Prospects of the inclusive $B \to D_s^{(*)} X$ decays at Belle (II)

Jarek Wiechczyński

13.11.2024

Plan of the talk

- Motivation
- My past work on Belle 1
- Initial studies on B2BII

  → signal MC

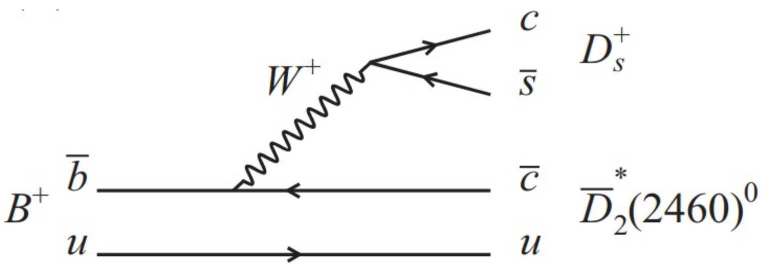
  → generic MC

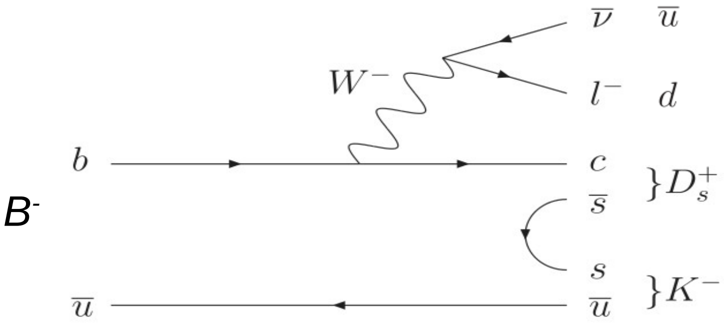
    → comparison of two FEI's

Motivation

Studying inclusive D_s X production in both upper and lower D_s vertex:

$B^+ \rightarrow D_s^+ X^0$ and $B^- \rightarrow D_s^+ X^{--}$



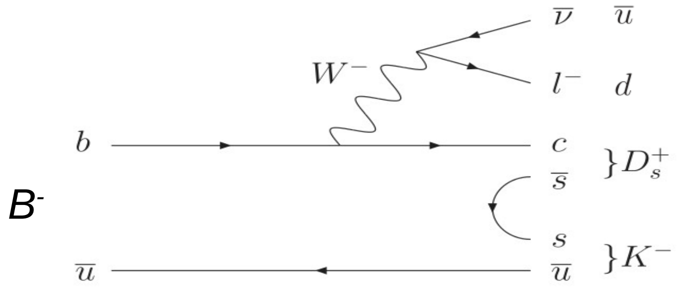


- Very accurate theoretical predictions for the inclusive decay rates
  → precise tests of the Standard Model

- $B \rightarrow D_s^{(*)} X$ decays account for a large background contribution to the semileptonic channels (like $b \rightarrow s\,ll$ transitions)

Motivation

lower D_s vertex



Experimentally measured the most common **exclusive** B decays do not fill out the **inclusive** value!

inclusive:

$B^+ \to D_s^- X$ $\quad (1.10\ ^{+0.40}_{-0.32}) \times 10^{-2}$

Phys.Rev.D 75 (2007) 072002

231 million BB-bar events recorded with the BABAR

exclusive:

$B^+ \to D_s^- D_s^+ K^+$ $\quad (1.2 \pm 0.4) \times 10^{-4}$ — Physical Review D, 108(3) – LHCb (2023)

$B^+ \to D_s^- \pi^+ K^+$ $\quad (1.80 \pm 0.22) \times 10^{-4}$

$B^+ \to D_s^{*-} \pi^+ K^+$ $\quad (1.45 \pm 0.24) \times 10^{-4}$

$B^+ \to D_s^- K^+ K^+$ $\quad (9.7 \pm 2.1) \times 10^{-6}$

J.Wiechczynski et al Phys.Rev.D 80 (2009) 052005

Phys.Rev.Lett. 100 (2008) 171803 (BaBAR)

$B^+ \to D_s^{(*)-} K^+ \ell^+ \nu_\ell$ $\quad (6.1 \pm 1.0) \times 10^{-4}$

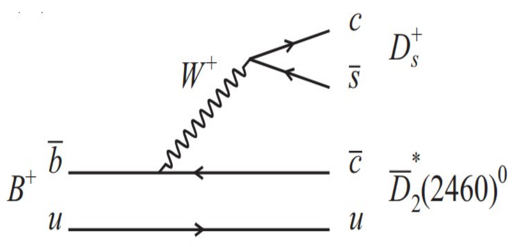
J.Stypula et al, Phys.Rev.D 86 (2012) 072007

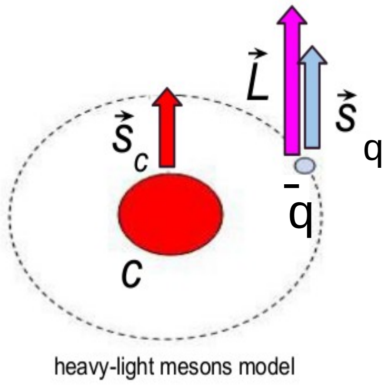
Phys.Rev.Lett. 107 (2011) 041804 (BaBar)

→ sum of low D_s^- vertex ~ **1 x 10^{-3}**

Motivation

upper D_s vertex → spektroscopy of cq (q= u,d) states



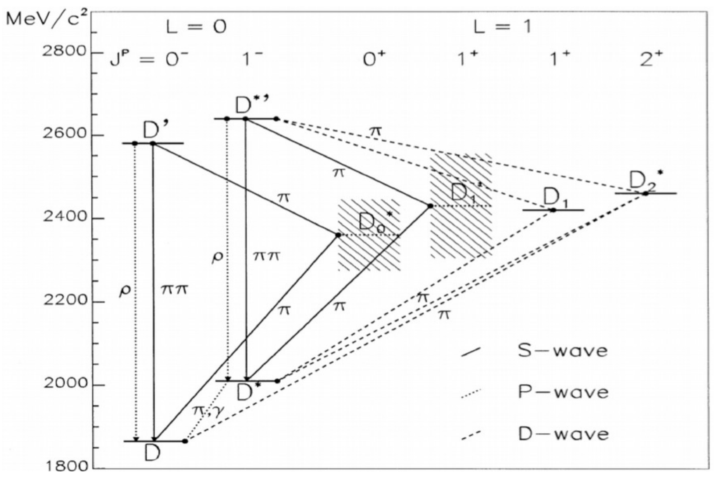


- For L=0 → well known D and D^* mesons $\vec{j}_q = \vec{L} + \vec{s}_q$
- For L=1 → four D^{**} states
  broad D_0^* and D_1' states (j_q=1/2)
  narrow D_1 and D_2^* states (j_q=3/2)

Radial excitation states (n=2):
For L=0 → D' and $D^{*\prime}$

Inclusive study of charmed mesons → missing mass (mx) analysis:

- orbital excited D^{**} production – seen in mx
- potential observation of radial excited states



Current values:

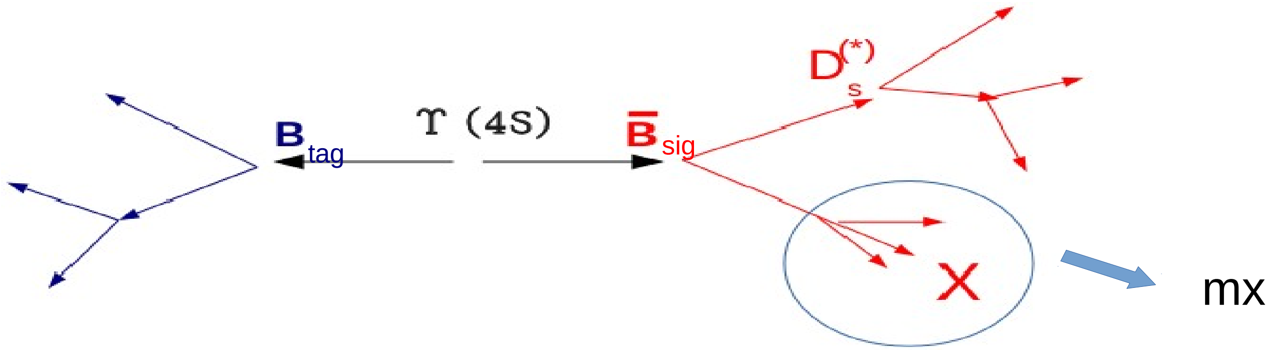
$B^+ \to D_s^{(*)+} \overline{D}^{**0}$ $(2.7 \pm 1.2) \times 10^{-2}$ Phys.Rev.D 62 (2000) 112003

$B^+ \to D_s^+ X$ $(7.9\,^{+1.4}_{-1.3}) \times 10^{-2}$ Phys.Rev.D 75 (2007) 072002

Method of the analysis and PLANS

1. Full reconstruction of B_{tag} meson in hadronic mode

2. Reconstruction of the $D_s^{(*)}$ meson from the remaining tracks



3.

→ BF calculaction for different charge configurations

Oliwia Krasowska
PHD student, Krakow

→ Study of the missing mass (mx)

$$mx = \sqrt{p_{miss}^2} = \sqrt{(p(\Upsilon(4S)) - p(B_{tag}) - p(D_s^{(*)}))^2}$$

- Spektroscopy of cq → Inclusive method, independent on the charm meson decay!
  Jarek Wiechczyński

Quick overview from my past work at Belle:

→ missing mass (mx) analysis for $B^+ \to D_s^{(*)+} X$

- Analysis was performed using Belle1 software (**basf1**)
  → my own modules module in C++
- Utilization of **FullRecon** package (NeuroBayes based - hadronic tagging) for B_{tag} reconstruction
- The analysis was already at the stage of internal Belle refering process ...

A lot of offline tools have been prepared for this study!

Belle Note 1473

Belle Note 1473
April 26, 2019

Searching for excited charm mesons in the inclusive $B^+ \to D_s^{(*)+} X$ measurement

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Abstract

The inclusive $B^+ \to D_s^{(*)+} X$ decays are studied using the ON $\Upsilon(4S)$ data sample of 772×10^6 pairs of $B\bar{B}$ mesons, collected by the Belle detector at KEKB, an asymmetric e^+e^- collider. The hadronic tagging and missing mass method are used to search for the orbital/radial excitation of the charm states, independently of their decay modes. In addition, the characteristics of inclusive $D_s^{(*)+} X$ final states can be compared for upper and lower vertex for the D_s production.

1 Introduction

The mechanism of the production of the charm resonances of the masses above 2.4 GeV/c^2 in B meson decays is still not well known. This is related to the main source of the uncertainty in the determination of the V_{cb} element of the CKM matrix [?]. To date we still observe some discrepancies between theoretical predictions and experiment results on this field [?].

The $c\bar{q}$ spectra is very reach and still in case of interest of many theoretical and experimental groups. The well established D and D^* mesons correspond to the ground state (L=0) of the $c\bar{u}$ system. The first orbital excitations (L=1), called jointly as D^{**}, comprises of four states. Two of them, D_1 and D_2^* characterized by total spin of the c quark $j_c = 3/2$, are relatively narrow and have been experimentally observed many times. The other two, D_1' and D_0^* with $j_c = 1/2$, are broad ($\sim$ 300 MeV) and thus more difficult to detect. Resonances with L>1 are also expected.

Except for the angular excitations, we also expect radially excited states. The lightest candidates with L=0 are called D' and $D^{*\prime}$, where the second one was firstly observed in $D^*\pi\pi$ mode by DELPHI [1]. However, some other studies did not see such state [2]. Figure 1 shows masses of cu spectrum predicted by Godfrey-Isgur model [3].

https://belle.kek.jp/secured/belle_note/gn1473/BN_dsx_ver1.pdf

Decay channels:

D_s was reconstructed in three decay modes:

$D_s \to \phi\pi$

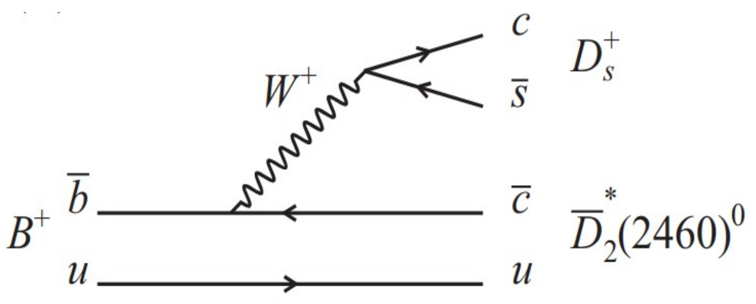
$D_s \to K^{*0}K$ and $D_s^* \to D_s\gamma$

$D_s \to K^0_s K$

So far, only charged B decays were considered!

Reference channels:

$B^+ \to D_s D^0$	$B^+ \to D_s^* D^0$
$B^+ \to D_s D^{*0}$	$B^+ \to D_s^* D^{*0}$



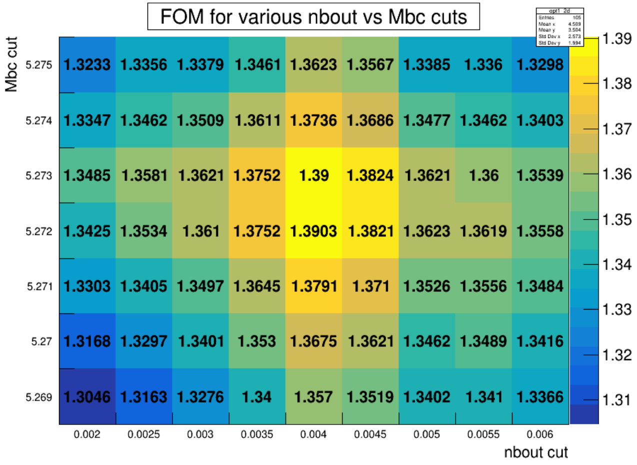
Simulated data samples:

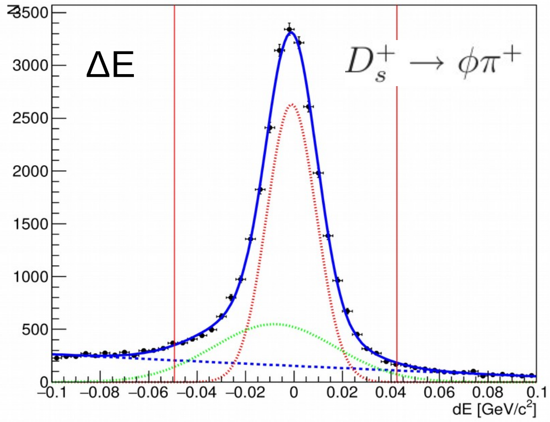
generic MC	# of sample
mixed	10 streams
charged	10 streams
charm	6 streams
uds	6 streams

dedicated $B \to D_s^{(*)} D^{(*)0}$	# of events
$B \to D_s D^0$	1 milion
$B \to D_s D^{*0}$	1 milion
$B \to D_s^* D^0$	1 milion
$B \to D_s^* D^{*0}$	1 milion

dedicated $B \to D_s^{(*)} D^{**}$	fraction of 2M (5M) events
$B \to D_s^{(*)} D_1^0$	0.2128
$B \to D_s^{(*)} D_2^{*0}$	0.5746
$B \to D_s^{(*)} D_1'^0$	0.1063
$B \to D_s^{(*)} D_0^{*0}$	0.1063

M_{bc} & 'nbout' cut optimization





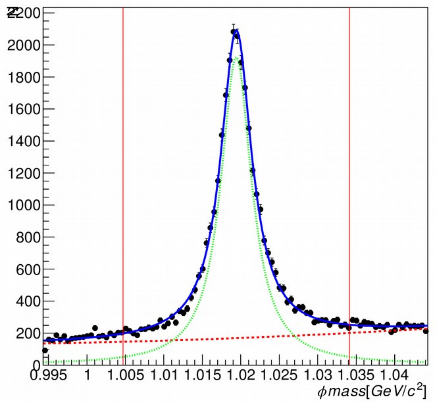
$|\Delta E + 3.4\ \text{MeV}| < 45.9\ \text{MeV}$

B_{tag}

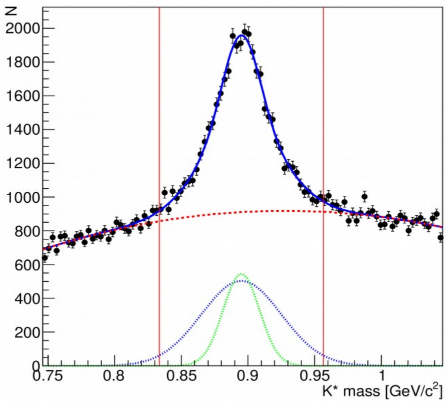
B_{sig}

Cuts on intermediate resonances

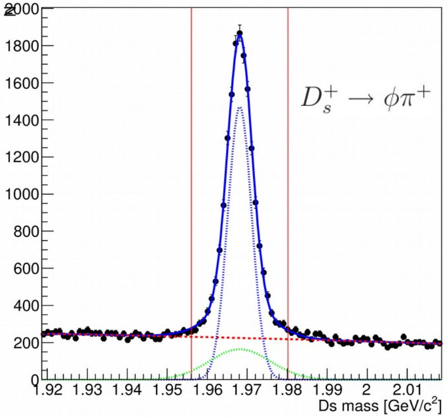
$|m_{KK} - m^{\phi}| < 14.7$ MeV
(3σ of the Breit-Wigner's width)



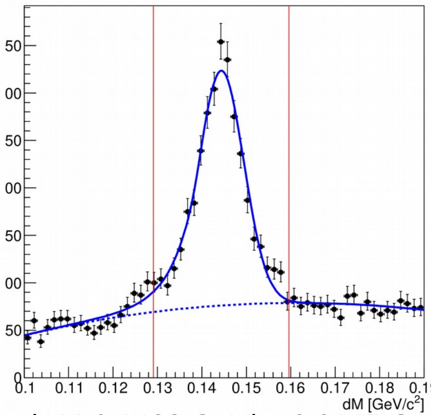
$|m_{K\pi} - m^{K^*}| < 61.5$ MeV
(2.5σ of weighted width)



mD_s and ΔM (for D_s^*) cuts:



$|m_{phi\ pi} - m^{Ds}| < 12.1$ MeV



$|\Delta M - 0.1438\ \text{GeV}| < 0.0145$ GeV

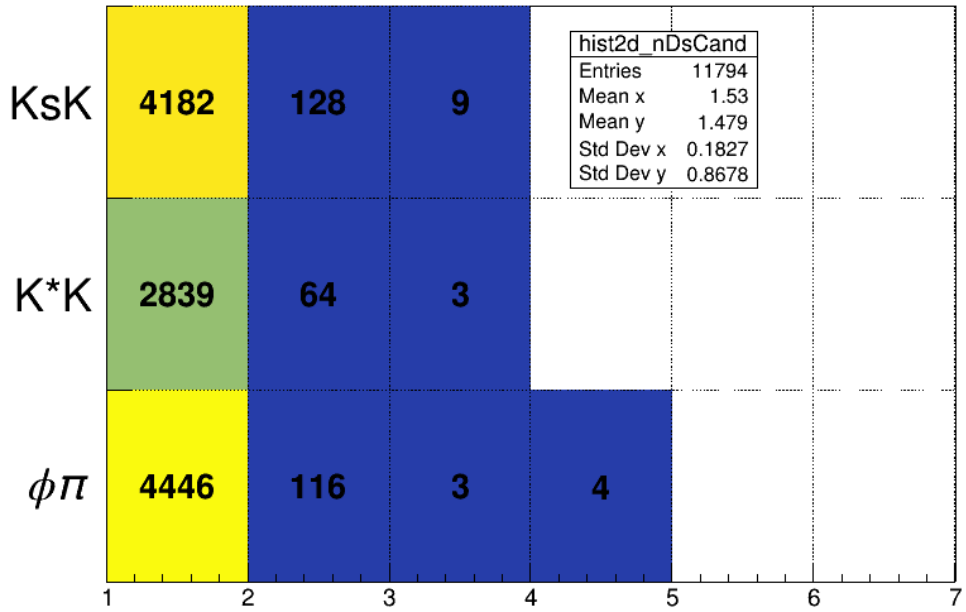
Best candidate selection

→ performed after applying all the cuts

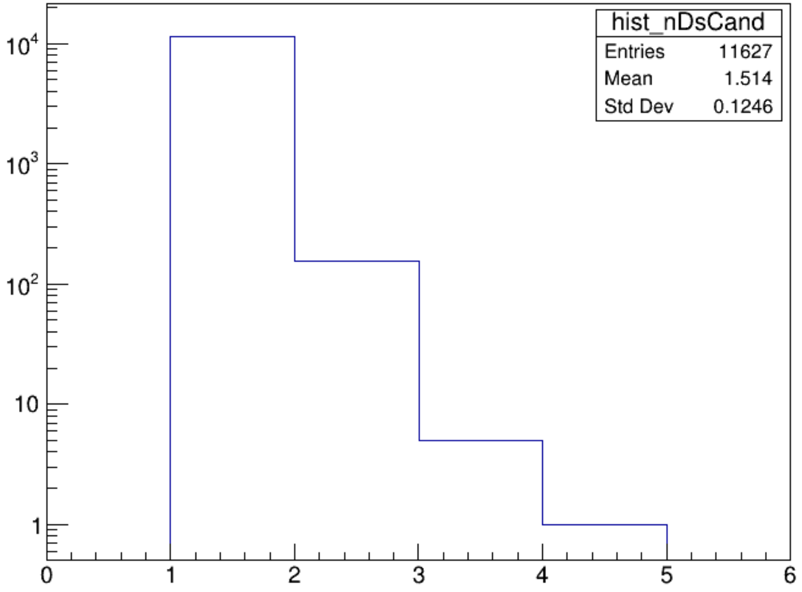
→ applied for B_{tag} and $D_s^{(*)}$ multiple candidates

→ based on 'nbout' and (mass diff)^2/σ^2

Number of D_s candidates VS D_s decay mode



MCgen



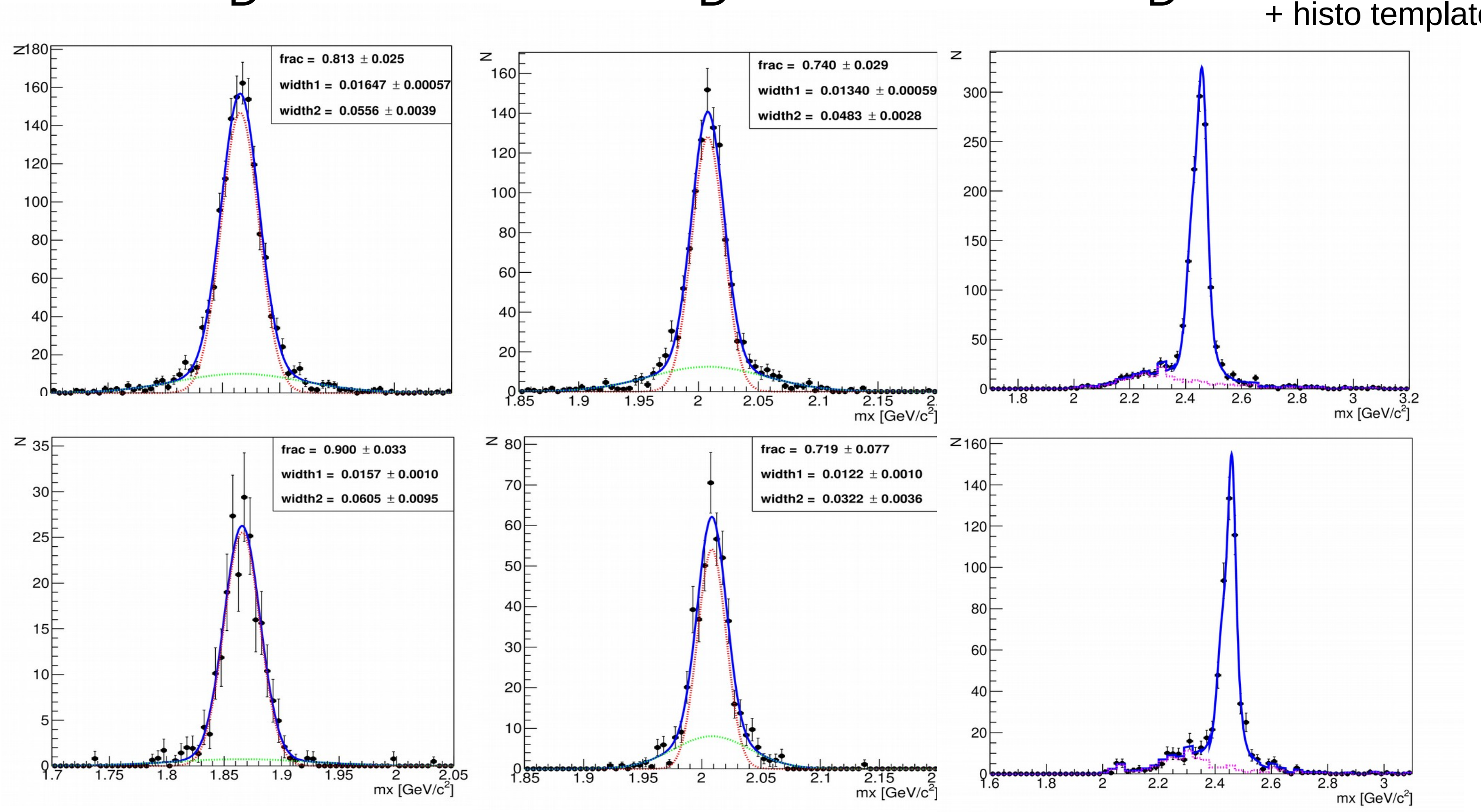
Missing mass analysis (signal MC) - signal components

2 Breit-Wigners
+ histo templates (wide states)

D^0 D^{*0} D^{**0}

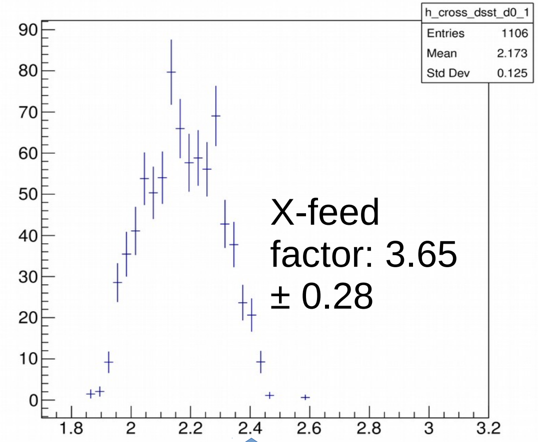
D_s

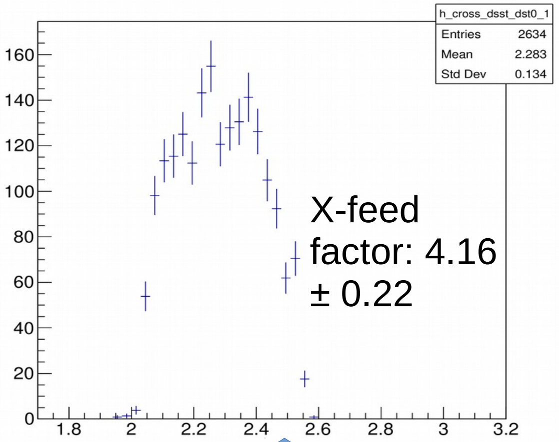
D_s^*

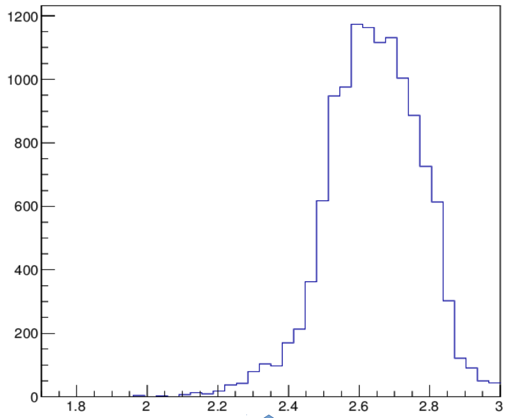


Missing mass analysis (signal MC) - Crossfeed components

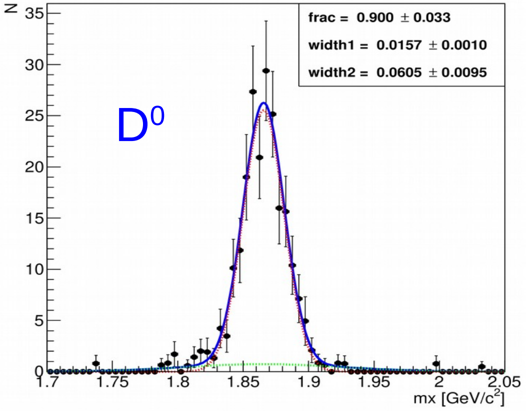
D_s

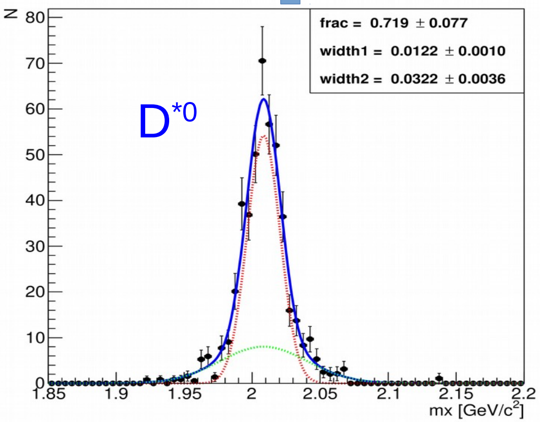


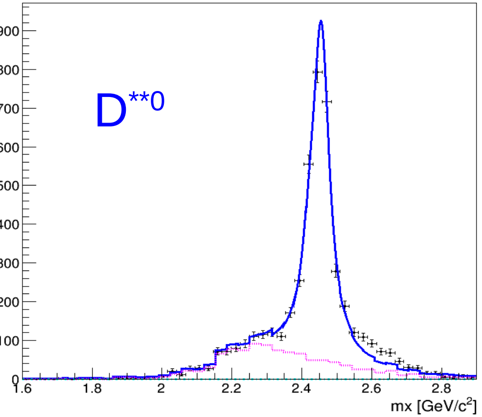




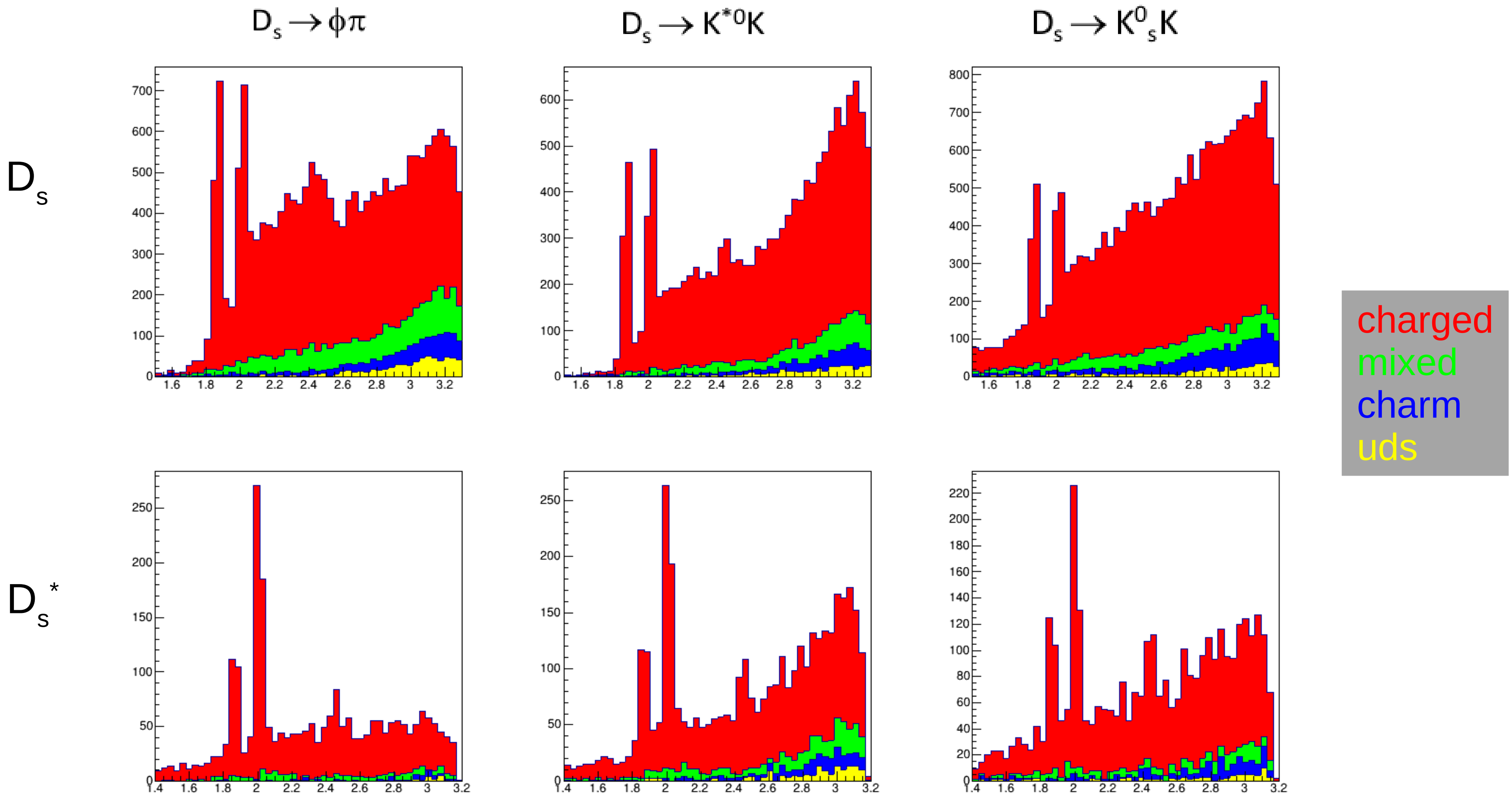
D_s^*



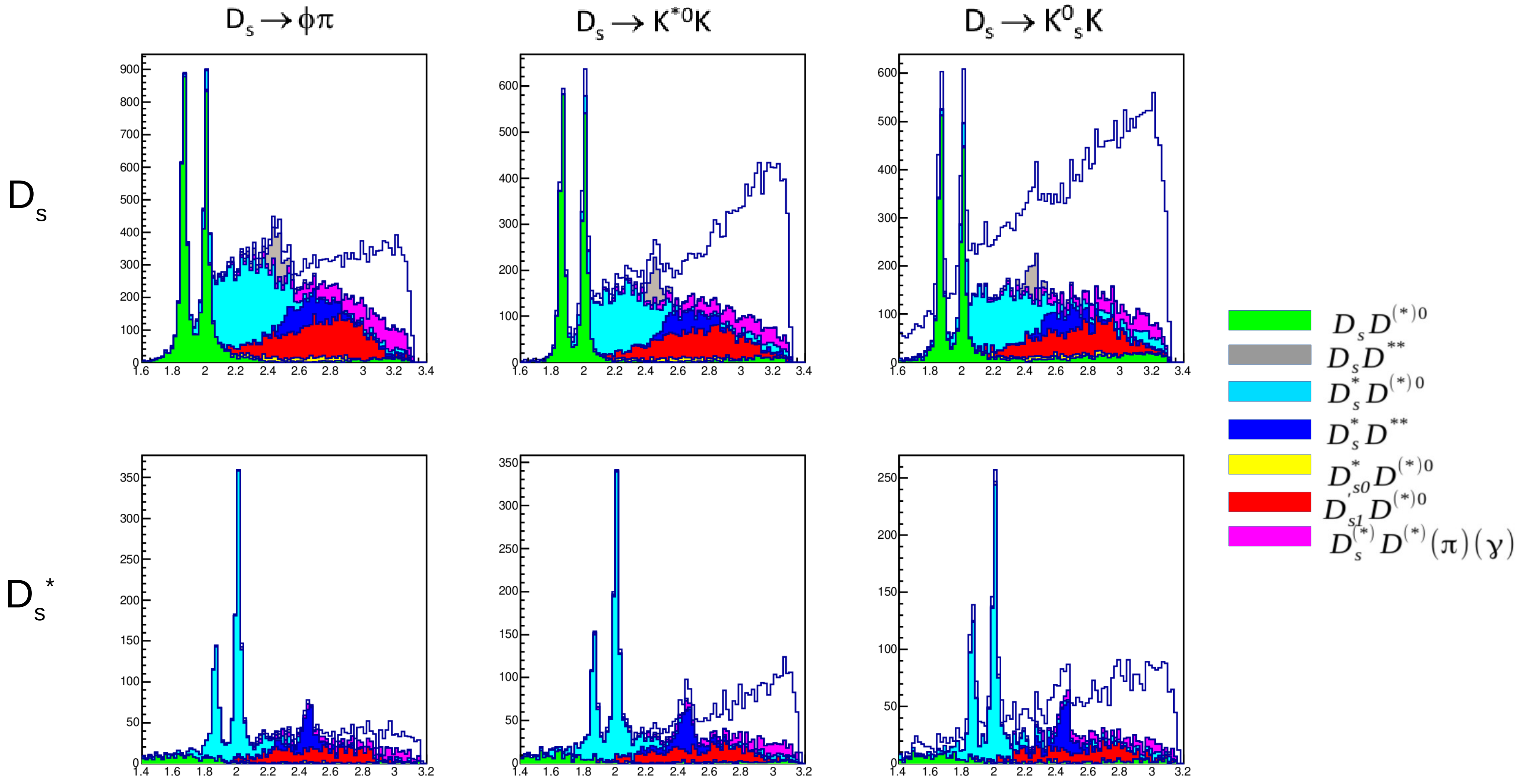




Mx distributions – contributions from 4 types of generic MC



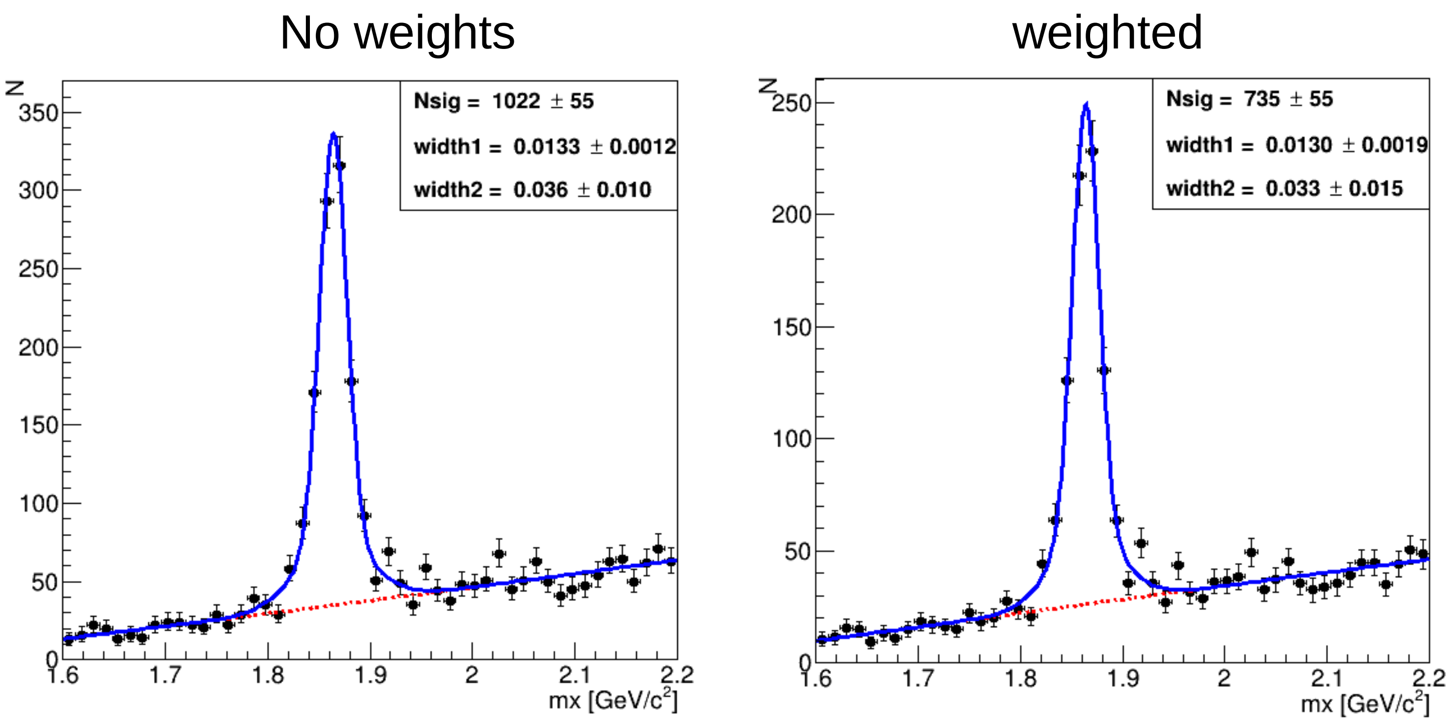
Mx distributions – specific signal and X-feed contributions from MCgen ‘charged’



