Analysis of heavy-flavour particles in ALICE with the O^2 analysis framework

Vít Kučera (CERN)
on behalf of the ALICE O^2 project

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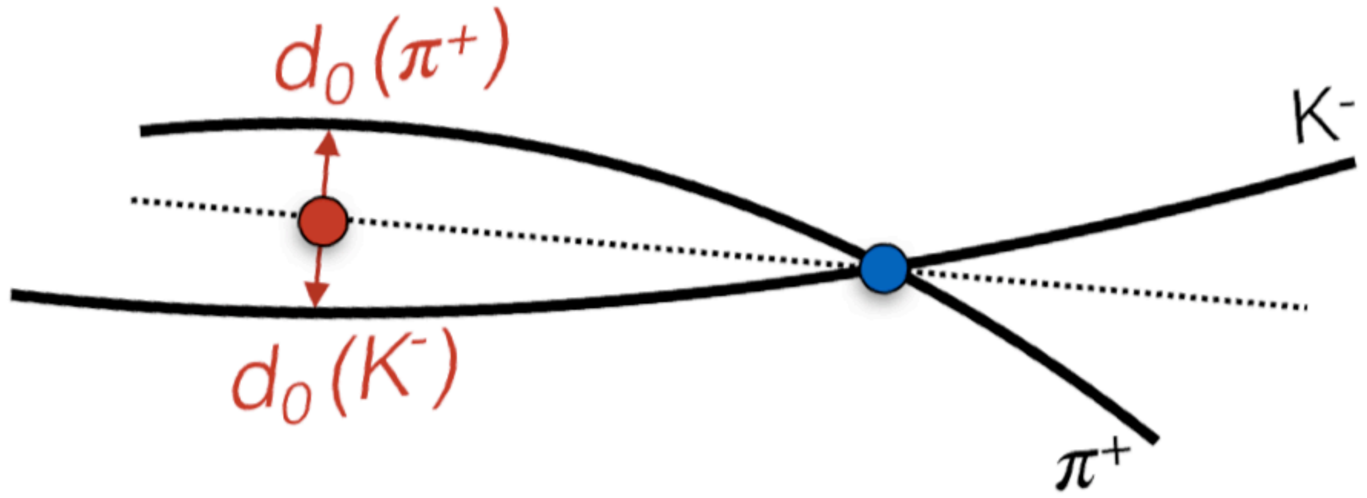
Heavy-flavour reconstruction in Run 3

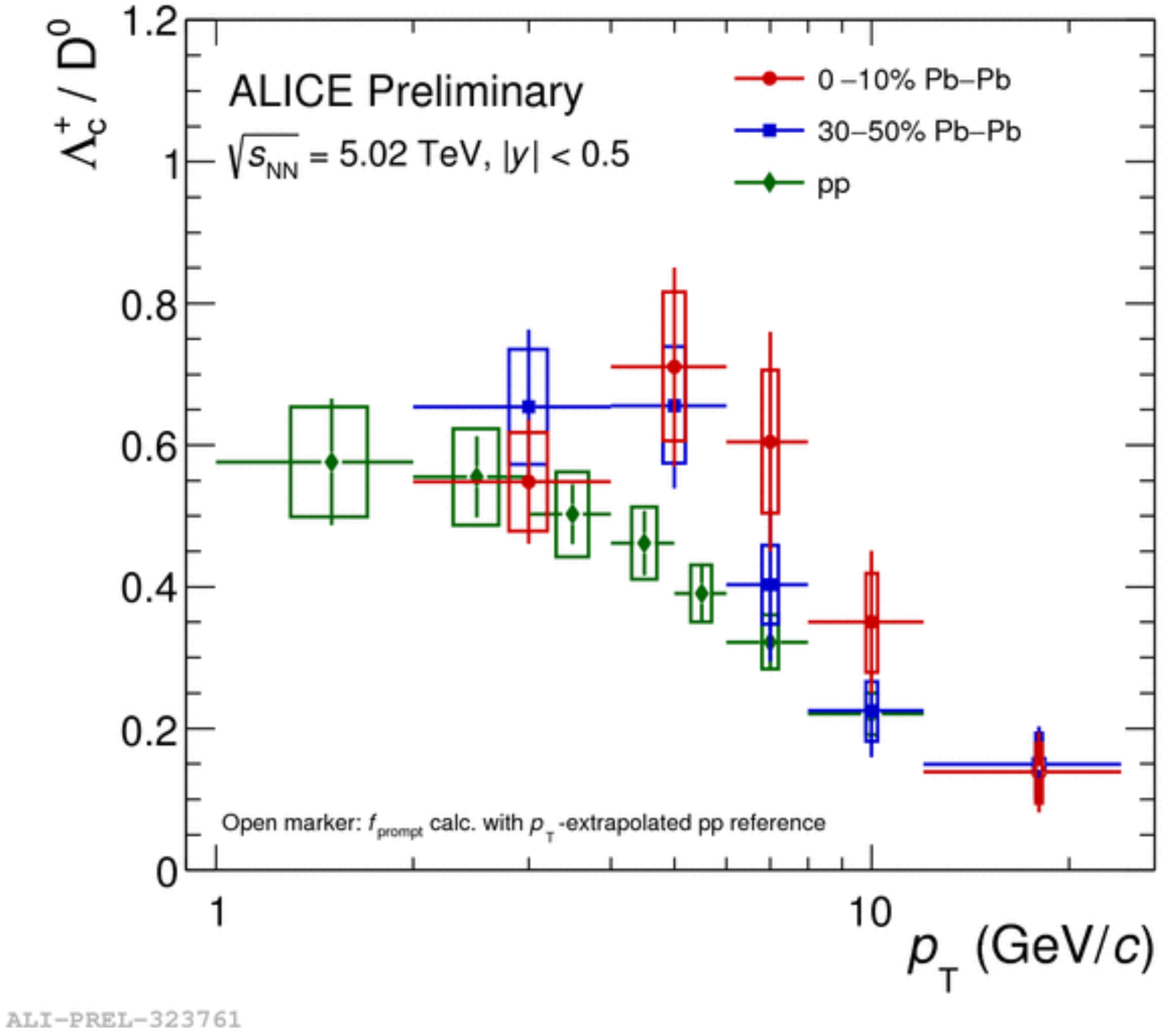
ALICE Run 3 challenges

- Precise measurements of heavy-flavour (HF) hadrons at the core of the physics programme
- Need to push reconstruction down to $p_T \approx 0$ and small DCA displacements
- Small signal/background ratio (low triggering efficiency in Pb–Pb)
- About 100 times more data to process (but not 100 times more resources!)



Full reconstruction of HF particles

- Double/triple/quadruple loop over tracks → **CPU time**
- Derived objects for HF (skims, candidate objects) → **disk space**
- **⇨ The most demanding CPU/disk process in Run 3**



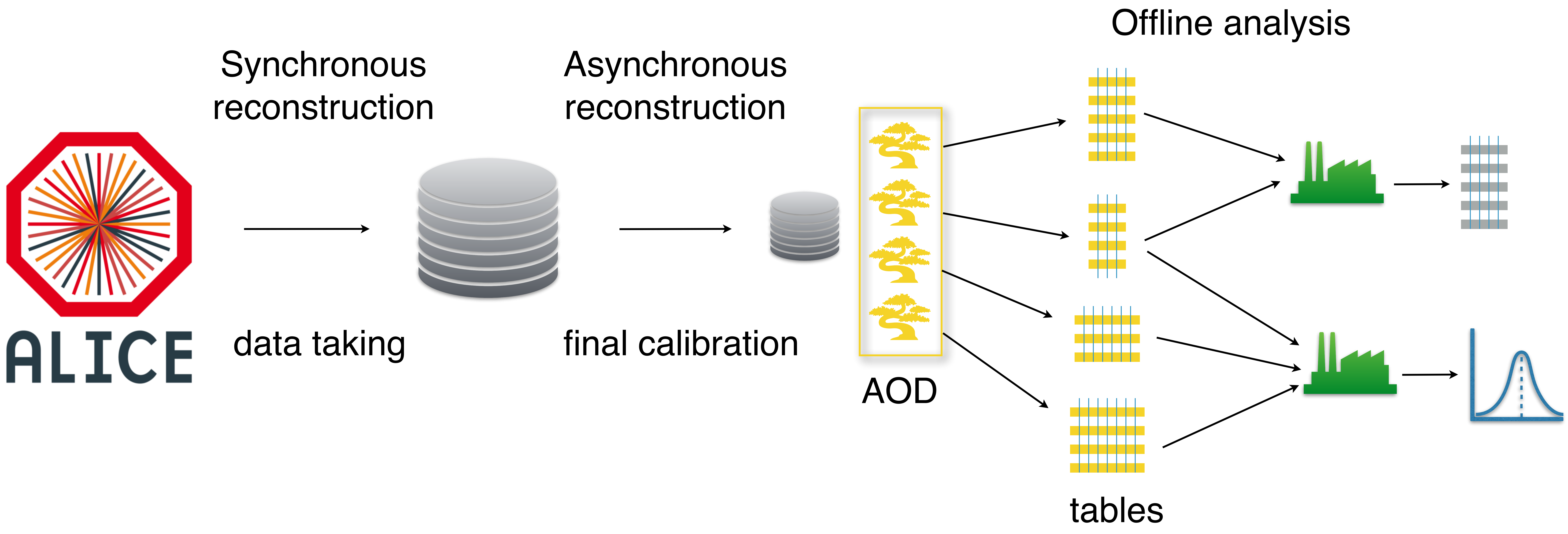
Pb–Pb in Run 2:

