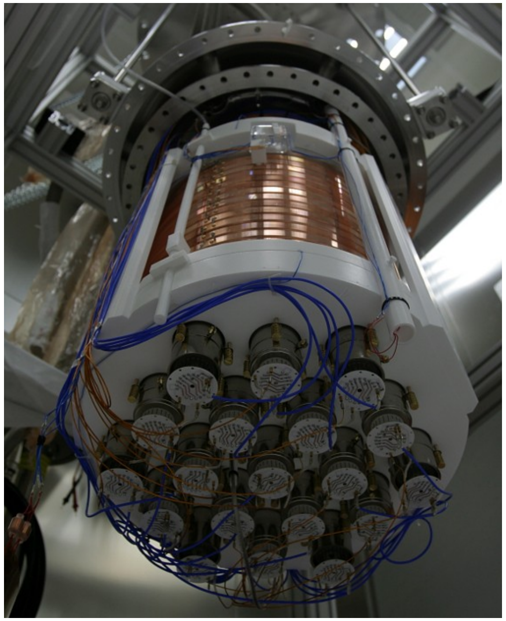
Dark matter search with cryogenic liquids



Nicola Rossi

IFAE 2014 – LNGS

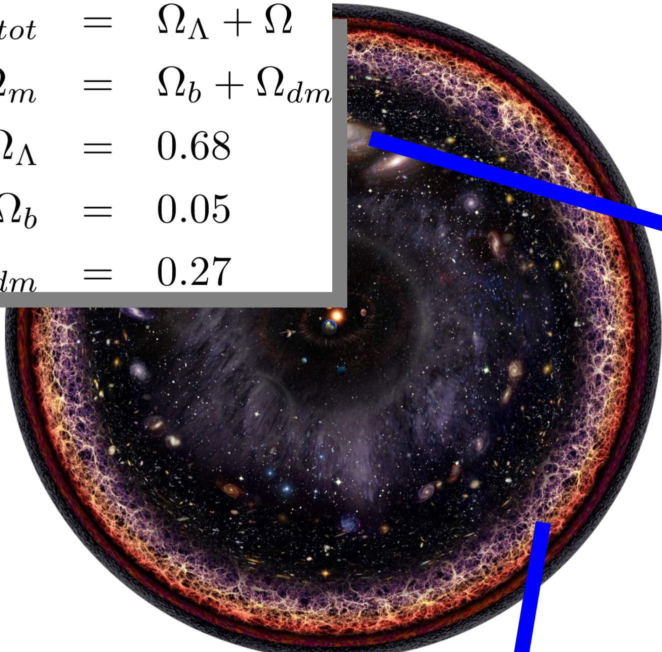
Summary

- The Dark Matter problem
- Direct search
- Dark Matter with cryogenic liquids
- Experiments with noble gases
- Xenon and Argon: detection techniques
- The DarkSide experiment @LNGS

Dark Matter Problem

Ingredients:

$$\Omega_{tot} = \Omega_\Lambda + \Omega$$
$$\Omega_m = \Omega_b + \Omega_{dm}$$
$$\Omega_\Lambda = 0.68$$
$$\Omega_b = 0.05$$
$$dm = 0.27$$



At every scale luminous objects move faster than one would expect if they move under the gravitational attraction of luminous objects only

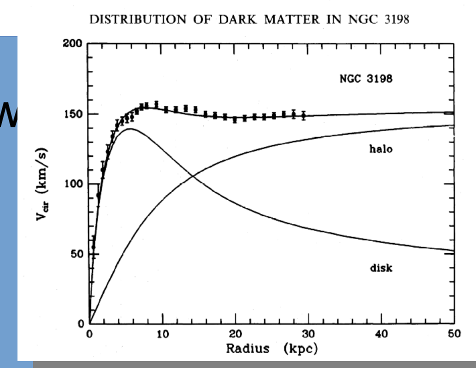
Galaxies should show the Keplerian fall

$$v(r) \propto 1/\sqrt{r}$$

$$v(r) \propto \sqrt{M(r)/r}$$

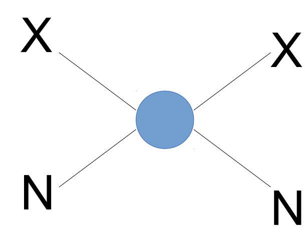
Dark matter halo

$$\rho(r) \propto 1/r^2$$



Large Scale structure
CMB

Candidates
- primordial black holes
- axions (few eV)
- sterile neutrinos (~keV)
- WIMP (~100 Gev)
- Wimpzillas (GUT scale)
- …???....



Techniques:
-Colliders
-Satellites
-Detectors

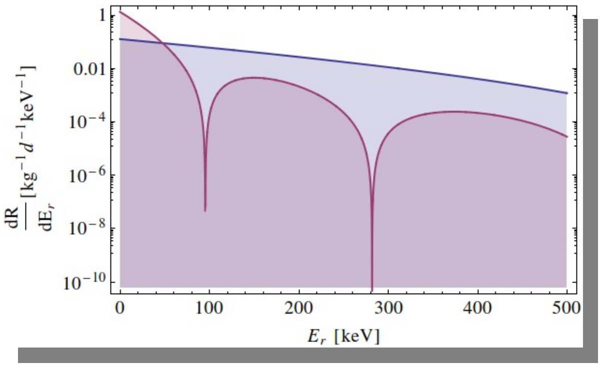
DM Particles:
- stable on cosmological scale
- weakly interacting with the e.m. field
- suitable density

Try different ways!

