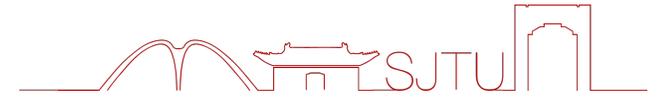




上海交通大学
SHANGHAI JIAO TONG UNIVERSITY



ECAL Energy Synthesis

Siyuan SONG

2023. Apr. 8

饮水思源 · 爱国荣校¹



1

Motivation

2

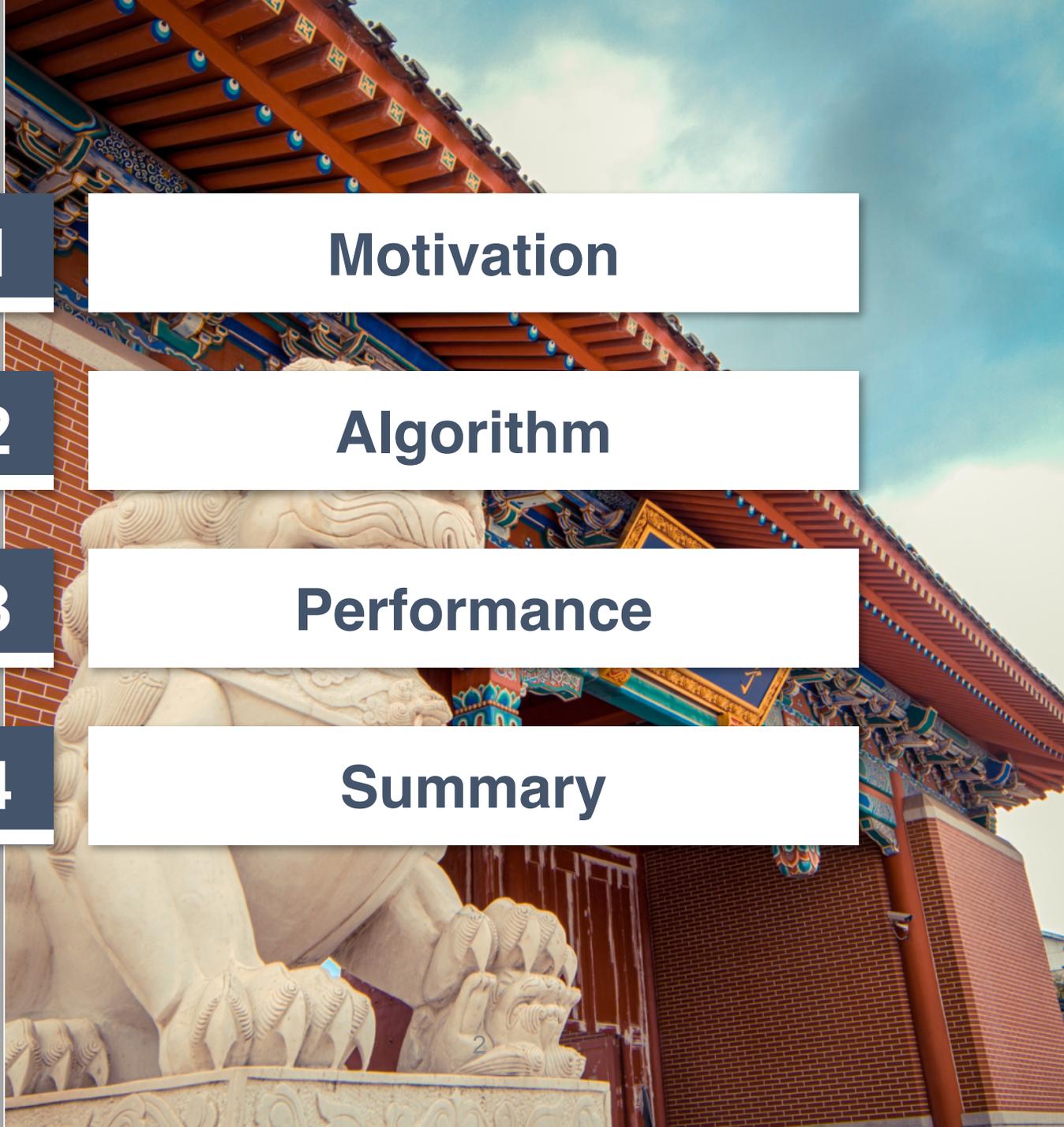
Algorithm

3

Performance

4

Summary

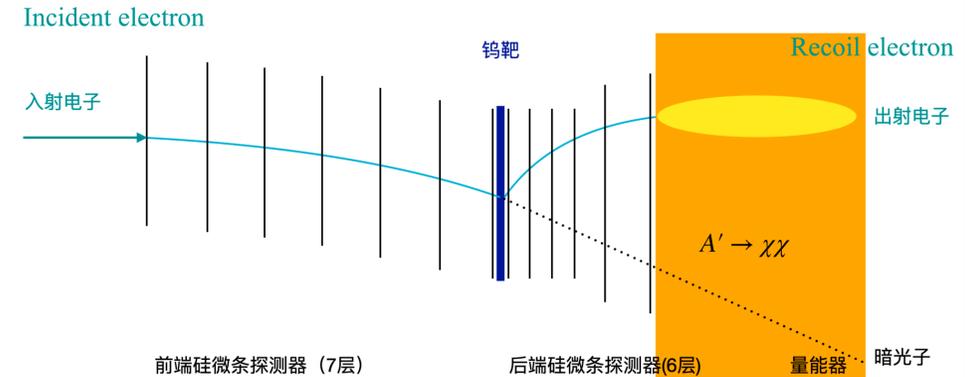
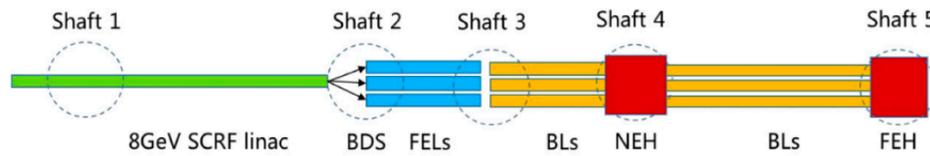




