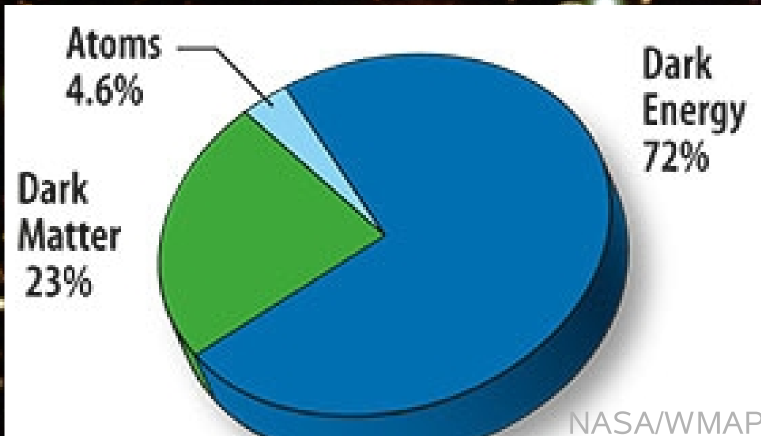
XENON – Results and Prospects

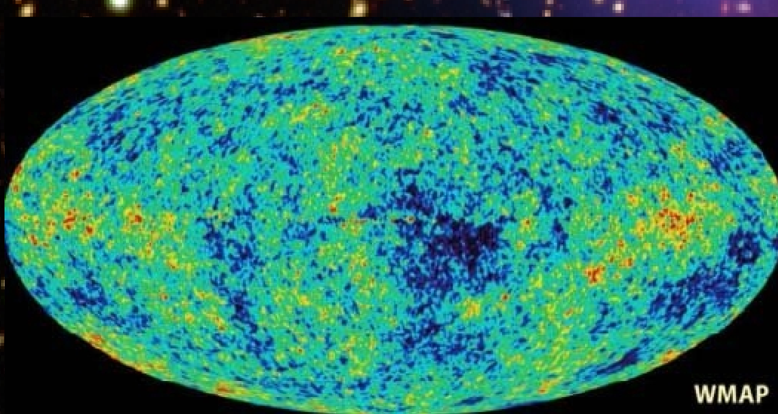
Marc Schumann *Physik Institut, Universität Zürich*

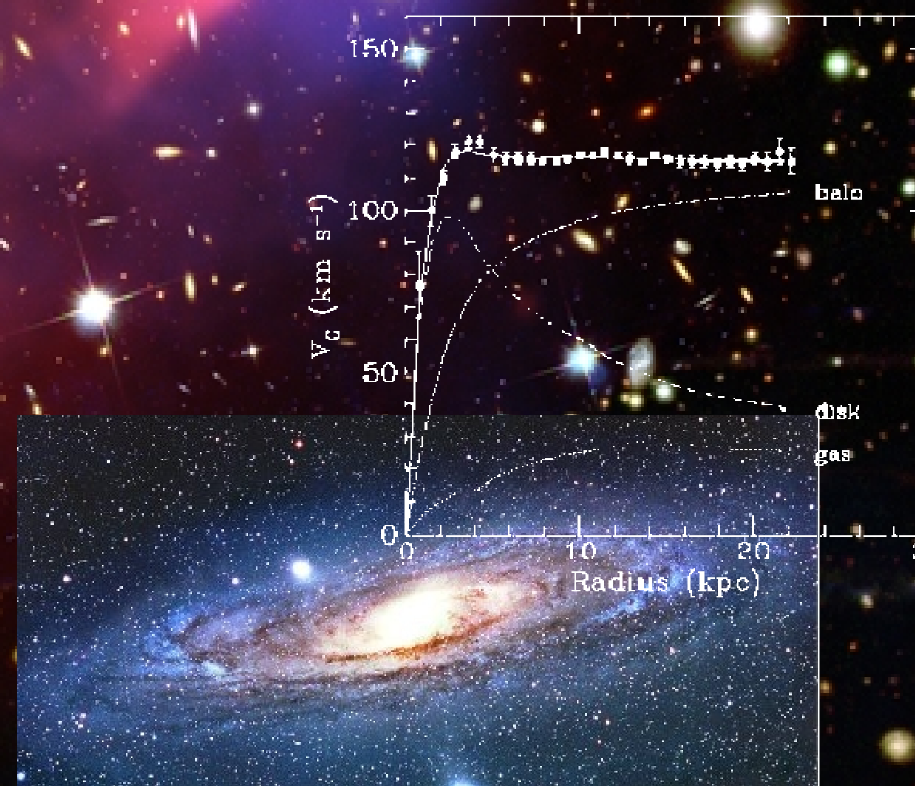
TPC 2010, Paris, December 15th, 2010

www.physik.uzh.ch/groups/groupbaudis/xenon/

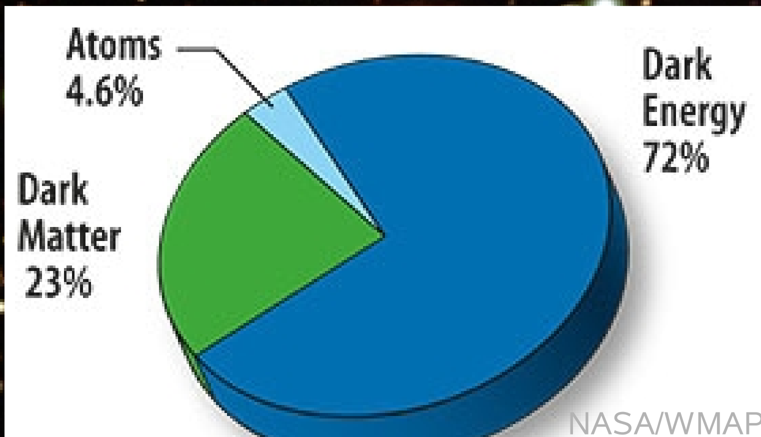
Dark Matter: (indirect) **Evidence**





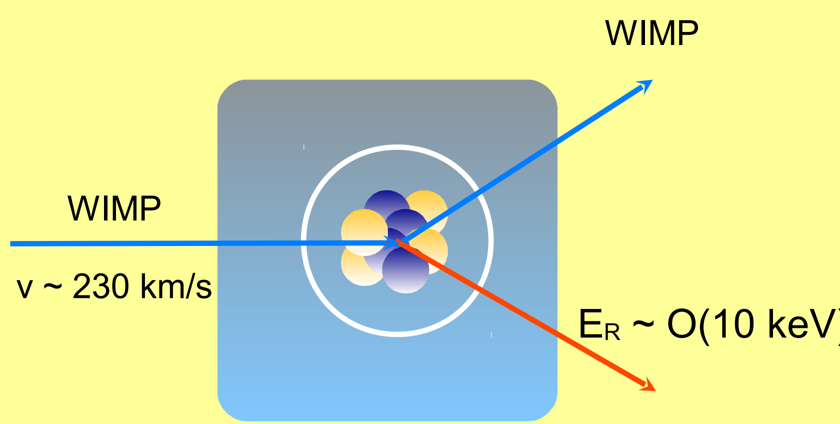


Dark Matter: (indirect) Evidence

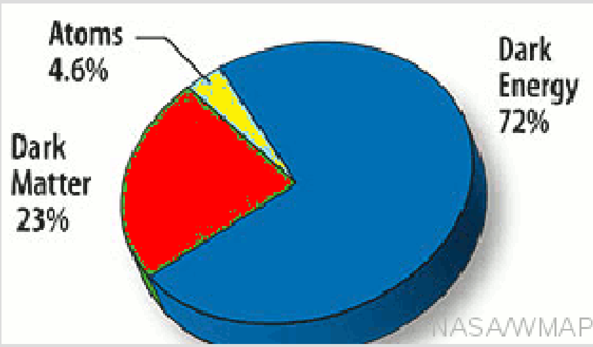


Direct Detection:

Elastic Scattering of WIMPs off target nuclei
→ nuclear recoil



Direct WIMP Detection



COUPP
PICASSO

Tracking:
Drift, DM-TPC

Phonons

CDMS
EDELWEISS

CRESST
ROSEBUD

Charge

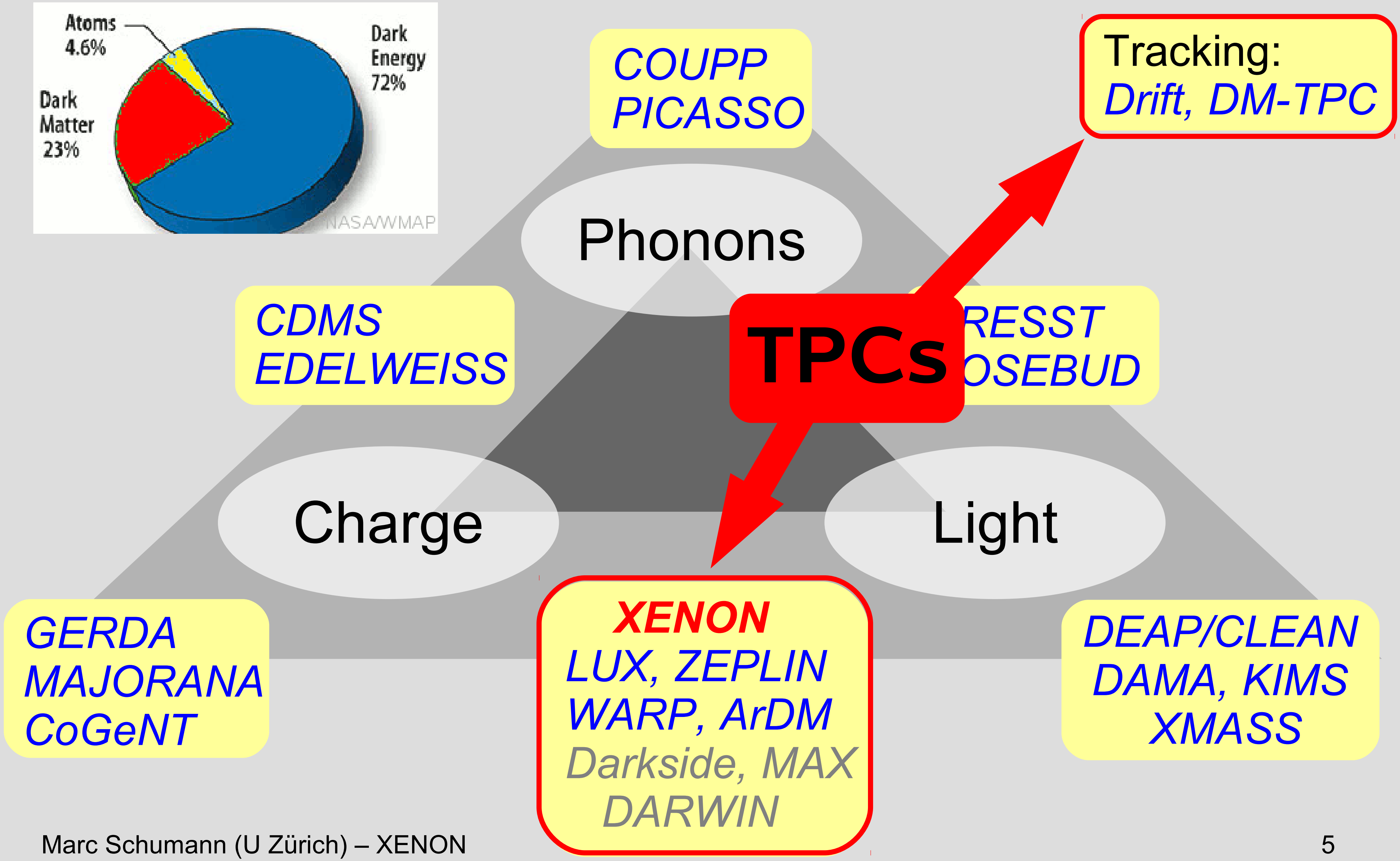
Light

GERDA
MAJORANA
CoGeNT

XENON
LUX, ZEPLIN
WARP, ArDM
Darkside, MAX
DARWIN

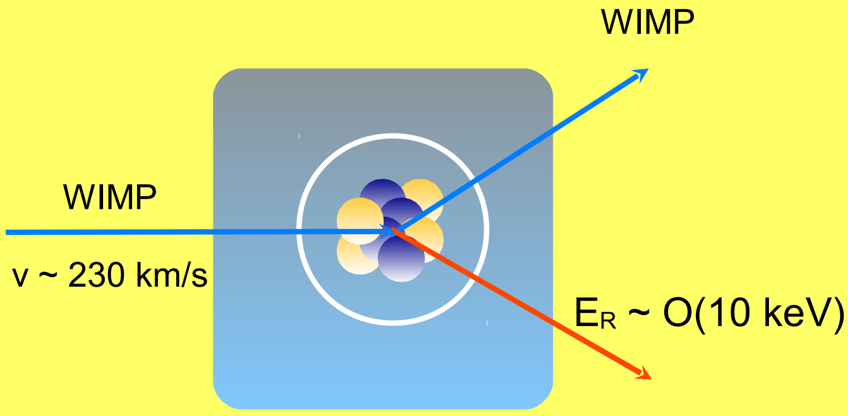
DEAP/CLEAN
DAMA, KIMS
XMASS

Direct WIMP Detection



Direct WIMP Search

Elastic Scattering of WIMPs off target nuclei
→ nuclear recoil



Recoil Energy: $$E_r = \frac{|\vec{q}|^2}{2m_N} = \frac{\mu^2 v^2}{m_N}(1 - \cos\theta) \sim \mathcal{O}(10 \text{ keV})$$

Event Rate: $$R \propto N \frac{\rho_\chi}{m_\chi} \langle \sigma_{\chi - N} \rangle$$

N	number of target nuclei
ρ_χ/m_χ	local WIMP density
$<\sigma>$	velocity-averaged scatt. X-section

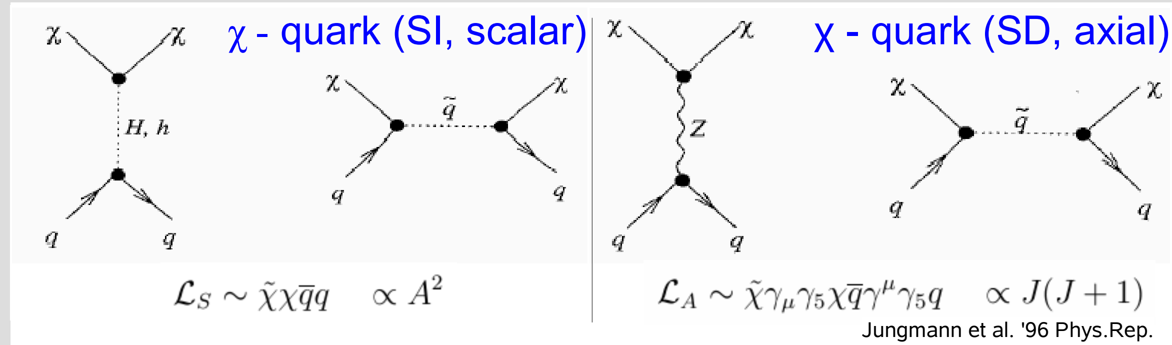
→ need information on halo and interaction to get rate

WIMP Interactions
Detector Requirements

XENON Dark Matter Project

Result: Tiny Rates

$R < 0.01$ evt/kg/day
$E_r < 100$ keV

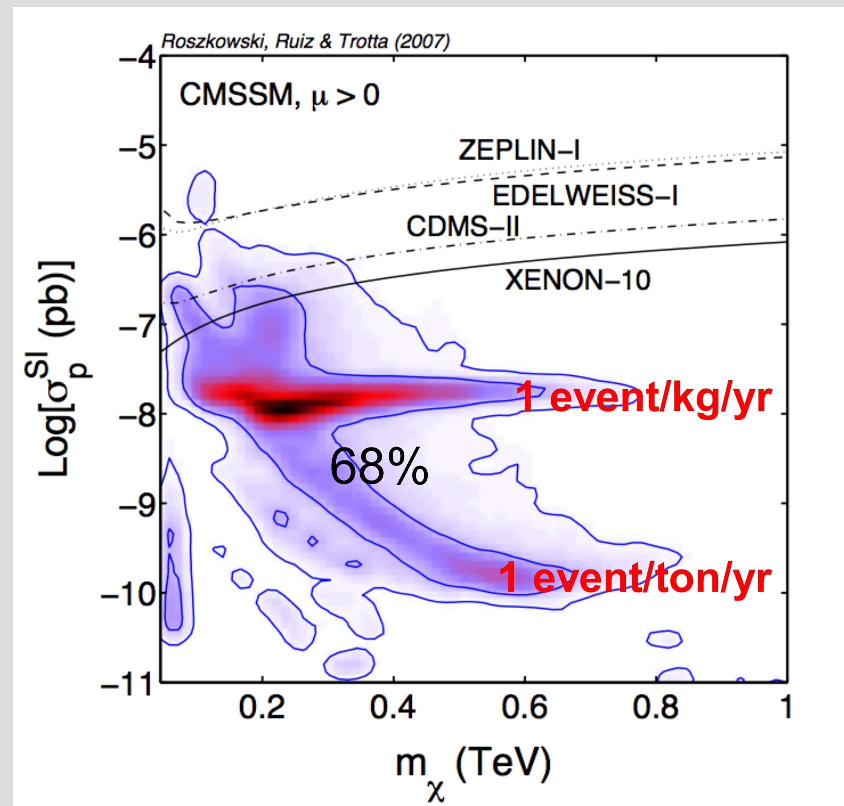


What do we look for?

- nuclear recoils, single scatters
- recoil spectrum falls with *E*
- dependence on *A*, spin?
- annual flux modulation?
- other possibilities? iDM, ...?

How to build a WIMP detector?

