Hadronization and Hadron Decays

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Outline

- Introduction
- Tuning in Herwig
- Some examples
- The Future

Introduction

- Yesterday Torbjörn talked about a lot of the issues in hadron–hadron collisions, particularly underlying event, MPI, collective effects,. . .
- I was asked to talk about hadronization and intrinsic $k_\perp$ with more of a Herwig/cluster model view.
- I'll try and discuss the issues, and mainly give examples of some of the things we've been looking at and the sort of data we are using.

Introduction

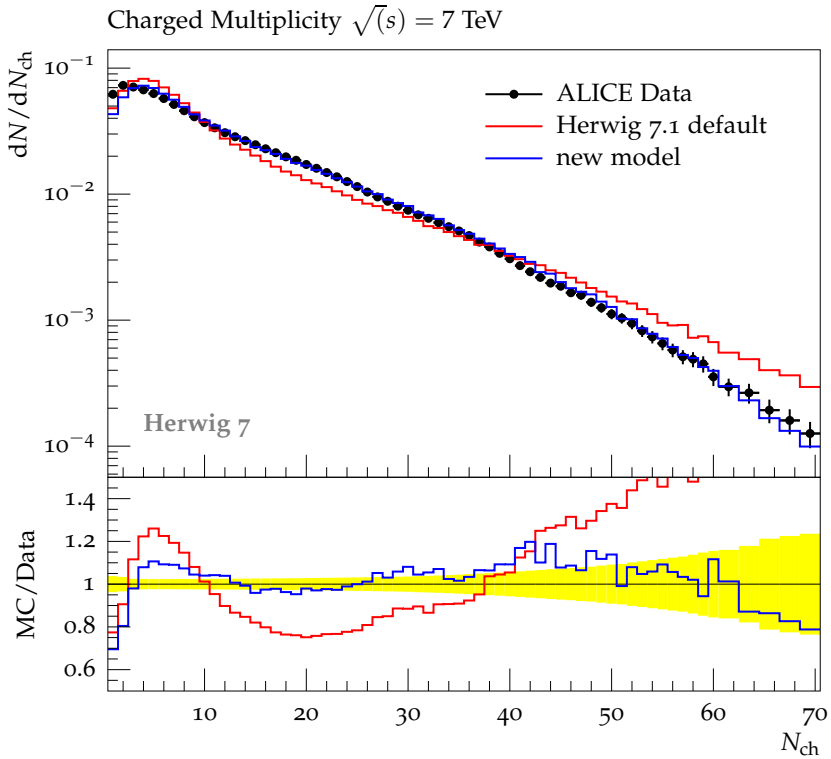
- So for hadronization the main issue is the differences we are seeing between e^+e^- and pp
- However some things are not even well understood in e^+e^- collisions.
- The main issue is baryon production and correlations.
- Other issues such as the production of excited states.

Tuning in Herwig

- Tune most hadronization/shower parameters to e^+e^- data.
- Use data from a wide range of energies from 10-200 GeV.
- Tune MPI, colour reconnection and intrinsic $k_\perp$ to hadron-hadron data.
- Compare each release with as much available data as possible.
- Make the plots and yoda files public with the release.
- The other place we make extensive use of data is when making improvements and developing new models.
- Often binary choices and model changes are more important than tuning.

