Measurements of production cross-sections and mixing of charm mesons at LHCb

... and **ReDecay**

Dominik Müller

CERN

LHCb UK meeting

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Thank you very much!

Overview

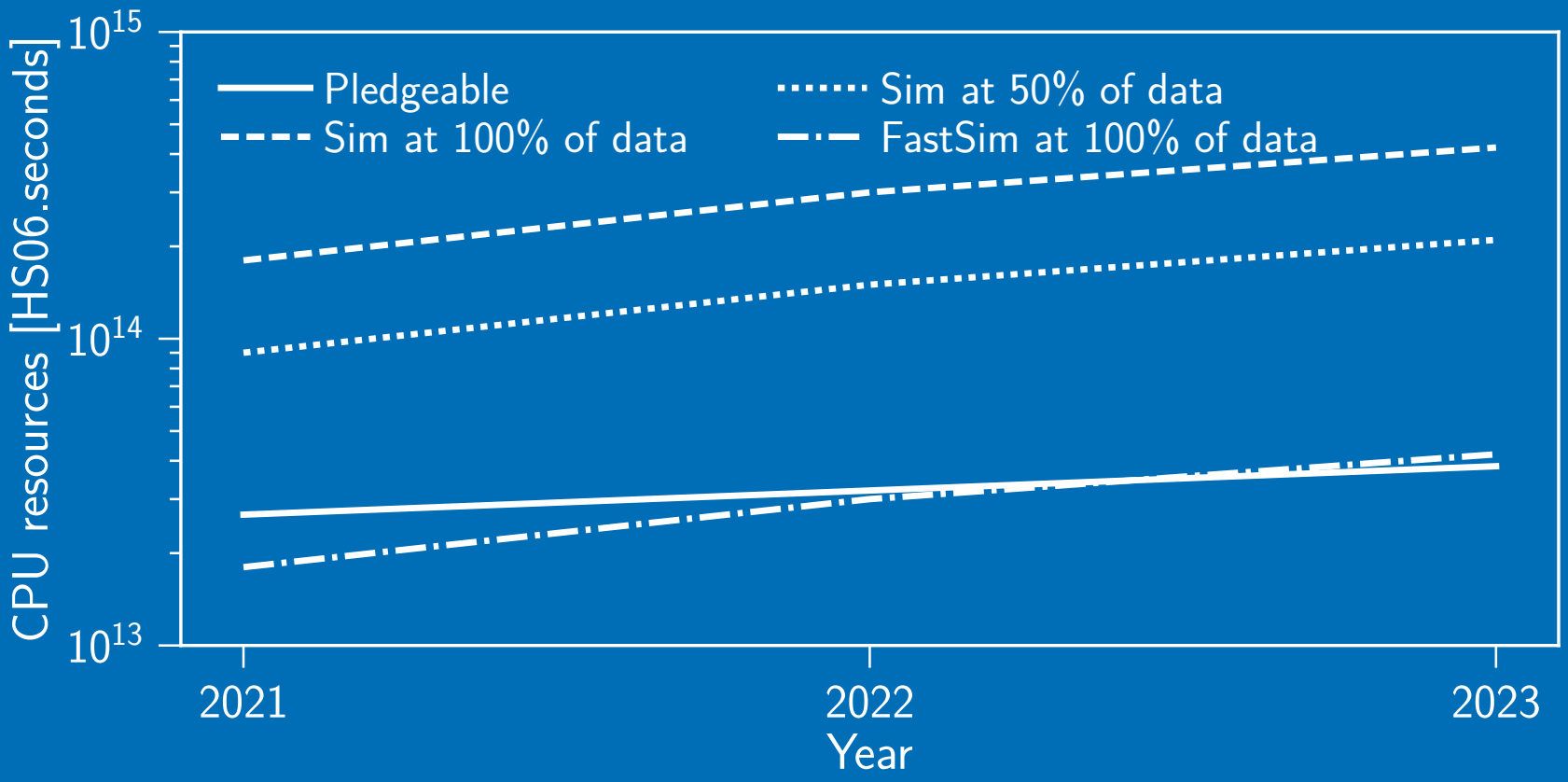
- Thesis: CERN-THESIS-2017-257
- What did I do?
  - ReDecay – fast simulation in LHCb
  - Run 2 charm meson cross-sections
  - Charm meson mixing studies
- What is this talk?
  - Summarise my thesis
  - Weighted and ordered by importance

ReDecay

A novel approach to speed up the simulation at LHCb

Eur. Phys. J. C 78 (2018) 1009

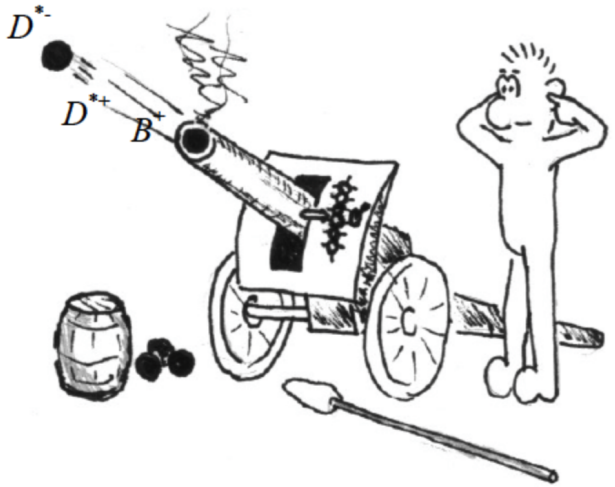
Motivation



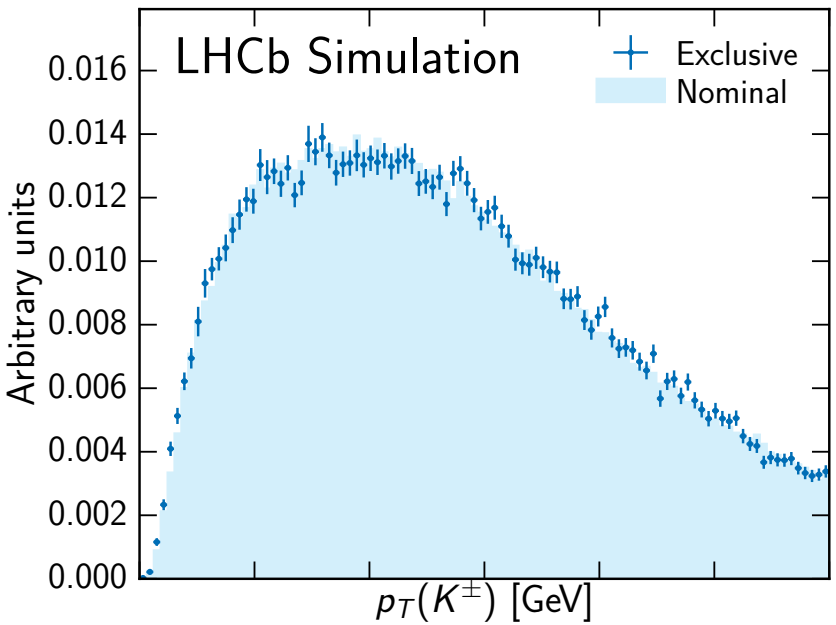
- Already today: **very long** waiting-times for samples!
- Vast majority limited by detector simulation speed
- **Goal: reduce time spent in it!**

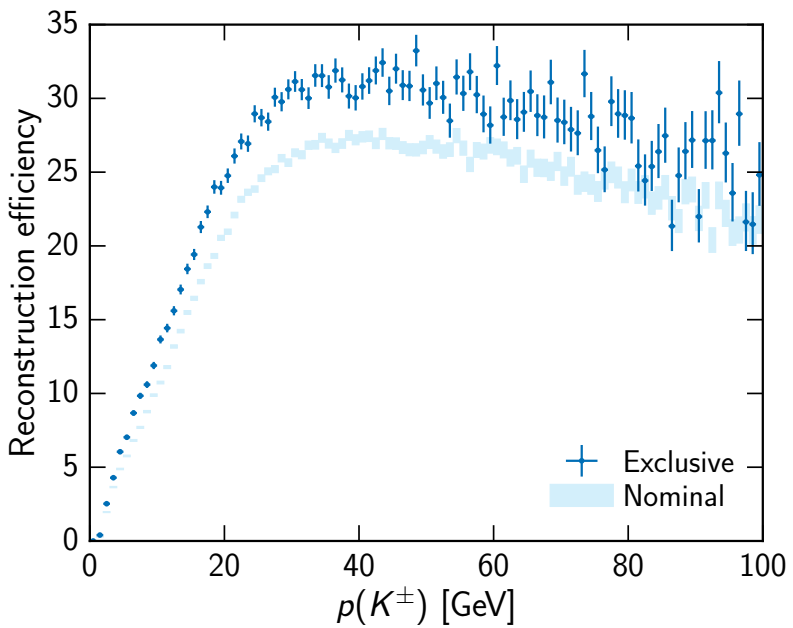
Particle Gun - a simulation only containing signal

