DEVELOPMENT OF HIGH-PERFORMANCE RECONSTRUCTION ALGORITHMS FOR DETECTING LONG-LIVED PARTICLES

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OUTLINE

- Overview of LHCb tracking & readout
- Long-lived particles (LLPs) in LHCb
- Reconstruction algorithm for LLPs
- **Optimization of a reconstruction algorithm**
- Optimization results analysis

LHCb TRACKING

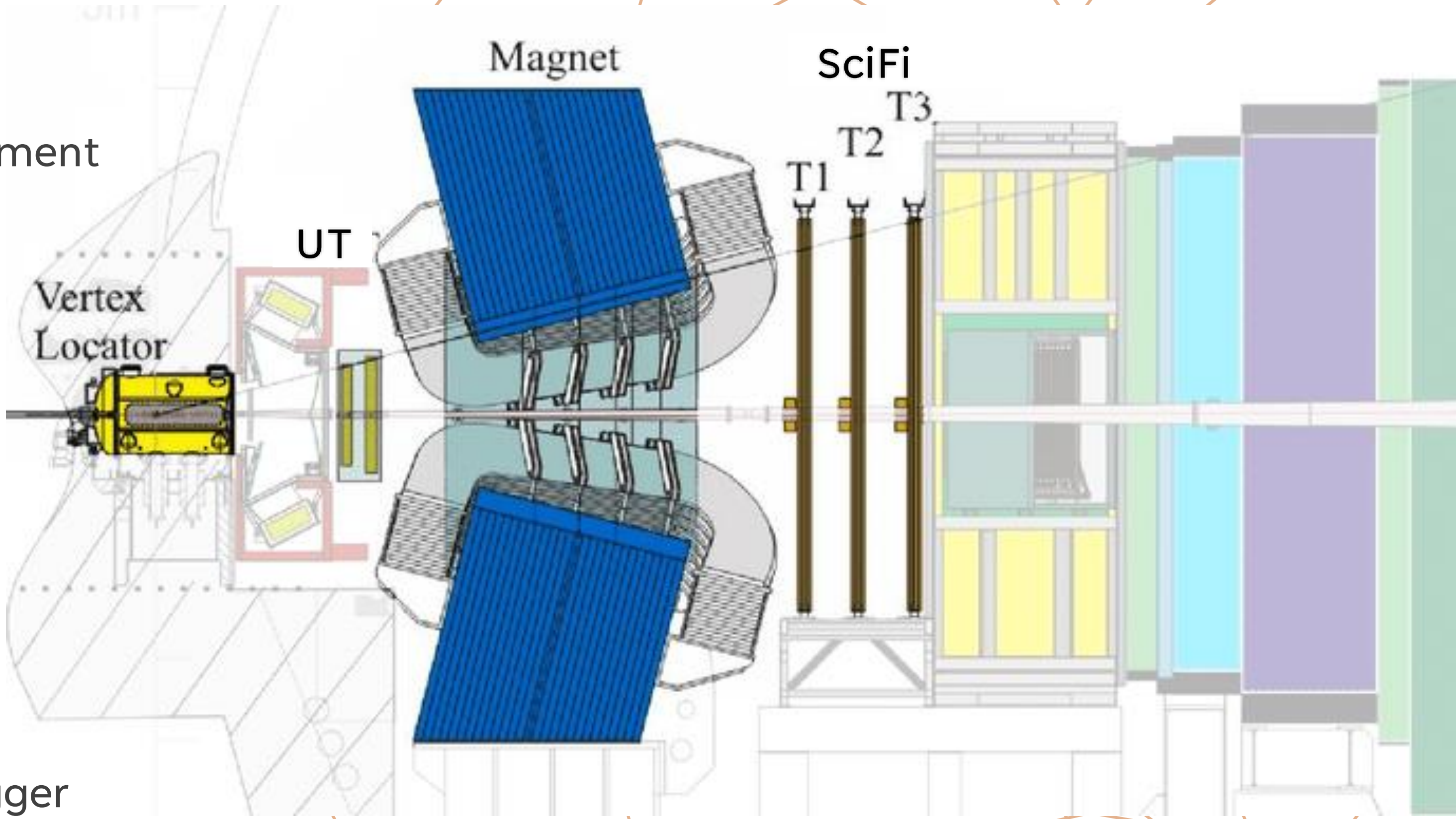
LHC*b* is a specialized b-physics experiment located on LHC (13 TeV, pp collisions)

Detectors, actively used in tracking:

- VELO – vertex locator
- UT – upstream tracker
- SciFi - Scintillating Fibre Tracker

Major detector updates in Run 3

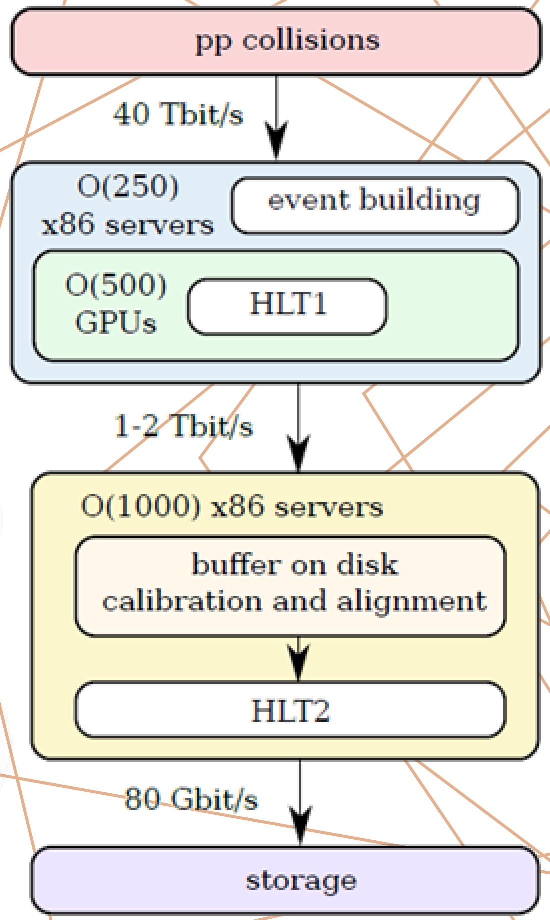
- Significantly updated readout & trigger strategy: no hardware trigger anymore



LHCb READOUT

Innovational GPU-enhanced LHCb data acquisition system [1] :

- x86 event building units
- 500 GPUs to process HLT1
- Only events selected by HLT1 are sent to the x86 servers processing HLT2.

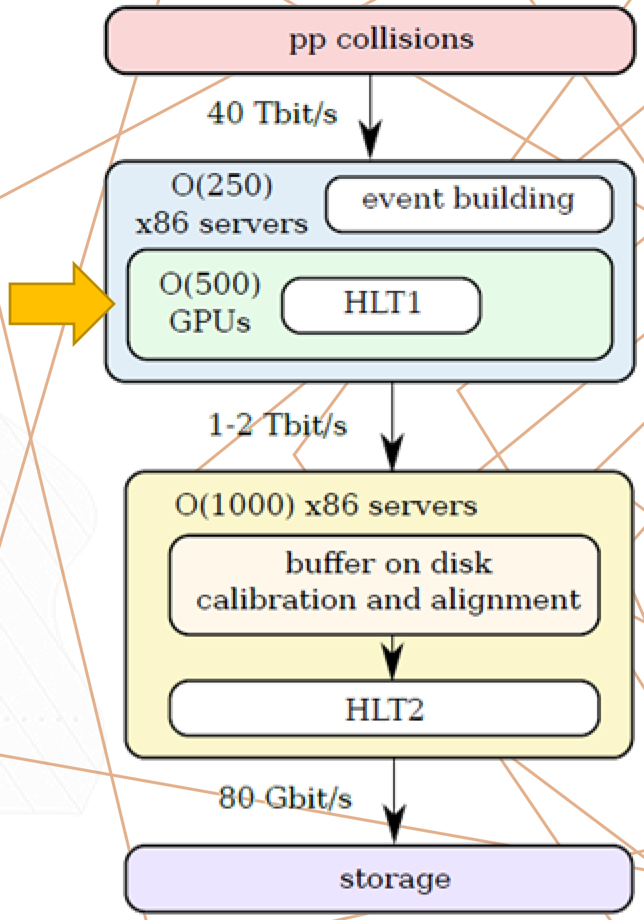


[1] Aaij, R., Albrecht, J., Belous, M. et al. Allen: A High-Level Trigger on GPUs for LHCb. Comput Softw Big Sci 4, 7 (2020).

