Early Measurements- Beauty Hadron Cross-sections

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Introduction

Broad aim: We want to measure beauty production cross-sections with hadronic final states, e.g.:

$$\sigma(pp \to B^{\pm} X) = \frac{N^{\pm}}{\mathcal{L} \times \mathcal{B}(B^{\pm} \to D^0 \pi^{\pm}) \times \mathcal{B}(D^0 \to K^{\pm} \pi^{\mp}) \times \epsilon_{tot}}$$

- $N^{\pm}$ **is the total number of signal events**
- $\mathcal{L}$ is the integrated luminosity
- $\mathcal{B}(B^{\pm} \to D^0 \pi^{\pm})$ and $\mathcal{B}(D^0 \to K^{\pm} \pi^{\mp})$ are branching ratios
- ϵ_{tot} **is the total efficiency**

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Efficiencies

The total efficiency has a number of inputs:

$$\epsilon_{tot} = \epsilon_{acc} \times R_{PID} \times R_{track+reco} \times \epsilon_{HLT1} \times \epsilon_{HLT2} \times \epsilon_{sel} \times \epsilon_{GEC}$$

- ϵ_{acc} is the fraction of signal with all final-state particles within the fiducial region of the detector acceptance
- R_{PID} is ratio of PID efficiencies of data compared to MC
- $R_{track+reco}$ is the ratio of tracking efficiencies of data compared to MC
- ϵ_{HLT1} is the efficiency of HLT1
- ϵ_{HLT2} is the efficiency of HLT2
- ϵ_{sel} is the efficiency of the offline selection
- ϵ_{GEC} is the Global Event Cut efficiency

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Calculating Acceptance (Generator) Efficiencies

- Acceptance efficiency is the proportion of events that lie within LHCb's detector acceptance.
- These requirements, known as *Daughters in LHCb* or (*DecProdCut*) are:
  - Daughter particles in range 0.01 (0.05) $< \theta <$ 0.4 for charged (neutral) particles
  - All daughters moving in the same direction (product of PZ of pairs of daughters is positive)
- To do this, we want to simulate a load of particle events (not applying this cut) and then count how many obey the requirements
- LHCb simulation software is known as *Gauss*
- Example options found here

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Removing DecProdCut

- Tutorials on general use of Gauss can be found here
- Go to Gen/DecFile/dkfiles and copy appropriate .dec file

```
# EventType: 11264011
#
# Descriptor: {[[B0]nos -> (D- => K+ pi- pi-) K+]cc, [[B0]os -> (D+ => K- pi+ pi+) K-]cc}
#
# NickName: Bd_D-K+
#
# Cuts: None
#
# Documentation: Includes resonances in D- decay
# EndDocumentation
#
# PhysicsWG: B2OC
# Tested: Yes
# Responsible: Nicola Serra
# Email: Nicola.Serra@cern.ch
# Date: 20100507
```

Decfiles package explained further here

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Removing DecProdCut

- Go to Gen/DecFile/options and copy {PARTICLE ID}.py

```
# Event Type: 11264011
#
# ASCII decay Descriptor: {[[B0]nos -> (D- => K+ pi- pi-) K+]cc, [[B0]os -> (D+ => K- pi+ pi+) K-]cc}
#
from Configurables import Generation
Generation().EventType = 11264011
Generation().SampleGenerationTool = "SignalRepeatedHadronization"
from Configurables import SignalRepeatedHadronization
Generation().addTool( SignalRepeatedHadronization )
Generation().SignalRepeatedHadronization.ProductionTool = "Pythia8Production"
from Configurables import ToolSvc
from Configurables import EvtGenDecay
ToolSvc().addTool( EvtGenDecay )
#ToolSvc().EvtGenDecay.UserDecayFile = "$DECFILESROOT/dkfiles/Bd_D-K+=DecProdCut.dec"
ToolSvc().EvtGenDecay.UserDecayFile = "$DECFILESROOT/dkfiles/Bd_D-K+.dec"
#Generation().SignalRepeatedHadronization.CutTool = "DaughtersInLHCb"
Generation().SignalRepeatedHadronization.SignalPIDList = [ 511,-511 ]
```

