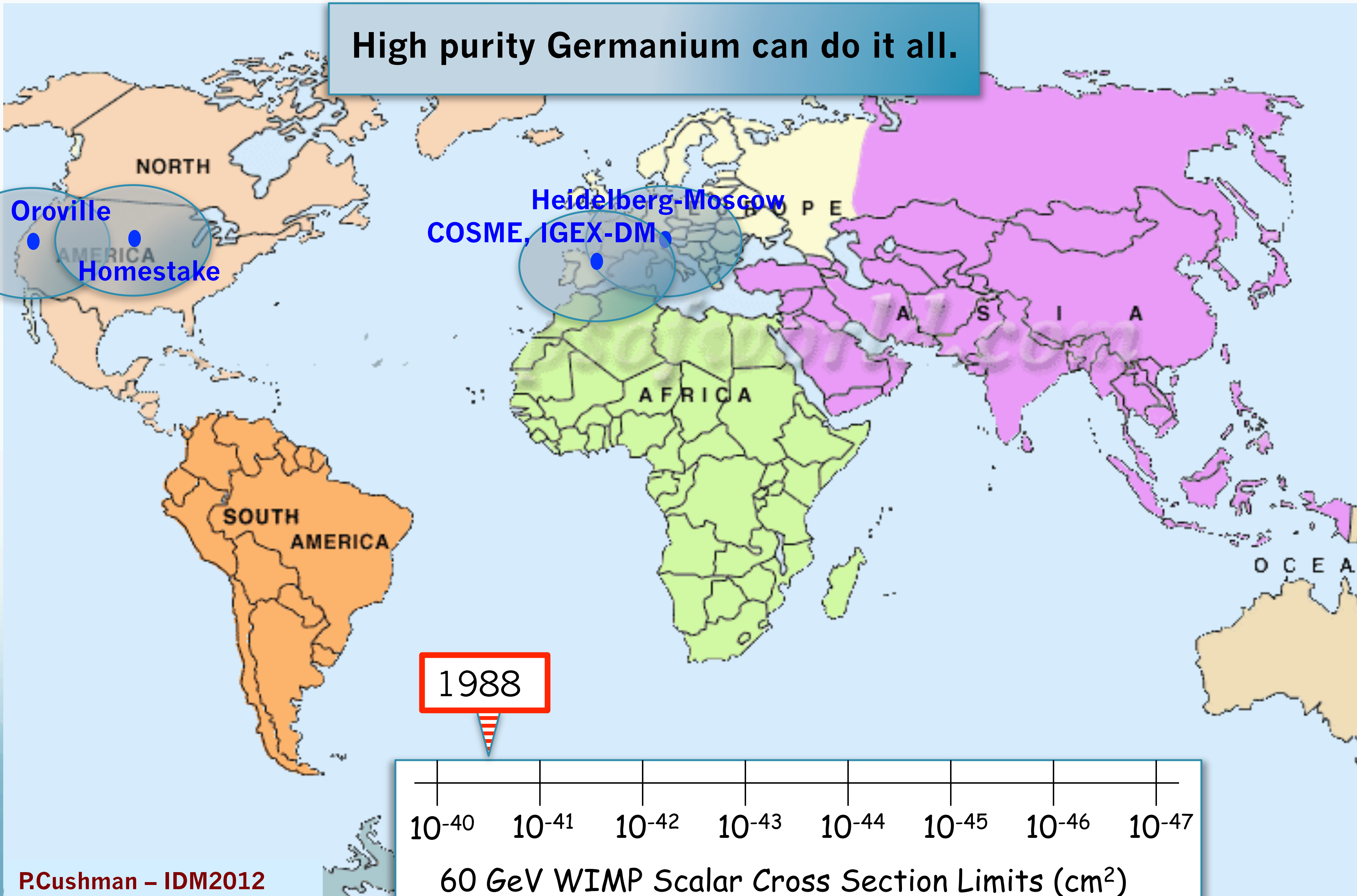
The Cryogenic Dark Matter Search Status and Future Plans

Priscilla Cushman
University of Minnesota

July 22, 2012

Identification of Dark Matter
Chicago, IL

A Brief History of Direct DM Searches



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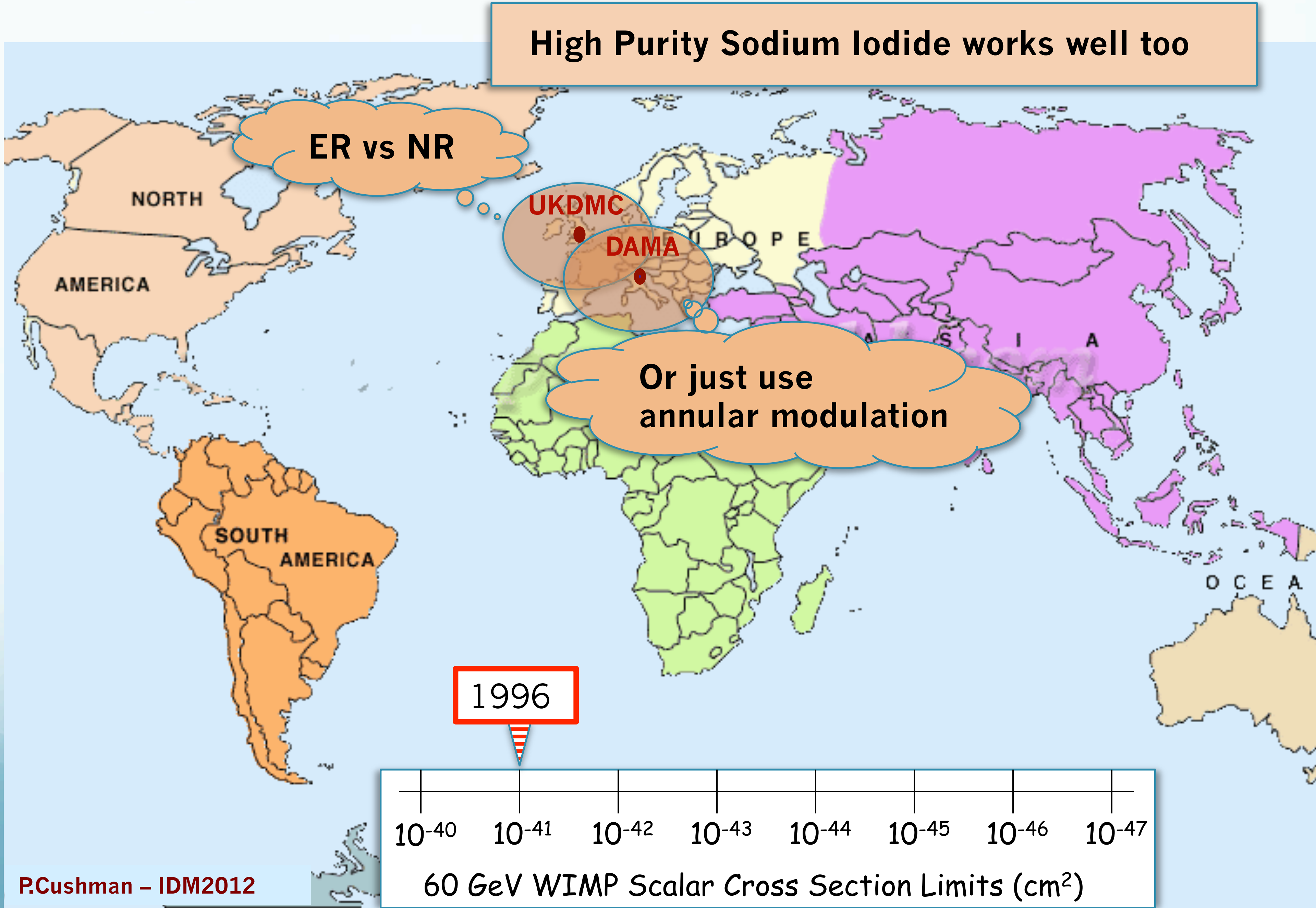

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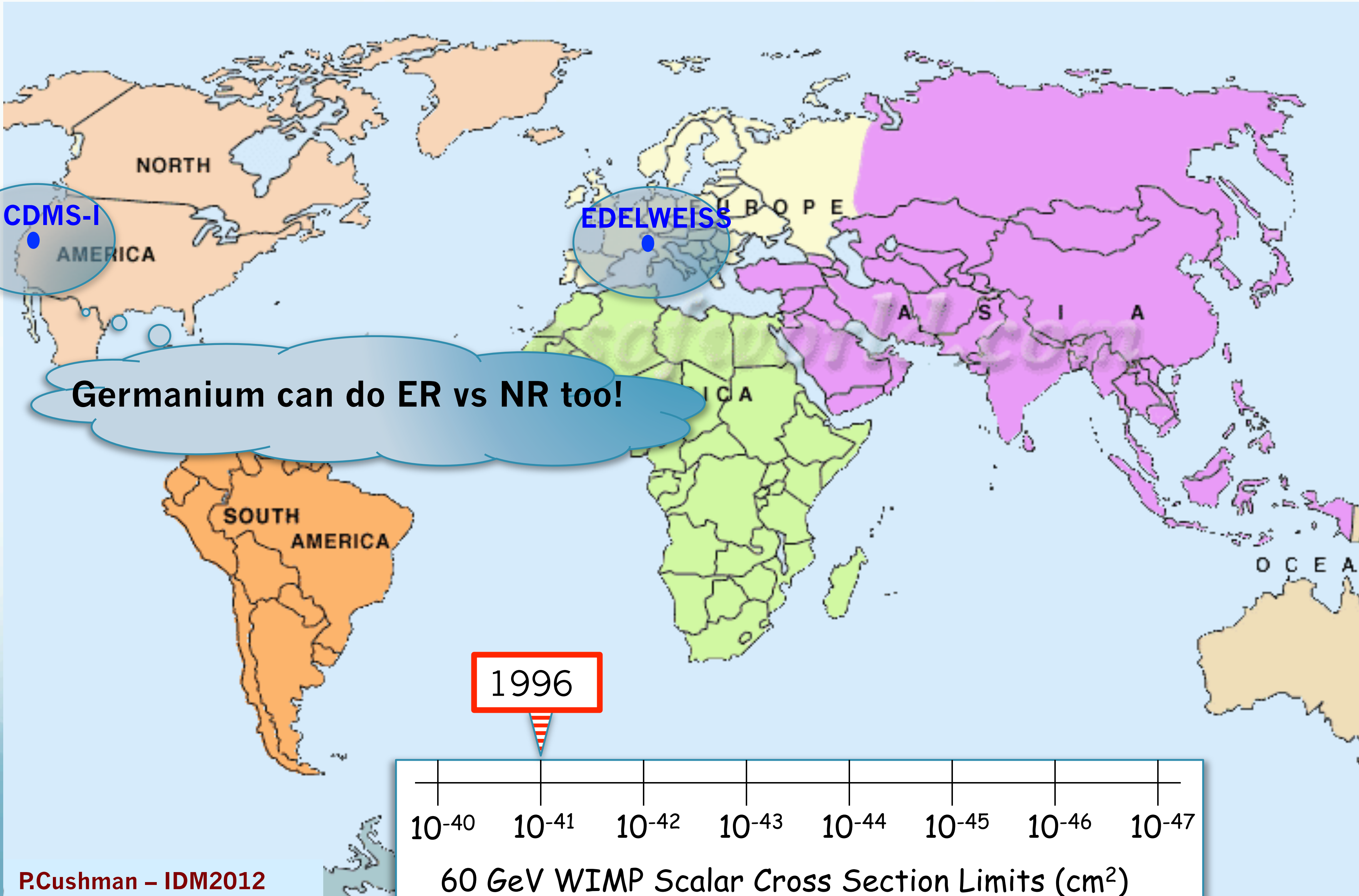

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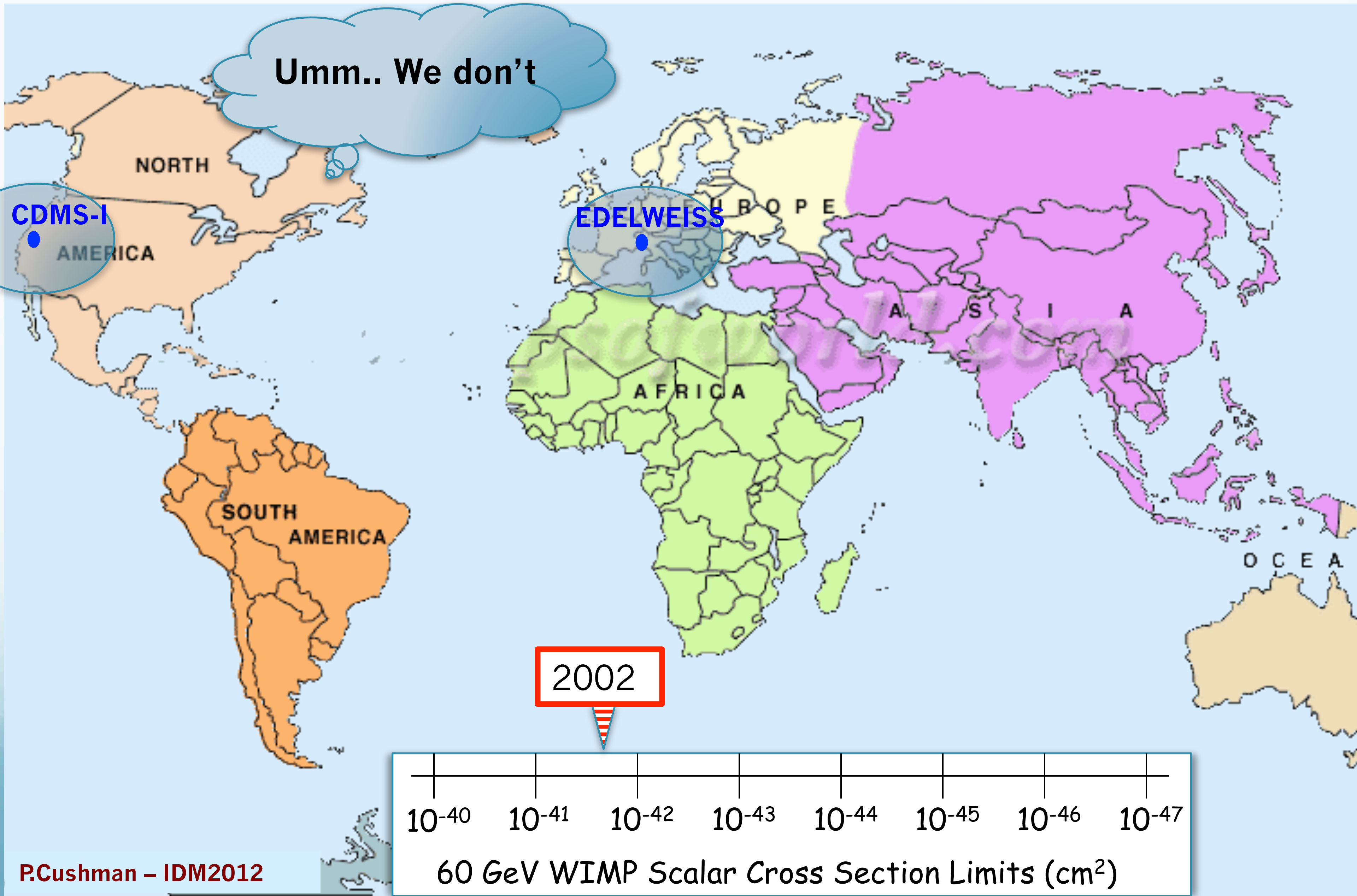

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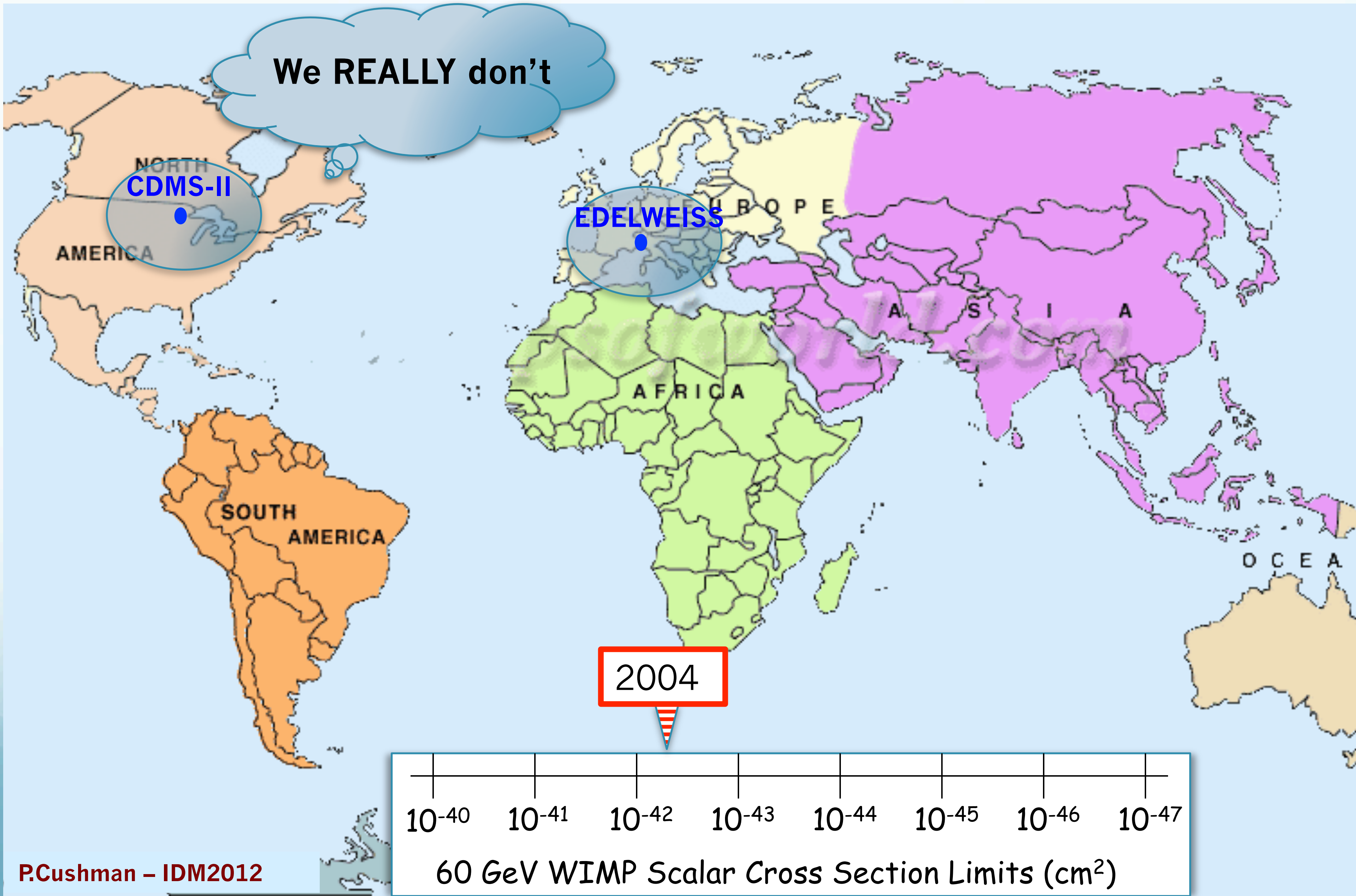

