2013 European Physical Society Conference on High Energy Physics (18-24 July)

Radiative *B* decays in LHCb

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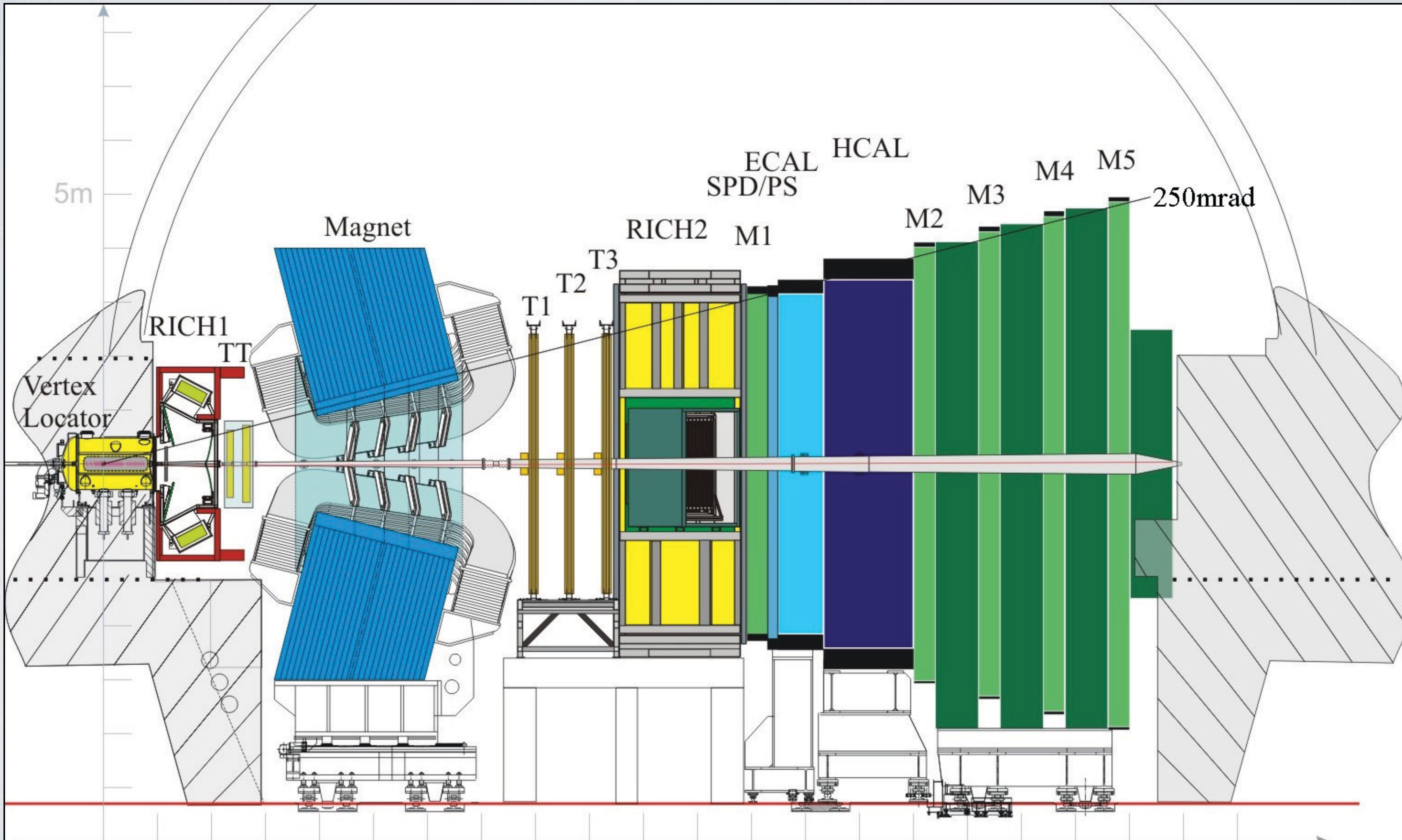
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