HLT1 - HIGH LEVEL TRIGGER

Allen [1] : A high-level trigger on GPUs for LHCb:

- CUDA-based framework
- Implement HLT1 stage
- Process up to 40 Tbit/s data rate:
  - Reconstruction of charged particles trajectories
  - Finding collision points
  - Identifying particles as hadrons or muons
  - Finding the displaced decay vertices

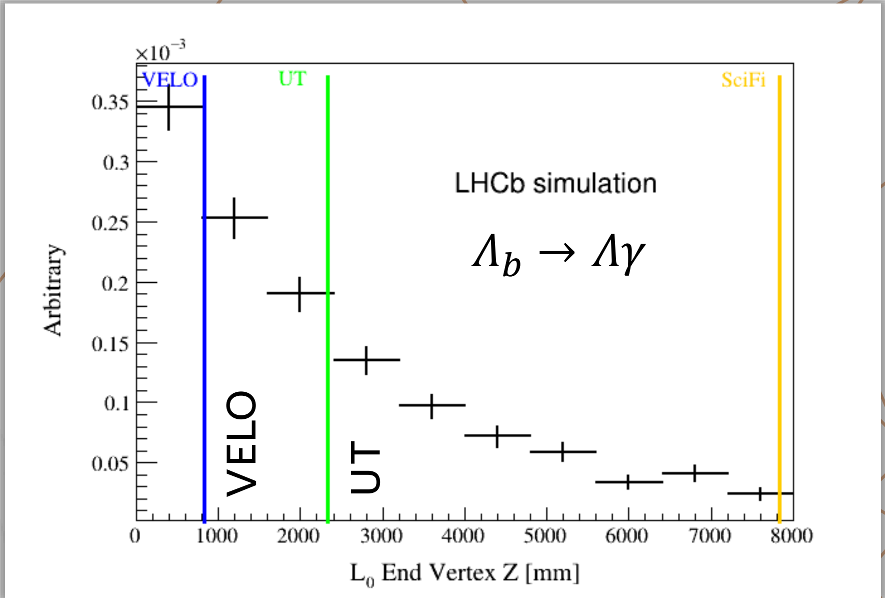


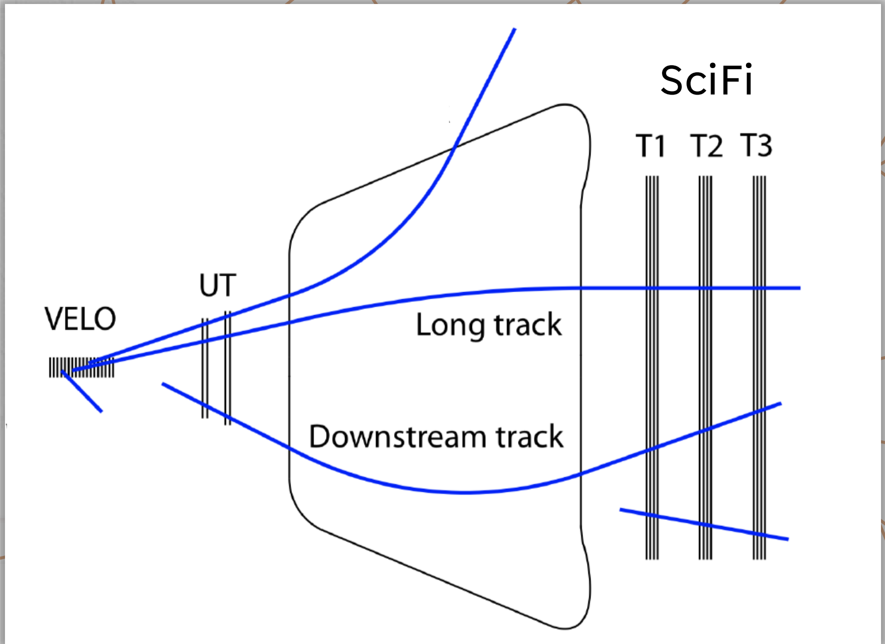
[1] https://gitlab.cern.ch/lhcb/Allen

LONG-LIVED PARTICLES

- Large fraction decays outside of VELO [1] :
  - For $\Lambda_b \to \Lambda\gamma$:
    - 51% - hits UT & SciFi (downstream)
    - 37% - hits SciFi only (T-tracks)
  - Benefits for not standard model particles?
- Global objective: **development of non-VELO trigger lines**

Constraints: output **trigger rate**, algorithm throughput





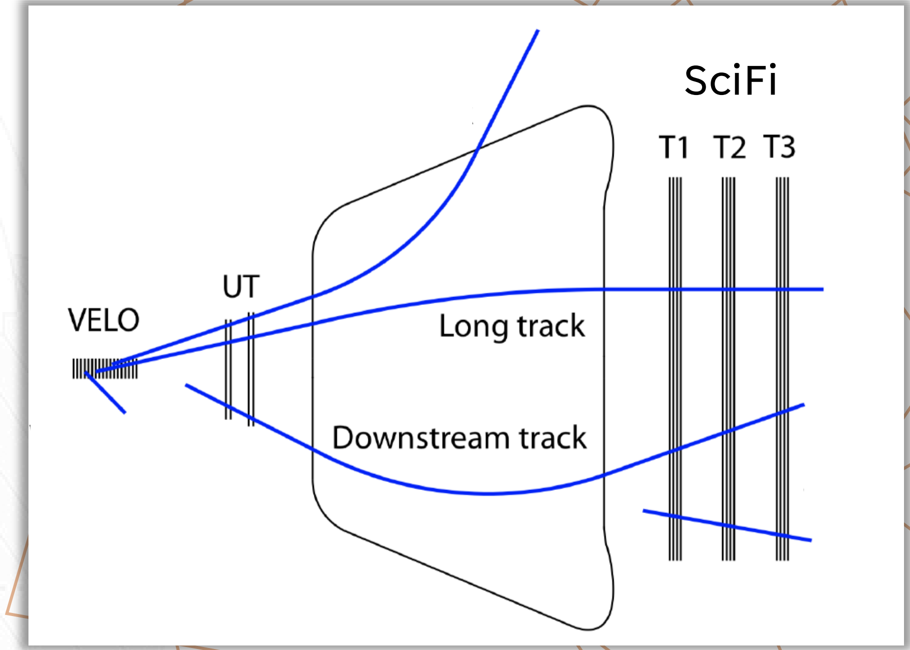
[1] Impact of the High Level Trigger for detecting Long-Lived Particles at LHCb Front. Big Data doi: 10.3389/fdata.2022.1008737

STRATEGY

- Reconstructed SciFi seeds consist of:
  - Long tracks (VELO – SciFi)
  - Downstream tracks (UT – SciFi)
  - T-Tracks (SciFi only)
  - Ghosts

Removing Long & Downstream tracks will significantly save the output trigger rate:

- Long-tracks reconstruction **needs optimization**
- Downstream reconstruction is under development



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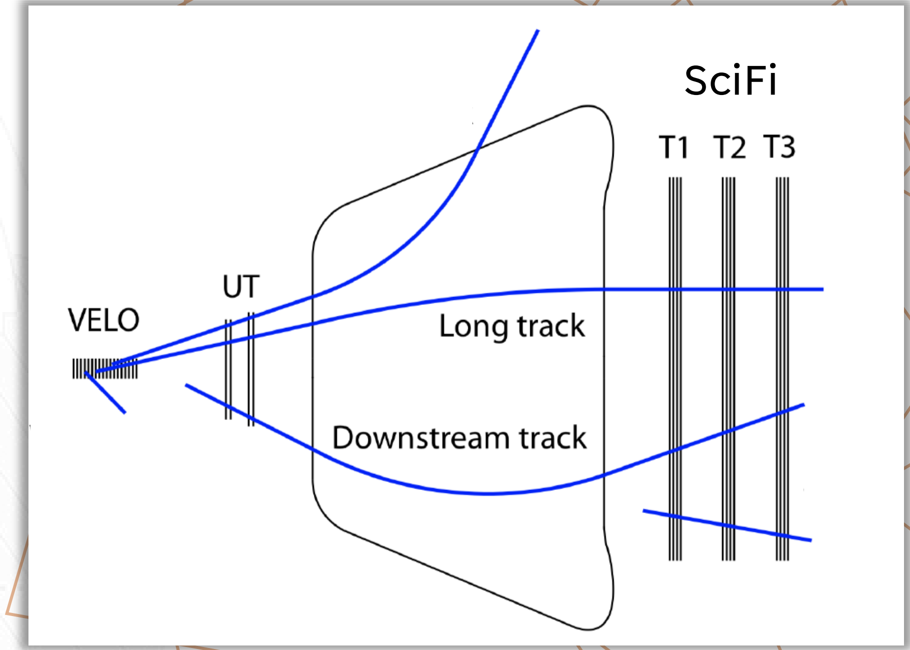

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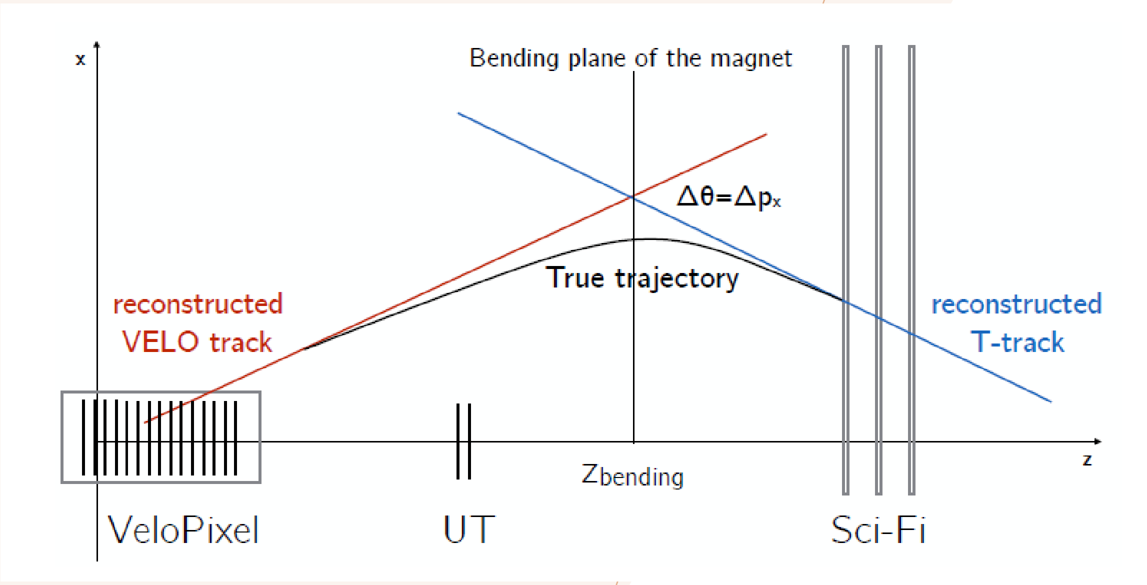
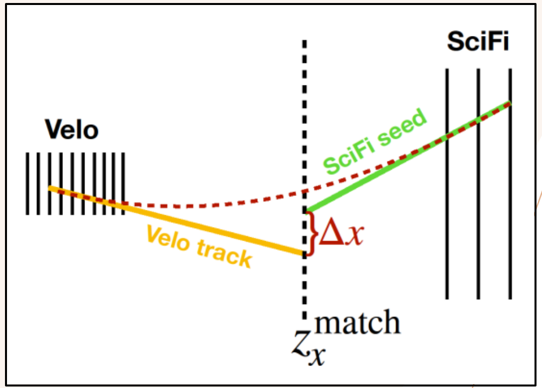
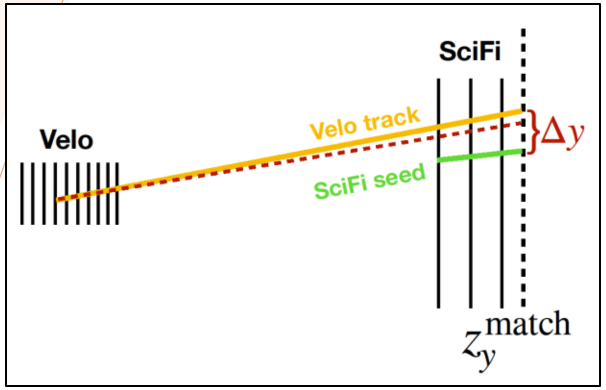
Project objective