Correction factors accounting for different efficiency of B_{tag} reconstruction for data & MC

Coefficients (weights) as
an additional variable in the ntuple
(function of nbout and Btag_mode):

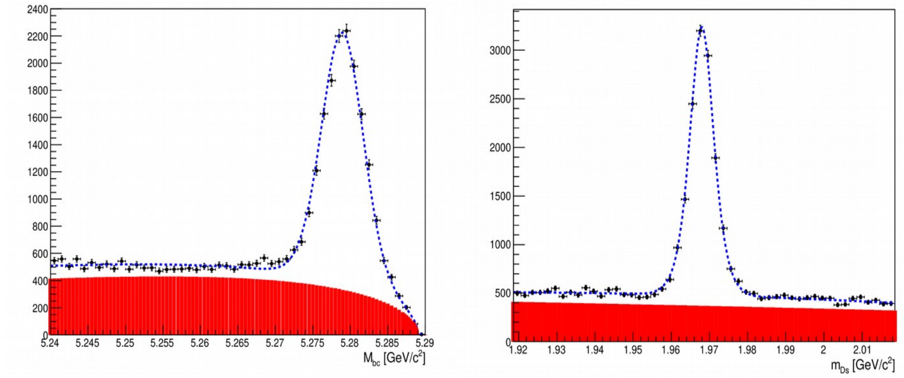
mx	*weight*
1.8931195	0.4300126
2.0606427	0.7606688
1.8585503	0.4488383
1.8858218	0.4390727
1.8622628	0.7349409
1.8216735	0.9423299
1.8470438	0.7705660
1.8505309	0.8022359
1.8264402	0.7321117
1.8660372	0.7349409
1.844468	0.7863315
1.8475010	0.9423299
1.9011440	0.5846295
1.8856973	0.4993443
1.8996472	0.6876546
1.8647035	0.4993443
1.8693547	1.1406257
1.8148039	0.8668448
1.8666857	0.8212286
2.552665	0.5518770
1.8735569	0.7349409
3.1571512	0.8596831
1.8591129	0.2374452
1.8742926	0.7913513
1.9223578	0.7606688
1.9909900	1.1005176
2.8411469	0.7747043
1.9634974	0.8699288
1.8587625	0.7705660
1.6779035	0.6632515
1.8605729	0.6876546
3.2150764	0.5291972
1.8897345	0.6874800
1.8635618	0.5846295



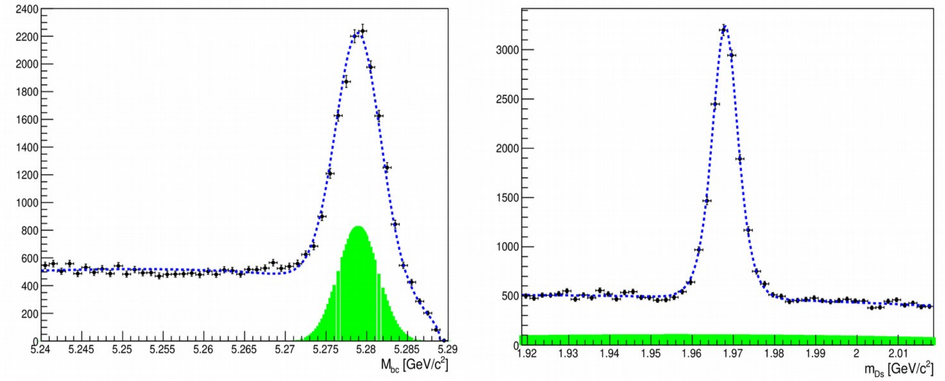
„Weighted fits" can be used for MC samples for better agreement with the data

Background analysis – 4 components based on M_{bc} & $m(D_s)$ distributions

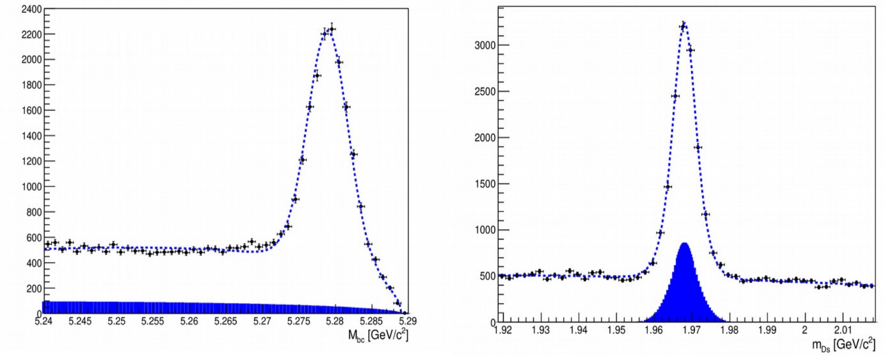
BCKG component:



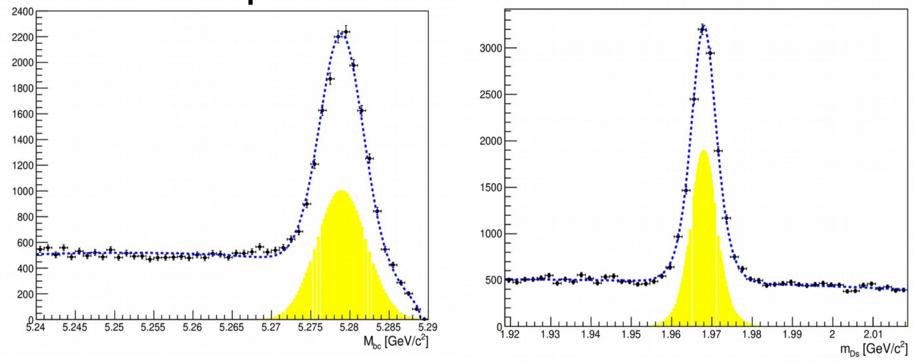
MBC component:



MDS component:

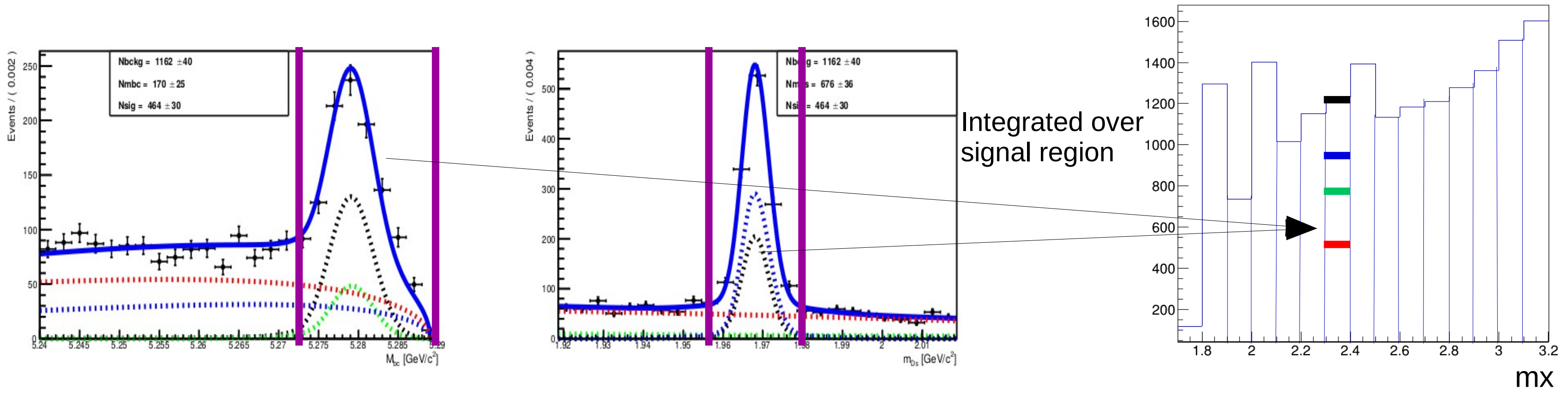


SIG component:



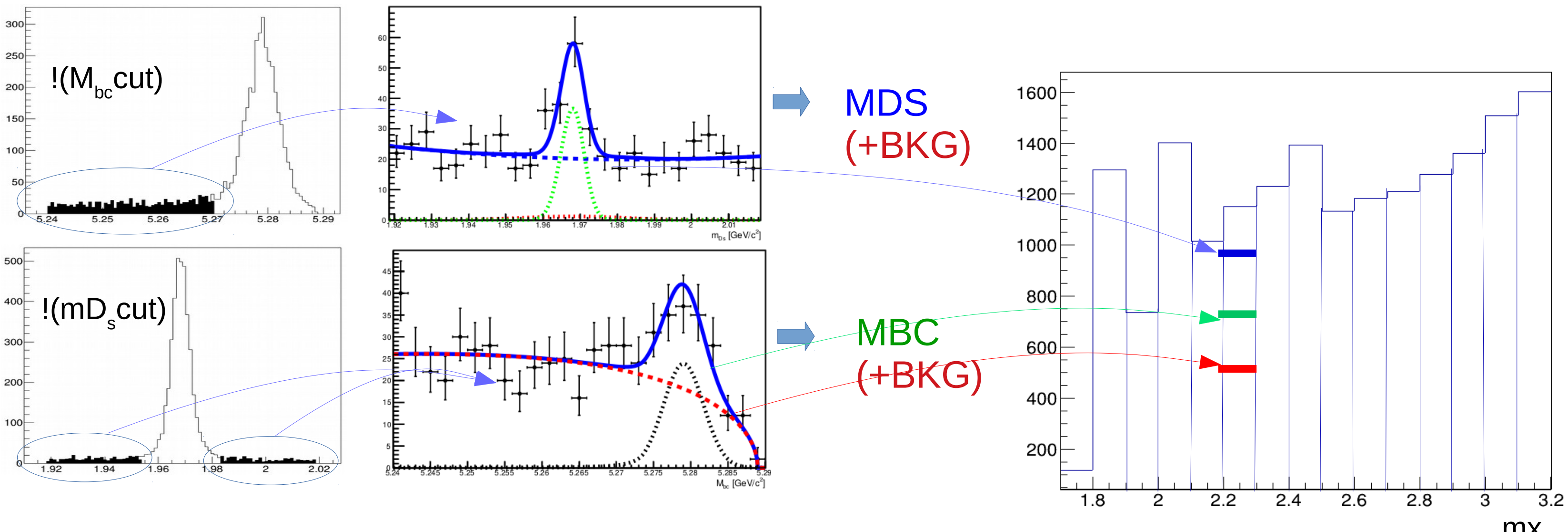
Background analysis – fits in different bins of missing mass

FIT 2D



2x FIT 1D

also for (blinded) data!

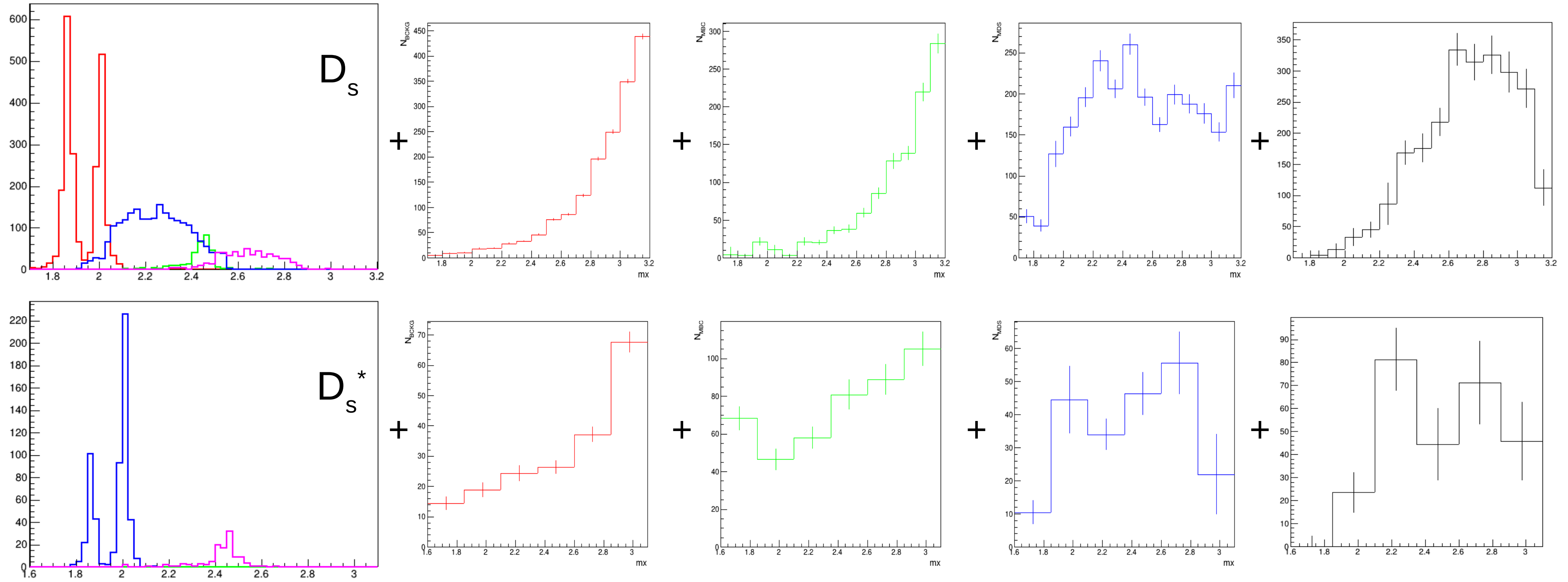


PDFs components for simultaneus fit to both *mxs* - **MCgen**

Fixed-shape signal/xfeed components with fixed relative normalization between D_s and D_s^*

