Search for new physics with the LHCb detector at CPPM

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with Olivier LEROY (director) and Simon AKAR

CPPM PhD Day

December 4, 2015

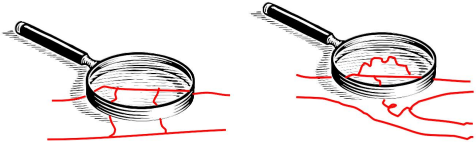
Outline

1. **LHCb overview**
   - Physics at LHCb
   - The LHCb detector at the LHC
   - Search for New Physics
     - Selected LHCb results
     - Rare decays
     - Mixing induced CP violation in B_s^0 (ϕ_s)

2. **Analysis of $B_s^0 \to \eta_c \phi$ decays**
   - Motivations
   - Events selection
   - Fit models
   - Preliminary results

Physics at LHCb

- LHCb is the LHC experiment dedicated to beauty and charm hadrons.
  - Compare precision measurements with clean predictions to find evidence for NP
  - Flavor sector:
    - very rich sector of the SM with precise theoretical predictions
    - loop processes are sensitive to energy scales well beyond those of the accelerators, thanks to virtual contributions.



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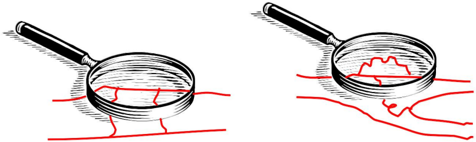

- Wide physics program:
  1. CKM and CP violation with *b* and *c* hadrons
  2. Rare decays of *b* and *c* hadrons
  3. Spectroscopy in *pp* interactions and *B* decays
  4. Electroweak and QCD measurements in the forward region
  5. Heavy quark production
  6. Exotica searches, ...

LHCb: super *b* and *c* factory at the LHC

- LHC is a proton-proton collider:
  runI: $\sqrt{s} = 7\,\mathrm{TeV}$ (2011), $8\,\mathrm{TeV}$ (2012)
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- Large $b\bar{b}$ production cross-section:
  $\sigma(pp \to b\bar{b}) = 286\mu$b at 7 TeV [PLB 694 (2010) 209]
- $\sigma(pp \to c\bar{c})$ 20 times larger!
- All kinds of b-hadrons produced (B^+, B^0, B_s^0, B_c^+, b-baryons, ...)

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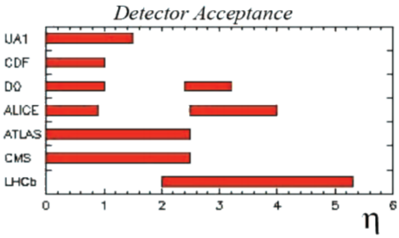
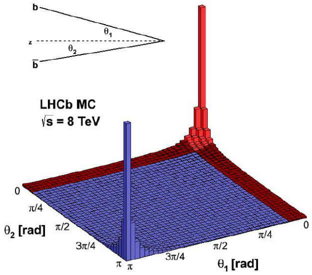
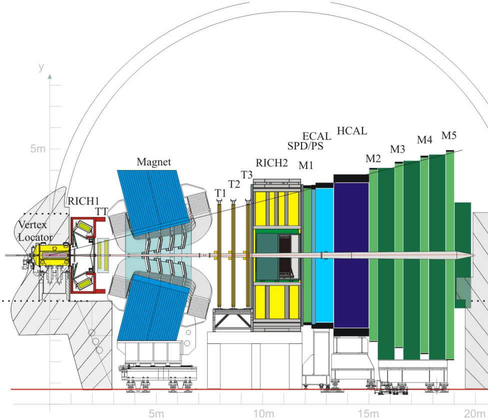
- All kinds of b-hadrons produced (B^+, B^0, B_s^0, B_c^+, b-baryons, ...)
- b-hadrons produced mainly at low angle:
  LHCb detector installed in the forward region
  $\rightarrow$unique pseudo-rapidity range





The LHCb detector [JINST 3 (2008 S08005)]

- Single-arm forward spectrometer:
  - Tracking system
    IP resolution $\sim 15\mu$m (at high p_T)
    $\delta p/p \sim 0.45\%$
  - RICH system
    Very good $K - \pi$ identification for
    $p \sim 2 - 100\,\mathrm{GeV}/c$
  - Calorimeters
    Energy measurement, identify π_0,γ,e
    + trigger
  - Muon detector
    muon identification + trigger



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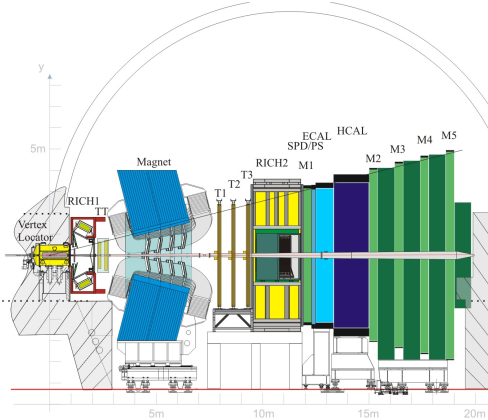

- Integrated luminosity:
  runI: 1 fb^{-1} (2011), 2 fb^{-1} (2012)
  runII (ongoing): 0.3 fb^{-1} (2015–2018)
  Instantaneous luminosity $\sim (1-4)\times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

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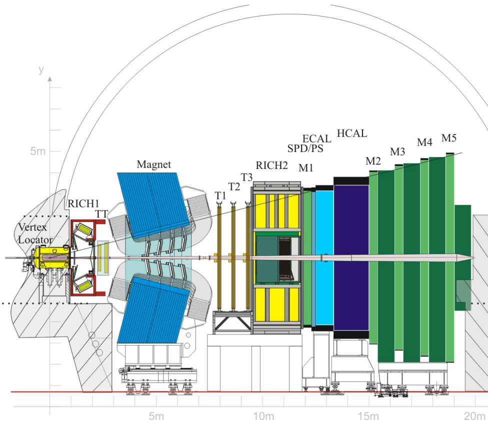

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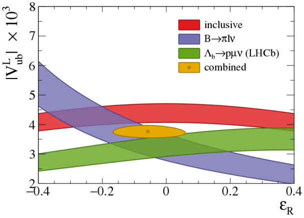
- Trigger reduces the *pp* rate from 40 MHz $\rightarrow$ 12.5 kHz in two steps:
  1) hardware (e.g. muon trigger built at CPPM)
  2) software

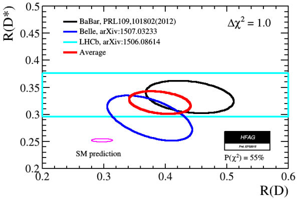
After LHCb runI

- Wide range of precise and outstanding physics results
- Some tensions with the Standard Model
- Nice and precise measurements not anticipated when designing LHCb

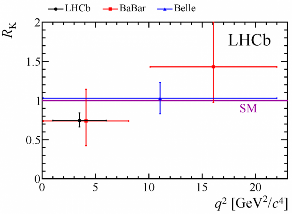
Some key results at LHCb



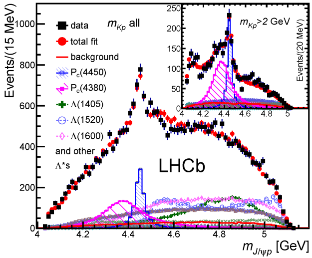
$|V_{ub}|$ with $\Lambda_b^0 \to p\mu^-\overline{\nu_\mu}$



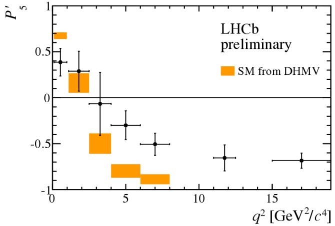
$\mathcal{R}(D^*)$ in $\overline{B^0} \to D^{*+}\tau^-\overline{\nu_\tau}$ tension with SM 2.1σ



Lepton universality with $B^+ \to K^+\ell^+\ell^-$ tension with SM 2.6σ

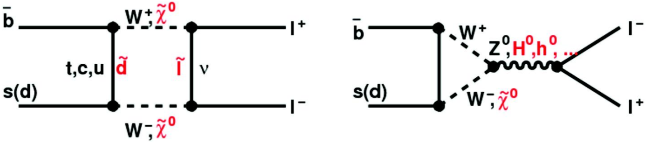


Observation of exotic pentaquarks

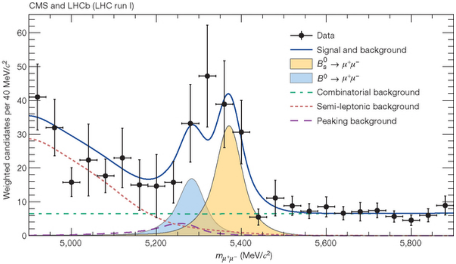


P'_5 in $B^0 \to K^{*0}\mu^+\mu^-$ tension with SM 3.7σ

Rare Decays: $B^0_{s,d} \to \mu^+\mu^-$ (at CPPM)



- Loop processes very suppressed in the SM.
  Precise theoretical prediction [C. Bobeth et al, PRL 112, (2013) 101801]:
- Sensitive to new physics
- Combination with CMS data [Nature 552 (2015) 68]:



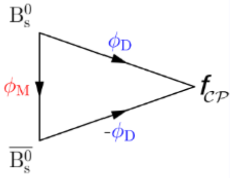
Rare Decays: τ in the final state (at CPPM)

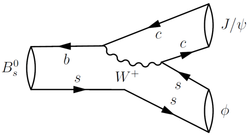
Pioneer work in progress

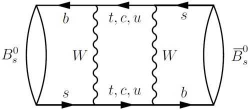
- $B \to \tau\tau$ and $B \to K^*\tau\tau$:
  - Rare decay with $\mathcal{B}(B \to \tau\tau) \sim 200 \times \mathcal{B}(B \to \mu\mu)$ in the SM
  - Experimentally very challenging
- $B \to \tau\mu$:
  - Lepton flavor violation

Mixing induced CPV in B_s^0 (at CPPM)

- Interference between B_s^0 decay to CP eigenstate either directly or via B_s^0–$\overline{B}_s^0$ oscillation gives rise to a CP violating phase $\phi_s^{J/\psi\phi} \equiv \phi_s = \Phi_\mathrm{M} - 2\Phi_\mathrm{D}$: golden mode: $B_s^0 \to J/\psi\,\phi$







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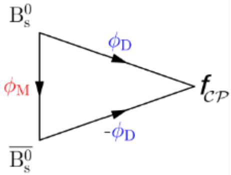
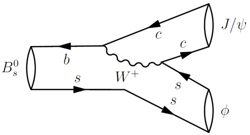
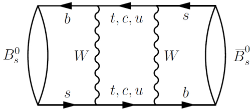




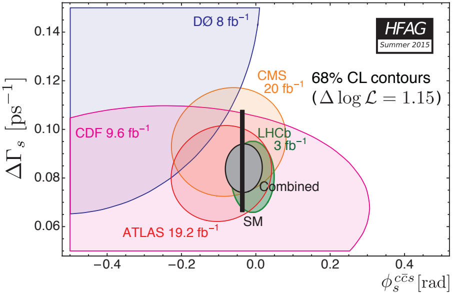


- Small and precise SM prediction:
  $\phi_s \simeq -2\beta_s = -(0.0376 + 0.0007 - 0.0008)\,\mathrm{rad}$
  with $\beta_s = \arg\left(-V_{ts}V_{tb}{}^{*} / V_{cs}V_{cb}{}^{*}\right)$
- Sensitive to NP in the mixing loop

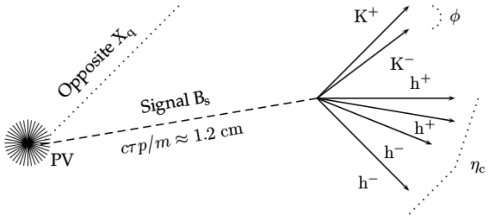
- Measured by fitting differential decay rates for B_s^0 and $\overline{B}_s^0$

Mixing-induced CPV in B_s^0 [arXiv:1411.3104]

- LHCb using only $B_s^0 \to J/\psi\, K^+K^-$:
  $\phi_s = -0.058 \pm 0.049 \pm 0.006\,\mathrm{rad}$
- World average:
  $\phi_s = -0.015 \pm 0.035\,\mathrm{rad}$



Analysis of $B_s^0 \to \eta_c \phi$ decays with the runI of LHCb



$B_s^0 \to \eta_c\phi$: Motivations

- Goal:
  - reduce the statistical uncertainty on ϕ_s
    $\Rightarrow$ add a new decay mode
- $\mathcal{B}(B_s^0 \to J/\psi\,(\mu^+\mu^-)\,\phi\,(KK)) \simeq 3.2 \times 10^{-5}$
  $\mathcal{B}(B_s^0 \to \eta_c\,(4h)\,\phi\,(KK)) \simeq 2.3 \times 10^{-5}$ (estimate)
  $\Rightarrow$ similar visible BR
  - study hadron modes: $h = \pi$ or K
    $\mathcal{B}(\eta_c \to K^+K^-\pi^+\pi^-)/\mathcal{B}(\eta_c(4h)) \sim 53\%$
    $\mathcal{B}(\eta_c \to \pi^+\pi^-\pi^+\pi^-)/\mathcal{B}(\eta_c(4h)) \sim 40\%$
    $\mathcal{B}(\eta_c \to K^+K^-K^+K^-)/\mathcal{B}(\eta_c(4h)) \sim 7\%$
- $N_S = \mathcal{L}_{\text{int}} \times \sigma_{b\bar{b}} \times f_{B_s^0} \times 2 \times \mathcal{B}(B_s^0 \to \eta_c(4h)\phi(KK)) \times \epsilon_{\text{tot}}$
  First estimation of sensitivity on ϕ_s with a MC based study (2006):
  $\sigma_{\phi_s}^{\eta_c\phi} \sim 0.1\sigma_{\phi_s}^{J/\psi\,\phi}$

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- **First step**: Discovery of $B_s^0 \to \eta_c\phi$ and measurement of its branching fraction with the runI of LHCb (3 fb^{-1})

Branching fraction of $B_s^0 \to \eta_c \phi$

$$\mathcal{B}^i_{meas}(B_s^0 \to \eta_c\phi) \;=\; \frac{N^i_{B_s^0\to\eta_c\phi}}{N^i_{B_s^0\to J/\psi\,\phi}} \times \mathcal{B}(B_s^0 \to J/\psi\,\phi) \times \frac{\mathcal{B}^i(J/\psi\to 4h)}{\mathcal{B}^i(\eta_c\to 4h)} \times \frac{\varepsilon^i_{B_s^0\to J/\psi\,\phi}}{\varepsilon^i_{B_s^0\to\eta_c\phi}}$$

with $i \in \{2K2\pi, 4\pi, 4K\}$

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3) $\frac{N_{B_s^0 \to \eta_c \phi}}{N_{B_s^0 \to J/\psi\,\phi}}$: extracted from unbinned maximum likelihood fit to data (see following)

Selection of signal events

A) A pre-selection is performed in two steps to reduce the combinatorial background:
   1) loose cut-based selection
   2) Boosted Decision Tree (BDT)

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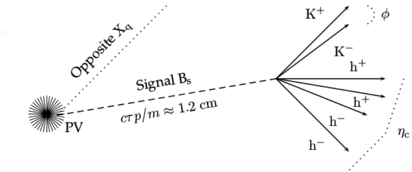
B) The final selection is optimized using another BDT together particle identification (PID) cuts

Pre-selection: cut-based



- An LHCb event contains ∼100 nearly parallel tracks
- Large part of combinatorial background:
  - has low transverse momentum (p_T)
  - comes from primary vertex (PV)

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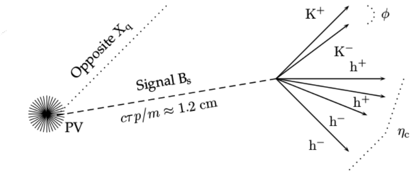


- An LHCb event contains ~100 nearly parallel tracks
- Large part of combinatorial background:
  - has low transverse momentum (p_T)
  - comes from primary vertex (PV)

Variable	Cut	
Hadrons from η_c		
p_T [MeV/c]	>	250.0
IP/χ^2	>	4.0
ProbNNk (Only for kaons)	>	0.13
ProbNNpi (Only for pions)	>	0.2
TRACK χ^2/dof	<	3.0
TRACK GhostProb	<	0.4
η_c		
DOCA χ^2	<	20.0
$\Sigma\, p_T$ (K^+, K^-, π^+, π^-) [MeV/c]	>	2500.0
Σ IP/χ^2 (K^+, K^-, π^+, π^-)	>	30.0
IP/χ^2	>	2.0
$\lvert m_{4h}$ - 3000.0$\rvert$ [MeV/c^2]	<	200.0
vertex χ^2/dof	<	9.0
Kaons of ϕ		
p_T	>	500.0
IP/χ^2	>	4.0
PIDK	>	0.0
ϕ		
p_T [MeV/c]	>	800.0
DOCA χ^2	<	30.0
IP/χ^2	>	2.0
$\lvert m_{KK} - m_{\phi}\rvert$ [MeV/c^2]	<	30.0
vertex χ^2	<	9.0
B_s^0		
$\lvert m_{4hKK} - m_{B_s^0}\rvert$ [MeV/c^2]	<	500.0
DIRA	>	0.99
vertex χ^2/dof	<	25.0
DLS	>	0.0

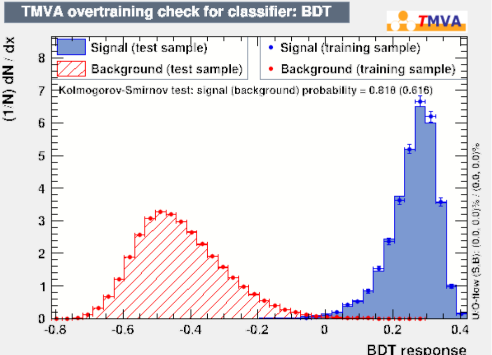
Pre-selection: BDT

- BDT trained with:
  - Signal: MC events
  - Background: Real Data Upper Side Band
    $\rightarrow$ invariant mass of 6 hadrons in [5800, 6000] MeV

Pre-selection: BDT

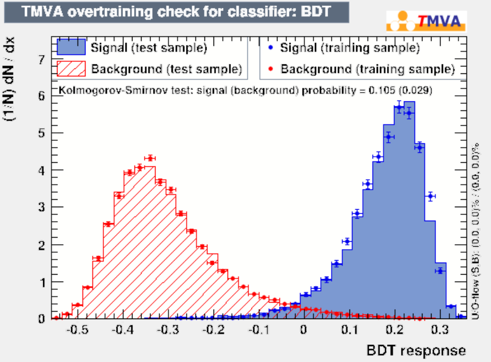
- BDT trained with:
  - Signal: MC events
  - Background: Real Data Upper Side Band
    $\rightarrow$ invariant mass of 6 hadrons in [5800, 6000] MeV
- List of variables used:
  - p_T of all particles (but B_s^0)
  - IP/χ^2 of all particles
  - B_s^0 decay time and vertex fit quality
  - Pointing

BDT response > 0 is used



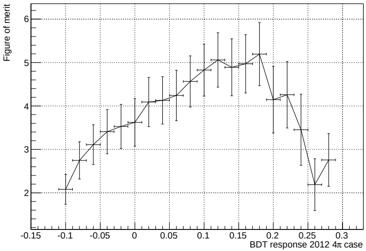
Offline selection: BDT

- BDT trained with:
  - Signal: MC TRUE events
  - Background: real data Upper Side Band: m(6h) > 5600 MeV
- List of variables used:
  - vertex χ^2, IP/χ^2, TRACK χ^2, pseudo-rapidity, time of flight, p_T
- BDT training result:



Optimization of the offline selection

- Procedure of optimization:
  FoM = $\frac{S}{\sqrt{S+B}}$, where
  $S \equiv$ Number of $B_s^0 \to 4h\phi$ candidates fitted (Gaussian)
  $B \equiv$ Number of combinatorial background fitted (Exponential)



1) Cut on BDT split by data taking periods and decay modes

2) Different PID cut applied according to the final state
   $B_s^0 \to \eta_c\phi$ with
   $\phi \to KK$ and
   $\eta_c \to KK\pi\pi$,
   $\eta_c \to \pi\pi\pi\pi$,
   $\eta_c \to KKKK$

Branching fraction of $B_s^0 \to \eta_c \phi$ (reminder)

$$\mathcal{B}^i_{meas}(B_s^0 \to \eta_c\phi) \; = \; \frac{N^i_{B_s^0 \to \eta_c \phi}}{N^i_{B_s^0 \to J/\psi\,\phi}} \times \mathcal{B}(B_s^0 \to J/\psi\,\phi) \times \frac{\mathcal{B}^i(J/\psi \to 4h)}{\mathcal{B}^i(\eta_c \to 4h)} \times \frac{\varepsilon^i_{B_s^0 \to J/\psi\,\phi}}{\varepsilon^i_{B_s^0 \to \eta_c \phi}}$$

with $i \in \{2K2\pi, 4\pi, 4K\}$

Fiting procedure

- The fit is performed in two steps:

  1) 2D fit ($m_{4hK^+K^-} \times m_{K^+K^-}$):

     - to disentangle event category:
       $B^0 \to 4h\phi$, $B^0 \to 4hKK$,
       $B_s^0 \to 4h\phi$, $B_s^0 \to 4hKK$,
       bkg$\to 4h\phi$ and bkg$\to 4hKK$

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      bkg$\to 4h\phi$ and bkg$\to 4hKK$

2) 1D fit (m_{4h}) with optimal backgroung substraction procedure:
    - to disentangle η_c, J/ψ and NR components

$B_s^0 \rightarrow \eta_c(4h)\phi(K^+K^-)$: Mass fit model

- Mass $4\mathrm{h}K^+K^-$:
  - $\rightarrow$ B_s^0: Hypathia[1] with μ and σ free and all other parameters fixed (MC)
  - $\rightarrow$ B^0: Hypathia with μ free and all other parameters equal to B_s^0
  - $\rightarrow$ Combinatorial background: Exponential with coefficient free

[1] Modified Gaussian with asymetric tails

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  - $\to$ B^0: Hypathia with μ free and all other parameters equal to B_s^0
  - $\to$ Combinatorial background: Exponential with coefficient free
- Mass 4h
  - $\to$ η_c: Voigtian: μ free, Breit-Wigner line shape width fixed to 32.2 MeV and σ of the convoluted Gaussian free
  - $\to$ J/ψ: Hypathia with μ and σ free, all other parameters fixed (MC)
  - $\to$ "Physical background", NR m(4h): Exponential with coefficient free

[1] Modified Gaussian with asymetric tails

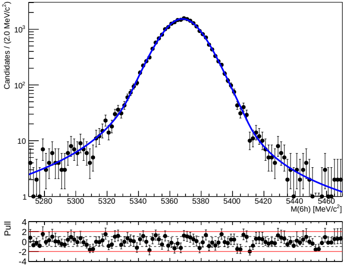
$B_s^0 \to \eta_c(4h)\phi(K^+K^-)$: Mass fit model