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Inputs: Acceptance (Generator) Efficiency

- Run with options file like this:

```
from Gauss.Configuration import *

#importOptions('$APPCONFIGOPTS/Gauss/Beam6500GeV-md100-nu1.6.py')
#importOptions('$APPCONFIGOPTS/Gauss/Beam7000GeV-md100-nu7.6-HorExtAngle.py')
#importOptions('$GAUSSOPTS/GenStandAlone.py')
#importOptions('$DECFILESROOT/options/11264001.py')
#importOptions('$LBPYTHIA8ROOT/options/Pythia8.py')

importOptions('$APPCONFIGOPTS/Gauss/Beam7000GeV-md100-nu7.6-HorExtAngle.py')
importOptions('$GAUSSOPTS/GenStandAlone.py')
#importOptions('$APPCONFIGOPTS/Gauss/EnableSpillover-25ns.py')
importOptions('$DECFILESROOT/options/11264011_noDecProdCut.py')
importOptions('$LBPYTHIA8ROOT/options/Pythia8.py')
importOptions('$APPCONFIGOPTS/Gauss/Gauss-Upgrade-Baseline-20150522.py')
#importOptions('$APPCONFIGOPTS/Gauss/G4PL_FTFP_BERT_EmNoCuts.py')


GaussGen = GenInit("GaussGen")
GaussGen.FirstEventNumber = 1
GaussGen.RunNumber = 231

Generation().SignalPlain.CutTool = ""

from Configurables import LHCbApp
#LHCbApp().DDDBtag = 'dddb-20170721-3'
#LHCbApp().CondDBtag = 'sim-20170721-2-vc-md100'
LHCbApp().DDDBtag = 'dddb-20201211'
LHCbApp().CondDBtag = 'sim-20201218-vc-md100'
LHCbApp().EvtMax = 100
```

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Calculating Generator Efficiencies

- Run Gauss with the previous options
- Convert output xgen to ntuple (using options file such as this)
- Apply DecProdCut selections in analysis script

```
import ROOT
f= ROOT.TFile.Open({ROOT_FILE}, "read")
t = f.Get("{}/MCDecayTree".format({TUPLE_NAME}))

num = t.GetEntries('Kplus_THETA > 0.01 && Kplus_THETA < 0.4 && '/
'piminus_THETA > 0.01 && piminus_THETA < 0.4 && piminus0_THETA > 0.01 '/
'&& piminus0_THETA < 0.4 && Kplus0_THETA > 0.01 && Kplus0_THETA < 0.4 '/
'&& Kplus_PZ * piminus_PZ > 0  && Kplus_PZ * piminus0_PZ > 0 && '/
'Kplus_PZ * Kplus0_PZ > 0')

denom = t.GetEntries('')
```

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Calculating HLT Efficiencies

Our procedure:

- MC simulation of our signal modes have been made and can be found on the bookkeeping at '/MC/Upgrade/Beam7000GeV-Upgrade-MagDown-Nu7.6-25ns-Pythia8/Sim10-Up08/11264001,11264011,12163001,13264021,15364010/XDIGI'
- Obtain "raw" sample by ntupling straight from xdigi. Example DaVinci options here
- Run HLT1 in *passthrough* followed by HLT2 (both in Moore) and make ntuple DaVinci
- Can apply HLT1 decsisions in analysis script after ntupling
- We find HLT1 efficiency *relative to HLT2*- TOS efficiencies for HLT1 and HLT2 now possible with HltEfficiencyChecker link

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HLT1 in Passthrough

HLT1 Passthrough line exists in default Allen configuration and HLT1 will run in passthrough by default.

