MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Rare B-decays

Frederik Beaujean

IMPRS workshop

Wildbad Kreuth, 28.07.2011

Our Task

How to win the Nobel prize?

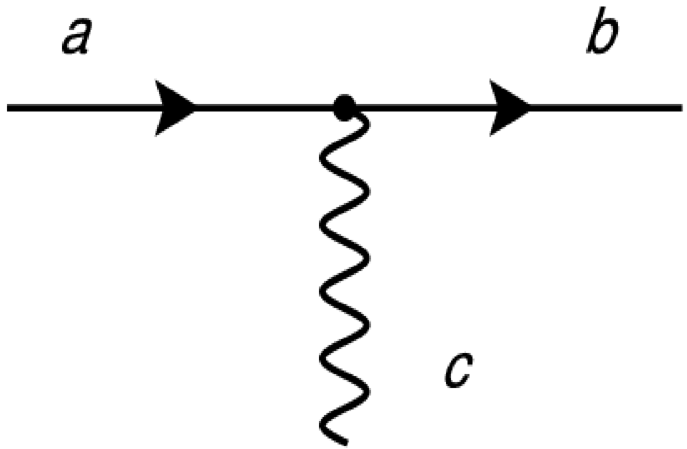
1) Technical application for greater good. **No!**
2) Find fundamentally new physics. **Try!**

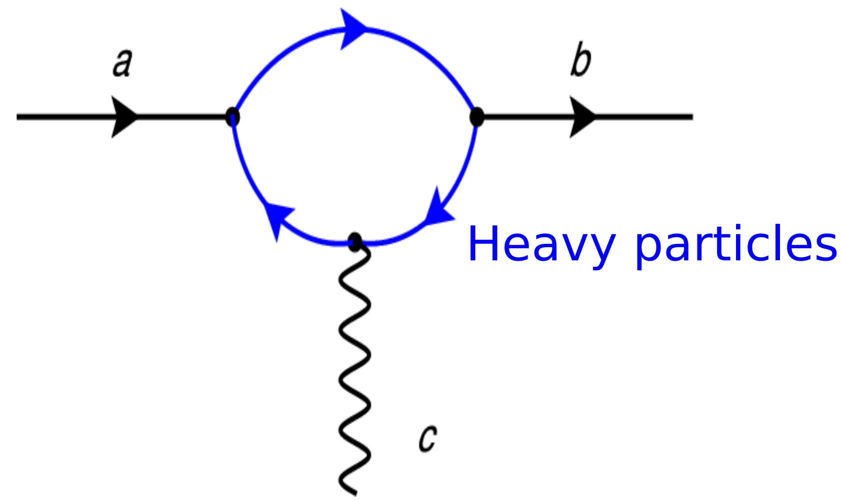
http://en.wikipedia.org/wiki/File:Nobel_medal_dsc06171.png

Particle physics:

1) Higher energy – on-shell
2) Higher precision – off-shell **Try!**

Loop contributions





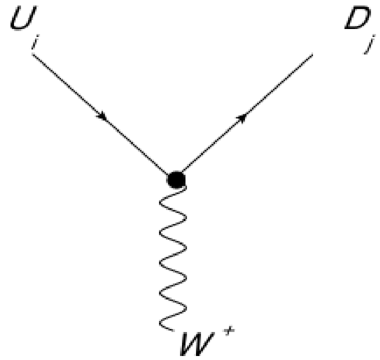
Use tree level prohibited reaction in SM:

- No suppression of New Physics (NP) vs SM at low energies
- Requires high experimental and theoretical precision

