Prospects on the measurement of the $B_s^0 \to \phi\gamma$ photon polarization at LHCb

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Outline

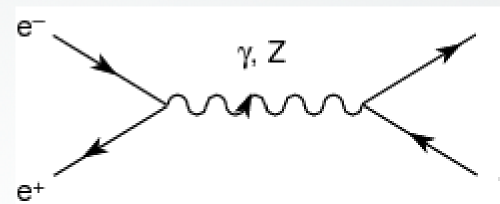
- Introduction
- A bit of theory
  - The $b \to s\gamma$ radiative penguin and the polarization fraction
  - The case of the B_s^0 meson
  - Sensitivity to NP
- Probing the photon polarization in LHCb
- Conclusions

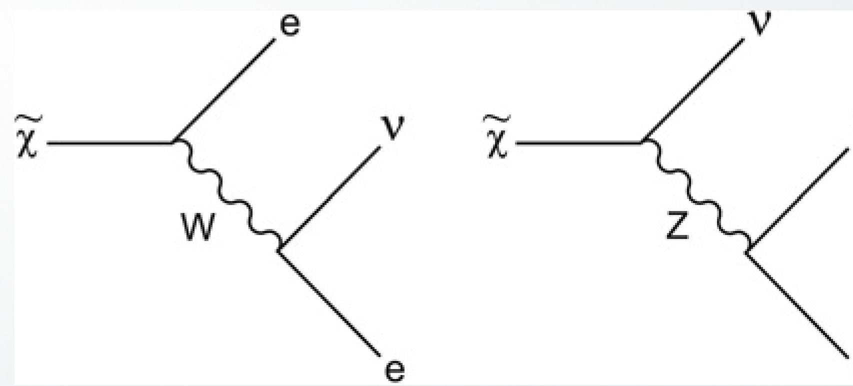
Introduction

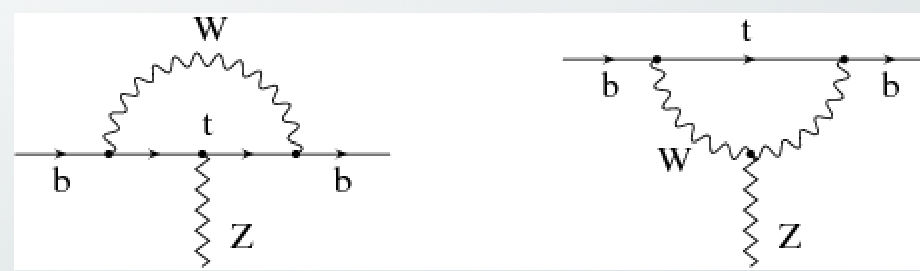
- The field of flavor physics is consistently reaping results, with great agreement between experiment and theory.
  - No clear signal of Beyond Standard Model physics (...?)
  - But SM is not the end of the story
    - Known unknowns: Mass hierarchy, neutrino mixing, dark matter, etc...
- The quest for new physics

Introduction

- Tree Level processes
  - Production of particles (eg. Z boson)
  - Leading order decays (eg neutralino → 2eν)
- Loops
  - Sometimes appear as N[N...]LO corrections to amplitudes

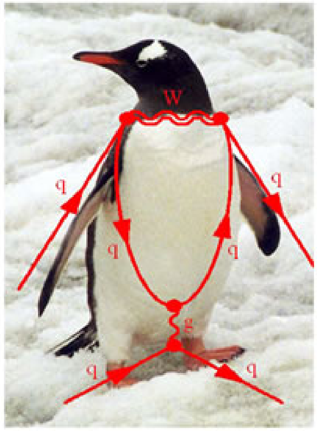


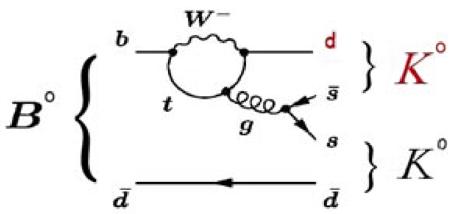


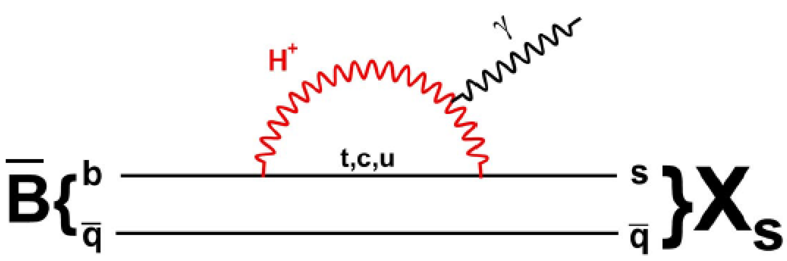


Introduction

- But some processes are forbidden at tree level, such as Flavor changing neutral currents (FCNC), and the leading order must have loops
- Penguin diagrams
  - Great probes for NP
  - More rare than tree level decays
    - Small branching fractions
      - < $O(10^{-5})$
    - Experimentally challenging





