LHCb Generator Tuning

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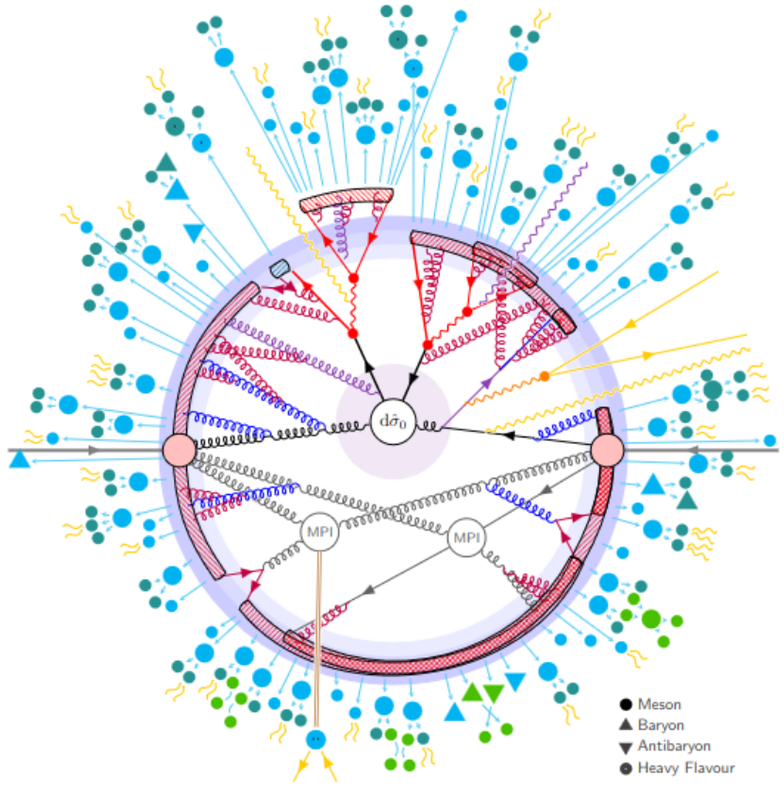
What we tune?

- All event generators are based on phenomenological models, these models have free parameters (highly correlated), which are a priori unknown.

Aim: Focus on **tuning Pythia 8** so our simulations are representative of our data,

- In future we may look to tune EPOS or Pythia + Angantyr. Possibly Herwig tuning as well.

- We tune based on parametrisation of the generator response using “RIVET” and “Professor”



What we tune?

Different sets of parameters control the different aspects of the proton-proton collisions

Descending in energy scale :

1. **The most energetic interaction**:

- Hard interaction,

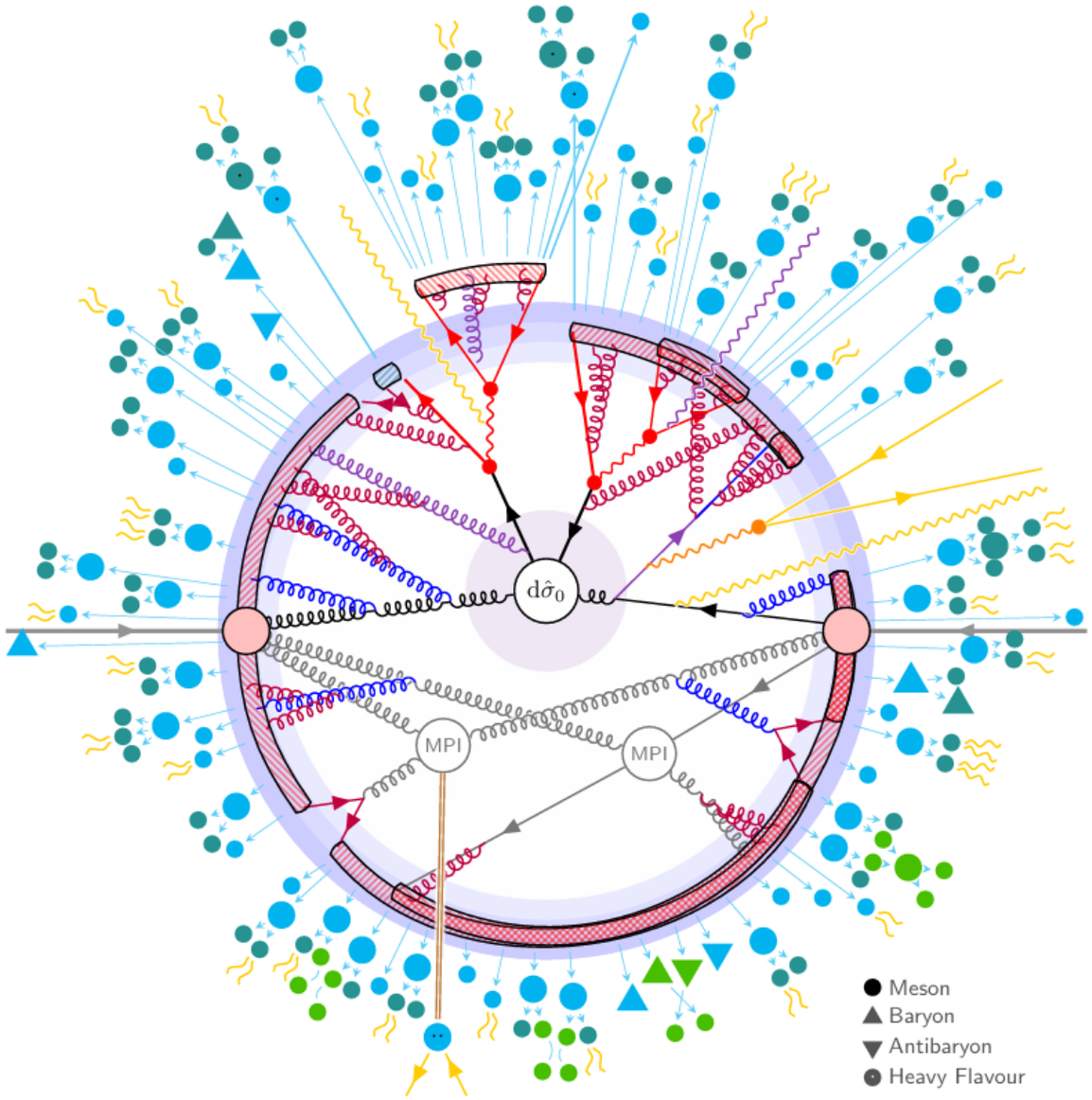
2. **The event evolution**:

- Initial and final state radiation
- Multi-Parton interactions (MPI)
- terminates at the hadronisation scale (PT0Ref, pTmin scale).