Motivation



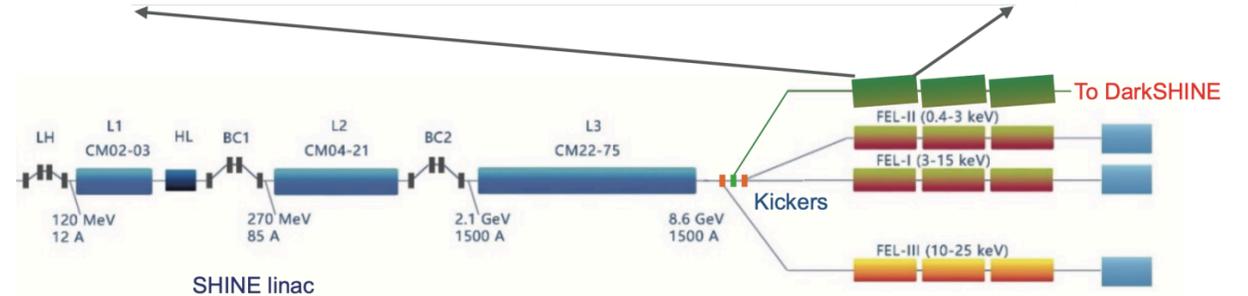
- DarkSHINE would be an electron-on-fixed-target experiment.
- 1 MHz, 8 GeV electron.



前端硅微条探测器 (7层)

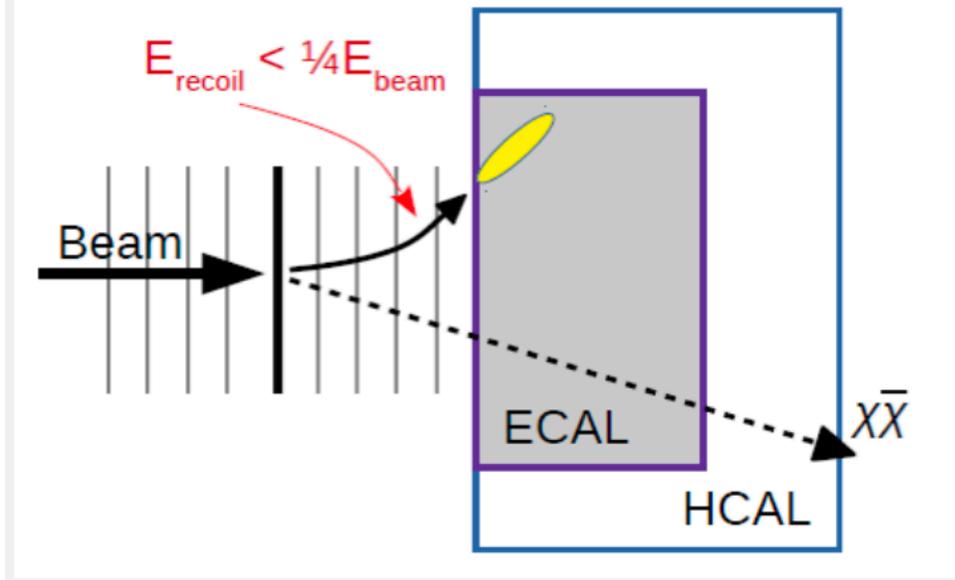
后端硅微条探测器(6层)

量能器 暗光子

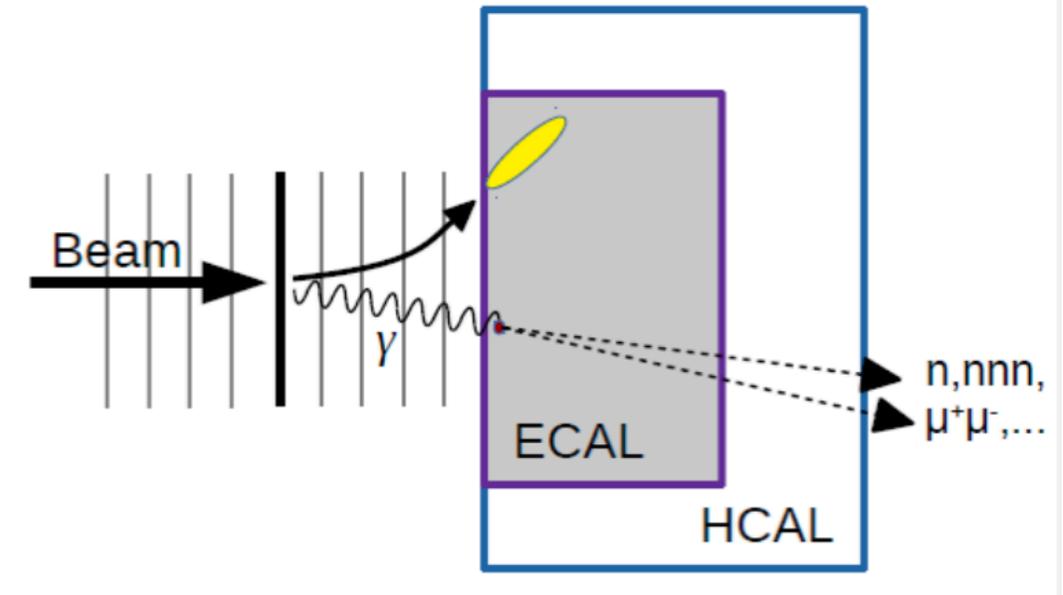


- **Signal:** dark photon with invisible decay dominates, escape detection.
- **Background:** most visible, bremsstrahlung, electron-nuclear interaction,...
- Dark photon is detected through missing energy and momentum approach.

