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SIMUB – a dedicated generator for B-meson production and decays

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SIMUB generator

- **SIMUB** has been originally developed for CMS by A. Bel'kov and S. Shulga
  It needs no modifications to be used for HERA-B
- **The starting version** of the package SIMUB is installed and tested on Linux (RedHat 6.x, 7.x) platform
- **The package and documentation** for user one can find on the SIMUB Package Home Page:
  http://cmsdoc.cern.ch/∼shulga/SIMUB/SIMUB.html
- **Lepton modes of B decays** were included in the generator with taking into account their full dynamics (time evolution, spin-angular correlations):
  - **Decays of $B_d^0\,,\bar{B}_d^0$ mesons:**

$$B_d^0\,,\bar{B}_d^0 \to D(\to K\pi)\,l\nu$$
$$B_d^0\,,\bar{B}_d^0 \to D^*(\to D\pi)\,l\nu$$
$$B_d^0\,,\bar{B}_d^0 \to J/\psi(\to ll)\,K^*(\to K\pi)$$

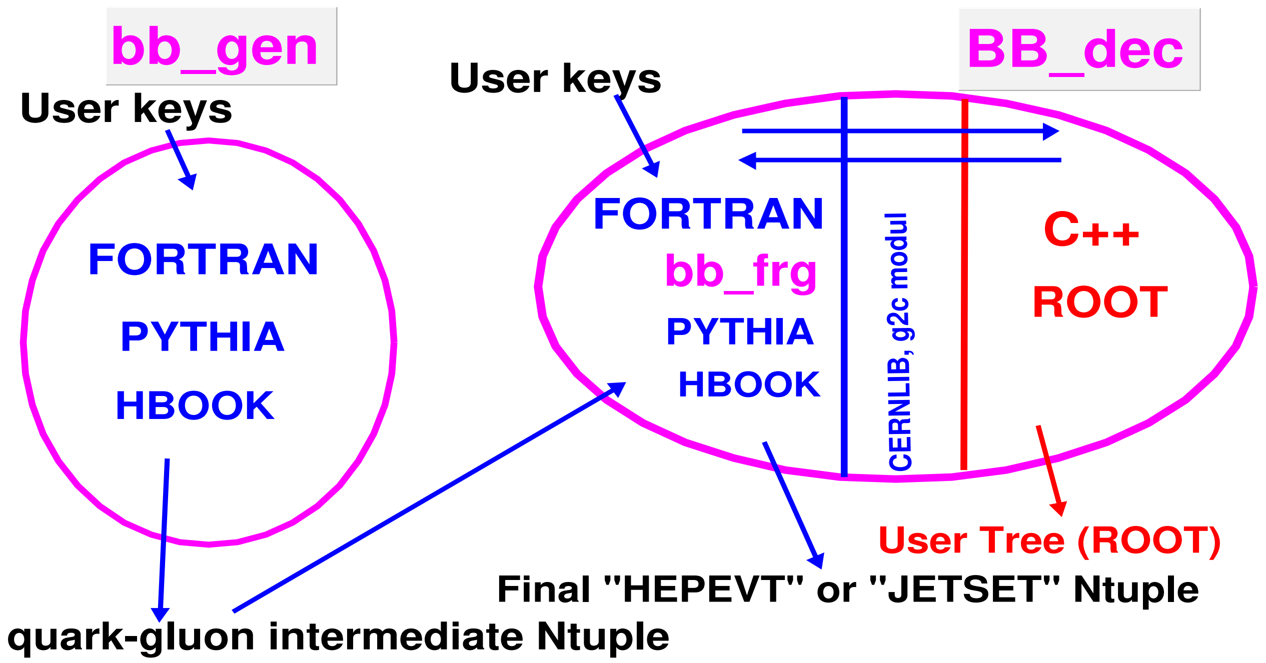
  - **Decays of $B^\pm$ mesons:**

$$B^\pm \to D(\to K\pi)\,l\nu$$
$$B^\pm \to D^*(\to D\pi)\,l\nu$$
$$B^\pm \to J/\psi(\to ll)\,K^*(\to K\pi)$$

  - **Decays of B_s^0, $\bar{B}_s^0$ mesons:**

$$B_s^0\,,\bar{B}_s^0 \to D_s(\to KK)\,l\nu$$
$$B_s^0\,,\bar{B}_s^0 \to J/\psi(\to ll)\,\phi(\to KK)$$

Structure and data flow



Programs:

