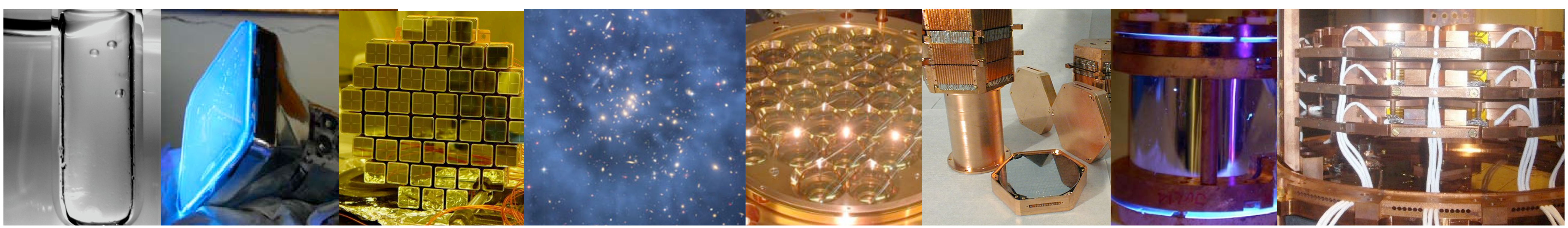
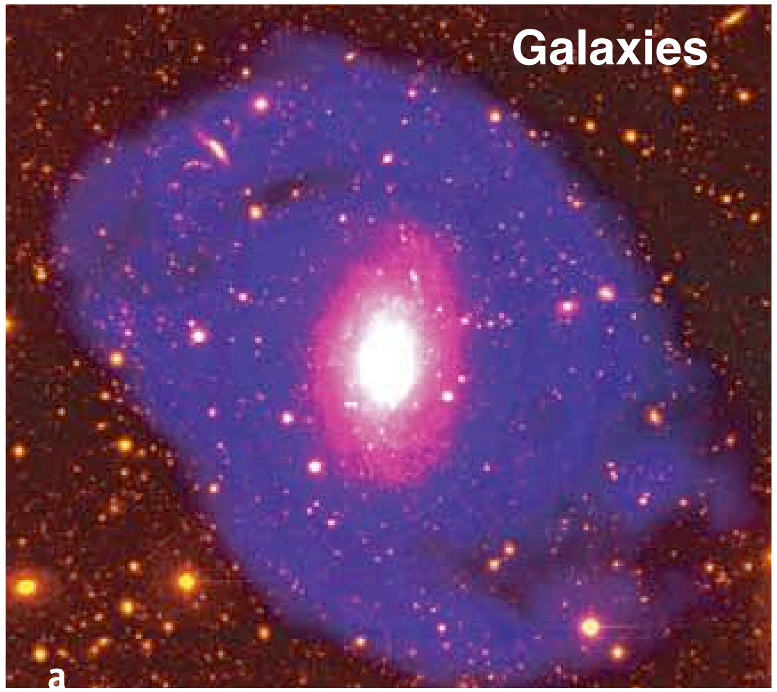
Direct Detection of Cold Dark Matter with CDMS and XENON

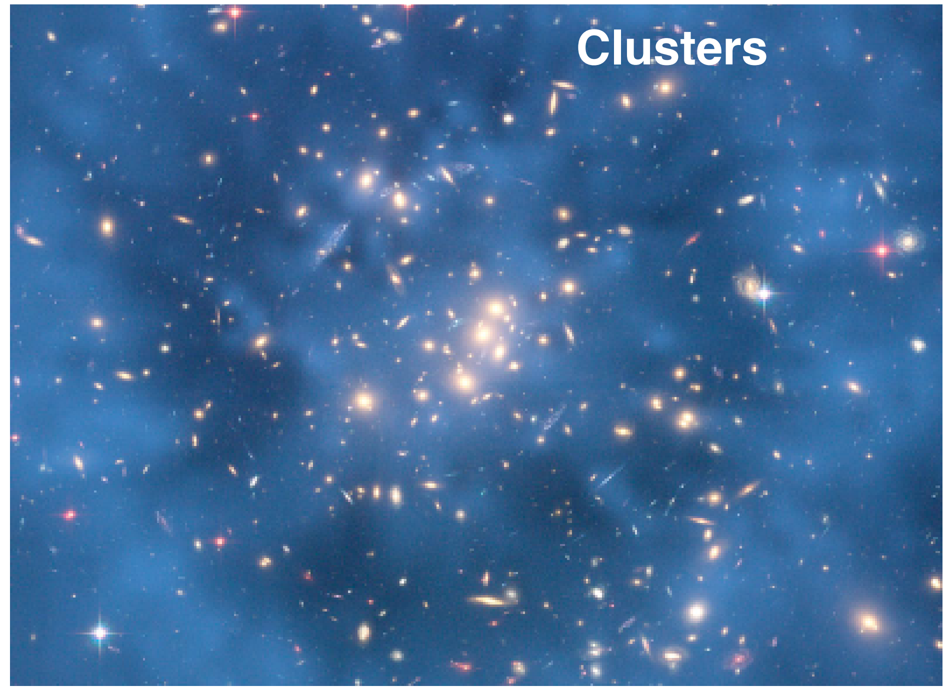
Laura Baudis, University of Zürich

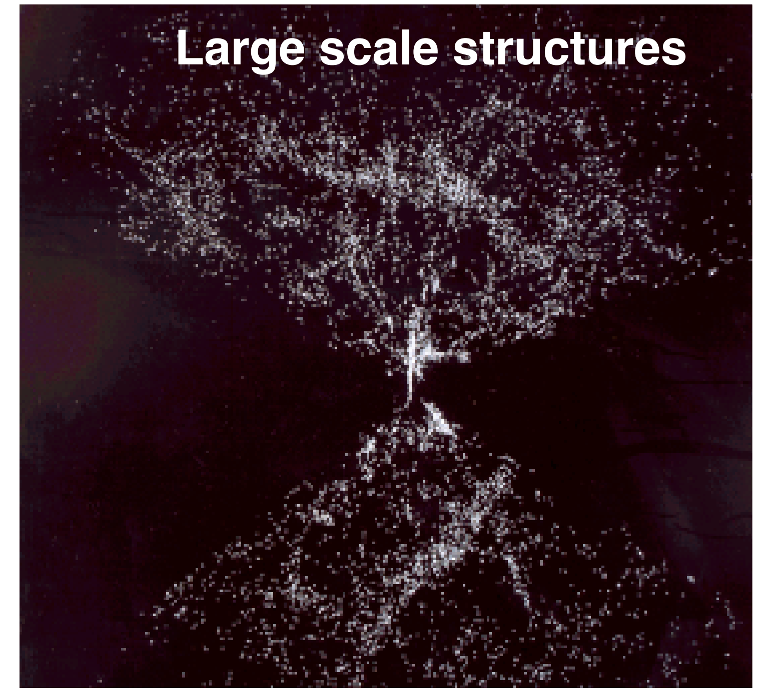
LAPP, Annecy-le-Vieux
June 27, 2008

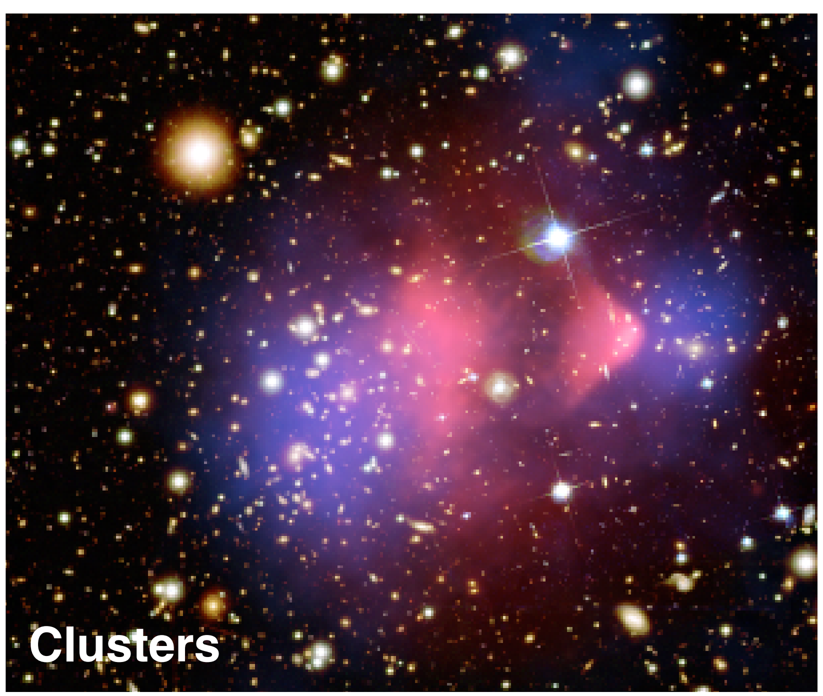


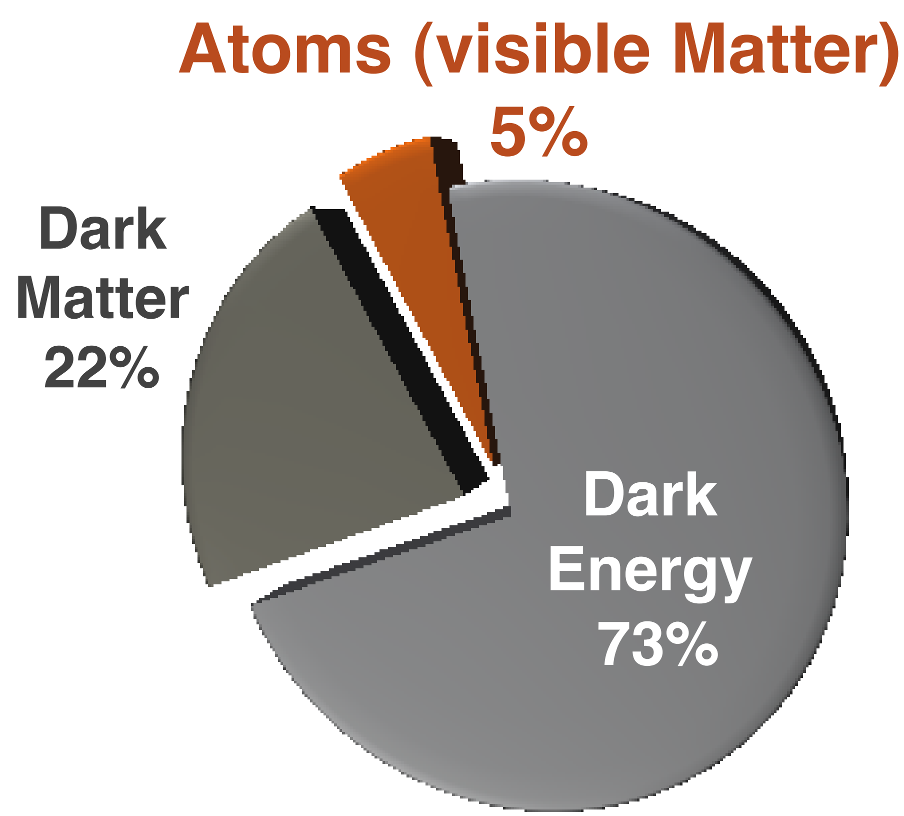
The Standard Model of Cosmology

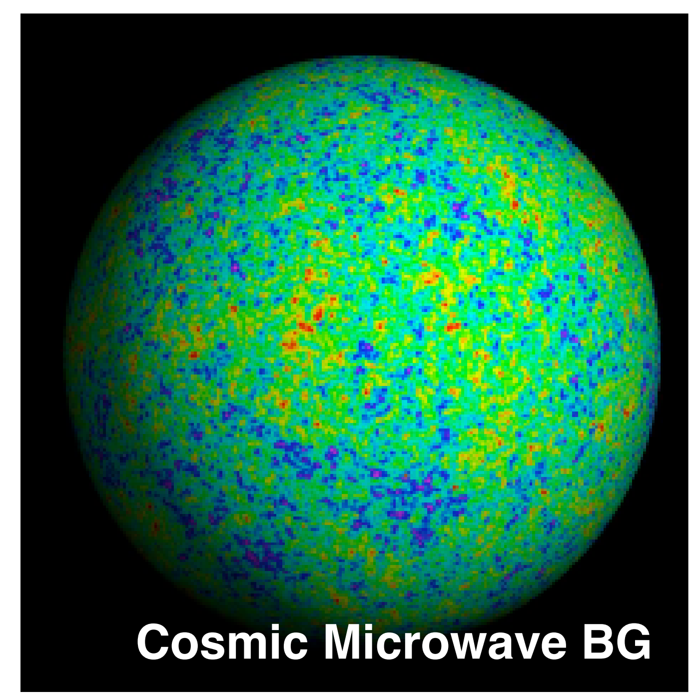




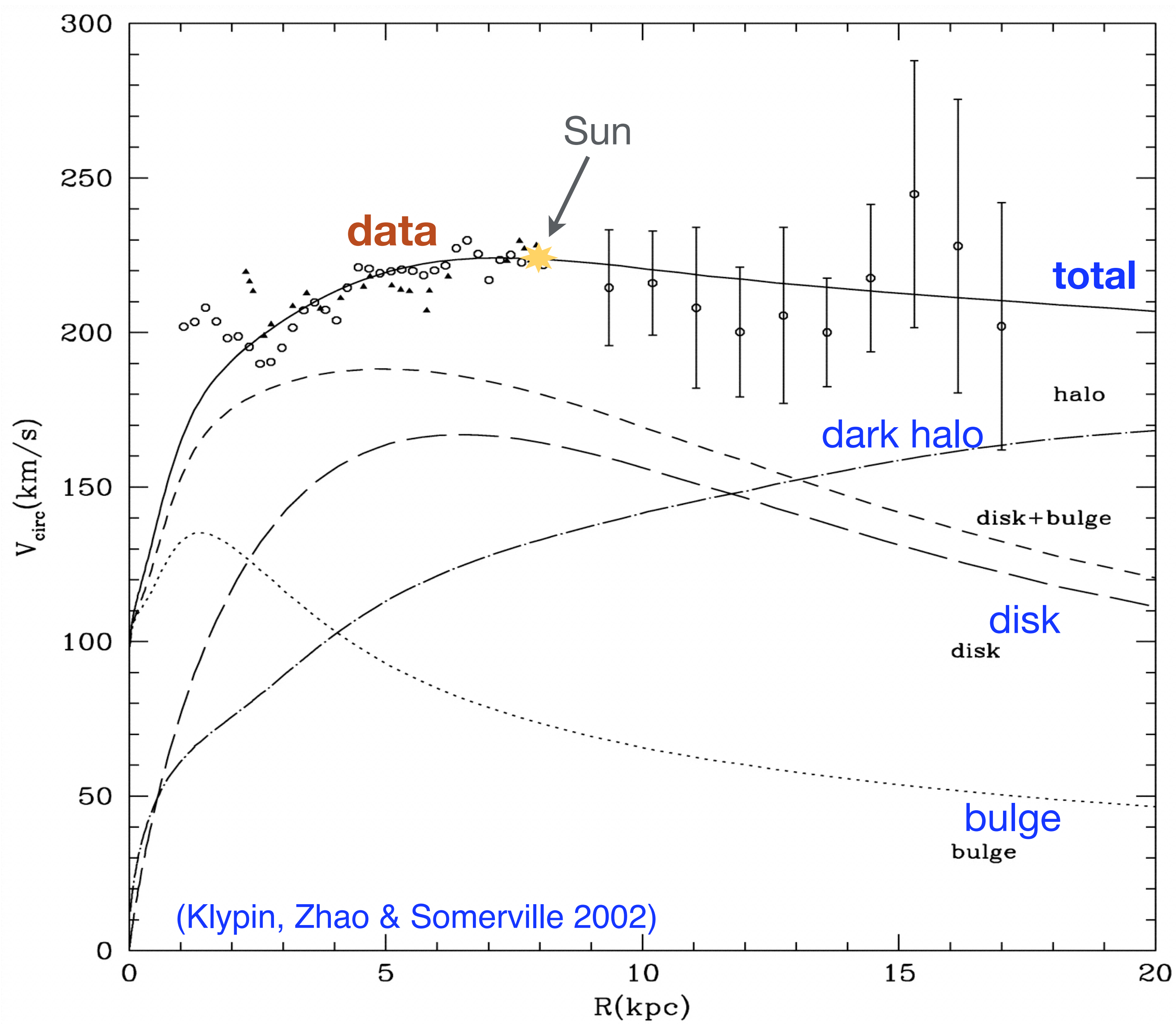








Dark Matter in the Milky Way



$$M_{tot,lum} \approx 9\times10^{10} M_{\odot}$$

$$M_{virial} \approx 1...2\times10^{12} M_{\odot}$$

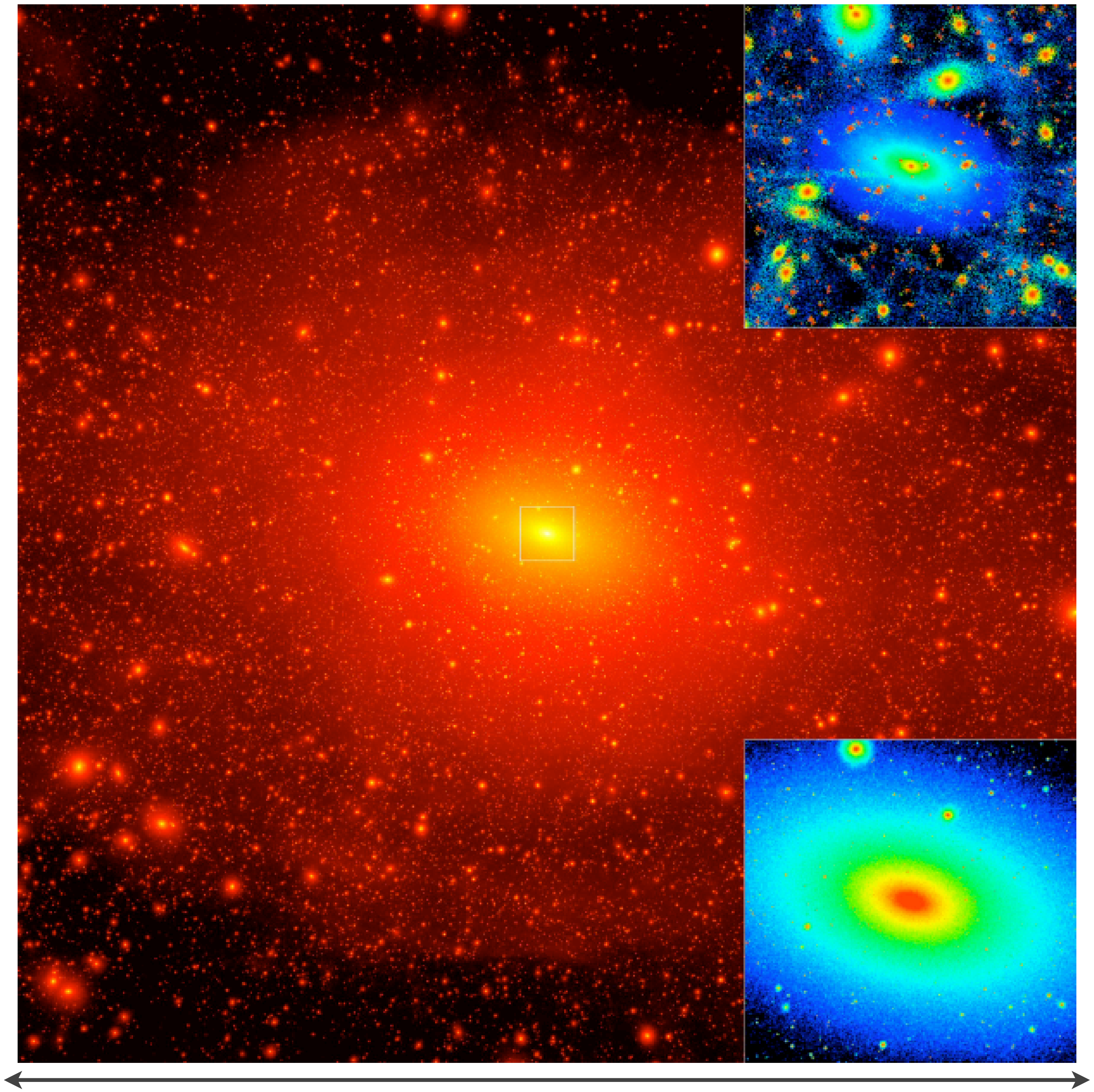
$$\rho_\chi \simeq 0.3\ GeVcm^{-3}$$

$$\rho_\chi \simeq 3000\ \mathrm{WIMPs}\cdot m^{-3}$$

$$(M_{WIMP} = 100\ \mathrm{GeV})$$

Laura

Simulations of the Milky Way Dark Halo



inner 20 kpc: phase space density

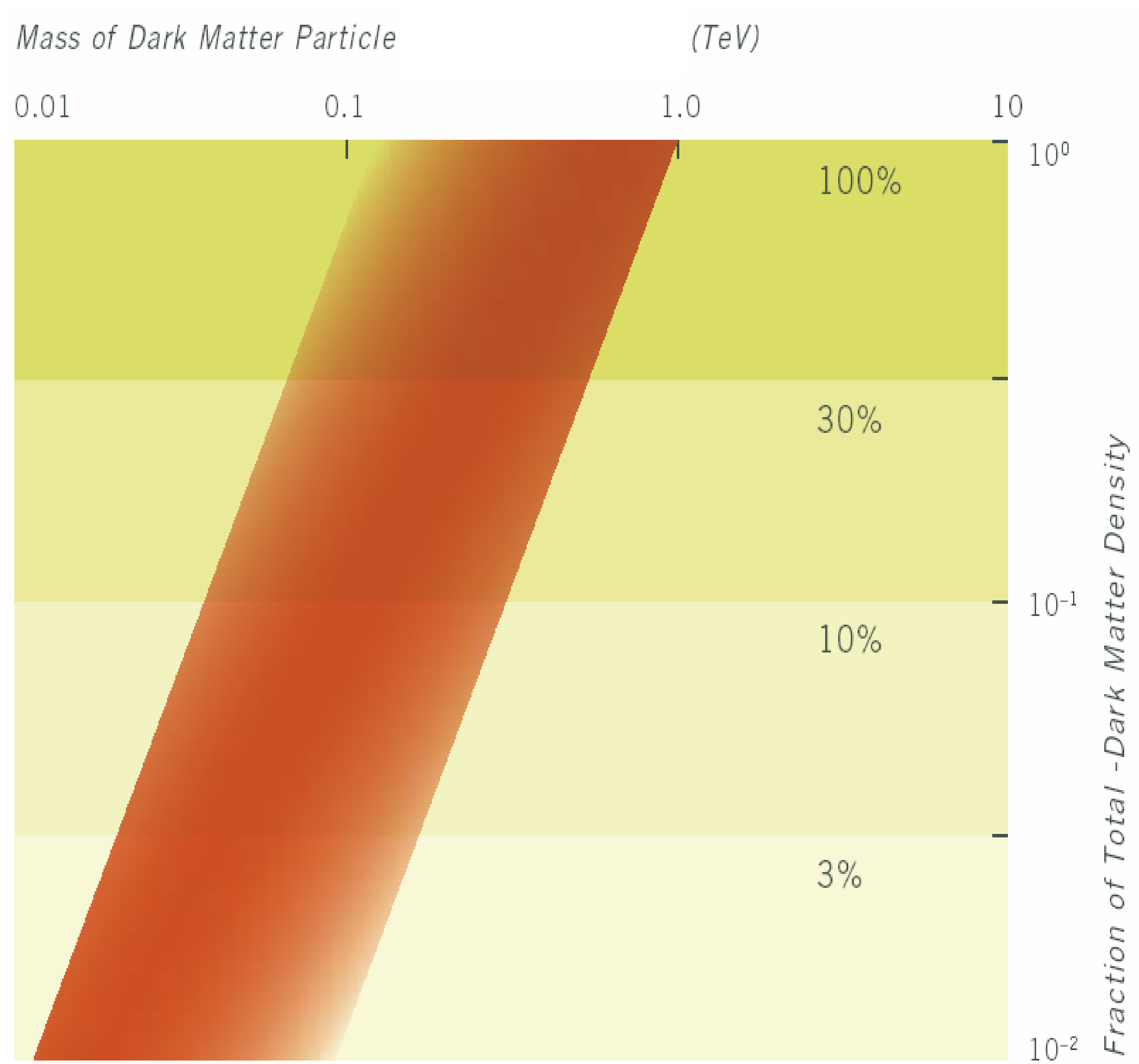
high resolution (10^9 particles) cosmological CDM simulation of a Milky Way type halo

inner 20 kpc: density

~ 600 kpc

Ben Moore et al, UZH, 2008
http://xxx.lanl.gov/pdf/0805.1244v1

Dark Matter Candidates: WIMPs



HEPAP LHC/ILC Subpanel (2006)

$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c} \approx \frac{3\times 10^{-27} cm^3 s^{-1}}{\langle \sigma_A v \rangle}$$

$$\sigma_A \sim \frac{\alpha^2}{m_\chi^2} \Rightarrow \Omega_\chi \propto m_\chi^2$$

$$\Omega_\chi \sim 0.2$$

$$\Rightarrow \langle \sigma_A v \rangle \sim 1 \text{ pb}$$

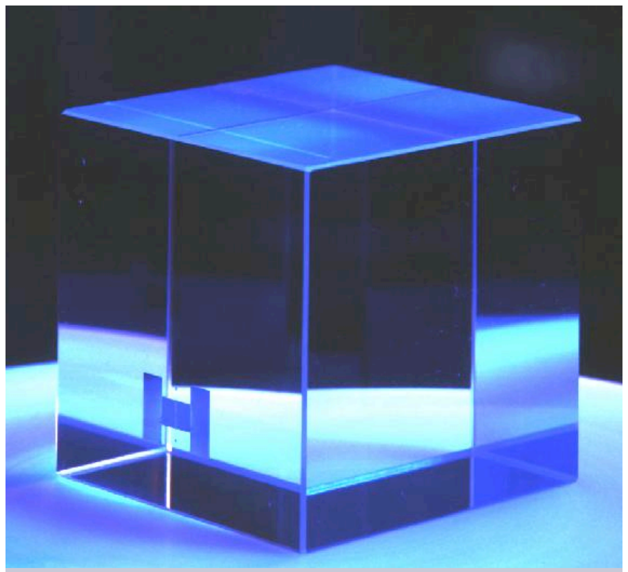
$$\Rightarrow m_\chi \sim 100 \text{ GeV - 1TeV}$$

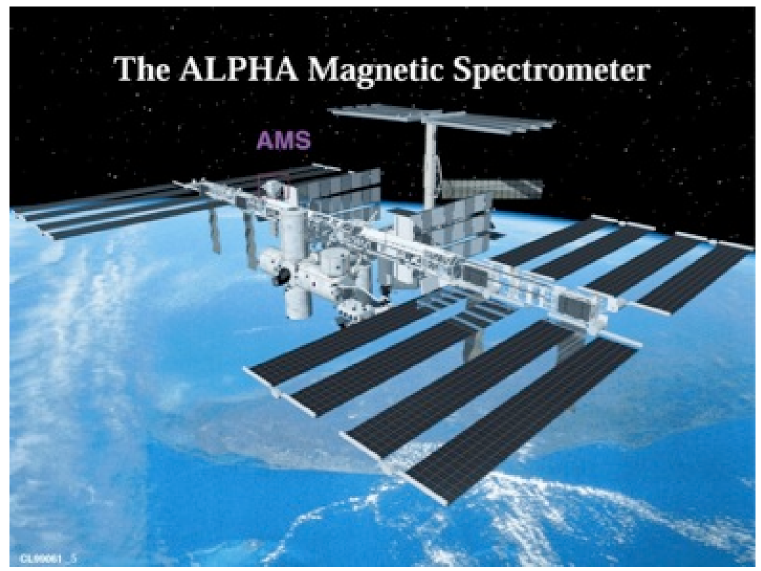
⇒ the relic density and mass point to the **weak scale**

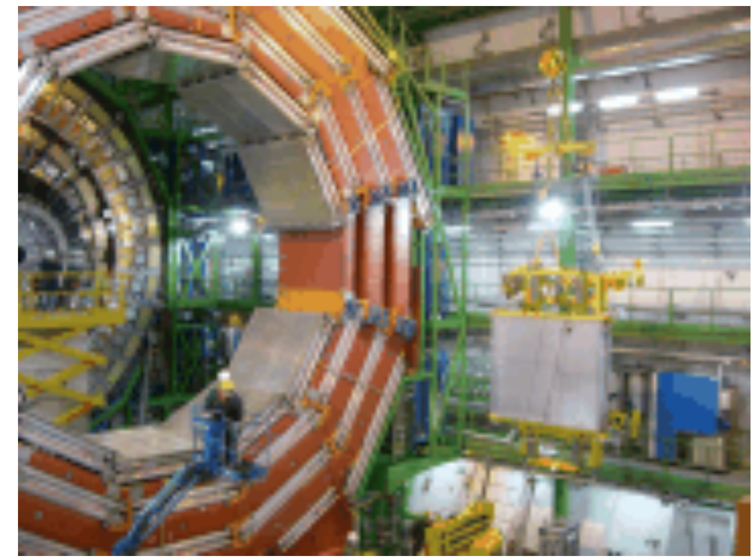
⇒ the new physics responsible for EWSB likely gives rise to a **dark matter candidate**

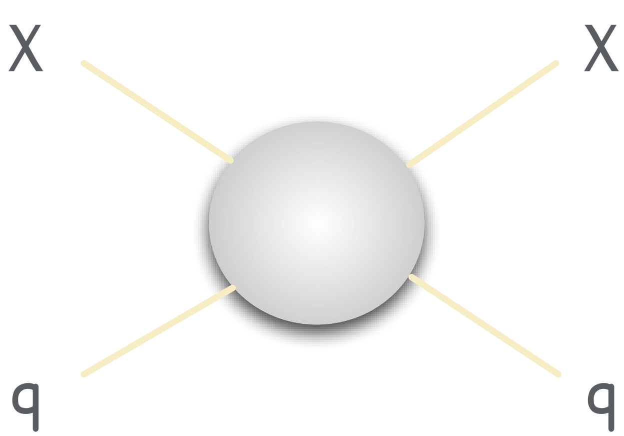
⇒ examples: LSP (neutralino), LKP (KK-partner of photon, or KK-partner of Z-boson)

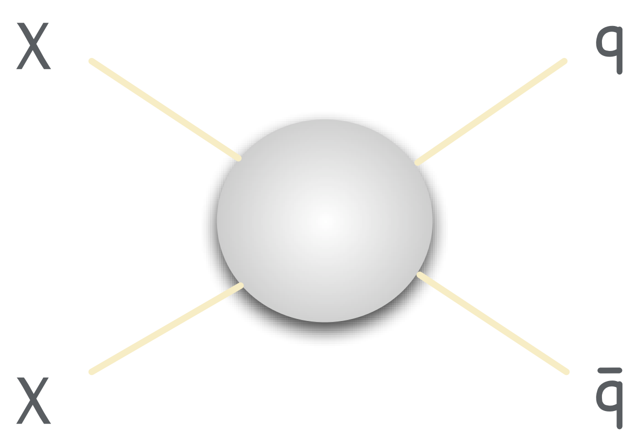
Approaches to (WIMP) Dark Matter Detection

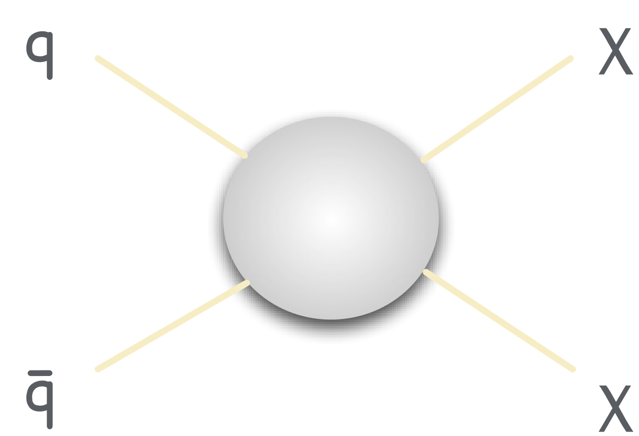










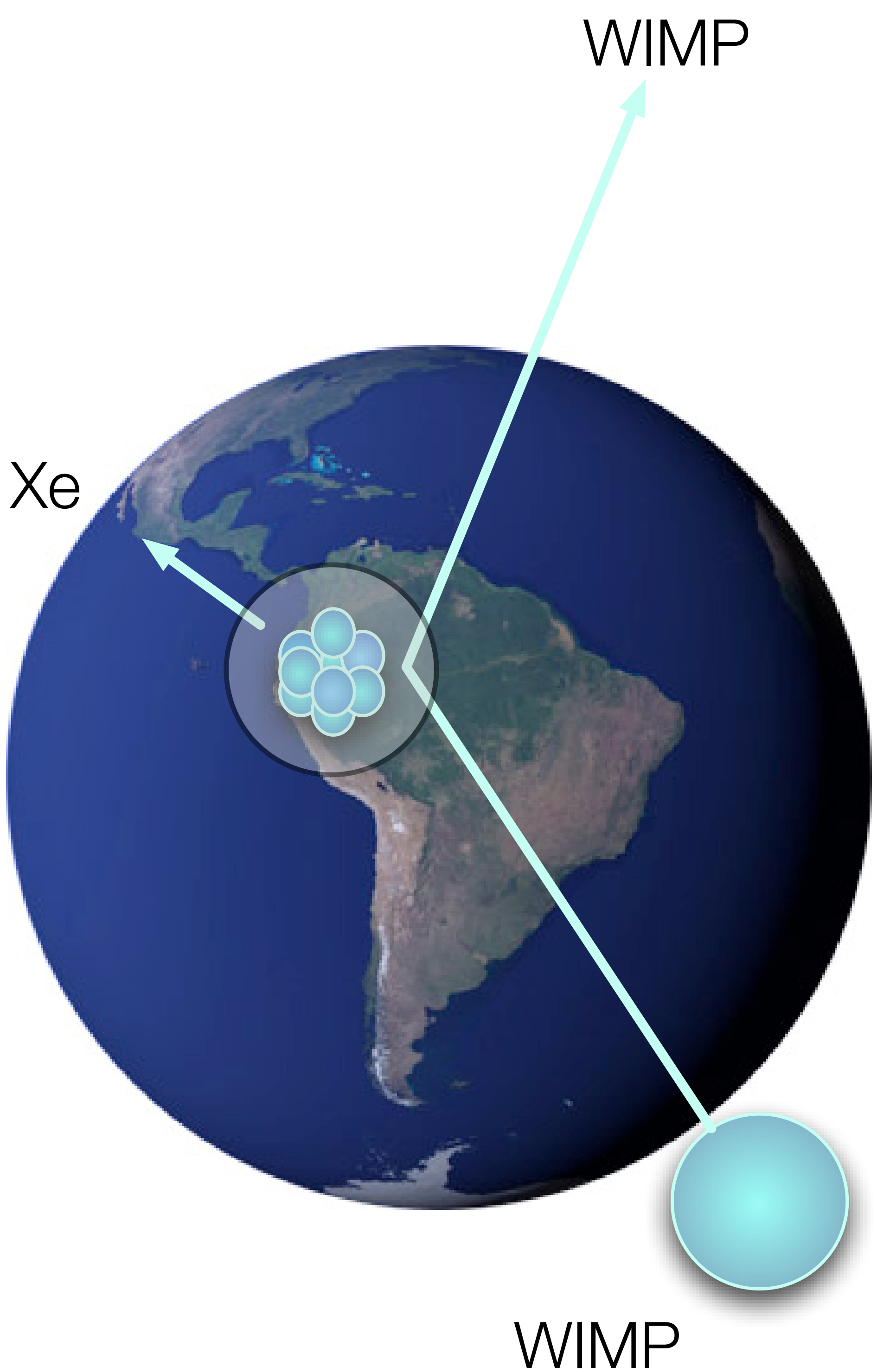


Direct

Indirect

Colliders

WIMP Detection: Scattering off Atoms



- Elastic collisions with atomic nuclei
- The recoil energy is:

$$E_R = \frac{|\vec{q}|^2}{2m_N} = \frac{\mu^2 v^2}{m_N}(1-\cos\theta) \leq 50\ keV$$

- and the expected rate:

Astrophysics

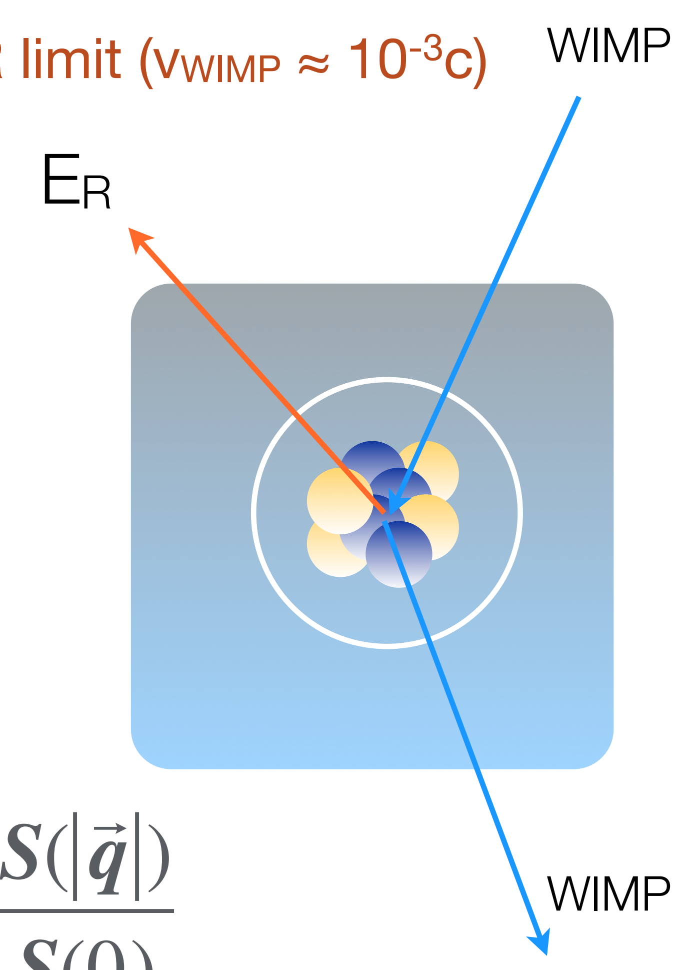
$$R \propto N \frac{\rho_\chi}{m_\chi} \sigma_{\chi N} \cdot \langle v \rangle$$

Detector

Particle physics

Cross section for elastic WIMP scattering

- Calculate the interaction of WIMPs with quarks and gluons (model dependent)
- Calculate the interaction with nucleons (need matrix elements of quark and gluon operators in a nucleon state)
- Calculate WIMP-nucleus cross section, using nuclear wave functions (‘coherence loss’ will reduce the cross section for heavy WIMPs/nuclei)
- Simplification: the WIMP-nucleus scatter takes place in the extreme NR limit ($v_{WIMP} \approx 10^{-3}c$)



➡ **scalar interaction** (WIMP couples to nuclear mass)

$$\frac{d\sigma}{d|\vec{q}|^2} = \frac{1}{\pi v^2}[Zf_p + (A-Z)f_n]F^2(E_R)$$

➡ **spin-spin interaction** (WIMP couples to nuclear spin)

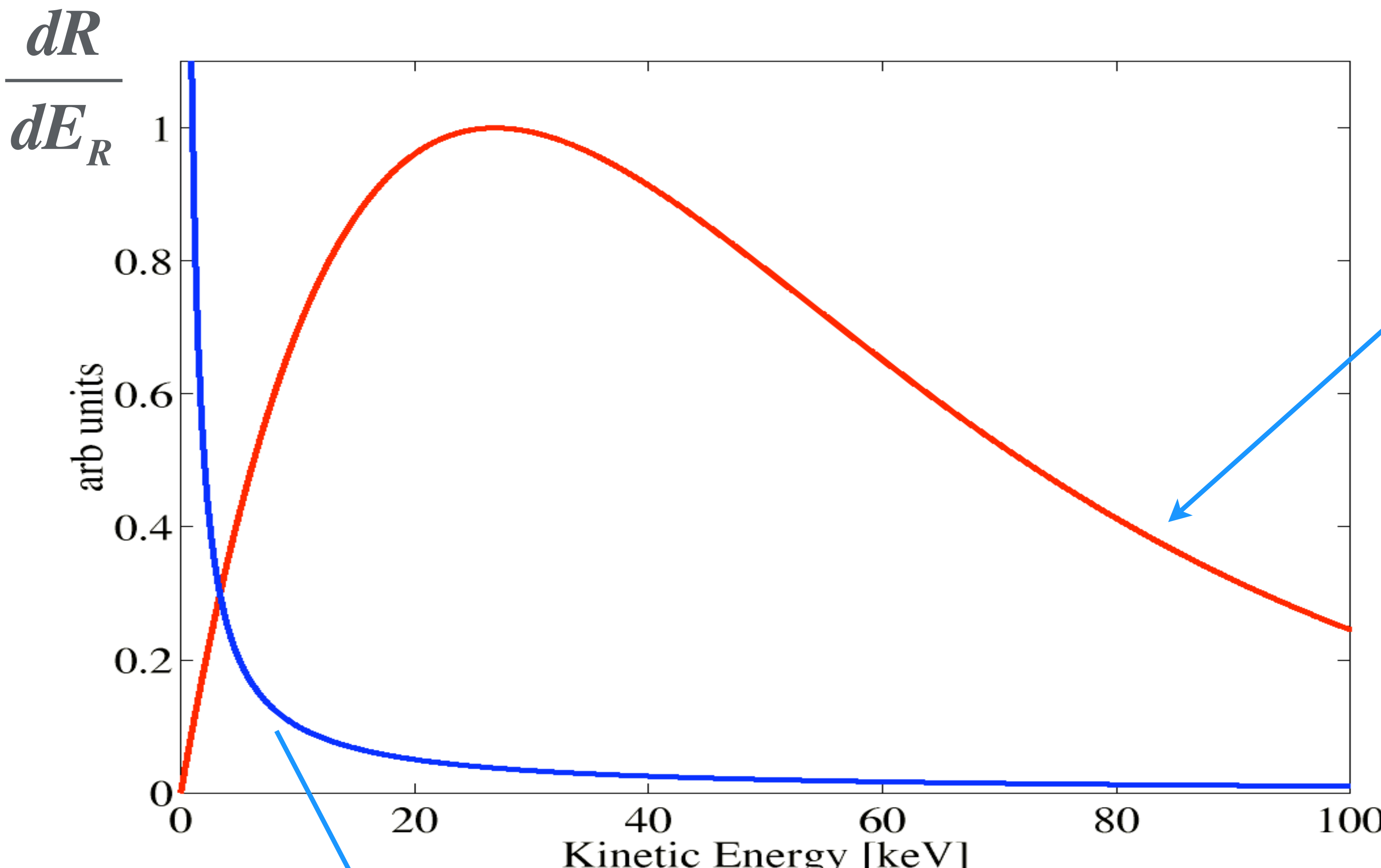
$$\frac{d\sigma}{d|\vec{q}|^2} = \frac{8}{\pi v^2}\frac{J+1}{J}G_F^2[a_p\langle N|S_p|N\rangle + a_n\langle N|S_n|N\rangle]\frac{S(|\vec{q}|)}{S(0)}$$

