Prospects for $|V_{xb}|$ from joint experiment+theory fits

LOI:RF/SNOWMASS21-RF1_RF0-TF5_TF6-CompF2_CompF0_Vaquero-116

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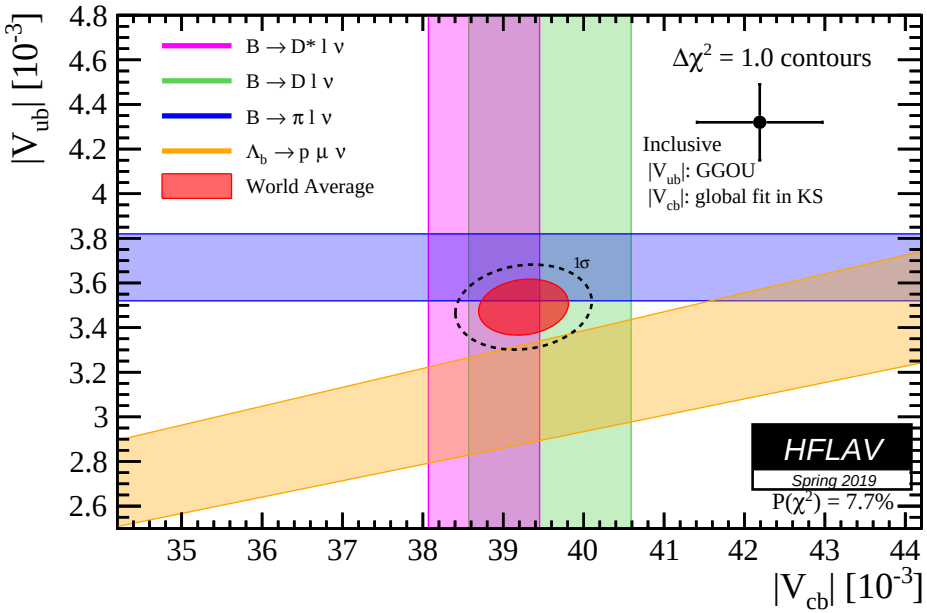
Snowmass'21 RPF meeting
October 2^{nd}, 2020

The $|V_{ub}|$-$|V_{cb}|$ saga: tree vs. penguin

- $|V_{ub}|/|V_{cb}|$ (tree) is $\propto$ side opposite to β (loops) in the UT.

- $\sim 3\sigma$ tension between inclusive/exclusive $|V_{ub}|$-$|V_{cb}|$.

- WA of β prefers inclusive $|V_{cb}|$ and exclusive $|V_{ub}|$.



- Focus on exclusive $|V_{cb}|$ from $\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell$ here. Problem has two parts: theory form-factor shapes and experimental rate normalization.

The FF shapes

- k, the $\overline{B} \to D^{(*)} W^*$ breakup mom. goes to zero at zero-recoil ($q^2_{\rm max}$).

- Rate $\propto k$ ($B \to D^*$) and $\propto k^3$ ($B \to D$) vanishes near zero-recoil. Only lattice here.

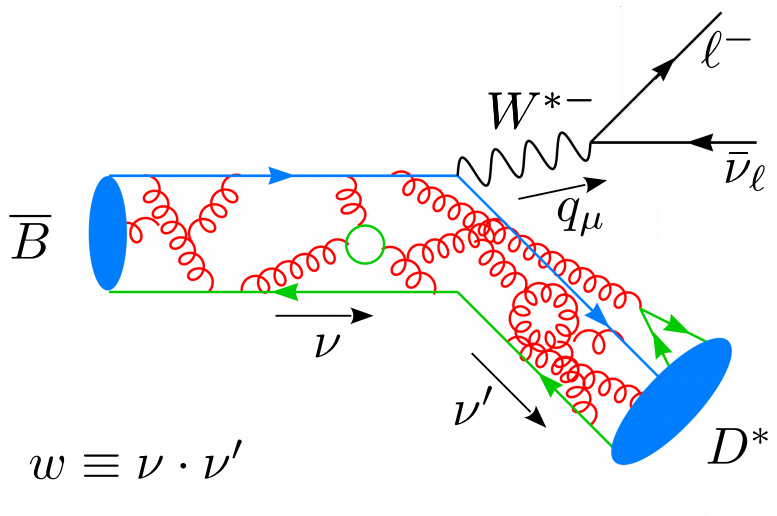
- $B \to D^*$: published lattice data only *at* zero-recoil. Off zero-recoil lattice needed asap!

