Search for $B^+ \to \mu^+ \nu_\mu$

Vitalii Lisovskyi

Supervisor: Xabier Cid Vidal

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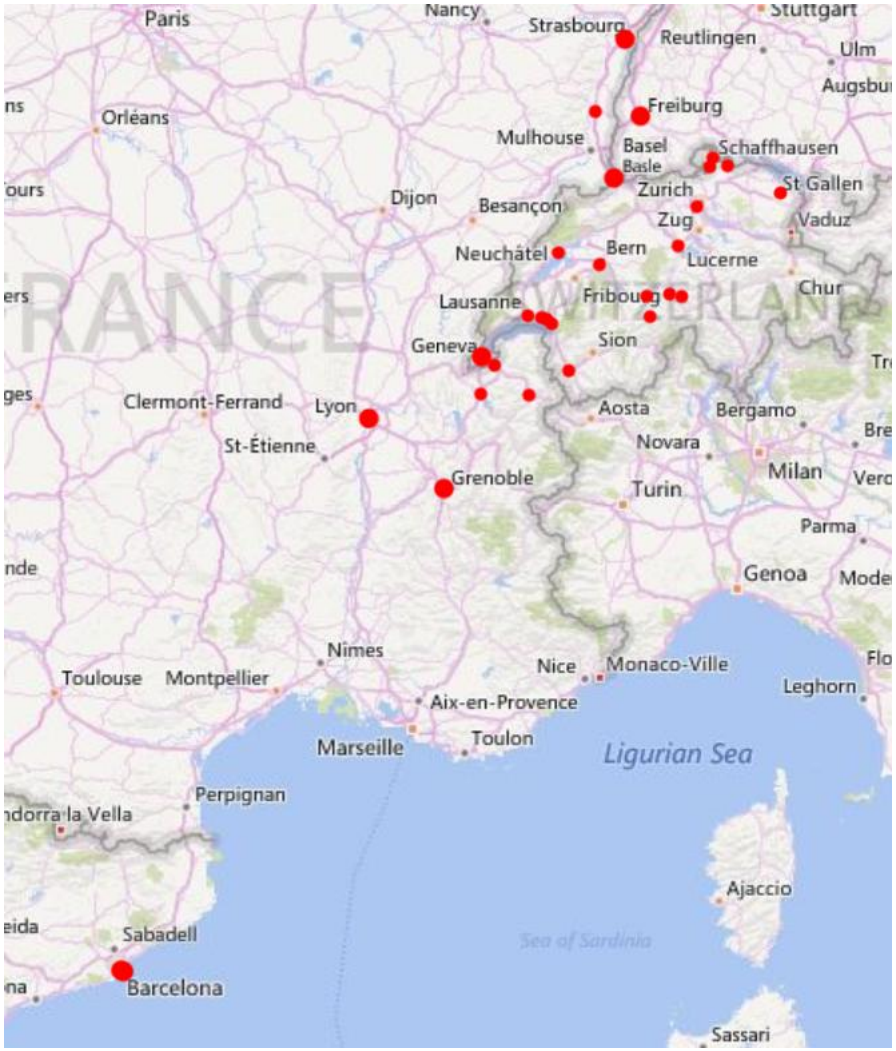
Who am I?

- Master student at Kharkiv National University
- Probably the youngest summer student (19 years old)

Activity

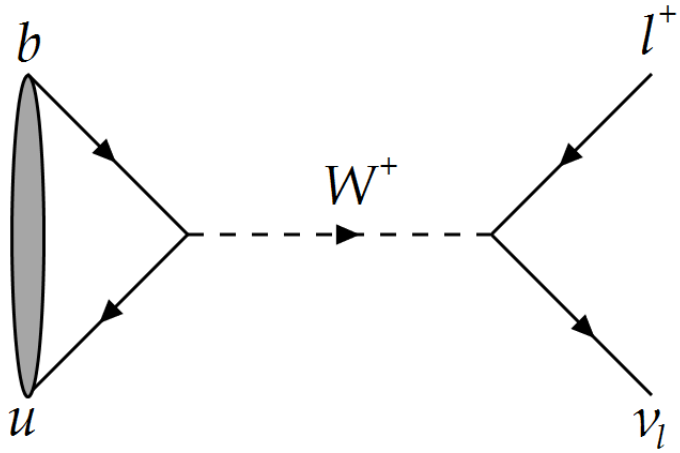
- I used all the weekends here for travelling
- Map of main visited places during these 7 weeks:



- In the weekdays, I attended lectures and worked on my project

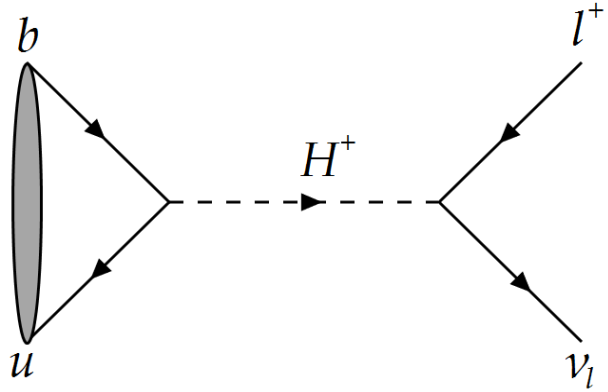
My project

- $B^+ \to \mu^+ \nu_\mu$ decay
- Suppressed by helicity conservation



- **SM:** BR($B^+ \to \mu^+ \nu_\mu$) ≈ 4·10^{-7}
- **New Physics:** possible existence of new charged mediators can increase BR

e.g.:



Analysis introduction

- My previous talk on VRD meeting: https://indico.cern.ch/event/371291/contribution/2/attachments/1129926/1614663/Vitalii_BMuNu_VRD.pdf
- Current best upper limit: around 2xSM

$$B_r < 1 \times 10^{-6}\ (90\%\ \mathrm{CL})\ (\mathrm{BaBar})$$

- **Can LHCb break this limit?**
  - We may have a chance
- **Challenging analysis:**
  - Only **neutrino and muon** in the final state, so the usual **invariant mass** reconstruction is **not possible**
  - We must find another variable to fit: **BDT fit**

Analysis introduction

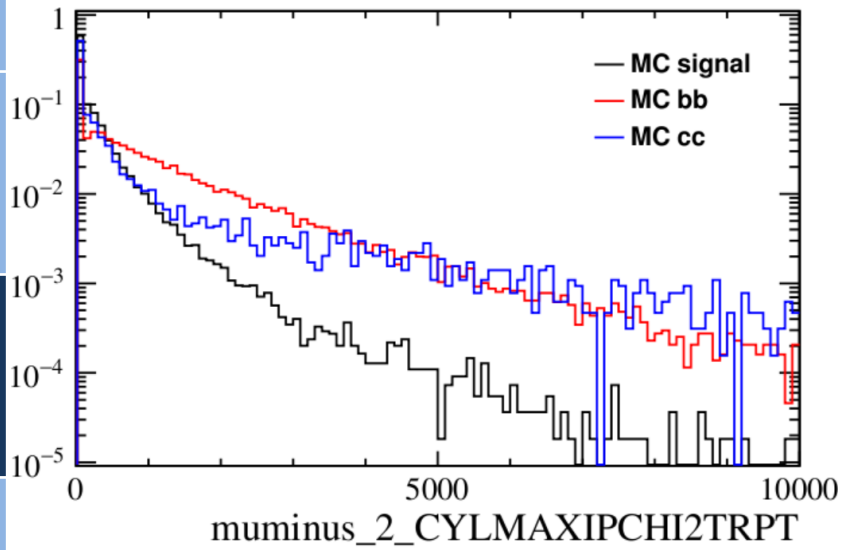
- Types of background: $b\bar{b}$ and $c\bar{c}$ production, with further semileptonic decays with muon in the final state
- Expected **number of signal events** is **smaller** than background, so **background must dominate** **in the data**
- **So, our first purpose is to ensure that these two types of background describe the data well**

