Kaon structure function at the EIC

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Outline

- Why kaon structure?
- Simulation workflow
- Preliminary reconstruction results

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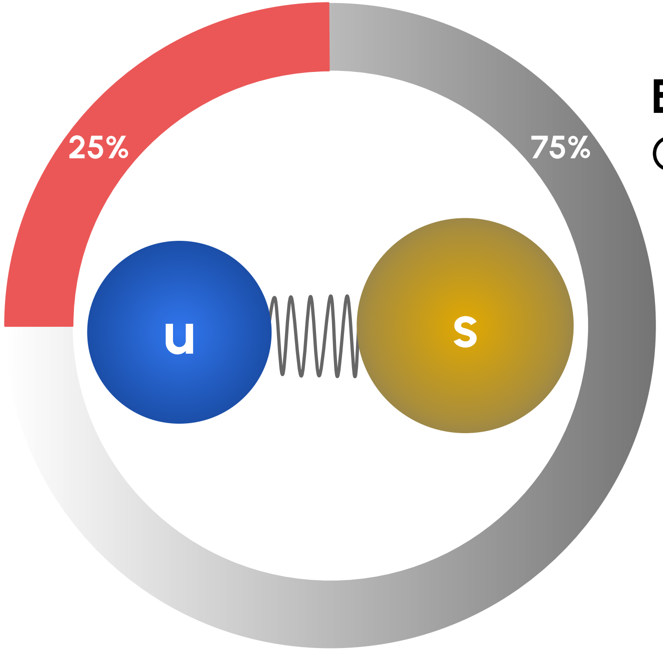
- Why kaon structure?
- **Method**: Sullivan process + Λ reconstruction at the EIC
- **Results**: projected uncertainties and constraints

Science Background: Pions and Kaons are vital to understand Hadron Structure

Example: Kaon Structure Functions
Allow for understanding interplay of different mass generation mechanisms

Higgs mechanism
Quark masses



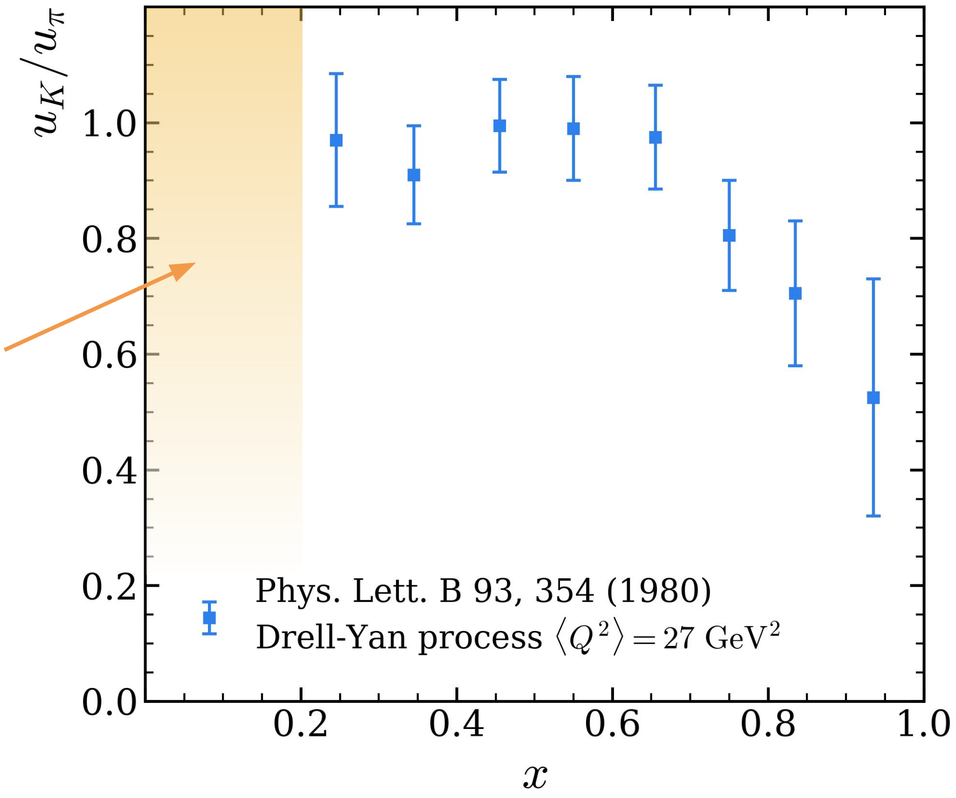
Emergent mass QCD
Quark motion, sea pairs

