ACTS Workshop 2023

Status of the GSF

09.11.2023

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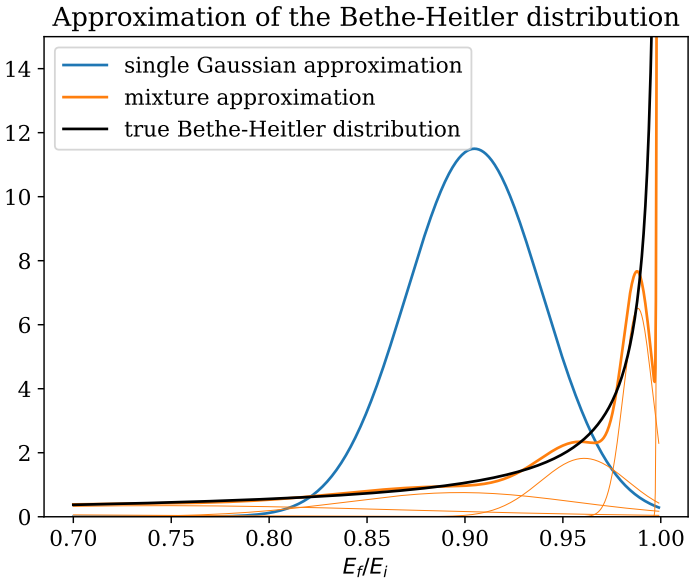
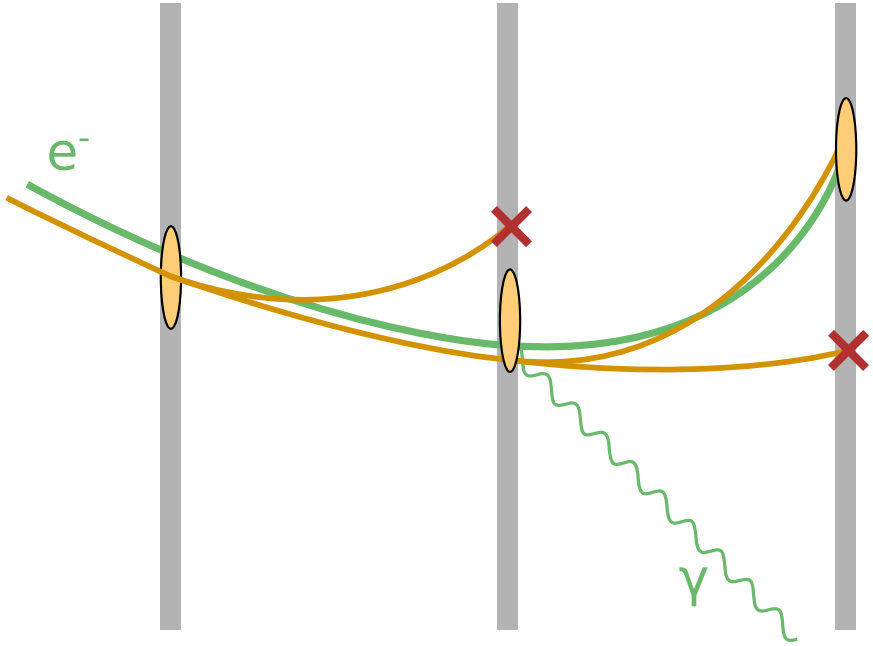
What is the GSF?

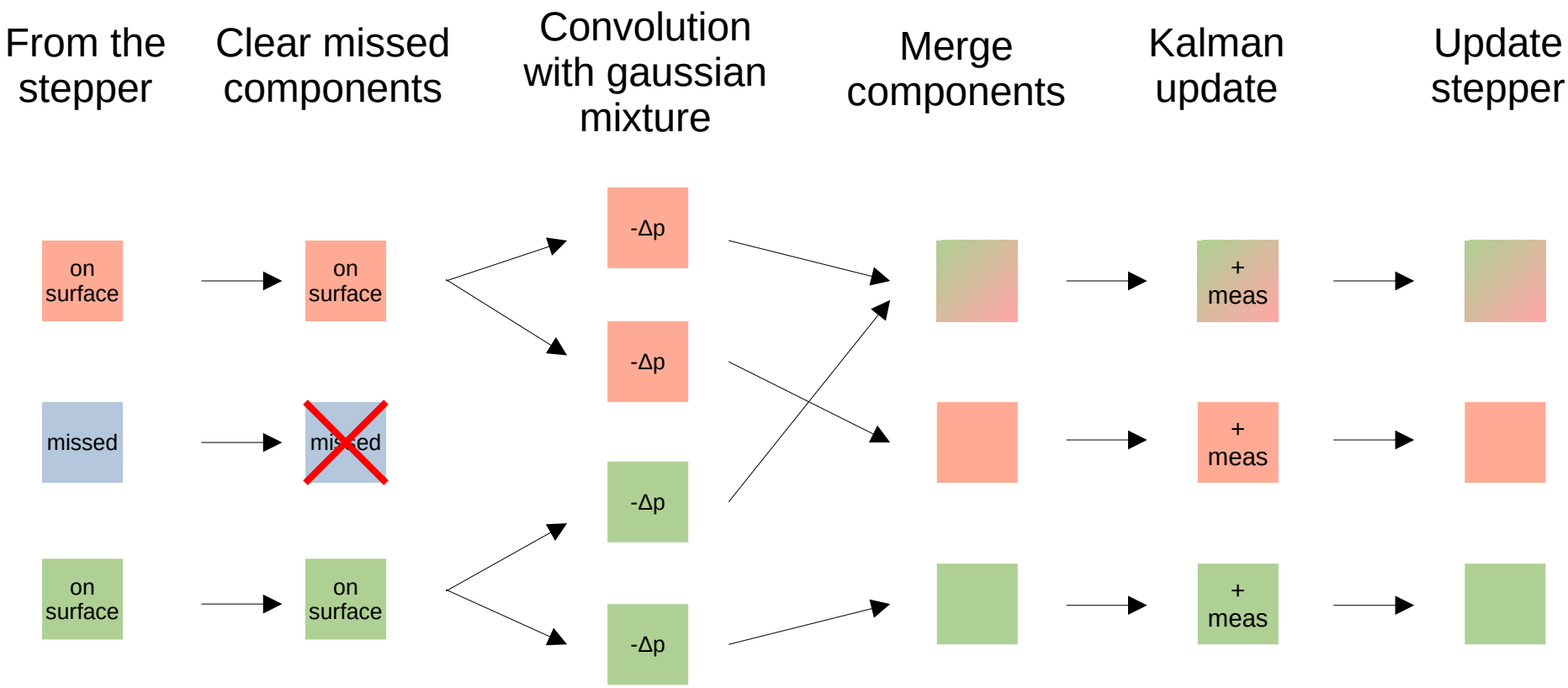
- Multi component Kalman Filter for Non-Gaussian noise
- Application: Electron fitting





$$p(\boldsymbol{x}) = \sum_i^N w_i \mathcal{N}(\boldsymbol{x}|\boldsymbol{\mu}_i, \boldsymbol{\Sigma}_i), \quad \sum_i^N w_i = 1$$

