Rivelazione con acceleratori di particelle di candidati WIMP di Materia Oscura

Walter M. Bonivento

INFN Sezione di Cagliari

…se Maometto non va alla montagna…

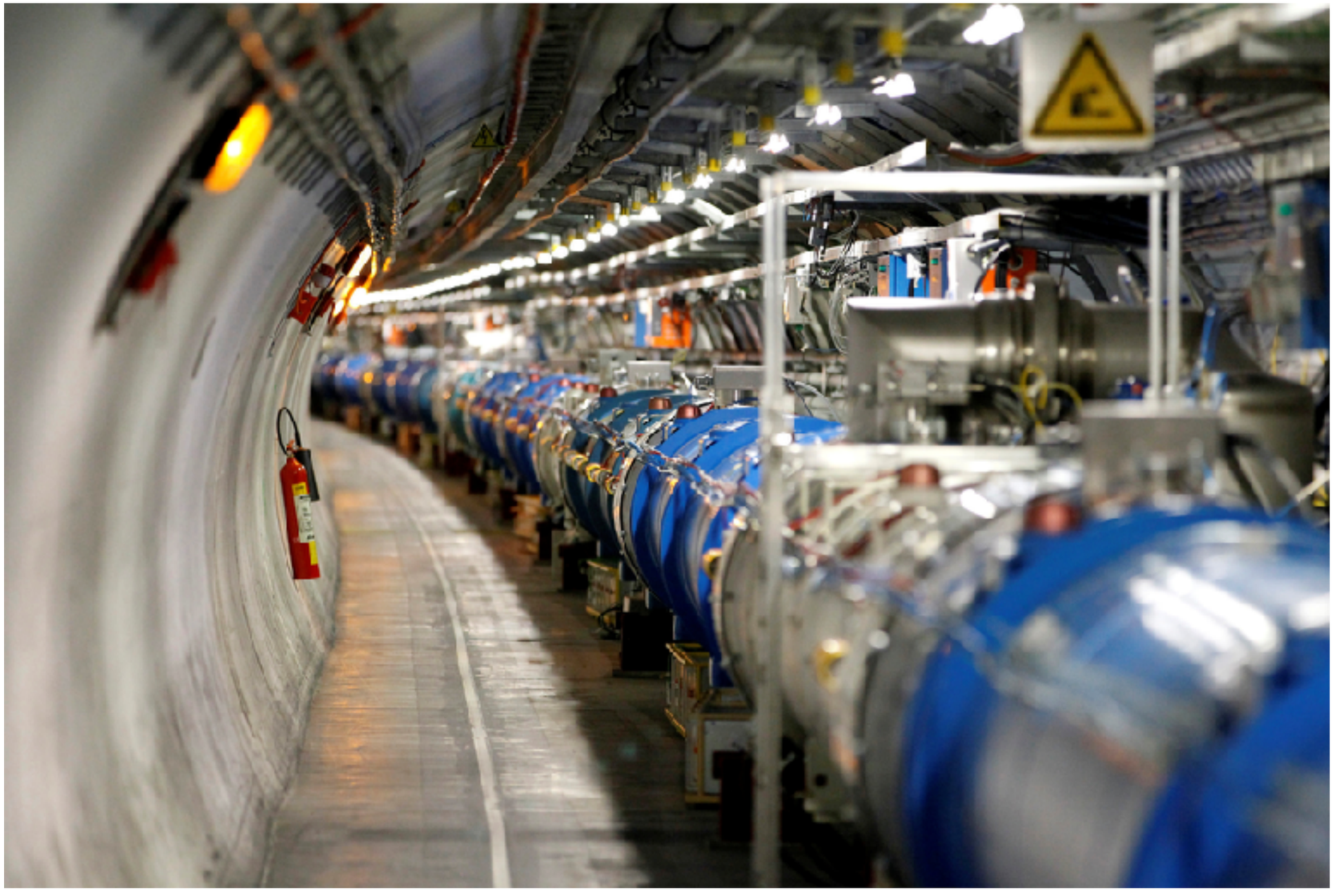
oltre a misurare la possibile interazione della materia oscura (DM) nella nostra galassia con dei dispositivi nei laboratori sotterranei, e' anche possible cercare di misurare la Materia Oscura "producendola" con acceleratori di particelle

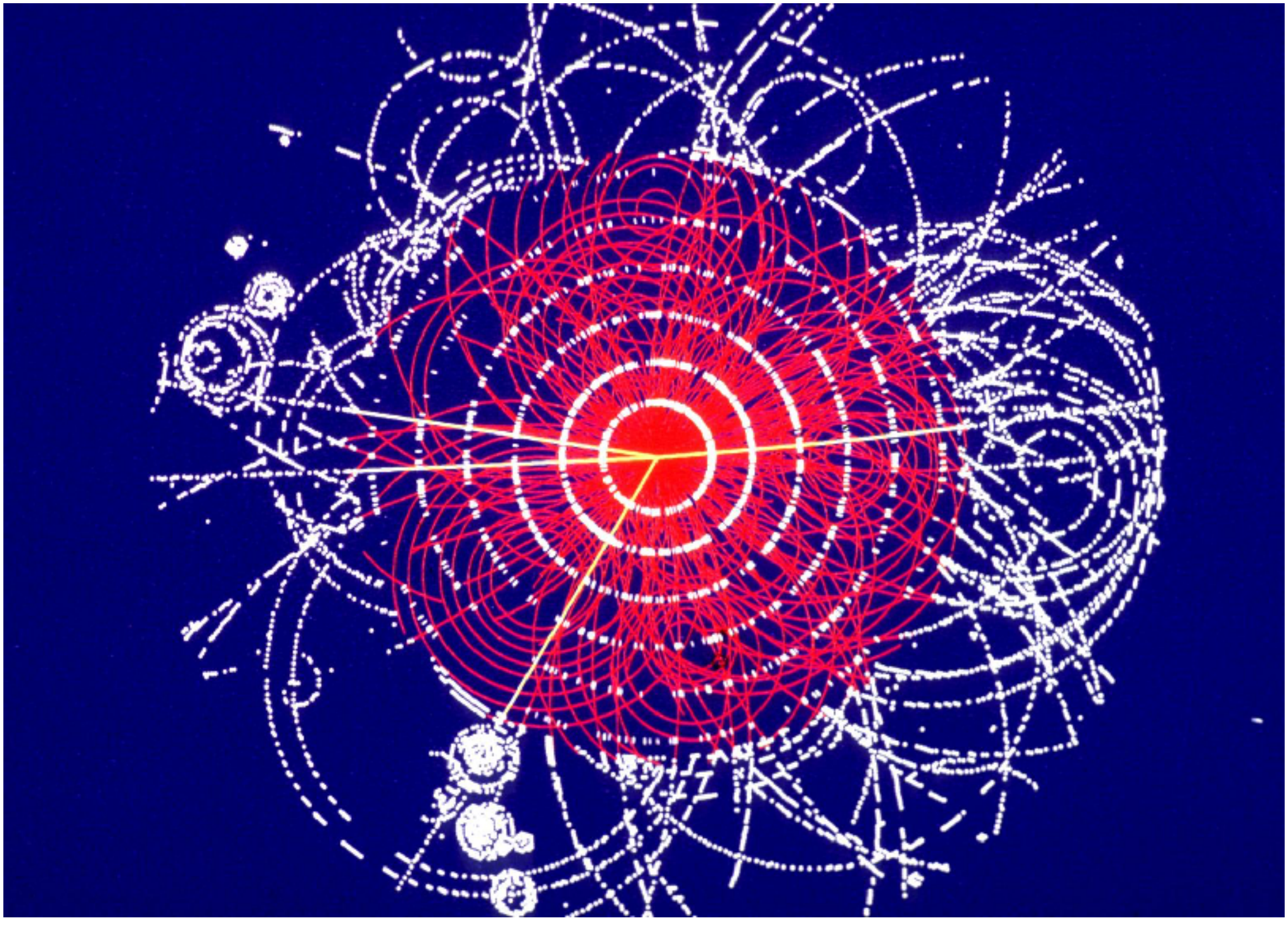
Cosa sono gli acceleratori di particelle in due parole

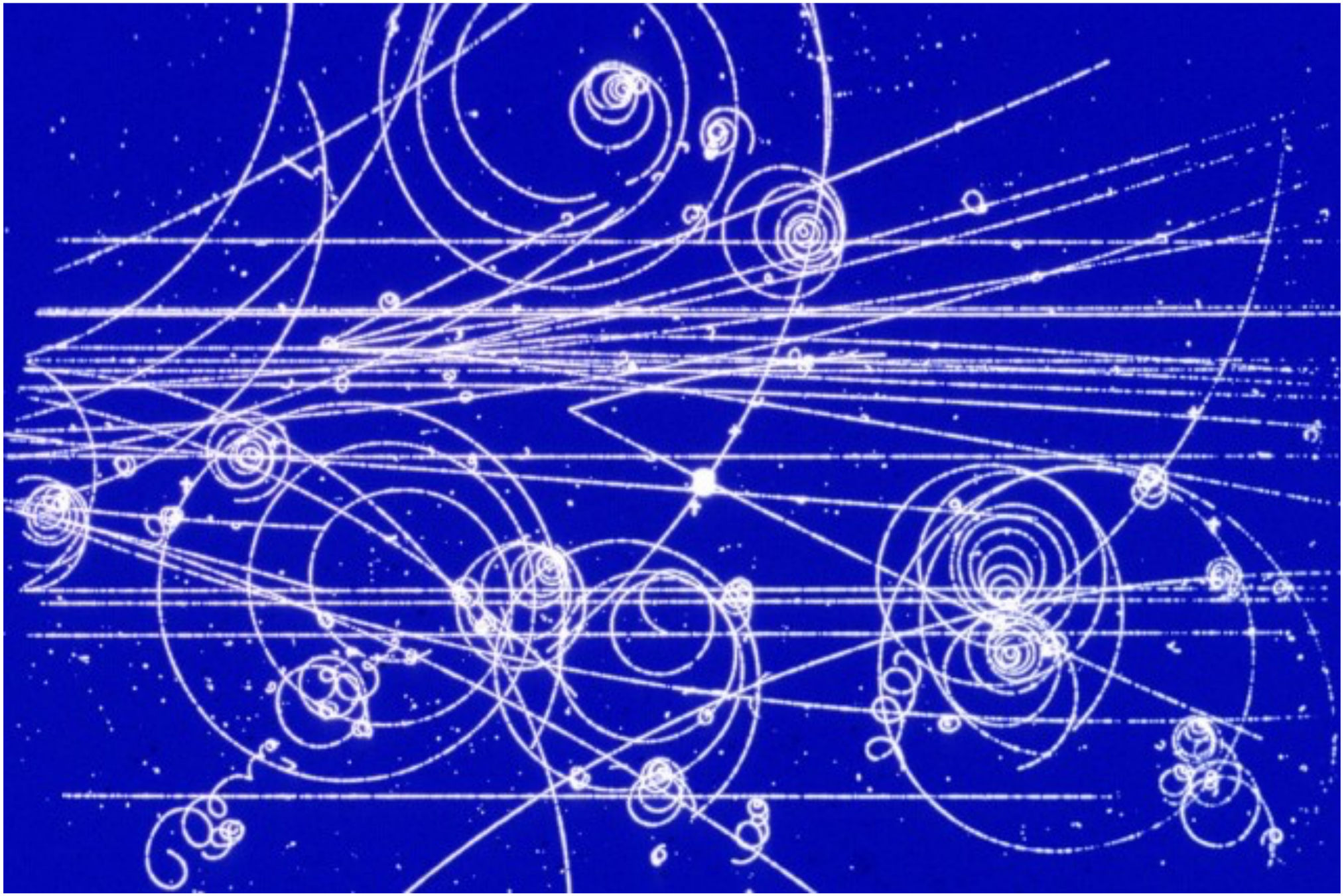
- urti tra particelle (o particelle-antiparticelle) accelerate (come?)

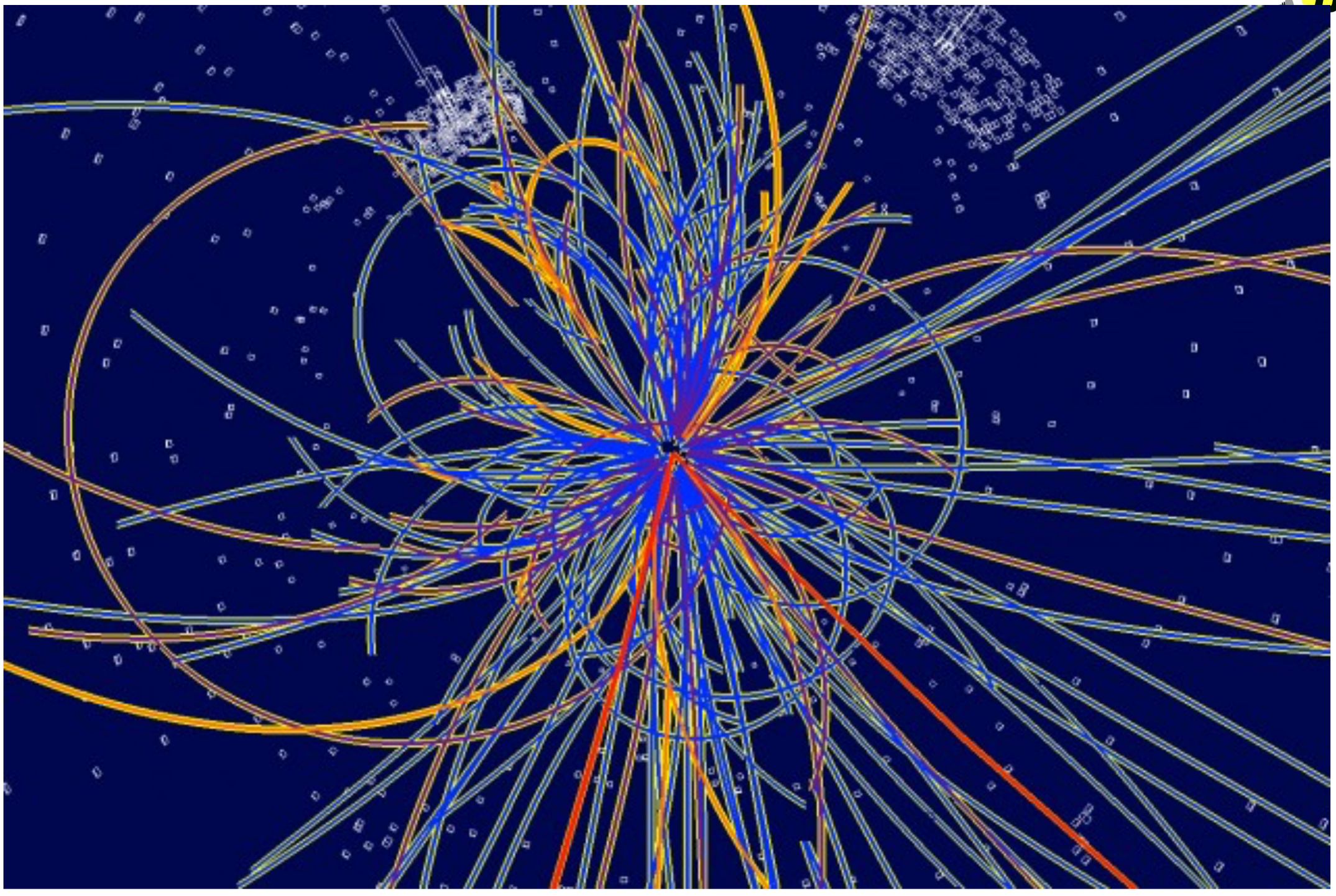
- traiettorie lineari o curve (come?)

- E=mc2 —> nuove particelle









avete mai letto

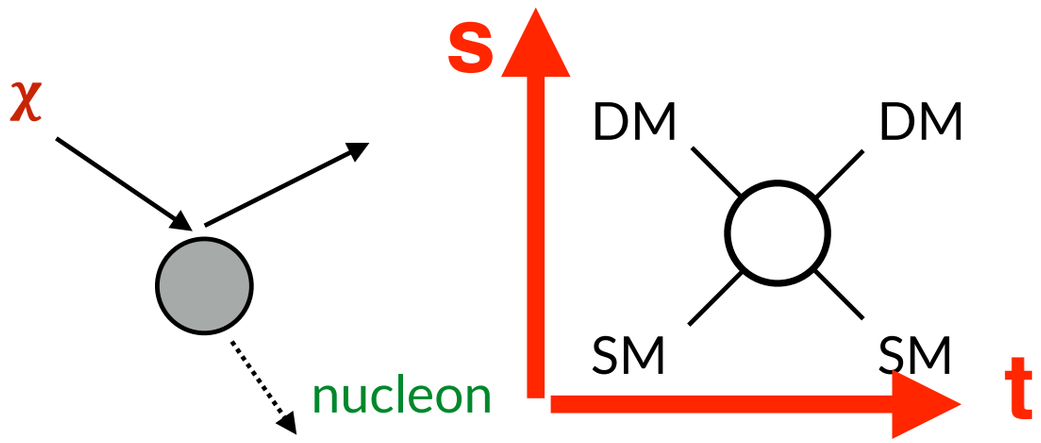
“il Tao della Fisica”?

leggete, leggete…

Perche’ usiamo gli anche gli acceleratori per rivelare la Materia Oscura e come?