Kaon is a Goldstone Boson and also the simplest
system with s-quark

Crucial need for
structure function data
There are only 8 data points worldwide

Current limited data on kaon structure

No coverage at low-x, where sea pairs dominate



Only a handful of data points, single Q^2, large uncertainties

Kaon structure models benchmark

- theoretical → + theoretical

Empirical models

Drell-Yan data fits

Kaon-data-driven
Small theory biais
Phys. Rev. D 45 (1992)

Global QCD fits

JAM collaboration

Multi-data-driven
with QCD constraints
Phys. Rev. Lett 121 (2018)

First principles

Dyson-Schwinger (DSE)

Theory-driven
Non-perturbative QCD
Eur. Phys. J. C 80 (2020)

+ data driven ← - data driven

Objective : project constraints on these models from EIC data

Currently under-constrained models : <u>any new data will be decisive</u>

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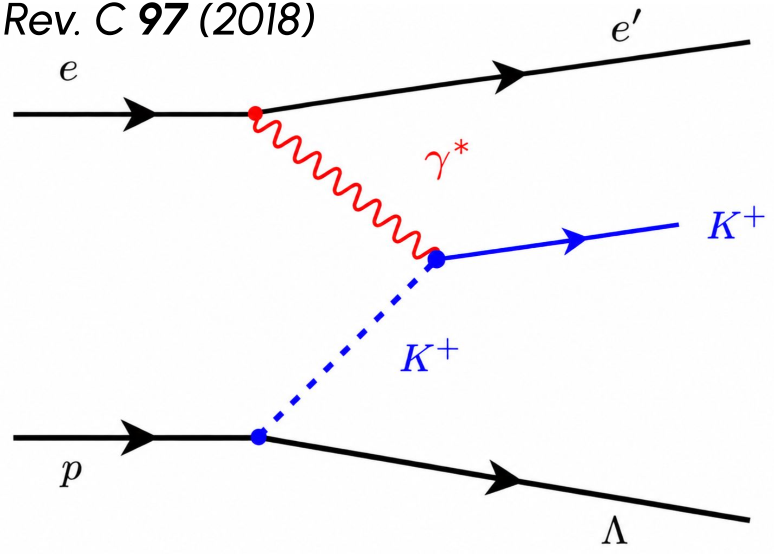
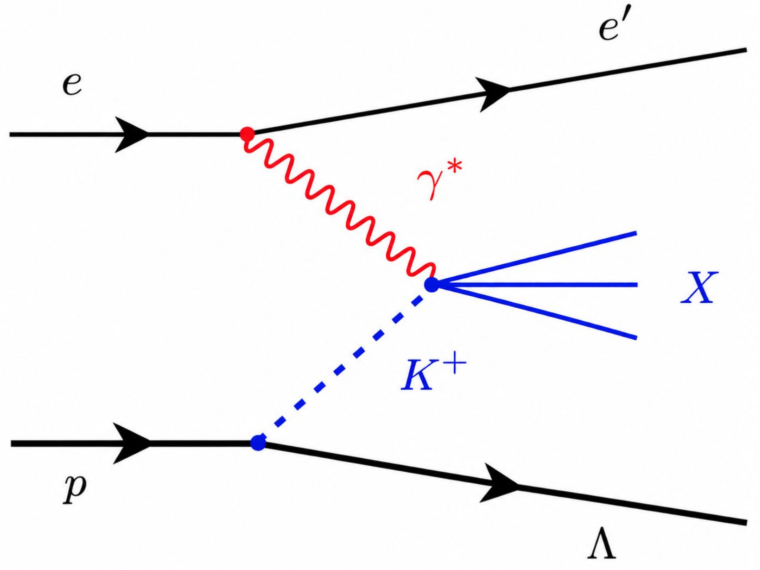
Experimental approach : Sullivan Process

Electron-proton collision cross-section presents meson-pole for spacelike |-t|
Phys. Rev. C ***97*** *(2018)*



