EvtGen HF decay studies

Jackie Brosamer (Lawrence Berkeley Lab)
On behalf of the ATLAS collaboration

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EvtGen use on ATLAS

Heavy Flavor and ATLAS physics

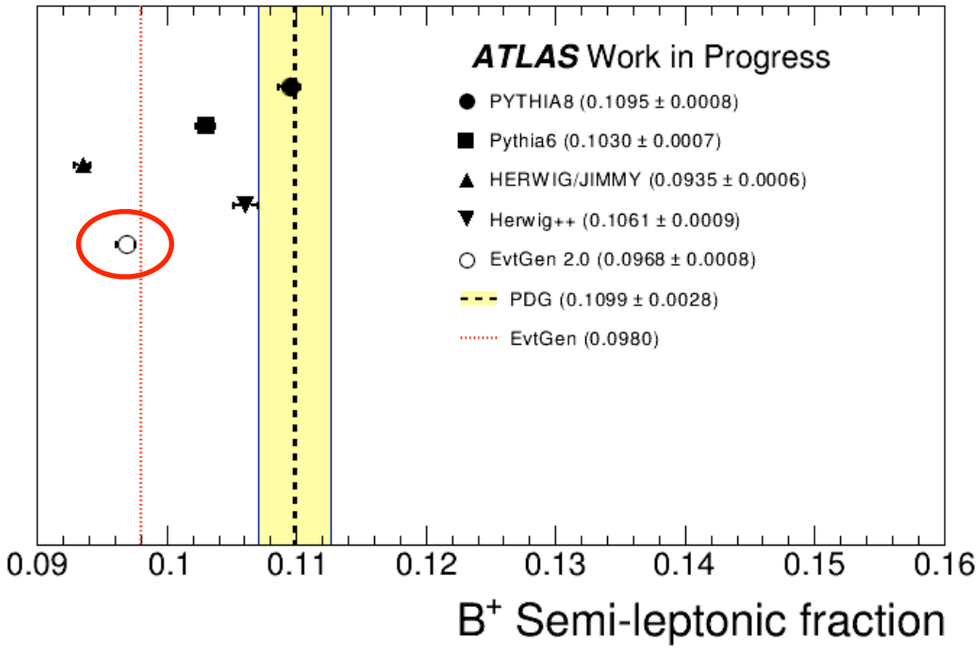
Most important applications for heavy flavor modeling:

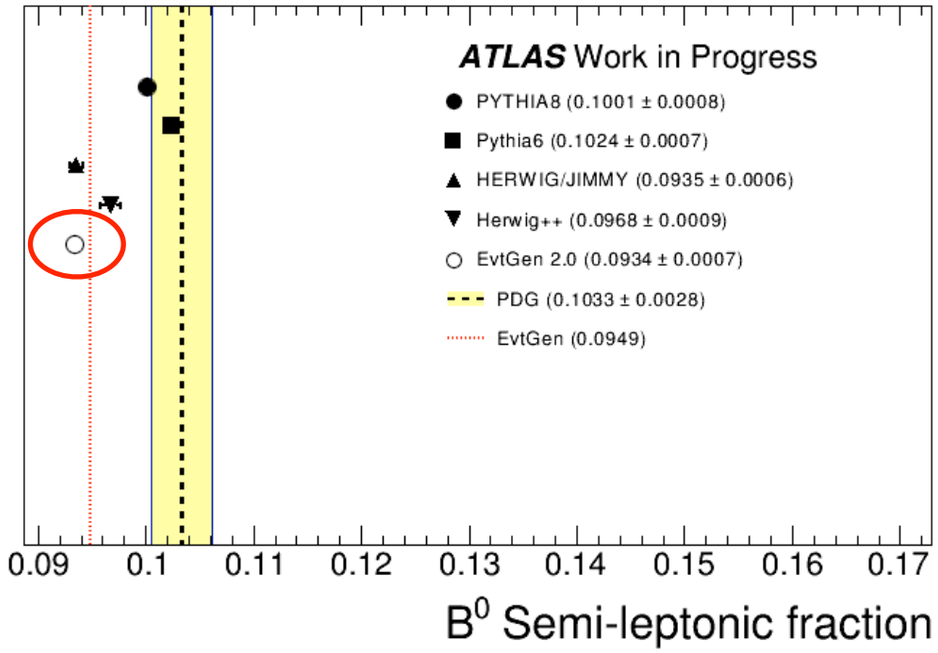
1. **Specific B decay modes for ATLAS B-physics group**
   - Similar use pattern to LHCb
   - Specific decay modes
   - Largely dependent upon di-lepton triggers
2. **b-tagging in jets**
   - Used by Top, Higgs, BSM searches
   - Multi-variate tagger with many input variables
     - Impact parameters, vertex mass, decay length, ratio of track energies, etc.
   - Monte Carlo determined efficiency and fake rate calibrated using data control samples
3. **c-tagging**
   - Soft muon in jets
   - $D^{(*)}$ and D^{+} reconstruction (no jet required)

