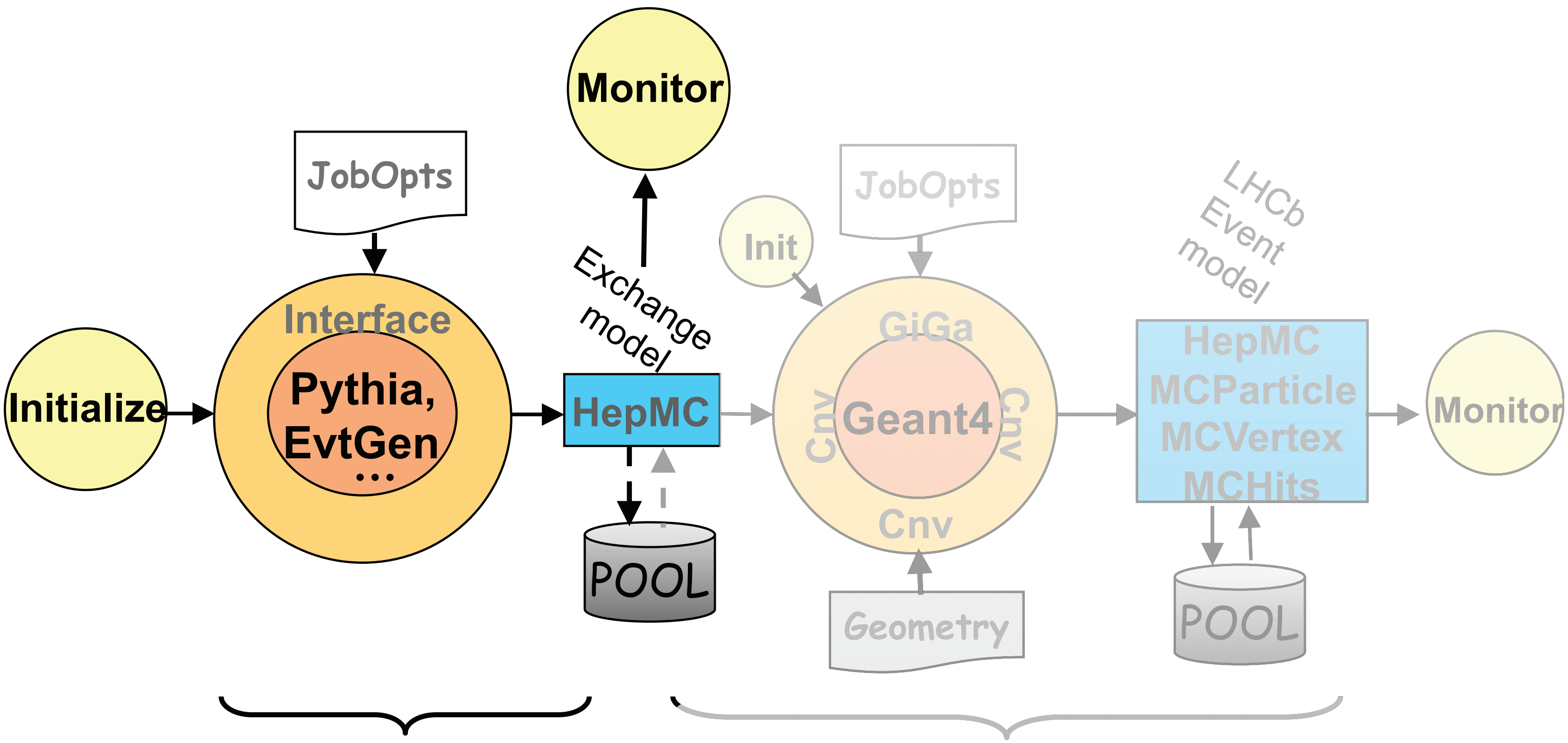
LHCb MC simulation

- The simulation application, Gauss, is a collection of “User Code” specialized for physics simulation based on the underlying OO software framework (Gaudi) used by all LHCb event processing software;
- Specialized algorithms and tools for generators (PYTHIA, EvtGen, ...) and detector simulation (Geant4);
- All generators “wrapped” into C++ code to make them “callable and controllable” from within the framework at run time.

LHCb MC simulation

Two INDEPENDENT phases normally run in sequence as in production, but generator phase can and it is run by itself.



