Photon 2017 (22–27 May 2017)

Rare radiative decays at LHCb

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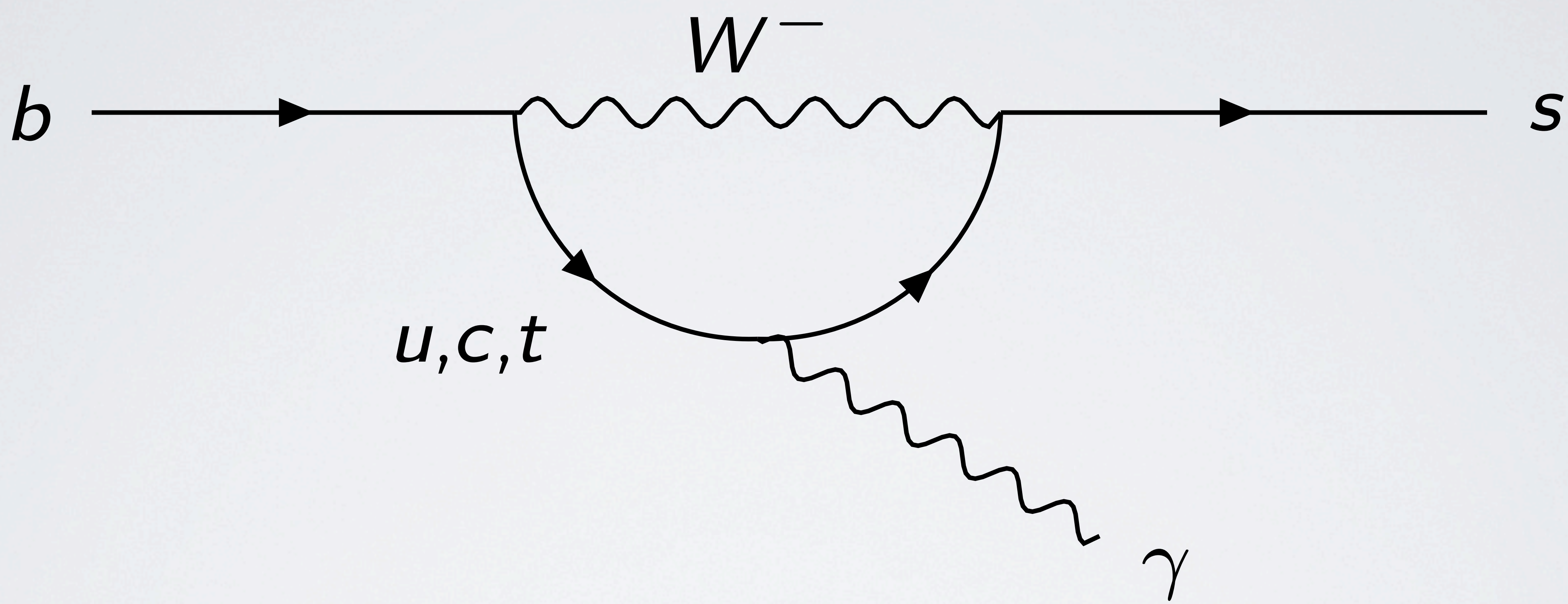
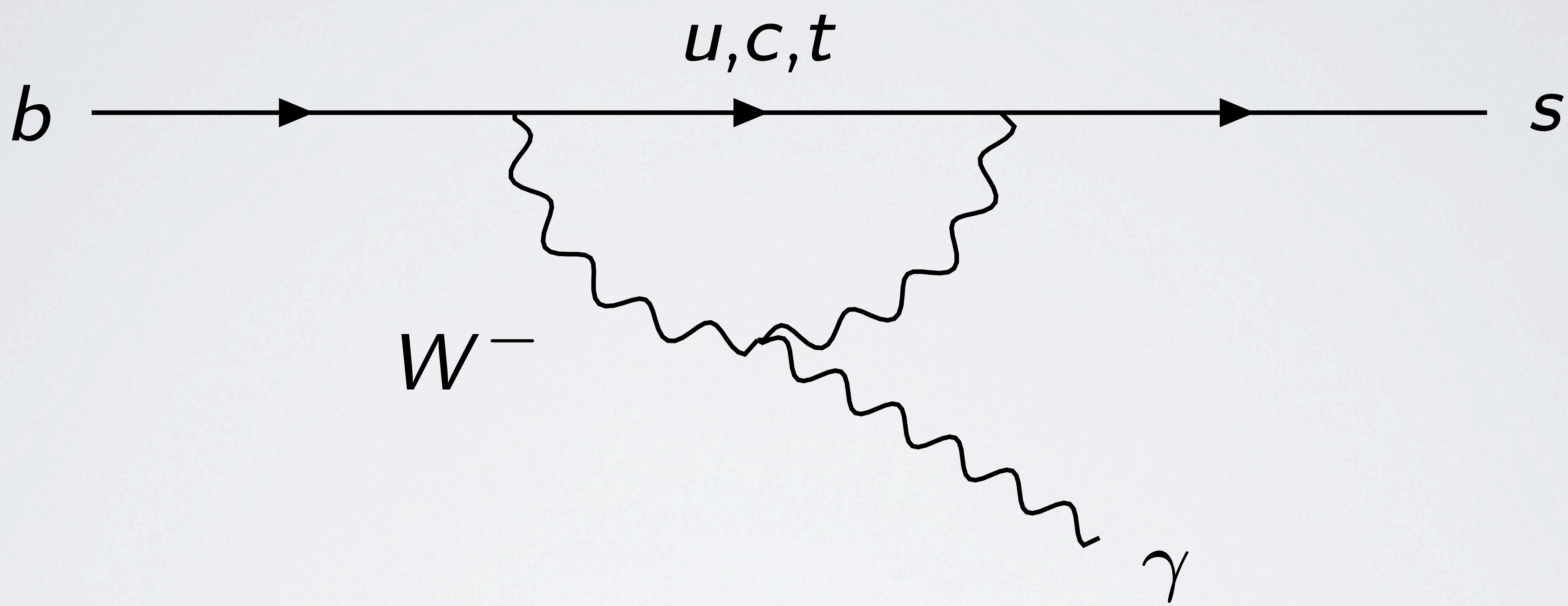


W^-
b
s
u,c,t
γ



b
u,c,t
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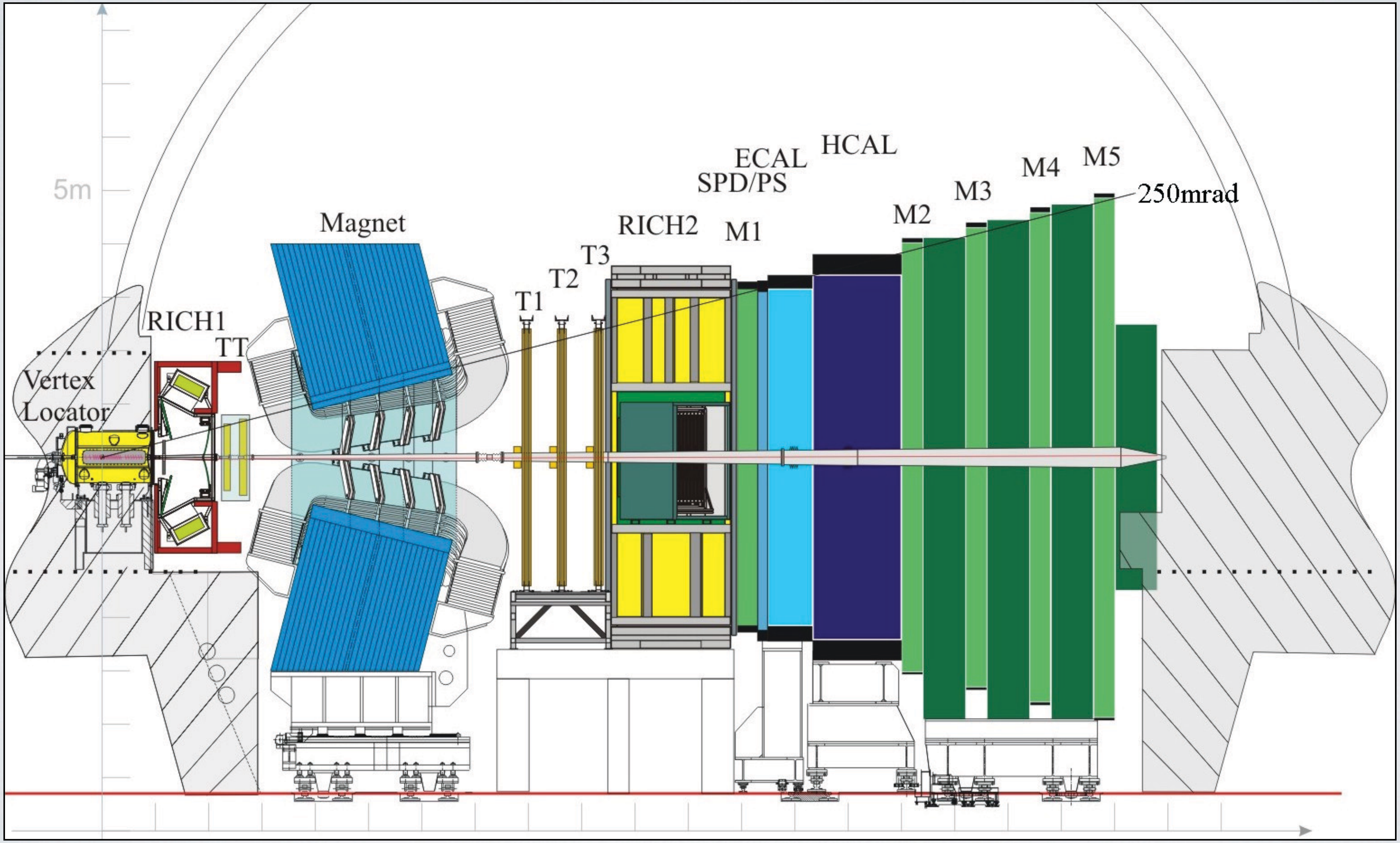
[JINST 3 (2008) S08005]