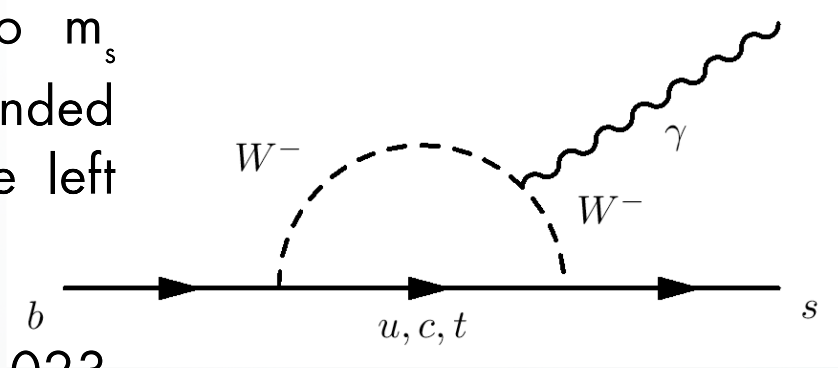


The b → sγ penguin

- The b → sγ transition, when described in the SM by the effective weak hamiltonian in terms of Wilson coefficients C_i and local operators O_i, the dominant contribution comes from the magnetic operator

$$O_{7\gamma}=\frac{e}{16\pi^2}[m_b(\bar{s}_{L\alpha}\sigma^{\mu\nu}b_{R\alpha})+m_s(\bar{s}_{R\alpha}\sigma^{\mu\nu}b_{L\alpha})]F_{\mu\nu}$$

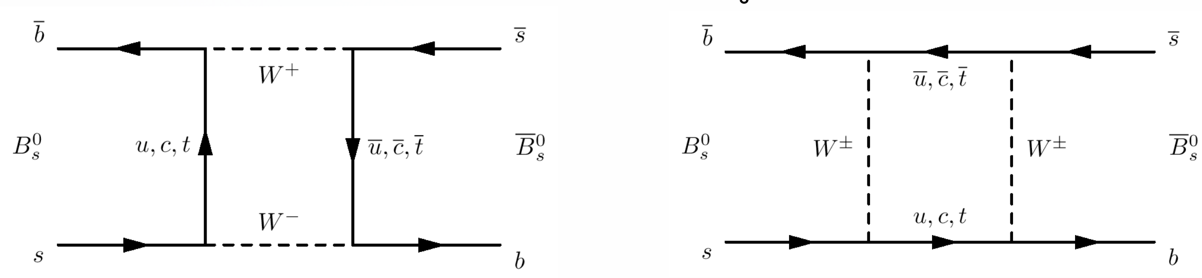
  - In which the term proportional to m_s describes the emission of right handed photons, greatly suppressed wrt the left handed component, since $m_s/m_b \sim 0.023$

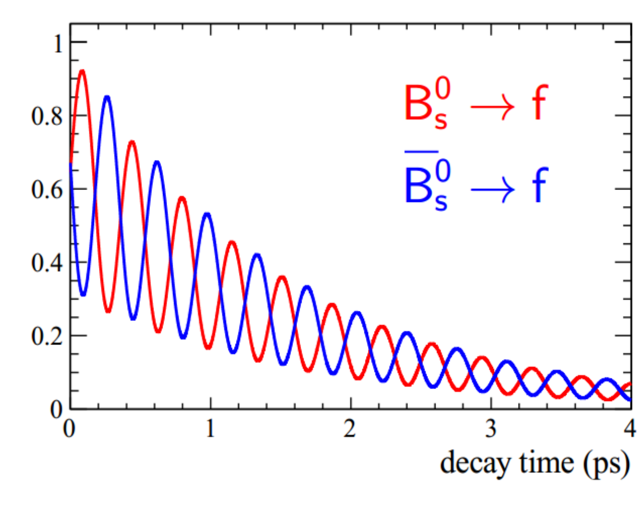


    - How to access the polarization fraction experimentally?

B meson decays

- Neutral mesons undergo flavor oscillations (mixing) through box diagrams, for the B_s^0 meson:





- For $B(\bar{B})$ mesons (at t=0) decaying to a CP eigenstate with a photon, the time dependent decay width is in general:

$$\Gamma(B_q(\bar{B}_q)\to f^{CP}\gamma)[t] \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - A^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm C\cos\Delta m_q t \mp S\sin\Delta m_q t\right)$$

- With ϕ the mixing angle and $\tan\psi$ the 'wrongly' polarized fraction

$$A^{\Delta} = \sin(2\psi)\cos\phi \quad \tan\psi = \frac{\bar{B}\to f^{CP}\gamma_R}{\bar{B}\to f^{CP}\gamma_L}$$

- $\Delta\Gamma_q$ (Δm_q) is the decay width (mass) difference of mass eigenstates

The B_s^0 meson

- One can measure the time dependent CP asymmetry

$$A_{CP}(B_s^0 \to \phi\gamma)[t] = \frac{N_{\bar{B}_s^0 \to \phi\gamma}(t) - N_{B_s^0 \to \phi\gamma}(t)}{N_{\bar{B}_s^0 \to \phi\gamma}(t) + N_{B_s^0 \to \phi\gamma}(t)} =$$

$$= \frac{S \sin(\Delta m_q t) - C \cos(\Delta m_q t)}{\cosh(\frac{\Delta\Gamma_s}{2} t) - A^{\Delta} \sinh(\frac{\Delta\Gamma_s}{2} t)}$$

