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Application of deep learning to the analysis for $B \to K^*\gamma$ in Belle II

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Belle II Overview

- **Goal**: discover new particles and phenomena beyond the Standard Model of particle physics
- Collaboration among **725+ physicists** from 104 institutes in 24 countries
- **50x** the data volume, **40x** rate of collisions relative to previous Belle experiment
- **PNNL led U.S.** (DOE) contribution to Belle II detector construction – now complete
- **Largest** ever U.S. science investment in Japan
  - More Ph.D. physicists (50+) and more institutions (14) than any other country
- SuperKEKB: single beam circulation was done **successfully** (phase 1 in 2016)
- Cosmic-ray **data taking is on-going**
- **Physics** run will start in **2018**

Accelerating discovery in HEP/NP with scalable computing solutions

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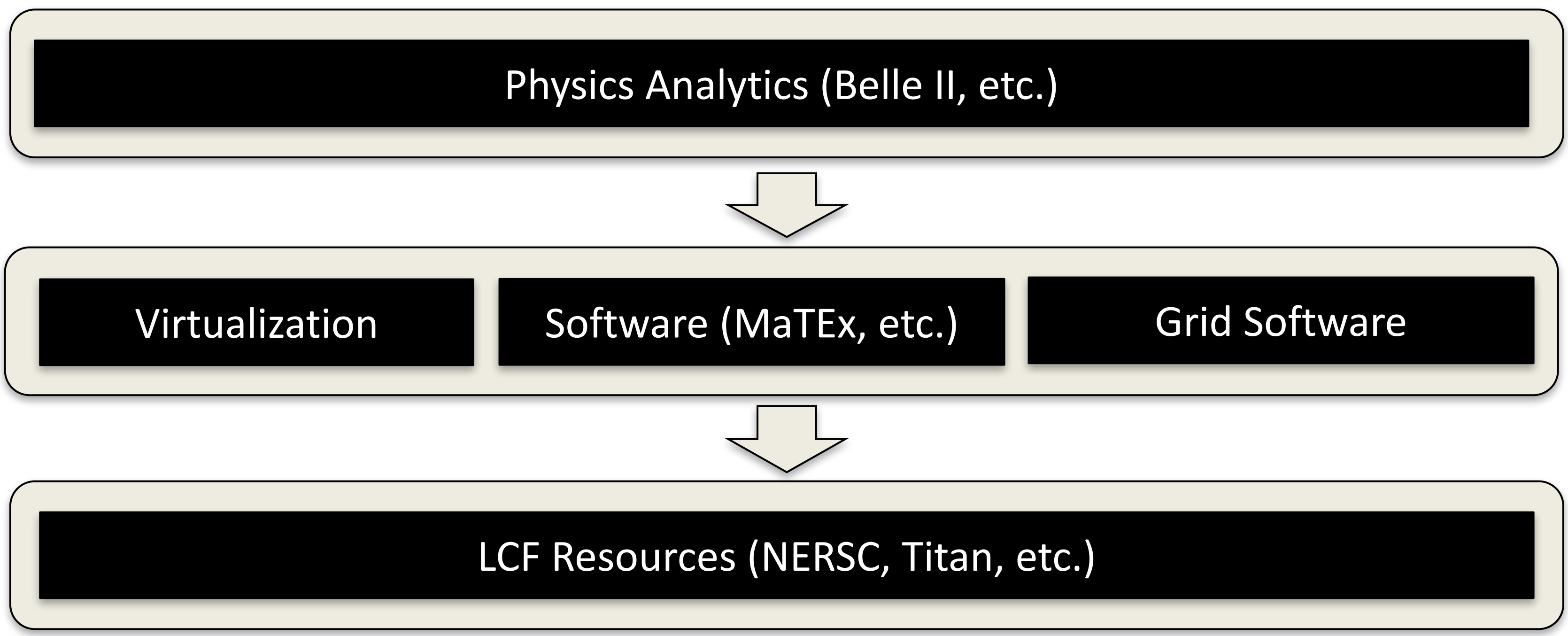
- PNNL leverages virtualization technologies use by PNNL's team to enable quick solutions to access the LCFs resources at NERSC (Edison/Cori) and ORNL (Titan)
- Currently working on a large scale demonstrator for Distributed Large Scale Data Analytics using MaTEx



