Hunting WIMPs - the XENON experiment

Eirini Tziaferi

University of Zürich

11 Deutsche Physikerinnentagung, 1 - 4/11/2007, Osnabrück

The XENON10 Collaboration

Columbia University Elena Aprile, Bin Choi, Karl-Ludwig Giboni, Sharmila Kamat, Yun Lin, Maria Elena Monzani, Guillaume Plante, Roberto Santorelli and Masaki Yamashita

University of Zürich Laura Baudis, Jesse Angle, Ali Askin, Martin Bissok, Alfredo Ferella, Marijke Haffke, Alexander Kish, Aaron Manalaysay, Stephan Schulte, Eirini Tziaferi

Brown University Richard Gaitskell, Simon Fiorucci, Peter Sorensen and Luiz DeViveiros

Lawrence Livermore National Laboratory Adam Bernstein, Chris Hagmann, Norm Madden and Celeste Winant

Case Western Reserve University Tom Shutt, Peter Brusov, Eric Dahl, John Kwong and Alexander Bolozdynya

Rice University Uwe Oberlack, Roman Gomez, Christopher Olsen and Peter Shagin

Yale University Daniel McKinsey, Louis Kastens, Angel Manzur and Kaixuan Ni

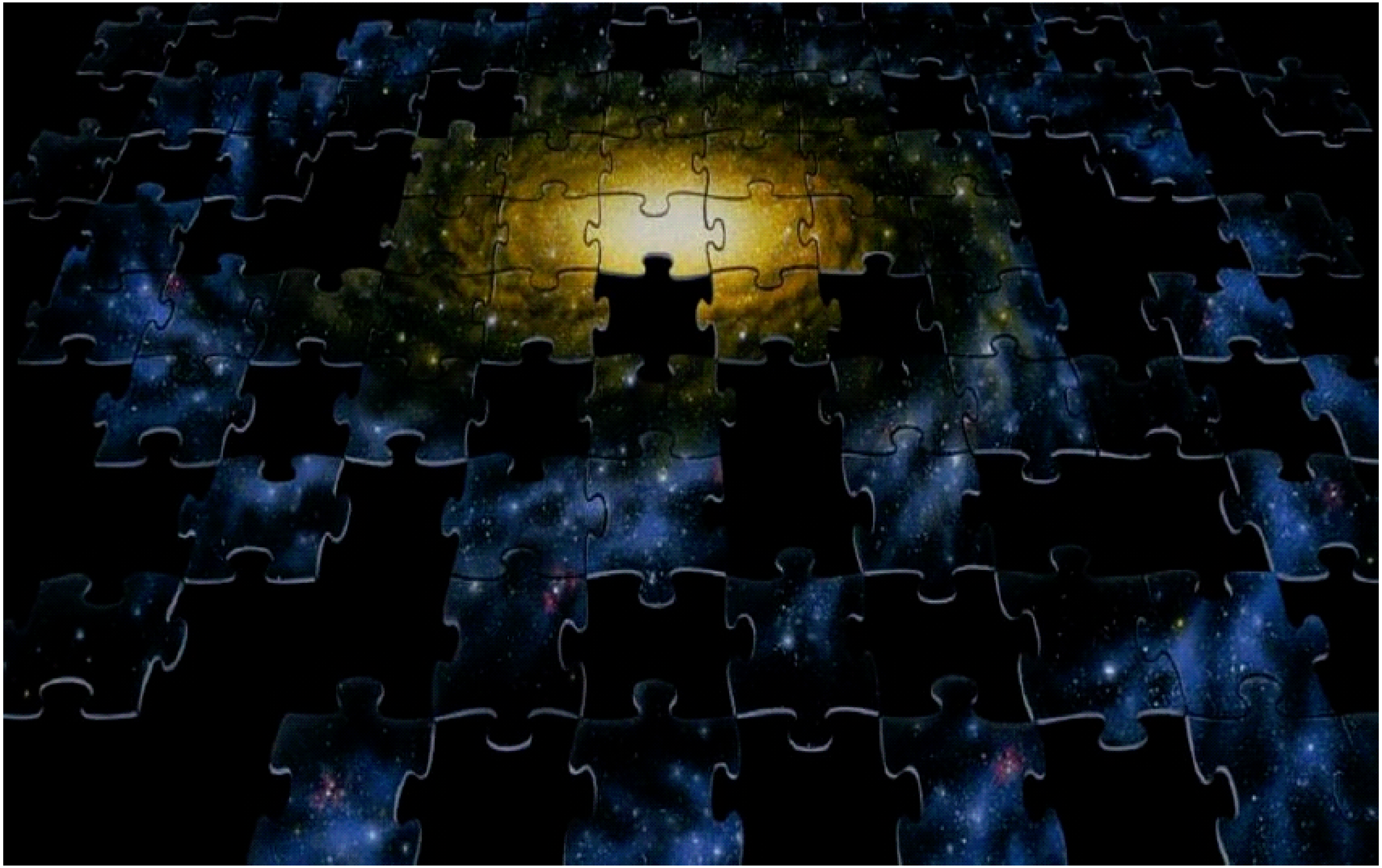
LNGS Francesco Arneodo and Serena Fattori

Coimbra University Jose Matias Lopes, Luis Coelho, Luis Fernandes and Joaquin Santos

Contents

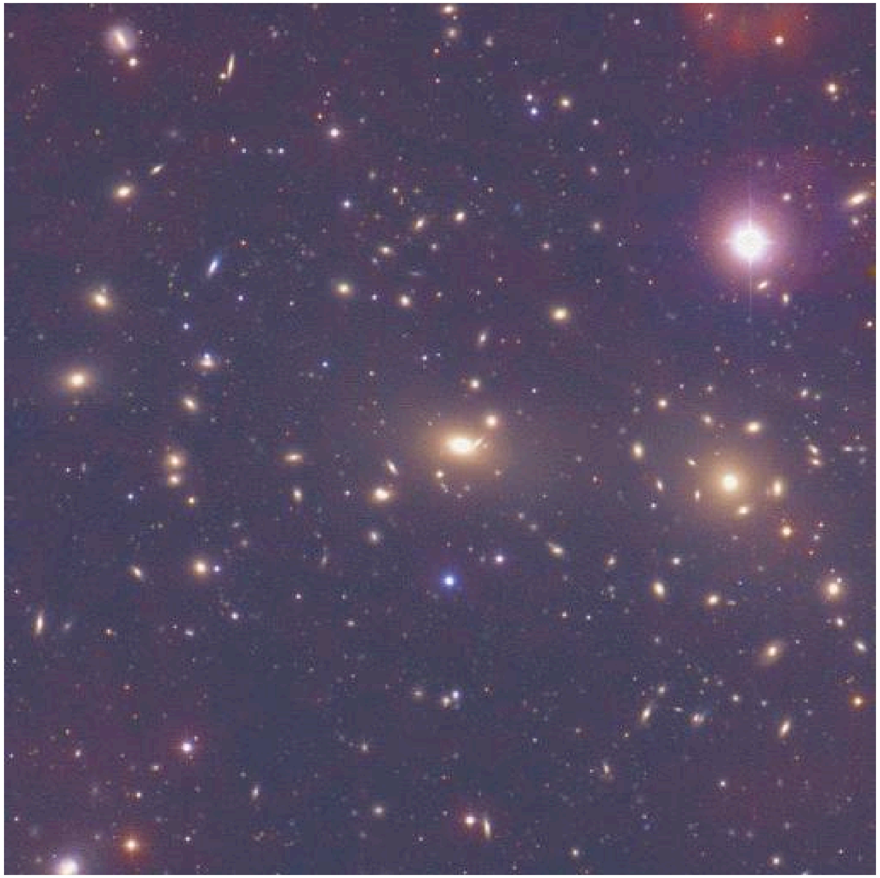
- **Introduction to Dark Matter**
  - Evidence
  - Candidates
  - SUSY
- **WIMP detection**
- **The XENON 10 experiment at Gran Sasso Underground Laboratory**

What is the Universe made off ?



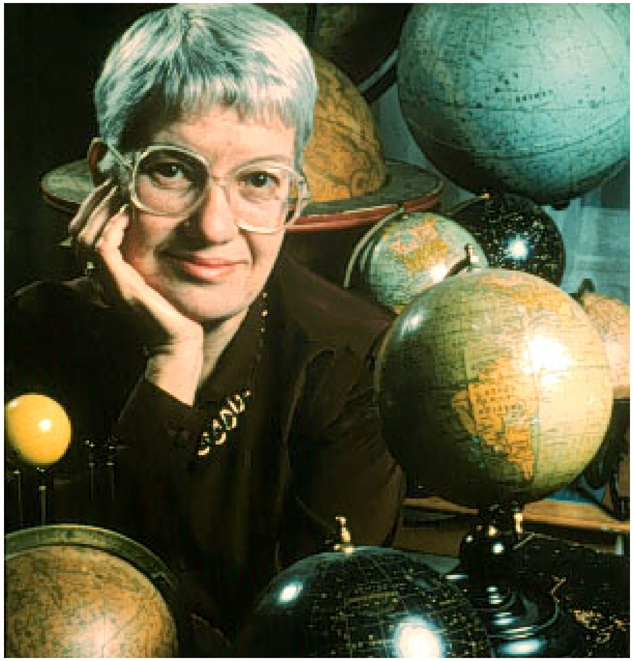
The **first evidence** of extra, invisible matter in a galaxy cluster (1933)

Fritz Zwicky (1898-1974)



Coma Galaxy Cluster

This "dark matter" has effects within individual galaxies also



Vera Rubin (1928 -)

Evidence for the existence of **Dark Matter** in small (galaxy) scale

NGC3198

r

10kpc

expected:

(beyond luminous region)

$$v_s = \sqrt{\frac{GM_G}{r}}$$

Evidence for the existence of **Dark Matter** in small (galaxy) scale

NGC3198

r

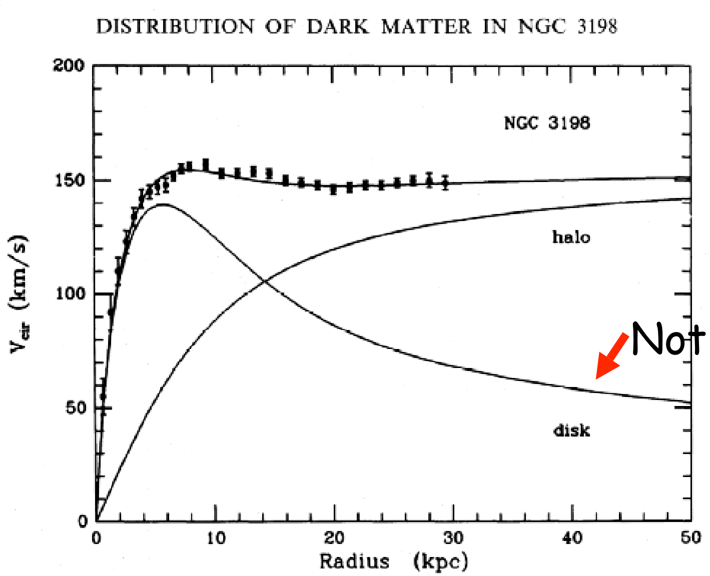
10kpc

expected:

(beyond luminous region)

$$v_s = \sqrt{\frac{GM_G}{r}}$$

Rotation curve



instead:

v_s ~ constant

out to large radii.

Evidence for the existence of **Dark Matter** in small (galaxy) scale

NGC3198

r

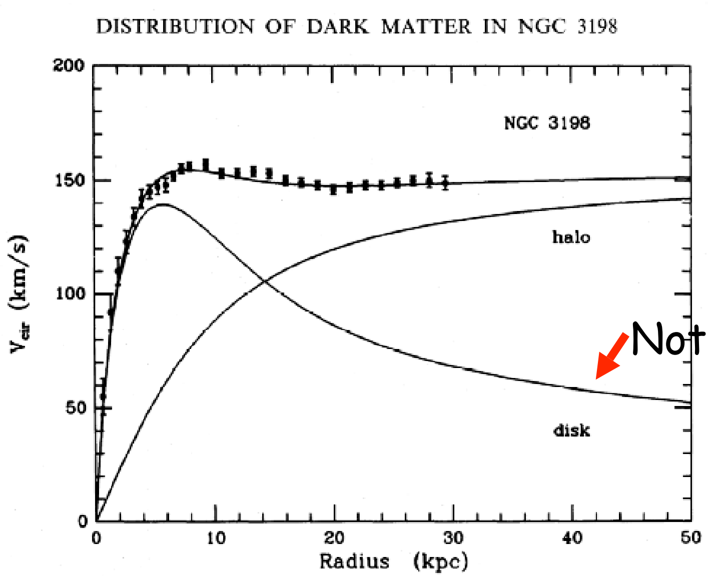
10kpc

expected:

(beyond luminous region)

$$v_s = \sqrt{\frac{GM_G}{r}}$$

Rotation curve



Not good fit

instead:

v_s ~ constant

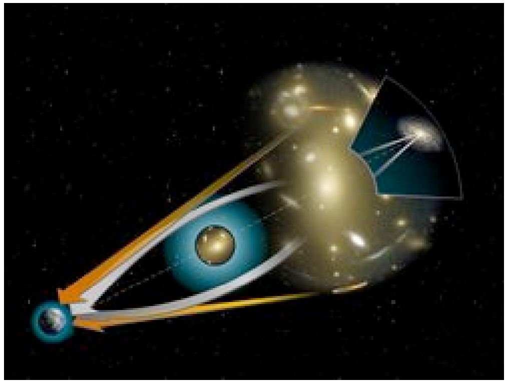
out to large radii.

Implication: large proportion of unseen, non-luminous matter present

10 x more matter than can be "seen"

Evidence for the existence of **Dark Matter** in large (galaxy cluster) scale

Gravitational Lensing:

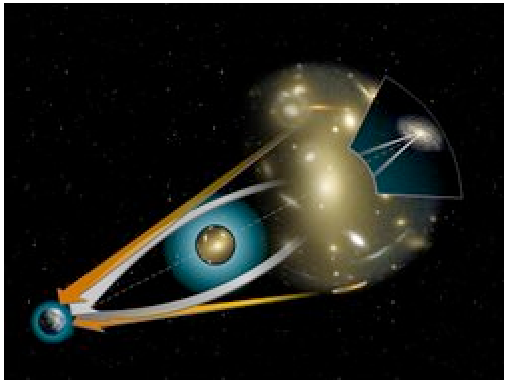


Distortion (e.g. rings or multiple images) caused by gravitational lens

Analysis of bending of light
by **galaxy clusters**
reveals **more mass** than visible

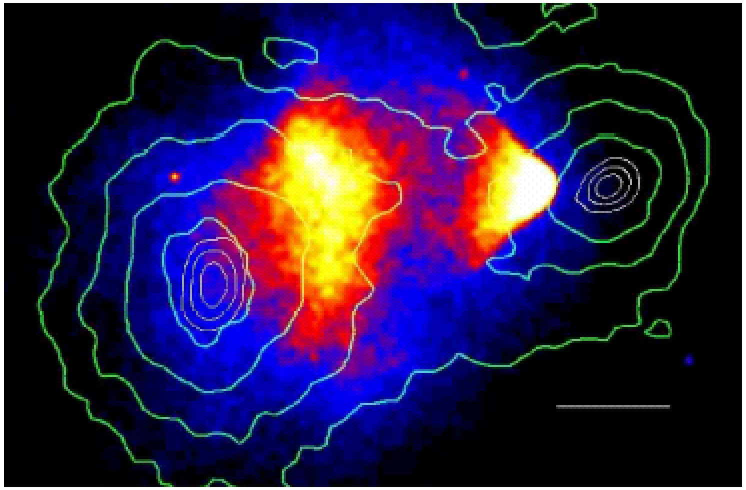
Evidence for the existence of **Dark Matter** in large (galaxy cluster) scale

Gravitational Lensing:



Distortion (e.g. rings or multiple images) caused by gravitational lens

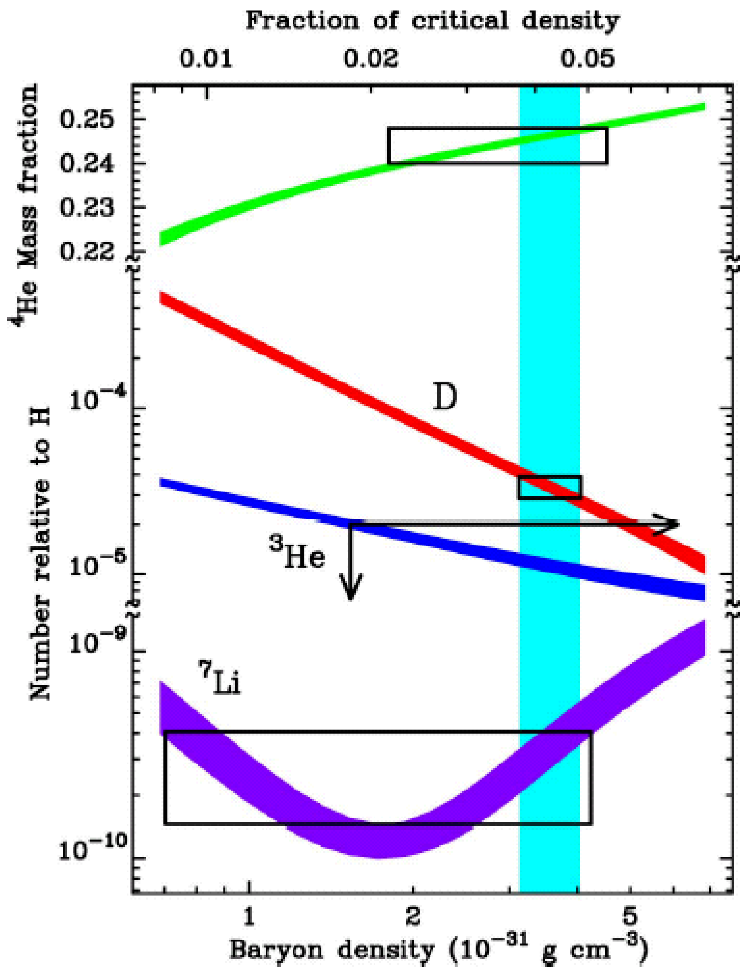
Analysis of bending of light by **galaxy clusters** reveals **more mass** than visible



But… 2 pieces of evidence tell us the majority of matter in the Universe is **NOT baryonic matter**…

But… 2 pieces of evidence tell us the majority of matter in the Universe is **NOT baryonic matter**…

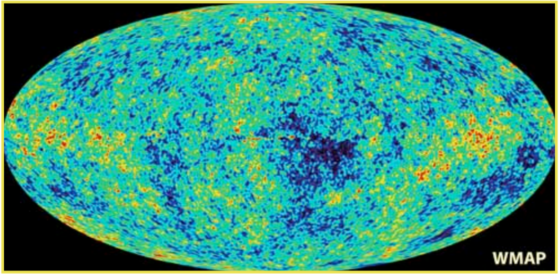
1. Big Bang Nucleosynthesis



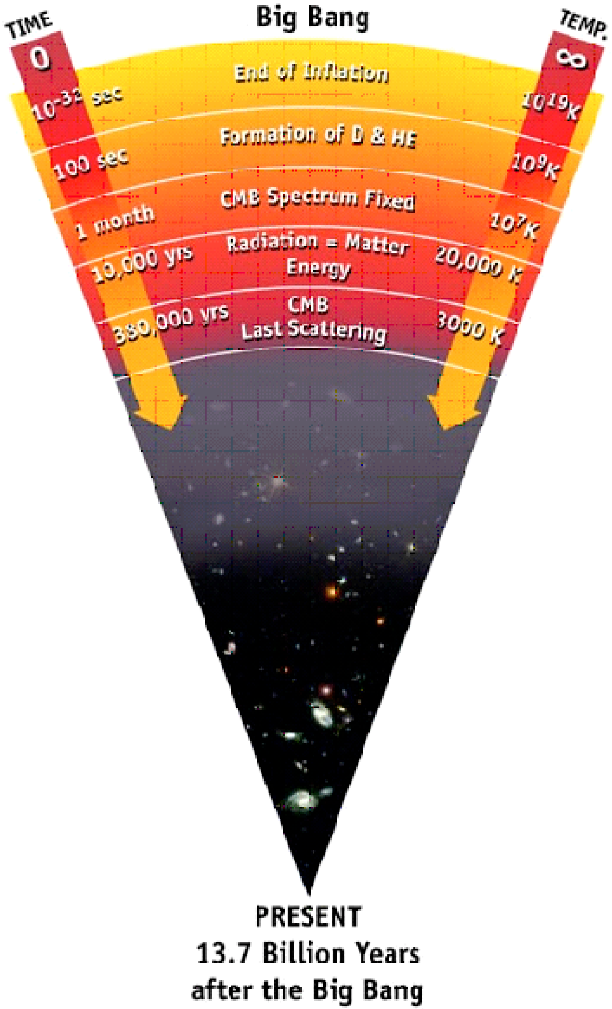
it constrains
the current baryon density
to a small fraction of the
overall matter density

2. Wilkinson Microwave Anisotropy (WMAP) measurements of the

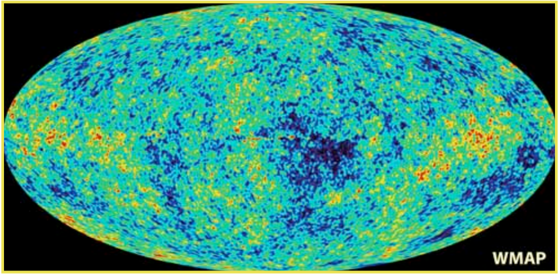
Cosmic Microwave Background



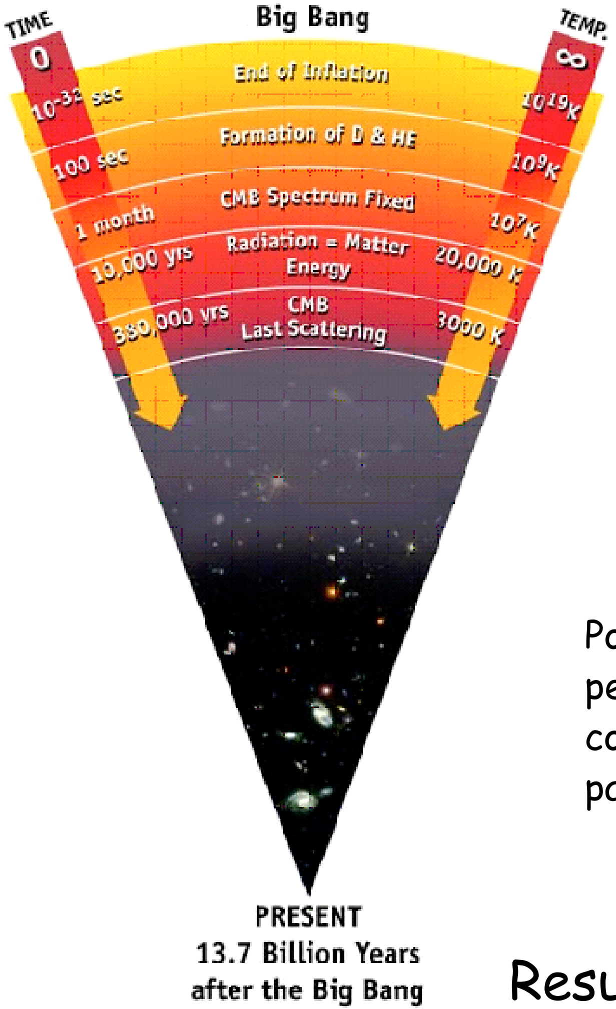
0.2° resolution of all sky Microwave Background