The LHCb experiment

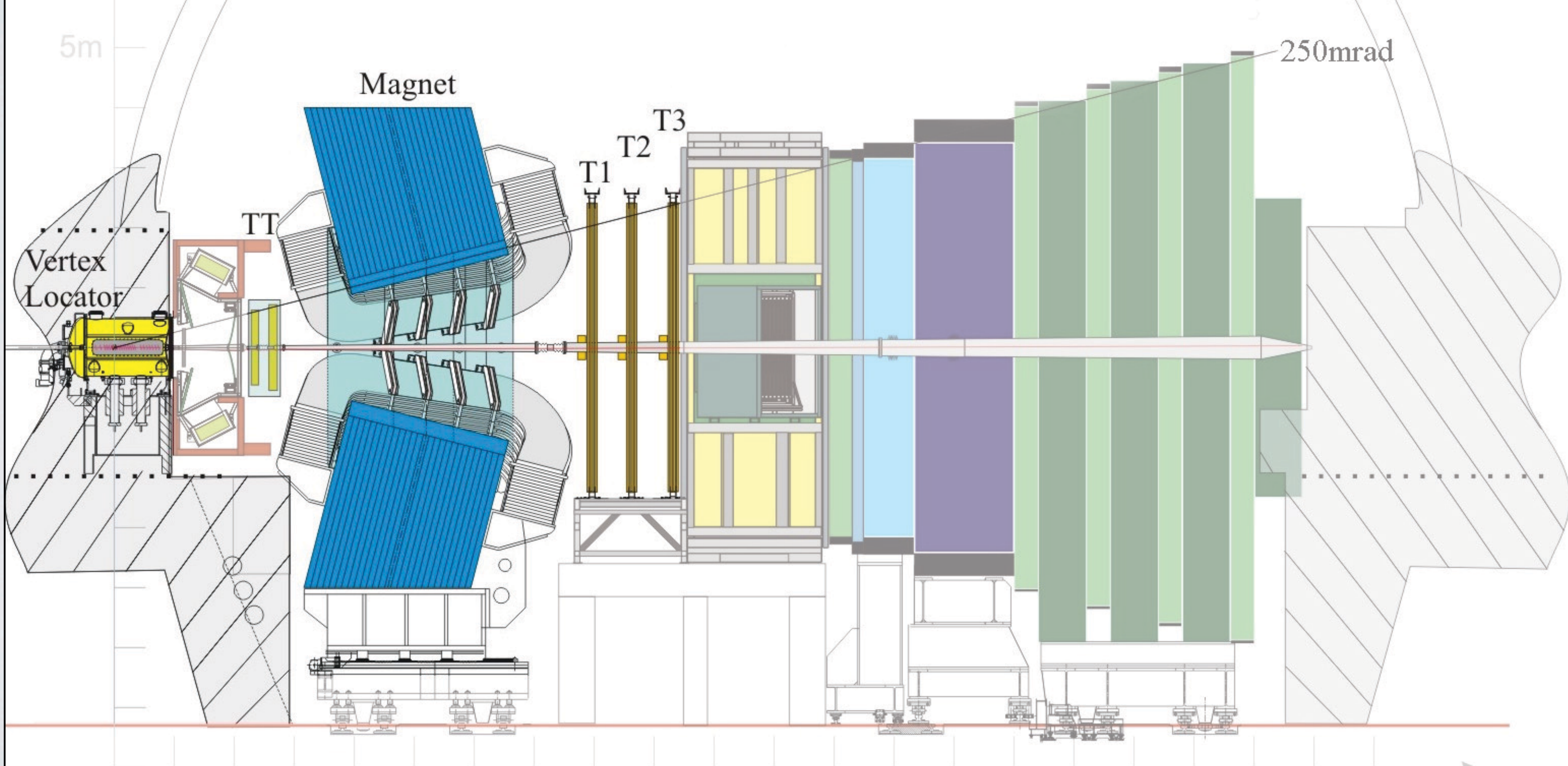


The LHCb experiment

Precise tracking

Good mass and IP resolution

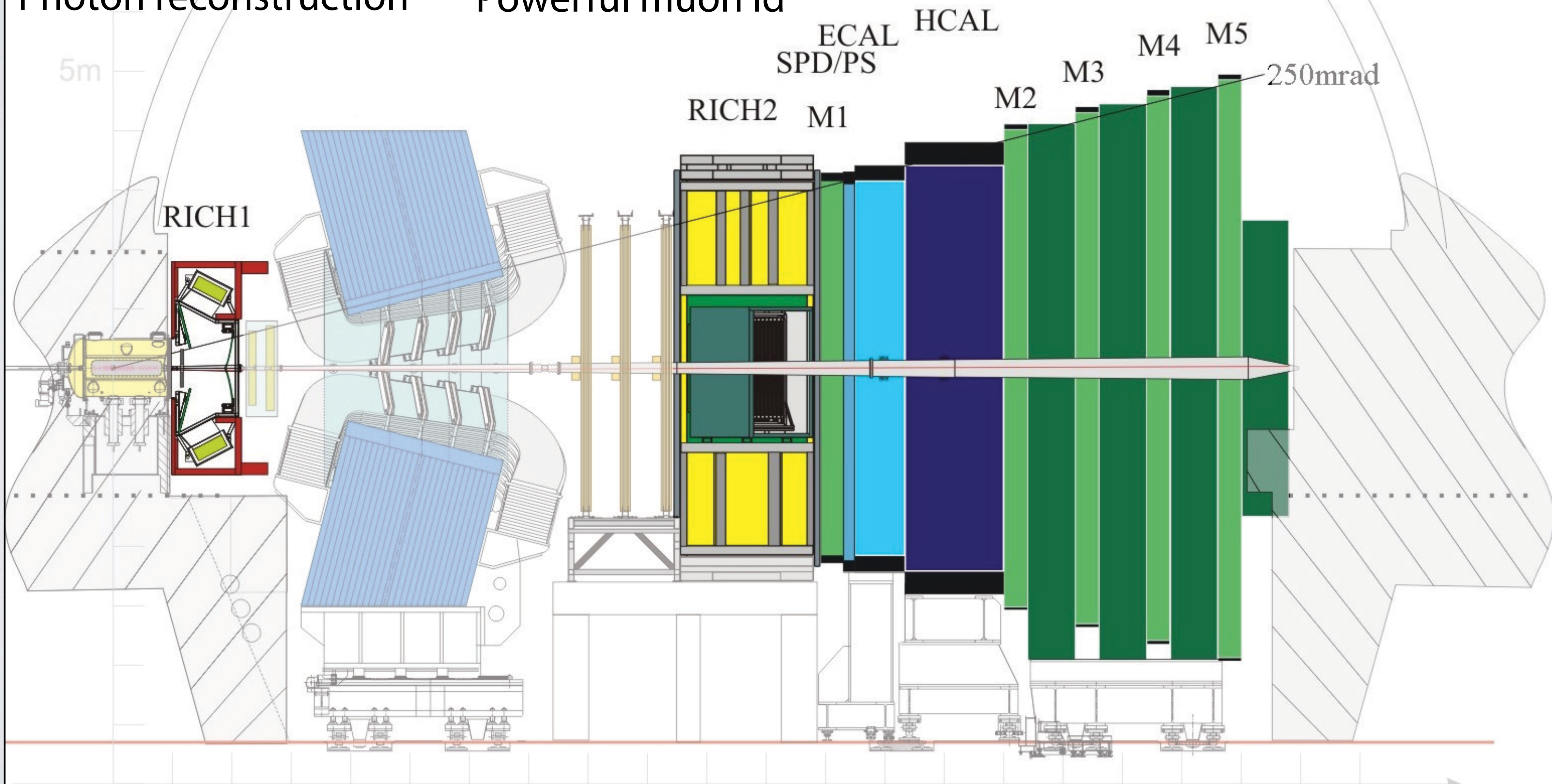
Good vertex resolution



The LHCb experiment

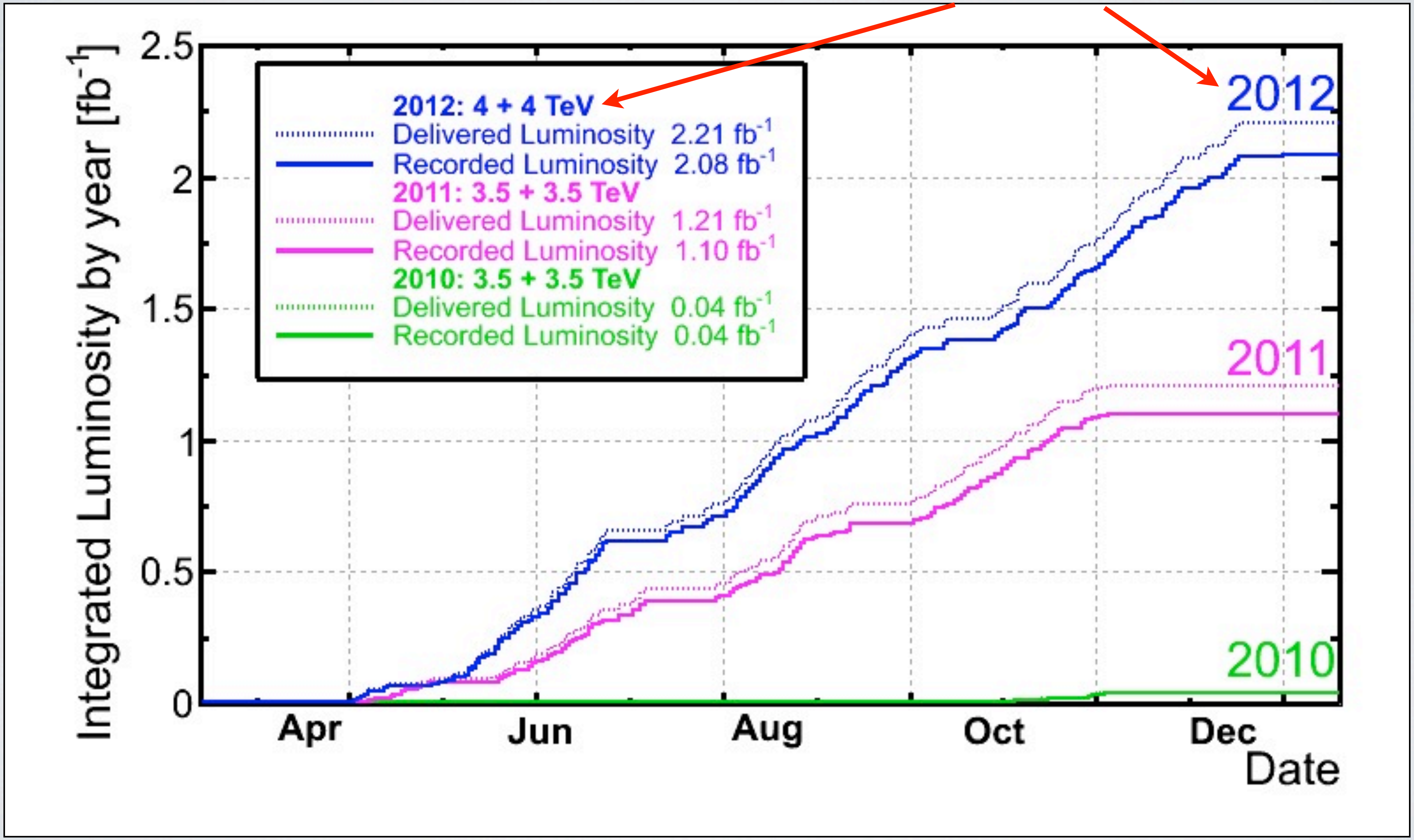
Calorimeter system
Trigger
Photon reconstruction