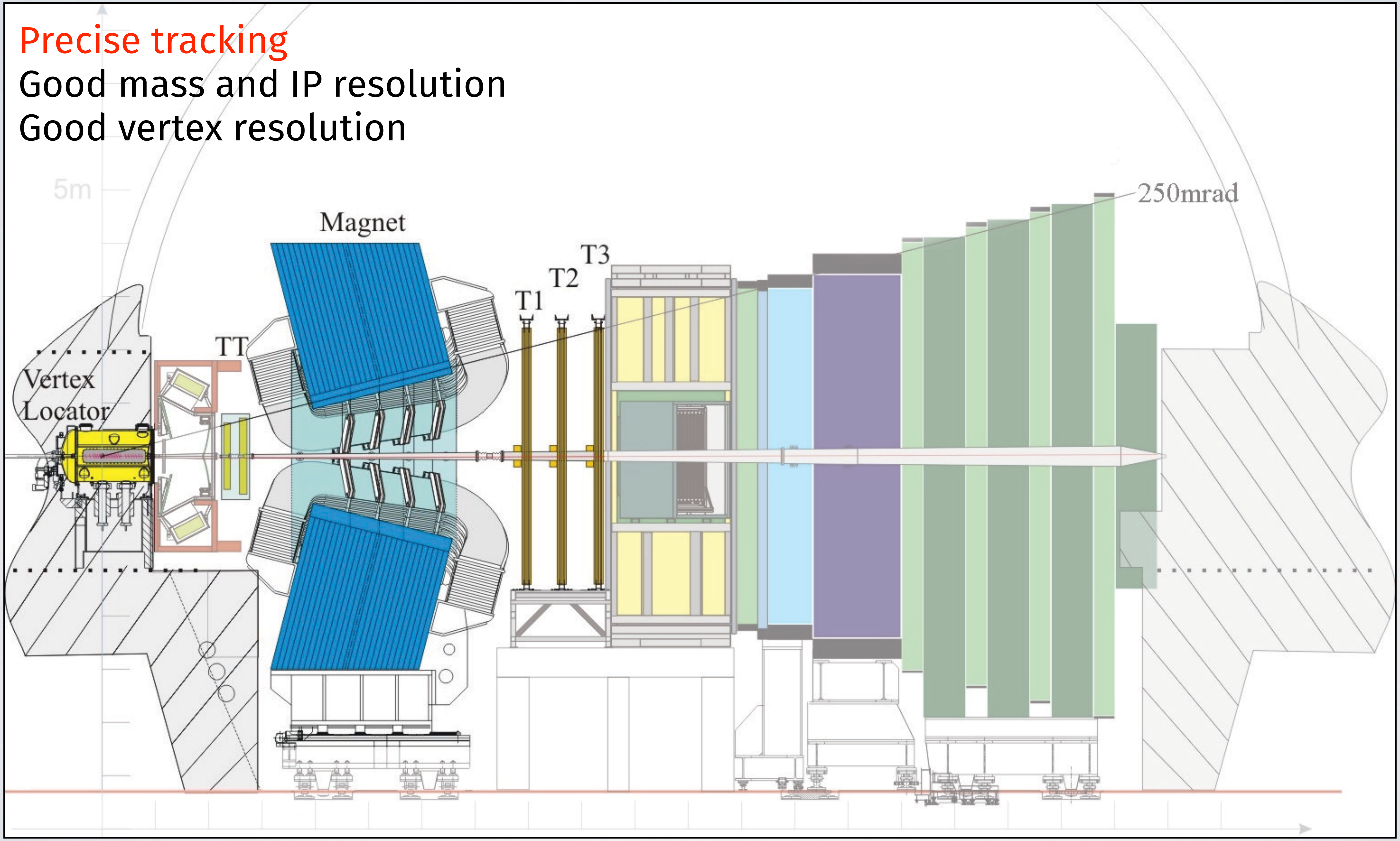
The LHCb experiment



[JINST 3 (2008) S08005]

The LHCb experiment

Precise tracking
Good mass and IP resolution
Good vertex resolution

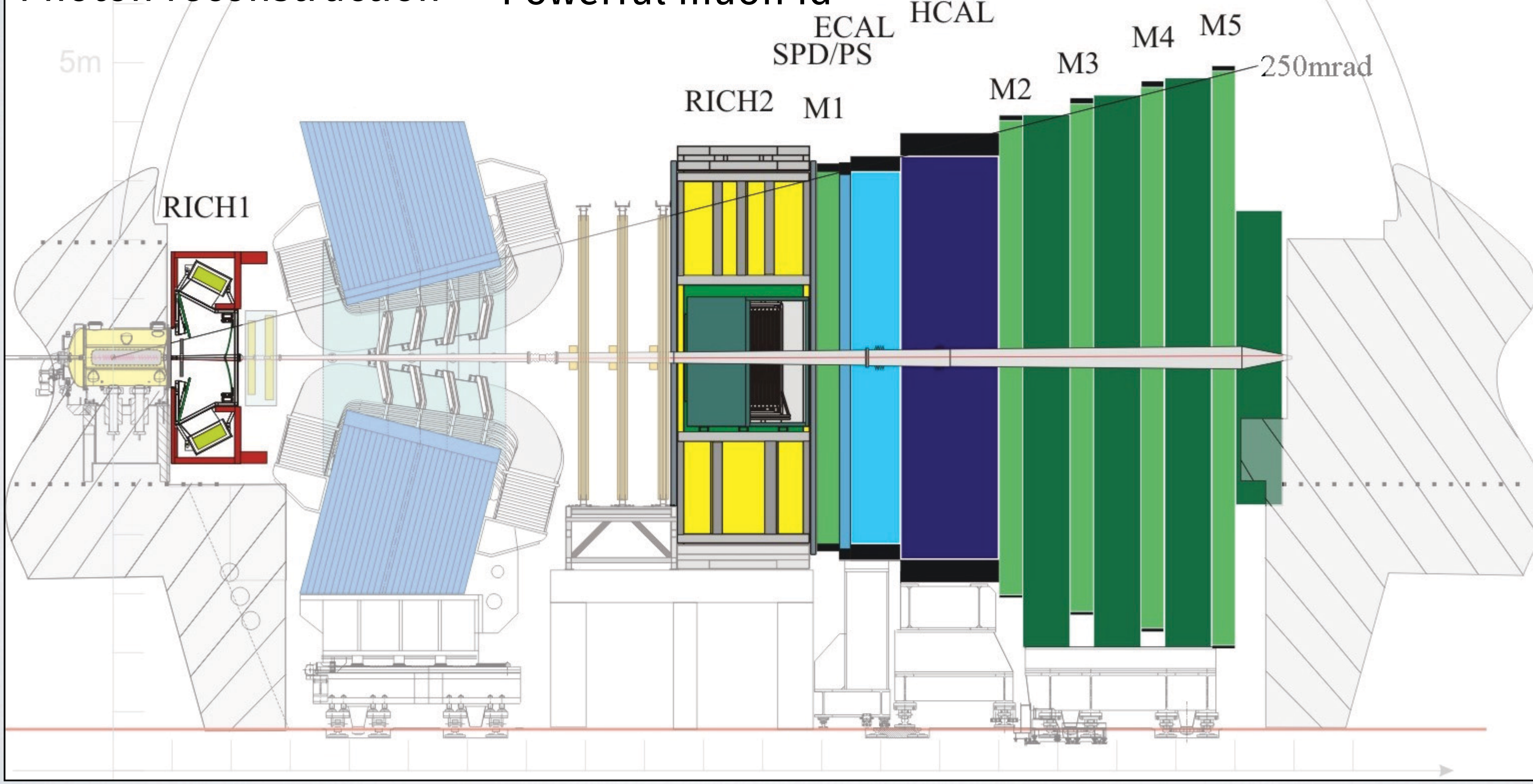


[JINST 3 (2008) S08005]

