# b-fragmentation in experimental analyses


Peter Schleper, Markus Seidel, Hartmut Stadie

Universität Hamburg


Nov 29, 2013

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

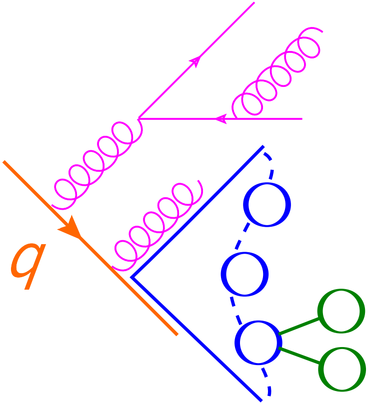
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

CMS

# Modelling of jets: From (b) quarks to detectable hadrons

1. Parton (from hard process)
2. Parton shower (Pythia, Herwig)
   - Gluon emission: $q \to qg$,
   - Gluon splitting: $g \to q\bar{q}, gg$
   - Good constraints from Z decays
3. Hadronization (Pythia, Herwig)
   - Non-perturbative formation of hadrons along colour strings
   - Steered by fragmentation functions and flavour parameters
4. Hadron decays (Pythia, Herwig, EvtGen)
   - Steered by decay tables




- Clean Z→hadrons events from LEP used for tuning model parameters
- Complete description of pp collisions also includes underlying event, colour reconnections...

Hadronization

Fragmentation functions

# Lund string fragmentation

- $q_0\bar{q}_0$ pair spans string with tension $\kappa \approx 1$ GeV/fm
- On string break
  - Production of new $q_1\bar{q}_1$ pair
  - $f(z) =$ fraction of $(E + p_z)$ taken by hadron $q_0\bar{q}_1$
  - $p_{x,y}$: Gauss with $\sigma = 0.3$ GeV
- Light flavour

$$f(z) \propto \frac{1}{z}(1-z)^a \exp\left(\frac{-bm_\perp^2}{z}\right)$$

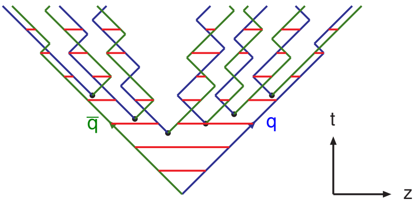
- Heavy flavour (Bowler extension)

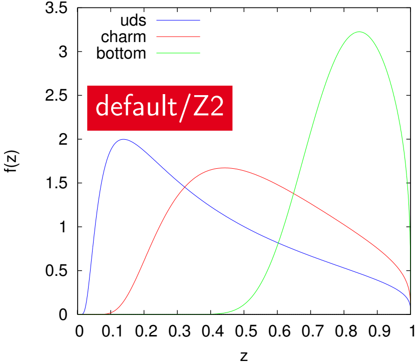
$$f(z) \propto \frac{1}{z^{1+r\cdot bm_\perp^2}}(1-z)^a \exp\left(\frac{-bm_\perp^2}{z}\right)$$

- Tunable parameters: $a, b, r$

  $a, b$ same for all flavours in Pythia6,
  $r$ can be separated to $r_c, r_b$

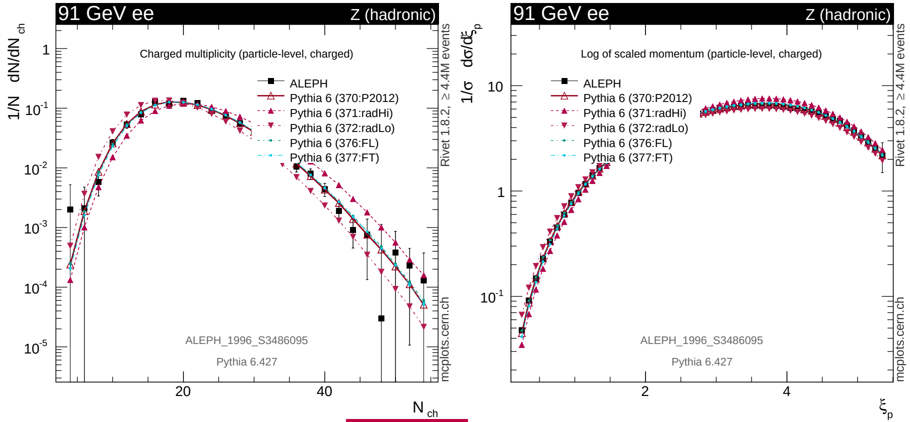
Motion of quarks and antiquarks in a $q\bar{q}$ system:



# All flavour fragmentation

- Use infrared-unsafe observables that are sensitive to hadronization
- $N_{ch}$, log of scaled momentum $\xi_p = -\ln(|p|/E_{beam})$
- P12FL → harder fragmentation, P12FT → softer fragmentation

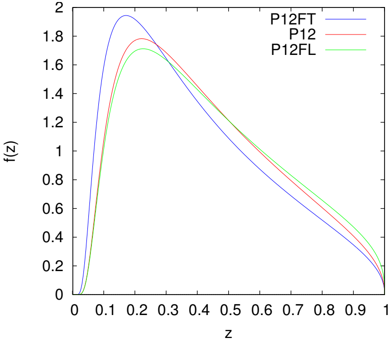


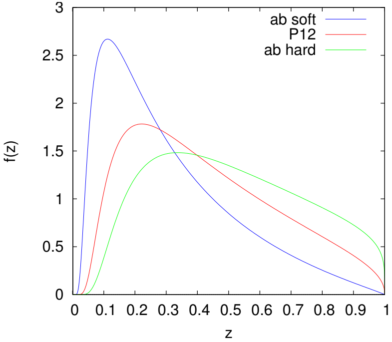

- Drawback: Sensitive to radiation, no visible impact of P12FL/FT

# Light-quark fragmentation variations

(left) P12 FT/FL variations

- Modest, cover spread of fragmentation tunings

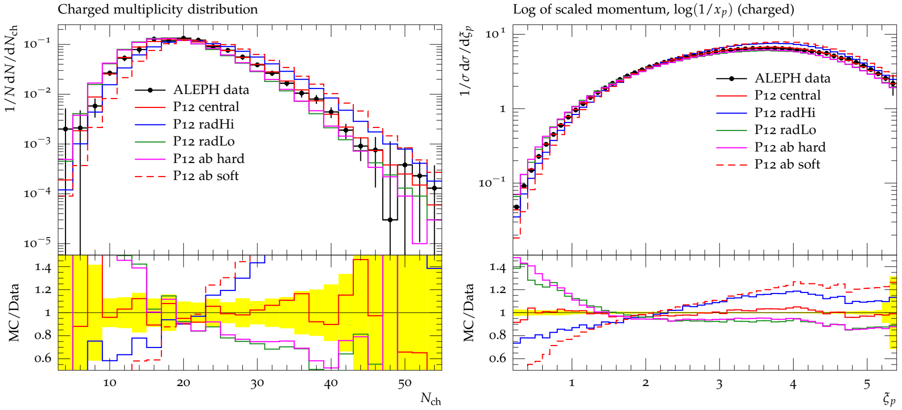



(right) P12 toy variations

- Try out large variations, modify universal parameters $a, b$
- Get feeling for impact of fragmentation functions