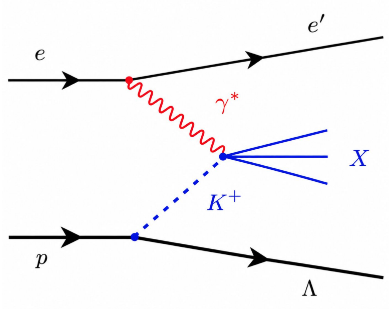
Form Factors
(exclusive limit)

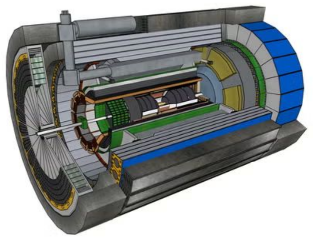


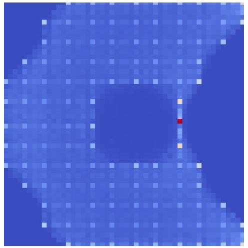
Structure Functions
(Tagged DIS)

Workflow for kaon structure projections at the EIC

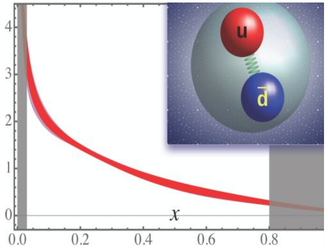
Generator	Simulation	Reconstruction	Uncertainty	Physics
Event generator Sullivan process github.com/avnishphy/kaon_sullivan_gen	HPC campaigns Geant4 transport ePIC https://github.com/JeffersonLab/meson-structure	Multi-detector Λ (SIDIS) Kinematics (electron, JB) https://github.com/eic/EICrecon	Statistical ΔN Detectors $\Delta\varepsilon$ Generator Δσ Background Kinematics bias	Constraining power kaon structure models







$$u_c(y_i) = \sqrt{\sum_{i=1}^{n}\left[\frac{\delta y_i}{\delta x_i}\cdot u(x_i)\right]^2}$$

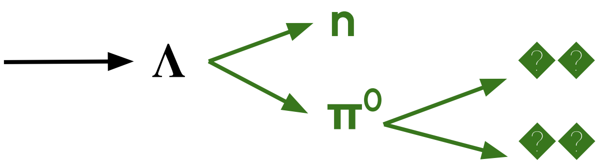


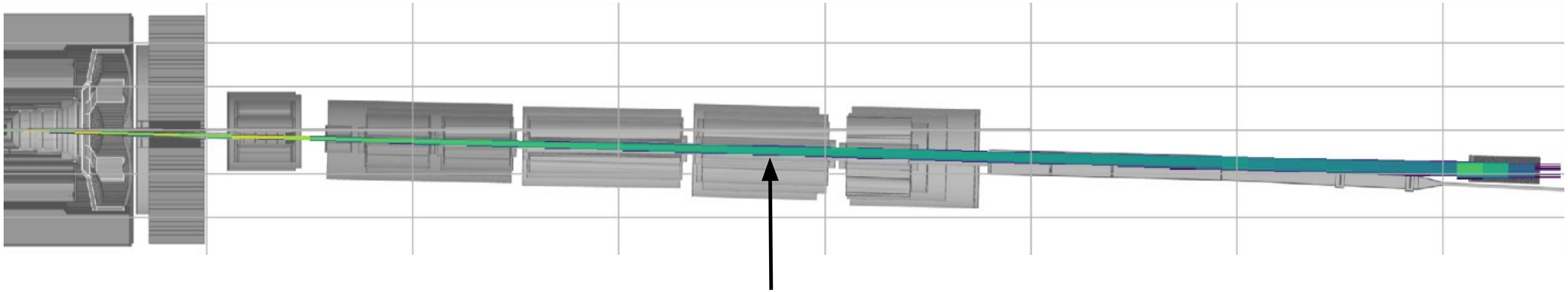
Λ reconstruction : experimental Considerations

Recoil Λ^0 is neutral:
looks like a neutron …
but decays

Two decay channels
Charged: $p + \pi^-$ (65 %)
Neutral: $n + \gamma + \gamma$ (35 %)

