

# Direct Dark Matter Detection

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Laboratori Nazionali del Gran Sasso

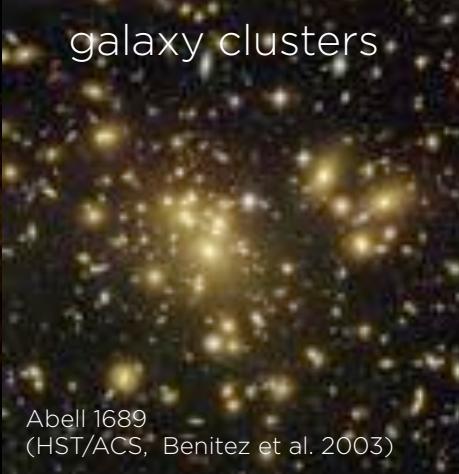


# Evidence for dark matter

large scale structure



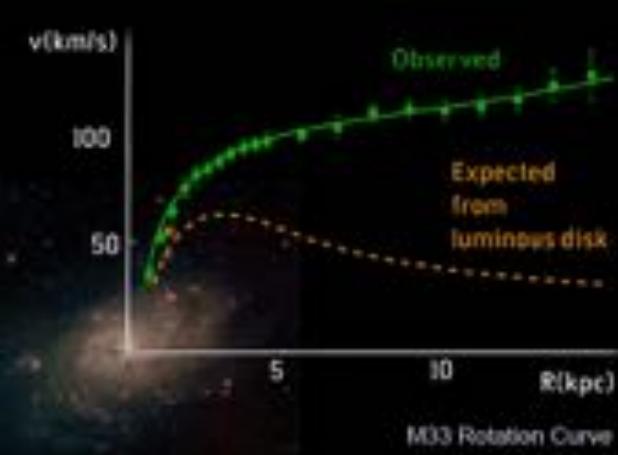
galaxy clusters



galaxy



Bullet cluster



Supernovae

Host Galaxies of Distant Supernovae

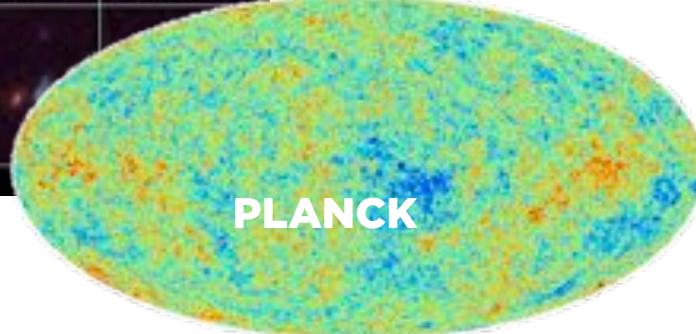


A. Riess

M33 Image: NOAO, AURA, NSF, T.A.Rector.