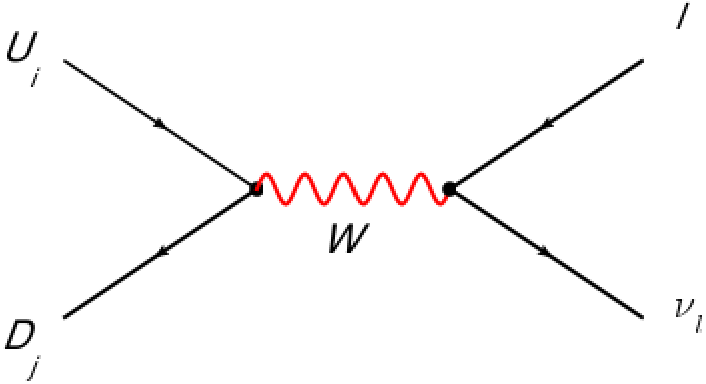
Flavor changes: standard model

$U_i = \{u, c, t\}$: $Q_U = +2/3$ $\quad D_j = \{d, s, b\}$: $Q_D = -1/3$

$$\mathcal{L}_{\rm CC} = \frac{g_2}{\sqrt{2}} (\bar{u}, \bar{c}, \bar{t}) \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \gamma^\mu P_L \begin{pmatrix} d \\ s \\ b \end{pmatrix} W_\mu^+$$

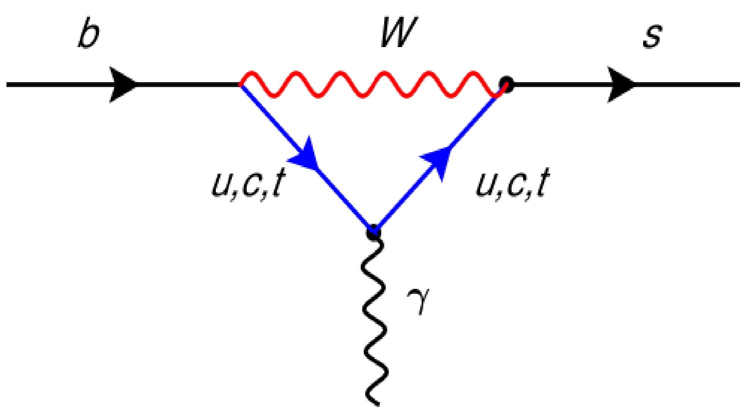


- Tree level: $U_i \to D_j \Rightarrow Q_i \neq Q_j$
  charged current



$$\mathcal{A} \sim G_F V_{ij}$$

- Loop level: $D_i \to D_j \Rightarrow Q_i = Q_j$
  neutral current (FCNC)



$$\mathcal{A} \sim e\, G_F \sum_{k=u,c,t} V_{kb} V_{ks}^* f(M_k)$$

B-mesons

- Look for basic flavor changing neutral current reactions

$$b \to s\gamma \Leftrightarrow B \to K^*\gamma \qquad Br \sim 10^{-4}$$

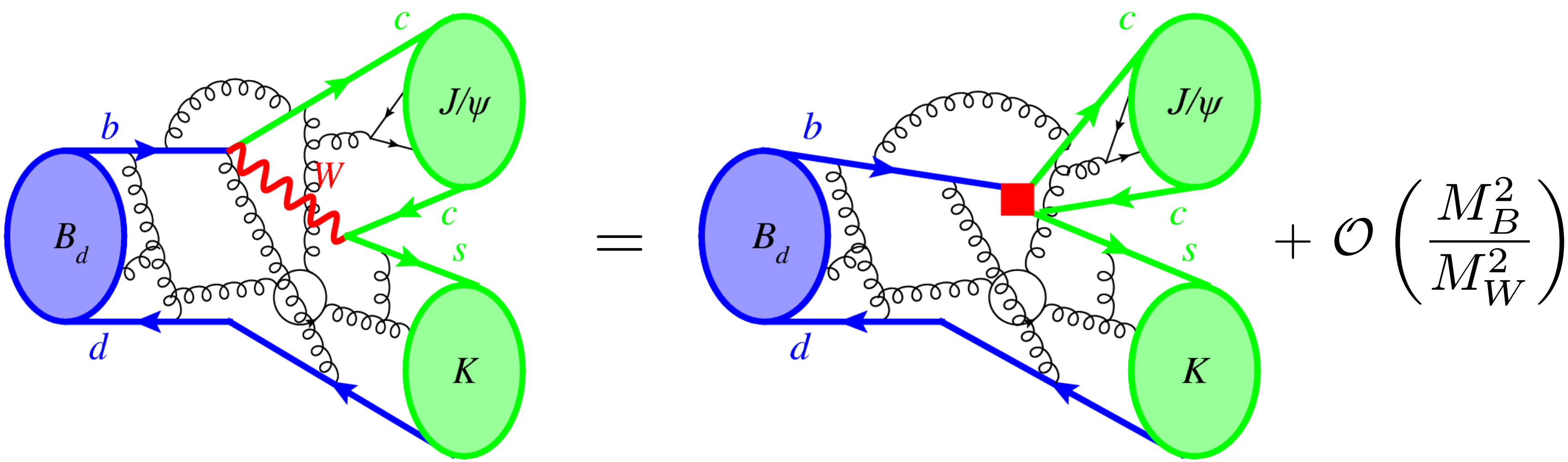
$$b \to s l^+ l^- \Leftrightarrow B \to K^{(*)} l^+ l^-,\ l = e, \mu \qquad Br \sim 10^{-6}$$