- $dN_{ch}/dy \approx 2000$ at mid rapidity in central collisions
- $O(10)$ s per minimum-bias event to reconstruct 2-prong HF candidates

Online–Offline (O^2) computing model

Designed to reduce volume of read-out data

- **Synchronous** reconstruction during data taking, data volume reduction
- **Asynchronous** reconstruction → Analysis Object Data (AOD) on disk (ROOT TTree)
- **Offline** analysis: AOD trees (collisions, tracks,…) → Apache Arrow tables processed by the analysis framework



O^2 data model

Table columns:

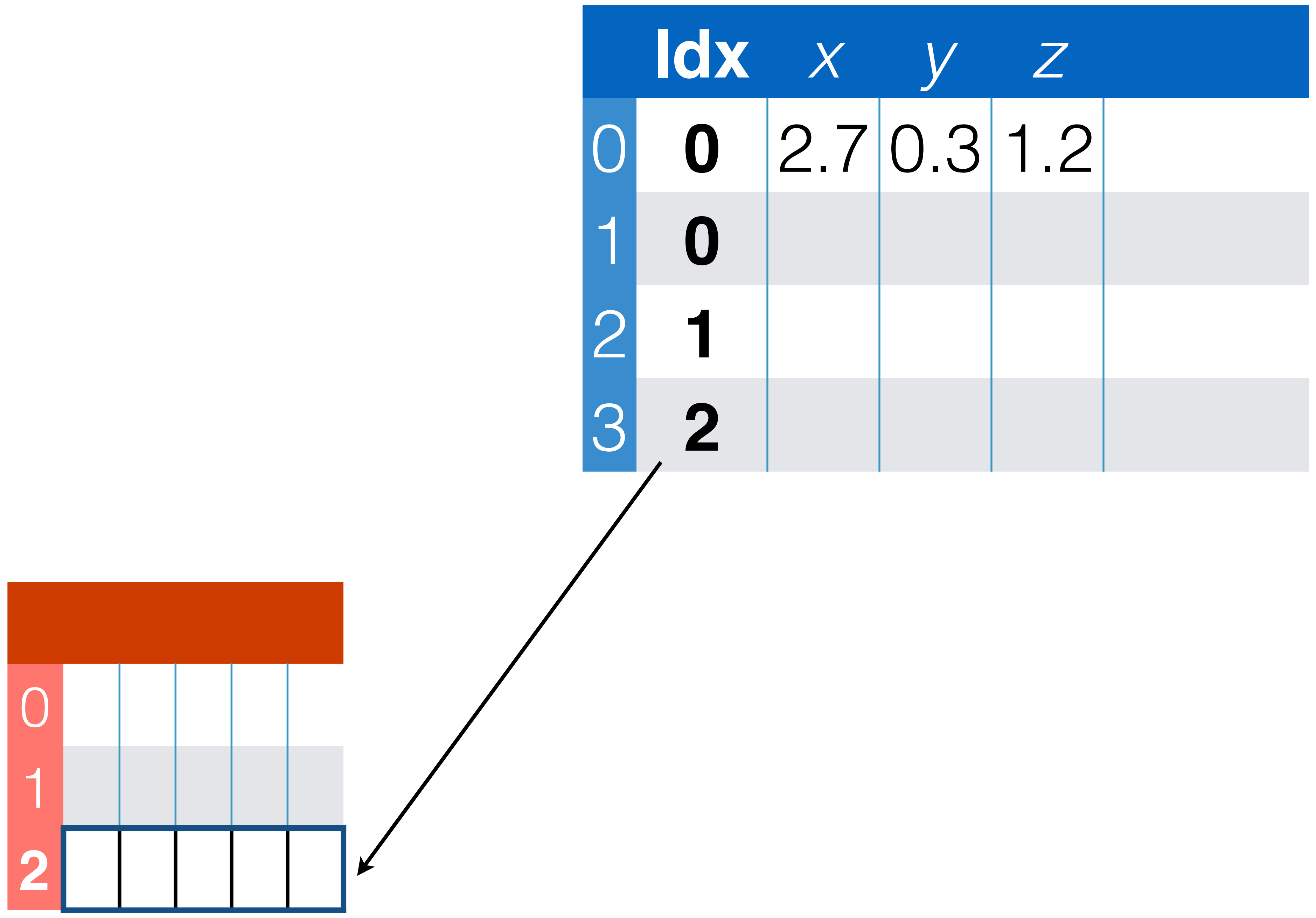
- **Static**: value (position, momentum, flag,…)

		x	*y*	*z*	
0		**2.7**	**0.3**	**1.2**	
1					
2					
3					

O^2 data model

Table columns:

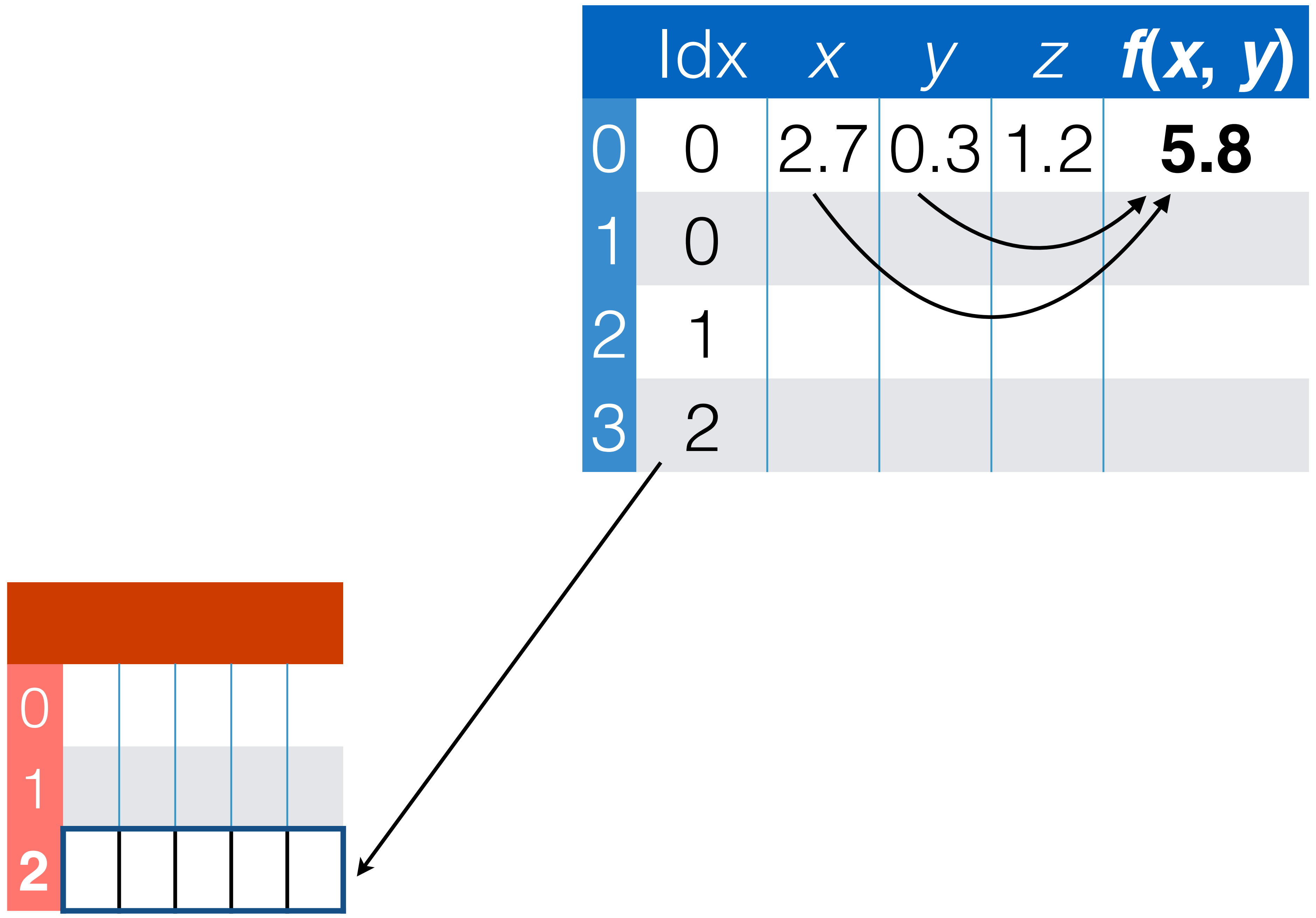
- Static: value (position, momentum, flag,…)
- **Index**: reference to rows in other tables (decay candidate → daughter track, track → collision)