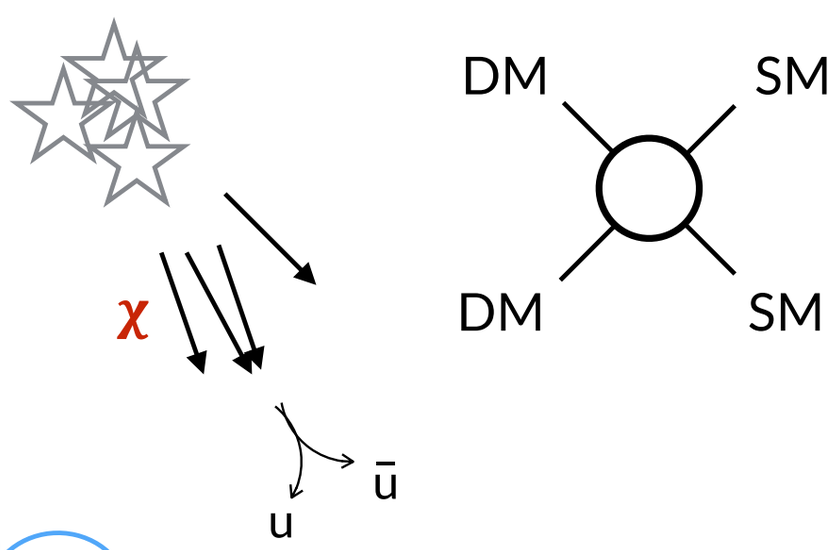
COME RIVELARE LA MATERIA OSCURA

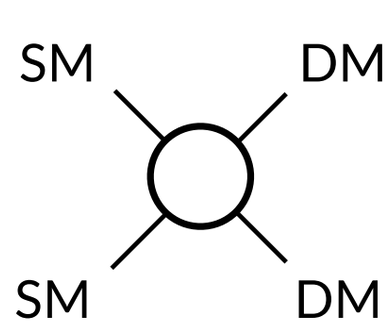
direct detection



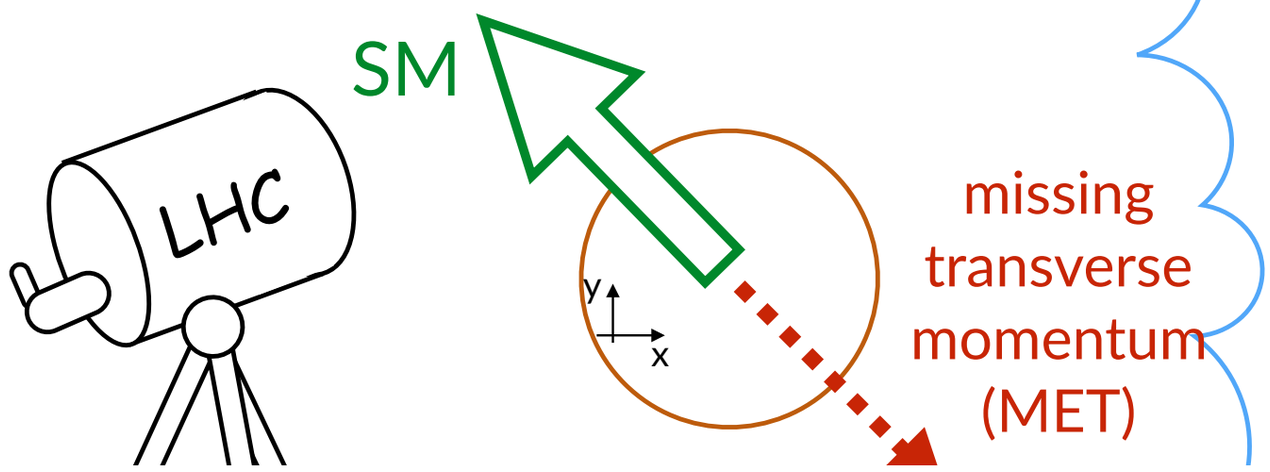
must know: nucleon form factors, DM local density, background levels…

indirect detection





must know: detector, reconstruction, SM backgrounds…



IL SETTORE NASCOSTO

Leading SM coupling to Neutral Hidden Sector

Portals

Scalar	Right-Handed neutrino	U(1)
$\mathcal{O}_s H^\dagger H$	$L H N_R$	$B_{\mu\nu} V^{\mu\nu}$

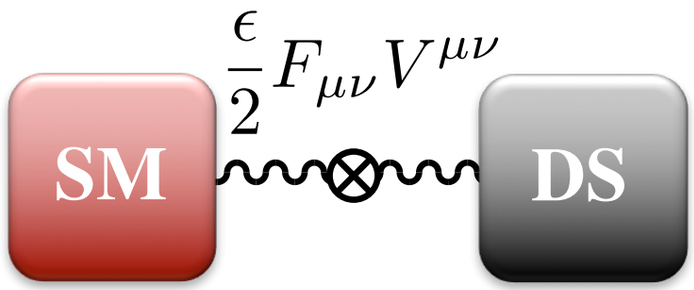
Partcelle del Settore Nascosto possono potenzialmente risolvere molti problemi aperti della Fisica delle Particelle come

Material oscura: WIMPs, assioni, neutrini sterili

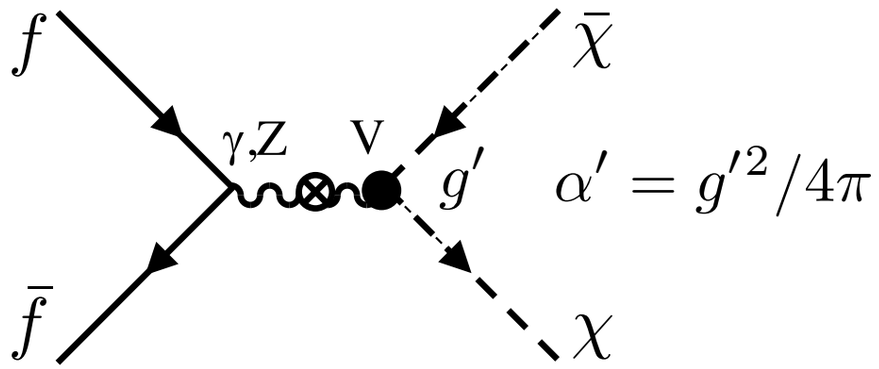
Bariogenesi: neutrini sterili

Masse dei neutrini attivi: neutrini sterili, see-saw

un esempio: IL PORTALE VETTORIALE

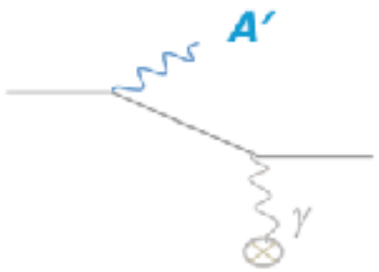


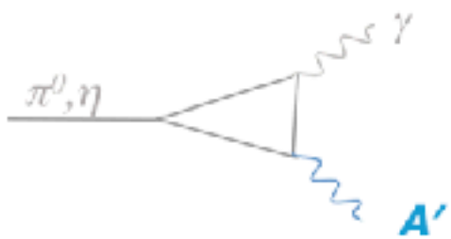
V e' il mediatore vettoriale (detto anche A o A') ed e' chiamato Dark (o Hidden) Photon e si mescola con il fotone con una probabilita' ϵ

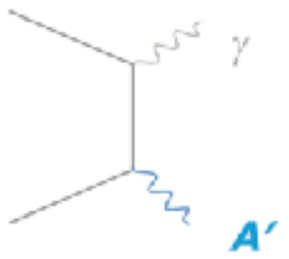


se ϵ e' piccolo e la massa di V e' piccola la vita media di V puo' essere molto lunga (decade dopo un lungo percorso)

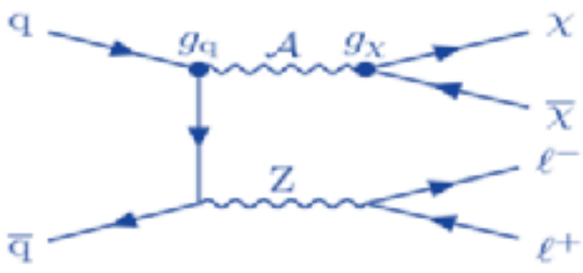
We use **electrons**, **positrons**, **protons**
(and also **muons**) in **fixed target** experiments

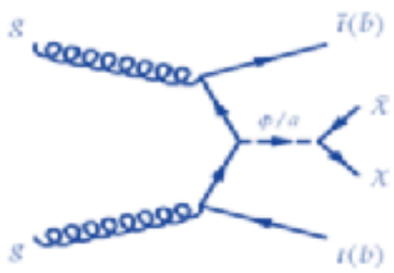






… as well as data from e^+e^-
and pp **collisions**





…

ogni diagramma che contiene un fotone
puo essere usato per produrre il fotone nascosto

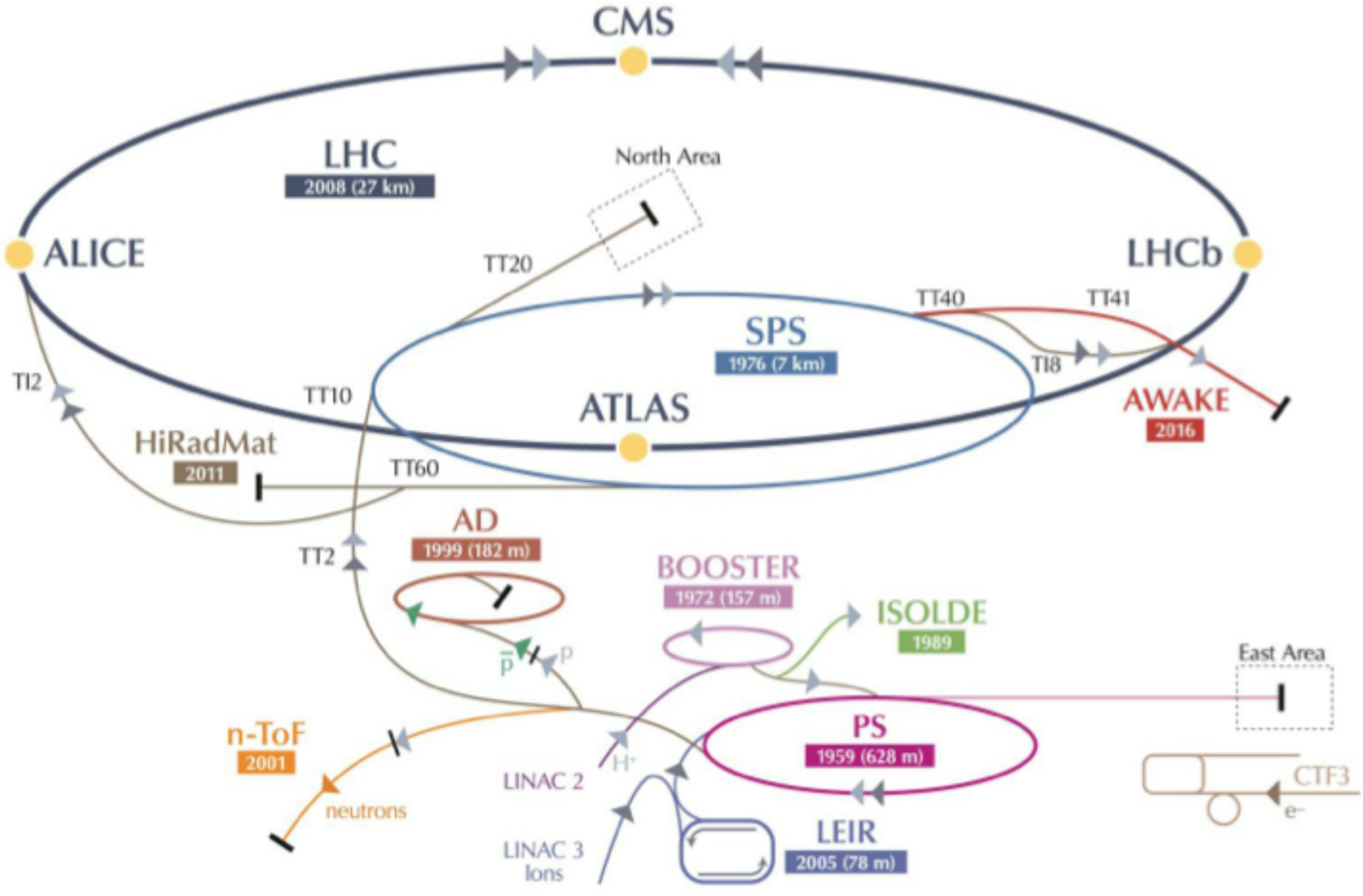
Map of facilities

+ LHC @ CERN

Time of facilities

+ LHC

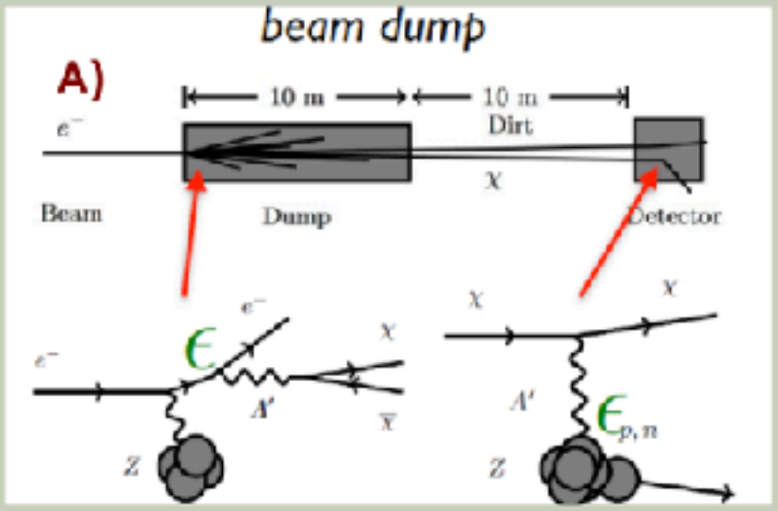

LHCb
ATLAS
CERN
SUISSE
FRANCE
SPS 7 km
ALICE
CMS
LHC 27 km



mappa degli acceleratori del CERN

Produzione e rivelazione di Materia Oscura

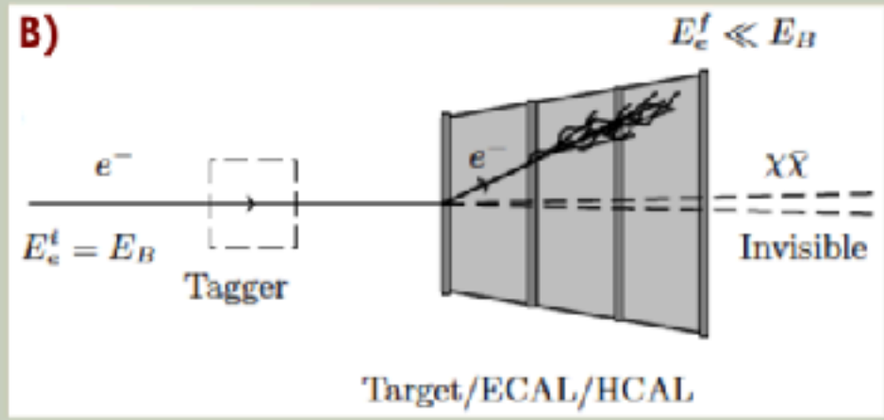
Positive evidence



$N \propto \varepsilon^4 \sim 10^{20}$ EOT (α_D and ε^2)

Negative evidence

Missing energy

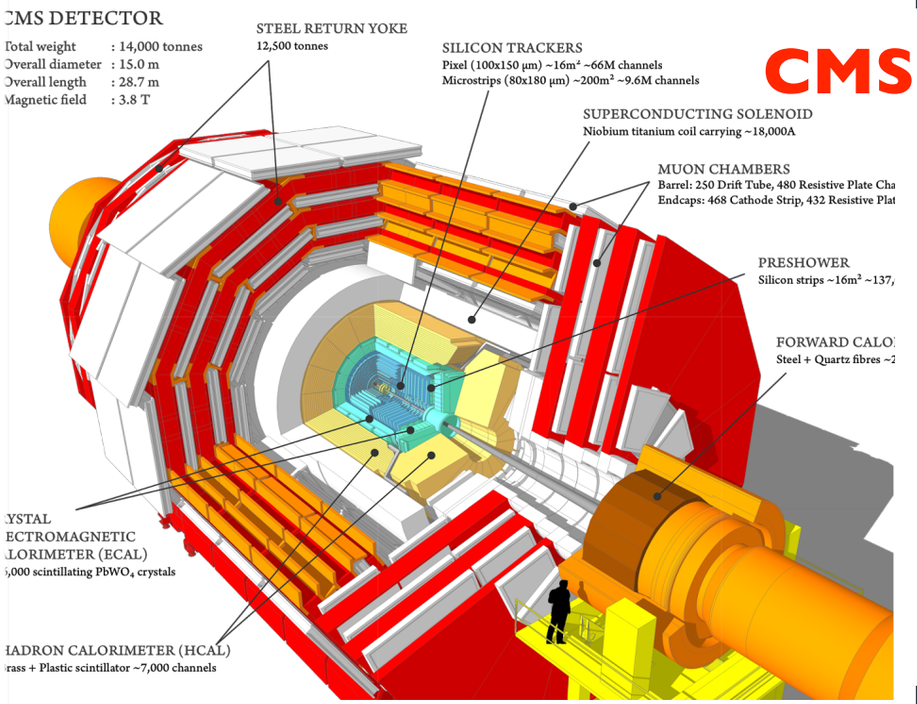


$N \propto \varepsilon^2$ (ε^2 only)

Come per la rivelazione diretta (vedi presentazione di Marco Razeti) si cerca una interazione della DM nel rivelatore

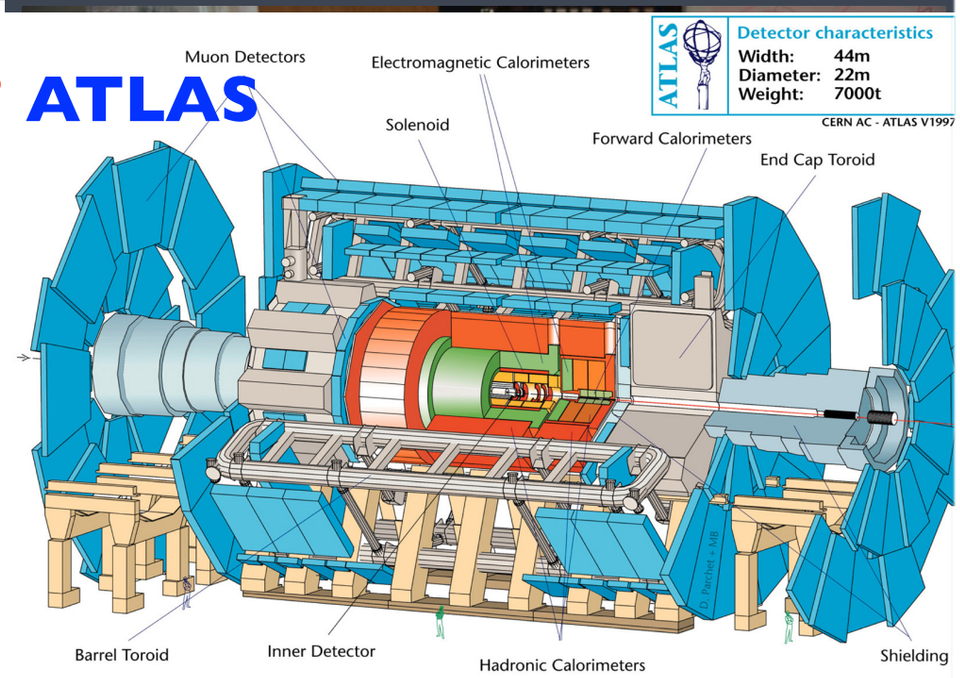
In questo caso invece ci si basa sulla cinematica dell'evento ricostruendo solo le particelle standard e utilizzando le leggi di conservazione dell'impulso e dell'energia

