Something

Stefano Lacaprara

stefano.lacaprara@pd.infn.it

INFN Padova

some meeting,
somewhere, sometime

Outline

1. AOD vs MiniAOD (Paolo)
2. B-mixing in $t\bar{t}$ events (Martino *et al.)*
3. P_5' measurement in $\mathrm{B}^0 \to \mathrm{K}^{*0}\mu^+\mu^-$ (Stefano Alessio)

AOD vs MiniAOD (Paolo)

Issue

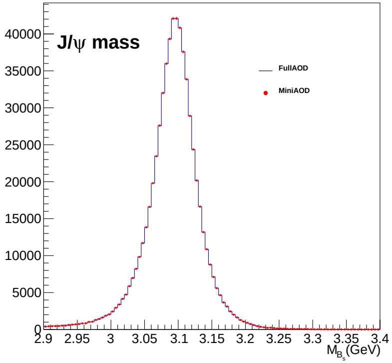
- AOD production and storage probably discontinued in 2017:
- MiniAOD only choice left?
- Any difference between AOD and MiniAOD for B reconstruction and analysis?
- $B_S^0 \to \mathrm{J}/\psi\phi$, $\mathrm{J}/\psi \to \mu^-\mu^+$, $\phi \to \mathrm{K}^+\mathrm{K}^-$
- Comparing same dataset 1 M events, same reconstruction, from AOD and from MiniAOD `BsToJpsiPhi_BMuonFilter_TuneCUEP8M1_13TeV-pythia8-evtgen`
- A newer version of MiniAOD already available but not yet used

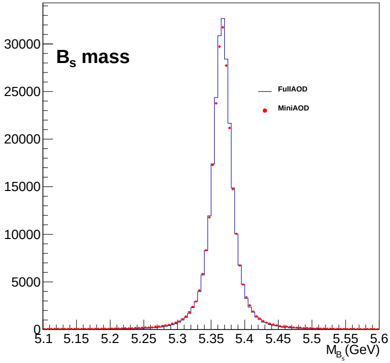
- $p_{T,\mu} > 3.0$ GeV
- $p_{T,K} > 0.7$ GeV
- $2.8\ \mathrm{GeV} < m_{J/\psi} < 3.4\ \mathrm{GeV}$
- $1.005\ \mathrm{GeV} < m_K < 1.035\ \mathrm{GeV}$
- $P(\chi^2_{\mathrm{vtx}}) > 0.02$

B_s^0 mass reconstructed with J/ψ mass constraint

Invariant masses distributions

	SIM	AOD	AOD&MiniAOD
J/ψ	1018280	662731	662731
B_s^0	528069	297150	255448

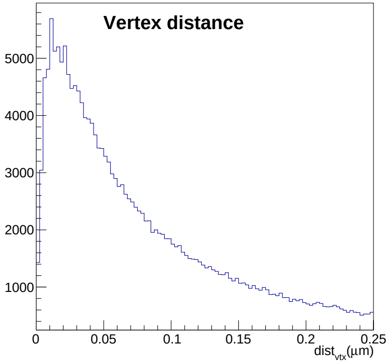


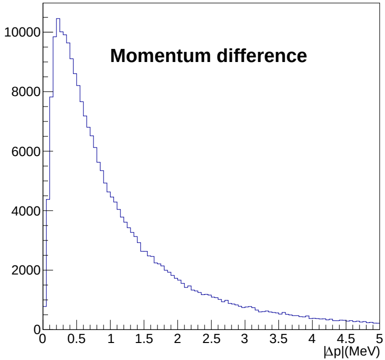


Event-by-event comparison

Compare each B_s^0 reconstructed in AOD with the same reconstructed in MiniAOD:

- compute vertex distance (3D)
- compute modulus of 3-momentum difference (sum of momenta extrapolated to vertex)



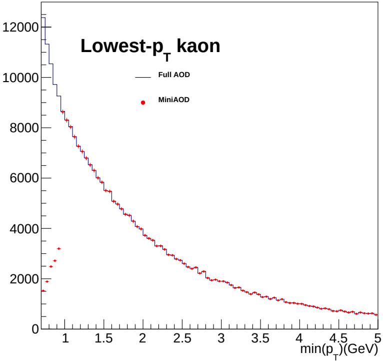


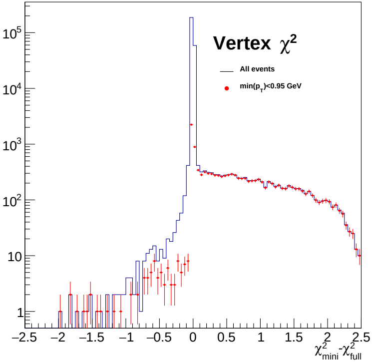
Dependence on p_T

Tracking information in MiniAOD:

- tracks with $p_T > 0.95$ GeV: momentum from PF candidates, approximate covariance matrix
- tracks from Inclusive Vertex Finder ("whitelist", no p_T cut: other tracks can be added)

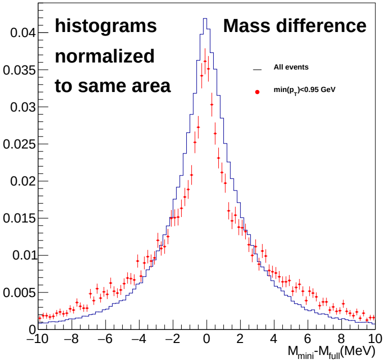
Efficiency difference concentrated at low-p_T





Mass comparison

Event-by-event mass difference



Update on B-mixing in tt events

Martino Margoni
9/3/2017

- Motivation

- Analysis Strategy:
  - Event Reconstruction
  - B flavor tagging at the production

- Caveats:
  - Work from Paolo (selection optimization) and Alessio (separation of b $\rightarrow$ l vs b $\rightarrow$ c $\rightarrow$ l) still to be included
  - Only Run 1 MC analyzed

- **Analysis will be performed on Run 2**

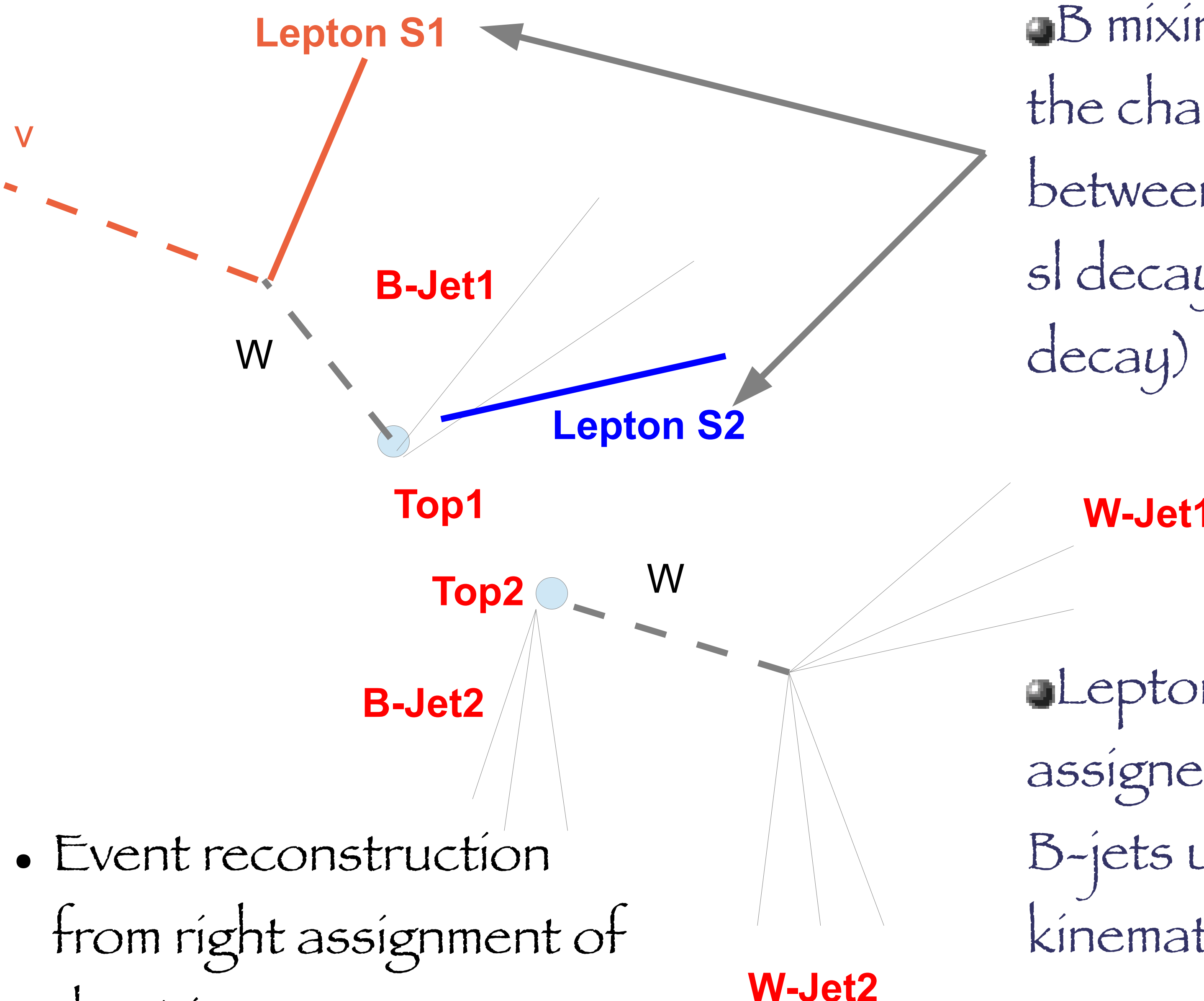
Motivation

- Semileptonic top decays $t\bar{t}$, $t \to l b \nu$, $\bar{t} \to \bar{b} X$
  - lepton tags the flavor of both the B-jets at the production time

- Arxiv 1212.4611 [Gedalia, Isidori et al.]: 3σ test of the D0 anomaly with 50 fb^{-1} at 14 TeV ($\delta A_{sl} \sim 0.15\%$)

- Interests of the integrated B mixing measurements:
  - Original Analysis
  - Compare $\chi(m_t)$ with $\chi(m_Z)$: test QCD factorization
  - First step towards CPV in B mixing

Analysis Strategy



- B mixing obtained exploiting the charge correlation between leptons S1 (from top sl decay) and S2 (from B sl decay)

- Lepton S2 has to be assigned to one of the two B-jets using topological and kinematic quantities