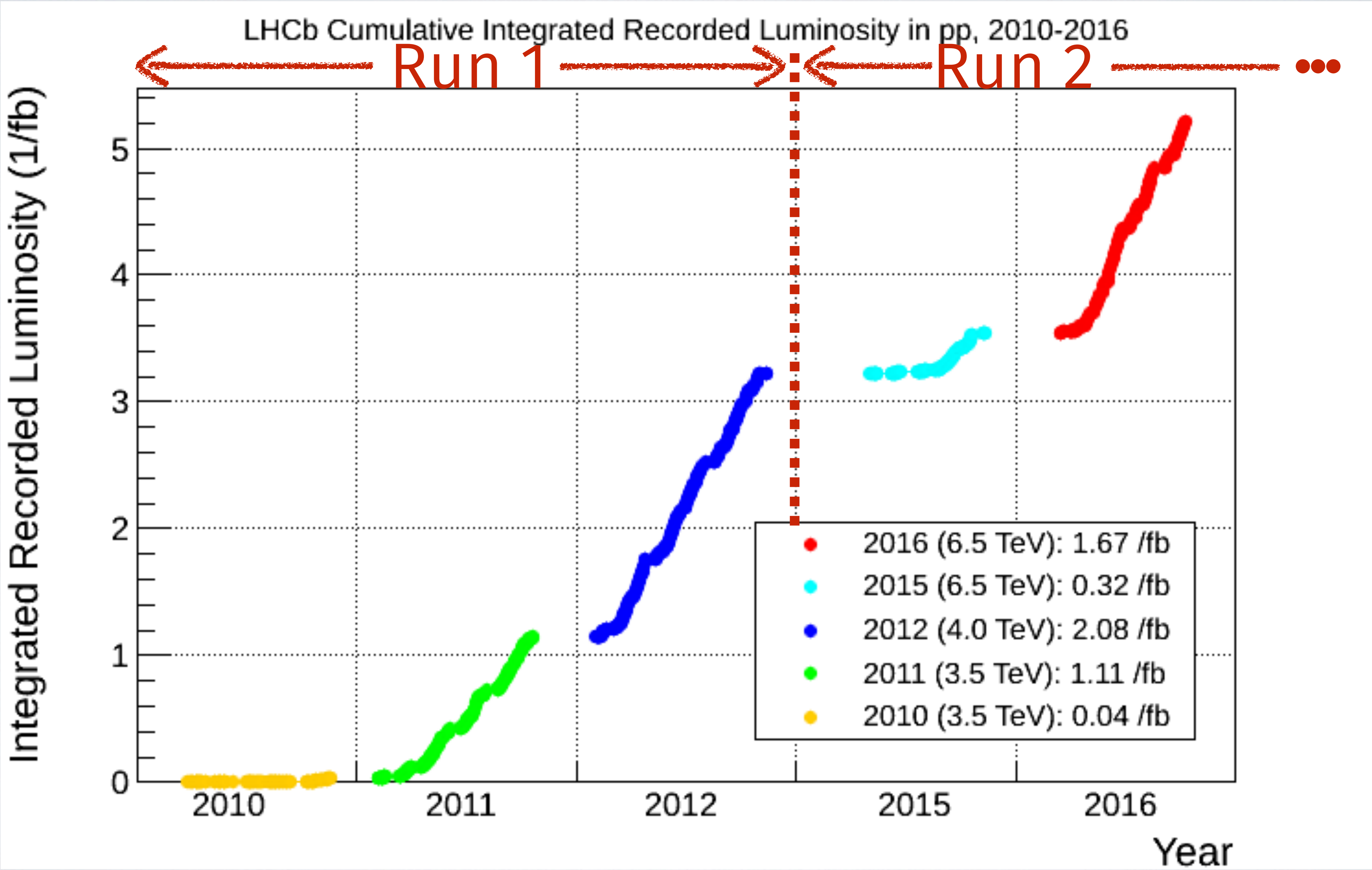
The LHCb experiment

Calorimeter system
Trigger
Photon reconstruction

Excellent particle identification
π/K separation over 2-100 GeV
Powerful muon id

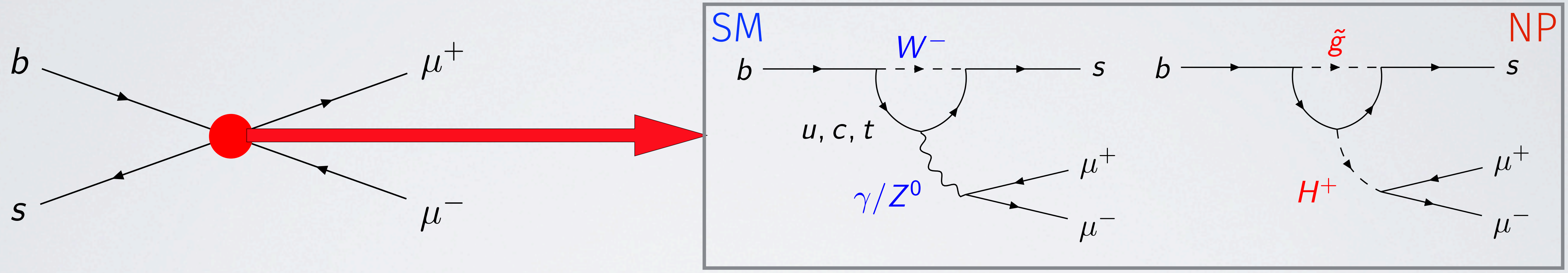


The LHCb data taking



Radiative decays

Rare decays of heavy mesons are FCNC (forbidden at tree level and thus highly suppressed) sensitive to quantum corrections from degrees of freedom at larger scales



Radiative decays are $b \to s\gamma$ FCNC

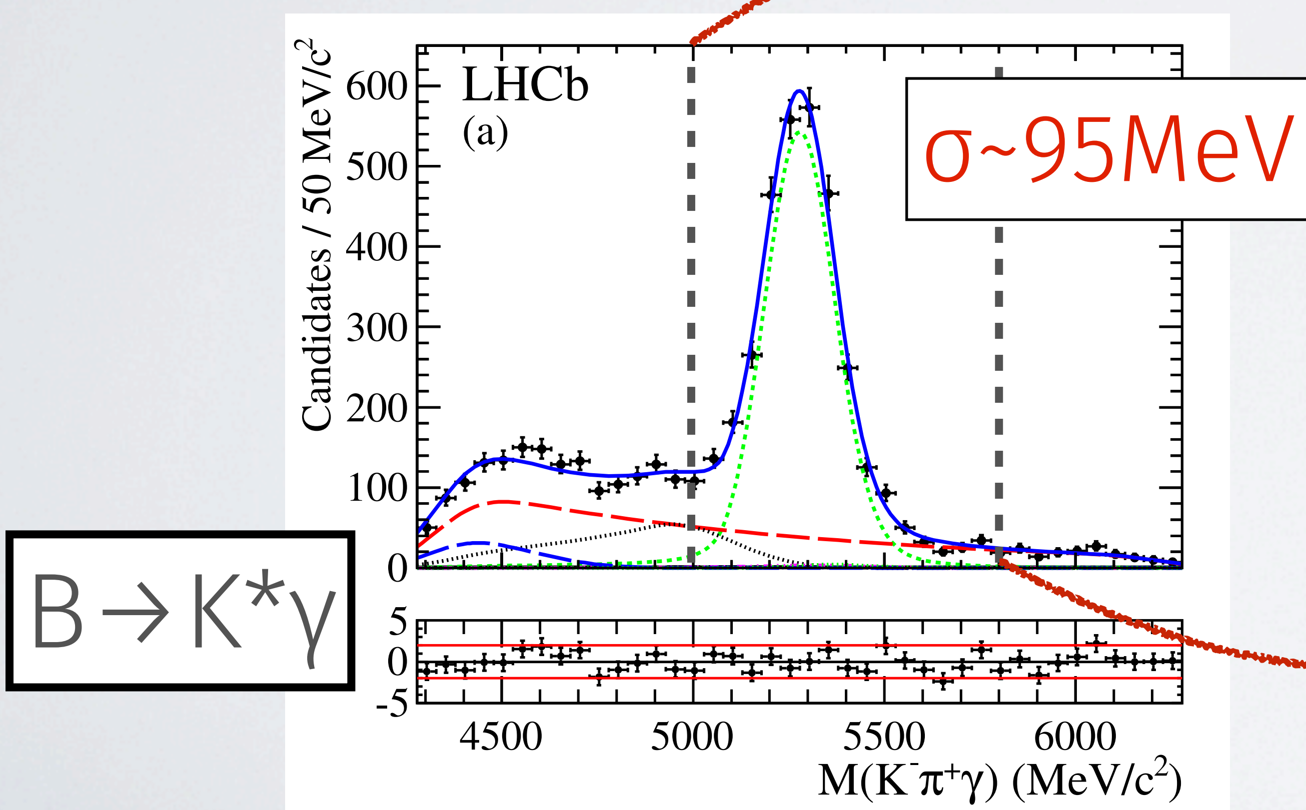
- Inclusive decays are clean, but hard experimentally
- Exclusive decays have large theoretical uncertainties, so need to find form-factor free observables (CP and isospin asymmetries)
- Null test of the SM: the photon polarisation

Challenges for radiative decays

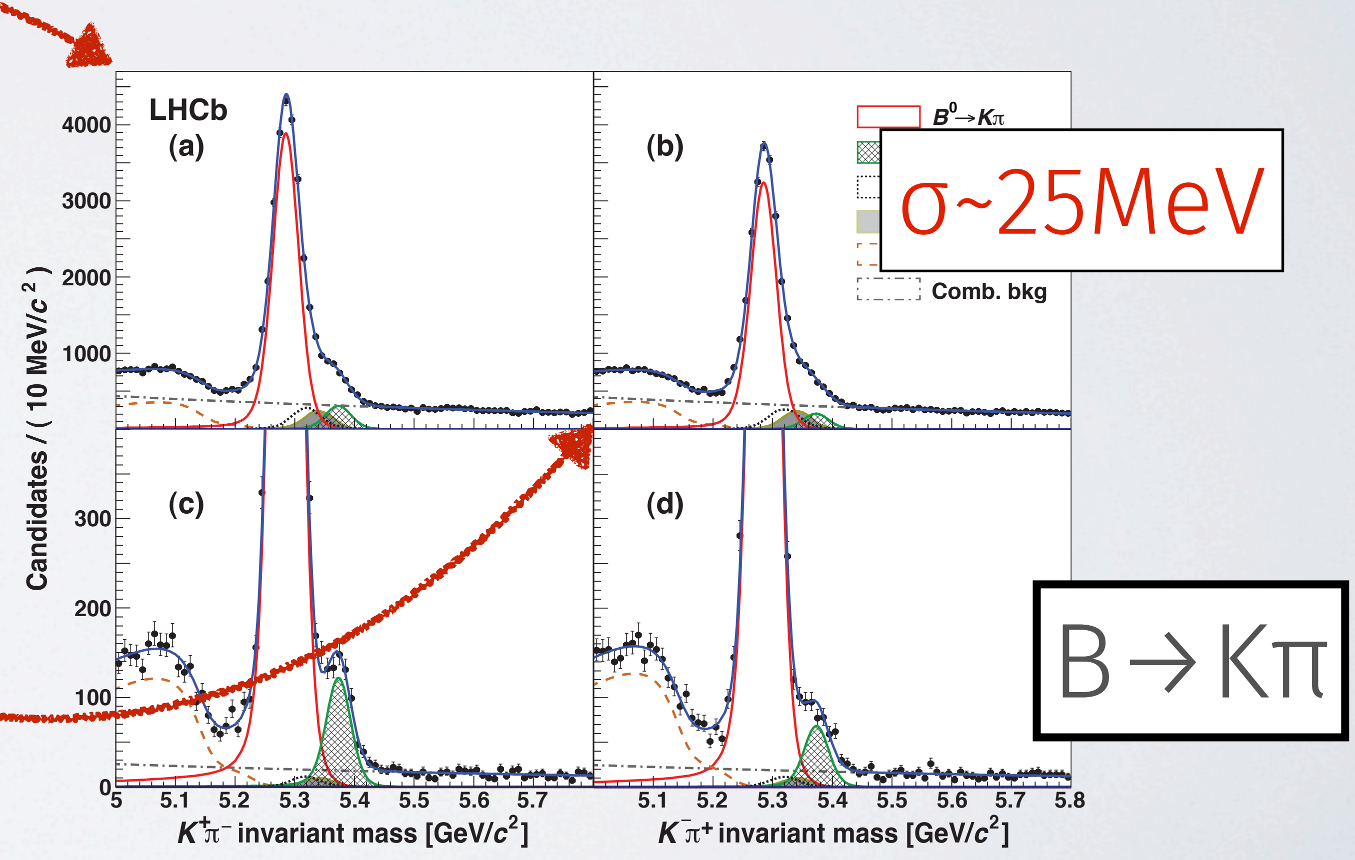
Distinct experimental signature with a high E_T photon

- Large levels of background are expected in a *pp* machine

Mass resolution dominated by photon reconstruction



[Nucl. Phys. B 867 (2012)]



[PRL 110 (2013) 221601]

Describing FCNC processes

FCNC are described by an effective Hamiltonian in the form of an Operator Product Expansion, which allows to identify the types of operators (O_i) that enter in each transition, along with their corresponding Wilson coefficients (C_i)

