NOTHING NEW ON THE B PHYSICS FRONT?

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- Higgs confirmed(?), but where is new physics?
- LHCb looking for new reactions in flavor sector

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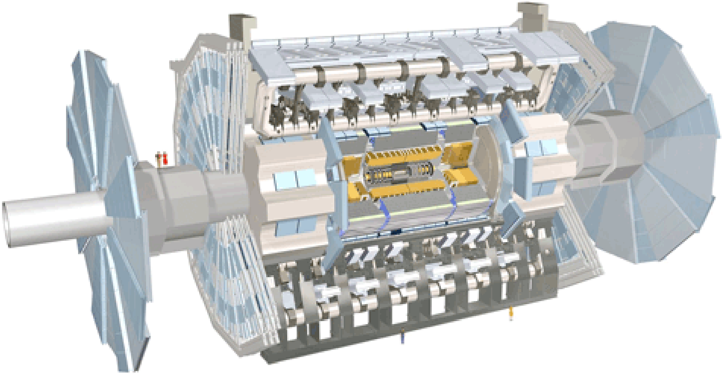
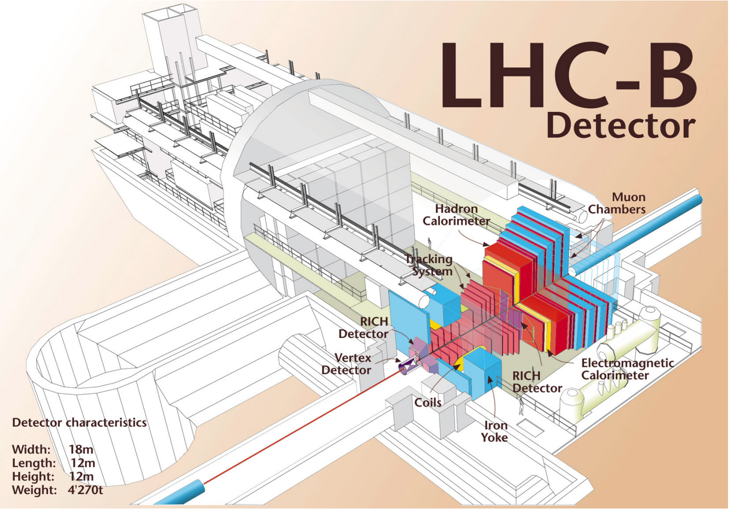


OUR GOAL

- Higgs confirmed(?), but where is new physics?
- LHCb looking for new reactions in flavor sector



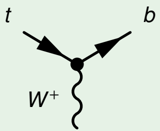
http://www.hep.phy.cam.ac.uk/lhcb/images/LHCb.jpg

Rare B decays

Flavour changes: only via charged currents and weak force

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

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

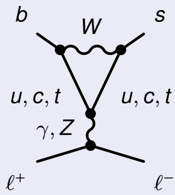


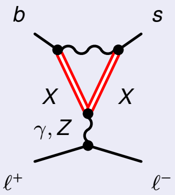
Flavour changing neutral currents in SM

Only at loop level
Partons: $b \to s\ell^+\ell^-$:
Hadrons: $B \to K^{(*)}\ell^+\ell^-$

- ⇒ no suppression of contributions beyond SM (BSM) wrt SM itself
- ⇒ indirect search for heavy particles up to $\mathcal{O}(100\text{ TeV})$

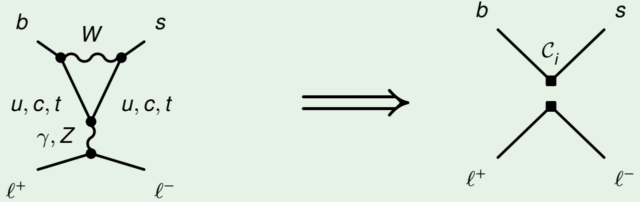
requires high precision, experimentally and theoretically !!!





