Detecting Dark Matter nuclear scatterings in FLArE

Sebastian Trojanowski
(strojanowski@camk.edu.pl)
AstroCeNT, Nicolaus Copernicus Astronomical Center
Polish Academy of Sciences

BNL discussion
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B. Batell, J.L. Feng, A. Ismail, F. Kling, R.M. Abraham, ST, Phys.Rev.D 104 (2021) 3, 035036
Also: B. Batell, J.L. Feng, ST, Phys.Rev.D 103 (2021) 7, 075023

ASTROCENT

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FLArE physics goals

Standard model

Neutrino measurements

>100k high-energy scatterings
(E ~ few hundred GeV)

>1k tau neutrino events

Several x 10^3 non-DIS events
- first measurements, good neutrino spectrum estimators

Implications for QCD, cosmic-rays

Beyond the Standard model

THIS TALK

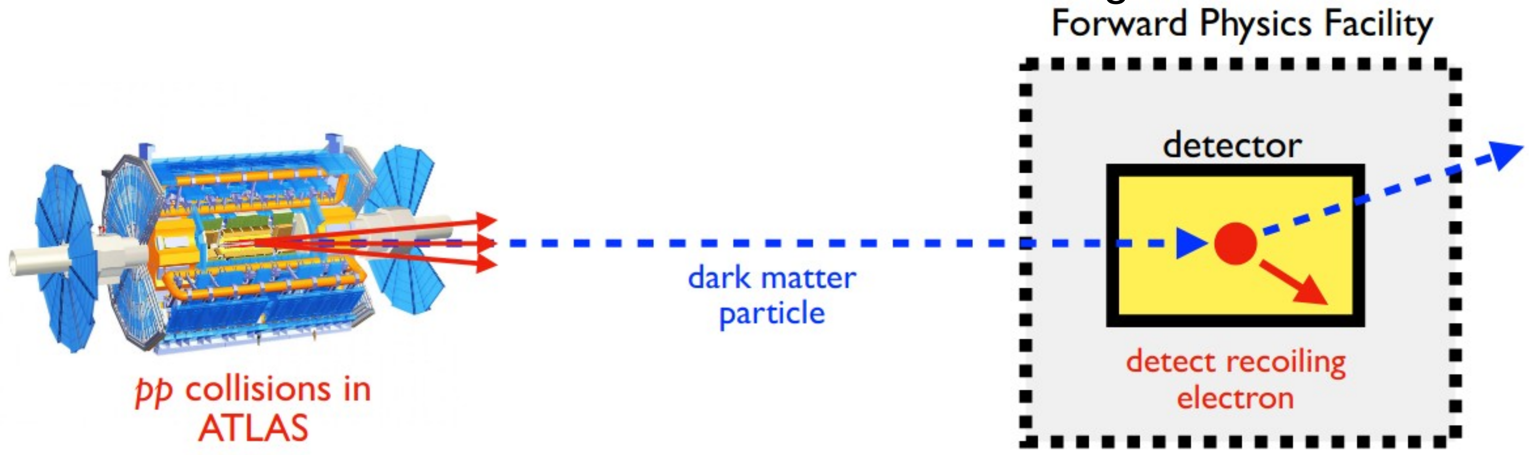
Light Dark matter (DM) search
- probing thermal targets,
- complementary to DM DD
- different signatures
  prefer low energy deposition

BSM neutrino physics:
(up)scattering to heavy neutral leptons
2011.04751, 2109.05032
Non-standard interactions EFT
2105.12136

Other searches (LLP decays,...)

Direct light DM detection at the LHC

• We focus on LDM particles produced in the far-forward region of the LHC
& their scattering in a distance detector



credit B. Batell

• This search is highly complementary to the traditional DM direct detection searches:

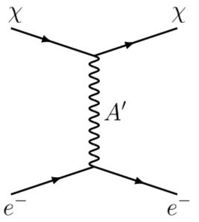
– probe of relativistic interaction rates of LDM (DM energy ~ a few hundred GeV)
[collider-boosted DM]

– the search is not sensitive to the precise abundance of χ DM component
(possible variations in cosmological scenario)
[collider-produced DM]

DM relic targets

Benchmark scenarios: dark vector portal to Majorana or scalar DM

$$\mathcal{L} \supset A'_\mu(\epsilon\, e\, J^\mu_{EM} + g_D\, J^\mu_D) \quad \mathcal{L} \supset \begin{cases} |\partial_\mu \chi|^2 - m_\chi^2 |\chi|^2 & \text{(complex scalar DM)} \\ \frac{1}{2}\bar{\chi} i\gamma^\mu \partial_\mu \chi - \frac{1}{2} m_\chi \bar{\chi}\chi & \text{(Majorana fermion DM)} \end{cases} \quad J^\mu_D = \begin{cases} i\chi^* \overleftrightarrow{\partial}_\mu \chi & \text{(complex scalar DM)} \\ \frac{1}{2}\bar{\chi}\gamma^\mu\gamma^5\chi & \text{(Majorana fermion DM)}\ . \end{cases}$$