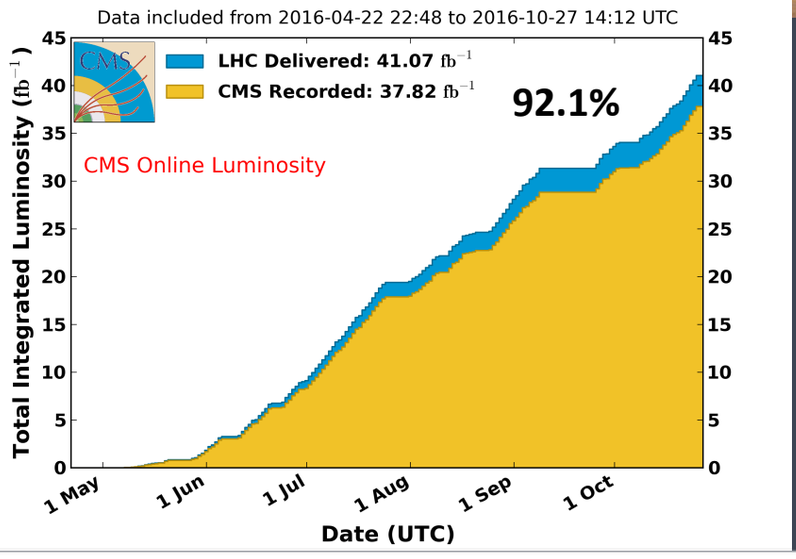
EXPERIMENTAL SETUP

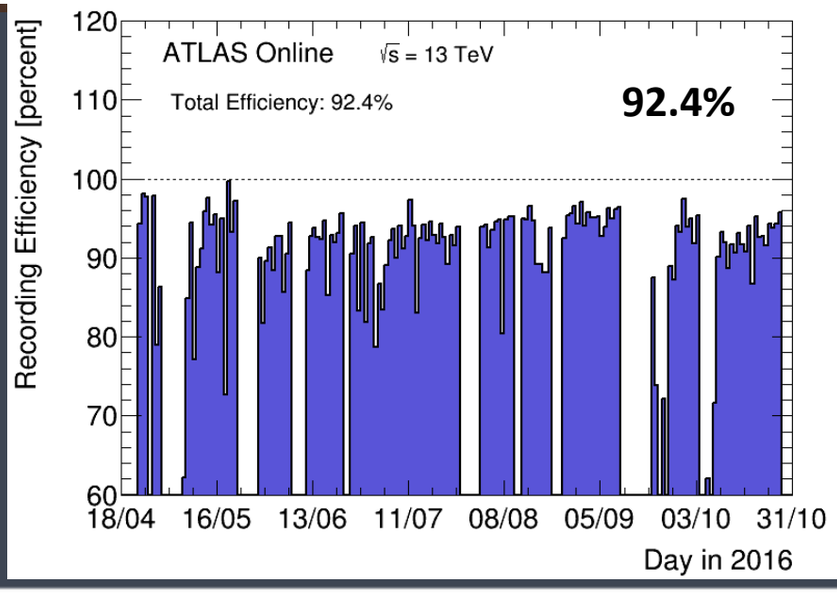


CMS

ATLAS







MISURE A LHC

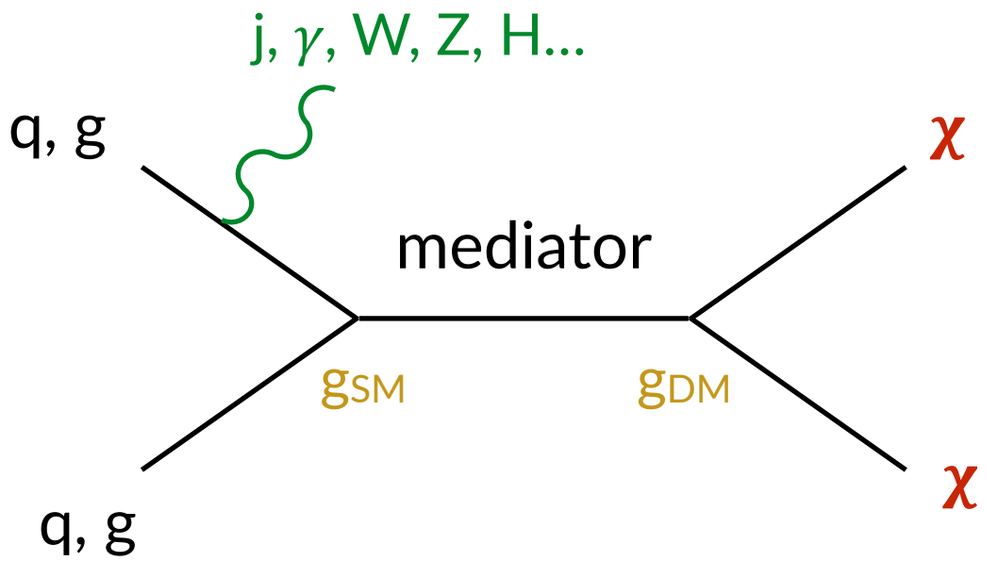
In questo caso ci si basa sulla cinematica dell'evento nel piano ortogonale ai fasci

MONO-X

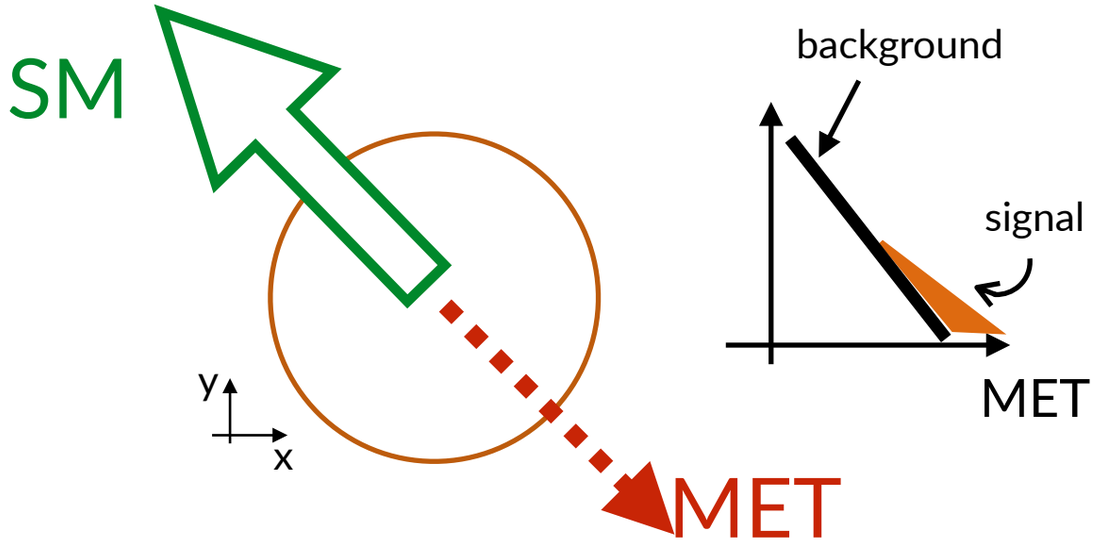
e.g.: Z'-like mediator, s-channel, tagging object from ISR

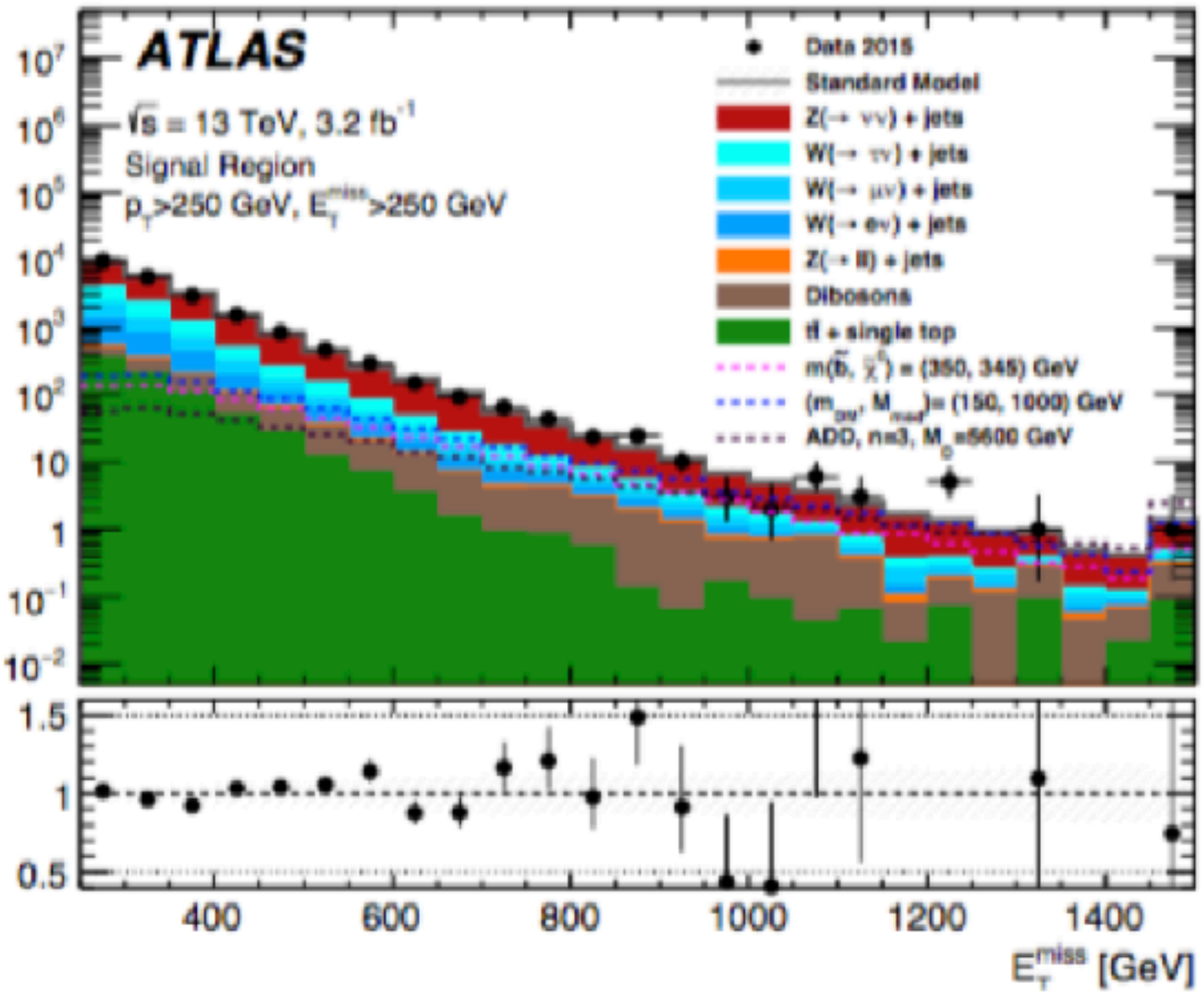
but also: $\chi\chi$XX interactions, t-channel...