Event Rate in a WIMP Detector

$$\frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{2 m_\chi \mu^2} F^2(E_R) \int_{v_{min}}^{v_{max}} \frac{f(v)}{v} dv$$

$$f(v)dv = \frac{4v^2}{v_0^3 \sqrt{\pi}} e^{-v^2/v_0^2} d^3 v$$

WIMP velocity distribution



$$F^2(E_R) = \left[\frac{3 j_1(qR_1)}{qR_1} \right]^2 e^{-(qs)^2}$$

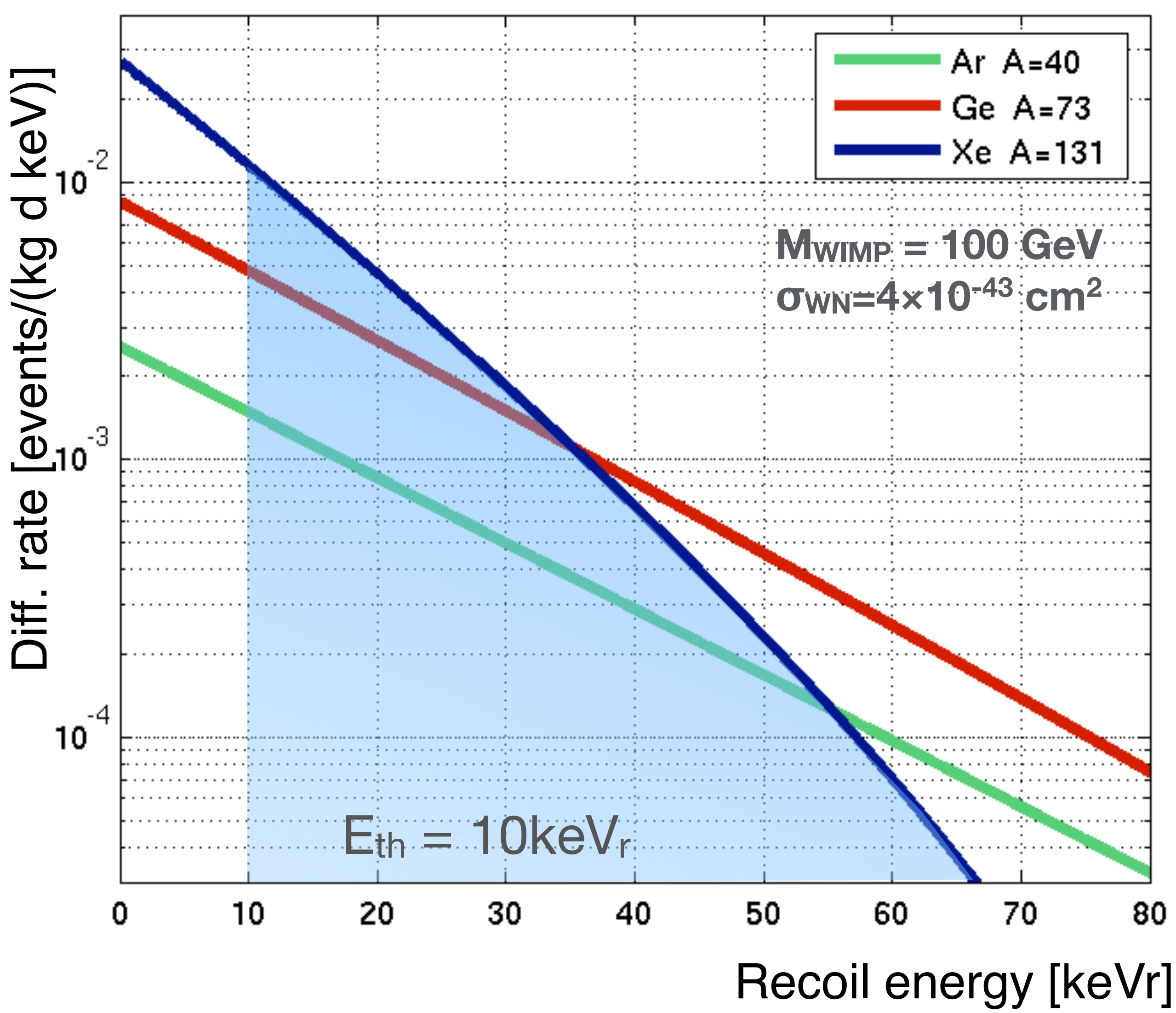
Wood-Saxon form factor (scalar couplings)

nuclear recoil spectrum (depends on the WIMP mass)

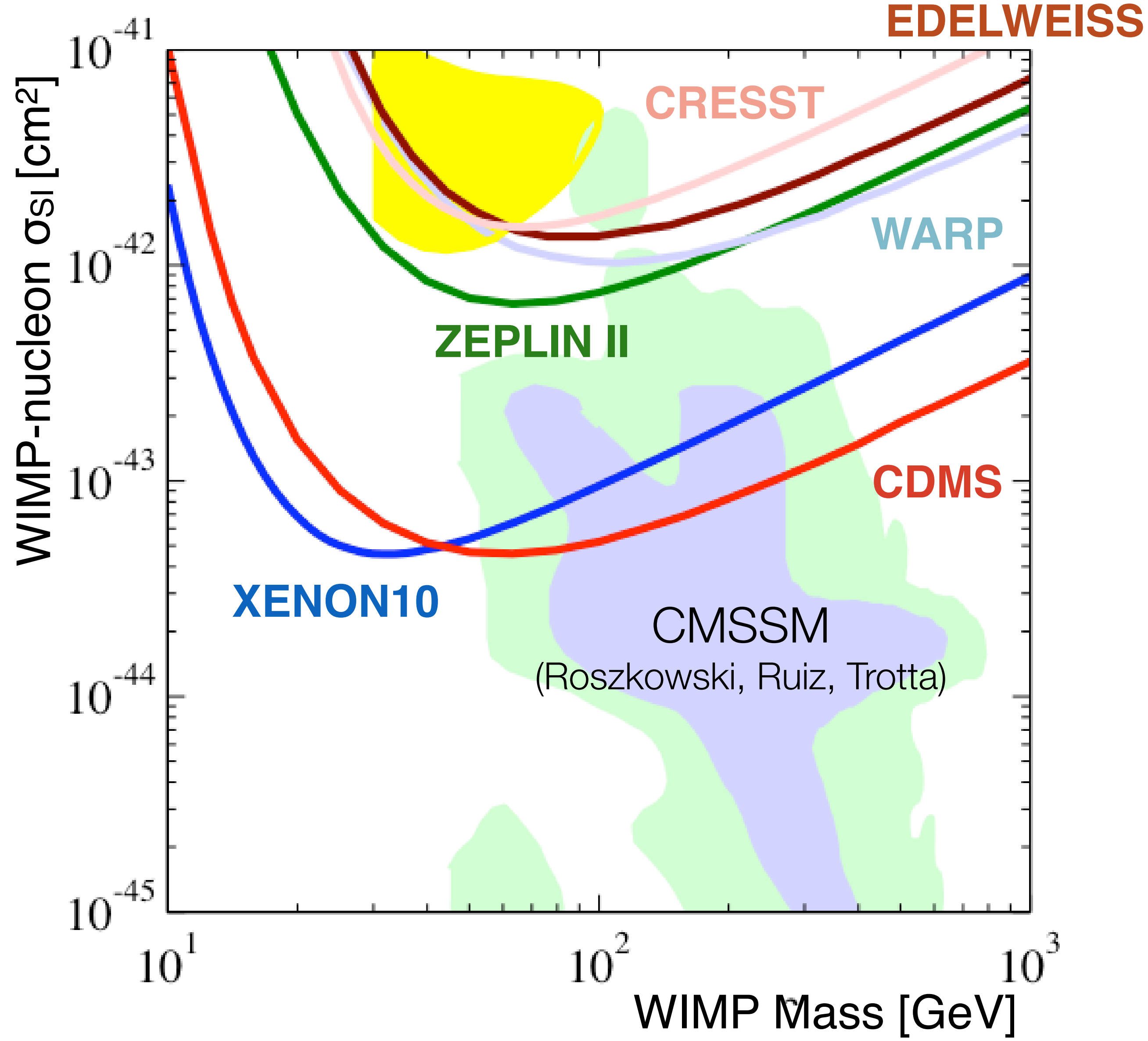
Predicted Rates in Different WIMP Targets

- Cross sections on nucleons: below ~ 10^{-7} pb!
- **Rates: << 1 event/kg/month**

Differential rates for different targets

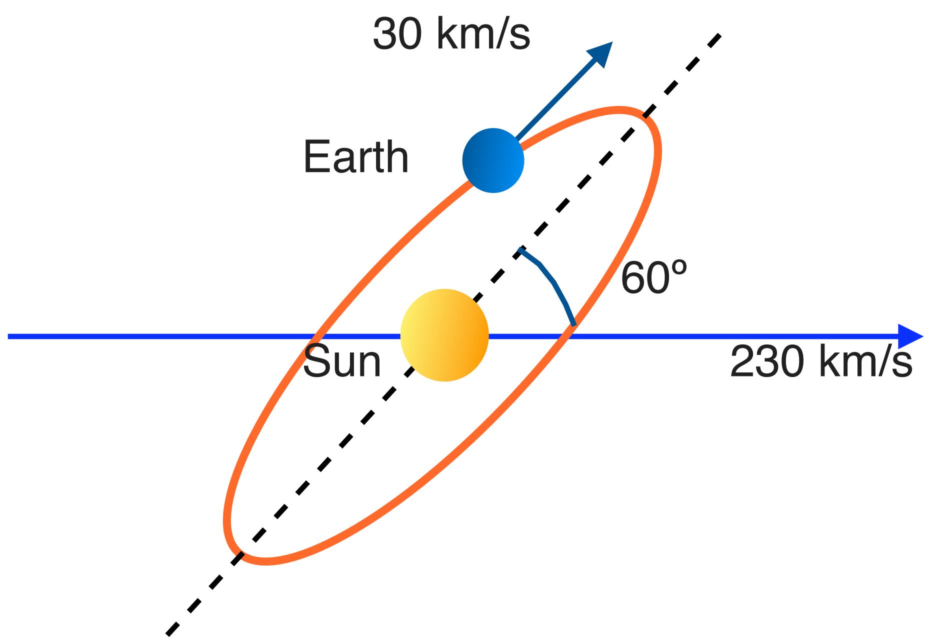


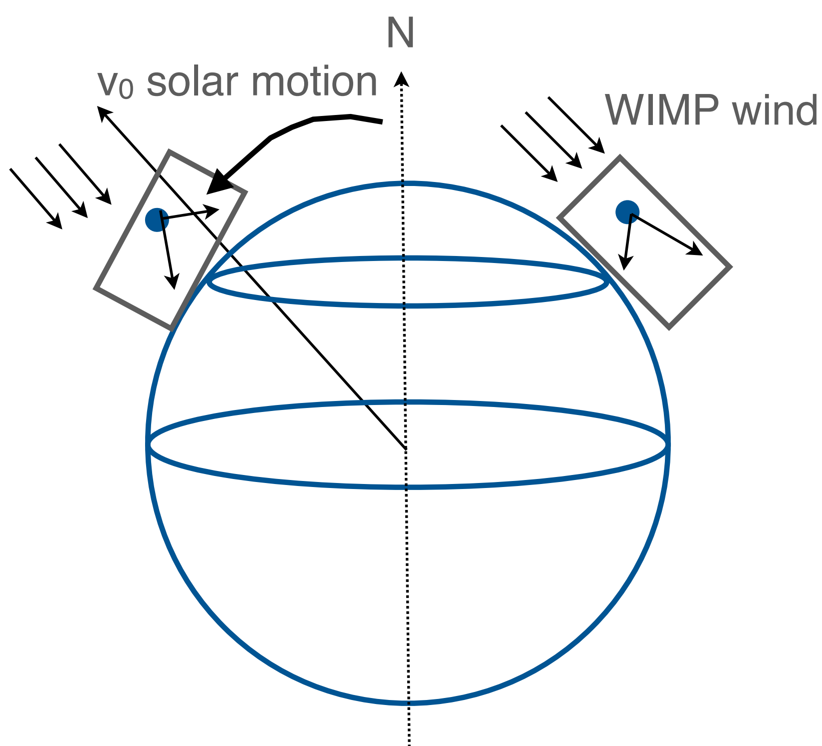
Cross sections (normalized to nucleons)



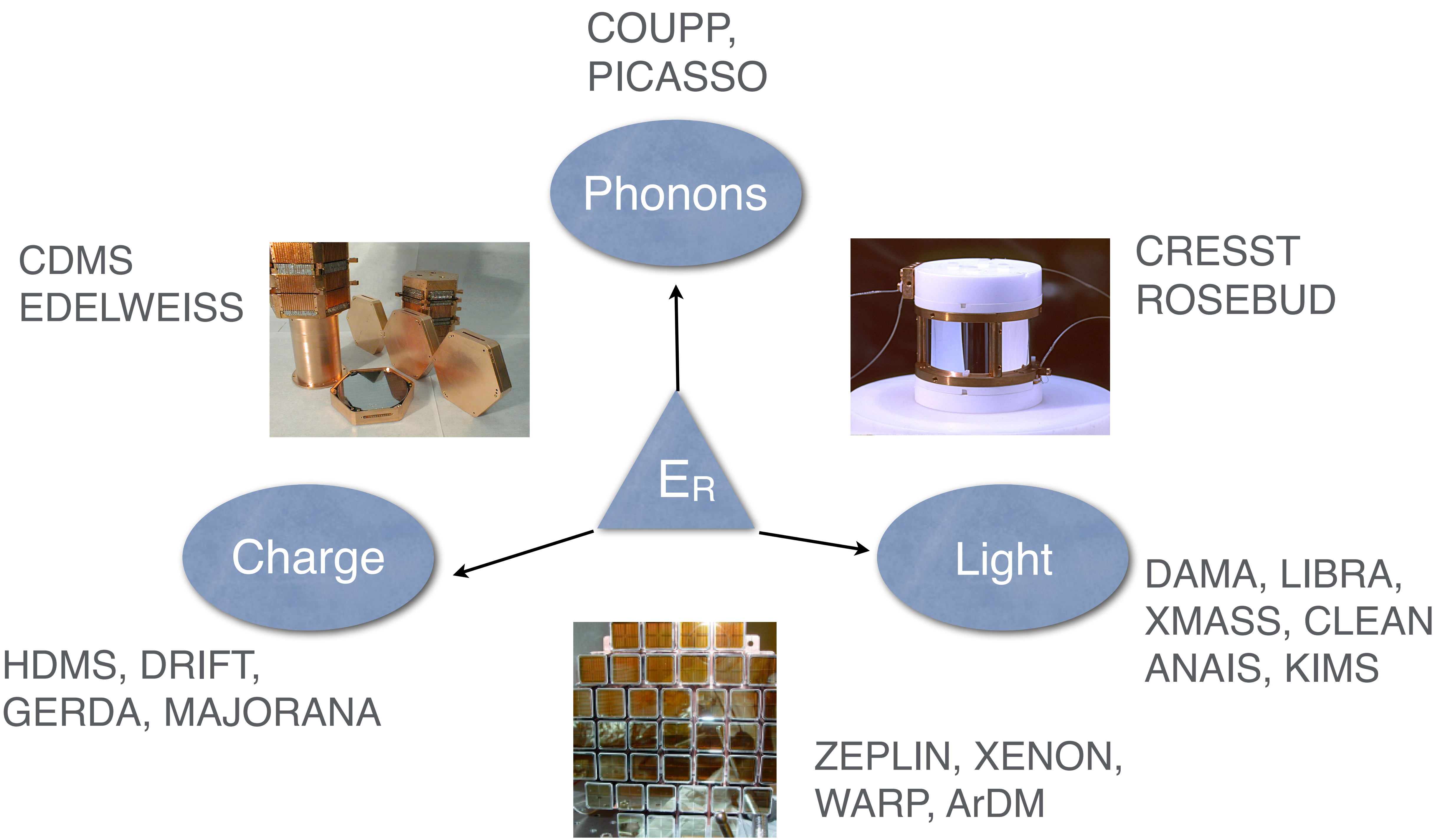
WIMP Signatures

- **WIMP interactions in detector should be:**
  - nuclear recoils
  - single scatters, uniform throughout detector volume
- **Spectral shape** (exponential, however similar to background)
- **Dependance on material** (A^2, $F^2(Q)$, test consistency between different targets)
- **Annual flux modulation** (~ 3% effect, most events close to threshold)
- **Diurnal direction modulation** (larger effect, requires low-pressure gas target)



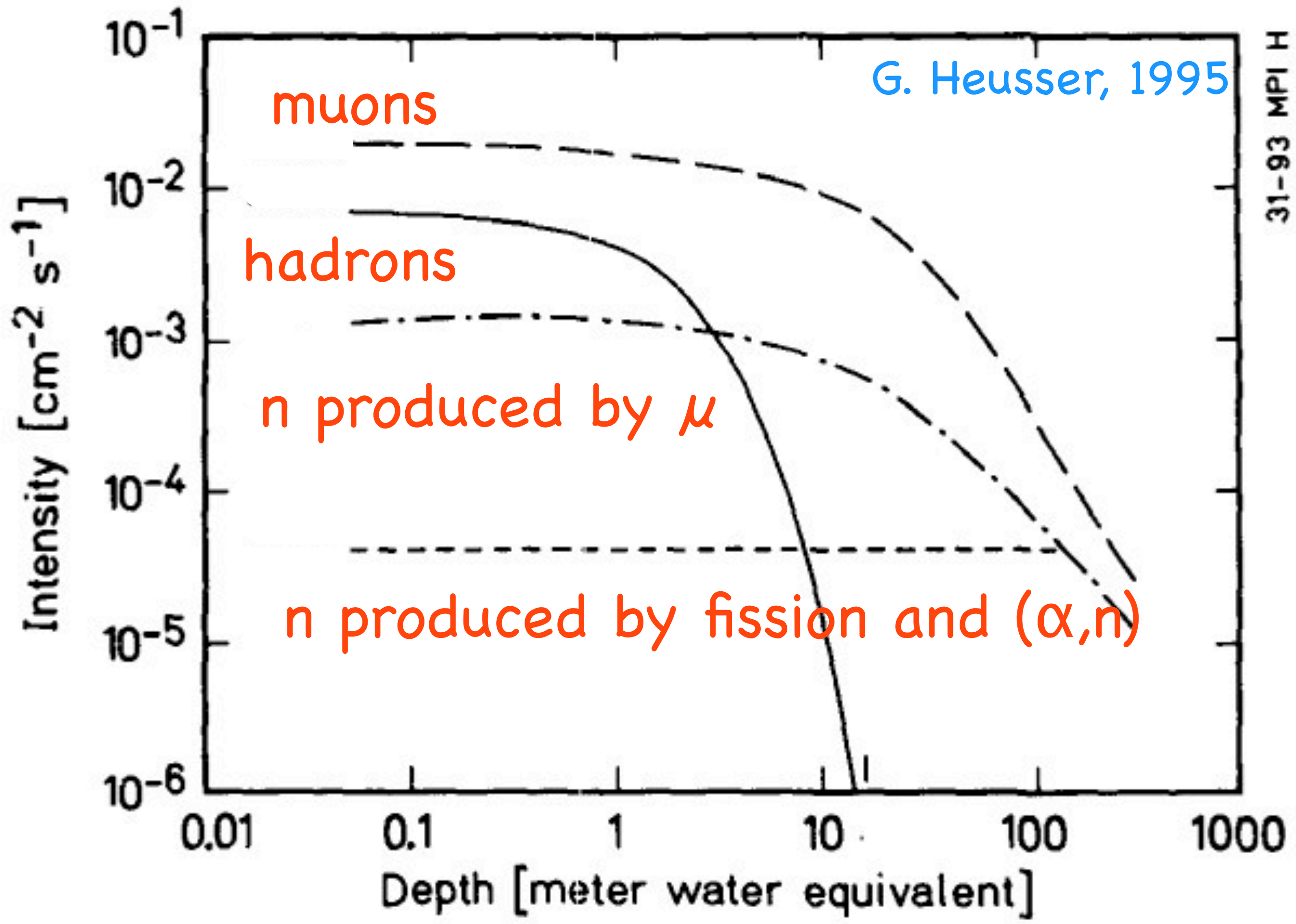


Direct WIMP Detection Experiments



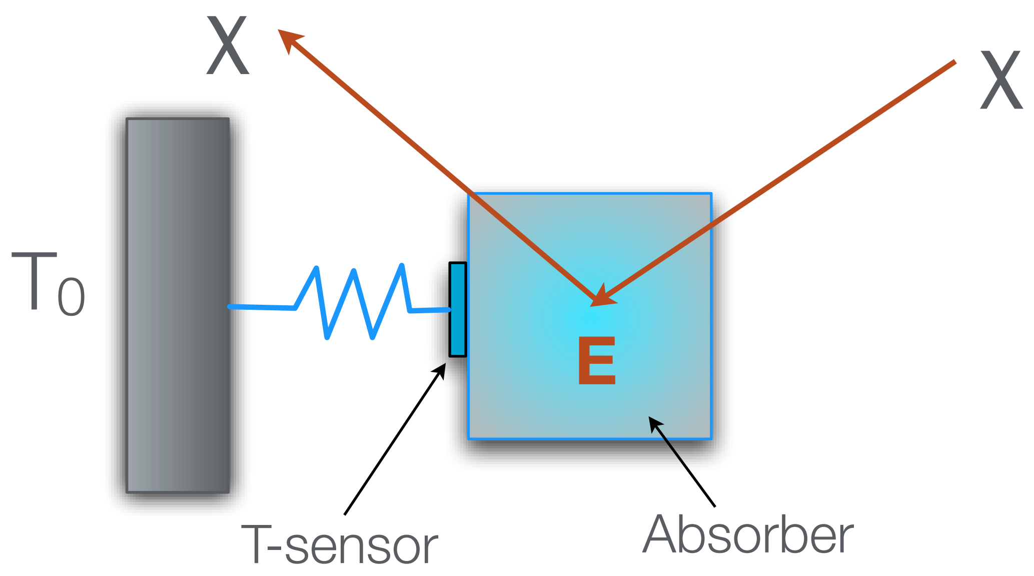
Challenges of Direct Detection Experiments

- **Low event rates** ⇒ ton-scale detectors
- **Small deposited energies** ⇒ low (~ few keV) energy thresholds
- **Low backgrounds**
  - shield against cosmic rays (deep underground laboratories → μ-spallation reactions)
  - low intrinsic radio-activity (ultra-pure materials → (α,n)-reactions)
  - shield radio-activity from surroundings (Pb, PE, H_2O, etc)
- **Good background rejection**
  - Particle identification
    - nuclear vs. electron recoils
  - Identification of surface events
  - Position sensitivity/fiducialisation
  - Self-shielding



Cryogenic Experiments at mK Temperatures

- **Principle:** a deposited energy E produces a temperature rise ΔT



$$\Delta T \propto \frac{E}{C(T)}$$

$$T \ll T_c \Rightarrow C(T) \propto T^3$$

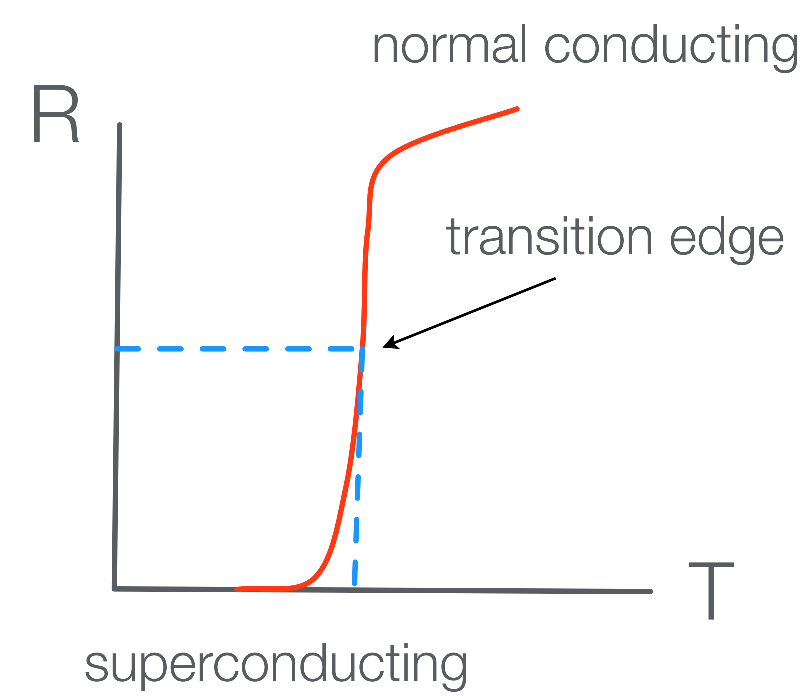
=> the lower T, the larger ΔT per unit of absorbed energy

- **T-sensors:**
  - **superconductor thermistors**

    (highly doped superconductor): NTD Ge → EDELWEISS
  - **superconduction transition sensors**

    (thin films of SC biased near middle of normal/SC transition):

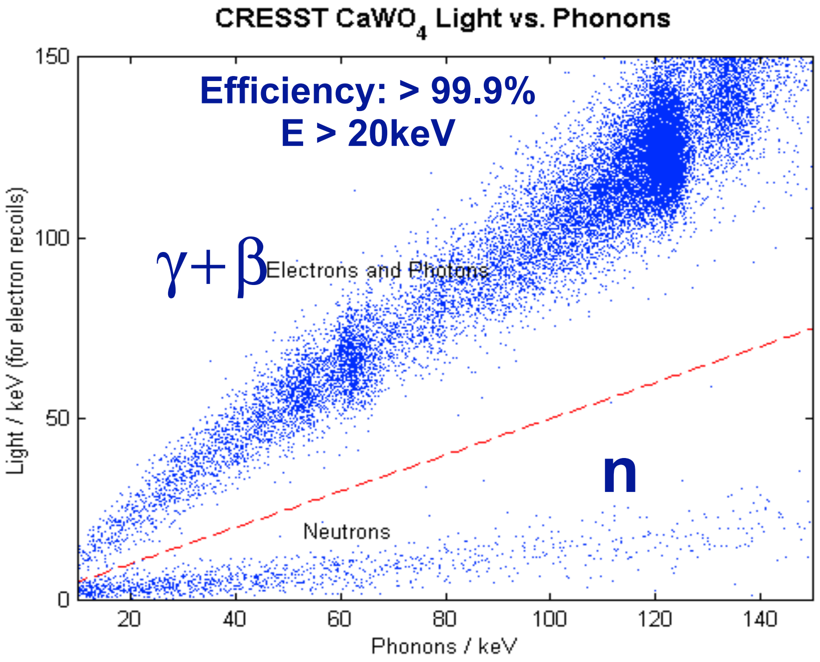
    TES→CDMS, SPT→CRESST



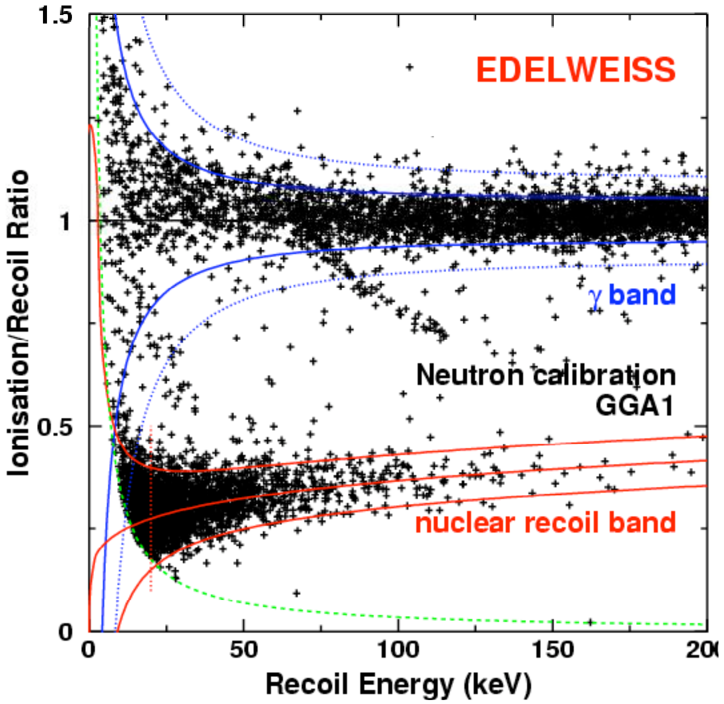
Cryogenic Experiments at mK Temperatures

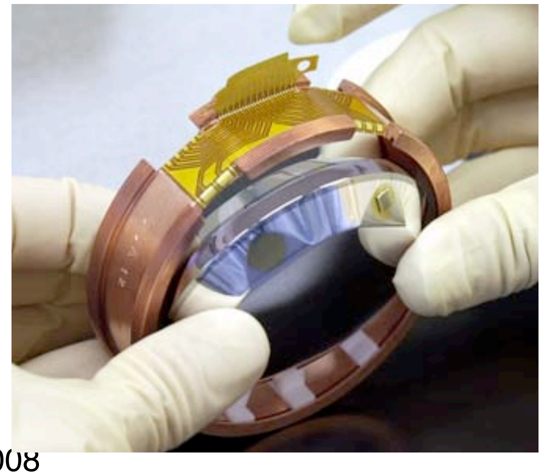
- **Advantages**: high sensitivity to nuclear recoils
  - measuring the full nuclear recoil energy in the phonon channel
  - low energy threshold (keV to sub-keV), good energy resolution
  - light/phonon and charge/phonon: nuclear vs. electron recoil discrimination

CRESST at LNGS

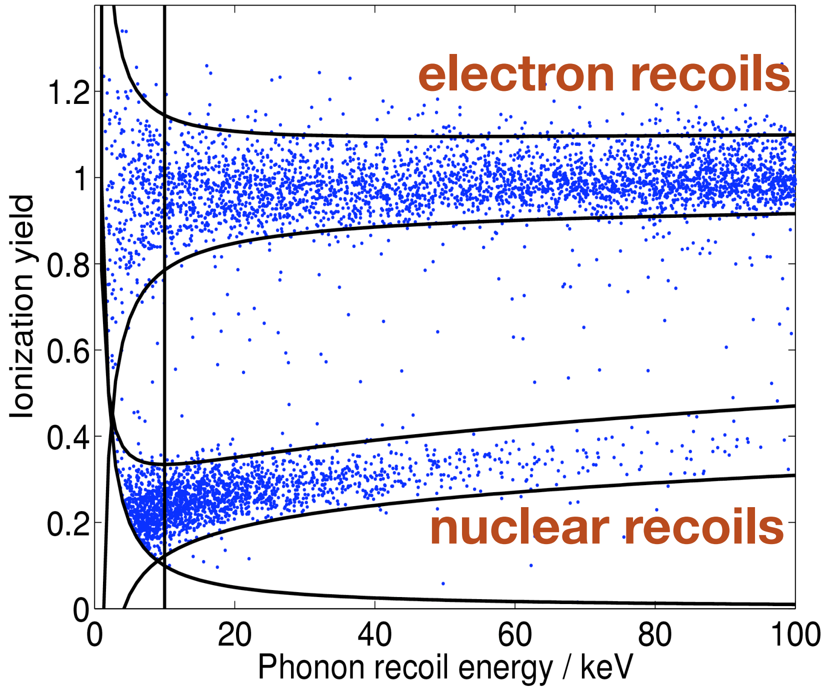


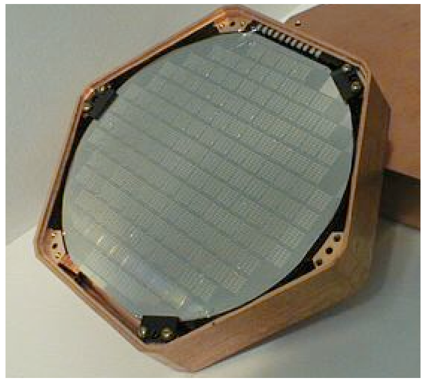
EDELWEISS at LSM





CDMS at Soudan

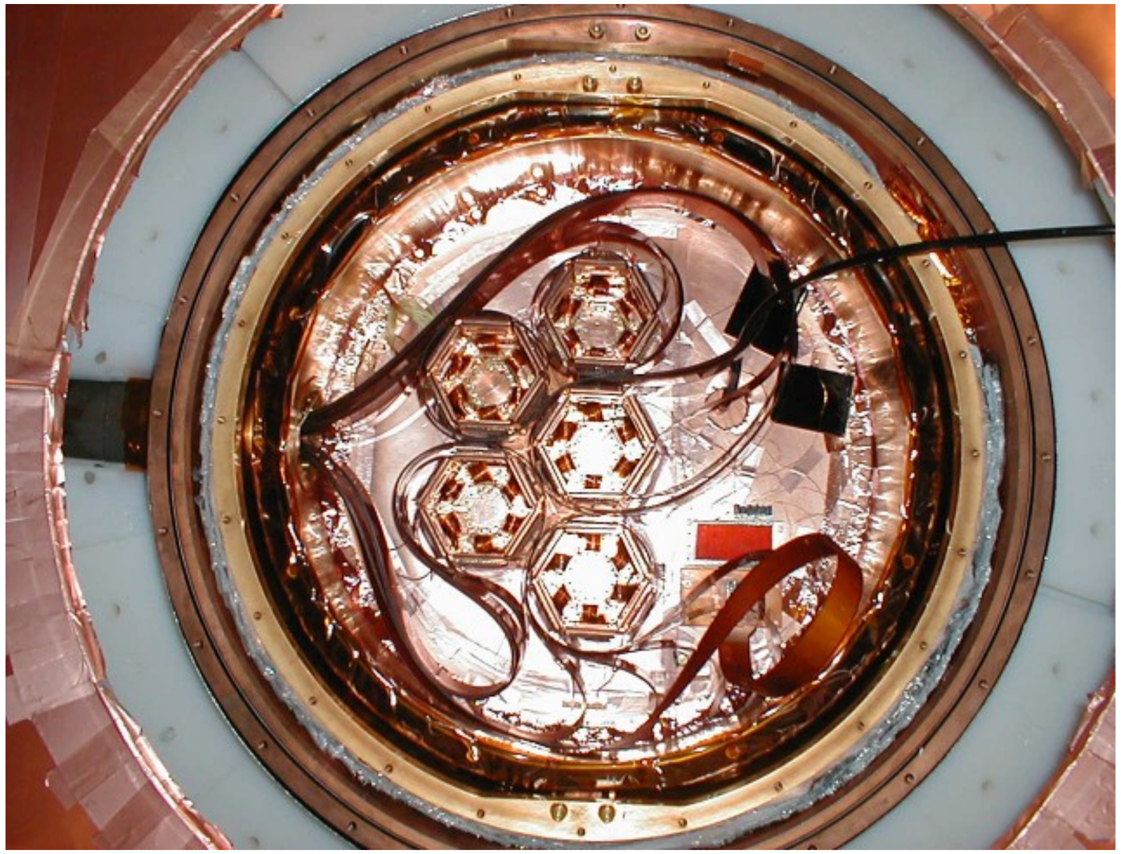




The CDMS Experiment at the Soudan Mine

At the Soudan Lab in Minnesota:
neutron background reduced from
1/kg/day → 1/kg/year

5 towers a 6 Ge/Si detectors
in the 'icebox' at ≈ 20 mK



The CDMS Collaboration

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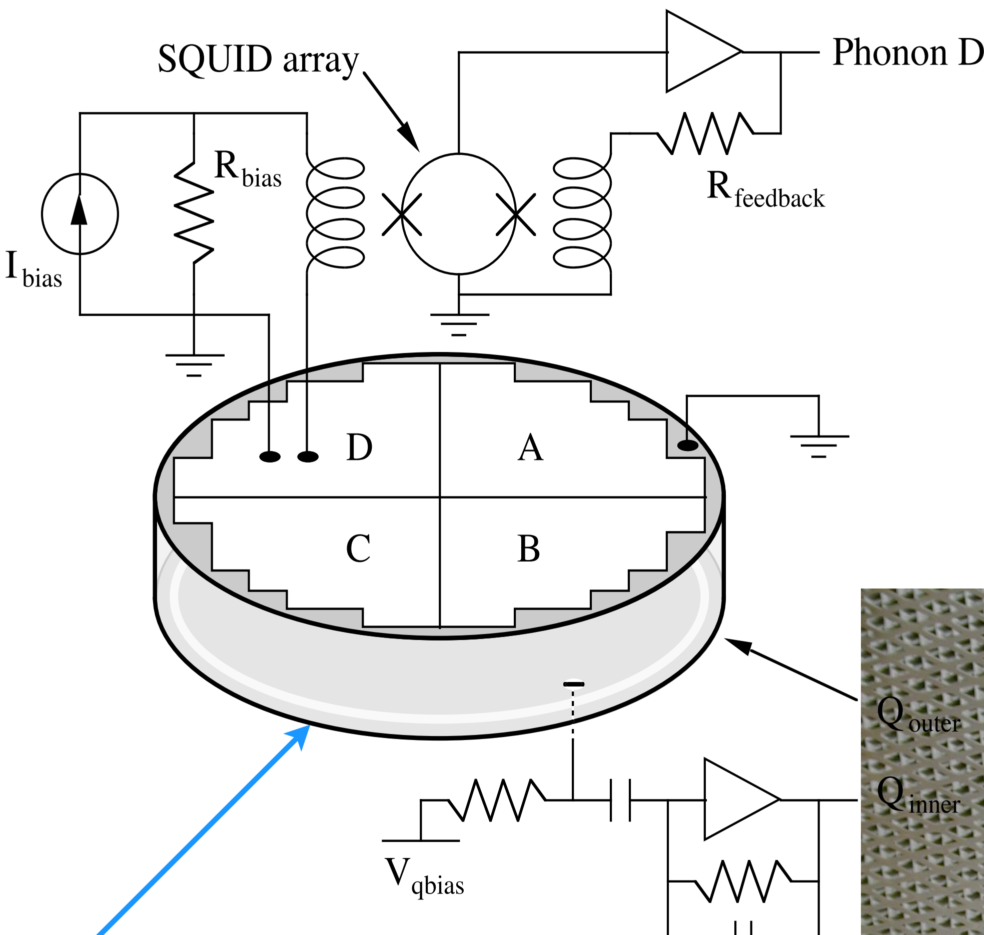
CDMS Detectors



Absorber:

250 g Ge or 100 g Si crystals

1 cm thick x 7.5 cm diameter

T-sensors:

photolithographically patterned thin films of Al+W, collecting athermal phonons

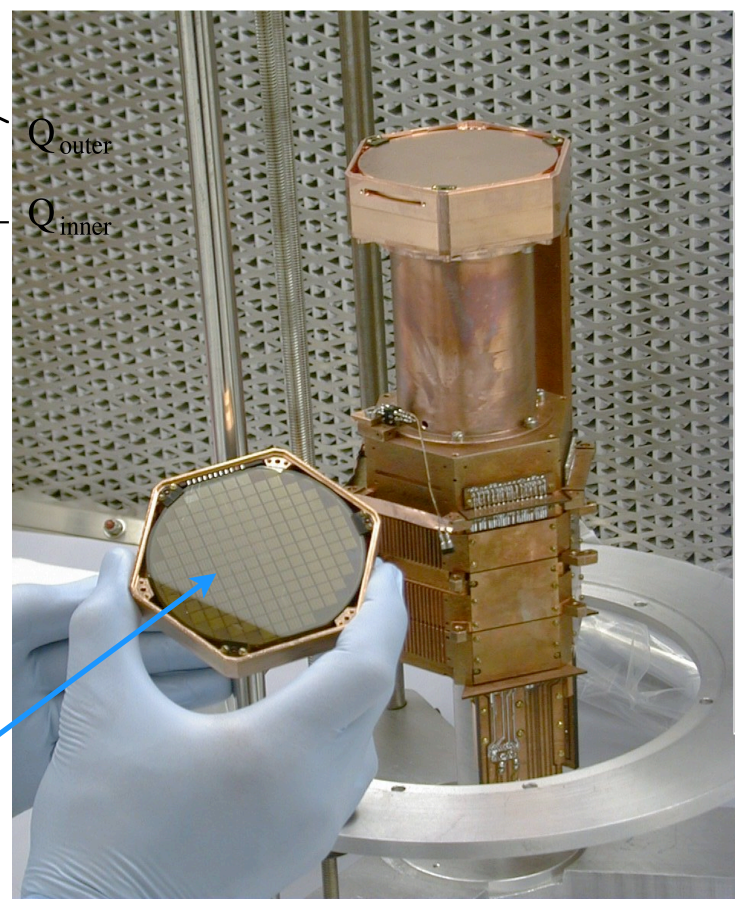
2 charge electrodes:

inner (Q_{inner}) disk shaped

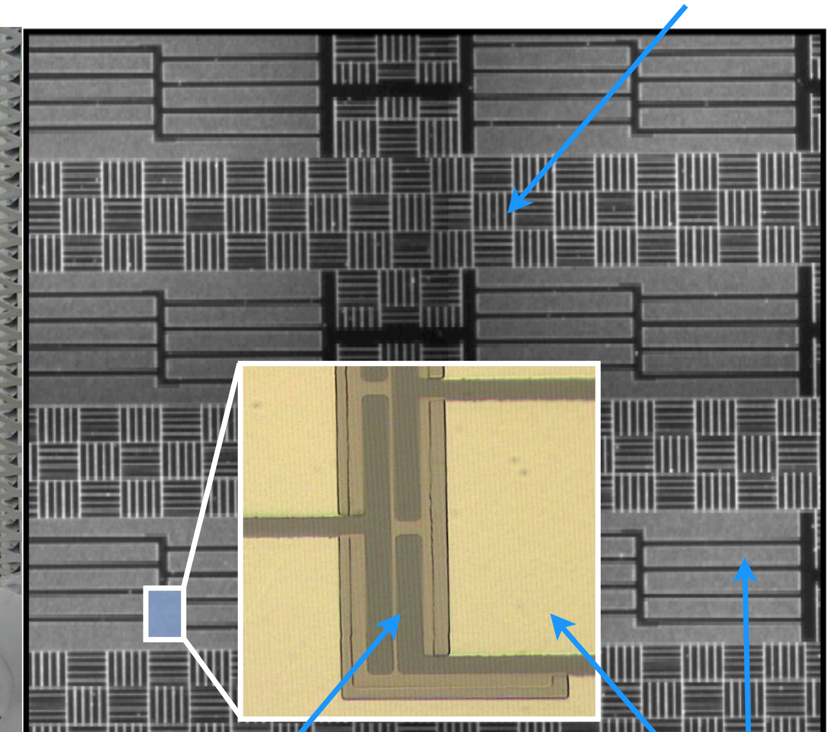
outer (Q_{outer}) ring-like

drift e⁻-h in E-field: **3 V/cm**

4144 QETs (4x1036)



passive tungsten grid



250 µm x 1 µm W (35 nm thick)

380 µm x 55 µm Al fins (300 nm thick)

The CDMS Phonon Signal

Interaction ⇒ THz (~ 4 meV) phonons

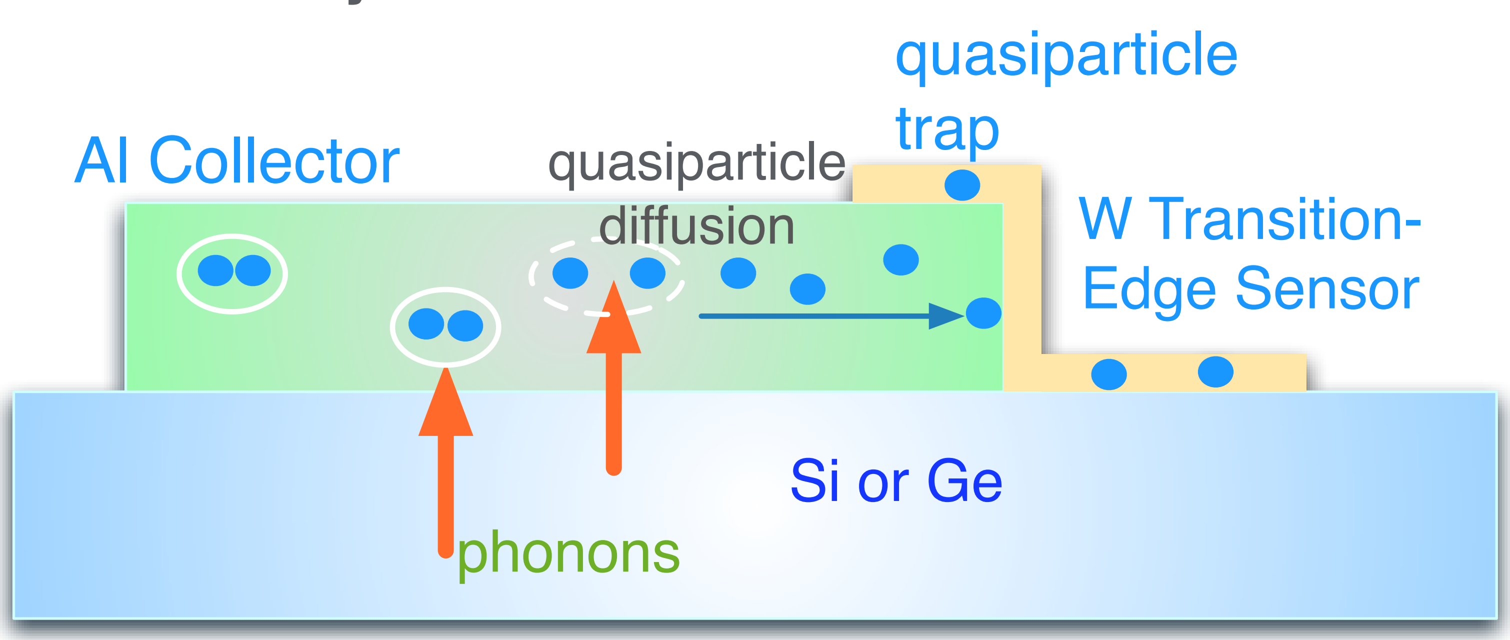
Phonons: propagate to SC Al-fins on the surface, break Cooper pairs ⇒ **quasiparticles**

