Real-time intelligent data processing for the next generation of particle imaging detectors

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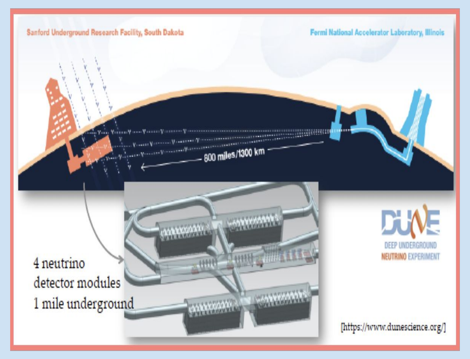
on behalf of the MicroBooNE, SBND and DUNE Collaborations

Snowmass Summer Meeting July 17-26, 2022

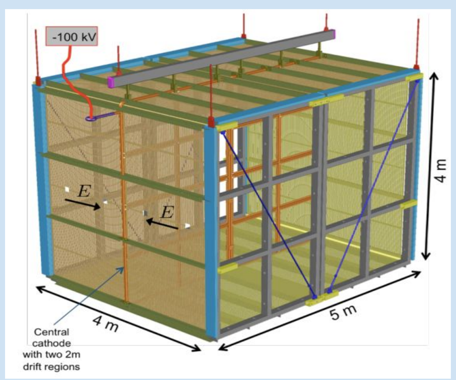
Particle Imaging Detectors

Next Generation- Deep Underground Neutrino Experiment (DUNE)



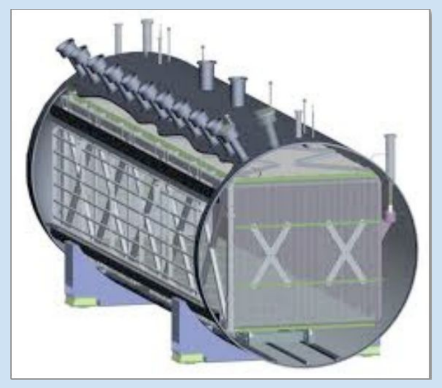
Expected data rates: 5TB/s
Expected to be Operational by 2030

Current Generation- Short Baseline Near Detector (SBND)



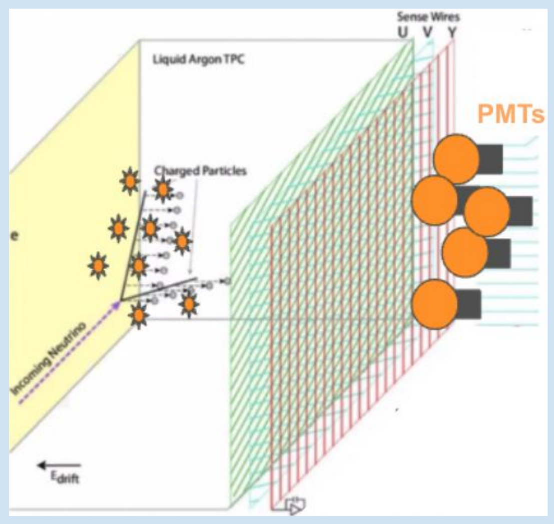
Expected data rates: 45GB/s
Expected to be Operational by 2023

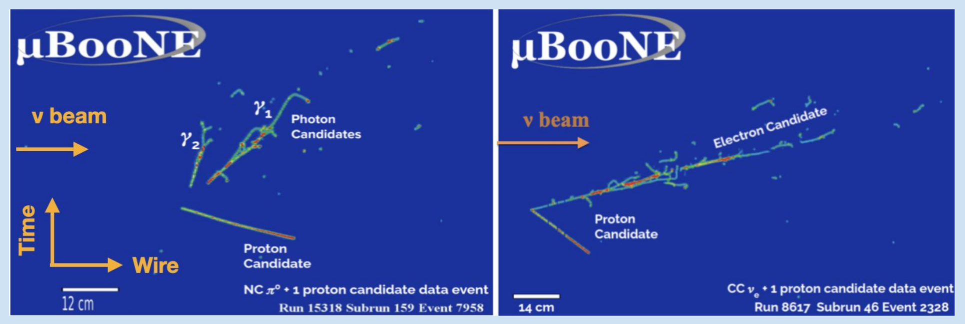
Past Generation- MicroBooster Neutrino Experiment (MicroBooNE)