Event Generation

primary event generator
specialized decay package
pile-up generation

Detector Simulation

geometry of the detector (LHCb → Geant4)
tracking through materials (Geant4)
hit creation and MC truth information (Geant4 → LHCb)

Generation of physics events

The generation algorithm uses tools, i.e. pieces of code realizing specific actions of the generation sequence:

- PileUpTool - Generation of number of pile-up events
- SampleGenerationTool - generate a given sample of events (minimum bias, inclusive, signal, ...)
- ProductionTool - Generation of one p-p interaction
- BeamTool - Generation of beam parameters (3 momentum)
- DecayTool - Decay of unstable particles,
- CutTool - Cut at generator level,
- FullGenEventCutTool - Cut on full event properties,
- VertexSmearingTool - Smearing of primary vertex.

Each tool has a generic interface and (at least) one specific implementation. This allows to use different methods to realize each action. For example, generation of p-p interactions can be done with PYTHIA or HERWIG, without changing the rest.

Generators used in production

The functionality of Production and Decay tools is implemented using external generator libraries

- PYTHIA6 to generate pp interactions up to hadronization - LHAPDF for PDF
- EvtGen to generate the decay and evolution of all particles, B hadrons, generic and user/signal.
  - delegate to PYTHIA when decay not present in decay table (called internally)
  - delegate to Photos for QED radiative corrections (called internally)

Ensure both production and decay use the same particle properties (masses, lifetimes, ...) via Gaudi particle property service;

HepMC used not only to save the events on output but also as exchange format between production and decay.

Current configuration

- PYTHIA 6.421.(2)
- LHAPDF 5.7.1
- Photos 215.(5)
  - Called inside the EvtGen package.
  - Used to generate radiative corrections for every decay modes.
  - We follow the updates. If the C++ version will be available, we are interested to test it.
- EvtGen - v11r6: version obtained by merging in 2009 the contributions from Babar, Belle, CDF, LHCb (A. Rys), with additional LHCb changes, models and updated decay files
  - B^0, B_s mixing
  - $B_s \to J/\psi\Phi$ correct time dependant angular distributions
  - rare semileptonic decay model using Wilson coefficients (e.g. $B \to K^*\mu\mu$
- HEPMC 2.03.(1)

Libraries linked directly from LCG builds

Evt. types, generator meth.

Minimum Bias: Keep all events generated by PYTHIA: elastic, diffractive, inelastic.

Inclusive: Extract events generated by PYTHIA with at least one b-(or c) hadron in 400 mrad w/r to the z axis. If all of these hadrons have $p_z < 0$, flip the whole event.

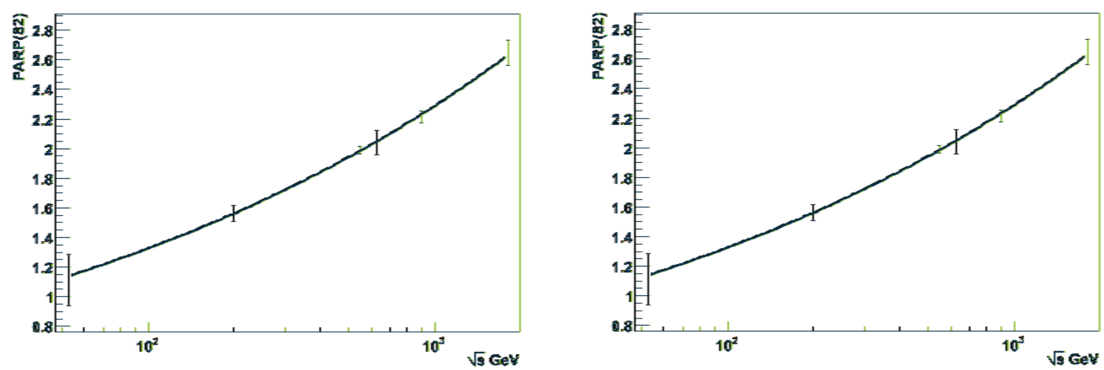
Signal: Extract events generated by PYTHIA containing one $B^{\pm}$ (or one $B^0/\bar{B}^0$, J/ψ, D_s^+/D_s^-, e.t.c.) in 400 mrad. If there are several candidates, choose randomly one. If it has p_z<0, flip the whole event. To speed up generation, if the interaction contains a b quark, repeat the hadronization process of PYTHIA until the interaction contains the B^+/B^-. Decay the signal candidate according to a forced channel with EvtGen. Decay B** and B mixing with EvtGen.

Special(Higgs, top, W, Z, ...): Keep all events generated by PYTHIA with special settings and passing specific generator level cuts (p_T(lepton) > 4 GeV). Decay Higgs, top, W, Z, ... with PYTHIA, all other particles with EvtGen.

