CBM: PFSimple: configurable package for decays reconstruction

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Meeting of developers and users of the KF code
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Introduction to Particle Finder Simple (PFSimple)

PFSimple is a physics analysis-oriented (offline) package for decays reconstruction

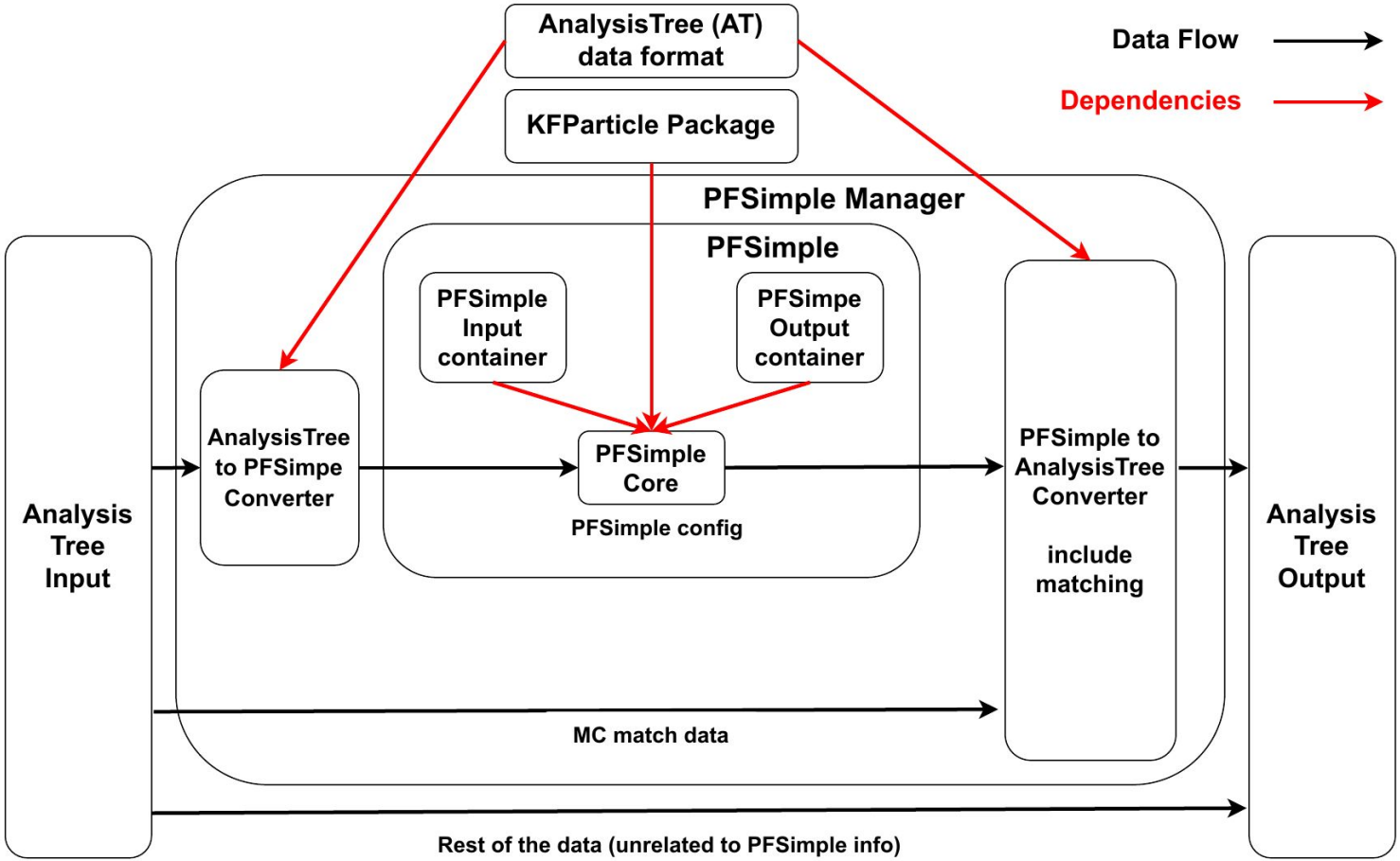
- Uses Kalman Filter mathematics implemented in KFParticle package
  (tracks extrapolation, construction decay candidates from daughter particles, etc.)
- Modular code design:
  - KFParticle (external package)
  - Internal I/O data containers
  - External I/O interface, currently for AnalysisTree (converters to AT for CBM, HADES, NA61, STAR)
  - Core of PFSimple (building decay candidates)
- Flexible configuration by user: each decay channel can be configured individually