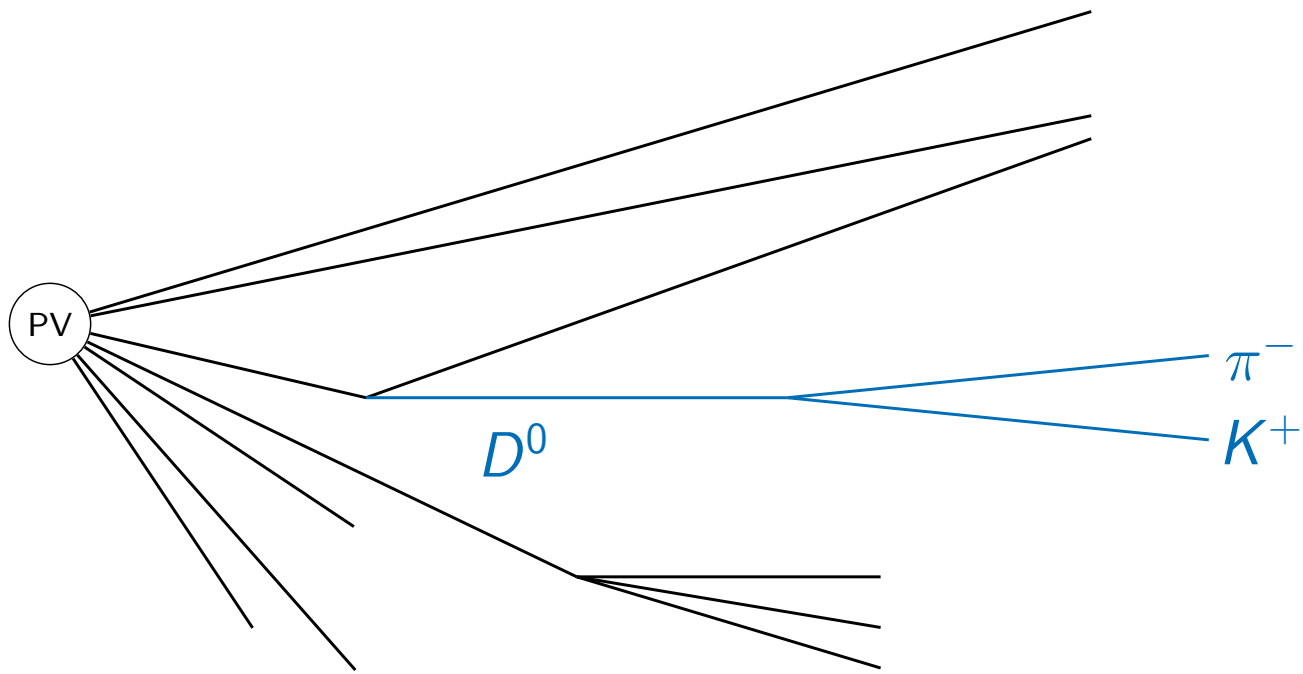
- Signal is main interest in simulation.
- A simulation of the signal candidate can be sufficient for some studies.



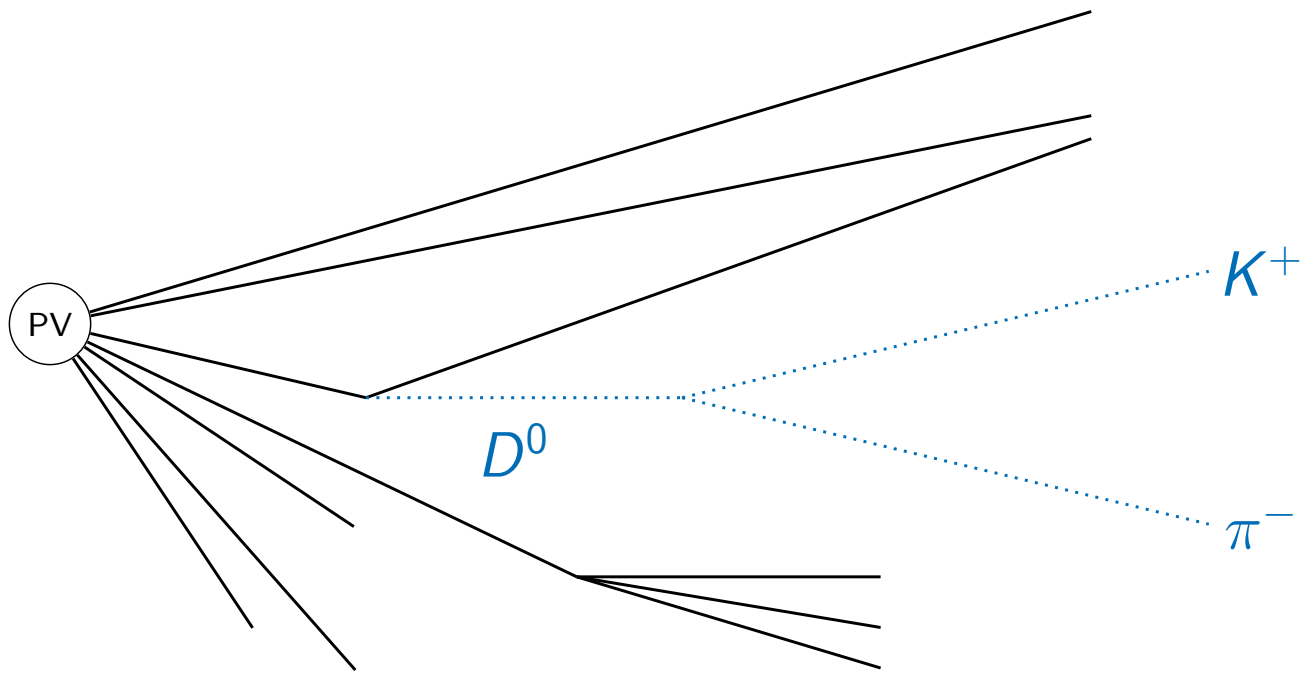
- About 30× faster
- Good agreement in kinematics
- Problem: efficiencies







- New D^0 decay vertex along the fixed momentum vector.
- New decay product kinematics.
- Same efficiencies and resolution (by construction).
- **10 to 50 times faster!**



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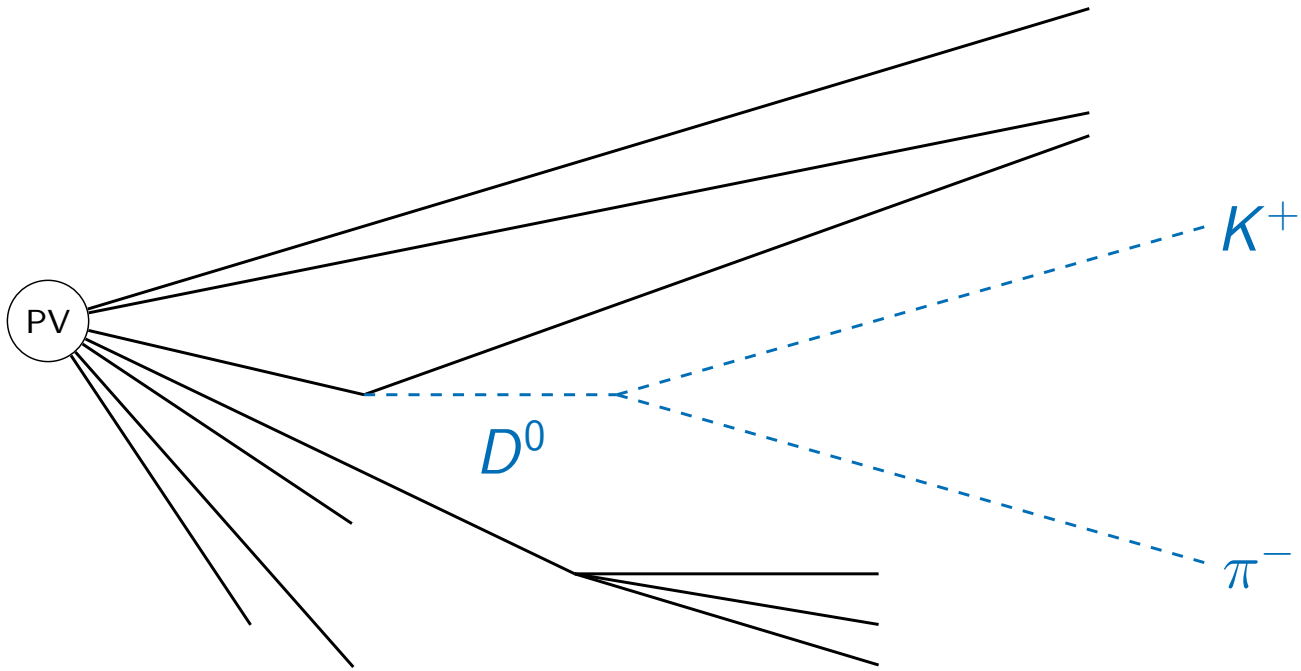