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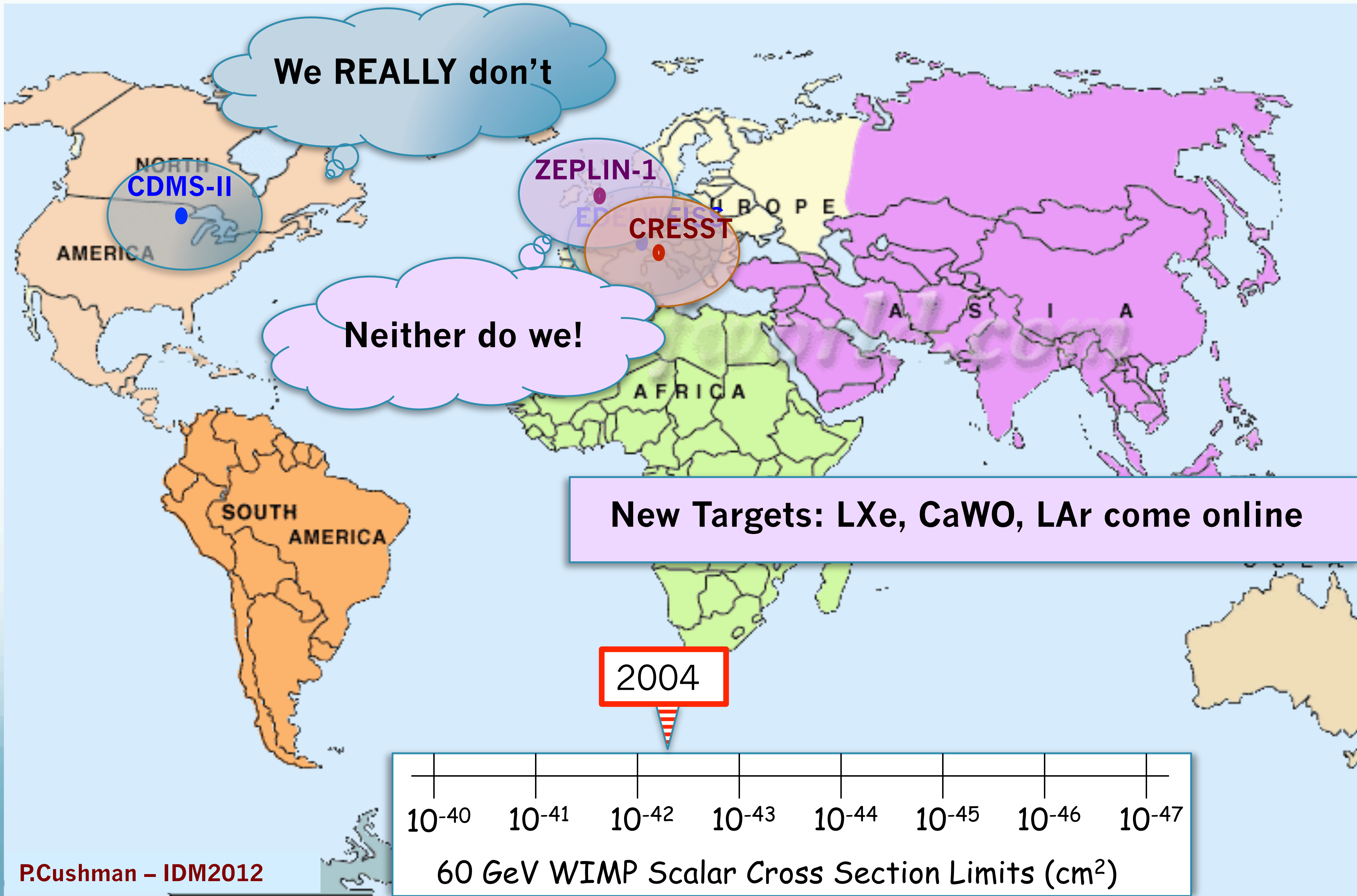

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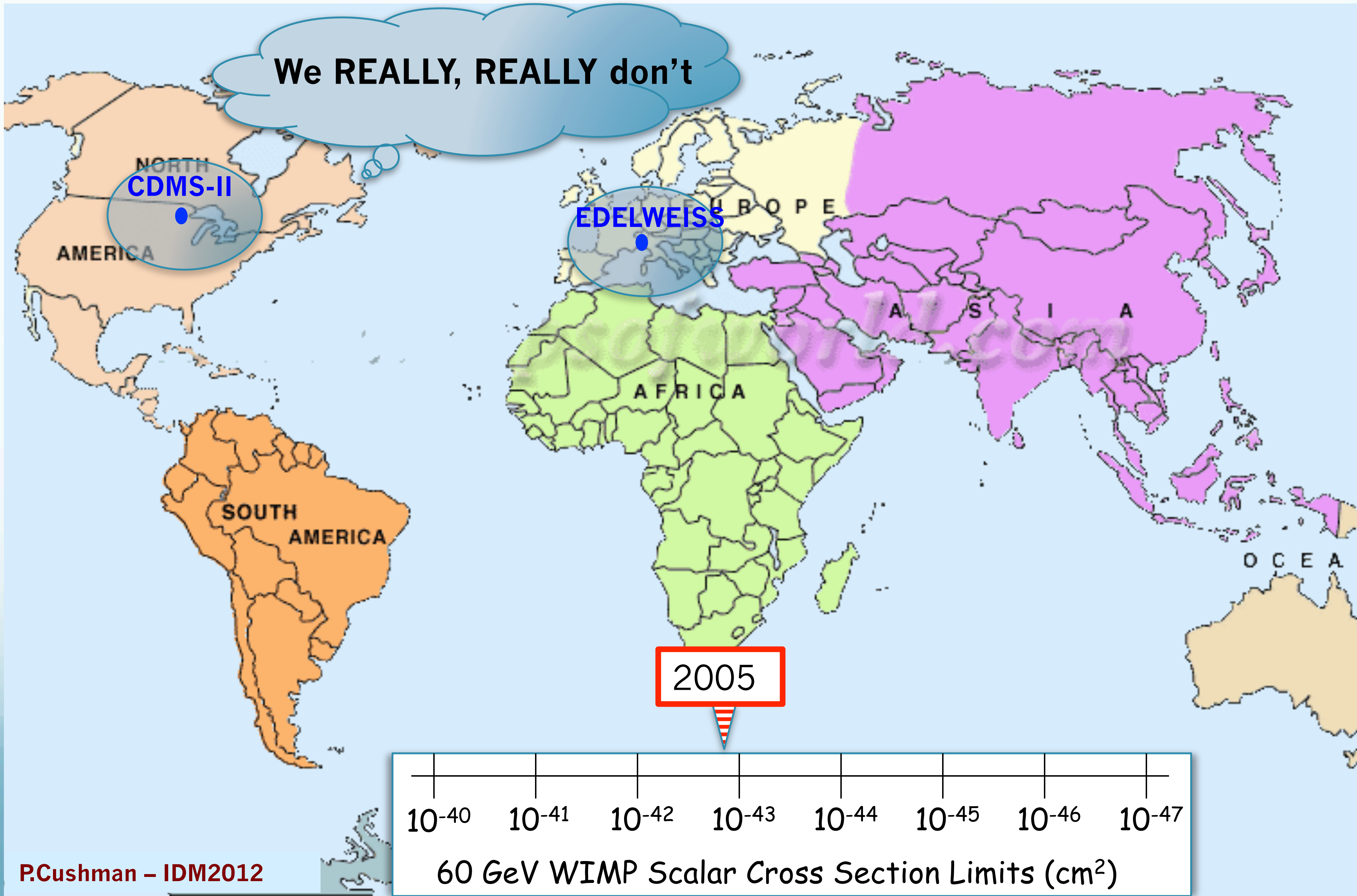

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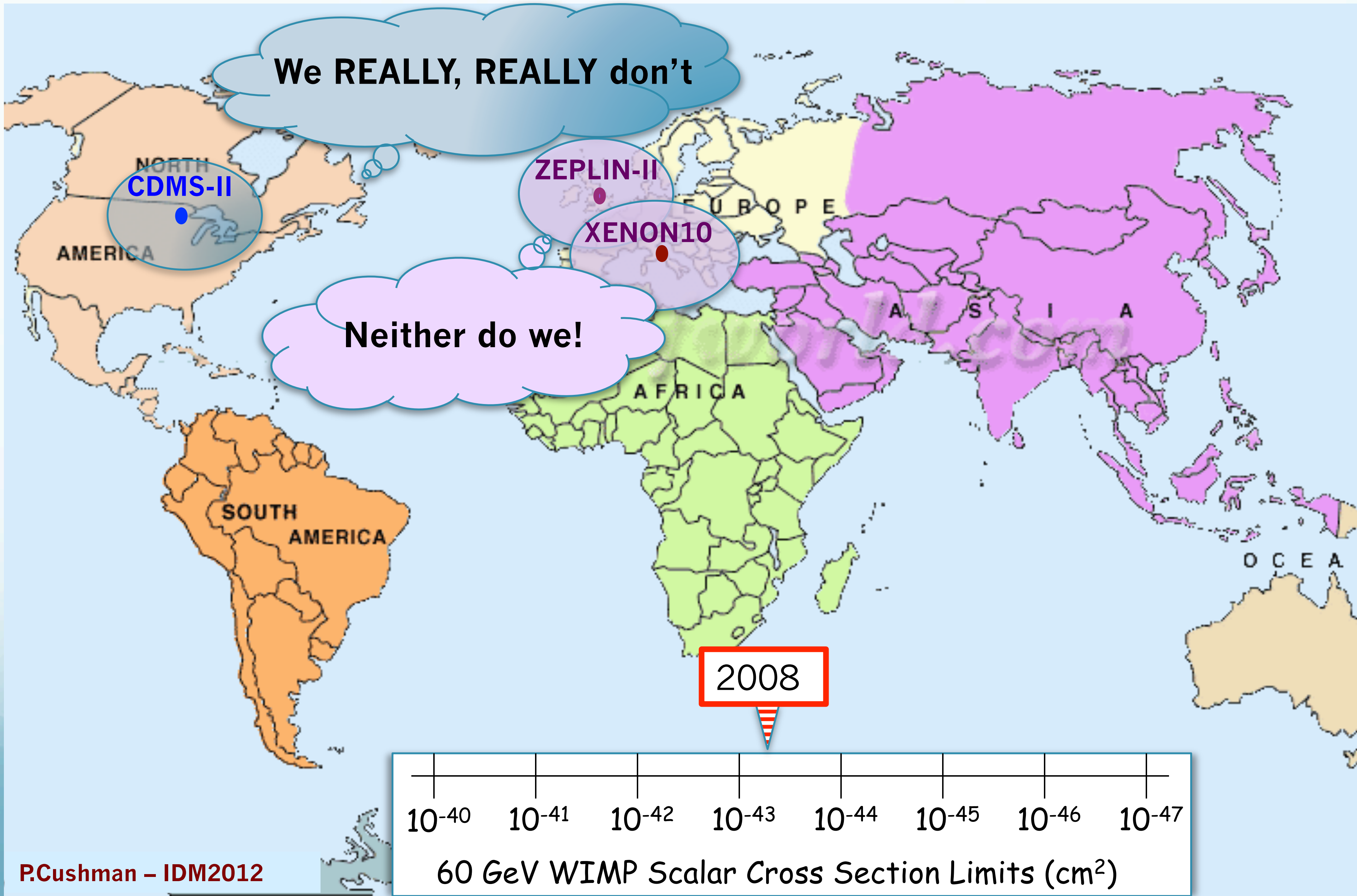

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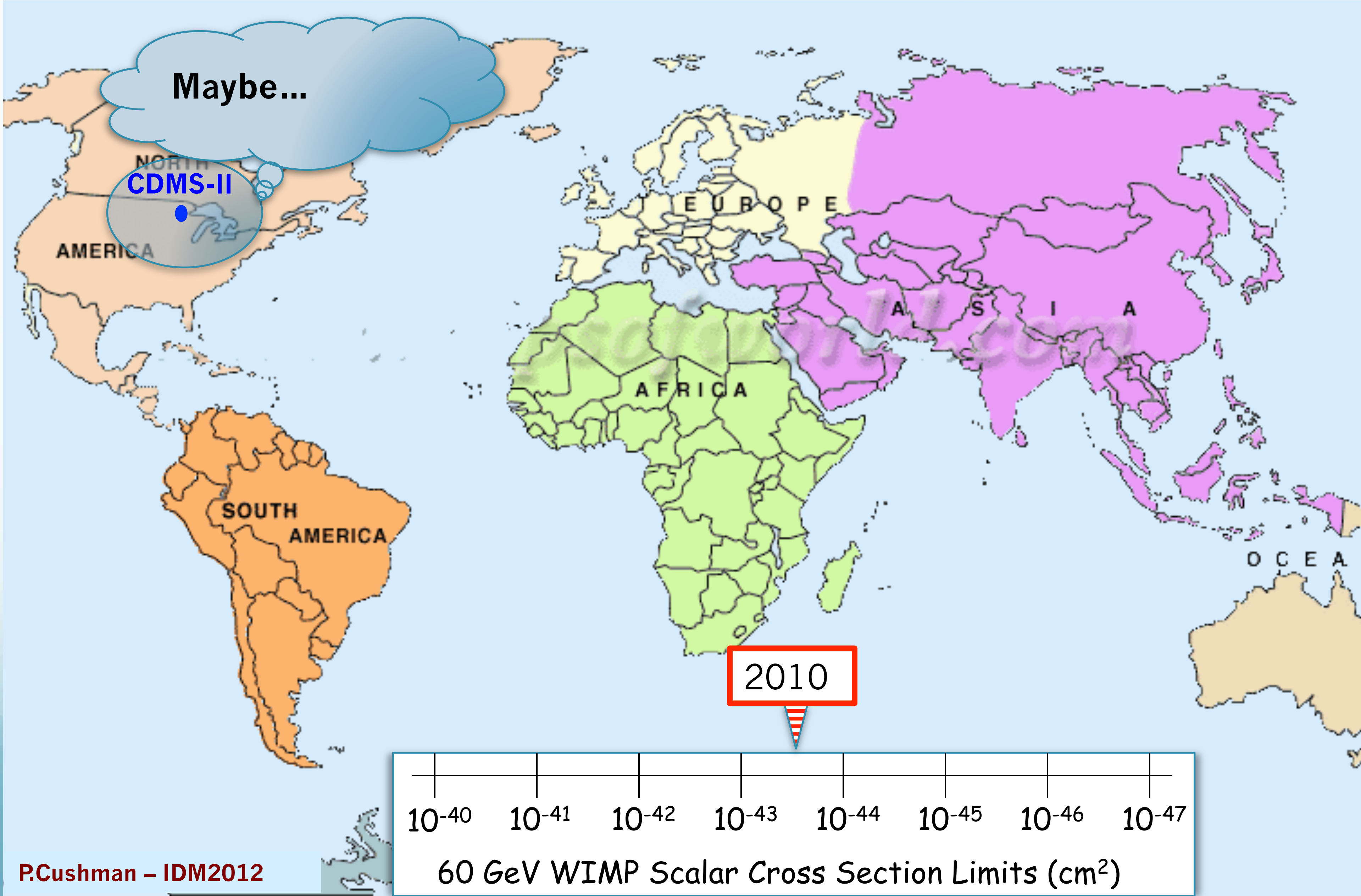

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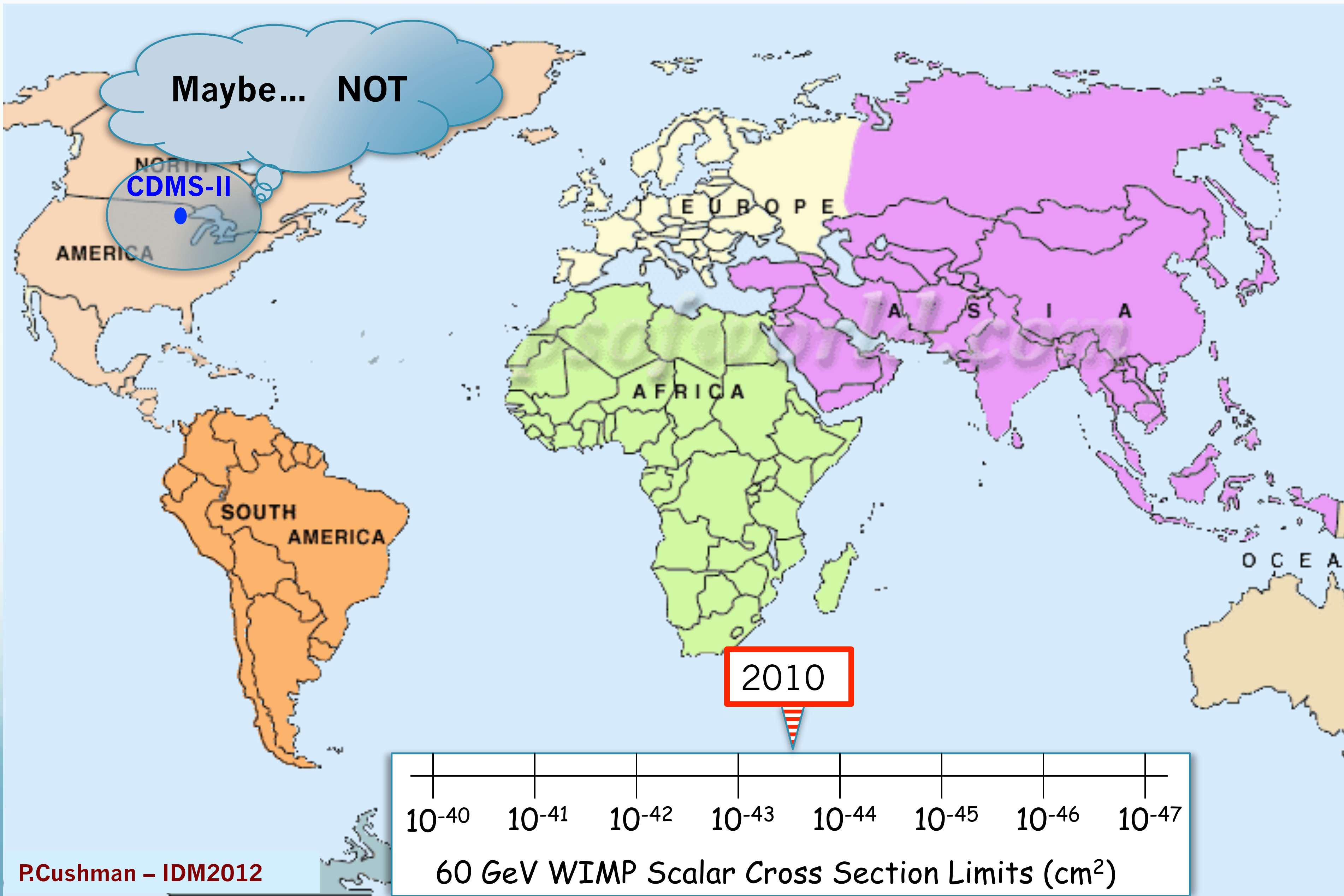

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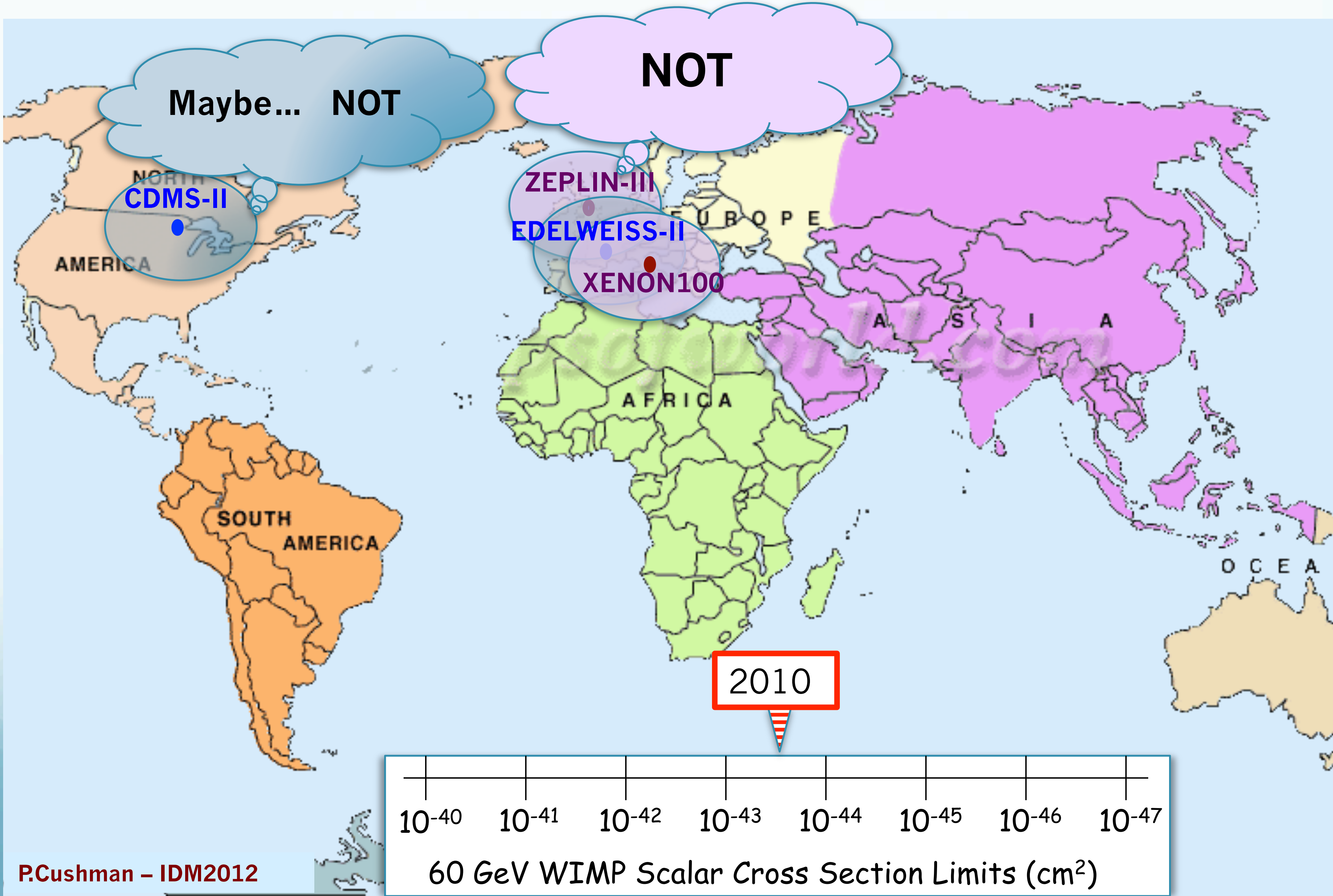

