IWCD PRISM for Dark Matter Direct Detection

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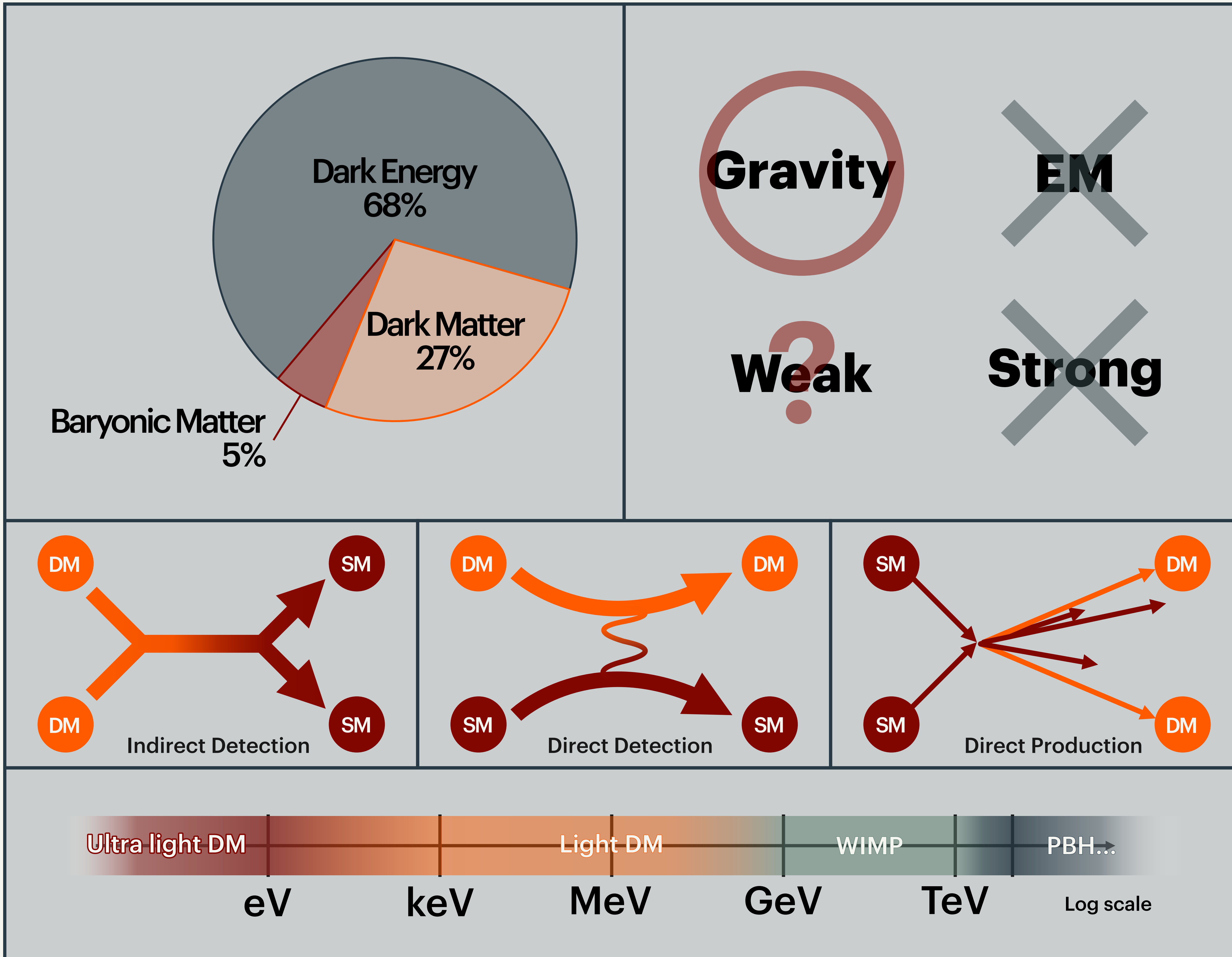
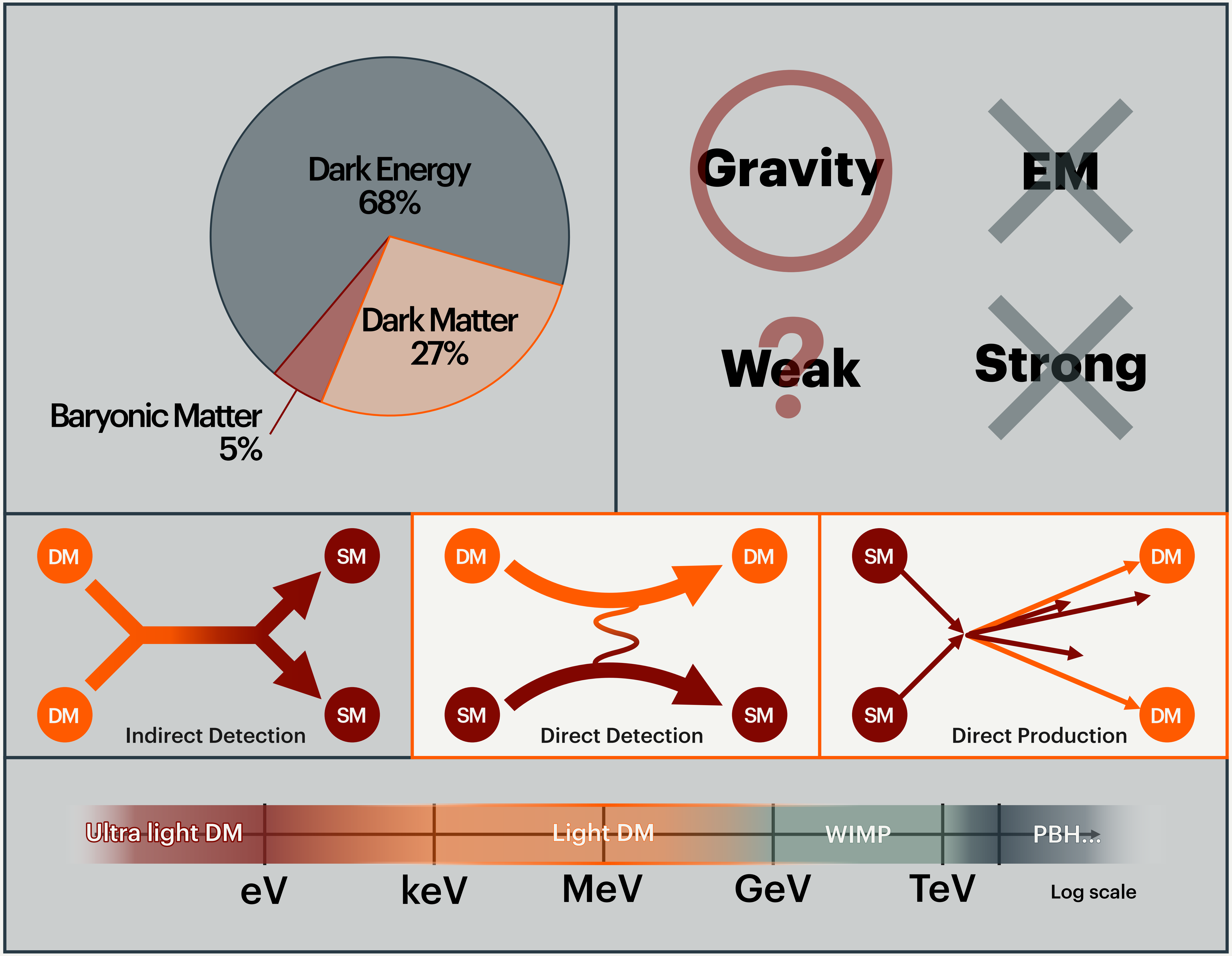
Dark matter


Dark Energy
68%
Dark Matter
27%
Baryonic Matter
5%
Gravity
EM
Weak
Strong
DM
SM
Indirect Detection
Direct Detection
Direct Production
Ultra light DM
Light DM
WIMP
PBH...
eV
keV
MeV
GeV
TeV
Log scale