- large total mass, high *A*
- low energy threshold
- ultra low background
- good background discrimination



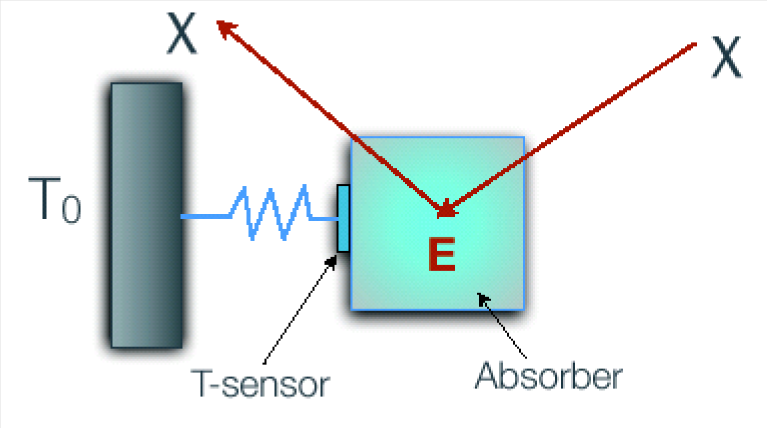
Outline

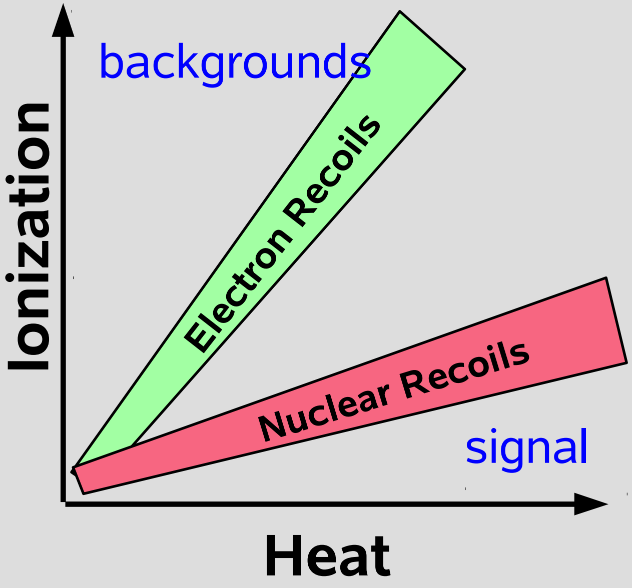
- Motivation: Dark Matter ✓
- Direct Dark Matter Detection ✓
- Some Recent Results
- XENON100
- The Future

CDMS: Cryogenic Detectors

Located underground in Soudan Lab, Minnesota (USA)

Principle: measure charge and heat (phonons)
a deposited energy *E* produces temperature rise *ΔT*





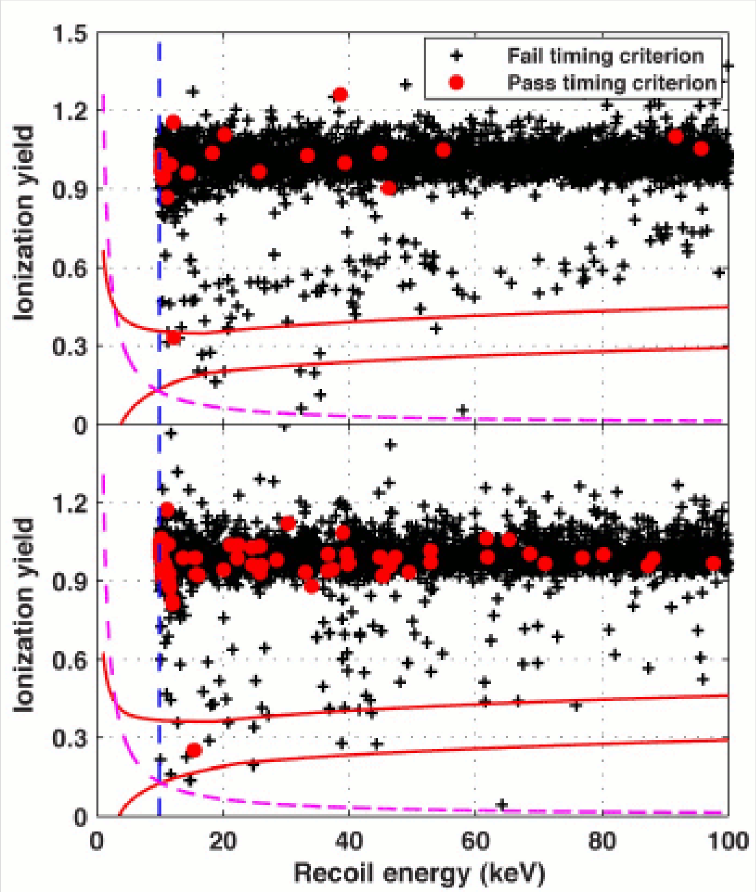
Crystals: Ge, Si cooled to few mK
➡ low heat capacity
➡ measurable µK temperature!

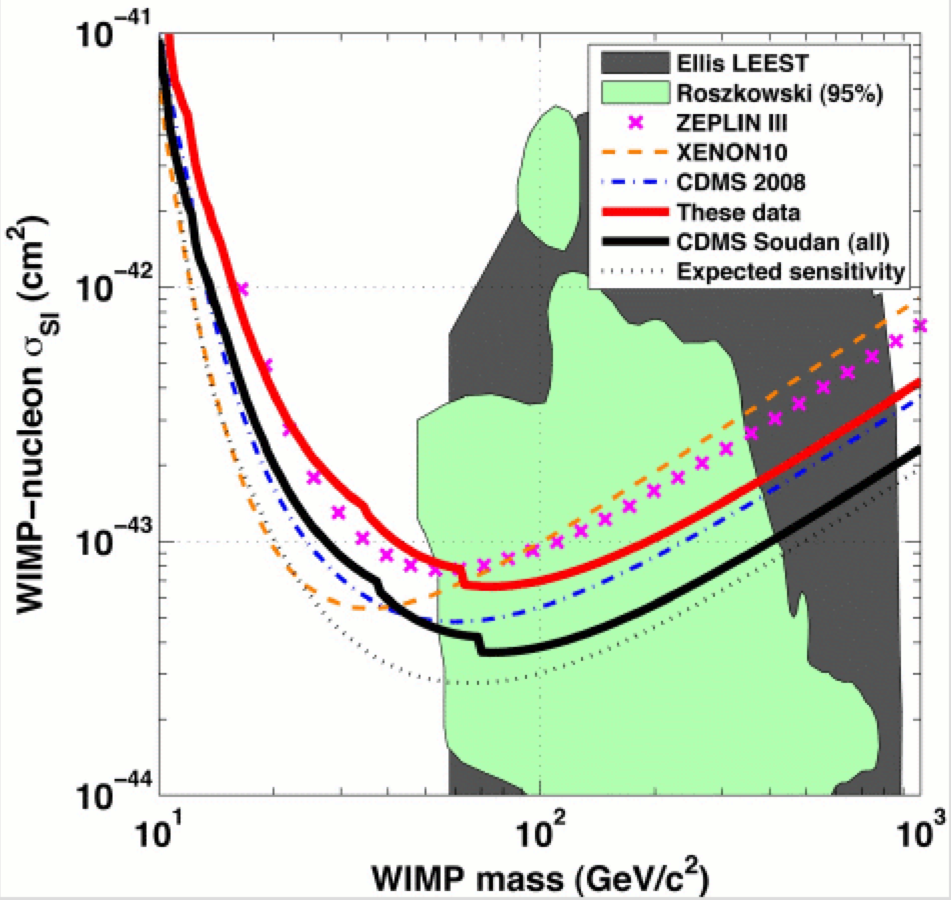
good discrimination
→ „backgound-free experiment“
→ BUT: reject surface events via PSA

similar: CRESST, EDELWEISS, Rosebud

The latest CDMS Result

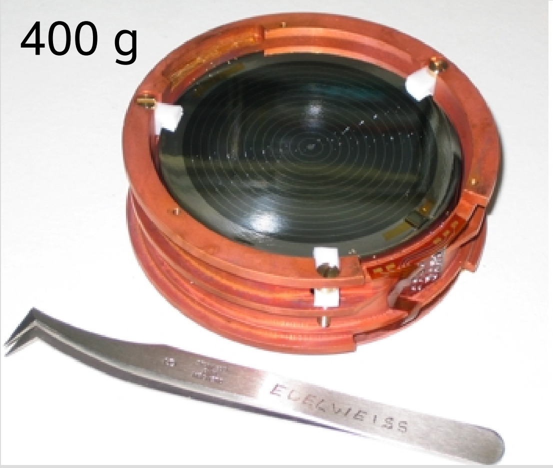
Science 327, 1619 (2010)

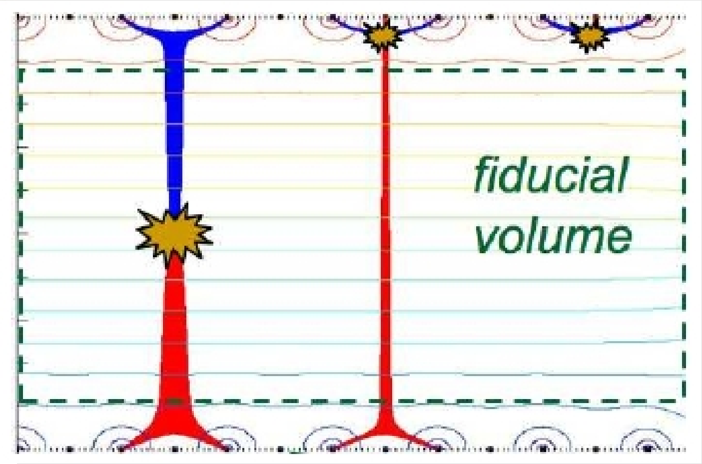




- 2 events remain after all cuts after un-blinding
- Background expection: 0.9 $\pm$ 0.2 events
- probability for 2 or more events: 23%

EDELWEISS-II



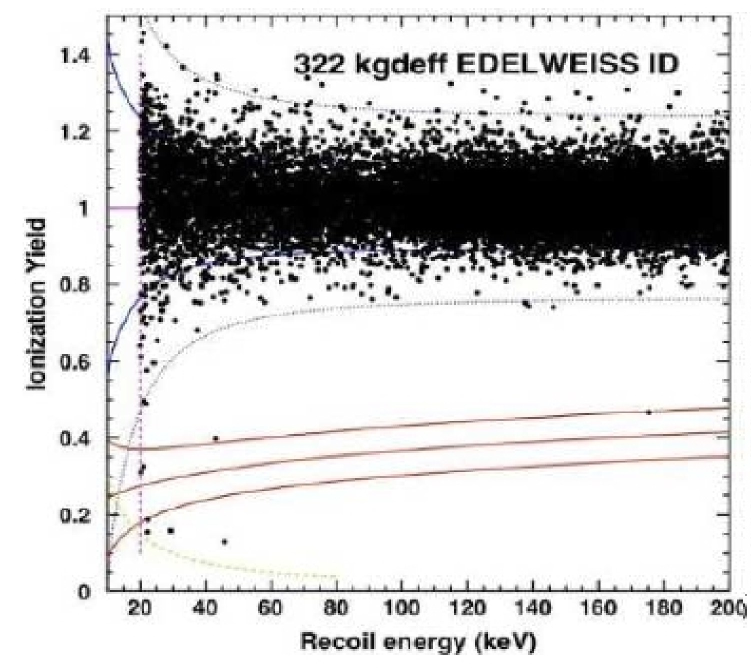


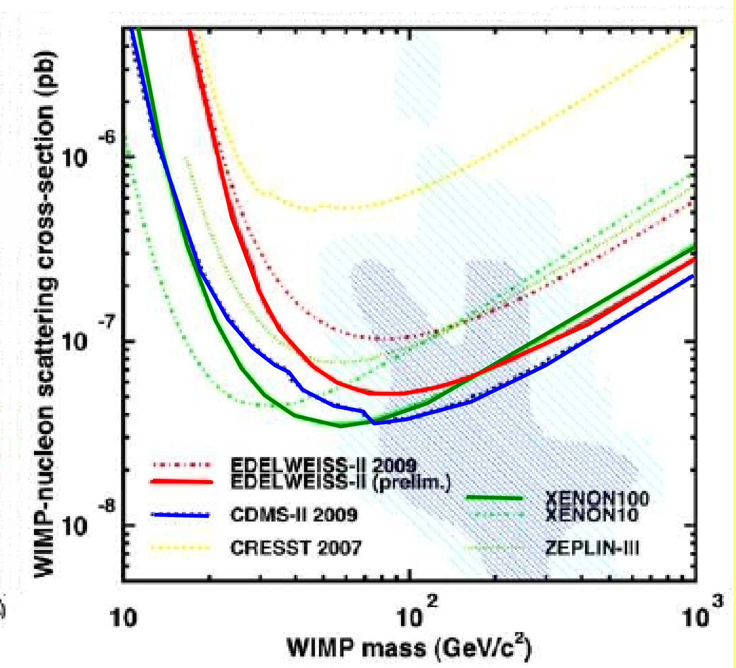
Cryogenic Germanium experiment located at LSM

InterDigit Electrodes allow fiducialization and surface rejection

New preliminary Result:

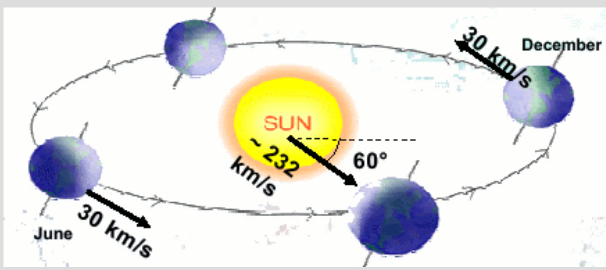
- 322 kg × days
- 5×10^{-44} @ 80 GeV/c^2
- Background starts to show up: 4 events in NR band, 1.9 expected @ 90%CL
- *arxiv:1011.2319*





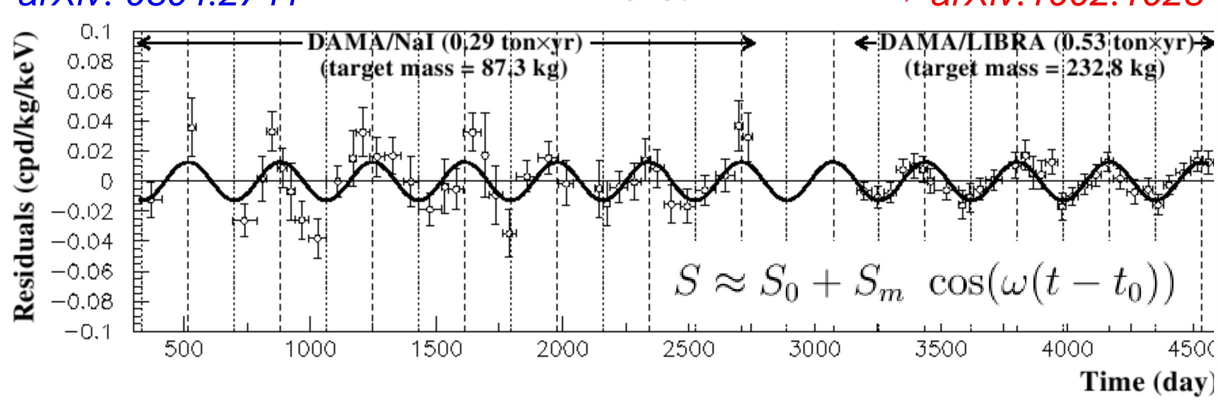
The DAMA Observation

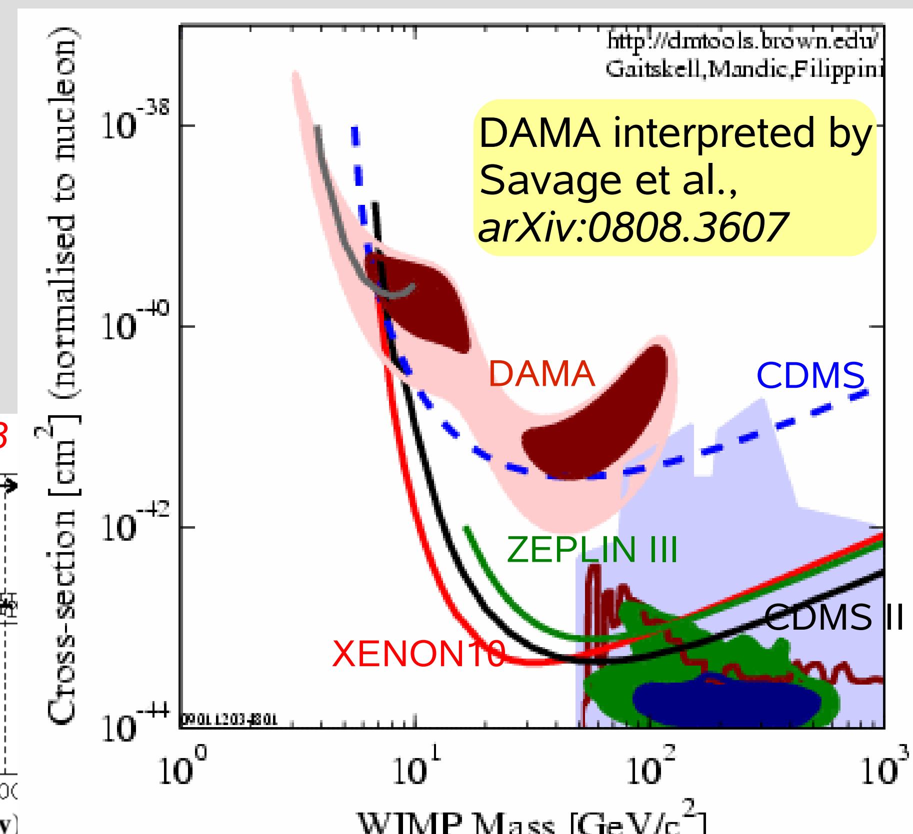
- DAMA: PMTs coupled to NaI Scintillators
  → extremely clean background necessary
- looks for annual modulation @ LNGS
- large mass and exposure: 0.82 ton years