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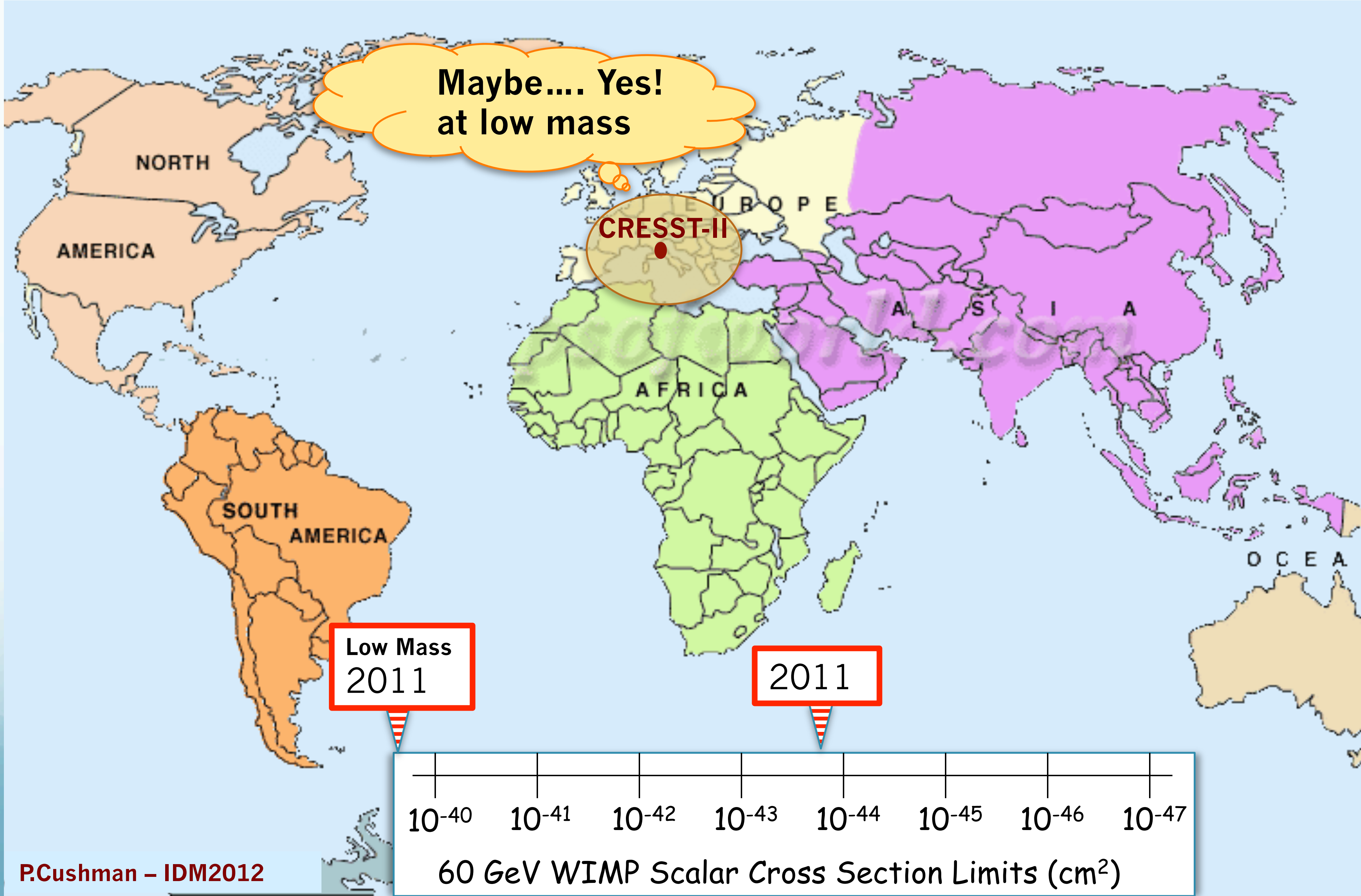

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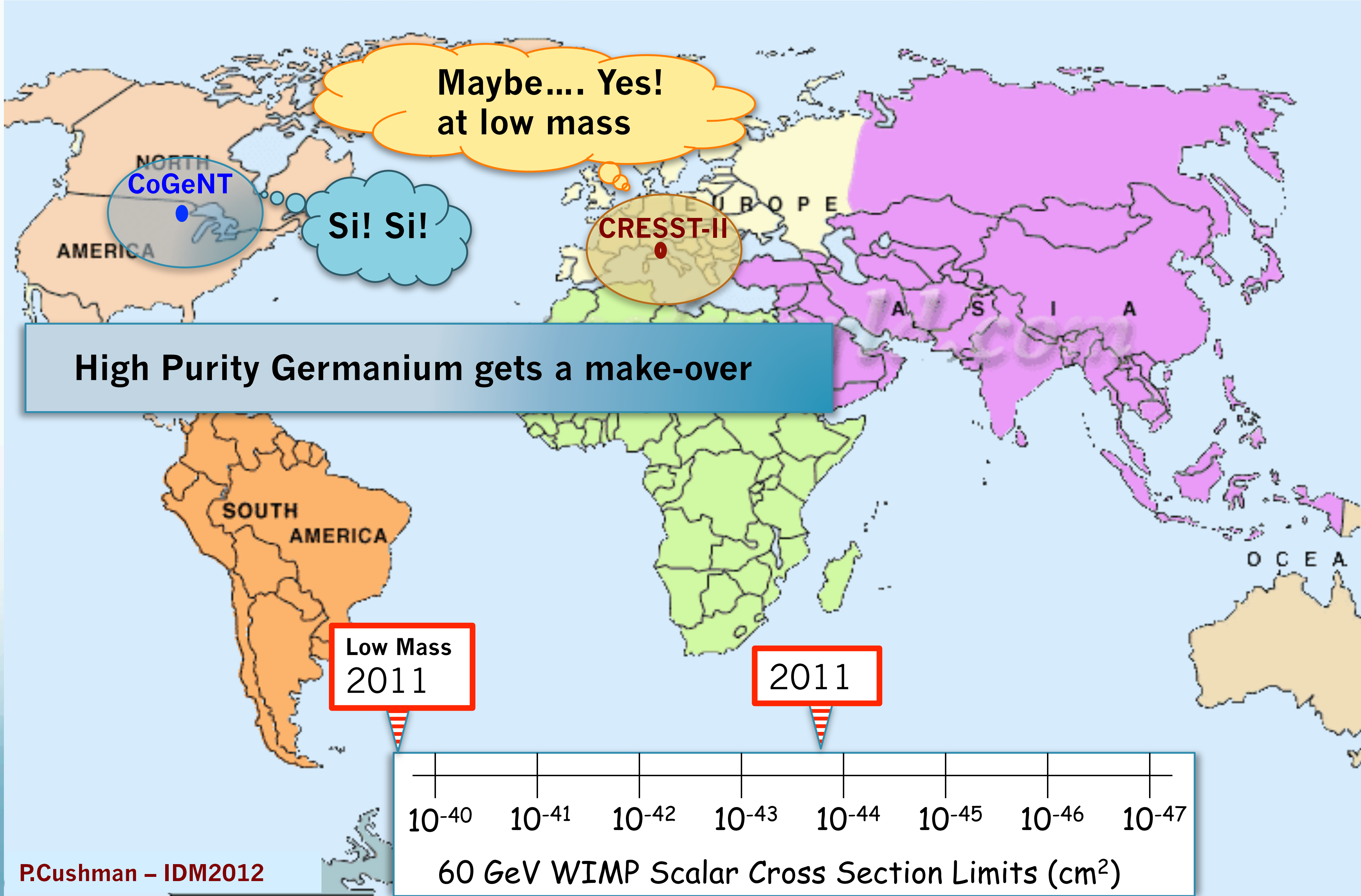

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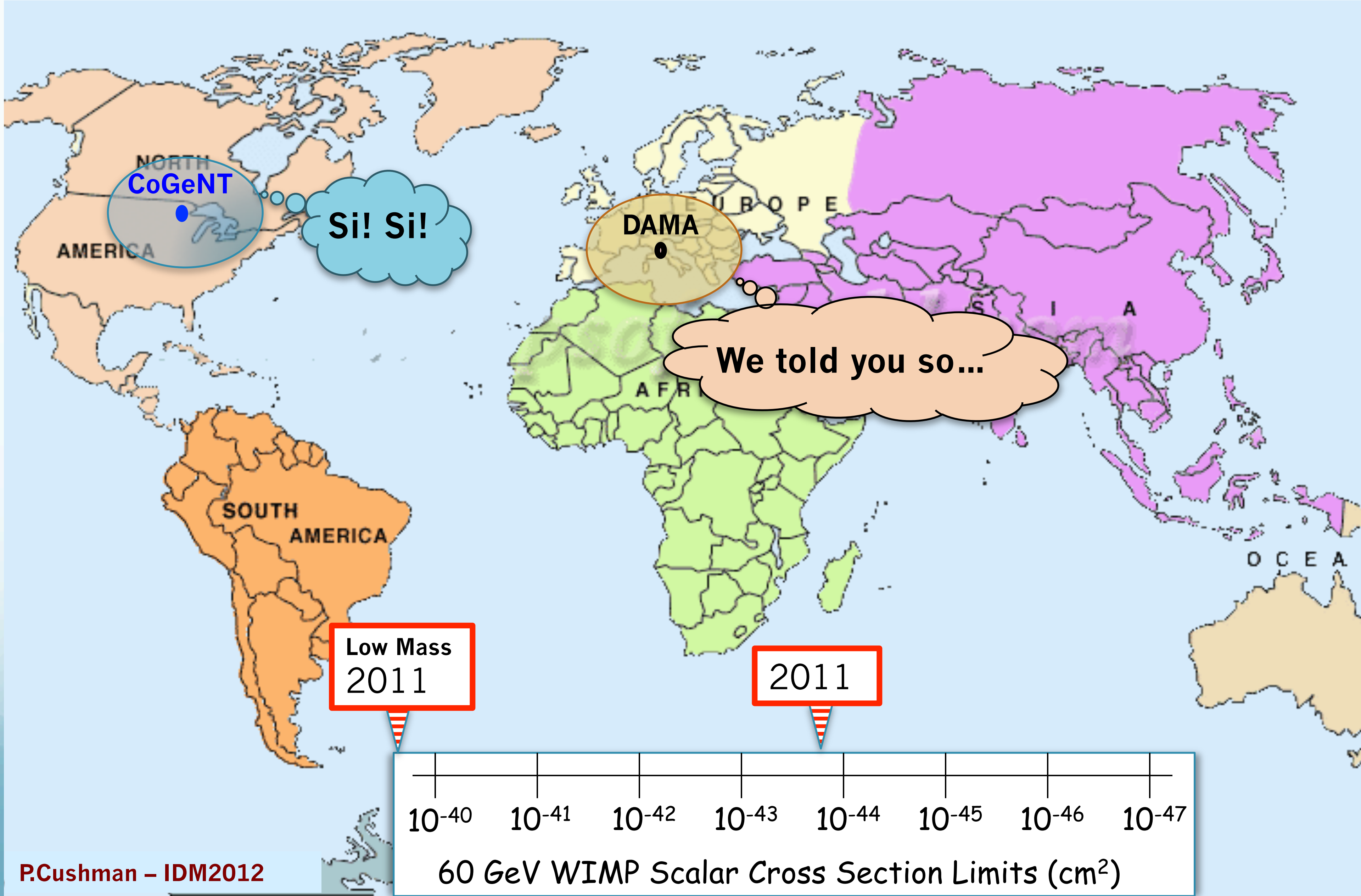

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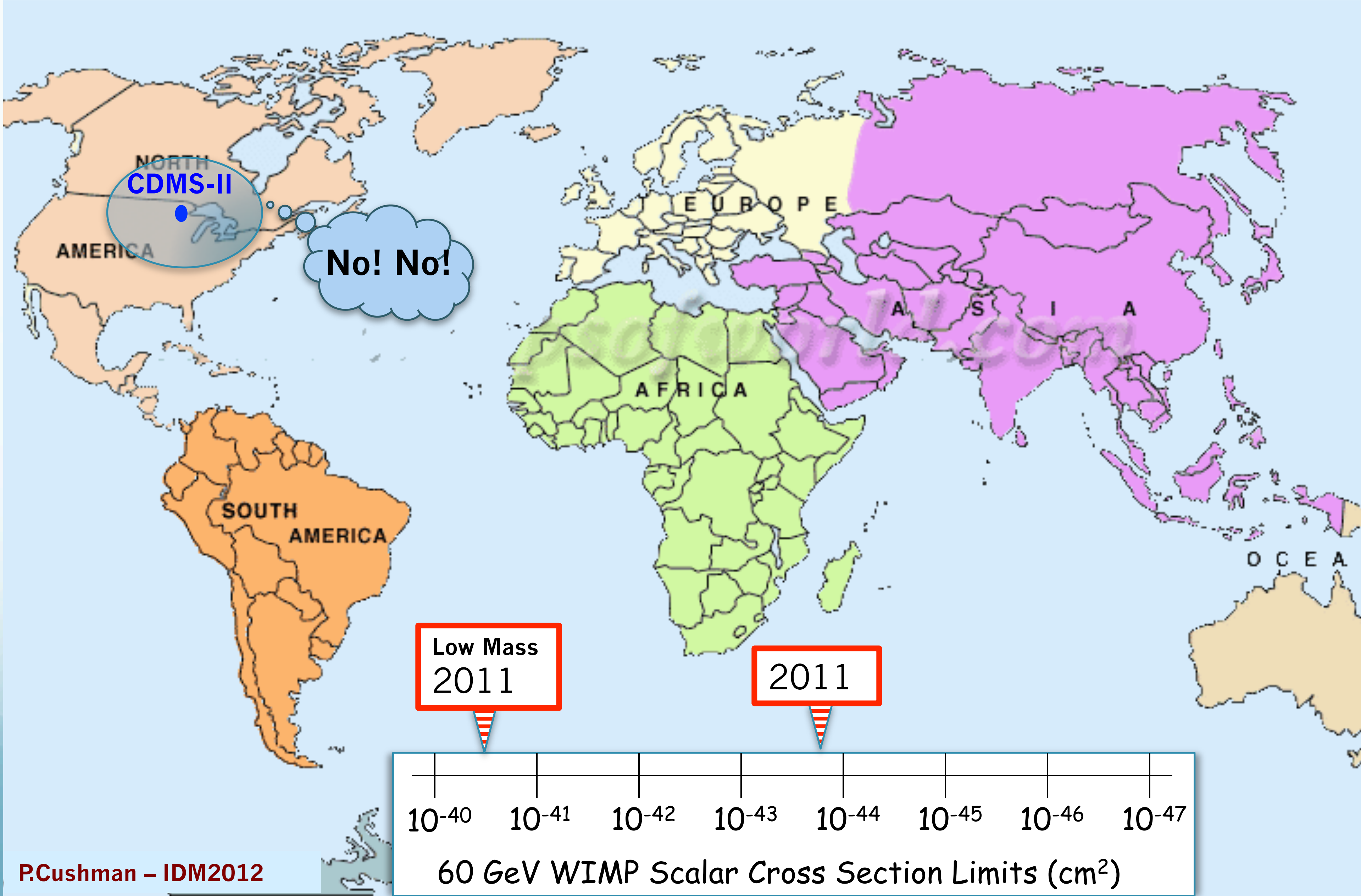

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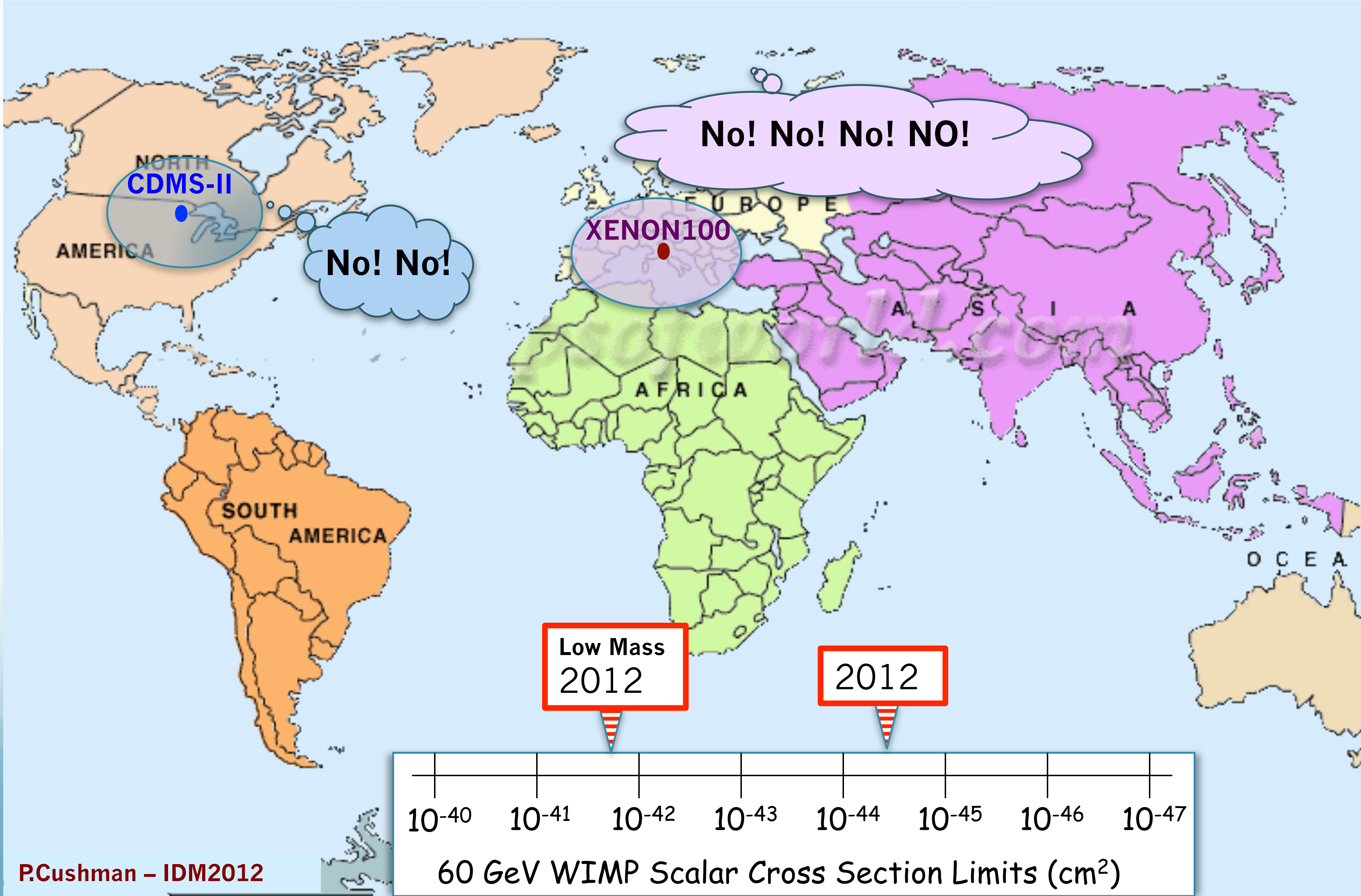


