PWGCF: Hands-on Session
Femto framework(s)

O2 Analysis Tutorial 3.0

09.11.2023

Anton Riedel, Georgios Mantzaridis, Jaime Gonzalez Gonzalez

Overview

- There are currently 3 femto frameworks available in O2Physics under PWGCF folder:

```
[anton@silver] ~/alice/O2Physics
> find ./PWGCF/ -type d -name "Femto*"
./PWGCF/FemtoDream
./PWGCF/FemtoUniverse
./PWGCF/FemtoWorld
```

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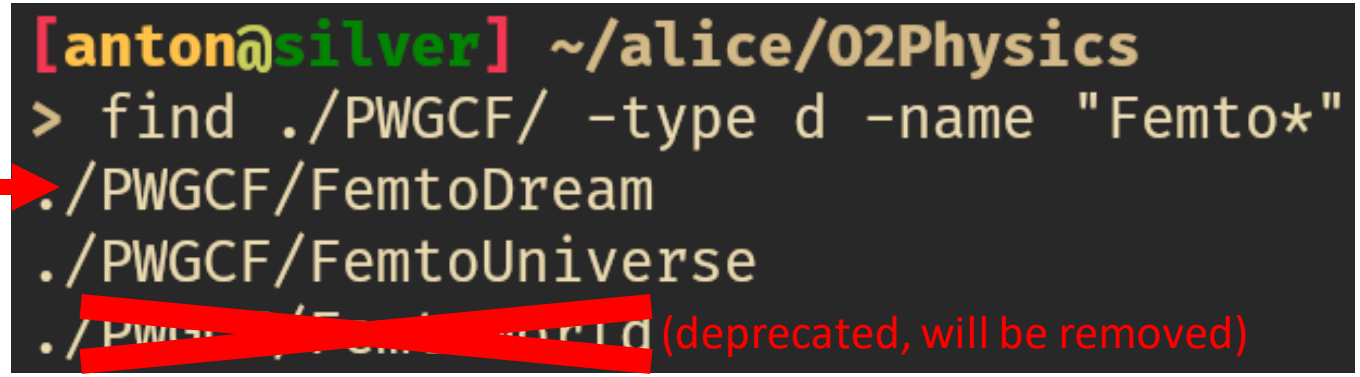
./PWGCF/FemtoWorld (deprecated, will be removed)
```

Overview

- There are currently 3 femto frameworks available in O2Physics under PWGCF folder:

Specialized for analyzing p-p data



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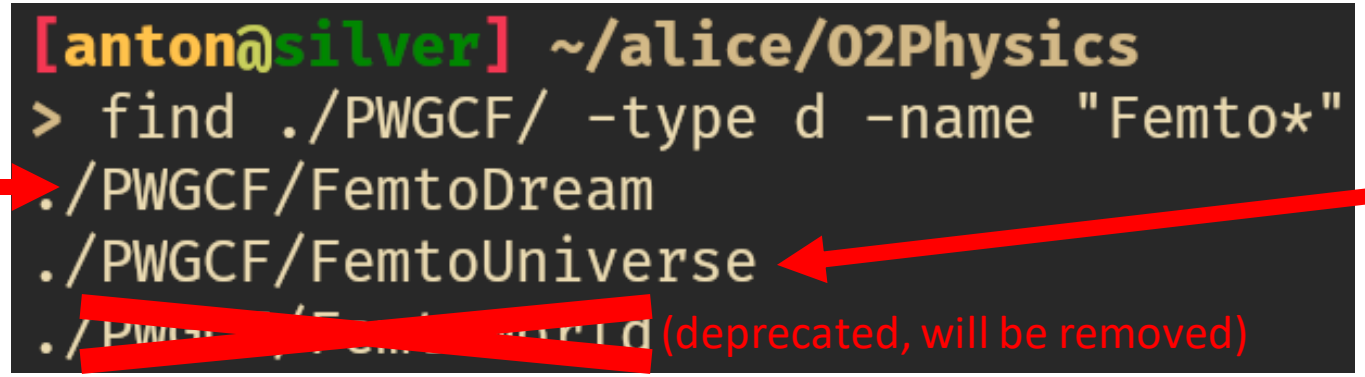

Specialized for analyzing Pb-Pb data

Overview

- There are currently 3 femto frameworks available in O2Physics under PWGCF folder:

Specialized for analyzing p-p data

```
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> find ./PWGCF/ -type d -name "Femto*"
./PWGCF/FemtoDream
./PWGCF/FemtoUniverse
./PWG[illegible]rld (deprecated, will be removed)
```

Specialized for analyzing Pb-Pb data

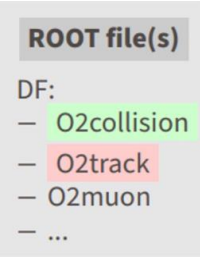
- FemtoDream and FemtoUniverse are independently developed frameworks (with common ancestry) for femto analysis but **they use the same data format!**