Effective theory

Operator matching



Decoupling of heavy from light particles

- short distance: effective coupling (Wilson coefficient) $\mathcal{C}_i$
- long distance: effective operator $\mathcal{O}_i$

$$\mathcal{L}_{\text{eff}}(\mu_b) = \mathcal{L}_{\text{QED}\times\text{QCD}}(u, d, s, c, b, e, \mu, \tau)$$

$$+ \frac{4G_F}{\sqrt{2}} V_{\text{CKM}} \sum_{\text{SM}} (\mathcal{C}_i + \Delta\mathcal{C}_i)\mathcal{O}_i + \sum_{\text{NP}} \mathcal{C}_j \mathcal{O}_j (???)$$

Global fit

Our goal

- Assume no new operators, $\mathcal{C}_i \in \mathbb{R}$
- Extract $\mathcal{C}_{7,9,10}$ and check for new physics

Bayes' theorem

posterior $\propto$ likelihood $\times$ prior

$$P(\mathcal{C}_i, \vec{\nu}|D) = \frac{P(D|\mathcal{C}_i, \vec{\nu}) P(\mathcal{C}_i, \vec{\nu})}{Z}$$

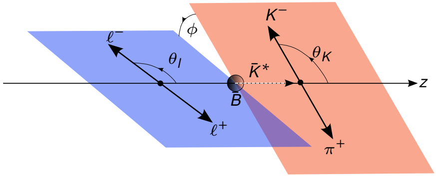
Our approach

- 59 observations from BaBar, Belle, CDF, LHCb $\Rightarrow D$
- theory uncertainty $\Rightarrow$ 28 nuisance parameters $\vec{\nu}$
- is $\mathcal{C}_i^{\mathrm{SM}}$ near best-fit point?
- remove nuisance parameters $P(\mathcal{C}_i|D) = \int \mathrm{d}\vec{\nu} P(\mathcal{C}_i, \vec{\nu}|D)$

EXAMPLE: $B \to K^*(\to K\pi)\ell^+\ell^-$ OBSERVABLES

q^2/GeV^2	[1, 6]	[14, 16]	[> 16]
$\mathcal{B}/10^{-7}$	$1.49^{+0.45}_{-0.40}$	$1.05^{+0.29}_{-0.26}$	$2.04^{+0.27}_{-0.24}$
A_{FB}	$-0.26^{+0.30}_{-0.27}$	$-0.70^{+0.22}_{-0.16}$	$-0.66^{+0.16}_{-0.11}$

TABLE: Belle 2009 (no systematics)



THREE BODY DECAY WITH VECTOR MESON K^*

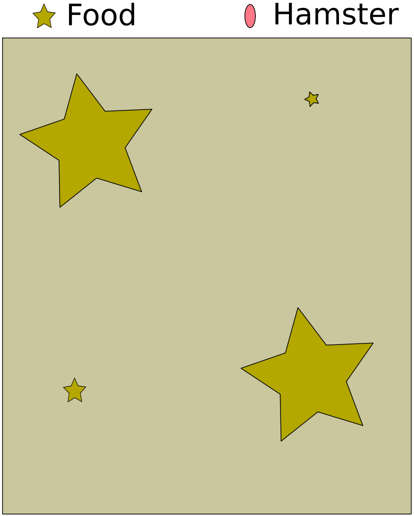
- $\Gamma = \Gamma(\theta_l, \theta_K, \phi, q^2), q^2 = (p_{\ell^+} + p_{\ell^-})^2 \Rightarrow \mathcal{O}(10)$ angular observables
- BaBar, Belle: $\mathrm{d}\Gamma/\mathrm{d}\theta_{l,K}$
- LHCb first to fully explore angular distribution; fall 2012?