3. **The creation of observable states**:

- Colour reconnection
- Hadronisation

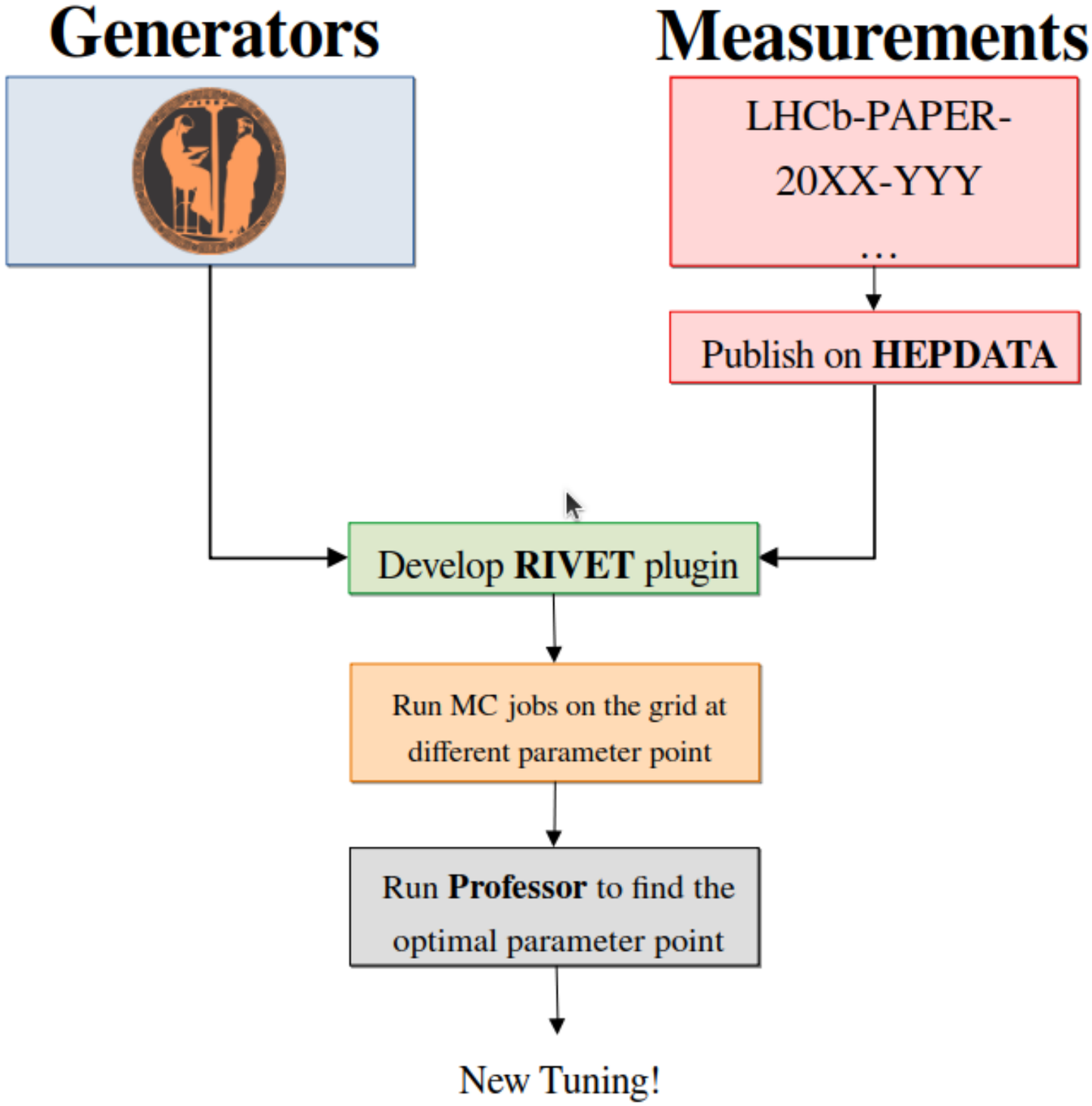
Note: EvtGen (how we decay our particles) is not part of the tune



Overview

- Generator tuning is of key importance to LHCb, with our current default tune taken (essentially) from Run 1 data,

- Current main goal is to have a **new global tune at LHCb**, which will require **smaller dedicated tunes**, and **more people-power**.



What has been done before?

Historic tunes:

- The current tune, performed on Run1 data:

Default tune.

- StringFlav parameters were updated in a tune in 2015 by Marco Adinolfi, Jessica Prisciandaro. See here

More Recent Studies:

- Studies performed by Marco Adinolfi, Mick Mulder

→ 2018 Tuning PYTHIA 8 for Sim 10

→ CR, and String flavour fragmentation

- Studies performed by Saliha Bashir

→ 2024 Recent Progress in Tuning

→ CR, String flavour fragmentation,
MPI parameters

Work to update preexisting tuning efforts performed in these sectors using new RIVET plugins not available at the time

LHCb Strategy for Tuning:

1. **Total Cross Section**:
Total pp interaction cross sections etc.

2. **Light flavour production and CR scheme tuning**:
Ratios of flavours, meson to baryon ratios, quark to diquark ratios.

3. **MPI parameters**:
Number of simultaneous parton-parton interactions

4. **Heavy Flavour parameters**:
Ratios of heavy flavours

5. **Explore other flavour, CR and MPI parameters**:
Specific tune for other sectors can also be performed, for example jets.

Total Cross Section

Marco Adonolfi
Mick Mulder
Saliha Bashir

1. **Total Cross Section**:

Total pp interaction cross sections, single Diffractive and double Diffractive cross section:

Example parameters:

SigmaTotal:sigmaTot

SigmaTotal:sigmaAX, SigmaTotal:sigmaXB

SigmaTotal:sigmaEl

SigmaTotal:sigmaXX

Example inputs:

LHCB_2015_I1333223

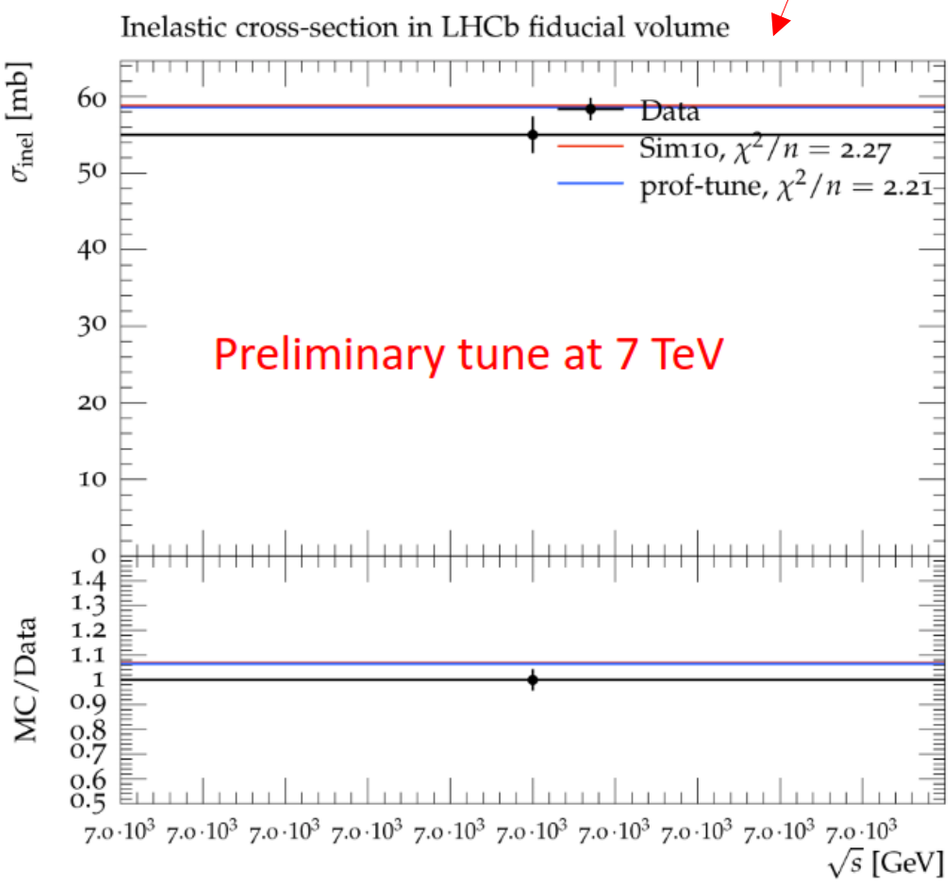
Measurement of inelastic cross section (7 TeV)

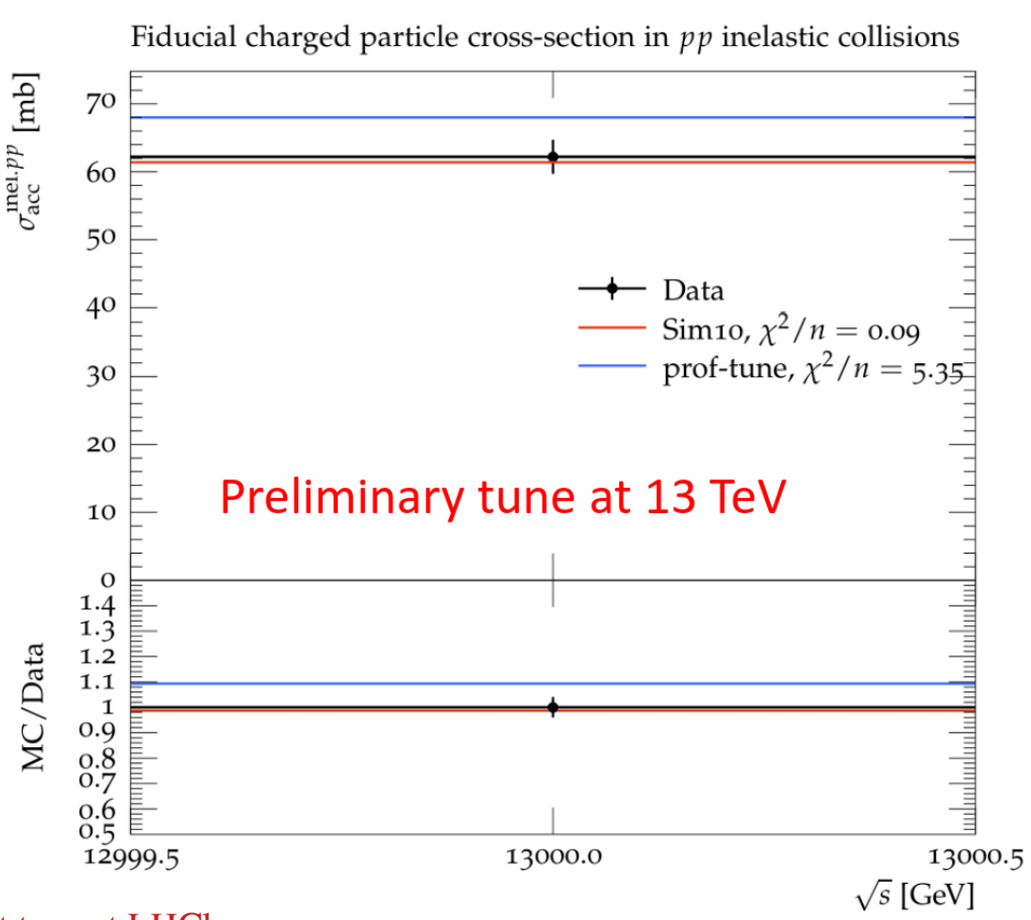
ATLAS_2011_I894867

Measurement of inelastic cross section (7 TeV)

LHCB_2018_I1665223

Measurement of inelastic cross section (13 TeV)





Sim10 refers to the current tune at LHCb

Flavour and CR

Marco Adonolfi
Mick Mulder

2. **CR scheme tuning**:

- How color fields rearrange themselves after the collision,
- Various schemes to implement these arrangements:
  - → MPI based scheme (Mode=0)
  - → QCD inspired scheme (Mode=1)
  - → Gluon move scheme (Mode=2)
- The aim of all these schemes is to minimise the total string length of the partonic configuration before the hadronisation process.