- Reminder:

$$B^0 = d\bar{b} \quad 5279.5 \text{ MeV} \qquad K^0 = d\bar{s} \quad 490.7 \text{ MeV}$$

$$B^+ = u\bar{b} \quad 5279.2 \text{ MeV} \qquad K^{0*} = d\bar{s} \quad 896.0 \text{ MeV}$$

Hadron decay – a multiscale problem



Typical interaction energy scales

Electroweak	$\gg$	hadron in restframe	$\gg$	QCD bound state
gauge bosons				
$M_W \approx 80\,\mathrm{GeV}$		$M_B \approx 5\,\mathrm{GeV}$		$\Lambda_{QCD} \approx 0.3\,\mathrm{GeV}$
$M_Z \approx 91\,\mathrm{GeV}$				
Top quark				
$M_t \approx 172\,\mathrm{GeV}$				

Effective field theory (EFT) =
separate long distance (QCD) from short distance (EW)

EFT: matching the full theory I

- short-distance vs long-distance. Replace Hamiltonian

$$\mathcal{H}^{\text{full}} \to \mathcal{H}^{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \mathcal{C}_i \mathcal{O}_i$$

only b → s

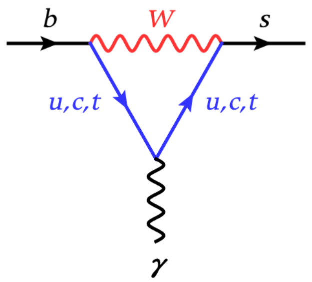
Wilson coefficient $\mathcal{C}_i$, effective operator $\mathcal{O}_i$

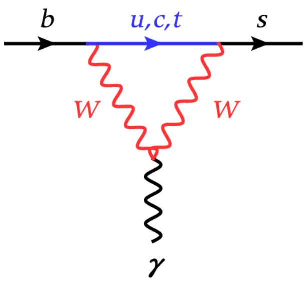
- In general: $\mathcal{C}_i \in \mathbb{C}$ but in SM $\mathcal{C}_i \in \mathbb{R}$
- Similar to Fermi's four fermion theory
- Matrix element $\langle K^* l^+ l^- | \mathcal{O}_i | B \rangle$

Observables $\sim |\langle K^* l^+ l^- | \sum_i \mathcal{C}_i \mathcal{O}_i | B \rangle|^2$

