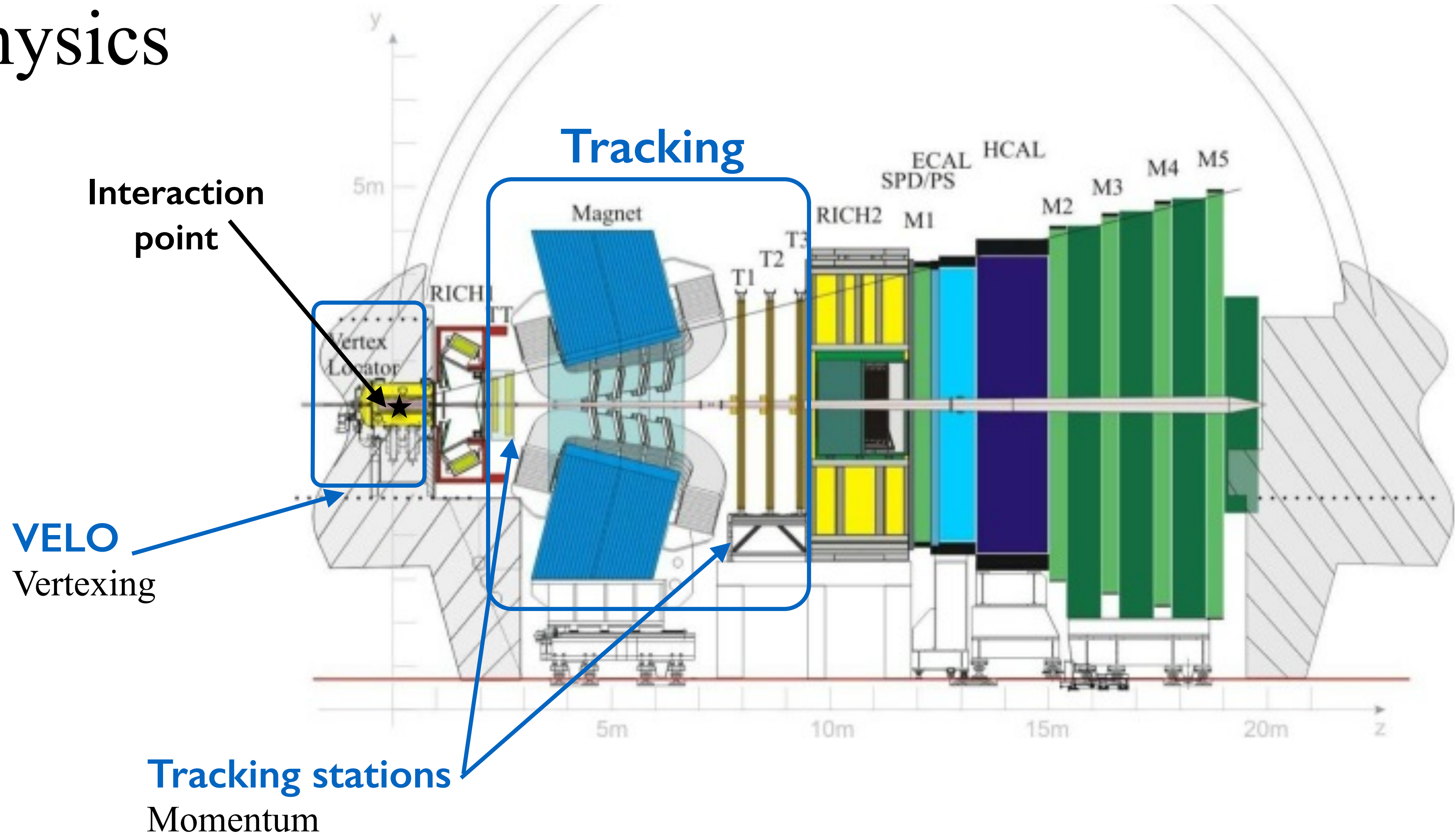
Observation of photon polarization in the $b \to s\gamma$ transition

Giovanni Veneziano

SPS Annual Meeting 2014
2014 CHIPP Annual Plenary Meeting and PhD/PostDoc Days
Fribourg, 01/07/2014

- Introduction to LHCb
- Study of photon polarization
  - ✓ First observation of photon polarization in the $b \to s\gamma$ transition
  - ✓ Toward the determination of λ_γ
- Conclusions

- LHCb is a forward detector ($2 < \eta < 5$) designed to study *b* physics



✓ Very precise vertex location (σ_{IP} = 20 μm)

✓ Excellent tracking resolution ($\Delta p/p$ = 0.4 - 0.6 %)

✓ Very good PID performances

✓ High-granularity calorimeter for photon reconstruction

✓ Three-step trigger reducing the rate to 5 kHz

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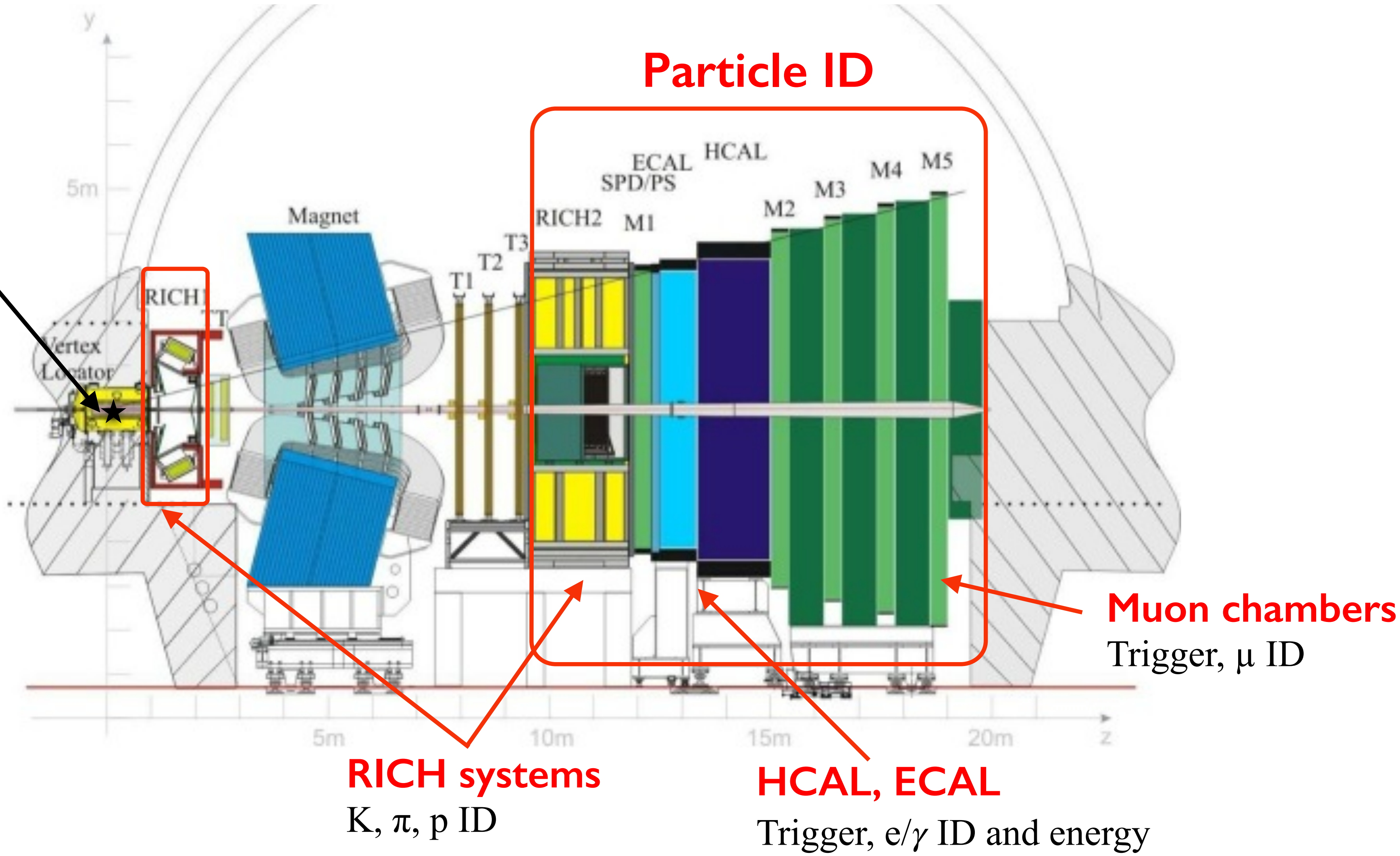

