$\Lambda_b \to p l \nu$ on the lattice

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CKM 2014
WGII: V_{ub} & V_{cb}

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Outline

- Motivation
- Background
- Published results ($m_b \to \infty$ limit)
- Preliminary results (physical m_b)

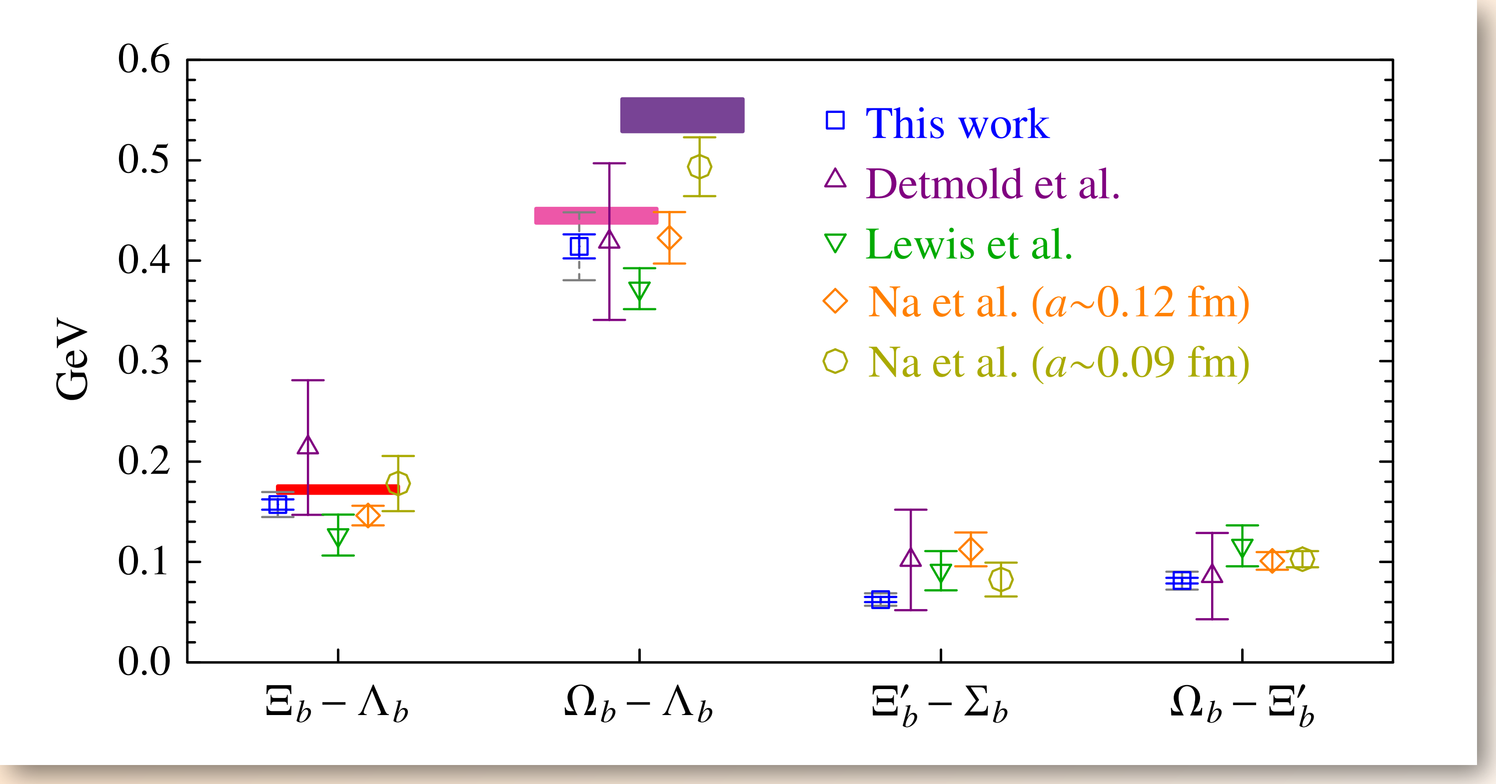
Motivation

- [Reminder: Λ_b is the isospin=0, beauty*=1 baryon]
- $\Lambda_b \to p\, l^- \nu$ is being measured at the LHC
- Test for new physics in b to u: $B \to \pi\, l\, \nu$ and $B_s \to K\, l\, \nu$ only expose the vector part of (V±A)
- Λ_b form factors are "simple" lattice quantities, in constrast to $B \to \rho\, l\, \nu$, $B_s \to K^*\, l\, \nu$
- $\Lambda_b \to p$ form factor calculation done in parallel with those for the rare $b \to s$ decay $\Lambda_b \to \Lambda\, l^+\, l^-$