Current Situation

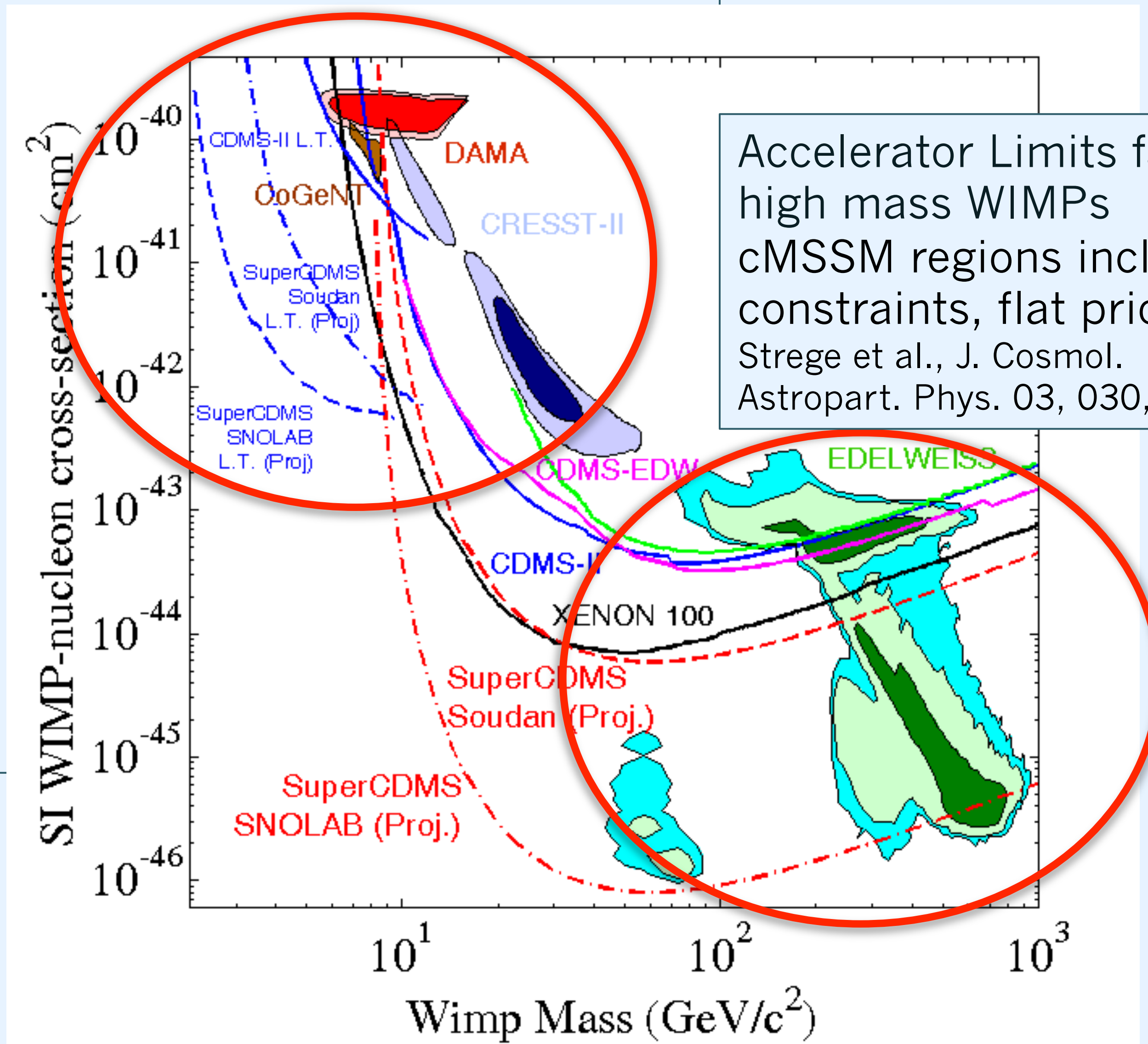
Hints from indirect detection
- γ–rays from galactic center (Fermi)
- synchrotron emission

+

DAMA ann. mod.

+

Excess in
- CoGeNT
- CRESST-II



Accelerator Limits favor high mass WIMPs
cMSSM regions incl. LHC constraints, flat priors
Strege et al., J. Cosmol. Astropart. Phys. 03, 030, (2012)

SuperCDMS Collaboration

California Institute of Technology
Z. Ahmed, J. Filippini, S.R. Golwala, D. Moore, R. Nelson

Fermi National Accelerator Laboratory
D. A. Bauer, F. DeJongh, J. Hall, D. Holmgren, L. Hsu, R.L. Schmitt, R. B. Thakur, J. Yoo

Massachusetts Institute of Technology
A. Anderson, E. Figueroa-Feliciano, S. Hertel, S.W. Leman, K.A. McCarthy,

NIST
K. Irwin

Queen's University
C. Crewdson, P. Di Stefano, J. Fox , O. Kamaev, S. Liu , C. Martinez, K. Page, P. Nadeau , W. Rau, Y. Ricci

Evansville College
A. Reisetter

Santa Clara University
B. A. Young

SLAC/KIPAC
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Southern Methodist University
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Stanford University
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University of Colorado Denver
B.A. Hines, M.E. Huber

University of Florida
T. Saab, D. Balakishiyeva, B. Welliver

FT-UAM/CSIC and Universidad Autonoma de Madrid
D. G. Cerdeño, L. Esteban, E. Lopez

University of Minnesota
H. Chagani, P. Cushman, S. Fallows, T. Hofer, M. Fritts, V. Mandic, M. Pepin, R. Radpour, A. Villano, J. Zhang

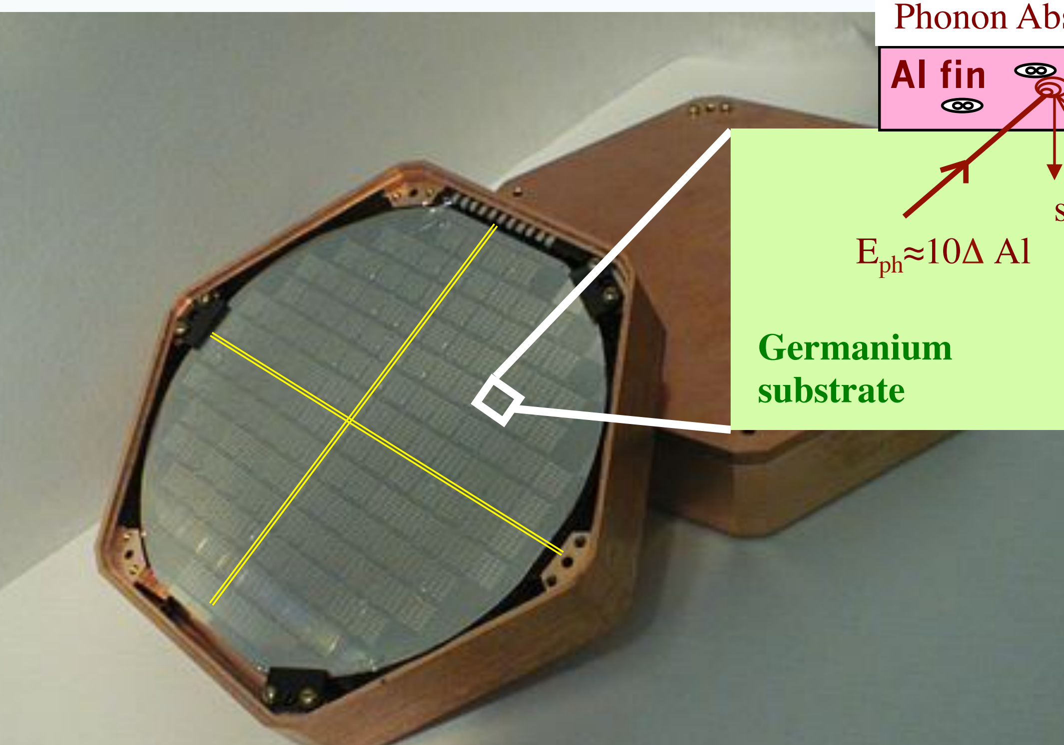
University of British Columbia
S. Oser, H. Tanaka

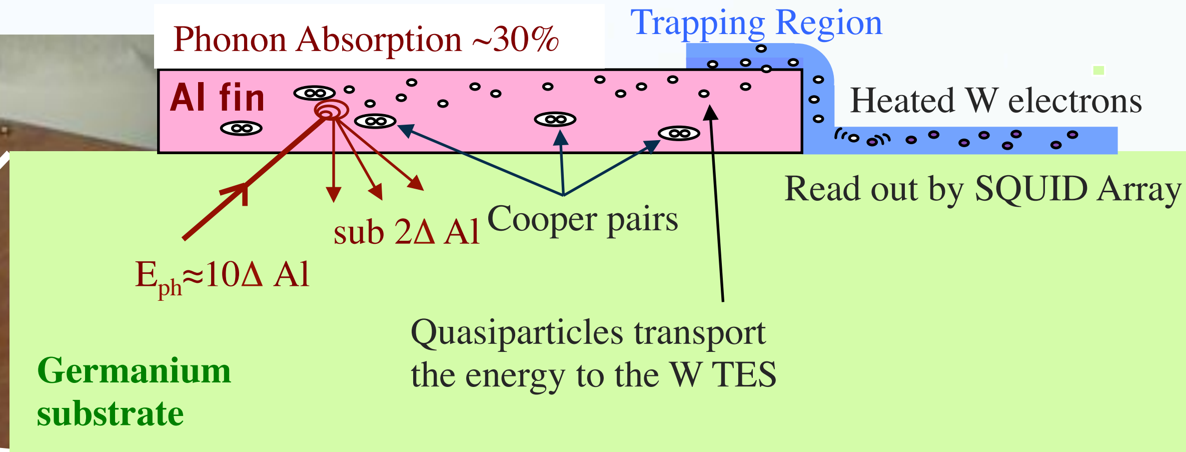
Z I P

CDMS Detectors (phonon readout)

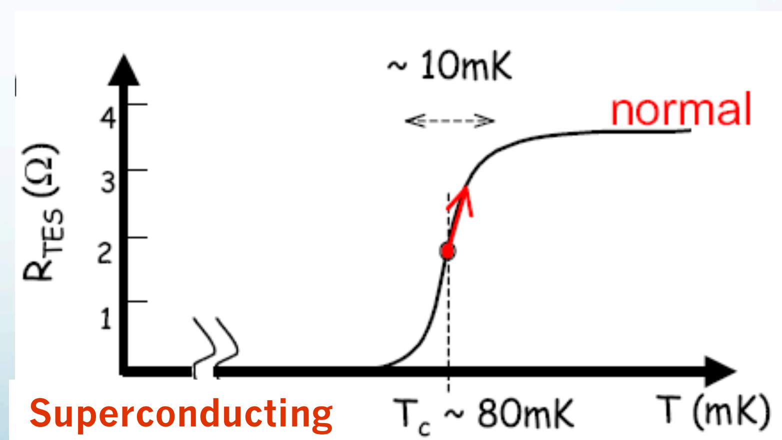
photolithographic patterning produces 4144 “thermometers”

(quasi-particle-assisted electrothermal-feedback transition-edge sensors)





1 cm thick x 7.5 cm diam crystals of
250 g Germanium or 100 g Silicon



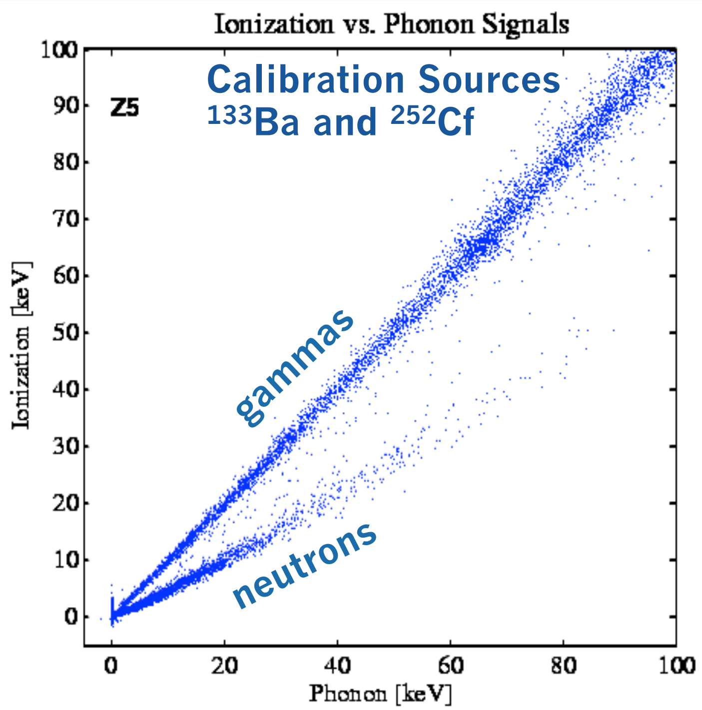
ZIP

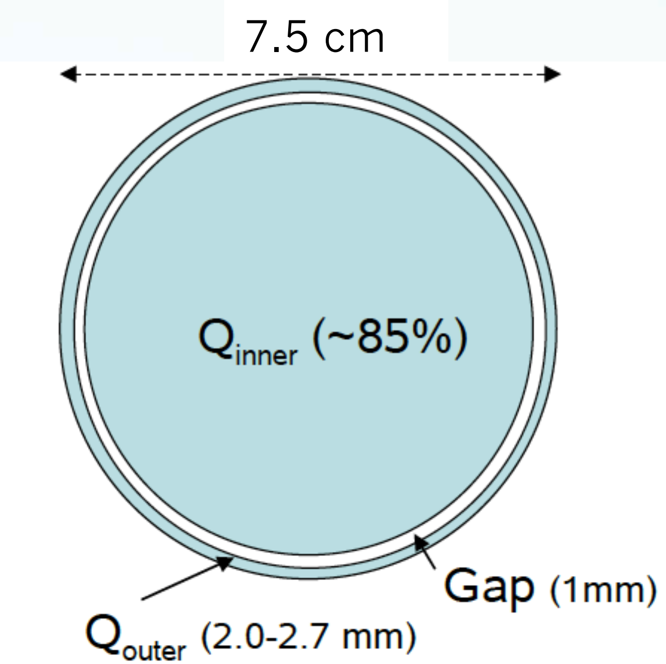
CDMS Detectors (ionization readout)

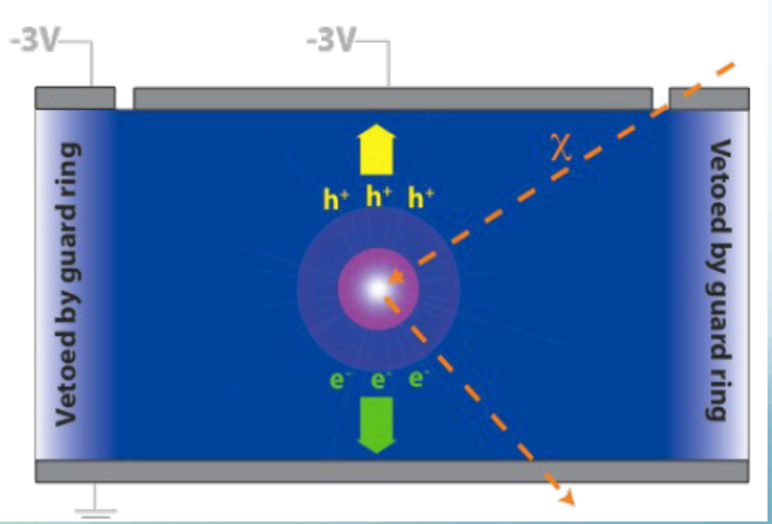
Concentric electrodes define a fiducial volume