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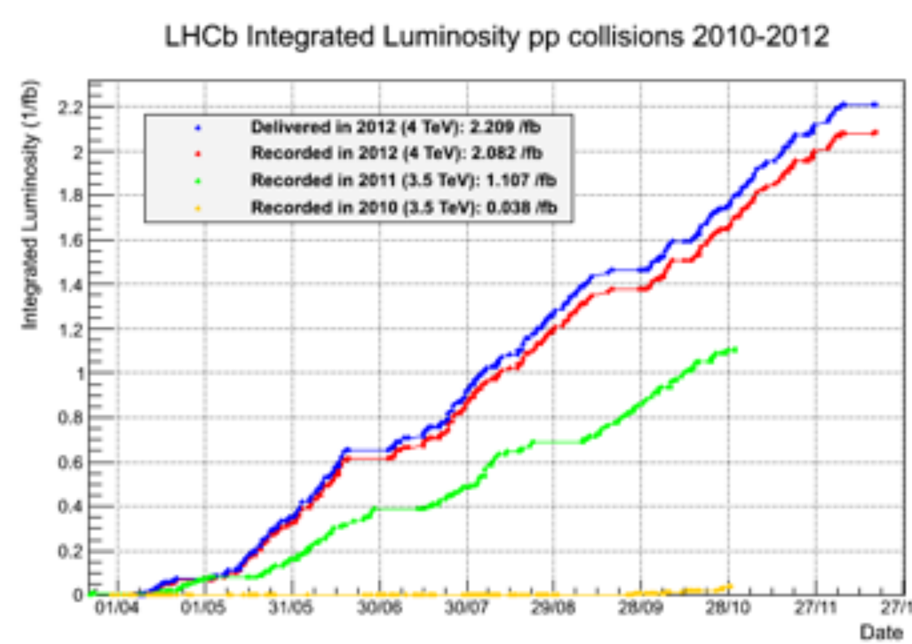

✓ A total luminosity of ~ 3 fb^{-1} has been recorded during LHC run I

✓ A luminosity upgrade is foreseen during the long shutdown of 2018-2019

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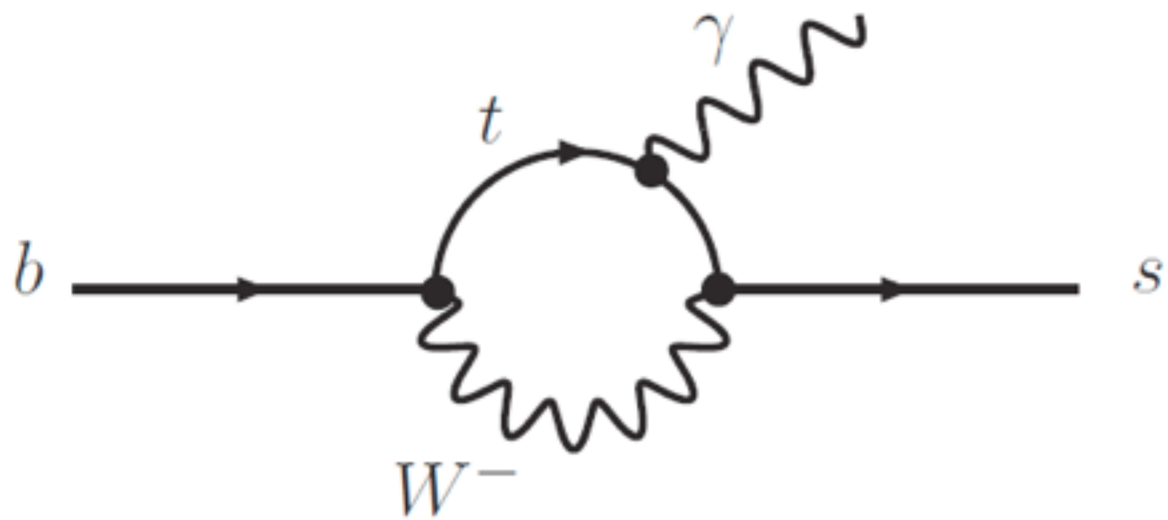
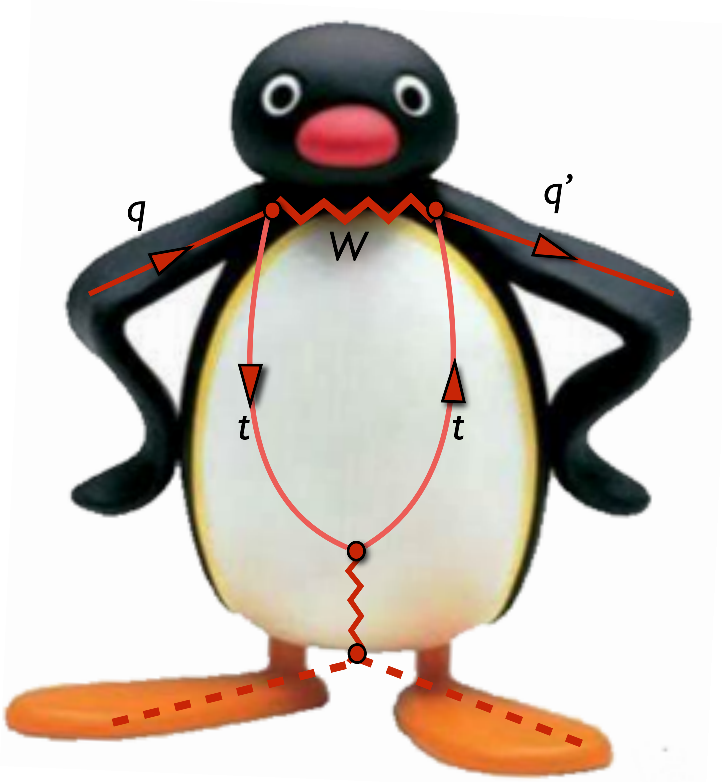
Motivation

- b → sγ transitions happen through FCNC penguin loops





- New Physics (NP) effects can affect the angular variables

✓ b → sγ photons are left-handed in the SM

✓ NP models (*e.g.* MSSM) predict a large right-handed component

✓ photon polarization λ_γ is affected

✓ λ_γ has not been measured yet

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

$c_{L,R}$ are the $b \to s\,\gamma_{L,R}$ amplitudes

Measuring the polarization

- Various (complementary) methods have been proposed for the determination of λ_γ

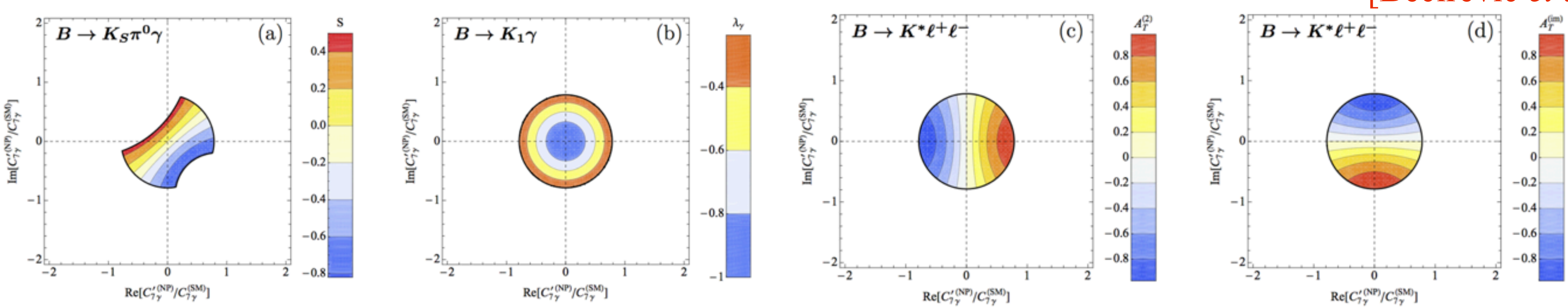
✓ Time-dependent analyses of $B_{(s)} \to f^{CP}\gamma$ (*e.g.* $B_s \to \phi\gamma$, $B^0 \to K_S\pi^0\gamma$)

✓ Transverse asymmetry in $B^0 \to K^*l^+l^-$

✓ Angular distributions of b-baryons: (*e.g.* $\Lambda_b \to \Lambda^{(*)}\gamma$, $\Xi_b \to \Xi^{(*)}\gamma$)

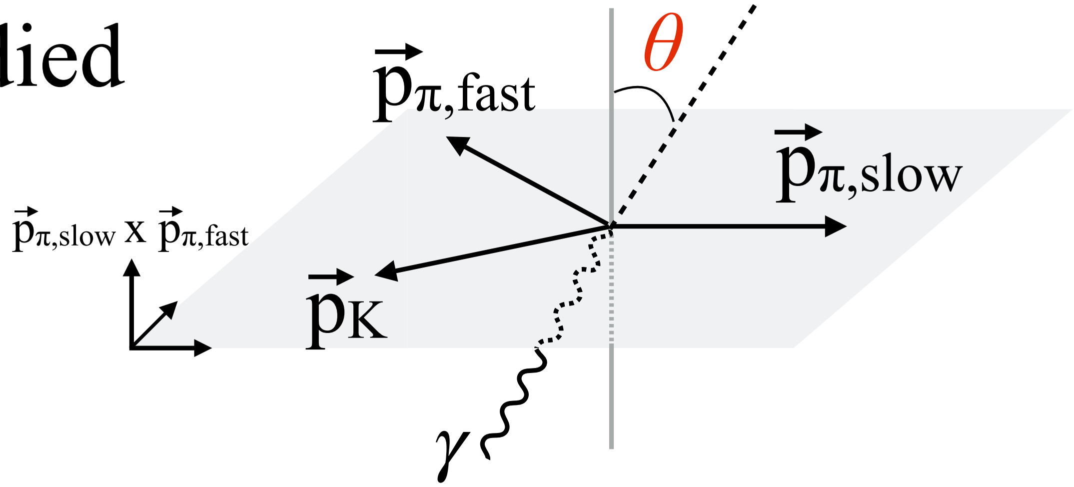
✓ **Angular distribution of radiative decays with three charged particles in the final state (*e.g.* $B^\pm \to K^\pm\pi^\mp\pi^\pm\gamma$)**

