

B PHYSICS PARKING PROGRAM: STATUS & GOALS



Greg Landsberg, Martino Margoni
CMS MB Meeting - 14/1/19

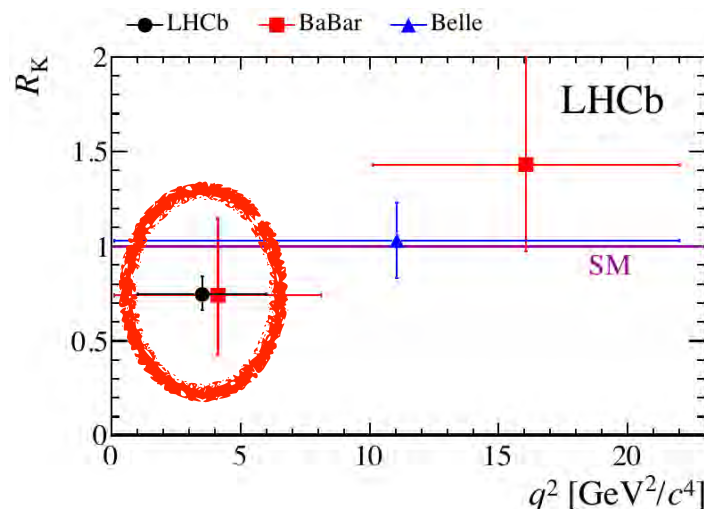


Introduction

- ♦ The B physics parking proposal was submitted to the CMS management in February 2018, with the main goal to make CMS competitive with LHCb in the $R(K)/R(K^*)$ measurements, which attracted a lot of attention in the last couple of years
- ♦ It also has a potential to enable a number of new measurements in B physics sector, which were not possible before
- ♦ The proposal was enthusiastically endorsed by the management and implemented in early May 2018
- ♦ The goal was "simple": record $\sim 10^{10}$ unbiased B hadron events in 2018, using the flexibility of the CMS data taking model



Flavor Anomalies: $R(K^{(*)})$



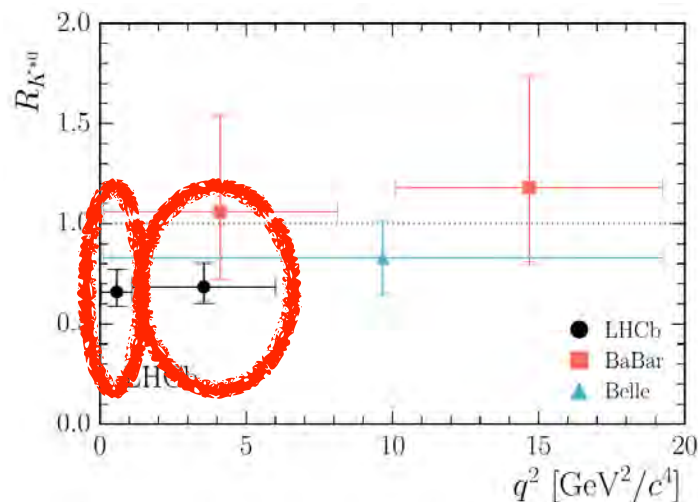
$$R_{K^{(*)}} = \frac{BR(B \rightarrow K^{(*)} \mu \mu)}{BR(B \rightarrow K^{(*)} e e)}$$

LHCb results in three q^2 bins of two channels:

$$R_K^{[1,6]} = 0.745_{-0.074}^{+0.090} \pm 0.036$$

$$R_{K^*}^{[0.045,1.1]} = 0.66_{-0.07}^{+0.11} \pm 0.03$$

$$R_{K^*}^{[1.1,6]} = 0.69_{-0.07}^{+0.11} \pm 0.05$$



3 observables deviating by $\sim 2\sigma - 2.5\sigma$ from the SM predictions

Bordone, Isidori, Pattori 1605.07633

Theory: $R_K^{[1,6]} = 1.00 \pm 0.01$, $R_{K^*}^{[1.1,6]} = 1.00 \pm 0.01$, $R_{K^*}^{[0.045,1.1]} = 0.91 \pm 0.03$



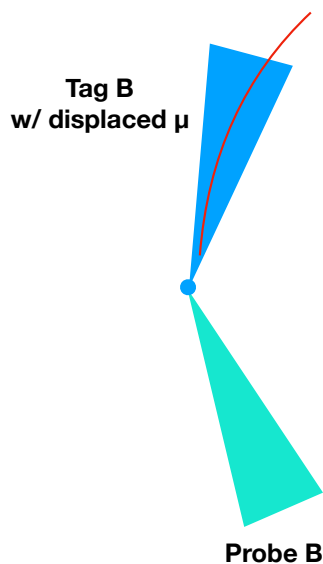
Documentation

- ♦ The proposal can be found here (April 4, 2018 XC meeting):
 - https://indico.cern.ch/event/718742/contributions/2954094/attachments/1626805/2590890/B_Parking_Proposal_V2.pdf

Proposal to collect a generic sample of $O(10^{10})$ B hadron decays designed to measure R_K and R_{K^*} in CMS using data parking in 2018

**Oliver Buchmueller,¹ Sara Fiorendi,² John Hakala,³ Mario Galanti,⁴
Georgios Karathanasis,⁵ Stefano Lacaprara,⁶ Greg Landsberg,³ Ka Tung Lau,³
Sandra Malvezzi,² Riccardo Manzoni,⁷ Martino Margoni,⁵ Fabrizio Palla,⁸
Maurizio Pierini,⁹ Paris Sphicas,^{5,9} and Mauro Verzetti.⁹**

Parking: Trigger Strategy



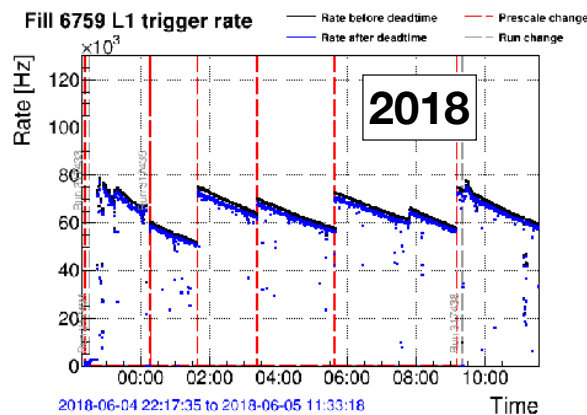
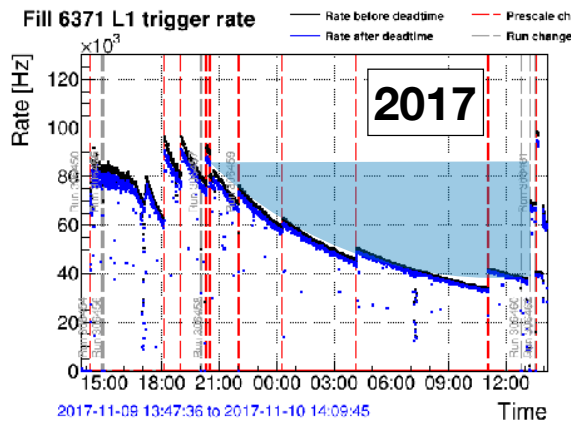
- As the luminosity drops, turn on various single-muon $|\eta|$ -restricted seeds, which allow to keep L1 rate constant and increase HLT rate toward the end of each fill

