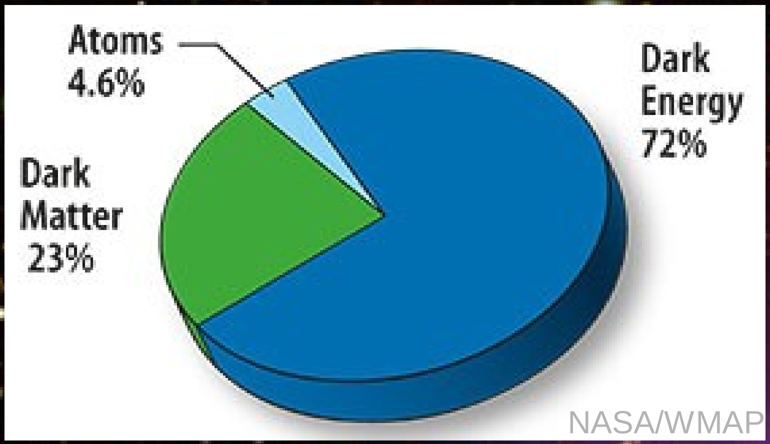
XENON

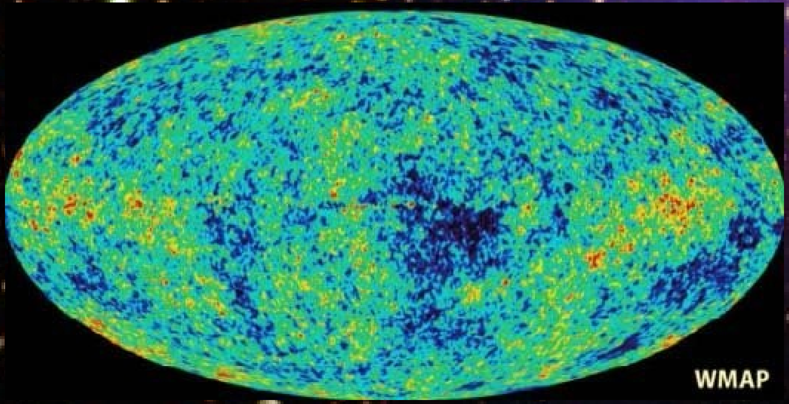
Marc Schumann *Physik Institut, Universität Zürich*

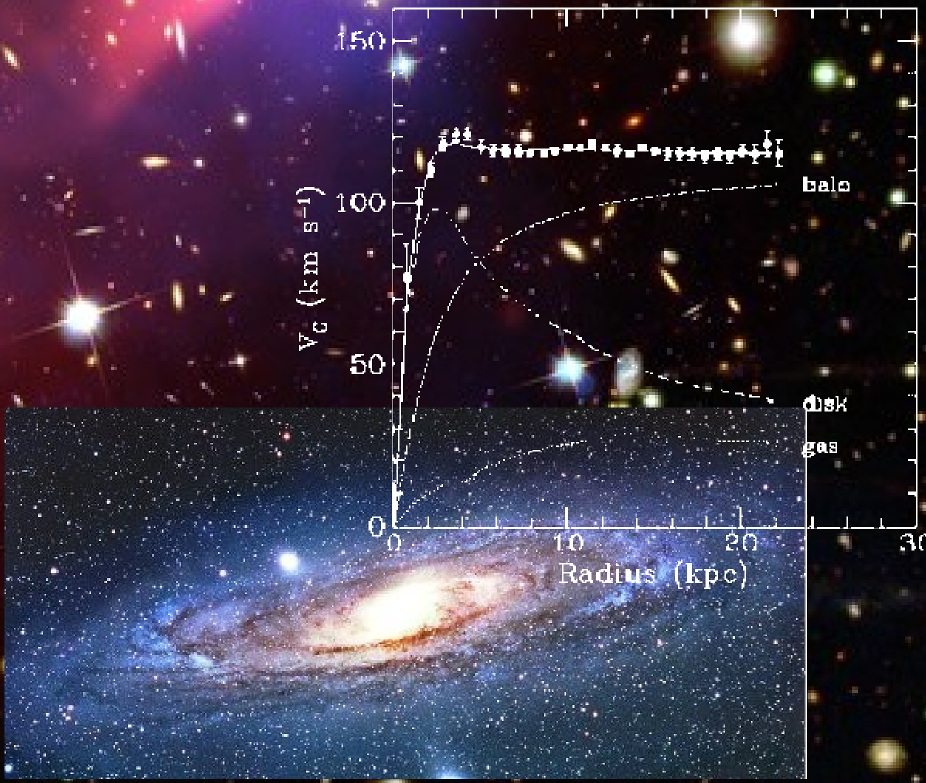
Bethe Forum 2011, Bonn, November 15, 2011

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

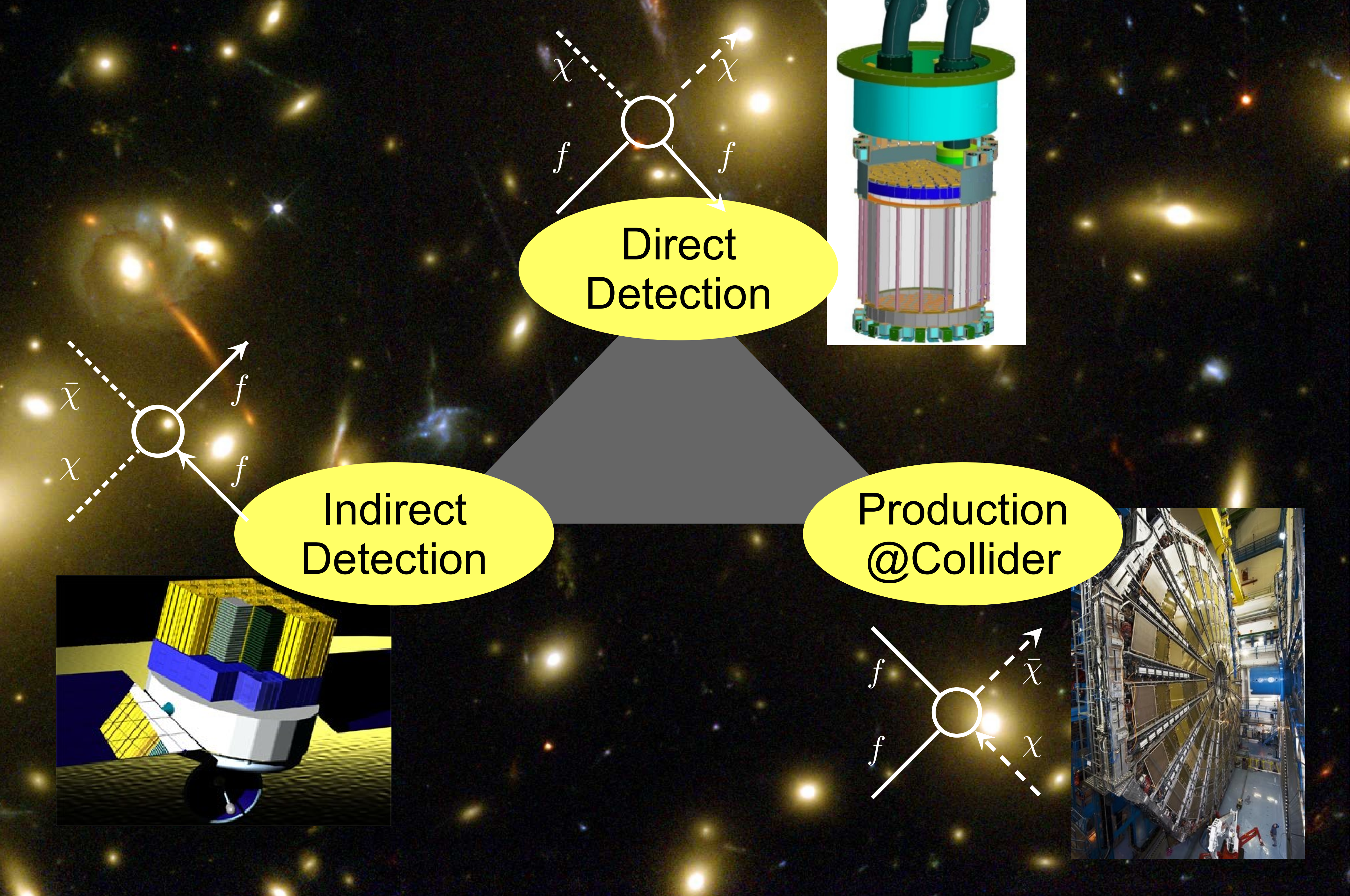
Dark Matter: (indirect) **Evidence**







Dark Matter Search



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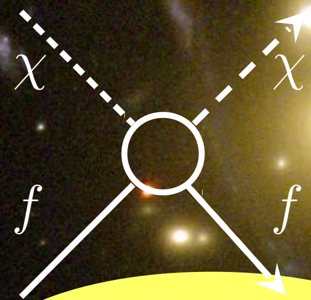
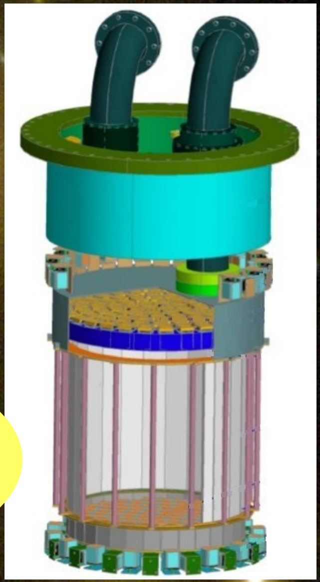
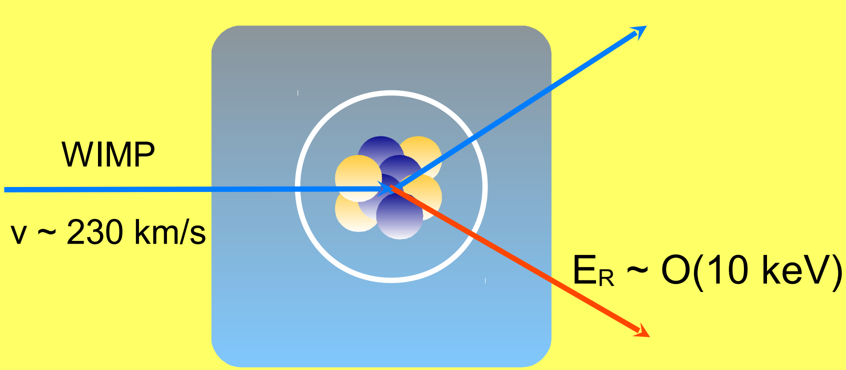


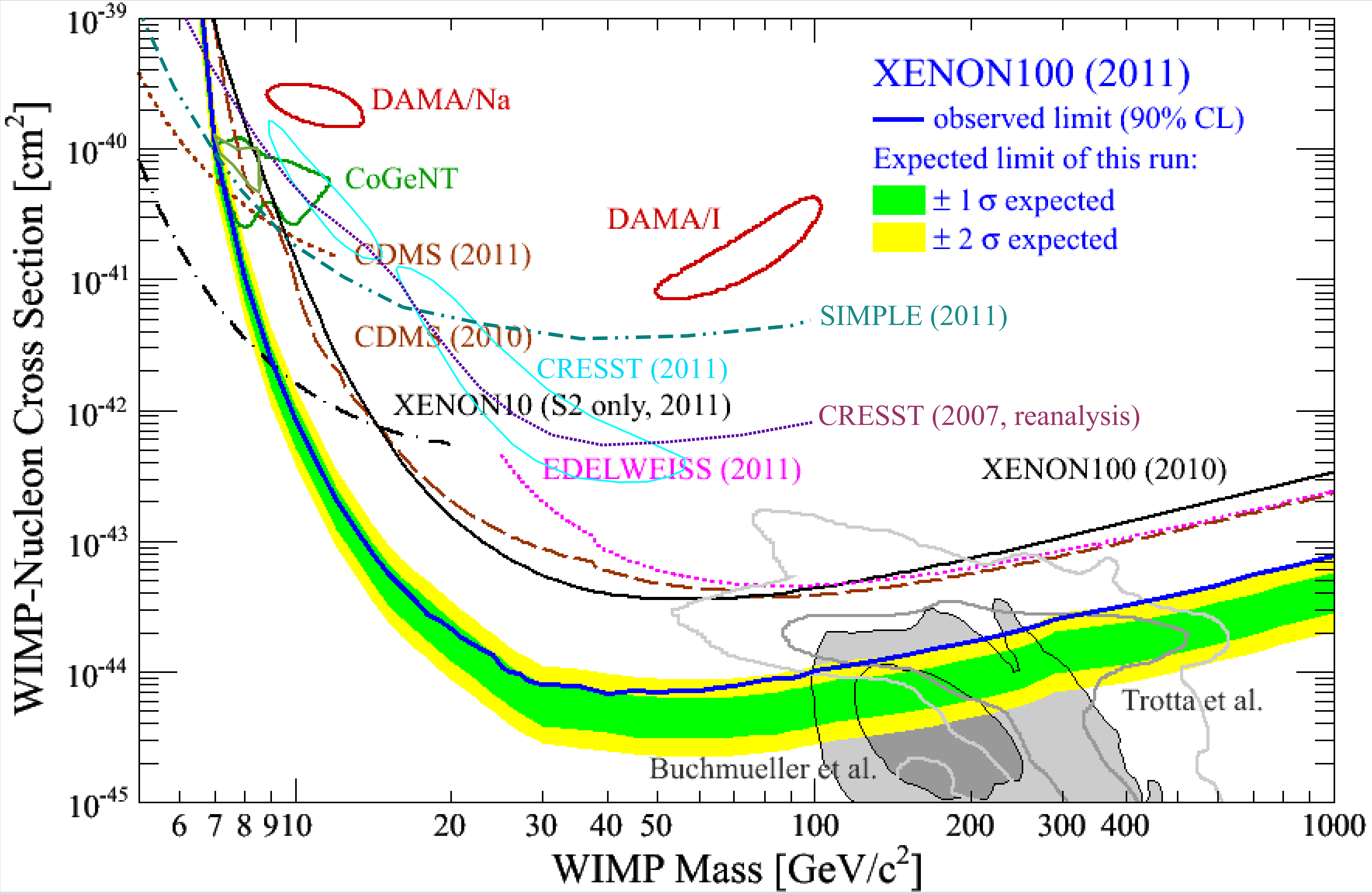
Direct Detection



Elastic Scattering of WIMPs off target nuclei
→ nuclear recoil

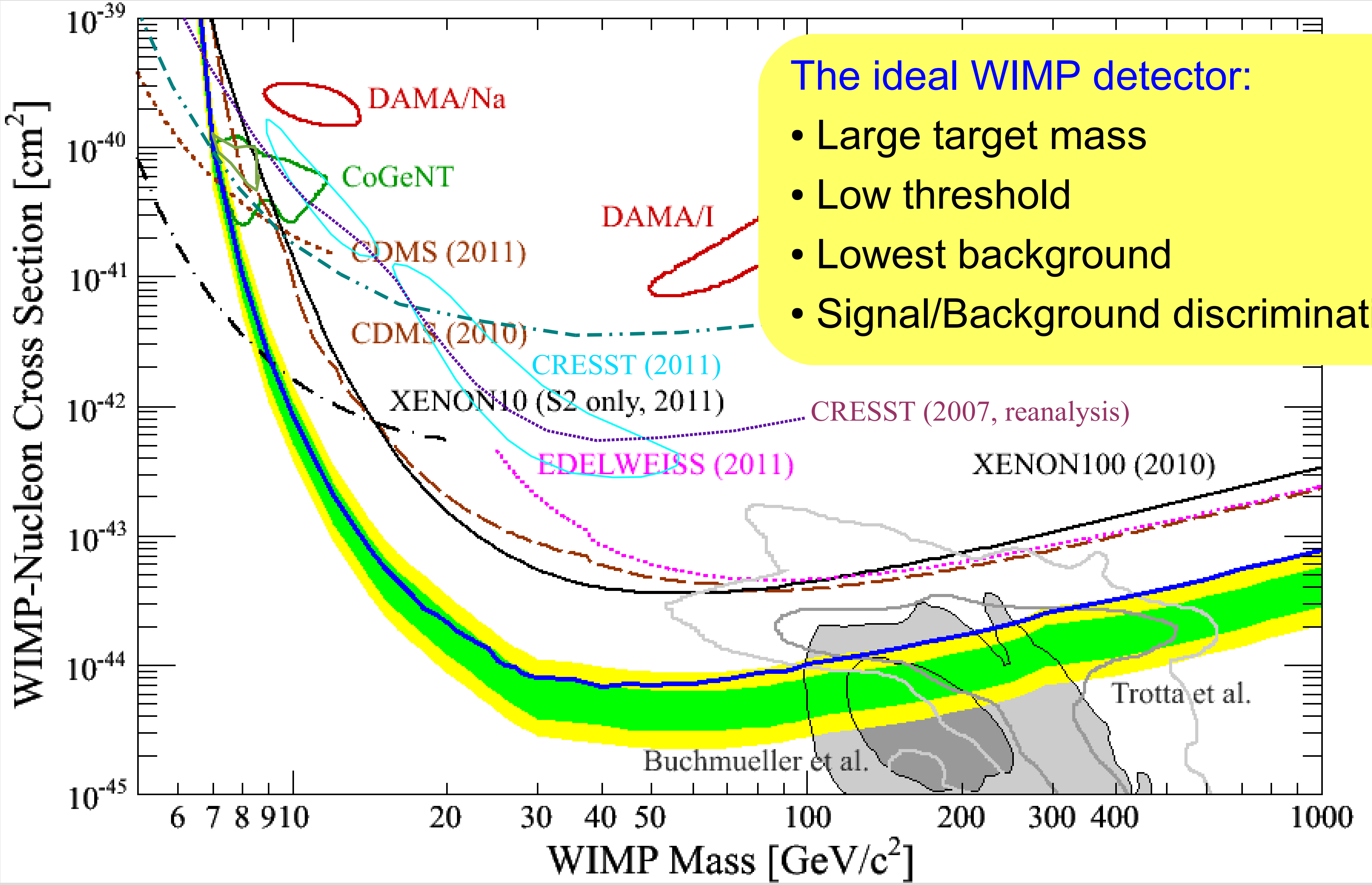


The current WIMP landscape



some results are missing!

The current WIMP landscape

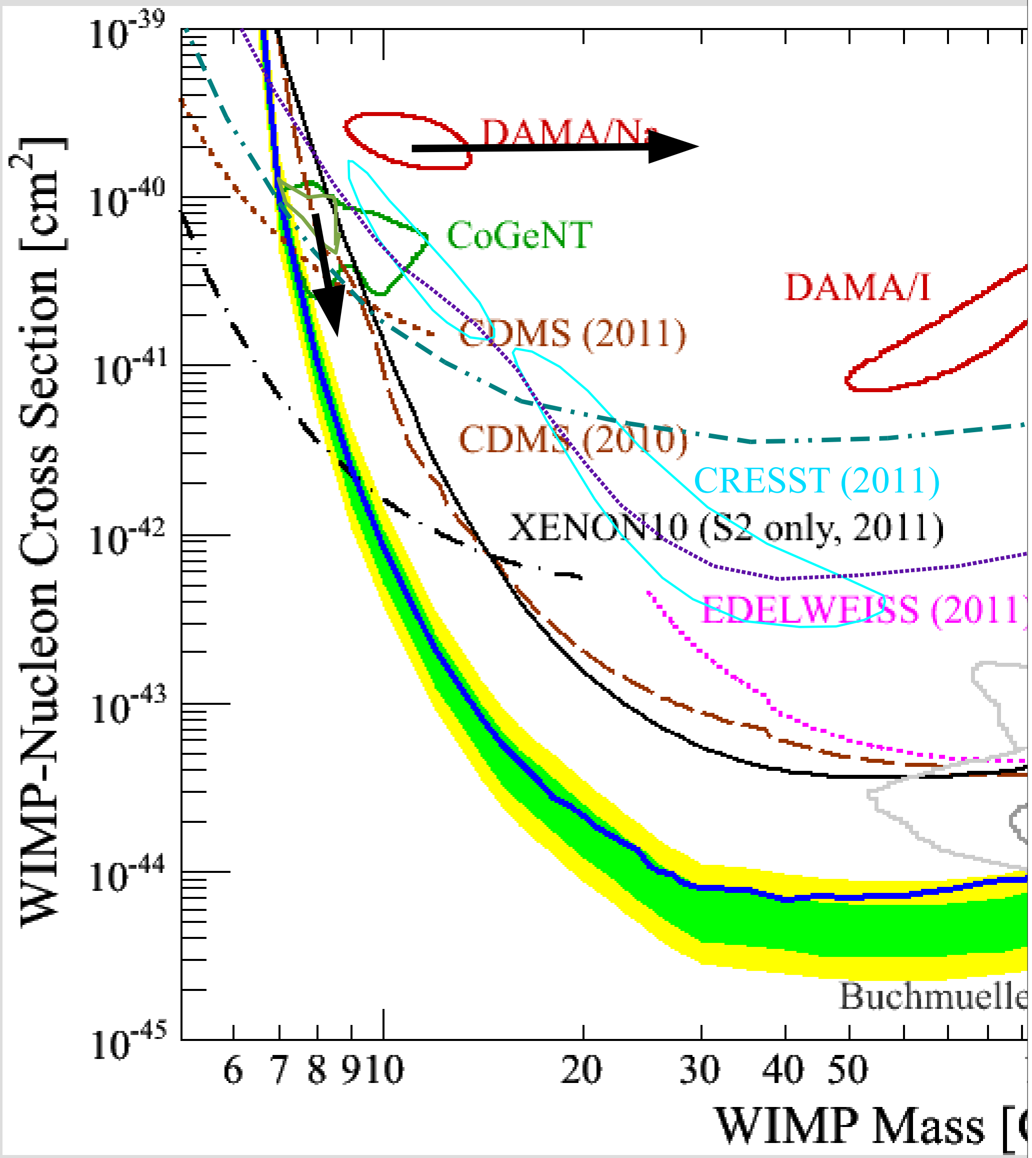


The ideal WIMP detector:

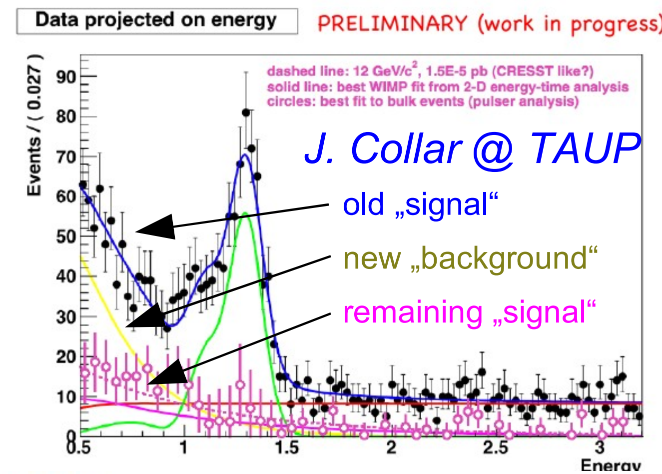
- Large target mass
- Low threshold
- Lowest background
- Signal/Background discrimination

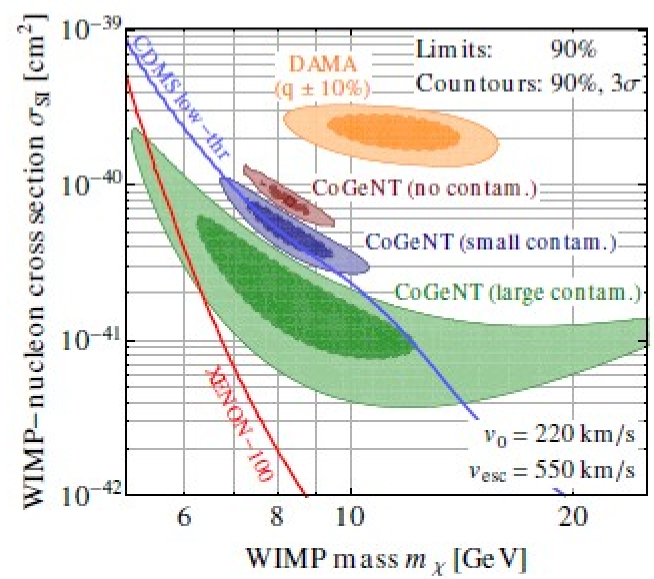
some results are missing!

The current WIMP landscape



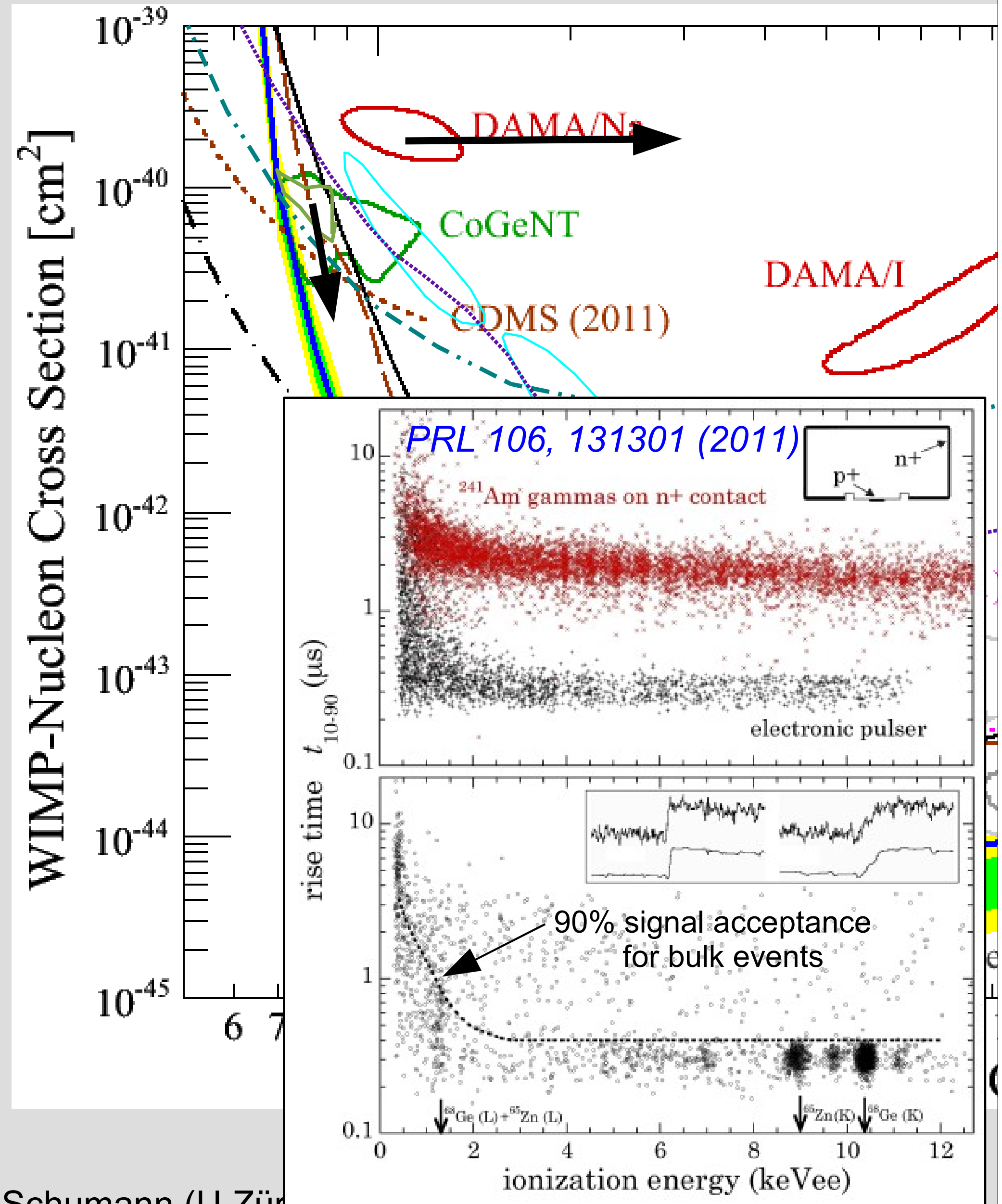
Recent CoGeNT news:





Kopp, Schwetz, Zupan, arXiv:1110.2721
Kelso, Hooper, Buckley, arXiv:1110.5338

The current WIMP landscape



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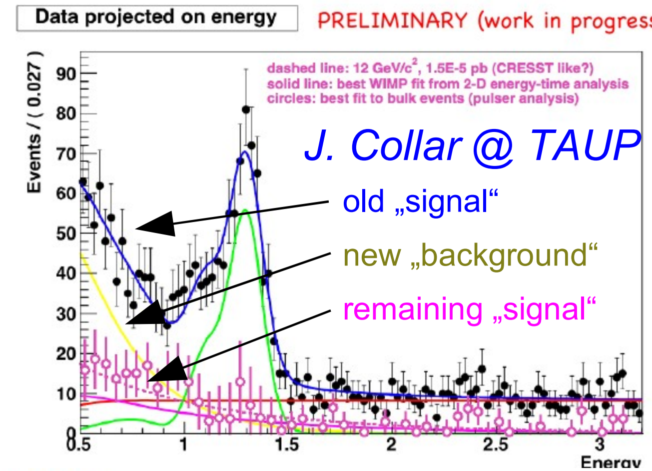
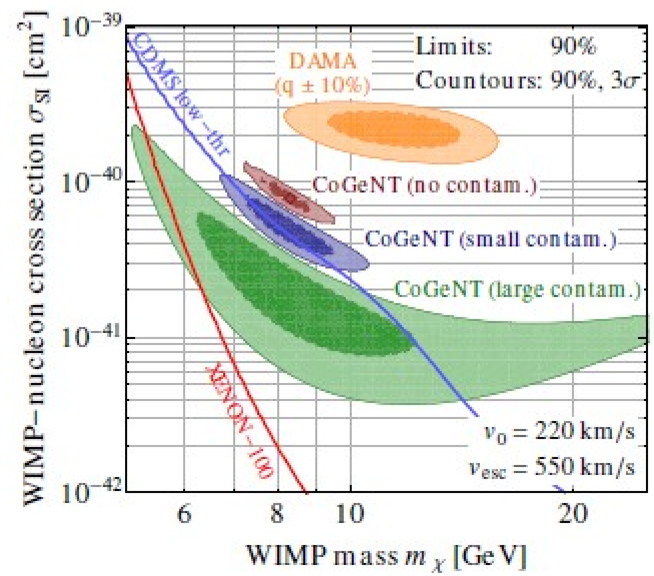




Kopp, Schwetz, Zupan, arXiv:1110.2721
Kelso, Hooper, Buckley, arXiv:1110.5338

Outline

Motivation: Dark Matter ✓

WIMP Search with Xenon

XENON100

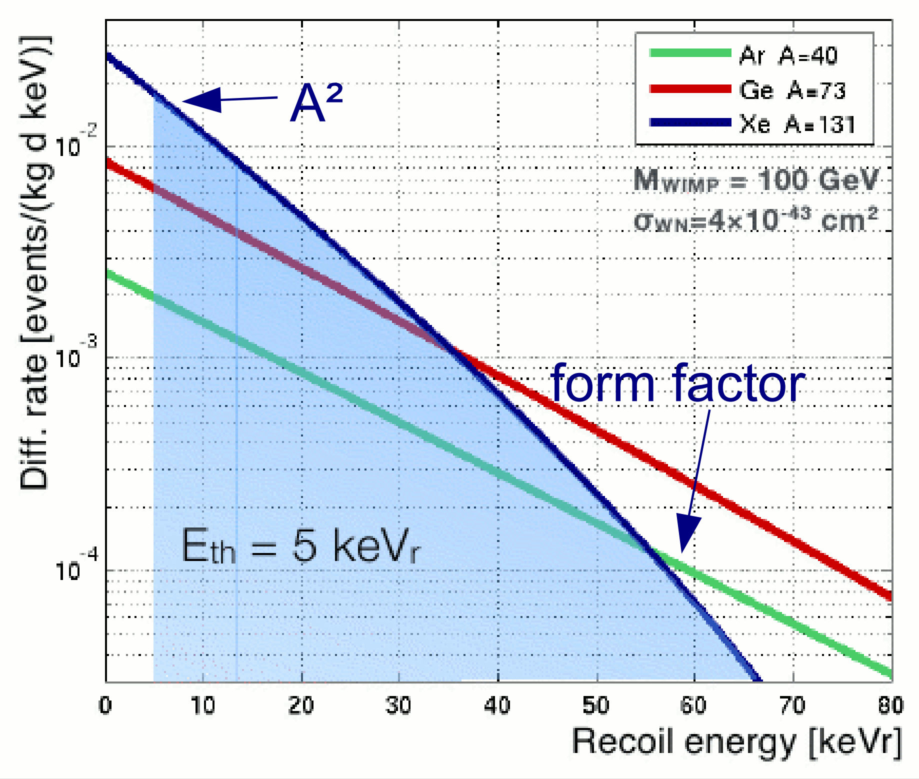
The new Results

Some Comments

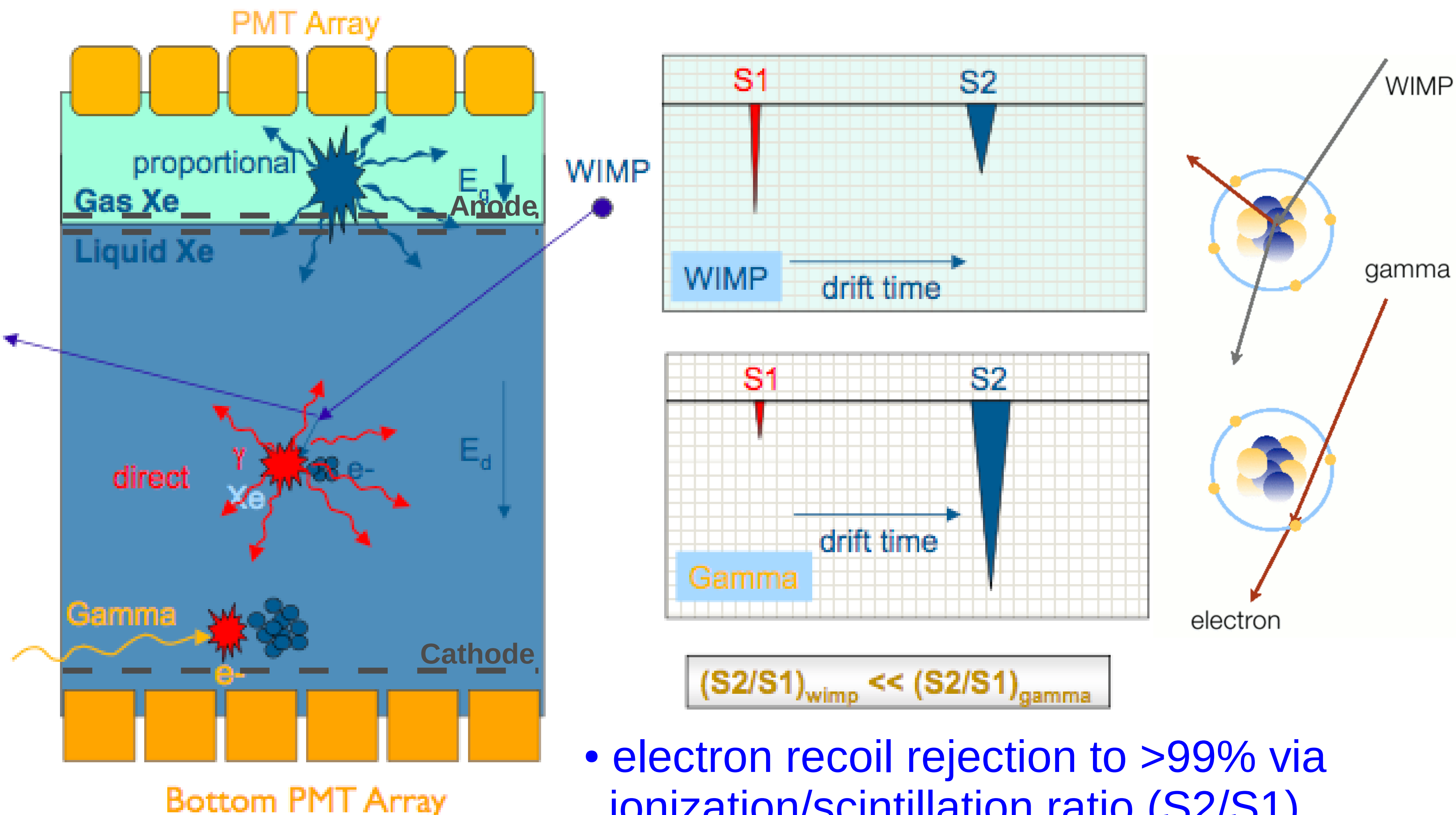
Presence and Future

Why WIMP Search with Xenon?