Signal



Background

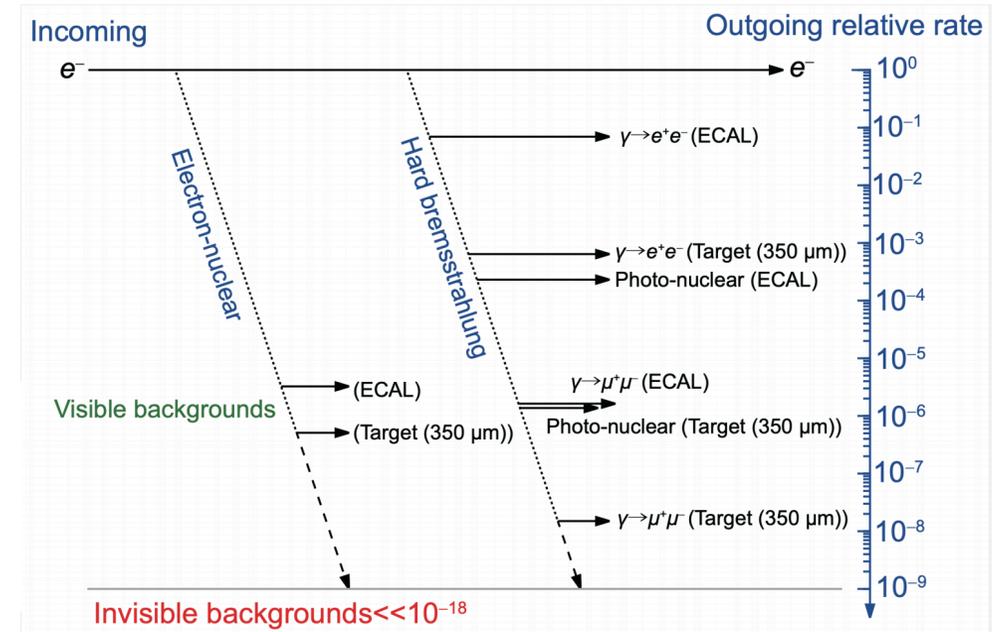
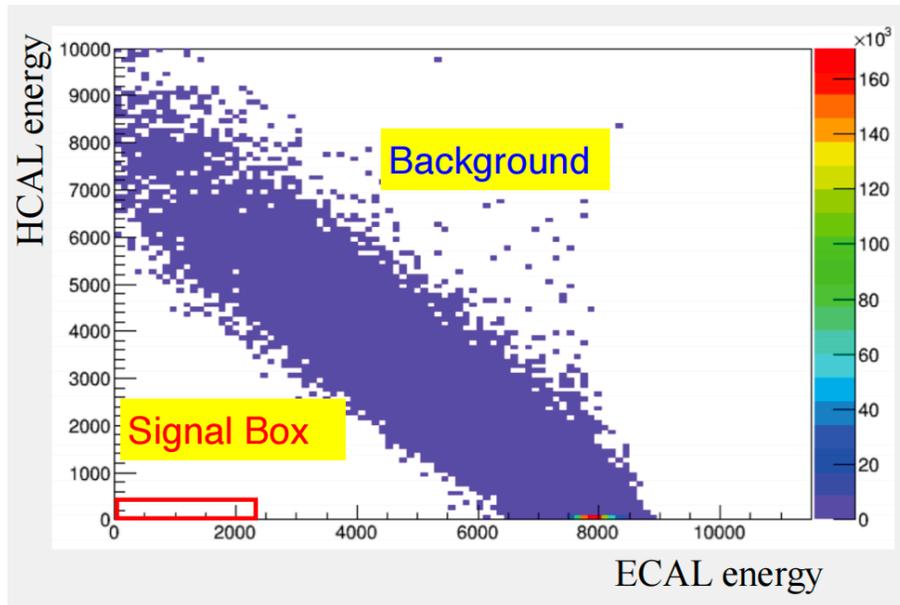




Motivation

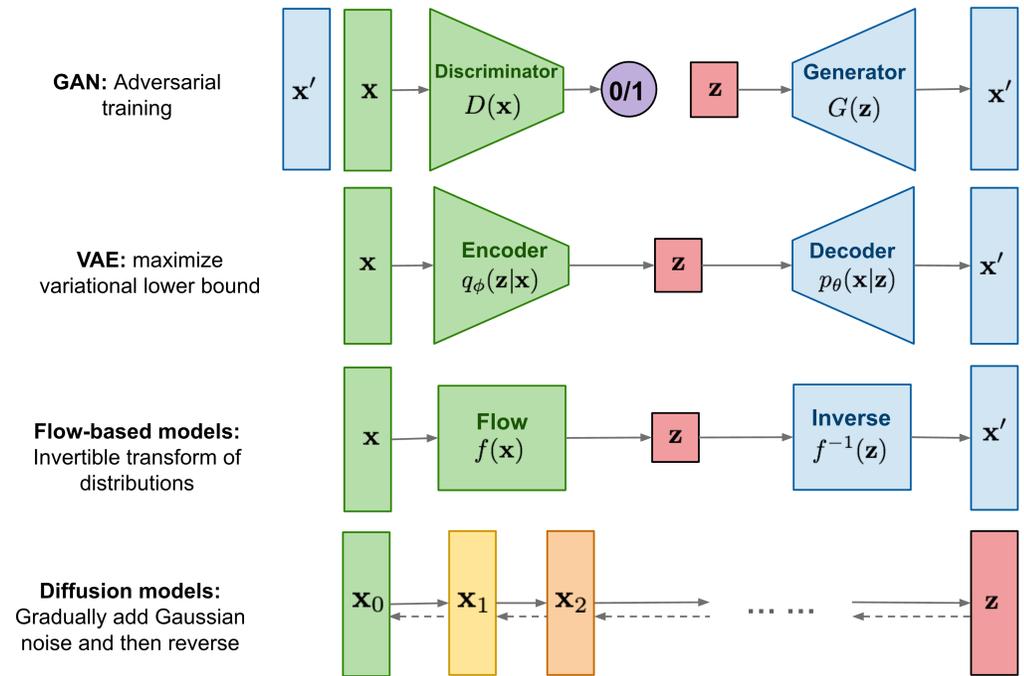


- There are still some backgrounds at low ECAL energy.
- Suppressing backgrounds in signal box is necessary.
- Background estimation
 - Generating 10^{14} EOTs backgrounds.





- **Full simulation - GEANT4**
 - **Widely used but cpu-intensive.**
 - **Generating 10^{14} EOTs inclusive backgrounds costs a lot.**
- **Fast simulation - Deep Learning Network**
 - **Data-driven, boosted by GPU.**
 - **Faster.**
 - **GAN, VAE, Diffusion...**



Different generative models

[1] Creswell A, White T, Dumoulin V, et al. Generative adversarial networks: An overview[J]. IEEE signal processing magazine, 2018, 35(1): 53-65.