O^2 data model

Table columns:

- Static: value (position, momentum, flag,…)
- Index: reference to rows in other tables (decay candidate → daughter track, track → collision)
- **Expression**: calculations with static columns ($p_{x,\text{ candidate}} = \sum p_{x,\text{ prong, }i}$)



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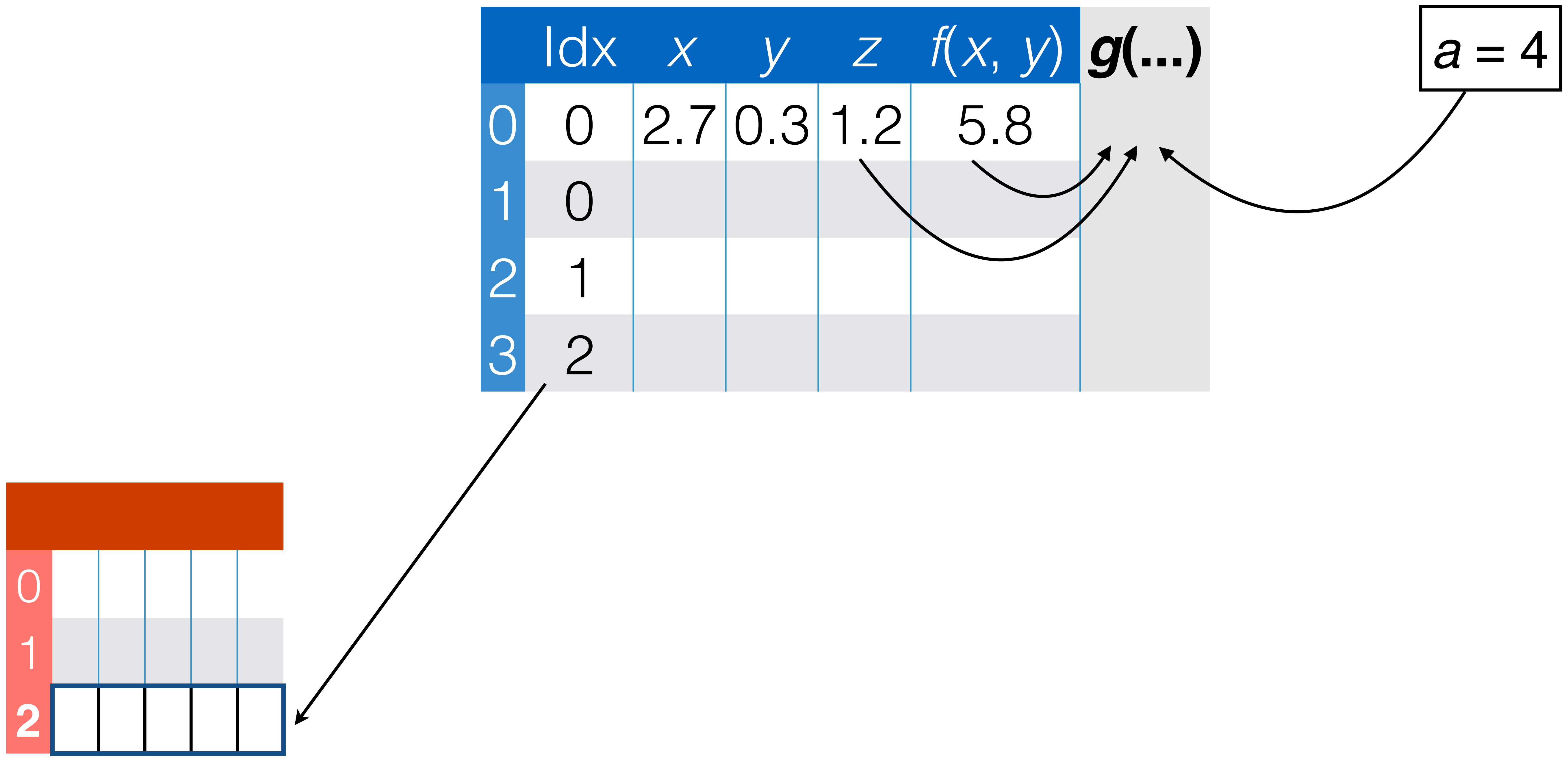
- Expression: calculations with static columns ($p_{x,\text{ candidate}} = \sum p_{x,\text{ prong, }i}$)
- **Dynamic**: functions operating on other columns; for on-demand calculations (invariant mass)



O² analysis framework

Table manipulation:

- **Join**: add new columns derived from the original table

	Idx	x	y	z	$f(x, y)$	$g(\ldots)$
0	0	2.7	0.3	1.2	5.8	
1	0					
2	1					
3	2					

\+

	u	v	w
0		3	
1		2	
2		0	
3		4	

O^2 analysis framework

ALICE

Table manipulation:

- Join: add new columns derived from the original table
- **Grouping**: iteration over tracks in the same collision

	Idx	*x*	*y*	*z*	*f*(*x*, *y*)	*g*(...)
0	**0**	2.7	0.3	1.2	5.8	
1	**0**					
2	**1**					
3	**2**					

+

	u	*v*	*w*
0		3	
1		2	
2		0	
3		4	

O^2 analysis framework

Table manipulation:

- Join: add new columns derived from the original table
- Grouping: iteration over tracks in the same collision
- **Declarative filtering** based on column content (instead of explicit loops)

	Idx	x	y	z	$f(x, y)$	$g(\ldots)$
0	0	2.7	0.3	1.2	5.8	
1	0					
2	1					
3	2					

+

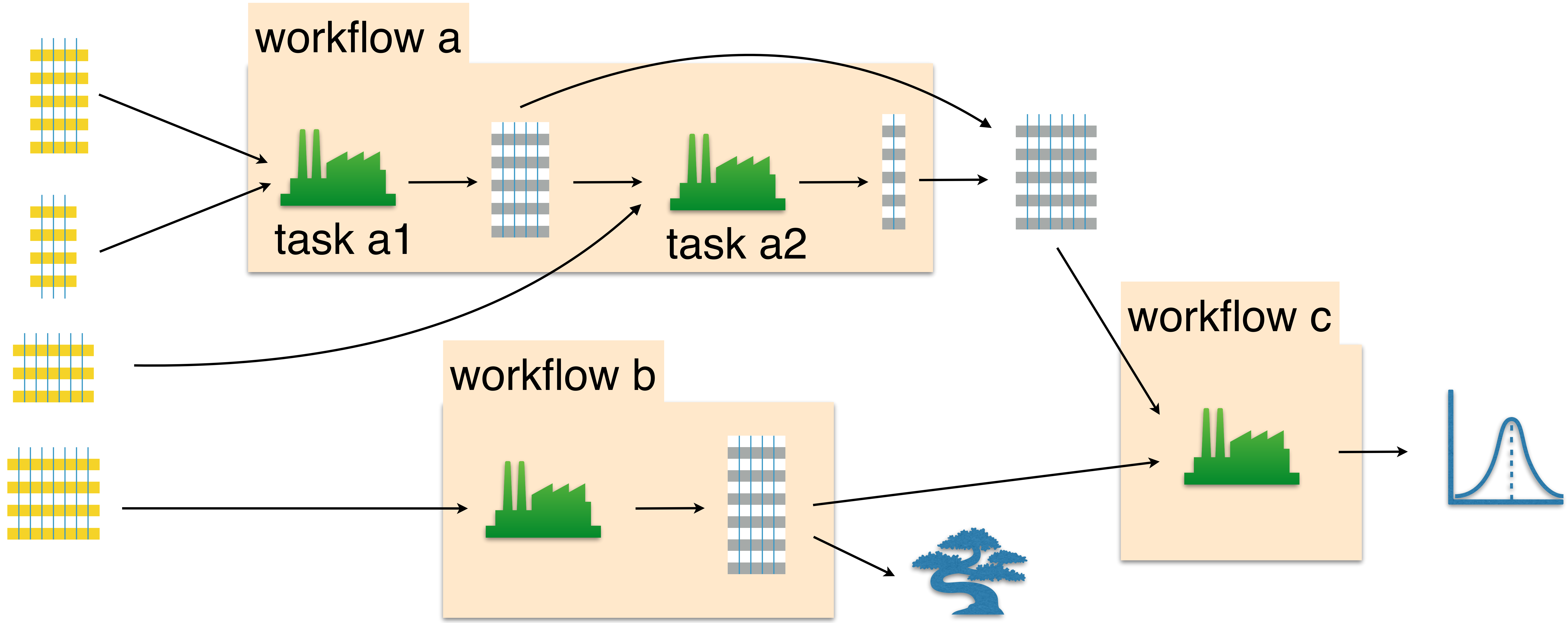
$v > 2$

	u	v	w
0		**3**	
1		2	
2		0	
3		**4**	

O² analysis framework

Modular workflow structure:

- Subscriptions to input tables determine topology.
- Configuration via JSON

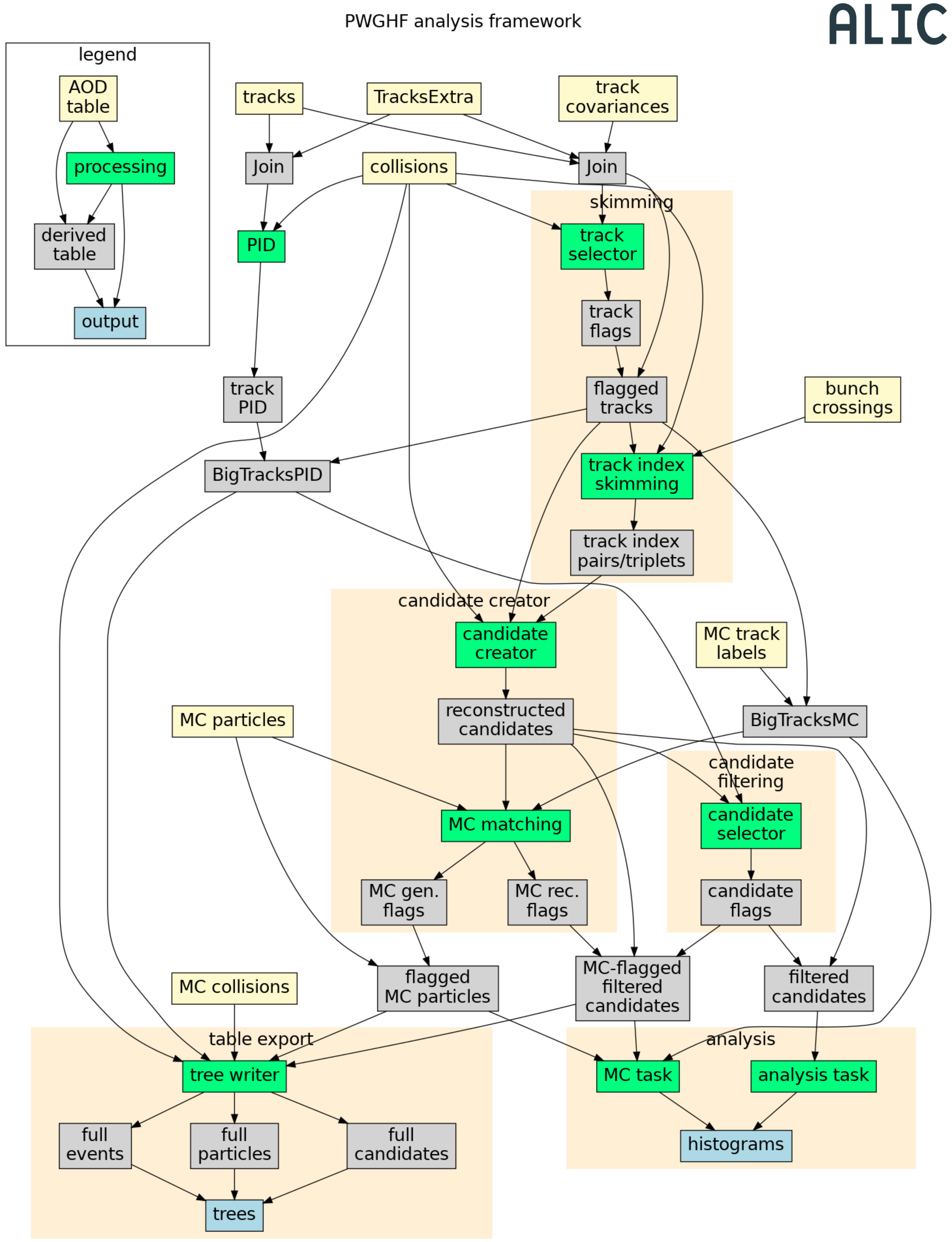



```
$ o2-a --aod-file AO2D.root | o2-b | o2-c
```

Overview of the HF analysis framework

Building blocks (workflows) of the framework:

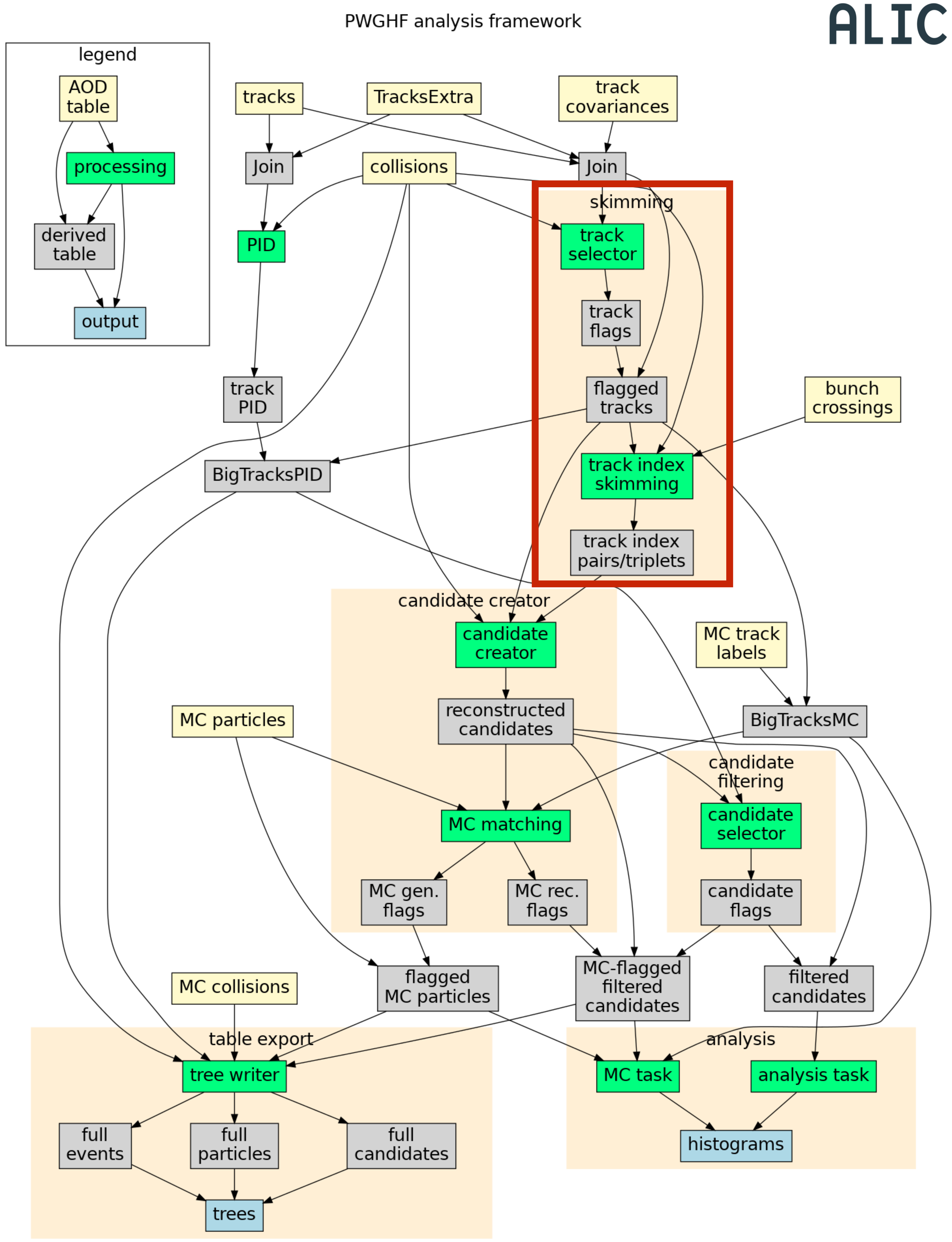
- Skimming
- Candidate creation
- Candidate filtering
- Analysis task
- Table export into trees
- Dedicated HF QA tasks