B_s^0 meson 2012 PDG values

$B_s^0 = \bar{b} s$, $\bar{B}_s^0 = \bar{s} b$

$m_{B_s^0} = 5366.77 \pm 0.24\ MeV$

$\tau = (1.497 \pm 0.015) \times 10^{-12}\ s$

$\Delta\Gamma_{B_s^0} = \Gamma_{B_{sL}^0} - \Gamma_{B_{sH}^0} = (0.100 \pm 0.013) \times 10^{-12}\ s^{-1}$

$\Delta m_{B_s^0} = m_{B_{sH}^0} - m_{B_{sL}^0} = (0.100 \pm 0.013) \times 10^{-10}\ MeV$

- The SM prediction for A^{Δ} is 0.047 ± 0.025 [Muheim et al., Phys.Lett.B664:174-179,2008]
- For B^0 mesons the sinh vanishes, since $\Delta\Gamma_d$ is << 1
- The advantage of the B_s^0 is that it has a sizable $\Delta\Gamma$
    - Sensitivity to the A^{Δ} parameter

The B_s^0 meson

- The general time dependent decay rate

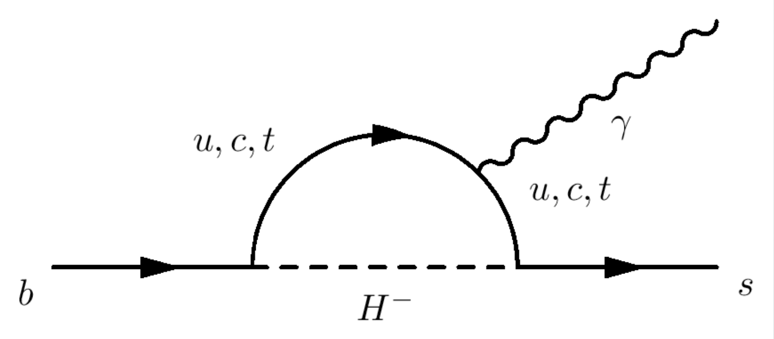
$$\Gamma(B_q(\bar{B}_q) \to f^{CP}\gamma)[t] \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - A^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm C\cos\Delta m_q t \mp S\sin\Delta m_q t\right)$$

- This requires tagging, combined with the small statistics this results
    - LHCb effective tagging power ~3.5%
- Without tagging, the time dependent decay rate reduces to

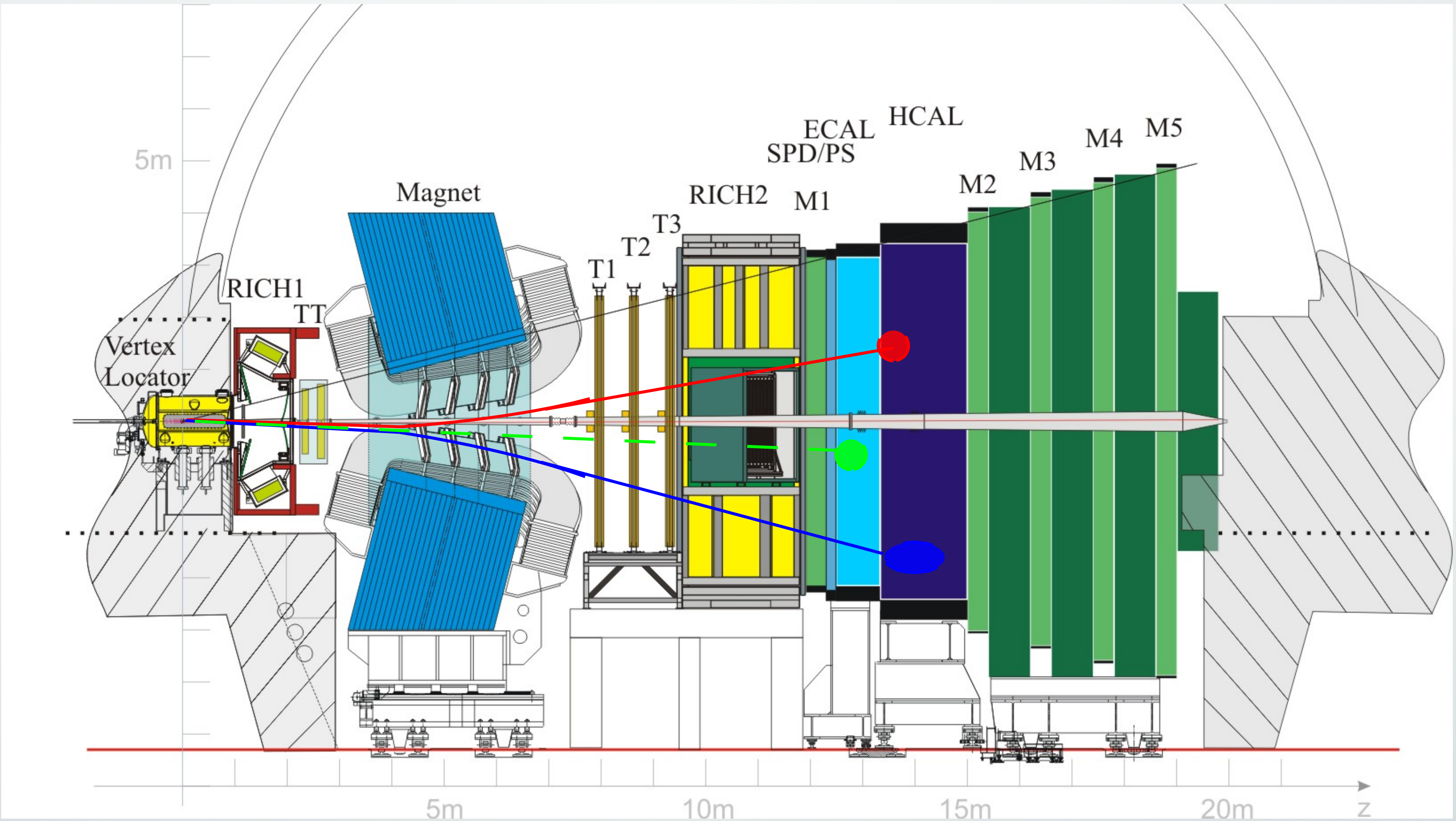
$$\Gamma(B_q)_{\text{Untagged}}[t] \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - A^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2}\right)$$