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum_i \Big\{ \underbrace{C_i O_i}_{\text{left-handed}} + \underbrace{C_i' O_i'}_{\substack{\text{right-handed} \\ \text{(suppressed in the SM)}}} \Big\} + \sum_i \underbrace{\frac{C_i^{\text{NP}}}{\Lambda^2} O_i^{\text{NP}}}_{\text{new physics}}$$

Describing FCNC processes

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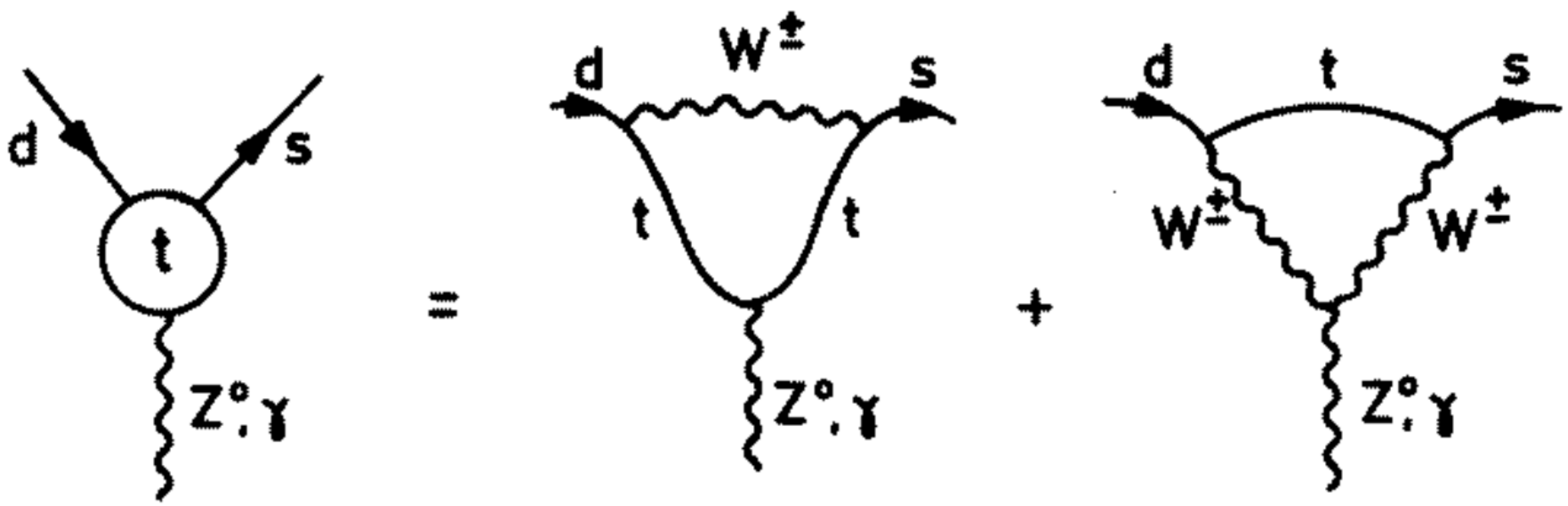
$\mathcal{H}_{\text{eff}}$ … $\mathcal{O}_i^{\text{NP}}$

…hysics

Photon polarization mainly concerned with

$$\mathcal{O}_{7\gamma} \sim m_b \bar{s}_L \sigma_{\mu\nu} b_R F^{\mu\nu}$$



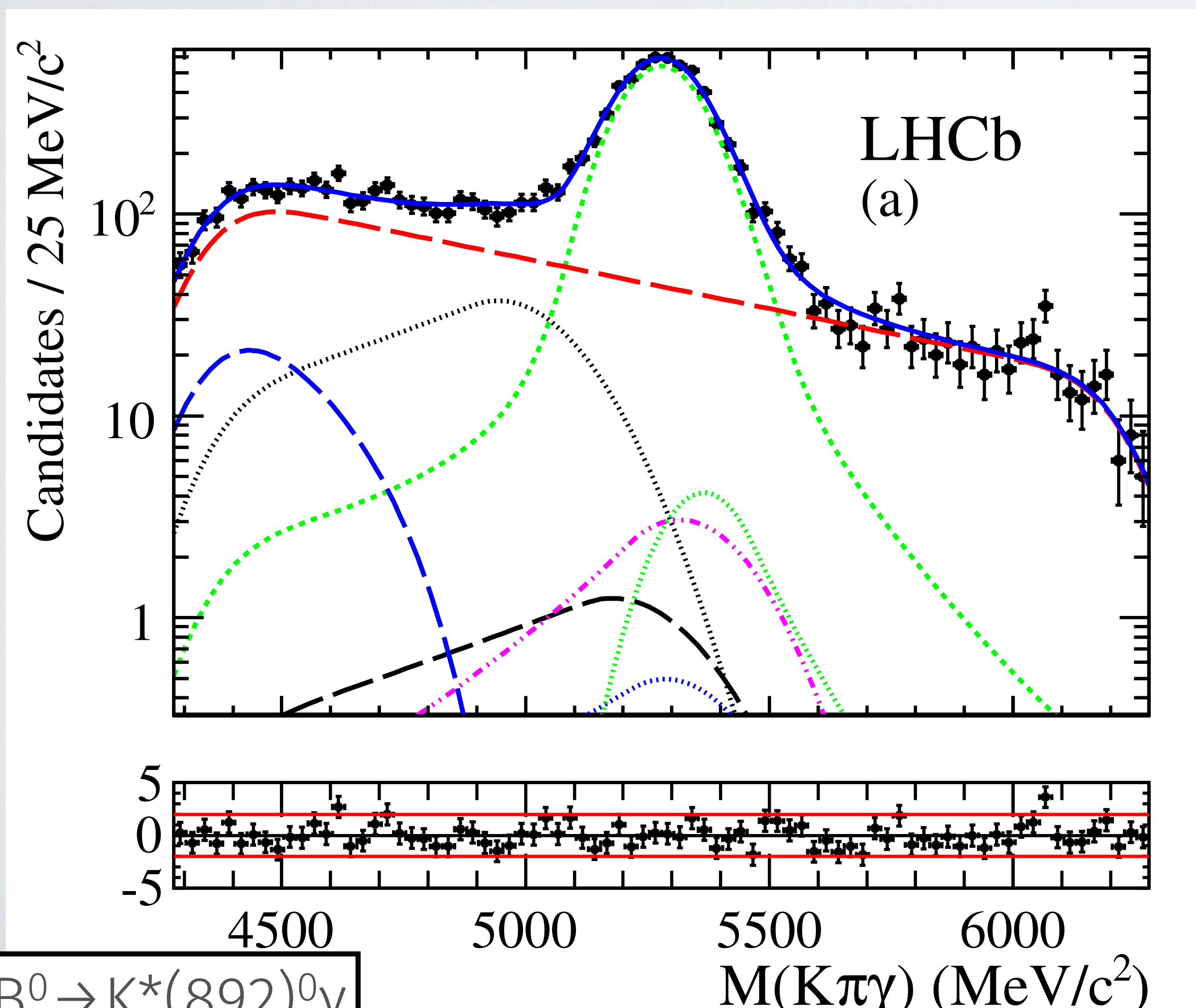
[Buras, hep-ph/9806471]

[JHEP 10 (2013) 183]

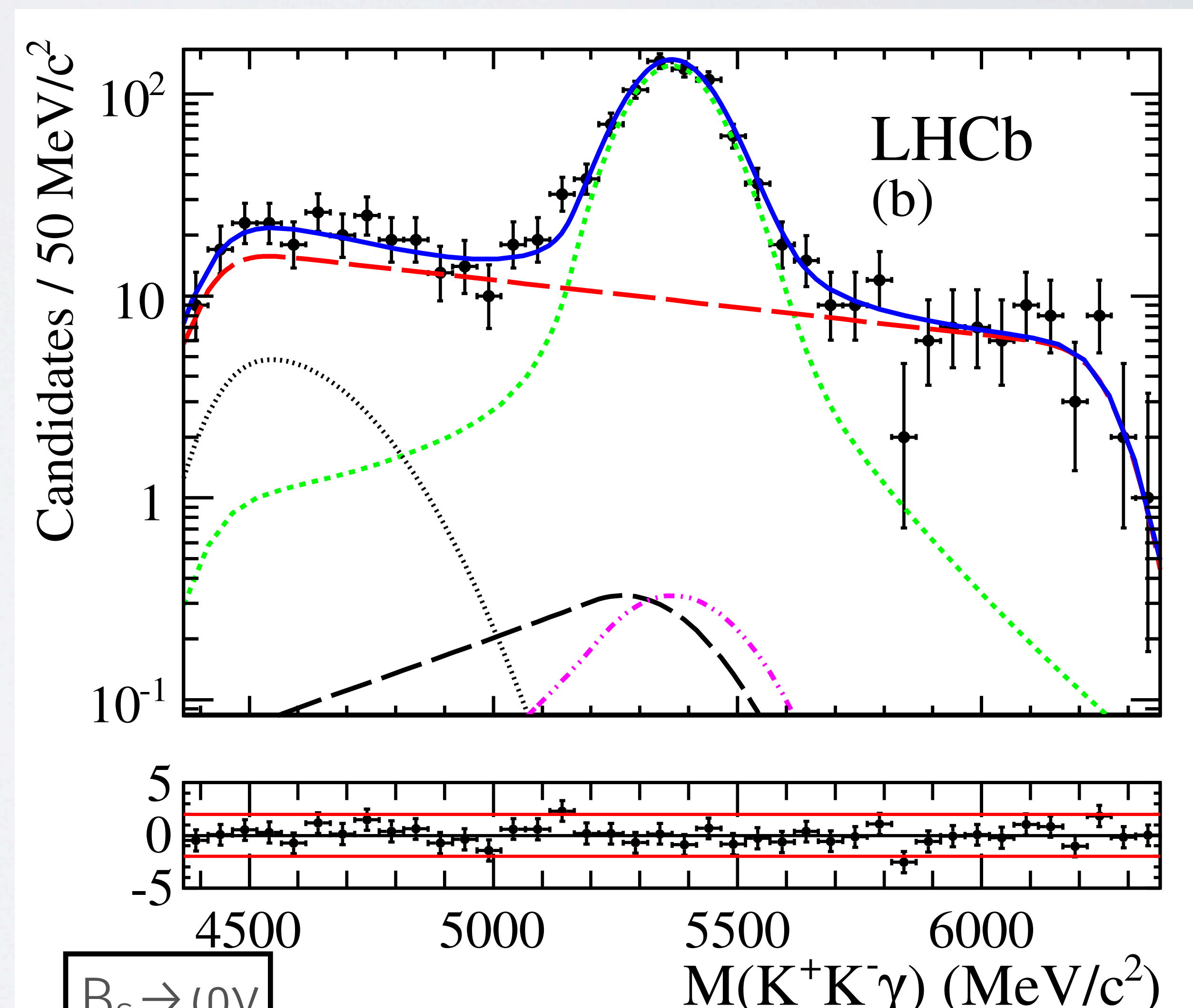
$B^0 \to K^{*0}\gamma$ and $B_s \to \varphi\gamma$ BF

