Radiative Decays at LHCb

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on behalf of the LHCb Collaboration

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Overview

The LHCb experiment.

Theory introduction:

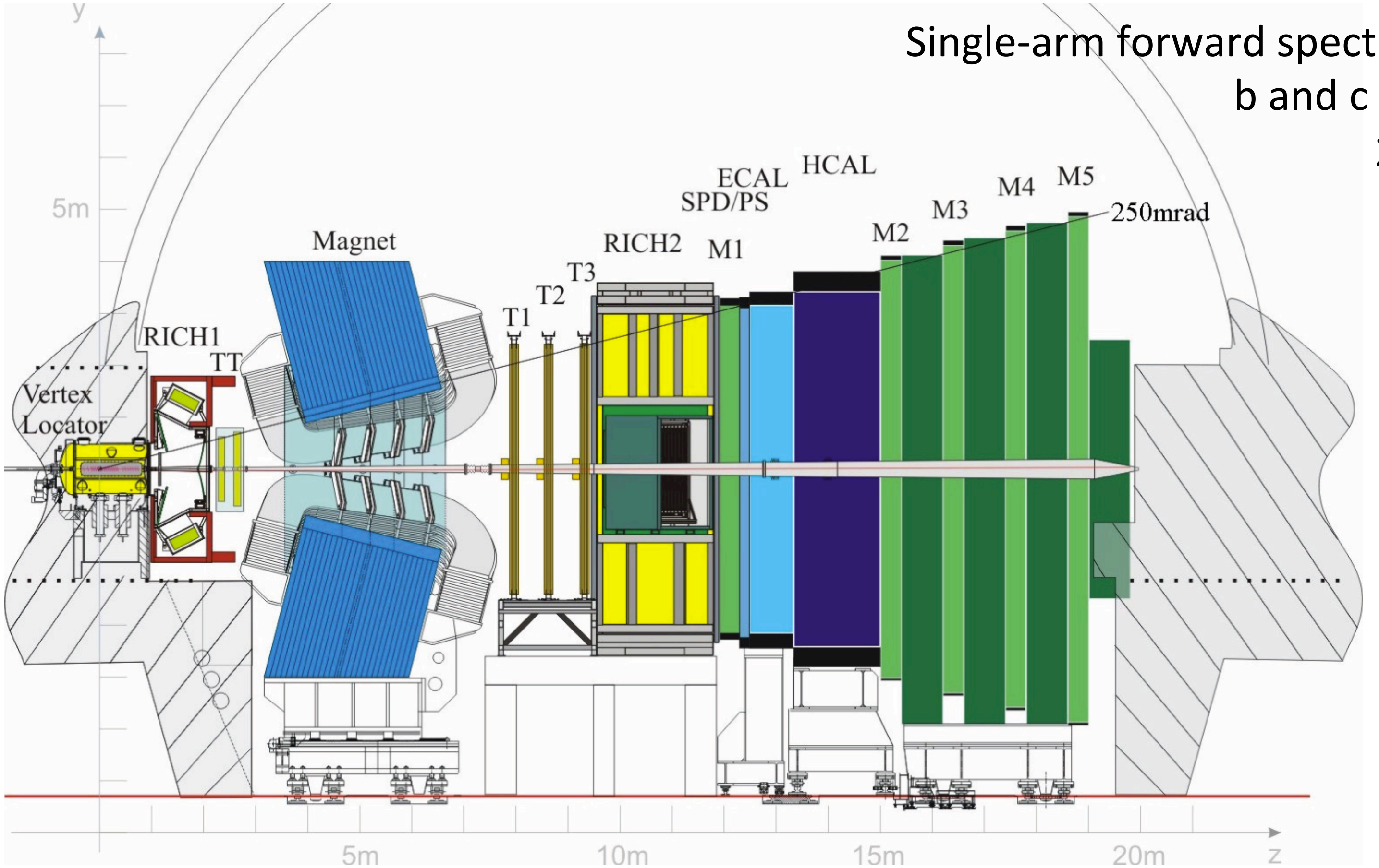
- Radiative decays within the SM and New Physics scenarios.

Measurement of the photon polarization with $B \rightarrow K\pi\pi\gamma$:

- Photon polarization in $B \rightarrow K_{res}\gamma$ decays.
- Up-down asymmetry. [PRL 112, 161801 (2014)]
- Angular fit.

Summary and Future.