(Charged: ongoing)
Currently: **neutral channel**





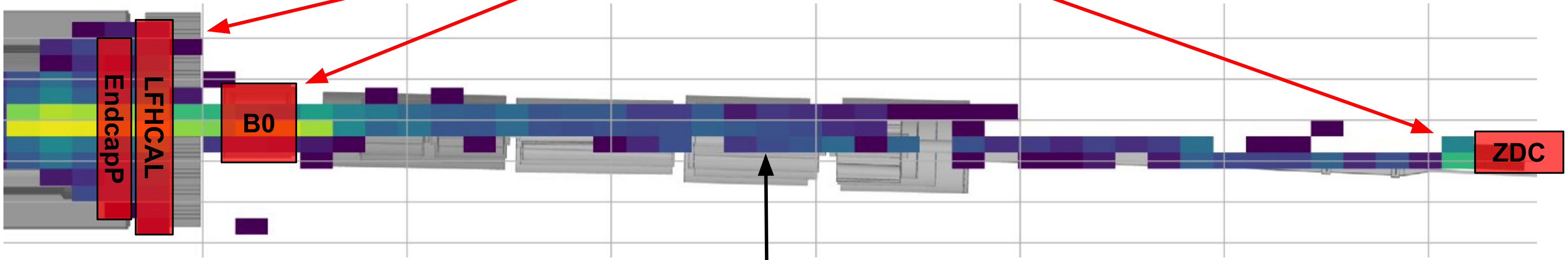
Λ decay points along ePIC setup at 18x275 GeV (tens of meters!)

Λ reconstruction : EICrecon update

Implemented algorithm
multi-detector triple
coincidence n + γ + γ

Involved detectors
EndcapP-Ecal, LFHCAL,
B0-Ecal, ZDC-Hcal

Improved acceptance
for realistic Λ (energy/
angle event generator)



γ-rays interaction-points from Λ neutral decay at 18x275 GeV

Meson SF Software Development Timeline Overview

Recent software efforts by the group in 2026

- January - March : Λ reconstruction algorithm implementation + calorimeters calibration (complete)
- February : Campaign + Λ reconstruction algorithm local tests (complete)
- March - May : DD4hep issue (https://github.com/eic/epic/issues/1069) and solution
  - Note: all global campaigns in that period did not generate useful Meson SF data
- April - June : EICrecon Pull Request (https://github.com/eic/EICrecon/pull/2622) (complete)
  - Note: April global campaign had Meson SF data, but **with old software (still not useful for anal.)**
- July : **New Issue change in ZDC Hcal Tiles** (https://github.com/eic/EICrecon/issues/2737)

More detail on software and analysis on the Meson SF Github page:
Campaigns: https://jeffersonlab.github.io/meson-structure/