- efficient, fast scintillator (178nm)
- high mass number *A*~131:
  SI: high WIMP rate @ low threshold
- high *Z*=54, high ρ~3 kg/l:
  self shielding, compact detector
- 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



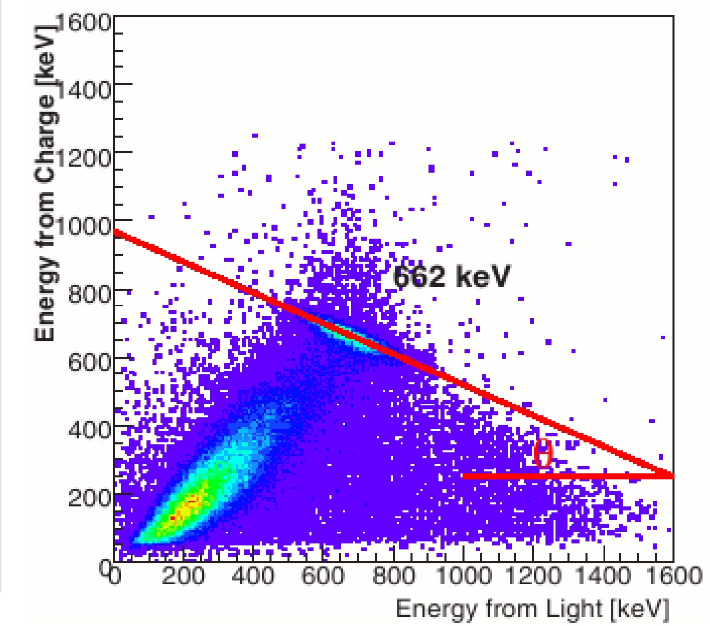
Dual Phase TPC

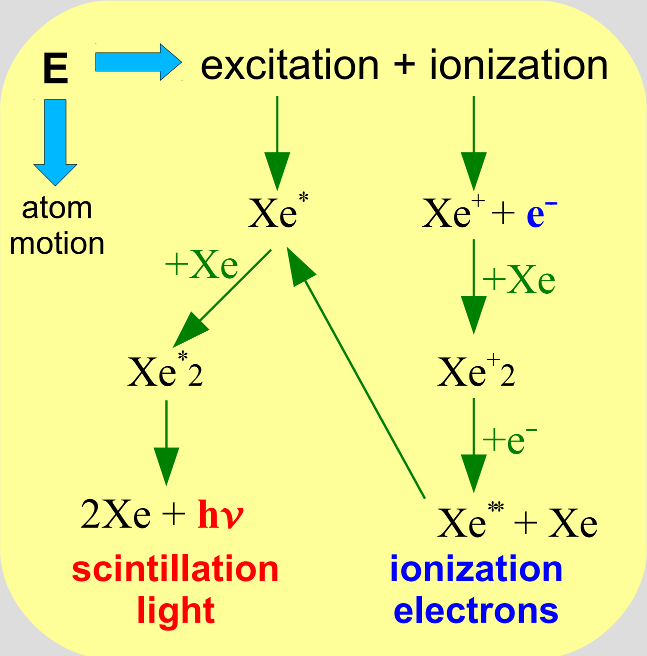


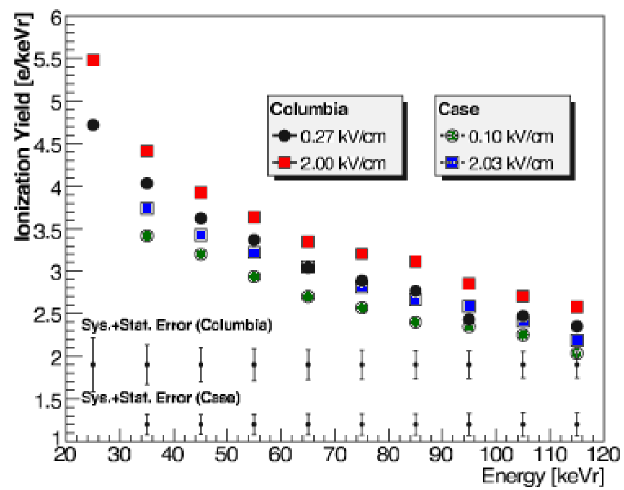
- electron recoil rejection to >99% via ionization/scintillation ratio (S2/S1)
- 3d position reconstruction in TPC
- multiple scatter rejection

Xenon: Light and Charge

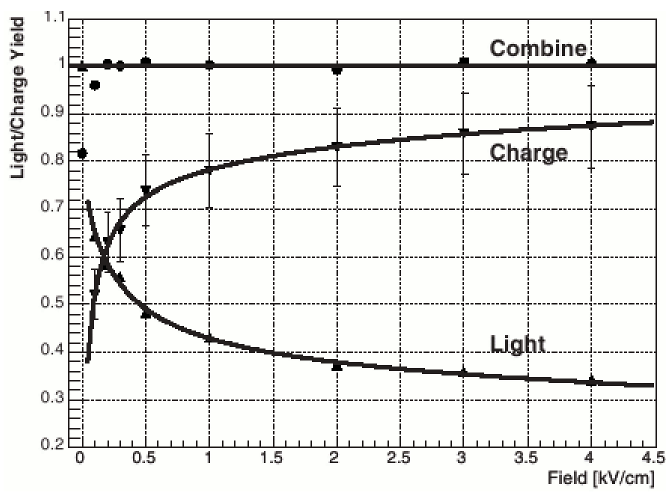
- energy deposited in LXe produces *electron-ion pairs* and *excited atom states*; both processes can lead to scintillation
- anti-correlation between charge and light ➡ improvement of energy resolution possible
- E-field dependence (field quenching)
- response also depends on particle energy





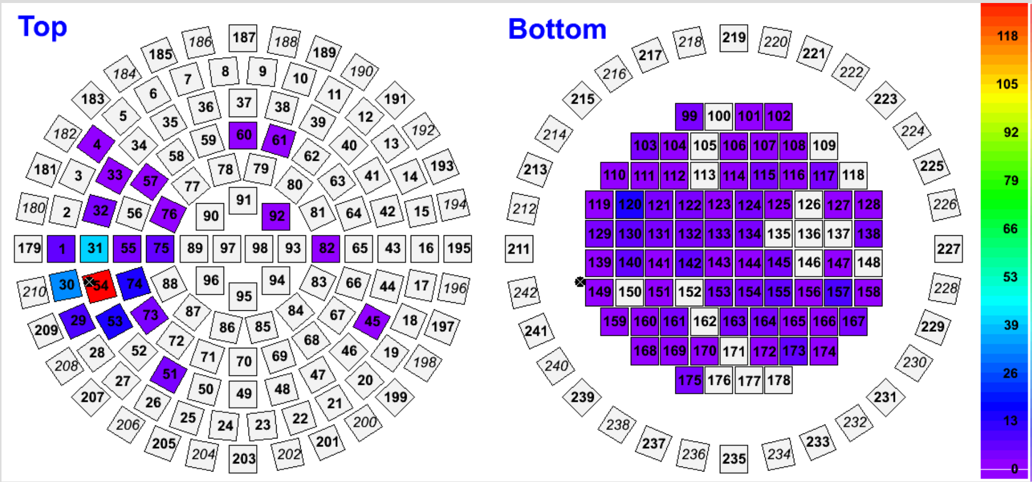


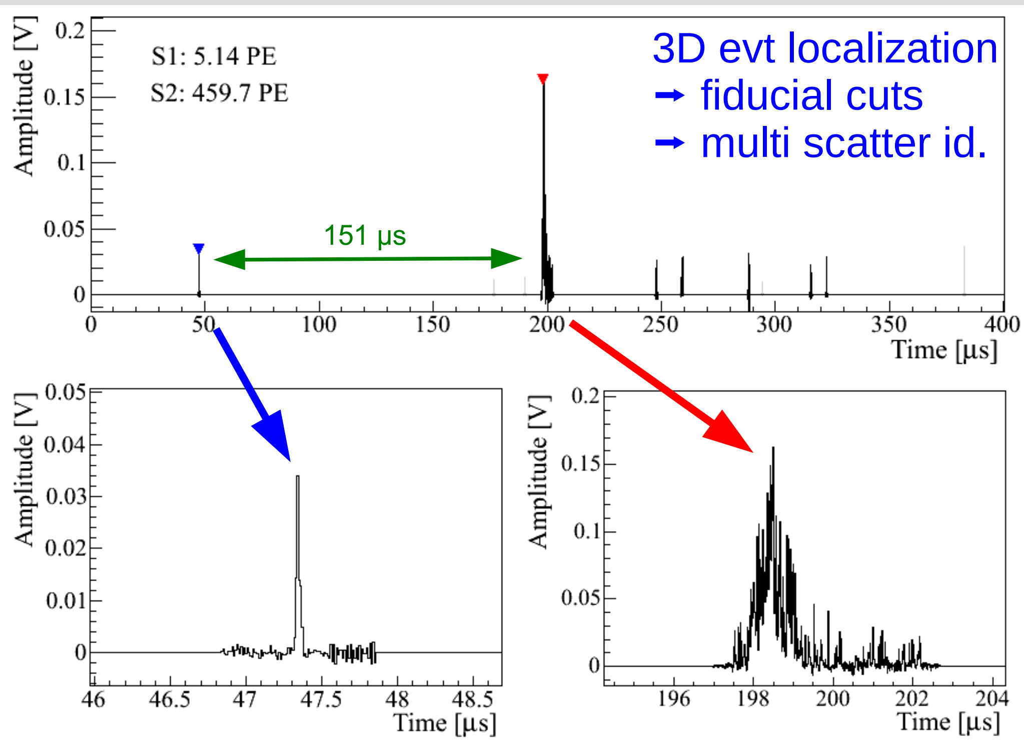
from: *Aprile et al., PRL 97, 081302 (2006)*



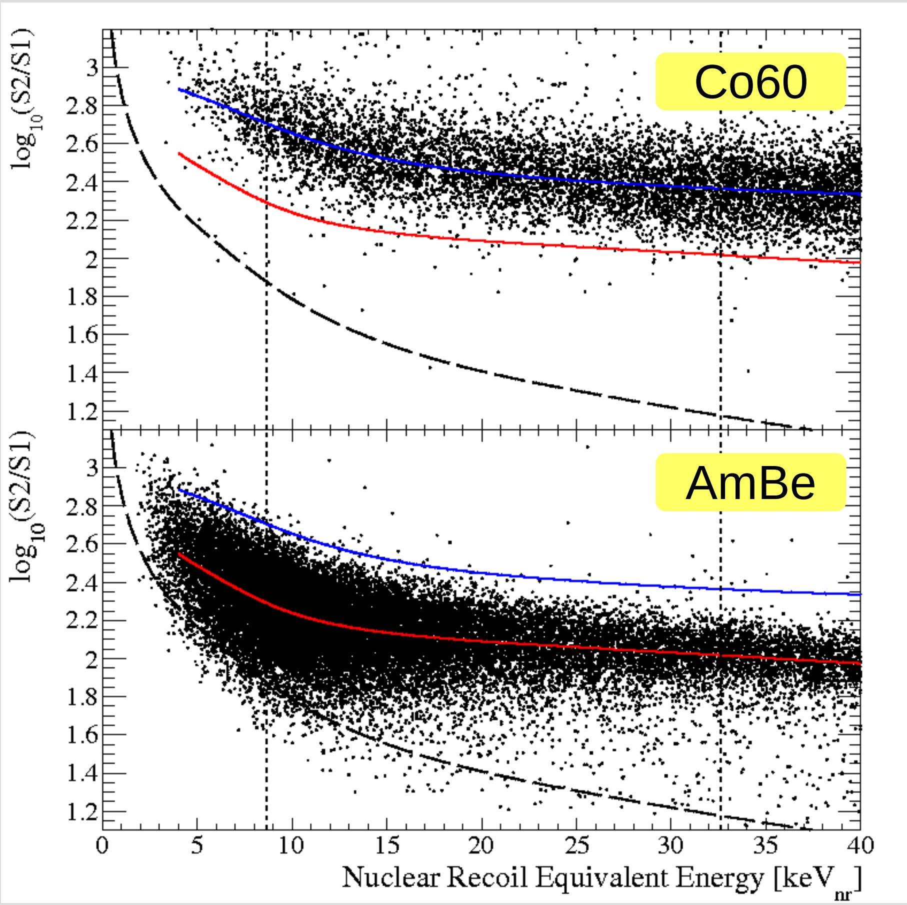
from: *Aprile et al., PRB 76, 014115 (2007)*

Localization / Discrimination





Discrimination:

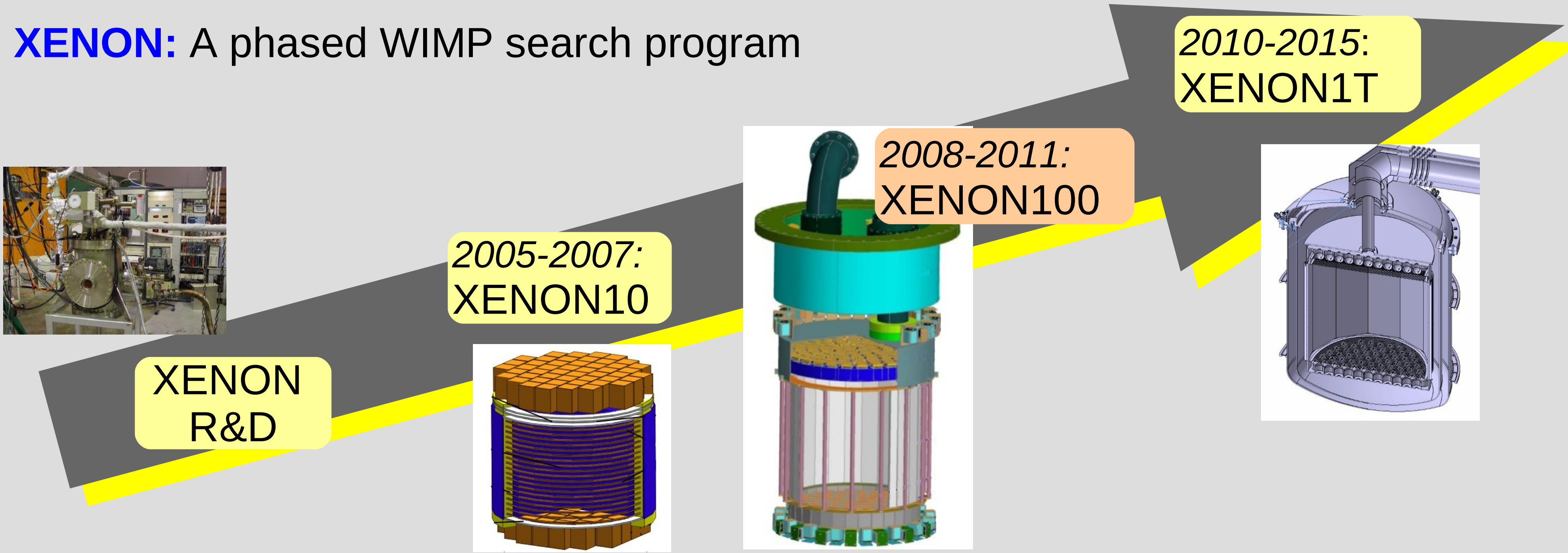


>99% rejection @ 50% acceptance

➡ definition of *WIMP search region*

The XENON program

XENON: A phased WIMP search program



Columbia | Rice | UCLA | U Zürich | Coimbra | LNGS | Mainz | SJTU

Bologna | MPIK | NIKHEF | Purdue | Subatech | Münster | WIS

XENON Collaboration

XENON Collaboration Meeting, LNGS 2011

XENON100

arXiv:1107.2155

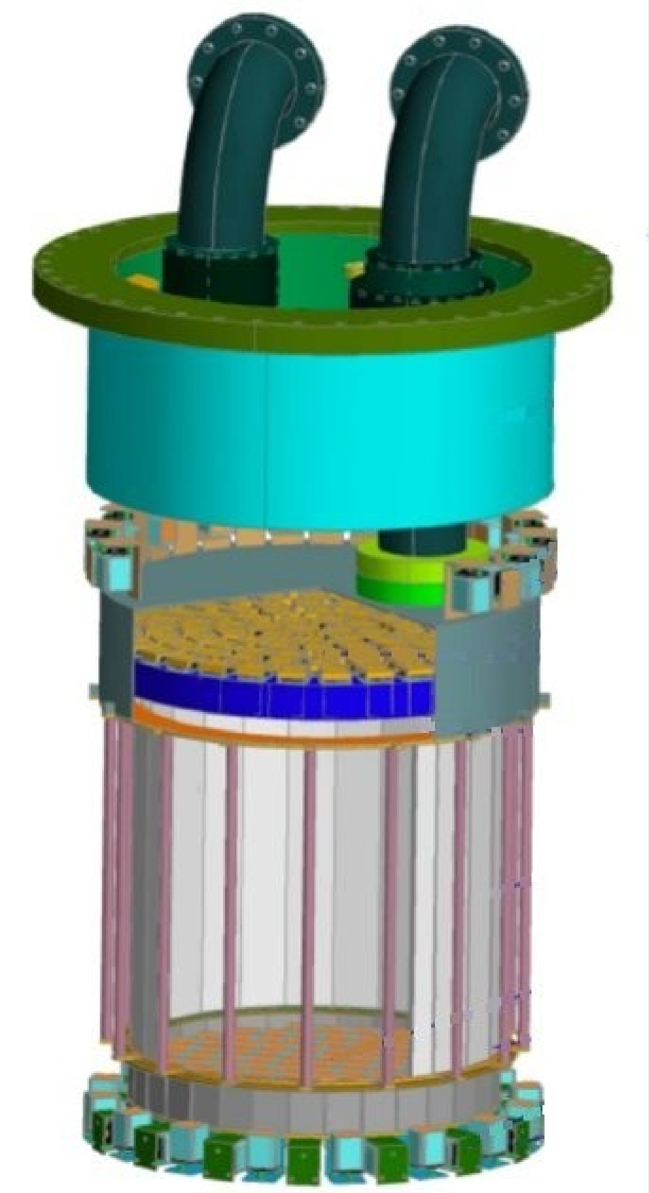
Goal (compared to XENON10)**:**
- increase target ×10
- reduce gamma background ×100

➞ 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
- passive shield
  (Pb, Poly, Cu, H_2O, N_2 purge)



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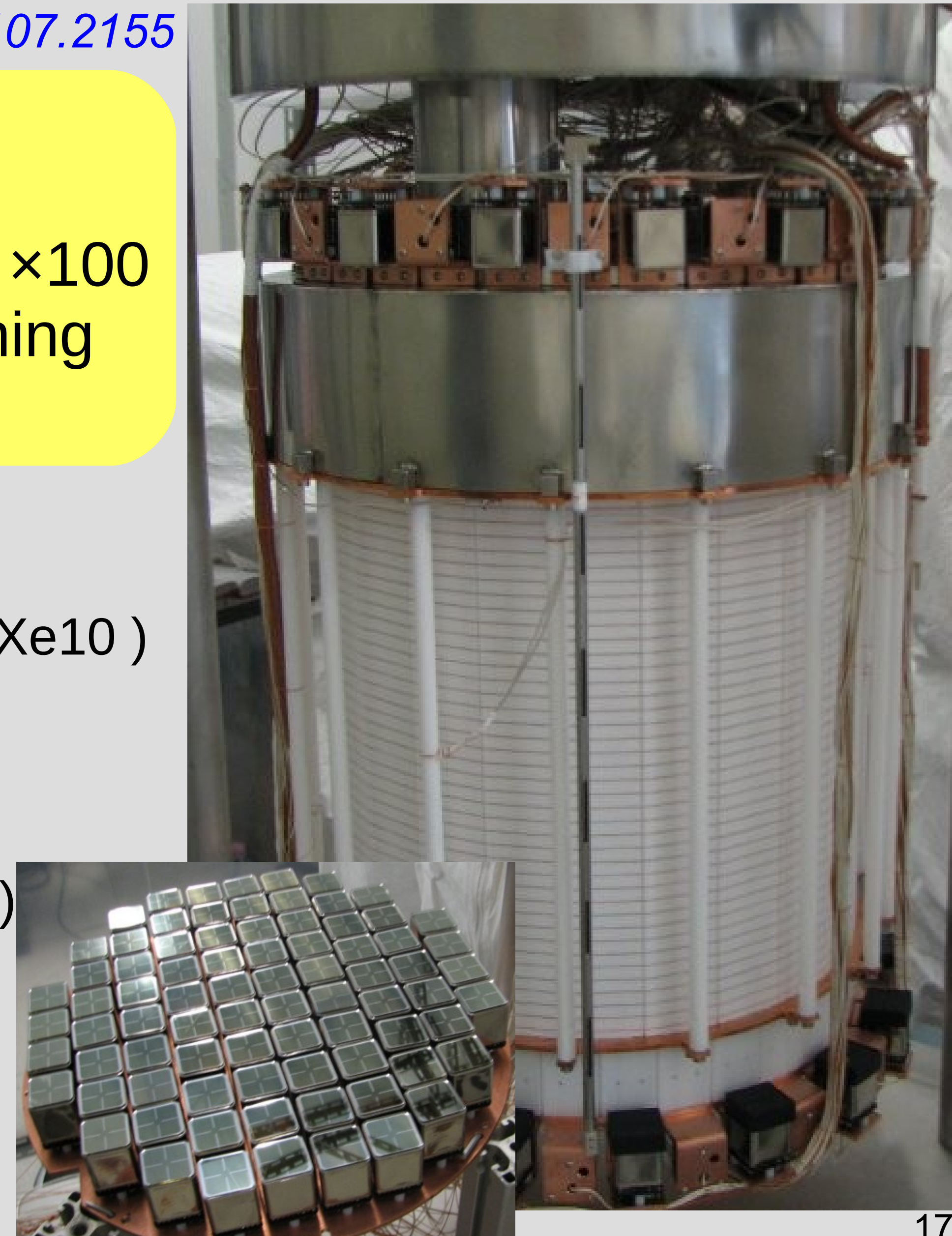

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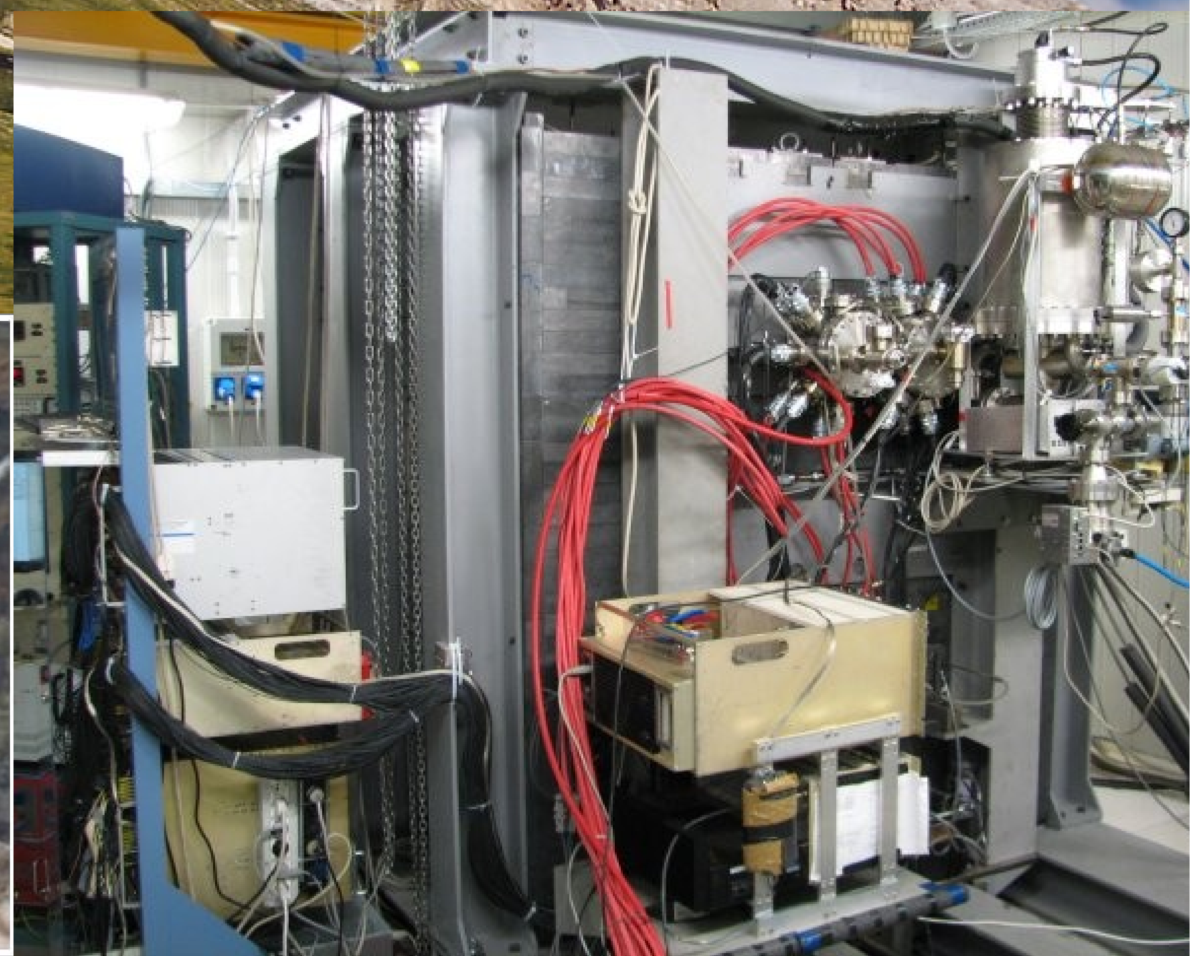
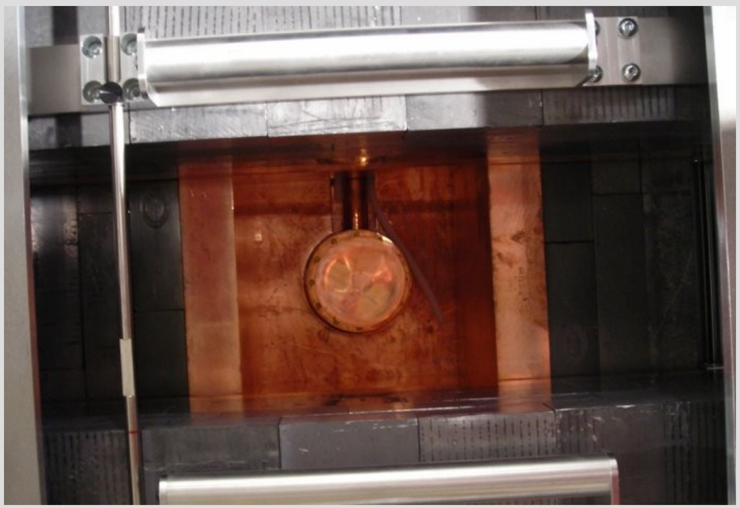
Laboratori Nazionali del Gran Sasso

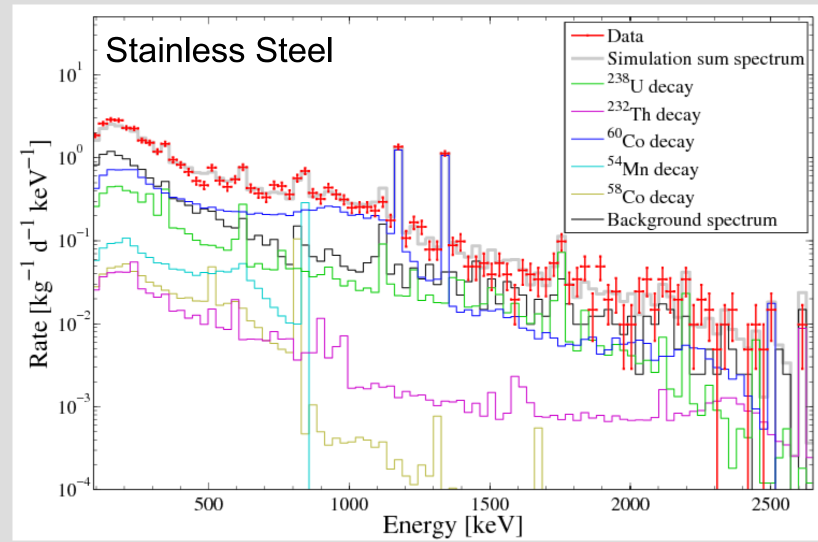


Material Screening

GATOR: 2.2kg high purity Ge detector operated by UZH @ LNGS

JINST 6, P08010 (2011)





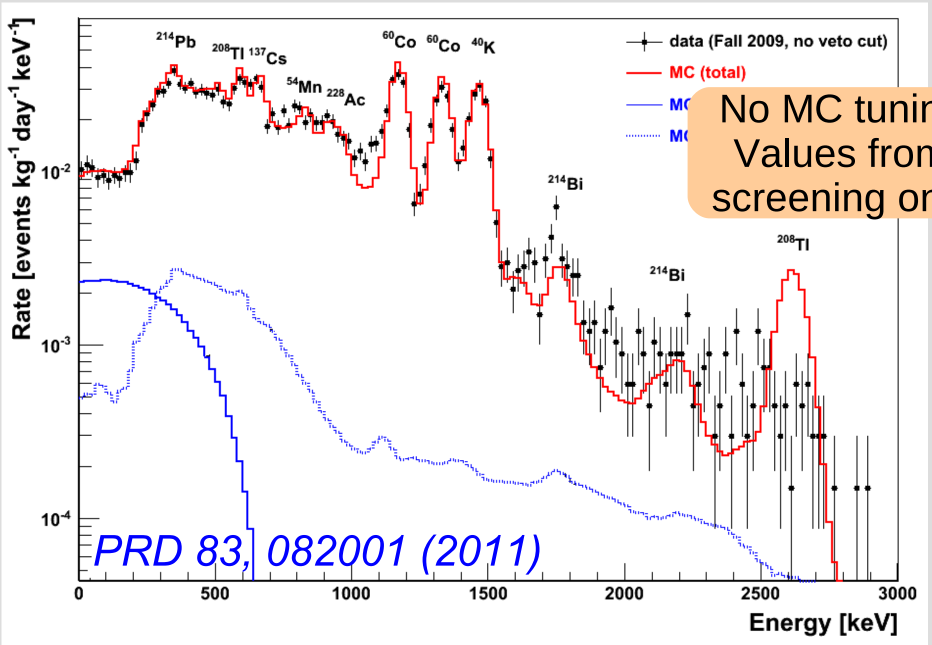
Component	Amount	Total radioactive contamination in materials [mBq/amount] ^{238}U / ^{226}Ra	^{232}Th	^{60}Co	^{40}K	other nuclides
Cryostat and 'diving bell' (316Ti SS)	73.61 kg	121.46	147.23	404.87	662.52	
Support bars (316Ti SS)	49.68 kg	64.58	144.07	69.55	352.73	
Detector PTFE	11.86 kg	0.71	1.19	0.36	8.89	
Detector copper	3.88 kg	0.85	0.62	5.21	0.78	
PMTs	242 pieces	60.50	111.32	181.50	1972.30	^{137}Cs: 41.14
PMT bases	242 pieces	38.72	16.94	2.42	38.72	
TPC resistor chain	1.5×10^{-3} kg	1.11	0.57	0.12	7.79	
Bottom electrodes (316Ti SS)	0.23 kg	0.43	0.45	2.14	2.36	
Top electrodes (316Ti SS)	0.24 kg	0.85	0.43	1.73	1.16	
PMT cables	1.80 kg	0.85	1.97	0.37	18.65	^{108m}Ag: 2.67
Copper shield	2.1×10^{3} kg	170.80	24.69	6.59	80.26	
Polyethylene shield	1.6×10^{3} kg	368.0	150.4	-	1120.0	
Lead shield (inner layer)	6.6×10^{3} kg	4.3×10^{3}	3.6×10^{3}	7.2×10^{2}	9.6×10^{3}	^{210}Pb: 1.7×10^{8}
Lead shield (outer layer)	27.2×10^{3} kg	1.1×10^{5}	1.4×10^{4}	2.9×10^{3}	3.8×10^{5}	^{210}Pb: 1.4×10^{10}

Screening results:
Astro. Part. Phys. 35, 43 (2011)

use results for Monte Carlo Simulations

XENON100 Background

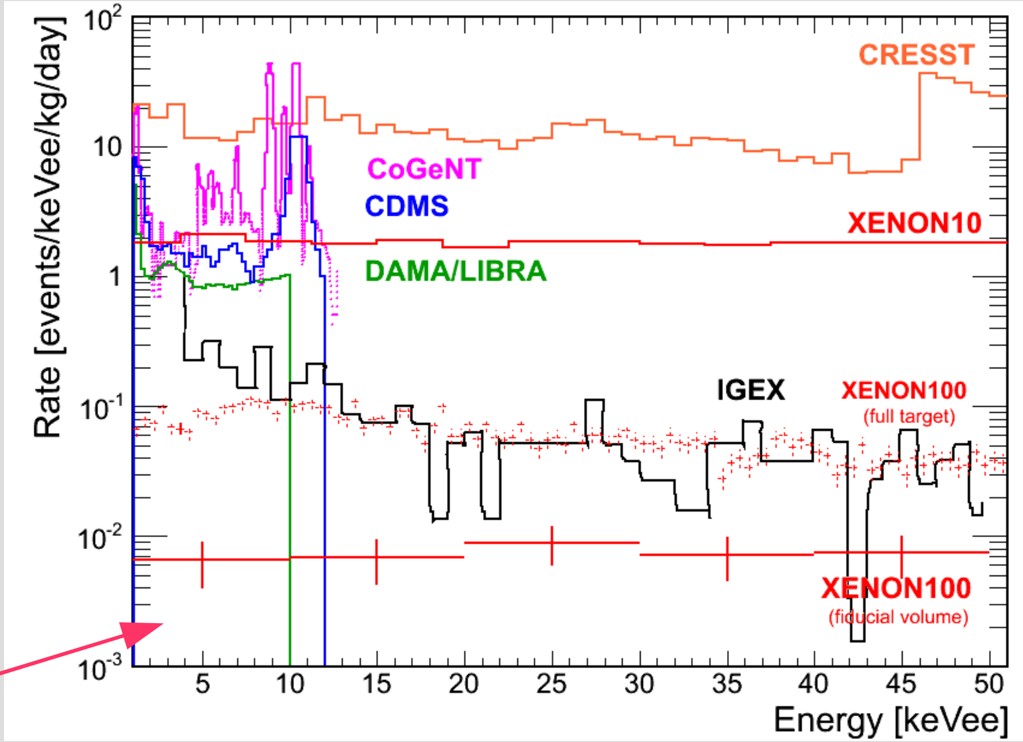
XENON Dark Matter Project



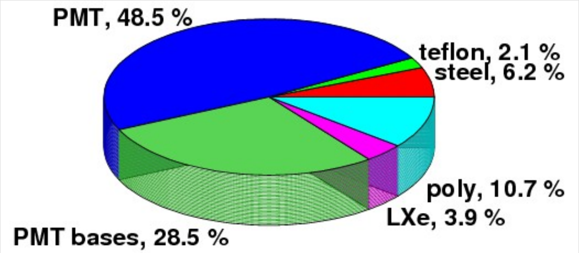
No MC tuning! Values from screening only.

Measured Background in good agreement with MC prediction.

At low energies: Lowest background ever achieved in a Dark Matter Experiment!

