



Opportunities in *Particle* and *Medical Physics*

- Activities overview -

Aula Amaldi 30/9/2019



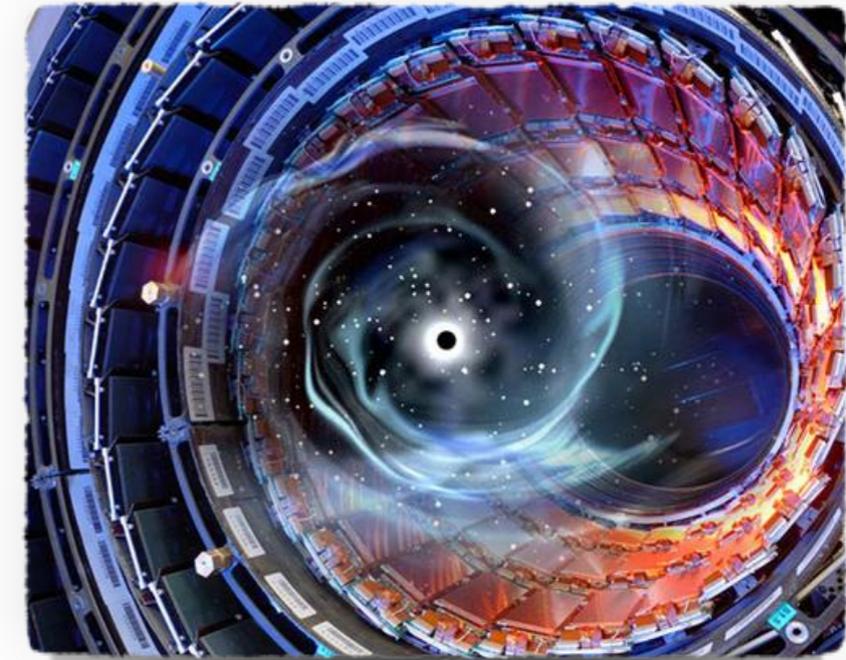
DIPARTIMENTO DI FISICA
SAPIENZA
UNIVERSITÀ DI ROMA



Dott. Livia Soffi

A journey into the heart of matter

- **Particles of matter** are the basic building blocks of everything in the universe.
- Here we study **how these blocks interact** to make the universe look and behave the way it does
- A reliable way to know what is the universe made of is by directly **enquiring of nature through experiments**



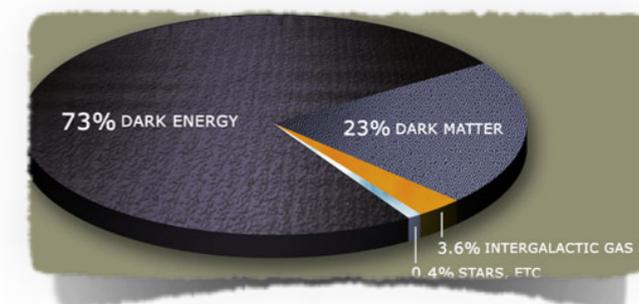
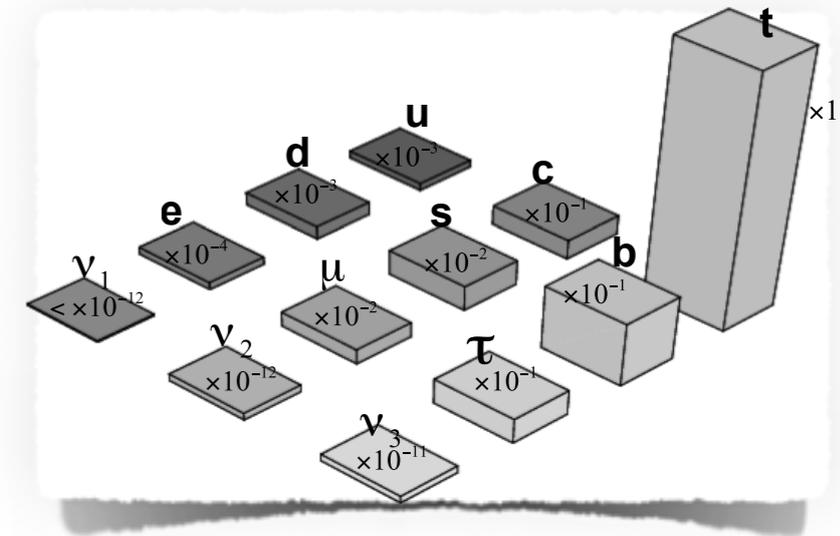
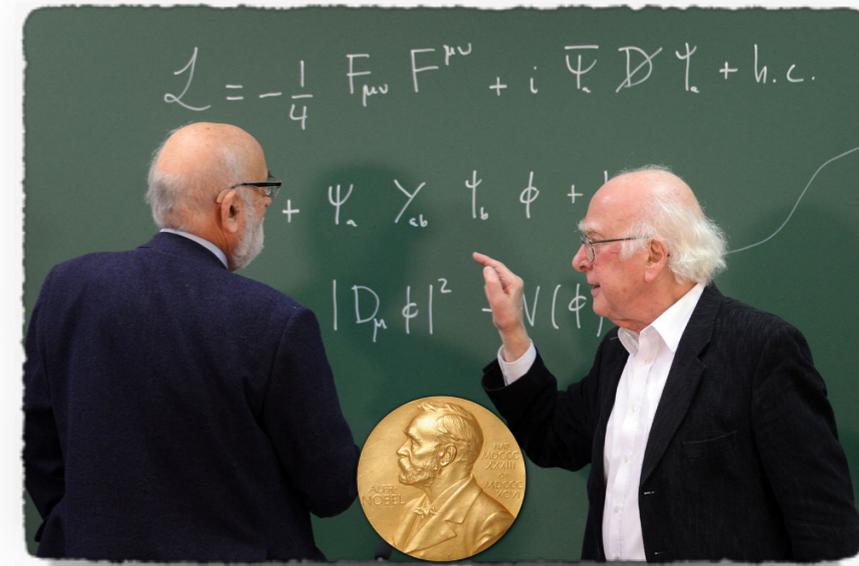
- What we learned:

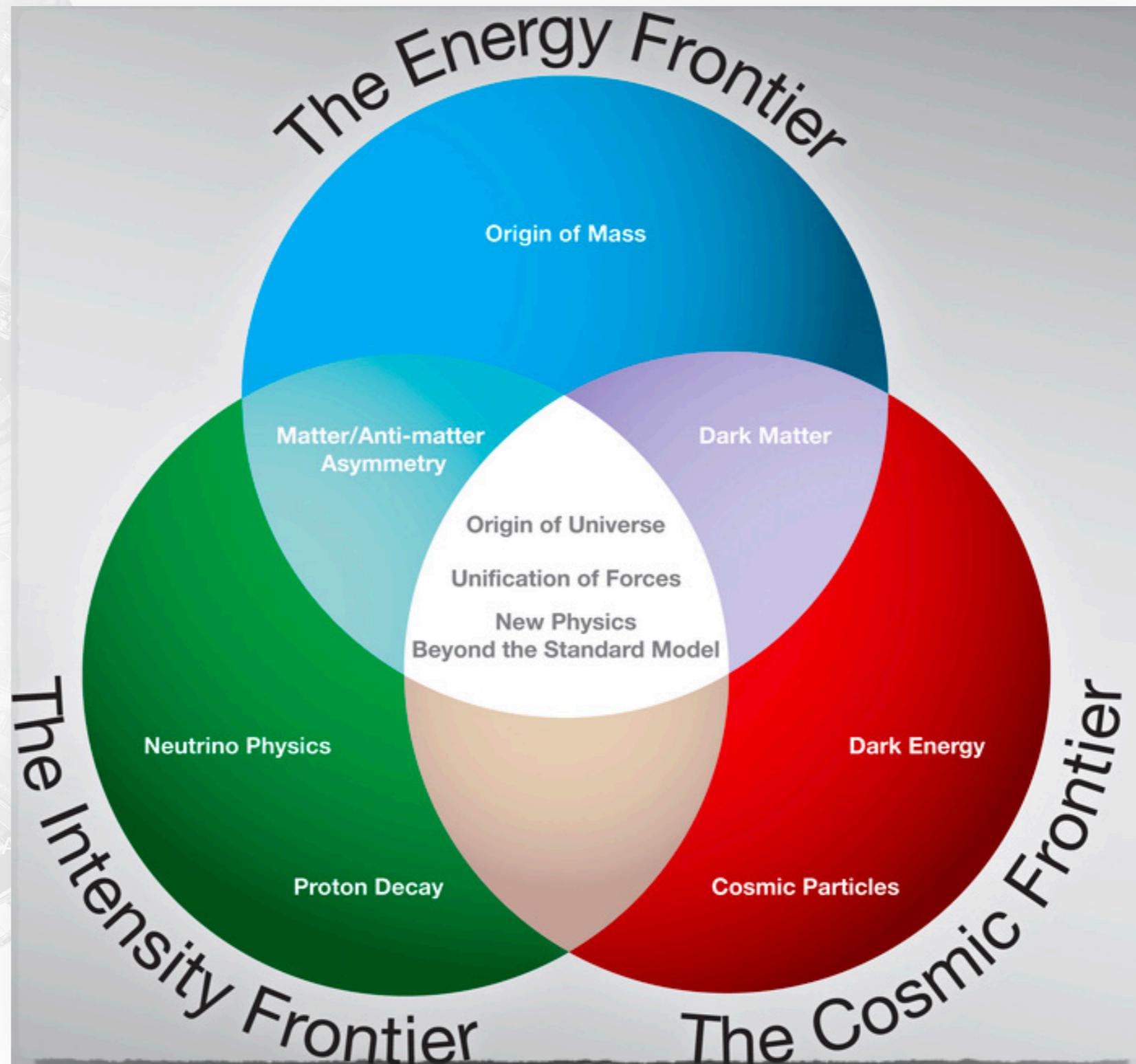
- **Complex structures** in the universe are made of **simple objects**
- Different phenomena are often **different manifestation of the same underlying physics**

	mass →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
	charge →	$2/3$	$2/3$	$2/3$	0	0
	spin →	$1/2$	$1/2$	$1/2$	1	0
		u up	c charm	t top	g gluon	H Higgs boson
QUARKS		$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
		$-1/3$	$-1/3$	$-1/3$	0	
		$1/2$	$1/2$	$1/2$	1	
		d down	s strange	b bottom	γ photon	
		$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
		-1	-1	-1	0	
		$1/2$	$1/2$	$1/2$	1	
		e electron	μ muon	τ tau	Z Z boson	
LEPTONS		$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
		0	0	0	± 1	
		$1/2$	$1/2$	$1/2$	1	
		ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
						GAUGE BOSONS

Solving the Unsolved in Particle Physics

- After 50 years of struggling we finally discovered the last elusive piece of the Standard Model : the **Higgs boson**
- Our understanding of the universe is **not complete** but this discovery opens a **new era of physics**
- What still do not know:
 - Why is **gravity** so weak compared to the Plank scale?
 - What is the origin of the **matter-antimatter** asymmetry we observe?
 - What is the true nature of **neutrinos**?
 - Why there are three generations of **fermions**?
 - What is the origin of **Dark Matter and Dark Energy**?