Overview of the HF analysis framework

Skimming

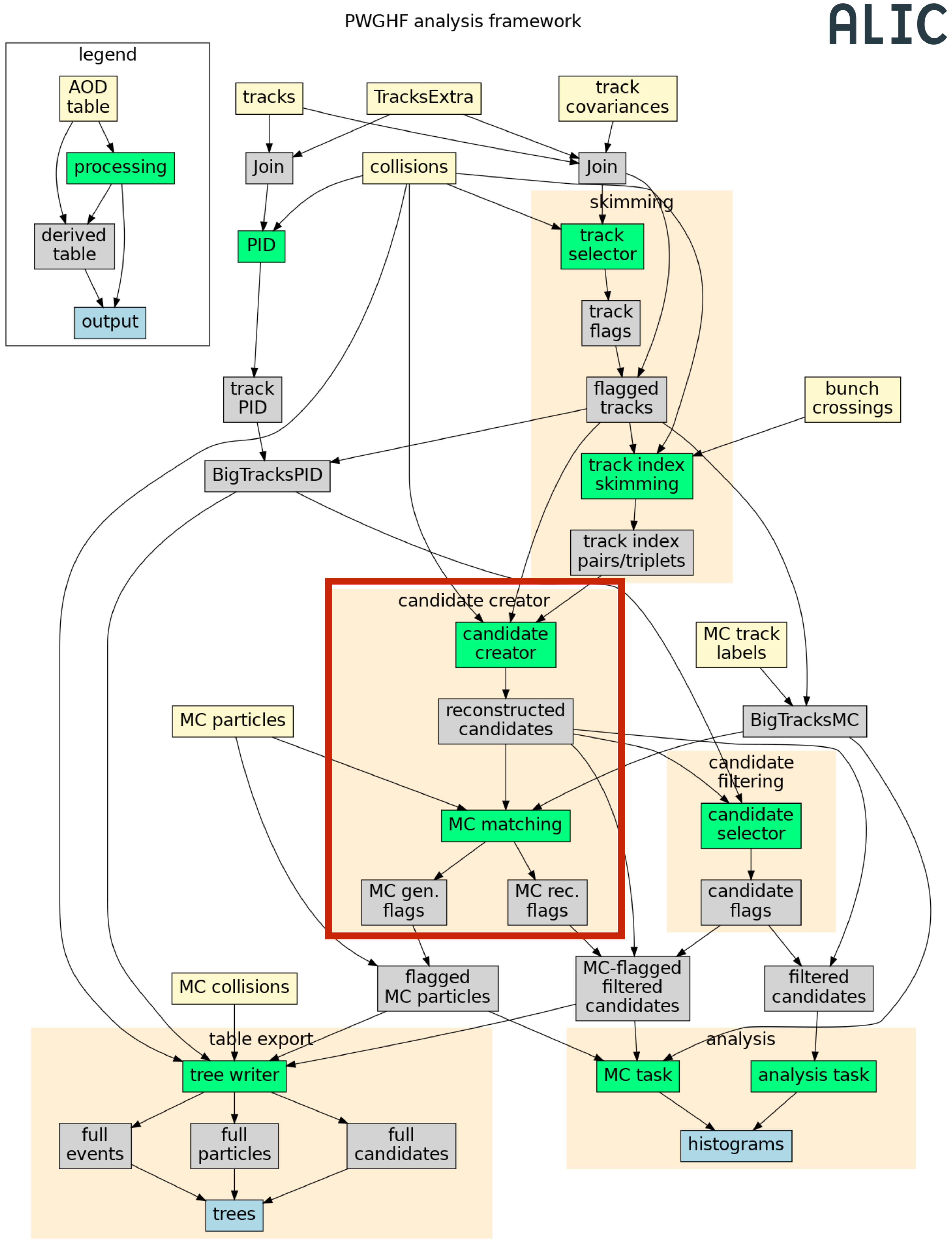
- Input: tracks grouped by collision
- Track selection (DCA, quality)
- Double/triple loop over tracks
- Secondary-vertex reconstruction
  - *N*-prong-dependent optimised algorithm
- Candidate preselection (invariant mass, p_{T}, cosine of pointing angle,…)
- Output: skimmed pairs/triplets of track indices



Overview of the HF analysis framework

Candidate creation

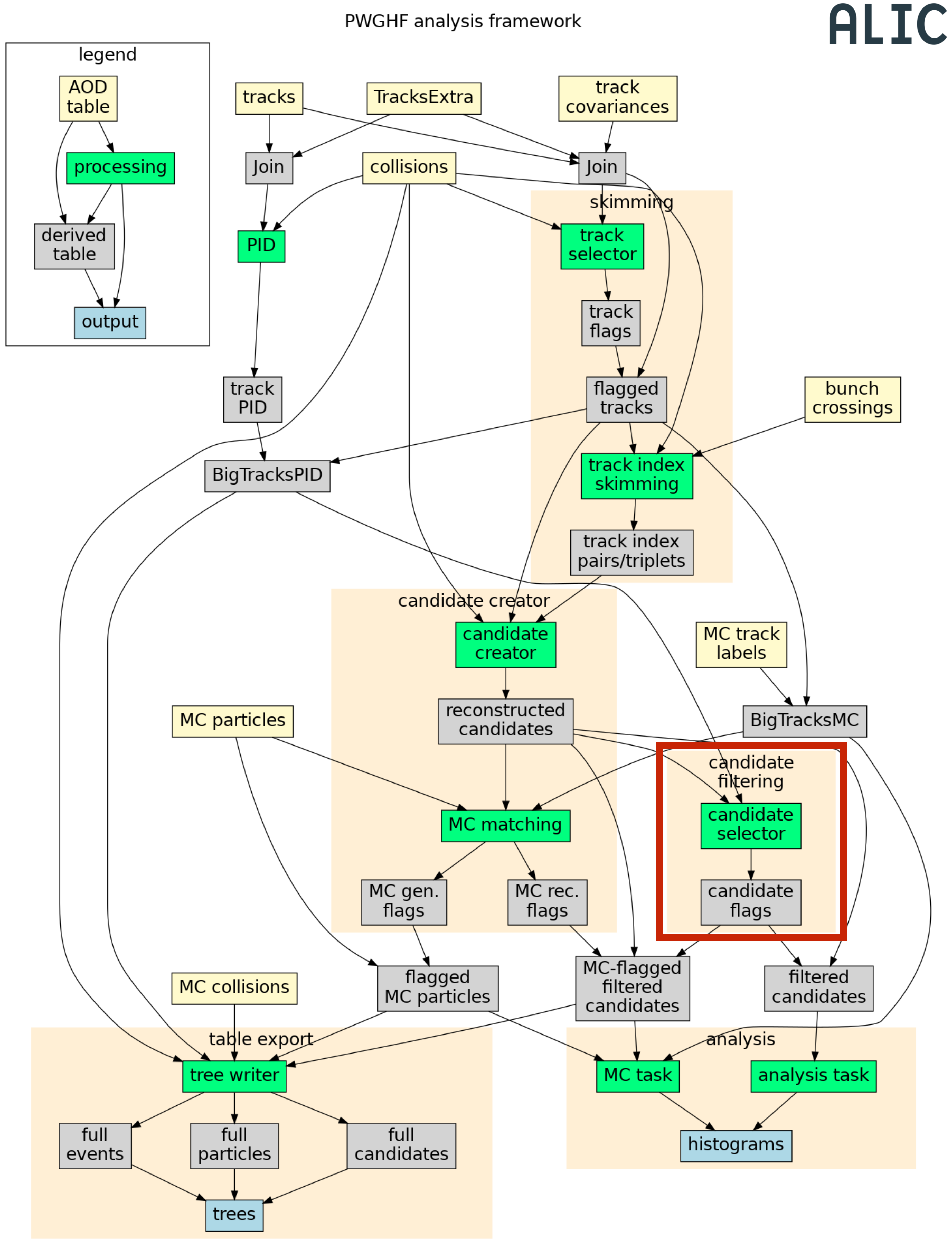
- Input: skimmed pairs/triplets of track indices
- Secondary-vertex reconstruction
- Candidate building (full information for selection and analysis)
- MC matching at rec. (candidate) and gen. (MC particle) levels
- MC origin tracing (prompt vs. non-prompt)
- Output:
  - Fully reconstructed HF candidates
  - MC flags