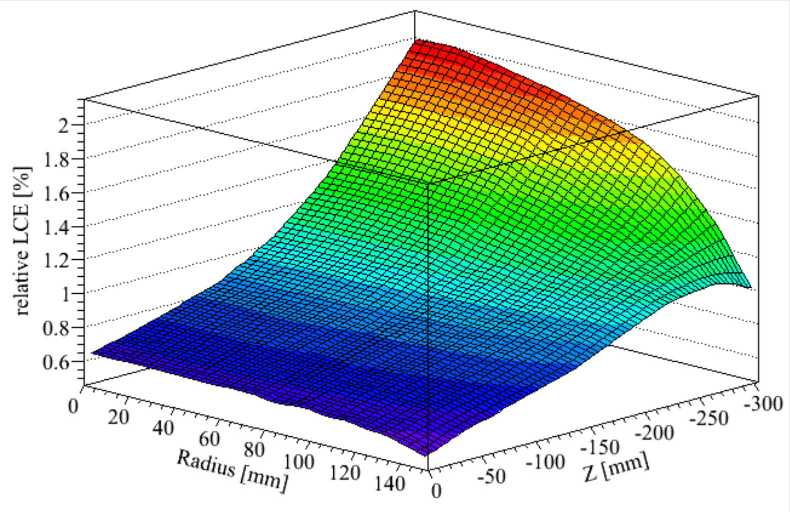


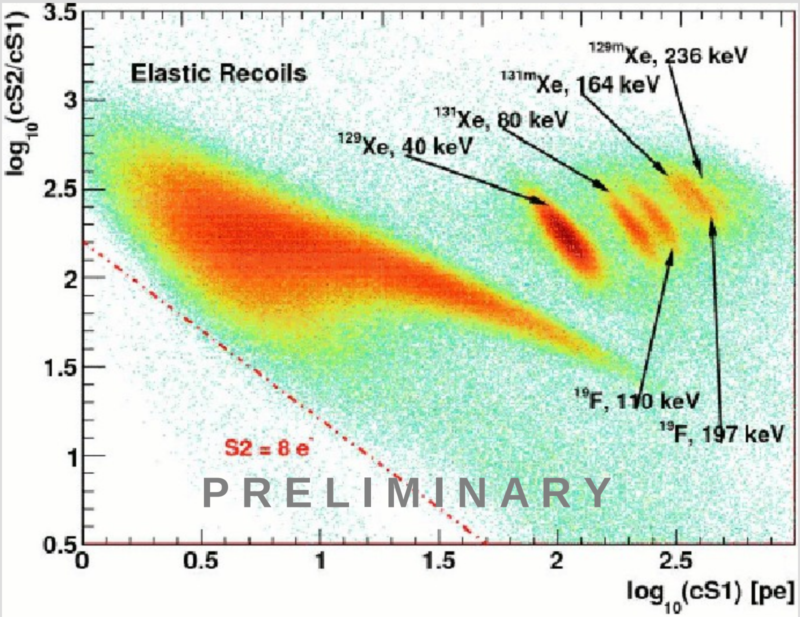
- 30 kg fiducial mass
- active LXe veto not used for this plot
- exploit anti-correlation between light and charge for better ER-energy scale



Xenon keVee-Scale not precisely known below 9 keVee

Selected Calibrations





arXiv:1107.2155

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, Th-232, Cs-137

Nuclear Recoil Band (Signal):
Neutrons: AmBe

➡ definition of WIMP search region, discrimination

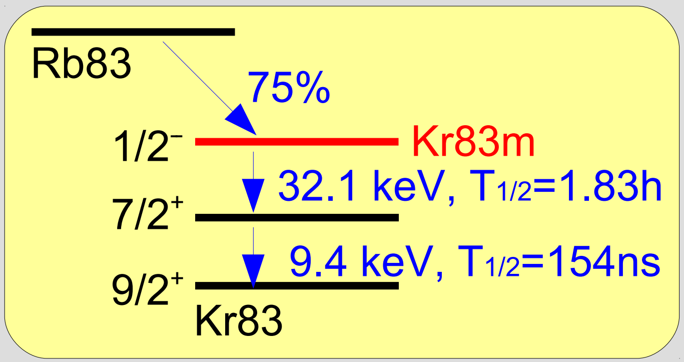
R&D: Calibration at low Energy

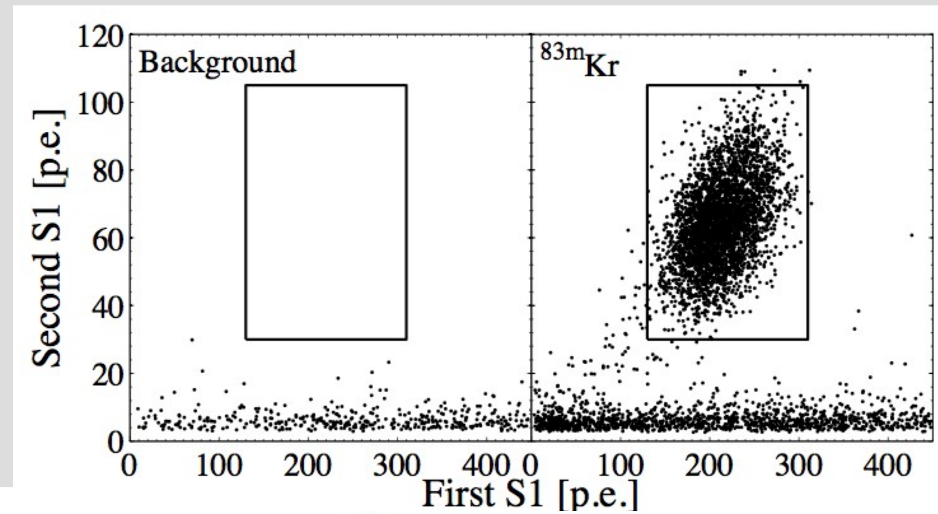
expect signal <40 keV (calibration from outside very difficult)

⇨ n-activated Xe131, Xe129m

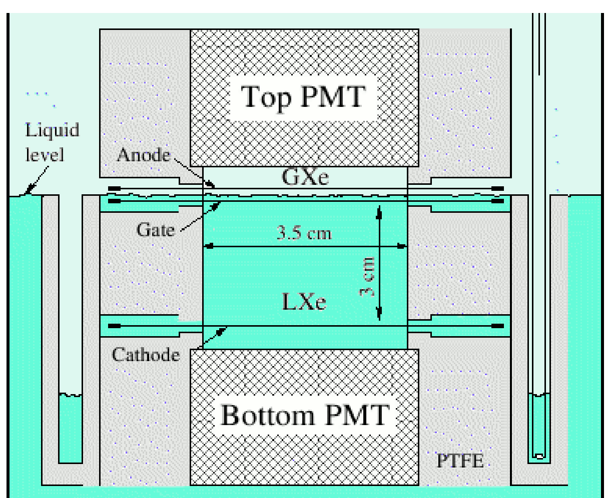
was used for Xe10, τ~O(10d)

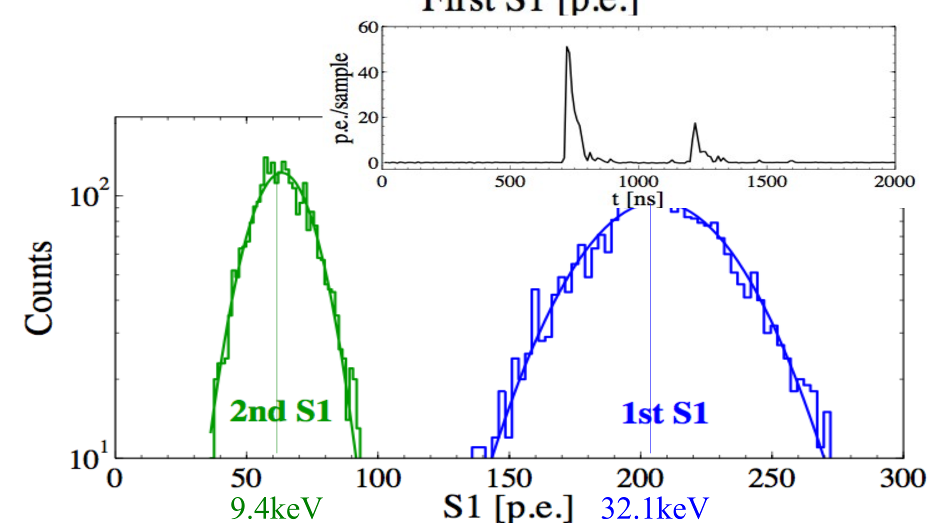
⇨ Kr83m





R&D in Zürich:





Manalaysay et al., Rev.Sci.Instr. 81, 073303 (2010)

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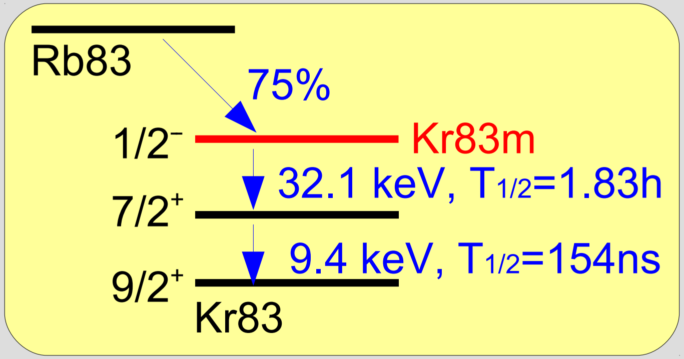

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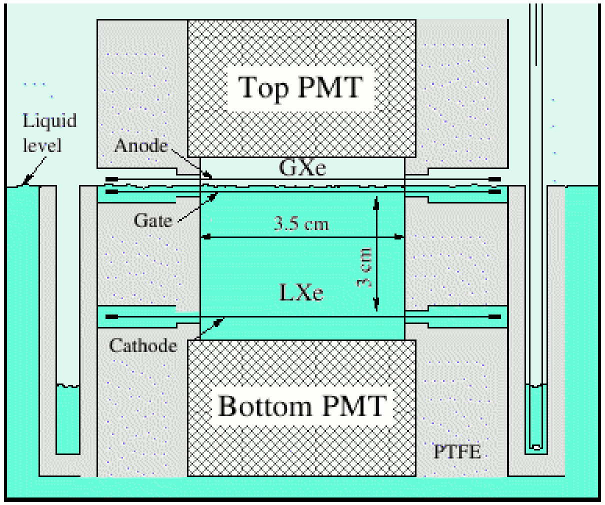

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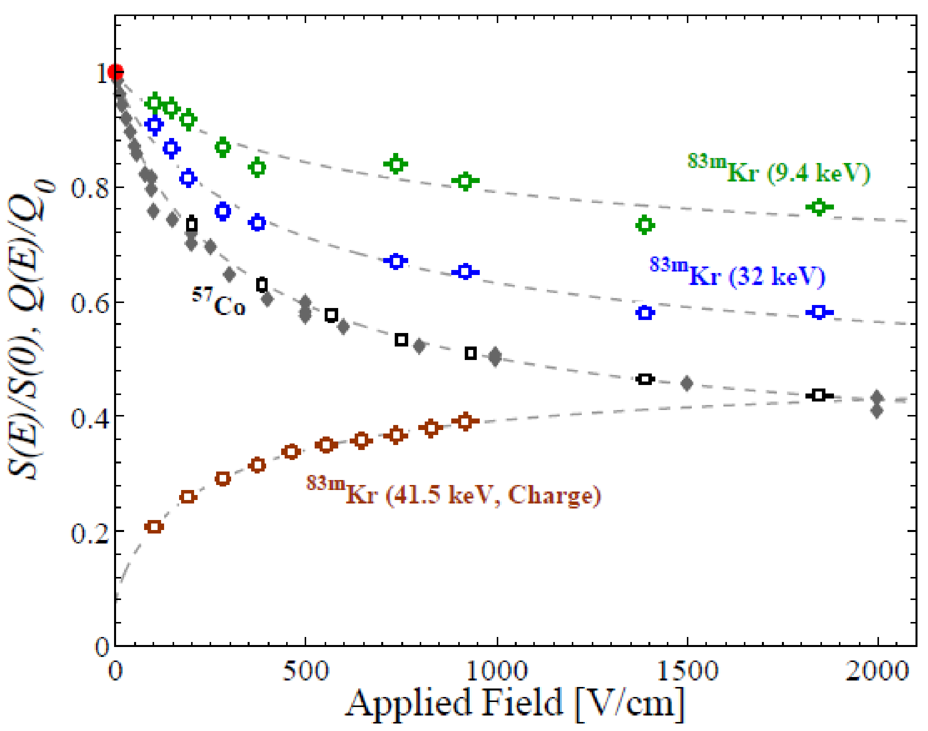
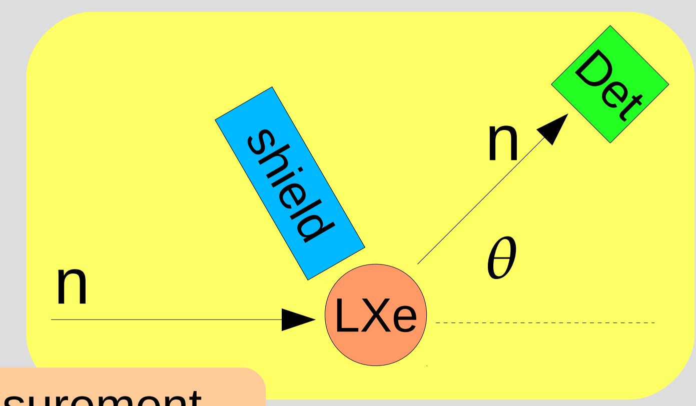


Nuclear Recoil Energy Scale

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

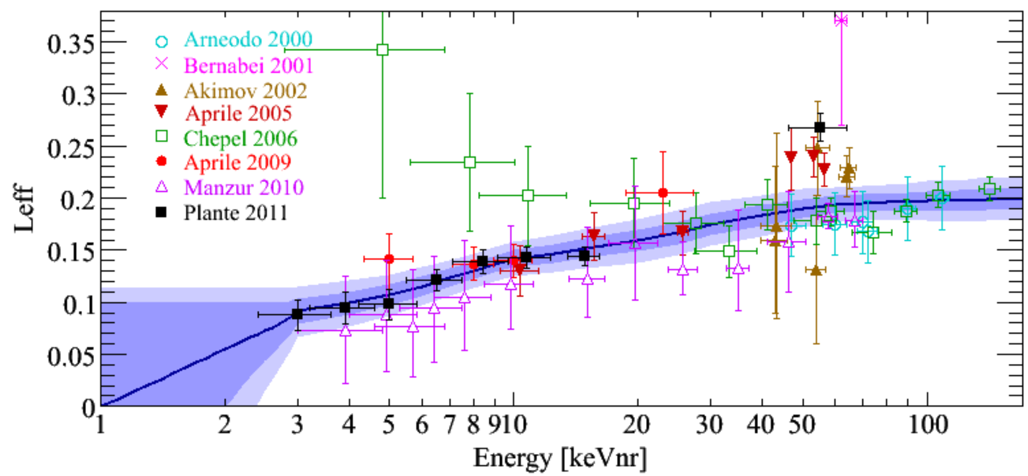
$$\mathcal{L}_{\rm eff}(E_{\rm nr}) = \frac{\mathrm{LY}(E_{\rm nr})}{\mathrm{LY}(E_{\rm ee} = 122\ \mathrm{keV})}$$

measurement principle:



New measurement
in preparation in Zürich

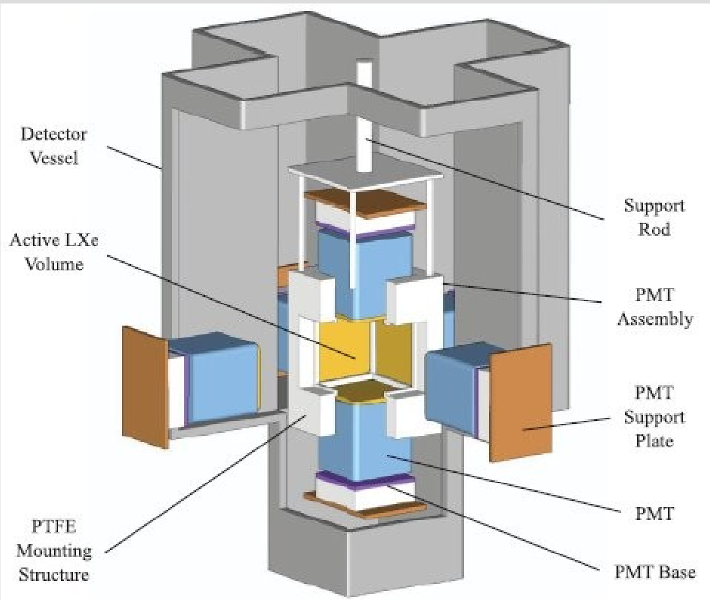
average over all direct measurements



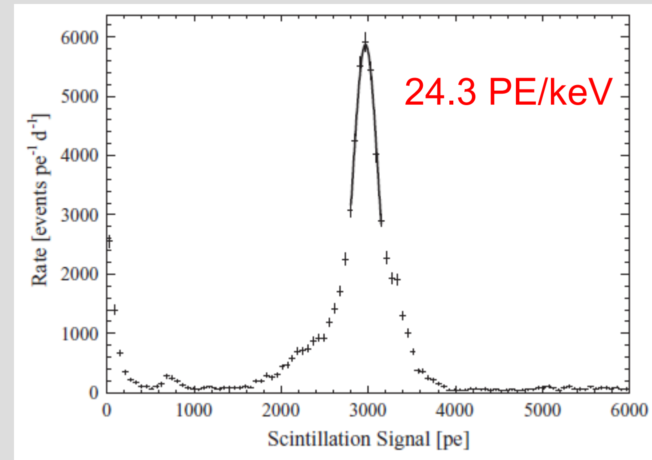
most recent measurements:
■ *Plante et al., PRC 84, 045805 (2011)*
△ *Manzur et al., PRC 81, 025808 (2010)*
for discussion of possible systematic errors see
A. Manalaysay, arXiv:1007.3746

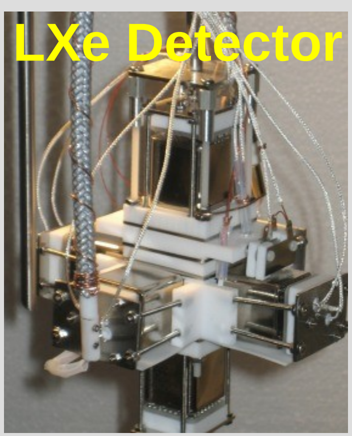
New Measurement @ Columbia

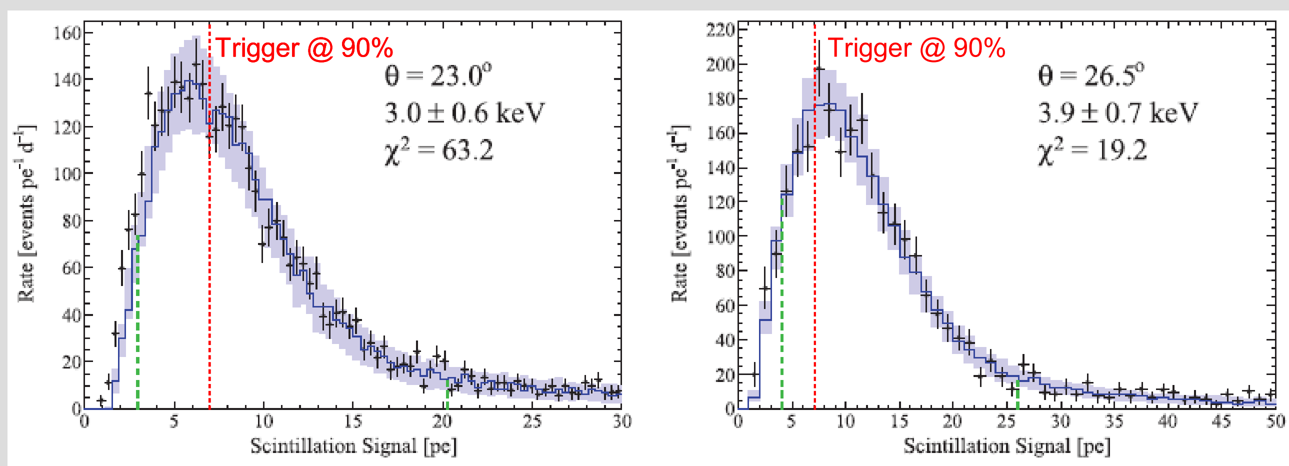
Plante et al., Phys. Rev. C 84, 045805 (2011)



- Approach: systematic „clean measurement“
- minimize double-scatters
- very high light yield
- full data vs MC analysis
- rate is no free parameter

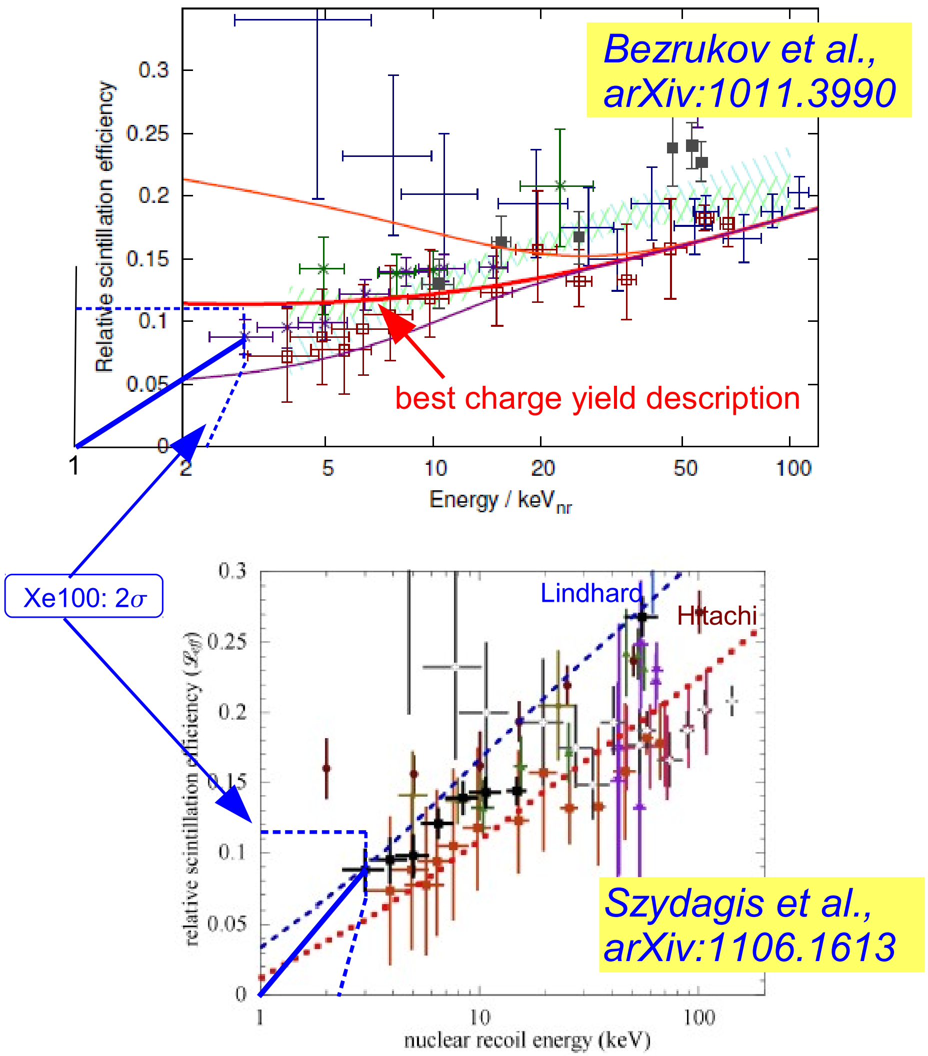


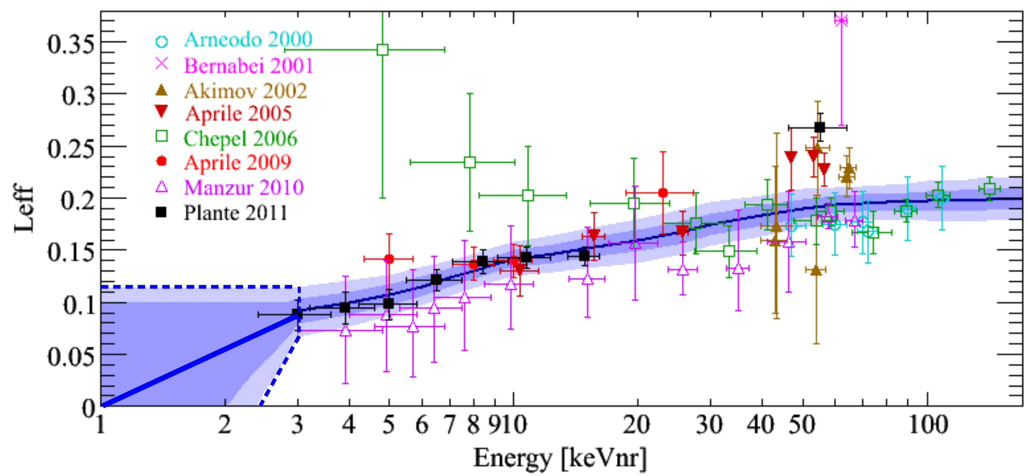




Nuclear Recoil Energy Scale

Some attempts to model L_{eff}:





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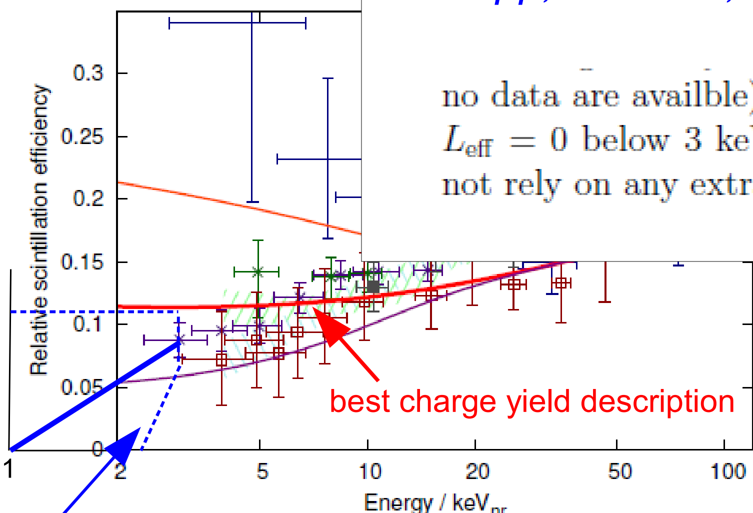
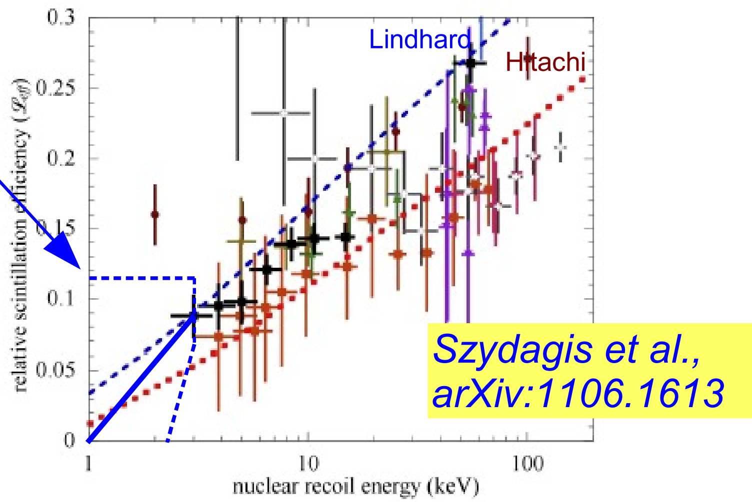
Nuclear Recoil Energy Scale

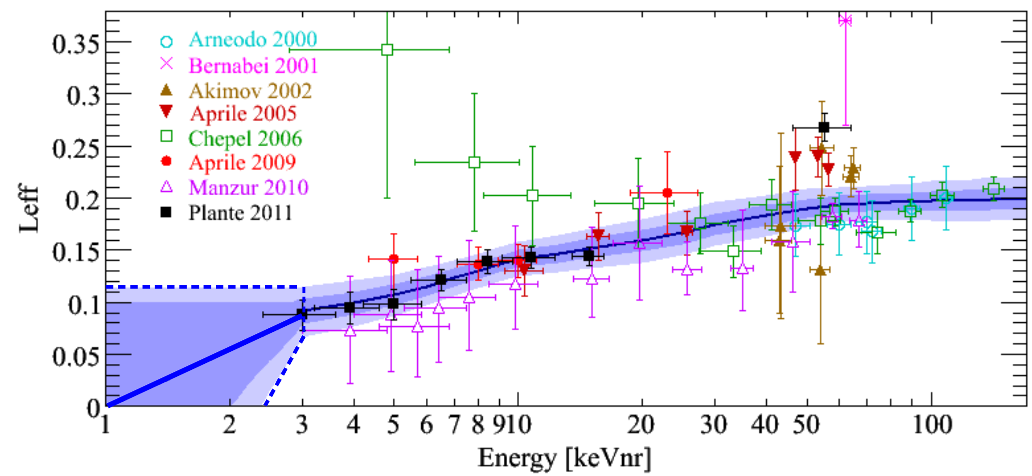
Some attempts

Kopp, Schwetz, Zupan: arXiv:1110.2721:

The assumptions on $\mathcal{L}_{\rm eff}$ below $E_{\rm nr} \approx 3$ keV (where no data are availble) have no impact on the XENON-100 exclusion curves. Even assuming $\mathcal{L}_{\rm eff} = 0$ below 3 keV, the limits remain essentially unchanged [4]. Hence, the result does not rely on any extrapolation into a region with no data.







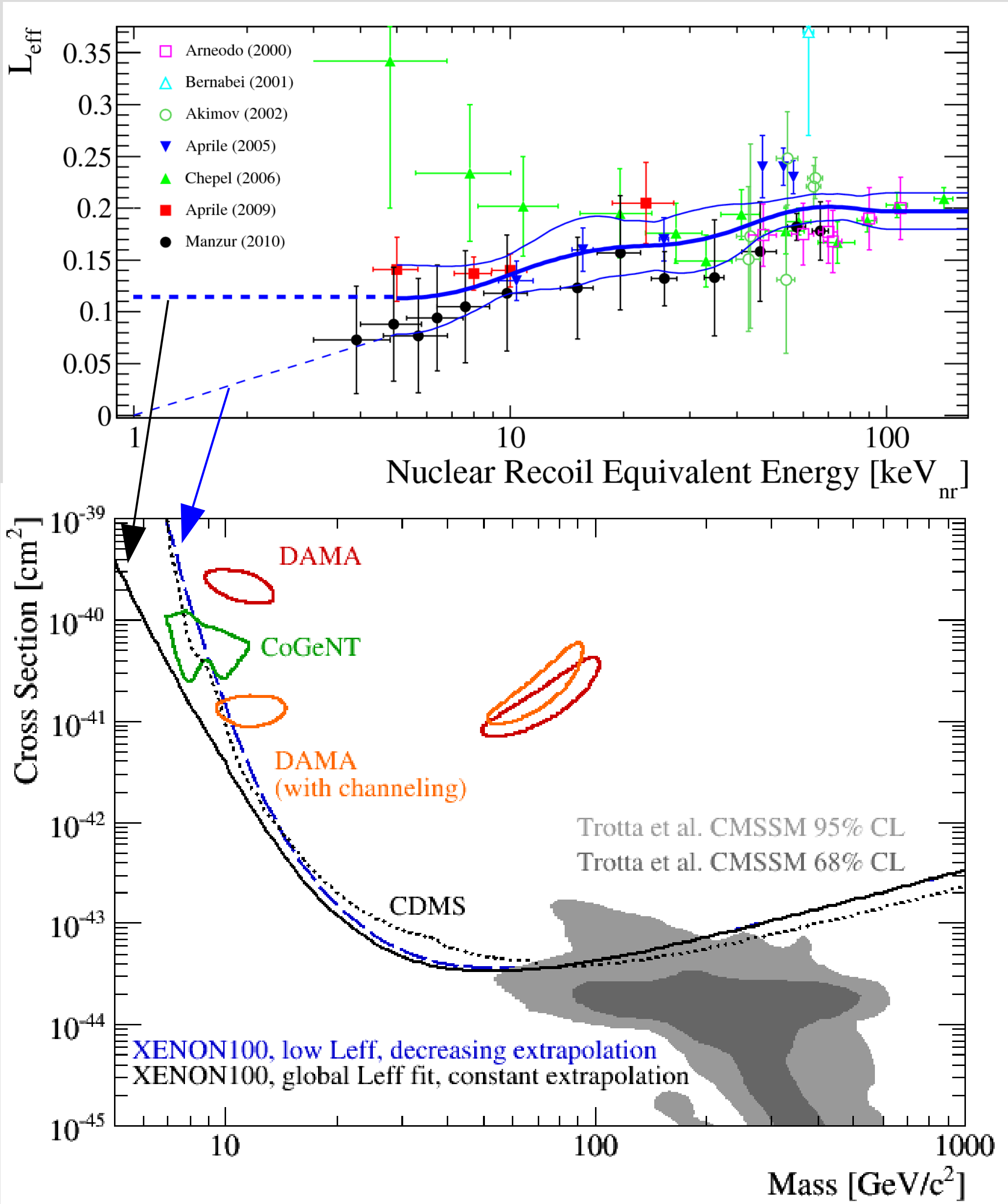
most recent measurements:

■ *Plante et al., PRC 84, 045805 (2011)*

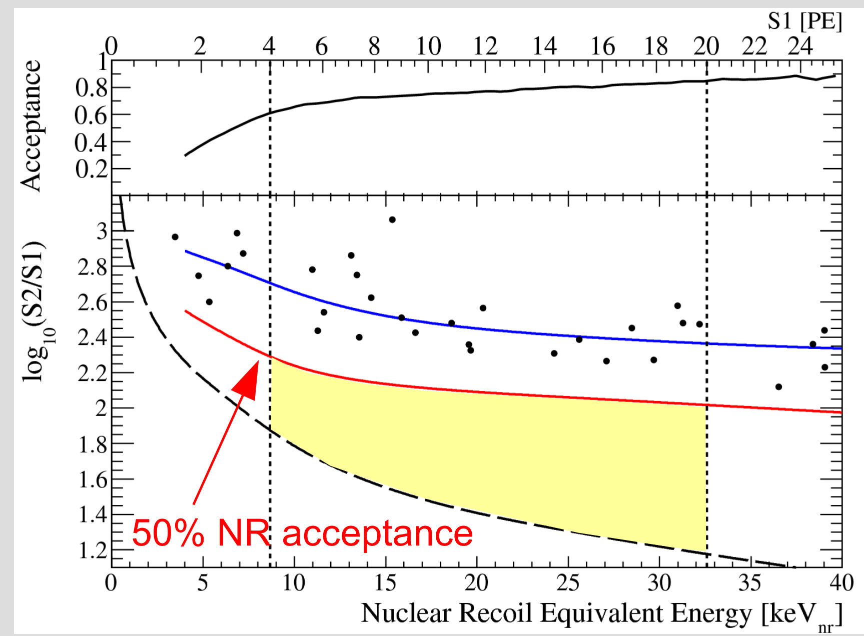
△ *Manzur et al., PRC 81, 025808 (2010)*

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

First Results from 11.2 days



- First result from 11.2 life days
- Data taken in late 2009
- formally non-blind analysis, but cuts defined on calibration data
- *PRL 105, 131302 (2010)*



Profile Likelihood Method

PRD 84, 052003 (2011)

Construct Likelihood function:

„NR like“ sideband measurement

NR scale measurement

dark matter measurement

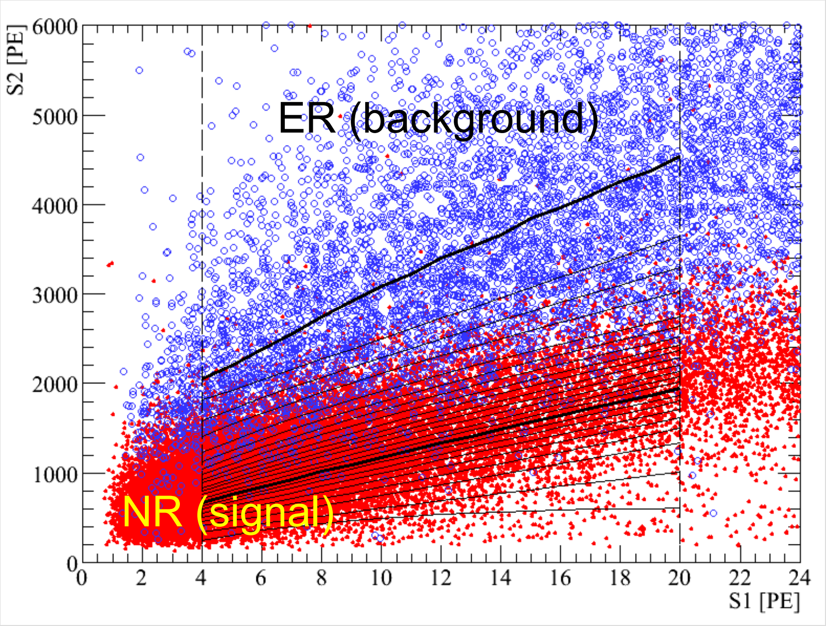
„ER like“ sideband measurement

v_{esc} measurement

$$\mathscr{L} = \boxed{\mathscr{L}_1(\sigma, N_b, \epsilon_s, \epsilon_b, \mathcal{L}_{\rm eff}, v_{\rm esc}; m_\chi)} \times \boxed{\mathscr{L}_2(\epsilon_s)} \times \boxed{\mathscr{L}_3(\epsilon_b)} \times \boxed{\mathscr{L}_4(\mathcal{L}_{\rm eff})} \times \boxed{\mathscr{L}_5(v_{\rm esc})}.$$

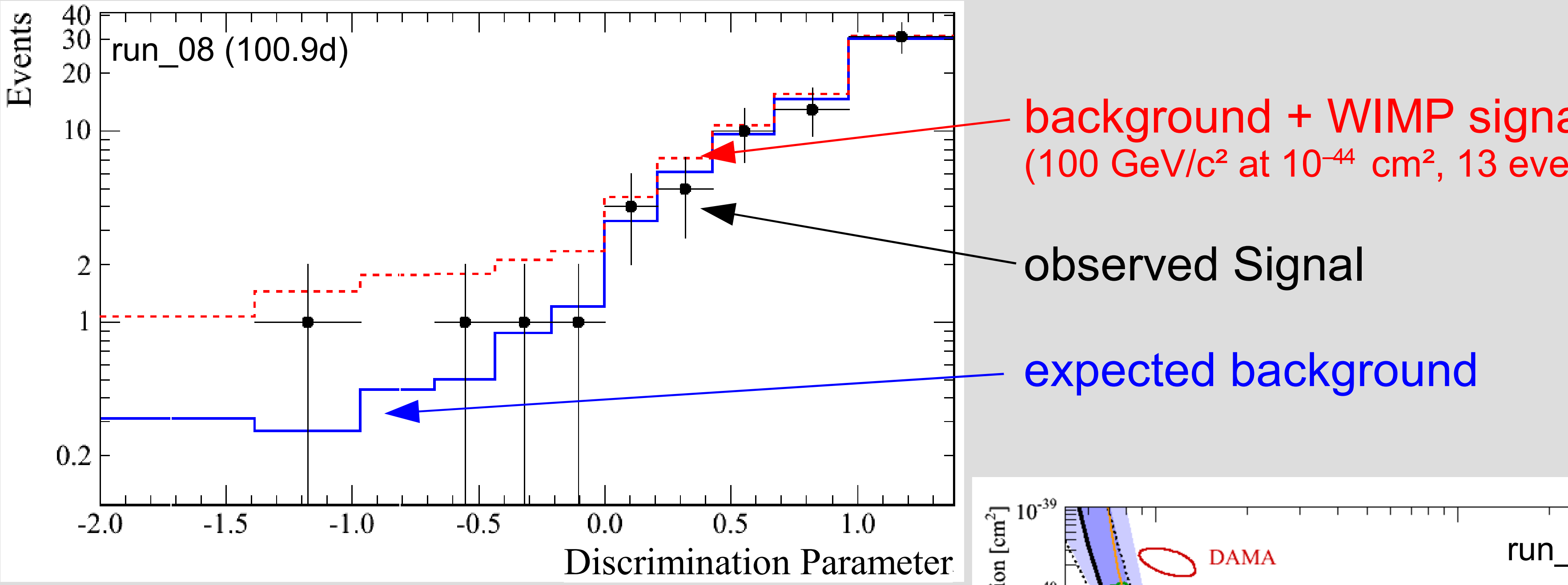
Profile Likelihood Method

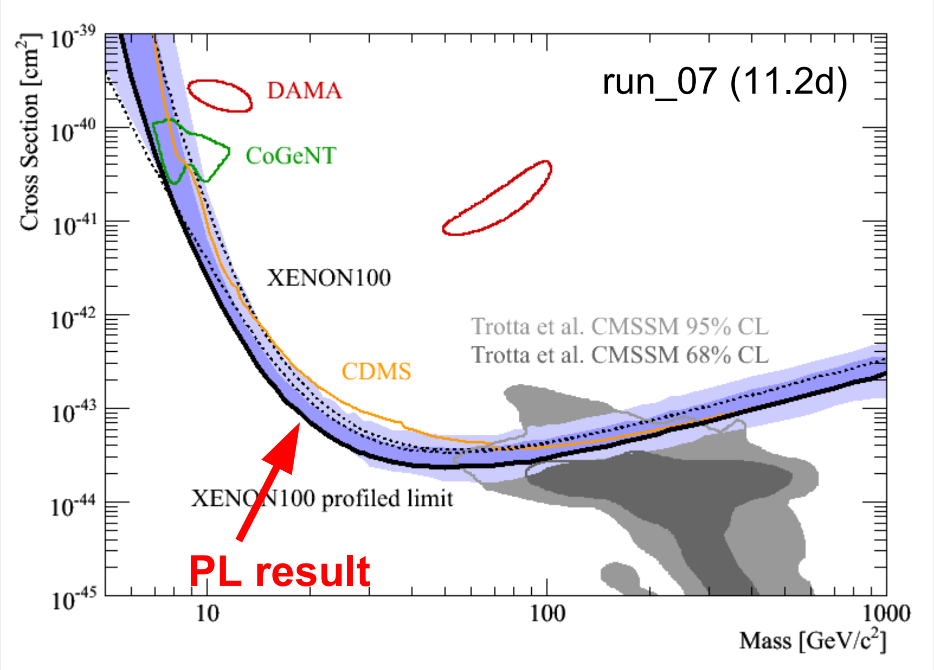
- natural transition from limit to detection
- account for systematic uncertainties
- use full S2/S1 space
- hypothesis (signal/bg) based on profile likelihood ratio
- σ is the interesting parameter; other nuisance parameters are profiled out
- method described in *arXiv:1007.1727*