- DAMA finds annual modulation @ 8.9σ C.L.
- BUT: result cannot be explained with standard neutralinos or KK Dark Matter, result in conflict with other experiments

arXiv: 0804:2741 2-6 keV *→ arXiv:1002.1028*

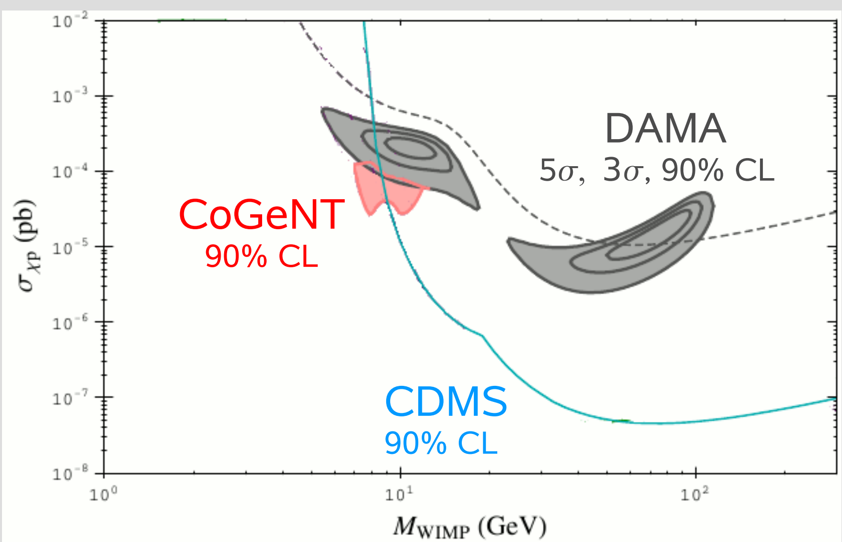


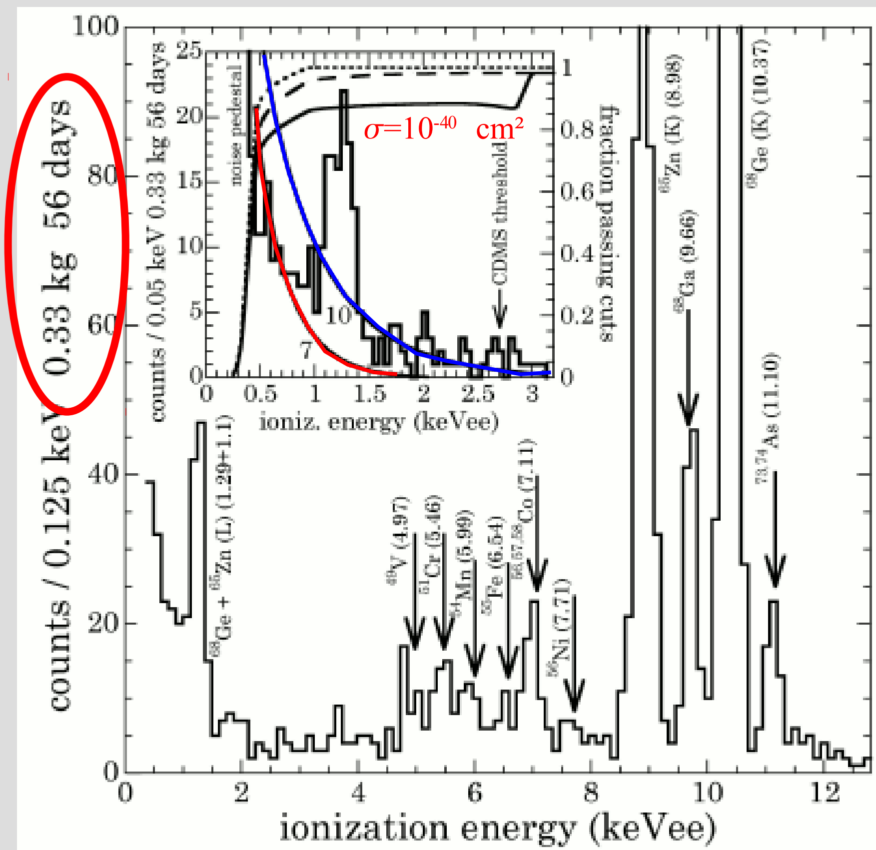


CoGeNT

arXiv:1002.4703

- CoGeNT: p-type point contact Ge-detector, ultra low noise
- prototype for MAJORANA, operated underground at Soudan
- very low threshold: 0.4 keVee (electronic noise)
- only one observable (charge), some pulse shape discrimination
- Excess at lowest energies
  → light mass WIMP claim
  (BUT: null hypothesis has similar χ^2)





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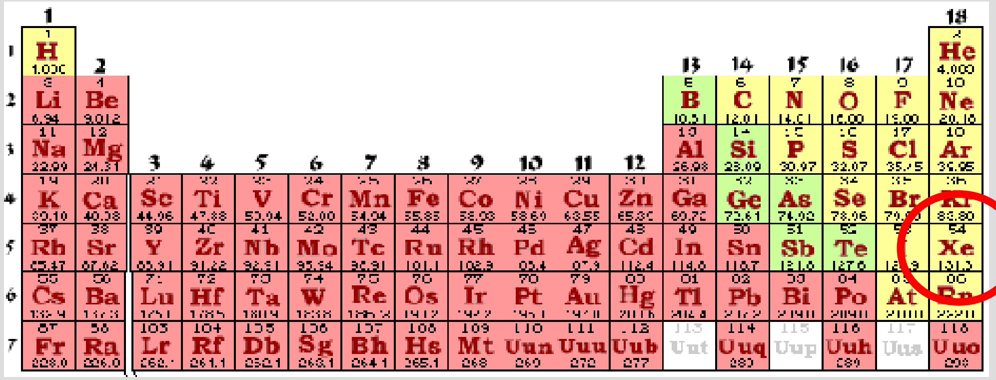
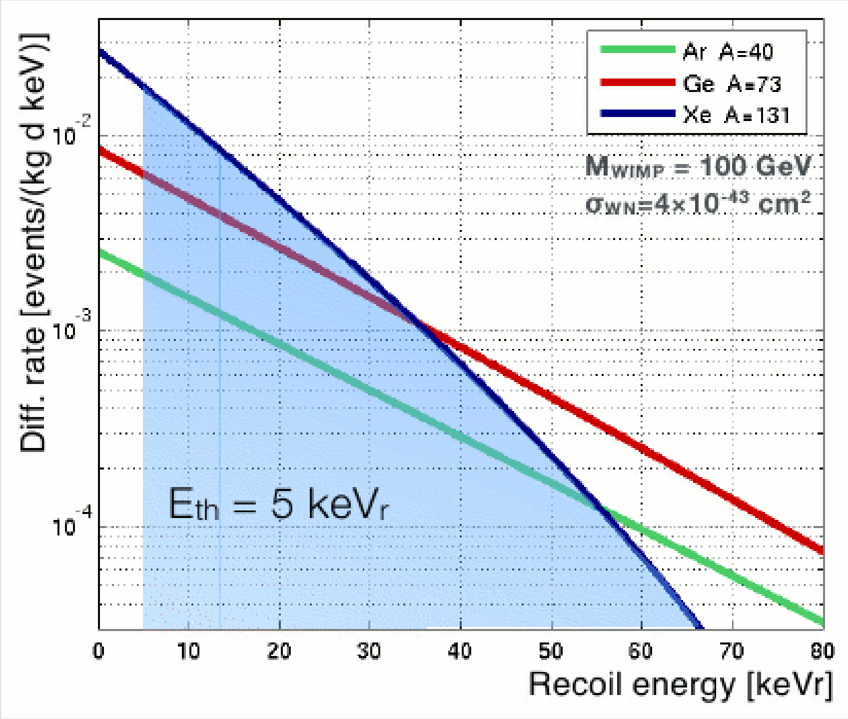
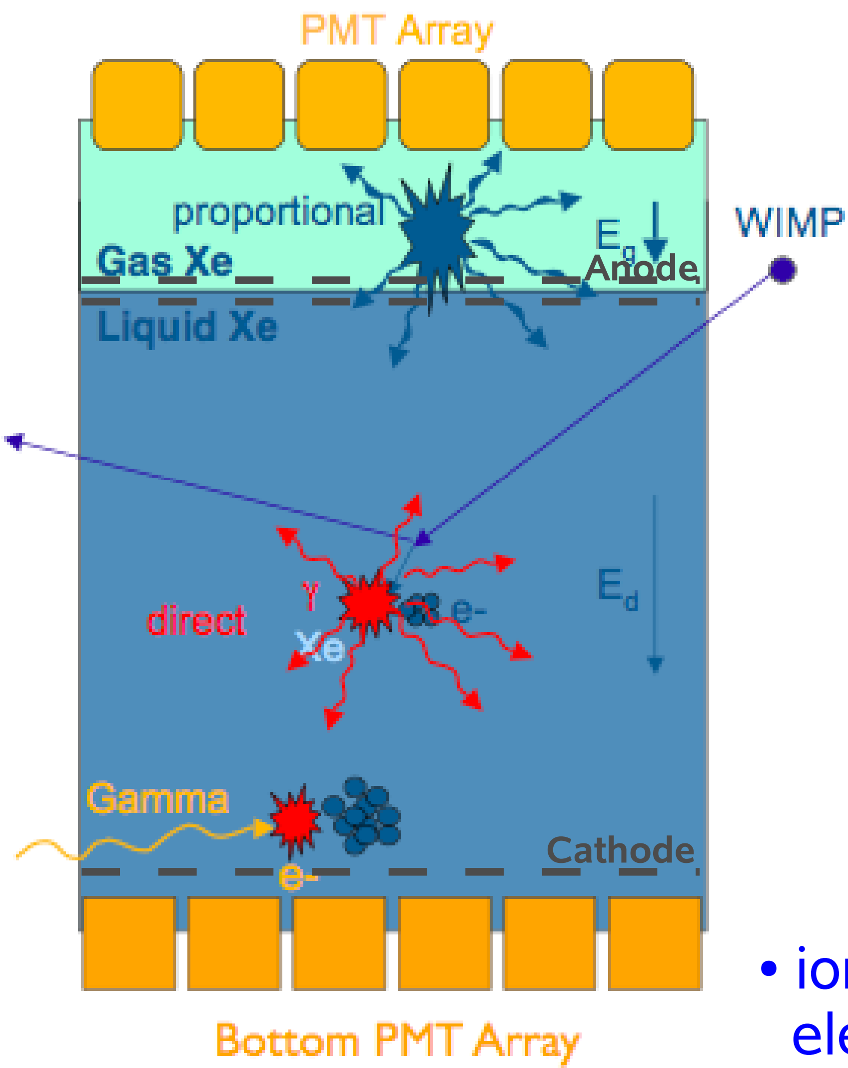
Why WIMP search with Xenon?

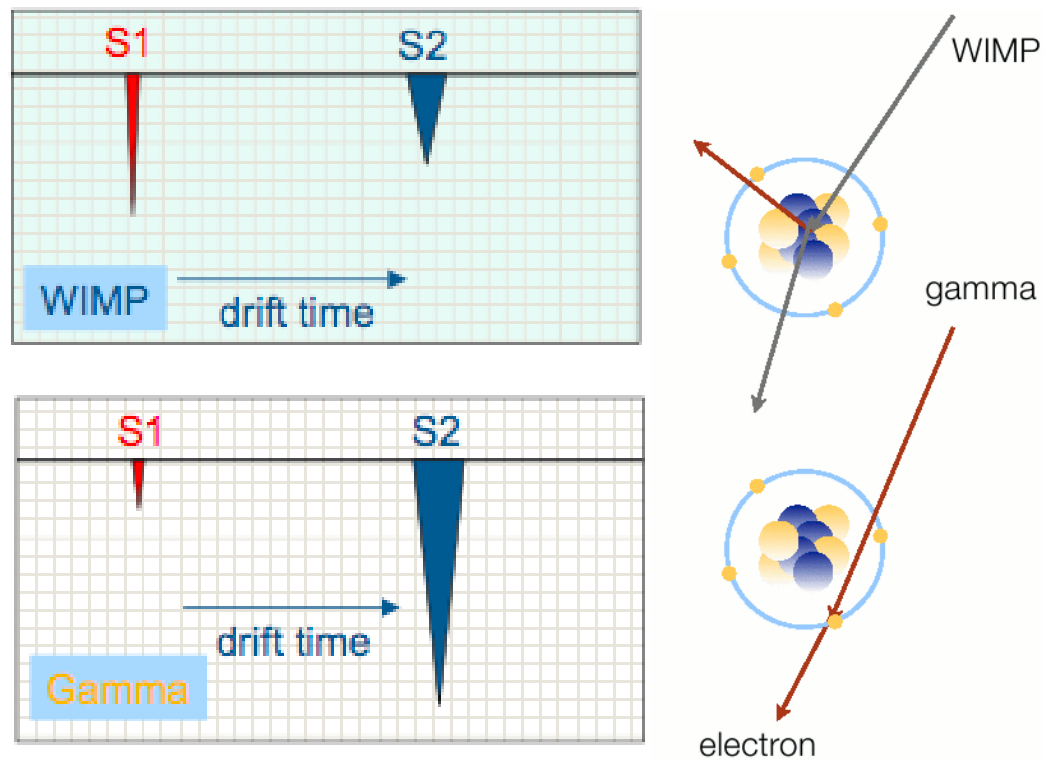
- efficient, fast scintillator (178nm)
- high mass number *A*~131:
  SI: high WIMP rate @ low theshold
- high atomic number *Z*=54,
  high density (~3kg/l):
  self shielding, compact detector
- 50% odd isotopes
  sensitive to spin-dependent couplings
- no long lived Xe isotopes,
  Kr-85 can be removed to ppt
- "easy" cryogenics @ –100°C
- scalability to larger detectors
- in 2-phase TPC:
  good background discrimination





Dual Phase TPC

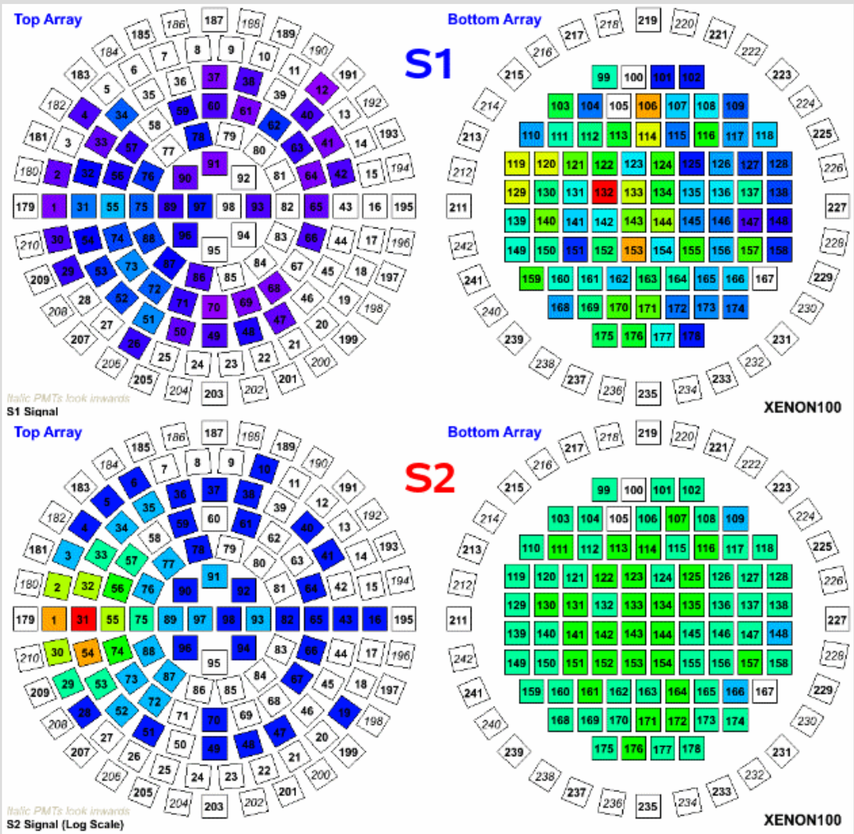


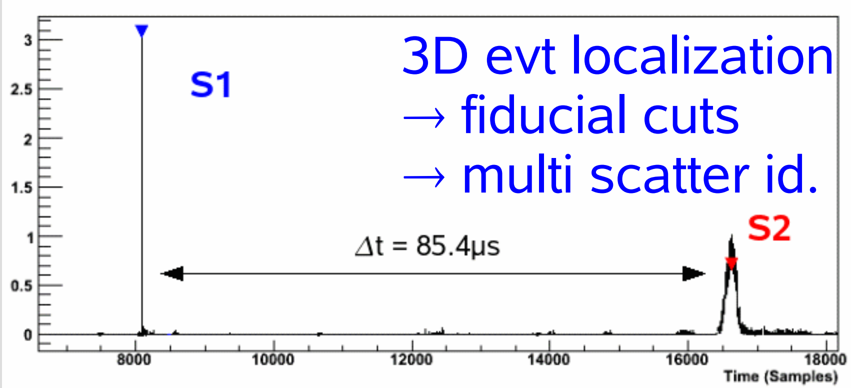


$(S2/S1)_{wimp} << (S2/S1)_{gamma}$

- ionization/scintillation ratio (S2/S1) allows electron recoil rejection to >99.5%
- 3D position reconstruction in TPC
- Multiscatter Rejection (= discrimination)

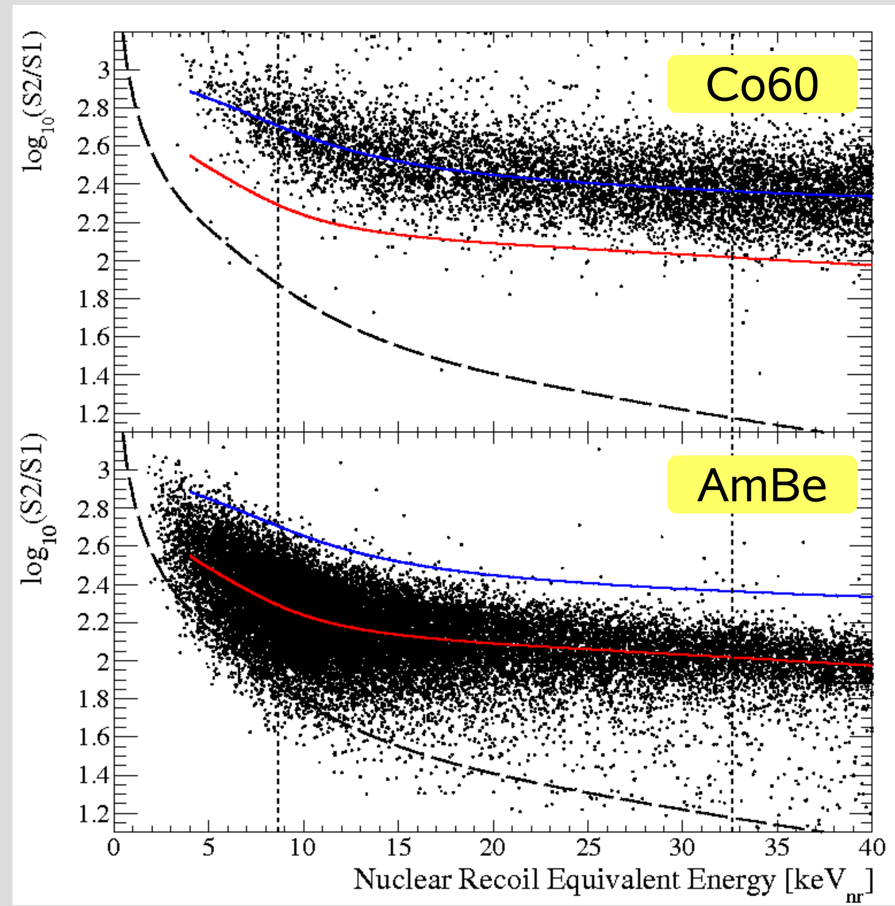
Localization / Discrimination





3D evt localization
→ fiducial cuts
→ multi scatter id.