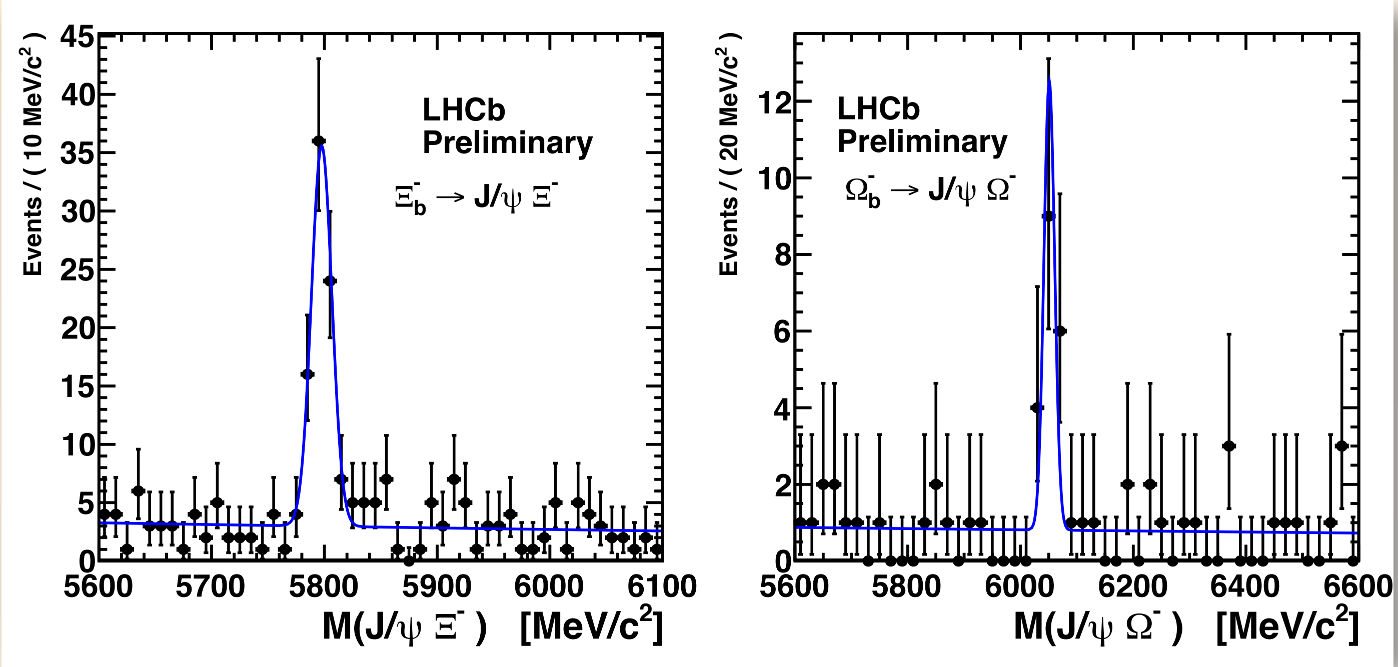
* beauty = −bottomness

Beautiful baryons on the lattice

- ✤ Unquenched LQCD *b* baryon mass splittings
- ✤ LQCD predicted smaller Ω_b mass than originally determined by DØ, later confirmed by CDF & LHC*b*
- ✤ LQCD calculations of $\Sigma_b{}^* \Sigma_b \pi$ and $\Sigma_b{}^{(*)} \Lambda_b \pi$ couplings (Detmold, Lin, Meinel, 2011-12)



from Lin, Cohen, Mathur, Orginos, PRD80 (2009)



LHCb-CONF-2011-60

$\Lambda_b \to p$ form factors

In general

$$\langle p|\bar{u}\gamma^\mu b|\Lambda_b\rangle = \bar{u}_p\left[f_1^V\gamma^\mu - f_2^V\frac{i\sigma^{\mu\nu}q_\nu}{m_{\Lambda_b}} + f_3^V\frac{q^\mu}{m_{\Lambda_b}}\right]u_{\Lambda_b}$$

$$\langle p|\bar{u}\gamma^\mu\gamma_5 b|\Lambda_b\rangle = \bar{u}_p\left[f_1^A\gamma^\mu - f_2^A\frac{i\sigma^{\mu\nu}q_\nu}{m_{\Lambda_b}} + f_3^A\frac{q^\mu}{m_{\Lambda_b}}\right]\gamma_5 u_{\Lambda_b}$$

In the $m_b \to \infty$ limit

$$\langle p(k',s')|\bar{u}\Gamma Q|\Lambda_Q(v,s)\rangle = \bar{u}_p(k',s')\left[F_1(k'\cdot v) + \not{v}F_2(k'\cdot v)\right]\Gamma u_{\Lambda_b}(v,s)$$

$\Lambda_b \to \Lambda$ form factors

In general

$$\langle \Lambda | \bar{s}\gamma^\mu b | \Lambda_b \rangle = \bar{u}_\Lambda \left[f_1^V \gamma^\mu - f_2^V \frac{i\sigma^{\mu\nu} q_\nu}{m_{\Lambda_b}} + f_3^V \frac{q^\mu}{m_{\Lambda_b}} \right] u_{\Lambda_b}$$

$$\langle \Lambda | \bar{s}\gamma^\mu \gamma_5 b | \Lambda_b \rangle = \bar{u}_\Lambda \left[f_1^A \gamma^\mu - f_2^A \frac{i\sigma^{\mu\nu} q_\nu}{m_{\Lambda_b}} + f_3^A \frac{q^\mu}{m_{\Lambda_b}} \right] \gamma_5 u_{\Lambda_b}$$