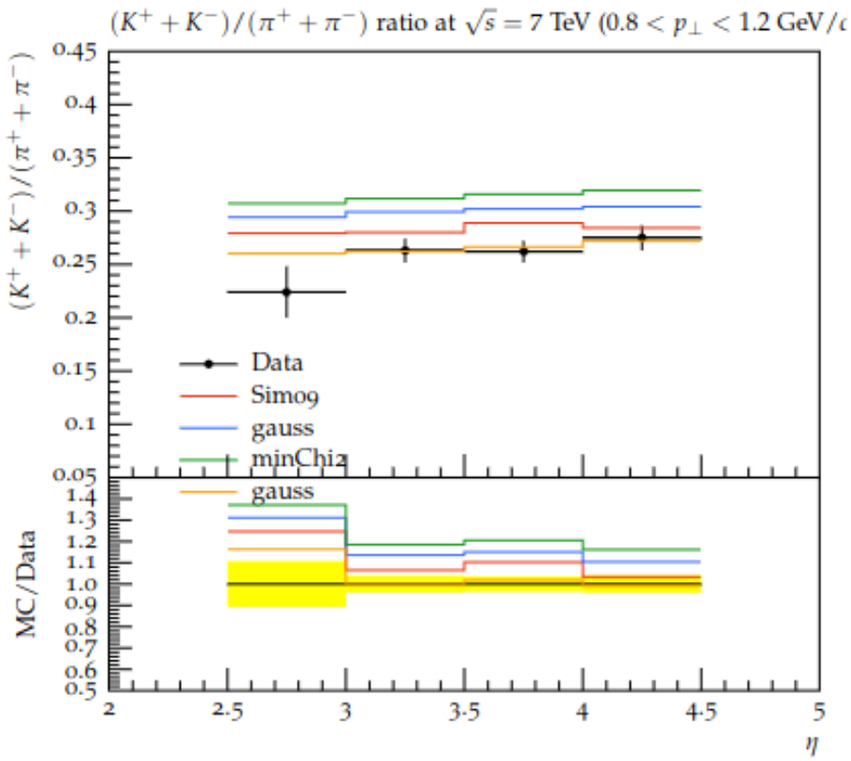
- Parameters are scheme-specific

- For the QCD inspired scheme (Mode =1); This string length itself is described in three different ways, determine by lambdaForm; With the m0 (hadronic mass scale) being the tunable parameters.

Previous work was performed comparing the different lambdaForm functions:

- lambdaForm = 1 was found to perform the best

Particle ratio at 7 TeV:



$\lambda = 0$

$\lambda = 1$

$\lambda = 2$

Example inputs:

→ Several production and ratio measurements at 7 TeV. etc.

LHCB_2012_I1119400
Prompt hadron production ratios in pp collisions

LHCB_2011_I917009
V^0 production ratios in pp collisions

Example parameters:
Mode
JunctionCorrection
m0
timeDilationpar

Flavour and CR

Saliha Bashir

2. **Light flavour production and CR scheme tuning**:

- Inherent correlation between the light flavour string parameters and the CR parameters (e.g. junction structures enhance baryon production)

- Employ a two stage process;

  1.a Freeze a set of StringFlav parameters and use it as input for a tune of the new CR model.

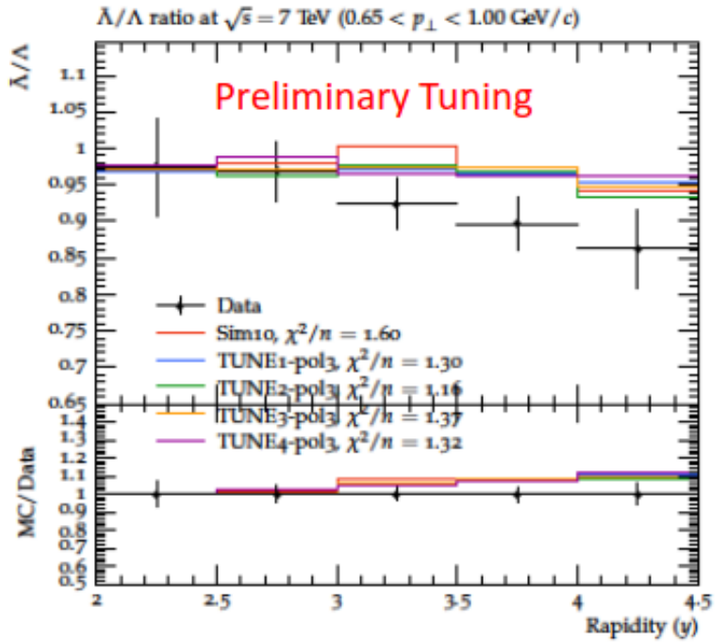
  1.b Freeze a set of CR parameters for each model and use it as input for a tune of the Flavour parameters,

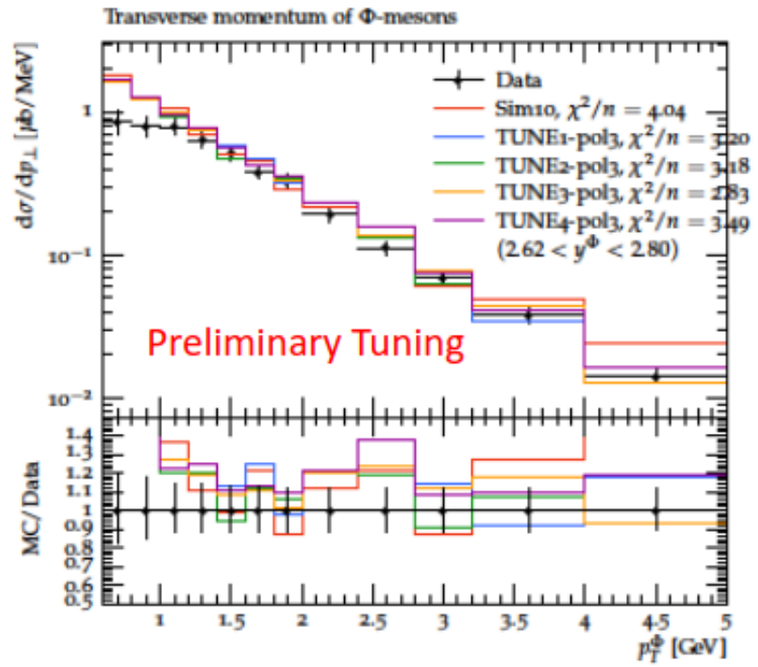
- Choose the best between these.

- Only compare with the QCD inspired scheme for this.

Sim10: Tune used in current production
TUNE1: only flavor parameters tuning
TUNE2: only CR parameters tuning
TUNE3: fix CR and tune flavor
TUNE4: fix flavor and tune CR

Previous work:





Example inputs:

→ Several production and ratio measurements at 7 TeV.

etc.