Dark matter



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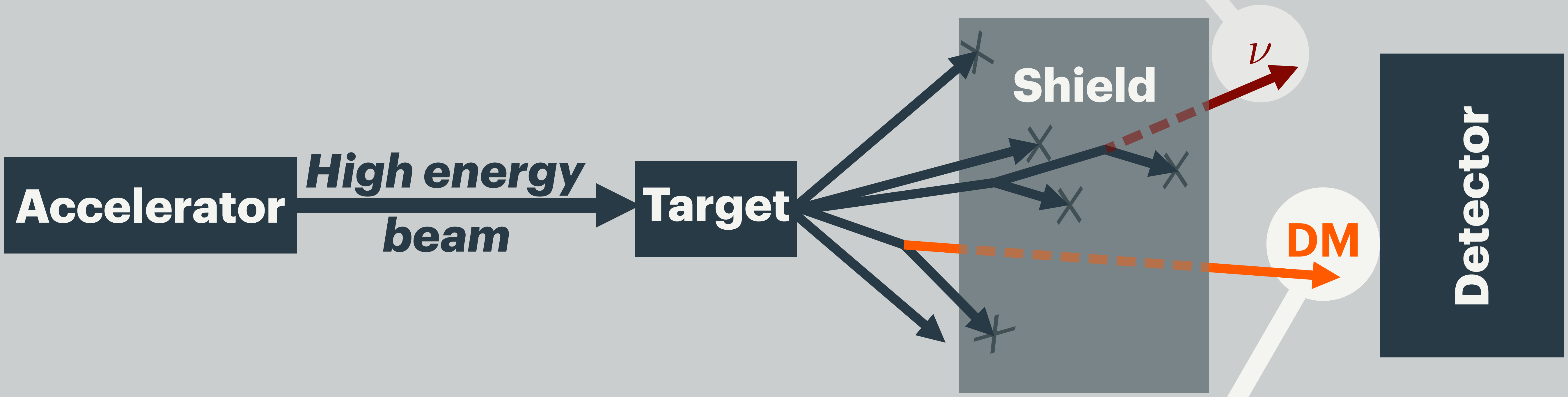
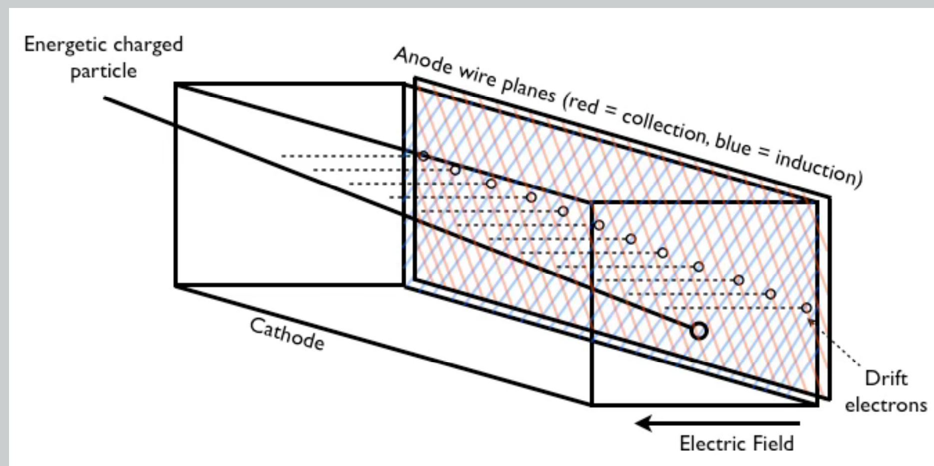
Neutrino beam experiment for DM search

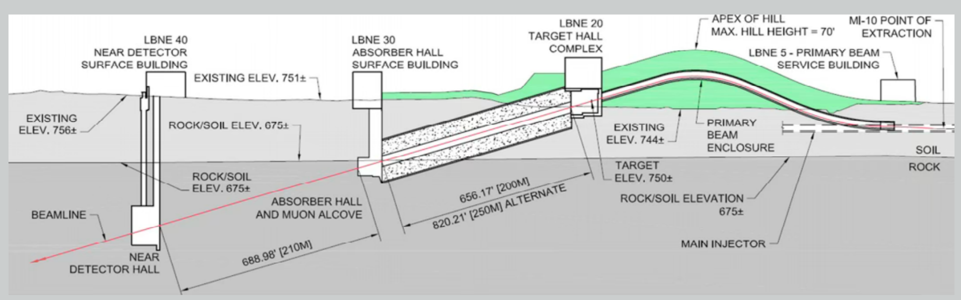
Studying standard model particles that are not absorbed by the shield such as ν



Noting that DM, like ν's, barely interacts with SM particles, this approach enables direct production and detection of DM at ν-beam facilities

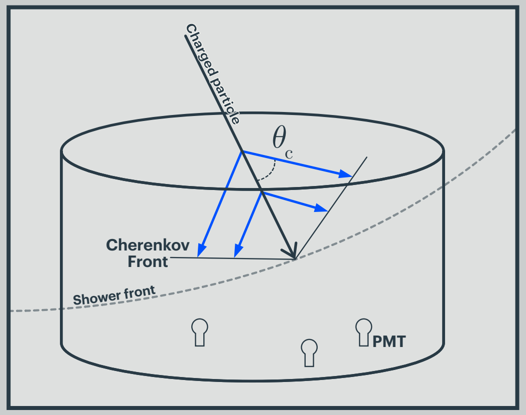
Neutrino beam experiment for DM search

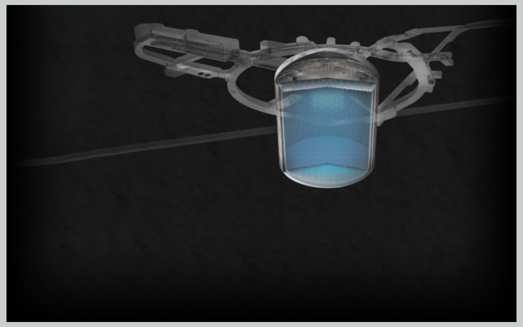


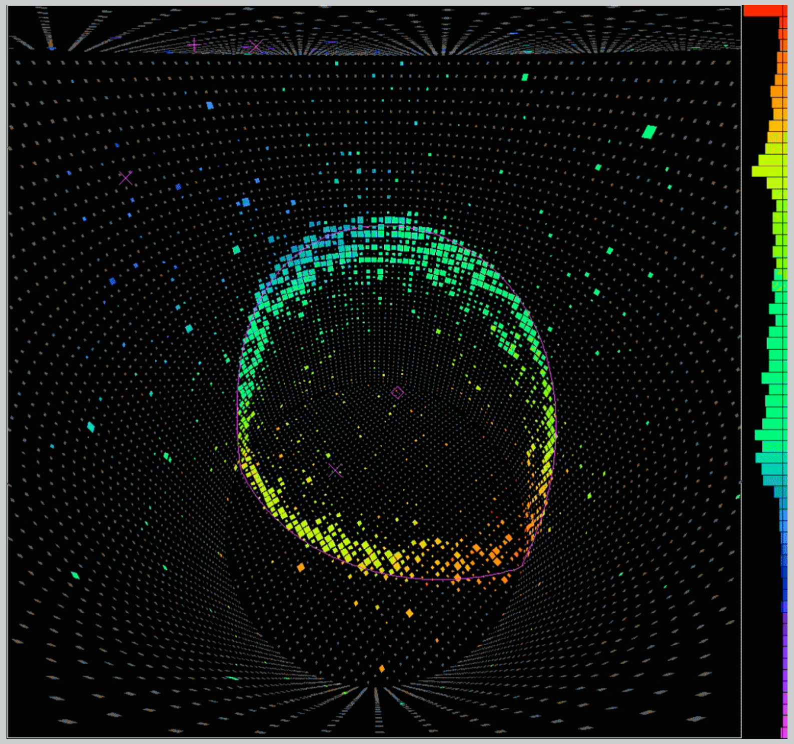


DUNE (Deep Underground Neutrino Experiment)

LArTPC (Liquid Argon Time Projection Chamber)