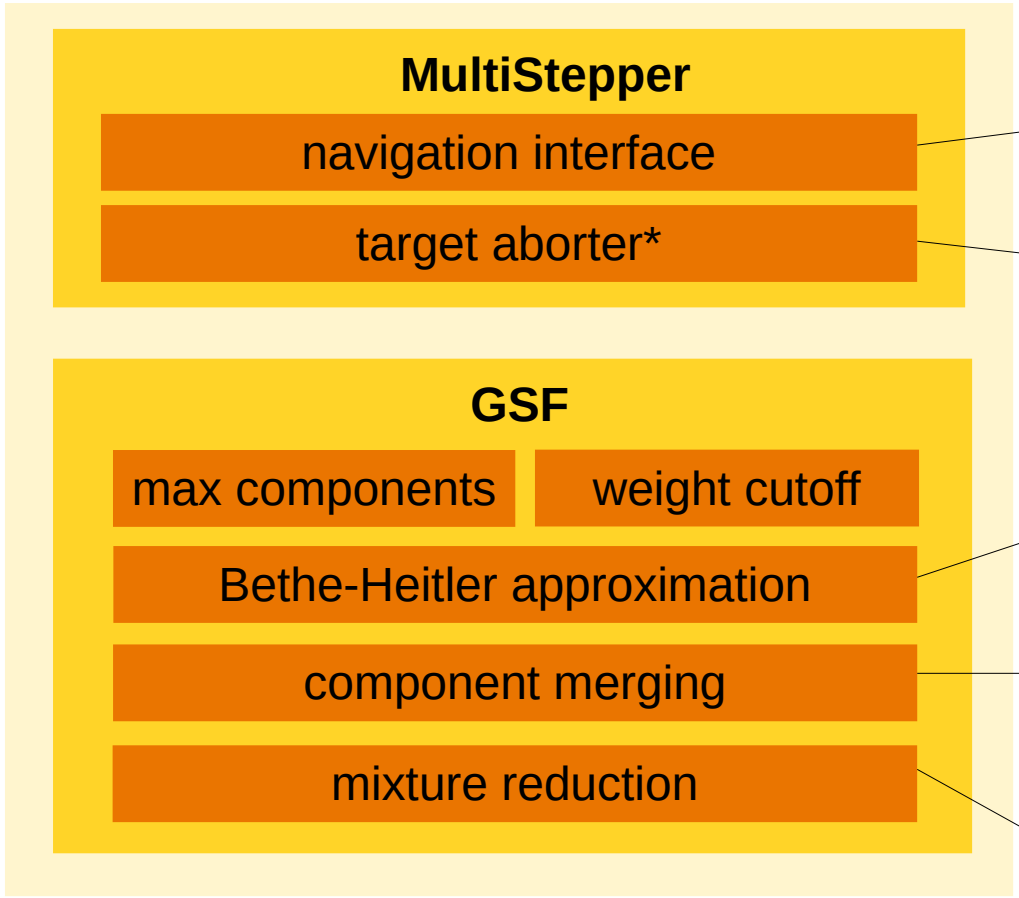
Algorithm overview



Status

- Implementation stable (more or less)
- Integrated in ACTS CI for stable performance
- This presentation:
  - Configuration options
  - Validation & performance study in ODD
  - Next steps
  - Debugging

Configuration



template-customizable, e.g.:
- mean
- max-weigth component
- max-momentum component

when target is reached?
- Each component
- Mean of components

template-customizable, currently implementation for ATLAS dataformat

For final parameters and MTJ, currently:
- mean
- maximum-weight
- mode

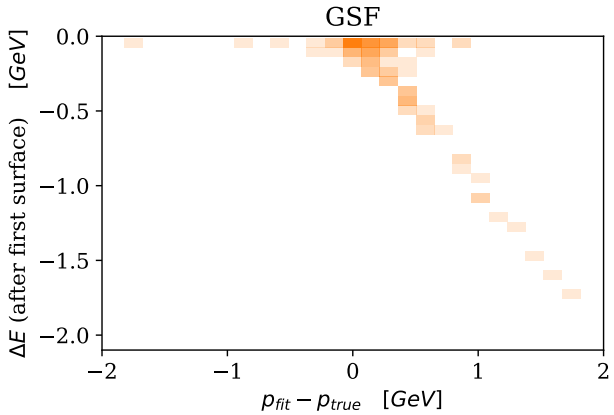
Configurable via Delegate:

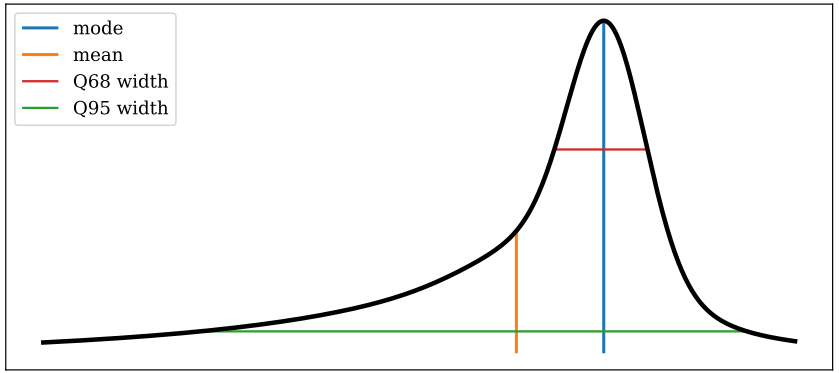
```
void f(vector<Component>, int maxComponents)
```

*currently not high-level configurable

Setup

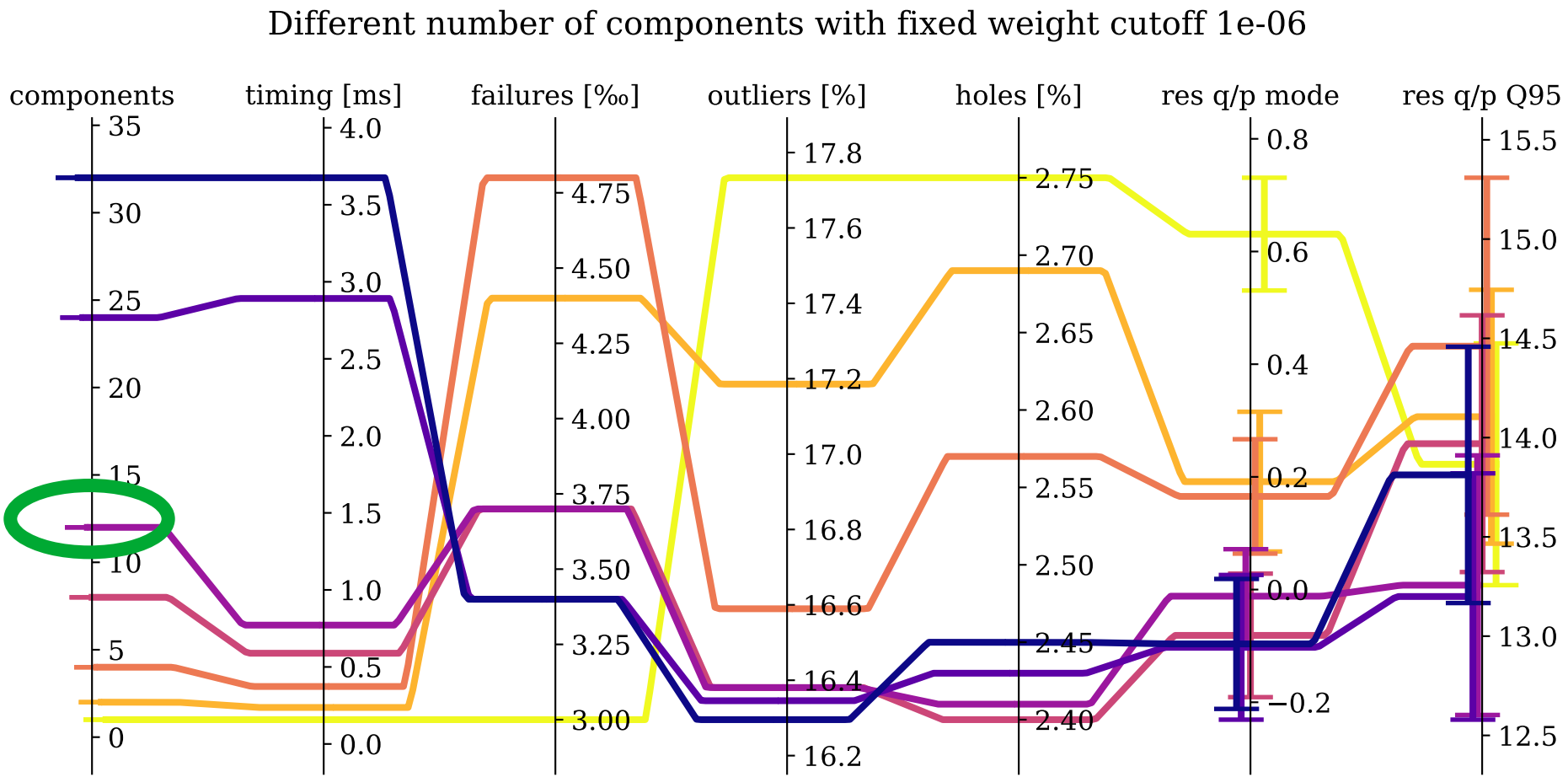
- 10^6 e^+e^- with Geant4 in ODD
  - Smeared digitization
  - Uniform |eta| < 3
  - Uniform 1GeV < pT < 100GeV
  - Remove unreconstructible particles
  - Remove fits with outliers / holes
- **Performance metrics:**
  - Failures, outliers*, holes
  - Sample mode of residuals (because of bias)
  - Q95 & Q68 width
  - Mean of Q95 interval