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



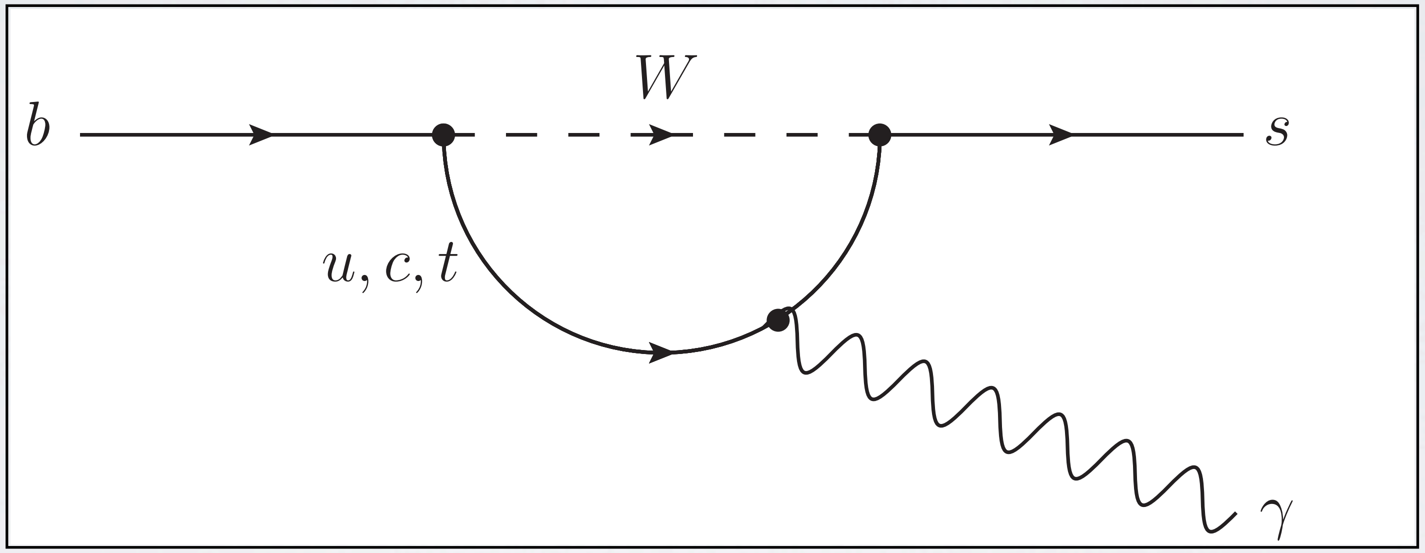
LHCb Run-I summary

This talk



Radiative *B* decays

- In the SM, effective FCNC are introduced by penguin (1-loop) diagrams, so they are a sensitive probe to new physics



- Radiative decays have a distinct experimental signature with a high E_T photon in the final state
  - Large levels of background are expected in a *pp* machine

Photon polarization

- In the SM, the photon from $b \to s\gamma$ decays is predominantly left handed.

$$|A(B \to K_{\rm res}\gamma \to P_1 P_2 P_3 \gamma)|^2 = |c_{\rm R}|^2 |\mathcal{M}_{\rm R}|^2 + |c_{\rm L}|^2 |\mathcal{M}_{\rm L}|^2$$

- **Photon polarization** is defined as

$$\lambda_\gamma \equiv \frac{|c_{\rm R}|^2 - |c_{\rm L}|^2}{|c_{\rm R}|^2 + |c_{\rm L}|^2}$$

$B \to K_{\rm res}\gamma_{\rm L,R}$ amplitudes

so λ_γ=-1 for B^- decays and +1 for B^+ decays

Kou et al, PRD83 (2011) 094007

Gronau et al, PRL88 (2002) 051802

$B \to K_{res}\gamma \to P_1P_2P_3\gamma$

- 3-body + photon decays allow to study photon polarization through the daughters of the kaon resonance
- For a given intermediate resonance, the differential decay rate depends on helicity amplitude J_μ and the photon direction θ

$$\frac{d\Gamma(B \to K_{res}\gamma \to P_1P_2P_3\gamma)}{ds\,ds_{13}\,ds_{23}\,d\cos\theta} \propto |\vec{\mathcal{J}}|^2(1+\cos^2\theta) + \lambda_\gamma\, 2\,\mathrm{Im}\left[\vec{n}\cdot(\vec{\mathcal{J}}\times\vec{\mathcal{J}}^*)\right]\cos\theta$$

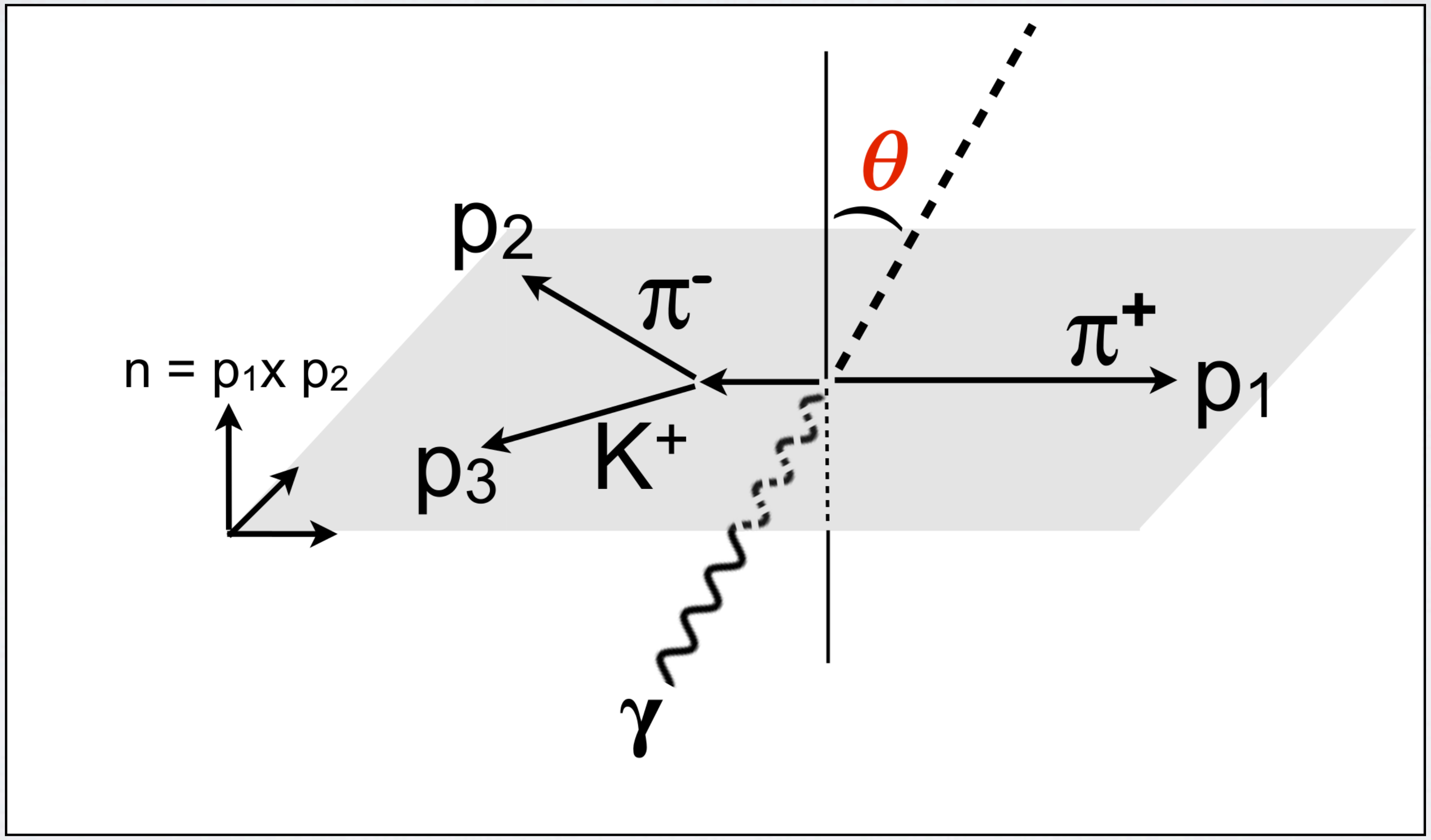
but for multiple resonances (up to spin 2)

$$\frac{d\Gamma(\sum B \to K_{res,i}\gamma \to P_1P_2P_3\gamma)}{ds\,ds_{13}\,ds_{23}\,d\cos\theta} \propto \sum_{j=0,\mathrm{even}}^{4} a_j(s_{13},s_{23})\cos^j\theta + \sum_{j=1,\mathrm{odd}}^{3} \lambda_\gamma\, a_j(s_{13},s_{23})\cos^j\theta$$