A Belle II physics analysis

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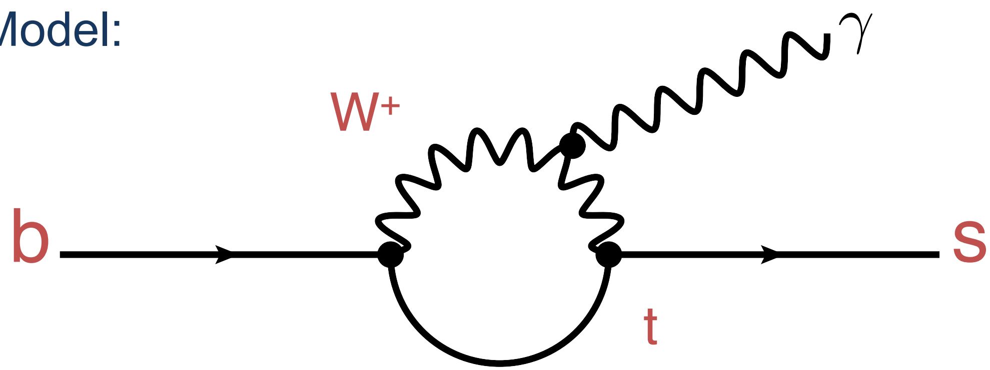
- $B \to K^*\gamma$ is a Flavor Changing Neutral Current (FCNC) and sensitive to New Physics (NP) contributions to C_7
  - Also strong constraint to global NP-Wilson coefficient fits
  - Recent phenomenology paper: [https://arxiv.org/abs/1608.02556]

Standard Model:



- Expect 50–70 events if we get **5fb^{-1}** of **physics Y(4S) next year**
- Goal: “re-observation”, validation of detector performance, and benchmarking measurement of A_{CP}?

Looking for new physics

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- B→K*γ is a FCNC and sensitive to NP contributions to C_7
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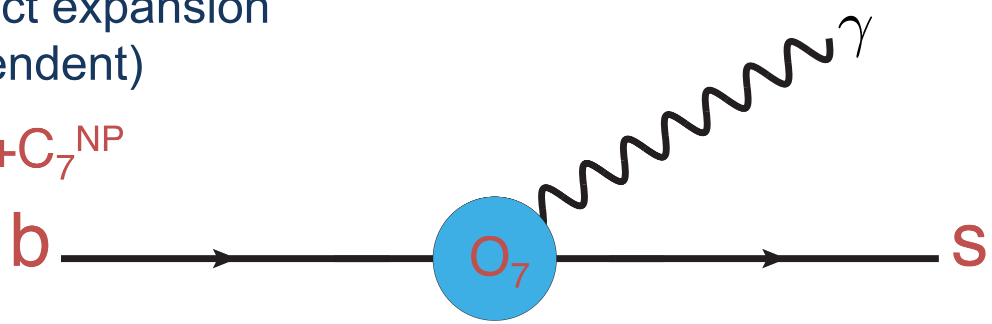
Operator product expansion
(~model independent)

$$C_7 = C_7^{SM} + C_7^{NP}$$



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Keras+TensorFlow classifier study

- Keras+TensorFlow are open source 'standard' python ML libraries
  [https://keras.io/] [https://www.tensorflow.org/]

- How well do these tools work for our use case? $B \rightarrow K^{*}\gamma$
  - **Pilot** investigation with Belle II simulation where we have well defined benchmarks (TMVA results)

- Same cocktail of variables as in TMVA training
- **Only training against B background for now**

cf.

