KOTO's computing experience on the Open Science pool

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KOTO: search for the very rare decay $K_L^0 \to \pi^0 \nu \bar{\nu}$

Target: Search for the $K_L^0 \to \pi^0 \nu \bar{\nu}$ decay

→ Only happens once every 33 billion kaon decays in the theory.

→ A golden mode that may further hint how the nature creates the matter-dominated Universe.

**Observed Universe: MATTER >> ANTI-MATTER**
Why OSG?

KOTO simulates copious events that can mimic signals using Monte Carlo method.

- Quantitatively evaluate the threat of each possible source.
- The accuracy relies on the number of simulated events.
- OSG is a perfect platform for KOTO to perform the Monte Carlo simulation.
History of OSG at KOTO

- **Initiated the OSG project**
  Simulated the first KOTO event using OSG machines.

- **Built the KOTO library**
  Started installing the full KOTO simulation library at OSG.

- **Deployed the stable version**
  Confirmed the results produced from OSG were expected.

- **Mass production**
  Kept job submissions for KOTO.

Timeline:
- 2022/05: Initiated the OSG project
- 2022/08: Built the KOTO library
- 2023/02: Deployed the stable version
- 2023/03: Mass production
Strategy to overcome the KOTO database problem

✓ KOTO implements a huge database (external files 20TB) to perform the simulation.
✓ Introduce “drawers” in database; only select the files to be used.

- **Database selector**
  - Process a random procedure to select the “drawer” in database.
- **Download external files**
  - Minimize the external file size and maximize #events to reduce the overhead time.
- **Simulate KOTO events**

Running time
Strategy to overcome the disk space problem

✓ KOTO’s standard output file is huge (20 GB).
  ✓ Hope to keep the overhead time small.
  ✓ Produce 10% of events first and only keep events in interest.
  ✓ Repeat this procedure 10 iterations.

Simulate KOTO events

Generate 10% events | Post-selection | • • • | Merge all output files

10 iterations

Running time
Workflow for OSG production

OSG access node

When production is completed.

OSG disk node

Speed = ~10 MB/s

OSG pool

Database selector

Download database files (Stash Cache)

Simulate events

Final MC @KEKCC

KEKCC is where the KOTO real data is stored.

Required time ~ 12 hr

A random process is involved to select a “drawer” in the KOTO database.

Only download the files that this job needs to minimize the overhead time.

Database selector

Download database files (Stash Cache)

Simulate events

Final MC @KEKCC

KEKCC is where the KOTO real data is stored.
Production rate comparison

Use the output file’s epoch (unix time) to evaluate the simulation production time.

- Average production rate (one account)
  - KEKCC = $3 \times 10^9 / 10$ hour.
  - OSG = $12 \times 10^9 / 10$ hour (no iteration).
    \[= 24 \times 10^9 / 10 \text{ hour (with iterations).} \]
    
    [Speed x 8]
Achievements

OSG contributes to the new data set.

- Produce more training samples for the neural network to enhance its performance.
- Further estimate the probability for some of the background mechanisms that were hard to study before.
KOTO future with OSG

More data is coming in the future.
OSG is needed to reach the sensitivity.

More physics topics may be studied at KOTO with the OSG resources.

Detailed Study of the $K_L \rightarrow \pi^0 \pi^0 \pi^0$ Dalitz Plot

Y.C. Tung,1 Y.B. Hsiung,1 J.K. Ahn,2 Y. Akune,3 V. Baranov,4 K.F. Chen,1 J. Comfort,5 M. Doroshenko,6,* Y. Fujiioka,3
T. Inagaki,5,7 S. Ichihara,5 N. Ichihara,5 H. Ichii,8 F. Iwao,8 T. Iwata,9 I. Kato,9 S. Kobayashi,3 S. Komatsubara,9
T. K. Komatsubara,9 T. Matsumura,12 A. Morita,12 T. Nomura,13,* S. Porokhovoy,4 K. S. Sidhu,14 Y. Stepanenko,4
T. Tsukamoto,14

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Search for the decay $K_L^0 \rightarrow 3\gamma$

Y. Suzuki,1 S. Adachi,1 T. Tsumura,1 M. T. Akasaka,1 Y. Saito,1 Y. Kato,1 J. Sekido,1 Y. Tanaka,2 E. Uchikawa,3
T. Inagaki,5,7 S. Ichihara,5 N. Ichihara,5 H. Ichii,8 F. Iwao,8 T. Iwata,9 I. Kato,9 S. Kobayashi,3 S. Komatsubara,9
T. K. Komatsubara,9 T. Matsumura,12 A. Morita,12 T. Nomura,13,* S. Porokhovoy,4 K. S. Sidhu,14 Y. Stepanenko,4
T. Tsukamoto,14

More physics topics may be studied at KOTO with the OSG resources.
Summary

- KOTO introduced the Monte Carlo simulation using OSG since 2022 and began the continuous job submission since March 2023.

- OSG has a major contribution to KOTO’s latest data set and will play a crucial role in the future.
Content of a KOTO docker image

https://hub.docker.com/r/chiehlin0212/koto-dev
Preliminary KOTO docker image construction

Build a KOTO docker image supporting

- ROOT (v6.22.02)
- GEANT4 (v10.05.01)
- e14lib (201605v6.2)

Library construction command lines

```
FROM opensciencegrid/osgvo-el7

# install cmake3
RUN yum -y install cmake3
RUN yum -y downgrade --disablerepo=osg */xrootd*

# install root
RUN mkdir -p root &&
    cd root &&
    wget https://stash.osgconnect.net/collab/project/KOTO/software/root_v6.22.02.source.tar.gz &&
    tar -xf root_v6.22.02.source.tar.gz &&
    mkdir -p build install &&
    cd build &&
    cmake3 -DCMAKE_INSTALL_PREFIX="/.../install" "./root-6.22.02" -Dx11=OFF -Dxft=OFF -Dbuiltin_xromd=ON -Dopengl=OFF &&
    cmake3 --build . --target install &&
```

Update the working image to OSG repository

Remote repository: can be seen by grid computers
Run a job to OSG pool

A job submission requires a configuration script.

```
/bin/bash
Universe = Vanilla
Executable = run_koto.sh
Requirements = HAS_SINGULARITY == TRUE
+SingularityImage = "/cvmfs/singularity.opensciencegrid.org/ppaschos/koto-dev:latest"
transfer_input_files = e14_201605.mac
Error = output.err.$(Cluster)$=$(Process)
Output = output.out.$(Cluster)$=$(Process)
Log = output.log.$(Cluster)$
should_transfer_files = YES
WhenToTransferOutput = ON_EXIT
request_cpus = 1
request_memory = 2GB
request_disk = 2GB
+ProjectName="collab.KOTO"
Queue 1
```

A script that generates 1000 $K^0_L \rightarrow 3\pi^0$ events.

Build KOTO container

Transfer GEANT4 setting file.

The first $K^0_L \rightarrow 3\pi^0$ MC file.