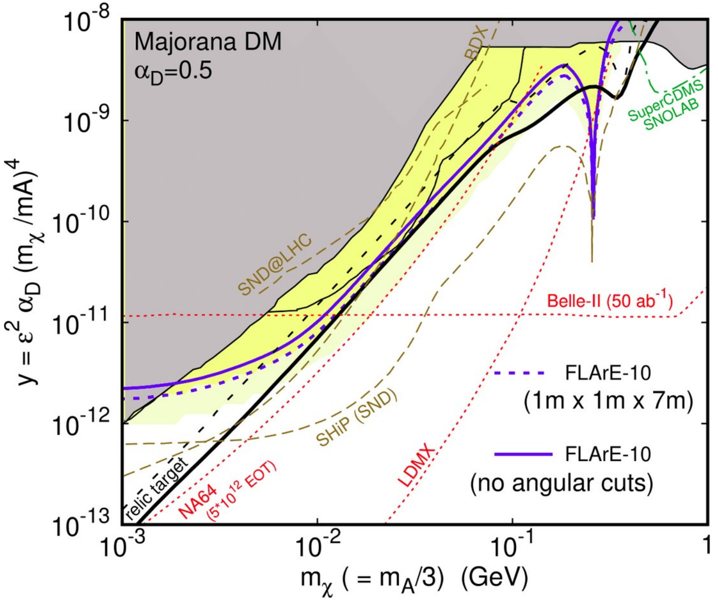
Relic target line: (thermal) $\Omega_\chi h^2$ = 100% DM

- above relic target line: underabundant χ DM
- below relic target line: too much χ DM (non-standard cosmology needed)

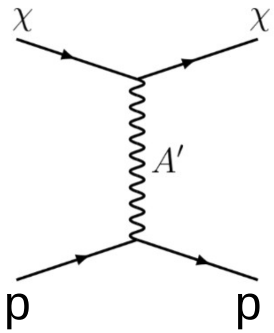
Neutrino-induced BG suppressed based on electron identification and (low) EM energy deposition in the detector

Good angular resolution is not essential

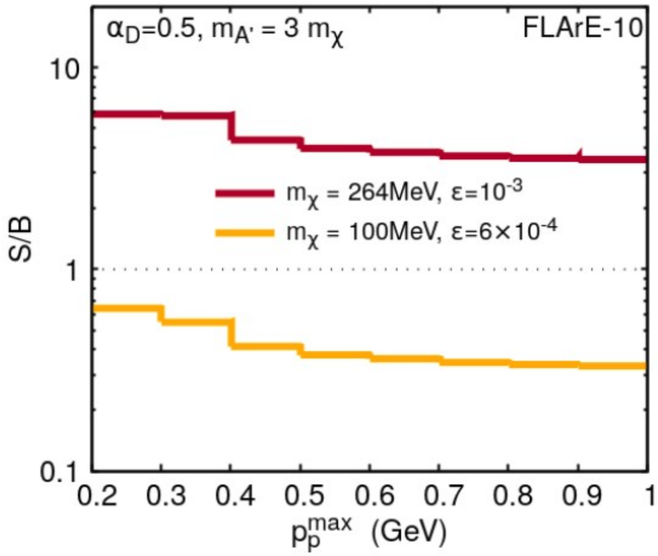
DM-electron scat.