Sara Fiorendi,
Riccardo Manzoni,
Mauro Verzetti

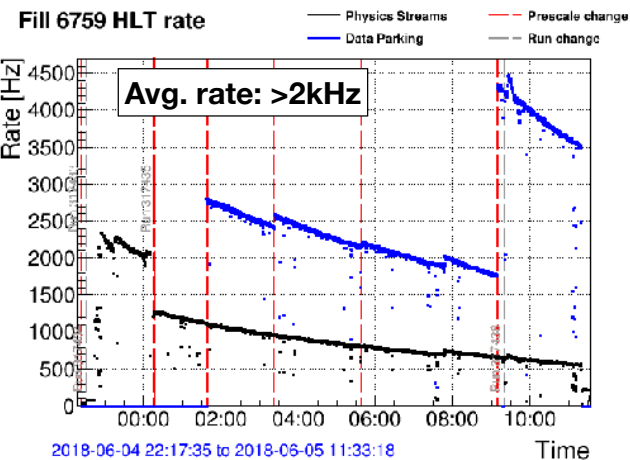
Lumi (E34)	L1 seed	HLT	rate	purity	#B
1.7	Mu12er1p5	Mu12_IP6	1585	0.92	10.5M
1.5	Mu10er1p5	Mu9_IP5	3656	0.80	21M
1.3	Mu8er1p5	Mu9_IP5	3350	0.80	20M
1.1	Mu8er1p5	Mu7_IP4	6153	0.59	33M
0.9	Mu7er1p5	Mu7_IP4	5524	0.59	29M

Trigger strategy — L1

$\langle \text{PU} \rangle = 20$



Trigger strategy — HLT





Where Are We Now?

- ◆ The parking program has been successfully finished without a single "incident" of saturating DAQ/Tier 0 transfers
- ◆ We have recorded $\sim 1.2 \times 10^{10}$ triggers, or nearly 10B b hadron pairs, thus accomplishing the original goal!
- ◆ Have all main MC samples needed for electron ID development and R measurements delivered over the Christmas break
 - ◉ Many thanks to the Computing/PPD/Ops/BPH MC contact for fast turnaround!
- ◆ Made significant progress in low- p_T electron reconstruction, eliminating the main sources of inefficiency below 2 GeV
- ◆ Finished preliminary studies and are preparing a skim for $R(K/K^*/\phi)$ measurements as a part of parked data reconstruction campaign (later this month)
- ◆ Finalizing incorporation of the parking effort into the new BPH structure, with the transition from operations to physics analysis
- ◆ Received a number of expressions of interest to do other studies with the parked data

New BPH Structure

BPH Conveners
Martino till 1/9/19
Greg till 1/9/20

Production & Properties
Giacomo – till 1/9/2019
Ruslan – till 1/9/2019

Exotica & Rare Decays
Sara – till 1/9/2019
Sergey– till 1/9/2020

Violation of Fundamental Symmetries
TBA – till 1/9/2019
TBA – till 1/9/2020

Software & Framework Coordinators
Paolo – till 1/9/2019
Thomas– till 1/9/2020

Electron Contact
Nancy – till 1/9/2019

Muon & Tracking Contact
Valentina till 1/9/2019

Trigger Contacts
Sergey– till 1/9/2019
Alessio– till 1/9/2019

MC Contact
Jordan till 1/9/2019

Upgrade Contact
Subir till 1/9/2019



Next Steps

- ◆ Finalizing everything for the reconstruction campaign (late Jan - early Feb, ~1 month long)
- ◆ The goal is to have everything reconstructed with best default reco + special RAW skim for the R measurements
 - ◉ Will allow full access to parked data for many analyses with continuing development of the low- p_T electron ID for the R measurements
- ◆ Discussing whether we need to keep AOD on disk for some period of time beyond the skim
- ◆ miniAOD remains the default format for most of parked data analyses

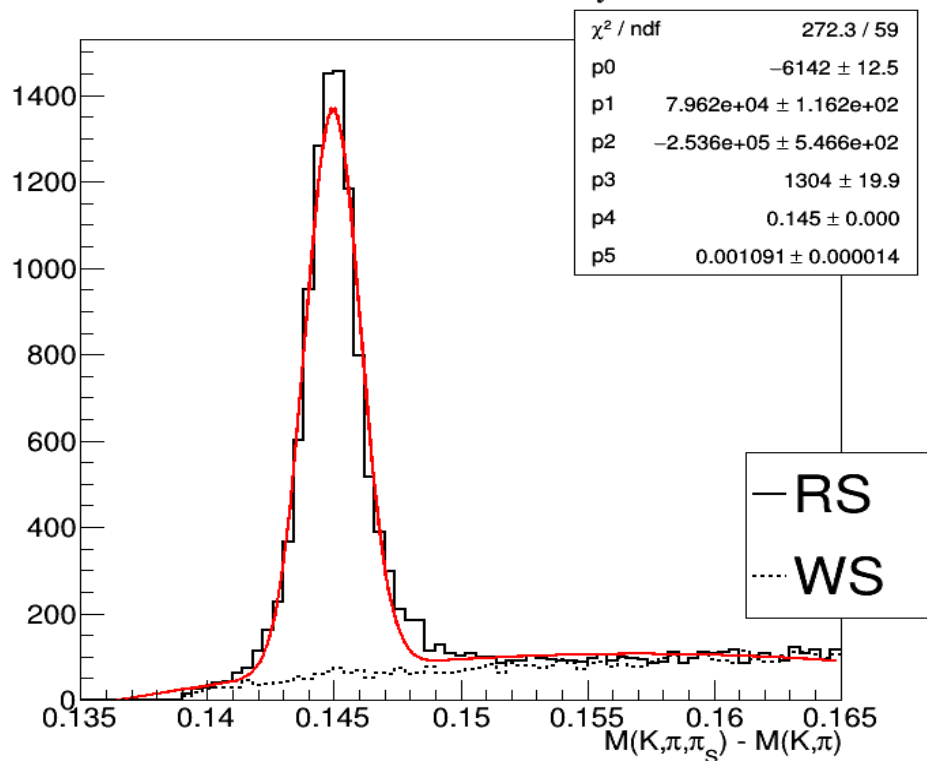


Purity Estimator

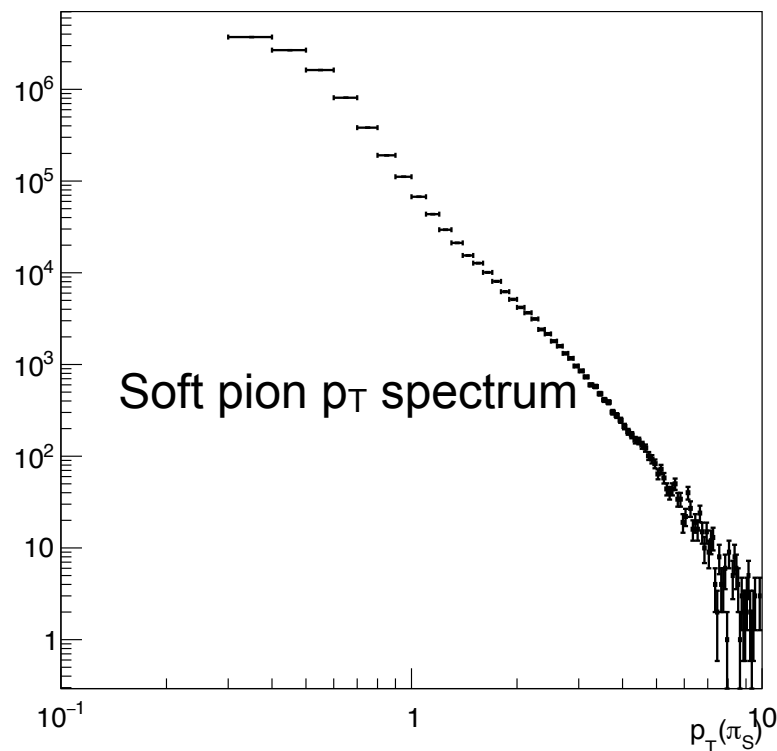
George Karathanasis

- Define purity as a fraction of triggers coming from $b \rightarrow \mu$ decays, using $B^0 \rightarrow D^* \mu \nu \rightarrow \mu K \pi \pi_s \nu$
- Measured purity of $\sim 73\%$ using a reconstructed fill ($\sim 5\%$ of the full parked data set)