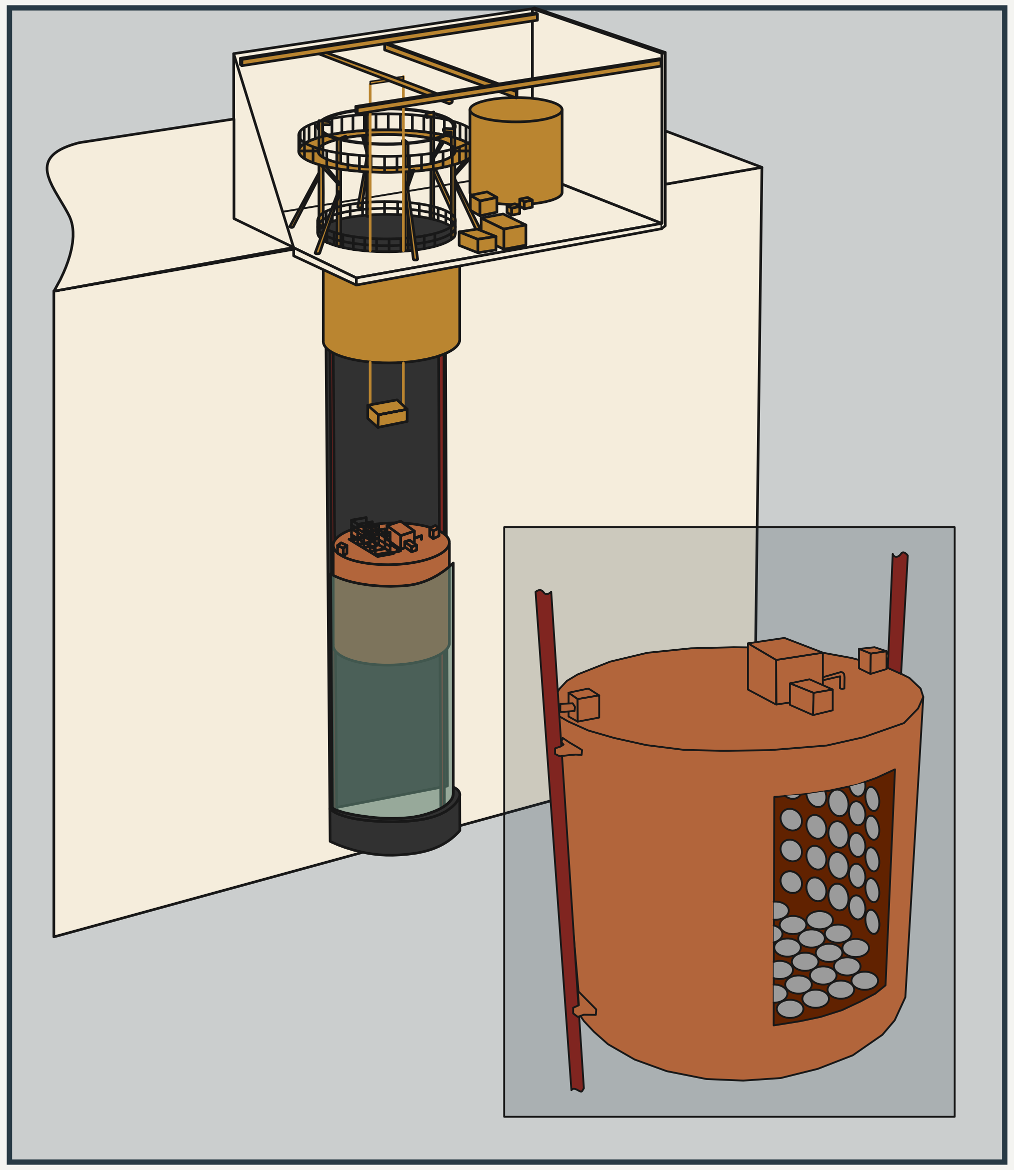


T2HK

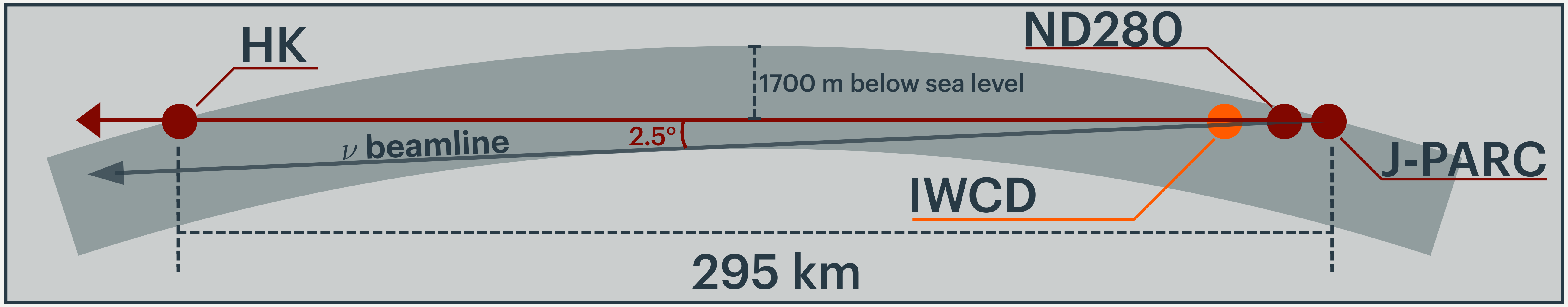
Far detector : HK - Water Cherenkov detector (~260 kton),