# Impact of large fragmentation variations



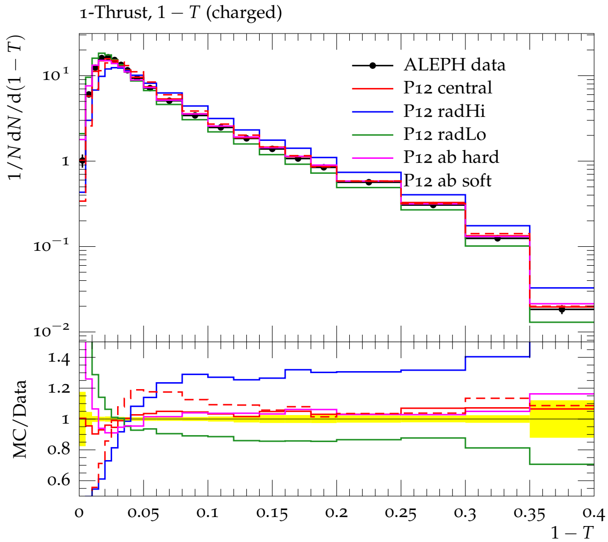

- Large fragmentation variations $\rightarrow$ visible impact on $N_{ch}, \xi_p$
- Behaviour still similar to radiation variation

# Disentangling fragmentation functions and radiation

**Thrust**

- 1-T=0: back-to-back
- 1-T=1/2: isotropic

- Different behaviour of event shapes for fragmentation and radiation
- Expect different scaling with $E_{beam}$




→ Take into account many measurements, iterate or use Professor

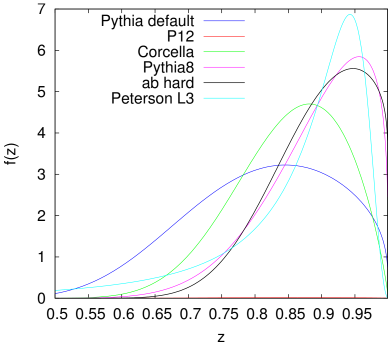
# Hadronization

## Fragmentation functions for bottom quarks

# b-fragmentation in LHC measurements

## Many functions on the market

- Different models (Bowler-Lund, Peterson, ...)
- Several parameter sets



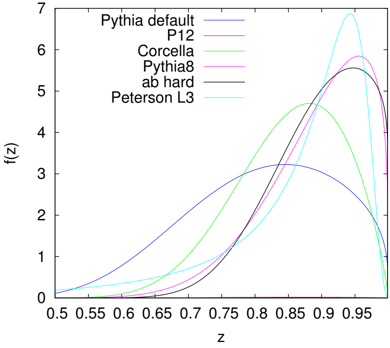

## Expect impact on...

- measurements of B hadrons or their decay products
- b-tagging for jets
- b jet energy scale: harder fragmentation $\rightarrow$ more energy in jet cone

# b-fragmentation function vs. observable $x_B$

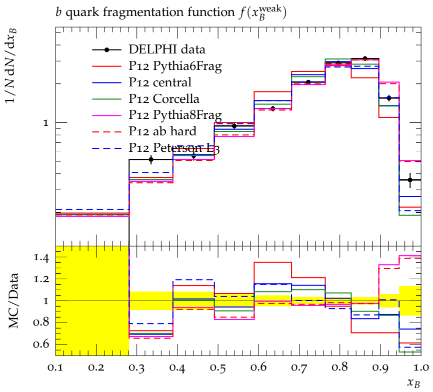
## Many functions on the market

- Different models (Bowler-Lund, Peterson, ...)
- Several parameter sets



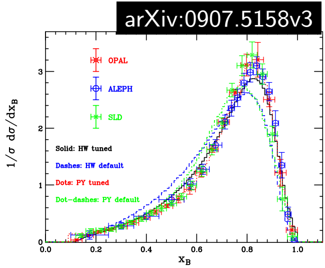

## Experimental observable

- Most useful: $x_B = E_B / E_{beam}$, with B-hadron $B$



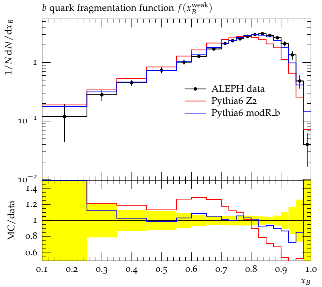
# Assigning an uncertainty on b-fragmentation

- Improved fit to $x_B$ by Corcella tune
- Compare default vs. Corcella?
- Issue: Impacts also light quarks
  - Included in jet energy corrections
  - Expect cancellation by simultaneous fits