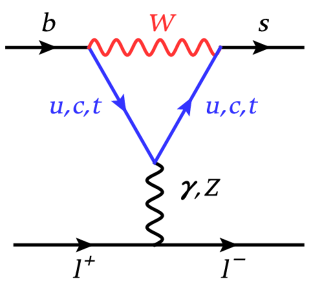
EFT: matching the full theory II

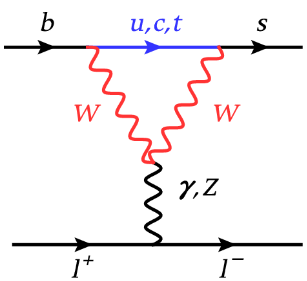
Full theory

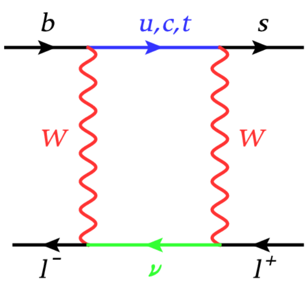




$$b \to s\gamma \Leftrightarrow B \to K^*\gamma$$



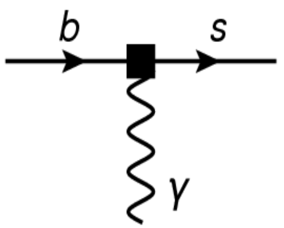




$$b \to s l^+ l^- \Leftrightarrow B \to K^{(*)} l^+ l^-$$

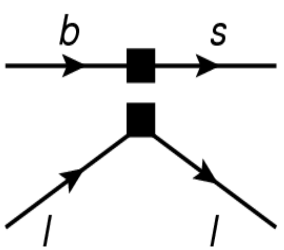
Effective theory

$\longrightarrow \mathcal{C}_7 \quad \times$



$$\mathcal{O}_7 = m_b\,[\bar{s}\sigma_{\mu\nu}P_R b]\,F^{\mu\nu}$$

$\longrightarrow \mathcal{C}_{9,10} \times$



$$\mathcal{O}_{9,10} = [\bar{s}\gamma_\mu P_L b]\,[\bar{l}\gamma^\mu(\gamma_5)l]$$

Leading order in G_F

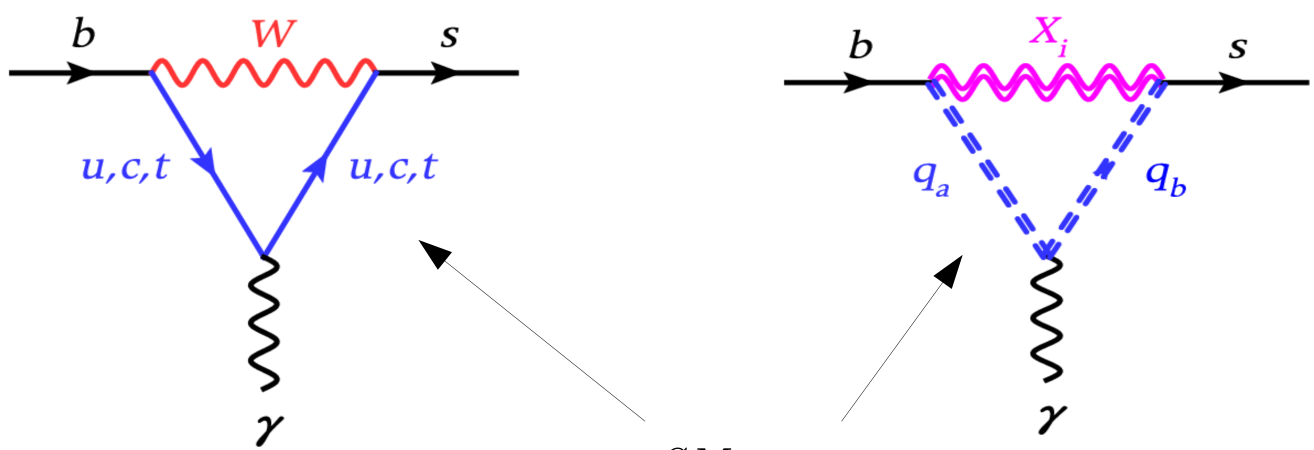
higher order QCD corrections known

New Physics

- New operators, e.g. chiral flip

$$\mathcal{O}_7 = m_b \left[\bar{s}\sigma_{\mu\nu} P_R b\right] F^{\mu\nu} \longleftrightarrow \mathcal{O}_7^{'} = m_b \left[\bar{s}\sigma_{\mu\nu} P_L b\right] F^{\mu\nu}$$

- New contribution to Wilson coefficient



$$\mathcal{C}_i \to \mathcal{C}_i = \mathcal{C}_i^{SM} + \Delta\mathcal{C}_i$$

- Corrections known for (N)MSSM, 2HDM...