CMS Preliminary



CMS Preliminary





What we Have on Tape

Mode	N_{2018}	f_B [17]	\mathcal{B}
Generic B hadrons			
B_d^0	4.99×10^9	0.4	1.0
B^\pm	4.99×10^9	0.4	1.0
B_s	1.56×10^9	0.1	1.0
b baryons	1.56×10^9	0.1	1.0
B_c	1.25×10^7	0.001	1.0
B hadrons total	1.25×10^{10}	1.0	1.0
Interesting B decays			
$B^0 \rightarrow K^* \ell^+ \ell^-$	3290	0.4	$\frac{2}{3} \times 9.9 \times 10^{-7}$ [14]
$B^\pm \rightarrow K^\pm \ell^+ \ell^-$	2250	0.4	4.51×10^{-7} [15]

More than 20x the entire BaBar B sample in 6 months!



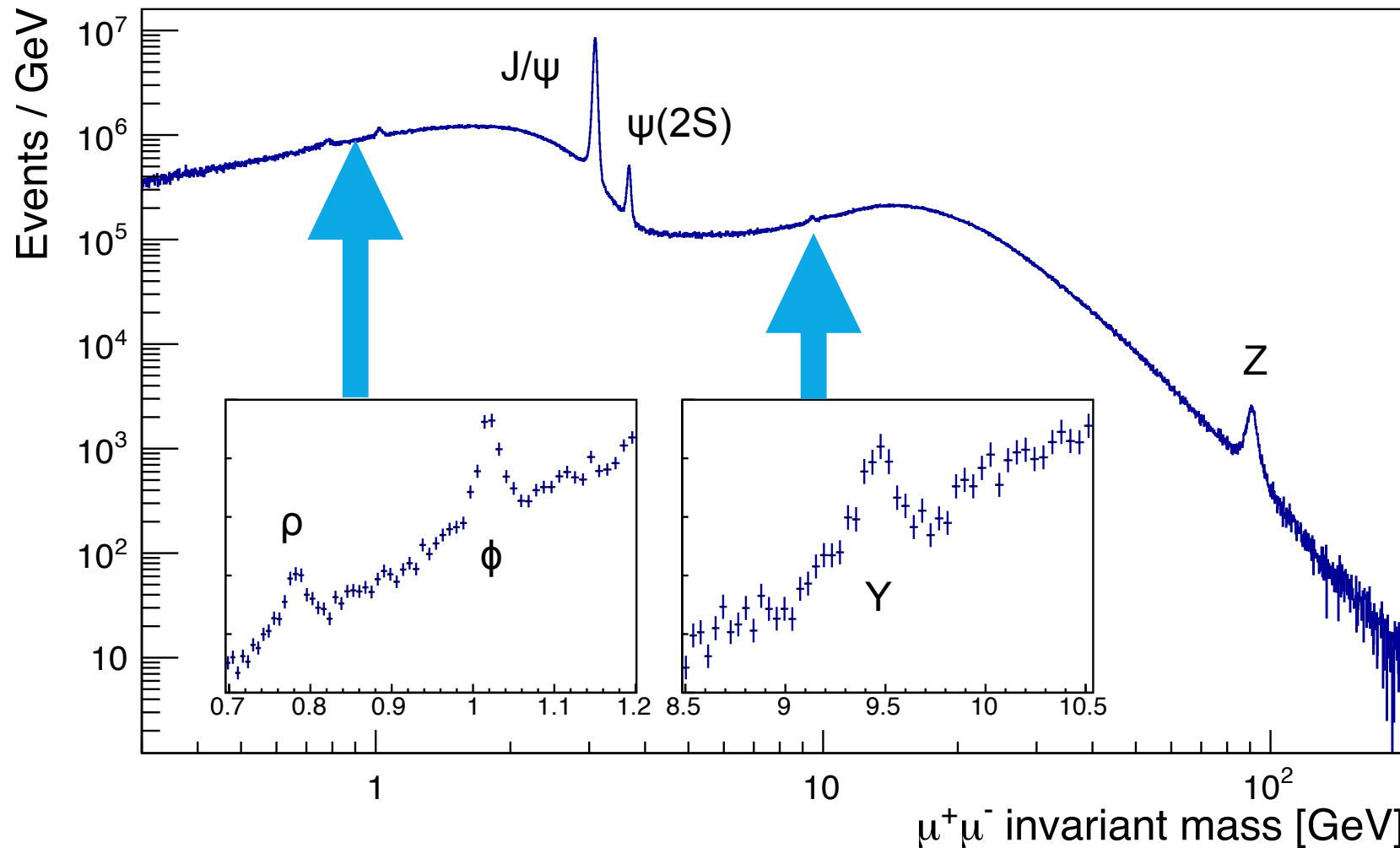
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Trigger-Level Dimuon Spectrum