$$\langle \Lambda | \bar{s} i\sigma^{\mu\nu} q_\nu b | \Lambda_b \rangle = \bar{u}_\Lambda \left[f_1^{TV} \frac{\gamma^\mu q^2 - q^\mu \not{q}}{m_{\Lambda_b}} - f_2^{TV} \frac{q^\mu}{m_{\Lambda_b}} \right] u_{\Lambda_b}$$

$$\langle \Lambda | \bar{s} i\sigma^{\mu\nu} q_\nu \gamma_5 b | \Lambda_b \rangle = \bar{u}_\Lambda \left[f_1^{TA} \frac{\gamma^\mu q^2 - q^\mu \not{q}}{m_{\Lambda_b}} - f_2^{TA} \frac{q^\mu}{m_{\Lambda_b}} \right] \gamma_5 u_{\Lambda_b}$$

In the $m_b \to \infty$ limit

$$\langle \Lambda(k', s') | \bar{s}\Gamma Q | \Lambda_Q(v, s) \rangle = \bar{u}_\Lambda(k', s') \left[F_1(k' \cdot v) + \not{v} F_2(k' \cdot v) \right] \Gamma u_{\Lambda_b}(v, s)$$

Lattice actions & parameters

RBC/UKQCD lattices (2+1 domain wall)

Static ($m_b = \infty$) heavy quarks

Set	β	$N_s^3 \times N_t \times N_5$	am_5	$am_s^{(sea)}$	$am_{u,d}^{(sea)}$	a (fm)	$am_{u,d}^{(val)}$	$m_\pi^{(val)}$ (MeV)	$m_N^{(val)}$ (MeV)	N_{meas}
C14	2.13	$24^3 \times 64 \times 16$	1.8	0.04	0.005	0.1119(17)	0.001	245(4)	1090(21)	2672
C24	2.13	$24^3 \times 64 \times 16$	1.8	0.04	0.005	0.1119(17)	0.002	270(4)	1103(20)	2676
C54	2.13	$24^3 \times 64 \times 16$	1.8	0.04	0.005	0.1119(17)	0.005	336(5)	1160(19)	2782
F23	2.25	$32^3 \times 64 \times 16$	1.8	0.03	0.004	0.0849(12)	0.002	227(3)	1049(25)	1907
F43	2.25	$32^3 \times 64 \times 16$	1.8	0.03	0.004	0.0849(12)	0.004	295(4)	1094(18)	1917
F63	2.25	$32^3 \times 64 \times 16$	1.8	0.03	0.006	0.0848(17)	0.006	352(7)	1165(23)	2782

1-loop operator matching: T Ishikawa *et al.*, JHEP 1105, 040 (2011)

Form factor shape

- In static limit, *z*-expansion is not applicable
- Instead, try monopole, dipole, etc. (Latter is a better fit to the data)
- Incorporate discretization and quark mass effects

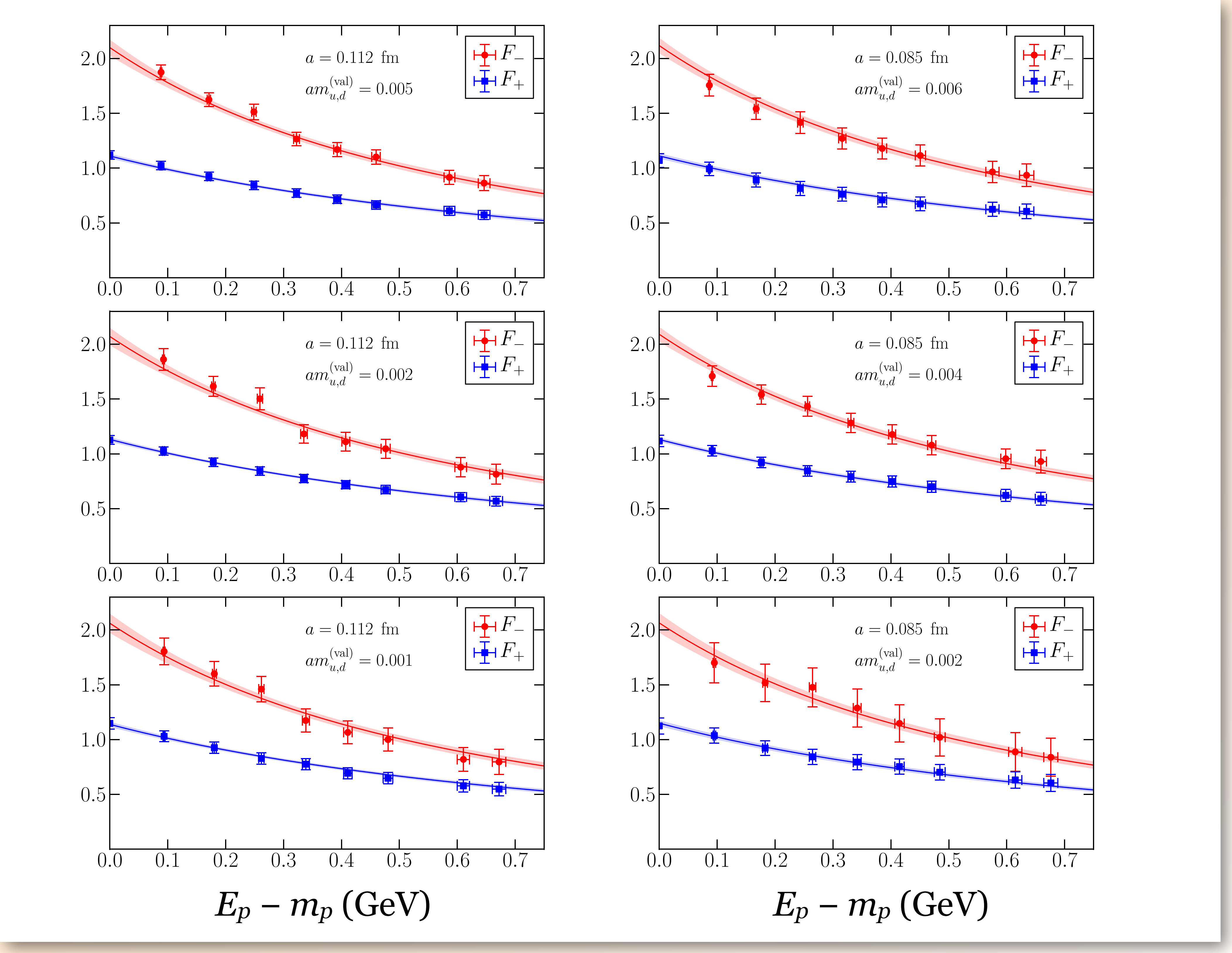
$$F = \frac{Y}{(X + E_p - m_p)^2}\left[1 + d(aE_p)^2\right]$$