- Mass 4hK^+K^-:
  - $\rightarrow$ B_s^0: Hypathia[1] with μ and σ free and all other parameters fixed (MC)
  - $\rightarrow$ B^0: Hypathia with μ free and all other parameters equal to B_s^0
  - $\rightarrow$ Combinatorial background: Exponential with coefficient free
- Mass 4h
  - $\rightarrow$ η_c: Voigtian: μ free, Breit-Wigner line shape width fixed to 32.2 MeV and σ of the convoluted Gaussian free
  - $\rightarrow$ J/ψ: Hypathia with μ and σ free, all other parameters fixed (MC)
  - $\rightarrow$ "Physical background", NR m(4h): Exponential with coefficient free
- Mass K^+K^-
  - $\rightarrow$ ϕ: Relativistic Breit-Wigner, with mass dependent width, convoluted with Gaussian: μ free, Relativistic Breit-Wigner line shape width fixed to 4.26 MeV and radius fixed to 3.0 (MC), σ of the convoluted Gaussian free
  - $\rightarrow$ S-wave (NR K^+K^-): Exponential with coefficient free

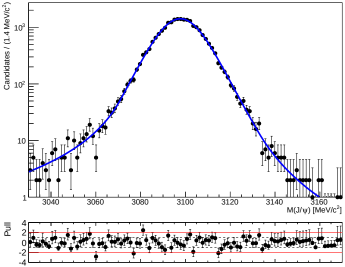
[1] Modified Gaussian with asymetric tails

Mass fit model: MC

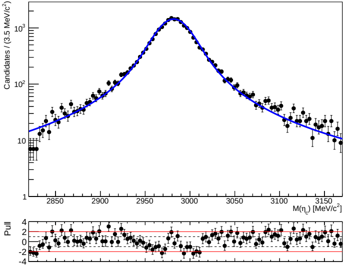
Mass 4hK^+K^-: B_s^0



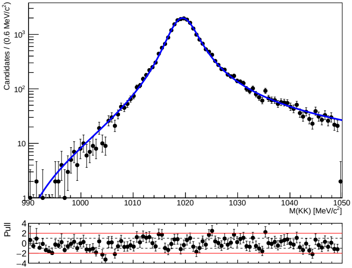
Mass 4h: J/ψ



Mass 4h: η_c

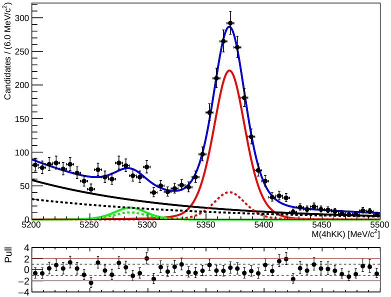


Mass K^+K^-: ϕ

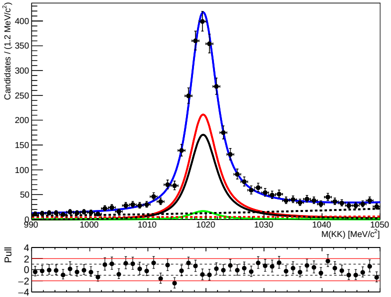


2D fit ($m_{4hK^+K^-} \times m_{K^+K^-}$): Result

Mass $4hK^+K^-$



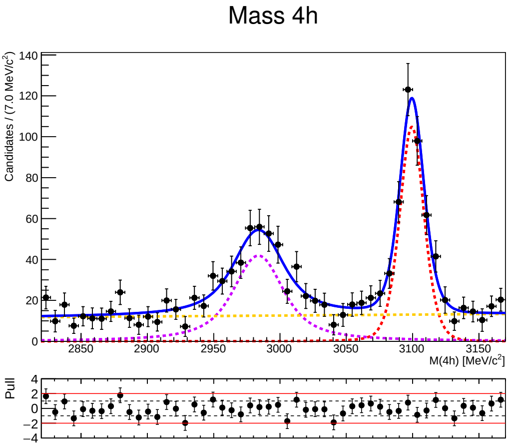
Mass K^+K^-



- Events are properly described:
  - $B^0 \to 4h\phi$ and $B^0 \to 4hKK$ full and dashed green lines, respectively
  - $B_s^0 \to 4h\phi$ and $B_s^0 \to 4hKK$ full and dashed red lines, respectively
  - bkg$\to 4h\phi$ and bkg$\to 4hKK$ full and dashed black lines, respectively
- The fit yields 1355$\pm$50 $B_s^0 \to 4h\phi$ events

1D fit (m_{4h}): Result

- $B_s^0 \to 4h\phi$ substract background are applied on the invariant mass 4h



$$\frac{N^{fit}_{B_s^0 \to \eta_c \phi}}{N^{fit}_{B_s^0 \to J/\psi\, \phi}} = 1.02 \pm 0.13$$

First observation of $B_s^0 \to \eta_c \phi$!

Preliminary branching fraction of $B_s^0 \to \eta_c \phi$

$$\mathcal{B}_{meas}(B_s^0 \to \eta_c \phi) \; = \; \frac{N_{B_s^0 \to \eta_c \phi}}{N_{B_s^0 \to J/\psi\, \phi}} \times \mathcal{B}(B_s^0 \to J/\psi\, \phi) \times \frac{\mathcal{B}(J/\psi \to 4h)}{\mathcal{B}(\eta_c \to 4h)} \times \frac{\varepsilon_{B_s^0 \to J/\psi\, \phi}}{\varepsilon_{B_s^0 \to \eta_c \phi}}$$

1) $\mathcal{B}(B_s^0 \to J/\psi\, \phi) \times \frac{\mathcal{B}(J/\psi \to 4h)}{\mathcal{B}(\eta_c \to 4h)}$ = $(3.3 \pm 0.5) \times 10^{-4}$

2) $\frac{\varepsilon_{B_s^0 \to J/\psi\, \phi}}{\varepsilon_{B_s^0 \to \eta_c \phi}}$ = 1.01 ± 0.01

3) $\frac{N_{B_s^0 \to \eta_c \phi}}{N_{B_s^0 \to J/\psi\, \phi}}$ = 1.02 ± 0.13

Preliminary (LHCb)

$\mathcal{B}_{\mathrm{meas}}^{\mathrm{prelim}}(B_s^0 \to \eta_c \phi)$ = $(3.31 \pm 0.43(\mathrm{stat}) \pm 0.50(\mathcal{B}) \pm 0.05(\mathrm{syst})) \times 10^{-4}$

Conclusions and prospects

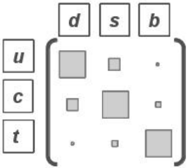
- Conclusions:
  - First observation of $B_s^0 \to \eta_c \phi$
  - Using 4h: $\mathcal{B}^{\text{prelim}}_{\text{meas}}(B_s^0 \to \eta_c \phi)$ = $(3.3 \pm 0.7) \times 10^{-4}$
- Analysis prospects:
  - Complete systematics study
  - Publish the BR
- Thesis prospects:
  - Start ϕ_s with runII

Backup

CKM matrix and Unitary Triangle

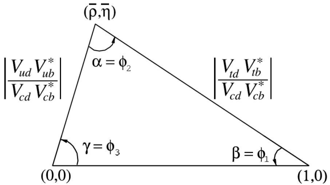
- The source of CPV in quark sector

$$\begin{pmatrix} d \\ s \\ b \end{pmatrix}' = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}^{\text{phys}}$$



V_{CKM} is unitary and can be parameterized with 4 parameters A, λ, ρ and η:

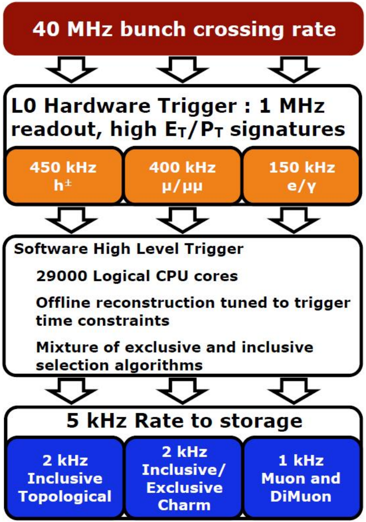
$$V_{\text{CKM}} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$



- Can't explain baryonic asymmetry in the universe
  $\rightarrow$ should be additional mechanism beyond SM
- Measure the CKM parameters to find inconsistencies in UT

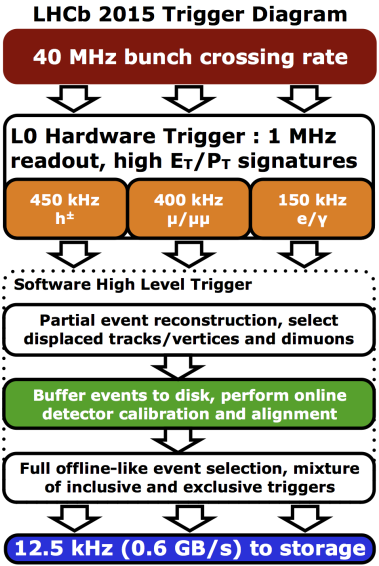
The LHCb Trigger in 2011–2012 (runI)

- L0 hardware trigger:
  - Find lepton, hadron with high p_T
  - Reduce the rate from 40 MHz to 1 MHz
- HLT1 software trigger:
  - Finds vertices in VELO
  - Tracks with high IP and p_T
- HLT2 software trigger:
  - Reconstruct all tracks in event
  - Select inclusive/exclusive b-hadrons
  - Output rate = 5 kHz



The LHCb Trigger in 2015–2018 (runII)

- L0 hardware trigger:
  - Find lepton, hadron with high p_T
  - Reduce the rate from 40 MHz to 1 MHz
- HLT1 software trigger:
  - Finds vertices in VELO
  - Tracks with high IP and p_T
- Alignement and calibration performed online!
- HLT2 software trigger:
  - Reconstruct all tracks in event
  - Select inclusive/exclusive b-hadrons
  - Output rate = 12.5 kHz



Efficiency computation: total efficiency

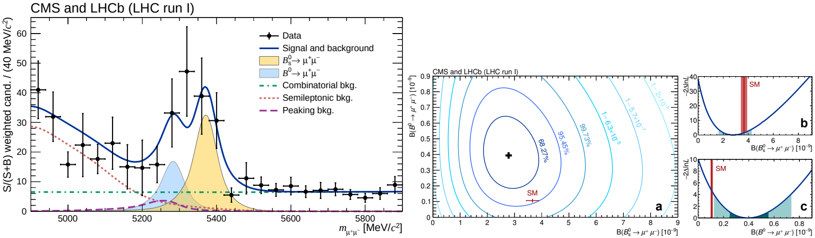
$$\varepsilon = \varepsilon^{\text{geo}}.\varepsilon^{\text{reco}}.\varepsilon^{\text{sel}}.\varepsilon^{\text{PID}}$$

- $(\varepsilon_{B_s^0 \to X\phi})_{geo}$ is given after MC generation
  $(\frac{\varepsilon_{B_s^0 \to J/\psi\,\phi}}{\varepsilon_{B_s^0 \to \eta_c\phi}})_{geo} = 1.008 \pm 0.005$
- $(\varepsilon_{B_s^0 \to X\phi})_{reco} = \frac{\mathcal{N}(\text{MC events reconstructed truth matched})}{\mathcal{N}(\text{MC events generated in the LHCb acceptance})}$
  $(\frac{\varepsilon_{B_s^0 \to J/\psi\,\phi}}{\varepsilon_{B_s^0 \to \eta_c\phi}})_{reco} = 0.9757 \pm 0.0018$
- $(\varepsilon_{B_s^0 \to X\phi})_{sel} = \frac{\mathcal{N}(\text{MC events reconstructed and selected truth matched})}{\mathcal{N}(\text{MC events reconstructed truth matched})}$
  $(\frac{\varepsilon_{B_s^0 \to J/\psi\,\phi}}{\varepsilon_{B_s^0 \to \eta_c\phi}})_{sel} = 1.030 \pm 0.009$
- $(\varepsilon_{B_s^0 \to X\phi})_{PID} = \frac{\mathcal{N}(\text{MC events reconstructed, selected truth matched and PID})}{\mathcal{N}(\text{MC events reconstructed and selected truth matched})}$
  $(\frac{\varepsilon_{B_s^0 \to J/\psi\,\phi}}{\varepsilon_{B_s^0 \to \eta_c\phi}})_{PID} = 1.000 \pm 0.007$

$$(\frac{\varepsilon_{B_s^0 \to J/\psi\,\phi}}{\varepsilon_{B_s^0 \to \eta_c\phi}})_{tot} = 1.01 \pm 0.01$$

$B \to \mu^+\mu^-$ combined analysis of CMS and LHCb

[CMS and LHCb, arXiv:1411.4413, submitted to Nature]



- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9}$ (6.2σ), first observation!
- $\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.9^{+1.6}_{-1.4} \times 10^{-10}$ (3.2σ) evidence for $B^0 \to \mu^+\mu^-$
- $\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s^0\to\mu^+\mu^-)} = 0.14^{+0.08}_{-0.06}$ (2.3σ of SM)

$B \to \mu^+\mu^-$ consequences

[Mahmoudi et al, arXiv1401.2145]

Modified from [D. Straub, Nuovo Cim. C035N1 (2012) 249]

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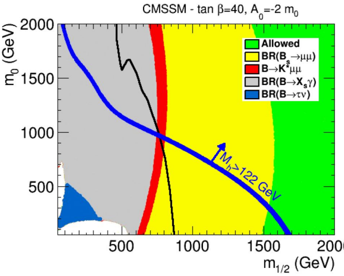
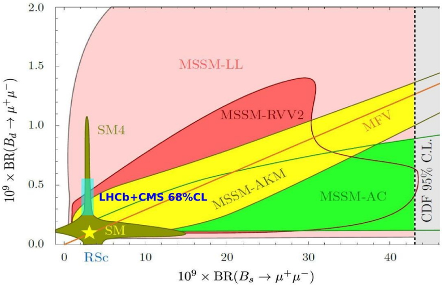


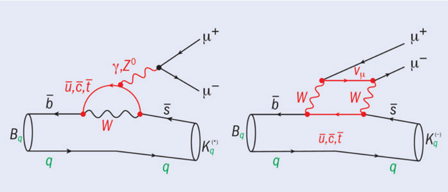
Black line corresponds to the direct limit by ATLAS 20.3 fb^{-1}

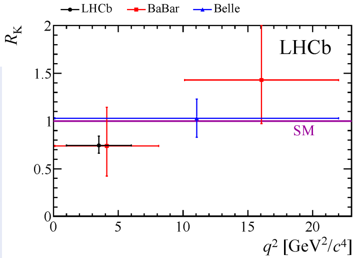


68% CL LHCb+CMS 2014 constraint in blue

Strong constraints on many NP models, in particular those with large tan β

Test of lepton universality with $B^+ \to K^+\ell^+\ell^-$ [PRL,113, 151601 (2014)]





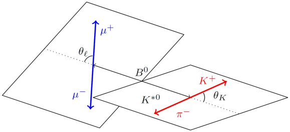
- Search for NP in the above loops $(q^2 = m^2_{\ell\ell})$

$$R_K \equiv \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)} = 1 \pm \mathcal{O}(10^{-3}) \text{ in the SM}$$

- $R_K(\text{LHCb}, 1 < \text{q}^2 < 6\,\text{GeV}^2/\text{c}^4) = 0.745^{+0.090}_{-0.074} \pm 0.036$ (2.6σ from SM)
- To be watched out with more statistics

$B^0 \to K^* \mu^+ \mu^-$ [JHEP 08 (2013) 131, PRL 111 (2013) 191801]

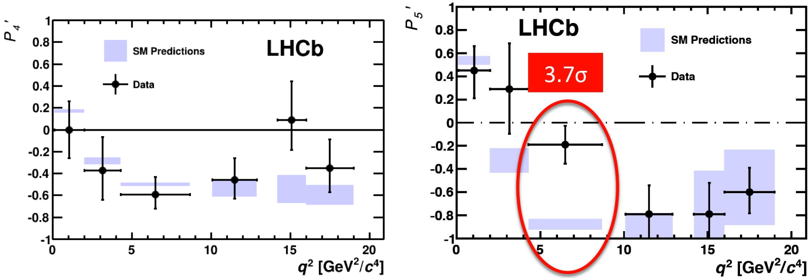
- Same motivations as $B^- \to K^- \ell^+ \ell^-$ (same SM loops, but with a vector in the final state)
- Complicated angular analysis with many observables:



$$\frac{1}{\mathrm{d}\Gamma/dq^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_\mathrm{L}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

- Can parameterize the angular coeff to be largely free of form factor uncertainties [S. Descotes-Genon et al, arXiv:1303.5794]
  e.g. $P_5' = \frac{S_5}{\sqrt{F_\mathrm{L}(1-F_\mathrm{L})}}$ where F_L is the fraction of longitudinal polarization, S_5 is the coefficient of $\sin 2\theta_K \sin\theta_\ell \cos\phi$ in the decay rate.

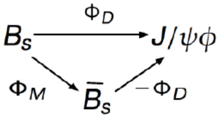
$B^0 \to K^{*}\ell^{+}\ell^{-}$ [JHEP 08 (2013) 131, PRL 111 (2013) 191801]

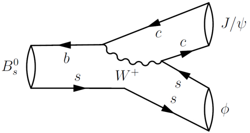


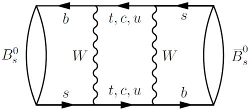
- Mainly compatible with the SM expect one angular variable
- Local 3.7σ discrepancy with SM prediction in 3rd bin of P_5'
- Look-elsewhere-effect-corrected SM p-value of this analysis is 0.5%
- Theoretical work ongoing to better understand this bin. NP contribution to EW penguin Wilson coeff C_9?
- LHCb update with full Run 1 data expected soon

Mixing induced CPV in B_s^0

- Interference between B_s^0 decay to $J/\psi\phi$ either directly or via B_s^0–$\overline{B}_s^0$ oscillation gives rise to a CP violating phase
$\phi_s^{J/\psi\phi} \equiv \phi_s = \Phi_\mathrm{M} - 2\Phi_\mathrm{D}$







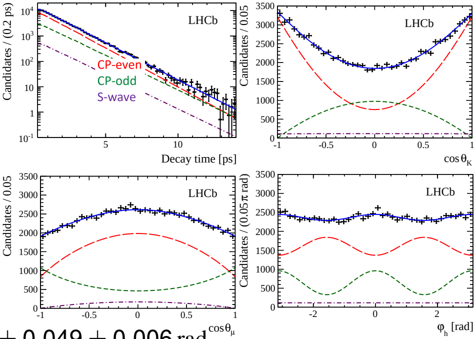
- In SM, $\phi_s \simeq -2\beta_s = -(0.0363 \pm 0.0013)\,\mathrm{rad}$, $\beta_s = \arg\left(-V_{ts}V_{tb}^{\;*}/V_{cs}V_{cb}^{\;*}\right)$
- Neglecting sub-leading diagrams, the same phase is expected in $B_s^0 \to D_s^+ D_s^-$ and $B_s^0 \to J/\psi\pi\pi$

- Measured by fitting differential decay rates for B_s^0 and $\overline{B}_s^0$:

$$\frac{\mathrm{d}^4\Gamma(B_s^0 \to J/\psi\phi)}{\mathrm{d}t\;\mathrm{d}\cos\theta_\mu\;\mathrm{d}\varphi_h\;\mathrm{d}\cos\theta_K} = f(\phi_s, \Delta\Gamma_s, \Gamma_s, \Delta m_s, M(B_s^0), |A_\perp|, |A_\parallel|, |A_S|, \delta_\perp, \delta_\parallel, \ldots)$$

Mixing-induced CPV in $B_s^0 \to J/\psi\, h^+ h^-$ [arXiv:1411.3104]

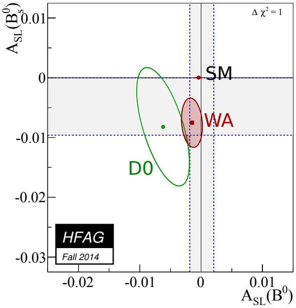
- Unbinned maximum likelihood fit (time, mass, angles, initial flavour)



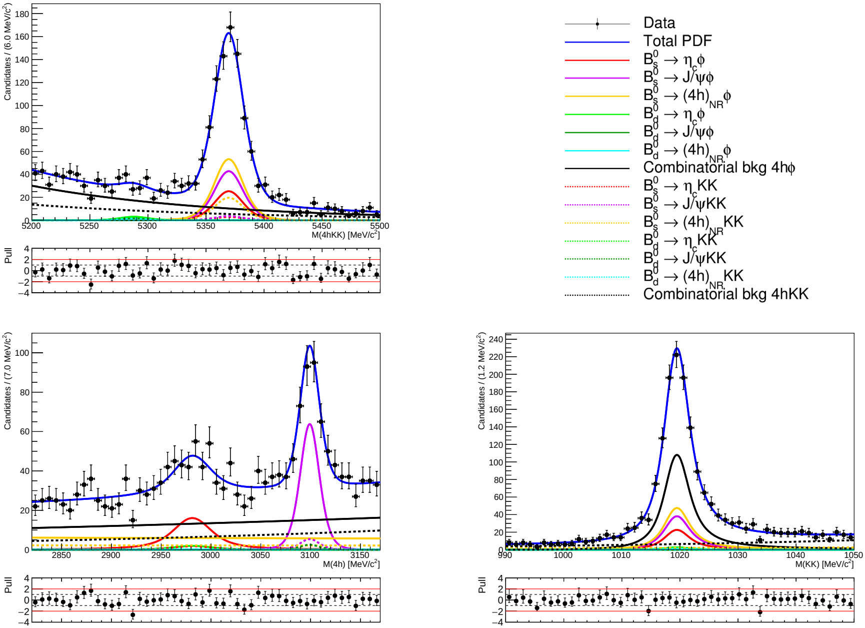
- $\phi_s = -0.058 \pm 0.049 \pm 0.006\,\mathrm{rad},$
- $\Gamma_s \equiv (\Gamma_{\mathrm{L}} + \Gamma_{\mathrm{H}})/2 = 0.6603 \pm 0.0027 \pm 0.0015\,\mathrm{ps}^{-1}$
- $\Delta\Gamma_s \equiv \Gamma_{\mathrm{L}} - \Gamma_{\mathrm{H}} = 0.0805 \pm 0.0091 \pm 0.0032\ \mathrm{ps}^{-1}$
- Combined with $B_s^0 \to J/\psi\pi^+\pi^-$: $\phi_s = -0.010 \pm 0.039$