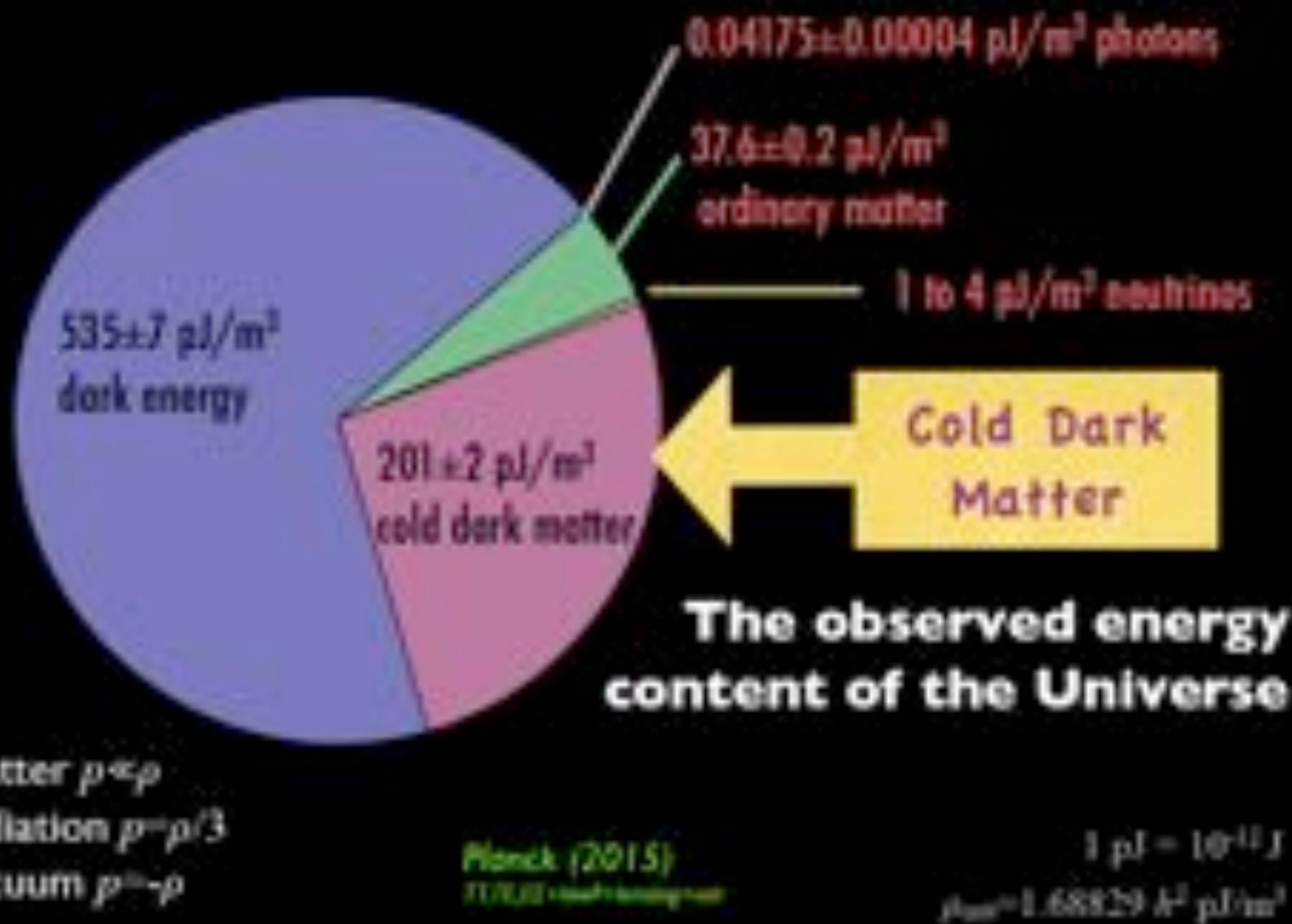
15.11.15

Karoline Schäffner - GSSI Scientific Fair

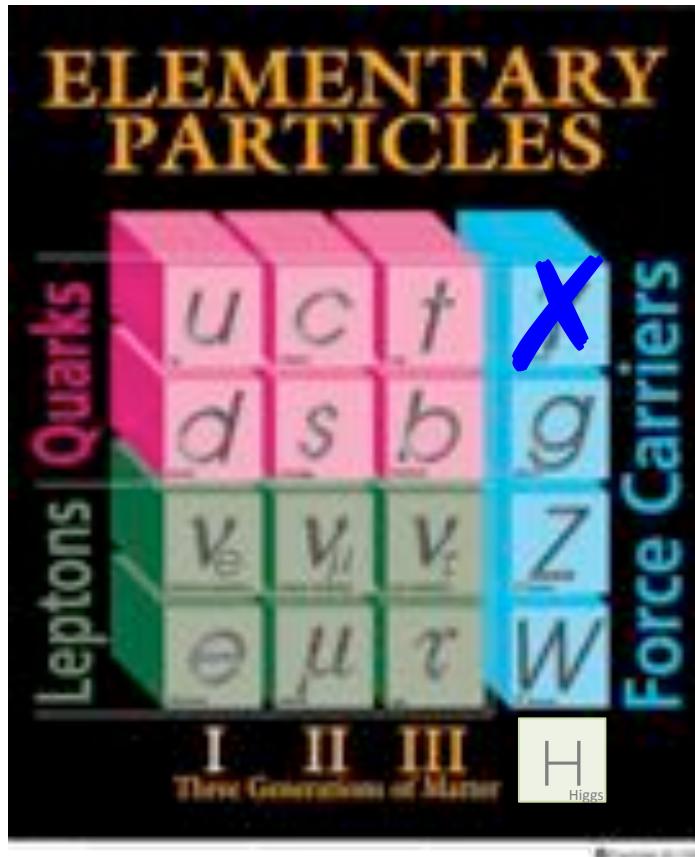


# Evidence for cold dark matter

Taken from Gondolo @ TAUP15

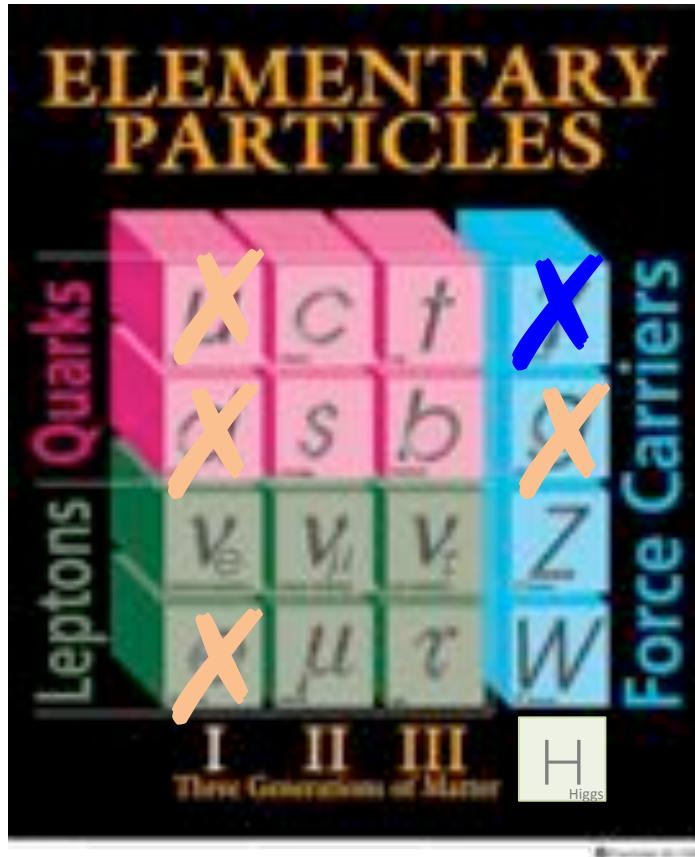


# Can dark matter be SM particle?



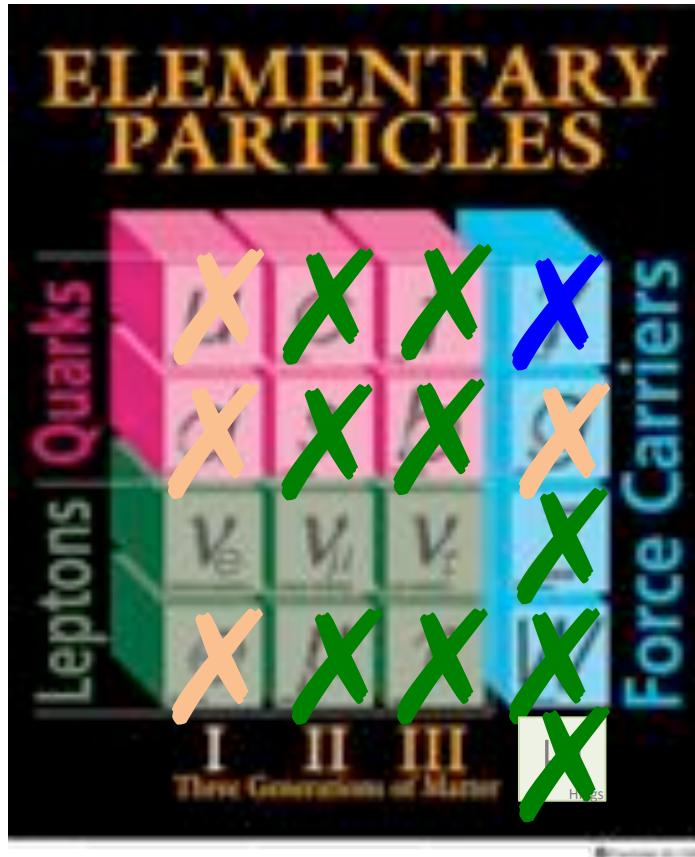
is the particle of light

# Can dark matter be SM particle?



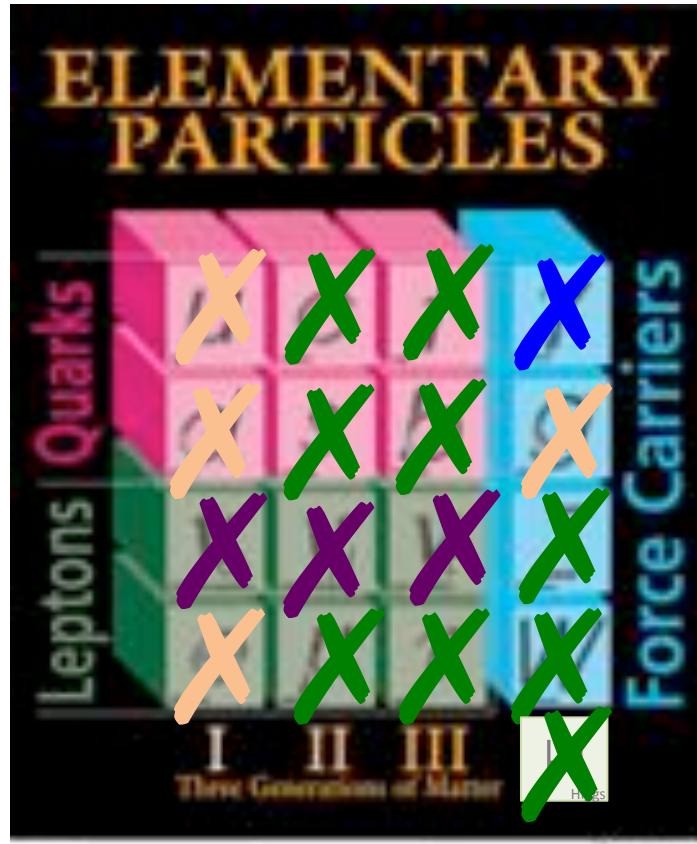
is the particle of light  
couples to plasma

# Can dark matter be SM particle?



is the particle of light  
couples to plasma  
disappears too quickly

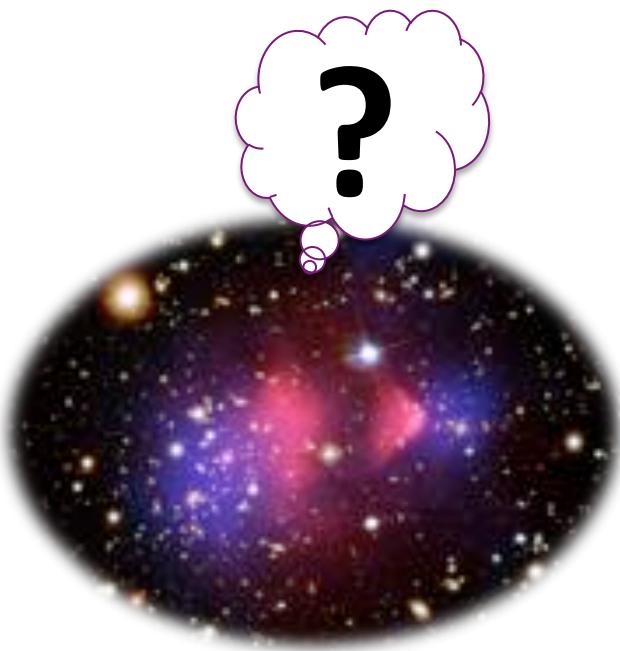
# Can dark matter be SM particle?



is the particle of light  
couples to plasma  
disappears too quickly  
is hot dark matter

SM particles cannot be  
non baryonic cold dark matter

# Dark matter candidates



lightest supersymmetric particle

heavy neutrino of 4<sup>th</sup> family

lightest Kaluza-Klein particle

sterile neutrinos, gravitinos

Bose-Einstein condensates, axions,  
axion clusters

solitons (Q-balls, B-balls, ...)

supermassive wimpzillas

... and many more !