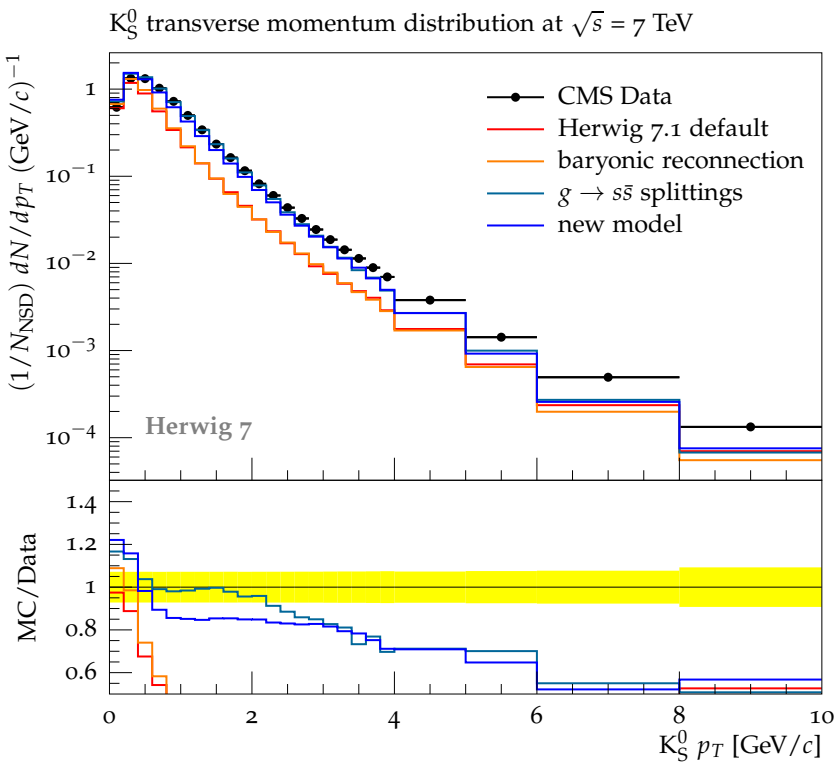
Baryonic Colour Reconnection

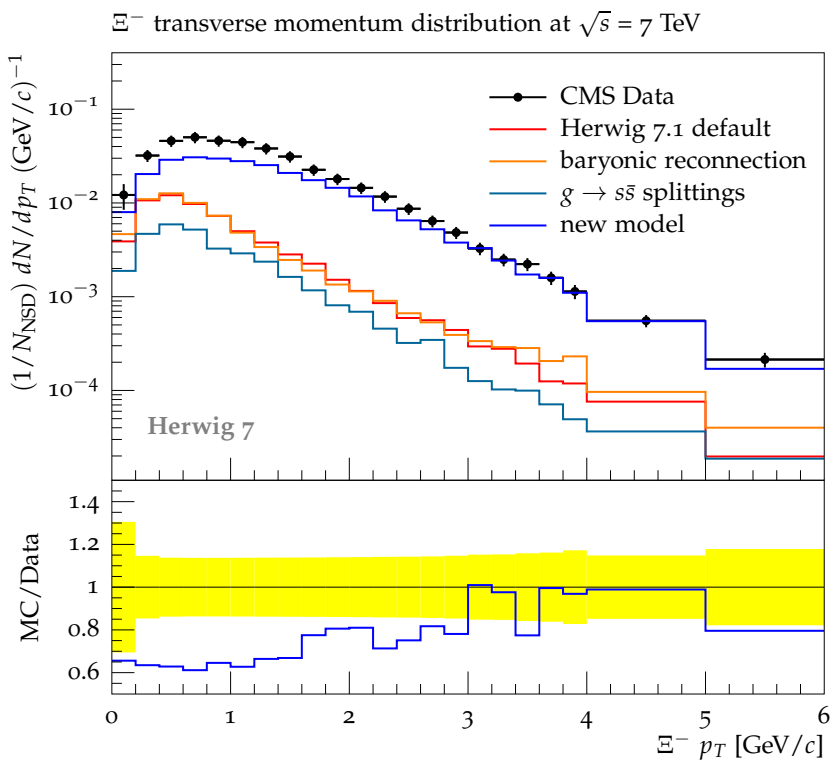
- Allow recombination of mesonic clusters to give baryonic ones.
- Based on proximity in momentum space
- Include non-perturbative $g \to s\bar{s}$ splitting in the cluster model.



S. Gieseke, P. Kirchgaeßer, Simon Plätzer Eur.Phys.J. C78 (2018) no.2, 99

Baryonic Colour Reconnection

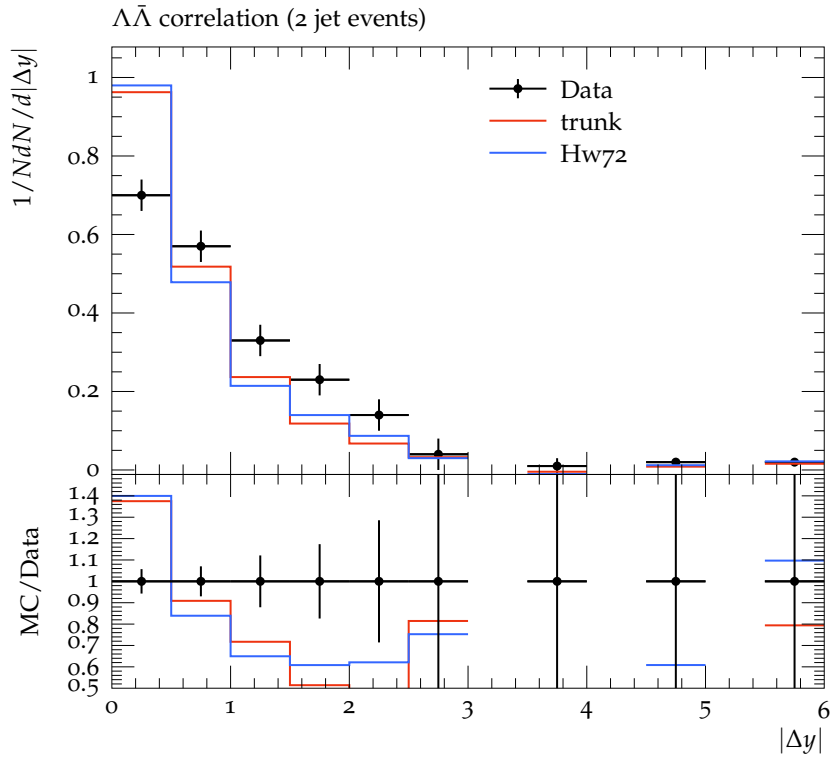




S. Gieseke, P. Kirchgaeßer, Simon Plätzer Eur.Phys.J. C78 (2018) no.2, 99

Baryon Correlations

- Reasonable number of analyses or baryon correlations.
- Both from LEP and some from B-factories.
- Often more difficult to write the Rivet analysis.
- More complicated observables, details missing from papers.