Overview of the HF analysis framework

Candidate filtering

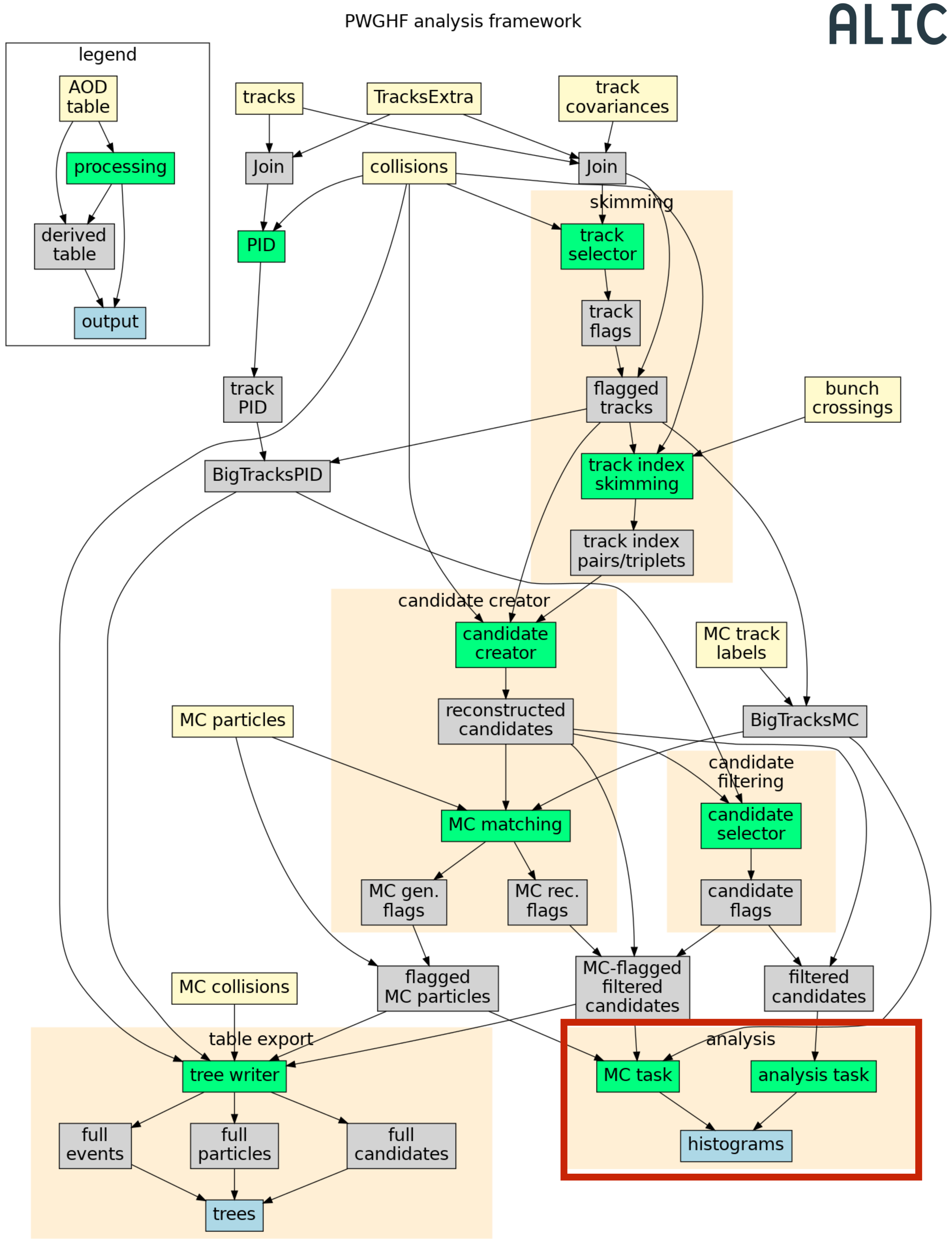
- Input:
  - Reconstructed candidates
  - Track PID
- Application of candidate selection criteria
  - Topological cuts
  - Daughter PID cuts
- Output: selection flags



Overview of the HF analysis framework

Analysis task

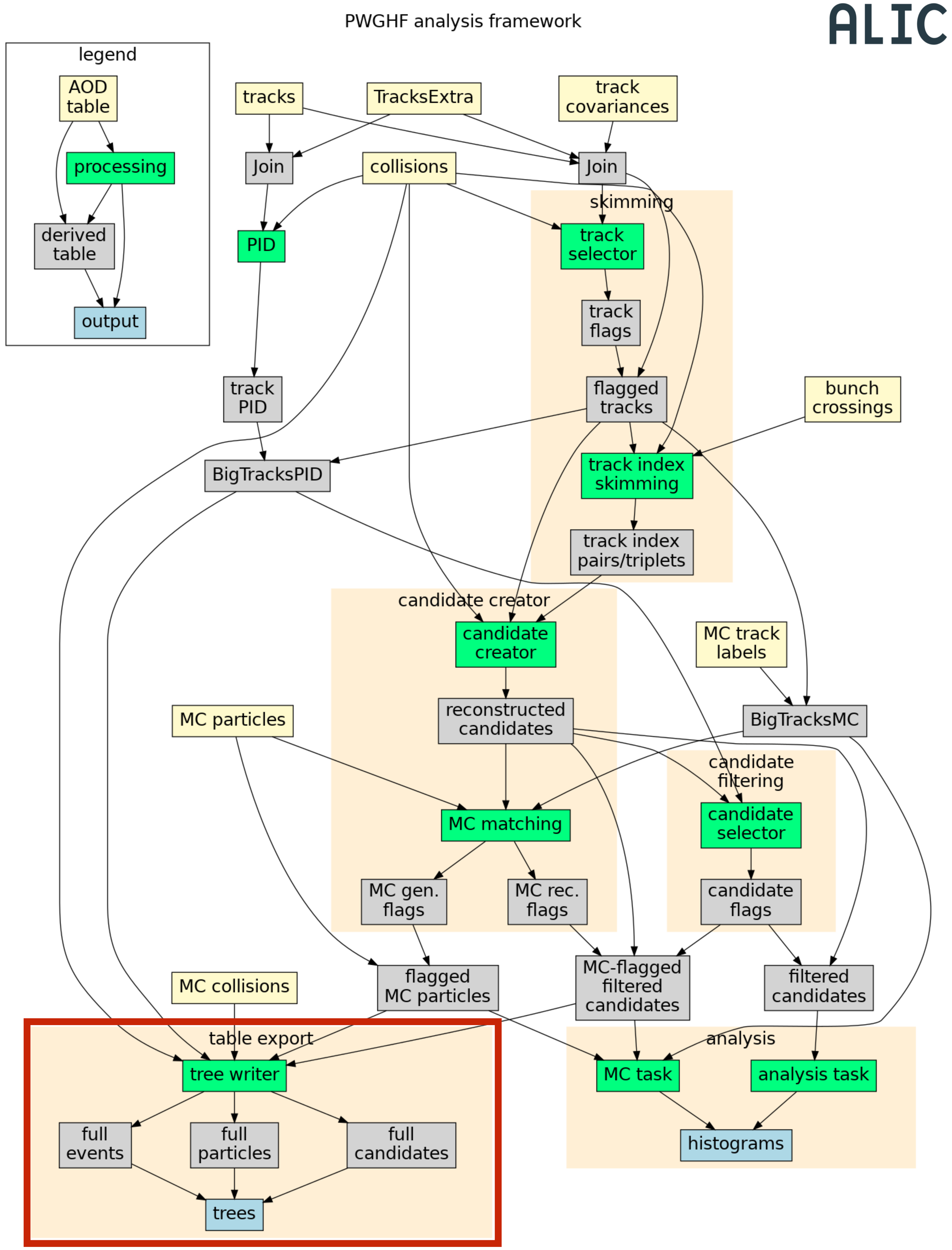
- Input:
  - Selected candidates
  - MC particles
  - MC flags
- Output: histograms
  - Kinematic properties
  - Signal vs. background
  - Reconstruction efficiency
  - Prompt vs. non-prompt



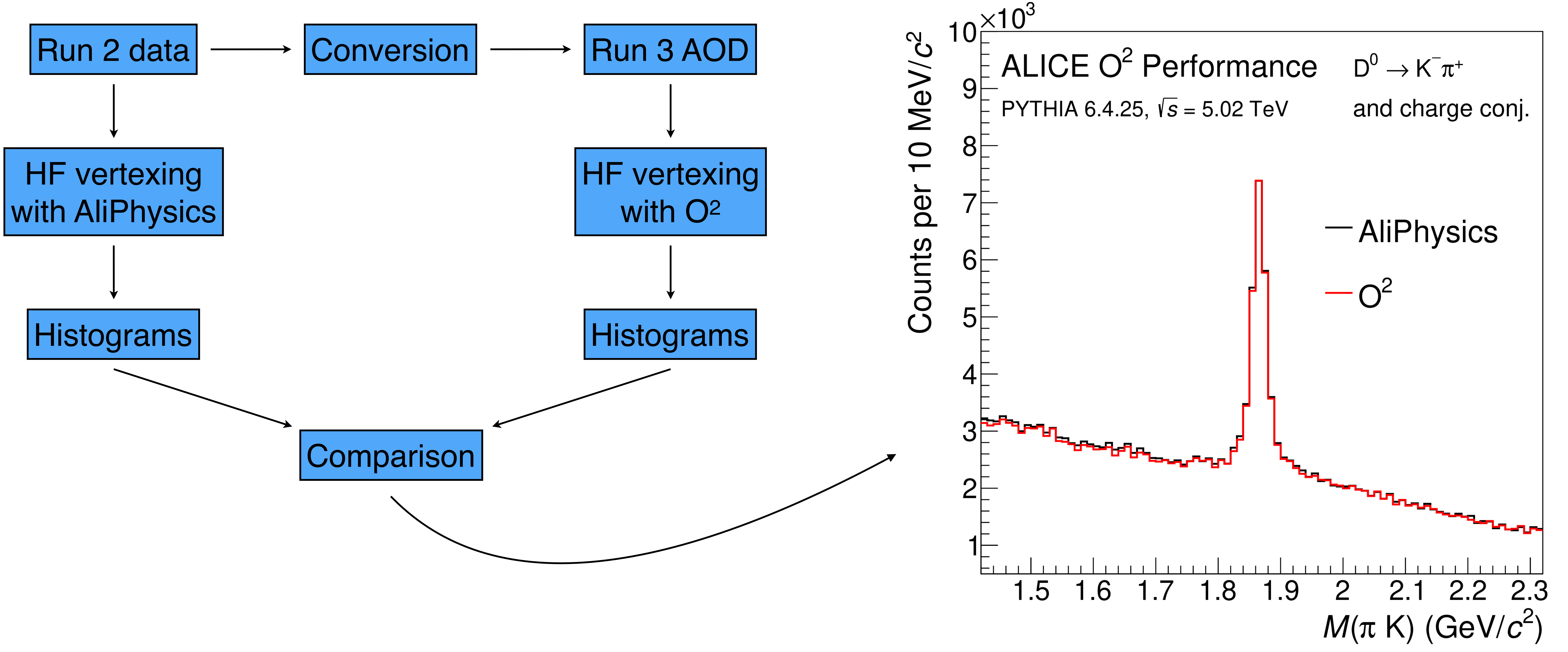
Overview of the HF analysis framework

Table export into trees

- Input:
  - Collisions
  - Tracks
  - MC particles
  - Candidates
  - Flags
- Creation of flat tables with full information
  - For postprocessing with external tools (e.g. Machine Learning)
- Output: ROOT trees