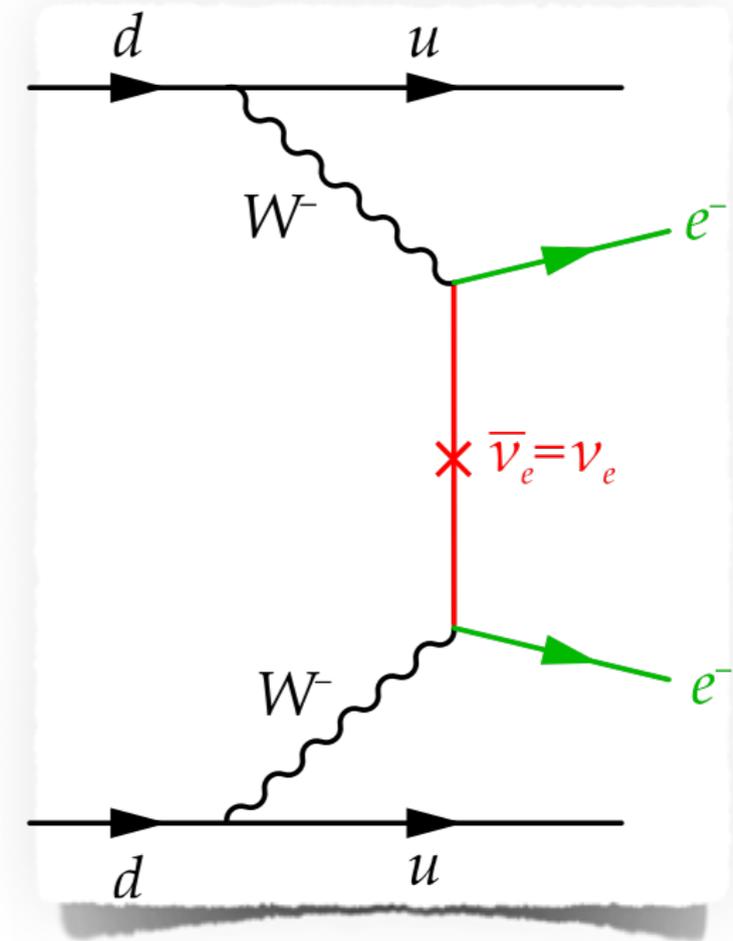
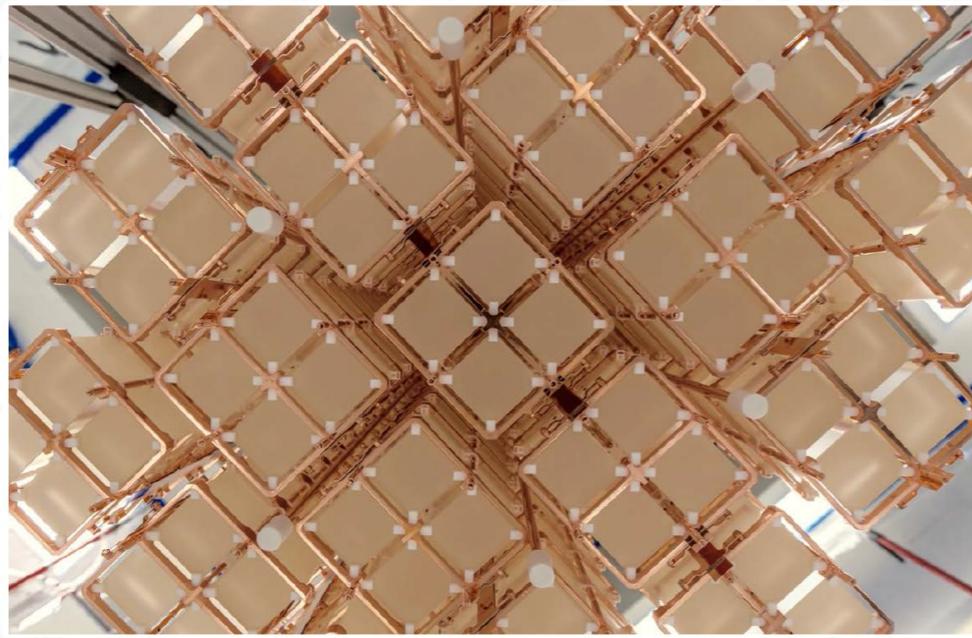




- **Pioneering technologies** as ways to explore the energy, intensity and cosmic frontier,
- **Bountiful list of experiments and opportunities** to be on the **cutting edge of scientific discovery**

Neutrino Physics: CUORE/CUPID at LNGS

- **CUORE**: Cryogenic Underground Observatory for Rare Events
- Study of **neutrino-less double beta decay** in nuclear transitions to investigate Majorana nature of neutrinos
- Exploit **cryogenic calorimeters** called bolometers to achieve excellent energy resolution and performance: **T < 10mK**

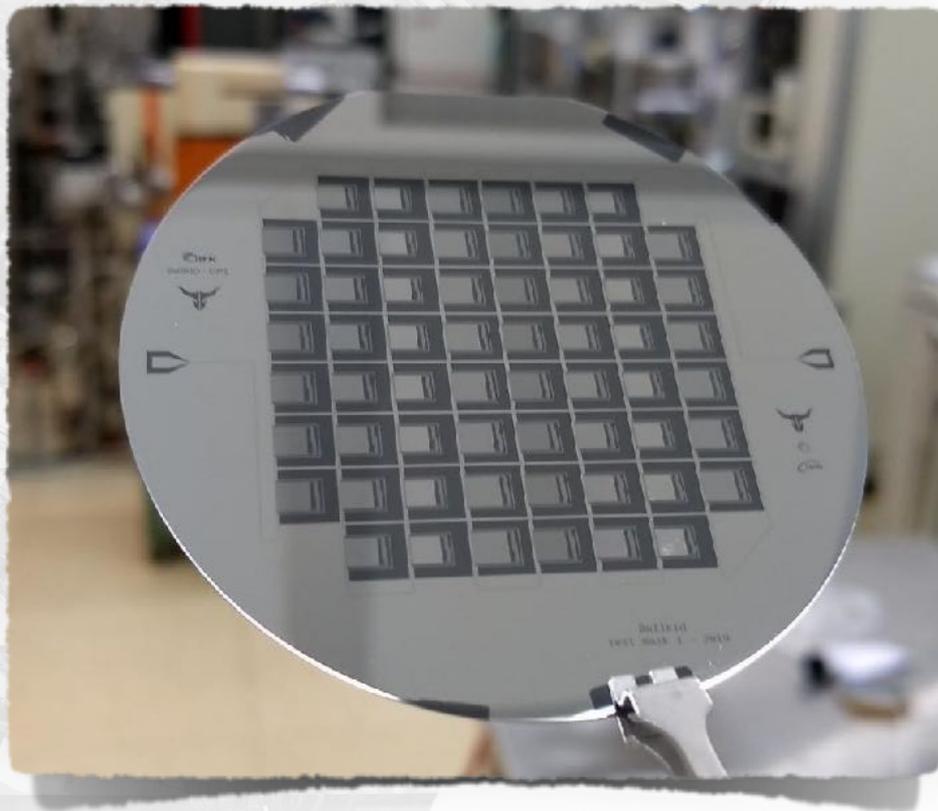
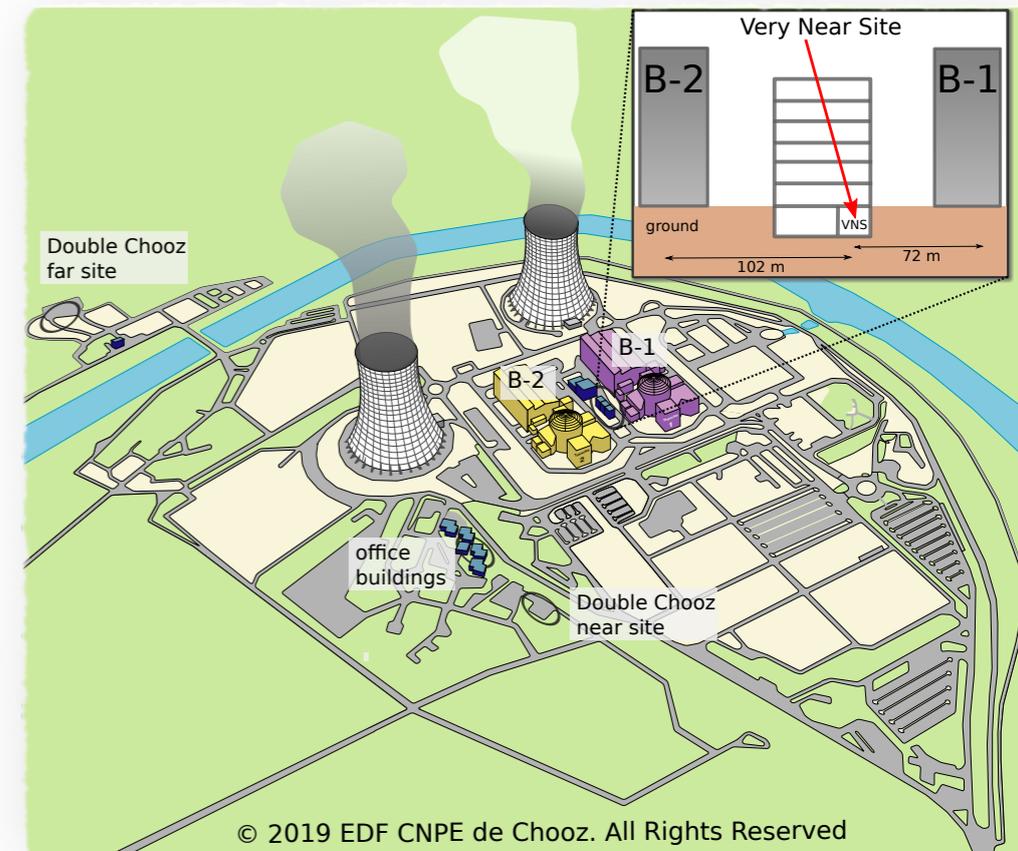


- **CUPID**: upgrade of the detector aiming to reduce by an order of magnitude the background (noise)

Activities ongoing: crystal growth, detector assembly and analysis technique developments

Neutrino Physics: NUCLEUS Experiment

- **Cryogenic Particle detector** at CHOOZ Nuclear Reactor in France.
- Explore **New Physics in Elastic Neutrino-Nucleus scattering Coherent**
- Ongoing activities: simulation, data analysis, detector construction.