Profile Likelihood Method

PRD 84, 052003 (2011)





need good understanding of background („background model“)

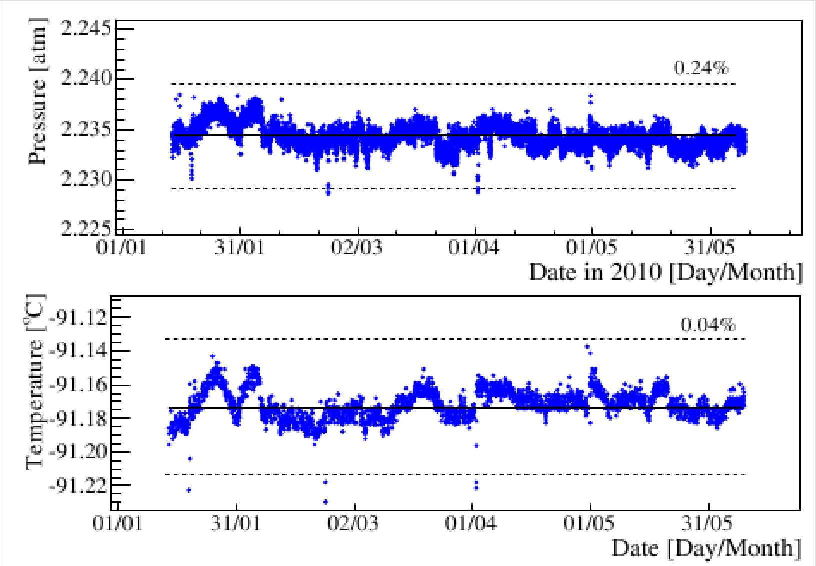
➡ but this is required by any low background experiment (regardless of the type of analysis)

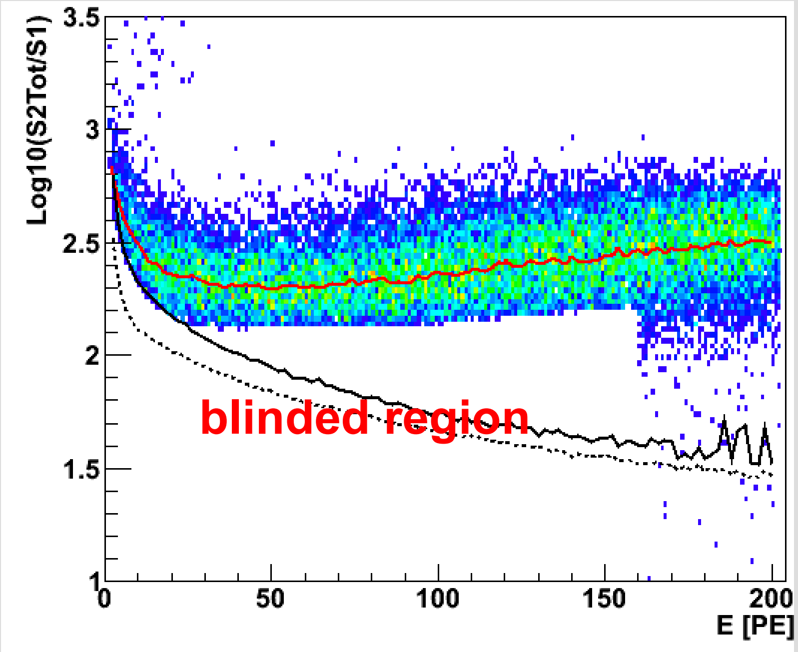
Outline

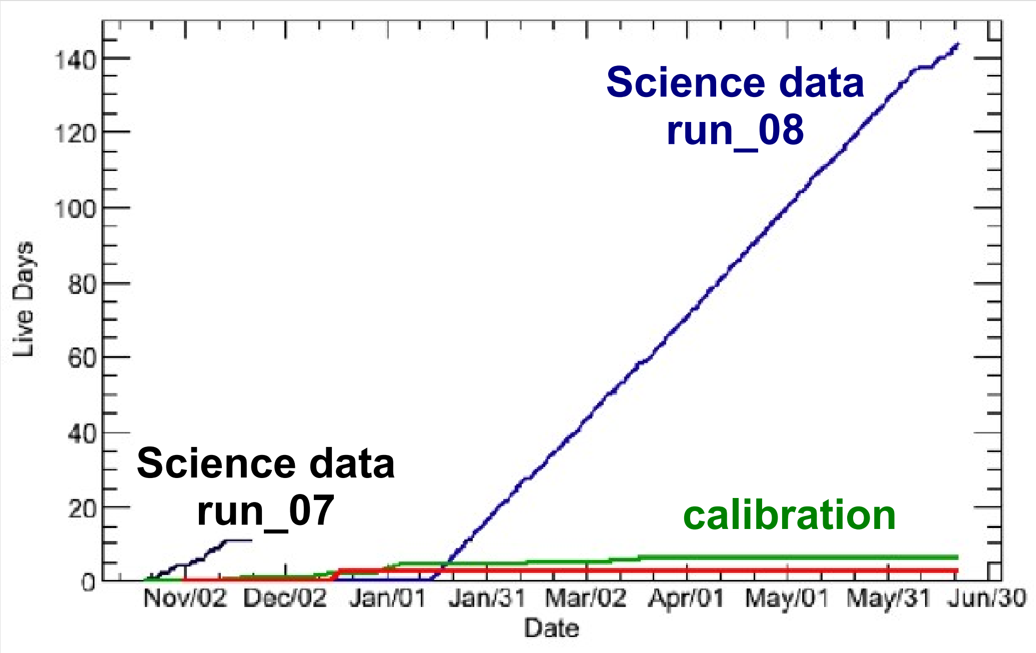
- Motivation: Dark Matter ✓
- WIMP Search with Xenon ✓
- XENON100 ✓
- **The new Results**
- Some Comments
- Presence and Future

The new XENON100 Data

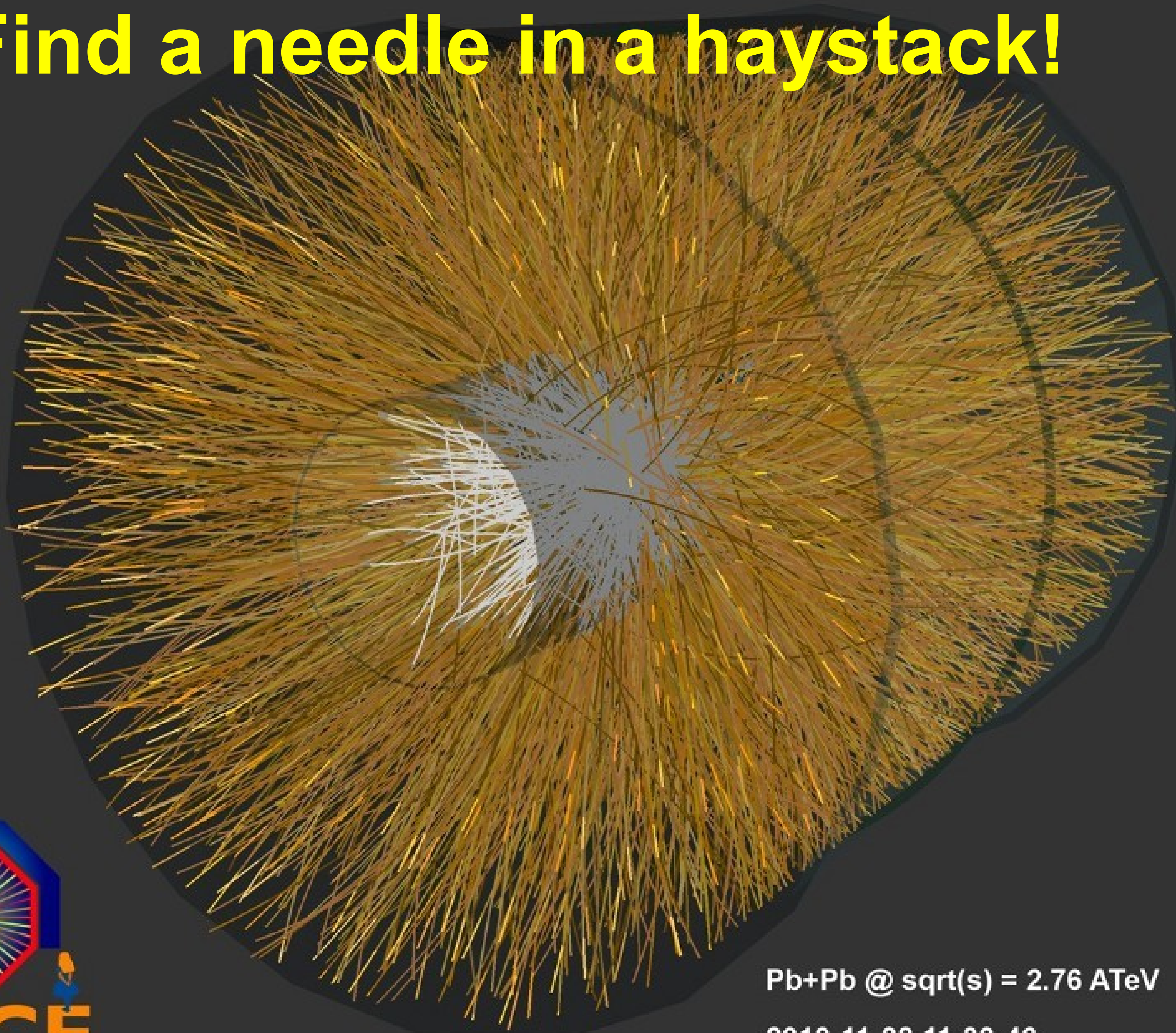
- data taken in first half of 2010
- 100.9 life days
- data blinded in ROI
- analysis and results in:
  PRL 107, 131302 (2011)







Find a needle in a haystack!



ALICE

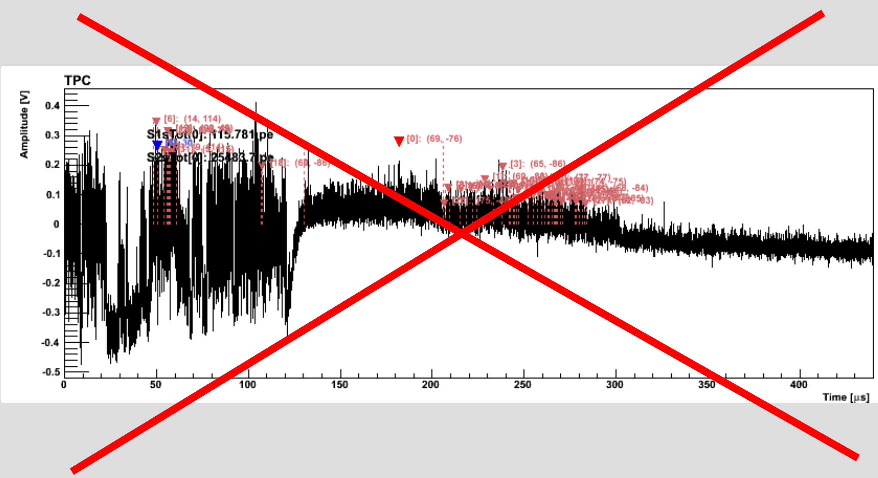
Pb+Pb @ sqrt(s) = 2.76 ATeV

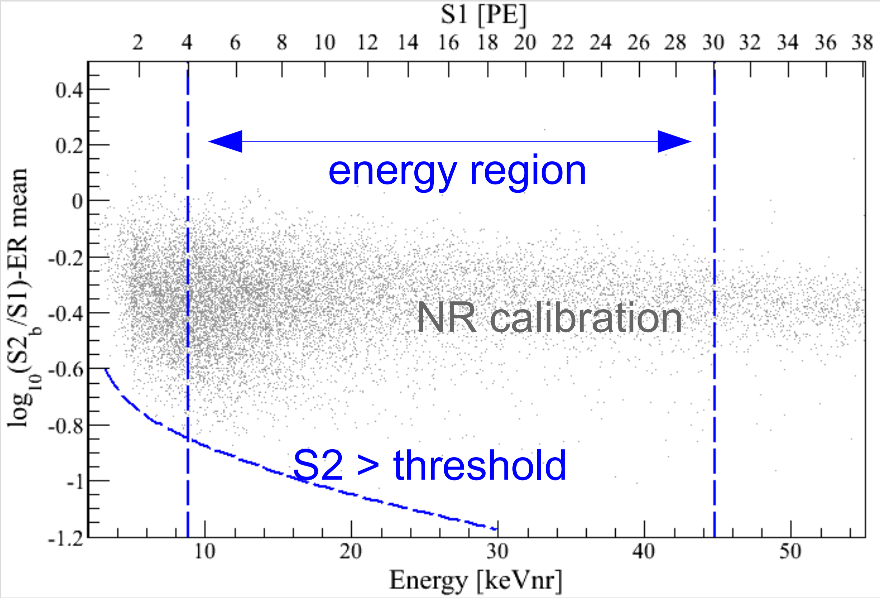
2010-11-08 11:30:46

Data Analysis

Basic Data Quality Cuts
- reject non useable waveforms (muons, micro-discharges, …)
- „hot spot“ cuts
- S1 noise cut

Energy Cuts
- low *E* region (S1)
- S2 software threshold
- require 2x S1 coincidence (against PMT dark current, noise)





Data Analysis

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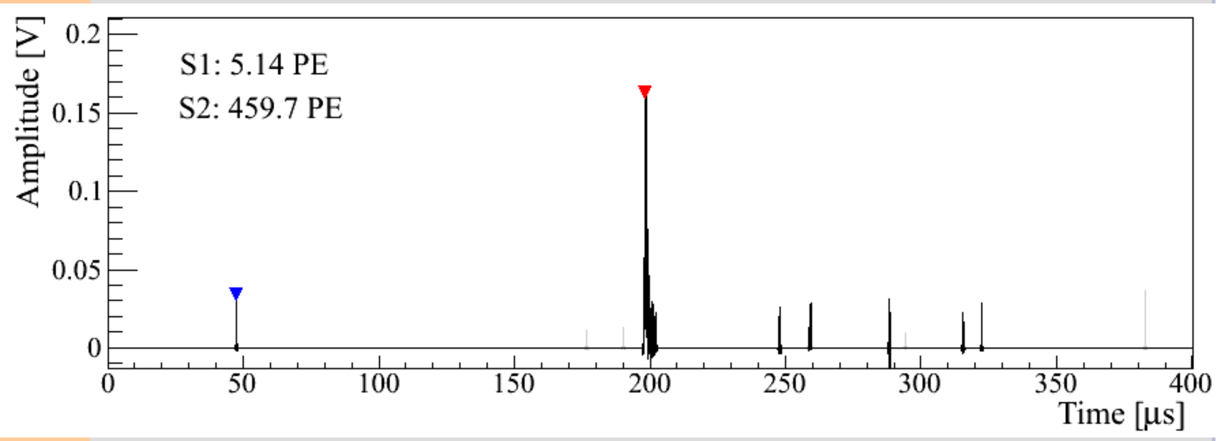
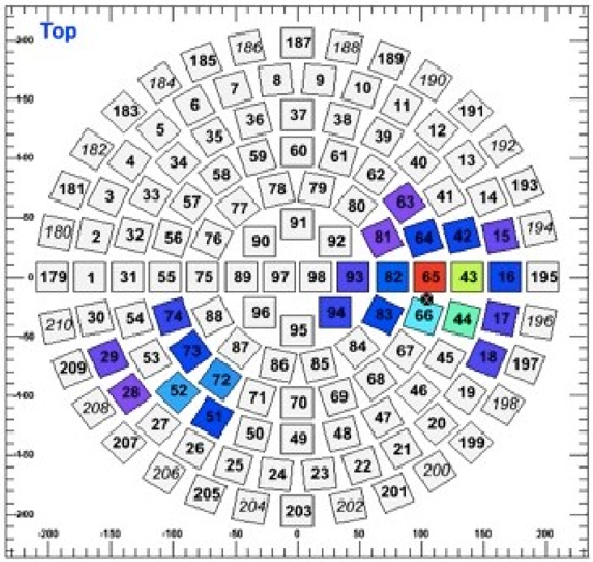
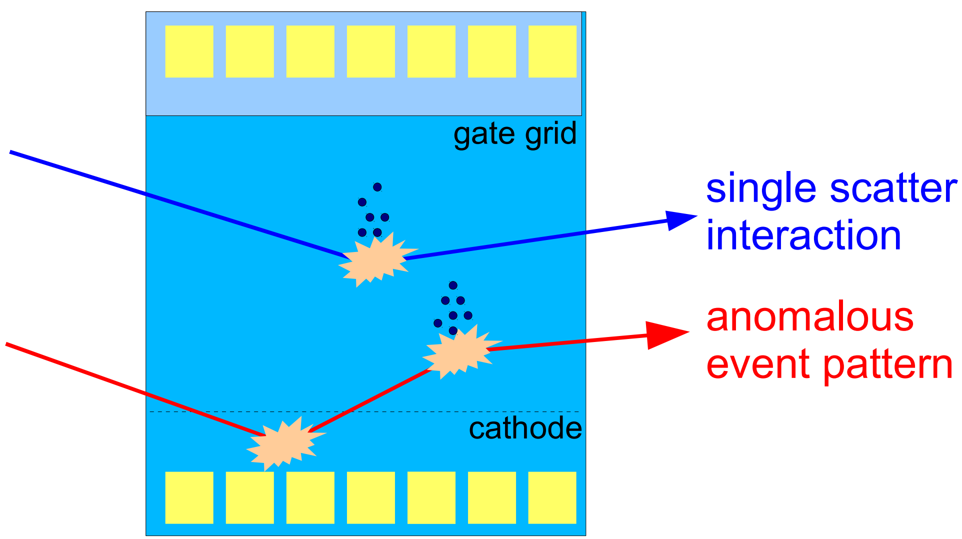
- require 2x S1 coincidence (against PMT dark current, noise)

Single Scatter Selection
(WIMPs interact only once!)
- only one S2 peak
- only one S1 peak
- active veto cut



Data Analysis





Energy Cuts
- low E region (S1)
- S2 software threshold
- require 2x S1 coincidence
  (against PMT dark current, noise)

Consistency Cuts
- S2 width cut
  (drift time ok? gas events)
- position reconstruction
- anomalous event rejection

Data Analysis

XENON Dark Matter Project

Basic Data Quality Cuts
- reject non useable waveforms (muons, micro-discharges, …)
- „hot spot“ cuts
- S1 noise cut

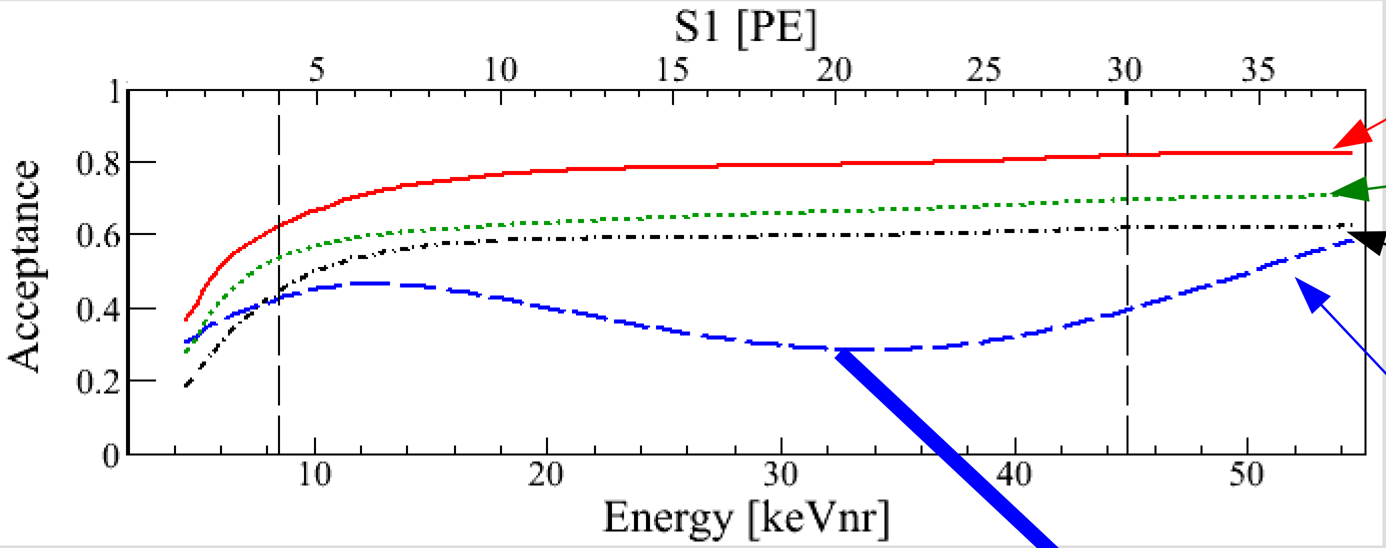
Energy Cuts
- low E region (S1)
- S2 software threshold
- require 2x S1 coincidence (against PMT dark current, noise)

Fiducial volume cut
NR/ER discrimination
(strict only for classical analysis)

Single Scatter Selection
(WIMPs interact only once!)
- only one S2 peak
- only one S1 peak
- active veto cut

Consistency Cuts
- S2 width cut (drift time ok? gas events)
- position reconstruction
- anomalous event rejection

Acceptance



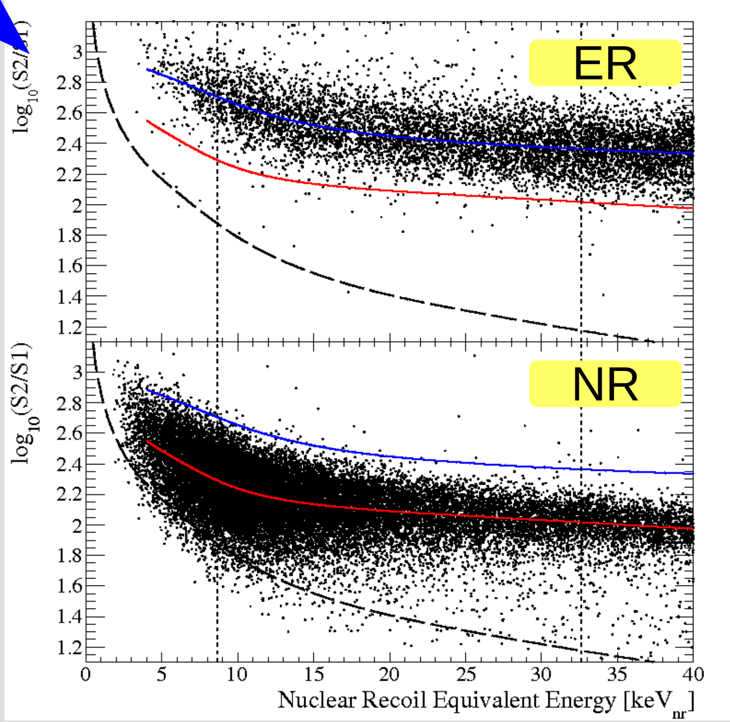
Cut Acceptance:

mχ≥50 GeV/c²

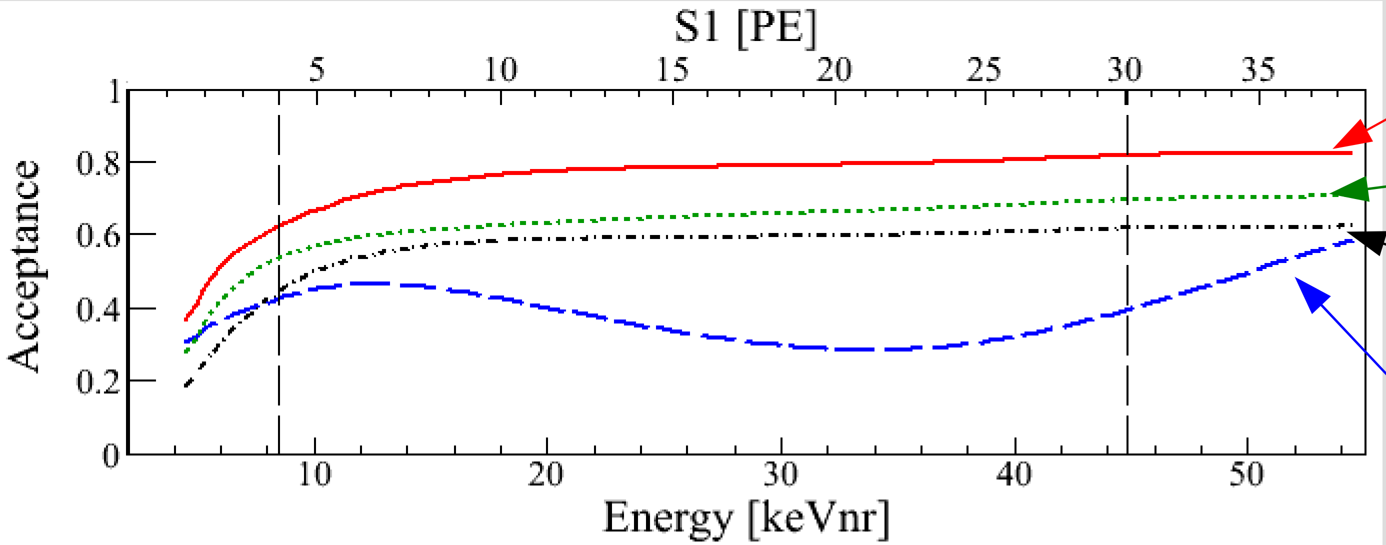
mχ=10 GeV/c²

mχ=7 GeV/c²

acceptance of 99.75% discrimination cut



Acceptance



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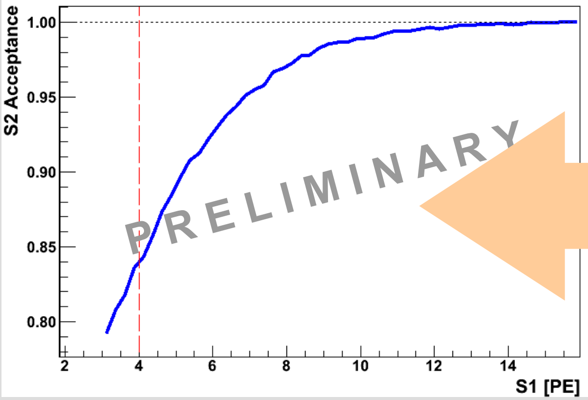
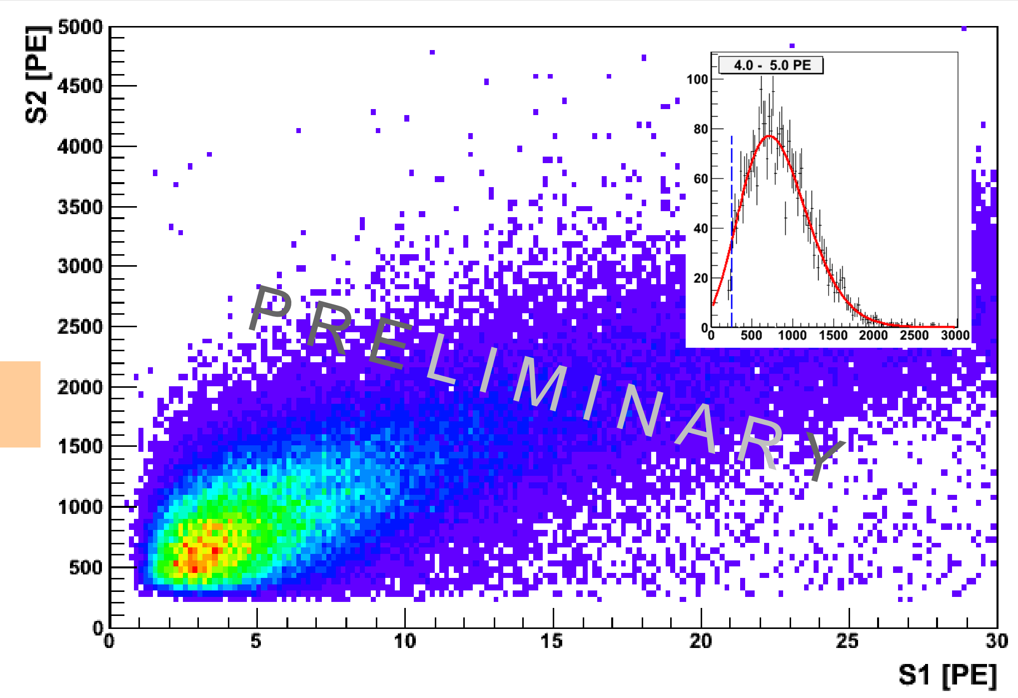
$m_\chi = 7$ GeV/c²

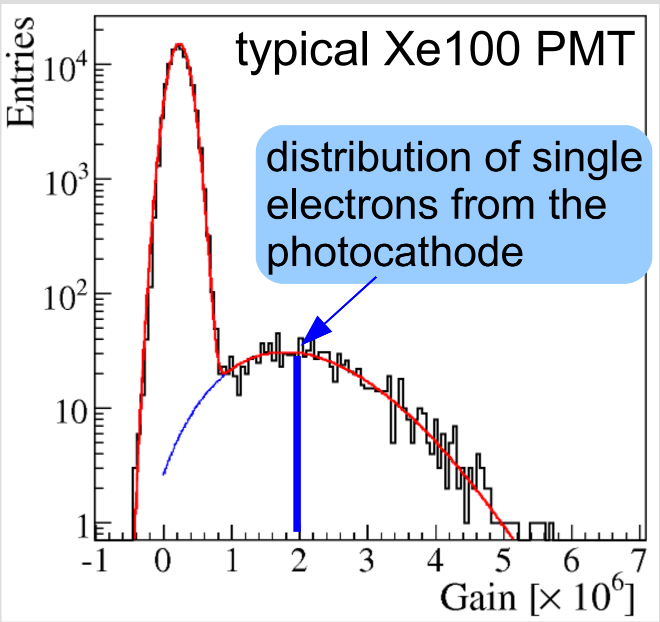
acceptance of 99.75% discrimination cut

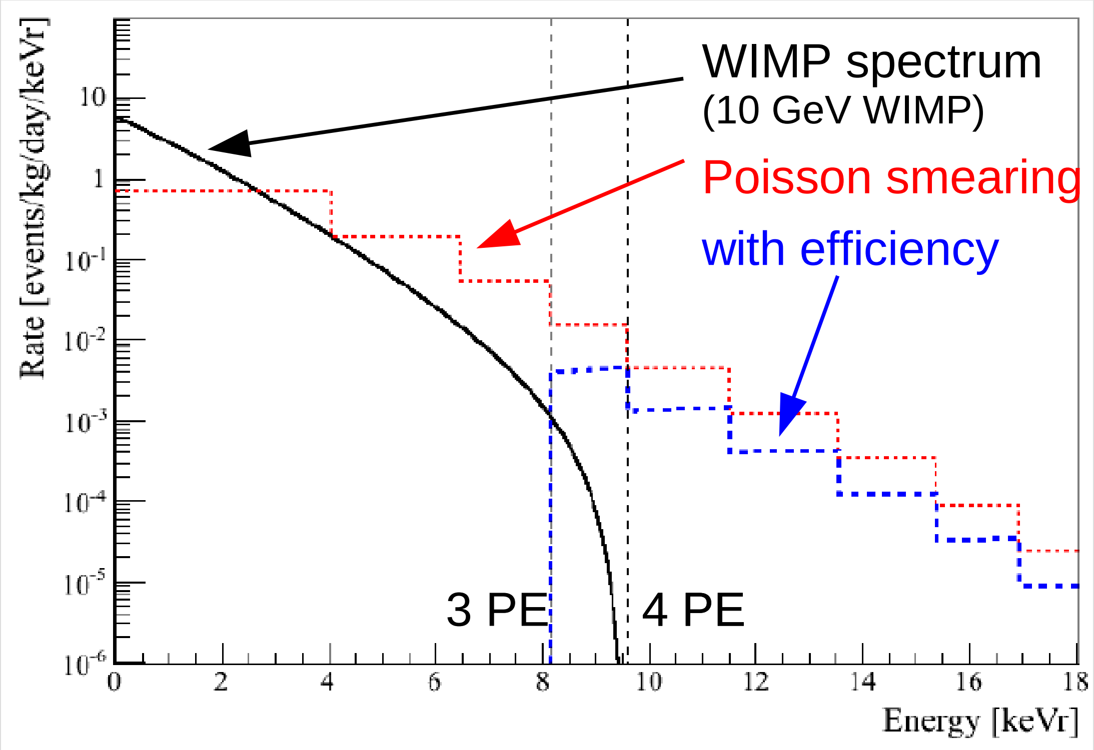
Determination of the S2>300 PE Acceptance:





Poisson Smearing



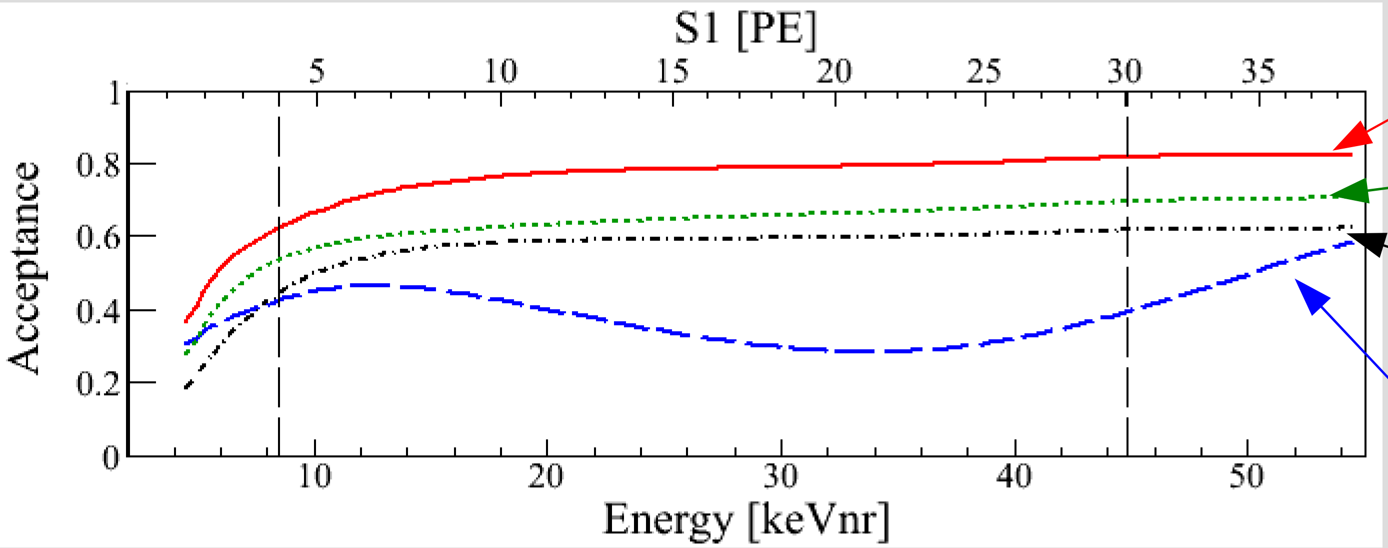


Resolution at low *E* is dominated by Poisson counting statistics
➡ a few photoelectrons seen by PMTs

WIMP spectrum is expected to drop exponentially with *E*
➡ more events make it above threshold than vice versa

All other contributions to the energy resolution (interaction in LXe etc.) are ignored.