Validation against Run 1+2 code



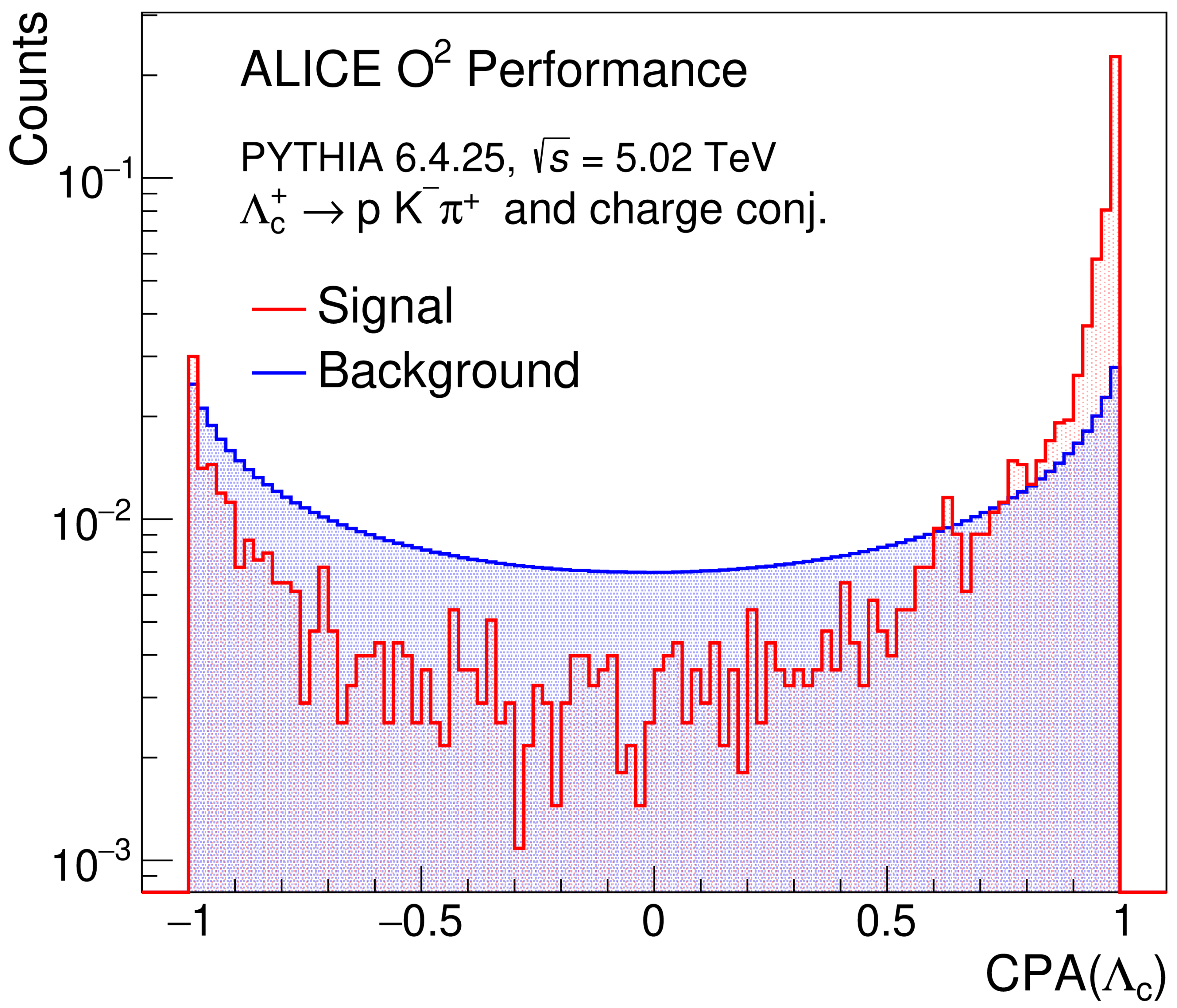
invariant mass of $D^0 \rightarrow K^- \pi^+$ candidates

