Discovering LLPs at DUNE: Background study

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Goals

- Previous studies assumed negligible backgrounds from neutrino interactions. We evaluated this assumption using basic selection cuts on event kinematic variables.
- We studied both ND argon detectors. While ND-GAr appears to be the better detector for rare-decay searches (similar volume, smaller background rate), ND-LAr will start taking data much earlier.
- No reconstruction involved here. Detector effects (resolution, efficiency, etc.) are considered using CDR predictions or published measurements from similar detectors (e.g., MicroBooNE).

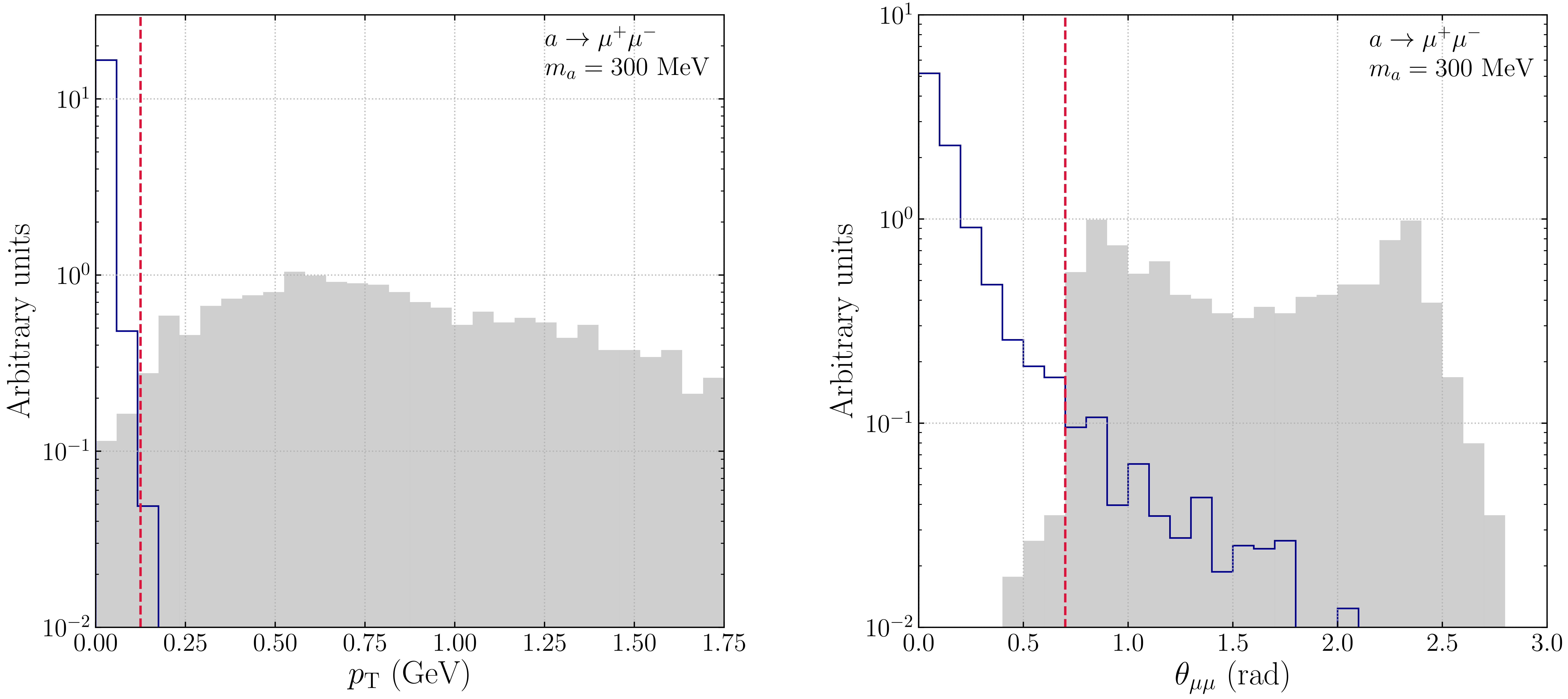
Data production

- Signal events:
  - Distribution of parent mesons from public flux files (for kaons) or dedicated Pythia production (for D mesons).
  - Meson decay to LLP, propagation to NDs and LLP decays done with our own code.
- Background events:
  - Public flux files (histograms) from TDR.
  - Large set of neutrino-argon interactions generated with GENIE.