$B^0 \to K^{*0}\gamma$ and $Bs \to \varphi\gamma$ BF ratio measured with 1/fb of data

$$\frac{BF(B^0 \to K^{*0}\gamma)}{BF(B^0_s \to \varphi\gamma)} = 1.23 \pm \text{(stat)} \pm 0.04\,\text{(syst)} \pm 0.10\,(f_s/f_d)$$



$B^0 \to K^*(892)^0\gamma$



$B_s \to \varphi\gamma$

[JHEP 10 (2013) 183]

A_{CP} in $B^0 \to K^{*0}\gamma$

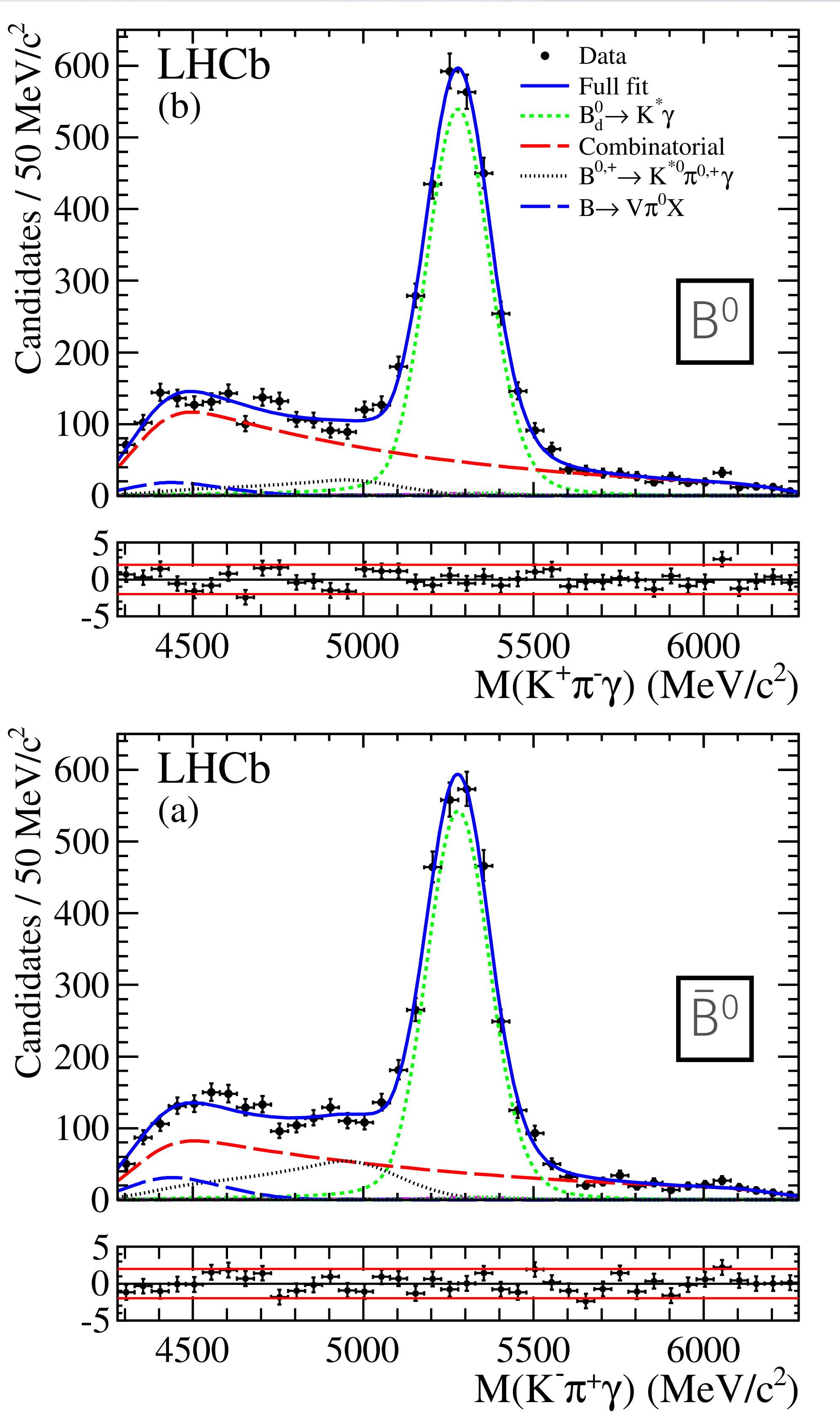
A_{CP} in $B^0 \to K^{*0}\gamma$ measured with 1/fb of LHCb data

$$A_{CP}(B^0 \to K^{*0}\gamma) = (0.8 \pm 1.7\,(\text{stat}) \pm 0.9\,(\text{syst}))\%$$

$$A_{CP}^{SM}(B^0 \to K^{*0}\gamma) = (-0.61 \pm 0.43)\%$$

Main systematic coming from A_{CP} in the background

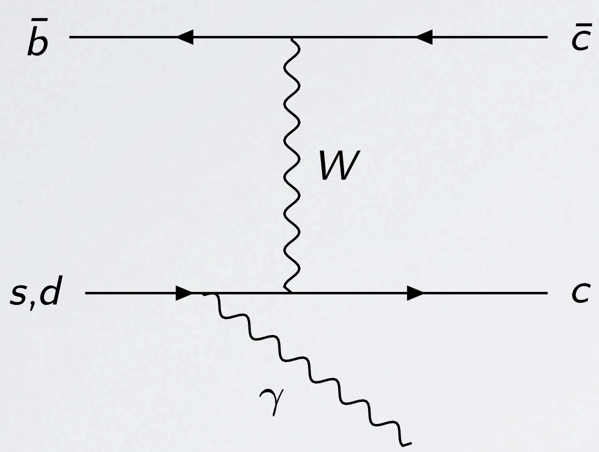
Update with full Run 1 coming soon (including ratio of BF), getting closer to systematic limitation



[PRD 92 (2015) 112002]