Keras+TensorFlow classifier setup

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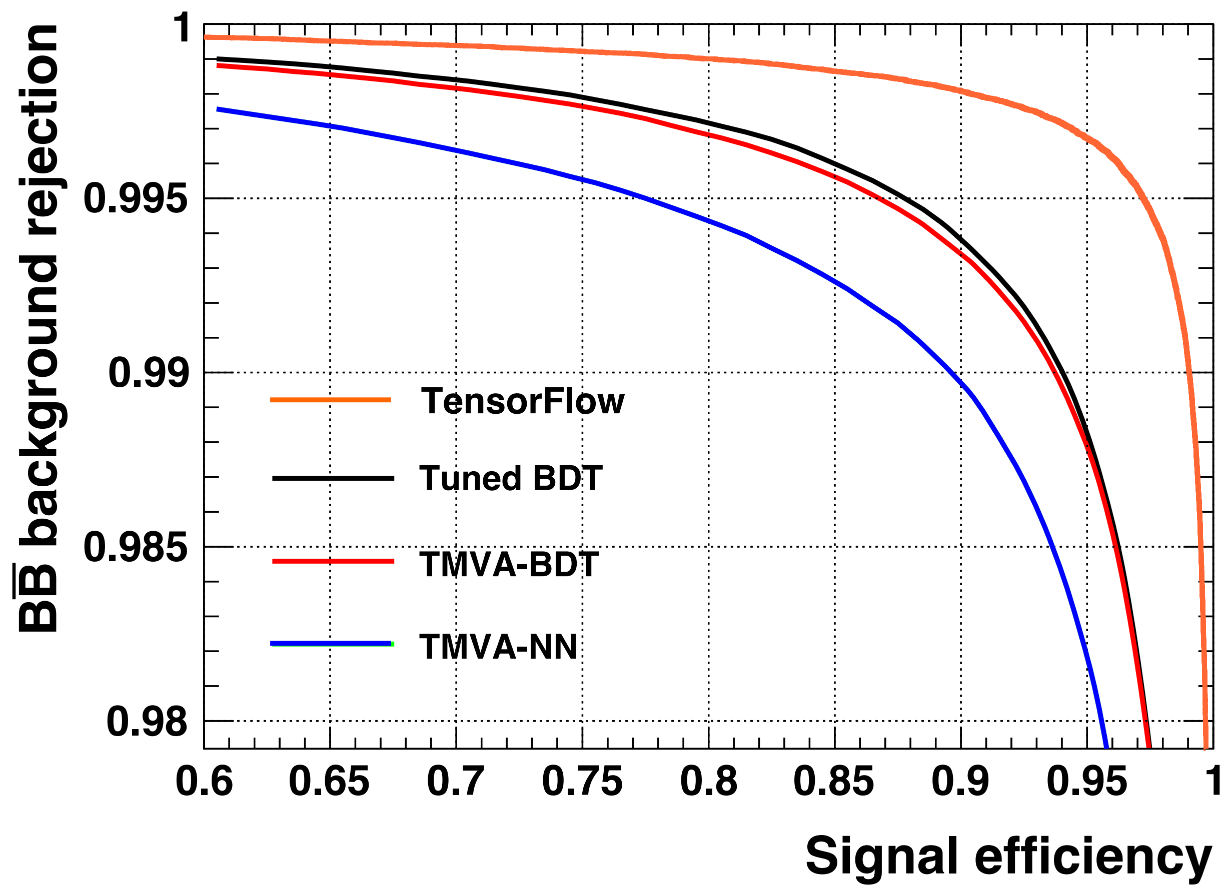
1. Label samples (in this case: signal or BB background)
   - Can extend categories for continuum (maybe individual qq samples)
2. Split 0.33 test, 0.66 training
3. Normalize variables
4. Define 6 layer 'fully connected' neural network
   - Dropout rate @ 15% .. avoid over-fitting [https://arxiv.org/abs/1207.0580]
5. Use Adam optimiser [https://arxiv.org/abs/1412.6980v8] to minimize **loss function = binary cross entropy**
   - Minimise misclassification
6. Validation on 0.25 of training sample
   - Continual evaluation through epochs 'sanity check'
7. Train for 10 epochs
   - Can increase as we get more confident: computing resources etc.

