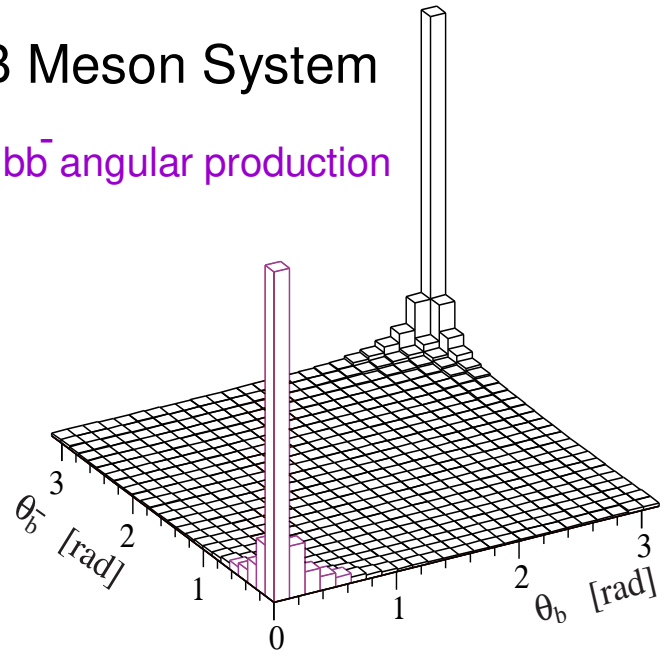
Event Generators in LHCb

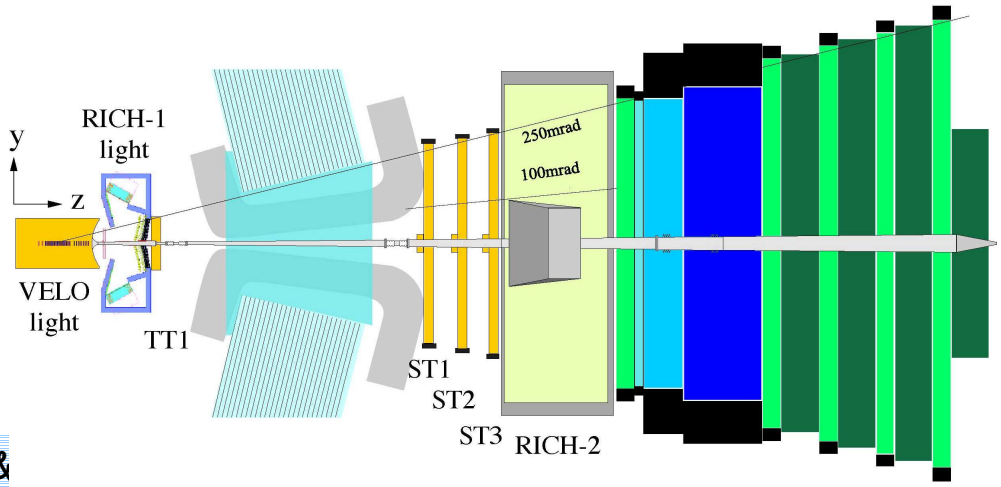
(with contributions from N. Brook and O. Schneider)

- Introduction
  - LHCb
  - Event generation framework
- Use of PYTHIA
  - Minimum bias
  - B-events
- HERWIG
- EvtGen
- Summary

LHCb Experiment

- Precision Measurements of CP violation in the B Meson System
  - measure CKM angles from the CP asymmetries in the final states of B-meson decays
  - large sample of events with Bd and Bs Mesons
  - most of the b hadrons are produced at small polar angles
  - possible to exploit b-hadrons correlation (both of them go either forward or both backward)
  - LHCb: Single Forward Arm Spectrometer with Open Geometry