Ka Tung Lau

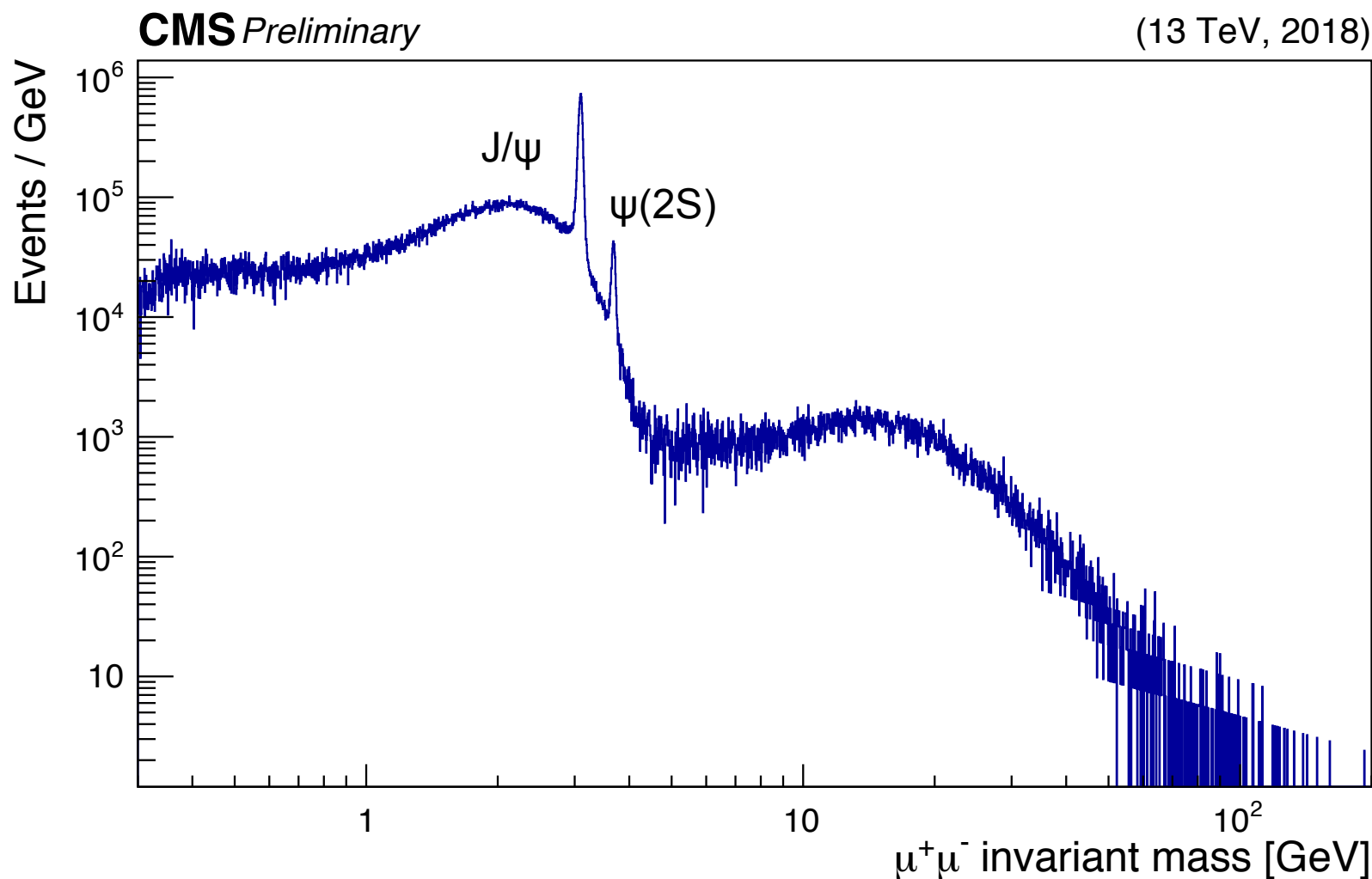
(13 TeV, 2018)

CMS Preliminary



Displaced Dimuons

Ka Tung Lau





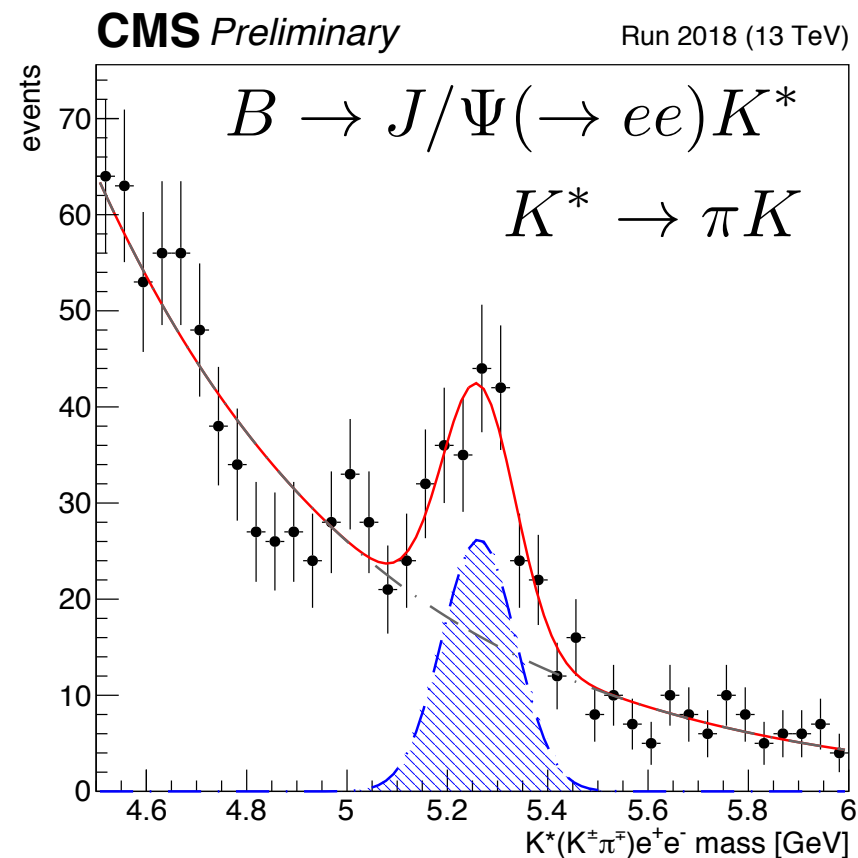
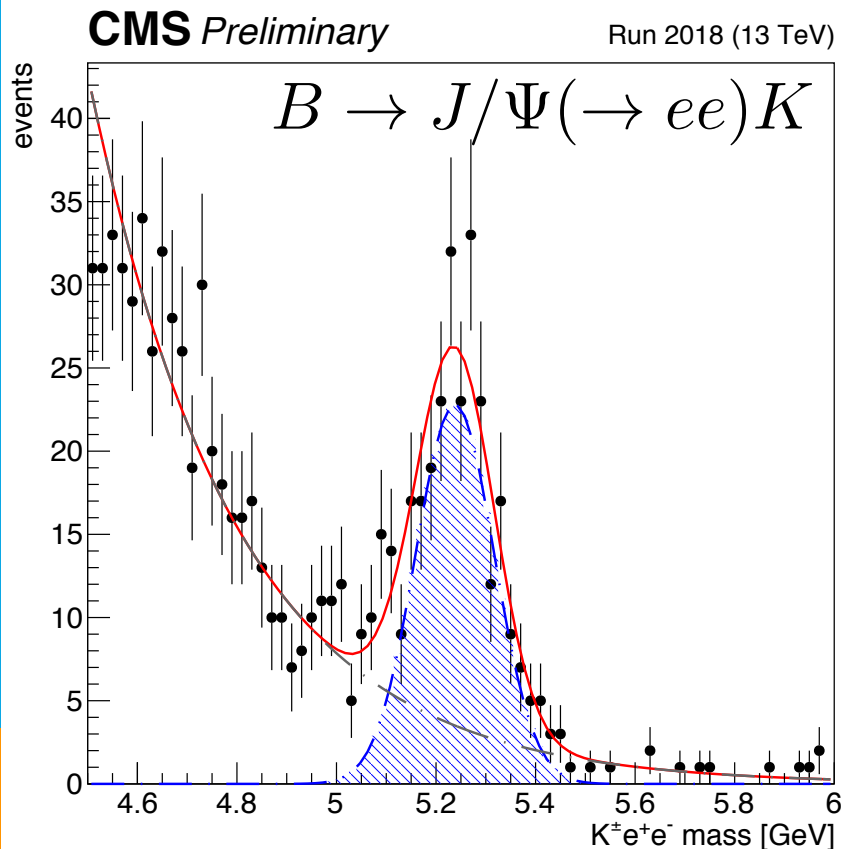
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First Electron Results

◆ First observation of these decays in CMS!