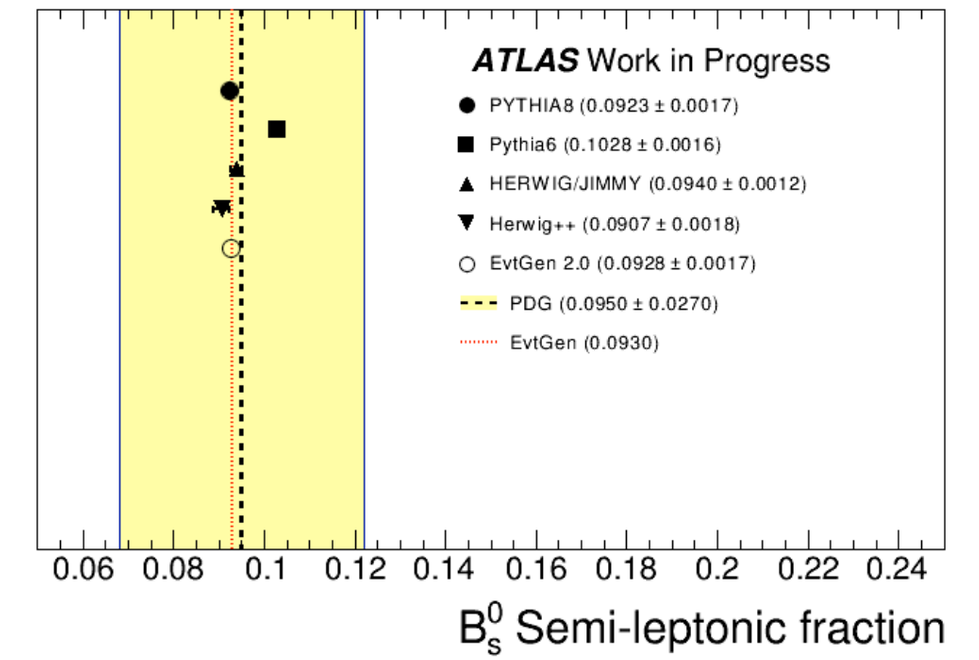
What ATLAS needs from EvtGen

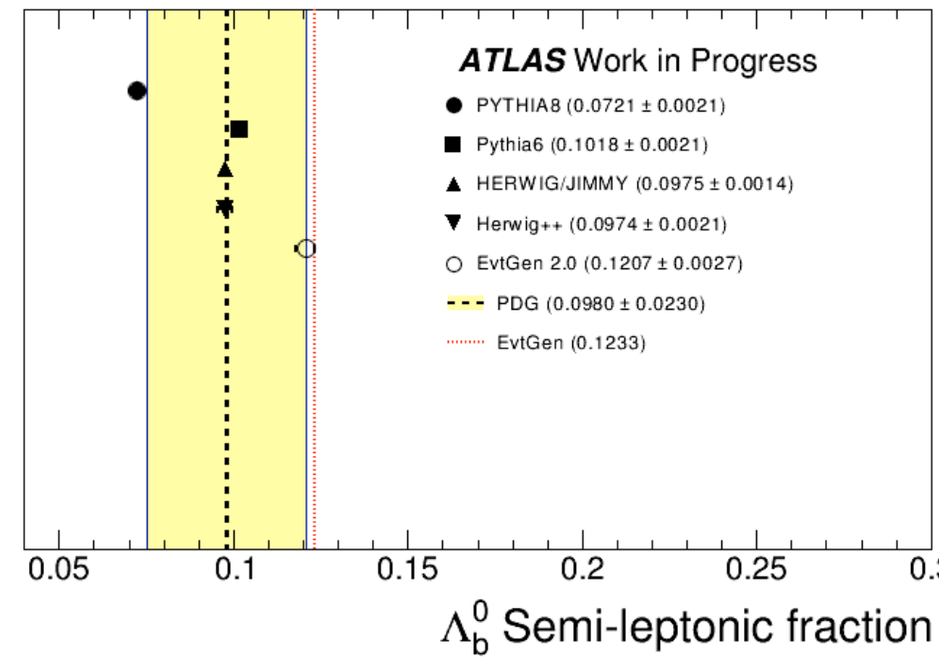
- **Good modeling of semi-leptonic decays for both charm and bottom**
  - Tagger scale factors measured using semi-leptonic rate and p_T^{rel} distributions
- **Good description of topological decay modes**
  - Inputs to the neural net taggers
- **Program relies heavily on default EvtGen decay table**
  - Have compared bottom and charm decays using this table to PDG 2012

Changes to ATLAS .dec file



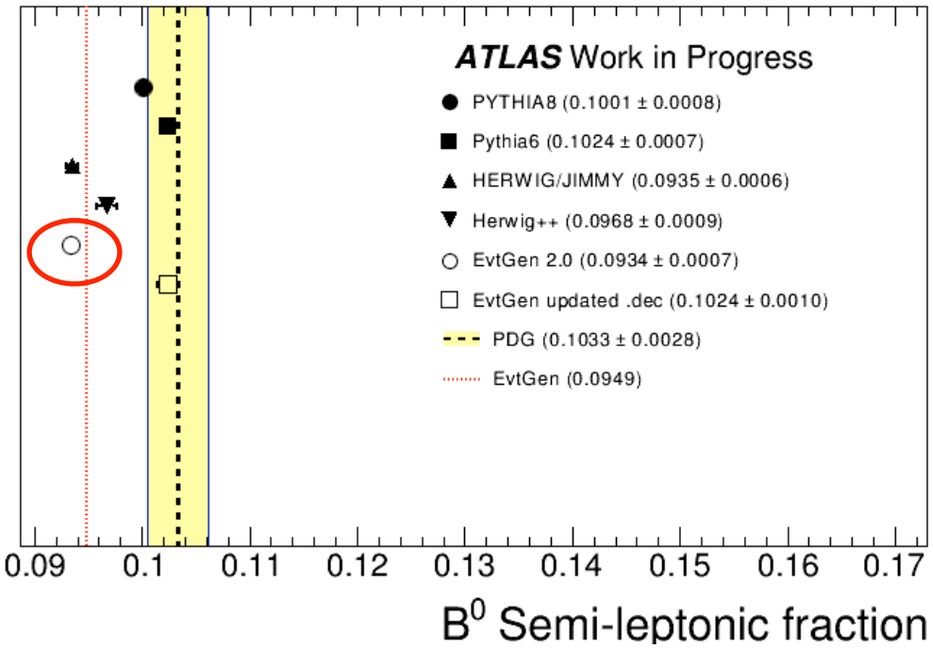


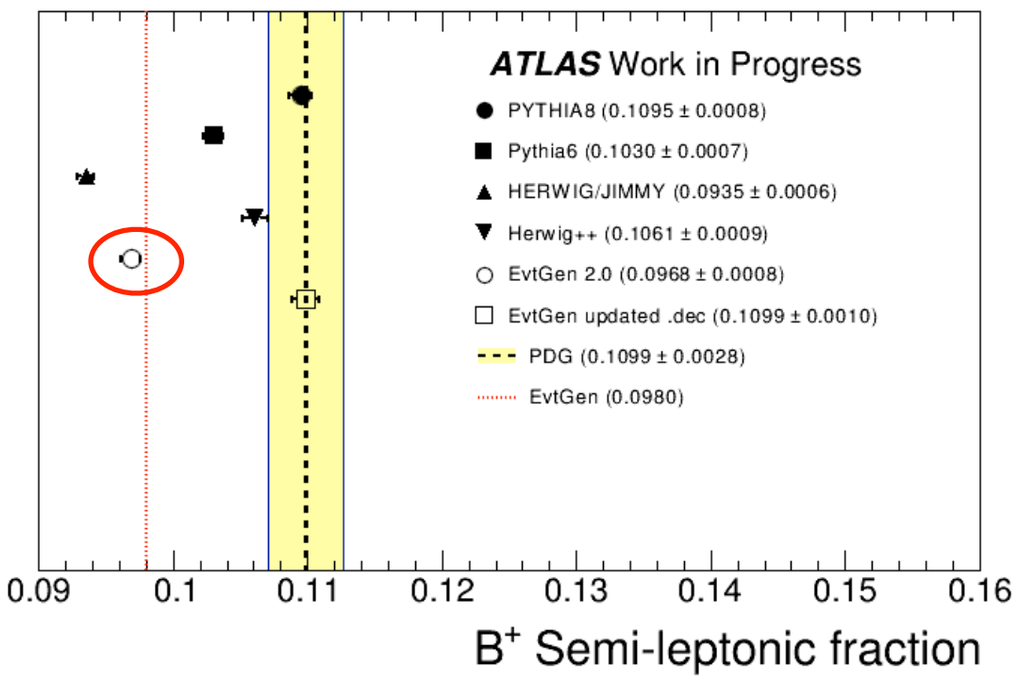




B-hadron semi-leptonic branching ratios in EvtGen 2.0

B semi-leptonic fraction in PDG





Particle Data Guide

B⁰	Γ_1	$B^0 \to \ell^+ \nu_\ell$ anything	$(1.033 \pm .028) \times 10^{-1}$
	Γ_2	$B^0 \to e^+ \nu_e X_c$	$.101 \pm .004$
	Γ_3	$B^0 \to D \ell^+ \nu_\ell$ anything	9.2 ± 0.8 %
B⁺	Γ_1	$B^+ \to \ell^+ \nu_\ell$ anything	$(1.099 \pm .028) \times 10^{-1}$
	Γ_2	$B^+ \to e^+ \nu_e X_c$	$.108 \pm .004$
	Γ_3	$B^+ \to D \ell^+ \nu_\ell$ anything	9.8 ± 0.7 %

Should EvtGen be tuned to Γ_1 or Γ_3?