- Event reconstruction from right assignment of the 4 jets

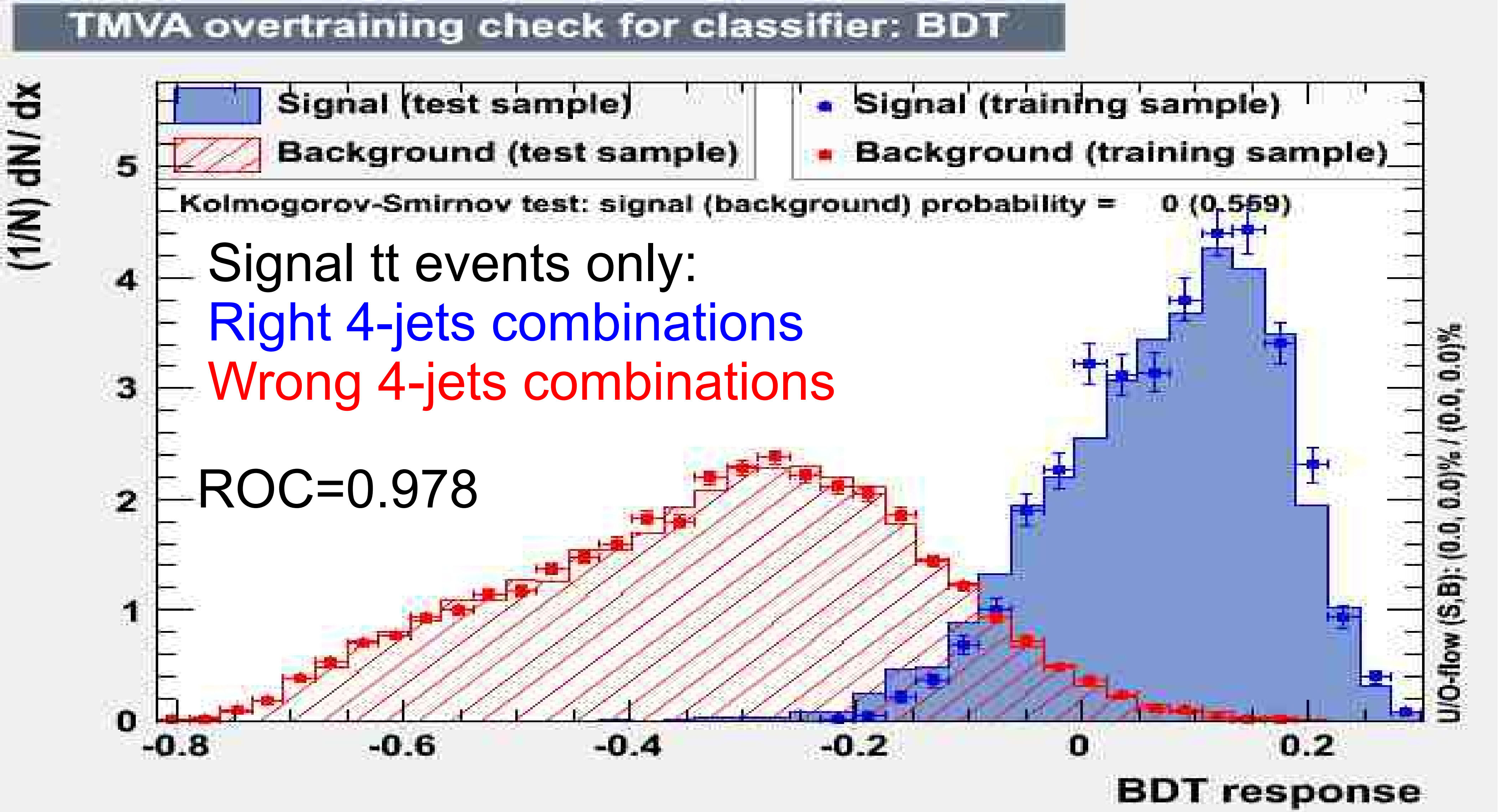
Event reconstruction

Goals:

- Right topological assignment of the 4-jets in the event
- B Flavor Tagging at the production for $t \rightarrow b \rightarrow (c) \rightarrow l$ events

TMVA Variables include:

- 4 jets spectra
- Angles between jets,
- $m(W \rightarrow jj)$
- $m(t \rightarrow \text{hadrons})$, $m(t \rightarrow Wb)$
- Btag info (only for jet with no leptons to avoid bias on χ)
- Lepton Pt wrt jet axis



By considering the 4-jets combination having maximum BDT:

Prob(4 jets right assignment) = 37.8 ± 0.7%

Prob(2 B-jets right assignment) = 53.2 ± 0.7%

Prob(at least 1 B-jet right assignment)= 75.7 ± 0.6%

Event Selection + Reconstruction

	Initial	Reco	Effi	Final Fraction
tt Semi Lep	1888	1028	54%	68.8± 1.2 %
tt Full Lep	1830	180	9.8%	12.0± 0.8 %
DY	179793	81	$4\ 10^{-4}$	5.1 ± 0.6 %
QCD	360095	80	$2\ 10^{-4}$	5.4 ± 0.6 %
W+jets	11947	74	$6\ 10^{-3}$	4.9 ± 0.6 %
WW+ZZ+WZ	619	4	$6\ 10^{-3}$	0.3 ± 0.1 %
Singletop	612	48	8%	3.2 ± 0.5 %

To be optimized

tt Full Lep and Singletop are mostly populated by signal events → Signal ~ 80%

B flavor tagging

- After the event reconstruction, the 4-jets combinations are ordered according to their BDT value

- For every muon from $t \rightarrow b \rightarrow (c) \rightarrow l$, we choose the highest BDT 4-jets combination in which the muon jet has been classified as a B-jet

- We compare the top assigned to the muon by the algorithm with the right top from MC truth

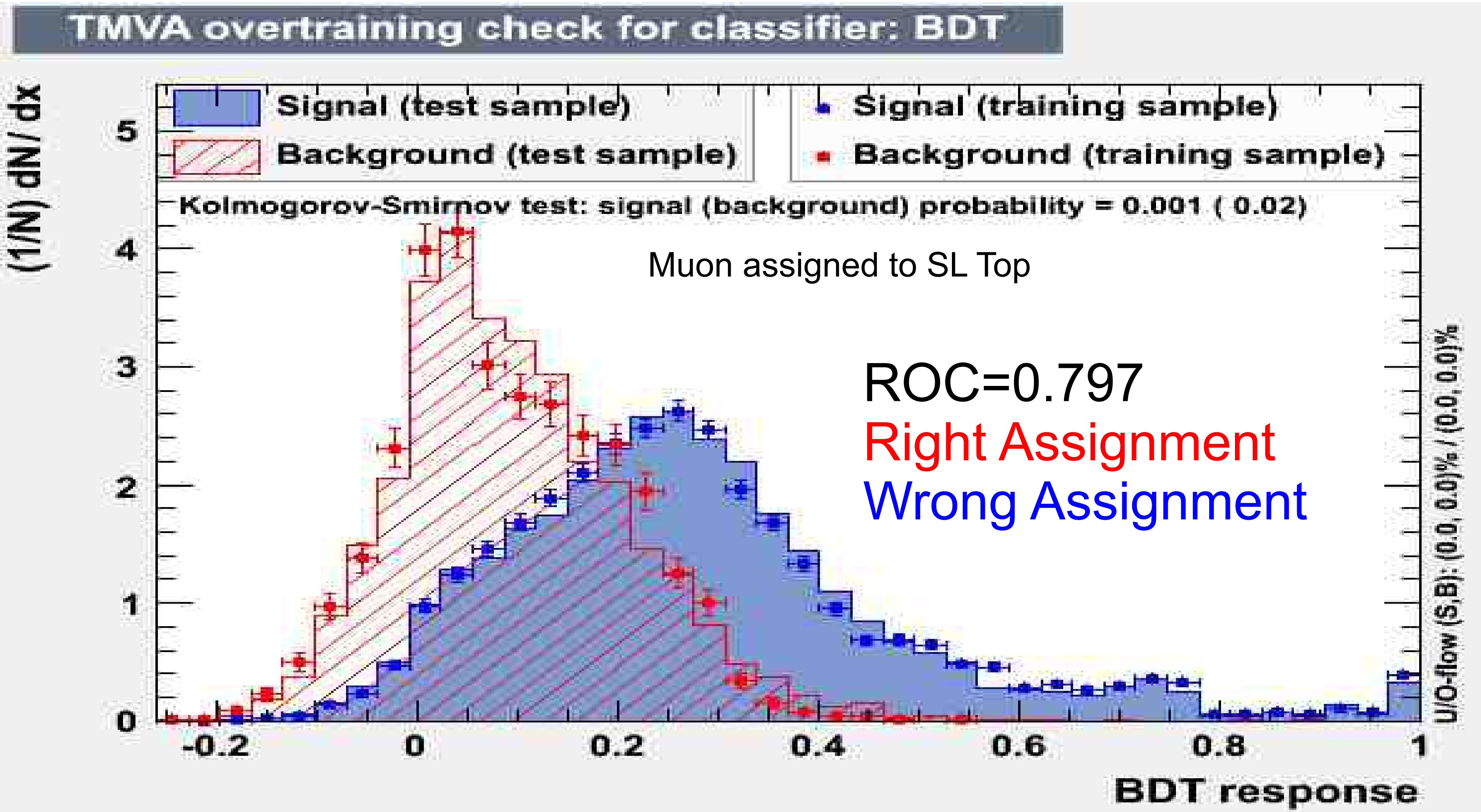
  - Fraction of right assignment if muon assigned to SL top:

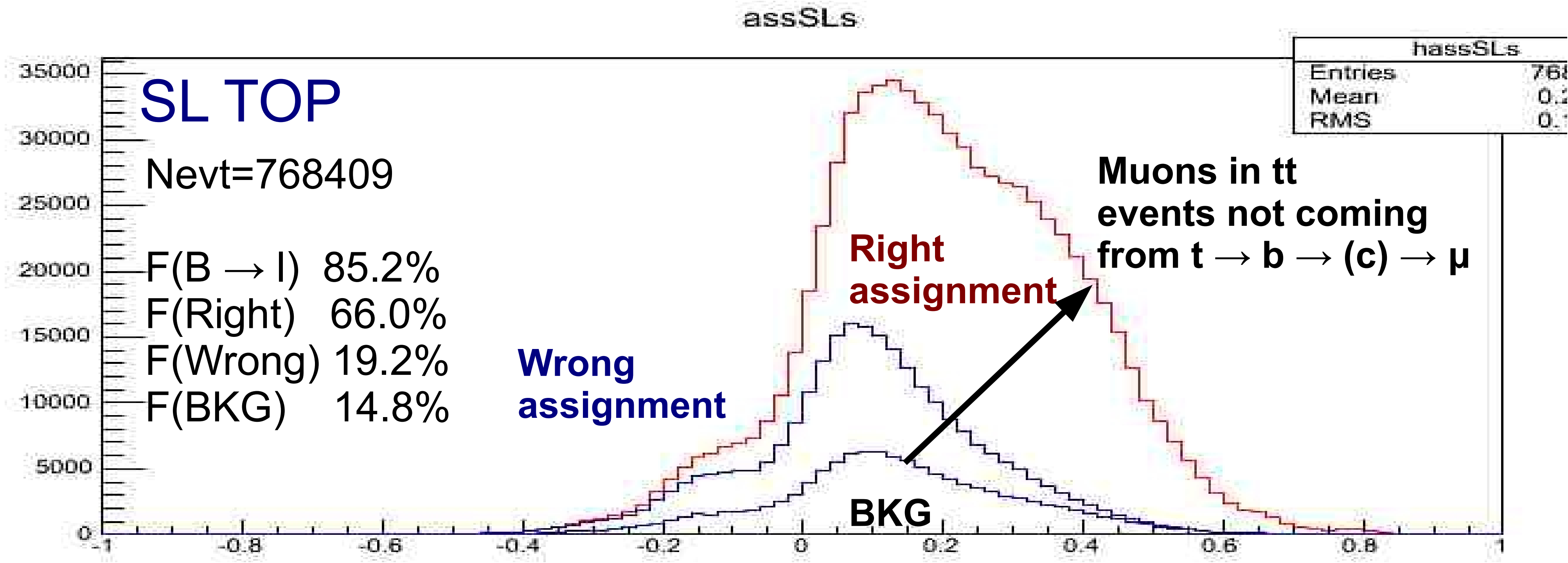
    $F = 75.04 \pm 0.19\% \rightarrow$ mistag ~ 25%