Moore tutorial found here
Example options files and instructions on how to run can be found here

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Persisting Trigger Decisions

Moore/Hlt/Hlt2Conf/options/hlt2_integration_test.py:

```
with reconstruction.bind(from_file=False):
        config = run_moore(options, make_lines, public_tools, allen_hlt1=True)
        dump_hlt2_configuration(config, "hlt2_integration.tck.json")
```

ntuple_options_<mode>_HLT1_passthrough.py:

```
def get_hlt2_unpackers(is_simulation):
    """Configures algorithms for reading HLT2 output.

    This is a temporary measure until support for Run 3 HLT2 output is added to
    an LHCb application.
    """
    unpacker = LHCb__UnpackRawEvent(
        'UnpackRawEvent',
        BankTypes=['ODIN'],
        RawBankLocations=['/Event/DAQ/RawBanks/ODIN'])

    dec_reports_hlt1 = HltDecReportsDecoder("Hlt1",SourceID="Hlt1",OutputHltDecReportsLocation="/Event/Hlt1/DecReports",OutputLevel=1)
    dec_reports = HltDecReportsDecoder(
        SourceID="Hlt2", OutputHltDecReportsLocation="/Event/Hlt2/DecReports")
    reading_algs = ([reading.decoder()] + reading.unpackers() + [dec_reports_hlt1] +[dec_reports] +[unpacker,createODIN()])
    if is_simulation:
        reading_algs = reading.mc_unpackers() + reading_algs
    return reading_algs
```

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Persisting Trigger Decisions

`ntuple_options_<mode>_HLT1_passthrough.py`::

```python
def configure_packed_locations(tck_location):
    """Configures HltANNSvc to know about packed locations and hlt2 decision names used in Moore.

    tck_location (string): Location of json file containing trigger configuration.

    """

    with open(tck_location) as f:
        tck = json.load(f)
    ann_config = tck["HltANNSvc/HltANNSvc"]
    HltANNSvc(PackedObjectLocations={
        str(k): v
        for k, v in ann_config["PackedObjectLocations"].items()
    })
    HltANNSvc(Hlt1SelectionID={
        str(k): v
        for k, v in ann_config["Hlt1SelectionID"].items()
    })
    HltANNSvc(Hlt2SelectionID={
        str(k): v
        for k, v in ann_config["Hlt2SelectionID"].items()
    })
```

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Persisting Trigger Decisions

`ntuple_options_<mode>_HLT1_passthrough.py::`

```
TriggerTool = dtt.addTupleTool("TupleToolTrigger/TriggerTool")
TriggerTool.VerboseHlt1 = True
TriggerTool.VerboseHlt2 = True
TriggerTool.FillHlt1=True
TriggerTool.FillHlt2=True
TriggerTool.Verbose=True
TriggerTool.Hlt1DecReports = "/Event/Hlt1/DecReports"
TriggerTool.Hlt2DecReports = "/Event/Hlt2/DecReports"
TriggerTool.TriggerList = [{list_of_trigger_lines_to_be_persisted}]
```

```
# Load the 'TCK's dumped from the HLT2 Moore job
configure_packed_locations("hlt2_integration_minbias.tck.json")

# Configure the unpacking of data (we assume we want MC information)
# and the running of the user algorithms. The order is important.
ApplicationMgr().TopAlg = get_hlt2_unpackers(is_simulation=True) + user_algs
```

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HLT Efficiencies Status

- Recently held up by a segmentation violation in Allen (see here)
- This was eventually fixed by Allen!775
- Inclusion of RetinaClusters will becoming new default for xdigi files in order to run successfully with Moore.
  - RetinaClusters can be added to xdigi files following instructions here.
  - Explanation of how to run without adding RetinaClusters to be added to Allen documentation.