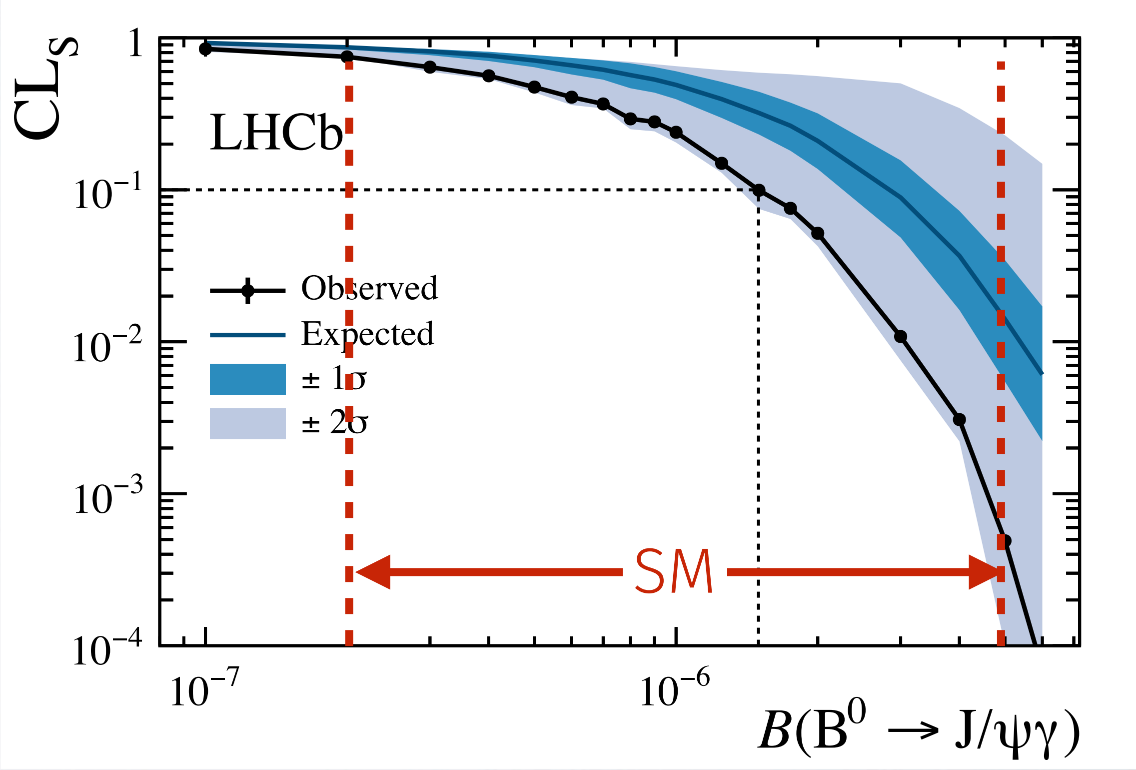
Search for $B \to J/\psi\gamma$

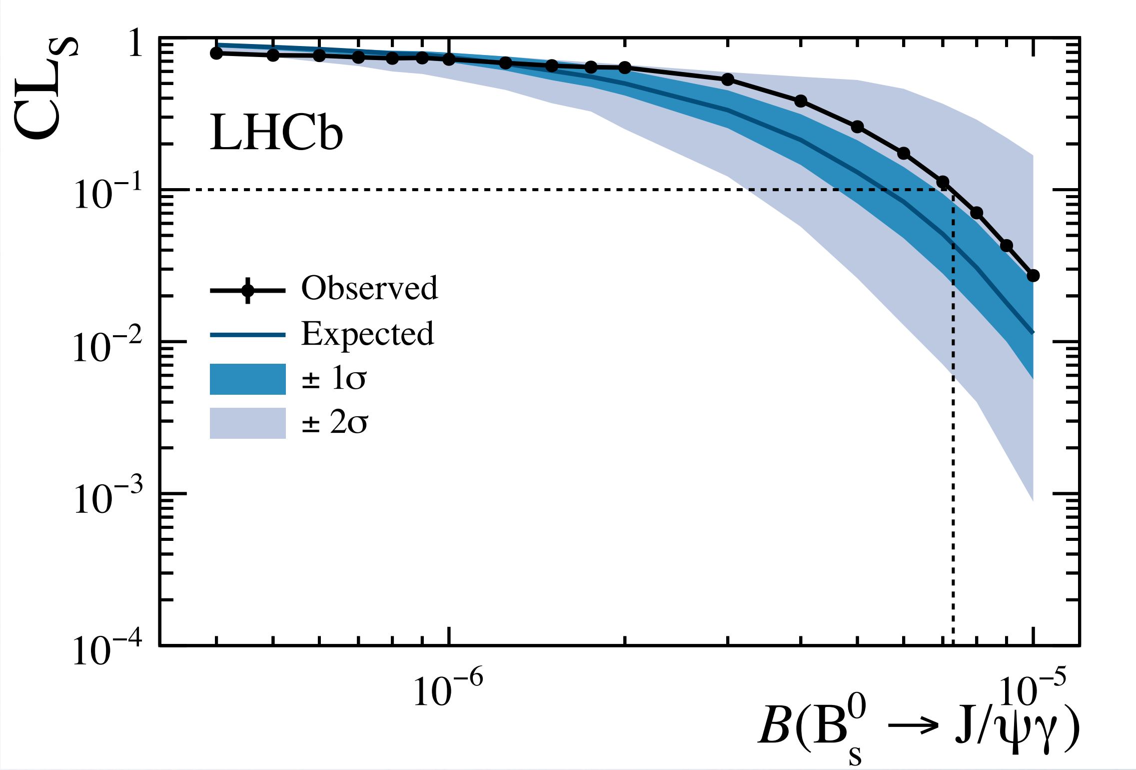
No FCNC, but *W* boson exchange diagram



Use of converted photons to improve background separation

$$BF(B_s^0 \to J/\psi\gamma) < 7.3 \times 10^{-6} \text{ at } 90\% C.L.$$
$$BF(B^0 \to J/\psi\gamma) < 1.5 \times 10^{-6} \text{ at } 90\% C.L.$$





Photon polarisation in the SM

The b→sγ process has a particular structure in the SM

$$\bar{s}\Gamma(b \to s\gamma)_\mu b = \frac{e}{(4\pi)^2}\frac{g^2}{2M_W^2}V_{ts}^* V_{tb} F_2 \bar{s} i \sigma_{\mu\nu} q^\nu \left(m_b \frac{1+\gamma_5}{2} + m_s \frac{1-\gamma_5}{2} \right) b$$

The *W* boson couples only left-handedly. This, combined with the chiral structure of the *b*→*sγ* process causes the photons to be (almost completely) circularly polarised

- The requirement of a chirality flip leads to left-handed photon dominance

Photon polarisation never been measured with precision

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$$b \to s\gamma_L$$
$$\bar{b} \to \bar{s}\gamma_R$$

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Photon polarisation never been measured with precision

Measuring the γ polarization

Time-dependent analyses of $B_{(s)} \to f^{CP}\gamma$, *e.g.*, $B_s \to \varphi\gamma$ and $B^0 \to K_S\pi^0\gamma$

Angular distribution of radiative decays with 3 charged tracks in the final state, *e.g.*, $B \to K\pi\pi\gamma$

b-baryons: $\Lambda_b \to \Lambda^{(*)}\gamma$, $\Xi_b \to \Xi^{(*)}\gamma$

Transverse asymmetry in $B^0 \to K^* l^+ l^-$ (pollution from C_9 and C_{10})

[PRL 118 (2017) 021801]

$B_s \to \varphi\gamma$ lifetime

The time-dependent decay rate of $B_s \to \varphi\gamma$ depends on the photon polarization

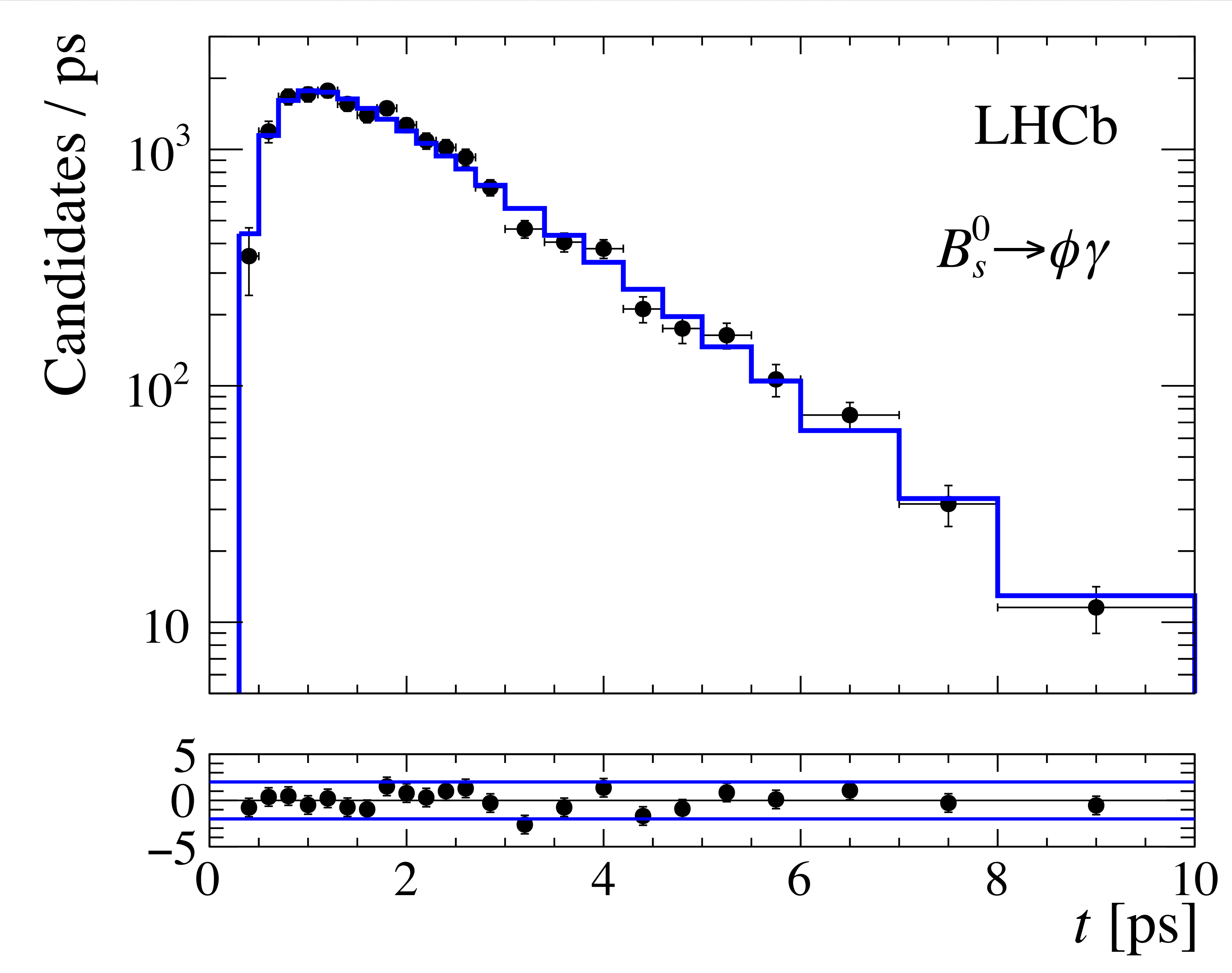
$$\Gamma(B_s^0(\bar{B}_s^0) \to \varphi\gamma)(t) \sim e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s}{2}\right) - \mathcal{A}^{\Delta}\sinh\left(\frac{\Delta\Gamma_s}{2}\right) \pm \mathcal{C}\cos(\Delta m_s t) \mp \mathcal{S}\sin(\Delta m_s t)\right]$$

Without distinguishing the flavor, we can measure A^{Δ} through the fit of the effective lifetime of the B_s

$$\mathcal{A}^{\Delta} = \sin 2\psi, \text{ with } \psi \equiv \frac{A(\bar{B}_s^0 \to \varphi\gamma_R)}{A(\bar{B}_s^0 \to \varphi\gamma_L)}$$

[PRL 118 (2017) 021801]

$B_s \to \varphi\gamma$ lifetime



$$\mathcal{A}^{\Delta} = -0.98^{+0.46}_{-0.52}\,^{+0.23}_{-0.20}$$

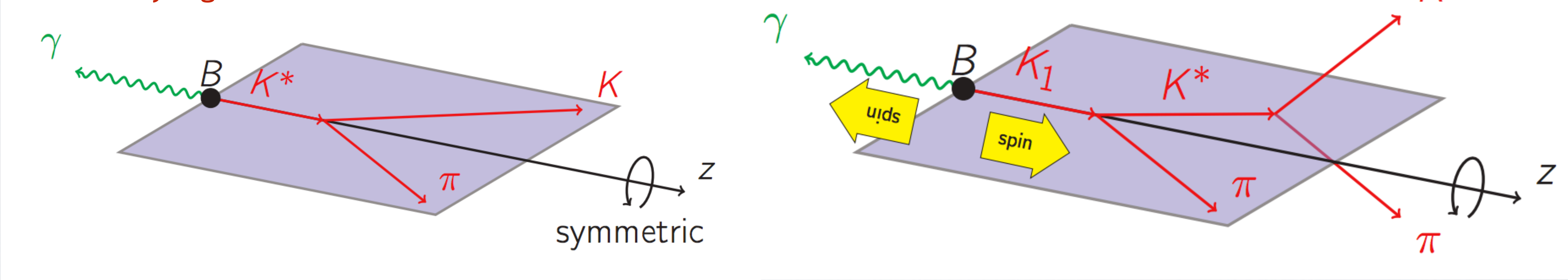
Consistent with SM at 2σ

$B^+ \to K\pi\pi\gamma$ angular analysis

Three tracks is the minimum needed to build a *P*-odd triple product proportional to the photon polarization using the final state momenta

$$\vec{p}_\gamma \cdot (\vec{p}_1 \times \vec{p}_2)$$

[From A. Tayduganov]