# Supersymmetric dark matter

Neutralinos (the most fashionable/studied WIMP)

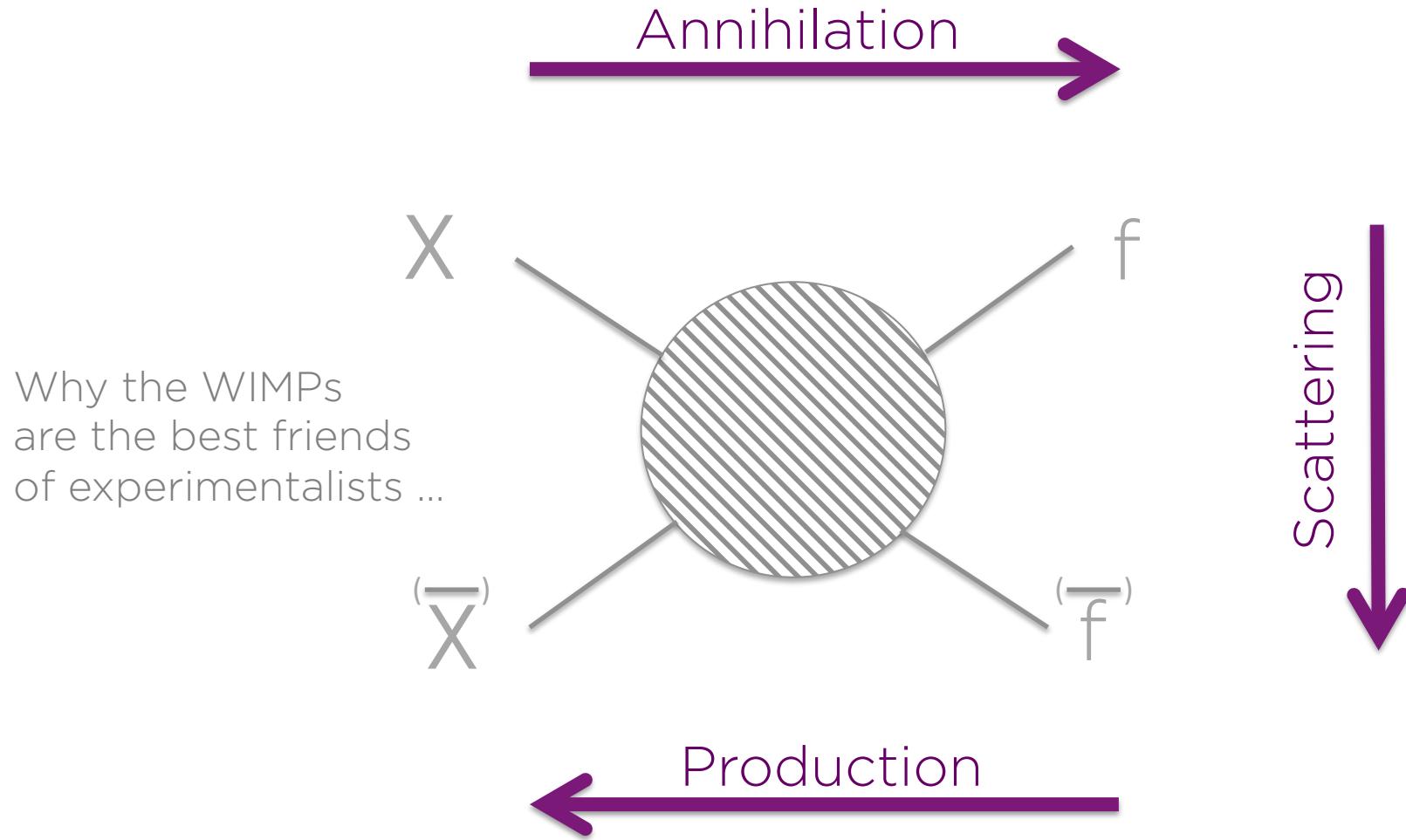
Sneutrinos (also WIMPs)

Gravitinos (SuperWIMPs)

Axinos (SuperWIMPs)

**WIMP = Weakly Interacting Massive Particle**

# WIMPs



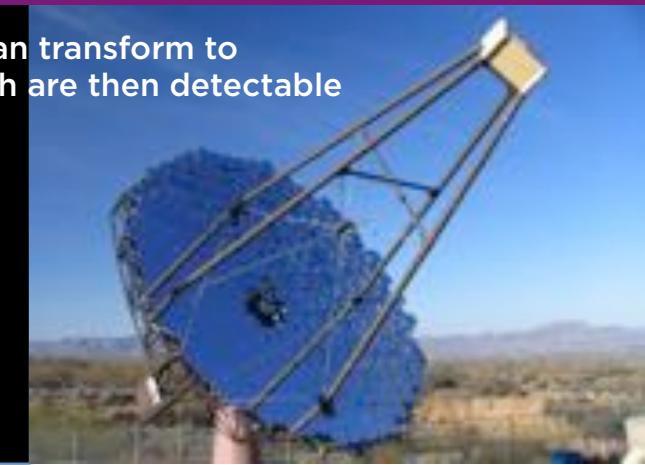
# Searches for particle dark matter

## COLLIDER



## INDIRECT

Dark matter particles can transform to ordinary particles, which are then detectable