```
[anton@silver] ~/alice/O2Physics
> find PWGCF/DataModel/ -name "Femto*"
PWGCF/DataModel/FemtoDerived.h
```

Skimming & Analysis

- Full chain of femto analysis

AO2D.root



Skimming & Analysis

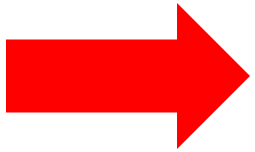
- Full chain of femto analysis

AO2D.root

ROOT file(s)

DF:
- O2collision
- O2track
- O2muon
- ...

Producer task

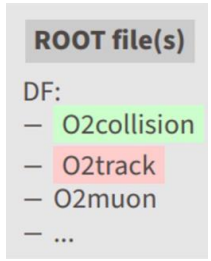


Store	Binding	Description
☐	FDExtMCParticles	FDEXTMCPARTICLE
☐	FDExtParticles	FDEXTPARTICLE
☐	FDMCLabels	FDMCLabel
☐	FDMCParticles	FDMCPARTICLE
☑	FDCollisions	FDCOLLISION
☑	FDParticles	FDPARTICLE

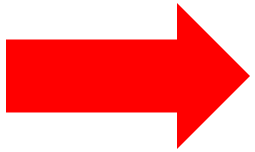
Skimming & Analysis

- Full chain of femto analysis

AO2D.root



Producer task



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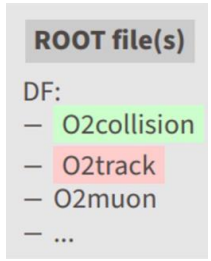
```
o2-analysis-cf-femtodream-producer
```

- Fill femto tables for analysis
- Only store events and tracks/V0/… fulfilling loosest selections
- Compute bitmask for track and PID selections
- Generate extended and/or MC tables for QA and more

Skimming & Analysis

- Full chain of femto analysis

AO2D.root



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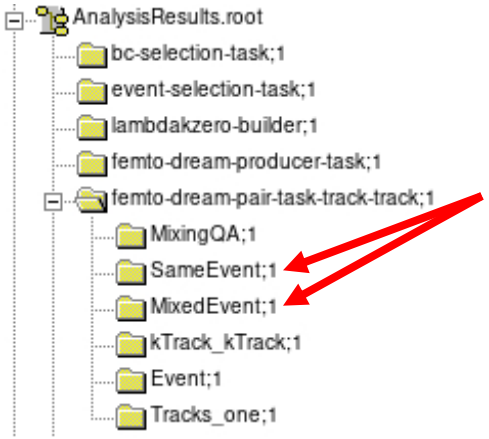
```
o2-analysis-cf-femtodream-producer
```

Pair task

AnalysisResults.root



Produce same and mixed event distributions for post-processing

- Fill femto tables for analysis
- Only store events and tracks/V0/… fulfilling loosest selections