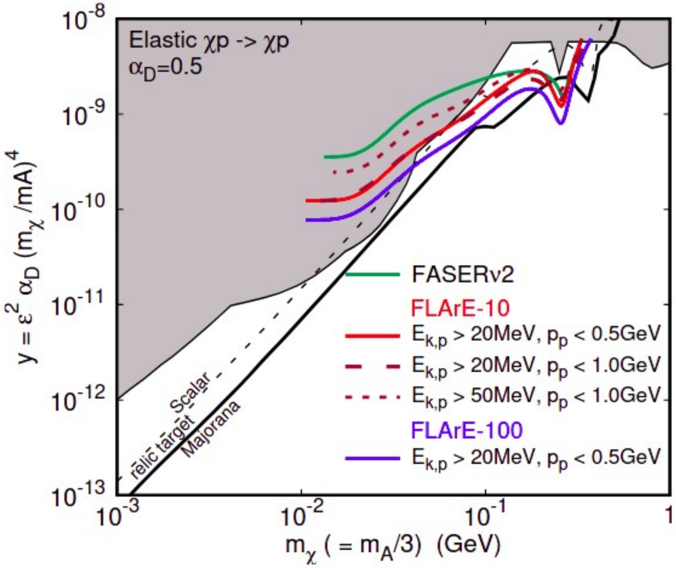


DM-nuclear scatterings – elastic

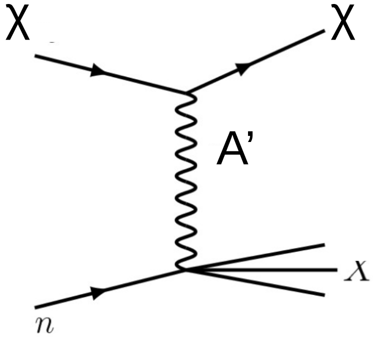


- DM can also elastically scatter off nucleons
- Signature: single proton track with p_p < 500 MeV or 1 GeV (no angular cut)
- We require $E_{k,p}$ > 20 or 50 MeV
- Impact of Final State Interactions (FSI) is taken into account (proton rescatterings before leaving nucleus)