Acceptance



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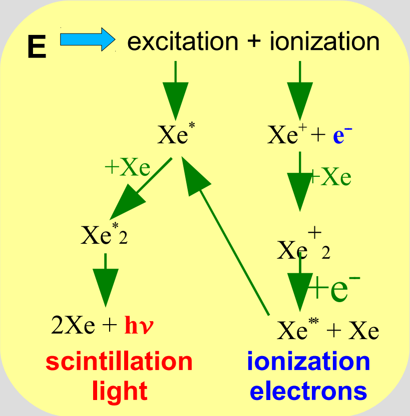
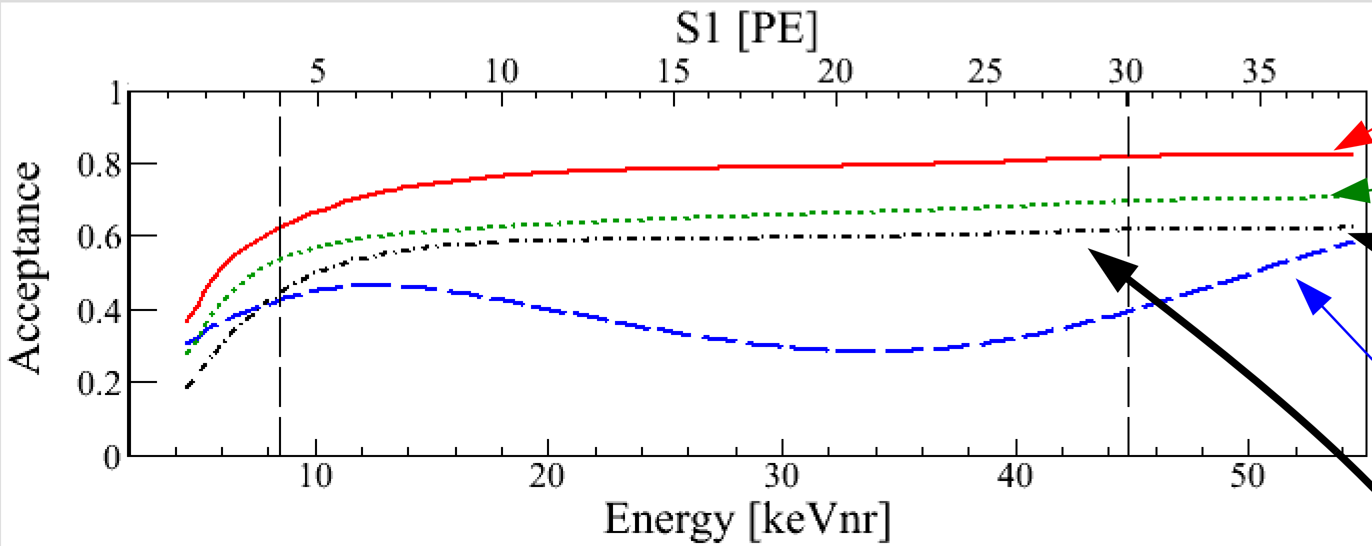


the two signals are detected independently

Acceptance



Cut Acceptance:

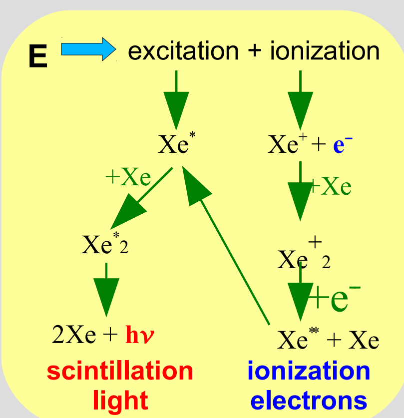
mχ≥50 GeV/c²

mχ=10 GeV/c²

mχ=7 GeV/c²

acceptance of 99.75% discrimination cut

spectrum is multiplied with acceptance and smeared with Poisson distribution



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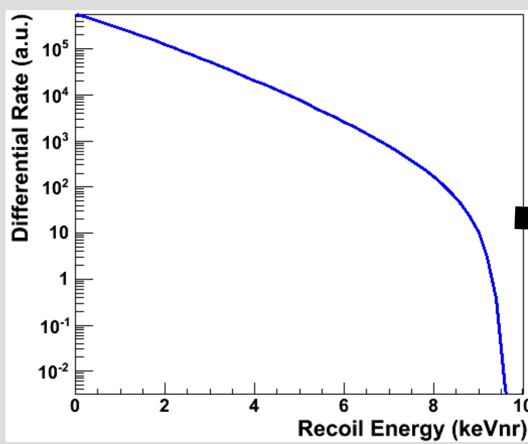
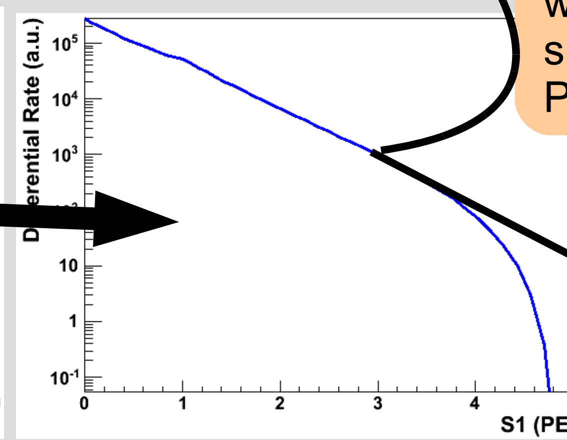
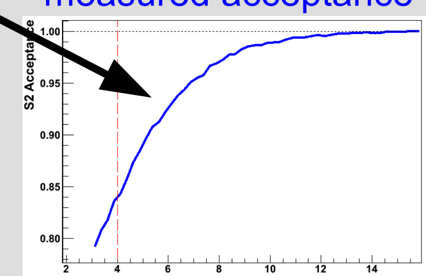


expected spectrum of a *X* GeV/c² WIMP



converted into the S1 light signal (before Poisson!)

measured acceptance



Background Prediction

Expected Background for

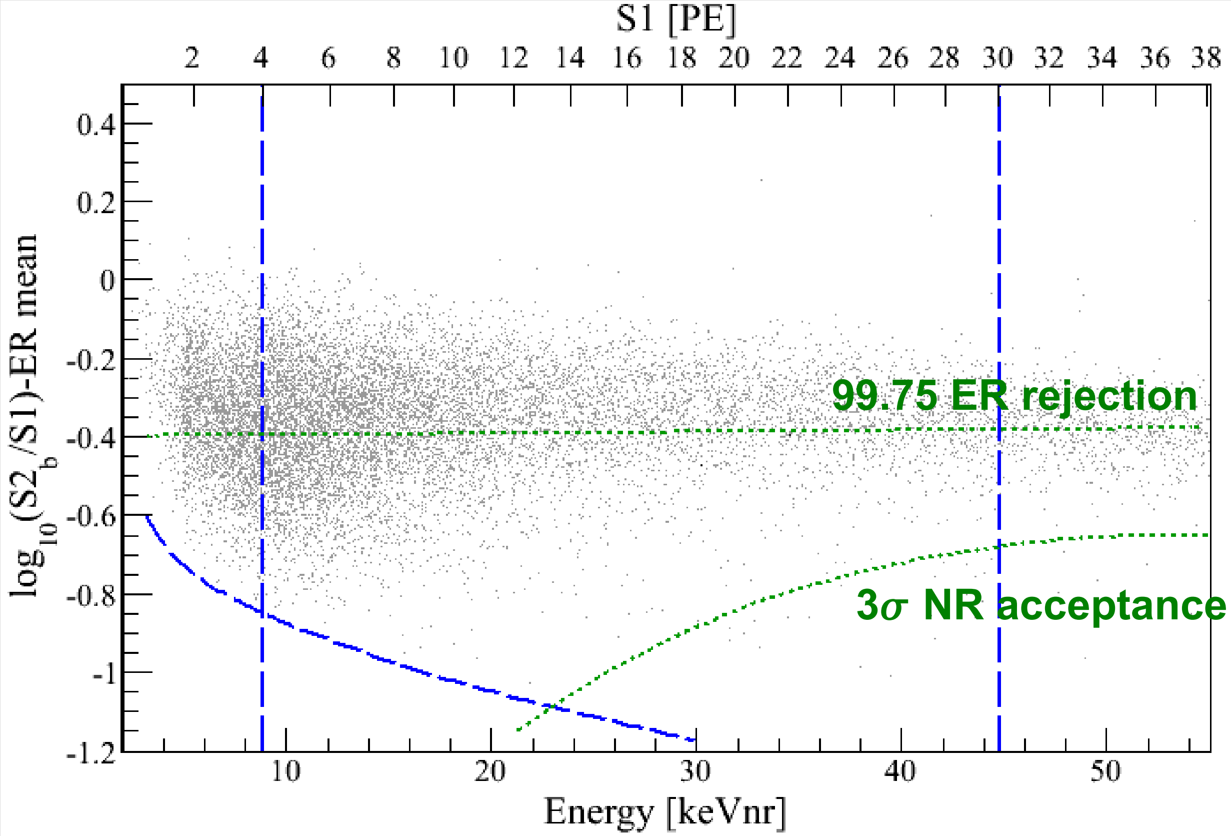
- 48 kg fiducial mass
- 100.9 live days
- 99.75% ER rejection

Gaussian Leakage:
1.14 ± 0.48

Anomalous Leakage:
0.56 ± 0.25

Neutron Background:
0.11 ± 0.08

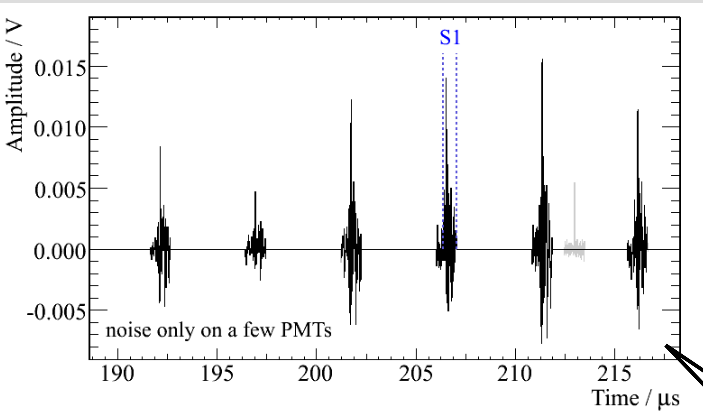
1.8 ± 0.6 events



➡ prediction based on data and MC

➡ prediction verified on high *E* sideband

Unblinding



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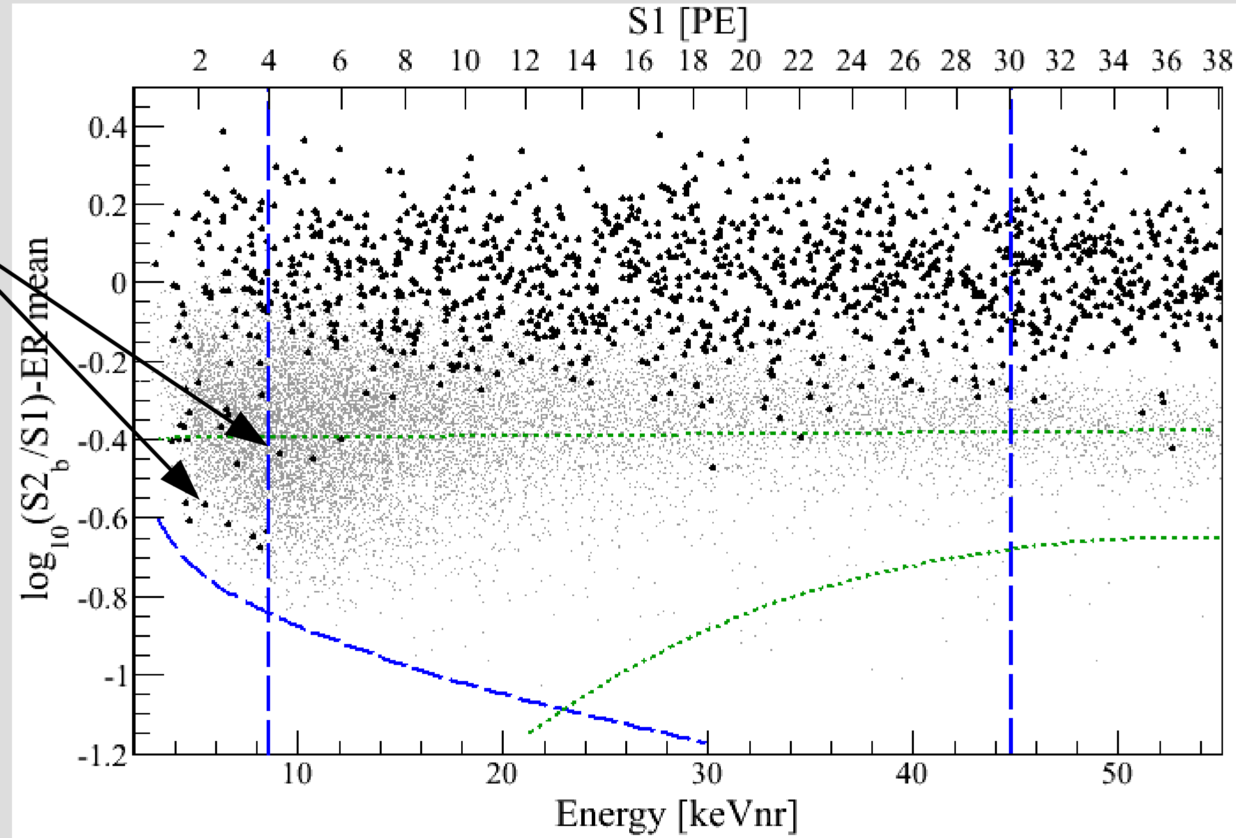
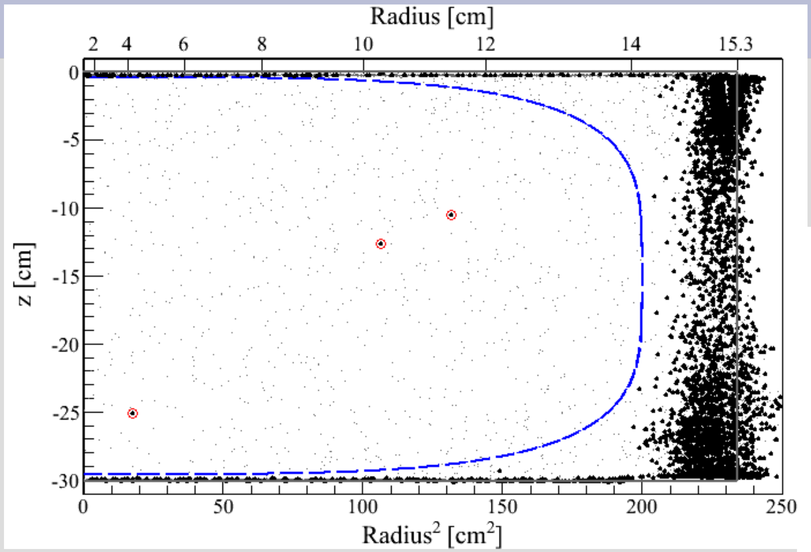


Population of noise events at threshold
➡ Some leak into WIMP search region
➡ Post-unblinding cut removes noise population

Result



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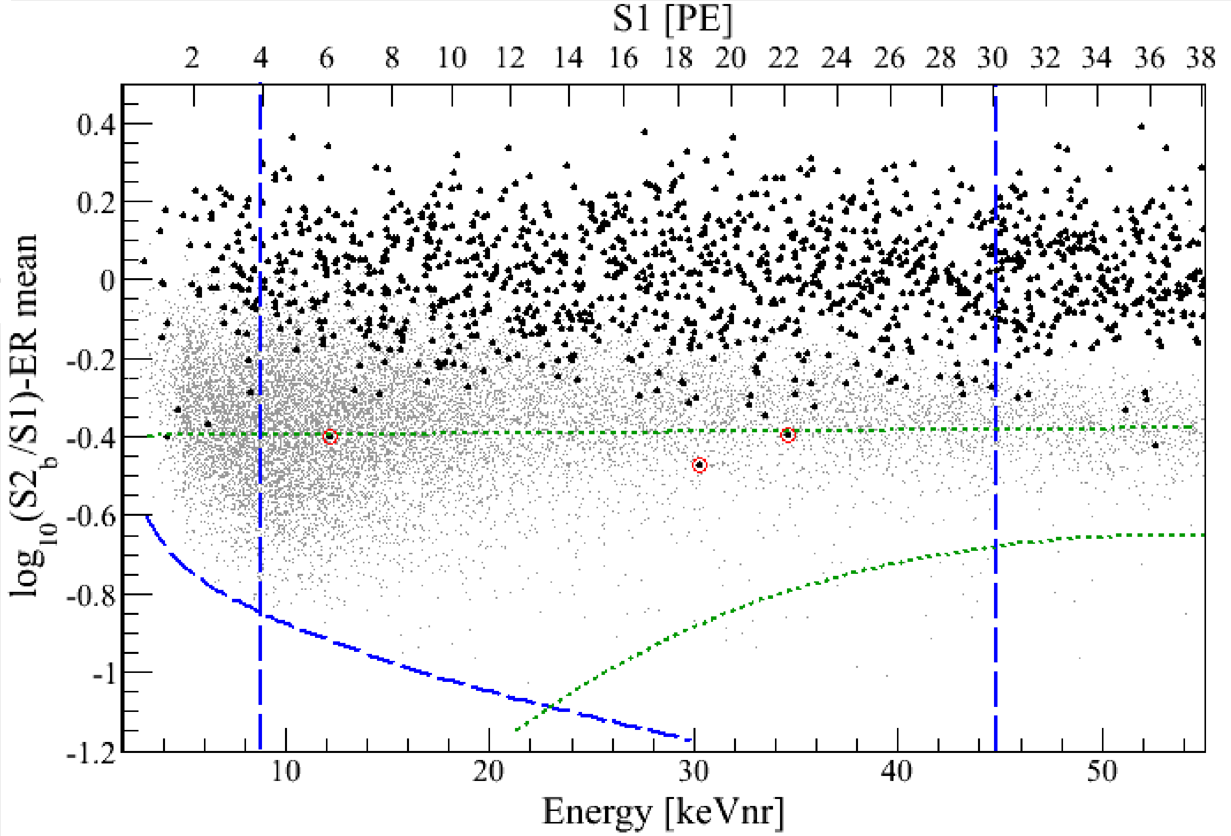
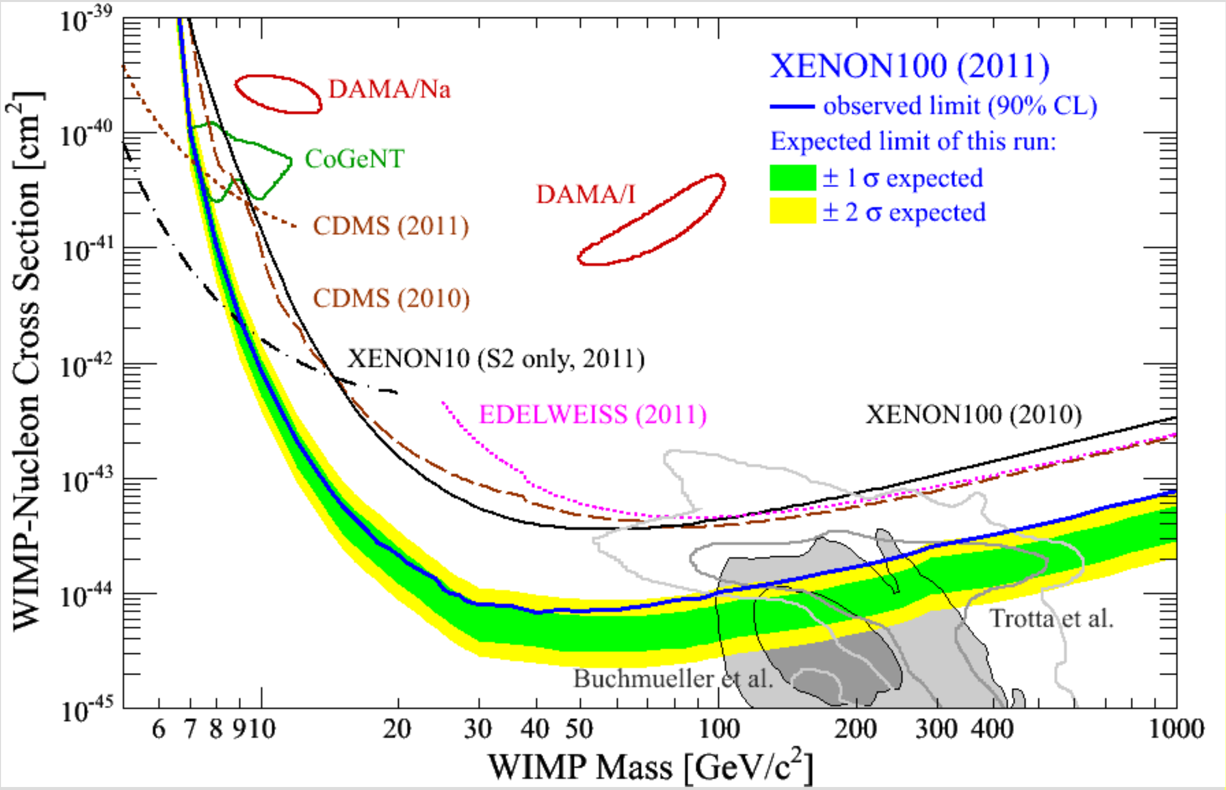


Observe 3 events

➡ likelihood for 3 or more events is 28%

➡ Profile Likelihood analysis does not yield significant signal ➡ calculate limit

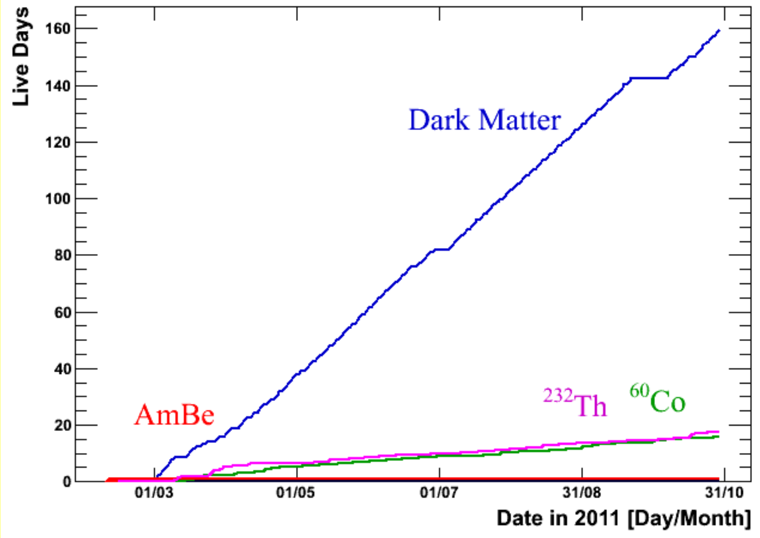
(spin-independent) WIMP Limit



PRL 107, 131302 (2011)

Limit derived with
Profile Likelihood method
PRD 84, 052003 (2011)

Detector is operational
with lower background level
and lowered trigger threshold



XENON100 sets the most sensitive
limit over a large WIMP mass range

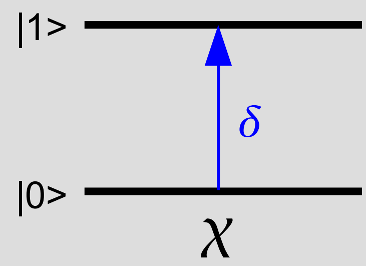
Challenges the CoGeNT, DAMA, CRESST-II
signals as being due to light mass WIMPs

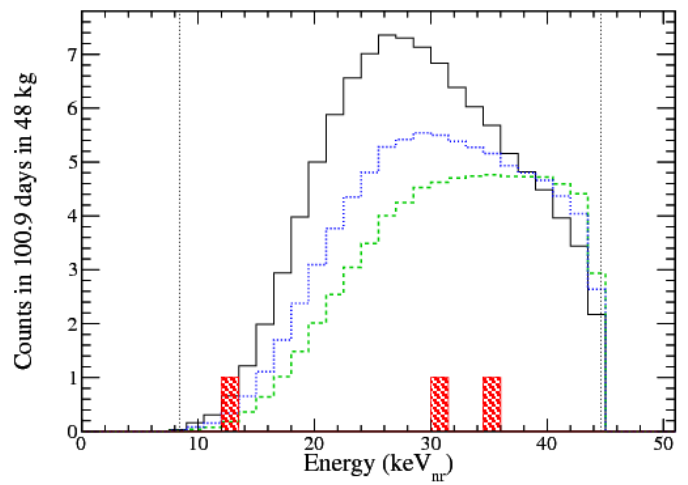
Inelastic Dark Matter

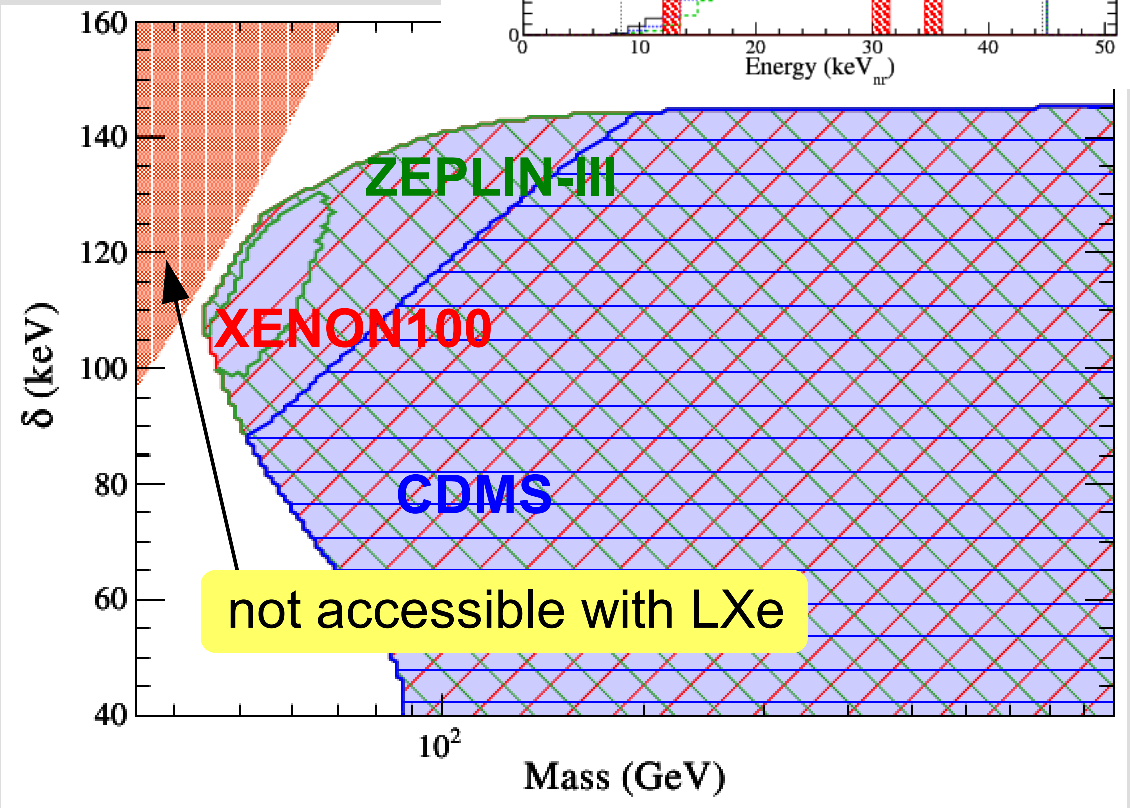
- Inelastic Dark Matter (IDM): tries to reconcile the result from DAMA with other expts
  Phys. Rev. D64, 043502 (2001)
- Dark Matter particle has an excited state, with an energy splitting δ

  → now: (m_χ, σ, δ)

  WIMP-nucleon interactions excite the WIMP, elastic scattering forbidden
  ➡ rate peaks at higher *E*
- XENON100 excludes the IDM interpretation of the DAMA result at 90% CL
  (scattering off I an Na)

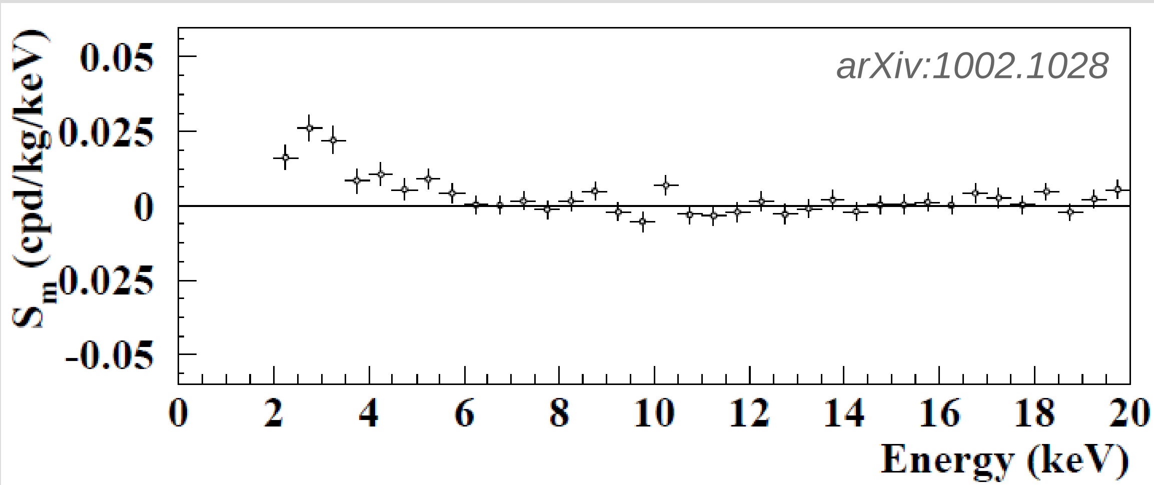




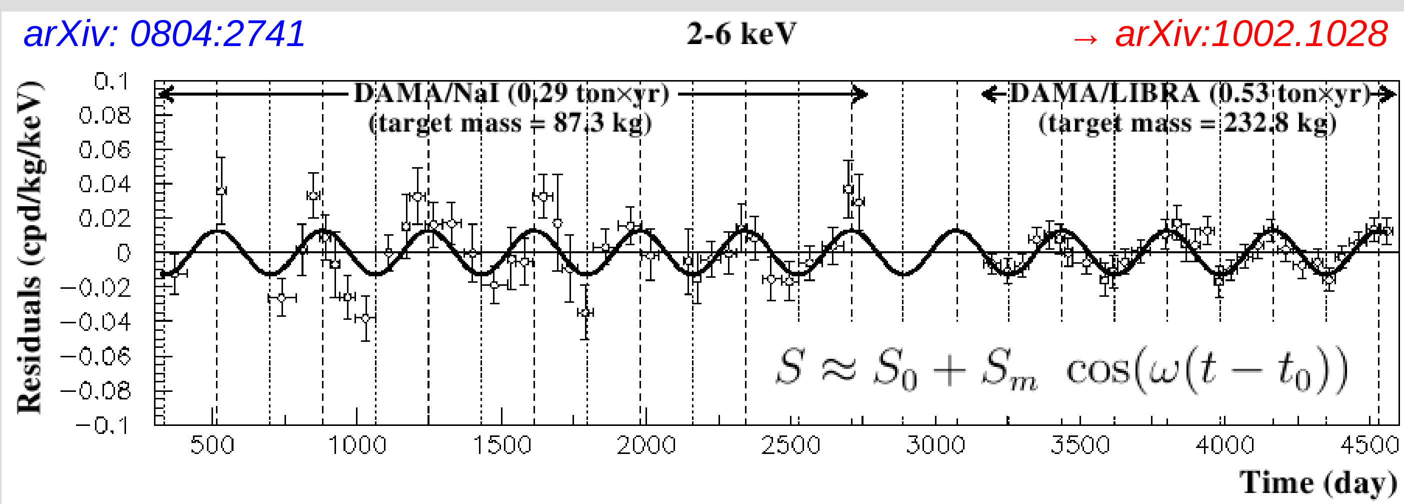


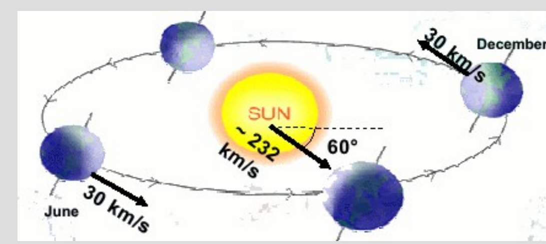
PRD 84, 061101 (2011)

Back to DAMA/Libra

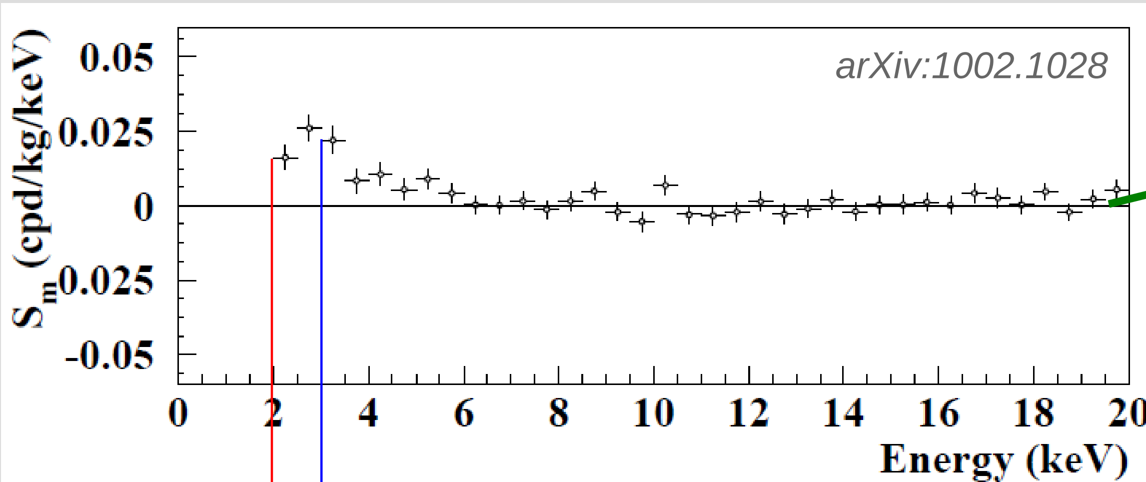


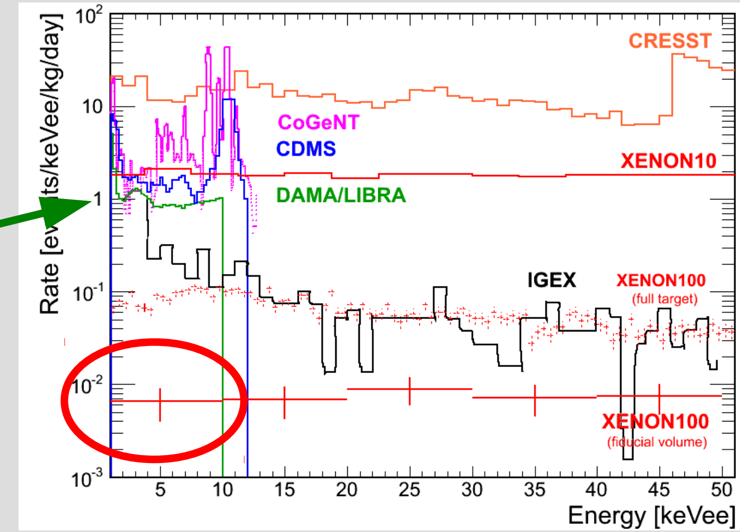
NaI(Tl) crystals at LNGS
annual modulation at 8.9σ





Back to DAMA/Libra





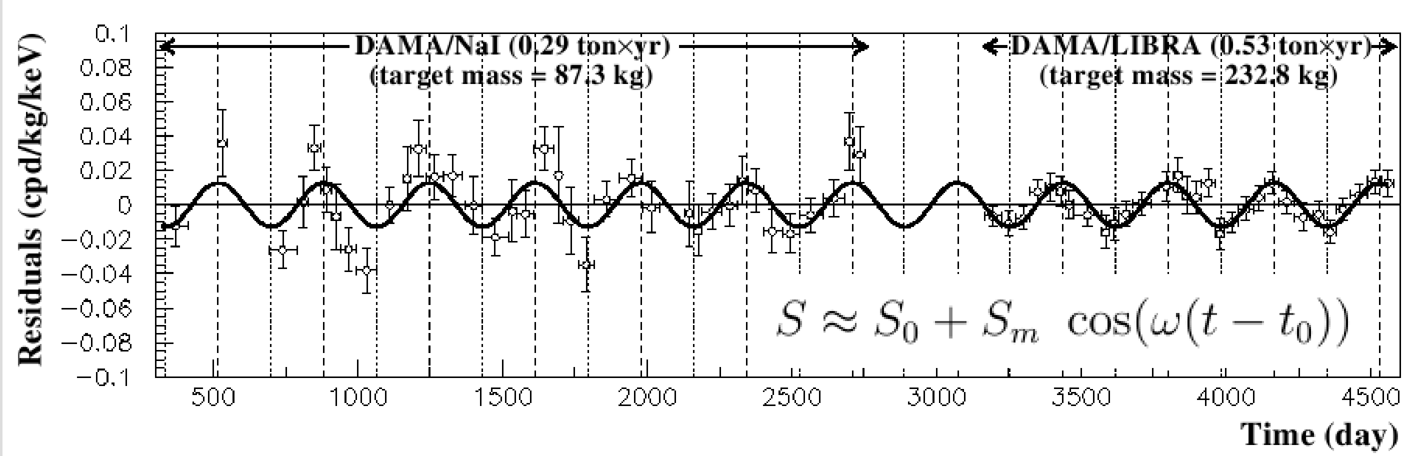
~6.7 keVr (Na)
~22.2 keVr (I)

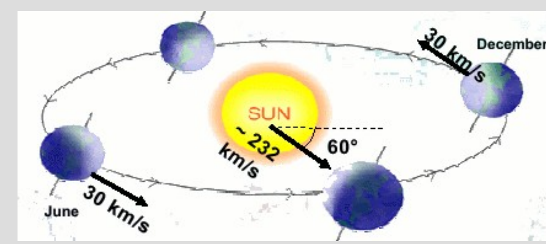
~10.0 keVr (Na)
~33.3 keVr (I)

„model independent“ comparison?
XENON modulation analysis?