- Compute bitmask for track and PID selections
- Generate extended and/or MC tables for QA and more

Skimming & Analysis

- Full chain of femto analysis

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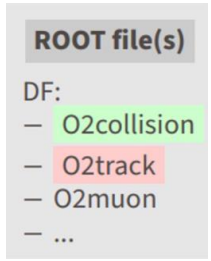

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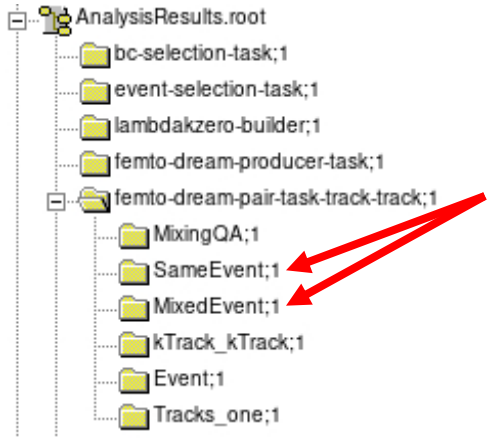


Produce same and mixed event distributions for post-processing

`o2-analysis-cf-femtodream-producer`

- Fill femto tables for analysis
- Only store events and tracks/V0/… fulfilling loosest selections
- Compute bitmask for track and PID selections
- Generate extended and/or MC tables for QA and more

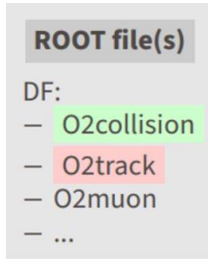
`o2-analysis-cf-femtodream-pair-track-track`

- Select particles according to the bitmask
- Pair tracks/V0s in single event for same event distribution
- Pair tracks/V0s across multiple events for mixed event distribution

Skimming & Analysis

- Full chain of femto analysis

AO2D.root



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Pair task

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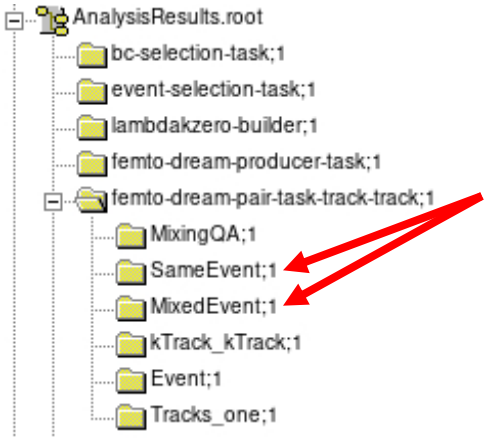


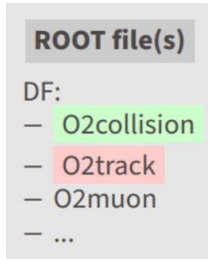
Produce same and mixed event distributions for post-processing

- Run full chain in one go
  - Femto tables are **generated in memory and immediately consumed** by the pair task, **only analysis output is saved to disk**
- Computationally very expensive to run full chain