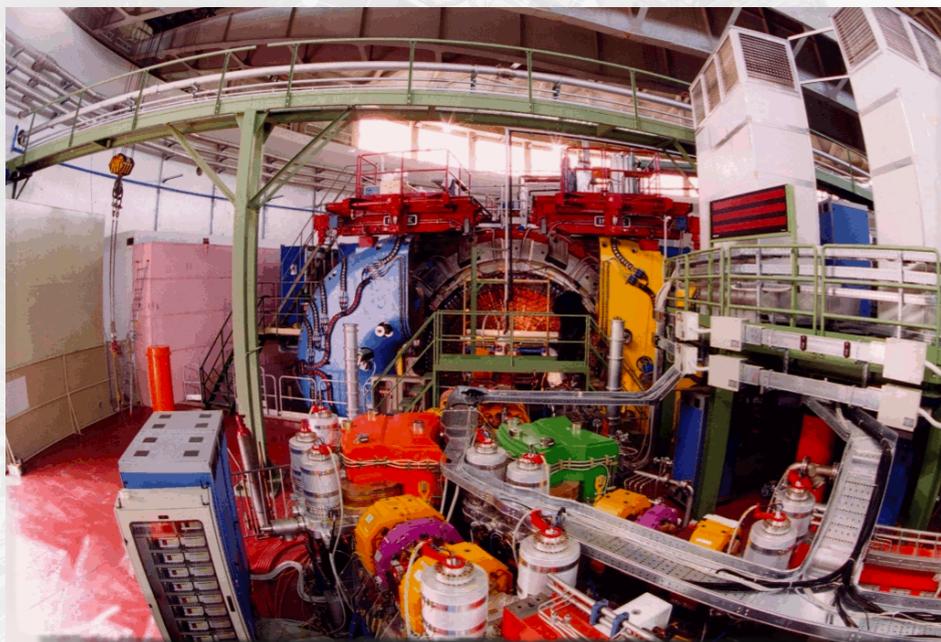
- **R&D on cryogenic detectors** for next-generation experiments on Neutrino scattering, Majorana neutrino, Dark Matter.
- Design, test and data analysis in the Cryogenic Detectors **lab at Sapienza**.

[Talk with more info at this link](#)

Exploring the Dark Sector: PADME, KLOE-2

- **PADME** (Positron Annihilation into Dark Matter Experiment) at INFN LNF
- **KLOE-2** is an experiments located at LNF at the DAFNE accelerator

$$e^+e^- \rightarrow \gamma A'$$



- Search for **dark photon**, a new particle connecting the SM with the dark unknown sector

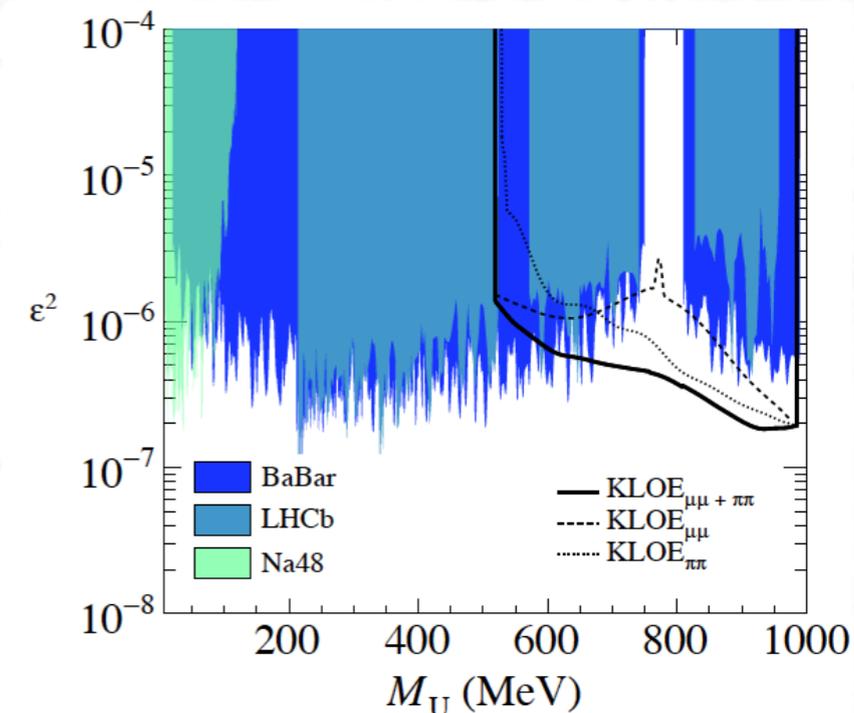
Standard Model

g W^\pm, Z γ

?

Dark Sector

forces + particles
dark matter?



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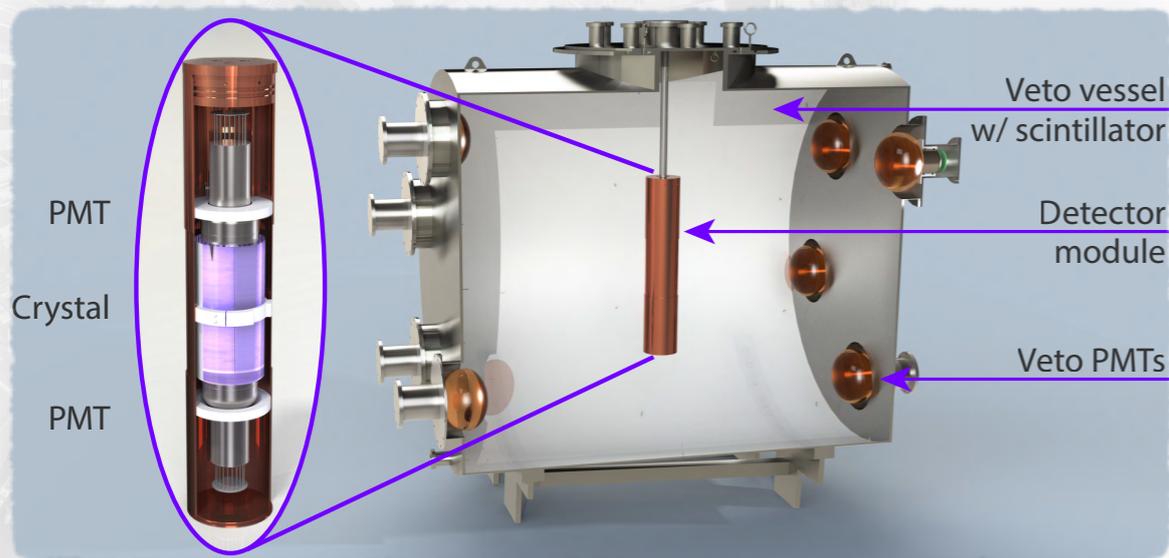
Livia Soffi, Sapienza & INFN Roma

Direct Detection of Dark Matter

- Observe **recoil of dark matter from nucleus**
- Very interesting signal observed by **DAMA** experiment at LNGS but not other confirmation

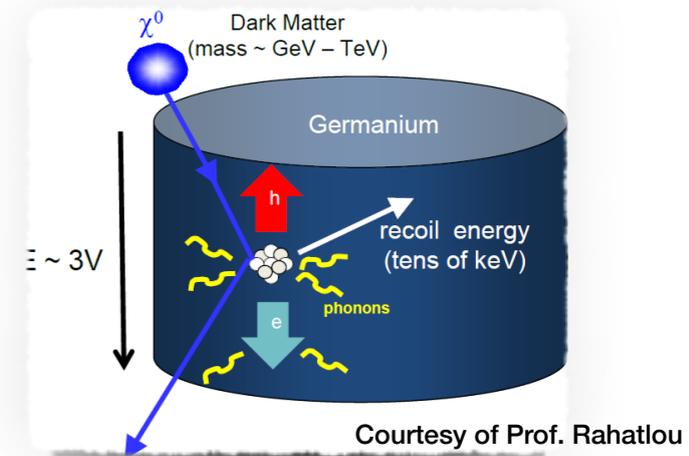
SABRE: New detector with NaI(Tl) aiming at reproducing DAMA measurement with two sites: LNGS and Australia

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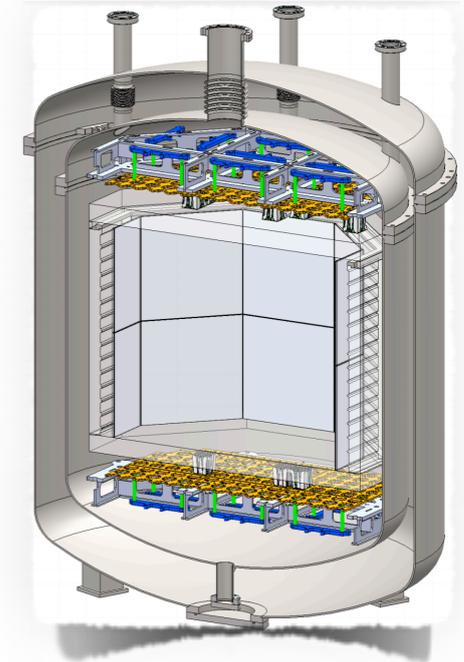
CNT: Carbon nanotubes to detect electron recoiling from DM with a mass as low as few MeV

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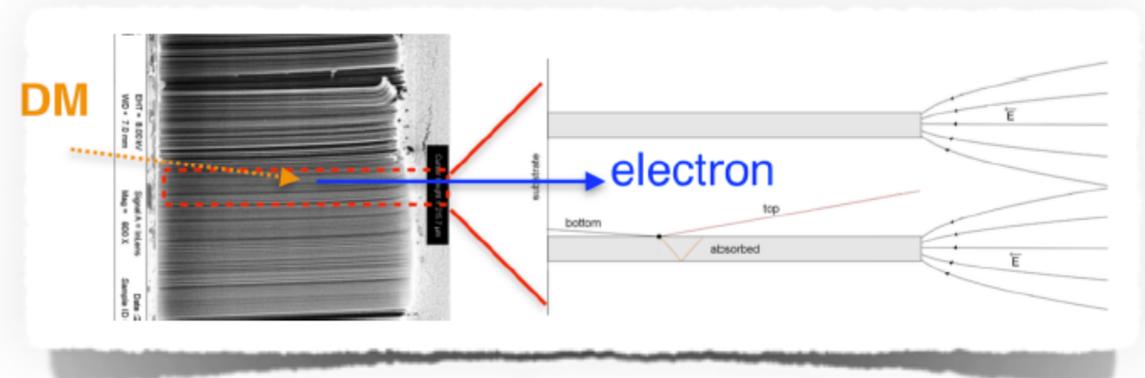