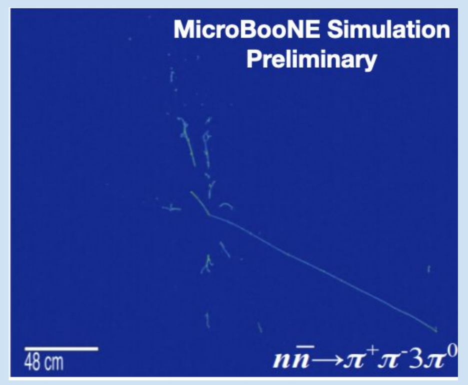
Data rates: 33 GB/s
Data taking: 2015-2021

Liquid Argon Time Projection Chamber (LArTPC) detectors



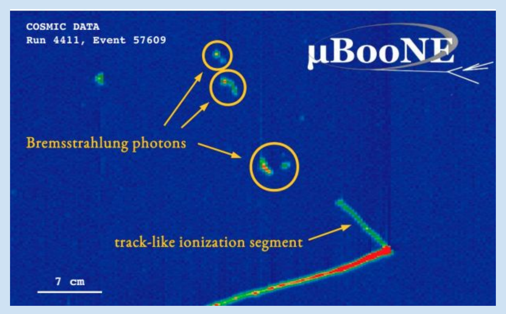


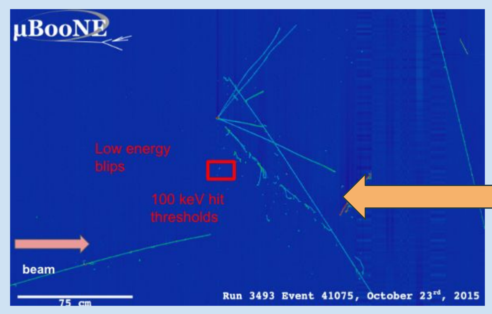
Excellent resolution



Rare physics processes: **baryon number violation**

Rich off-beam physics program



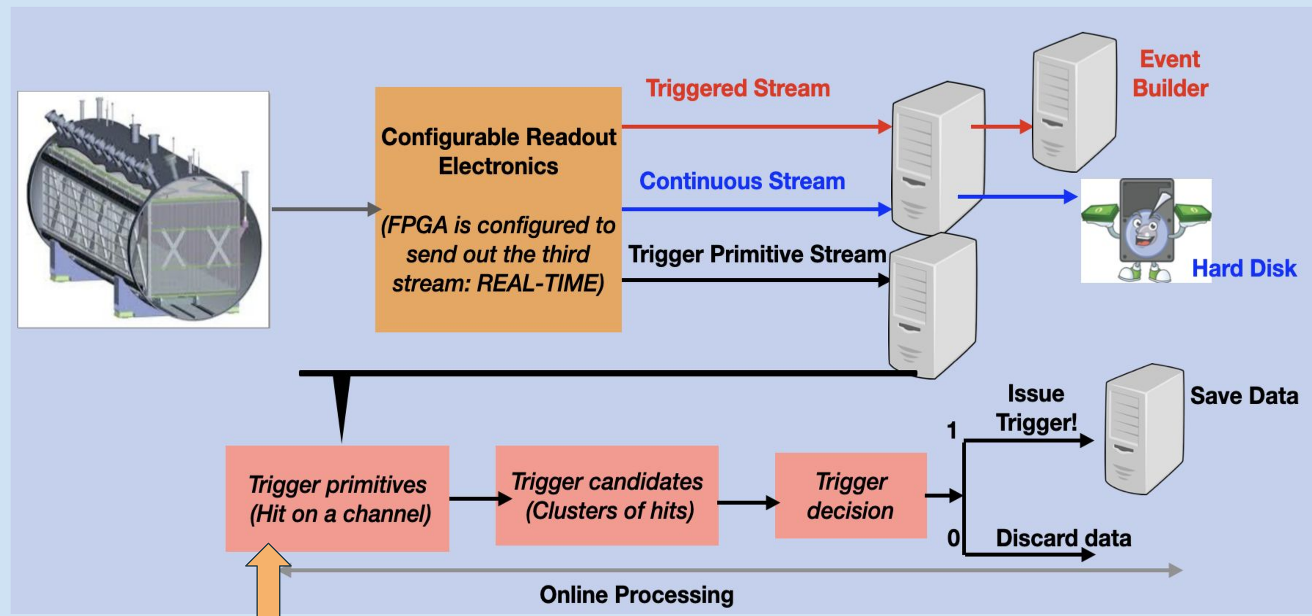