MATCHING ALGORITHM

Input: track segments from VELO and SciFi

- Extrapolate both SciFi and VELO tracks as straight lines to a matching position (kink approximation).
    - For x: matching position inside the magnet, derived per track from magnetic field parametrization.
    - For y: matching at the end of SciFi.
- For every SciFi track:
    - Filter VELO tracks by distance between extrapolated points and slope difference.
    - Construct χ^2 for every pair VELO-SciFi
    - Select the best long-track candidate

MATCHING CONSTRAINTS

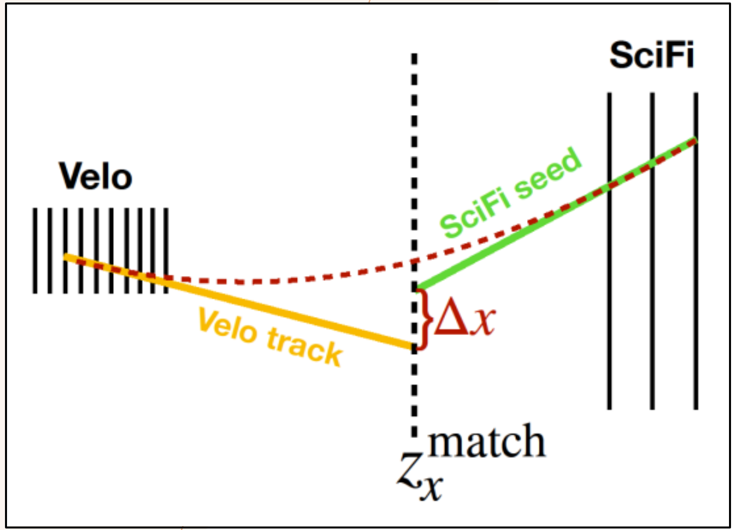
Slope:

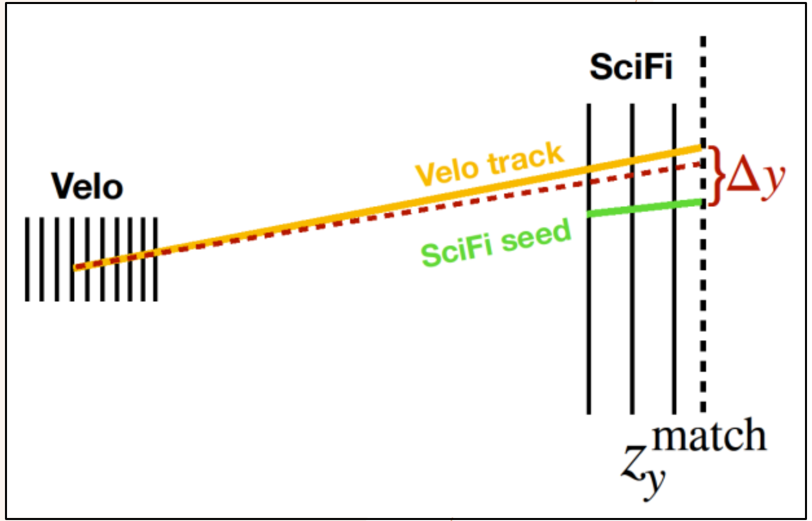
$$\left|dtx \stackrel{\text{def}}{=} tx_{velo} - tx_{scifi}\right| < \overline{dtx} = 1.5$$
$$\left|dty \stackrel{\text{def}}{=} ty_{velo} - ty_{scifi}\right| < \overline{dty} = 0.02$$

Interception of extrapolated tracks:

$$|dxs \stackrel{\text{def}}{=} xS - xV| < \overline{dxs} = 20\ mm$$
$$|dys \stackrel{\text{def}}{=} yS - yV| < \overline{dys} = 150\ mm$$

Default values:	
$\overline{dtx}$:	1.5
$\overline{dty}$:	0.02
$\overline{dxs}$:	20 mm
$\overline{dys}$:	150 mm
$fdty$:	937.5
$fdtx$:	10
$dxTol^2$:	80
$dxTolSlope^2$:	8000
$dyTol^2$:	180
$dyTolSlope^2$:	450000





CALCULATION OF χ^2

$$\frac{(xS - xV)2}{tolX} + \frac{(yS - yV)2}{tolY} + fdty\,(ty_{velo} - ty_{scifi})^2 + fdtx(tx_{velo} - tx_{scifi})^2$$

$$tolX = dxTol^2 + (tx_{velo} - tx_{scifi})^2\, dxTolSlope^2$$
$$tolY = dyTol^2 + ({tx^2}_{velo} + {tx^2}_{scifi})\, dyTolSlope^2$$

Additional cut $\chi^2 < 2.5$ in the end!

GENERAL APPROACH

All the developments are done within LHCb framework

Total number of parameters: 11

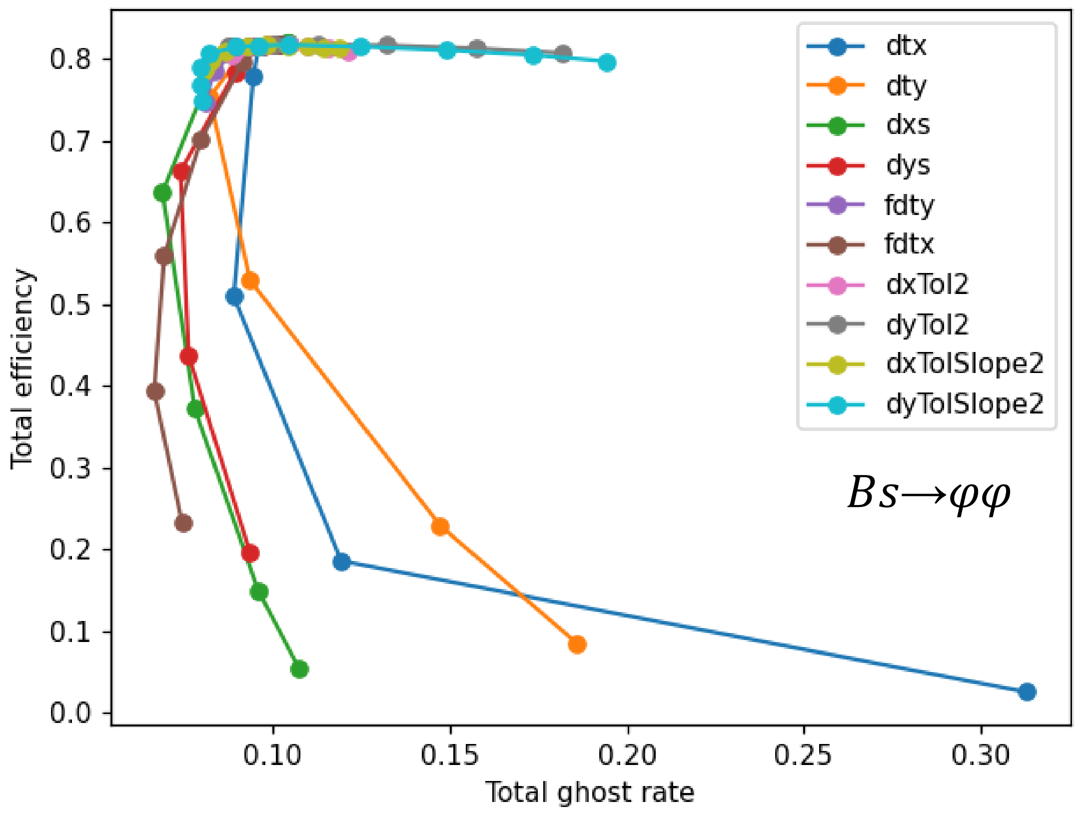
Step 1: Optimization of non χ^2 cut parameters (10):