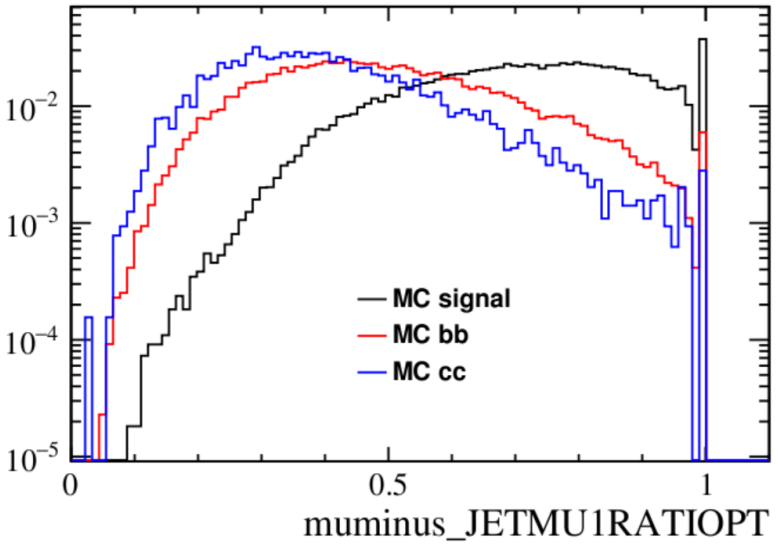
Analysis introduction

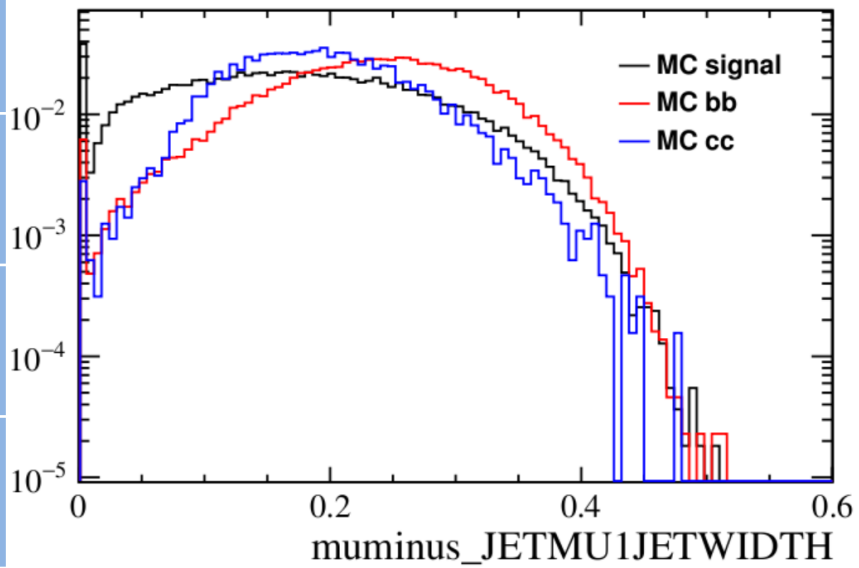
- **Data:** 2012 LHCb data, around 78.6 pb^{-1}
- Stripping cuts:
  - muon p_t>5 GeV/c and IPχ^2>400
  - select events with low multiplicity (<150 tracks)
- **MC:** stripping filtered production
  - signal: 54818 events
  - $b\bar{b}$: 43563 events
  - $c\bar{c}$: 6410 events
- We use variables of different types:
  - Global physics variables
  - Cylinder and cone variables
  - Jet variables

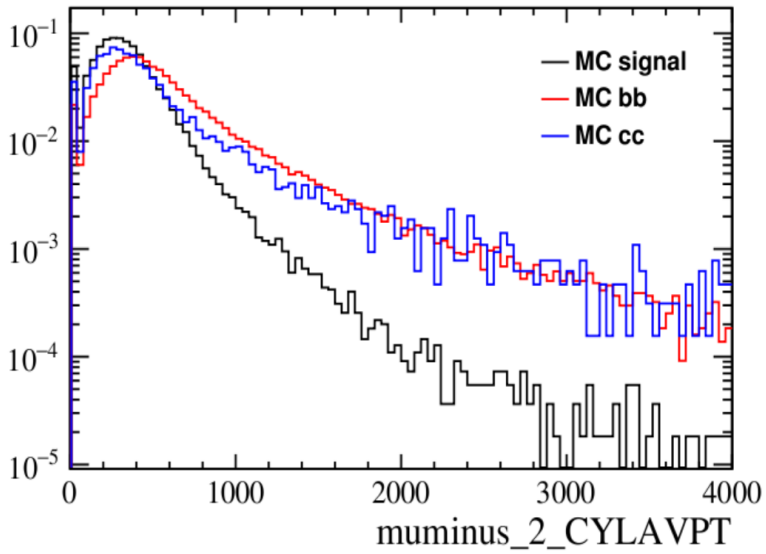
Variables distributions

- Some variables look different for signal, bb and cc:



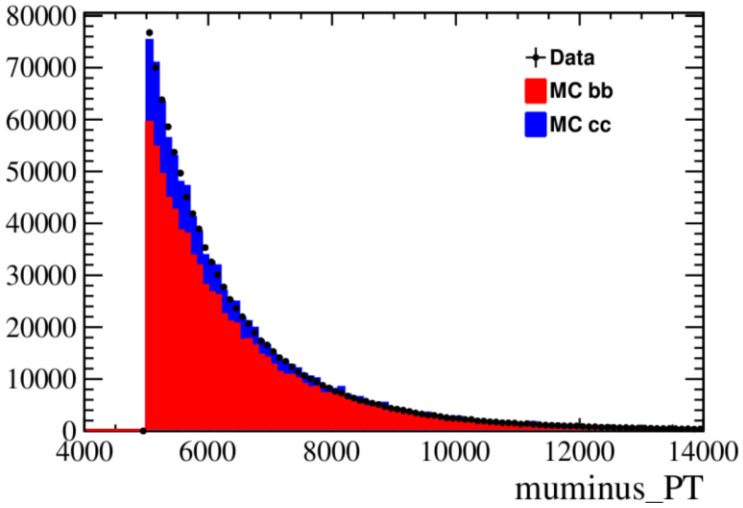


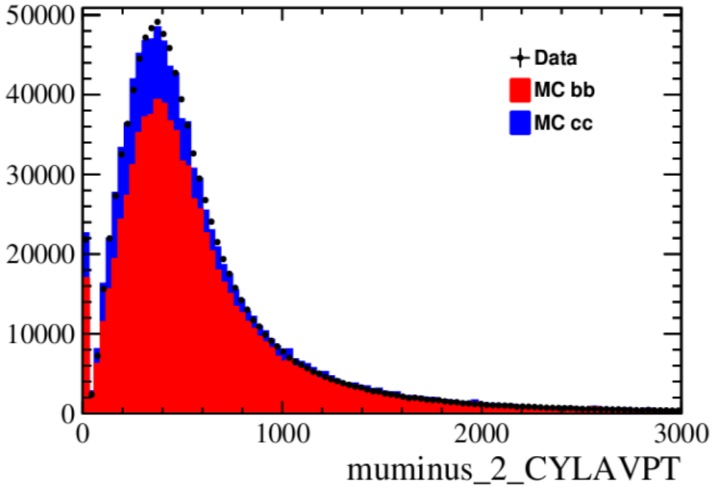


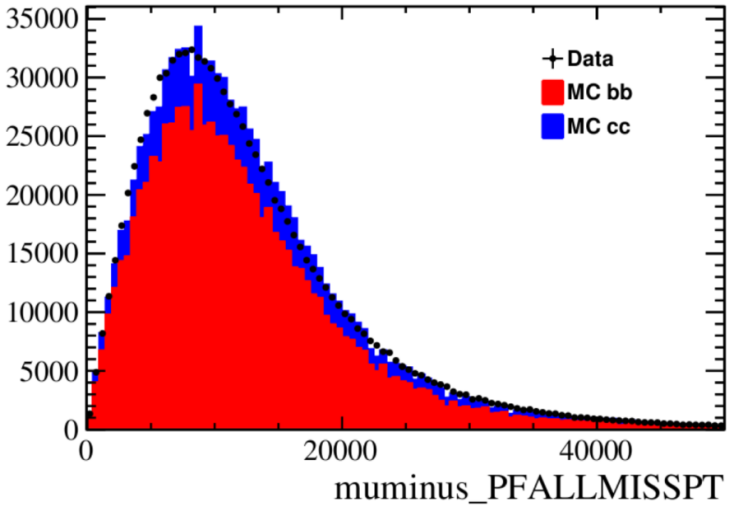


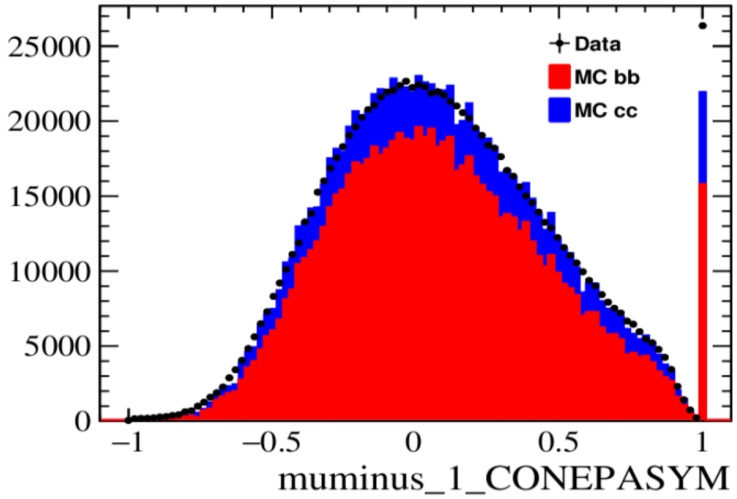
Variables distributions

Plots: **data** vs sum of **MC bb** and **MC cc**.
MC distributions are **reweighted** to match multiplicity in data and **multiplied by expected number** of each background type