$B^+ \to K\pi\pi\gamma$ angular analysis

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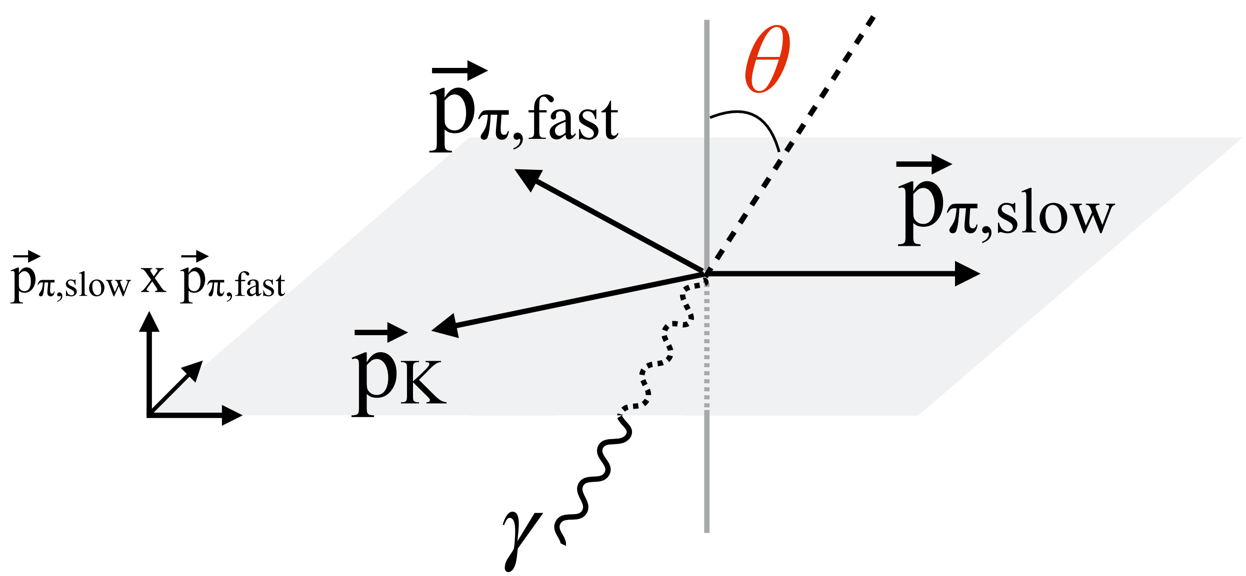
The photon polarisation can be inferred from the polarisation of the *K* resonance



[From A. T

symmetric

[PRL 112 (2014) 161801]

$B^+ \to K\pi\pi\gamma$ angular analysis

For a given $K_{\text{resonance}} \to K\pi\pi$, the decay amplitude is a function of the Dalitz variables and the photon polarization

The $K_{\text{resonance}}$ spectrum is very complex, but the photon polarization only enters the decay rate with odd powers of $\cos\theta$, so one can study the angular distribution in bins of $K\pi\pi$ mass

$$\frac{\mathrm{d}\,\Gamma(B^+ \to K_{\text{res}} \to K^+\pi^-\pi^+\gamma)}{\mathrm{d}\,s\,\mathrm{d}\,s_{13}\,\mathrm{d}\,s_{23}\,\mathrm{d}\cos\theta} \propto \sum_{j=\text{even}} a_i(s_{13}, s_{23}) \cos^j\theta + \text{Pol}_\gamma \sum_{j=\text{odd}} a_i(s_{13}, s_{23}) \cos^j\theta$$

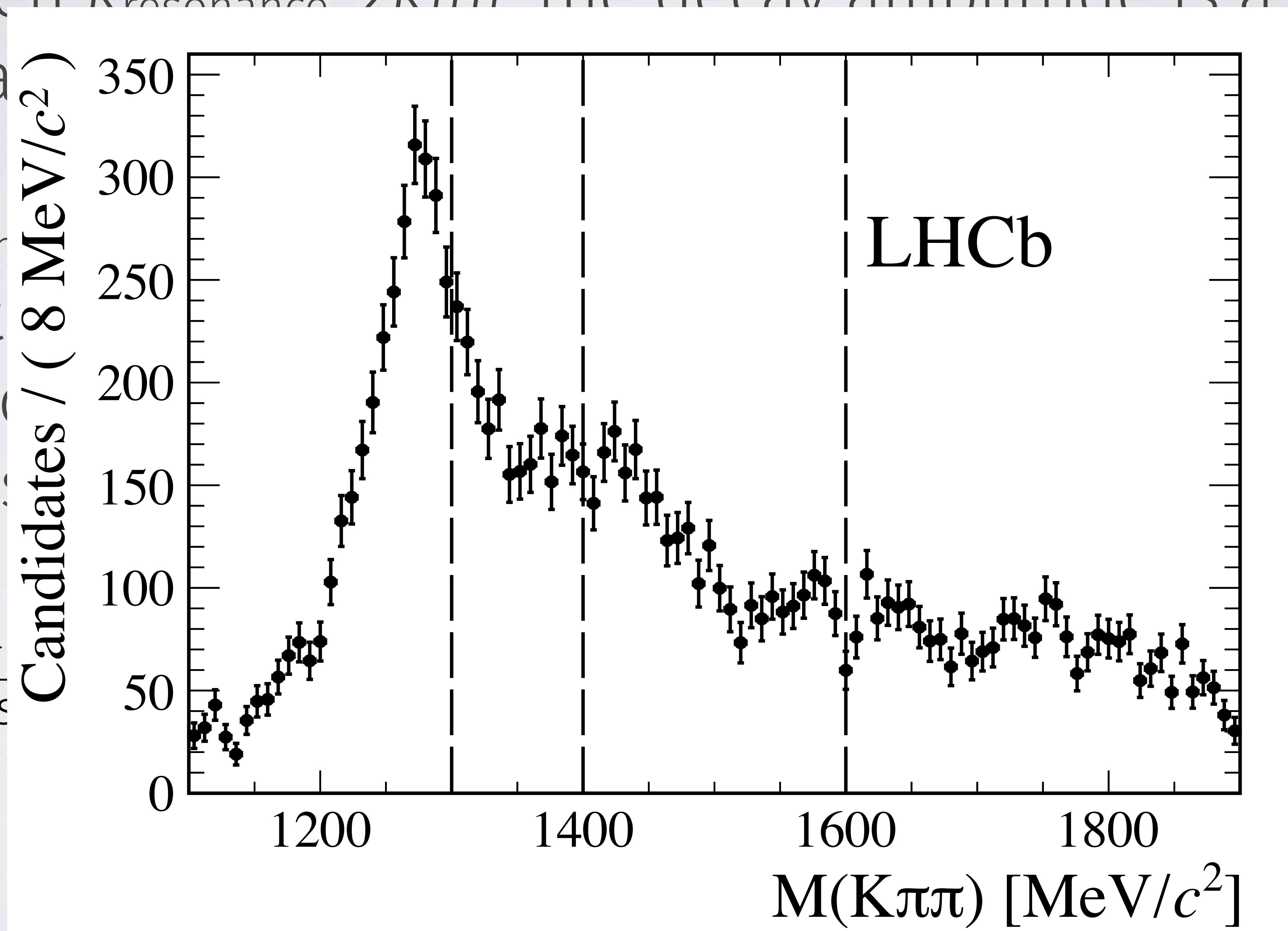
[PRL 112 (2014) 161801]

$B^+ \to K\pi\pi\gamma$ angular analysis

For a given $K_{resonance} \to K\pi\pi$, the decay amplitude is a function of the Da

The K_{resor} ... on polarizat ... vers of cosθ, so ... ns of Kππ mas

$$\frac{d\Gamma(B^+ \to}{d s\, d s} \quad s_{23}) \cos^j \theta$$



[PRL 112 (2014) 161801]

$B^+ \to K\pi\pi\gamma$ angular analysis

Without Dalitz information it is not possible to extract the value of the photon polarisation, but by calculating the up-down asymmetry we can determine if the photon is polarised or not

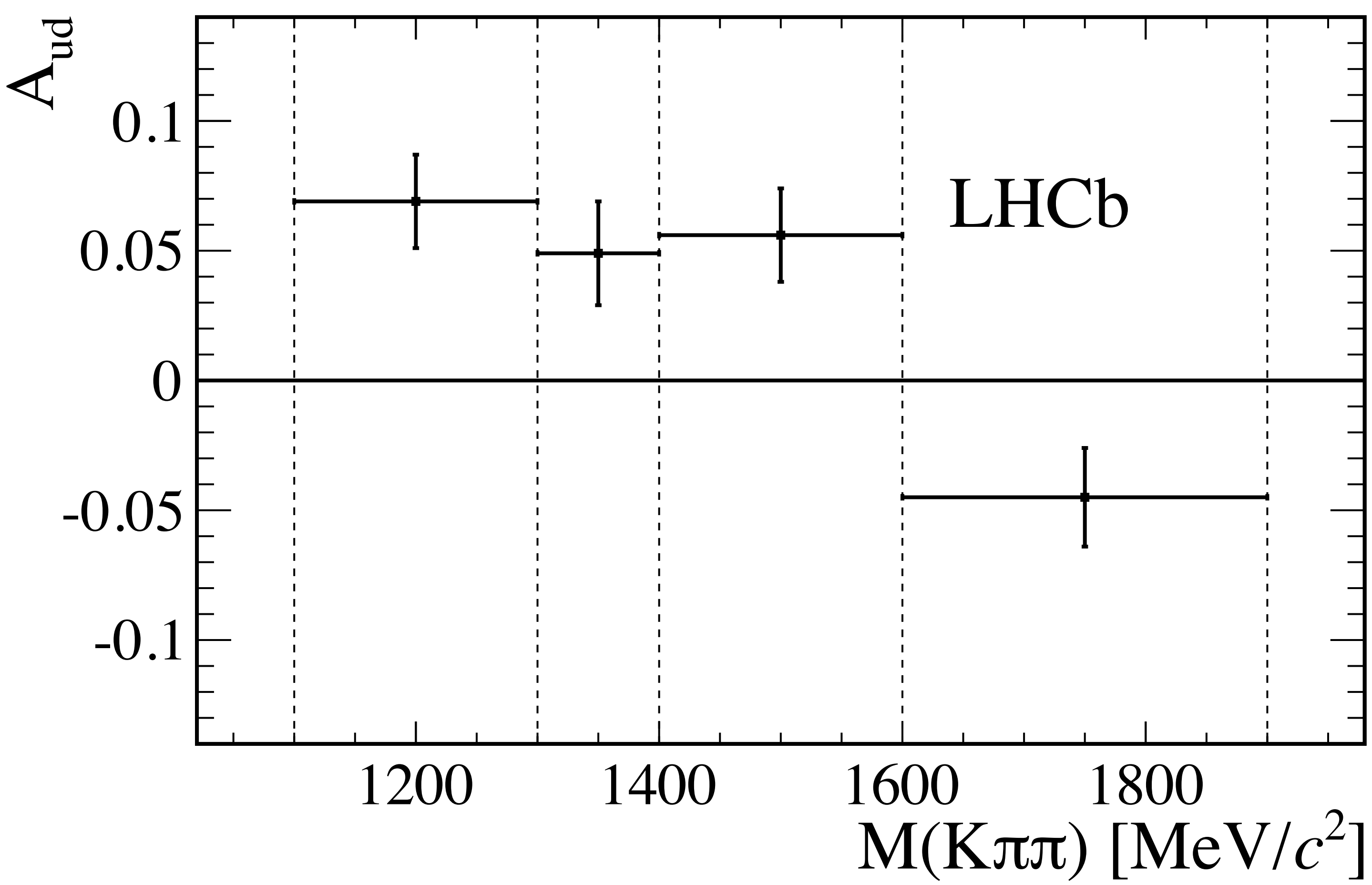
$$\mathcal{A}_{\mathrm{UD}} \equiv \frac{\int_0^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta} - \int_{-1}^0 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}}{\int_{-1}^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}} = C\lambda_\gamma$$