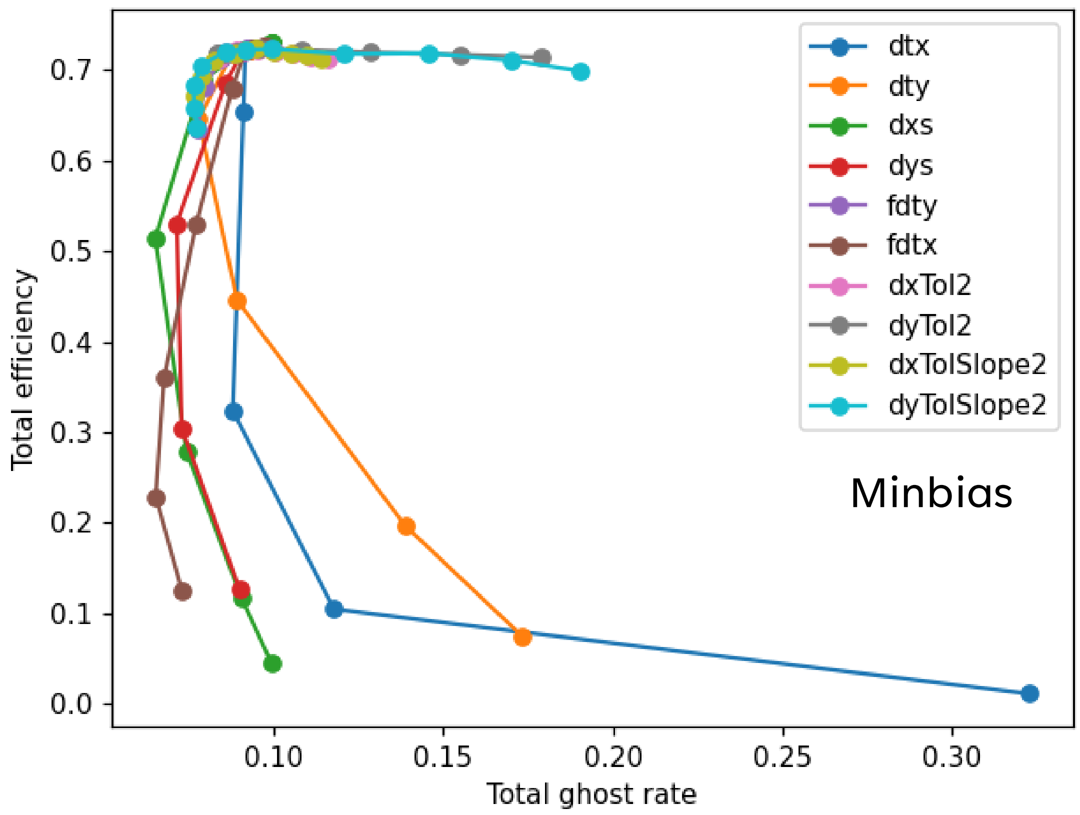
- Get relevant parameters only
  - Sweep only one parameter at a time, to check its own impact
  - Multiply parameter by some factor in range $10^{-2} - 10^2$
- Try to find the best combination of selected parameters, that will decrease trigger/ghost rates with keeping efficiency high

Step 2: Optimization of χ^2 cut:

- Simple sweep on χ^2 cut

TOTAL EFFICIENCY VS GHOST RATE





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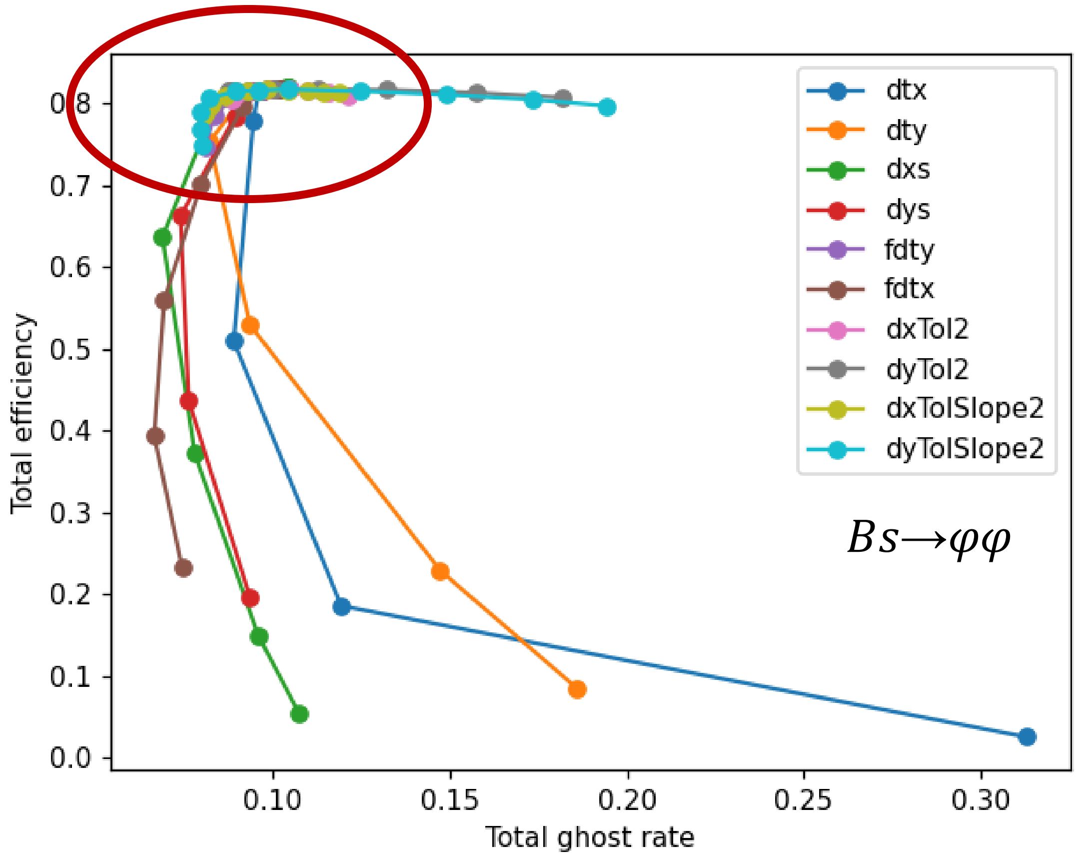