Gronau et al, PRL88 (2002) 051802

Definition of θ

$$\cos\theta \equiv -\frac{\vec{p}_\gamma}{|\vec{p}_\gamma|}\cdot\hat{n} \qquad \hat{n} \equiv \frac{\vec{p}_1 \times \vec{p}_2}{|\vec{p}_1 \times \vec{p}_2|}$$



Gronau et al, PRL88 (2002) 051802

Up-down asymmetry

- Up down asymmetry is defined as

single resonance

$$\mathcal{A}_{\mathrm{UD}} \equiv \frac{\int_0^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta} - \int_{-1}^0 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}}{\int_{-1}^1 \mathrm{d}\cos\theta \frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta}} = \frac{3}{4}\lambda_\gamma \frac{\int \mathrm{d}s\mathrm{d}s_{13}\mathrm{d}s_{23} \mathrm{Im}\left[\vec{n}\cdot(\vec{\mathcal{J}}\times\vec{\mathcal{J}}^*)\right]}{\int \mathrm{d}s\mathrm{d}s_{13}\mathrm{d}s_{23}|\mathcal{J}|^2}$$

  - Up-down asymmetry is proportional to λ_γ
  - If J is known, the up-down asymmetry would allow to compute the photon polarization λ_γ

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$B \to K\pi\pi\gamma$ at LHCb

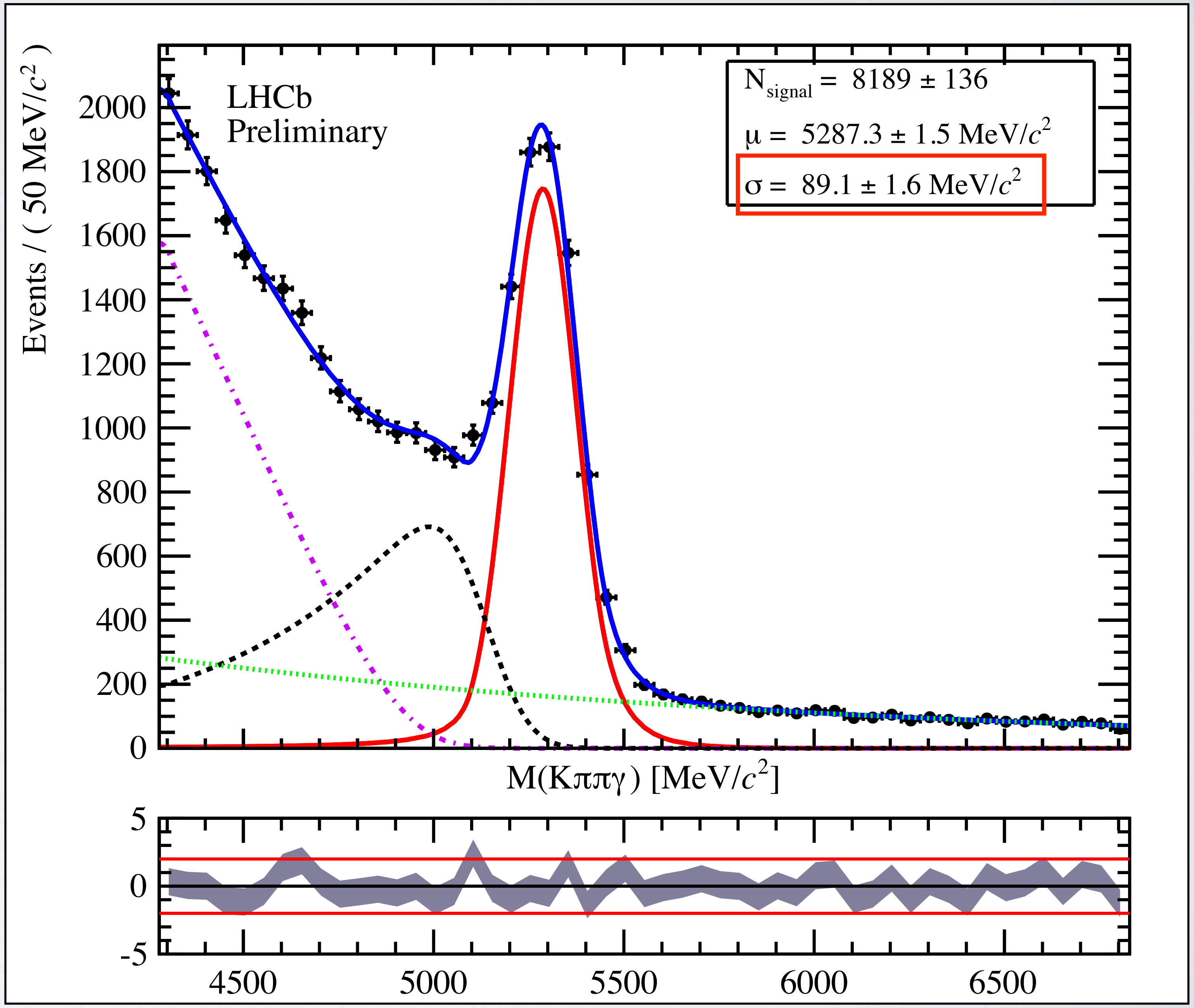
- Aim is to extract inclusive *CP* and up-down asymmetries
  - *CP* asymmetry extracted from a simultaneous unbinned maximum likelihood fit in the the [1.1,1.9] GeV $K\pi\pi$ invariant mass range
  - Up-down asymmetry extracted from a simultaneous unbinned maximum likelihood fit in a selected $K\pi\pi$ invariant mass region
- Since measurement is inclusive, up-down asymmetry cannot be converted to photon polarization,

$$\mathcal{A}_{\mathrm{UD}} \propto \lambda_\gamma$$

so significance with respect to no-polarization is extracted

Mass fit

- Fit components
  - Signal
  - Combinatorial
  - Missing π
  - Partially reconstructed
- Fit $\chi^2/\mathrm{ndf} = 0.84$