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Estimating Signal Yields Example

- Binned differential cross-sections for $pp \to B^+ X$ taken from LHCb-ANA-2016-005
- Assume $\mathcal{L} = 100 pb^{-1}$ and multiply by this
- Multiply by $\mathcal{B}(B^\pm \to D^0 \pi^\pm) = (4.68 \pm 0.13) \times 10^{-3}$ and $\mathcal{B}(D^0 \to K^\pm \pi^\mp) = (3.95 \pm 0.031) \times 10^{-2}$
- Multiply by binned acceptance and HLT efficiencies

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Estimated $B^+ \to (D^0 \to K^+\pi^-)\pi^+$ Signal Yields

p_T (GeV/c)	$2.0 < y < 2.5$	$2.5 < y < 3.0$	$3.0 < y < 3.5$	$3.5 < y < 4.0$	$4.0 < y < 4.5$
0.0 - 0.5	nan ± nan	nan ± nan	nan ± nan	nan ± nan	nan ± nan
0.5 - 1.0	nan ± nan	nan ± nan	nan ± nan	nan ± nan	nan ± nan
1.0 - 1.5	nan ± nan	nan ± nan	nan ± nan	nan ± nan	nan ± nan
1.5 - 2.0	nan ± nan	nan ± nan	0.0 ± 0.0	164.0 ± 83.0	66.0 ± 47.0
2.0 - 2.5	nan ± nan	169.0 ± 99.0	640.0 ± 173.0	833.0 ± 186.0	818.0 ± 179.0
2.5 - 3.0	nan ± nan	152.0 ± 88.0	1386.0 ± 261.0	2351.0 ± 354.0	1312.0 ± 235.0
3.0 - 3.5	nan ± nan	450.0 ± 151.0	2307.0 ± 355.0	3616.0 ± 453.0	1907.0 ± 303.0
3.5 - 4.0	nan ± nan	980.0 ± 235.0	3196.0 ± 426.0	3066.0 ± 400.0	1817.0 ± 295.0
4.0 - 4.5	nan ± nan	1430.0 ± 266.0	3088.0 ± 408.0	3767.0 ± 463.0	2132.0 ± 324.0
4.5 - 5.0	0.0 ± 0.0	2362.0 ± 346.0	3444.0 ± 429.0	2818.0 ± 380.0	1909.0 ± 306.0
5.0 - 5.5	51.0 ± 51.0	2132.0 ± 327.0	4486.0 ± 483.0	3518.0 ± 423.0	1855.0 ± 291.0
5.5 - 6.0	341.0 ± 123.0	2144.0 ± 326.0	5097.0 ± 521.0	2940.0 ± 389.0	1883.0 ± 299.0
6.0 - 6.5	124.0 ± 72.0	2805.0 ± 371.0	3807.0 ± 430.0	2283.0 ± 317.0	1246.0 ± 233.0
6.5 - 7.0	512.0 ± 142.0	2563.0 ± 346.0	3444.0 ± 402.0	1568.0 ± 250.0	1165.0 ± 234.0
7.0 - 7.5	368.0 ± 125.0	2632.0 ± 343.0	2720.0 ± 334.0	2832.0 ± 349.0	947.0 ± 192.0
7.5 - 8.0	386.0 ± 120.0	2095.0 ± 312.0	1770.0 ± 263.0	1557.0 ± 238.0	785.0 ± 160.0
8.0 - 8.5	605.0 ± 172.0	2258.0 ± 310.0	2412.0 ± 322.0	1516.0 ± 244.0	852.0 ± 186.0
8.5 - 9.0	488.0 ± 150.0	1781.0 ± 264.0	1967.0 ± 274.0	1315.0 ± 225.0	553.0 ± 141.0
9.0 - 9.5	281.0 ± 101.0	1499.0 ± 236.0	1477.0 ± 254.0	1839.0 ± 270.0	811.0 ± 178.0
9.5 - 10.0	401.0 ± 123.0	1092.0 ± 203.0	1211.0 ± 218.0	1072.0 ± 200.0	558.0 ± 148.0
10.0 - 10.5	659.0 ± 169.0	1678.0 ± 265.0	874.0 ± 187.0	1213.0 ± 212.0	366.0 ± 113.0
10.5 - 11.5	383.0 ± 81.0	1288.0 ± 165.0	920.0 ± 130.0	556.0 ± 100.0	504.0 ± 97.0
11.5 - 12.5	388.0 ± 88.0	686.0 ± 119.0	856.0 ± 128.0	459.0 ± 86.0	246.0 ± 72.0
12.5 - 14.0	287.0 ± 60.0	637.0 ± 89.0	476.0 ± 79.0	407.0 ± 69.0	185.0 ± 46.0
14.0 - 16.5	226.0 ± 43.0	403.0 ± 54.0	416.0 ± 58.0	295.0 ± 45.0	133.0 ± 29.0
16.5 - 23.5	129.0 ± 20.0	165.0 ± 21.0	127.0 ± 18.0	85.0 ± 15.0	40.0 ± 11.0
23.5 - 40.0	22.0 ± 5.0	25.0 ± 5.0	15.0 ± 4.0	13.0 ± 4.0	3.0 ± 2.0