CPV in B^0 and B_s^0 mixing

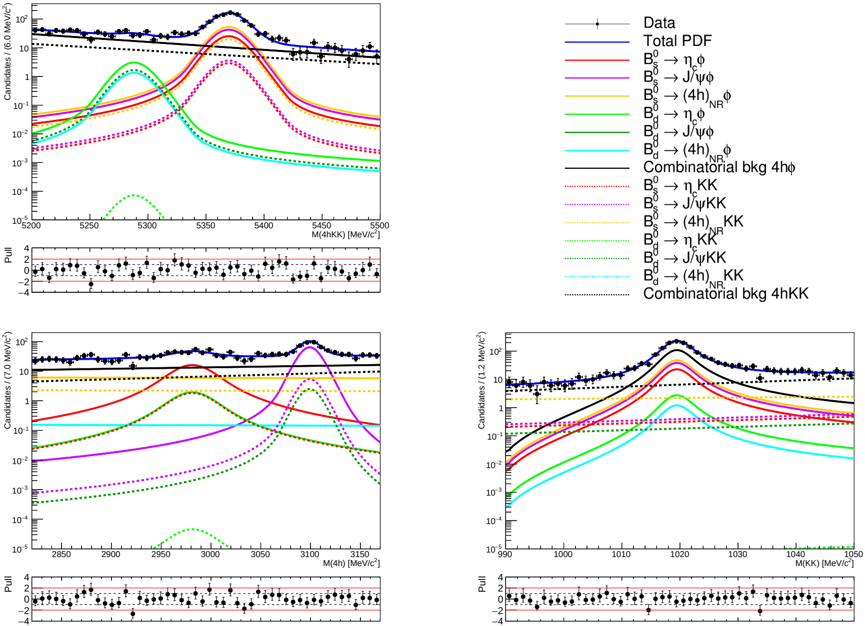
- Semileptonic asymmetry $A_{\mathrm{SL}}^{q} = \frac{\Gamma(\bar{B}_q \to B_q \to f) - \Gamma(B_q \to \bar{B}_q \to \bar{f})}{\Gamma(\bar{B}_q \to B_q \to f) + \Gamma(B_q \to \bar{B}_q \to \bar{f})}$ very small in the SM
- *D* measures the di-muon asymmetry, A_{SL}^{b}, mixture of semileptonic asymmetries in B_s^0 (Asls) and B^0 (Asld). $\sim 3\sigma$ from SM [D0, PRD 89 (2014) 012002]
- Same approach delicate at *pp* collider due to production asymmetries. LHCb measures individually:
  Asls $= (-0.06 \pm 0.50 \pm 0.36)\%$, 1 fb^{-1}, [LHCb, PLB 728 (2014) 607]
  Asld $= (-0.02 \pm 0.19 \pm 0.30)\%$, 3 fb^{-1}, [arXiv:1409.8586]
  Compatible with both SM and *D*



Fit 3D (mass 4h, mass 6h, mass 2h) 2K2pi



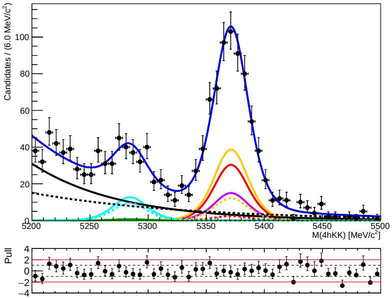
Fit 3D (mass 4h, mass 6h, mass 2h) 2K2pi

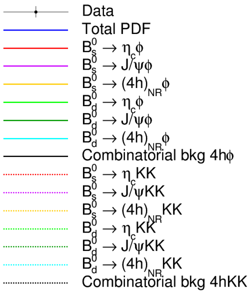


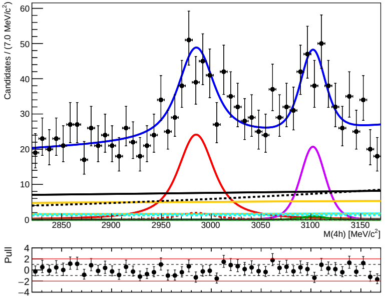
All modes yield 2K2pi

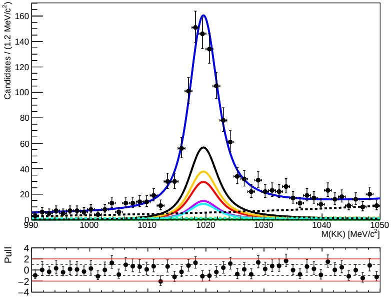
	N^{fit}
$N^{fit}_{B^0\to\eta_c KK}$	0 ± 18
$N^{fit}_{B^0\to\eta_c\phi}$	17 ± 7
$N^{fit}_{B^0\to J/\psi\, KK}$	9 ± 5
$N^{fit}_{B^0\to J/\psi\,\phi}$	0 ± 2
$N^{fit}_{B^0\to NRKK}$	0 ± 5
$N^{fit}_{B^0\to NR\phi}$	7 ± 15
$N^{fit}_{B^0_s\to\eta_c KK}$	16 ± 16
$N^{fit}_{B^0_s\to\eta_c\phi}$	141 ± 24
$N^{fit}_{B^0_s\to J/\psi\, KK}$	20 ± 12
$N^{fit}_{B^0_s\to J/\psi\,\phi}$	238 ± 22
$N^{fit}_{B^0_s\to NRKK}$	109 ± 26
$N^{fit}_{B^0_s\to NR\phi}$	296 ± 38
N^{fit}_{4hKK}	338 ± 29
$N^{fit}_{4h\phi}$	674 ± 41

Fit 3D (mass 4h, mass 6h, mass 2h) 4pi

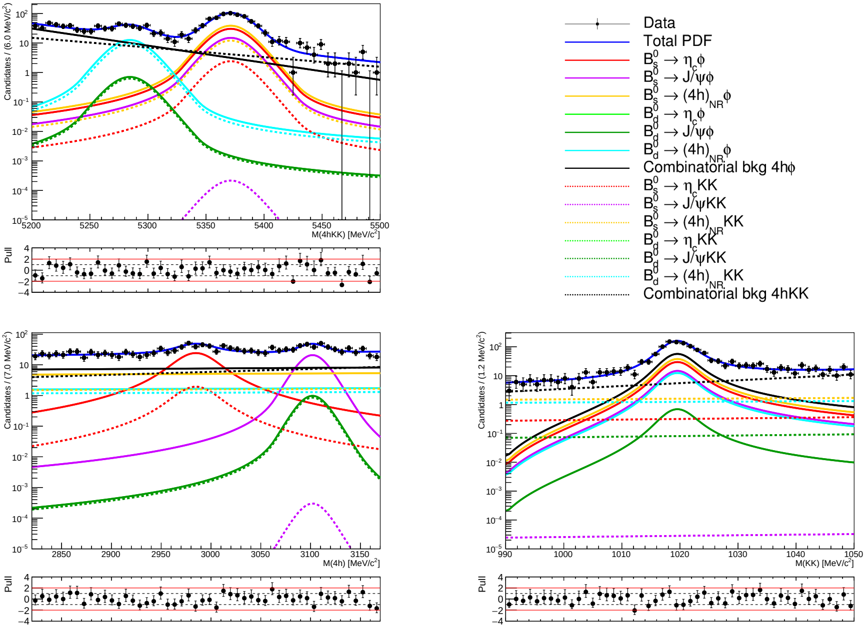








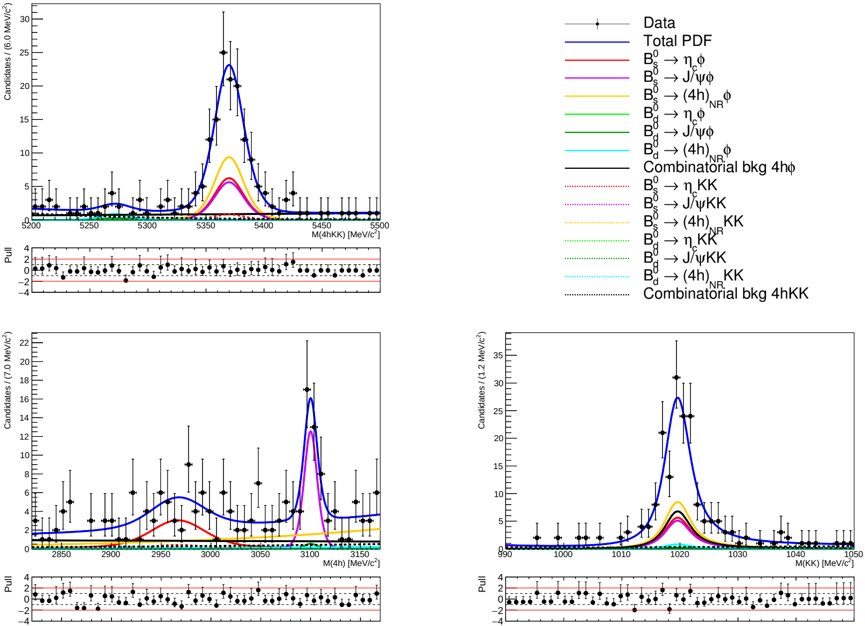
Fit 3D (mass 4h, mass 6h, mass 2h) 4pi



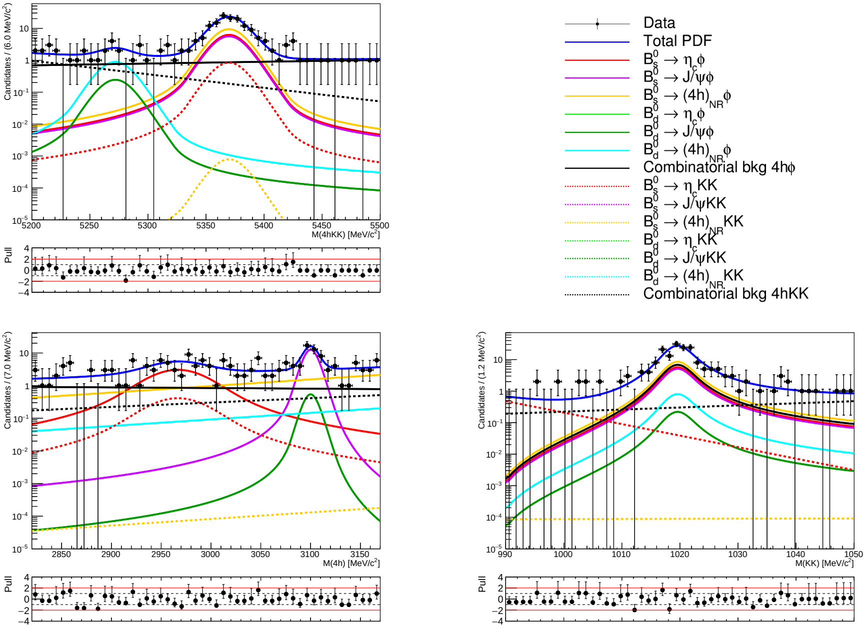
All modes yield 4pi

	N^{fit}
$N^{fit}_{B^0\to\eta_c KK}$	0 ± 2
$N^{fit}_{B^0\to\eta_c\phi}$	0 ± 4
$N^{fit}_{B^0\to J/\psi\, KK}$	4 ± 7
$N^{fit}_{B^0\to J/\psi\,\phi}$	5 ± 9
$N^{fit}_{B^0\to NRKK}$	62 ± 18
$N^{fit}_{B^0\to NR\phi}$	83 ± 24
$N^{fit}_{B_s^0\to\eta_c KK}$	16 ± 15
$N^{fit}_{B_s^0\to\eta_c\phi}$	199 ± 26
$N^{fit}_{B_s^0\to J/\psi\, KK}$	0 ± 17
$N^{fit}_{B_s^0\to J/\psi\,\phi}$	98 ± 20
$N^{fit}_{B_s^0\to NRKK}$	79 ± 23
$N^{fit}_{B_s^0\to NR\phi}$	253 ± 40
N^{fit}_{4hKK}	298 ± 31
$N^{fit}_{4h\phi}$	380 ± 39

Fit 3D (mass 4h, mass 6h, mass 2h) 4K



Fit 3D (mass 4h, mass 6h, mass 2h) 4K



All modes yield 4K

	N^{fit}
$N^{fit}_{B^0\to\eta_c KK}$	0 ± 0
$N^{fit}_{B^0\to\eta_c\phi}$	0 ± 0
$N^{fit}_{B^0\to J/\psi\, KK}$	0 ± 0
$N^{fit}_{B^0\to J/\psi\,\phi}$	1 ± 1
$N^{fit}_{B^0\to NRKK}$	0 ± 1
$N^{fit}_{B^0\to NR\phi}$	5 ± 2
$N^{fit}_{B^0_s\to\eta_c KK}$	5 ± 1
$N^{fit}_{B^0_s\to\eta_c\phi}$	35 ± 4
$N^{fit}_{B^0_s\to J/\psi\, KK}$	0 ± 0
$N^{fit}_{B^0_s\to J/\psi\,\phi}$	32 ± 4
$N^{fit}_{B^0_s\to NRKK}$	0 ± 422
$N^{fit}_{B^0_s\to NR\phi}$	53 ± 6
N^{fit}_{4hKK}	16 ± 3
$N^{fit}_{4h\phi}$	42 ± 5

Used data samples

- Real Data
  - Momentum scale calibration applied
  - Full stat of run1
    - 2011: 0.98 fb^{-1}
    - 2012: 1.99 fb^{-1}
  - Stripping 21(r1)
  - Stream: BHADRON.MDST
  - Stripping Line: StrippingBs2EtacPhiBDTLine see 29/01/2015 talk
- MC Sim08g Pythia8:
  - DecFile: Bs_Jpsiphi,hhhh=DecProdCut.dec
    6 065 927 events
    - $B_s^0 \to J/\psi(KK\pi\pi)\phi(KK)$
    - $B_s^0 \to J/\psi(\pi\pi\pi\pi)\phi(KK)$
    - $B_s^0 \to J/\psi(KKKK)\phi(KK)$
  - DecFile: Bs_etacphi,hhhh=update2015,DecProdCut.dec
    6 123 927 events
    - $B_s^0 \to \eta_c(KK\pi\pi)\phi(KK)$
    - $B_s^0 \to \eta_c(\pi\pi\pi\pi)\phi(KK)$
    - $B_s^0 \to \eta_c(KKKK)\phi(KK)$

Trigger lines

- 6 hadrons in the final state

L0HadronDecision_TOS || L0Physics_TIS
&&
Hlt1TrackAllL0Decision_TOS
&&
Hlt2Topo(2,3,4)BodyBBDTDecision_TOS || Hlt2IncPhiDecision_TOS

Branching fraction of $B_s^0 \to \eta_c \phi$

$$\mathcal{B}^i_{meas}(B_s^0 \to \eta_c \phi) = \frac{N^i_{B_s^0 \to \eta_c \phi}}{N^i_{B_s^0 \to J/\psi\,\phi}} \times \mathcal{B}(B_s^0 \to J/\psi\,\phi) \times \frac{\mathcal{B}^i(J/\psi \to 4h)}{\mathcal{B}^i(\eta_c \to 4h)} \times \frac{\varepsilon^i_{B_s^0 \to J/\psi\,\phi}}{\varepsilon^i_{B_s^0 \to \eta_c \phi}}$$

with $i \in \{2K2\pi, 4\pi, 4K\}$

1) Inputs $\mathcal{B}(B_s^0 \to J/\psi\,\phi)$, $\mathcal{B}^i(J/\psi \to 4h)$ and $\mathcal{B}^i(\eta_c \to 4h)$ taken from PDG (see backup 69)
2) Efficiencies computed using exclusive η_c and J/ψ MC (see following)
   - We factorize the total efficiency as:
     $\varepsilon = \varepsilon^{\text{geo}}.\varepsilon^{\text{reco}}.\varepsilon^{\text{sel}}.\varepsilon^{\text{PID}}$
     with sel = (trigger + stripping + offline selection and BDT)
3) $\frac{N_{B_s^0 \to \eta_c \phi}}{N_{B_s^0 \to J/\psi\,\phi}}$: extracted from unbinned maximum likelihood fit to data (see following)

Efficiency computation: geometric

- Table is given after MC generation

Years	Efficiency (%): geometric		Ratio
	$B_s^0 \rightarrow \eta_c \phi$	$B_s^0 \rightarrow J/\psi\ \phi$	
MC2011	0.1601 ± 0.0005	0.1610 ± 0.0005	1.006 ± 0.005
MC2012	0.1616 ± 0.0006	0.1631 ± 0.0006	1.009 ± 0.005
Total	0.1609 ± 0.0005	0.1620 ± 0.0005	1.008 ± 0.005

- $\left(\frac{\varepsilon_{B_s^0 \rightarrow J/\psi\ \phi}}{\varepsilon_{B_s^0 \rightarrow \eta_c \phi}}\right)_{geo} = 1.008 \pm 0.005$

Efficiency computation: selection

- $\left(\varepsilon_{B_s^0 \to X\phi}\right)_{sel} = \frac{\mathcal{N}(\text{MC events reconstructed and selected truth matched})}{\mathcal{N}(\text{MC events reconstructed truth matched})}$

$\longrightarrow$ selected means: trigger + stripping + offline selection and BDT

Mode	Efficiency (%): selection				Ratio
	$B_s^0 \to \eta_c \phi$		$B_s^0 \to J/\psi\,\phi$		
	Mag Down	Mag Up	Mag Down	Mag Up	
2011 KKpipi mode	3.38 ± 0.08	3.19 ± 0.07	3.34 ± 0.08	3.33 ± 0.08	1.016 ± 0.023
2012 KKpipi mode	6.2 ± 0.07	6.13 ± 0.08	6.55 ± 0.08	6.23 ± 0.08	1.036 ± 0.013
2011 pipipipi mode	5.45 ± 0.13	5.38 ± 0.12	5.61 ± 0.14	5.6 ± 0.14	1.034 ± 0.025
2012 pipipipi mode	4.94 ± 0.09	5.1 ± 0.09	5 ± 0.1	5.34 ± 0.1	1.03 ± 0.019
2011 KKKK mode	5.22 ± 0.29	4.64 ± 0.28	4.65 ± 0.25	4.55 ± 0.24	0.931 ± 0.05
2012 KKKK mode	6 ± 0.23	5.6 ± 0.22	6.19 ± 0.21	5.83 ± 0.2	1.04 ± 0.04
Total	5.21 ± 0.04	5.12 ± 0.04	5.35 ± 0.04	5.3 ± 0.04	1.03 ± 0.009

- $\left(\frac{\varepsilon_{B_s^0 \to J/\psi\,\phi}}{\varepsilon_{B_s^0 \to \eta_c \phi}}\right)_{sel} = 1.030 \pm 0.009$

Efficiency computation: PID

- $(\varepsilon_{B_s^0 \to X\phi})_{PID} = \frac{\mathcal{N}(\text{MC events reconstructed, selected truth matched and PID})}{\mathcal{N}(\text{MC events reconstructed and selected truth matched})}$
- used PIDCalib package:
  1) We created calibration sample for K and π with PID cut (value optimize after the BDT selection, see backup)
  2) We run the calibration over the reference
  3) We recalculate the statistical uncertainties taking into account the size of the reference

Mode	Efficiency (%): PID $B_s^0 \to \eta_c \phi$ Mag Down	$B_s^0 \to \eta_c \phi$ Mag Up	$B_s^0 \to J/\psi\, \phi$ Mag Down	$B_s^0 \to J/\psi\, \phi$ Mag Up	Ratio
2011 KKpipi mode	86.31 ± 0.17	86.61 ± 0.17	86.63 ± 0.17	86.26 ± 0.19	0.9998 ± 0.0020
2012 KKpipi mode	86.66 ± 0.10	85.52 ± 0.11	86.47 ± 0.10	85.58 ± 0.11	0.9992 ± 0.0012
2011 pipipipi mode	81.12 ± 0.18	80.78 ± 0.19	81.12 ± 0.21	81.11 ± 0.20	1.0021 ± 0.0024
2012 pipipipi mode	81.54 ± 0.15	80.60 ± 0.15	81.38 ± 0.17	80.52 ± 0.16	0.9986 ± 0.0019
2011 KKKK mode	91.1 ± 0.5	91.7 ± 0.4	91.6 ± 0.4	91.5 ± 0.4	1.002 ± 0.005
2012 KKKK mode	91.10 ± 0.30	90.63 ± 0.35	91.68 ± 0.25	90.25 ± 0.30	1.0011 ± 0.0033
Total	84.90 ± 0.07	84.24 ± 0.07	85.16 ± 0.07	84.47 ± 0.07	1.000 ± 0.007

- $\left(\frac{\varepsilon_{B_s^0 \to J/\psi\, \phi}}{\varepsilon_{B_s^0 \to \eta_c \phi}}\right)_{PID} = 1.000 \pm 0.007$

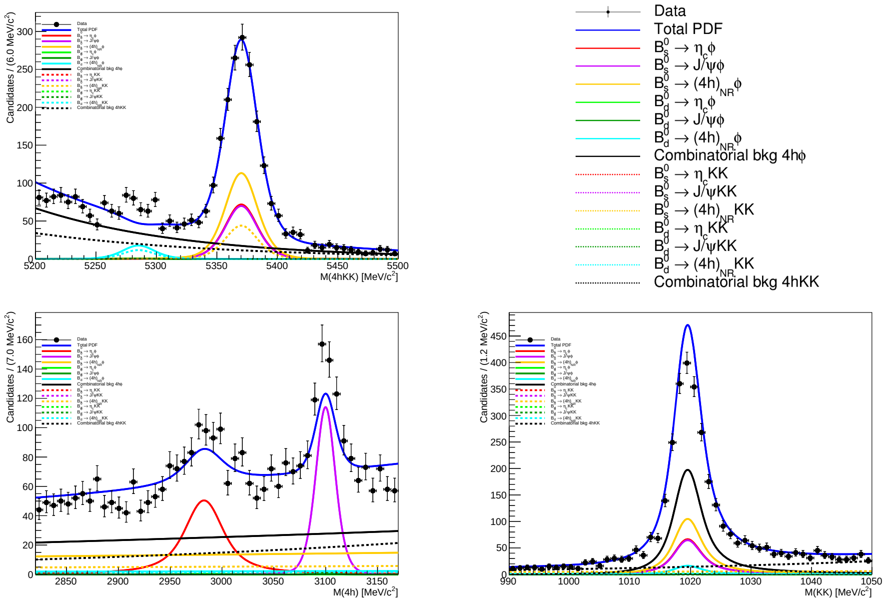
Definition of true MC candidate in our Tuples

- Signal ($B_s^0 \to \eta_c\ \phi$), BKGCAT:
  - $B_s^0 = 0 || B_s^0 = 10$
  - $\eta_c = 0 || \eta_c = 10$
  - $\phi = 0$
- Control channel ($B_s^0 \to J/\psi\ \phi$), BKGCAT:
  - $B_s^0 = 0 || B_s^0 = 10$
  - $\phi = 0$
  - Without Stripping Line: $J/\psi = 0 || J/\psi = 10$
  - With Stripping Line: $J/\psi = 20$

- The intermediate resonance from J/ψ or η_c are not in the decay descriptor
- The Stripping Line needs the decay descriptor written with η_c

BKGCAT=0: true NR signal
BKGCAT=10: all intermediate states of the decay descriptor are not correctly reconstructed
BKGCAT=20: the true MC particle defined in the decay descriptor is not a signal decay