  - Fraction of right assignment if muon assigned to Had top:

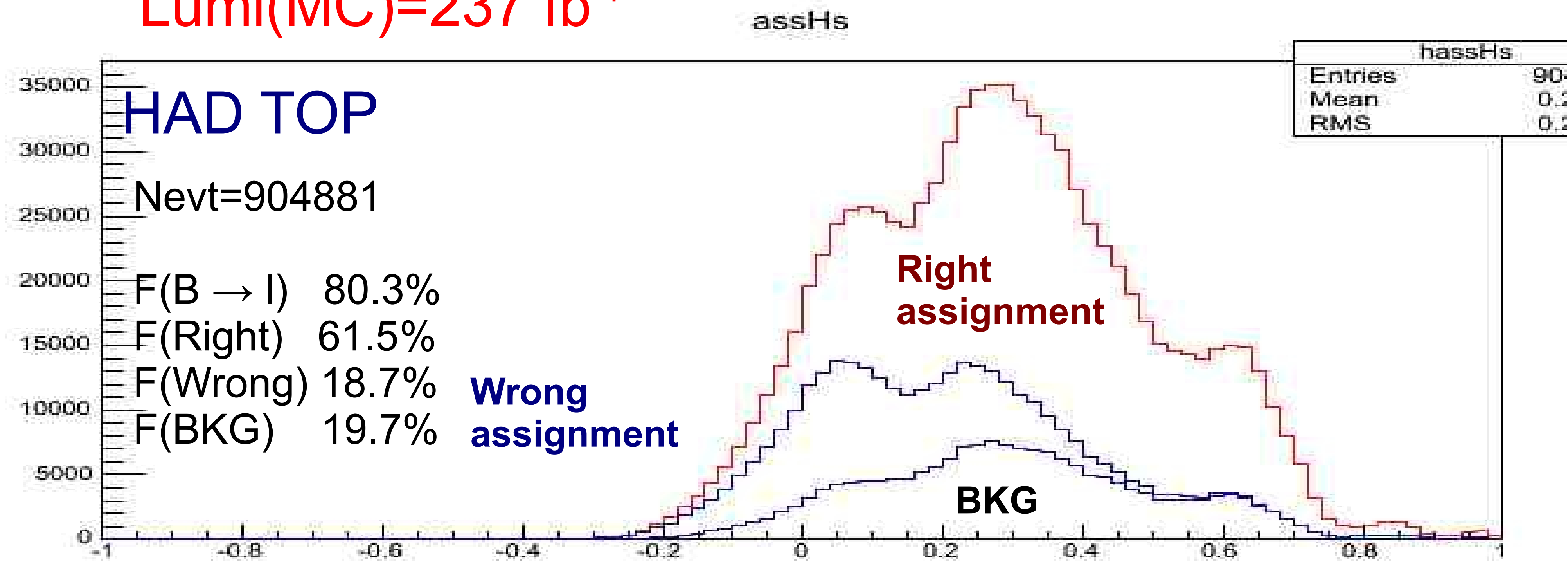
    $F = 79.47 \pm 0.19\% \rightarrow$ mistag ~ 20%

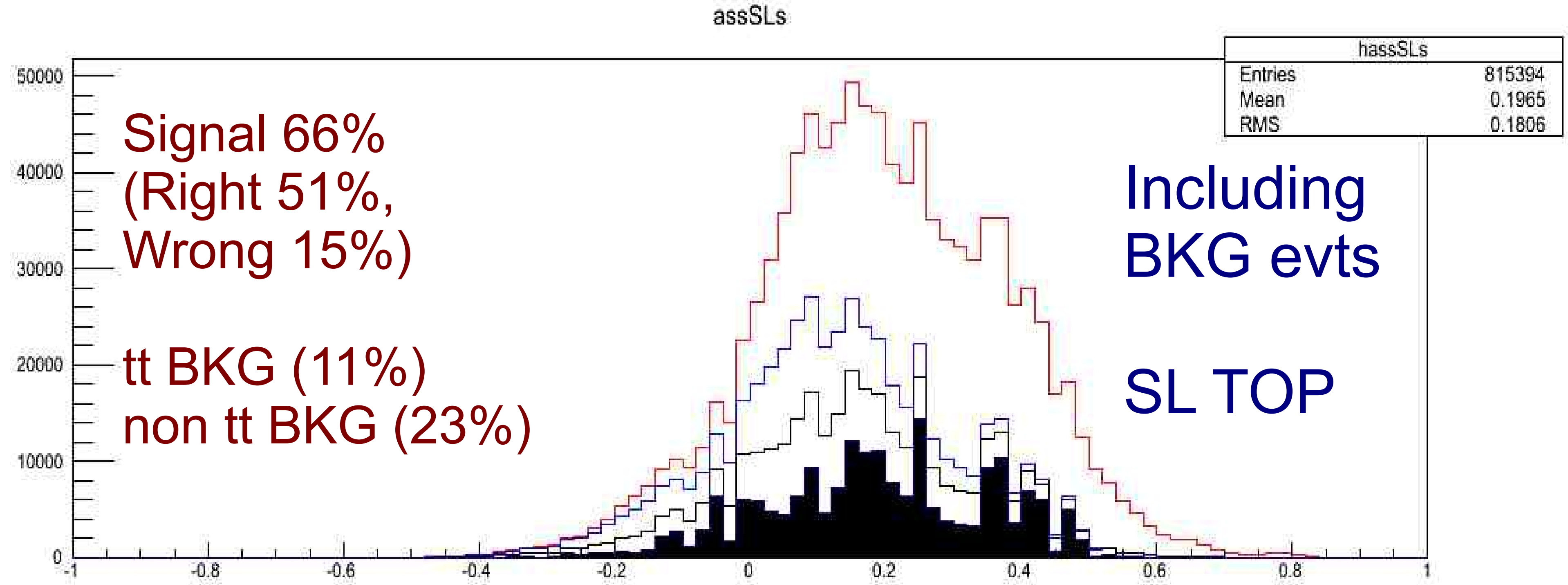
Define an additional BDT using angular variables to improve the performance

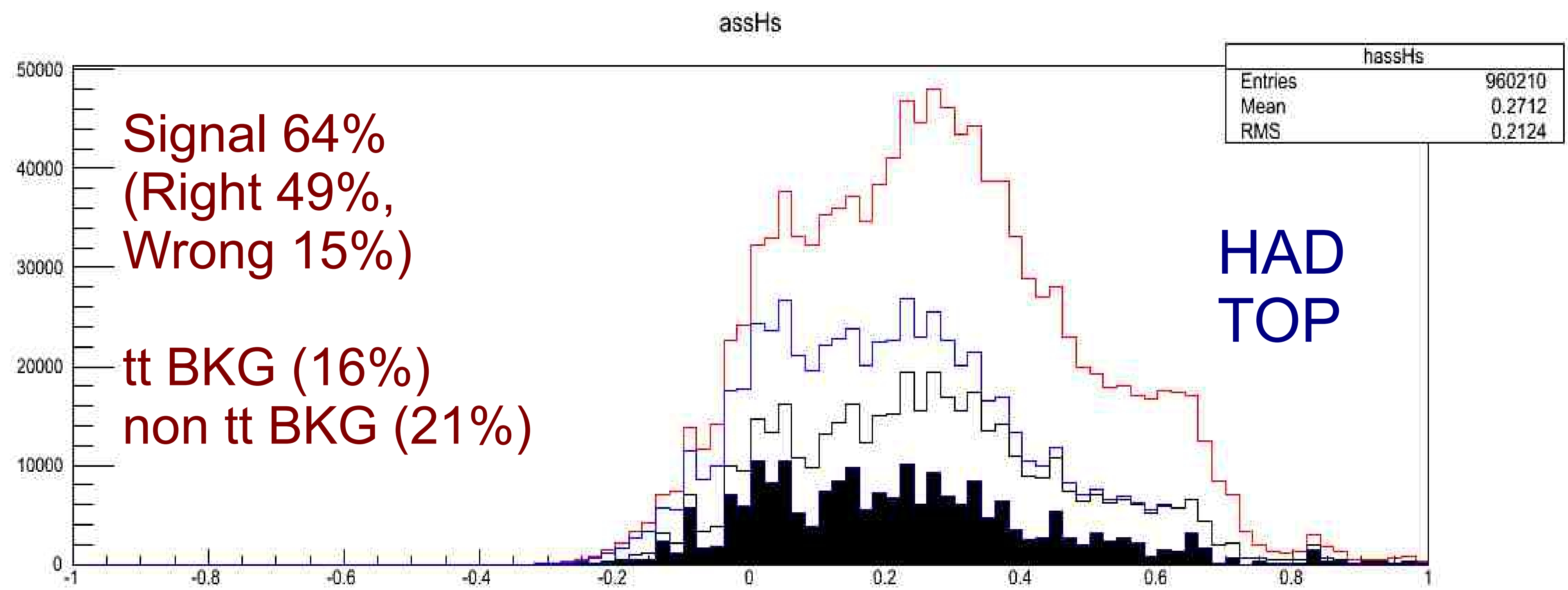




Lumi(MC)=237 fb^{-1}




assSLs
hassSLs
Entries 815394
Mean 0.1965
RMS 0.1806
Signal 66%
(Right 51%,
Wrong 15%)
tt BKG (11%)
non tt BKG (23%)
Including
BKG evts
SL TOP
50000
40000
30000
20000
10000
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


assHs
hassHs
Entries 960210
Mean 0.2712
RMS 0.2124
Signal 64%
(Right 49%,
Wrong 15%)
tt BKG (16%)
non tt BKG (21%)
HAD
TOP
50000
40000
30000
20000
10000
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

Mixing in top decays: projections

"Fixed" flavour at creation:

$$N_{\text{same}} = \bar{\chi} N_{\text{tot}} \quad ; \quad N_{\text{oppo}} = (1 - \bar{\chi}) N_{\text{tot}}$$

Run-1 analysis (muon only)

- Expected statistical error on mixing: $\sigma_\chi \sim 2 \cdot 10^{-3}$
- Expected statistical error on asymmetry: $\sigma_A \sim 2 \cdot 10^{-2}$

Run-2 analysis

- $\mathcal{L}_2 \sim 100\ \text{fb}^{-1} \sim 5\mathcal{L}_1$
- $\sigma_{tt,2} \sim 4\sigma_{tt,1}$
- same trigger thresholds for muons, slightly higher for electrons ($p_T > 17, 12$ GeV)

} 20 times higher statistics

$\sigma_{\chi(\text{stat})} \sim 0.5 \cdot 10^{-3}$; $\sigma_{A(\text{stat})} \sim 0.5 \cdot 10^{-2}$