For ATLAS, propose tune with smaller uncertainty Γ_1.

Update to inclusive.dec

1. Use PDG value for B→D* e ν
2. Rescale remaining semi-leptonic BR to match PDG inclusive value (Γ_1).
3. Rescale 4-body quark PYTHIA decays so that total B branching ratios sum to 1.

Changes to .dec file for B^+, B^0

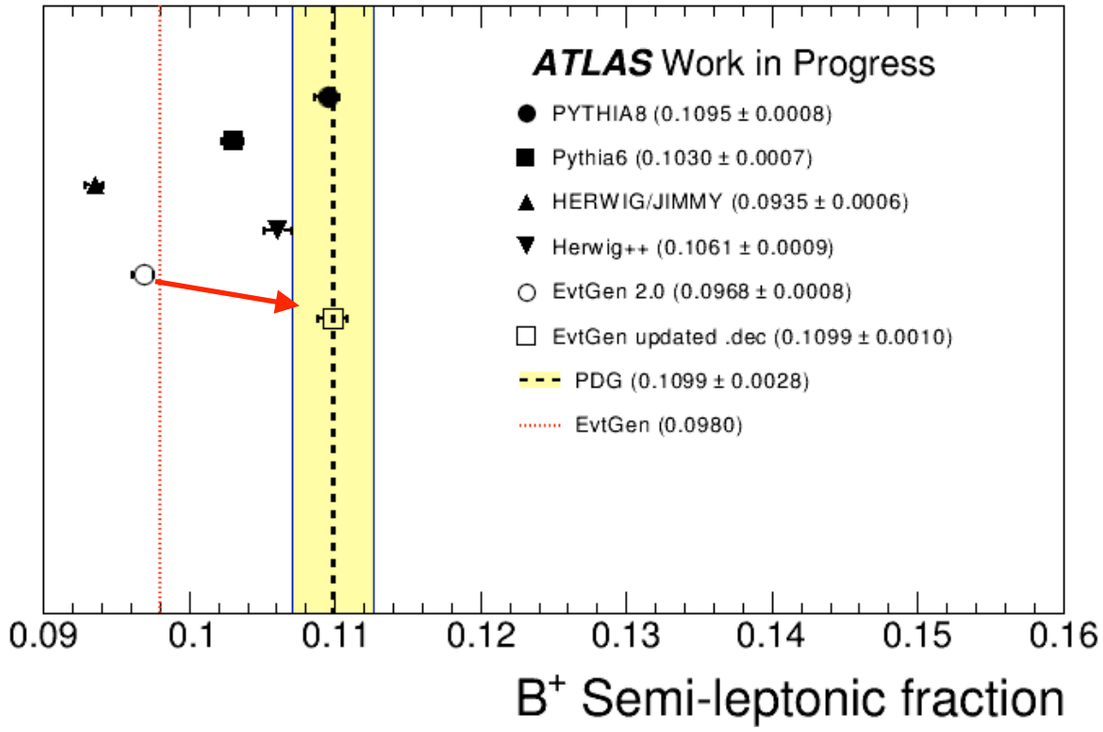
EvtGen 2.0 inclusive.dec

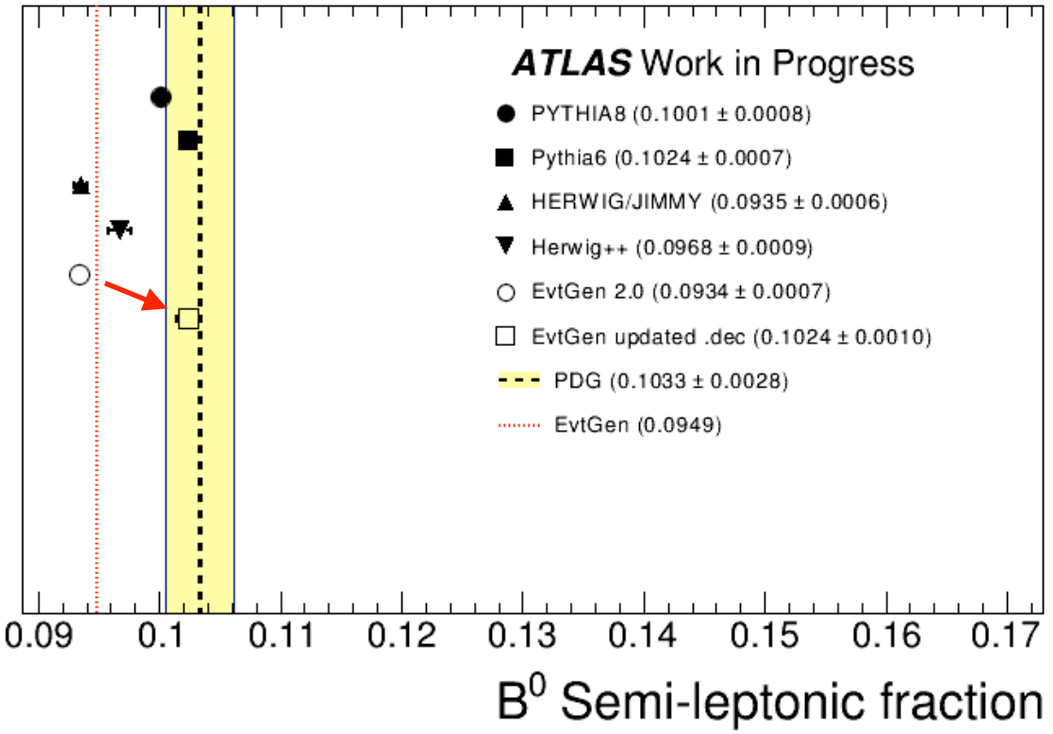
```
Decay B+
# Updated to PDG 2008
#                    b -> c semileptonic
#
0.056800000 anti-D*0 e+       nu_e
Reconstructed PDG2011]
0.022300000 anti-D0 e+       nu_e
 0.0040    anti-D_10    e+    nu_e          PHO
 0.0024    anti-D_0*0    e+    nu_e          PH
 0.0007    anti-D'_10    e+    nu_e          PH
 0.0018    anti-D_2*0    e+    nu_e          PH
 0.0061000 00 D*-      pi+      e+       nu_e
PDG2011]
 0.0003    anti-D*0  pi0    e+    nu_e     PHO
# covered by other decays
 0.0000    D-    pi+    e+    nu_e     PHOTOS
 0.0010    anti-D0  pi0    e+    nu_e     PHOT
```