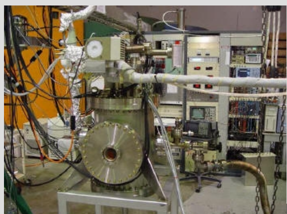
Discrimination:



~99.5% bg rejection
@ 50% acceptance *(Xe10 performance)*
definition of *WIMP search region*

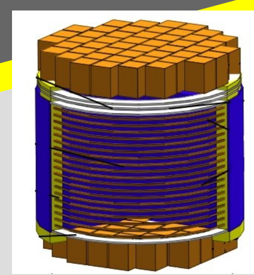
The XENON program

XENON: A phased WIMP search program

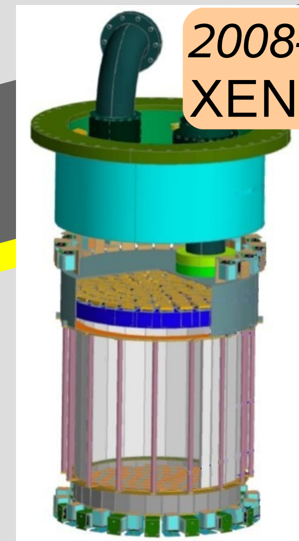


XENON R&D

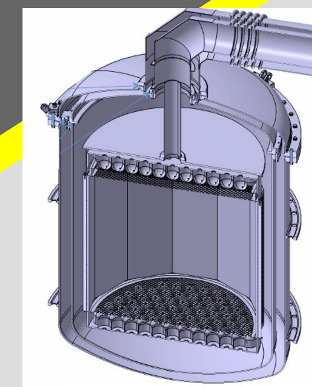
2005-2007: XENON10



2008-2011: XENON100



2010-2015: XENON1T



Columbia · *Rice* · *UCLA* · *U Zürich* · *Coimbra* · *LNGS* · *SJTU*

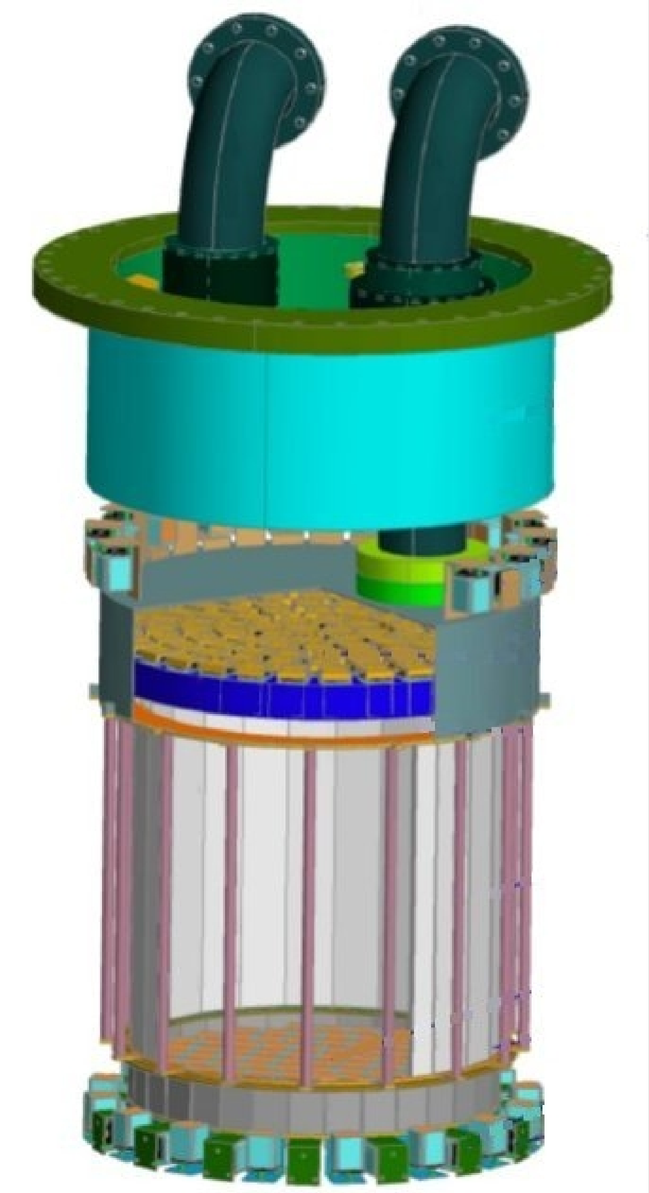
Bologna · *MPIK* · *NIKHEF* · *Mainz* · *Subatech* · *Münster* · *WIS*

XENON100

Goal (compared to XENON10)**:**
- increase target ×10
- reduce gamma background ×100

→ material selection & screening
→ detector design

Quick Facts:
- 161 kg LXe TPC (mass: 10 × Xe10)
- 62 kg in target volume
- active LXe veto (≥4 cm)
- 242 PMTs
- improved Xe10 shield
  (Pb, Poly, Cu, H_2O, N_2 purge)



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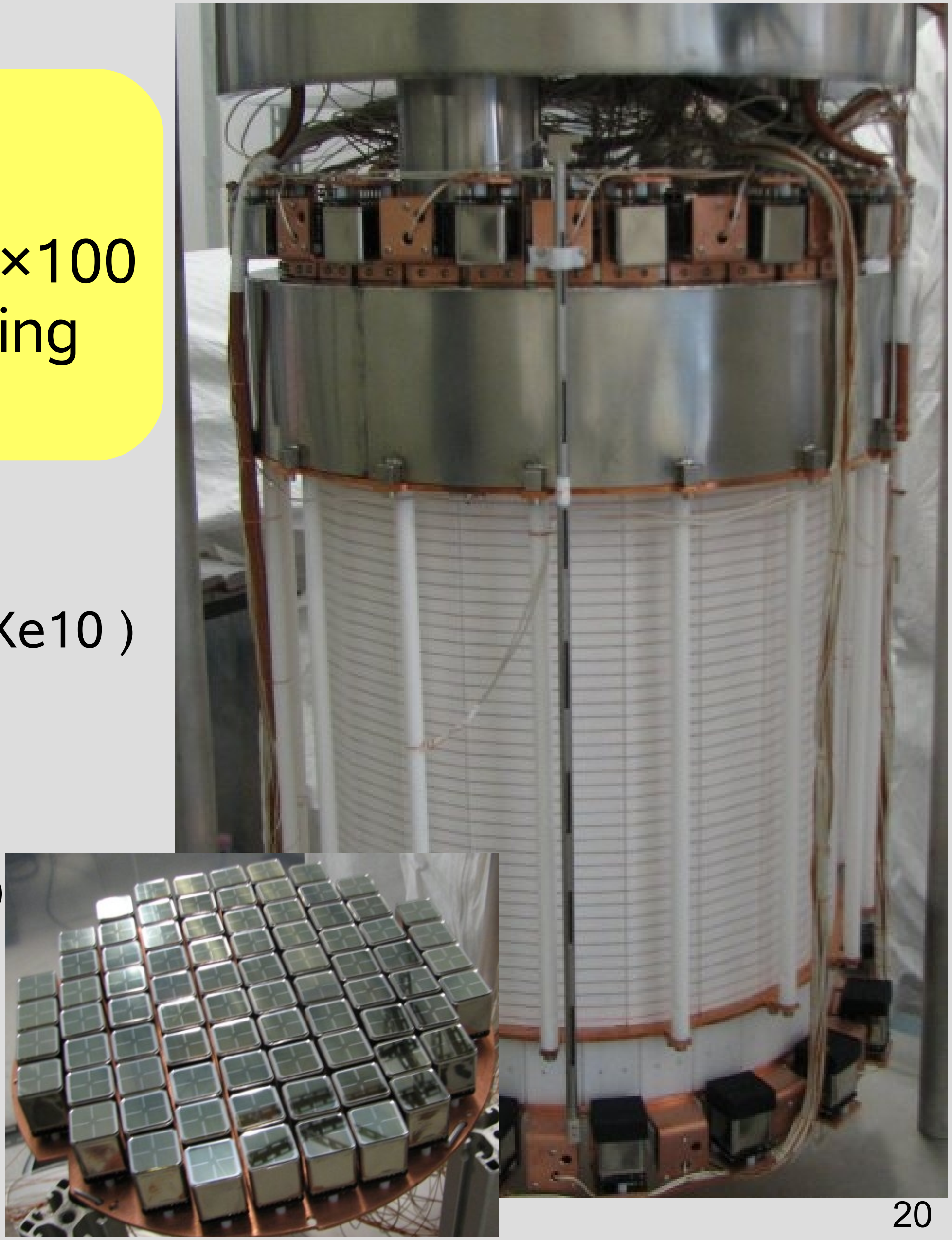

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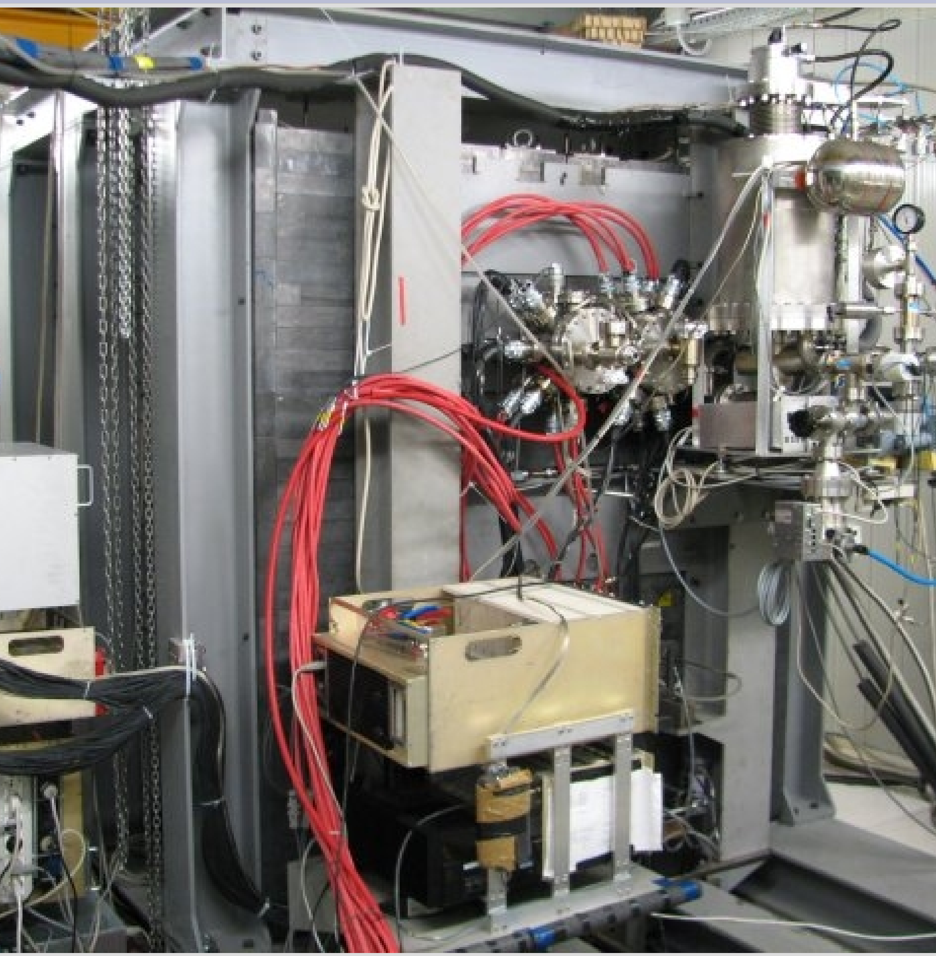
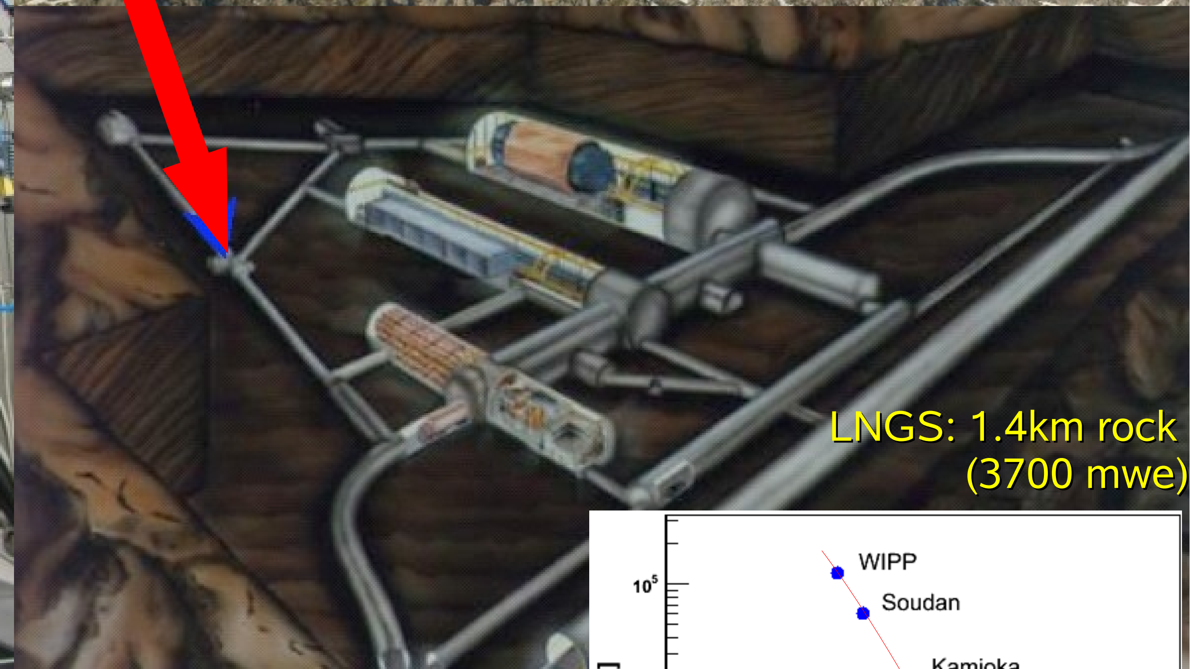
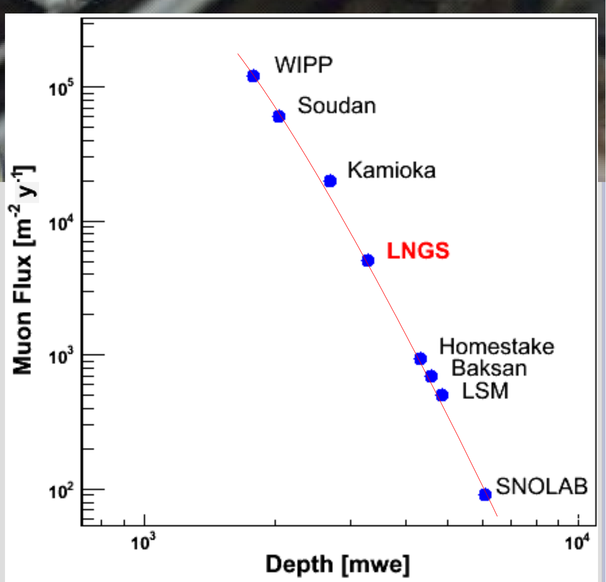
• improved Xe10 shield
(Pb, Poly, Cu, H_2O, N_2 purge)

XENON100 @ LNGS

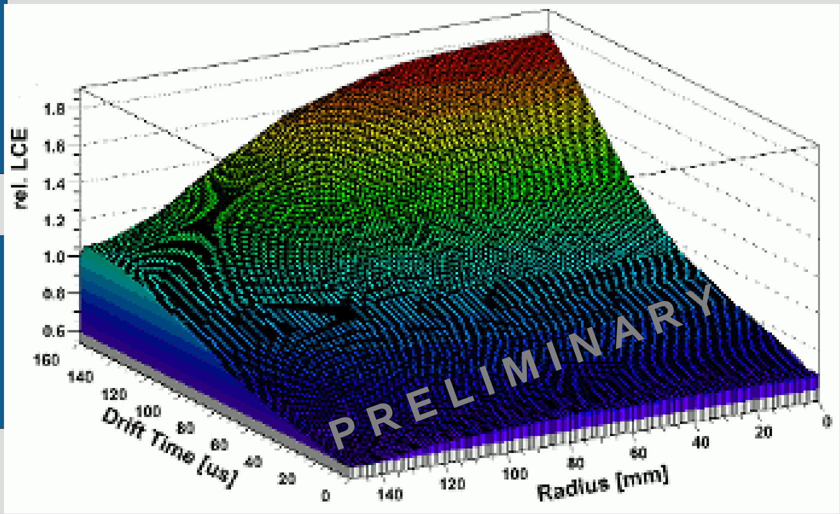


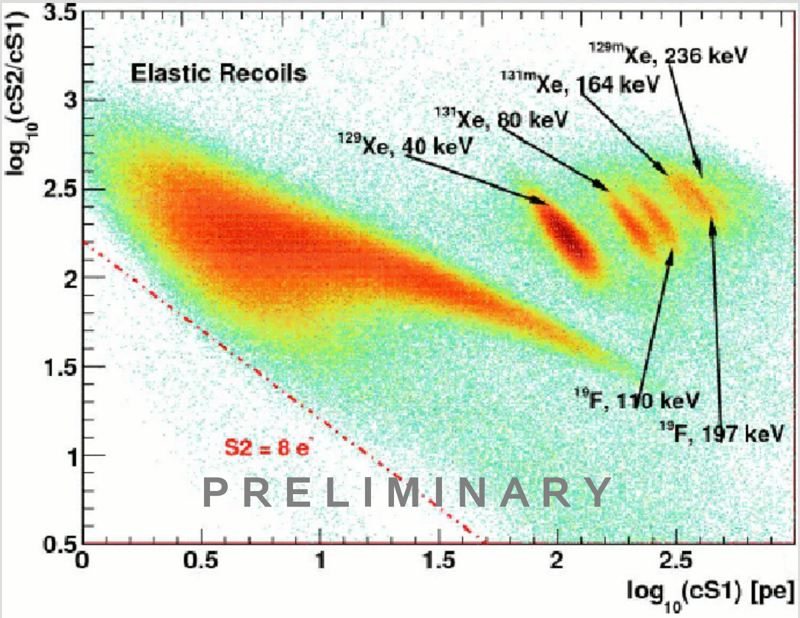




- underground since end of February 08
- first filled with Xe in mid May 08
- extensive calibrations, first science data