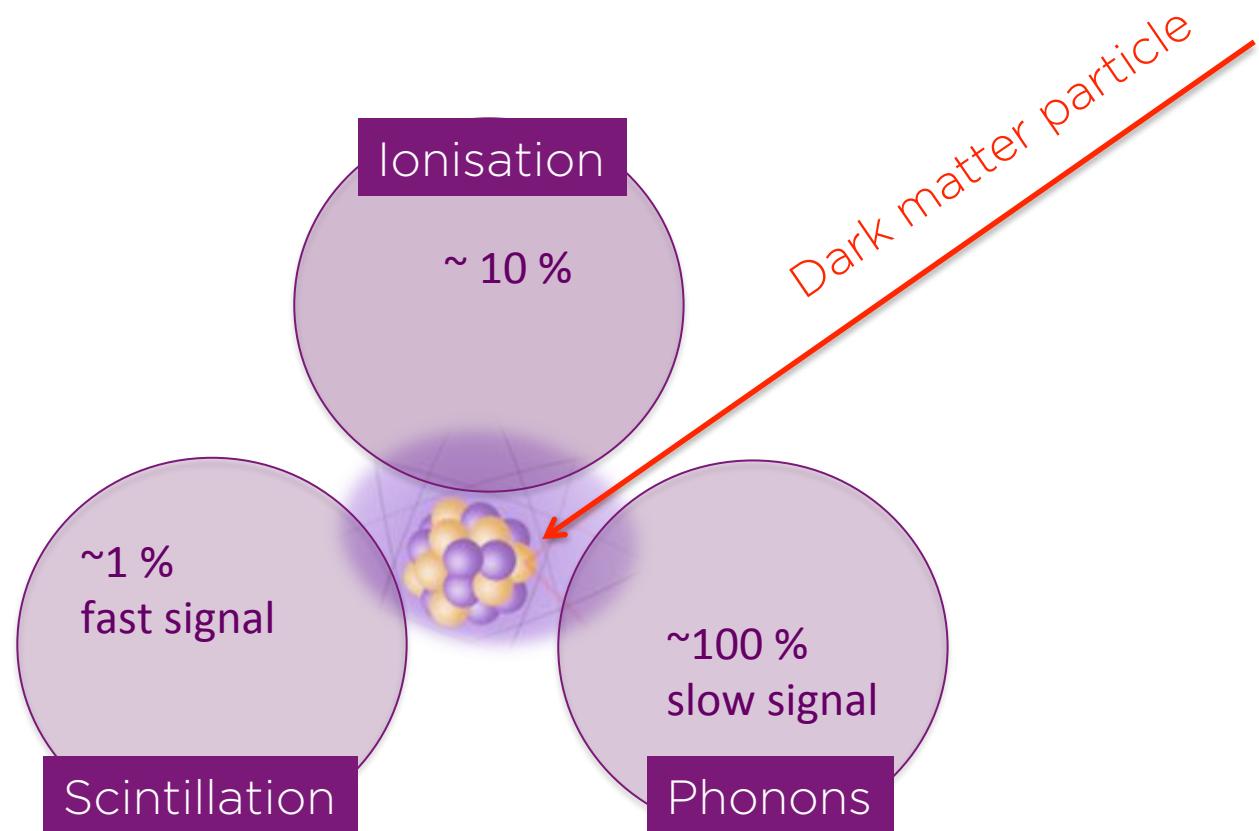


## DIRECT



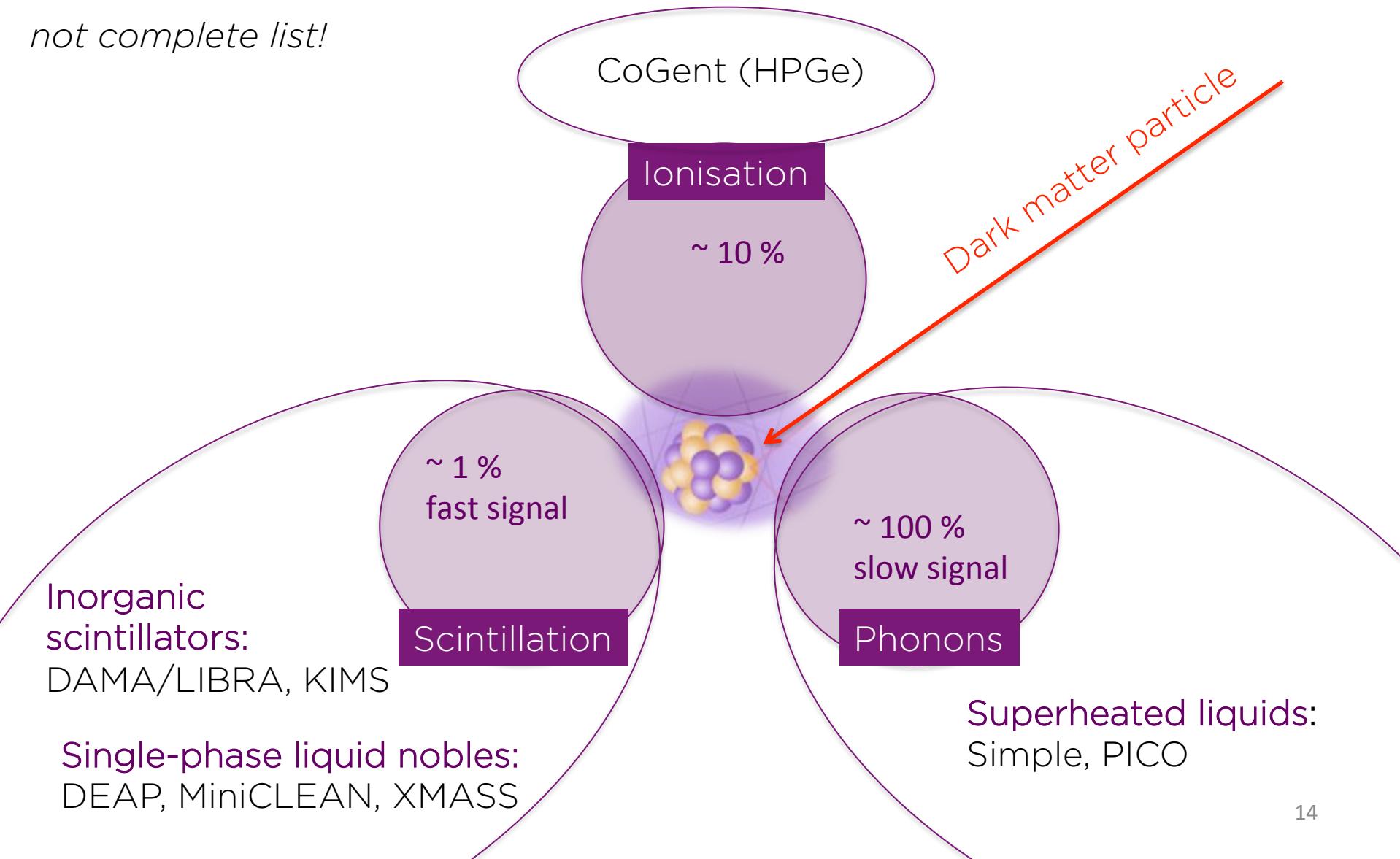
# DIRECT DETECTION

# Direct detection channels



# Detection channel

*not complete list!*



# Detection channel

*not complete list!*

2-phase noble liquids:  
XENON, LUX/LZ,  
Darkside

Inorganic  
scintillators:  
DAMA/LIBRA, KIMS

Single-phase liquid nobles:  
DEAP, MinICLEAN, XMASS

CoGent (HPGe)

Ionisation

~ 10 %

~ 1 %  
fast signal

Scintillation

Scintillating  
calorimeters  
CRESST-II

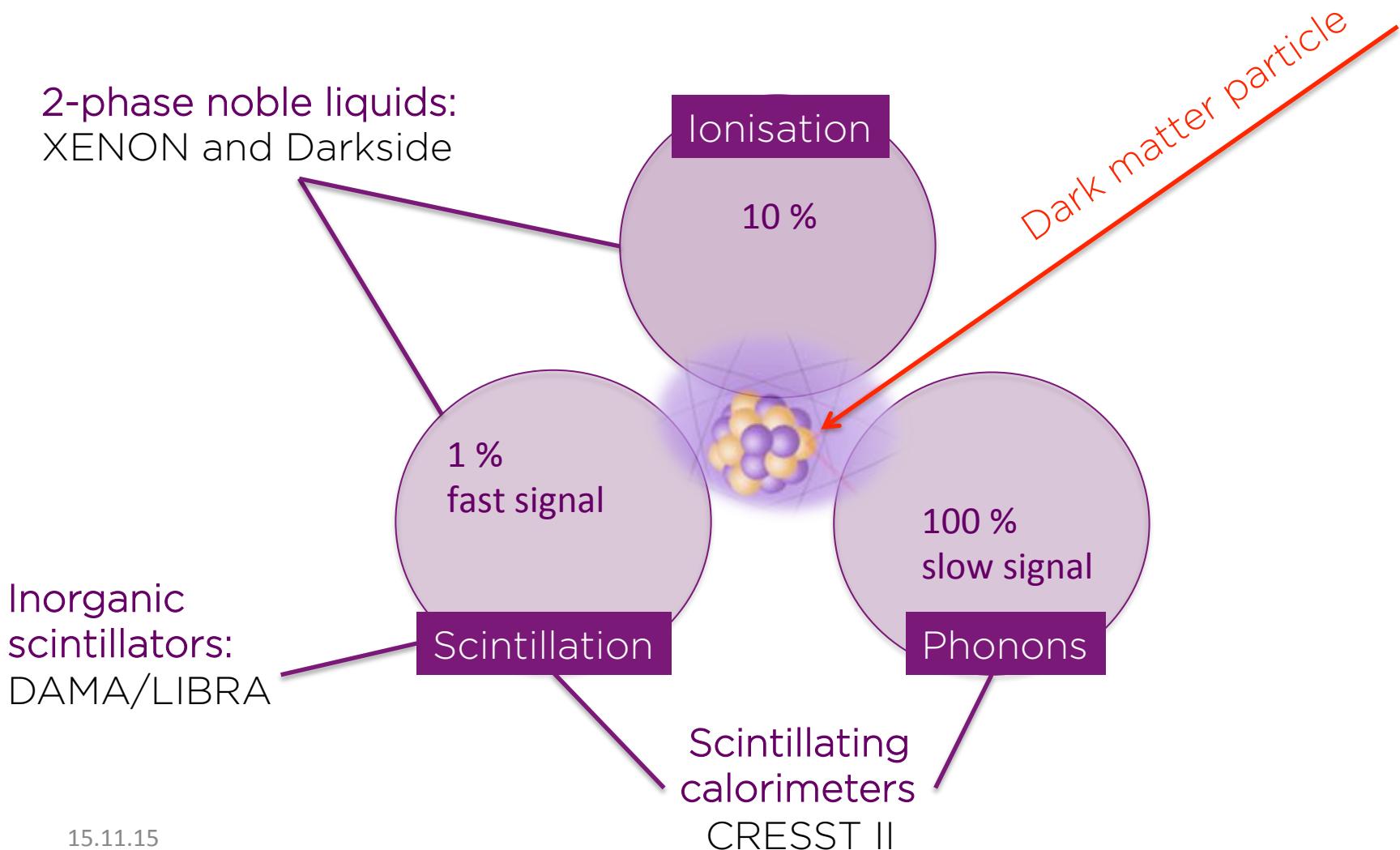
Semiconducting  
calorimeters:  
CDMS, Edelweiss