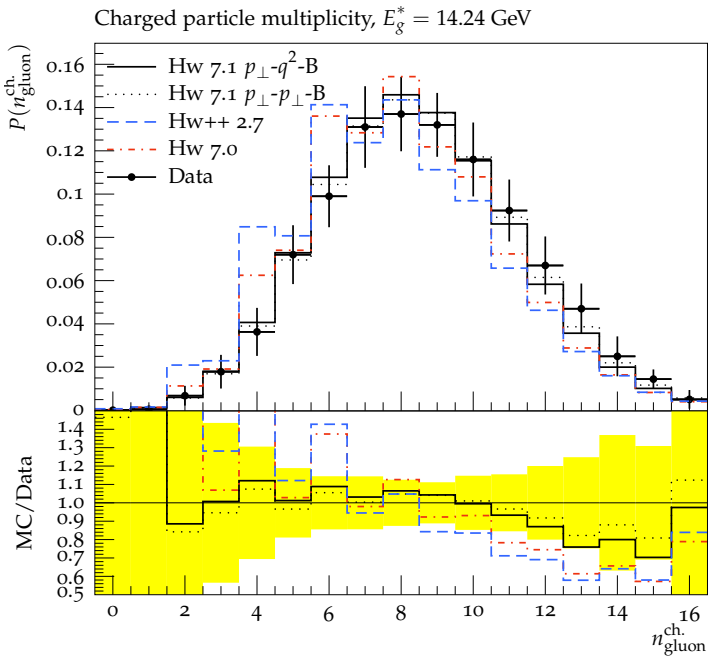
OPAL Eur.Phys.J.C 13 (2000) 185-195

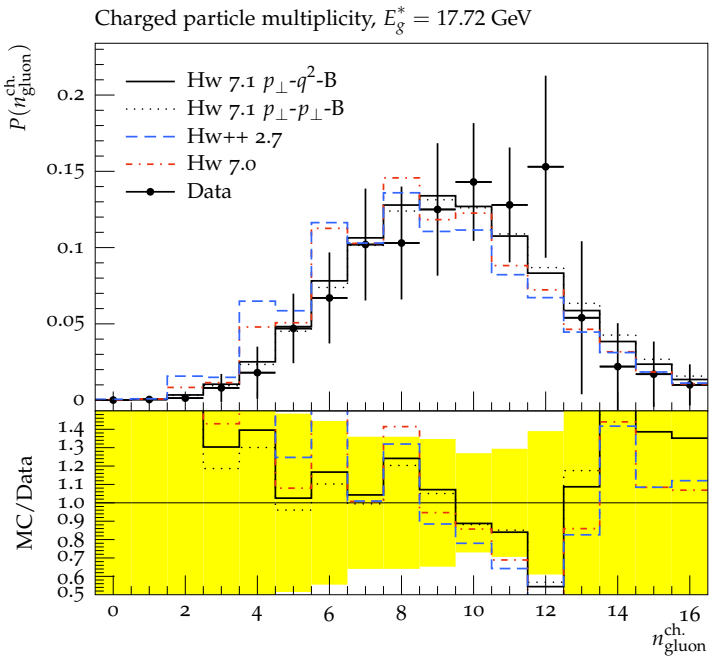
Quark vs Gluon Jets

Reichelt, Richardson, Siodmok Eur.Phys.J.C 77 (2017) 12, 876

- Differences seen between HERWIG and PYTHIA modelling of quark and gluon jets.
- Problem but little available data.
- Most LHC data useless as the output of a neural net/BDT etc.
- Mainly used data from LEP, implemented new Rivet analyses, some issues with the observables used and corrections applied.
- Issues with the colour-reconnection model.