ATLAS 2014Inclusive.dec

```
#
Decay B+
# Updated to PDG 2008, modified by JB 1/2014
#                    b -> c semileptonic
#
0.057 anti-D*0 e+       nu_e
PDG2011 #JB change to 2011 PDG value
0.0223 anti-D0 e+       nu_e
change to 2011 PDG value
0.006484768212568 64 anti-D_10    e+    nu_e
0.003890860927541 18 anti-D_0*0    e+    nu_e
0.001134834437199 51 anti-D'_10    e+    nu_e
0.002918145695655 89 anti-D_2*0    e+    nu_e
0.009889271524167 17 D*-      pi+      e+  nu_e
rescaled to add up to PDG inc SL
0.000486357615942648 anti-D*0  pi0    e+    nu_e
inc SL
0.0000    D-    pi+    e+    nu_e     PHOTOS  GOITY_
0.001621192053142 16 anti-D0  pi0    e+    nu_e
```

1. **Yellow:** Change to PDG value
2. Blue: Rescale so that SL modes sum to match inclusive PDG value (Γ_1)





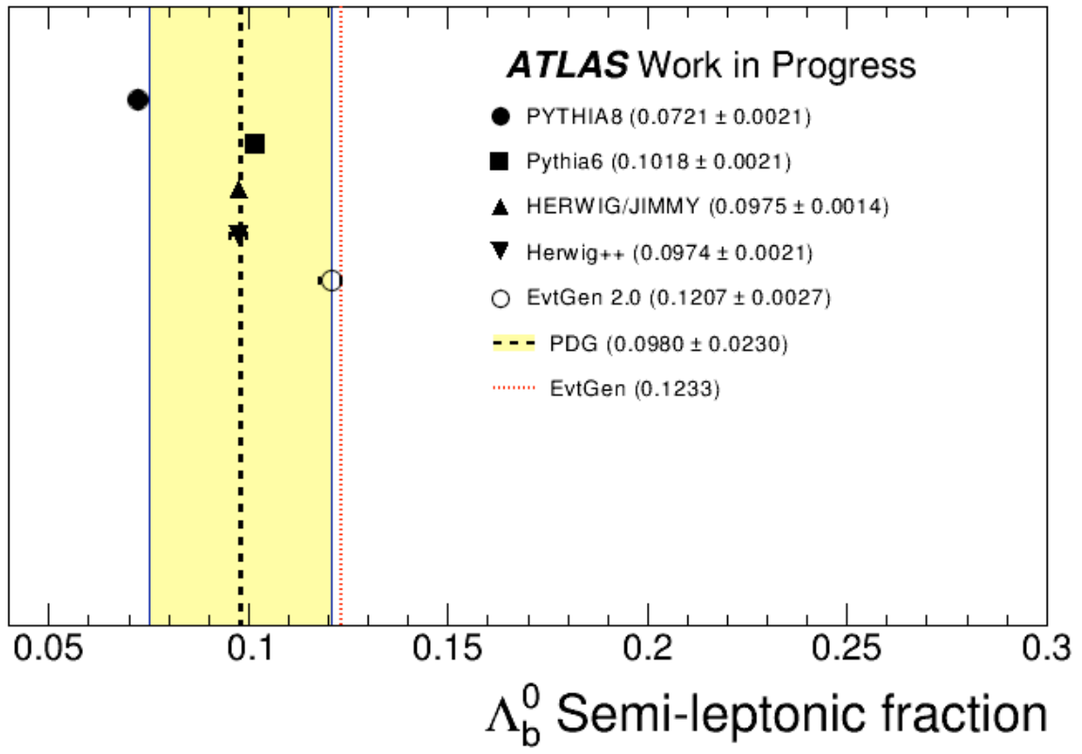
B-hadron semi-leptonic branching ratio after update