Current implementation includes 2-body, 3-body and cascade decays

- Topological variables (χ^2_{prim}, χ^2_{geo}, χ^2_{topo}, L/ΔL, DCA, etc.) are streamed into the output container for further analysis (e.g. save to file, fill histograms, optimize selection criteria with ML)

PFSimple source code and instructions available at github.com/HeavyIonAnalysis/PFSimple
AnalysisTree is a universal, standalone physics analysis-friendly data format: github.com/HeavyIonAnalysis/AnalysisTree

PFSimple modularity



PFSimple configuration example

PFSimple configuration (definition of decays and selection criteria) implemented via compilable C++ code

(possible in future to use YAML/JSON configuration)

Available configurations: 2-body Λ, K^0_S (2-body), hypernuclei (3-body) and Ξ^-, Ω^- (cascades).

Example: $\Lambda \rightarrow p\pi^-$

```
const int pid_mode = 1; // MC-PID

Daughter proton(2212);
Daughter pion(-211);
Mother lambda(3122);

proton.SetCutChi2Prim(3.);  // Daughter-related cuts
pion.SetCutChi2Prim(3.);

lambda.SetCutChi2Geo(3);    // Mother-related cuts
lambda.SetCutDistance(1);
lambda.SetCutLdL(5);

//   proton.CancelCuts();   // Alternative: switch
//   pion.CancelCuts();     // off all the cuts
//   lambda.CancelCuts();

Decay lambda_pi_p("lambda", lambda, {pion, proton});
```

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```

$K^0_S \to \pi^+\pi^-$

```
const int pid_mode = 1; // MC-PID

Daughter pion_pos(211);
Daughter pion_neg(-211);
Mother kshort(310);

pion_pos.SetCutChi2Prim(3.);  // Daughter-related cuts
pion_neg.SetCutChi2Prim(3.);

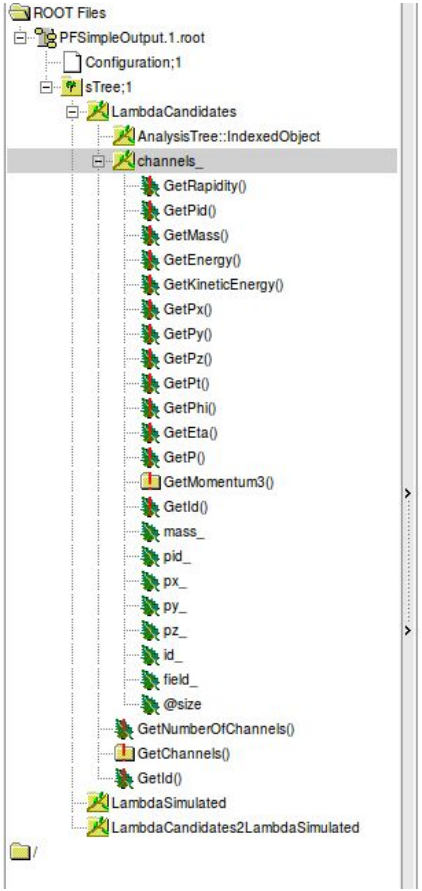
kshort.SetCutChi2Geo(3);    // Mother-related cuts
kshort.SetCutDistance(1);
kshort.SetCutLdL(5);

//   pion_pos.CancelCuts();   // Alternative: switch
//   pion_neg.CancelCuts();     // off all the cuts
//   kshort.CancelCuts();

Decay kshort_pi_p("kshort", kshort, {pion_neg, pion_pos});
```