PYTHIA @ LHCb

- PYTHIA 6.4 (LHAPDF-CTEQL61) with Interleaved Multiple Interaction (MI) model tuned to agree with experiments measured particle multiplicities;
- Retune $p_{T,min}$ (done in the past for PYTHIA 6.2 with old MI model)
- Tune to central charge particle densities from UA5 and CDF
- Find PARP(82) value for new MI model at each energy
- PARP(82) extrapolated to LHC energy using equation (suggested by PYTHIA)

$$p_\perp = p_{\perp min}{}^{LHC} \left(\frac{\sqrt{s}}{14TeV}\right)^{2\epsilon}$$



- Included in the retune are the PARJ(11 - 17) settings tuned to correctly reproduce excited meson states important for us relative fraction of B mesons

LHCb-99-028

PYTHIA @ LHCb

Introduce Color Octet Model for Quarkonia production:

- only prompt J/ψ was generated in the past with color-singlet model
- known not to reproduce correctly production at Tevatron, now generate prompt J/ψ with also color-octet production (available in PYTHIA 6.4)
- larger cross section + harder spectrum
- add possibility to produce simultaneously $\psi(2S)$, ψ(3770), $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, $\Upsilon(4S)$ and $\Upsilon(5S)$.

LHCb-2007-042

PYTHIA 8

- not yet used for production but integrated in GAUSS, consistency checks with PYTHIA 6, working and giving reasonable results; the integration rather easy.
- Still details to study: status code of particles, repeated hadronization method, use of user processes, ...
- validation work discontinued two years ago due to the lack of manpower although latest version available in Gauss.

Other generators in Gauss

Gauss allows to use other production and decay engine than the default ones

- HERWIG 6.510.(3) + Jimmy 4.31.(3) + MC@NLO
- Hijing 1.383.bs.2 for beam-gas events
- HiddenValley HV 0.403
- AlpGen 2.1.2

Other generators in Gauss

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- HERWIG 6.510.(3) + Jimmy 4.31.(3) + MC@NLO
  - A $b\bar{b}$ event generator different from PYTHIA useful for estimates of systematic uncertainties.
  - Work in progress to resolve some outstanding issues: correct handling of MC@NLO negative weights; correct behaviour for pile-up; checking/optimisation of tunable parameters.
  - Interfacing to MC@NLO is difficult: implemented as a standalone program rather than as a library of routines; designed so that results need to be written to file for rereading, and can't be passed directly to a showering routine.
  - Limited support for further development in this area at present. In future may move to HERWIG++, and use POWHEG instead of MC@NLO.
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  - Code embedded into LHCb framework and run inside Gauss generator step.
  - The update of the code, built within the LHCb environment (to e.g. newer version of original HV), is not trivial task.
- AlpGen 2.1.2

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- AlpGen 2.1.2
  - used it to simulate 4b, 4c and 2b2c-events, which are considered as one of the major background for Hidden Valley and other high-pt physics.
  - work has been done with large help of theory people from John Hopkins University
  - not working within new Gauss versions, recommissioning phase.

Other generators in Gauss

- BCVEGPY
- SHERPA 1.3.

Other generators in Gauss

- BCVEGPY
  - extension to PYTHIA
  - for Bc production, private build
- SHERPA 1.3.

Other generators in Gauss

- BCVEGPY
- SHERPA 1.3.
  - Sherpa as ProductionTool with EvtGen as well as PYTHIA with Sherpa as DecayTool.
  - Sherpa as DecayTool: Signal decays are possible, but CP-violation does not work when using signal decays. Mass smearing still complicated, as PYTHIA particles have to come on-shell. Work in progress.
  - Sherpa as ProductionTool: Incl. $b\bar{b}$ is possible but need to use PYTHIA for Pile-Up, as Sherpa can not produce Minimum Bias. Inclusion of Minimum Bias, would be a feature we would be happy to see in near future.
  - Sherpa as Production+DecayTool: Is planned, as it would help us to benefit from the spin correlations used in Sherpa. As long as no Minimum Bias is available in Sherpa, we will have to use PYTHIA for Pile-up.
  - Wish list: We would really appreciate if signal decays would become standard in Sherpa, e.g. part of the Run.dat steering files. Most important topic for us is correct simulation of CP violation when using signal decays as well as the correct simulation of the influences of CP violation on the angular distributions, e.g. in $B_s \rightarrow J/\psi\Phi$ or $B_s \rightarrow \Phi\Phi$ etc.

Other generators in Gauss

- BCVEGPY
- SHERPA 1.3.

Small experiment, not infinite amount of people, hard to find people to integrate the generators in our framework, but ...

Gauss is able to read the ”external” events produced by any generator in LHA format both as parton-level ”hard” event, where Gauss will perform the subsequent hadronization, and as ”final hadronized” event.

We can study practically all generators if one offers as input LHA-xml or HepMC Ascii files . For production through full simulation chain, on the Grid, one needs though to interface them to Gauss