
Radiative Decays at LHCb

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L International Meeting on Fundamental Physics and XV CPAN days

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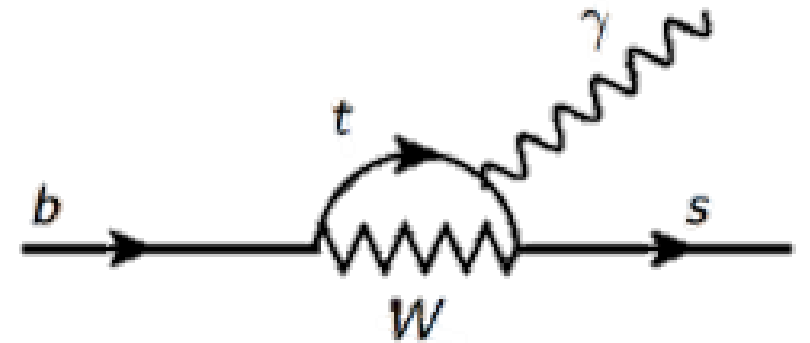


Outline

- Radiative decays: Interest
- Radiative decays: Challenges
- $B \rightarrow K^* \gamma$ isospin asymmetry
- Run 3 preparation: Trigger selections

Radiative decays– Interest

- Flavour Changing Neutral Current (FCNC)
- Probe to New Physics via loop contributions
- $\mathcal{H}_{eff} \propto V_{ts}^* V_{tb} (C_7 O_7 + C_7' O_7')$
- Electromagnetic dipole operators
- Mostly left-handed photons in SM



Radiative decays– Interest

- Different inputs from different observables

$$\mathcal{CP} \rightarrow \text{Im}(C_7)$$

$$\mathcal{B}(A \rightarrow BC) \rightarrow (|C_7|^2 + |C_7'|^2)$$

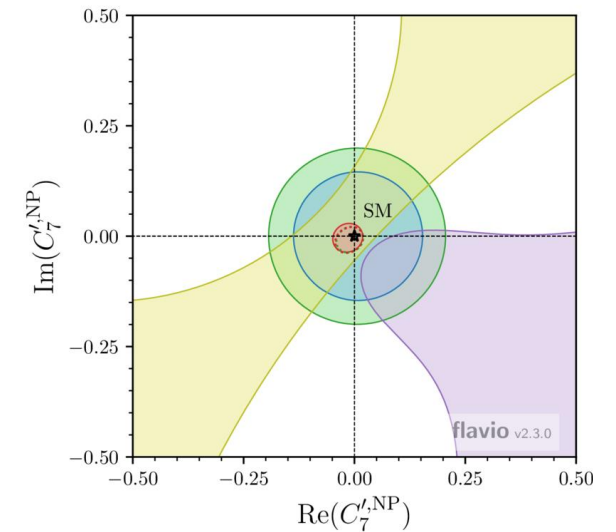
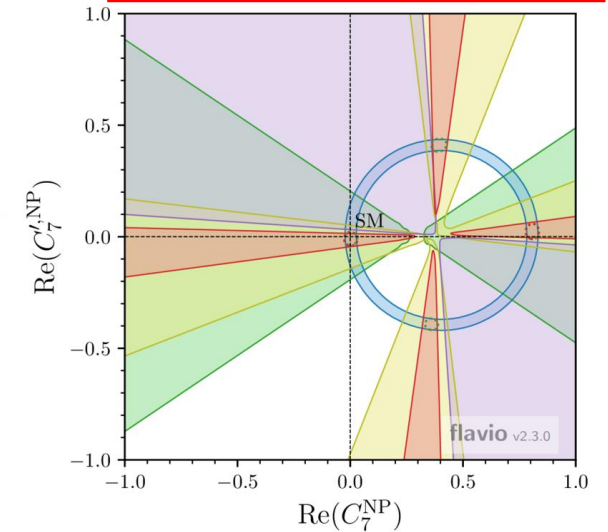
$$\gamma_{(L/R)} \rightarrow |C_7'/C_7|$$

LHCb + B-factories

Constraints at 1σ

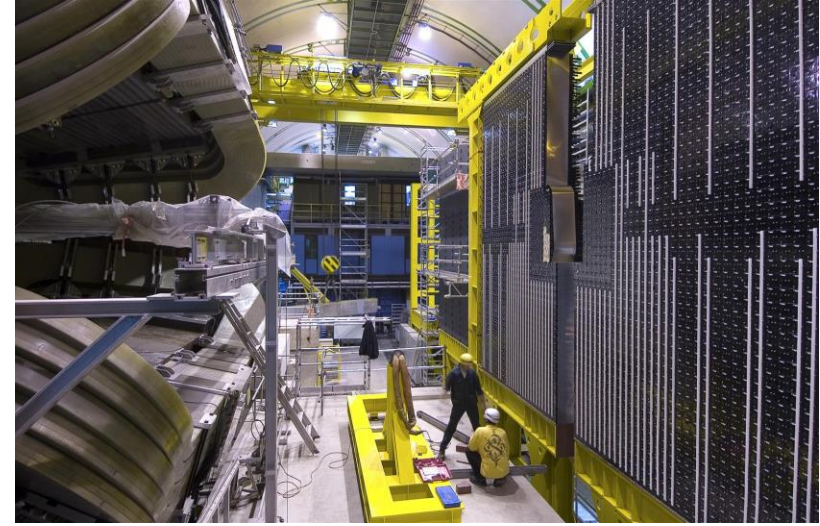
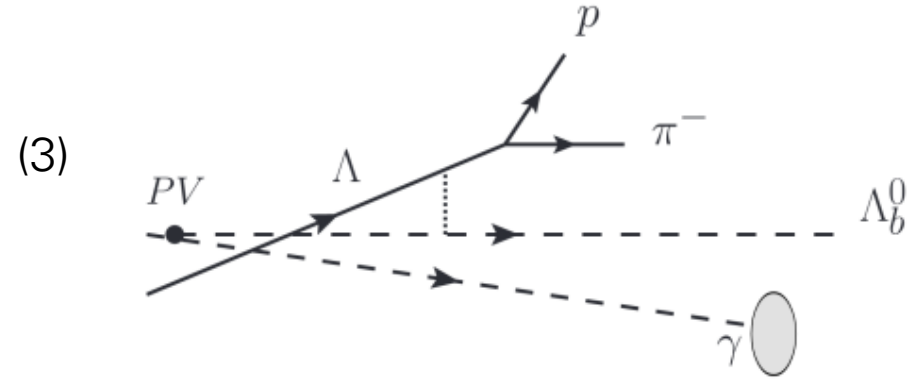
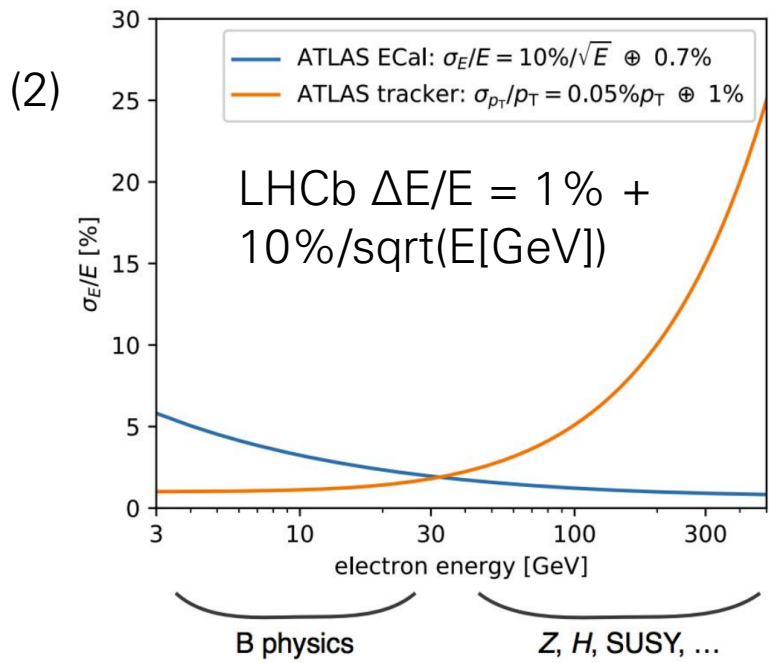
- $\Lambda_b^0 \rightarrow \Lambda \gamma$
- $\mathcal{B}(B \rightarrow X_s \gamma)$
- $B^0 \rightarrow K_S^0 \pi^0 \gamma$
- $B_s^0 \rightarrow \phi \gamma$
- $B^0 \rightarrow K^{*0} e^+ e^-$
- ⋯ Global no $\Lambda_b^0 \rightarrow \Lambda \gamma$
- ⋯ Global

