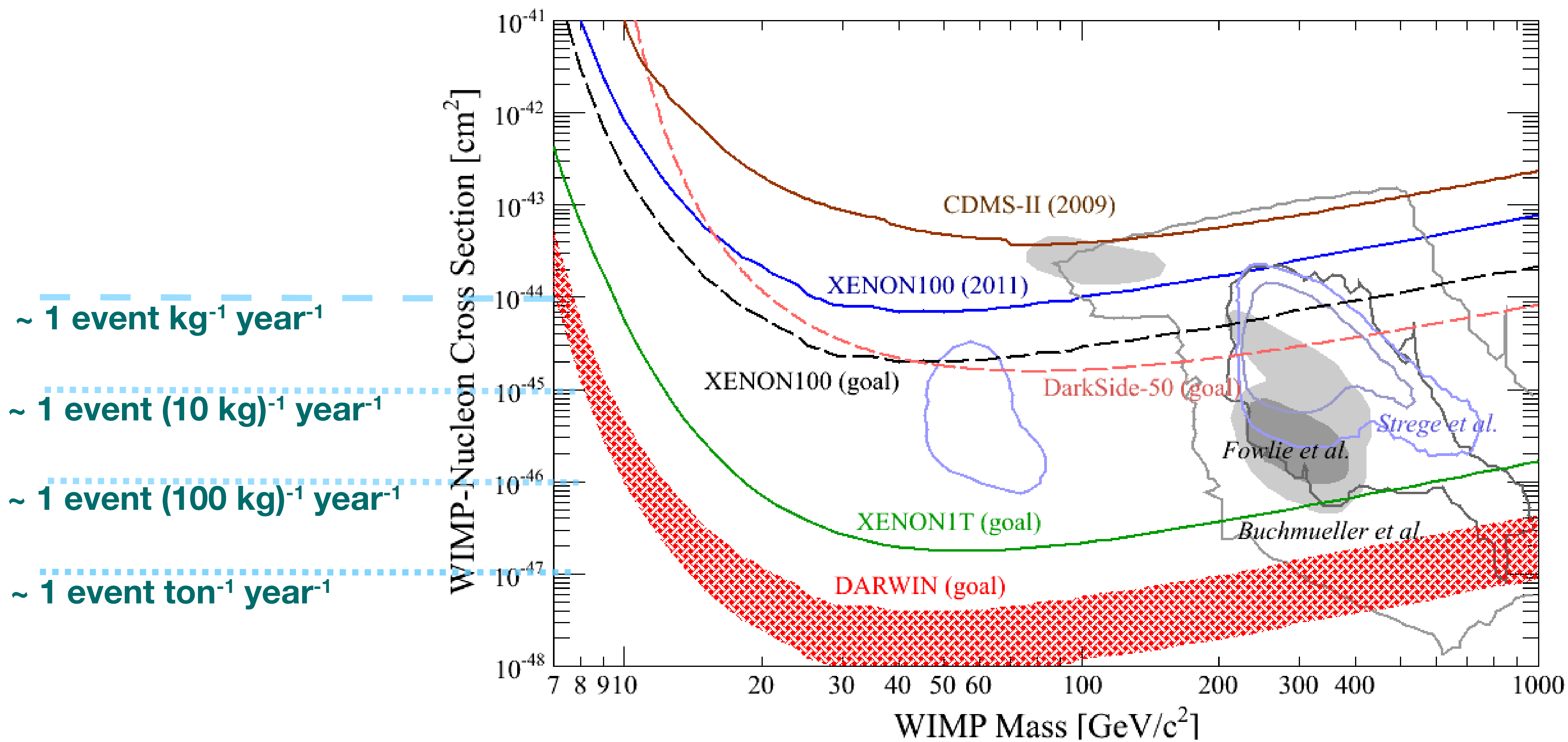
2νββ: EXO measurement of ^{136}Xe $T_{1/2}$

Assumptions: 50% NR acceptance, 99.5% ER discrimination, 80% flat cut acceptance.