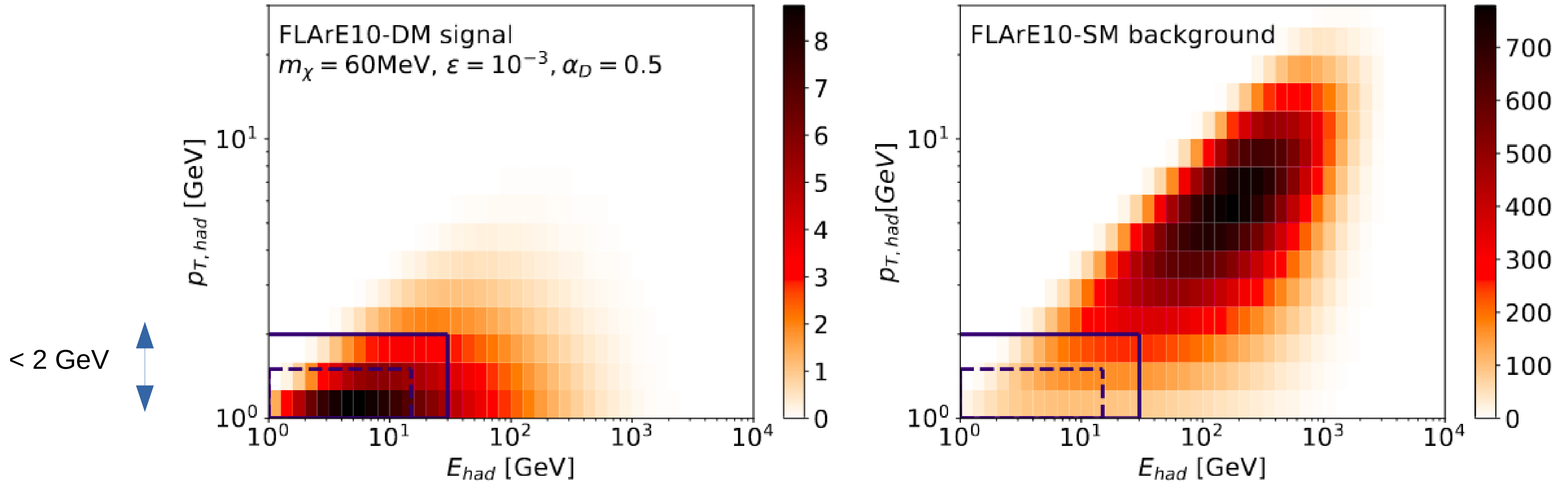




DM nuclear scatterings – DIS

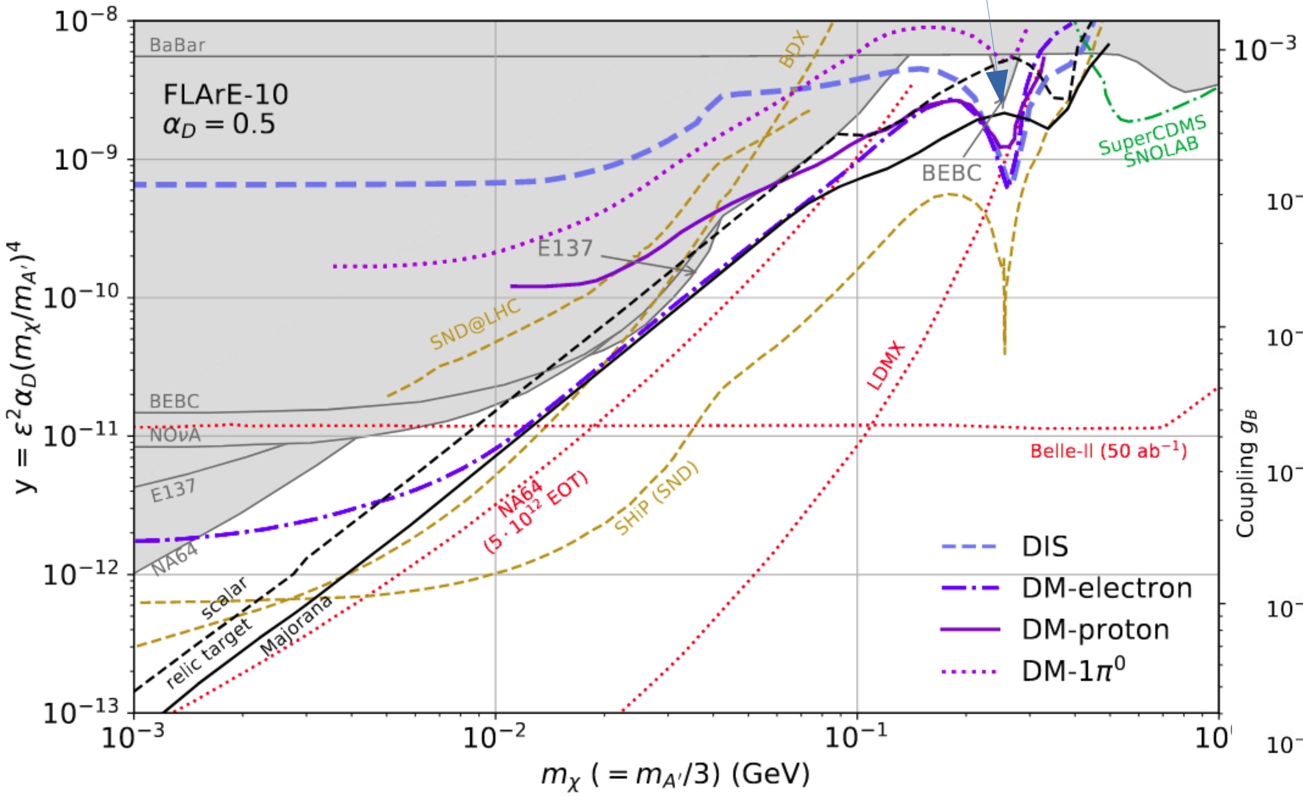


- DM can also scatter non-elastically: a) resonant pion production
  b) DIS (more tracks)
- BG from neutrino NC scatterings can be suppressed based on hadronic E and p_T measurements
- Parton energy and momentum used as a proxy, more detailed detector simulations needed



Expected sensitivity reach

elastic and DIS signatures
help probing m_χ ~ few hundred MeV and….

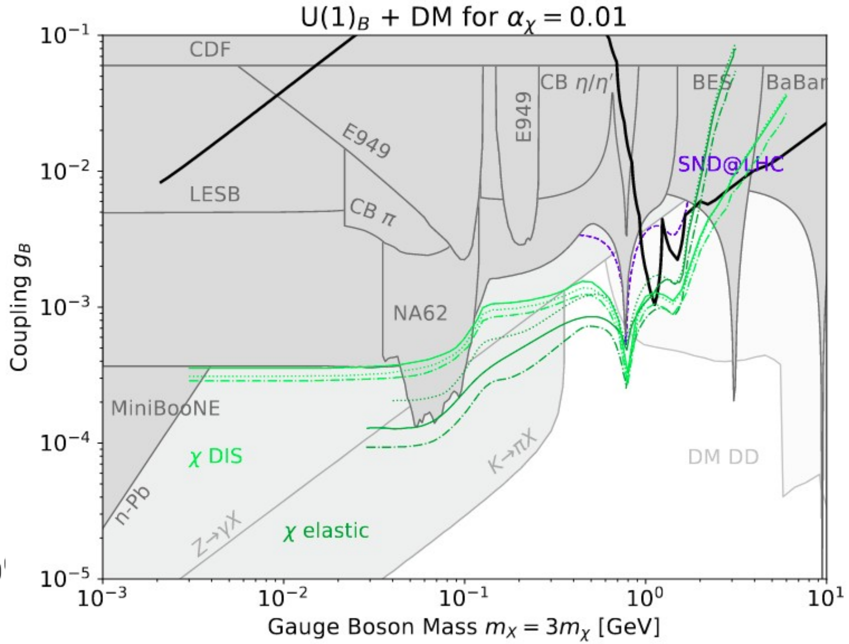


become crucial for

Leptophobic DM

B. Batell, J.L. Feng, M. Fieg, A. Ismail, F. Kling, R.M. Abraham, ST

In preparation



Conclusions

- LHC can be a light DM factory, most of high-energy such dark species will go down the beam pipe and avoid detection