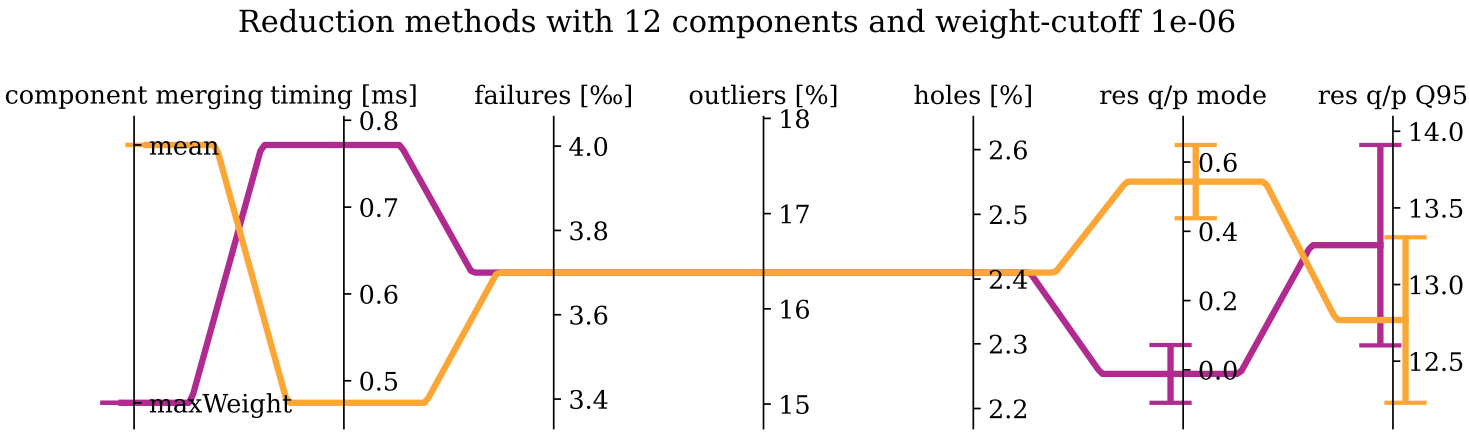
*surfaces missed on reverse pass

Number of components?



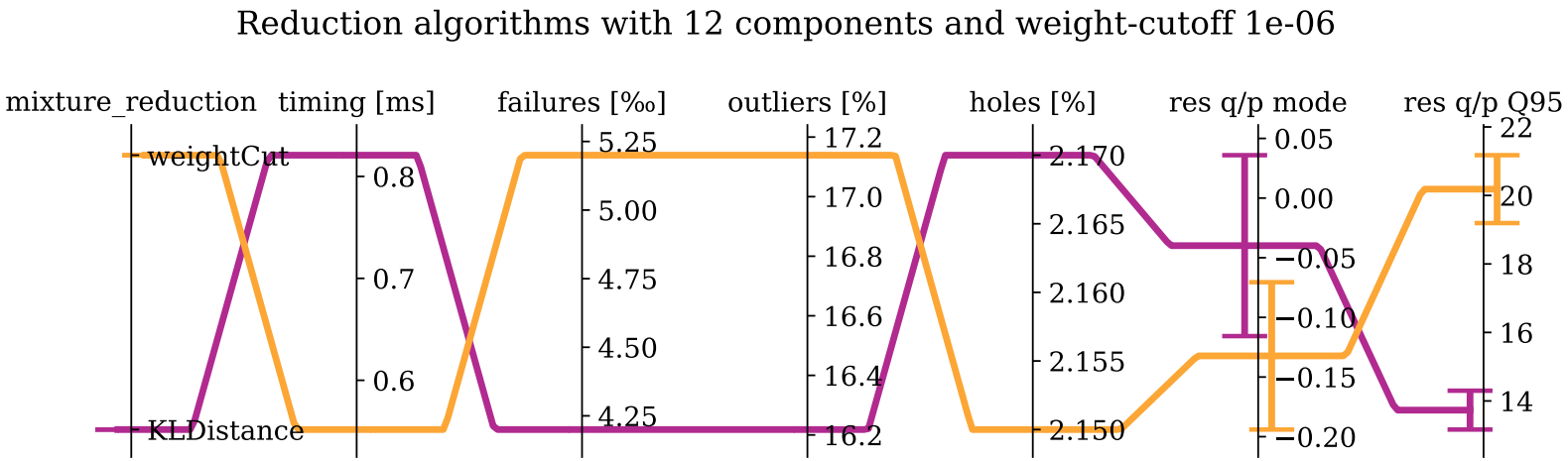
How to create mixture?

- How to make final parameters from gaussian mixture?
  - Mean → estimate influenced by tail
  - Mode → not yet merged, expensive
  - **Max weight component** →cheap, our best guess without further measurment constraint