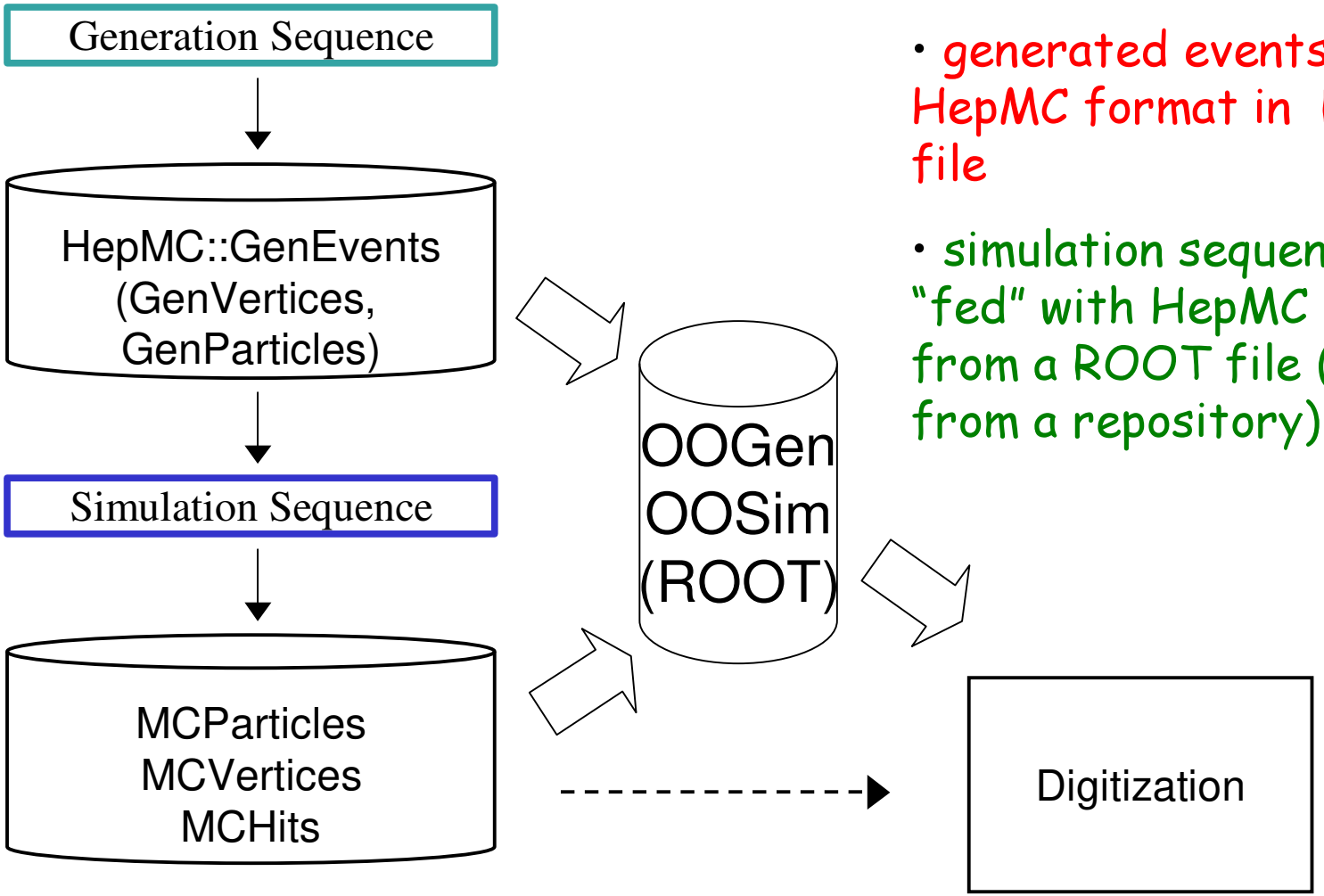
MC application – old way

- Fortran simulation application
- primary generator - Pythia 6.205
- decay package – QQ 9.02
  - called from within Geant3 (Fortran) event loop, to generate particular decay channels
  - a large number of existing “decay files” prepared (by LHCb)

MC application – new way

- underlying OO software framework (Gaudi) used by all LHCb event processing software
- all generators “wrapped” into C++ code to make them “callable and controllable” from within Gaudi framework
- primary generator - Pythia 6.205 (the same as before)
  - interfaced to HepMC
- decay package – EvtGen
  - interfaced to HepMC
  - using “forced decay” mechanism from Geant4 to generate particular channels
  - “decay files” need to be rewritten (translated from QQ)

