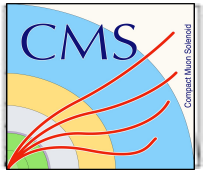
B Parking: Status update

Compact Muon Solenoid experiment at CERN's LHC



HELLENIC REPUBLIC
National and Kapodistrian University of Athens

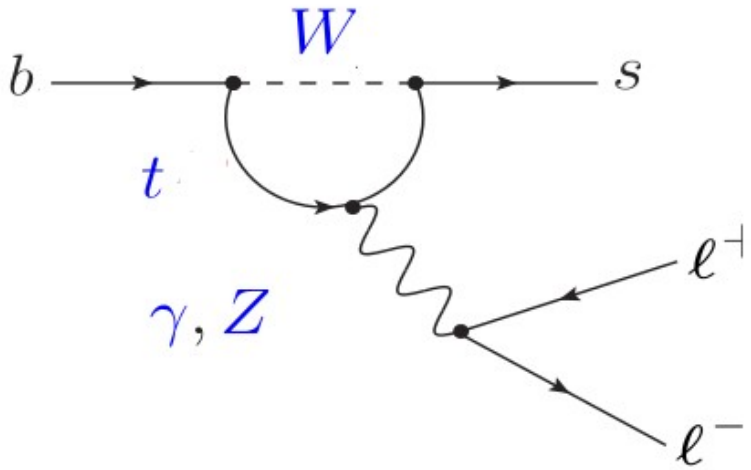
H.F.R.I. Hellenic Foundation for Research & Innovation

GSRT GENERAL SECRETARIAT FOR RESEARCH AND TECHNOLOGY

G. Karathanasis on behalf of B-Parking group

Physics Motivation

- EWK couplings of leptons to gauge bosons are independent of lepton flavour
→ lepton flavour “universality” (LFU)
- Flavour-changing neutral currents (FCNC) prohibited at tree level; only through loop (penguin/box) Feynman diagrams (GIM mechanism)
→ FCNC ideal for testing LFU



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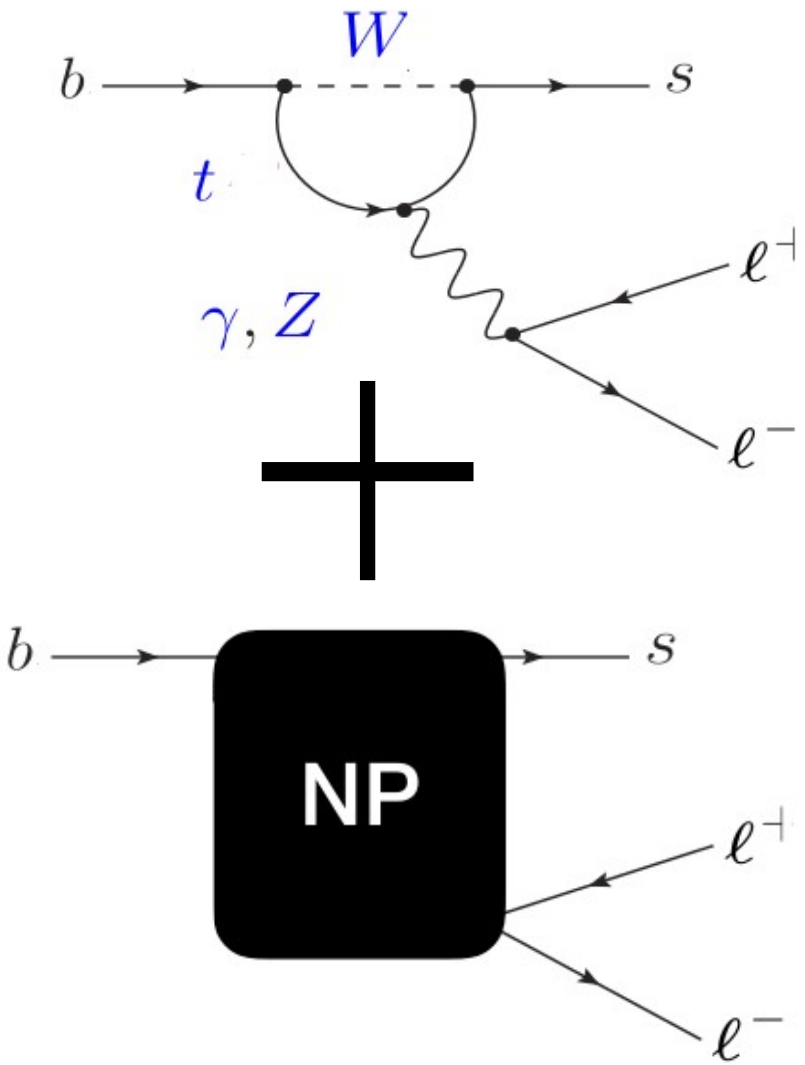
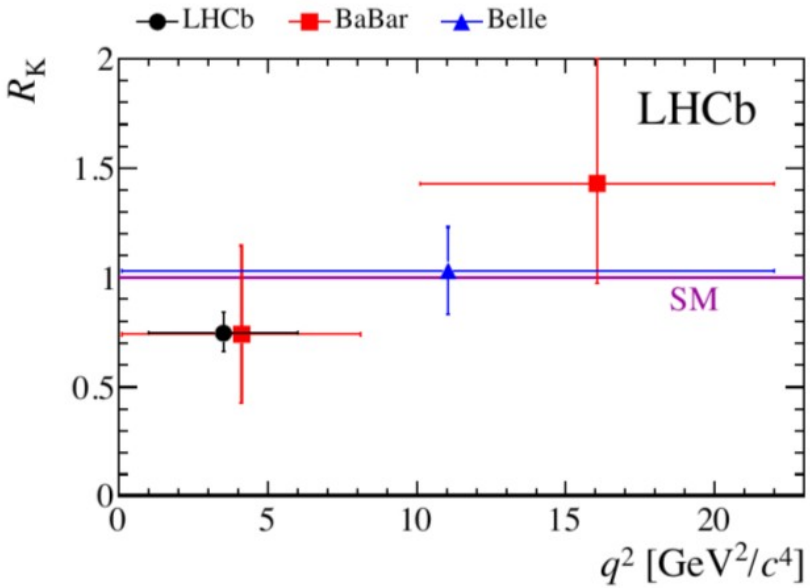
→ FCNC ideal for testing LFU