Preliminary Machine learning results for B→K*γ

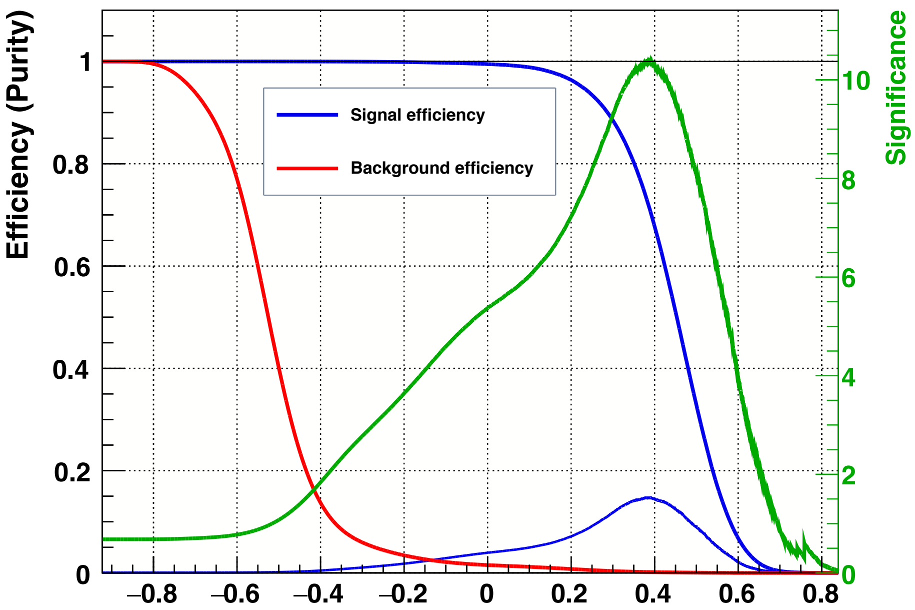
- Improvements seen with **TensorFlow** neural networks *cf.* TMVA
- Becoming industry standard, actively maintained / improved
- Benchmarking in 'easy' mode: precursor to trying out with more complex analysis (e.g. **$B \to K^{(*)}\tau\tau$**)