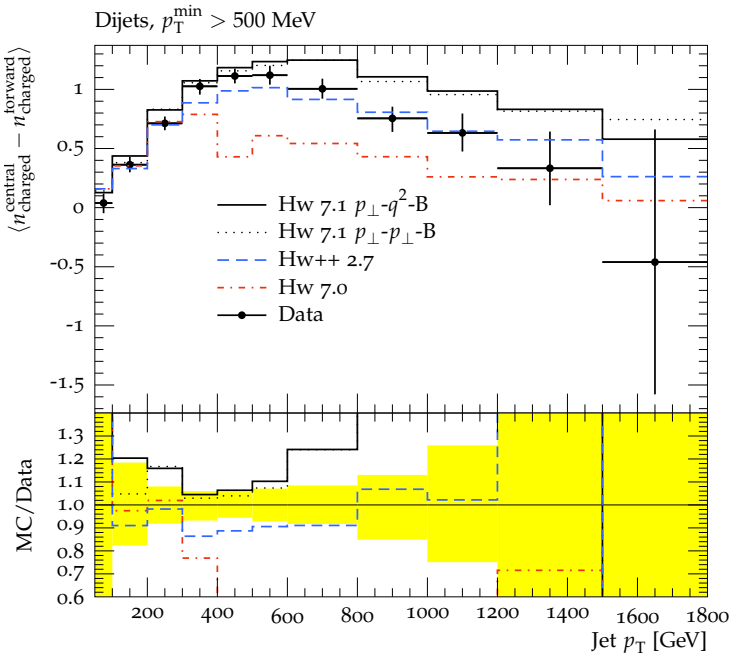
LEP Data

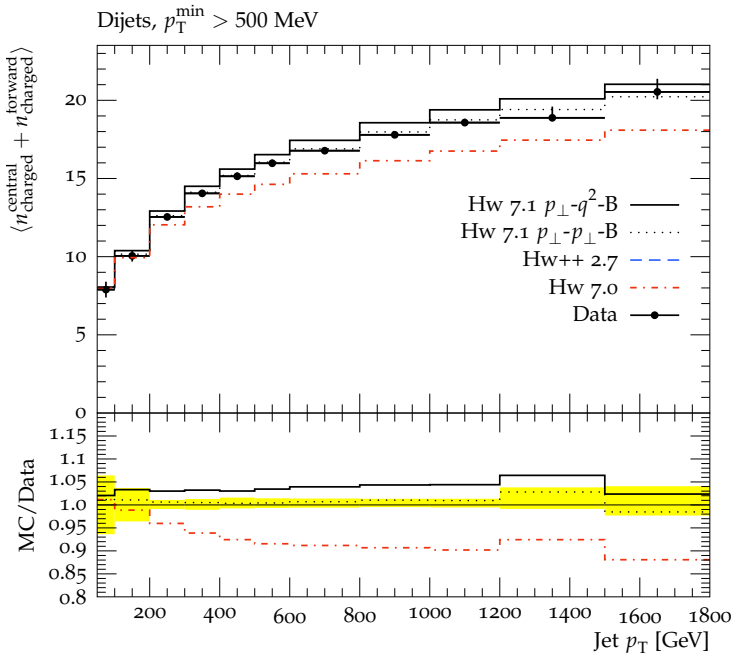




Herwig 7 compared to data from OPAL Phys.Rev.D 69 (2004) 032002

ATLAS Charged Multiplicity in Jets





Herwig 7 compared to data from ATLAS Eur.Phys.J.C 76 (2016) 6, 322

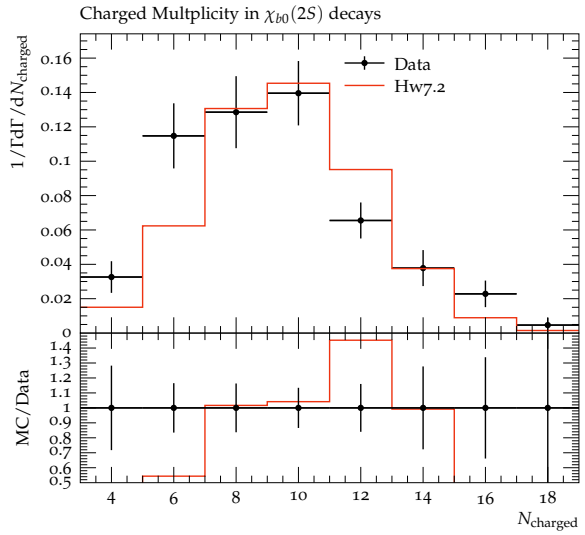
Up-to-date plots

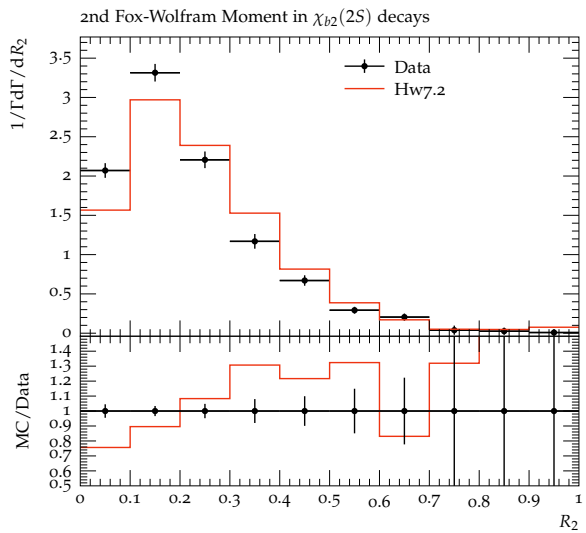
Quark vs Gluon Jets

- Clearly will continue to be of interest.
- Need data we can use rather than results it is impossible to compare to.
- If an analysis can't be implemented in Rivet its unlikely to be of much use.
- Also some interesting things in e^+e^- collisions

$\chi^0_{b0,2}$ Decays

- At low energy but gives 2 gluon jets.
- Copiously produced in $\Upsilon(3S)$ decays.
- Old results CLEO Phys.Rev.D 46 (1992) 4822-4827
- Much larger datasets now available.
- Also things like enhanced baryon production.