  - Use **only on small/medium dataset** for testing and QA

Skimming & Analysis

- Full chain of femto analysis

AO2D.root



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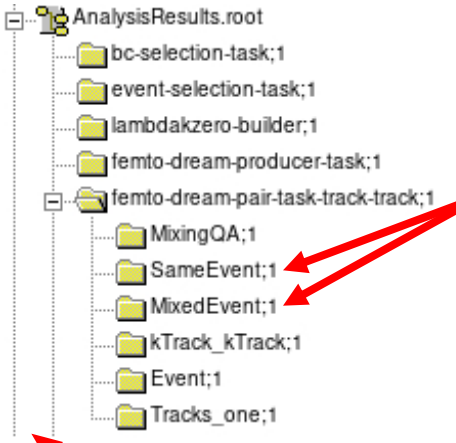
Pair task

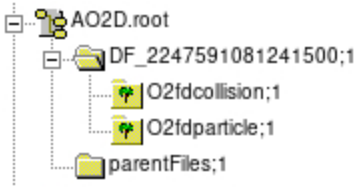
AnalysisResults.root



Produce same and mixed event distributions for post-processing

Run producer task alone and save its output to disk
-> Derived data

AO2D.root Containing femto tables only



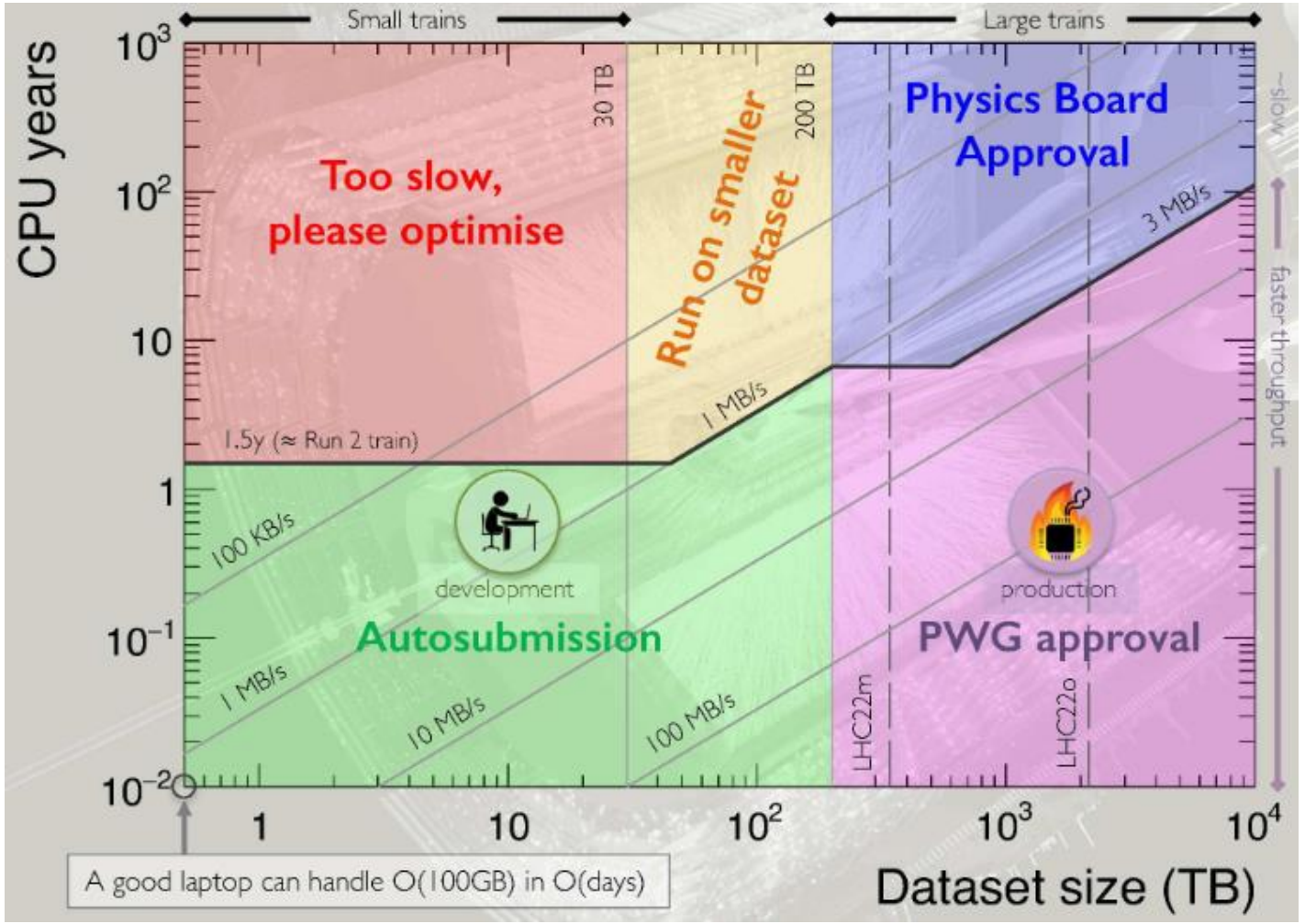
Run pair task alone with **derived data as input**

- Split (final) analysis into **2 parts**
  1. Run skimming up front and **remove unnecessary information to reduce the size of the data**
  2. Run the **analysis on derived data**
- Computationally **very efficient, especially for doing systematics**

Skimming & Analysis of whole 22 data (3PB)

Hyperloop test of femtodream producer task

Number of input files	1
Input size	2.4 GB
Output size	12.4 MB
Output size (AO2D only)	12.3 MB
Reduction Factor	196
PSS Memory	Max: 3.7 GB Avg: 3.6 GB Slope: 1.4 MB/s
Private Memory	Max: 2.6 GB Avg: 2.4 GB Slope: 594.1 KB/s
Timing	CPU: 9m 40s Wall: 12m 44s
Throughput	3.2 MB/s/core
Expected resources	33y 291d 16.4 TB



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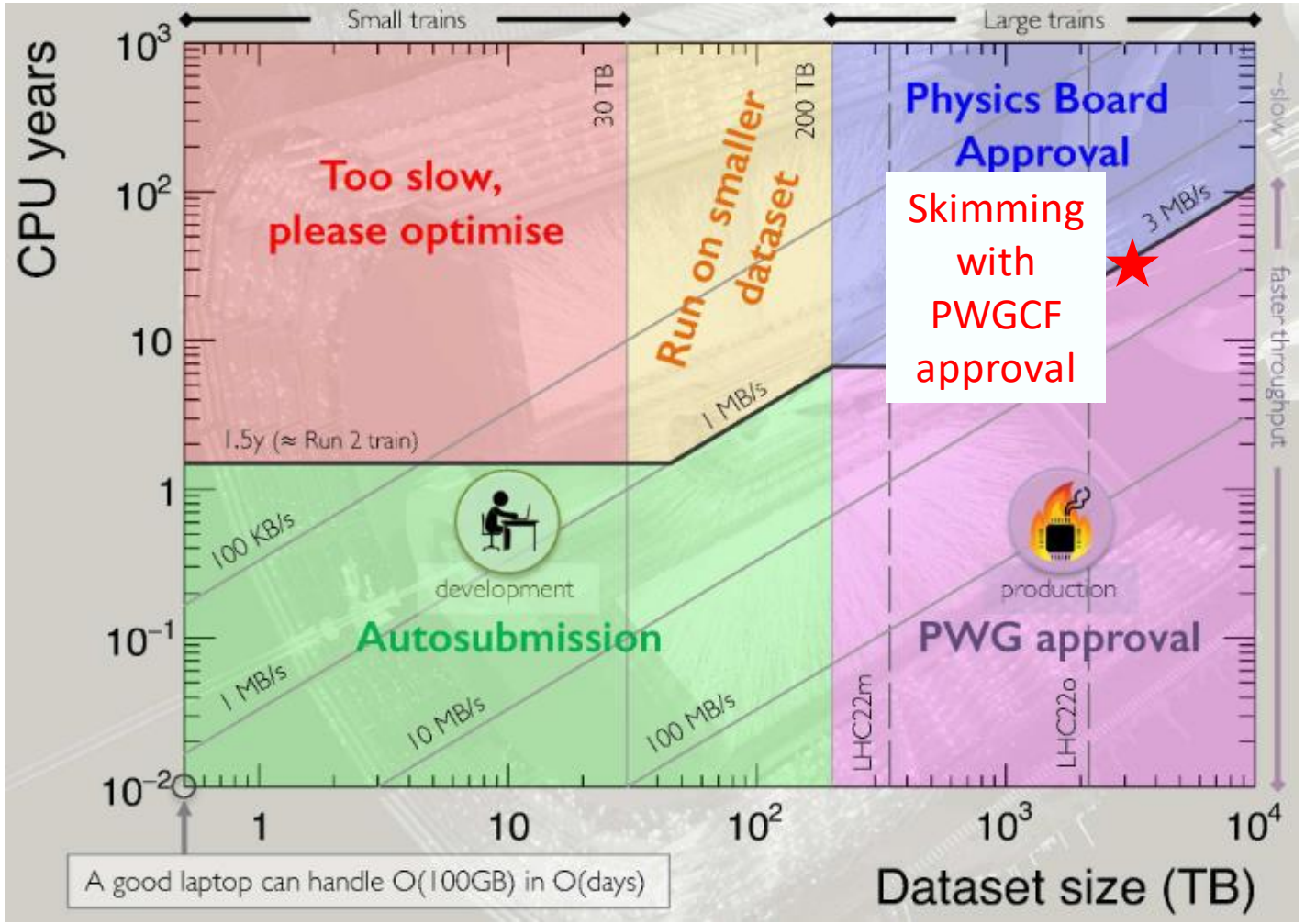

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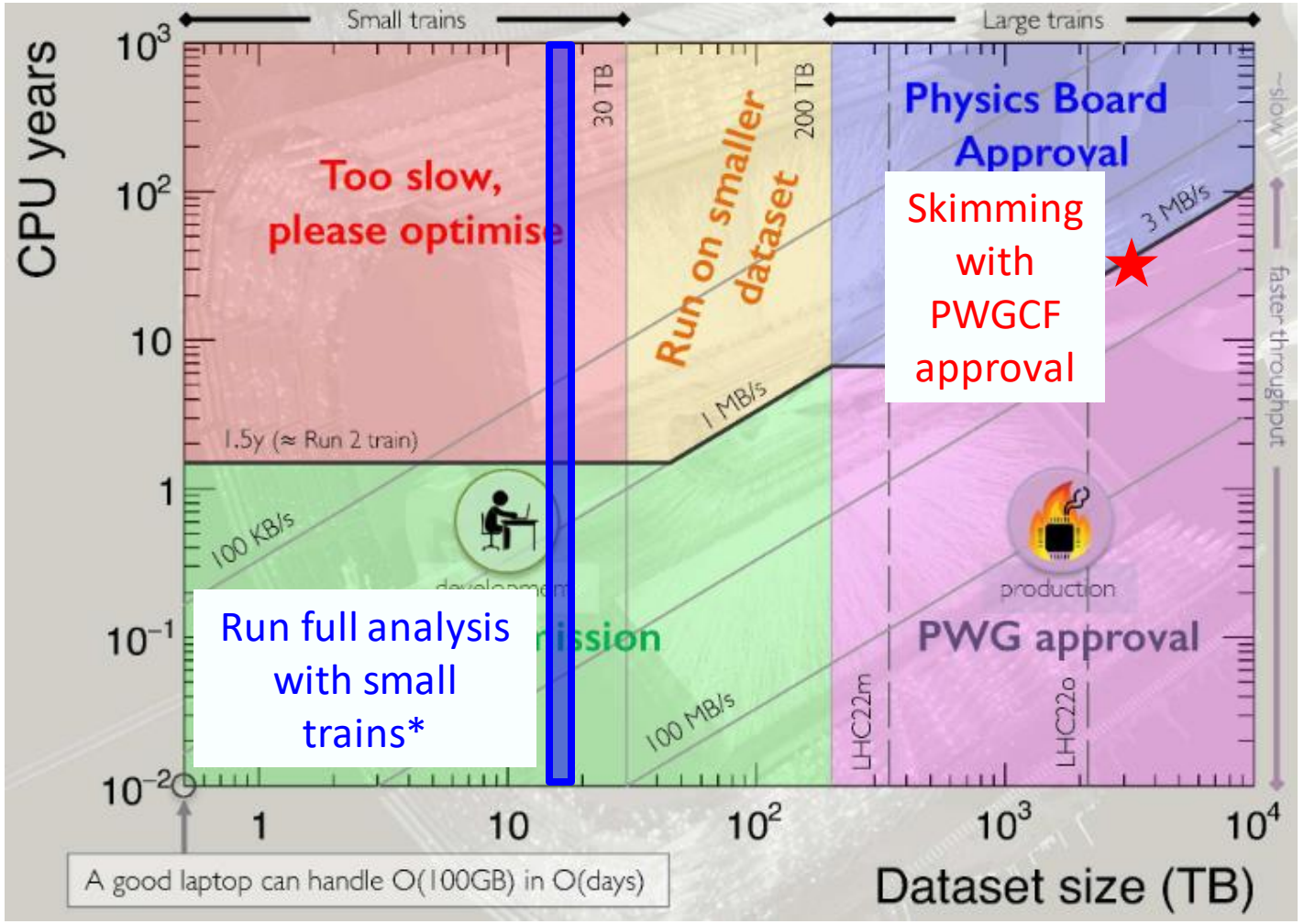

Bitmask for track cuts

dpl-config.json