● Out-of-the-box electron ID, ~5% of data

Sara Fiorendi
Riccardo Manzoni



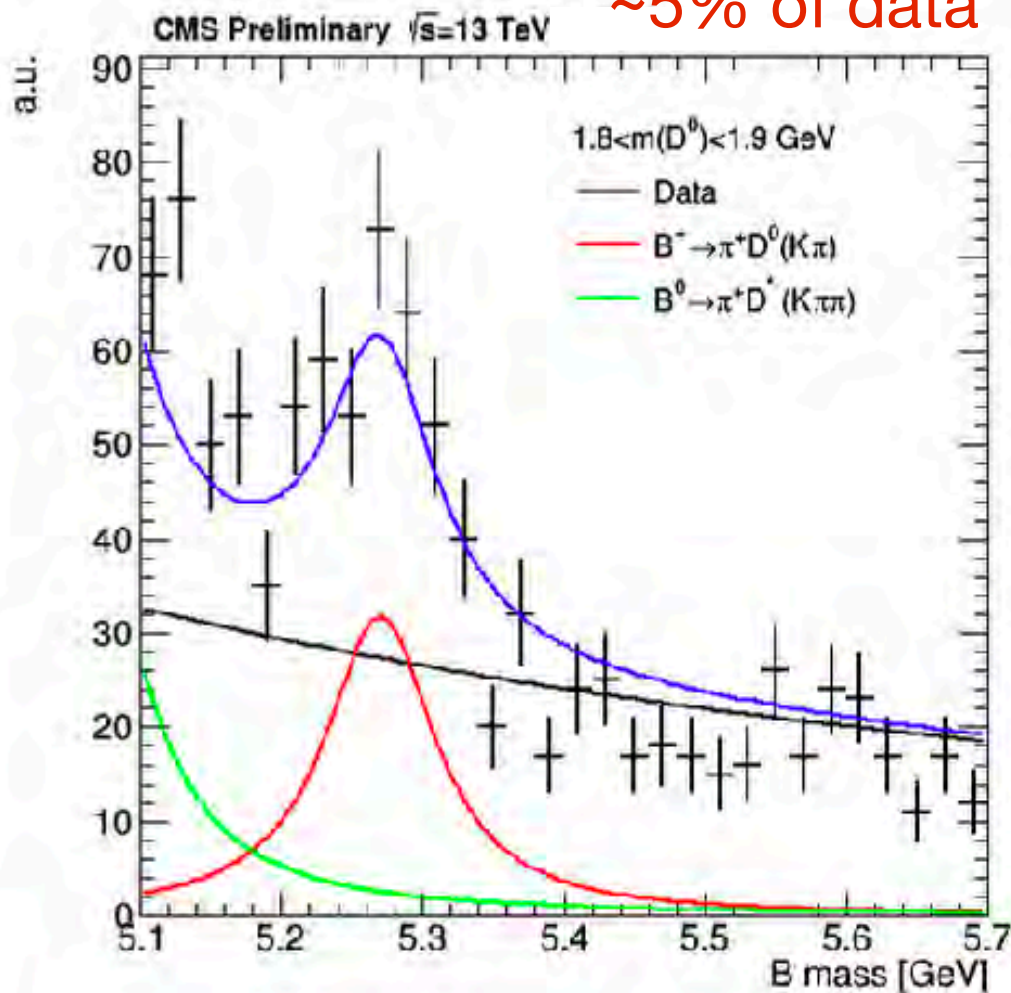


First All-Hadronic Decay

Thomas Strebler

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

~5% of data

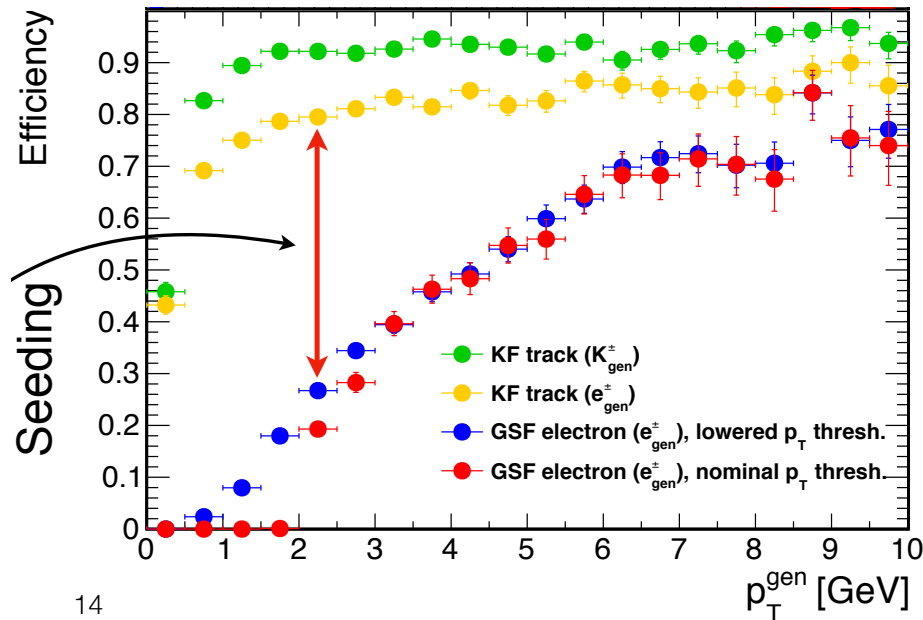
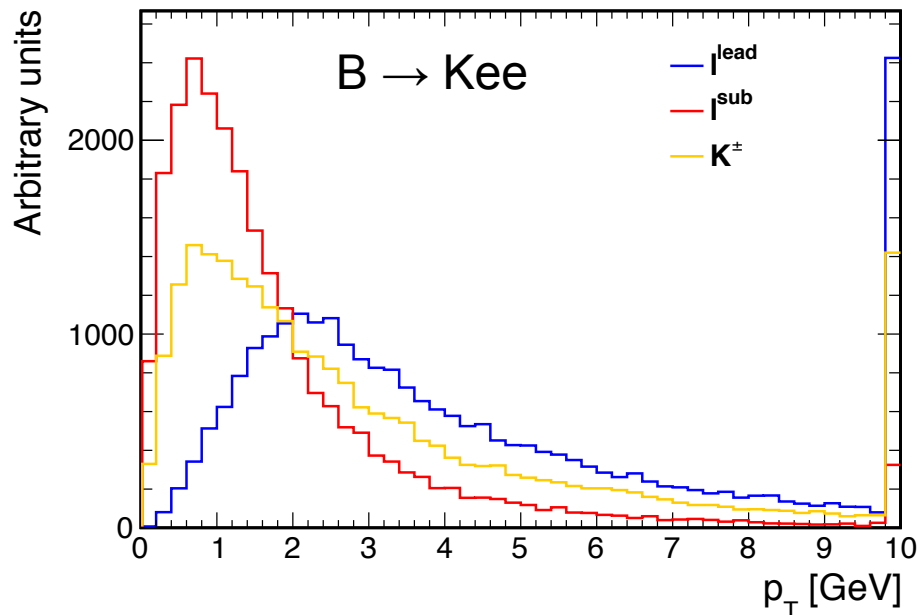




Challenges of $R(K/K^*/\phi)$

- ◆ Main challenge: $\text{Br} \sim 10^{-7}$
- ◆ This is why need $\sim 10^{10}$ B's!
- ◆ Low-energy electron reconstruction
 - ◉ Need significant investment to improve it down to ~ 1 GeV