Quasiparticles: diffuse in 10 μs through the Al-fins and are trapped in the W-TES ⇒ release their binding energy to the W electrons

The electron system T is raised⇒ increased R

The TES is voltage biased and operated in the ETFB-mode

Current change is measured by SQUIDs



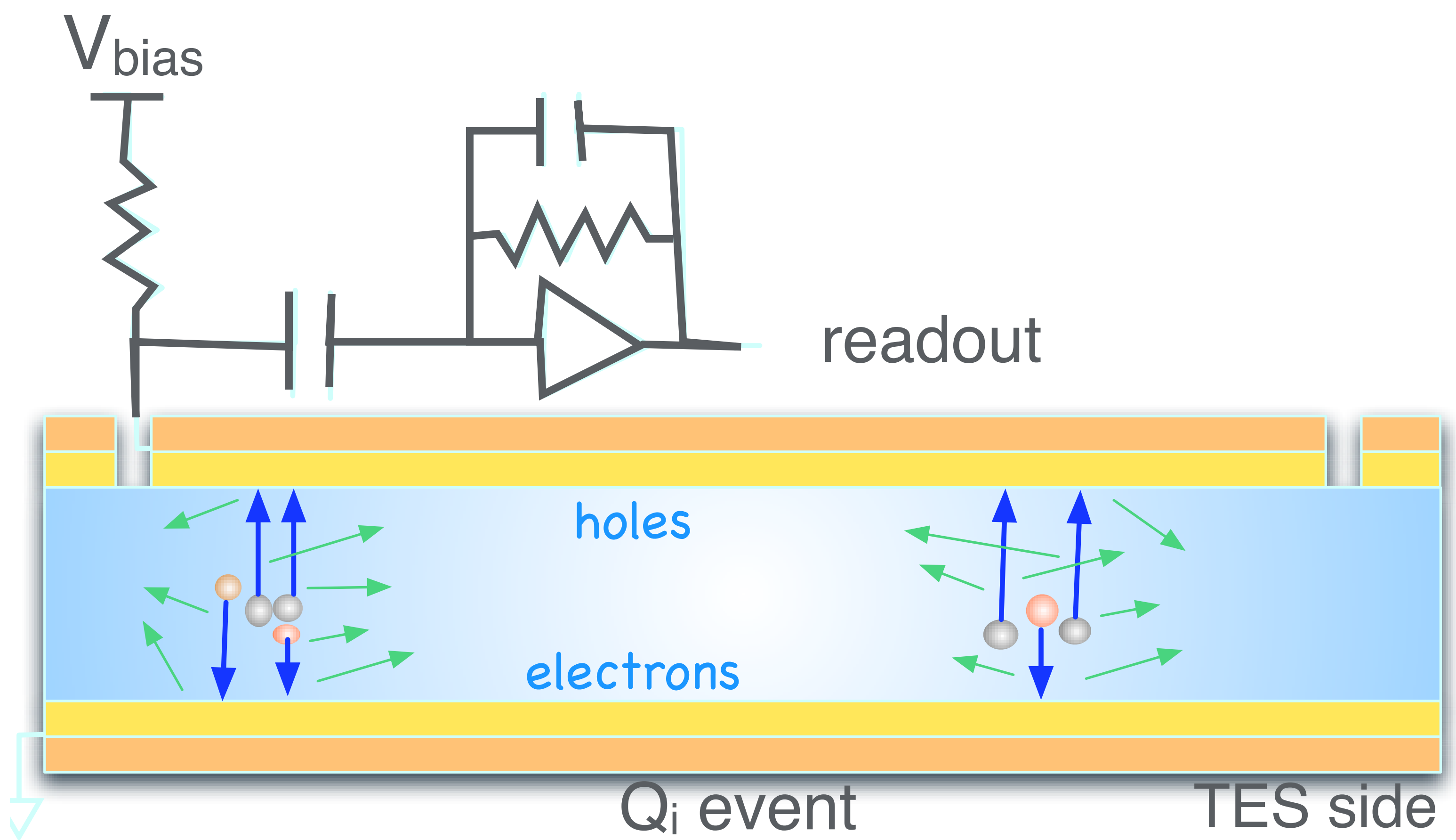
The CDMS Charge Signal

Interaction: breaks up the e⁻-hole pairs in the crystal, separated by E-field
=> Charge is collected by electrodes on the surface of the crystal

Two charge channels:

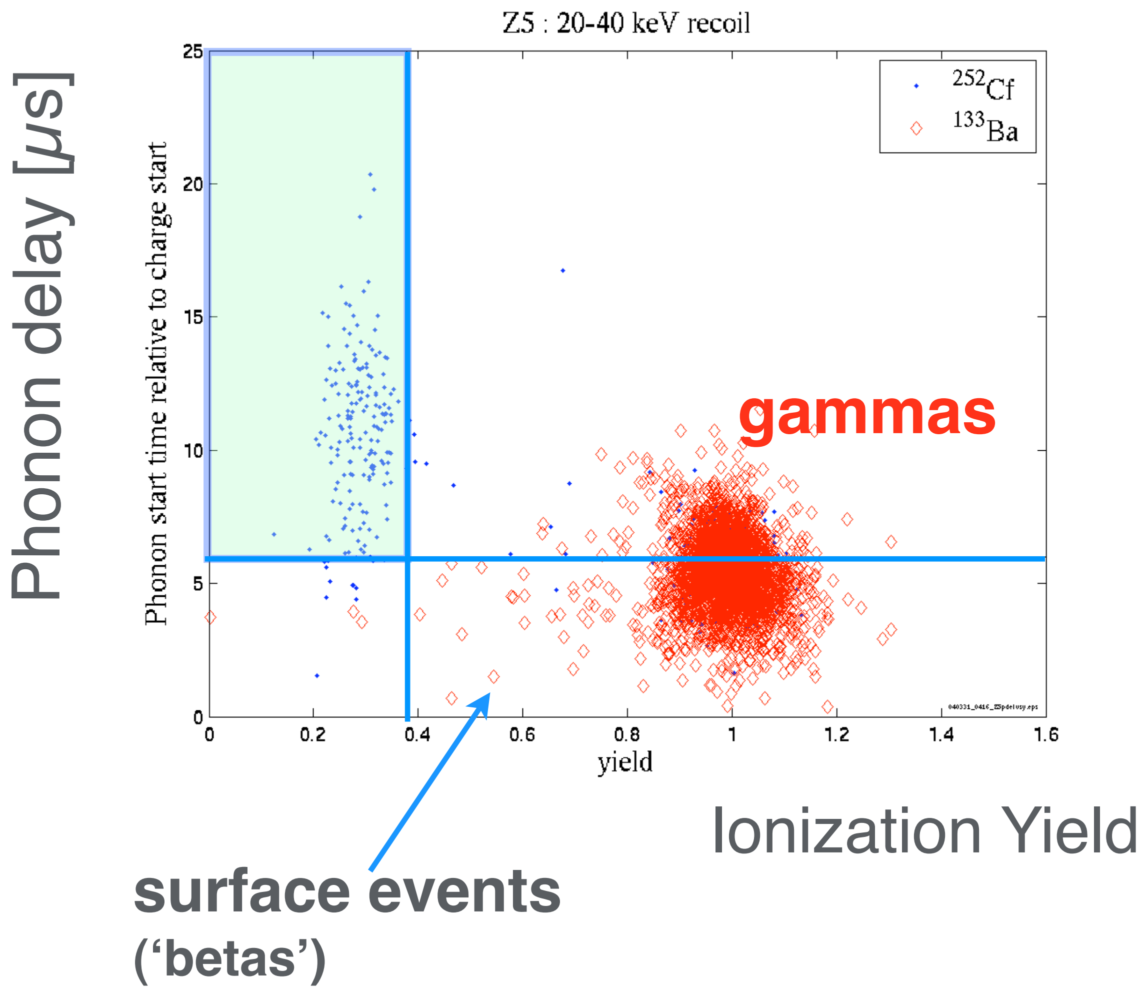
disk in the center (≈85% of surface) + ring at the edge of the crystal surface

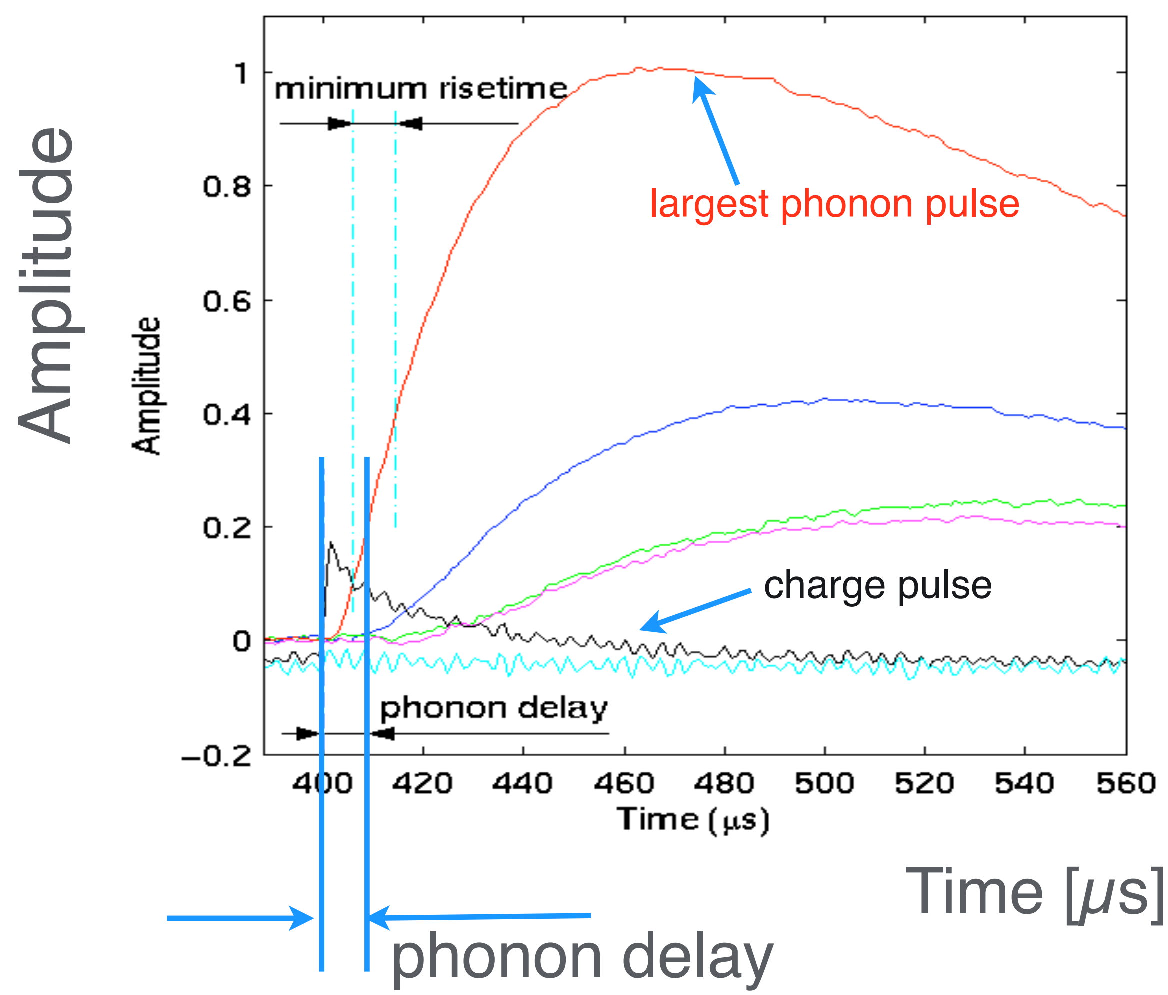
Events within few μm of the surface: deficit charge collection ("dead layer")



CDMS Event Discrimination

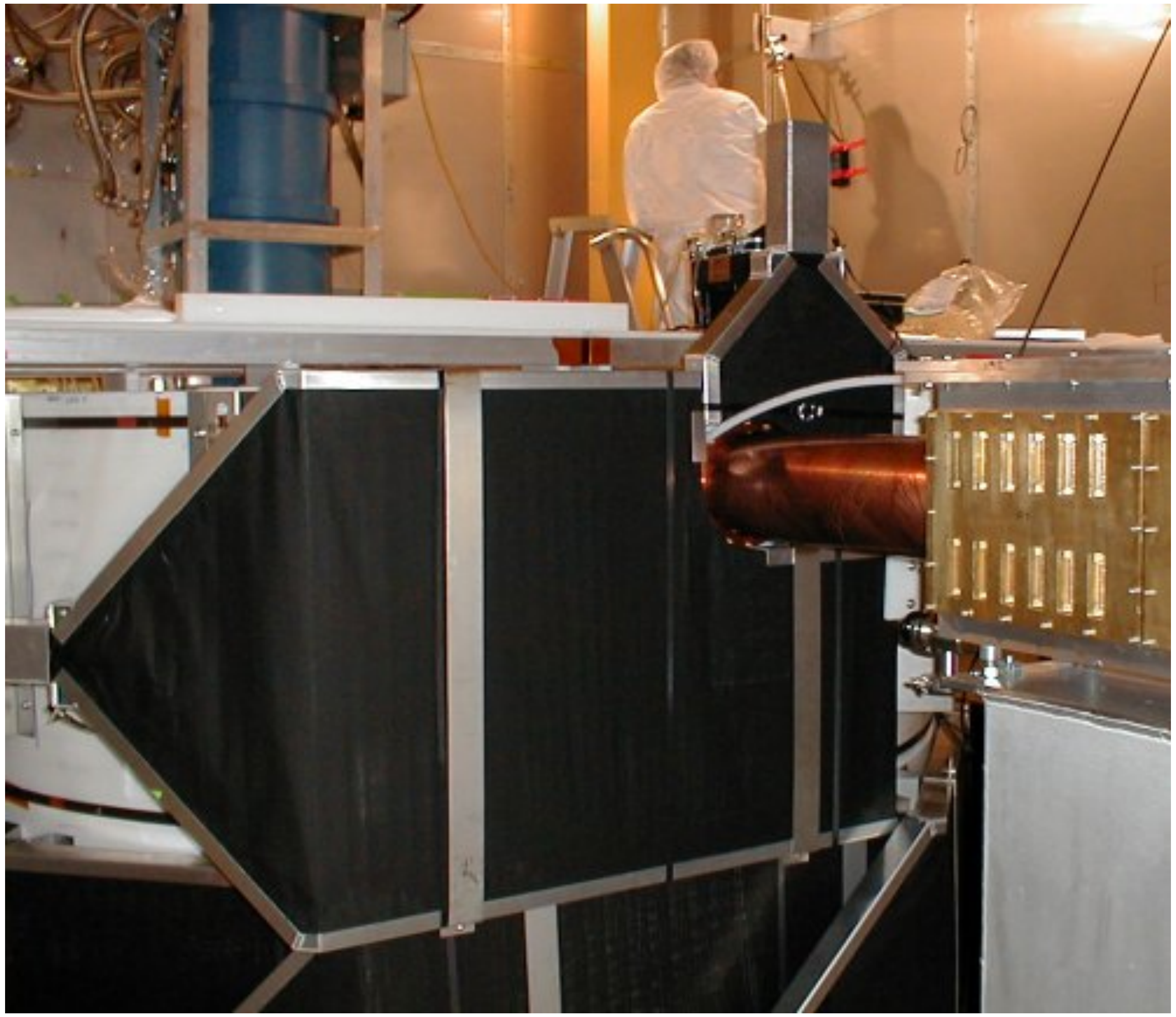
- Use risetime of the phonon pulse, and Δt between the charge and the phonon signal, along with the partition of energy among the 4 quadrants, to identify x-y position and depth (surface vs bulk) of interaction
- Surface event rejection based on phonon timing (2 x 10^{-3} misidentified events)

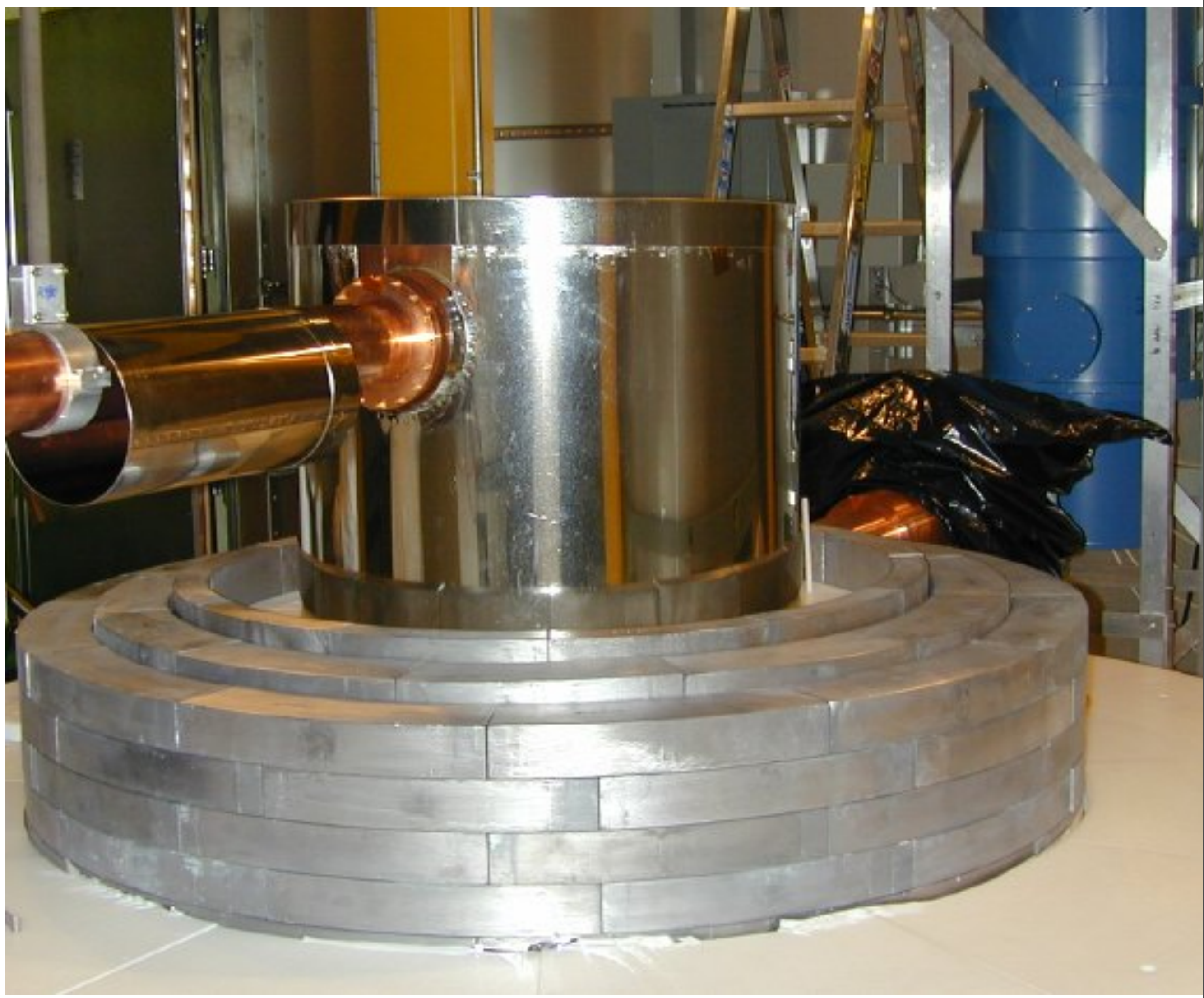




Ionization yield alone: Rejects >99.9% of gammas, >75% of 'betas'
Ionization+phonon timing: Rejects >99.9999% of gammas, >99% of 'betas'

CDMS Setup at Soudan



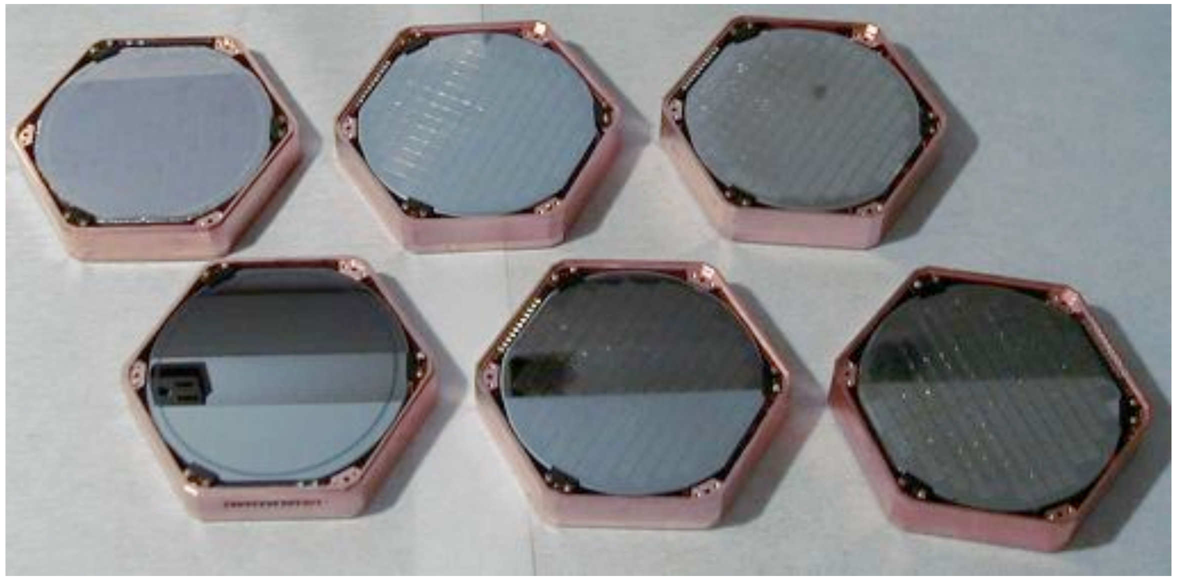


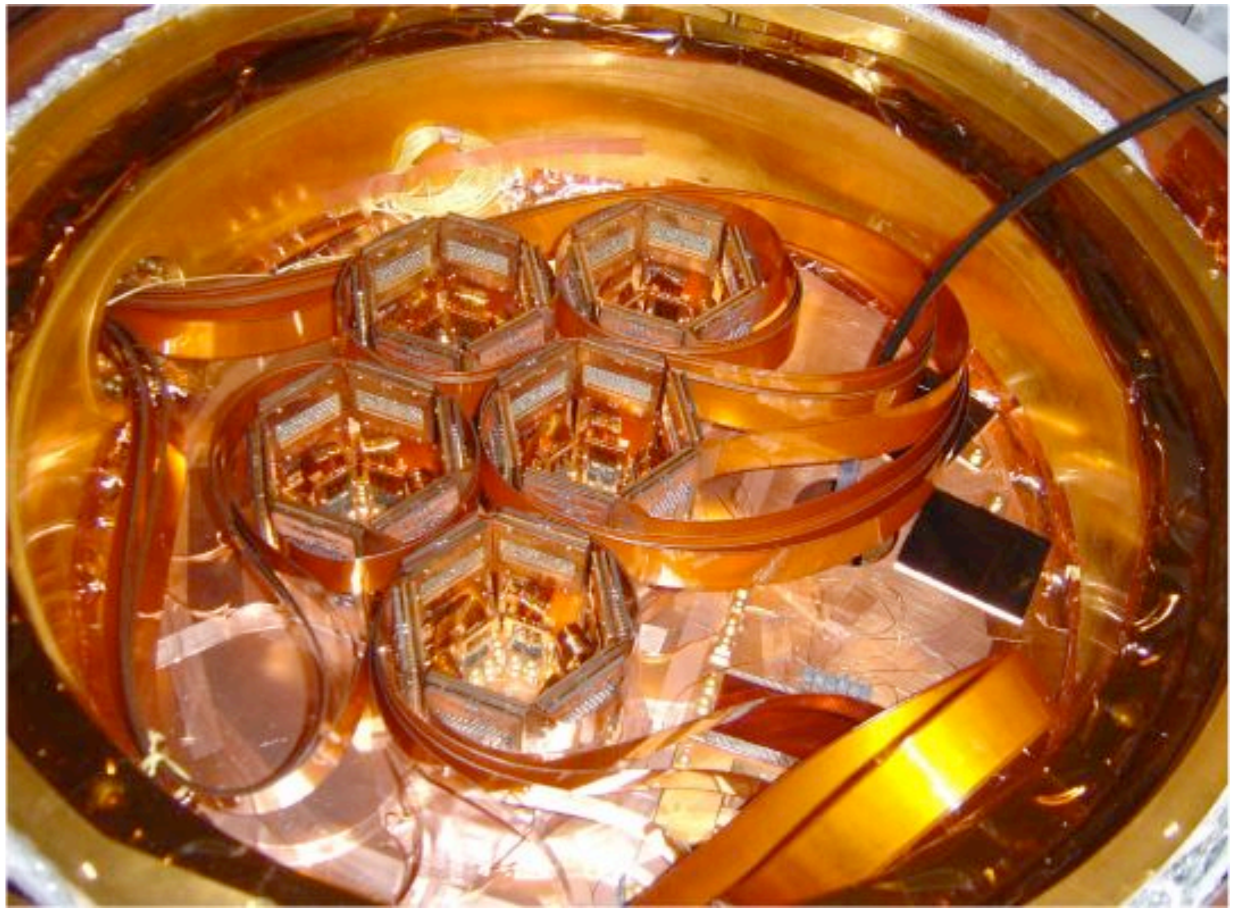
40 × 5 cm thick scintillator panels
read out by 2'' Hamamatsu PMTs
> 99.9% efficiency for through-going μ's
rate ≈ 1 muon/minute

40 cm outer polyethylene
22.5 cm lead
10 cm inner polyethylene
3 cm of copper (Σ_{cans})

CDMS WIMP Search Runs at Soudan

First 2 runs (R118, R119, 2003-2004):
with one and two towers (6 Ge, 6 Si detectors)
for a total of ≈ 60 kg days exposure in Ge
Results in 2004-2005: PRL93, PRL96, PRD72





Currently:

Since October 2006: science runs with a total of 5 towers (4.75 kg Ge, 1.1 kg Si)

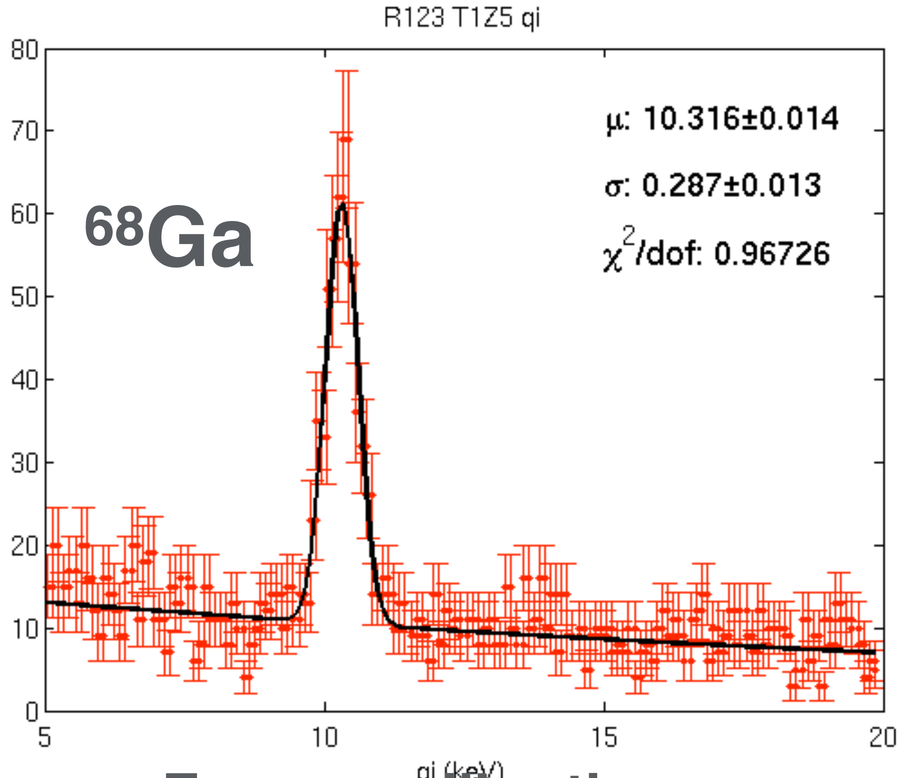
Run 123: 430 kg d Ge

Run 124: 224 kg d Ge

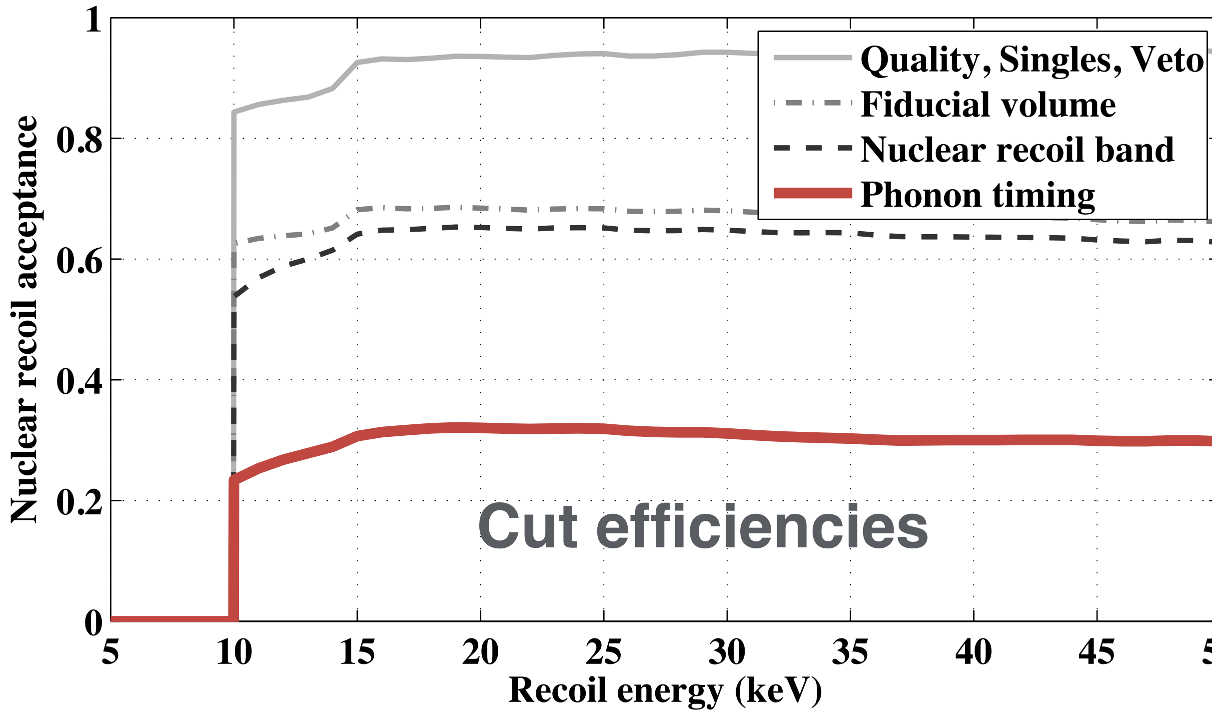
Run 125 + 126: 740 kg d Ge

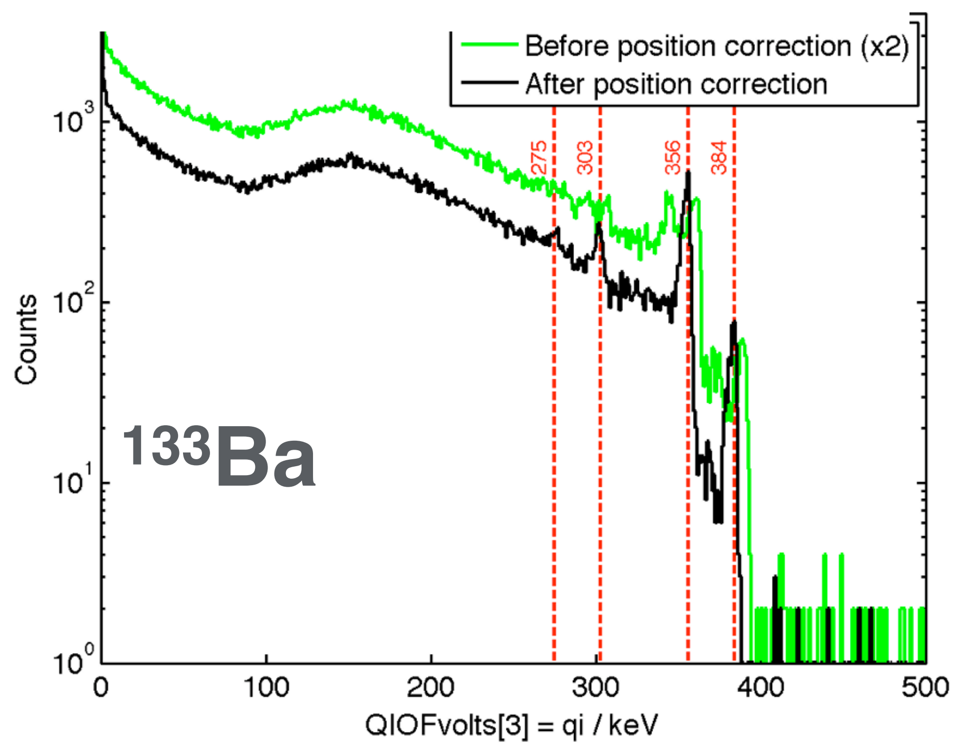
Run 127: ongoing

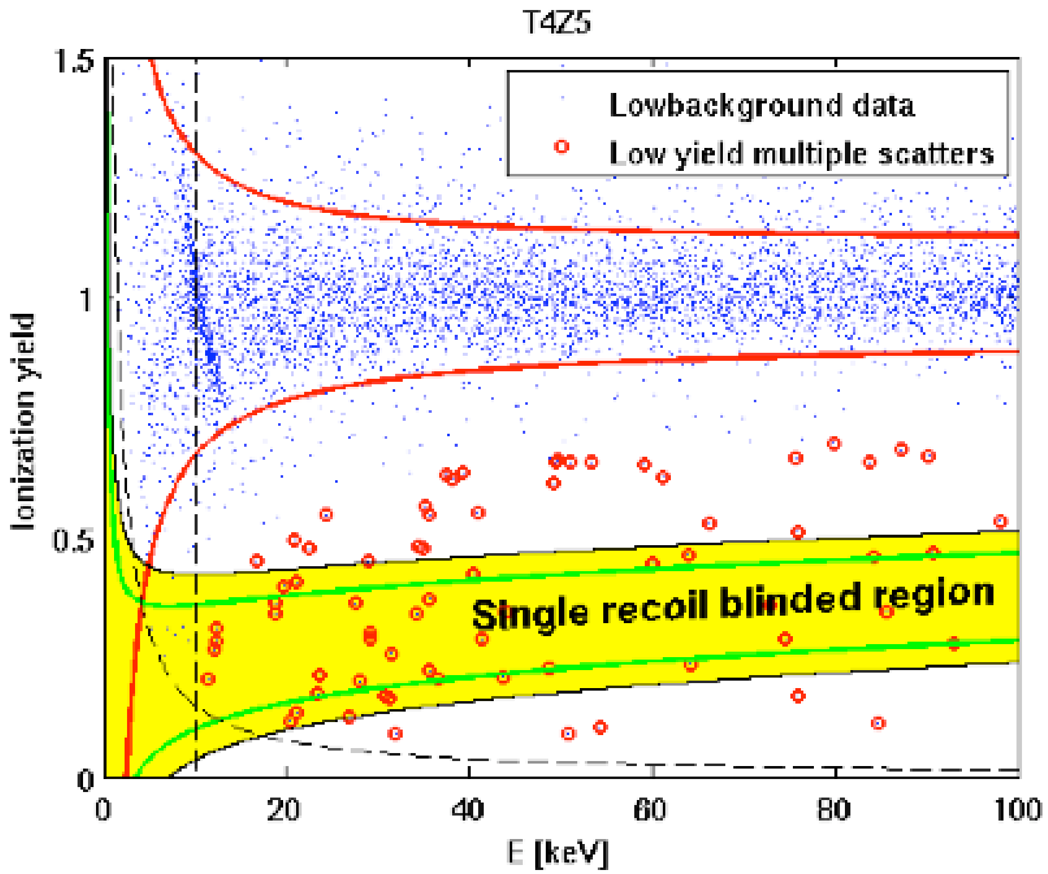
CDMS 5-Tower “Blind” Analysis



Energy calibration

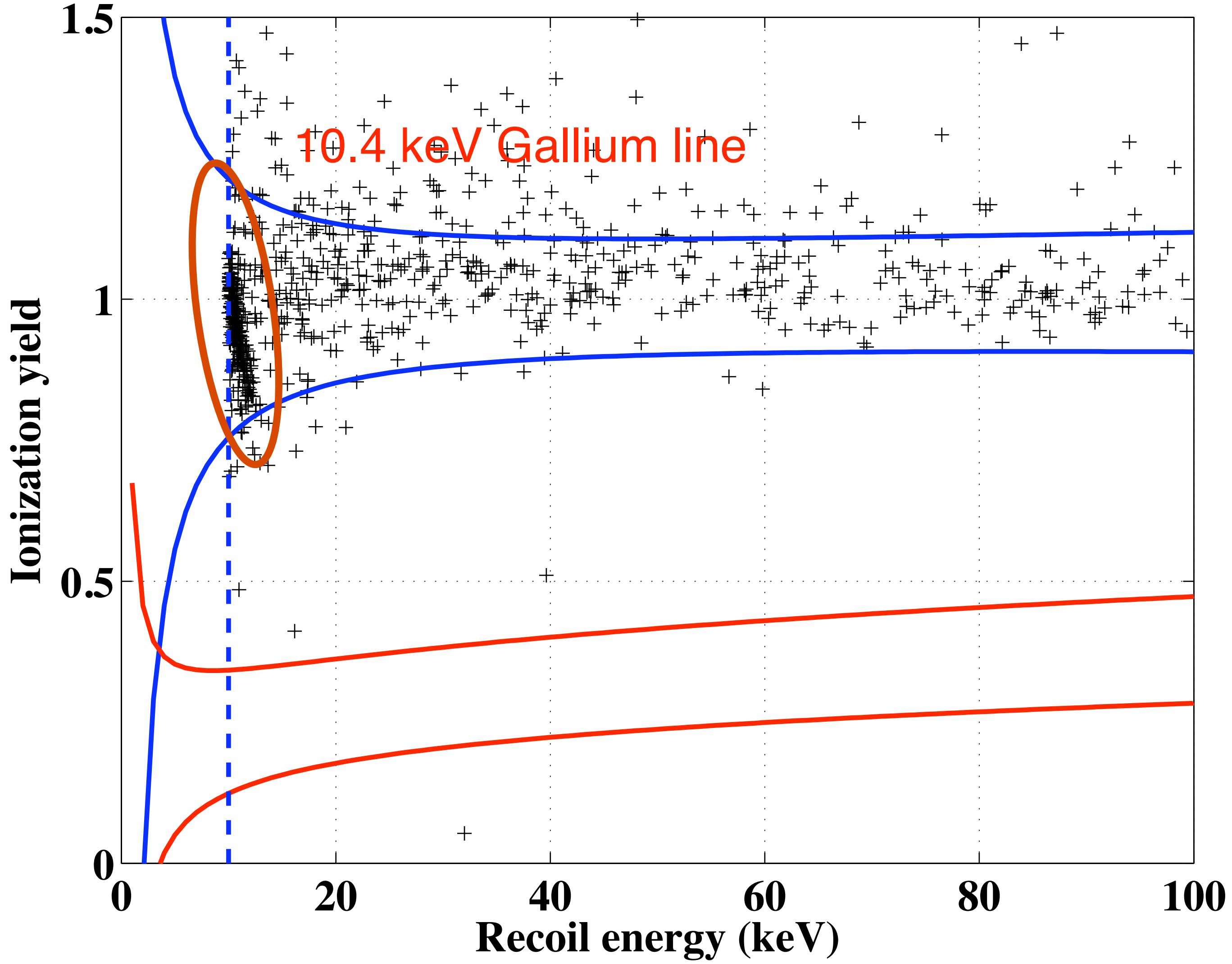






CDMS 5-Tower WIMP Search Data

After all cuts; 15 Ge ZIPs, 397 raw kg days



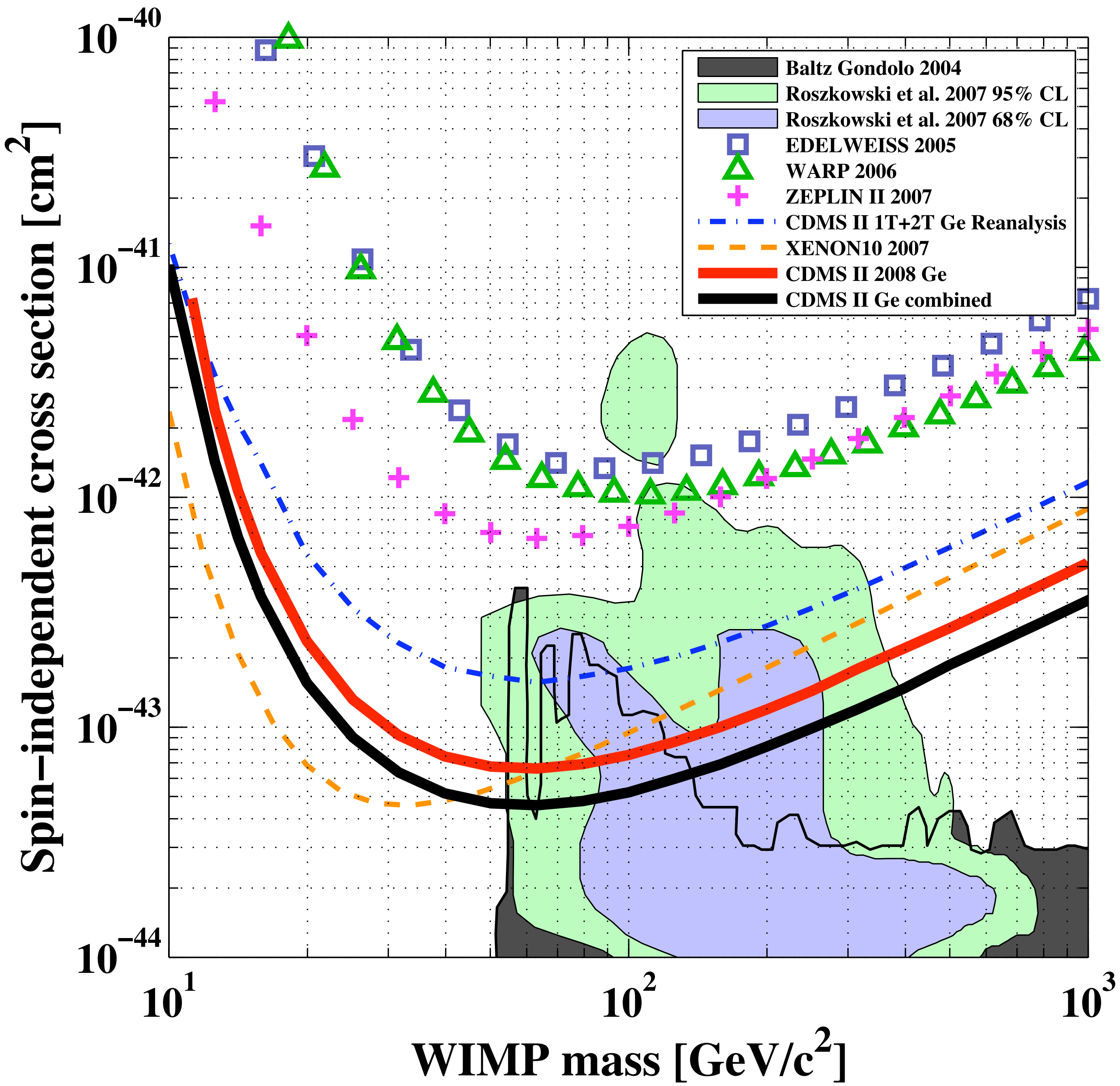
ZERO events in signal region!