Variables distributions

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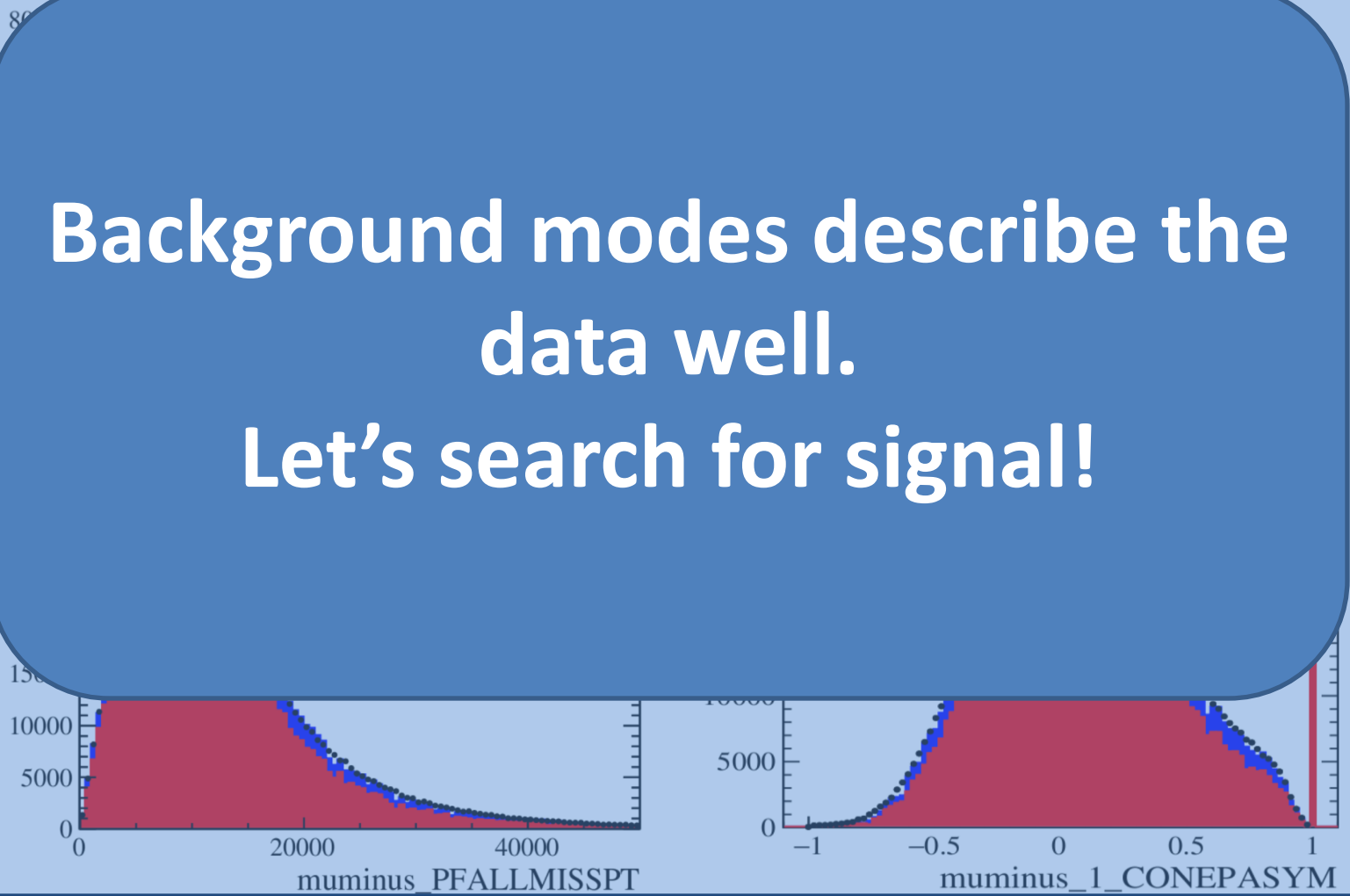
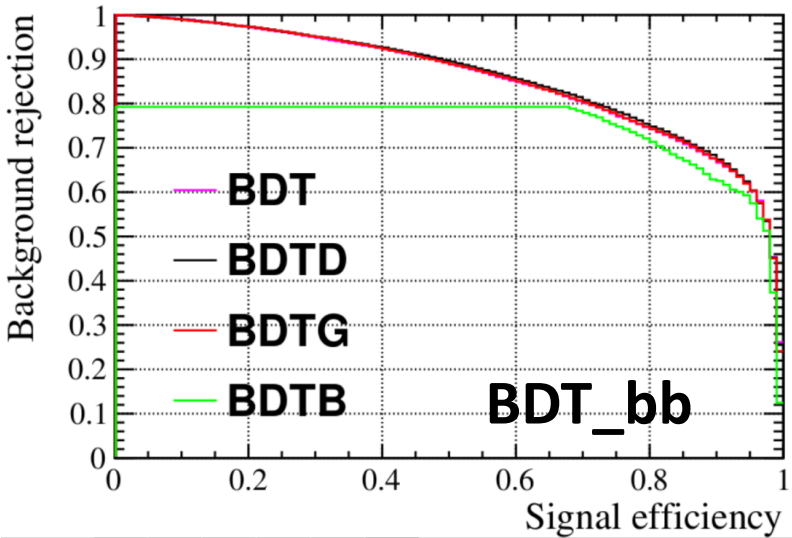
MC distributions are **reweighted** to match the multiplicity in data and **multiplied by expected number** of each background type

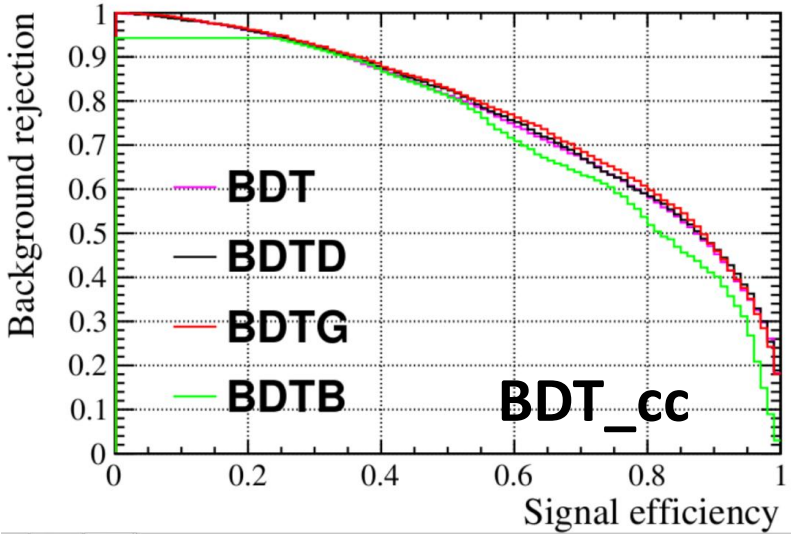
Background modes describe the data well.
Let's search for signal!



Multivariate analysis

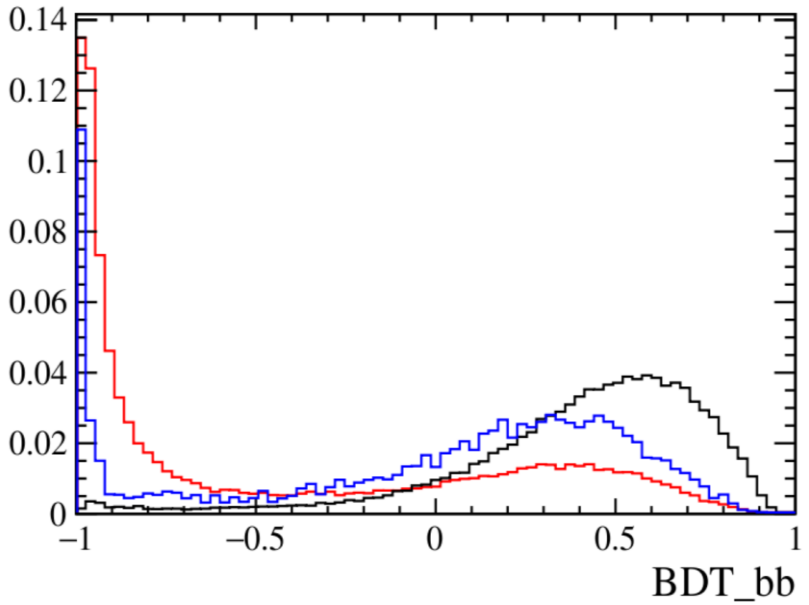
- **Two BDT variables: BDT_bb and BDT_cc**
- For training these BDTs we use:
  - **Same signal** sample (signal MC)
  - **Same** discriminating **variables** (*list was optimized*)
  - **Different background** samples: $b\bar{b}$ MC for BDT_bb and $c\bar{c}$ MC for BDT_cc
- BDTG method chosen as one giving the best separation