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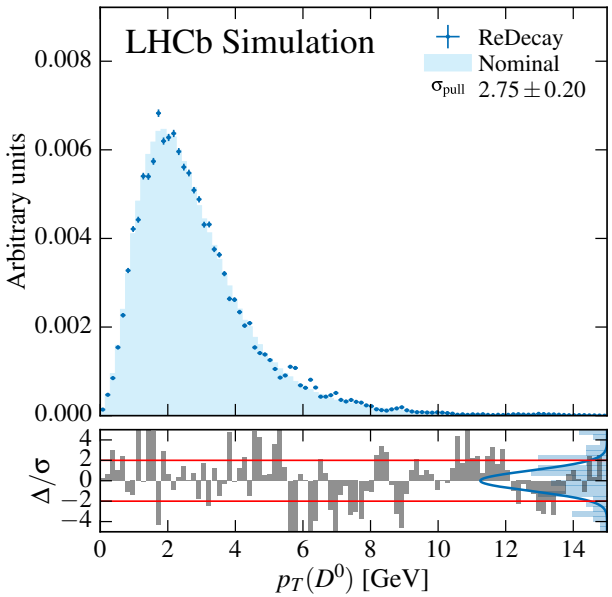
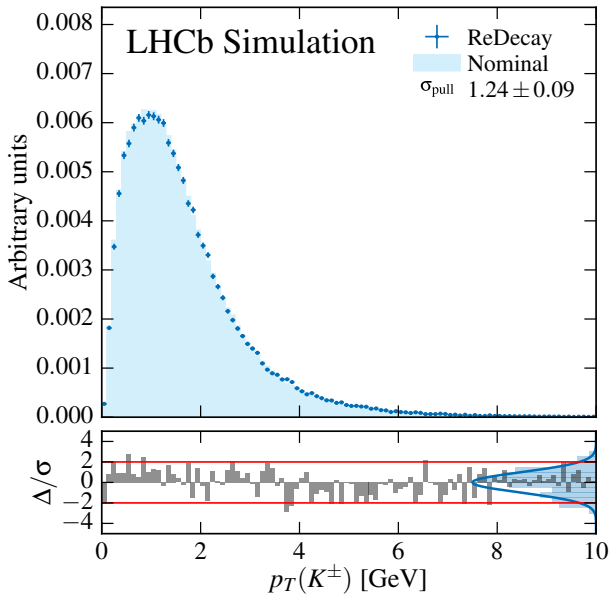
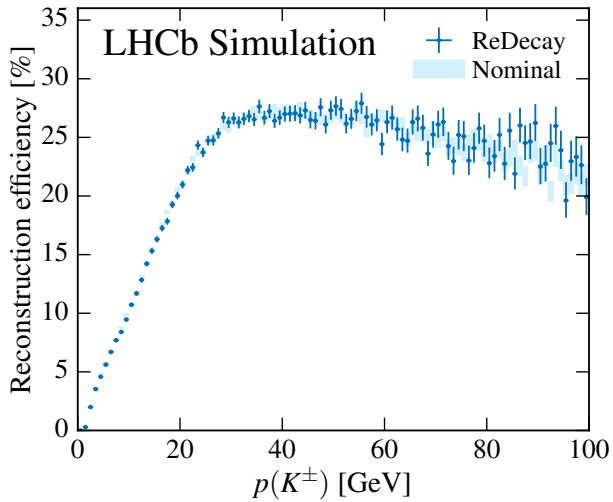
Good agreement with nominal simulation with 100 redecays



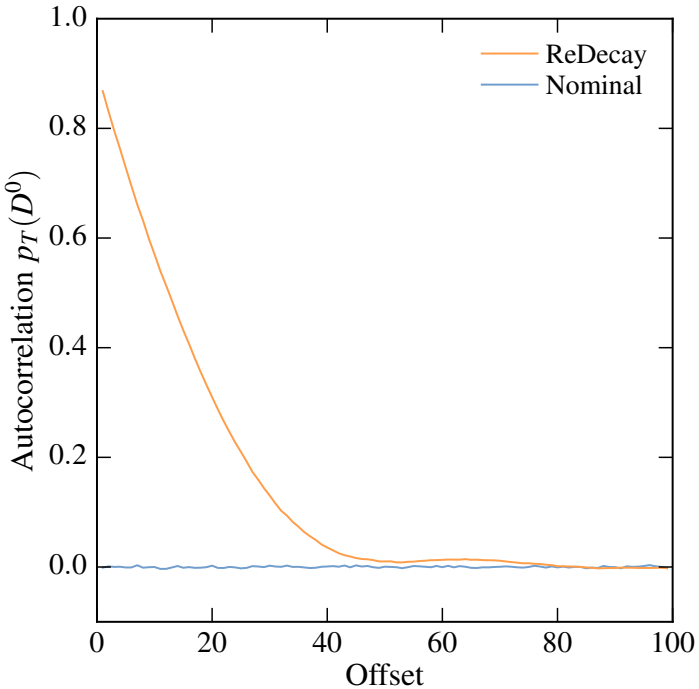


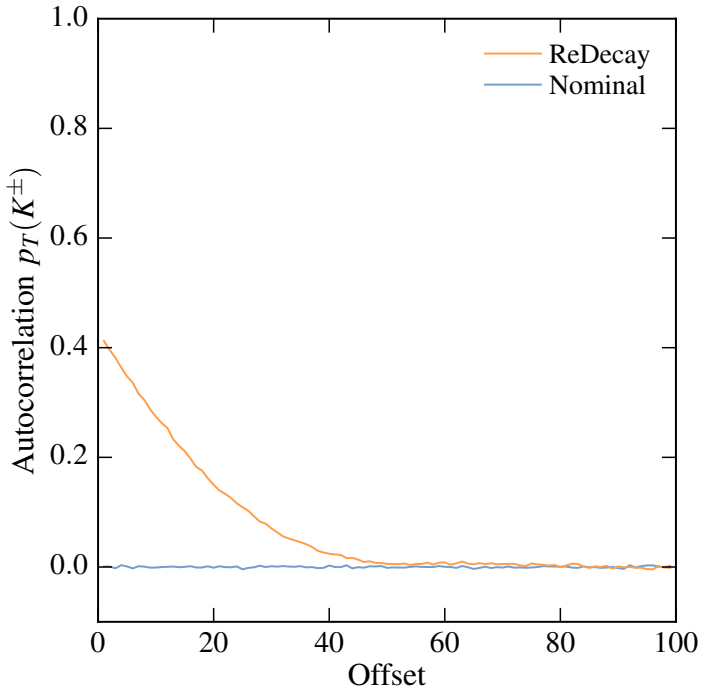


- All shapes in perfect agreement
- <u>However:</u> events correlated ➡ funny pulls

- Autocorrelation (correlation of a random number with its future)?

$$R(\tau) = \frac{1}{(N-\tau)\,\sigma^2} \sum_{t=1}^{N-\tau} (x_t - \mu)(x_{t+\tau} - \mu)\,,$$