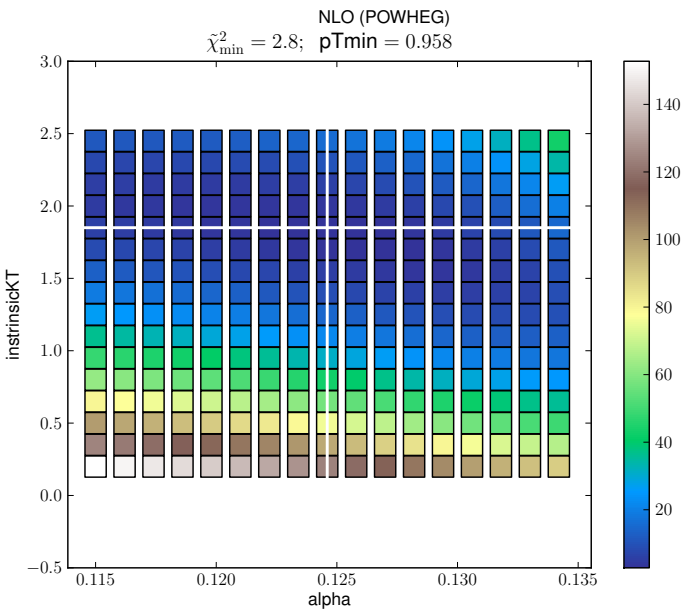


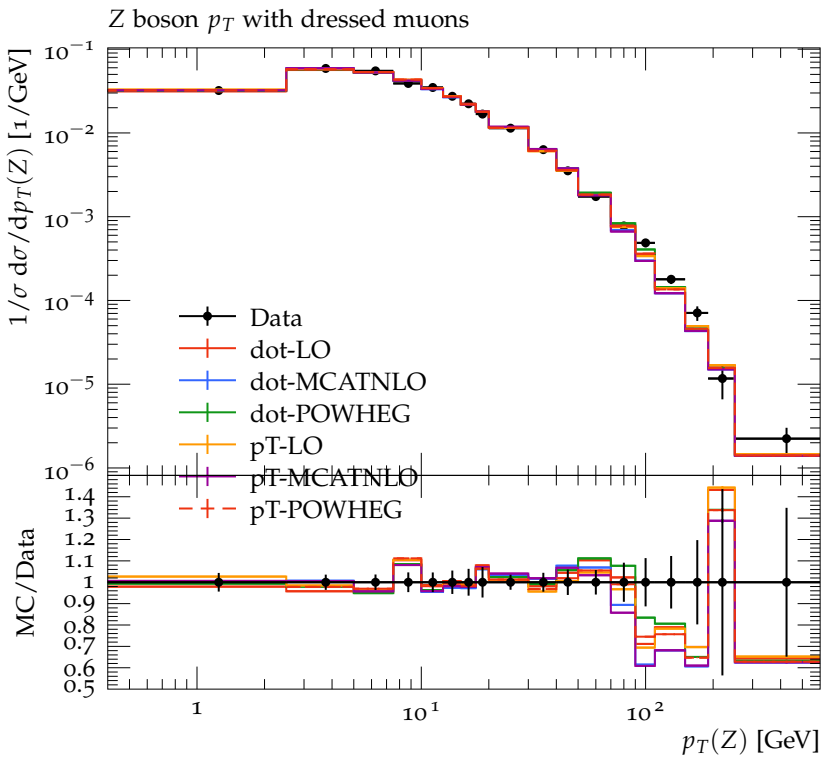


Intrinsic $k_\perp$

- Important for the W mass measurement.
- Tuned to fit the data, mainly Z $p_\perp$ and ϕ^*.
- There is an issue with over-tuning and producing a parameterization of the data rather than a prediction.
- Also perturbative interplay with the tuning of α_S in the parton shower and effects of matching to higher orders.
- Tune using ATLAS and CMS data at 7 TeV.