[Becirevic *et al.*]



Theory

- The decays $B^\pm \rightarrow K^\pm \pi^\mp \pi^\pm \gamma$ are studied



- The decay rate reads

$$\frac{d\Gamma}{dcos\theta} \propto \sum_{i=0,2,4} a_i\, cos^i\theta + \lambda_\gamma \sum_{j=1,3} a_j\, cos^j\theta$$

- The up-down asymmetry

$$\mathcal{A}_{\rm ud} \equiv \frac{\int_0^1 {\rm dcos}\,\theta \frac{{\rm d}\Gamma}{{\rm dcos}\,\theta} - \int_{-1}^0 {\rm dcos}\,\theta \frac{{\rm d}\Gamma}{{\rm dcos}\,\theta}}{\int_{-1}^1 {\rm dcos}\,\theta \frac{{\rm d}\Gamma}{{\rm dcos}\,\theta}}$$

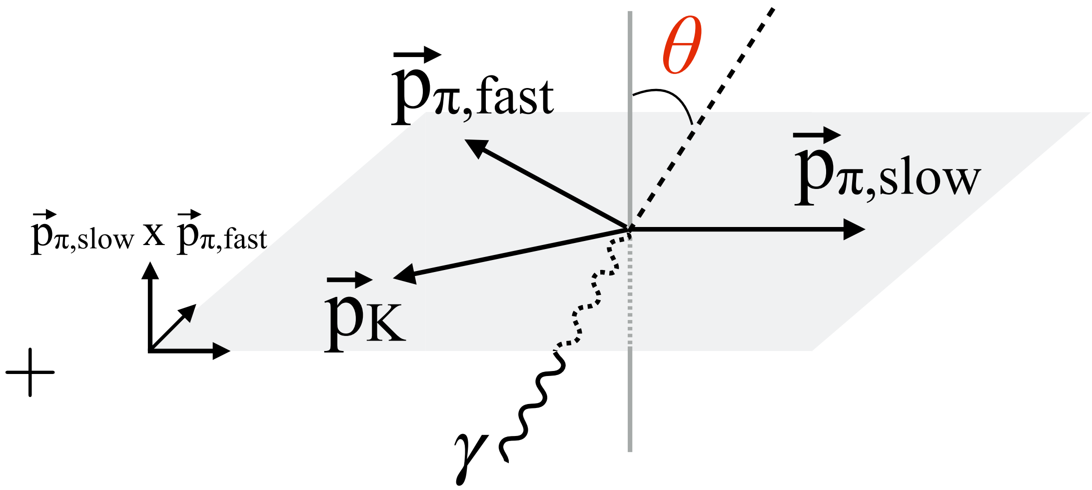
✓ proportional to λ_γ

[Gronau *et al.*, PRL88 (2002) 051802]
[Kou *et al.*, PRD83 (2011) 094007]

Theory

- Up-down asymmetry originates from the interference between
  - ✓ intermediate resonance amplitudes

$$K_1(1270)^+ \to K^*(892)^0\pi^+$$
$$\to \rho(770)K^+$$



  - ✓ *S*- and *D*-wave amplitudes

$$K_1(1270)^+ \to K^*(892)^0\pi^+$$
$$J^P : 1^+ \to 1^-0^-$$
$$L = 0, 2$$

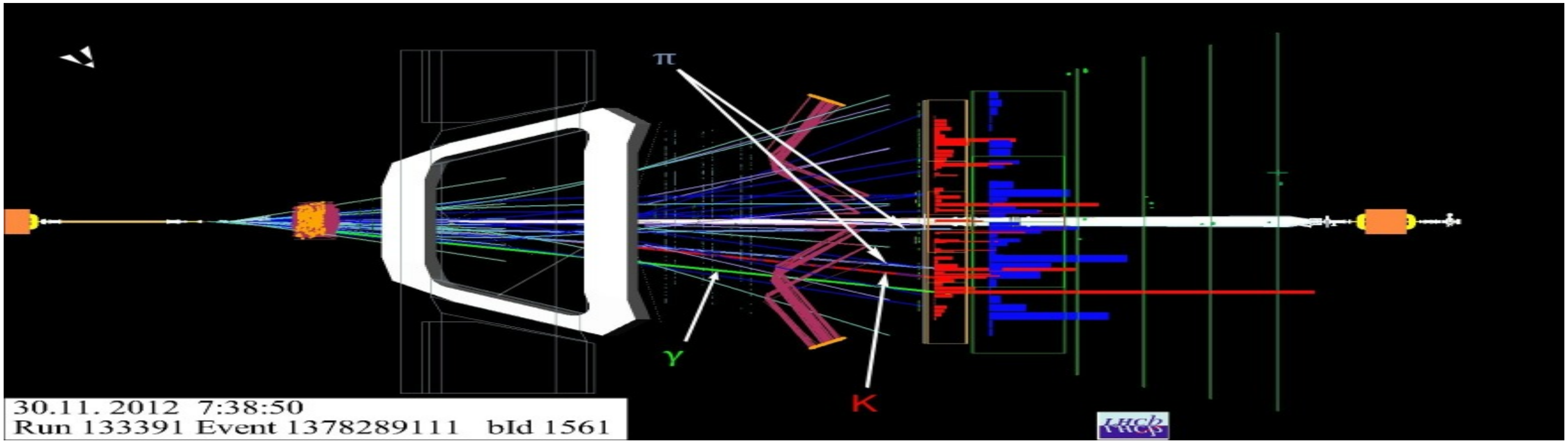
  - ✓ two intermediate $K^*\pi$ with different charges

$$K_1(1270)^0 \to K^*(892)^0\pi^0$$
$$\to K^*(892)^+\pi^-$$

Only for neutral modes !

[Gronau *et al.*, PRL88 (2002) 051802]