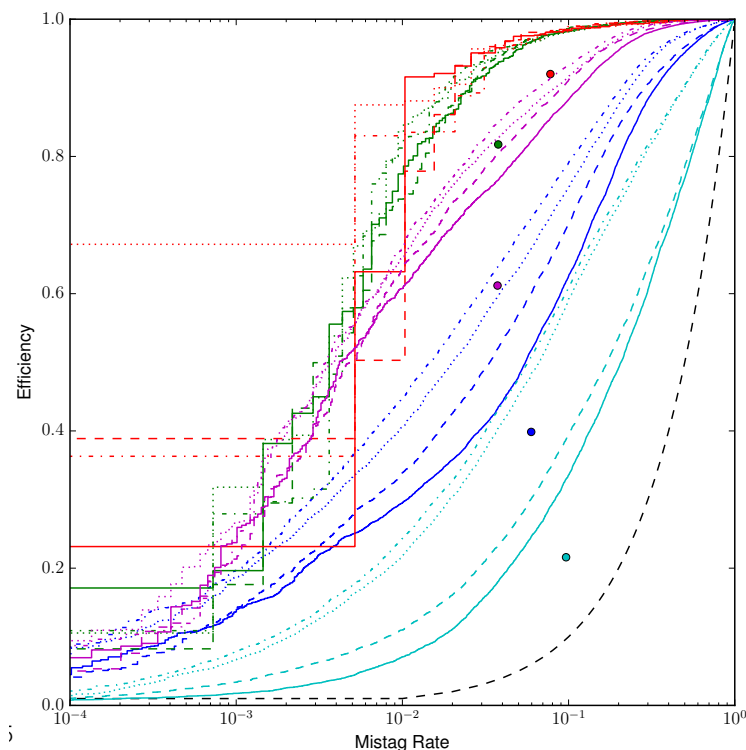
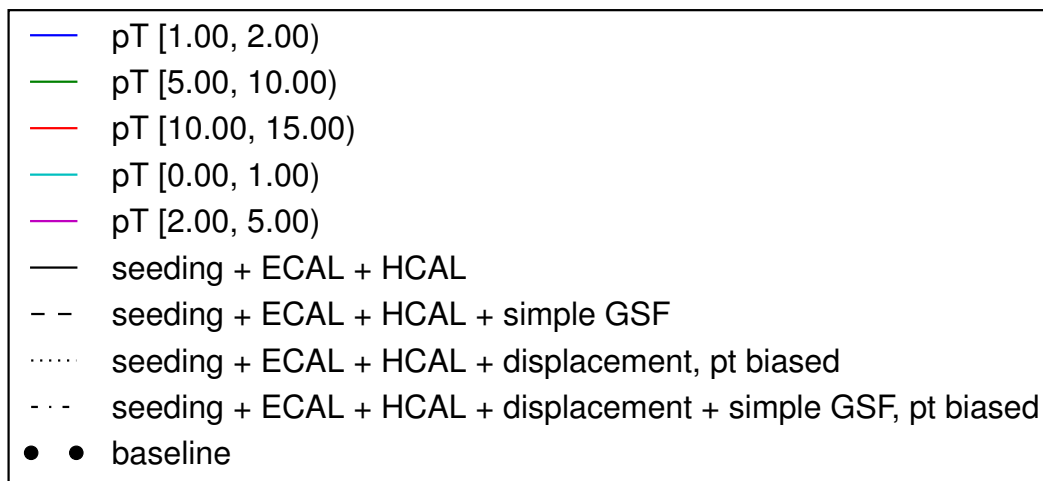
Rob Bainbridge





New Seeding

- ◆ Solution: create an alternative reco path for low-pT electrons
 - ◉ Remove limitations of the current seeding without touching PF reconstruction
 - ◉ Focus on improving the efficiency for low-p_T electrons by using a combination of ECAL supercluster seeding and track seeding





Status of the Electron PR

- ◆ Existing PR (up to GsfTracks):
 - ◉ FastSim and Phase 2 integration done
 - ◉ Timing/memory/storage review: all OK, except for the timing for the default path
 - ◉ To be studied: Code optimization? Raise p_T thresh (e.g. to 0.7 GeV)?
- ◆ Code continues to be reviewed by RECO/AT, minor code development continues
- ◆ Next PR (full chain) - expected this week:
 - ◉ Developed seeding module to "link" ElectronSeeds and PselD
 - ◉ BDT outputs from seeding are now stored in ValueMaps, indexed by electron
 - ◉ miniAOD integration essentially done
 - ◉ FullSim recipe in 10.4 and also back-ported to 10.2
- ◆ Also: developed new ID Producer module (can replace existing Egamma ID tools)



Asymmetric Conversions

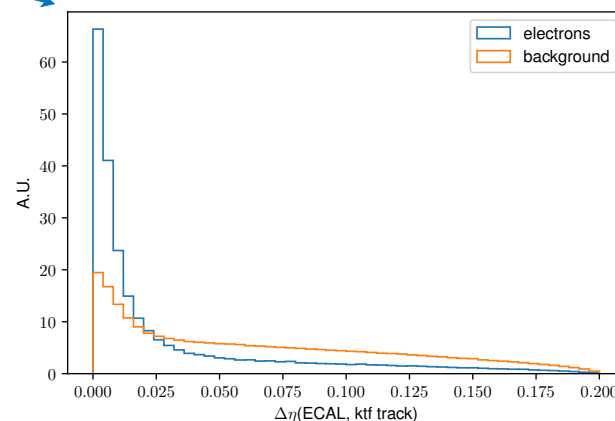
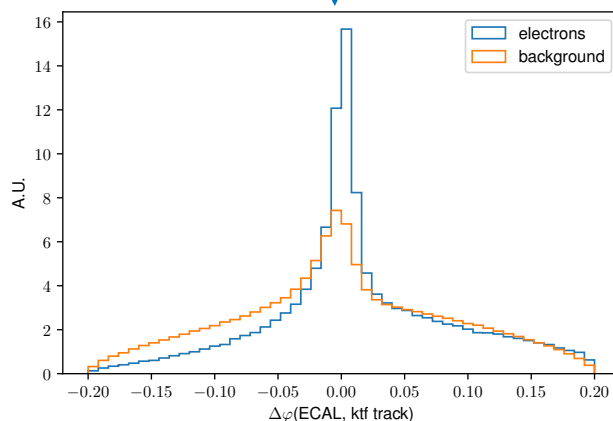
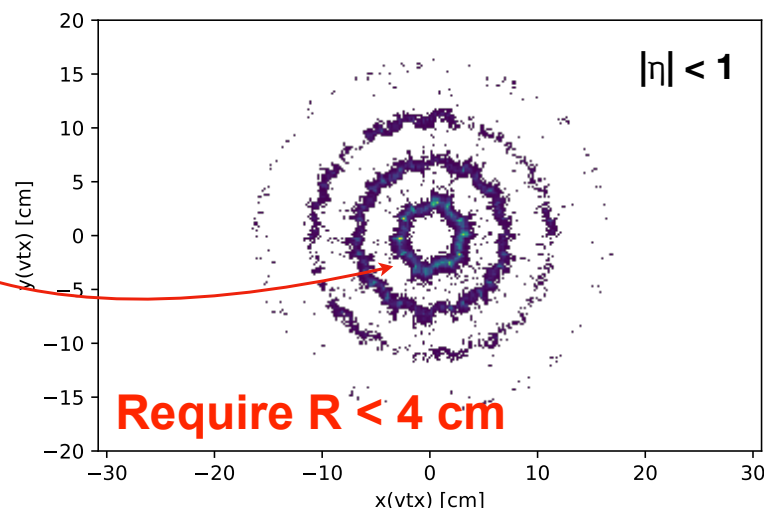
- ◆ Use asymmetric conversions to study low- p_T electrons