~ 100 %  
slow signal

Phonons

Superheated liquids:  
Simple, PICO

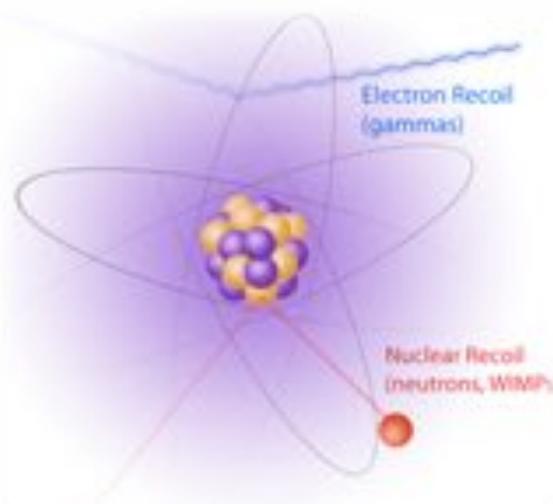
# Dark matter searches @ LNGS



# Dark matter detection

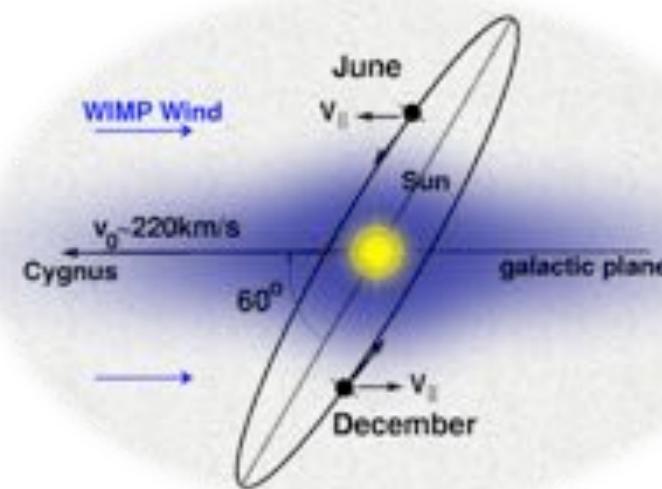
## Counting experiments

- detect and identify the energy deposit following a WIMP scatter
- detector with very low background conditions



## Modulation experiments

- search for **annual modulation** signal caused by the seasonal variation of the Earth's velocity with respect to the dark matter halo
- a large target mass is of advantage



# Comparison of results

## Counting experiments

- Detect and identify the energy deposit of a nuclear recoil event following a WIMP scatter
- detector with very low background conditions

## Modulation experiments

- search for annual modulation signal caused by the seasonal variation of the Earth's velocity with respect to the dark matter halo
- a large target mass is of advantage