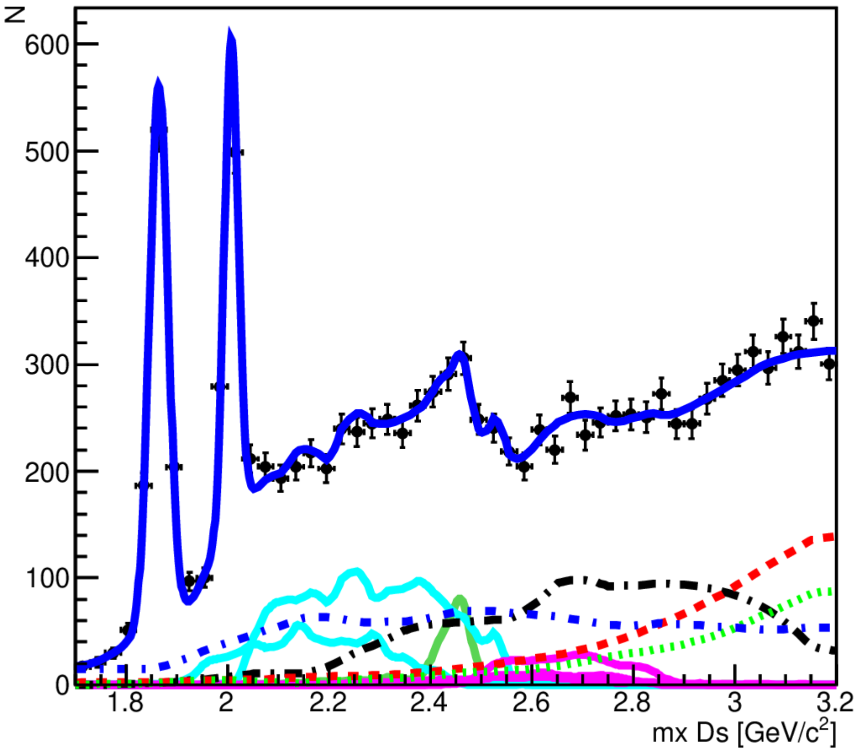
Fixed / bounded normalization

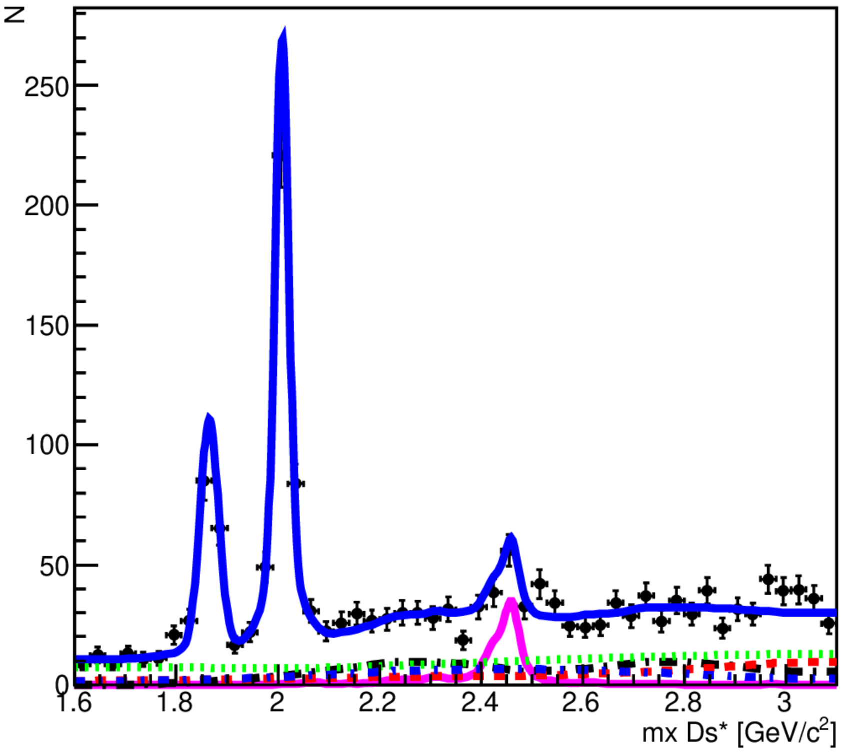
BCKG MBC MDS SIG_{rest}



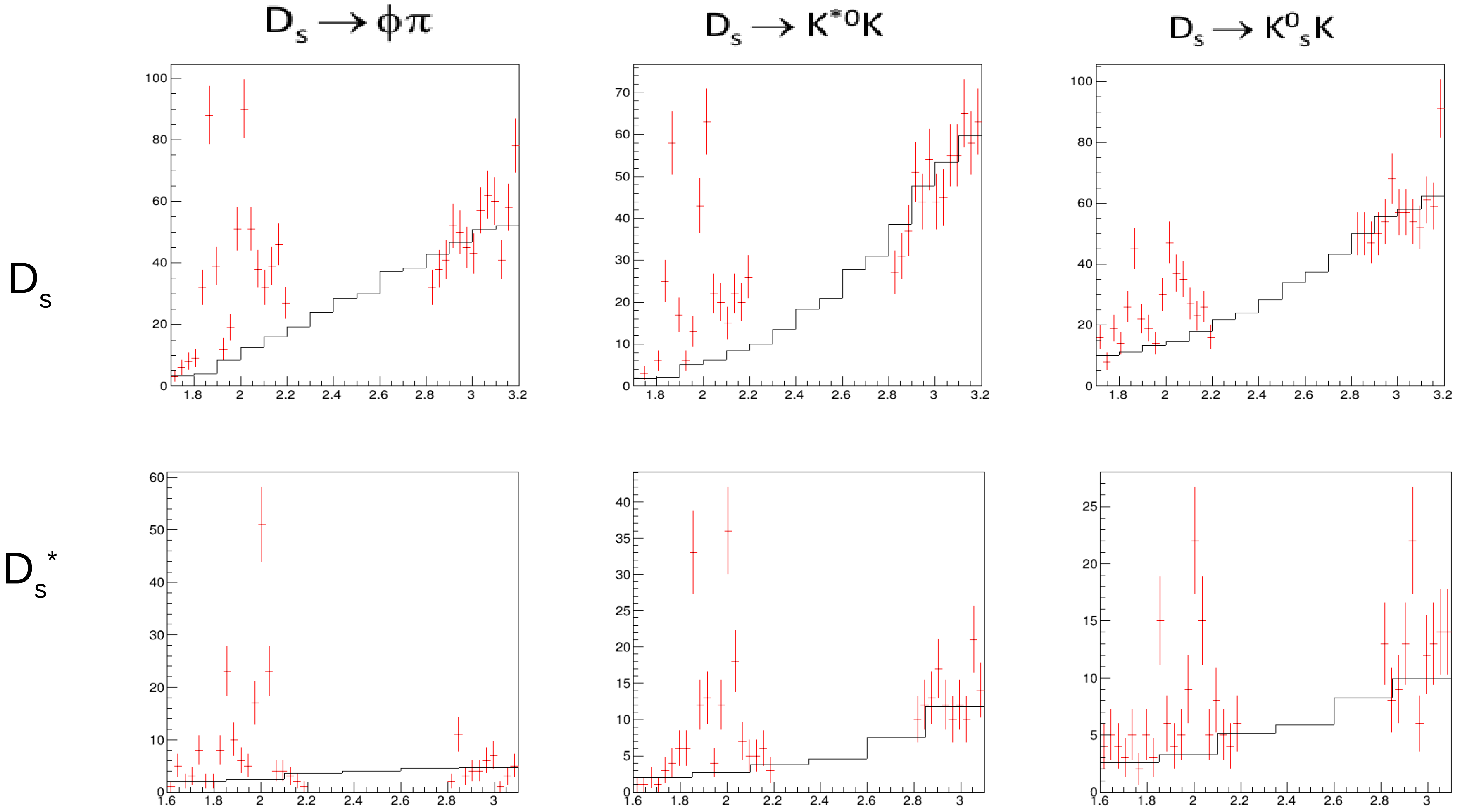
From 2D fits

Simultaneous Fit to MCgen (signals + x-feeds + 4 background contributions)





Comparison of data (mx in control regions) and scaled MC



Initial studies on B2BII

- Dedicated Monte Carlo:
  $B^{-} \rightarrow D_s^{-} D^{**}$ and $B^{+} \rightarrow D_s^{*-} D^{**}$

```
Decay B-
0.1063   myD_s- D_0*0
0.1063   D'_10  myD_s-
0.2128   D_10  myD_s-
0.5746   D_2*0  myD_s-
Enddecay
```

```
Decay B-
0.1063   myD_s*- D_0*0
0.1063   D'_10  myD_s*-
0.2128   D_10  myD_s*-
0.5746   D_2*0  myD_s*-
Enddecay
```

(Belle1 decayDec)

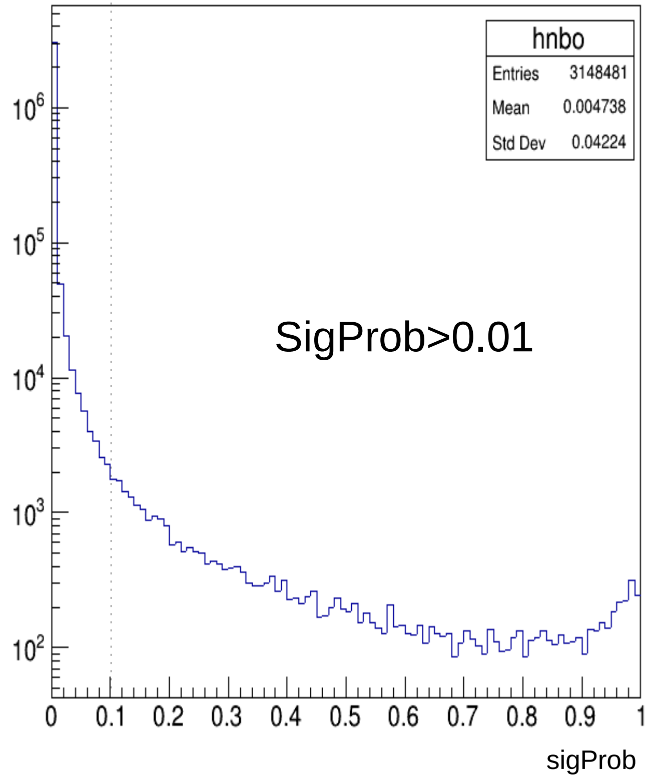
$D_s \rightarrow \phi\pi$
$\phi \rightarrow KK$

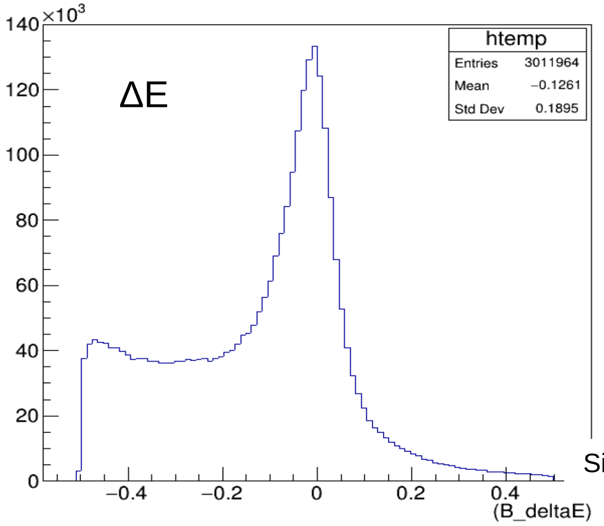
$D_s^{*} \rightarrow D_s\gamma$

- B_{tag} reconstruction with (default) hadronic FEI
- FastBDT algorithm to distinguish good gammas (from D_s^{*}) from beam bkg & fake photons

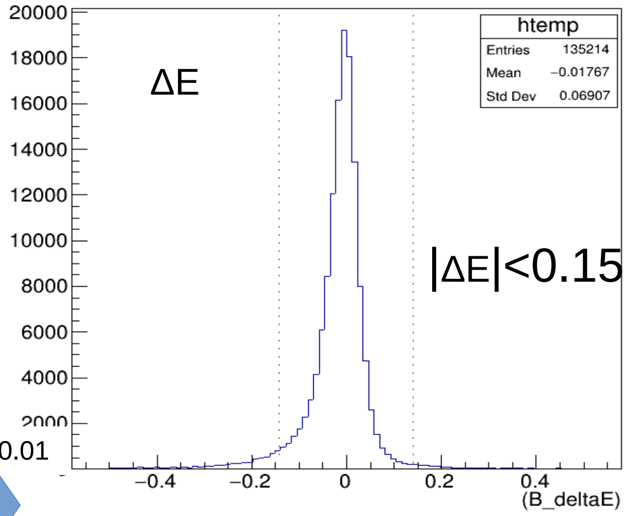
→ ***pybdt_bb>0.3 and pybdt_fp>0.3   (Meihong Liu)***

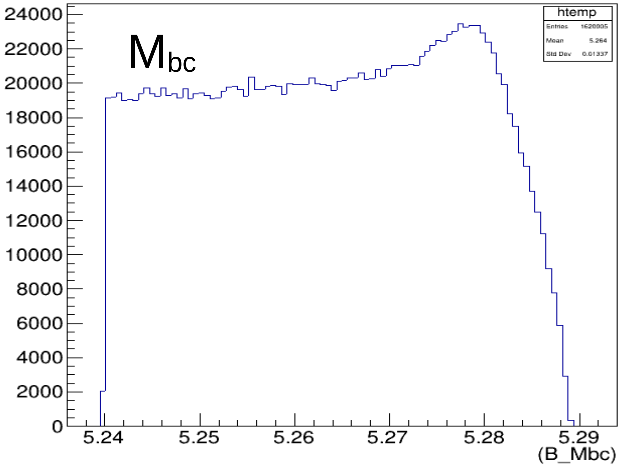
B_{tag} variables (preliminary, arbitrary cuts)

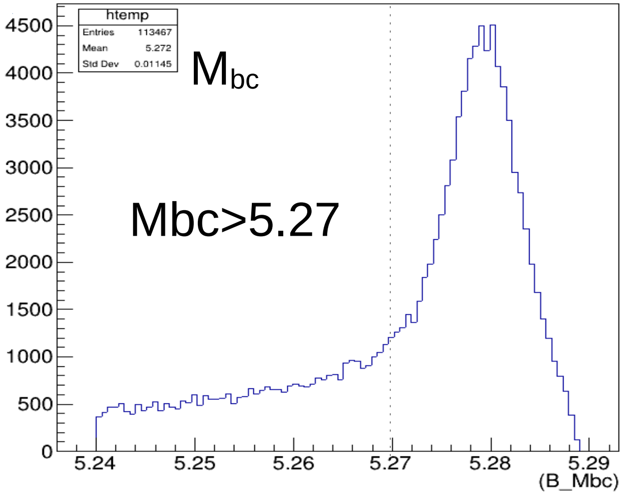




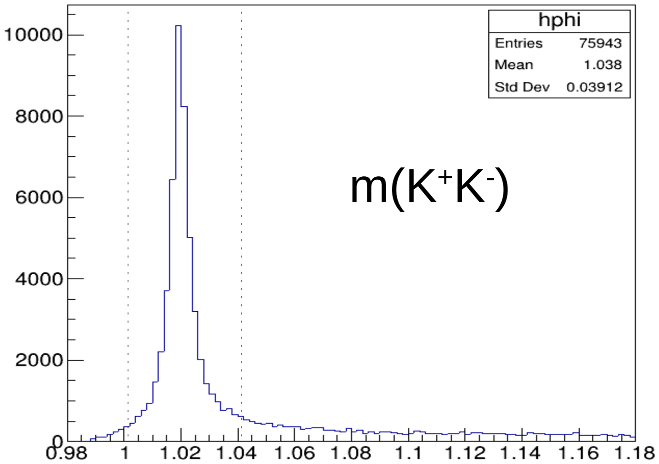
SigProb>0.01



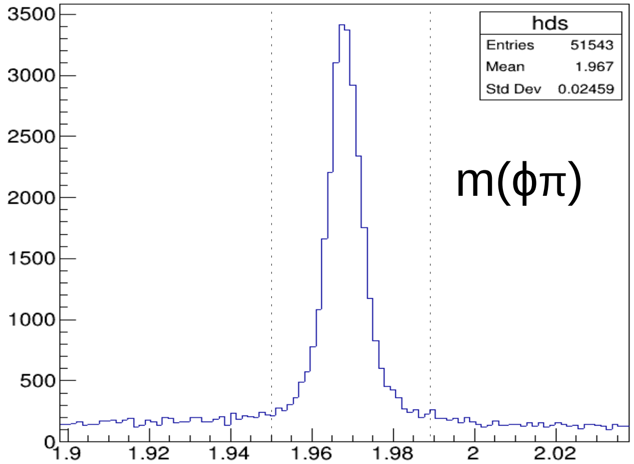




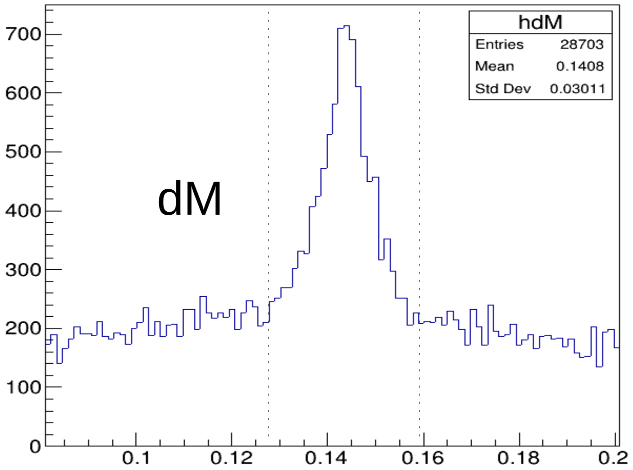
$D_s^{(*)}$ variables (preliminary, arbitrary cuts)



|mphi-1.021|<0.02

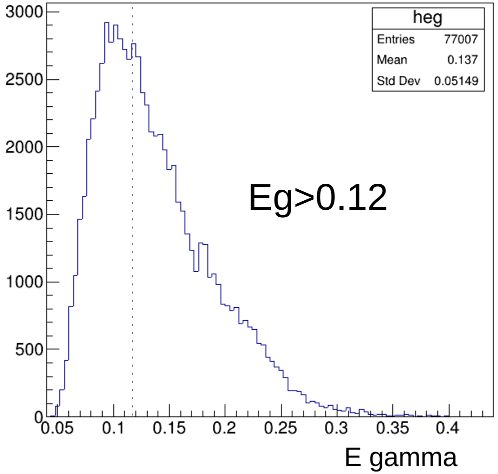


|mDs-1.968|<0.02



|dM-0.1438|<0.015

photon for D_s^*



Best candidate selection:

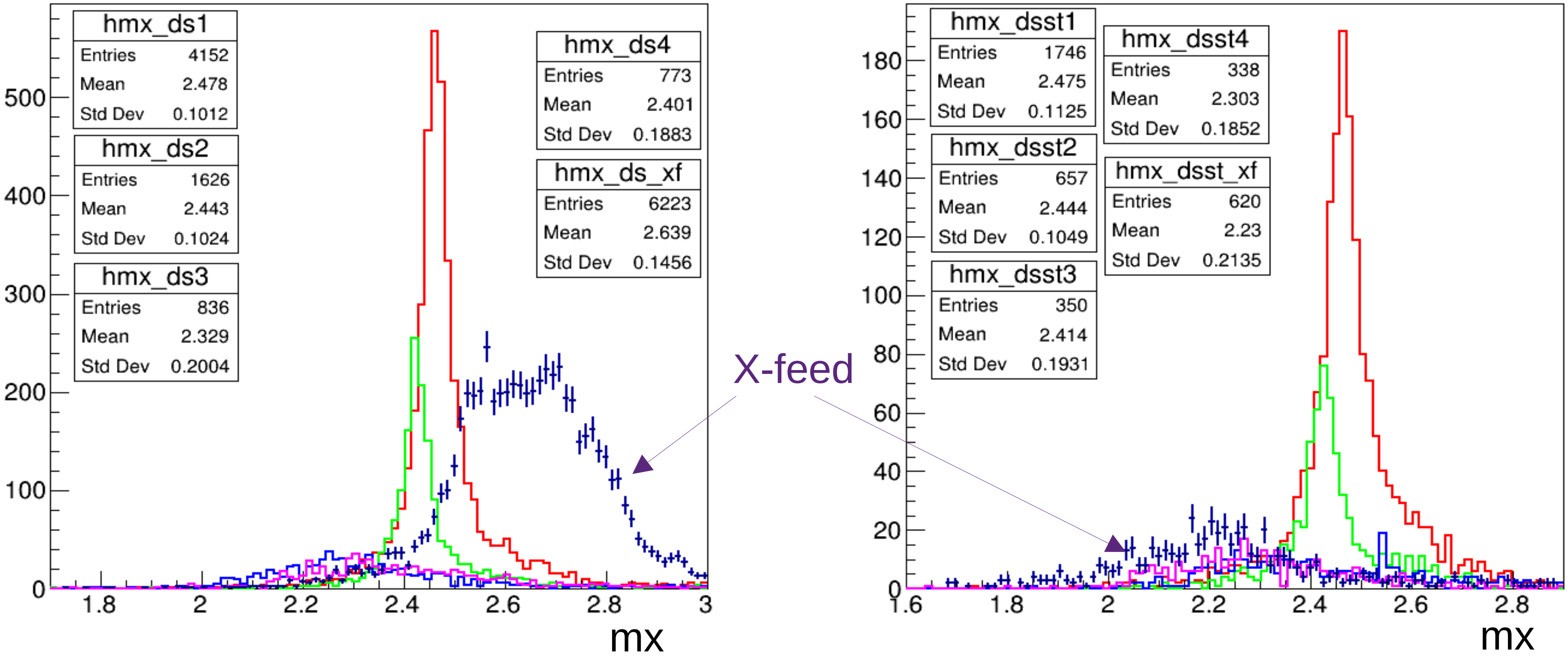
- B_{tag}: the best **sigProb** value
- D_s: the highest **χ^2 probability** (vx fit)
- D_s^*: the lowest **|dM-0.1438|** value

D_s^* is favoured over D_s if:
|dM-0.1438|<0.015 and Eg>0.12 (good photon)