0.6 ± 0.5 (stat) **± 0.2** (syst) Ge background expected from surface events -> **0 events seen**

Neutron background: < 0.1 (cosmogenic); < 0.03 (Poly, Cu, (α,n)); < 0.1 (Pb, fission) expected

CDMS New Results

- **Spin-Independent WIMP upper limits (90% CL) and SUSY predictions:**



Strongest spin-independent limit on WIMP-nucleon cross sections for M_W >~ $M_Z/2$

> 2 x data in hand, analysis in progress

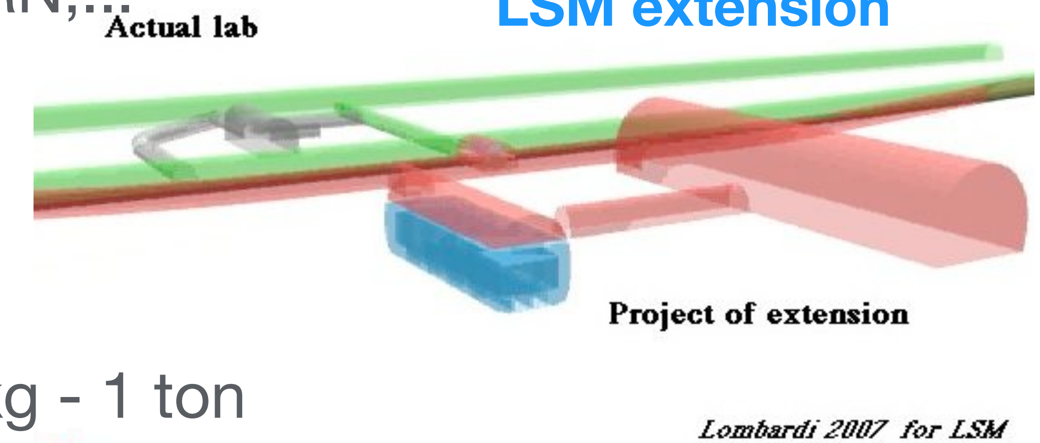
Run 127 continues

Preprint: arXiv: 0802.3530
Submitted to PRL

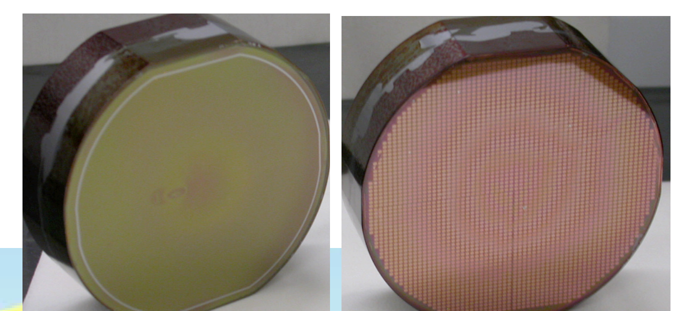
Future mK Cryogenic Dark Matter Experiments

- **EURECA (European Underground Rare Event Calorimeter Array)**
- Joint effort: CRESST, EDELWEISS, ROSEBUD, CERN,...
- Mass: 100 kg - 1 ton, multi-target approach
- FP7 proposal for design study submitted

LSM extension



- **SuperCDMS (US/Canada):** 3 phases 25 kg - 150 kg - 1 ton
- 640 g Ge detectors with improved phonon sensors
- 4 prototype detectors built and tested

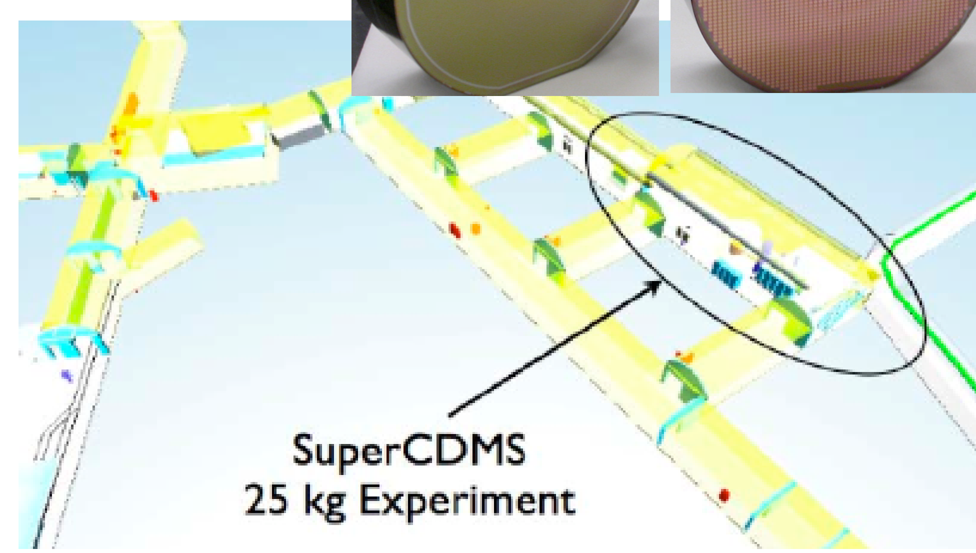


R&D for SuperCDMS:

1” thick **SuperZIPs** (0.64 kg)

2 SuperTowers at Soudan

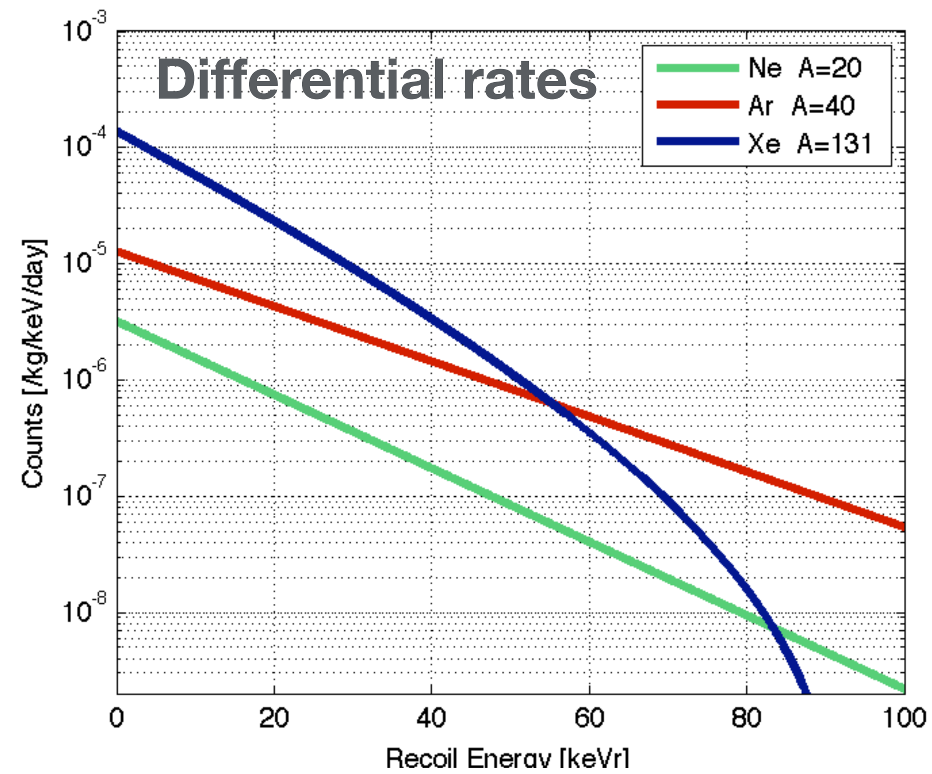
7 SuperTowers at SNOLAB

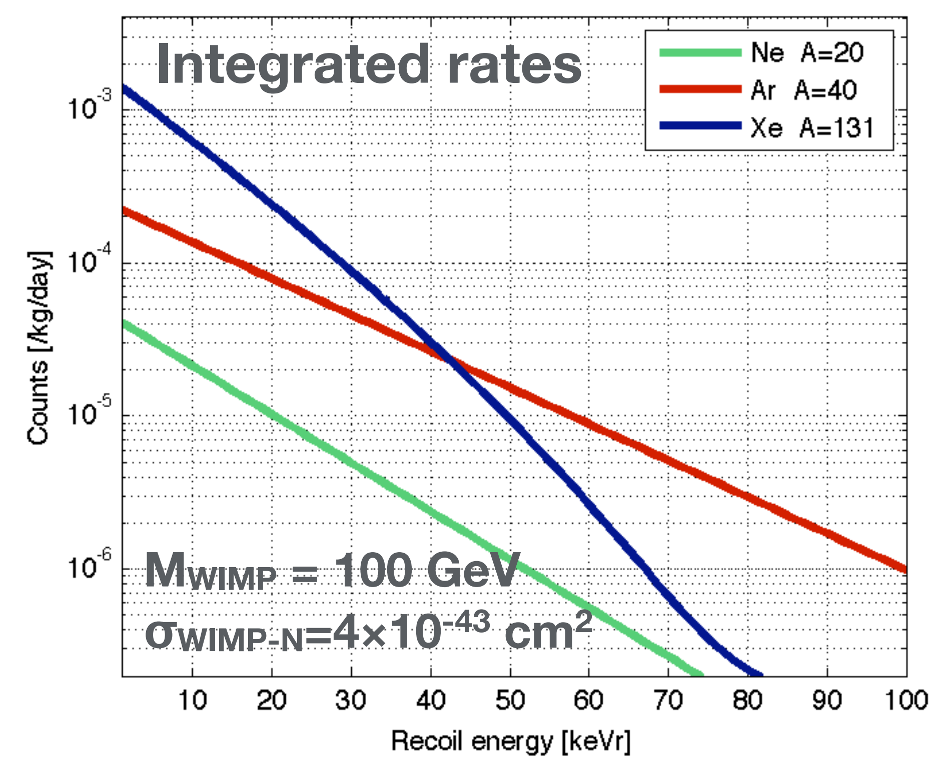


Noble Liquids as Dark Matter Detectors

Dense, homogeneous targets/detectors
High scintillation/ionization yields
Commercially easy to obtain and purify

	Scintillation Light	**Intrinsic Backgrounds**
Ne (A=20) $60/kg 100% even-even nucleus	**85 nm** requires wavelength shifter	Low BP (20 K), all impurities frozen out No radioactive isotopes
Ar (A=40) $2/kg 100% even-even nucleus	**128 nm** requires wavelength shifter	Natural Ar contains ^{39}Ar at 1Bq/kg, corresp. to ~150 ev/kg/day/keV at low energies
Xe (A=131) $800/kg 50% odd nuclei (^{129}Xe, ^{131}Xe)	**175 nm** UV quartz PMT window	No long lived isotopes ^{85}Kr can be removed by active charcoal filter or distillation

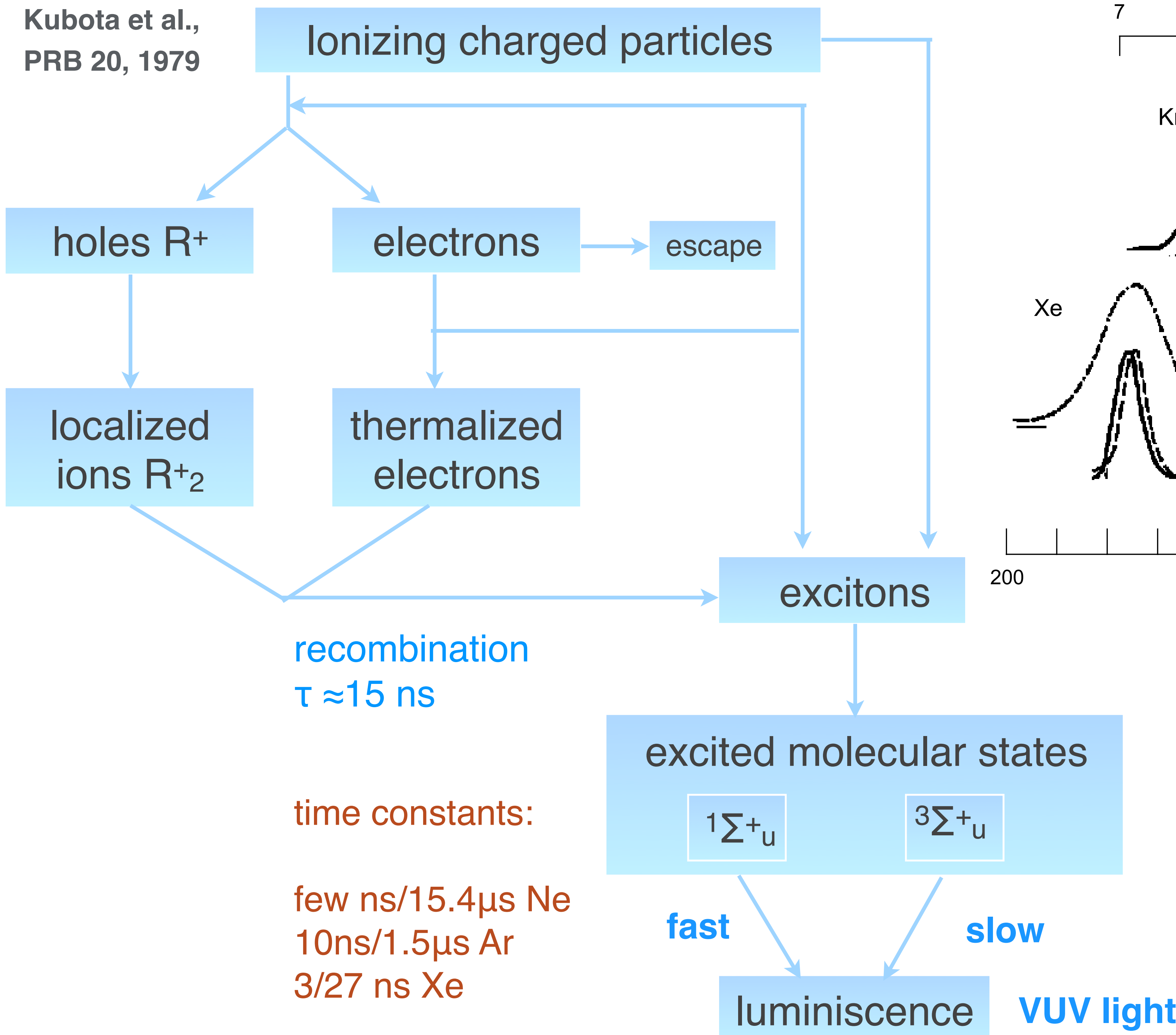


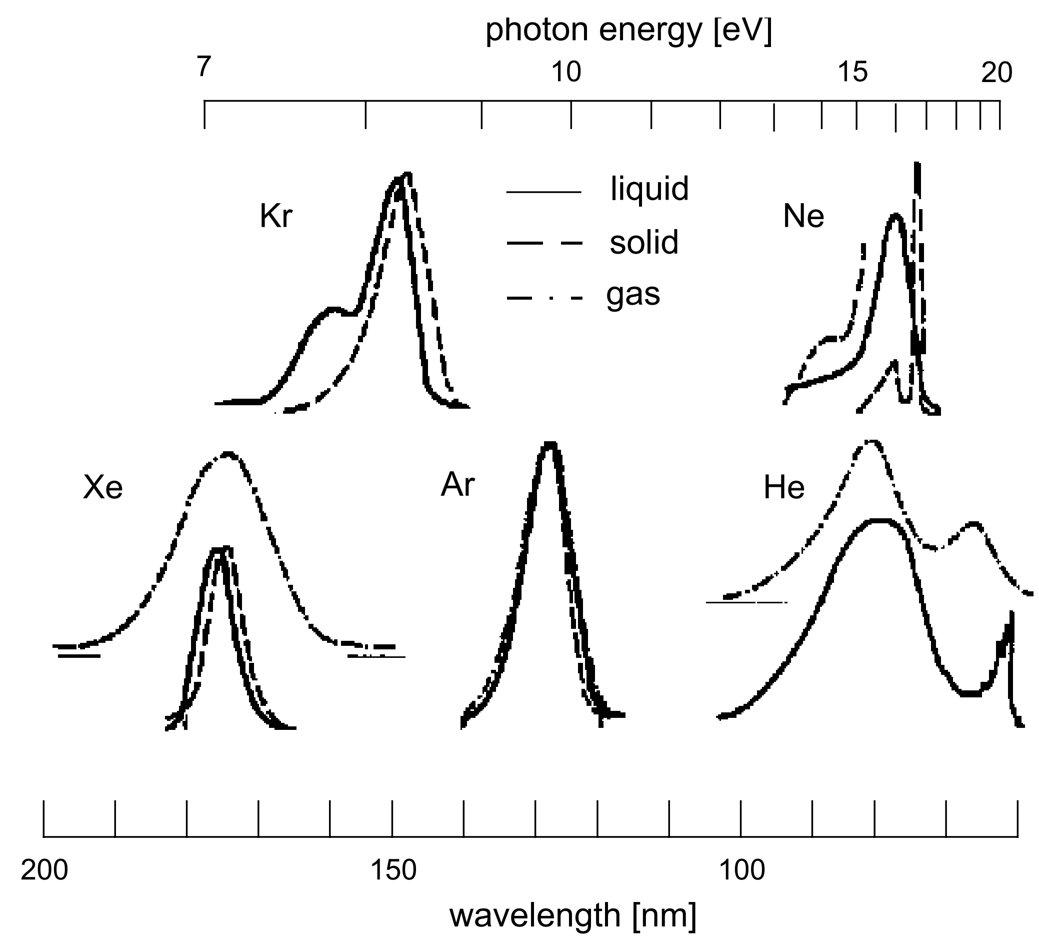


Laura Baudis, University of Zurich, LAPP seminar, Annecy, June 2008

Charge and Light in Noble Liquids

Kubota et al., PRB 20, 1979



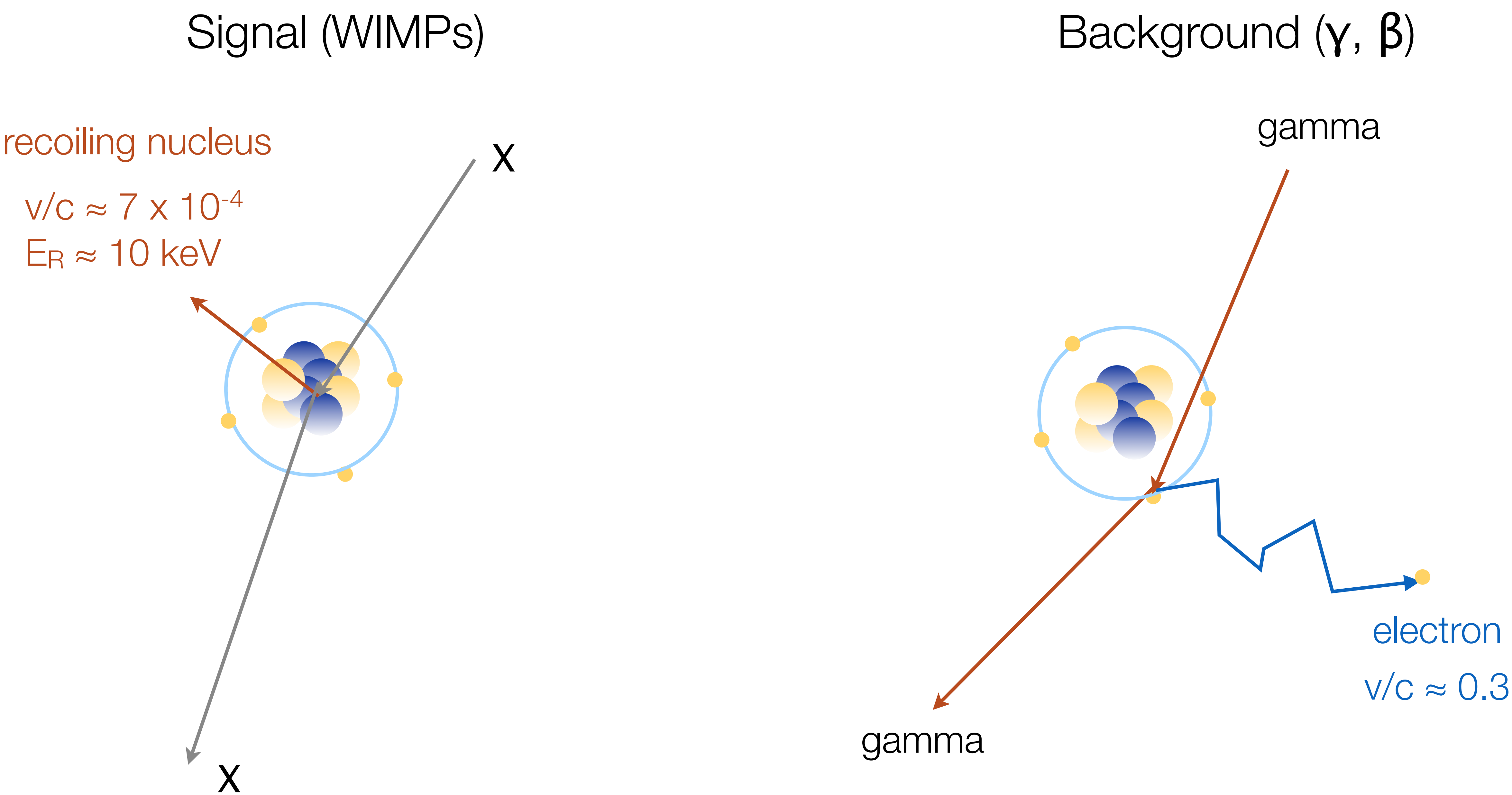


$\lambda_{LNe} \sim 77.5\ nm$

$\lambda_{LAr} \sim 128\ nm$

$\lambda_{LXe} \sim 175\ nm$

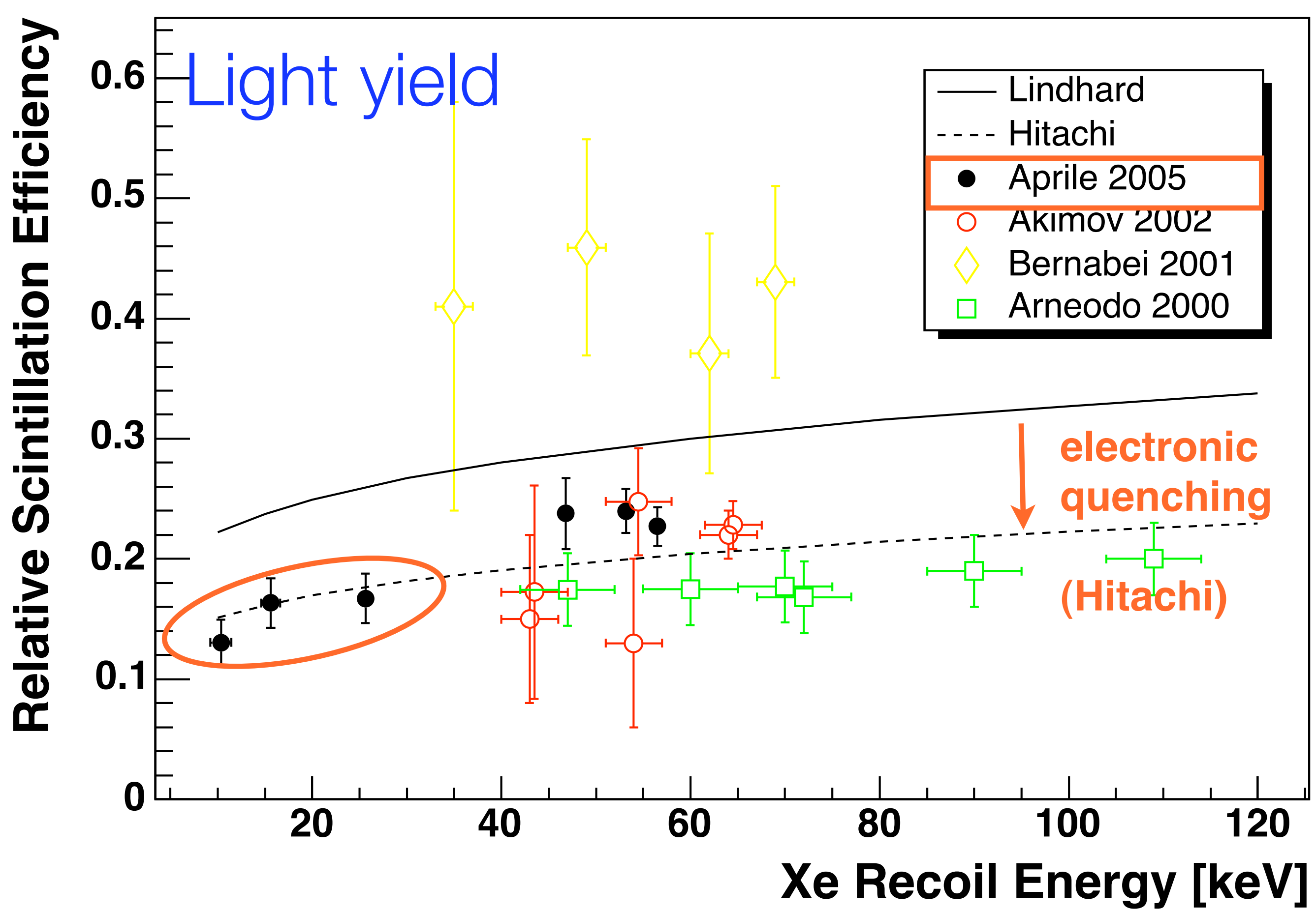
Charge and Light in Noble Liquids



Excitation/Ionization depends on dE/dx!
=> discrimination of signal (**WIMPs ⇒ NR**) and
(most of the) background (**gammas ⇒ ER**)!

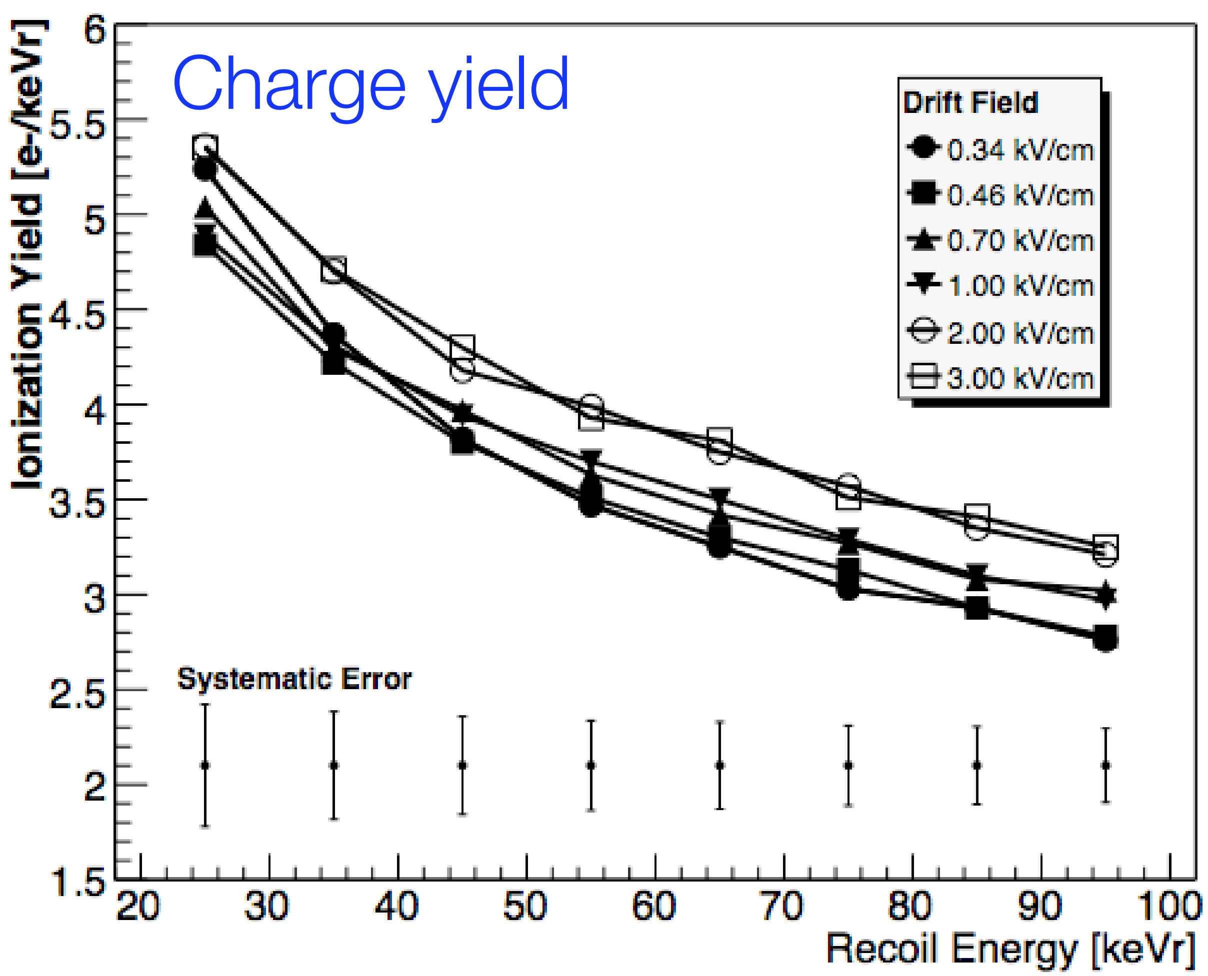
Liquid Xenon for Dark Matter Searches

- light and charge yield measured at **low nuclear recoil energies** for the first time



Data down to 10 keVr; yield: 13% - 20% from 10 keVr to 60 keVr. Good agreement with prediction by Hitachi (Astrop. Phys. 24, 2005) at low recoil energies

Aprile et al., Phys. Rev. D. 72 (2005)

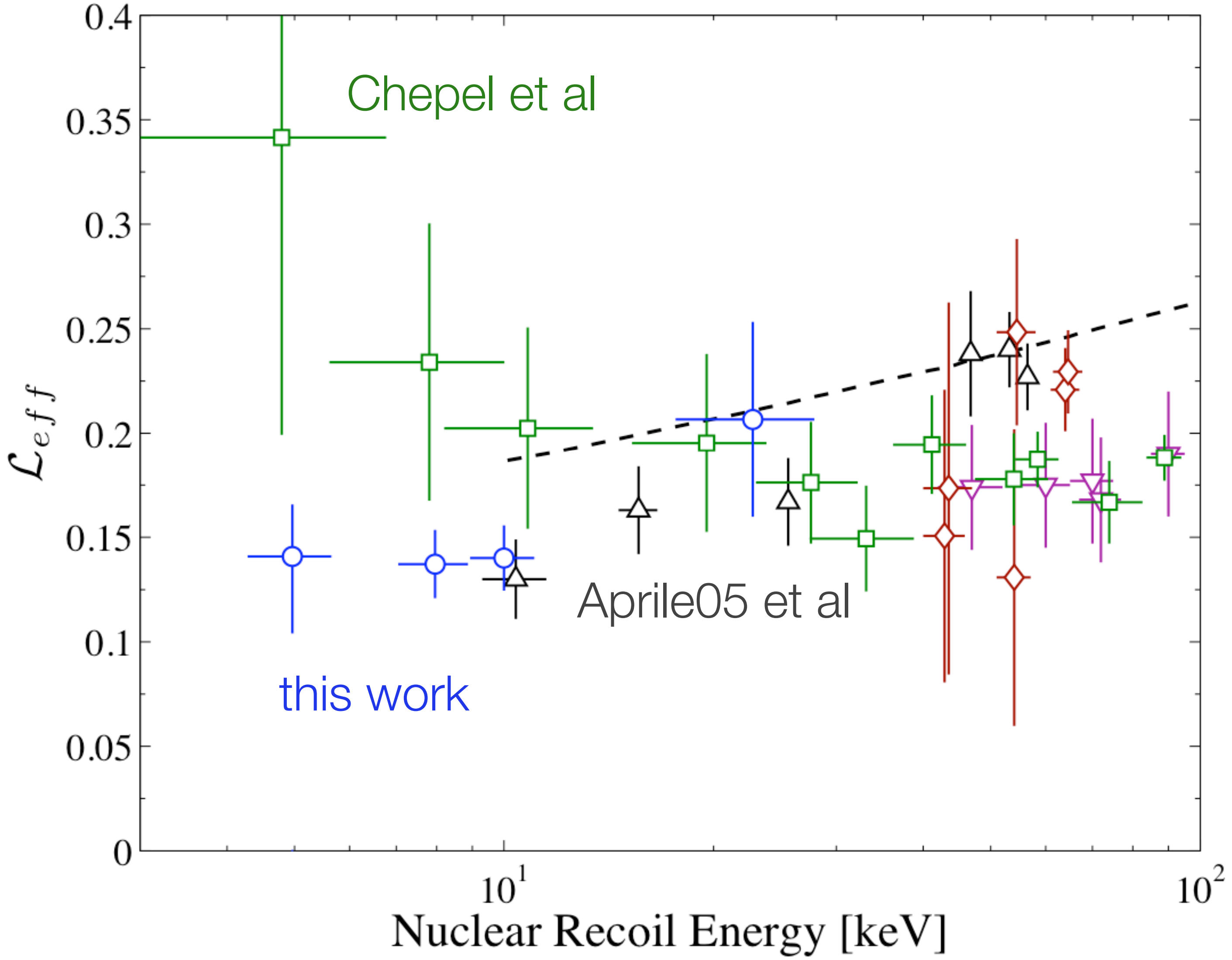


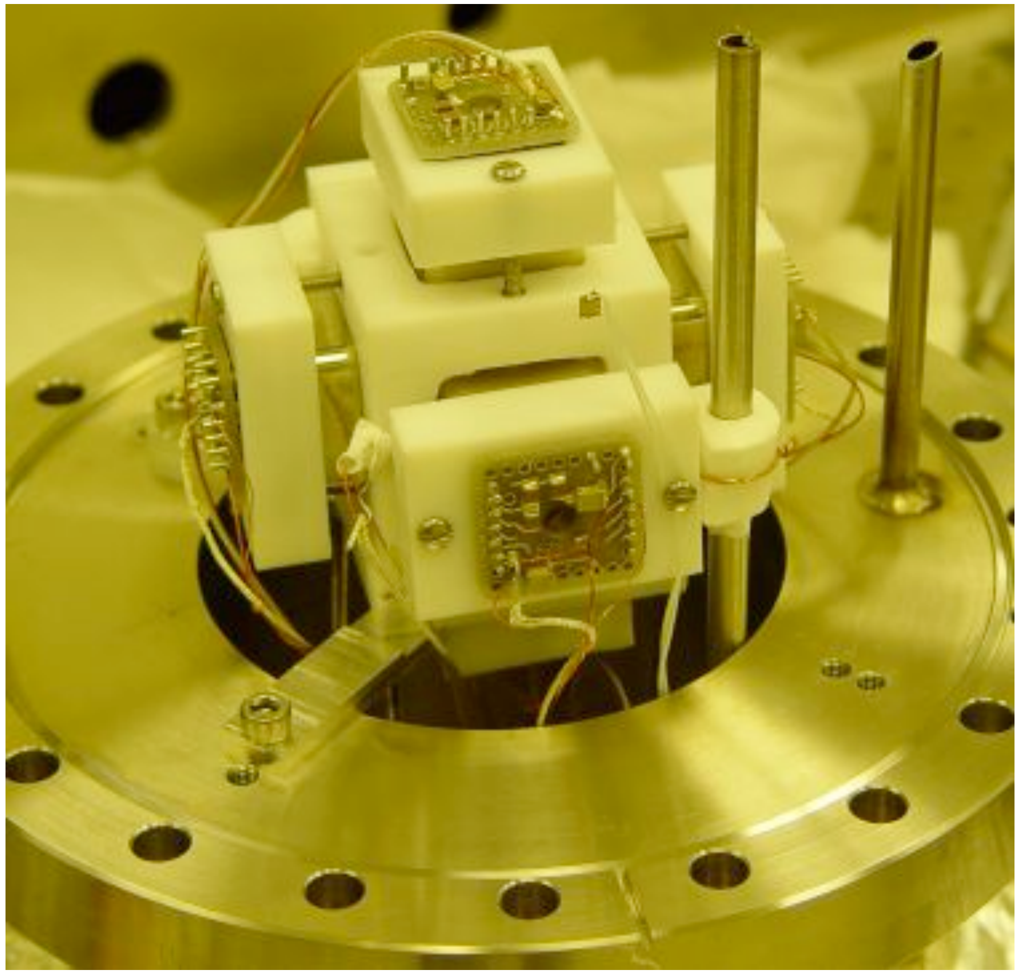
Weak dependence on electric field
Yield increases at low recoil energies

Aprile et al., Phys. Rev. Lett. 97 (2006)

New measurements of the Light Yield in LXe

- Columbia + Zurich: at RaRAF (Nevis Labs), 1 MeV n-beam
- Detector: XeCube, 6 R8520 PMTs, 2.5 cm^3 LXe, zero field





Publication in preparation

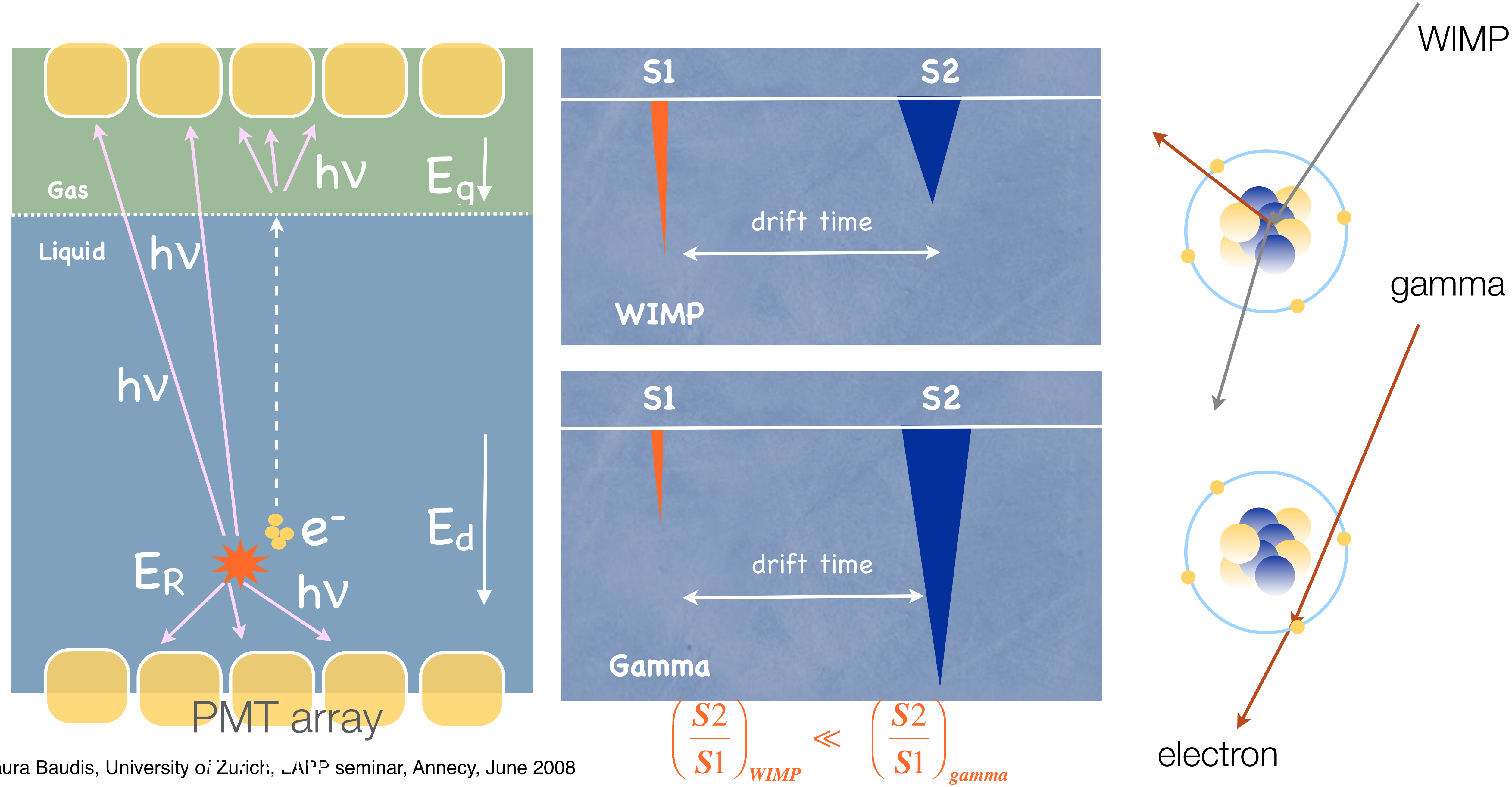
Noble Liquid Detectors: Existing Experiments and Proposed Projects

	Single Phase (liquid only) PSD	**Double Phase (liquid and gas) PSD and Charge/Light**
Neon (A=20)	miniCLEAN (100 kg) CLEAN (10-100 t)	SIGN (high P Ne gas)
Argon (A=40)	DEAP-I (7 kg) miniCLEAN (100 kg) CLEAN (10-100 t)	ArDM (1 ton) WARP (3.2 kg) WARP (140 kg)
Xenon (A=131)	ZEPLIN I XMASS (100 kg) XMASS (800 kg) XMASS (23 t)	ZEPLIN II + III (31 kg, 8 kg) XENON10, XENON100 LUX (300 kg), XENON1t

- **Single phase:** e^--ion recombination occurs; singlet/triplet ratio is 10/1 for NR/ER
- **Double phase:** ionization and scintillation; electrons are drifted in ~ 1kV/cm E-field

Two-Phase (Liquid/Gas) Detection Principle

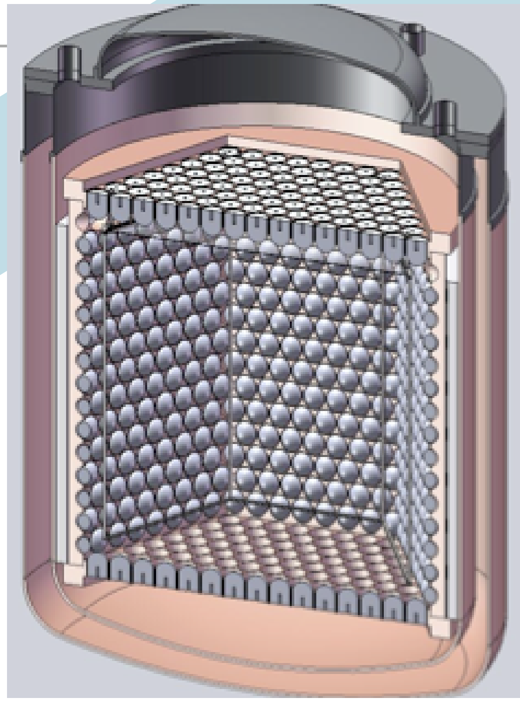
- **Prompt (S1) light signal** after interaction in active volume; charge is drifted, extracted into the gas phase and detected **directly**, or as **proportional light (S2)**
- **Challenge:** ultra-pure liquid + high drift field; efficient extraction + detection of e⁻



The XENON Program

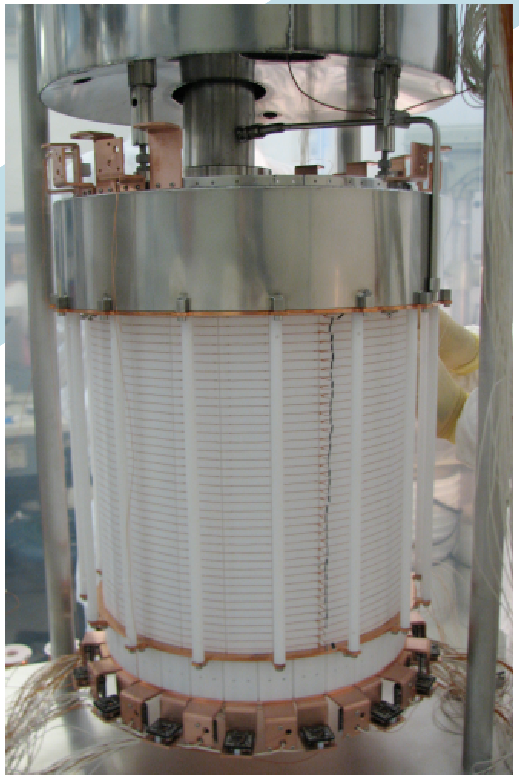
???