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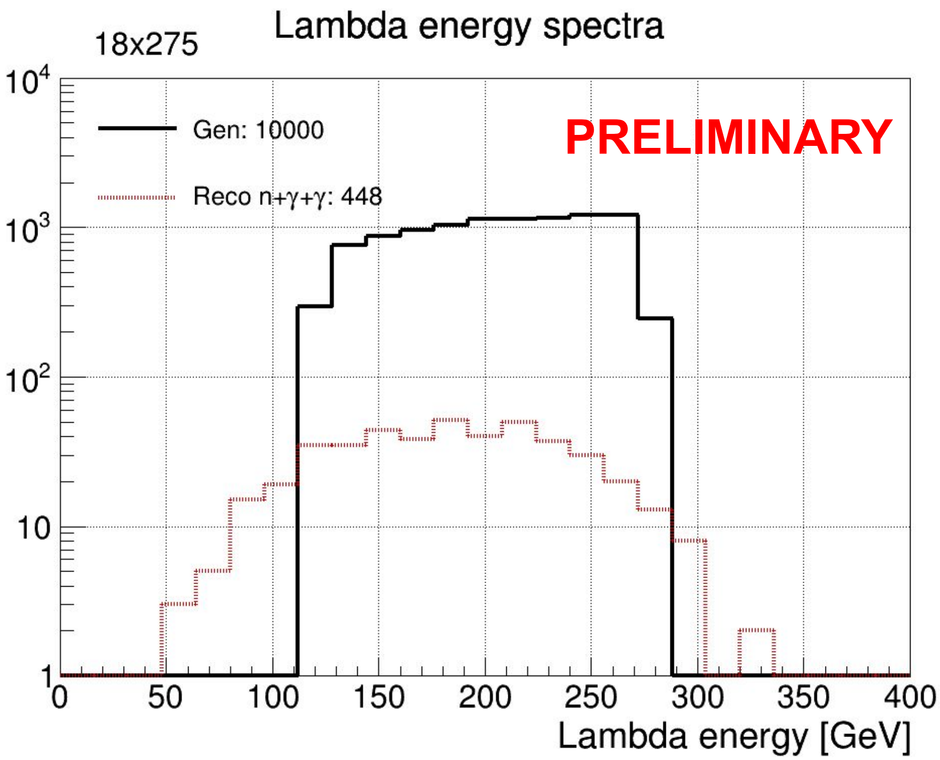
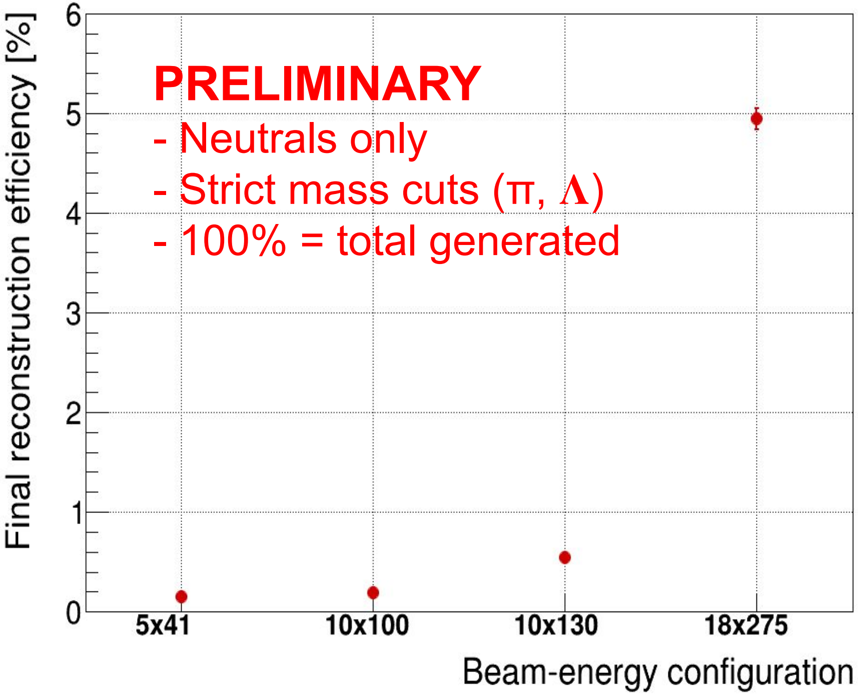
Λ reconstruction preliminary results





Λ reconstruction : impact of physics and clustering

```
=== 18x275 : Lambda efficiency budget ===
stage                                              count     eff [%]
Generated Lambda                                 10000.0     100.000
Lambda decayed before ZDC (79.5%)                 7950.0      79.500
Lambda -> n pi0 (35.8%)                           2846.1      28.461
---------------------------------------------------------------------
ZDC acceptance, normalized to Lambda -> n pi0
stage                                              count    frac [%]
1 neutron in ZDC                                  2434.0      85.524
1 gamma in ZDC                                    2720.0      95.573
2 gammas in ZDC                                     73.0       2.565
1 neutron + 2 gammas in ZDC                         66.0       2.319
---------------------------------------------------------------------
n + 2 gammas in ZDC                                 66.0       0.660
Final reconstructed Lambda, all detectors          448.0       4.480
Gain from other calo (B0, LFHCAL, Endcap)                     +3.814
```

Physical loss >70%

High acceptance (85-95%)

Strong impact of **clustering** ($\pi^0 \to \gamma\gamma$ boost)

Could potentially be improved with an optimized algorithm?

If not limited by clustering
0.85 * 0.95² * 0.28 ~ 20%
EicC fast-simulation value