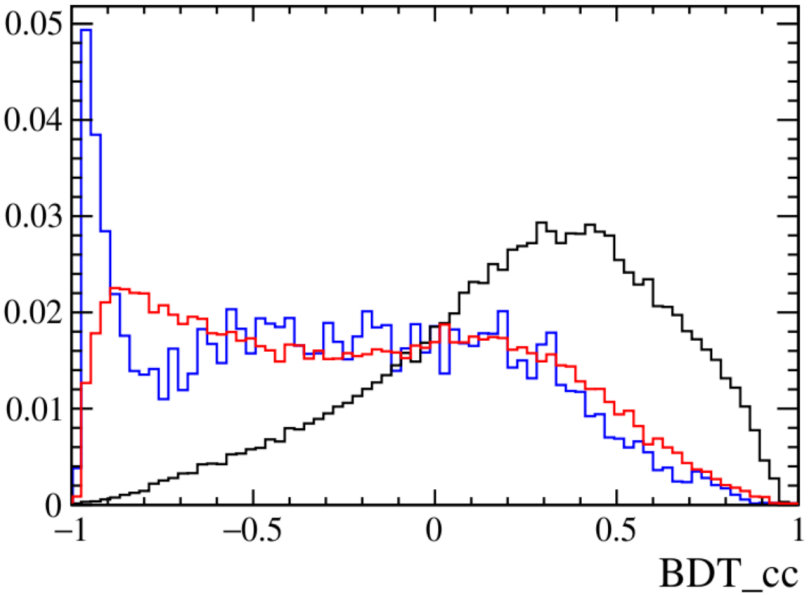




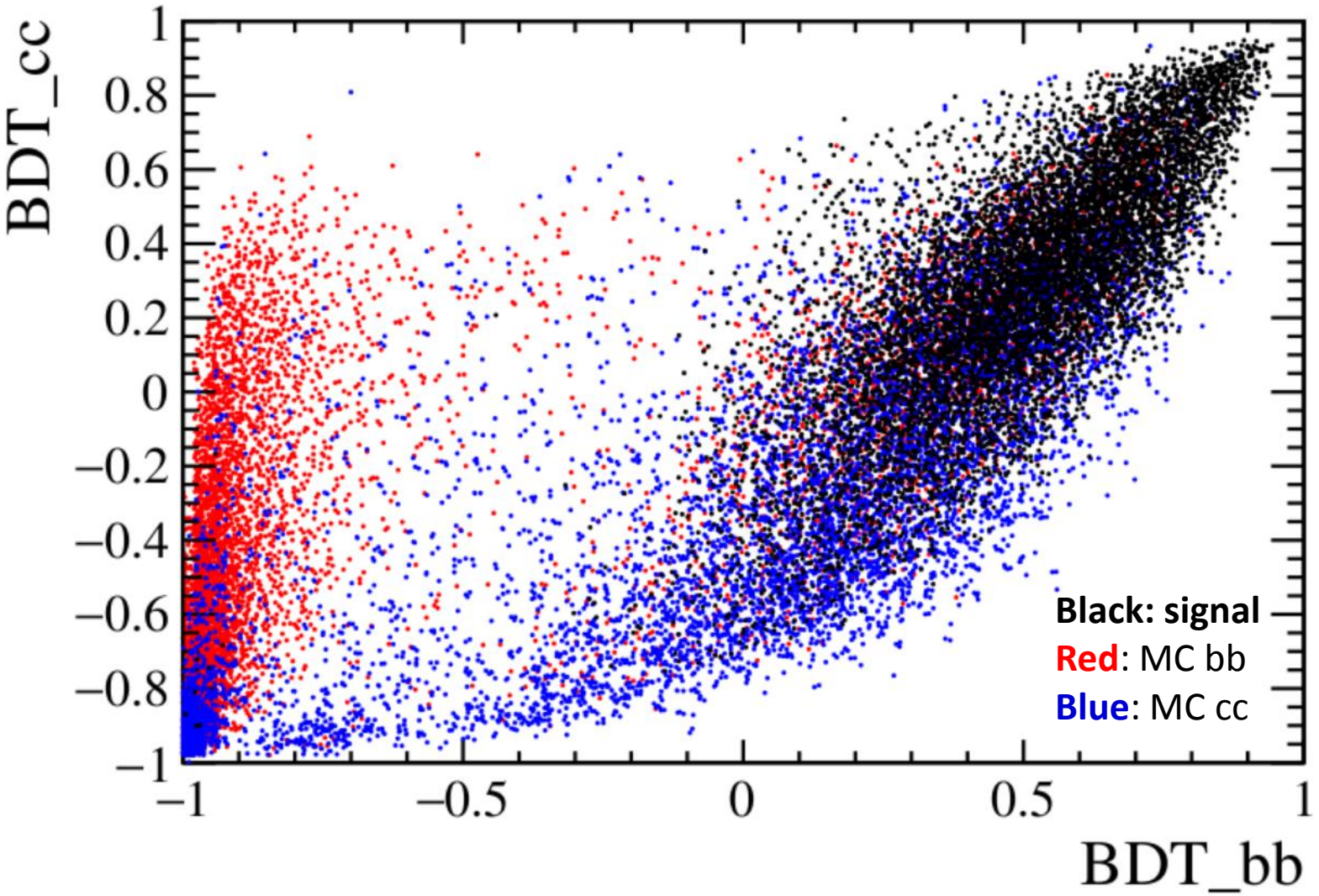
BDT distributions

- BDT variables distributions for signal and background modes
- **Black:** MC signal
- **Red**: MC $b\bar{b}$
- **Blue**: MC $c\bar{c}$

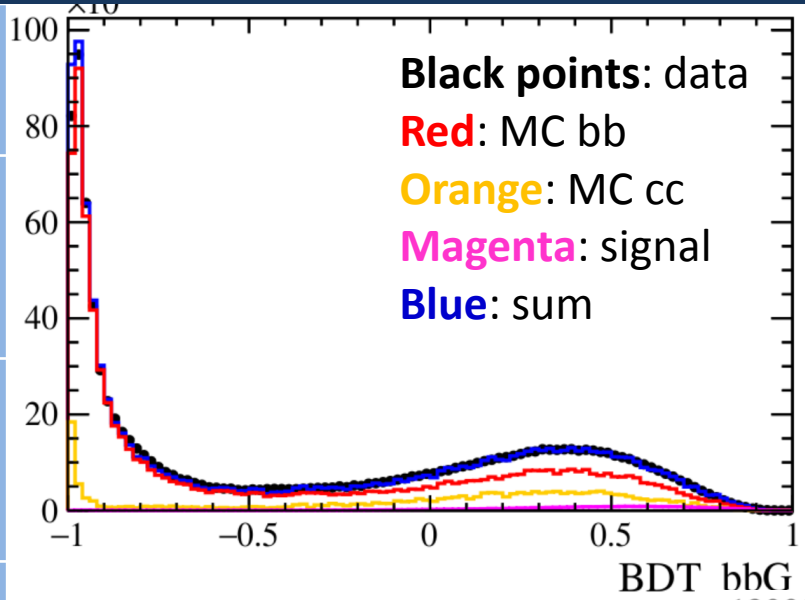




BDT distributions



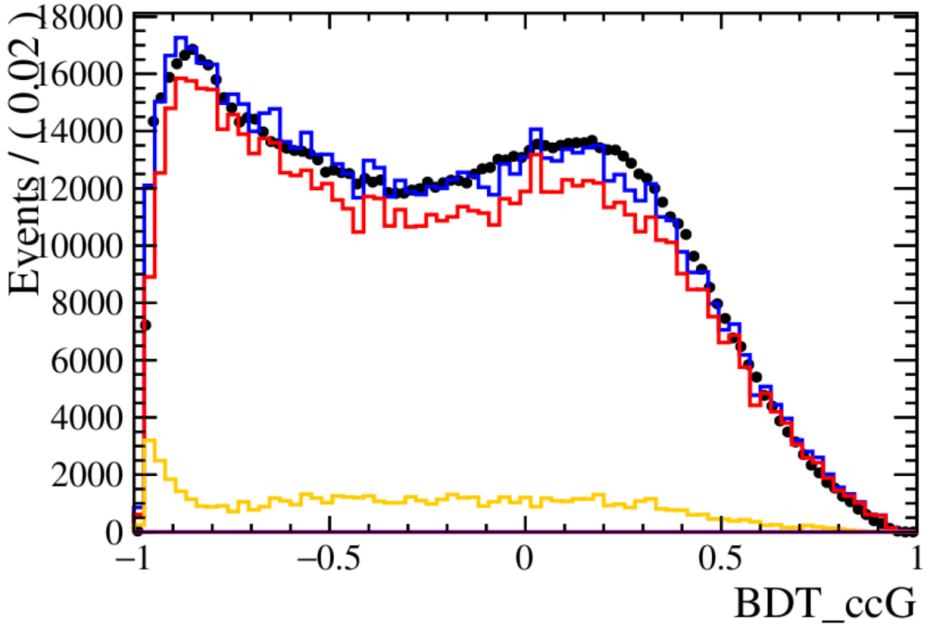
BDT fit on data



- Fit is unstable
- BDT_cc has many fluctuations due to low statistics of MC $c\bar{c}$
- 2D fit does not converge

BDT_bb fit:
nbb = 7.98575e+05 ± 1.57606e+03
ncc = 1.99501e+05 ± 1.81548e+03
ns = 2.58996**e+04** ± 9.04427e+02

BDT_cc fit:
nbb = 9.37571e+05 ± 3.03045e+03
ncc = 8.64169e+04 ± 2.60308e+03
ns = 2.37610**e-04** ± 1.55329e+01



Future perspectives of analysis

- **$b\bar{b}$ and $c\bar{c}$** backgrounds are **dominant**
- Describe the data well ⟶ reasonable fit
- **Uncertainties** of fits are much larger than expected number of events so **we can't push a BR limit down right now**, but…
  - MC samples with large number of events
  - BDT training including more variables
  - 2D BDT fit with nonuniform binning
  - Higher statistics during Run II
  - …

That's not all…

- I also help with $K_s \to \mu\mu$ analysis
  - co-supervised by **Jessica Prisciandaro**
- *A longer talk on it I will present on VRD meeting tomorrow…*
- Goal of the analysis: **search** for this decay
- My contribution:
  - Calculating reconstruction and stripping efficiencies
  - Fit of dominant misID background mode