$$X = X_0 + c[m_\pi^2 - (m_\pi^{\rm phys})^2]$$

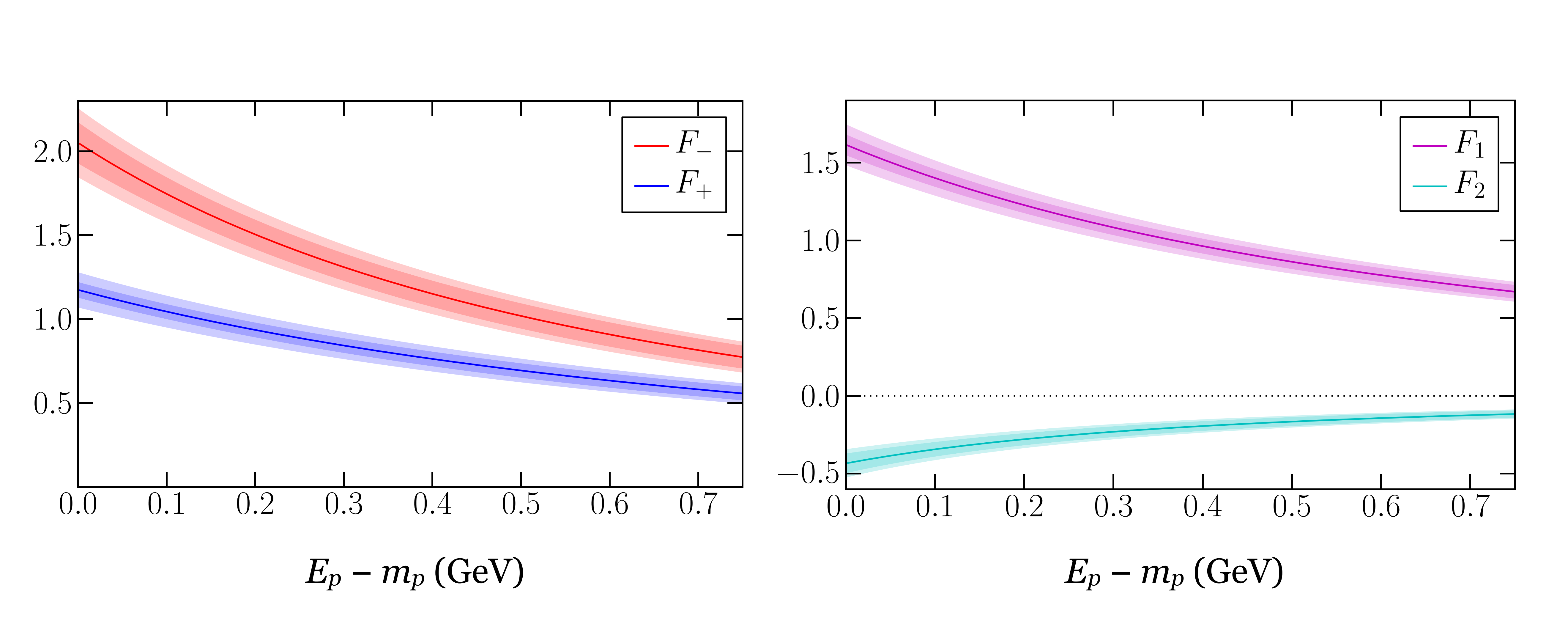
- In practice, *c*'s & *d*'s small, consistent with zero [except $c_{l,+} = 0.094(32)$ in the $\Lambda_b \to \Lambda$ calculation]