Contribution of other calorimeters for decay products falling out of ZDC

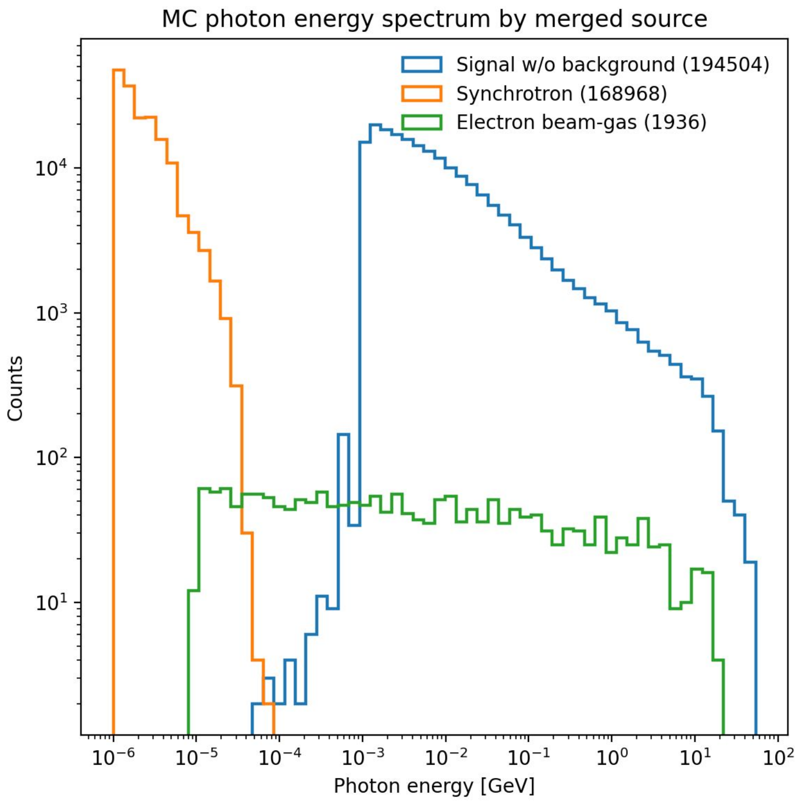
Machine background : cocktail 1

18x275 machine background cocktail (1)

github.com/eic/simulation_campaign_datasets

- Synchrotron radiation (14 kHz)
- Electron beam-gas (317 Hz)
- Coulomb (1.3 Hz)
- Touscheck (0.7 Hz)

Background γ-rays : many (low-energy)
Background neutrons : 0
Background Λ : 0
Reconstructed false Λ : 0



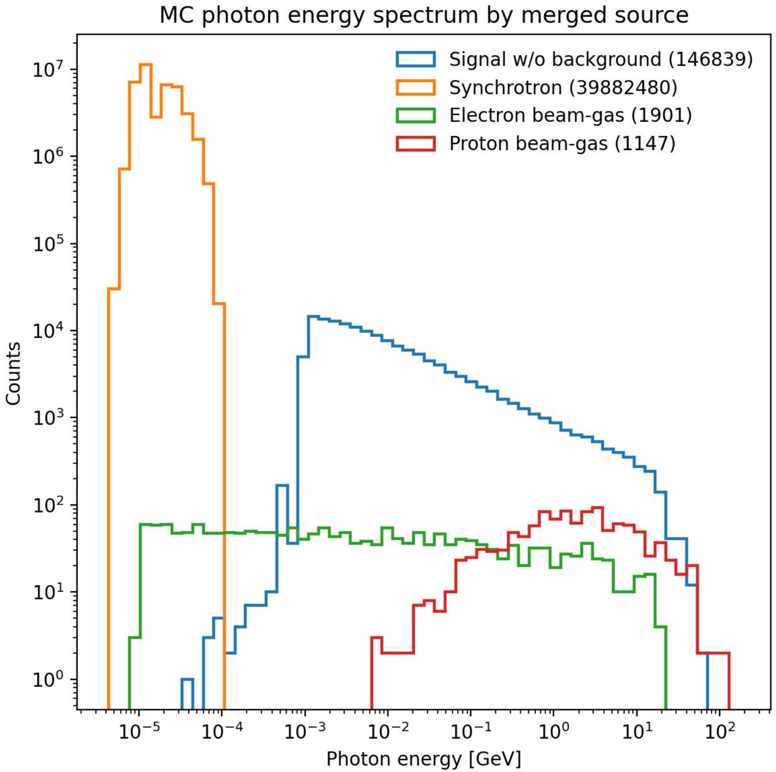
Machine background : cocktail 2

18x275 machine background cocktail (2)