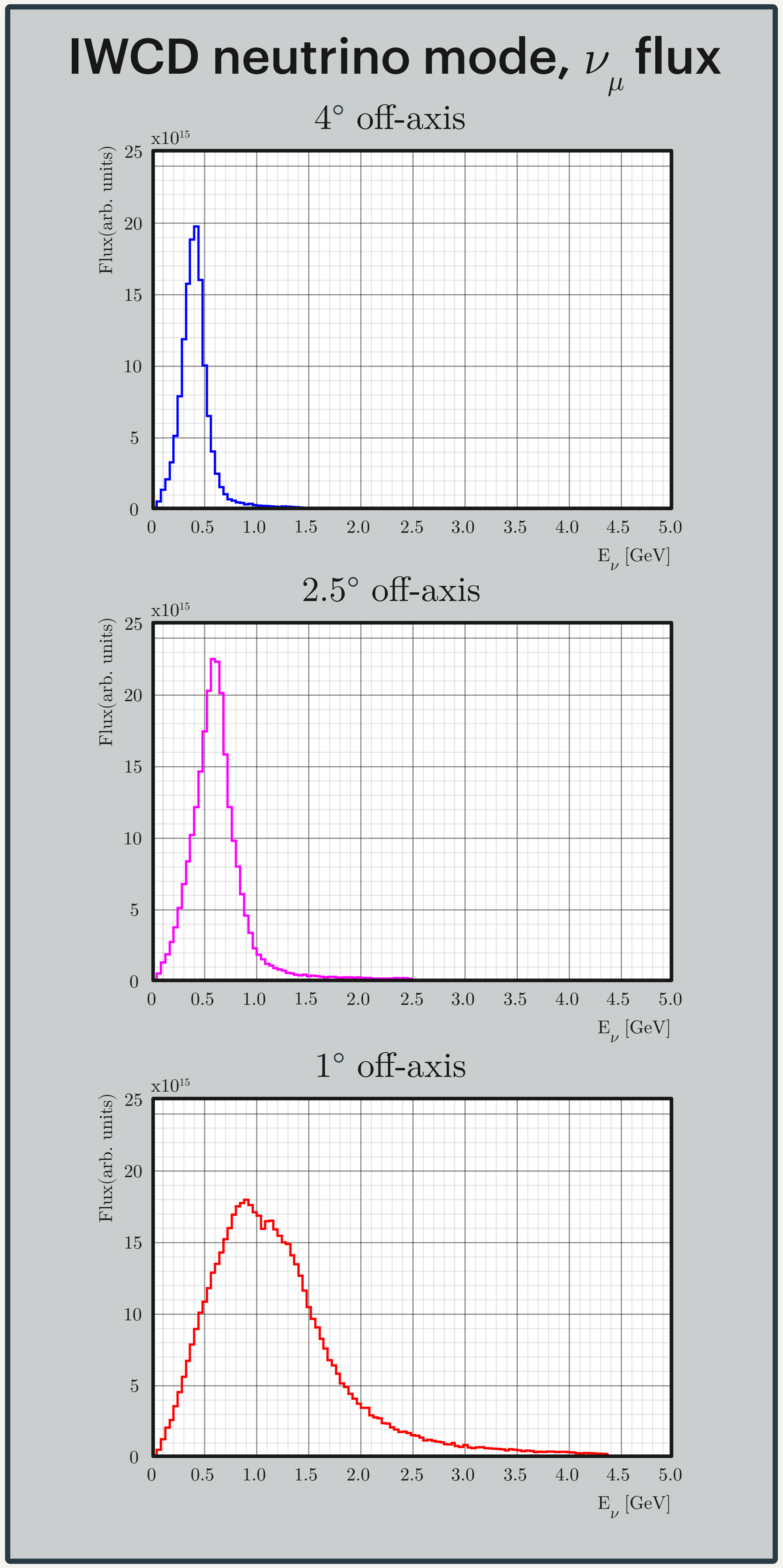
Near detector : ND280, IWCD

IWCD-PRISM : Overview



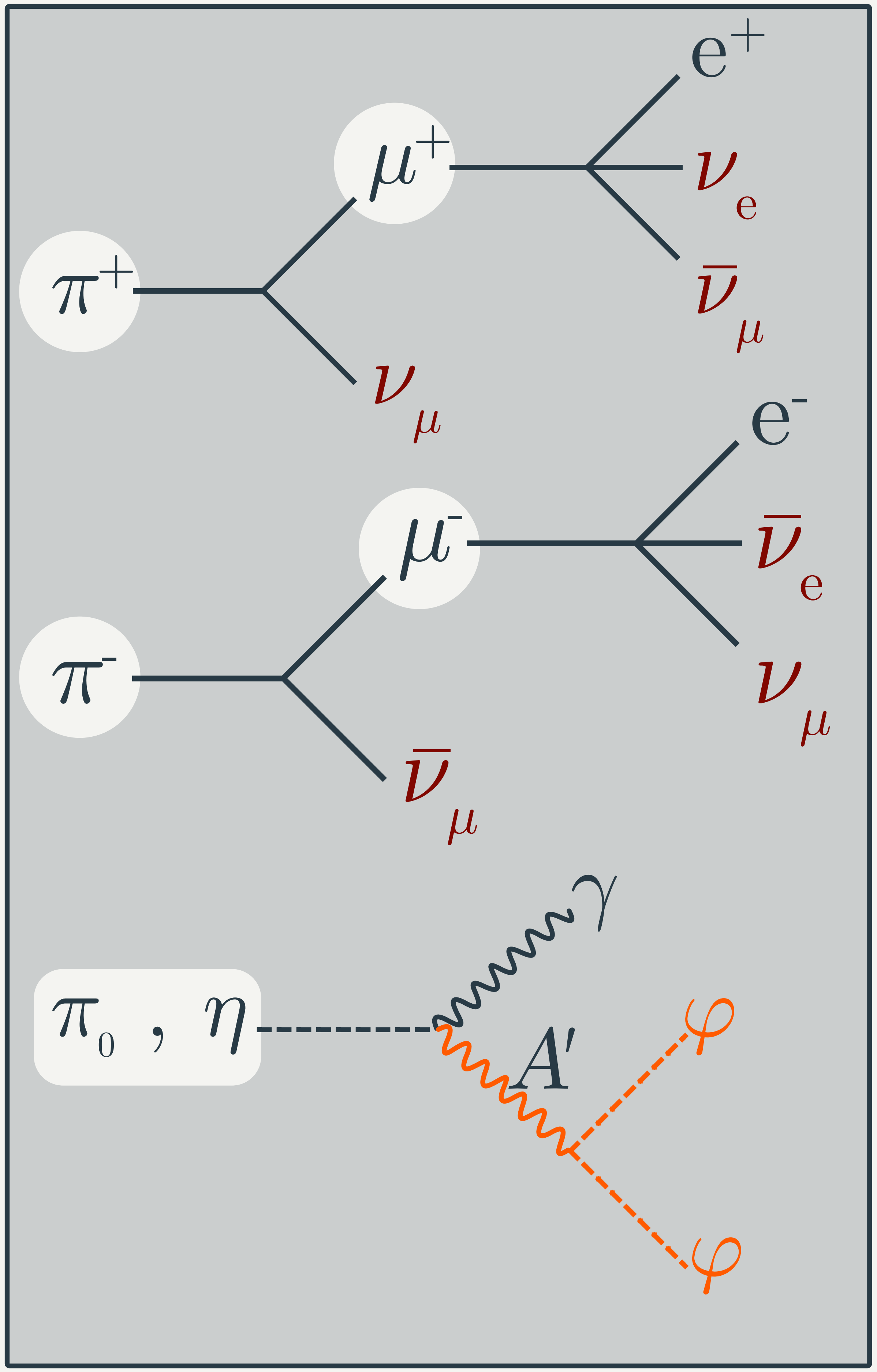
- 0.6 kt pure water Cherenkov detector
- 750 m downstream the beam
- Planned as a near detector of T2HK
- nuPRISM Feature
- (Optional) Gd-doped water





- Vertically movable feature : 1°~ 4° off axis from beamline
- Proposed to reduce significant systematic uncertainties related to the ν flux and the ν cross sections [arXiv:1412.3086]
- PRISM feature allows for focusing the analysis on the neutrino energy region of interest

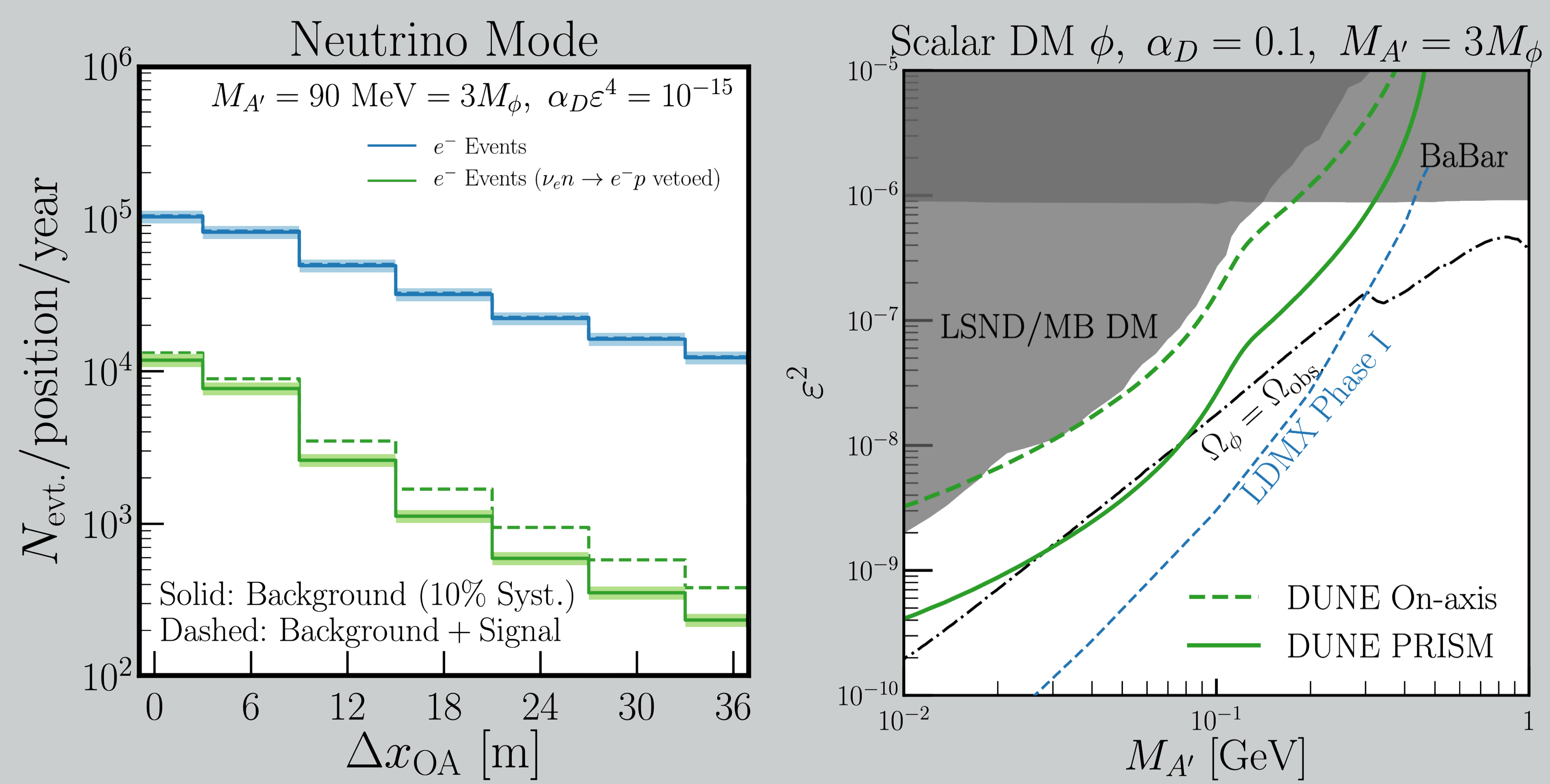
IWCD-PRISM : nuPRISM feature



- At J-PARC, a set of magnetic horns located around of the target is used to focus the charged particles, which produce the aligned ν beam
- Dark photon produced from neutral mesons are unaffected by the horns and thus have a wide, less focused distribution