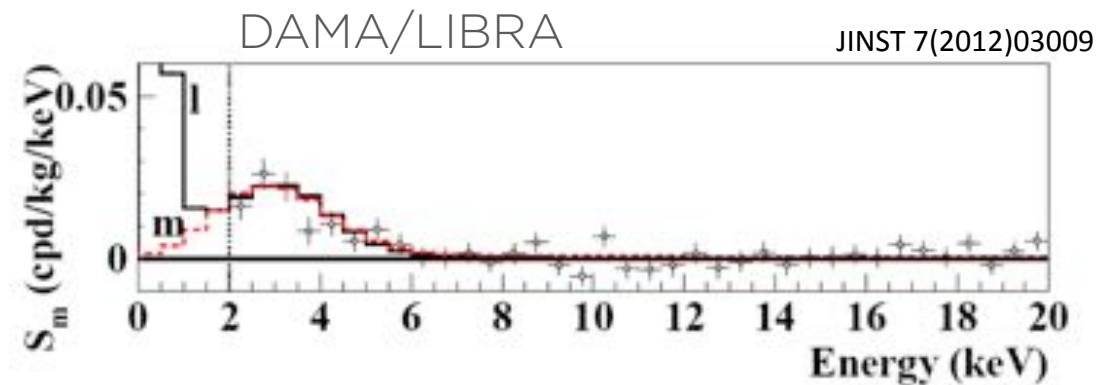


comparison of result to counting experiments requires model assumption

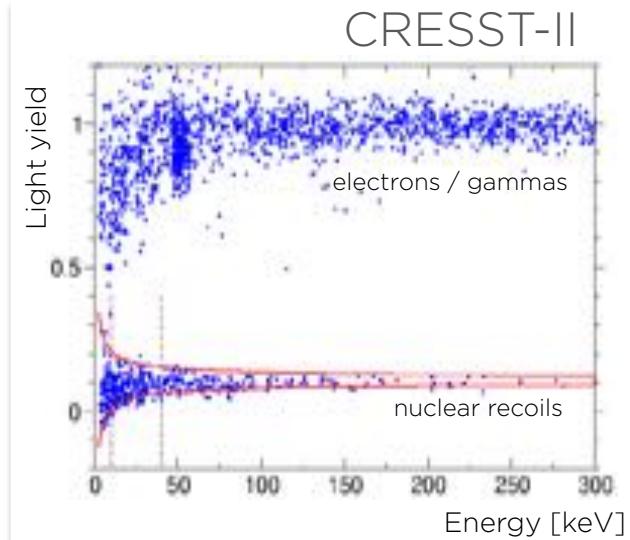
taken from Belli, NDM15

# Number of detection channels

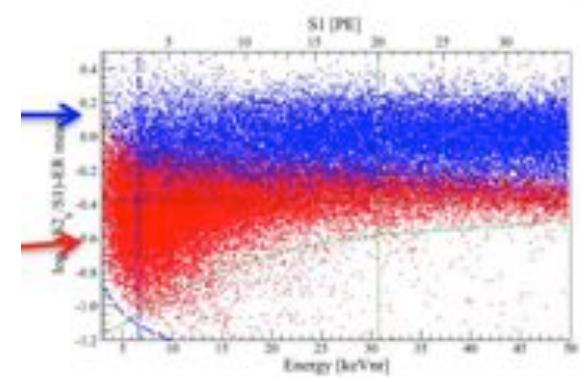
1-channel detection  
energy spectrum



2-channel detection  
particle discrimination



XENON 100

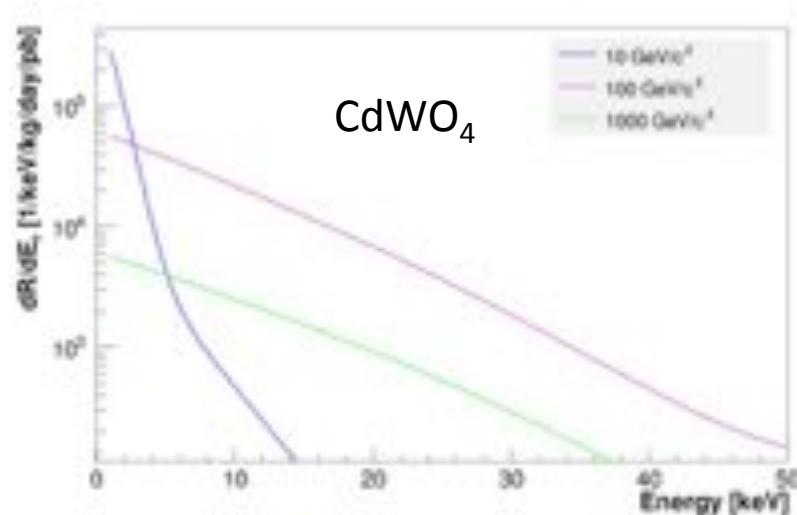
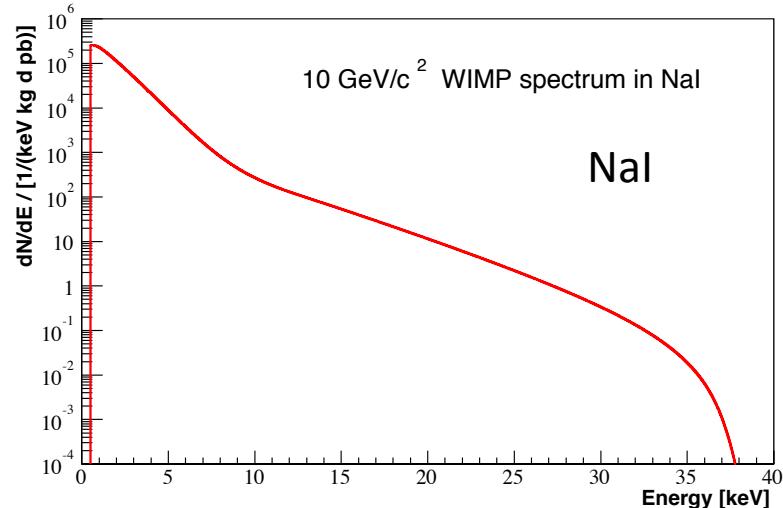


# Detection rate (nuclear recoils!!)

Just an example:

- Maxwell-Boltzmann distribution for the velocity of the WIMPs
- Helm form factor with Lewin/Smith parametrization
- energy threshold of 0 keV
- exposure of 1 kg day
- WIMP-nucleon cross section of 1 pb

**low recoil energies (~ 10 keV)  
small event rates (< 10 kg<sup>-1</sup> y<sup>-1</sup>)**

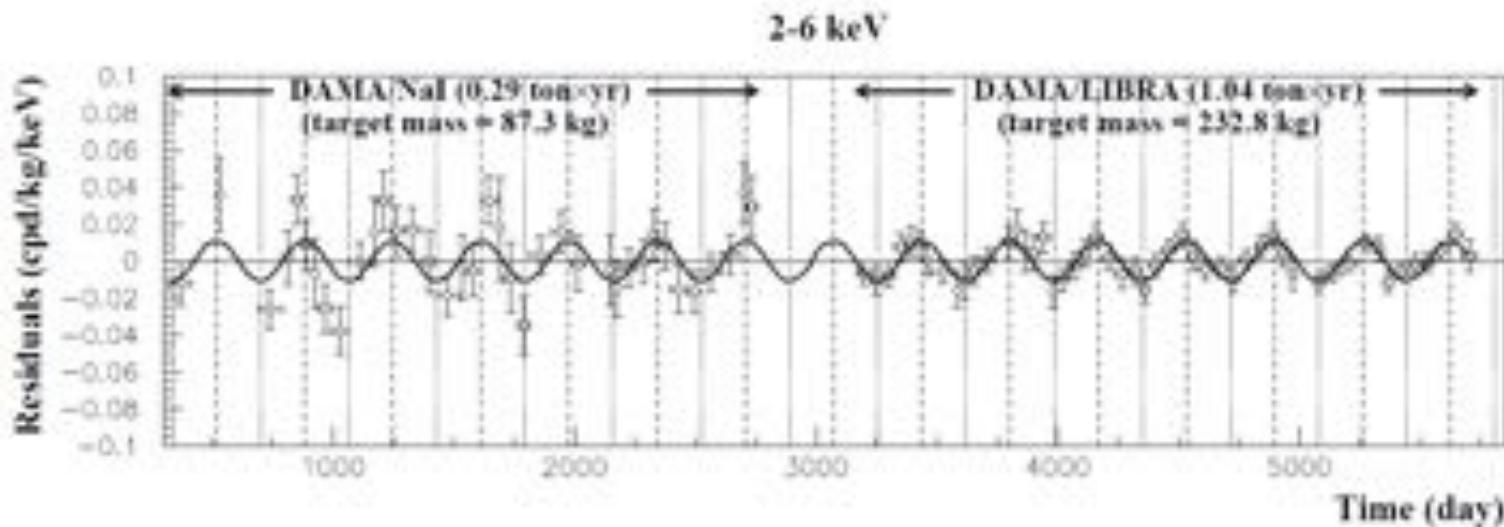


# Experiments @ LNGS

# DAMA/LIBRA

- Detector material:  
250 kg of high pure NaI (Tl) crystals
- 1 channel detection:  
scintillation light using dedicated PMTs

Positive evidence for the presence of DM particles  
in the galactic halo supported at  $9.3\sigma$  C.L.  
(total: 14 annual cycles and 1.33 ton y of exposure)

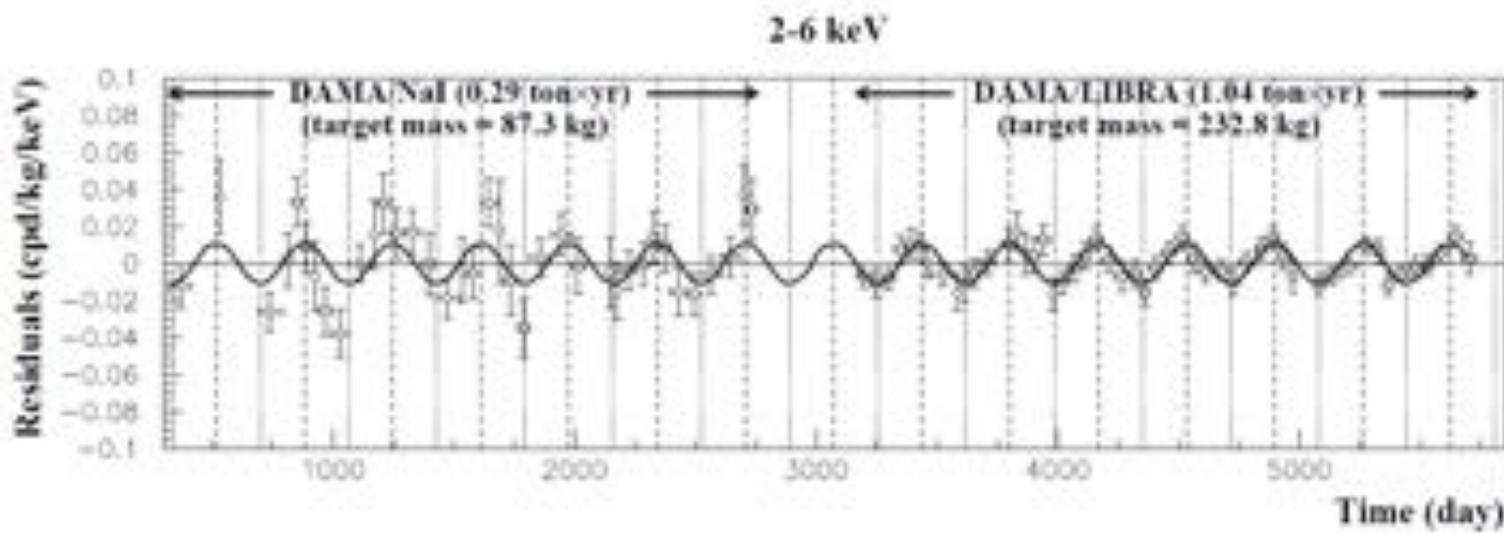


# DAMA/LIBRA

Riccardo Cerulli,  
Vincenzo Caracciolo (AdR),  
Valentyna Mokina (Post Doc),  
Clara Taruggi (Student)