LHCB_2012_I1119400

Prompt hadron production ratios in pp collisions

LHCB_2011_I917009

V^0 production ratios in pp collisions

Parameters used:

Flavour Parameters:

- mesonSvector,
- probQQtoQ,
- probStoUD,
- probSQtoQQ,

CR Parameters:

- lambdaForm = 2,
- Mode = 1
- JunctionCorrection (how easily junctions form),
- m0 (protection against small mass systems),
- PT0Ref

MPI tuning

Saliha Bashir

4. **MPI parameters**:

Number of simultaneous parton-parton interactions

Example parameters:

alphaSvalue

Ecmpow

pT0Ref

$$p_{T0} = p_{T0}^{\mathrm{Ref}} \left(\frac{\sqrt{s}}{\sqrt{s_0}} \right)^{\epsilon}$$

-The parameter p_{T0} separates the perturbative from the non-perturbative regions and depends on the center-of-mass energy sqrt(s)

This prior study focused also on altering the weights based on what experiment the data came from:

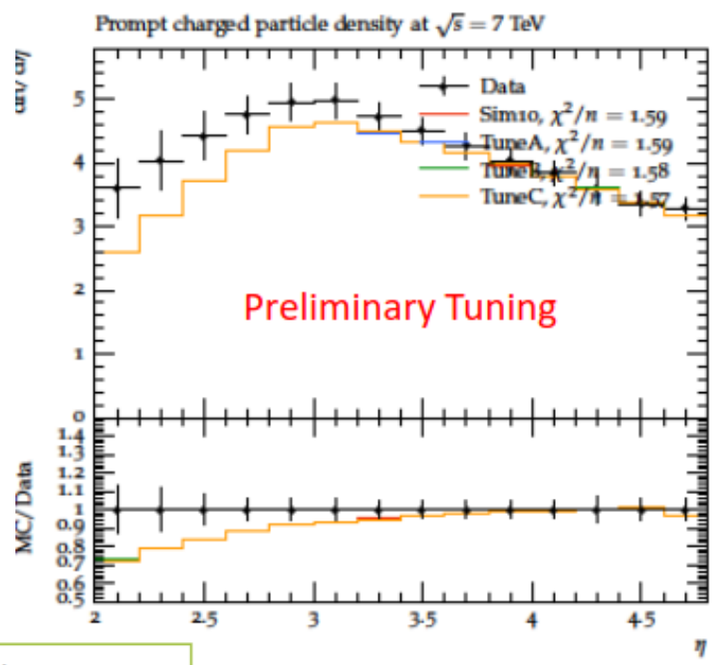
Example inputs:

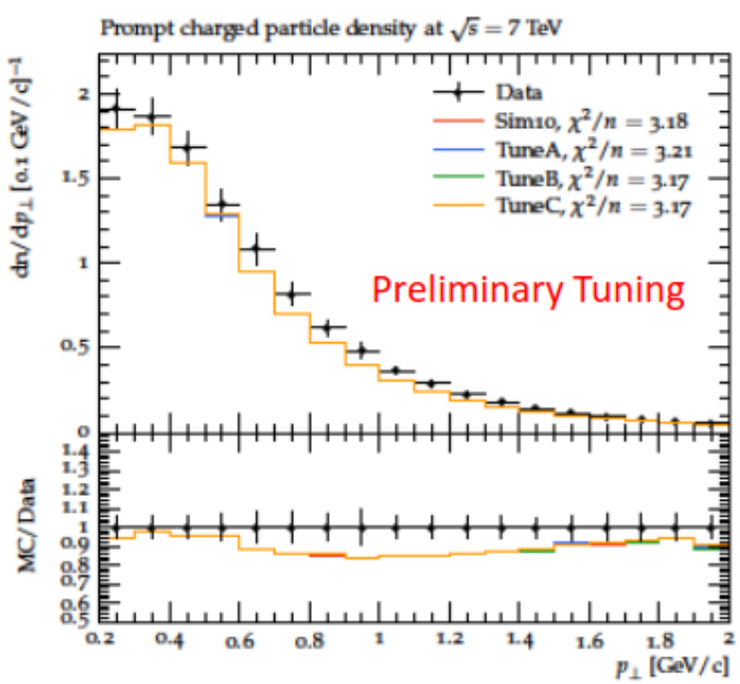
LHCB_2014_I1281685

Charged particle multiplicities and densities in pp collisions

ATLAS_2010_S8918562

Track based minimum bias measurements





Comparison with different jobs (1 million events)

- Sim10: Tune used in current production
- TuneA: Measurements with same weights.
- TuneB: Measurements with different weights (LHCb is favored)
- TuneC: Only LHCb measurements

Tuning campaign plan

5. **Heavy Flavour parameters**:
Ratios of heavy flavours

Example parameters:
D hadron properties
B hadron properties
e.g
StringFlav:mesonCvector
StringFlav:probQQ1toQQ0
Quarkonia properties:
e.g. Charmonium / Bottonium states

Example inputs:
Charm/beauty/quarkonia differential cross sections.
e.g.
LHCB_2016_I1490663
Charm hadron differential cross-sections in p_T and η

Aim: By the end of the year having a 'draft' LHCb tune, having tried all 5 sets of variables.
→ Update preexisting tuning efforts using new RIVET plugins not available at the time,
→ Idea of the sequence is to have a **correct picture of the underlying event** before producing a t**une for the heavy quark** sector.

LHCb Strategy for Tuning:

Marco Adonolfi
Riccardo Bonacci

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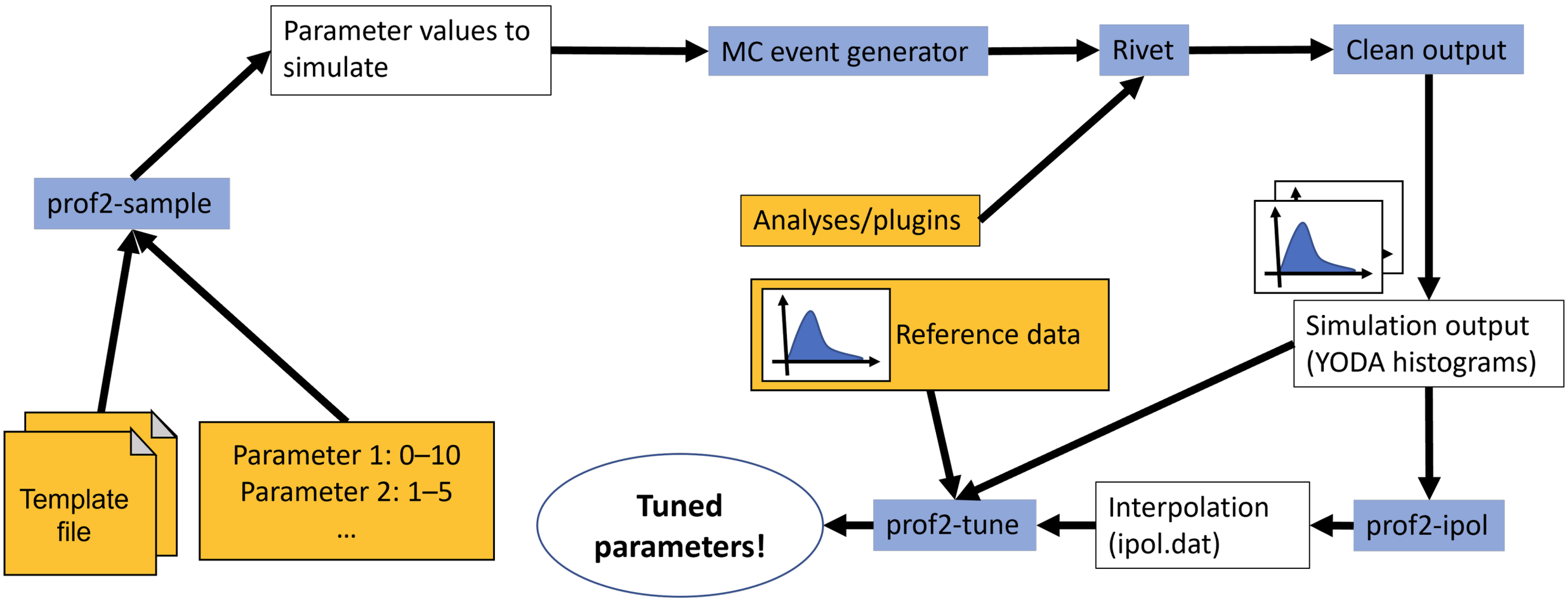
Infrastructure

Professor workflow:

Parameter-tuning GitLab page

Parameter-tuning documentation

Adam Morris



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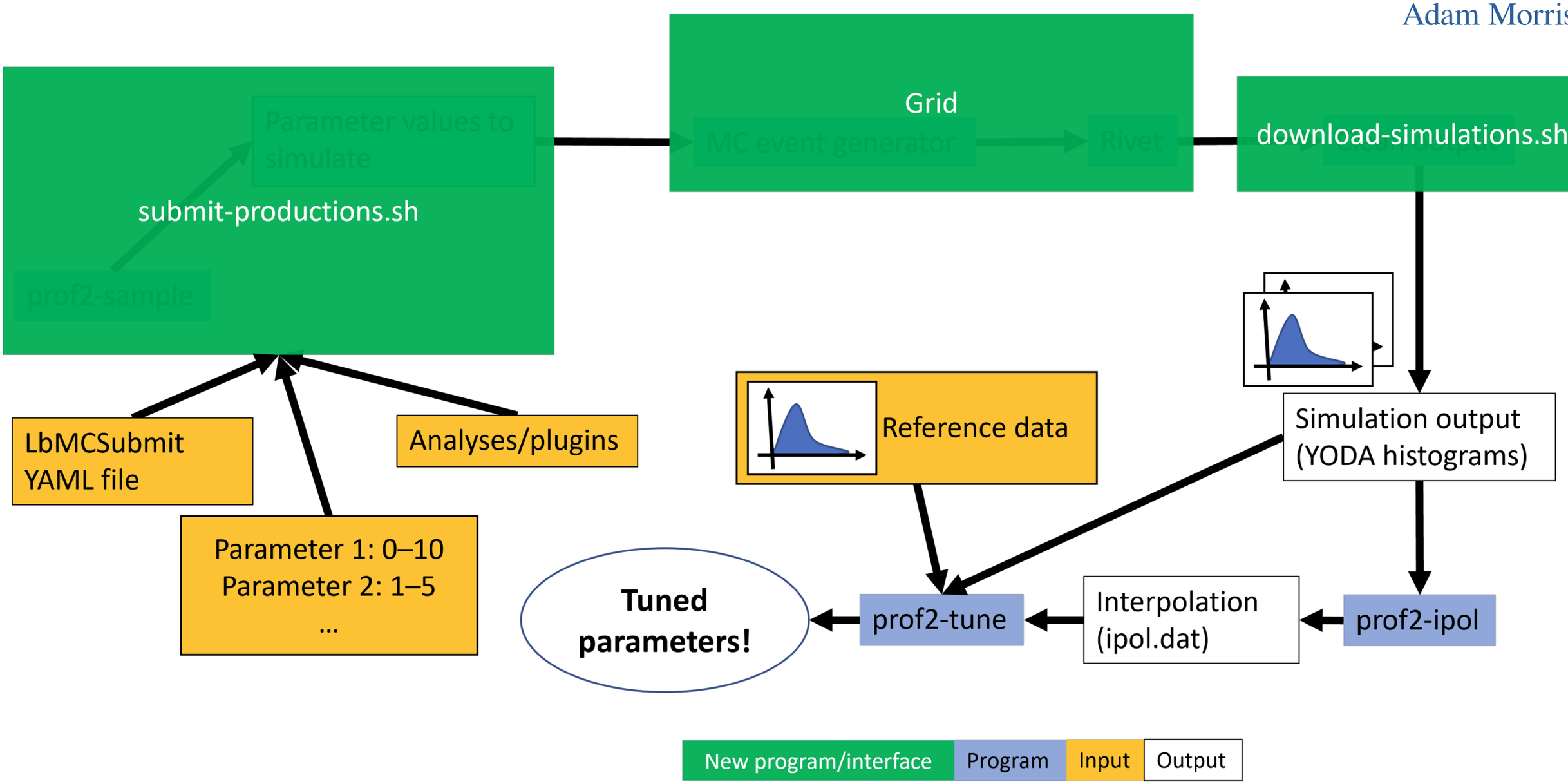