Not competitive with LHCb, but a measurement with a new technique

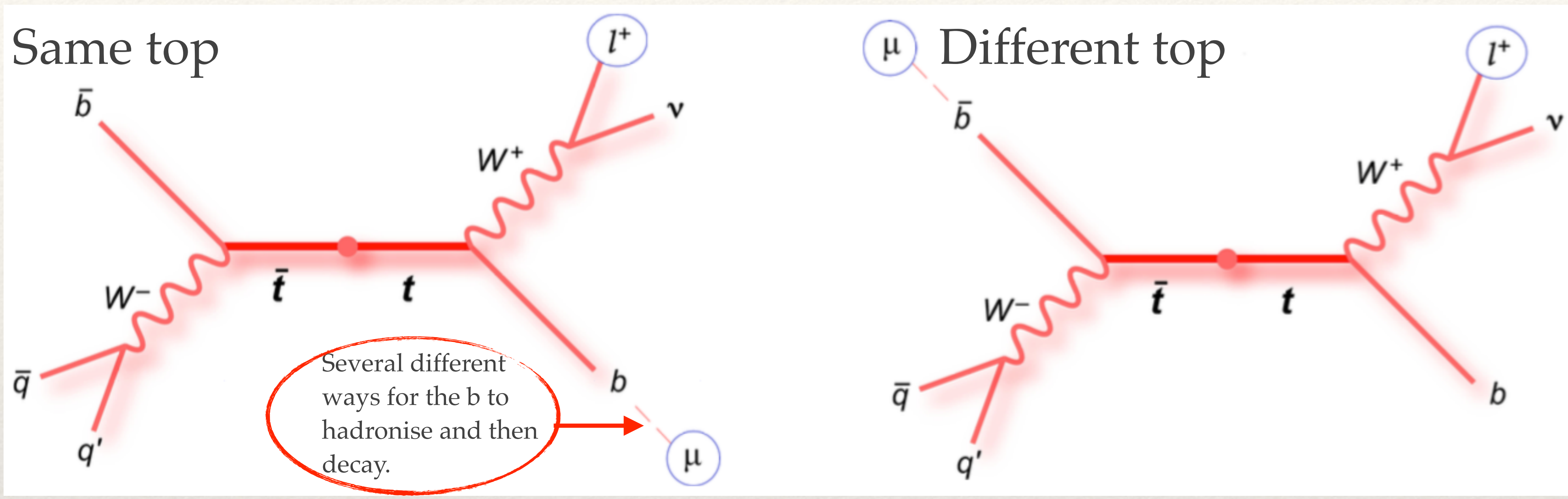
Next Steps

- Use DATA/MC comparison of the variables used in the BDTs (Student+Stefano)
- Merge with Paolo selection. Optimization of TMVA
- b $\rightarrow$ mu vs b $\rightarrow$ c $\rightarrow$ mu separation using Alessio code
- Definition of PDF and fit on MC (closure test) and Data

Analysis follows the procedure outlined by O. Gedalia et al., Phys. Rev. Lett. 110 (2013) 232002.

CP violation in *b* decays using top quark pairs

- 20.3 fb^{-1} of 8TeV data (*pp* collisions)



- Measure same and opposite sign lepton pairs to compute mixing and direct CP asymmetries from observed N^{++}, N^{--}, N^{+-} and N^{-+} rates:

$$N^{ij} = N^{q_\mu q_W}$$

- Mistag probability is 21%:

	N_j^{++}	N_j^{--}	N_j^{+-}	N_j^{-+}
N_i^{++}	0.79	0.00	0.00	0.21
N_i^{--}	0.00	0.79	0.21	0.00
N_i^{+-}	0.00	0.21	0.79	0.00
N_i^{-+}	0.21	0.00	0.00	0.79

$$A^{b\ell}_{\rm mix} = \frac{\Gamma\left(b \to \bar{b} \to \ell^+ X\right) - \Gamma\left(\bar{b} \to b \to \ell^- X\right)}{\Gamma\left(b \to \bar{b} \to \ell^+ X\right) + \Gamma\left(\bar{b} \to b \to \ell^- X\right)},$$

$$A^{bc}_{\rm mix} = \frac{\Gamma\left(b \to \bar{b} \to \bar{c} X\right) - \Gamma\left(\bar{b} \to b \to c X\right)}{\Gamma\left(b \to \bar{b} \to \bar{c} X\right) + \Gamma\left(\bar{b} \to b \to c X\right)},$$

$$A^{b\ell}_{\rm dir} = \frac{\Gamma\left(b \to \ell^- X\right) - \Gamma\left(\bar{b} \to \ell^+ X\right)}{\Gamma\left(b \to \ell^- X\right) + \Gamma\left(\bar{b} \to \ell^+ X\right)},$$

$$A^{c\ell}_{\rm dir} = \frac{\Gamma\left(\bar{c} \to \ell^- X_L\right) - \Gamma\left(c \to \ell^+ X_L\right)}{\Gamma\left(\bar{c} \to \ell^- X_L\right) + \Gamma\left(c \to \ell^+ X_L\right)},$$

$$A^{bc}_{\rm dir} = \frac{\Gamma\left(b \to c X_L\right) - \Gamma\left(\bar{b} \to \bar{c} X_L\right)}{\Gamma\left(b \to c X_L\right) + \Gamma\left(\bar{b} \to \bar{c} X_L\right)},$$

J. High Energ. Phys. (2017) 2017: 7

CP violation in b decays using top quark pairs

ATLAS EXPERIMENT

- Hard lepton from W-boson tags b quark via $t \to bW^+ \to b\ell^+\nu$
- Soft muon (SMT algorithm*) from $b \to X\mu\nu$ probes the decay chain.
- Require 2 leptons in an event:

Same sign leptons:

$$t \to \ell^+\nu\ (b \to \bar{b}) \to \ell^+\,\ell^+\,X\,,$$
$$t \to \ell^+\nu\ (b \to c) \to \ell^+\,\ell^+\,X\,,$$
$$t \to \ell^+\nu\ (b \to \bar{b} \to c\,\bar{c}) \to \ell^+\,\ell^+\,X\,,$$

Opposite sign leptons:

$$t \to \ell^+\nu\, b \to \ell^+\,\ell^-\,X\,,$$
$$t \to \ell^+\nu\ (b \to \bar{b} \to \bar{c}) \to \ell^+\,\ell^-\,X\,,$$
$$t \to \ell^+\nu\ (b \to c\,\bar{c}) \to \ell^+\,\ell^-\,X\,,$$

- Use standard top reconstruction for a $t\bar{t}$ $\ell + jets$ event.
- Require a displaced vertex (b candidate) tagged with SMT algorithm.
- Fully reconstruct $t\bar{t}$ candidate with KLFitter[#].

$$P(b \to \ell^+) = \frac{N(b \to \ell^+)}{N(b \to \ell^-) + N(b \to \ell^+)} = \frac{N^{++}}{N^{+-} + N^{++}} = \frac{N^{++}}{N^{+}},$$
$$P(\bar{b} \to \ell^-) = \frac{N(\bar{b} \to \ell^-)}{N(\bar{b} \to \ell^-) + N(\bar{b} \to \ell^+)} = \frac{N^{--}}{N^{--} + N^{-+}} = \frac{N^{--}}{N^{-}},$$
$$P(b \to \ell^-) = \frac{N(b \to \ell^-)}{N(b \to \ell^-) + N(b \to \ell^+)} = \frac{N^{+-}}{N^{+-} + N^{++}} = \frac{N^{+-}}{N^{+}},$$
$$P(\bar{b} \to \ell^+) = \frac{N(\bar{b} \to \ell^+)}{N(\bar{b} \to \ell^-) + N(\bar{b} \to \ell^+)} = \frac{N^{-+}}{N^{--} + N^{-+}} = \frac{N^{-+}}{N^{-}},$$

$$A^{ss} = \frac{P(b \to \ell^+) - P(\bar{b} \to \ell^-)}{P(b \to \ell^+) + P(\bar{b} \to \ell^-)}, \qquad A^{os} = \frac{P(b \to \ell^-) - P(\bar{b} \to \ell^+)}{P(b \to \ell^-) + P(\bar{b} \to \ell^+)},$$

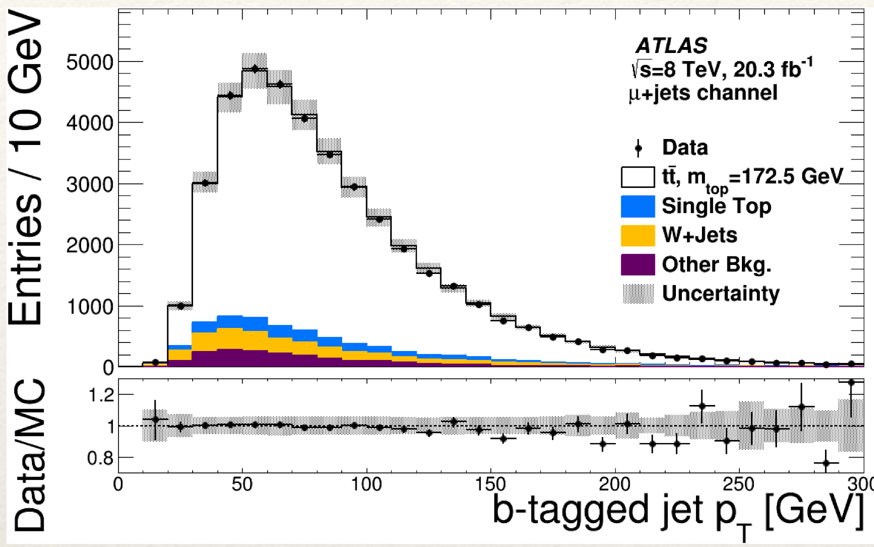
$$A^{ss} = r_b A^{b\ell}_{\text{mix}} + r_c\left(A^{bc}_{\text{dir}} - A^{c\ell}_{\text{dir}}\right) + r_{c\bar{c}}\left(A^{bc}_{\text{mix}} - A^{c\ell}_{\text{dir}}\right)$$
$$A^{os} = \widetilde{r}_b A^{b\ell}_{\text{dir}} + \widetilde{r}_c\left(A^{bc}_{\text{mix}} + A^{c\ell}_{\text{dir}}\right) + \widetilde{r}_{c\bar{c}} A^{c\ell}_{\text{dir}}$$

- The r 's are decay rate fractions in fiducial region

J. High Energ. Phys. (2017) 2017: 7; *see JINST 11 (2016) P04008 for details of the SMT algorithm; [#]see Nucl. Instrum. Meth. A 748 (2014) 18–25 for the Kinematic Likelihood fitter description.

CP violation in *b* decays using top quark pairs

ATLAS EXPERIMENT



	e+jets		μ+jets	
WW, WZ , WW	50	$\pm$ 7	45	$\pm$ 5
Z+jets	800	$\pm$ 80	450	$\pm$ 60
Multijet	1 800	$\pm$ 1 400	1 500	$\pm$ 330
Single top	1 800	$\pm$ 150	2 000	$\pm$ 150
W+jets	2 500	$\pm$ 160	2 800	$\pm$ 150
$t\bar{t}$	30 000	$\pm$ 1 900	34 000	$\pm$ 2 000
Expected	37 000	$\pm$ 2 600	41 000	$\pm$ 2 300
Data	36 796		40 807	

- Good agreement between observed and expected yields.