Overall framework

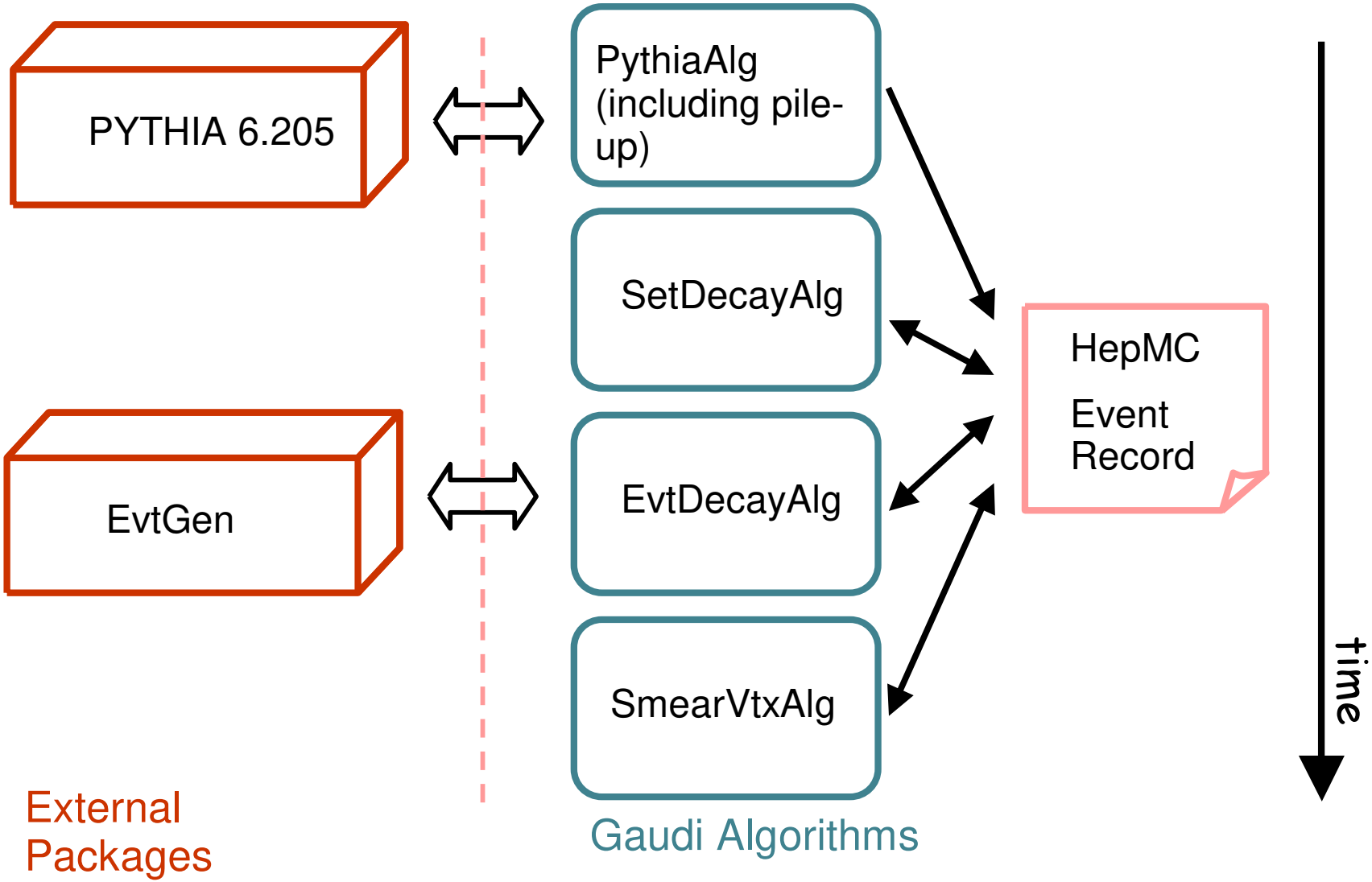


- possibility of running each stage separately or in sequence
- generated events saved in HepMC format in ROOT file
- simulation sequence can be "fed" with HepMC events from a ROOT file (coming from a repository)

Overall framework

- persistency provided by the expt (& LCG) framework (Gaudi, SEAL+POOL in the future)
- particle data provided by the framework (Gaudi ParticleDataSvc)
  - would like to interface it to “standard” HepPDT
  - service that should be provided by the future generic simulation framework?

Event generation sequence



Event generation sequence

- spillover handled at the digitization stage (several events combined with the time coordinate appropriately shifted)
  - should be done at generator level? (probably not)
- machine background – added at the digitization level

Current configuration

- currently LHCb use PYTHIA 6.205
  - tuned to UA5 data using a multiple (parton-parton) interaction model
  - use CTEQ4L (with appropriate Pt cut-off)
  - all events generated with msel=2
- b events are selected from min. bias events
- EvtGen used for decays (BaBar, Belle, CDF & D0)
  - replacing QQ v 9.02

Minimum Bias in PYTHIA

- Multiple interactions
  - needed to describe UA5 and CDF multiplicities.
  - Shape best described by varying impact parameter model with a single Gaussian matter distribution (LHCb99-028)
- pQCD cross-section divergent for small P_t
  - Regularise with running P_t cut-off (hep-ph/0001032)
- Energy dependence of P_t cut-off tuned for each PDF
  - Compare for predictions with PYTHIA 6.205
  - Using CTEQ4 L

Pythia - LHCb tuning

- Use non-single-diffractive data (UA5 and CDF)
- Values that minimise the difference from measured central dN/dη used to fit function,

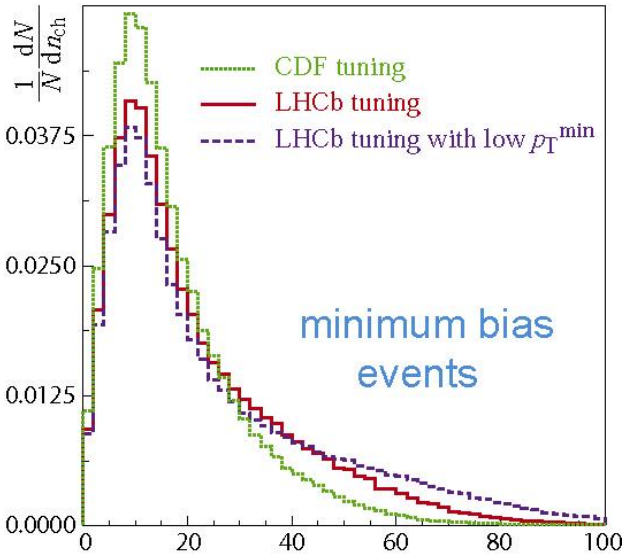
$$P_{T\,\min} = P_{T\,\min}^{LHC}\left(\frac{\sqrt{s}}{14TeV}\right)^{\varepsilon}$$

$$P_{T\,\min}^{LHC} = 3.47 \pm 0.17 \quad \text{GeV/c}$$

$$\varepsilon = 0.174 \pm 0.010$$

CDF tuning – uses double Gaussian for description of data (PYTHIA MI model 4)