Courtesy of Prof. Rahatlou

DarkSide-50 (DS-50):
50 kg active mass of liquid argon at LNGS

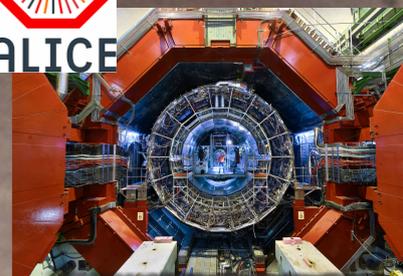
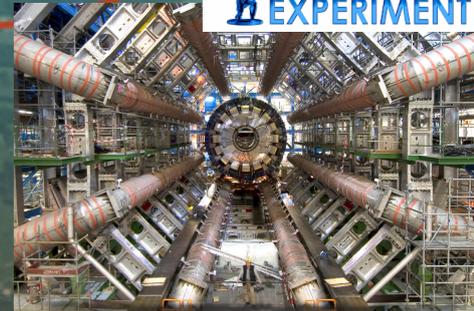


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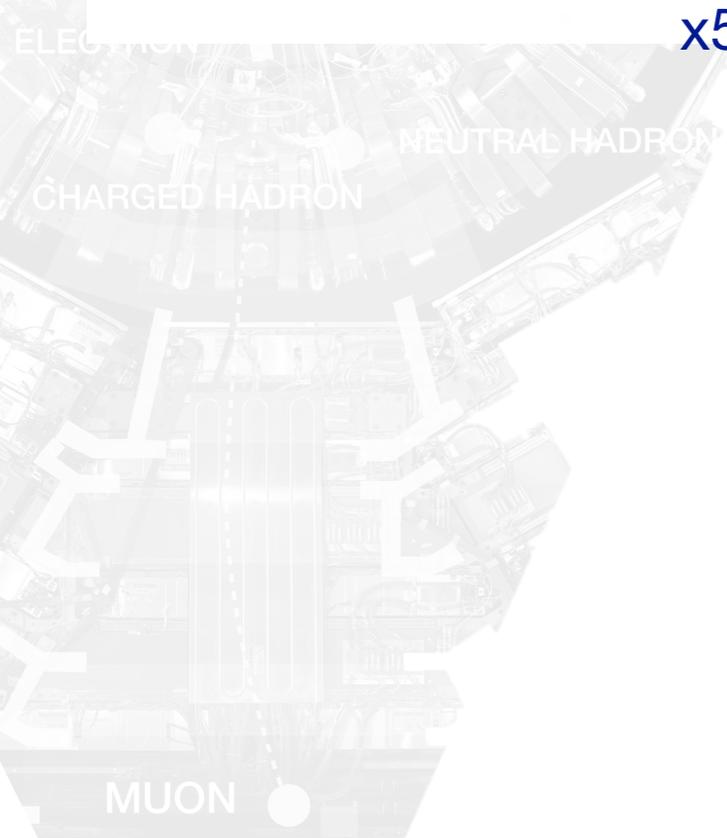
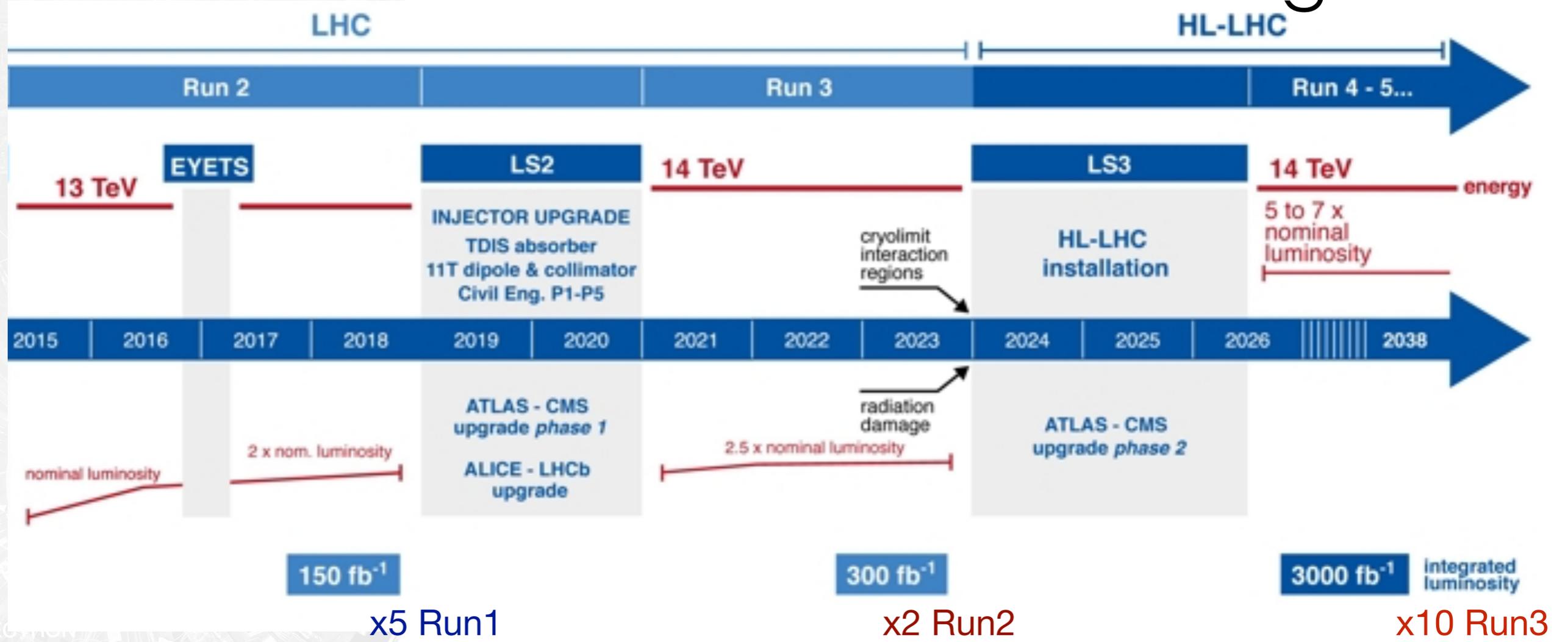


The energy frontier: The Large Hadron Collider

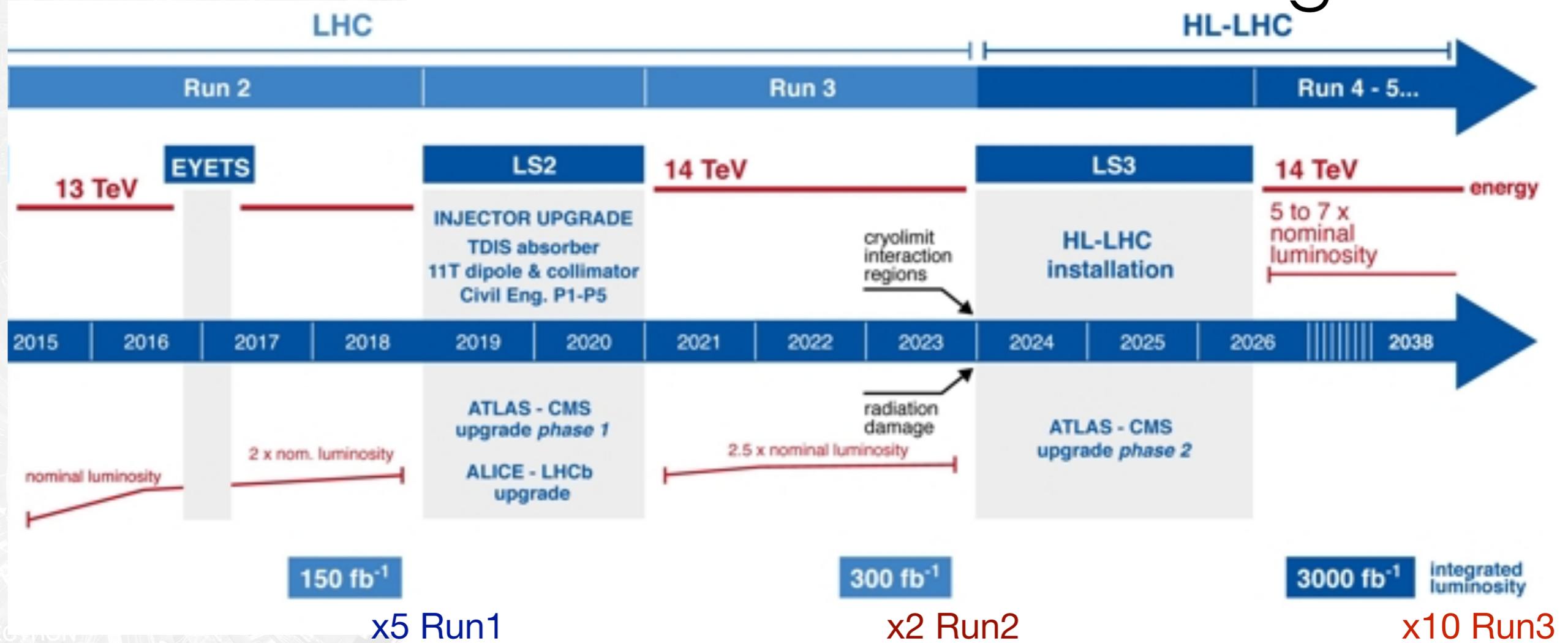
*..A tool to probe the structure of
matter & fundamental
interactions...*