Results of update to .dec file

Better agreement with PDG inclusive measurement

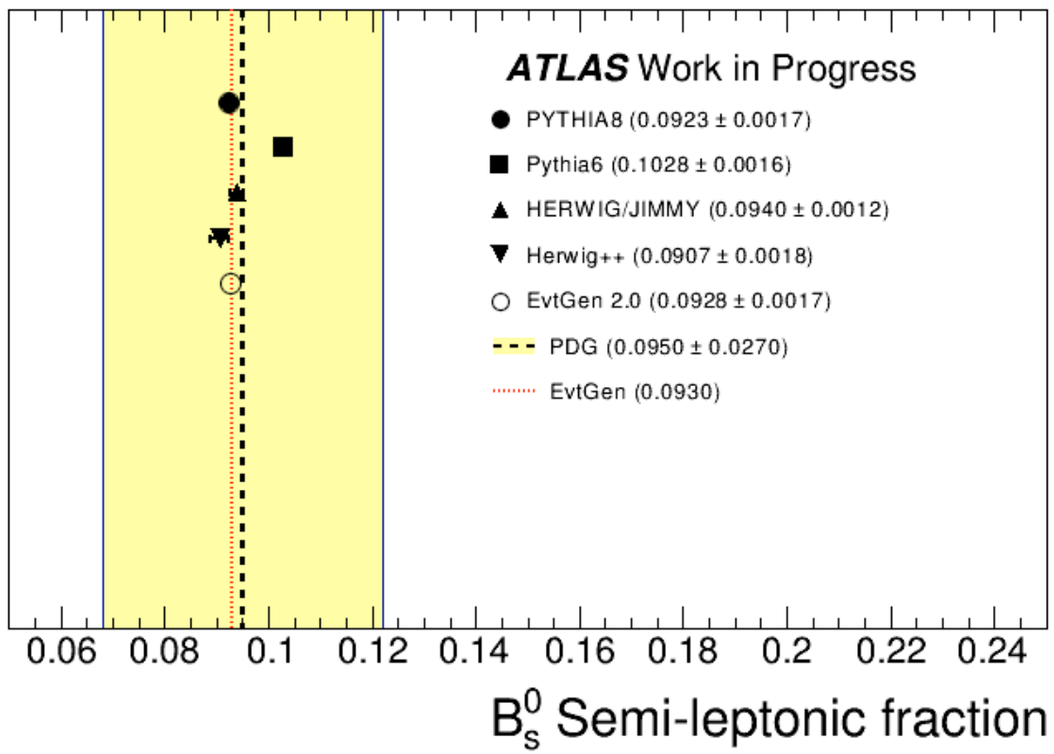
Λ_b and B_s

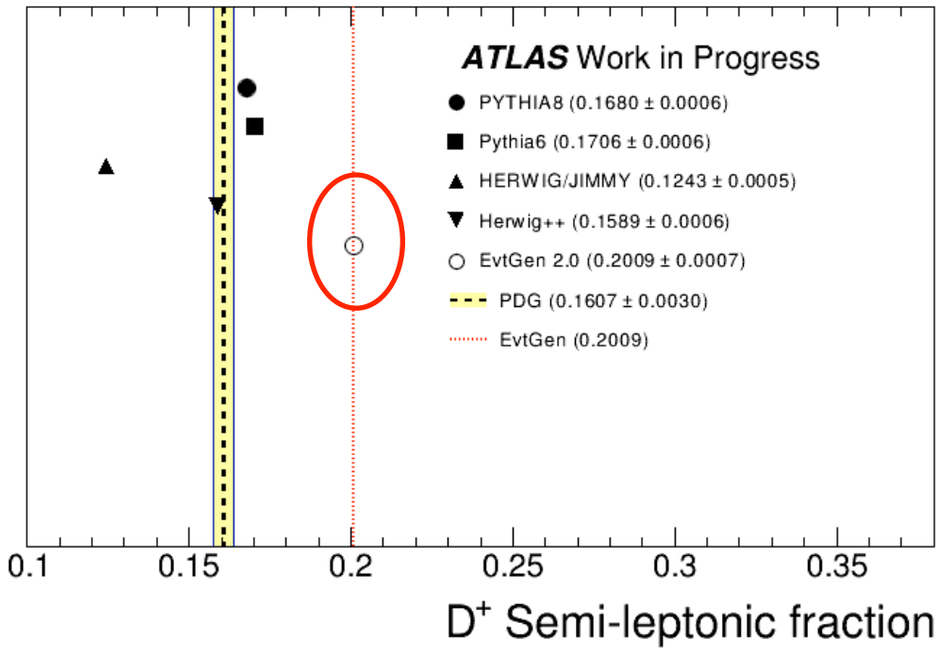
- Λ_b
  - Unclear what to do because inclusive measurements are smaller than the sum of exclusive measurements
  - Will consult with PDG experts, but leave default for now
- B_s
  - Agreement with PDG within one σ, so leave unmodified

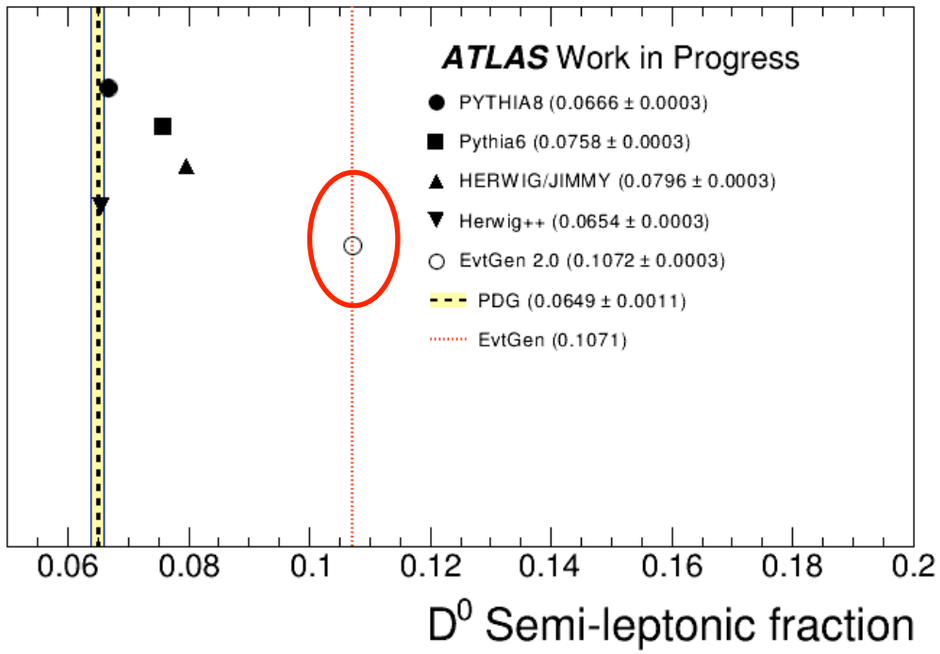


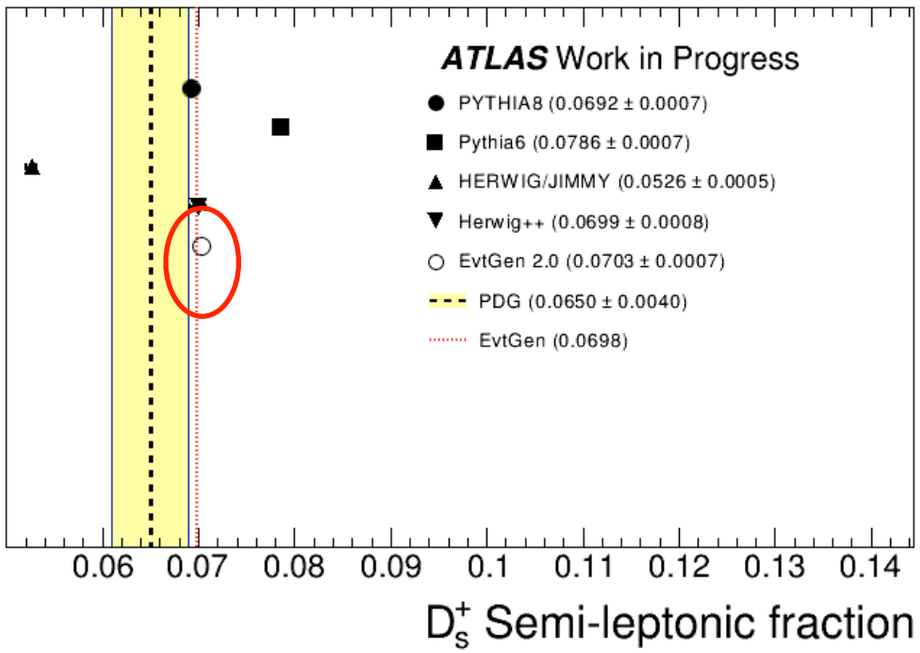
Particle Data Guide

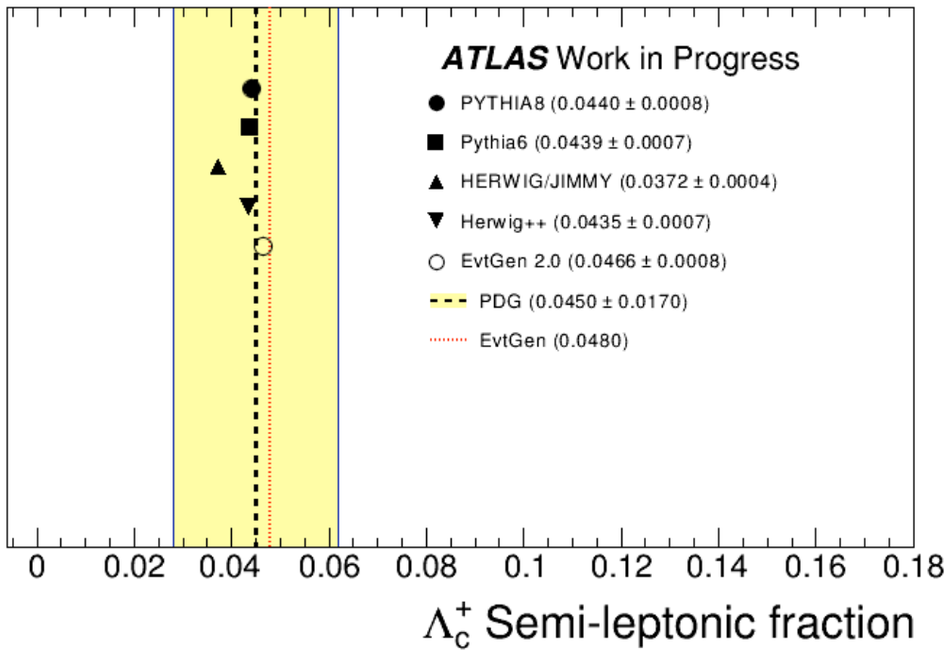
Γ_{11}	$\Lambda_b^0 \to \Lambda_c^+ \ell^- \bar{\nu}_\ell$ anything	9.8 ±2.2 %
Γ_{12}	$\Lambda_b^0 \to \Lambda_c^+ \ell^- \bar{\nu}_\ell$	$(6.5\ ^{+3.2}_{-2.5}) \times 10^{-2}$
Γ_{13}	$\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \ell^- \bar{\nu}_\ell$	5.6 ±3.1 %