Stripping efficiency

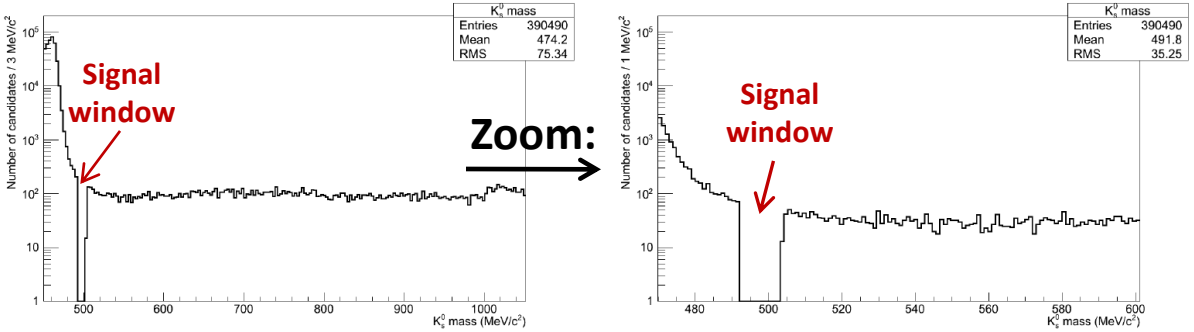
- Stripping cuts efficiencies studied on $K_s \to \mu\mu$ (signal) and $K_s \to \pi\pi$ (normalization channel):

Stripping cuts efficiencies

cuts	$\pi\pi$ separately		$\mu\mu$ separately		$\pi\pi$ all together		$\mu\mu$ all together	
	eff, %	err, %	eff, %	err, %	eff, %	err, %	eff, %	err, %
$\mu^{\pm}\_\mathrm{IP}\chi^2 > 100$	**76.65**	0.06	**77.90**	0.09	**76.64**	0.06	**77.90**	0.09
$AMAXDOCA(K_s^0) < 0.3$	**87.51**	0.05	**97.91**	0.03	**90.83**	0.05	**99.74**	0.0130
$DIRA(K_s^0) > 0$	**98.49**	0.02	**97.91**	0.03	**99.80**	0.01	**99.74**	0.01
$FD(K_s^0) * m(K_s^0)/p(K_s^0) > 0.1 * 89.53 * 0.29979$	**72.60**	0.07	**71.86**	0.10	**86.60**	0.06	**86.60**	0.09
$IP(K_s^0) < 0.4$	**88.88**	0.05	**91.07**	0.06	**90.89**	0.06	**91.60**	0.08
$p_T(\mu^{\pm}) > 250$	**34.17**	0.07	**31.65**	0.10	**35.86**	0.10	**33.77**	0.13
$400 < m(K_s^0) < 600$ or $m(K_s^0) > 465$	**99.18**	0.01	**99.86**	0.01	**99.99**	0.00	**99.99**	0.01
all stripping cuts	-	-	-	-	**19.61**	0.06	**18.99**	0.08

Fit of misID background mode

- Some pions can be **misidentified** as muons → huge **misID background** with shifted mass peak (but *still covering the signal window*)

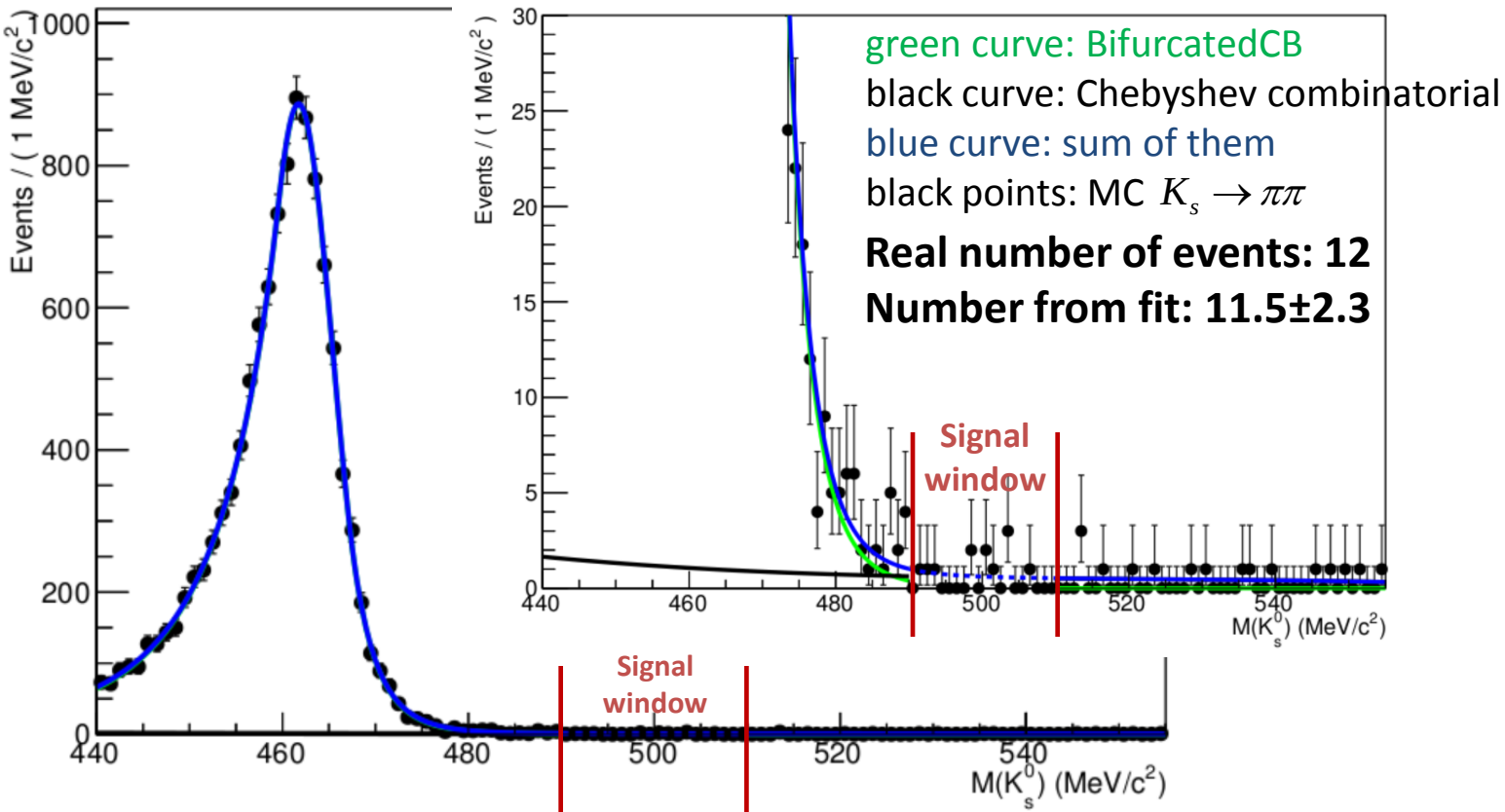


(a) Full mass range (b) Region around signal

- Necessary to obtain a **best fit** of this background **in the signal window**
  - I used $K_s \to \pi\pi$ MC with 0/1/both pions misIDd as muons
  - Tried different shapes to describe it
  - Compared the real number of events *in the signal window* with the integral under the fit

Fit of misID background mode

- The **best shape**: **Bifurcated Crystal Ball + Chebyshev 3rd order**
  - I checked the applicability of this fit to 2011 minbias data
  - Looked on fit behavior after different cuts, e.g. on BDT
- **My fit model describes the background shape well**