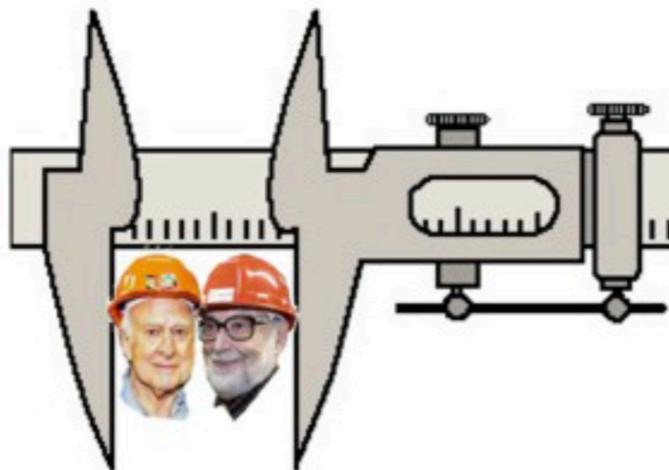
The Big Picture



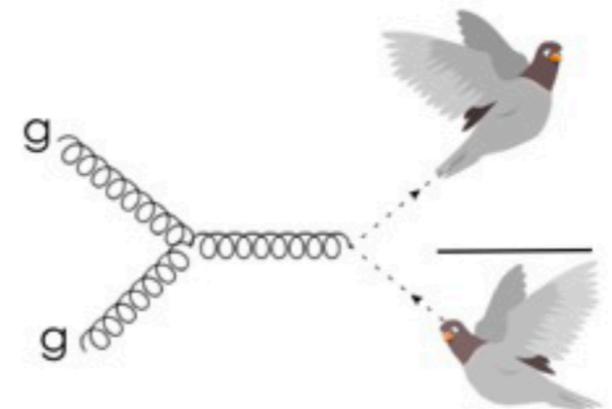
The Big Picture



- **Precise measurements** of Standard Model observables



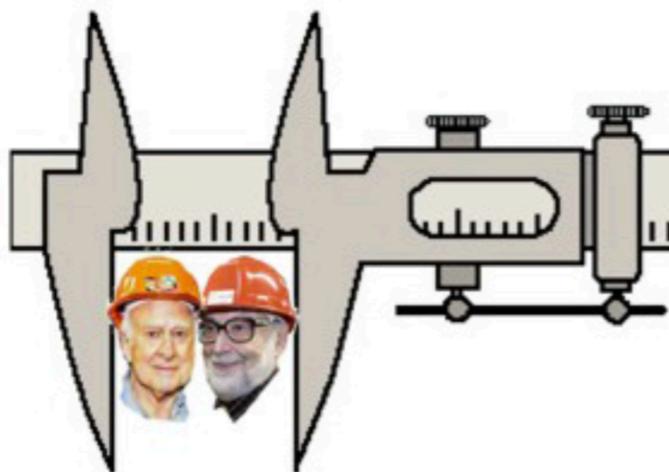
- Model Independent searches for **non conventional final states**



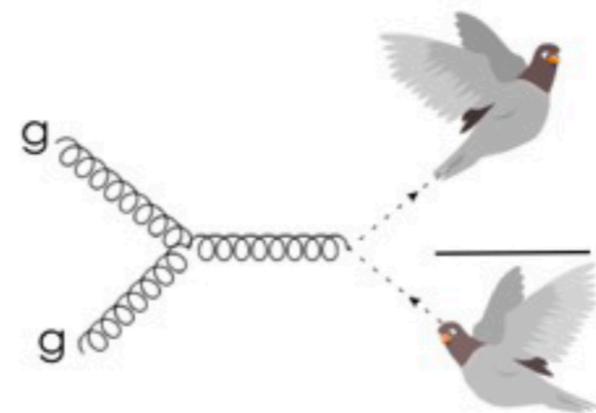
The Big Picture



- **Precise measurements** of Standard Model observables

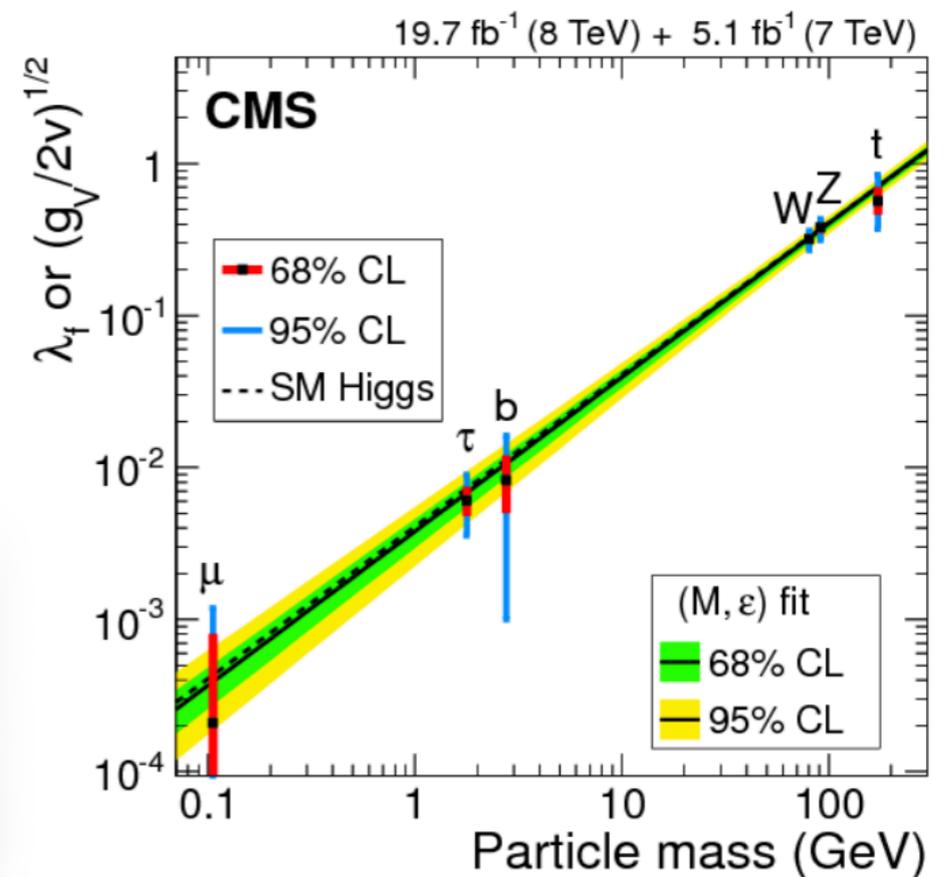
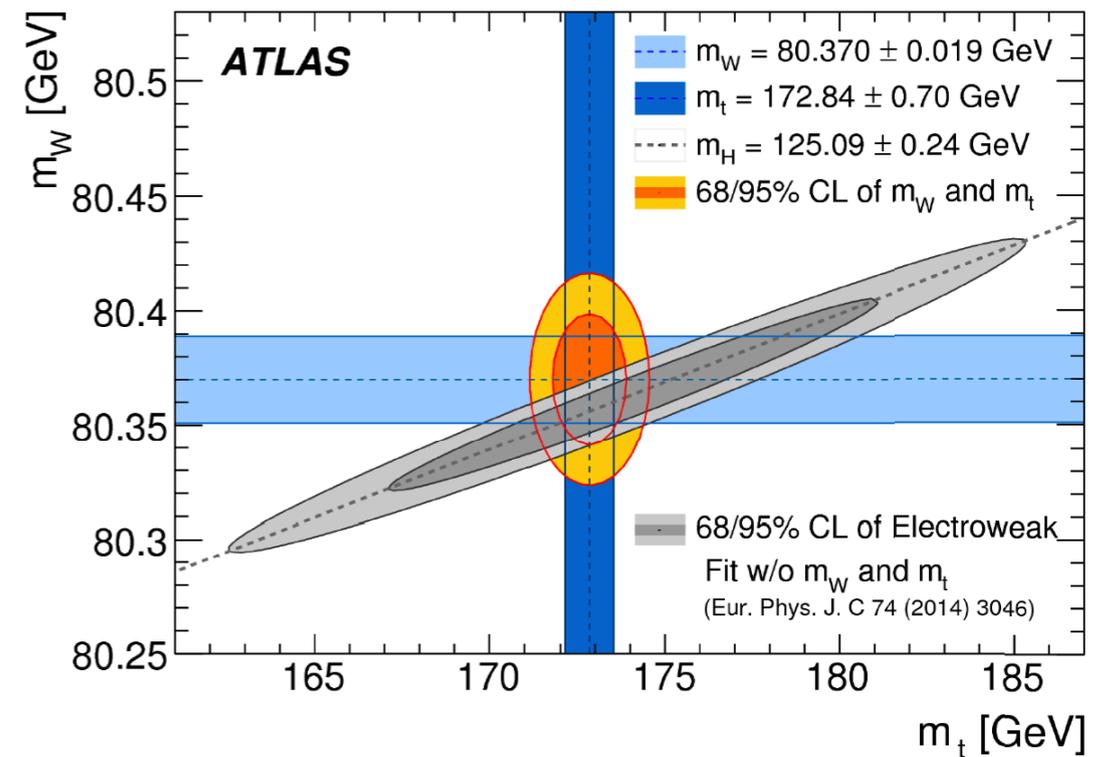


- Model Independent searches for **non conventional final states**



Standard Model at the LHC

- Non negligible effect of new particles and interaction on m_W w/ **uncertainty < 10 MeV**
- Extraordinary opportunity to test the **internal consistency of the SM**
- Establish **Higgs boson** role in fermion mass generation **with % precision**
- Very **challenging**: low cross section and the complex final state + combination of **various decay channels**



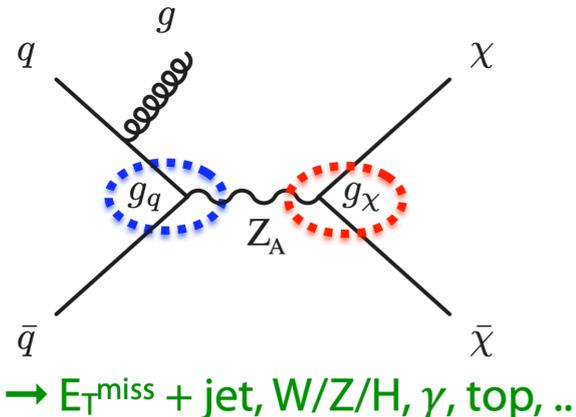
mass	charge	spin	u	c	t	g	H
~2.3 MeV/c ²	2/3	1/2	up	charm	top	gluon	Higgs boson
~4.8 MeV/c ²	-1/3	1/2	down	strange	bottom	photon	
0.511 MeV/c ²	-1	1/2	electron	muon	tau	Z boson	
<2.2 eV/c ²	0	1/2	electron neutrino	muon neutrino	tau neutrino	W boson	

QUARKS (u, c, t, d, s, b), **LEPTONS** (e, mu, tau, nu_e, nu_mu, nu_tau), **GAUGE BOSONS** (g, photon, Z, W), **Higgs boson** (H)