Direct Search

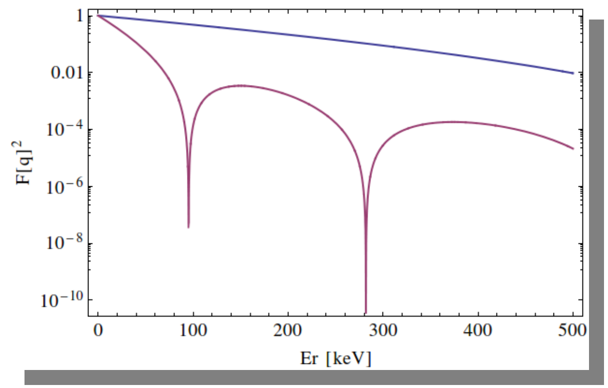
$$\frac{dR}{dE_r} = \frac{\sigma}{2\mu_2 m_\chi} F^2 \rho \int \frac{f(v)}{v} dv \times \varepsilon_E / q_E \otimes r_E$$

Differential rate



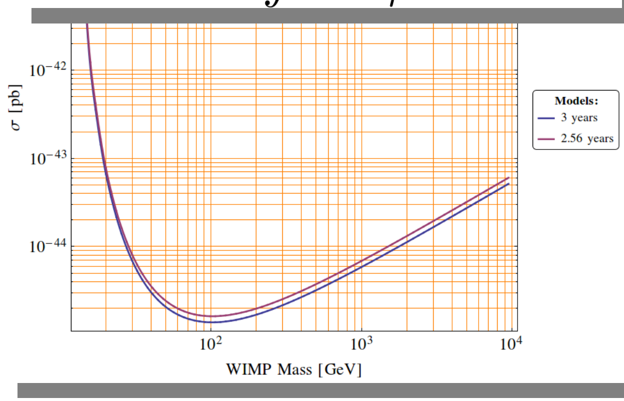
σ = WIMP-nucleus cross section
spin dependent ~ J(J+1)
spin independent ~ A^2
μ = reduced mass
Mx = WIMP mass

Nuclear Form Factor

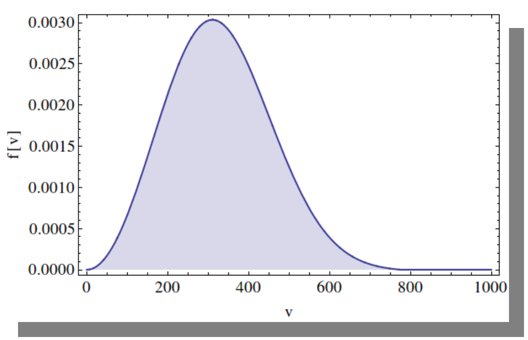


Sensitivity plots
2.3 events
90 % CL

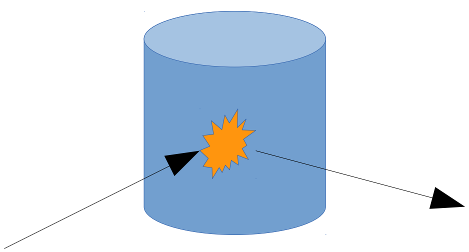
$$\text{exposure} \times \int \frac{dR}{dE_r} dE_r = 2.3$$



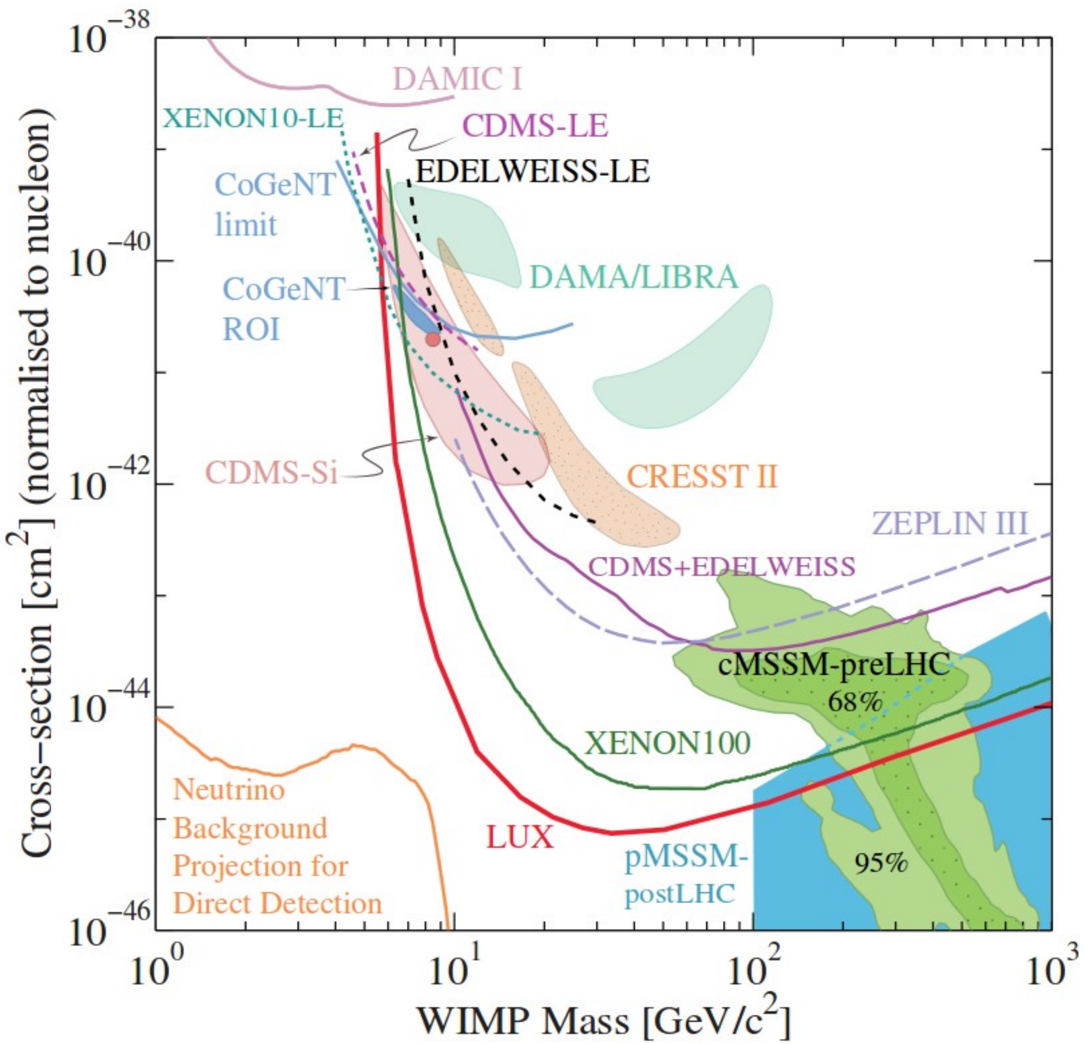
Standard Halo:
ρ = 0.3 GeV/cm^3 local density
vE = 232 Earth velocity
v0 = 220 Local velocity
v_esc = 544 km/2 Escape velocity



ε = efficiency
q = quenching
r = resolution



Current Scenario (PDG 2013)



Spin dependent sensitivity plot

Noble gases are dominating the sensitivity plots with the highest sensitivities for the spin-independent hypothesis