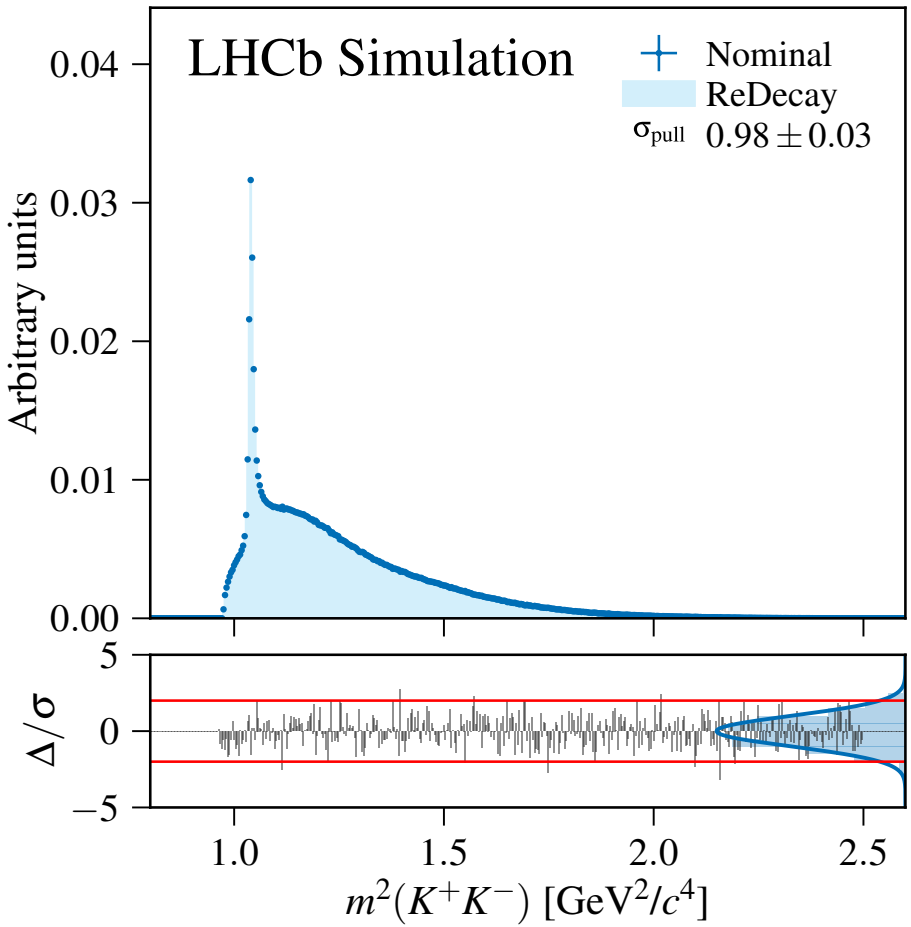


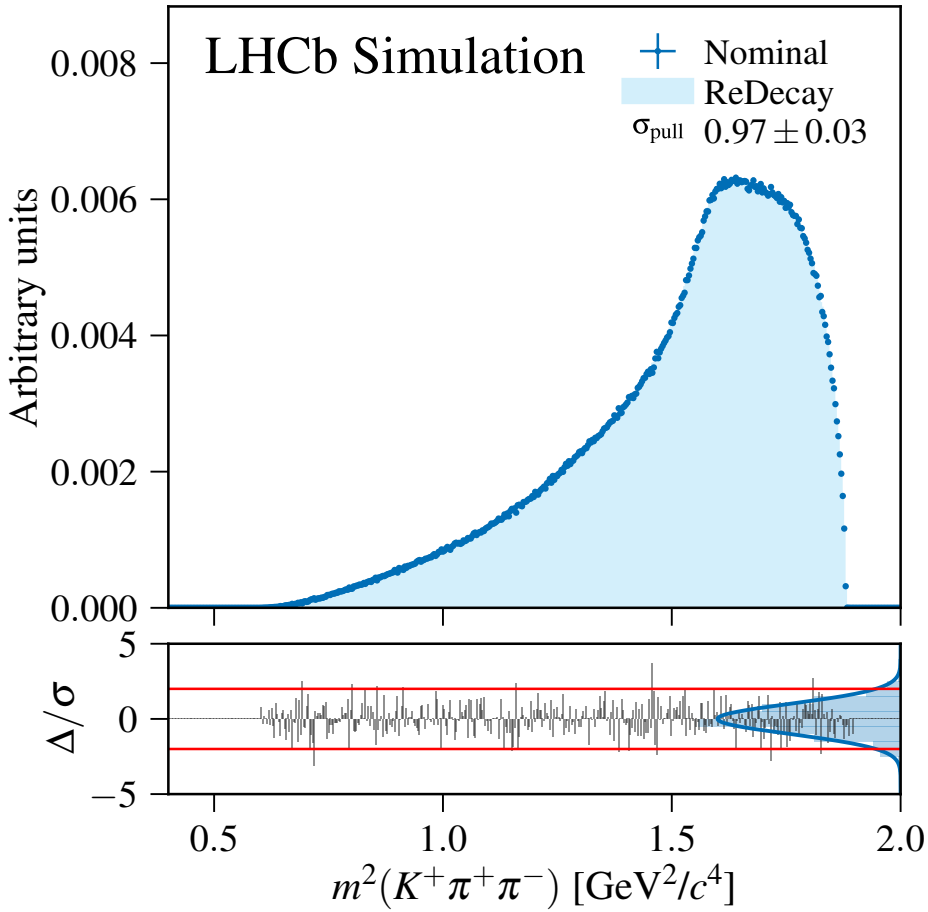


How to deal with the statistical uncertainty

- Sample original events and take all redecayed replicas
- **However:** might not be necessary!

Dalitz variables of $D^0 \to K^+K^-\pi^+\pi^-$ using naive $\sqrt{N}$ uncertainties

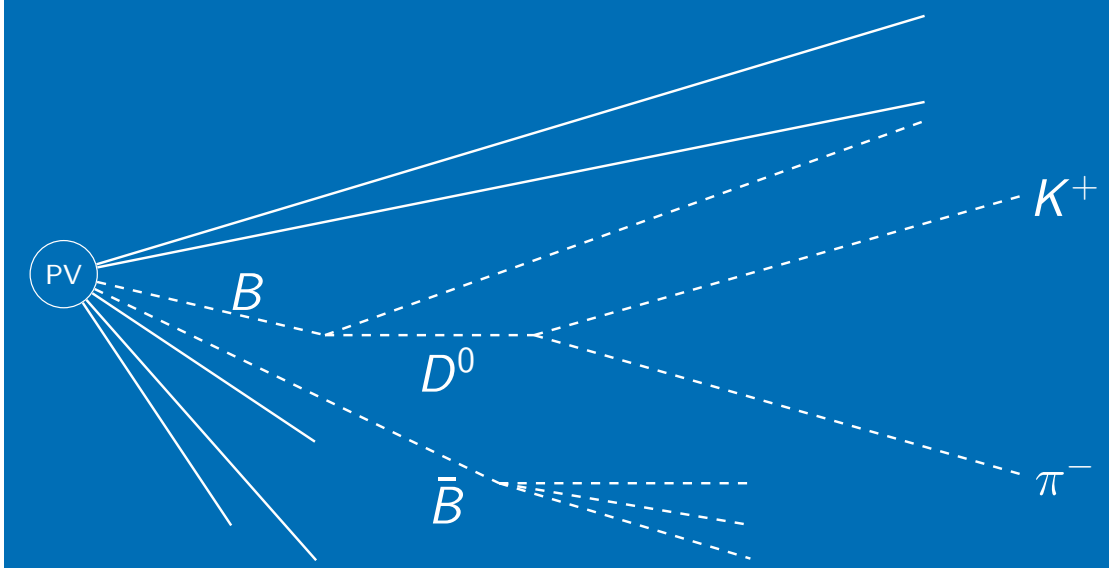




How does it work?

- Implemented as a ProductionTool (i.e. replaces Pythia)
- Same logic to find and decay the signal
- Very flexible: can implement fancier things than just 'redecay the signal'

Default in production: ReDecay everything heavier



- ReDecay everything heavier than the signal
- Might be just the signal, usually some heavier resonances
- Usually captures both heavy flavour branches of $c\bar{c}$ and $b\bar{b}$
- More variation in each ReDecay, less correlations

Future: choice of ReDecay modes

With decreasing speed:

Signal only

- Ideal if only the signal is of interest.
- Possibly largest correlations.