Charge traps neutralized by
LED flashing on a regular basis

Combine with Phonon Signal to get
Discrimination between ER and NR





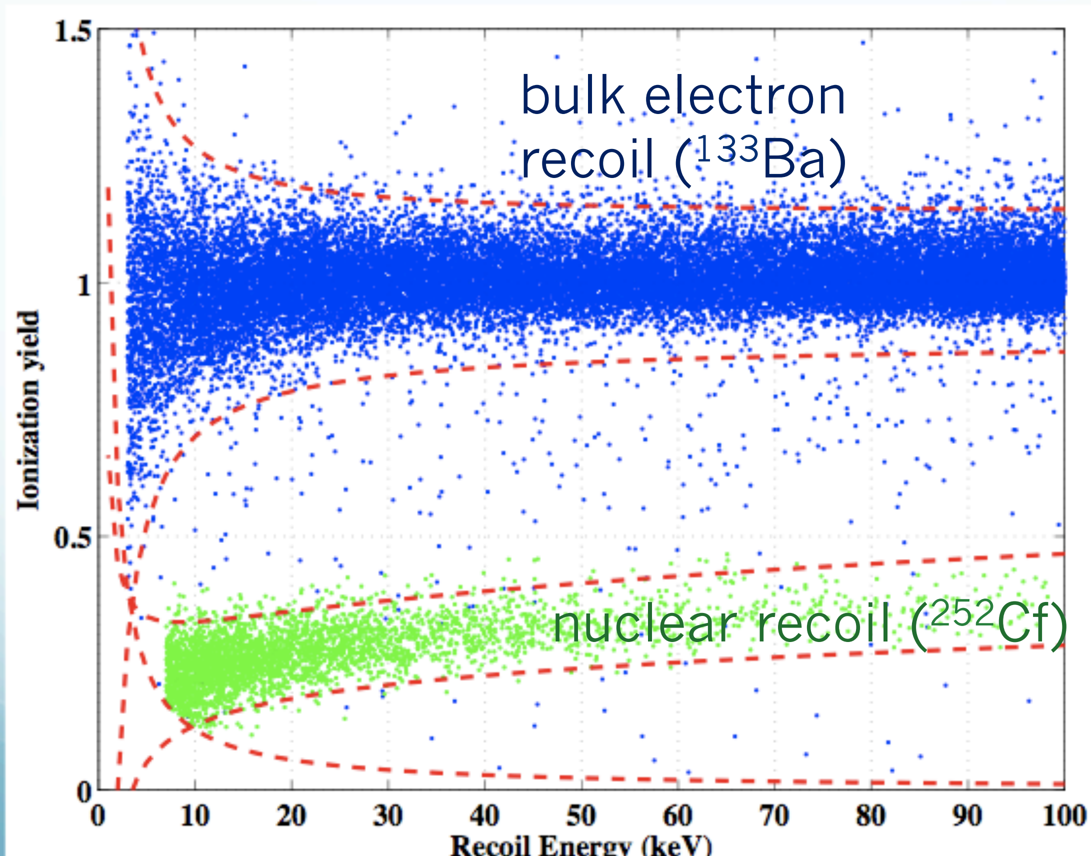


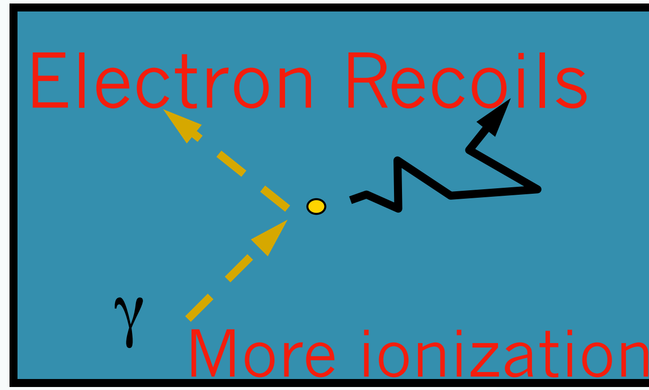
ZIP

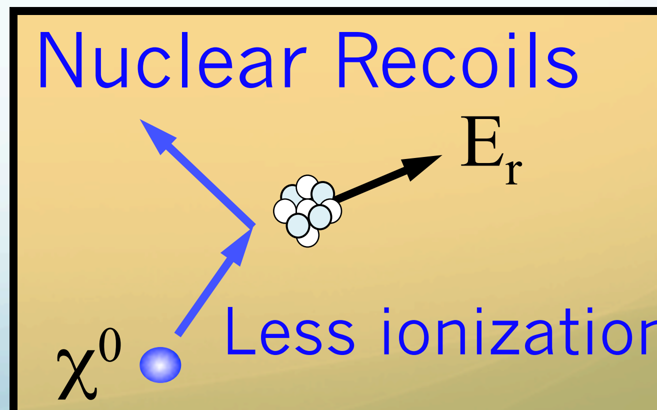
Yield = Bulk Gamma Rejection

$$= \frac{\text{ionization energy}}{\text{phonon energy}}$$

Primary electron recoil rejection >10,000:1







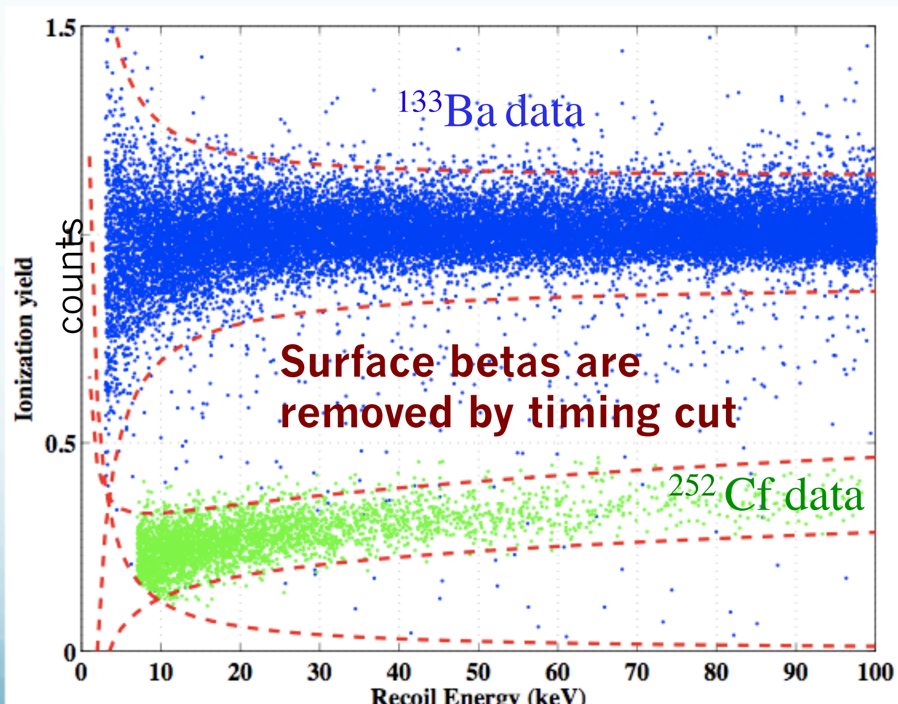
ZIP

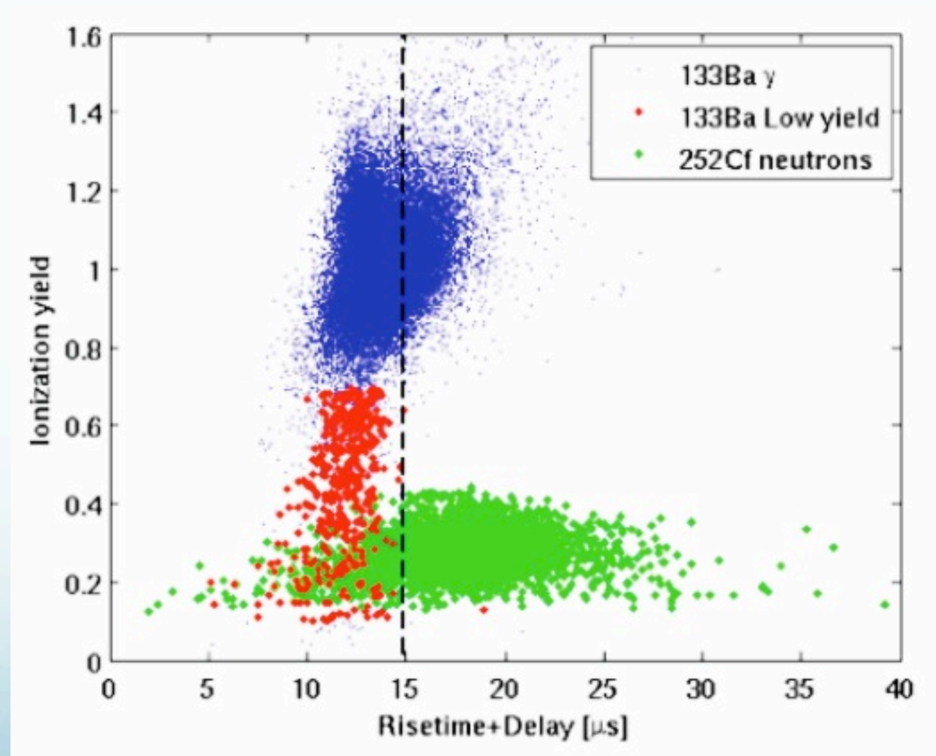
CDMS: Surface Event Rejection via phonon timing

Any trace β-emitters on a detector surface have incomplete ionization and can fake a nuclear recoil.

Yield = Normalized and position-corrected Ionization to Phonon ratio

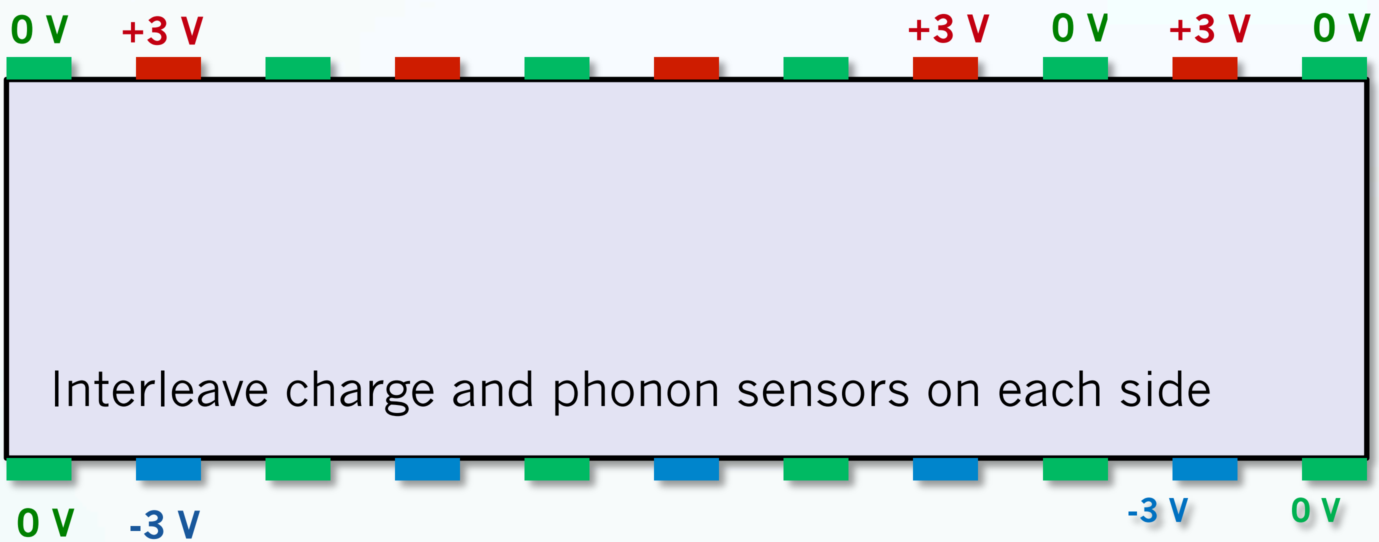
Calibration Data

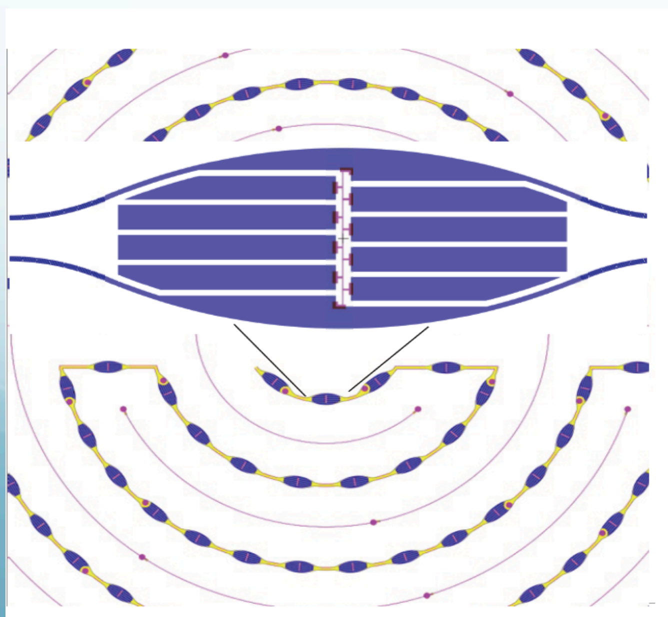


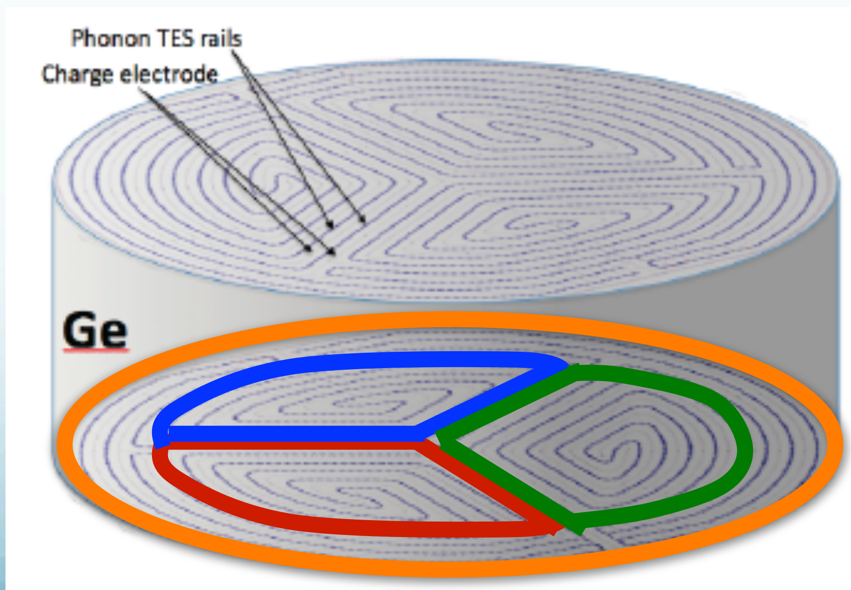


iZIP

SuperCDMS: Surface Event Rejection via interleaved electrodes







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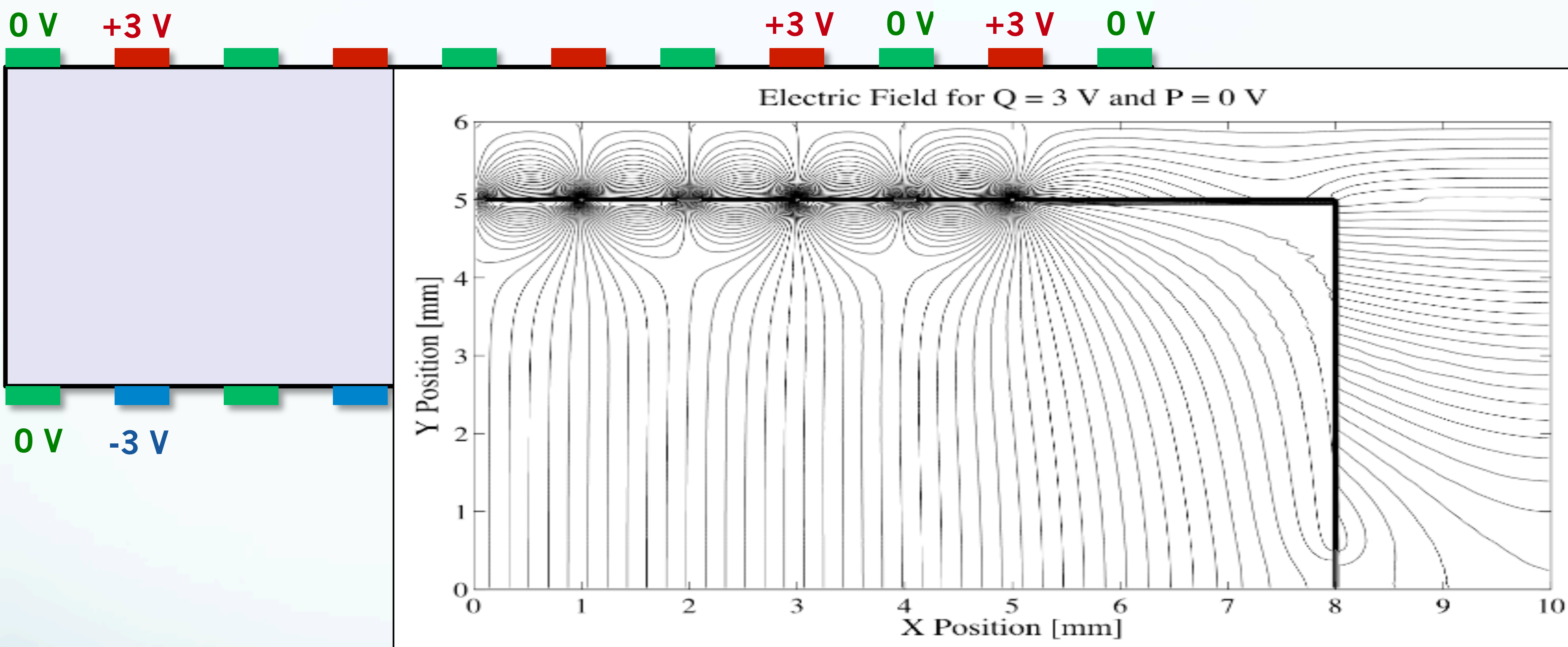
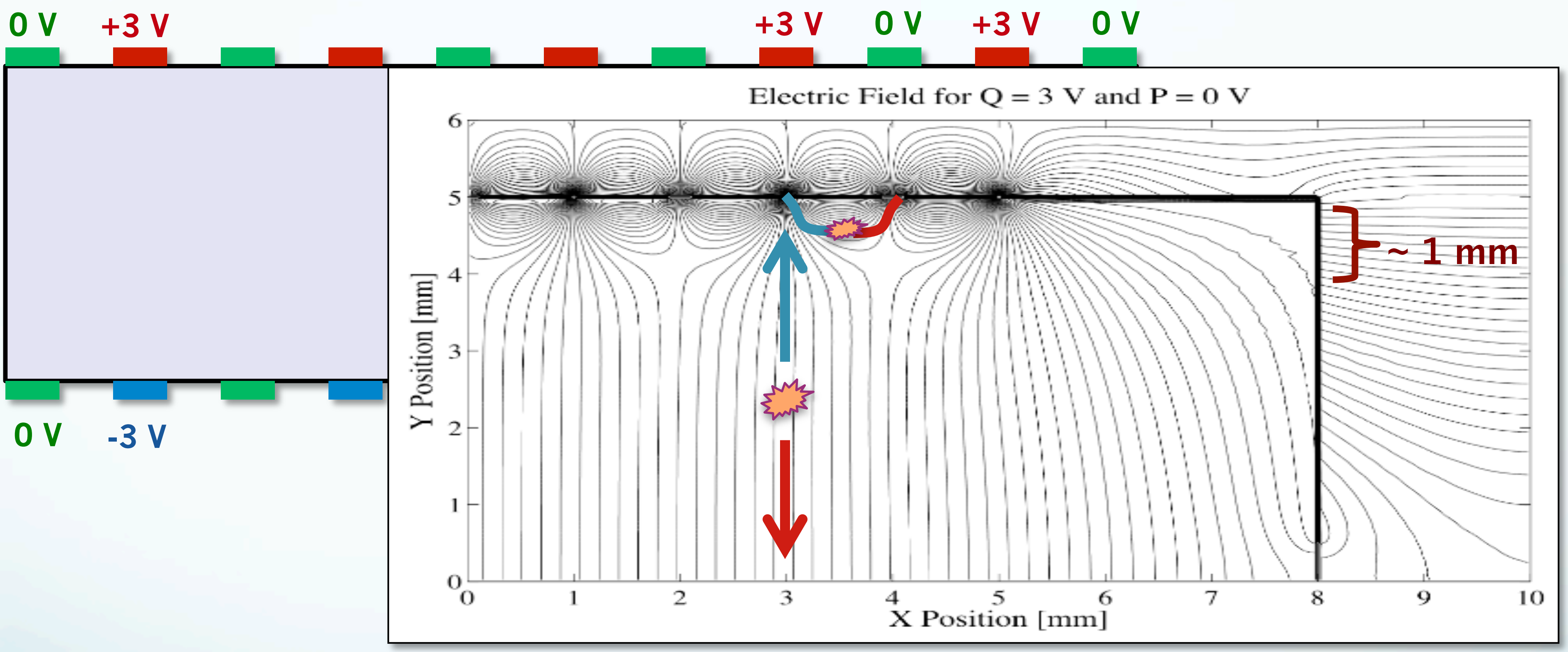


iZIP

SuperCDMS: Surface Event Rejection via interleaved electrodes

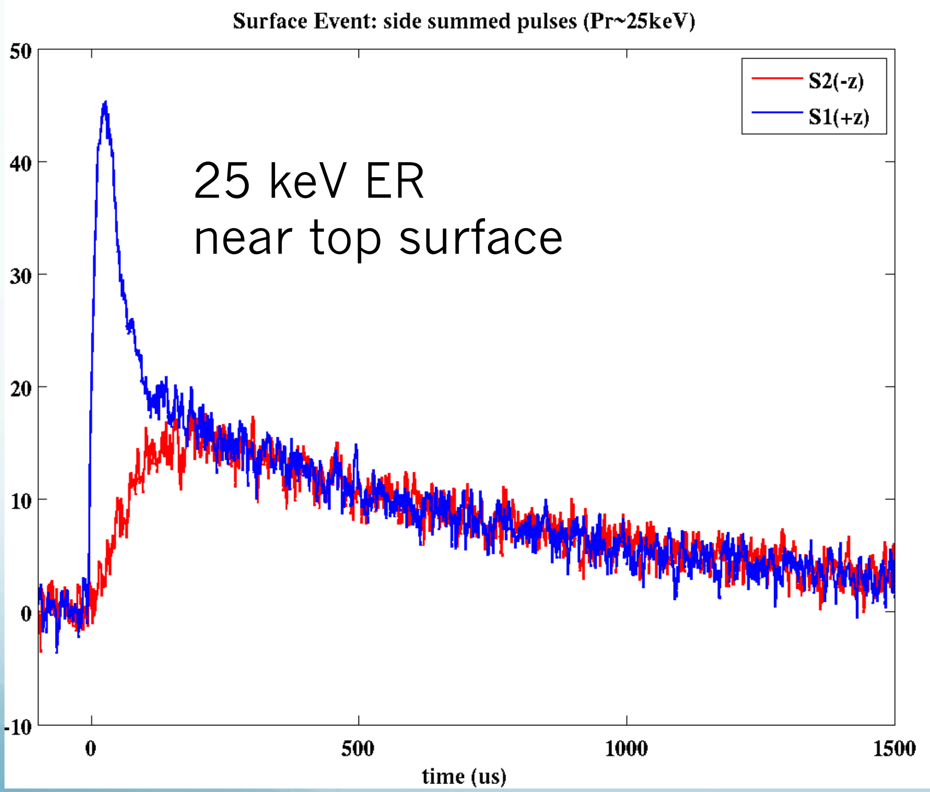


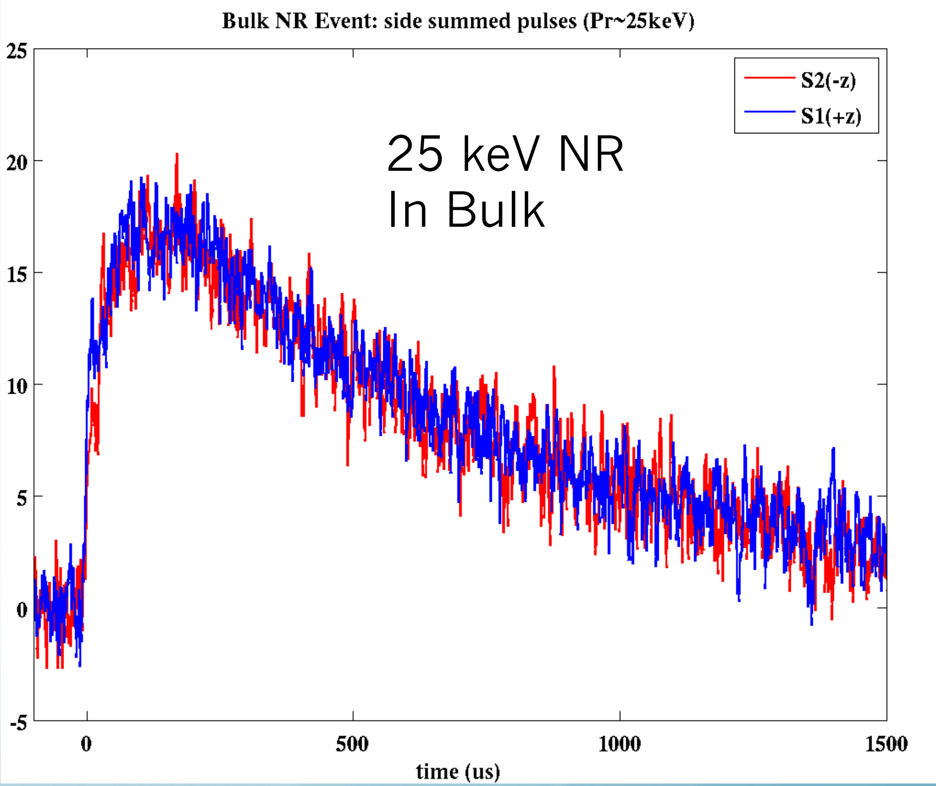
Surface events will fail a charge symmetry cut

iZIP

Still have rejection via phonons too!