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PID Efficiencies

Will have multiple PID (DLL) cuts on each final state track

- Multiple options explored to determine efficiencies of these cuts
  - PIDGen2/PIDCorr not suitable as control of systematics associated with kernel width/templating less reliable
  - Cross-sections will be systematically limited
- Move forward with PIDCalib2

Investigated several options within PIDCalib2

- Would rather not have to re-create HLT2 lines and selections with PID cuts removed
  - Correction histograms that give the ratio between data and MC PID response to correct MC after PID cuts have been made
- Cross-section measurements are performed in bins of p_T and η
  - Instead of using sWeighted calibration data (nominal PIDCalib2 method) do separate fits in bins of p_T and η - simple cut and count method
  - Removes problem that signal and background shapes in the calibration samples are correlated with kinematics of the track = no systematic for sWeighting

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HLT2 Line Update

- Bs2DsPi
  - LAZY_AND: Hlt2B2OC_BdToDsmPi_DsmToKpKmPim_Line #=150000 Sum=8
  - 1e+6 * 8./150000. = 53.33 Hz
- Bd2DPi
  - LAZY_AND: Hlt2B2OC_BdToDmPi_DmToPimPimKp_Line #=150000 Sum=11
  - 1e+6 * 11./150000. = 73.33 Hz
- Bd2DK
  - LAZY_AND: Hlt2B2OC_BdToDmK_DmToPimPimKp_Line #=150000 Sum=10
  - 1e+6 * 10./150000. = 66.66 Hz
- Lb2LcPi
  - LAZY_AND: Hlt2B2OC_LbToLcpPi_LcpToPKPi_Line #=150000 Sum=6
  - 1e+6 * 6./150000. = 40.00 Hz
- Bu2D0Pi
  - LAZY_AND: Hlt2B2OC_BuToD0Pi_D0ToHH_Line #=150000 Sum=11
  - 1e+6 * 11./150000. = 73.33 Hz

Rates calculated using 150,000 input HLT1 filtered minbias events.
All lines well below 100 Hz.

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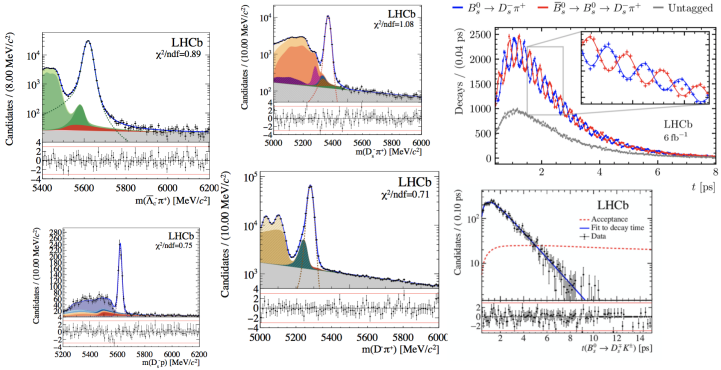
Fitting

- We are using PhysFit/B2DXFitters package (a part of Urania), a common ROOT based tool to study $B \to DX$ transitions.
- Verified during Run1 and Run2 in +10 physics analyses.
- Setup instructions: link, MDFit tutorial: link.