Heaviest ancestor (known to EvtGen)

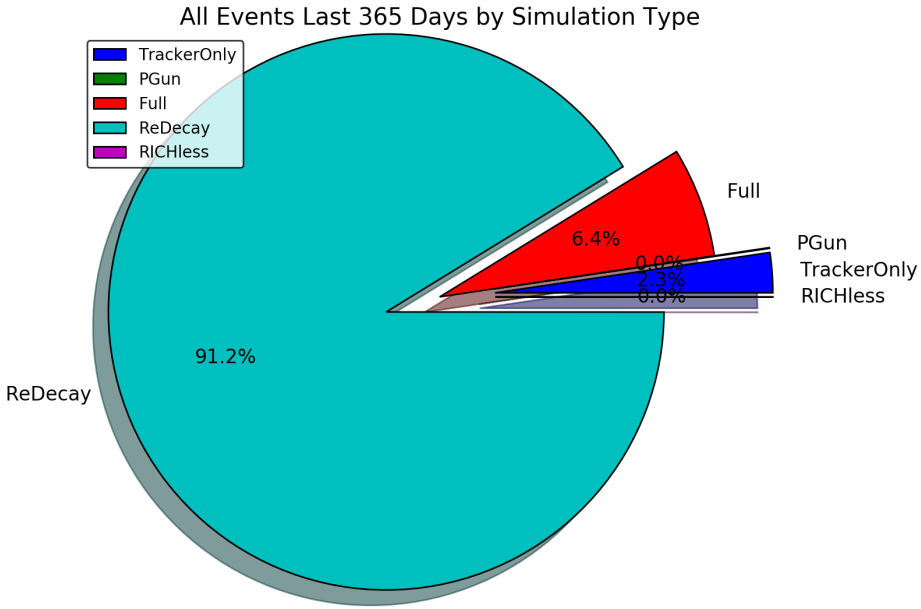
- Captures secondary decays and heavier resonances

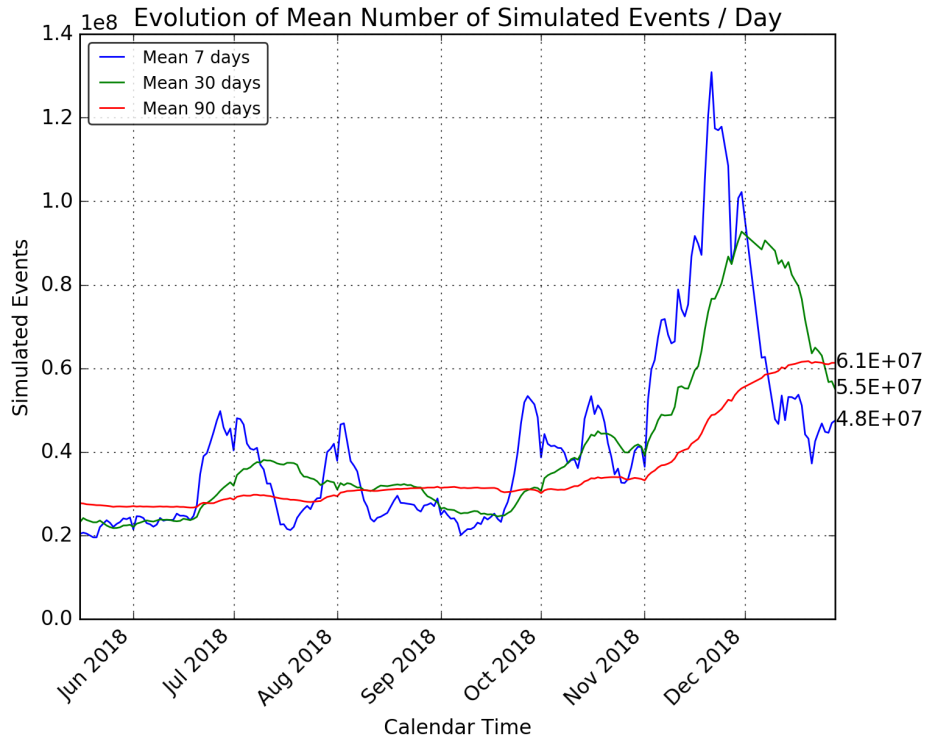
Everything heavier than signal (known to EvtGen)

- Captures secondary decays and heavier resonances
- Likely captures opposite heavy flavour
- Very useful for opposite side tagging

[WIP] All heavy flavour hadrons (known to EvtGen)

- Mostly the same as 'Everything heavier'





First published use-case: LHCb-PAPER-2018-038

"Measurement of the charm-mixing parameter y_{CP}"

- 500 million events simulated

Charm cross-sections

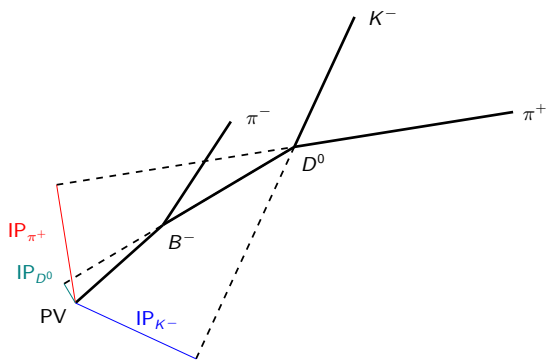
At $\sqrt{s} = 5\,\text{TeV}$ and $\sqrt{s} = 13\,\text{TeV}$

JHEP 03 (2016) 159
JHEP 06 (2017) 1

Idea

- Measure D^0, D^+, D^{*+} and D_s^+ production
- Good "test" that everything is working
- Input to QCD calculations

- First charm publication using TurboStream
- Cut-based selection
- Fit m and χ^2_{IP} in (p_{T}, y) bins