what happens



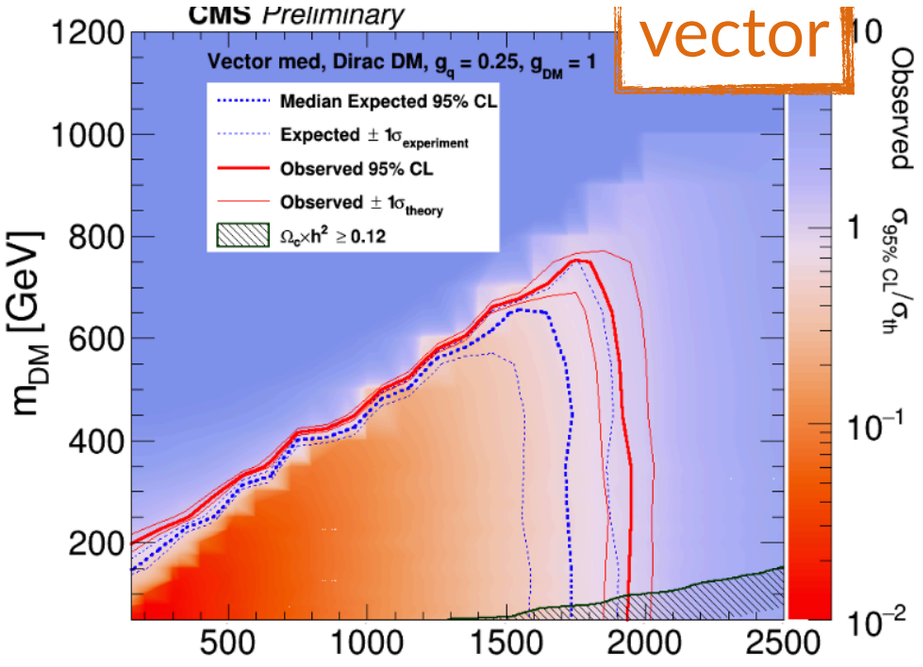
what we see

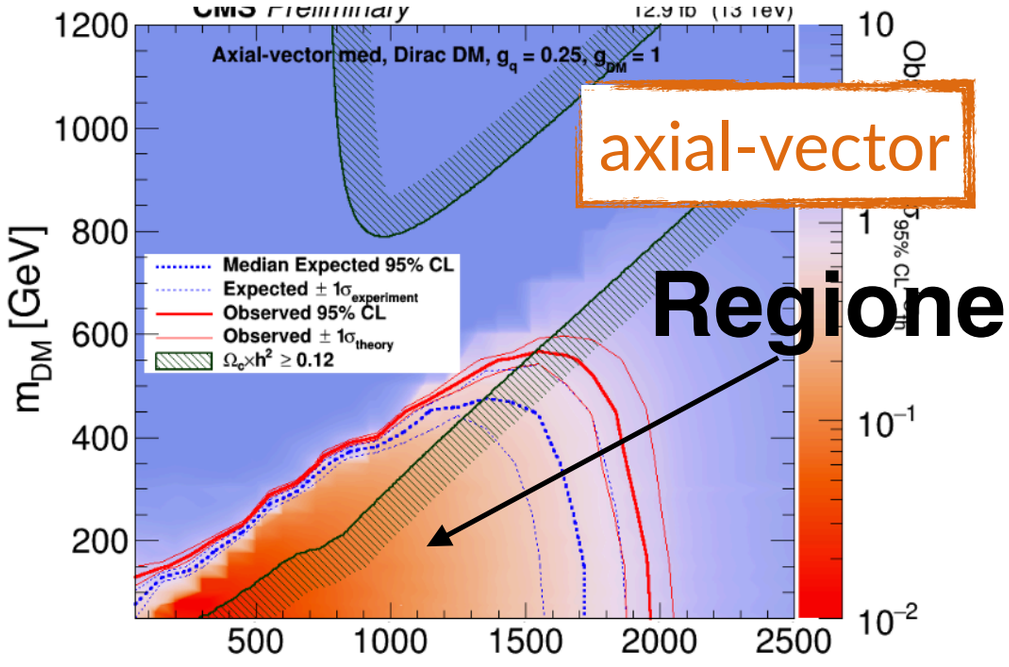




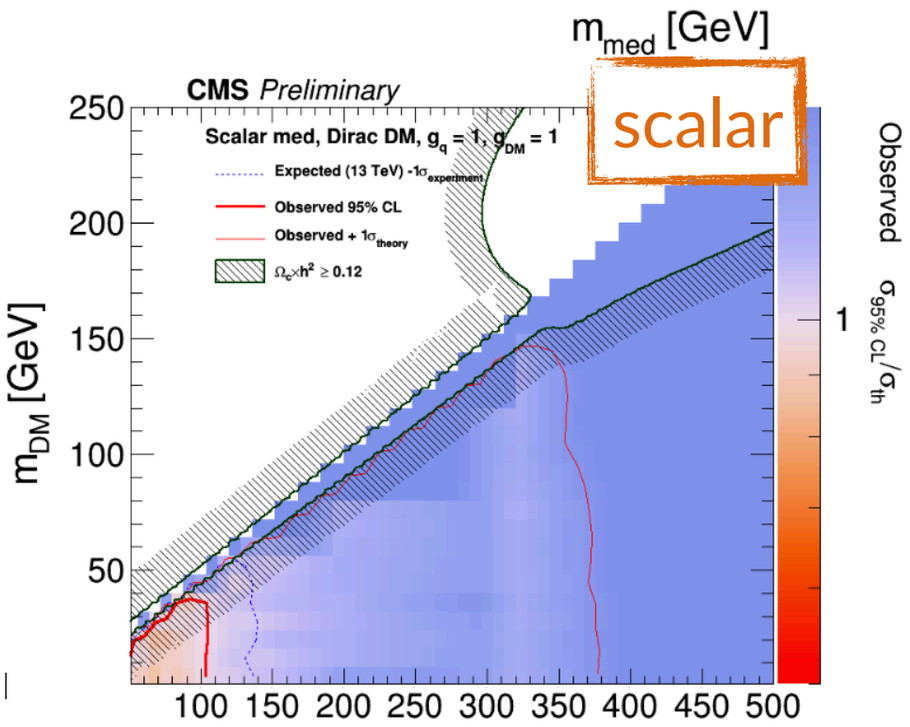
un esempio di grafico sperimentale

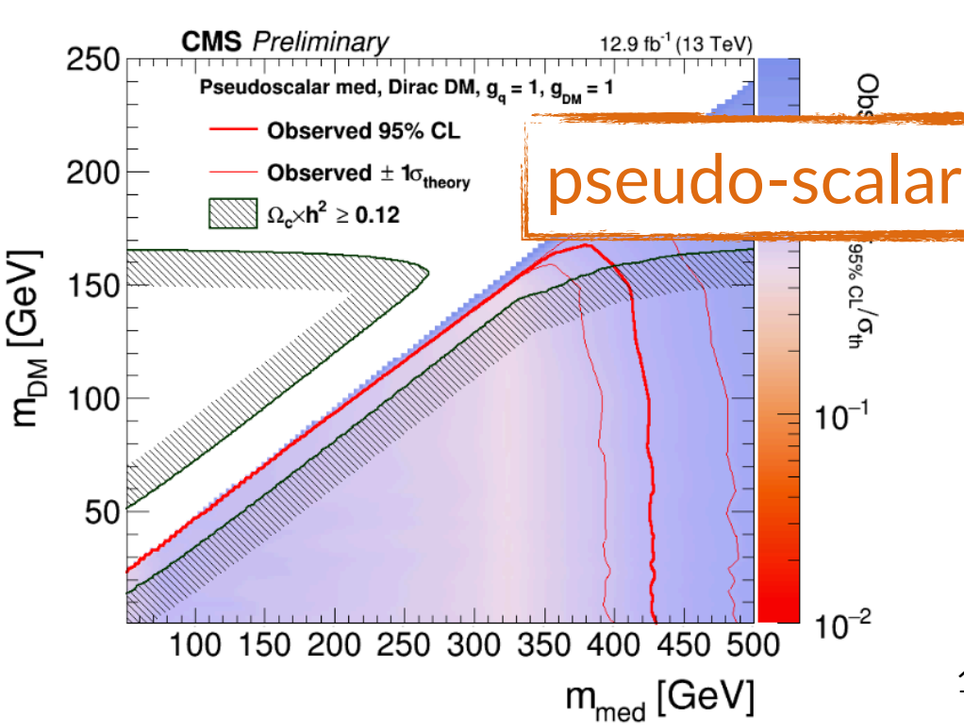
Diversi mediatori possibili





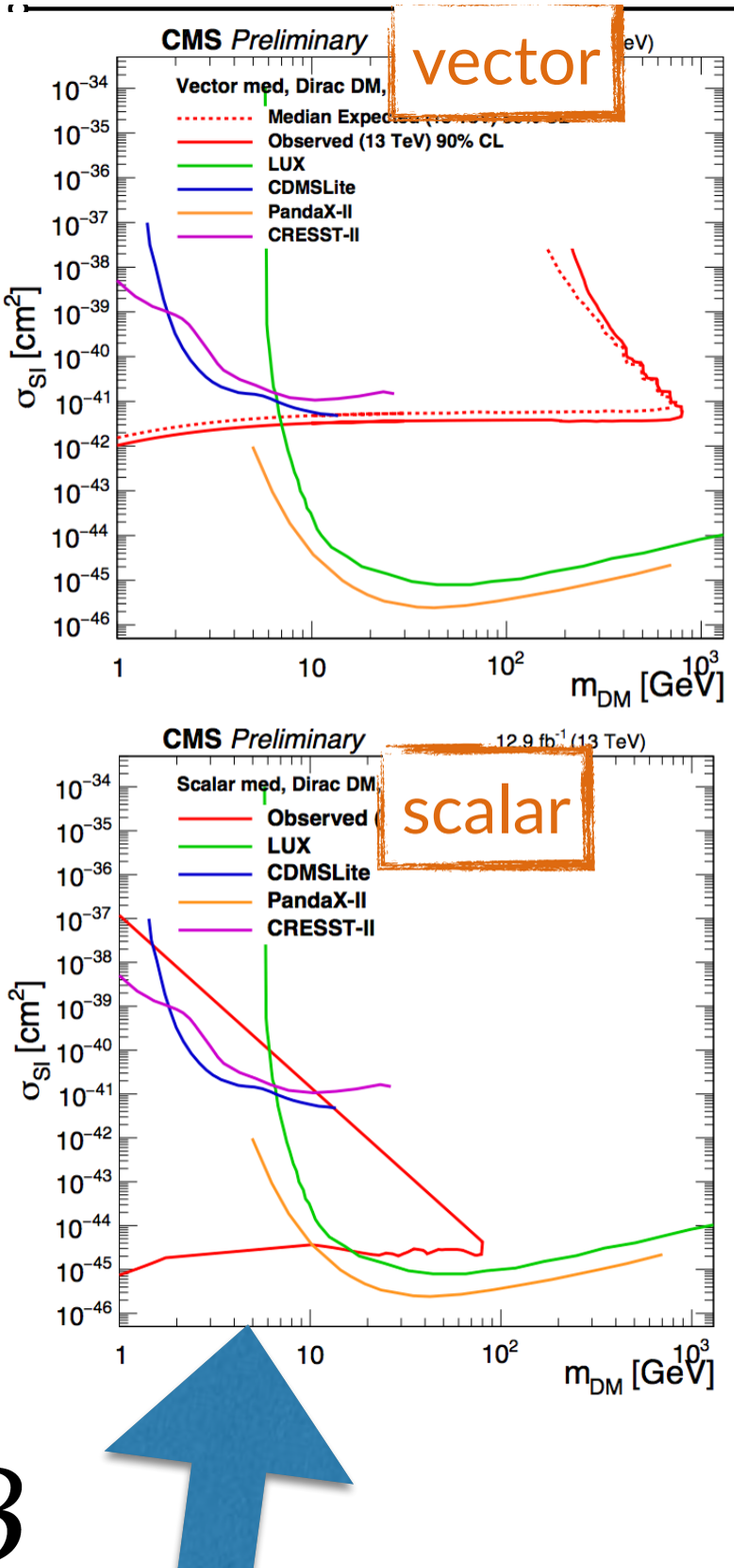
Regione esclusa

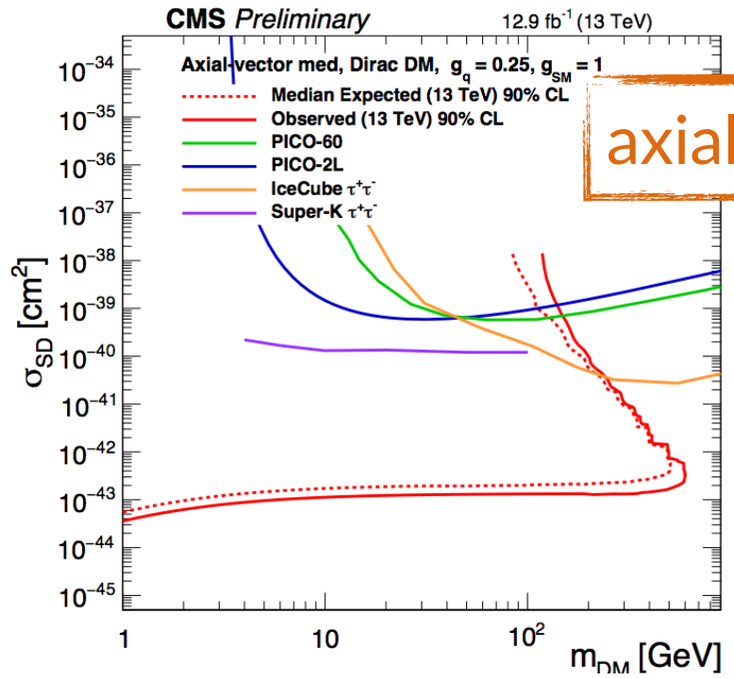




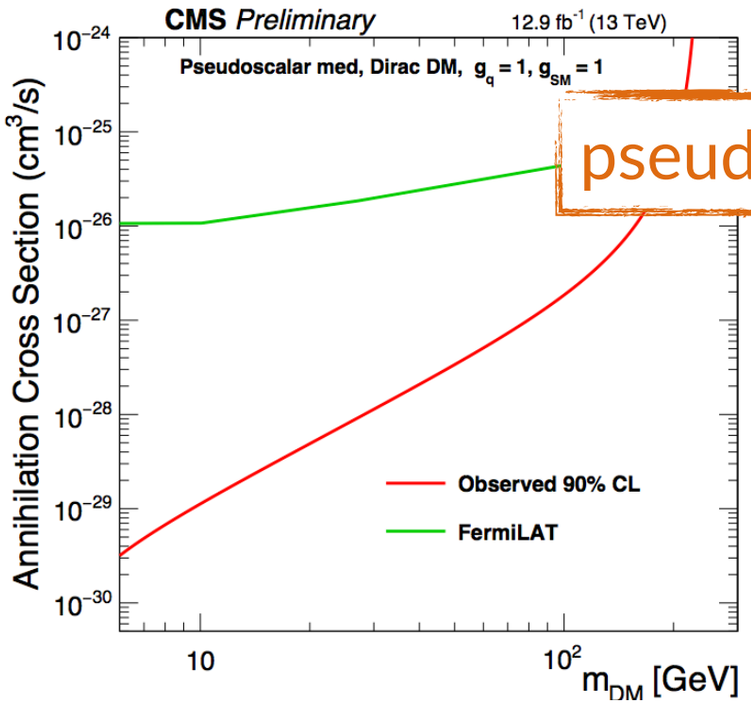
Dark matter fermionica: ϵ assunta grande —>vita media 0

Confronto con le ricerche dirette





algorithm:
1) choose couplings
2) look for excess
3) use low-q^2 approx to convert exclusion into DM-nucleon scattering x-sec



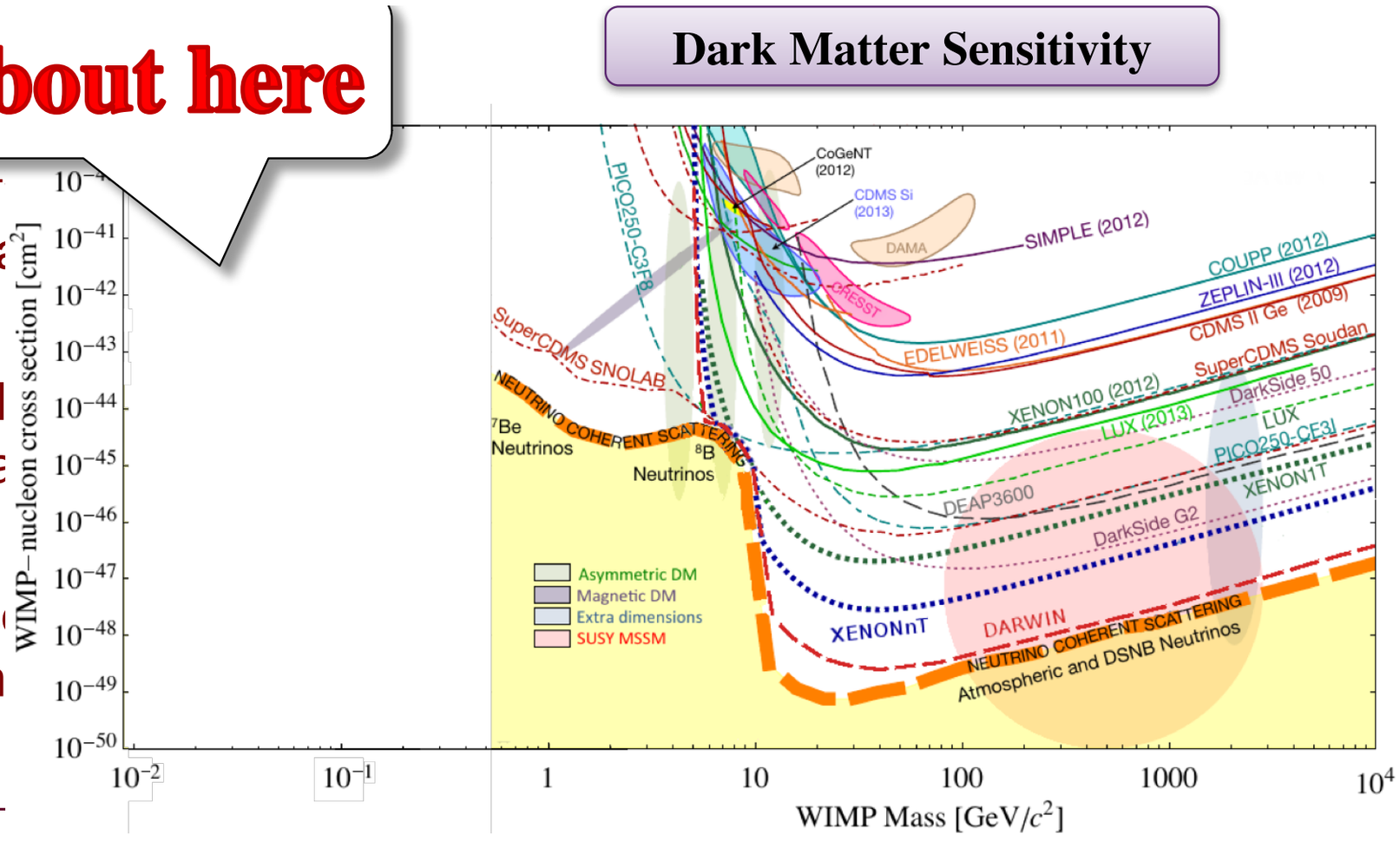
Q - can we use other constraints to limit the parameter space we need to probe?

Per masse basse dove le ricerche dirette non sono sensibili???? serve “boost”

What about here

sections (10-
correct relic a

- Conflicting cl
  ruled out pha
- A rich dark s
  bypasses “m



Acceleratori per la ricerca di Materia Oscura per masse tra MeV e GeV

Existing accelerators

- CEBAF & LERF@JLAB
- DAΦNE LINAC
- SPS extracted beams@CERN

- Colliders:

DAΦNE, LHC, SuperKEKB, BES-III

Approved new accelerators

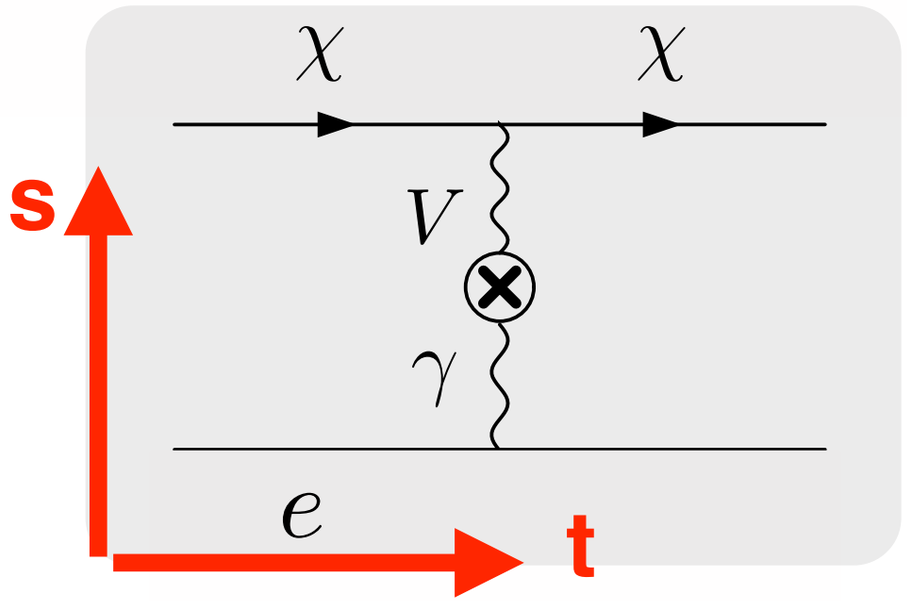
– MESA@Mainz

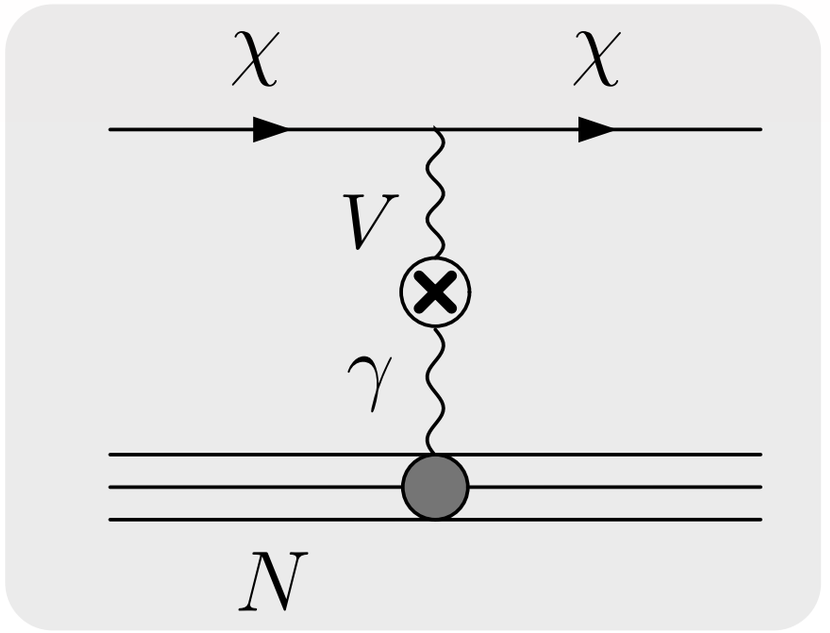
Proposed accelerators **upgrades**

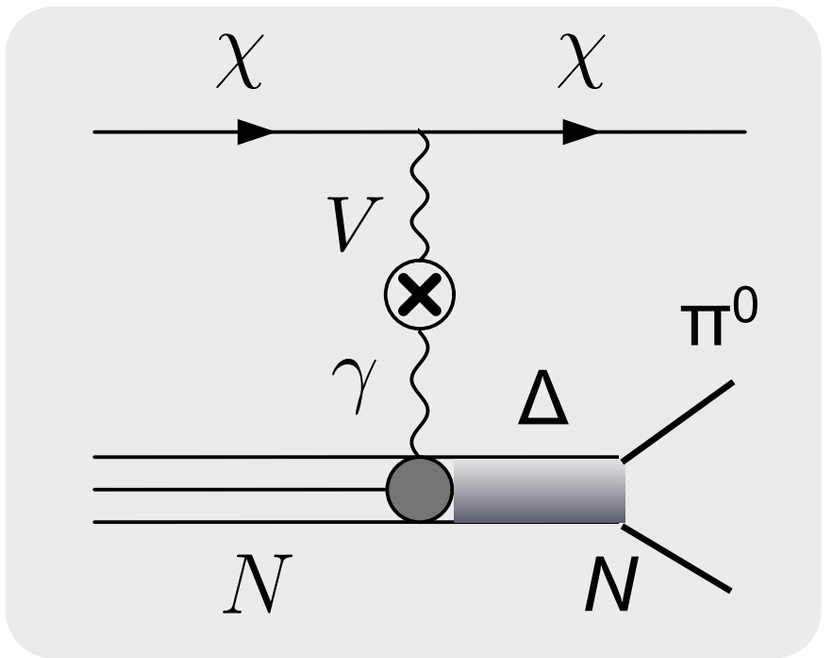
– DASEL@SLAC
– BDF@CERN (SHiP)
– Positrons from Synchrotron@Cornell
– VEPP-3 bypass
– Positrons from DAΦNE ring?

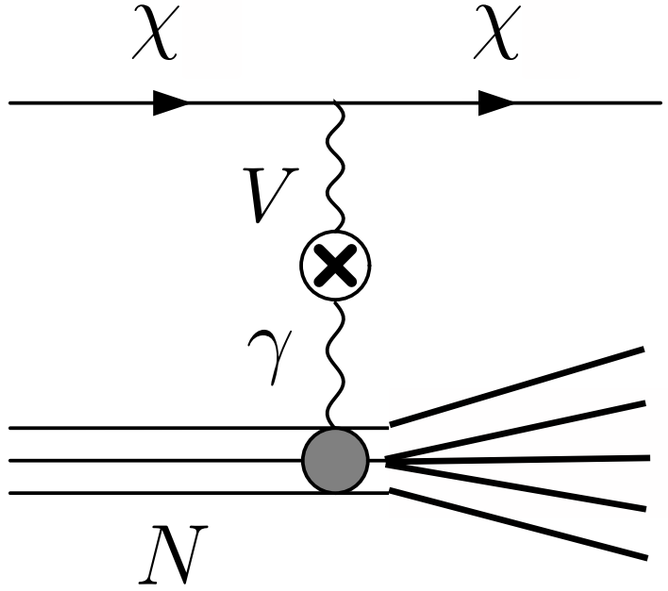
Esperimenti con la rivelazione diretta

Interazione della Materia Oscura nei rivelatori







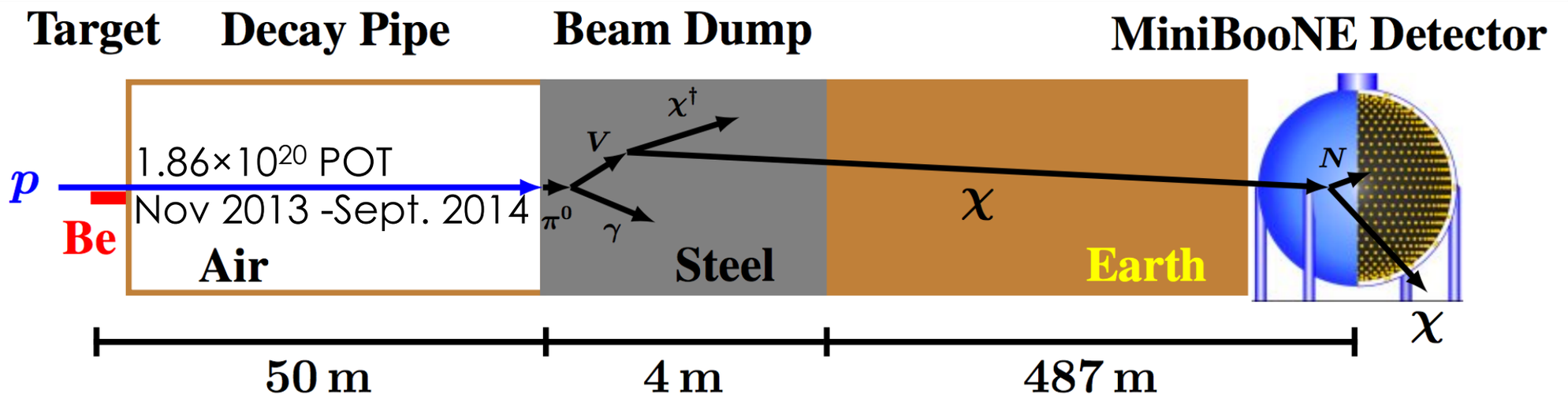


Mimics scattering of neutrinos, which provide dominant background[13]


ASTA
Advanced Superconducting
Test Accelerator
Test-Beam and
Fixed-Target Beamlines
Muon
Complex
Linac and
Booster
Project X
(under construction)
MINOS-NOvA
To Minnesota
LBNE (under construction)
To South Dakota
Booster
Neutrino
Beam

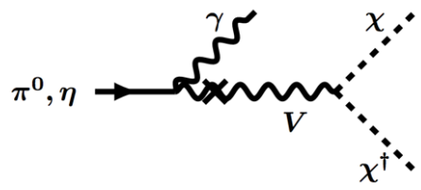
Fermilab

MiniBooNE at Fermilab

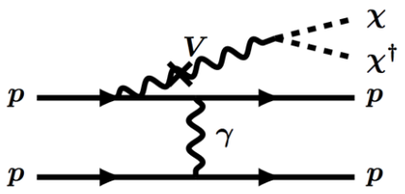


Production ($O(\epsilon^2 g_D)$)