```
"ConfTrkPtMin": {
    "values": [
        "0.5",
        "0.4",
        "0.6"
    ]
},
"ConfTrkPtMax": {
    "values": [
        "4"
    ]
},
"ConfTrkEtaMax": {
    "values": [
        "0.8",
        "0.77",
        "0.83"
    ]
},
```

O2track from AO2D.root

O2Tracks from AO2D.root			
Index	1	2	…
p_T	0.55	0.42	…
eta	0.79	0.9	…
…	…	…	…

Index	p_T min			p_T max	|eta| max			…
	>0.4	>0.5	>0.6	<4	<0.83	<0.8	<0.77	…
1								…
2								…

Bitmask for track cuts

dpl-config.json

```
"ConfTrkPtMin": {
    "values": [
        "0.5",
        "0.4",
        "0.6"
    ]
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O2track from AO2D.root

O2Tracks from AO2D.root			
Index	1	2	…
p_T	0.55	0.42	…
eta	0.79	0.9	…
…	…	…	…

Track 1 passed pT>0.5, set bit to 1

Track 2 did not pass pT>0.5, set bit to 0

Index	p_T min			p_T max	|eta| max			…
	>0.4	>0.5	>0.6	<4	<0.83	<0.8	<0.77	…
1	1	1	0					…
2	1	0	0					…

Bitmask for track cuts

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        "0.4",
        "0.6"
    ]
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    ]
},
"ConfTrkEtaMax": {
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1	1	1	0	1				…
2	1	0	0	1				…

Bitmask for track cuts

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    "values": [
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        "0.4",
        "0.6"
    ]
},
"ConfTrkPtMax": {
    "values": [
        "4"
    ]
},
"ConfTrkEtaMax": {
    "values": [
        "0.8",
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    ]
},
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O2track from AO2D.root

O2Tracks from AO2D.root			
Index	1	2	…
p_T	0.55	0.42	…
eta	0.79	-0.9	…
…	…	…	…

Index	p_T min			p_T max	|eta| max			…
	>0.4	>0.5	>0.6	<4	<0.83	<0.8	<0.77	…
1	1	1	0	1	1	1	0	…
2	1	0	0	1	0	0	0	…

Bitmask for track cuts

- Use cutculator in femtodream to compute the bitmask for the selections you need
- Cutculator takes as input the configuration of your producer task

```
[O2Physics/latest] ~ $> o2-analysis-cf-femtodream-cutculator dpl-config.json
Welcome to the CutCulator!
Found femto-dream-producer-task in dpl-config.json
Do you want to work with tracks or V0s (T/V)? >T
Do you want to manually select cuts or create systematic variations(M/V)? >M
Selection: Sign of the track - (-1 1 )
 > 1
Selection: Minimal pT (GeV/c) - (0.4 0.5 0.6 )
 > 0.5
Selection: Maximal pT (GeV/c) - (4 )
 > 4
Selection: Maximal eta - (0.83 0.8 0.77 )
 > 0.8
```

Invoke cutculator with the configuration of your producer as input

Bitmask for track cuts

- Use cutculator in femtodream to compute the bitmask for the selections you need
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Do you want to manually select cuts or create systematic variations(M/V)? >M
Selection: Sign of the track - ( -1 1 )
 > 1
Selection: Minimal pT (GeV/c) - ( 0.4 0.5 0.6 )
 > 0.5
Selection: Maximal pT (GeV/c) - ( 4 )
 > 4
Selection: Maximal eta - ( 0.83 0.8 0.77 )
 > 0.8
```

Select the cuts you want from the available options

Bitmask for track cuts

- Use cutculator in femtodream to compute the bitmask for the selections you need
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Selection: Sign of the track - (-1 1 )
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Selection: Minimal pT (GeV/c) - (0.4 0.5 0.6 )
 > 0.5
Selection: Maximal pT (GeV/c) - (4 )
 > 4
Selection: Maximal eta - (0.83 0.8 0.77 )
 > 0.8
```
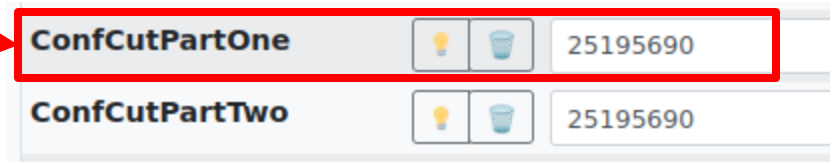

```
++++++++++++++++++++++++++++++++
CutCulator has spoken - your selection bit is
00000001100000000111010010101010 (bitwise)
25195690 (number representation)
PID for these species is stored:
Proton : 0
++++++++++++++++++++++++++++++++
```