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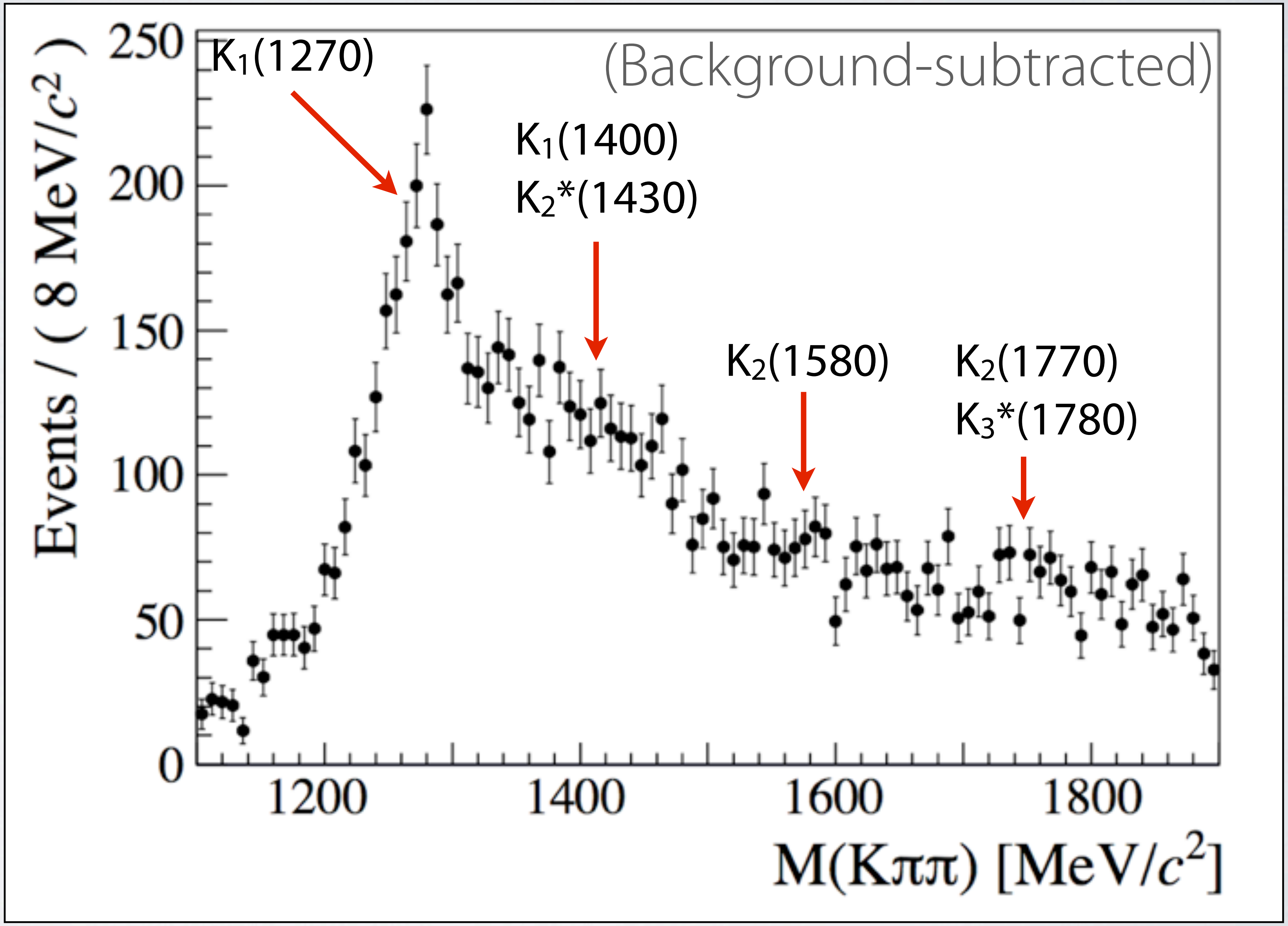
Kππ mass spectrum

- Can't isolate individual components without amplitude analysis
  - Asymmetry measurements need to be inclusive



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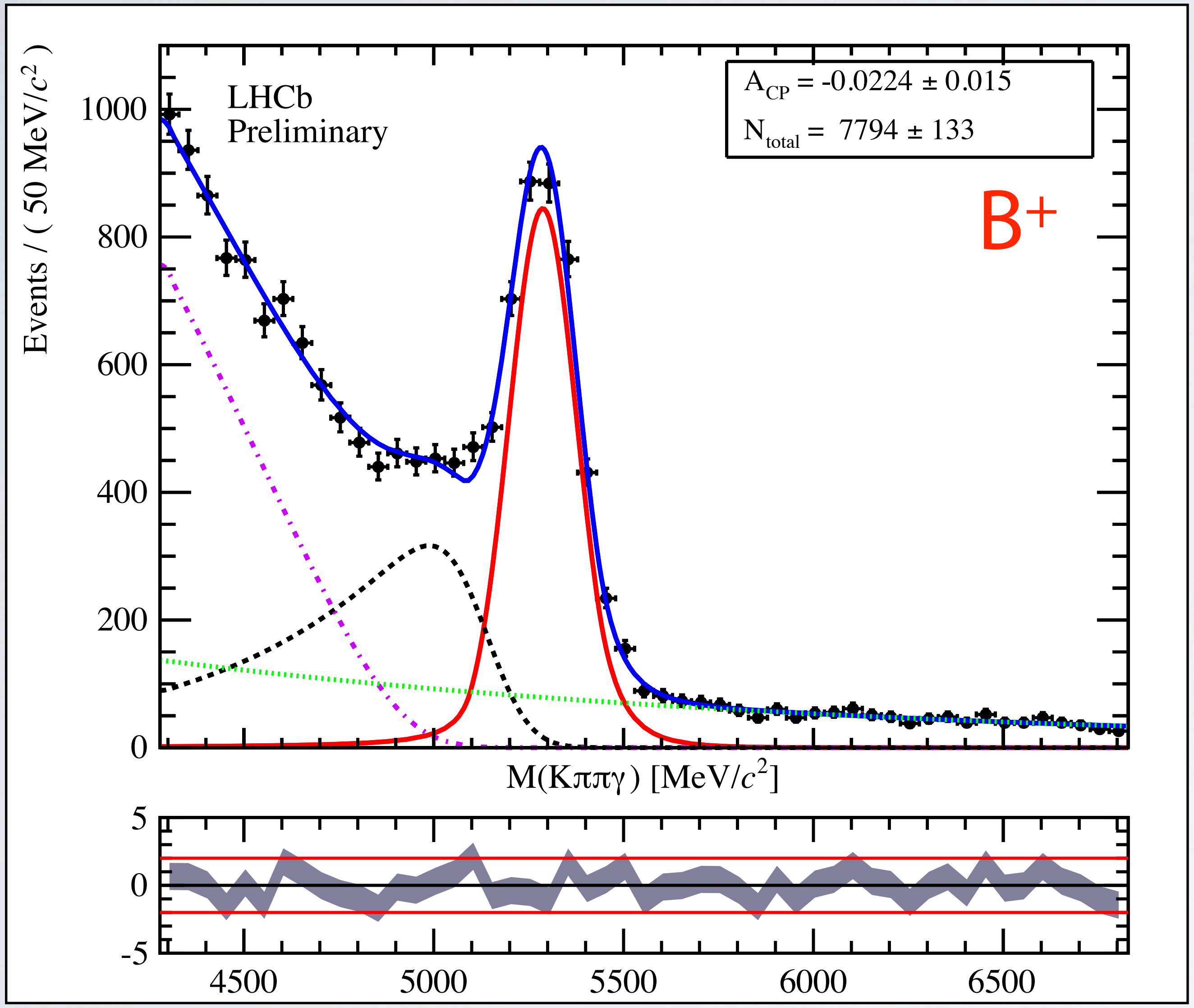
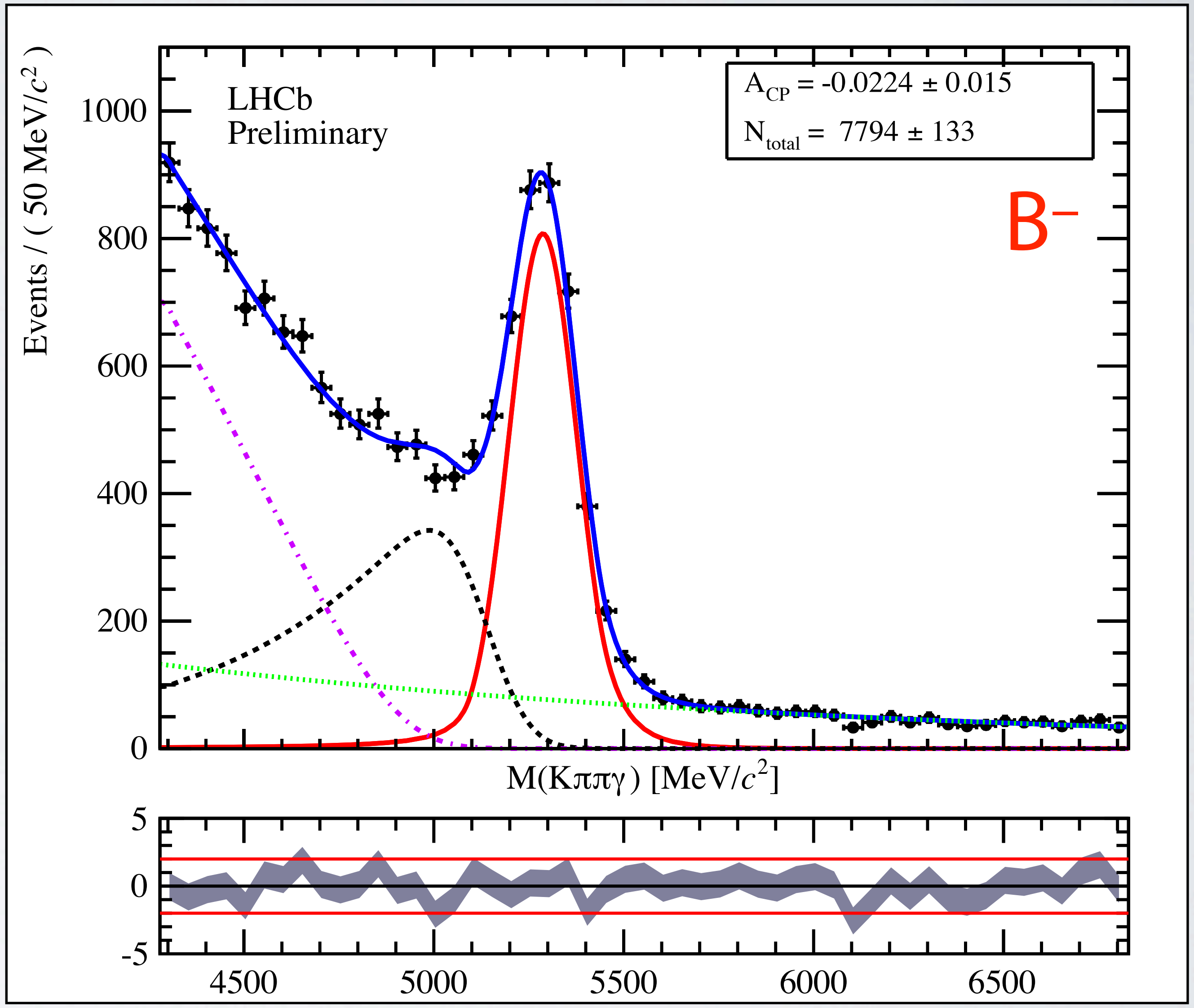
A_{CP} fit result