Form factors on each ensemble

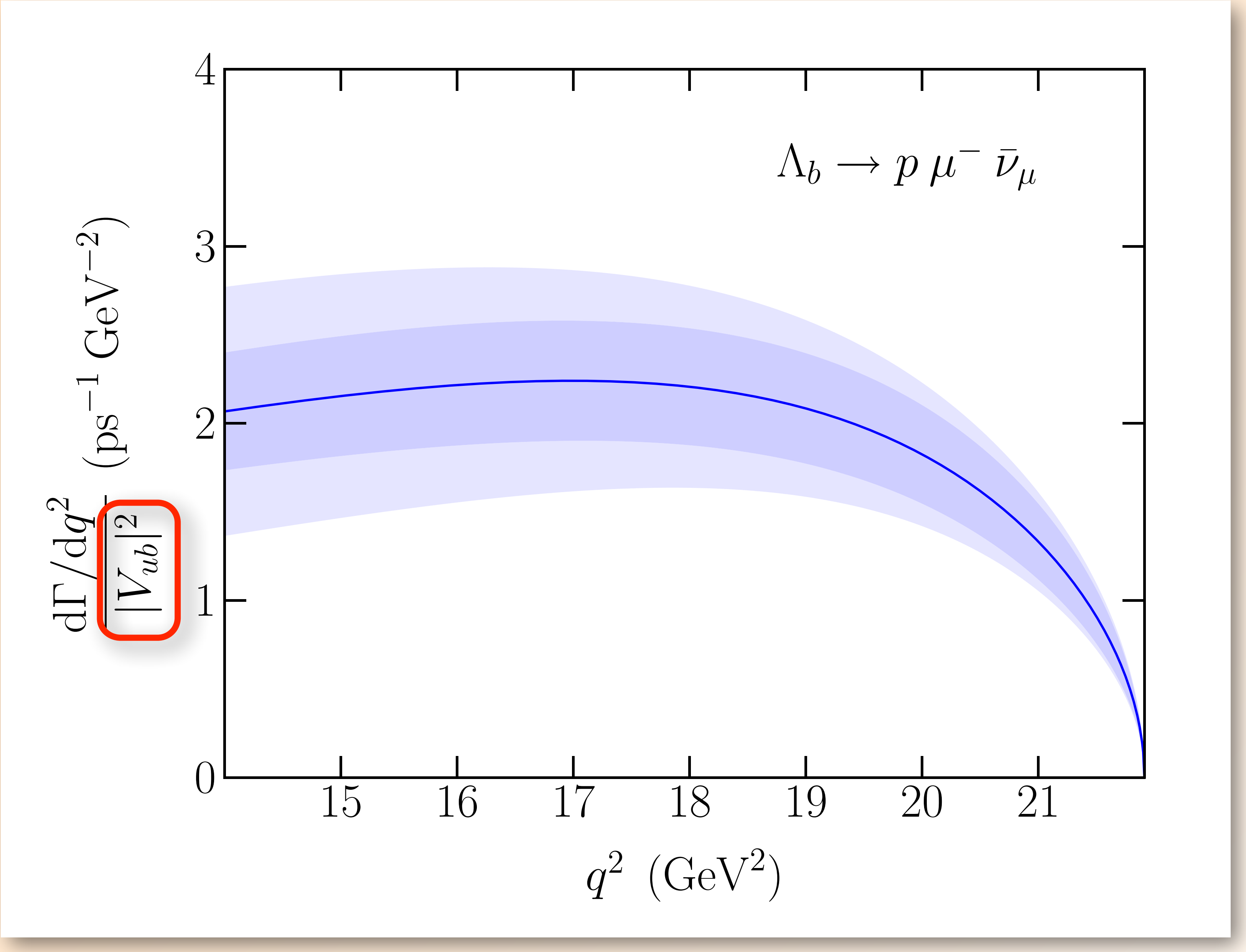
$$F_{\pm} = F_1 \pm F_2$$



Form factors, physical limit



Decay rate $\Lambda \to p\,\mu\,\nu$

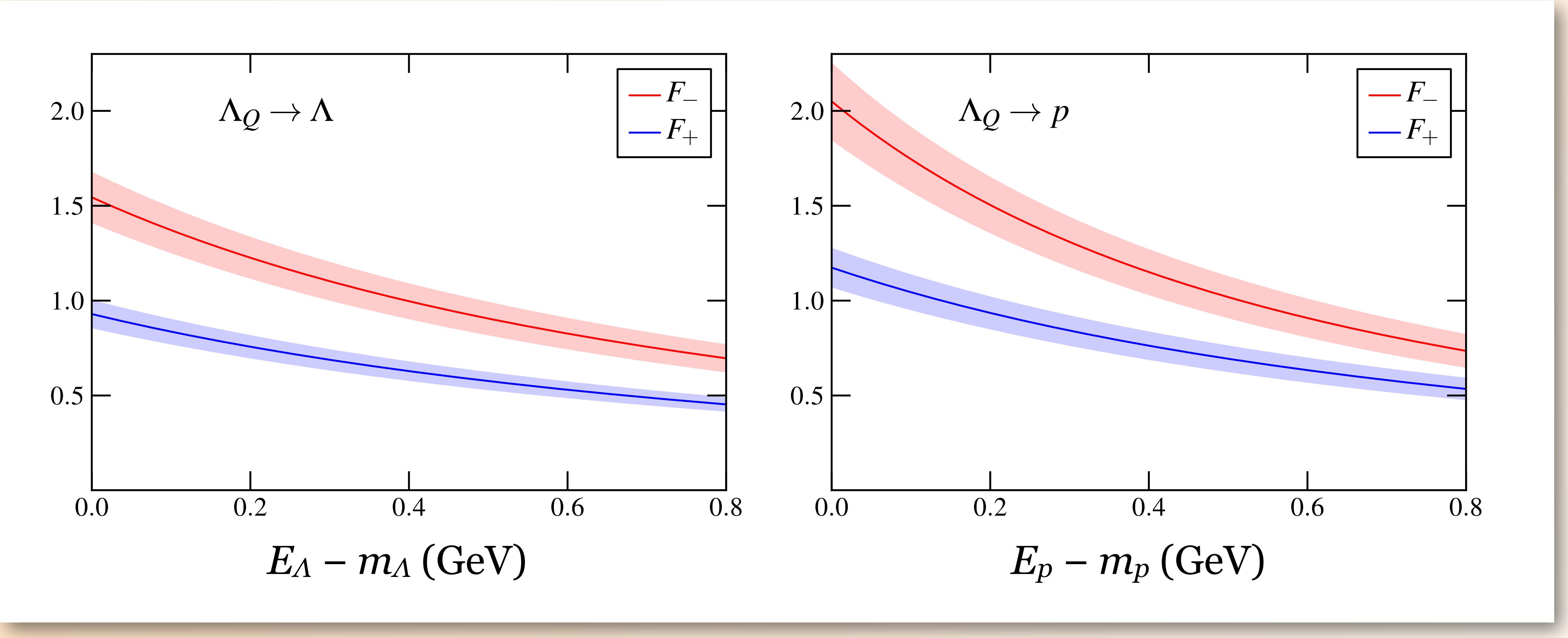


Outer error band includes estimate of terms beyond LO static approximation: $\sim \sqrt{\frac{\Lambda_{QCD}^2}{m_b^2} + \frac{|\mathbf{k}'|^2}{m_b^2}}$

Detmold, Lin, Meinel, Wingate, PRD88 (2013)