Neutral-Meson Decay

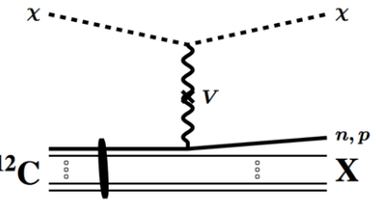


Proton Bremsstrahlung

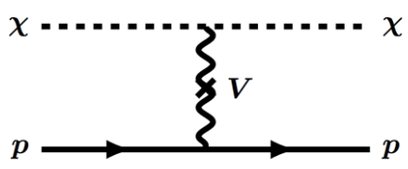


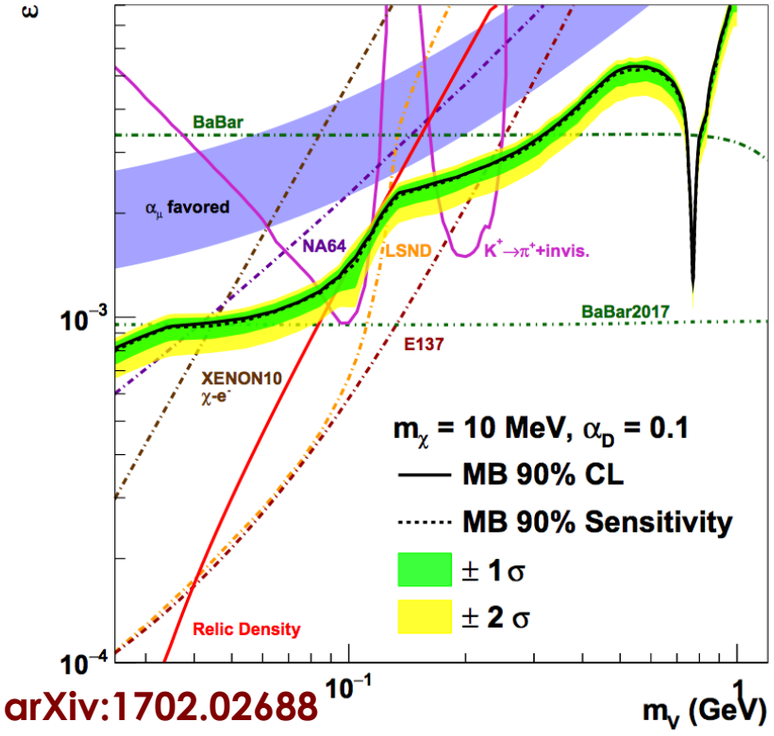
Detection ($O(\epsilon^2 g_D)$)

Elastic Bound Nucleon

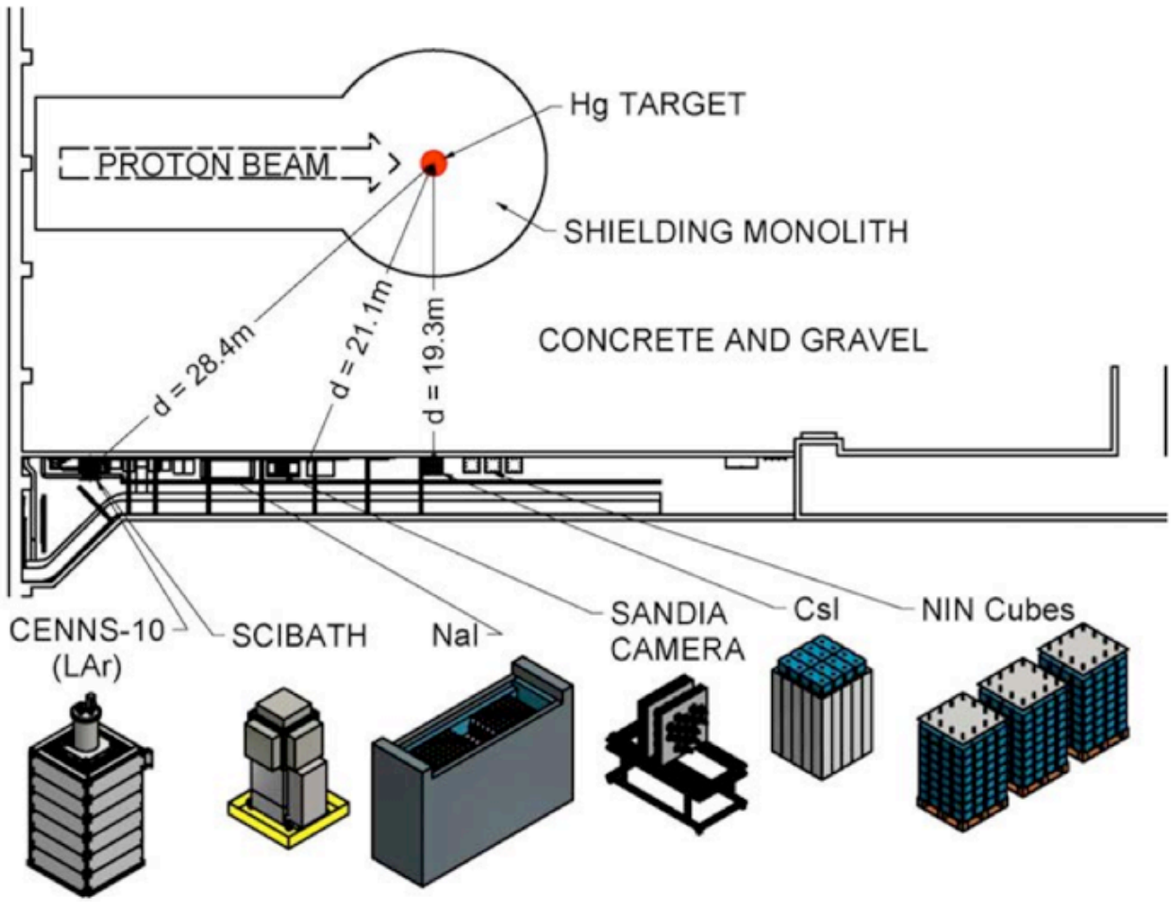


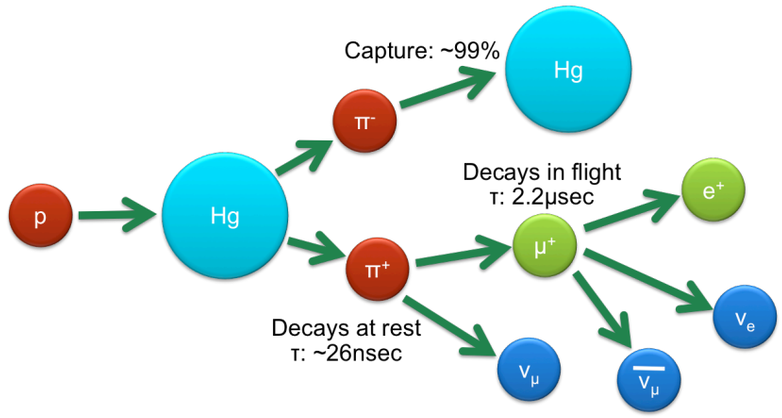
Elastic Free Nucleon





arXiv:1702.02688

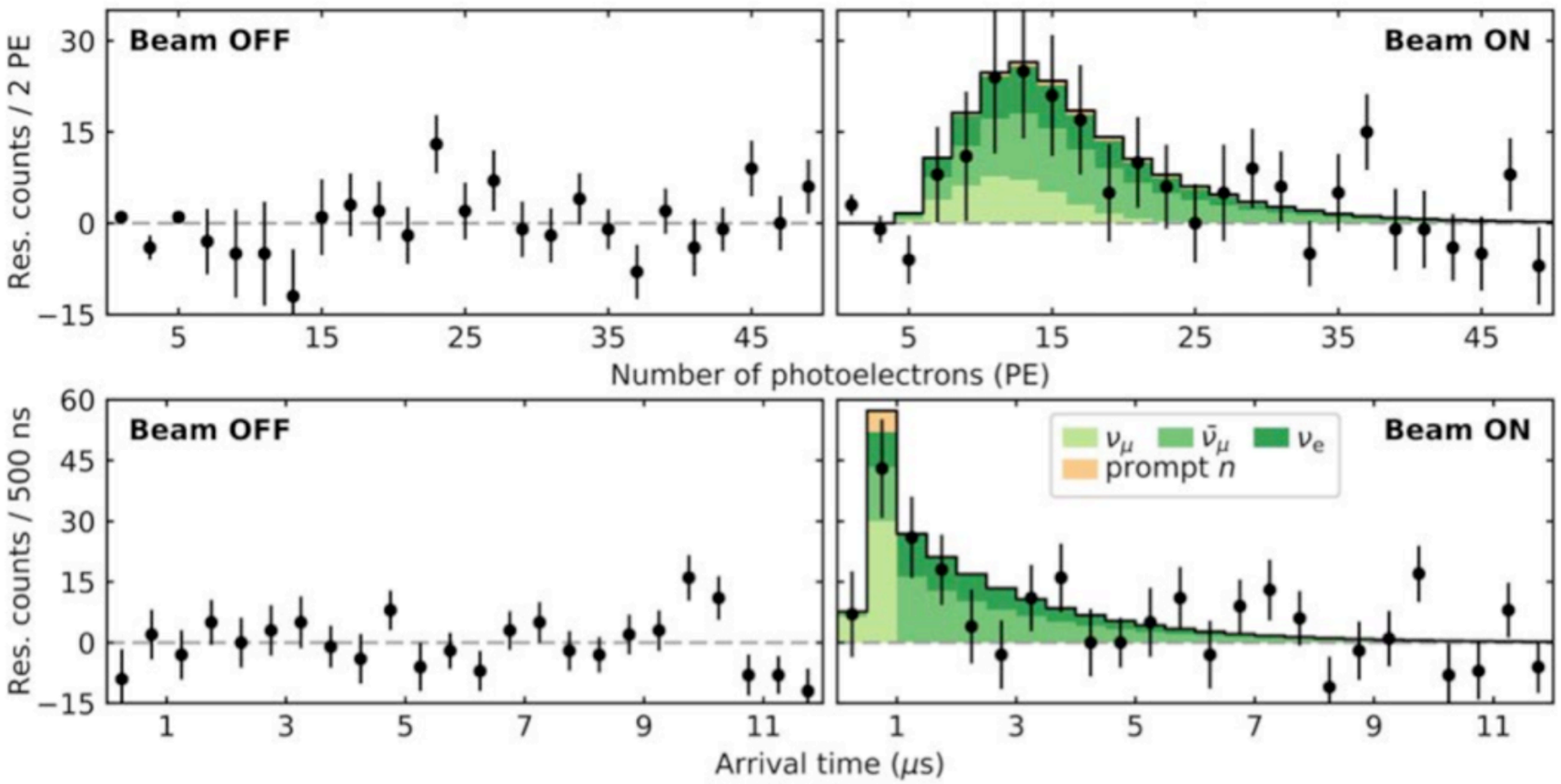




Esperimento COHERENT alla SNS a Oak-Ridge

COHERENT (SNS)

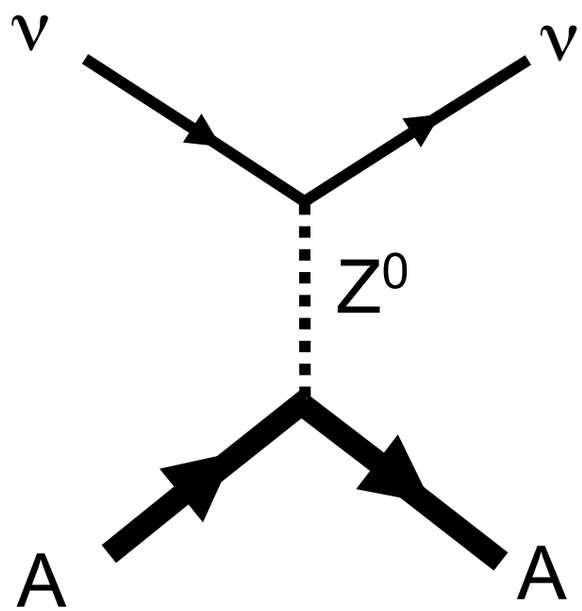
Recent detection of coherent ν scattering, consistent with the SM allows constraints to be set on any new contributions

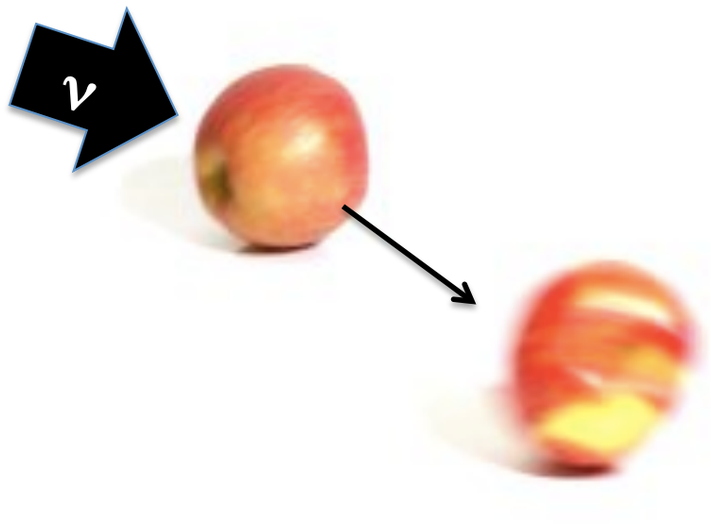


Coherent elastic neutrino-nucleus scattering (CEvNS)

$$\nu + A \rightarrow \nu + A$$

A neutrino smacks a nucleus via exchange of a Z, and the nucleus recoils as a whole; **coherent** up to $E_\nu \sim 50$ MeV



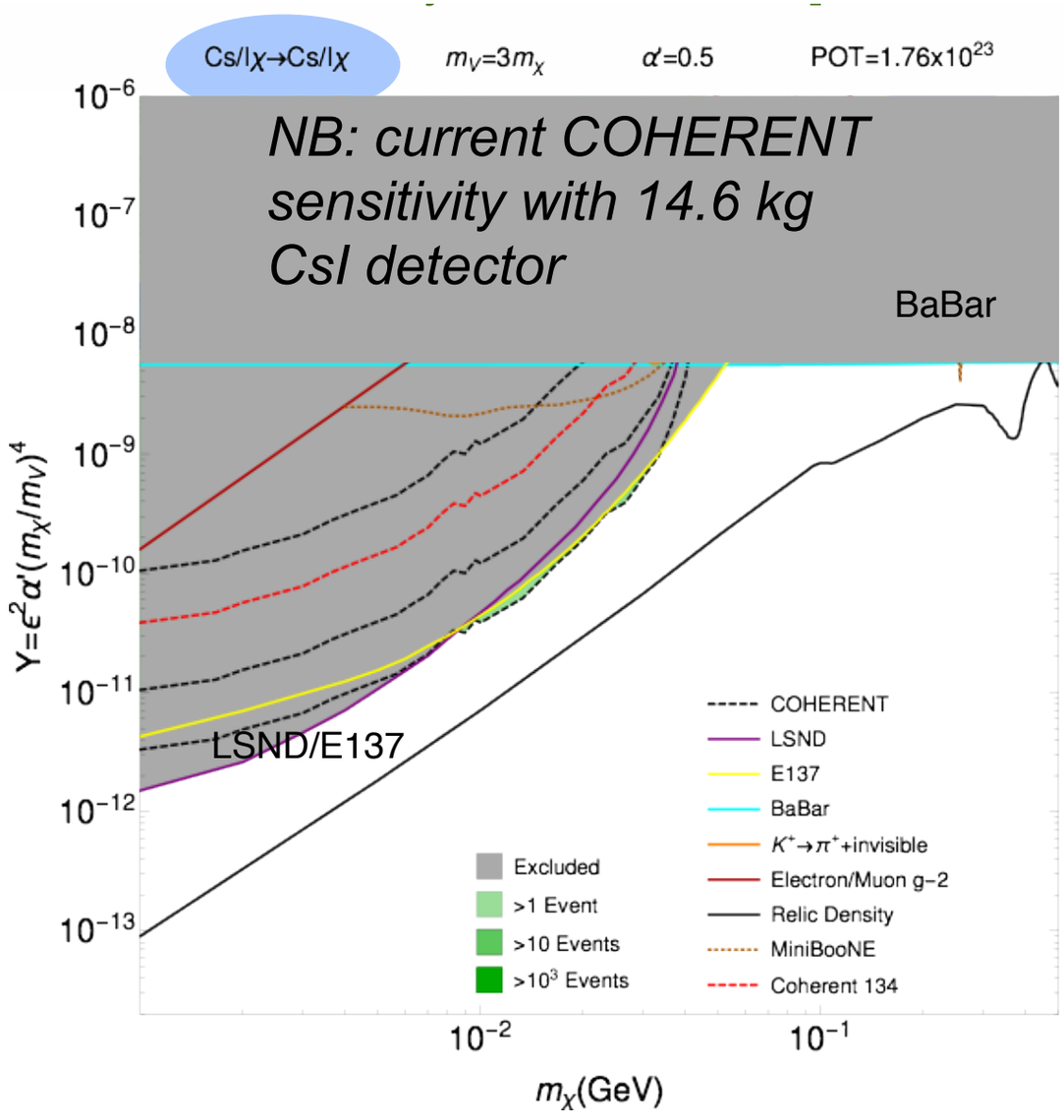


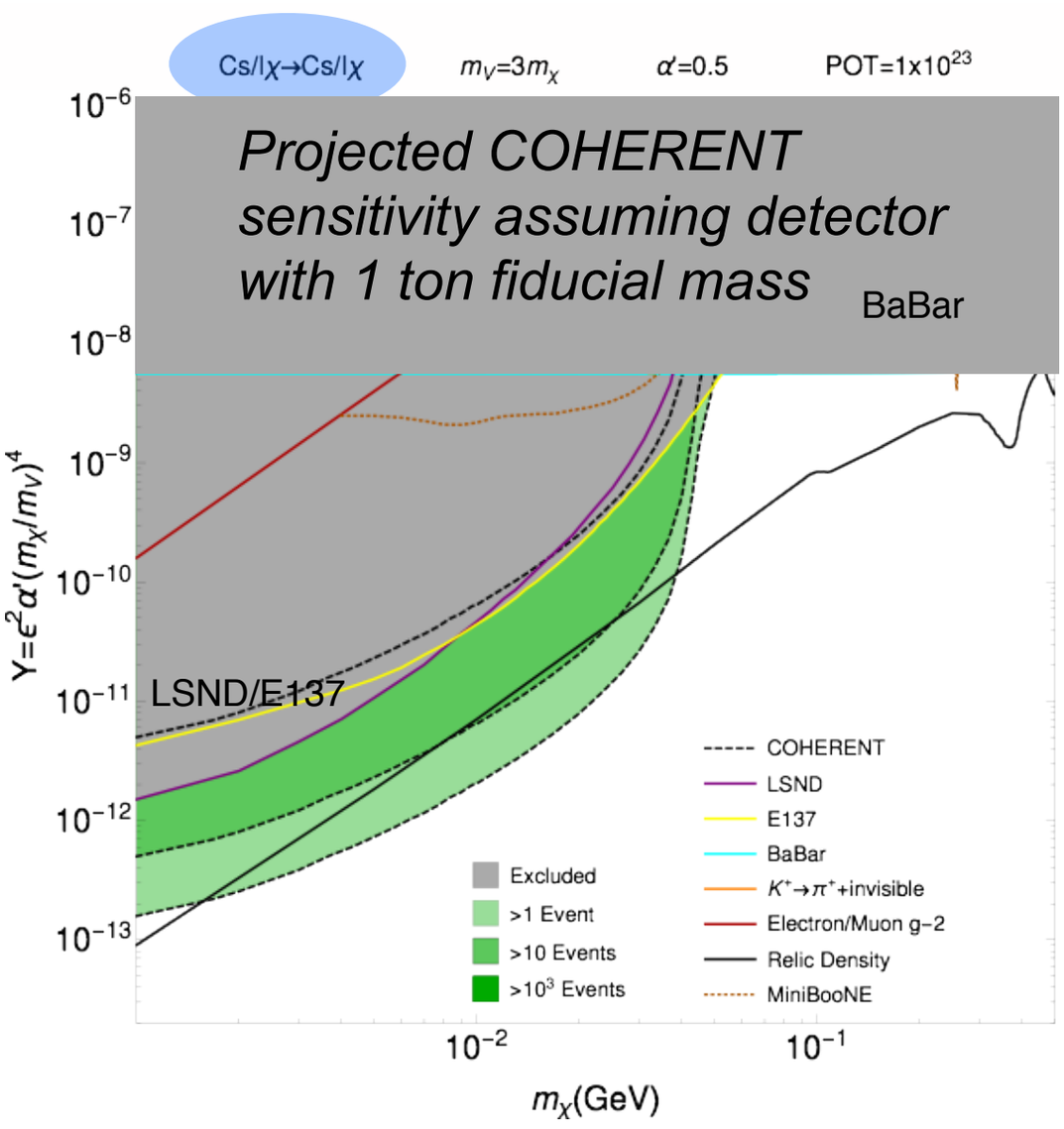
Nucleon wavefunctions in the target nucleus are **in phase with each other** at low momentum transfer

$$\frac{d\sigma}{d\Omega} \sim A^2 |f(\mathbf{k}', \mathbf{k})|^2$$ Momentum transfer $$\mathbf{Q} = \mathbf{k}' - \mathbf{k}$$