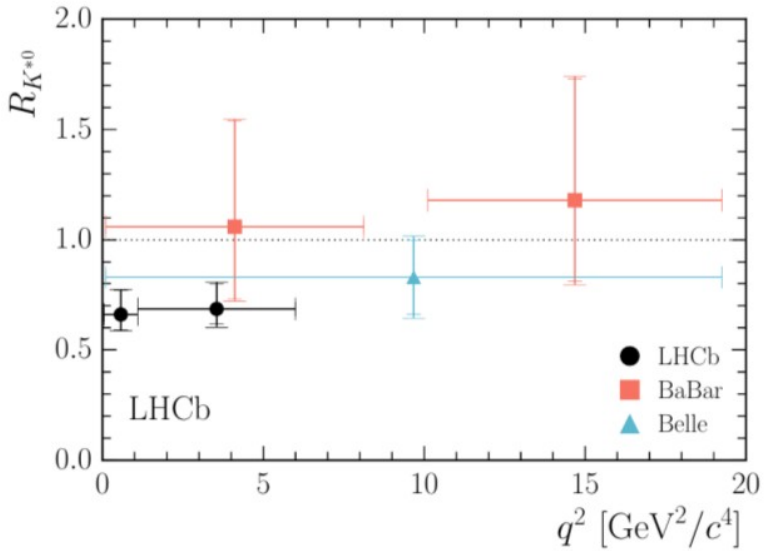
- FCNC process are rare → sensitive to existence of new Physics (NP)
- Violation of LFU (difference in e/μ/τ couplings) would be stunning evidence for NP



Recent measurements

- Deviations from SM (~2.0σ-2.5σ from predicted values) reported by LHCb, most notably in R_K and R_{K^*}
- With $R_K = \frac{Br(B \to K \mu^+ \mu^-)/Br(B \to K J/\psi(\to \mu^+ \mu^-))}{Br(B \to K e^+ e^-)/Br(B \to K J/\psi(\to e^+ e^-))}$ → 0.745 ±0.036 [1]
- And $R_{K^*} = \frac{Br(B \to K^* \mu^+ \mu^-)/Br(B \to K^* J/\psi(\to \mu^+ \mu^-))}{Br(B \to K^* e^+ e^-)/Br(B \to K^* J/\psi(\to e^+ e^-))}$ → 0.66 ±0.03, for q^2 [0.045-1.1] GeV [2]; 0.69 ±0.05, for q^2 [1.1-6] GeV [2]





- Also deviating from SM are Br measurements [3-5] and angular observables of rare b → s decays [5-6]

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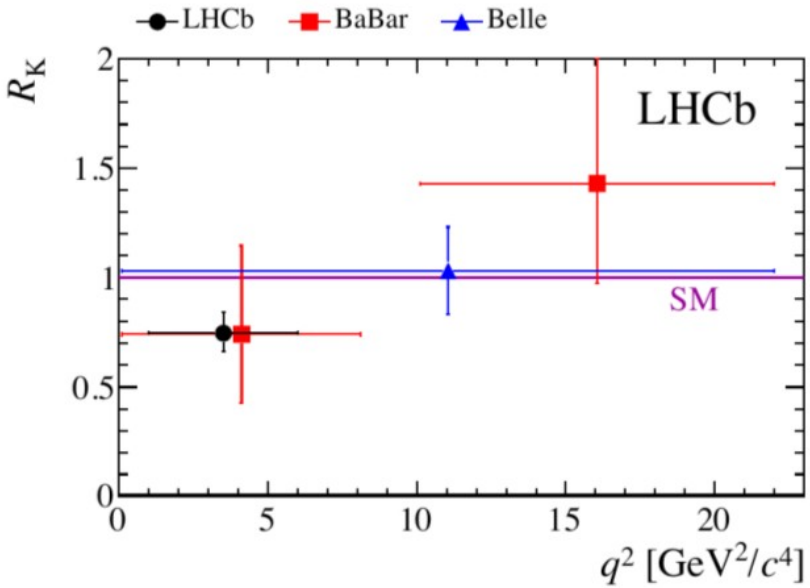
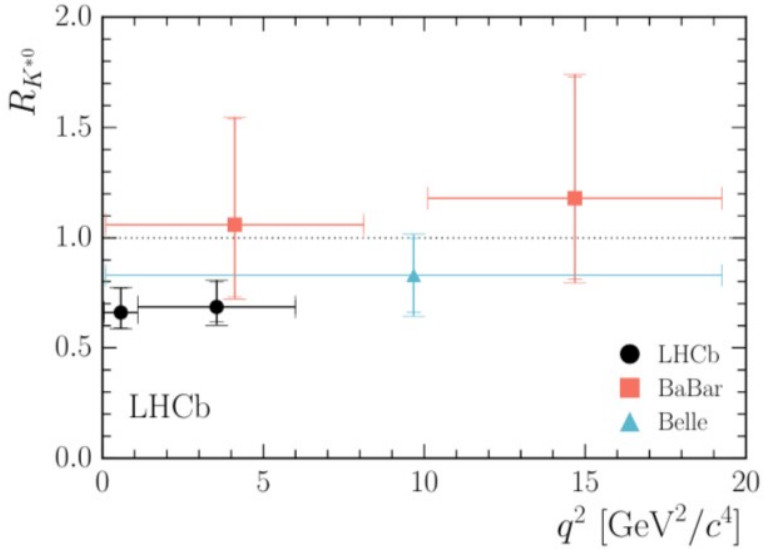