Comparison: Λ vs. p final states

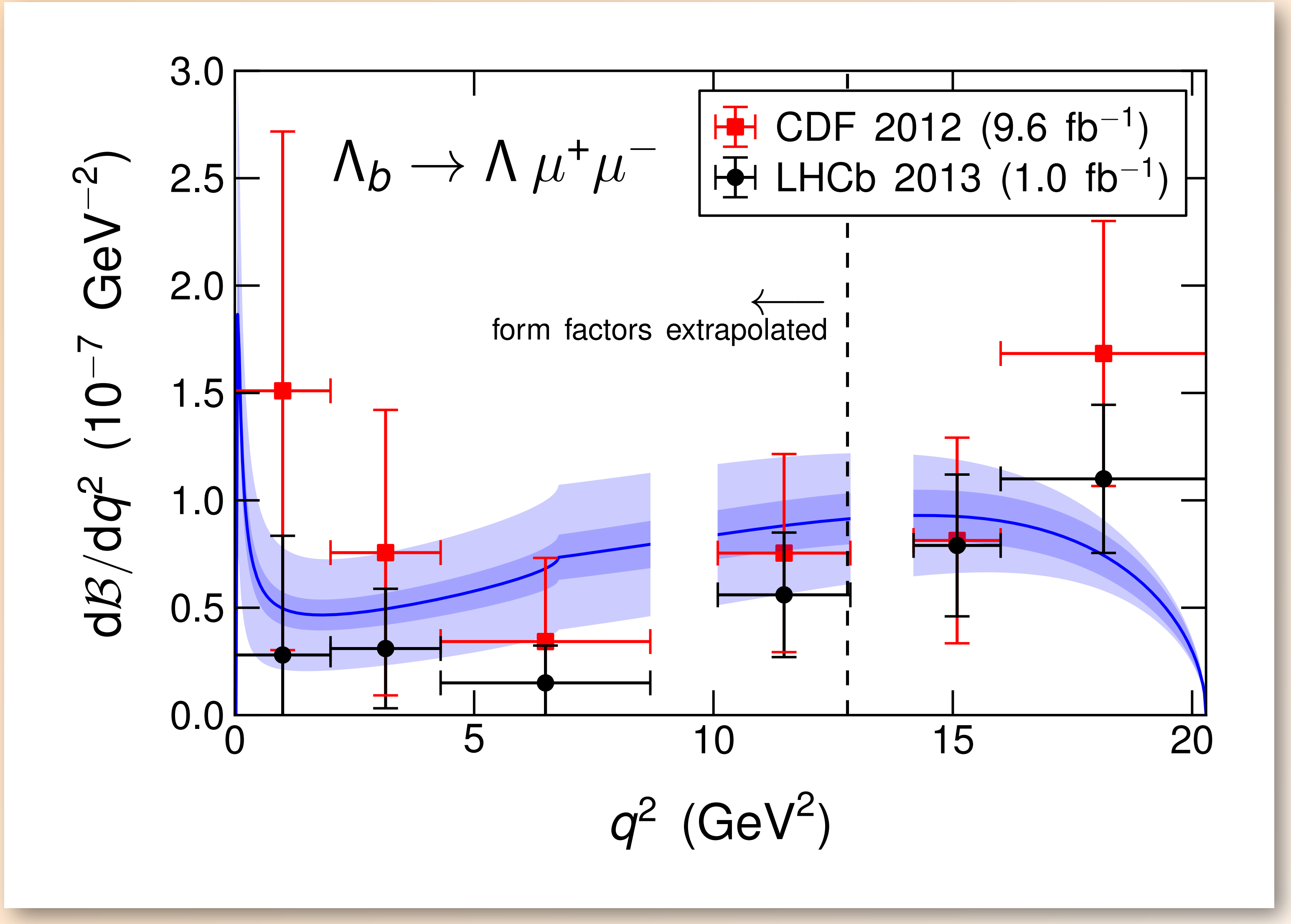
$$F_{\pm} = F_1 \pm F_2$$



Error bands: statistical + 8% lattice systematic uncertainties

figure from S Meinel, Lattice 2013