Surface event discrimination can also be seen in phonon pulse shape differences (timing) and energy partition in z-direction



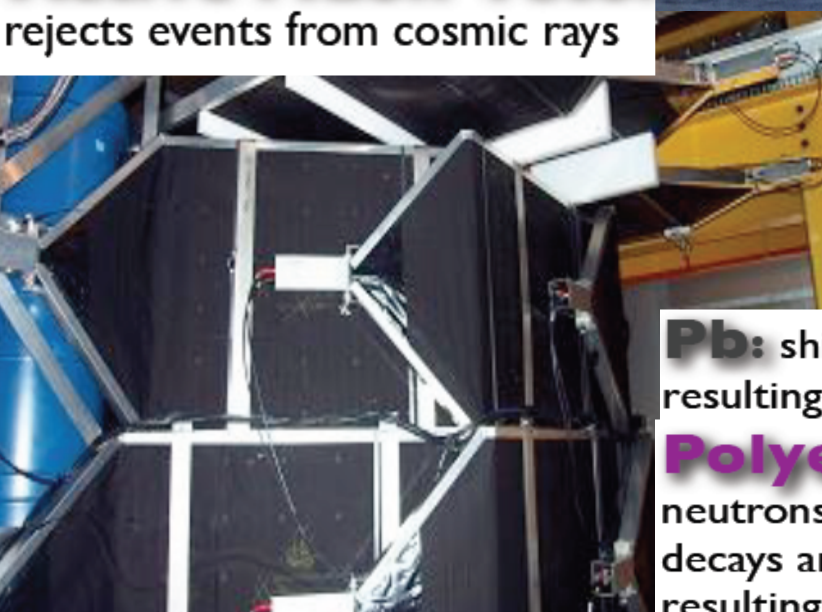


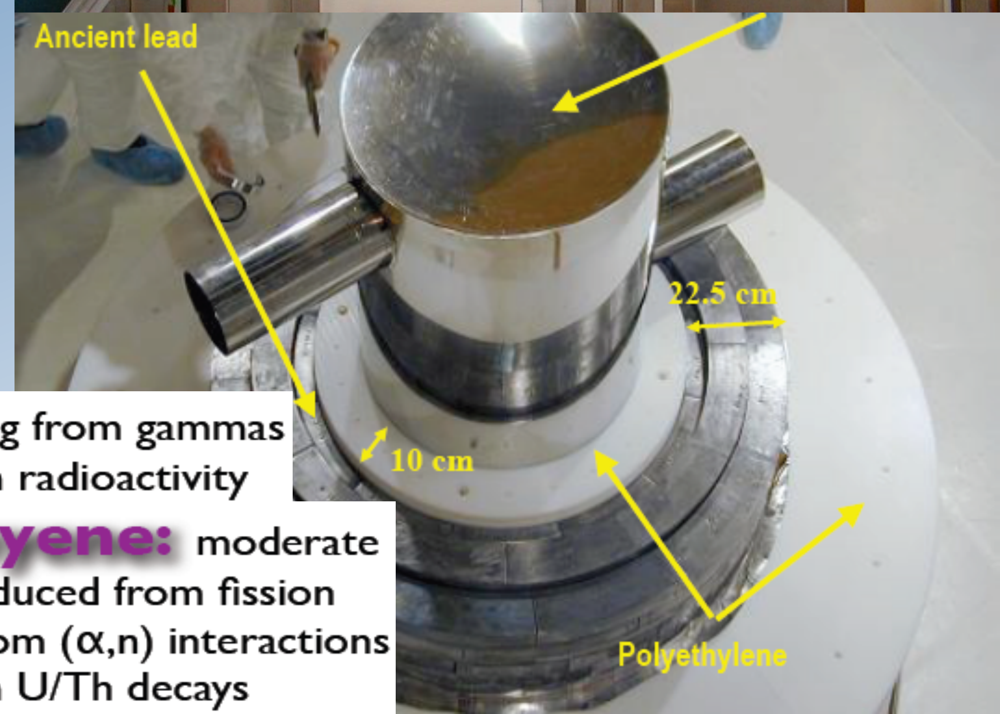
2100 mwe underground

Passive Shielding

Active Muon Veto:

rejects events from cosmic rays





Pb: shielding from gammas resulting from radioactivity

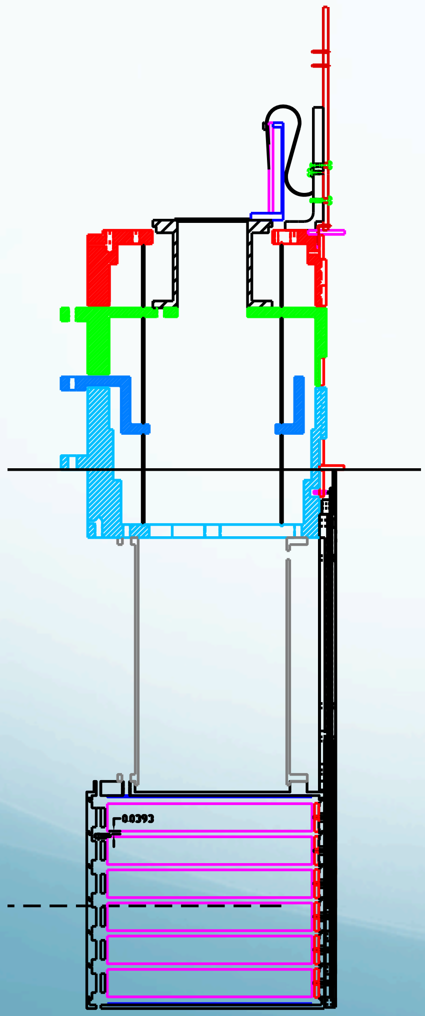
Polyethyene: moderate neutrons produced from fission decays and from (α,n) interactions resulting from U/Th decays

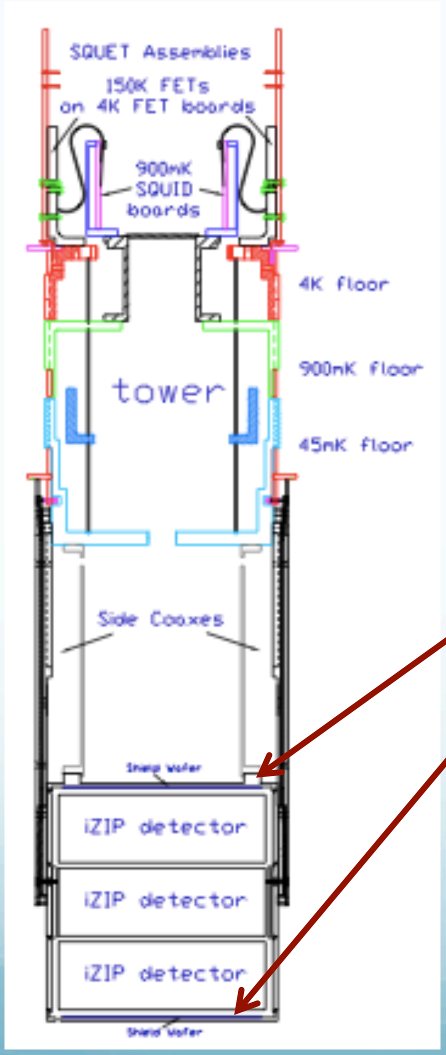

Tyvek


Fitting SuperCDMS into Soudan

CDMS II ZIP Tower

SuperCDMS Soudan iZIP Tower





Only 3 detectors per tower

Re-use CDMS electronics

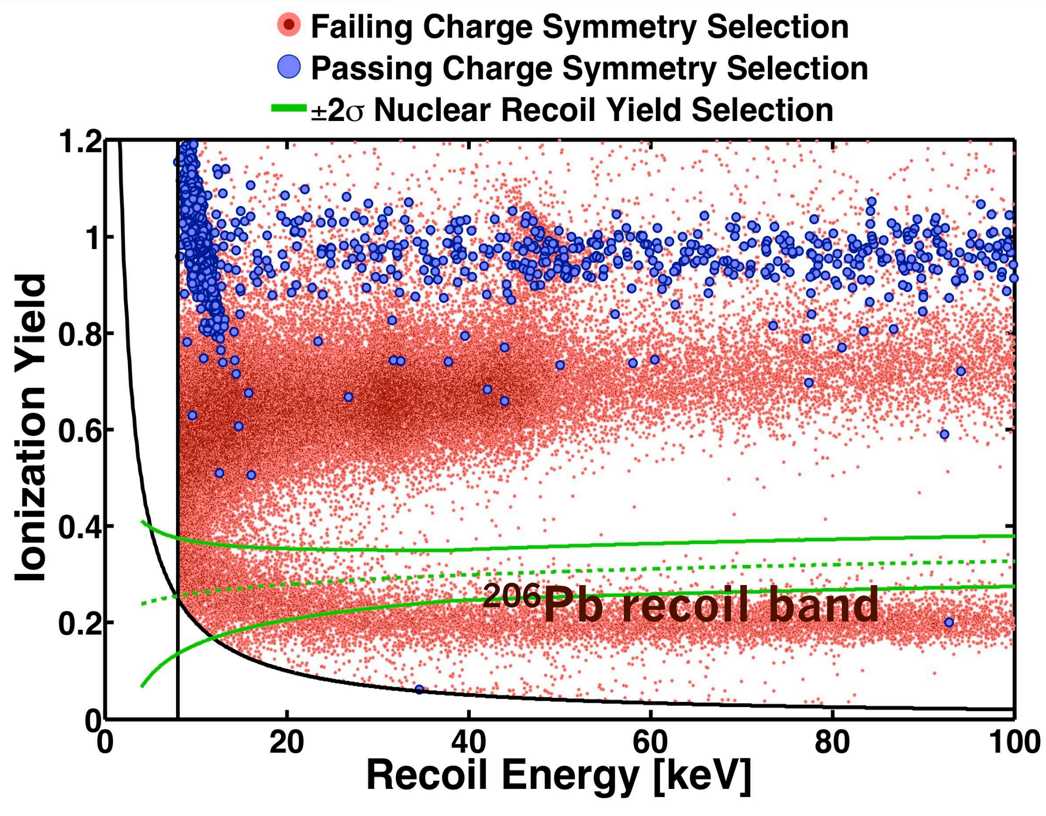
Total fiducial mass increased

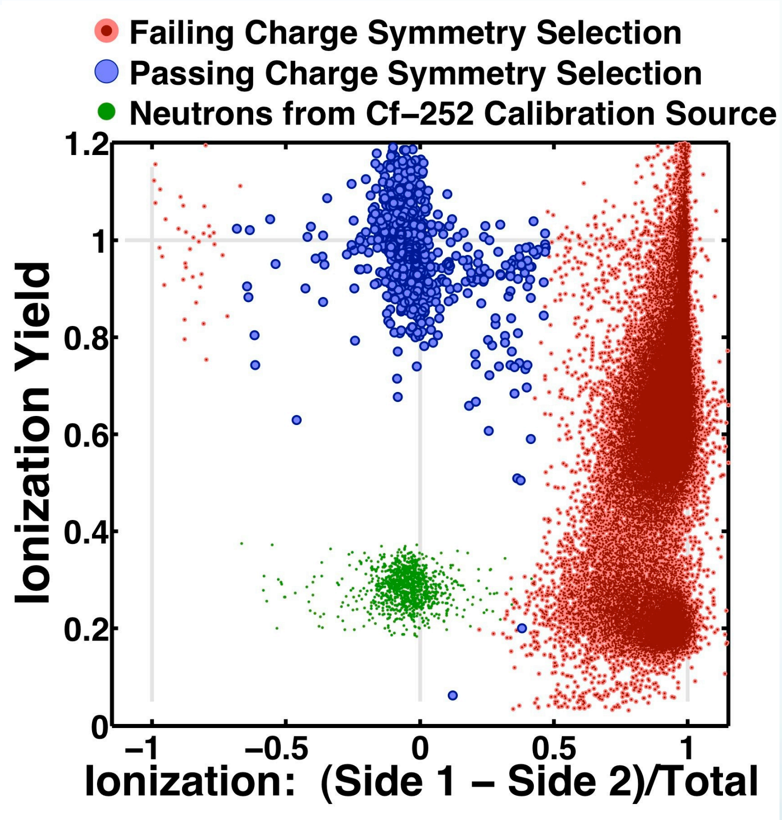
Tower 3 includes ^{210}Pb plated wafer sources (50 events/hour) to test surface evt rejection

Primary means of determining surface event rejection of iZIP

SuperCDMS Soudan Data: Surface Event Rejection

^{210}Pb ➔ $^{210}Bi^*/Bi$ ➔ ^{210}Po which then alpha decays to ^{206}Pb





Demonstrated Rejection (Soudan, 900 live hours with ^{210}Pb source)
<2.9 x 10^{-5} @ 63% WIMP fiducial cut

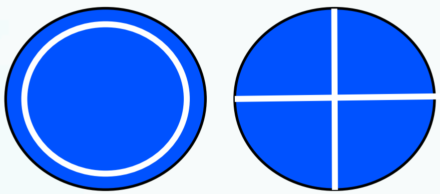
Demonstrated Rejection (surface test facility with ^{109}Cd source)
<2.9 x 10^{-5} @ 74% WIMP fiducial cut

An Evolving Detector

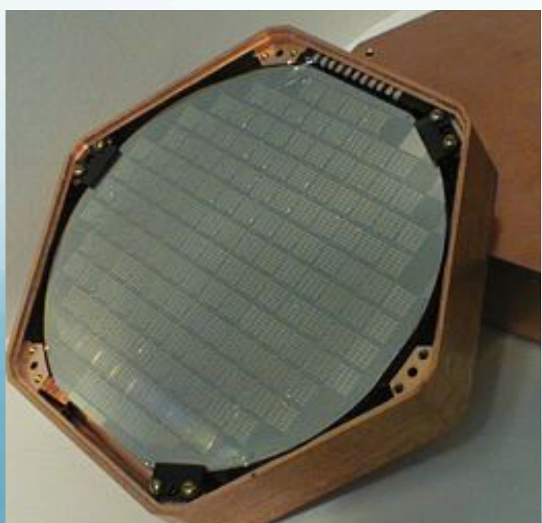
CDMS II

Single-sided
1 cm thick
3”diameter
250 g Ge

2 charge + 4 phonon



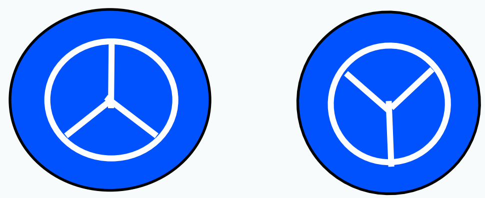
5 towers of 6 det each



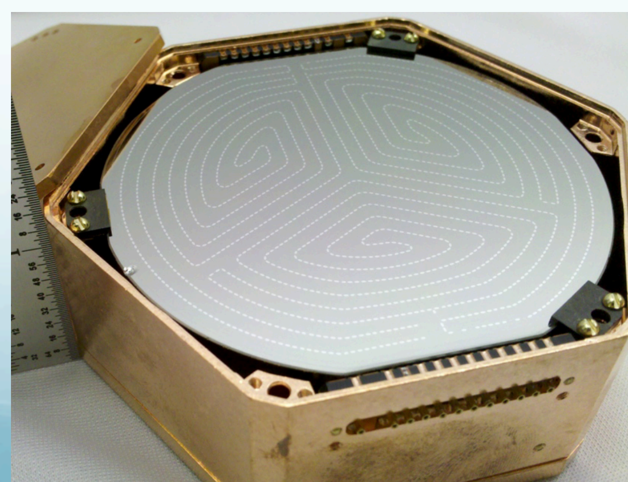
SuperCDMS Soudan

Double-sided
2.5 cm thick
3”diameter
620 g Ge

2 charge + 2 charge
4 phonon + 4 phonon



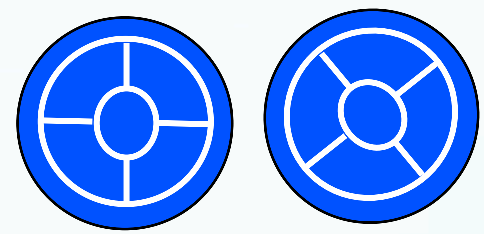
5 towers of 3 det each



SuperCDMS SNOLAB

Double-sided
3.3 cm thick
4”diameter
1.38 kg Ge

2 charge + 2 charge
6 phonon + 6 phonon



24 towers of 6 det each

An Evolving Detector

CDMS II

Papers Published

WIMP search 10<E<100keV
CDMS-Edelweiss Combined
Limits on Inelastic DM
Axion limits
Low threshold Ge
Annual Modulation
IDM talk by Scott A Hertel

Papers in process

Reanalysis: improved pulse-finding at low E_r with 4 analysis techniques
IDM talk by Joseph Kiveni
(Tom Hofer)

Silicon data from Reanalysis

Nuclear Recoil Energy Scale

SuperCDMS Soudan

Engineering run 2011
Physics run in progress

Demonstrate new interleaved technology

Establish excellent Background Rejection

$\sigma_{SI} \sim 5 \times 10^{-45}$ cm^2 for 60 GeV/c^2 WIMP

Concentrate on a competitive limit of $\sigma_{SI} \sim 10^{-41}$ for 5 GeV/c^2

Explore Luke phonon amplification mode
$\sigma_{SI} \sim 10^{-41}$ for 3 GeV/c^2 (80 keV$_{ee}$ threshold)

SuperCDMS SNOLAB

Ongoing R&D

100 mm detector
- procurement
- fabrication
- testing
- production (6 det/mo)