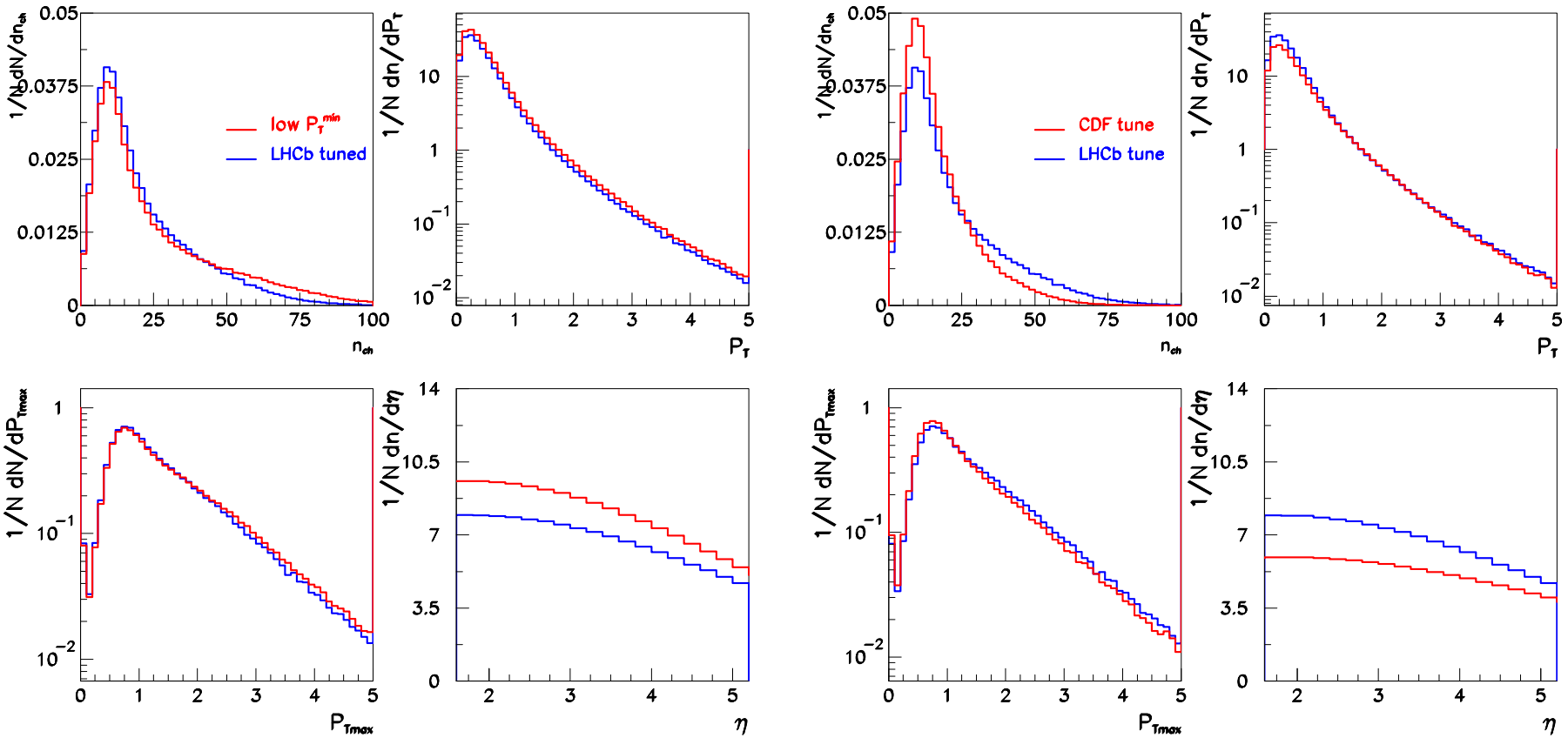
PYTHIA Event Multiplicity at LHCb



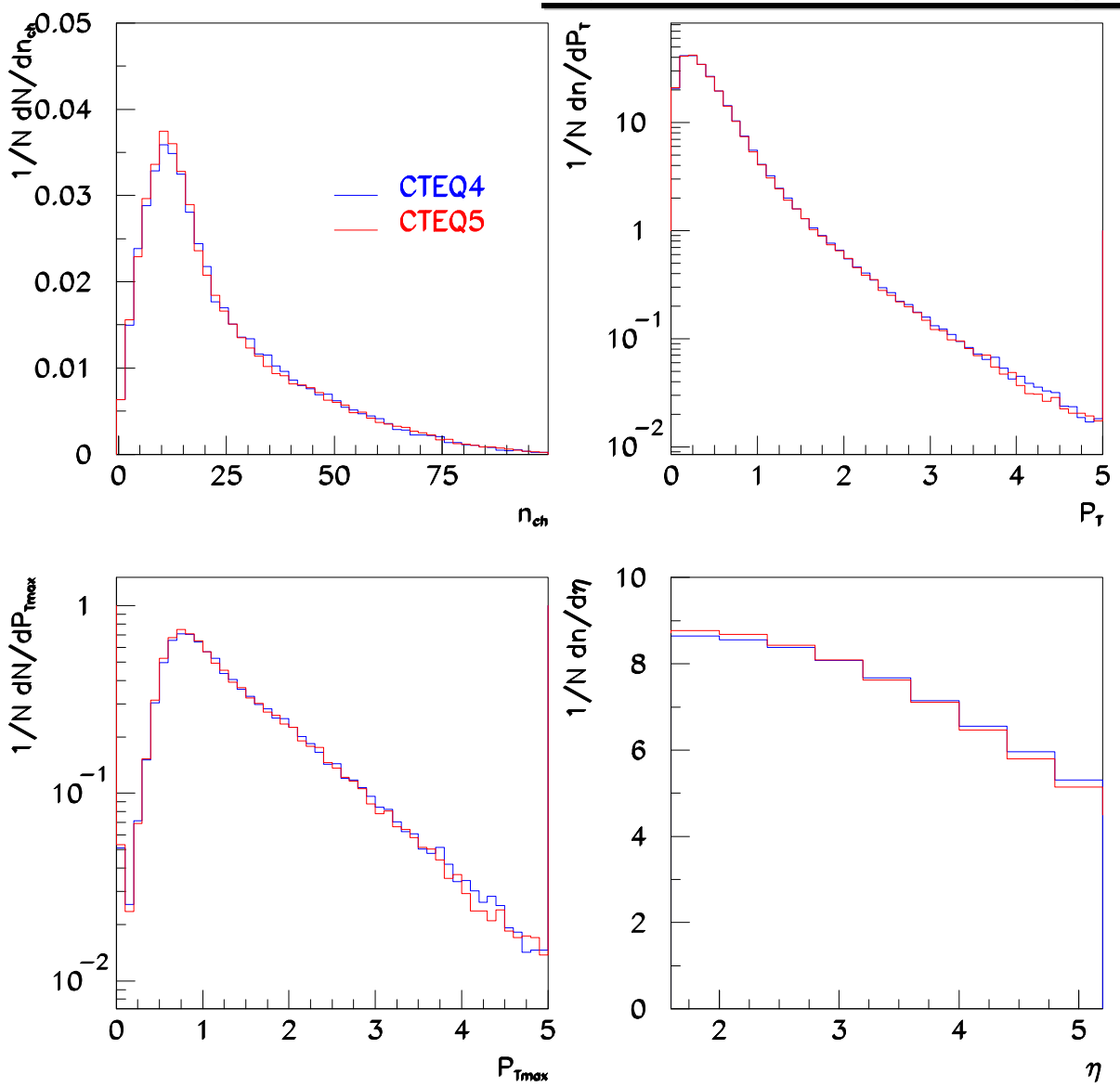
Average charged multiplicity	Minimum bias
CDF tuning at 14 TeV	16.53 ± 0.02
LHCb tuning, default p_T^{min}	21.33 ± 0.02
LHCb tuning, 3σ low p_T^{min}	25.46 ± 0.03

Min bias event shapes

No large differences in P_T distributions



Min bias events at LHCb



Changing PDFs (CTEQ4L & CTEQ5L)- again essentially identical for min bias events (for same tuning)