XENON1t



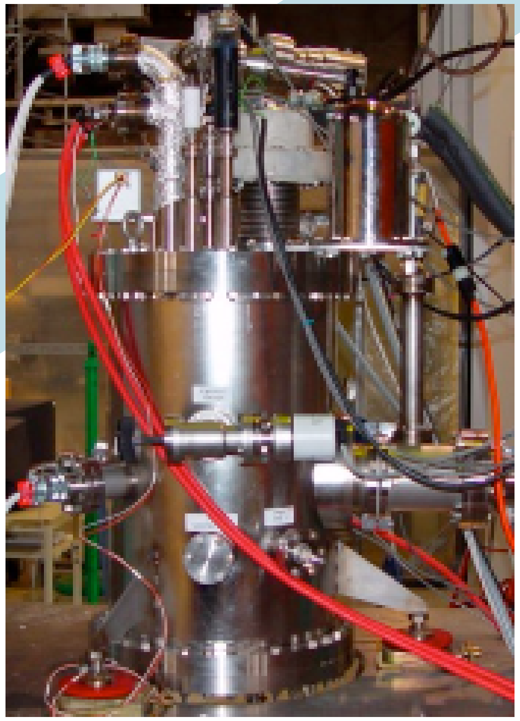
2009-2011 ?

XENON100



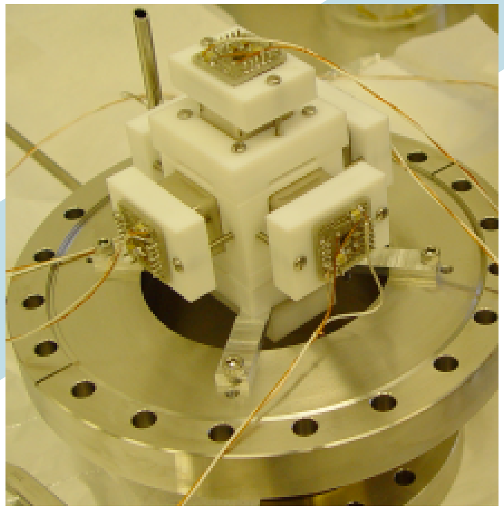
in progress

XENON10



2006-2007

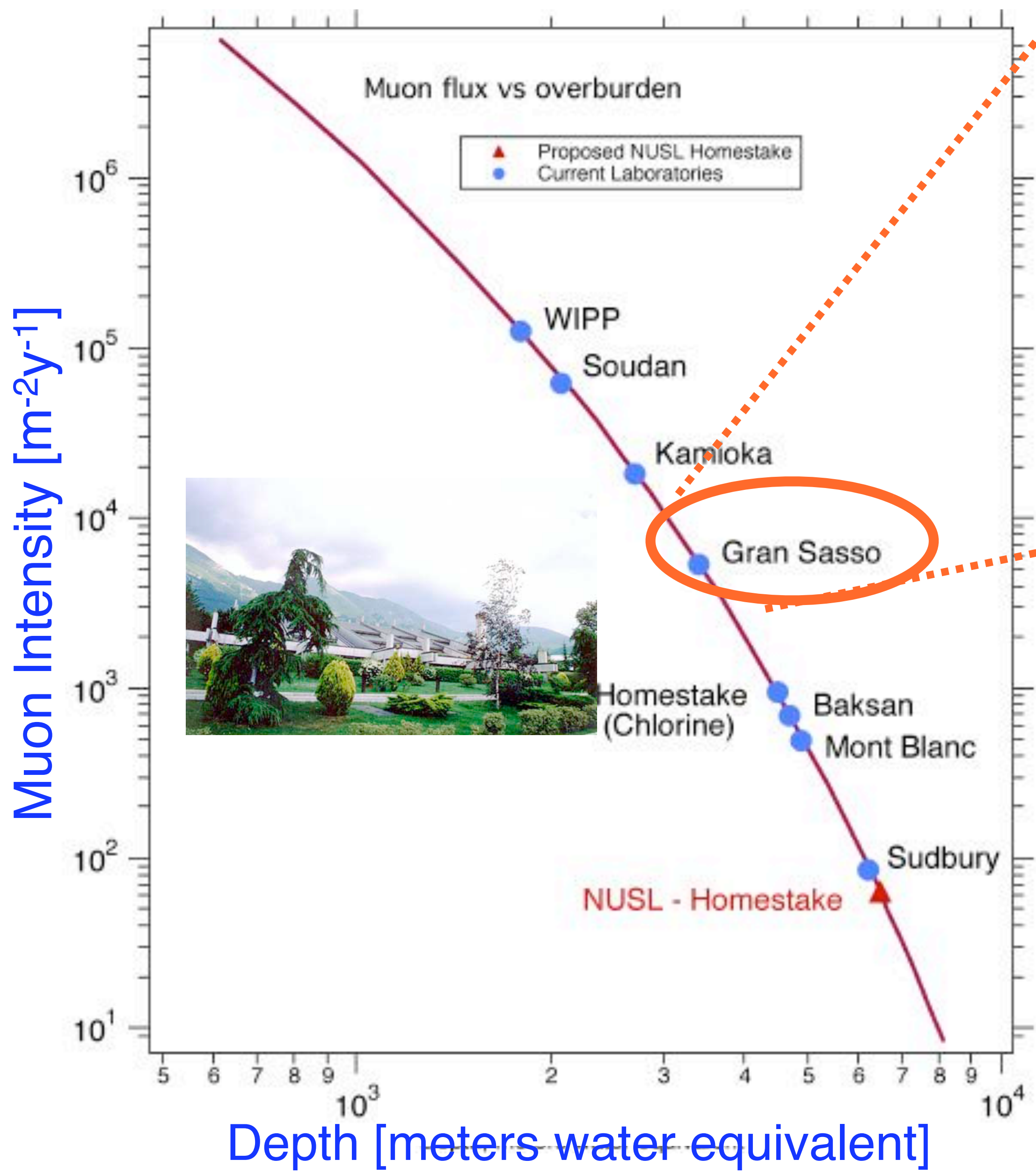
XENON R&D

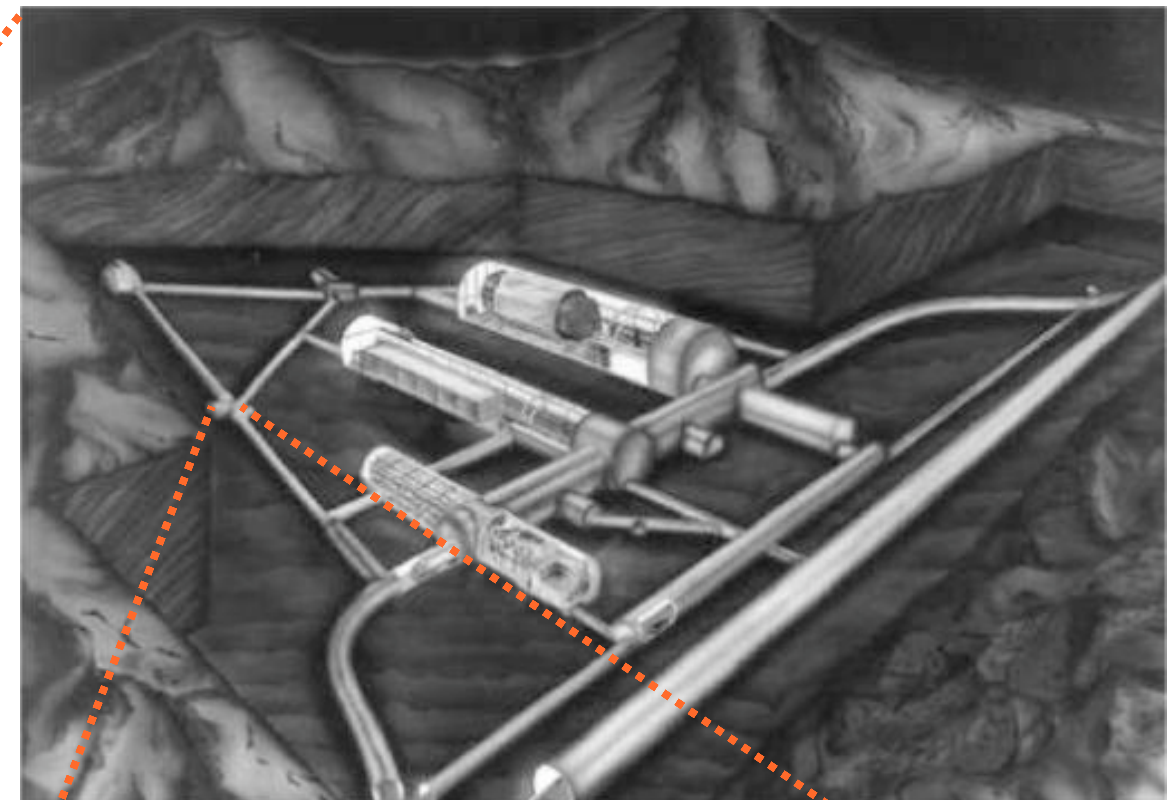


ongoing

XENON10 at the Gran Sasso Laboratory

~3600 m.w.e; muon flux ≈ 1 m^{-2} h^{-1}

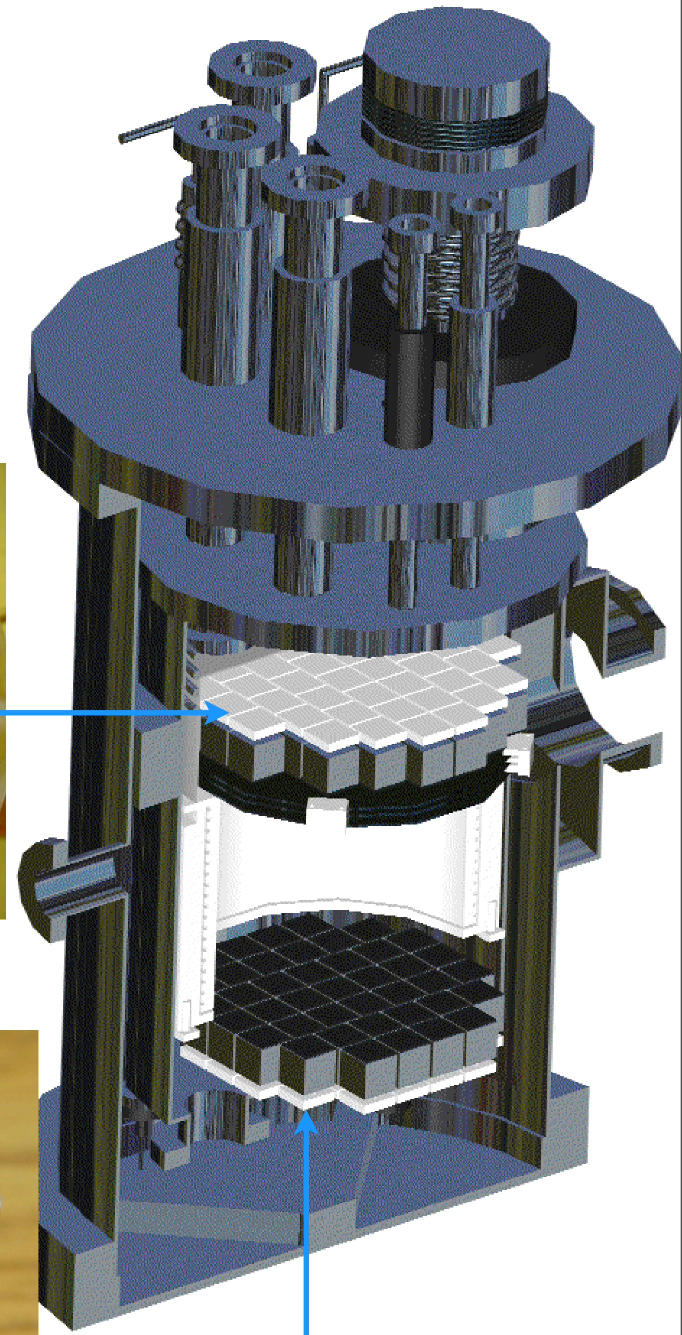


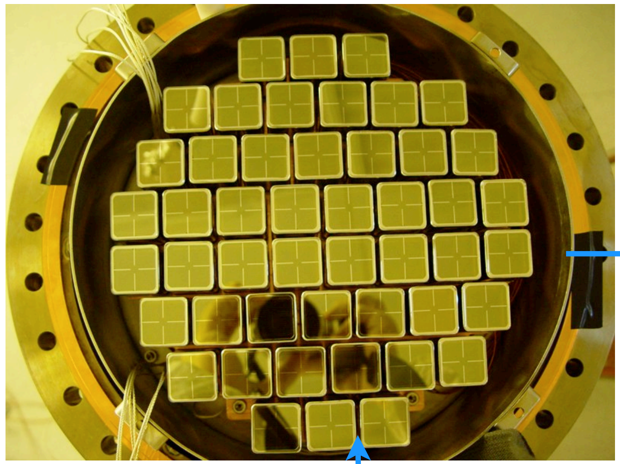


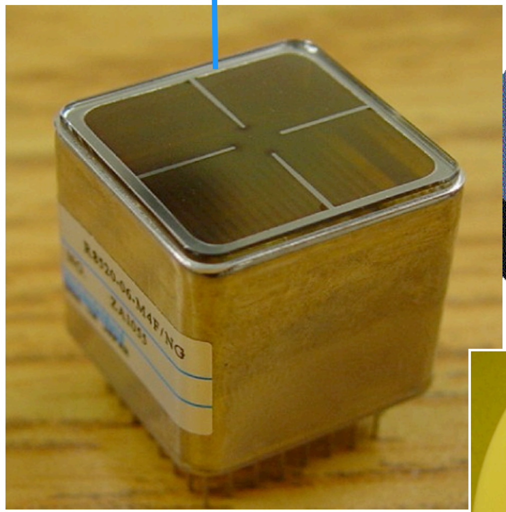
Laura Baudis, University of Zurich, LAPP seminar, Annecy, June 2008

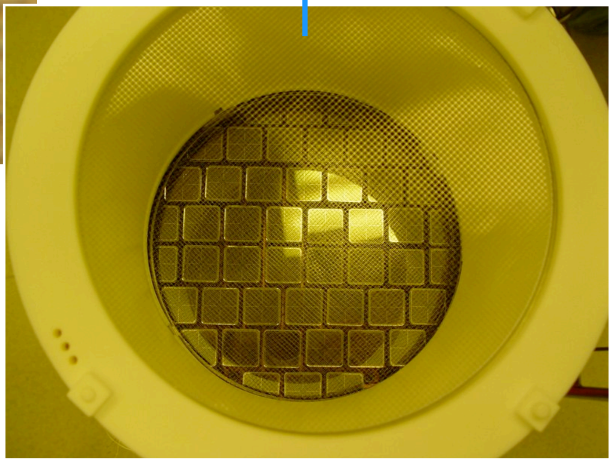
The XENON10 Detector

- **22 kg of liquid xenon**
  - ➡15 kg active volume
  - ➡20 cm diameter, 15 cm drift
- **Hamamatsu R8520 1”×3.5 cm PMTs**
  bialkali-photocathode Rb-Cs-Sb,
  Quartz window; ok at -100°C and 5 bar
  Quantum efficiency > 20% @ 178 nm
- **48 PMTs top, 41 PMTs bottom array**
  - ➡x-y position from PMT hit pattern; $\sigma_{x\text{-}y} \approx$ 1 mm
  - ➡z-position from Δt_{drift} ($v_{d,e^-} \approx$ 2mm/μs), $\sigma_Z \approx$0.3 mm
- **Cooling: Pulse Tube Refrigerator (PTR),**
  90W, coupled via cold finger (LN_2 for emergency)



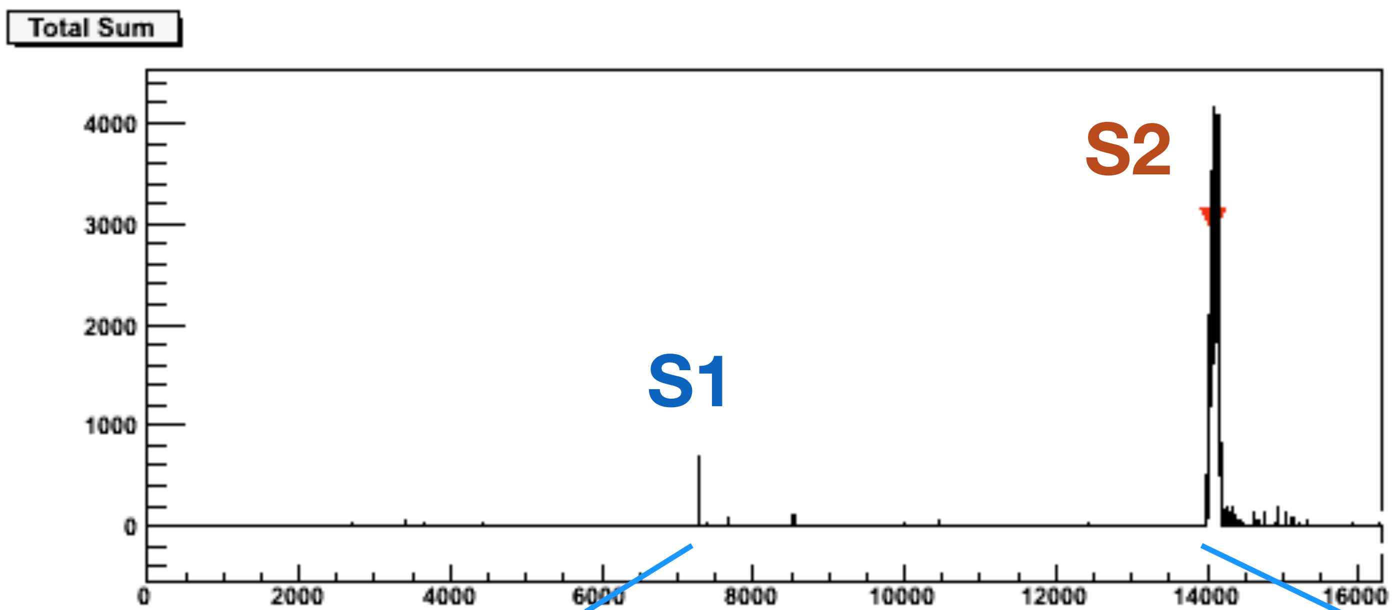




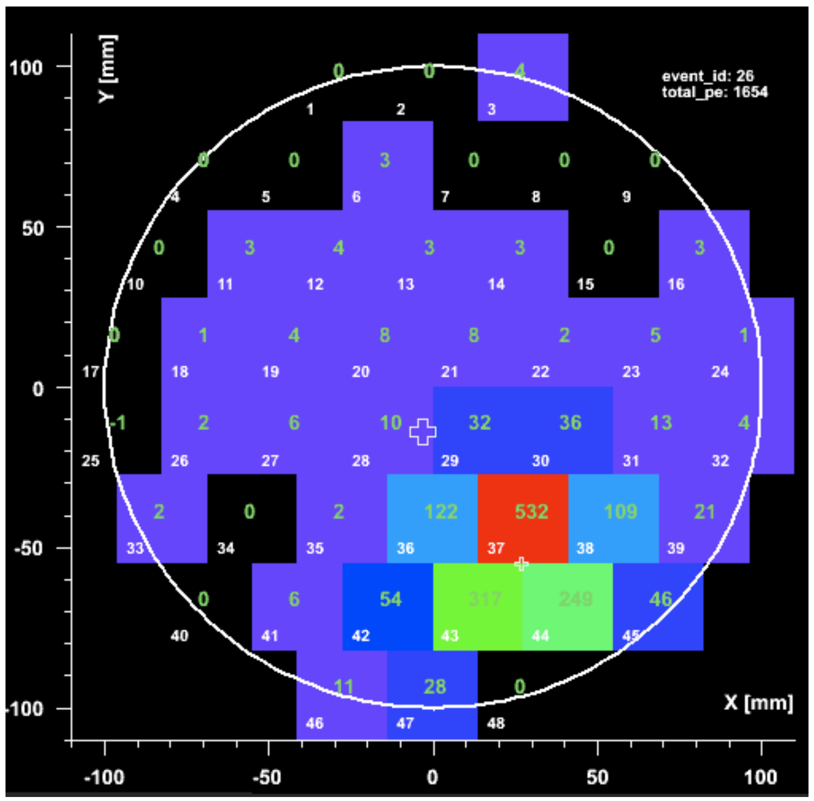


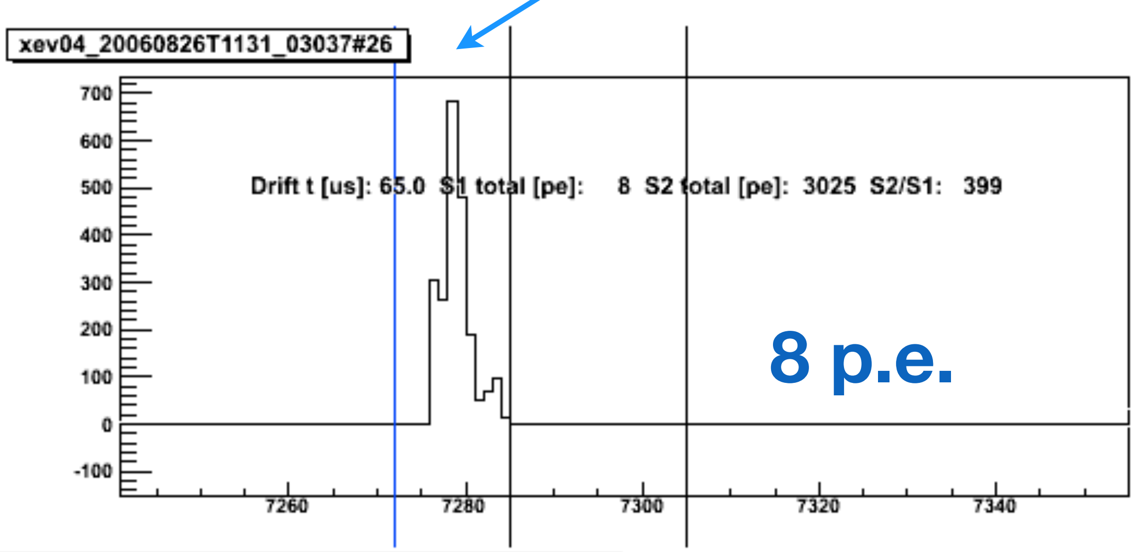
Typical XENON10 Low-Energy Event

- **4 keV$_{ee}$ event; S1: 8 p.e => 2 p.e./keV**

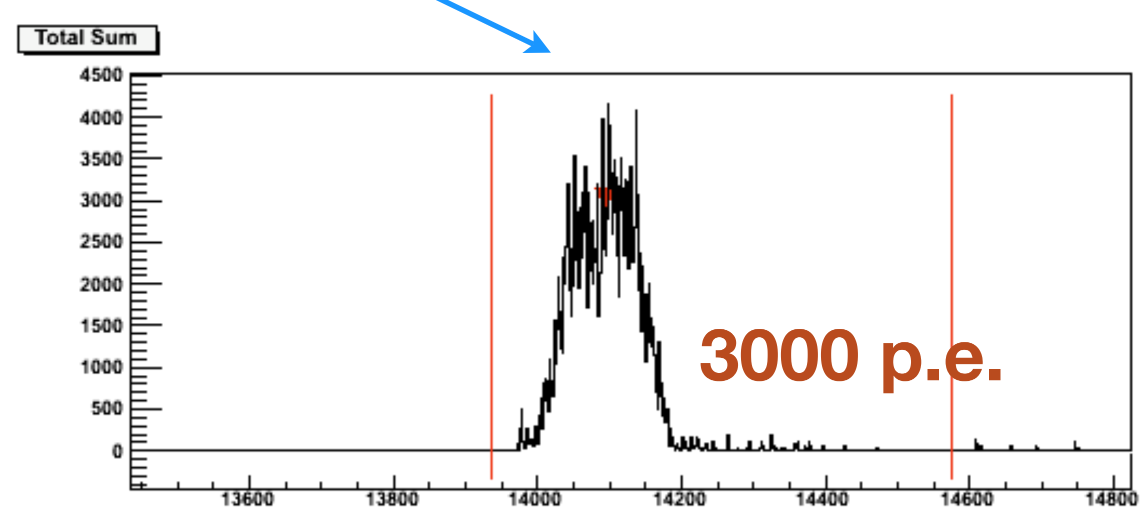


Hit pattern of top PMTs





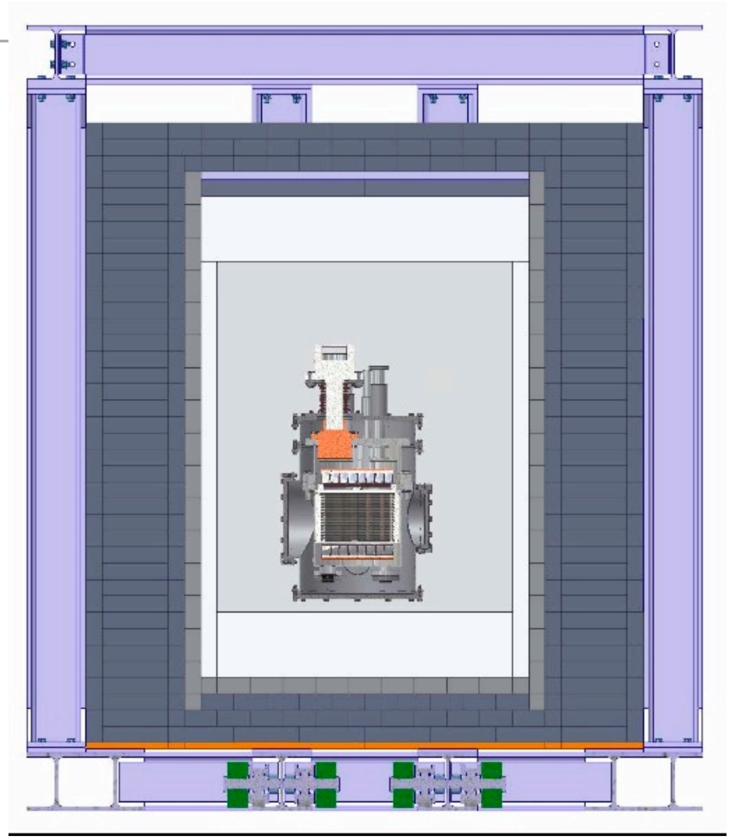
S1

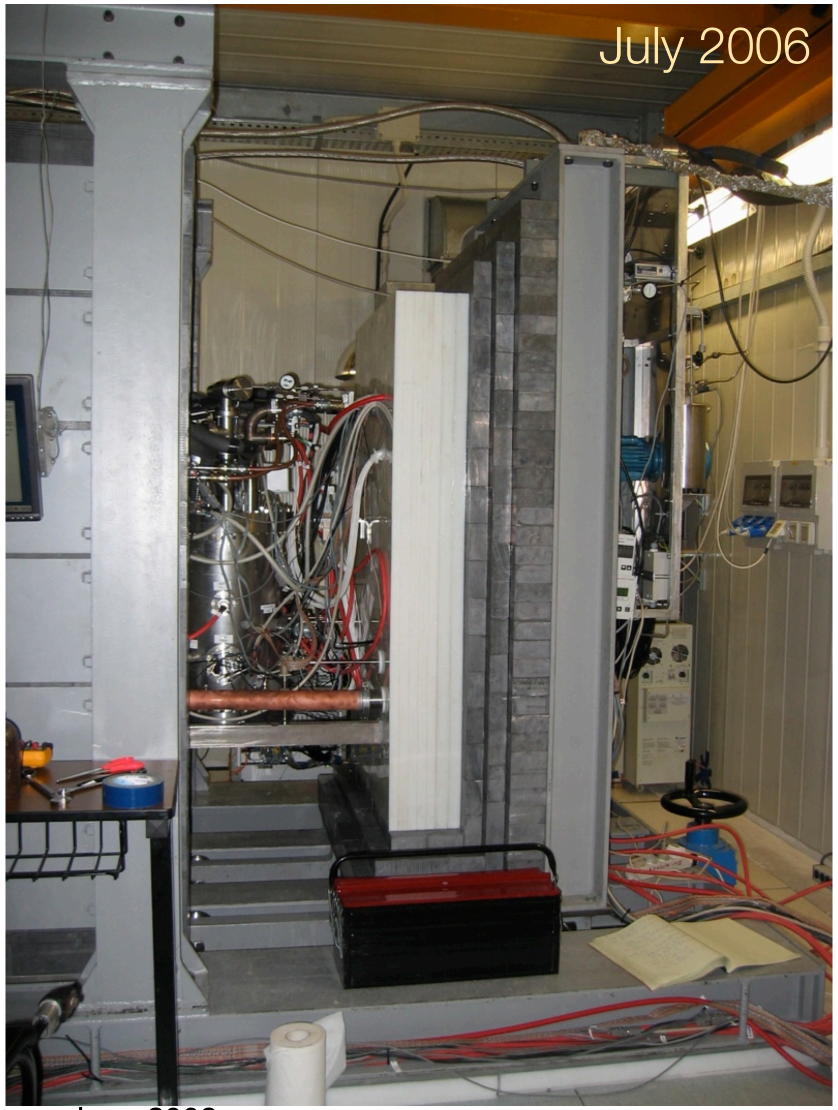


S2

XENON10 at the Gran Sasso Laboratory

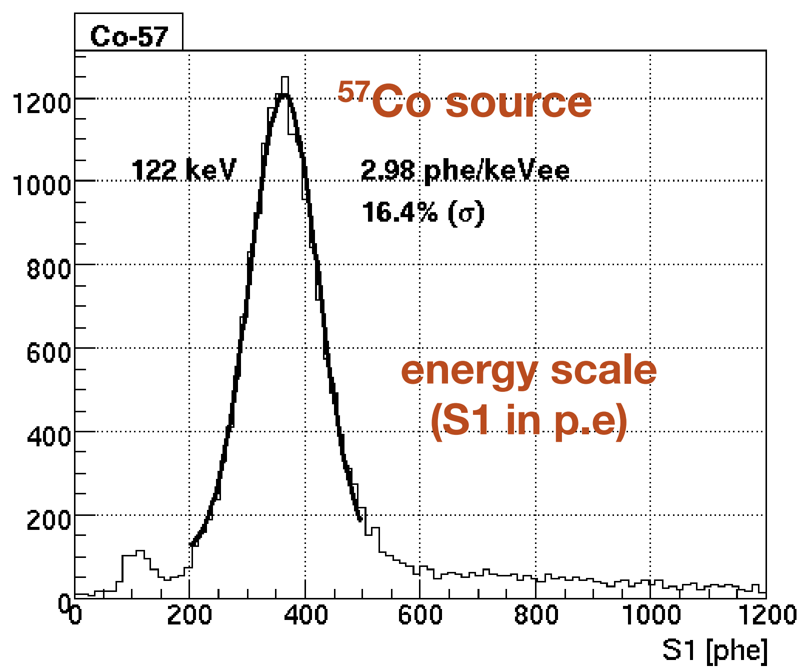
- **March 06:** detector first installed/tested outside the shield
- **July 06:** inserted into shield (20 cm Pb, 20 cm PE, Rn purge)
- **August 24, 06 - February 14, 07: first WIMP search run**

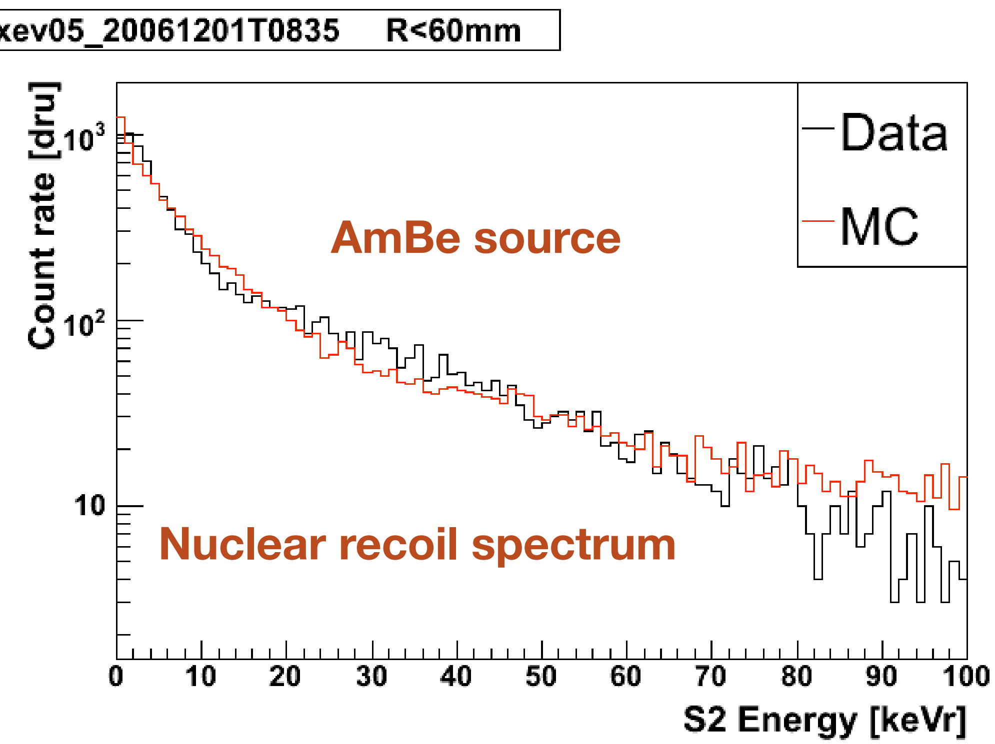


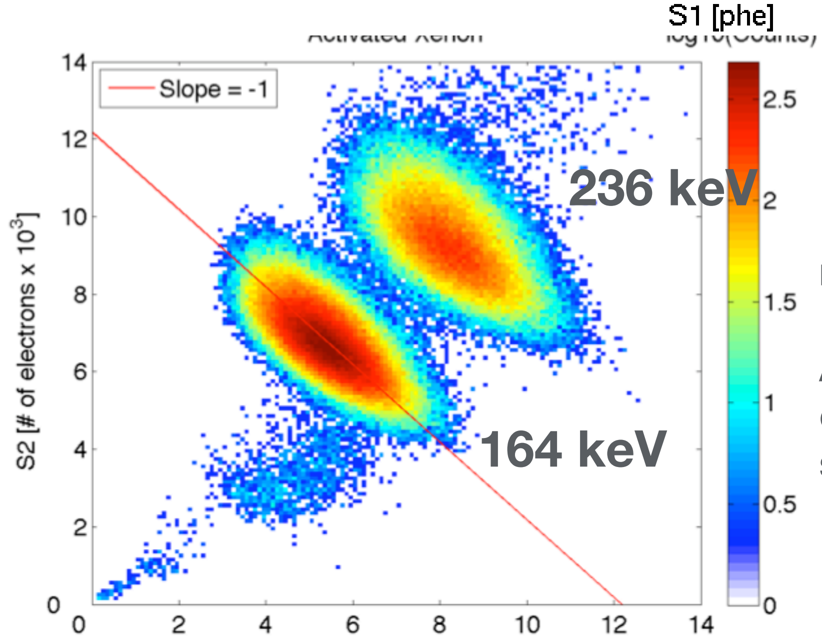


XENON10 Calibrations: Gammas and Neutrons

- **Sources**: ^{57}Co, ^{137}Cs, AmBe, n-activated Xe (^{131m}Xe, ^{129m}Xe) -> determine energy scale and resolution; position reconstruction; uniformity of detector response, positions of ER and NR band, electron lifetime: (1.8±0.4) ms => << 1ppb (O_2 equiv.) purity

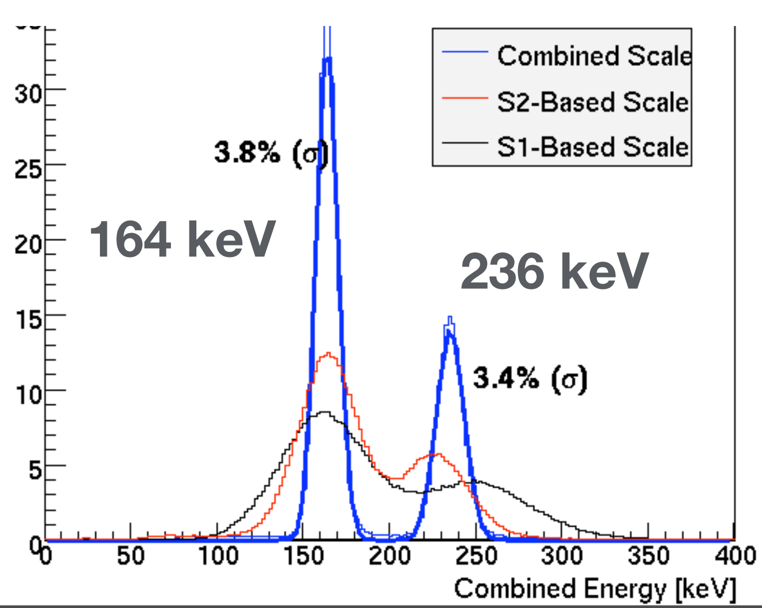






n-activated Xe:

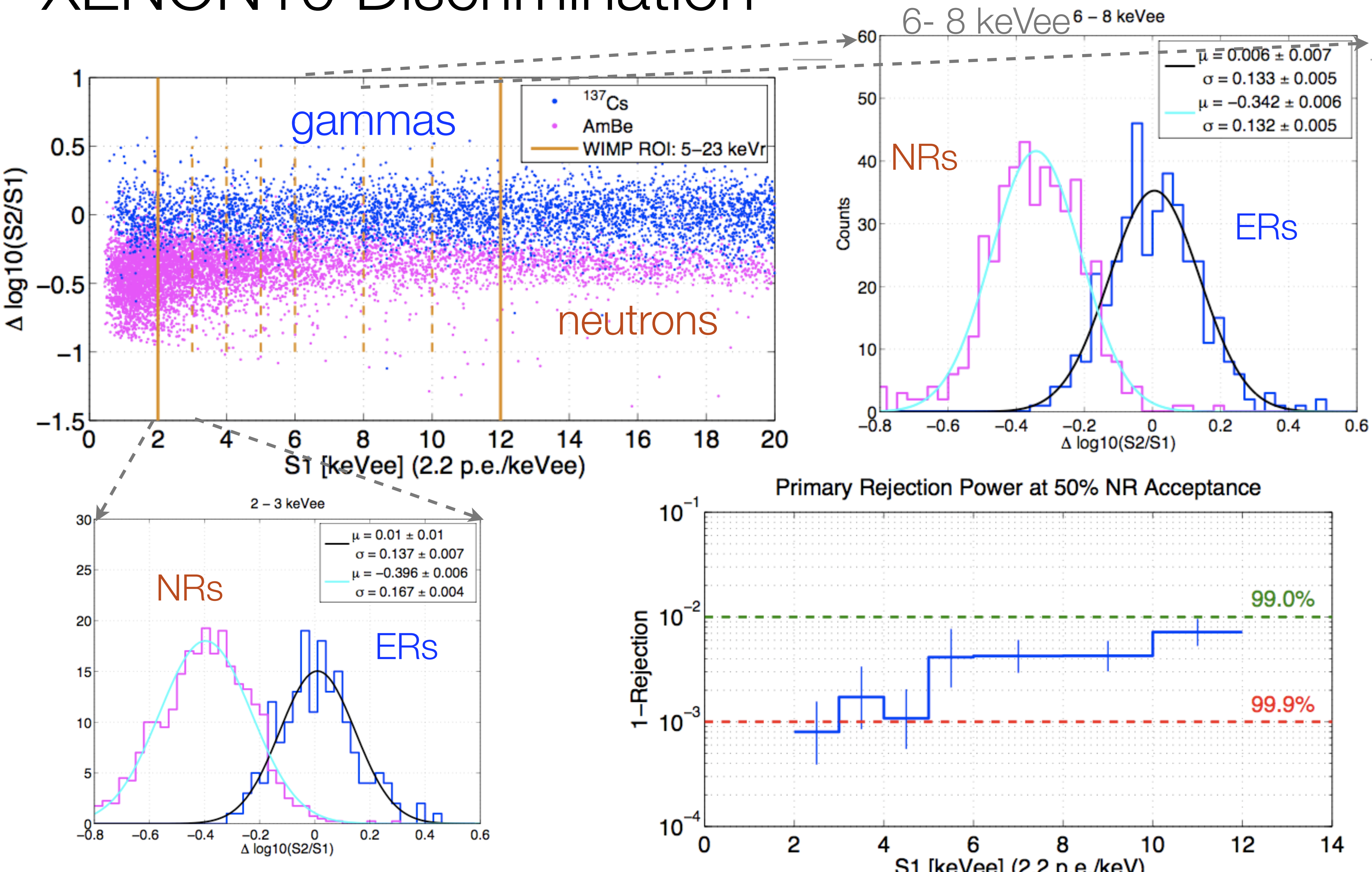
Anti-correlation of charge/light signals



n-activated Xe:

Combined energy spectrum

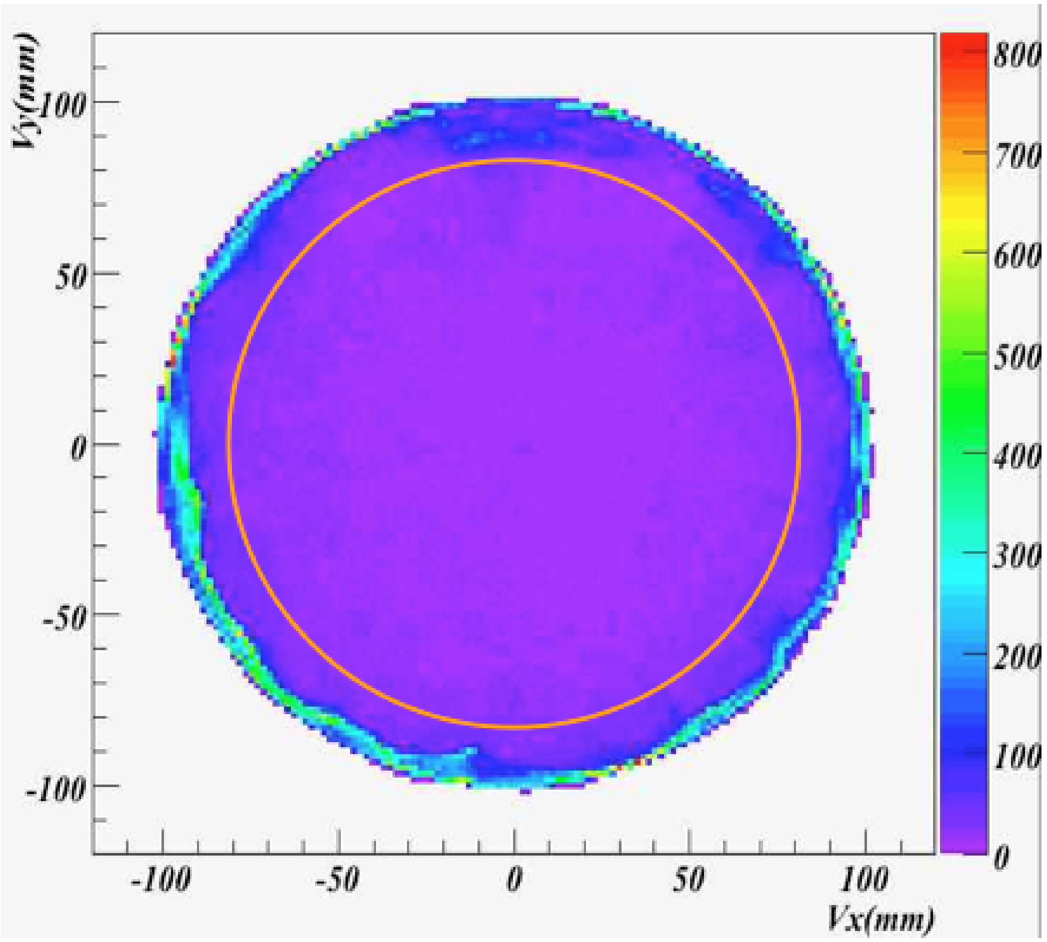
XENON10 Discrimination

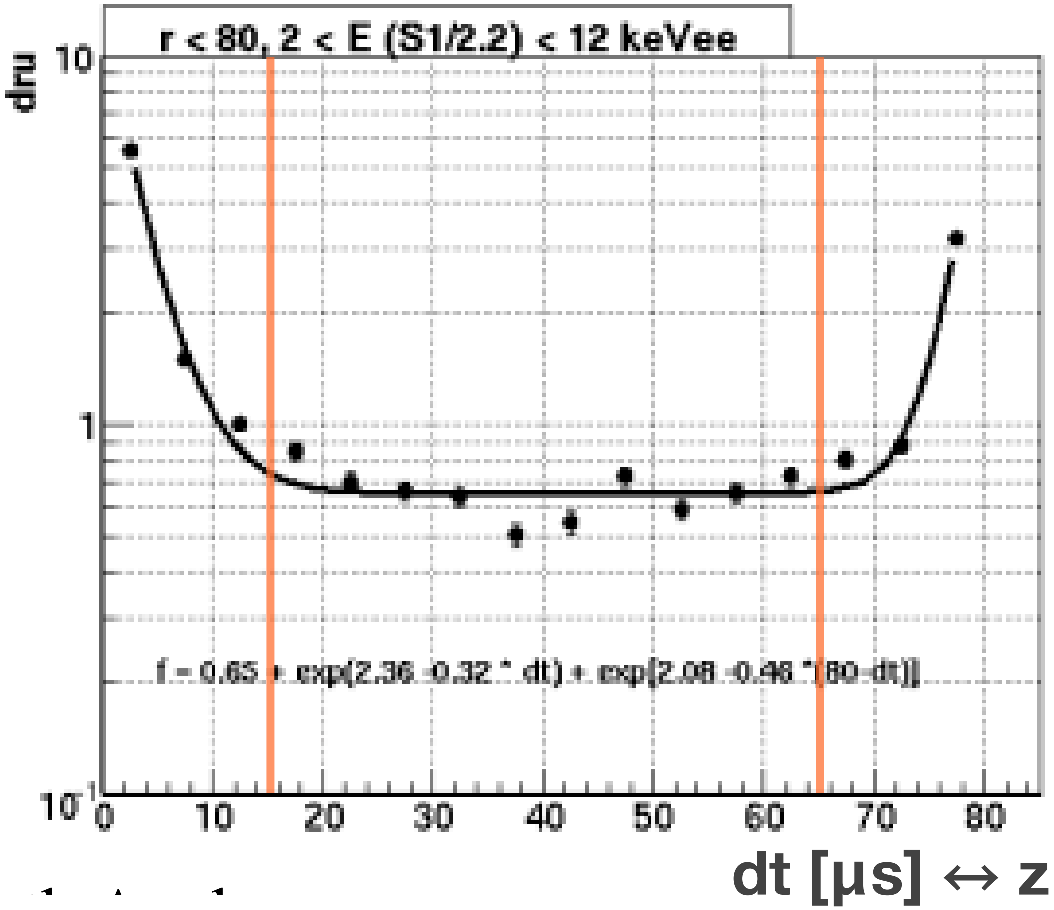


- **Rejection is > 99.6% for 50% Nuclear Recoil acceptance**
  - ➡ **Cuts:** fiducial volume (remove events at teflon edge where poor charge collection)
  - ➡ Multiple scatters (more than one S2 pulse)

XENON10 Blind WIMP Analysis Cuts

- **Energy window: 2 - 12 keVee -> based on 2.2 p.e./keVee**
  - ➡Basic Quality Cuts (QC0): remove noisy and uninteresting (no S1, multiples, etc) events
  - ➡Fiducial Volume Cuts (QC1): capitalize on LXe self-shielding
  - ➡High Level Cuts (QC2): remove anomalous events (S1 light pattern)

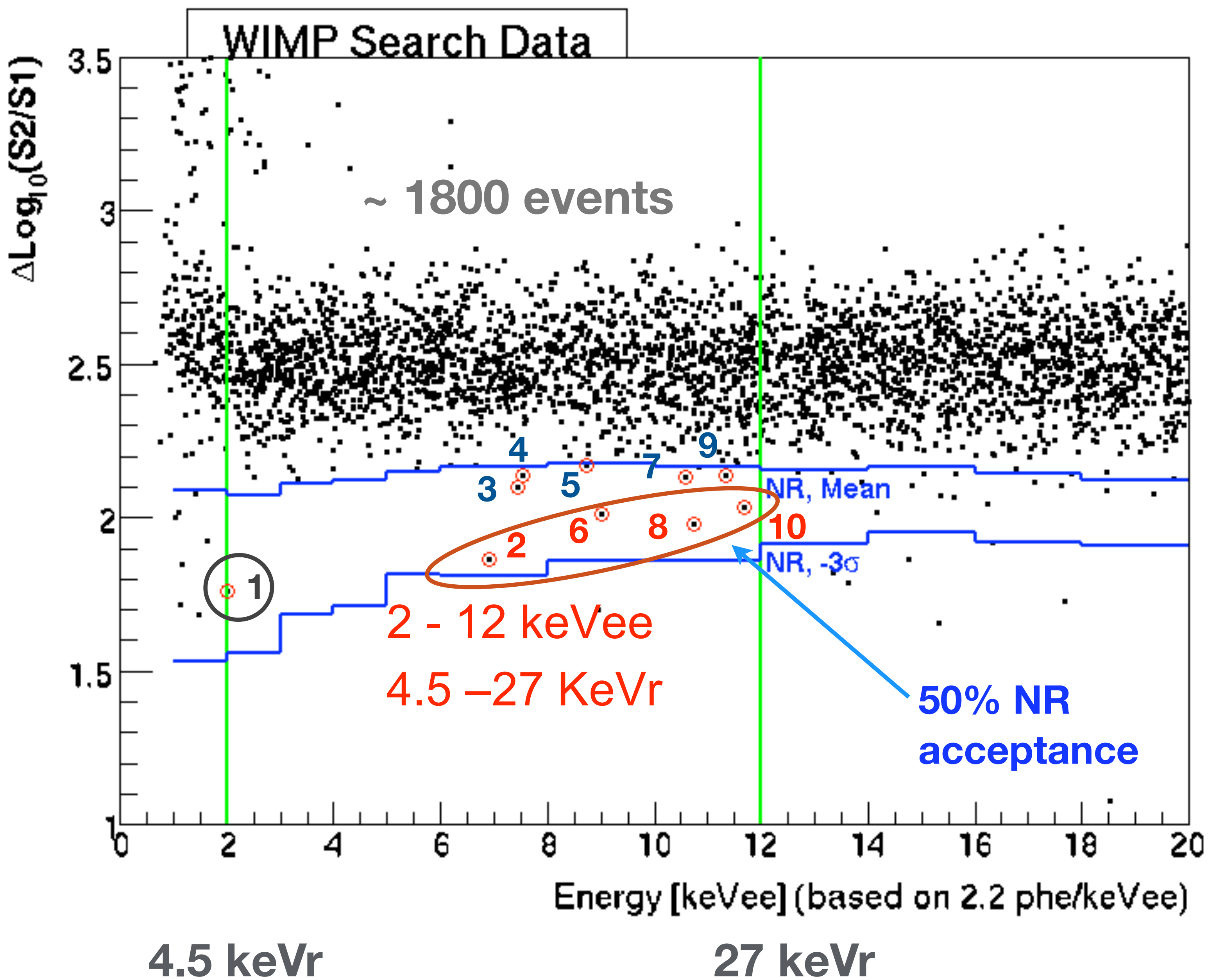




- **Fiducial Volume Cut: 15 μs < dt < 65 μs, r < 80 mm => fiducial mass = 5.4 kg**
- **Overall Background** in Fiducial Volume: ~ **0.6 events/(kg · day · keV)**

XENON10 WIMP Search Data

- WIMP search run Aug. 24. 2006 - Feb. 14, 2007: ~ **60 (blind) live days**
- **136 kg-days exposure** = 58.6 live days × 5.4 kg × 0.86 (ε) × 0.50 (50% NR acceptance)



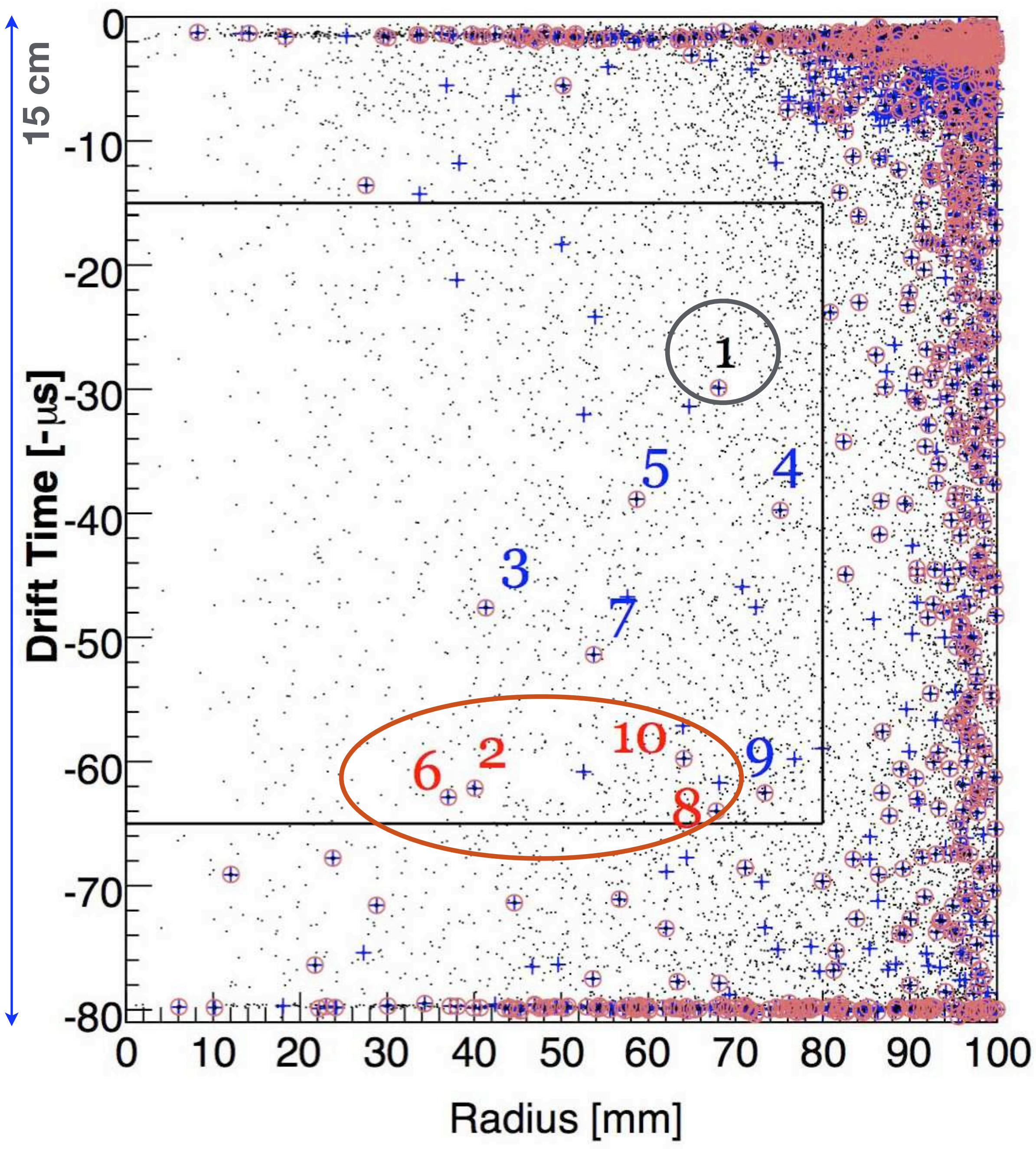
WIMP 'Box' defined at

50% acceptance of NRs (blue lines): [Mean,-3σ]

10 events in 'box' after all cuts
7.0 ($^{+1.4}_{-1.0}$) statistical leakage expected from the gamma (ER) band

NR energy scale based on constant 19% QF

Spatial Distribution of Events



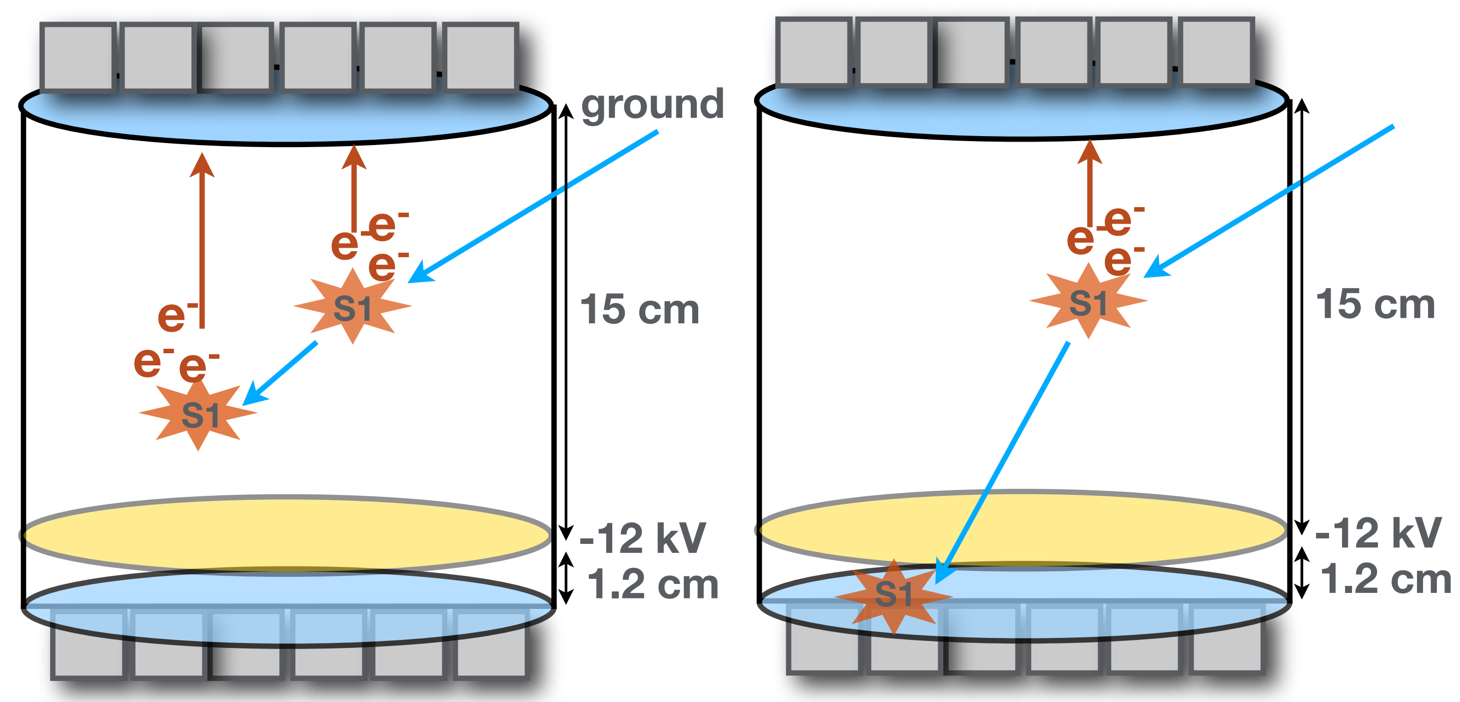
'Gaussian events': nr. 3, 4, 5, 7,9

'Non-Gaussian events': nr: 1, 2, 6, 8, 10

Ev. nr. 1: S1 due to noise glitch (a posteriori)

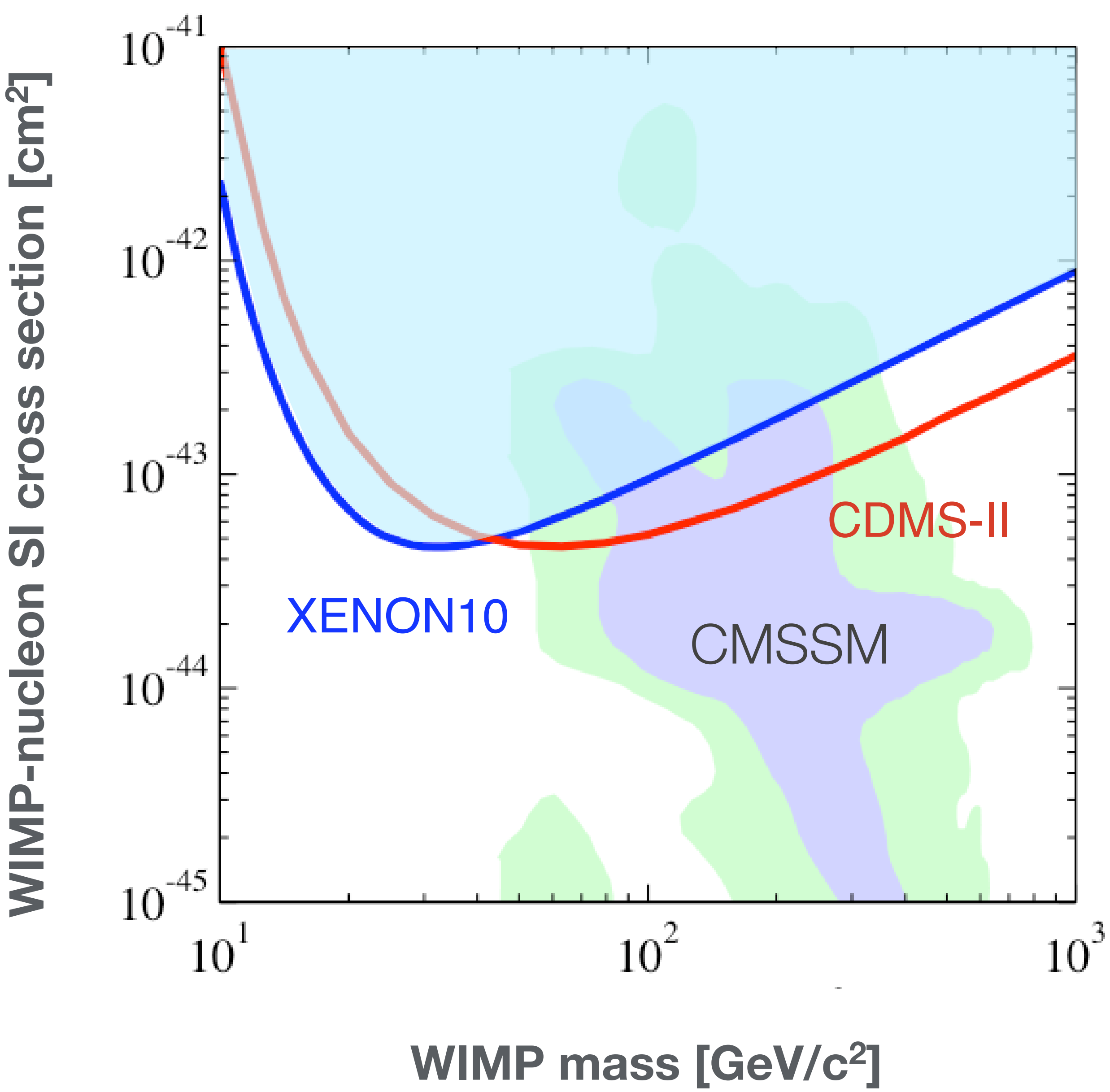
Ev. 2, 6, 8, 9 -> not WIMPs!

Likely explanation: reduced S2/S1-events due to double scatters with one scatter in a 'dead' LXe region => no S2 for 2nd scatter



XENON10 WIMP Search Results for SI Interactions

- To set limits: all 10 events considered, thus no background subtraction performed
- Probe the elastic, SI WIMP-nucleon σ down to ≈ **4 × 10^{-44} cm^2** (at M_{WIMP} = 30 GeV)



Upper limits in WIMP-nucleon cross section derived with Yellin Maximal Gap Method [PRD 66 (2002)]

At 100 GeV WIMP mass

9.0 × 10^{-44} cm^2 (no background subtraction, red curve)

5.5 × 10^{-44} cm^2 (known background subtracted, not shown)

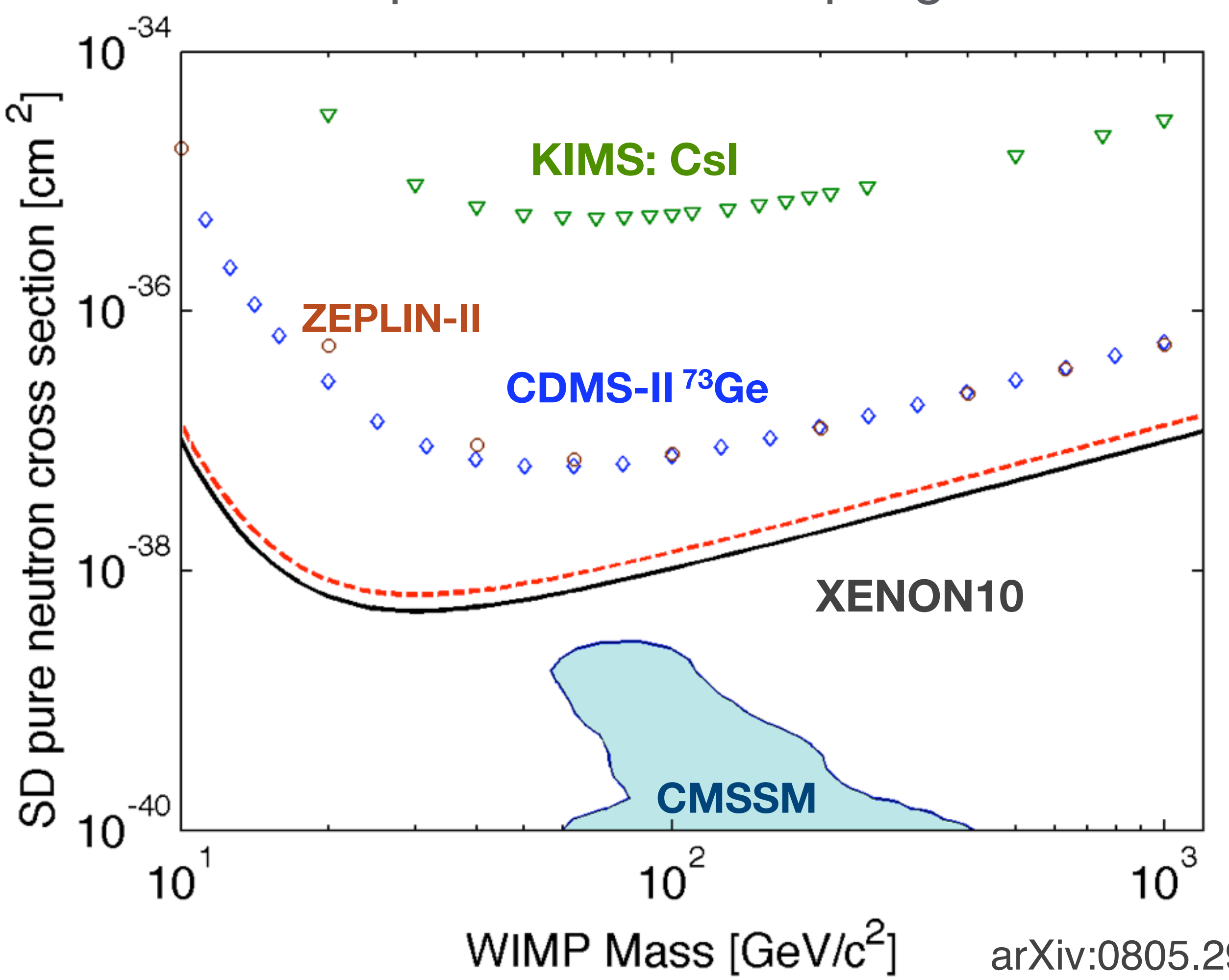
Factor 6 below previous best limit

Phys. Rev. Lett. **100**, 021303 (2008)

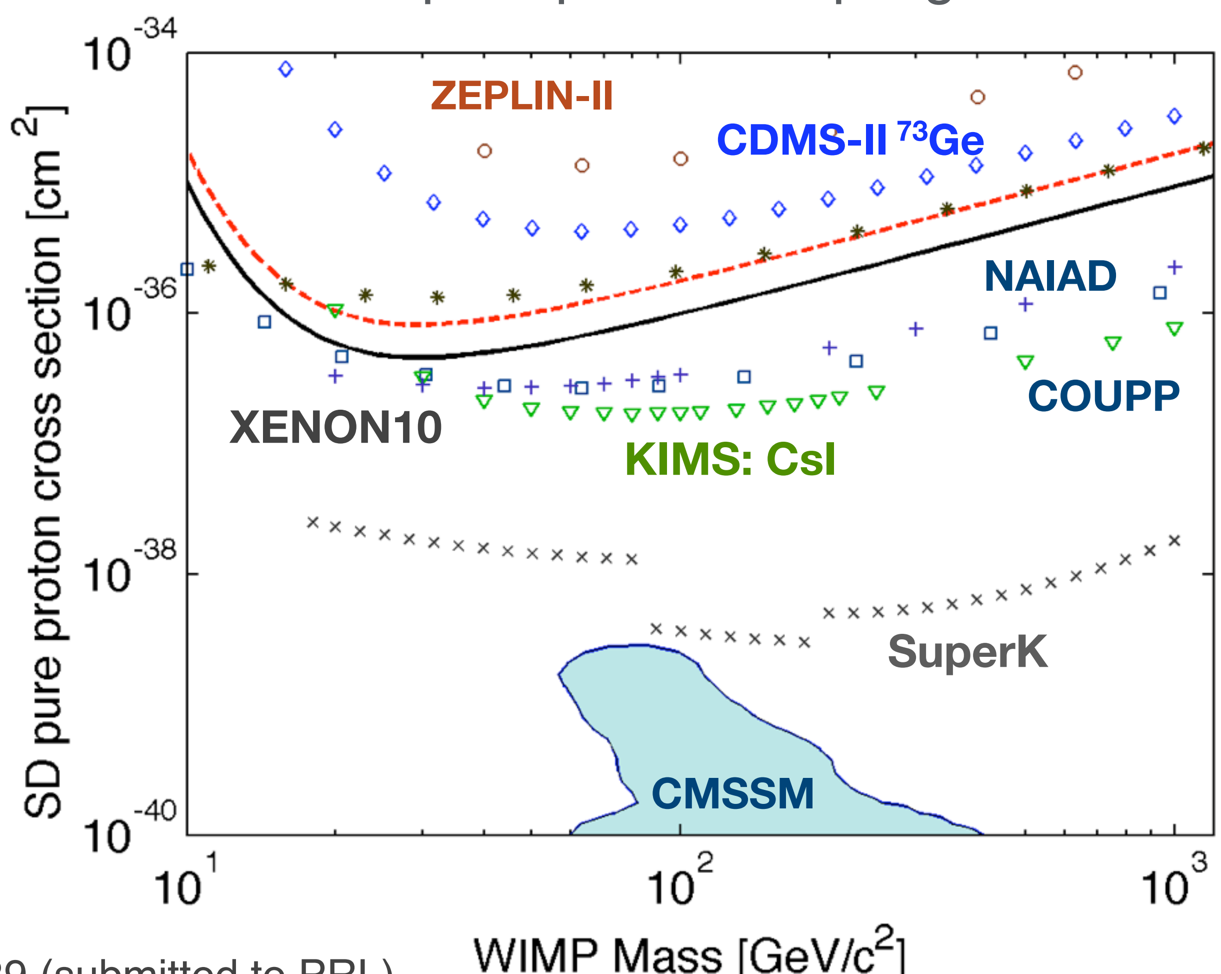
XENON10 WIMP Search Results for SD Interactions

- natural Xe: ^{129}Xe, 26.4 %, spin 1/2, ^{131}Xe, 21.2%, spin 3/2
- use shell-model calculations by Ressel and Dean [PRC 56, 1997] for <S_n>, <S_p>
- upper limits: Yellin Maximal Gap method, **no background subtraction**

pure neutron couplings



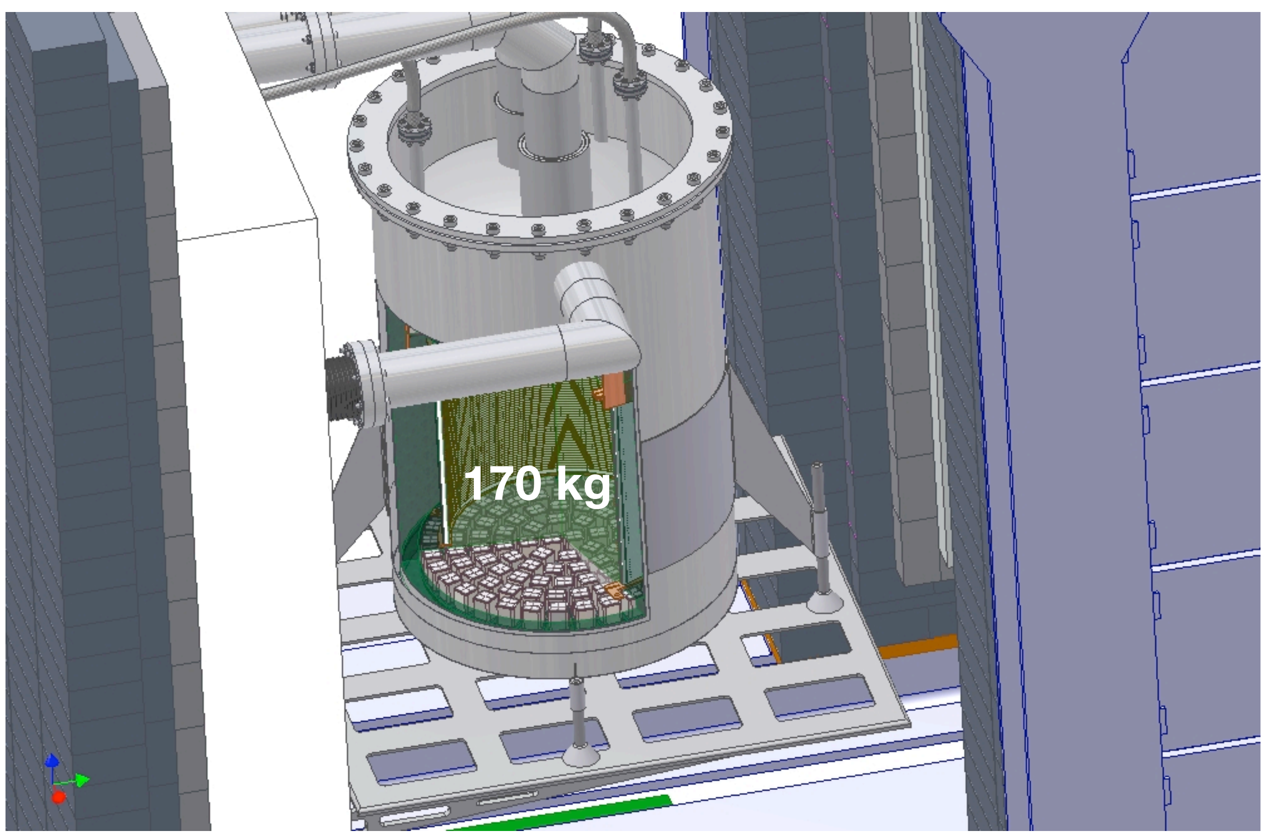
pure proton couplings



arXiv:0805.2939 (submitted to PRL)

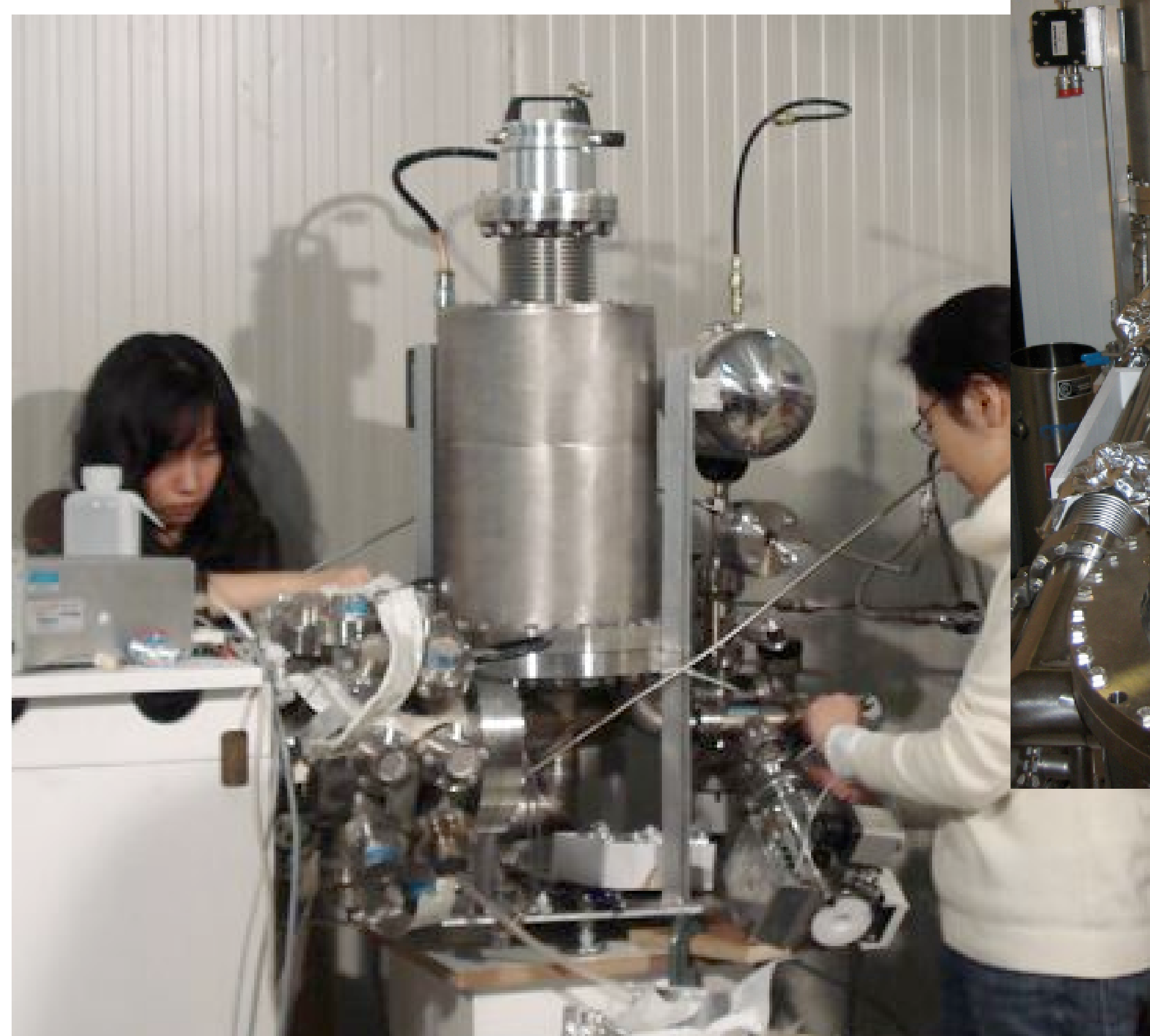
The XENON100 Experiment

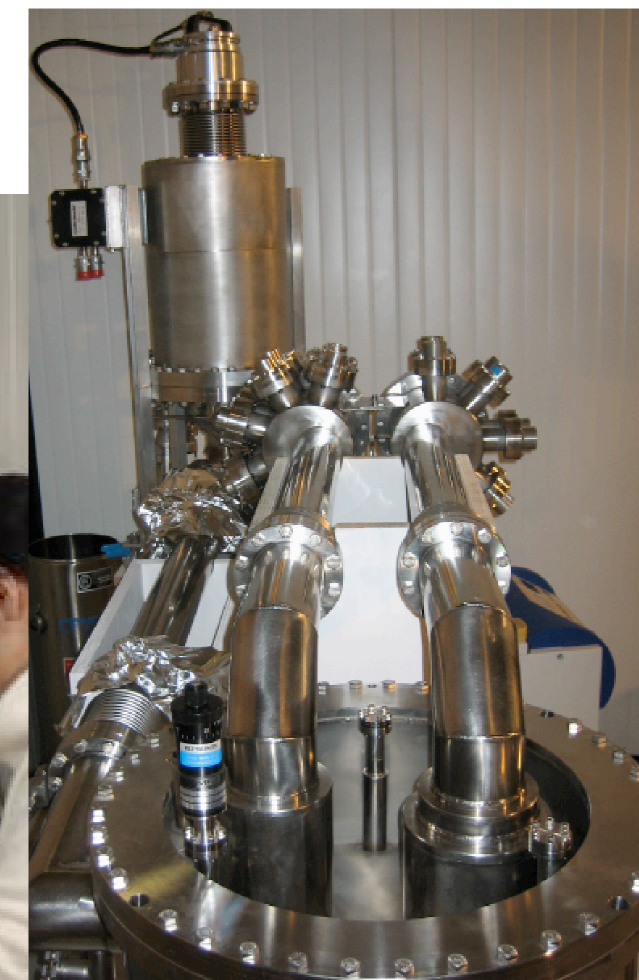
- Goals:
  - ➡increase mass by x 10
  - ➡decrease backgrounds by x 100
  - - through material selection + screening,
  - - active veto shield and detector design
- Status: under commissioning at LNGS



XENON100 Cryogenic System

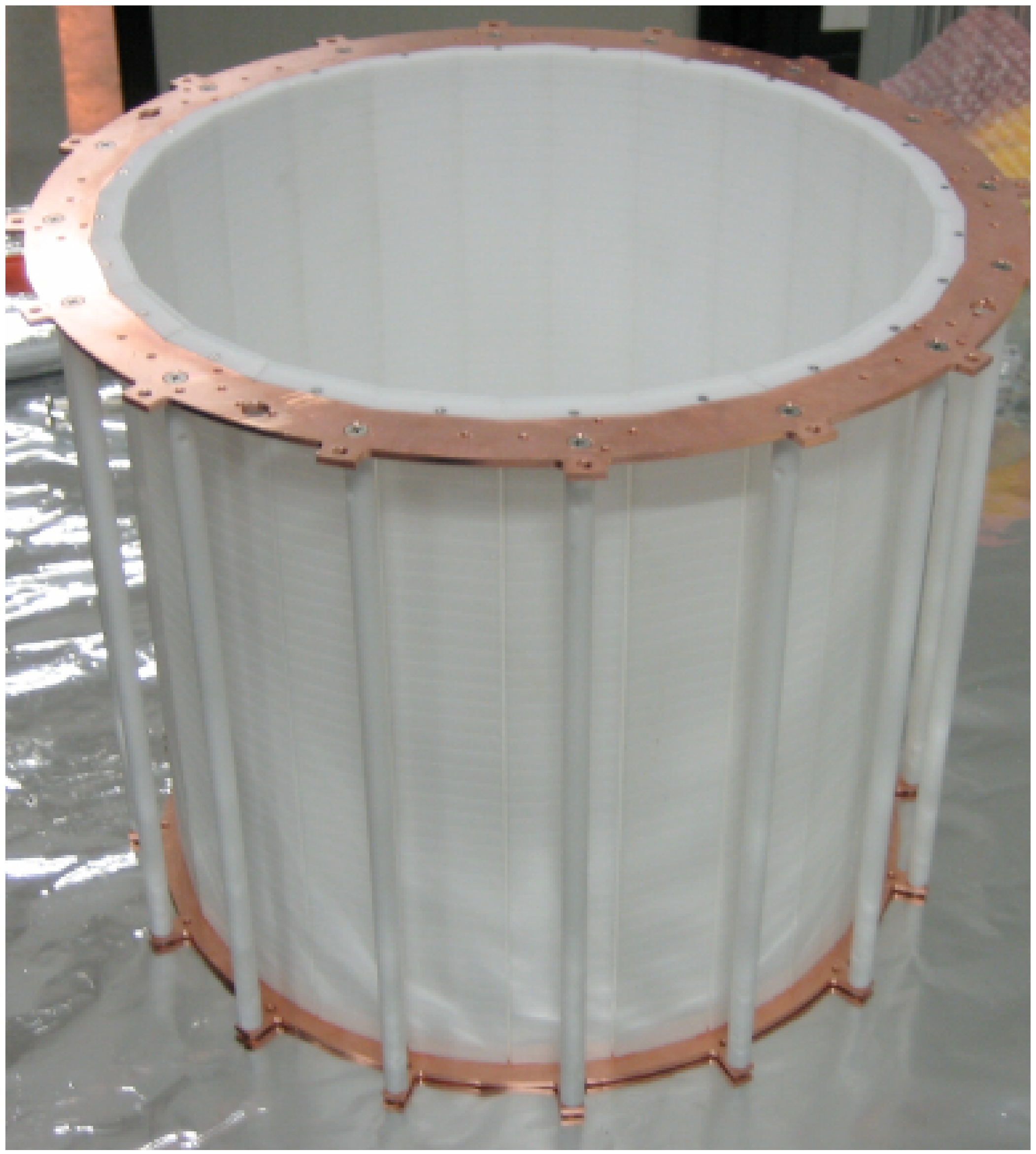
- High-purity, double walled stainless steel cryostat (Nironit steel) assembled and tested at LNGS
- 170 W cryocooler installed and tested (Xe is liquefied outside of the Cu/PE/Pb shield)