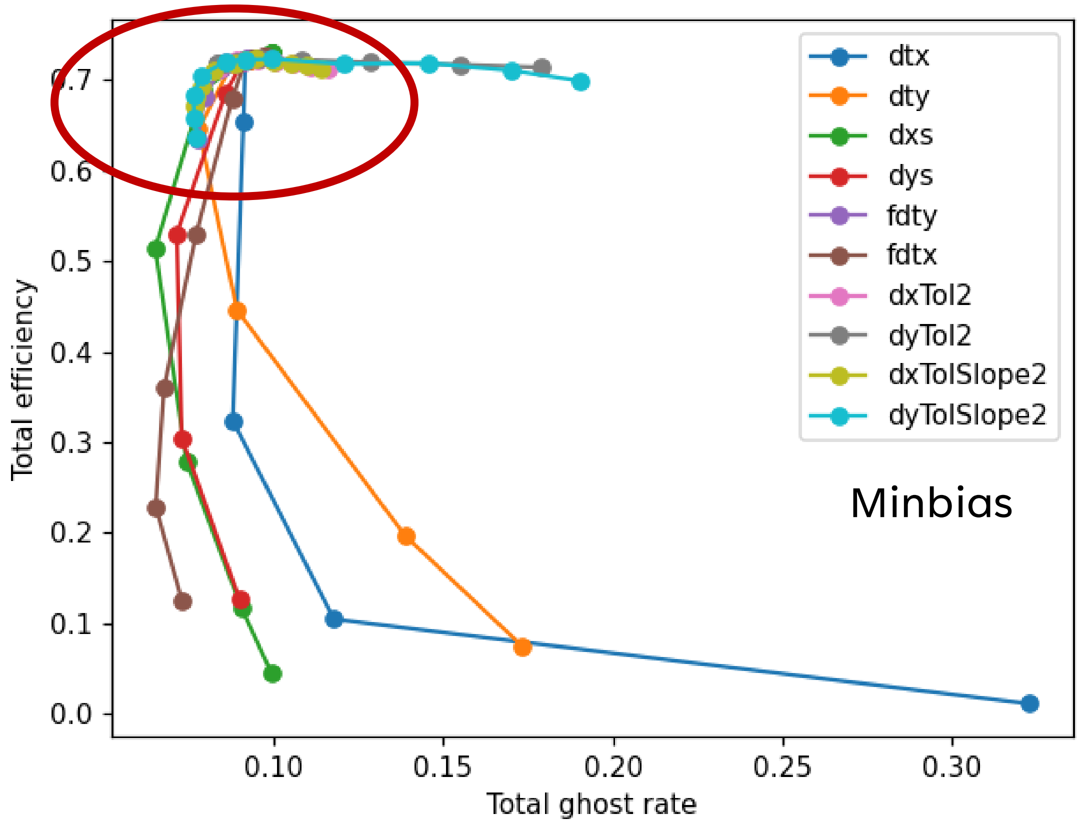

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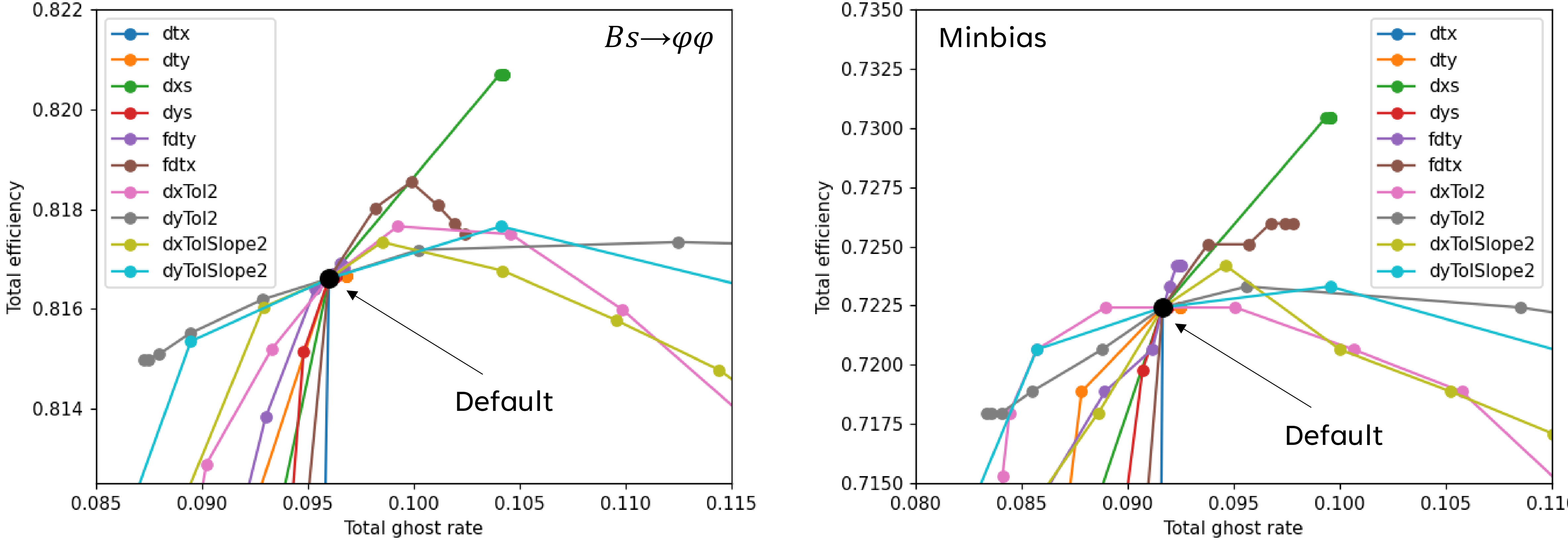

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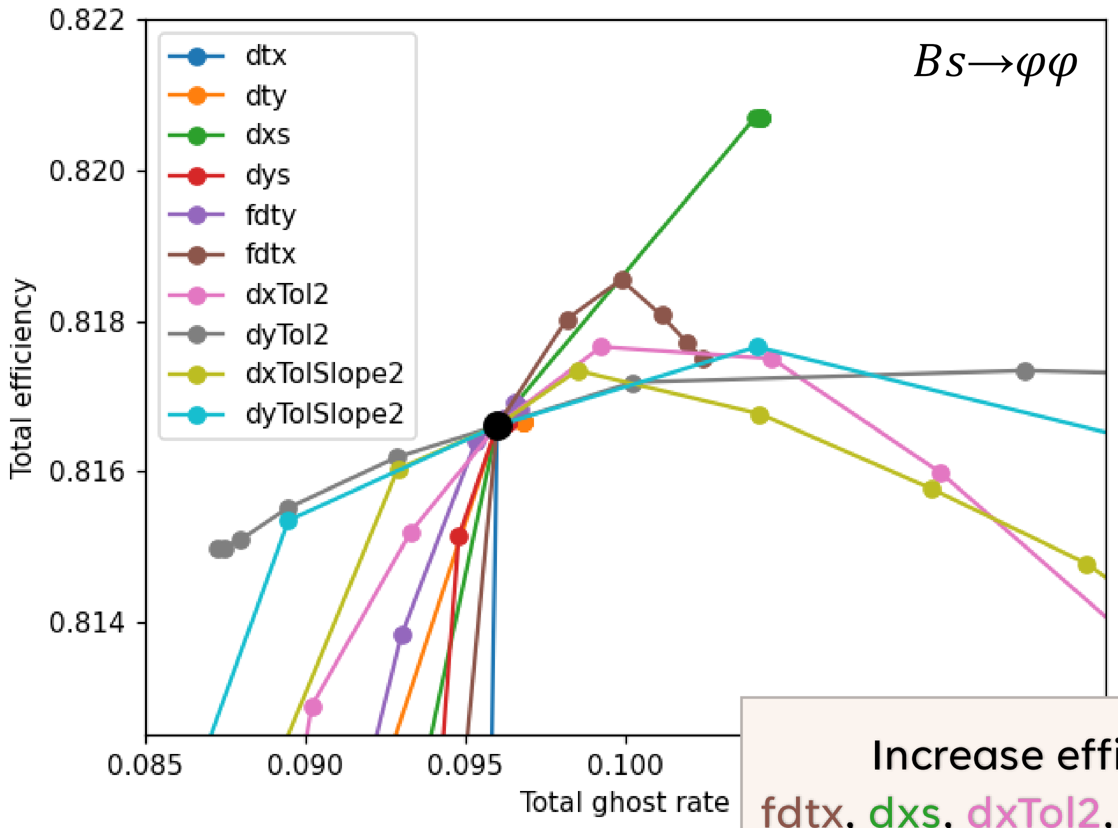
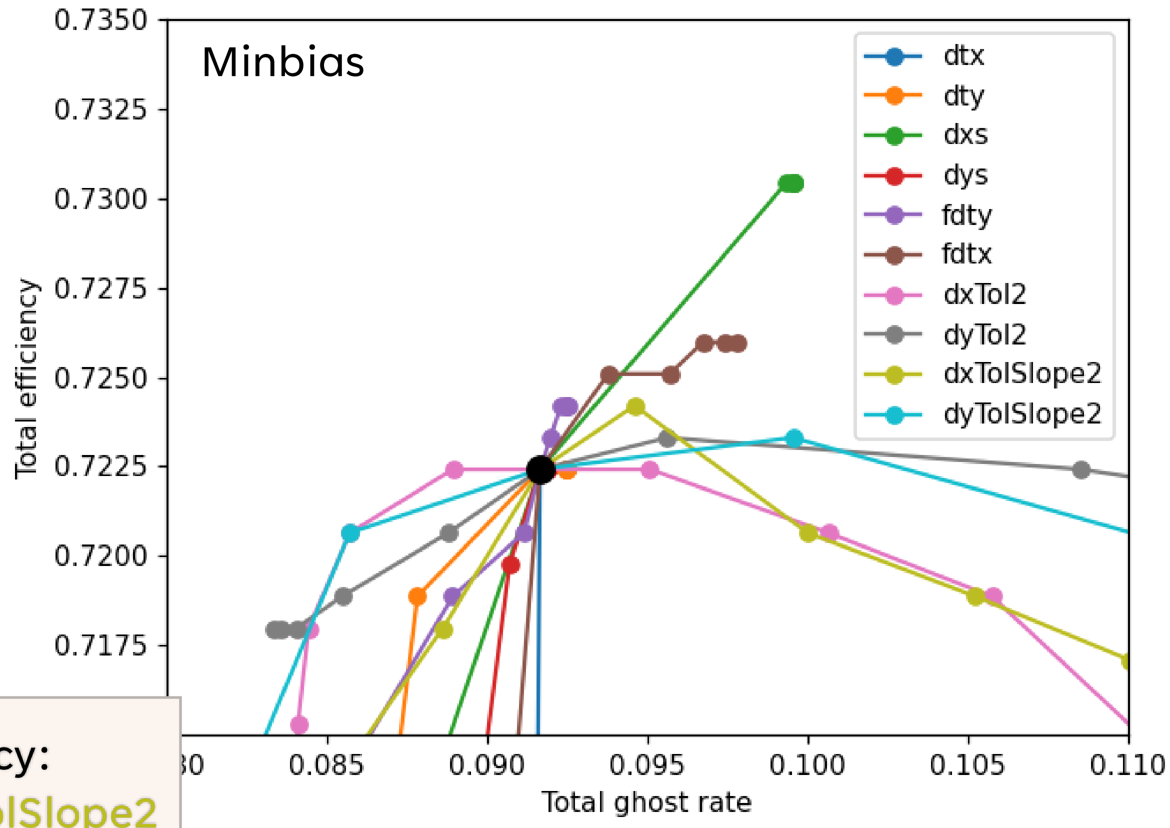
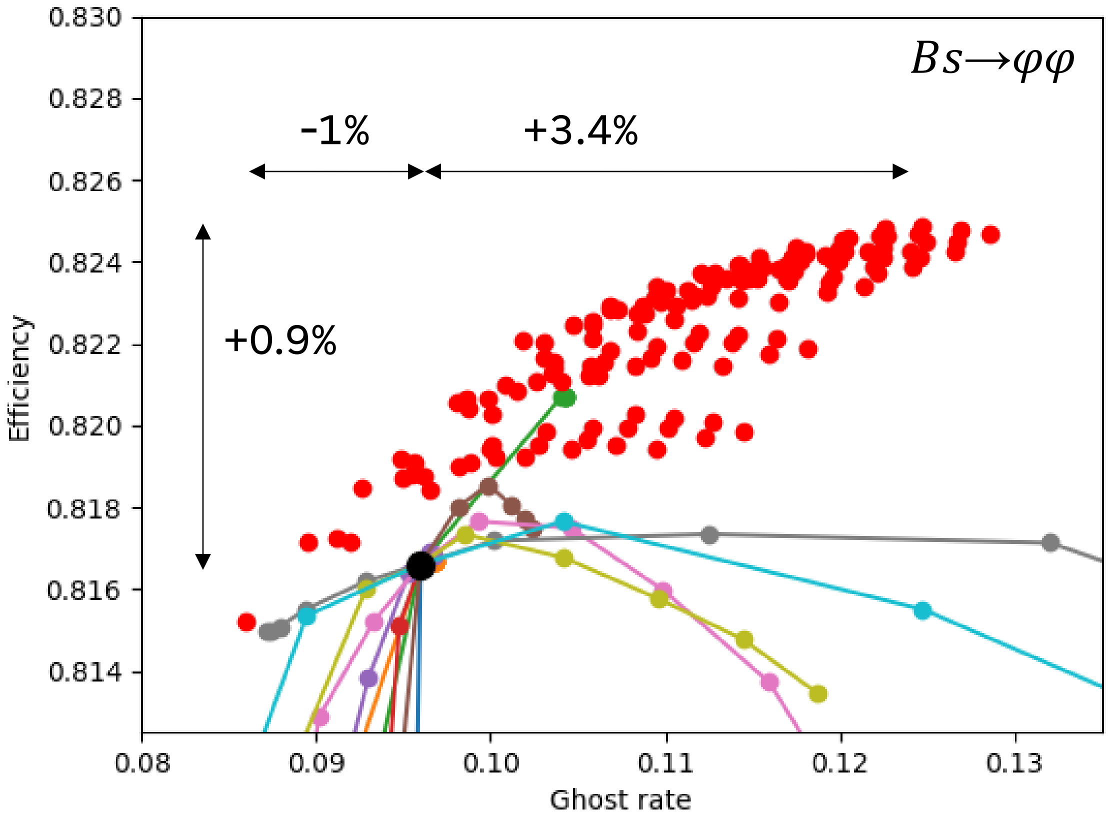