DISCRETE SYMMETRIES

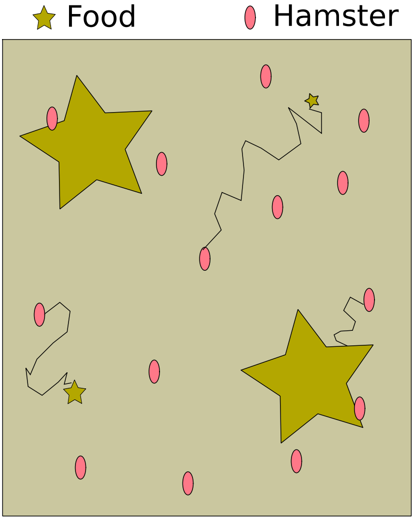
- typical dependence: $\mathcal{B} \propto \mathcal{C}_i\mathcal{C}_j$
- Invariance under $\mathcal{C}_i \to -\mathcal{C}_i, \mathcal{C}_7 \to -\mathcal{C}_{-7}$

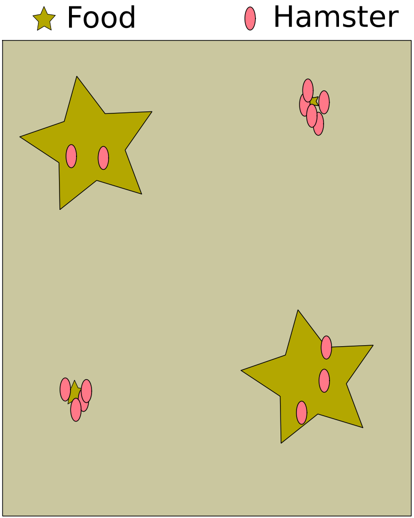
Numerical challenge

- Marginalization: draw samples from posterior
- Multimodal, complicated posterior ⇒ single evaluation $\mathcal{O}(0.2\,\mathrm{s})$
- 30D ⇒ curse of dimensionality
- Try with Markov chains (local random walk)



http://www.flickriver.com/photos/tags/cricetuscricetus/interesting/

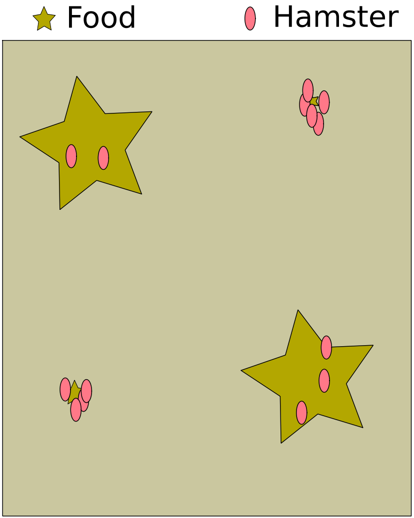

Food
Hamster

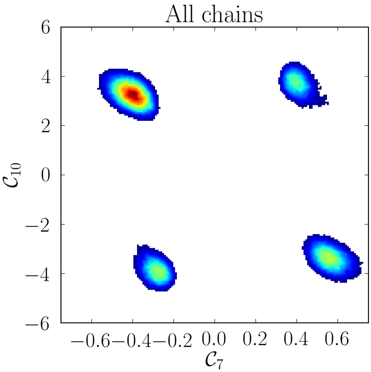


PROBLEMS

- hamsters stay at first food encountered
- #hamsters $\neq$ size of food pile

Markov chains are hamsters





Which of the four is important?

Importance sampling

Integration with importance sampling

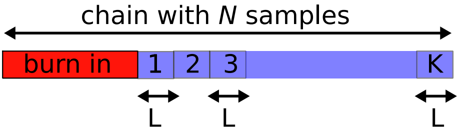
$$\int d\vec{\theta} P(\vec{\theta}) = \int d\vec{\theta} \frac{P(\vec{\theta})}{q(\vec{\theta})} q(\vec{\theta}) = \mathbb{E}_q \left[\frac{P}{q} \right]$$
$$\approx \frac{1}{N} \sum_{i=1}^{N} \frac{P(\vec{\theta}_i)}{q(\vec{\theta}_i)} = \frac{1}{N} \sum_{i=1}^{N} w_i, \; \vec{\theta}_i \sim q(\vec{\theta})$$

Maximum efficiency if $P = q$. How to choose a good proposal q?

