Boosted Dark Matter at DUNE

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University of Pittsburgh

JB, Y. Cui, Y. Zhao: JCAP 1502 (2015) no.02, 005
JB: In Progress
Assadi, JB, Convery, Cui, Graham, Necib, Petrillo, Stocks, Tsai, Zhao: In Progress (DUNE TDR)

December 4, 2018

PONDD

Outline

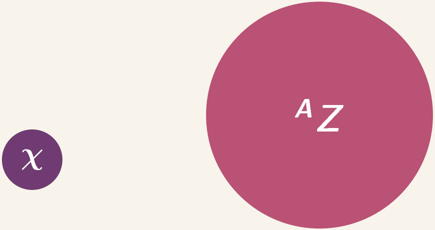
- Motivation & Models
- Flux & Interaction Modeling
- Detection & Results

Motivation & Models

Beyond the minimal WIMP

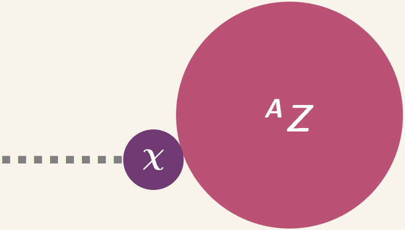
- Spin-dependent interactions dominate
- Velocity suppression at low v
- Non-SM annihilation modes
- Non-minimal stabilization symmetry
- Multi-component DM sector
- **High(er) velocity flux (i.e. boosted)**