Readout improvements
- Tower engineering
- new SQUID arrays
- JFET ➔ HEMT

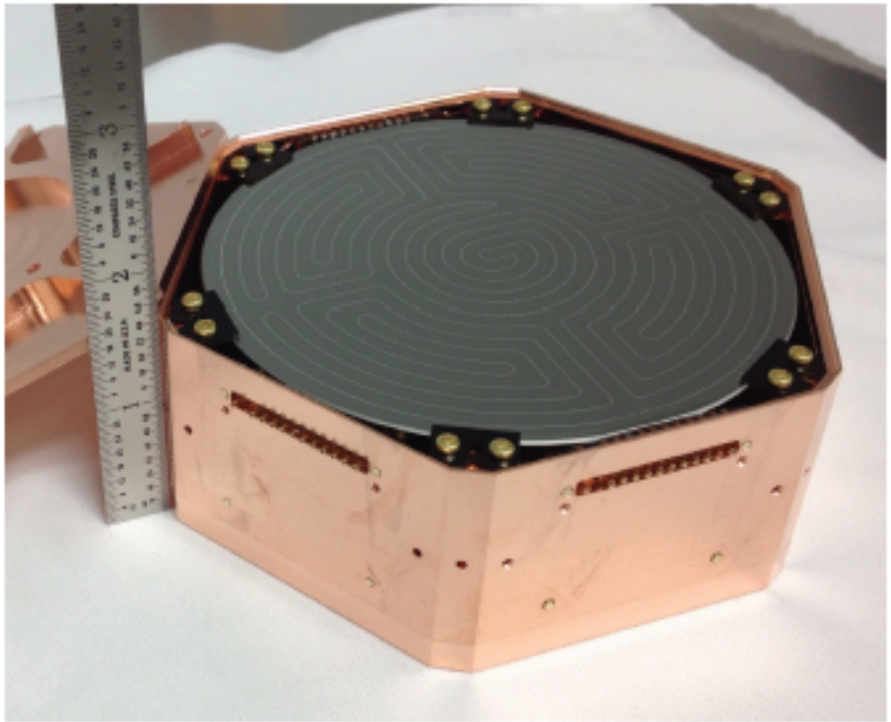
Installation @ SNOLAB
- Shielding design
- Cryogenic System
- Neutron Veto

IDM talk by Silvia Scorza

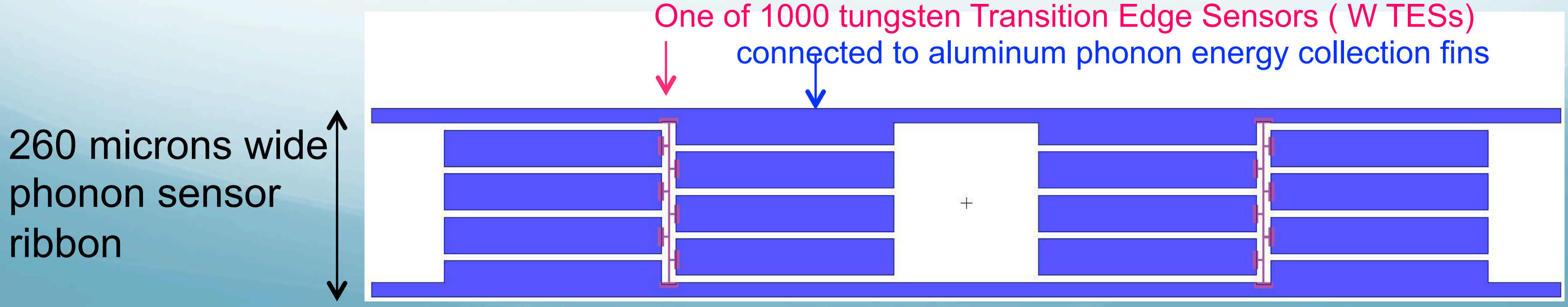
Run 200 kg for 4 years
$\sigma_{SI} < 8 \times 10^{-47}$ cm^2 for 60 GeV/c^2 WIMP

Testing 4" diameter Detector Now

See IDM talk by Hassan Chagani

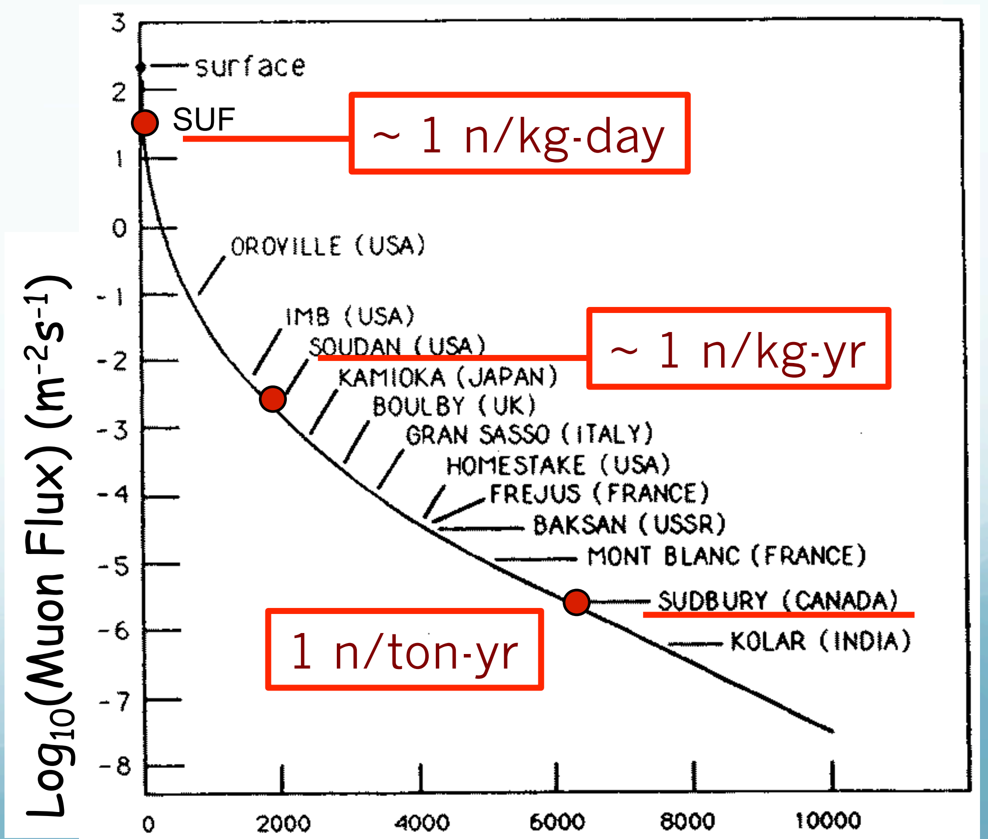


6-channel mask design is compatible with CDMS legacy electronics



CDMS Background Rejection keeps pace with Exposure

Experiment	Net Exposure	Cosmo neutrons	Shield neutrons	Surface events	Fiducial Volume
CDMS-I SUF	28 kg-d	18	---	2	---
CDMS-II Soudan	1 kg-y	.01	.07	1.2	37%
SuperCDMS Soudan	6 kg-y	.07	.34	.005	68%
SuperCDMS SNOLAB	385 kg-y	.03	.1	<.24	73%



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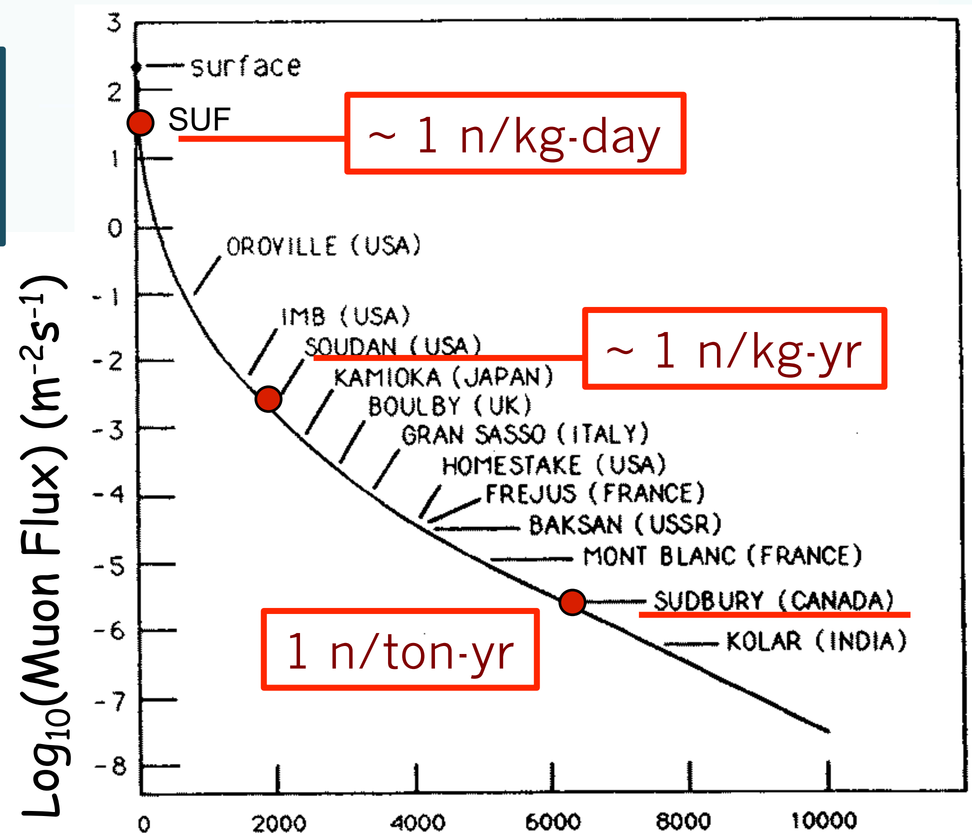
The beauty of SuperCDMS technology
Bulk photon rejection 10^{-7}
Surface "beta" rejection 10^{-5}



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The beauty of SuperCDMS technology
Bulk photon rejection 10^{-7}
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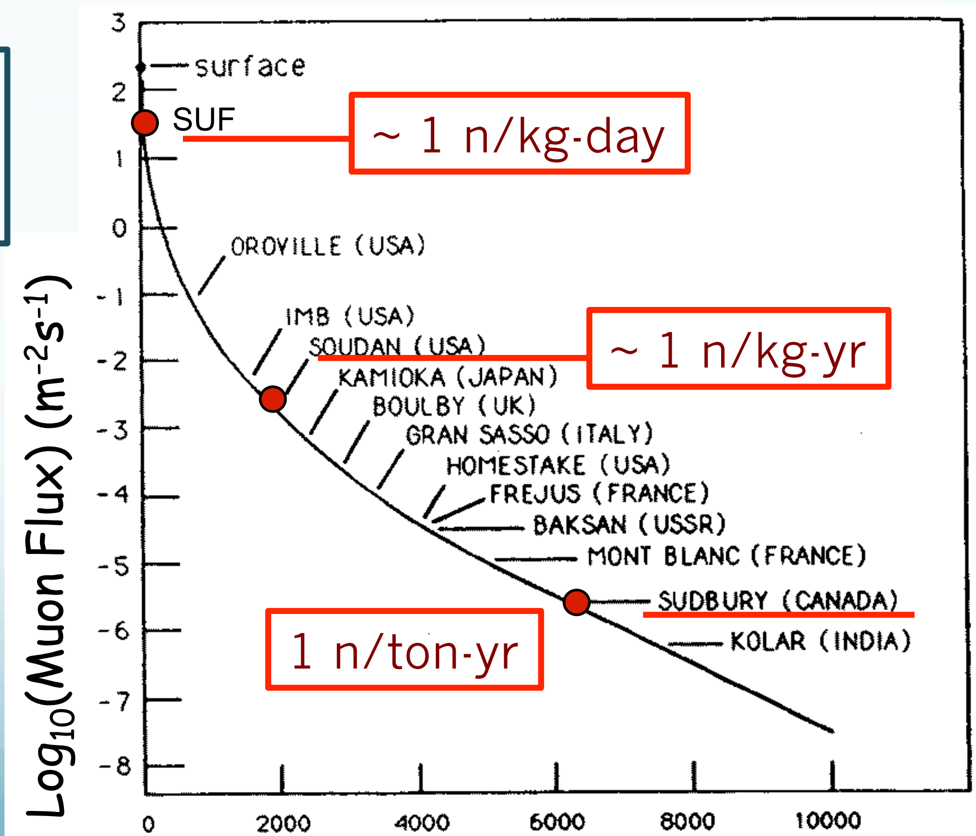
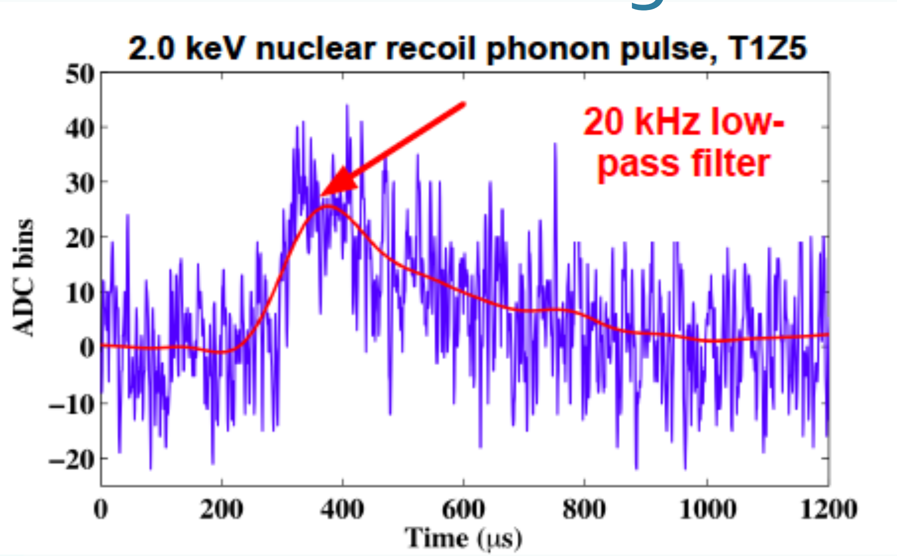
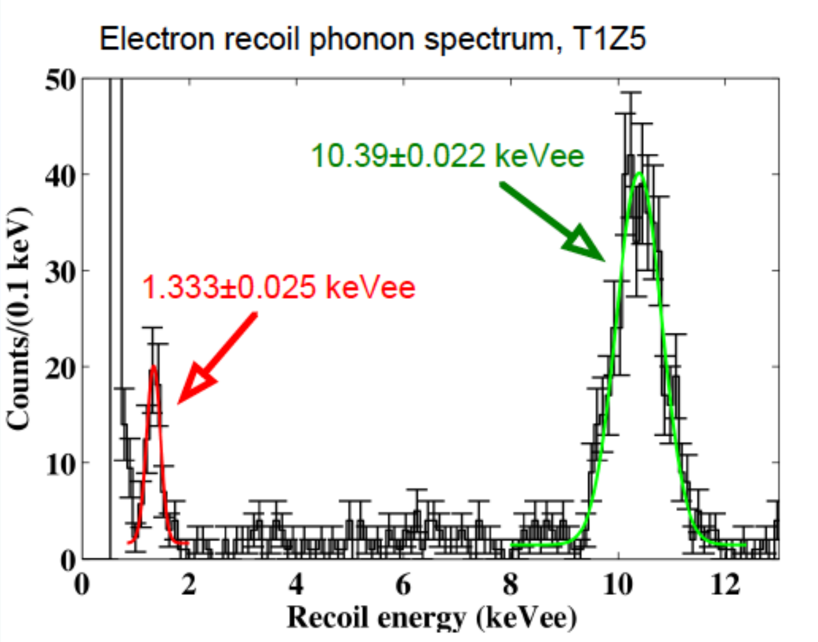
No muon veto at SNOLAB
Neutron veto/monitor could reduce dependence on shielding radiopurity



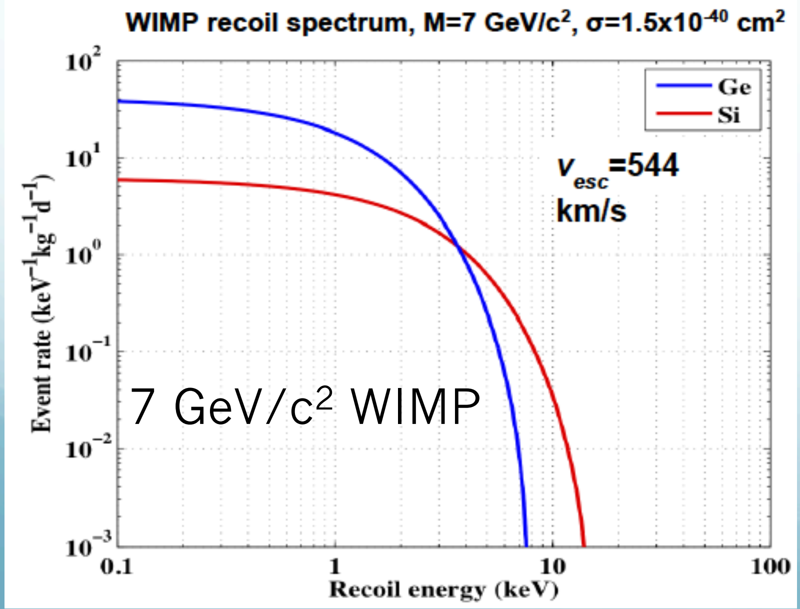
Moving to Lower Thresholds



Phonon signal is still reasonable,
But risetime is less useful



phonon and ionization energy calibration uses the $^{71}Ge \rightarrow {}^{71}Ga$ neutron activation lines from the ^{252}Cf source run



Germanium still wins out for 5-10 keV
Silicon may do better for 2-5 keV

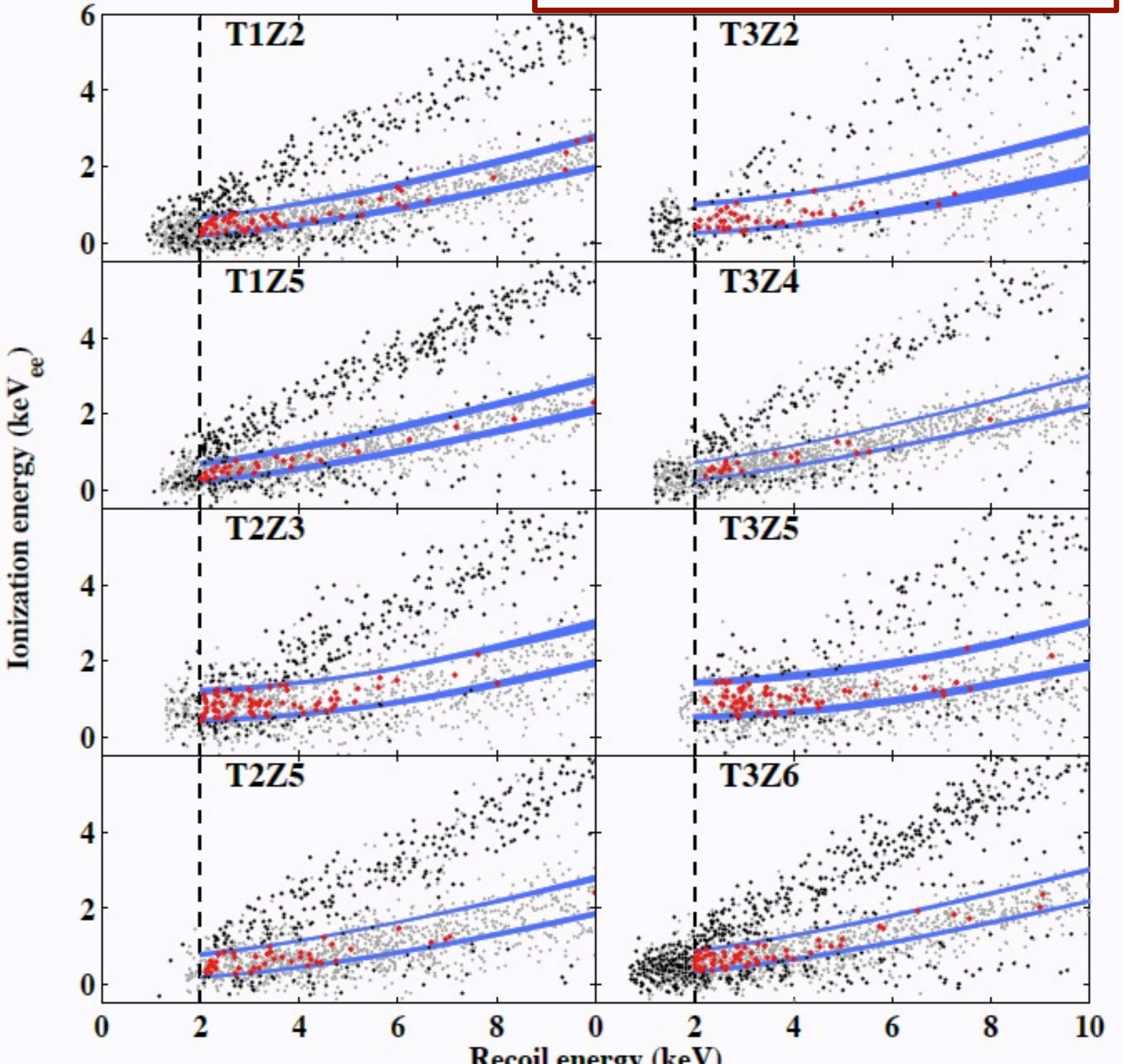
CDMS Candidate Selection

Black: WIMP search data
Red: Candidate NR
Blue: NR band def'n
Grey: ^{252}Ca Calibration