Missing mass distributions

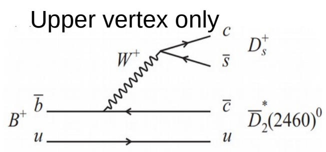
Signal MC: $B^- \rightarrow D_s^{(*)-} D^{**}$

D_s reconstruction $\quad$ D_s^* reconstruction

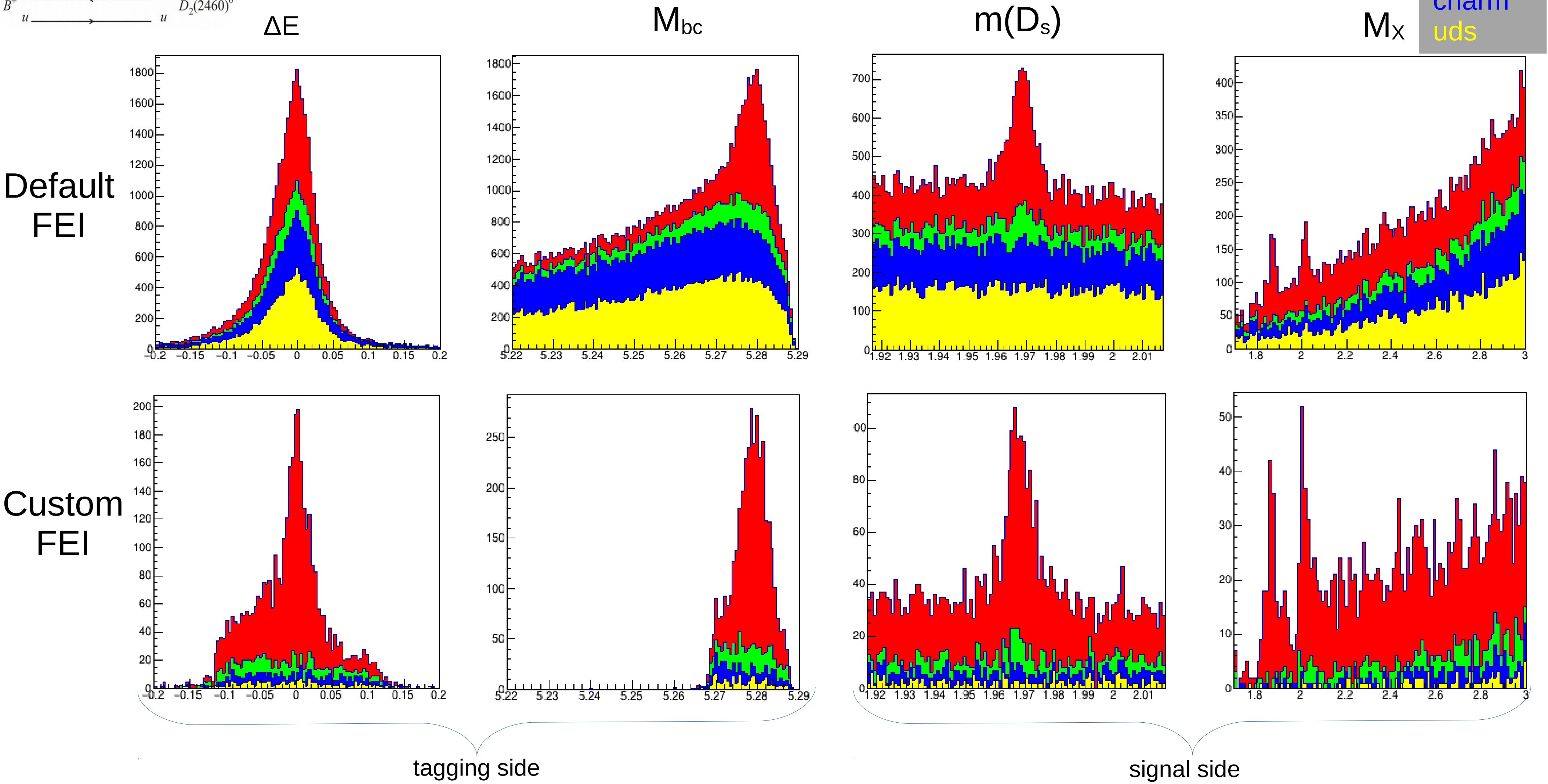


Study of generic Monte Carlo (Belle 1)

- One stream of MC (uds, charm, mixed, charged)
- Using B2BII
- Comparison between **default FEI** and **custom FEI** (Roman, Murad)
- For both $\mathbf{D_s}$ and $\mathbf{D_s^*}$ reconstruction

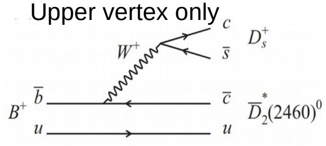


B → D_s X reconstruction on Belle MC generic



B → $\mathbf{D_s^*}$ X reconstruction on Belle MC generic

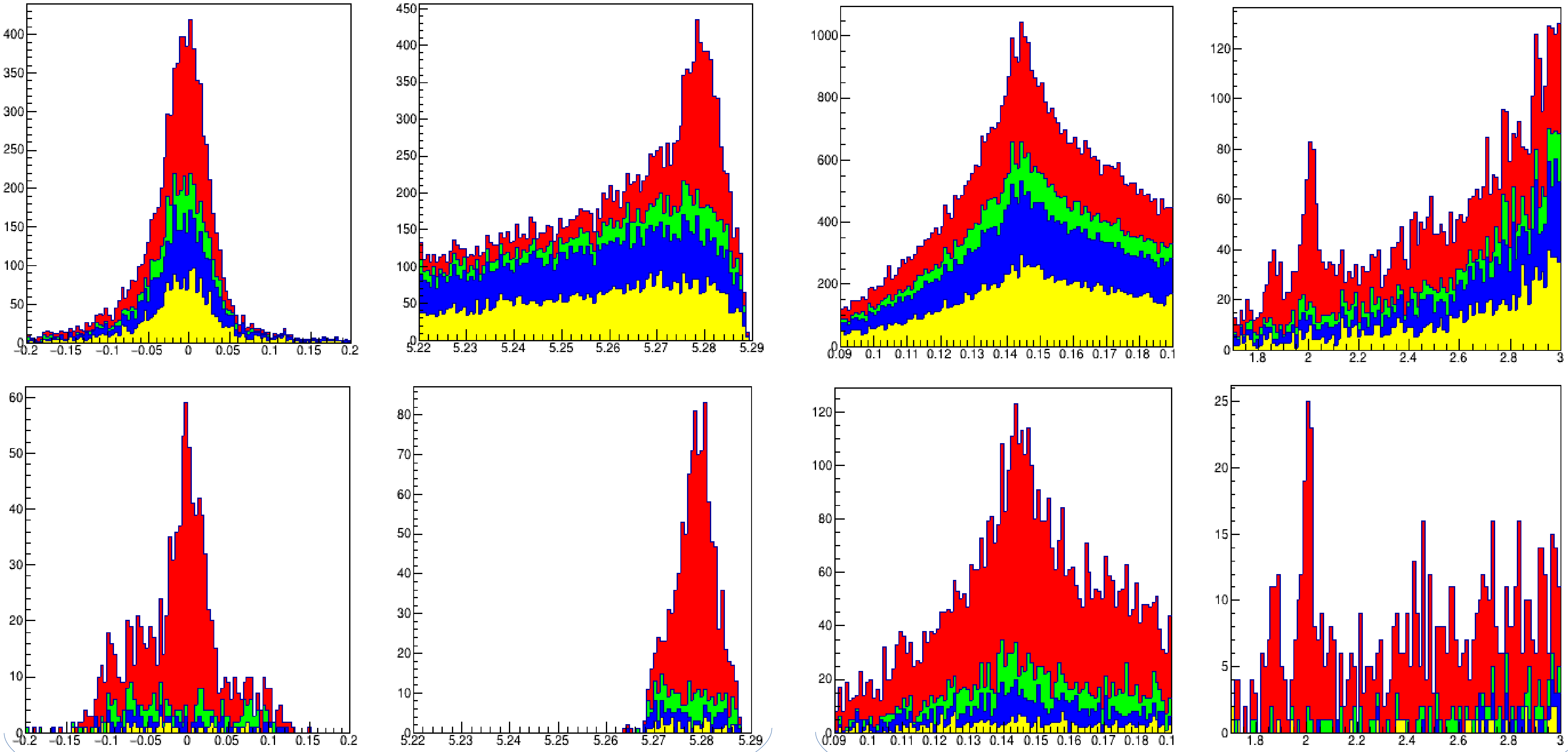
Upper vertex only



ΔE | M_{bc} | $m(D_s)$ | M_X

Default FEI

Custom FEI

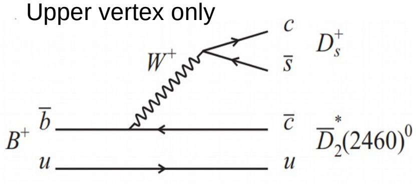


tagging side

signal side

B_{tag} decay modes composition

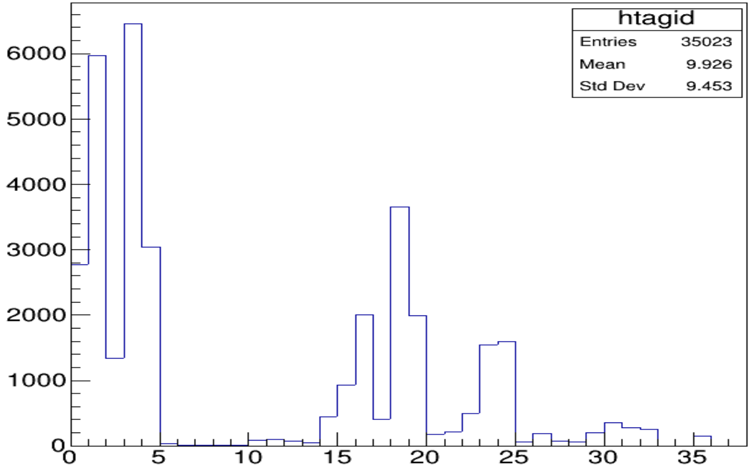
Upper vertex only

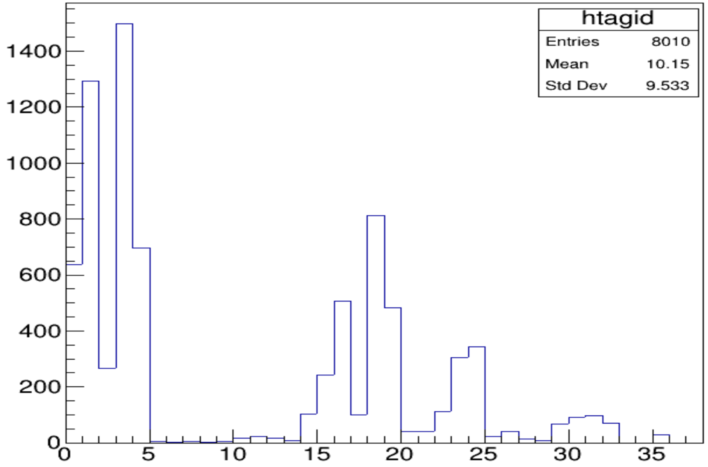


D_s reco

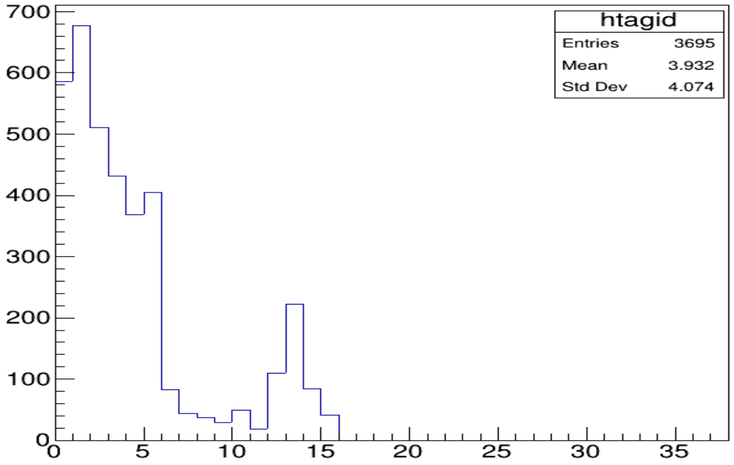
D_s^* reco

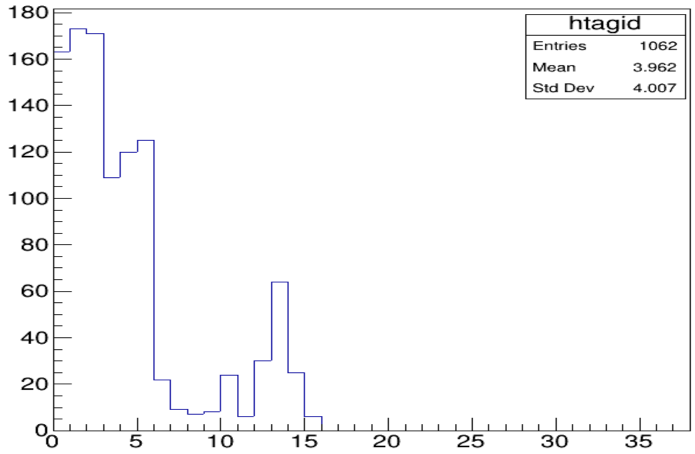
Default FEI





Custom FEI





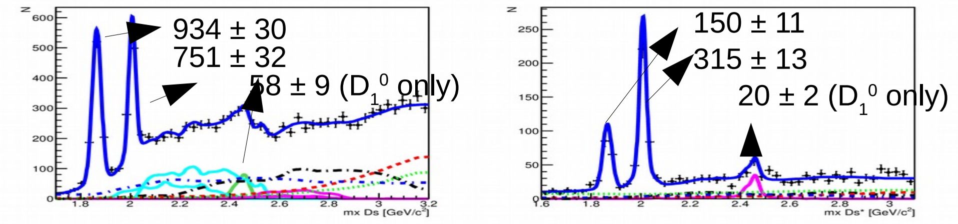
Status & plans

- Analysis has just been restarted from the beginning using basf2 software
  → collaboration with IITB (and maybe IITM) group
- Full Event Interpretation (hadronic FEI) is used to reconstruct B_{tag}
  → possible utilization of the **custom FEI**
- Both branching fraction (for different charge configurations) and recoil mass (Mx) will be studied
- We aim to combine Belle1 (B2BII) + Belle II data sample
- Plan of adding neutral $B^0 \to D_s X$

BACKUP

Toy MC for simultaneous fit to MCgen

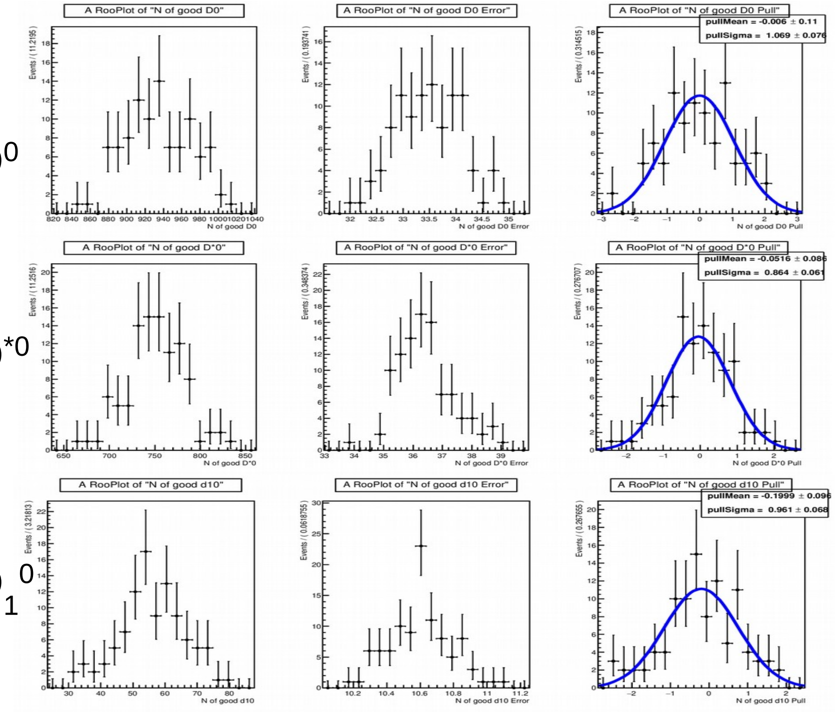
Nominal fit



D_sD^0

D_sD^{*0}

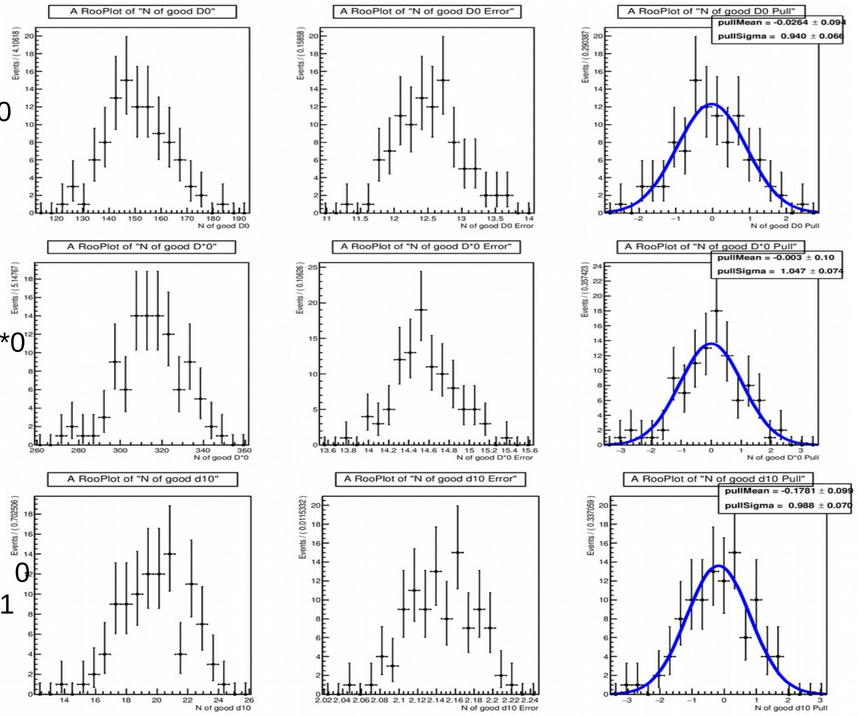
$D_sD_1^0$



$D_s^*D^0$

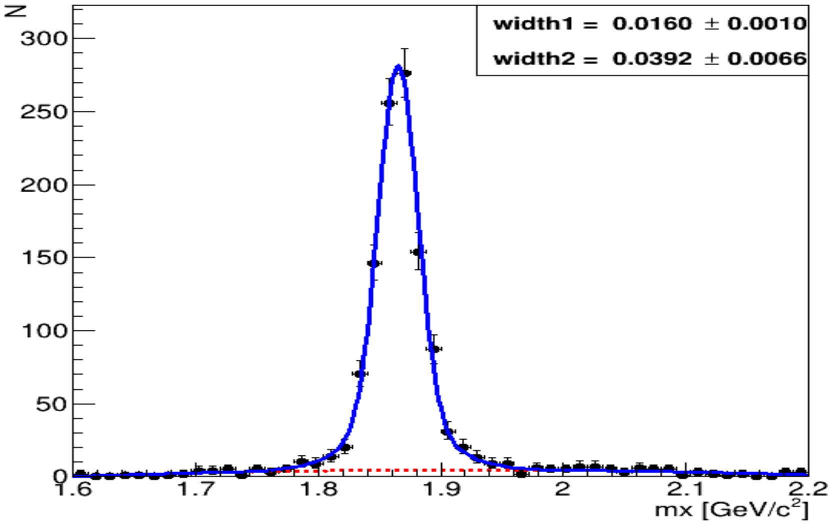
$D_s^*D^{*0}$

$D_s^*D_1^0$



Attempt to systematics – $D^{(*)0}$ signal shape: two Gaussians + fraction

Fit to missing mass distribution for **D_sD^0 signal**
– only shape parameters are floating