Analysis strategy & results

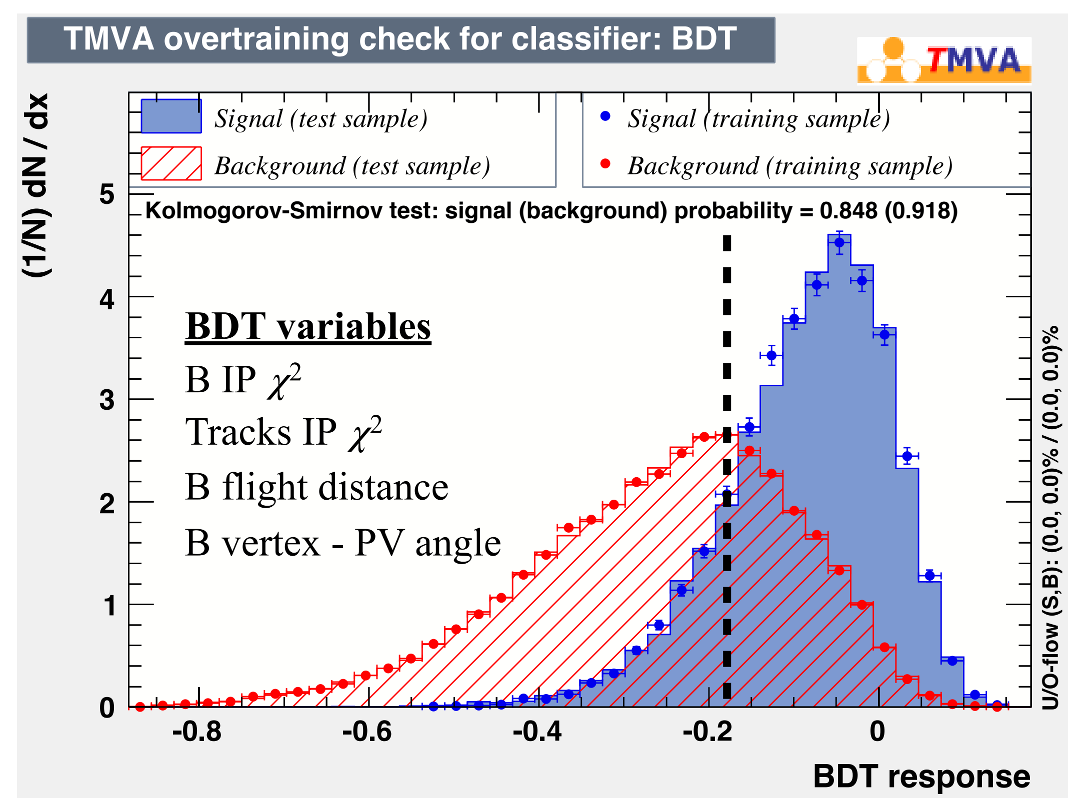


event selection

pre-selection

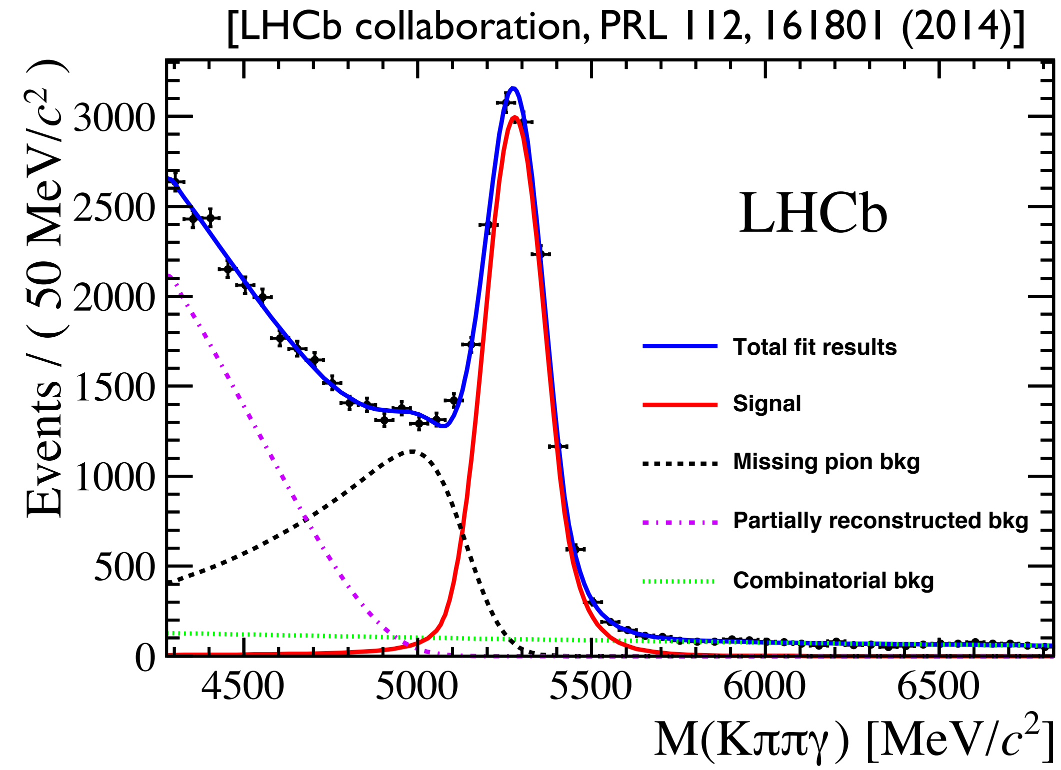
Track IP χ^2	> 16	
Max track p_T	> 1200	MeV/c
Min track p_T	> 500	MeV/c
K Prob(K)*(1-K Prob(π))	> 0.2	
π^+ Prob(π^+)*(1-π^+ Prob(K))	> 0.2	
π^- Prob(π^-)*(1-π^- Prob(K))	> 0.2	
$K^+\pi^-\pi^+$ vertex isolation χ^2	> 2	
K_{res} vertex χ^2	< 20	
B mass-constrained $m_{K^+\pi^-\pi^+}$ mass window	$[1100, 1900]$	MeV/c^2
Photon E_T	> 3000	MeV
Photon CL	> 0.25 and $\neq 0.5$	
Photon/π^0 separation	> 0.6	
B p_T	> 2500	MeV/c
B vertex χ^2	< 20	
B IP χ^2	< 20	
K^+ π^- π^0 mass	> 2000	MeV/c^2
π^+ π^0 mass	> 1100	MeV/c^2
Fiducial cut on $\lvert p_x \rvert$	$\leq 0.317(p_z - 2400)$	MeV/c

boosted decision tree

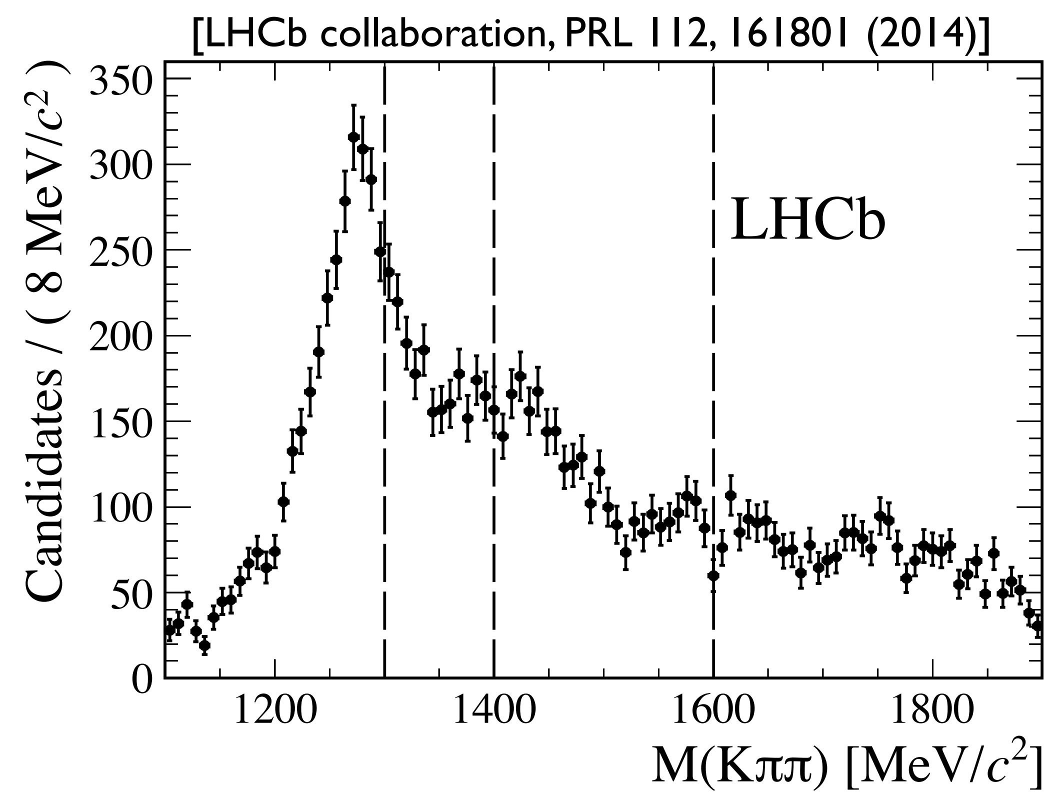


Analysis strategy & results

- Full mass fit
  - ✓ 3 fb^{-1} of data
  - ✓ ~ 14,000 signal events
  - ✓ the background-subtracted Kππ mass spectrum is determined
  - ✓ the distribution of signal events in bins of cosϑ in four $M_{K\pi\pi}$ intervals is obtained



J	K	Mass	Width
1+	K1(1270)	1272 ± 7	90 ± 20
	K1(1400)	1403 ± 7	174 ± 13
1-	K*(1410)	1414 ± 15	232± 21
	K*(1680)	1717 ± 27	322 ± 110
2+	K*2(1430)	1426 ± 2	99 ± 3
2-	K2(1770)	1773 ± 8	186 ± 14
	K2(1820)	1816 ± 13	276 ± 35