## Variation based on Z2

- $r_b$ is relevant parameter for $x_B$ hardness, leave others ($a$, $b$) untouched
- Tuned to cover uncertainty on $x_B$

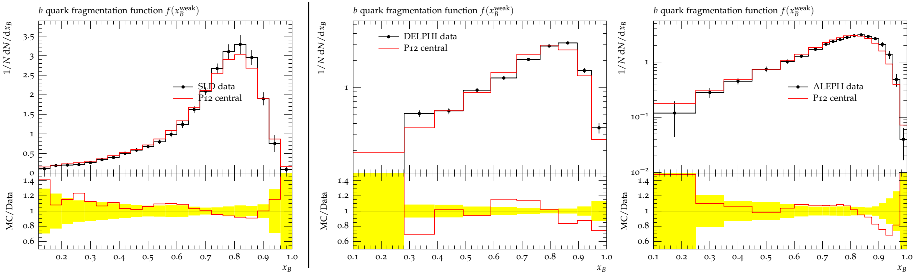



## Possible recipe

- MAX($x_B$ uncertainties,
  retune $r_b$ to minimal $\chi^2$)
- Would cover non-optimal hadronization tuning of Z2

# Which measurements to take into account?

- SLD vs. DELPHI vs. ALEPH (OPAL and L3 in Rivet?)



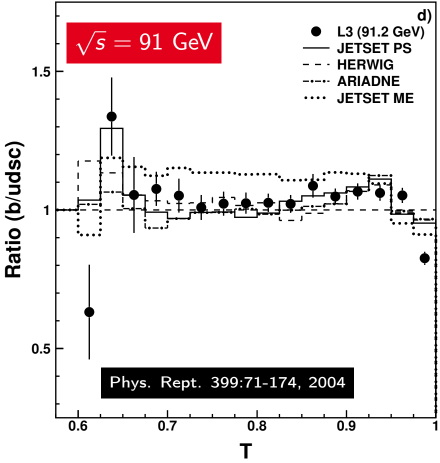

- SLD favors softer fragmentation but large uncertainties for high $x_B$, probably needs retuning of a,b to correct shape
- LEP favors harder fragmentation, decent description achievable by $r_b$ moving peak

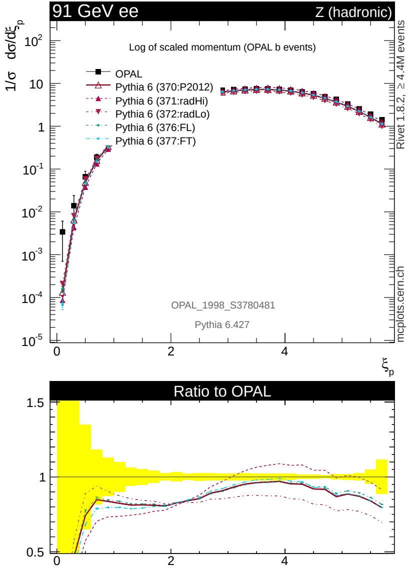
If $r_b$ variations give stable (and sensible) fit results for both:

- Could use SLD as *down*, LEP as *up* variation

# Other observables for b-fragmentation

- (left) Thrust ratio b/udsc at L3
- (right) Log of scaled momentum in b events



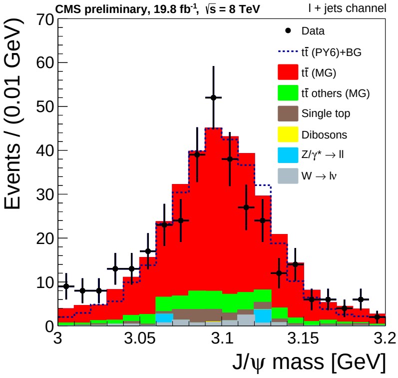



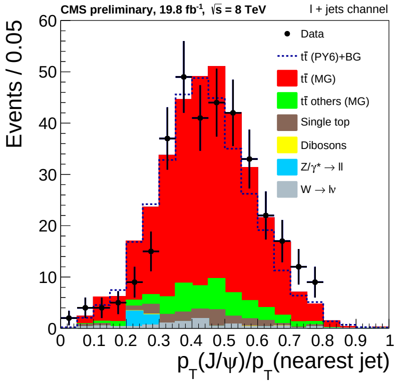
Hadron decays

$J/\Psi$ production

# New measurements based on $B \to J/\Psi + X$

- Preparations for measurement of $m_t$ using $B \to J/\Psi \to \mu^+\mu^-$ (CMS PAS TOP-13-007)

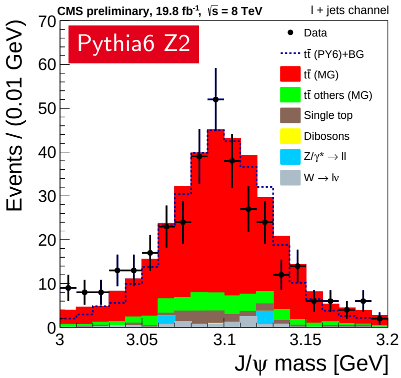


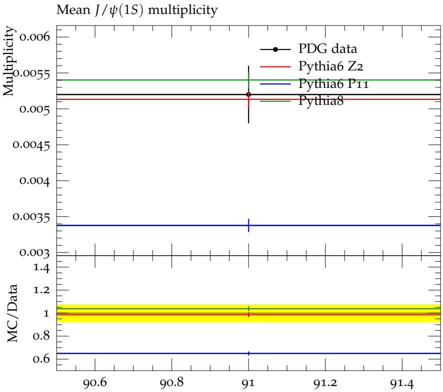




- Will allow to measure $m_t$ by $m_{\ell\mu^+\mu^-}$, independent of hadron responses
- Requires good understanding of $J/\Psi$ production inside b jets

# $J/\Psi$ in different tunes

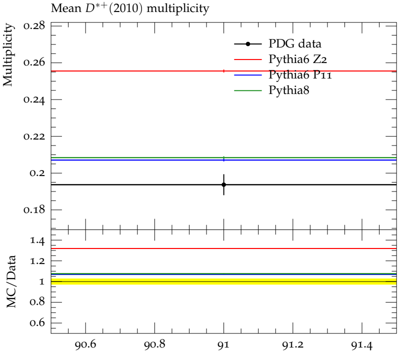
- Observation: Correct $J/\Psi$ multiplicity in tune Z2, too low in P11
- Mismatch also visible in LEP Z$\rightarrow$hadrons events

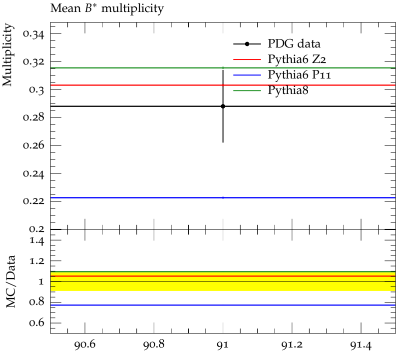


# Heavy-flavoured spin-1 mesons in different tunes

- Difference in Hadronization: Probabilities for charmed spin-1 mesons in flavour combination (Z2: P=0.75, P11: P=0.54)
- (left) P11 improves $D^{*+}$ multiplicity
- (right) P11 has too few $B^{*}$, may affect $J/\Psi$ $p_T$ (to be studied)
- How can it impact decay BRs to $J/\Psi$?