Nancy Marinelli
Mauro Verzetti

Other datasets are also being considered

Use conversions stemming from the first pixel layer/beampipe

Example of discriminating variables used in the seeding

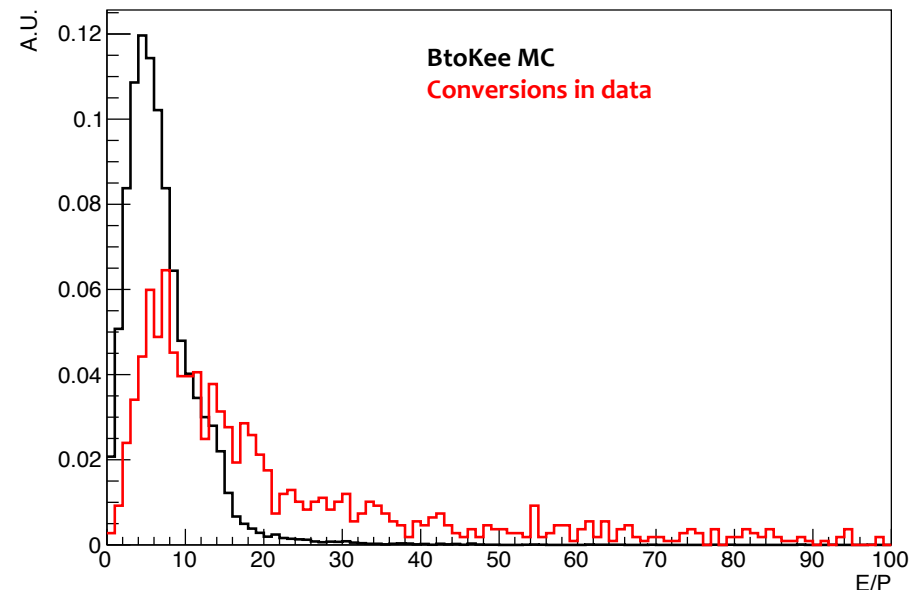
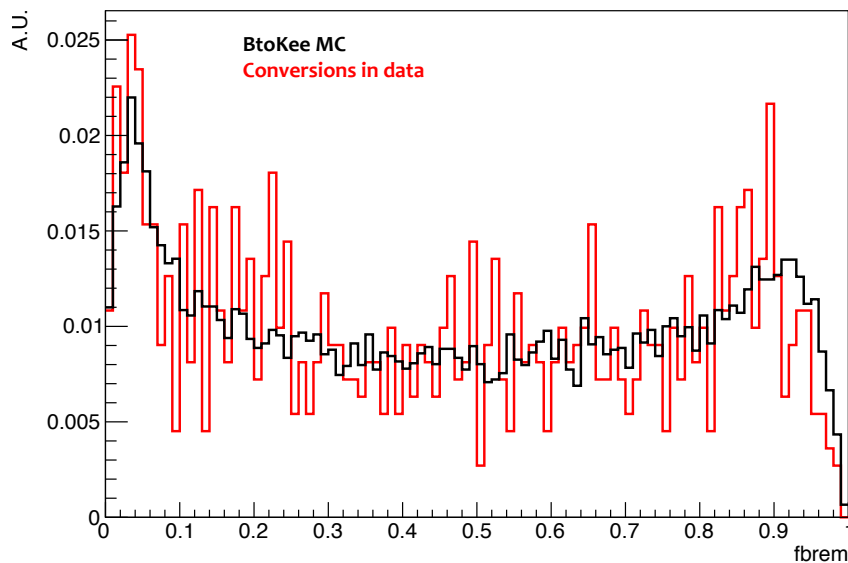


Conversion in Data

Nancy Marinelli

◆ First look at data is very promising:

- ◉ Similar fraction of bremsstrahlung energy in small fraction of data and signal MC
- ◉ E/p is higher in data, but this is expected as for conversions the energy should match the momentum of a pair, not a single track

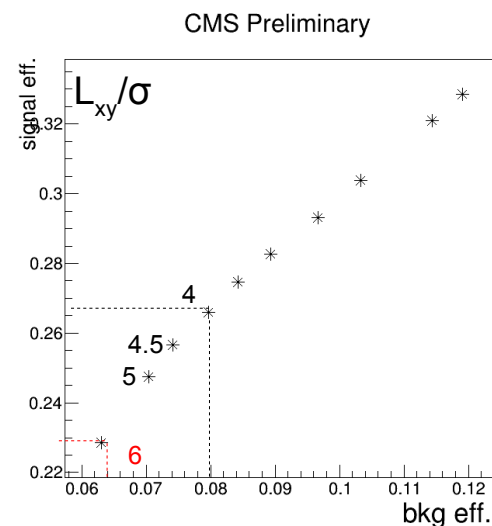
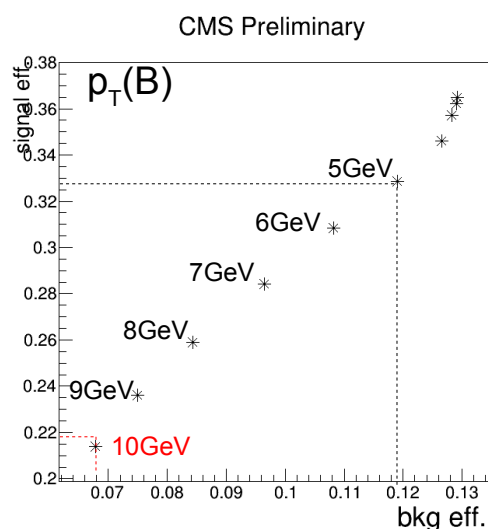
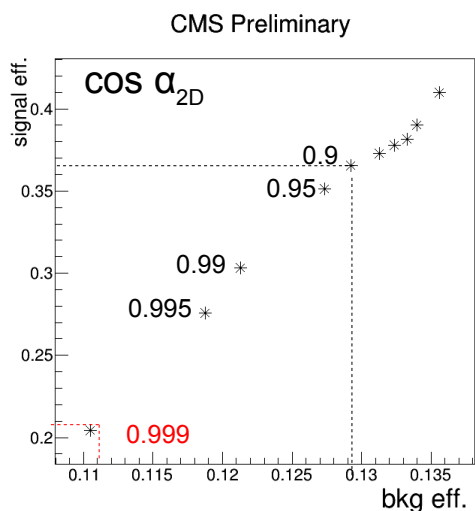




Skim Status

- Given that the new electron ID is not finalized, preparing a O(a few %) skim to be stored in RAW format necessary for R measurements
 - Looking for a 3-track displaced good-quality vertex with some kinematic requirements on the tracks
 - Require one of the tracks to be an electron (to be updated with the latest electron ID from earlier slides)
 - About 40% efficient for the signal; allows to reduce the event rate to ~2%
 - PR exists for the R(K) skim; adding R(K^{*}/φ) by requiring an extra track and some kinematic requirements