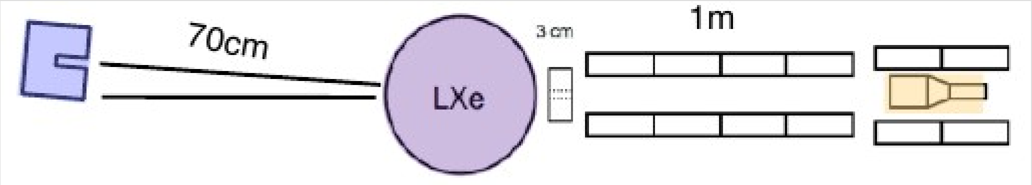
arXiv: 0804:2741

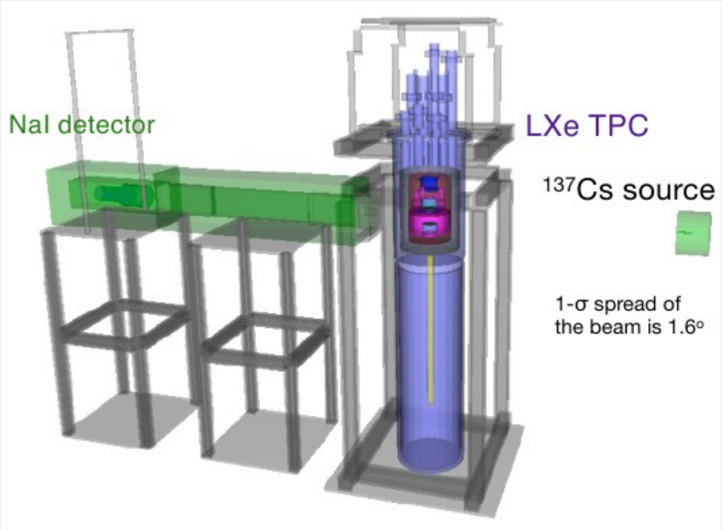
→ arXiv:1002.1028



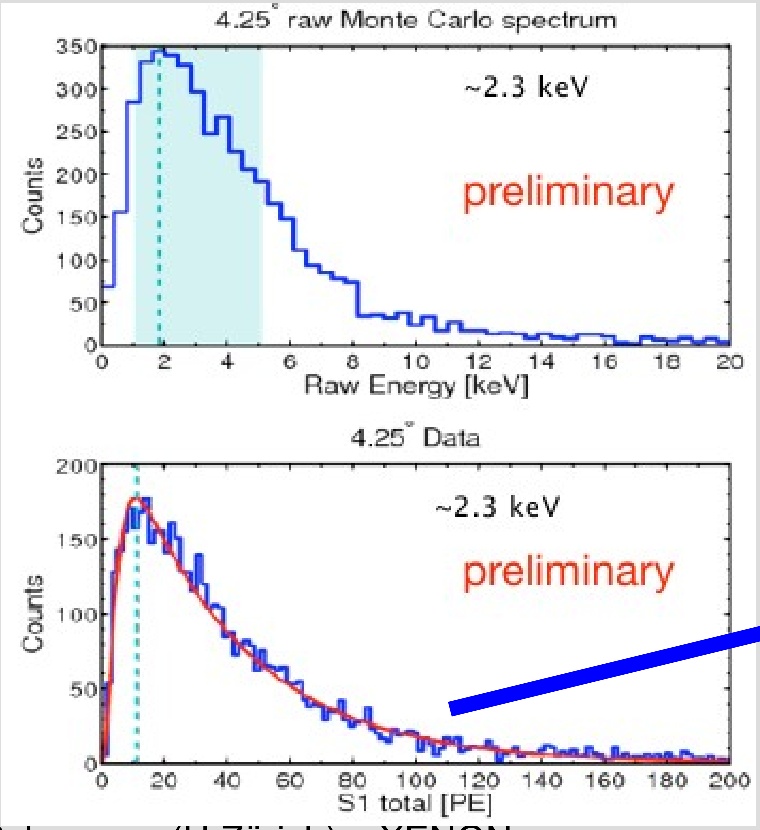


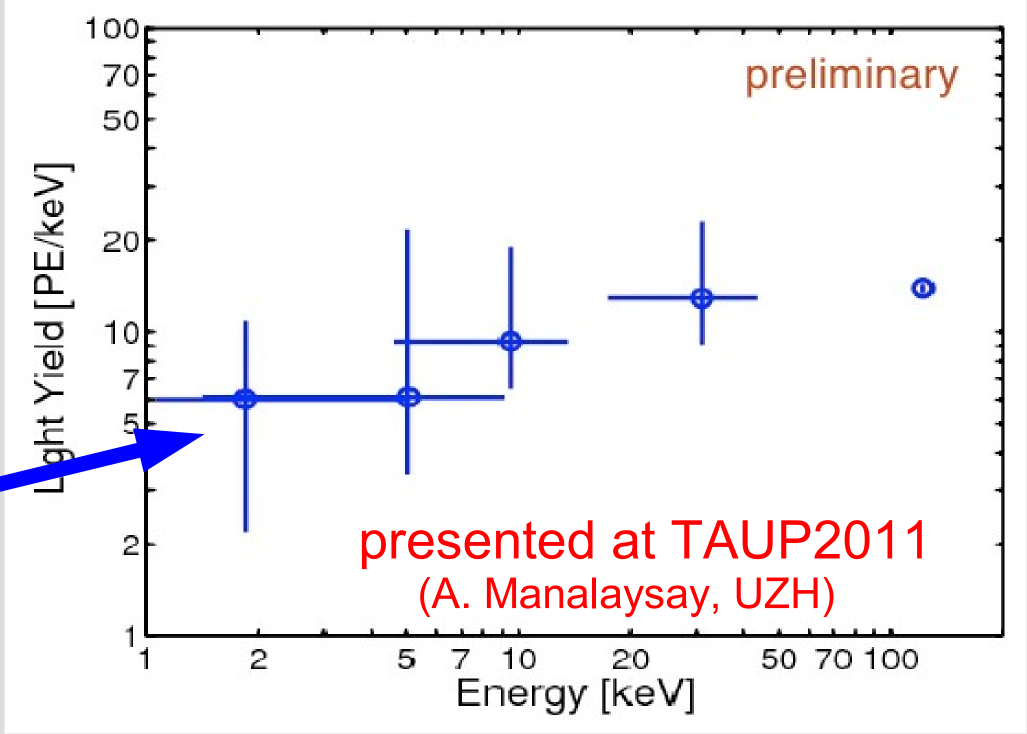
Low Energy Response to ER





Compton Scatter Measurement in Zürich indicates that LXe „sees“ electronic recoil interactions around ~2.3 keV (at zero-field)





Outline

Motivation: Dark Matter ✓

WIMP Search with Xenon ✓

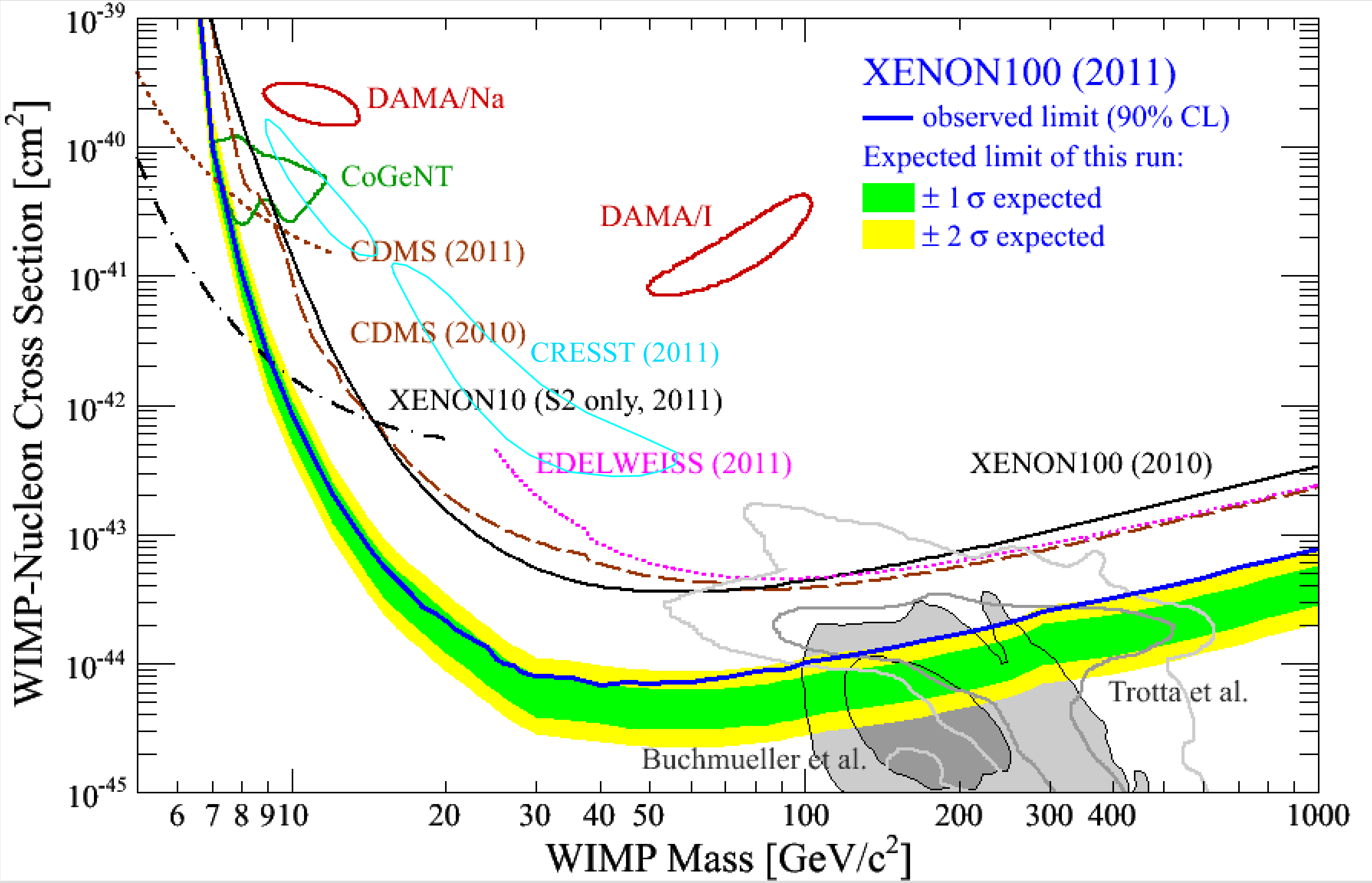
XENON100 ✓

The new Results ✓

Some Comments

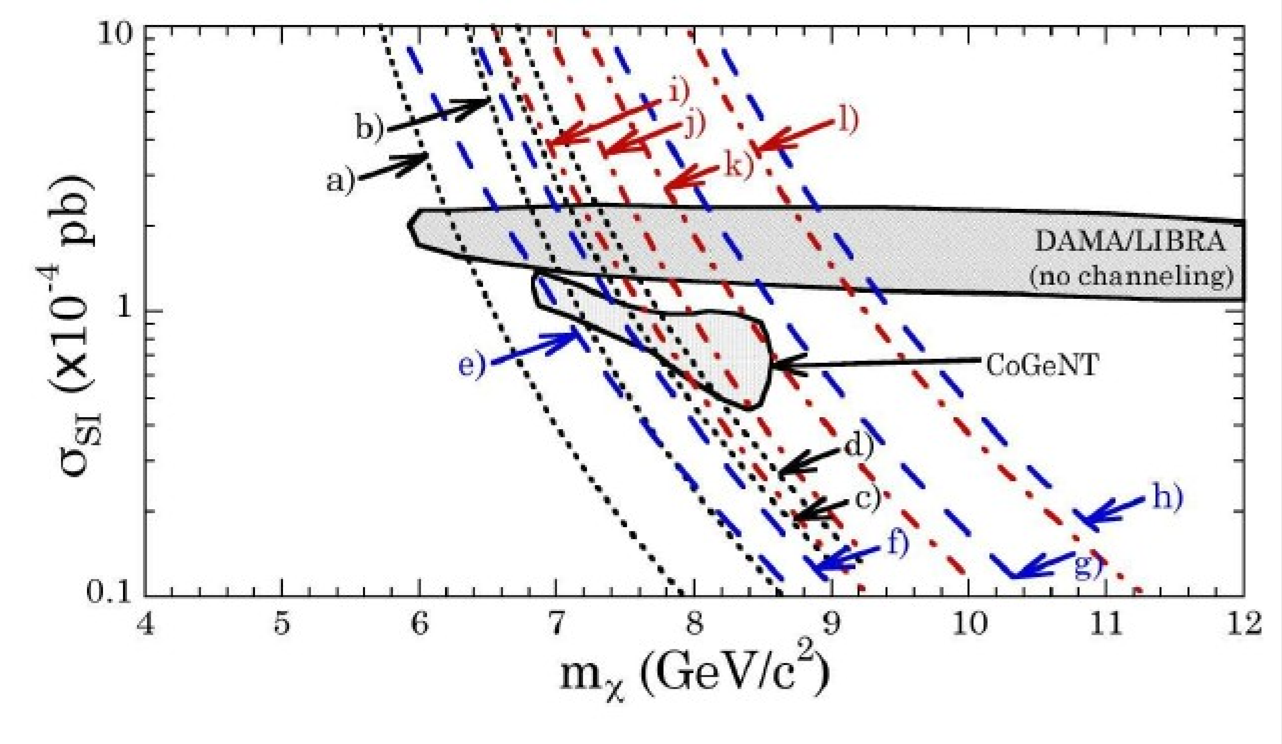
Presence and Future

The current WIMP landscape



Criticism or Confusion?

J. Collar, arXiv:1106.0653



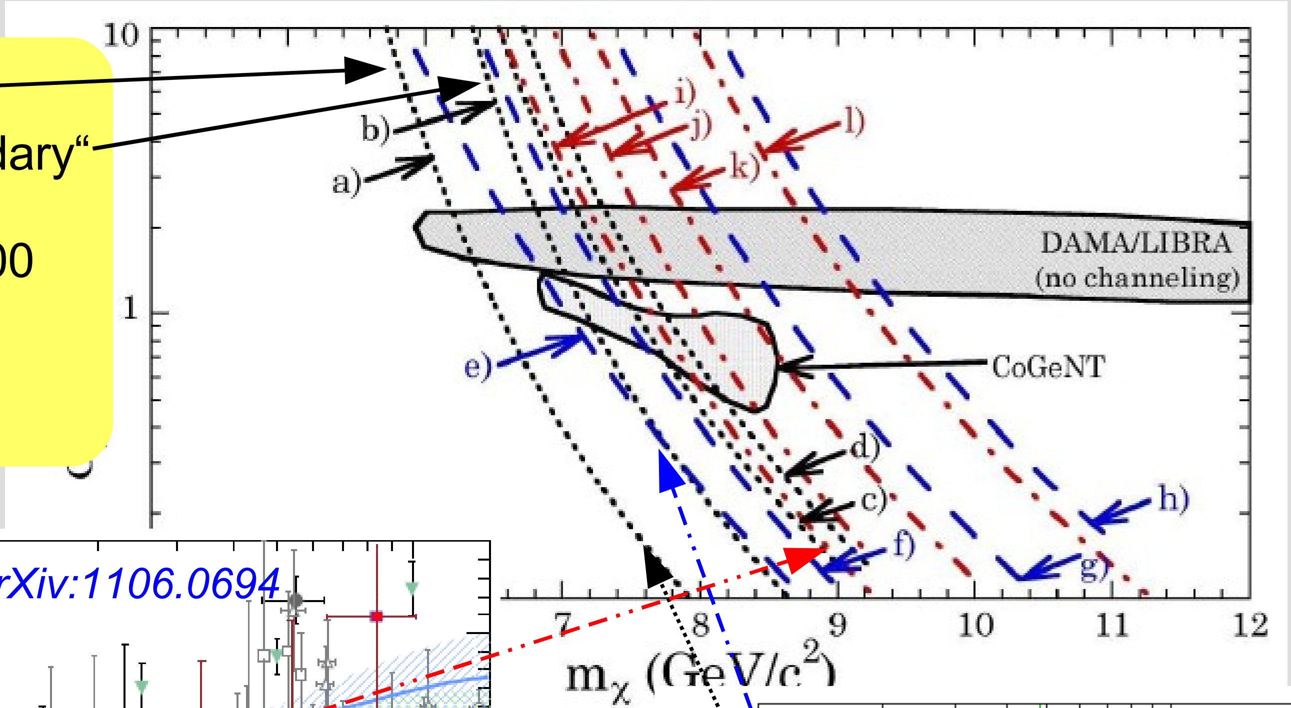
Criticism or Confusion?

J. Collar, arXiv:1106.0653

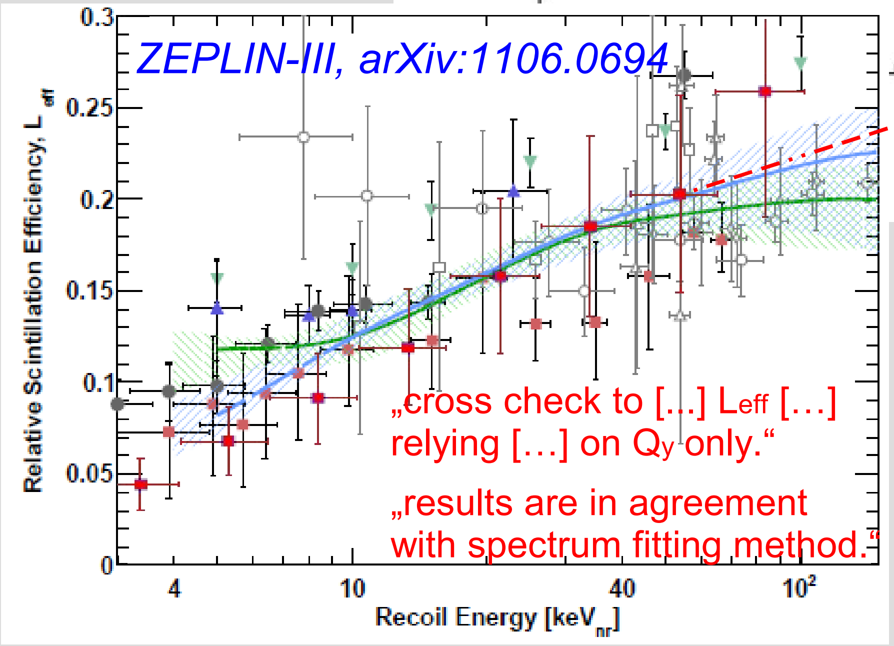
„Central value“

„lower 2σ boundary“

BUT: XENON100 quotes real 90% CL limit (including ΔLeff)

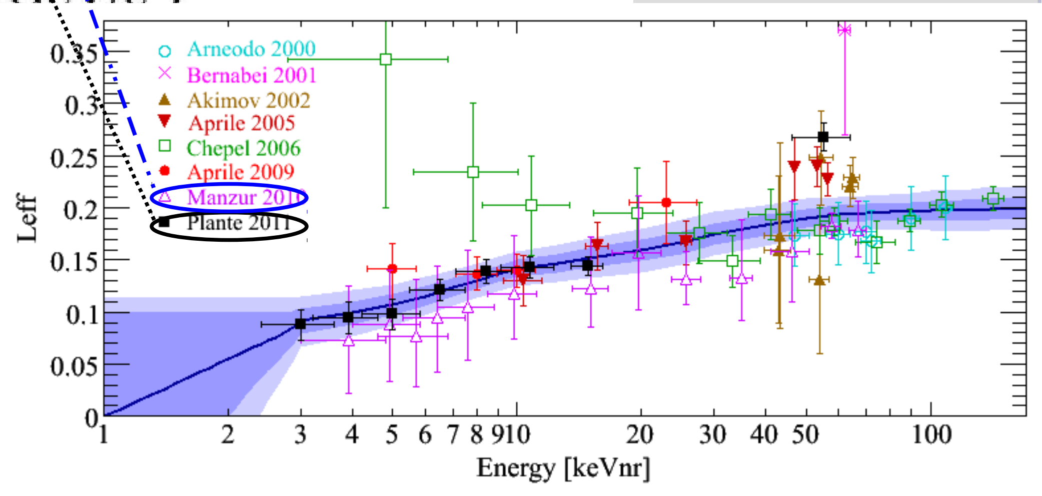


ZEPLIN-III, arXiv:1106.0694



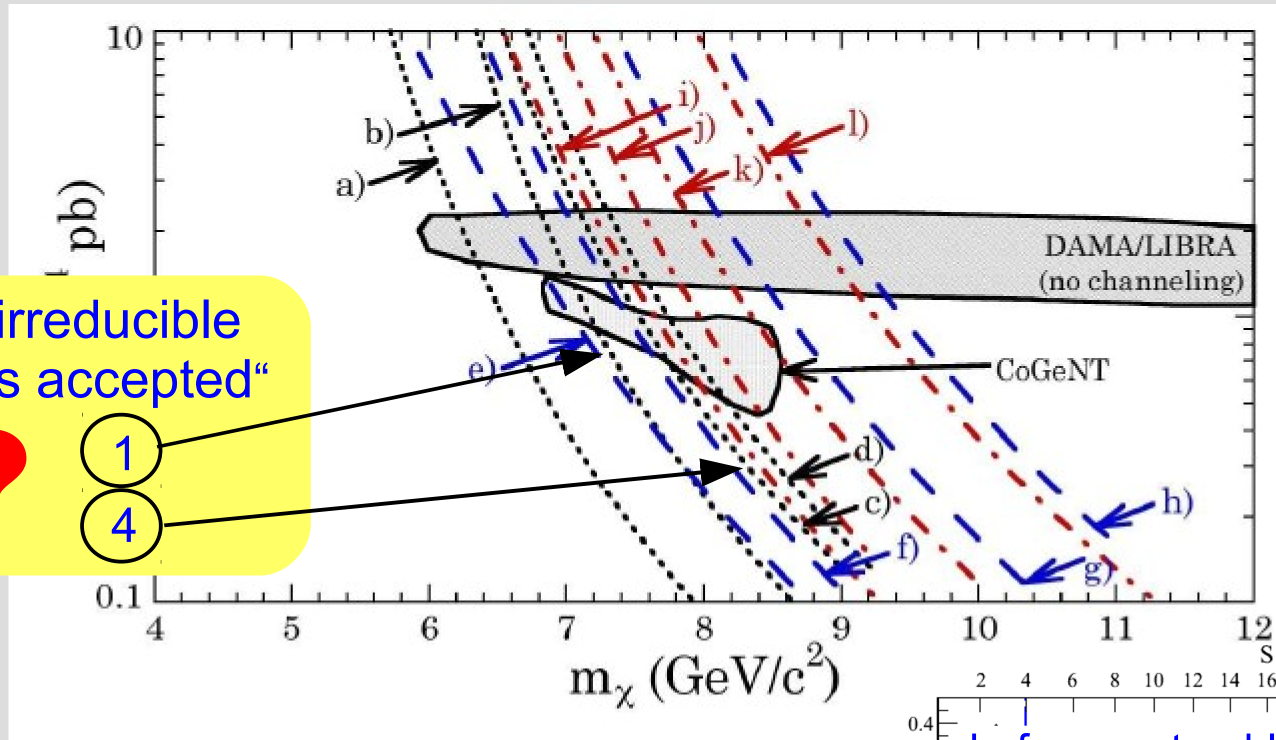
„cross check to […] Leff […] relying […] on Q_y only.“

„results are in agreement with spectrum fitting method.“



Criticism or Confusion?

J. Collar, arXiv:1106.0653



„number of irreducible recoil events accepted“

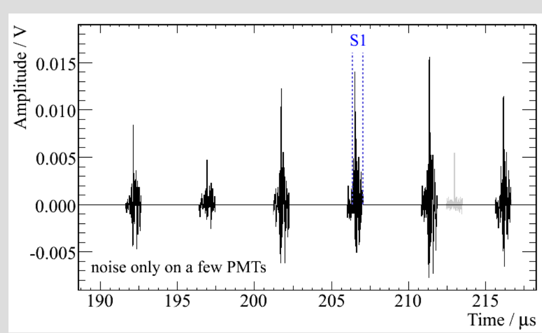
???

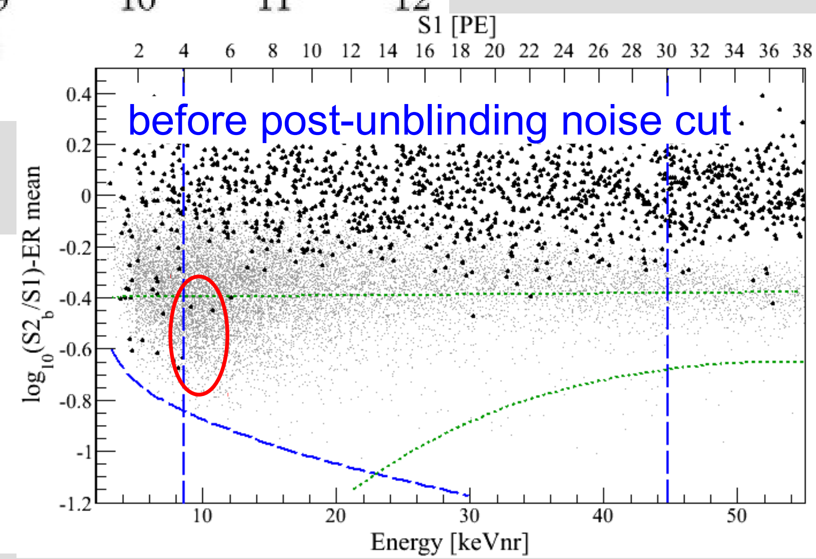
1

4

Electronic Noise:

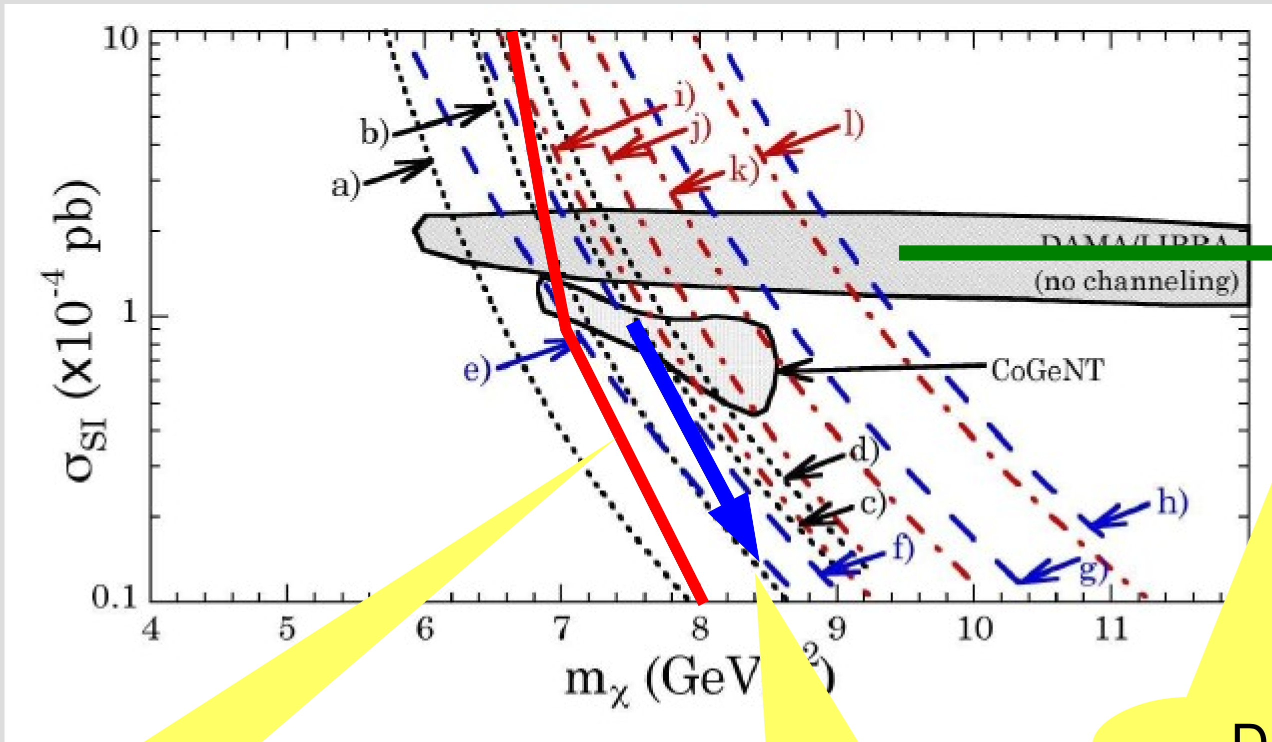
- on a few PMTs only
- periodic, correlated
- visible on dead channels!
- whole population rejected by post-unblinding cut





Criticism or Confusion?

J. Collar, arXiv:1106.0653

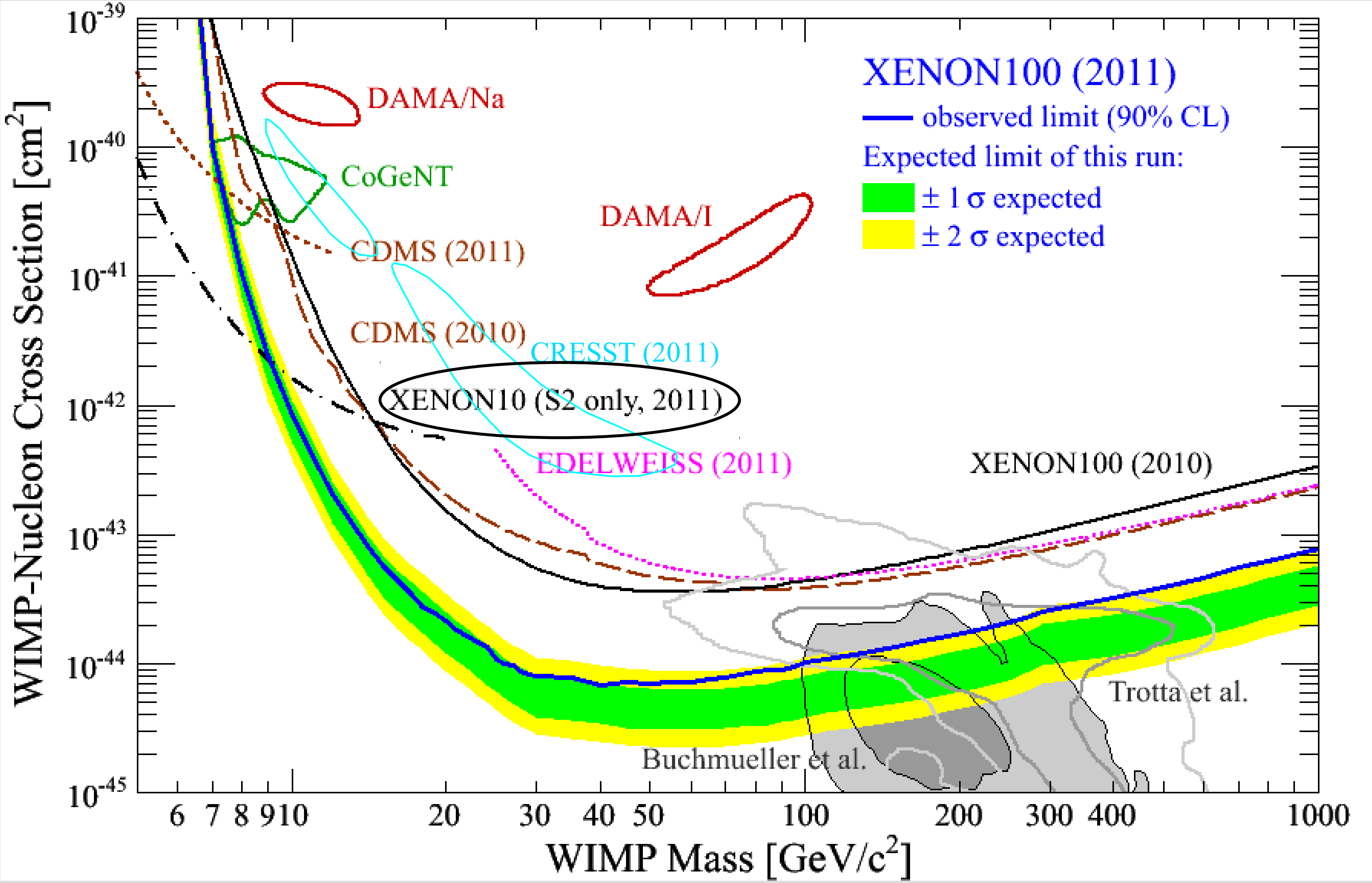


XENON100
published in PRL
PRL 107, 131302 (2011)

CoGeNT
Surface Background?
J. Collar, talk at TAUP
Kopp et al., arXiv:1110.2721
Kelso at al., arXiv:1110.5338

DAMA/Libra
NaI Quenching???
J. Collar, talk at TAUP
Kopp et al., arXiv:1110.2721
Kelso at al., arXiv:1110.5338

The current WIMP landscape



XENON10 „S2 only“ Analysis

PRL 107, 051301 (2011)

„standard“ two-phase TPC

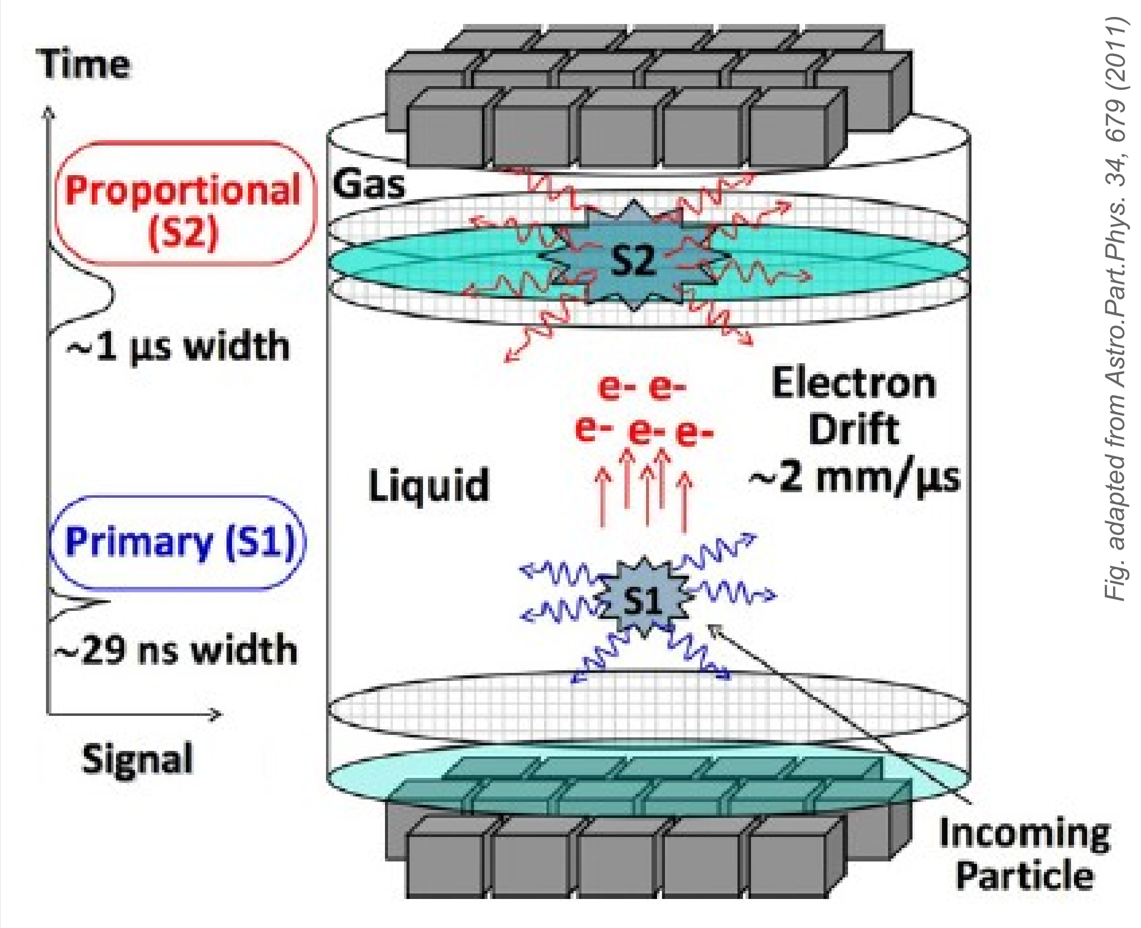
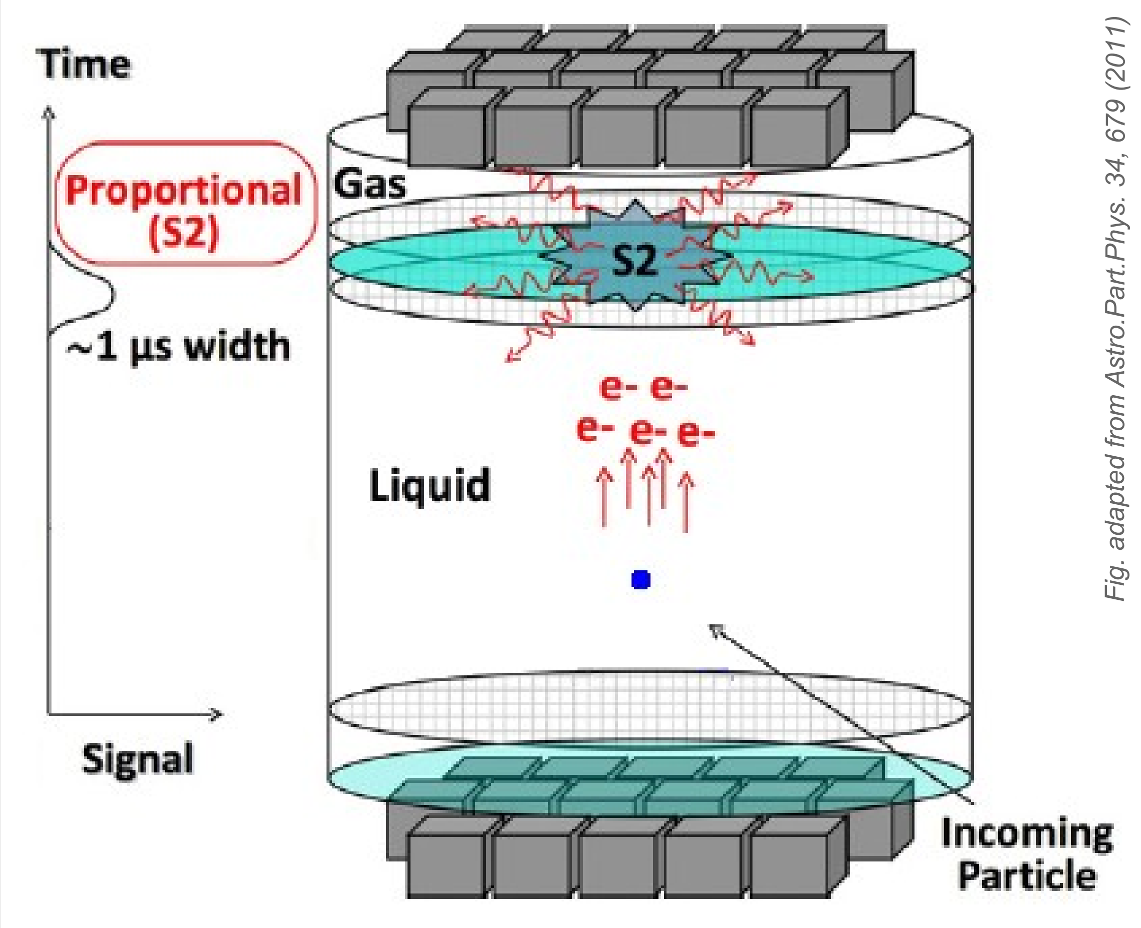


Fig. adapted from Astro.Part.Phys. 34, 679 (2011)