$$\mathcal{A}_{CP}^{raw} = -0.022 \pm 0.015$$

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Extracting A_{CP}

- The raw A_{CP} obtained from the fit is corrected to obtain the physical *CP* asymmetry
  - Charged B meson production asymmetry
  - Particle interaction with matter (cross-section) asymmetry (K^+ vs K^-)
  - Geometrical detection asymmetries
- Corrections are extracted from control channels and from data corresponding to different magnet polarities

Gronau et al, PRL88 (2002) 051802

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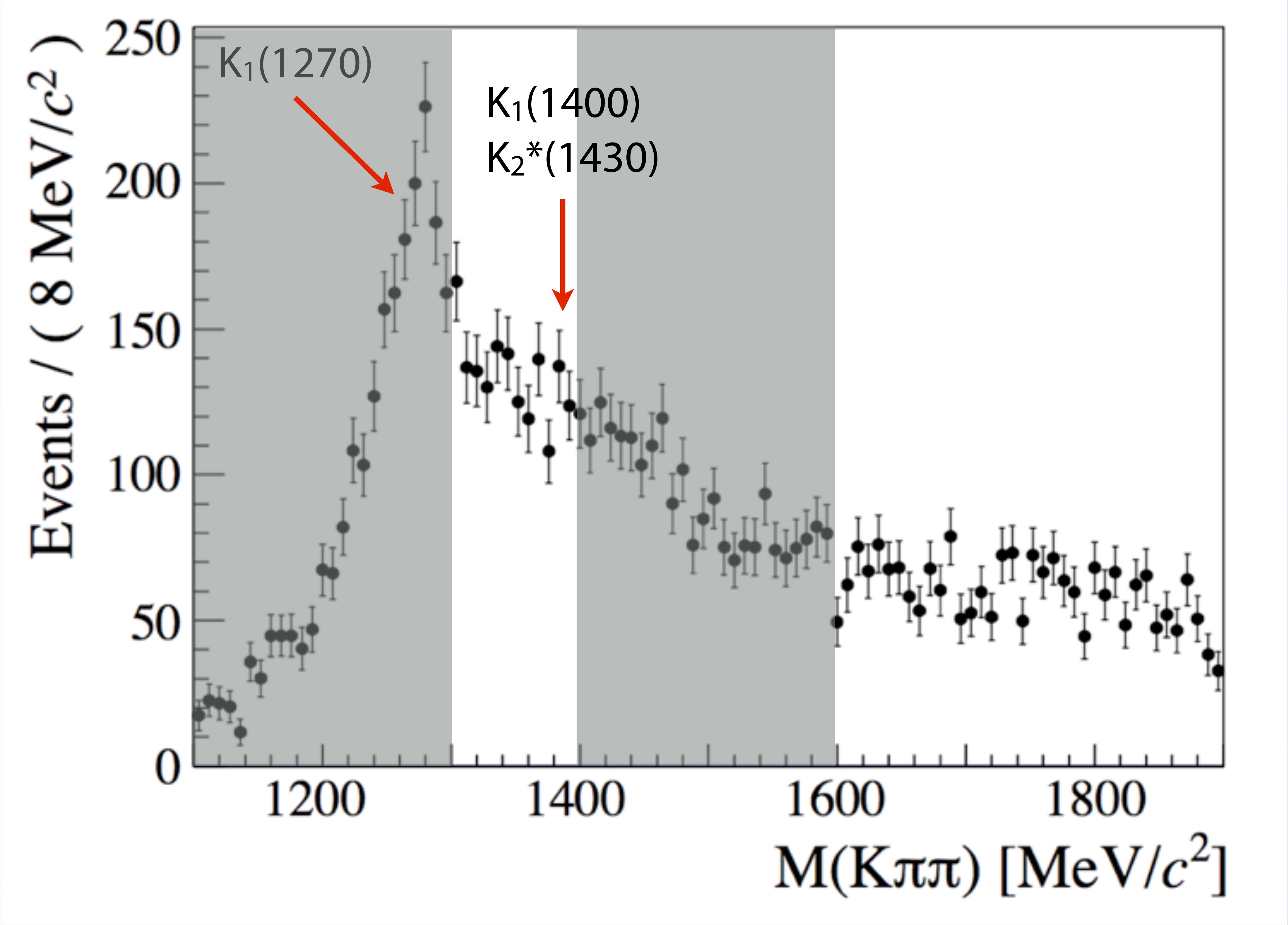
Up-down asymmetry fit range