George Karathanasis





Towards $R(\phi)$

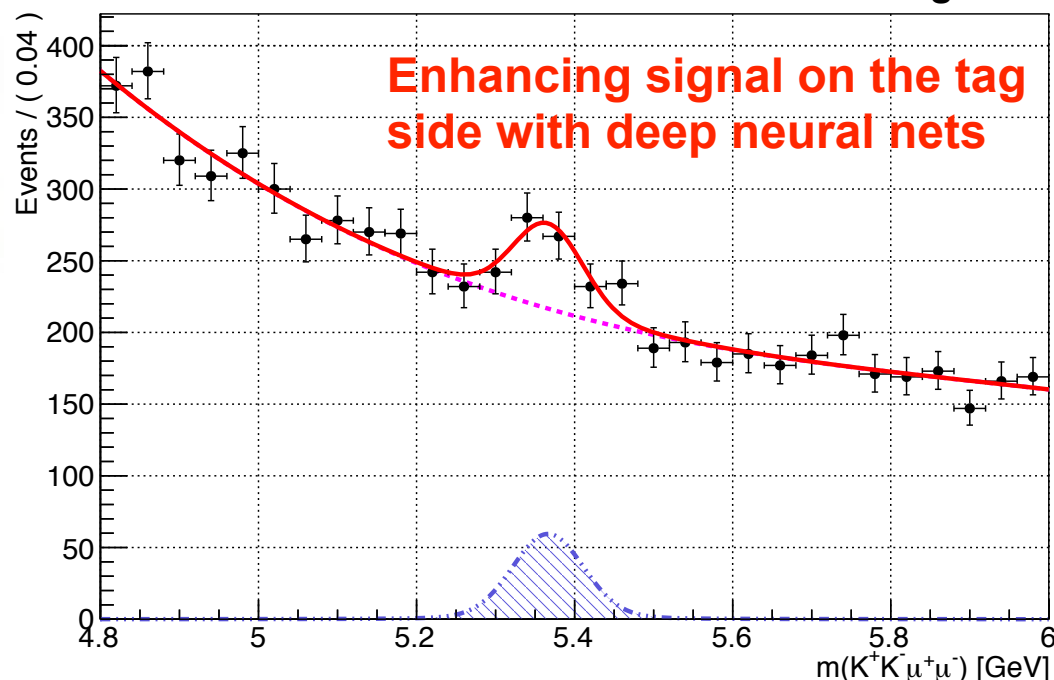
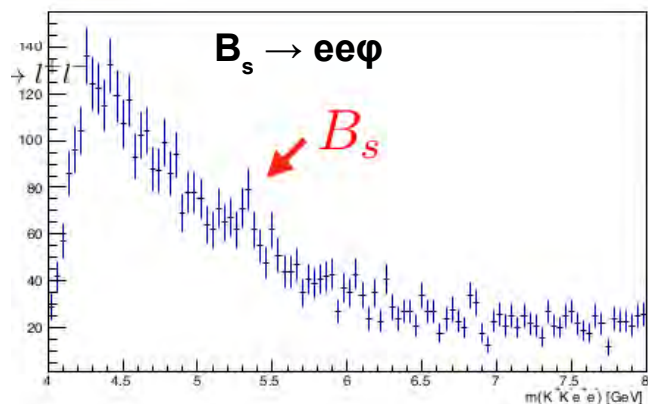
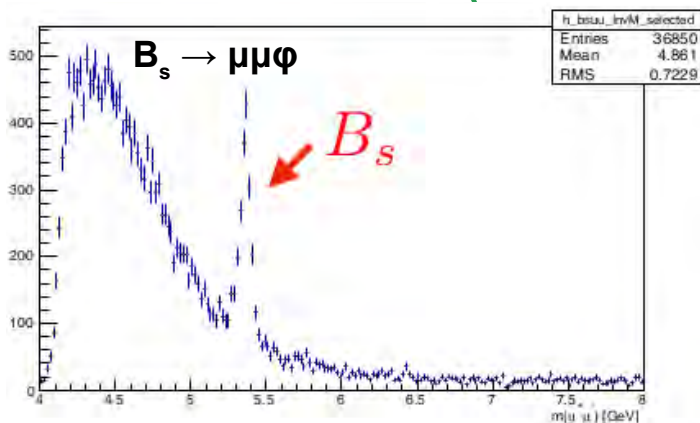
- ◆ The $R(\phi)$ ratio has not been measured before
- ◆ Theoretically as clean as (and combinable with) $R(K^*)$
- ◆ Expect comparable number of events to the $R(K^*)$ measurement (x6 lesser yield, but lower bkg.)

Ka Tung Lau

~5% of data

MVA Cut: 0.80

CMS Work in Progress





Other Uses

- ◆ So far, we only brainstormed other potential physics cases - planning for a workshop in early summer at CERN with invited theorists to have a more focused approach
- ◆ Some (rough) ideas:
 - ◉ Rare B_s decays: $\tau\tau$, $\phi\phi$, KK , $K\pi$, K^*K^* , $K\tau\tau$, $K^*\tau\tau$
 - ◉ $R(D^{(*)})$ measurement
 - ◉ Flavor violating decays: $B_{(s)} \rightarrow \tau\mu$, τe
 - ◉ CP-violation in various decays, using opposite-side tagging
 - ◉ Perhaps even probe $\tau \rightarrow 3\mu$ via $3 \times 10^8 D^{(*)}\tau\nu$ decays $\rightarrow D^{(*)}\mu\mu\mu\nu$
 - ◉ **Your favorite topic here**



Commitments/Interest

♦ Low- p_T τ ID for $R(D/D^*)$ and $B_s(\tau\tau)$ measurements

- ◉ Yuta Takahashi, Stefano Leontsinis (U Zurich), Pablo Matorras (Santander)
 - ✦ Presentations at the [BPH meeting tomorrow](#)
- ◉ Sandro Fonseca, Jordan Martin, Eliza Melo, Felipe Silva (Rio), Nuno Leonardo (LIP)
- ◉ Caltech

♦ CP-violation measurements:

- ◉ Demonstration of feasibility: Maurizio Pierini (CERN)
- ◉ CPV in $B_s \rightarrow J/\psi\phi$: U's of Padova, Pisa, Madras
- ◉ CPV in $B_s \rightarrow \phi\phi$: U of Padova

♦ Minimum bias studies:

- ◉ Charm cross section: Achim Geiser, Nur Jomhari (DESY)
- ◉ Sexaquarks: Steven Lowette (VUB)

♦ $\Lambda_b \rightarrow \Lambda\gamma$

- ◉ Kajari Mazumdar (TIFR)



Quintessential CMS!

- ◆ This challenging program would not have been possible if not for quintessential CMS strength:
 - ◉ Everybody pulled together and were willing to take calculated risks to make this happen!
- ◆ 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



Conclusions

- ◆ We have succeeded in a bold and aggressive program of putting $\sim 10^{10}$ b hadron decays on tape last year
- ◆ Required to push the CMS resources, but offers a very handsome potential for the LS2 years
- ◆ Unique opportunity to test several flavor anomalies before Belle II and the LHCb trigger upgrade
- ◆ Significantly enhances the B physics potential in CMS and makes us competitive on a number of measurements that were not possible before
- ◆ Looking for many people to join and help with logistic, particle ID, reconstruction, and - of course! - the analysis!
- ◆ Open to new ideas and proposals on how to use this wealth of data, which we are about to uncover