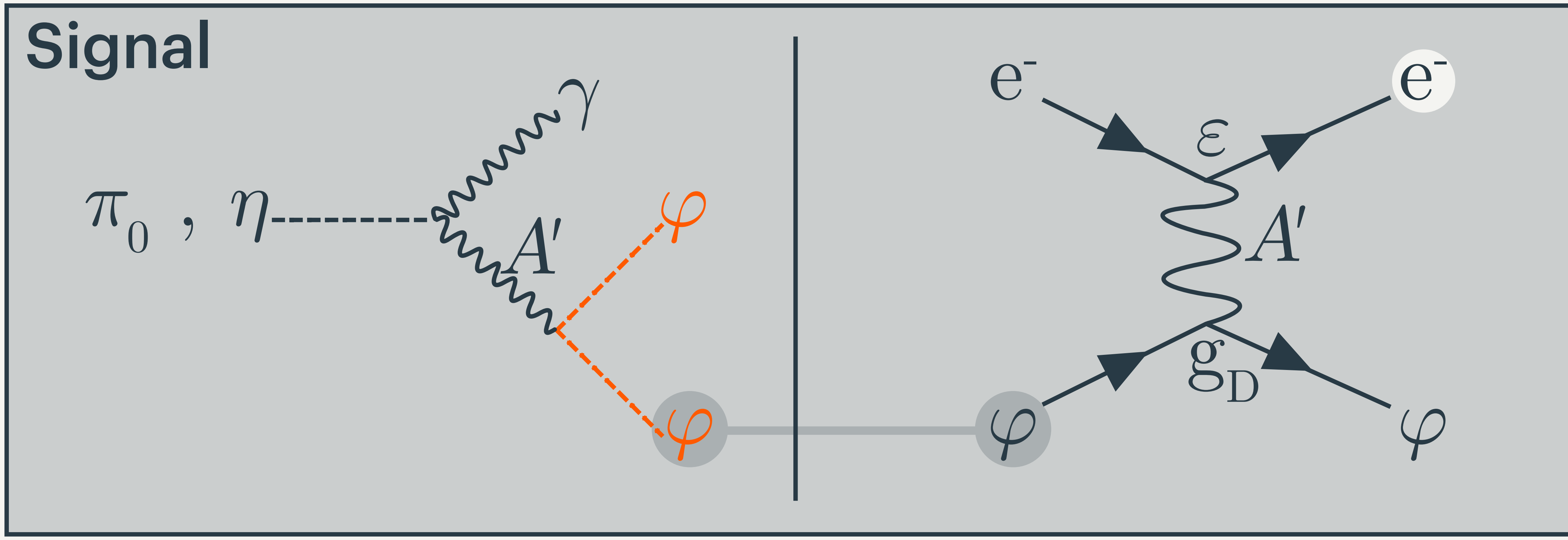
Motivation & Previous study

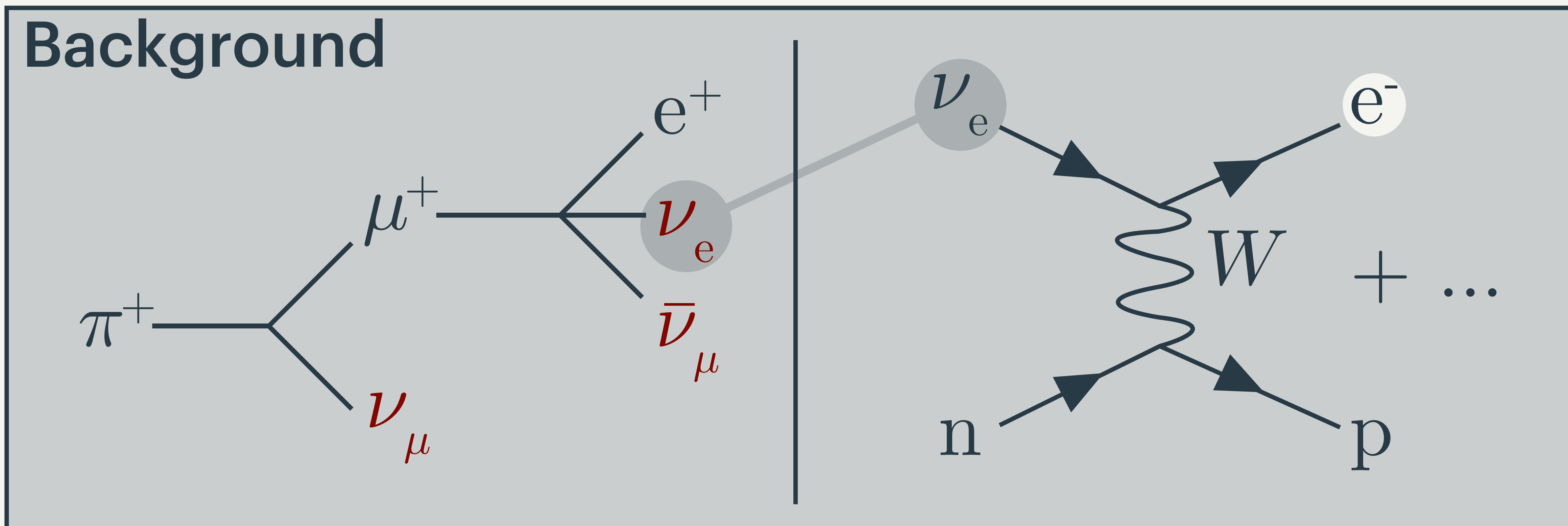
- We expect the PRISM feature to enhance the S/B ratio by reducing the background ν flux
- Correlated flux uncertainty can be controlled by data collected from multiple detector positions



[arXiv:1903.10505]

Simulation Framework





The DM signal was modeled with the BdNMC simulator, and the ν background with the GENIE event generator