Differential b.f. $\Lambda_b \to \Lambda\, \mu^+ \mu^-$



Note: $C_9^{NP} < 0$ would imply a decrease in the b.f.

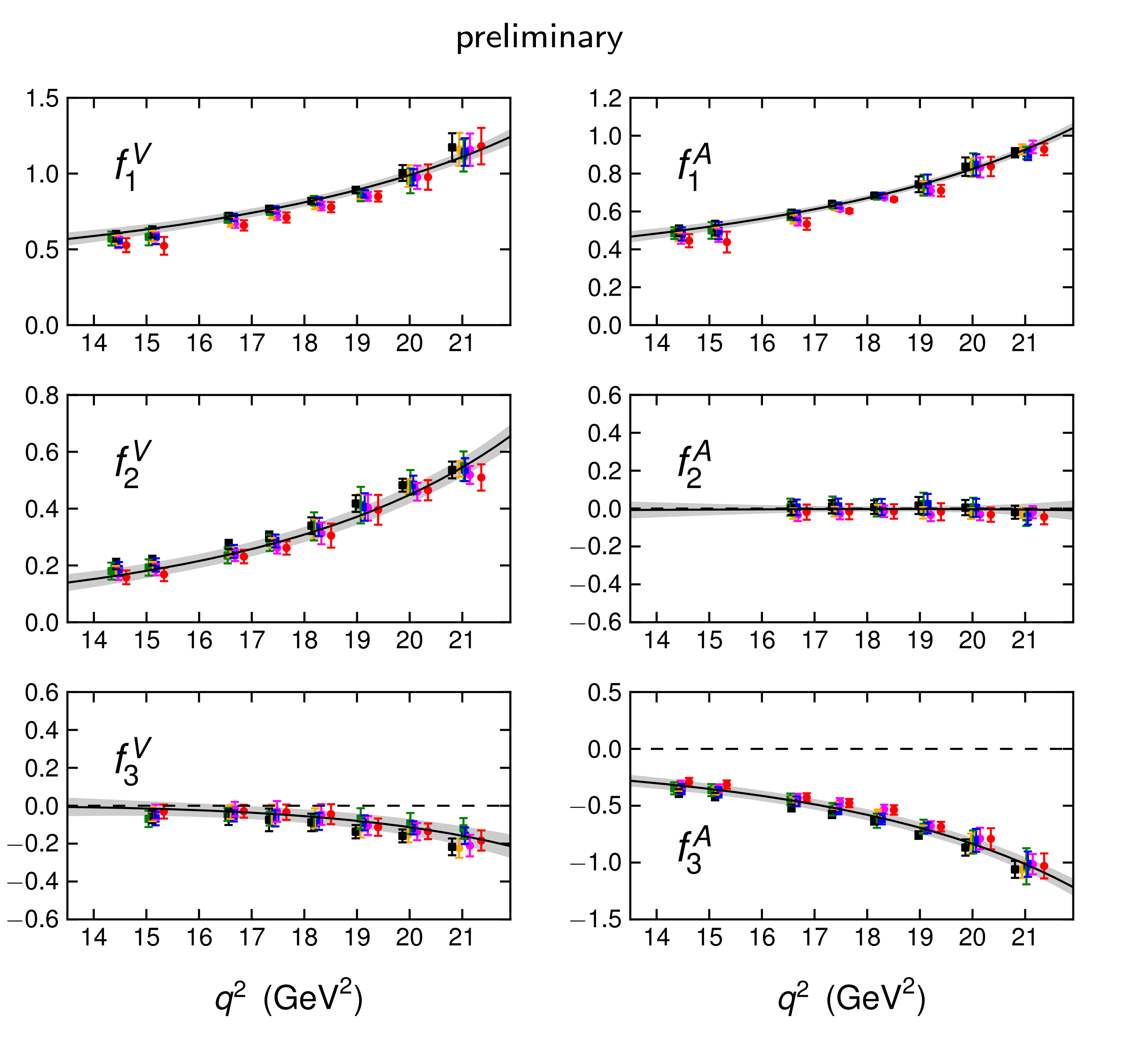
S Meinel, Lattice 2013, update of Detmold, Lin, Meinel, Wingate, PRD87 (2013)