Intrinsic $k_\perp$

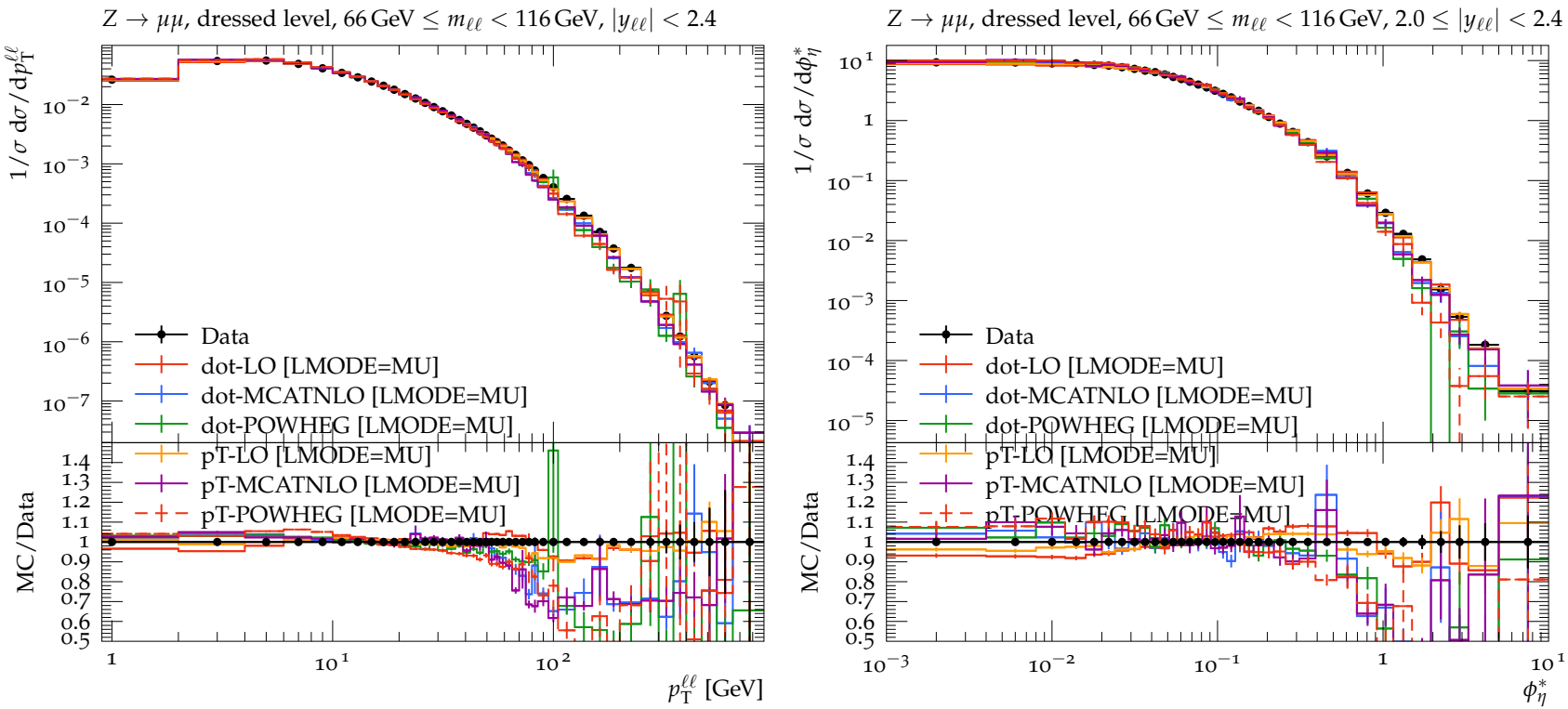




In progress: G. Bewick, S. Ferrario Ravasio, PR

data from CMS Phys.Rev. D85 (2012) 032002

Intrinsic $k_\perp$



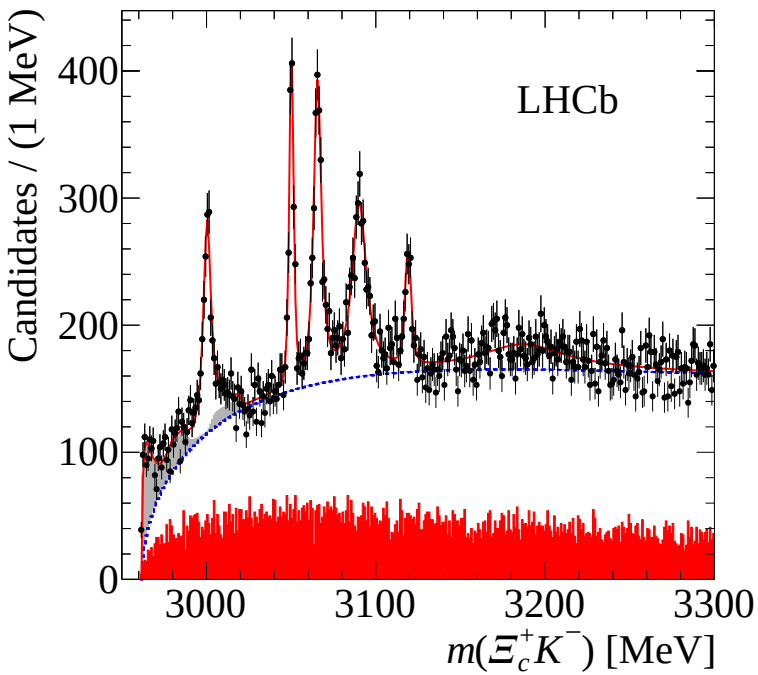
In progress: G. Bewick, S. Ferrario Ravasio, PR