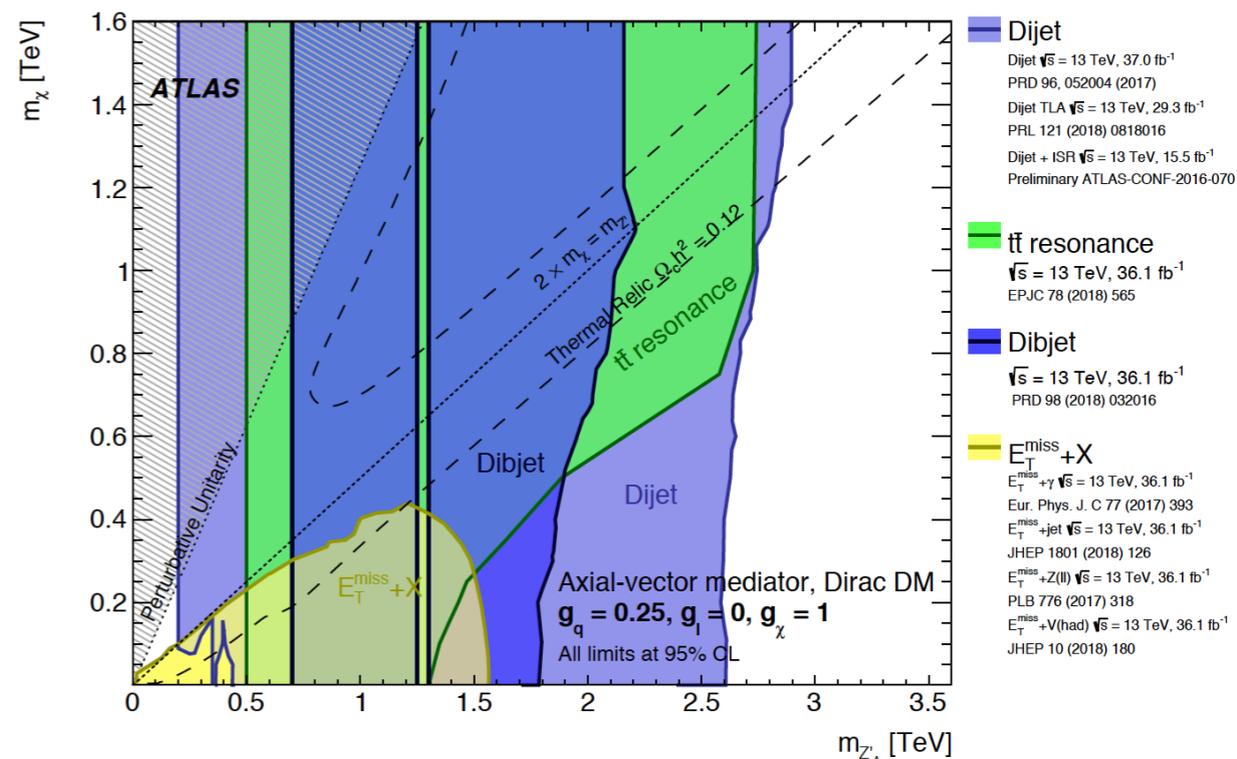
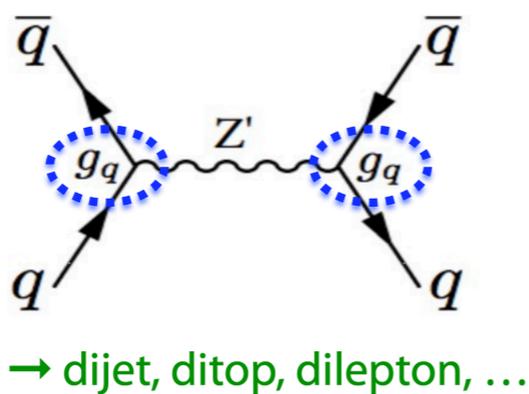
Going weirder at the LHC

- If exist, **Dark Matter** can be produced at LHC

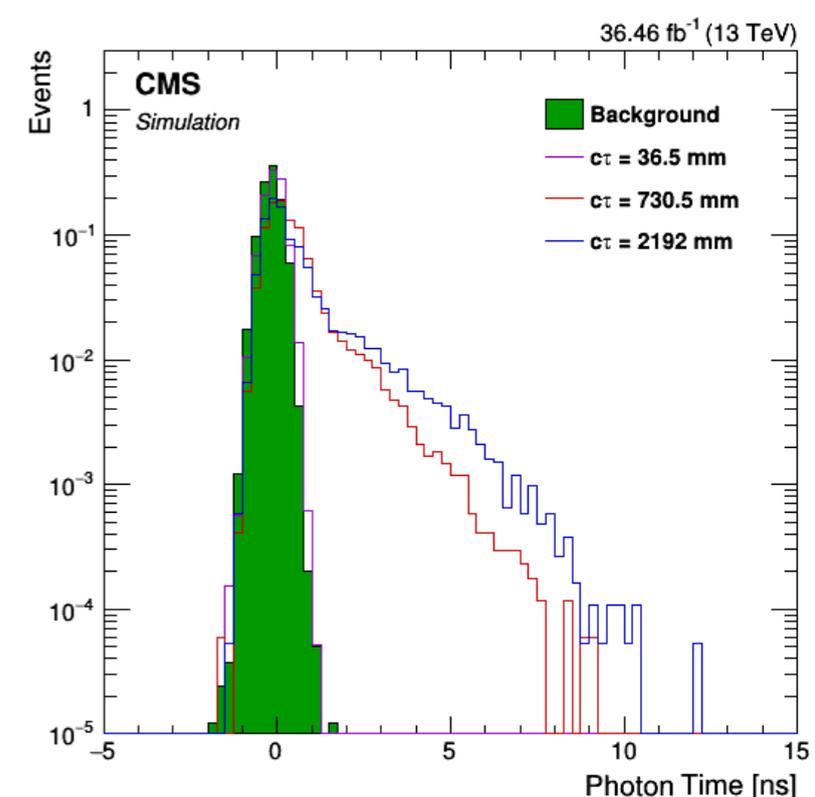
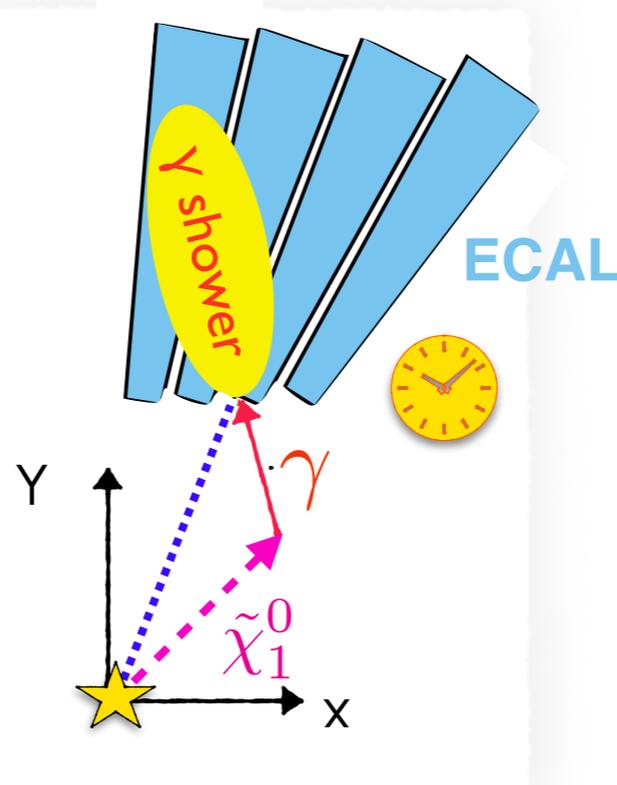
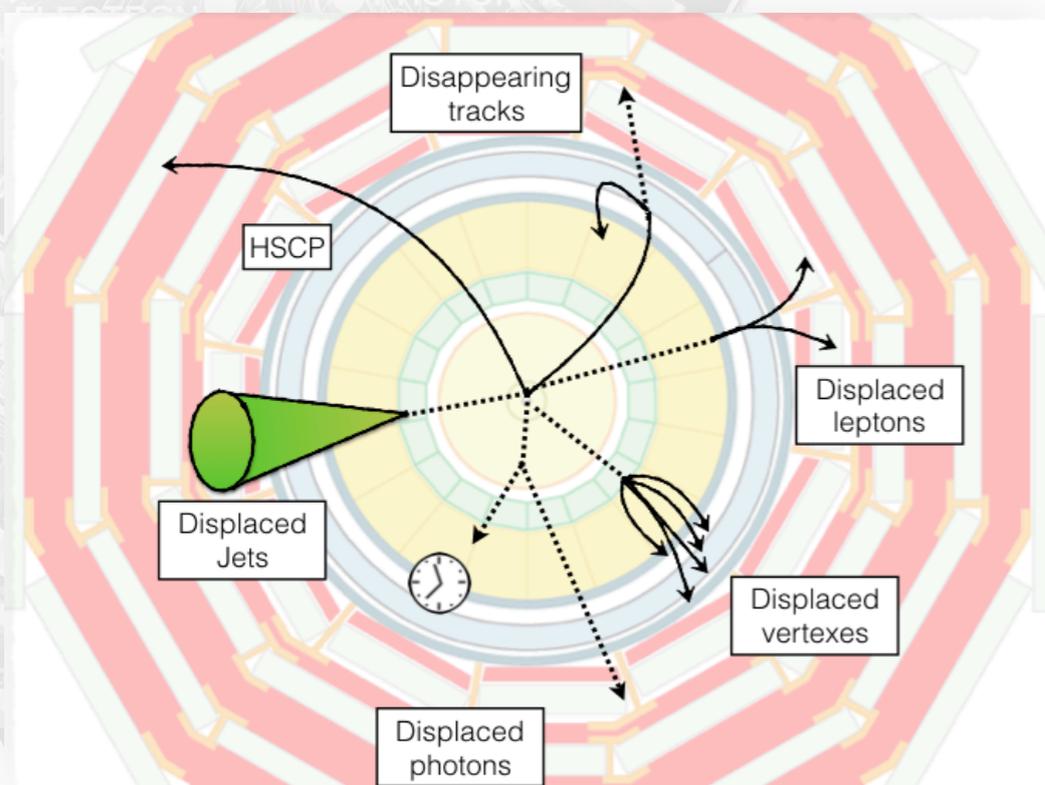
SM \rightarrow mediator \rightarrow DM
 \rightarrow **Mono-X signature**



SM \rightarrow mediator \rightarrow SM
 \rightarrow **Visible (resonant) signature**



- Strong interest in **long-lived particles** at colliders



Detectors Upgrade and R&D

- **LHC Phase-2 upgrade for 2026:** maintain excellent performance of the detector in efficiency, resolution, and background rejection

-> withstand **pileup and radiation damage particularly demanding forward regions**

- **ATLAS : 'New Small Wheels'** precision tracking and trigger **'Micromegas' chambers** to measure the **position** of the particles better than **$50 \mu m$**

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- **CMS:** MIP **timing** detector to mitigate large pileup and assign a time w/ **30 ps resolution** to particles and vertices

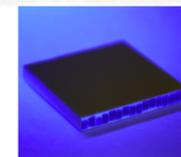
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Activities: Prototypes **characterization** and **simulated studies** to evaluate effective performances