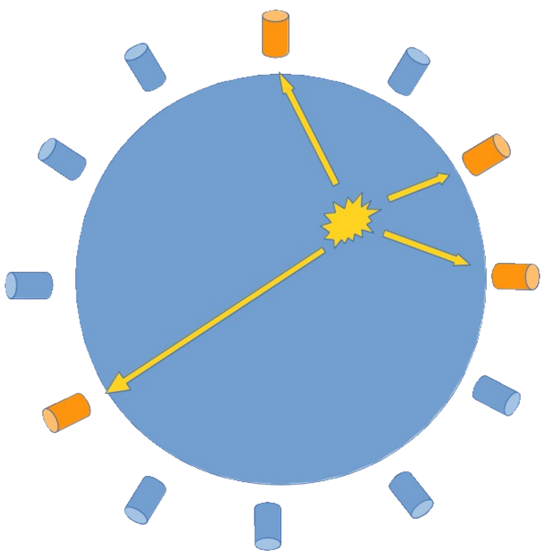
Contrasting results between LXe results and other experiments

Is DM Xenophobic???

WIMP is @ 10 GeV?

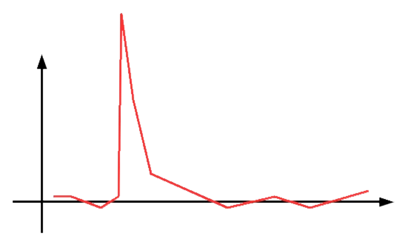
It worths to investigate with different techniques!!!

Detector Concepts

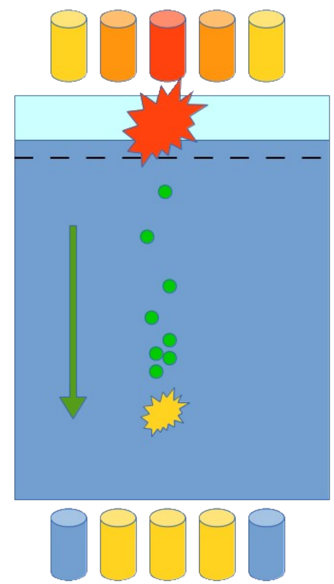


Scintillation
(prompt)

Single phase:
- Liquid

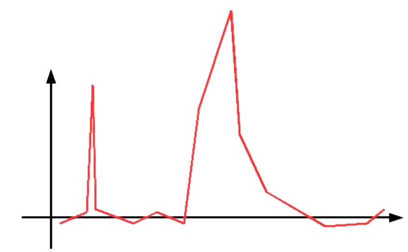


S1



Scintillation + Ionization
(prompt+delayed)

Double phase
- Liquid
- Gas



S1+S2

Xenon:
Xenon100 (LNGS)
LUX (Homestake)
XMASS (Kamioka)
Zeplin (Boulby)
PandaX (Jinping)

Argon:
DarkSide50 (LNGS)
ArDM (Canfranc)
CLEAN (SNOlab)
DEAP (SNOlab)

Helium-Neon
DEAP (SNOlab)
R&D

Important

Scintillation and ionization depend on particle property

WIMP and
Nuclear recoils
Electron recoils

Noble liquid targets

Chemistry

Target	Xe	Ar
Z	54	18
A	131.1	39.9
Boiling Point °K	165	87
Density [g/cm^3]	2.94	1.4
in Atm ppm	9340	0.09
Price	Expensive	Cheap (AAr)

Scintillation light

Scintillation [nm]	178	128
Fast comp. [ns]	4	6
Slow comp. [ns]	27	1600

Light Yield

LT ph.e./Kev	46	40

Spin
Ar: spin dependent
Xe: spin dependent and independent Xe129 (J = ½, 26.2%) and Xe131 (J=3/2 21.8%)

Contaminants:

Ur238, Th232 chain

Kr85, Ar39
Rn220

Neutrons from rock (α, n) and sf and Cosmogenic (from muons)

Possible solution:
Underground laboratories
High purity materials
Shielding, veto, ...

Argon

- Both scintillation and ionization
- Abundant (cheap, scalability)
- Self shielding
- Excellent e.m. background discrimination (slow and fast component, even in single phase)
- Established technique
- High Energy recoil not strongly suppressed by Form Factor (Also with high threshold)

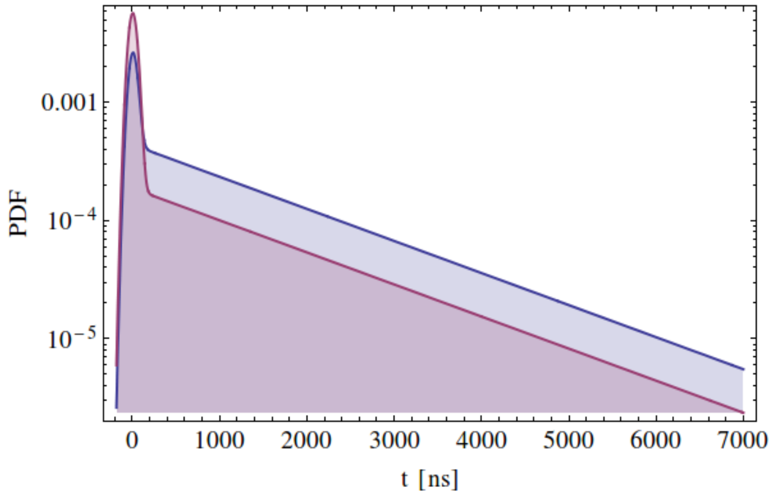
- High threshold
- Very high background (Ar 39 ~1Bq/kg)... underground depleted argon! 1/150 factor suppression (a bit expensive)
- light wavelength shifting with TPB.
- Cryogenic at -180°C

Xenon

- Scintillation and ionization
- Low threshold: low mass sensitivity
- Scintillation in VUV (178 nm)
- High denisity: self shielding, scalability
- No long lived Xe isotopes
- Kr85 removable ppt
- Cryogenic @ -100 °C

- Less abundant
- Expensive
- Less background discrimination compared with Argon
- No PSD in scintillation light