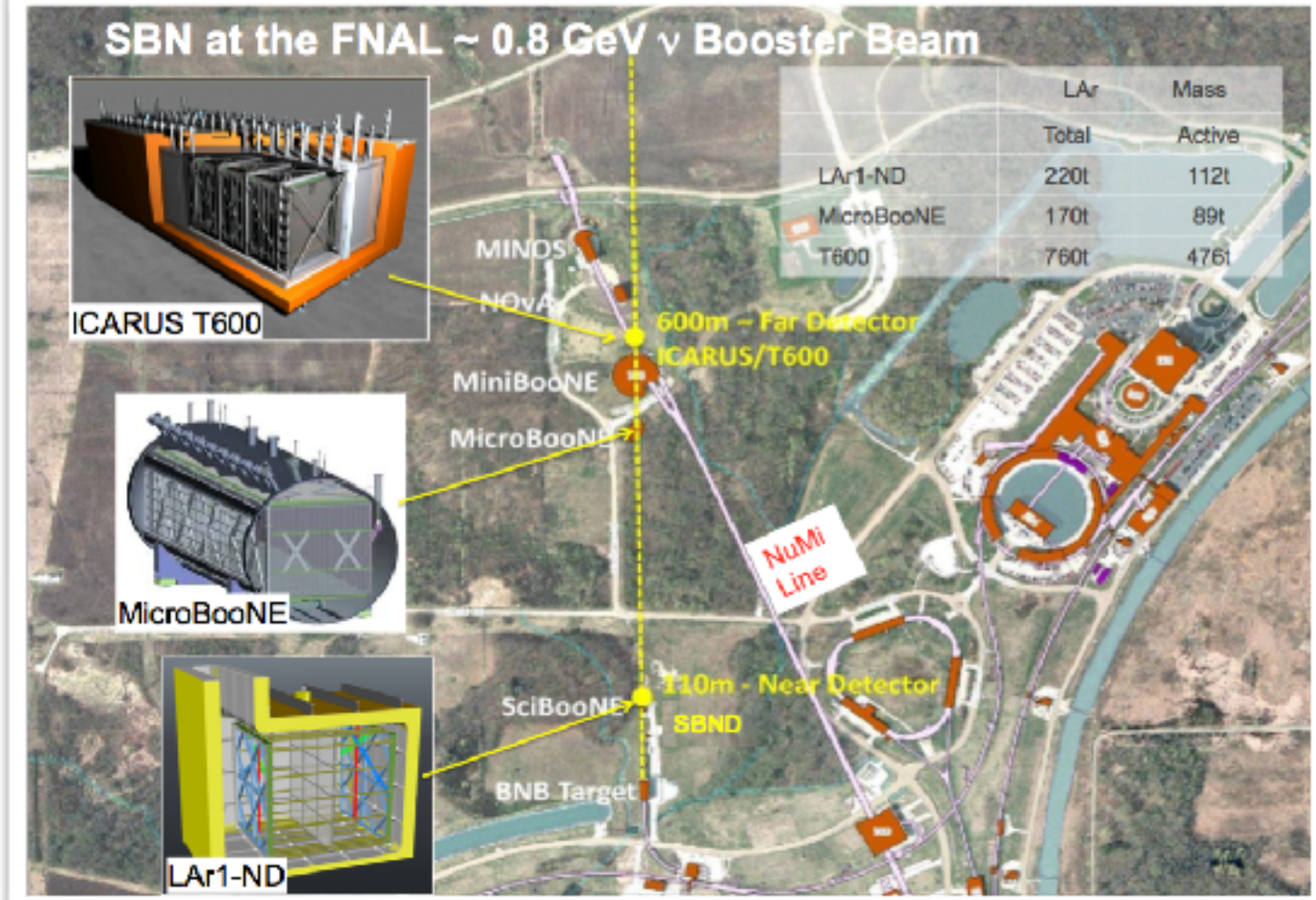
For $QR << 1$,

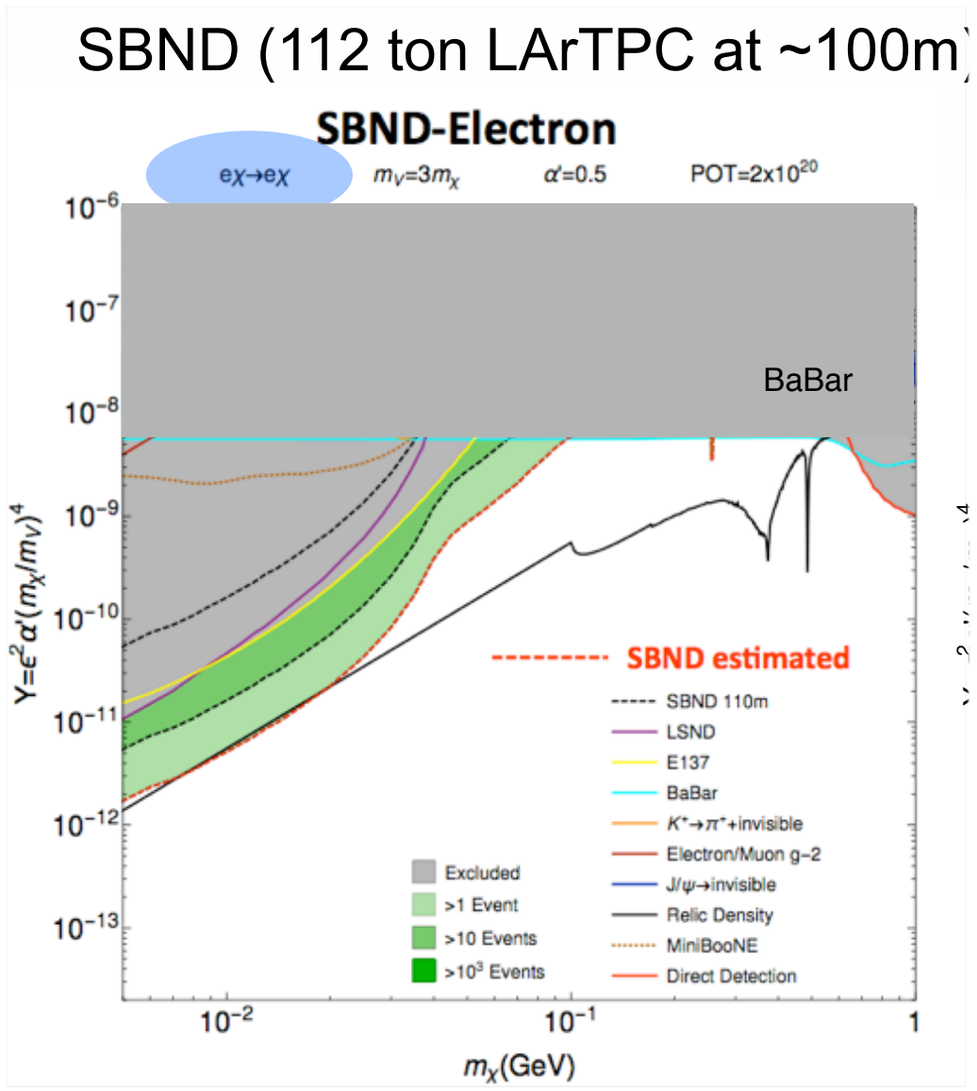
[total xscn] ~ A^2 * [single constituent xscn]


Cs/Iχ→Cs/Iχ
m_V=3m_χ
α'=0.5
POT=1.76x10^{23}
NB: current COHERENT sensitivity with 14.6 kg CsI detector
BaBar
LSND/E137
COHERENT
LSND
E137
BaBar
$K^+\to\pi^+$+invisible
Electron/Muon g−2
Relic Density
MiniBooNE
Coherent 134
Excluded
>1 Event
>10 Events
>10^3 Events
$Y=\epsilon^2\alpha'(m_\chi/m_V)^4$
m_χ(GeV)

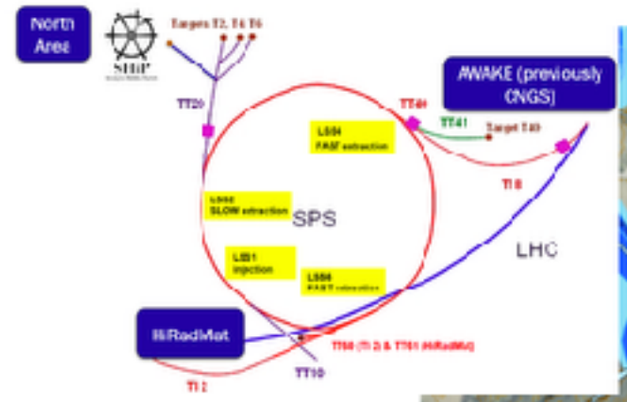

Cs/Iχ→Cs/Iχ
m_V=3m_χ
α'=0.5
POT=1x10^{23}
Projected COHERENT sensitivity assuming detector with 1 ton fiducial mass
BaBar
LSND/E137
COHERENT
LSND
E137
BaBar
$K^+\to\pi^+$+invisible
Electron/Muon g−2
Relic Density
MiniBooNE
Excluded
>1 Event
>10 Events
>10^3 Events
$Y=\epsilon^2\alpha'(m_\chi/m_V)^4$
m_χ(GeV)

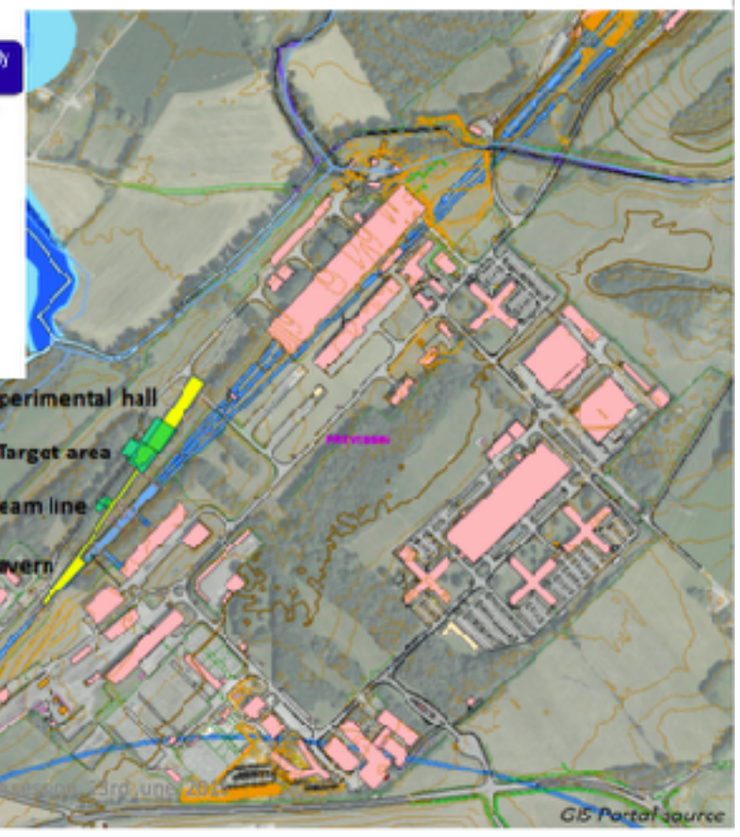
Progetti in costruzione: SBND





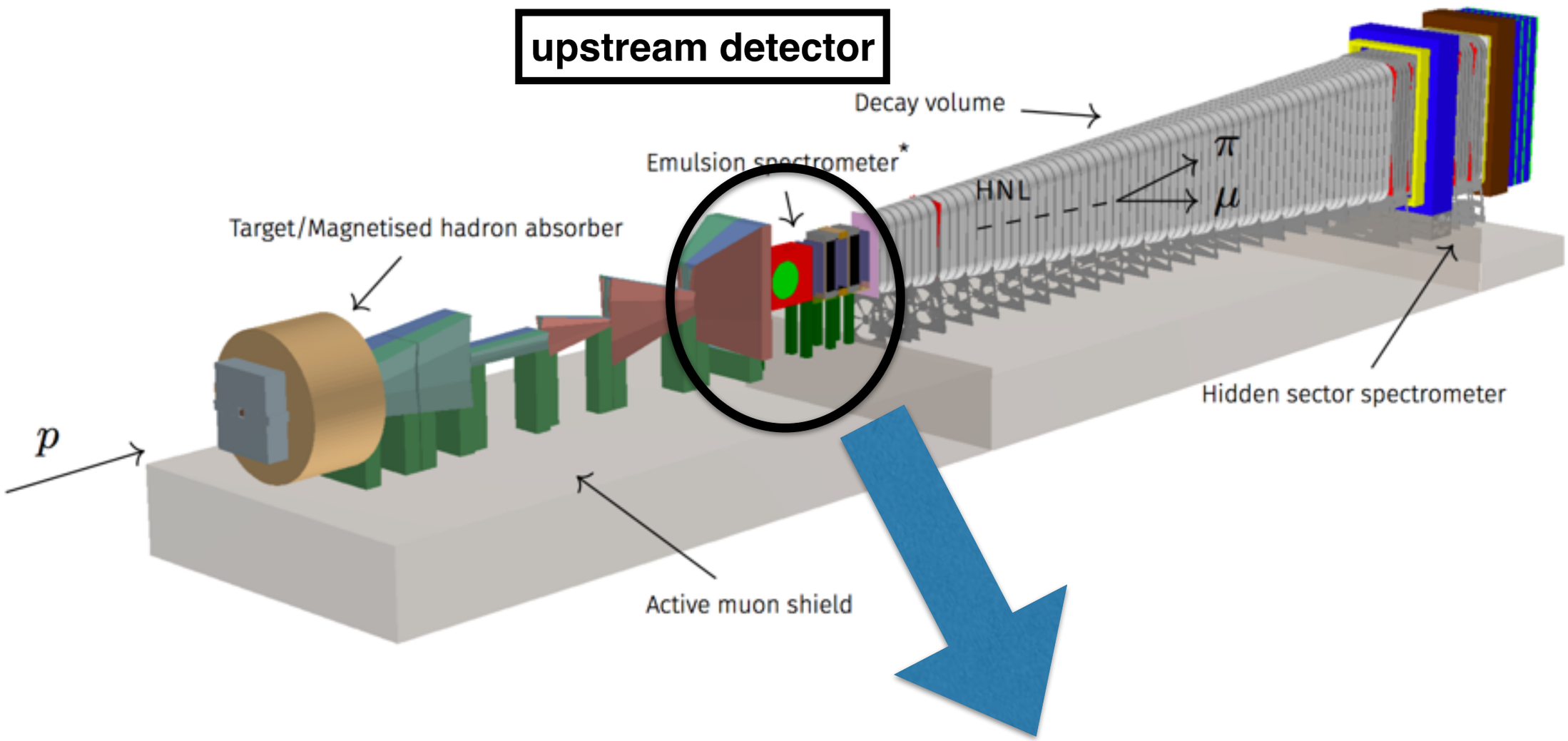
SHiP is a PROTON BEAM DUMP experiment proposed at CERN with the SPS p beam of 400GeV with $2x10^{20}$pot/5 years





The SHiP facility is located on the North Area, and shares the TT20 transfer line and slow extraction mode with the fixed target programmes

It would make good use of the full SPS intensity that, apart from the ~2fill/day of the LHC, is not exploited

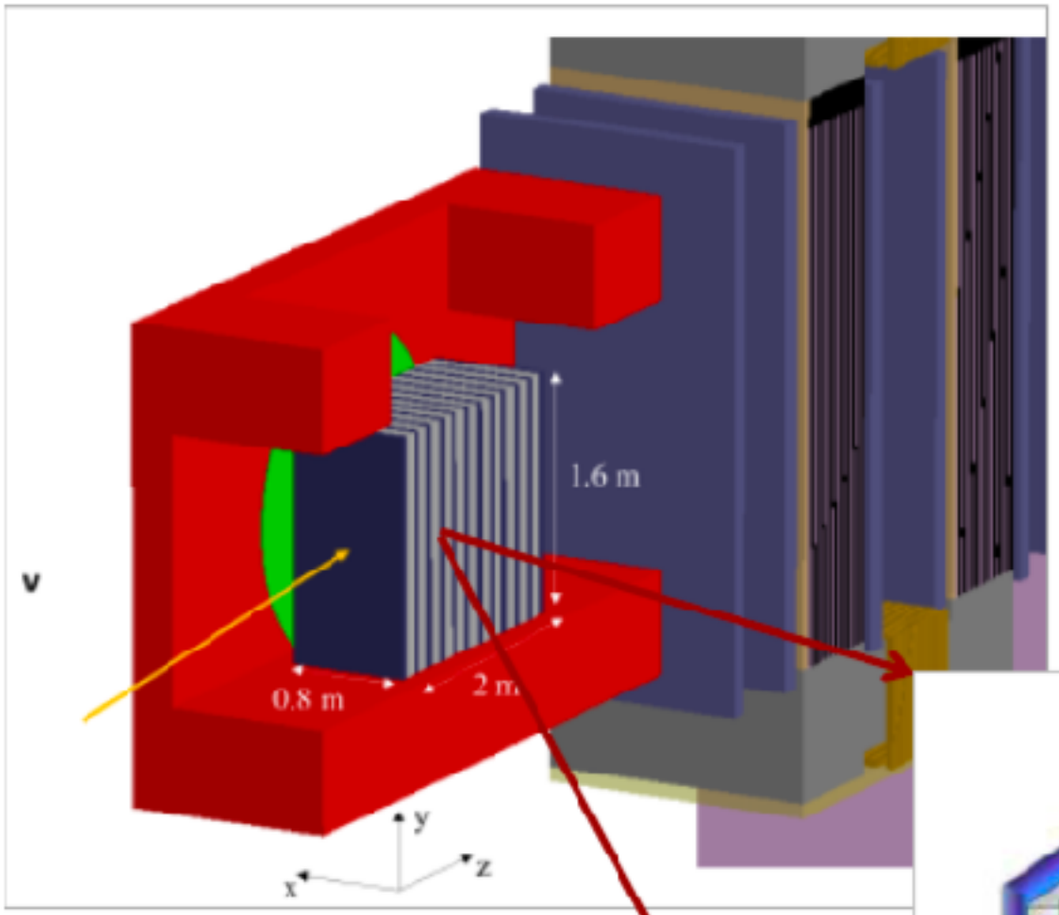


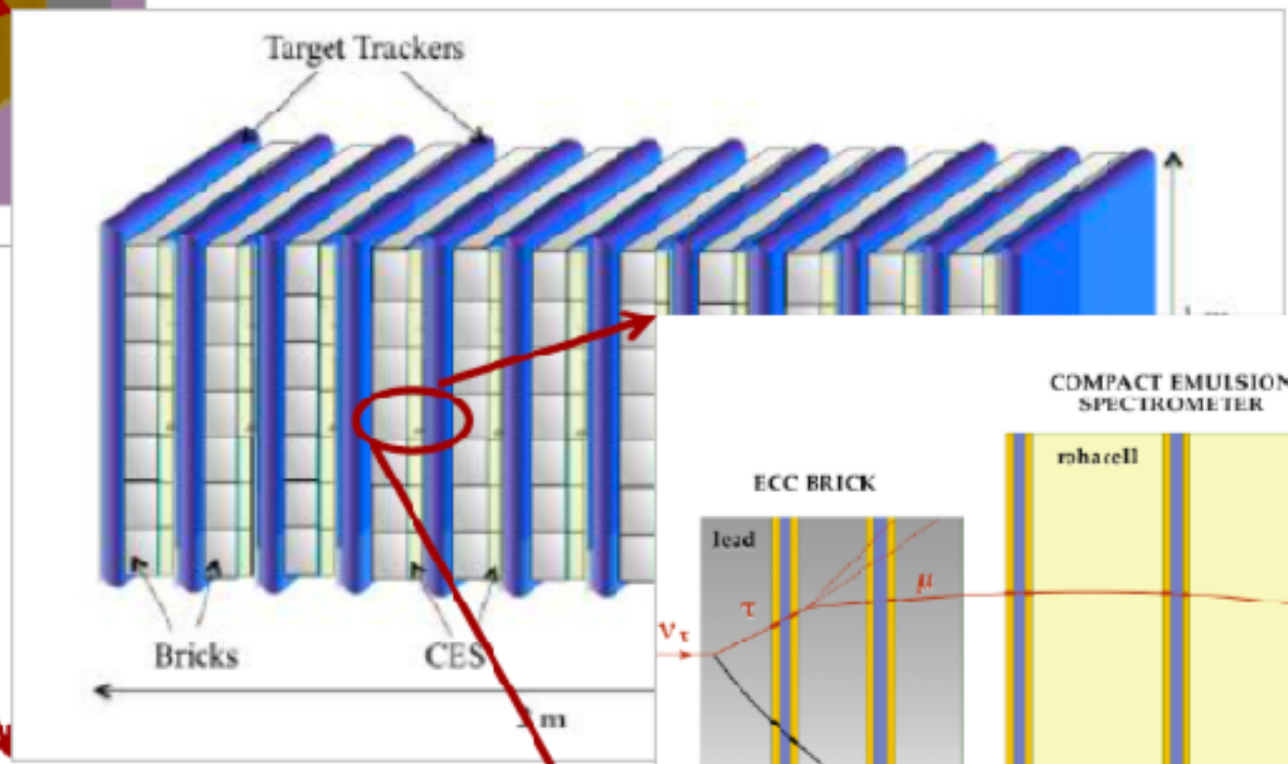
signature: a >= two track decay vertex in the decay tunnel