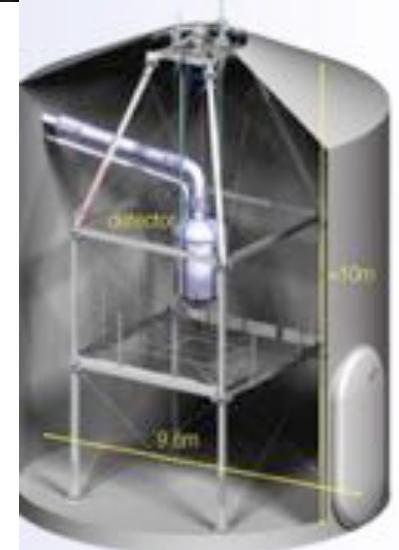
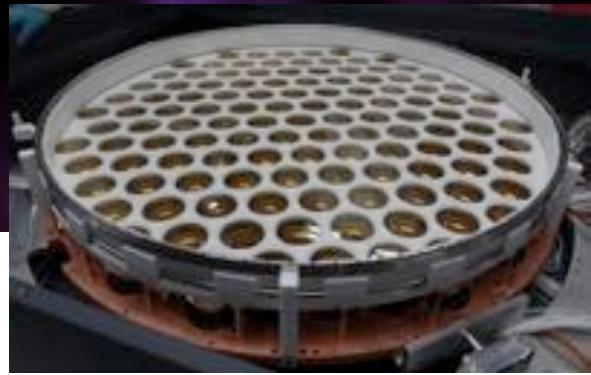
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# XENON project

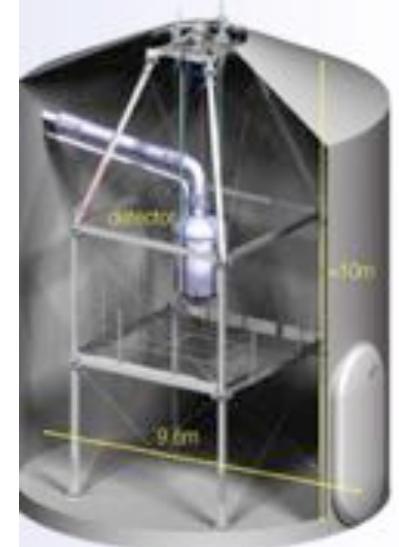
- Detector material:  
liquid Xe
- 2 channel detection with TPC technique  
simultaneous measurement of scintillation  
and ionization
- XENON 100
  - total of 161 kg of Xe and 62 kg inside TPC
  - successful operation for 225 live days and  
competitive/best limits on different  
possible dark matter interactions (SD, SI,  
axion-like, axion-electron, ect.)
- XENON 1T
  - under construction/commissioning
  - First data are expected by the end of the year



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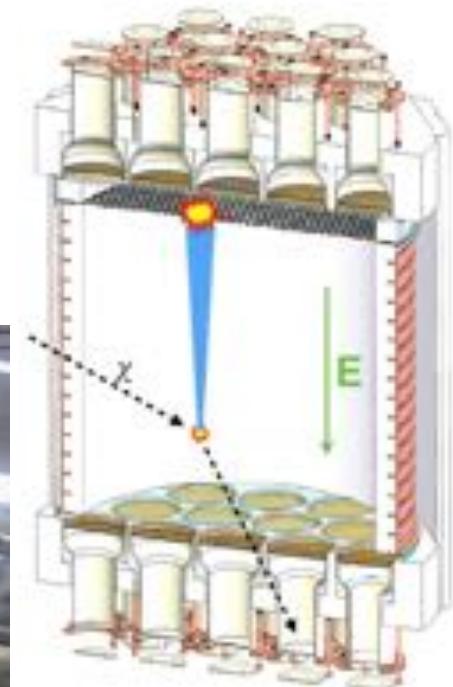
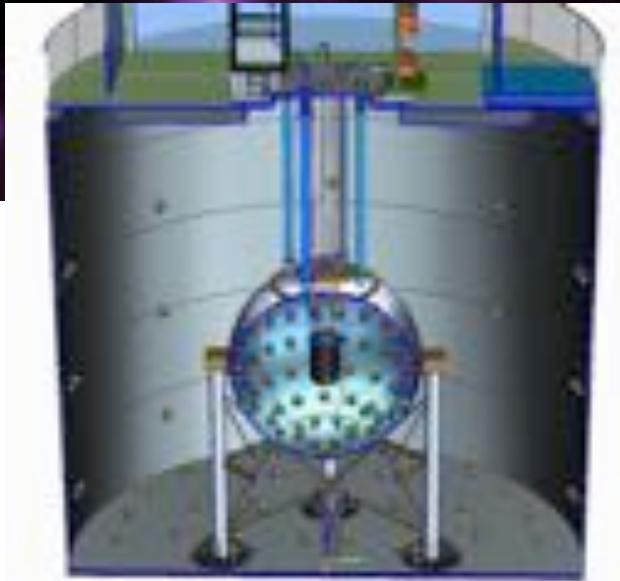
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Andrea Molinario (Post-doc)  
and colleagues



# DARKSIDE

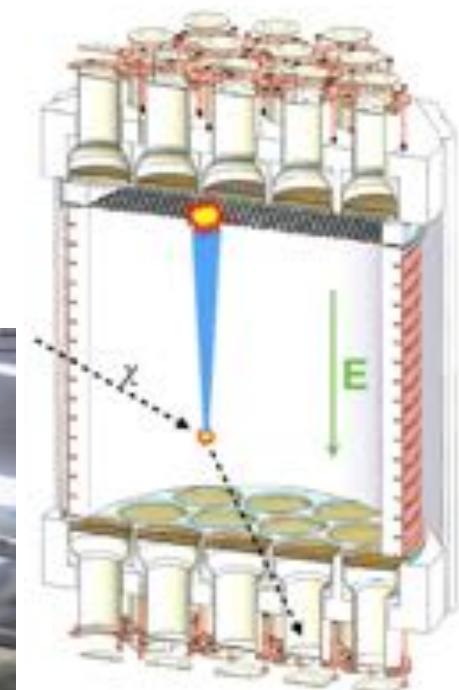
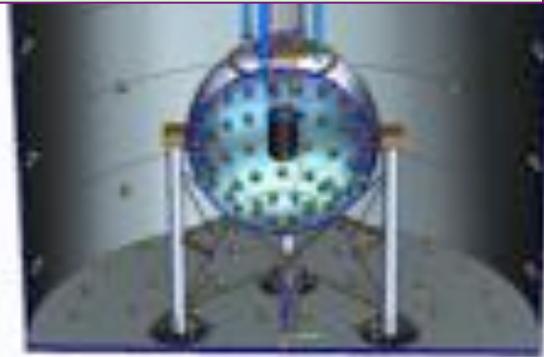
- Detector material:  
liquid Ar
- 2 channel detection with TPC technique  
simultaneous measurement of scintillation  
and ionization
- DS-50
  - total of 153 kg of Ar and 46 kg of active mass
  - full detector system functioning in low  
background mode
  - extended dark matter run with underground  
LAr started in April 2015
- Future planning on DS-20k  
ongoing



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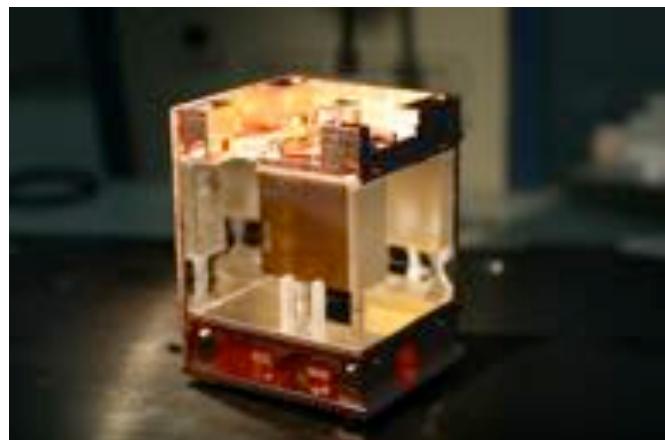
Claudio Savarese (PhD),  
Andrea Mandarano (PhD),  
Maria Bossa (PhD)