Sensitivity to NP

- Other models can be probed through this observable
  - In the Left Right Symmetric Model (LRSM), A^{Δ} can be as high as 0.7[Atwood et al. arXiv:hep-ph/9704272v1]
  - Other models that involve new particles participating in the loop could modify the properties of this decay
    - Two Higgs doublet models (2HDM)
    - SUSY
  - Updated theoretical predictions would be desirable

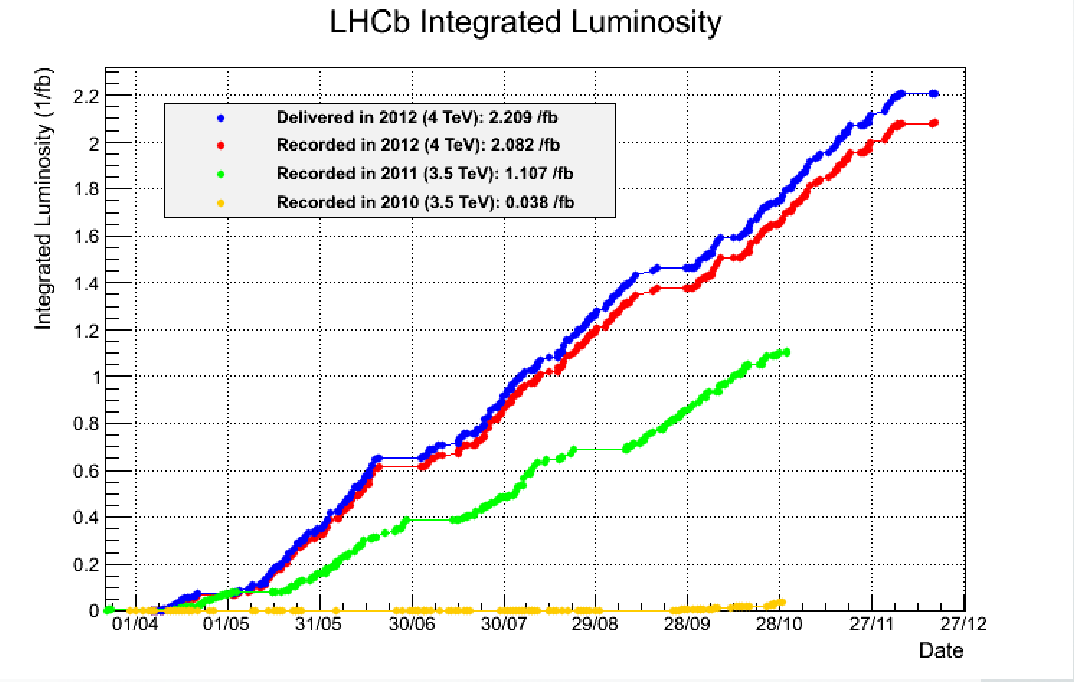


The LHCb Detector



$B_s^0 \to \phi\gamma$ in LHCb

- 3 fb^{-1} collected in 2011 (7 TeV)-2012 (8 TeV)
- Long shutdown (LS1) 2013-2014
- Accumulate up to 7 fb^{-1} 2015-2017 at 14 TeV
- **Upgrade** in LS2 2018
- 5 fb^{-1} per year to 50 fb^{-1} in total
  - BaBar/Belle collected 1.2 ab^{-1} at $\Upsilon(4S)$
    - Mostly $B\bar{B}$ (1nb)
  - Belle II 50 ab^{-1} expected (~2020)
- LHCb $pp \to b\bar{b}$ pair production cross section
  - 284 μb at 7 TeV[Phys.Lett.B694:209-216,2010]
  - 527.3 μb at 14 TeV[sim]
- Hadronization fraction to B_s^0, f_s = 9%[Phys. Rev. D 85, 032008 (2012)]