Other decays can be easily configured, e.g. $D^0 \to \pi^+ K^-$

PFSimple candidates in AnalysisTree container




```
user@user-X55VD:~/cbmdir/working/pfsimple_merge$
 root -l PFSimpleOutput.1.root
root [0]
Attaching file PFSimpleOutput.1.root as _file0..
.
(TFile *) 0x1bcd190
root [1] Configuration->Print()
This is a
The Tree has the following branches:

Branch LambdaCandidates (id=0) consists of:
  floating fields:
   chi2geo (id=5)
   chi2primneg (id=1)
   chi2primpos (id=0)
   chi2topo (id=9)
   cosineneg (id=4)
   cosinepos (id=3)
   cosinetopo (id=8)
   distance (id=2)
   eta (id=-6)
   l (id=6)
   ldl (id=7)
   mass (id=-5)
   p (id=-10)
   pT (id=-2)
   phi (id=-1)
   px (id=-7)
   pxerr (id=13)
   py (id=-8)
   pyerr (id=14)
   pz (id=-9)
   pzerr (id=15)
   rapidity (id=-3)
   x (id=10)
   y (id=11)
   z (id=12)
  integer fields:
   daughter1id (id=3)
   daughter2id (id=4)
   is_signal (id=5)
   isfrompv (id=0)
   nhitsneg (id=2)
   nhitspos (id=1)
   pid (id=-4)
  boolean fields:
```

- Decay kinematics*
  - energy and 3-momentum components
  - inv. mass
- Decay vertex coordinates*

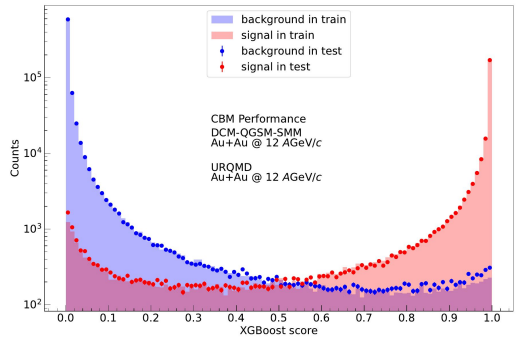
*) Uncertainties of all parameters are provided

- Topological variables
  - X^2_{prim}, X^2_{geo} , X^2_{topo}
  - DCA
  - L/ΔL
  - …
- (If available) MC-matching for mother and daughter particles

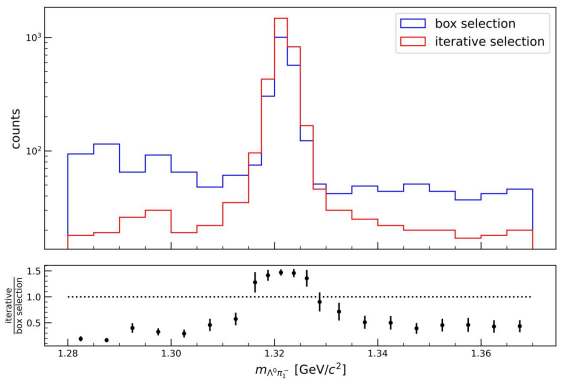
PFSimple application at CBM

(Multi)strange hadrons production: ML selection optimization

S. Khan, PhD thesis @ Uni Tübingen



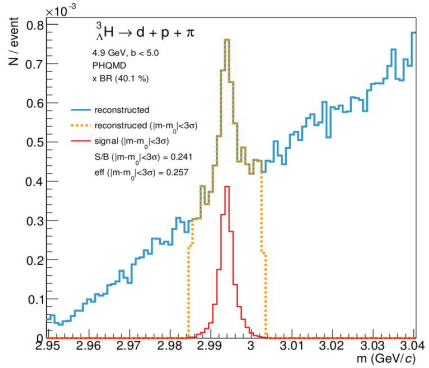
L.-K. Kümmerer, BA thesis @ Uni Heidelberg

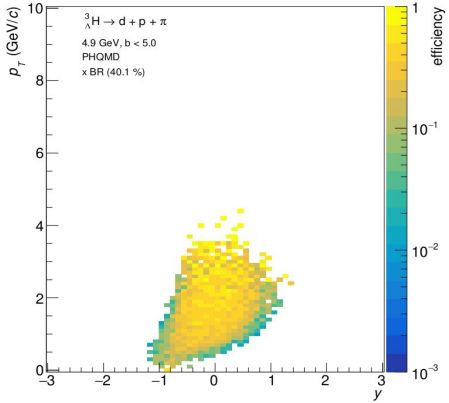


(**top**) XGBoost score for signal and background;
(**bottom**) comparison between ML-optimized and box selection