XENON10 „S2 only“ Analysis

PRL 107, 051301 (2011)

trade z-position+discrimination for lower threshold



XENON10 „S2 only“ Analysis

PRL 107, 051301 (2011)

trade z-position+discrimination for lower threshold

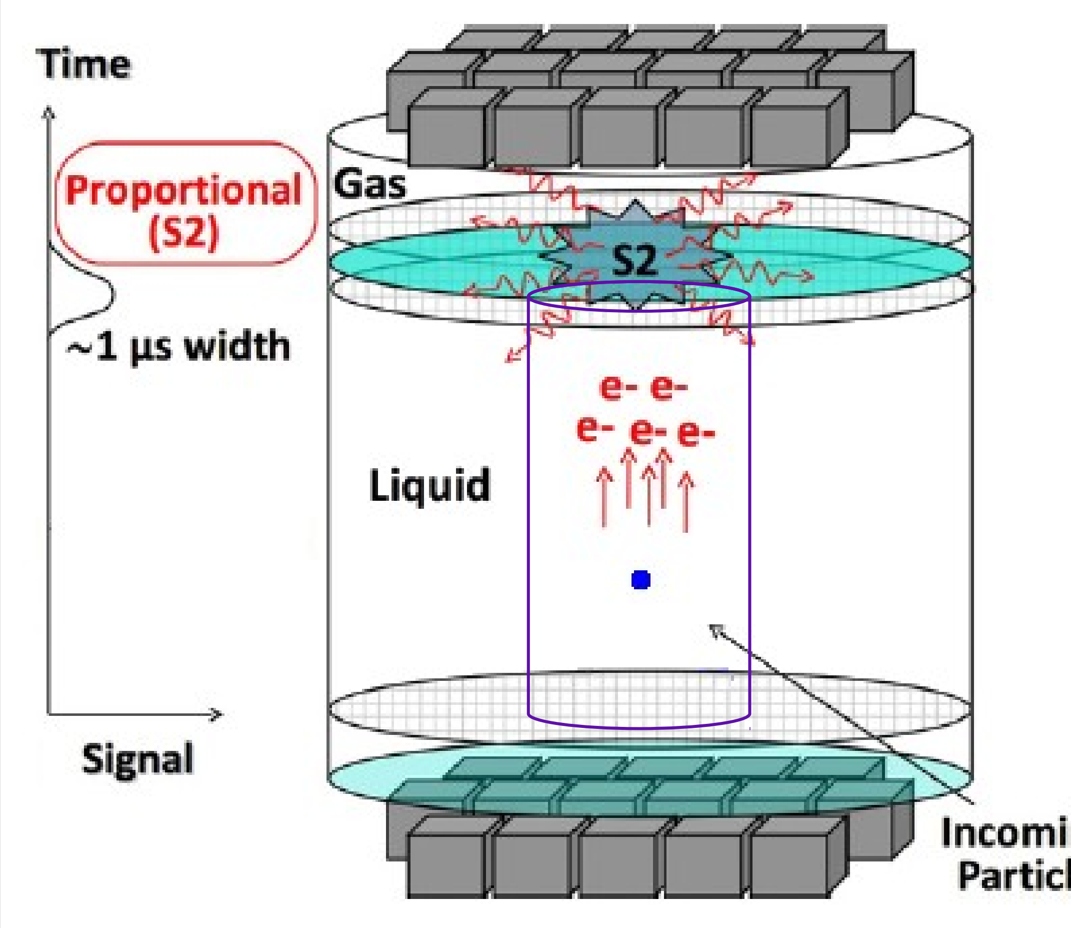


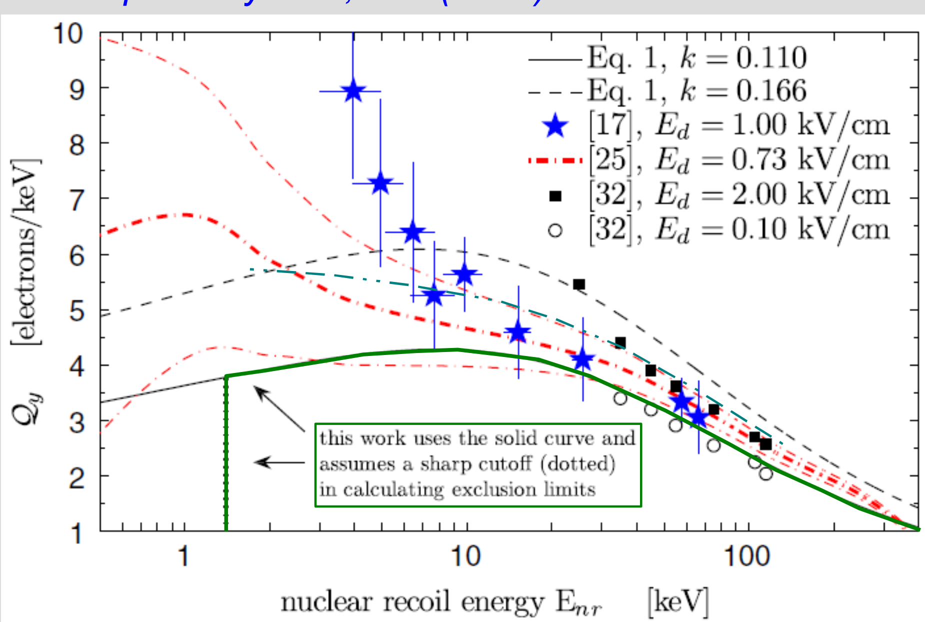
Fig. adapted from Astro.Part.Phys. 34, 679 (2011)

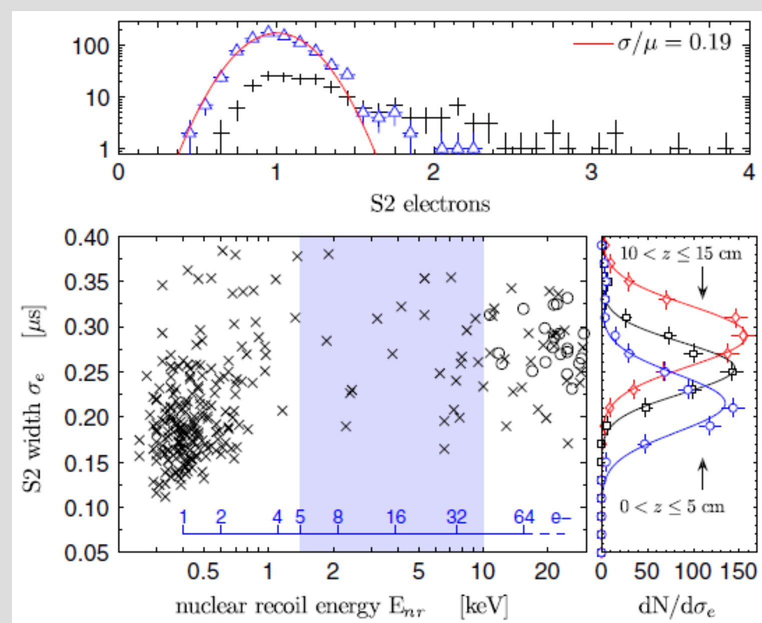
XENON10 „S2 only“ Analysis

PRL 107, 051301 (2011)

- 12.5d data from 2006
- trigger threshold at single electron level; data not used before
- require S2>5 e⁻ (~1.4 keV)
- radial cut r<3 cm, basically no z-cut → 1.2 kg
- choosing Q_y 40% higher (lower) would yield a 2x stronger (weaker) limit @ 7 GeV/c²

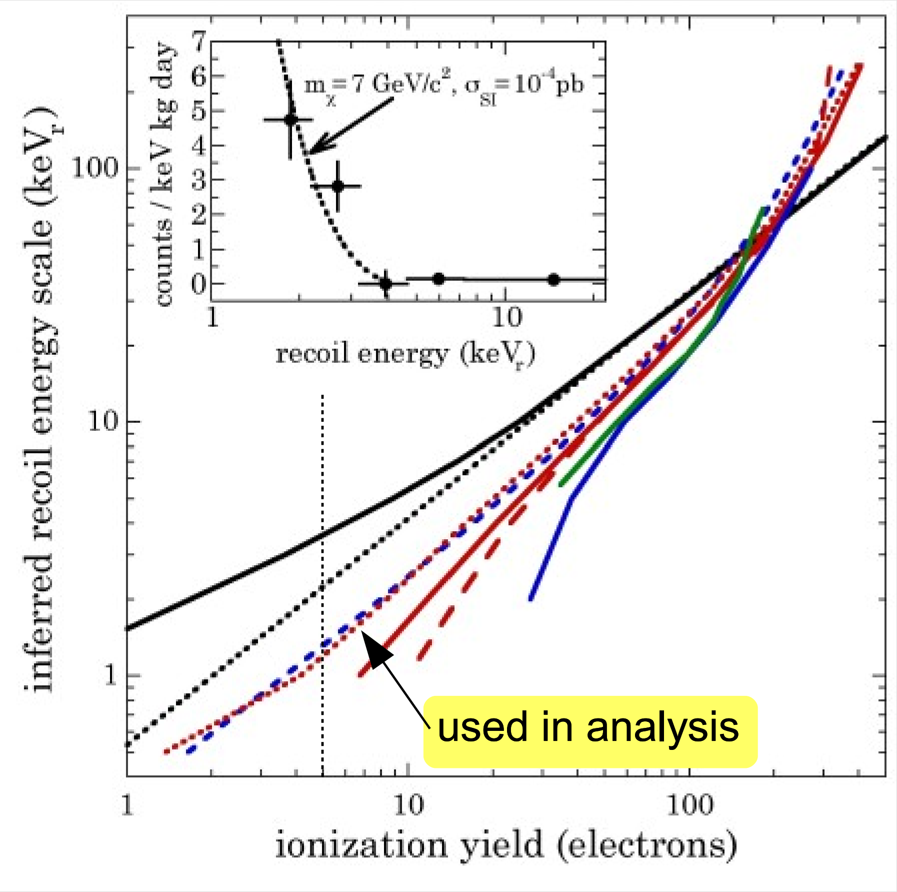
Models:
Sorensen/Dahl, PRD83, 063501 (2011)
Bezrukov et al., – – Astropart.Phys. 35, 119 (2011)





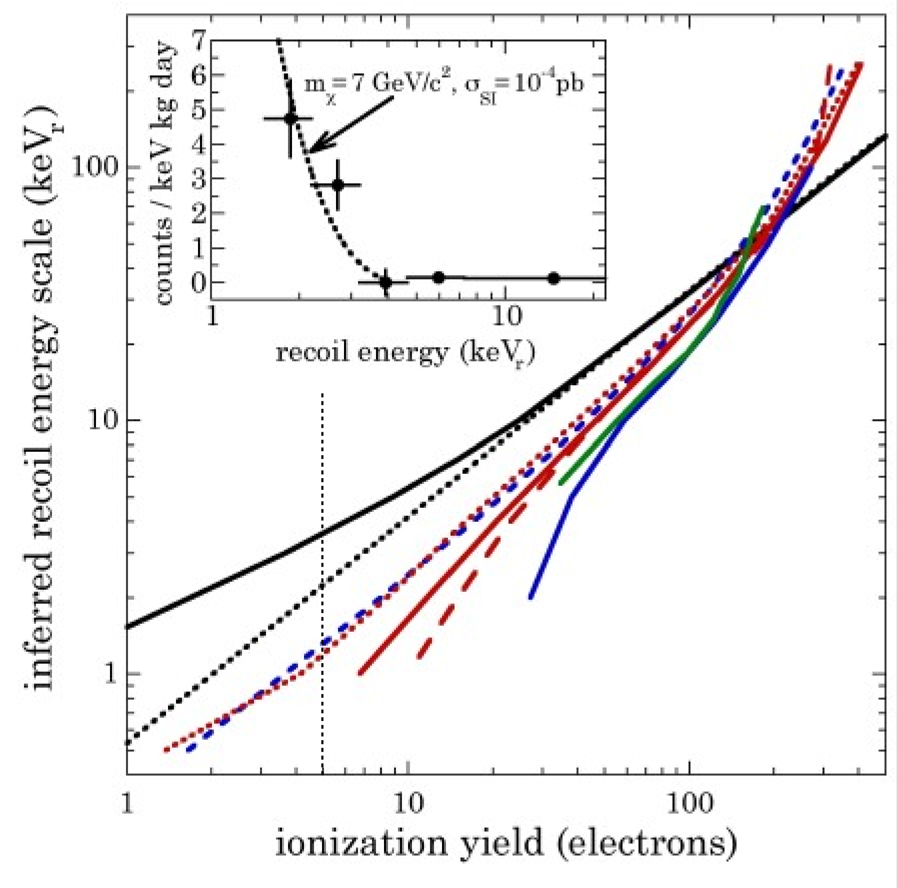
Criticism or Confusion?

J. Collar, arXiv:1106.0653

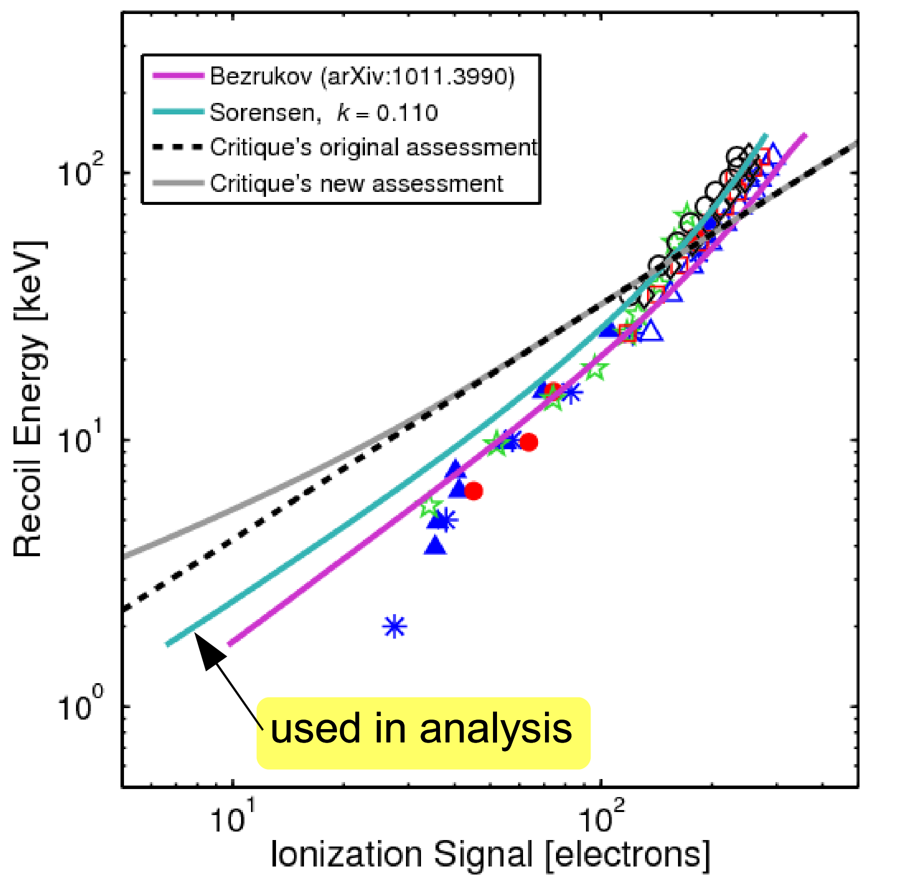


Criticism or Confusion?

J. Collar, arXiv:1106.0653

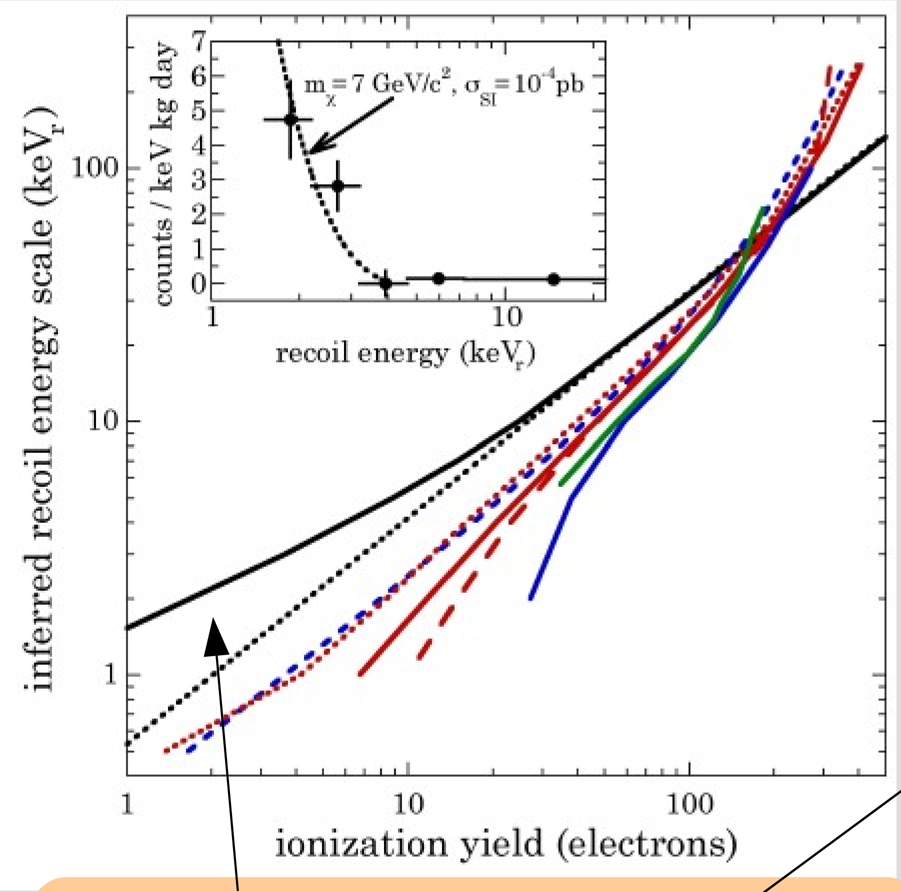


Let's add the datapoints...

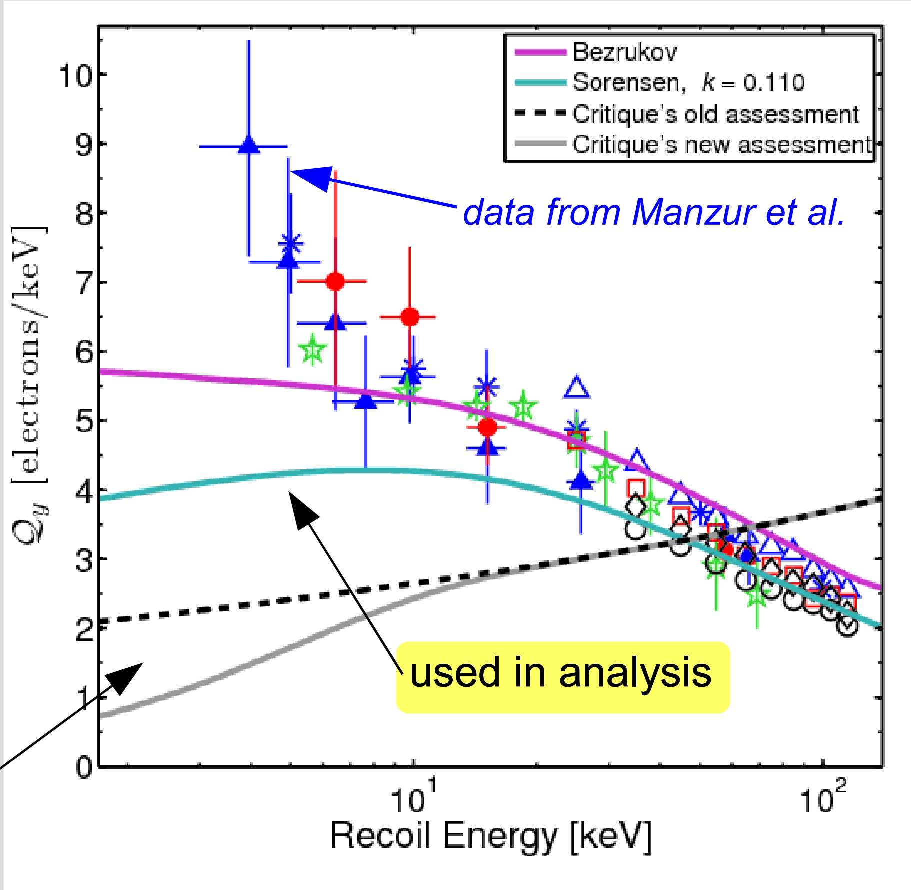


Criticism or Confusion?

J. Collar, arXiv:1106.0653



And put it in the usual style...



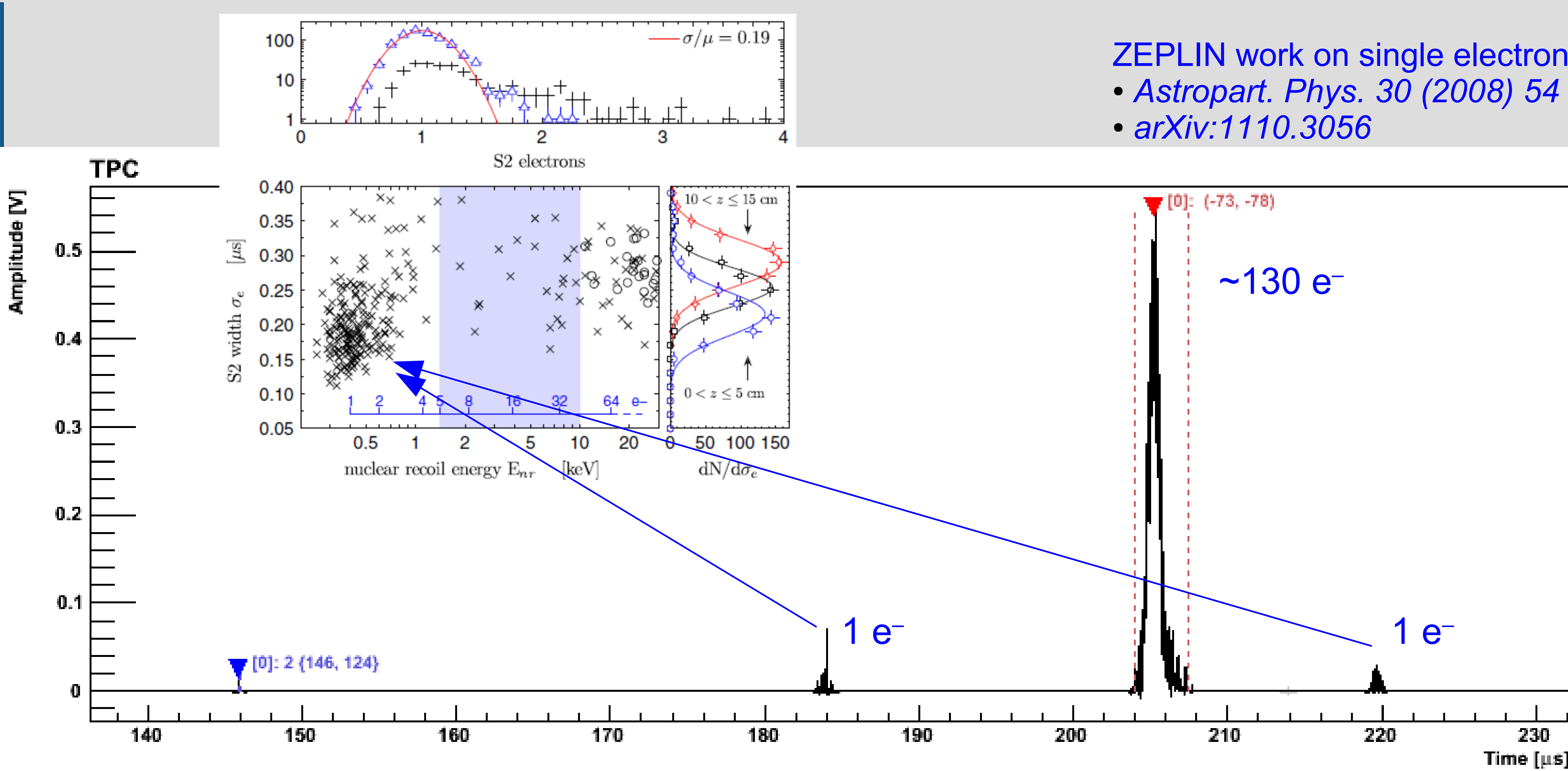
„Predictions“ are due to a mistake. Xenon is not Germanium! One has to consider the electron-ion recombination and the exciton to ion ratio, which vary with E.

Conclusion: only if Q_y is incompatible with data and theoretical understanding one can avoid the XENON10 contraints.

Criticism or Confusion?

XENON
Dark Matter Project

ZEPLIN work on single electrons:
- *Astropart. Phys. 30 (2008) 54*
- *arXiv:1110.3056*



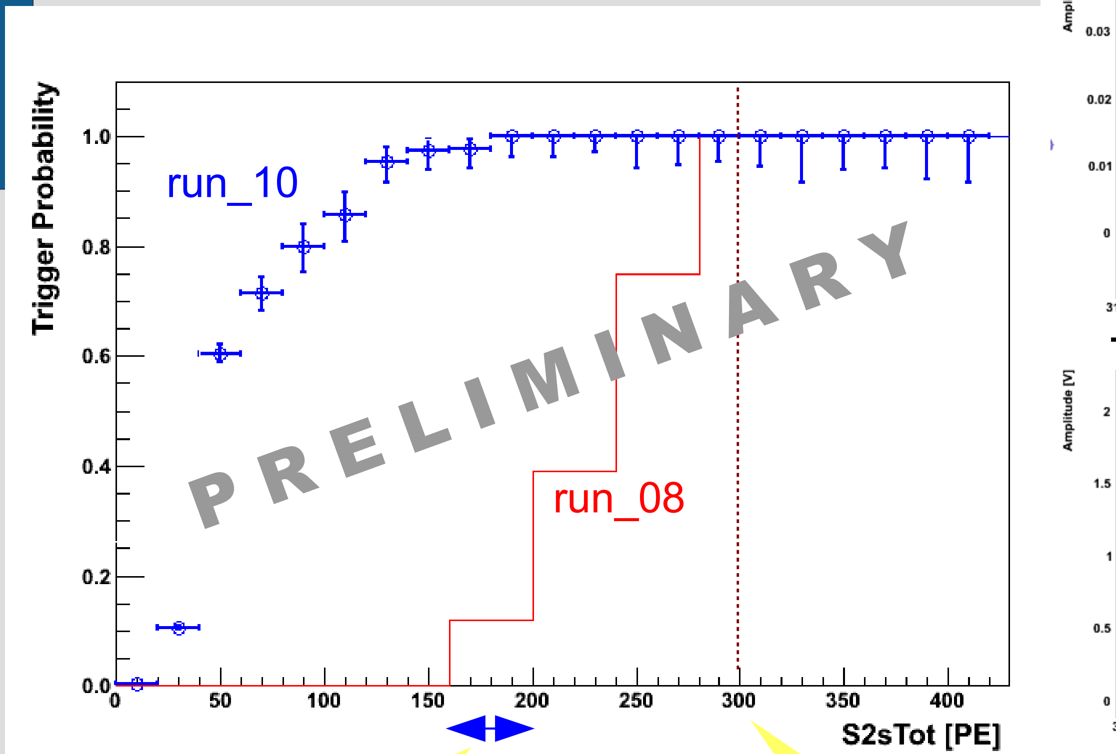
Conclusion: only if Q_y is incompatible with data and theoretical understanding one can avoid the XENON10 contraints.

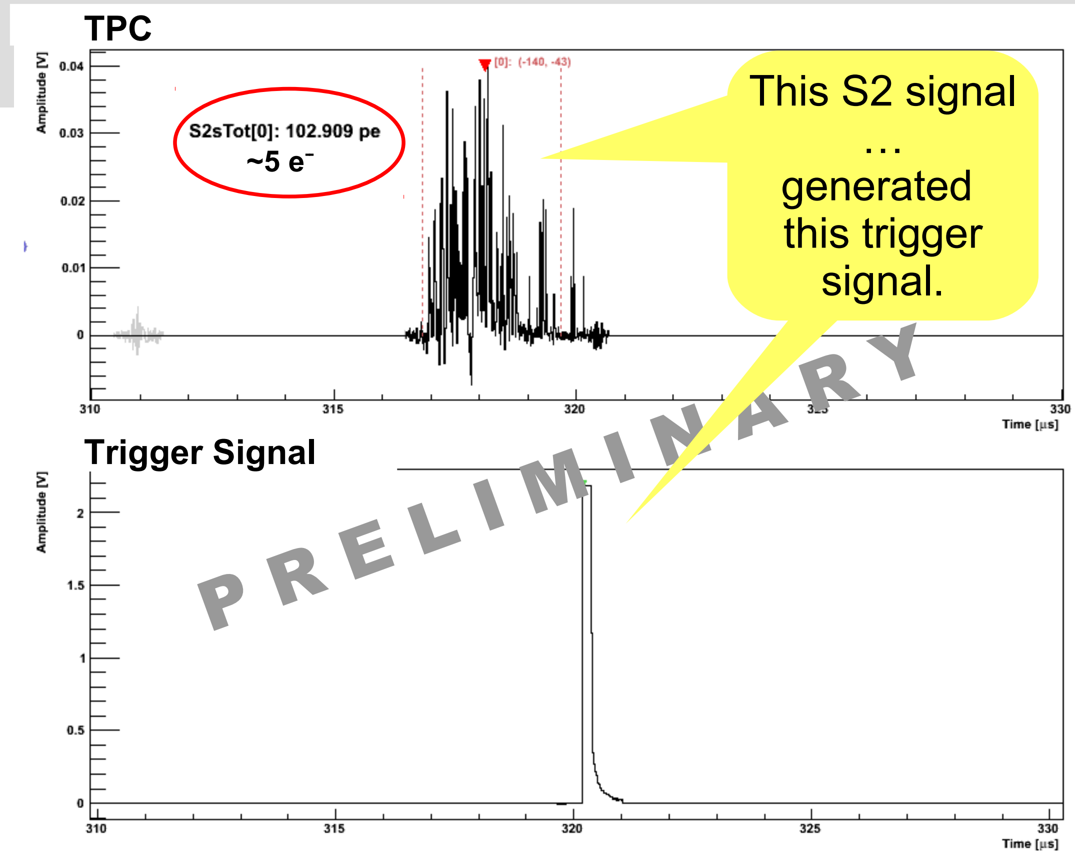
Outline

- Motivation: Dark Matter ✓
- WIMP Search with Xenon ✓
- XENON100 ✓
- The new Results ✓
- Some Comments ✓
- **Presence and Future**

Improved Trigger Threshold

- Low energy signals are S2-triggered
- dedicated measurement of threshold

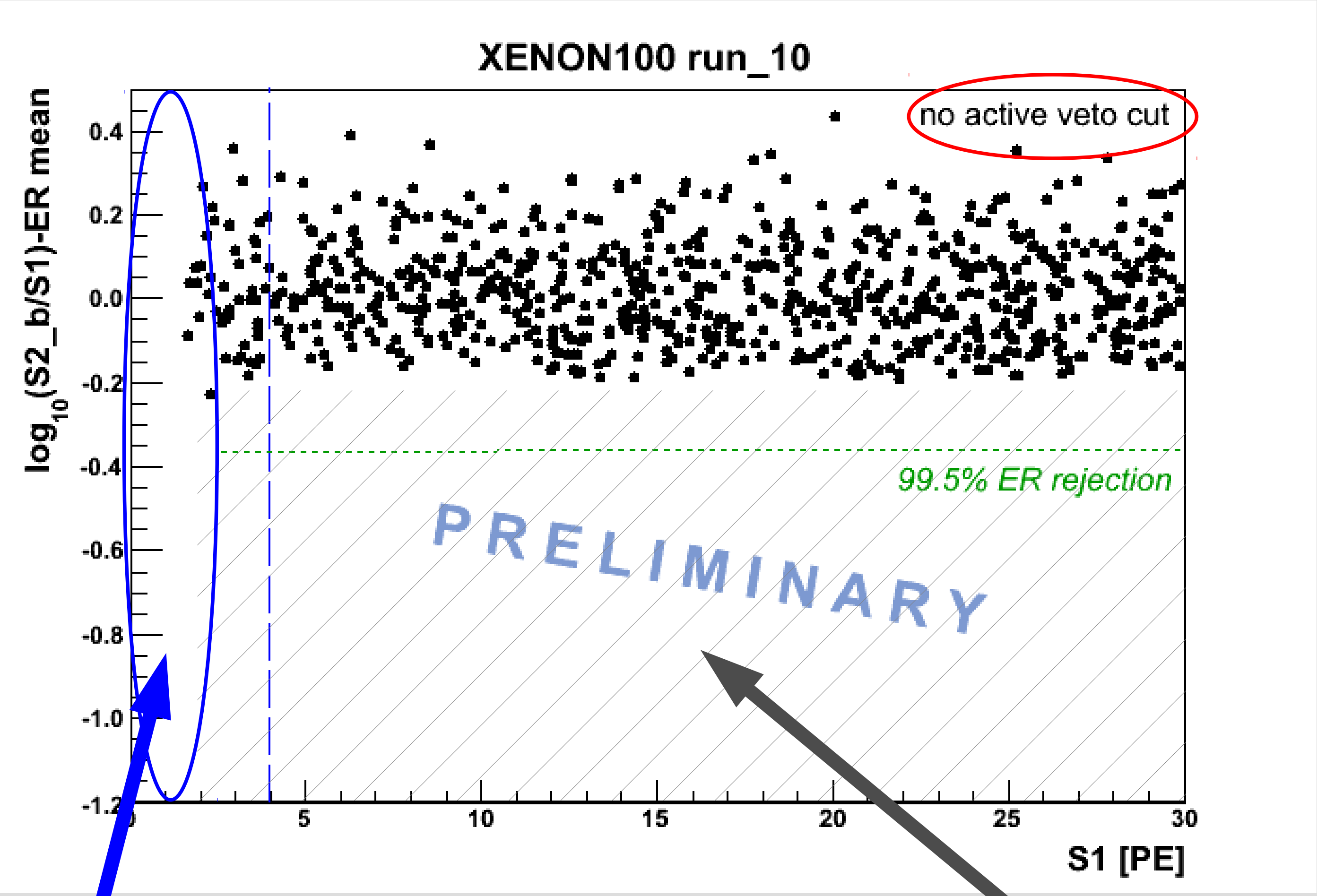




run_10 S2 analysis threshold not defined yet

run_08 S2 analysis threshold

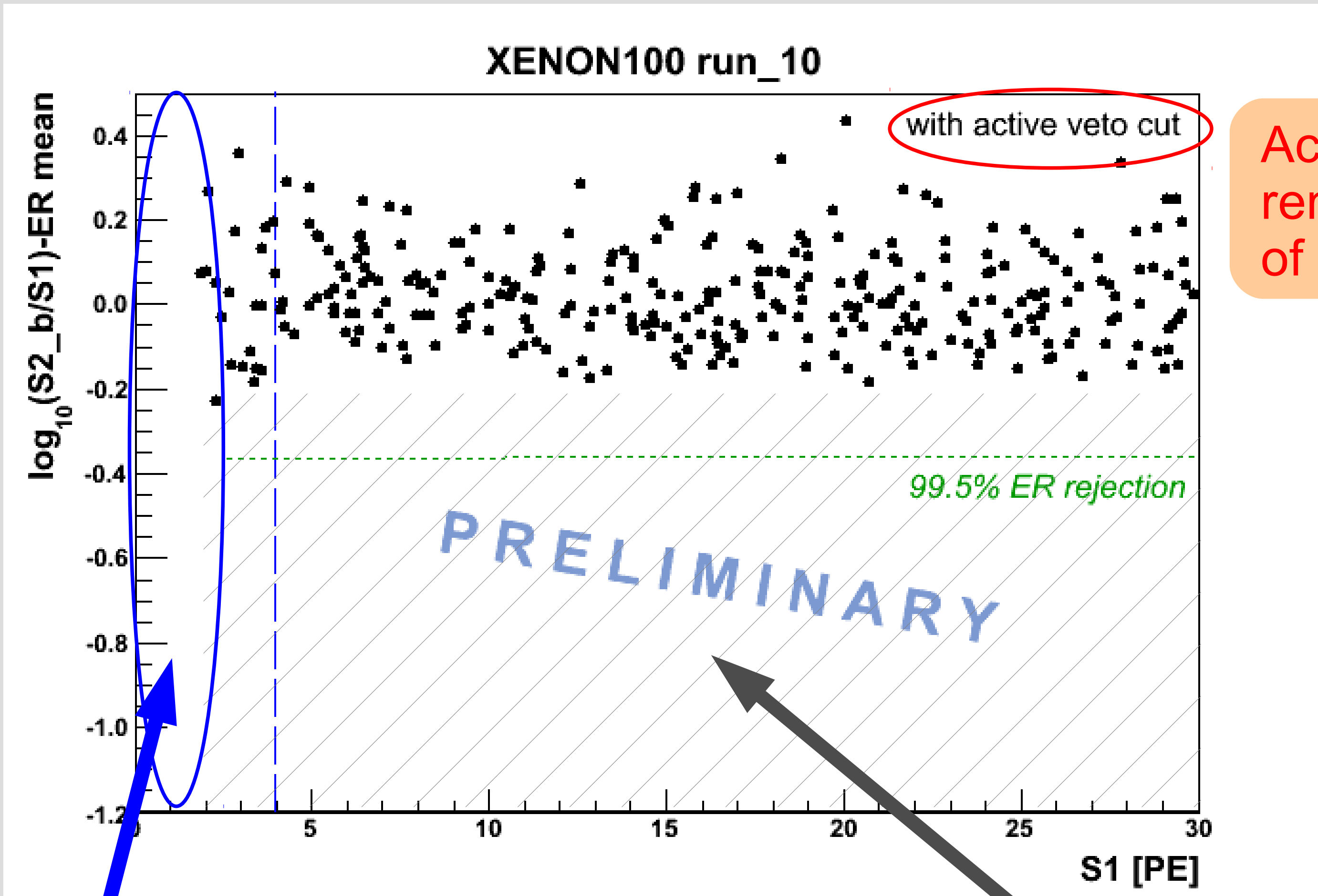
News from the current DM run



No electronic noise present

Blinded Dark Matter Search Region

News from the current DM run



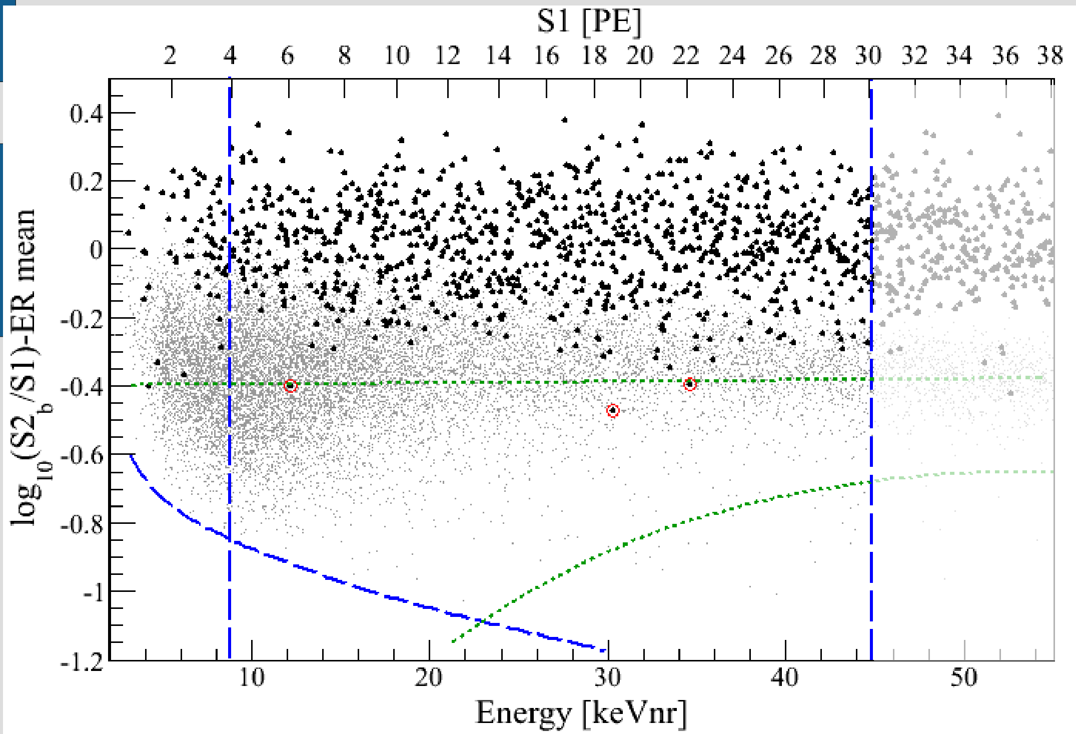
Active veto cut removes >50% of background