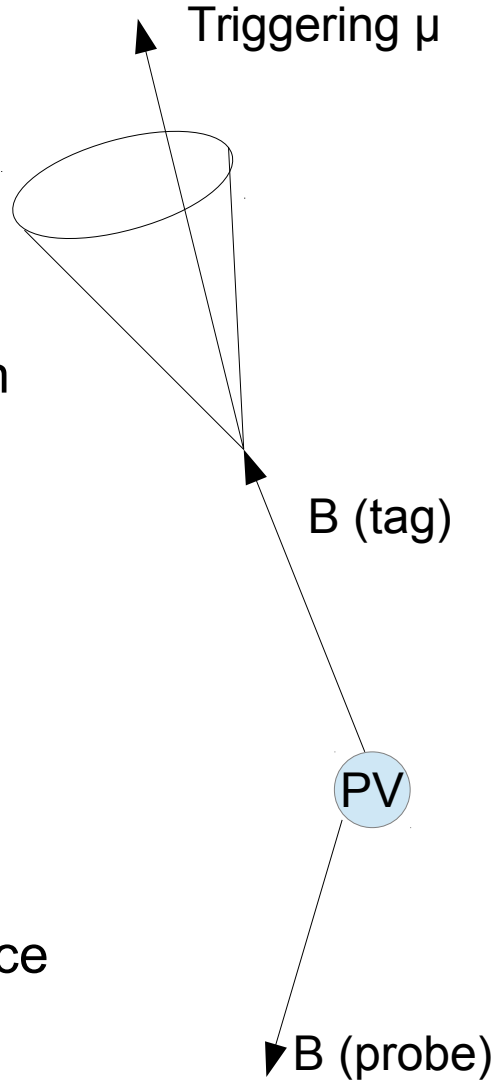
- Also deviating from SM are Br measurements [3-5] and angular observables of rare b → s decays [6-7]
- **B-Parking goal: Collect enough b hadrons to study rare B processes that can give evidence for new Physics with CMS (competitive to LHCb and before Belle II)**

B-Parking: An unbiased B sample

- CMS B physics trigger menu is primarily μ-based

  → we can get B → μμK **but not B → eeK**

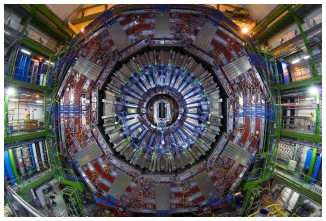
- Idea: use an opposite side tag approach to collect a large unbiased sample of B decays
  - Triggering on one B (tag) in order to collect unbiased B on the other side (probe)
  - Successfully used in the past (LEP, B factories, LHCb)
  - **Generic B sample that can be used for many studies**
    - e.g.: rare decays ($B_S \rightarrow \varphi\varphi$), CP violation e.t.c.
- Use CMS infrastructure and store ("park") those events, then process them during LS2
- B (tag): can be provided by B pure trigger → Single Muon since the BF(b → μX,including b->c->μX) is ≈20% and σ(b) is huge
- B → μμK or eeK has BF of 10^{-7} → very small and with ~10% reconstruction efficiency **need ~ 10^{10} B**



Trigger Studies

Trigger Strategy

- Strategy:
  - L1 seeds enhanced in b hadron decays
  - Refinement in HLT
  - Save 2kHz in DAQ
- L1 seeds:
  - Single μ L1 seeds pure (~40%) in B decays
  - Progressively lower p_T thresholds for constant 8kHz of rate
- HLT:
  - Reconstruct L3 μ, impose p_T and impact parameter parameter (IP) cuts
  - Rate reduction at 2kHz (average throughput)
- Store events in single copies



40MHz

L1 Trigger

Combinations of single μ seeds

8kHz

HLT Trigger

Further reduction with more accurate p_T and IP

2kHz

DAQ

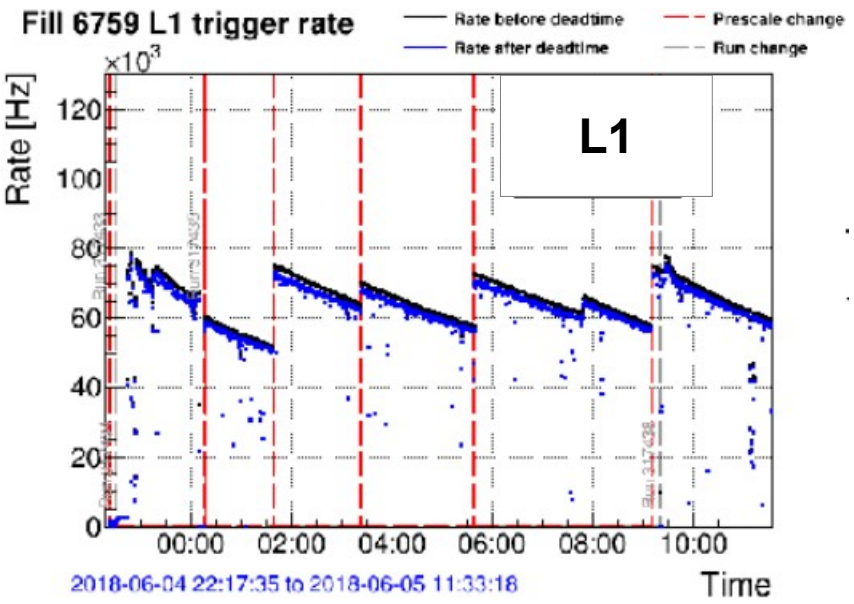
Single copy, data parking

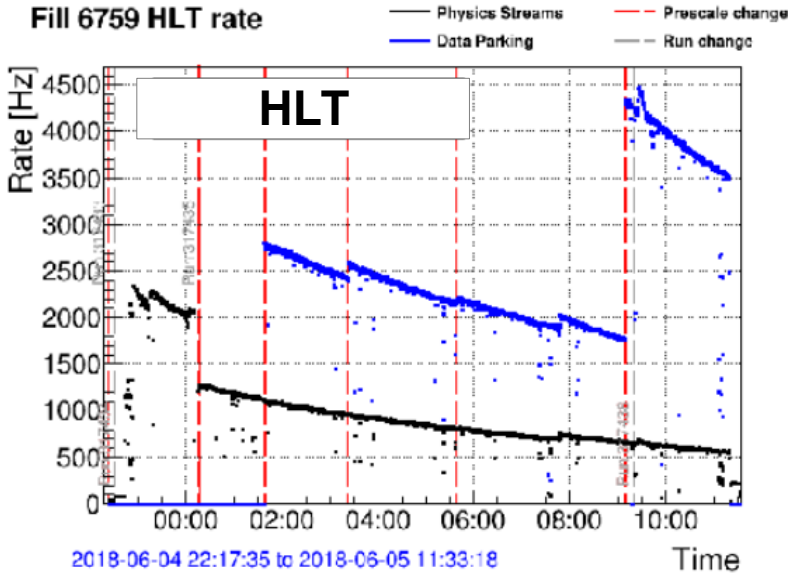
L1 Seeds/HLT Paths development

- Tuning/optimizing paths for maximum performance, during data-taking
- As luminosity decreases, η-restricted seeds keep the L1 rate constant
- HLT **main** paths: HLT_Mu9_IP6,5,4
- Trigger strategy optimized for **high purity using MC**