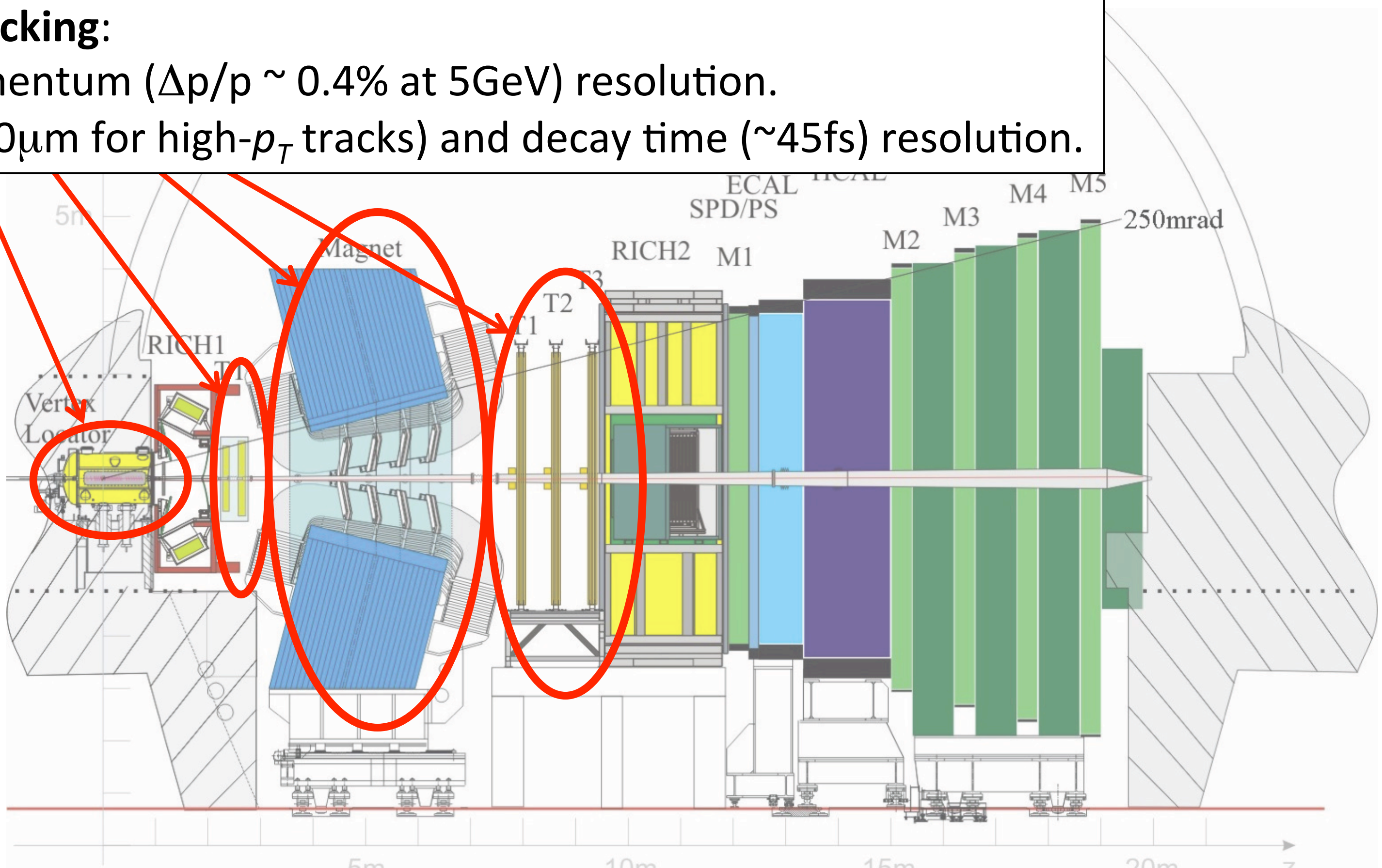
The LHCb Experiment



Single-arm forward spectrometer
b and c hadrons
$2 < \eta < 5$

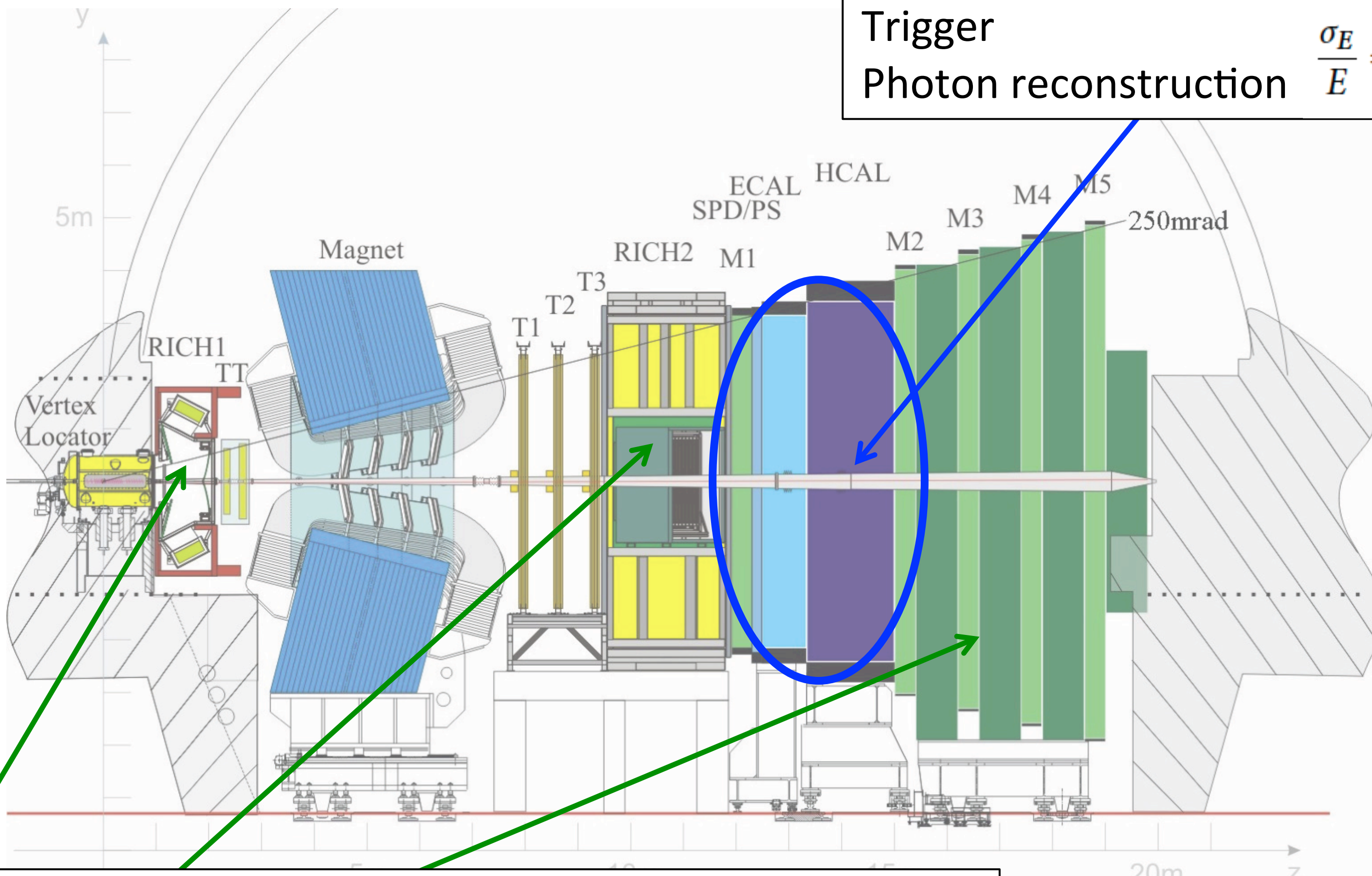
The LHCb Experiment

Precise tracking:
Good momentum (Δp/p ~ 0.4% at 5GeV) resolution.
Good IP (20μm for high-p_T tracks) and decay time (~45fs) resolution.



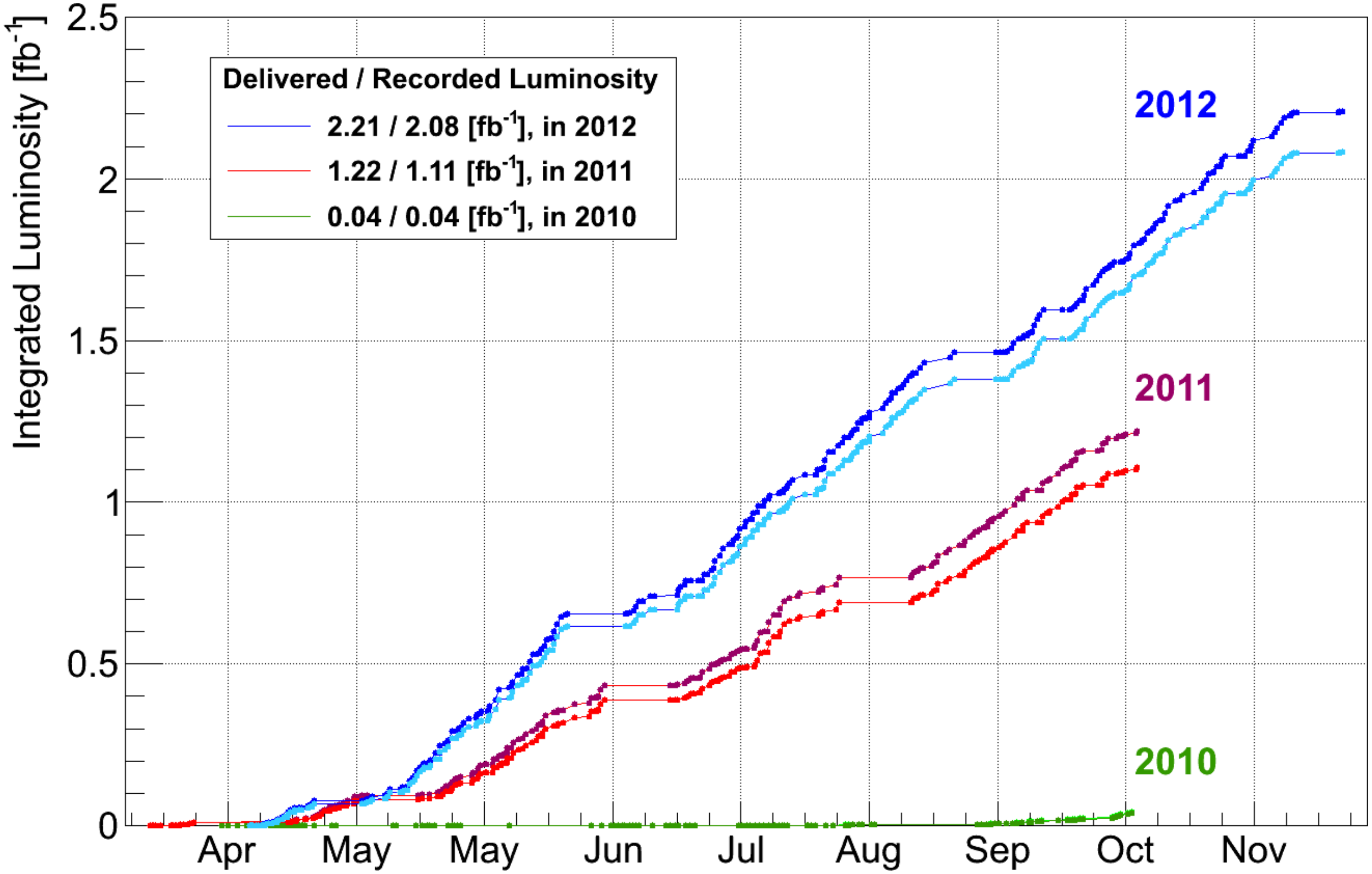
The LHCb Experiment

Calorimeter system:
Trigger
Photon reconstruction $\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E}} \oplus 1\%$