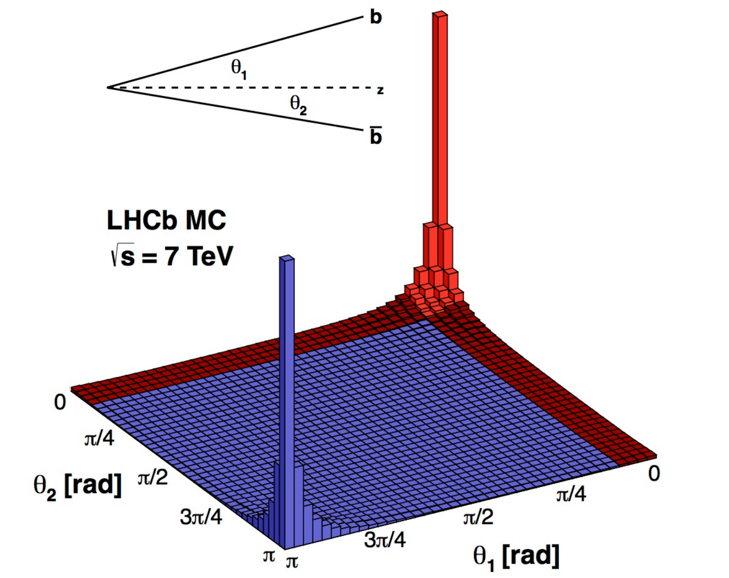


$B_s^0 \to \phi\gamma$ in LHCb

- We can then estimate a B_s^0 production cross section
  - 51.2 µb at 7 TeV, 95 µb at 14 TeV
- Measurement of B_s^0 production cross section at 7 TeV[JHEP08(2013)117] (including detector acceptance)

$$\sigma(pp \to B_s^0 + X) \quad = \quad 10.5 \pm 0.2\,(\text{stat.}) \pm 0.8\,(\text{syst.}) \pm 1.0\,(\text{norm.})\ \mu\text{b},$$

- $BR(B_s^0 \to \phi\gamma) = (5.7\pm0.3)\cdot10^{-5}$
- $BR(\phi \to K^+K^-) = 0.489\pm0.005$
- $B_s^0 \to \phi(\to K^+K^-)\gamma$ produced per fb^{-1}
  - 584k at 7 TeV
  - 1086k at 14 TeV
- 52 M produced in total with 50 fb^{-1} (without efficiencies)

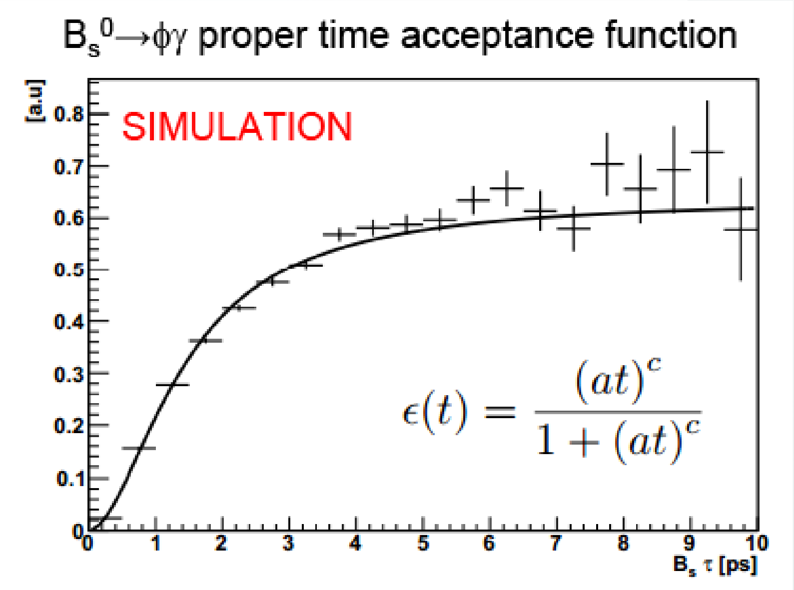


$B_s^0 \to \phi\gamma$ in LHCb

- Acceptance and experimental efficiency (Trigger, Reconstruction, Selection...) further reduces the available signal yield
  - Current selection yield is ~3k signal events with $3fb^{-1}$
  - Selection currently being optimized to maximize the efficiency
    - Multivariate methods studied considerably improve the signal yield wrt a cut based strategy
- Uncertainties are at present statistically dominated

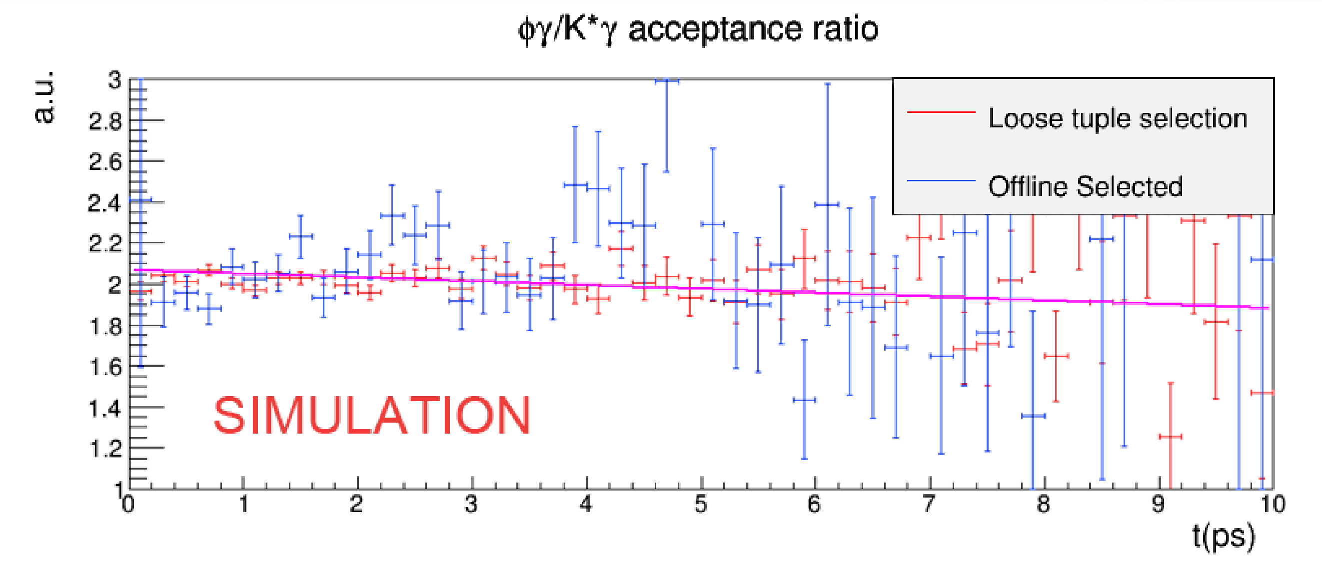
$B_s^0 \to \phi\gamma$ photon polarization