B^0 events at LHCb

- b events are selected from min. bias events
  - is there a better way?
  - what is the most realistic way of generating bb events?
  - important to better understand relative fraction of different bb production mechanisms (gluon fusion, etc)
- Forced Fragmentation:

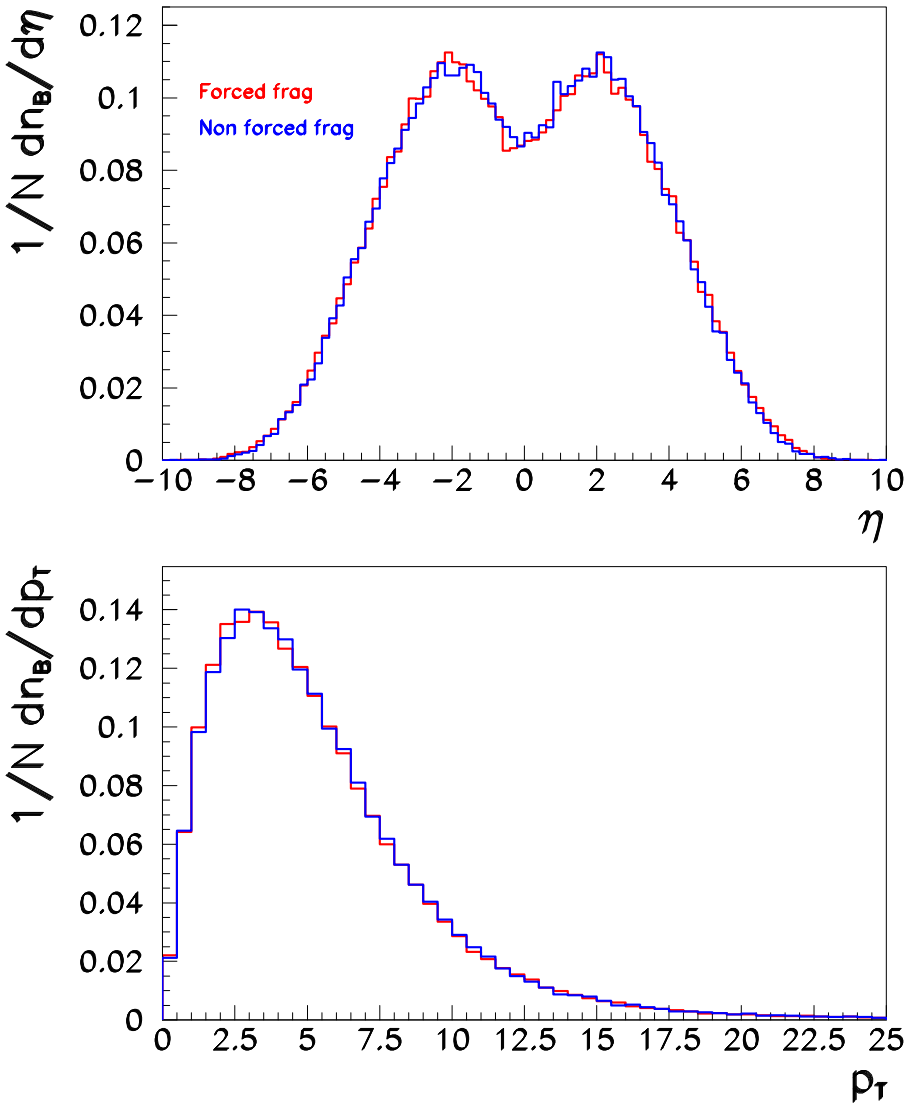
LHCb modified PYTHIA routine that selects the parton and hadron flavours in fragmentation (PYKFDI)