Increase efficiency:
fdtx, dxs, dxTol2, dxTolSlope2
Decrease ghost rate:
dyTol2, dyTolSlope2

TOTAL EFFICIENCY VS GHOST RATE

- Loop over all selected parameters combinations gives a lot of points
- Need to select a few characteristic points for conclusions
  - With a better ghost rate
  - With a better efficiency
  - A few intermediates

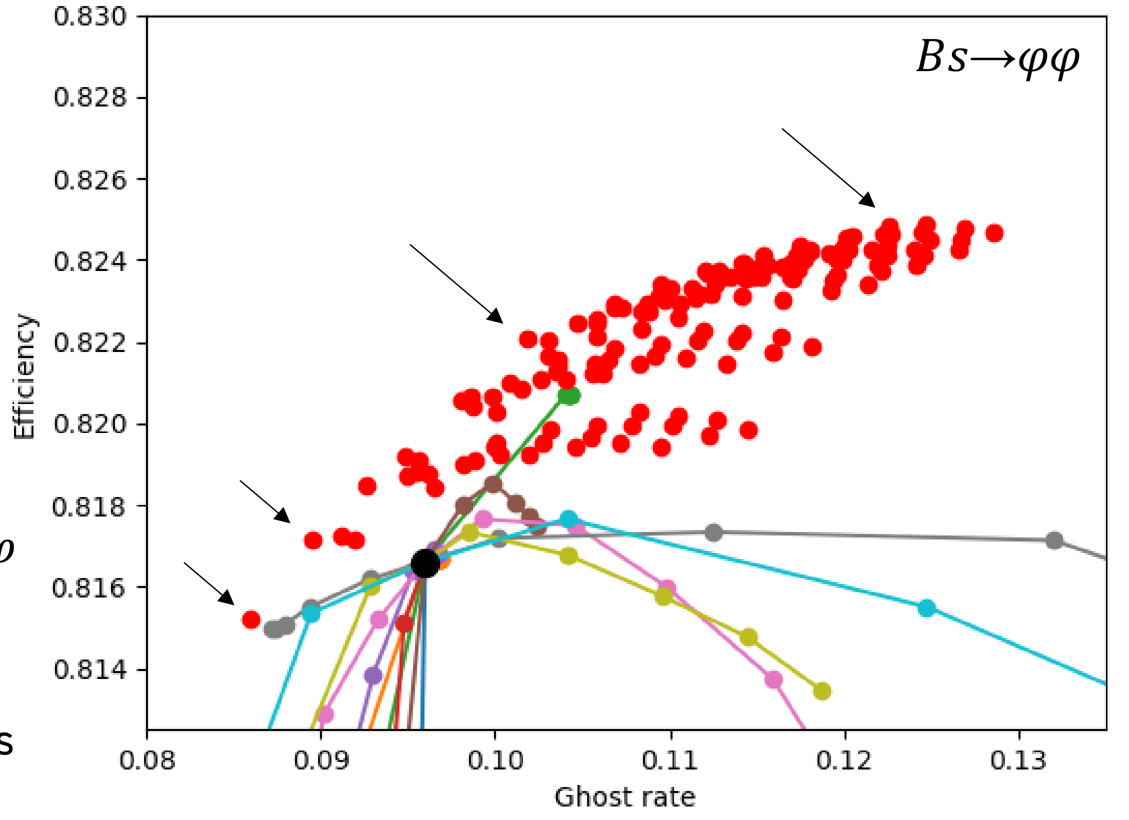


TOTAL EFFICIENCY VS GHOST RATE

	Default value	Multiplicators: Best ghost rate	Int1	Int2	Best efficiency
dtx	*1.5*	*1*	*1*	*1*	*1*
dty	*0.02*	*1*	*1*	*1*	*1*
dxs	*20*	*1*	*1.12*	*1.24*	*1.6*
dys	*150*	*1*	*1*	*1*	*1*
fdty	*937.5*	*1*	*1*	*1*	*1*
fdtx	*10*	*0.2*	*0.2*	*0.2*	*0.2*
dxtol2	*80*	*1.6*	*1.6*	*1.6*	*1.6*
dytol2	*180*	*0.07*	*0.07*	*0.07*	*1*
dxtolslope2	*8000*	*1.6*	*1.6*	*1.6*	*1.6*
dytolslope2	*450000*	*0.5*	*0.5*	*0.9285*	*1.3571*
Efficiency	**81.66%**	**81.52%**	**81.71%**	**82.21%**	**82.48%**
Ghost rate	**9.60%**	**8.60%**	**8.95%**	**10.19%**	**12.25%**
Efficiency (p > 5 GeV, pT > 1 GeV)	**89.5%**	**89.43%**	**89.62%**	**89.85%**	**90.03%**
Hlt1TrackMVA [kHz]	618 *± 42*	528 *± 39*	528 *± 39*	600 *± 42*	660 *± 44*
Hlt1TwoTrackMVA [kHz]	738 *± 46*	663 *± 44*	675 *± 44*	741 *± 46*	789 *± 48*
Hlt1LowPtDiMuon [kHz]	1521 *± 67*	1458 *± 64*	1479 *± 65*	1593 *± 67*	1749 *± 70*
Sequence throughput [kevts/s]	**124.0**	**125.4**	**124.7**	**123.5**	**122.3**