LHCb-PAPER-2021-030



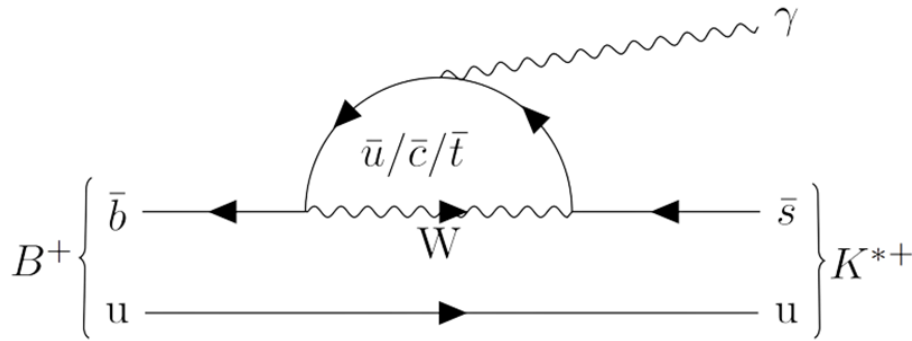
Radiative decays – challenges

1. Small branching ratios $\sim O(10^{-5})$
2. Limited resolution w.r.t. tracking
3. Lack of direction information





Analysis: $B \rightarrow K^* \gamma$ Isospin Asymmetry



$$\Delta_{Iso} = \frac{\Gamma(B^0 \rightarrow K^{*0} \gamma) - \Gamma(B^\pm \rightarrow K^{*\pm} \gamma)}{\Gamma(B^0 \rightarrow K^{*0} \gamma) + \Gamma(B^\pm \rightarrow K^{*\pm} \gamma)}$$

- Partial uncertainty cancellation \rightarrow cleaner observable
- Flavor changing neutral current (FCNC) \rightarrow New Physics sensitive
- Isospin asymmetry test

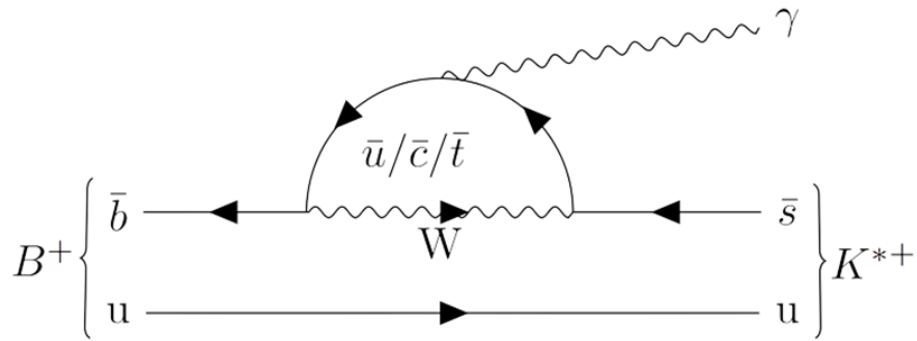


Previous Measurements and Predictions

- BELLE
 - [Evidence of breaking](#) (3.1σ)
[+6.2 \pm 1.5(stat) \pm 0.6(syst) \pm 1.2(f+ \pm /f00)]%
- BELLE II
 - [first results](#) statistically dominated (around 1/5 of first measurement's yield)
- Theory
 - SM Theoretical expectations: 2% - 8%
 - NP models: can be > 20%



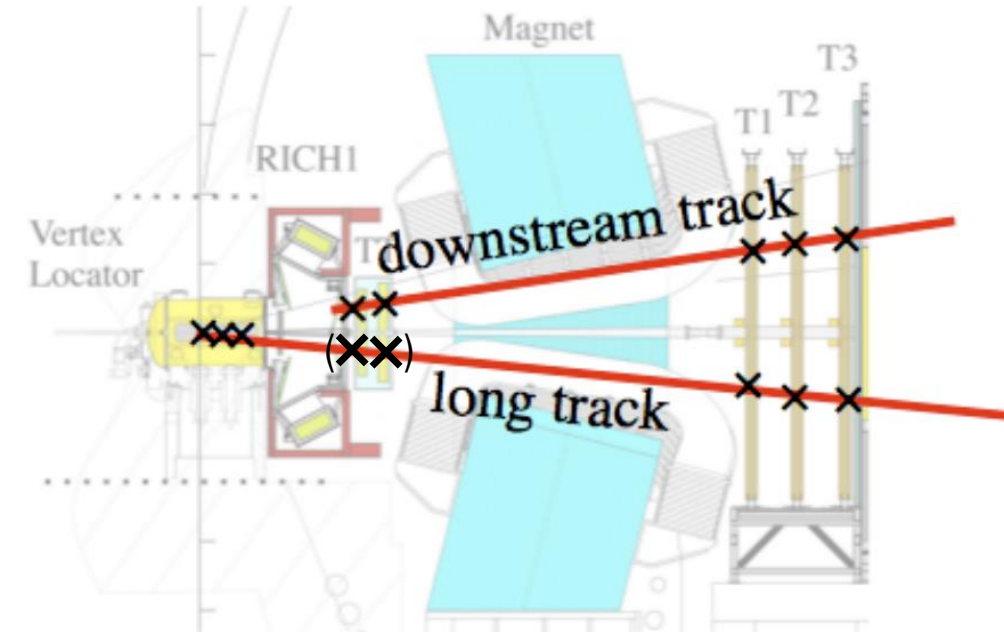
Channels



- B_d channel: $B^0 \rightarrow (K^{*0} \rightarrow K^\pm \pi^\mp) \gamma$
- B_u channel: $B^\pm \rightarrow (K^{*\pm} \rightarrow (K_S^0 \rightarrow \pi\pi) \pi^\pm) \gamma$
 - LL and DD K_S^0

Not using
 π^0, K_L^0 !

LHCb-TALK-2010-083



$$\tau_{K_S^0} \approx 0.9 * 10^{-10}$$

\gg

$$\tau_{B^0} \approx 1.5 * 10^{-12}$$



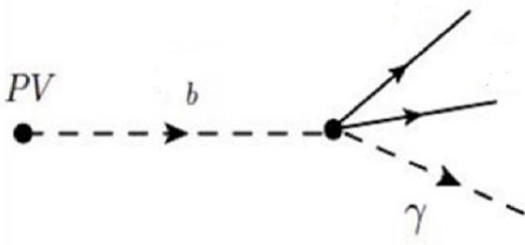
Strategy

- Preselection (kinematic rectangular cuts)
- MVA Selection (BDT)
- Efficiencies and corrections
- Yield (fit)
- Isospin Asymmetry (Blinded)

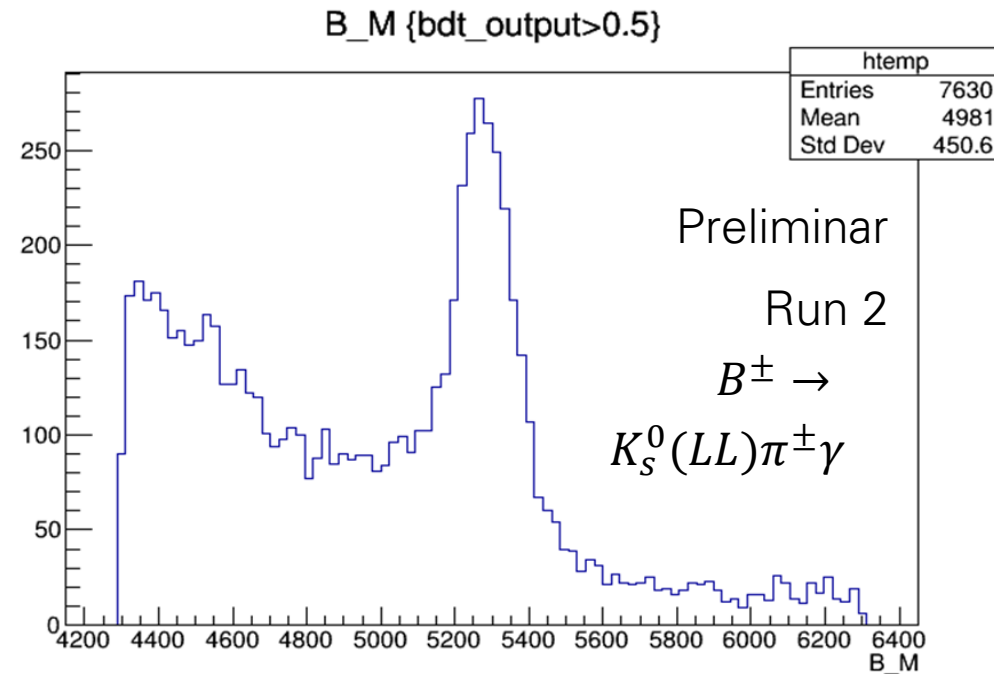


Strategy – Selection

- Preselection:
 - Large Background rejection
 - Vertex displacement
 - Impact parameter
 - Track quality
 - ...