- We aim to measure the photon polarization fraction
- Currently the fit framework is under development, several options being explored
  - Untagged ML B_s^0 proper time fit
    - The proper time acceptance function must be well determined
    - Extract the proper time acceptance function from a fit to control channels (complementary)
      - $B^0 \to K^{*0}\gamma$
        - Higher yield
      - $B_s^0 \to J/\psi\phi$
        - Cleaner channel



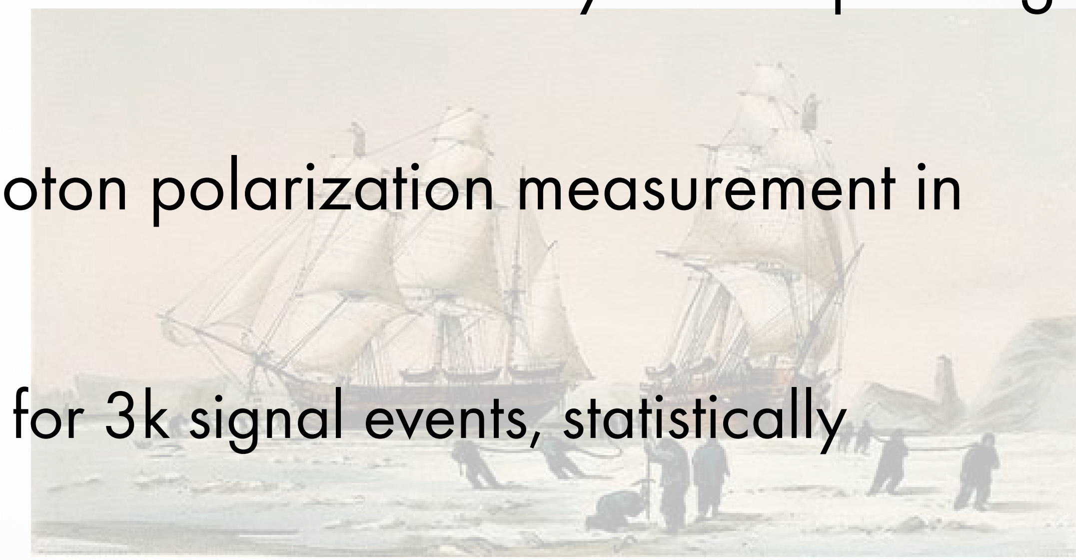
$B_s^0 \to \phi\gamma$ photon polarization

- Fit framework under development, several options being explored
  - Binned proper time ratio ($B_s^0 \to \phi\gamma$ / $B^0 \to K^{*0}\gamma$)
    - Similar resolution functions
    - Acceptance ratio is flat and well known after carefully designing the selection
    - Statistical sensitivity to A^{Δ} under study
      - estimated around 0.3 for 3k B_s^0 events



Conclusions

- Precision measurements of radiative B decays allow probing BSM physics



- Untagged $B_s^0 \to \phi\gamma$ photon polarization measurement in progress
  - Sensitivity to $A^{\Delta} \sim 0.3$ for 3k signal events, statistically dominated
    - Expected to be ~0.2 with the next data taking period
    - <0.1 with the upgraded run ($50\mathrm{fb}^{-1}$)
    - Systematics associated to proper time acceptance look under control

$$A^{\Delta} = \sin(2\psi)\cos\phi \quad \tan\psi = \frac{\bar{B} \to f^{CP}\gamma_R}{\bar{B} \to f^{CP}\gamma_L}$$

Thanks for your attention

Backup Slides

Formulae

- b → sγ/g weak effective Hamiltonian in OPE

$$H_{eff} = \frac{-G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \left(\sum_{i=1}^{6} C_i \cdot O_i + C_{7\gamma} \cdot O_{7\gamma} + C_{8G} \cdot O_{8G} \right)$$

Radiative decays at LHCb

- LHCb has published measurements on radiative decays such as
  - The ratio of Branching fractions of $B^0 \to K^{*0}\gamma$ and $B_s^0 \to \phi\gamma$

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.23 \pm 0.06\,(\mathrm{stat.}) \pm 0.04\,(\mathrm{syst.}) \pm 0.10\,(f_s/f_d)$$