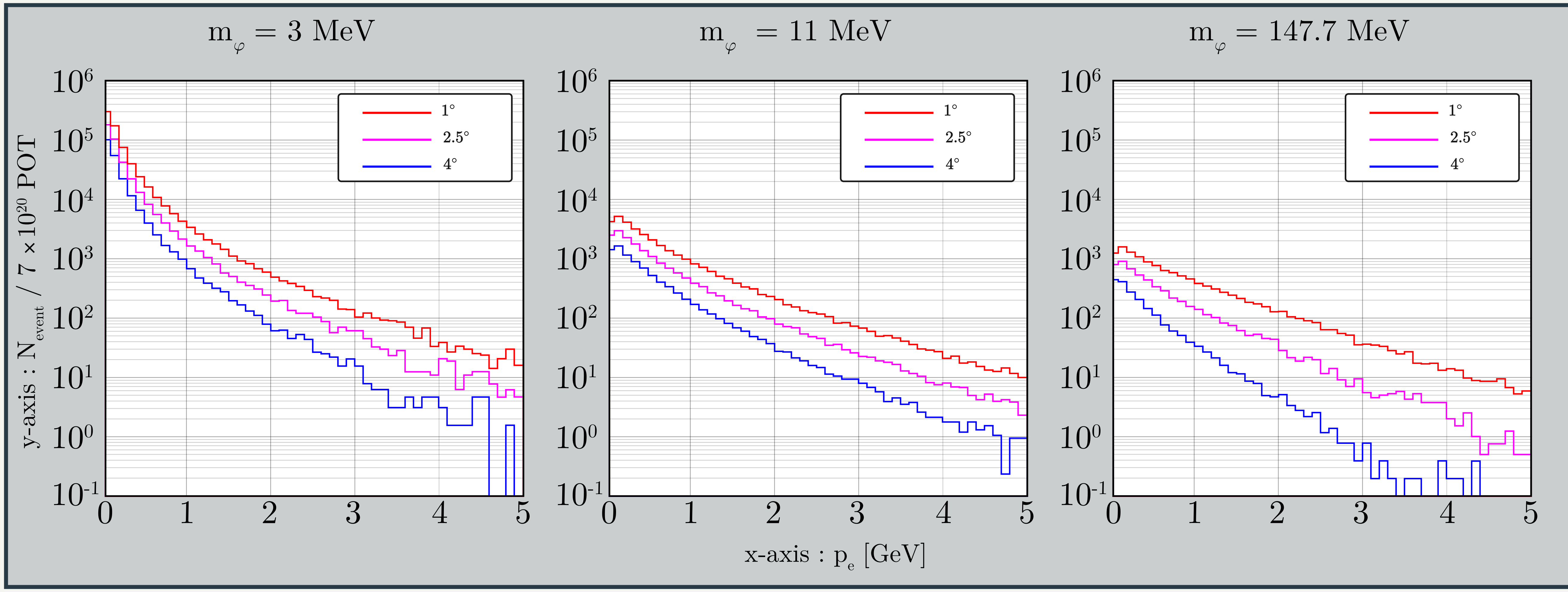
Signal simulation : BdNMC code [arXiv:1609.01770]

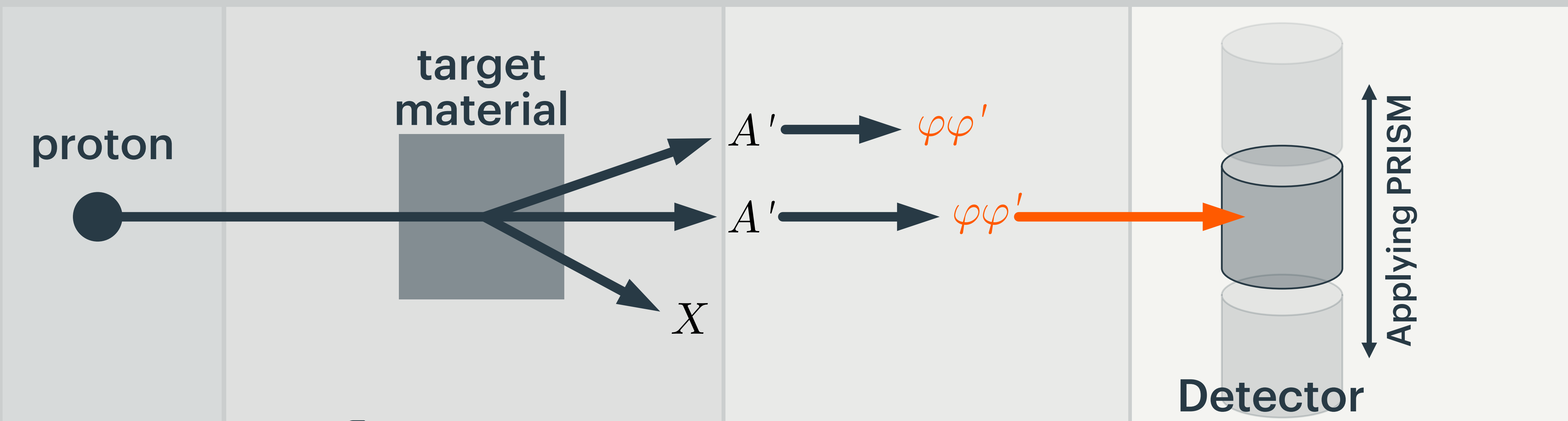
- m_{DM} : 3 ~ 266.6 MeV
- offset : 1°, 2.5°, 4°
- 10^8 trial / 7×10^{20} POT
- dark photon model* (Scalar DM)
- proton beam energy : 30 GeV
- Only considered π, η decay (BMPT model for π)

* Lagrangian

$$\alpha_D = \frac{g_D^{\ 2}}{4\pi} = 0.1,\ m_{A'} = 3m_{\varphi}$$

Signal simulation : BdNMC code[arXiv:1609.01770]

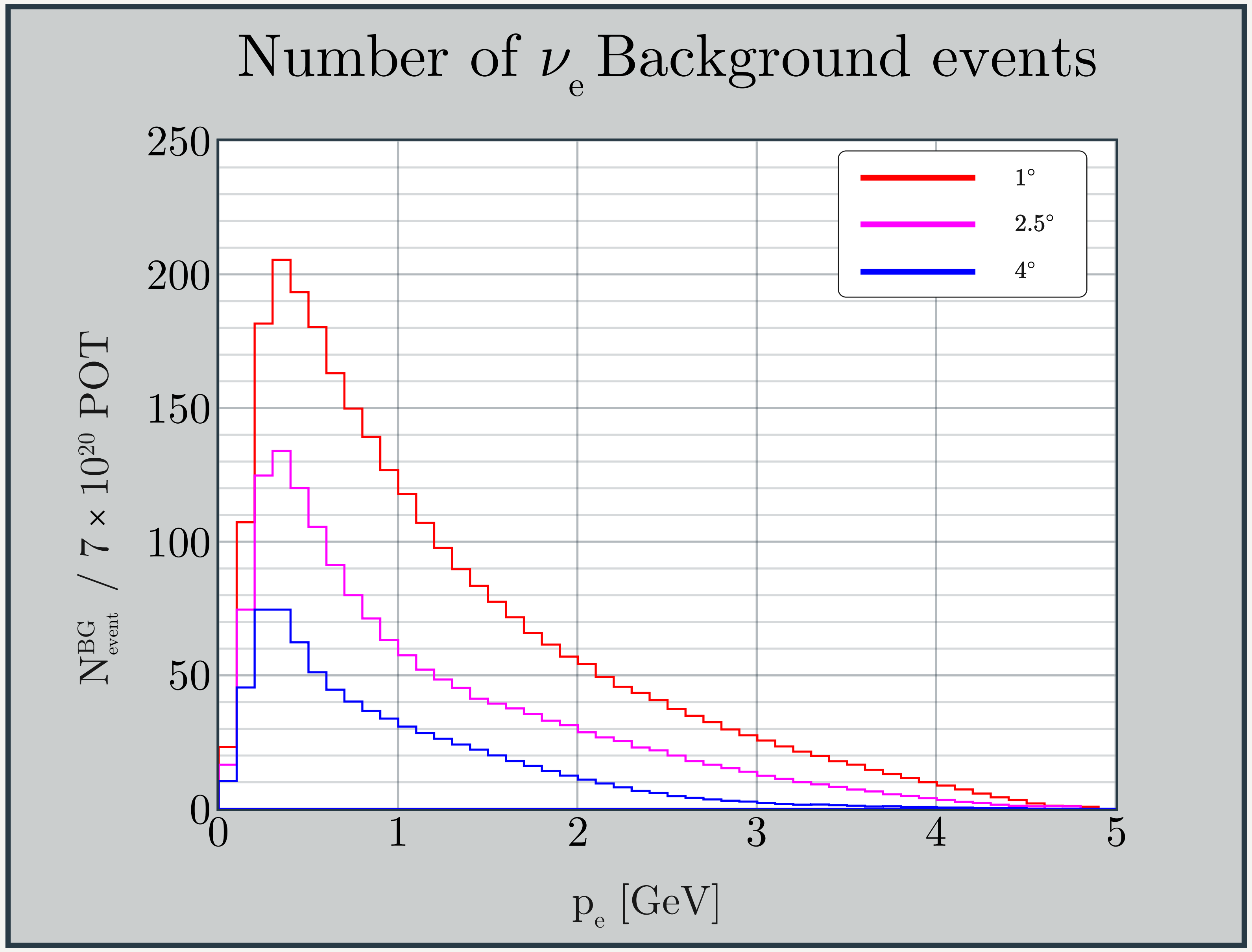




$$\frac{1}{\text{trial}} \times \frac{\sigma_{pN \to A' + X}}{\sigma_{pN}} \times \text{POT} \times \text{Br}(A' \to \varphi\varphi') \times P_{max} \times \eta \times n_{interactions}$$