	Data (10^{-2})		MC (10^{-2})		Existing limits (2σ) (10^{-2})		SM prediction (10^{-2})	
A^{ss}	-0.7	$\pm$ 0.8	0.05	$\pm$ 0.23	-		$< 10^{-2}$	[19]
A^{os}	0.4	$\pm$ 0.5	-0.03	$\pm$ 0.13	-		$< 10^{-2}$	[19]
A^{b}_{mix}	-2.5	$\pm$ 2.8	0.2	$\pm$ 0.7	< 0.1	[95]	$< 10^{-3}$	[96] [95]
$A^{b\ell}_{\mathrm{dir}}$	0.5	$\pm$ 0.5	-0.03	$\pm$ 0.14	< 1.2	[94]	$< 10^{-5}$	[19] [94]
$A^{c\ell}_{\mathrm{dir}}$	1.0	$\pm$ 1.0	-0.06	$\pm$ 0.25	< 6.0	[94]	$< 10^{-9}$	[19] [94]
A^{bc}_{dir}	-1.0	$\pm$ 1.1	0.07	$\pm$ 0.29	-		$< 10^{-7}$	[97]

- Competitive results (σ~%-level) obtained for mixing and direct CP asymmetries through this measurement
- Also measured A^{bc}_{dir}.

Existing constraints/SM predictions from:
[19] O. Gedalia et al., Phys. Rev. Lett. **110** (2013) 232002,
[94] Decotes-Genon et al., Phys. Rev. D **87** (2015).
[95] HFAG, arXiv:1412.7515.
[97] S. Bar-Shalom et al., Phys. Lett. B **694** (2011) 374–379

J. High Energ. Phys. (2017) 2017: 7

New CMS results on $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ decay studies

- Introduction
- Event selection
- Decay rate and total p.d.f.
- An interesting statistical problem …
- Signal evidence & fit validation
- Systematic uncertainties
- Preliminary results
- Summary

22/3/2017

Moriond 2017 EW Session

Mauro Dinardo
Università degli Studi di Milano Bicocca and INFN - Italy
On behalf of the CMS collaboration

Introduction

$B^0 \to K^{*0}\,\mu^+\,\mu^-$ described within Standard Model (SM) as flavour-changing neutral-current process

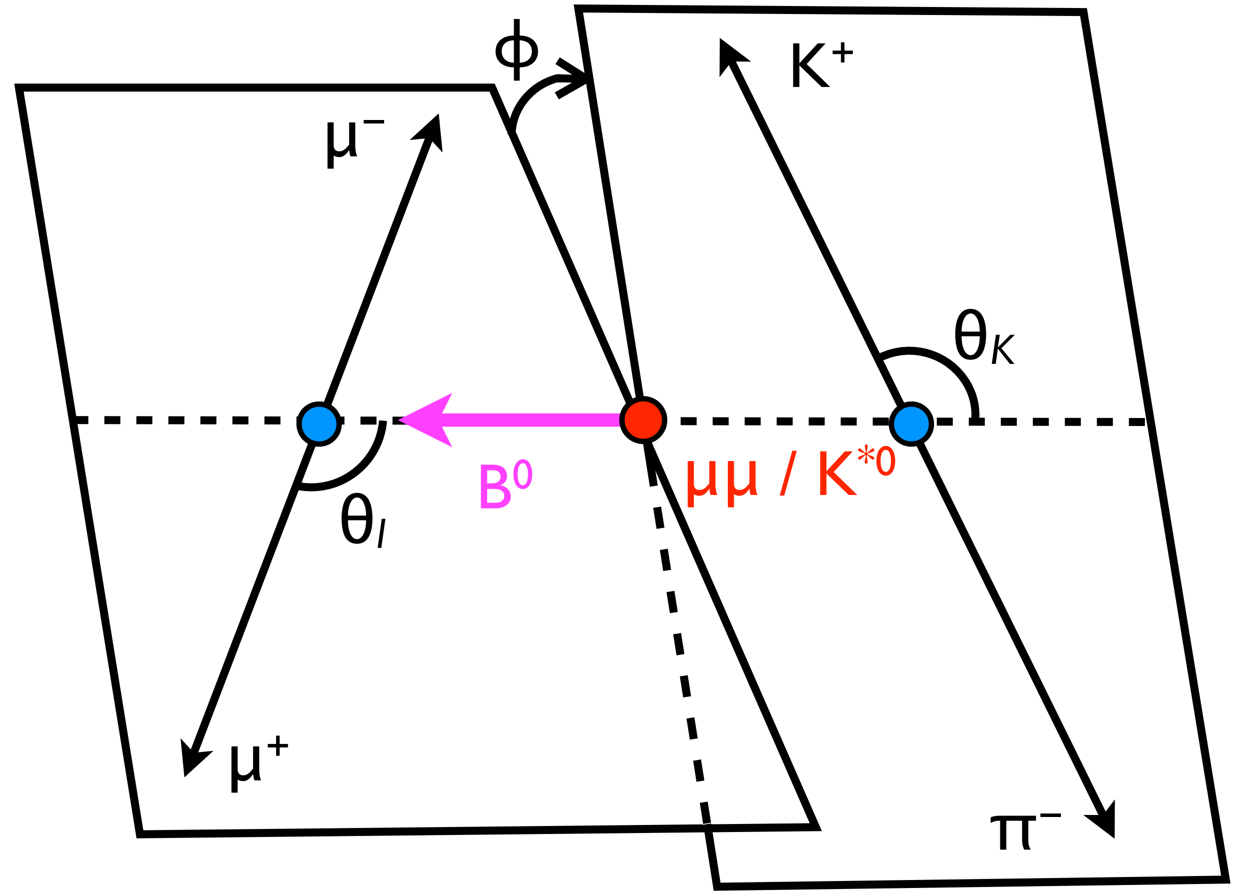
Decay fully described as a function of three angles (θ_l, θ_K, Φ) and dimuon invariant mass squared, q^2

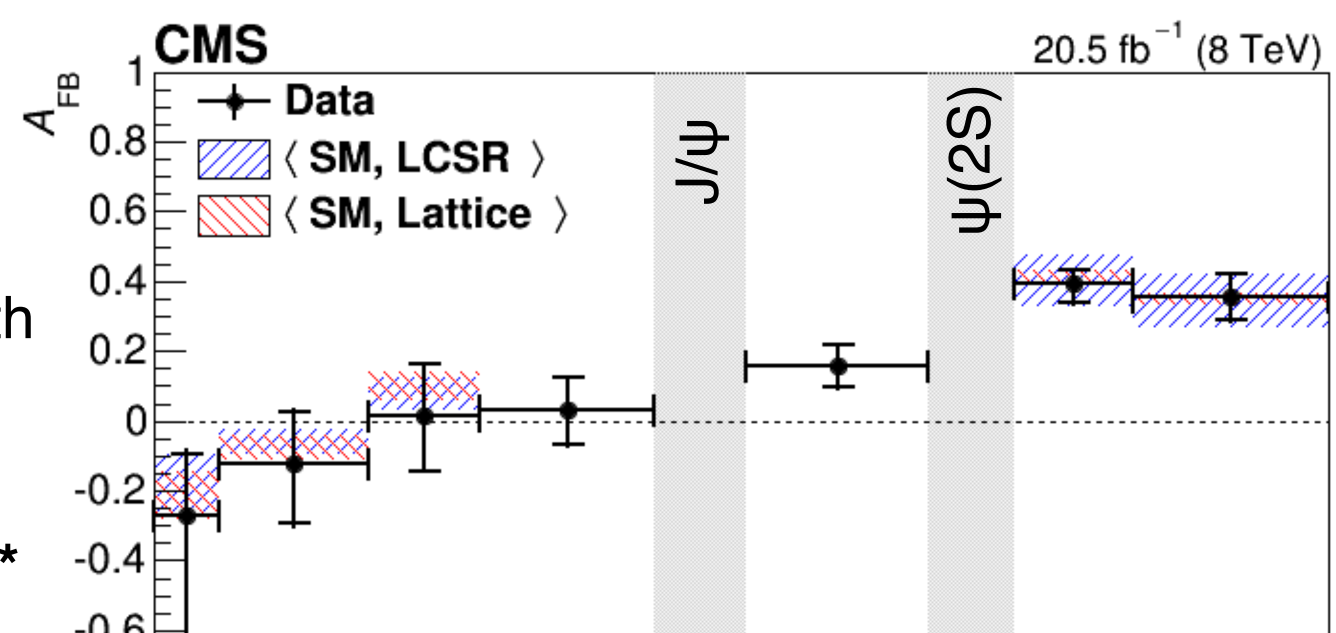
Robust SM calculations of several angular parameters, *e.g.* forward-backward asymmetry of the muons, A_{FB}, longitudinal polarisation fraction of the K^{*0}, F_L, $P5'$ (see next slides) are available for much of the phase space

⬇

Discrepancy of the angular parameters vs q^2 with respect to SM indicates new physics

This talk is about extension of previous analysis* (same 2012 data set, 20.5 fb^{-1} (8 TeV)): new angular parameters, P_1 and P_5'





*PLB 753 (2016) 424: A_{FB}, F_L, d$\mathcal{B}F$/dq^2

Event selection

Dedicated **low mass displaced dimuon trigger** during **2012** data taking
Most important selections to discriminate signal and reduce trigger rate:

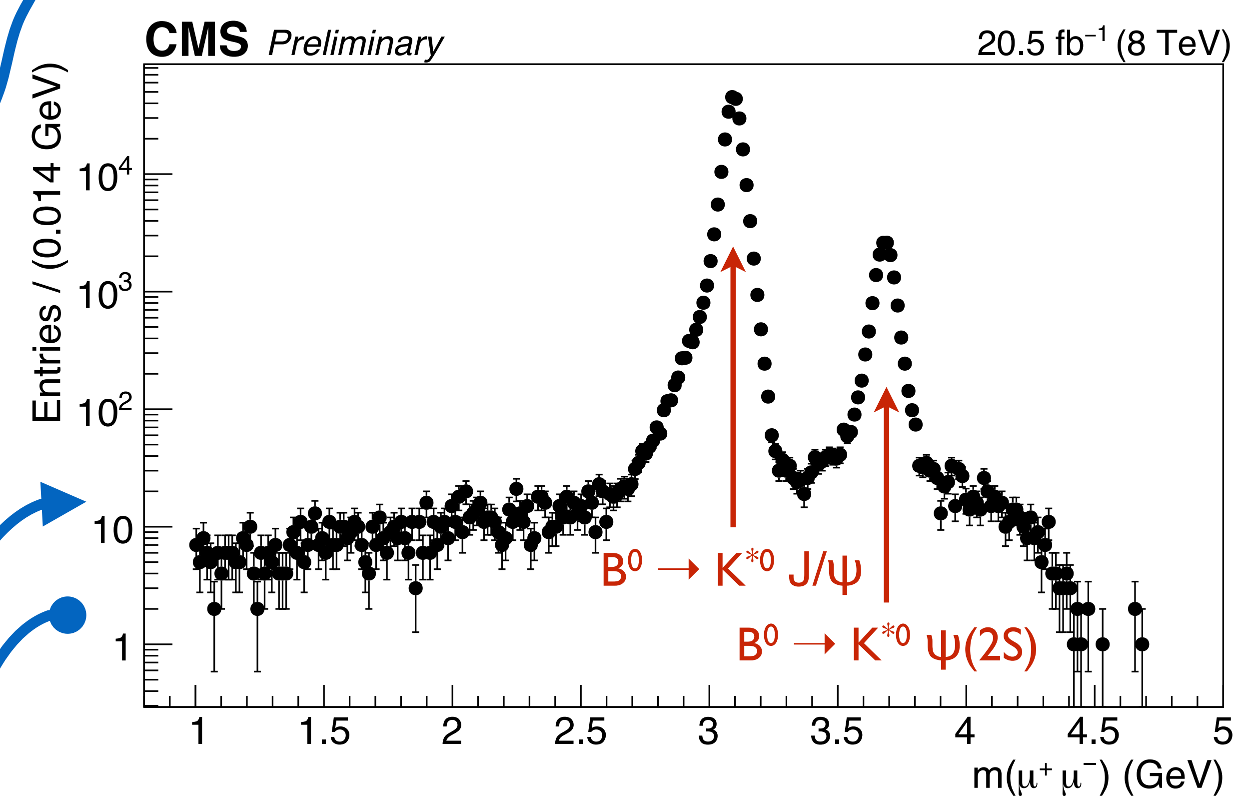
- single muon $p_T >$ **3.5** GeV
- dimuon $p_T >$ **6.9** GeV
- **1** $< m(\mu\mu) = q <$ **4.8** GeV
- $L / \sigma >$ **3** w.r.t. beamspot
- Vtx CL > **10%**