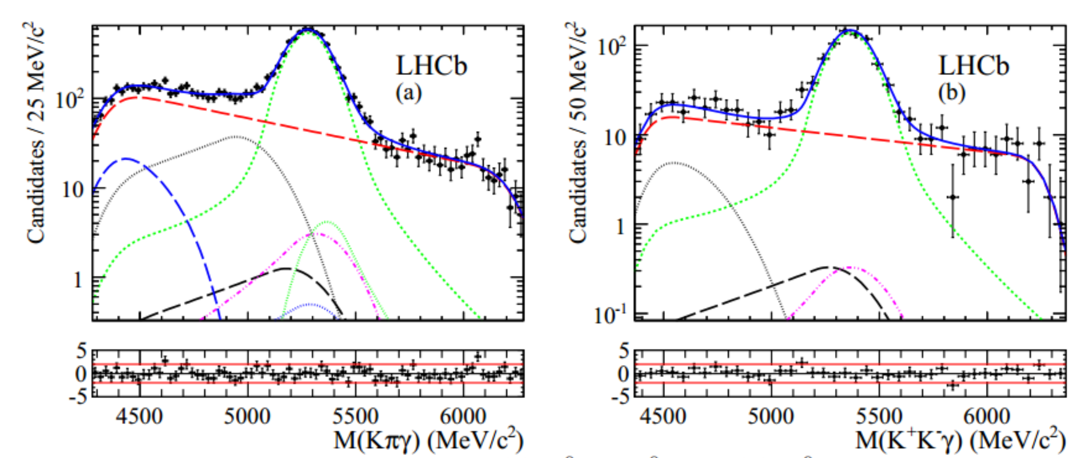
  - The direct CP violation in $B^0 \to K^{*0}\gamma$

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = (0.8 \pm 1.7\,(\mathrm{stat.}) \pm 0.9\,(\mathrm{syst.}))\%$$

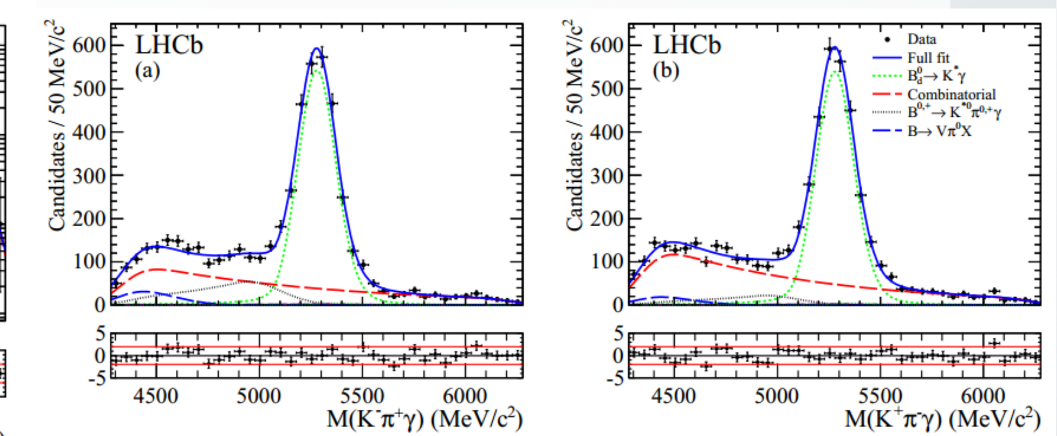
Both Nuclear Physics, Section B 867 (2013), pp. 1-18

- – Most precise measurements to date

More on these results during the LHC session in V. Rives Molina talk



Invariant-mass distributions of the (a) $B^0 \to K^{*0}\gamma$ and (b) $B_s^0 \to \phi\gamma$ candidates.



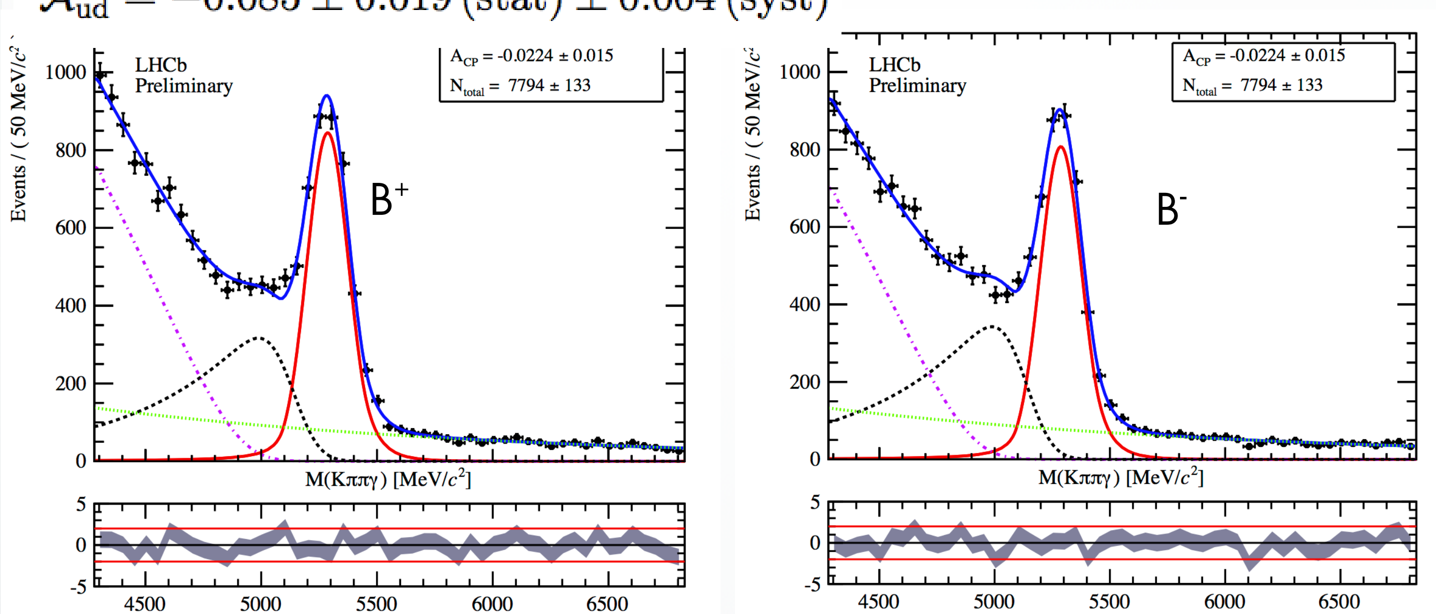
Invariant-mass distributions of the (a) $\overline{B}^0 \to \overline{K}^{*0}\gamma$ and (b) $B^0 \to K^{*0}\gamma$ decay candidates.