Di-muon decay channel

- Main background are CC events with charged pions.
- **1st cut:** Two muon-like (i.e., muons or charged pions) tracks only.
  - Different detection thresholds considered for LAr and GAr.
- **2nd cut:** PID and charge measurements.
  - ND-GAr excels at this up to very high momenta.
  - For ND-LAr, we assume that this measurement is done with the help of the TMS, but this reduces the acceptance significantly.
- **3rd cut:** Transverse momentum.
- **4th cut:** Angle between muon tracks.

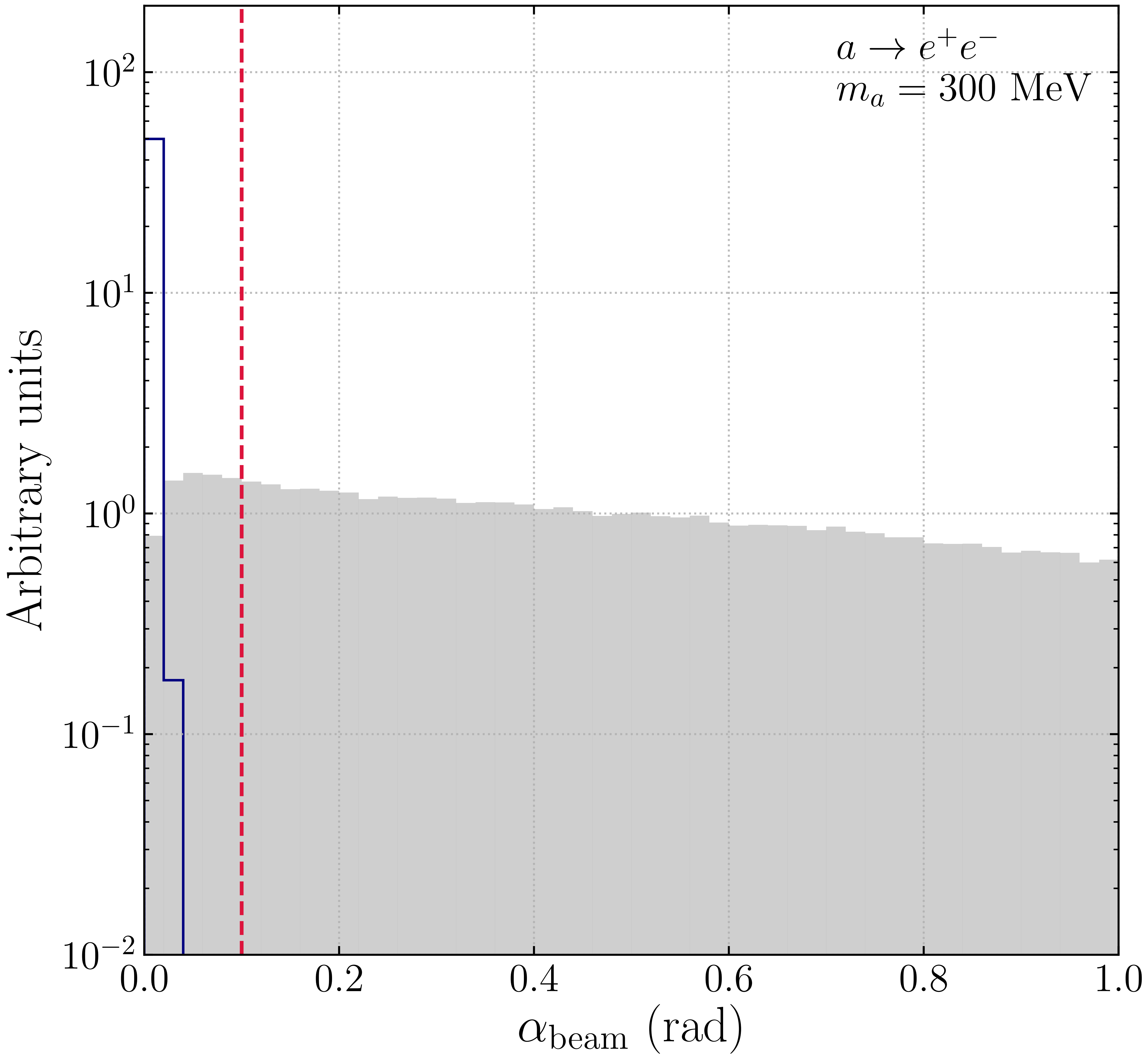
Di-muon decay channel



Electron-positron decay channel

- Main background: single-photon conversion from neutral pion decays.
- Conservative estimation of ND-LAr reconstruction efficiency based on MicroBooNE.
- **1st cut:** Two electron-like tracks/showers in TPC.
  - We estimated the conversion efficiencies for both LAr and GAr.
- **2nd cut:** Reconstructed LLP direction pointing back to target.
- **3rd cut:** The angle between the tracks/showers cannot be used in this case, as the electron and the position produced in the gamma conversion have similar opening angle to signal events.