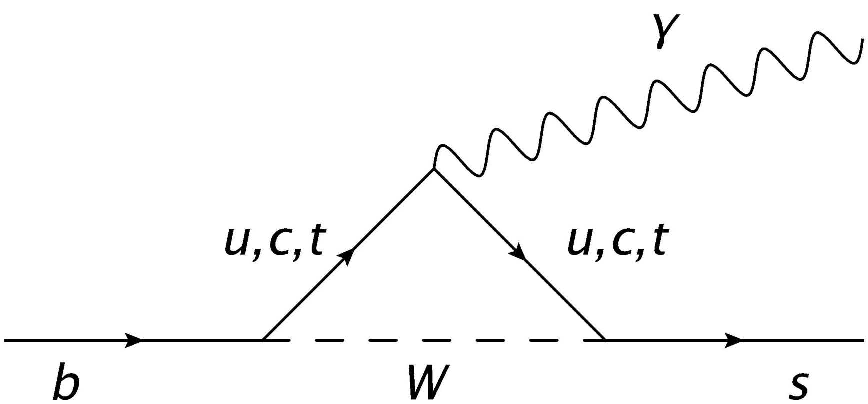
Excellent particle identification:
π/K separation over 2-100 GeV (ε_K ~ 90% for ~5% π→K mis-ID)
Powerful muon ID (ε_μ ~ 97% for ~1-3% π→μ mis-ID)

LHCb Run-I Performance



Radiative *B* Decays within the SM

- Radiative decays are FCNC processes ($b \rightarrow s\gamma$), not allowed at tree level:
  - They proceed through penguin transitions.
- Many possible observables reachable at the LHC:
  - Branching ratios, photon polarization (as a null-test of the SM) and different asymmetries (CP, isospin).
- Exclusive decays difficult from theoretical point of view due to form factor:
  - Need to find form-factor free observables (use of ratios that cancel out the form factors..).

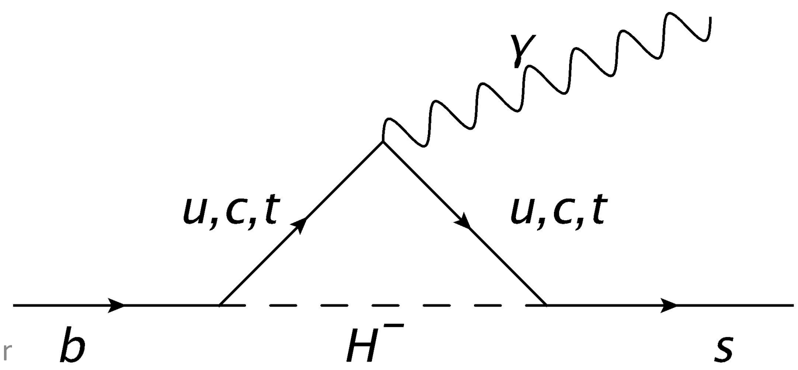


Radiative *B* Decays within New Physics

- The photon in the final state allows studies not reachable through other analyses.

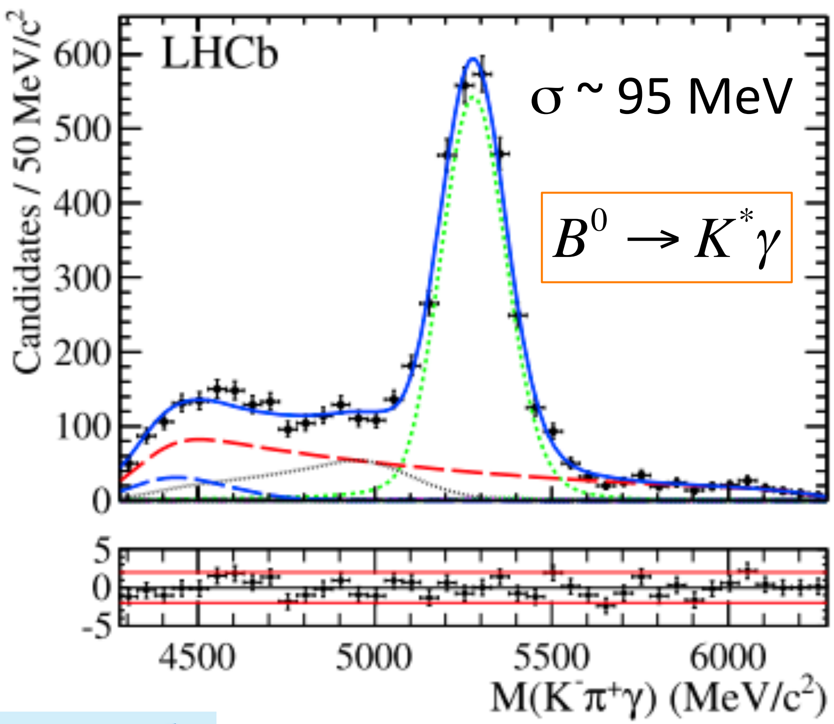
- The SM predicts the photon to be (almost completely) left-handed polarized (corrections of order m_s/m_b).

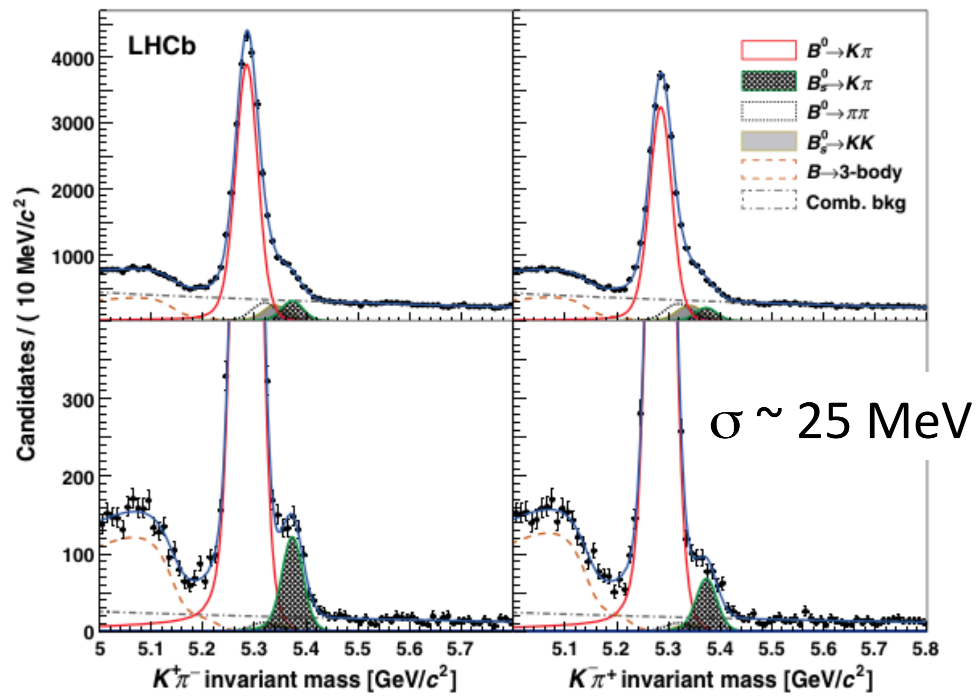
- Several NP models introduce right-handed currents. New particles could change the chirality inside the loop, producing chiral enhancement:
  - m_t/m_b from LRSM [Babu *et at.*, Phys.Lett.B333:196-201,1994].
  - m_{SUSY}/m_b in SUSY with δ_{RL} mass insertions [Gabbiani *et al.*, Nuclear Physics B 477 (1996) 321-352].