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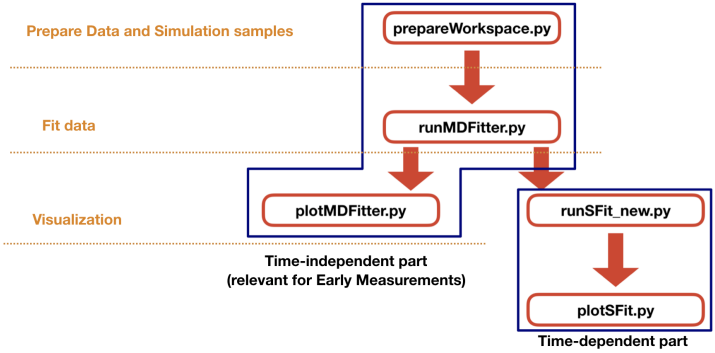
Fitting

- Small extensions needed for effective fitting in η, p_T bins.
- All modes: $B^+ \to D^0\pi$, $B^0 \to D^-\pi^+/K$, $B_s^0 \to D_s^-\pi^+$, $\Lambda_b^0 \to \Lambda_c^+\pi^-$ available within one package sharing most of the code.
- User side: setting up configuration files.
- Basic workflow:



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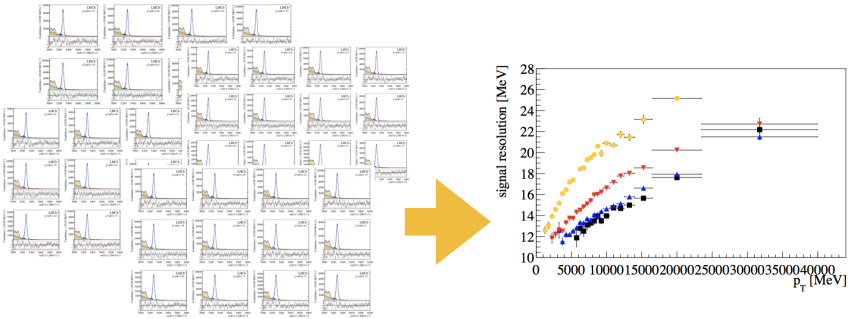
What are we doing now?

Two ways for Run3 data preparation:

- study Run2 data,
- perform large scale toys.

Study Run2 data: signal resolution dependence in η, p_T.



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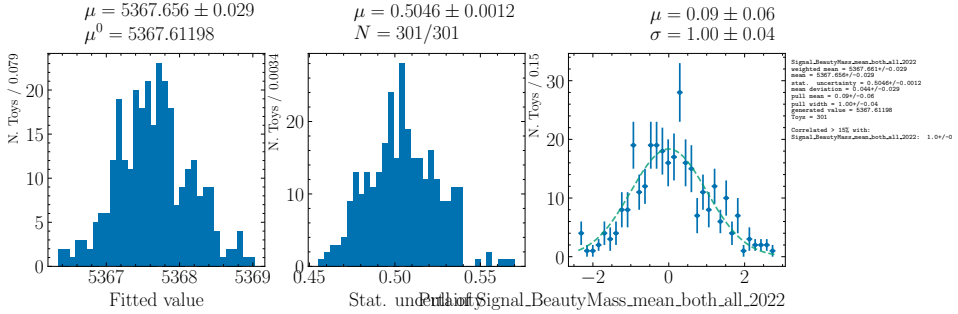
What are we doing now?

Large scale toys studies.

- Generate and fit back a large scale of samples.
- Comment: no code sharing between generation and fitting, which increase robustness of studies.
- Check if model unbiased with limited statistic of 1000 signal candidates.



See here for example snakefile and instructions on pull studies

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Conclusions

Presented the different pieces of software and techniques used so far in our analysis

- Simulation using Gauss with DecProdCut removed
- Trigger selection using Moore, with HLT1 in passthrough and trigger decisions persisted
- Fitting using Urania's PhysFit/B2DXFitter

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