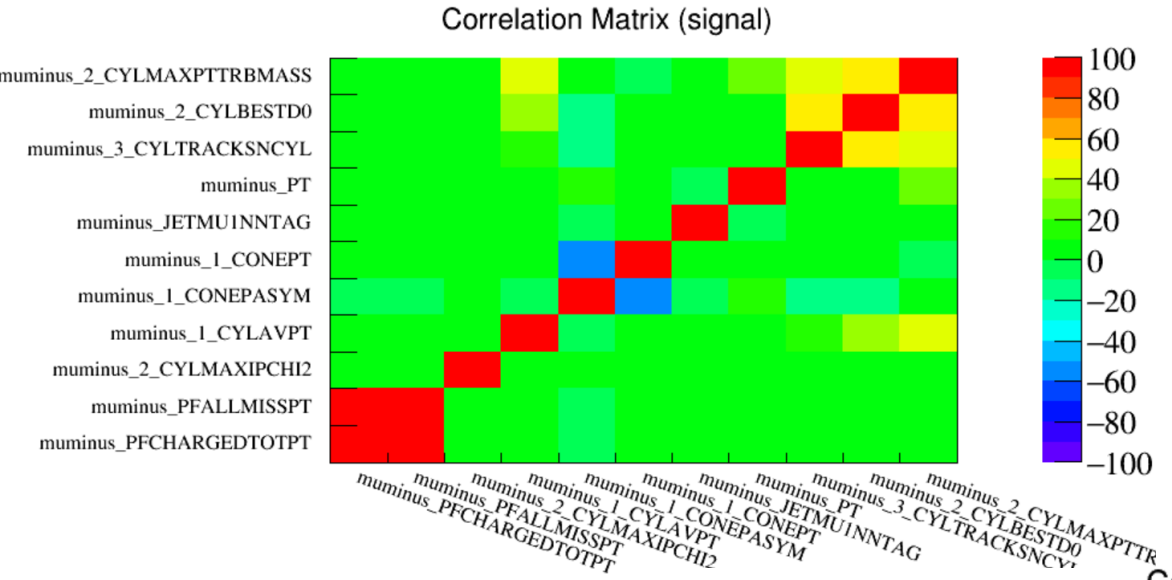
Conclusions

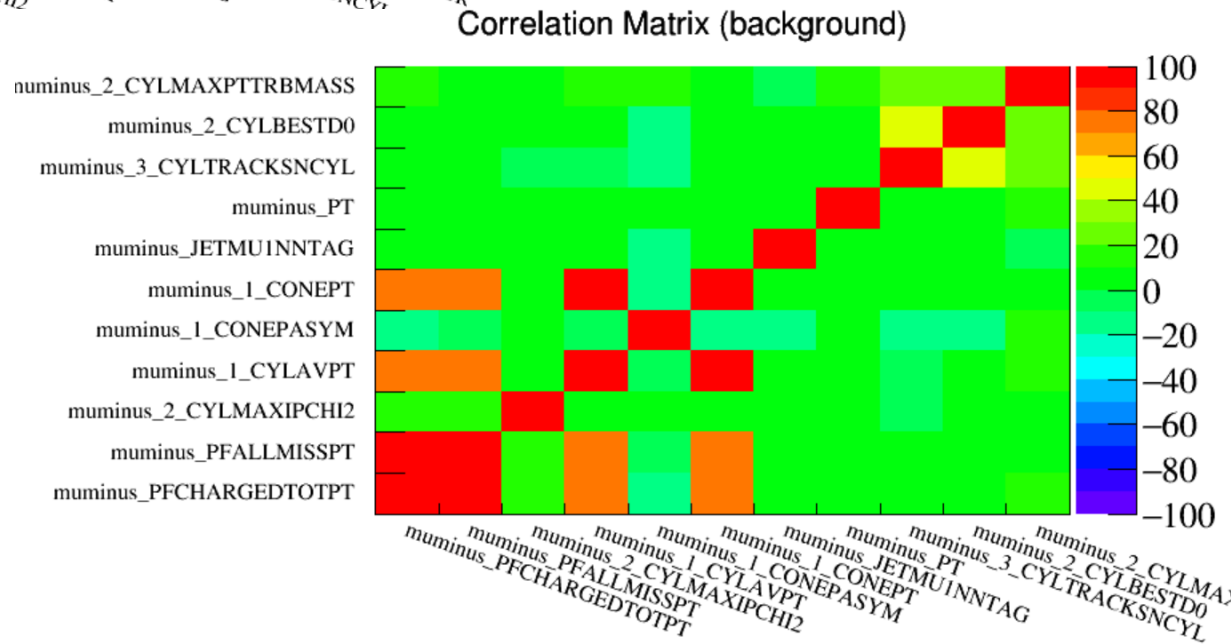
- That's still not all, but my time is over…
- $B^+ \to \mu^+ \nu_\mu$ analysis:
  - Dominant background modes understood
  - BDT trained and fitted
  - To continue analysis we need much machine and man power
- $K_s \to \mu\mu$ analysis:
  - Stripping cuts efficiencies calculated, the least efficient cuts identified
  - The best fit of the dominant background channel developed
- Much new knowledge and experience obtained

Thank you for your attention!

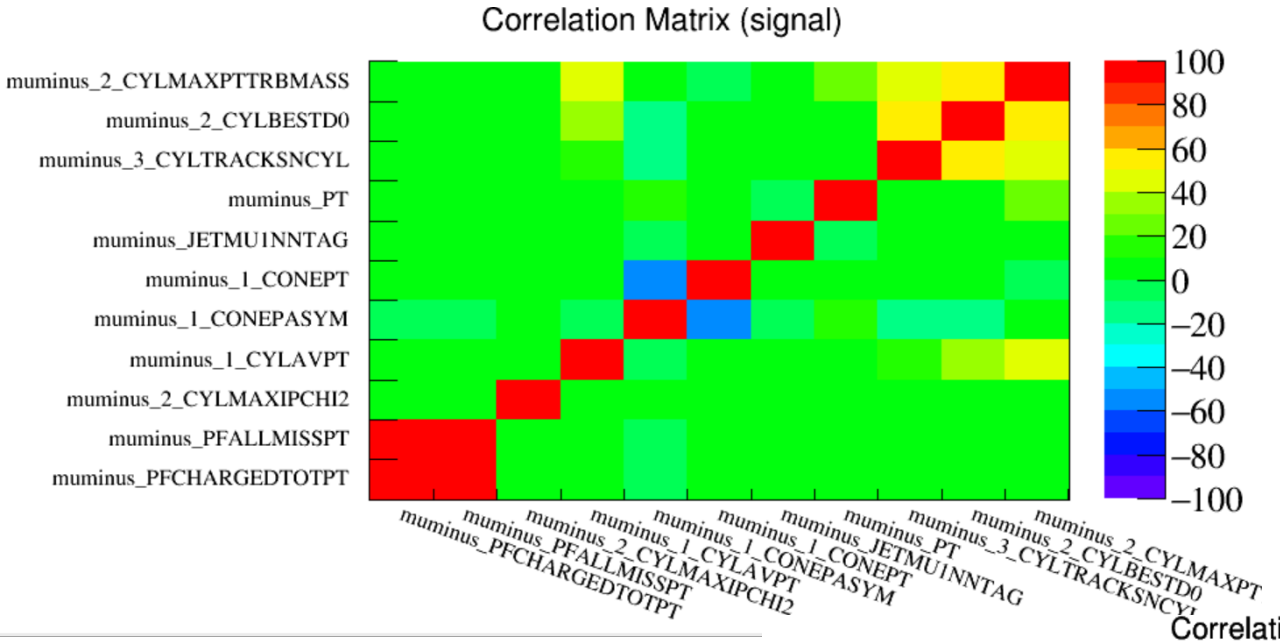
Backup slides

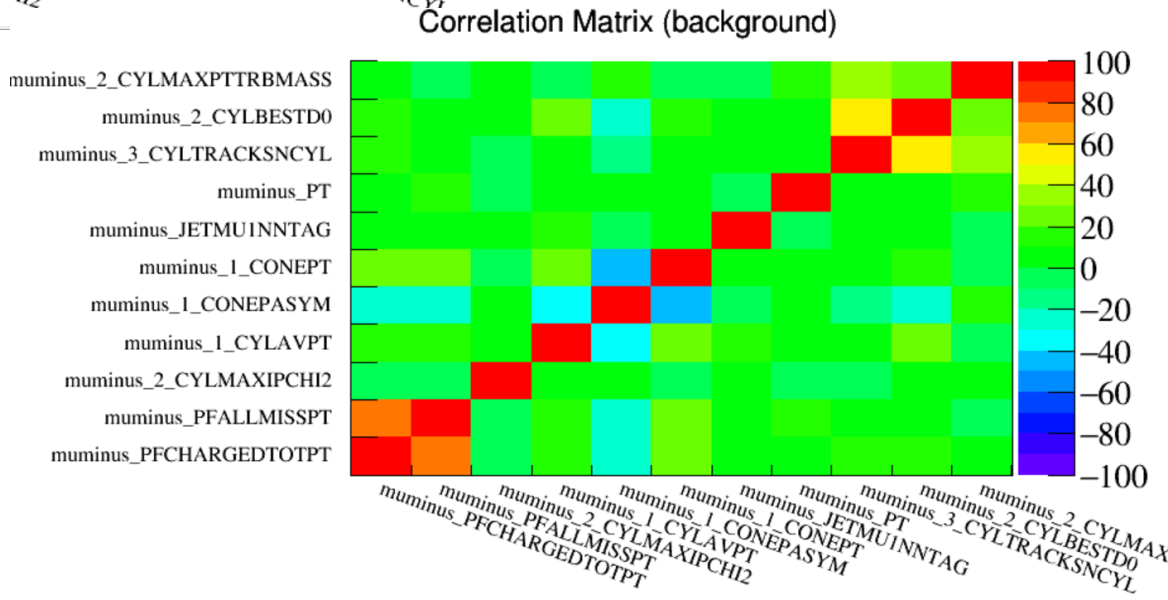
BDT_bb correlation matrices





BDT_cc correlation matrices





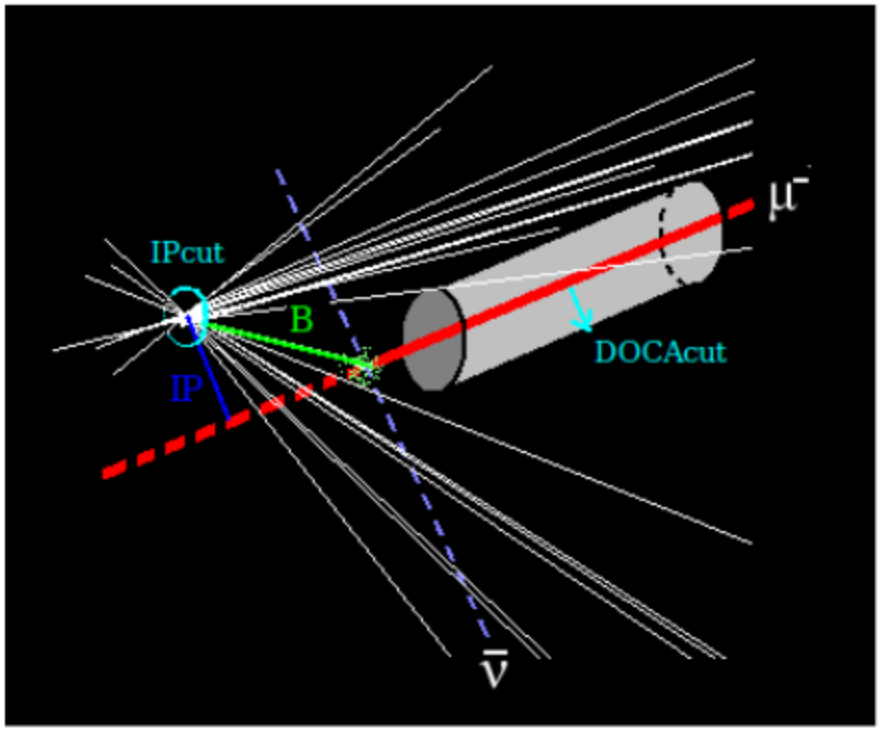
Isolation Definition (II)

- We want to select isolated muons → consider a cylinder around our muon track.
- Focus on low multiplicity events → set maximum number of tracks<150.
- Isolation conditions: (considering only Long and VELO tracks)

◇ Tracks in the event outside the cylinder → every track has a DOCA with the signal muon greater than the DOCA*cut* established.