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# CRESST-II

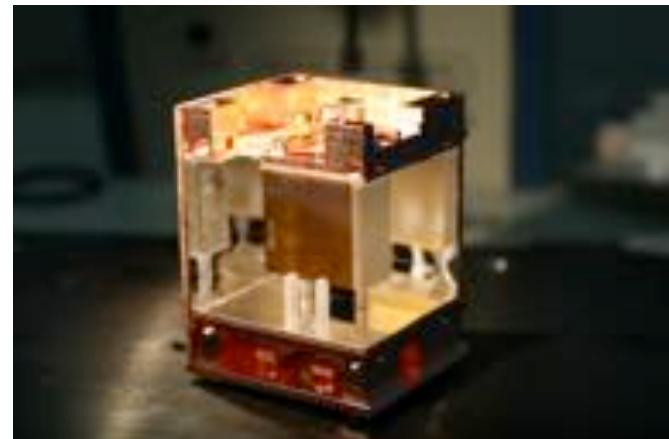
- Detector material:  
calcium tungstate crystal - CaWO<sub>4</sub>
- 2 channel detection with scintillating bolometers  
simultaneous measurement of scintillation light  
and the phonon signal
- CRESST-II
  - 52 kg days of exposure
  - low threshold of 307 eV
  - explore masses in the sub-GeV/c<sup>2</sup> range
- CRESST-III
  - explore even lower mass region
  - start end of 2015



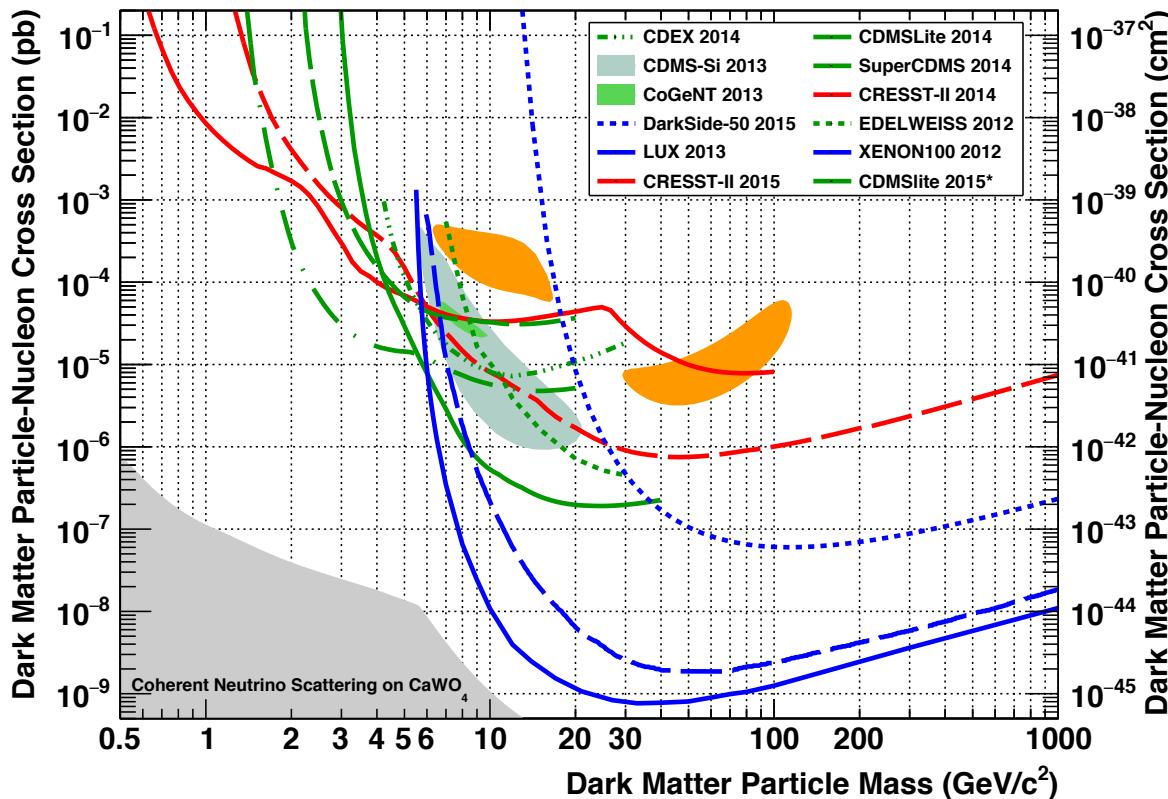
# CRESST-II

Paolo Gorla

- Detector material:  
Calcium tungstate crystal  $\text{CaWO}_4$
- 2 channel detection with scintillating bolometers  
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- CRESST-II
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  - low threshold of 307 eV
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- CRESST-III
  - explore even lower mass region
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# Present dark matter landscape



## Counting experiments

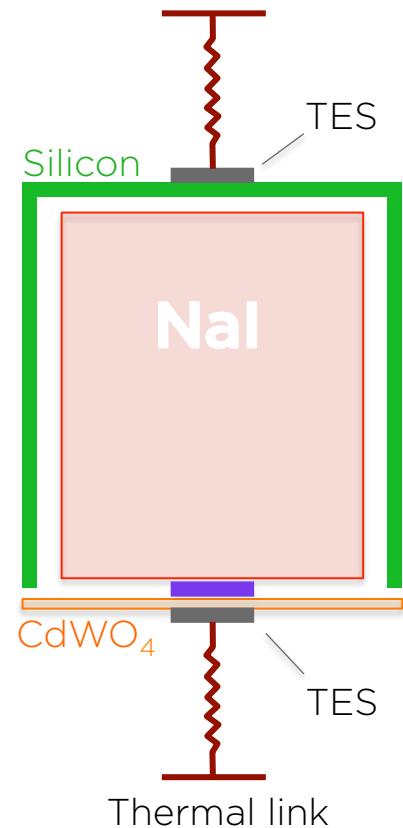
- Hint for WIMP-signal in: Ge, Si,
- No WIMP-signal in: LXe, LAr,  $\text{CaWO}_4$ ,  $\text{CsI(Tl)}$

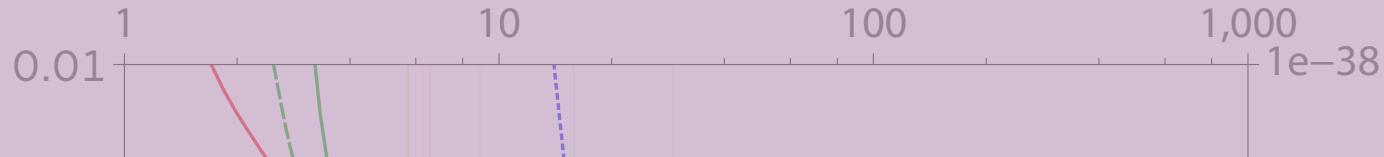
## Modulation experiments

- DAMA/LIBRA observes a statistically robust signal in 14 annual cycles using  $\text{NaI(Tl)}$

# COSINUS R&D project

- Detector material:  
NaI (undoped)
- 2 channel detection with a scintillating bolometer  
simultaneous measurement of scintillation  
and phonon signal
- COSINUS  
develop first NaI detector with particle discrimination,  
with the goal to
  - give an answer to the question of the interaction  
channel participating in the modulation signal observed  
by DAMA/LIBRA
  - by increasing in target mass include the possibility for  
modulation detection





# TAKE AWAY MESSAGE:

- controversial situation in DM field
- for discovery of new particle a modulation signal is a robust signature
- **BUT**: DM discovery requires consistent picture in more than one experiment
- LNGS plays a main role in the field of direct dark matter search

THUS .... VERY exciting years ahead and

still a lot of interesting work to do!