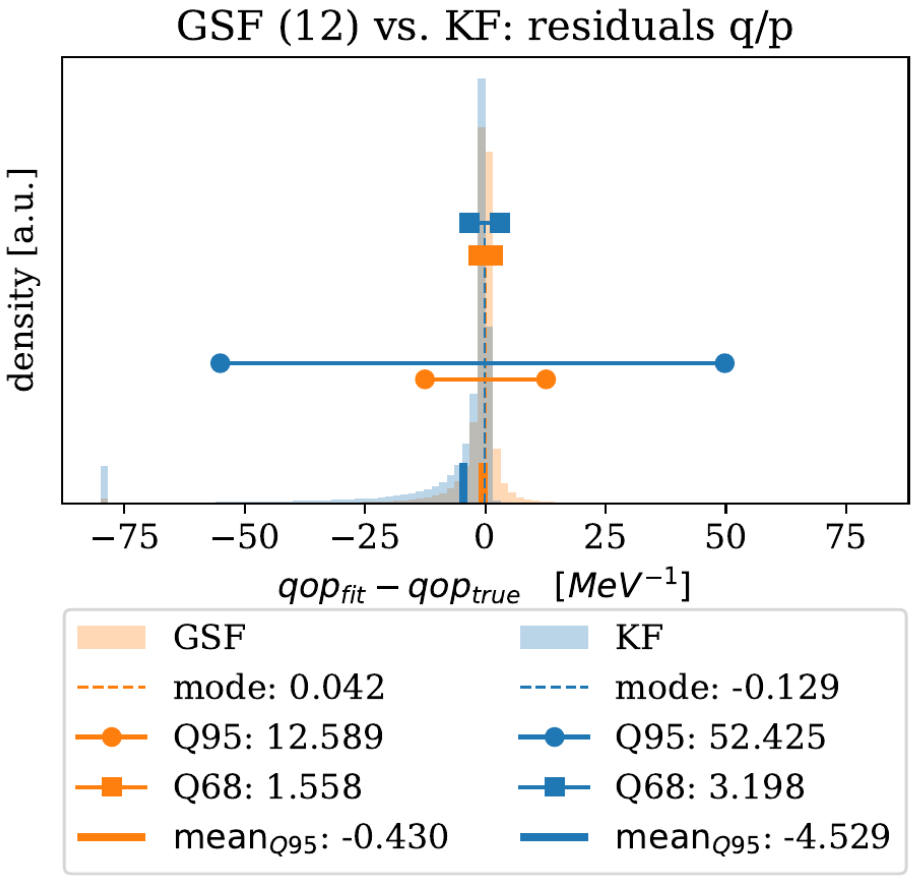


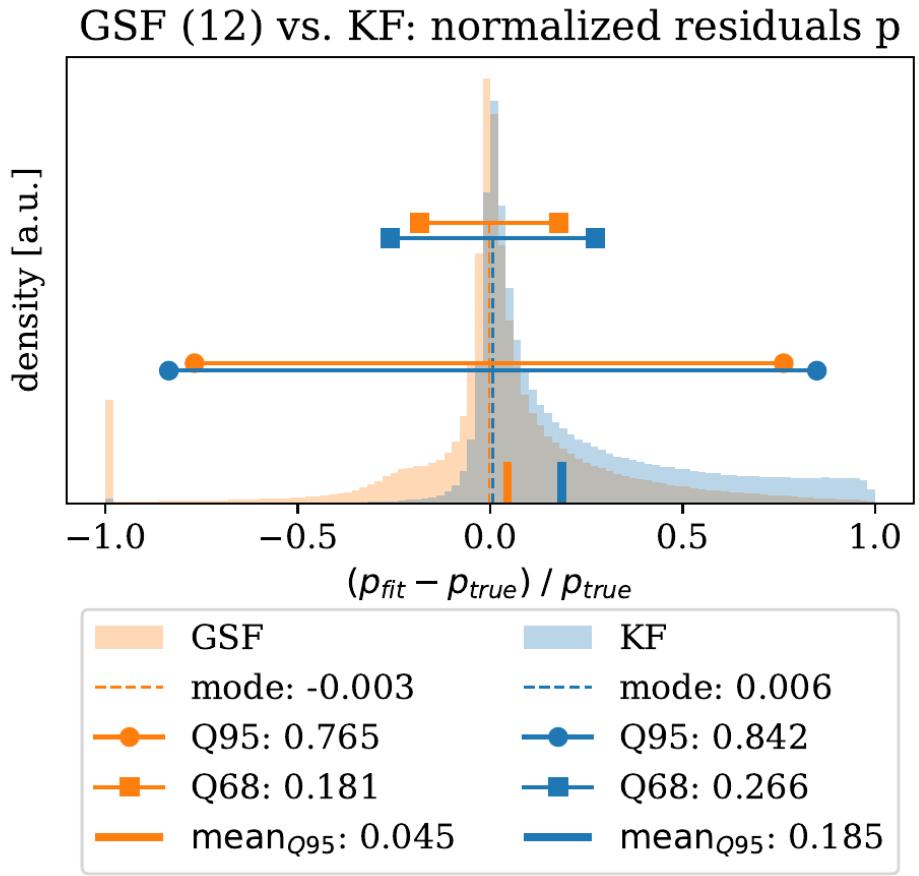
Mixture reduction

- How to make final parameters from gaussian mixture?
  - weightCut (keep only largest weights)
  - **Greedy symmetric KL-Distance merger**



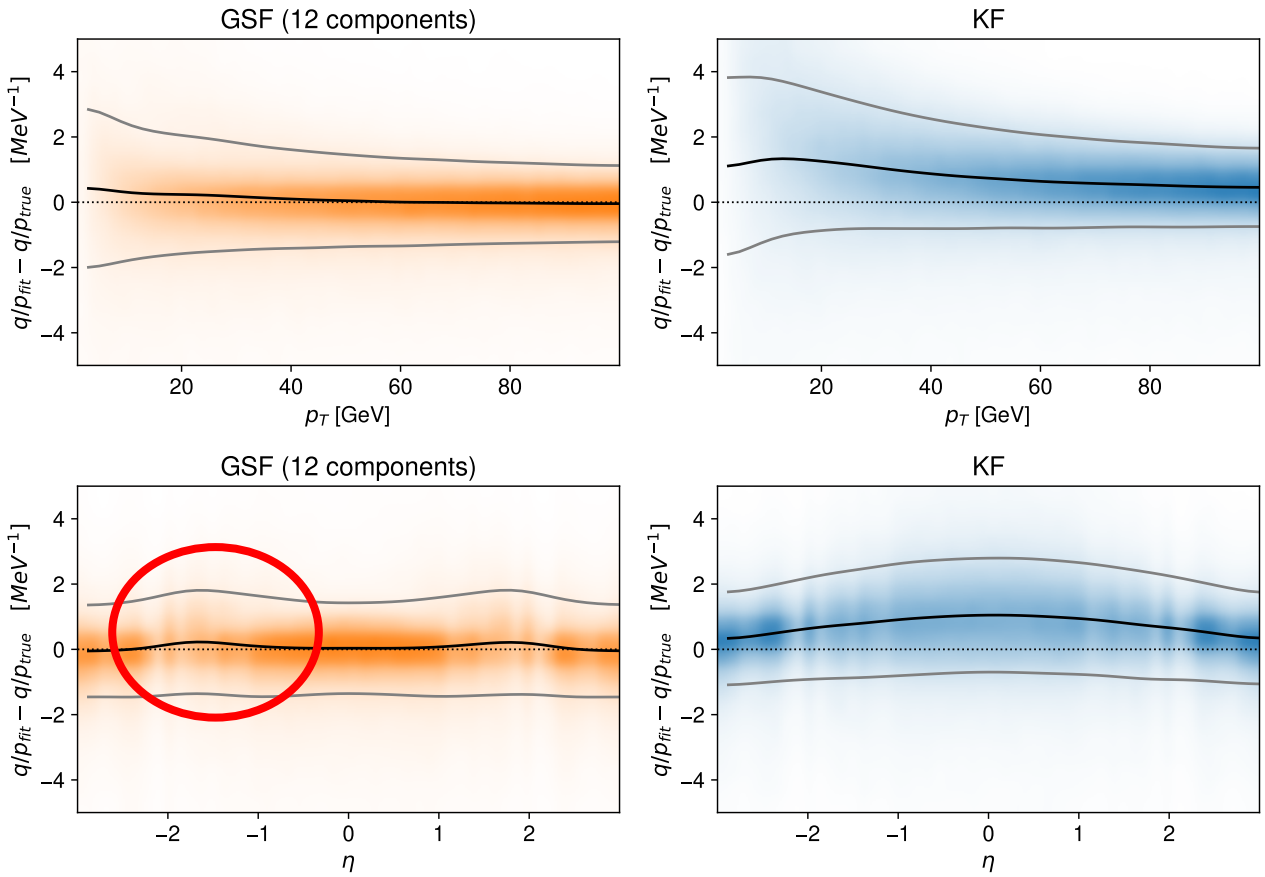
Momentum fit GSF vs KF





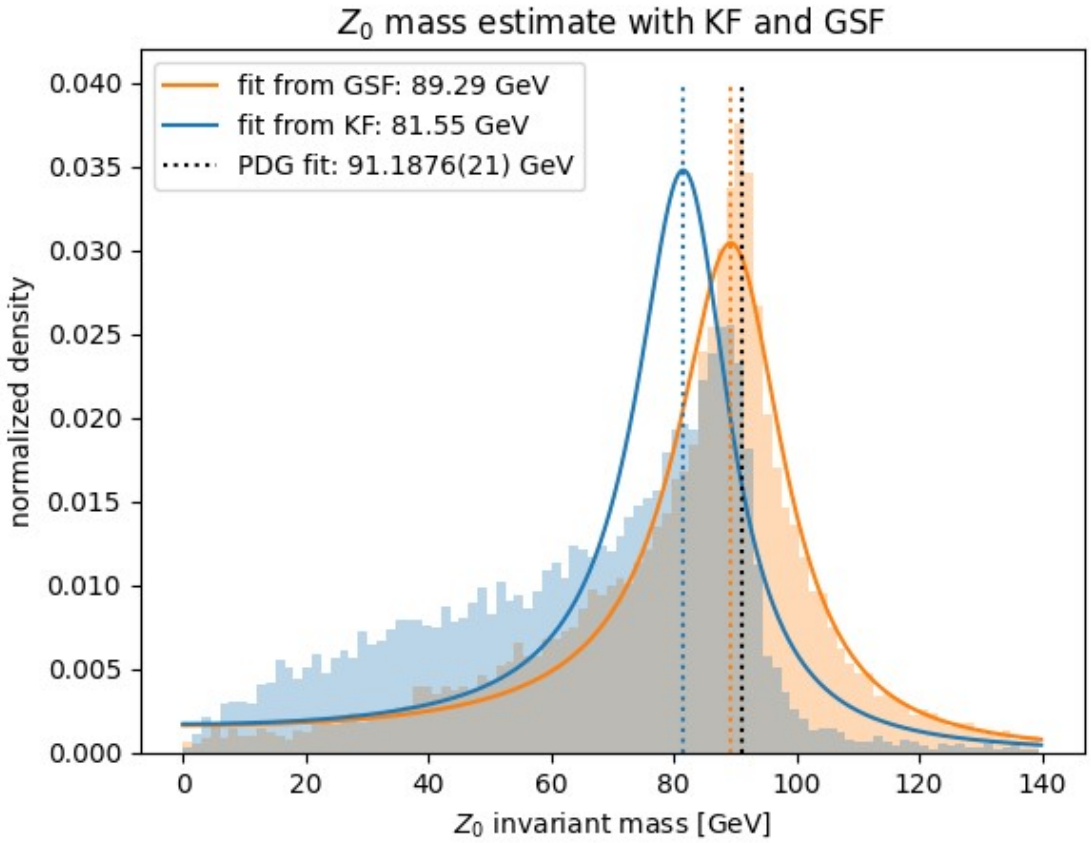
η and p_T dependence

- Here:
  - Black line: mean
  - Grey lines: standard deviation
- Still issues around |η| ≈ 1.5
  - Material mapping?
  - Bethe-Heitler approximation not good enough?