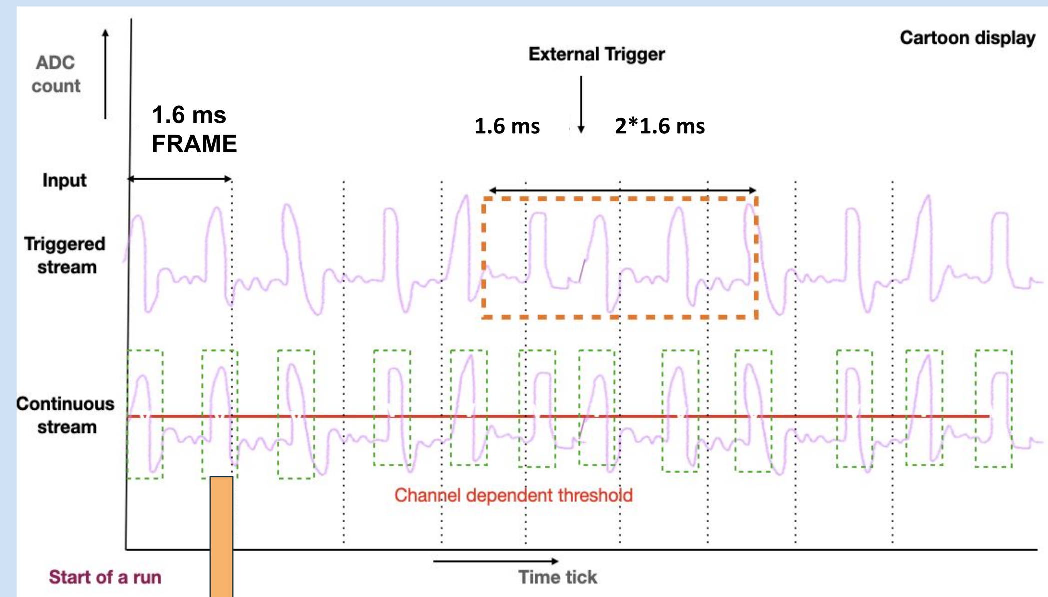
Low energy blips

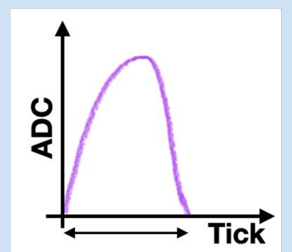
Data Processing Schemes

- For DUNE, processing > 5TB/s data would be computationally challenging
  - Requires intelligent data-processing and data-reduction schemes.

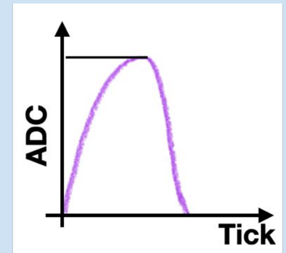
TPC-based trigger - Currently being demonstrated with MicroBooNE, soon with SBND