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Up-down asymmetry formalism

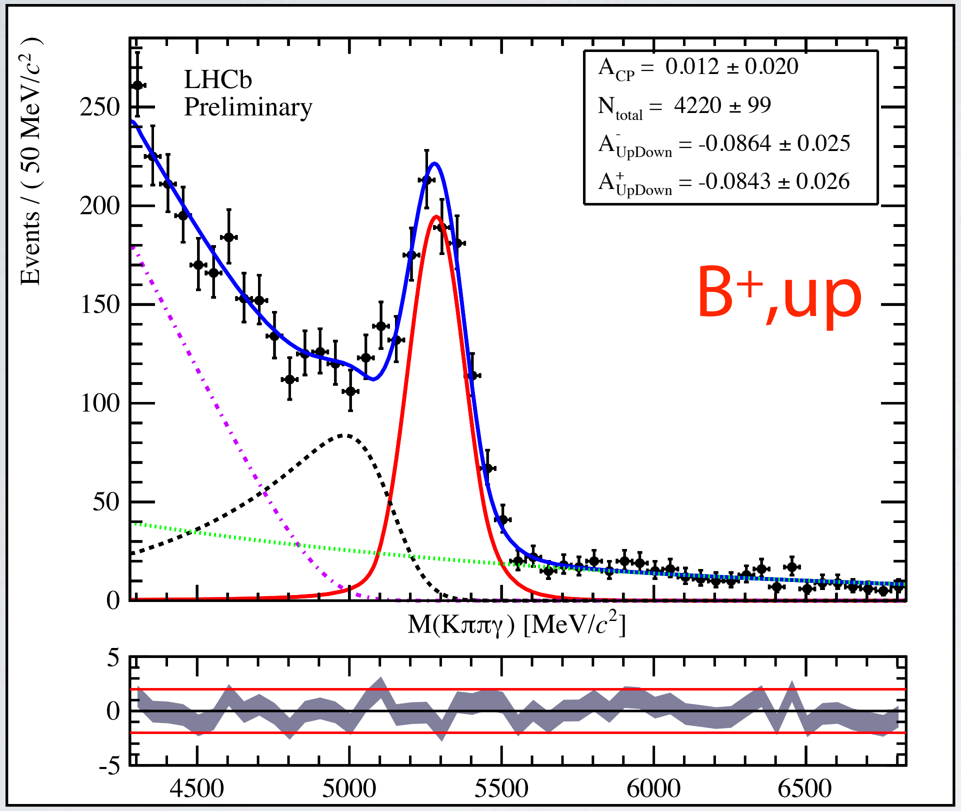
- The up down asymmetry for each charge of the *B* meson is defined as

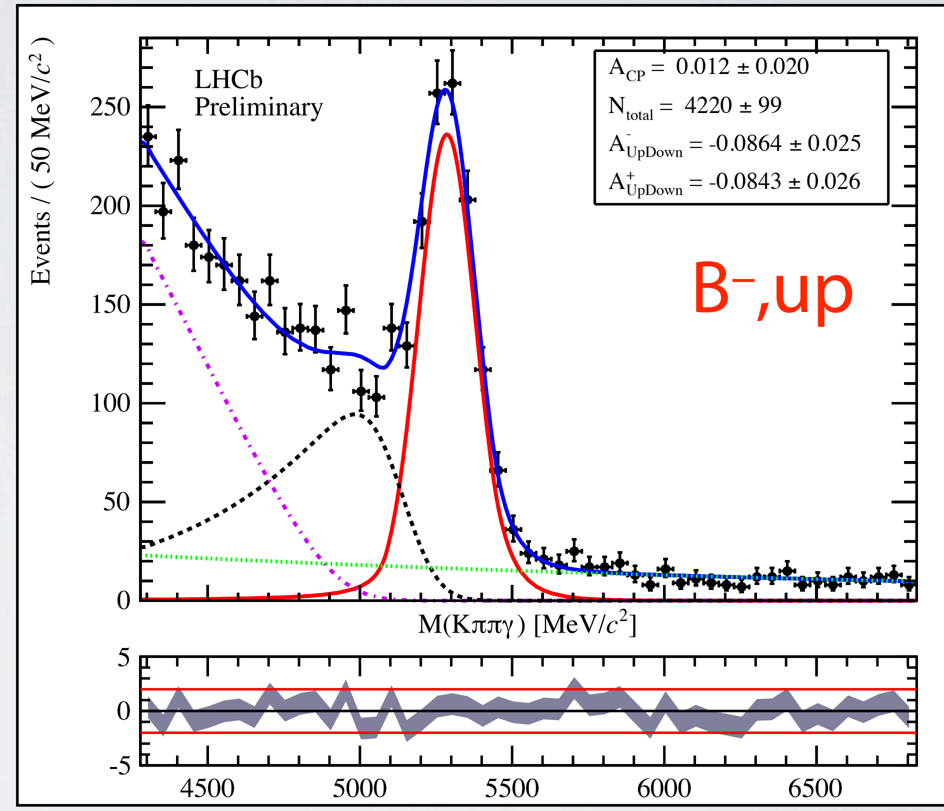
$$\mathcal{A}_{\text{UD}}^{\pm} = \pm \frac{U^{\pm} - D^{\pm}}{U^{\pm} + D^{\pm}}$$

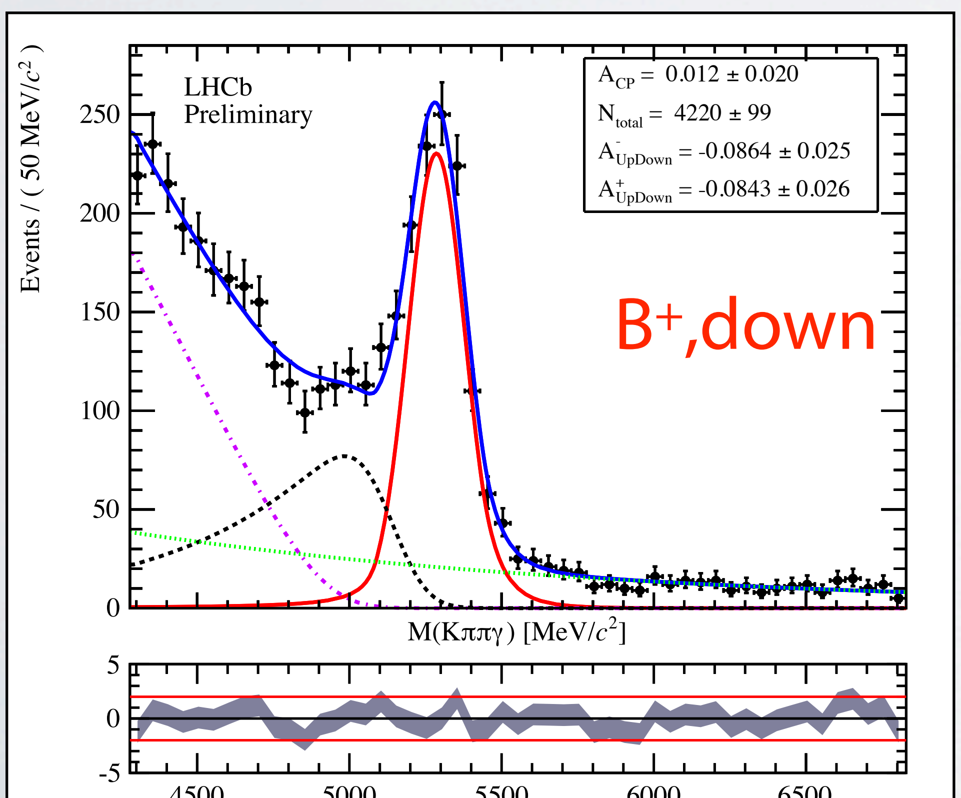
so both asymmetries have the same sign (NB: photon polarization changes sign with *b* quark)