Selected Calibrations





Position dependent Corrections:
Cs-137, AmBe inelastic (40 keV),
Xe* (164 keV)
Kr-83m (planned)

➡ Agreement better than 3%

Electron Lifetime:
Cs-137

➡ ~200 µs (11.2d), up to 400 µs (run_08)

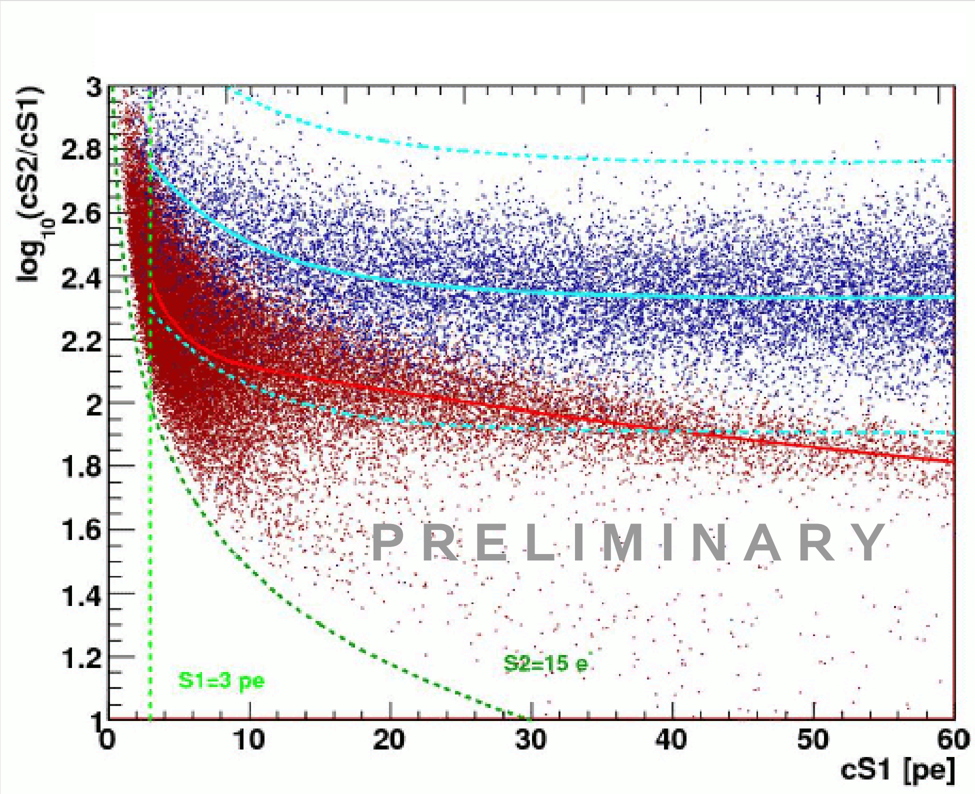
Electron Recoil Band (Background):
Co-60, Cs-137, Th-228

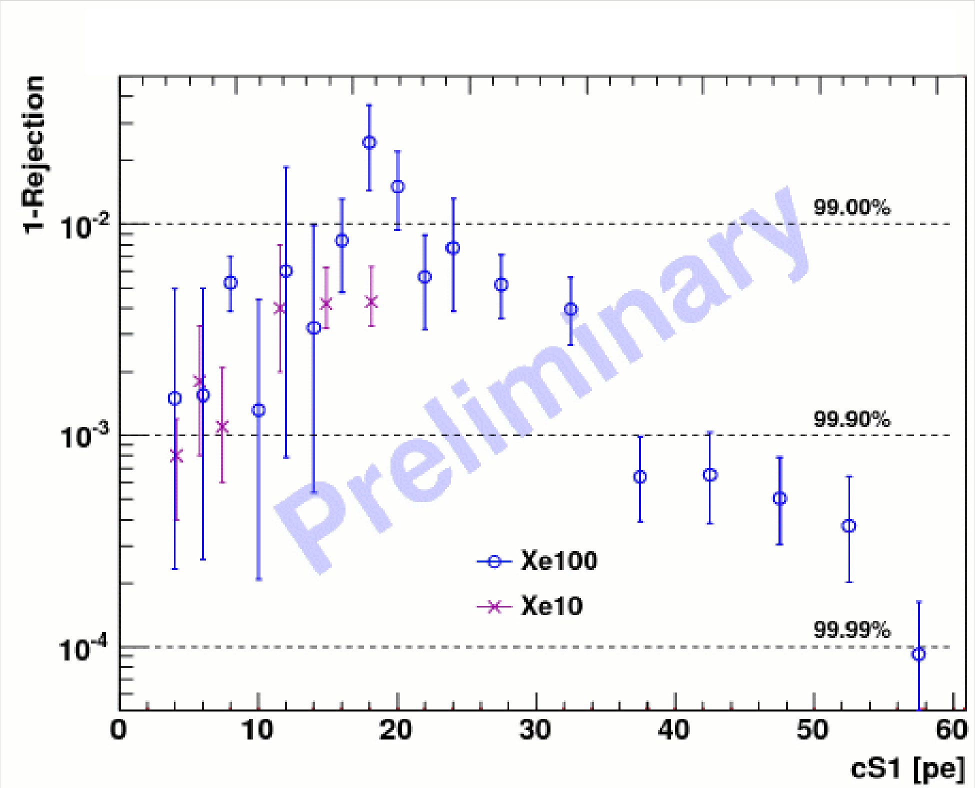
Nuclear Recoil Band (Signal):
Neutrons: AmBe

➡ definition of WIMP search region, discrimination

ER / NR Discrimination

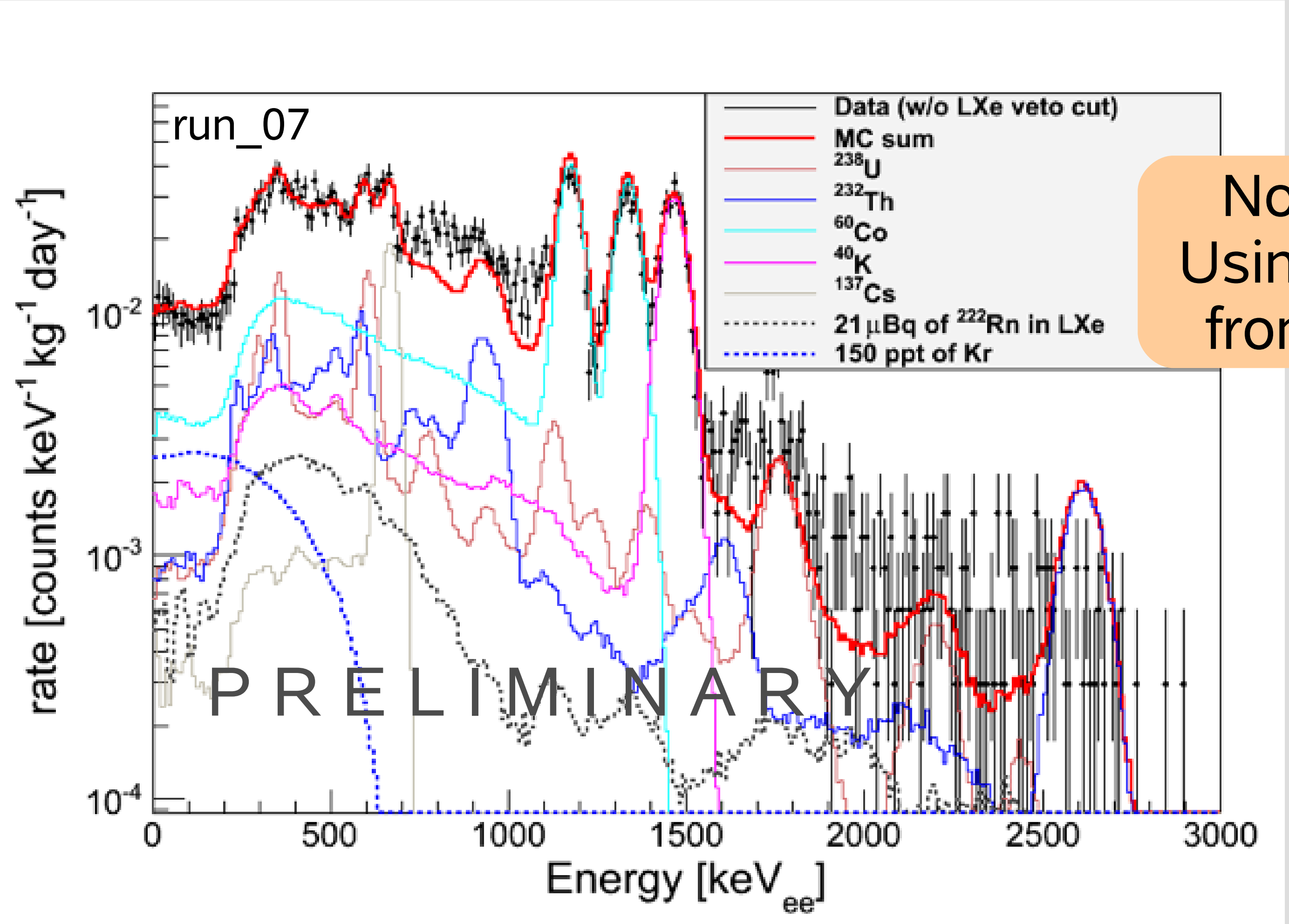
XENON Dark Matter Project





- ER/NR discrimination via S2/S1 ratio
- Discrimination efficiency similar to XENON10 (>99%)

XENON100 Background

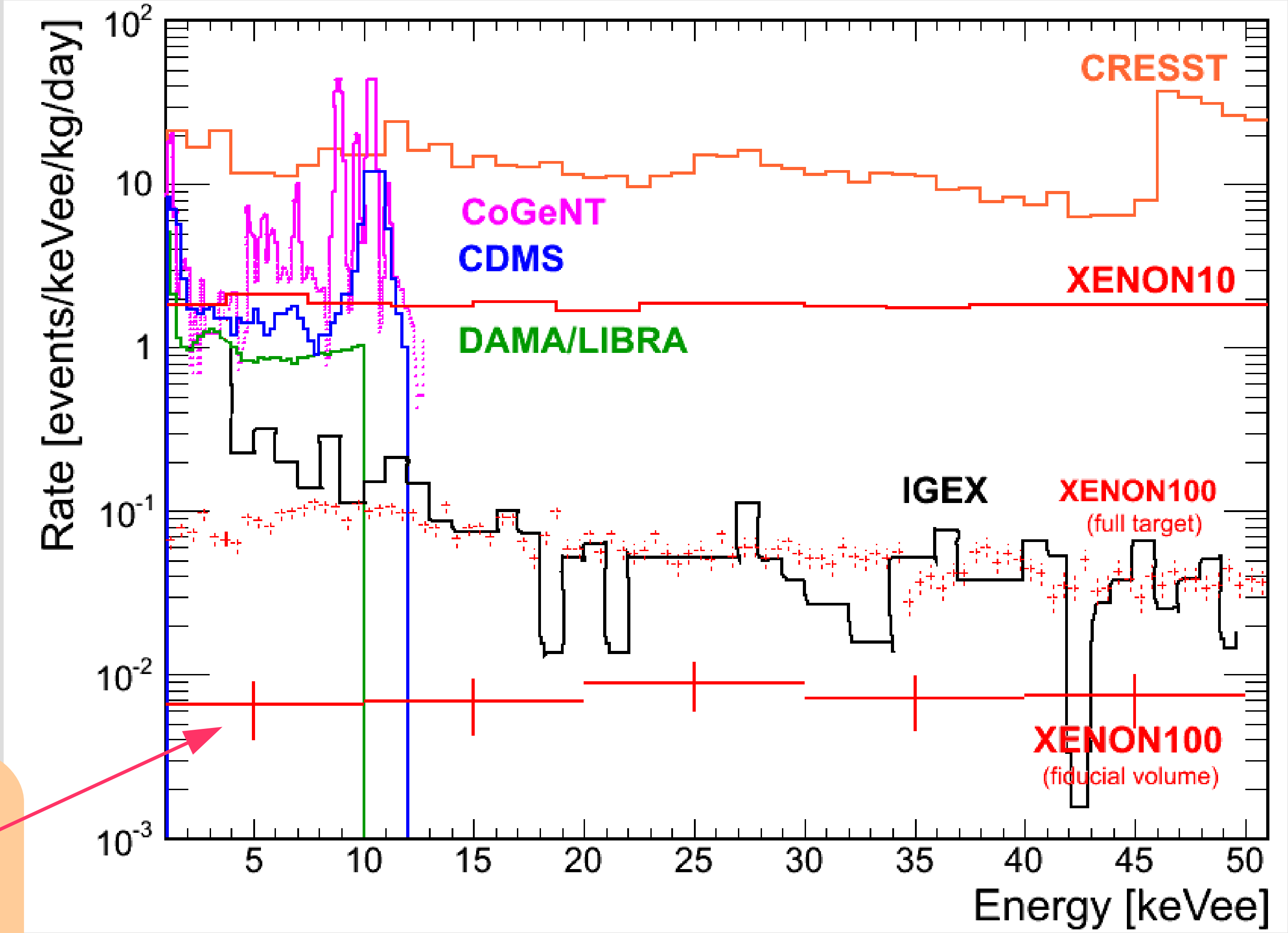


No MC tuning!
Using only values from screening.

- 30 kg fiducial mass
- active LXe veto not used for this plot
- exploit anti-correlation between light and charge for better ER-energy scale

Measured Background in good agreement with Monte Carlo prediction.

Background Comparison



Xenon keVee-Scale not precisely known below 9 keVee

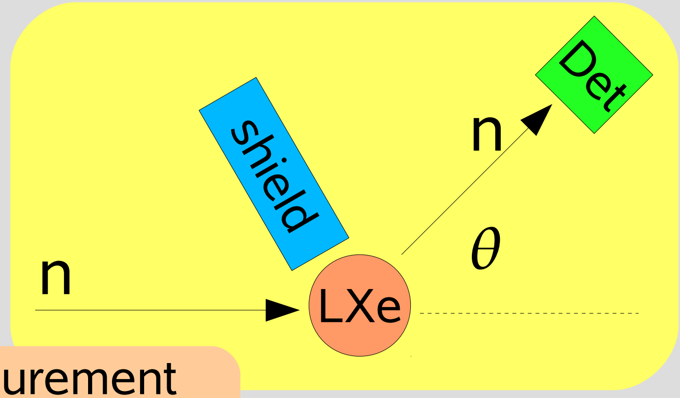
At low energies this is the lowest Background ever achieved in a Dark Matter Experiment!

Nuclear Recoil Scale

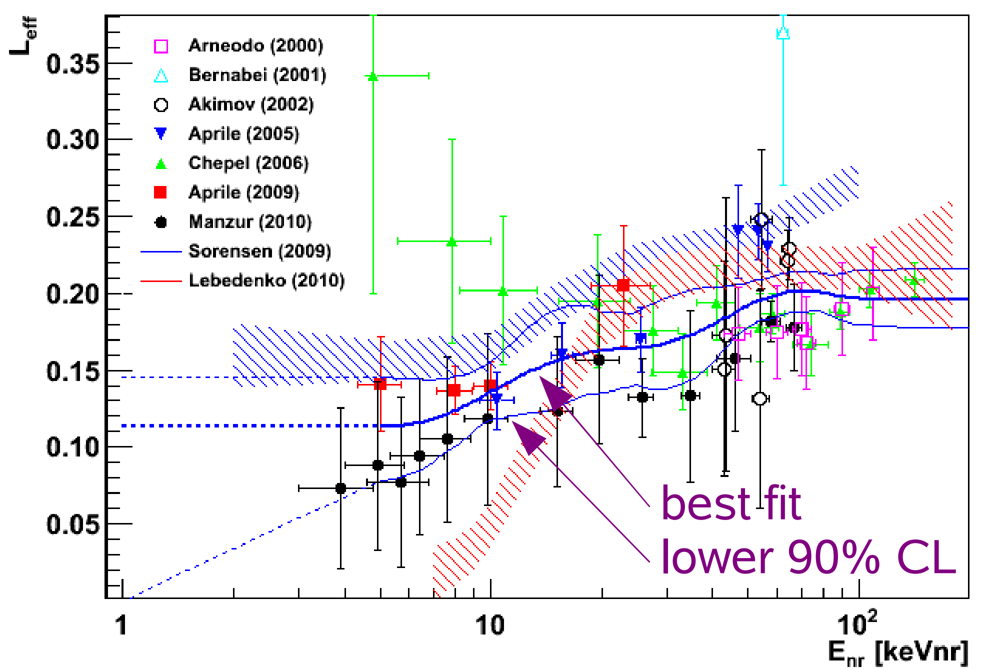
- WIMPs interact with Xe nucleus
  ➞ nuclear recoil (*nr*) scintillation (β and γ's produce electron recoils)
- absolute measurement of *nr* scintillation yield is difficult
  ➞ measure relative to ^{57}Co (122keV)
- relative scintillation efficiency $\mathcal{L}_{eff}$:

$$\mathcal{L}_{\rm eff}(E_{\rm nr}) = \frac{\rm LY(E_{nr})}{\rm LY(E_{ee} = 122\ keV)}$$

measurement principle:



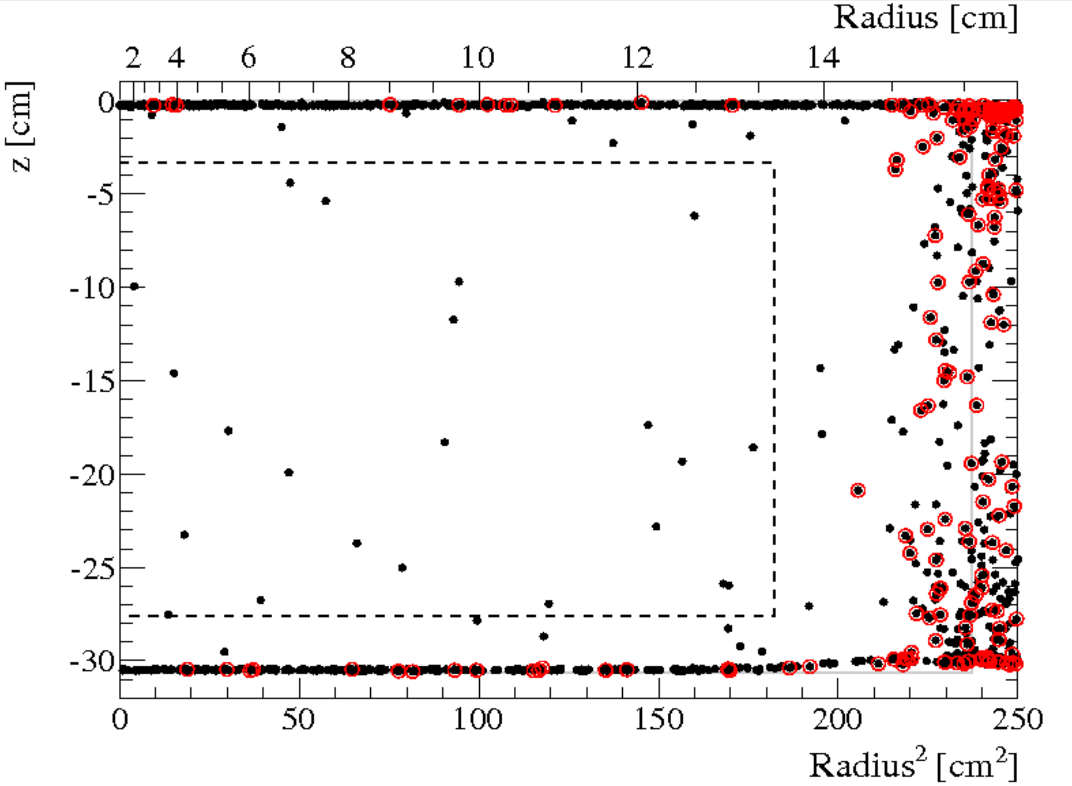
New measurement ongoing at Columbia;
In preparation in Zürich



most recent measurements:
- Aprile et al., PRC 79, 045807 (2009)
- Manzur et al., PRC 81, 025808 (2010)

for discussion of possible systematic errors see *A. Manalaysay, arXiv:1007.3746*

First XENON100 Data

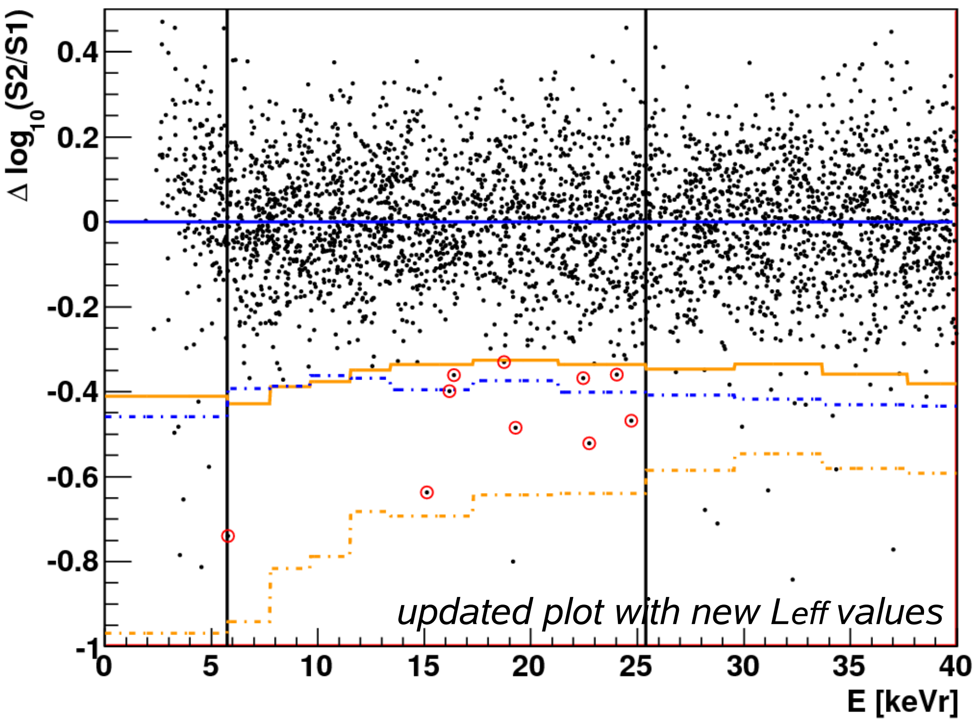


- Energy cut: <30 keV$_{nr}$
- make use of excellent self-shielding capability of LXe
- 40 kg fiducial mass

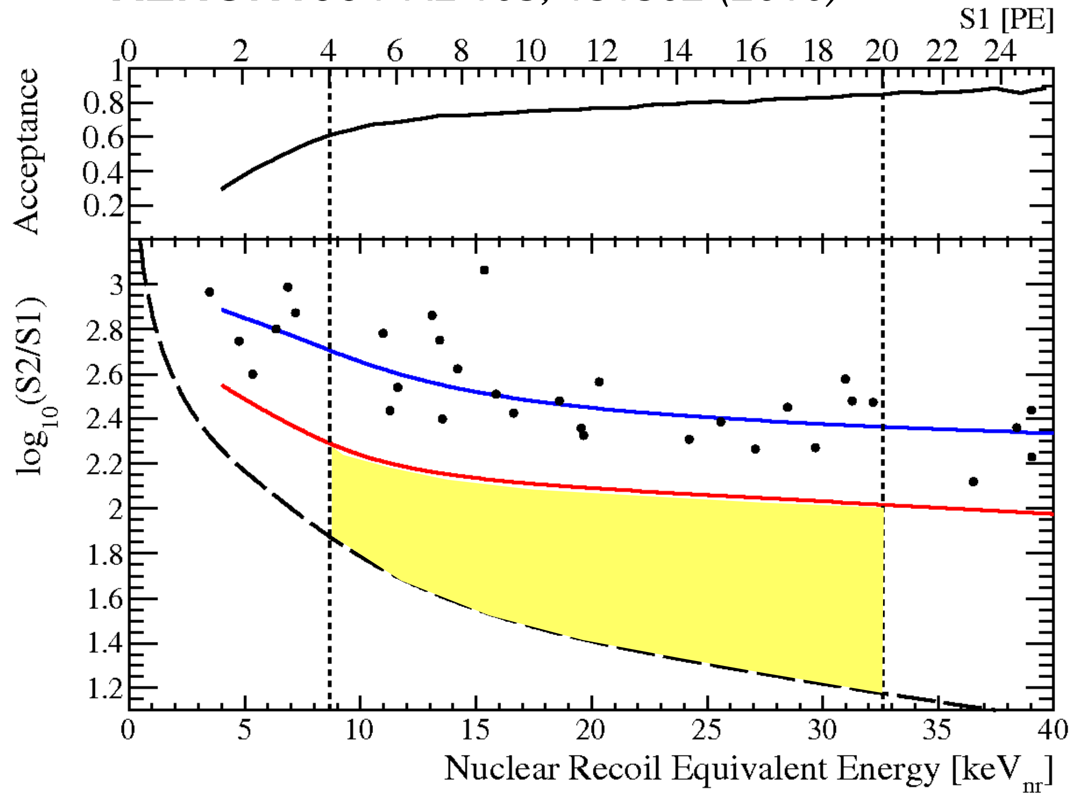
- Background data taken in stable conditions Oct-Nov 2009
- 11.2 life days
- Data was not blinded
- But: Cuts developed and optimized on calibration data only
- *PRL 105, 131302 (2010) arXiv:1005.0380*

A Look at the Bands

XENON10 *PRL 100, 021303 (2008)*



XENON100 *PRL 105, 131302 (2010)*

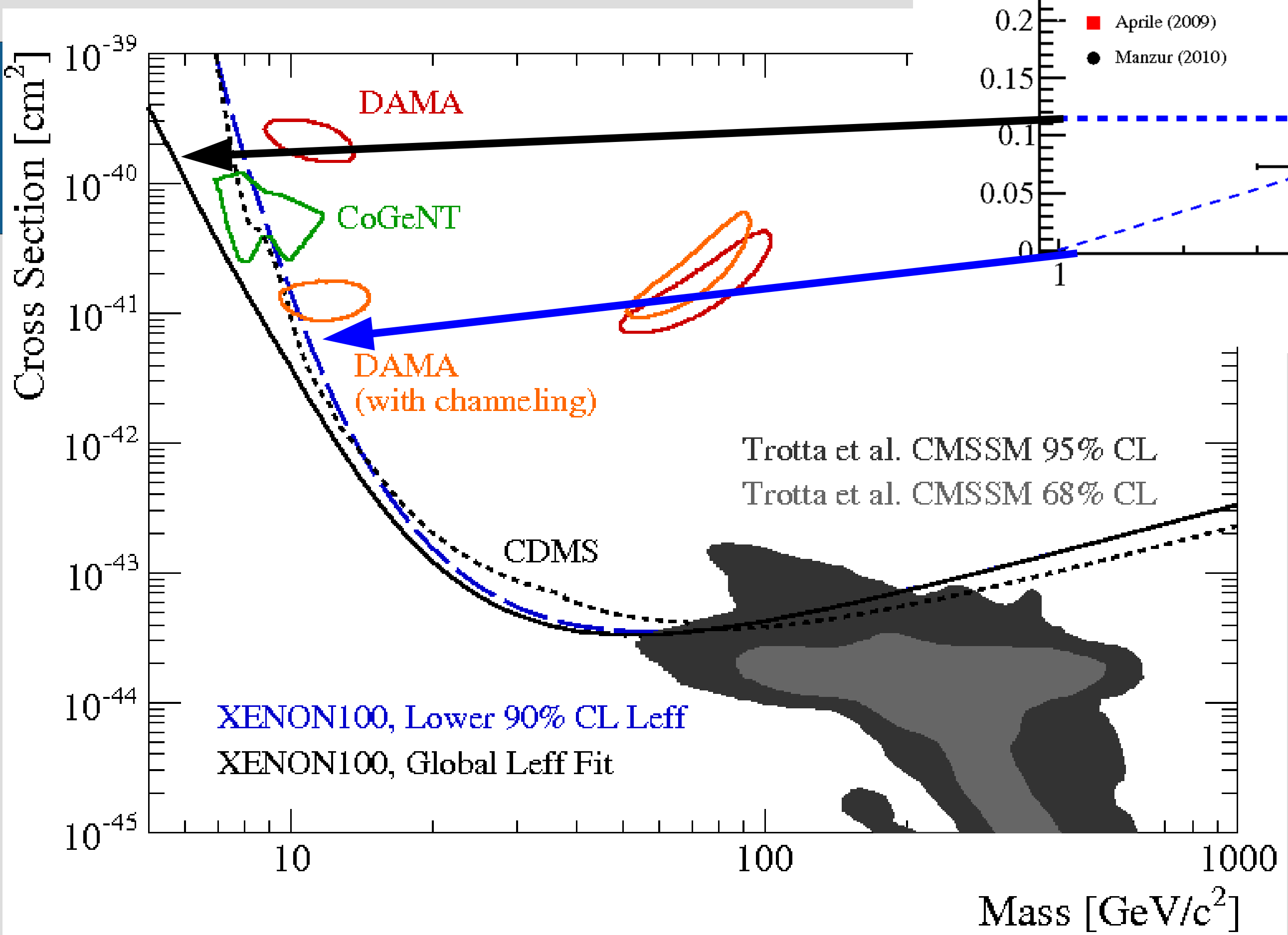


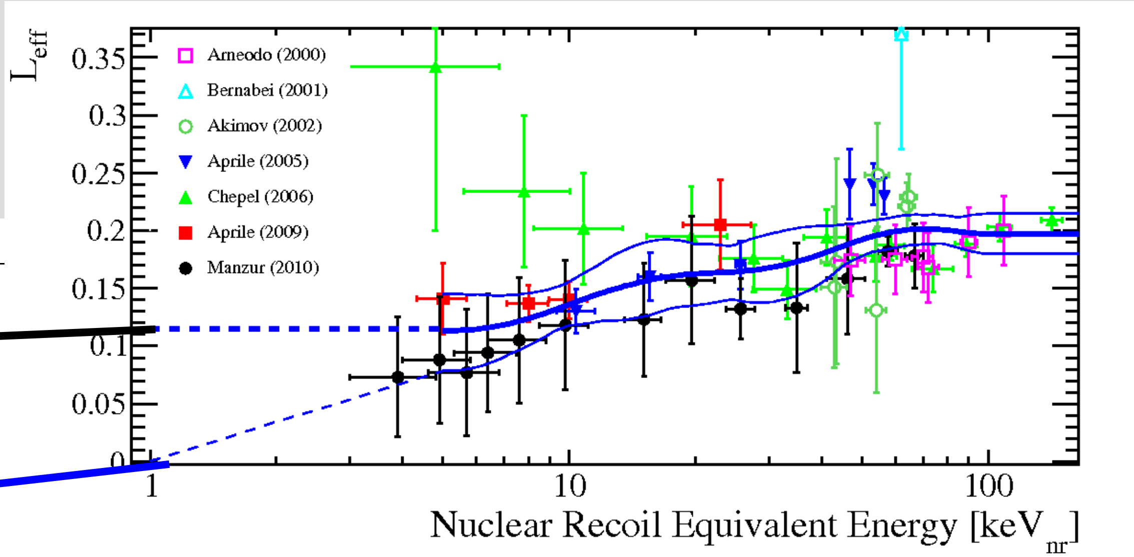
- Background free in 11.2 days after S2/S1 discimination
- Both plots show similar exposure

NR acceptance = 50%
cut efficiency ~ 60-85 %
(conservative)
Background expectation $\ll 1$

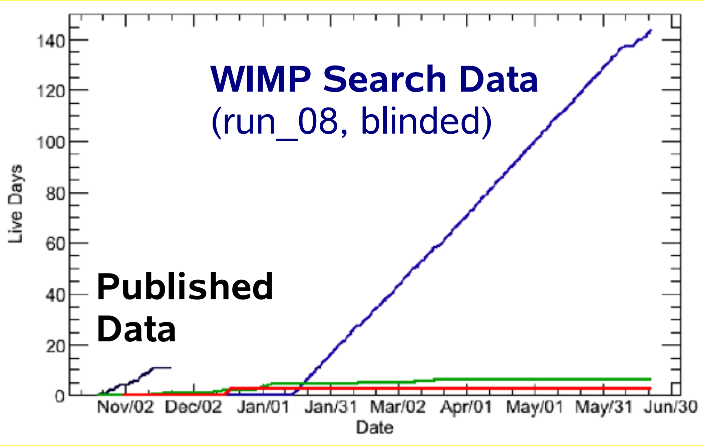
A first Limit from XENON100

PRL 105, 131302 (2010)
arXiv: 1005.0380



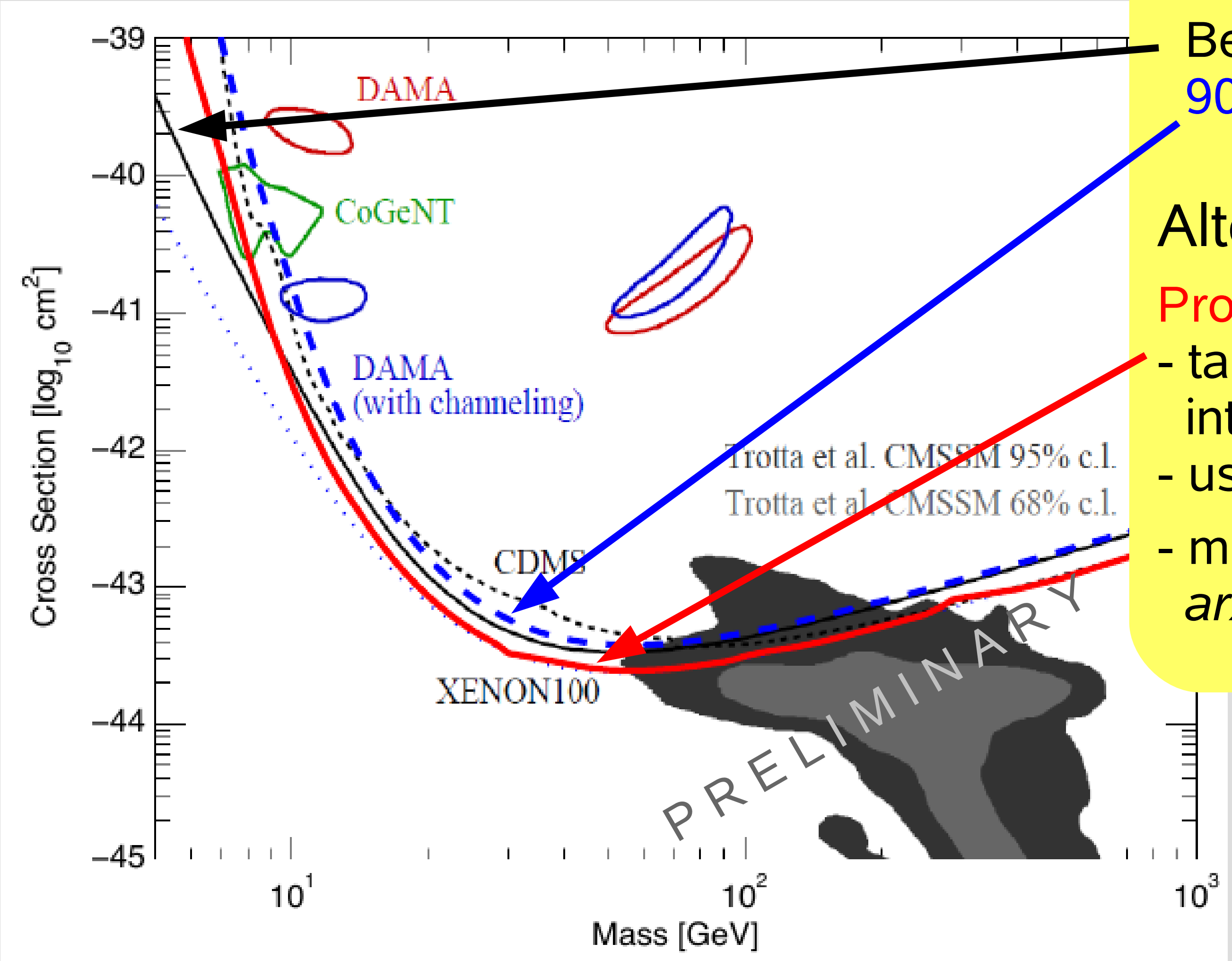


This is just a first glimpse!
We have much more (blinded) data on tape.