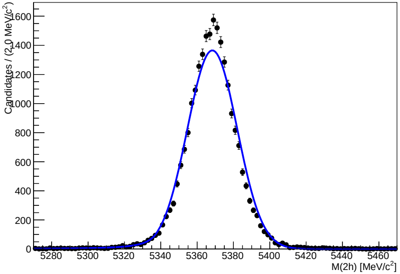
Fit 3D with negative yield

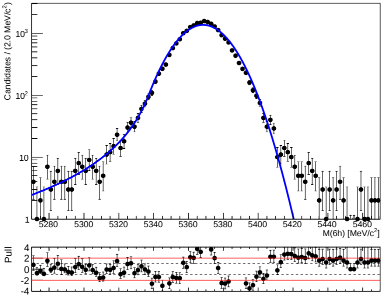


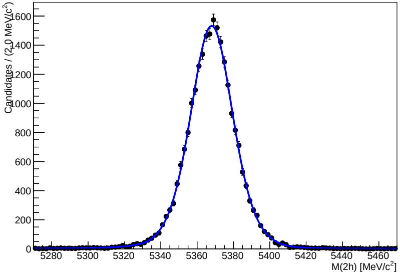
Fit 3D result: shape parameters with negative yield

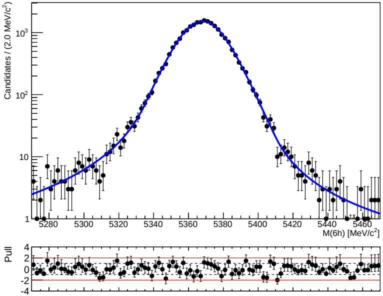
```
COVARIANCE MATRIX CALCULATED SUCCESSFULLY
FCN=25973 FROM HESSE     STATUS=OK        594 CALLS       6924 TOTAL
                    EDM=368.06    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                INTERNAL      INTERNAL
 NO.   NAME      VALUE            ERROR       STEP SIZE       VALUE
  1  Bs_kNR_4h    5.30469e-04   4.86051e-04   1.86259e-06   5.30469e-04
  2  EtacMean    2.98260e+03   2.05098e+00   4.55868e-04   1.30289e-01
  3  PhiMean    1.01987e+03   7.50387e-02   8.24517e-05  -6.60038e-03
  4  Resolution_2h_Phi   1.03377e+00   1.44010e-01   1.41236e-04  -1.11208e+00
  5  Resolution_4h_Etac   9.59493e+00   3.48332e+00   1.53719e-03  -9.54154e-02
  6  ipa_m       5.28519e+03   3.15603e+00   2.16405e-01  -3.84705e+00
  7  ipa_m_jpsi   3.09985e+03   7.69664e-01   8.36158e-04   6.06027e-01
  8  ipa_ms      5.37019e+03   4.48585e-01   5.17945e-04   6.92451e-01
  9  ipa_s_jpsi   1.15274e+01   9.61494e-01   1.06403e-03  -3.14943e+00
 10  ipa_ss      1.57949e+01   4.98294e-01   4.01853e-04   1.59665e-01
 11  kCombi_4hPhi  -7.96039e-03   5.66016e-04   2.16122e-07  -7.96039e-04
 12  kCombi_4h_KK   2.14310e-03   5.88499e-04   1.19272e-05   2.14311e-03
 13  kCombi_4h_Phi   8.83311e-04   4.16452e-04   1.65558e-06   8.83311e-04
 14  kCombi_6h   -6.46857e-03   7.05351e-04   2.82904e-07  -6.46857e-04
 15  kSWaves_2h   6.75956e-01   9.72413e-06   3.73968e-05   6.76472e-02
 16  kSWaves_2h_Combi   1.85417e-02   3.05119e-03   1.24127e-06   1.85417e-03
 17  kSWaves_2h_NR   4.78778e-03   5.50356e-03   2.19921e-06   4.78778e-04
 18  nBd2EtacKK  -1.00000e+02   4.99360e-01   2.76075e-03  -1.57078e+00
                        WARNING -   - ABOVE PARAMETER IS AT LIMIT.
 19  nBd2EtacPhi   2.48788e+00   1.44367e+01   9.70682e-04   2.52686e+00
 20  nBd2JpsiKK  -1.00000e+02   4.99360e-01   2.76075e-03  -1.57078e+00
                        WARNING -   - ABOVE PARAMETER IS AT LIMIT.
 21  nBd2JpsiPhi   2.86637e+00   9.40247e+00   7.06330e-04   6.21874e-01
 22  nBd2NRKK    6.11796e+01   2.37578e+01   1.04509e-03   6.58329e-01
 23  nBd2NRPhi   9.30068e+01   3.64578e+01   6.91520e-04   2.90793e-01
 24  nBs2EtacKK  -1.00000e+02   4.99722e-01   1.81734e-03  -1.57078e+00
                        WARNING -   - ABOVE PARAMETER IS AT LIMIT.
 25  nBs2EtacPhi   3.78863e+02   3.51819e+01   4.29625e-04   2.66003e-01
 26  nBs2JpsiKK  -1.00000e+02   4.99584e-01   2.22578e-03  -1.57075e+00
                        WARNING -   - ABOVE PARAMETER IS AT LIMIT.
 27  nBs2JpsiPhi   3.68684e+02   2.81130e+01   3.56974e-04   2.30996e-01
 28  nBs2NRKK    2.31793e+02   3.08442e+01   3.86963e-04   1.06175e-01
 29  nBs2NRPhi   5.97720e+02   5.43970e+01   3.38130e-04   1.96707e-01
 30  nCombiKK    6.67359e+02   4.76397e+01   3.41186e-04   3.41306e-01
 31  nCombiPhi   1.12703e+03   5.91034e+01   2.93076e-04   5.26731e-01
```

B_s^0 model fit (CB or hypatia)

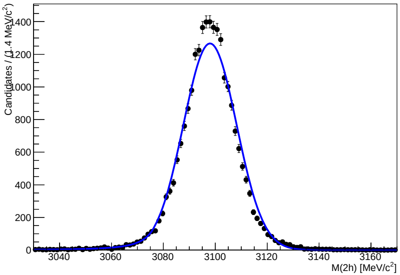


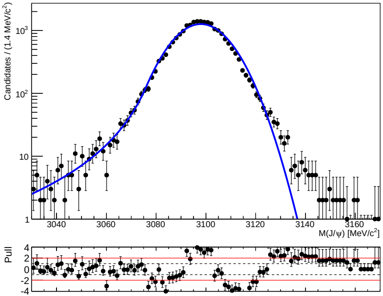


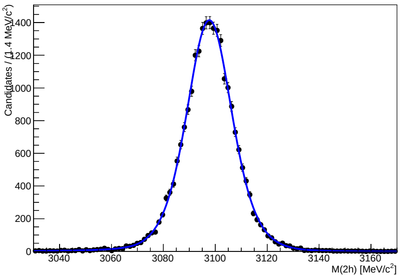


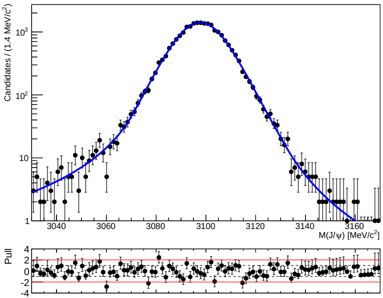


J/ψ model fit (CB or hypatia)

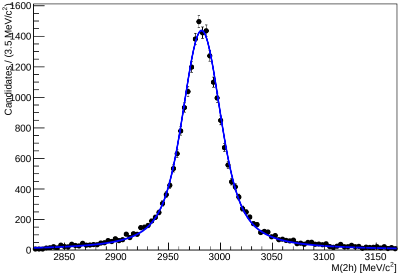


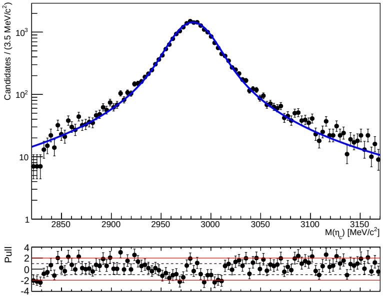


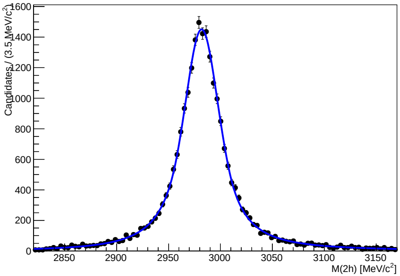


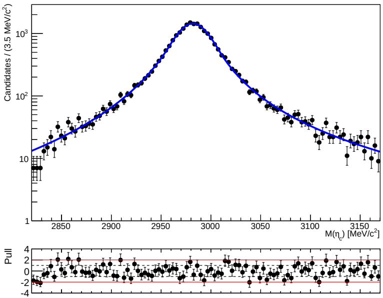


η_c model fit (Voigtian or hypatia)

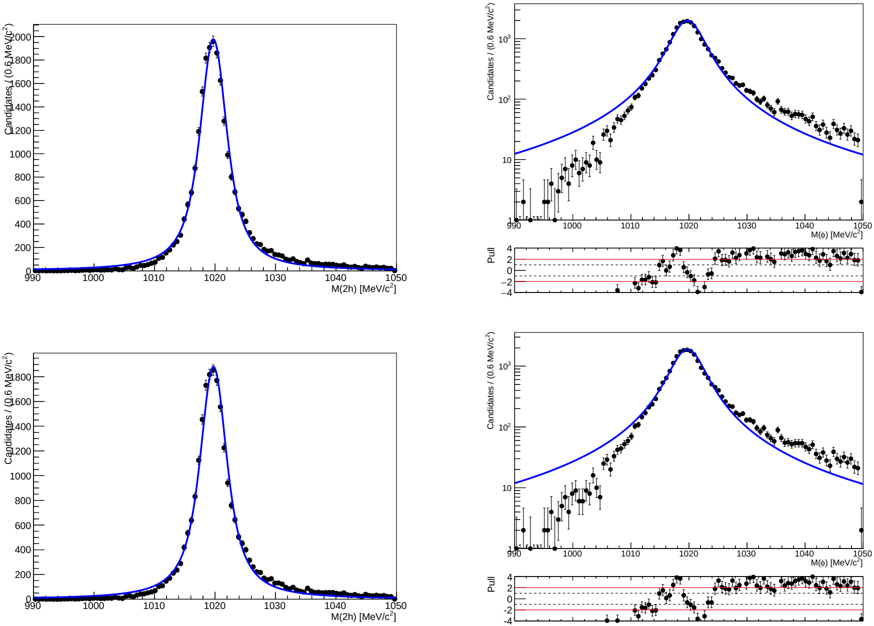




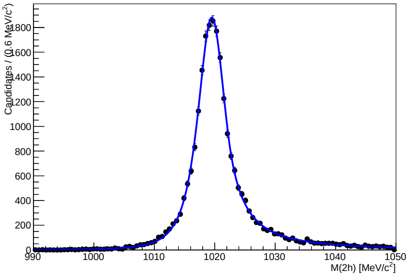


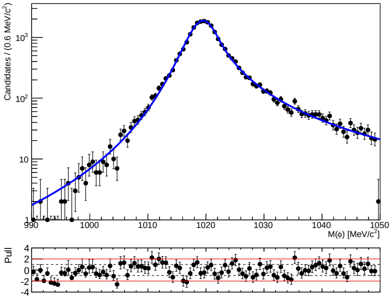


ϕ model fit (BW convoluted with Gaussian or CB)



ϕ model fit (hypatia)





Mass fit models tested $B_s^0 \to \eta_c(4h)\phi(K^+K^-)$

- Mass 6h:

$\rightarrow$ B_s^0: CB with μ and σ free and all other parameters fixed (MC)

$\rightarrow$ B^0: CB with μ free and all other parameters equal to B_s^0

$\rightarrow$ Combinatorial background: Exponentials with coefficient free

- Mass 4h

$\rightarrow$ η_c: Voigtian: μ free, Breit-Wigner line shape width fixed to 32.2 MeV and σ of the convoluted Gaussian free

$\rightarrow$ J/ψ: CB with μ and σ free, all other parameters fixed (MC)

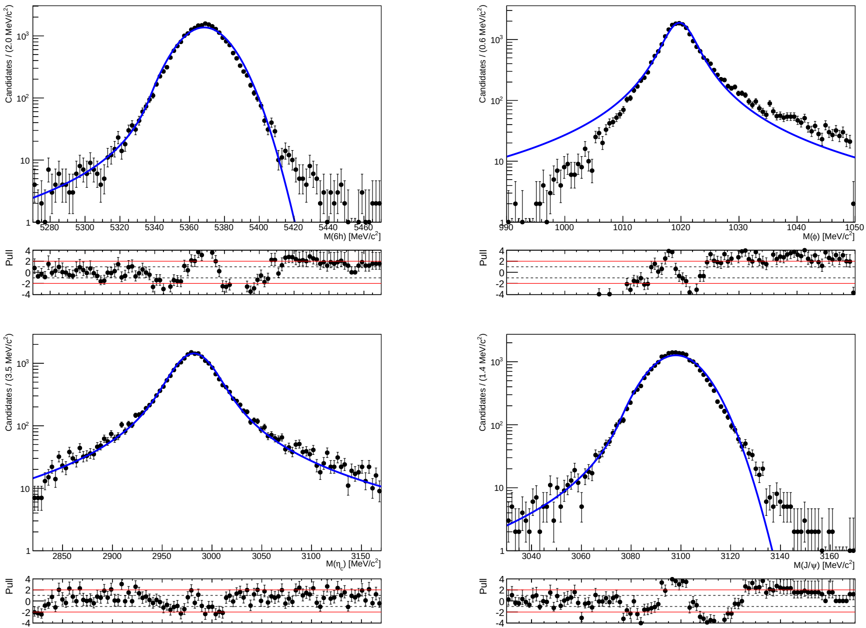
$\rightarrow$ "Physical background", NR m(4h): Exponentials with coefficient free

- Mass K^+K^-

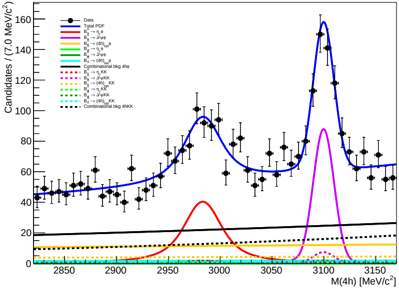
$\rightarrow$ ϕ: BW convoluted with CB: μ free, Breit-Wigner line shape width fixed to 4.27 MeV and σ of the convoluted CB free and all other parameters fixed (MC)

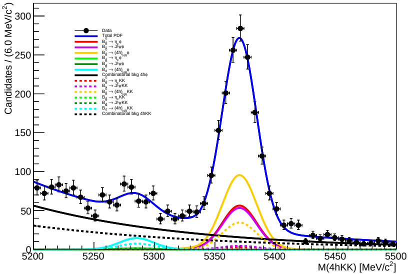
$\rightarrow$ S-waves: Exponentials with coefficient free

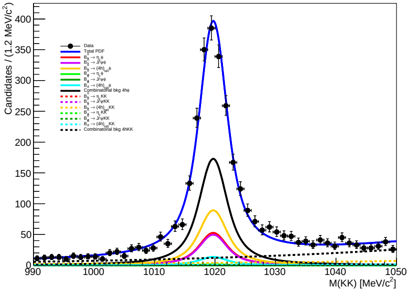
MC model fit CB and voigtian(B_s^0, ϕ, η_c and J/ψ)



Fit 3D with tested model (mass 4h, mass 6h, mass 2h)







	N^{fit}
$N^{fit}_{\eta_c}$	339 ± 36
$N^{fit}_{J/\psi}$	320 ± 26
$\frac{N^{fit}_{\eta_c}}{N^{fit}_{J/\psi}}$	1.06 ± 0.14

$$\mathcal{B}^{\text{prelim}}_{\text{meas}}(B^0_s \to \eta_c \phi) = (3.53 \pm 0.48(\text{stat}) \pm 0.54(\mathcal{B}^*) \pm 0.04(\text{syst eff})) \times 10^{-4}$$

Selection efficiency without Hlt2IncPhiDecision_TOS

- $(\varepsilon_{B_s^0 \to X\phi})_{sel} = \frac{\mathcal{N}(\text{MC events reconstructed and selected truth matched})}{\mathcal{N}(\text{MC events reconstructed truth matched})}$

Trigger Line	Efficiency (%): selection $B_s^0 \to \eta_c \phi$ Mag Down	$B_s^0 \to \eta_c \phi$ Mag Up	$B_s^0 \to J/\psi\, \phi$ Mag Down	$B_s^0 \to J/\psi\, \phi$ Mag Up	Ratio
2011 KKpipi mode	3.22 $\pm$0.07	3.05 $\pm$0.07	3.21 $\pm$0.07	3.19 $\pm$0.07	1.02 $\pm$0.024
2012 KKpipi mode	5.9 $\pm$0.07	5.8 $\pm$0.07	6.21 $\pm$0.08	5.88 $\pm$0.07	1.033 $\pm$0.013
2011 pipipipi mode	5.23 $\pm$0.12	5.19 $\pm$0.12	5.35 $\pm$0.13	5.4 $\pm$0.13	1.031 $\pm$0.025
2012 pipipipi mode	4.77 $\pm$0.09	4.93 $\pm$0.09	4.85 $\pm$0.09	5.16 $\pm$0.1	1.032 $\pm$0.019
2011 KKKK mode	4.88 $\pm$0.28	4.27 $\pm$0.26	4.43 $\pm$0.24	4.35 $\pm$0.24	0.958 $\pm$0.05
2012 KKKK mode	5.63 $\pm$0.22	5.13 $\pm$0.21	5.77 $\pm$0.2	5.34 $\pm$0.19	1.03 $\pm$0.04
Total	4.97 $\pm$0.04	4.88 $\pm$0.04	5.1 $\pm$0.04	5.03 $\pm$0.04	1.03 $\pm$0.009

Table: Selection efficiency to each modes

- $\left(\frac{\varepsilon_{B_s^0 \to J/\psi\, \phi}}{\varepsilon_{B_s^0 \to \eta_c \phi}}\right)^{tot}_{sel} = 1.028 \pm 0.009$

about 5% of signal lost

Estimation of $\mathcal{B}(B_s^0 \to \eta_c(4h)\phi(KK))$

$$\begin{aligned}\mathcal{B}(B_s^0 \to \eta_c(4h)\phi(KK)) &= \mathcal{B}(B_s^0 \to \eta_c\phi) \times \mathcal{B}(\eta_c \to 4h) \times \mathcal{B}(\phi \to KK) \\ &\simeq 2.3 \times 10^{-5}\end{aligned}$$

- $\mathcal{B}(B_s^0 \to \eta_c\phi)$:
  - $d = s$ hypothesis

$\rightarrow \frac{\mathcal{B}(B_s^0 \to \eta_c\phi)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)} = \frac{\mathcal{B}(B_d \to \eta_c K^0)}{\mathcal{B}(B_d \to J/\psi\, K^0)}$

- $\eta_c \to K^+K^-\pi^+\pi^-$ $\sim$ 53%
  - $\mathcal{B}(\eta_c \to K^+K^-\pi^+\pi^-)$ NR
  - $\mathcal{B}(\eta_c \to K_0^* K^-\pi^+)$
  - $\mathcal{B}(\eta_c \to K_0^* \overline{K}_0^*)$
  - $\mathcal{B}(\eta_c \to f_2(1270)f_2'(1525))$
  - $\mathcal{B}(\eta_c \to f_2(1270)f_2(1270))$
- $\eta_c \to \pi^+\pi^-\pi^+\pi^-$ $\sim$ 40%
  - $\mathcal{B}(\eta_c \to \pi^+\pi^-\pi^+\pi^-)$ NR
  - $\mathcal{B}(\eta_c \to \rho_0\rho_0)$
  - $\mathcal{B}(\eta_c \to f_2(1270)f_2(1270))$
- $\eta_c \to K^+K^-K^+K^-$ $\sim$ 7%
  - $\mathcal{B}(\eta_c \to K^+K^-K^+K^-)$ NR
  - $\mathcal{B}(\eta_c \to \phi K^+K^-)$
  - $\mathcal{B}(\eta_c \to \phi\phi)$

Mode	$\mathcal{B}$ from PDG
$\rho_0 \to \pi^+\pi^-$	(1.00 ± 0.00)
$\omega \to \pi^+\pi^-$	$(1.53 \pm 0.13)\times 10^{-2}$
$K_0^* \to K^+\pi^-$	(0.67 ± 0.00)
$\phi \to K^+K^-$	$(48.9 \pm 0.5)\times 10^{-2}$
$f_2(1270) \to \pi\pi$	$(8.48 \pm 0.24)\times 10^{-1}$
$f_2(1270) \to \pi^+\pi^-$	$(5.65 \pm 0.16)\times 10^{-1}$
$f_2(1270) \to K\bar{K}$	$(4.6 \pm 0.4)\times 10^{-2}$
$f_2(1270) \to K^+K^-$	$(3.07 \pm 0.27)\times 10^{-2}$
$a_2(1320) \to K\bar{K}$	$(4.9 \pm 0.8)\times 10^{-2}$
$a_2(1320) \to K^+K^-$	$(3.3 \pm 0.5)\times 10^{-2}$
$K_1(1400) \to K\rho$	$(0.30 \pm 0.30)\times 10^{-1}$
$K_1(1400)^\pm \to K^\pm\rho_0$	$(0.20 \pm 0.20)\times 10^{-1}$
$K_2^*(1430) \to K\pi$	$(3.3 \pm 0.8)\times 10^{-1}$
$f_2'(1525) \to K\bar{K}$	$(8.87 \pm 0.22)\times 10^{-1}$
$f_2'(1525) \to K^+K^-$	$(5.91 \pm 0.15)\times 10^{-1}$
$f_2'(1525) \to \pi\pi$	$(0.82 \pm 0.15)\times 10^{-2}$
$f_2'(1525) \to \pi^+\pi^-$	$(0.55 \pm 0.10)\times 10^{-2}$

Decay modes (2/8)

Mode	$\mathcal{B}$ from PDG
$\eta_c \to K^+K^-K^+K^-$ (NR)	$(1.47 \pm 0.31) \times 10^{-3}$
$\eta_c \to \phi K^+K^-$	$(0.29 \pm 0.14) \times 10^{-2}$
$\eta_c \to \phi(K^+K^-)K^+K^-$	$(1.4 \pm 0.7) \times 10^{-3}$
$\eta_c \to \phi\phi$	$(1.76 \pm 0.20) \times 10^{-3}$
$\eta_c \to \phi(K^+K^-)\phi(K^+K^-)$	$(4.2 \pm 0.5) \times 10^{-4}$
$\eta_c \to f_2(1270)f_2(1270)$	$(0.98 \pm 0.25) \times 10^{-2}$
$\eta_c \to f_2(1270)(K^+K^-)f_2(1270)(K^+K^-)$	$(0.92 \pm 0.26) \times 10^{-5}$
$\eta_c \to (K^+K^-K^+K^-)$	$(3.3 \pm 0.8) \times 10^{-3}$