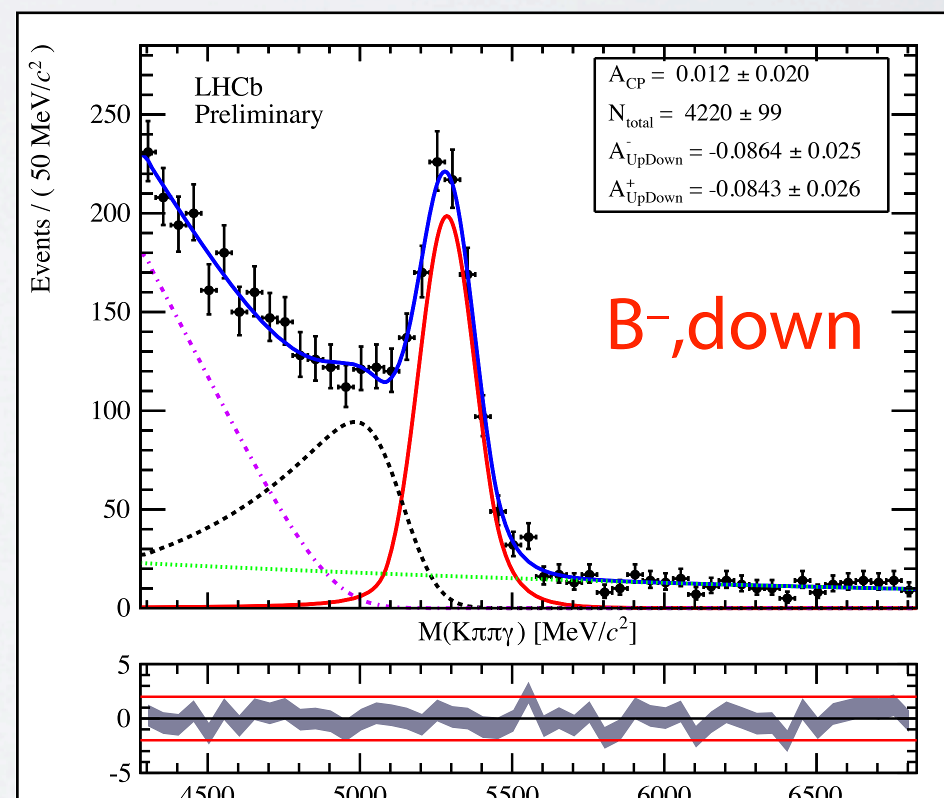
- In addition, raw A_{CP} is also fitted in this range

Up-down asymmetry fit result









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Up-down asymmetry result

- The up down asymmetry for each charge is found to be

$$\mathcal{A}_{\mathrm{UD}}^{+} = -0.084 \pm 0.026\,(\mathrm{stat})\ {}^{+0.004}_{-0.003}\,(\mathrm{syst})$$
$$\mathcal{A}_{\mathrm{UD}}^{-} = -0.086 \pm 0.025\,(\mathrm{stat}) \pm 0.002\,(\mathrm{syst})$$

with significances s^{+}=3.2σ and s^{-}=3.4σ

- Raw A_{CP} found compatible with previous result in the full $K\pi\pi$ mass range

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Results and conclusions (I)

- $B^+ \to K^+\pi^-\pi^+\gamma$ has been observed in the [1100,1900] $K\pi\pi$ mass range

$$N = 8189 \pm 140\,(\text{stat.})\,^{+450}_{-390}\,(\text{syst.})\ \text{events}$$

- CP asymmetry (consistent with 0) has been measured for the first time in $B^+ \to K^+\pi^-\pi^+\gamma$

$$\mathcal{A}_{CP} = -0.007 \pm 0.015\,(\text{stat.}) \pm 0.008\,(\text{syst.})$$

Results and conclusions (II)

- Since A^+ and A^- are independent measurements of the same quantity, the are combined to obtain

$$\mathcal{A}_{\mathrm{ud}} = -0.085 \pm 0.019\,(\mathrm{stat}) \pm 0.003\,(\mathrm{syst})$$

and for the first time evidence of photon polarization in $b \to s\gamma$ has been measured, with significance of 4.6σ

- Input from theory is needed to translate this result into a value of the photon polarization λ_γ

Thank you

Measuring photon polarization

- In order to measure photon polarization, *J* needs more than one amplitude with relative phase, *i.e.*, interference:
  - Interference between intermediate resonance amplitudes, eg, $K_1(1270)$ through $K^*\pi$ and through ρK
  - Interference between *S* and *D* wave
  - Interference between two $K^*\pi$ states with different charges, eg, $K_1(1270)^0$ through $K^{*0}\pi^0$ and $K^{*+}\pi^-$

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Backgrounds

× Combinatorial (exponential)

× Partially reconstructed background (Argus ⊗ Gaussian)

- Missing π, $B\to K\pi\pi\eta(\to\gamma\gamma)$ (negligible) and general partial.

✓ Peaking backgrounds

- $B^+ \to \overline{D}^0(\to K^+\pi^-\pi^0)\,\pi^+$, $B^+ \to \overline{D}^{*0}(\overline{D}^0(\to K^+\pi^-)\gamma\,)\pi^+$ and $B^+ \to K^{*+}(\to K^+\pi^0)\,\pi^+\,\pi^-$

✓ Contamination from neutral $B^0\to K_1(1270)^0\gamma$

✓ Crossfeed from $B^+\to \pi\pi\pi\gamma$

Fits

- Three different fits are performed
  - Single mass fit, full sample with no fiducial cut
  - A_{CP} fit, simultaneous fit on B^+ and B^- samples on the full $K\pi\pi$ mass range with fiducial cut
  - Full asymmetry fit, simultaneous fit on $(B^+, B^-) \times$ (up, down) categories on a selected region in $K\pi\pi$ mass
- Signal as double-tail CB, with fixed tails from MC (μ and σ free)
- Partially reconstructed and combinatorial background shapes are free, missing π shape is fixed from MC

A_{CP} fit

- Simultaneous fit to + and - signs of the *B* candidate
- Signal yields are independent, we fit N_{total} and A_{CP}
- Background
  - Shapes shared between + and -, except combinatorial
  - Allow for *CP* violation
- Fit stability is checked with toy MC and profile likelihoods

Up-down asymmetry fit

- Simultaneous fit to (+, -) × (up,down) categories
- Signal yields are independent, we fit N_{total}, A_{CP}, A^{+} and A^{-}
- Background
  - Shapes shared between categories, except combinatorial, which has different shape for B^{+} and B^{-}
  - Allow for *CP* violation
- Fit stability is checked with toy MC, profile likelihoods and by splitting into 2 regions of $K\pi\pi$ mass

Production and detection asym

- The sum of A_P and A_D is taken from the $B^+ \rightarrow J/\psi K^+$ studies
  - Since signal and $B^+ \rightarrow J/\psi K^+$ involve a charged *B* and have same number of *K* in the final state, production and detection asymmetries are equal
  - A possible systematic in the detection asymmetry remains due to different kinematics

$$\mathcal{A}_{\mathrm{P}} + \mathcal{A}_{\mathrm{D}} = 0.013 \pm 0.008$$

Instrumental asymmetry bias

- Caused by the magnetic field, which breaks the left-right symmetry.
  - Partially solved by flipping the magnet polarity, some bias may remain due to asymmetry in luminosity for each magnet polarity
- Extract raw A_{CP} by magnet polarity to estimate the bias

$$\Delta\mathcal{A}_{CP}^{\mathrm{raw}} = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} \times \frac{\mathcal{A}_{CP}^{\mathrm{raw},\uparrow} - \mathcal{A}_{CP}^{\mathrm{raw},\downarrow}}{2} = 0.002 \pm 0.001$$

Momentum dependence of A_D

- $B^+ \to J/\psi\ K^+$ has different kinematics than our signal, so if A_{CP} depends on the kaon momentum we may have a systematic error
  - Such dependence was not seen in B→Kπ analysis
- Split the sample in two bins of K momentum, fit raw A_{CP} to evaluate difference
  - Difference of two fits ~$\sigma_{stat}/3$, so no sensitivity to momentum dependency (no systematic)