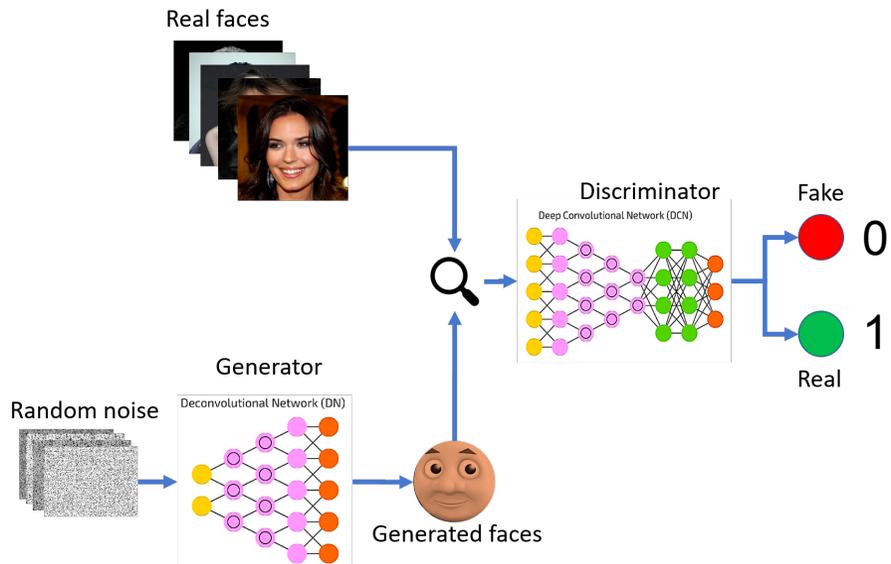
[2] Bank D, Koenigstein N, Giryas R. Autoencoders[J]. arXiv preprint arXiv:2003.05991, 2020.

[3] Song, Yang; Sohl-Dickstein, Jascha; Kingma, Diederik P.; Kumar, Abhishek; Ermon, Stefano; Poole, Ben (2021-02-10). "Score-Based Generative Modeling through Stochastic Differential Equations.



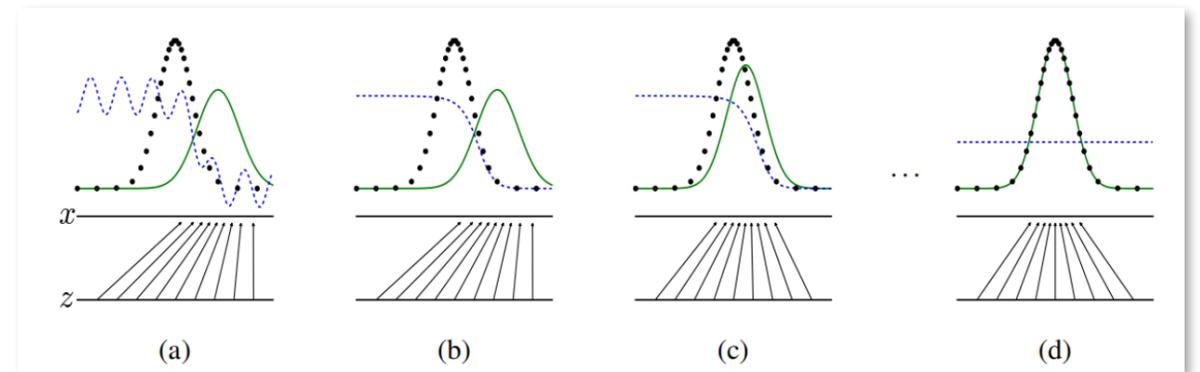
Generative Adversarial Networks (GAN)

- A data-driven model.
- Including two sets of Net (Generator + Discriminator).



$$\min_G \max_D V(D, G) = \mathbb{E}_{\mathbf{x} \sim p_{\text{data}}(\mathbf{x})} [\log D(\mathbf{x})] + \mathbb{E}_{\mathbf{z} \sim p_z(\mathbf{z})} [\log(1 - D(G(\mathbf{z})))]$$

Pushed by value function



Iteration

Green: Generative distribution
Black: Real data distribution

Conditional GAN (CGAN)

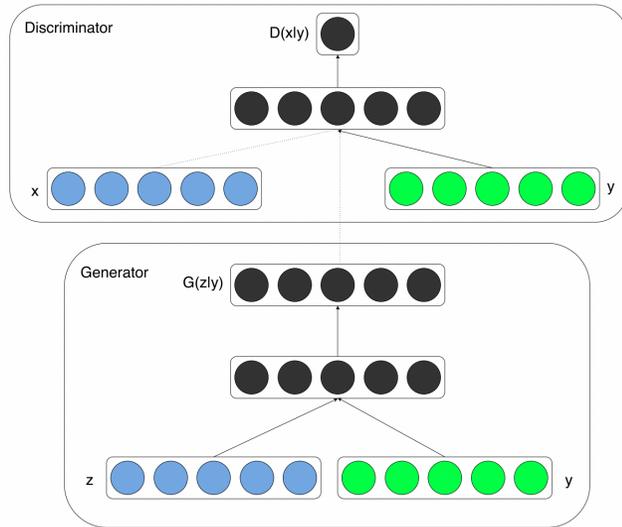
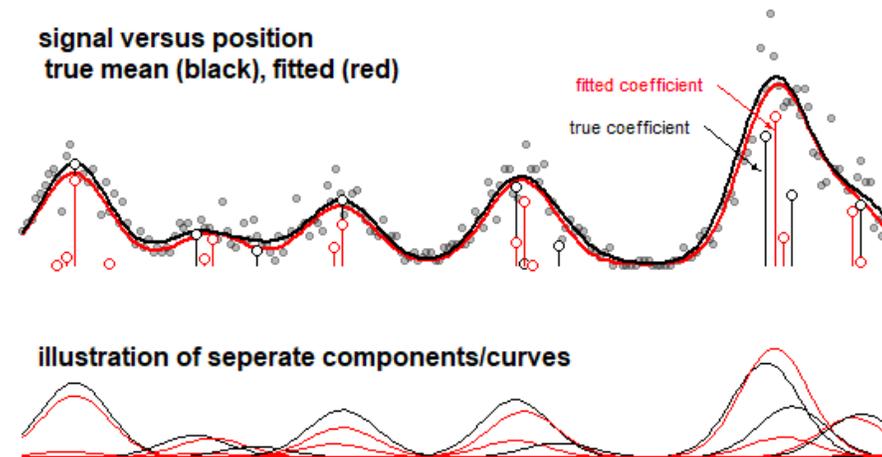