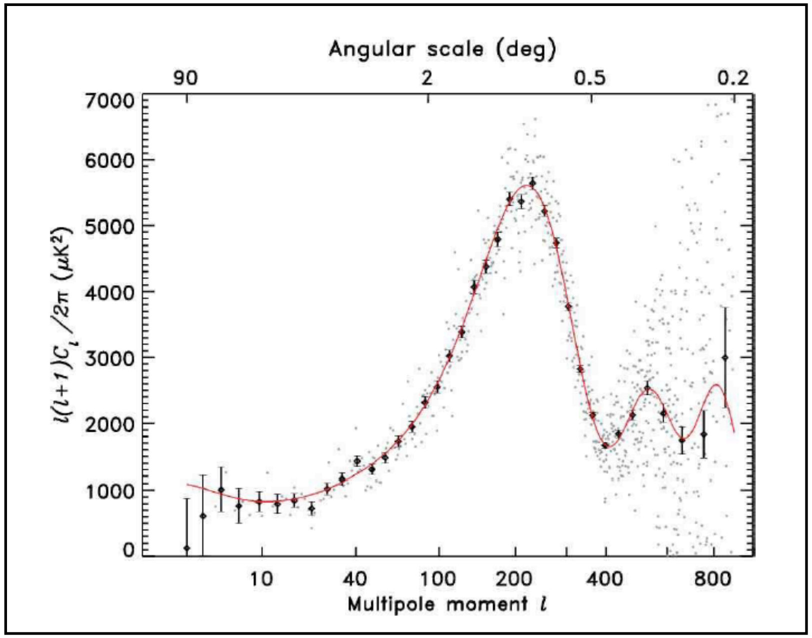


2. Wilkinson Microwave Anisotropy (WMAP) measurements of the Cosmic Microwave Background



0.2° resolution of all sky Microwave Background





Position & size of peaks sensitive to cosmological parameters

Results constrains many cosmological parameters …

Density parameters:

$$\boxed{\Omega = \rho/\rho_C}$$

$\Omega_m = 0.22$

$\Omega_B = 0.042$

$\Omega_{Rad} \sim 10^{-5}$

$\Omega_\Lambda = 0.77$

Density parameters:

$$\boxed{\Omega = \rho/\rho_C}$$

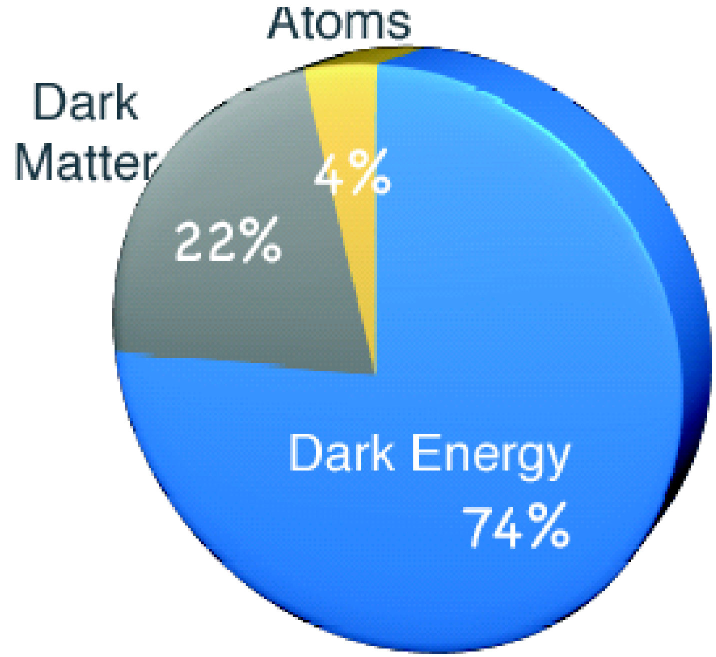
$\Omega_m = 0.22$

$\Omega_B = 0.042$

$\Omega_{Rad} \sim 10^{-5}$

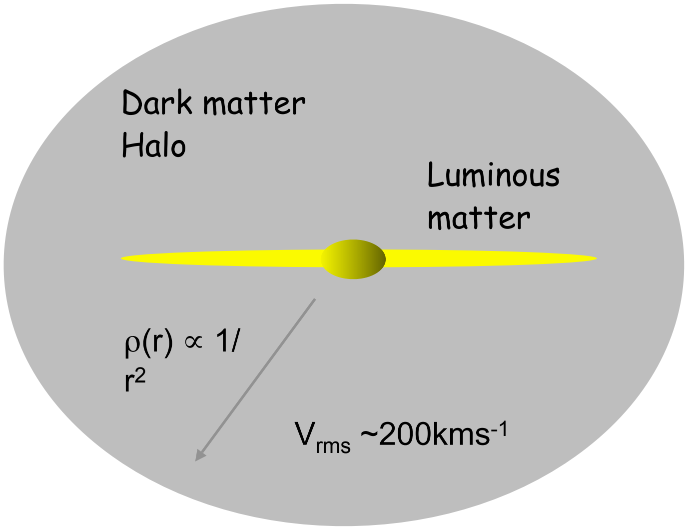
$\Omega_\Lambda = 0.77$

The cosmic pie!



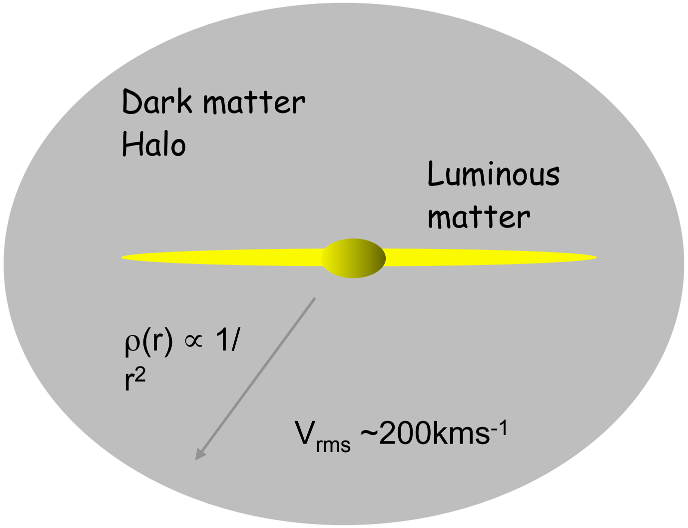
Dark Matter distribution

Dark Matter distributed
not as disk - but as a **HALO**



Dark Matter distribution

Dark Matter distributed
not as disk - but as a **HALO**



Highest resolution cosmological DM simulation of a Milky Way type Halo

M_{halo} ~10^{12}M

10000 subhalos!

Actual density depends on Halo Model

Simplest = **Isothermal Sphere Halo Model**:

Smooth spread of particles in sphere (ρ~ $1/r^2$)

Dark Matter candidates:

Dark Matter candidates: $\nearrow$ Baryonic $\longrightarrow$ MACHOs (Massive Astrophysical Compact Halo Objects)

Dark Matter candidates: → Baryonic → MACHOs (Massive Astrophysical Compact Halo Objects)

Dark Matter candidates: → Non-Baryonic

Dark Matter candidates:

Baryonic → MACHOs
(Massive Astrophysical
Compact Halo Objects)

Non-Baryonic

Hot

neutrino

Dark Matter candidates:

Baryonic → MACHOs (Massive Astrophysical Compact Halo Objects)

Non-Baryonic

Hot

neutrino

Cold

Kaluza-Klein Axions (in theories with extra dimensions)

WIMPs (Weakly Interacting Massive Particles)

SUSY candidates: lightest neutralino

m > 30GeV

Cold Thermal Relics and the Weak Scale

- If a massive, weakly interacting particle (**WIMP**) existed in the early Universe

$$\boxed{\chi + \bar{\chi} \leftrightarrow l + \bar{l}}$$

- for $\Gamma > H$, it was in equilibrium

Cold Thermal Relics and the Weak Scale

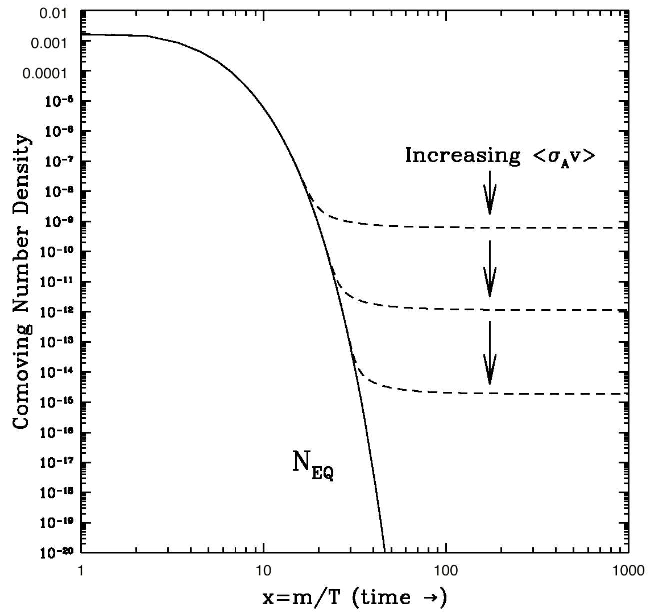
- If a massive, weakly interacting particle (**WIMP**) existed in the early Universe

$$\boxed{\chi + \bar{\chi} \leftrightarrow l + \bar{l}}$$

- for $\Gamma > H$, it was in equilibrium

- after $\Gamma < H$ => "**freeze-out**", we are left with a **relic density**

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



Cold Thermal Relics and the Weak Scale

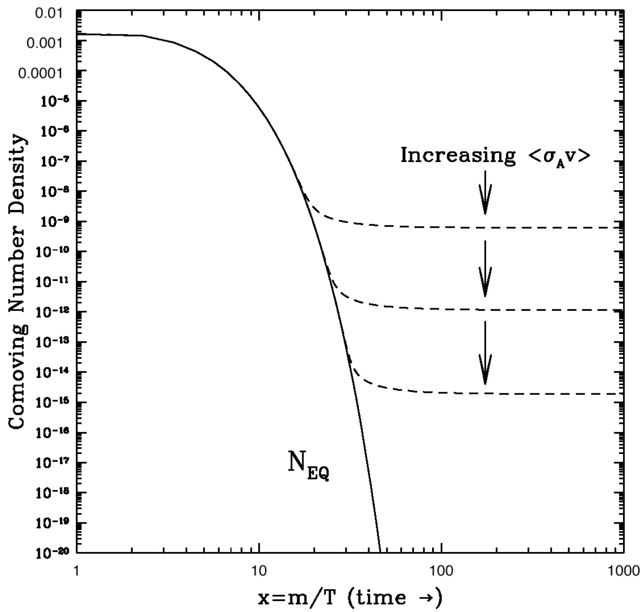
- If a massive, weakly interacting particle (**WIMP**) existed in the early Universe

$$\boxed{\chi + \bar{\chi} \leftrightarrow l + \bar{l}}$$

- for $\Gamma > H$, it was in equilibrium

- after $\Gamma < H$ => "**freeze-out**", we are left with a **relic density**

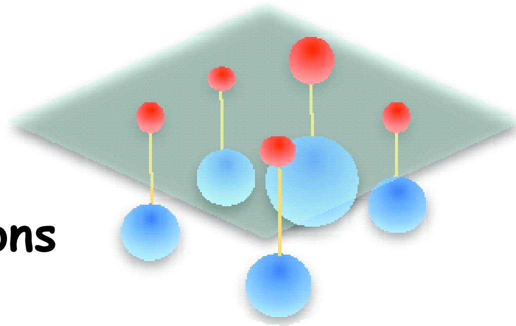
$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c} \approx \frac{3 \times 10^{-27} cm^3 s^{-1}}{\langle \sigma_A v \rangle}$$



If $m_\chi \sim m_W$, then Ω_χ remarkably close to the value required for the dark matter in the universe!

$\Rightarrow$The new physics gives rise to a dark matter candidate

Supersymmetry (SUSY)

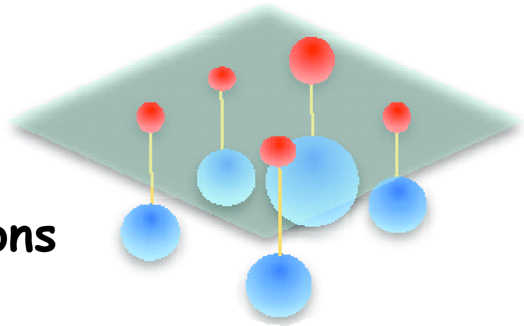


- new fundamental space-time symmetry: **fermions** $\leftrightarrow$ **bosons**

  => SM particles get superpartners

  (differ in spin by $\frac{1}{2}$, otherwise same quantum numbers)

Supersymmetry (SUSY)



- new fundamental space-time symmetry: **fermions** ↔ **bosons**

  => SM particles get superpartners

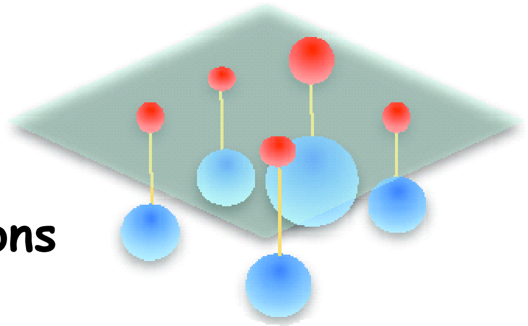
  (differ in spin by $\frac{1}{2}$, otherwise same quantum numbers)

- to prevent proton decay a discrete symmetry (**R-parity**) is imposed

  → $R = (-1)^{3B+L+2S}$

  → R = 1 for SM particles, R = -1 for SUSY particles

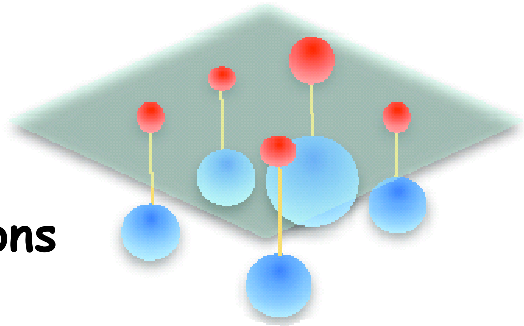
Supersymmetry (SUSY)



- new fundamental space-time symmetry: **fermions** ↔ **bosons**
  => SM particles get superpartners
  (differ in spin by $\frac{1}{2}$, otherwise same quantum numbers)
- to prevent proton decay a discrete symmetry (**R-parity**) is imposed
  → $R = (-1)^{3B+L+2S}$
  → R = 1 for SM particles, R = -1 for SUSY particles

sparticles can only decay in an odd number of sparticles (+ SM particles)
the lightest SUSY particle is stable and likely becomes a dark matter candidate

Supersymmetry (SUSY)



- new fundamental space-time symmetry: **fermions** $\leftrightarrow$ **bosons**

  => SM particles get superpartners

  (differ in spin by ½, otherwise same quantum numbers)

- to prevent proton decay a discrete symmetry (**R-parity**) is imposed

  $\rightarrow$ $R = (-1)^{3B+L+2S}$

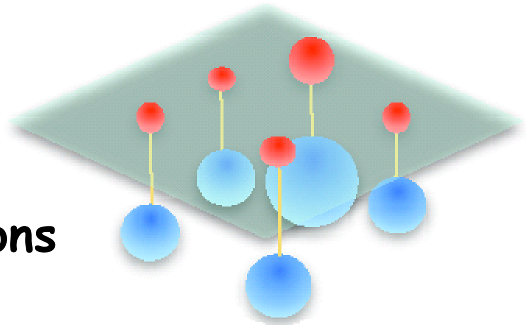
  $\rightarrow$ R = 1 for SM particles, R = -1 for SUSY particles

sparticles can only decay in an odd number of sparticles (+ SM particles)

the lightest SUSY particle is stable and likely becomes a dark matter candidate

$$\chi_1^0 = \alpha_1 \tilde{B} + \alpha_2 \tilde{W} + \alpha_3 \tilde{H}_u^0 + \alpha_4 \tilde{H}_d^0$$

Supersymmetry (SUSY)



- new fundamental space-time symmetry: **fermions** ↔ **bosons**
  => SM particles get superpartners
  (differ in spin by ½, otherwise same quantum numbers)
- to prevent proton decay a discrete symmetry (**R-parity**) is imposed
  → $R = (-1)^{3B+L+2S}$
  → R = 1 for SM particles, R = -1 for SUSY particles

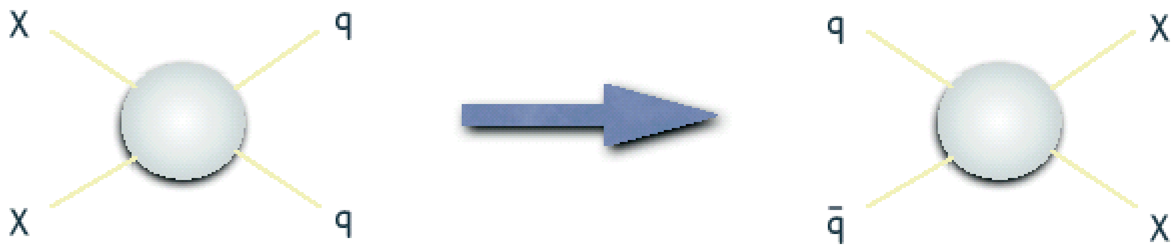
sparticles can only decay in an odd number of sparticles (+ SM particles)
the lightest SUSY particle is stable and likely becomes a dark matter candidate

$$\chi_1^0 = \alpha_1 \tilde{B} + \alpha_2 \tilde{W} + \alpha_3 \tilde{H}_u^0 + \alpha_4 \tilde{H}_d^0$$

When SUSY was first developed it was in no way motivated by the existence of dm candidate.
This connection could be

either a mere coincidence
or a hint that SUSY is responsible for dark matter!

WIMP Detection: Accelerators



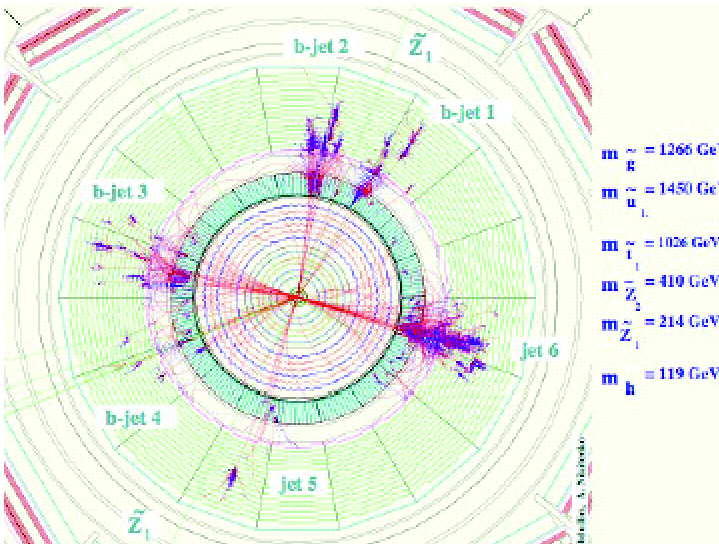
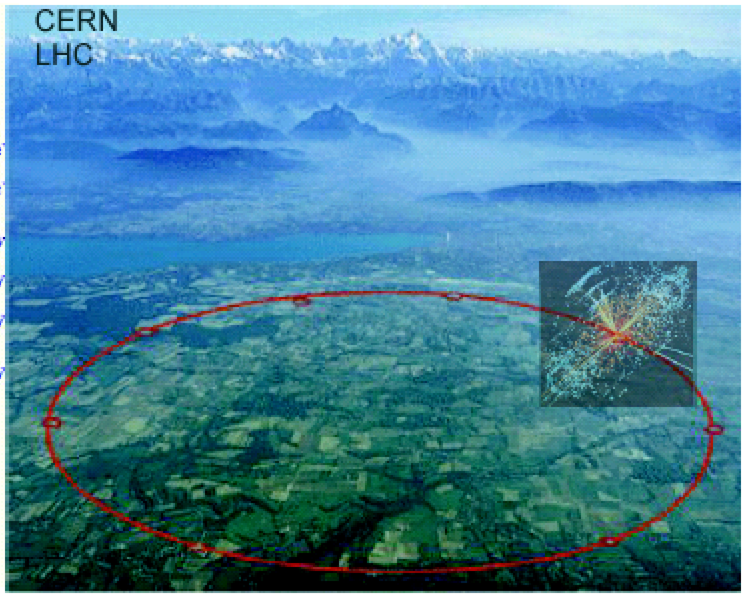
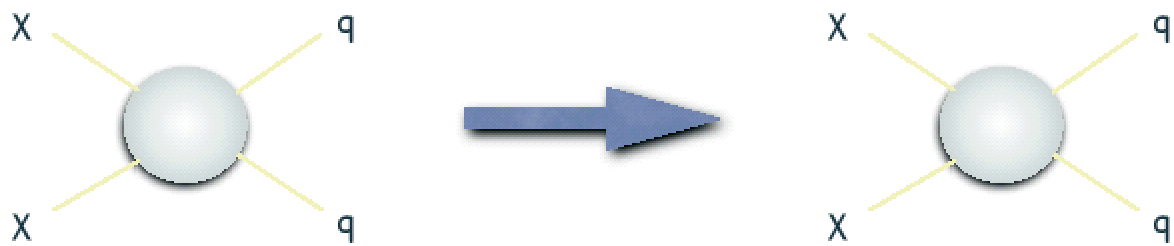
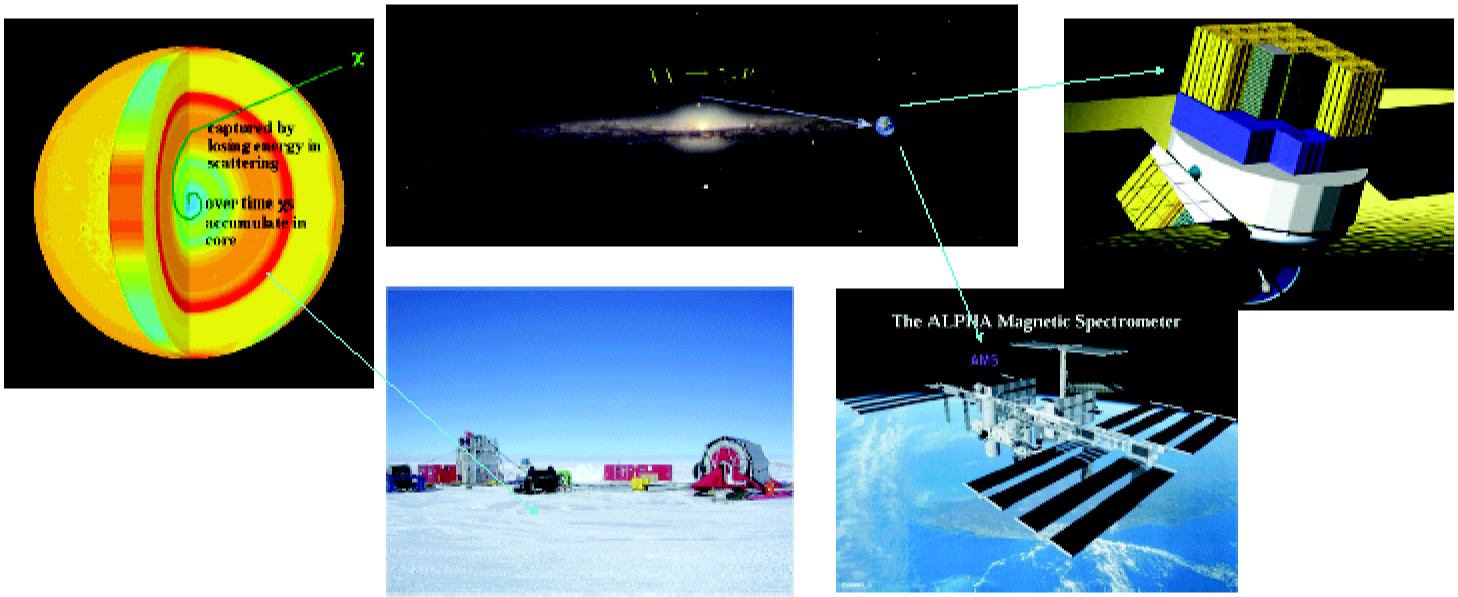