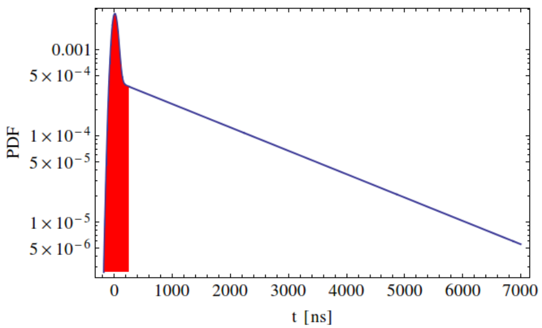
Pulse shape discrimination



1. Scintillation light (Es. Ar)

$$f(t) = \frac{Q}{\tau_F} e^{-t/\tau_F} + \frac{1-Q}{\tau_S} e^{-t/\tau_S} \otimes \text{Gaus.}$$

Q = 0.7 nucler recoil
Q = 0.3 e.m.



f-prompt

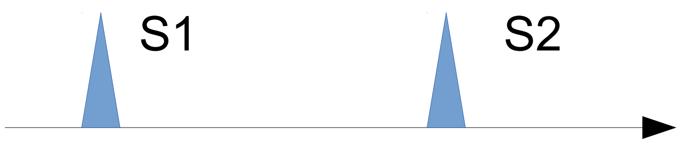
$$fPrompt = \frac{\int_{t_0}^{t_d} f(t)dt}{\int_{t_0}^{\infty} f(t)dt}$$

Better:
- Gatti Parameters
- Likelihood ration
- Neural network

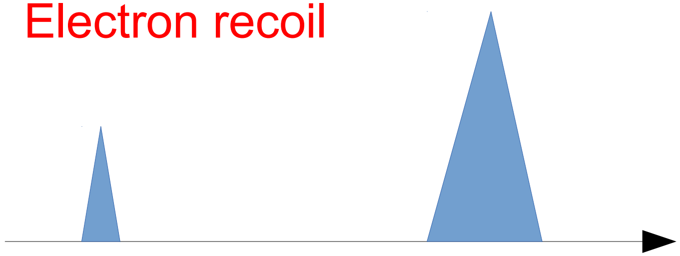
…

2. S2/S1 ratio

Nuclear recoil

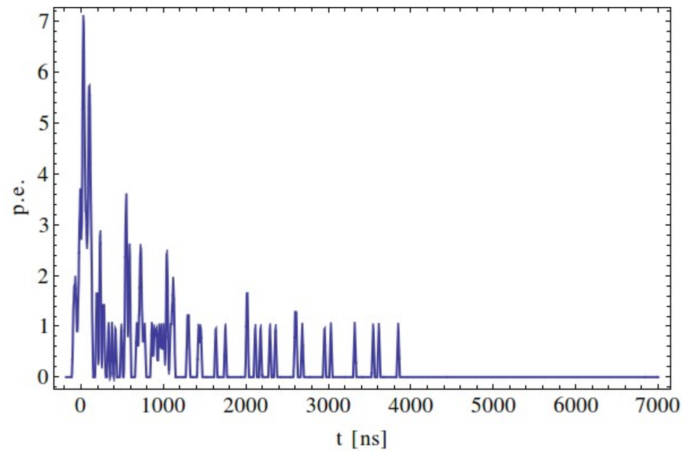


Electron recoil



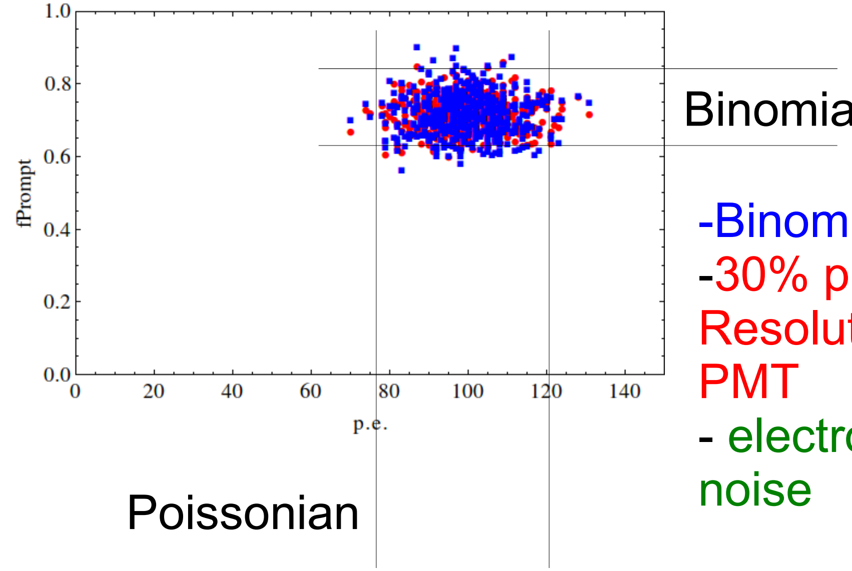
$$S_2 = S_{ion} \otimes f_{\text{gas}} \otimes \text{Box}$$