Beyond the static approximation

- S Meinel is extending the calculation beyond static action
- RBC/UKQCD lattice ensembles
- Relativistic heavy quark action: Fermilab method with nonperturbatively tuned coefficients. (RBC/UKQCD collab)
- "Mostly nonperturbative" operator matching (Fermilab)
- Replace pole model with *z*-expansion
- Result: dramatic reduction of systematic uncertainties

$\Lambda_b \to p$ form factors

Status of S Meinel's ongoing calculation

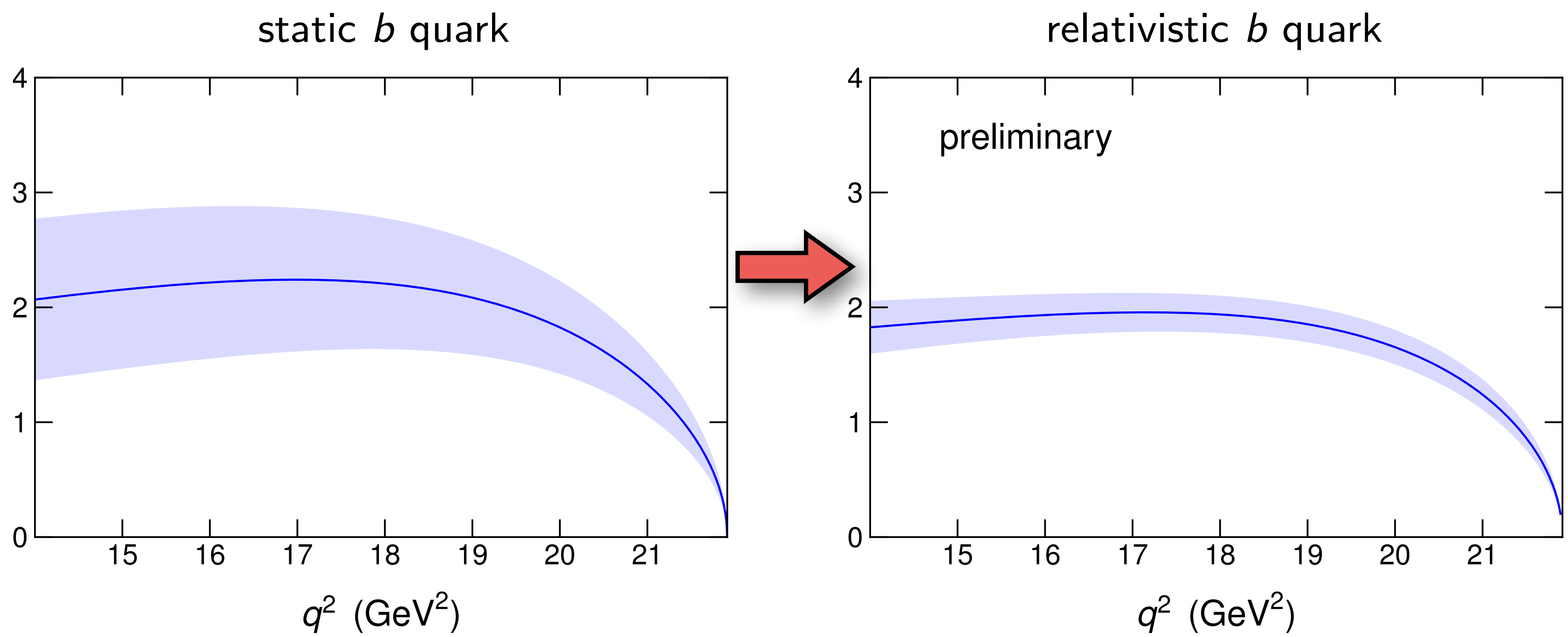


S Meinel at FPCP 2014

Predicted precision

$\Lambda_b \to p\,\mu^-\,\bar{\nu}_\mu$

$\frac{d\Gamma/dq^2}{|V_{ub}|^2}$ $(\mathrm{ps}^{-1}\,\mathrm{GeV}^{-2})$



Total uncertainties shown.

S Meinel at FPCP 2014

Conclusions

- First lattice calculations of Λ_b form factors
- $\Lambda_b \to p\, l^- \nu$: Novel method to determine $|V_{ub}|$
- $\Lambda_b \to \Lambda\, l^+ l^-$: complements $B \to K^{(*)} l^+ l^-$ and $B_s \to \varphi\, l^+ l^-$
- Look forward to experimental measurements

References

$\Lambda_b \to p$

W Detmold, C-J D Lin, S Meinel, M Wingate

Phys. Rev. D 88, 014512 (2013) [arXiv:1306.0446]

$\Lambda_b \to p$, etc.

S Meinel

Lattice 2013 [arXiv:1401.2685], FPCP 2014 slides

$\Lambda_b \to \Lambda$

W Detmold, C-J D Lin, S Meinel, M Wingate

Phys. Rev. D 87, 074502 (2013) [arXiv:1212.4827]