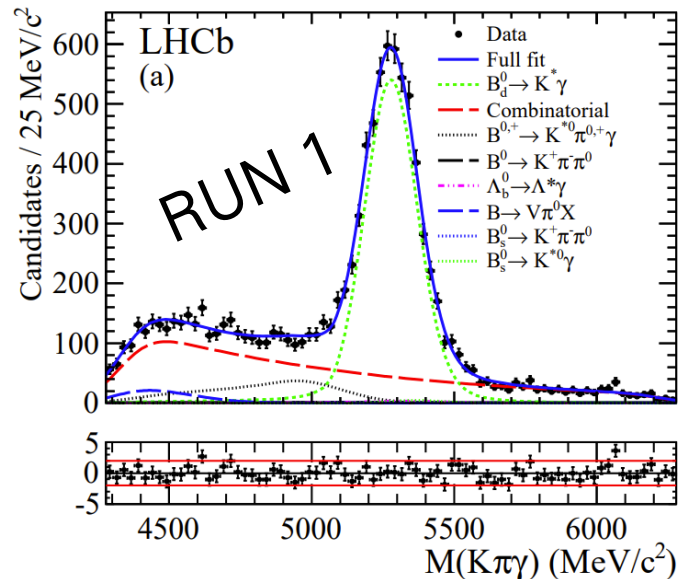
- BDT Selection:
 - Optimization of signal sensitivity





Strategy- Δ_{Iso} extraction (WIP)

- Fit (Yields):
Backgrounds control



LHCb-PAPER_2012-019

- Efficiencies & Corrections:
 - Trigger, Stripping, tracking, PID, ...

- Isospin Asymmetry

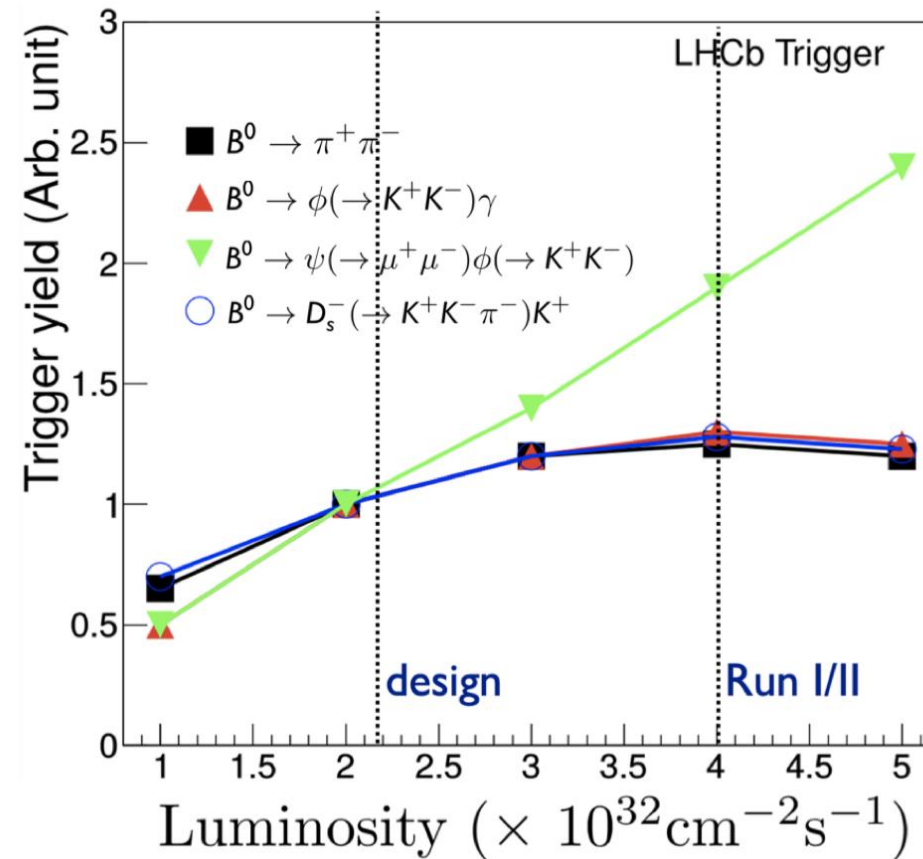
$$\Delta_{Iso} = \frac{\Gamma(B^0 \rightarrow K^{*0}\gamma) - \Gamma(B^\pm \rightarrow K^{*\pm}\gamma)}{\Gamma(B^0 \rightarrow K^{*0}\gamma) + \Gamma(B^\pm \rightarrow K^{*\pm}\gamma)}$$

- Systematics



Trigger at LHCb

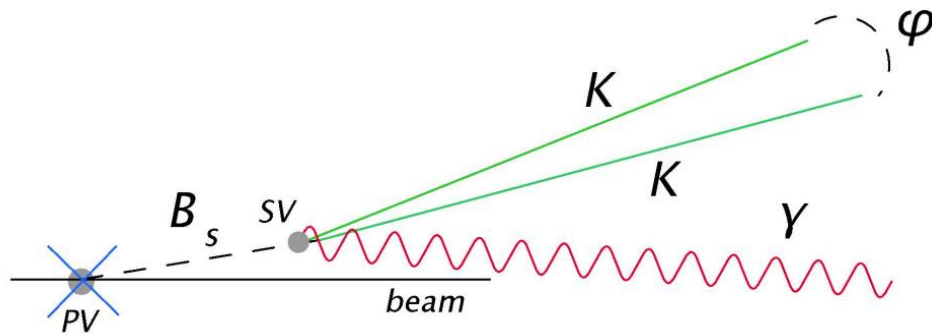
- Full software trigger
- Two stages
 - HLT1 O(50) lines
 - HLT2 O(2000) lines





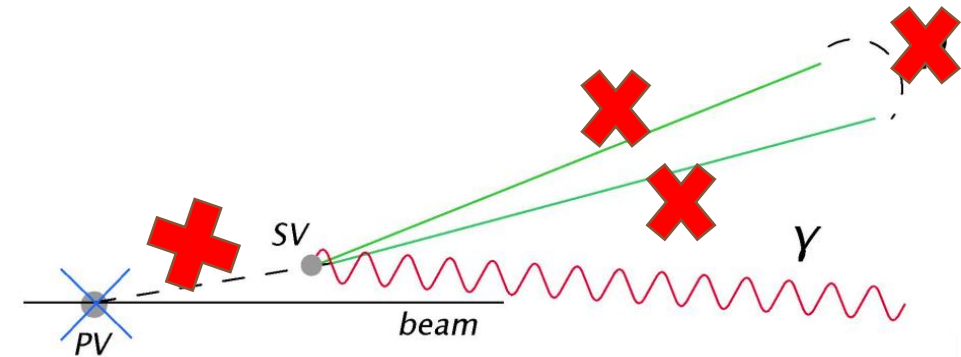
Trigger lines: exclusive/inclusive

Exclusive



- Focus in **one decay signature**

Inclusive

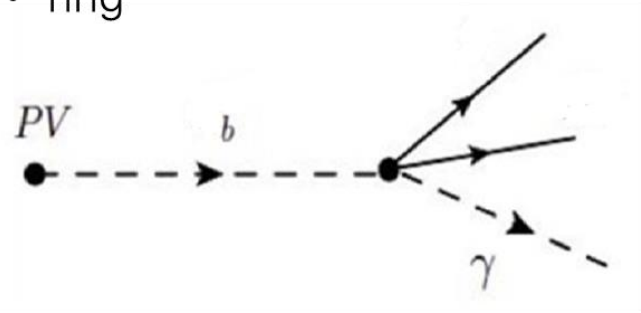


- Selects all events of **common topology**
 - No Particle Identification (PID) cut
 - No Intermediate mass cut
 - Can be used for data mining