Current proposal

Lumi (E34)	L1 seed	HLT	rate	purity	#B
1.7	Mu12er1p5	Mu12_IP6	1585	0.92	10.5M
1.5	Mu10er1p5	Mu9_IP5	3656	0.80	21M
1.3	Mu8er1p5	Mu9_IP5	3350	0.80	20M
1.1	Mu8er1p5	Mu7_IP4	6153	0.59	33M
0.9	Mu7er1p5	Mu7_IP4	5524	0.59	29M





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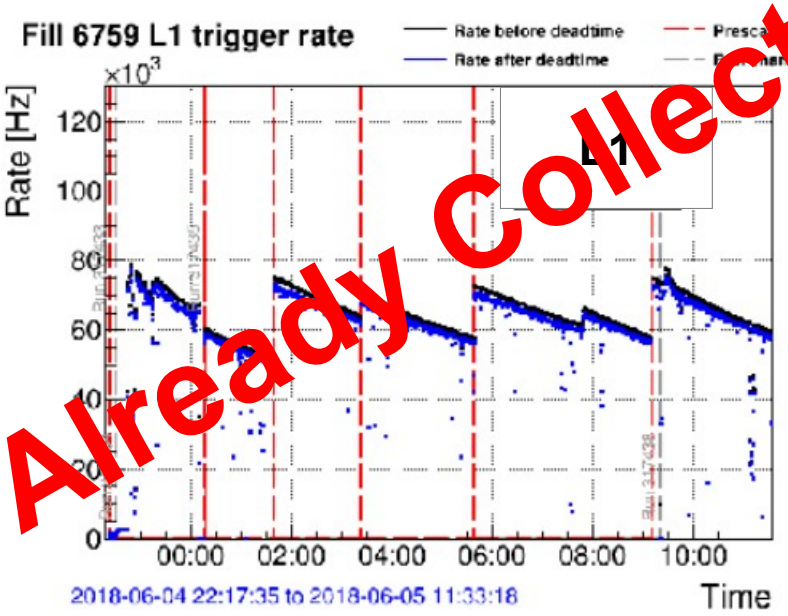
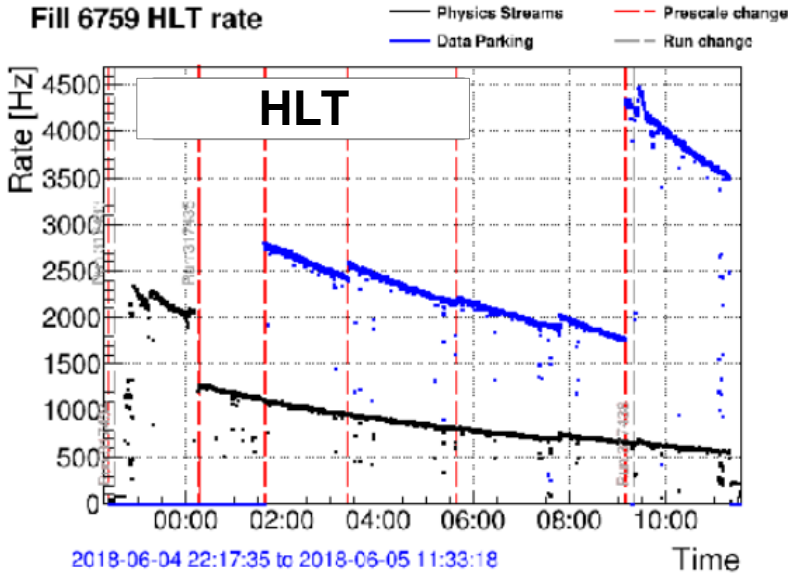
Already Collected 10^{10} Events !!!