Figure 1: Conditional adversarial net

$$\min_G \max_D V(D, G) = \mathbb{E}_{x \sim p_{data}(x)} [\log D(x|y)] + \mathbb{E}_{z \sim p_z(z)} [\log(1 - D(G(z|y)))]$$

Non-negative Least Squares (NNLS)

$$\operatorname{argmin}_X \| AX - b \|^2 \text{ subject to } X \geq 0$$



- It is to solve a kind of constrained least-squares regression problem.

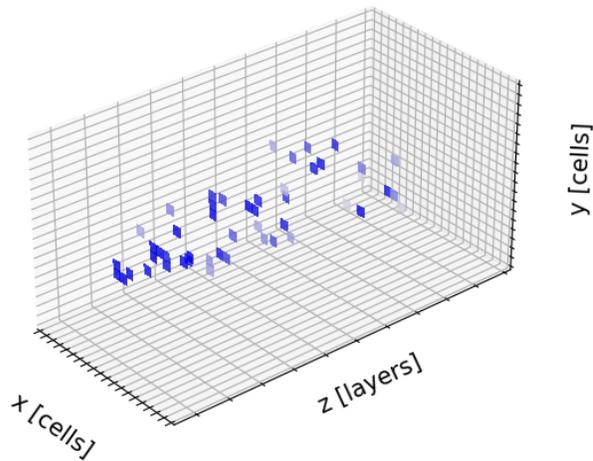
[1] Mirza M, Osindero S. Conditional generative adversarial nets[J]. arXiv preprint arXiv:1411.1784, 2014.

[2] Chen D, Plemmons R J. Nonnegativity constraints in numerical analysis[M]/The birth of numerical analysis. 2010: 109-139.

DarkSHINE fast simulation

Why CGAN?

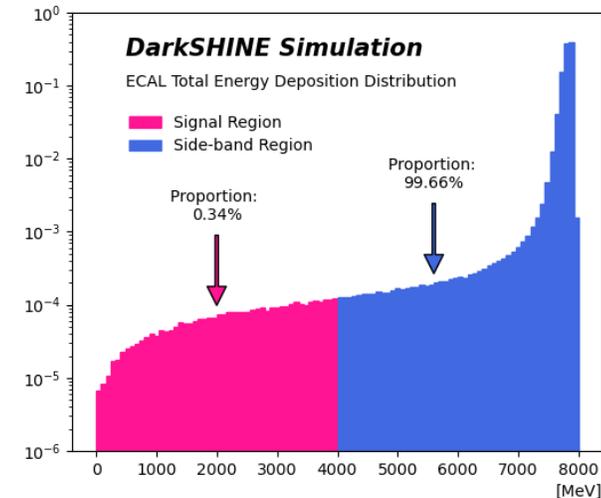
- Each shower can be treated as an “image”.
- CGAN can condition the output with different ECAL energy.
- Avoid “model collapse” in a large energy range.