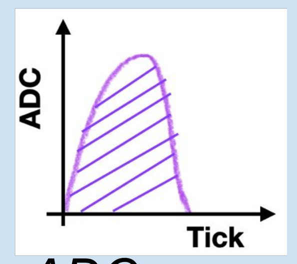




Time over threshold

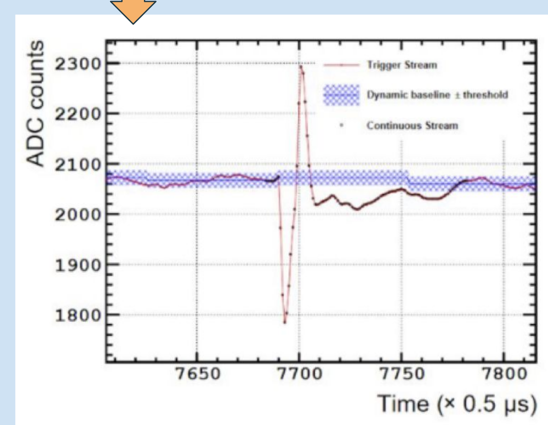


Maximum amplitude



ADC Integral

Summary of ionisations per wire

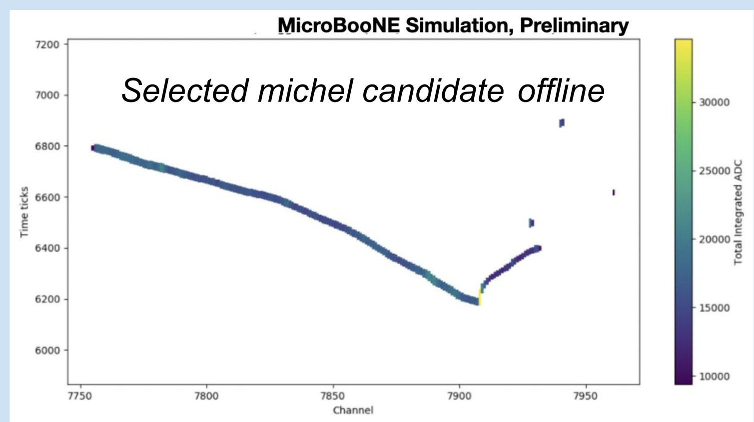


Zero-suppressed waveform [2]

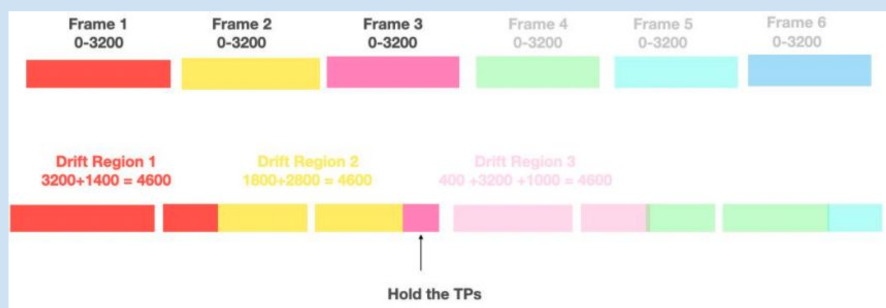
- The TPC-based trigger can be used to trigger on any off-beam activity including rare signals.
  - Future possibility includes triggering on some of the on-beam activities.

On-going Development and Demonstration

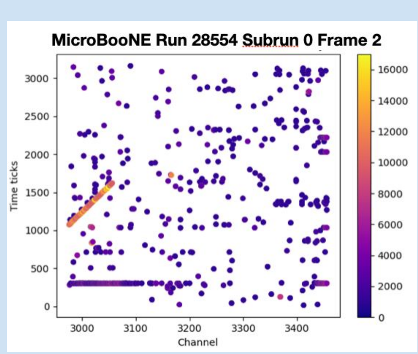
- Offline development and validation using MicroBooNE data.
- Developed trigger to tag Michel electron topology.
- Used **topological** *(change in directionality)* and **calorimetric** *(energy in Bragg peak)* information.
- 2% efficiency in selecting such events



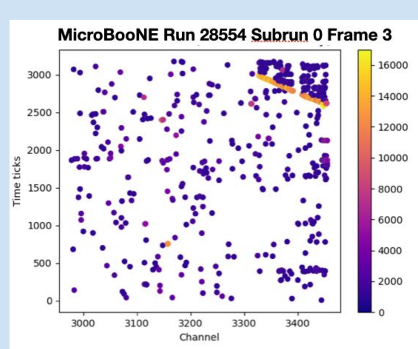
Online Processing begins with generating drift regions (2.3ms Event) from frames (1.6 ms)