Application: $Z_0 \rightarrow e^-e^+$

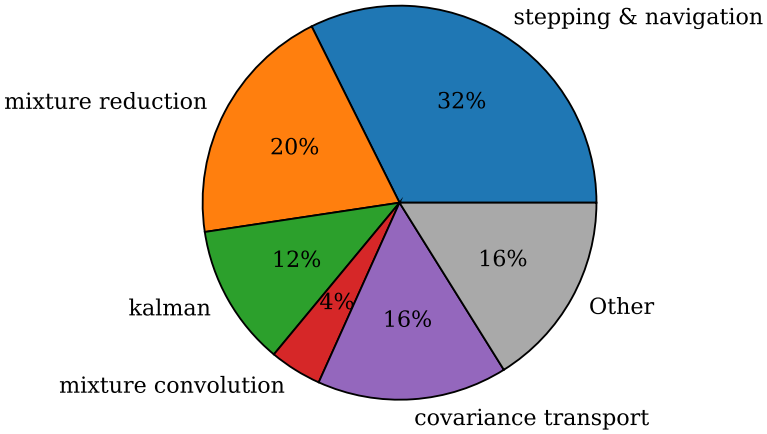
- Setup:
  - Force $Z_0 \rightarrow e^-e^+$ in pythia
  - Simulate with Geant
  - Fit with KF & GSF
- Fit Breit-Wigner to invariant mass distribution of Z_0
  - Clear improvement of GSF

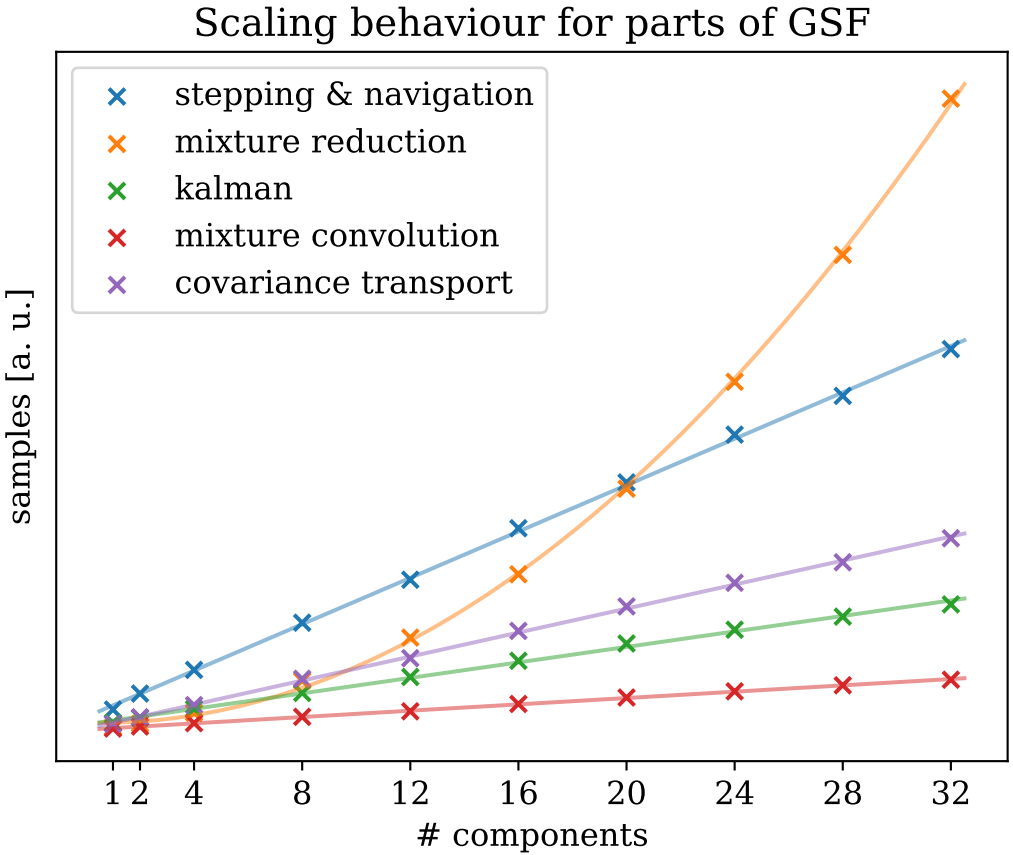


Computational performance

- Big contribution:
  - Multi-component stepping
  - Mixture reduction

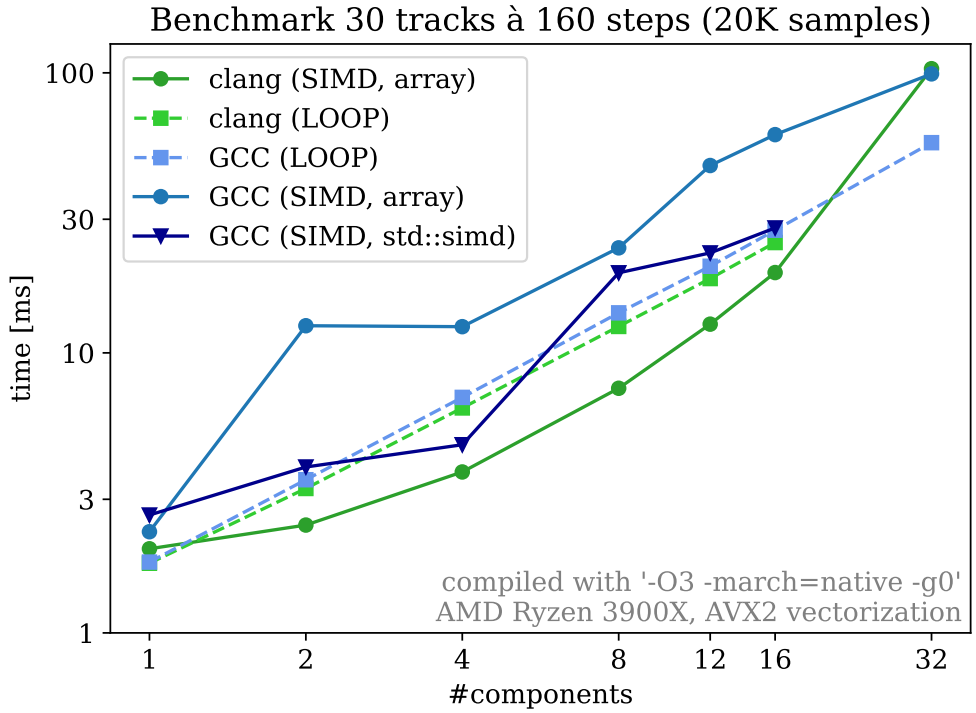
12 components:





SIMD Stepper

- Idea: vectorized operations for component processing
- Implemented `MultiEigenStepperSIMD` with 2 backends
  - Auto-vectorization with `std::array`
  - `std::experimental::simd`
- GCC not so good, but clang shows some decent speed-up
  - 8 components, speedup ~1.7
  - Less then expected on AVX2



p=1GeV, B-field=2T, free propagation

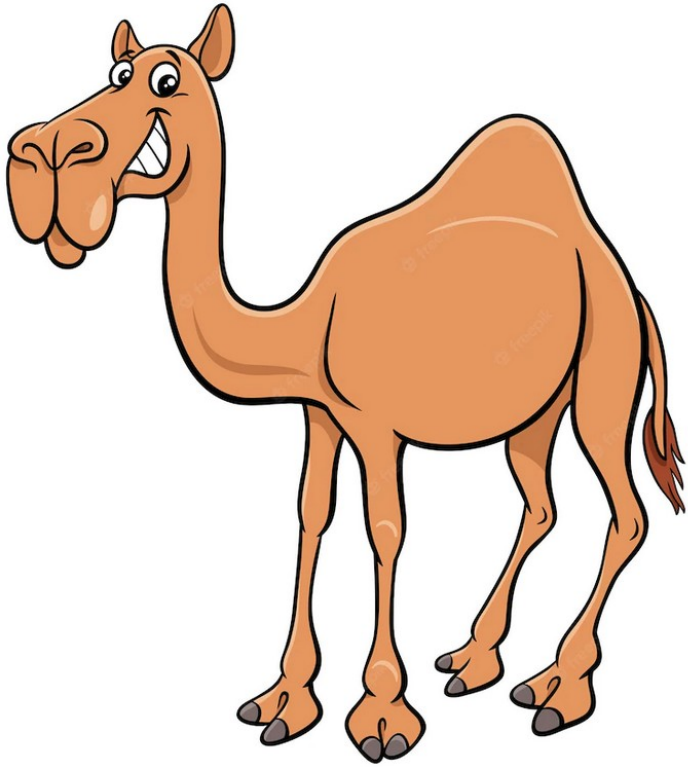
TODO

- Improve BetheHeitler Approximation for ODD
  - Provide tool for fitting parameterization
- Investigate
  - multiple scattering more in detail
  - Propagation failures
  - Errors / pull distributions
- Experiment integration would be helpful to improve further
- More performance optimization

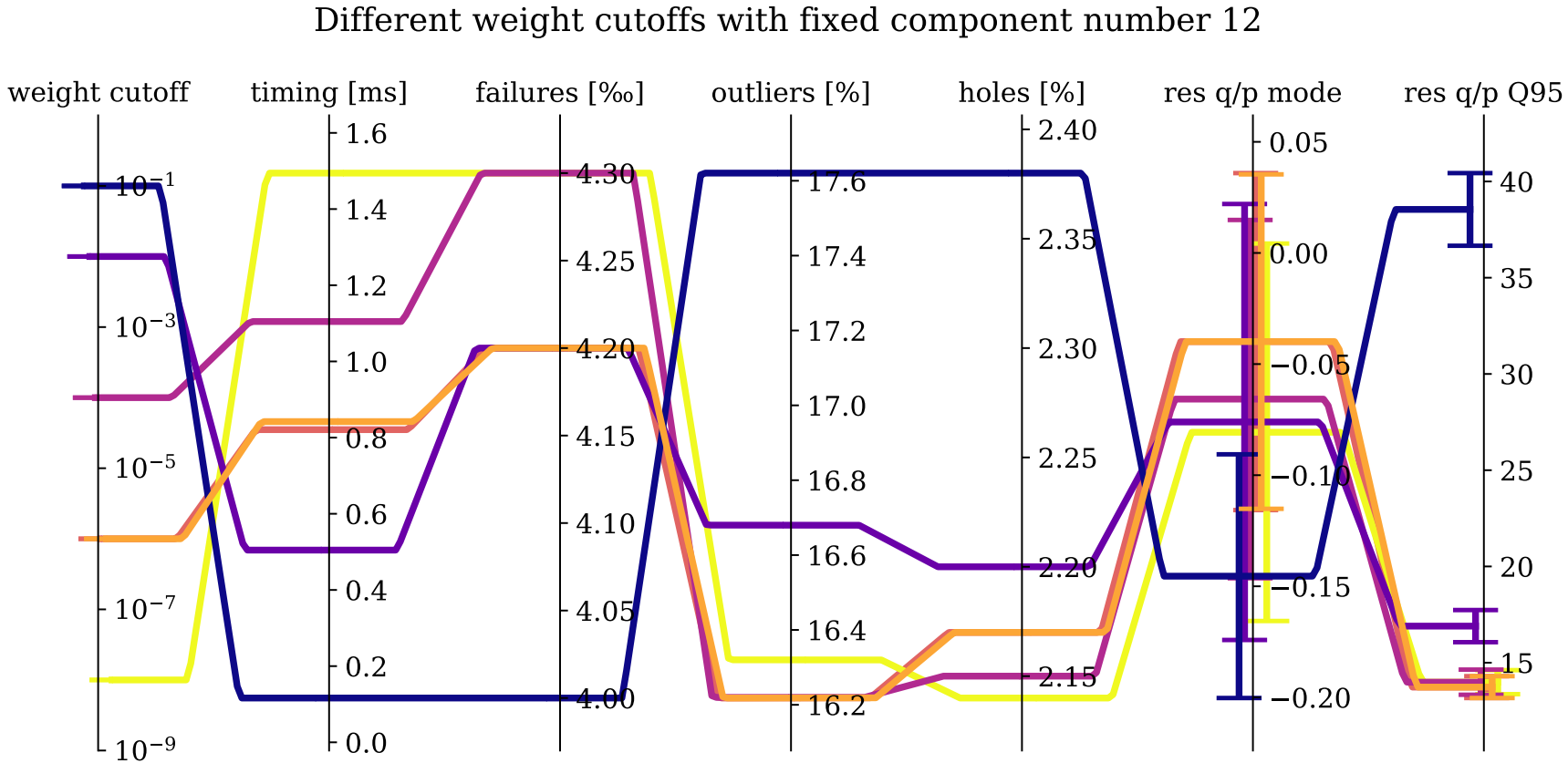
Other stuff: GSF debugger

- Live demo (hopefully)