New: Alternative Interpretation

XENON Dark Matter Project



XENON100 PRL:

Best fit limit

90% lower CL *L*eff limit

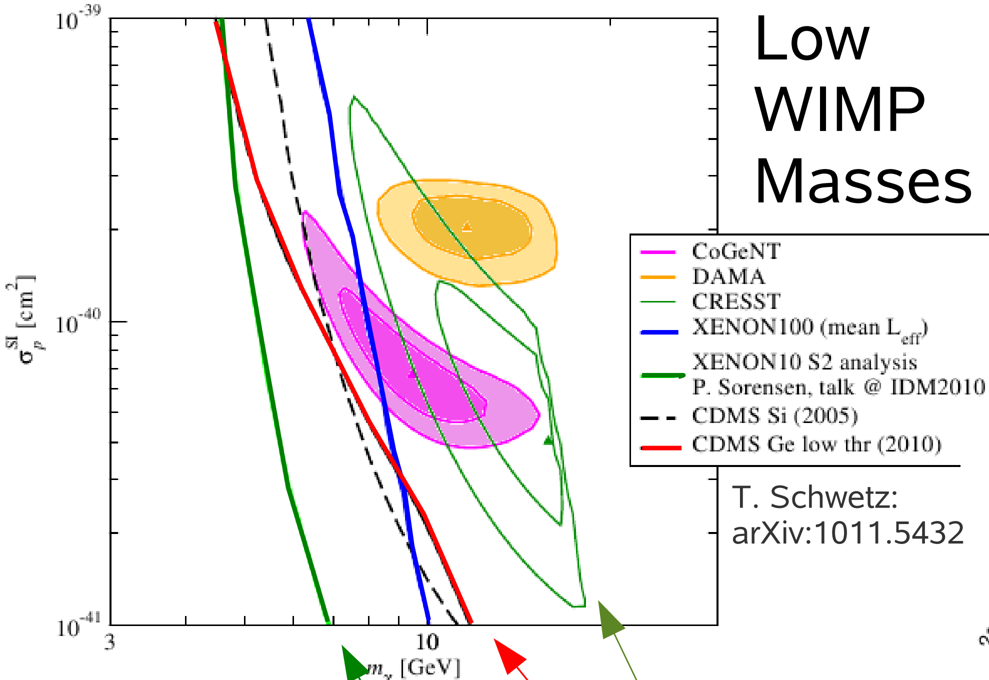
Alternative Interpretation:

Profile Likelihood Method

- takes *L*eff uncertainties into account
- uses full log(S2/S1) space
- method described in *arXiv:1007.1727*

WIMP Limits: State of the Art

Low WIMP Masses



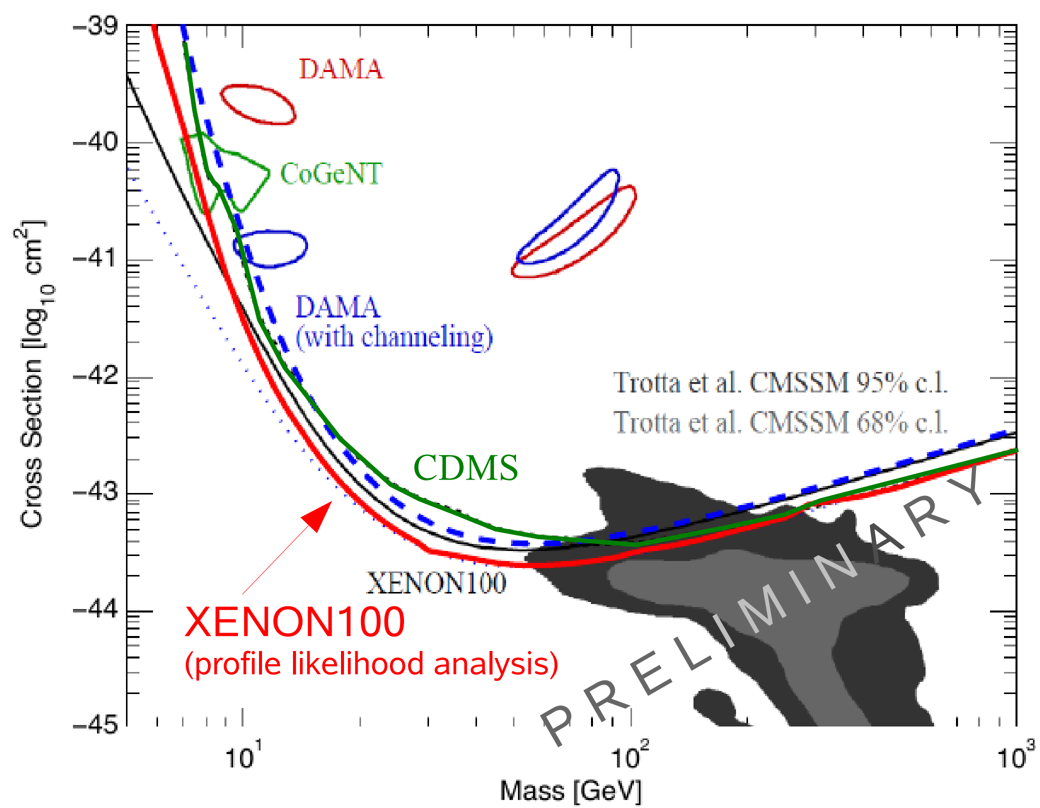
T. Schwetz: arXiv:1011.5432

P. Sorensen / XENON10
Talk at IDM2010, *to be published*

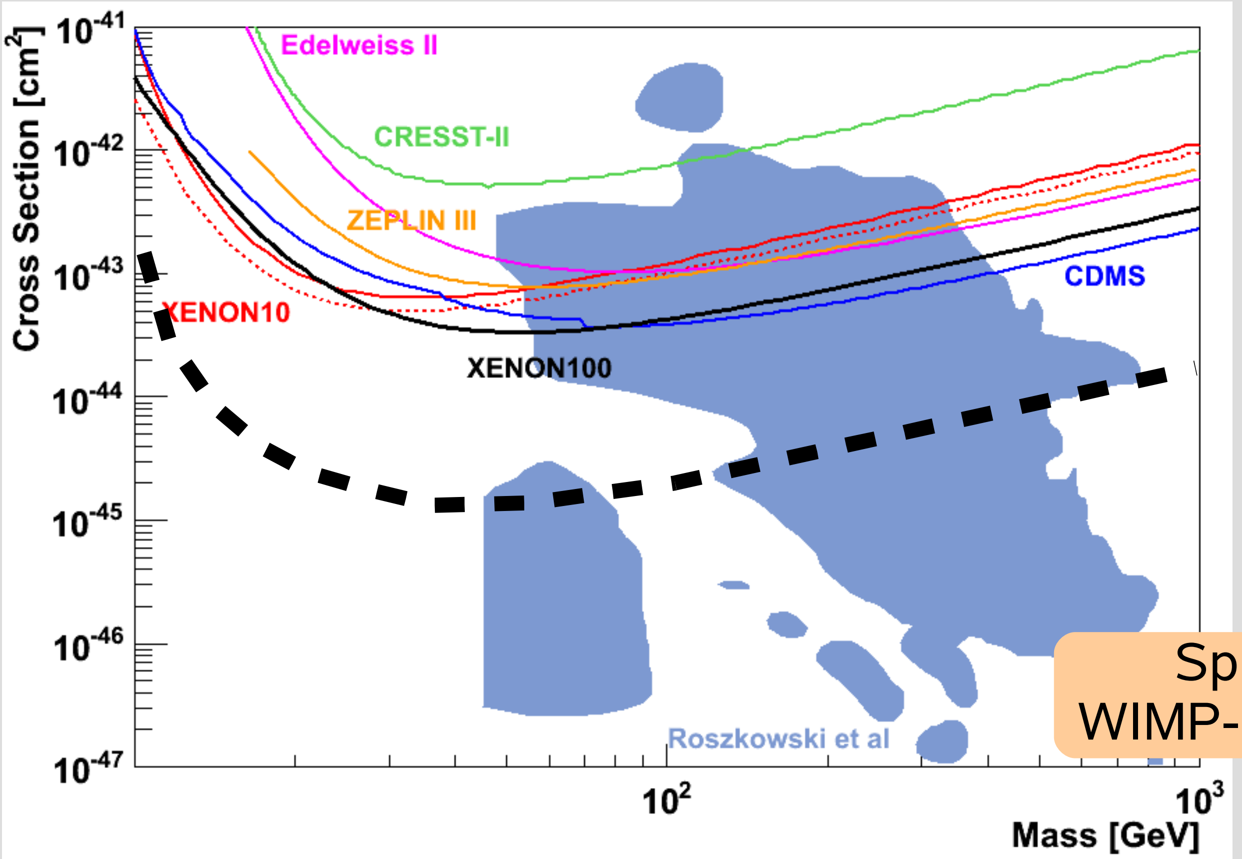
CDMS II: *arXiv:1011.2482*

W. Seidel / CRESST-II
Talk at IDM2010

High WIMP Masses



XENON100: Sensitivity



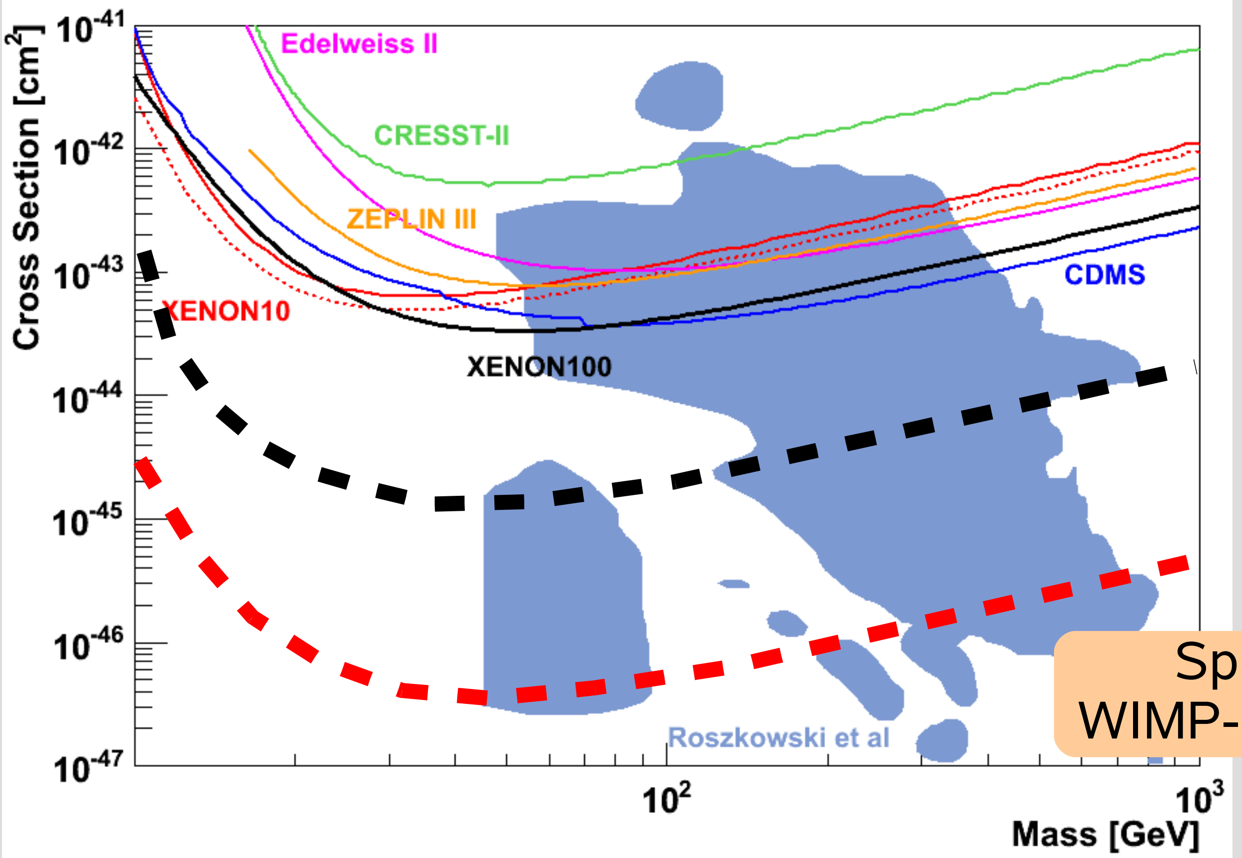
XENON100

Spin-independent WIMP-nucleon interaction

50 kg Target: 40 days $\sigma = 6\times10^{-45}$ cm² (@ 100 GeV)

30 kg Target: 200 days $\sigma = 2\times10^{-45}$ cm² (@ 100 GeV)

XENON100: Sensitivity



XENON100

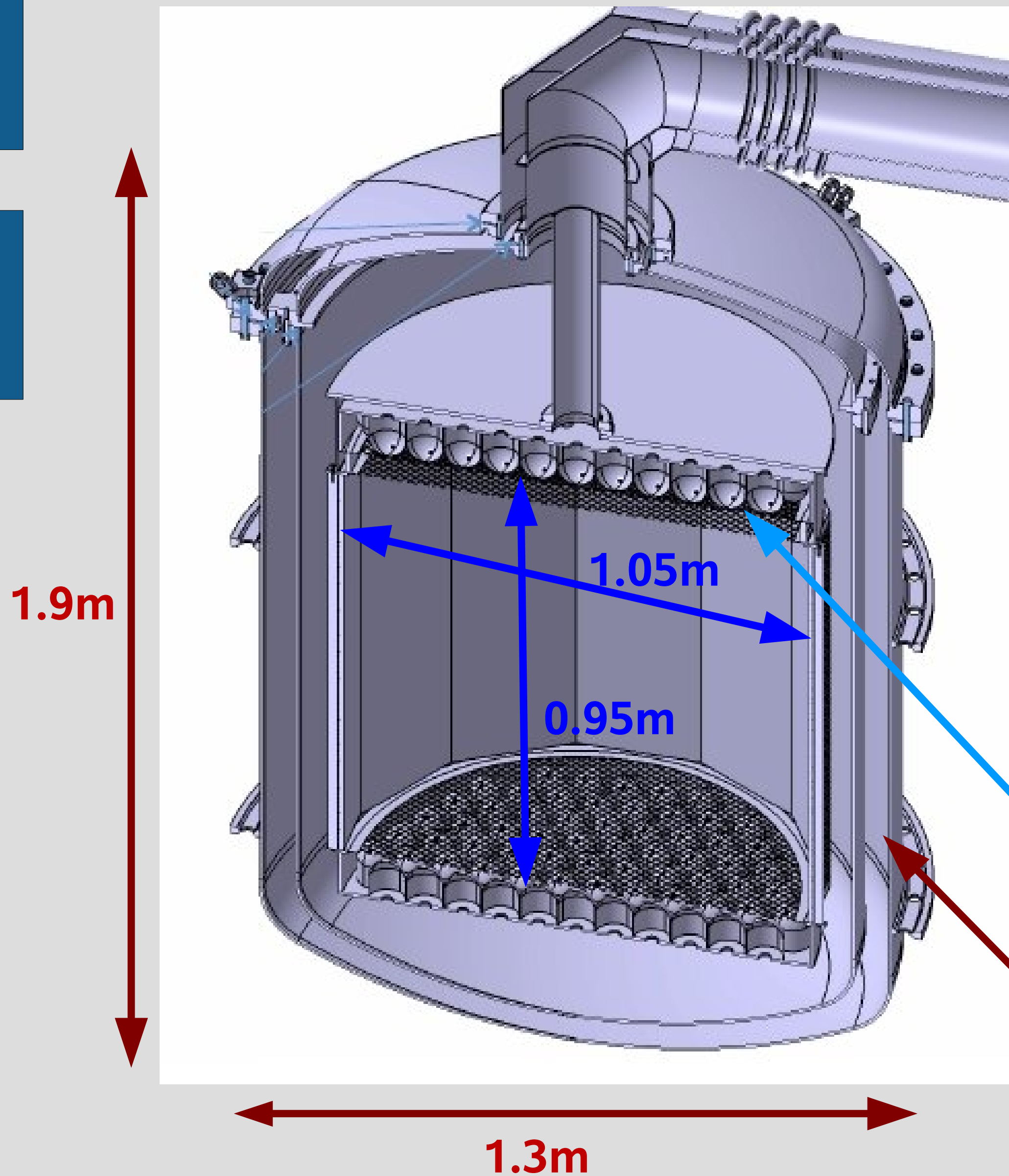
XENON1T

Spin-independent WIMP-nucleon interaction

50 kg Target: 40 days $\sigma = 6\times10^{-45}$ cm² (@ 100 GeV)

30 kg Target: 200 days $\sigma = 2\times10^{-45}$ cm² (@ 100 GeV)