Use the bitmask as input for your pair task to select tracks

Configuration of pair-task-track-track



Bitmask for PID cuts

$$n\sigma_{TPCTOF} = \sqrt{n\sigma_{TPC}^2 + n\sigma_{TOF}^2}$$

dpl-config.json
(Producer)

```
"ConfTrkPIDnSigmaMax": {
    "values": [
        "3",
        "2.5",
        "3.5"
    ]
},
```

PID information of tracks from helper tasks			
Index	1	2	…
NsigmaTPC (Proton)	1.2	2.8	…
NSigmaTOF (Proton)	0.5	5.6	…
…	…	…	…

dpl-config.json
(Producer)

```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

Species	Proton					
	3		2.5		3.5	
Index	<|TPC|	<|TPCTOF|	<|TPC|	<|TPCTOF|	<|TPC|	<|TPCTOF|
1						
2						

Bitmask for PID cuts

$$n\sigma_{TPCTOF} = \sqrt{n\sigma_{TPC}^2 + n\sigma_{TOF}^2}$$

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(Producer)

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Index	1	2	…
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NSigmaTOF (Proton)	0.5	5.6	…
…	…	…	…

dpl-config.json
(Producer)

```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

Species	Proton					
	3		2.5		3.5	
Index	<|TPC|	<|TPCTOF|	<|TPC|	<|TPCTOF|	<|TPC|	<|TPCTOF|
1						
2						

from PID.h

```
static constexpr ID Electron = 0;
static constexpr ID Muon = 1;
static constexpr ID Pion = 2;
static constexpr ID Kaon = 3;
static constexpr ID Proton = 4;
static constexpr ID Deuteron = 5;
static constexpr ID Triton = 6;
static constexpr ID Helium3 = 7;
static constexpr ID Alpha = 8;
```

Bitmask for PID cuts

$$n\sigma_{TPCTOF} = \sqrt{n\sigma_{TPC}^2 + n\sigma_{TOF}^2}$$

dpl-config.json
(Producer)

```
"ConfTrkPIDnSigmaMax": {
    "values": [
        "3",
        "2.5",
        "3.5"
    ]
},
```

PID information of tracks from helper2222 tasks			
Index	1	2	…
NsigmaTPC (Proton)	2.8	-3.2	…
NSigmaTOF (Proton)	0.5	5.6	…
…	…	…	…

Track 1 passed
|nsigma_TPC|<3, set bit to 1

Track 2 did not pass
|nsigma_TPC|<3, set bit to 0

dpl-config.json
(Producer)

```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

Species	Proton					
	3		2.5		3.5	
Index	<|TPC|	<|TPCTOF|	<|TPC|	<|TPCTOF|	<|TPC|	<|TPCTOF|
1	1		0		1	
2	0		0		1	

Bitmask for PID cuts

$$n\sigma_{TPCTOF} = \sqrt{n\sigma_{TPC}^2 + n\sigma_{TOF}^2}$$

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(Producer)

```
"ConfTrkPIDnSigmaMax": {
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        "3",
        "2.5",
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    ]
},
```

PID information of tracks from helper2222 tasks			
Index	1	2	…
NsigmaTPC (Proton)	2.8	-3.2	…
NSigmaTOF (Proton)	-0.5	5.6	…
	…	…	…

Track 1 passed
|nsigma_TPCTOF|<3, set bit to 1

Track 2 did not pass
|nsigma_TPCTOF|<3,
set bit to 0

dpl-config.json
(Producer)

```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

Species	Proton					
	3		2.5		3.5	
Index	<|TPC|	<|TPCTOF|	<|TPC|	<|TPCTOF|	<|TPC|	<|TPCTOF|
1	1	1	0	0	1	1
2	0	0	0	0	1	0

Support for TOF only selections will be added in the future

Bitmask for PID cuts

dpl-config.json
(Producer)

```
"ConfTrkPIDnSigmaMax": {
    "values": [
        "3",
        "2.5",
        "3.5"
    ]
},
```

```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

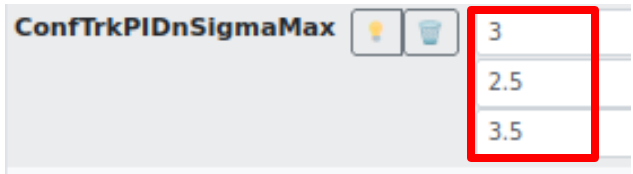
Bitmask for PID cuts

dpl-config.json
(Producer)

```
"ConfTrkPIDnSigmaMax": {
    "values": [
        "3",
        "2.5",
        "3.5"
    ]
},
```

```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

Configuration of
pair task



Copy
ConfTrkPIDnSigmaMax
array

Bitmask for PID cuts

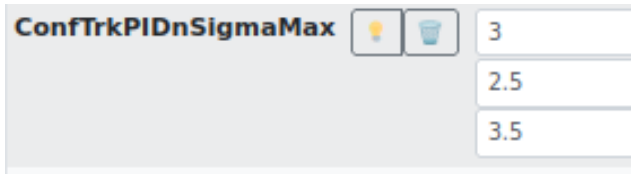
dpl-config.json
(Producer)