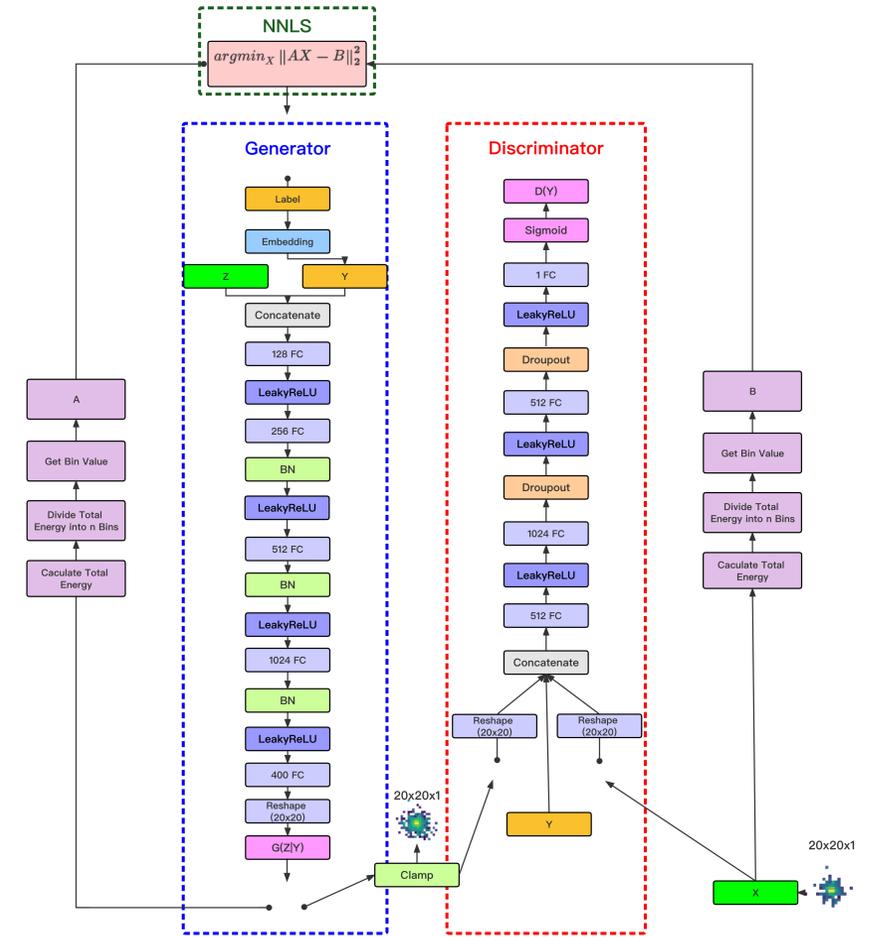
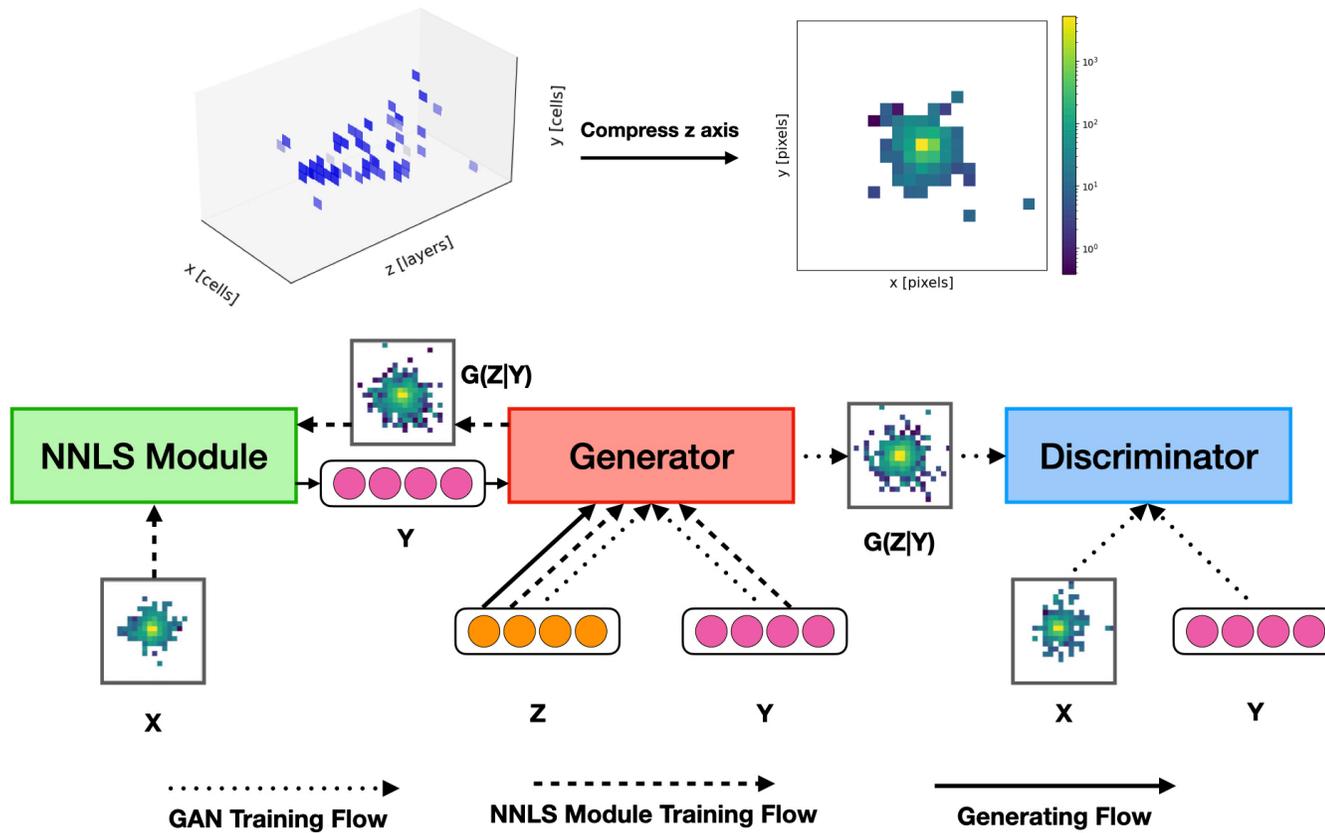
3D shower in ECAL

Why NNLS?

- The ECAL energy deposit distribution is unknown.
- NNLS would guide generator to fit this distribution.