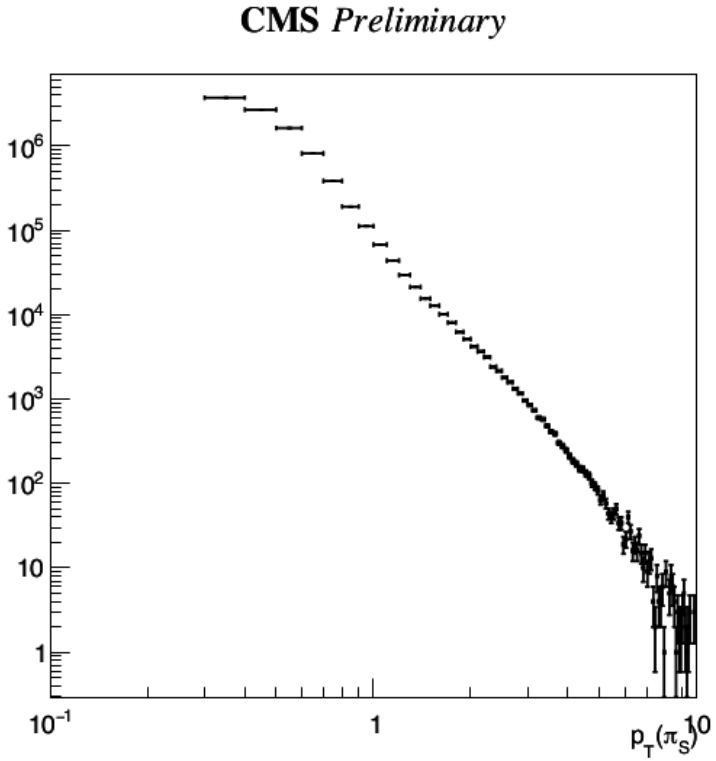


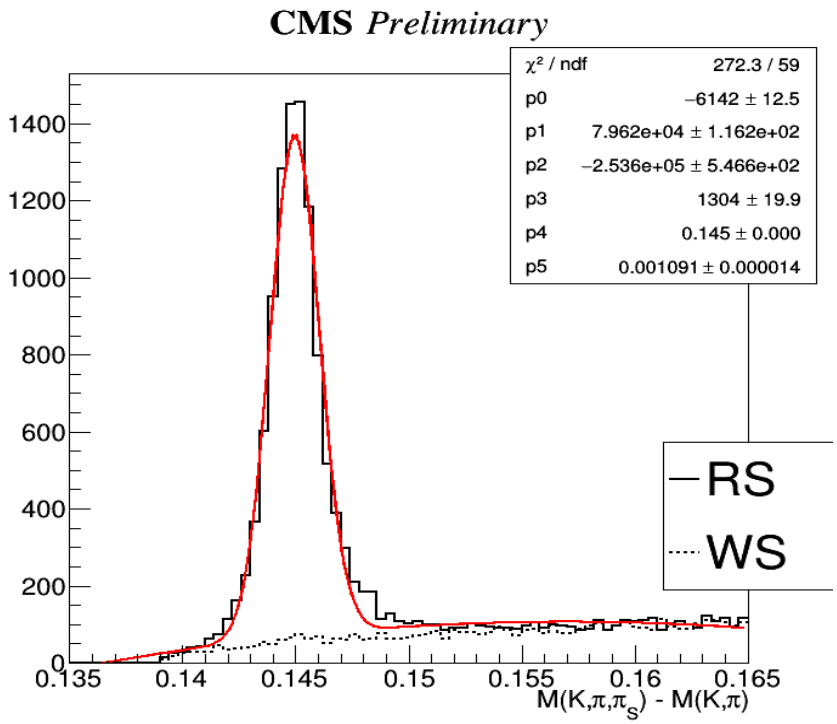
Purity measured with B → D*μν

- b purity: fraction of single-μ triggered events from b decays: $P_b = \frac{N(b \to \mu X)}{N(\mu)}$
- Reconstruct B → D*μν with D*→ $D^0\pi_s$→ (π K) π_s,
- Generate and run on MC for acceptance * efficiency

For Mu9_IP6 trigger

- Put everything together → **$P_b \approx 0.73$, in agreement with MC**
- Left: π_s p_T distribution – starting from 300MeV !
- Right: M(K,π,π_s) – M(K,π); RS= correct sign μ ; WS= wrong μ sign (combinatorial bkg)



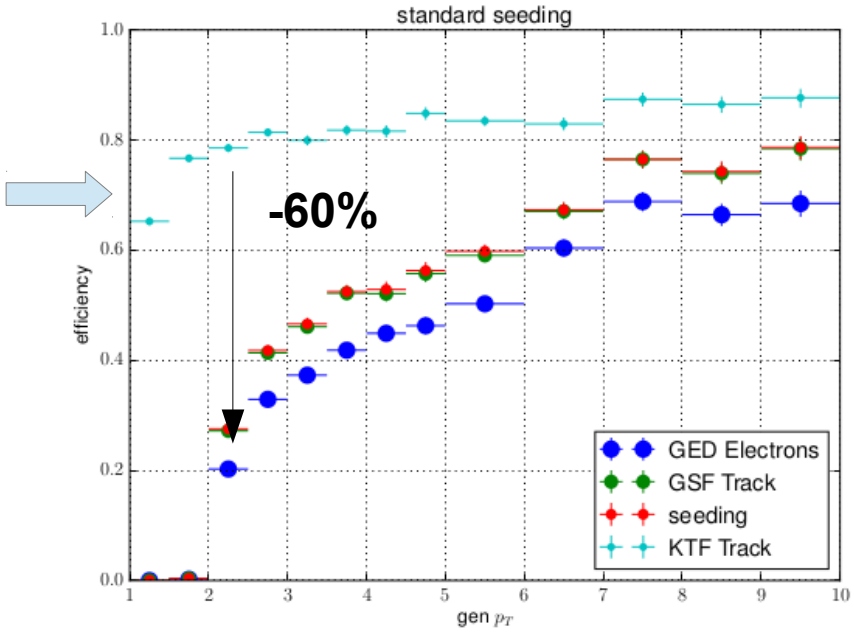


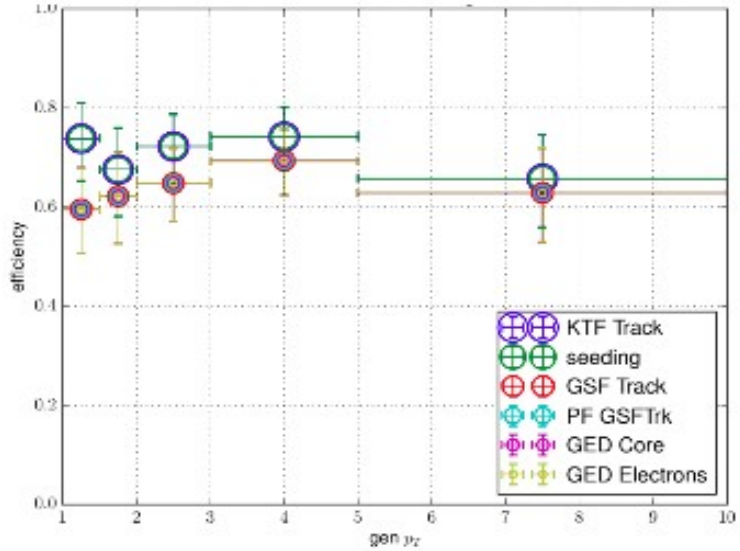
Electron Reconstruction

Electron reconstruction

One of main challenges is the low p_T e reconstruction

- Investigated where low p_T (e) efficiency is lost
- Inefficiencies: Seeding and PF-e/γ steps
- Tried with different seedings:
  - Efficiency increased but not enough (30%-50%)
- PF-e/γ step: under study
- Aiming for a new tool outside of PF (lower plot)