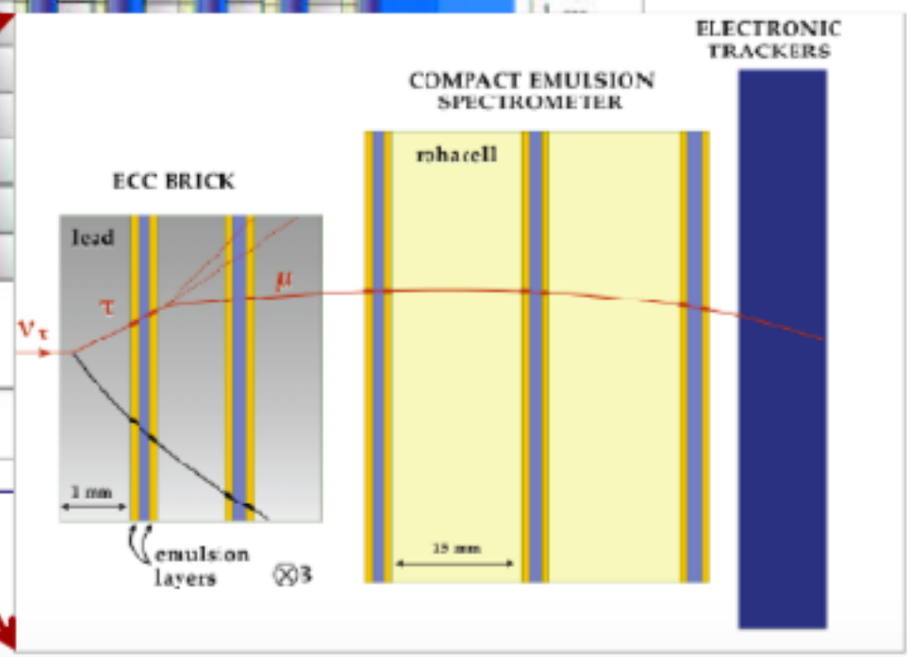
DIRECT EVIDENCE OF NP :
DETECTION of dark matter particles with masses below few GeV
neutrino-e- scattering

Neutrino target:

- Modular structure made of *ECC bricks*: sandwich of plates of high Z passive material interleaved with thin emulsion films
- **Brick** walls interleaved with planes of electronic trackers → provide time stamp, link muon tracks in emulsion to downstream **muon spectrometer**







Dimensions: 0.8 x 2 x 1.6 m^3
Number of ECC bricks: ~ 900
Total mass: ~ 7 tons
Horizontal magnetic field

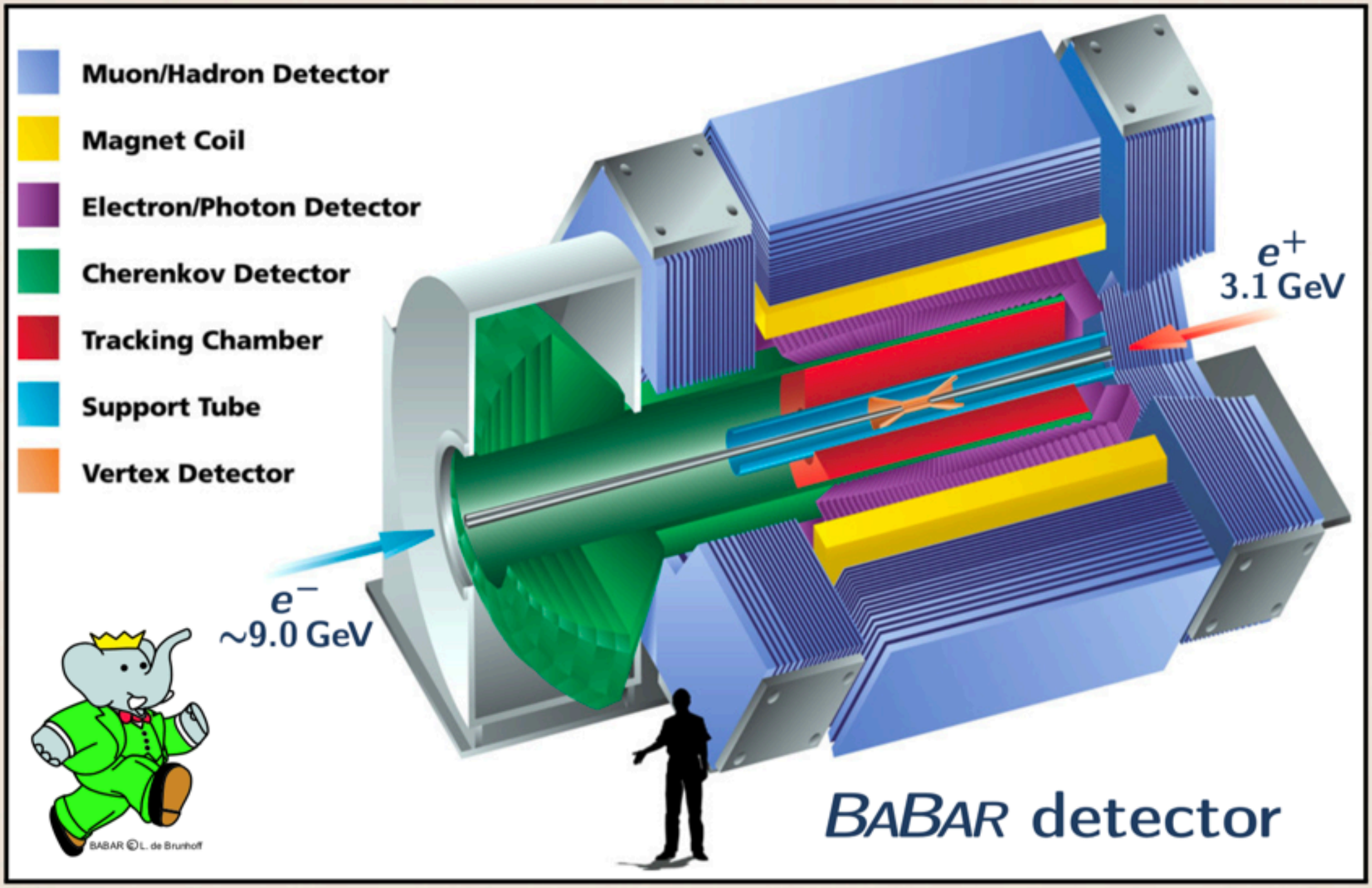
EPS 2017, 5-12 July, Venezia

Esperimenti in corso con la rivelazione di materia oscura per via cinematica o indiretta:

due players: collisori e+e- e esperimento NA62 al CERN

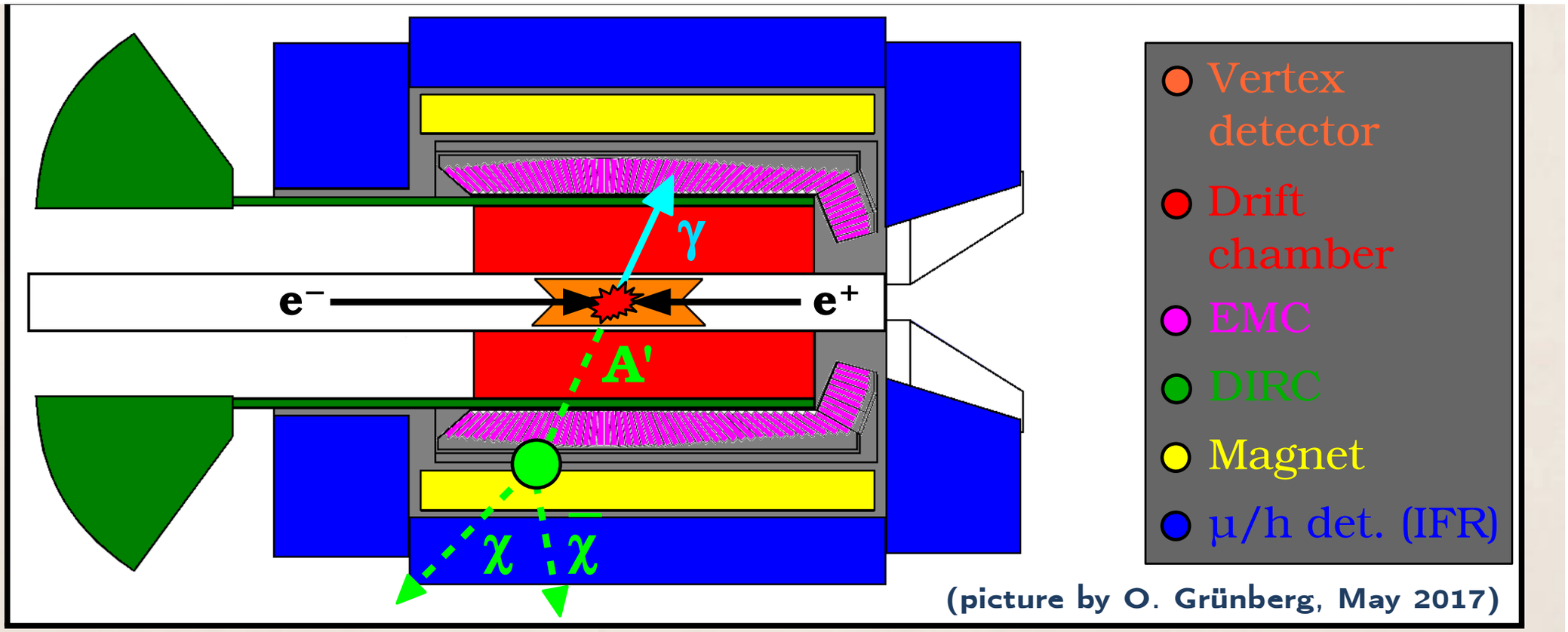
SLAC Collisore PEP , esperimento BABAR

BABAR detector at PEP-II, SLAC National Accelerator Laboratory

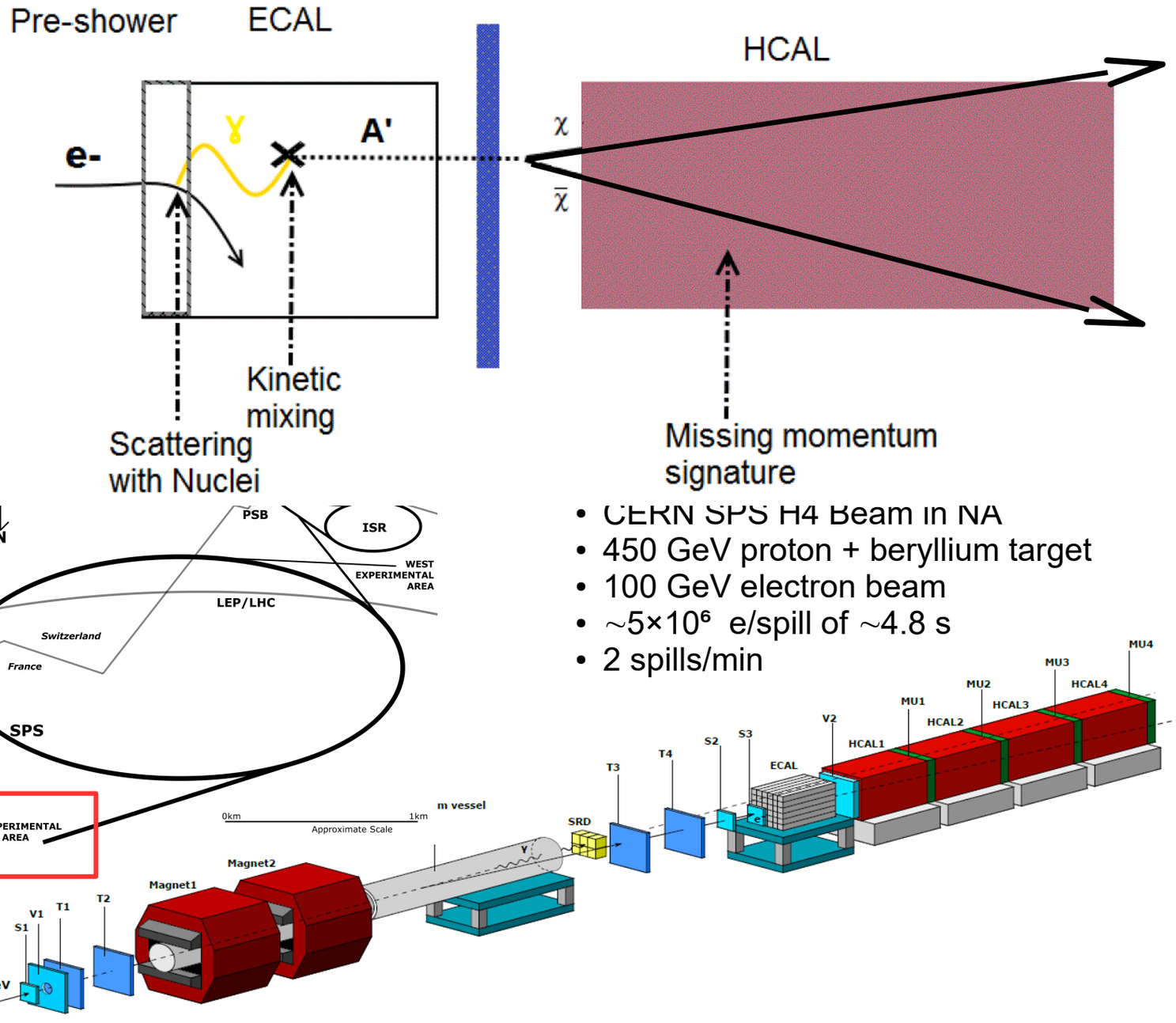


BABAR main focus: study of CP violation in B mesons

In questo caso ci si basa sulla cinematica dell'evento ricostruendo sia l'energia sia l'impulso mancante (ovvero la massa)

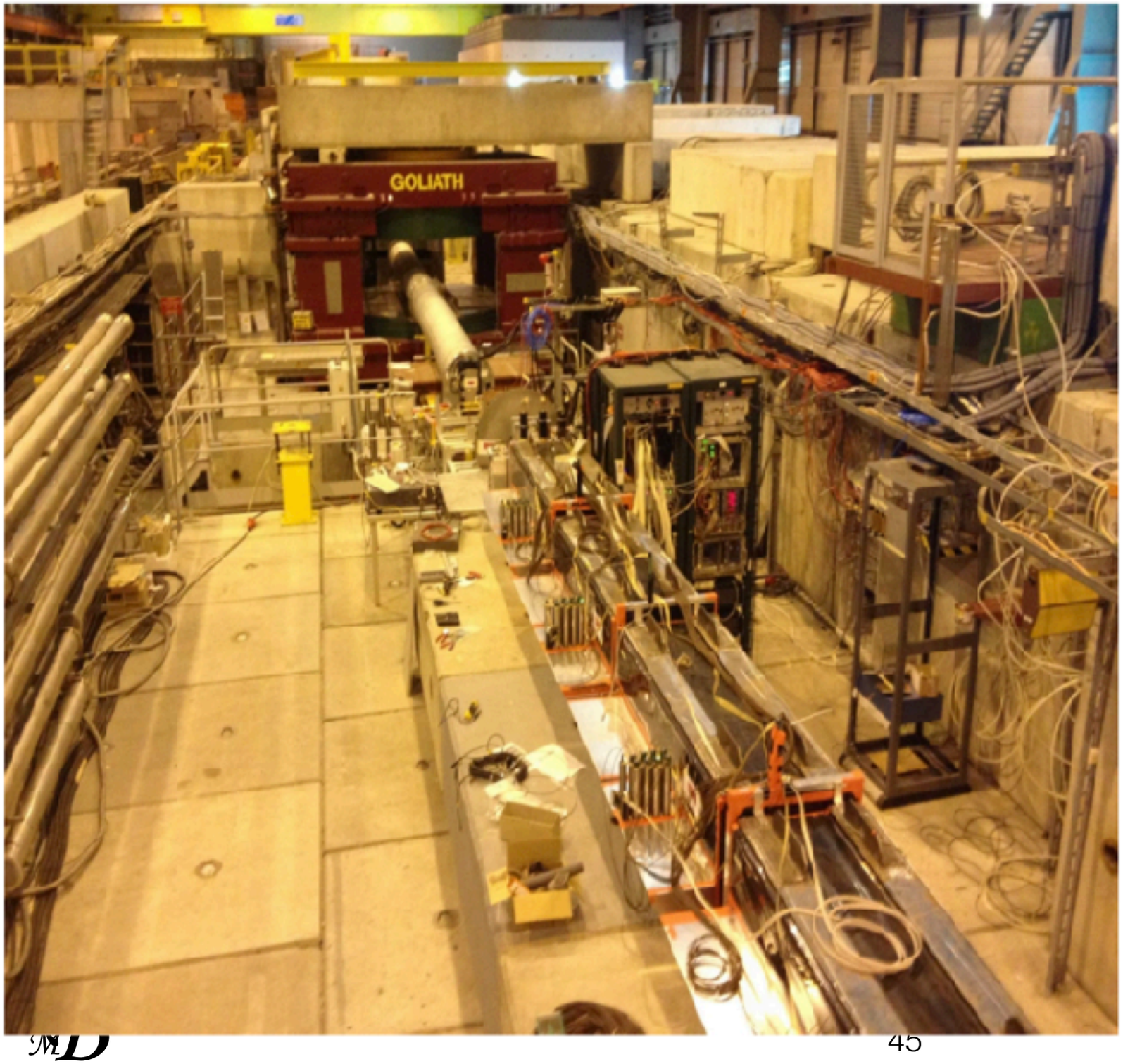


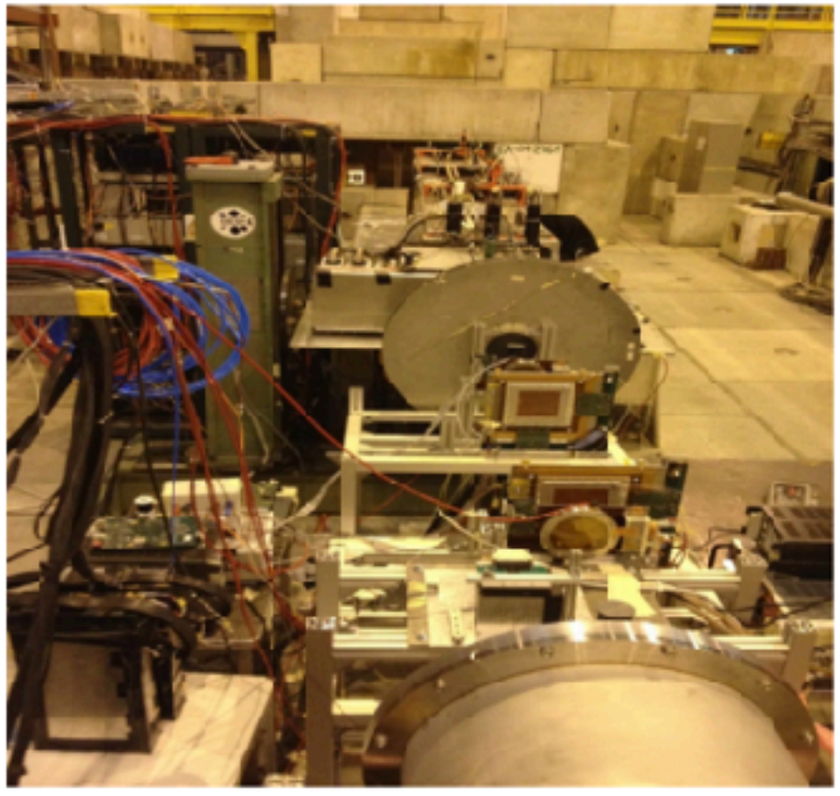
NA64 al CERN: ricostruzione cinematica con energia mancante