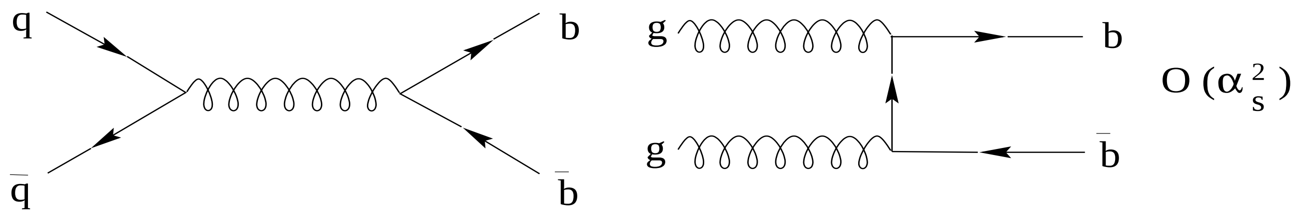
- bb_gen – generates $b\bar{b}$ events and stores them into JETSET ntuple (FORTRAN, PYTHIA)
- BB_dec – performs fragmentation, simulates B decays and stores full event into standard HEPEVT or JETSET ntuple (C++, ROOT, PYTHIA, FORTRAN)

Data files:

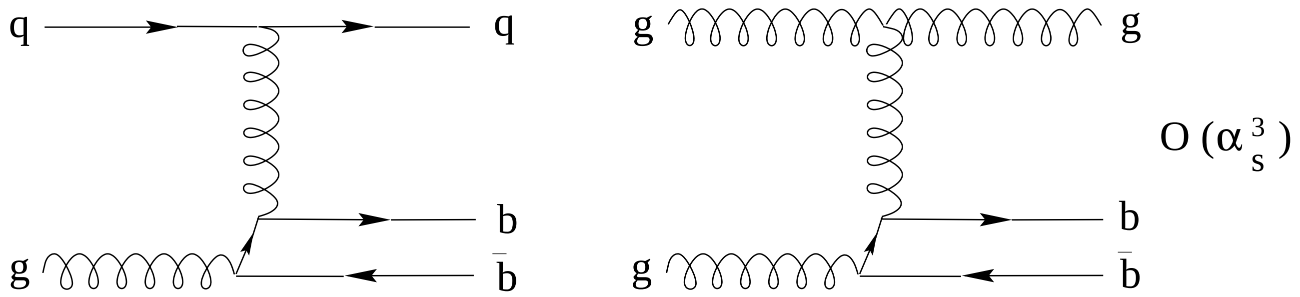
- bb_X_YYY – $b\bar{b}$ quarks (ntuple)
- bb_frg.ntpl – B-mesons (ntuple)
- BB_dec_tab – decays of B-particles (text-file)
- HEPEVT.ntpl – full event kinematics (ntuple)

Correlated $b\bar{b}$ production

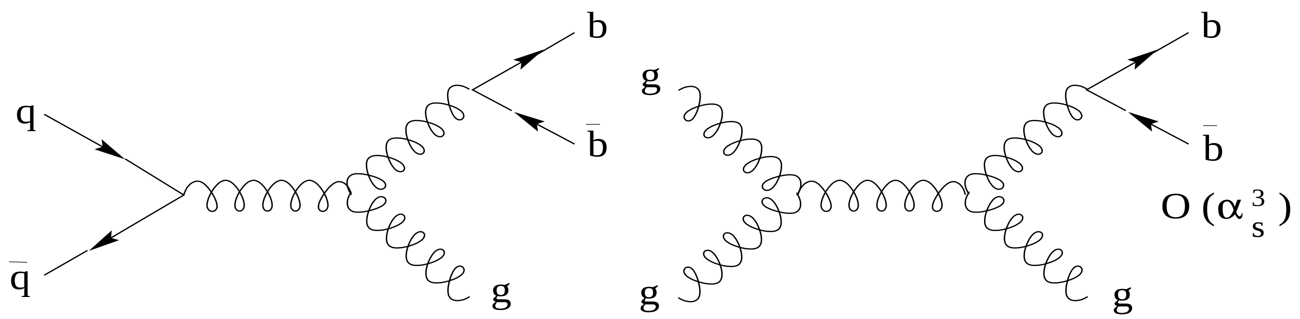
- **Direct production** in the hard scattering processes of parton fusion $q\bar{q} \to b\bar{b}$ or $gg \to b\bar{b}$:



- **Flavour excitation:** a heavy flavour from the parton distribution in proton is put on the mass shell by the hard scattering $bq \to bq$ or $bg \to bg$ with a parton of the other proton ($g \to b\bar{b}$) splitting in the initial-state shower evolution:

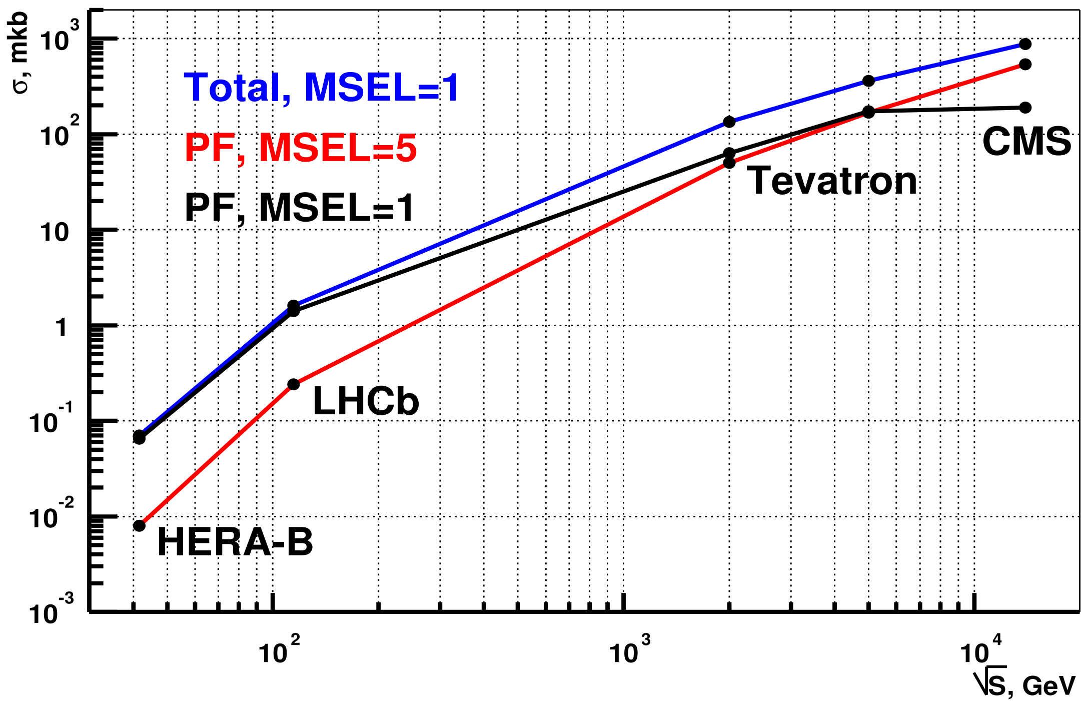


- **Gluon splitting:** splitting $g \to b\bar{b}$ in the final-state shower evolution, but without production of any heavy flavours in the hard scattering:



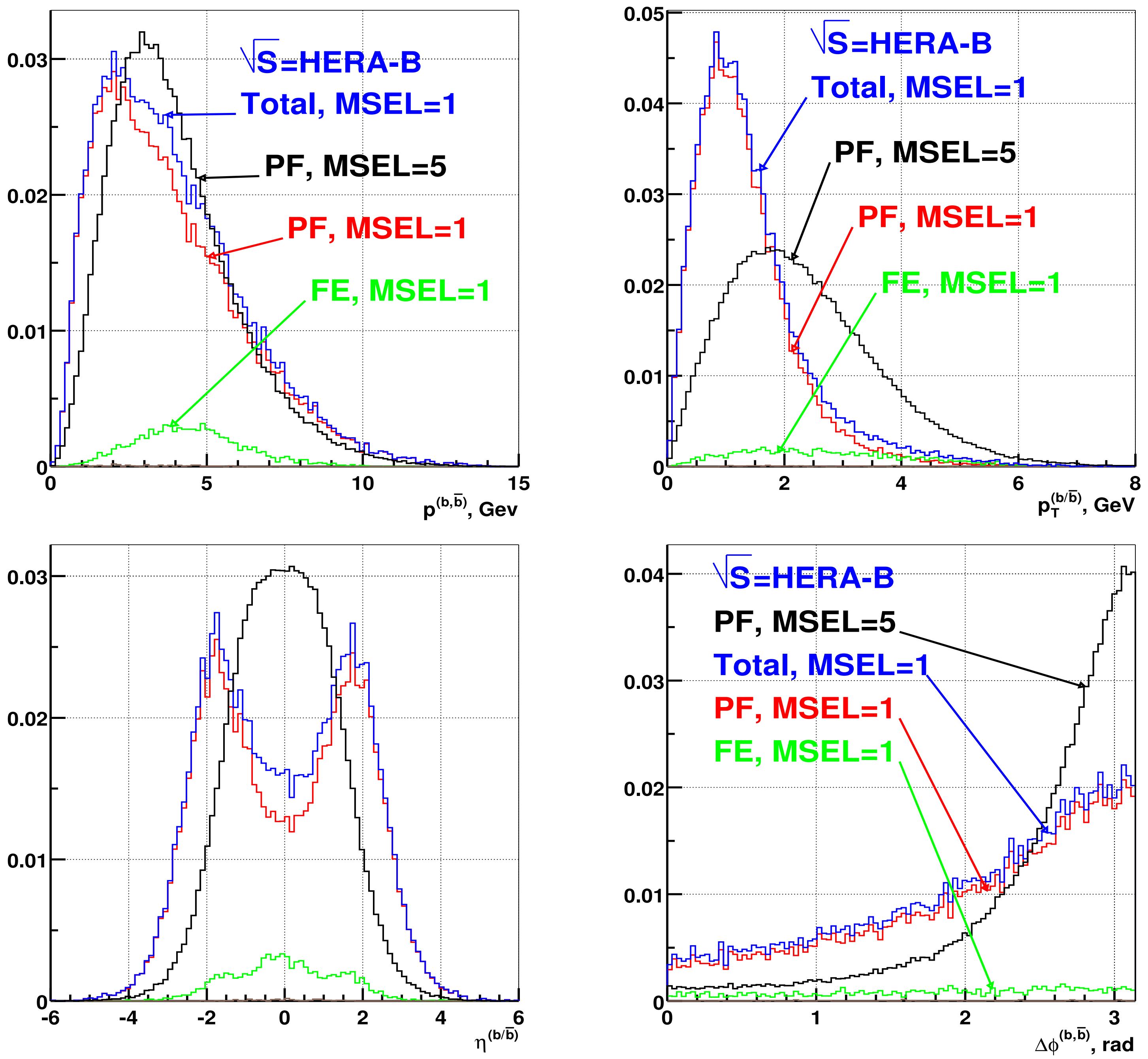
Production of $b\bar{b}$ pairs

- **Minimum bias events, MSEL = 1**
  - All QCD $2 \to 2$ subprocesses
  - All three mechanisms (parton fusion, flavour excitation, gluon splitting) contribute to $b\bar{b}$ production
    The rate of $b\bar{b}$ events is about $\sim 10^{-6}$ of all generated pp interactions
  - Massless matrix elements are used for quark generation
- **Bottom $b\bar{b}$ production, MSEL = 5**
  - In each event the $b\bar{b}$ pair is generated
  - Only parton fusion contributes to the $b\bar{b}$ production
  - Massive matrix elements are used for quark generation
- At HERA-B energies the parton fusion dominates
- At LHC energies the NLO order graphs of flavour excitation and gluon splitting dominate