- Turning it around: what can flavor physics teach us about QCD? HQS.

- Do experiment/lattice agree in the overlapping q^2 region? "Clean" $R_{1,2}$ ratios between 3 FFs from $B \to D^*$.

HQET for $\overline{B} \to D^*$

- w: relativistic γ factor of D^* in B RF
- At $\frac{\Lambda_{\rm QCD}}{m_{b,c}} \to 0$ limit, only w matters.
- Heavy Quark Symm (HQS): $\{b^\uparrow, b^\downarrow, c^\uparrow, c^\downarrow\}$ (spin-flavor symm.)
- Non-pert. QCD effects pushed into a single universal FF, $\zeta(w)$.



- In time scales $\ll \Lambda_{\rm QCD}^{-1}$ Dirac structure in the weak current irrelevant

$$\frac{\langle D^*(v',\varepsilon)|V^\mu|\overline{B}(v)\rangle}{\sqrt{m_B m_{D^*}}} = i h_V(w)\epsilon^{\mu\nu\alpha\beta}\varepsilon^*_\nu v'_\alpha v_\beta$$

$$\frac{\langle D^*(v',\varepsilon)|A^\mu|\overline{B}(v)\rangle}{\sqrt{m_B m_{D^*}}} = h_{A_1}(w)(w+1)\varepsilon^{*\mu} - h_{A_2}(w)(\varepsilon^*\cdot v)v^\mu - h_{A_3}(w)(\varepsilon^*\cdot v)v'^\mu$$