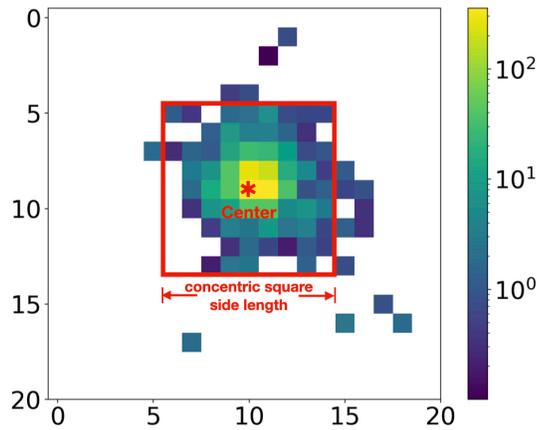


NNLS+CGAN Architecture



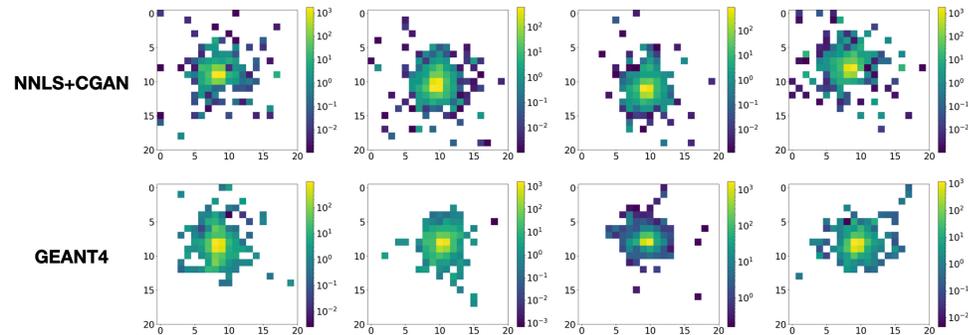
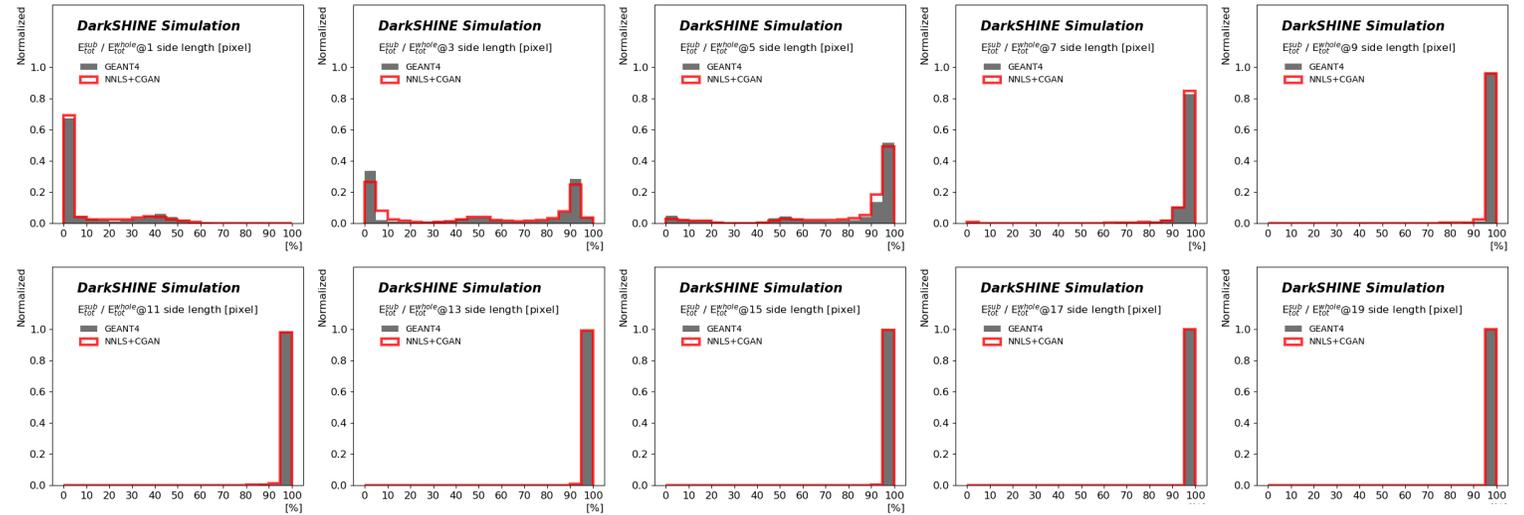
Schematic illustration

The jet image topology could be reproduced.

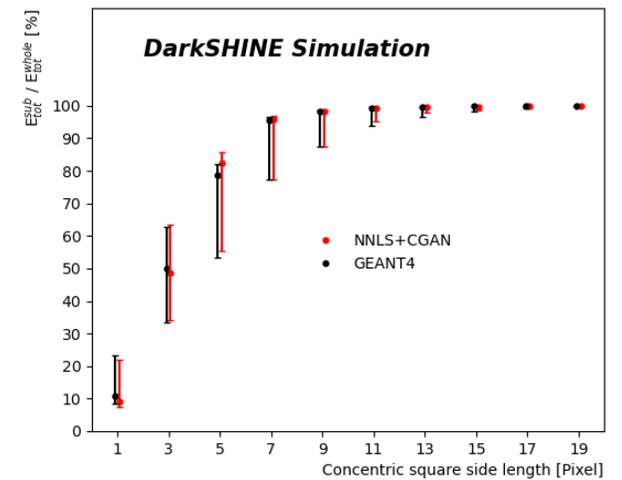


Define a energy center:

$$(x, y) = \left(\frac{\sum (E_i * x_i)}{\sum E_i}, \frac{\sum (E_i * y_i)}{\sum E_i} \right)$$



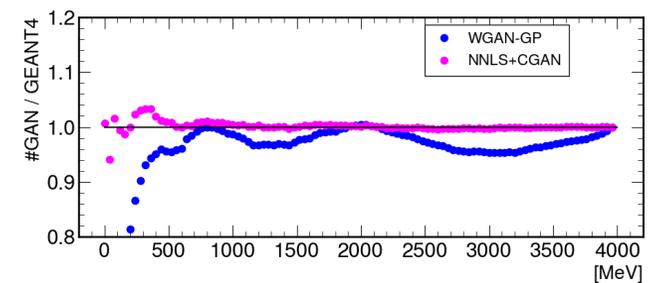
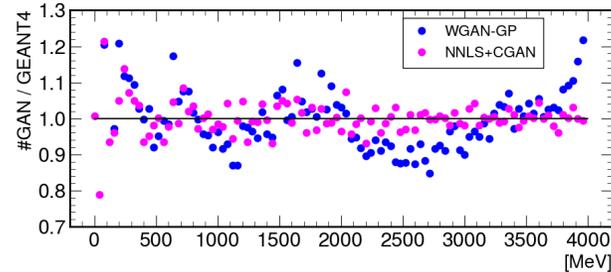
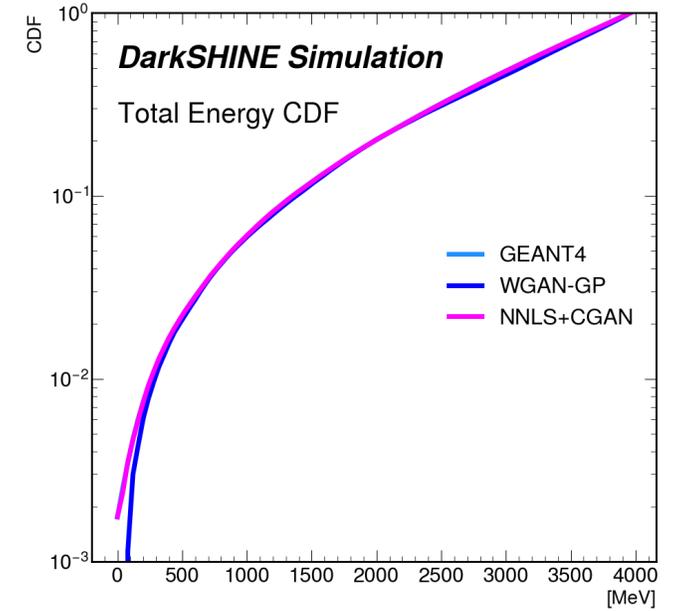
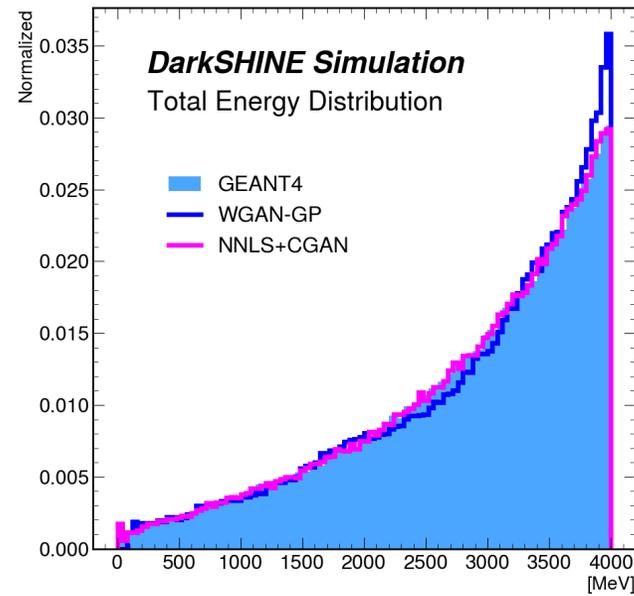
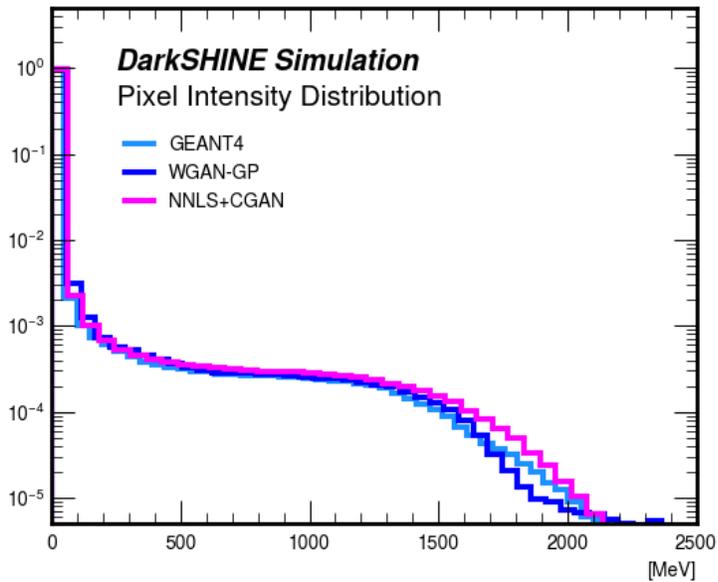
4 example jet images of two methods separately