- Handles the fragmentation of b-quarks forcing the "transition" into any pre-selected hadrons
- Pre-selected B hadron always generated from string (i.e. no production from other B resonances)
- B kinematics been checked for Λ_b, B_c, B_s, B^+ and B_d

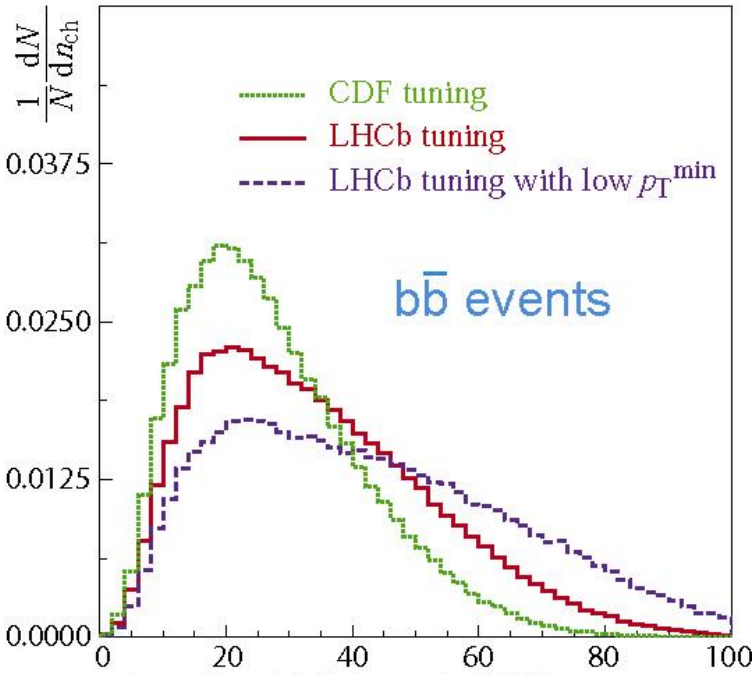
B^0 events at LHCb

Forced Fragmentation of B^0

η and p_T distributions between forced and "natural" fragmentation are compatible