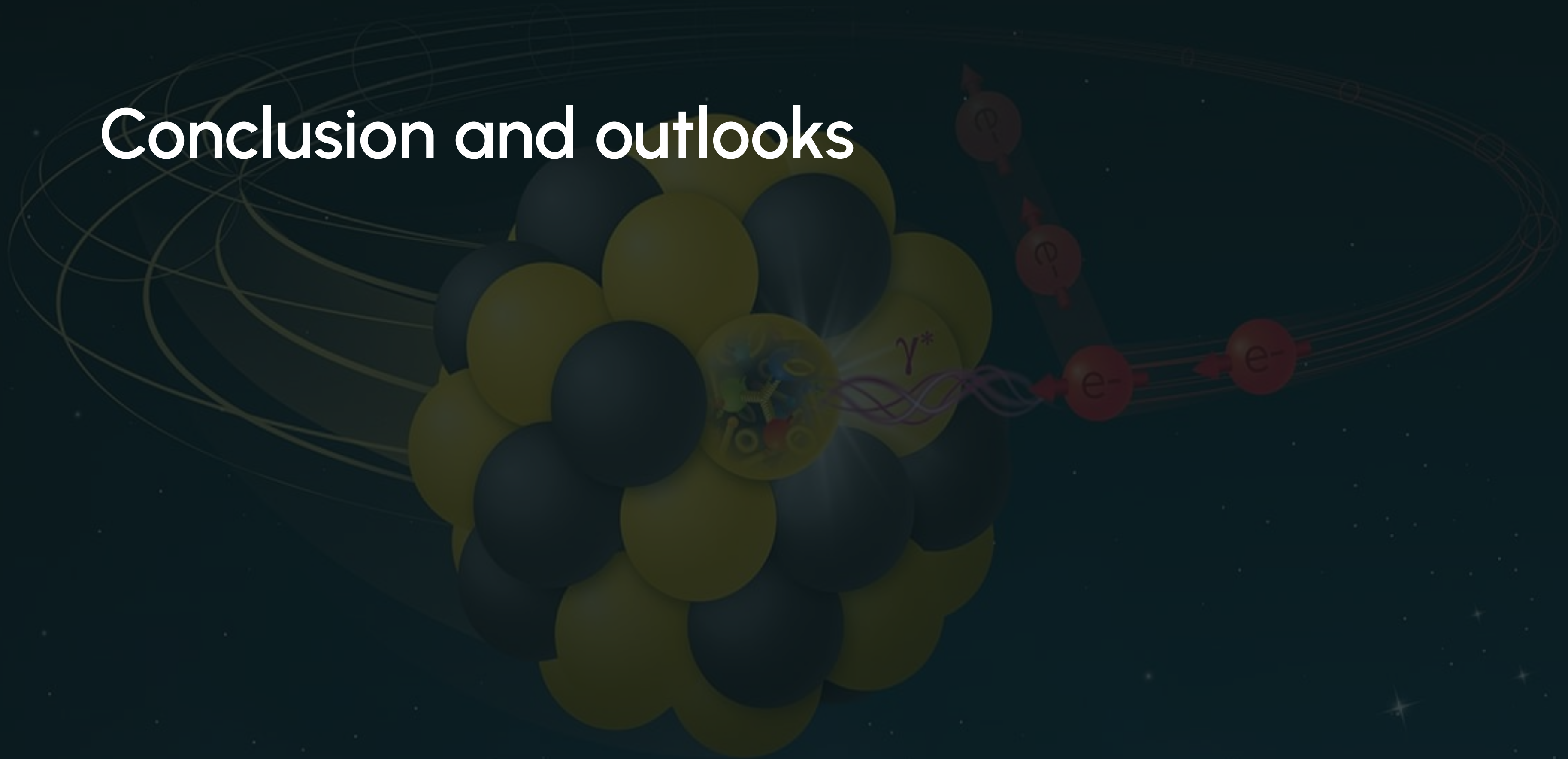
github.com/eic/simulation_campaign_datasets

- Synchrotron radiation (3.3 GHz)
- Electron beam-gas (317 Hz)
- Coulomb (1.3 Hz)
- Touscheck (0.7 Hz)
- Proton beam gas (6 kHz)

Background γ-rays : many (all energies)
Background neutrons : +35%
Background Λ : + 1 %
Reconstructed false Λ : 0



Conclusion and outlooks



Conclusion and Outlooks

- Promising reconstruction of Lambdas in SIDIS at the EIC
- Fix the ZDC Tiles issue : https://github.com/eic/EICrecon/issues/2737
- Re-evaluate projected uncertainties for kaon SF
    - Including undecayed Lambdas and/or charged decay products
    - Complete background studies (machine+physics merged)
- Uncertainty quantification
    - Sources : detectors geometry and response, event generator, etc.