Fig. from Howie Baer

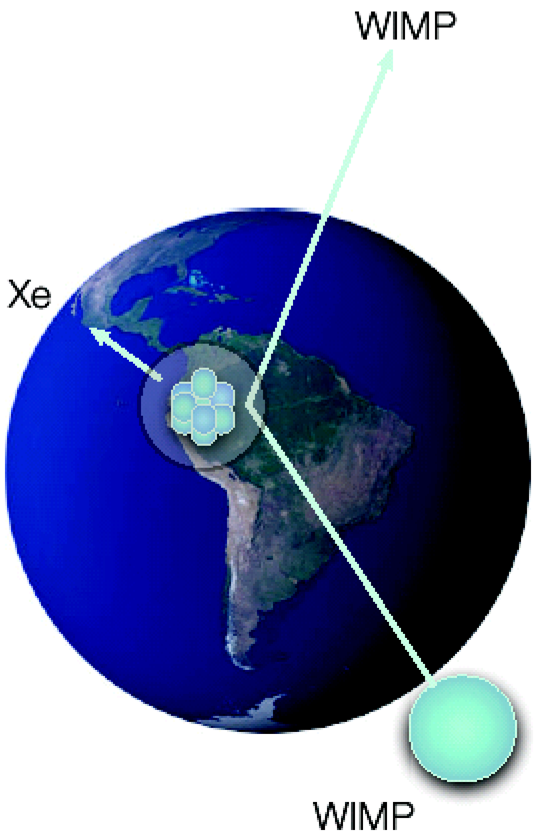


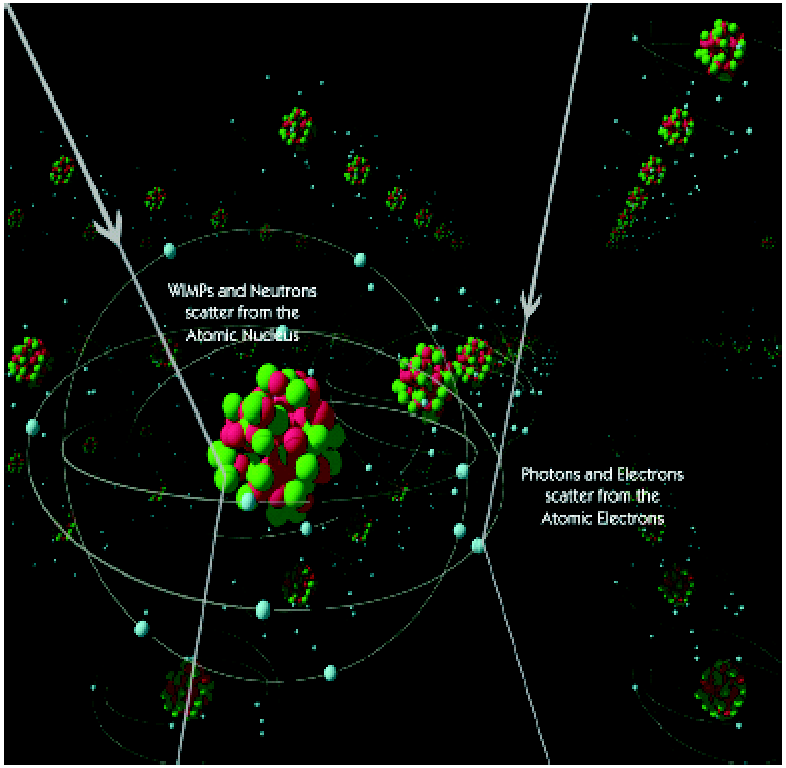
WIMP Detection: Annihilation Products





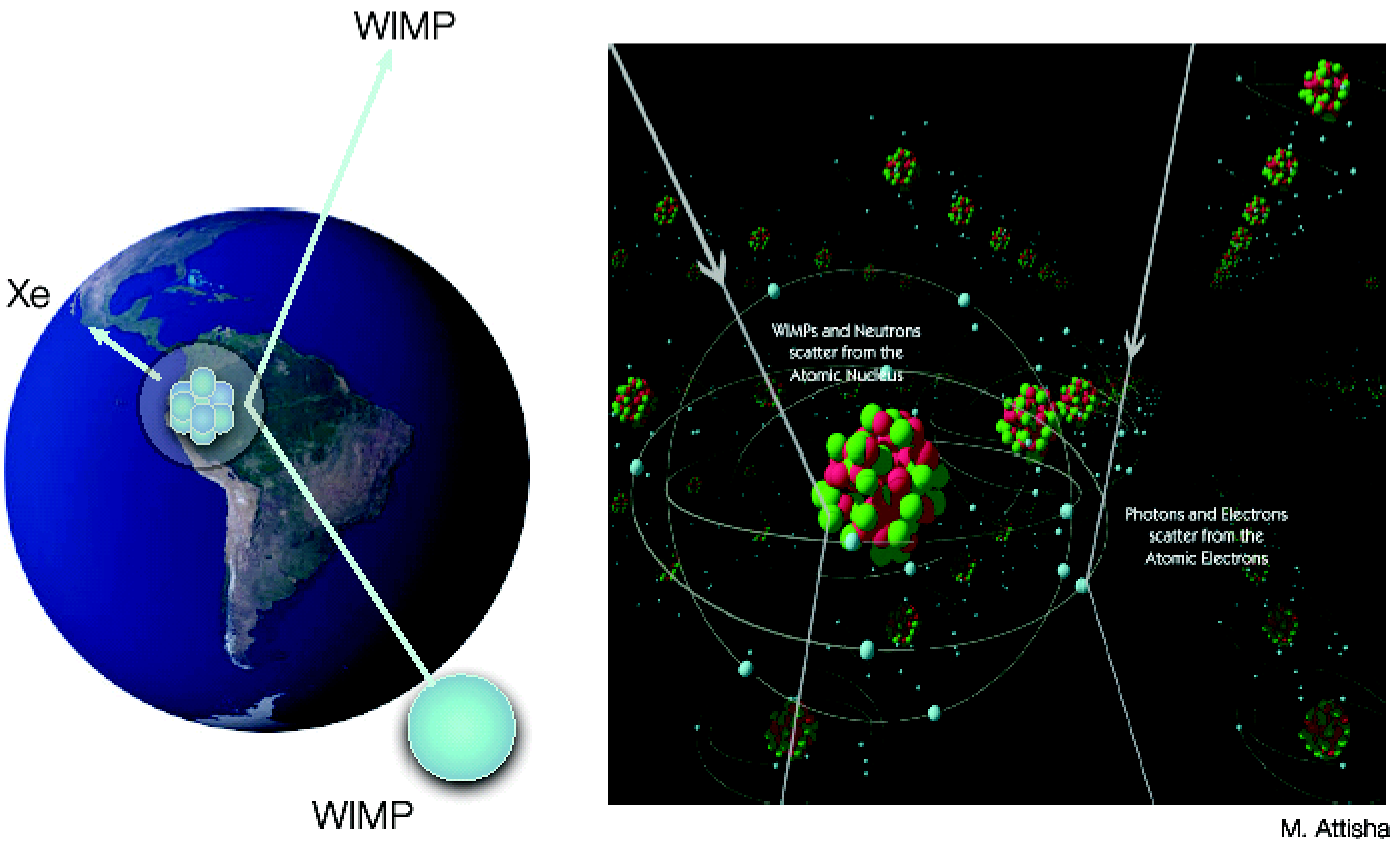
WIMP Detection: Scattering off Atoms





M. Attisha

WIMP Detection: Scattering off Atoms



WIMP + ordinary matter → nuclear recoils (nr)

WIMP signatures

- **WIMP interactions in detectors should be:**
  nuclear recoils
  single scatters

- **Spectral shape**
  the recoil spectrum should fall with energy, however similar to bg

- **Dependence on material** (A^2, spin-dependence)
  test consistency between different targets

- **Annual flux modulation** (~3%)

- **Diurnal direction modulation** (~7%)

scalar interaction:
coupling to the nuclear mass
axial-vector interaction:
couple to the nuclear spin

Key WIMP Detector Requirements

**** Very small interaction rate : less than 0.1 events/kg/day

Detector must have...

Key WIMP Detector Requirements

**** Very small interaction rate :   less than 0.1 events/kg/day

Detector must have…

High Mass

Key WIMP Detector Requirements

**** Very small interaction rate :   less than 0.1 events/kg/day

Detector must have...

High Mass

- High total mass => ton - scale detectors

Key WIMP Detector Requirements

**** Very small interaction rate :   less than 0.1 events/kg/day

Detector must have…

High Mass

- High total mass => ton - scale detectors
- High Atomic mass (A)

Key WIMP Detector Requirements

**** Very small interaction rate :   less than 0.1 events/kg/day

Detector must have…

High Mass

- High total mass => ton - scale detectors
- High Atomic mass (A)

Very low **Energy Threshold**

Key WIMP Detector Requirements

**** Very small interaction rate :   less than 0.1 events/kg/day

Detector must have…

High Mass

- High total mass => ton - scale detectors
- High Atomic mass (A)

Very low **Energy Threshold**

- expected recoil energy less than 100 keV

Key WIMP Detector Requirements

**** Very small interaction rate :   less than 0.1 events/kg/day

Detector must have...

High Mass

- High total mass => ton - scale detectors
- High Atomic mass (A)

Very low **Energy Threshold**

- expected recoil energy less than 100 keV

Minimise **BACKGROUND** Radioactivity

Key WIMP Detector Requirements

**** Very small interaction rate : less than 0.1 events/kg/day

Detector must have...

High Mass

- High total mass => ton - scale detectors
- High Atomic mass (A)

Very low **Energy Threshold**

- expected recoil energy less than 100 keV

Minimise **BACKGROUND** Radioactivity

=> Select Materials Used

Use Shielding

Go DEEP UNDERGOUND...

Key WIMP Detector Requirements

**** Very small interaction rate : less than 0.1 events/kg/day

Detector must have…

High Mass

- High total mass => ton - scale detectors
- High Atomic mass (A)

Very low **Energy Threshold**

- expected recoil energy less than 100 keV

Minimise **BACKGROUND** Radioactivity

=> Select Materials Used

Use Shielding

Go DEEP UNDERGOUND…

Good **Backaround discrimination**

Minimise Background Radioactivity

Decay of trace samples of isotopes of naturally occurring elements (**Uranium**, **Thorium**, **Potassium**) in detector or surrounding materials result in release of **gammas** and **neutrons** both of which can interact with the target to produce <100keV signals.

Minimise Background Radioactivity

Decay of trace samples of isotopes of naturally occurring elements (**Uranium**, **Thorium**, **Potassium**) in detector or surrounding materials result in release of **gammas** and **neutrons** both of which can interact with the target to produce <100keV signals.

$T_{1/2} \sim 5\times10^{9}$ yrs

Uranium $^{238}U \xrightarrow[\alpha]{} {}^{234}Th \xrightarrow[\beta]{} {}^{234m}Pa \xrightarrow[\beta]{} {}^{234}U \xrightarrow[\alpha]{} {}^{230}Th \xrightarrow[\alpha]{} {}^{226}Ra \xrightarrow[\alpha]{} {}^{222}Rn \xrightarrow[\alpha]{} {}^{218}Po \ldots$

$T_{1/2} \sim 10^{10}$ yrs

Thorium $^{232}Th \xrightarrow[\alpha]{} {}^{228}Ra \xrightarrow[\beta]{} {}^{228m}Ac \xrightarrow[\beta]{} {}^{228}Th \xrightarrow[\alpha]{} {}^{224}Ra \xrightarrow[\alpha]{} {}^{220}Rn \xrightarrow[\alpha]{} {}^{216}Po \ldots$

Gammas are released at many stages. **Alphas** produced can be captured by target nuclei, creating unstable nuclei which then release neutrons ('αn' reaction).

Minimise Background Radioactivity

Decay of trace samples of isotopes of naturally occurring elements (**Uranium**, **Thorium**, **Potassium**) in detector or surrounding materials result in release of **gammas** and **neutrons** both of which can interact with the target to produce <100keV signals.

$T_{1/2} \sim 5 \times 10^9$ yrs

Uranium $\;{}^{238}\mathrm{U} \xrightarrow[\alpha]{} {}^{234}\mathrm{Th} \xrightarrow[\beta]{} {}^{234m}\mathrm{Pa} \xrightarrow[\beta]{} {}^{234}\mathrm{U} \xrightarrow[\alpha]{} {}^{230}\mathrm{Th} \xrightarrow[\alpha]{} {}^{226}\mathrm{Ra} \xrightarrow[\alpha]{} {}^{222}\mathrm{Rn} \xrightarrow[\alpha]{} {}^{218}\mathrm{Po} \ldots$

$T_{1/2} \sim 10^{10}$ yrs

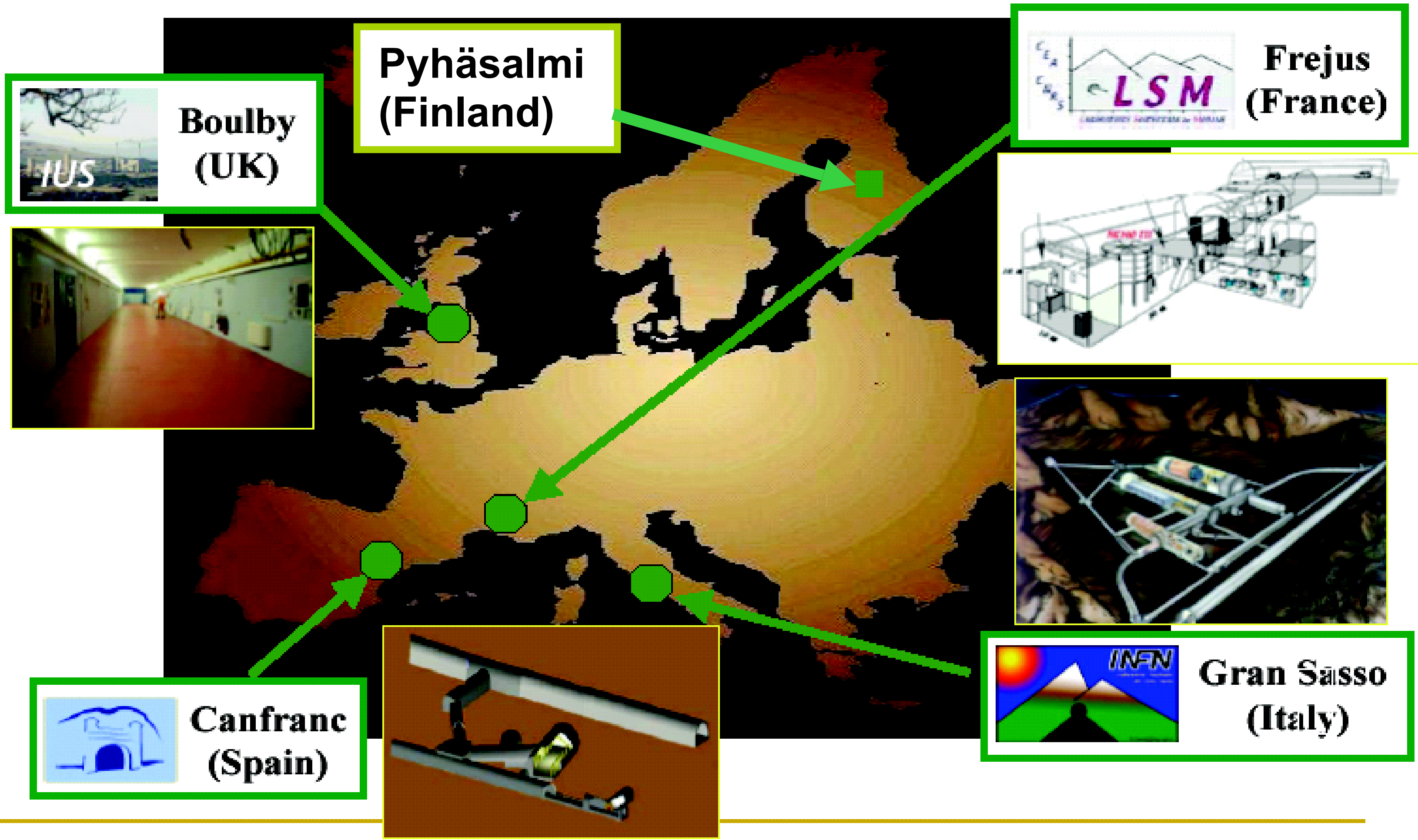
Thorium $\;{}^{232}\mathrm{Th} \xrightarrow[\alpha]{} {}^{228}\mathrm{Ra} \xrightarrow[\beta]{} {}^{228m}\mathrm{Ac} \xrightarrow[\beta]{} {}^{228}\mathrm{Th} \xrightarrow[\alpha]{} {}^{224}\mathrm{Ra} \xrightarrow[\alpha]{} {}^{220}\mathrm{Rn} \xrightarrow[\alpha]{} {}^{216}\mathrm{Po} \ldots$

Gammas are released at many stages. **Alphas** produced can be captured by target nuclei, creating unstable nuclei which then release neutrons ('αn' reaction).

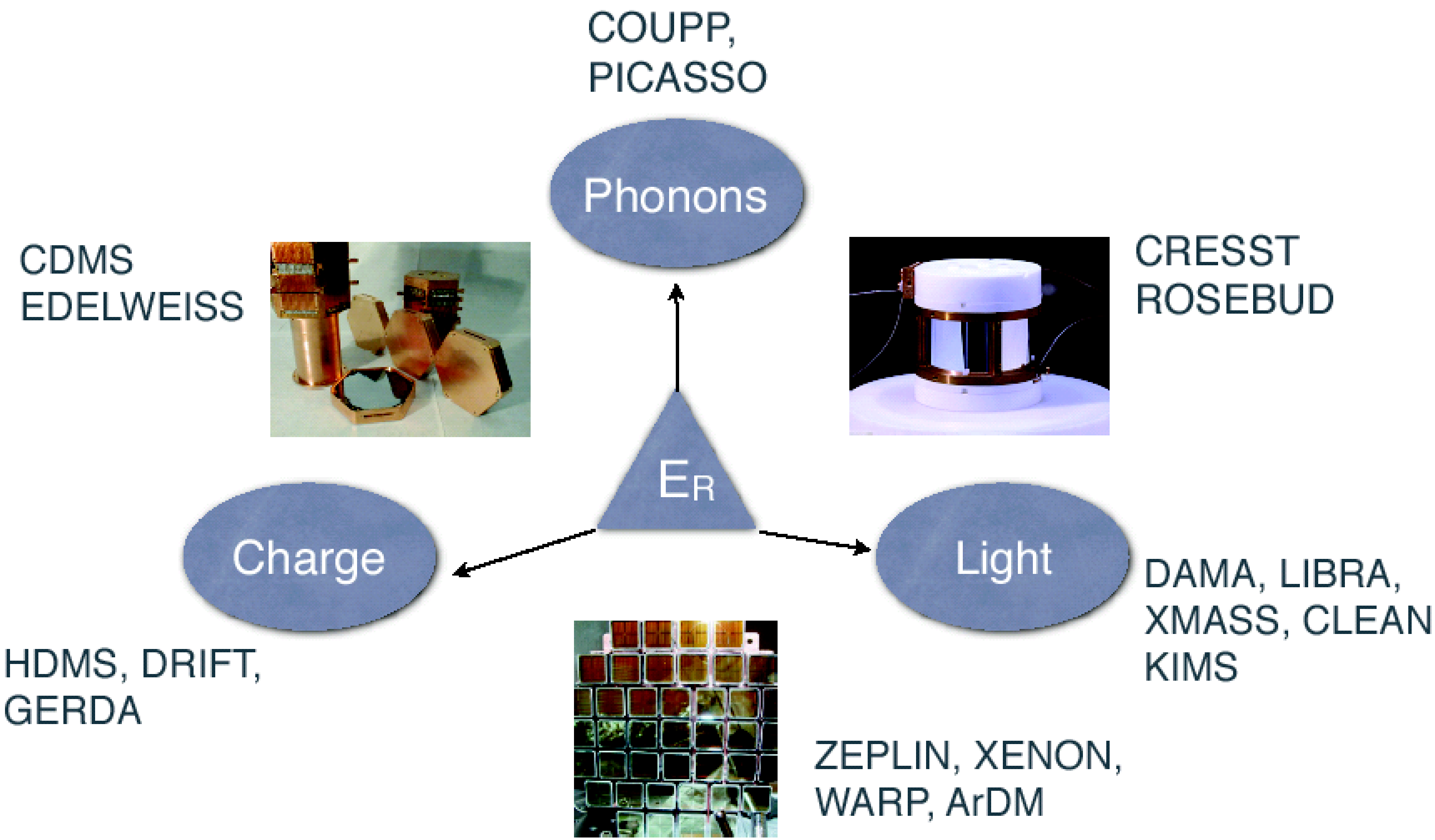
Neutrons are the most dangerous background as they interact similarly to WIMPs…making discrimination difficult !!!