PSD and threshold

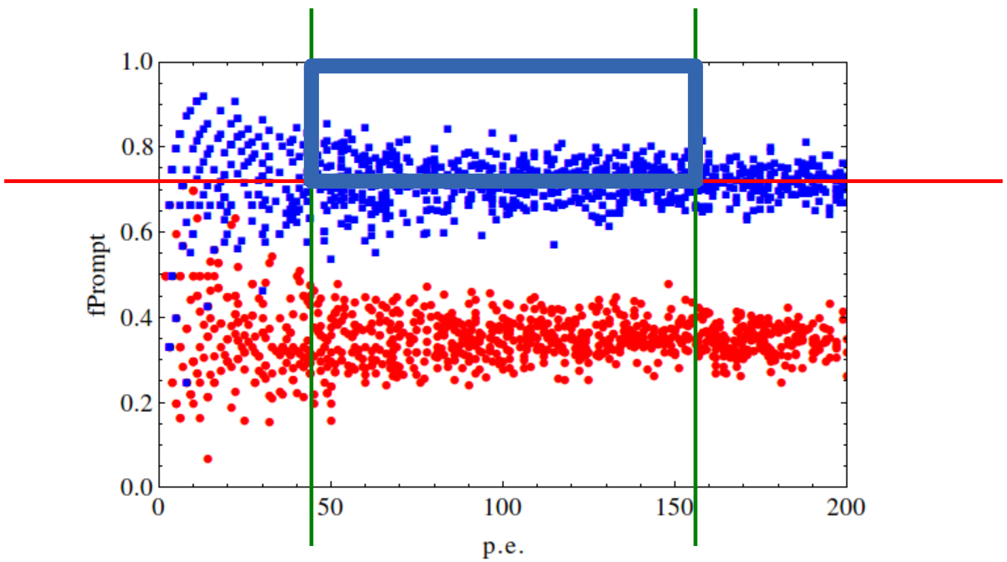


Signals: distribution of Photoelectrons from PDF

Monochromatic signal



-Binomial
-30% p.e. Resolution PMT
- electronic noise



Combined effect

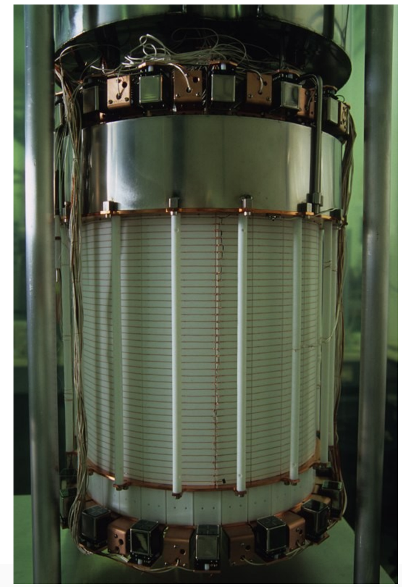
Low background
High Light Yield
Reduce electronic noise

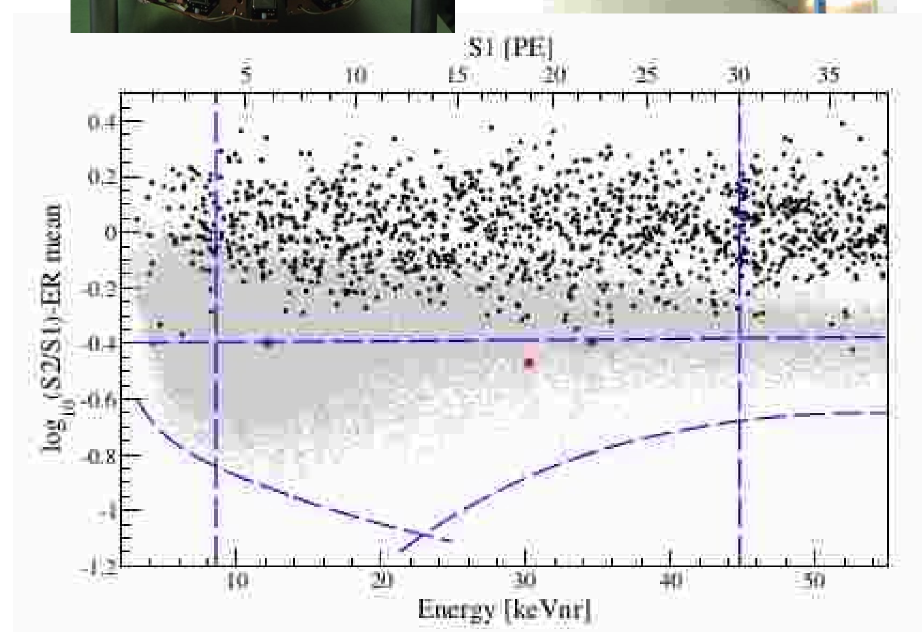
- Define your PSD parameter
- Select your acceptance region (50% nuclear recoil)
- Define the threshold
- Estimate the leakage
- Estimate your golden region

Xenon100 Experiment (@LNGS -2011)

- TPC double phase LXe
- 62 Kg Target
- Low threshold
- Lowest limit in 2011
- 1471 Kg x d acceptance corrected
- 3 events observed fully compatible with the background
- **Future: 1T experiment**

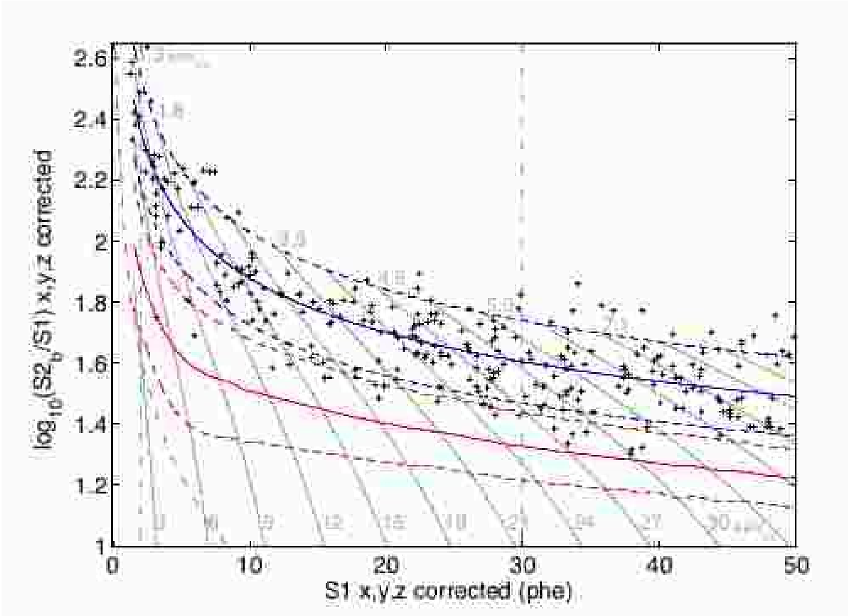
  (under construction at LNGS)





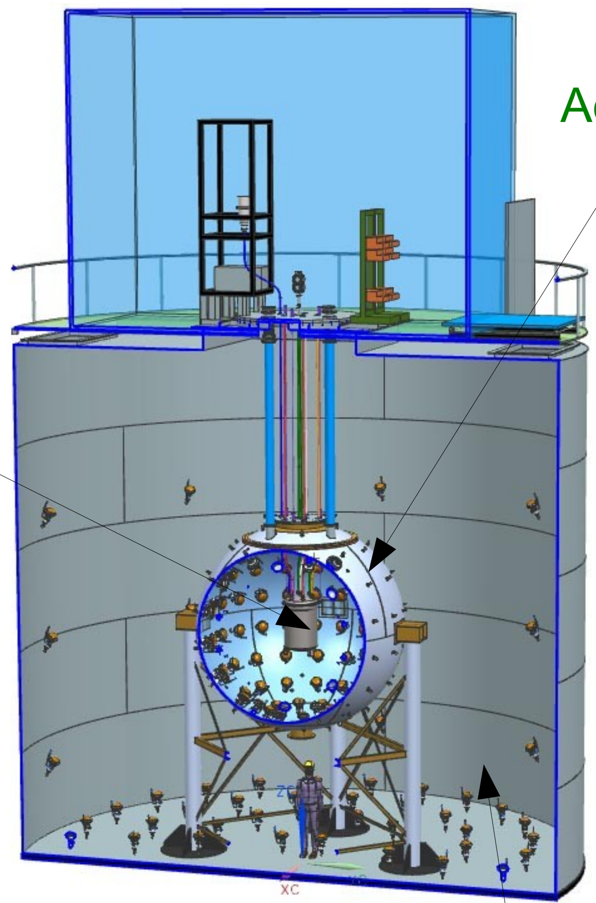
LUX (@Homestake, 2013)