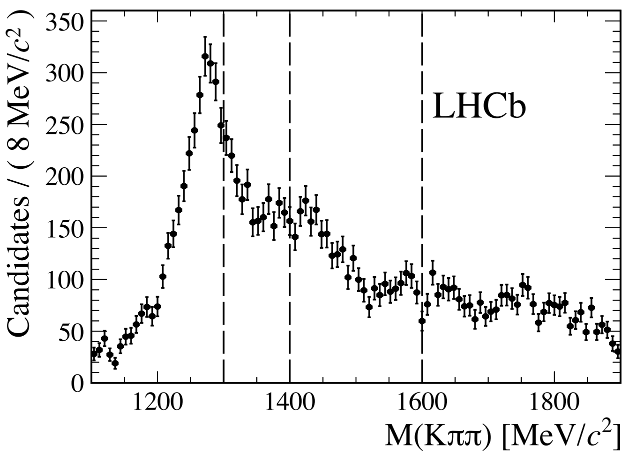
[PRL 112 (2014) 161801]

$B^+ \to K\pi\pi\gamma$ angular analysis

W
va
dc
pc

Determination of non-zero polarization at 5.2σ, but theory input and full amplitude analysis are needed to determine the exact value of the polarisation





[LHCb, JHEP 04 (2015) 064]

And $B^0 \to K^{*0} e^+ e^-$

Angular analysis at very low $m(e^+e^-)$, sensitive to photon polarisation as $m(e^+e^-) \to 0$

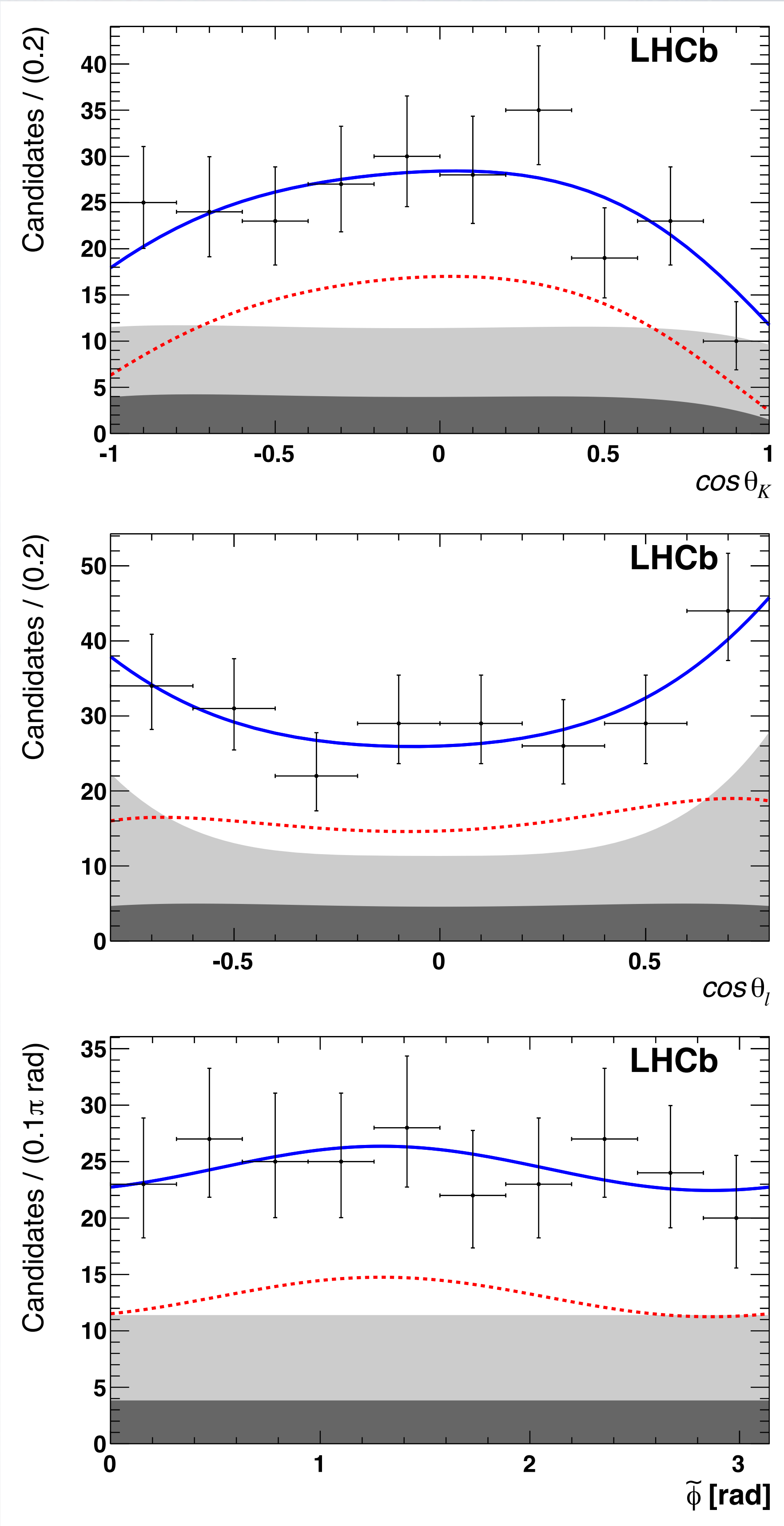
Simplified angular distribution with 4 observables

$$F_L = 0.16 \pm 0.06 \pm 0.03$$

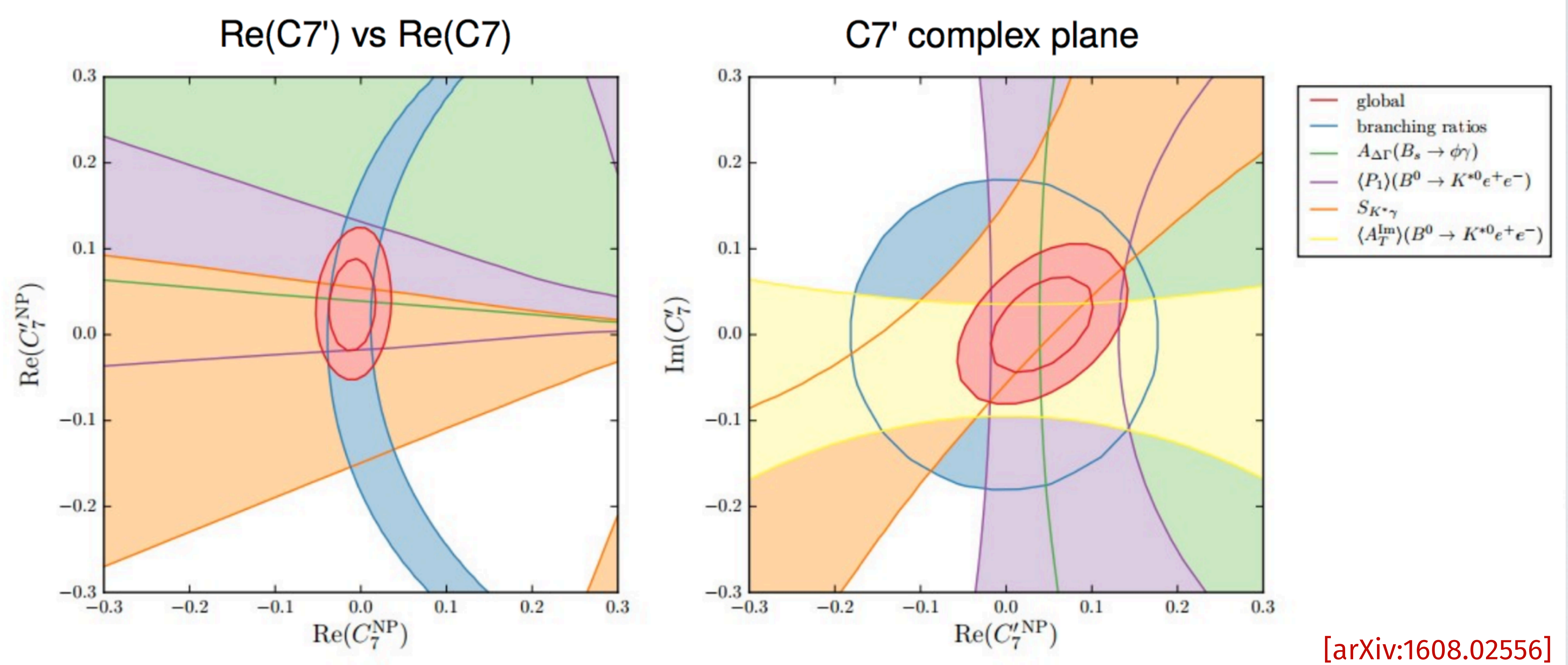
$$A_T^{\text{Re}} = 0.10 \pm 0.18 \pm 0.05$$

$$A_T^{(2)} = -0.23 \pm 0.23 \pm 0.05$$

$$A_T^{\text{Im}} = 0.14 \pm 0.22 \pm 0.05$$



Putting everything together



[arXiv:1608.02556]

Conclusions and future plans

LHCb has fulfilled its core radiative decays measurements with Run 1 data

While no analyses have been updated with Run 2 data, new results can be expected very soon

- Very close to reaching systematics limitation

LHCb has a rich program of radiative *b* decays and plans to study the photon polarisation in new, more complex ways

- Tagged $B_s \to \varphi\gamma$ analysis, amplitude analysis of $B^0 \to K\pi\pi\gamma$, angular analyses of *b*-baryons, $b \to d\gamma$ transitions…

Radiative charm decays are very challenging due to background with π^0