Both $K^+\pi^-$ and $K^-\pi^+$ mass hypothesis are computed

- $p_T >$ **0.8** GeV
- DCA / $\sigma >$ **2** w.r.t. beamspot
- $|m(K\pi) - m(K^{*0}_{PDG})| <$ **90** MeV at least one of the two mass hypothesis must lie in the window
- $m(KK) >$ **1.035** ($\Phi(1020)$ particle rejection)

Two CP-states, $B^0 \to K^{*0}$ **($K^+ \pi^-$)** $\mu^+ \mu^-$ and $B^0_{bar} \to K^{*0}_{bar}$ **($K^- \pi^+$)** $\mu^+ \mu^-$, difficult to disentangle (no particle ID) ➜ **CP-state assignment based on mass hypothesis closer to K^{*0} PDG mass (mistag rate ~14%)**

- **Both B^0 and B^0_{bar} mass hypothesis are computed:**
- $p_T >$ **8** GeV
- $|\eta| <$ **2.2**
- $|m(K\pi\mu\mu) - m(B^0)_{PDG}| <$ **280** MeV for at least one of the two mass hypothesis
- Vtx. CL > **10%**
- $L / \sigma >$ **12** w.r.t. beamspot
- $\cos(\alpha) >$ **0.9994** angle in transverse plane between B^0 momentum and B^0 line of flight (w.r.t. beamspot)
- If more than one candidate ➜ choose best B^0 vtx CL



Signal and control samples are treated identically
Signal candidates obtained by **J/ψ and $\psi(2S)$ rejections**

The decay rate

Two channels can contribute to the final state $K^+ \pi^- \mu^+ \mu^-$:

- **P-wave** resonant channel, $K^+ \pi^-$ from the meson vector resonance K^{*0} decay
- **S-wave** non-resonant channel, $K^+ \pi^-$ don't come from any resonance

We have to parametrise both decay rates ➜ **14** parameters ➜ given the number events in **2012 data set**, we need to reduce number of free angular parameters to allow the fit to converge ➜ exploit the odd symmetry of trigonometric functions, *i.e.* **fold** decay rate around $\boldsymbol{\Phi = 0}$ and $\boldsymbol{\theta_l = \pi / 2}$

S-wave and S&P-wave interference

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_l\mathrm{d}\cos\theta_K\mathrm{d}\phi} = \frac{9}{8\pi}\left\{\frac{2}{3}\left[\left(\boxed{F_S} + \boxed{A_S}\cos\theta_K\right)\left(1-\cos^2\theta_l\right) + \boxed{A_S^5}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right] + \left(1-\boxed{F_S}\right)\left[2\boxed{F_L}\cos^2\theta_K\left(1-\cos^2\theta_l\right) + \frac{1}{2}\left(1-\boxed{F_L}\right)\left(1-\cos^2\theta_K\right)\left(1+\cos^2\theta_l\right) + \frac{1}{2}\boxed{P_1}\left(1-\boxed{F_L}\right)\left(1-\cos^2\theta_K\right)\left(1-\cos^2\theta_l\right)\cos 2\phi + 2\boxed{P_5'}\cos\theta_K\sqrt{\boxed{F_L}\left(1-\boxed{F_L}\right)}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right]\right\}$$

P-wave

Decay rate depends upon **6** angular parameters:

- **F_S, A_S, F_L**: fixed to published CMS measurements on same data set (Φ integrated out)
- **P_1, P_5'**: measured parameters in this analysis (Φ dependance)
- **A^5_S**: nuisance parameter

The probability density function

$$\text{p.d.f.}(m,\theta_K,\theta_l,\Phi) = \boxed{Y_S^C}\Big[\boxed{S^C(m)}\,\boxed{S^a(\theta_K,\theta_l,\phi)}\,\boxed{\epsilon^C(\theta_K,\theta_l,\phi)}$$

Correctly tagged events

Mistag fraction

$$+\frac{\boxed{f^M}}{1-f^M}\,\boxed{S^M(m)}\,\boxed{S^a(-\theta_K,-\theta_l,\phi)}\,\boxed{\epsilon^M(\theta_K,\theta_l,\phi)}\Big]$$

Mistagged events

$$+\boxed{Y_B\, B^m(m)\, B^{\theta_K}(\theta_K)\, B^{\theta_l}(\theta_l)\, B^{\phi}(\phi)},$$

Background

- Signal contribution: mass shape (double gaussian), decay rate, and 3D efficiency function
- Background contribution: mass shape (exponential) and factorised polynomial functions for each angular variable

- Fit performed in two steps:
  1. Fit sidebands to determine background shape
  2. Fit whole mass spectrum, 5 free parameters:
     - signal (**Y_S**) and background (**Y_B**) yields
     - **P_1**, **P_5'**, and **A^5_s** angular parameters

- Use unbinned extended maximum likelihood estimator
- Measurement performed 7 times (one in each q^2 bin)

q^2 bin index	$m^2(\mu\mu)$ (GeV^2)
1	1 – 2
2	2 – 4.3
3	4.3 – 6
4	6 – 8.68
5	10.9 – 12.86
6	14.18 – 16
7	16 – 19

Mauro Dinardo, Università degli Studi di Milano Bicocca and INFN

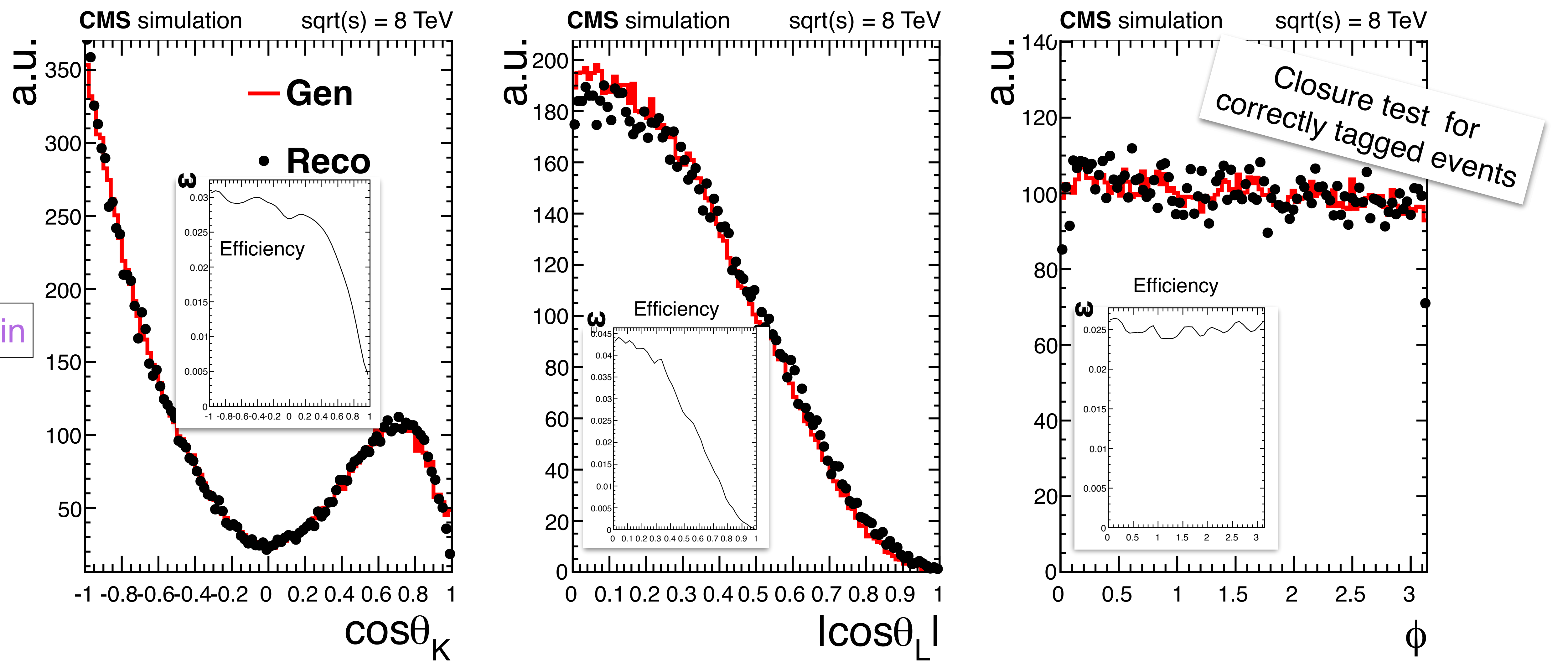
Efficiency function

- Numerator and denominator of efficiency are separately described with nonparametric technique implemented with a kernel density estimator on unbinned distributions
- Final efficiency distributions in the p.d.f. obtained from the ratio of 3D histograms derived from the sampling of the kernel density estimators

Closure test:

- compute efficiency with half of the MC simulation and use it to correct the other half
- same test performed both for correctly and mistagged events independently