Challenges for Radiative Decays at LHCb

- 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.

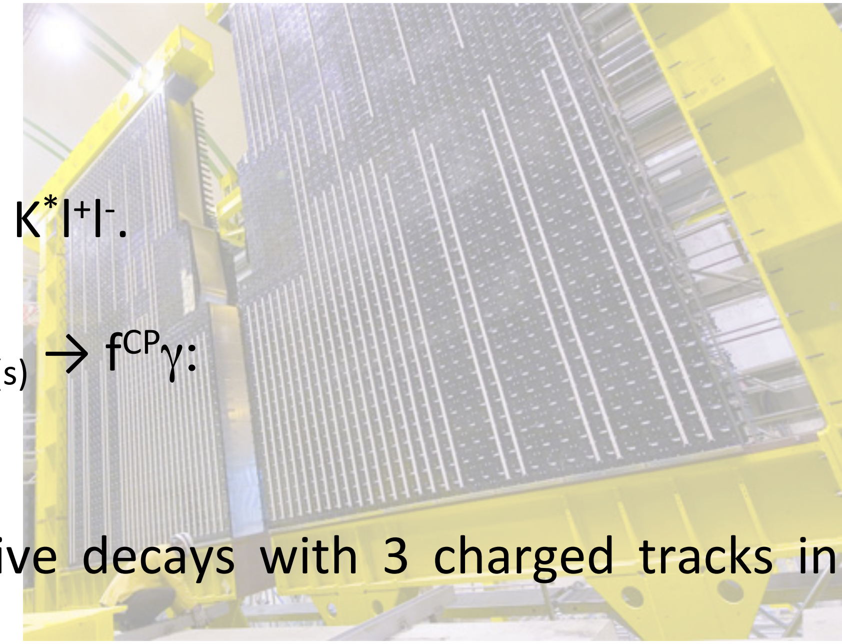




[Nucl. Phys. B 867 (2012) 1-18]

[PRL 110(2013) 221601]

Measuring the γ Polarization



Different approaches:

- Transverse asymmetry in $B^0 \rightarrow K^* l^+ l^-$.
- Time-dependent analyses of $B_{(s)} \rightarrow f^{CP}\gamma$:
  - $B_s \rightarrow \phi\gamma$ and $B^0 \rightarrow K_s\pi\gamma$
- Angular distribution of radiative decays with 3 charged tracks in the final state:
  - $B \rightarrow K\pi\pi\gamma$, $B \rightarrow \phi K\gamma$, $B \rightarrow \pi\pi\pi\gamma$
- b-baryons decays: $\Lambda_b \rightarrow \Lambda^{(*)}\gamma$

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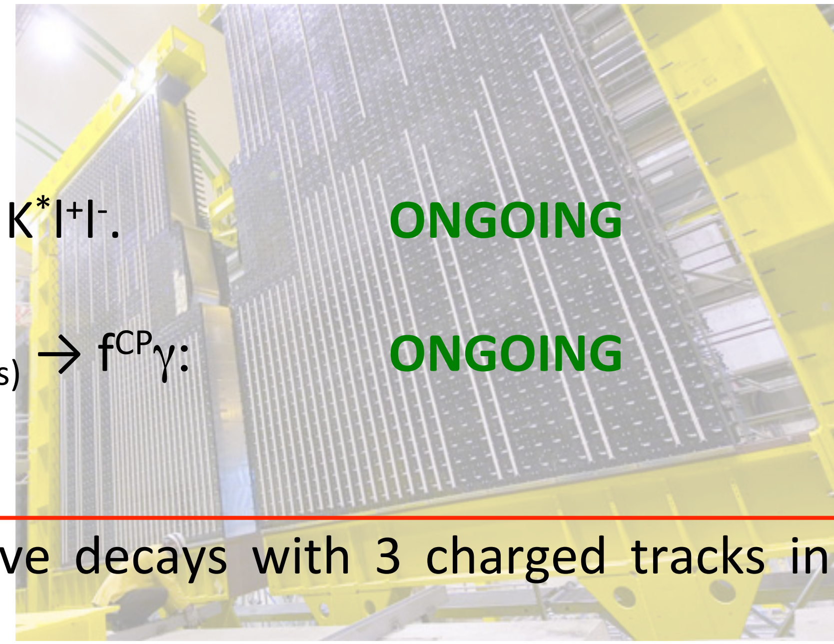

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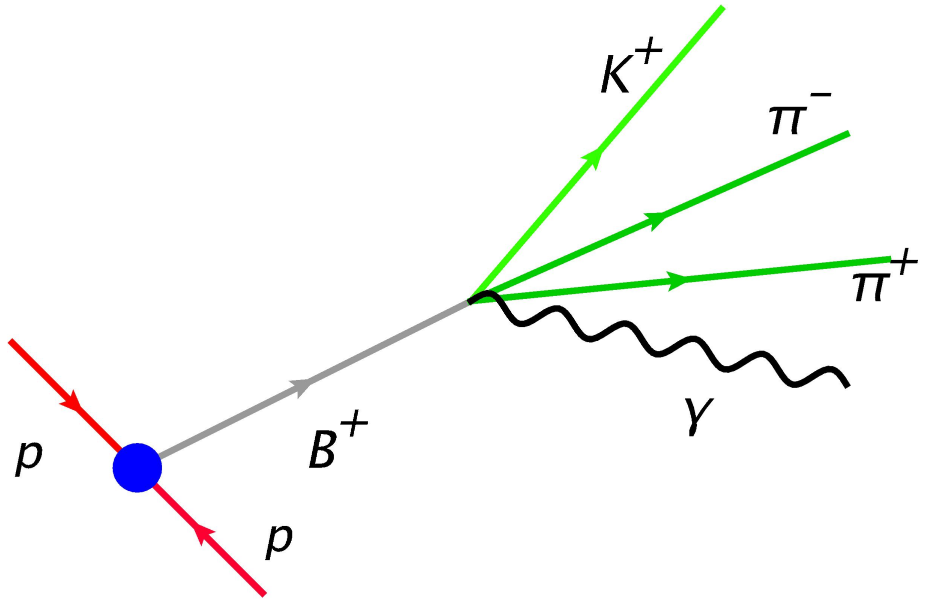
Today's talk, with $B \to K\pi\pi\gamma$
[PRL 112, 161801 (2014)]

B→Kππγ at LHCb

Inclusive study of the Kππ system with mass range of [1.1, 1.9] GeV.

Use of the whole Run-I dataset, corresponding to $3fb^{-1}$.

Study of angular distributions to search for the photon polarization.