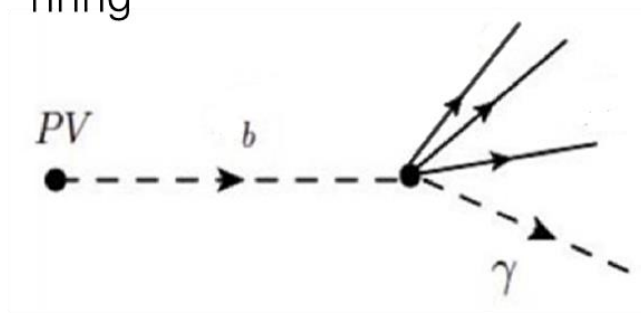


Radiative Inclusive lines

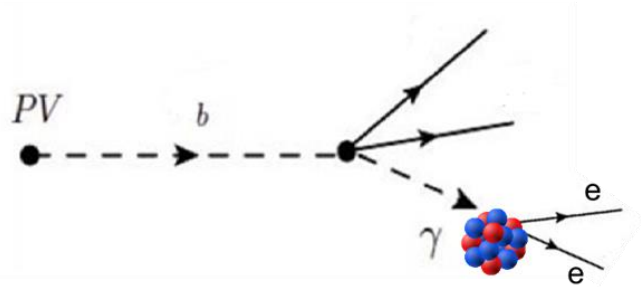
- hhg



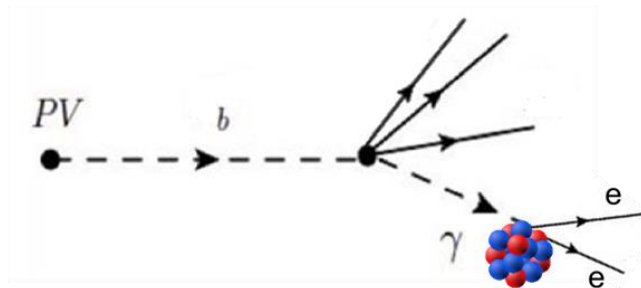
- hhhg



- hhg_converted



- hhhg_converted

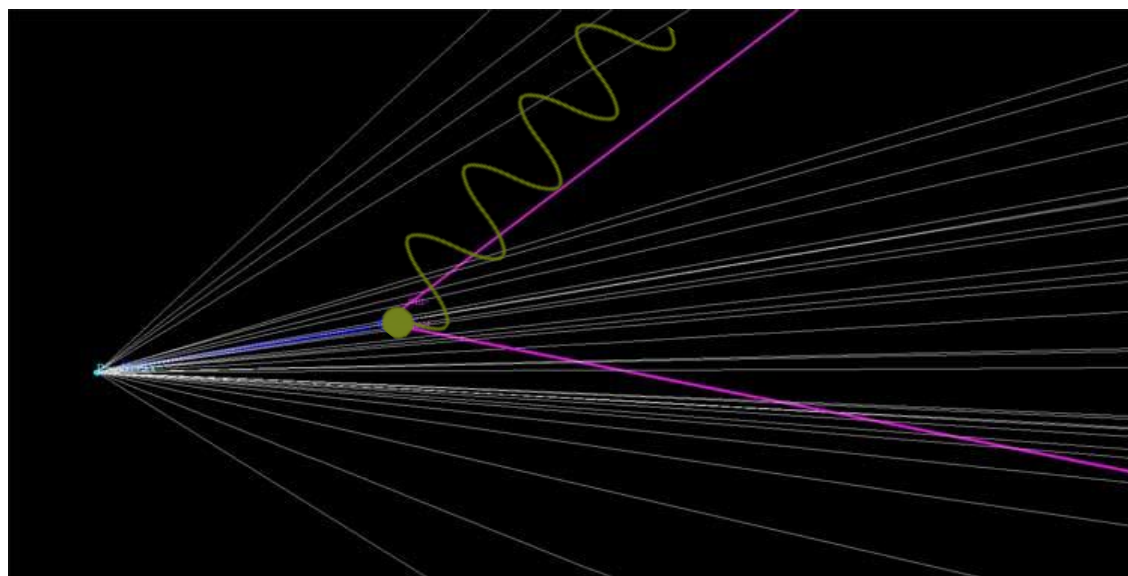


h can be:

- Charged hadron (pi, K, p)
- KS0, Lambda0



Radiative Inclusive lines: Strategy

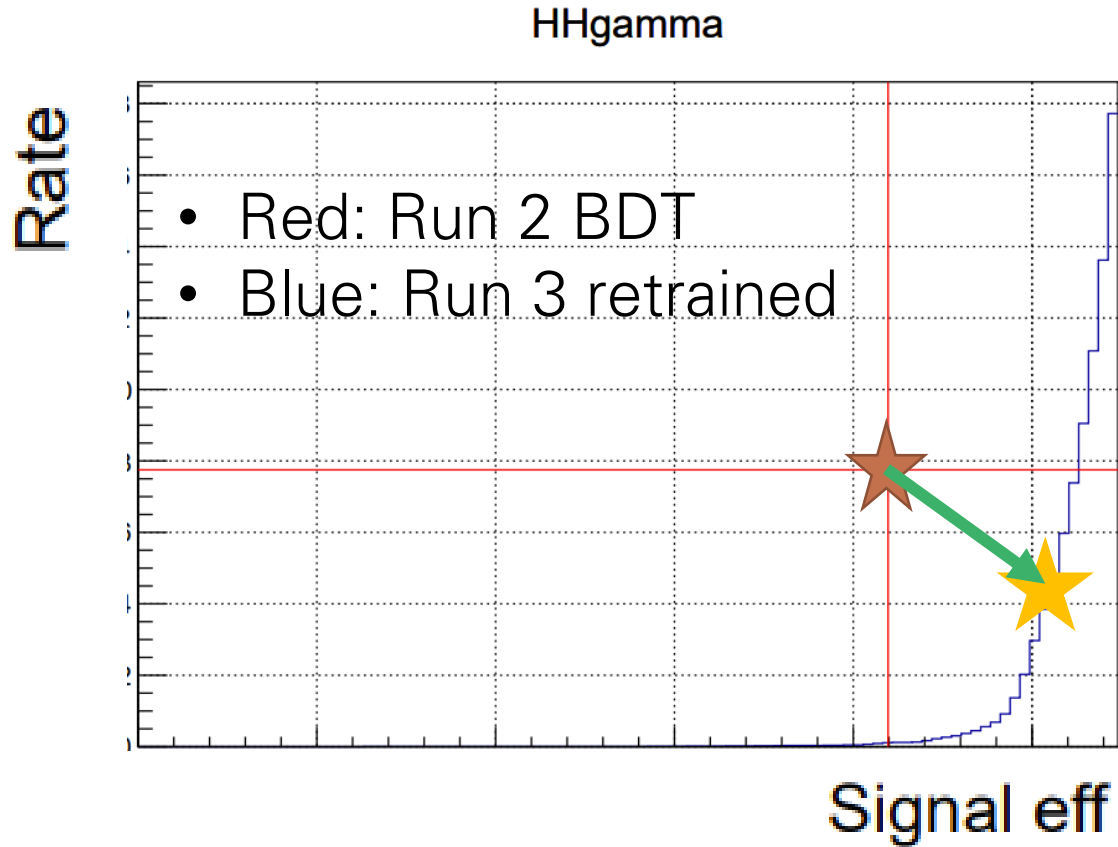


LHCb Event Display

- Build candidates
 - Filter tracks
 - Combine tracks
 - Combine photons
- Preselection based on kinematic cuts
- MVA Selection trained on cocktail of signals



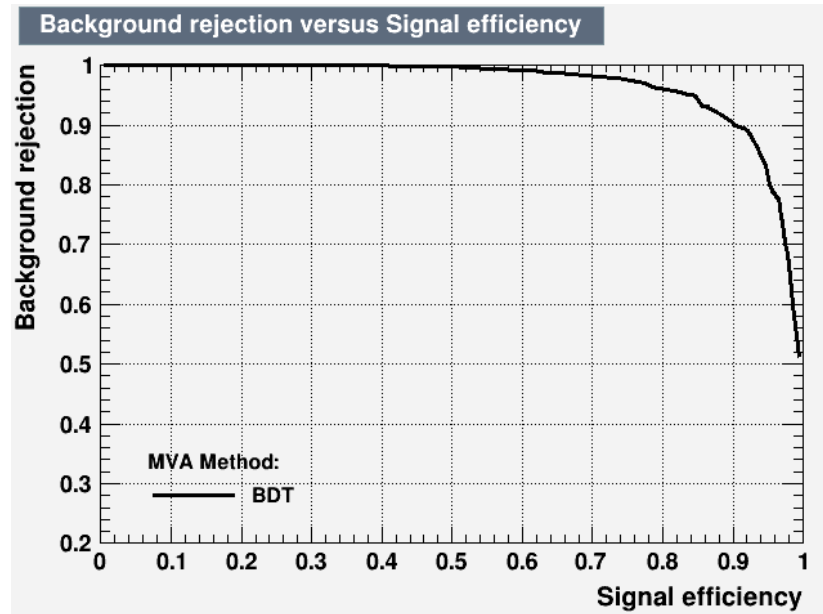
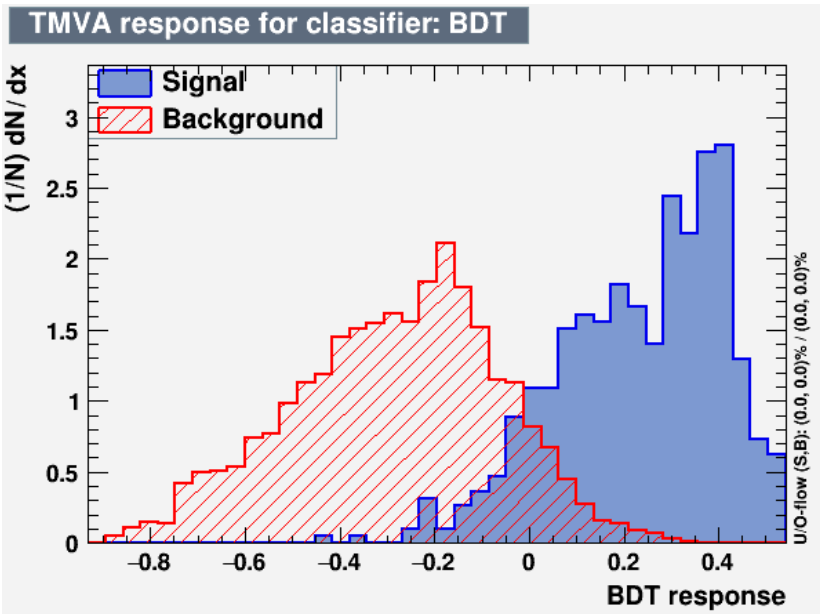
Results – run2 to run 3 – Baseline