Hypernuclei production

S. Gläßel, C. Blume, CBM Progress report 2022

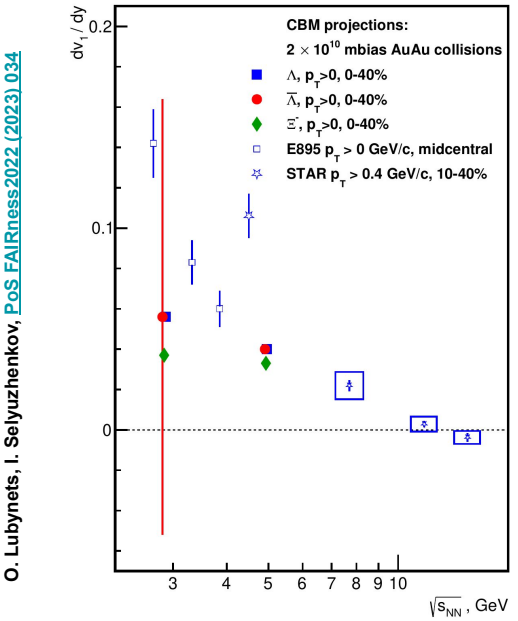




(**top**) Hypertriton invariant mass distribution
(**bottom**) (p_T, y) reconstruction efficiency

Collective flow of strange hadrons

O. Lubynets, I. Selyuzhenkov, PoS FAIRness2022 (2023) 034



Performance for strange hadrons dv_1/dy measurement

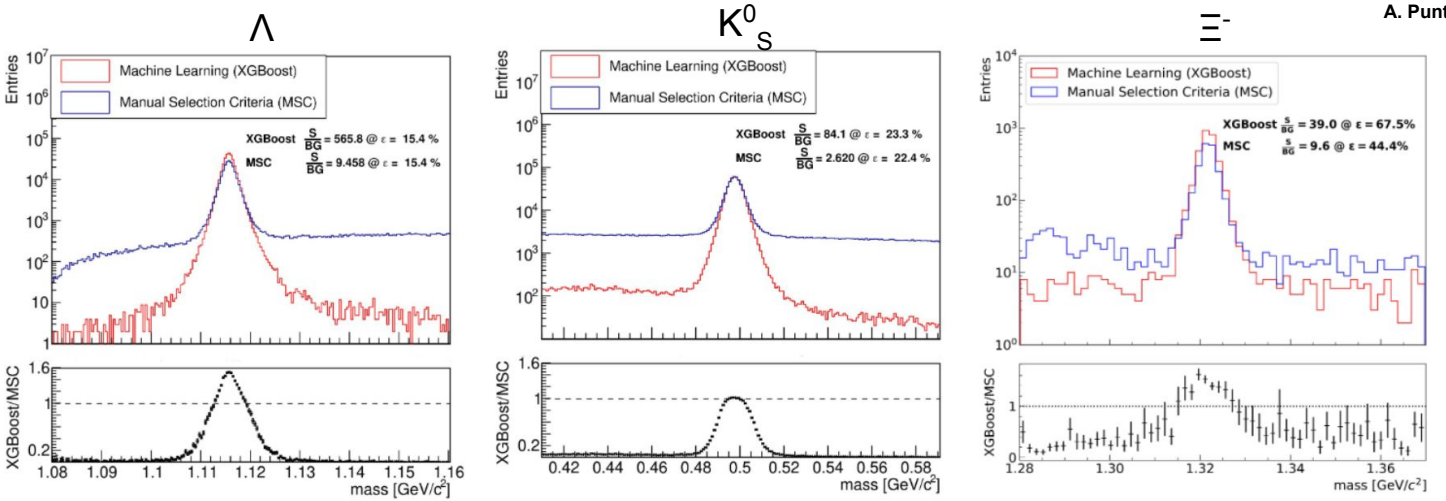
(Multi-)strange hadron analysis with ML

- Boosted Decision Tree (BDT) algorithm - supervised ML
- Improved iterative procedure: 2 BDT models are trained and applied in sequence
  - 1-st model is trained on full (BG dominated) sample: used to suppress overall background without signal loss
  - 2-nd model is trained on reduced BG sample: optimized signal/BG separation
  - 2-step approach provides better performance than a single BDT model

More detailed in BA thesis of L.-K. Kümmerer

BDT vs. box selection

A. Puntke et al., QM2023 poster



BDT selection shows better performance for both background rejection and signal efficiency compared to the box selection