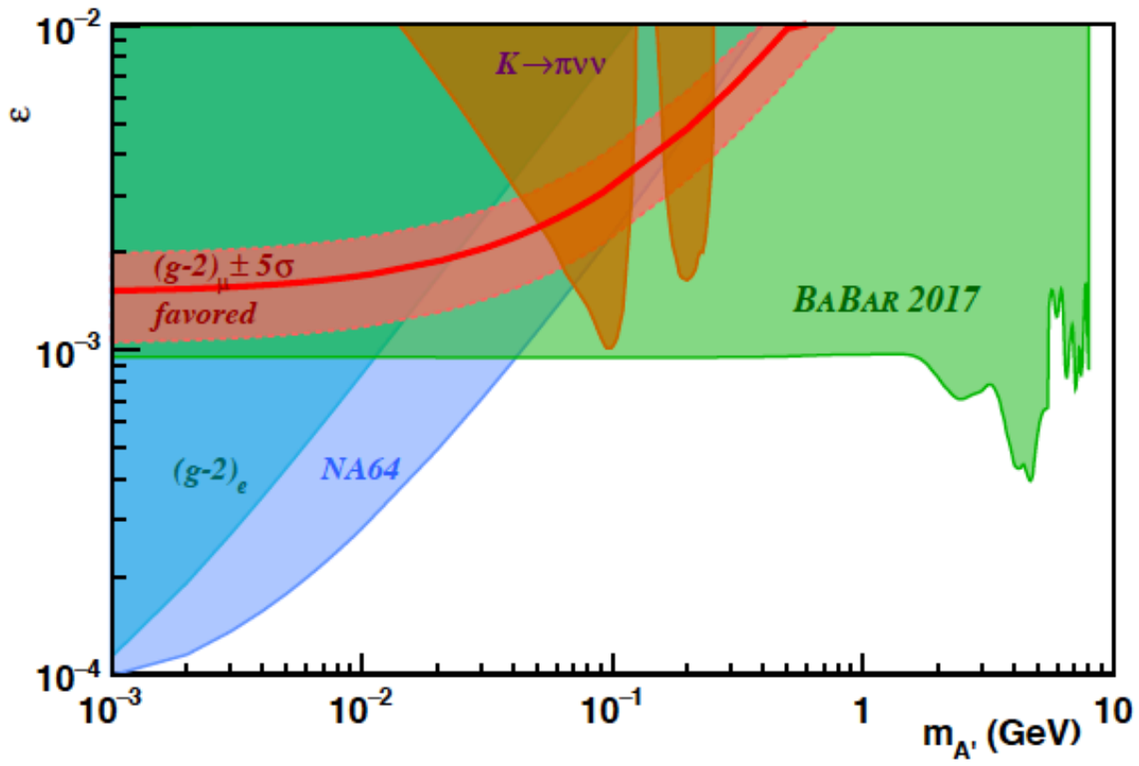
- CERN SPS H4 Beam in NA
- 450 GeV proton + beryllium target
- 100 GeV electron beam
- ~5×10⁶ e/spill of ~4.8 s
- 2 spills/min

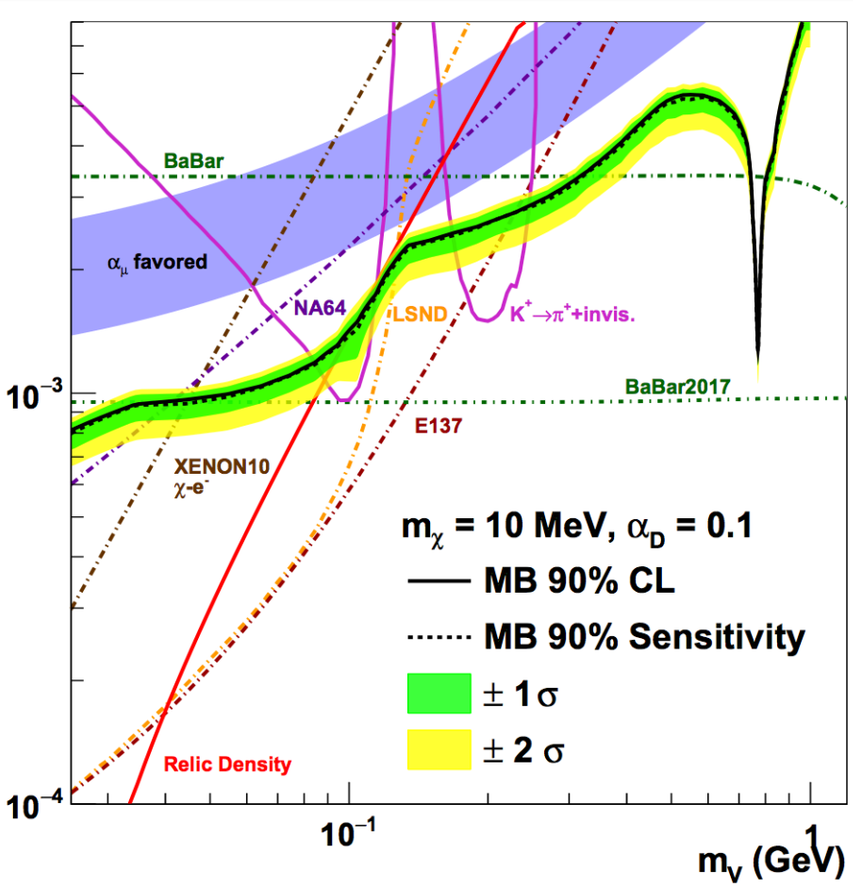
The NA64 detector





Present status of exclusions





Jefferson Lab

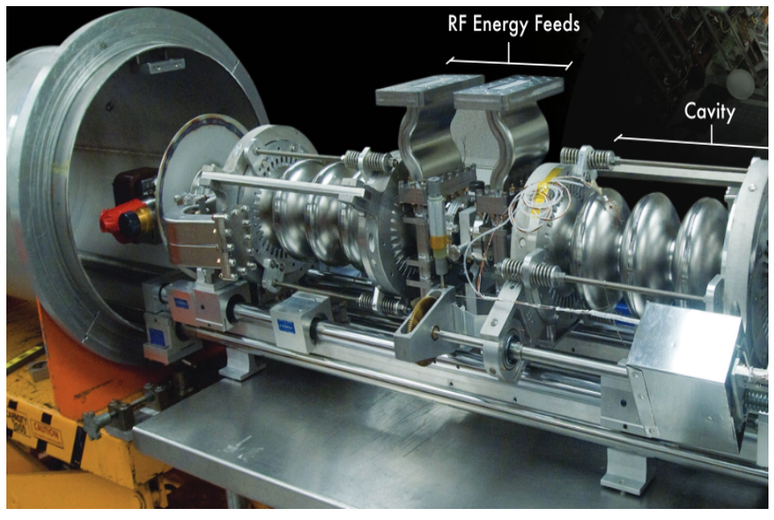
Operated for the DOE Office of Science-Nuclear Physics

Jefferson Lab Research:

- Experimental, computational and theoretical nuclear physics
- Accelerator Science, SRF technologies and FEL
- Radiation detectors and medical imaging
- Cryogenic technology
- 1530 users from 236 institutions and 31 countries

CEBAF

SRF

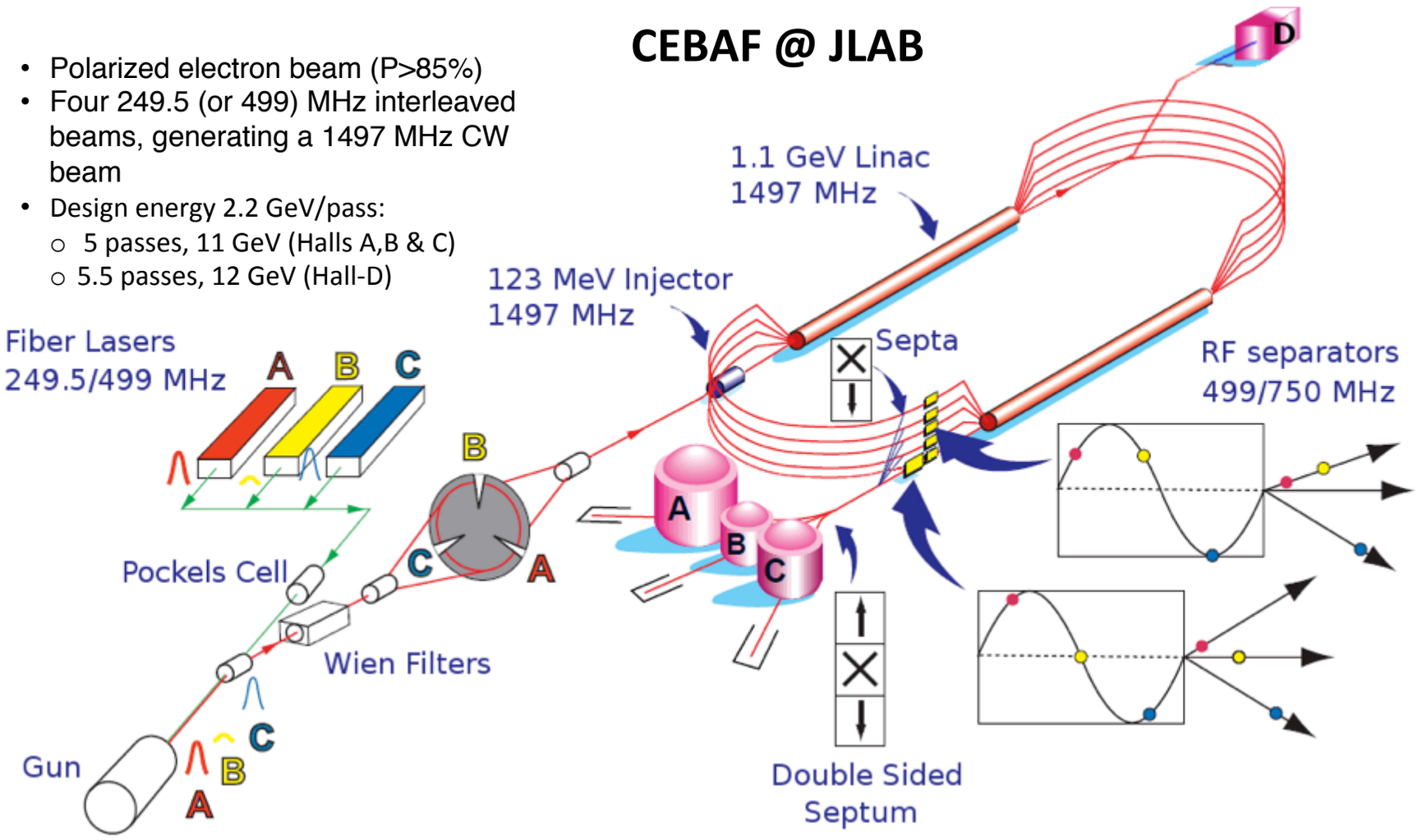


Cryogenics

U.S. DEPARTMENT OF ENERGY | Office of Science JSA Jefferson Lab

- Polarized electron beam (P>85%)
- Four 249.5 (or 499) MHz interleaved beams, generating a 1497 MHz CW beam
- Design energy 2.2 GeV/pass:
  - 5 passes, 11 GeV (Halls A,B & C)
  - 5.5 passes, 12 GeV (Hall-D)

CEBAF @ JLAB

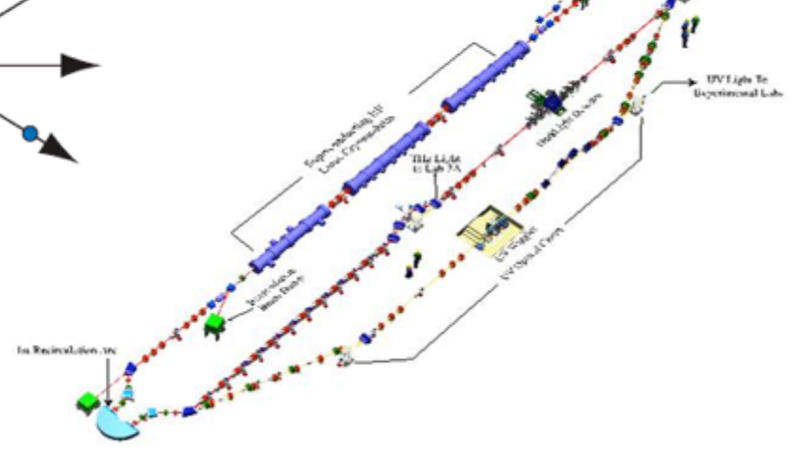


- Flexible extraction options for ABC, 1st…5th pass
- Hall A & C 1 MW high power dumps

Emittance < 10 (5) nm rad horizontal(vertical)
Energy spread <5 10^{-4}

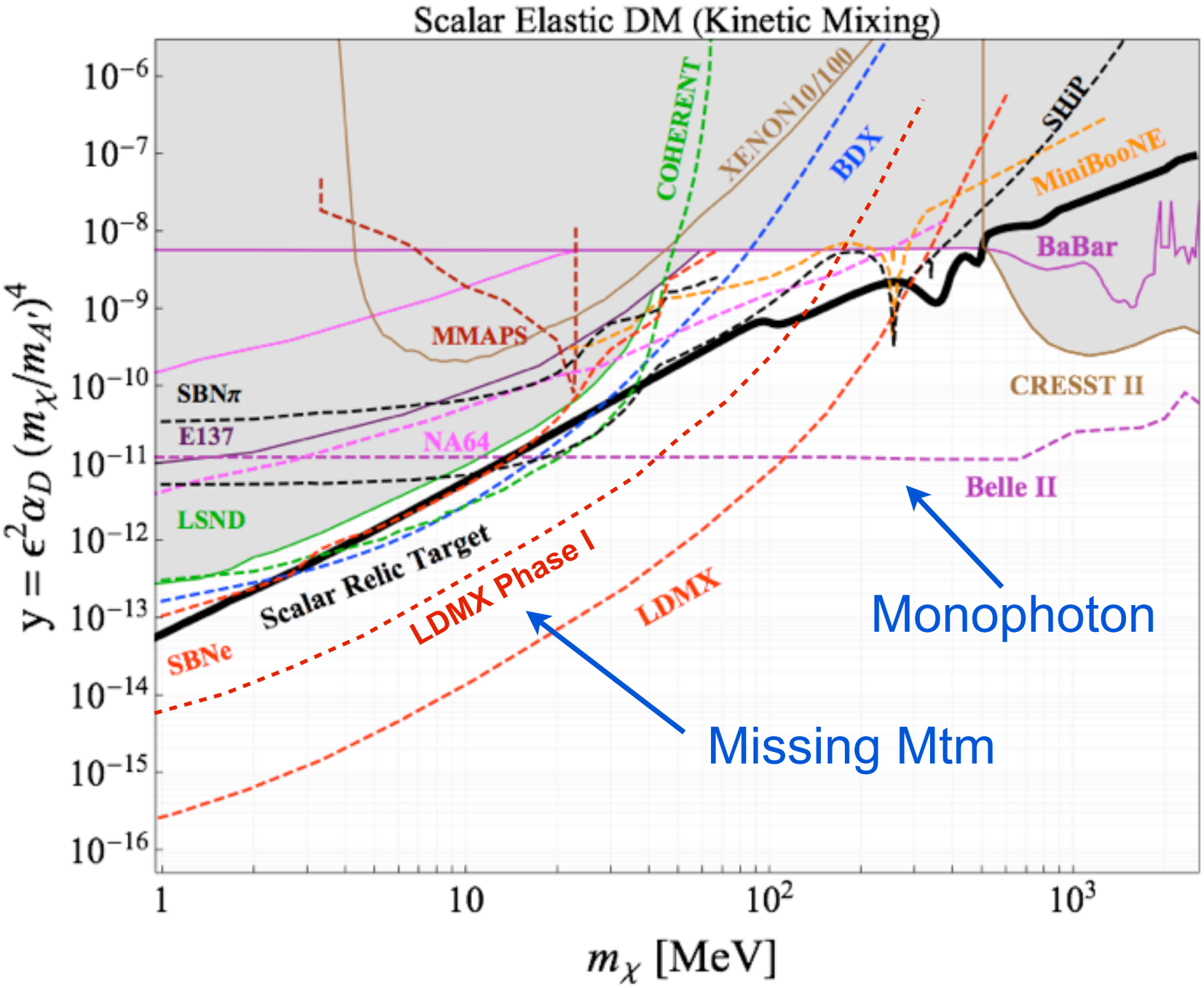
LERF @ JLAB

An energy-recovery superconducting linear accelerator of ~170 MeV



APEX in Hall-A
HPS in Hall-B
BDX behind Hall-A dump

DarkLight



Event rate ~ ε^2 for missing E/mtm vs ε^4 for scattering, but requires control of backgrounds

Possibile produrre direttamente la Materia Oscura agli acceleratori

Ricerche complementari alle ricerche dirette nei laboratori sotterranei!