Background simulation : GENIE [arXiv:0910.2517]

- Inject ν_e flux calculated by T2HK collaboration. [theses.hal.science/tel-03935726]
- Only considered ν_e induced electrons as background
- All interaction channels (CCQE dominated)
- Normalized by convoluting CCQE cross-section

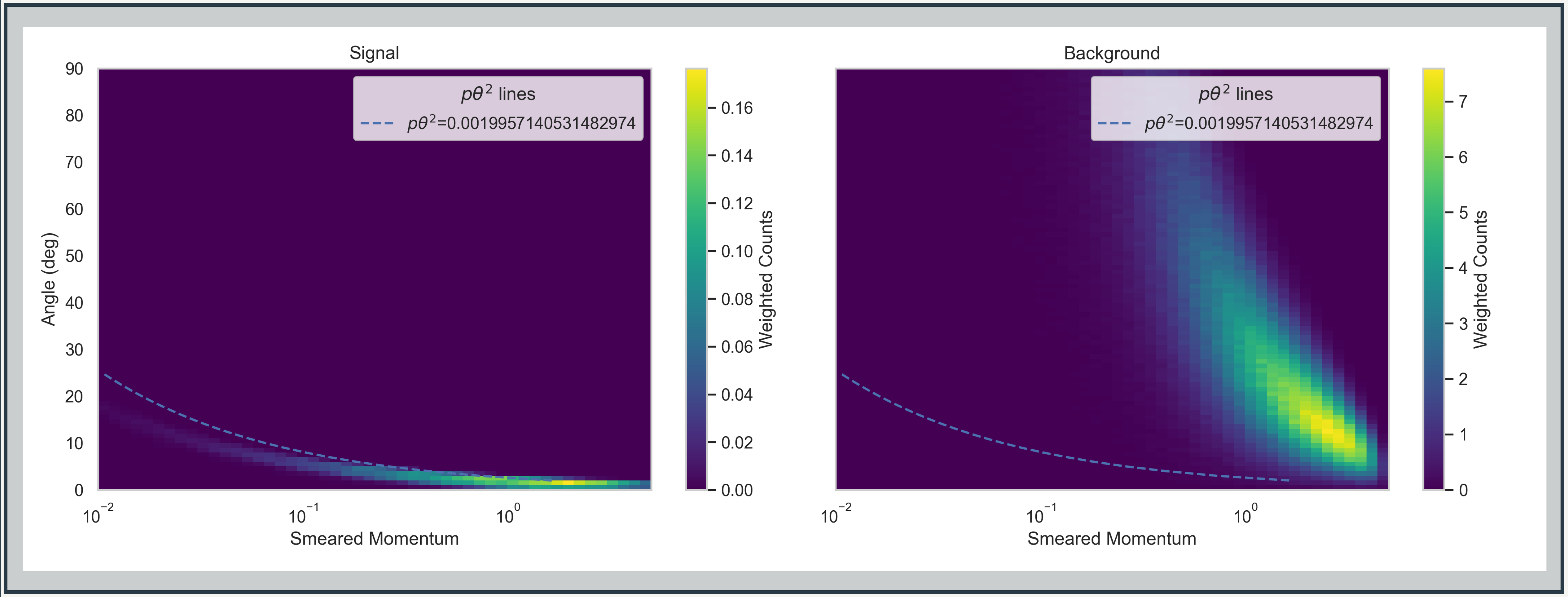


Log-likelihood fitting

$$\mathscr{L}_{ij} = -\left(\left(\frac{\epsilon}{\epsilon_0}\right)N_{ij}^{\phi} + N_{ij}^{\nu}\right) + N_{ij}^{\nu}\ln\left(\left(\frac{\epsilon}{\epsilon_0}\right)N_{ij}^{\phi} + N_{ij}^{\nu}\right) - \ln(N_{ij}^{\nu}!)$$

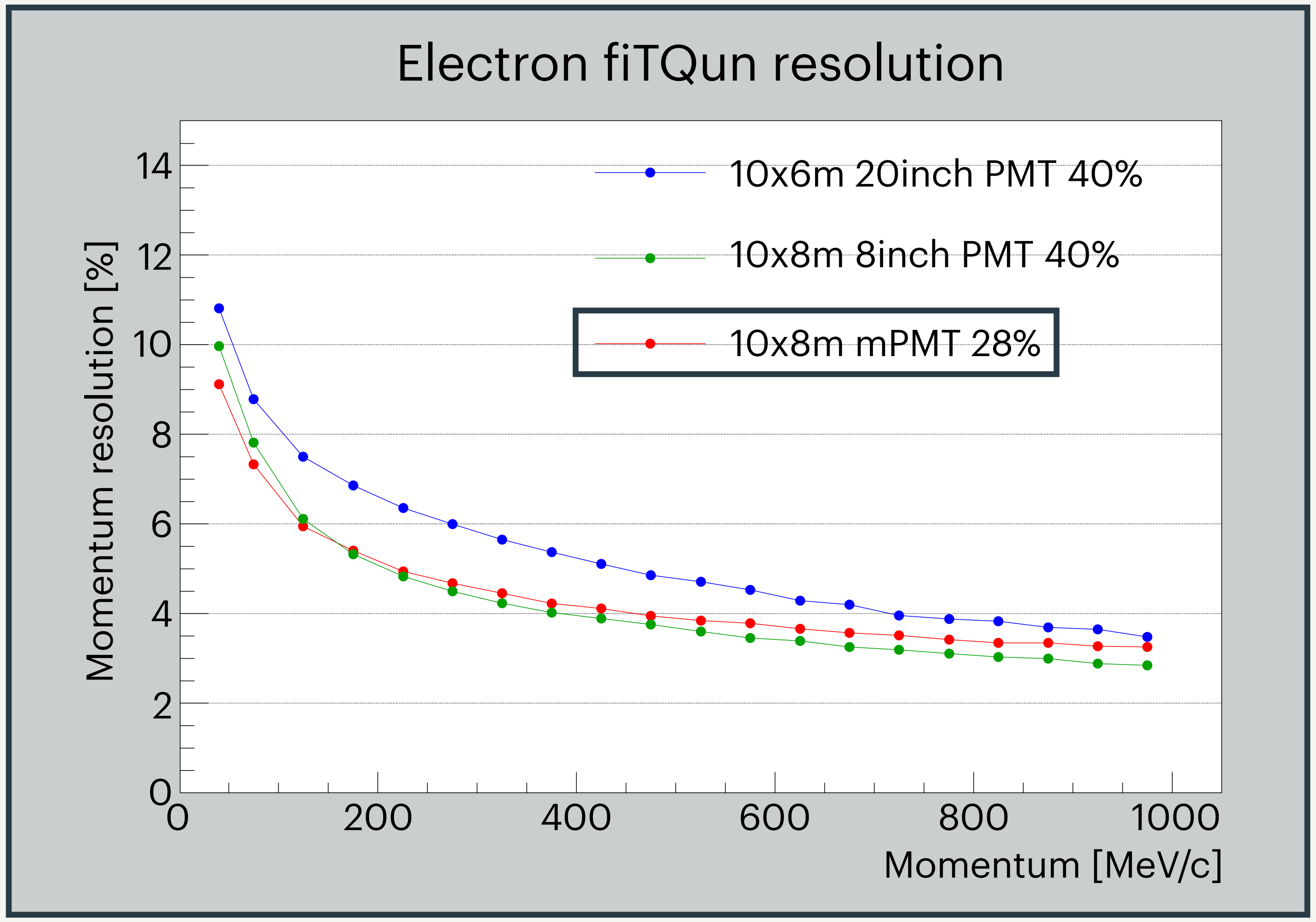
- 2-dimensional likelihood (location : 3 bins, E : 50 bins)
- Assumed Poisson distribution
- Fitted expected background (Asimov data set) with signal + background for 7×10^{20} POT
- Using $\mathrm{p}\theta^2$ cut to reduce background
- Including momentum resolution & position-dependent systematic uncertainties is evaluated to test robustness