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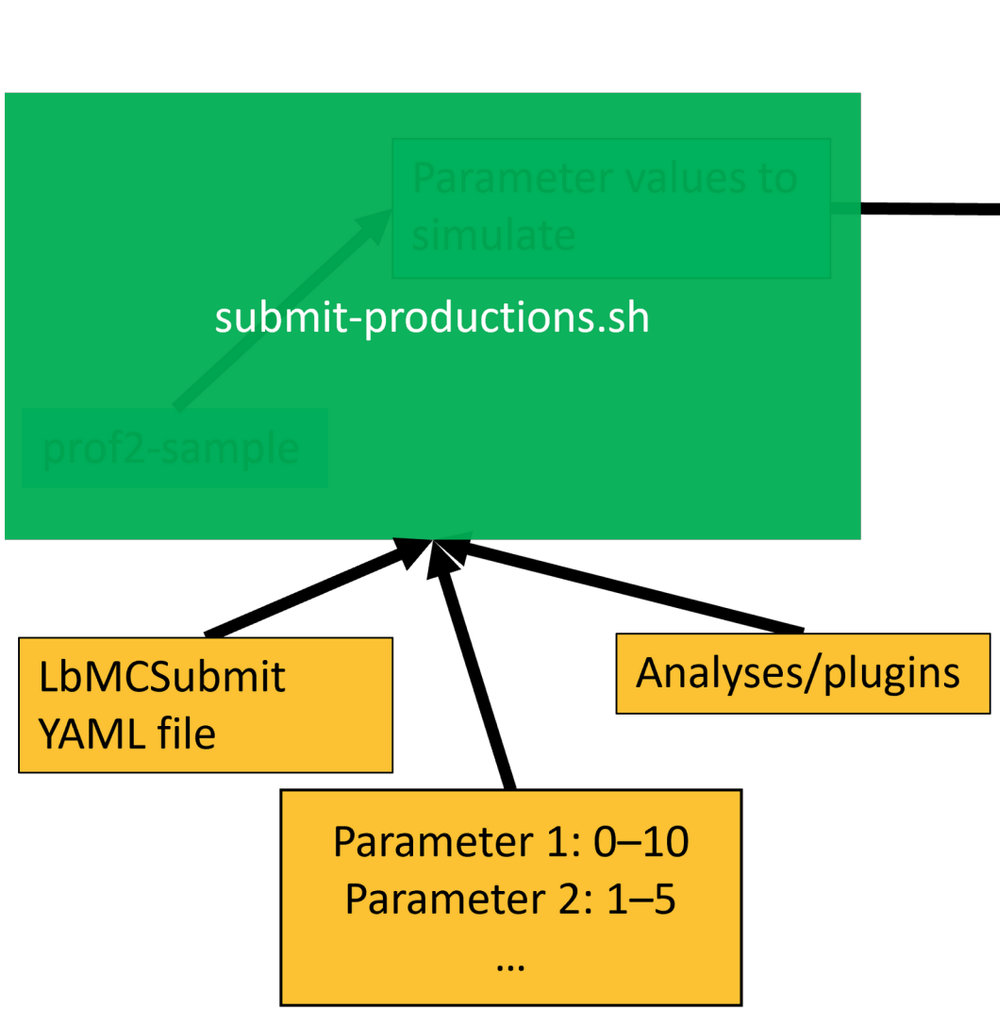


Part 1:

- Define input stage0.yaml, parameters and their ranges,

- Jobs are prepped at a bunch of parameter points (stage6.yaml produced),

- Jobs then run on the grid to generate MC samples at each parameter point

Infrastructure

Professor workflow:

Part 2:

- Download the (YODA) MC histograms,

- And perform an interpolation between parameter points,

- Professor then finds the optimal parameter points through a χ^2 metric.

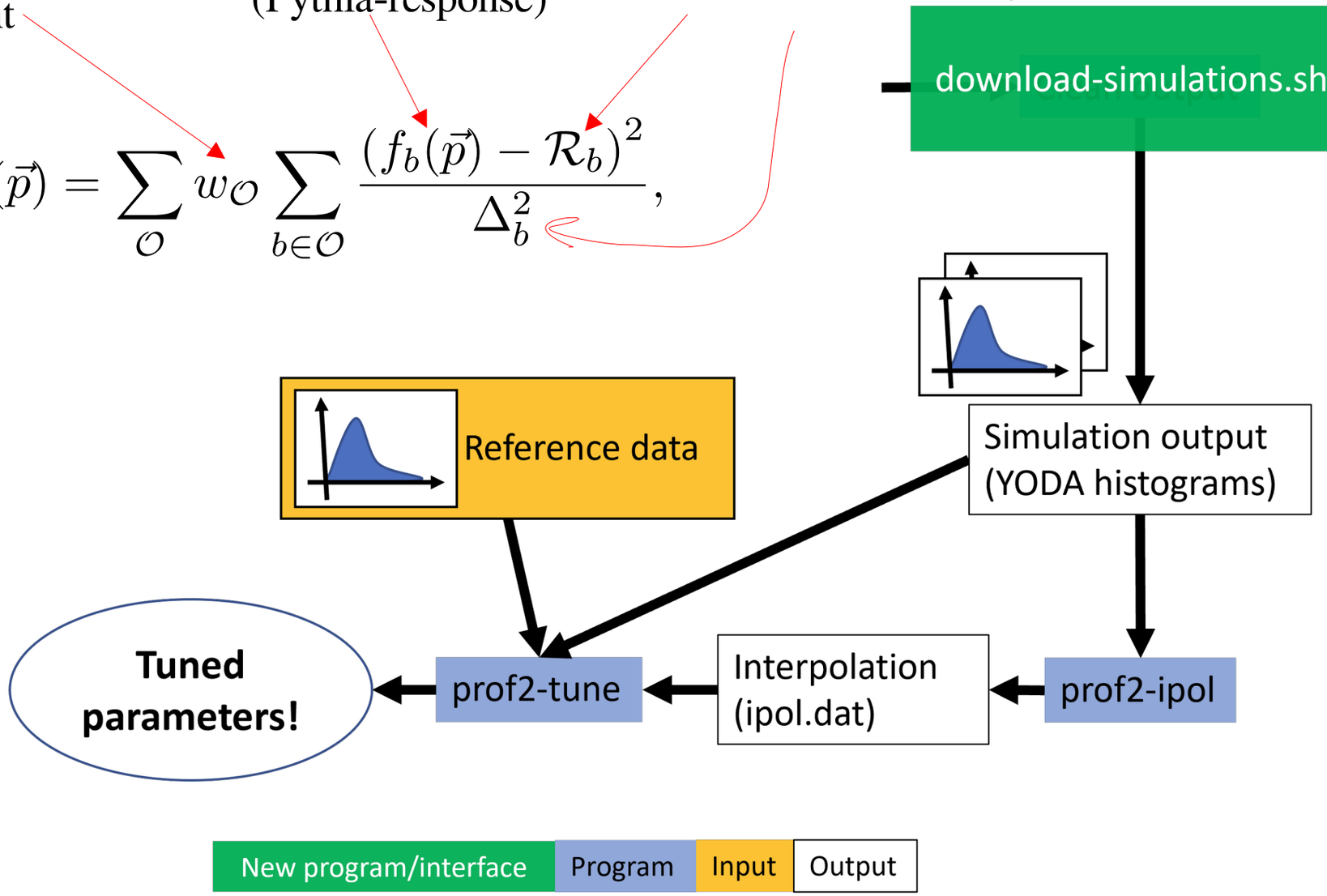
Professor 2

Observable weight

Prediction (Pythia-response)

Nature (and uncertainty)

$$\chi^2(\vec{p}) = \sum_{\mathcal{O}} w_{\mathcal{O}} \sum_{b \in \mathcal{O}} \frac{\left(f_b(\vec{p}) - \mathcal{R}_b\right)^2}{\Delta_b^2},$$



Current work

Jan Peter Wagner
Ryunosuke O'Neil
Adam Morris
Michal Kreps
Chris Burr
Riccardo Bonacci

Infrastructure development:

- Up until now these tuning jobs have been performed independently, and there was a growing need to create a centralised place for LHCb tunes to be stored / distributed,

→ This type of MC jobs require lots of babysitting (lots of parameter points, lot of jobs.