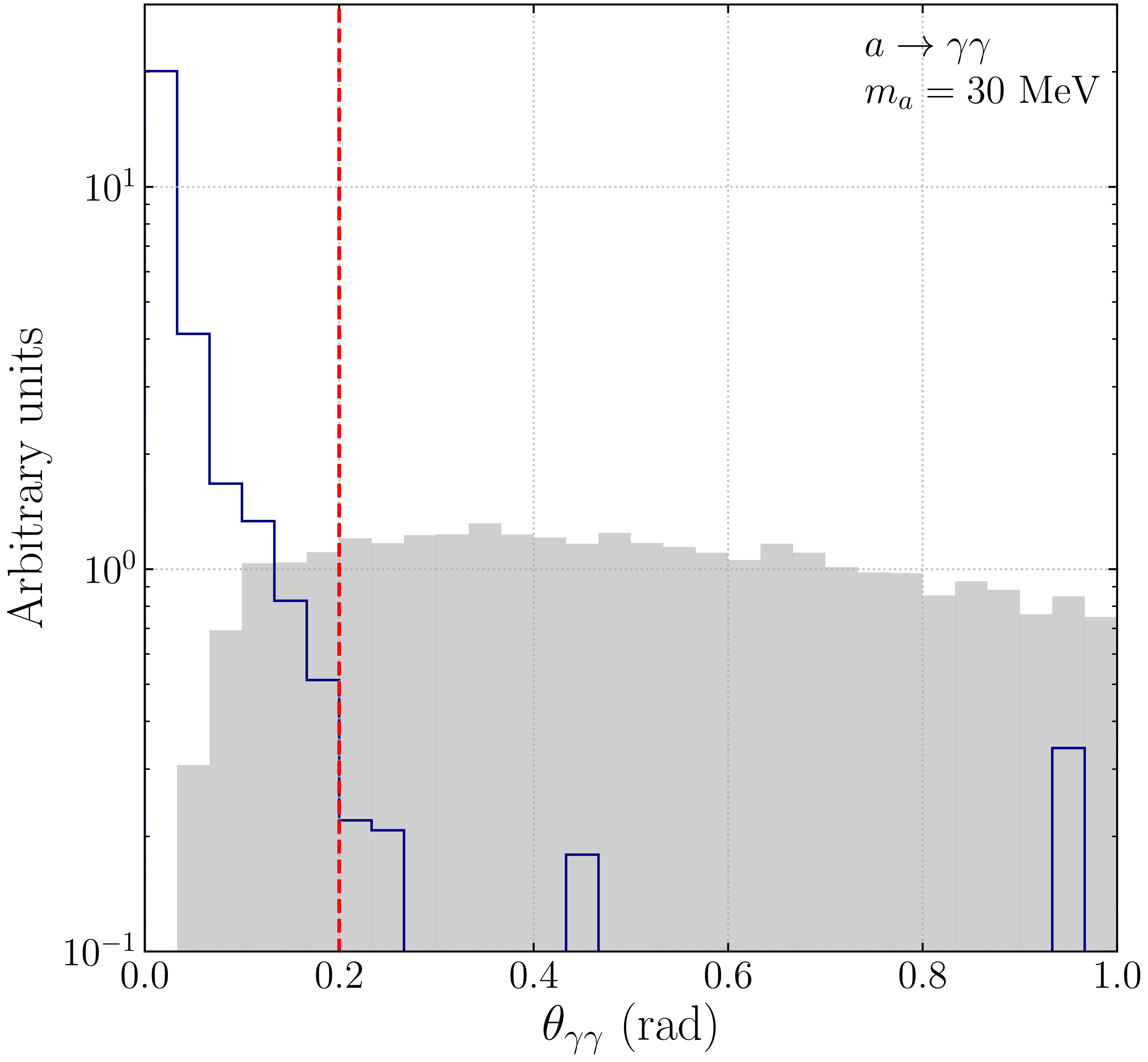
Electron-positron decay channel



Di-photon decay channel

- Main background: neutral pion decays.
- Conservative estimation of ND-LAr reconstruction efficiency based on MicroBooNE.
- **1st cut:** Two photon showers in detector.
  - In the case of ND-GAr, we use exclusively the ECAL.
- **2nd cut:** Reconstructed LLP direction pointing back to target.
- **3rd cut:** Angle between showers.
  - Poorer resolution in the case of ND-GAr.