- These light DM particles can scatter off electron or nuclei in the far-forward detectors

- Probing DM interactions in the relativistic regime; complementary to DM direct detection

- Complementary DM signals, possiblity to probe leptophobic DM;

- Essential experimental features for DM search:

  – ability to disentangle electrons/protons and identify single tracks

  – sensitivity to low-energy signals even below GeV

  – timing info to reject muon-induced BG

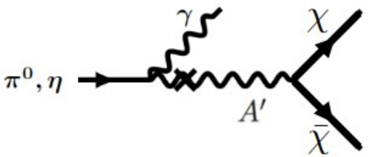
Light DM at the LHC

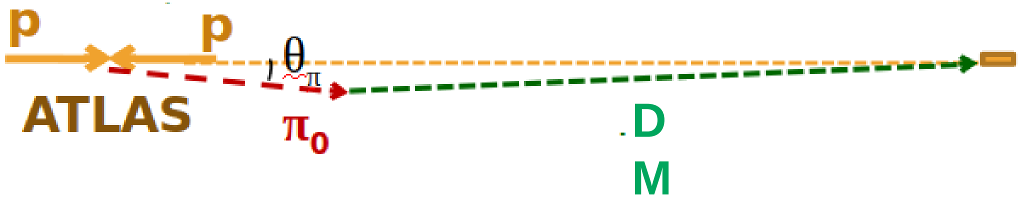
- LHC can be a very efficient light DM (LDM) factory

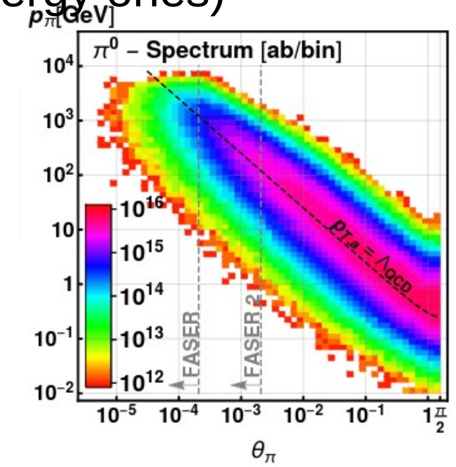
- LDM direct detection requires suppressing SM backgrounds – difficult in typical LHC experiments

- ...but many LDM particles will go down the beam pipe (especially high energy ones)

Example: DM production in rare decays of light mesons







other prod. modes include i.a. proton-proton bremsstrahlung

$pp \rightarrow pp(A' \rightarrow \chi\chi)$

FASER Collaboration, hep-ph/1811.12522, hep-ex/1908.02310

- Far-forward search for light long-lived particles and studies of high-energy neutrino interactions to be initiated during Run 3 with FASER and FASERν detectors

Neutrino-induced BG

Elastic $\chi p \to \chi p$		ν-induced backgrounds	DM: $m_\chi = 100$ MeV, $\varepsilon = 6 \times 10^{-4}$
FASERν2	$p_p > 300$ MeV, $p_p < 1$ GeV	310	34
FLArE-10	$E_{k,p} > 20$ MeV, $p_p < 500$ MeV	100	37
	$E_{k,p} > 20$ MeV, $p_p < 1$ GeV	125	42
	$E_{k,p} > 50$ MeV, $p_p < 1$ GeV	120	23
FLArE-100	$E_{k,p} > 20$ MeV, $p_p < 500$ MeV	810	260
	$E_{k,p} > 20$ MeV, $p_p < 1$ GeV	1050	310
	$E_{k,p} > 50$ MeV, $p_p < 1$ GeV	1010	165

DIS	ν-induced backgrounds			DM: $m_\chi = 60$ MeV, $\varepsilon = 10^{-3}$			DM: $m_\chi = 188$ MeV, $\varepsilon = 10^{-3}$		
Detector	no cuts	loose cuts	strong cuts	no cuts	loose cuts	strong cuts	no cuts	loose cuts	strong cuts
FASERν2	154k	7.4k	2.9k	700	335	210	440	170	100
FLArE-10	82k	5k	2k	380	185	116	250	95	55
FLArE-100	528k	38k	15k	2.3k	1.1k	748	1.5k	615	361