Minimise Background Radioactivity

Cosmic ray muons induced neutrons => Go deep underground



Direct WIMP dark matter experiments

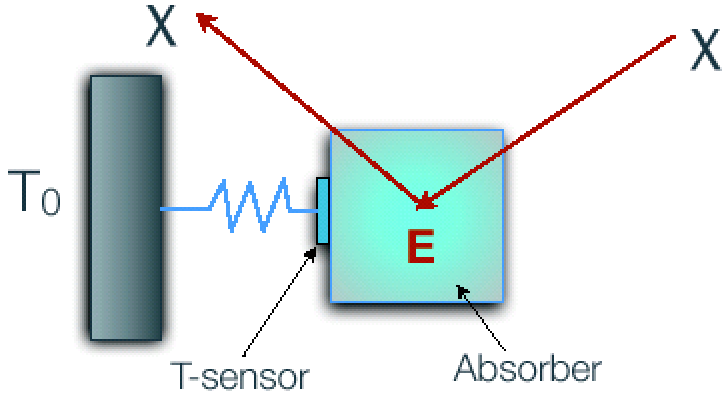


Combination for better discrimination!

Direct Detection Techniques

1. Phonon collection – Cryogenic detectors

Principle: a deposited energy E produces temperature rise ΔT



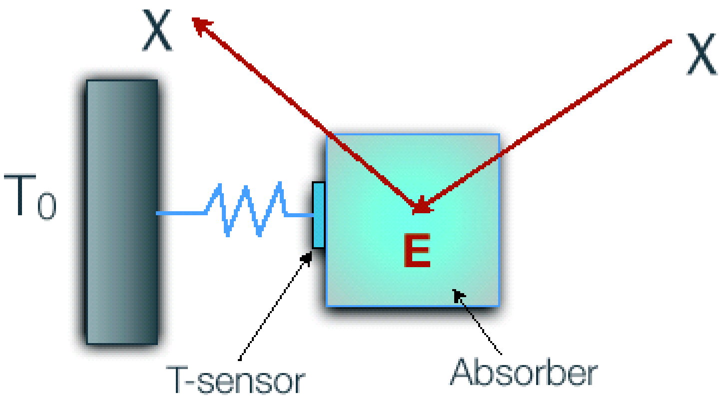
$$\Delta T \propto \frac{E}{C(T)}$$

The lower T, the larger ΔT per unit of absorbed energy

Direct Detection Techniques

1. Phonon collection – Cryogenic detectors

Principle: a deposited energy E produces temperature rise ΔT



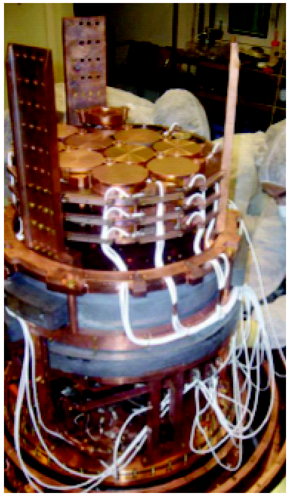
$$\Delta T \propto \frac{E}{C(T)}$$

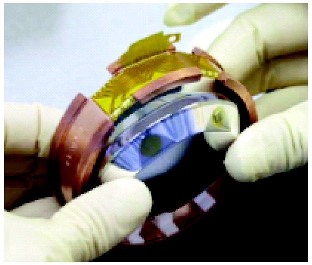
The lower T, the larger ΔT per unit of absorbed energy

Crystals: Ge, Si , $CaWO_4$

cooled to few mK => heat capacity low

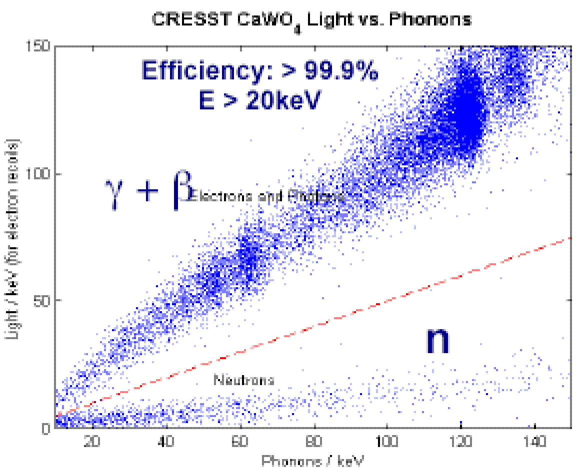
=> measurable μK temperature!



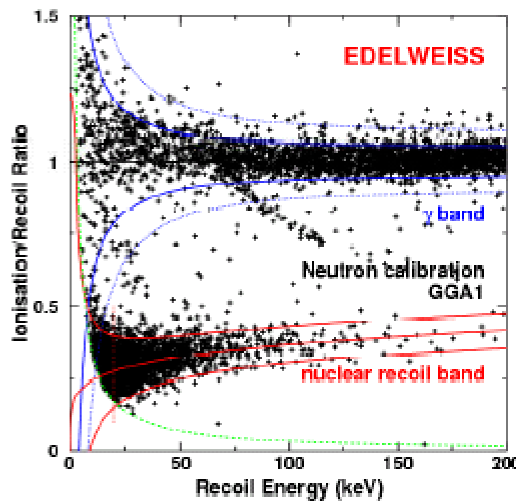


1. Phonon collection – Cryogenic detectors

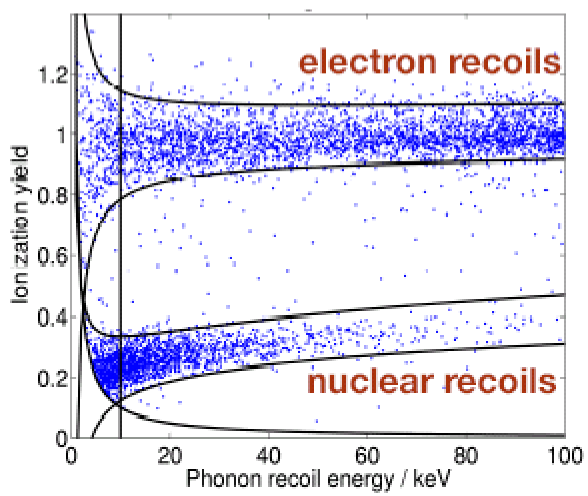
+ Excellent discrimination



CRESST



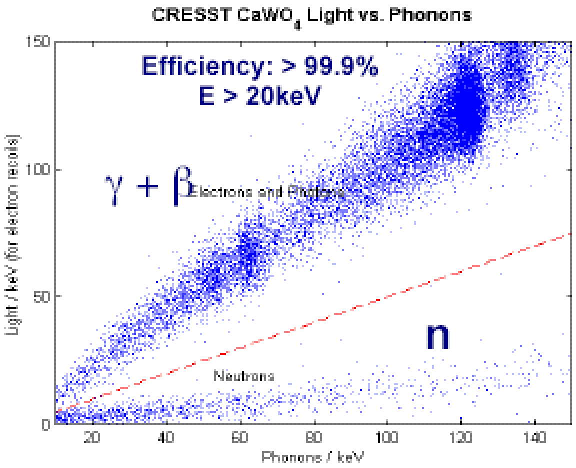
EDELWEISS



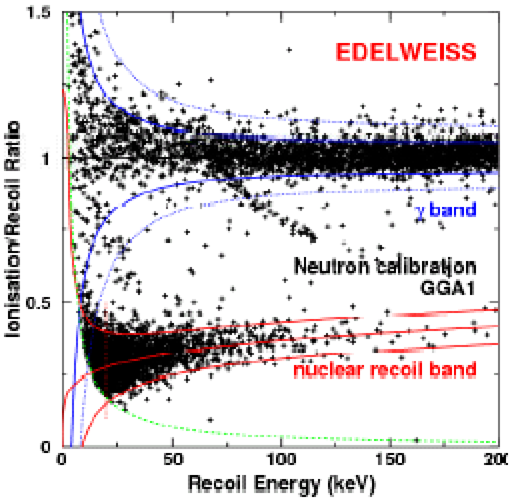
CDMS

1. Phonon collection – Cryogenic detectors

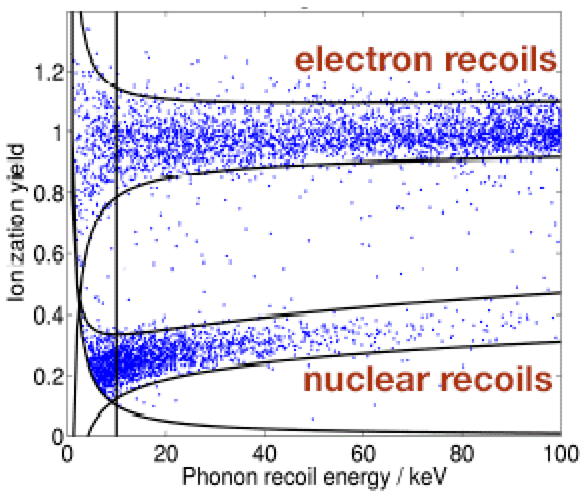
+ Excellent discrimination



CRESST



EDELWEISS



CDMS

+ Low threshold (sub-keV)
+ High purity
- Cost, difficult to scale up
- Difficult to cool

Direct Detection Techniques

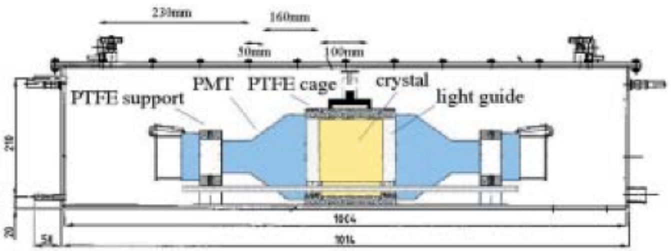
2. Scintillation

Direct Detection Techniques

2. Scintillation

a. First generation - Past

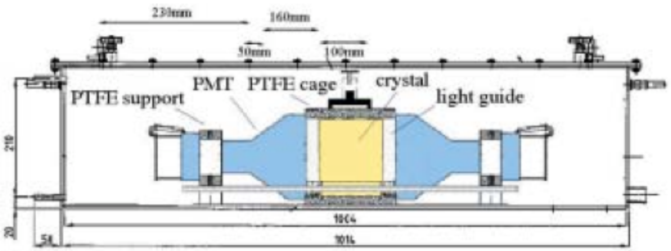
crystals: NaI
+ light and heavy nuclei
- Limited sensitivity



Direct Detection Techniques

2. Scintillation

a. First generation - Past



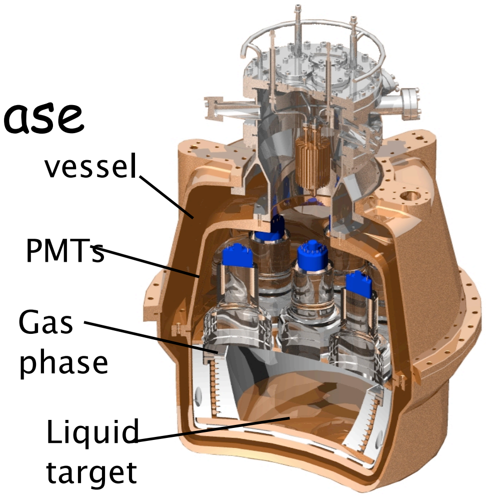
crystals: NaI

+ light and heavy nuclei
- Limited sensitivity

b. Second generation - Present

target: noble gases (Xe, Ar) based on the 2-phase liquid-gas concept

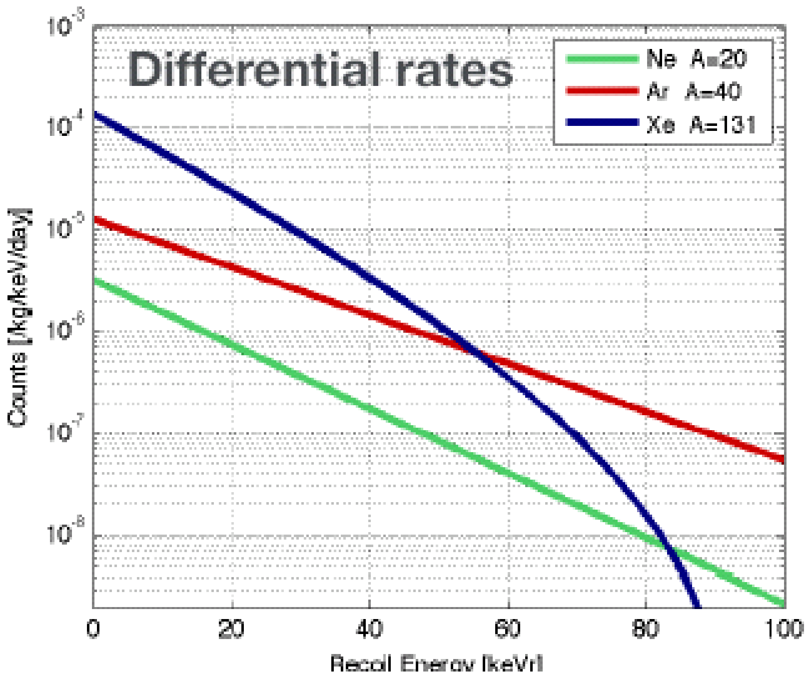
+ better sensitivity than crystal
- but not better than cryogenic detectors
+ easier to scale up…

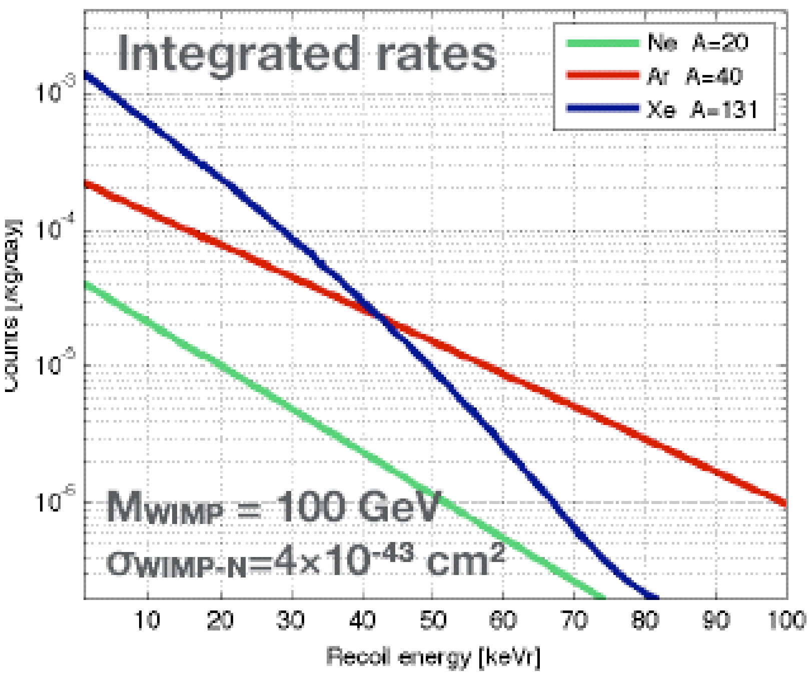


2. Scintillation – Noble liquids as dm detectors

Element	Scintillation Light	Intrinsic Backgrounds
Ne (A=20) 60$/Kg 100% even-even nucleus	85nm requires wavelength shifter	No radioactive isotopes
Ar (A=40) 2$/Kg 100% even-even nucleus	128nm requires wavelength shifter	Natural Ar contains ^{29}Ar at 1Bq/Kg corresponding to ~150events/kg/day/keV
Xe (A=121) 800$/Kg 50% odd nuclei ^{129}Xe, ^{131}Xe	175nm UV quartz PMT window	No long lived isotopes ^{85}Kr can be removed can be removed by distillation

2. Scintillation – Noble liquids as dm detectors





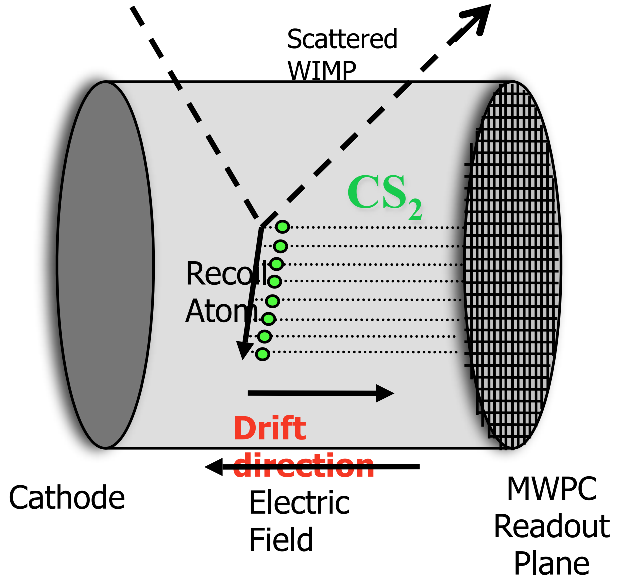
Direct Detection Techniques

3. Ionisation – Gas directional detectors

target: low pressure gas (CS_2)

+ directionality

- low mass



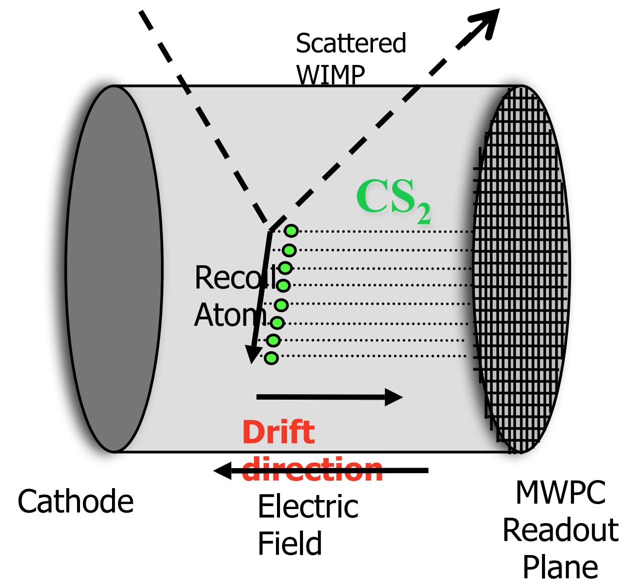
Direct Detection Techniques

3. Ionisation –
Gas directional detectors

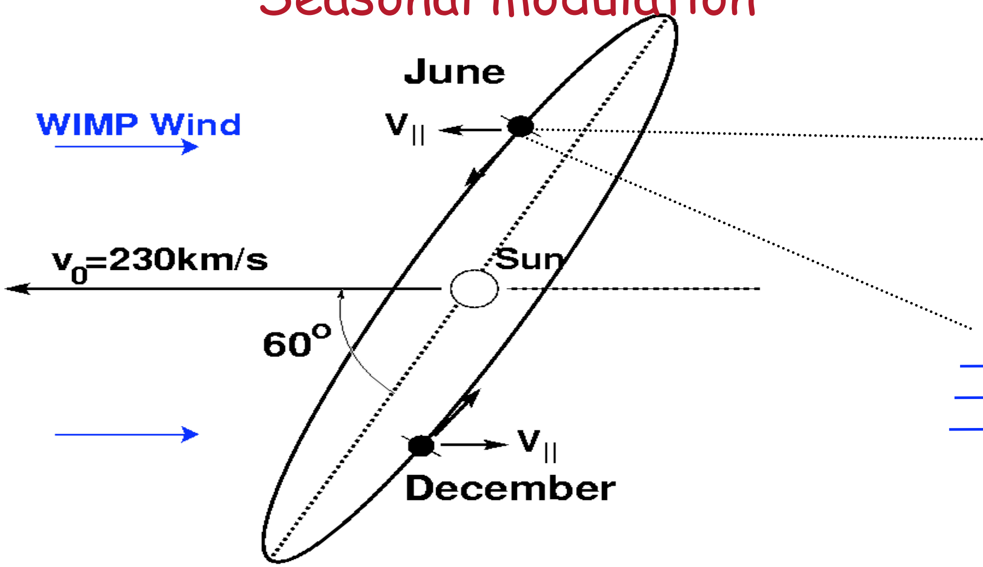
target: low pressure gas (CS_2)

+ directionality

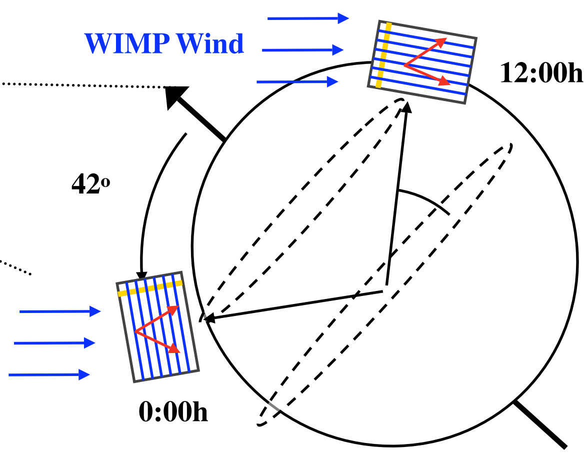
- low mass



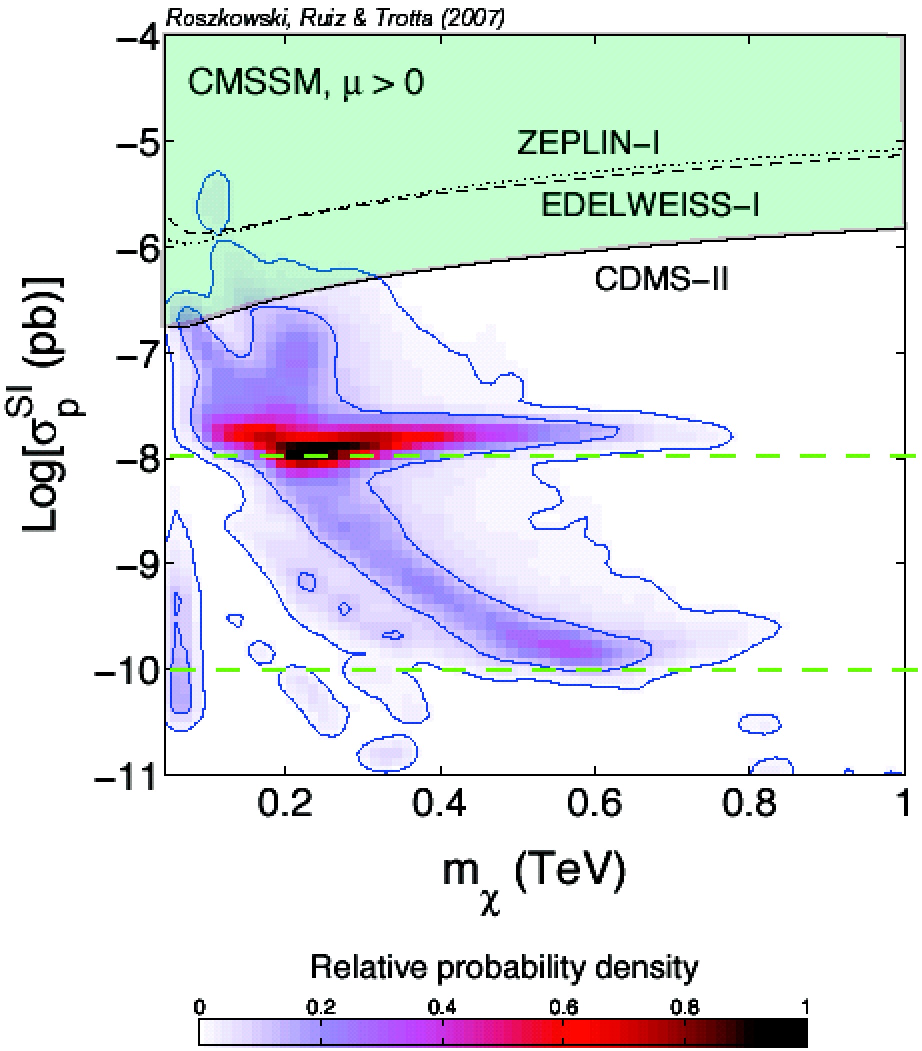
Seasonal modulation



Sidereal modulation



Experiments and SUSY Predictions



excluded by CDMS-II
(situation before 2007)

0.05 events/kg/day

1 event/kg/yr

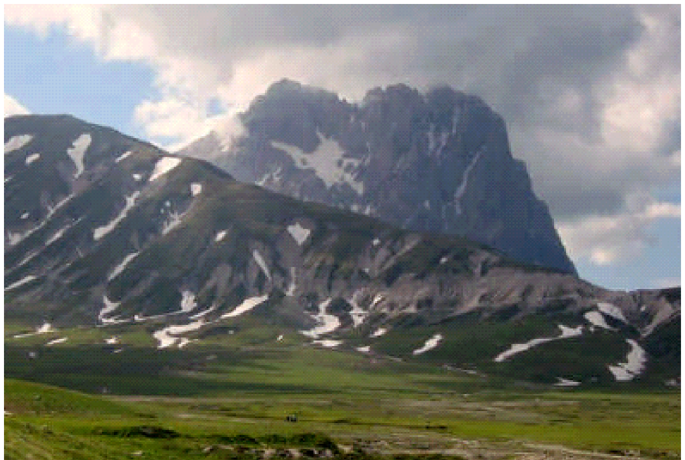
CDMS-II, XENON10, COUPP, CRESST-II, EDELWEISS-II, ZEPLIN-III,...