Radiative decays at LHCb

- CP and up-down asymmetries in $B^+ \to (K\pi\pi)^+\gamma$ decay[LHCb-CONF-2013-009]

$$\mathcal{A}_{CP} = -0.007 \pm 0.015\,(\mathrm{stat})\,^{+0.012}_{-0.011}\,(\mathrm{syst})$$

$$\mathcal{A}_{\mathrm{ud}} = -0.085 \pm 0.019\,(\mathrm{stat}) \pm 0.004\,(\mathrm{syst})$$



More on these results during the LHC session in V. Rives Molina talk

- The branching fraction of $B^0 \to K^{*0}e^+e^-$ at low dilepton mass[arXiv:1304.3035, submitted to JHEP]

$$\mathcal{B}(B^0 \to K^{*0}e^+e^-)^{30-1000\,\mathrm{MeV}/c^2} = (3.1\,^{+0.9}_{-0.8}\,^{+0.2}_{-0.3} \pm 0.2) \times 10^{-7}$$

LHCb Tagging Power

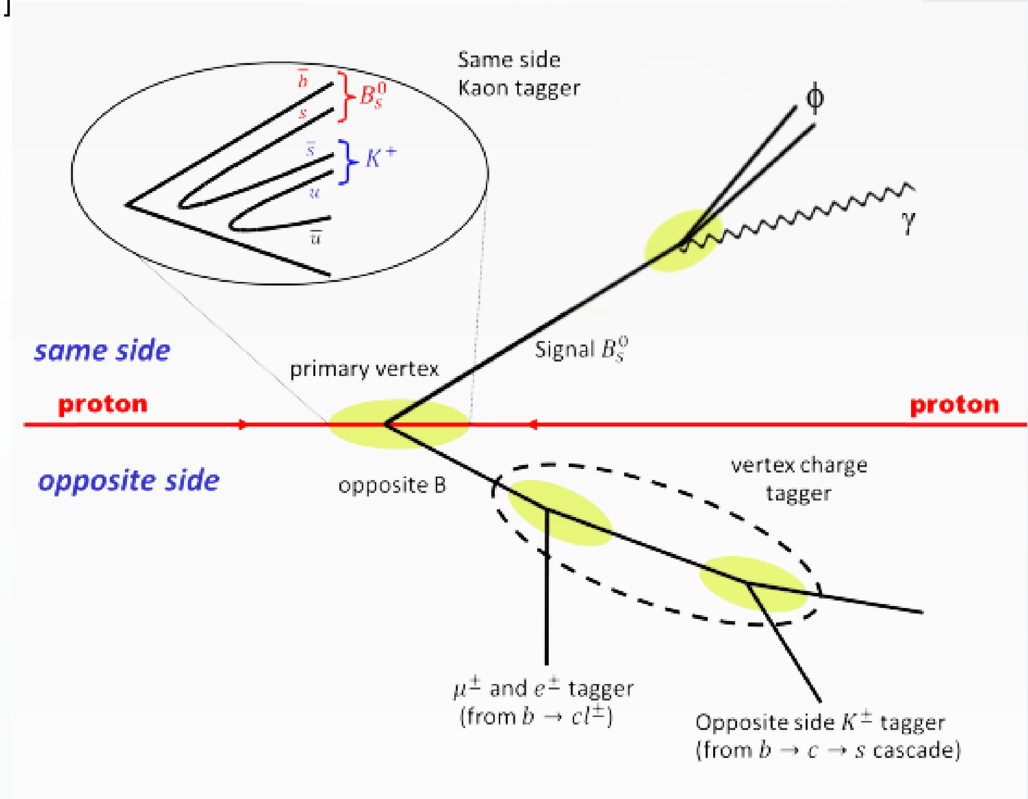
- CP asymmetry measurements require flavor tagging
- Low tagging power [New J. Phys. 15 (2013) 053021]

$$\text{Tagging efficiency } \epsilon = \frac{\text{Tagged Candidates}}{\text{All Candidates}}$$

$$\text{Mistag probability } \omega = \frac{\text{Tagged wrong}}{\text{Tagged}}$$

$$\text{Dilution } D = (1 - 2\omega)$$

$$\text{Combined tagging power } \epsilon D^2 = 3.5 \pm 0.5\,\%$$



- Small BR + Small tagging power
- Great reduction of the statistical power