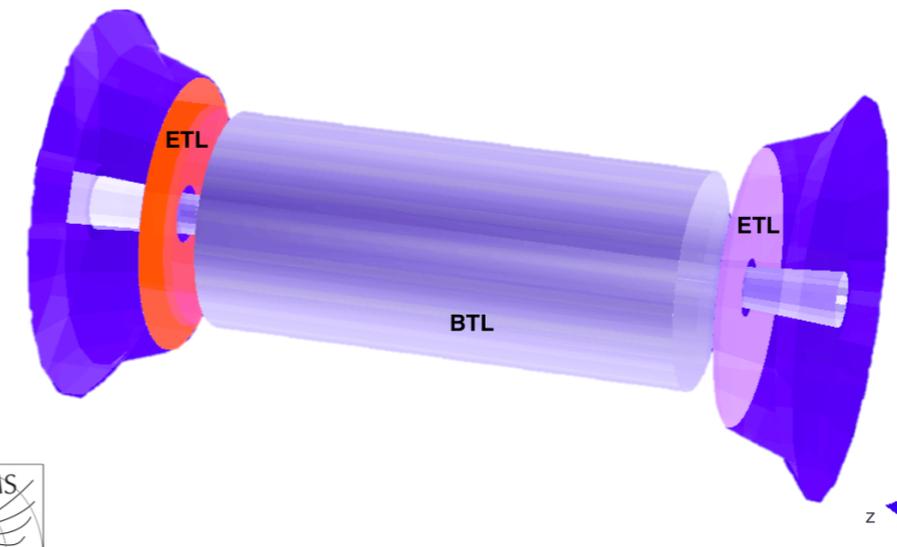
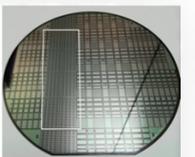
BTL: LYSO bars + SiPM readout:

- TK / ECAL interface: $|\eta| < 1.45$
- Inner radius: 1148 mm (40 mm thick)
- Length: ± 2.6 m along z
- Surface ~ 38 m²; 332k channels
- Fluence at 4 ab⁻¹: 2×10^{14} n_{eq}/cm²



ETL: Si with internal gain (LGAD):

- On the CE nose: $1.6 < |\eta| < 3.0$
- Radius: $315 < R < 1200$ mm
- Position in z: ± 3.0 m (45 mm thick)
- Surface ~ 14 m²; ~ 8.5 M channels
- Fluence at 4 ab⁻¹: up to 2×10^{15} n_{eq}/cm²

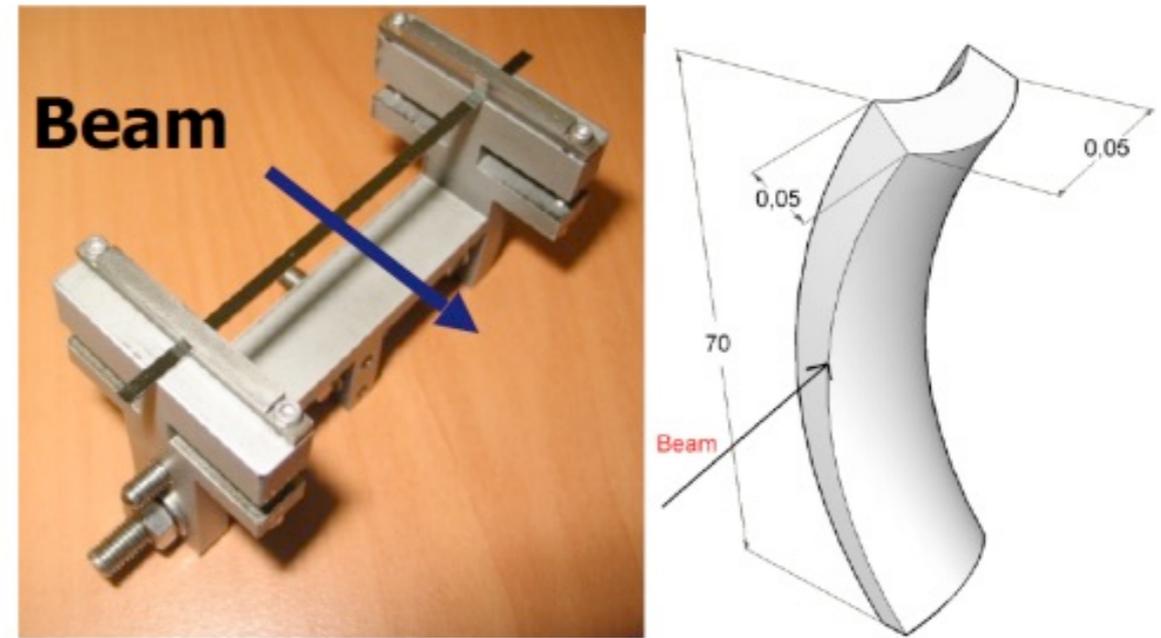
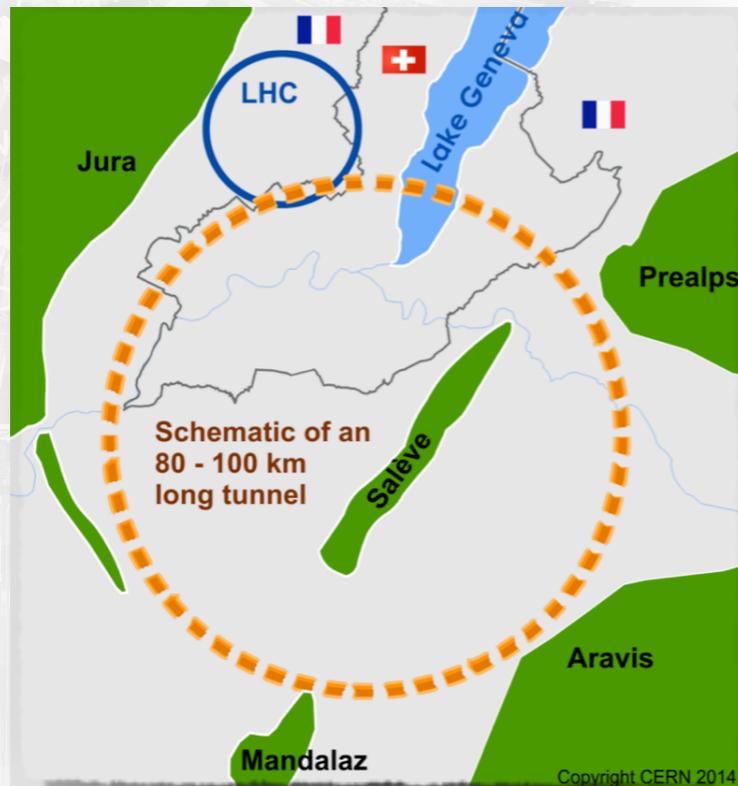


Colliders beyond LHC

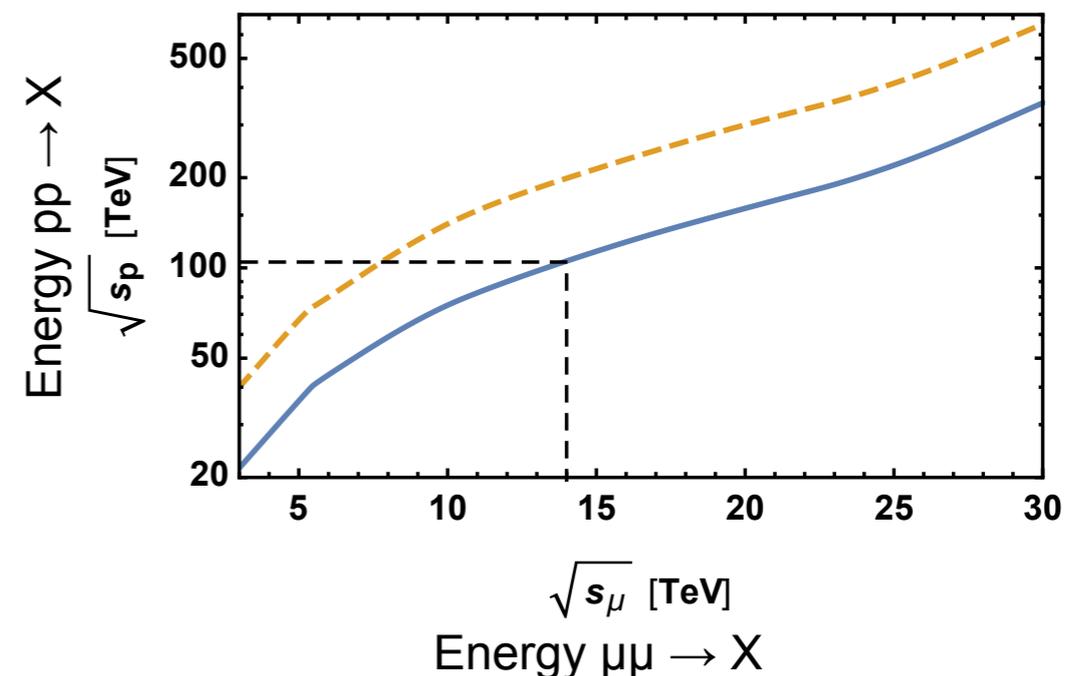
- **CRYSBEAM:** Crystal channeling to extract high energy hadron beams from an accelerator; feasibility study of a fixed target experiment, study of hadronic swarms.

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- **FCC:** 100 TeV with 100 km tunnel



- **Muon collider:** much higher energies for colliders of reasonable size + point-like projectile



<https://www.roma1.infn.it/>

Medical Applications with the Applied Radiation Physic Group

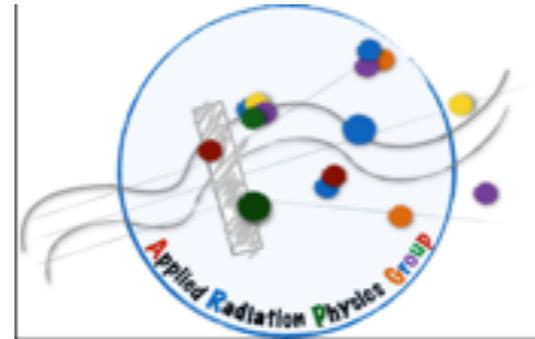


NUCLEAR MEDICINE

CHIRONE
(Radio Guided Surgery)

WIDMAPP
(Dosimetry for Target Radio
Therapy)

DOSE PROFILER
(Particle Therapy dosimetry)



HADRON THERAPY

FOOT
(RBE in PT)

FRED
(TPS with GPU)

MONDO
(Fast Neutron Detection)

PAPRICA

GENIALE
(Low Energy Nuclear Interactions)

ARTIFICIAL INTELLIGENCE IN MEDICINE

MARIANNE
(Imaging for stadiation)