- 2-phase LXe TPC
- 118.3 Kg x 85 days exposure
- LY = 8.8 ph.e./keVee
- 2-30 ph.e. Window
- <u>No events in 50% NR region</u>
- @Present: <u>best limit</u> on spin-independent plot



DarkSide Program (LNGS 2013)

- **DarkSide10**
  - 2-phase TPC LAr
  - prototype 10kg
  - LY and PSD test
- **DarkSide50**
  - 50 kg depleted LAr
  - first run
  - active veto performances
- **DarkSide G2**
  - 3 ton LAr
  - WIMP sensitivity @ 10^-47 cm^2



- Stainless sphere for the veto 1.5 m shielding
110 8" PMT (30 ton TMB + PC, C14 eccess)
- 1000t HP Water tank with 80 8" PMT
- TPC with 38 3" PMT R11065 H. low radioactivity
- Stainless steel cryostat 150 Lt + Cold amplifiers
HHV = drift: 0.2 kV/cm and, extraction: 2.8 kV/cm

Depleted argon

- Ar is 1% gas in atmosphere, produced by K40 decay
- Ar39 is produced in atmosphere by cosmic muon interaction
- Ar39 is a beta emitter (565 KeV, T = 269 y)
- Ar39 activity is 1 Bq/Kg (WIMP 100 Gev = 10^-4 Ev/Kg/day)
- Needs: High PSD efficiency, and high threshold
- Ar underground (from low U-Th rocks) is ~1/150 less radioactive

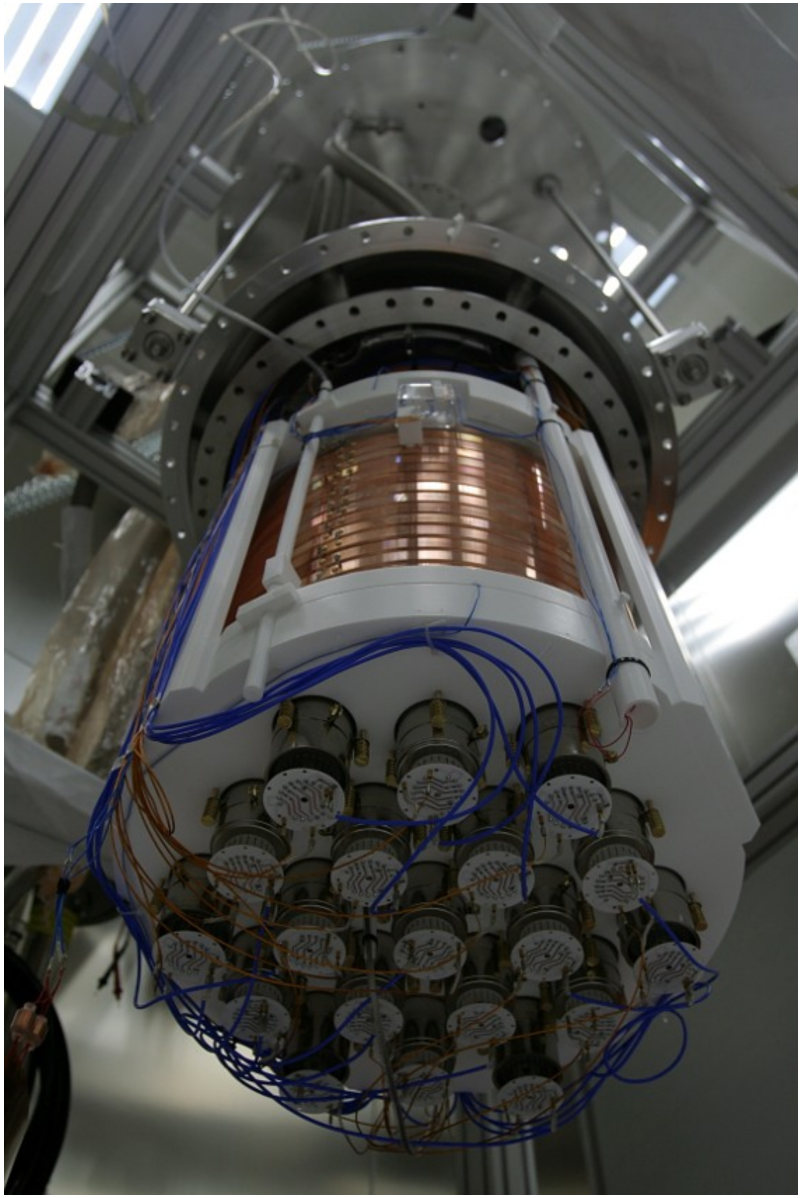
DarkSide50 Status

- TPC and veto started from Oct 2013 with atmospheric argon
- DAQ and data analysis
- Feb2014: 3 x 10^7 Ar39 events: 6.5 live days ~ 3 year of depleted Ar run
- First result @ DM2014
- Background free detector over 280 kg day exposure

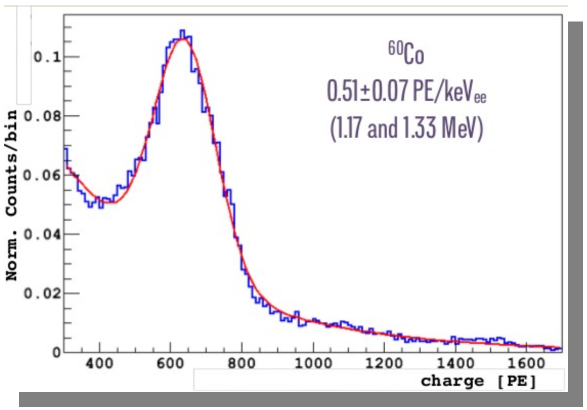
- Electron life time ~5ms (increasing) as compared with the ~300 us drift time