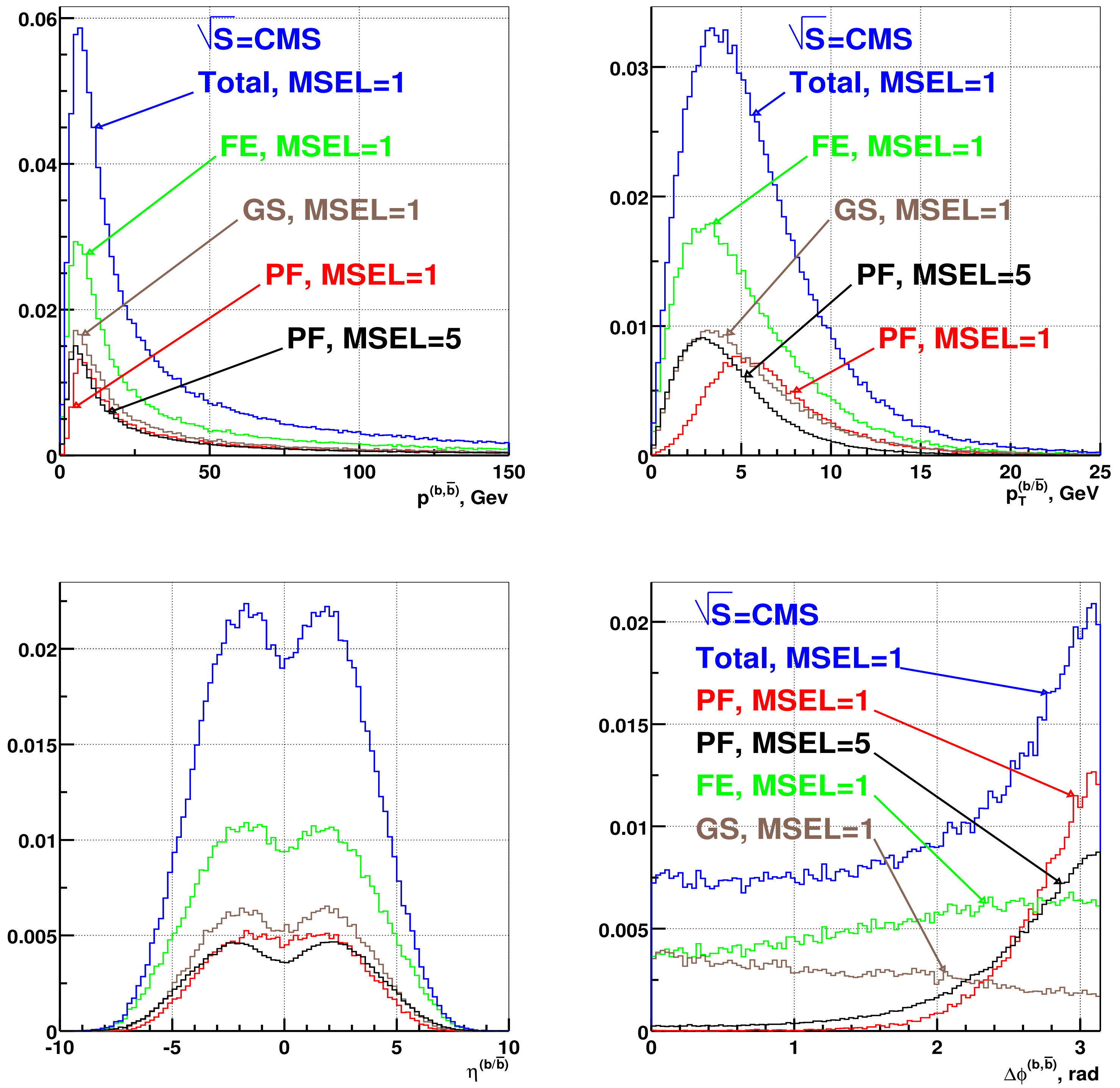


Contribution of mechanisms

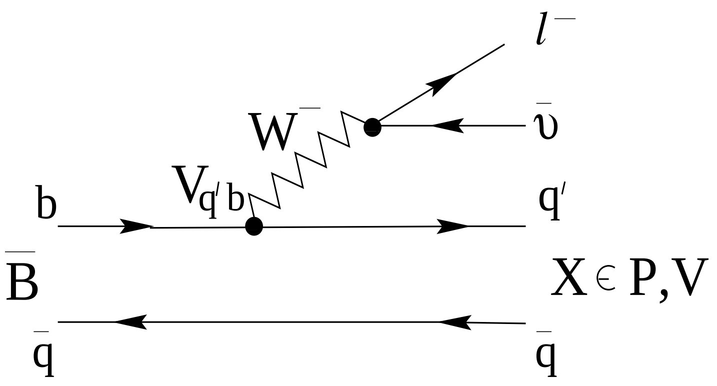
HERA-B: $\sqrt{S} = 41.6$ GeV, CM frame
Distributions of $b\bar{b}$ on momentum p, transverse momentum p_T, pseudorapidity $\eta = \frac{1}{2}\ln(\frac{p+p_L}{p-p_L})$, and azimuthal angular distance $\Delta\phi$

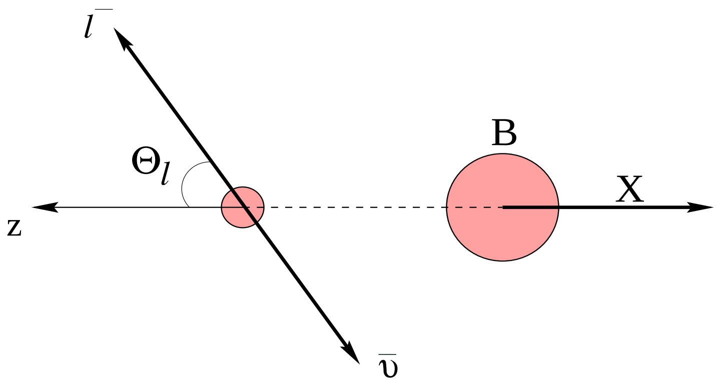


LHC: $\sqrt{S} = 14$ TeV, CM frame



Semileptonic B decays





- Momentum transfered and angular distribution for $B \to Xl\nu$ ($X \in P, V$) in general case:

$$\frac{d\Gamma(\overline{B}_q \to X_{q'\bar{q}} l\nu)}{dq^2\, d\cos\theta_l\, d\chi_l} = \frac{G_F^2}{(2\pi)^4}|V_{q'b}|^2 \frac{(q^2-m_l^2)P_X}{8M_B^2 q^2} L_{\mu\nu}H^{\mu\nu}$$

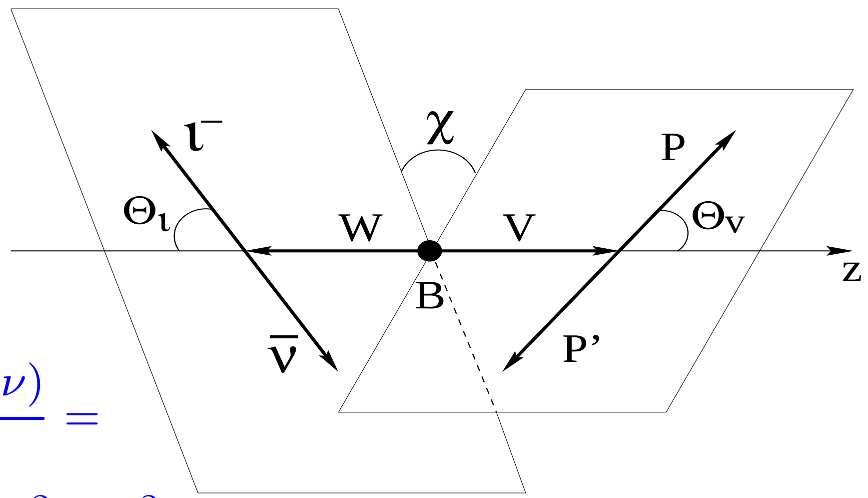
- For decays $B \to Pl\nu$:

$$L_{\mu\nu}H^{\mu\nu} = \frac{1}{2}(q^2-m_l^2)\,[\sin^2\theta_l |H_0^P|^2$$
$$+\frac{m_l^2}{q^2}(\cos^2\theta_l|H_0^P|^2 + |H_t^P|^2 + 2\cos\theta_l\,\mathrm{Re}(H_t^P H_0^{P*}))]$$

- For decays $B \to Vl\nu$:

$$L_{\mu\nu}H^{\mu\nu} = \frac{1}{4}(q^2-m_l^2)\,\{(1+\cos^2\theta_l)(|H_+^V|^2 + |H_-^V|^2)$$
$$+2\sin^2\theta_l\,|H_0^V|^2 + 2\eta\cos\theta_l(|H_+^V|^2 - |H_-^V|^2)$$
$$+\frac{m_l^2}{q^2}[\sin^2\theta_l\,(|H_+^V|^2 + |H_-^V|^2) + 2\cos^2\theta_l\,|H_0^V|^2$$
$$+2|H_t^V|^2 + 4\cos\theta_l\,\mathrm{Re}(H_t^V H_0^{V*})]\}$$

❖ For decays $B \to V(\to PP')l\nu$:



$$\frac{d\Gamma(\overline{B}_q \to V_{q'\bar{q}}(\to PP')l\nu)}{dq^2\, d\cos\theta_l\, d\chi_l\, d\cos\theta_V} =$$

$$B(\to PP')\frac{G_F^2}{(2\pi)^4}|V_{q'b}|^2\frac{(q^2-\mu^2)P_V}{12M_B^2 q^2}$$

$$\times\frac{9}{32}\{4|H_0|^2(\sin^2\theta_l + \frac{m_l^2}{q^2}\cos^2\theta_l)\cos^2\theta_V$$

$$+(|H_+|^2 + |H_-|^2)(1+\cos^2\theta_l + \frac{m_l^2}{q^2}\sin^2\theta_l)\sin^2\theta_V$$

$$+2\eta\,(|H_+|^2 - |H_-|^2)\cos\theta_l\,\sin^2\theta_V + 4|H_t|^2\frac{m_l^2}{q^2}\cos^2\theta_V$$

$$-2\mathrm{Re}(H_+H_-^*)(1-\frac{m_l^2}{q^2})\sin^2\theta_l\,\cos 2\chi\,\sin^2\theta_V$$

$$-\mathrm{Re}(H_+H_0^* + H_-H_0^*)(1-\frac{m_l^2}{q^2})\sin 2\theta_l\,\cos\chi\,\sin 2\theta_V$$

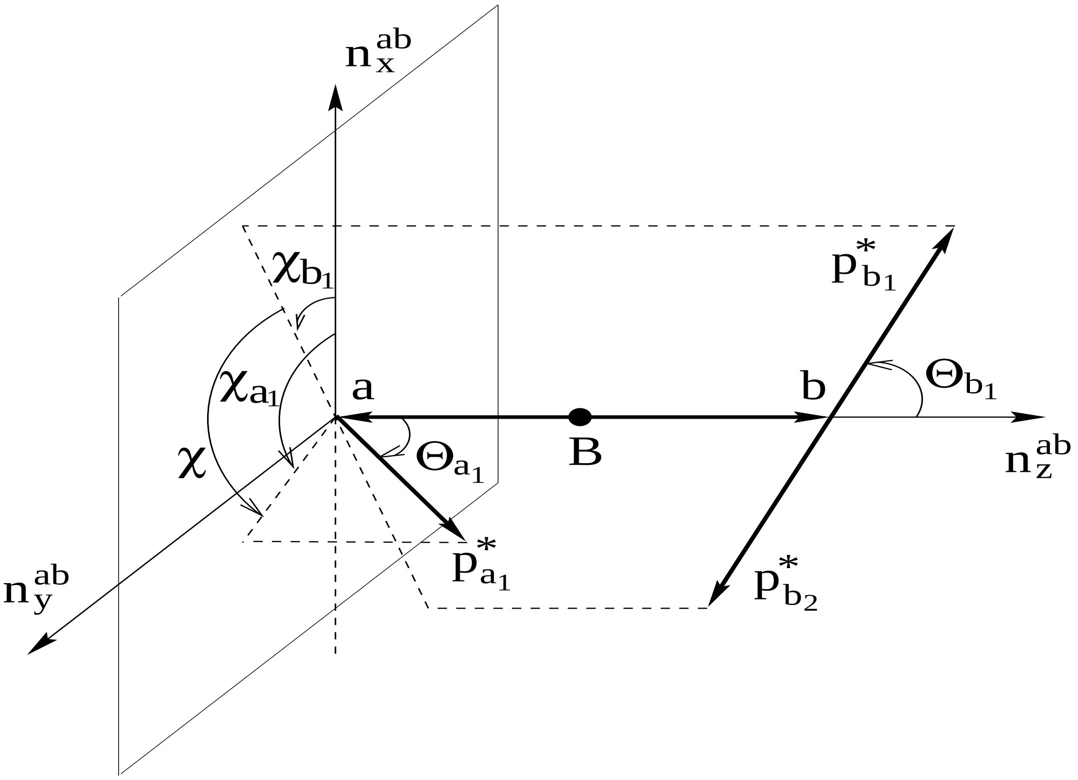
$$-2\eta\mathrm{Re}(H_+H_0^* - H_-H_0^*)\sin\theta_l\,\cos\chi\,\sin 2\theta_V$$