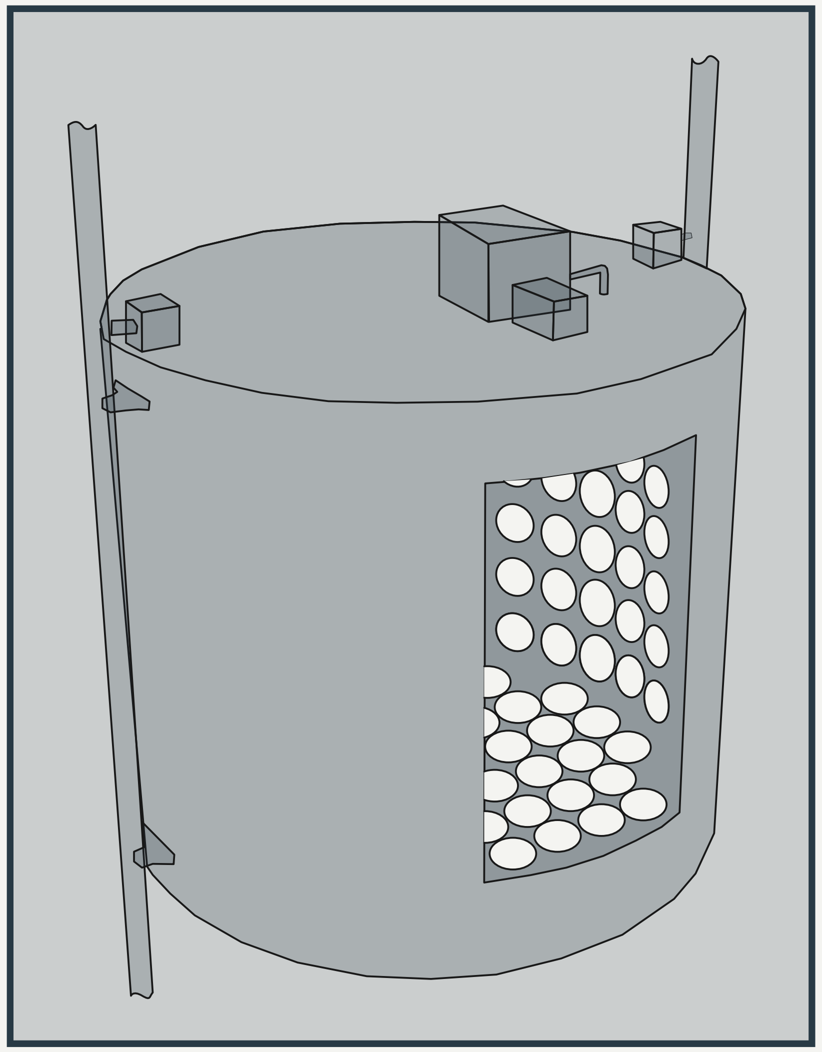
Log-likelihood fitting : $p\theta^2$ cut



- $p\theta^2$ is useful to analyse momentum-angle correlation and remove large portion of background
- Using $p\theta^2$ cut (90% signal) remaining bkg : 0.2% ~ 1.5%

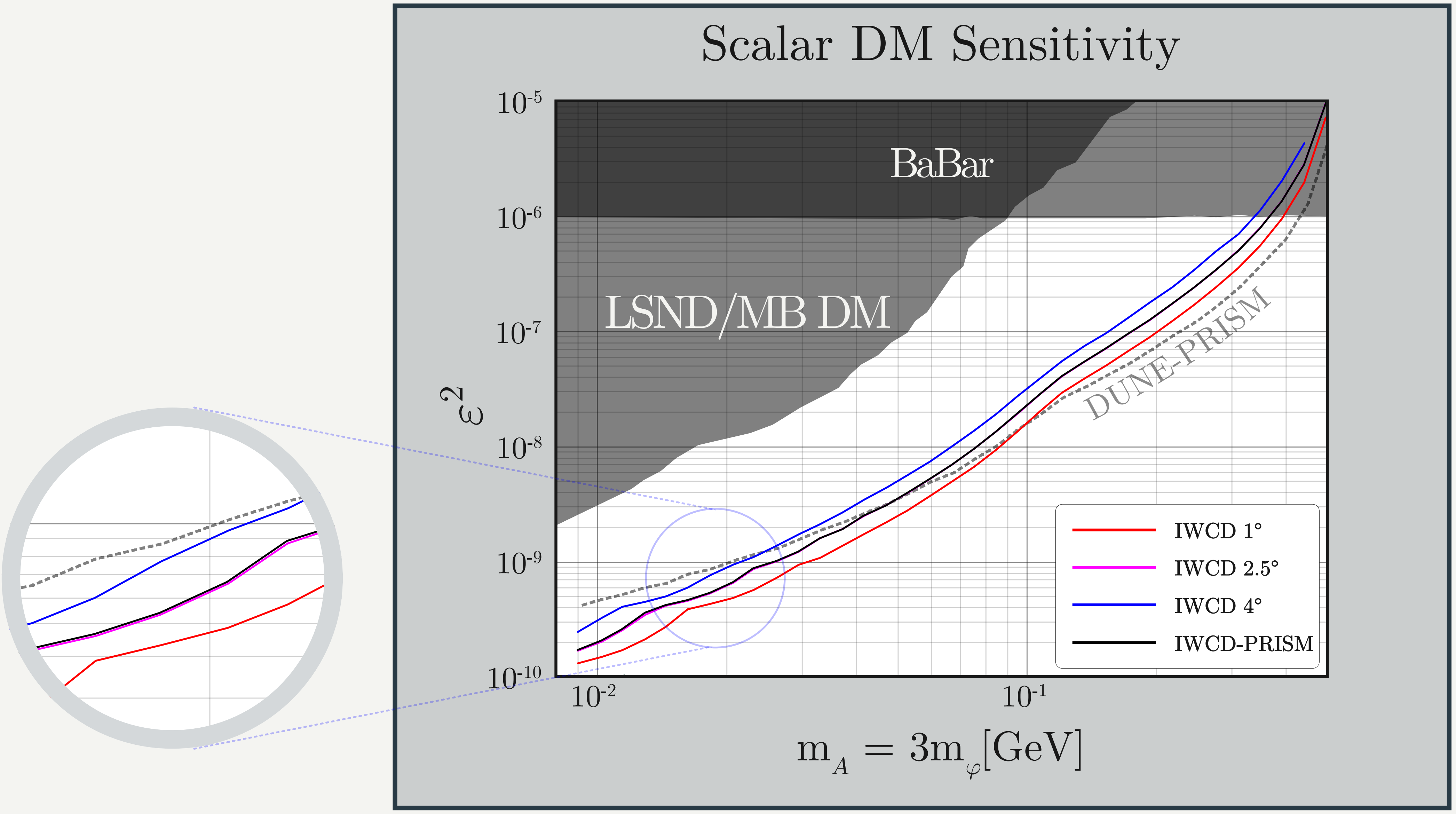
Log-likelihood fitting : Realization





- Smearing: Apply fiTQun momentum resolution tuned to the IWCD's mPMT layout to obtain reconstructed-level spectra
- Likelihood: Calculation log-likelihood with 20% position dependent systematical uncertainties and 10% overall normalization uncertainties

Log-likelihood fitting : Limit plot



- At high mass range, DUNE has advantage due to higher energy proton beam
- IWCD(7×10^{20} POT) shows better sensitivity than DUNE (1.1×10^{21} POT) in the low energy range

* DISCLAIMER : Exact IWCD statistical error not yet applied

Conclusion

Summary

- We study IWCD-PRISM sensitivity for dark matter search
- With spectral information, taking data at on-axis position shows the best sensitivity
- The $\mathrm{p}\theta^2$ cut is useful for reducing background
- Including momentum smearing based on PMT's momentum resolution
- IWCD shows better sensitivity at low energy range compared to DUNE-PRISM

Future improvement

- Angular resolution
- Exact systematic error
- Additional production channel (proton bremsstrahlung, etc.)