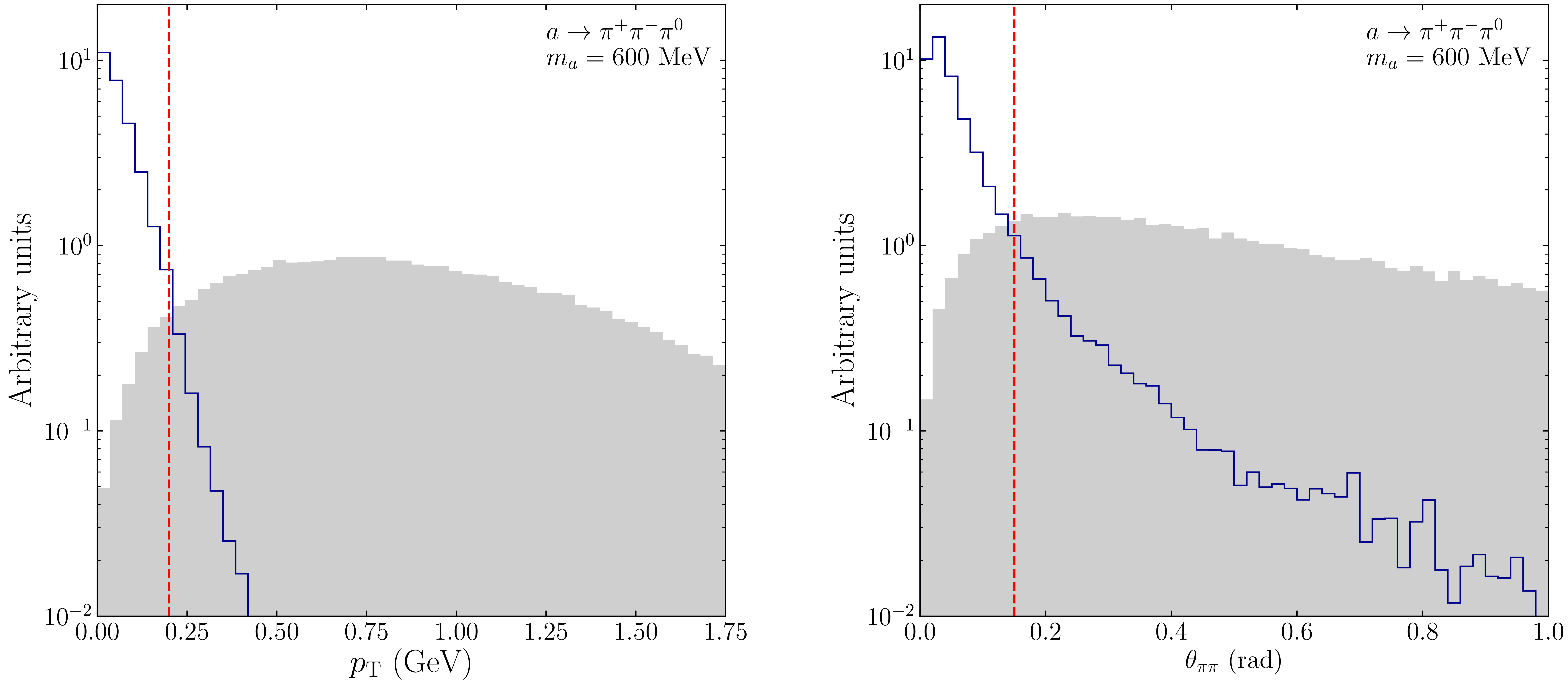
Di-photon decay channel



Tri-pion decay channel

- **1st cut:** Two muon-like (i.e., muons or charged pions) tracks and 2 photon showers.
- **2nd cut:** PID and charge measurements.
- **3rd cut:** Transverse momentum.
- **4th cut:** Angle between charged pion tracks.

Tri-pion decay channel



Results

TABLE I. Signal efficiencies and background event rates for the different decay channels, before and after event selection according to the cuts discussed in the main text. Results are shown separately for the two DUNE near detectors considered. Background event rates are provided per year, and for the total fiducial volume considered for each detector. We highlight in bold type the large backgrounds expected for some of the decay channels, as well as the reduced LAr ND signal efficiencies for most decay channels considered.

	Selection cut	Signal efficiency		Background rate	
		ND-LAr	ND-GAr	ND-LAr	ND-GAr