1 event/t/yr

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

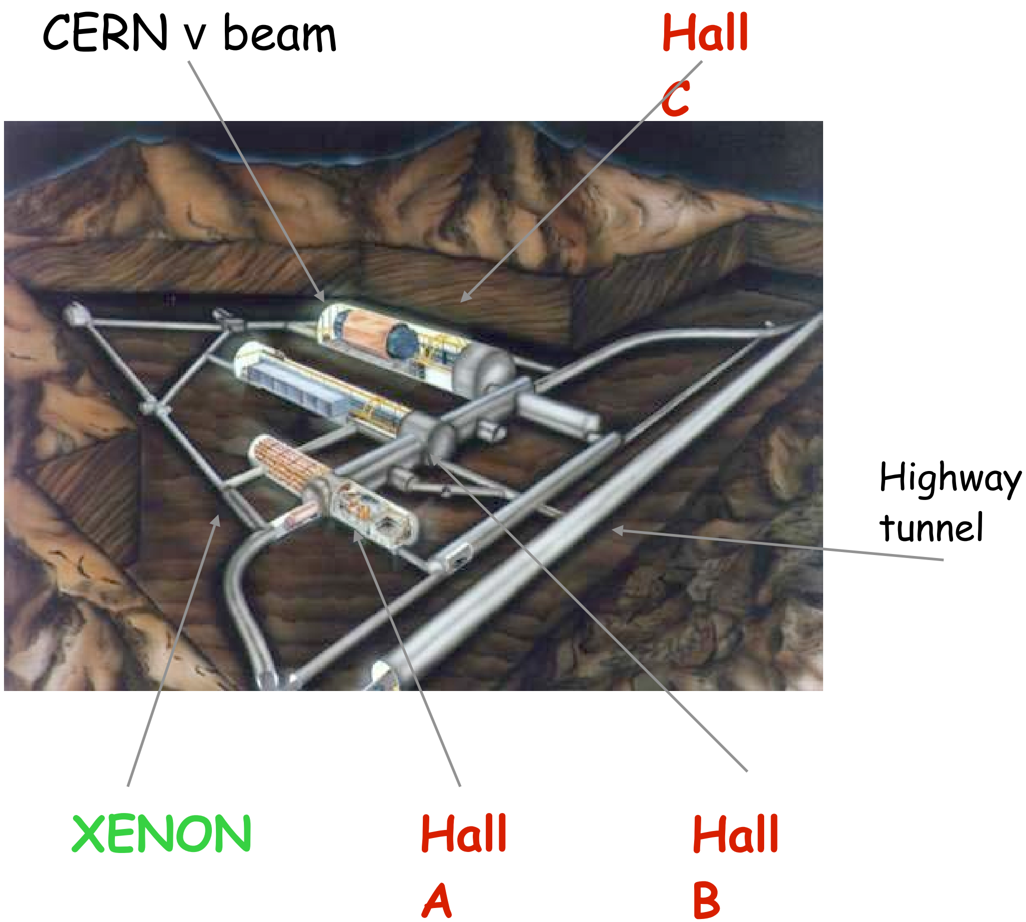
CMSSM in 2007
http://xxx.lanl.gov/abs/0705.2012

The **XENON** dark matter experiment



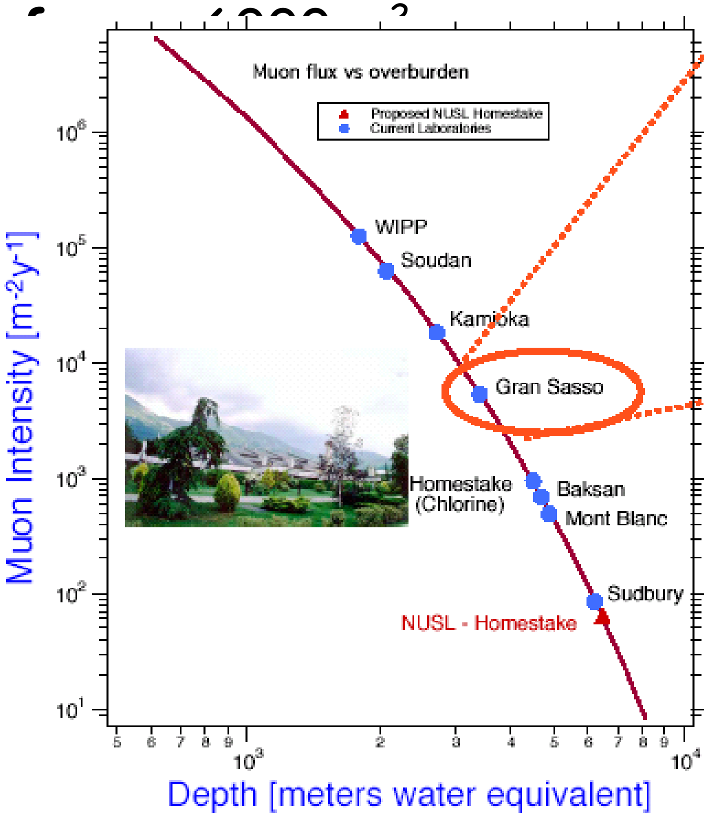
The Gran Sasso Underground Area

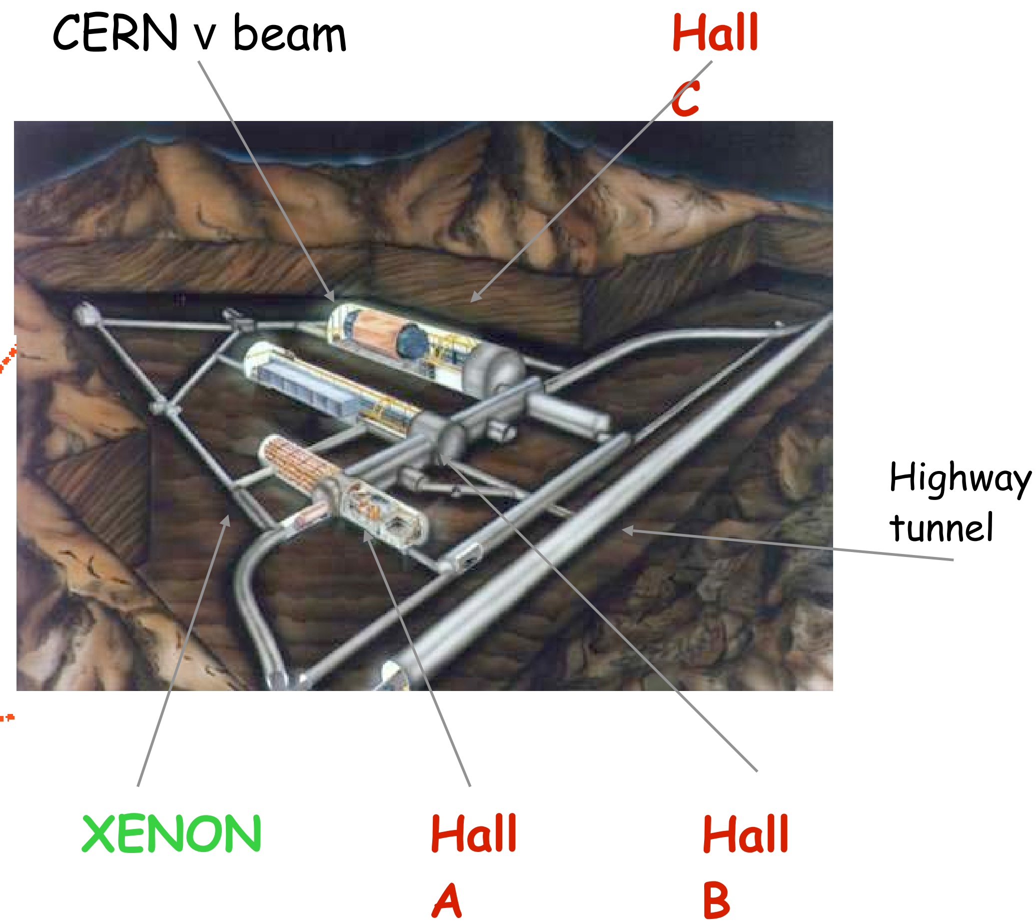
Location: Gran Sasso Tunnel (Abruzzi, Italy)
Depth: 1400 m (3800 mwe),
Underground area : 3 halls
Total volume : 180000 m^3,
Surface: > 6000 m^2



The Gran Sasso Underground Area

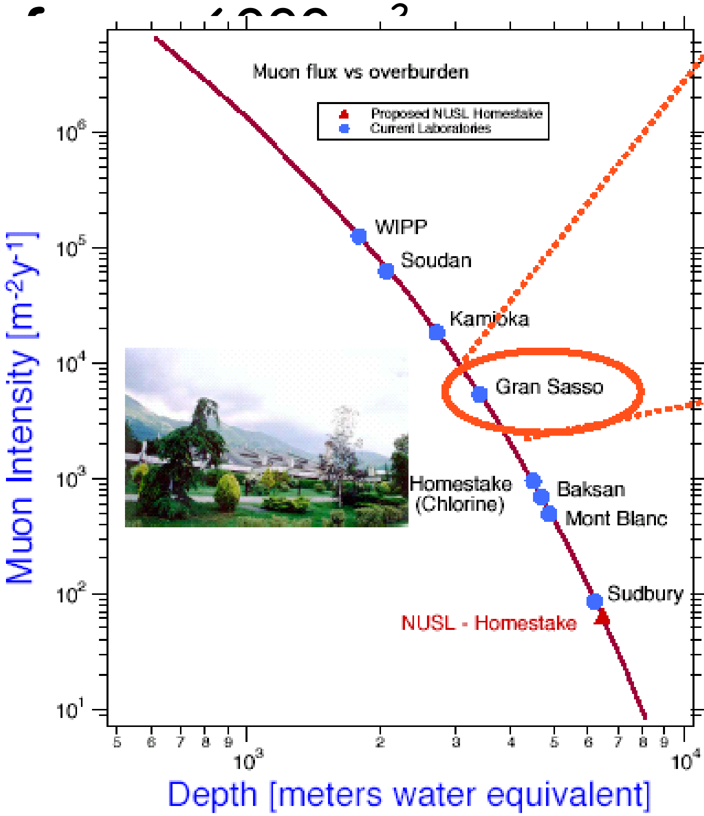
Location: Gran Sasso Tunnel (Abruzzi, Italy)
Depth: 1400 m (3800 mwe),
Underground area : 3 halls
Total volume : 180000 m^3,

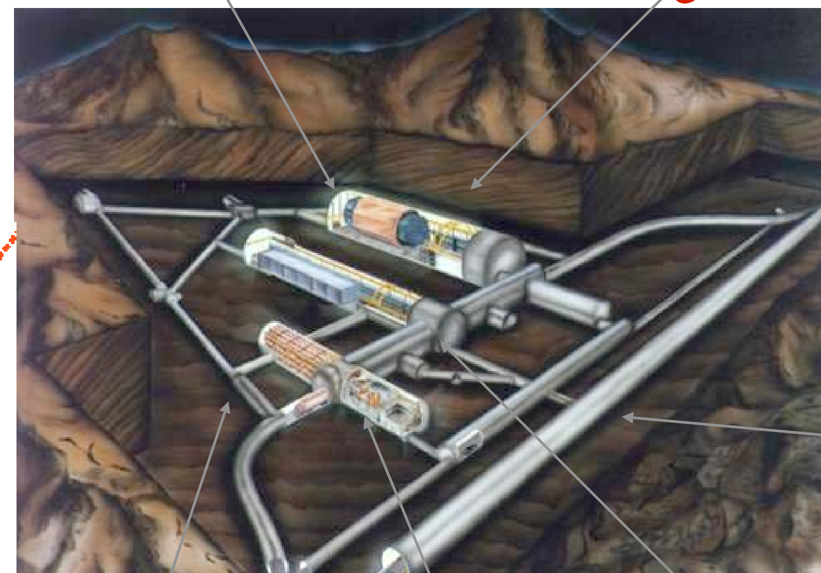




The Gran Sasso Underground Area

Location: Gran Sasso Tunnel (Abruzzi, Italy)
Depth: 1400 m (3800 mwe),
Underground area : 3 halls
Total volume : 180000 m^3,
Su



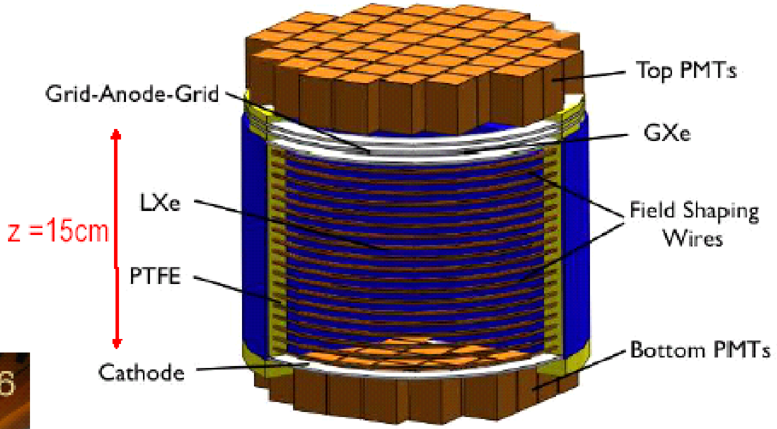


$\boxed{\text{muon flux} = 1 m^{-2} h^{-1}}$

10^6 lower than on surface

XENON 10 at the Gran Sasso Laboratory

- March 06: detector first installed/tested outside shield
- July 06: inserted into shield (20cm Pb, 20 cm PE)
- Aug 06 – Feb07: WIMP search run
- May – Oct 07: bg and cal data with upgraded detector



XENON 10 at the Gran Sasso Laboratory

The XENON10 Detector

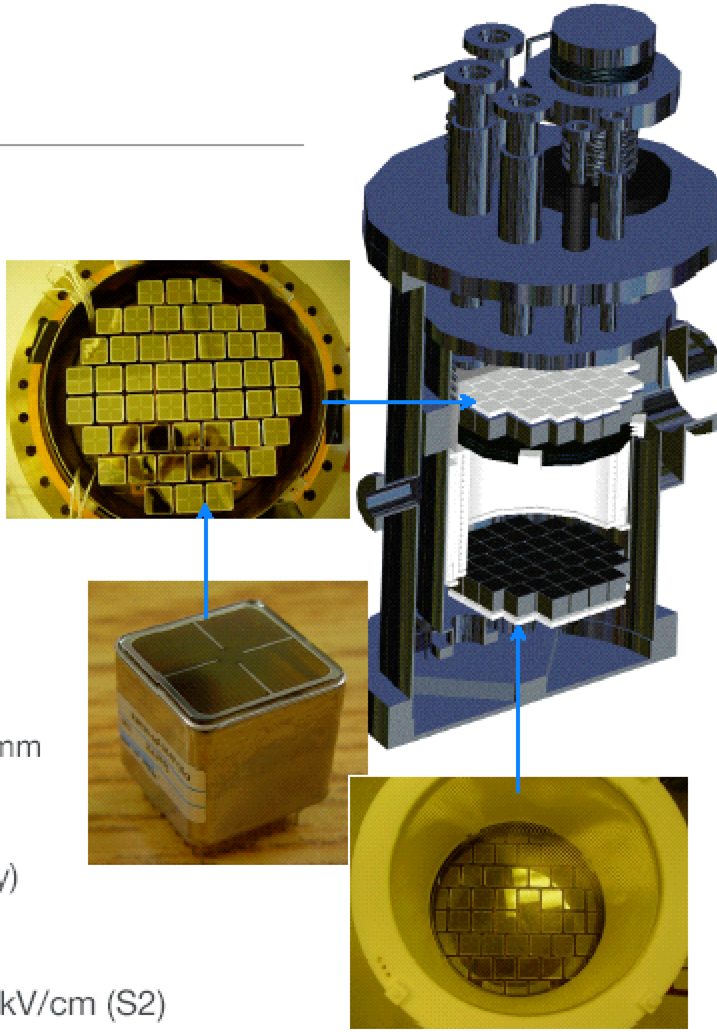
- **22 kg of liquid xenon**
  - ➡ 15 kg active volume
  - ➡ 20 cm diameter, 15 cm drift
- **Hamamatsu R8520 1”×3.5 cm PMTs**

  bialkali-photocathode Rb-Cs-Sb,

  Quartz window; ok at -100ºC and 5 bar

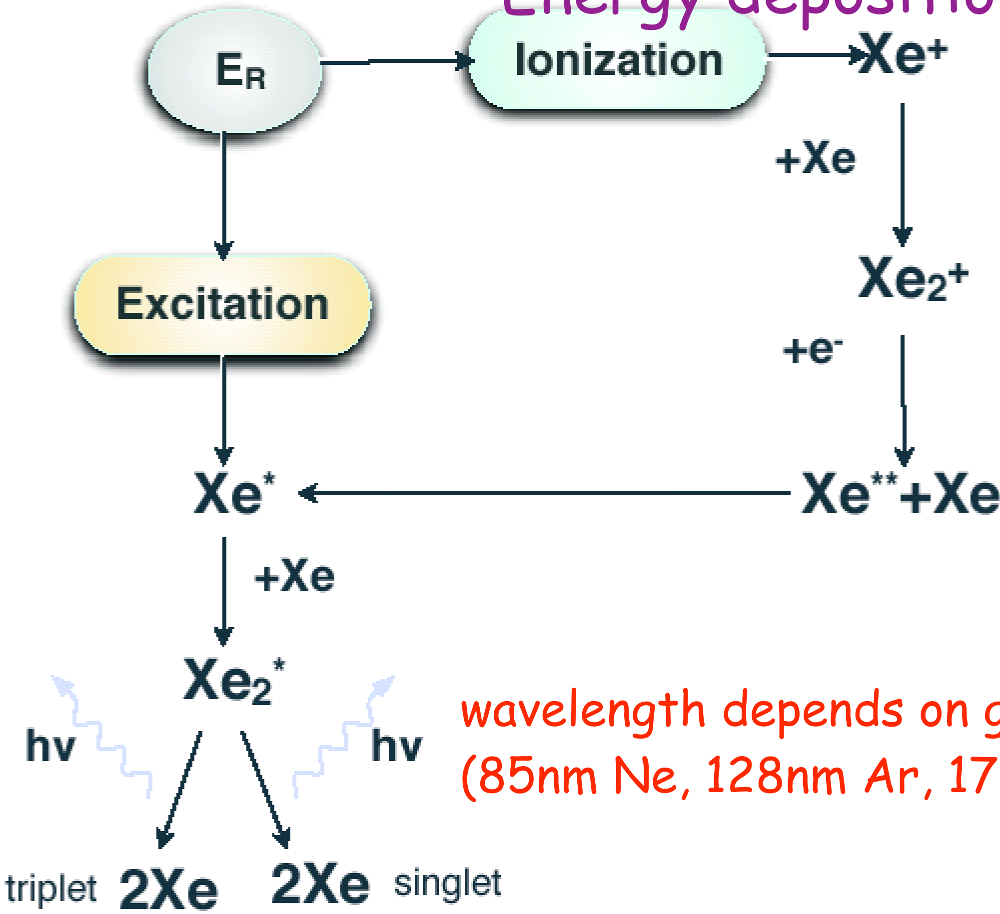
  Quantum efficiency > 20% @ 178 nm
- **48 PMTs top, 41 PMTs bottom array**
  - ➡ x-y position from PMT hit pattern; $\sigma_{x\text{-}y} \approx 1$ mm
  - ➡ z-position from Δt_{drift} ($v_{d,e-} \approx$ 2mm/µs), $\sigma_z \approx 0.3$ mm
- **Cooling: Pulse Tube Refrigerator (PTR),**

  90W, coupled via cold finger (LN_2 for emergency)
  - ➡ LXe maintained at T = 180 K and P=2.2 atm
- **12 kV cathode:** E_d=0.73 kV/cm (drift), E_{gas}=9kV/cm (S2)
- **Xe purification: high T getter**



Charge and Light in Noble Liquids

Energy deposition



$$
\begin{aligned}
\mathrm{Xe}^* + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^* \\
\mathrm{Xe}_2^* &\rightarrow 2\mathrm{Xe} + h\nu
\end{aligned}
$$