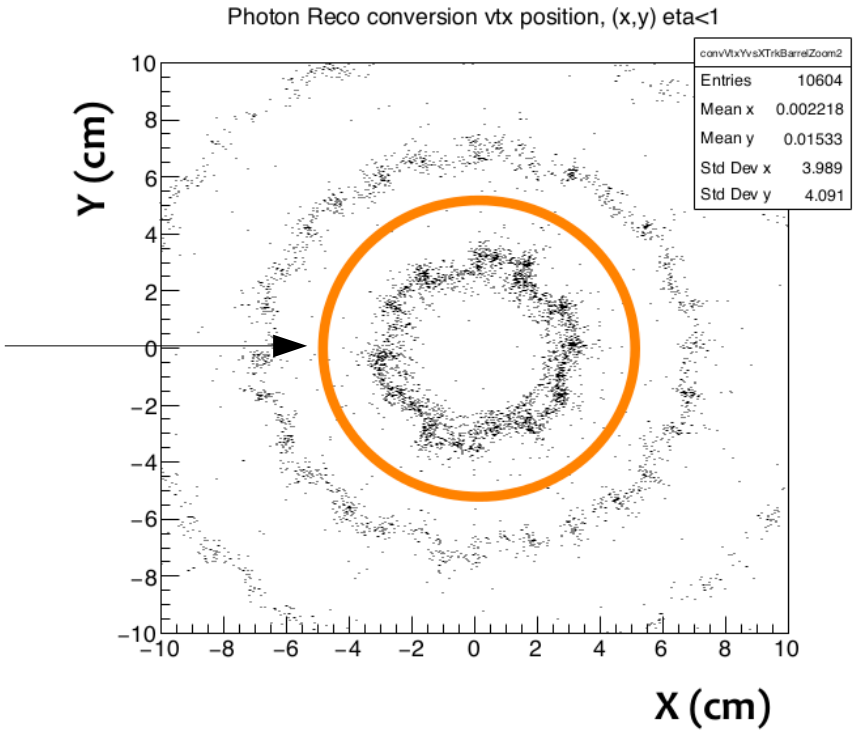


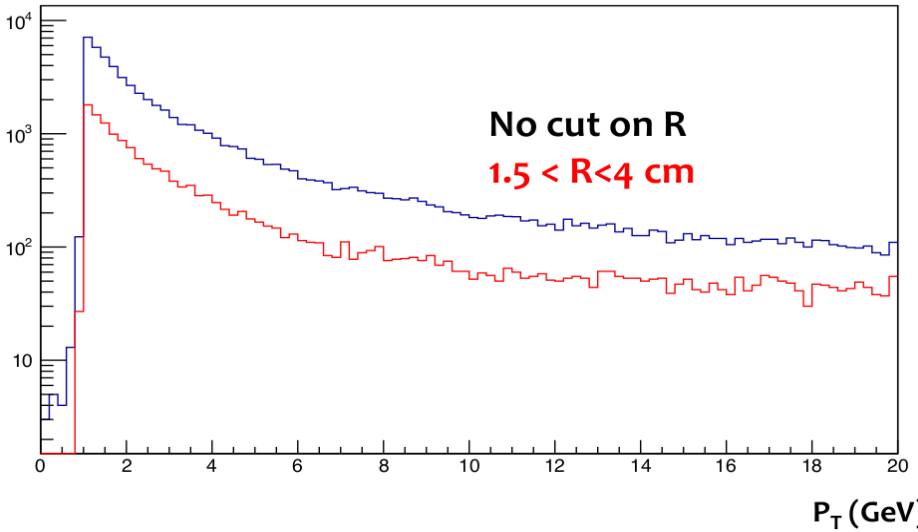


New reconstruction:
- Do not change PF algo
- Add a standalone chain tailor made for low p_T e
- Use Machine Learning techniques to control fakes

Conversions: Low p_T(e) sample

- In order to tune e reconstruction for low p_T, **need a very pure data sample**
- Use general tracks → find distinct γ→ee signature
- Focus only in conversions from 1st PIX layer (1.5cm<R<4cm – upper plot)
- ...then run the gsfElectron reconstruction
- Lower plot: p_T(e) from conversions



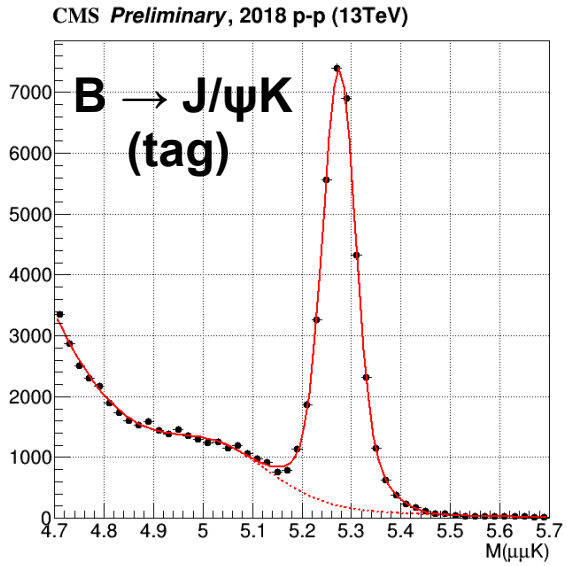


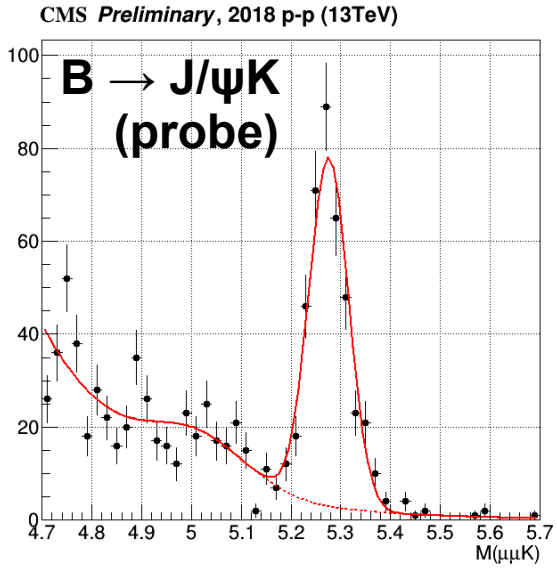
Sample purity ~98%

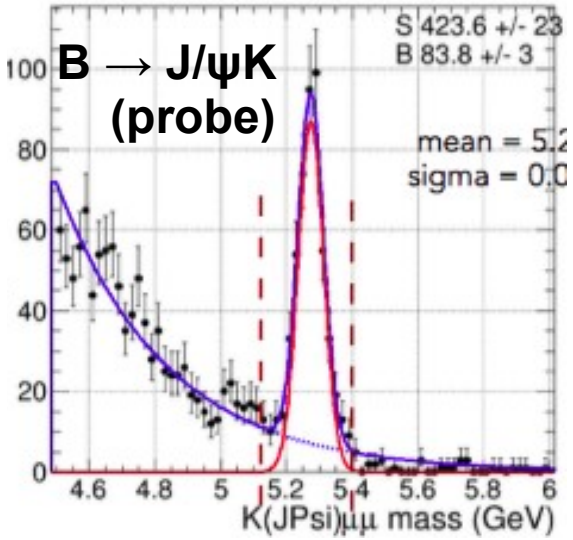
B Reconstruction (using **only 470M** events)