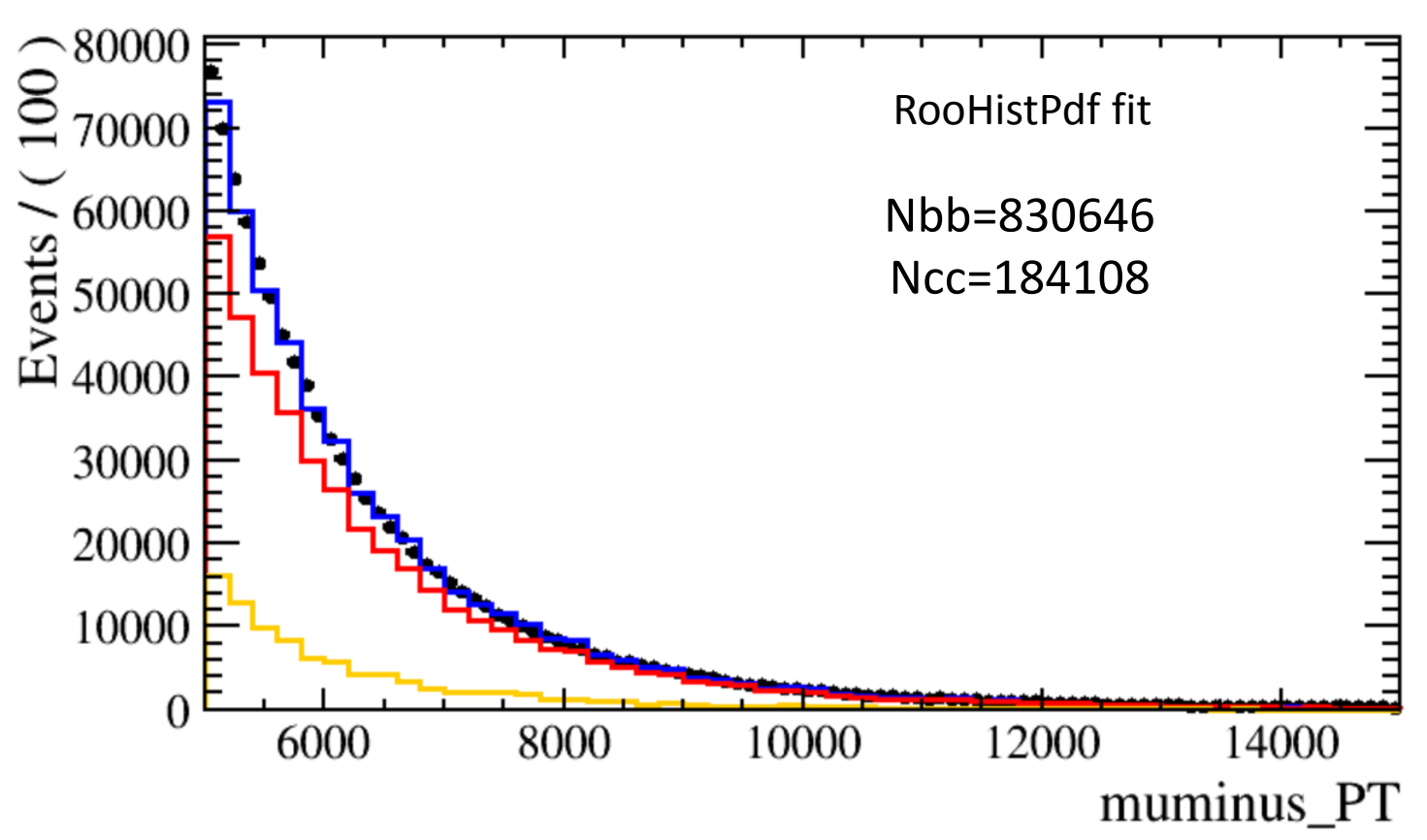
◇ Tracks inside the cylinder are allowed if:

- They are pointing to the PV (track IP smaller than IP*cut*).
- The invariant mass of the system track+muon is larger than the B^+ mass (idea: track+muon+missing ν system is not a 3-body decay from a B meson).



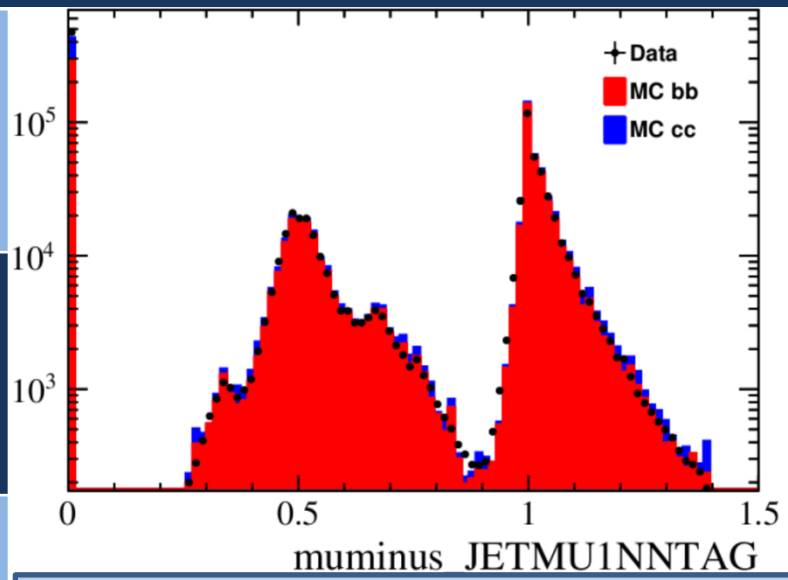
Variables used

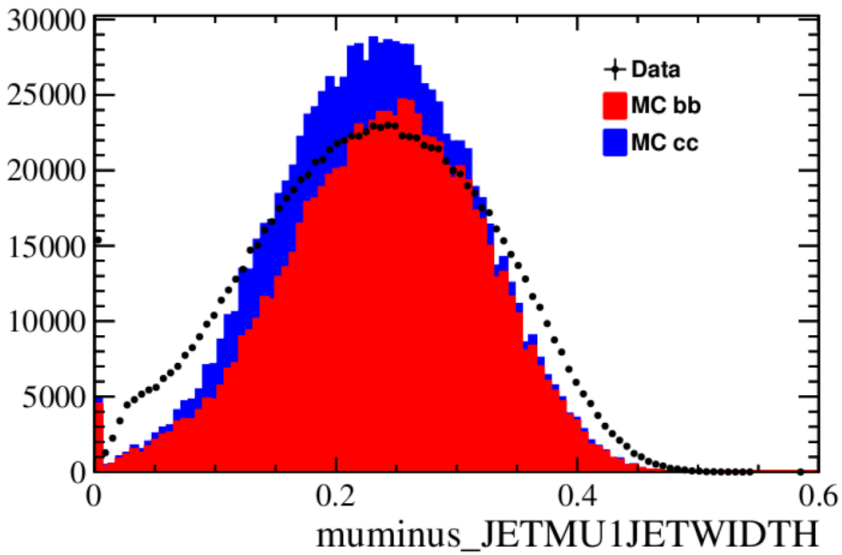
- We use variables of different types:



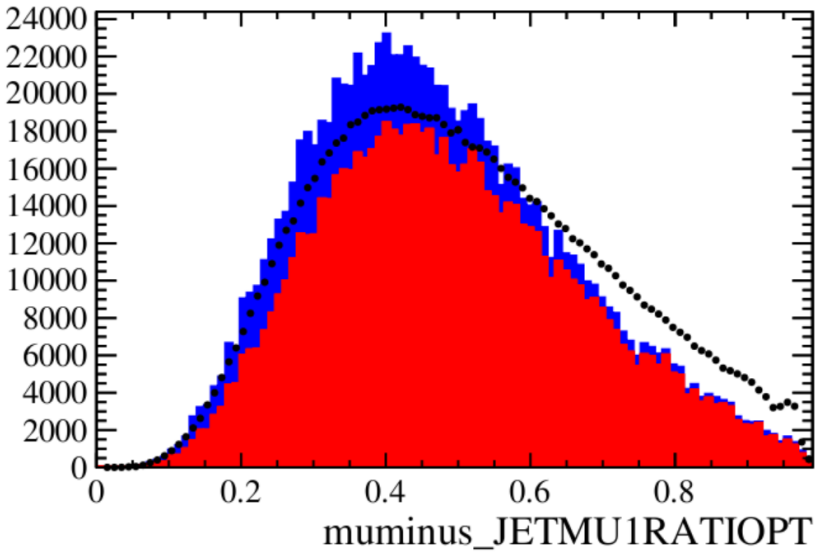
- MC distributions are **reweighted** to match the multiplicity in data
  - MC distributions are multiplied by expected number of each background type