Decay modes (3/8)

Mode	$\mathcal{B}$ from PDG
$J/\psi \to K^+K^-K^+K^-$ (NR)	$(7.6 \pm 0.9) \times 10^{-4}$
$J/\psi \to \phi K\bar{K}$	$(1.83 \pm 0.24) \times 10^{-3}$
$J/\psi \to \phi(K^+K^-)K^+K^-$	$(6.0 \pm 0.8) \times 10^{-4}$
$J/\psi \to \phi f_2(1270)$	$(0.72 \pm 0.13) \times 10^{-3}$
$J/\psi \to \phi(K^+K^-)f_2(1270)(K^+K^-)$	$(1.08 \pm 0.22) \times 10^{-5}$
$J/\psi \to \phi f_2'(1270)$	$(0.8 \pm 0.4) \times 10^{-3}$
$J/\psi \to \phi(K^+K^-)f_2'(1270)(K^+K^-)$	$(0.23 \pm 0.12) \times 10^{-3}$
$J/\psi \to (K^+K^-K^+K^-)$	$(1.60 \pm 0.17) \times 10^{-3}$

Decay modes (4/8)

Mode	$\mathcal{B}$ from PDG
$\eta_c \to K^+K^-\pi^+\pi^-$ (NR)	$(0.69 \pm 0.11)\times 10^{-2}$
$\eta_c \to K_0^* K^-\pi^+$	$(2.0 \pm 0.7)\times 10^{-2}$
$\eta_c \to K_0^*(K^+\pi^-)K^-\pi^+$	$(1.3 \pm 0.5)\times 10^{-2}$
$\eta_c \to K^*\overline{K}^*$	$(0.70 \pm 0.13)\times 10^{-2}$
$\eta_c \to K_0^*\overline{K}_0^*$	$(2.3 \pm 0.4)\times 10^{-3}$
$\eta_c \to K_0^*(K^+\pi^-)\overline{K}_0^*(K^-\pi^+)$	$(1.04 \pm 0.19)\times 10^{-3}$
$\eta_c \to f_2(1270)f_2'(1525)$	$(0.97 \pm 0.32)\times 10^{-2}$
$\eta_c \to f_2(1270)(\pi^+\pi^-)f_2'(1525)(K^+K^-)$	$(0.32 \pm 0.11)\times 10^{-2}$
$\eta_c \to f_2(1270)(K^+K^-)f_2'(1525)(\pi^+\pi^-)$	$(1.6 \pm 0.6)\times 10^{-6}$
$\eta_c \to f_2(1270)f_2(1270)$	$(0.98 \pm 0.25)\times 10^{-2}$
$\eta_c \to f_2(1270)(\pi^+\pi^-)f_2(1270)(K^+K^-)$	$(1.7 \pm 0.5)\times 10^{-4}$
$\eta_c \to f_2(1270)(K^+K^-)f_2(1270)(\pi^+\pi^-)$	$(1.7 \pm 0.5)\times 10^{-4}$
$\eta_c \to (K^+K^-\pi^+\pi^-)$	$(2.5 \pm 0.5)\times 10^{-2}$

Decay modes (5/8)

Mode	$\mathcal{B}$ from PDG
$J/\psi \to K^+K^-\pi^+\pi^-$ (NR)	$(6.6 \pm 0.5) \times 10^{-3}$
$J/\psi \to K_0^* \overline{K}_0^*$	$(2.3 \pm 0.7) \times 10^{-4}$
$J/\psi \to K_0^*(K^+\pi^-)\overline{K}_0^*(K^-\pi^+)$	$(1.02 \pm 0.31) \times 10^{-4}$
$J/\psi \to a_2(1320)\rho_0$	$(3.6 \pm 0.7) \times 10^{-3}$
$J/\psi \to a_2(1320)(K^+K^-)\rho_0(\pi^+\pi^-)$	$(1.19 \pm 0.31) \times 10^{-4}$
$J/\psi \to K_0^* \overline{K}_2^*(1430)$	$(6.0 \pm 0.6) \times 10^{-3}$
$J/\psi \to K_0^*(K^+\pi^-)\overline{K}_2^*(1430)(K^-\pi^+)$	$(1.33 \pm 0.14) \times 10^{-3}$
$J/\psi \to K_1(1400)^\pm K^\mp$	$(0.38 \pm 0.14) \times 10^{-2}$
$J/\psi \to K_1(1400)^\pm(K^\pm\rho_0(\pi^+\pi^-))K^\mp$	$(0.4 \pm 0.4) \times 10^{-4}$
$J/\psi \to \phi f_2(1270)$	$(0.72 \pm 0.13) \times 10^{-3}$
$J/\psi \to \phi(K^+K^-)f_2(1270)(\pi^+\pi^-)$	$(2.0 \pm 0.4) \times 10^{-4}$
$J/\psi \to \phi\pi^+\pi^-$	$(9.4 \pm 0.9) \times 10^{-4}$
$J/\psi \to \phi(K^+K^-)\pi^+\pi^-$	$(4.6 \pm 0.4) \times 10^{-4}$
$J/\psi \to (K^+K^-\pi^+\pi^-)$	$(8.9 \pm 0.5) \times 10^{-3}$

Decay modes (6/8)

Mode	$\mathcal{B}$ from PDG
$\eta_c \to \pi^+\pi^-\pi^+\pi^-$ (NR)	$(0.97 \pm 0.12)\times 10^{-2}$
$\eta_c \to \rho\rho$	$(1.8 \pm 0.5)\times 10^{-2}$
$\eta_c \to \rho_0\rho_0$	$(0.60 \pm 0.17)\times 10^{-2}$
$\eta_c \to \rho_0(\pi^+\pi^-)\rho_0(\pi^+\pi^-)$	$(0.60 \pm 0.17)\times 10^{-2}$
$\eta_c \to f_2(1270) f_2(1270)$	$(0.98 \pm 0.25)\times 10^{-2}$
$\eta_c \to f_2(1270)(\pi^+\pi^-) f_2(1270)(\pi^+\pi^-)$	$(3.1 \pm 0.8)\times 10^{-3}$
$\eta_c \to (\pi^+\pi^-\pi^+\pi^-)$	$(1.88 \pm 0.22)\times 10^{-2}$

Decay modes (7/8)

Mode	$\mathcal{B}$ from PDG
$J/\psi \to \pi^+\pi^-\pi^+\pi^-$ (NR)	$(3.57 \pm 0.30)\times 10^{-3}$
$J/\psi \to \omega\pi^+\pi^-$	$(8.6 \pm 0.7)\times 10^{-3}$
$J/\psi \to \omega(\pi^+\pi^-)\pi^+\pi^-$	$(1.32 \pm 0.15)\times 10^{-4}$
$J/\psi \to (\pi^+\pi^-\pi^+\pi^-)$	$(3.70 \pm 0.30)\times 10^{-3}$

Mode	$\mathcal{B}$ from PDG
$\eta_c \to (4h)$	$(\ 4.7 \pm 0.6\ )\times 10^{-2}$
$J/\psi \to (4h)$	$(14.1 \pm 0.6\ )\times 10^{-3}$
$B_s^0 \to J/\psi\phi$	$(10.7 \pm 0.9\ )\times 10^{-4}$

	$\eta_c \to 4K$	$\eta_c \to \phi\phi$	$\eta_c \to 2K2\pi$	$\eta_c \to K_0^* \overline{K}_0^*$	$\eta_c \to 4\pi$
$\eta_c \to \phi\phi$	16				
$\eta_c \to 2K2\pi$	10	21			
$\eta_c \to K_0^* \overline{K}_0^*$	9	18	11		
$\eta_c \to 4\pi$	12	25	16	14	
$\eta_c \to f_2(1270) f_2(1270)$	3	6	4	3	5

Correlation matrix of $\eta_c \to$ 4h

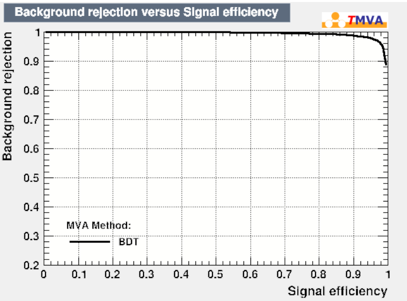
Expected contribution in "NR"

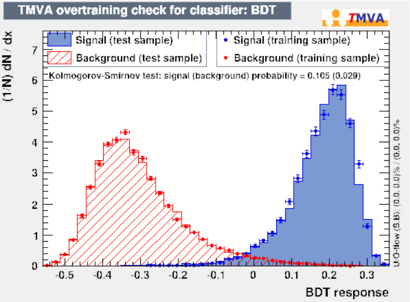
- $\eta_c \to KK\pi\pi$
  - $B_s^0 \to D_s D_s$
    where $D_s \to \phi\pi$ or $D_s \to KK\pi$
  - $B_s^0 \to \phi\, 4h$
  - $B_s^0 \to \phi\phi\phi$
- $\eta_c \to \pi\pi\pi\pi$
  - $B_s^0 \to D_s\pi\pi\pi$
- ...

Offline BDT

Offline selection BDT

- BDT trained with:
  - Signal: MC TRUE events
  - Background: real data Upper Side Band: m(6h) > 5600 MeV
- List of variables used:
  - ENDVERTEX, IPCHI2, TRACKCHI2, DIRA, FD, PT
- BDT traning result:



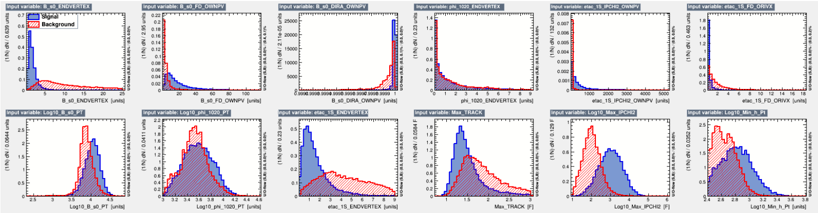


2012 $2K2\pi$ case

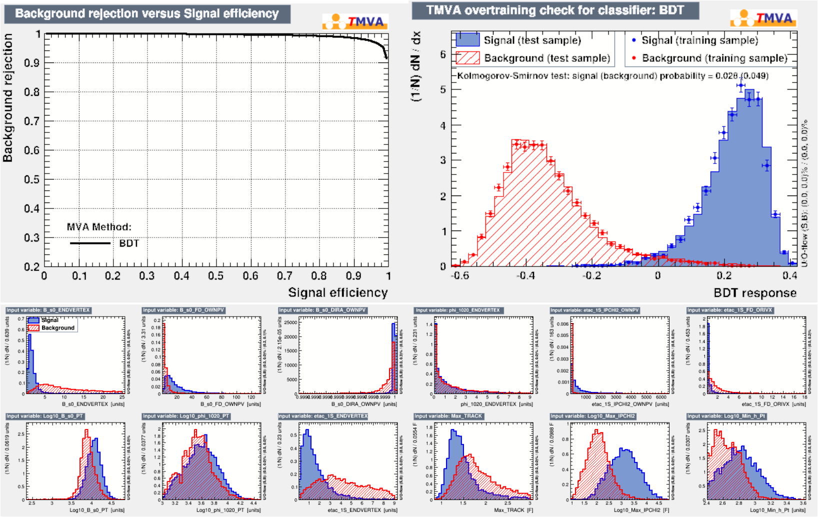
Variables ranked by the BDT (2012 $2K2\pi$ case)

Rank	Variable	Importance
1	B_s^0:ENDVERTEX(χ^2/ndof)	1.061×10^{-1}
2	Log_Max_IPCHI2	1.037×10^{-1}
3	Log_Min_PT	9.899×10^{-2}
4	η_c:ENDVERTEX(χ^2/ndof)	9.657×10^{-2}
5	Max_TRACK_CHI2	9.643×10^{-2}
6	ϕ:Log_PT	9.521×10^{-2}
7	B_s^0:Log_PT	9.229×10^{-2}
8	ϕ:ENDVERTEX(χ^2/ndof)	8.527×10^{-2}
9	B_s^0:FD_OWNPV	6.474×10^{-2}
10	η_c:FD_ORIVX	6.190×10^{-2}
11	B_s^0:DIRA_OWNPV	4.976×10^{-2}
12	η_c:IPCHI2_OWNPV	4.899×10^{-2}

- Max and Min is applied to hadrons (K, π)

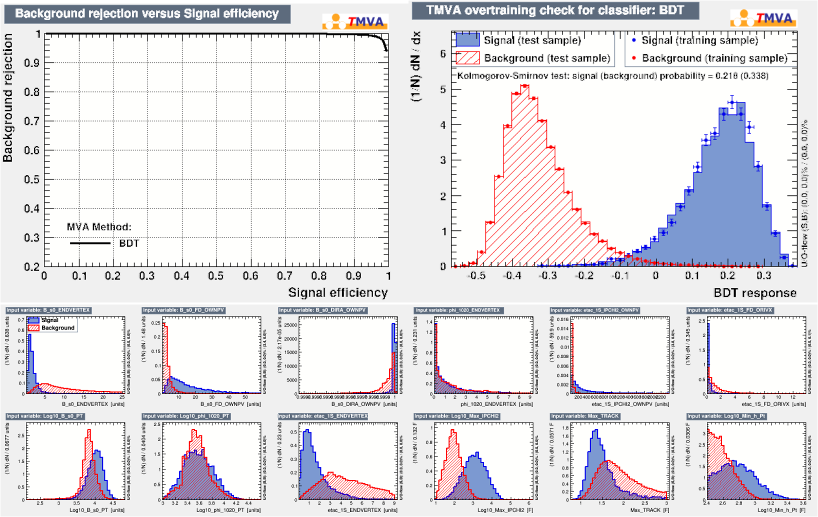


Offline selection BDT



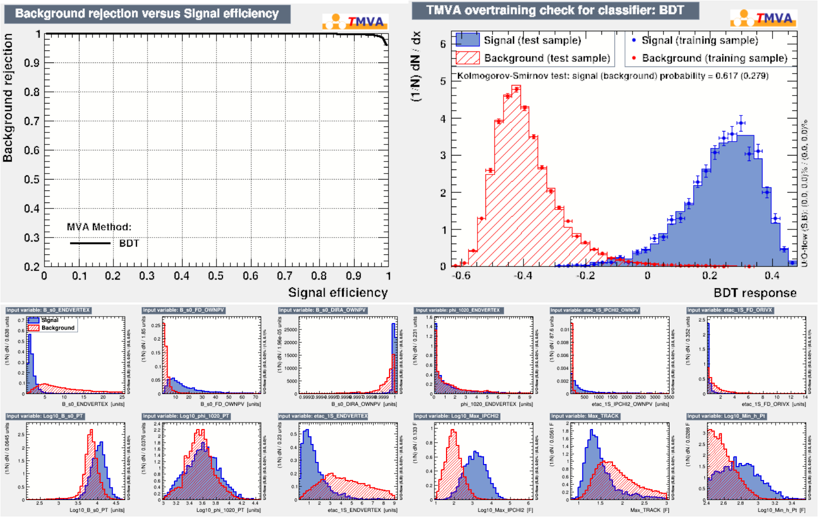
2011 2K2π case

Offline selection BDT



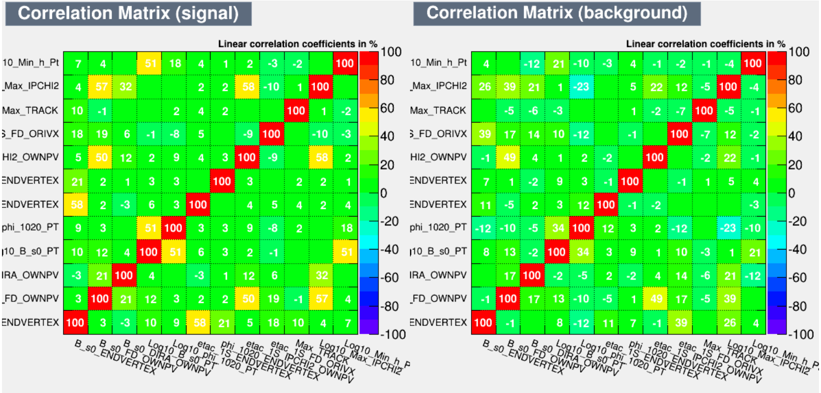
2012 4π case

Offline selection BDT



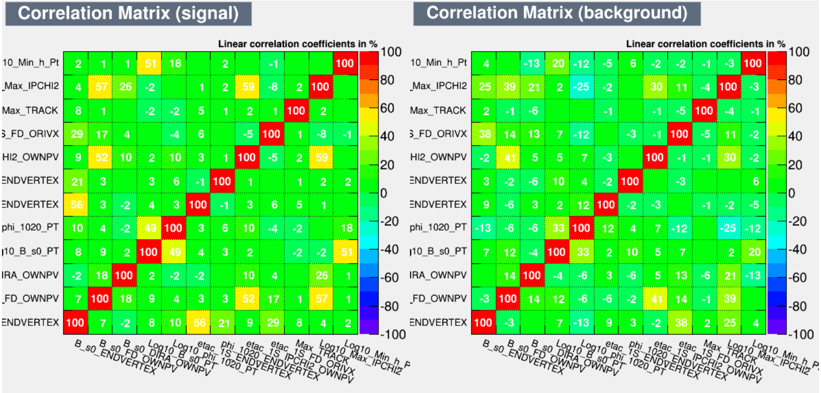
2011 4π case

Correlation matrix of BDT's variables



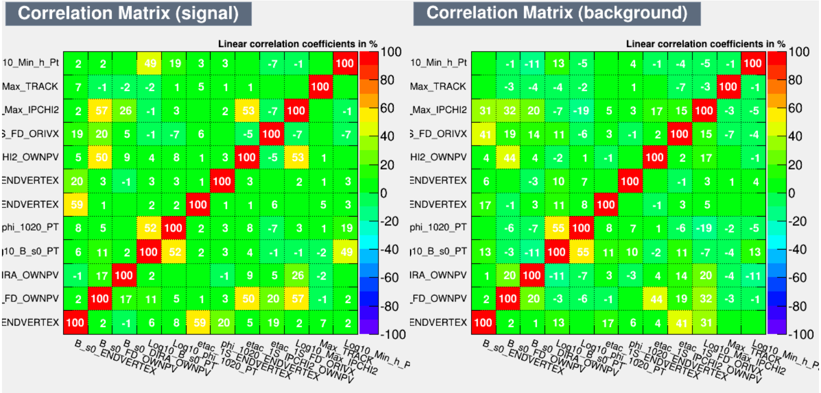
2012 2K2π case

Correlation matrix of BDT's variables



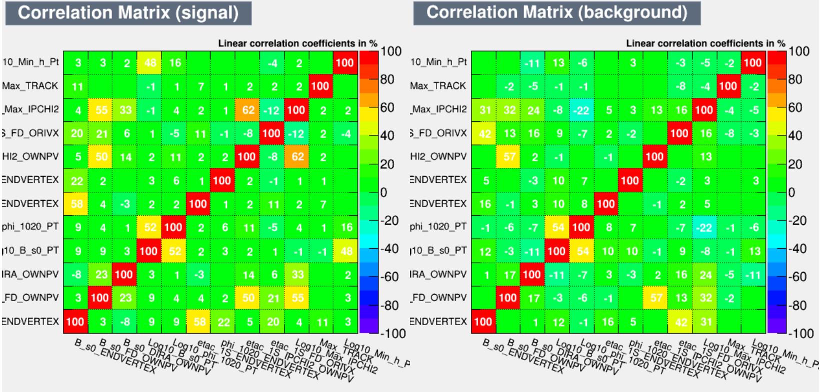
2011 2K2π case

Correlation matrix of BDT's variables



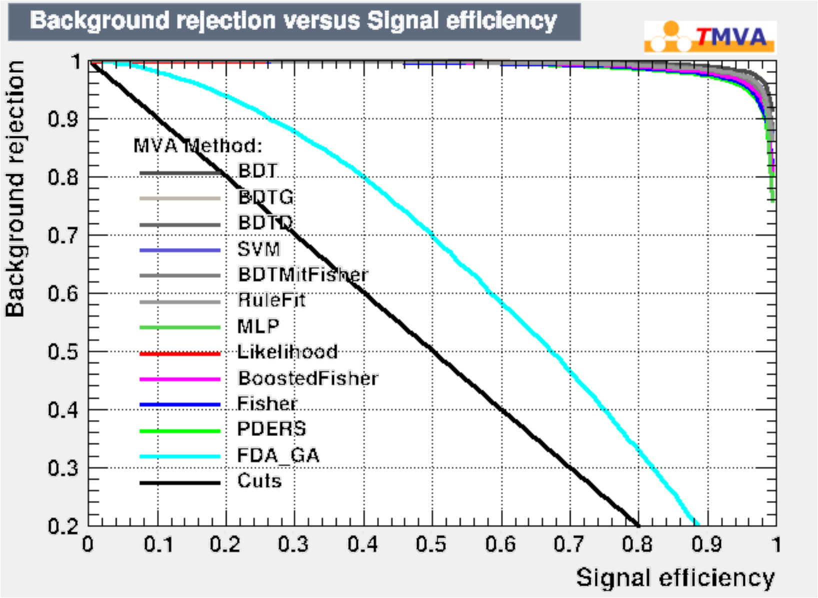
2012 4π case

Correlation matrix of BDT's variables



2011 4π case

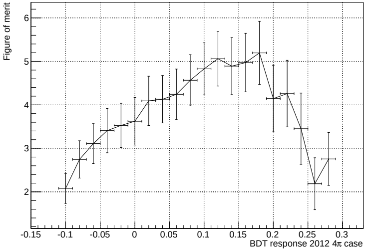
Background rejection for different method



BDT and PID output optimization

- The optimization is only to remove maximum of combinatorial background

- Procedure of optimization:
  FoM = $\frac{S}{\sqrt{S+B}}$, where
  $S \equiv$ Number of $B_s^0 \to 4h\phi$ event fitted (Gaussian)
  $B \equiv$ Number of combinatorial background fitted (Exponential)



1) BDT: Optimization of the FoM done separately for the year and the decay mode

2) ProbNN cut done with 2012 4π case:
   - K from ϕ: ProbNNk > 0.1 ; ProbNNpi < 0.7
   - π from η_c: ProbNNk < 0.6 ; ProbNNpi > 0.225
   - K from η_c: ProbNNk > 0.13 (Stripping line cut)

Stripping 21

Stripping 21, cut-based preselection (1/2)

- Efficiency of individual cut with MC:
  MC2012 Sim08e Signal decay $B_s^0 \to \eta_c\,(KK\pi\pi)\,\phi\,(KK)$