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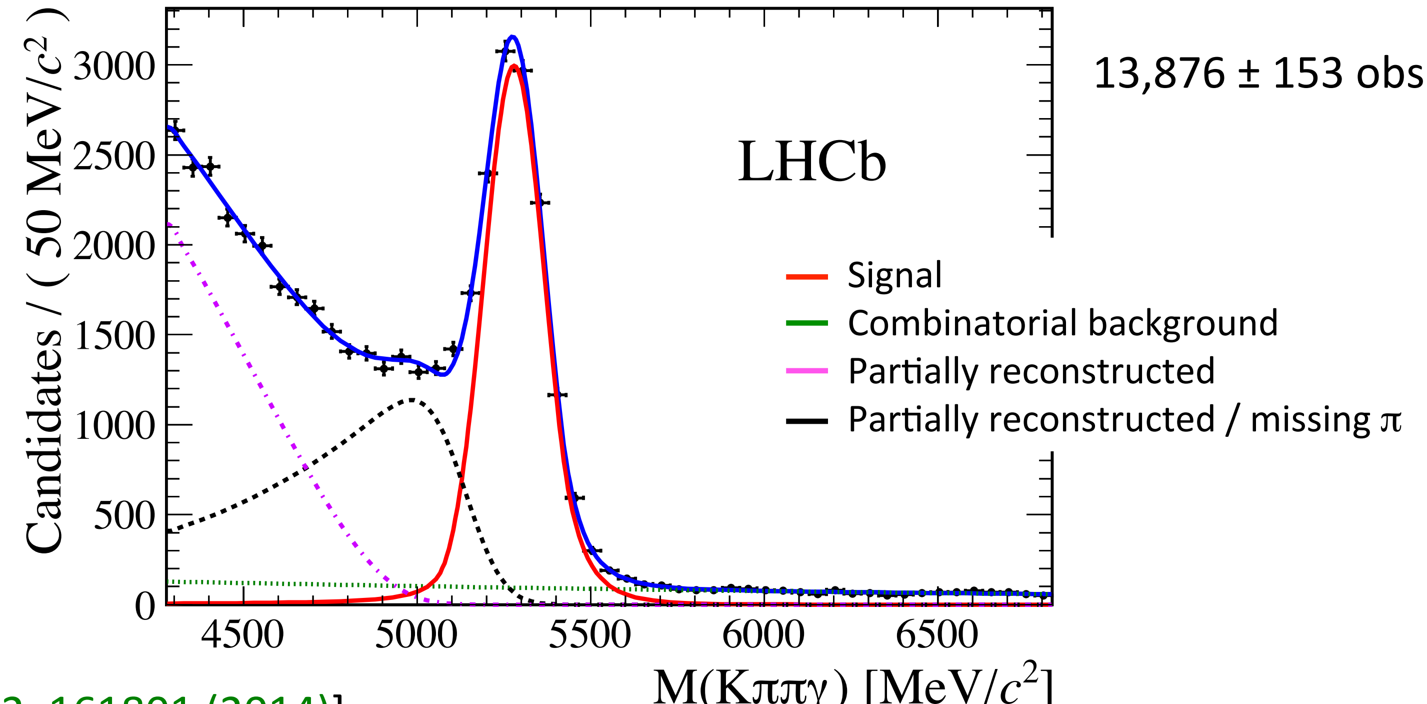
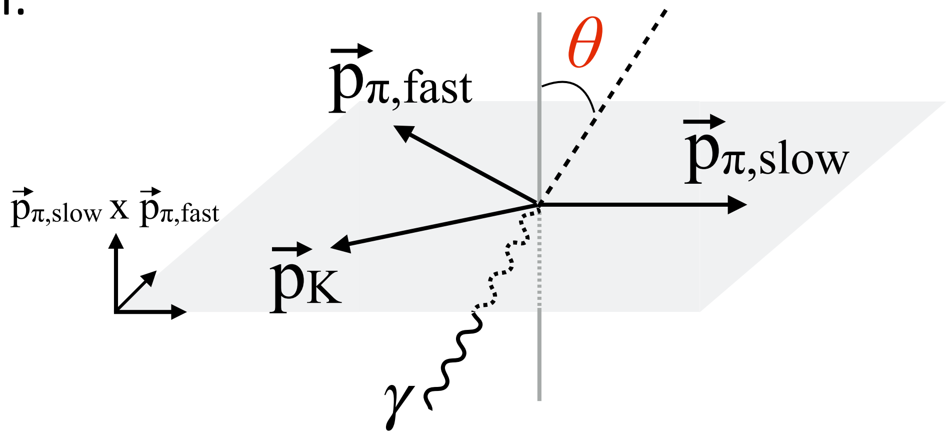


13,876 ± 153 observed events
σ ~ 88MeV

[PRL 112, 161801 (2014)]

Towards the photon polarization

The angular structure of the decay can be used to find the photon polarization:



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

where *C* accounts for the integral over the Dalitz plot and the angular distribution [PRL 112, 161801 (2014)].

Photon Polarization in $B \to K_{res}\gamma$

Photon polarization given by:

$$\lambda_\gamma = \frac{|c_R|^2 - |c_L|^2}{|c_R|^2 + |c_L|^2}$$

Weak amplitudes

Gronau *et al.* [PRD 66 054008] show that the γ polarization is independent of the *K* resonance:

$$\frac{|c_R|}{|c_L|} = \frac{|C_{7R}|}{|C_{7L}|} \Rightarrow \lambda_\gamma = \frac{|C_{7R}|^2 - |C_{7L}|^2}{|C_{7R}|^2 + |C_{7L}|^2}$$

+1 for $\bar{b}$
-1 for b

The amplitude of a K resonance decay can be written in terms of the helicity amplitude J_μ:

$$A_{L(R)}(s, s_{13}, s_{23}, \cos\theta) = \varepsilon^{\mu}_{K,L(R)} J_\mu$$

Polarization vector

Contains all the amplitude info

"easy" if only **one** (1^+) intermediate resonance [Kou *et al*, PhysRevD.83.094007] [Gronau *et al*, PhysRevD.66.054008]:

$$\frac{d\Gamma(B \to K_{res}\gamma \to K\pi\pi\gamma)}{ds\, ds_{13}\, ds_{23}\, d\cos\theta} \propto \frac{1}{4}|\vec{J}|^2 (1+\cos^2\theta) + \lambda_\gamma \frac{1}{2}\cos\theta\, \mathrm{Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]$$