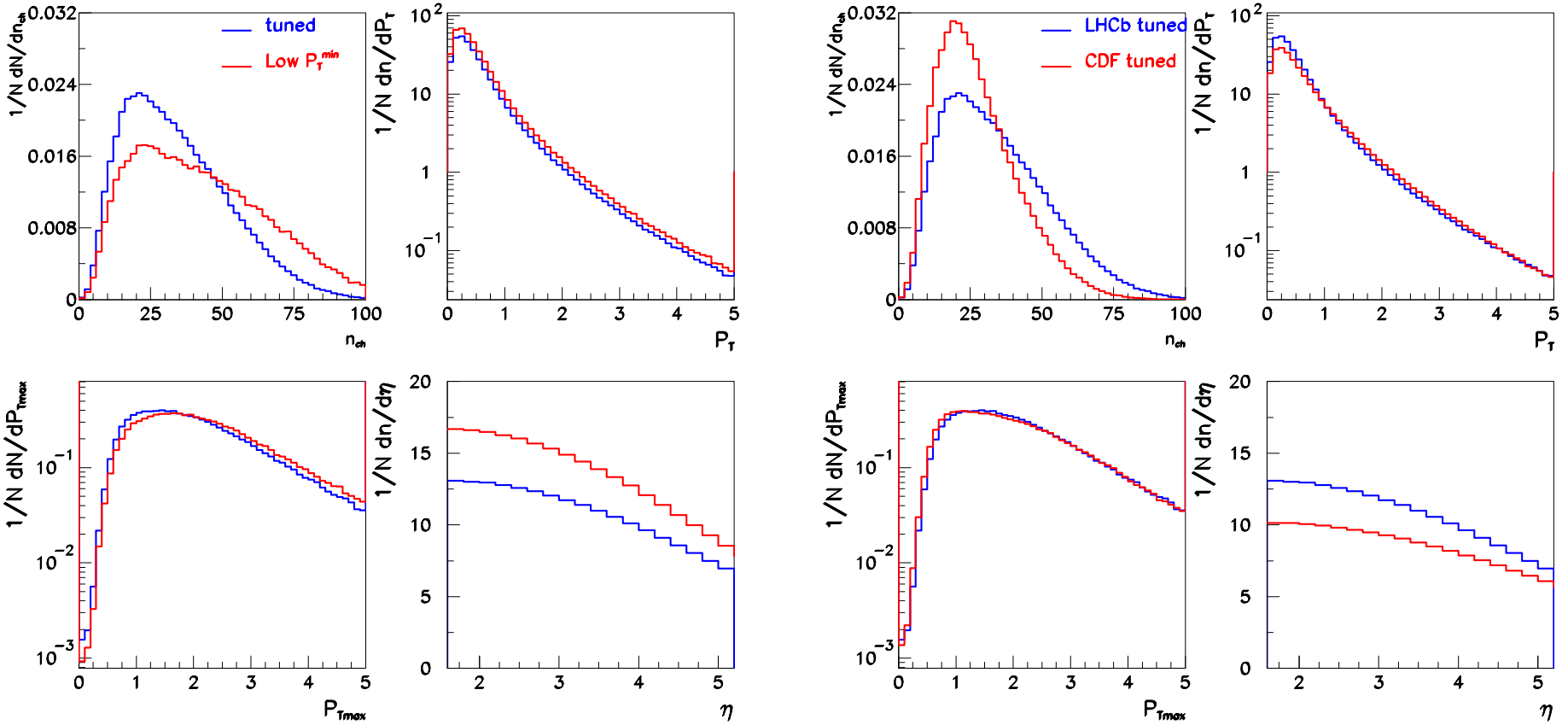


B^0 events at LHCb



Average charged multiplicity	bb
CDF tuning at 14 TeV	27.12 ± 0.03
LHCb tuning, default p_T^{min}	33.91 ± 0.03
LHCb tuning, 3σ low p_T^{min}	42.86 ± 0.03

B^0 events at LHCb



Differences in $\langle n_{ch} \rangle$ ~same % change for b-events

More noticeble difference in P_T dist^{bns}

Herwig

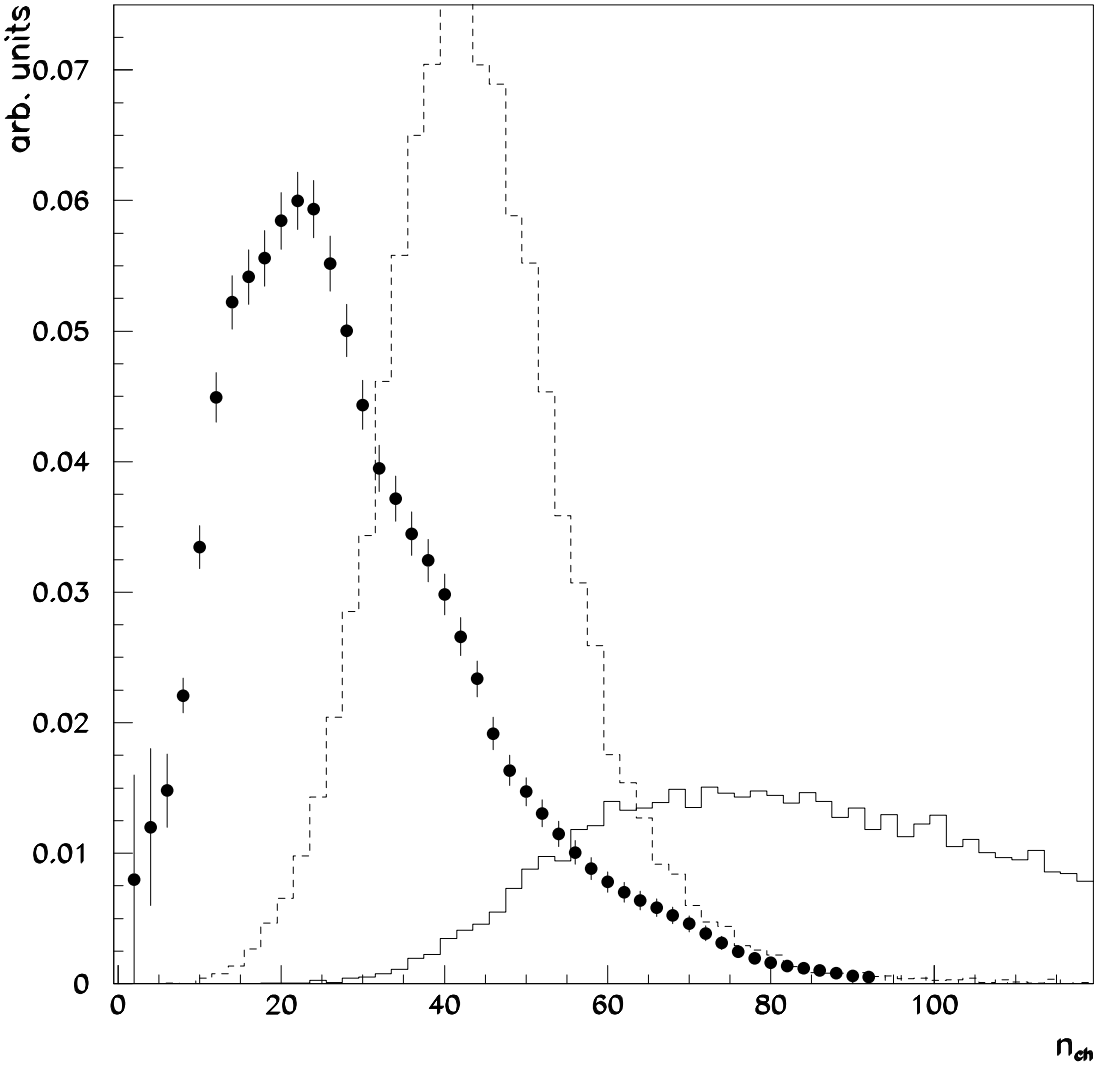
- seems interesting as an alternative to Pythia:
  - •Different hadronisation mechanism – clusters as opposed to strings
  - •Different implementation of parton showers – p_T ordering compared to angular ordering
  - •HERWIG known from e^+e^- to give larger contribution of gluon splitting to heavy quarks $g \rightarrow bb$
- but:
  - •no multiple interactions