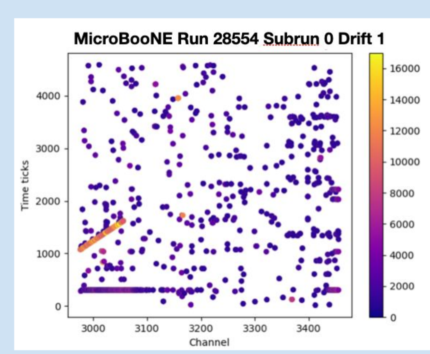
FRAME NUMBER 2



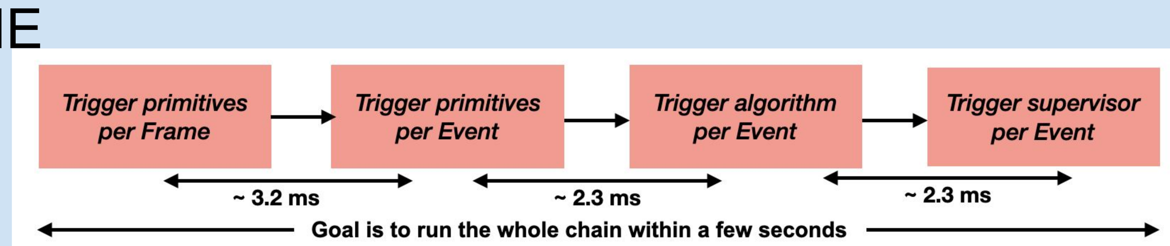
FRAME NUMBER 3



DRIFT 1



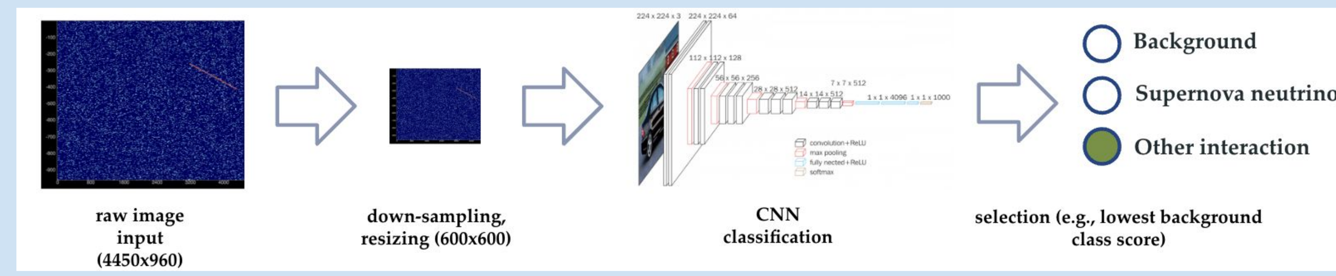
Following DUNE strategy [1]

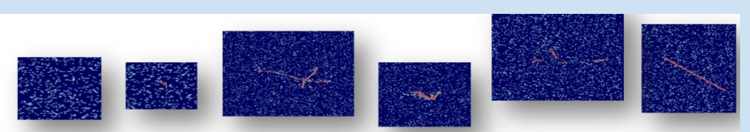


Future Possibilities

- Implement TPC-based trigger in SBND with a future goal of deploying in DUNE.
  - Utilize machine learning (ML) tools to target low and high energy activities with higher efficiency → demonstrated with DUNE simulated images of interactions

Uses CNN with VGG16 network architecture for image classification





"empty" score cut	"empty" eff.	SN eff.	n-nbar osc. eff.	atmo. eff.	p-decay eff.	cosmic eff.
0.1	0.73%	88.18%	99.98%	92.24%	99.29%	92.57%
0.01	0.14%	83.27%	99.98%	91.01%	99.18%	92.46%
0.001	0.033%	77.11%	99.98%	89.76%	99.04%	92.24%
0.0001	0.011%	69.74%	99.97%	88.39%	98.74%	91.71%

~90% decision accuracy but high latency ~5 ms to run over 2.25 ms image.

Sample	Train Size	Test Size	Accuracy (%) ϵ_{NB}	ϵ_{LE}	ϵ_{HE}	Inference Time (ms)
NB	12,023	4,027	99.53	0.47	0.12	1.6±0.1
LE	12,050	3,970	4.01	94.48	1.51	
HE	10,137	3,417	3.63	6.15	90.22	

Online inference in GPU** using smaller than VGG16 network architecture → **>3x improvement in inference time.

Fixed-point (QAT)	NB	LE	HE
true_NB	99.68%	0.32%	0%
true_LE	3.90%	94.69%	1.41%
true_HE	3.25%	6.35%	90.40%
total accuracy		95.16%	

[Y. Jwa, *et al.* arXiv:2201.05638]

- Possibility to use ML tools on specialized hardware such as FPGA **(power efficient)**

Conclusions

- Online data selection is currently being demonstrated with MicroBooNE.
- Important proof-of-principle for upcoming SBND and future DUNE experiments

References

- [1] B. Abi et al., *JINST* **15** T08010 (2020).
- [2] P. Abratenko et al., *JINST* **16** *P02008 (2021).*
- [3] Y.J. Jwa, G. Guglielmo, L. Arnold, L. Carloni, G. Karagiorgi, *Front.Artif.Intell. 5 (2022) 855184.*

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