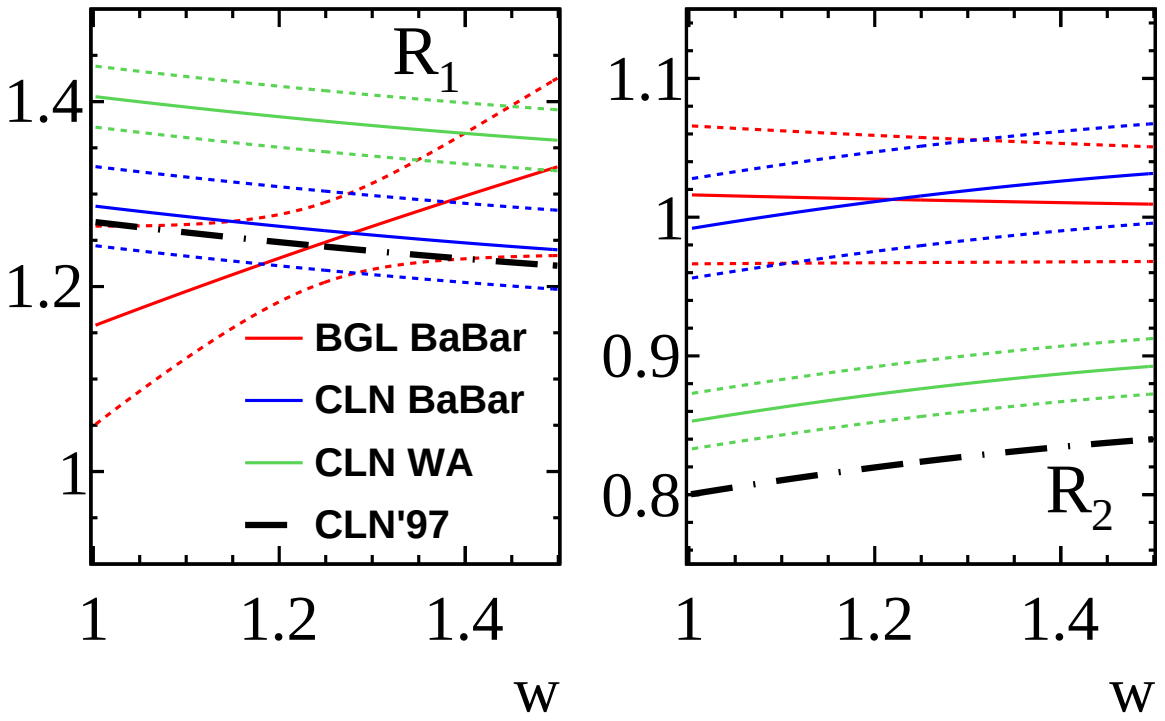
$$A_1 = \frac{w+1}{2} r' h_{A_1}$$

$$A_2 = \frac{r h_{A_2} + h_{A_3}}{r'} \equiv \frac{R_2 h_{A_1}}{r'}$$

$$V = \frac{h_V}{r'} \equiv \frac{R_1 h_{A_1}}{r'}$$

- HQS limit: $\{h_V, h_{A_1}, h_{A_3}\} \to \zeta(w)$ and $h_{A_2} \to 0$. $r' \equiv \frac{2\sqrt{m_{D^*} m_B}}{(m_{D^*}+m_B)}$

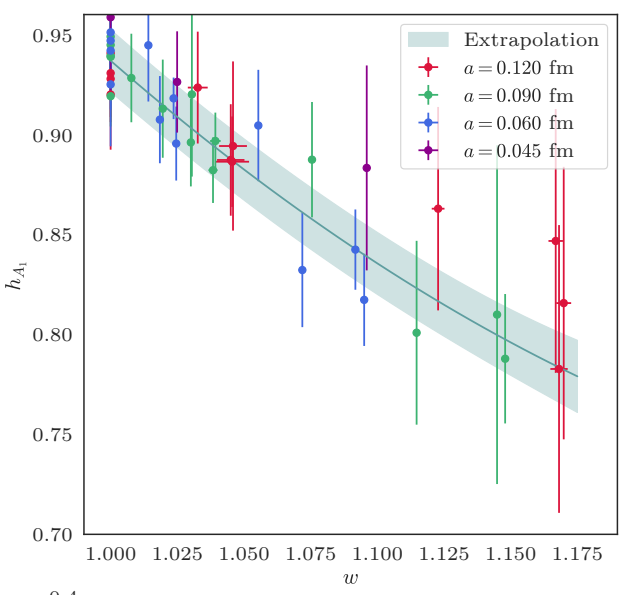
BABAR $\overline{B} \to D^*$ results – $R_{1,2}$ ratios [PRL 123 (2019) 091801]

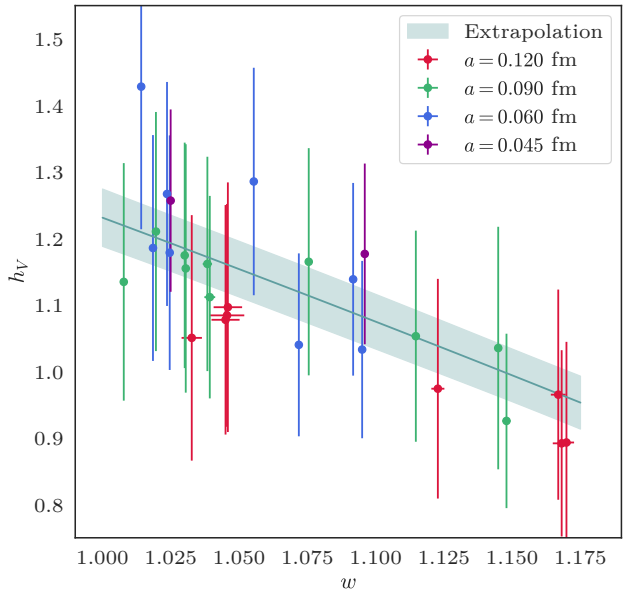


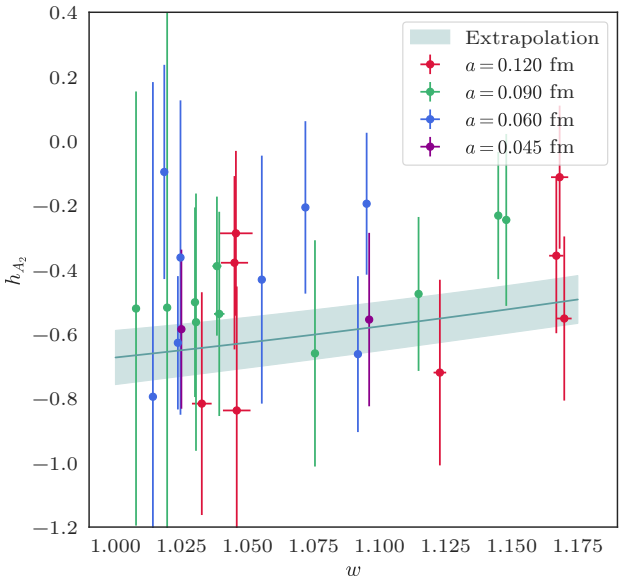
- Hadronic tagging + full 4-d analysis.
- Included the $R_{1,2}$ curves (w/o errors) from the original Caprini paper.