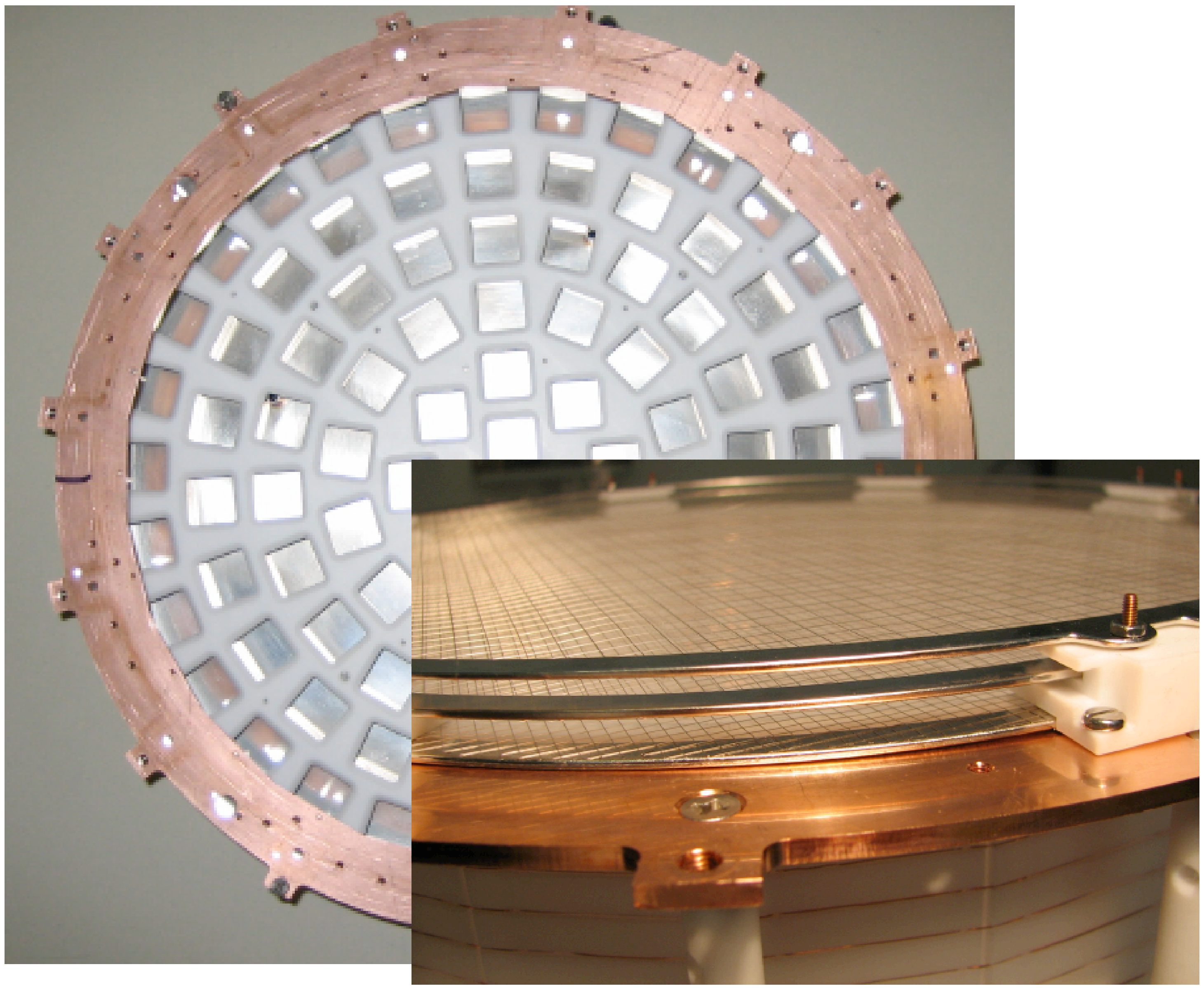




XENON100 inner TPC Structure

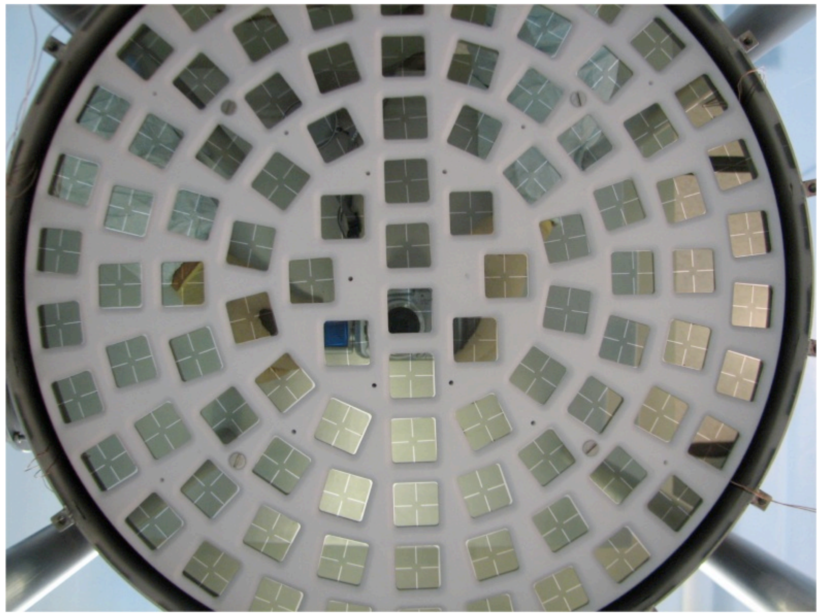
- Inner TPC: PTFE structure; OFRP Cu for inner PMT holder, Nironit steel for bell
- cathode: -30 kV, drift field of 1kV/cm; extraction field of 5 kV
- 40 field shaping rings for field homogeneity

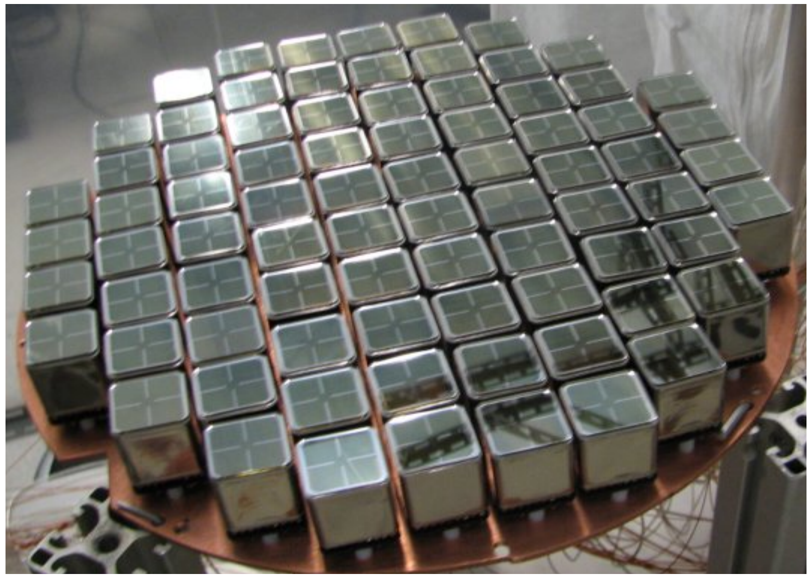


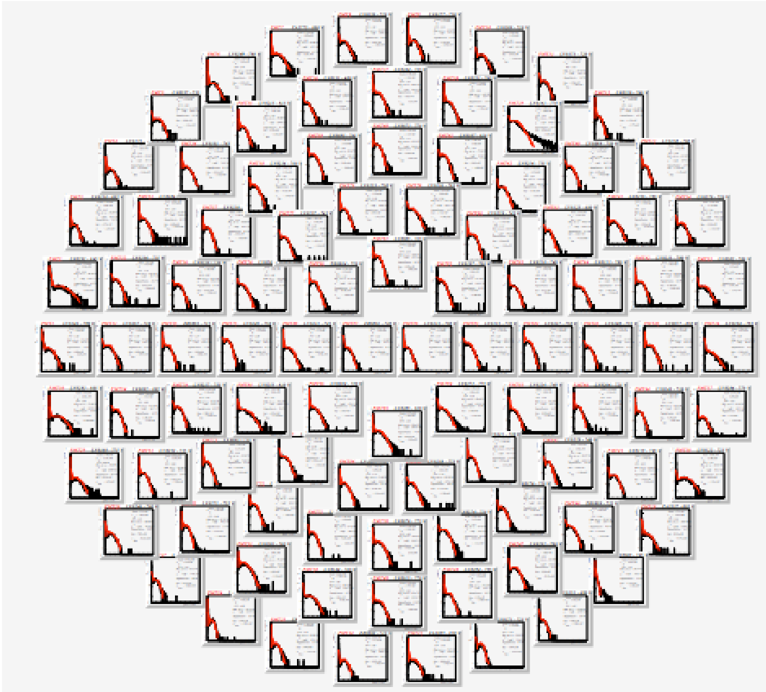


XENON100 PMTs

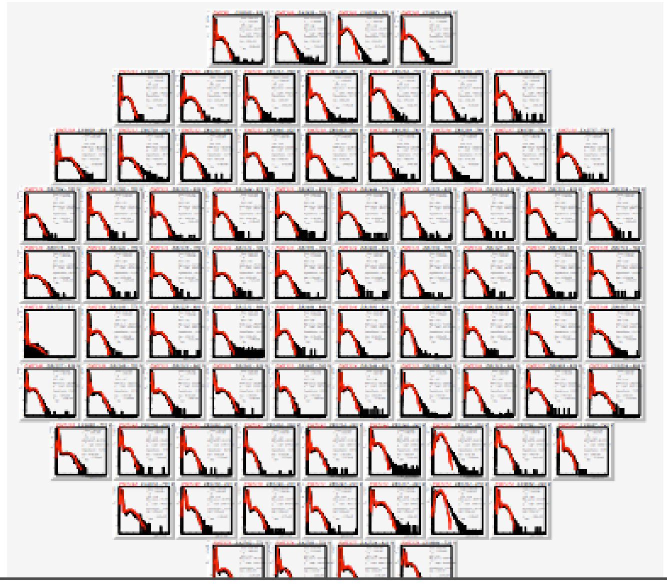
- 242 (Hamamatsu R8520) 1”x1”, low radioactivity PMTs; 80 with high QE of 33%
- 98 top: for good fiducial volume cut efficiency
- 80 bottom: for optimal S1 collection efficiency (thus low threshold); 64 in active LXe shield
- PMT gain calibration with blue LEDs; the SPE response is measured







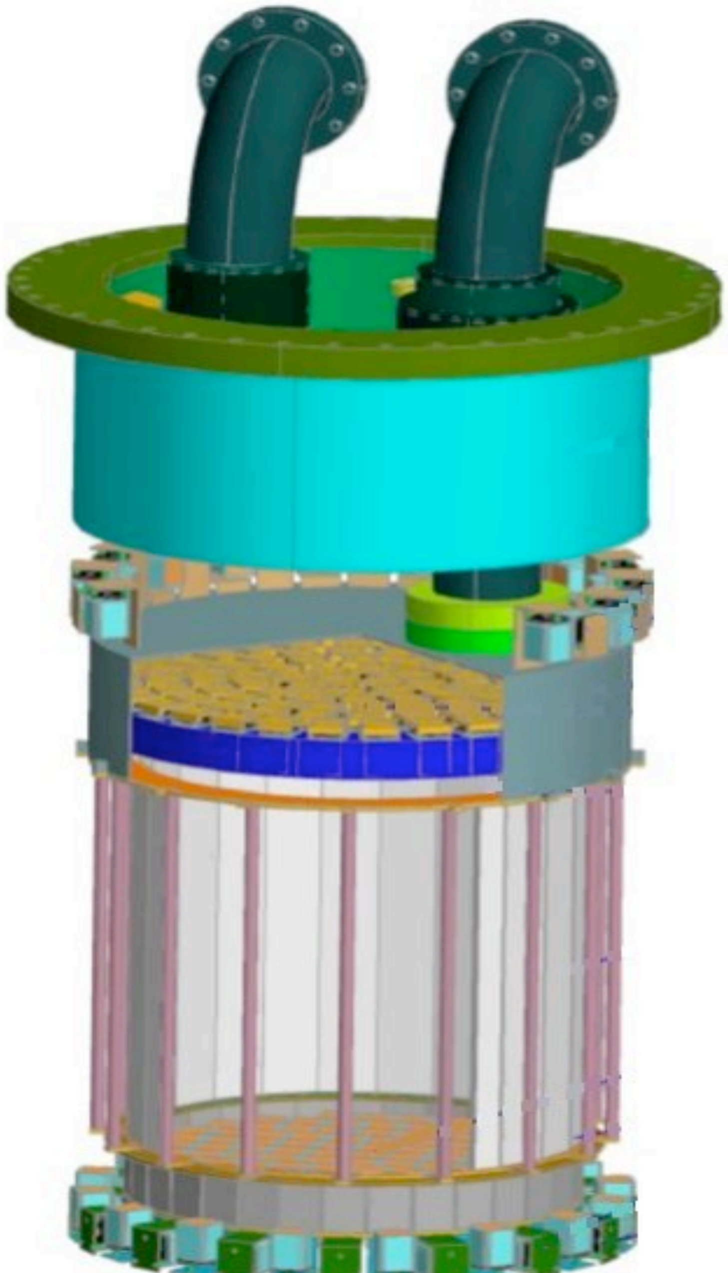
top PMT array
(gain equalized to $2x10^6$)



bottom PMT array
(gain equalized to $2x10^6$)

The XENON100 Detector

- TPC (total of 170 kg LXe) with active veto (100 kg LXe) installed underground since February 2008
- Xe purchased and purified to ppt ^{85}Kr-levels ($T_{1/2}$ = 10.7 y, β^- 678 keV); dedicated column on its way from Japan -> LNGS



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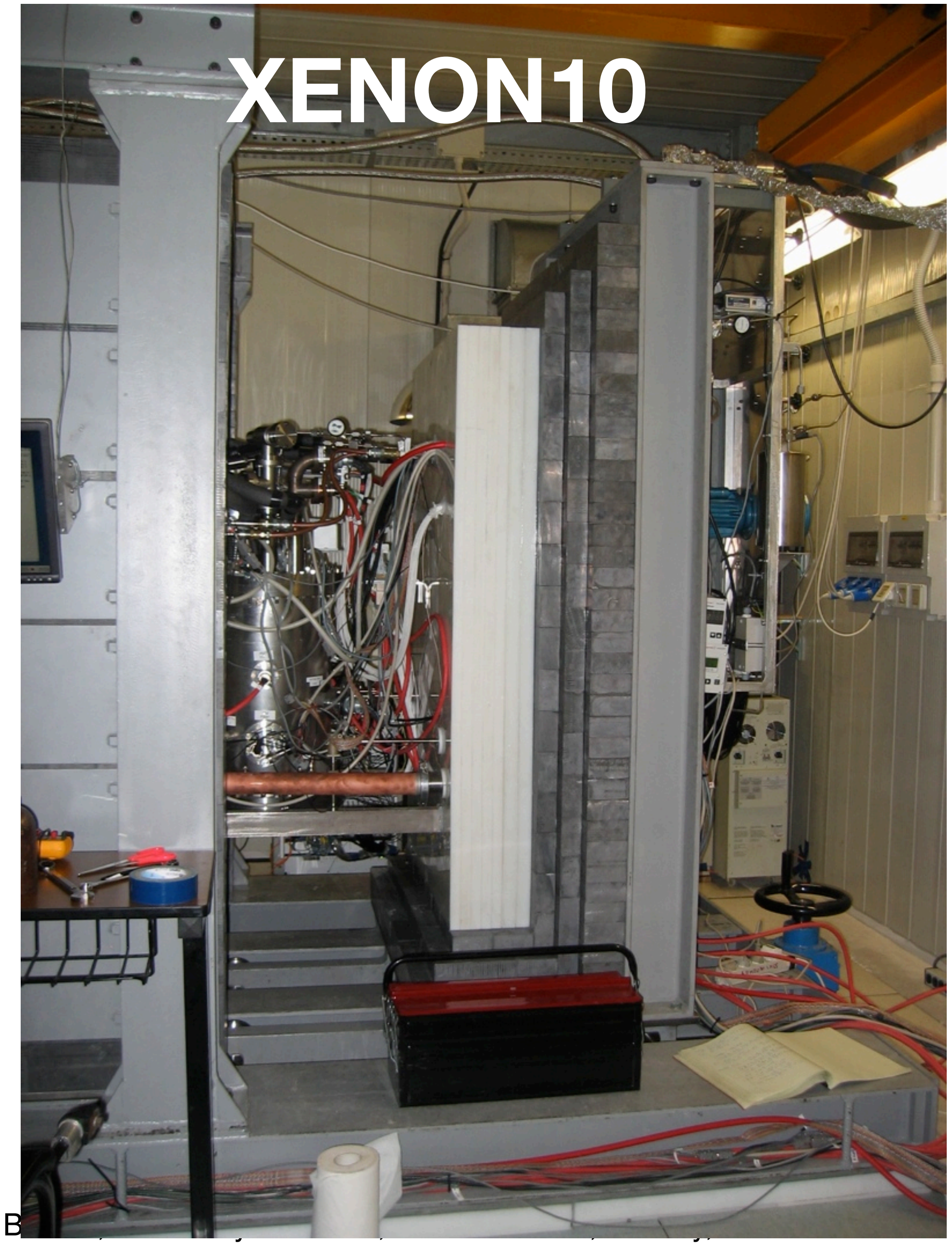
June 2008

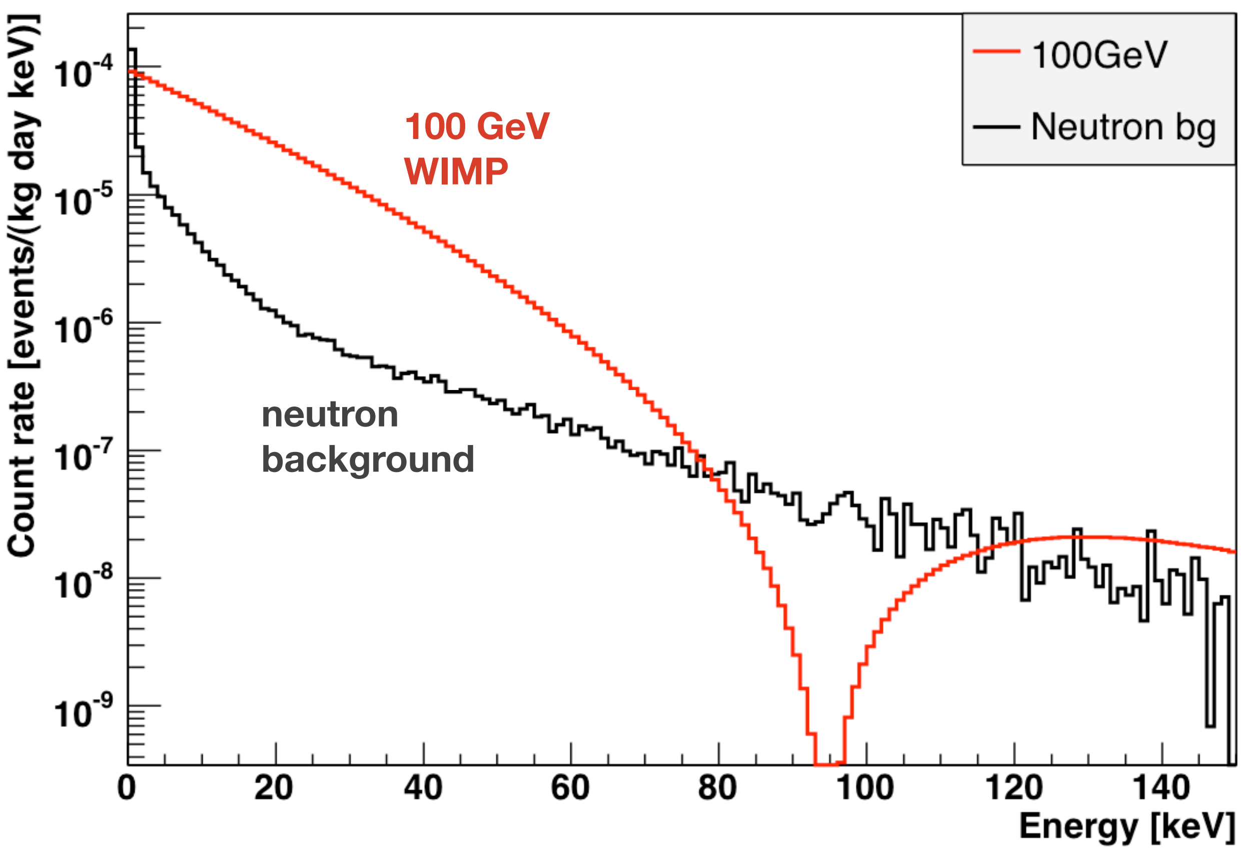
The XENON100 Shield and Status

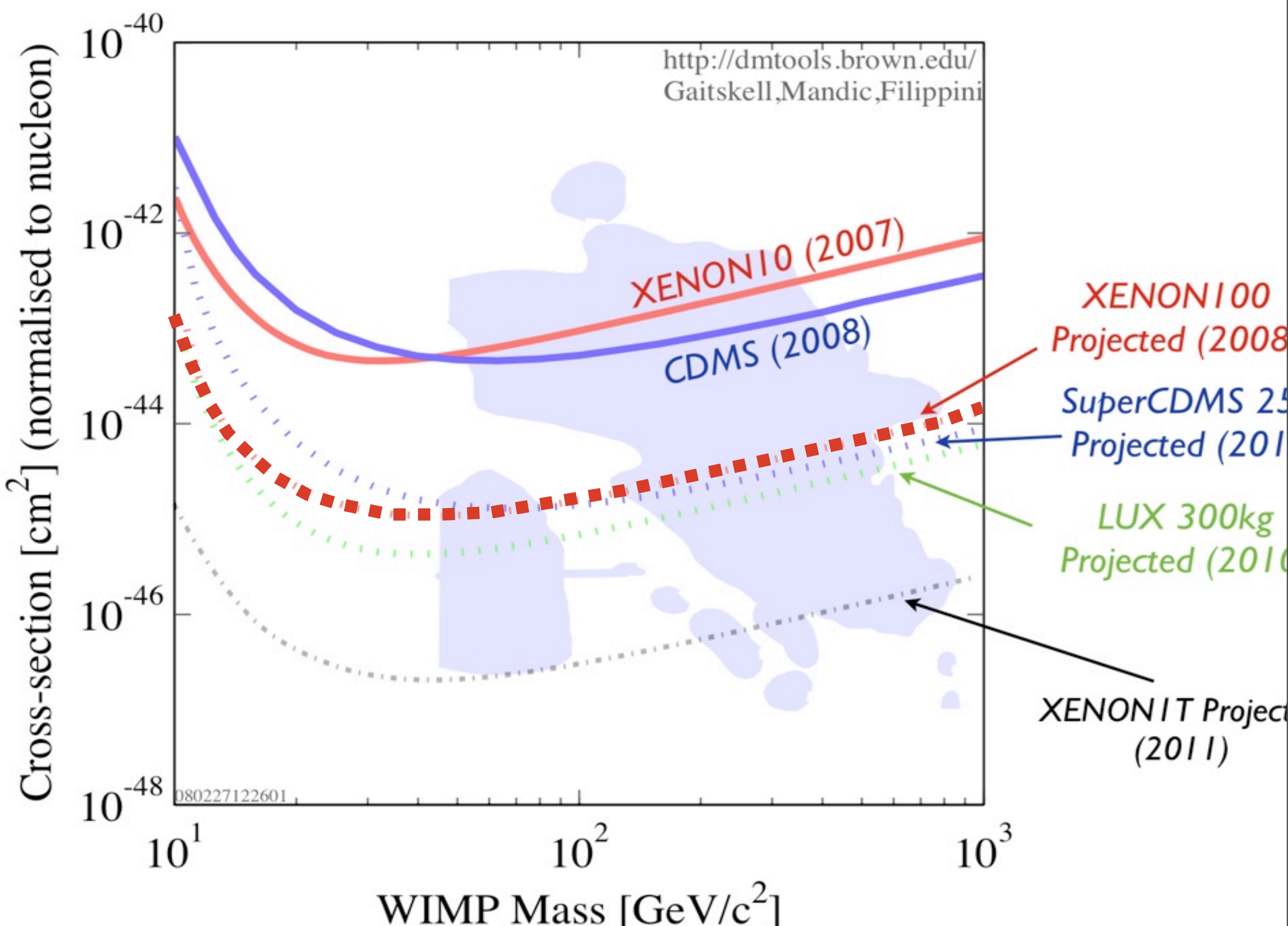
- Shielding modifications: cryogenics, feed-throughs, cables etc outside shield (+ 5 cm Cu)
- Detector is filled with LXe; calibration runs in progress.
- Plan to start WIMP search: ~ fall 2008



XENON100 Backgrounds and Expected Sensitivity

- Background predictions: based on material screening data and MC simulation
- Background of electromagnetic origin: ~ 11 mdru (PMTs, steel, poly are dominant)
- Neutron background: ~ 1.7 μdru (single NRs, Teflon, PMTs, steel dominate) => 0.6 single NRs/year

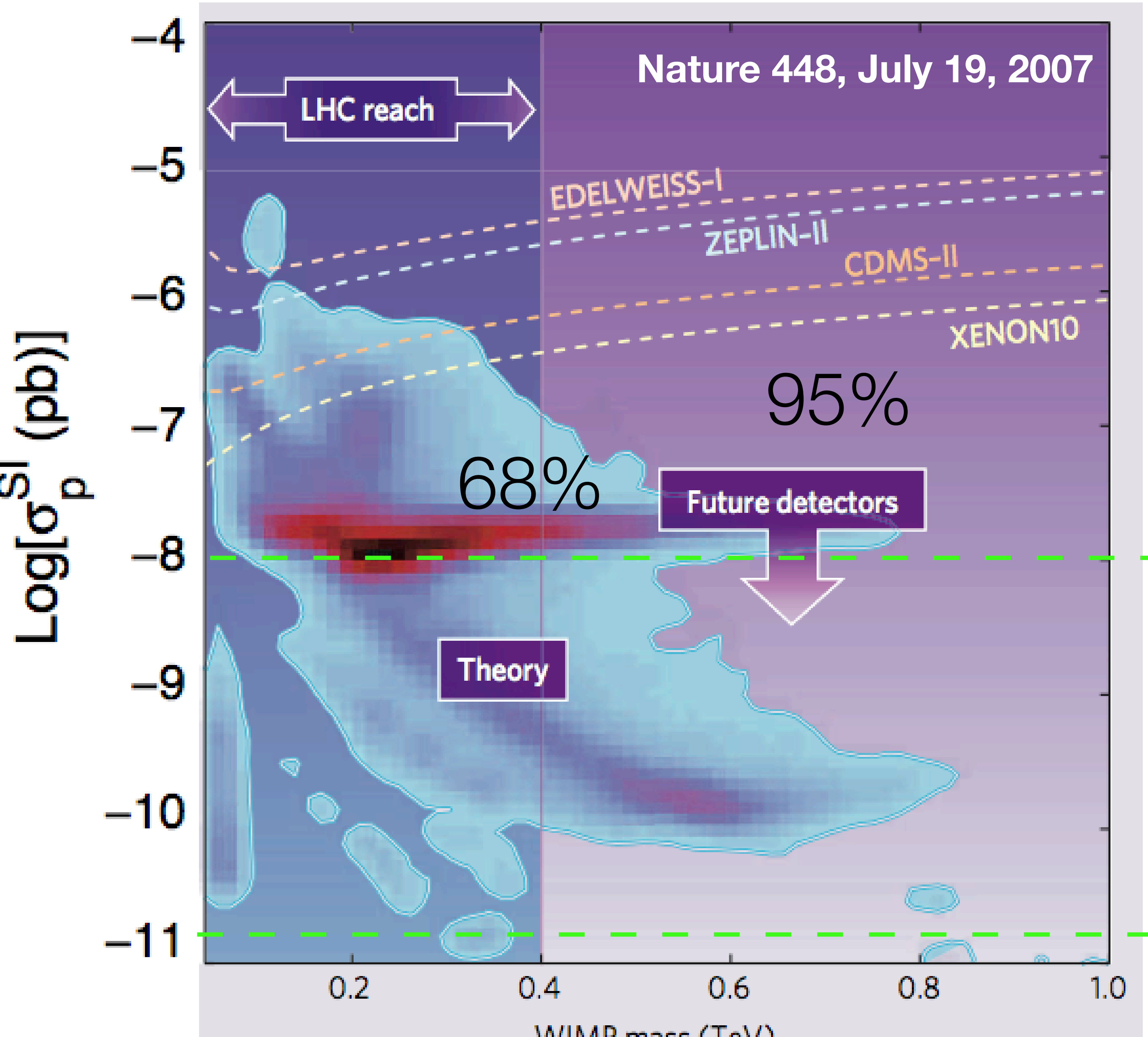




Laura Baudis, University of Zurich, LAPP seminar, Annecy, June 2008

Summary

Many different techniques/targets are being employed to search for dark matter particles
Sensitivities are now approaching the theoretically interesting regions!
Next generation projects: should reach the ≲ 10^{-10} pb level => WIMP (astro)-physics



Theory example: CMSSM (Roszkowski, Ruiz, Trotta)

1 event/kg/yr

CDMS-II, XENON100, COUPP,
CRESST-II, EDELWEISS-II, ZEPLIN-III,...

1 event/t/yr

SuperCDMS1t, WARP1t, ArDM
XENON1t, EURECA, ELIXIR, XMASS, ...

more slides

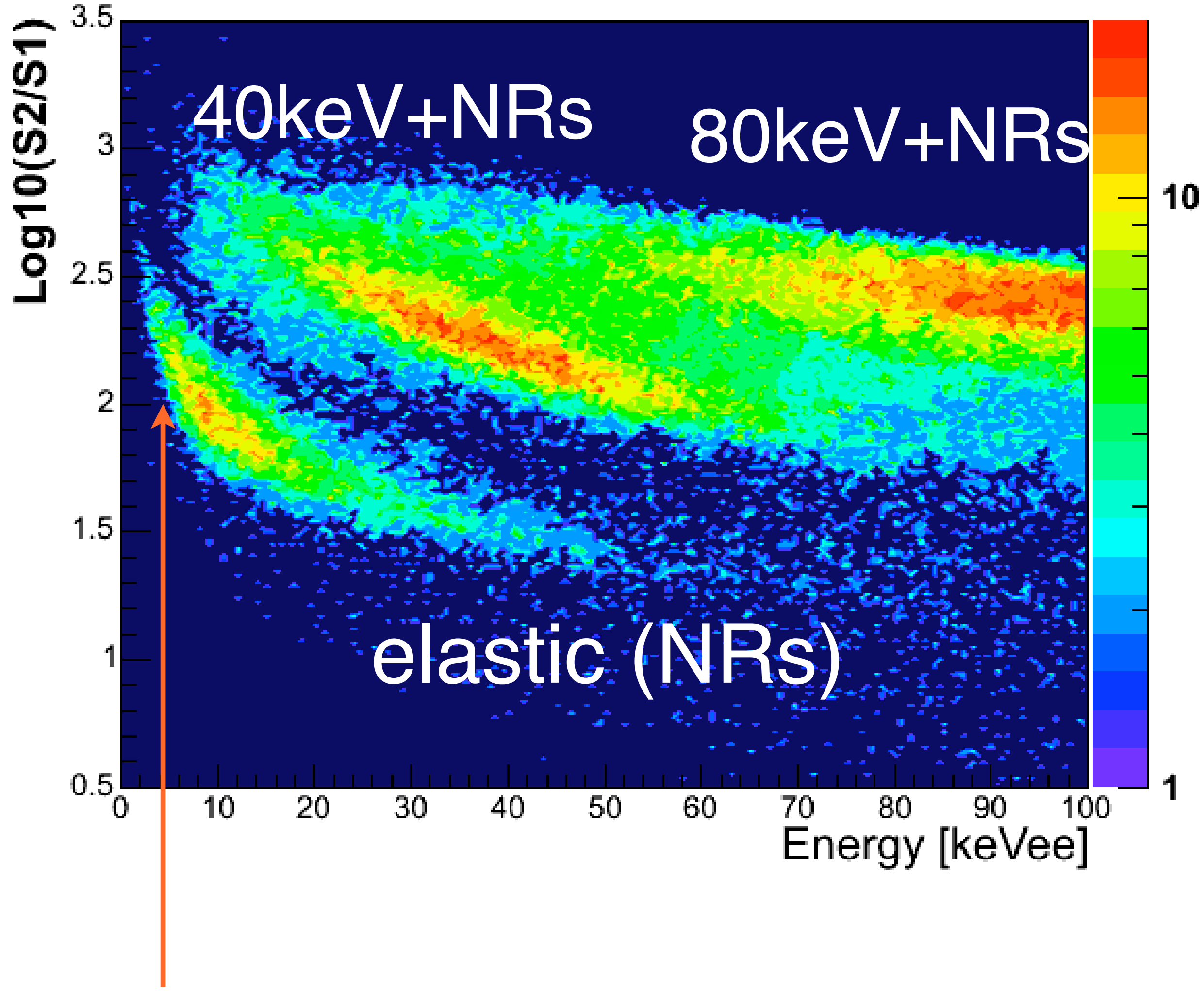
LXe and Other Noble Liquids as Detector Media

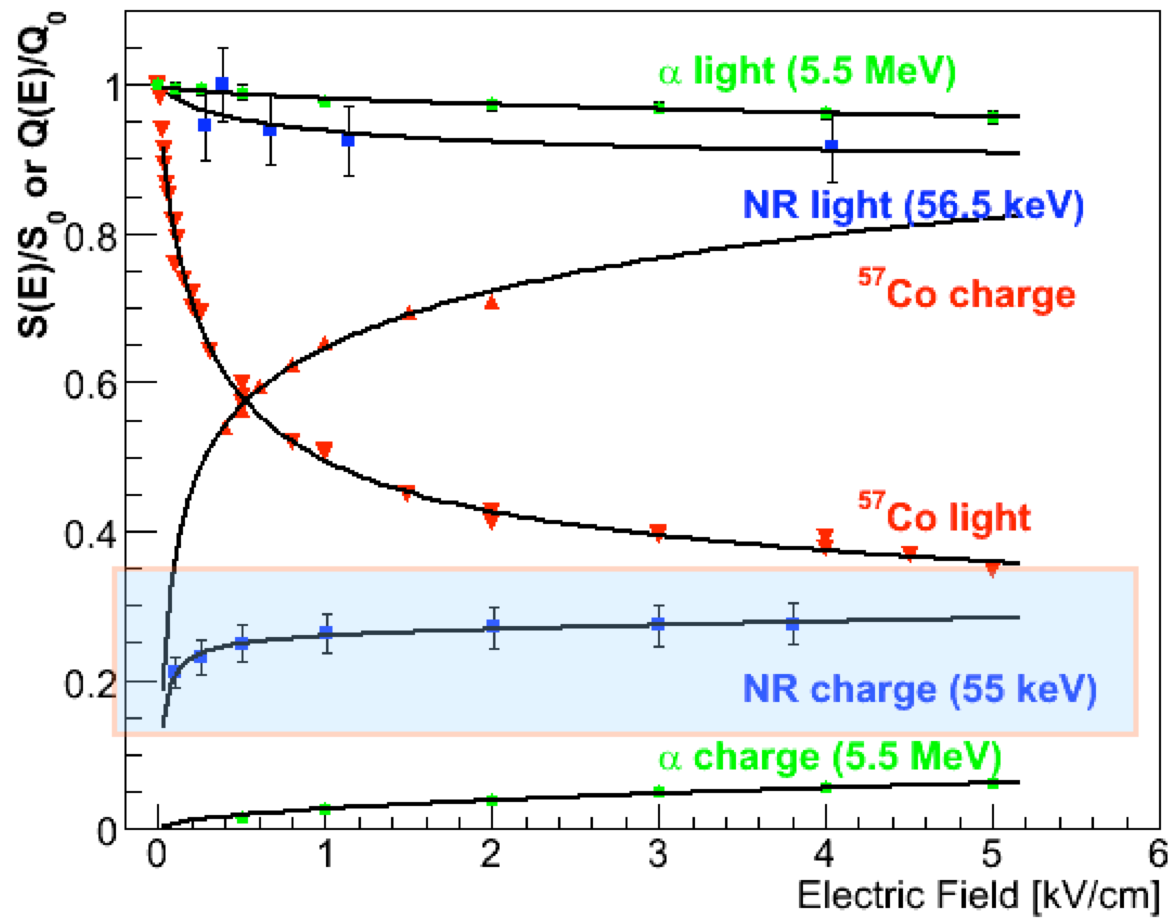
	Z (A)	BP (T_b) at 1 atm [K]	liquid density at T_b [g/cc]	ionization [e^-/keV]	scintillation [photon/keV]
He	2 (4)	4.2	0.13	39	15
Ne	10 (20)	27.1	1.21	46	7
Ar	18 (40)	87.3	1.40	42	40
Kr	36 (84)	119.8	2.41	49	25
Xe	54 (131)	165.0	3.06	64	46

- Liquid noble gases yield both charge and light
- Scintillation is decreased (~ factor 2) when drift field to extract charge is applied

Ionization Yield and Discrimination in Liquid Xenon

AmBe n-source





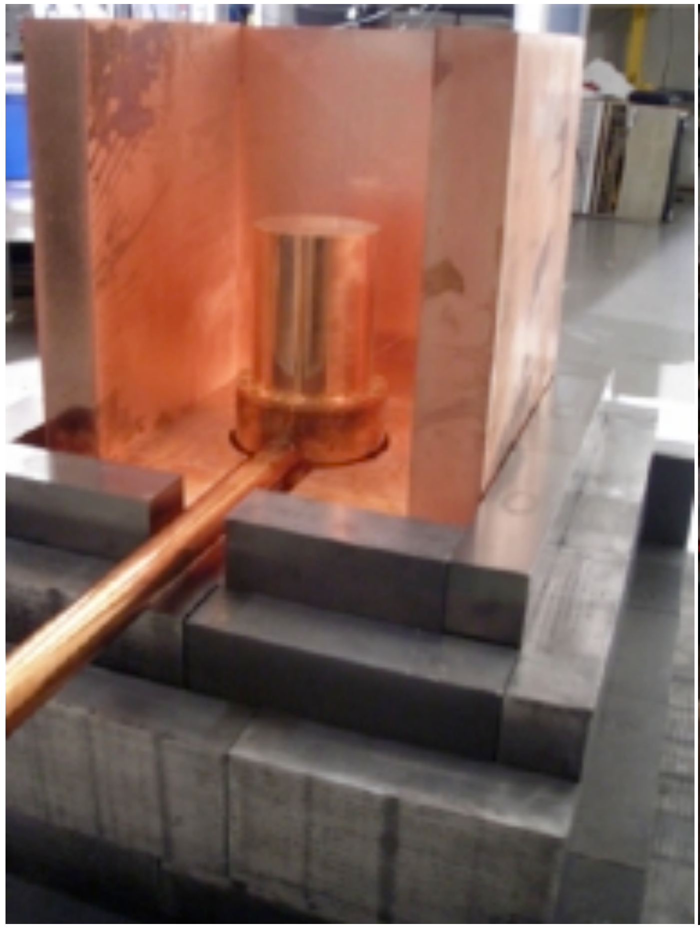
Electric Field [kV/cm]

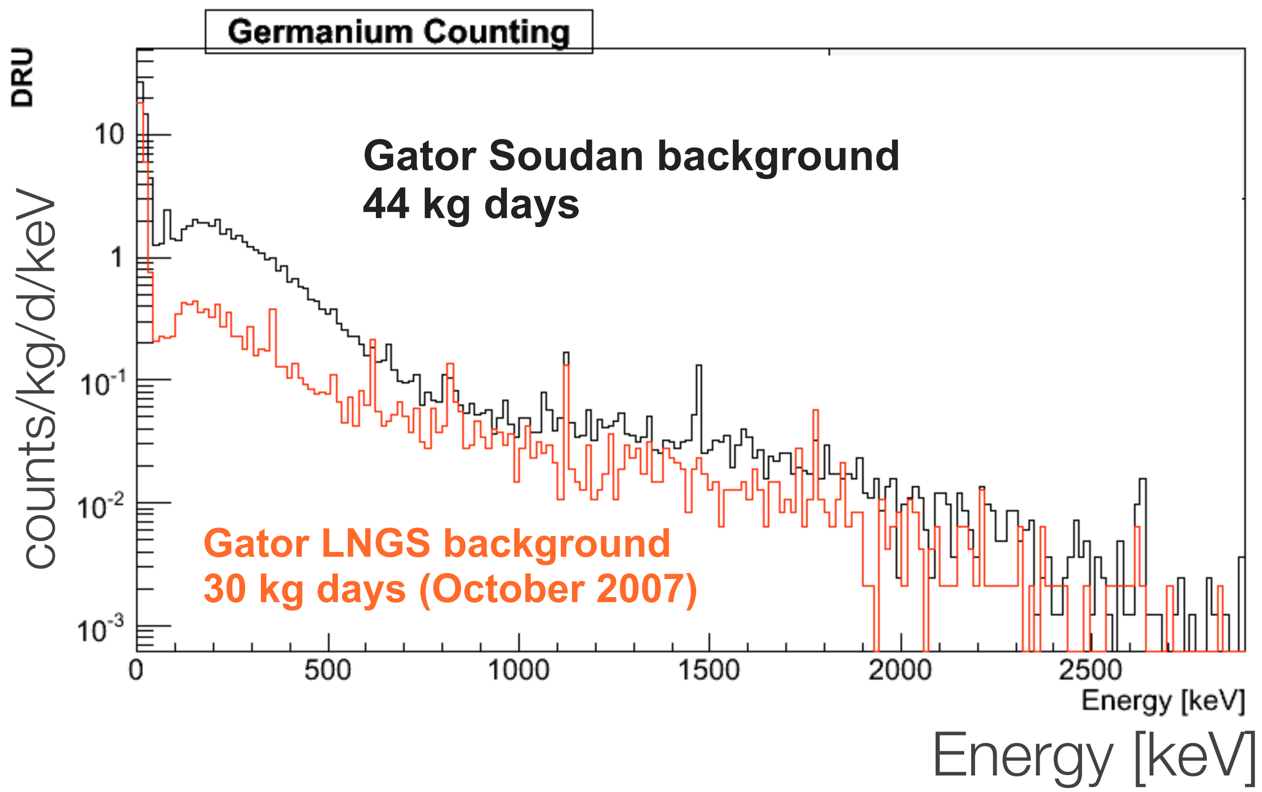
5 keVee energy threshold = 10 keVr
good discrimination (>99%) between NR und ER

Aprile et al., Phys. Rev. Lett. 97 (2006)

New XENON100 material screening facility

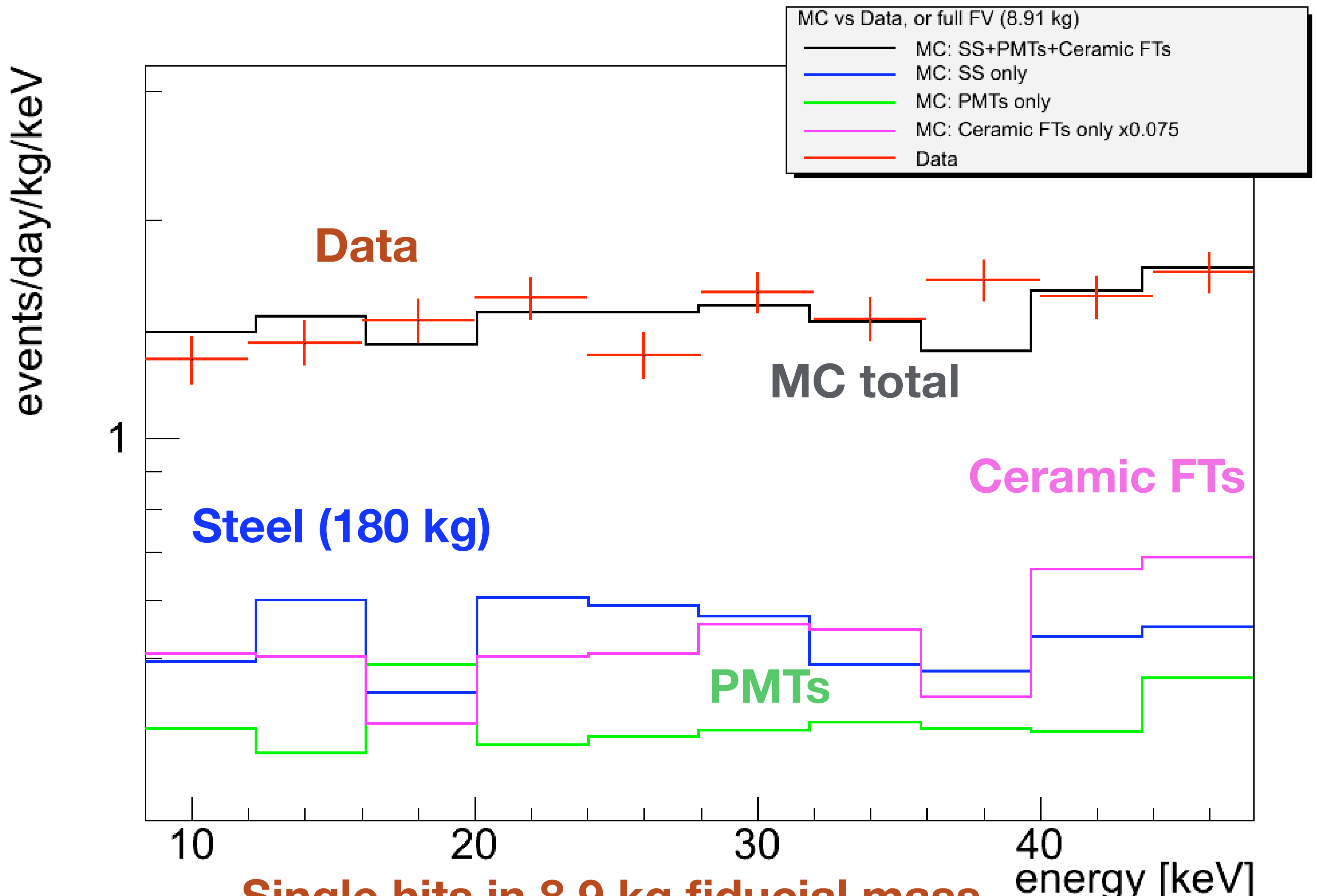
- Ultra-low background, 100 % efficient (2 kg) HPGe-spectrometer
- Shield: 5 cm of OFRP Cu (Norddeutsche Affinerie); 20 cm Plombum Pb (inner 5 cm: 3 Bq/kg ^{210}Pb), air-lock system and Nitrogen purge against Rn
- **First background spectrum: < 1 event/kg d keV above 40 keV**
- Goal: screen all XENON100 detector/shield components for a complete BG model