Variable	Cut		Efficiency (%)		
K^+ of η_c					
PT [MeV]	>	250.0	97.76	$\pm$	0.07
IPCHI2_OWNPV	>	4.0	88.09	$\pm$	0.15
ProbNNk	>	0.13	93.93	$\pm$	0.11
TRACK_CHI2NDOF	<	3.0	100	$\pm$	0.00
K^- of η_c					
PT [MeV]	>	250.0	97.79	$\pm$	0.07
IPCHI2_OWNPV	>	4.0	88.31	$\pm$	0.15
ProbNNk	>	0.13	93.91	$\pm$	0.11
TRACK_CHI2NDOF	<	3.0	100	$\pm$	0.00
π^+ of η_c					
PT [MeV]	>	250.0	94.34	$\pm$	0.11
IPCHI2_OWNPV	>	4.0	88.61	$\pm$	0.15
ProbNNpi	>	0.2	97.90	$\pm$	0.07
TRACK_CHI2NDOF	<	3.0	100	$\pm$	0.00
π^- of η_c					
PT [MeV]	>	250.0	94.40	$\pm$	0.11
IPCHI2_OWNPV	>	4.0	88.97	$\pm$	0.15
ProbNNpi	>	0.2	97.97	$\pm$	0.07
TRACK_CHI2NDOF	<	3.0	100	$\pm$	0.00
η_c					
ΣPT (K^+, K^-, π^+, π^-) [MeV]	>	2500.0	96.79	$\pm$	0.08
Σ IPCHI2_OWNPV (K^+, K^-, π^+, π^-)	>	30.0	93.03	$\pm$	0.12
IPCHI2_OWNPV	>	2.0	94.32	$\pm$	0.11
MM [MeV]	<	3071.0	96.13	$\pm$	0.09
MM [MeV]	>	2891.0	96.35	$\pm$	0.09
ENDVERTEX_CHI2/NDOF	<	9.0	99.70	$\pm$	0.03

Stripping 21, cut-based preselection (2/2)

- MC2012 Sim08e Signal decay $B_s^0 \to \eta_c\,(KK\pi\pi)\,\phi\,(KK)$

Variable	Cut		Efficiency (%)		
K^+ of ϕ					
PT	>	500.0	92.36	$\pm$	0.13
IPCHI2_OWNPV	>	4.0	91.35	$\pm$	0.13
PIDK	>	0.0	96.68	$\pm$	0.08
K^- of ϕ					
PT	>	500.0	92.20	$\pm$	0.13
IPCHI2_OWNPV	>	4.0	91.34	$\pm$	0.13
PIDK	>	0.0	96.73	$\pm$	0.08
ϕ					
PT [MeV]	>	800.0	95.53	$\pm$	0.10
DOCACHI2	<	30.0	99.96	$\pm$	0.01
IPCHI2_OWNPV	>	2.0	95.09	$\pm$	0.10
MM [MeV]	<	1049.455	96.48	$\pm$	0.09
MM [MeV]	>	989.455	100	$\pm$	0.00
ENDVERTEX_CHI2	<	9.0	95.81	$\pm$	0.09
B_s^0					
MM [MeV]	<	5866.77	100	$\pm$	0.00
MM [MeV]	>	4866.77	100	$\pm$	0.00
DIRA_OWNPV	>	0.99	98.13	$\pm$	0.06
ENDVERTEX_CHI2/NDOF	<	25.0	100	$\pm$	0.00
$B_s^0 \to \eta_c \phi$			37.07	$\pm$	0.23

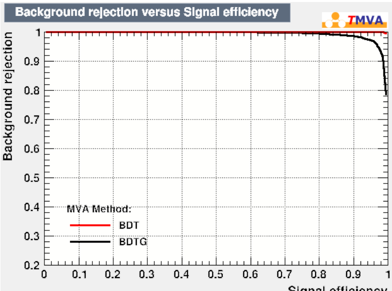
Stripping 21, final selection with BDT

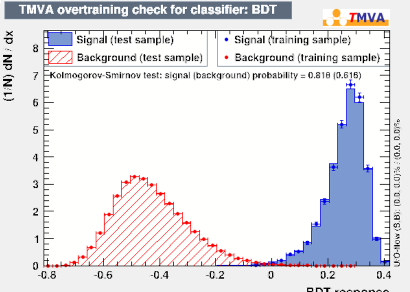
- BDT trained with:
  - Signal: MC 2012 TRUEID events
  - Background: real data 2012 Down BHADRONCOMPLEEVENT.DST
    $\rightarrow$Upper Side Band: invariante mass of 6 hadrons in [5800;6000] MeV

- List of variables used:
  - PT of all particles except of B_s^0
  - IPCHI2 of all particles
  - Decay time of B_s^0, and vertex fit as returned by the DTF with PV constraint
  - Direction angle (DIRA)

BDT works better than BDTG $\rightarrow$ BDT efficiency: 95.54% (BDT response > 0)

$$\varepsilon_{tot} = 37.07\% \times 95.54\% = 35.41\%$$

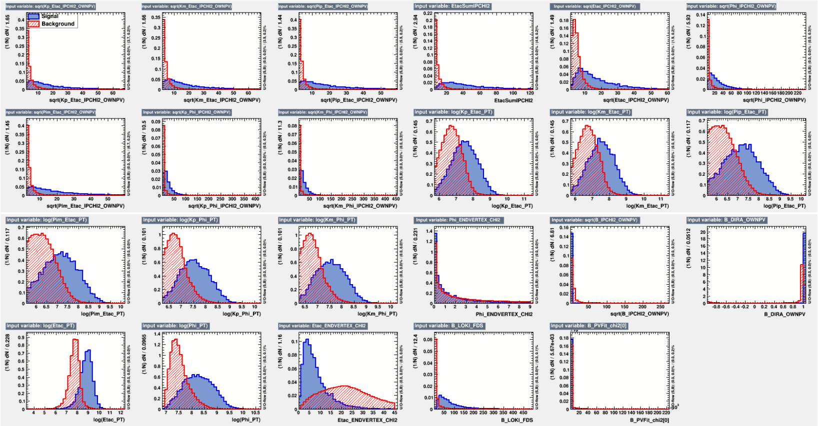




Variables ranked by the BDT (Stripping 21)

Rank	Variable	Importance
1	B_DIRA_OWNPV	8.549×10^{-2}
2	sqrt(B_IPCHI2_OWNPV)	8.206×10^{-2}
3	log(Etac_PT)	7.773×10^{-2}
4	log(Phi_PT)	6.085×10^{-2}
5	B_LOKI_FDS	5.679×10^{-2}
6	Etac_ENDVERTEX_CHI2	5.429×10^{-2}
7	EtacSumIPCHI2	4.604×10^{-2}
8	log(Km_Etac_PT)	4.441×10^{-2}
9	sqrt(Phi_IPCHI2_OWNPV)	4.369×10^{-2}
10	log(Kp_Phi_PT)	4.343×10^{-2}
11	Phi_ENDVERTEX_CHI2	4.256×10^{-2}
12	log(Pim_Etac_PT)	4.208×10^{-2}
13	log(Kp_Etac_PT)	4.150×10^{-2}
14	log(Km_Phi_PT)	4.060×10^{-2}
15	log(Pip_Etac_PT)	3.722×10^{-2}
16	sqrt(Pip_Etac_IPCHI2_OWNPV)	3.354×10^{-2}
17	sqrt(Pim_Etac_IPCHI2_OWNPV)	3.332×10^{-2}
18	sqrt(Kp_Phi_IPCHI2_OWNPV)	3.070×10^{-2}
19	sqrt(Etac_IPCHI2_OWNPV)	2.942×10^{-2}
20	sqrt(Km_Phi_IPCHI2_OWNPV)	2.634×10^{-2}
21	sqrt(Kp_Etac_IPCHI2_OWNPV)	2.541×10^{-2}
22	sqrt(Km_Etac_IPCHI2_OWNPV)	1.419×10^{-2}
23	B_PVFit_chi2	8.331×10^{-3}

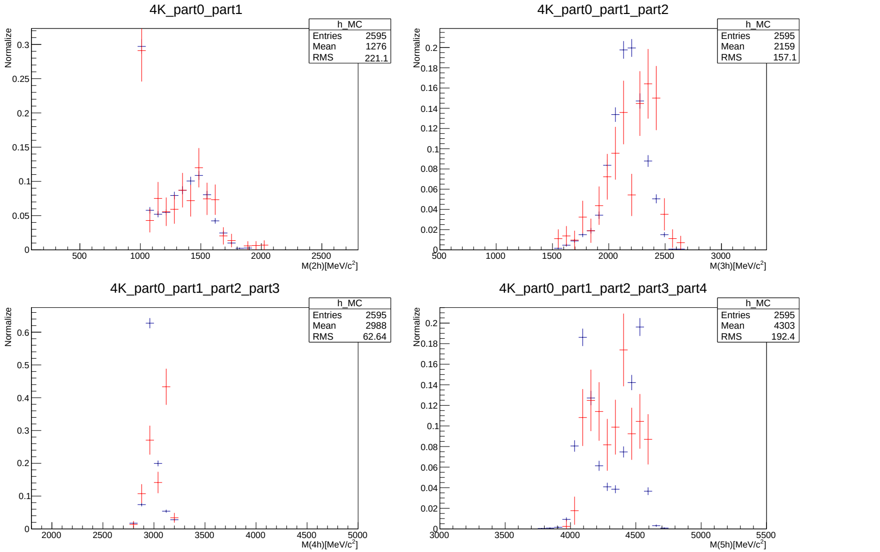
Distributions of the variables included in the BDT



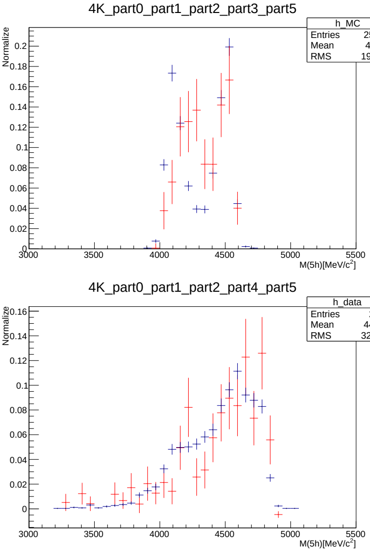
m$_{nh}$ histogram

- MC Sim08e with Stripping 21 line and final selection: $B_s^0 \to \eta_c(4h)\phi(KK)$ (blue)
- Real data Stripping 21(r1) BHADRON.MDST StrippingBs2EtacPhiBDTLine and final selection (red)