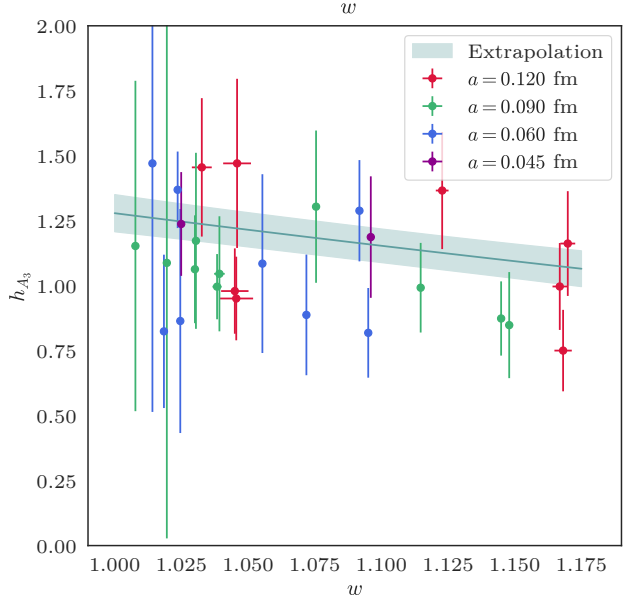
- *BABAR* BGL: $R_1(1) \approx 1.2$ and the slope is positive; $R_2 \approx 1$ and flat.
- What does lattice say?...

Preliminary $\overline{B} \to D^*$ from FNAL/MILC lattice







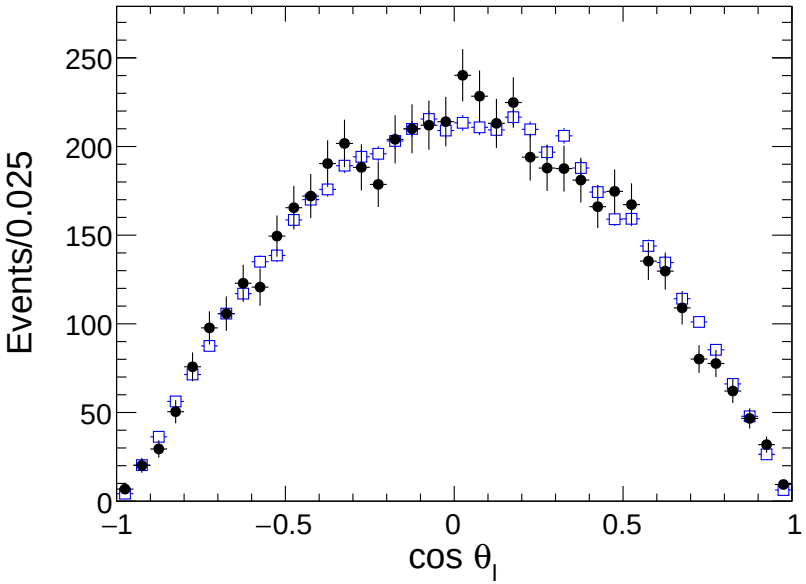


- Preliminary (+blinded) results from FNAL/MILC (A. Vaquero)
- Chiral continuation extrapolation.
- $h_{A1,V}$ lower uncertainty. $h_{A2,A3}$ uncertainties larger.
- To converge soon.
- Also JLQCD...