Thermal relic dark matter is slow



$v \sim 10^{-3}$

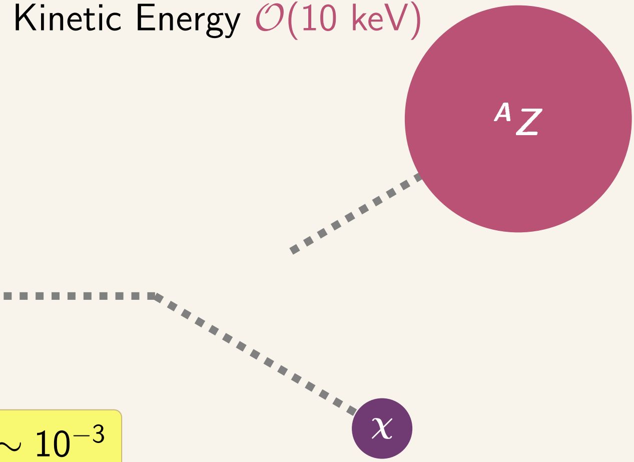
Thermal relic dark matter is slow



$v \sim 10^{-3}$

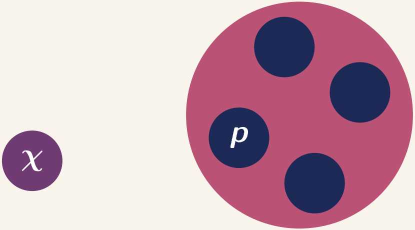
Thermal relic dark matter is slow

Nuclear Kinetic Energy $\mathcal{O}(10\text{ keV})$



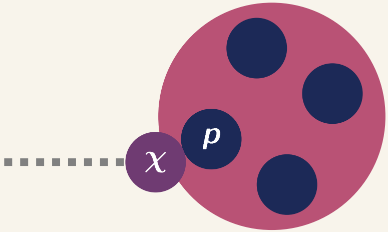
$v \sim 10^{-3}$

Boosted DM: "Elastic" scattering



$v \sim 1$

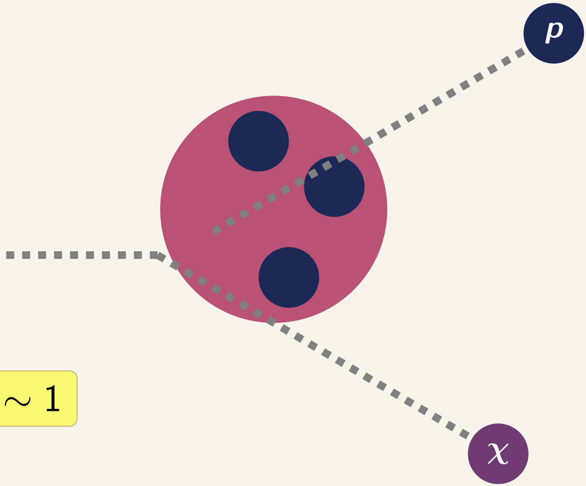
Boosted DM: "Elastic" scattering



$v \sim 1$

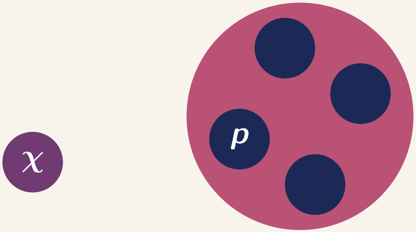
Boosted DM: “Elastic” scattering

Nucleon Kinetic Energy $\mathcal{O}(100\text{ MeV})$



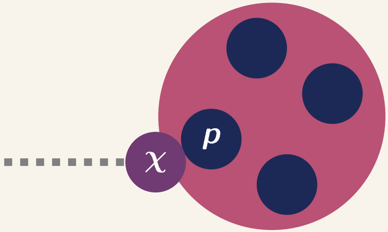
$v \sim 1$

Boosted DM: Inelastic scattering



$\gamma \gg 1$

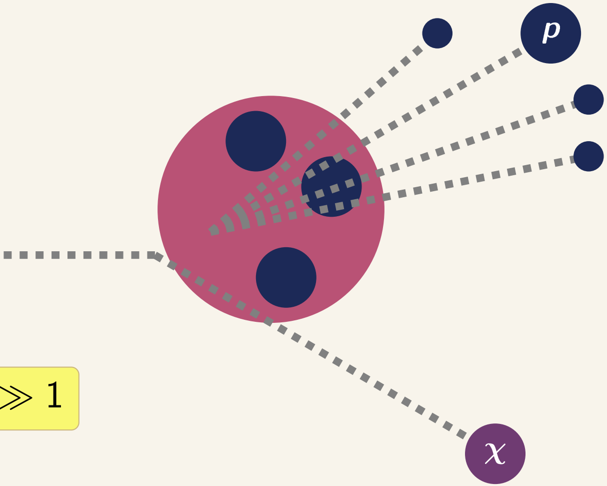
Boosted DM: Inelastic scattering



$\gamma \gg 1$

Boosted DM: Inelastic scattering

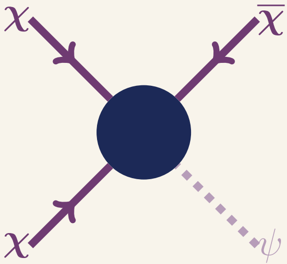
Multihadron Production



$\gamma \gg 1$

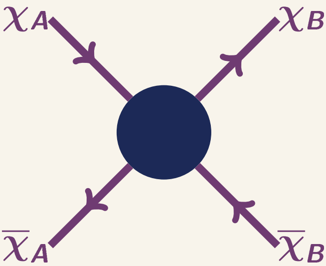
Simple BDM models exist

Z_3 Dark Matter with semi-annihilation



$v \approx 0.6$

Two component Dark Matter



$v = \sqrt{1 - m_B^2/m_A^2}$

First benchmark: Axial Z'

- In addition to annihilation, there is a scattering process that allows for detection

$$\mathcal{L} \supset -Q_\chi^{V,(A)} g_{Z'} Z'_\mu \bar{\chi}\gamma^\mu(\gamma^5)\chi - \sum_f Q_f^{V,(A)} g_{Z'} Z'_\mu \bar{q}_f\gamma^\mu(\gamma^5)q_f$$

- As a first benchmark, take

$$Q_i^V = 0$$

The Pieces

$$N = \Phi \times \sigma_{\chi,T} \times \epsilon \times N_T \times \Delta t$$

Φ: Flux from Sun, Galactic Center, Beam?