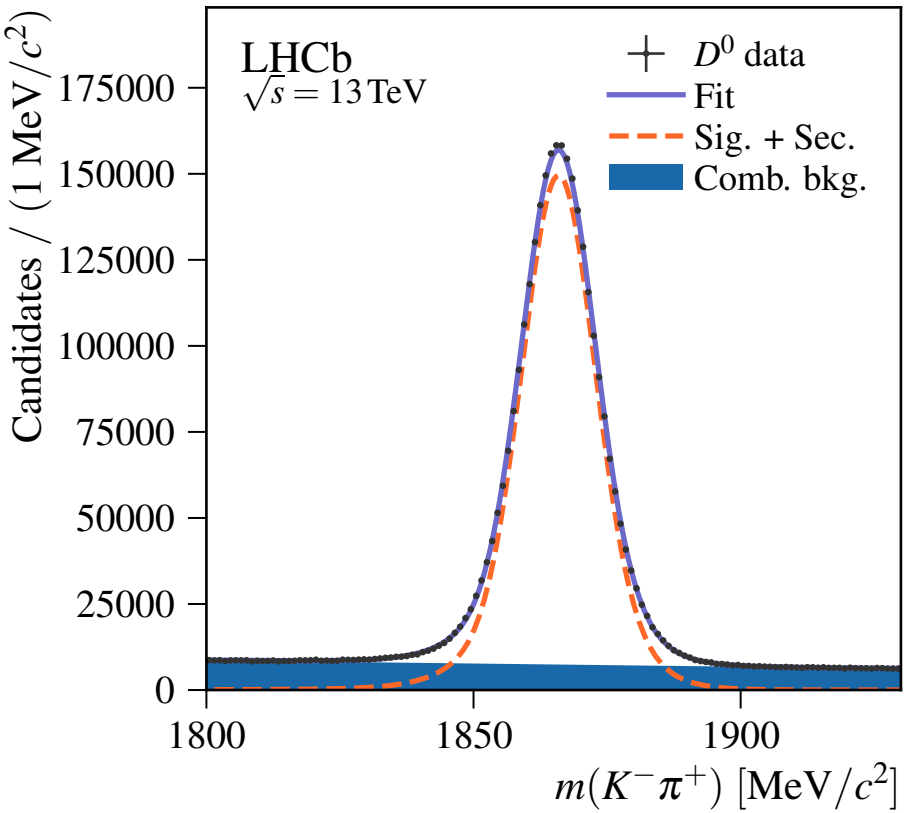
The $\sqrt{s} = 5\,\text{TeV}$ pp data

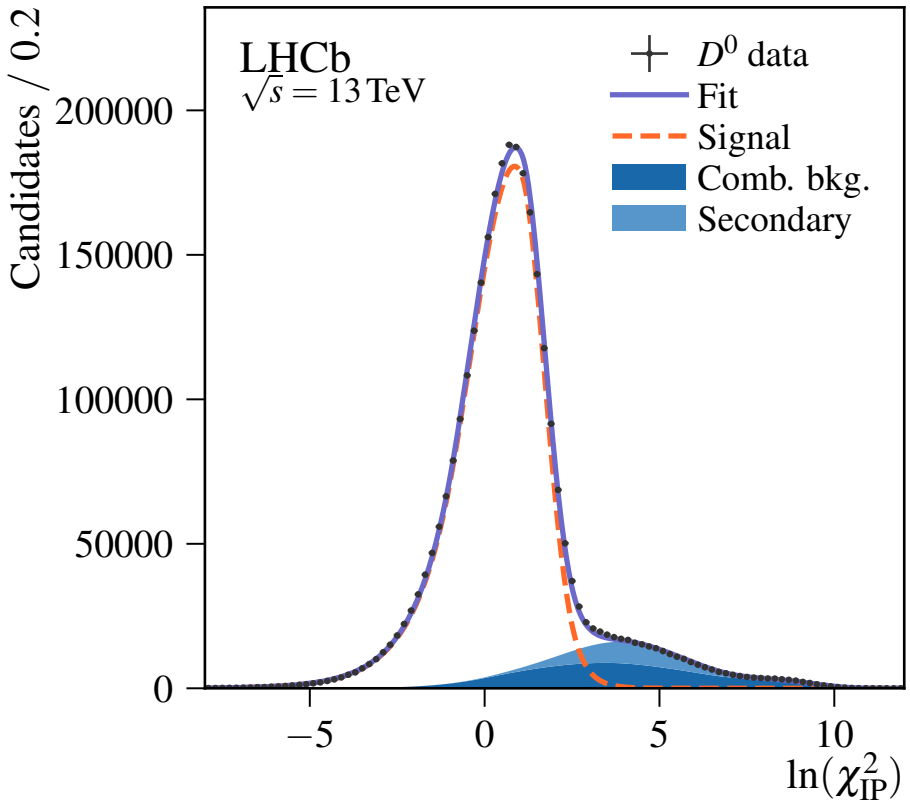
- End of 2016: a little pp data at $\sqrt{s} = 5\,\text{TeV}$
- Had reproducible analysis framework
- Just press the button ...

Fits for D^0 at $\sqrt{s} = 13\,\text{TeV}$

Two stage fit:

1. Fit m to constrain comb. bkg. in signal window
2. Fit χ^2_{IP}





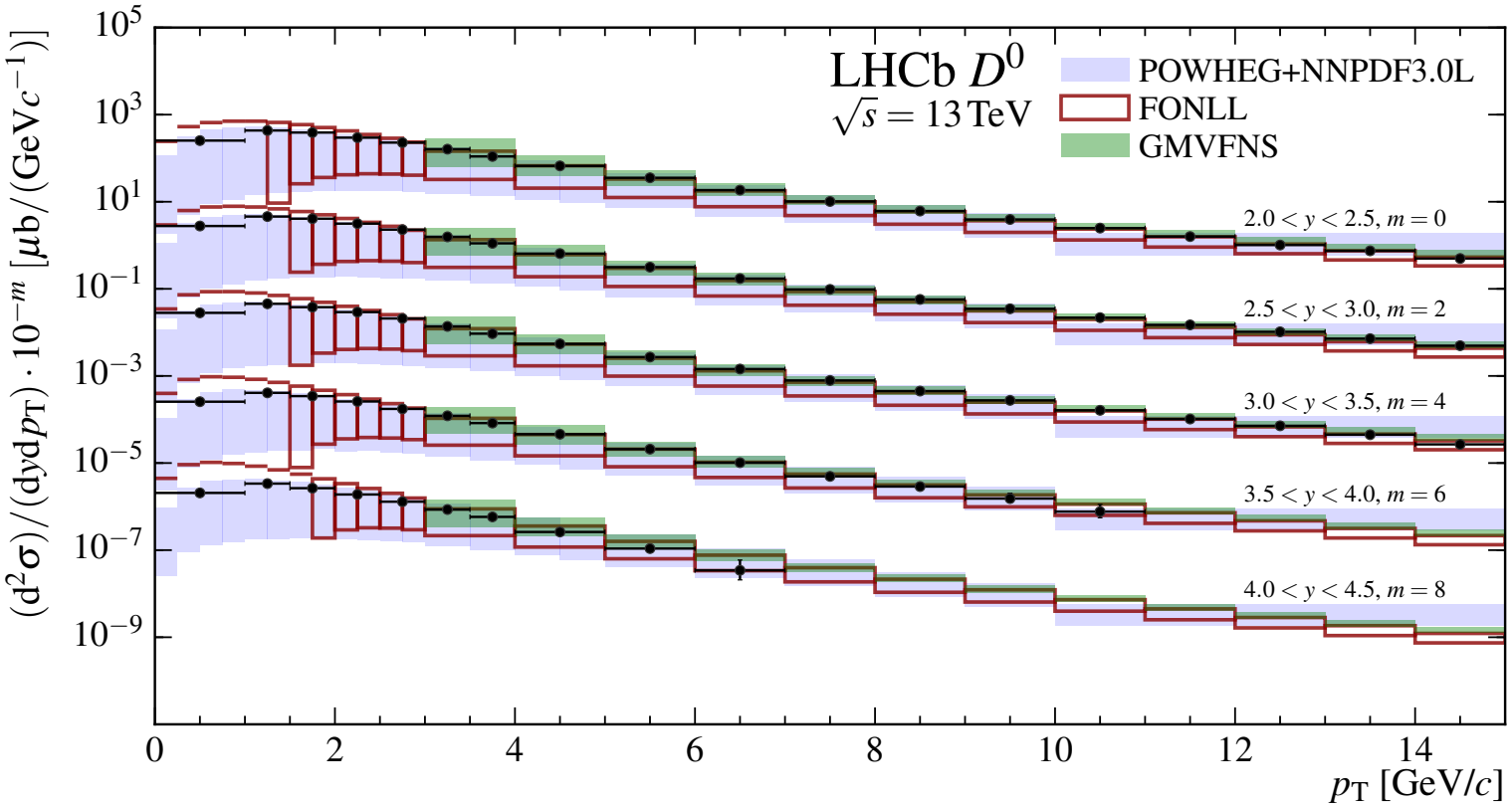
Efficiencies:

- From MC, with PID and tracking corrections

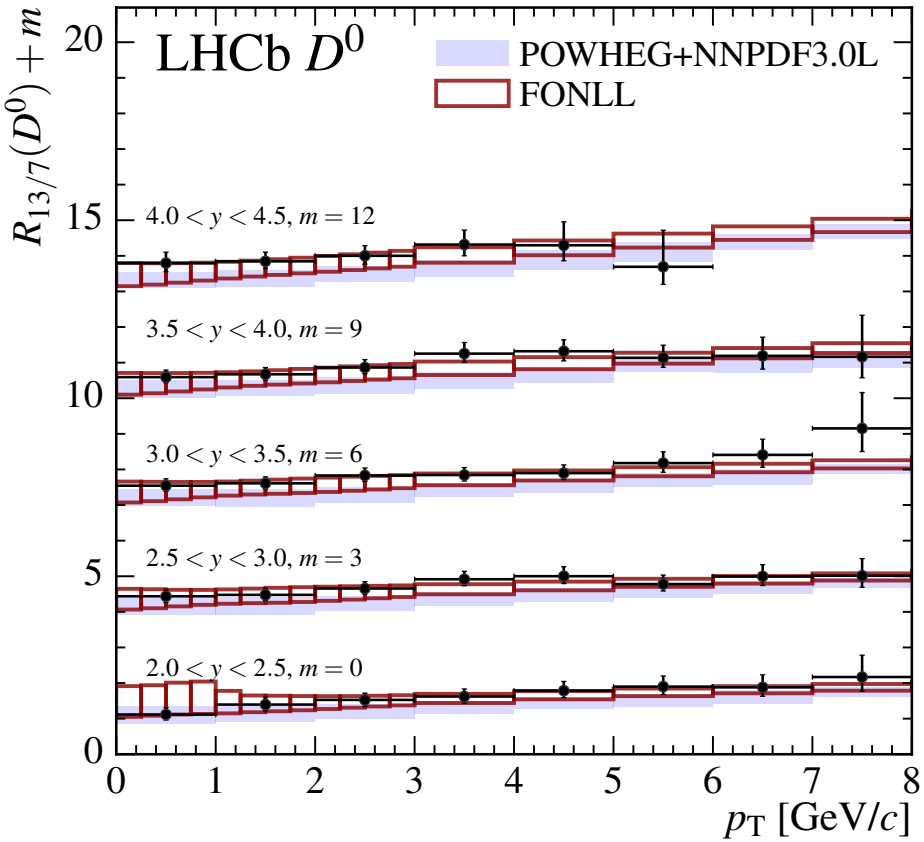
Results – double-differential cross-sections