$$+8\mathrm{Re}(H_tH_0^*)\frac{m_l^2}{q^2}\cos\theta_l\,\cos^2\theta_V$$

$$+2\mathrm{Re}(H_+H_t^* + H_-H_t^*)\frac{m_l^2}{q^2}\sin\theta_l\,\cos\chi\,\sin 2\theta_V\}$$

Decay $B_s^0 \to J/\psi(ll)\phi(KK)$

- Helicity frame for $B_s^0 \to b(\to b_1 b_2)a(\to a_1 a_2)$



- Angular distribution:

$$\frac{d^3\Gamma_t}{d\cos\Theta_{a_1}\, d\cos\Theta_{b_1}\, d\chi} \propto |A_0(t)|^2 4\cos^2\Theta_{b_1}\sin^2\Theta_{a_1} +$$
$$|A_{||}(t)|^2 2\sin^2\Theta_{b_1}(1-\sin^2\Theta_{a_1}\cos^2\chi) +$$
$$|A_{\perp}(t)|^2 2\sin^2\Theta_{b_1}(1-\sin^2\Theta_{a_1}\sin^2\chi) -$$
$$\mathrm{Im}(A_{||}^*(t)A_{\perp}(t))2\sin^2\Theta_{b_1}\sin^2\Theta_{a_1}\sin 2\chi +$$
$$\mathrm{Re}(A_0^*(t)A_{||}(t))\sqrt{2}\sin 2\Theta_{b_1}\sin 2\Theta_{a_1}\cos\chi +$$
$$\mathrm{Im}(A_0^*(t)A_{\perp}(t))\sqrt{2}\sin 2\Theta_{b_1}\sin 2\Theta_{a_1}\sin\chi$$

$A_0(t)$, $A_{||}(t)$, $A_{\perp}(t)$ – transversity amplitudes
There time evolution is defined by physical parameters:
$A_0(0)$, $A_{||}(0)$, $A_{\perp}(0)$, Γ, $\Delta\Gamma$, Δm, ϕ

B-decay generators

- QQ – is used in CLEO and LHCb collaborations
  Cascade decays are generated successively and the decay products can correlate on angle Θ_{a_1}, Θ_{b_1}. No correlation on angle χ