Model independent analysis in terms of $\mathcal{C}_i$

Toolkit

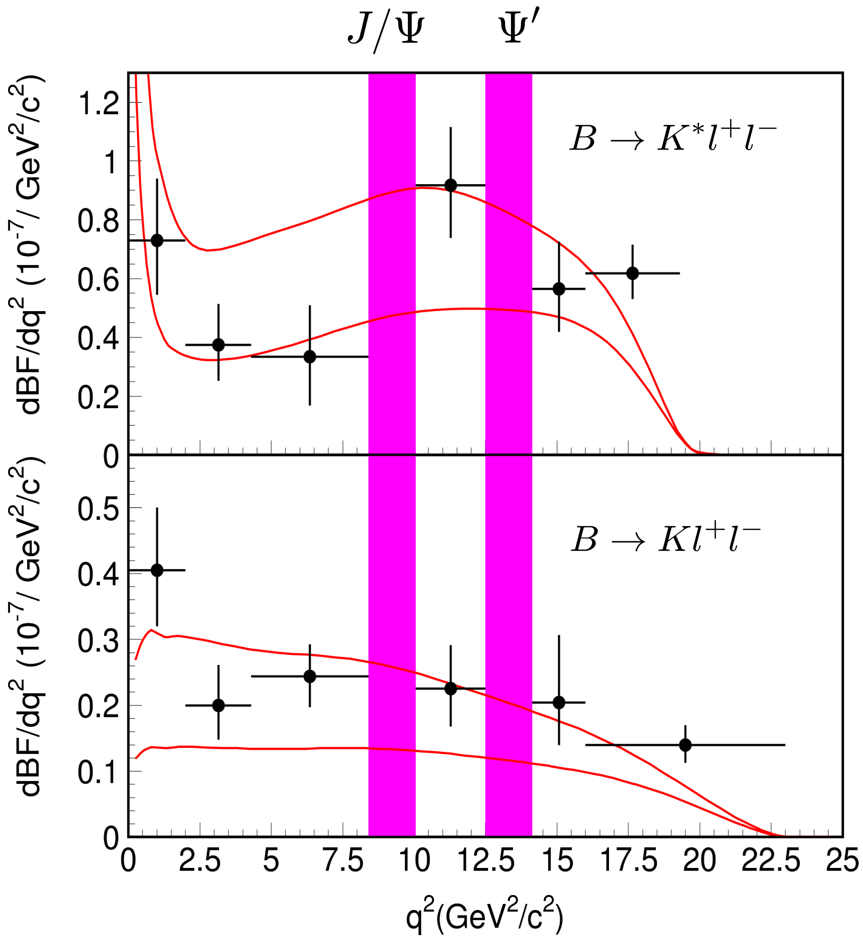
- Number of decays and associated observables to probe $\mathcal{C}_{7,9,10}$
- Focus on $B \to K^*\gamma,\ B \to K^{(*)}l^+l^-$: branching ratio, A_{FB}, F_L ...
- Tool to calculate predictions and compare with observations: EOS
  http://project.het.physik.tu-dortmund.de/eos/

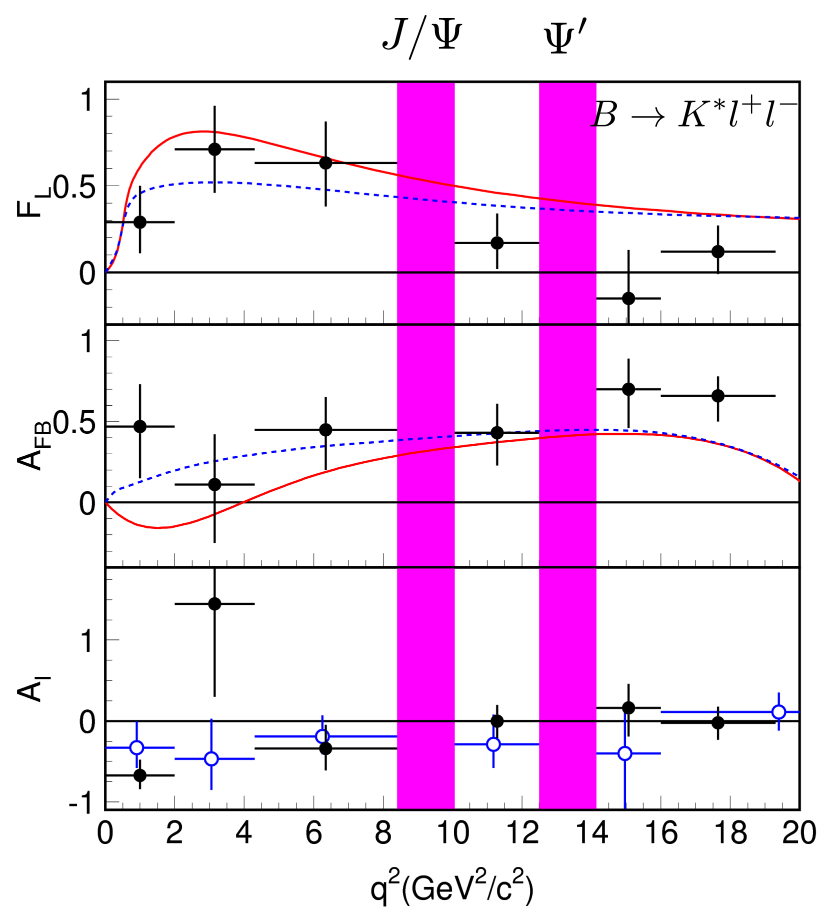
People involved: D. van Dyk, C. Wacker (Dortmund)
C. Bobeth (IAS-TUM, Universe Cluster, Garching)
F. B.