# $J/\Psi$ production in resonance decays

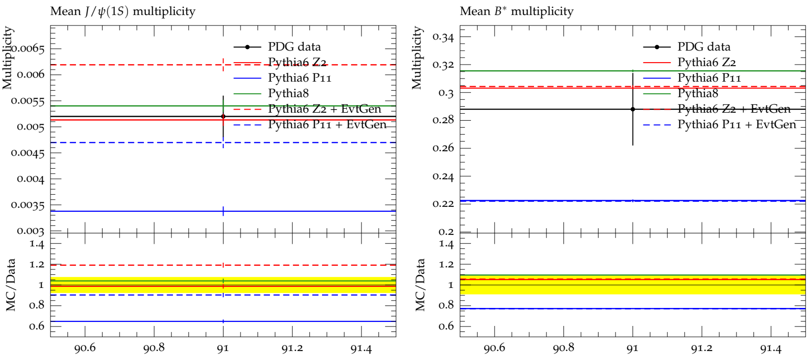
1. **Parton shower** Production via gluon emission and splitting
   - $c_1 \to c_1 g \to c_1 c_2 \bar{c}_2 \to J/\Psi + c_2$
   - Very rare: 6 $J/\Psi$ mesons in 20,000 $Z \to c\bar{c}$ events
2. **Hadronization** Charm/bottom not produced in string fragmentation
3. **Hadron decays** Specified in decay tables
   - Need $\mathrm{BR}\,(B \to J/\Psi + \ldots) \sim 0.013$ to get correct multiplicity
   - Explicit branching ratios to $J/\Psi$
     - Pythia6: $\mathrm{BR}\,(B \to J/\Psi + \ldots) = 0.002$
     - Pythia8: $\mathrm{BR}\,(B \to J/\Psi + \ldots) = 0.005$
   - Production via $\chi_{c1}, \Psi\,(2S)$ only in Pythia8 (BR$\sim$0.002)
   - Implicit branching ratio via decay to strings
     $B \to c\bar{c}\bar{s}\,(u/d)$ + subsequent flavour combination
     - $\mathrm{BR}\,(B \to \text{strings}) = 0.08 \leftarrow$ huge!
     - Meson formation then steered by **hadronization** parameters
     - Gives $\mathrm{BR}\,(B \to J/\Psi + \ldots) \sim 0.013 \times P\,(\text{charmed spin-1 mesons})$

# Hadron decays

# Improvements by EvtGen?

# EvtGen for $J/\Psi$ production

- EvtGen provides improved description of hadron decays
- Higher explicit BRs to $J/\Psi$ (like Pythia8)
- $J/\Psi$ rate in P11+EvtGen ok; too large in Z2+EvtGen




- Slight flavour retuning needed for using EvtGen correctly
- EvtGen not suitable as drop-in replacement, ongoing studies in CMS

# EvtGen: B meson decay parameters

## Lifetimes

| $c\tau$ | PDG (EvtGen) | Pythia6 |
|---|---|---|
| $B^0$ | 0.4557+/-0.0021 | 0.468 |
| $B^+$ | 0.4923+/-0.0024 | 0.462 |

- EvtGen uses PDG value
- Important for b-tagging but absorbed in scale factors
- Measurements based on B decay length need reweighting

## Semi-leptonic branching ratios

| BR | PDG $B \to \ell^+ \nu_\ell X$ (Pythia) | PDG $B \to D\ell^+ \nu_\ell X$ (EvtGen) |
|---|---|---|
| $B^0$ | 0.1033+/-0.0028 | 0.092+/-0.008 |
| $B^+$ | 0.1099+/-0.0028 | 0.098+/-0.007 |

- BR in EvtGen refers to less precise measurement, 1% difference
- Impact on the low-response tail of the jet response (per-mille level)

# Summary

- Precise top measurements at the LHC are becoming sensitive to finer aspects of modelling
- Improve understanding to decrease/solidify systematic uncertainties

## Hadronization

- Use variations of b-fragmentation to evaluate uncertainty
  - Procedure limited to $e^+e^-$ at $\sqrt{s} = 91$ GeV
  - Uncertainties for extrapolating to pp and higher energies?
- Useful to have: direct measurement of b-JES in pp

## Hadron decays

- Large portion of $J/\Psi$ production steered by hadronization parameters
- EvtGen improves description of B decays but needs some retuning