B → J/ψ(→μμ)K / B → μμK

- B reconstructed from μ-pair and a K ; cuts applied to maximize S/√(S+B)
- B → μμK: still not enough data (only 470M from 10B have been processed)



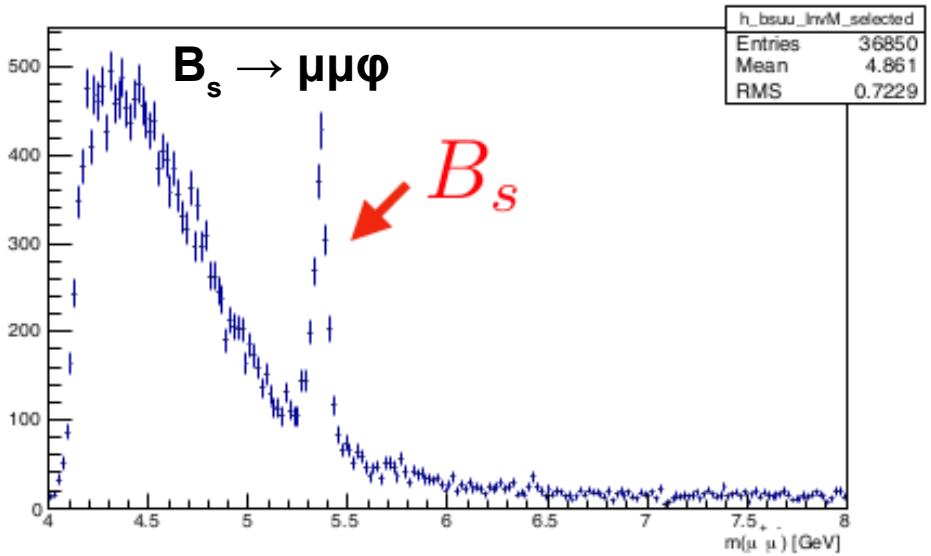


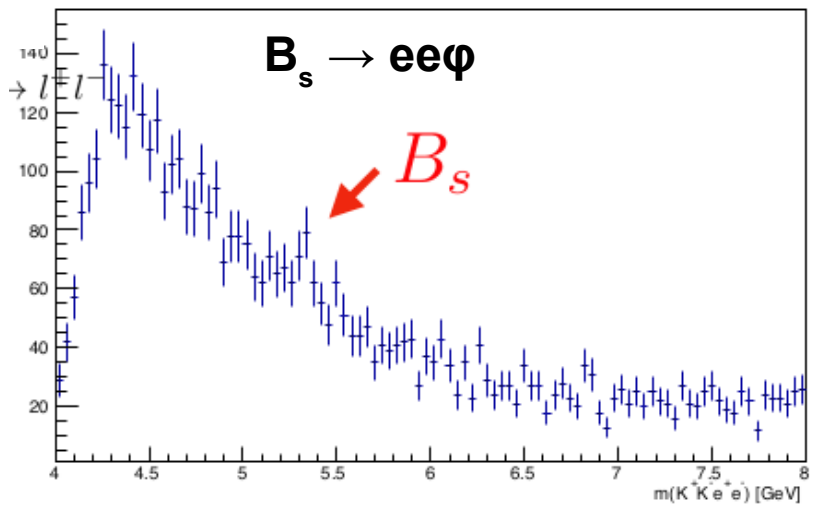


- Next step: Sychronizing B reconstruction codes

$B_s \rightarrow J/\psi\,(\rightarrow\mu\mu$ or $\rightarrow ee)\varphi$

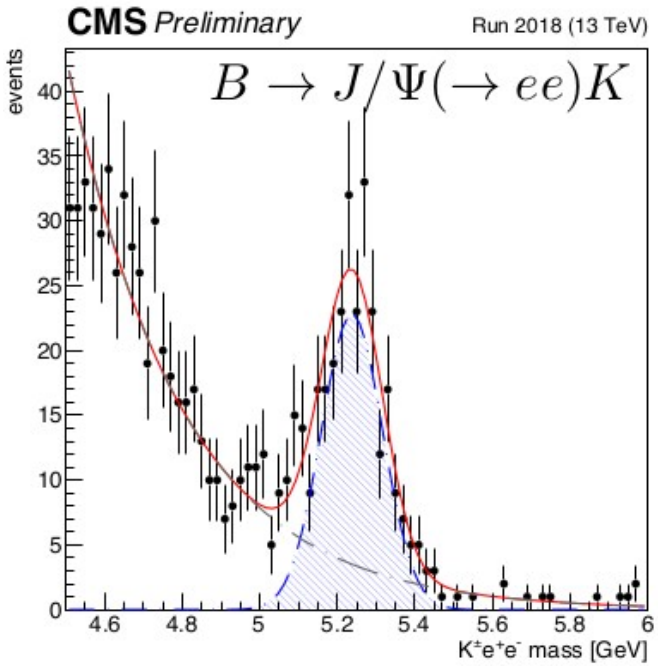
- Reconstruct B_S from e(μ) pair and two tracks
- Helpful for e-ID development
- Difference in B_S in μμ because of triggering μ
- **Expected B_S=550**