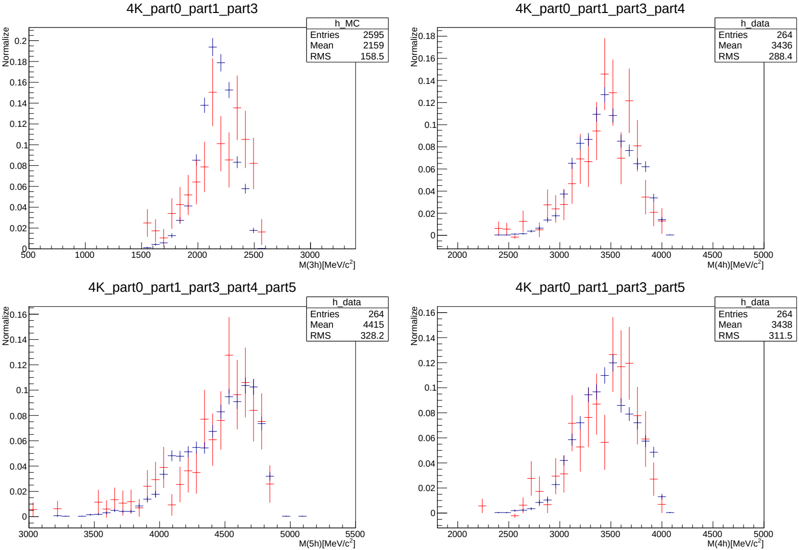
m_{nh}: Data versus MC



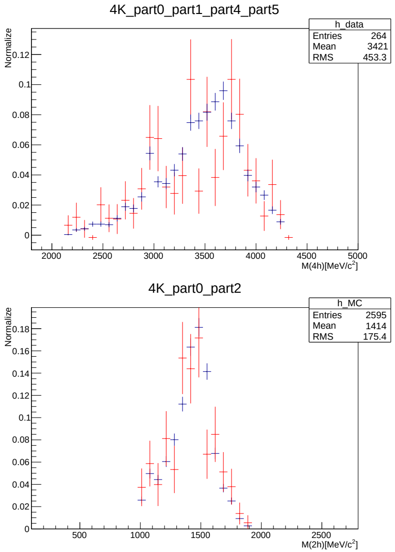
m_{nh}: Data versus MC



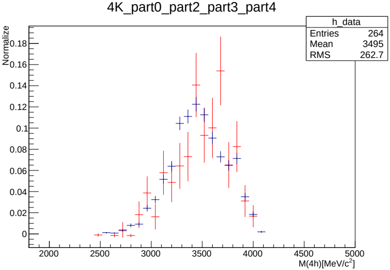
m_{nh}: Data versus MC

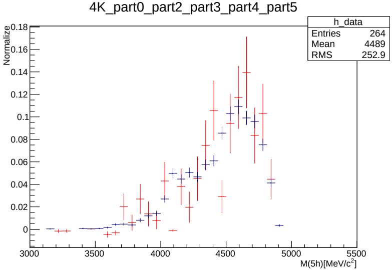


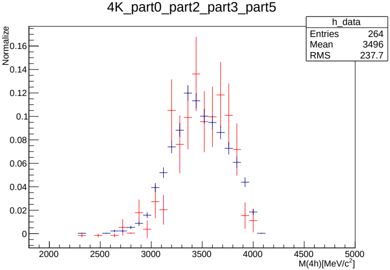
m_{nh}: Data versus MC

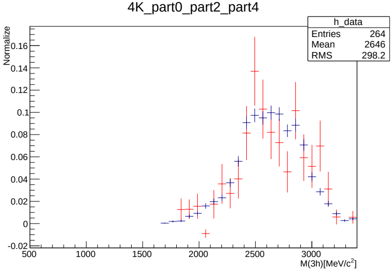


m_{nh}: Data versus MC

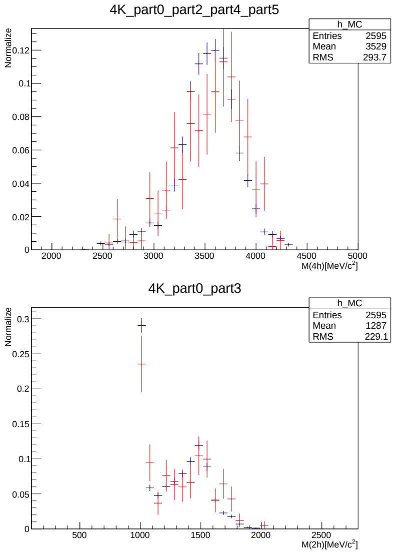




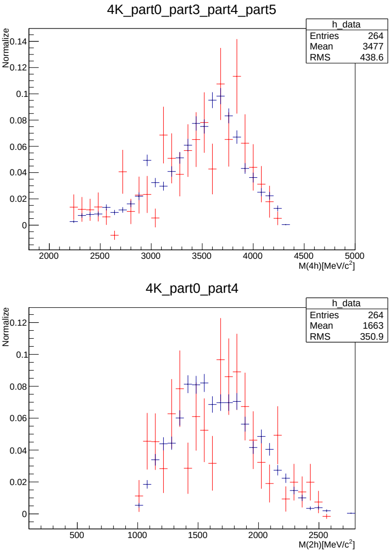




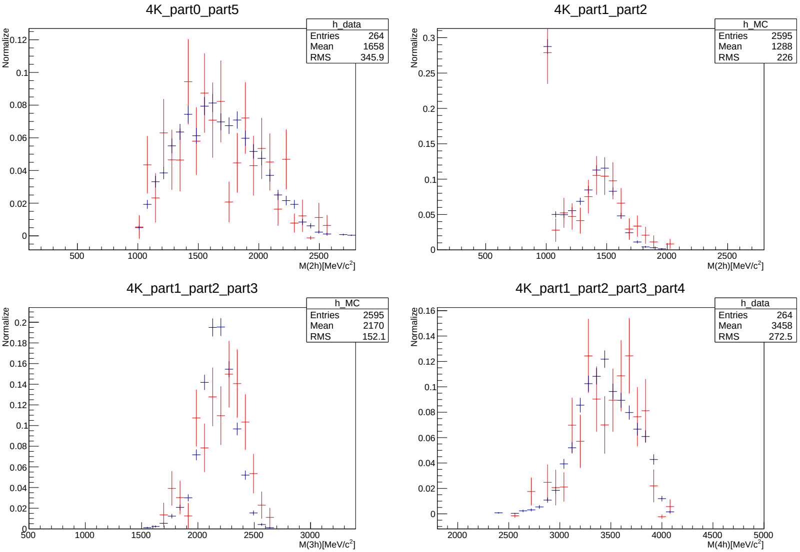
m_{nh}: Data versus MC



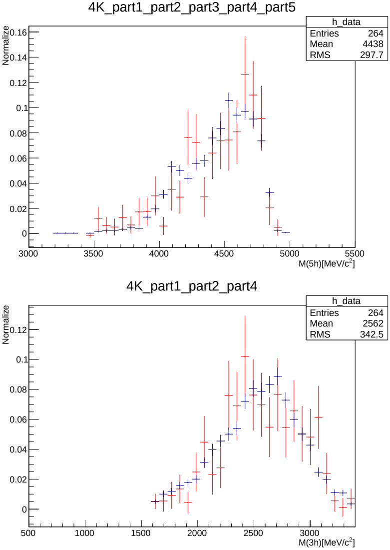
m_{nh}: Data versus MC



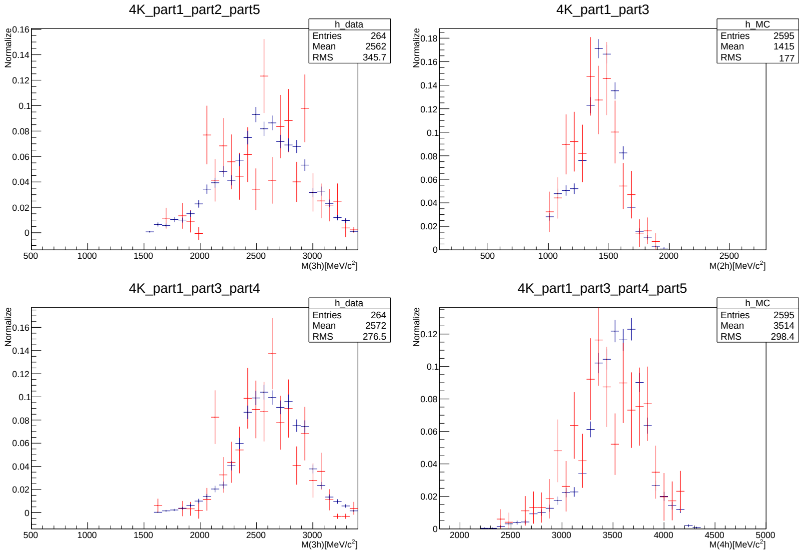
m_{nh}: Data versus MC



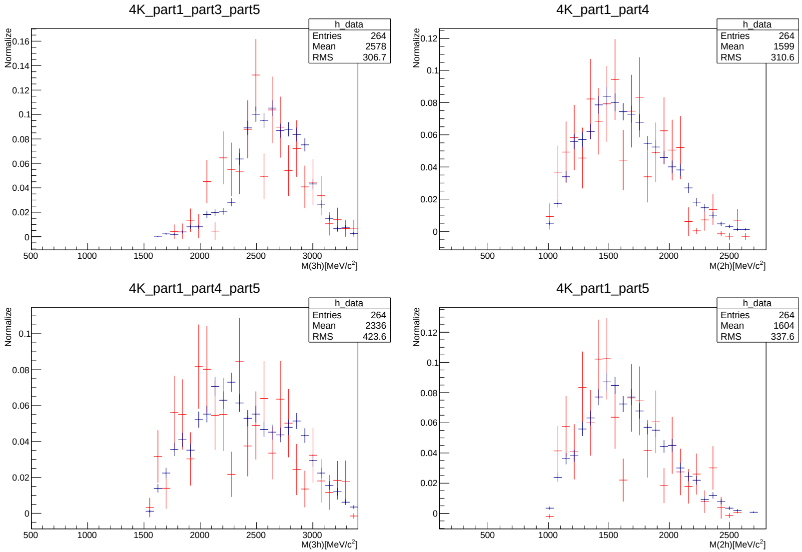
m_{nh}: Data versus MC



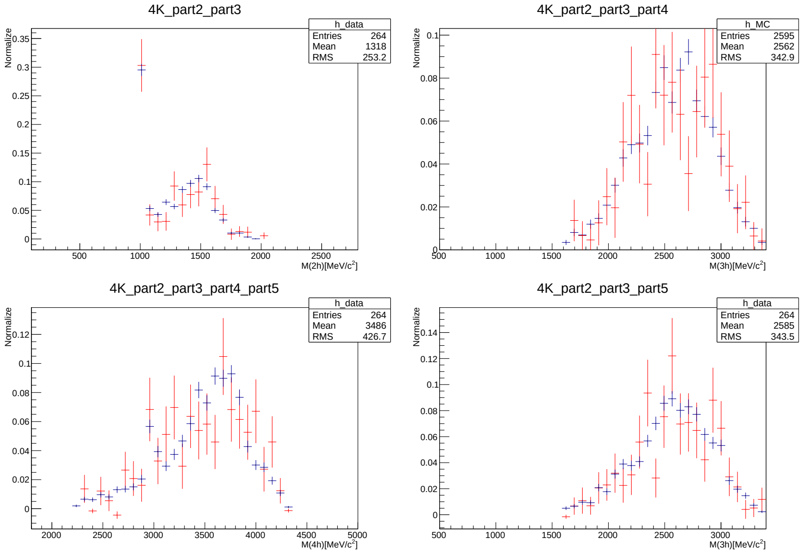
m_{nh}: Data versus MC



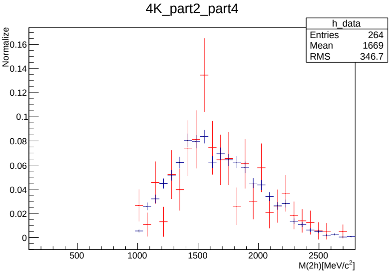
m_{nh}: Data versus MC

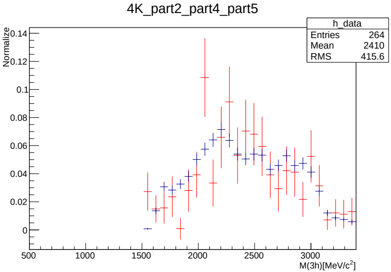


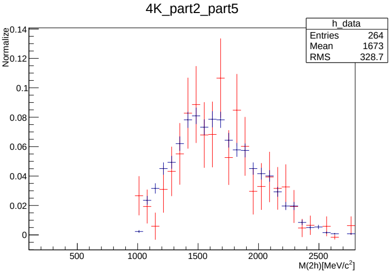
m_{nh}: Data versus MC

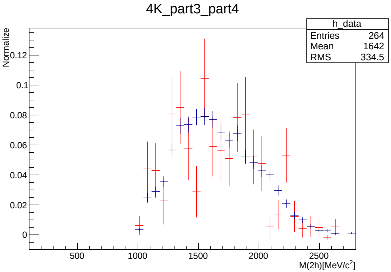


m_{nh}: Data versus MC

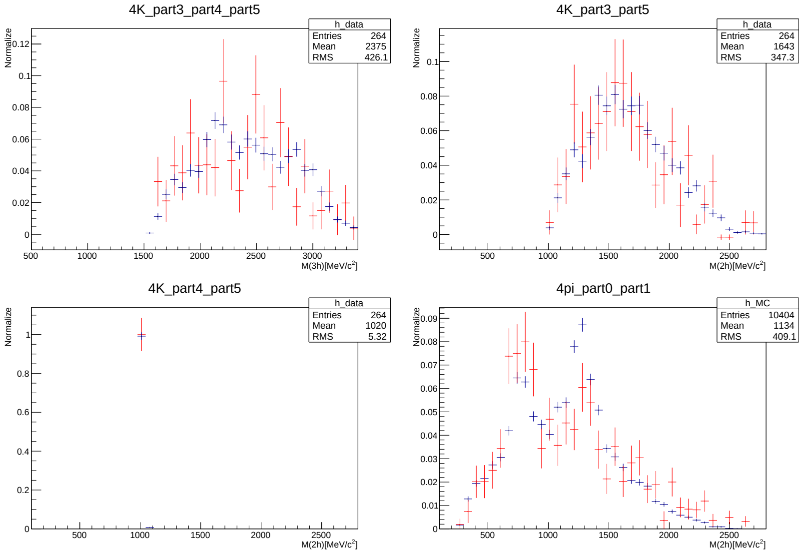








m_{nh}: Data versus MC



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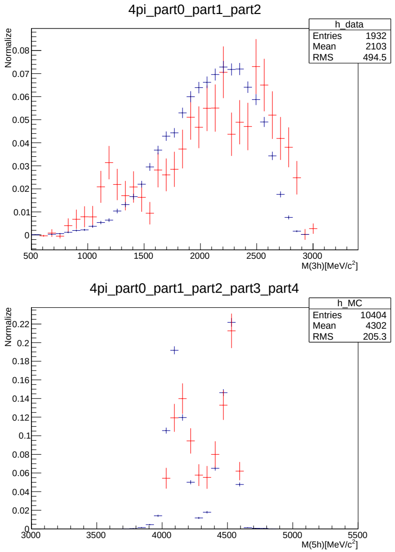
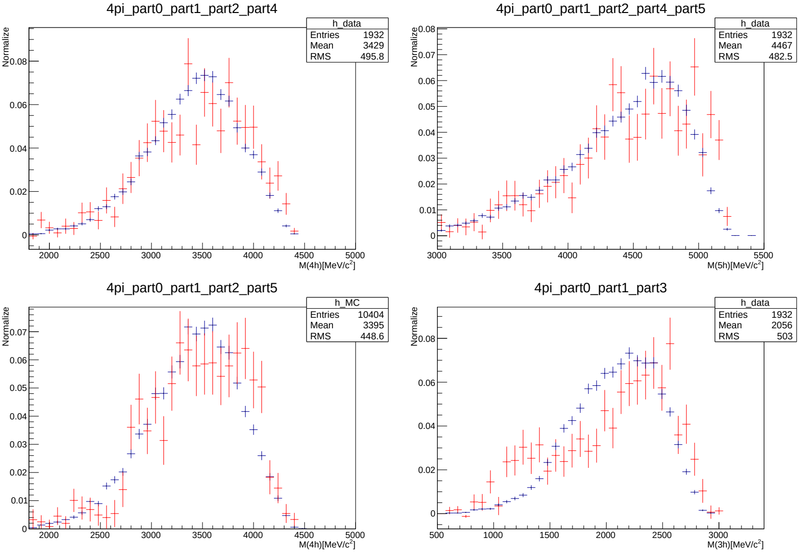
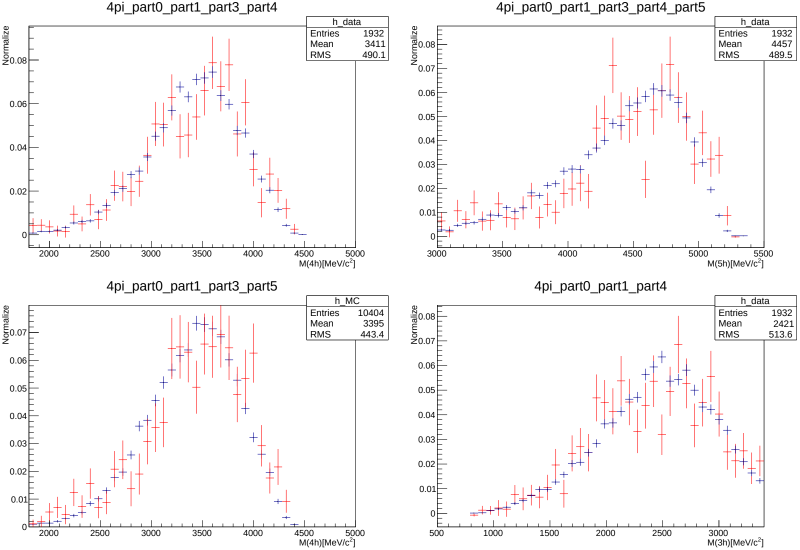


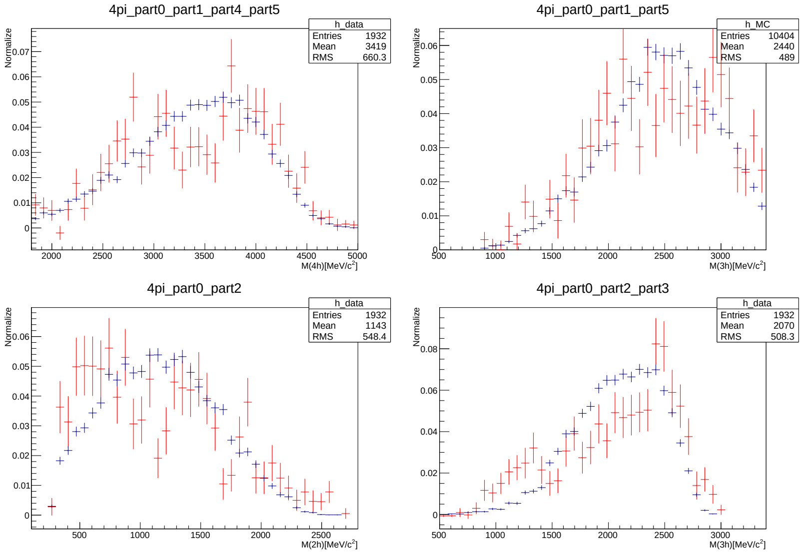
m_{nh}: Data versus MC



m_{nh}: Data versus MC



m_{nh}: Data versus MC



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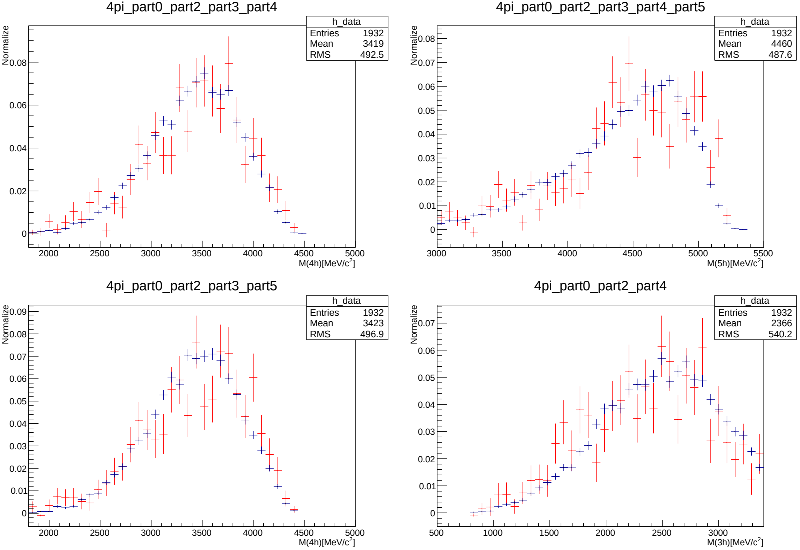
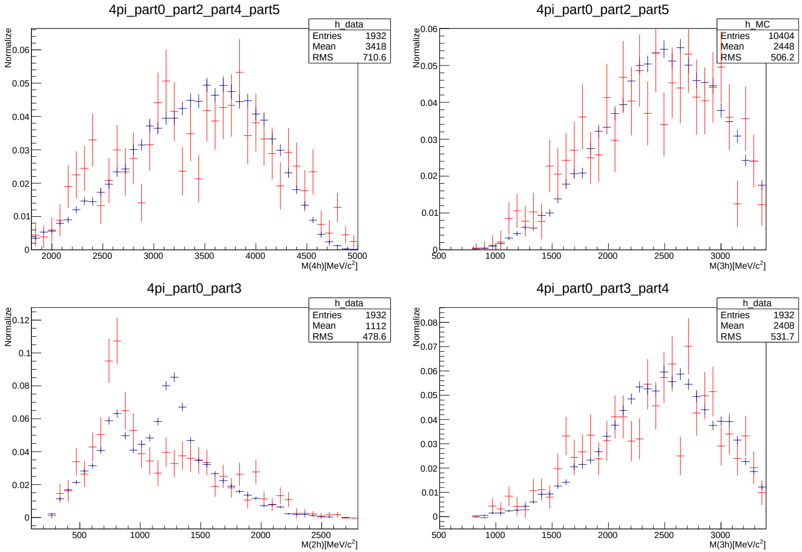
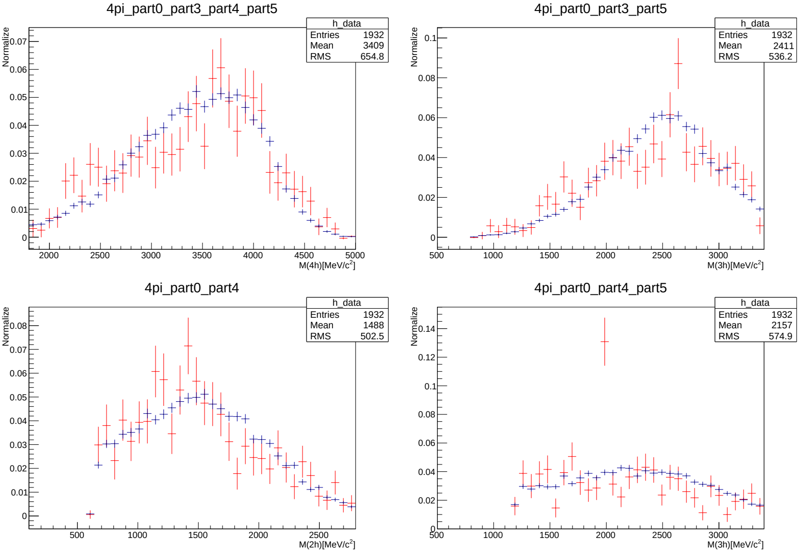