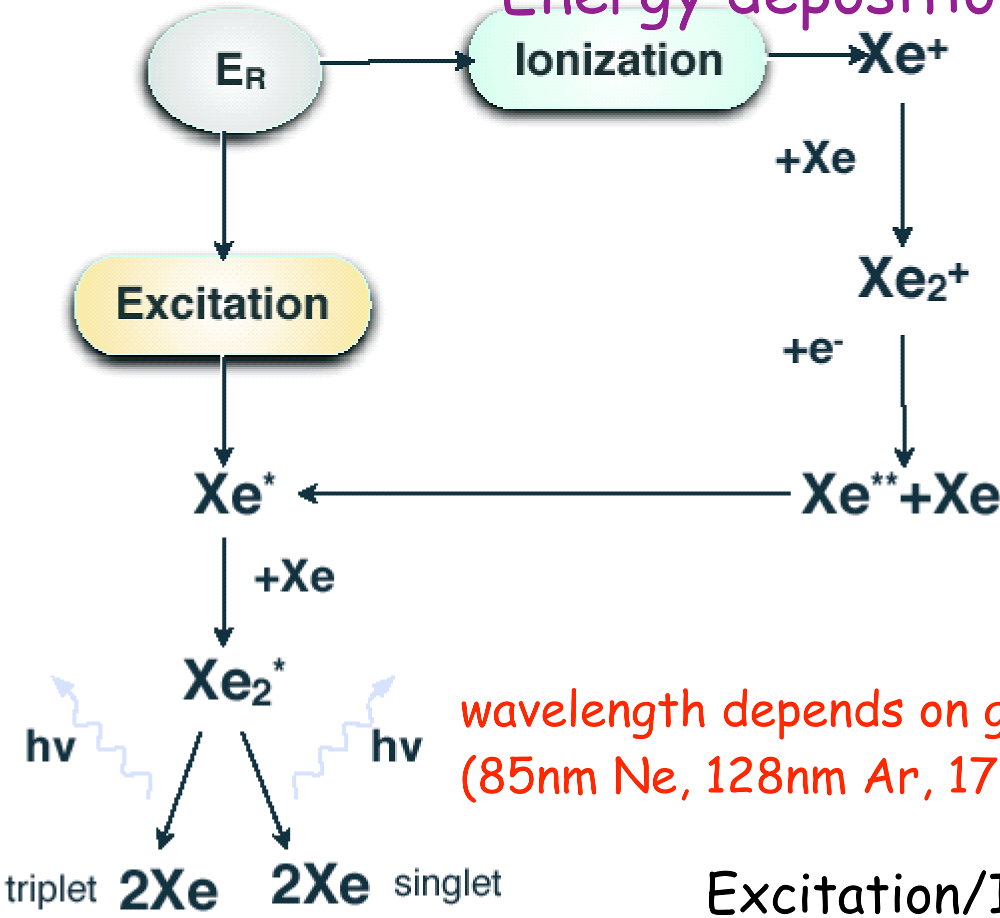
$$
\begin{aligned}
\mathrm{Xe}^+ + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^+ \\
\mathrm{Xe}_2^+ + e^- &\rightarrow \mathrm{Xe}^{**} + \mathrm{Xe} \\
\mathrm{Xe}^{**} &\rightarrow \mathrm{Xe}^* + \mathrm{heat} \\
\mathrm{Xe}^* + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^* \\
\mathrm{Xe}_2^* &\rightarrow 2\mathrm{Xe} + h\nu
\end{aligned}
$$

wavelength depends on gas
(85nm Ne, 128nm Ar, 175nm Xe)

time constants depend on gas
(few ns/15.4μs Ne, 10ns/1.5μs, 3/27ns Xe)

Charge and Light in Noble Liquids

Energy deposition



$$\begin{aligned} \mathrm{Xe}^* + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^* \\ \mathrm{Xe}_2^* &\rightarrow 2\mathrm{Xe} + h\nu \end{aligned}$$

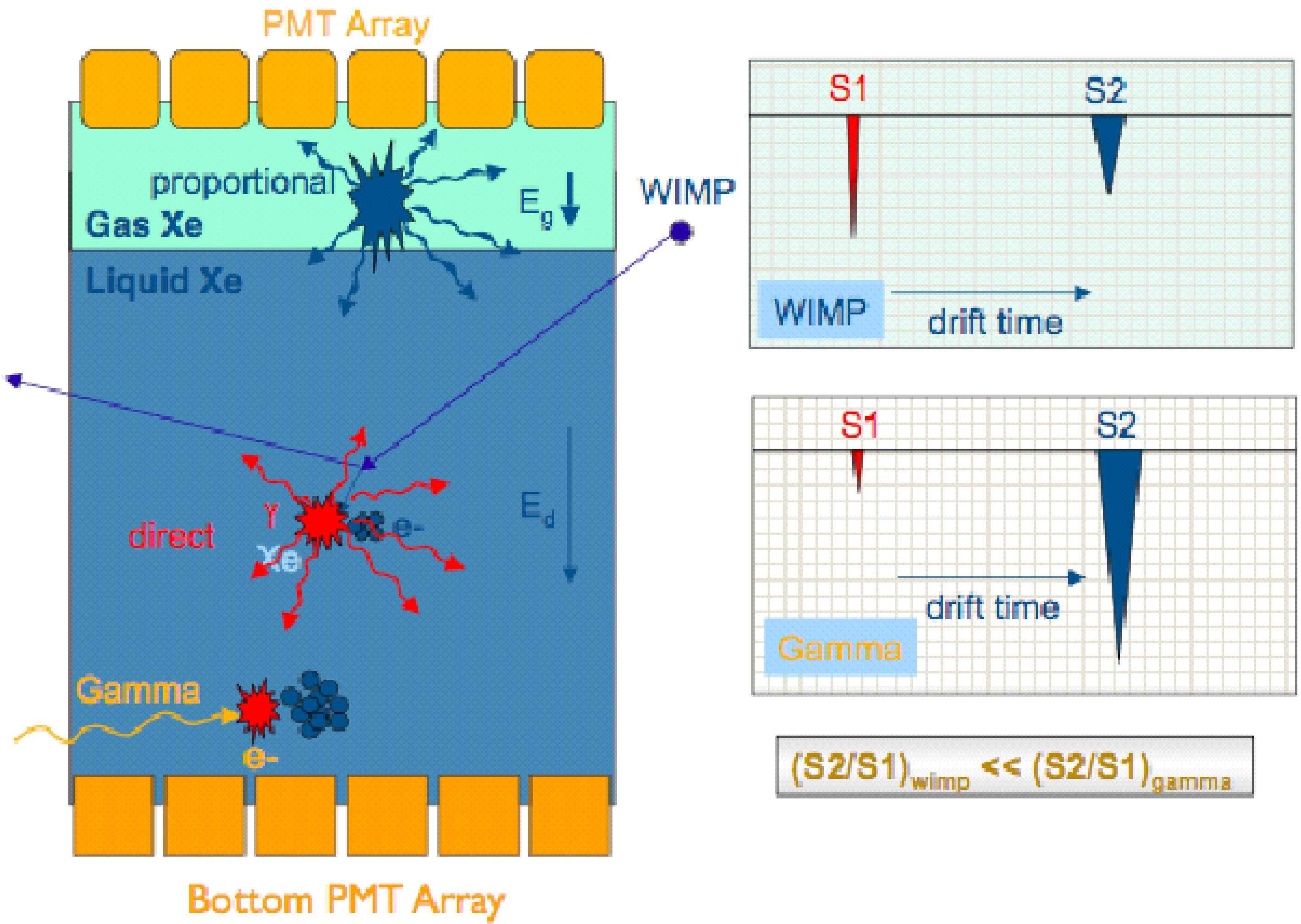
$$\begin{aligned} \mathrm{Xe}^+ + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^+ \\ \mathrm{Xe}_2^+ + e^- &\rightarrow \mathrm{Xe}^{**} + \mathrm{Xe} \\ \mathrm{Xe}^{**} &\rightarrow \mathrm{Xe}^* + \mathrm{heat} \\ \mathrm{Xe}^* + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^* \\ \mathrm{Xe}_2^* &\rightarrow 2\mathrm{Xe} + h\nu \end{aligned}$$

wavelength depends on gas
(85nm Ne, 128nm Ar, 175nm Xe)

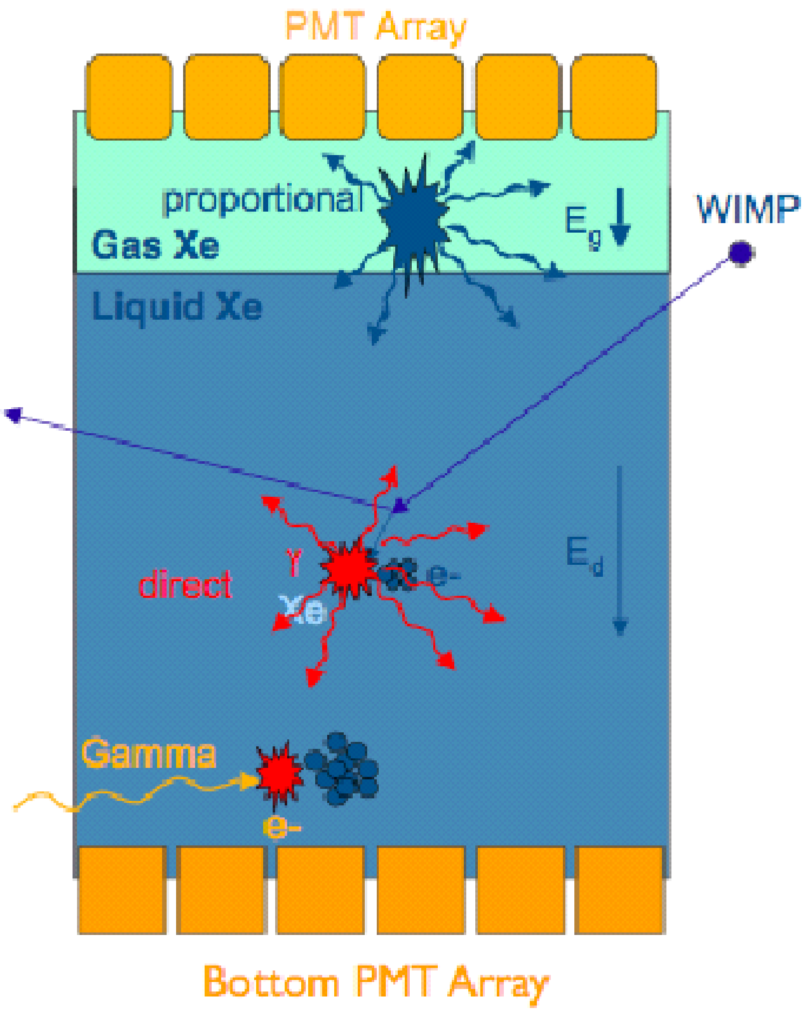
Excitation/Ionization depends on dE/dx
$\Rightarrow$ discrimination of signal (WIMPs=> NR)
and most of the bg (gammas=> ER)

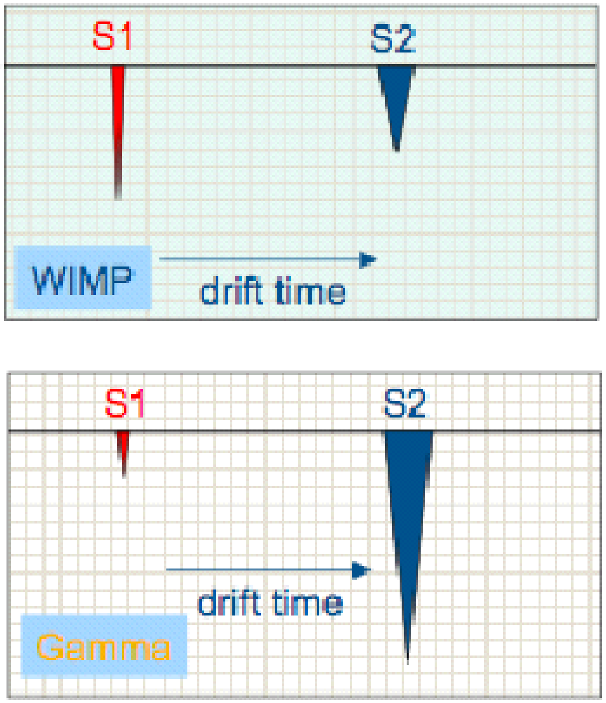
time constants depend on gas
(few ns/15.4µs Ne, 10ns/1.5µs, 3/27ns Xe)

Charge and Light in Noble Liquids



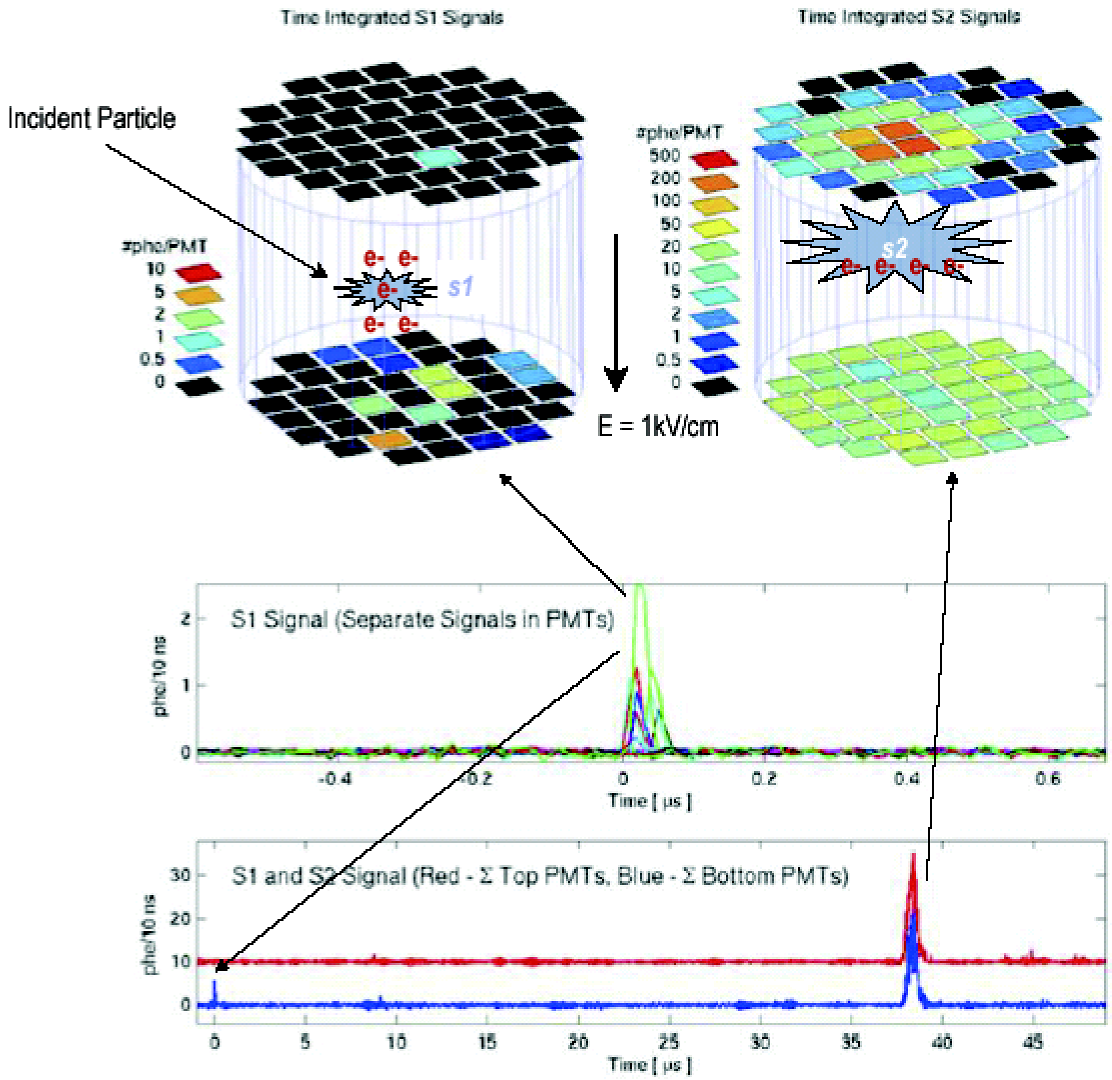
Charge and Light in Noble Liquids





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

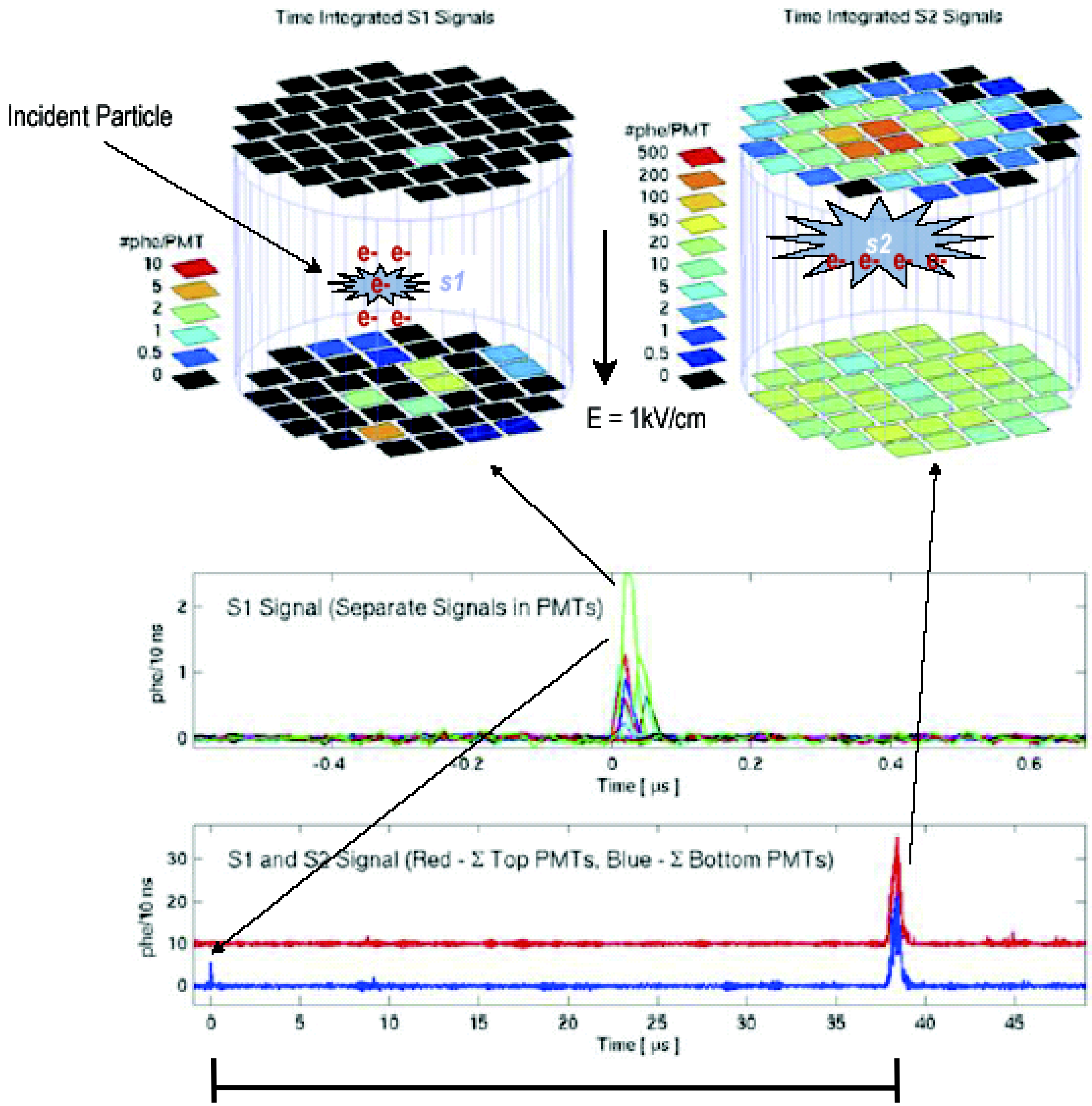
Discrimination!



The S2 sum of 34 centre PMT of the top array provides the event trigger.

The S1 signal associated with each trigger event is searched . A coincident signal in at least 2 PMTs is required.

S2 hardware threshold = 100 pe (corresponding to 4 e^- extracted from the liquid)

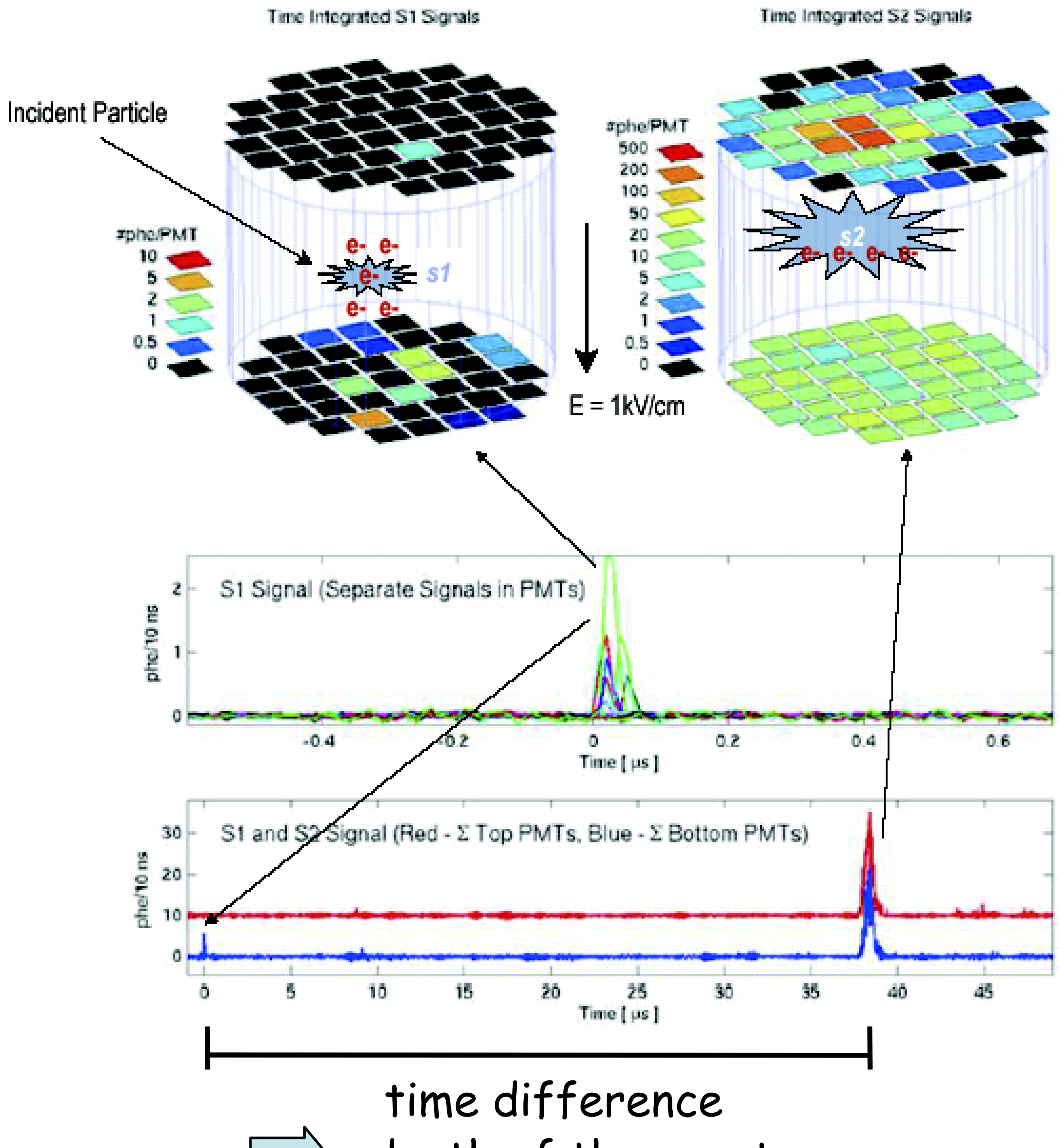


time difference

The S2 sum of 34 centre PMT of the top array provides the event trigger.