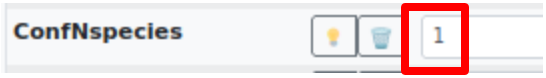
```
"ConfTrkPIDnSigmaMax": {
    "values": [
        "3",
        "2.5",
        "3.5"
    ]
},
```

```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

Length = 1

Configuration of
pair task





Copy
ConfTrkPIDnSigmaMax
array

Specify number of particle species with PID information, here only 1

Bitmask for PID cuts

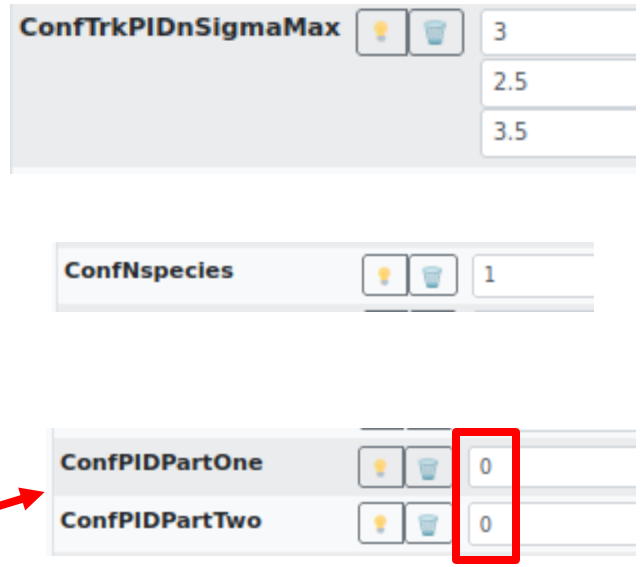
dpl-config.json
(Producer)

```
"ConfTrkPIDnSigmaMax": {
    "values": [
        "3",
        "2.5",
        "3.5"
    ]
},
```