$\mu^+\mu^-$	Two μ-like tracks only	1.00	1.00	3545674	70656
	PID μ and opposite charge sign	0.40	1.00	6226	124
	Transverse momentum < 0.125 GeV/c	0.40	0.99	99	2
	Angle between muons < 0.7 rad	0.40	0.94	0	0
e^+e^-	Two e-like tracks/showers	0.10	1.00	9432	145
	Reconstructed ALP direction	**0.10**	0.99	180	15
$\gamma\gamma$	Two γ showers only	0.05	0.79	36276	14222
	Reconstructed ALP direction	0.05	0.79	6938	**7923**
	Angle between γ showers	**0.05**	—	**1367**	—
$\pi^+\pi^-\pi^0$	Two μ-like tracks, two γ showers	0.04	0.81	2030490	40462
	PID $\pi^\pm$ and charge sign	0.04	0.81	431035	8589
	Transverse momentum < 0.2 GeV/c	0.04	0.79	17182	342
	Angle between pions < 0.15 rad	**0.04**	0.69	**946**	19

Conclusions

- Only the di-muon decay channel appears to be background-free.
- ND-GAr better, in general, than ND-LAr except for the di-photon channel (in which we rely entirely on the ECAL).
- Conservative estimation of selection efficiencies. Full simulation and reconstruction required to improve this.