Discrimination performances test:

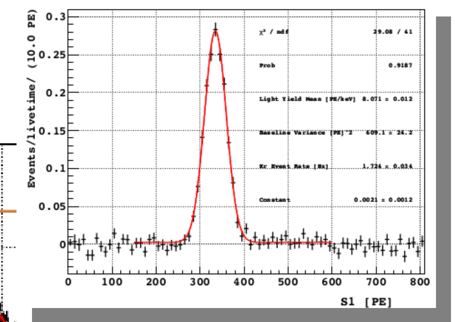
- 3D reconstruction
- s2/s1
- fPrompt

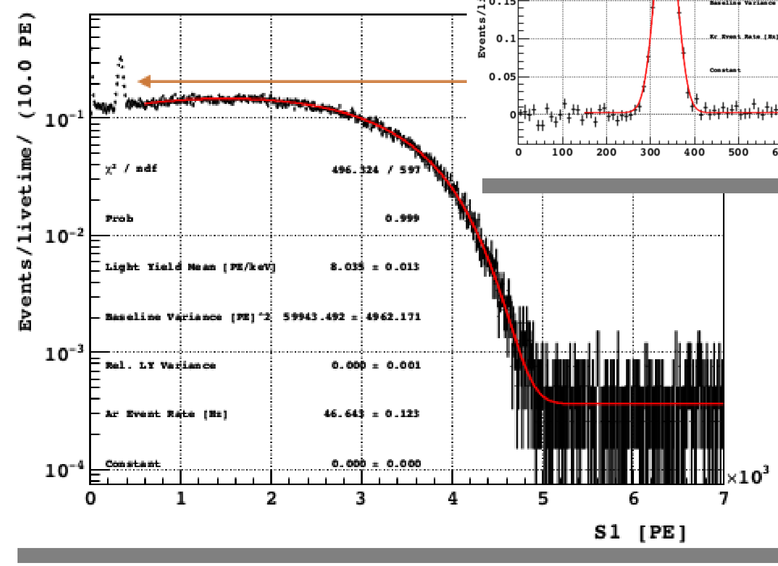


Preliminary result

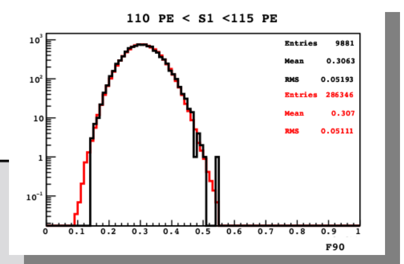


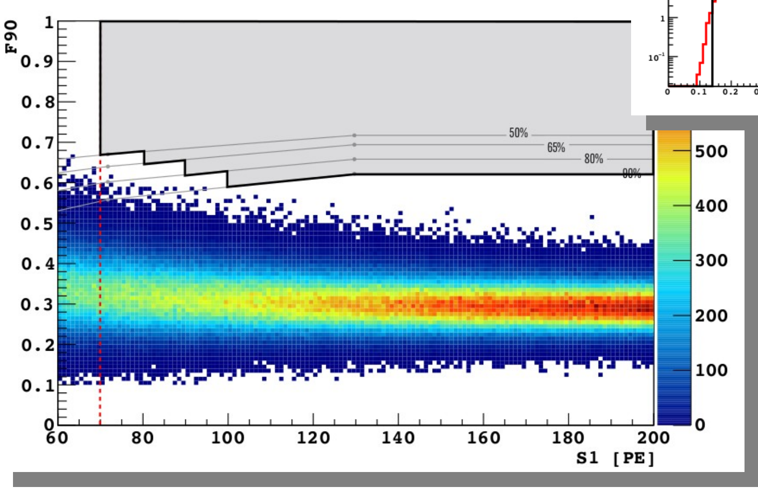
Excellent Light Yield:
LY~8 ph.e. At null field (Kr 83 source = 41.5 keV) and Ar 39 spectrum 565keV





Good LY in neutron veto
LY~ 0.5 ph.e./keV





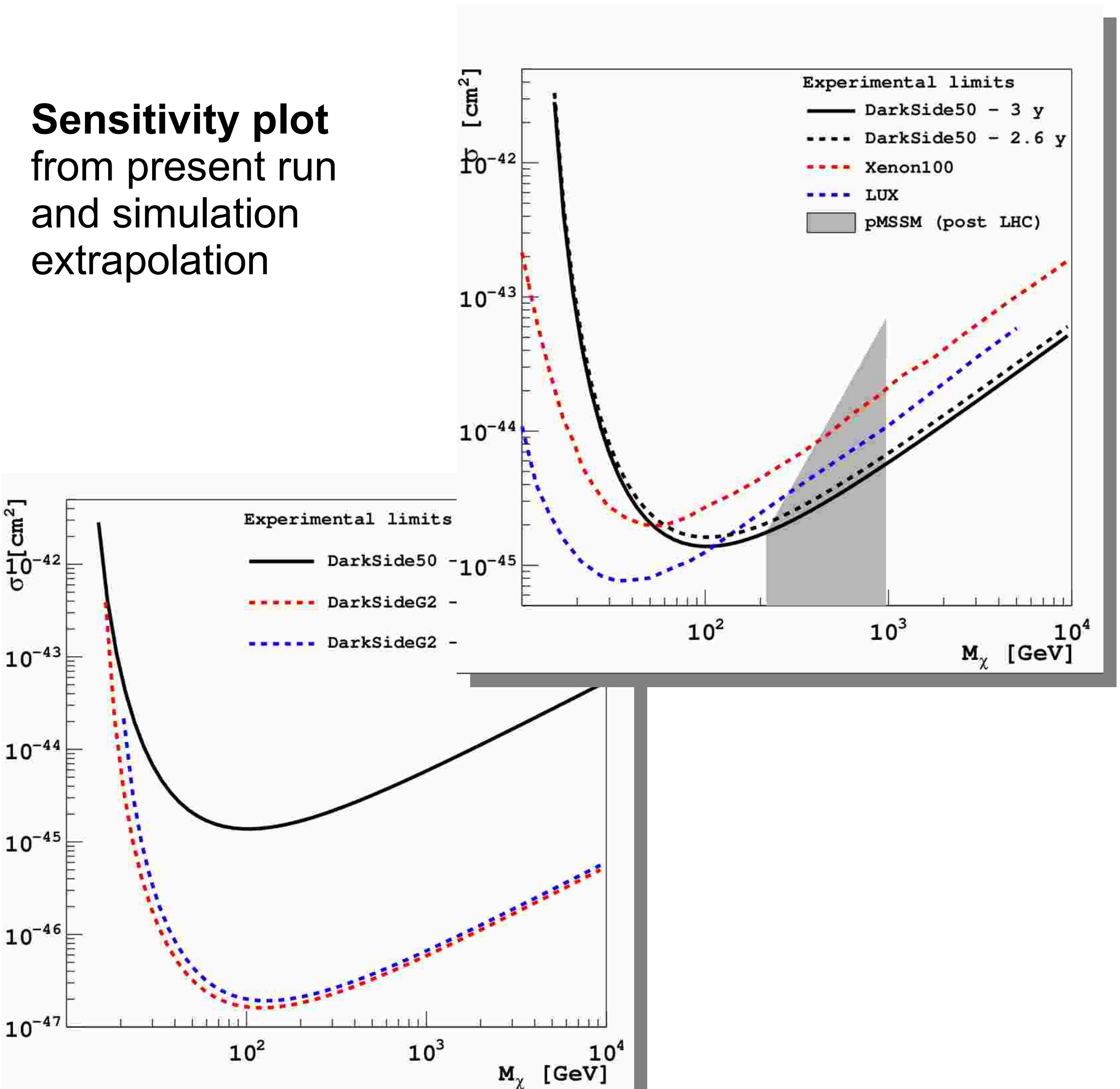
f-Ptompt pulse shape discrimination in AAr 6.3 live days, well established, first extrapolation for the UAR 278 kg day AAr → 41851 kg day UAr