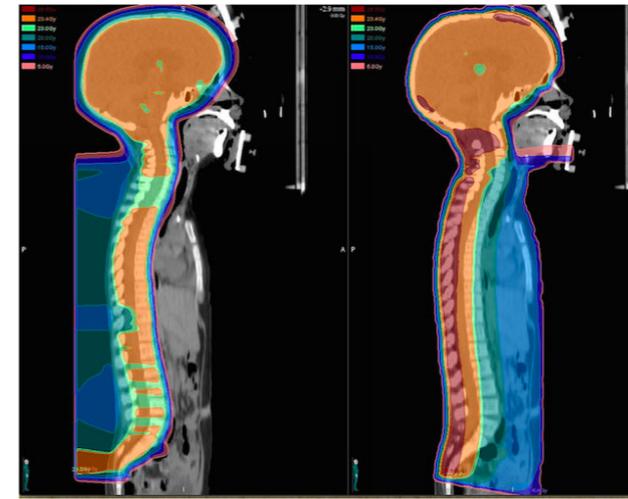
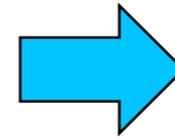
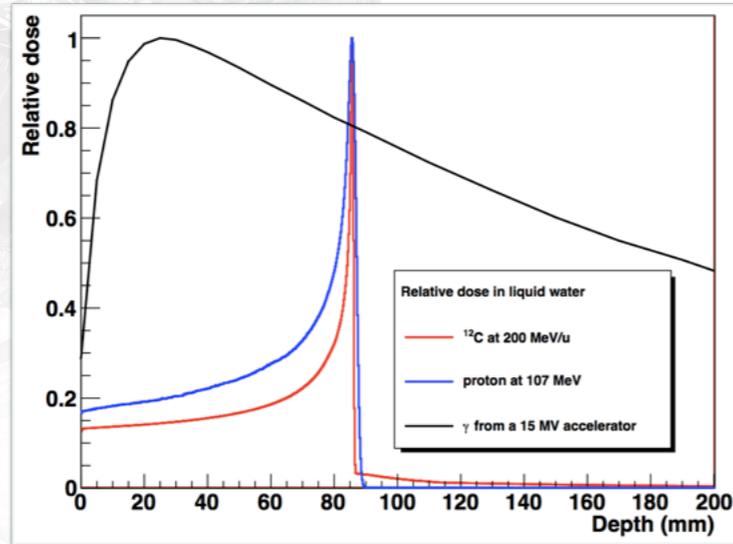
NEPTUNE
(¹⁹F-MRI)

FILOBLU
(Patient-Doctor
interactions)

<http://arpg-serv.ing2.uniroma1.it/arpg-site/>

Hadron Therapy and Dose Monitoring

- Concentrate release of energy inside tumor due to **release of energy in ionization**
- Based on **nuclear reactions** between the projectile and the patient



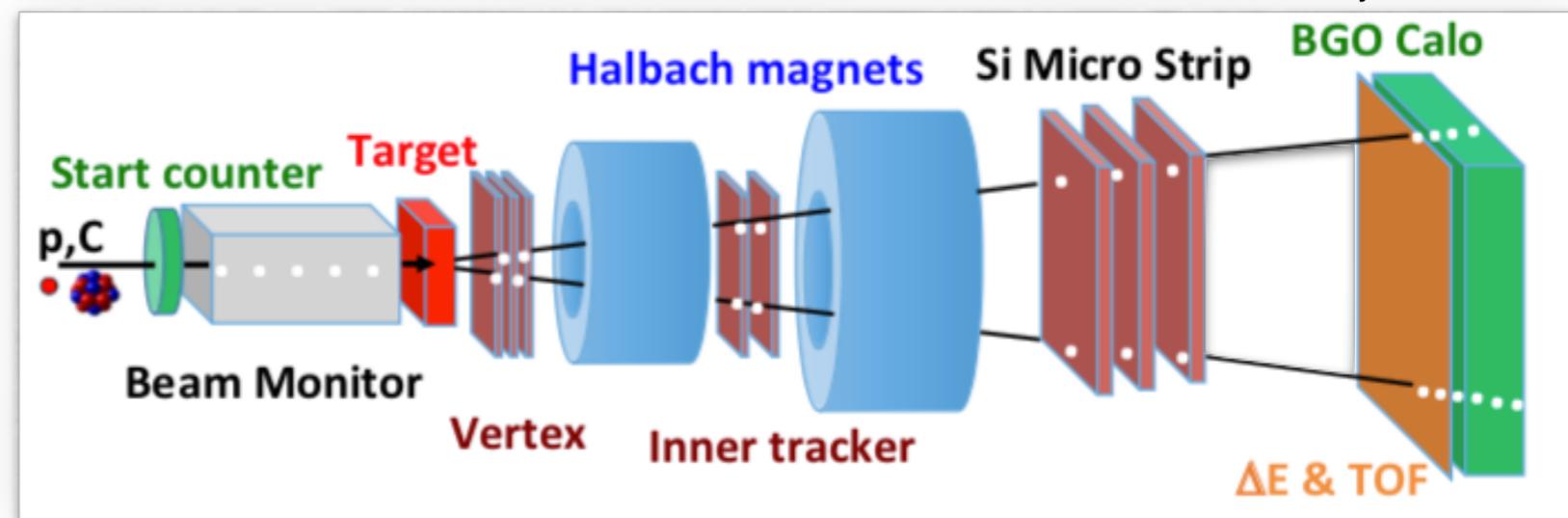
Courtesy of Prof. A. Sarti

- About **10% of biological effect** due to secondary fragments which give contribution also **outside the tumor region**

- **Dose Profiler**: Exploit secondary particles detection as an online monitor of the dose

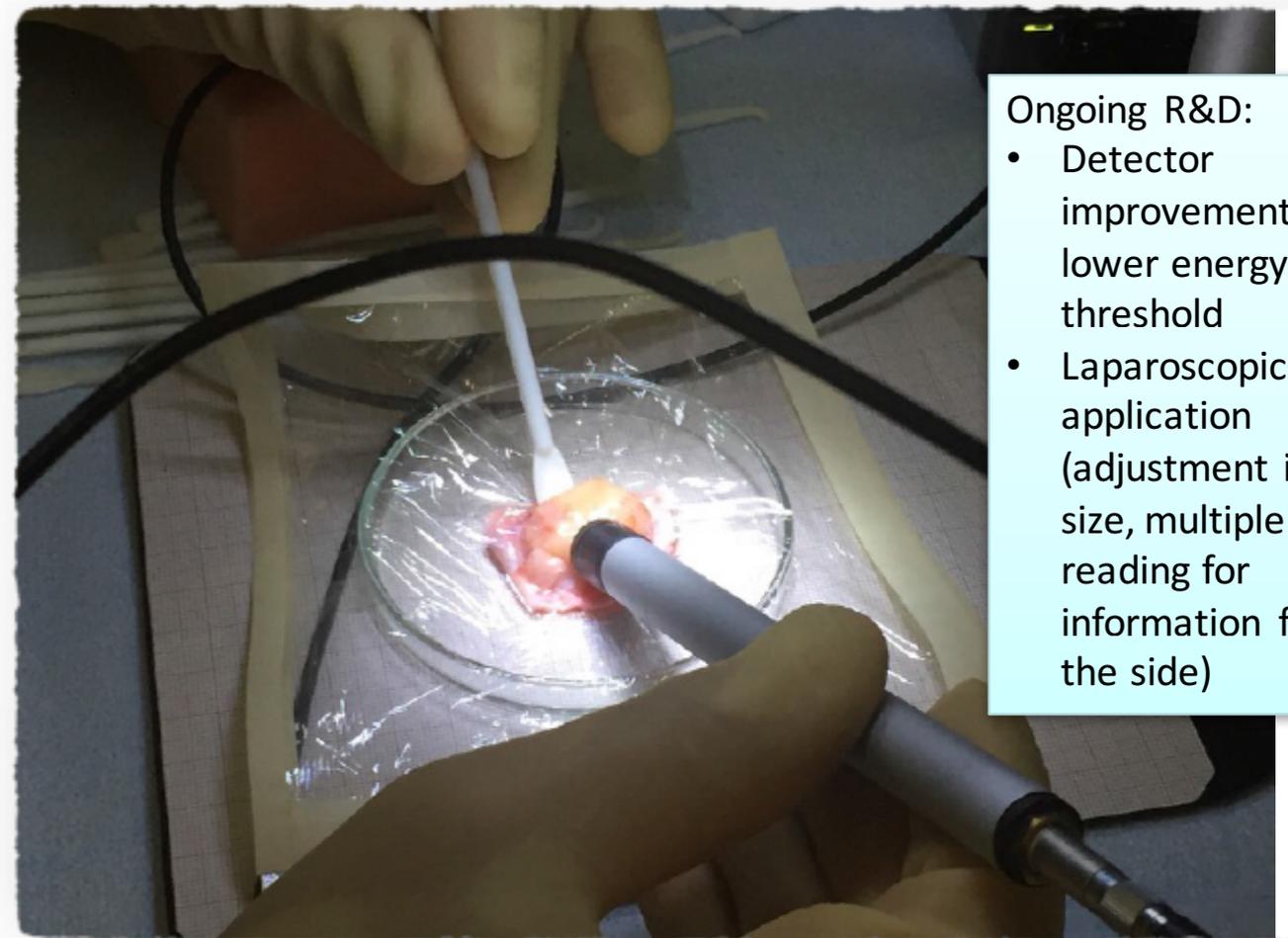
- **FOOT: beam monitoring** took first data in 04/2019

Courtesy of Prof. A. Sarti



Radio Guided Surgery

- Develop **radiation detectors** that the surgeon can use to **detect residuals/lymphnodes** during the surgery . This can be done once injecting a radioactive tracker into the patient
 - Use of β - tracers (**electrons**):
 - Detect electrons that travel ~ 100 times less than γ
 - No background** from photons
 - Shorter time** to have a response
 - Smaller and more versatile detector
 - **Reduced effect** of nearby healthy tissues
 - Reduced dose** to medical staff



Ongoing R&D:

- Detector improvements to lower energy threshold
- Laparoscopic application (adjustment in size, multiple reading for information from the side)

Useful Links and Contacts

- I tried to give you a comprehensive overview of the research **opportunities in particle and medical physics in this department.**

- Due to time constraints I did not manage to cover other activities as:

- **LHC-b** @ CERN (b-physics @ LHC)

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- **MEG** @ PSI di Zurich (new physics with $\mu \rightarrow e\gamma$)

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- **AMS2** on the ISS (anti matter and dark matter)

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- **DAMA** @ LNGS (direct dark matter detection)

<https://www.lngs.infn.it/it/dama>

- More information can be found at the **INFN website**:

<http://www.roma1.infn.it/>

and at the **ARPG page**:

<http://arpg-serv.ing2.uniroma1.it/arpg-site/>

- A summary of these activities is presented in the Scientific Report of our Department:

<https://www.phys.uniroma1.it/fisica/sites/default/files/allegati/ScientificReport2014-2016.pdf>

- List of available theses on phys.uniroma1.it:

<https://www.phys.uniroma1.it/fisica/sites/default/files/showcase/showcase.html>

- You can obviously **contact me** any time and I will re-direct you to the right person to talk with

livia.soffi@uniroma1.it or www.roma1.infn.it/~lsoffi/index.html