Combined $\overline{B} \to D^{(*)}$ data + theory fits

- Non-zero recoil $\overline{B} \to D$ lattice data exist already [PRD 92(2015), 034506]
- Combined *unbinned* BABAR $\overline{B} \to D^{(*)}$ + lattice + HQET fits.
- Formalism from Bernlochner *et al.* [PRD 95(2017), 115008]. Expansion in α_s, $1/m_{c,b}$ with inputs from QCDSR + errors.
- Allows floating $\zeta(1)$ (leading IW function) to test departures from HQS.
- Does not require lattice $\overline{B} \to D^*$ $w > 1$ data, but these would be very welcome!
- Additional complication for $\overline{B} \to D$ is background subtraction for 2d angular analysis in q^2-$\cos\theta_\ell$. Compare with lattice $B_s^0 \to D_s$ HPQCD HISQ FFs [PRD 101(2020), 074513].

Hadronic tagging: non-extended fits



- Hadronic tagging allows excellent resolution in the kinematic variables
- Eg.: *BABAR* $\overline{B} \to D$ data directly shows the expected $\sin^2\theta_l$ distribution.

- Great for non-extended fits to disentangle the individual FF *shapes*.

Hadronic tagging: normalization issues

- Getting overall normalization needs $\epsilon_{\rm tag}$. Poorly known hadronic BFs can lead to a large uncertainty here.
- Also depends on the signal-side: D^* much cleaner than D.

Exclusive Branching Fraction: B^0 -> D^- lnu

The average BF is the result of a one-dimensional fit to the measurements listed.

Experiment	BF (rescaled) [%]	Parameters	Remarks
ALEPH	2.32 +/- 0.18 +/- 0.36	input parameters	Phys.Lett.B395:373-387,1997
CLEO	2.15 +/- 0.13 +/- 0.16	input parameters	Phys.Rev.Lett.82:3746,1999
BABAR	2.19 +/- 0.11 +/- 0.14	input parameters	Phys.Rev.Lett.104:011802,2010
BELLE	2.43 +/- 0.04 +/- 0.12	input parameters	Phys.Rev.D93:032006,2016
Average	**2.31 +/- 0.04 +/- 0.09**	**chi2/dof = 2.20/3 (CL = 0.531)**	eps pdf

Exclusive Branching Fraction: B^+ -> D^0bar lnu

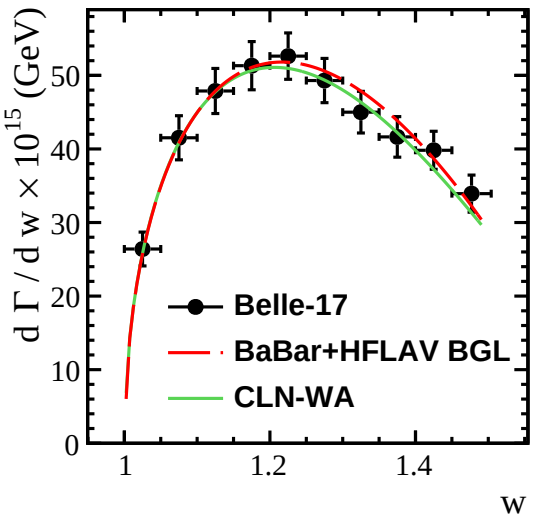
The average BF is the result of a one-dimensional fit to the measurements listed.

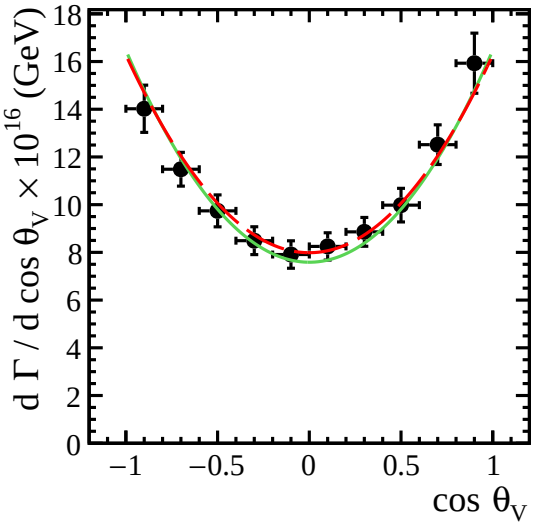
Experiment	BF (rescaled) [%]	Parameters	Remarks
CLEO	2.19 +/- 0.13 +/- 0.17	input parameters	Phys.Rev.Lett.82:3746,1999
BABAR	2.19 +/- 0.08 +/- 0.13	input parameters	Phys.Rev.Lett.104:011802,2010
BELLE	2.53 +/- 0.04 +/- 0.12	input parameters	Phys.Rev.D93:032006,2016
Average	**2.35 +/- 0.03 +/- 0.09**	**chi2/dof = 3.78/2 (CL = 0.151)**	eps pdf