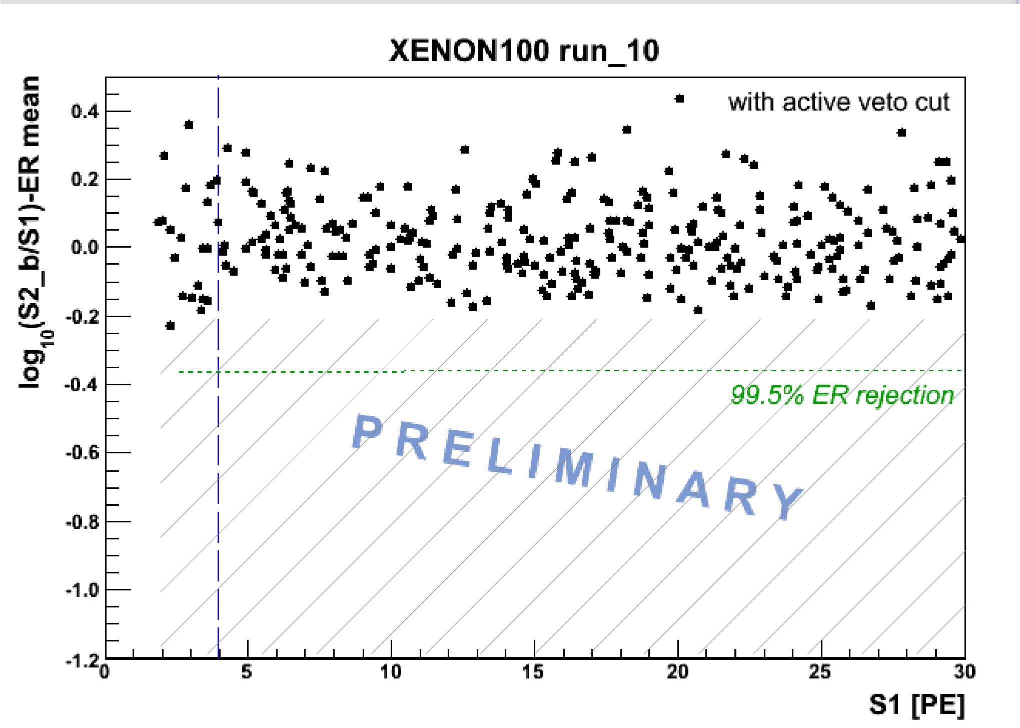
No electronic noise present

Blinded Dark Matter Search Region

Comparison with the latest results

Phys. Rev. Lett. 107, 131302 (2011)





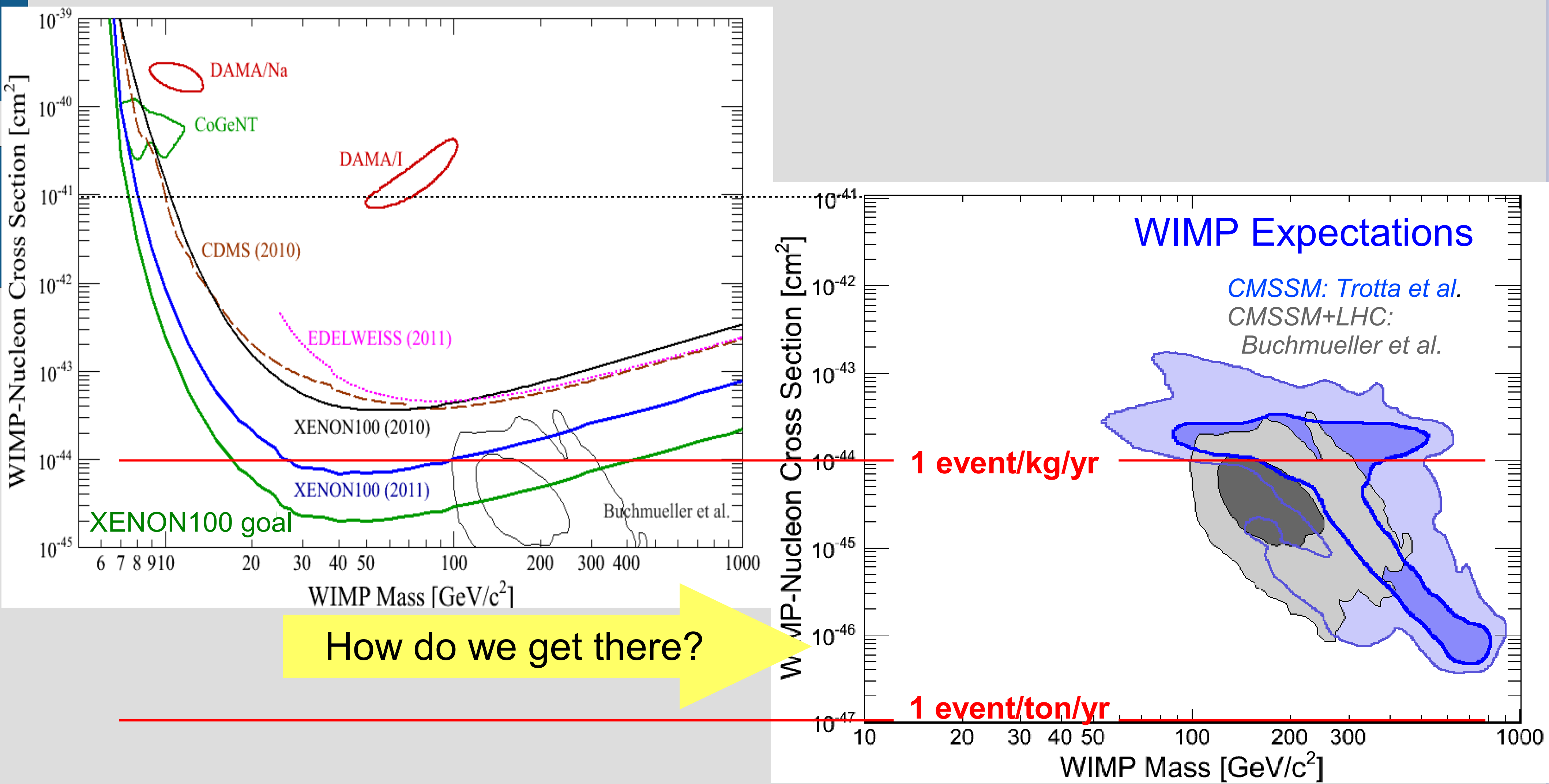
almost identical cut acceptance

Fiducial Mass:	48 kg
Lifetime:	100.9 days

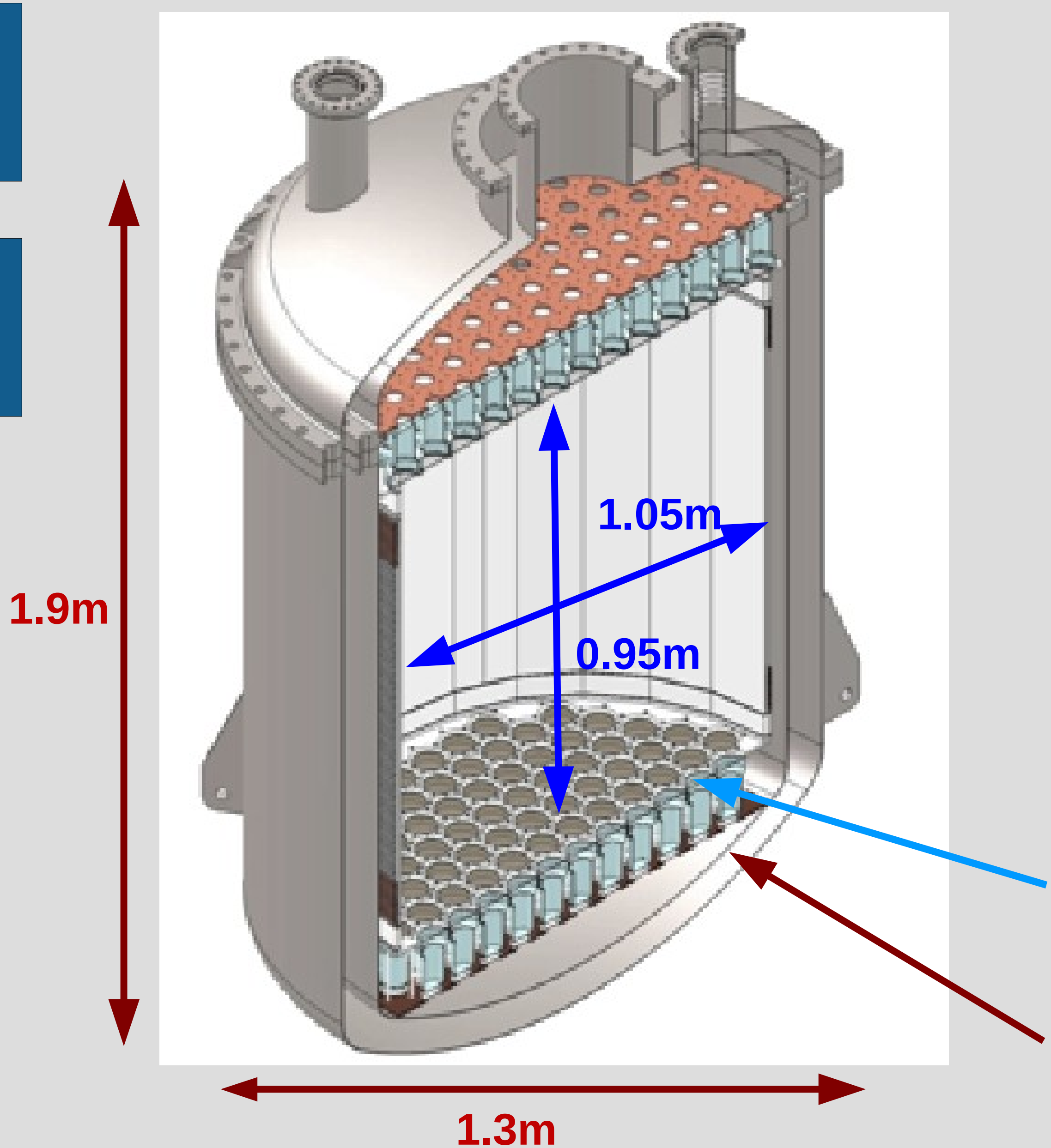
Fiducial Mass:	48 kg
Lifetime:	132.5 days

run_10 is still ongoing!

XENON100: Sensitivity



The next step: XENON1T

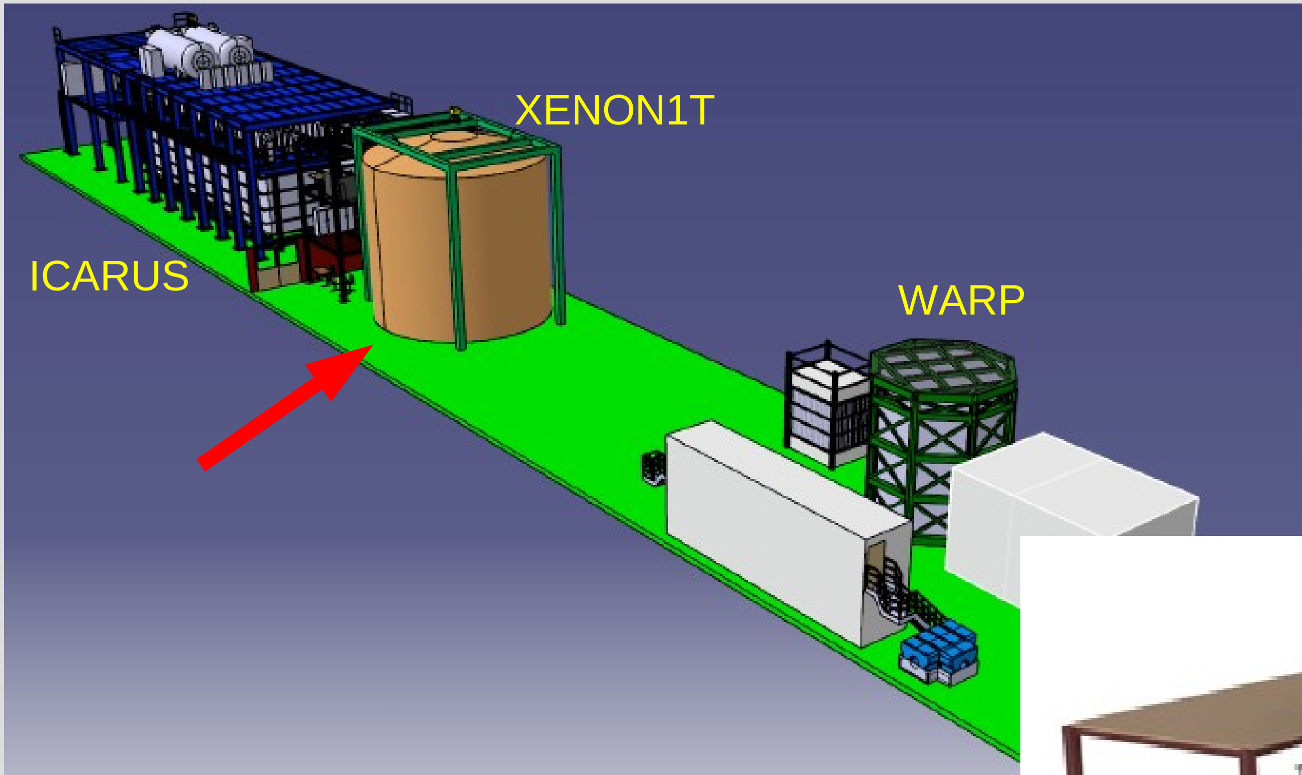


- 2.4t LXe ("1m³ detector")
  1t fiducial mass
- 100x lower background
  (10 cm self shielding,
  low radioactivity components)
- Timeline: 2010 – 2015
- start construction in 2012

Low Radioactivity Photon Detectors (3”, Total ~270)

Ti Cryostat
(or low rad. stainless steel)

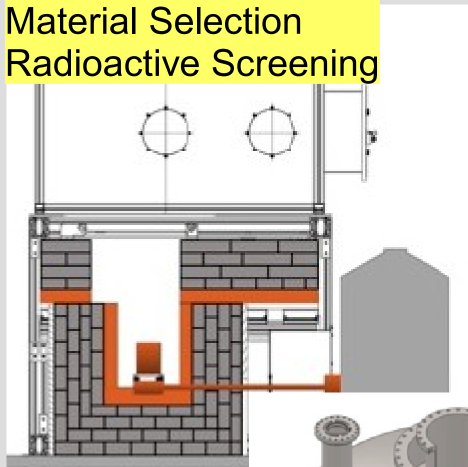
XENON1T @ LNGS

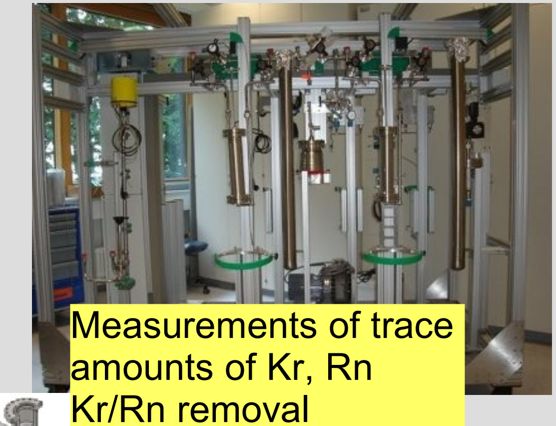


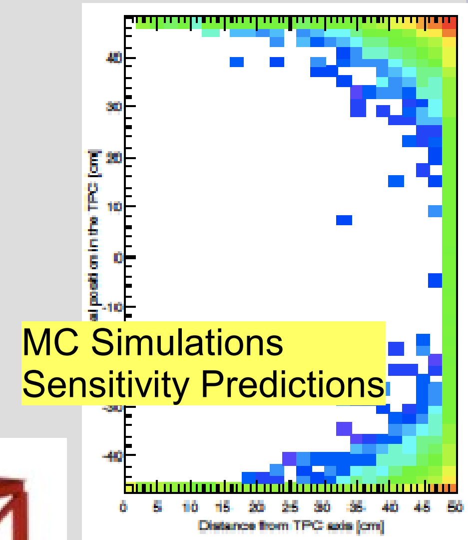
XENON1T
@ LNGS (Hall B)
➞ 5 m water shield
acting as
active muon veto

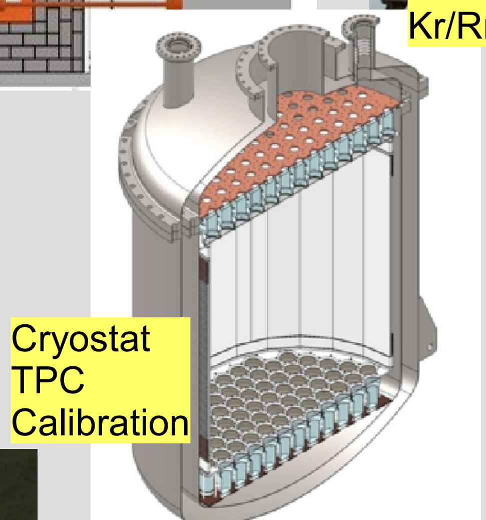
- Proposal and TDR submitted to LNGS
- Approved by INFN end of April 2011

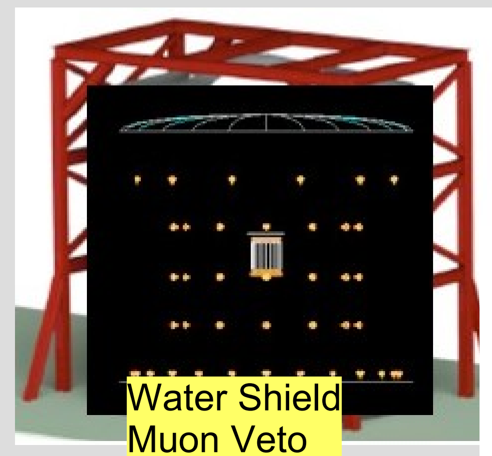
XENON1T: R&D Efforts

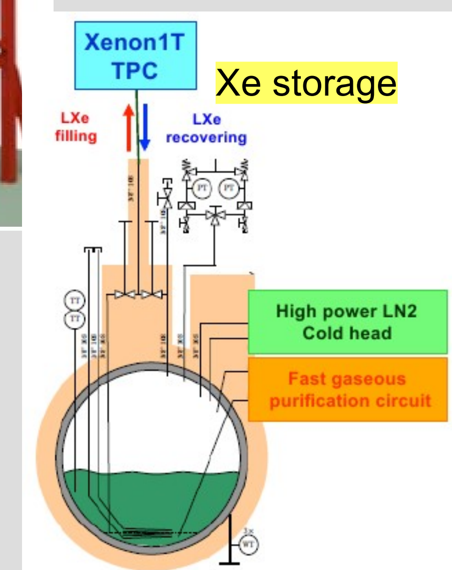


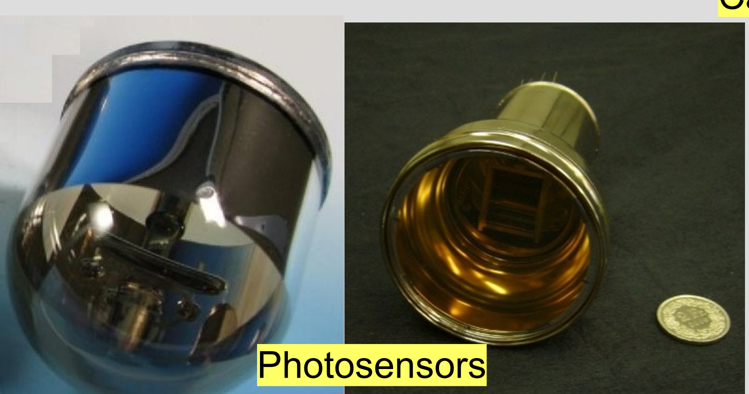


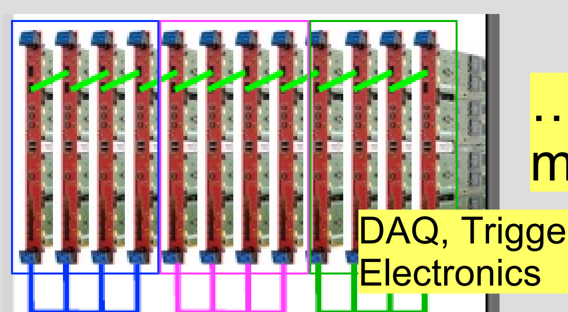






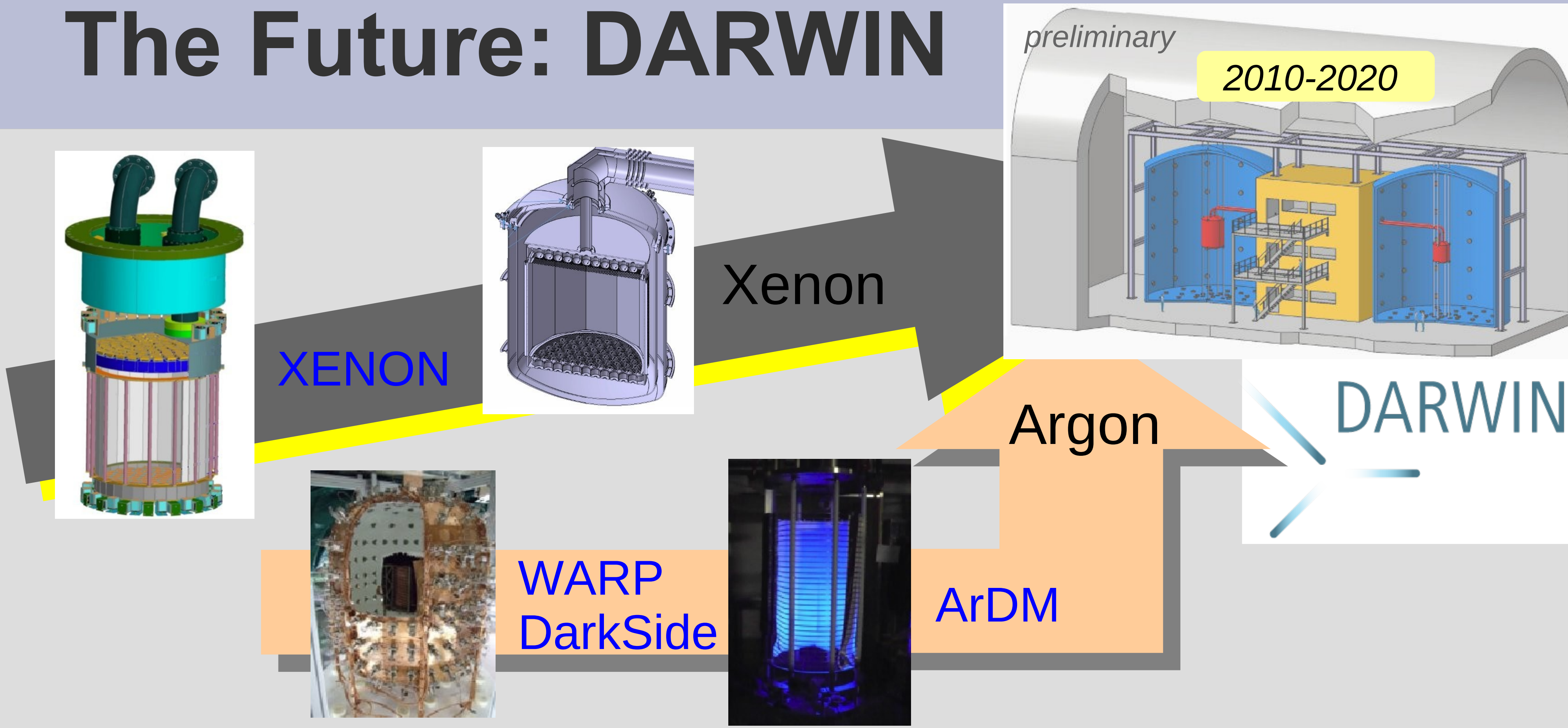






… and many
more things...

The Future: DARWIN

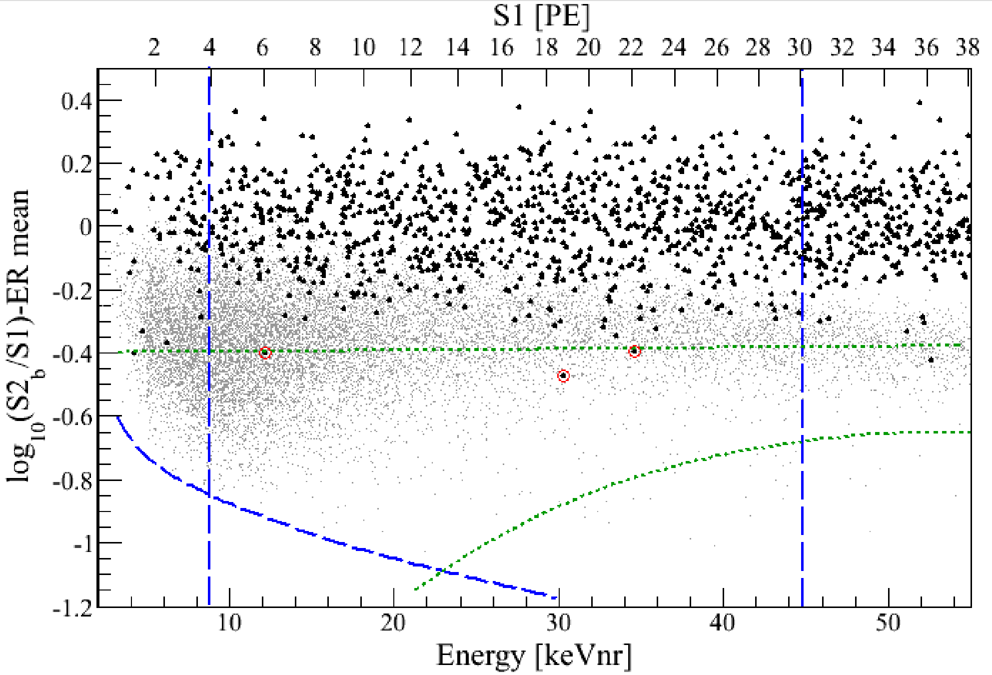


DARWIN – Dark Matter WIMP Search with Noble Liquids

- *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 using one or both targets
- Physics goal: $\sigma < 10^{-47}$ cm²

http://darwin.physik.uzh.ch

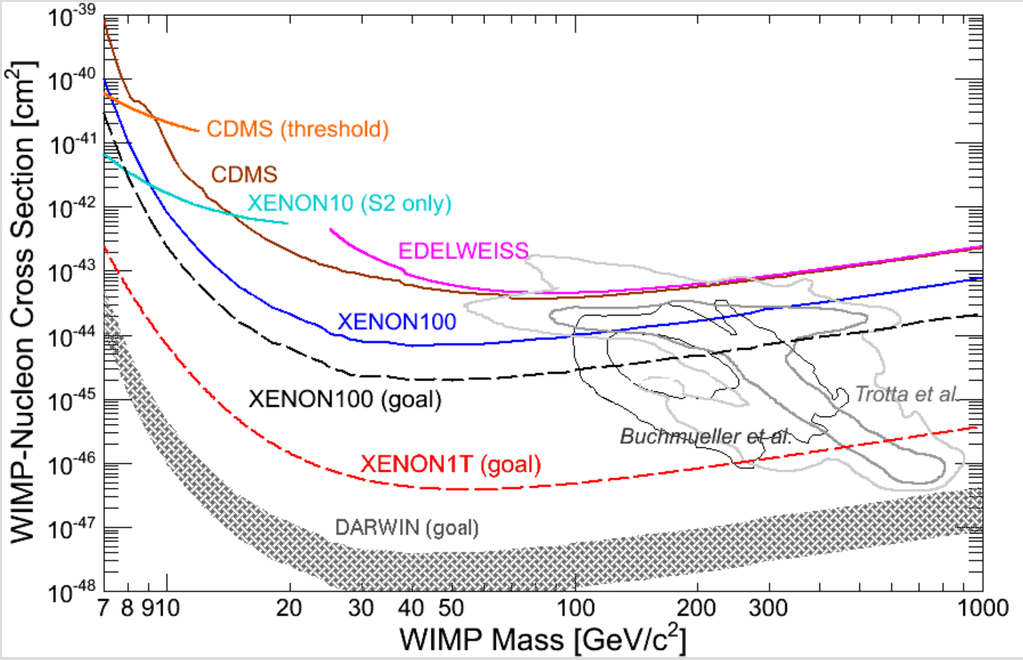
Summary



- Dark Matter: One of the big unsolved puzzles
- **XENON100**
  62 kg dual-phase LXe TPC
- extremely low background
- new results from 100d data: *PRL 107, 131302 (2011)*

Two new projects upcoming:

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



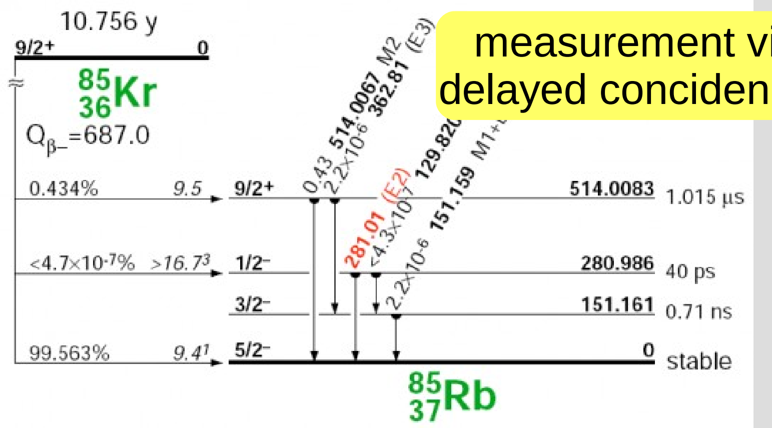
Backup

Kr-85-Removal

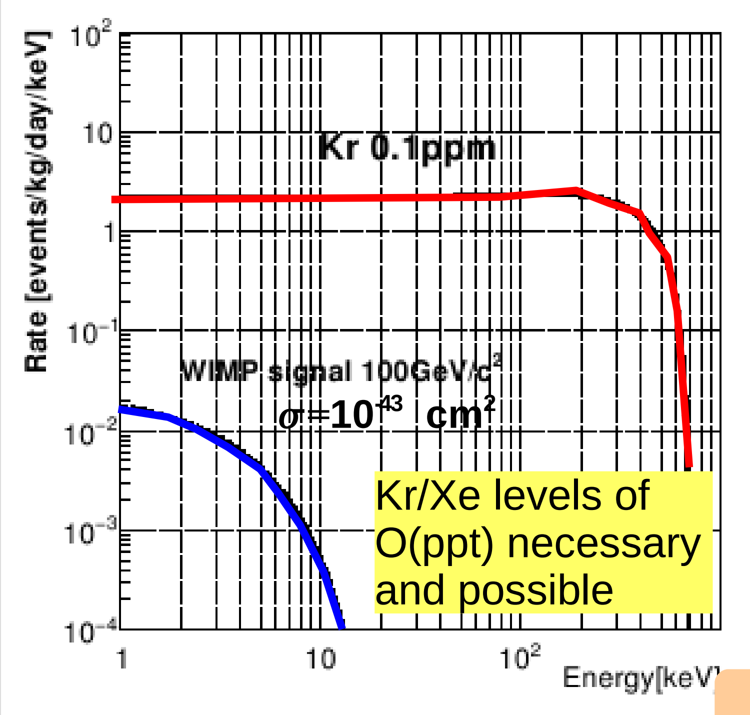
- Xe has no long lived radioactive isotope
- BUT: Xe contains Kr-85

in air:	Kr/Xe ~ 10
in Xe gas (commercial)	Kr/Xe ~ ppm-ppb
necessary (Xe100)	Kr/Xe ~ 100 ppt (<1 evt in 0.5 yr)

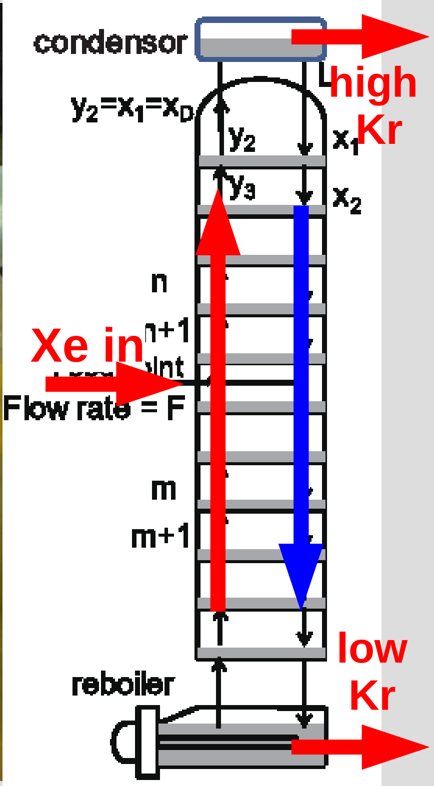
➞ dedicated Kr-85 removal to ppt level



measurement via delayed concidences



Kr/Xe levels of O(ppt) necessary and possible



used successfully

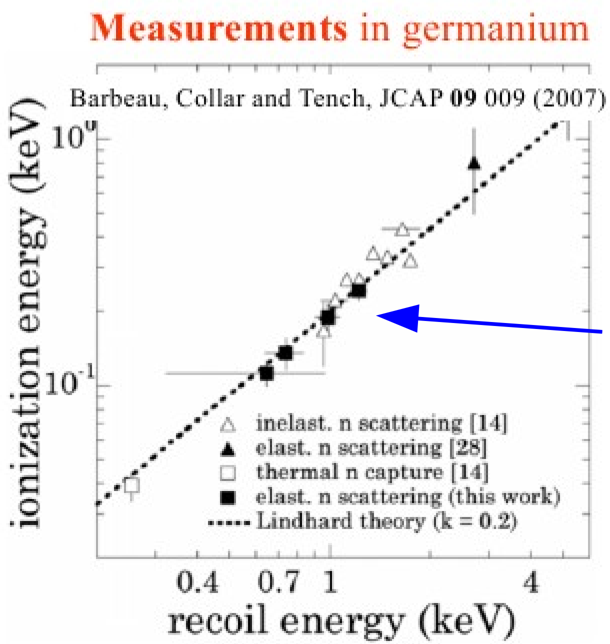
XMASS, Astro.Part.Phys. 31 (2008)

Mistake in Collar Prediction

(argumentation adapted from P. Sorensen, talk at TAUP)

XENON Dark Matter Project

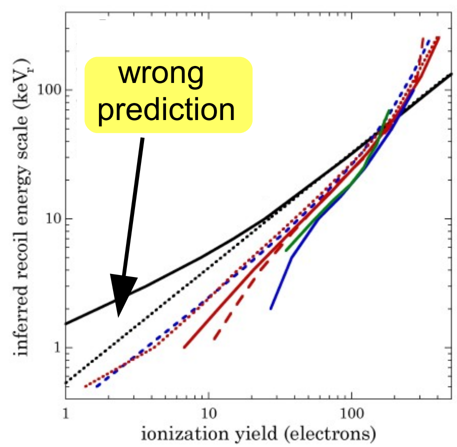
Lindhard gives an expression for the expected fraction of NR energy transferred to electrons (=detectable), the rest is lost to heat



Mat. Fys. Medd. Dan. Vid. Selsk. **33**, no. 10 (1963)

More precisely, for an incoming particle of energy E we ask for that part η of the total energy loss, E, which is ultimately given to electrons, and that part ν, which is ultimately left in atomic motion.

$$\left(\frac{d\varepsilon}{d\varrho}\right)_e \cdot \bar{\nu}'(\varepsilon) = \int_0^{\varepsilon^2} \frac{dt}{2\,t^{3/2}} \cdot f(t^{1/2}) \left\{ \bar{\nu}\left(\varepsilon - \frac{t}{\varepsilon}\right) - \bar{\nu}(\varepsilon) + \bar{\nu}\left(\frac{t}{\varepsilon}\right) \right\}$$



In xenon, energy is not only transformed into charge but also into light; the fraction is energy dependent.
Lindhard theory applies to the *total energy loss which is ultimatively given to electrons*, i.e. the total number of quanta:

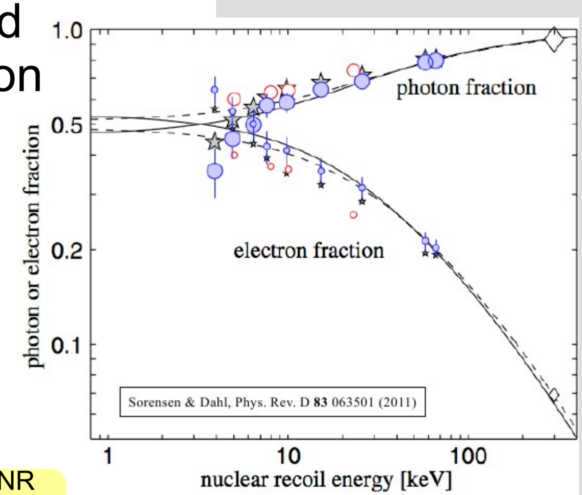
$$E_{nr} = \epsilon(n_\gamma + n_e)/f_n$$

av. energy to create a single quantum (~14 eV)

nb of primary scintillation photons

nb of primary ionization electrons

fraction of NR energy transferred to electrons



note: in Ge, n_γ=0