- Large conditions change
- Retraining was mandatory!
- Baseline used in 2022
 - 1.1 kHz
 - Efficiencies w.r.t HLT1
 - ~10% (control channels)
 - ~ 8% ($B^+ \rightarrow h^+ V^0 \gamma$)
 - ~ 4% ($B^+ \rightarrow X \pi^0 \gamma$)



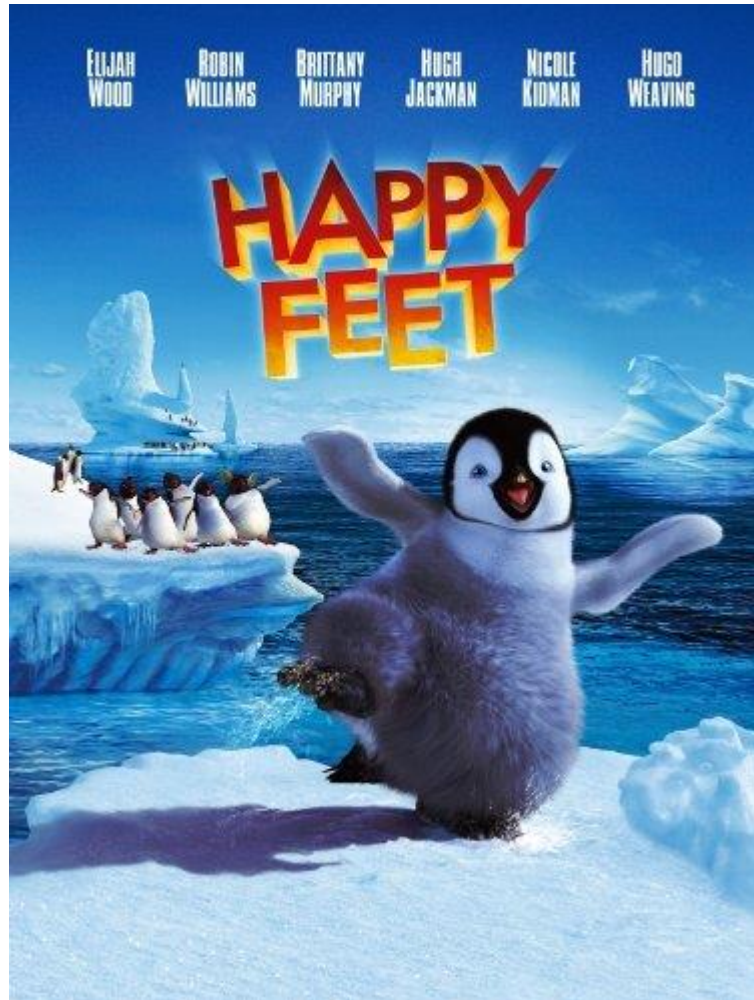
Results – Run 3 – WIP Optimization



- All available samples
- Real data for background
- Full optimization study

Summary

- Radiative rare decays are a potential tool for observation of NP hints and an active field of interest
- The Barcelona LHCb group is involved widely in the radiative program
- B to KstGamma Isospin Asymmetry: ongoing analysis
- Towards the future: radiative HLT2 inclusive lines in run 3



**Thank you for
your attention**

Salón de Baile
@ Palacio de la Magdalena
2nd October 2023



Backup

Radiative decays– Interest

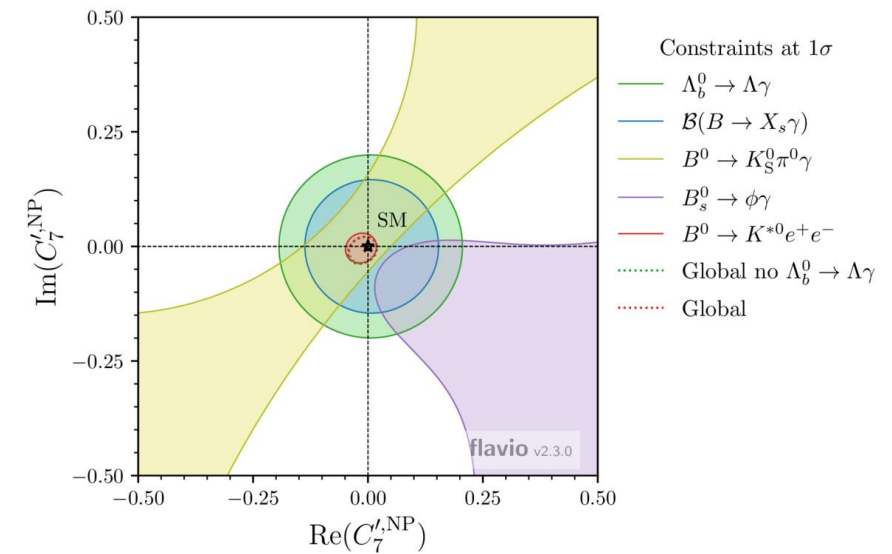
Left-handed C_7

$BR \propto (C_7^{SM} + C_7^{NP})^2 + (C_7'^{NP})^2$

- 5% precise prediction only for inclusive BR (quark-level)
M. Misiak et al JHEP 06(2020)175
- 5% precise inclusive BR
HFLAV average 2022 **B-factories**
- ImC_7 measured with direct A_{CP}
- $B \rightarrow K_S \pi^0 \gamma$ and similar
HFLAV average 2015 **B-factories**
- Tagged time-dep. analysis of $B_s \rightarrow \phi \gamma$
PRL 123(2019)8-081802 **LHCb**

Right-handed C_7'