→ **Coleration Matrix** for shape parameters:

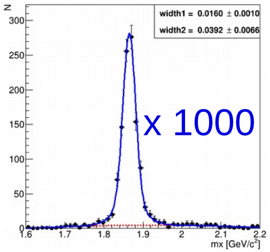
	frac	width1	width2
frac	1	0.8389	0.851
width1	0.8389	1	0.6947
width2	0.851	0.6947	1

Covariance Matrix

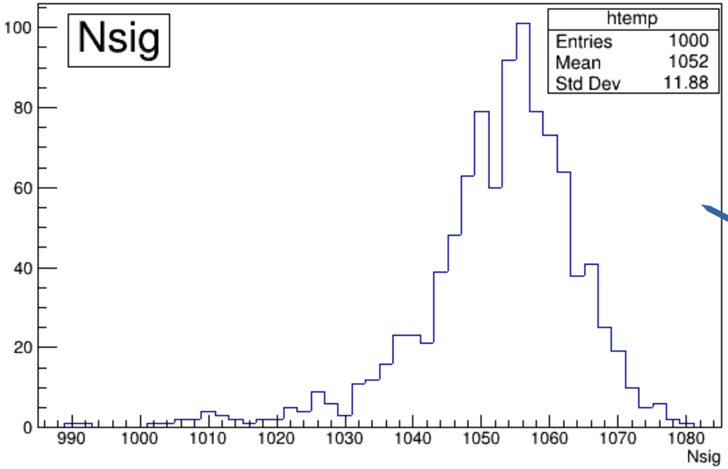
	frac	width1	width2
frac	0.005505	6.363e-05	0.0004199
width1	6.363e-05	1.045e-06	4.723e-06
width2	0.0004199	4.723e-06	4.423e-05

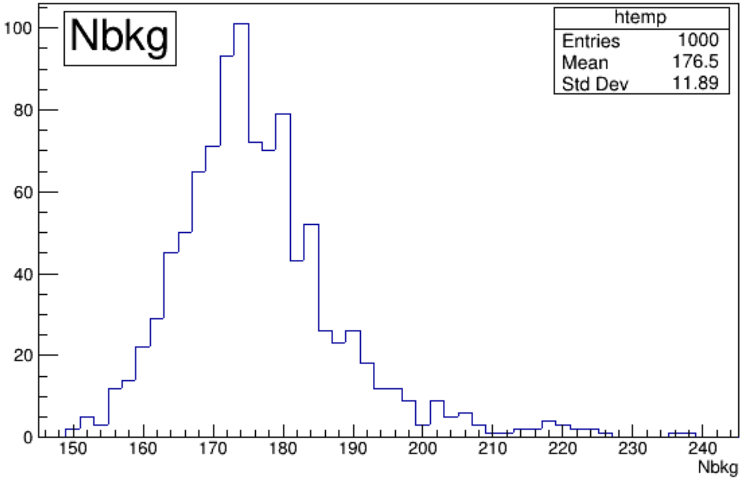
Generation of 1000 sets of shape parameters (**width¹**, **width²**, **frac**) based on Covariance Matrix

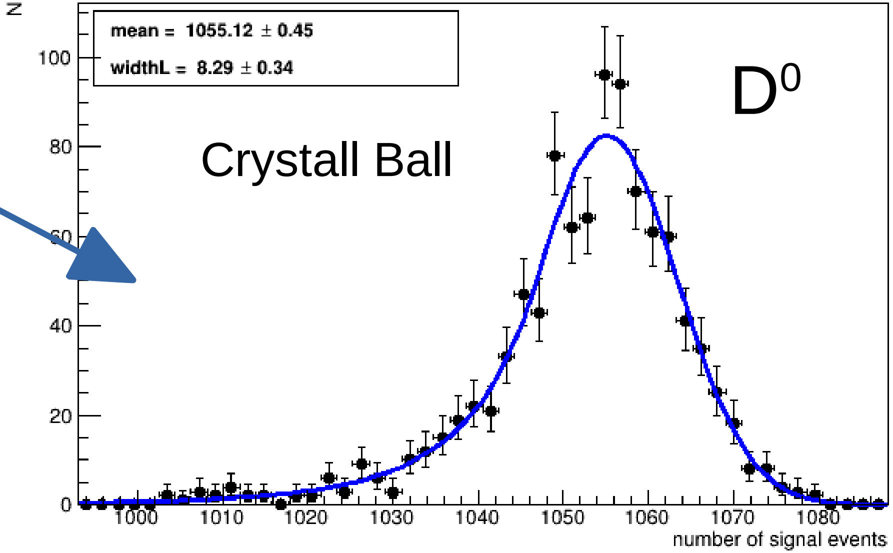
Fit for each set of fixed shape parameters (**width**[1]**, width**[2]**, frac**) → 1000 fits



→ distribution: *Nsig (and Nbckg)* - free fit parameters







Floating Parameter	FinalValue +/-	Error
alpha	1.0476e+00 +/-	1.74e-01
mean	1.0551e+03 +/-	4.49e-01
n	6.8388e+00 +/-	4.88e+00
widthL	8.2921e+00 +/-	3.37e-01

→ syst. ~0.8% (??)

Particle Physics Summer Student Programme 2022 (IFJ PAN, Krakow)

→ inclusive BF

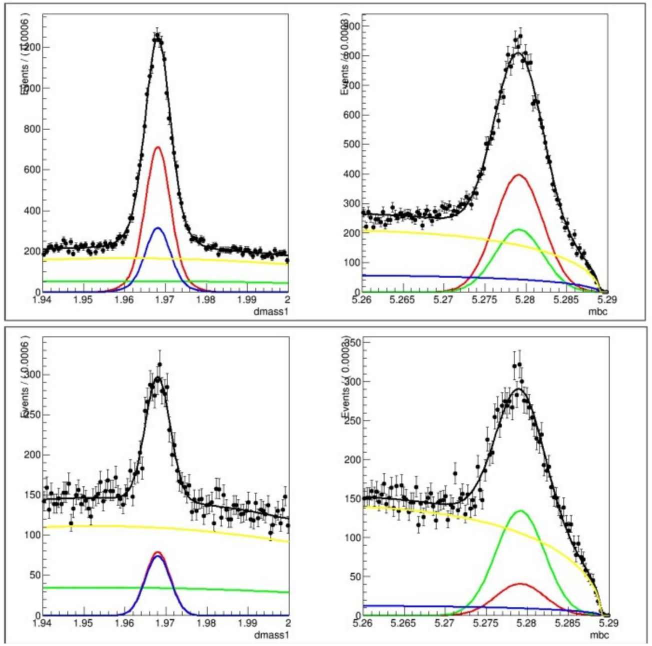
MC

Signal extraction

Based on 2D unbinned maximum likelihood fit for Mbc and Ds

Ds from upper vertex

Ds from lower vertex



$$N_{sig}^{up} = 9884.9 \pm 219.0$$

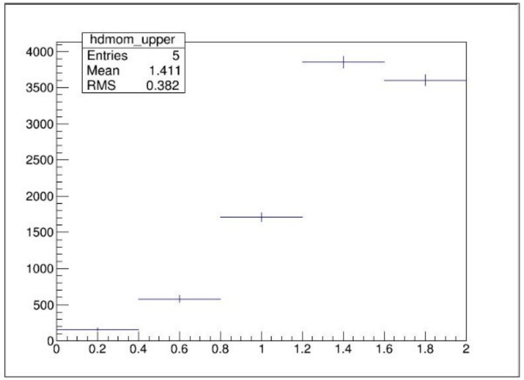
total fit
good Btag and good Ds
good Btag and wrong Ds
wrong Btag and good Ds
wrong Btag and wrong Ds

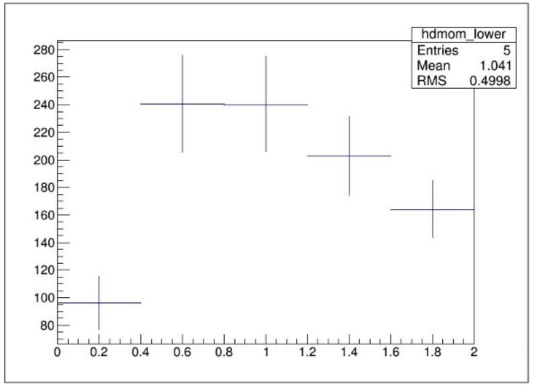
$$N_{sig}^{low} = 1010.4 \pm 17.9$$

$$\frac{\mathcal{B}(B^- \to D_s^+ X)}{\mathcal{B}(B^- \to D_s^+ X) + \mathcal{B}(B^- \to D_s^- X)} =$$

9.27 ± 0.24 (stat) % MC
8.96 ± 1.67 (stat) % data

D_s momentum distribution



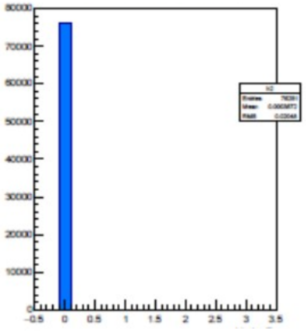


Particle Physics Summer Student Programme 2017 (IFJ PAN, Krakow)

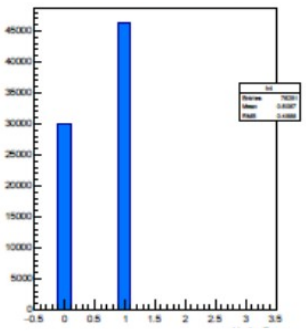
$\rightarrow$ X analysis for $B^+ \rightarrow D_s^- X$

Monte Carlo $B^+ \rightarrow D_s^- K^+ e^+ \nu$

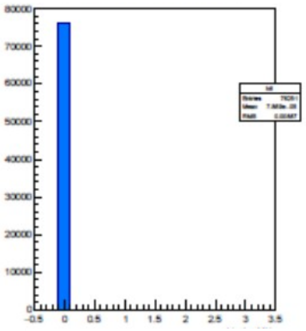
n(e^-)



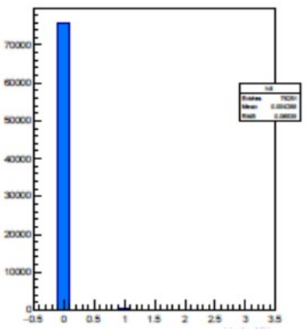
n(e^+)



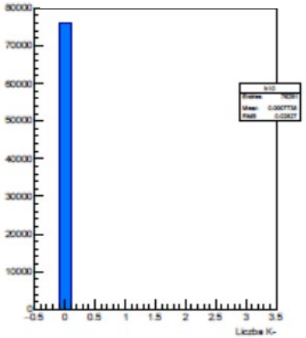
n(μ^-)



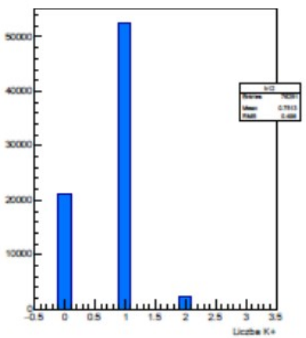
n(μ^+)



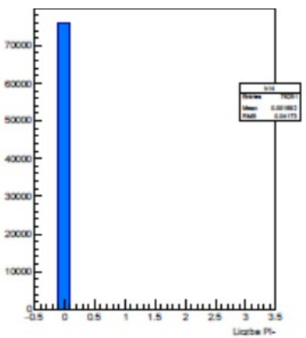
n(K^-)



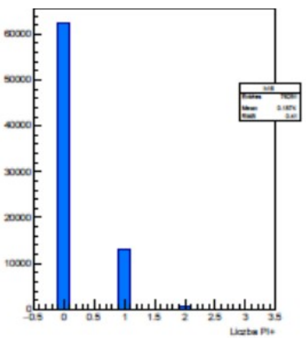
n(K^+)



n(π^-)



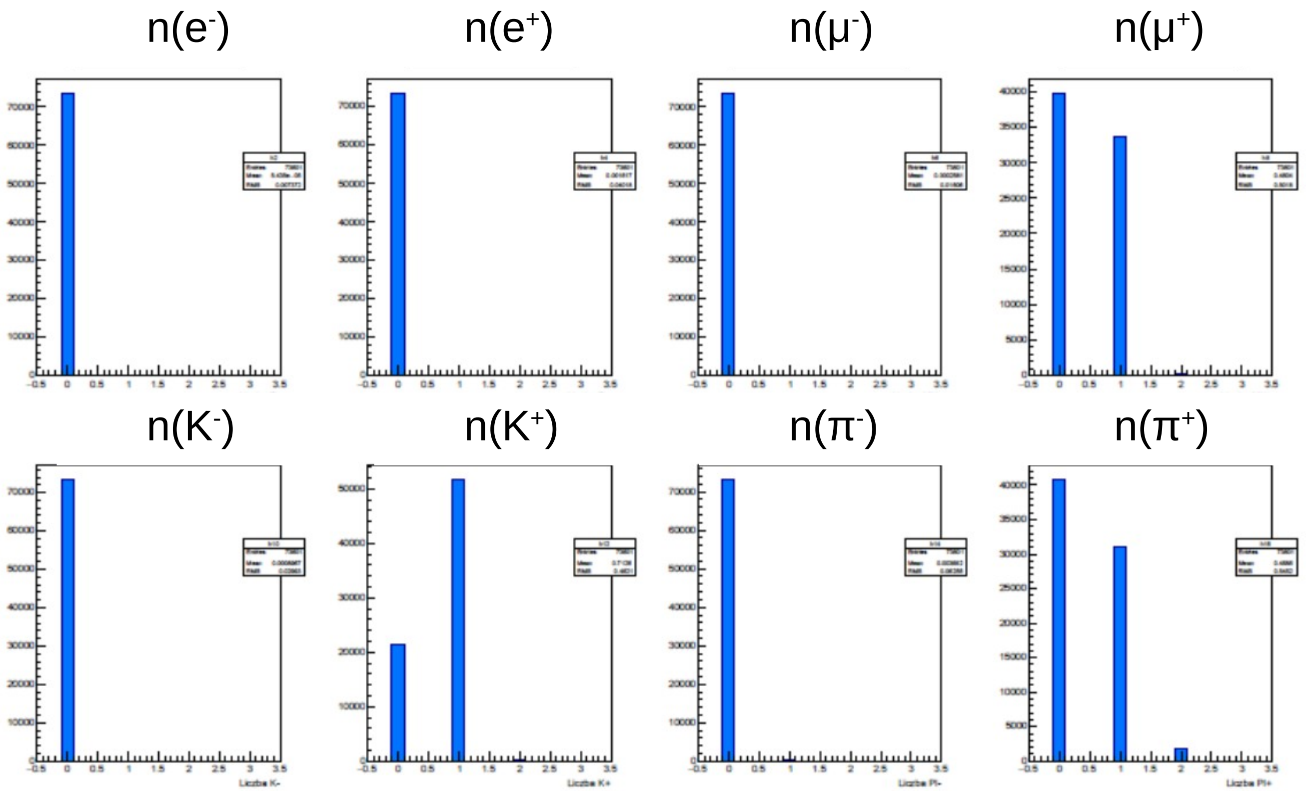
n(π^+)



Particle Physics Summer Student Programme 2017 (IFJ PAN, Krakow)

→ X analysis for $B^+ \to D_s^- X$

Monte Carlo $B^+ \to D_s^- K^+ \mu^+ \nu$



Main cuts

B tag:

$|\Delta E + 5.8| < 40.0$ MeV
$M_{bc} > 5.27$ GeV
cs-nbout > 0.01
$B_{tag} = B^+$

Signal side:

1.5 GeV < mx < 3.2 GeV
$|m(D_S)-m(D_S)^{PDG}| < 3\sigma$
$B_{flav} * d_{flav} < 0$

$L(K/\pi)>0.4$ (for K)
$L(\pi/K)>0.1$ (for π)
L(mu,e)<0.95 (veto)

After applying all cuts:
Best B_{tag} and $D_s^{(*)}$ selection:

- B_{tag} of highest nbout
- best D_S:

→ min $\frac{(m(D_S)-m(D_S)^{PDG})^2}{\sigma^2}$

or → CL_{DS} (from mass constained fit)

$D_s^* \rightarrow D_s \gamma$

Ds*:
photons to Ds* cannot come from z π^0 which are defined as:
- 118 MeV < $m(\pi^0)$ < 150 MeV
- $E_{\gamma 1,2}$ > 50 MeV
- $chi^2 < 50$

Ds* is prefered over **Ds** if:

- $E\gamma$ > 130 MeV
- $|m(D_S^*)-m(D_S)-0.1438|<13$ MeV (mass diff.)