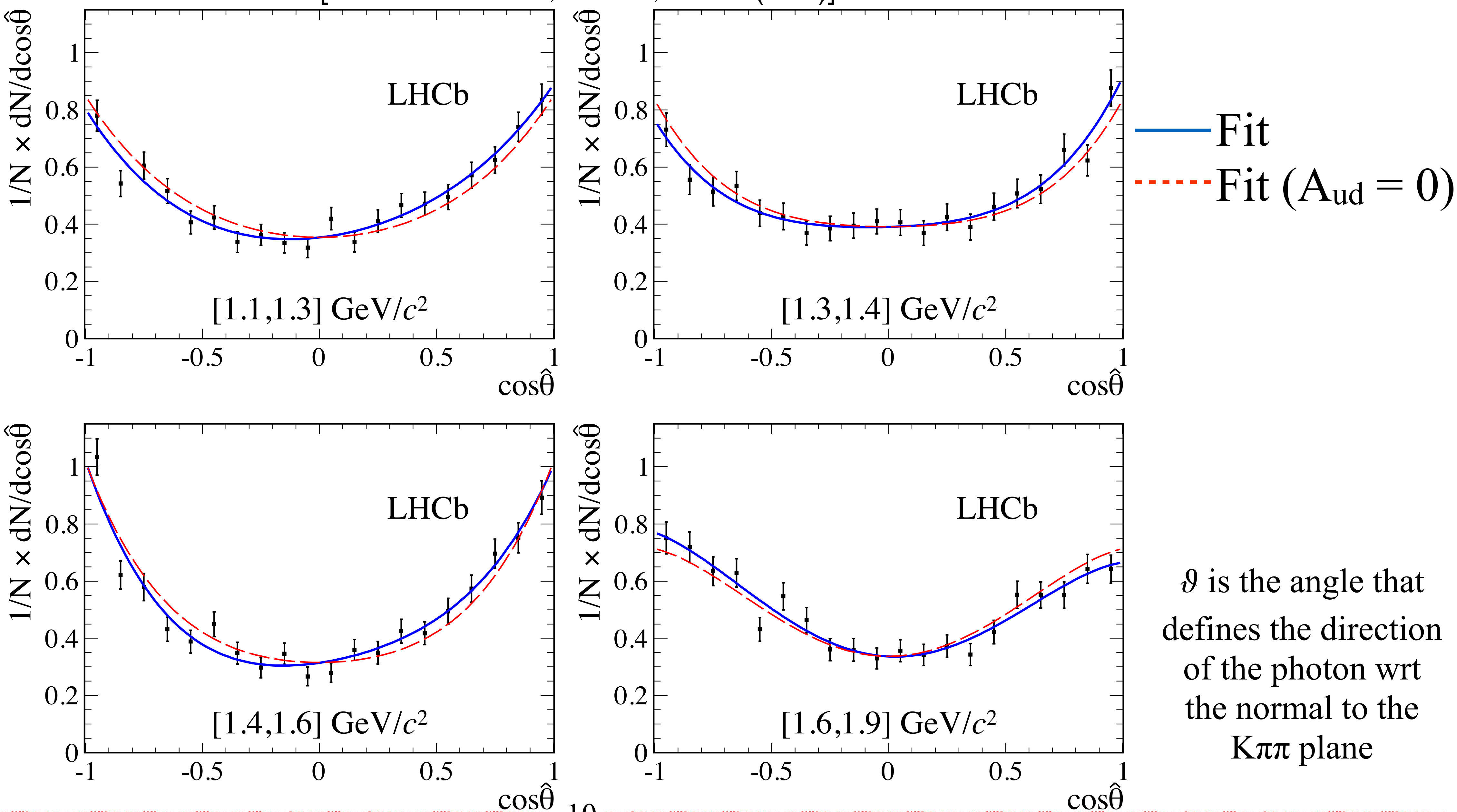


Analysis strategy & results

- Angular distribution fit
  - ✓ 4th-order function of Legendre polynomials

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

[LHCb collaboration, PRL 112, 161801 (2014)]



ϑ is the angle that defines the direction of the photon wrt the normal to the $K\pi\pi$ plane

Analysis strategy & results

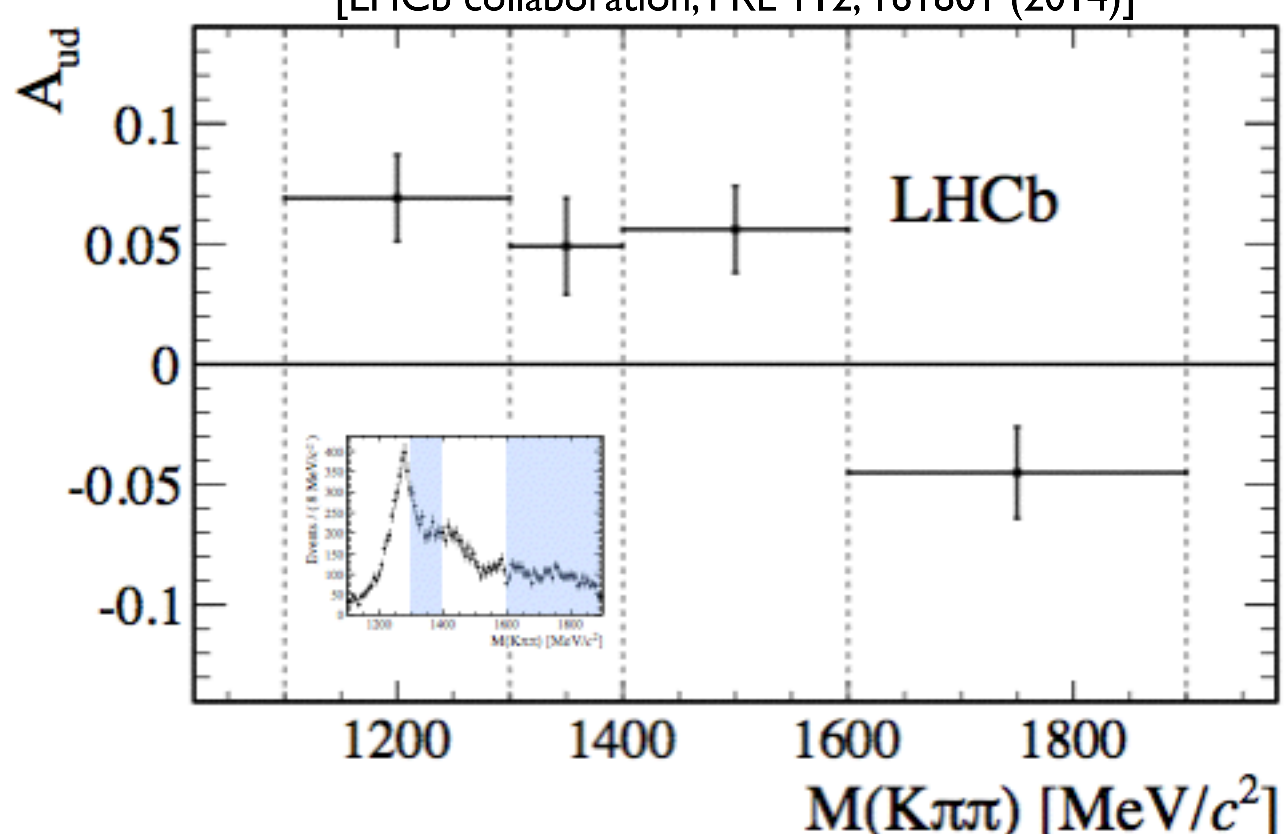
- Angular distribution fit
  - ✓ 4th-order function of Legendre polynomials

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

  - ✓ up-down asymmetries are calculated

$$\mathcal{A}_{UD} = \frac{c_1 - c_3/4}{2c_0}$$

[LHCb collaboration, PRL 112, 161801 (2014)]

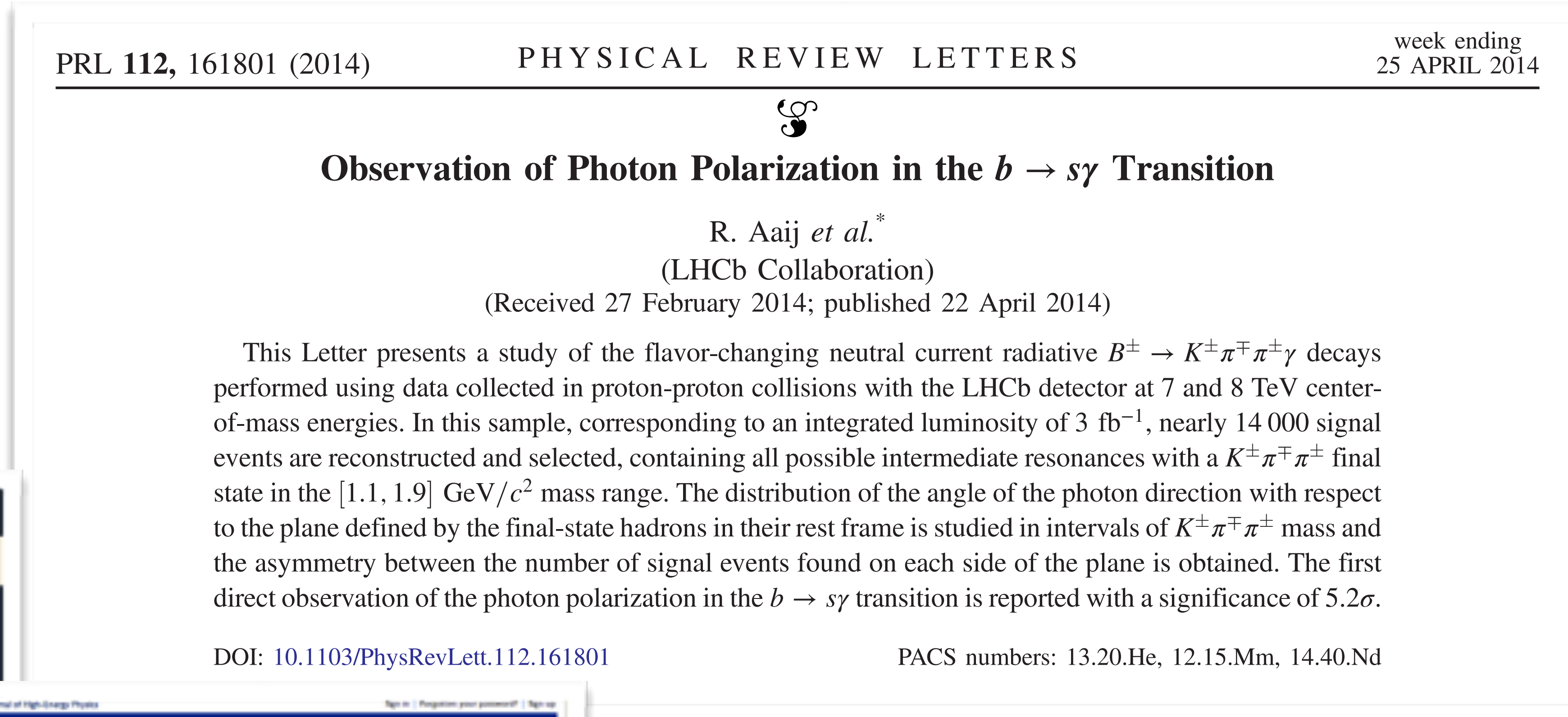


A nonzero A_{ud} is found at 5.2 σ significance level !