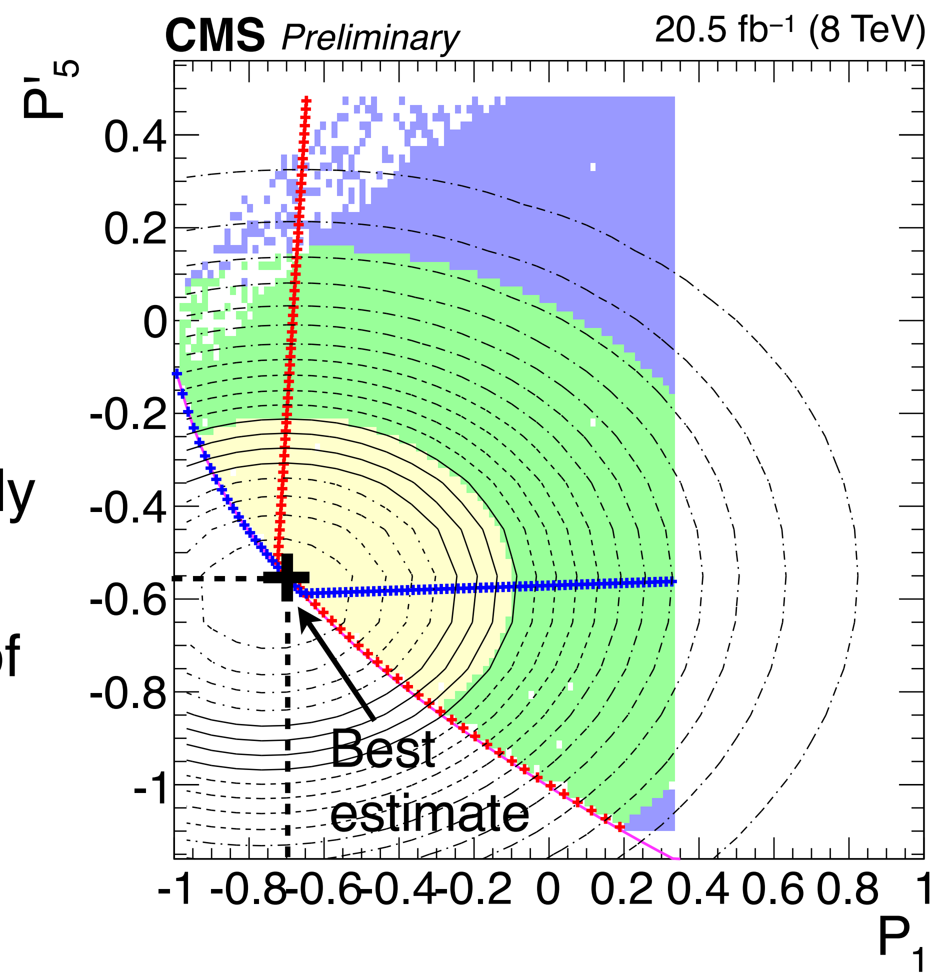
2nd q^2 bin



An interesting statistical problem …

- The decay rate can become negative for certain values of the angular parameters (**P_1**, **P_5'**, **A^5_s**)
- The presence of such a physically allowed region greatly complicates the numerical maximisation process of the likelihood by `MINUIT` and especially the error determination by `MINOS`, in particular next to the boundary between physical and unphysical regions
- The **best estimate** of **P_1** and **P_5'** is computed by:
  - discretise the bi-dimensional space **P_1-P_5'**
  - maximise the likelihood as a function of **Y_S**, **Y_B**, and **A^5_s** at fixed values of **P_1**, **P_5'**
  - fit the likelihood distribution with a 2D-gaussian function
  - the maximum of this function inside the physically allowed region is the best estimate

- To ensure correct coverage for the **uncertainties** of **P_1** and **P_5'**, the Feldman-Cousins method is used in a simplified form: the confidence interval's construction is performed only along two 1D paths determined by profiling the 2D-gaussian description of the likelihood inside the physically allowed region



2nd q^2 bin

Color code Log Likelihood (LL):

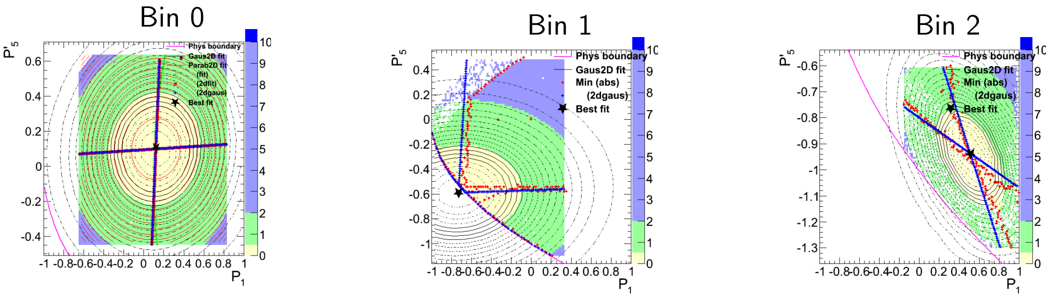
- yellow = 0 to 0.5 LL
- green = 0.5 to 2 LL

Paths:

- Profile likelihood for P_1
- Profile likelihood for P_5'

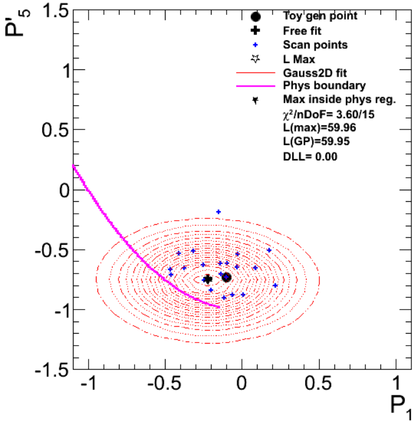
Procedure description

- start from the 2D $\mathcal{L}(P_1, P'_5)$ computed on data, taking into account the physical boundaries
- Then we fit it with a bivariate gaussian function and profile it vs P_1 and P'_5, respectively, looking for maximum along the profile;
  - more robust than consider just the absolute maximum of the $\mathcal{L}$ along the profile.
  - if we hit a physical boundary, the minimum can be along the boundary itself
- Then we generate 100 (data-like size) toys using as input parameters P_1 and P'_5.
  - To save CPU time not for all points, but we start around $\Delta \log \mathcal{L} = 0.5$



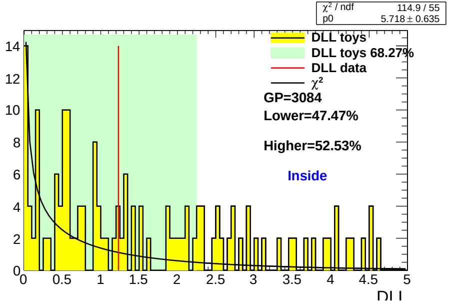
Each toy is fitted with the full pdf as done for data

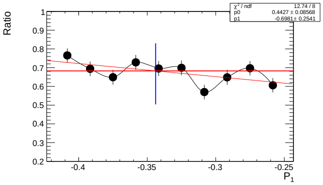
- we repeat the fit with 20 different set of 20 initial values of P_1 and P_5'
  - to find the absolute max, we fit the 20 values with a 2D gauss function
  - the max must be inside the physical region
- Eventually, we have 100 toys, and 100 values for the likelihood.

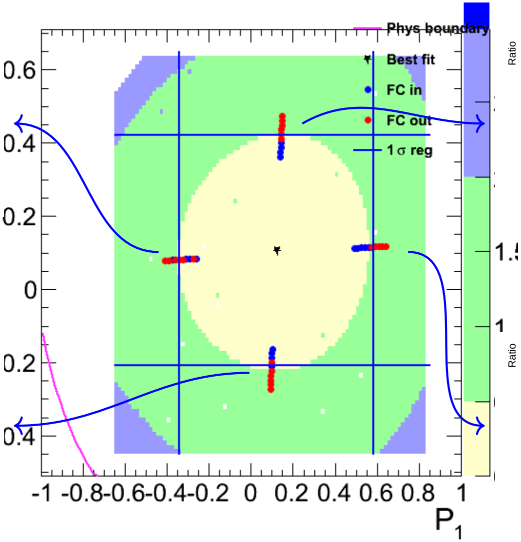


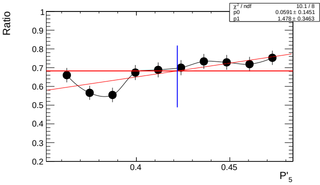
- We compute $\Delta \log \mathcal{L}$ for each toy
  - compared with the min along the profile
  - [black/yellow histo]$\rightarrow$
- and $\Delta \log \mathcal{L}$ for data for that gen point
  - [red line]$\rightarrow$
- **ratio**=(# toys with DLL(toy)<DLL(Data))/(#toys)
- If **ratio** $< 68.27\%$
  - [green area]$\rightarrow$
- then generation point is inside the 1σ boundary for data, otherwise it's outside.
- repeat for $P_1(P_5')$ upper(lower) bound: 4 "directions"

An example of DLL toys distribution compared with DLL(Data) (red)



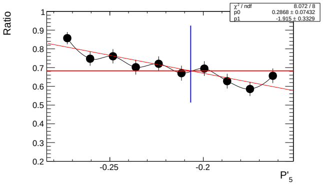


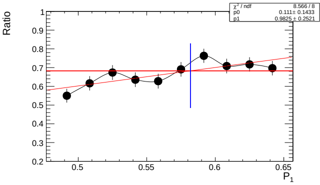




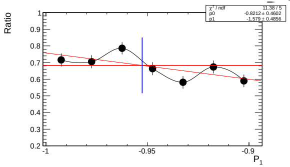
Done
Done

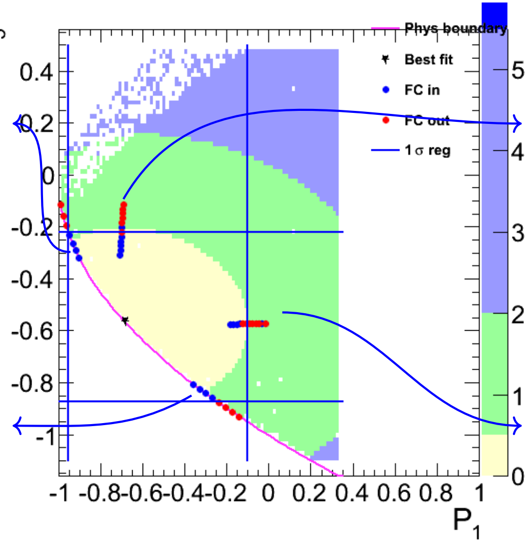
Done
Done

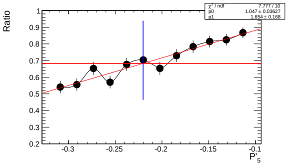




Bin 1 NEW

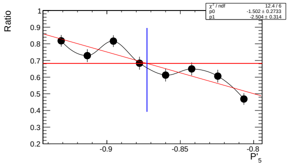


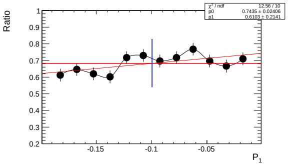




Done
Done

Done
Done





Numbers

- Number of points in the P_1, P_5' space investigated: 903
- Number of toys generated: 90 300
- Number of UML fit performed in total: 1 900 000
- Number of jobs submitted: $\sim$ 90 000
- Maximum number of jobs running at once: 750
- Average wall clock time for a job: $\sim 1.6\ h$
- Total wall clock time by all jobs: $\sim 5.2 \cdot 10^8\ s = 15\,000\ h = 6\,000\ d = 1.65\ y$
- Actual time spent so far $\sim$ 2.5 mounth, not counting the two months spent by Alessio with his coverage study to try and demonstrate that this effort was not needed.
- and ~~counting~~ **STOP** . . .