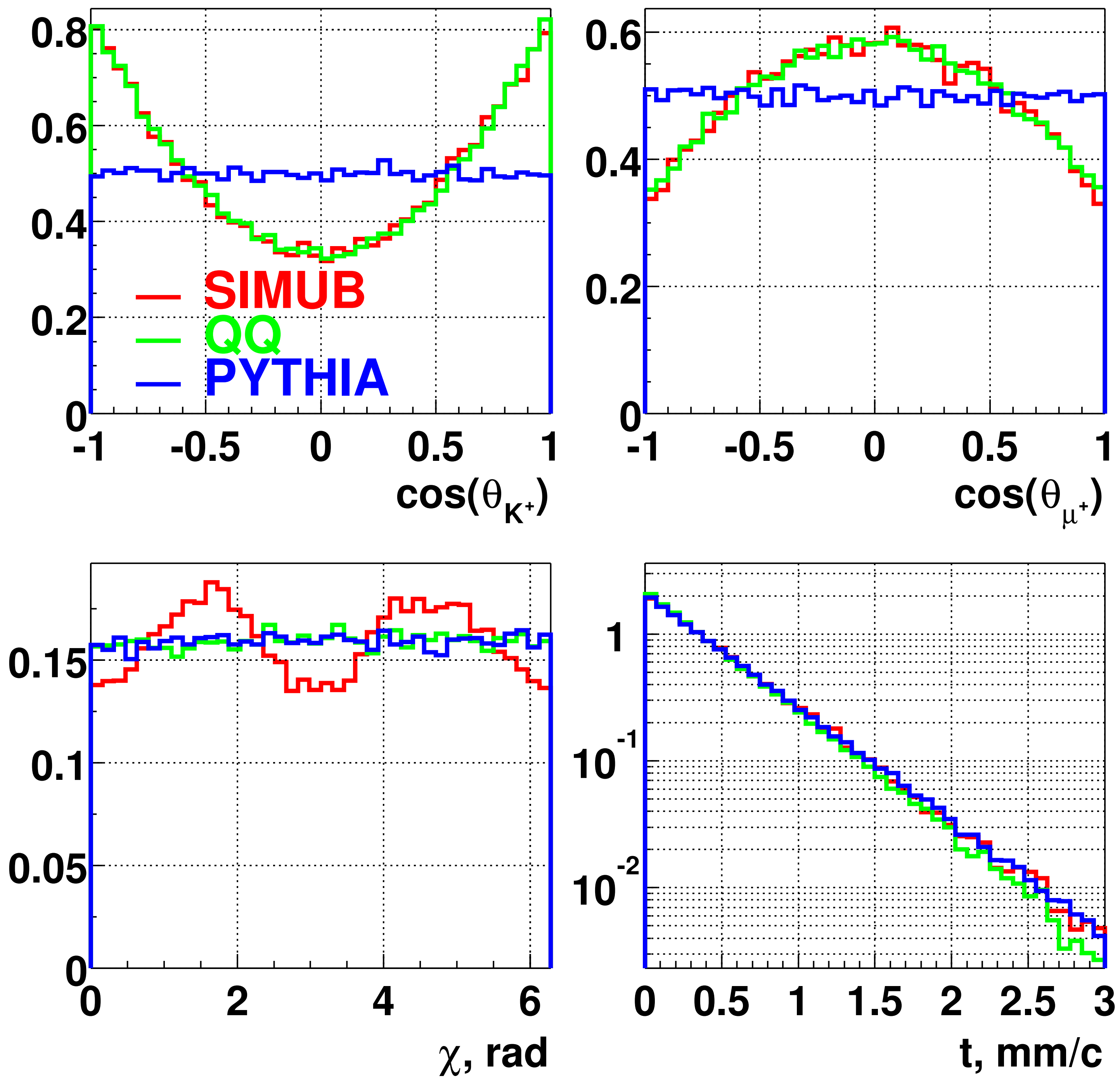
- Pythia – performs decays just into phase space without taking into account spin-angular correlations

- EvtGen – is used in BaBar collaboration
  Decays of $B_s^0, \bar{B}_s^0$ are not included in the package

- SIMUB – developed at JINR by A. Belkov and S. Shulga and is used in the CMS collaboration
  It includes all the theoretical refinements of B decay dynamics (time evolution, angular correlations, CKM matrix elements, CP violating phases, etc.)

Spin-angular correlations

Helicity frame



Conclusion

- **SIMUB provides two regimes** of B-decay generation:
  - simulation of decay after fragmentation in BB_dec with taking into account dynamical angular distributions – dynamical mode
  - simulation of decays by PYTHIA into phase space – PYTHIA mode
- The semileptonic exclusive channels and "golden" decays $B_s^0 \to J/\psi\phi$, $B^0 \to J/\psi K^*$ are implemented both in dynamical and PYTHIA modes
- **SIMUB** package provides MC simulation tools for exclusive B-trigger studies
- **SIMUB** package provides unique tools for physics studies of dynamical mechanisms of the semileptonic and "golden" B-decay channels
- The package was used by PRS/$b - \tau$ of CMS collaboration for MC mass production to study $B_s^0 \to J/\psi\phi$ decay
- The package was used in HERA-B collaboration for Monte Carlo study of the possibility to measure asymmetry in B and $\bar{B}$ production using semileptonic B decays

Outlooks

- In July 22nd, 2003, the program for B_c **production** as PYTHIA external process has been integrated in the SIMUB by using rules from the Les Houches (2001) accords.

- The B_c-production program, we have used, was created by A.Berezhnoi (gluon+gluon interaction part) and Yu.Gouz (implementation into PYTHIA) according to B_c-production matrix elements calculated within the theory developed by A.Berezhnoi, A.Likhoded, V.Kiselev

- **Our plans** for nearest future:

  - to include in the SIMUB also the B_c-production generation with matrix elements calculated by Zhang Zhao-xi et al.(ITP, Beijing)

  - to perform the detail MC studies and comparison of B_c production in various models

  - to investigate the possibilities to study B_c decays in leptonic modes at the CMS