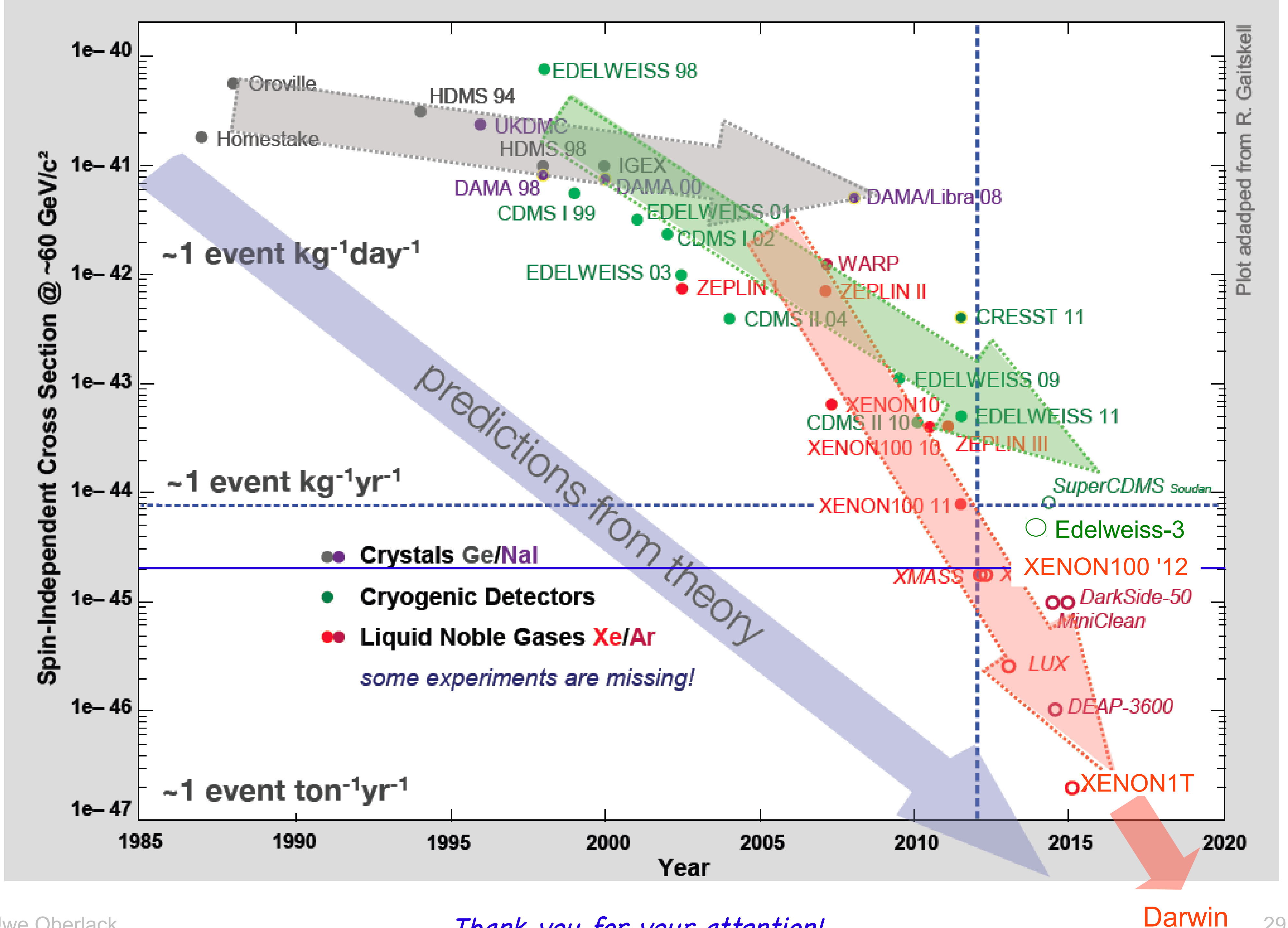
2νββ background can be reduced by using depleted xenon.

Expected sensitivity

Goal is not exclusion limits, but WIMP detection!



Outlook



Thank you for your attention!