$\sigma_{\chi,T}$: Dark matter-target nucleus cross-section

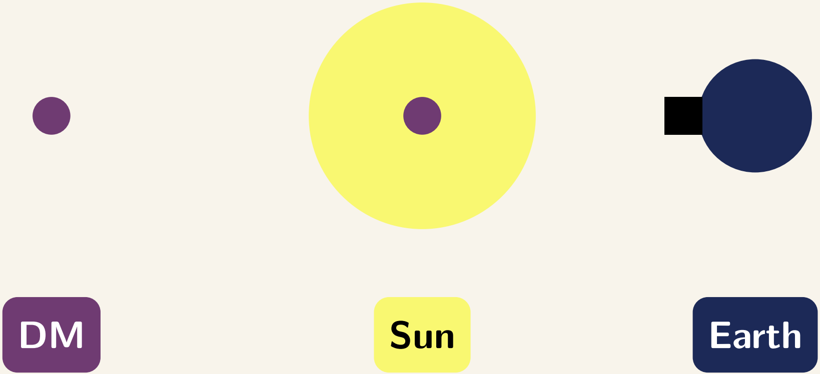
ϵ: Signal efficiency

N_T: # of target nuclei in detector, $6 \times 10^{32}/Z/\text{kton}$

Δt: Live time of detector

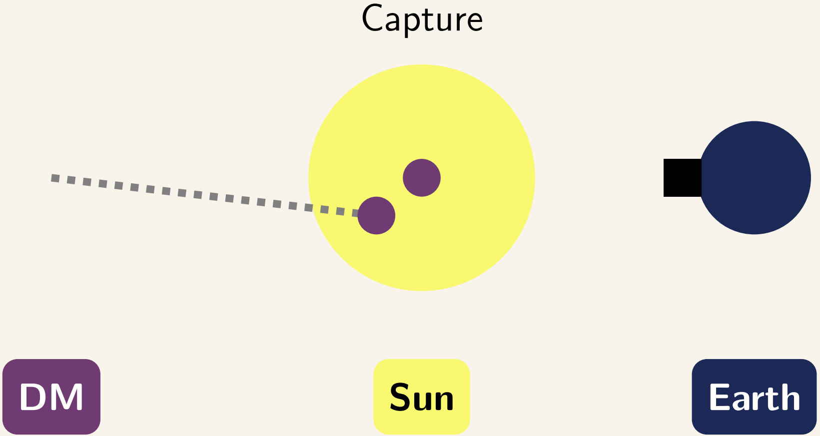
Flux & Interaction Modeling

Solar capture & detection



JB, Cui, Zhao, JCAP 1502 (2015) 005

Solar capture & detection



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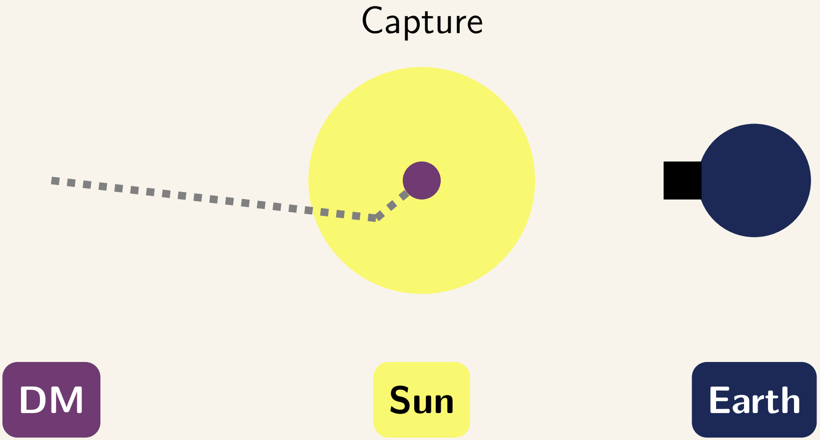
Solar capture & detection



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Solar capture & detection

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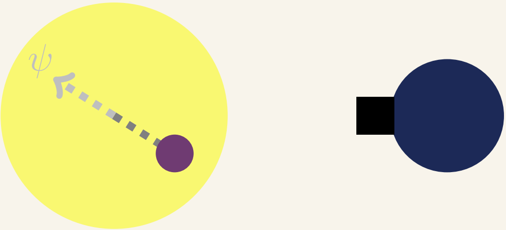
Solar capture & detection