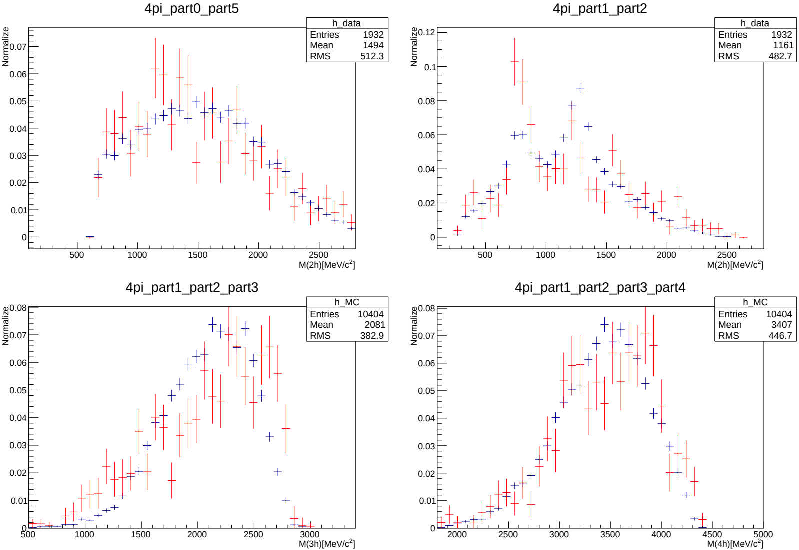
m_{nh}: Data versus MC



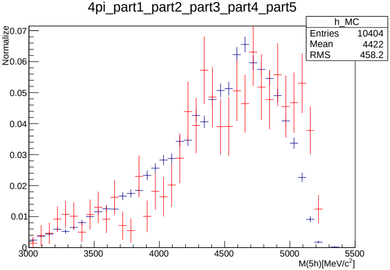
m_{nh}: Data versus MC

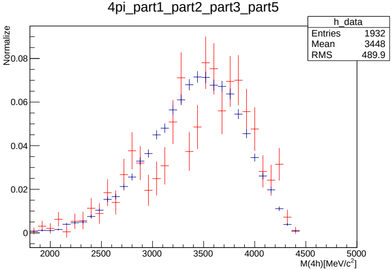


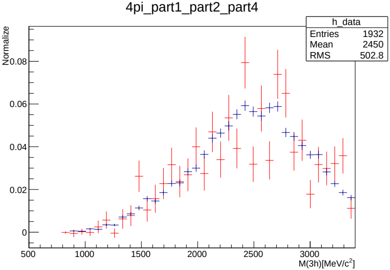
m_{nh}: Data versus MC

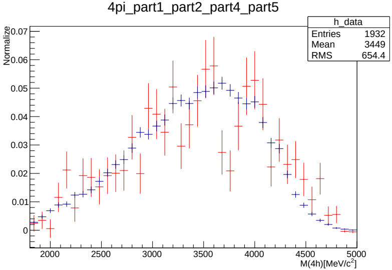


m_{nh}: Data versus MC

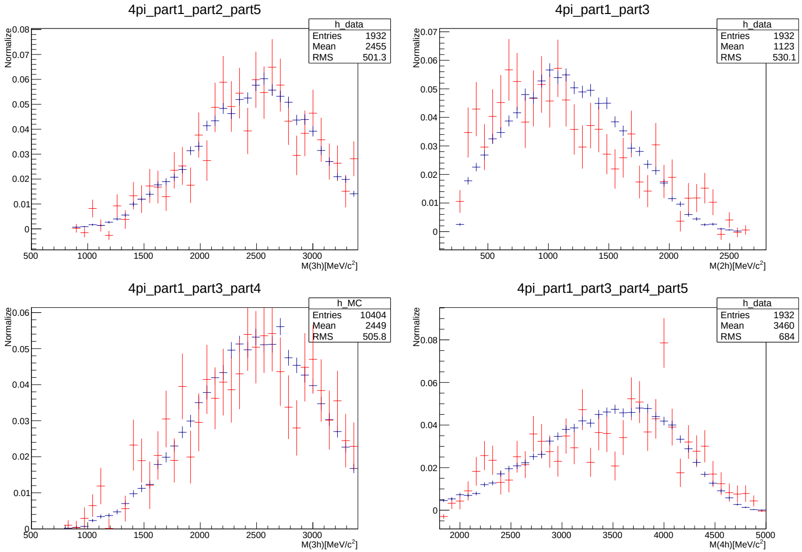




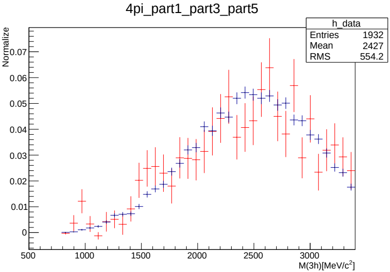


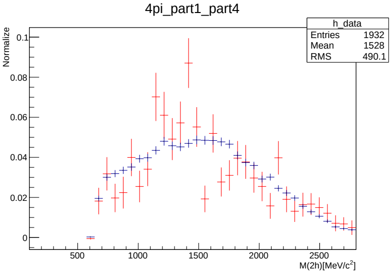


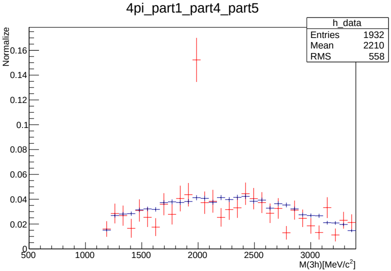
m_{nh}: Data versus MC



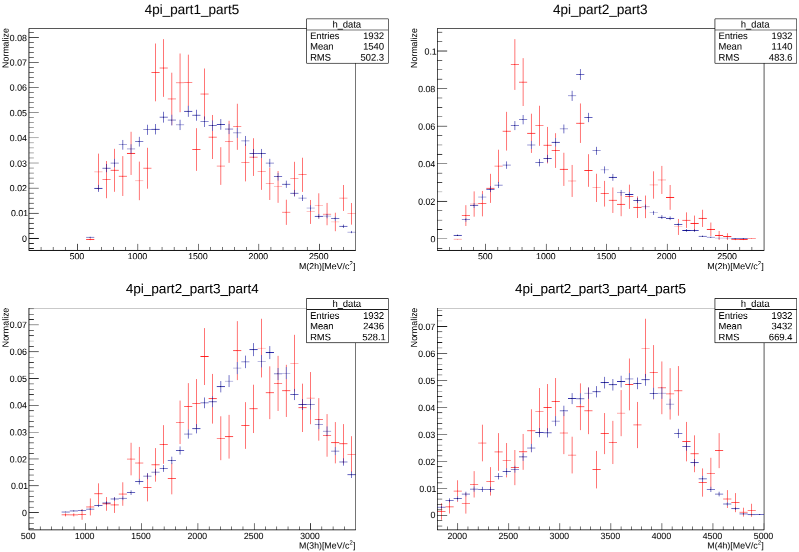
m_{nh}: Data versus MC



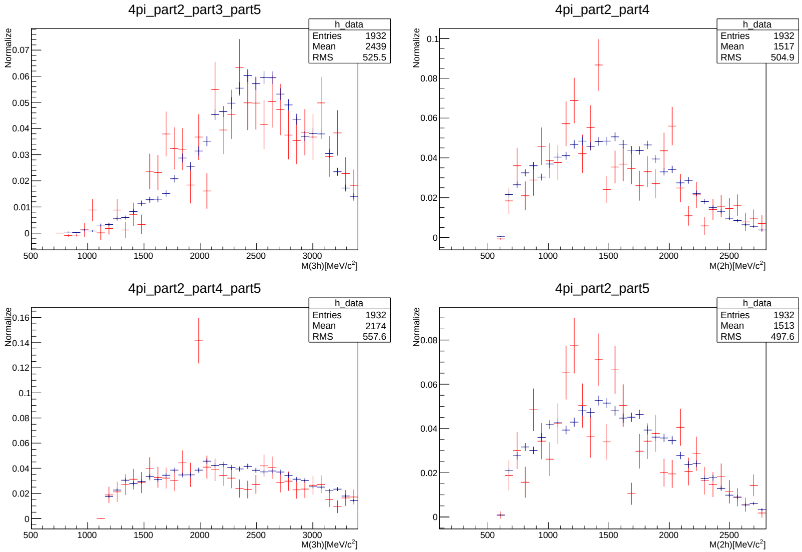




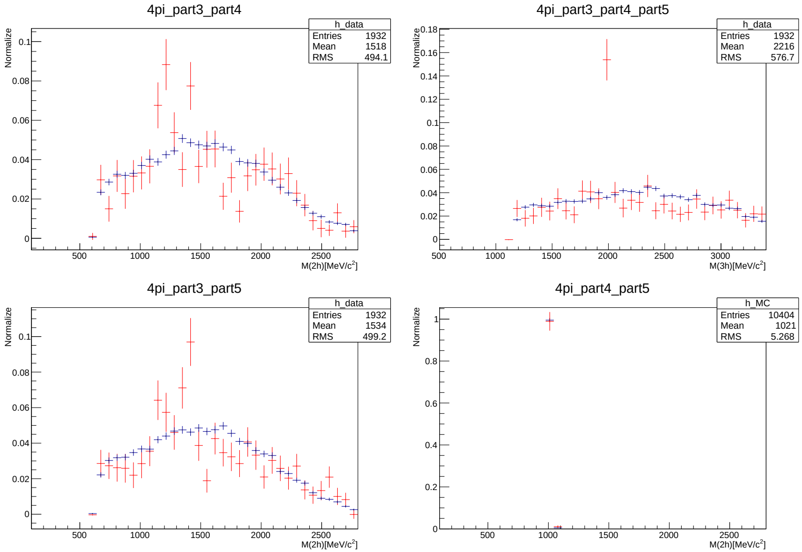
m_{nh}: Data versus MC



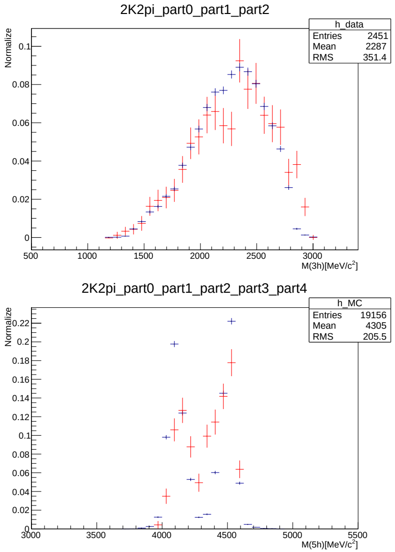
m_{nh}: Data versus MC



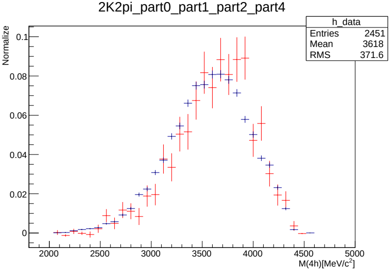
m_{nh}: Data versus MC

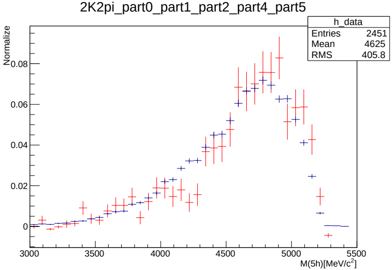


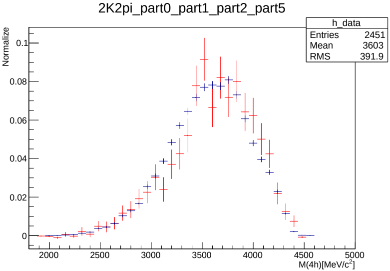
m_{nh}: Data versus MC

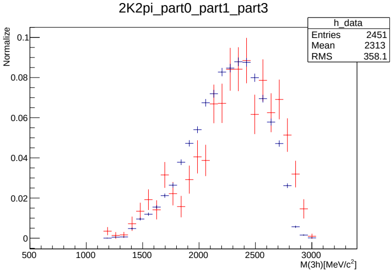


m_{nh}: Data versus MC

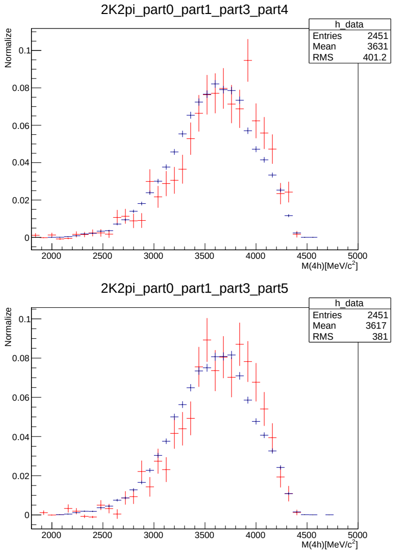




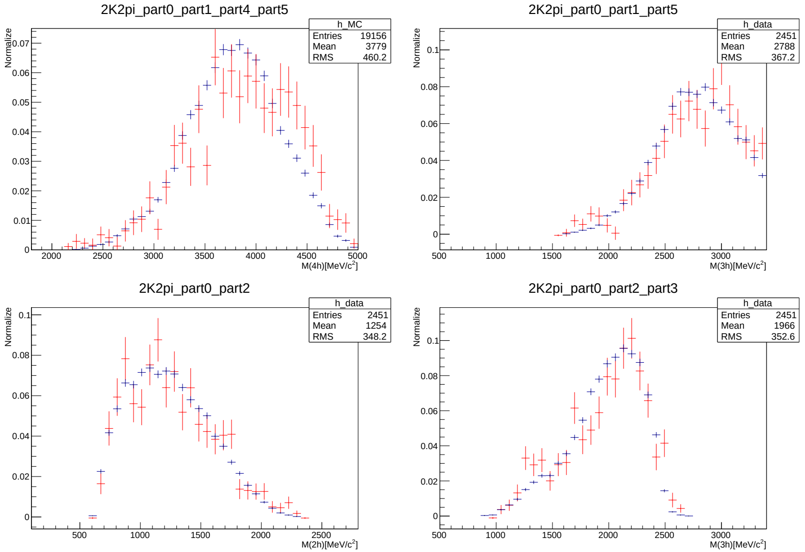




m_{nh}: Data versus MC



m_{nh}: Data versus MC



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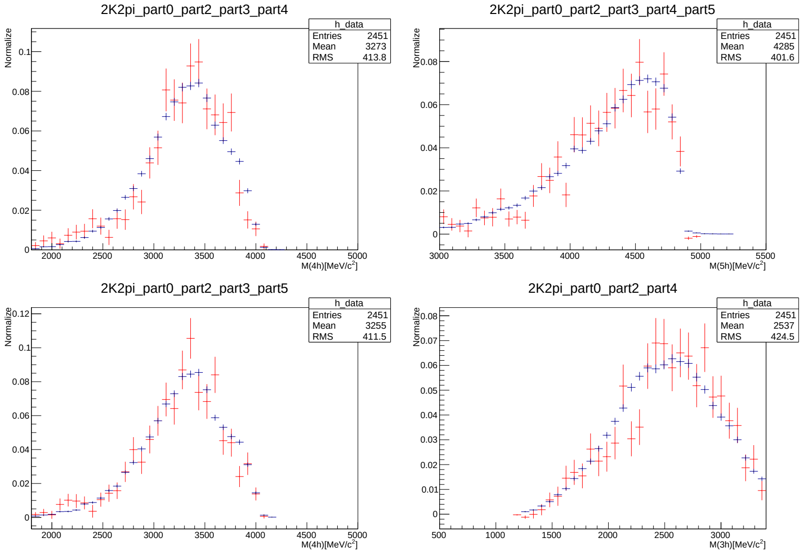

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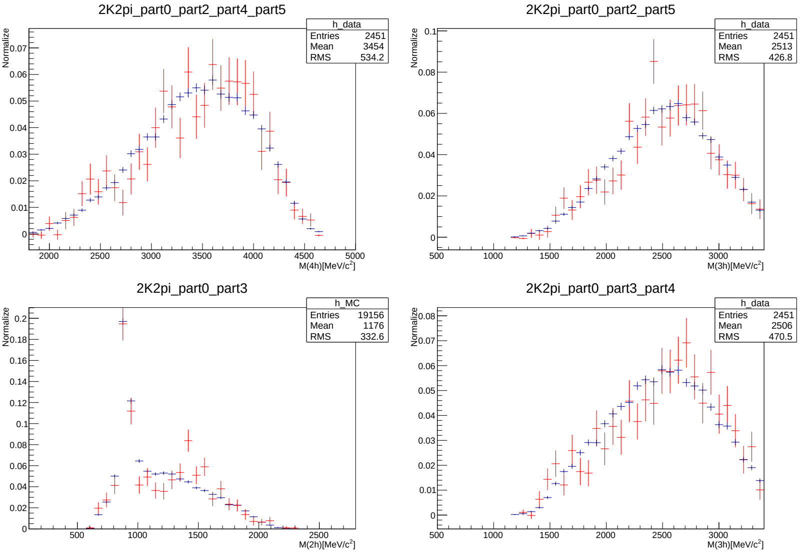

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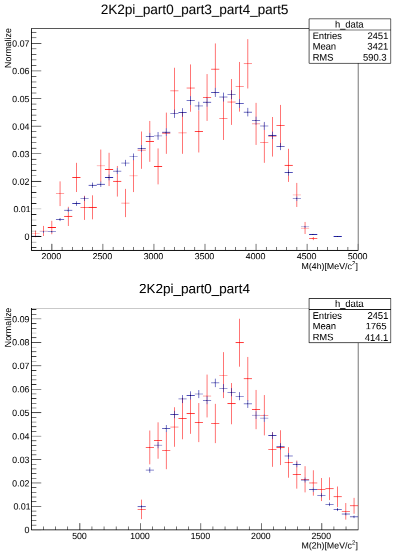

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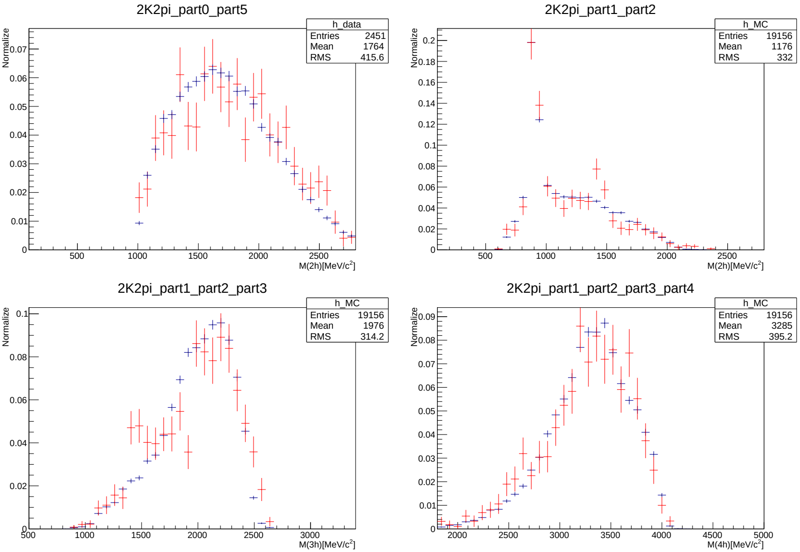

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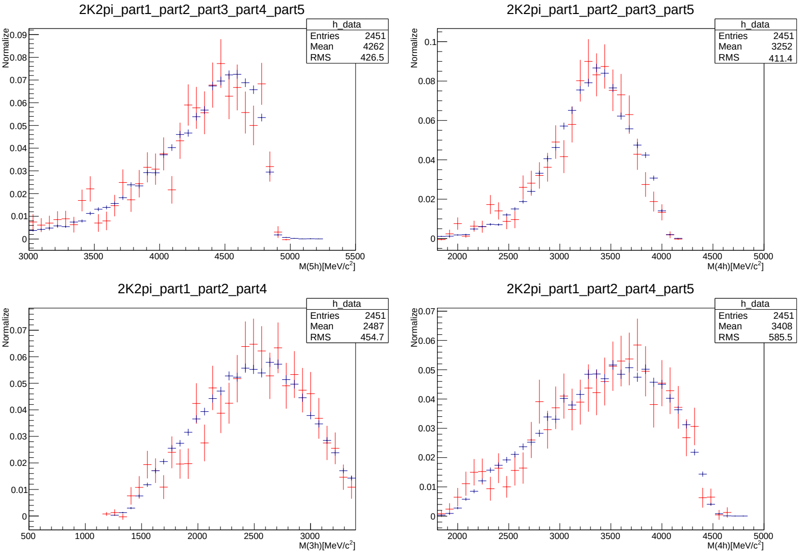
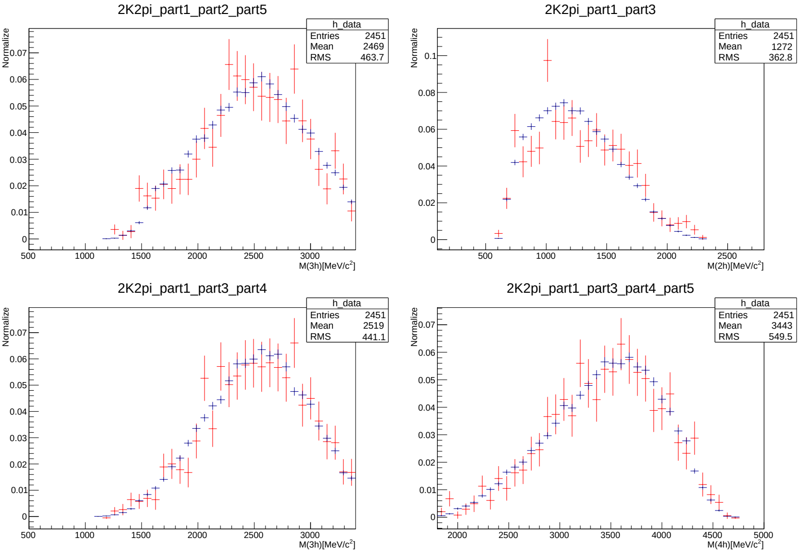


m_{nh}: Data versus MC



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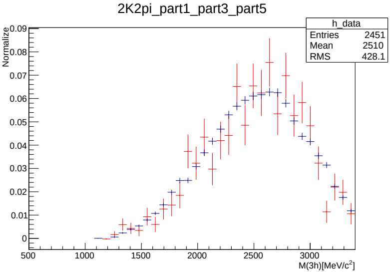
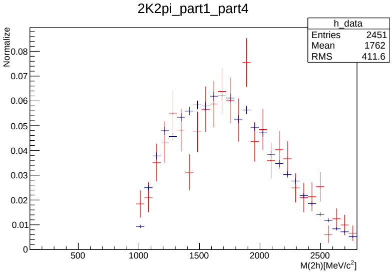
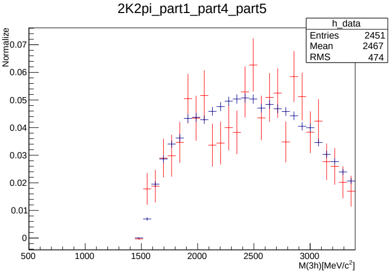
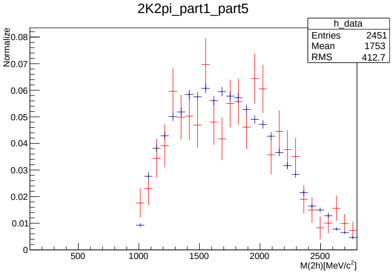
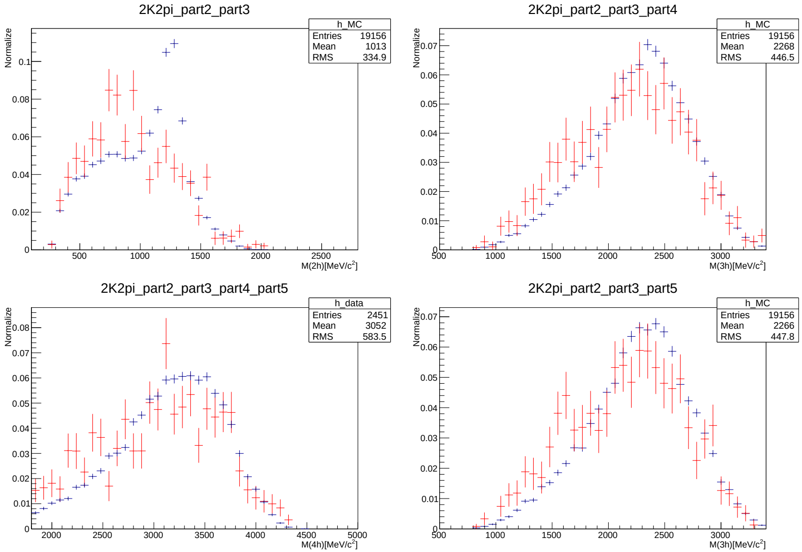




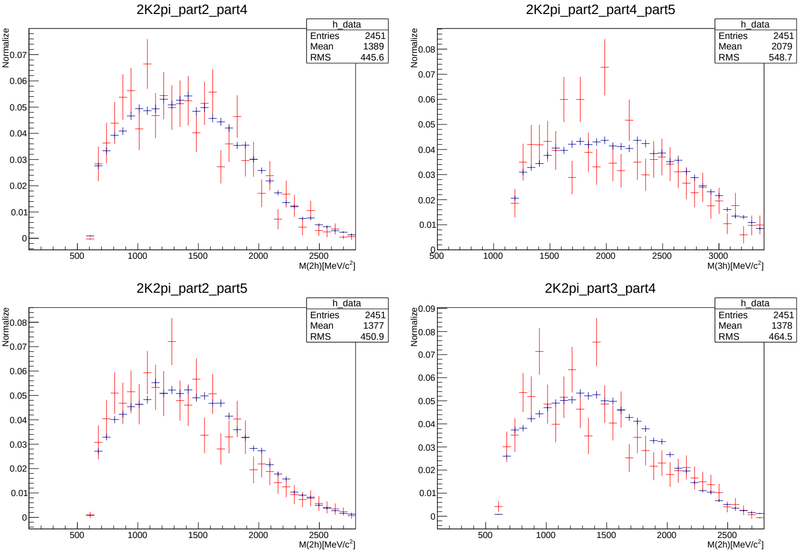




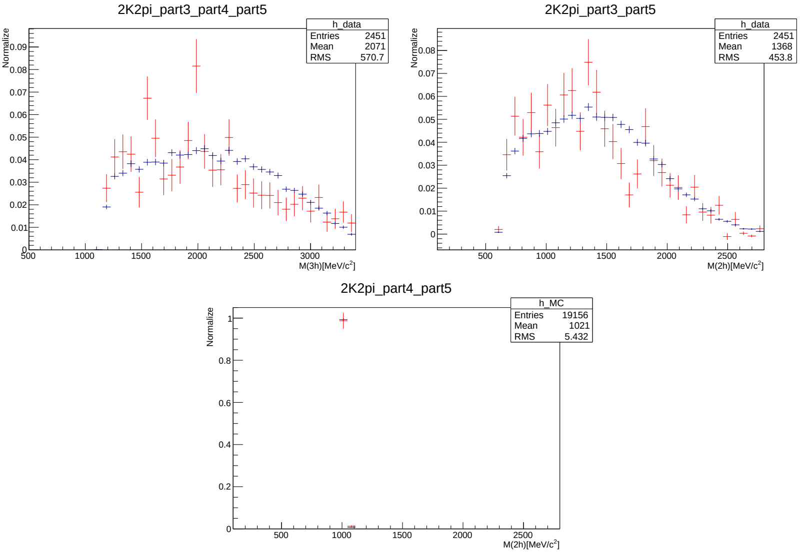
m_{nh}: Data versus MC



m_{nh}: Data versus MC



m_{nh}: Data versus MC



Fit result

Fit 3D result: shape parameters

```
**********
**   18 **HESSE    1.55e+04
**********
COVARIANCE MATRIX CALCULATED SUCCESSFULLY
FCN=26369.8 FROM HESSE     STATUS=OK          592 CALLS        1624 TOTAL
                    EDM=0.000280878    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                INTERNAL      INTERNAL
 NO.   NAME      VALUE            ERROR       STEP SIZE       VALUE
  1  Bs_kNR_4h    4.45032e-04   5.08227e-04   1.92524e-06   4.45032e-04
  2  EtacMean     2.98242e+03   2.02580e+00   4.51499e-04   1.21065e-01
  3  PhiMean      1.01987e+03   7.49549e-02   8.29745e-05  -6.57696e-03
  4  Resolution_2h_Phi   1.01830e+00   1.44557e-01   1.43643e-04  -1.11559e+00
  5  Resolution_4h_Etac   9.56109e+00   3.38626e+00   1.50498e-03  -9.89937e-02
  6  ipa_m        5.28666e+03   3.03718e+00   2.97948e-03   9.83070e-01
  7  ipa_m_jpsi   3.09977e+03   7.71660e-01   8.31897e-04   5.86949e-01
  8  ipa_ms       5.37021e+03   4.48713e-01   5.23731e-04   6.96243e-01
  9  ipa_s_jpsi   1.16669e+01   9.83529e-01   1.07406e-03   4.76957e-02
 10  ipa_ss       1.58120e+01   4.98654e-01   4.05794e-04   1.63116e-01
 11  kCombi_4hPhi  -7.97820e-03   5.63442e-04   1.08512e-06  -7.97820e-04
 12  kCombi_4h_KK   2.01685e-03   5.98946e-04   1.20985e-05   2.01685e-03
 13  kCombi_4h_Phi   9.12797e-04   4.12646e-04   8.29276e-06   9.12797e-04
 14  kCombi_6h   -6.51162e-03   7.13198e-04   1.43842e-06  -6.51162e-04
 15  kSWaves_2h   -2.43473e-04   1.89154e-02   3.21894e-05  -2.43473e-05
 16  kSWaves_2h_Combi   1.85808e-02   3.07654e-03   1.25897e-06   1.85808e-03
 17  kSWaves_2h_NR   6.41926e-03   7.04879e-03   1.29737e-05   6.41926e-04
 18  nBd2EtacKK   2.75709e-07   1.98394e+01   2.67593e-02  -1.57099e+00
                                WARNING -   - ABOVE PARAMETER IS AT LIMIT.
 19  nBd2EtacPhi   4.89550e+00   1.66666e+01   4.69704e-03  -7.39114e-01
 20  nBd2JpsiKK   1.40874e+01   8.81089e+00   2.46863e-03  -6.08806e-02
 21  nBd2JpsiPhi   2.79219e-07   1.97273e+01   2.65676e-02  -1.57099e+00
                                WARNING -   - ABOVE PARAMETER IS AT LIMIT.
 22  nBd2NRKK     5.36808e+01   2.26201e+01   1.65632e-03   7.36826e-02
 23  nBd2NRPhi    8.60906e+01   3.43597e+01   5.01615e-03  -1.39546e-01
 24  nBs2EtacKK   3.61269e+01   2.09088e+01   9.84860e-04  -6.92847e-01
 25  nBs2EtacPhi   3.56710e+02   3.69032e+01   4.22998e-04   1.90179e-01
 26  nBs2JpsiKK   1.16035e+01   1.51020e+01   1.65887e-03  -8.75602e-01
 27  nBs2JpsiPhi   3.63616e+02   2.92794e+01   3.58434e-04   2.13675e-01
 28  nBs2NRKK     1.95326e+02   3.55106e+01   4.73068e-04  -2.20476e-01
 29  nBs2NRPhi    6.14300e+02   5.53814e+01   3.43670e-04   2.30640e-01
 30  nCombiKK     6.60799e+02   4.70448e+01   3.41370e-04   3.27417e-01
 31  nCombiPhi    1.13375e+03   5.97768e+01   2.97169e-04   5.37123e-01
```

2D Fit result: shape parameters

```
COVARIANCE MATRIX CALCULATED SUCCESSFULLY
FCN=5981.3 FROM HESSE     STATUS=OK          166 CALLS         941 TOTAL
                 EDM=3.66594e-05    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                INTERNAL      INTERNAL
 NO.   NAME      VALUE            ERROR       STEP SIZE       VALUE
  1  PhiMean      1.01987e+03   7.49817e-02   7.90800e-06  -6.53456e-03
  2  Resolution_2h_Phi   1.01398e+00   1.44654e-01   6.85736e-05  -1.11657e+00
  3  ipa_m       5.28478e+03   2.88298e+00   7.32257e-04   6.40396e-01
  4  ipa_ms      5.37016e+03   4.58667e-01   2.52379e-04   6.83143e-01
  5  ipa_ss      1.62201e+01   5.32643e-01   2.06191e-04   2.46515e-01
  6  kCombi_4hPhi  -8.16386e-03   5.96615e-04   1.07733e-07  -8.16387e-04
  7  kCombi_6h   -6.54176e-03   7.18643e-04   1.37600e-07  -6.54176e-04
  8  kSWaves_2h   5.85377e-03   5.27589e-03   5.08088e-06   5.85377e-04
  9  kSWaves_2h_Combi   1.82499e-02   3.05348e-03   5.99096e-07   1.82500e-03
 10  nBdKK       6.44114e+01   2.41515e+01   4.34404e-04  -3.63862e-01
 11  nBdPhi      1.07427e+02   2.96334e+01   2.35664e-04  -6.06861e-01
 12  nBsKK       2.47782e+02   3.21815e+01   2.31978e-04  -8.87079e-03
 13  nBsPhi      1.35466e+03   5.01202e+01   6.05650e-05  -9.70473e-02
 14  nCombiKK     6.62604e+02   4.77496e+01   1.63388e-04   3.31232e-01
 15  nCombiPhi    1.09412e+03   5.94849e+01   1.36533e-04   4.76677e-01
```

sFit result: shape parameters

```
FCN=-815.139 FROM MIGRAD    STATUS=CONVERGED     111 CALLS         437 TOTAL
                     EDM=3.37148e-07    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME       VALUE            ERROR          SIZE      DERIVATIVE
  1  Bs_kNR_4h    3.57690e-04   4.85025e-04   8.68871e-06   5.31541e-01
  2  EtacMean     2.98374e+03   1.93867e+00   1.92021e-03  -1.04733e-03
  3  Resolution_4h_Etac   9.98833e+00   3.28558e+00   6.41213e-03  -9.02455e-05
  4  ipa_m_jpsi   3.09946e+03   6.74731e-01   3.06389e-03   4.78979e-04
  5  ipa_s_jpsi   1.10558e+01   8.47293e-01   4.21921e-03  -7.06240e-04
  6  nBs2EtacPhi   3.59376e+02   3.07600e+01   3.33422e-05   1.96271e-02
  7  nBs2JpsiPhi   3.66558e+02   2.53460e+01   2.89690e-05  -1.88946e-01
  8  nBs2NRPhi    6.28713e+02   4.15479e+01   2.44196e-05  -2.51269e-01
```