Belle II simulation, preliminary

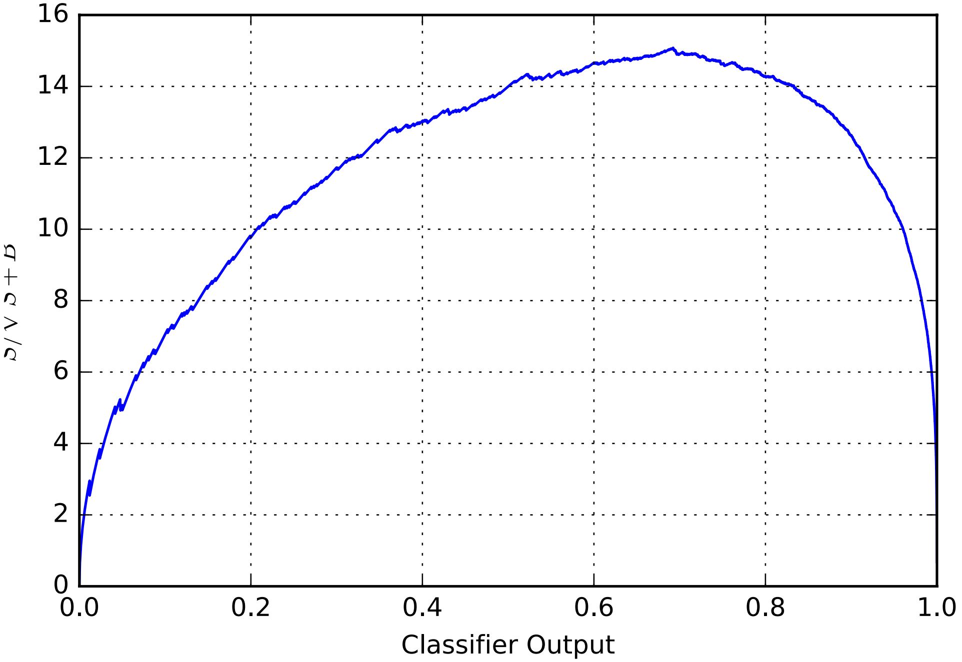


Preliminary Machine learning significance results for B→K*γ

Winning TMVA classifier



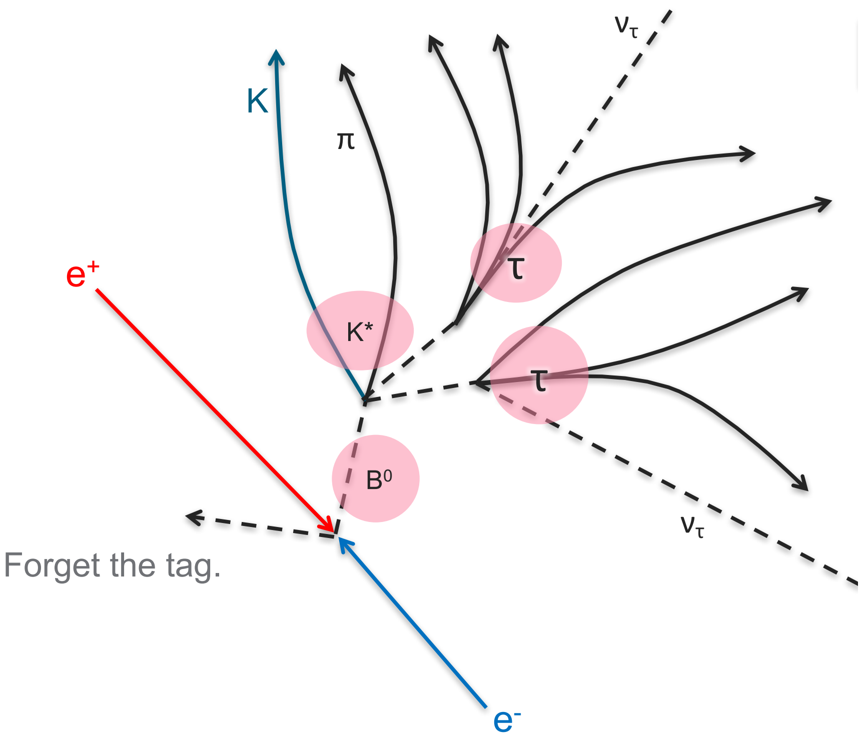
Kera+TensorFlow classifier



- You should compare the green LH to blue RH
- The Kera+TensorFlow neural net has a smoother plateau at optimal
  - Less systematics headache due to choice of cut point
- **45%** gain in significance = S/√S+B

Thoughts on Machine learning for $B \to K^{(*)}\tau\tau$

- Much more complicated final states. Example fully hadronic decay:
  - 3 vertices
  - 8 tracks
- Use “low” level information such as vertices, tracks, track quality, PID, etc.
- Staged classification



MaTEx: Scalable Deep Learning Software on HPC

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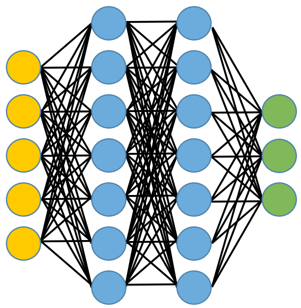