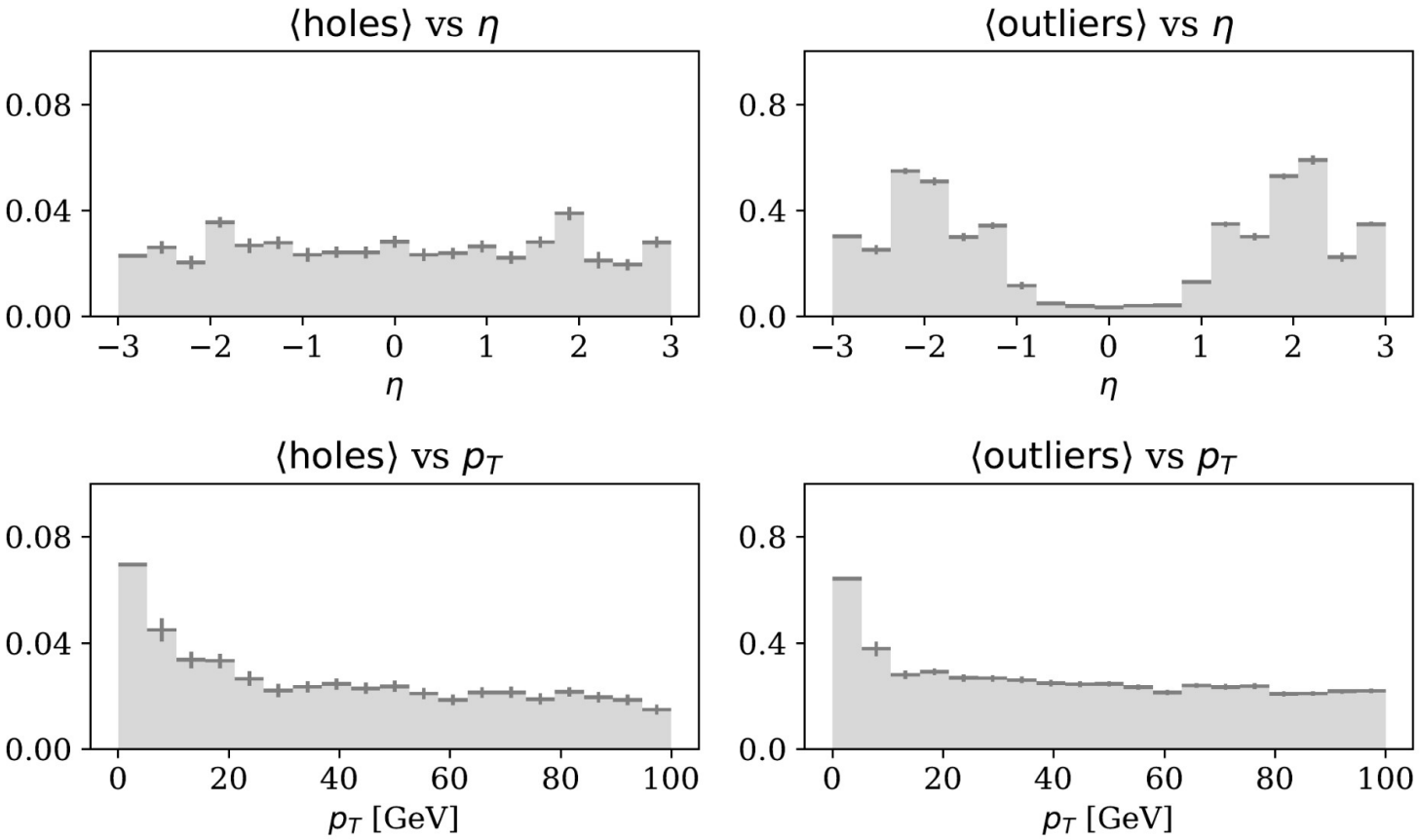
Backup



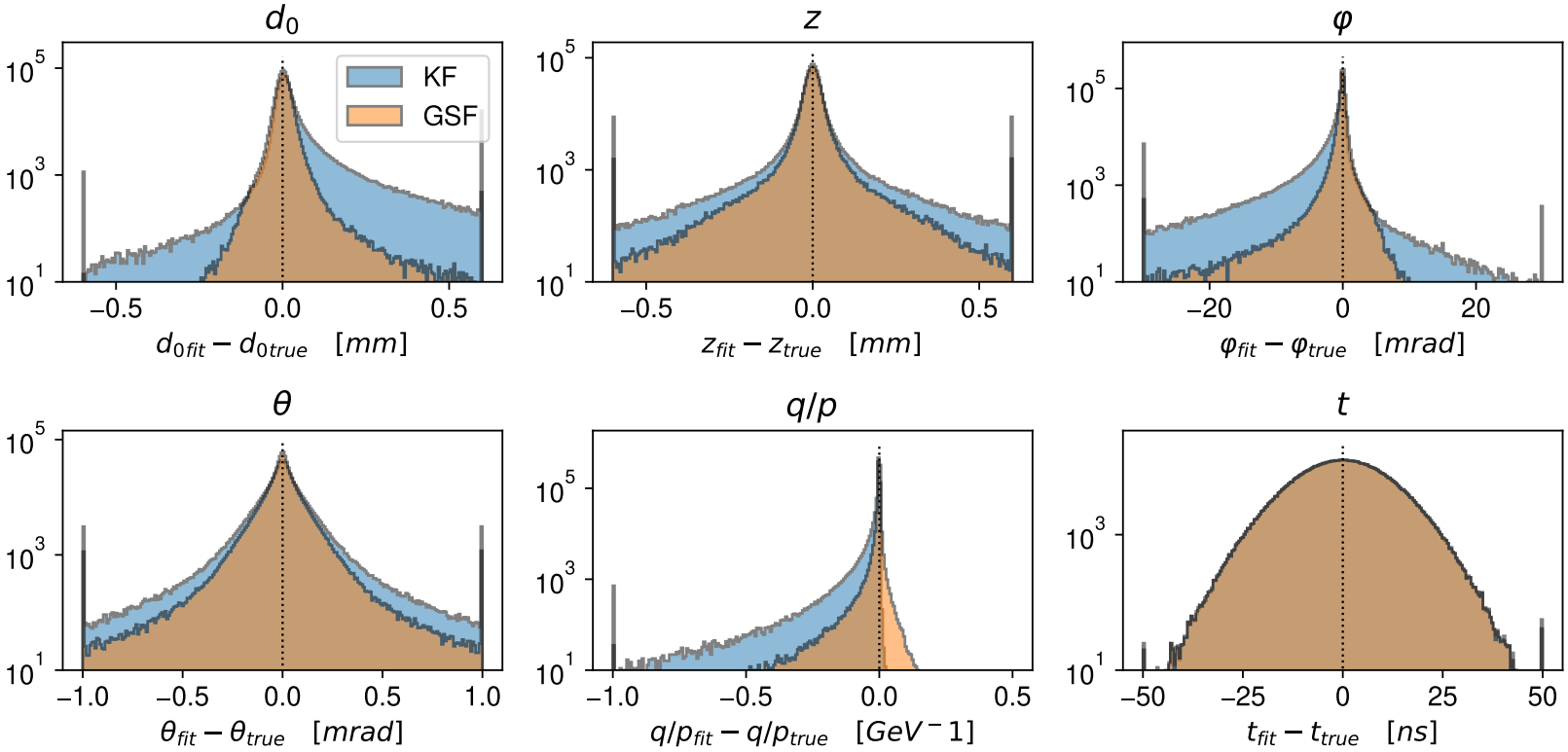
Weight cutoff



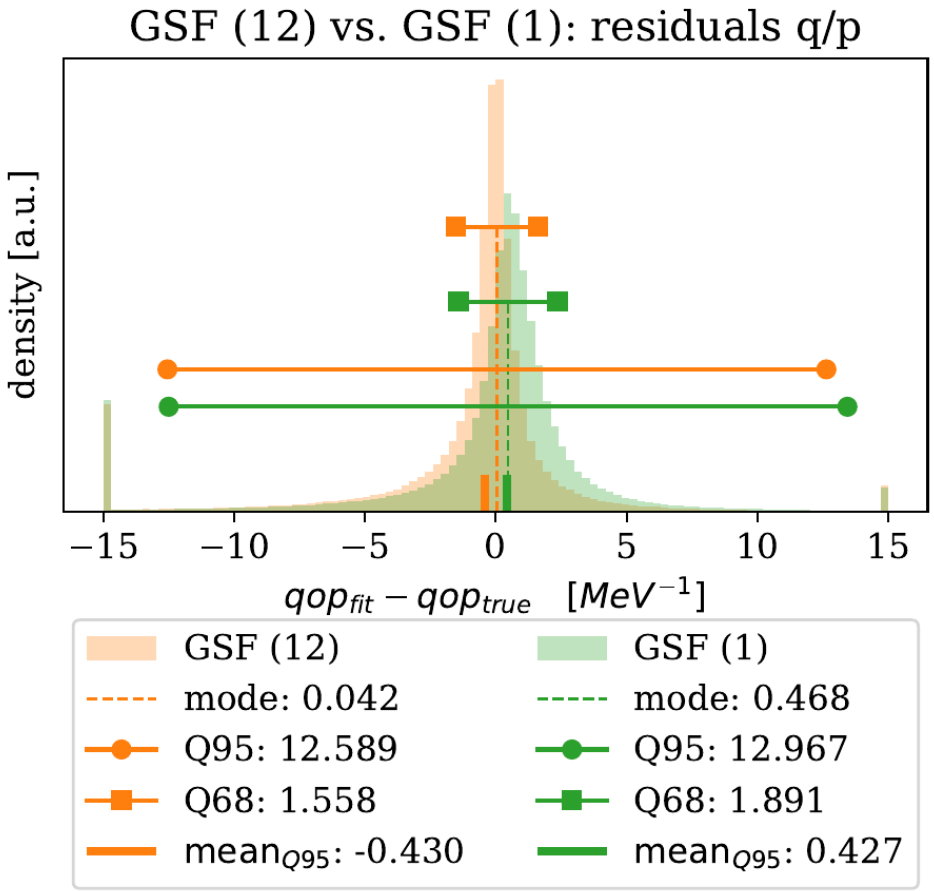
Holes, Outliers

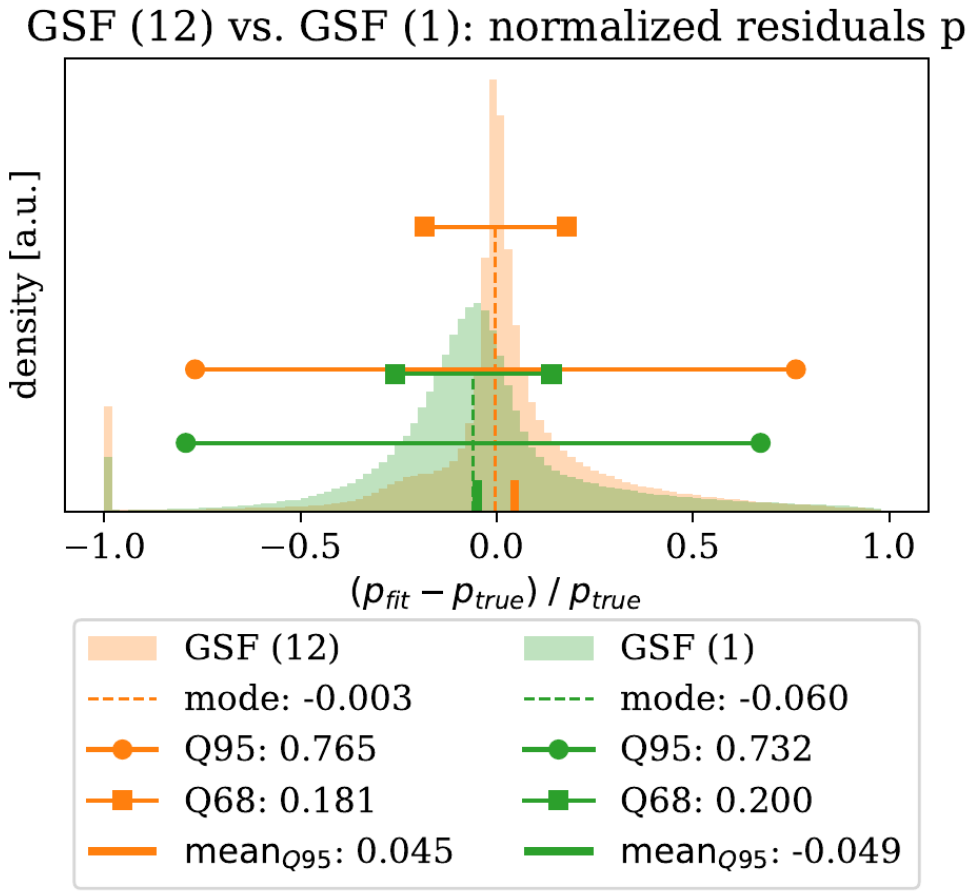


More residulas

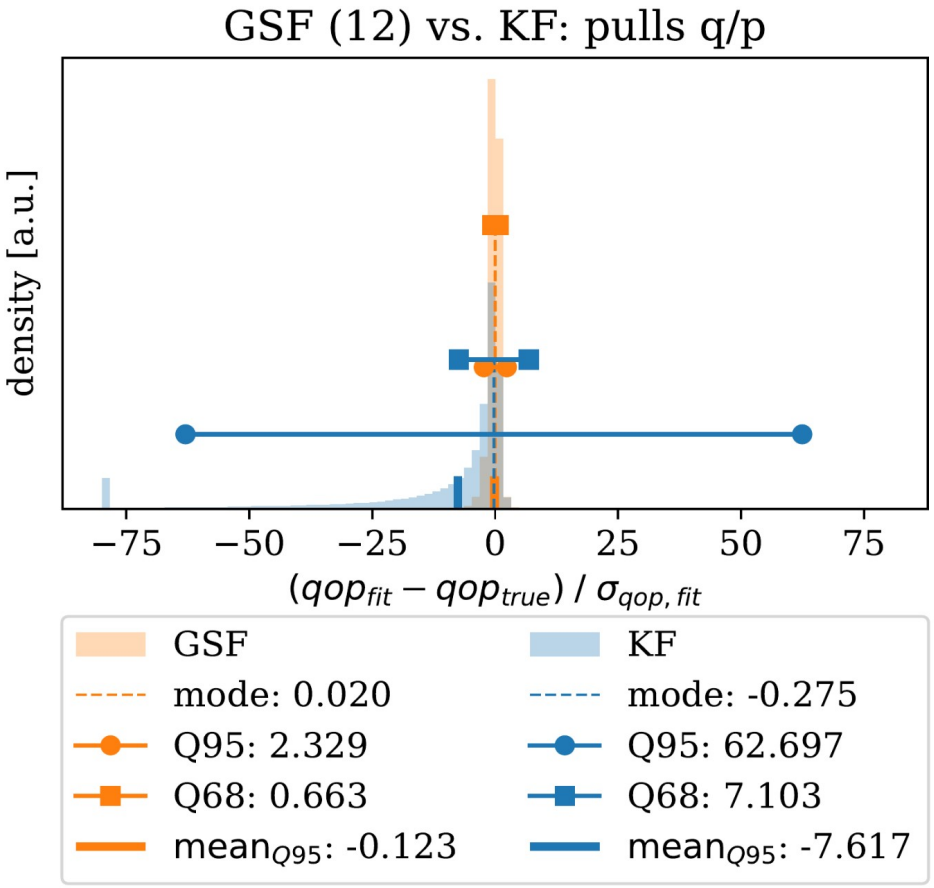


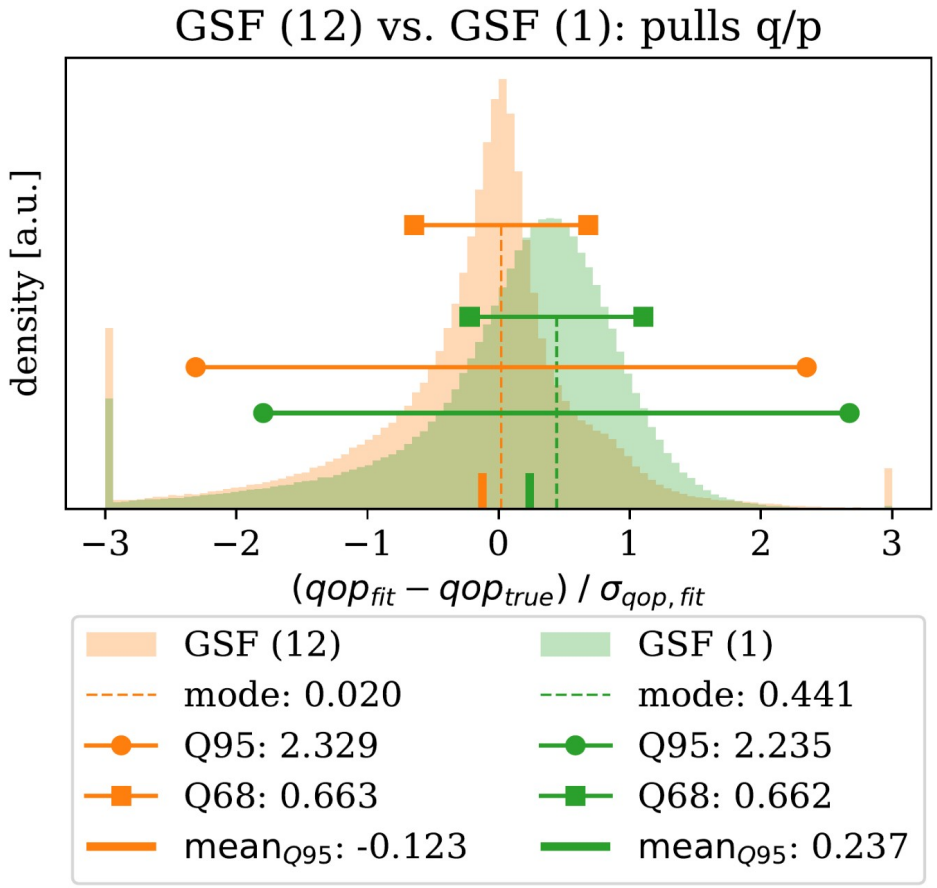
GSF(12) vs GSF(1)





Pulls


GSF (12) vs. KF: pulls q/p
density [a.u.]
−75 −50 −25 0 25 50 75
$(qop_{fit} - qop_{true}) / \sigma_{qop,\,fit}$
GSF
mode: 0.020
Q95: 2.329
Q68: 0.663
$mean_{Q95}$: -0.123
KF
mode: -0.275
Q95: 62.697
Q68: 7.103
$mean_{Q95}$: -7.617


GSF (12) vs. GSF (1): pulls q/p
density [a.u.]
−3 −2 −1 0 1 2 3
$(qop_{fit} - qop_{true}) / \sigma_{qop,\,fit}$
GSF (12)
mode: 0.020
Q95: 2.329
Q68: 0.663
$mean_{Q95}$: -0.123
GSF (1)
mode: 0.441
Q95: 2.235
Q68: 0.662
$mean_{Q95}$: 0.237

e^- vs. μ resolution

- Here:
  - Mean absolute error (don't weight outliers to much)
  - Q95 interval
- Investigate difference to muon
  - multiple scattering?