The S1 signal associated with each trigger event is searched . A coincident signal in at least 2 PMTs is required.

S2 hardware threshold = 100 pe (corresponding to 4 e^- extracted from the liquid)

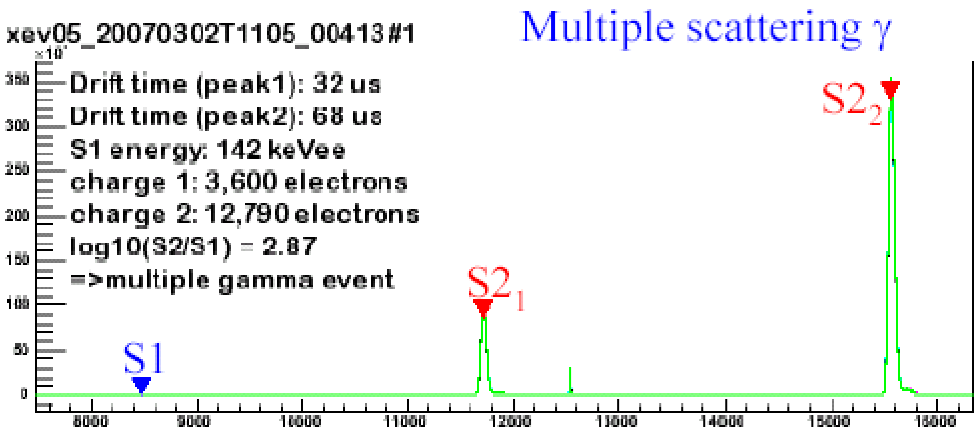


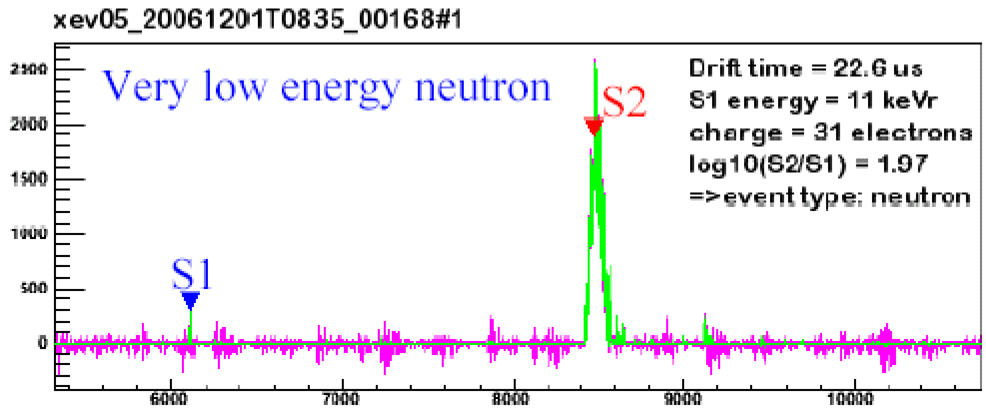
The S2 sum of 34 centre PMT of the top array provides the event trigger.

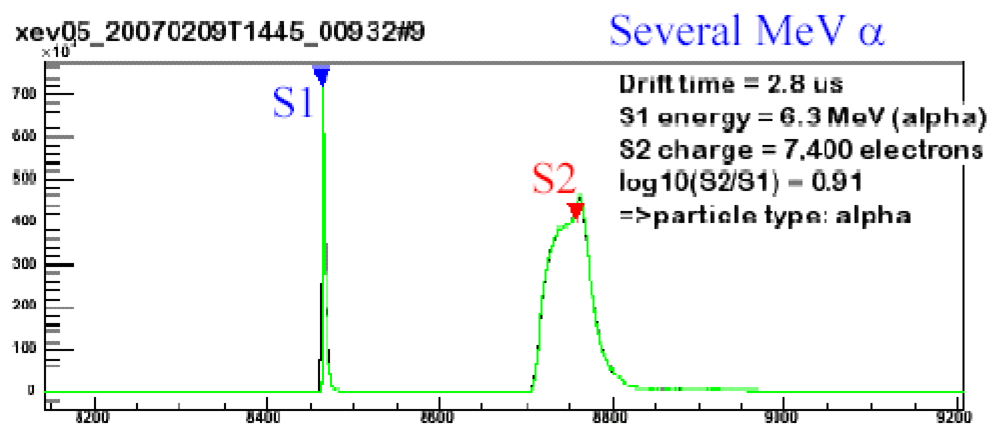
The S1 signal associated with each trigger event is searched . A coincident signal in at least 2 PMTs is required.

S2 hardware threshold = 100 pe (corresponding to 4 e^- extracted from the liquid)

XENON10 events...







XENON 10 gamma calibration

Gamma sources: ^{57}Co, ^{137}Cs;

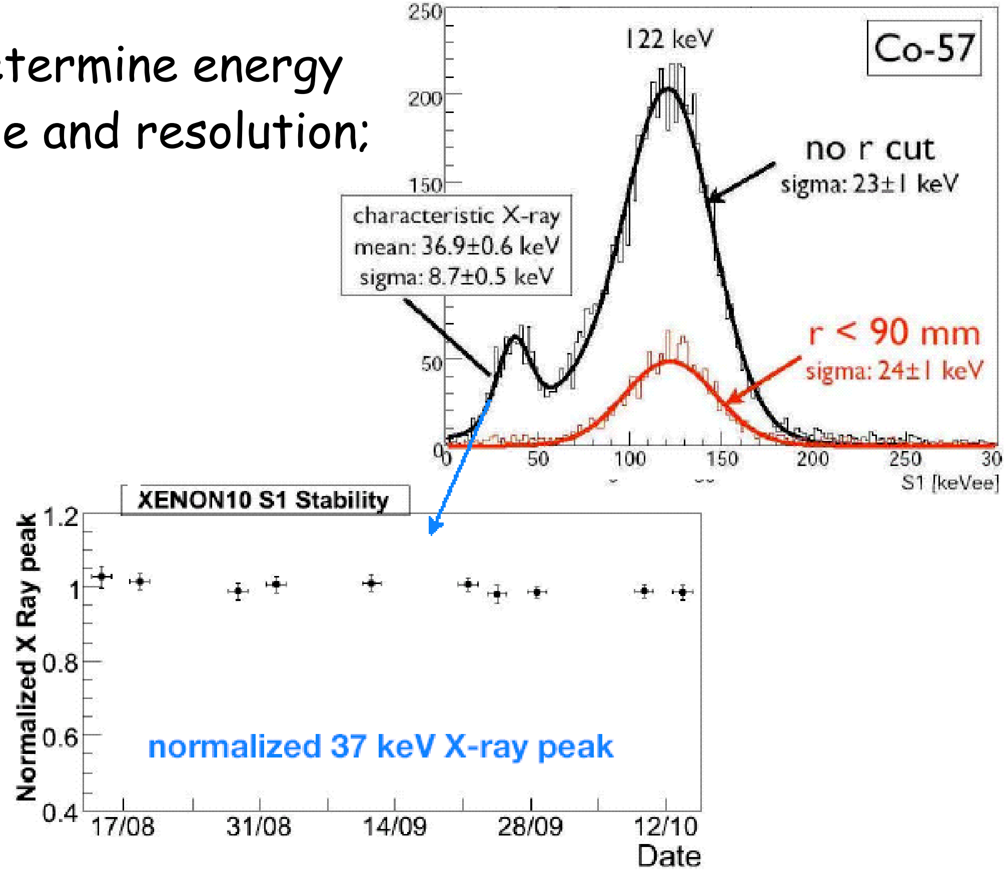
- Light yield from ^{137}Cs: 2.2 pe/keV
- electron lifetime (2.0 ± 0.4) ms => << 1 ppb (O_2 equival.) purity

XENON 10 gamma calibration

Gamma sources: ^{57}**Co**, ^{137}**Cs**;

- Light yield from ^{137}Cs: 2.2 pe/keV
- electron lifetime (2.0 ± 0.4) ms => << 1 ppb (O_2 equival.) purity

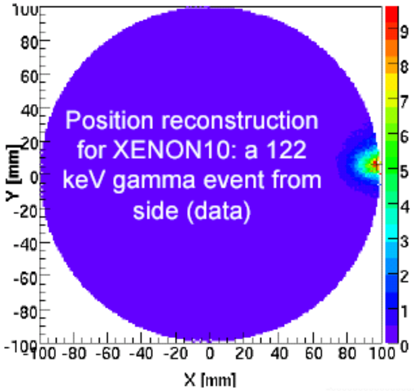
- determine energy scale and resolution;



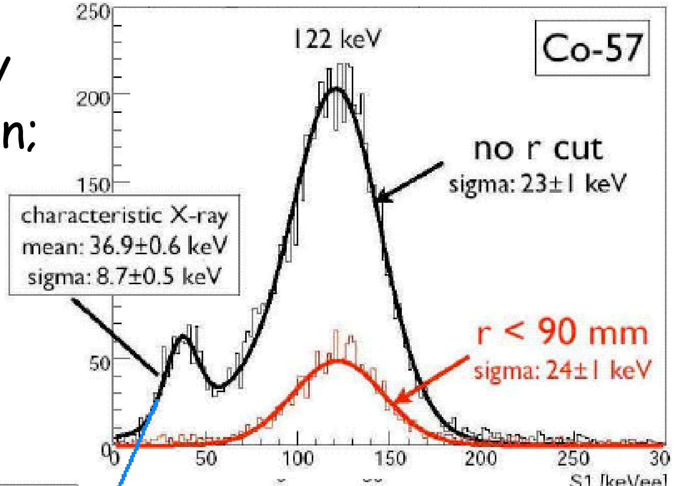
XENON 10 gamma calibration

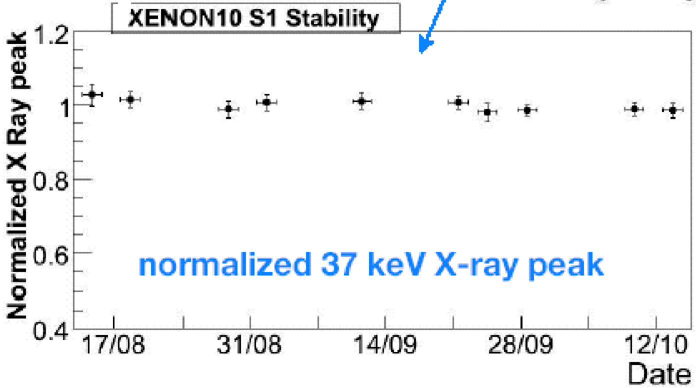
Gamma sources: ^{57}Co, ^{137}Cs;

- Light yield from ^{137}Cs: 2.2 pe/keV
- electron lifetime (2.0 ± 0.4) ms => << 1 ppb (O_2 equival.) purity



- determine energy scale and resolution;



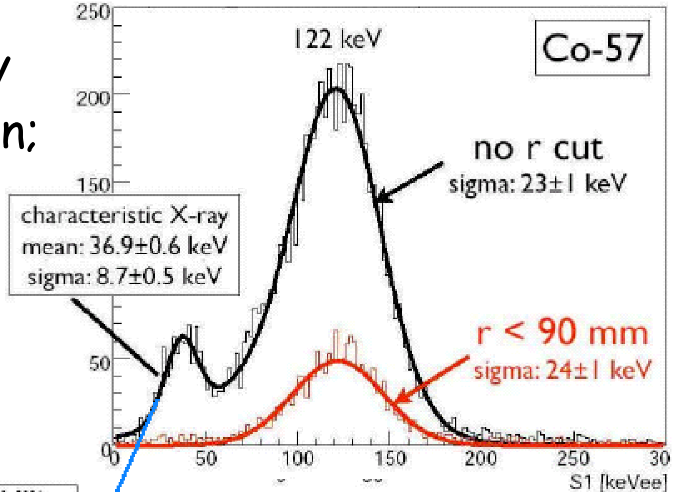


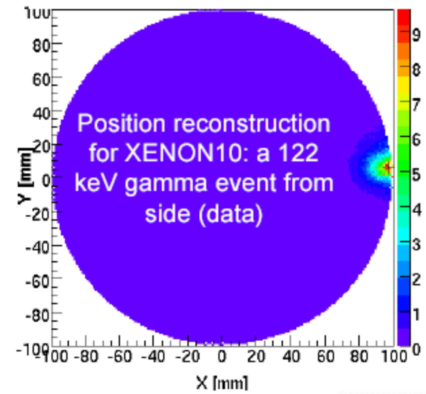
XENON 10 gamma calibration

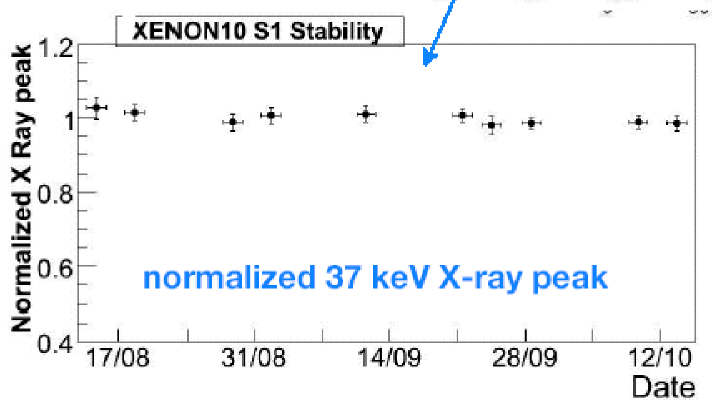
Gamma sources: ^{57}Co, ^{137}Cs;

- Light yield from ^{137}Cs: 2.2 pe/keV
- electron lifetime (2.0 ± 0.4) ms => << 1 ppb (O_2 equival.) purity

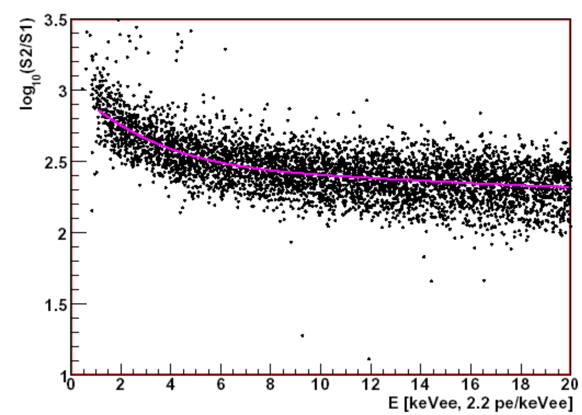
- determine energy scale and resolution;







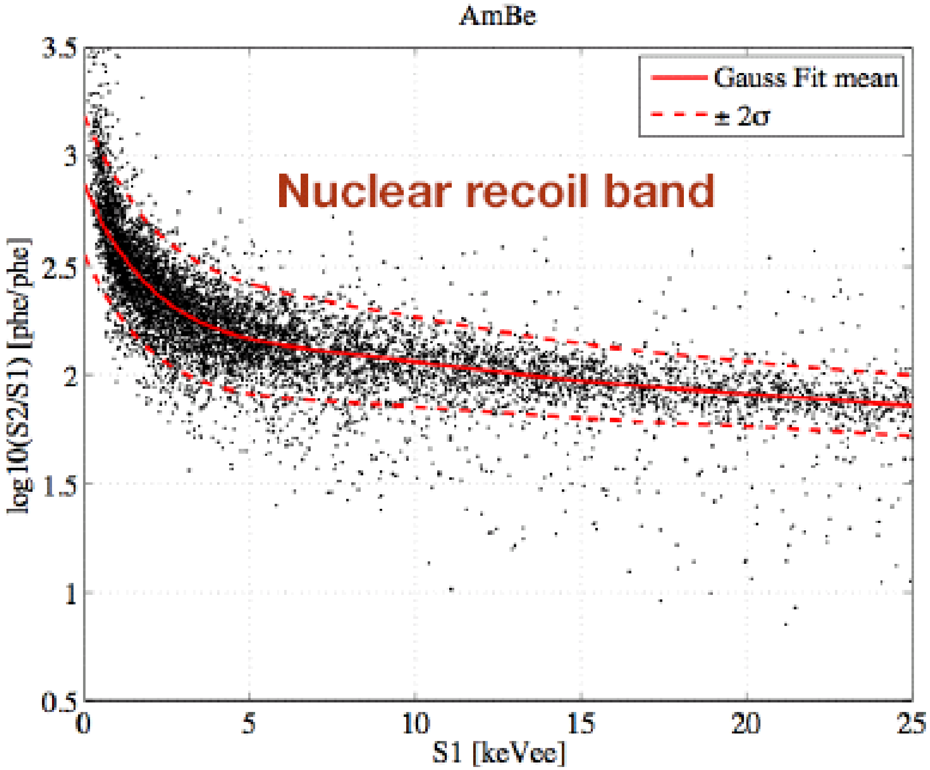
- position of gamma band



XENON 10 neutron calibration

Neutron source: **AmBe** (E_{max}= 10 MeV) ~ 3.7 MBq (220 n/s) in shield

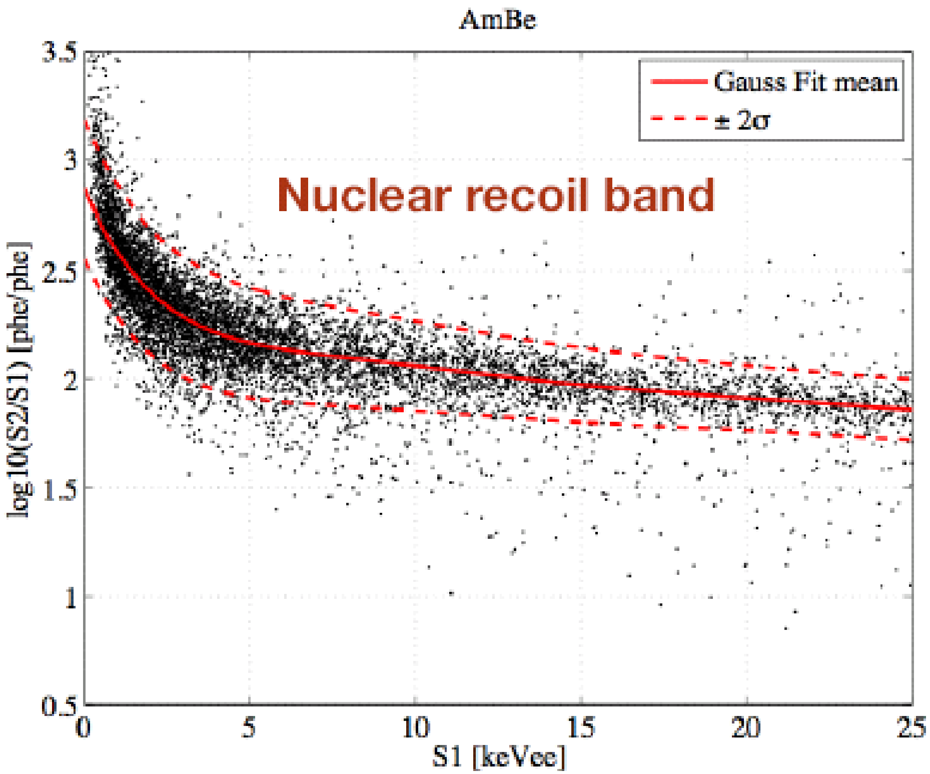
In situ calibration: 1/12/2006 => determination of the nuclear recoil band



XENON 10 neutron calibration

Neutron source: **AmBe** (E_{max}= 10 MeV) ~ 3.7 MBq (220 n/s) in shield

In situ calibration: 1/12/2006 => determination of the nuclear recoil band



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)

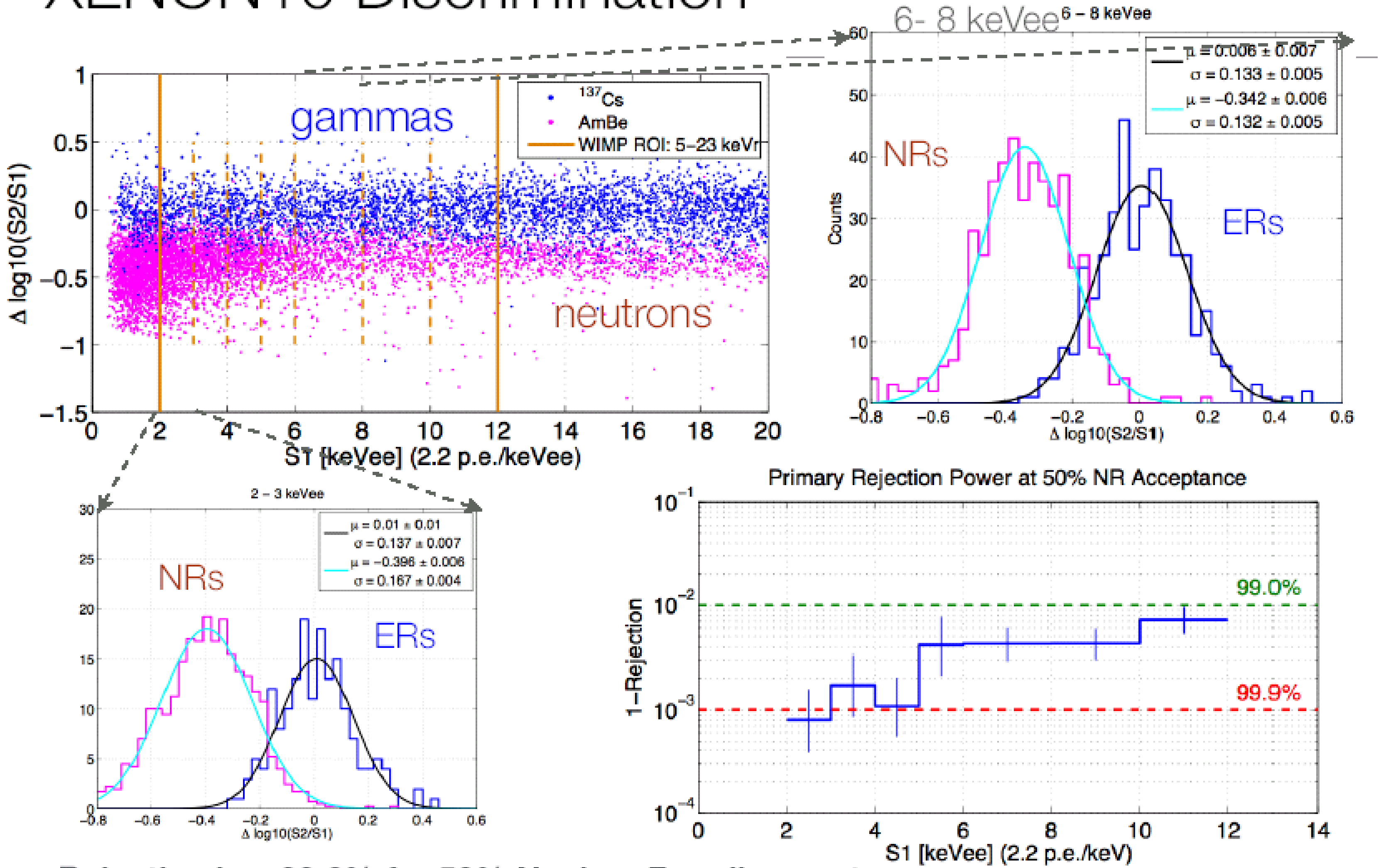
$$E_{nr} = \frac{S1}{L_y \cdot L_{eff}} \times \frac{S_{er}}{S_{nr}}$$