Nuclear recoil acceptance from **SCENE** experiment

First extrapolation for future runs

Sensitivity plot comparison

Sensitivity plot from present run and simulation extrapolation

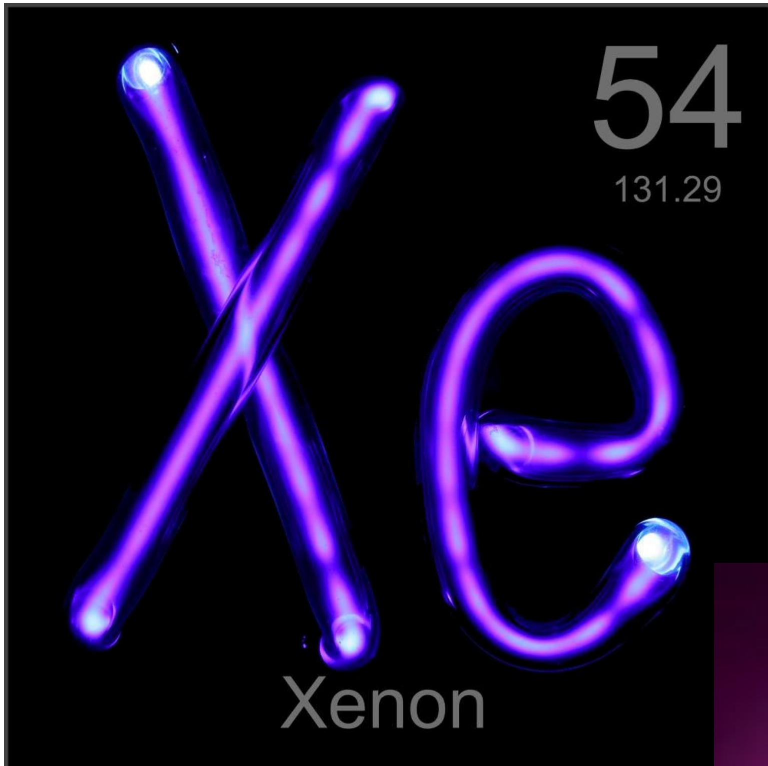


The DS50 UAr run will reach a sensitivity competitive with LXe for large WIMP masses where we expect the MSSM candidates

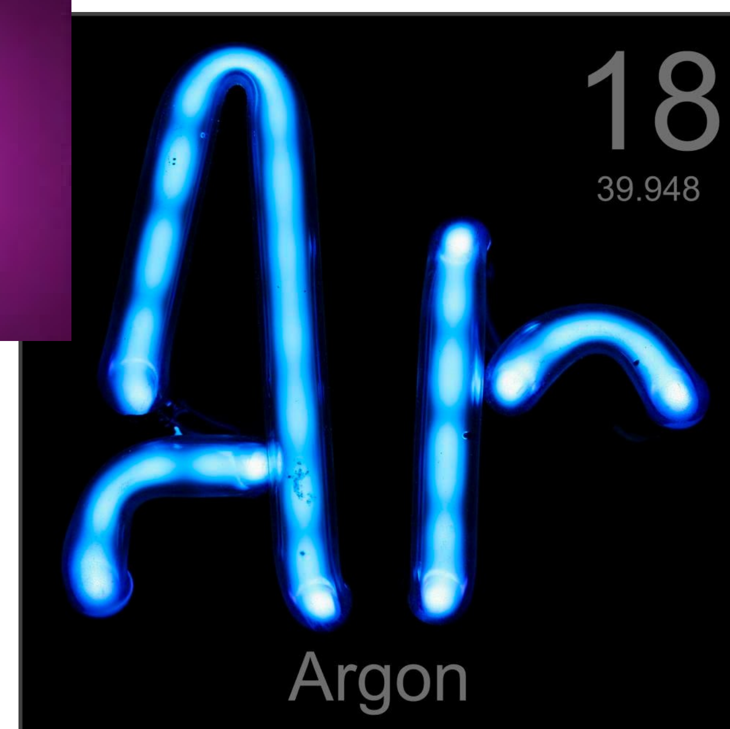
DS G2 will reach cross section of order of 10^-47 cm^2 competitive with Xenon1t and future LXe experiments

Conclusions

- Astrophysical observations converge to the existence of dark matter particles
- Different techniques allow us to probe the physical properties of dark matter
- Liquid noble gases are allowed us to reach the best limits for the spin independent interaction
- LXe and LAr are both competitive and they show complementary performances
- LAr in few years will be competitive with LXe experiment exposure already reached


54
131.29
Xe
Xenon


merci


18
39.948
Ar
Argon