γ polarization goes with odd powers of cosθ

Photon Polarization in B → $K_{res}\gamma$

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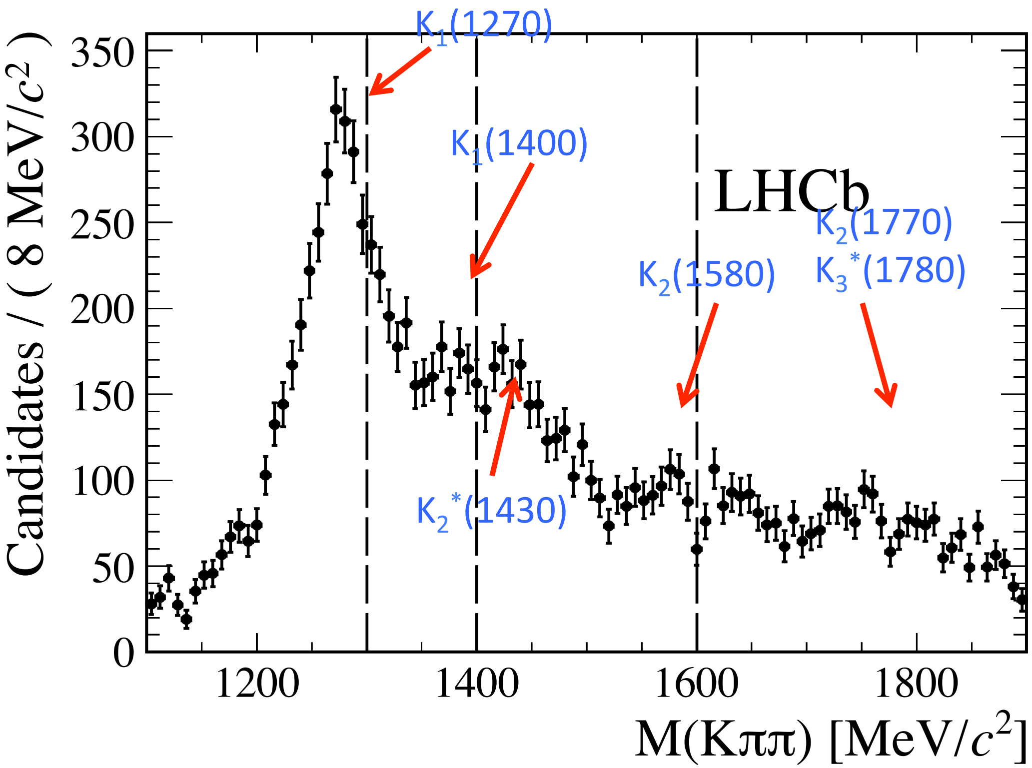
$$\frac{d\Gamma(B \to K_{res}\gamma \to K\pi\pi\gamma)}{ds\,ds_{13}\,ds_{23}\,d\cos\theta} \propto \frac{1}{4}|\vec{J}|^2 (1 \ldots]$$

Unfortunately, not the case

B→Kππγ



Many contributions, interference between 1^+, 1^-, 2^+ resonances [Gronau *et al*, PhysRevD.66.054008] impossible to separate without full amplitude analysis.

Inclusive analysis with theoretically motivated binning (chosen beforehand). The angular analysis is performed region by region.

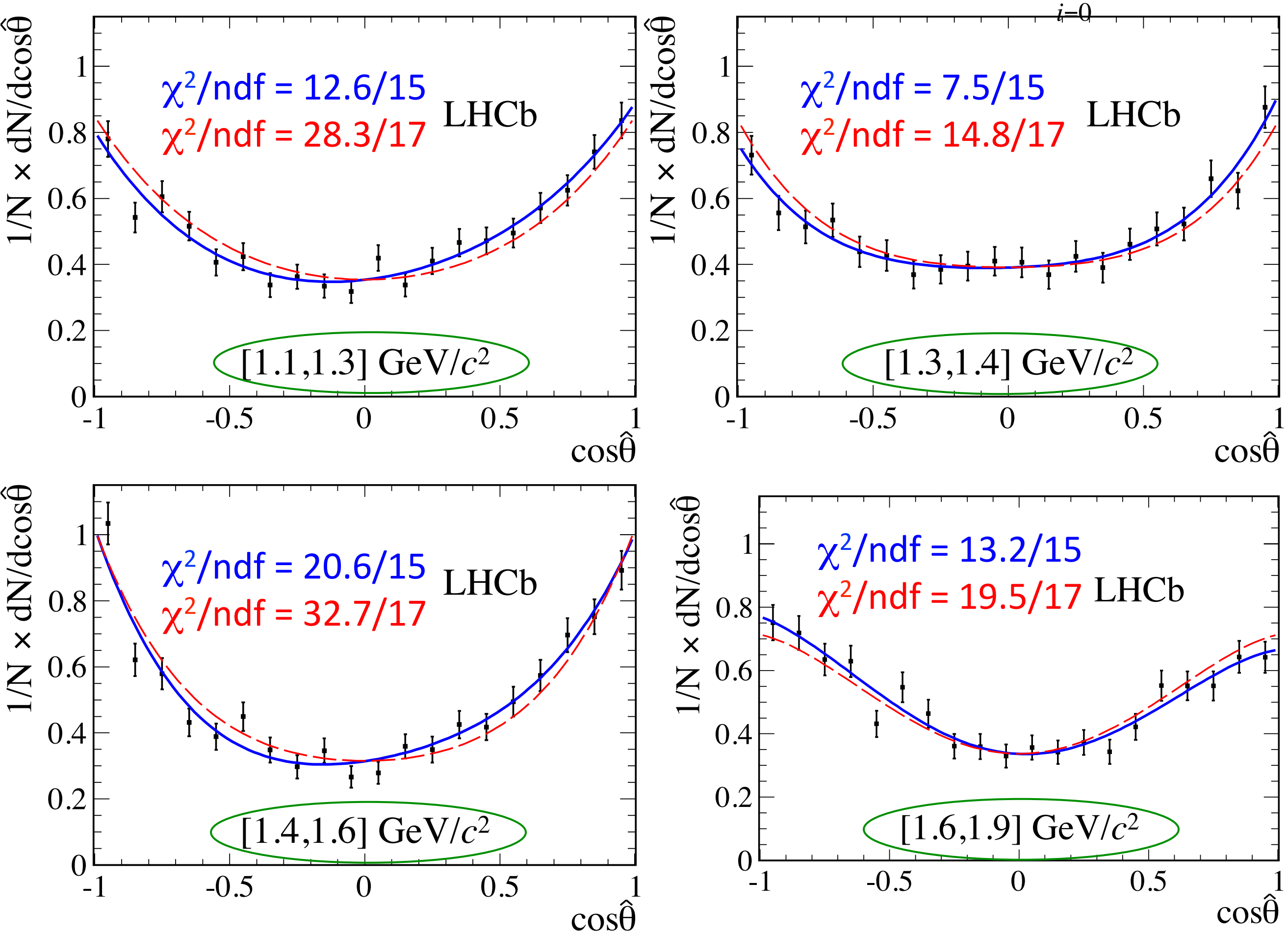
$$\frac{d\Gamma(\Sigma B \to K_{res}\gamma \to P_1 P_2 P_3 \gamma)}{ds\, ds_{13}\, ds_{23} \cos\theta} \propto \sum_{j=even} a_j(s_{13}, s_{23}) \cos^j\theta + \lambda_\gamma \sum_{j=odd} a_j(s_{13}, s_{23}) \cos^j\theta$$

λ_γ goes with odd powers of $\cos\theta$

Angular fit coefficients

Angular distributions for each Kππ mass region fitted with combination of Legendre polynomials (up to order 4):

$$f(\cos\hat{\theta}; c_0 = 0.5, c_1, c_2, c_3, c_4) = \sum_{i=0}^{4} c_i L_i(\cos\hat{\theta})$$



Nominal Fit
No polarization

[PRL 112, 161801 (2014)]