Eγ cut optimization

MC generic (charged)

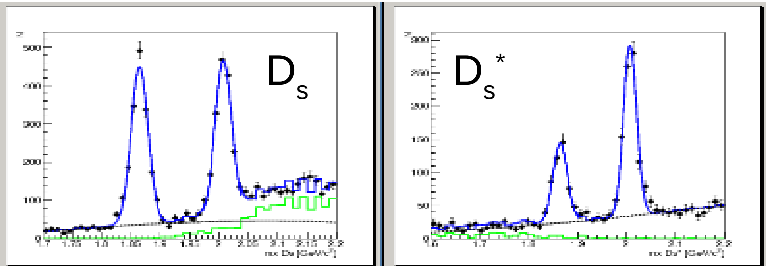
Mx distribution for D_s and D_s^* fitted simultaneously for mx<2.2 GeV

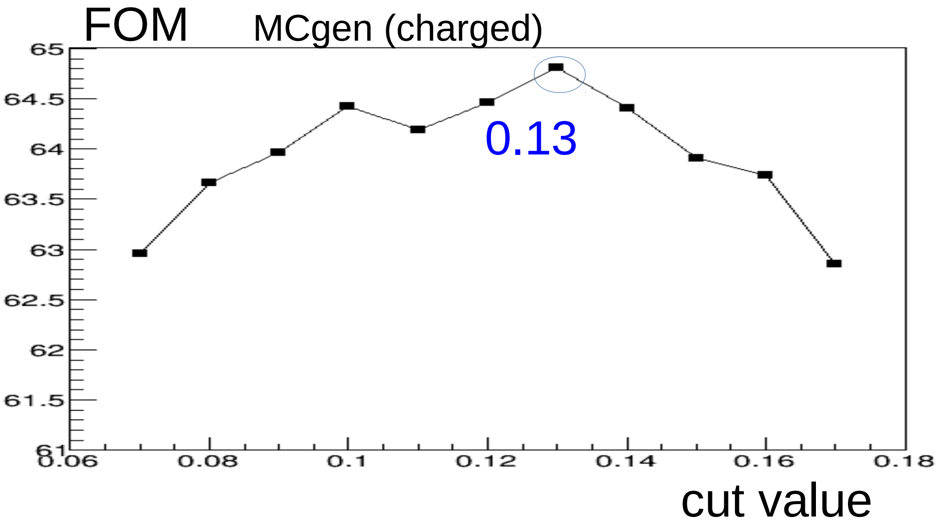
$FOM = FOM_{Ds} + FOM_{Ds^*}$

$$FOM_{Ds(*)} = \frac{S}{\sqrt{B+S}}$$

S – sum of the D^0 and D^{*0} yields

B – sum of the **combinatorial background** and crossfeed



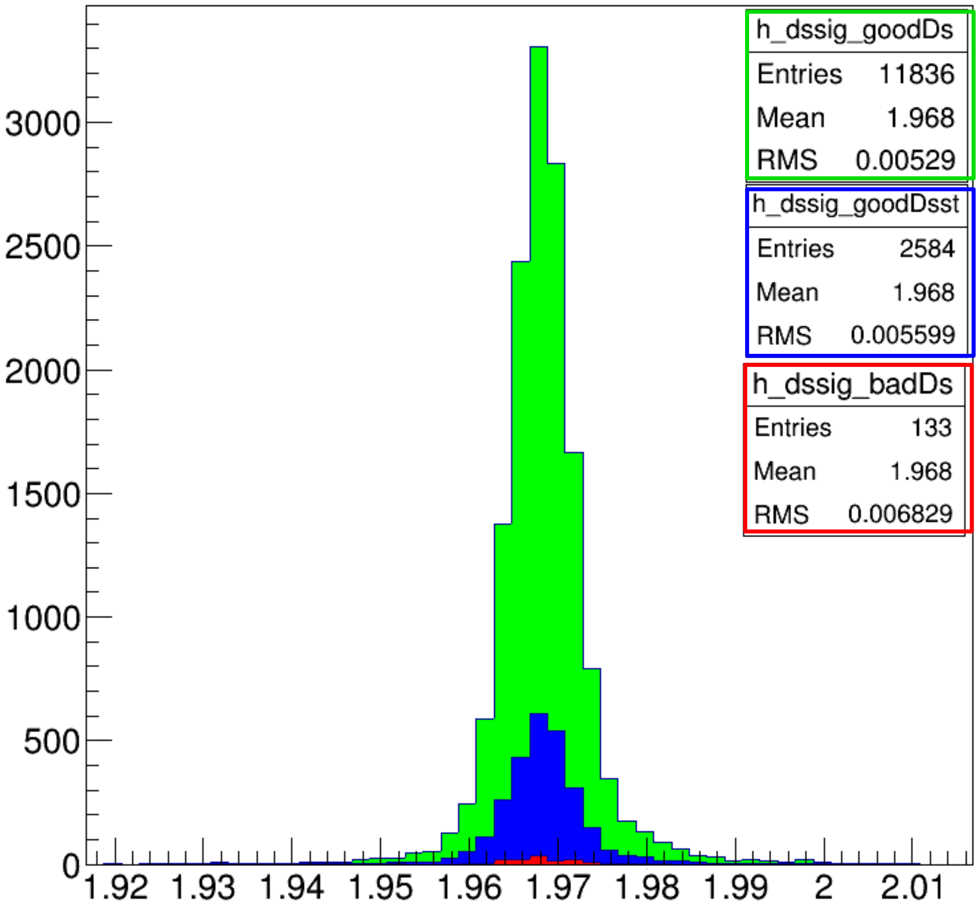


Truth Matching – Ds

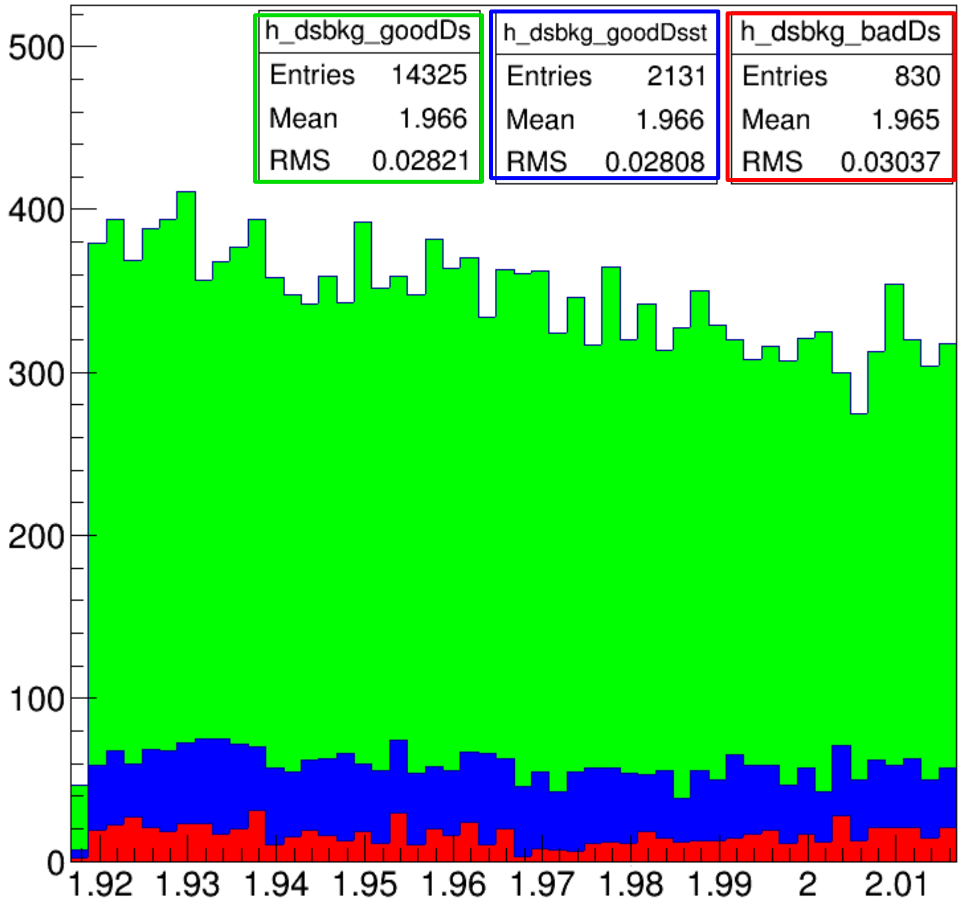
$D_s^+ \to \phi\pi^+$

MCgen $B^{\pm}$

Ds flag==1



Ds flag!=1



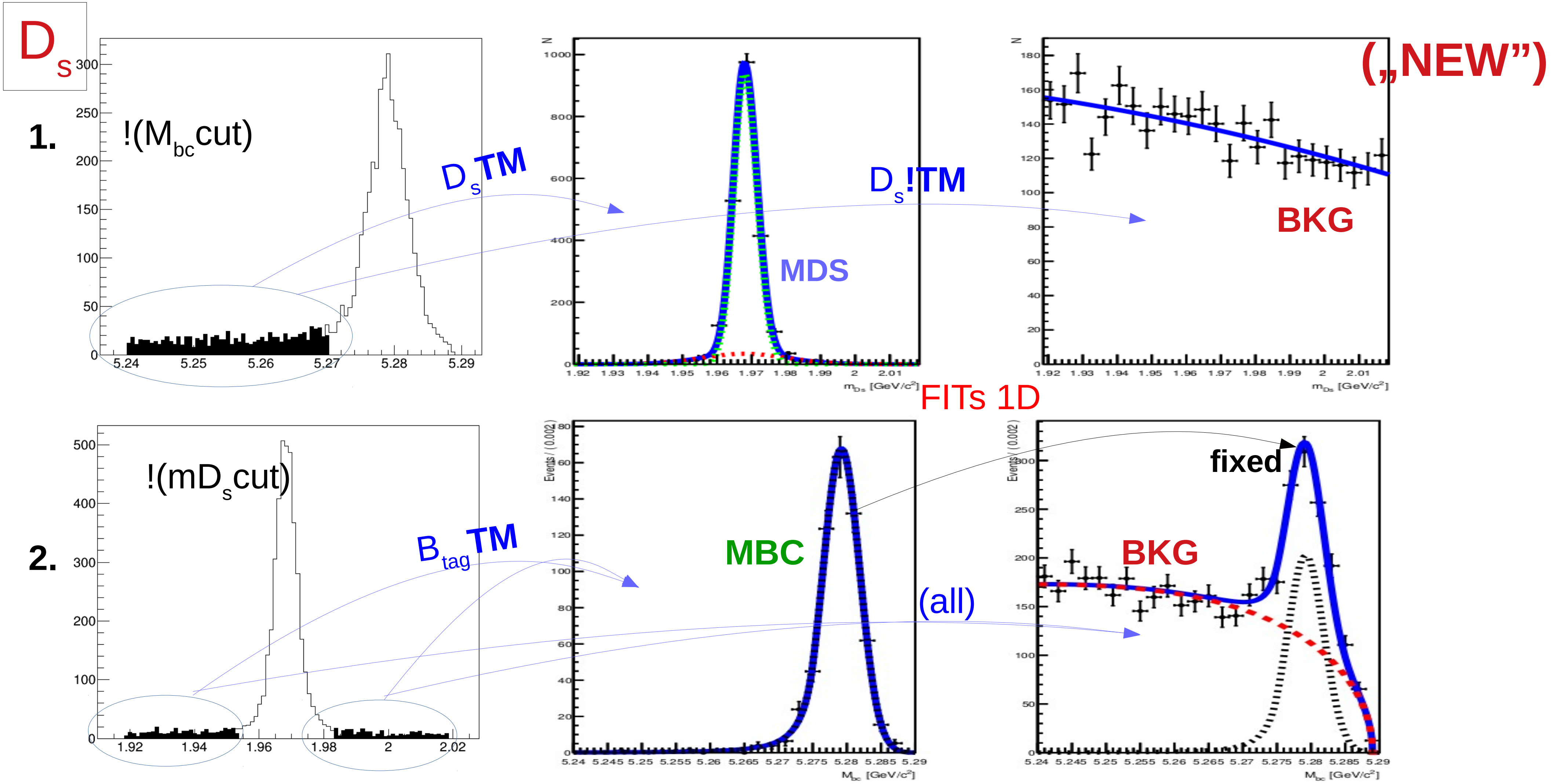
BestDs:

Removed in favour of Ds*

Removed by better Ds candidate

Kept

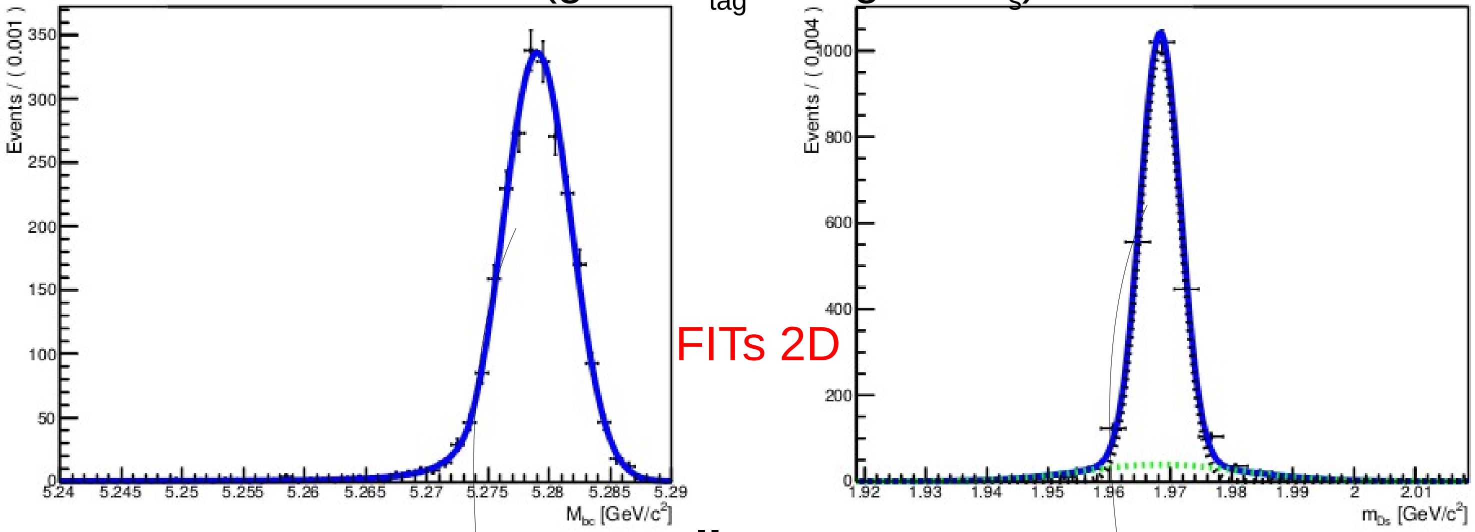
Determination of the shape parameters for (BCKG, **MBC**, **MDS**, **SIG**) comp. in a wide regions of *mx*



TM (good B_{tag} and good D_s)

(„NEW”)

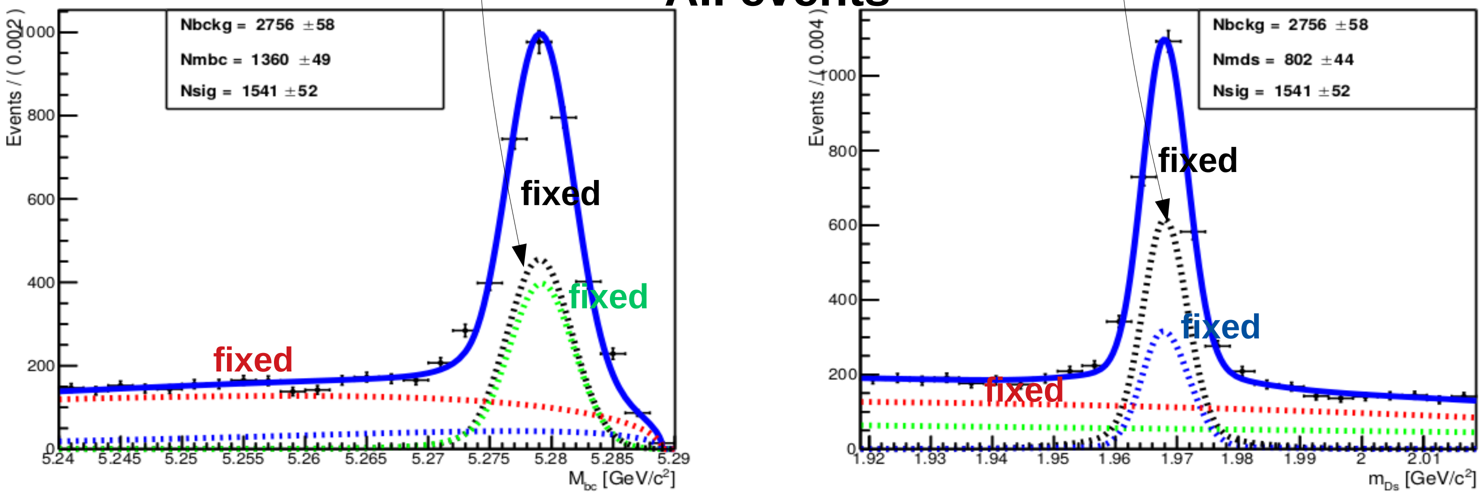
3.



Extract:
SIG parameters

All events

4.