Multiple Interactions in HERWIG

- In principle MI not available within HERWIG
- In practice, interface program (JIMMY – Butterworth, Forshaw & Walker) allows MI
- Also available, ad-hoc modelling of the “soft underlying” event (SUE - based on UA5 model)
- Parameter available for tuning in both JIMMY and SUE options.

Comparison of JIMMY and UA5 Data

- essentially one "free" parameter which is the p_T^{min} of the hard scatt.



As p_T^{min} ↑ the # of scatters decrease & predictions approach UA5 data.

Failed to find a setting that could describe the data. No further study presented here.

EvtGen

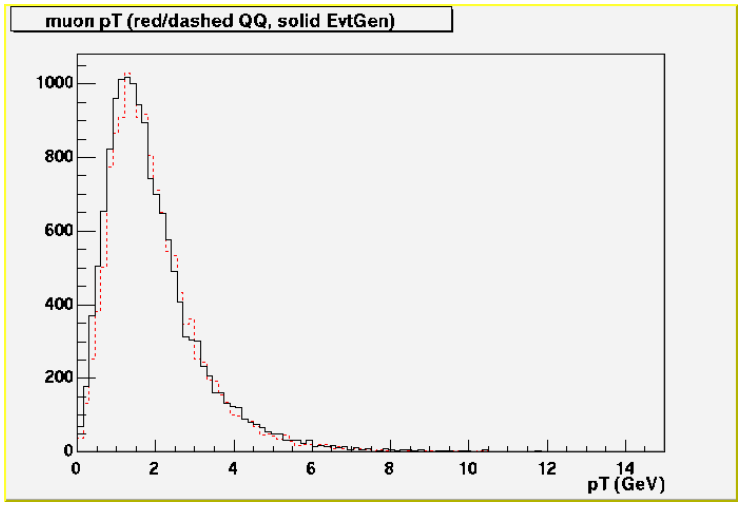
- we are (and will be) using it but are concerned with lack of “official” support, release policy, etc
- couldn’t EvtGen work directly with HepMC?
- common decay files (maintained by LCG)?

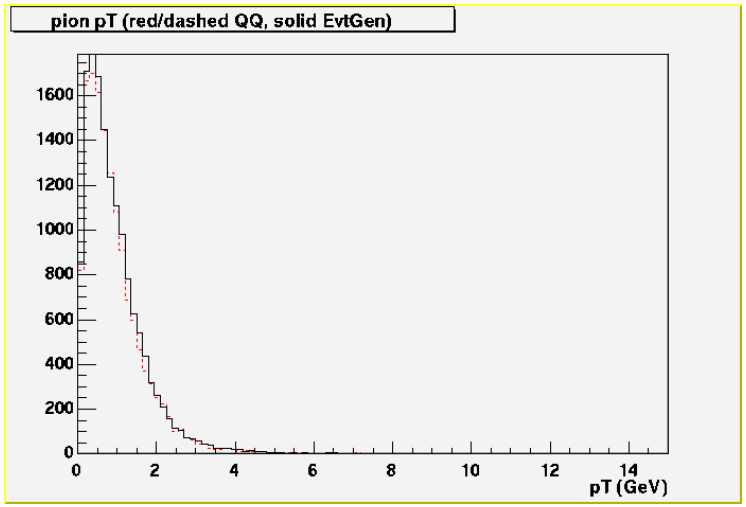
EvtGen vs QQ validation

- B0-> J/psi(mu mu) K0S(pi pi)
  - Muon and Pion pT distribution

QQ	EvtGen
No. = 14232	14904
Mean = 1.968	1.932
RMS = 1.247	1.309

QQ	EvtGen
No. = 14232	14904
Mean = 0.9362	0.949
RMS = 0.8014	0.8135





What we would like to have..

- tools for testing/comparing/tuning MC generators
  - Generic tools not used in LHCb so far
  - Welcome development of common project a la HZTOOL/JetWeb
    - Need to include hadronic data
      - UA5
      - FNAL – corrected data !!!!!!!!!!
- HERWIG
  - not yet used in LHCb
  - keen on seeing development in Herwig++

Summary

- "unhealthy" in hadron collider environment to rely on a single generator – but work still needed on HERWIG
- keen to see development of generic tools for use with generators
- exchange of knowledge on use of EvtGen in hadronic environment & e^+e^-
- better understand contribution from different bb production mechanisms
- keen to see 'official' support for EvtGen, HepMC and HepPDT(?)
- hope for w/s to develop cross collaboration (accelerator lab) programme of work