Annihilation



DM

Sun

Earth

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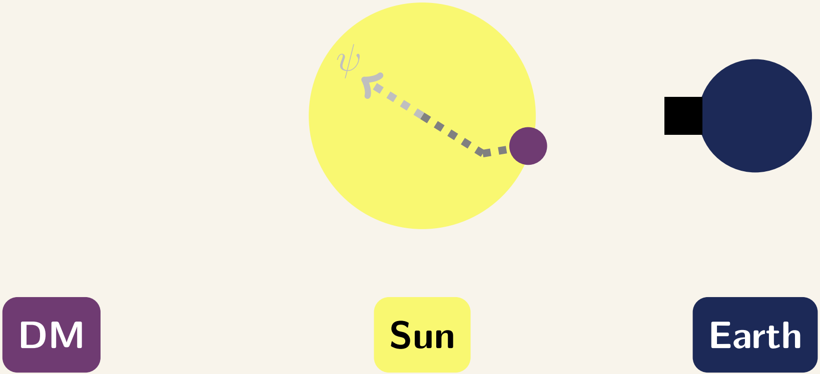
Solar capture & detection

Rescattering



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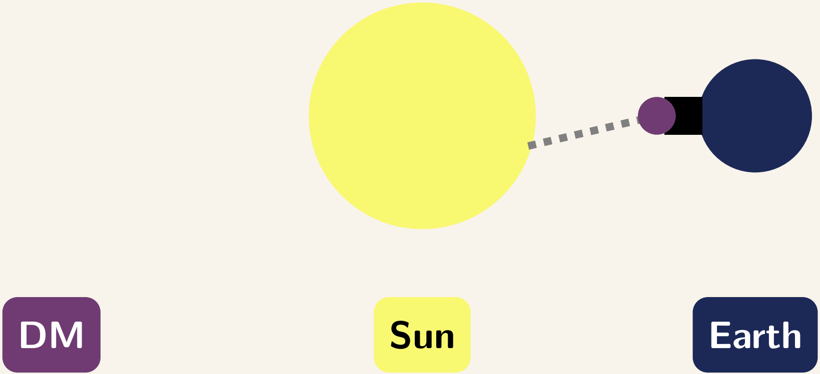
Solar capture & detection

Detection



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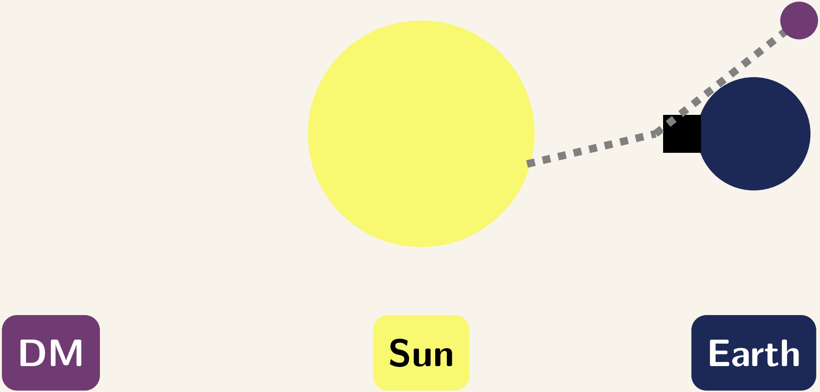
Solar capture & detection

Detection



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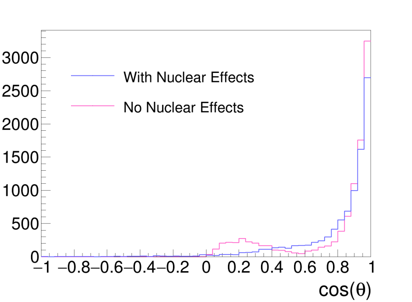
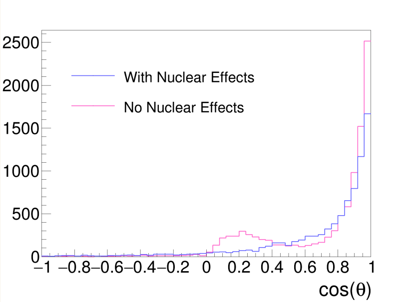
A New Tool

- Elastic scattering off free nucleons analytically calculable
- Nuclear physics at scale 250 MeV
- DIS above scale 2 GeV
- New Monte Carlo tool as part of GENIE

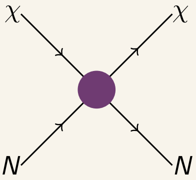
Nuclear Effects Matter





Courtesy of Yun-Tse Tsai!