Extract:
- *argus for MDS*
- polynomial for *MBC*

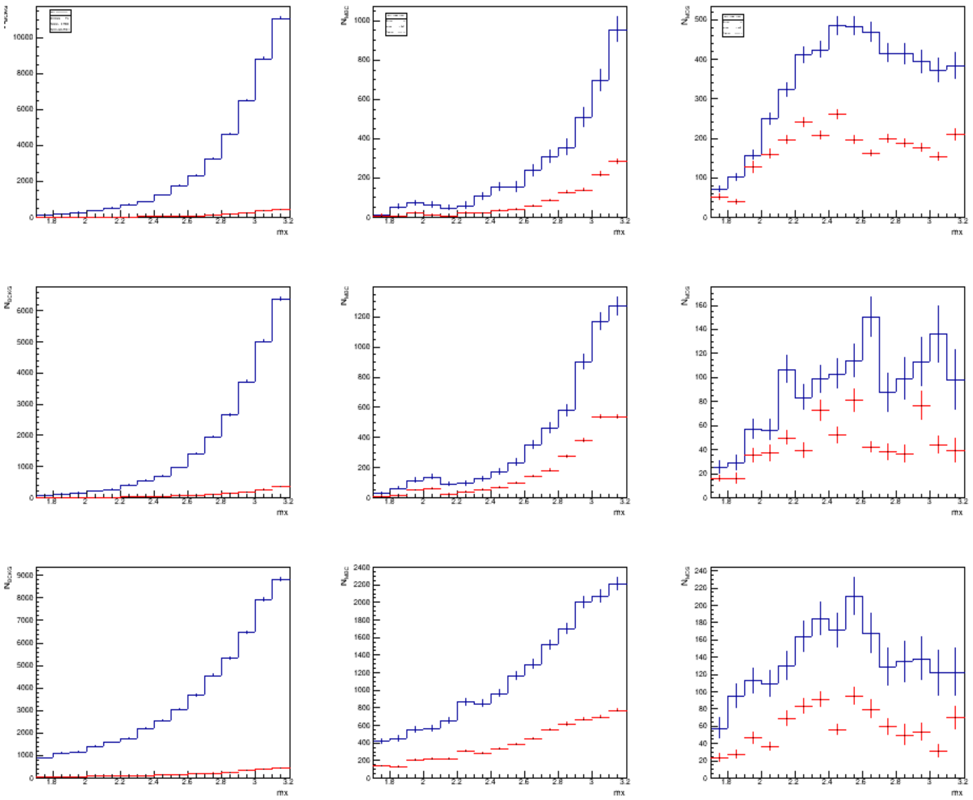
MCgen: 1D-FITs vs 2D-FITs

$D_s \to \phi\pi$

$D_s \to K^{*0}K$

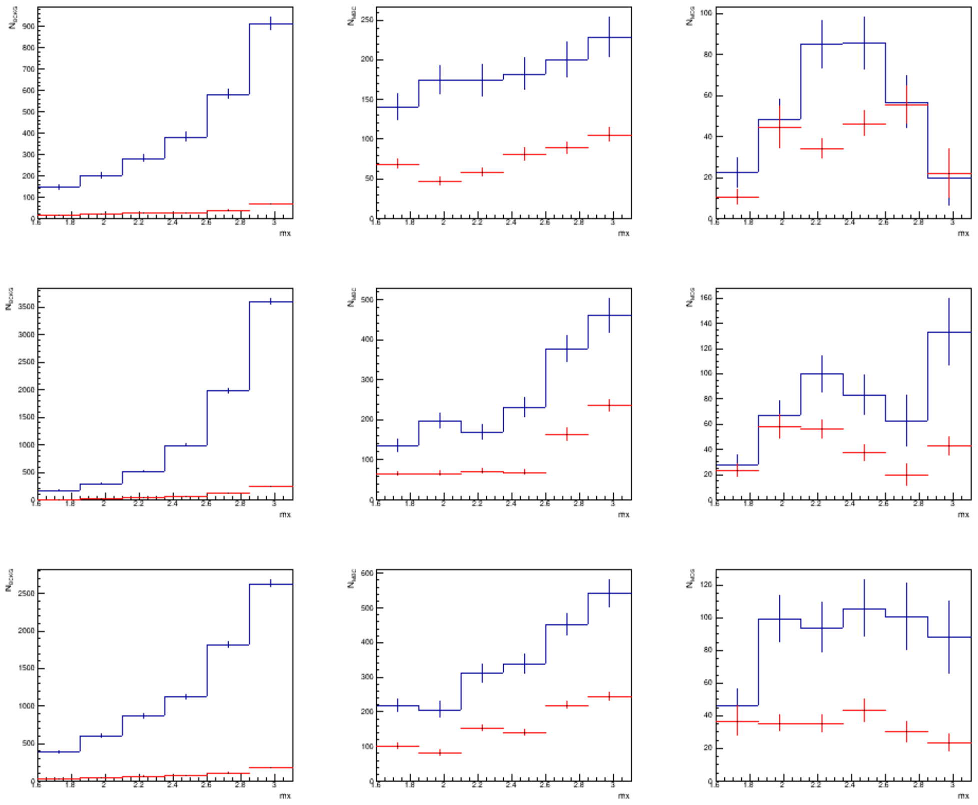
$D_s \to K^0{}_s K$

BCKG | MBC | MDS



D_s

BCKG | MBC | MDS



D_s*

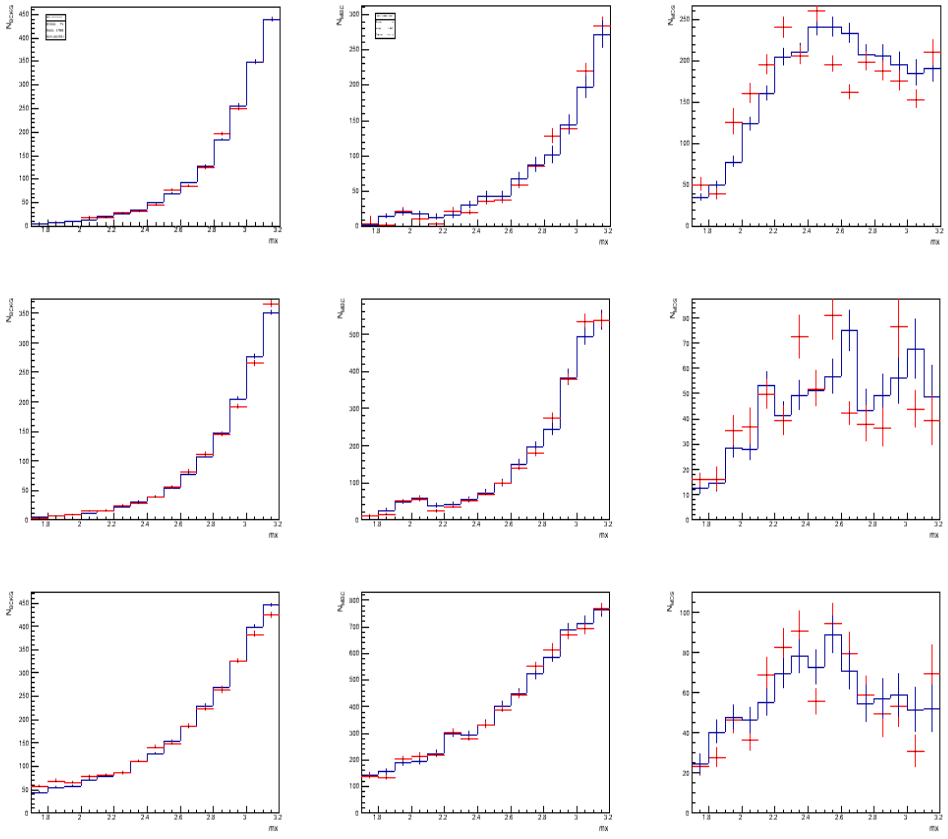
MCgen: 1D-FITs vs 2D-FITs (rescaled)

$D_s \to \phi\pi$

$D_s \to K^{*0}K$

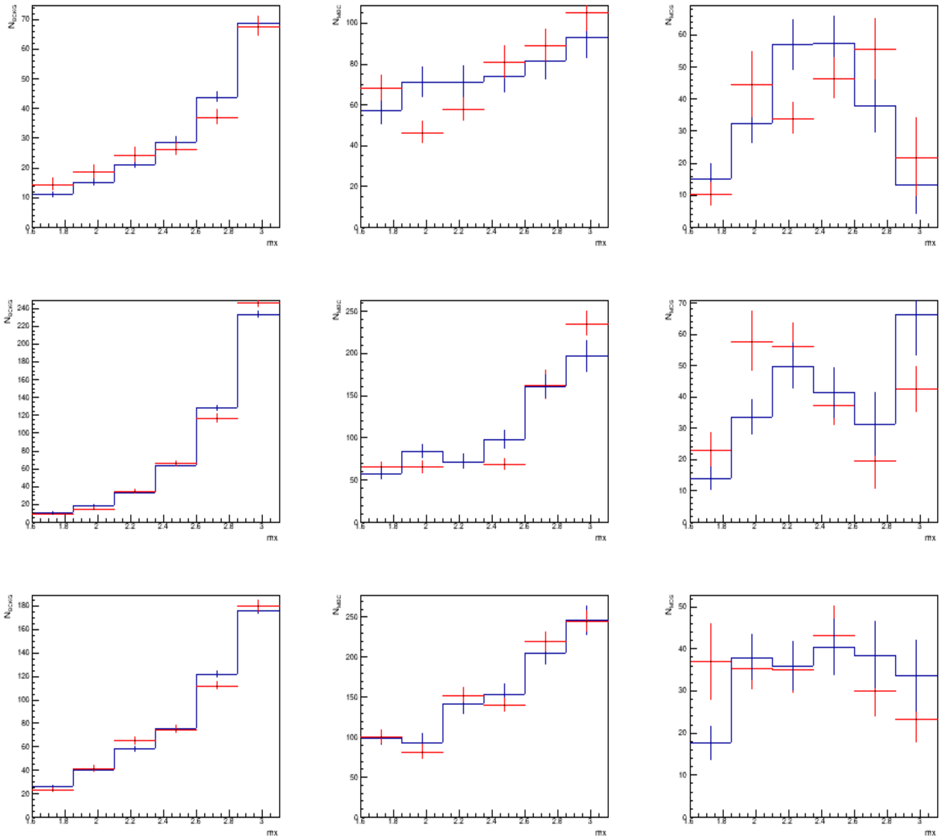
$D_s \to K^0{}_s K$

BCKG | MBC | MDS



D_s

BCKG | MBC | MDS



$D_s{}^*$

$D_s \to \phi\pi$

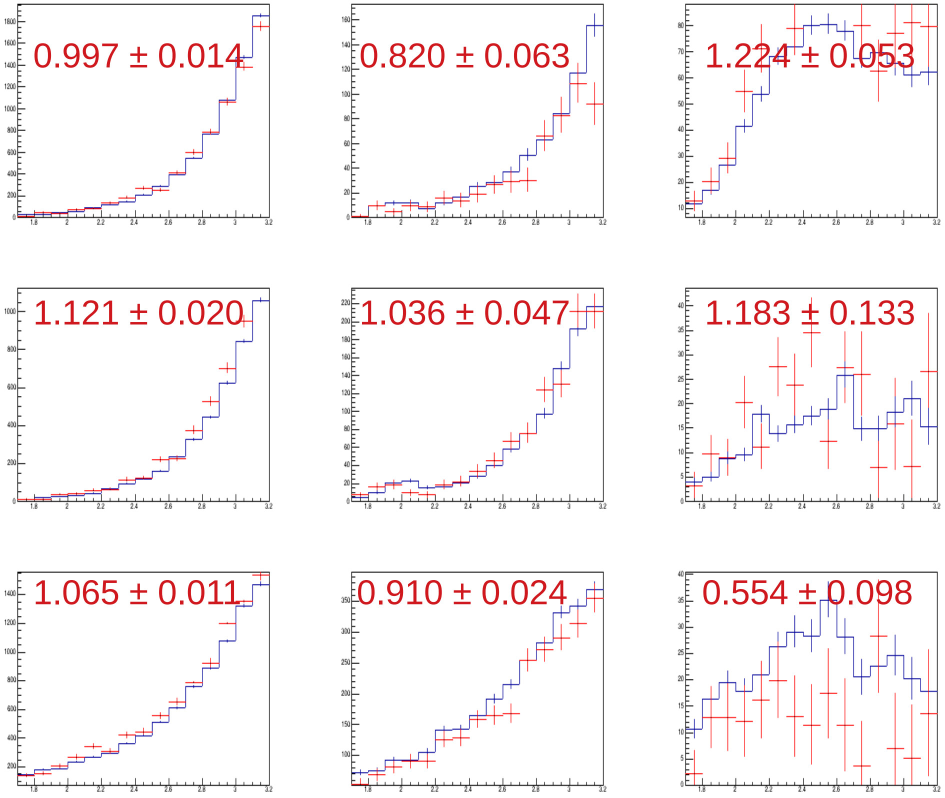
$D_s \to K^{*0}K$

$D_s \to K^0_s K$

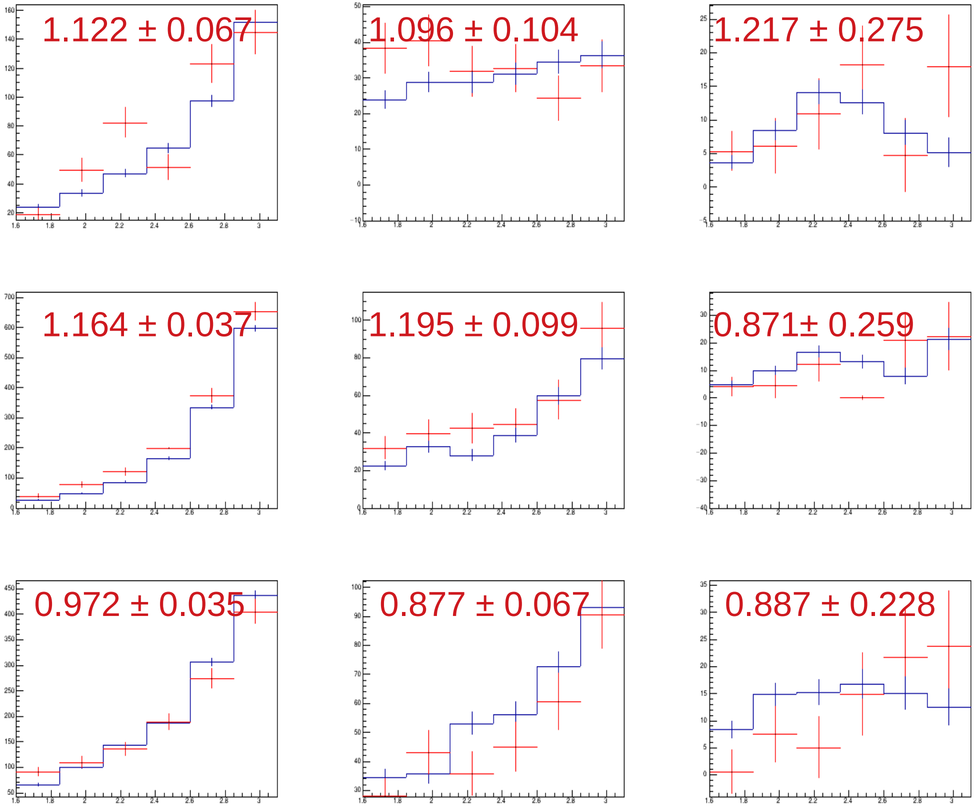
1D-Fit results for DATA and MCgen

SF_{data} - scale factors based on normalizations' comparison

BCKG	MBC	MDS



BCKG	MBC	MDS



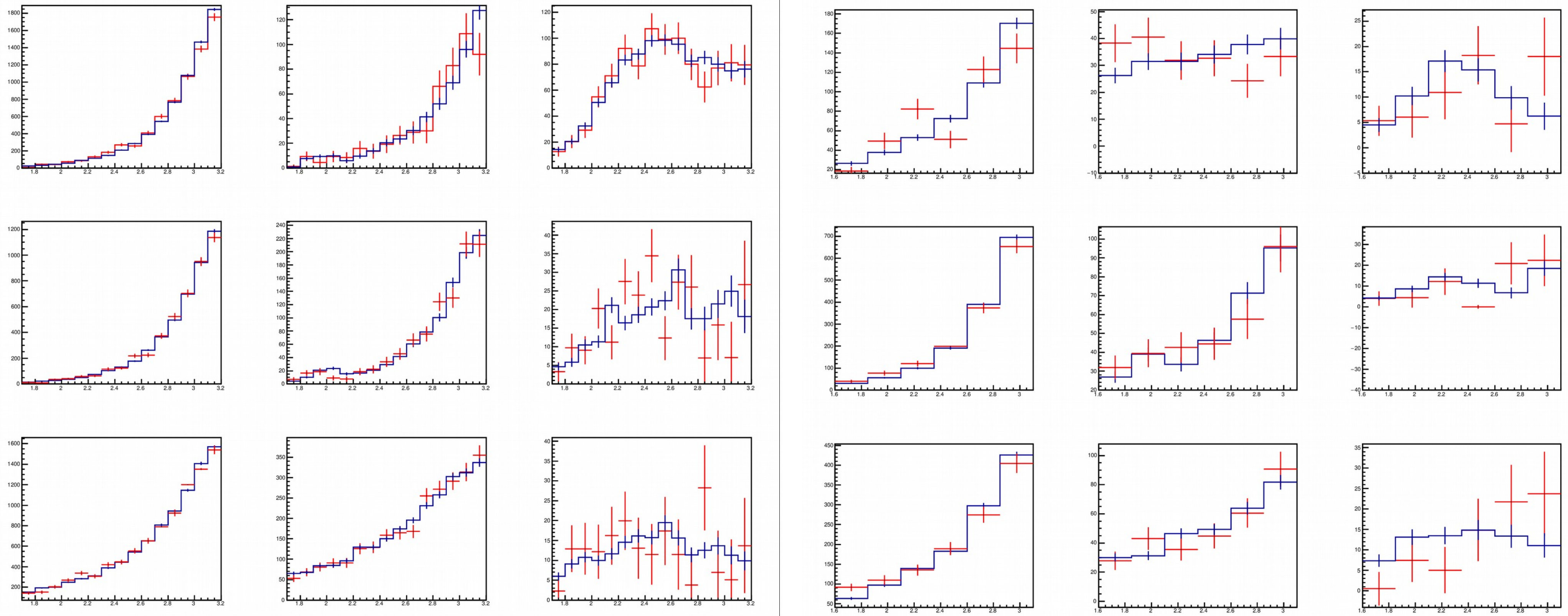
$D_s \to \phi\pi$

$D_s \to K^{*0}K$

$D_s \to K^0_sK$

1D-Fit results for DATA and MCgen **scaled**

BCKG MBC MDS | BCKG MBC MDS



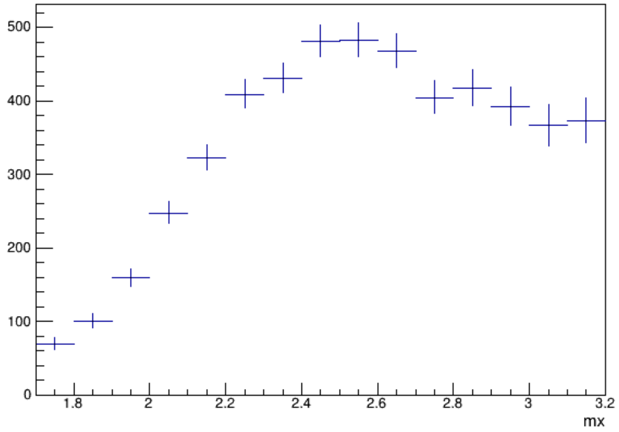
D_s D_s^*

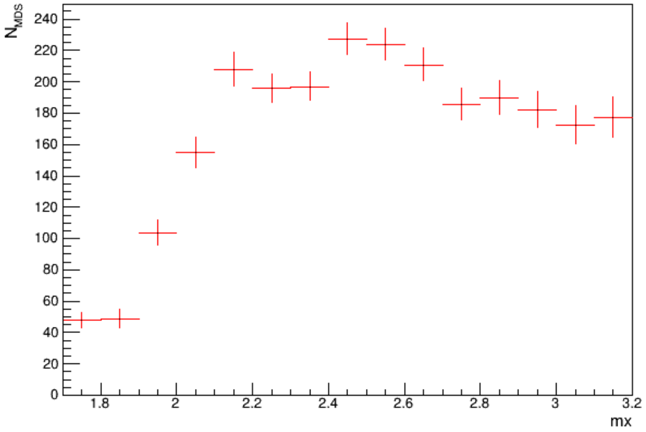
Strategy for DATA

Fit1D

Fit2D

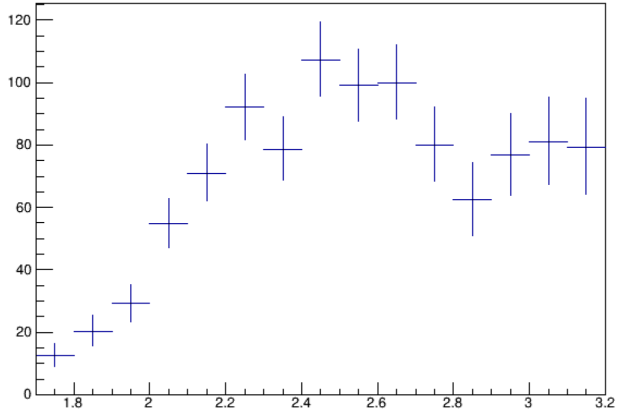
MC





SF_{data}

Data



Possible strategy:

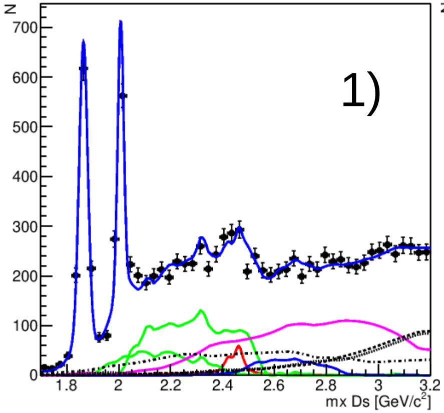
- use background shapes obtained from Fits2D
- Scale them by SF_{data} coefficients
- Fix them in the fit to data
- ….

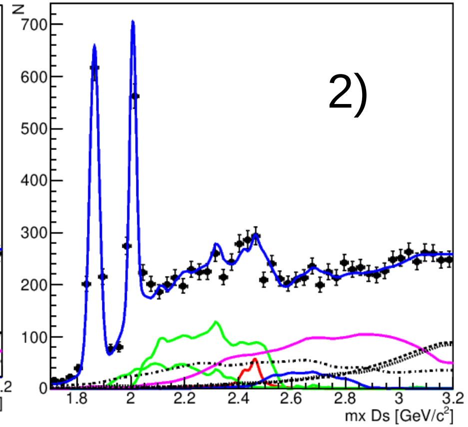
Systematics

1000 fits for the whole MCgen sample
with shape parameters' variation for D^0 i D^{*0}:

- **width2/width1 (!!)**
- frac

(results for D_s reconstruction only)





... 1000)