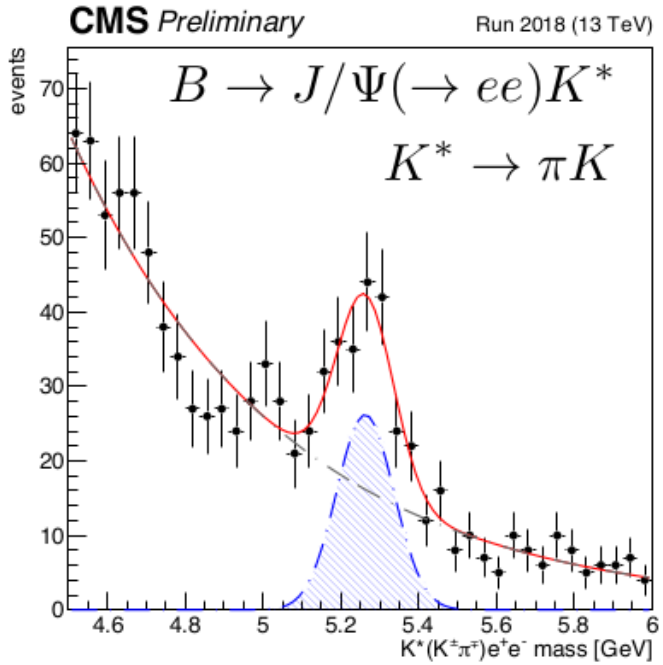




B → J/ψ(→ee)K / B→J/ψ(→ee)K*

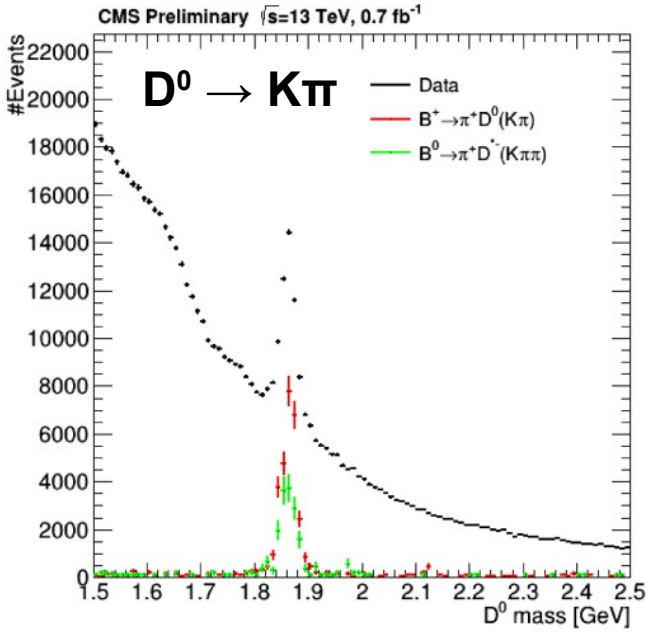
- Reconstruction of B in eeK and eeK* channels
- Even with the current e-ID a decent reconstruction

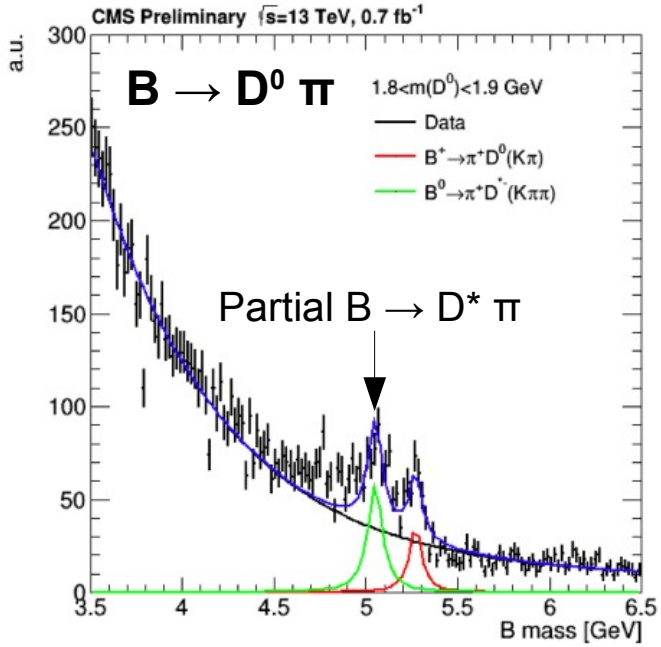




$B \rightarrow D^0(\rightarrow K\pi)\pi$

- First observation in CMS:
  - Can complement D*lv, for purity measurement
  - Can be used study of CP violation
- Large combinatorics in hadronic state → use charge combinations .&. vertex requirements
- Fitted $B \rightarrow D^0(\rightarrow K\pi)\pi$: 55.4 +/- 6.6 events





Other uses of B Parking Sample

- Rare B_S decays: ττ,φφ,KK,Kπ,K*K*,Kττ,K*ττ
- R(D*) measurement
- Flavour violating decays: $B_{(S)} \rightarrow \tau\mu,\tau e$
- CP-Violation in various decays, using opposite-side tagging
- Probe $\tau \rightarrow 3\mu$ via $B \rightarrow D^* \tau\nu$
- And much more (open call to CMS creativity...)

Acknowledgements

- Many thanks to Run Coordination, Trigger/TSG, DAQ, Computing & Offline, T0 Operations, PPD, Physics Coordination, EGM for strong support and a lot of help!

- The success of the B Physics Parking initiative is a success of the entire CMS and a demonstration of our strength and flexibility in pursuing novel topics via novel means

Summary

- A brief status of B Parking analysis presented
- Strong results in e-reconstruction, B reconstruction/selection
- **Already at 80% of the required B number (10^{10} B) – reach our goal until run 2 ends!**
- …. and a lot of work still ongoing!

- Plan for following months:
  - Finalize the low p_T electron reconstruction
  - Work on optimal B selection, using MVA method(s)
  - Work on purity measurement for more triggers

Back up

References

[1] R. Aaij, et al. (LHCb), JHEP 08, 055 (2017), 1705.05802

[2] R. Aaij,Aaij, et al. (LHCb), Phys. Rev. Lett. 113, 151601 (2014),

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[6] LHCb collaboration,Angular analysis of the $B \to K^*\mu\mu$ decay using $3fb^{-1}$ of integrated luminosity

[7] Belle collaboration, S. Wehle et al., Lepton- avor-dependent angular analysis of $B \to K^*ll$ hys. Rev. Lett. 118 (2017) 111801