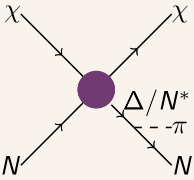
Three different processes



Elastic

Relatively easy

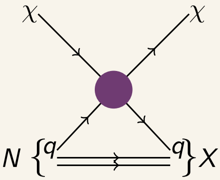
Needs form factor



Resonant

Dominated by Δ, N^*
$W \in [1, 2]$ GeV

Needs a model



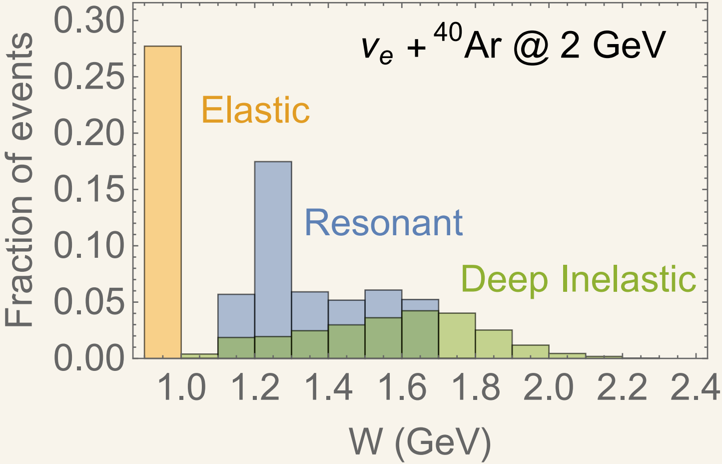
Deep Inelastic

Use standard parton model

DM beam?

Rein & Sehgal: Ann.Phys.133, 79 (1981)

All processes could be important



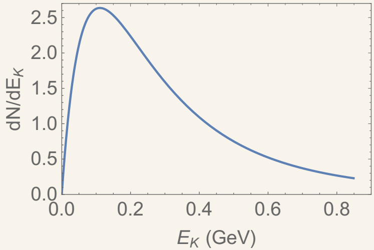
Current Status of BDM in GENIE

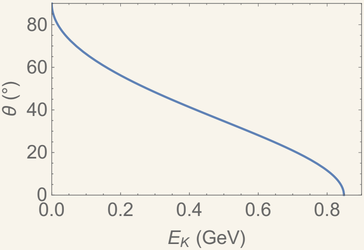
- ✓ Fermion or scalar DM, axial Z' coupling
- ✓ Elastic and DIS implemented
- ✓ Framework mostly set for further models
- ✓ Integrated into GENIE v3

Detection & Results

Backround reduction

- Protons recoil within $\theta \sim 40^\circ$ of the sun
- Background mostly near-isotropic atmospheric ν
- Large sideband to control systematics





Looking with water Čerenkov

Physical energy threshold:

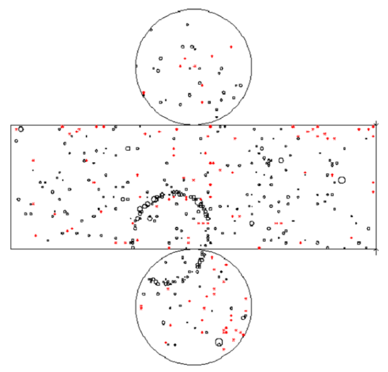
$$E_{K,recoil} = 480 \text{ MeV}$$

Hard to reconstruct inelastic

Experiments:

Super-Kamiokande

Hyper-Kamiokande



Super-Kamiokande: PRD79 (2009) 112010

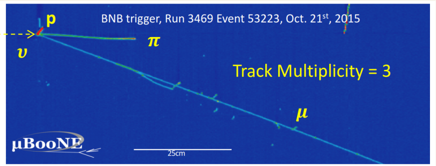
A future in liquid argon TPCs

Threshold:
$E_{K,recoil} \lesssim 50$ MeV

Inelastic reconstruction possible

Experiments

- LArIAT, MicroBooNE
- ArgoNeuT, ProtoDUNE
- SBND, ICARUS
- DUNE

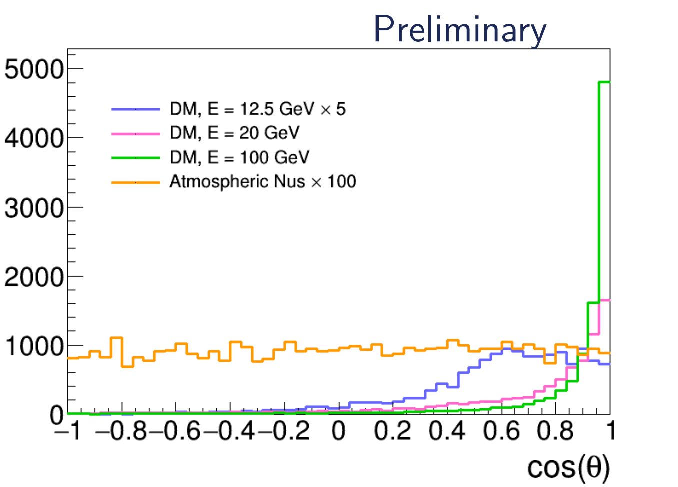


Yellow captions from talk by Luo

Detector Response

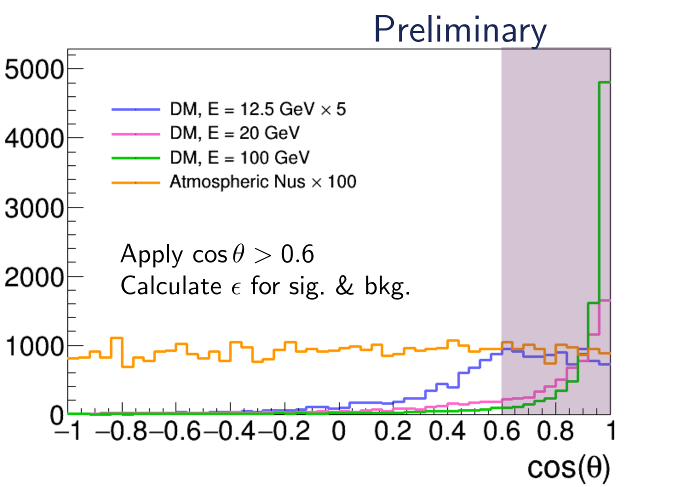
- Angular resolution: From CDR
- Energy resolution: See Alex Friedland's talk
- Detector threshold (in KE): From CDR
- Detector acceptance
- Reconstruction efficiency
- Particle ID efficiency

Angular Distribution (Total P)



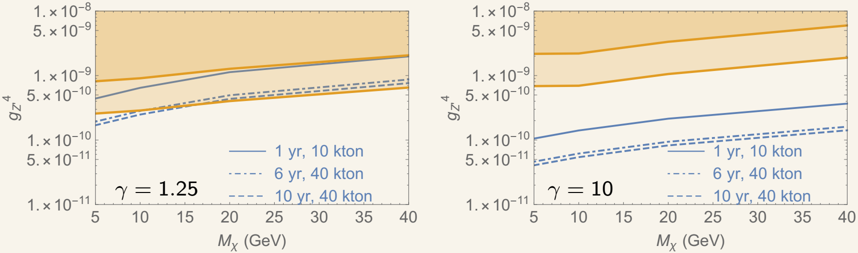
Courtesy of Yun-Tse Tsai

Angular Distribution (Total P)



Courtesy of Yun-Tse Tsai

Preliminary Results



- ▶ Super-Kamiokande: 22.5kt fiducial volume, 6 yrs
- ▶ No angular cut to reduce atmo bkg for Super-K
- ▶ Efficiency (resolution, other FS particles)?

Conclusions

- Traditional direct detection continues to put pressure on minimal WIMP scenarios
- Boosted dark matter models are an alternative with signals at large volume neutrino detectors
- New Monte Carlo tools required to determine sensitivity to BSM at fixed target experiments