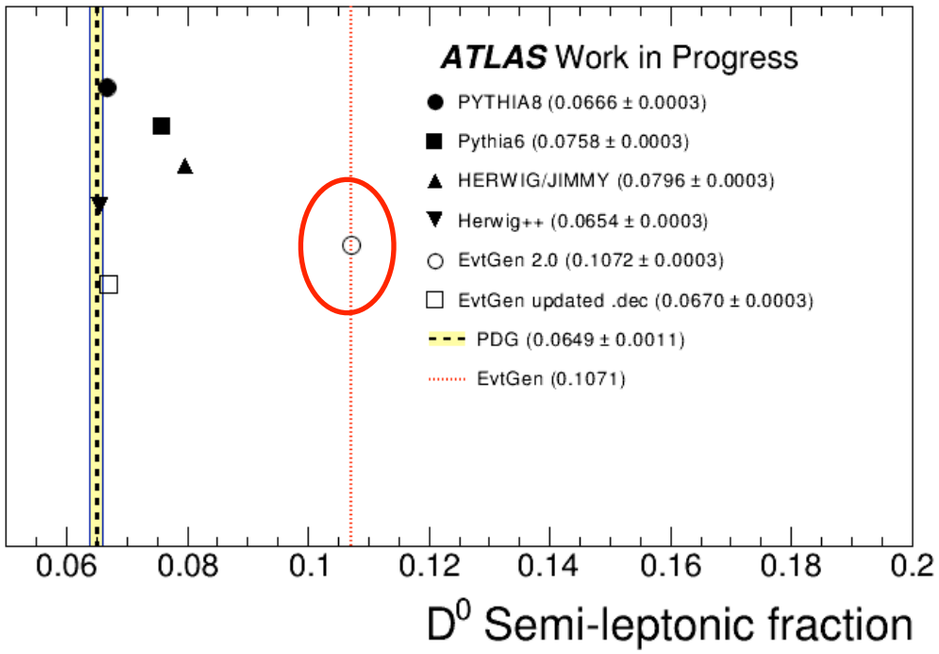


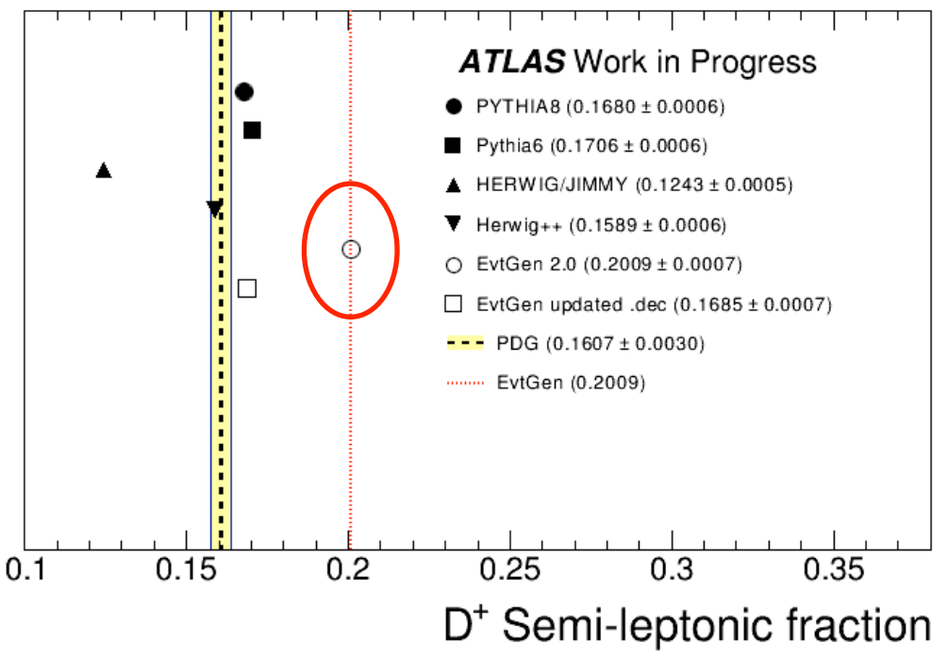


C-hadron semi-leptonic branching ratios with EvtGen 2.0

2006 inclusive.dec showed better agreement with PDG (since little change in experimental values)

C semi-leptonic fraction in PDG





Particle Data Guide

D+

Γ_{17}	$D^+ \to K^- \pi^+ e^+ \nu_e$	4.00 ±0.10 %
Γ_{18}	$D^+ \to \overline{K}^*(892)^0 e^+ \nu_e$, $\overline{K}^*(892)^0 \to K^- \pi^+$	(3.68 ±0.10) ×10^{-2}

▼Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

D0

Γ_{34}	$D^+ \to \overline{K}^*(892)^0 e^+ \nu_e$	(5.52 ±0.15) ×10^{-2}
Γ_5	$D^0 \to e^+$ anything	6.49 ±0.11 %

D+ :double counting error with indentation.

Not straightforward to update since no PYTHIA decays to take up extra as with the B mesons.