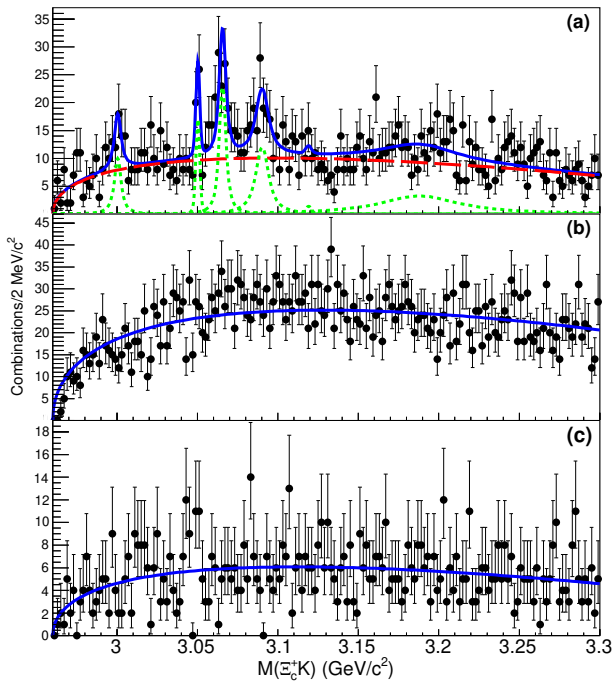
data from Eur.Phys.J.C 76 (2016) 5, 291

Excited States

- Clearly a lot of excited states there, often we just ignore them and include the lowest states.
- Mainly due to the poorly determined properties, in the baryon sector even for the ground states.
- Actually a lot of data in the charm sector (mainly at $E_{\mathrm{CMS}} \sim 10.5$ GeV) but for many excited states data from ARGUS/CLEO I is all that's usable.
- Older ARGUS/CLEO papers tend to include rates and often spectra
- Newer papers often just include PDG quantities (mass, width, BR)

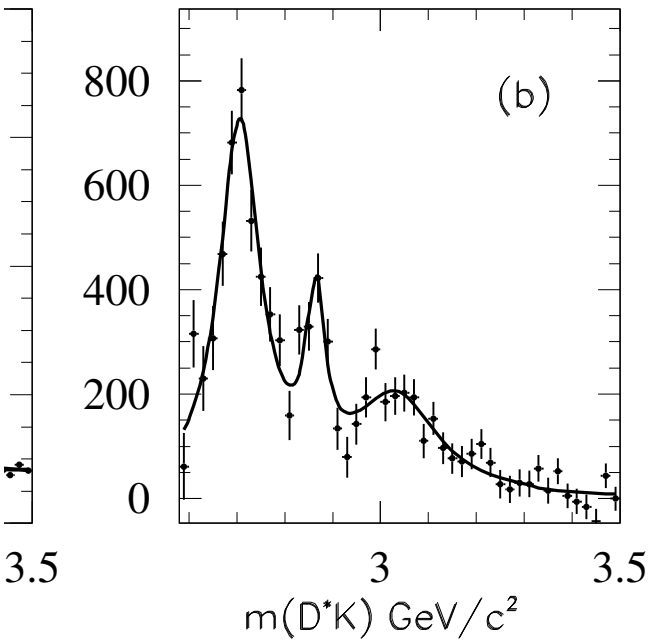
Excited States: $\Omega_c^* \to \Xi_c^+ K^-$