↓

1st observation of photon polarization in $b \to s\gamma$ transitions

- This result has renewed the interest of the scientific community on this subject



PRL **112,** 161801 (2014) PHYSICAL REVIEW LETTERS week ending 25 APRIL 2014

Observation of Photon Polarization in the $b \to s\gamma$ Transition

R. Aaij *et al.*[*]
(LHCb Collaboration)
(Received 27 February 2014; published 22 April 2014)

This Letter presents a study of the flavor-changing neutral current radiative $B^\pm \to K^\pm \pi^\mp \pi^\pm \gamma$ decays performed using data collected in proton-proton collisions with the LHCb detector at 7 and 8 TeV center-of-mass energies. In this sample, corresponding to an integrated luminosity of 3 fb^{-1}, nearly 14 000 signal events are reconstructed and selected, containing all possible intermediate resonances with a $K^\pm \pi^\mp \pi^\pm$ final state in the [1.1, 1.9] GeV$/c^2$ mass range. The distribution of the angle of the photon direction with respect to the plane defined by the final-state hadrons in their rest frame is studied in intervals of $K^\pm \pi^\mp \pi^\pm$ mass and the asymmetry between the number of signal events found on each side of the plane is obtained. The first direct observation of the photon polarization in the $b \to s\gamma$ transition is reported with a significance of 5.2σ.

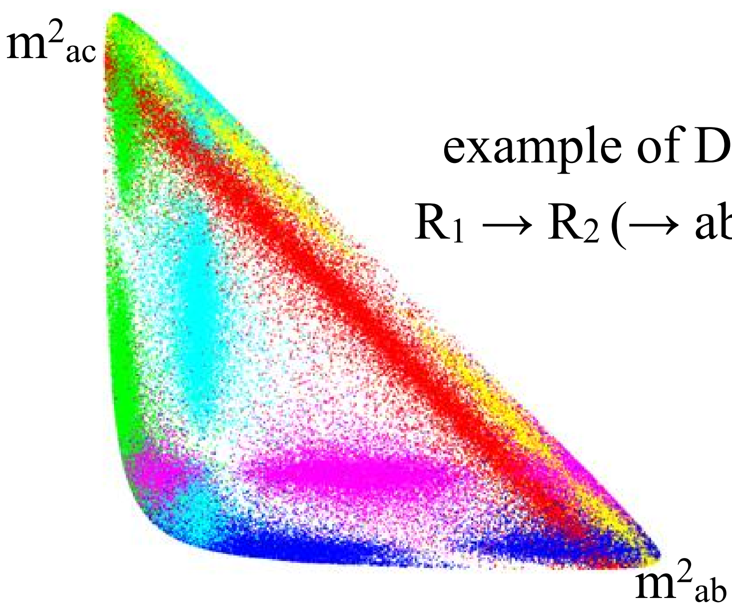
DOI: 10.1103/PhysRevLett.112.161801 PACS numbers: 13.20.He, 12.15.Mm, 14.40.Nd

Next step will be the first determination of λ_γ !

- In order to achieve the first measurement of λ_γ, a Dalitz analysis will be performed

- The mass distributions of the final ππ, Kπ and Kππ states will be exploited to build a multidimensional Dalitz plot, allowing us to study the interferences between the resonances peaking in the Kππ mass interval of interest

- Once the resonances contributions are separated, a resonance by resonance A_{ud} will be calculated



example of Dalitz plot

$R_1 \rightarrow R_2 (\rightarrow ab)\, c \rightarrow abc$

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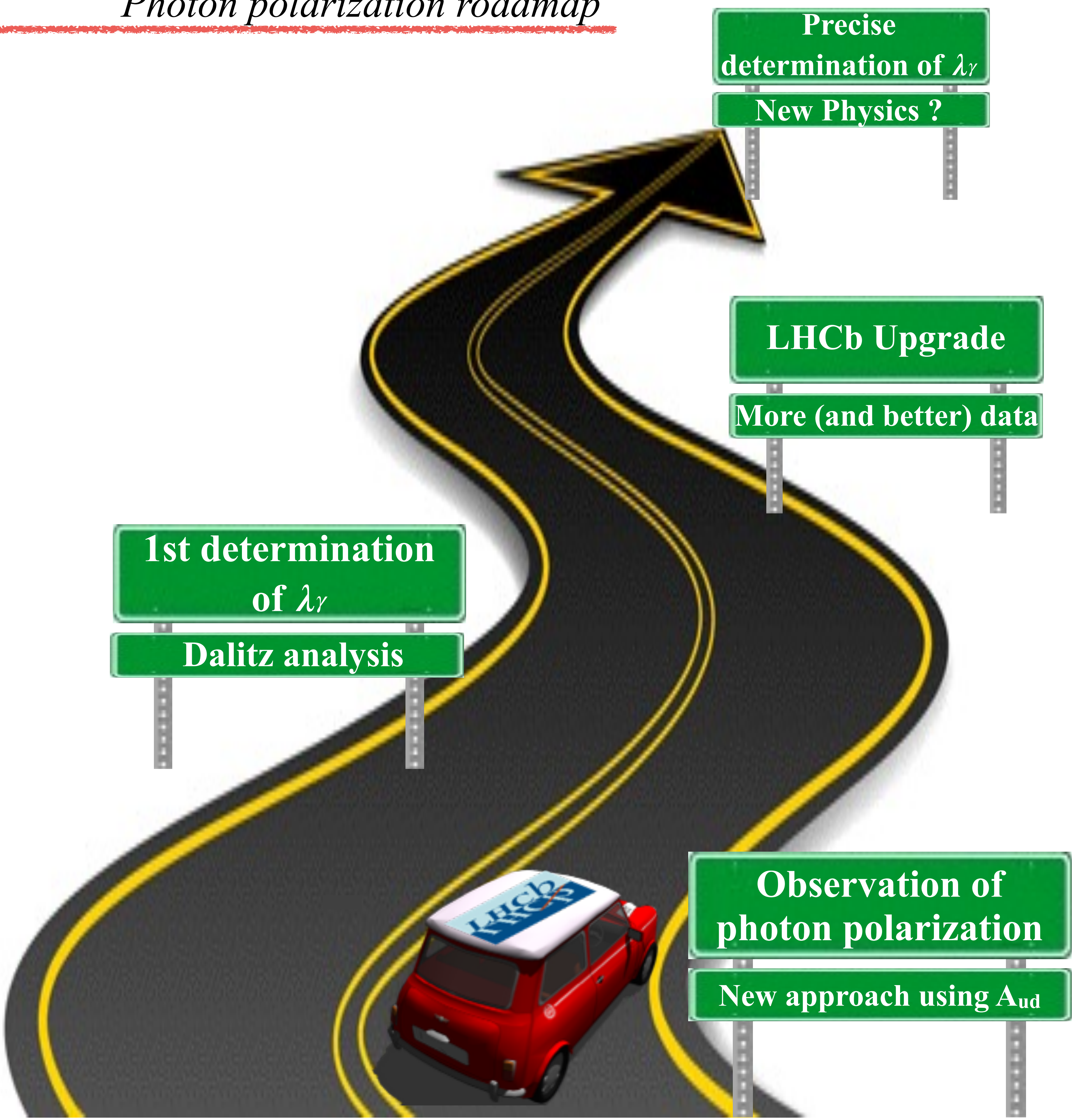
Photon polarization roadmap