Solution: Revert all C mesons to 2006 EvtGen decay table from BaBar

Changes to .dec file for D^+, D^0, D_s

EvtGen 2.0 inclusive.dec

```
Decay D+
0.055300000 anti-K*0 e+       nu_e
0.088300000 anti-K0 e+       nu_e
0.002773020 anti-K_10 e+       nu_e
0.002927076 anti-K_2*0 e+       nu_e
0.004050000 pi0      e+       nu_e
0.001330000 eta      e+       nu_e
0.000385142 eta'     e+       nu_e
0.002200000 rho0     e+       nu_e
0.001600000 omega    e+       nu_e
0.041000000 K-       pi+      e+       nu_e
0.001078397 anti-K0 pi0      e+       nu_e
```

Sum: .20944

Γ_{17}	$D^+ \to K^- \pi^+ e^+ \nu_e$	4.00 ±0.10 %
Γ_{18}	$D^+ \to \overline{K}^*(892)^0 e^+ \nu_e$, $\overline{K}^*(892)^0 \to K^- \pi^+$	$(3.68 \pm 0.10) \times 10^{-2}$

▼ Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

Γ_{34}	$D^+ \to \overline{K}^*(892)^0 e^+ \nu_e$	$(5.52 \pm 0.15) \times 10^{-2}$

ATLAS 2014Inclusive.dec

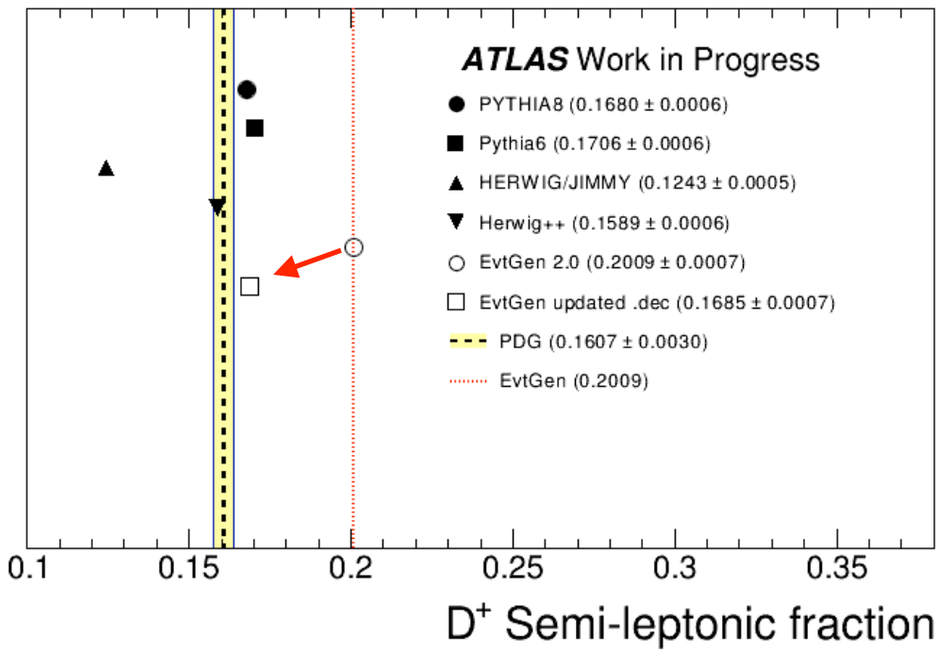
```
Decay D+
0.0554   anti-K*0  e+  nu_e
0.0900   anti-K0    e+  nu_e
0.0036   anti-K_10  e+  nu_e
0.0038   anti-K_2*0 e+  nu_e
0.0043   pi0  e+  nu_e
0.0026   eta  e+  nu_e
0.0005   eta' e+  nu_e
0.0028   rho0 e+  nu_e
0.0028   omega e+  nu_e
0.0027   K-  pi+  e+ nu_e
0.0014   anti-K0  pi0  e+  nu_e
```

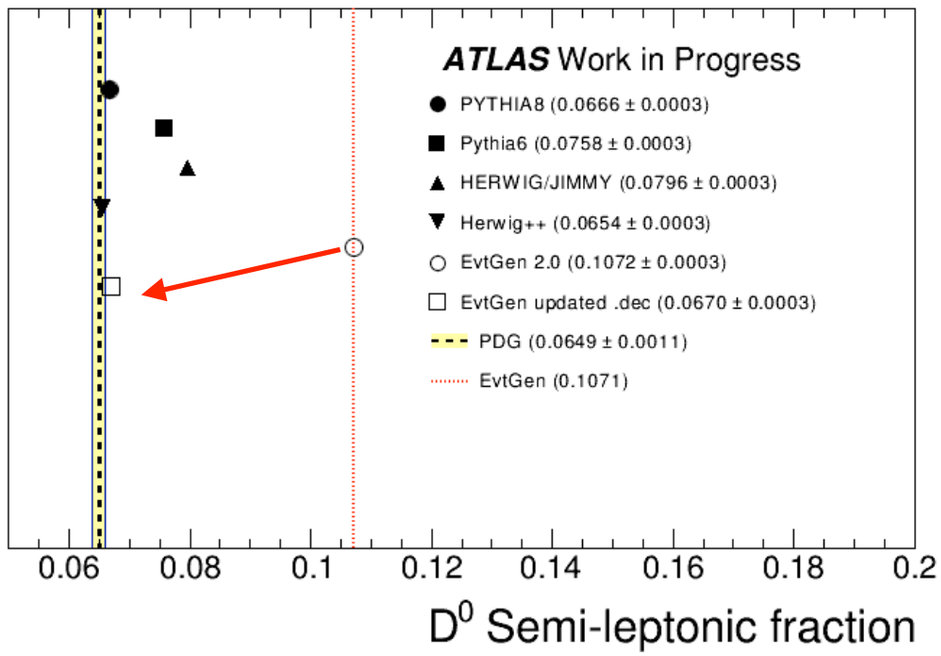
Sum: .1699

	$D^+ \to e^+$ semileptonic	$(1.607 \pm .030) \times 10^{-1}$

Revert all decay modes to 2006 values

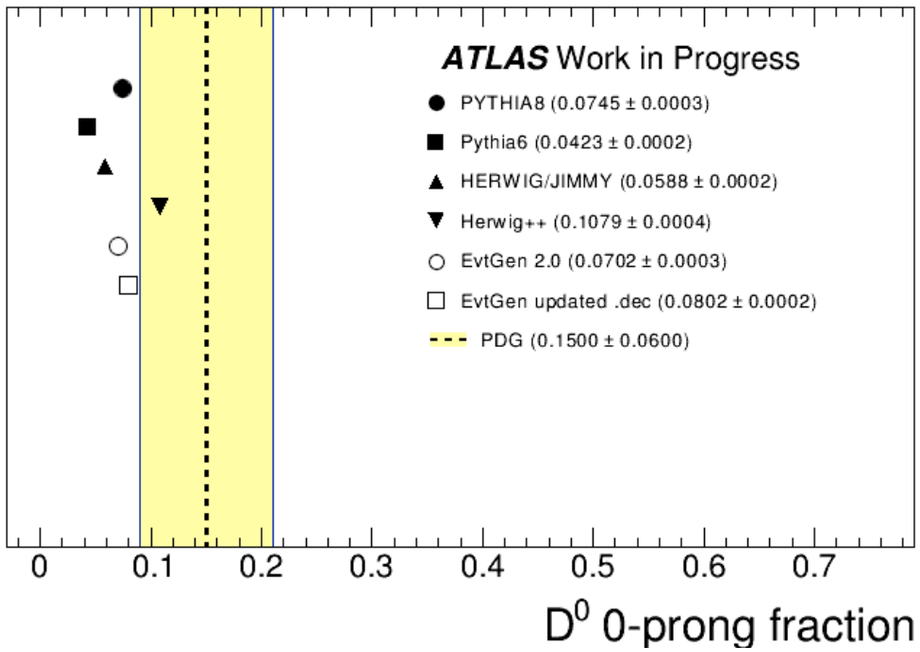
Yellow mode includes blue (though don't sum because from different experiments)