Theory vs Experiment $B \to K^{(*)} l^+ l^-$

- No reliable theory predictions near charmonium resonances
- Results from BaBar, Belle, CDF, LHCb

arxiv:0904.0770 Belle





- Two interesting regions of dilepton momentum $q^2 = (p_{l^+} + p_{l^-})^2$

Bayesian analysis method

- Calculate the predictions in terms of Wilson coefficients $\vec{C}$
- Construct likelihood incorporating theoretical uncertainties as nuisance parameters $\vec{\nu}$
- Typically use Gaussian priors for $\vec{\nu}$ and uniform priors for $\vec{C}$
- Extract posterior of $\vec{C}$ using Bayes' theorem

$$P\left(\vec{C}|\mathrm{data}\right) \propto \int \mathrm{d}\vec{\nu}\; P\left(\mathrm{data}|\vec{C},\vec{\nu}\right) \cdot P_0\left(\vec{C},\vec{\nu}\right)$$

- Run Markov Chain Monte Carlo to samples from posterior
- Check compatibility with SM predictions for $\vec{C}$ (semi model-indep.)

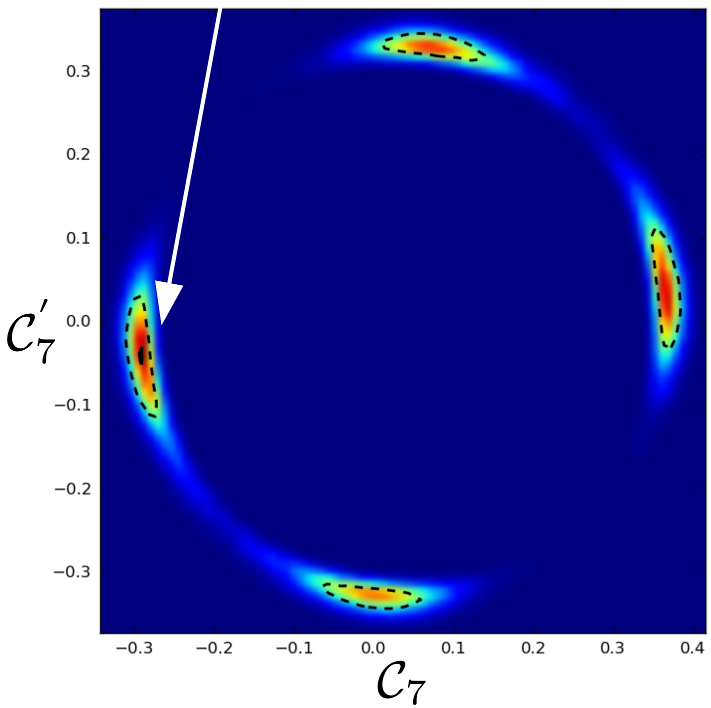
Fit results

- Analyze only $B \to K^* \gamma$ using measurements of BR and S_K from Babar, Belle, Cleo
- Allow flipped chirality operator

$$\Delta\mathcal{H} = \mathcal{C}_7'\mathcal{O}_7'$$

- Restrict to $\mathcal{C}_7, \mathcal{C}_7' \in \mathbb{R}$
- New physics with opposite chirality well possible
- SM fully OK

$\mathrm{SM}: \mathcal{C}_7 \approx -0.3, \mathcal{C}_7' \approx 0$



Need more exp. results

preliminary

Summary + Outlook

- **Objective: finding/constraining new physics in rare B-decays with sophisticated fit**
- **New data: LHCb, Belle II, SuperB**
- **Final results also from Belle, BaBar, CDF+D0**

The End