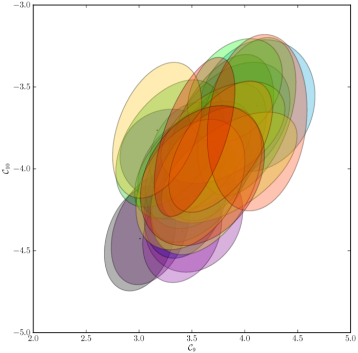
Population Monte Carlo (PMC) Cappé (2008), Kilbinger(2009)

- Assume mixture density $q(\vec{\theta}) = \sum_{j=1}^{m} \alpha_j q_j(\vec{\theta} \,|\, \vec{\mu}, \Sigma)$, α: weight, q_j: Gauss, Student-T
- Draw N samples $\vec{\theta}_i$ from q and compute w_i
- Make $q \to P$ by updating $\alpha_j, \vec{\mu}_j, \Sigma_j$

INITIAL PROPOSAL



- bad initial proposal in 30D
  $\Rightarrow$ most components die out
  $\alpha_1 = 1,\ \alpha_i = 0, i > 1$
- hamsters know where to go
- split chain of length N into patches of length L
- patch mean and covariance
  $\Rightarrow q_j(\vec{\mu}, \Sigma)$



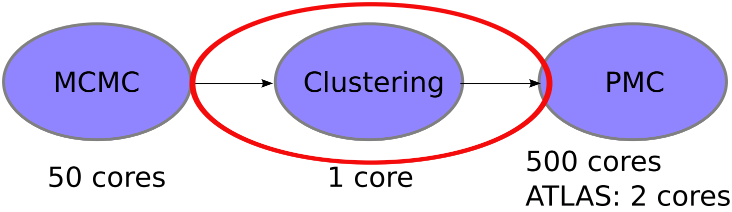
EXAMPLE

single chain, $N = 60000, L = 1000$, burn in = 6000 $\Rightarrow K = 54$ components.
With 50 chains $\Rightarrow$???

GOAL: CONDENSE INFORMATION

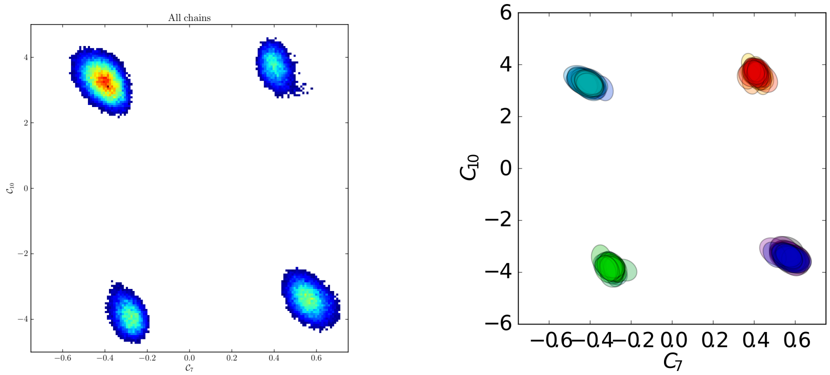
- Have mixture with M components $f(\vec{\theta}) = \sum_{l=1}^{M} \beta_l f_l(\vec{\theta}\,|\,\vec{\mu}_l, \Sigma_l)$,
- Want mixture with $m \ll M$ components $q(\vec{\theta}) = \sum_{j=1}^{m} \alpha_j q_j(\vec{\theta}\,|\,\vec{\mu}_j, \Sigma_j)$
- Find q “closest” to to f

THE BIG PICTURE



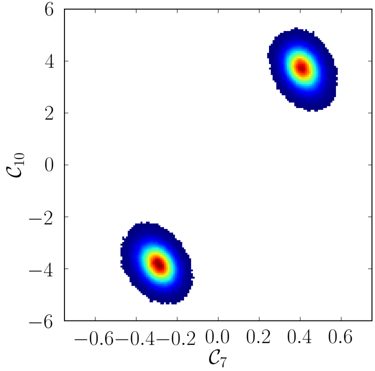
- cope with multimodality
- massive parallelization $\Rightarrow$ run over night