$Bs \to \varphi\varphi$

Minbias



TOTAL EFFICIENCY VS GHOST RATE

Selected

	Default value	Multiplicators: Best ghost rate	Int1	Int2	Best efficiency
dtx	*1.5*	*1*	*1*	*1*	*1*
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dxs	*20*	*1*	*1.12*	*1.24*	*1.6*
dys	*150*	*1*	*1*	*1*	*1*
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dxtol2	*80*	*1.6*	*1.6*	*1.6*	*1.6*
dytol2	*180*	*0.07*	*0.07*	*0.07*	*1*
dxtolslope2	*8000*	*1.6*	*1.6*	*1.6*	*1.6*
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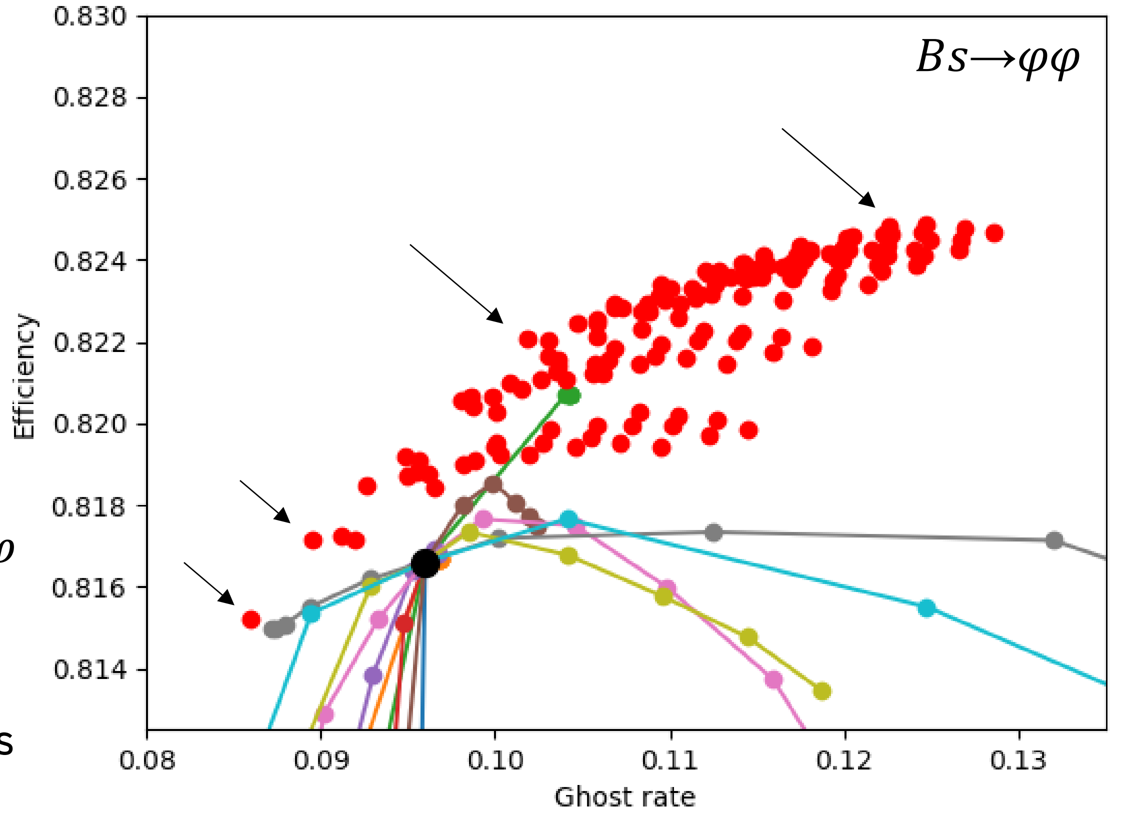
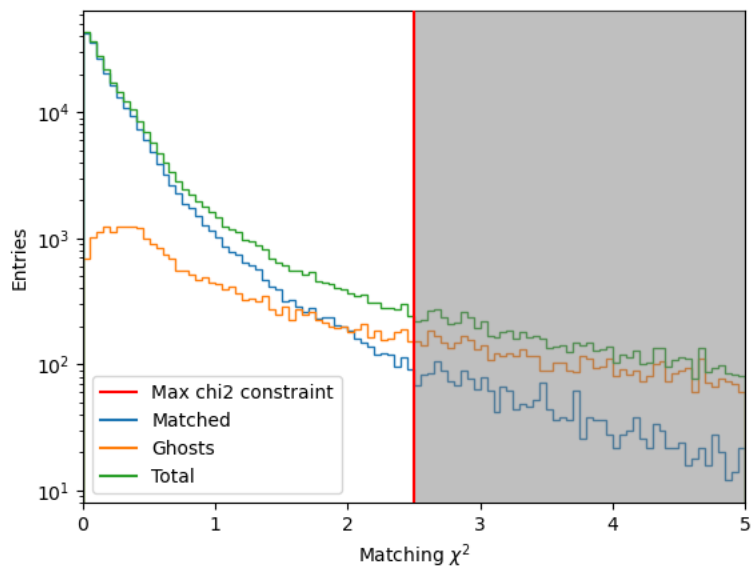
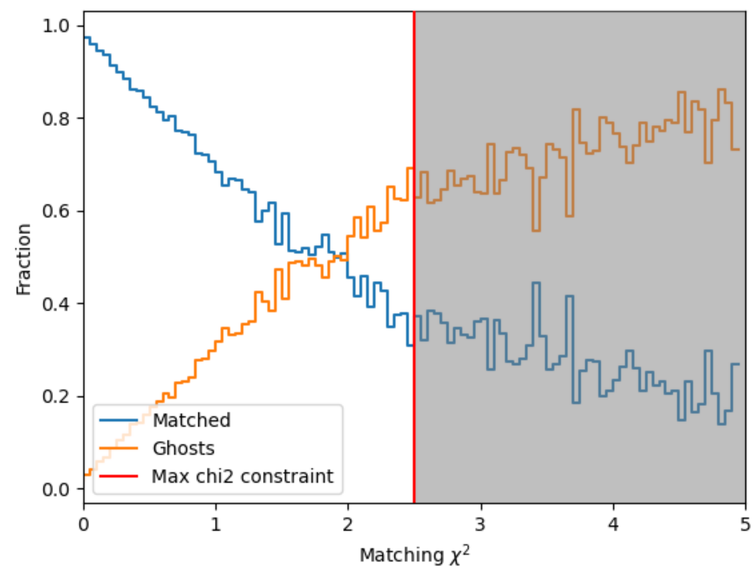






MATCHING χ^2 DISTRIBUTION

After modifying χ^2 calculation parameters, it's needed to check the max χ^2 cut **(default value is 2.5)**

- Starting from $\chi^2 = 2$, there are more ghost tracks than true matched
- Most of the real tracks have $\chi^2 < 1.5$

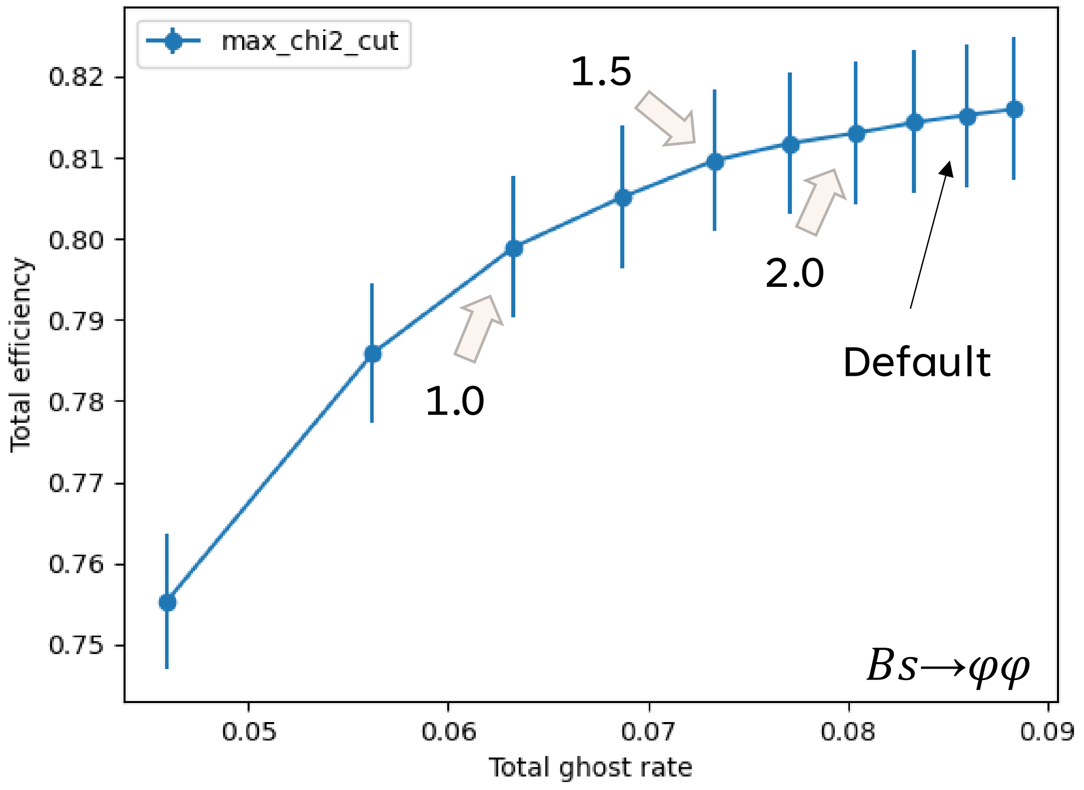
It's obvious, that χ^2 cut should be optimized

OPTIMIZATION STRATEGY

- Make a sweep on χ^2 cut in the range [0.5 – 2.75] with step 0.25
- Plot results on efficiency-ghost rate plane

TOTAL EFFICIENCY VS GHOST RATE

	Default 2.5	New χ^2 cut value 1.0	1.5	2.0
Efficiency	**81.52** ± *0.9*%	**79.89** ± *0.9*%	**80.96** ± *0.9*%	**81.30** ± *0.9*%
Ghost rate	**8.60%**	**6.32%**	**7.33%**	**8.04%**
Efficiency (p > 5 GeV, pT > 1 GeV)	**89.43%**	**88.79%**	**89.16%**	**89.32%**
Hlt1TrackMVA [kHz]	528 ± *39*	372 ± *33*	429 ± *36*	483 ± *38*
Hlt1TwoTrackMVA [kHz]	663 ± *44*	561 ± *41*	597 ± *42*	639 ± *43*
Hlt1LowPtDiMuon [kHz]	1458 ± *64*	1221 ± *59*	1359 ± *62*	1422 ± *64*
Hlt1TwoTrackKs [kHz]	51 ± *12*	51 ± *12*	51 ± *12*	51 ± *12*
Sequence throughput [kevts/s]	**122.5**	**125.0**	**123.2**	**122.6**