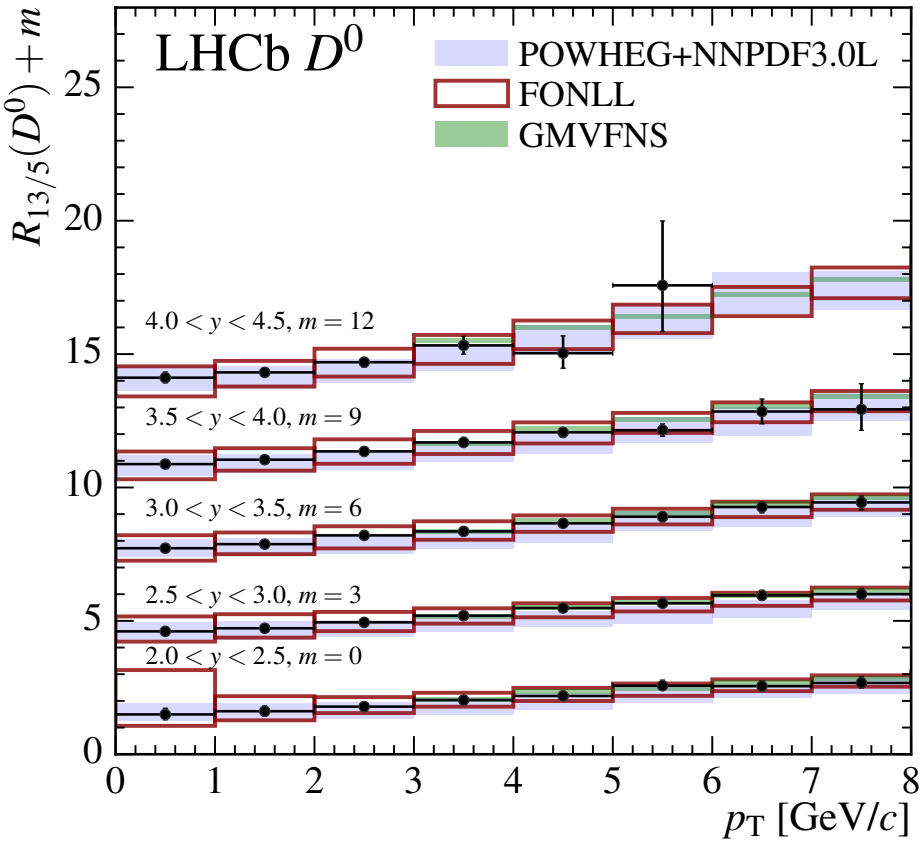
Results:

1. **Main**: Double-differential cross-section in (p_T, y) bins
2. Precise ratios between different centre-of-mass
3. Ratios between different mesons



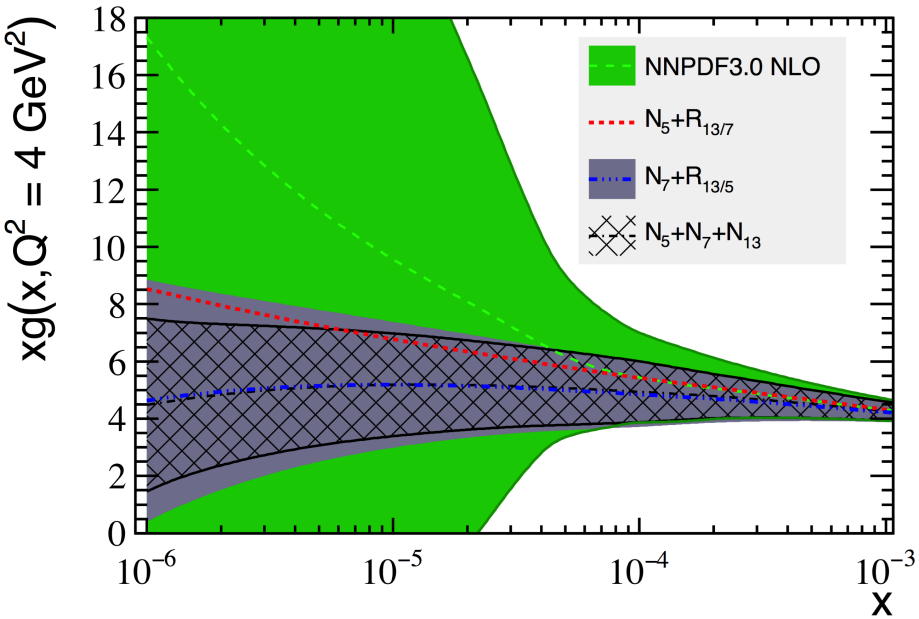
Using LHCb result at $\sqrt{s} = 7\,\text{TeV}$

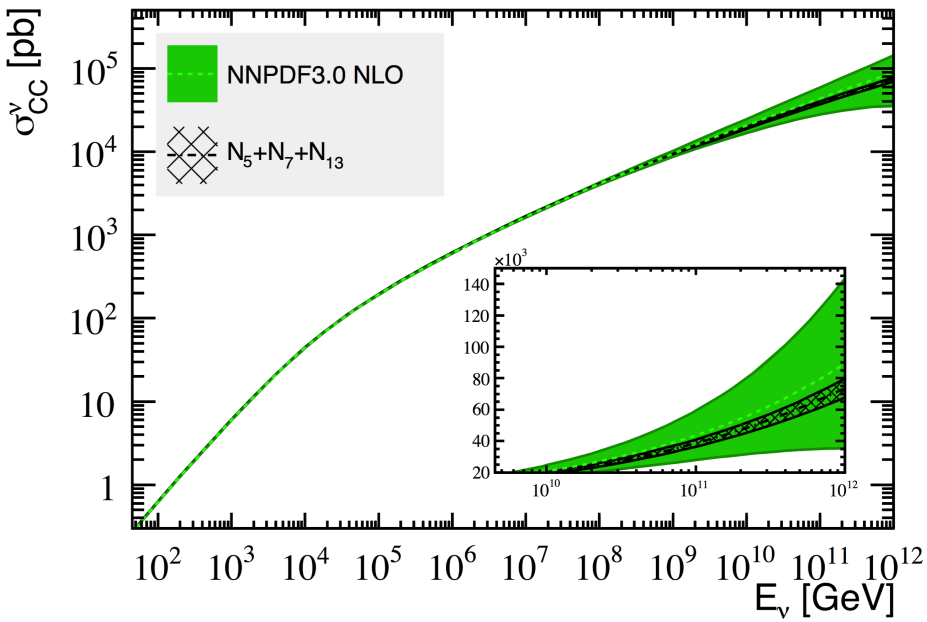




Results – interpretation

- Pretty good agreement, QCD actually works
- Gauld et al. (Phys. Rev. Lett. 118 (2017) 072001) constraints on low x gluon PDF:

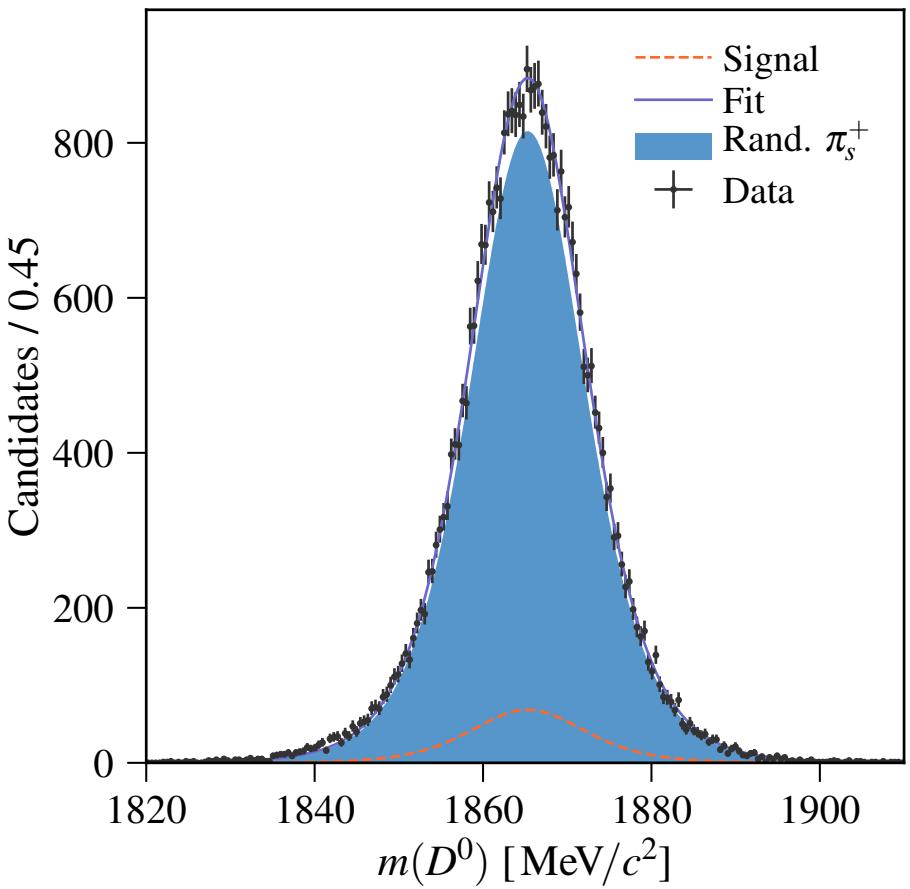


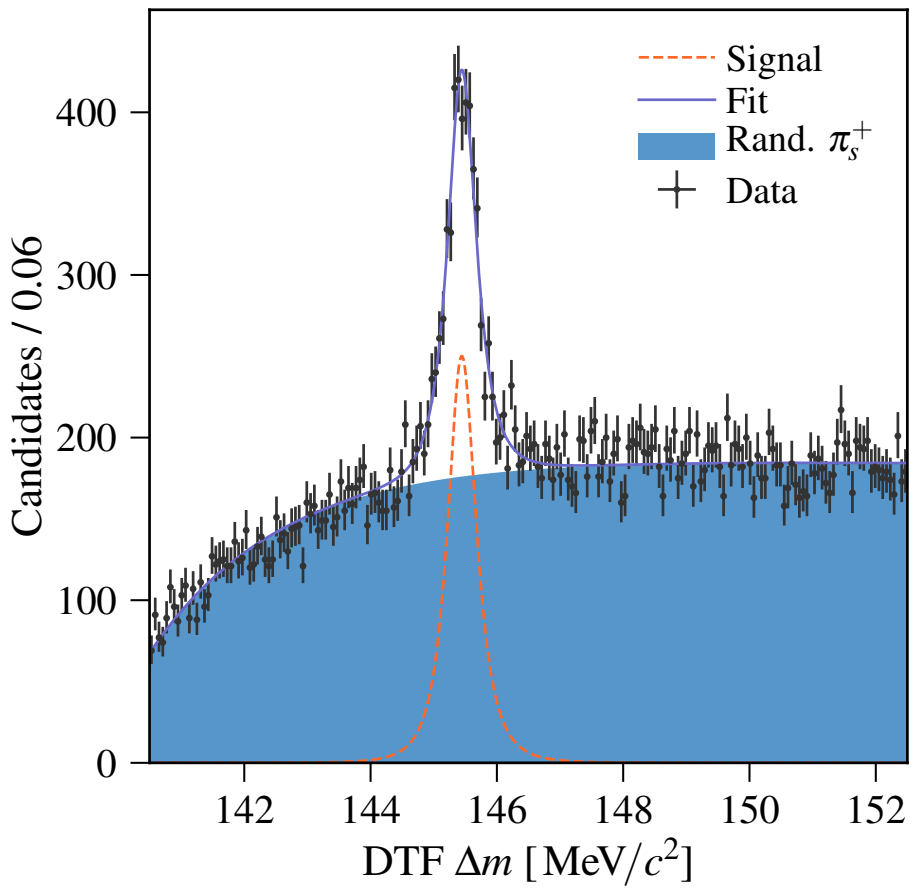


Charm mixing

Overview

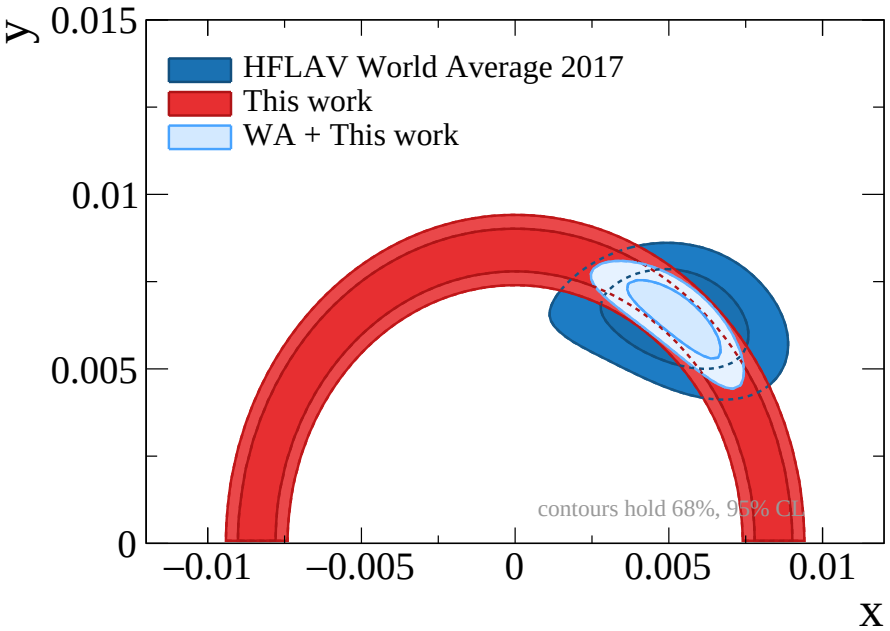
- Explored precision of model-dependent measurement
- Using Tim Evan's models (with fixed right-sign)
- 6D fit implemented in GooFit
- 2015+2016 data
- Non-parametric data-driven efficiencies

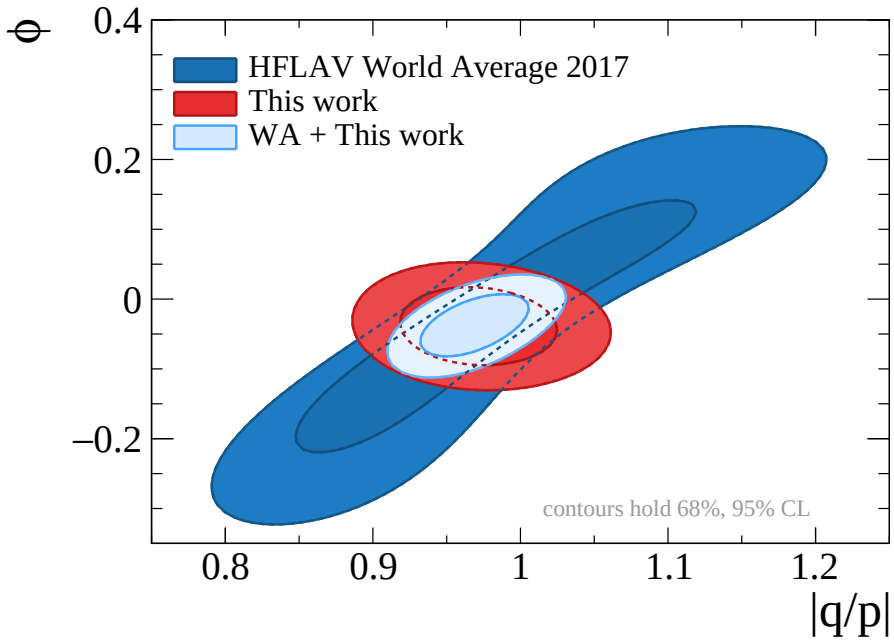




Estimated precision

- Toys with yields as measured in data
- Systematic uncertainties set equal to stat. uncertainties





- Continued by John Cobbledick et al. (Manchester & Cincinnati)

Summary

- Again thank you very much for the price!
- Thanks to everyone who has helped me during my PhD!