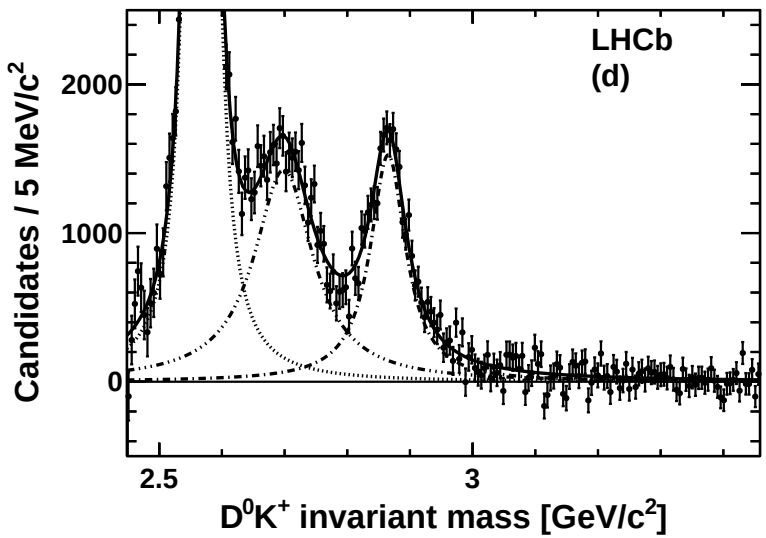




LHCb Phys.Rev.Lett. 118 (2017) 18, 182001, BELLE Phys.Rev.D 97 (2018) 5, 051102

Excited States: $D^*_{sJ} \to DK$



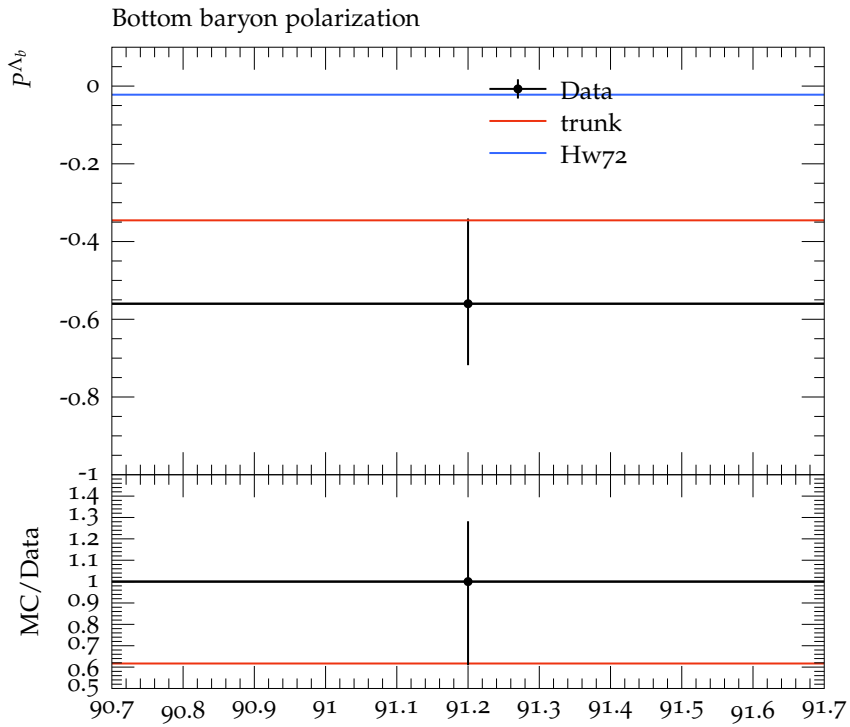


BaBaR Phys.Rev.D 80 (2009) 092003, LHCb JHEP 10 (2012) 151

Polarizations

Got interested in excited production rates

- improve modeling of heavy quark fragmentation.
- polarization shower→ heavy hadrons (effected by production rates)



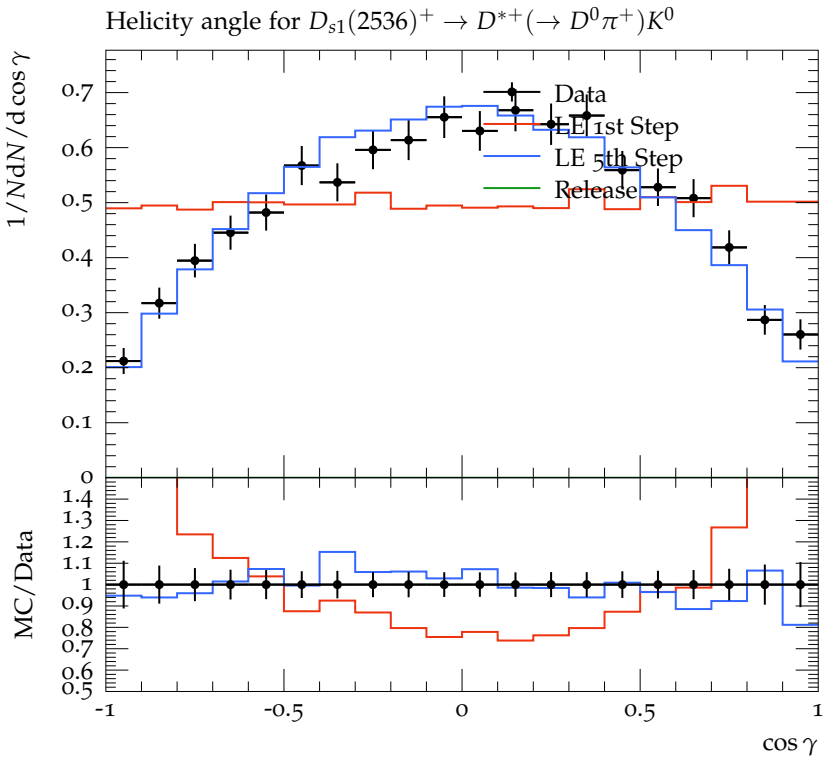
OPAL Phys.Lett. B444 (1998) 539-554

In progress: PR and M. Masouminia

Decays

Decays of excited states affect spectra and polarizations of the lighter states

- Often little data in HEPData or numerically.
- Rivet analyses based on extracting data from figures in papers



BELLE Phys.Rev.D 77 (2008) 032001

In progress: PR and M. Masouminia

Decays

- Particular problem with modeling hadron decays.
- EvtGen was tuned to private data by BaBar and BELLE.
- Little data publicly available, in many cases have to use results from ARGUS/CLEO I
- Would be great to get more data, numerically, in HEPData, and in Rivet.

Measurements

- We're in an era of precision physics at the LHC, we need measurements which will stand the test of time.
- Unless you're measuring a number in the PDG you should be able to write Rivet analysis of what you are measuring, otherwise you should really think about what it is you're doing.
- A good measurement will be used and stand the test of time.
- We have a duty to preserved the numbers (most funding agencies now require this) and really a Rivet analysis which can reproduce what was done.
- Very hard for us to use data without a Rivet analysis.

Conclusions

- We're in an era of high precision physics, with at the LHC unprecedented amounts of data.
- We need to use this to improve our models.
- Impossible if we can compare with the data.
- We often forget that most e^+e^- data is for centre-of-mass energies 10-11 GeV, we need to use this data more.
- Lots of areas where we can improve our models.