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)

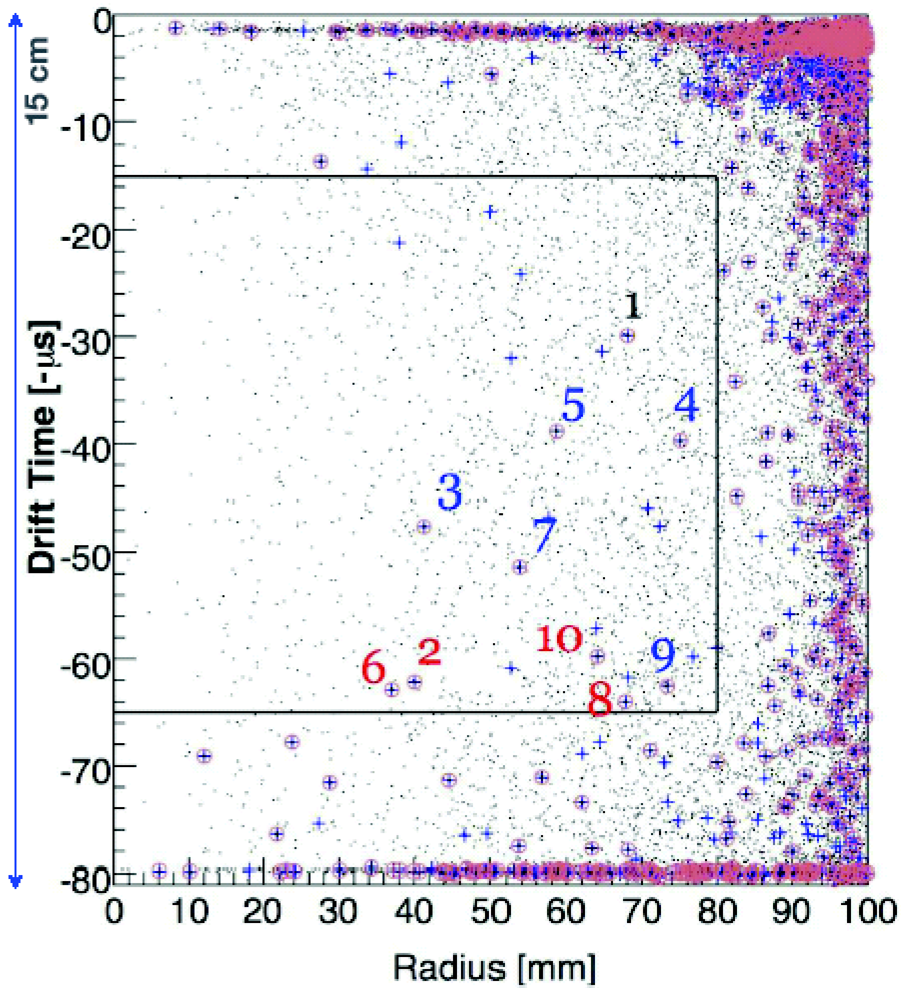
Quenching of scintillation yield for NRs due to field (0.93 at 0.73 kV/cm)

XENON10 Discrimination



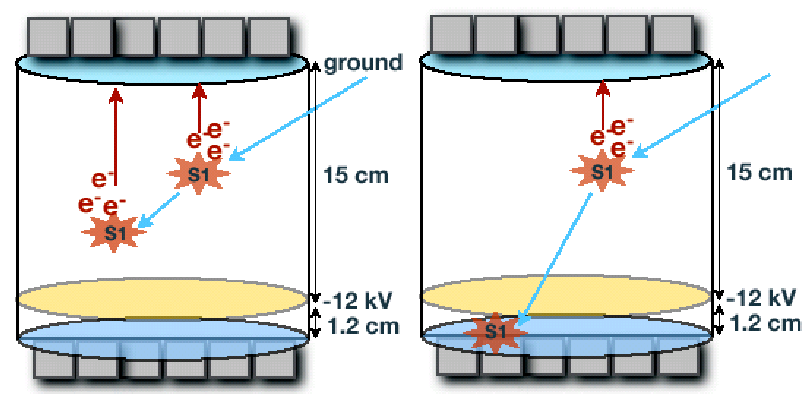
- **Rejection is > 99.6% for 50% Nuclear Recoil acceptance**
  - ➡ **Cuts:** fiducial volume (remove events at teflon edge where poor charge collection)
  - ➡ Multiple scatters (more than one S2 pulse)

XENON 10 WIMP search data
Spatial distribution of events



Due to high stopping power of LXe, the bg rate in the central part is lower than that near the edges

⇨ fiducial cuts



XENON 10 WIMP search data

WIMP search run 24/8/2006 – 14/2/2007: ~ 60 (blind) live days

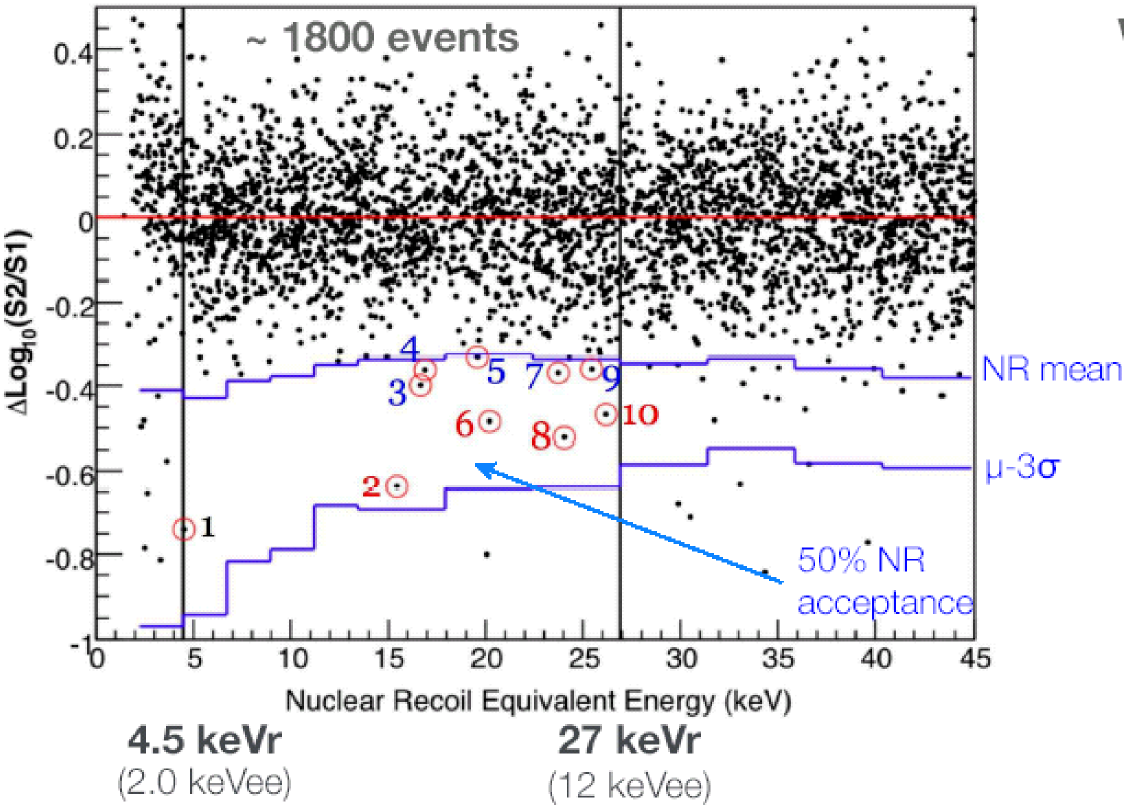
136 Kg-days exposure = 58.6 live days x 5.4 kg x 0.86 (ε) x 0.50

(50% NR acceptance)

XENON 10 WIMP search data

WIMP search run 24/8/2006 – 14/2/2007: ~ 60 (blind) live days

136 Kg-days exposure = 58.6 live days x 5.4 kg x 0.86 (ε) x 0.50 (50% NR acceptance)



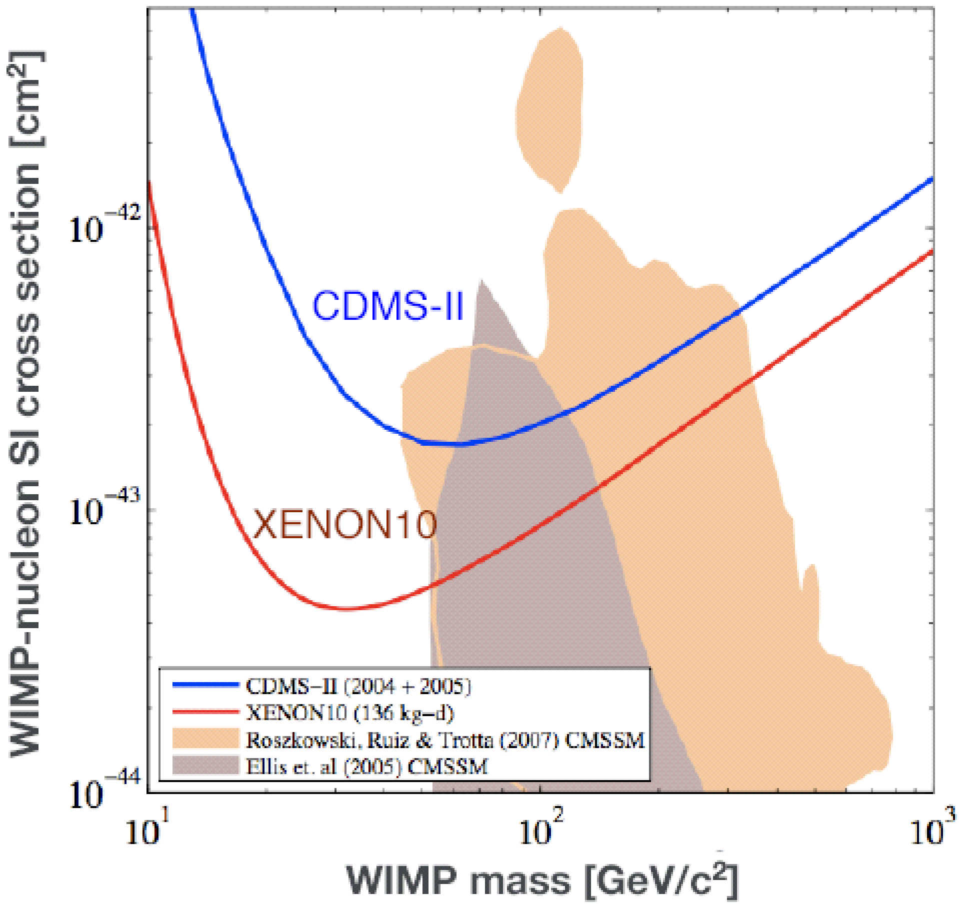
50% acceptance of NRs (blue lines): [Mean, 3σ]

10 events after all cuts

7.0 $^{(+2.1}{}_{-1.0})$ statistical leakage expected from the gamma (ER) band

XENON 10 results

To set limits all 10 events considered, thus no bg subtraction performed



At **100 GeV WIMP mass:**

$9.0 \cdot 10^{-44}$cm^2 (red curve)

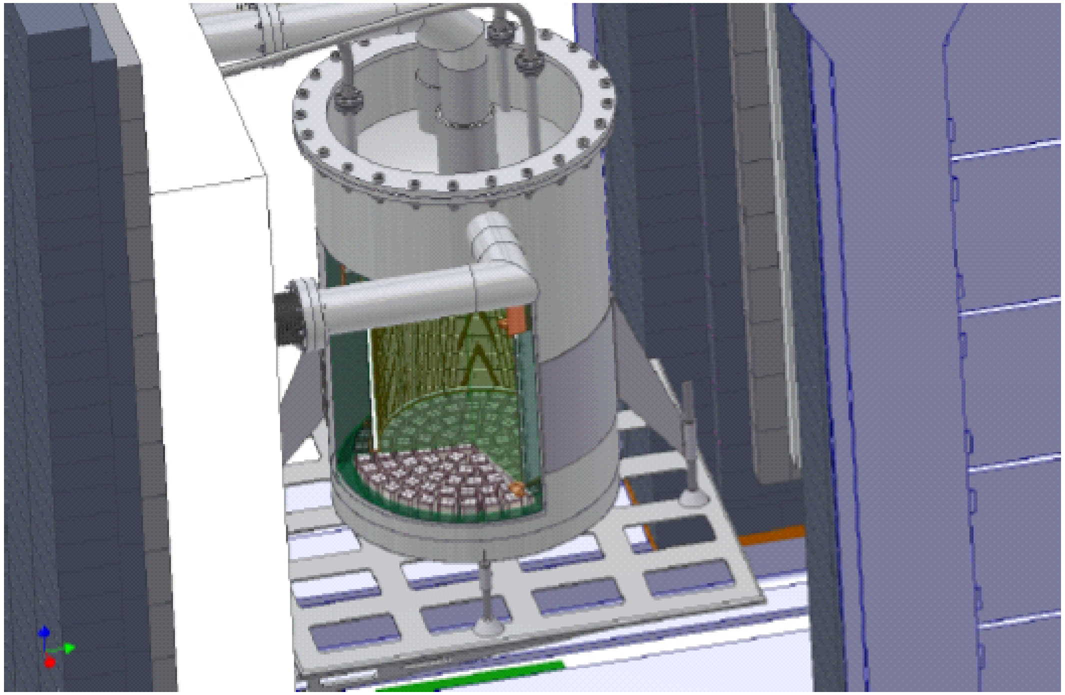
$5.5 \cdot 10^{-44}$cm^2
(known background subtracted, not shown)

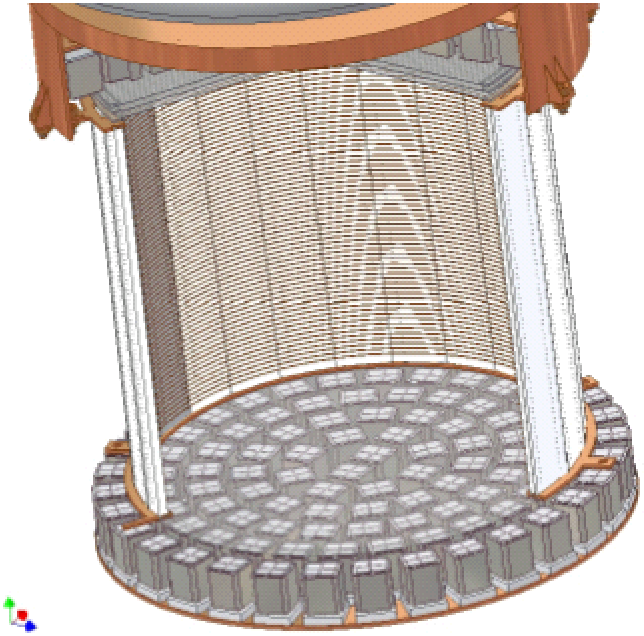
Factor 6 below previous best limit

Results submitted to PLR
arXiv: 0706.0039

XENON 100

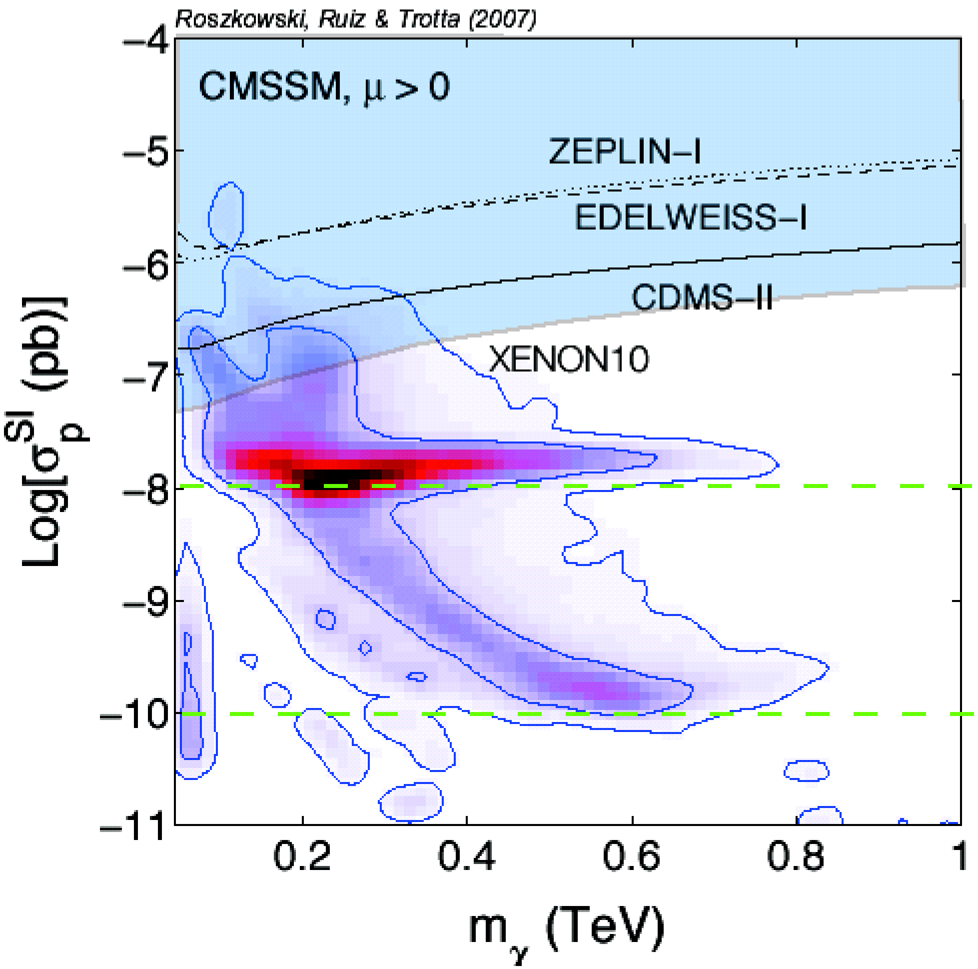
- New detector in current shielding at LNGS is under construction; 150 kg LXe (70 kg target), active veto, 250 low activity 1 inch PMT; feed-throughs outside the shield
- Dedicated material screening facility at LNSG
- Construction: end 2007; installation spring 2008; **results by end of 2008**
- Expect to test cross section of 9×10^{-45} cm^2 (at 100 GeV WIMP mass)





15cm radius, 30 cm drift

Summary



excluded by XENON10
(2007)

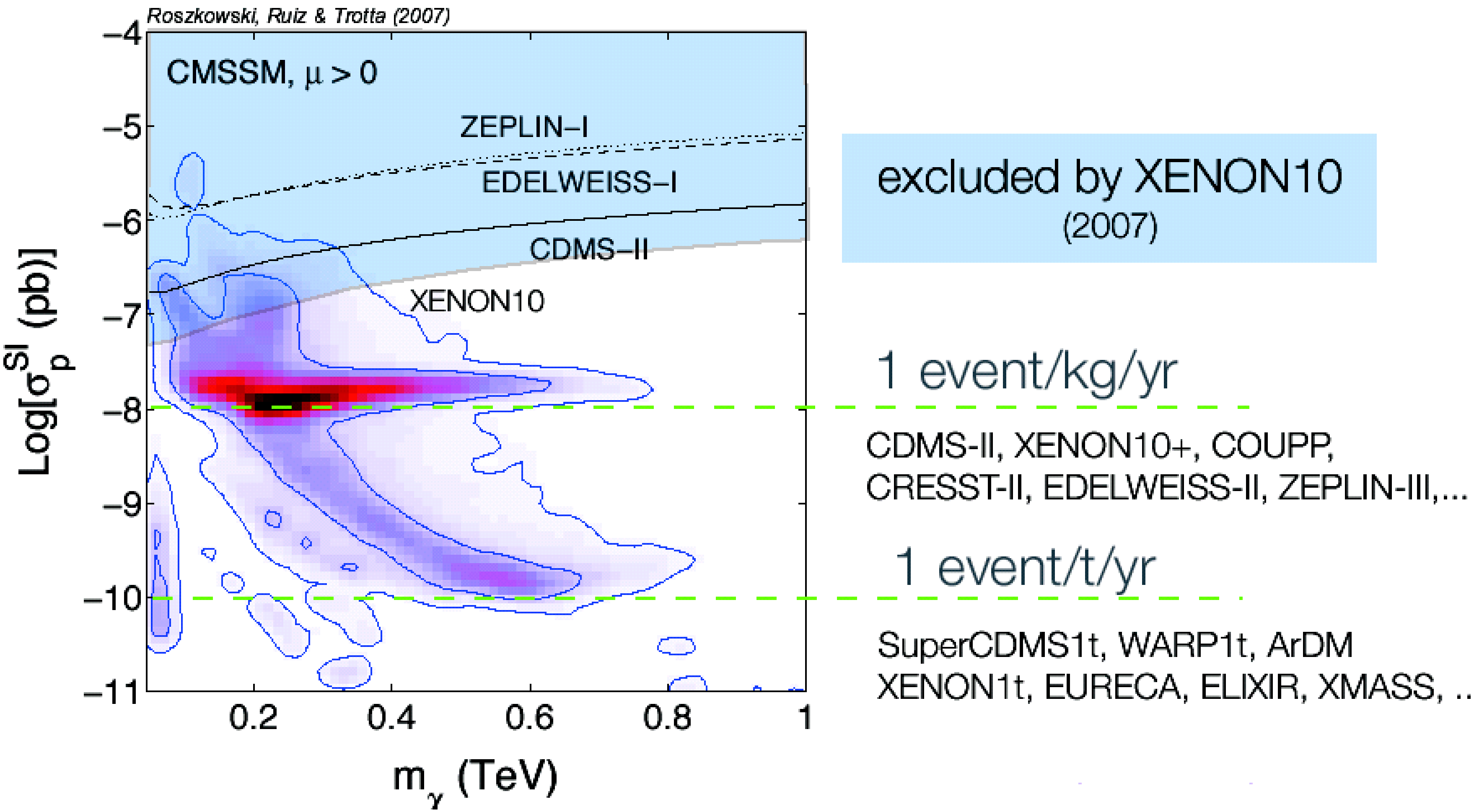
1 event/kg/yr

CDMS-II, XENON10+, COUPP,
CRESST-II, EDELWEISS-II, ZEPLIN-III,...

1 event/t/yr

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

Summary



The discovery of dark matter is of fundamental importance to cosmology, astrophysics and particle physics …

Vielen Dank !