First results: Selection parameters

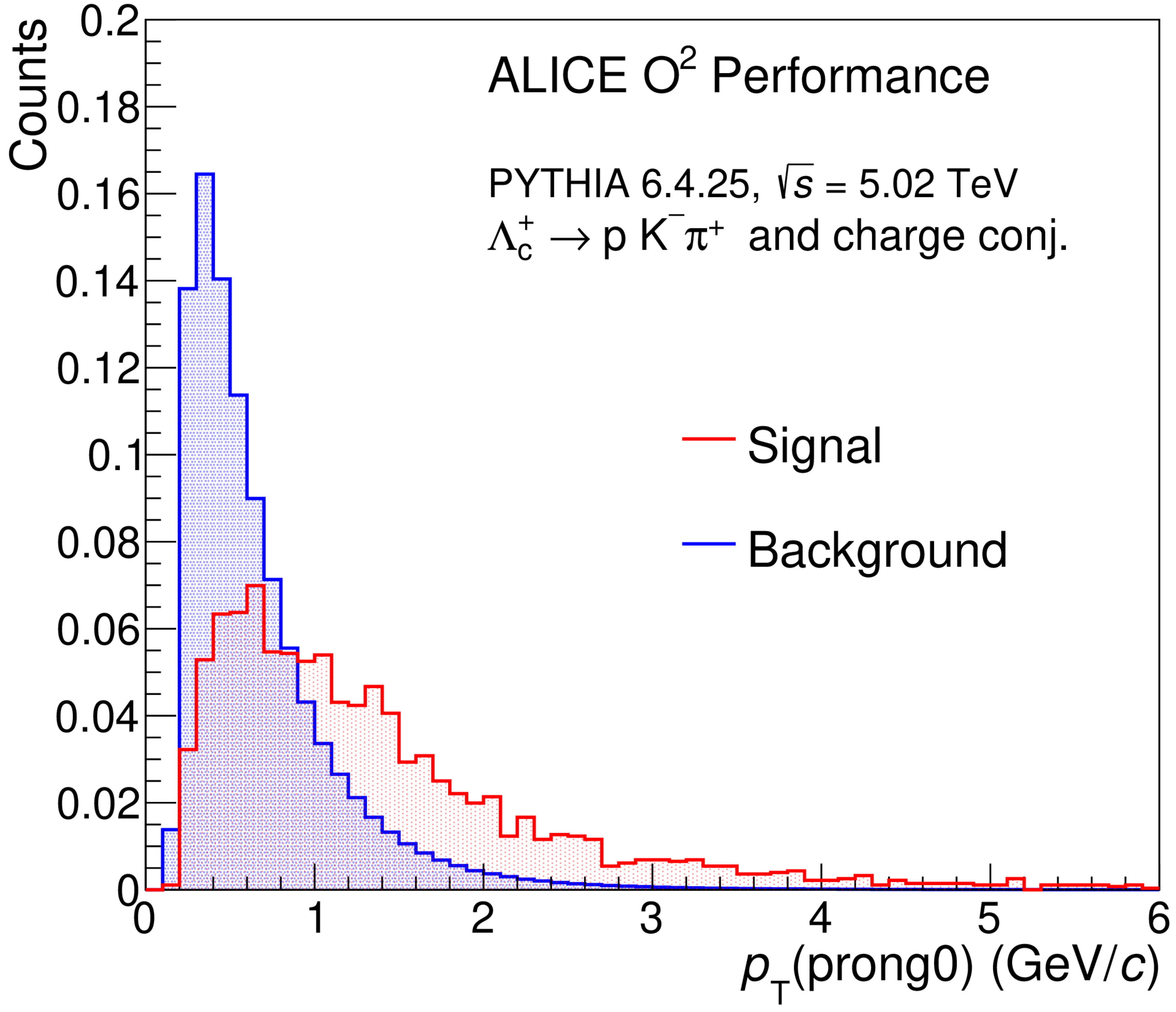
Run 2 MC converted to O^2 format

$\Lambda_c^+ \rightarrow p\, K^- \pi^+$ candidates

good separation of signal from background



cosine of pointing angle

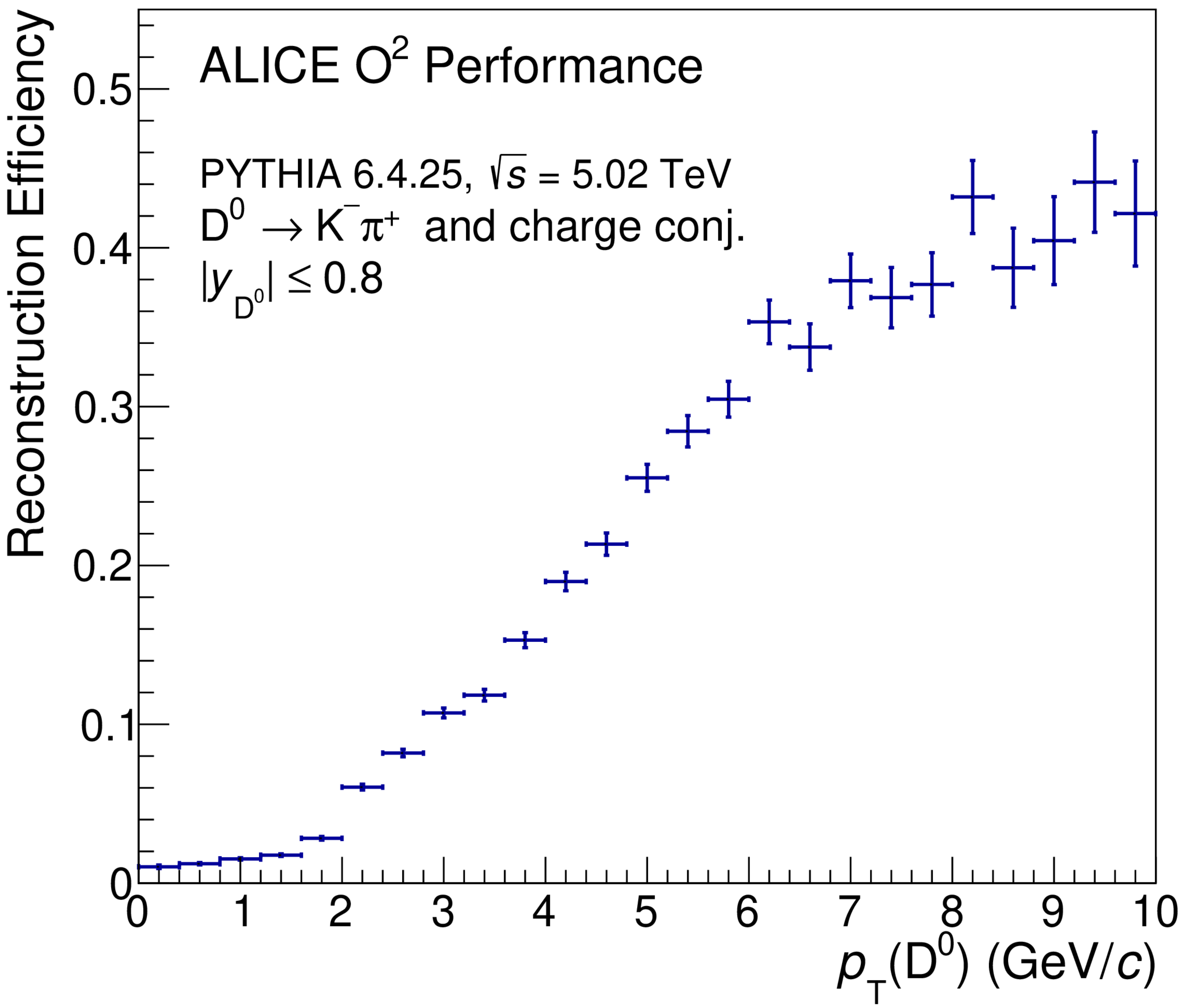


transverse momentum of the first prong

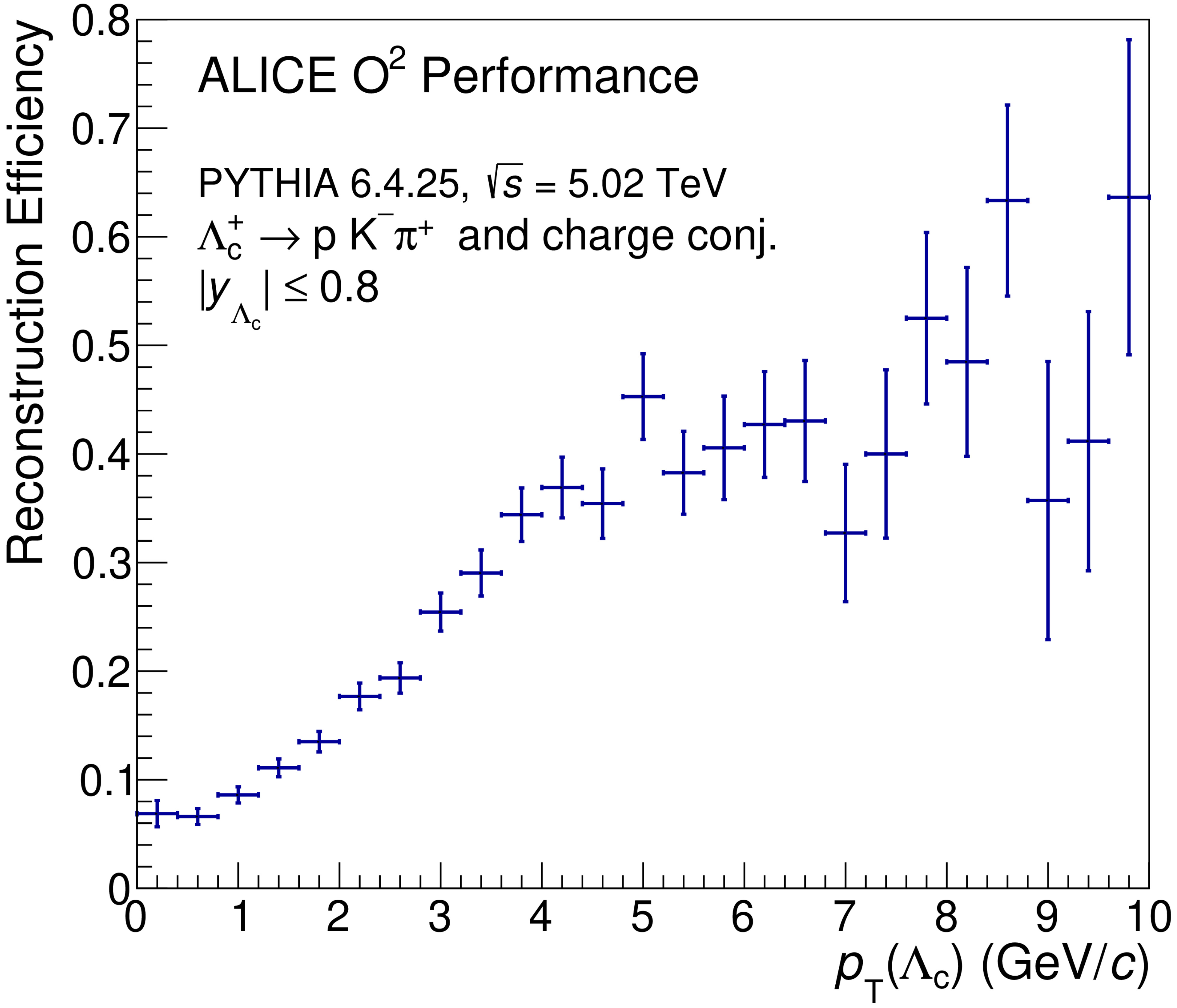
First results: Reconstruction efficiencies

Run 2 MC converted to O^2 format

$D^0 \rightarrow K^- \pi^+$



$\Lambda_c^+ \rightarrow p K^- \pi^+$



Available analyses

Extensively benefitting from the modular workflow structure and grouping by collision

- $D^0 \to \pi^+ K^-$
  - $B^+ \to D^0\text{bar}\ \pi^+ \to \pi^- K^+ \pi^+$
  - D^0–D^0bar correlations
- $J/\psi \to e^+ e^-$
  - $X(3872) \to J/\psi\ \pi^+ \pi^- \to e^+ e^- \pi^+ \pi^-$
- $D^+ \to \pi^+ K^- \pi^+$
- $\Lambda_c^+ \to p K^- \pi^+$
- $\Xi_c^+ \to p K^- \pi^+$
- $\Lambda_c^+ \to p K^0_S \to p \pi^+ \pi^-$ (built on top of V^0 candidate tables)

Next/ongoing steps

- QA/validation tools
- More channels that require intermediate HF decays (e.g. B, X,…)
- More complex analyses (e.g. HF correlations)
- Improve performance of O^2 vertexer for HF decays
    - Use KF Particle Finder package (better momentum resolution?)
    - Investigate vertexing with Deep Neural Networks
        - (fast first vertex reconstruction and candidate preselection)
- Validation and studies of MC Run 3/5 simulations:
    - Crucial for preparing good preselections of HF candidates in Pb–Pb
    - Starting point for defining and optimising selections for online software HF triggering in pp
        - (fast filtering to reduce data saved on disk)

See more at:

https://alice-o2-project.web.cern.ch/

https://github.com/AliceO2Group/AliceO2

Thanks for your attention