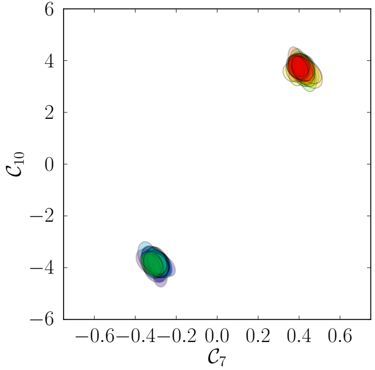
ALGORITHM AT WORK: GLOBAL FIT



Initial proposal from Markov chains

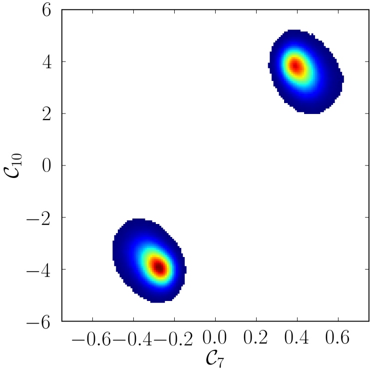
Algorithm at work: global fit

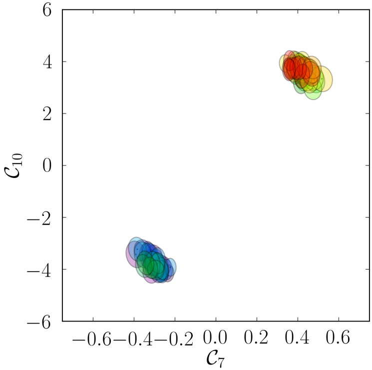




After first PMC update:
two modes suppressed by $10^9 - 10^{11}$

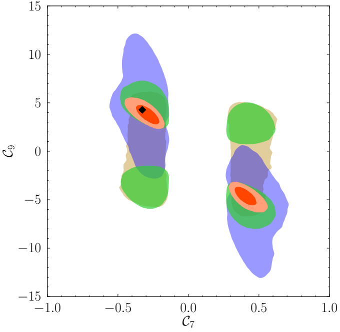
Algorithm at work: global fit





Converged after 10 PMC updates

Physics result: Wilson coefficients

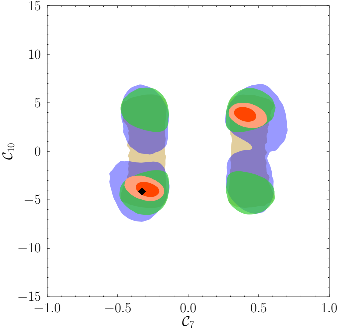


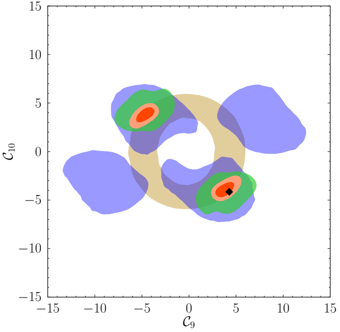
2σ contours of $B \to K^*\gamma$ with

1. $B \to K\bar{\ell}\ell$
2. $B \to K^*\bar{\ell}\ell$, low q^2
3. $B \to K^*\bar{\ell}\ell$, high q^2.

1 and 2σ contours with all data.

Standard Model: ◆





Model comparison

Models

1. $SM \equiv$ fixed $\mathcal{C}$, variable $\vec{\nu}$
2. extended model $M \equiv$ variable $\mathcal{C}$, $\vec{\nu}$

Posterior odds

$$\frac{P(SM|D)}{P(M|D)} = \frac{P(D|SM)}{P(D|M)} \cdot \frac{P(SM)}{P(M)} \approx 800 \cdot \frac{P(SM)}{P(M)}$$

$\Rightarrow$ Occam's razor favors simpler model

Conclusion

1. Improved Monte Carlo method
2. No signs of new physics in rare B decays