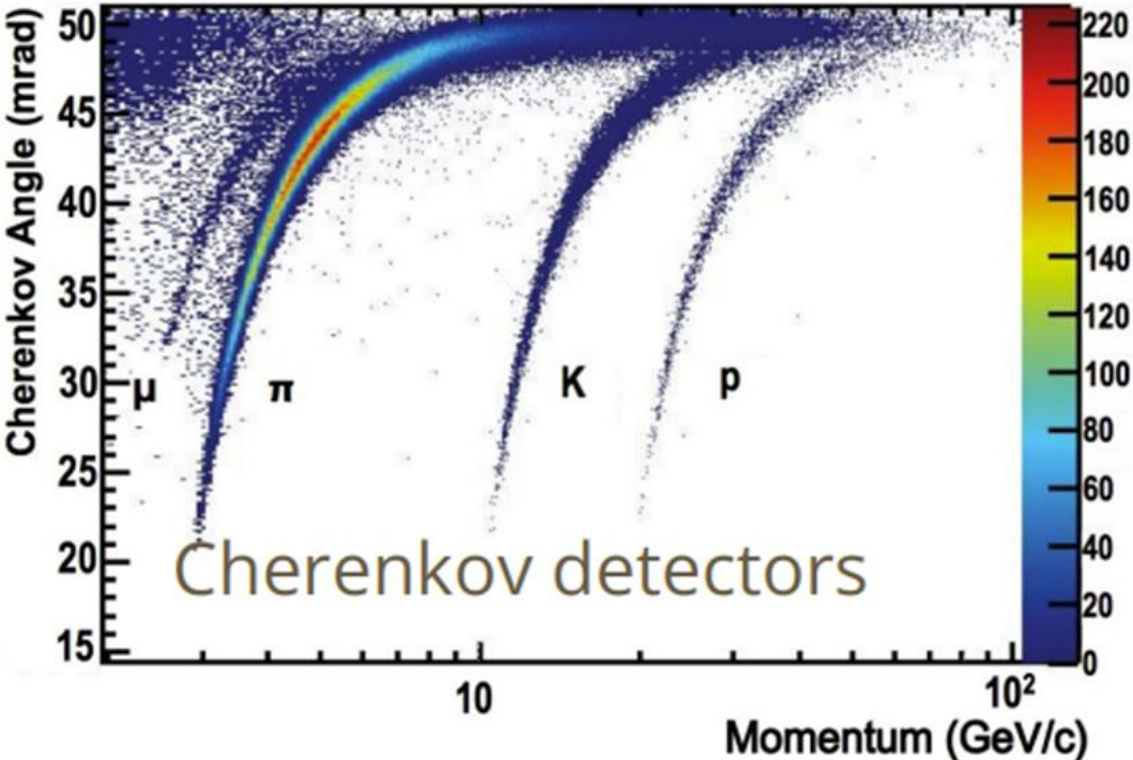
- Mixing induced CP asymm. in $B \rightarrow K_S \pi^0 \gamma$ (et al)
HFLAV average 2015 **B-factories**
- $\Delta\Gamma_s$ induced rate asymm. in $B_s \rightarrow \phi \gamma$ at LHCb
PRL 123(2019)8-081802 **LHCb**
- Transverse asymmetries in $B^0 \rightarrow K^* e^+ e^-$ at LHCb
JHEP 12(2020)081 **LHCb**
- Angular analysis of $\Lambda_b \rightarrow \Lambda \gamma$ at LHCb
PRD 105(2022)5-1.051104 **LHCb**
- Full amplitude analysis of $B^+ \rightarrow K^+ \pi^- \pi^+ \gamma$ at LHCb
LHCb
coming soon...



LHCb-PAPER-2021-030

[EWpenguin_LHCb_Borsato](#)

PID





Radiative Inclusive lines: Strategy - MVA

- MVA Selection trained on cocktail of signals. Minimum Bias MC as Background

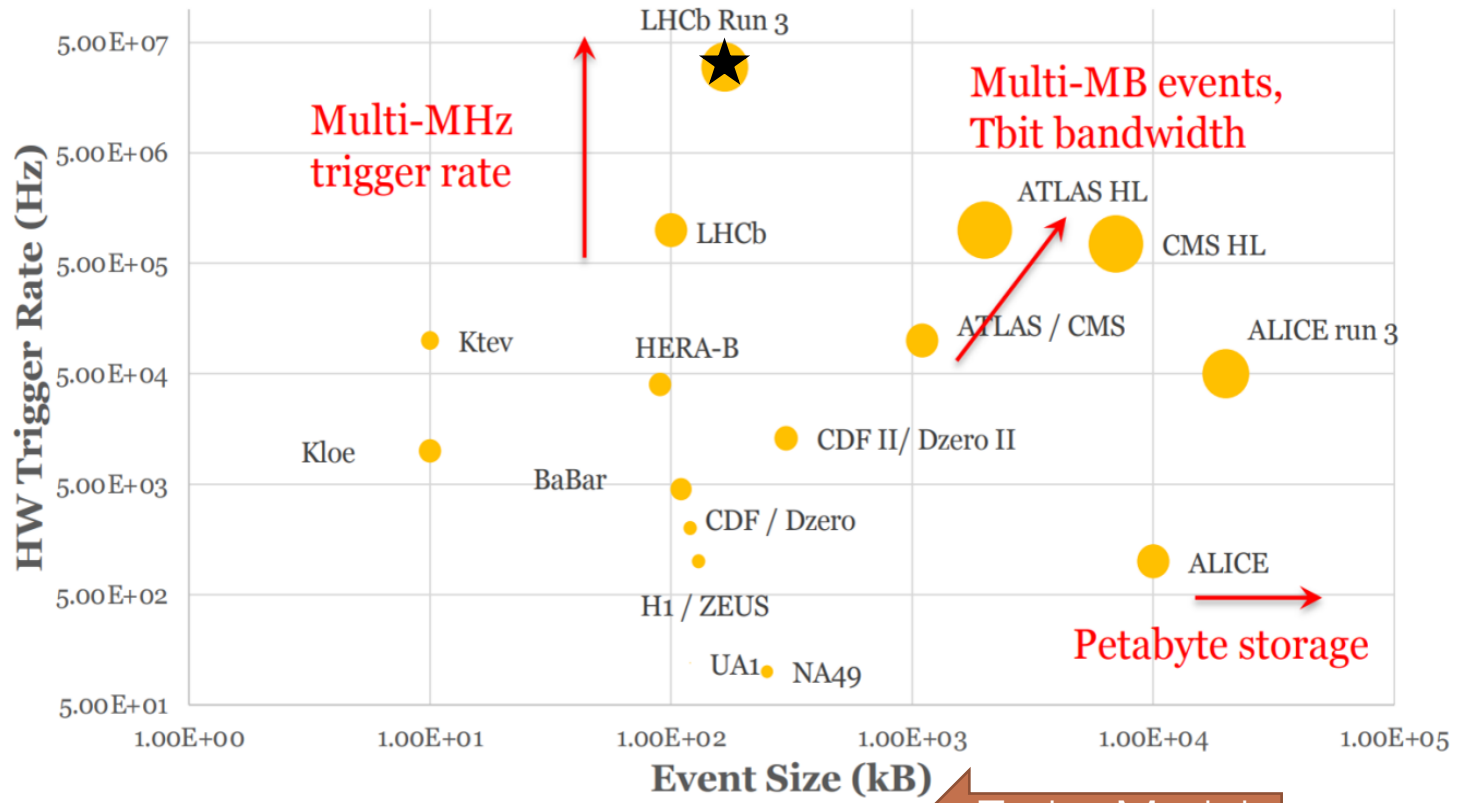
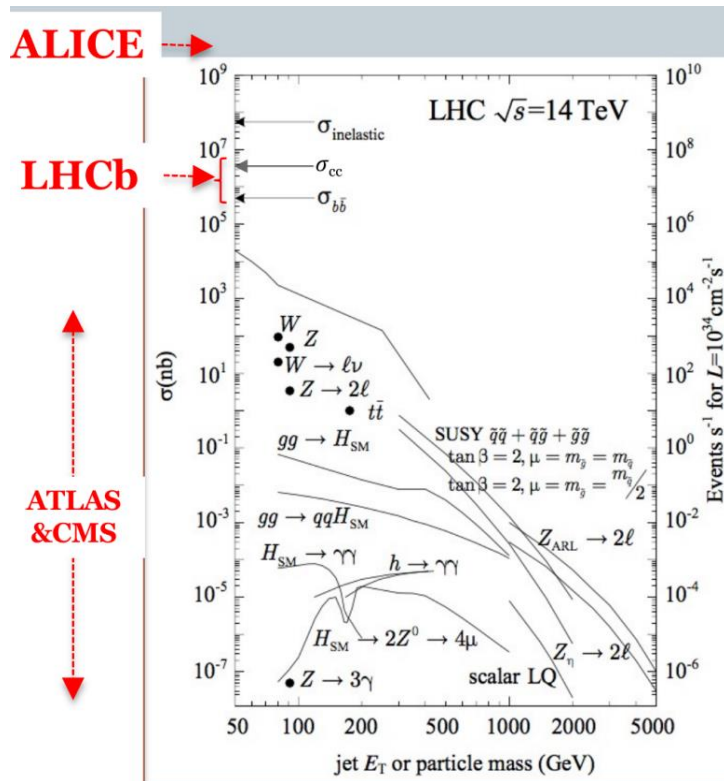
2h+gamma	3h+gamma
$B^0 \rightarrow (K^* \rightarrow K^+ \pi^-) \gamma$	$B^+ \rightarrow (K_1^+ \rightarrow K^+ \pi^- \pi^+) \gamma$
$B_s^0 \rightarrow (\phi \rightarrow K^+ K^-) \gamma$	$B^+ \rightarrow (\phi \rightarrow K^+ K^-) K^+ \gamma$
$B^0 \rightarrow (\rho \rightarrow \pi^+ \pi^-) \gamma$	$B^0 \rightarrow (\phi \rightarrow K^+ K^-) (K_S^0 \rightarrow \pi^+ \pi^-) \gamma$
$\Lambda_b \rightarrow (\Lambda_0^* \rightarrow p K^-) \gamma$	$B^0 \rightarrow (\phi \rightarrow K^+ K^-) (K^* \rightarrow K^+ \pi^-) \gamma$
$B^- \rightarrow ((\Lambda^0 \rightarrow p \pi^-) p) \gamma$	$B^0 \rightarrow (\phi \rightarrow K^+ K^-) (\phi \rightarrow K^+ K^-) \gamma$
$B^+ \rightarrow ((K_S^0 \rightarrow \pi^+ \pi^-) \pi^+) \gamma$	
$B_s^0 \rightarrow (\phi \rightarrow K^+ K^-) \pi^0 \gamma$	
$B^0 \rightarrow (K_1^0(1270) \rightarrow K^+ \pi^- \pi^0) \gamma$	