Comparing with GEANT4 and WGAN-GP

- The NNLS+CGAN lines up with GEANT4's data well merited in ECAL total energy distribution.

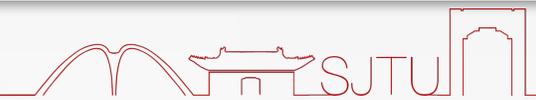




Computational time speed-up

Method	Hardware	1×10^5 Samples in Signal Region	Speed-up
GEANT4	Intel Xeon ICX Platinum 8358 (32 Cores)	82720.59s	-
NNLS+CGAN	NVIDIA P100	58.24s	1420
NNLS+CGAN	NVIDIA V100	5.73s	14436
NNLS+CGAN	NVIDIA A100	2.52s	32825

Table 1: Computational time required for generating 1×10^5 samples and an evaluation of NNLS+CGAN compared with the full simulation computational time.





Conclusion & Outlook

- **NNLS+CGAN can work for ECAL energy data synthesis.**
- **$\times 10^4$ speed-up could be achieved.**
- **It can be upgraded to provide shower shape for detailed analysis.**

THANKS for you attention!



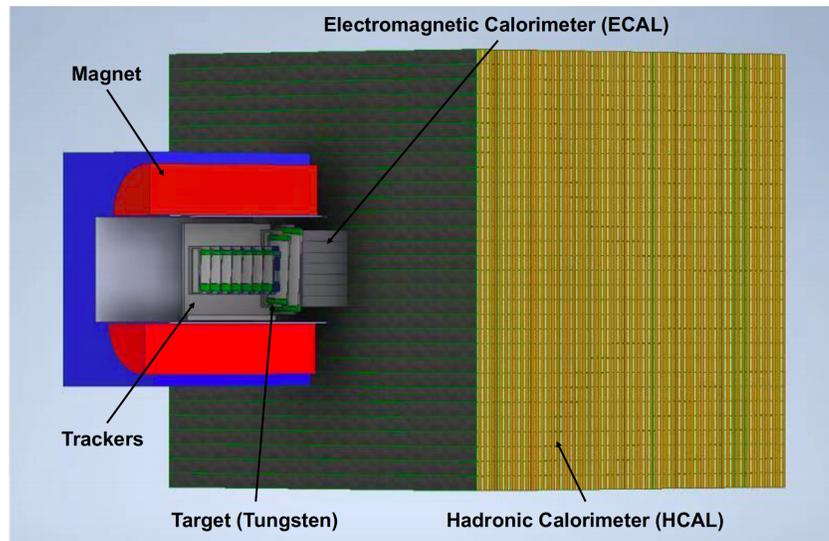


感谢聆听

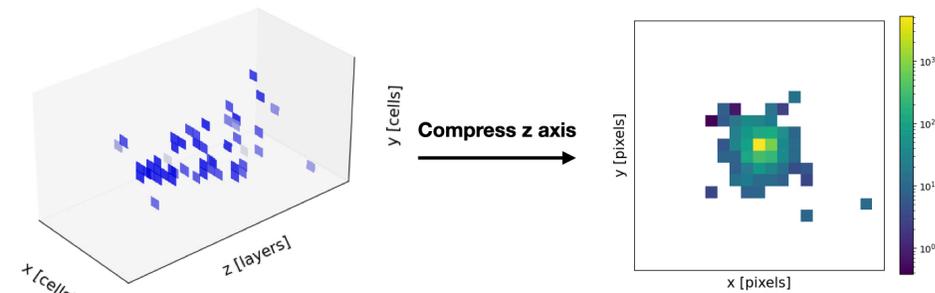
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ECAL (baseline-1.0)

- 20x20x11 LYSO crystals.
- $44X_0$ total decay length - fully deposit the final state e and γ energies.



DarkSHINE detector design



ECAL event display