```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

Index = 0

Configuration of
pair task



Copy
ConfTrkPIDnSigmaMax
array

Specify number of particle species with PID information, here only 1

Specify the index to select the particle species, here 4 (=Proton) is at index 0

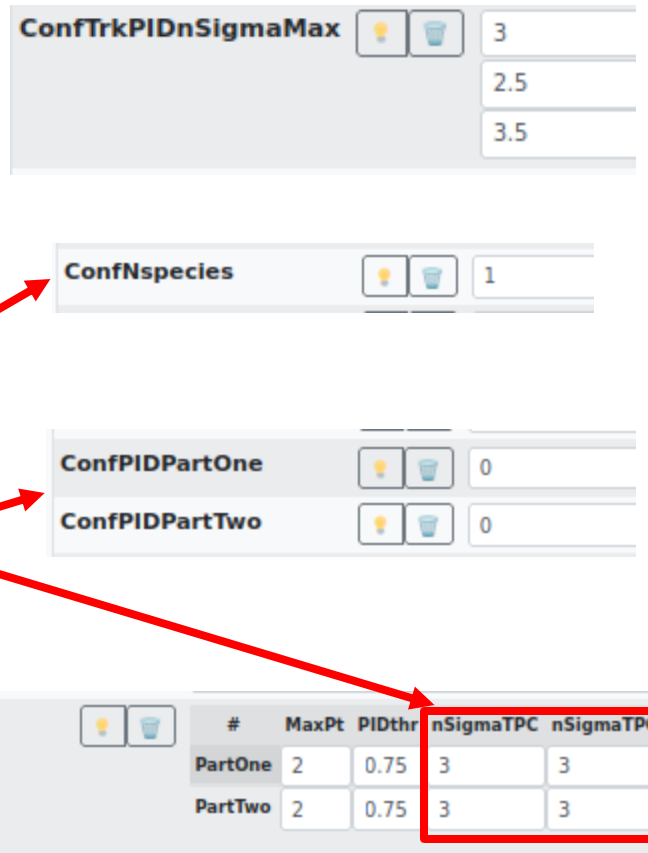
Bitmask for PID cuts

dpl-config.json
(Producer)

```
"ConfTrkPIDnSigmaMax": {
    "values": [
        "3",
        "2.5",
        "3.5"
    ]
},
```

```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

Configuration of
pair task



Copy
ConfTrkPIDnSigmaMax
array

Specify number of particle species with PID information, here only 1

Specify the index to select the particle species, here 4 (=Proton) is at index 0

Specify the nsigma of the PID selection for TPC and TPCTOF

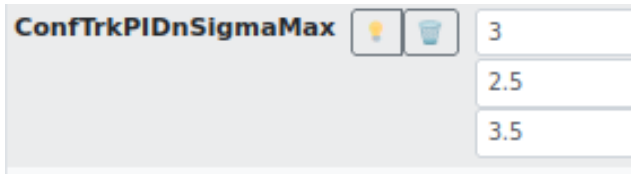
Bitmask for PID cuts

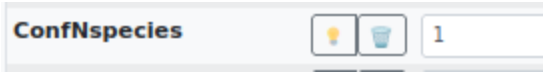
dpl-config.json
(Producer)

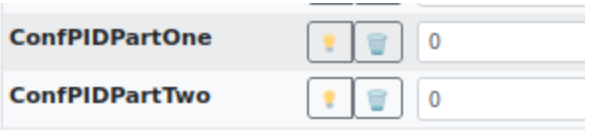
```
"ConfTrkPIDnSigmaMax": {
    "values": [
        "3",
        "2.5",
        "3.5"
    ]
},
```

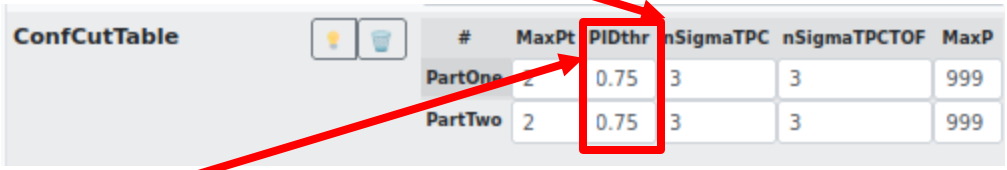
```
"ConfTrkPIDspecies": {
    "values": [
        "4"
    ]
},
```

Configuration of
pair task









Copy
ConfTrkPIDnSigmaMax
array

Specify number of particle species with PID information, here only 1

Specify the index to select the particle species, here 4 (=Proton) is at index 0

Specify the nsigma of the PID selection for TPC and TPCTOF

Momentum at which PID selections switches from TPC to TPCTOF

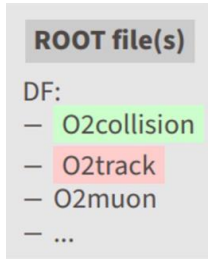
Bitmask for PID cuts

- PID selections will be **simplified** in the future
  - probably add functionality to the cutculator to also produce a single bitmask for one PID selections to be used as input to the pair task
- Internals of FemtoDream still very much under active development
  - Performance optimazations
  - Support for cascades/resonances/…
  - More modular design of the producer task
  - …

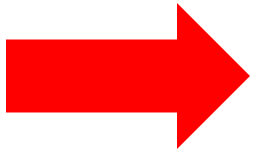
How do I know that my bitmasks are correct?

- Full chain of femto analysis

AO2D.root



Producer task



Store	Binding	Description
☐	FDExtMCParticles	FDEXTMCPARTICLE
☑	FDExtParticles	FDEXTPARTICLE
☐	FDMCLabels	FDMCLabel
☐	FDMCParticles	FDMCPARTICLE
☑	FDCollisions	FDCOLLISION
☑	FDParticles	FDPARTICLE

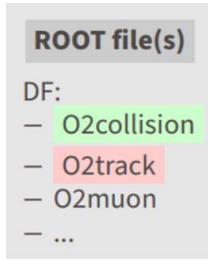
```
o2-analysis-cf-femtodream-producer
```

- Fill femto tables for analysis
- Only store events and tracks/V0/… fulfilling loosest selections
- Compute bitmask for track and PID selections
- **Generate extended and/or MC tables for QA and more**

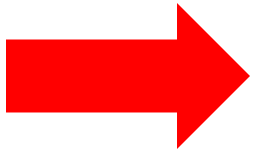
How do I know that my bitmasks are correct?

- Full chain of femto analysis

AO2D.root

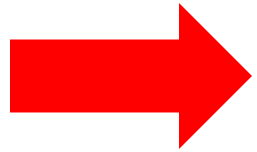


Producer task

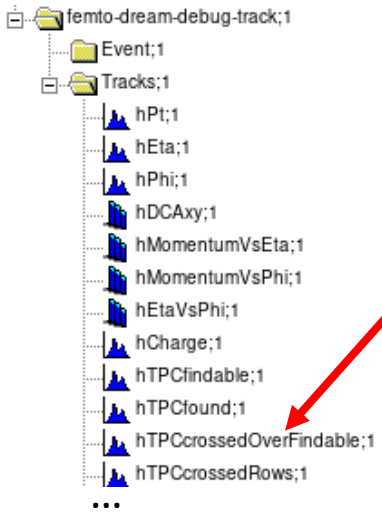


Store	Binding	Description
☐	FDExtMCParticles	FDEXTMCPARTICLE
☑	FDExtParticles	FDEXTPARTICLE
☐	FDMCLabels	FDMCLabel
☐	FDMCParticles	FDMCPARTICLE
☑	FDCollisions	FDCOLLISION
☑	FDParticles	FDPARTICLE

Debug task



AnalysisResults.root



Distributions with track properties and PID

`o2-analysis-cf-femtodream-producer`

- Fill femto tables for analysis
- Only store events and tracks/V0/… fulfilling loosest selections
- Compute bitmask for track and PID selections
- **Generate extended and/or MC tables for QA and more**

`o2-analysis-cf-femtodream-debug-track`

- **Select particles according to the bitmask**
- Fill distributions of all available track properties and PID for all supported particle species
- **Check distributions to see if bitmask is applied correctly**

HANDS-ON START

Exercises for the femto tutorial can be found here:

```
[anton@silver] ~/alice/O2Physics
> ls Tutorials/PWGCF/FemtoFramework/src/*
Tutorials/PWGCF/FemtoFramework/src/CFTutorialTask1.cxx
Tutorials/PWGCF/FemtoFramework/src/CFTutorialTask2.cxx
Tutorials/PWGCF/FemtoFramework/src/CFTutorialTask3.cxx
Tutorials/PWGCF/FemtoFramework/src/CFTutorialTask4.cxx
Tutorials/PWGCF/FemtoFramework/src/CFTutorialTask5.cxx
Tutorials/PWGCF/FemtoFramework/src/README.md
Tutorials/PWGCF/FemtoFramework/src/run.sh
```

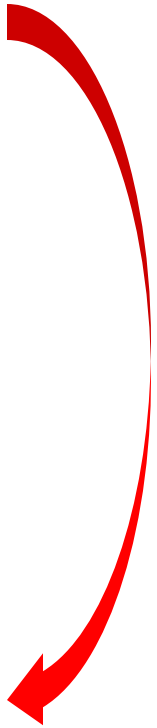
The source files contain comments on what needs to be implemented

HANDS-ON START

GOAL: Implement an analysis task in O2Physics for pairing tracks to compute same and mixed event distributions using derived data as input (similar to the pair-track-track task that is already available in femtodream)

There are 5 exercise Tasks:

- **Task 1:**
  - Implement filters for tracks and events
- **Task 2:**
  - Implement track selections using bitmasks (-> Slide 17-23)
- **Task 3:**
  - Implement PID selection using bitmasks (-> Slide 24-33)
- **Task 4:**
  - Implement particle pairing in same events to compute same event distribution
- **Task 5:**
  - Implement event mixing and particle pairing across multiple events to compute the mixed event distribution



Tasks build on top of each other, meaning the solution of Task 1 is the starting point of Task 2 and so on