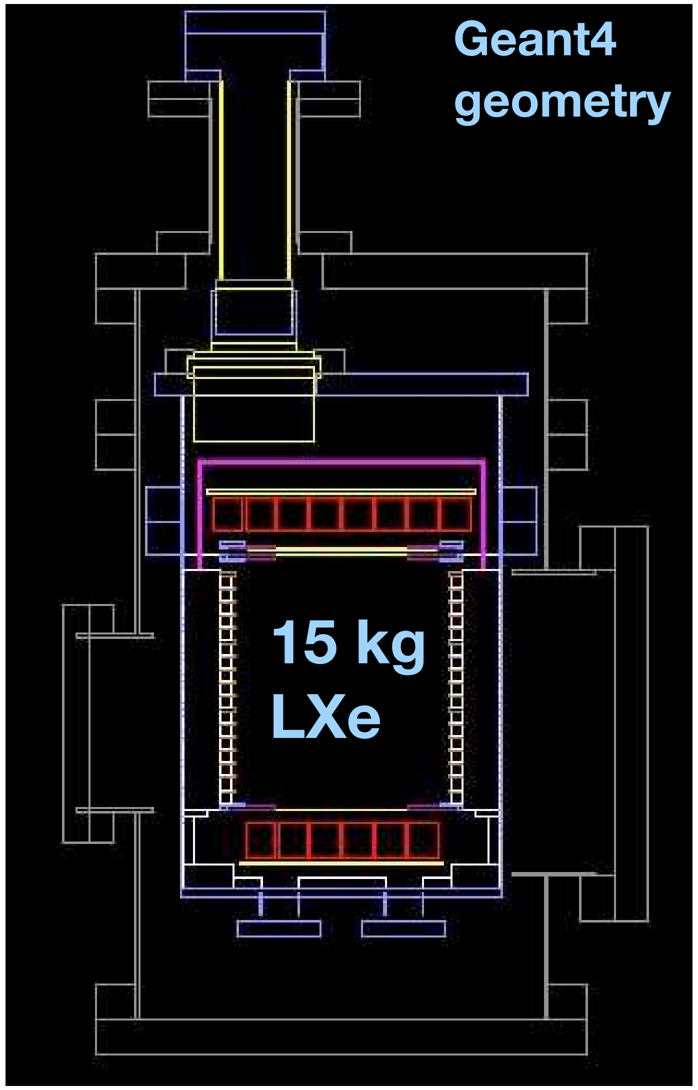


XENON10 Backgrounds: Data and MC Simulations

- **Gamma BG**: dominated by steel (inner vessel and cryostat = 180 kg), ceramic FTs, PMTs
- **Neutron BG**: subdominant for XENON10 sensitivity goal (MC: < 1 event/year from (α,n) in materials and < 5 events/year from μ-induced n's)
- **Red crosses**: data; **Black curve**: sum of background contributions from MC
  - ➡ ~ 1event/(kg d keV) (1 dru) (for r < 8 cm fiducial volume cut -> 8.9 kg)

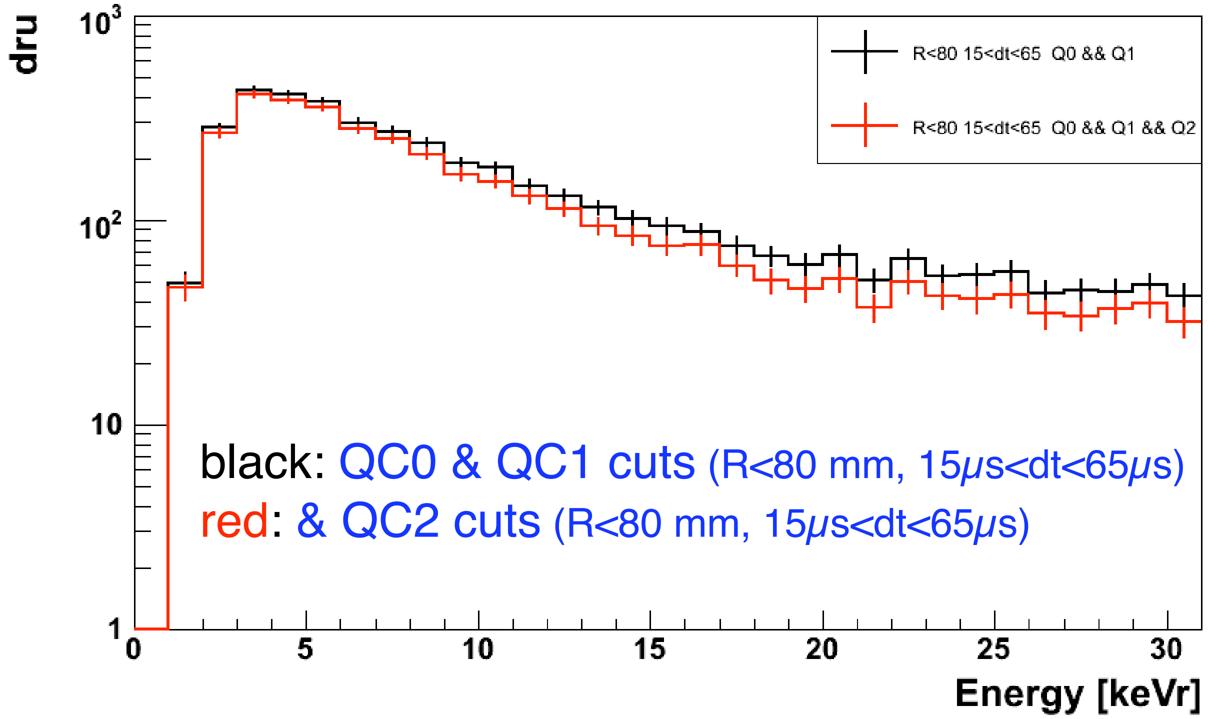


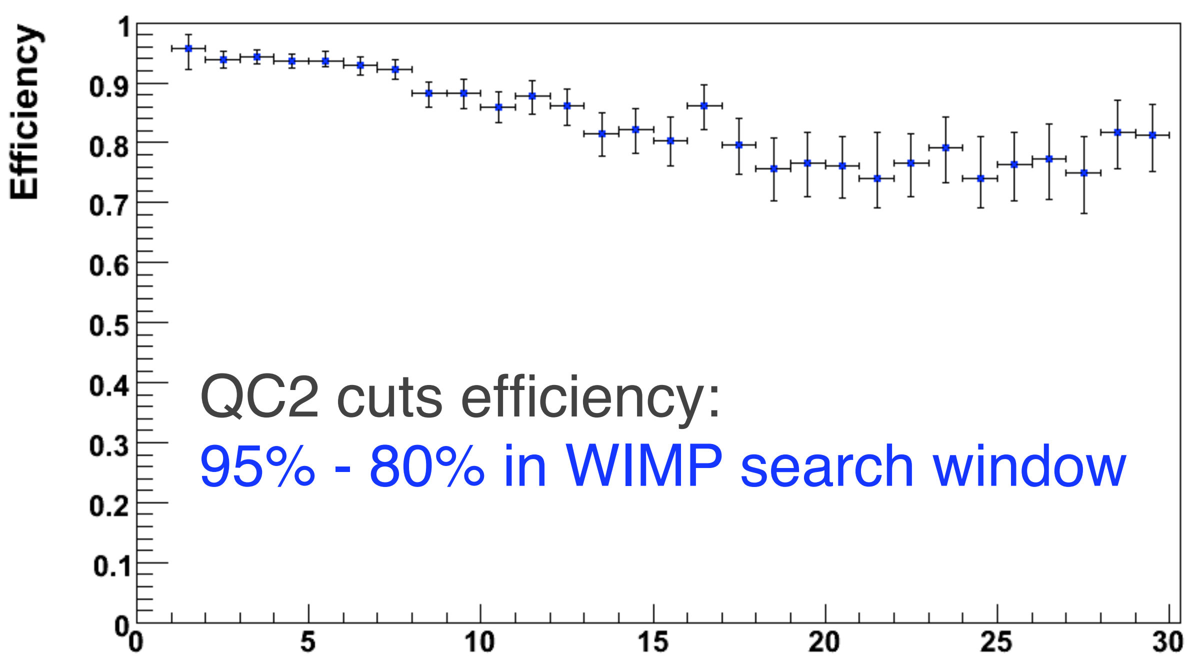
Single hits in 8.9 kg fiducial mass



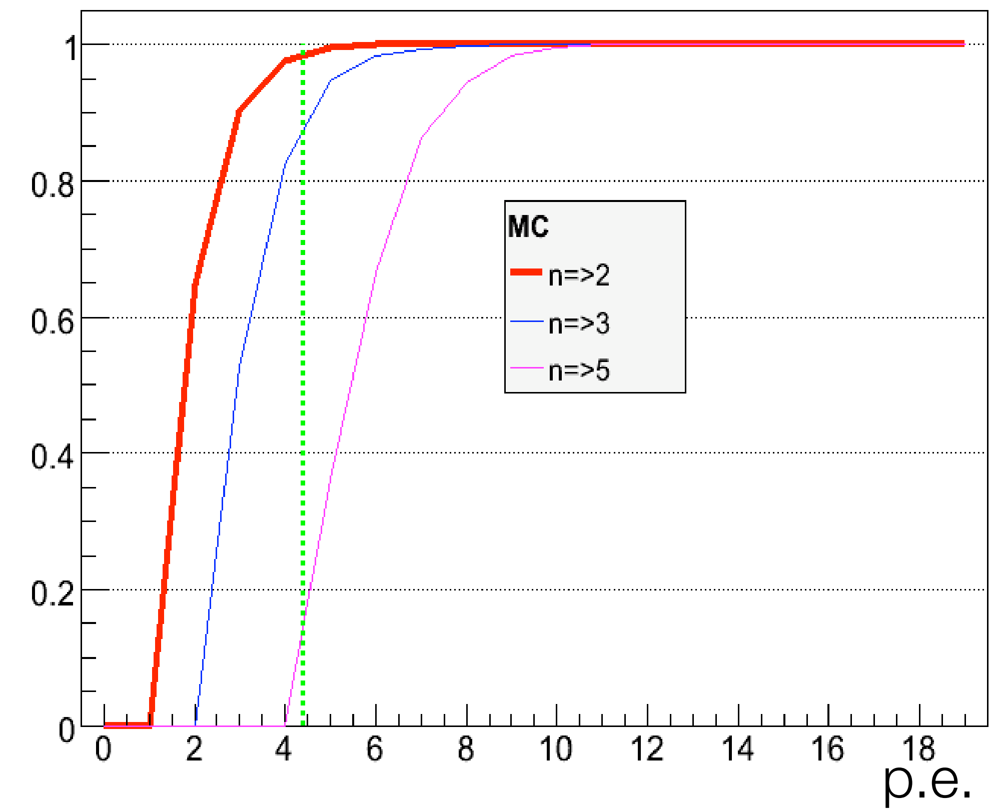
Analysis Cut Efficiencies

neutron data





S1 efficiency



Trigger: S2 sum signal from top PMTs
S2 threshold: 300 p.e. (~ 20 e^-)
(gas gain of a few 100s allows 100% S2 trigger efficiency)

S1 signal associated with S2: searched for in offline analysis -> coincidence of 2 PMT hits
S1 energy threshold is set to 4.4 p.e. (efficiency is 100% at 2 keVee)

XENON10 Neutron Calibration

Energy of nuclear recoils (NRs)

Measured signal in nr. of p.e.

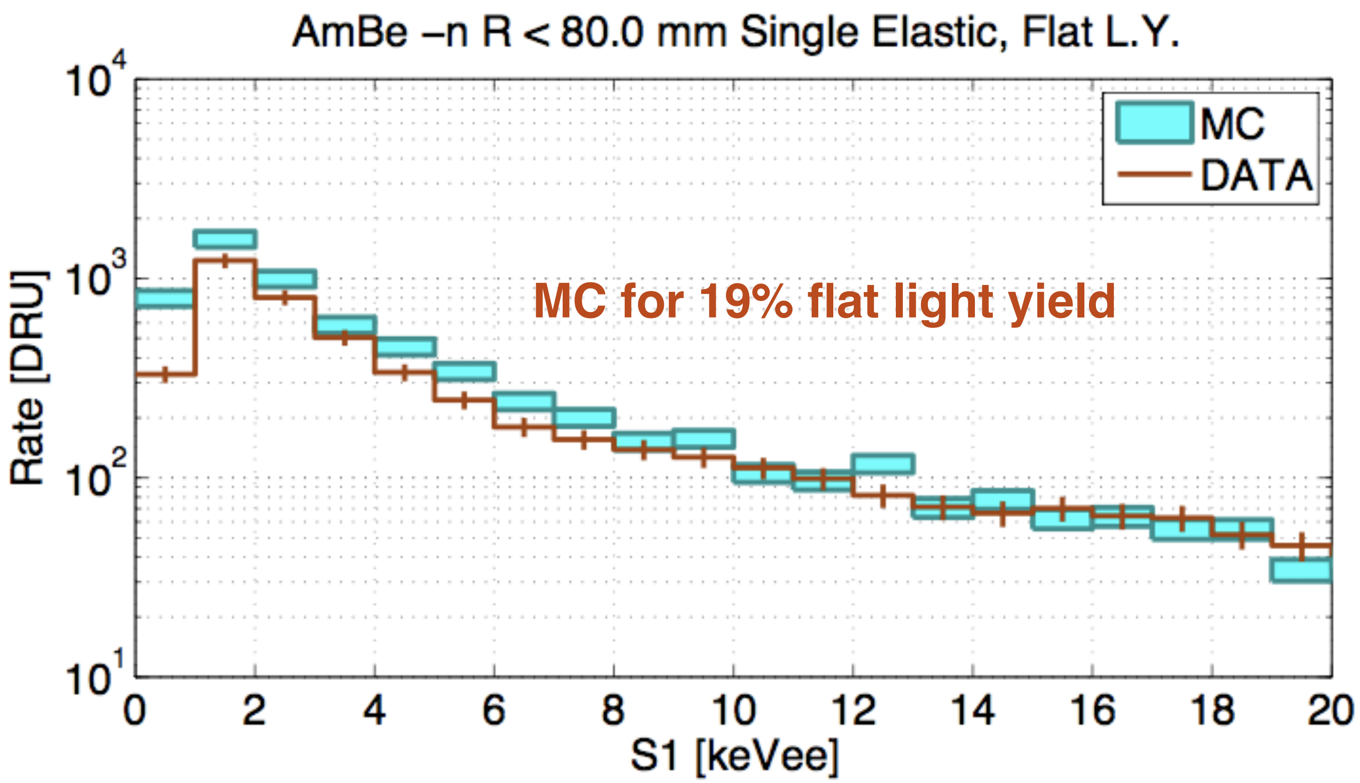
Quenching of scintillation yield for 122 keV γ's due to field (0.54 at 0.73 kV/cm)

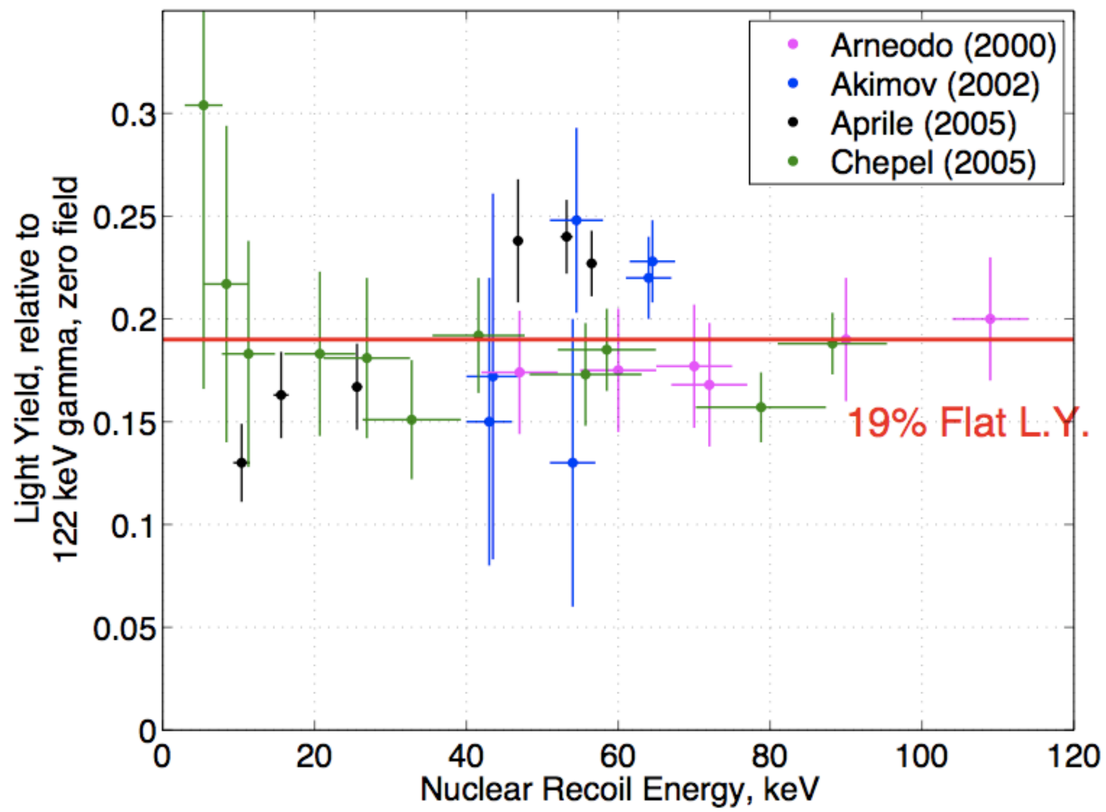
$$E_{nr} = \frac{S1}{L_y \cdot \mathcal{L}_{eff}} \times \frac{S_{er}}{S_{nr}}$$

Light yield for 122 keV γ in p.e. (3.00 p.e./keV)

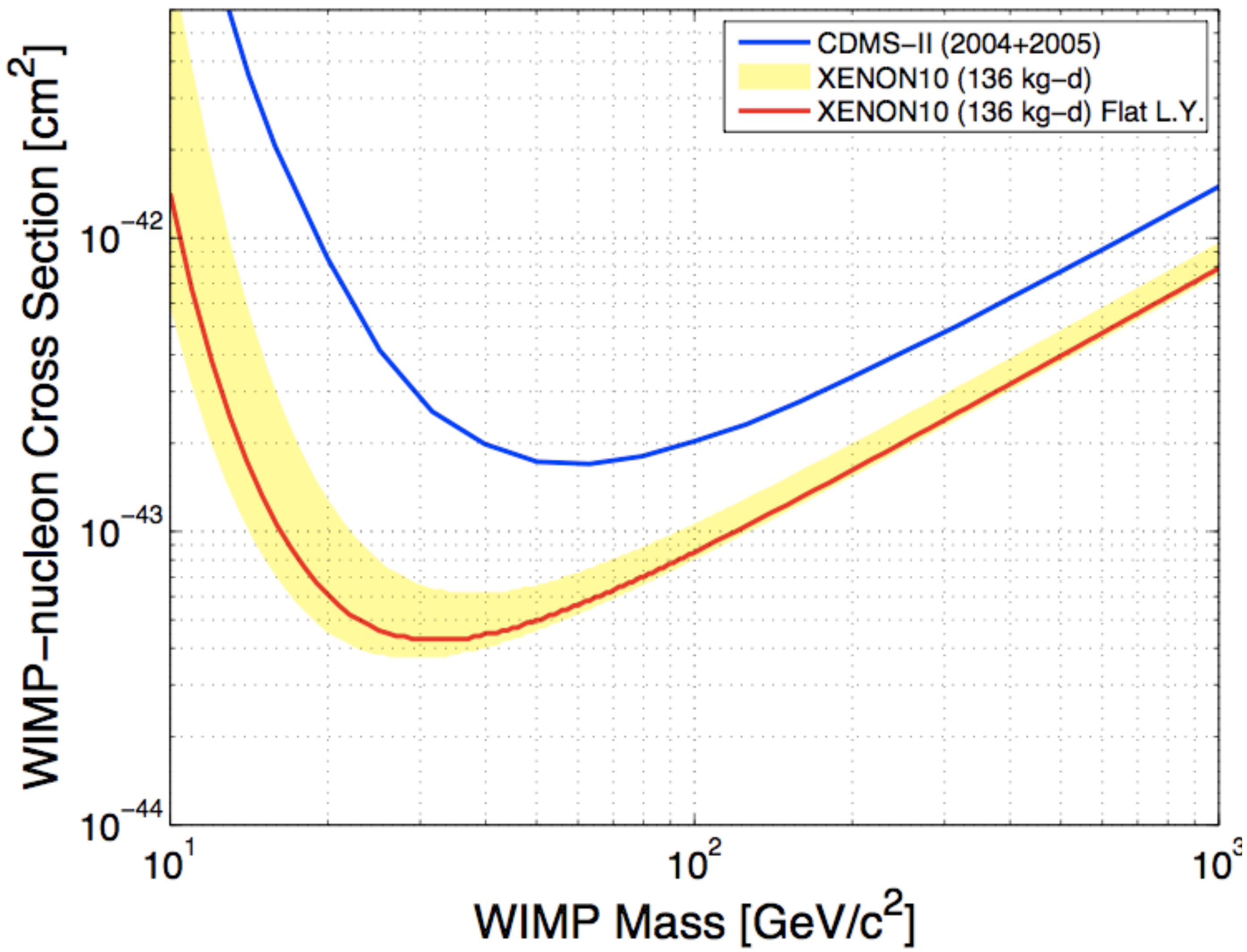
Relative scintillation efficiency of NRs to 122 keV γ's at zero field (flat value: 0.19)

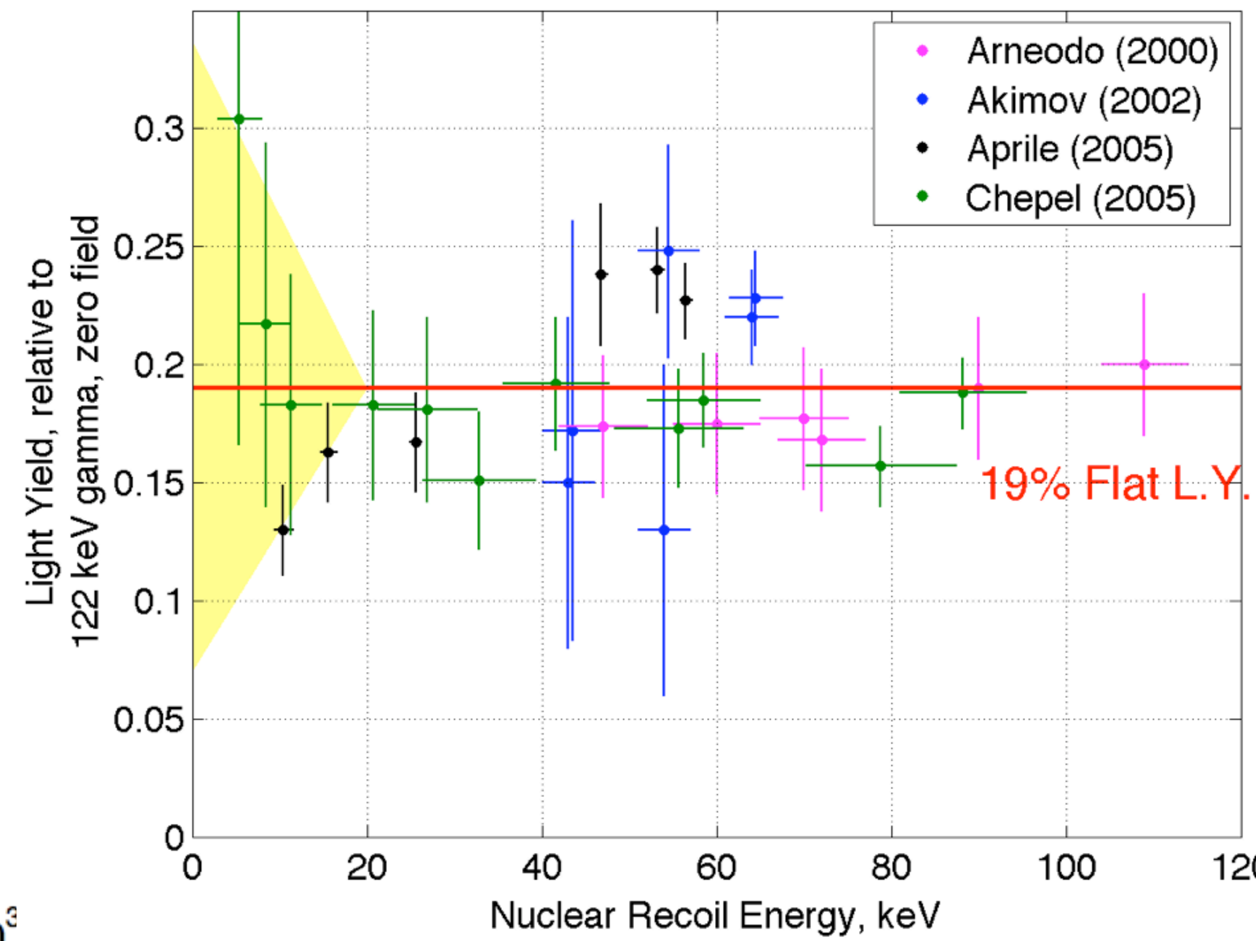
Quenching of scintillation yield for NRs due to field (0.93 at 0.73 kV/cm)





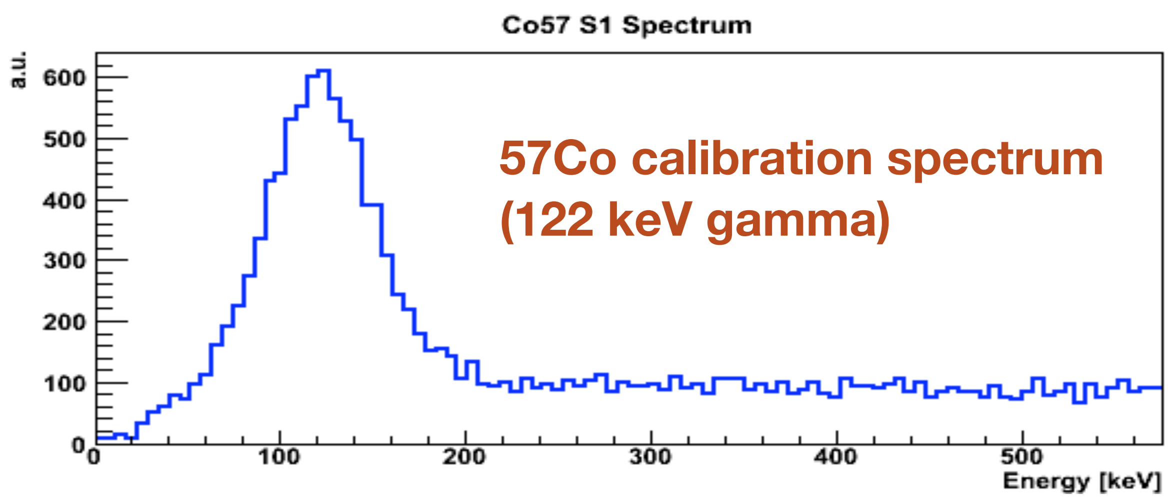
XENON10 Results: Effect of Light Yield Uncertainty





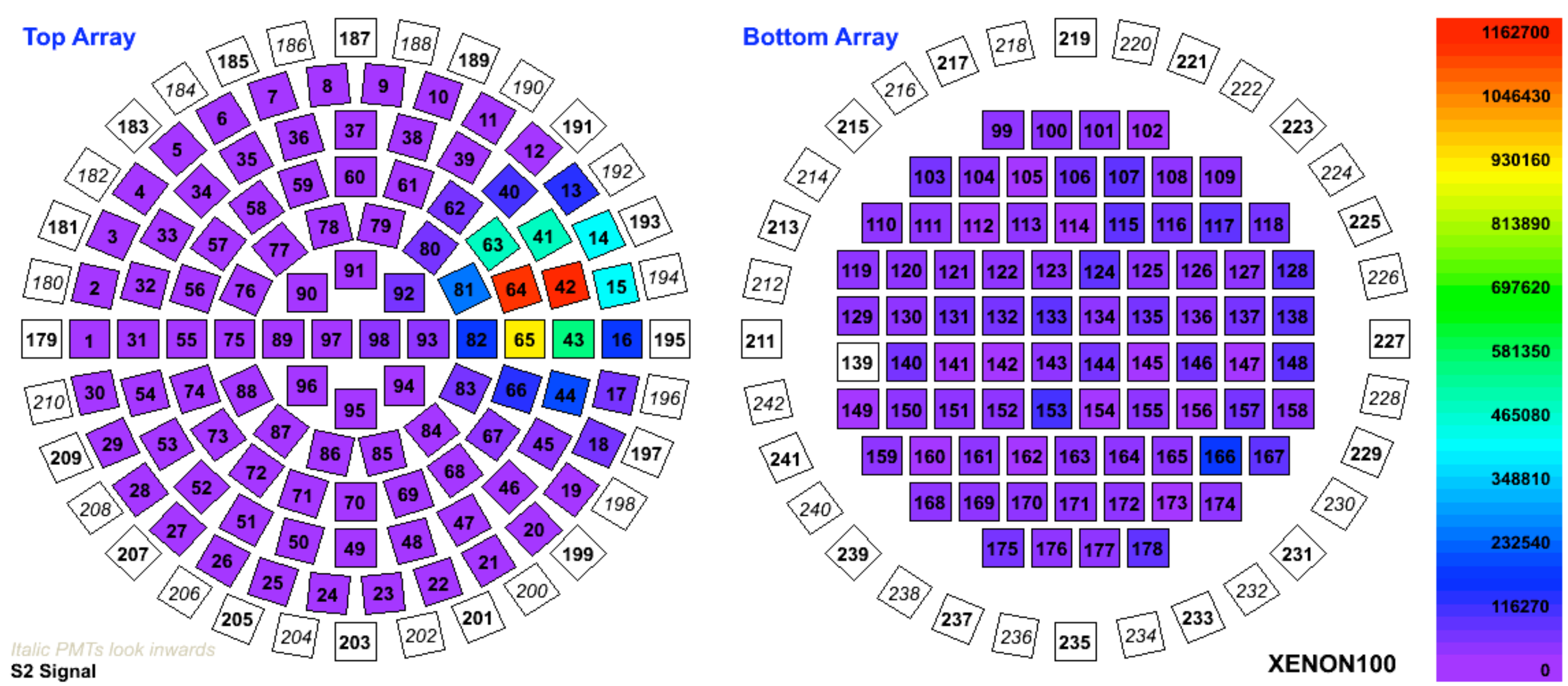
XENON100: first calibration spectrum

- Measurements to characterize detector performance are underway
- Analysis tools are being developed



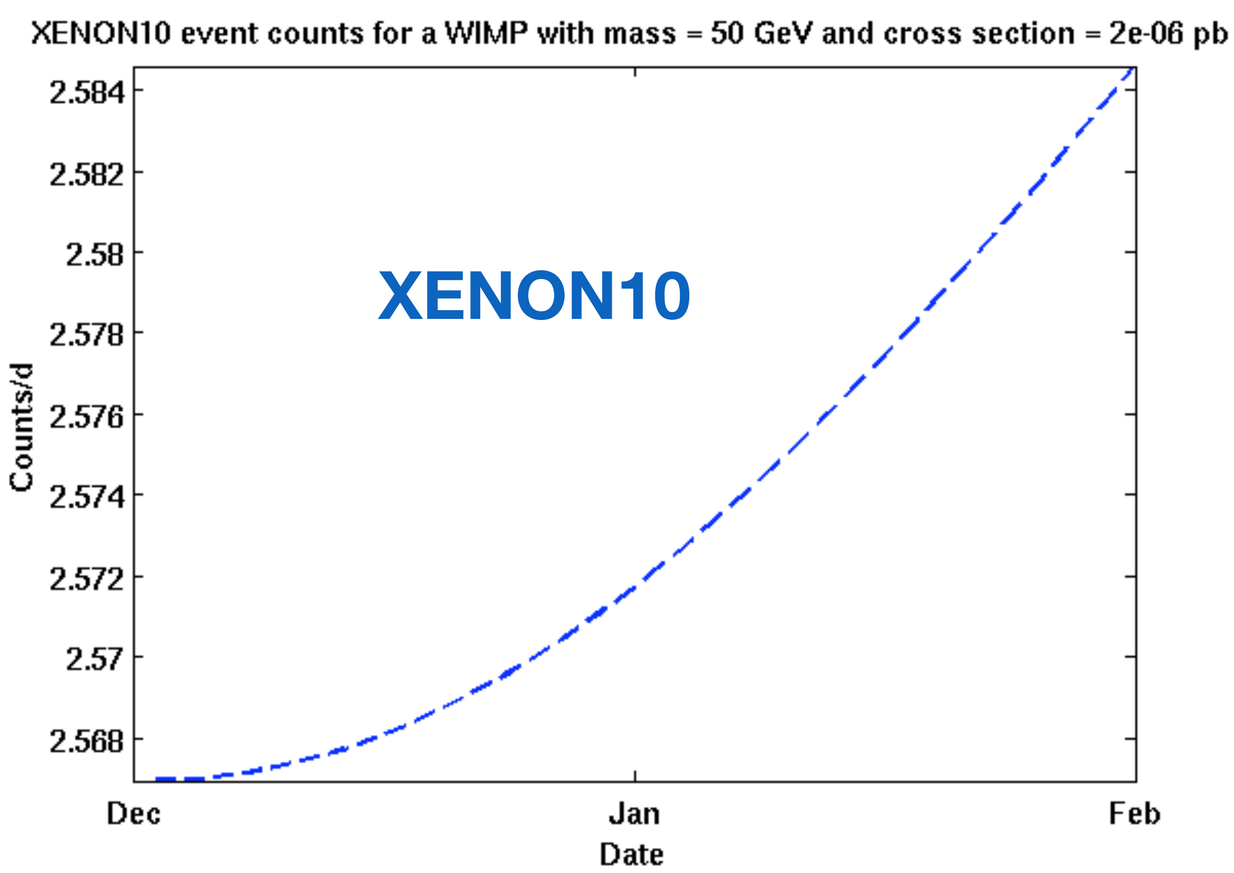
Bottom PMT array (S1 signal)

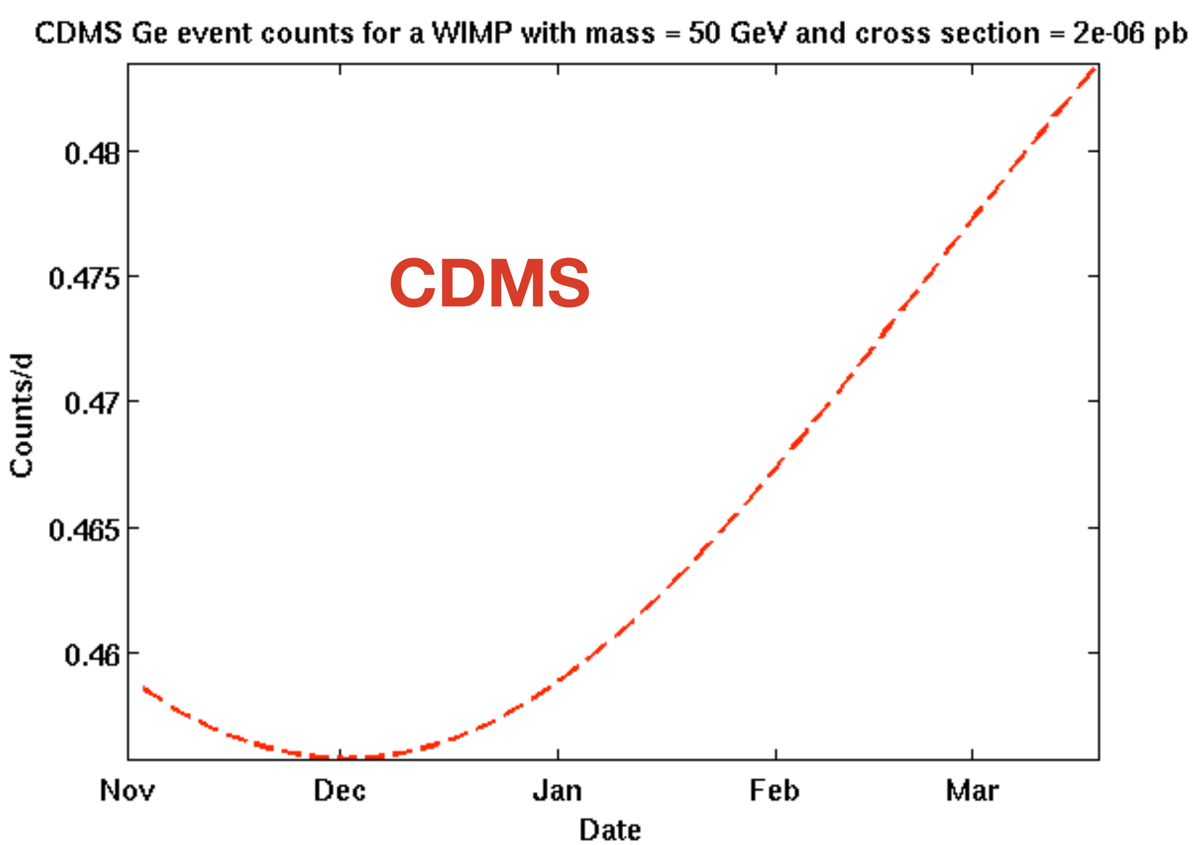
Top PMT array (S2 signal)



Predicted Rates in XENON10/CDMS if DAMA would see WIMPs

- **Assumption:** m_W = 50 GeV, σ_{SI} = 2x10^{-6} pb
- **XENON10:** 136 kg day, 4.5-27 keVr => 162 events
- **CDMS R123/124:** 397.8 kg day in Ge, 10-100 keVr => 62 events





T. Bruch, UZH

The Case of a WIMP Signal

- CDMS 2005 90% CL corresponds to **< 1 event/(10 kg day)** in Ge
- Assume we detect **8 events** at the rate of **1 event/(50 kg day)** in Ge

➡ mass and cross section determined as shown

➡ SI vs SD determined from different targets

➡ suggest properties to look for at LHC/ILC

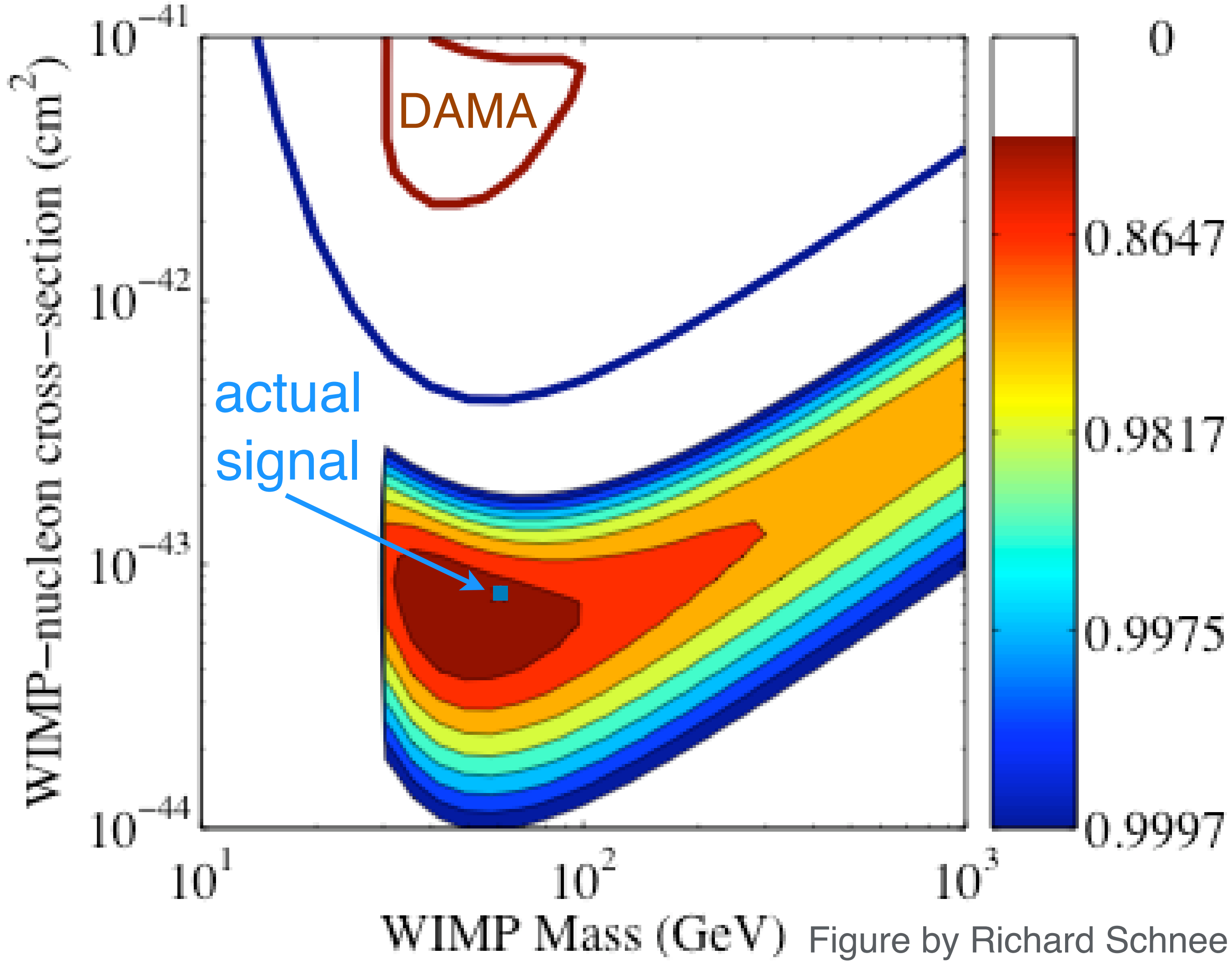


Figure by Richard Schnee

A convincing signal would motivate large TPC to measure the direction of the incoming WIMP (DRIFT)