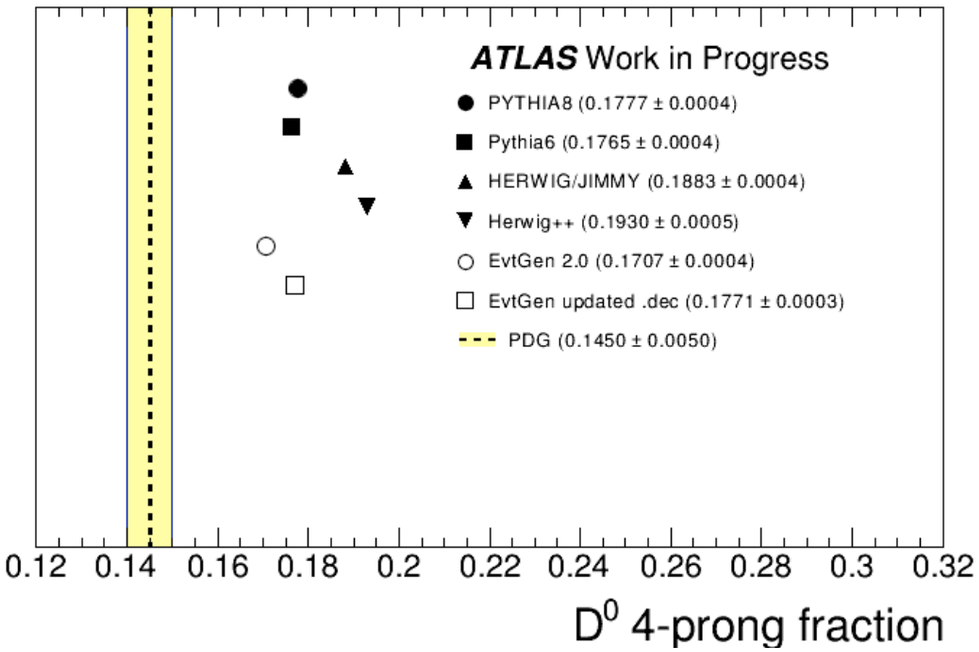


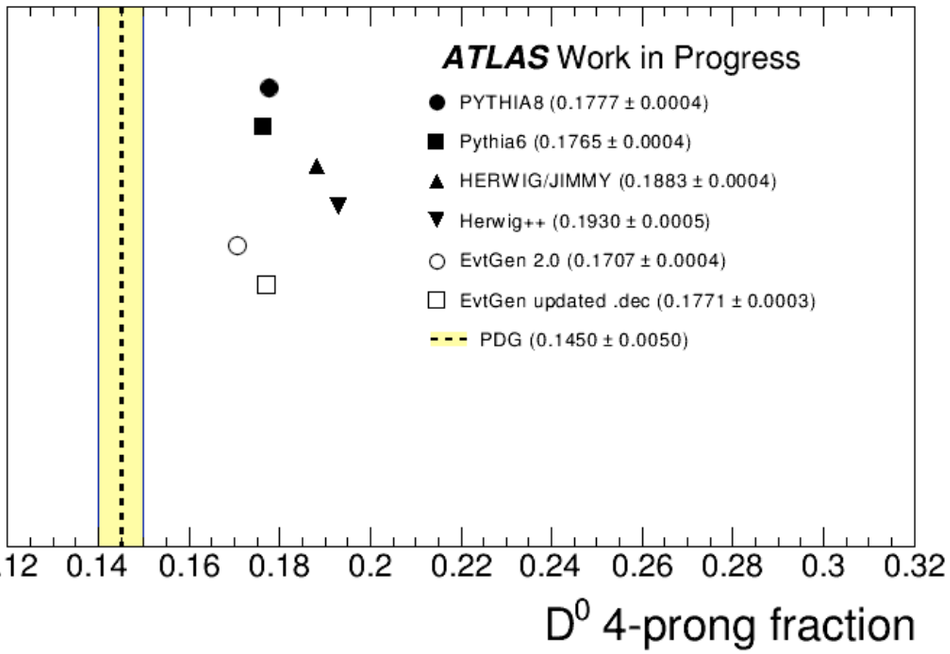


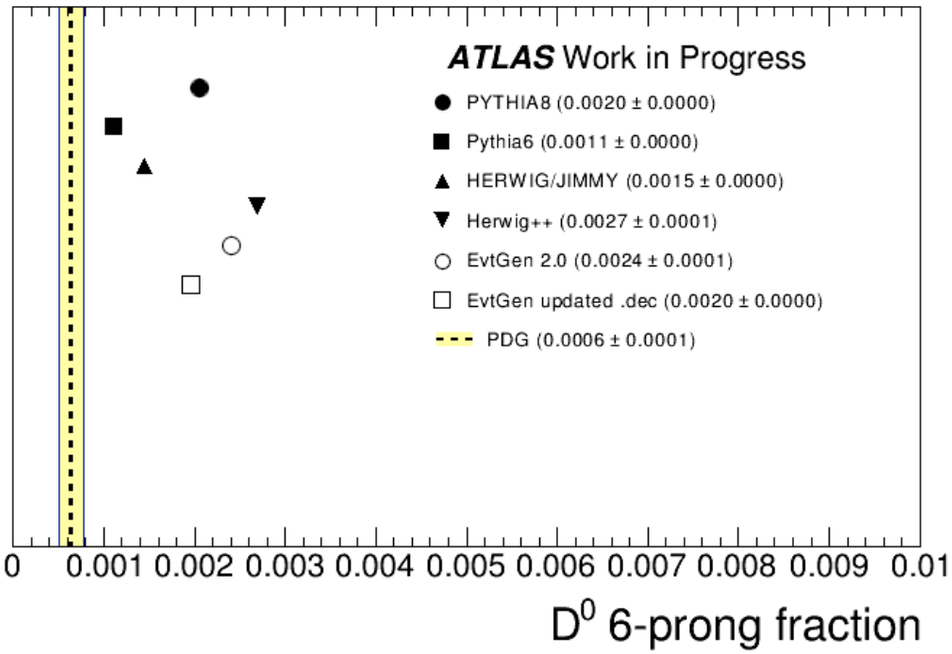
C-hadron semi-leptonic branching ratio after update

Better agreement with PDG









Topological D0 decays

- D^0 only particle with topological fractions in PDG
- Agreement with PDG value not good
- Note that update doesn't change these fractions

Conclusions

- Propose small changes to B mesons
  - Change B->D+e+ν modes to PDG values
  - Scale rest of semi-leptonic modes to match best inclusive semi-leptonic measurement
  - Put extra in Pythia 4-body decays
- Revert C mesons to 2006 BaBar decay table to correct for double counting
- Topological modes examined for D_0
  - Do other topological fractions exist? B's?