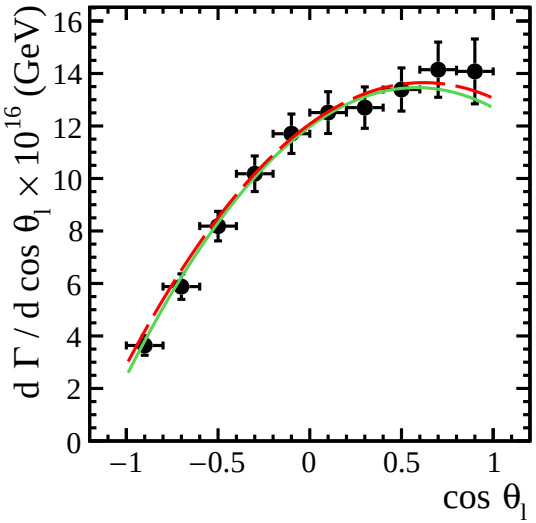
- Earlier tagged *BABAR*/Belle don't quite agree in $\overline{B} \to D$ BFs.
- $|V_{cb}|$ issue might be tied to $\epsilon_{\rm tag}$, not necessarily FFs.

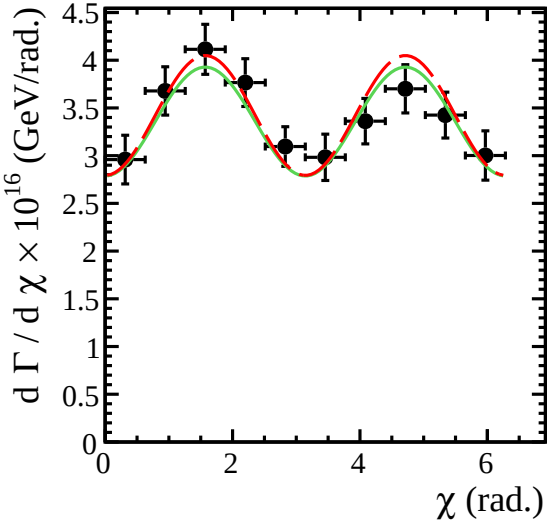
Hadronic tagging: normalization issues (cntd.)

Overlay, *not* a fit:





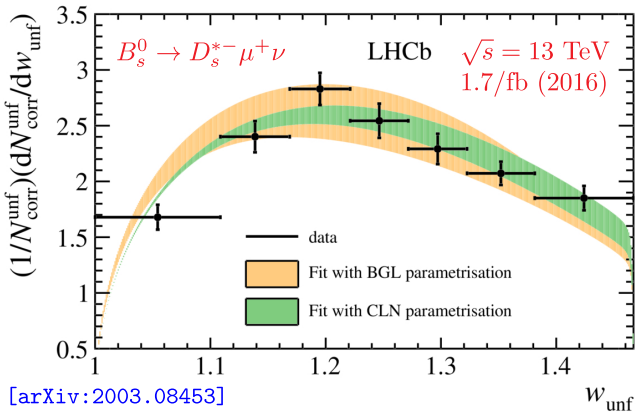




- No apparent problems in the normalization with (unpublished) Belle-17 $\overline{B} \to D^*$ data wrt *BABAR*-19.

(Immediate) Road ahead

- Some further tagged FF analyses from *BABAR* on $\overline{B} \to D^{(*)}$ expected.
- MILC/JLQCD nonzero recoil $\overline{B} \to D^*$ FFs $\Rightarrow$ high priority!
- Hopefully these will lead to better understanding of higher order HQET corrections.
- Systematics on absolute normalizations for hadronic tagging from Belle II need to be better understood for precision $|V_{xb}|$.



[arXiv:2003.08453]

- LHCb has majorly started using B_s^0 SL decays. $|V_{cb}|$ [PRD101 (2020), 072004] + FF shapes.
- $|V_{ub}|/|V_{cb}|$ from $B_s^0 \to K\mu\nu$ in the pipeline.
- $B_s^0 \to D_s^{(*)}$ golden modes for lattice!