Trigger Lines

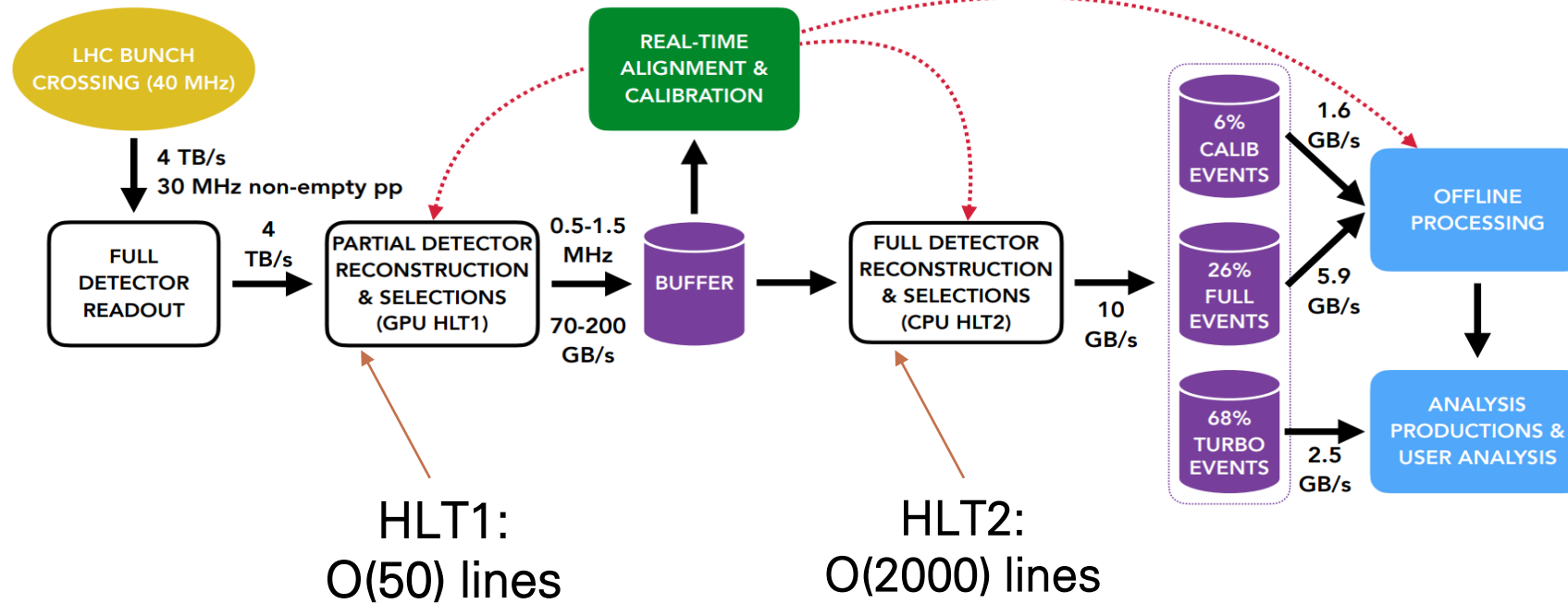
- σ_{bb} , σ_{cc} fairly high compared to e.g. Higgs

Bandwidth = Rate x EvtSize



Turbo Model

Trigger Lines







Trigger Lines

- HLT1: O(50) lines
 - Mostly based on Tracking

- HLT2: O(1500) lines
 - Target specific Physics channel(s)

- B DECAYS TO CHARMONIUM ...
- B DECAYS TO OPEN CHARM
- CHARMLESS B-HADRON DECAYS
- B-HADRONS AND QUARKONIA
- CHARM PHYSICS
- FLAVOUR TAGGING
- LUMINOSITY
- QCD, ELECTROWEAK AND EXOTICA
- RARE DECAYS   **RADIATIVE DECAYS** live here
- SEMILEPTONIC B DECAYS
- DETECTOR PERFORMANCE
- IONS AND FIXED TARGET



MVA

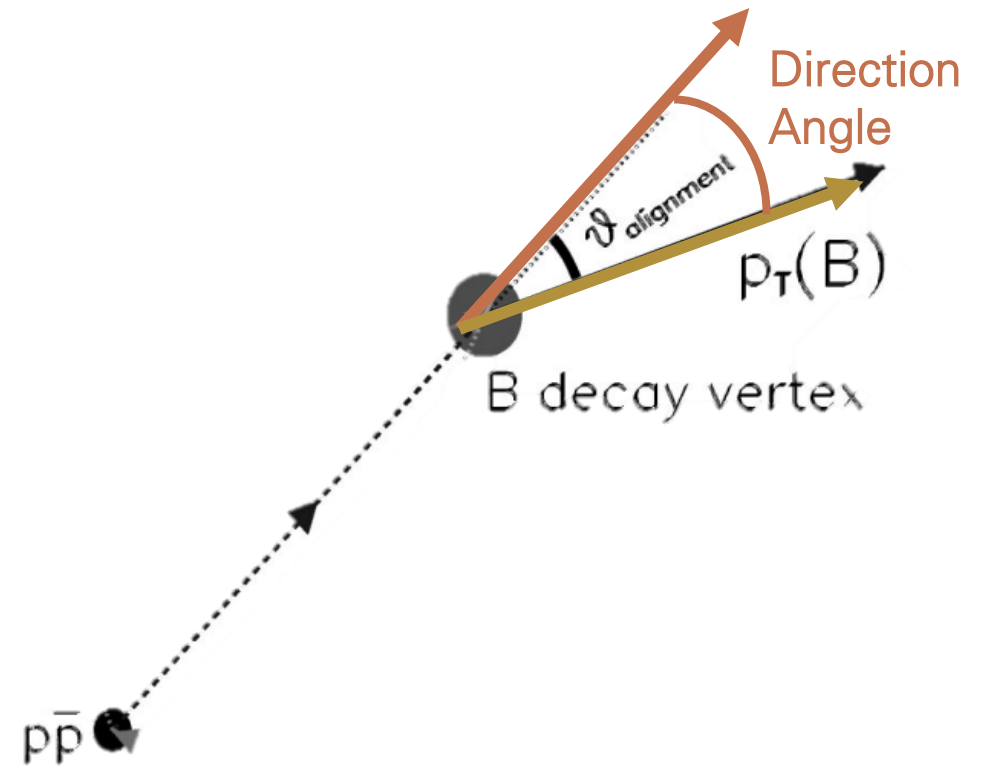
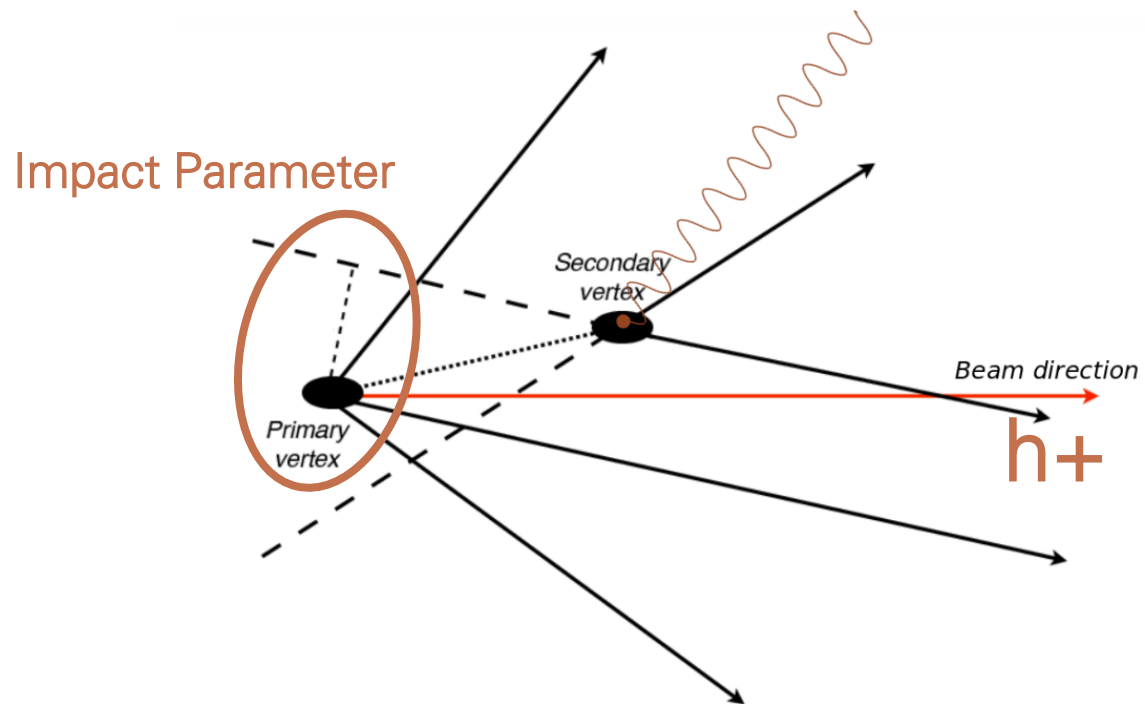
- BDT