FeedForward

Back-propagation

TensorFlow

K + TensorFlow

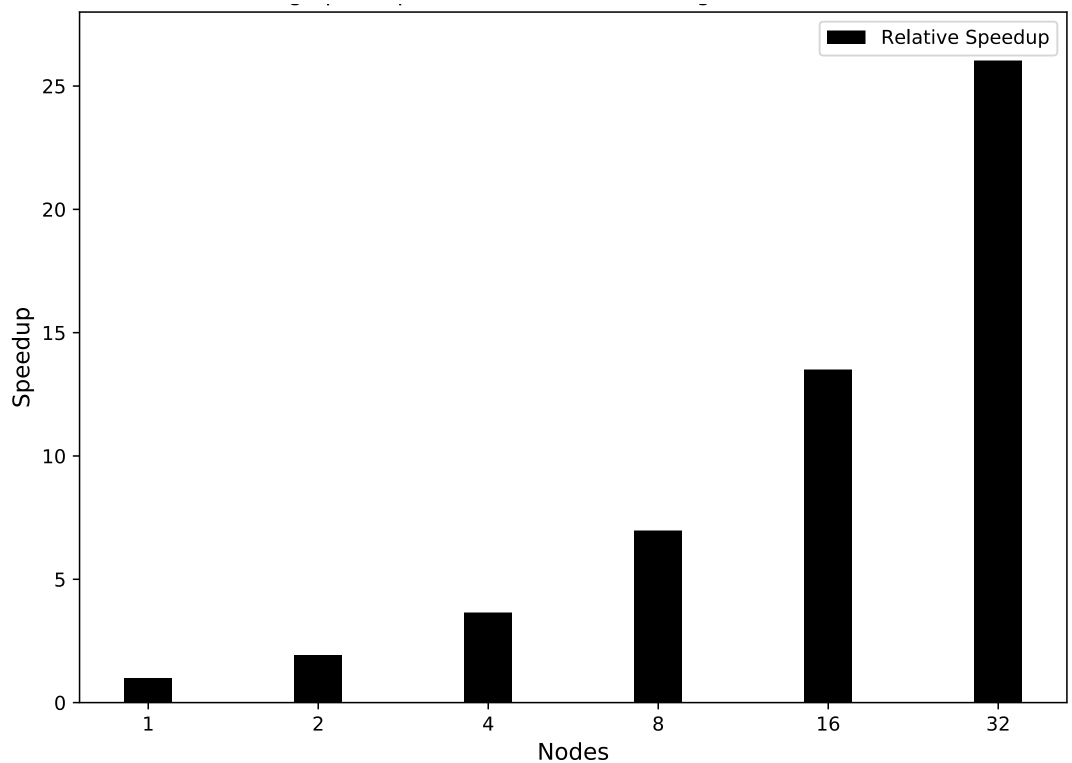
Caffe

NERSC

OLCF
Oak Ridge Leadership Computing Facility

1) Open source software with users in academia, laboratories and industry
2) Supports graphics processing unit (GPU), central processing unit (CPU) clusters/LCFs with high-end systems/interconnects
3) Machine Learning Toolkit for Extreme Scale (MaTEx): [hpc.pnl.gov/matex]
4) *100+ visits/day, ~20 unique visits/day, 3-5 clones/day from github (> 1K clones)*

MaTEx computing performance using HEP image like data



- Using up to 32 compute nodes on Cori provides **~26x** speedup
- Conceptually similar to iTOP “ring image” DL study for Belle II PID
- Current evaluation and testing is undergoing on Titan and Summitdev architectures