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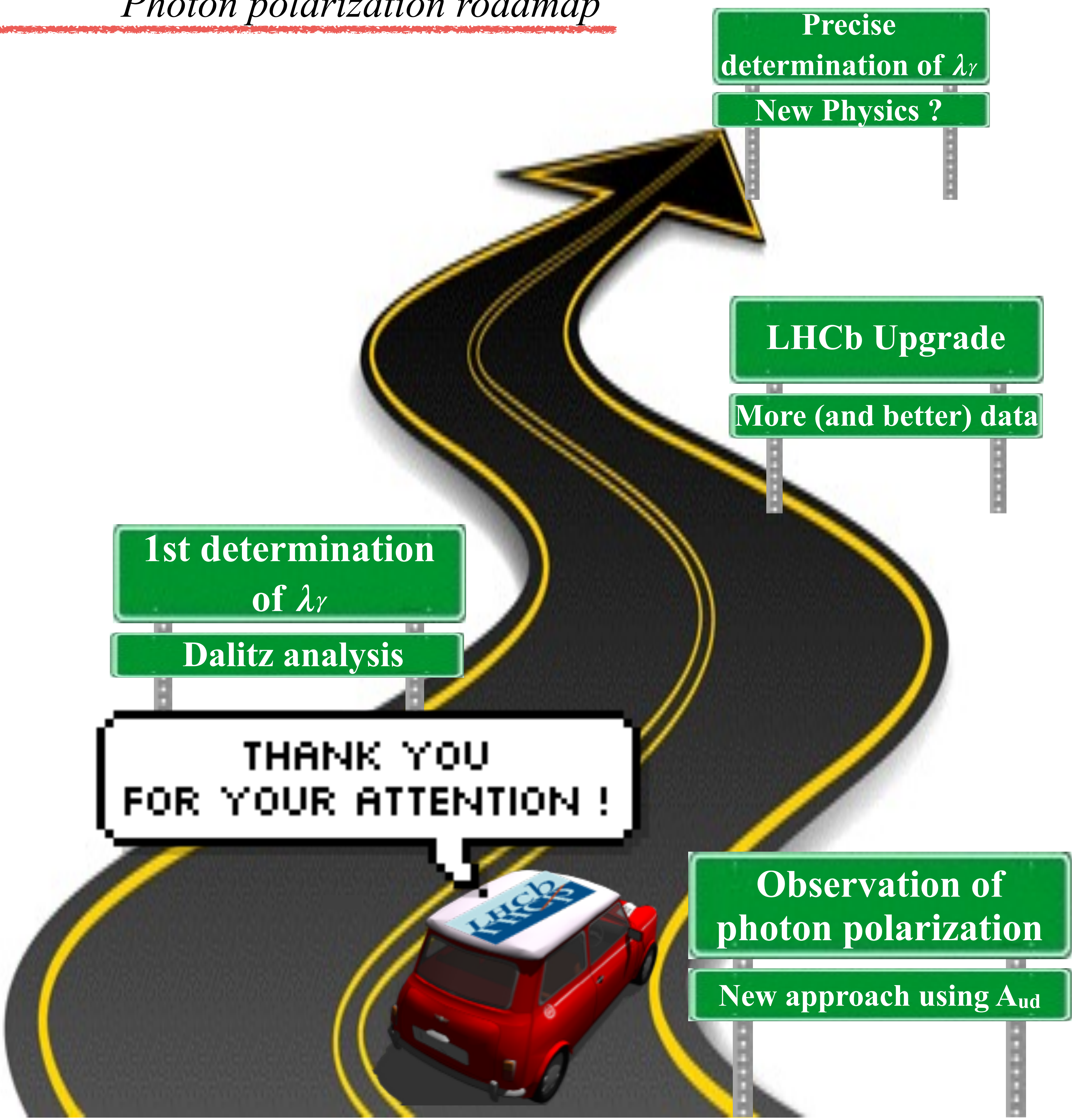
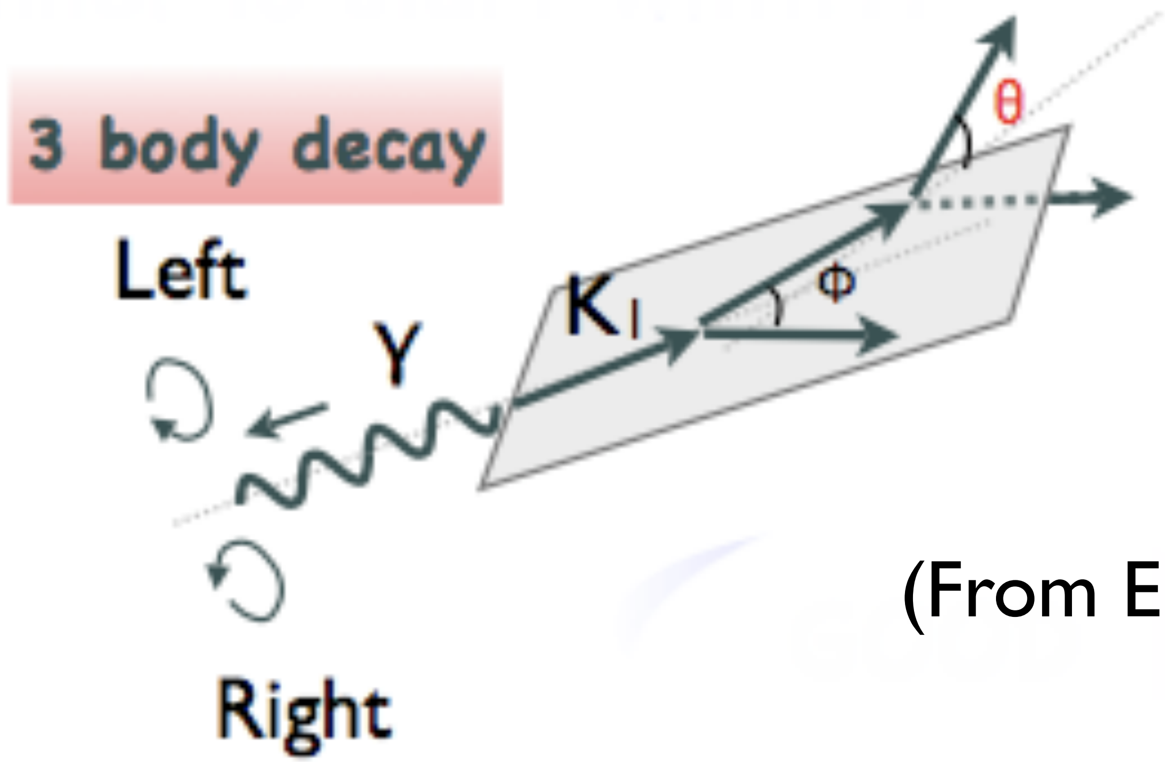


Backup

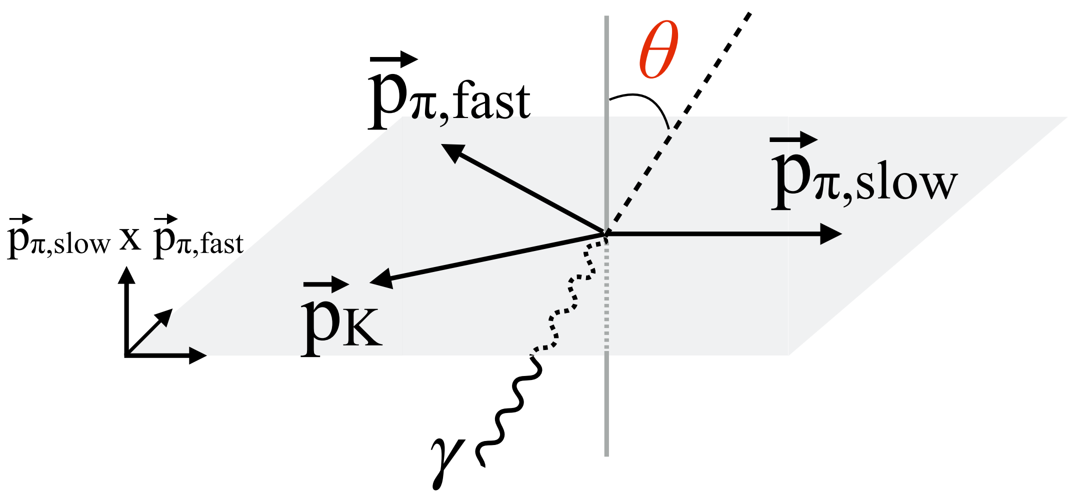
- Photon polarization can be inferred from the kinematic distribution of the *hhh* three-body decay



(From E.Kou)

- It requires three bodies to form a parity-odd triple product $\vec{p}_\gamma \cdot (\vec{p}_1 \times \vec{p}_2)$
- The sign of the triple product identifies the photon polarization

- The photon angle ϑ is defined as the angle between $-\mathbf{p}_\gamma$ and the normal to the plane defined by $\mathbf{p}_{\mathbf{slow}} \times \mathbf{p}_{\mathbf{fast}}$



- A loose preselection is applied after the Stripping selection

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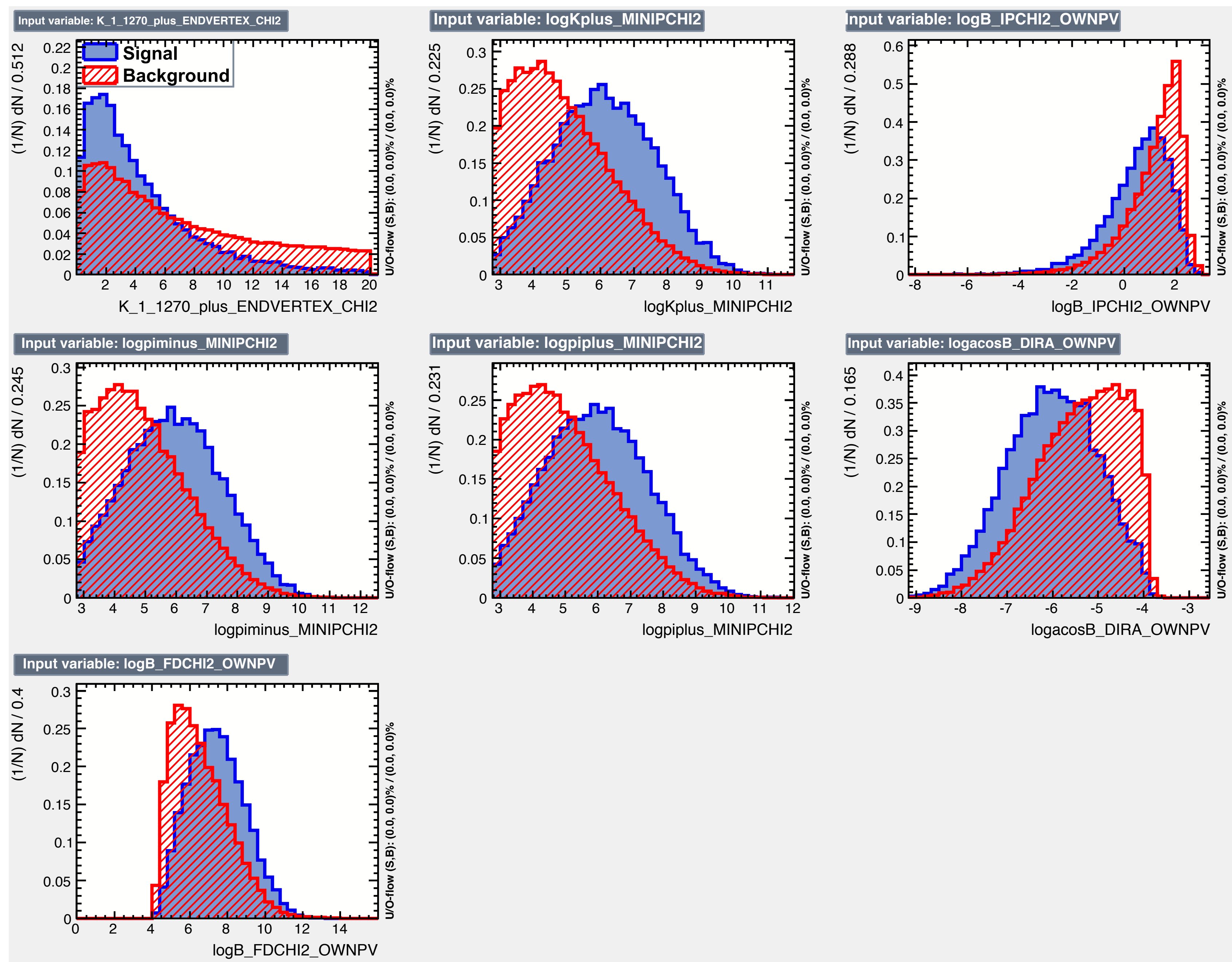
Fiducial cut on $\|p_x\|$	$\leq 0.317(p_z - 2400)$	MeV/c