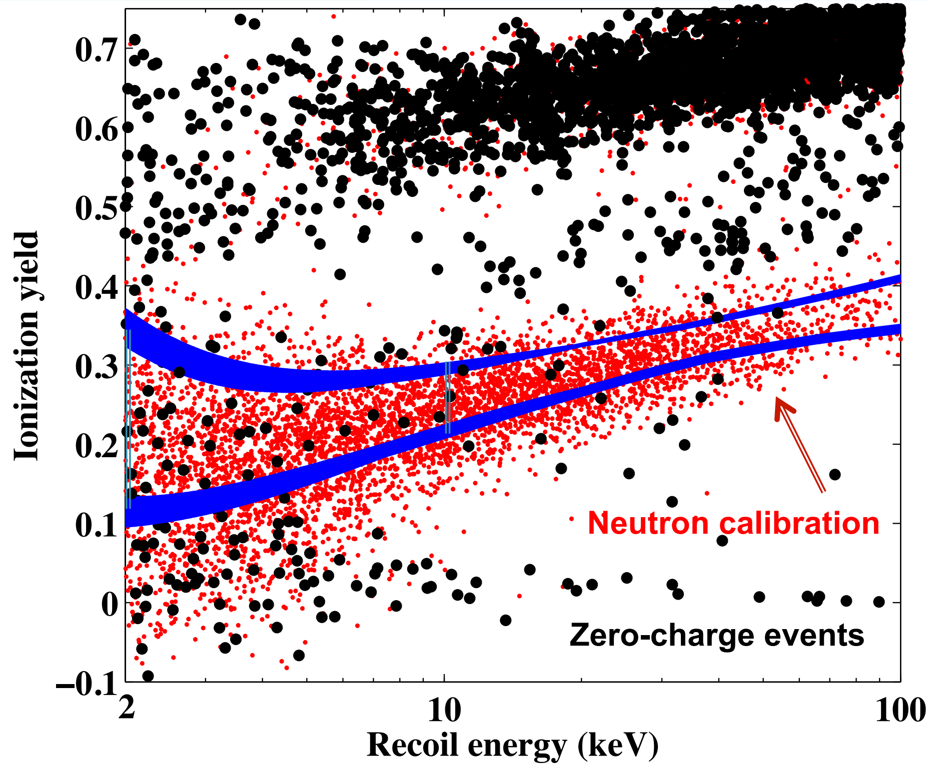
Nuclear recoil acceptance region (+1.25, -0.5) σ band in **ionization energy**

Phonon threshold cut
$E_p > 6\sigma$ noise

Recoil threshold cut
$E_r > 2$ keV.



Yield for best detector (T1Z5)



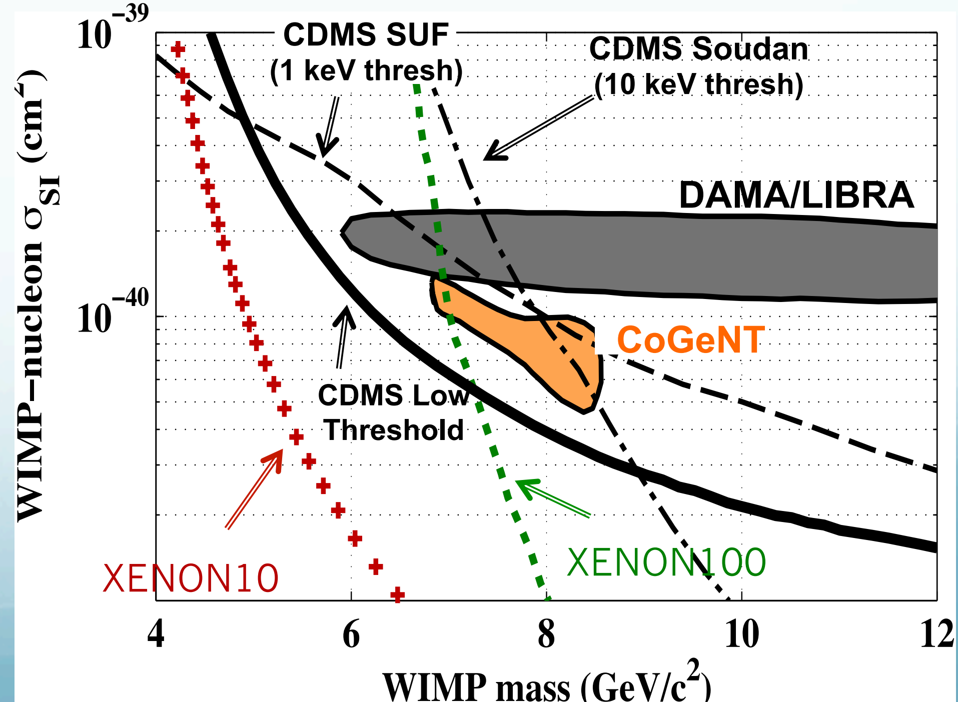
What do we give up at low threshold ?

Risetime compromised ➔ No phonon timing cut

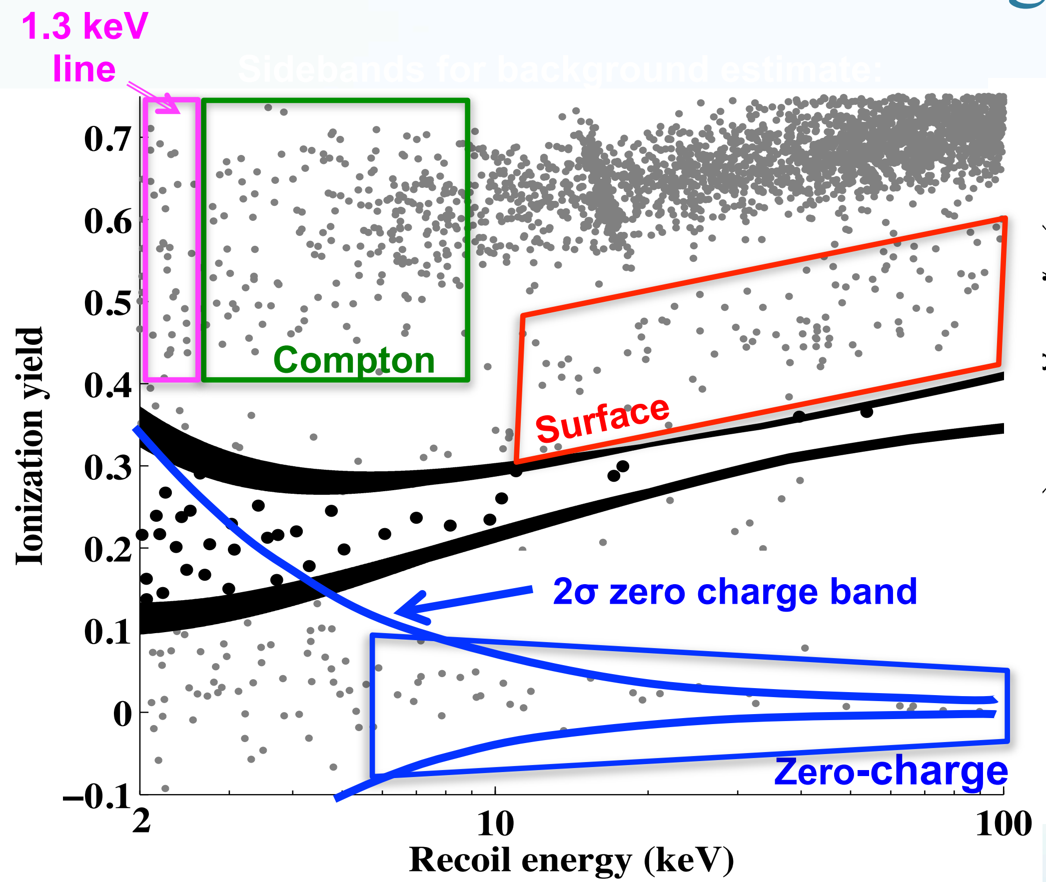
Ionization signals too small ➔ No fiducial cut

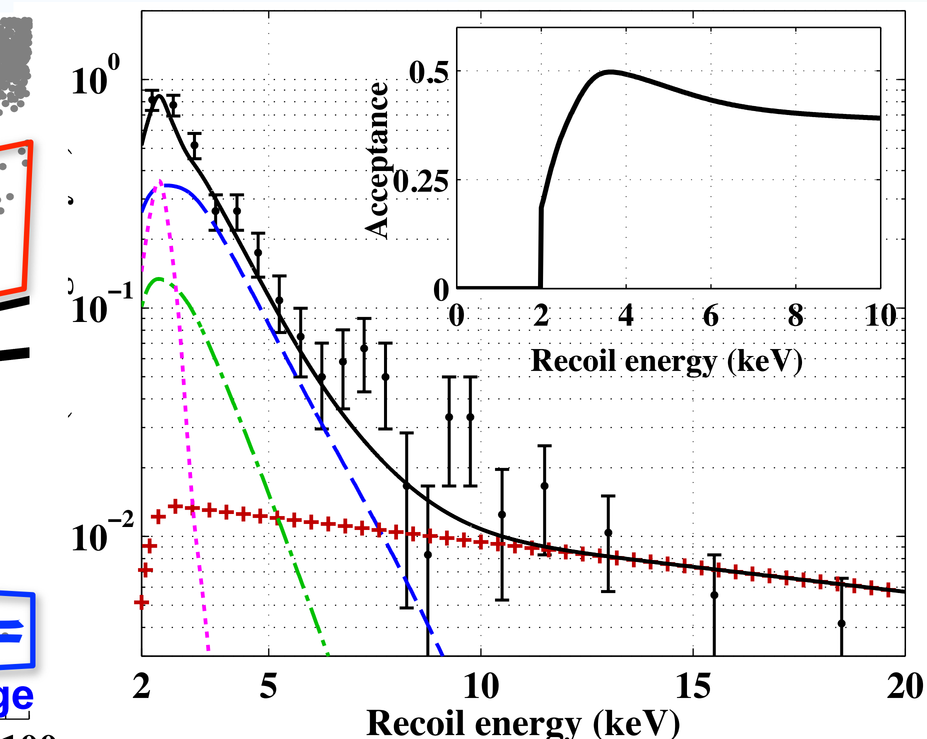
No longer "background-free"

Optimum Interval method sets 90% CL limits in the presence of ALL events in band



However, all candidate events are consistent with Background

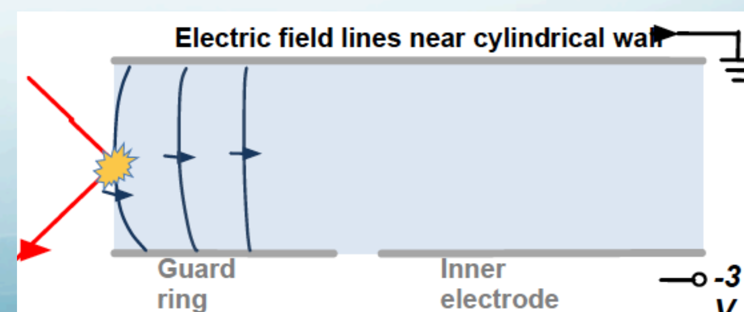




Dominated by **zero charge events.**

As fiducial cut fails and penetration depth decreases

SuperCDMS will do much better



SuperCDMS will target the low threshold region early !

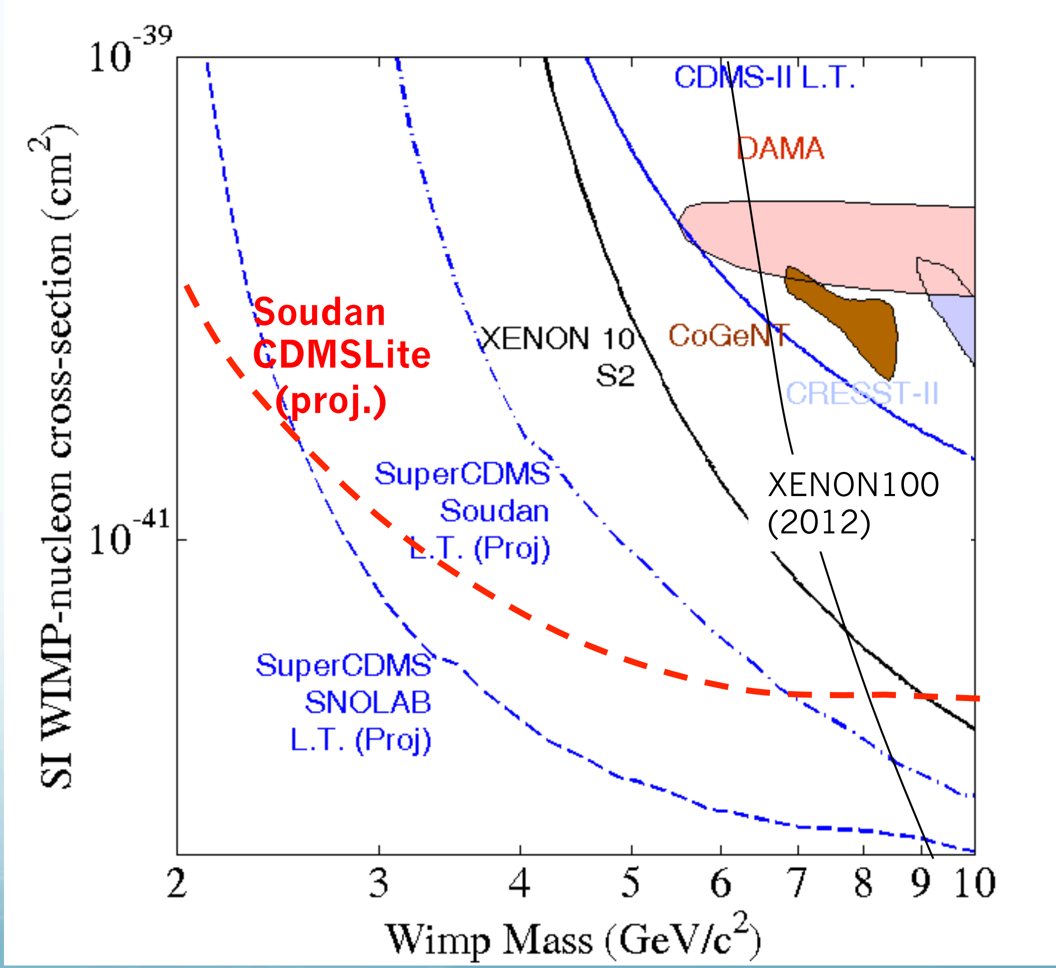
Zero charge events are already much less in the current run with iZIPs

Additional handles in data:
- phonon outer ring fiducial cut
- many new parameters to study
  - e.g. phonon z-partition

Better understanding of the phonon and charge propagation physics with a sophisticated new detector Monte Carlo

See IDM talk by Daniel Brandt

Run a subset of detectors at high bias voltage to amplify phonon signal: "CDMSLite"



CDMSLite: **L**ow **I**onization **T**hreshold **E**xperiment

See IDM talk by Ritoban Basu Thakur

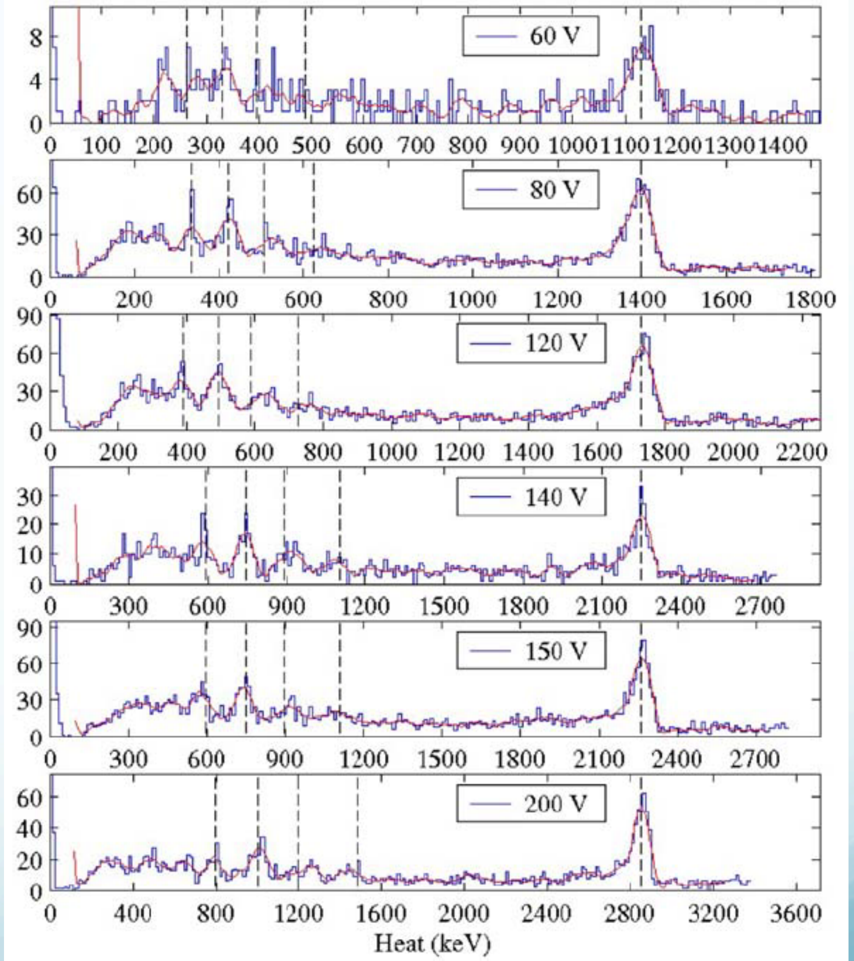
$$E(\text{phonon}) = E(\text{recoil}) + \frac{eV_b}{\varepsilon} E(\text{charge})$$

Luke Phonons interfere with timing cut and complicate yield discrimination
So CDMS runs with V_b <10 (Luke Gain ~ 2) to minimize effect

For low threshold, crank up the gain and lose the separate ionization channel.

For V_b ~ 70 v (Ge iZIP stable running)
Gain ~ 24
Threshold ~ 85 eV_{ee}

Early CDMS Silicon ZIP tests



^{241}Am lines (14, 18, 21, 26 and 60 keV)

D.S. Akerib et al. NIM A520 (2004)

SuperCDMS provides complementary technique and competitive limits for a broad range of WIMP masses

iZIP technology provides a **compact**, **modular** approach with a **wealth of information** on an event-by-event basis.

Background rejection is already sufficient for ton-scale experiments

bulk photon leakage: **10^{-7}** Surface event rejection: **10^{-5}**

Soudan Runs (2012-14)

Demonstrate iZIP operation and final background reduction

Run still statistics-limited, but data and simulation ➔ already achieved !

Confirm limits for 60 GeV WIMP with germanium technology

Explore new parameter space for low mass WIMPs

Better discrimination at low energy

A long stable run could provide new annual mod. and axion limits.

2013 R&D

Scale up our detectors to higher mass. *Already testing the 4" detectors*

Streamline detector fab ➔ 6 iZIPs per month

Prepare new tower hardware, readout electronics, DAQ, Cryo and shield

SNOLAB 200 kg (24 towers) run gets us to $< 8 \times 10^{-47}$ cm^2 @ 60 GeV/c^2 running at SNOLAB (deeper site, higher purity shielding)