TOTAL EFFICIENCY VS GHOST RATE

Selected

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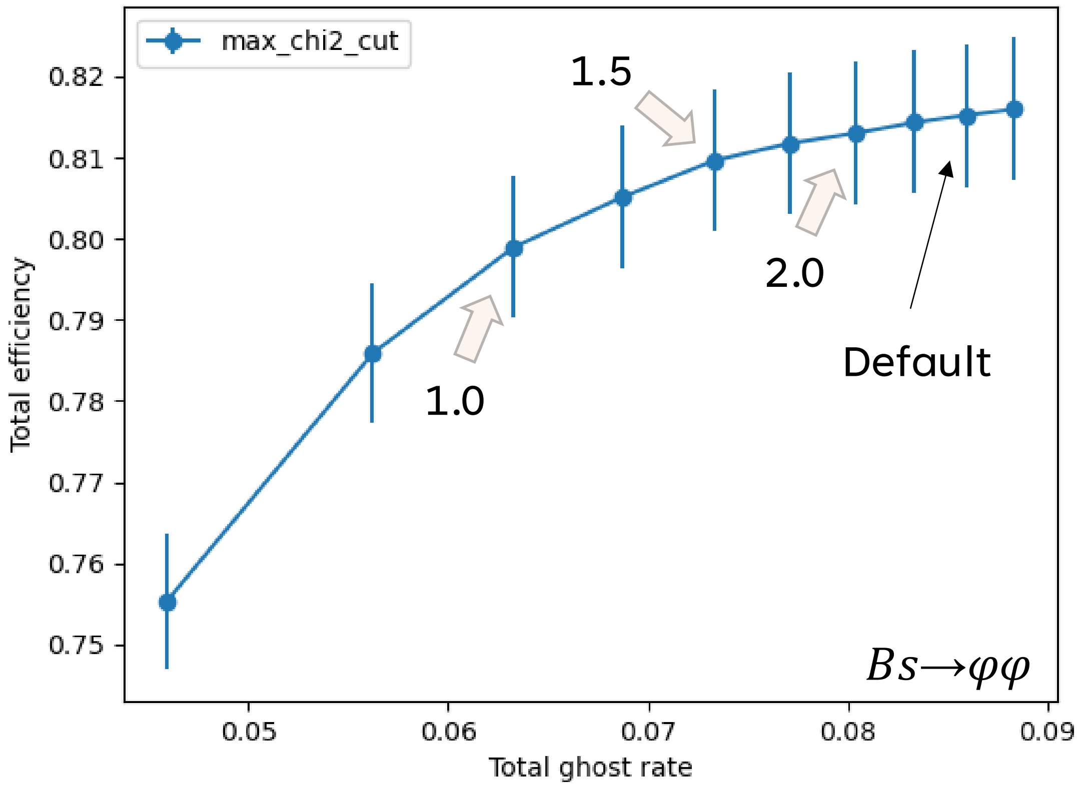
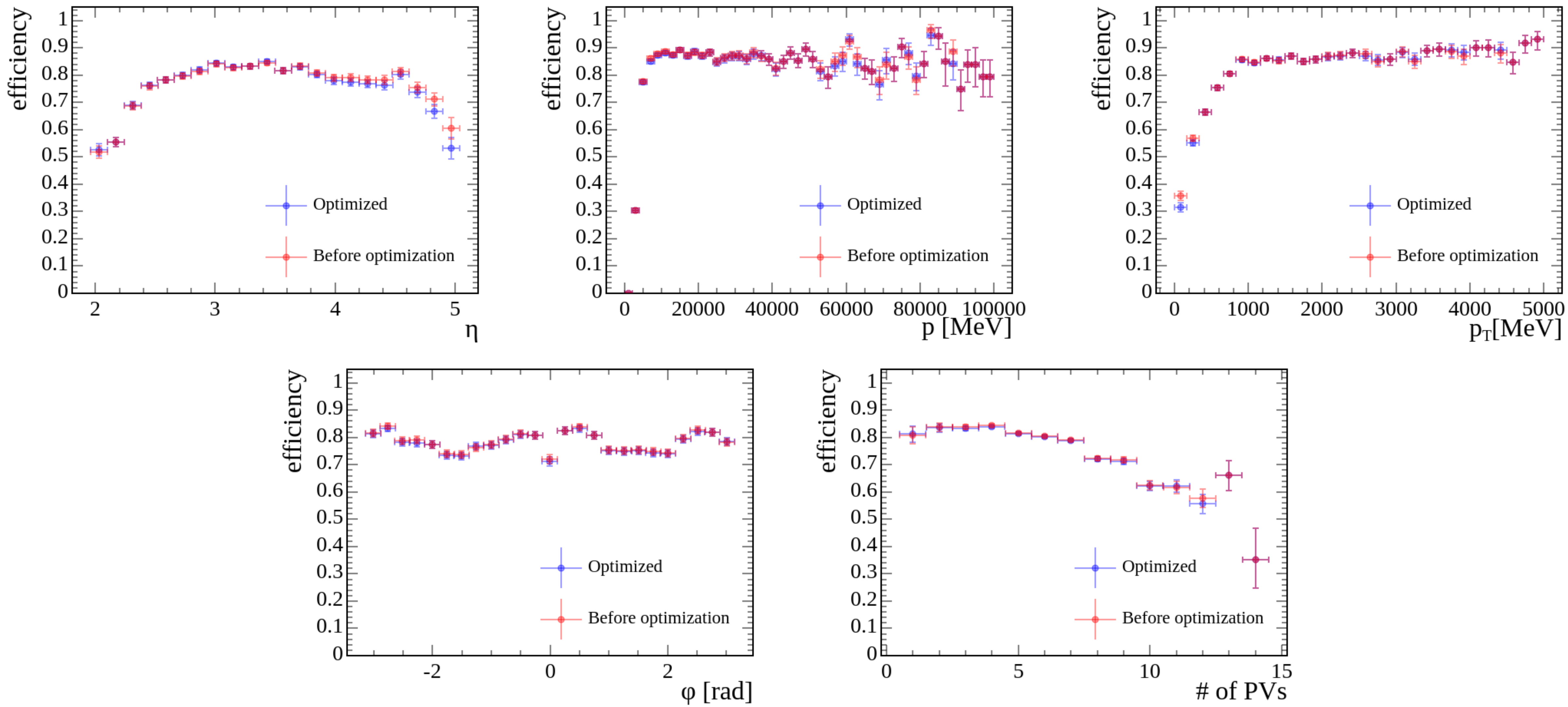
Hlt1TwoTrackKs [kHz]	51 ± 12	51 ± 12	51 ± 12	51 ± 12
Sequence throughput [kevts/s]	**122.5**	**125.0**	**123.2**	**122.6**



EFFICIENCY COMPARISON ($Bs \to \varphi\varphi$)



GHOST RATE COMPARISON ($Bs \rightarrow \varphi\varphi$)

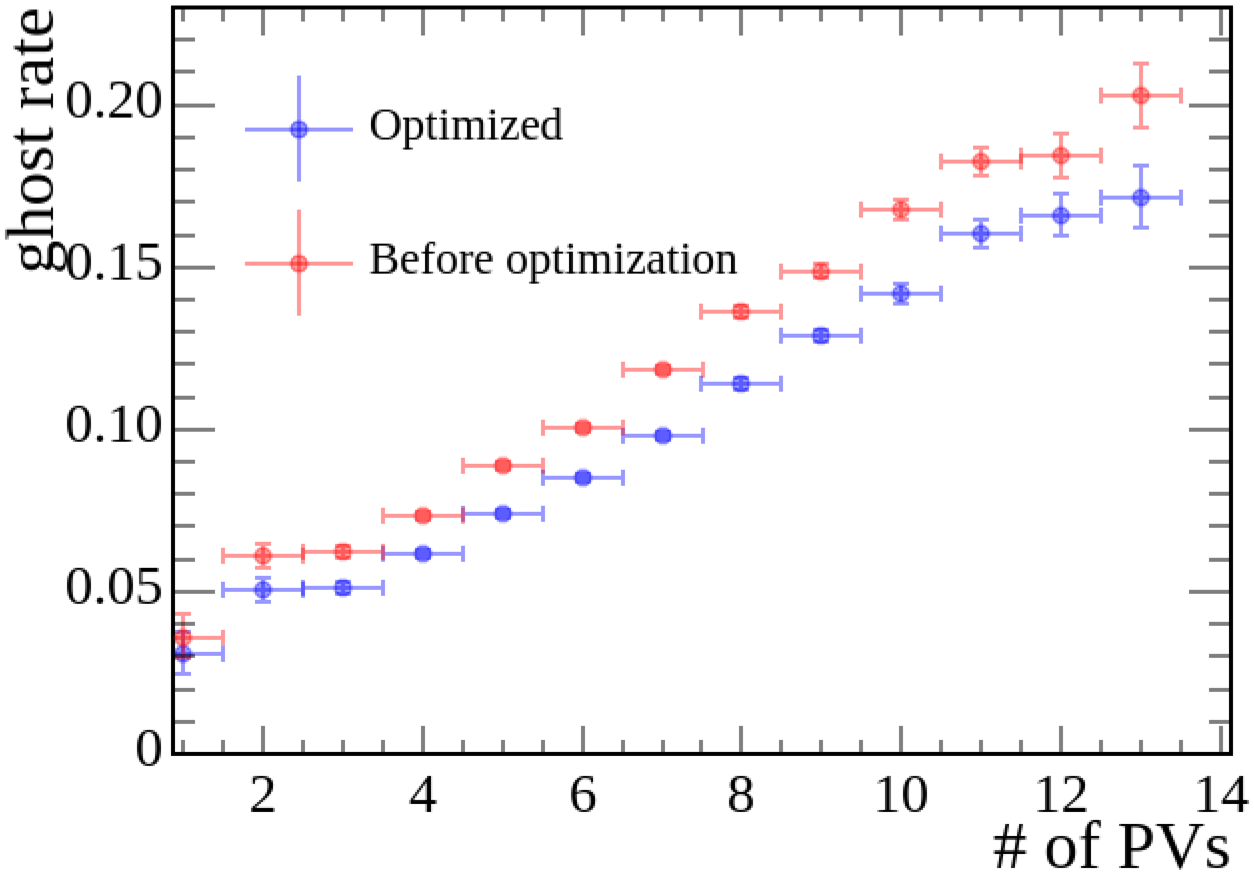
Total efficiency changes:

-0.36%

(within errors)

Total ghost rate changes:

-1.56%



SUMMARY

- Optimized matching algorithm for Long-tracks reconstruction:

Efficiency: -0.36% **Ghost rate: -1.56%**

- The results are implemented within Allen software (merge request [!989](!989))

Next steps:

- Implementation of T-tracks trigger line and its optimization

THANK YOU FOR YOUR ATTENTION

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