Belle II iTOP Particle IDentification

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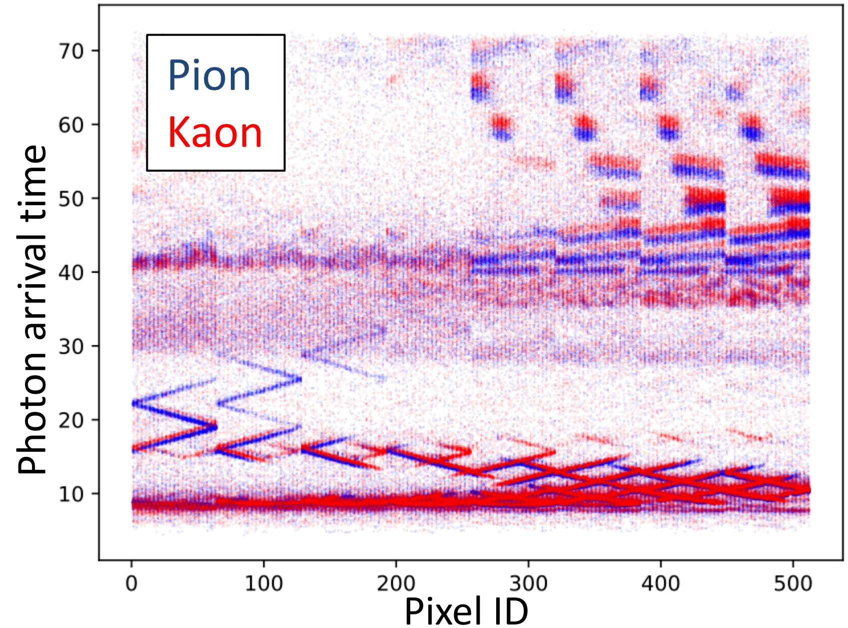
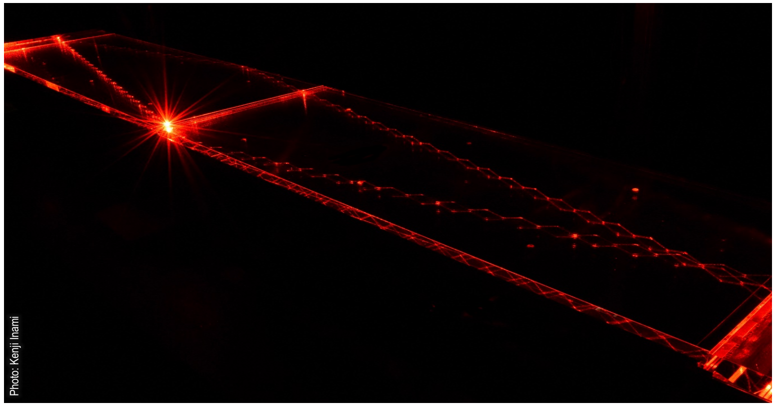
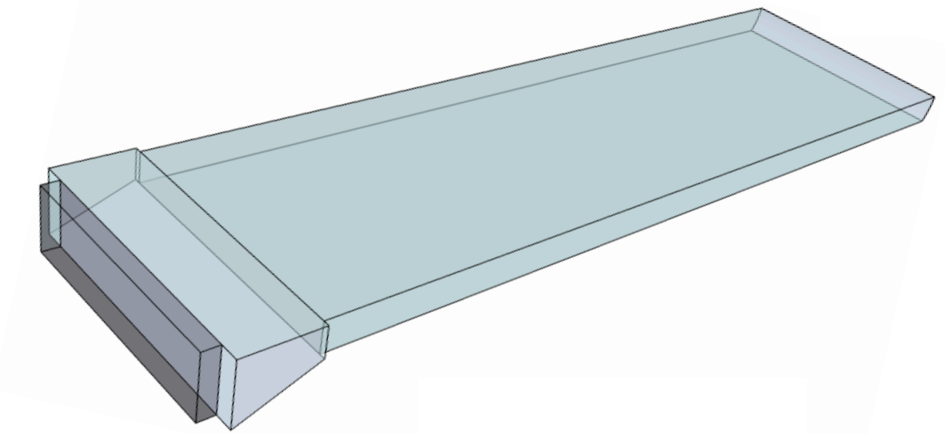
- The Belle II iTOP detector provides PID by comparing between the particle hypothesis and the "measuring" of the Cherenkov angle
- Currently using an analytical solution based on track momentum vector and impact parameters (angle/position)
- Previously, minimization solutions were considered computing prohibitive because of the phase space and edge effects
- Scalable DL might provide a solution for a robust PID by training over the phase space using LCFs







Grid Components for NERSC

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DIRAC

Workload Management Agent

SiteDirector

- Using modified *GlobusComputingElement*

Resource Definition

OSG.CORI.us

- Defined as *GlobusComputingElement*
- *Mapped to PNNL StorageElement*

OSG.EDISON.us

- Defined as *GlobusComputingElement*
- *Mapped to PNNL StorageElement*

/cvmfs/belle.cern.ch

-Sync repo to docker

Docker

pnnlhep/osg-compute

MaTEx

Belle II HPC Docker

pnnlhep/b2-AB-CD-DE

NERSC

Pull and register into Edison/Cori shifter

Grid submit with docker image and volume host/docker mount points for input/ouput/repo

Summary

- Deep learning is used for Belle II analysis
  - TensorFlow is available within the Belle 2 software framework
  - Kera+TensorFlow shows clear improvements in $B \rightarrow K^{*}\gamma$ analysis
  - Investigating more complicated signals such as $B \rightarrow K^{(*)}\tau\tau$

- Belle II are developing workflows that can use MaTEx for “big” jobs that use GPUs on Titan
  - DL application on iTOP images can provide improved and robust PID

- Belle II Grid analysis workflow chain are being developed to run on HPC