H1t2BToHHGamma	H1t2BToHHHGamma	H1t2BToHH(H)GammaEE
$B \chi_{IP_{PV}}^2$	$B \chi_{IP_{PV}}^2$	$B m_{corr}$
$h \min(\chi_{IP_{PV}}^2)$	$h \min(\chi_{IP_{PV}}^2)$	$B \chi_{vtx}^2$
γp_T	γp_T	$\text{sum}(h^\pm p_T)$
-	γp	$B \eta$
$B m_{corr}$	$B m_{corr}$	$B \chi_{VD}^2$
$(h^+ h^-) m_{corr}$	-	$\min(h^\pm p_T)$
$B \chi_{FDPV}^2$	$B \chi_{FDPV}^2$	$\#(\text{child } (\chi_{IP_{PV}}^2 < 16))$
$B \chi_{vtx}^2$	$B \chi_{vtx}^2$	$B \chi_{IP_{PV}}^2$
DOCA (h^+, h^-)	$h^\pm \text{Track max}(\chi^2/\text{ndf})$	$\#(\text{child } (\chi_{IP_{PV}}^2 > 16 \ \& \ p_T > 1 \text{ GeV}))$



Kinematic/Geometric variables

- Preselection based on kinematic cuts

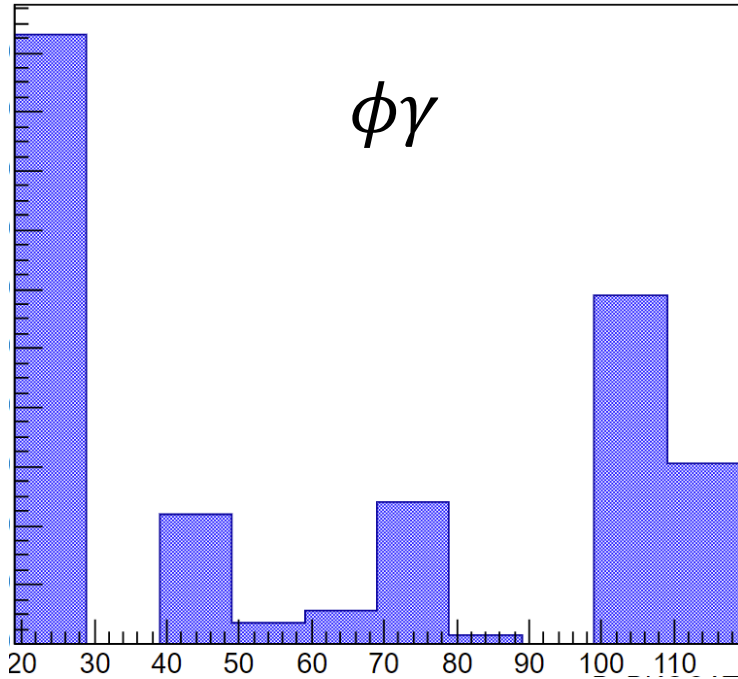


Sprucing



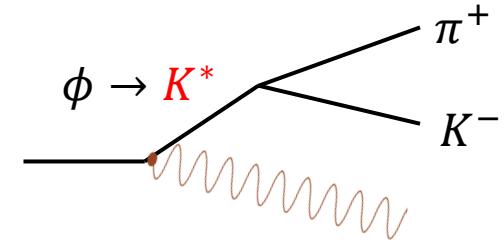
Strategy - Backgrounds

'B_BKGCAT'



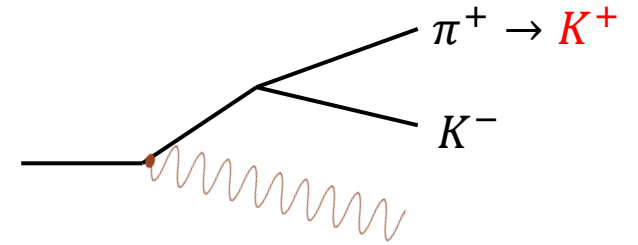
- 20: Ressonance

✓ (incl)



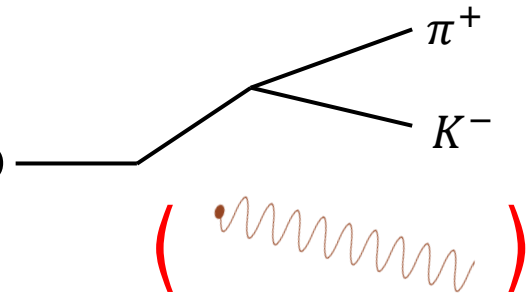
- 30: Miss ID

✓ (incl)



- 40/50: Partially reco

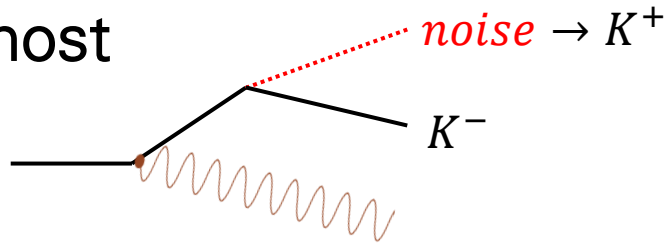
✓(?) (incl)



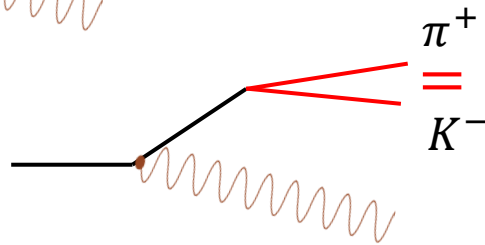


Strategy - Backgrounds

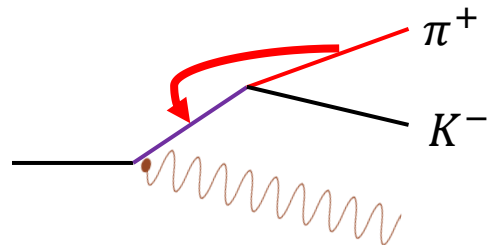
- 60: Ghost



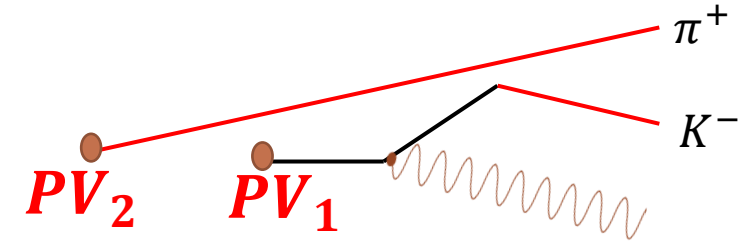
- 63: Clone



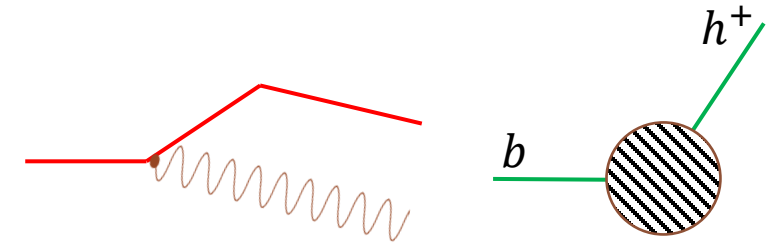
- 66: Hierarchy



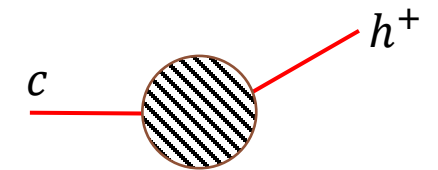
- 70/80: Combinatorics



- 100: b



- 110: c



- 120: None of the above