Angular fit analysis

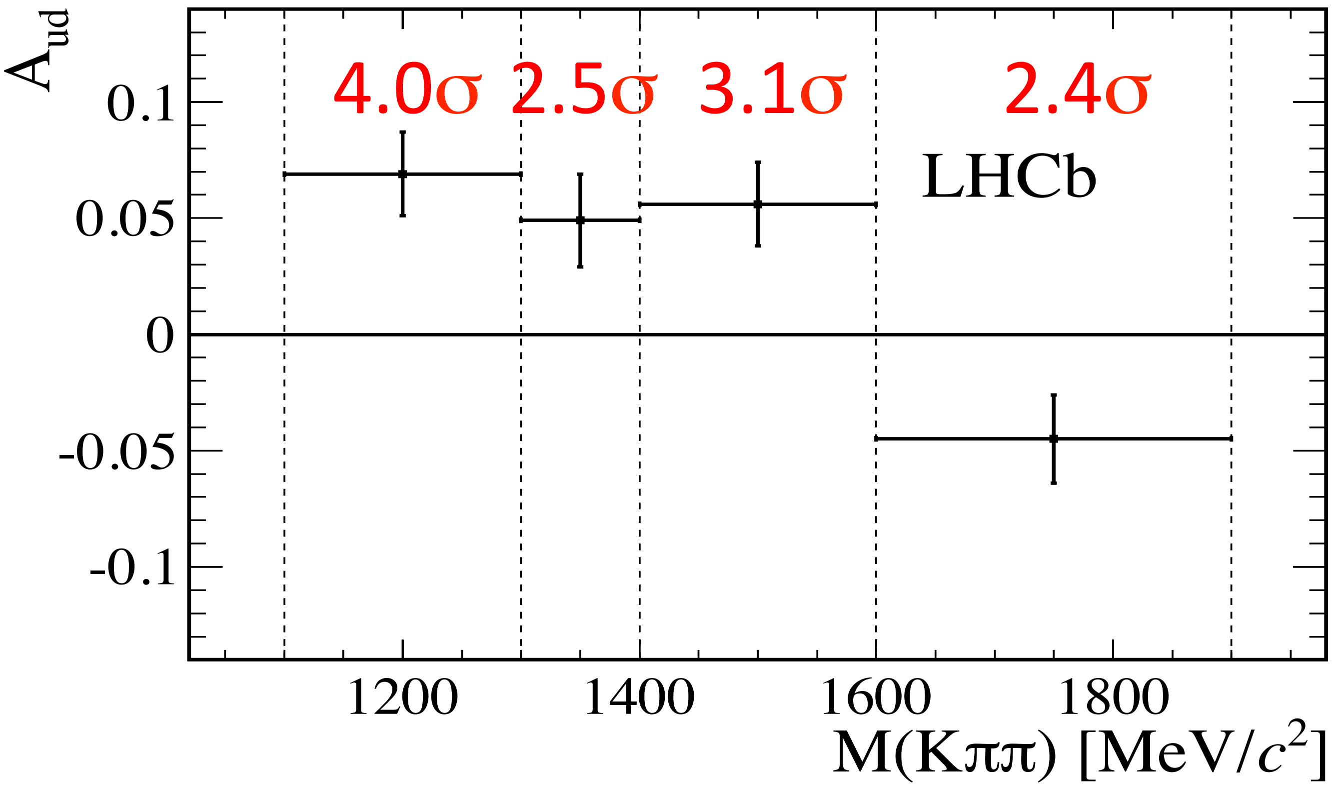
From the different values for the coefficients we can extract a value for the A_{UD} for each of the $K\pi\pi$ invariant mass region.

The up-down asymmetry is determined by: $A_{UD} = c_1 - \frac{c_3}{4}$

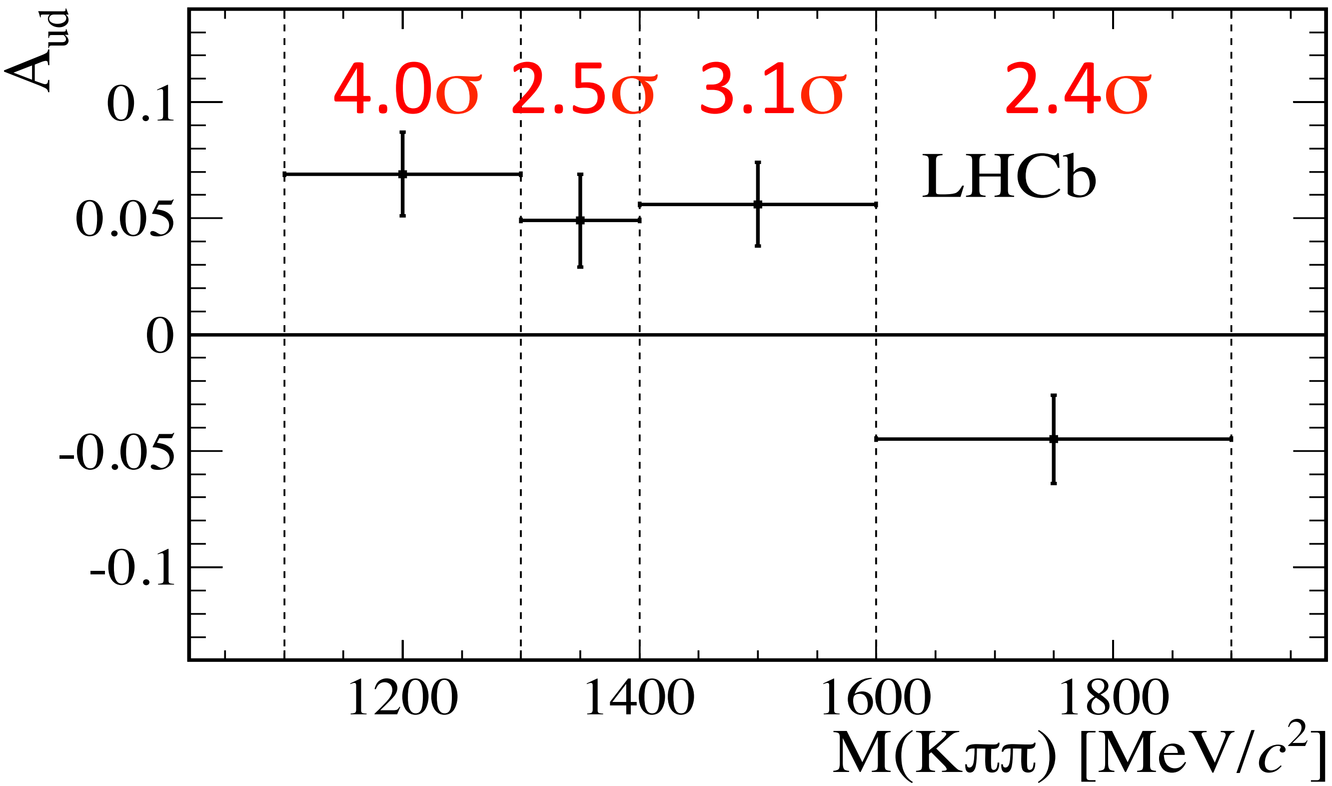
	[1.1, 1.3]	[1.3, 1.4]	[1.4, 1.6]	[1.6, 1.9]
c_1	6.3 ± 1.7	5.4 ± 2.0	4.3 ± 1.9	-4.6 ± 1.8
c_2	31.6 ± 2.2	27.0 ±2.6	43.1 ± 2.3	28.0 ± 2.3
c_3	-2.1 ± 2.6	2.0 ± 3.1	-5.2 ± 2.8	-0.6 ± 2.7
c_4	3.0 ±3.0	6.8 ± 3.6	8.1 ± 3.1	-6.2 ± 3.2
A_{UD}	6.9 ±1.7	4.9 ± 2.0	5.6 ± 1.8	-4.5 ± 1.9

This is a statistically-limited analysis.

Up-down asymmetry results



Up-down asymmetry significance



Combining the four bins, the significance of the A_{UD} being different from zero is of **5.2σ**. This can't be translated into a measurement of the γ polarization due to theoretical limitations.

First observation of photon polarization in b→sγ transitions

Summary and Future

A study of $B \to K\pi\pi\gamma$ decay is performed on $3fb^{-1}$ data sample.

We have reported the first observation of photon polarization in $b \to s\gamma$ transitions, with a 5.2σ significance.

More theoretical input is needed to translate measured up-down asymmetry into a measurement of the photon polarization.