- A multivariate approach is used to discriminate between signal and background

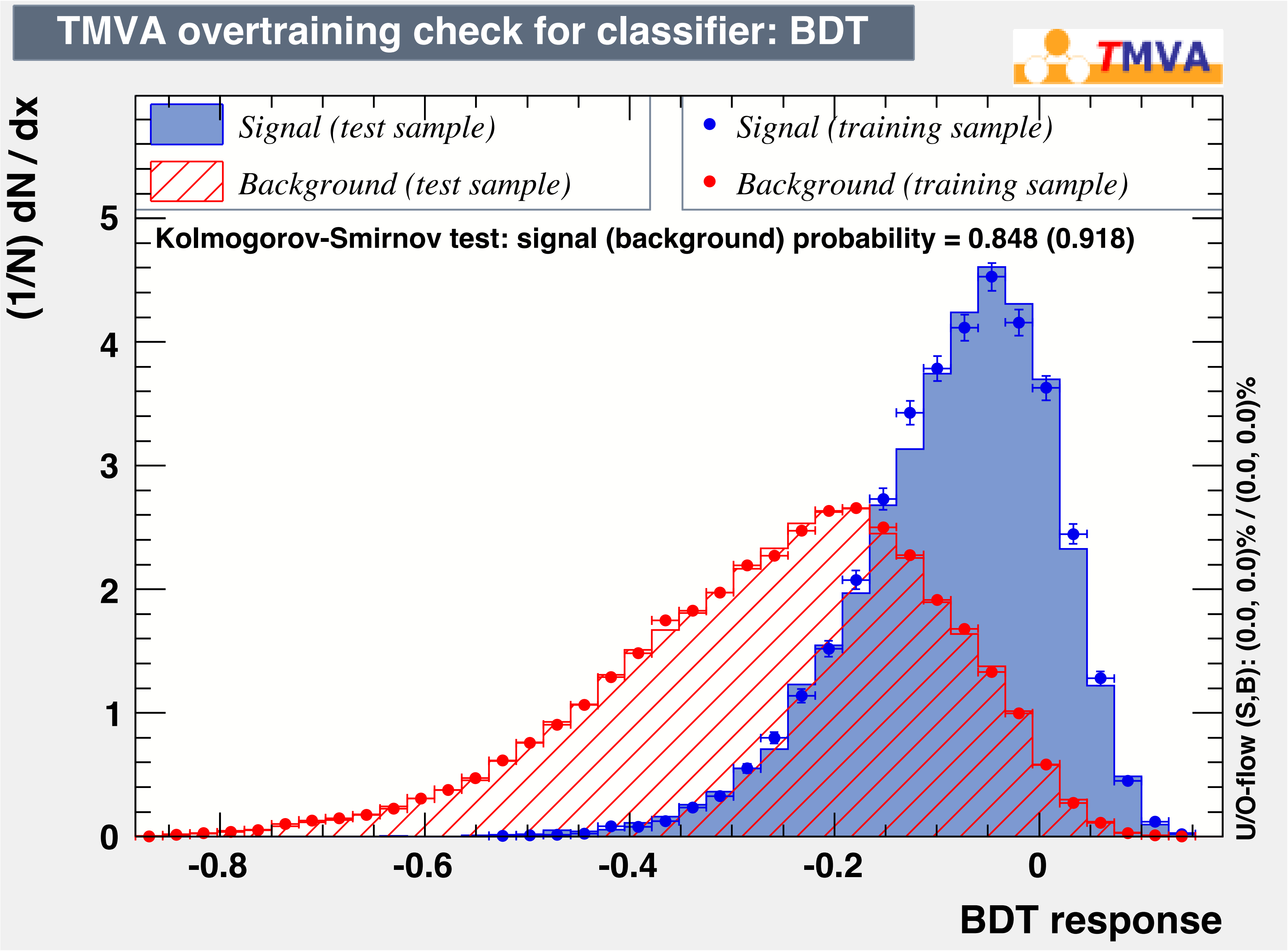
- A Boosted Decision Tree (BDT) is used

  - Background (data sidebands) and signal (MC) for our BDT variables

  - variables that may be not well described by MC have not been added in the BDT (pre-selection)



- BDT performance
  - response and overtraining



  - signal/background optimization gives BDT response >~ -0.18

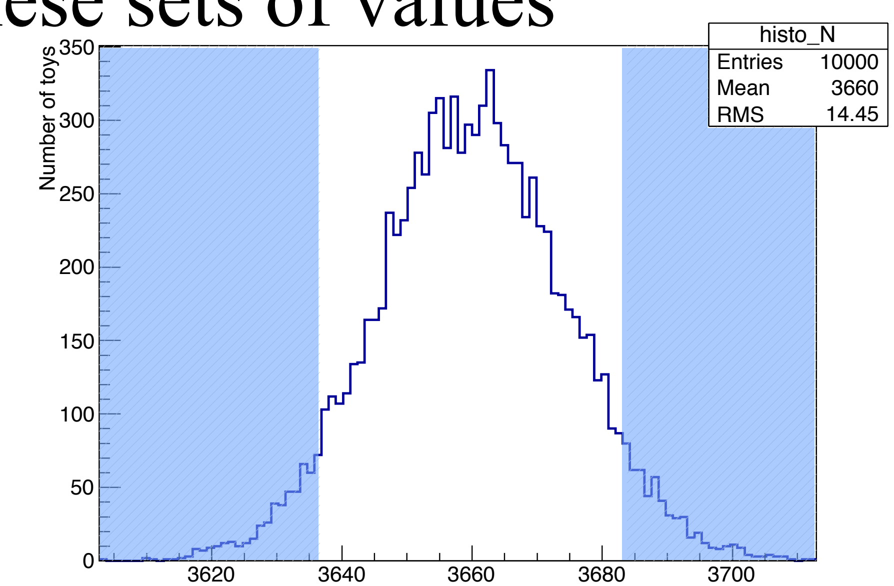
Analysis strategy & results

- Angular distribution fit

✓ the fit parameters c_i are determined

	$[1.1, 1.3]$	$[1.3, 1.4]$	$[1.4, 1.6]$	$[1.6, 1.9]$	GeV/c^2
c_1	6.3 ± 1.7	5.4 ± 2.0	4.3 ± 1.9	-4.6 ± 1.8	x 10^{-2}
c_2	31.6 ± 2.2	27.0 ± 2.6	43.1 ± 2.3	28.0 ± 2.3	x 10^{-2}
c_3	-2.1 ± 2.6	2.0 ± 3.1	-5.2 ± 2.8	-0.6 ± 2.7	x 10^{-2}
c_4	3.0 ± 3.0	6.8 ± 3.6	8.1 ± 3.1	-6.2 ± 3.2	x 10^{-2}
$\mathcal{A}_{\rm ud}$	6.9 ± 1.7	4.9 ± 2.0	5.6 ± 1.8	-4.5 ± 1.9	x 10^{-2}

- The systematical uncertainties are given by
  - the choice of the fit model
    - different shapes are used to describe signal and bkg
    - the error is assigned as the difference between the results of the nominal fit and the systematics one
  - fixing parameters from simulation
    - the parameters fixed from simulation are generated gaussianly around the nominal fit value accounting for their correlations
    - the fit is performed many times using these sets of values
    - the uncertainty is obtained using the central interval criterion at 90% CL



- The systematical uncertainties are given by
  - bin migration
    - some events may migrate from one bin to the next one because of the detector resolution
    - pseudo-experiments are generated according to the distribution, then smeared with the resolution
    - the bin-by-bin differences in yield between the smeared and non-smeared datasets are used to describe the covariance matrix for such systematics