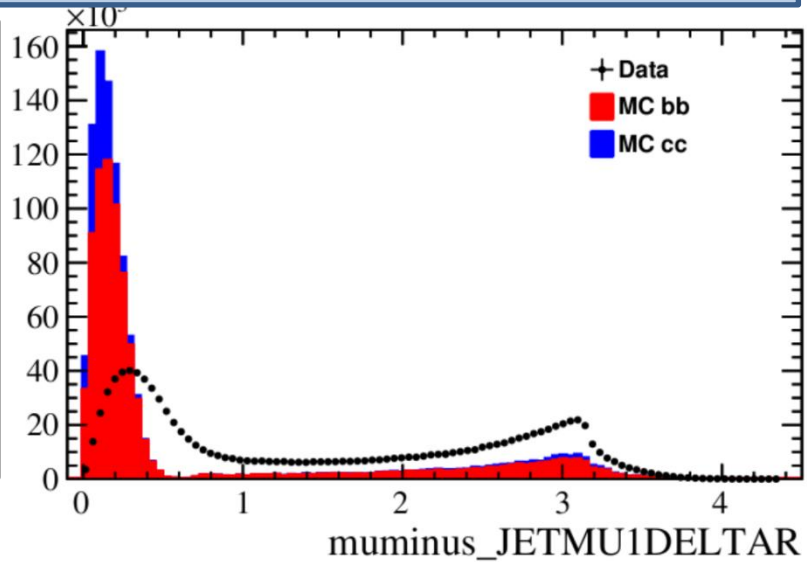
Jet variables





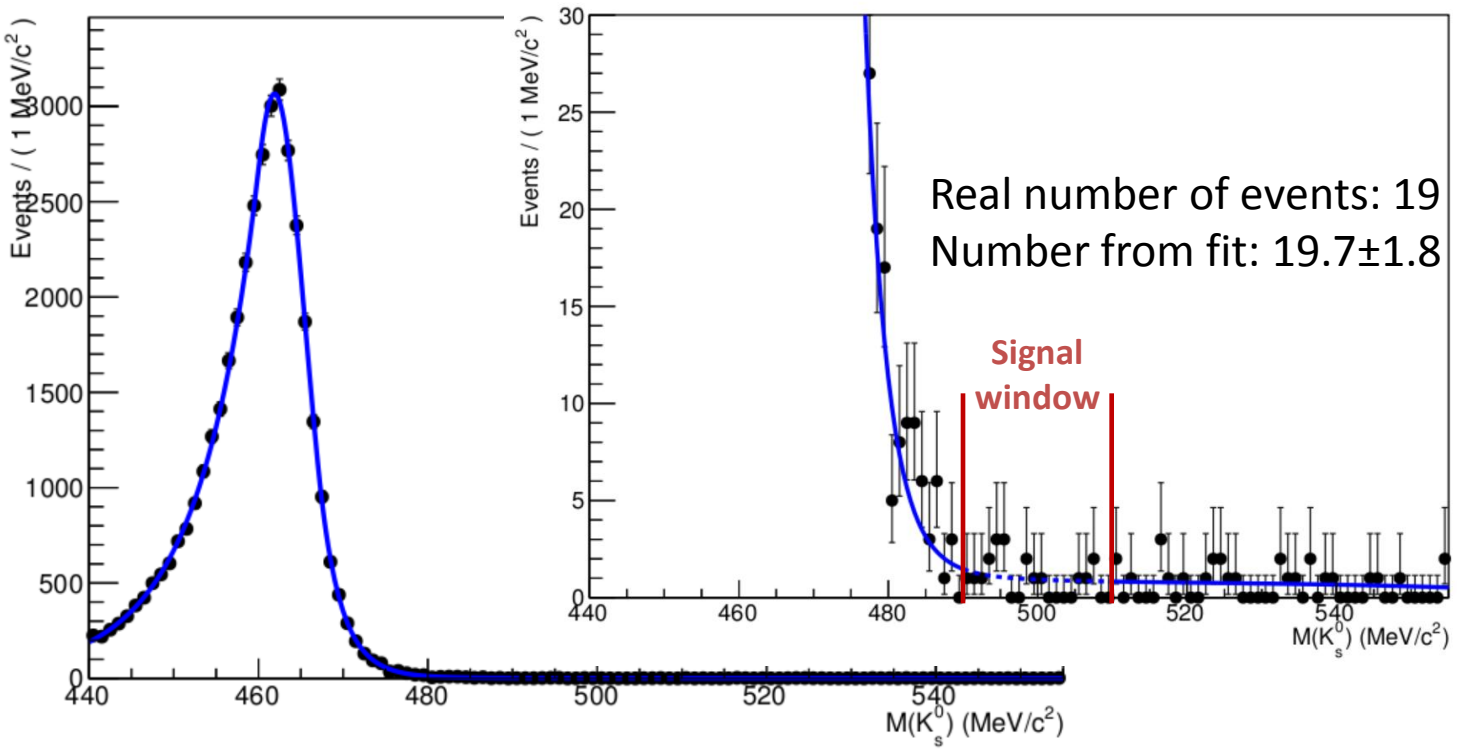
Some problems with jets variables – trying to solve





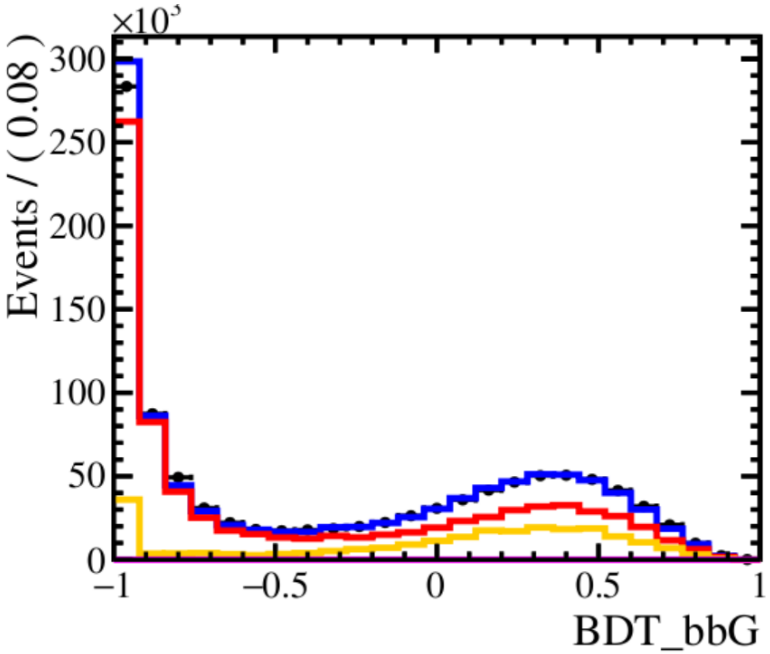
Fit of misID background mode

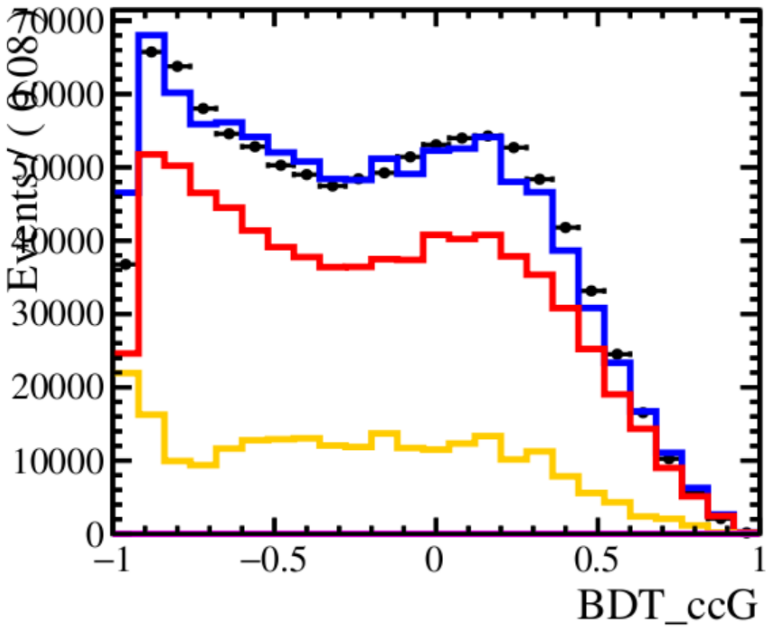
- Then I checked the applicability of this fit to 2011 minimum bias data (proved absence of signal there)
- Looked on fit behavior after different cuts, e.g. on BDT
- My fit model describes the background shape well



2D BDT fit on data

RooHistPdf fit





- Fit is unstable
- BDT_cc has many fluctuations due to low statistics of MC cc

Stripping efficiency

- Stripping cuts efficiencies studied on $K_s \to \mu\mu$ (signal) and $K_s \to \pi\pi$ (normalization channel):

Reconstruction efficiencies

$\pi\pi$		$\mu\mu$	
eff, %	err, %	eff, %	err, %
16.92	0.02	**8.44**	0.02

Stripping cuts efficiencies

	$\pi\pi$ separately		$\mu\mu$ separately		$\pi\pi$ all together		$\mu\mu$ all together	
cuts	eff, %	err, %	eff, %	err, %	eff, %	err, %	eff, %	err, %
$\mu^{\pm}$_IP$\chi^2 > 100$	**76.65**	0.06	**77.90**	0.09	**76.64**	0.06	**77.90**	0.09
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