The measurement of the photon polarization at LHCb is also promising with:

- Proper time distribution of $B_s \to \phi\gamma$.
- Transverse asymmetry in $B \to K^*ee$.
- Angular distribution in $B \to \phi K\gamma$.
- Radiative b-baryon decays: $\Lambda_b \to \Lambda^{(*)}\gamma$, $\Xi_b \to \Xi^{(*)}\gamma$.

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THANK YOU!

Back-up

Up-down asymmetry

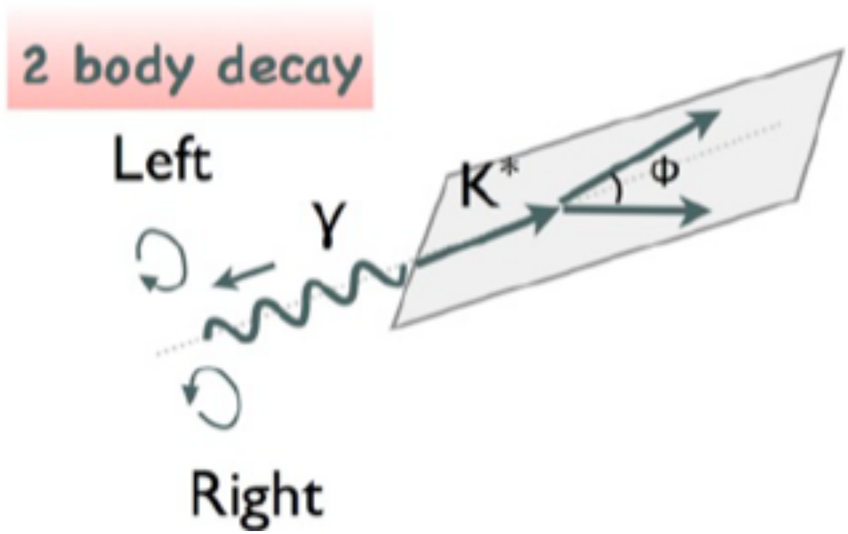
$$A_{UD} \equiv \frac{\int_0^1 d\cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 d\cos\theta \frac{d\Gamma}{d\cos\theta}} = \frac{3}{4}\lambda_\gamma \frac{\int ds\, ds_{13}\, ds_{23}\, \mathrm{Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]}{\int ds\, ds_{13}\, ds_{23}\, |\vec{J}|^2}$$

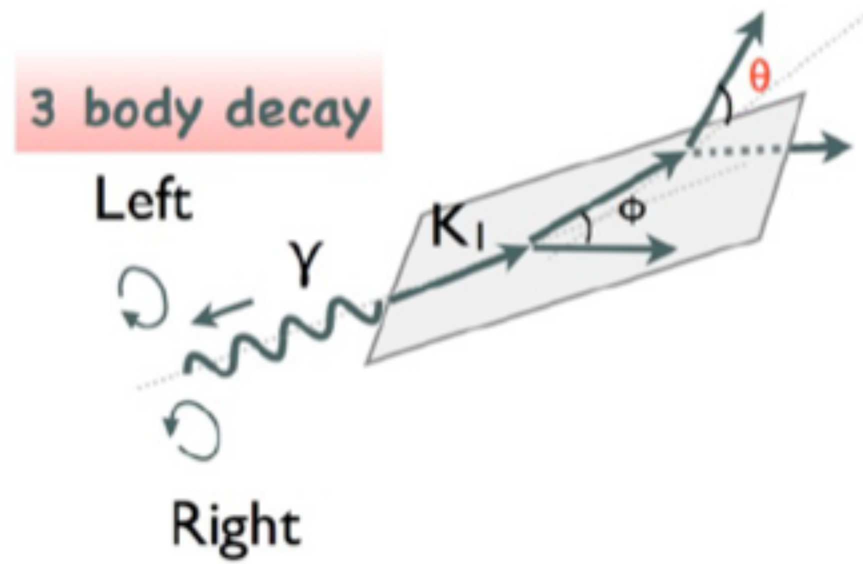
In the case of a single resonance

If *J* is known, the up-down asymmetry allows the computation of the photon polarization

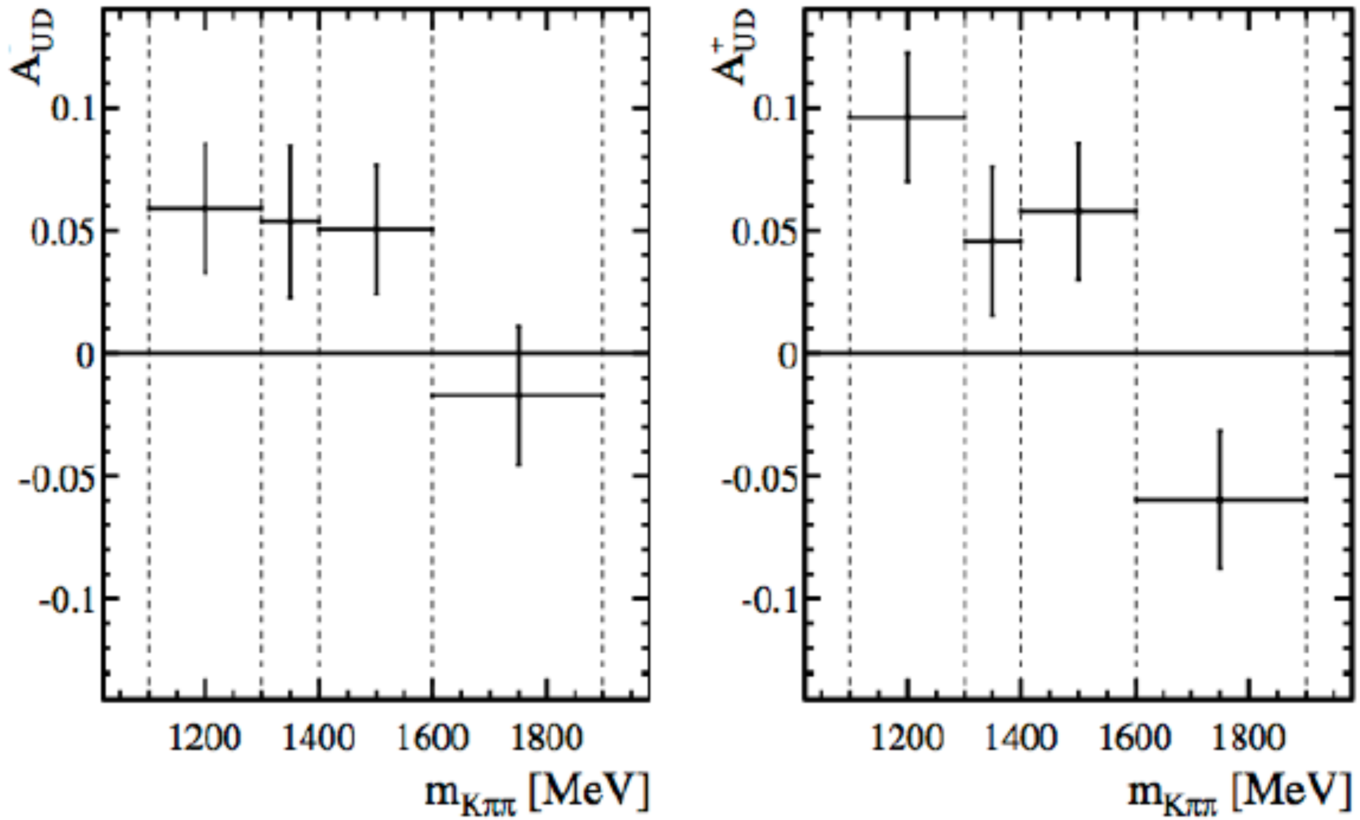
Why three charged particles?

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





Up-down asymmetry with counting method



The counting method gives compatible results