Some exclusive hadron processes in G4 and their importance for NA64

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NA64 and hadron program

- The main purpose of the NA64 is to search for Dark Matter in the electron beam by measuring the missing energy. The main subdetector is the ECAL as an active target
- However, recently, the physics program was further developed to include also searches in the hadron beams.
- In this case the Dark Matter particles could manifest themselves in invisible decays of pi0, eta, eta', K0, rho mesons.
- Such mesons have very small or zero probability of SM invisible decays

NA64 and hadron program

- Source of π^0, η, η': charge exchange reaction
  π^- p -> π^0 n Here, η or η' can be created instead of π^0
- Source of K0: similar reaction
  K^- p -> K^0 n
- Another source of K0, important at low energy:
  π^- p -> K^0 Λ
- Source of ρ^0:
  γ p -> ρ^0 p (can be coherent on nucleus)

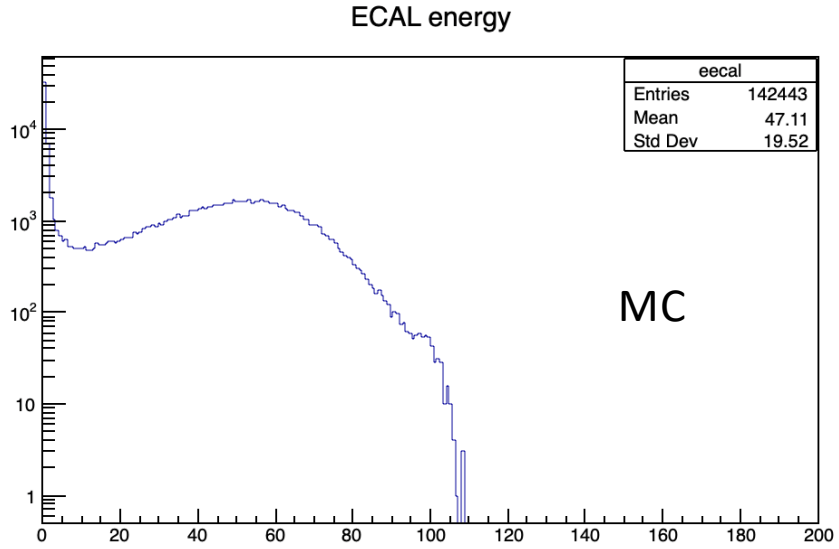
Charge exchange π^0, η, η':

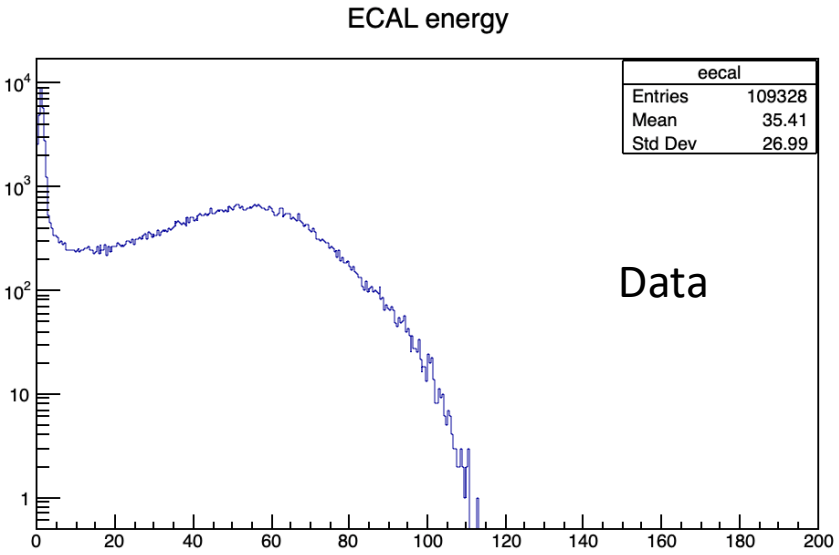
- First result on η, η' is already obtained and published. Concurrent sensitivity for η' is obtained
- Big uncertainty on the cross sections (is not measured on all nuclei). A recent paper from NA64 members on the fits to data. There is the idea to measure it, so the simulation is needed.
- The possibility to continue on the PS T9 beam at 15 GeV is being considered.
- The process is recently implemented in G4 by V. Ivantchenko with a student. Preliminarily tested at 40 GeV for π^0, η on carbon, iron (G4 master from November)
- Further tests and improvements are needed. There are still warnings, cross sections to be checked.
- Is it possible to simulate nuclear effects such as excitation and even desintegration at high momentum transfers?

Charge exchange π^0, η, η':

- I observed that this process is present in G4 iwith physics list FTFP_BERT in inelastic interactions at 40 GeV on the level compatible with measured cross sections.
- However, together with it, in many cases almost all energy is transmitted to π^0 in processes which are not charge exchange (additional π). As a result, there is a bump in the energy deposition distribution in ECAL in the hadron beam.
- We discussed this with Alberto several years ago

Energy distribution in ECAL





Bump ~300 events (0.25%) in default G4

Not seen in data.

Real energy resolution ~3.5%

Small number of events, but important as background

Patching G4 to avoid bump

```
pcrfcms18>diff G4FTFParameters.cc.orig G4FTFParameters.cc
577,578c577,578
<        if ( ! fArrayParCollPionProj[indexTune].IsProjDiffDissociation() )
<           SetParams( 2,      0.0 , 0.0 ,          0.0  , 0.0 , 0.0, 0.0  ,  -100.0 );  // Projectile diffraction
---
> //       if ( ! fArrayParCollPionProj[indexTune].IsProjDiffDissociation() )
> //          SetParams( 2,      0.0 , 0.0 ,          0.0  , 0.0 , 0.0, 0.0  ,  -100.0 );  // Projectile diffraction
```

- This patch removes the bump and charge exchange reactions
- Is used in NA64 simulations since ~2017 (however we do not rely quantitatively on this BG simulation)
- In simulations for the charge exchange cross section measurements we can avoid double counting.

Other exclusive reactions

- Reaction $\pi^- p \rightarrow K^0 \Lambda$ is observed in G4 without patch at 40 GeV. However, at 16 GeV this reaction disappears, although the measured cross section is 2 times higher. Also, I suspect that not exclusive processes, but the ones with high transfer to strange particles, are overestimated.
- $\gamma p \rightarrow \rho^0 p$ According to Alberto not known in G4.

Conclusion

- Simulation of exclusive reactions listed above would be very useful for the NA64 hadron program
- It can also contribute to the general accuracy of G4 simulations