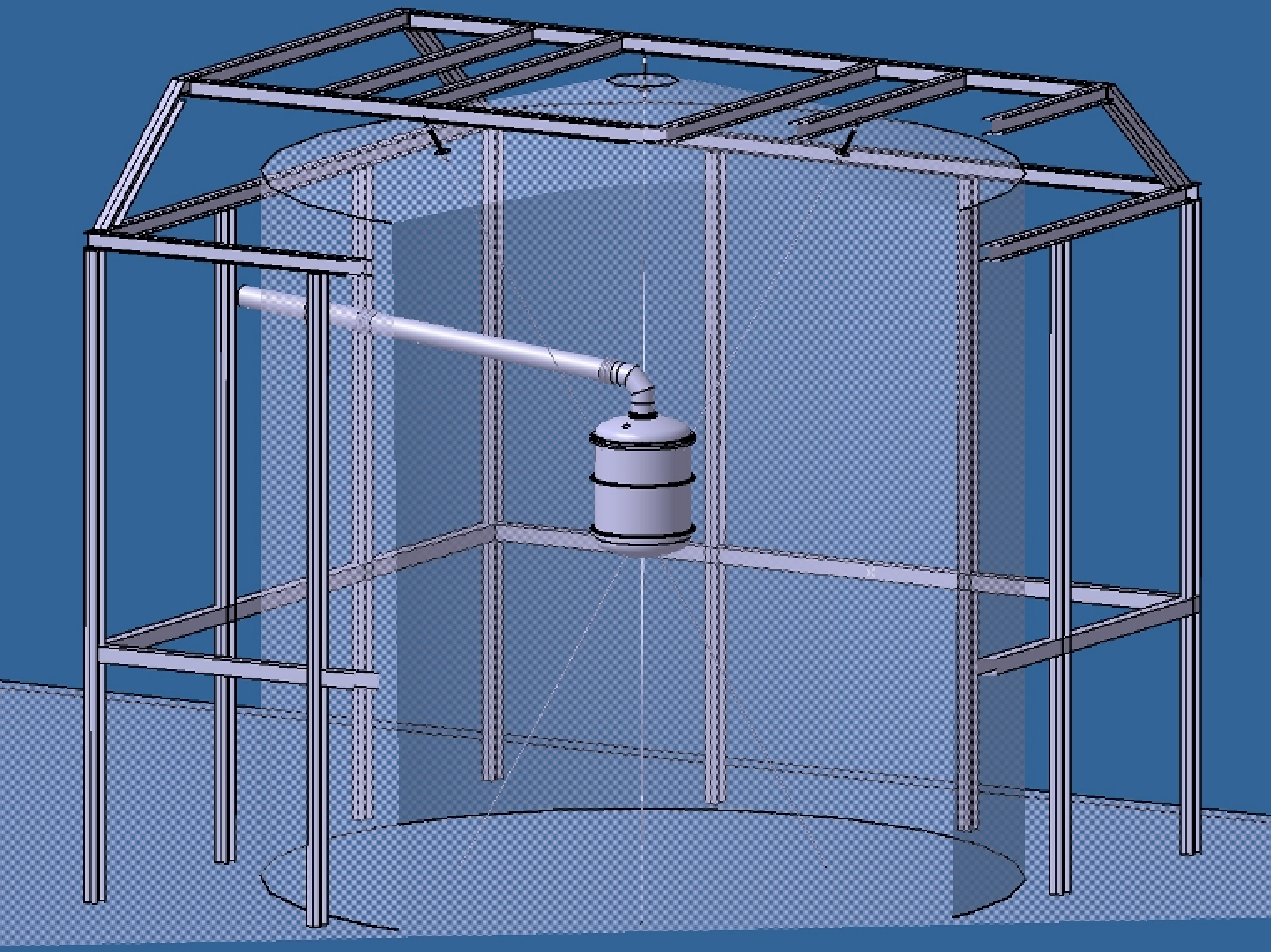
The next step: XENON1T



- 2.4t LXe ("1m³ detector")
  1t fiducial mass
- 100x lower background
  (10 cm self shielding, QUPID)
- MC studies, design studies already started 2009
- proposal and TDR submitted; currently: working on the details; secure funding
- Timeline: 2010 – 2015

Low Radioactivity Photon Detectors (3" QUPID, Total 242)

Ti Cryostat
(or low rad. stainless steel)

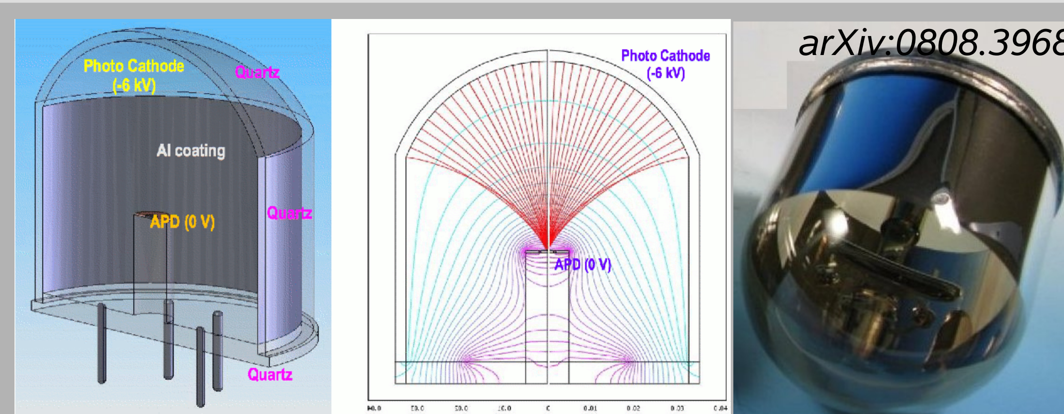


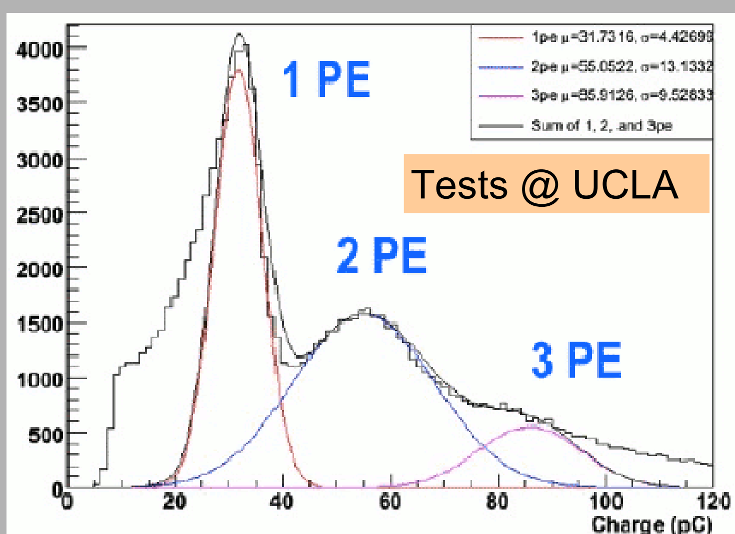
Photosensors

QUPID

Quartz Photon Intensifying Detector

- developed by UCLA group (Arisaka/Wang)
- very low radioactivity
  APD, quartz, no voltage divider
- ongoing tests and R&D at UCLA

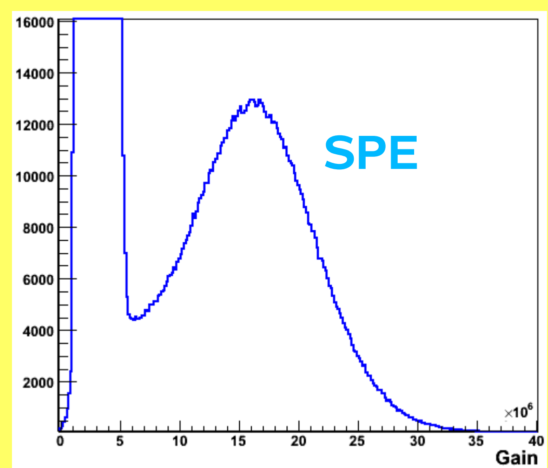




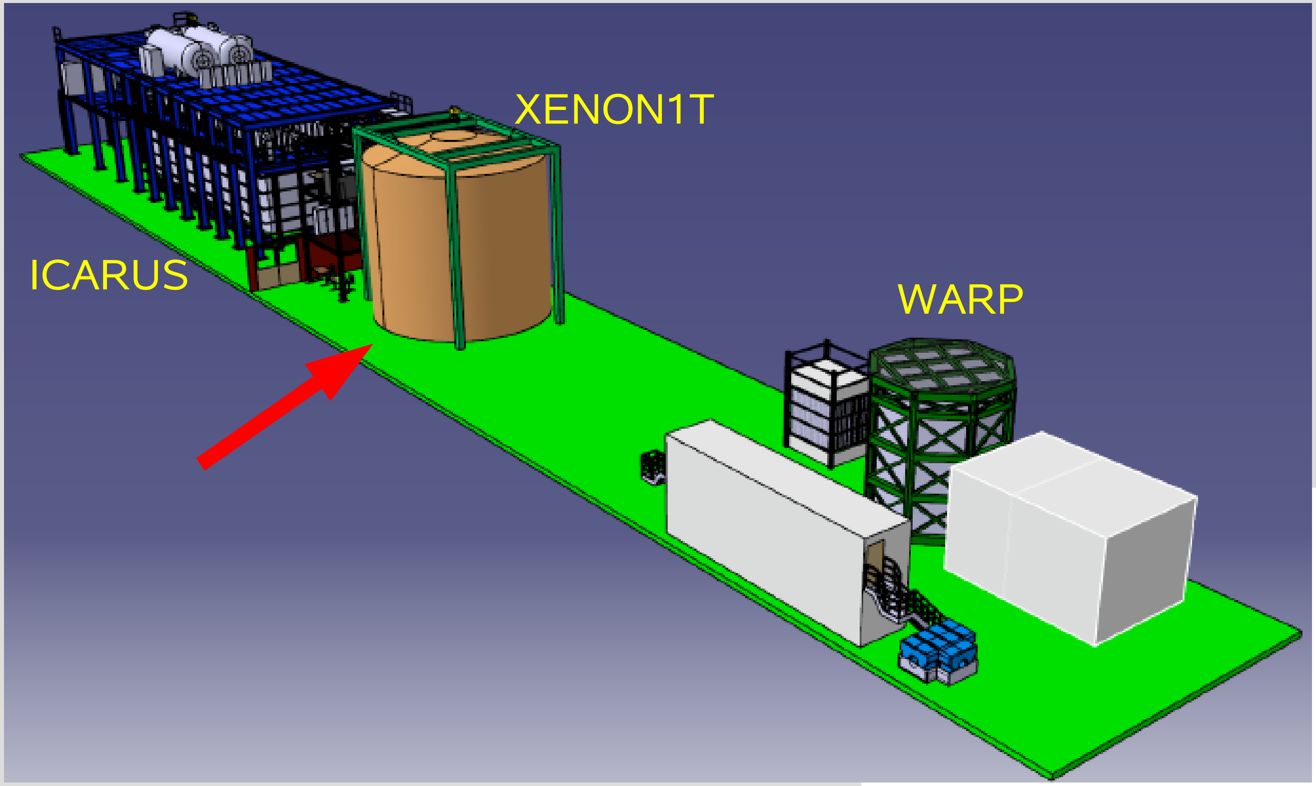
Alternative:

Hamamatsu R11410

3" PMT	high gain
LXe operation	low radioactivity

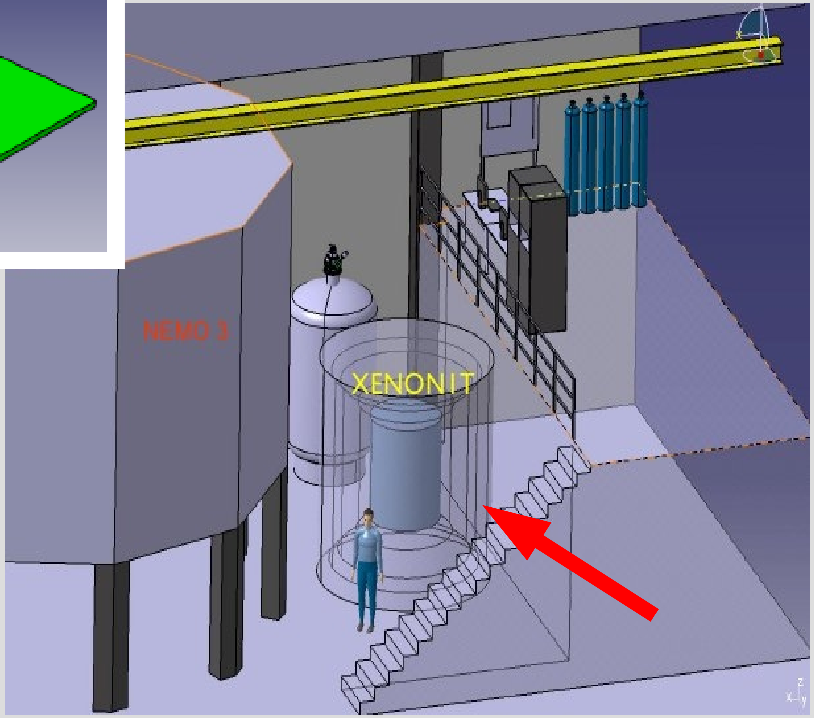


XENON1T: Location?

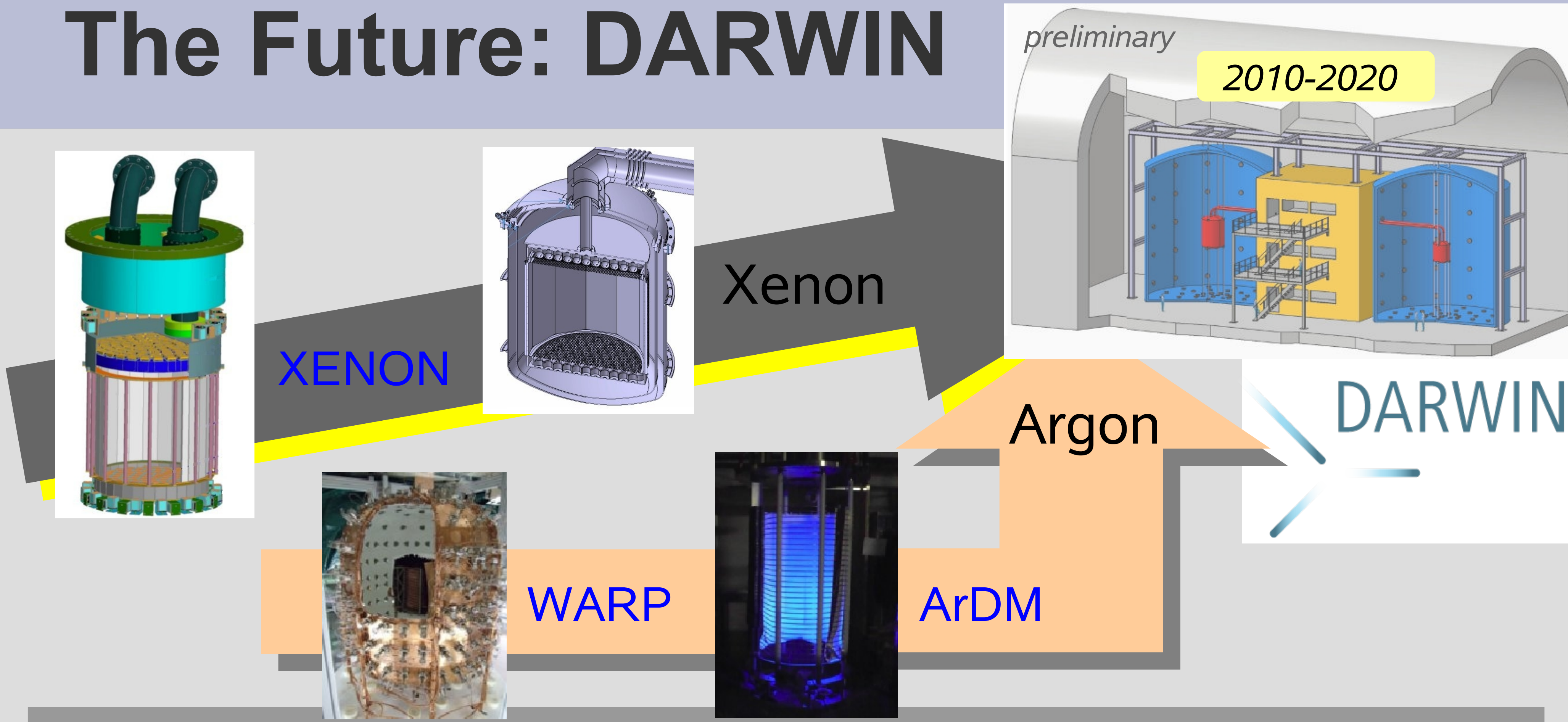


XENON1T
@ LNGS (Hall B)
➞ 5 m water shield acting as active muon veto

XENON1T @ LSM
➞ solid shield (55cm poly, 20cm Pb, 15cm poly, 2cm ancient Pb, >99% muon veto)



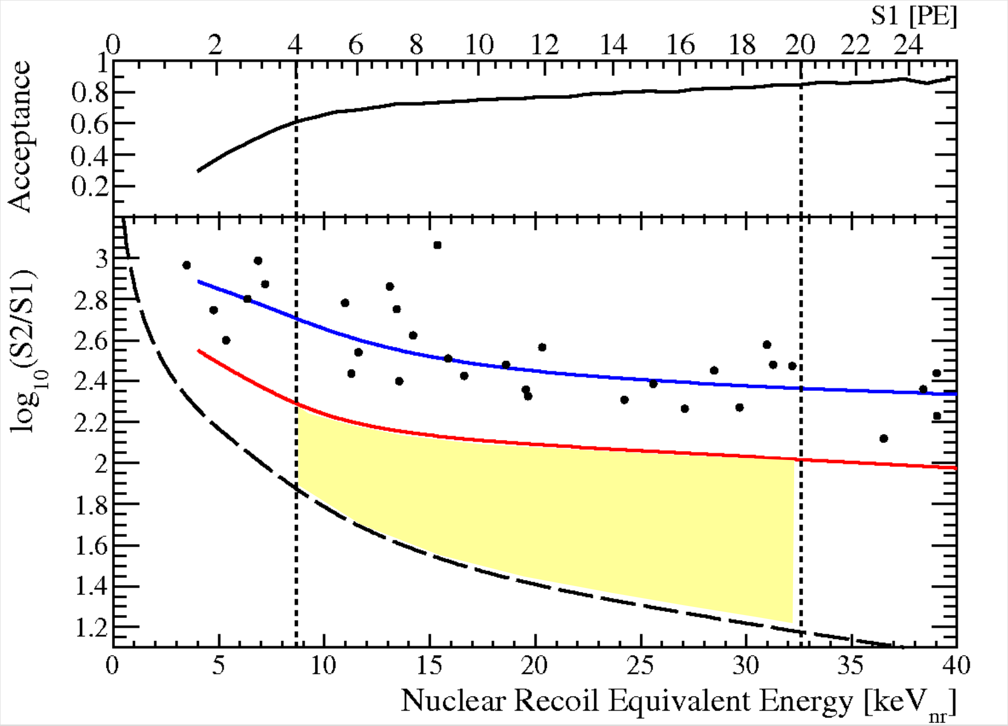
The Future: DARWIN



DARWIN – Dark Matter WIMP Search with Noble Liquids

- *R&D and Design Study* for a next generation noble liquid facility in Europe. Approved by ASPERA in late 2009
- Coordinate existing European activities in LXe and LAr towards a multi-ton Dark Matter facility
- Physics goal: probe WIMP cross sections well below 10^{-47} cm²

Summary



- Dark Matter: One of the big unsolved puzzles
- **XENON100**
  62 kg dual-phase LXe TPC
- extremely low background
- first results from 11.2d data:
  PRL 105, 131302 (2010)

Two new projects upcoming:

- **XENON1T**
  1 ton LXe target mass
- **DARWIN**
  multiton LXe/LAr detector