→ Often lost when people move on from tuning.

- Development ongoing to incorporate this into our current software for submitting MC requests.

→ Adding a new “tuning” optional field into our MC submission process

→ Allowing tuning requests to be like “normal” MC requests,

→ Hopefully allows for more people try tunes, and also,

→ For them to be somewhat centralised. How exactly do other detector groups perform and store tunes?

lhcb-simulation/lbmcsubmit!287

lhcb-dpa/analysis-productions/LbAPI!443

Current work

Adam Morris
Riccardo Bonacci

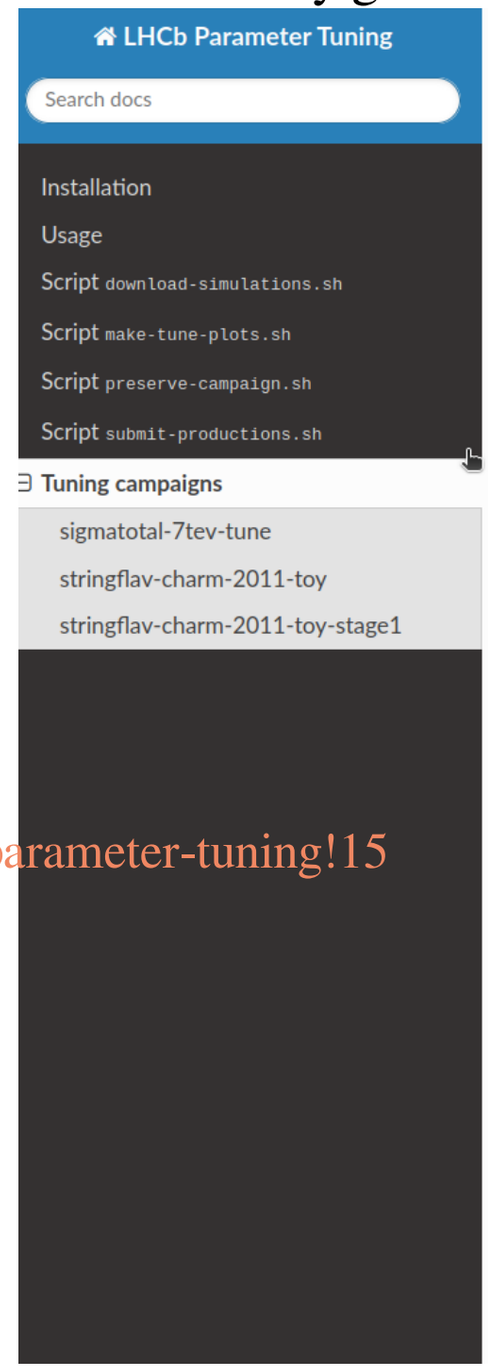
Infrastructure development:

- These outputs histograms can be accessible on BKK (along with the specific parameter point), and downloaded from there to proceed with Professor interpolation and tuning.

- These two stages can be displayed in a tuning campaign webpage such as this for preservation and documentation. lhcb-simulation/parameter-tuning!15

- Possibly once tunes are performed, they can be compared using MCPlots.

e.g. documented tune listing preview, (page is automatically generated from CI script:




```
STAGE0_YAML="campaigns/sigmatotal-7tev-tune/mc-specification.stage0.yaml" \
RIVET_ANALYSES="LHCB_2015_I1333223,ATLAS_2011_I894867,ATLAS_2012_I1084540,ALICE_2012_I1181770,C
RIVET_PLUGIN_DIR="/home/bonacci/Tuning/RIVET/RIVET_3_1_11/rivet/analyses/plugin-sigmatotal-7tev
N_SAMPLES=1000 \
N_SUBJOBS=10 \
./submit-productions.sh -submit
```

Still a draft

stringflav-charm-2011-toy

Tuning of Pythia 8 StringFlav (strangeness / vector-meson / diquark) parameters against LHCb 2011 minimum-bias identified-particle measurements.

- **Folder:** campaigns/stringflav-charm-2011-toy
- **Rivet analyses:** LHCB_2011_I919315, LHCB_2011_I917009, LHCB_2012_I1119400
- **Samples (parameter points):** 85
- **Plots:** Browse data-vs-MC comparison

Parameters tuned

Pythia parameter	Min	Max
StringFlav:mesonSvector	0.0	3.0
StringFlav:probQQtoQ	0.0	1.0
StringFlav:probSQtoQQ	0.0	1.0
StringFlav:probStoUD	0.0	1.0

Submit command

```
PARAM_FILE="campaigns/stringflav-charm-2011-toy/parameter_ranges.txt" \
CMND_FILE="campaigns/stringflav-charm-2011-toy/params_to_tune.cmnd" \
STAGE0_YAML="campaigns/stringflav-charm-2011-toy/mc-specification.stage0.yaml" \
RIVET_ANALYSES="LHCB_2011_I919315,LHCB_2011_I917009,LHCB_2012_I1119400" \
RIVET_PLUGIN_DIR="RIVET_3_1_11/rivet/analyses/pluginLHCb" \
N_SAMPLES=85 \
N_SUBJOBS=15 \
./submit-productions.sh -submit
```

Outlook

- Working in close collaboration with the LHCb physics coordinator team for a new tuning campaign.

- The LHCb physics coordinator team is coordinating the efforts with the specific working groups to develop relevant plugins, will be trying to get to the urgent ones on the Rivet analysis coverage page.

- Software and Computing colleagues are helping to develop the infrastructure for easy deployment and documentation of tunes,

- We are interested in incorporating tunes into the MCPlots ecosystem,

→ Potentially might require new infrastructure (i.e. private internal build for work-in-progress tunes vs publicly released tunes in the official MC plots system).

STAY TUNED!