Comparison with $\Delta \log \mathcal{L} = 0.5$

Results and confidence level $\Delta \log \mathcal{L} = 0.5$

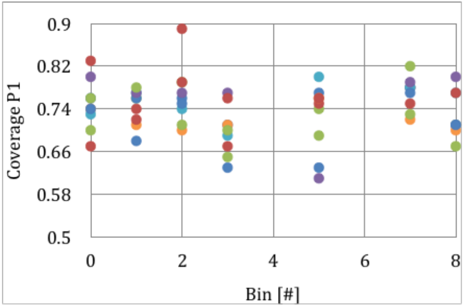
Bin	P_1	FC	CM	Hyb	P'_5	FC	CM	Hyb
0	0.12	$^{+0.46}_{-0.47}$	$^{+0.44}_{-0.463}$	$^{+0.42}_{-0.447}$	0.10	$^{+0.32}_{-0.31}$	$^{+0.313}_{-0.333}$	$^{+0.313}_{-0.333}$
1	−0.69	$^{+0.58}_{-0.27}$	$^{+0.59}_{-0.267}$	$^{+0.537}_{-0.25}$	−0.57	$^{+0.34}_{-0.31}$	$^{+0.35}_{-0.29}$	$^{+0.35}_{-0.29}$
2	0.53	$^{+0.24}_{-0.33}$	$^{+0.333}_{-0.36}$	$^{+0.297}_{-0.32}$	−0.96	$^{+0.22}_{-0.21}$	$^{+0.23}_{-0.163}$	$^{+0.23}_{-0.163}$
3	−0.47	$^{+0.27}_{-0.23}$	$^{+0.307}_{-0.25}$	$^{+0.283}_{-0.23}$	−0.64	$^{+0.15}_{-0.19}$	$^{+0.18}_{-0.183}$	$^{+0.18}_{-0.183}$
5	−0.53	$^{+0.2}_{-0.14}$	$^{+0.153}_{-0.137}$	$^{+0.16}_{-0.14}$	−0.69	$^{+0.11}_{-0.14}$	$^{+0.097}_{-0.12}$	$^{+0.107}_{-0.123}$
7	−0.33	$^{+0.24}_{-0.23}$	$^{+0.257}_{-0.23}$	$^{+0.25}_{-0.227}$	−0.66	$^{+0.13}_{-0.2}$	$^{+0.143}_{-0.17}$	$^{+0.143}_{-0.17}$
8	−0.53	$^{+0.19}_{-0.19}$	$^{+0.217}_{-0.21}$	$^{+0.207}_{-0.2}$	−0.56	$^{+0.12}_{-0.12}$	$^{+0.137}_{-0.143}$	$^{+0.137}_{-0.143}$

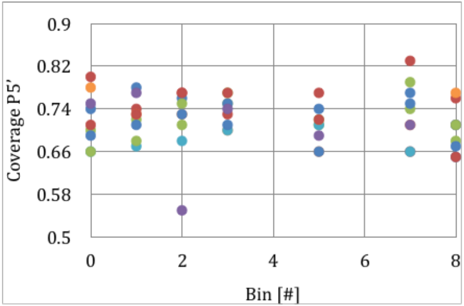
FC: Feldman-Cousins — CM: $DLL < 0.5$ — Hyb: bayesan approach on profiled $\mathcal{L}$

In red the most significant (?) differences

Custom-MINOS method

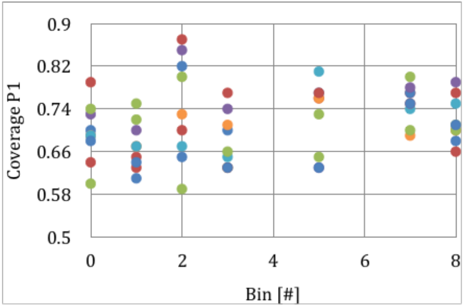
- The same idea as MINOS, but compued *by-hand* on the likelihood grid
- Looking for the outermost points in the scan with $\Delta NLL \leq 0.5$
- The boundary could affect the validity of this method
- The coverage was tested to be compatible with the expectations

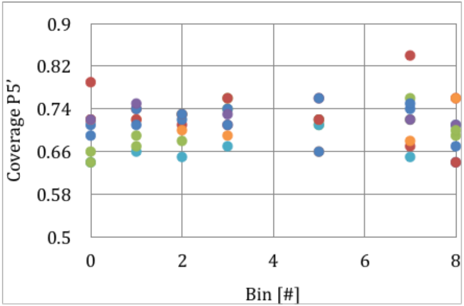




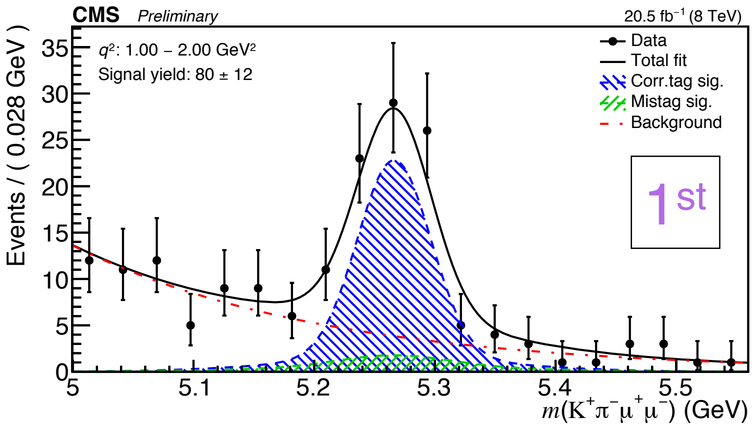
Hybrid-bayesian method

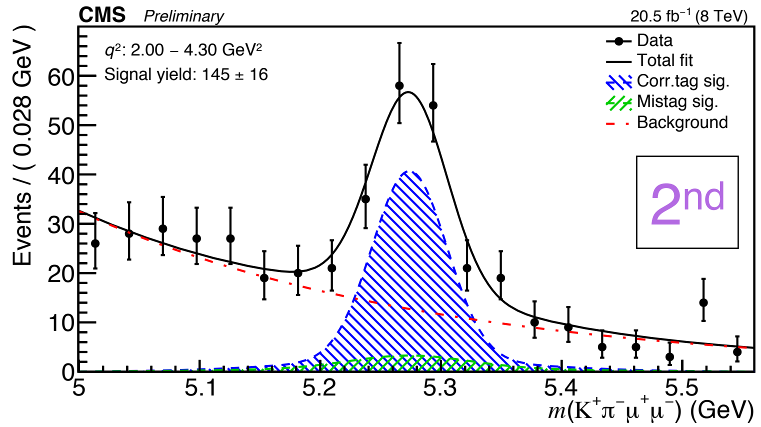
- For each parameter, the 2D likelihood scan is profiled to get a 1D function
- The Bayes theorem is applied to it, with a prior uniform inside the range of validity
- The confidence interval is defined to contain the 68% of the posterior distribution integral
- The coverage was tested to be compatible with the expectations

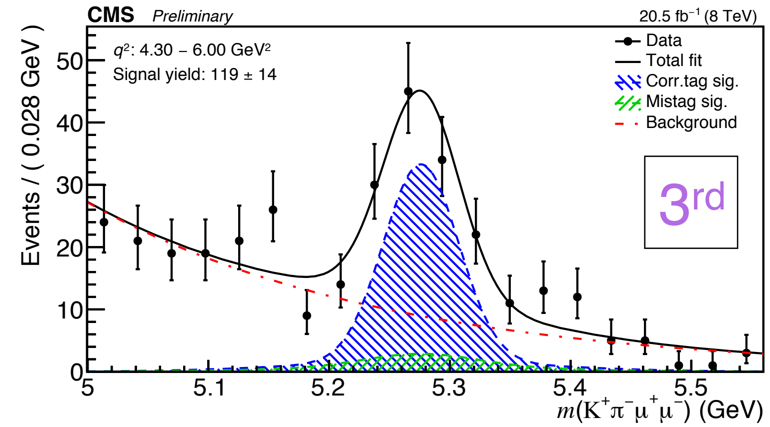


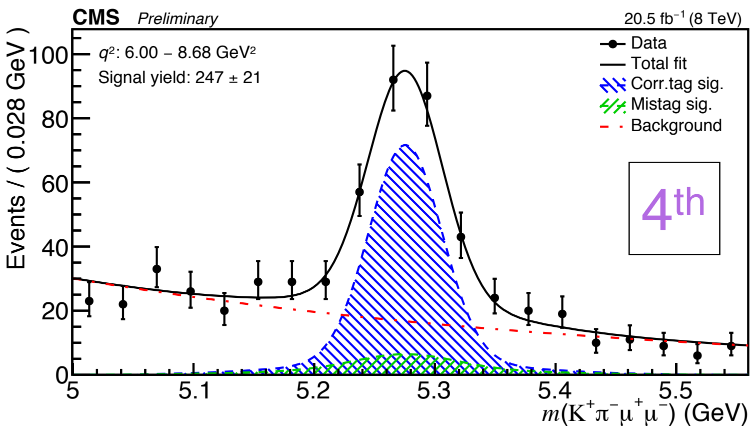


Signal evidence

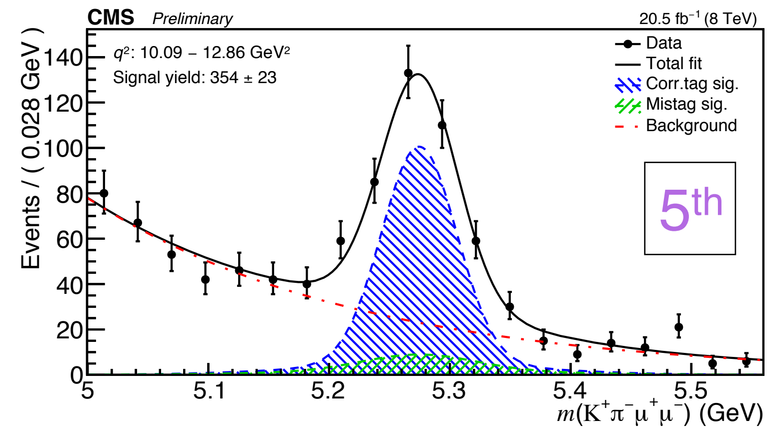




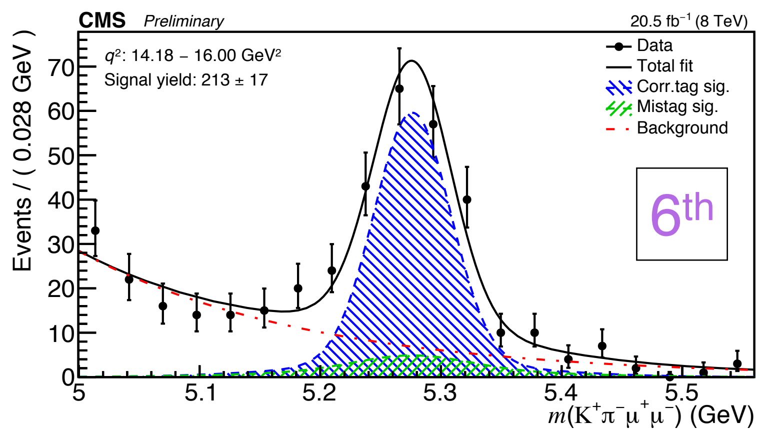


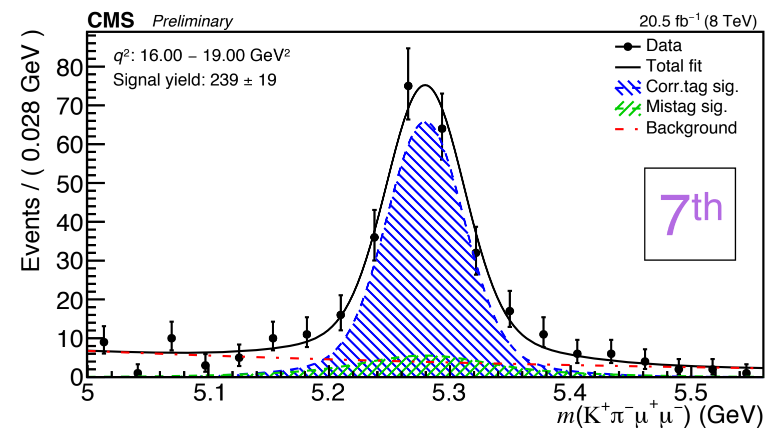


$B^0 \to K^{*0}\, J/\psi$



$B^0 \to K^{*0}\, \psi(2S)$





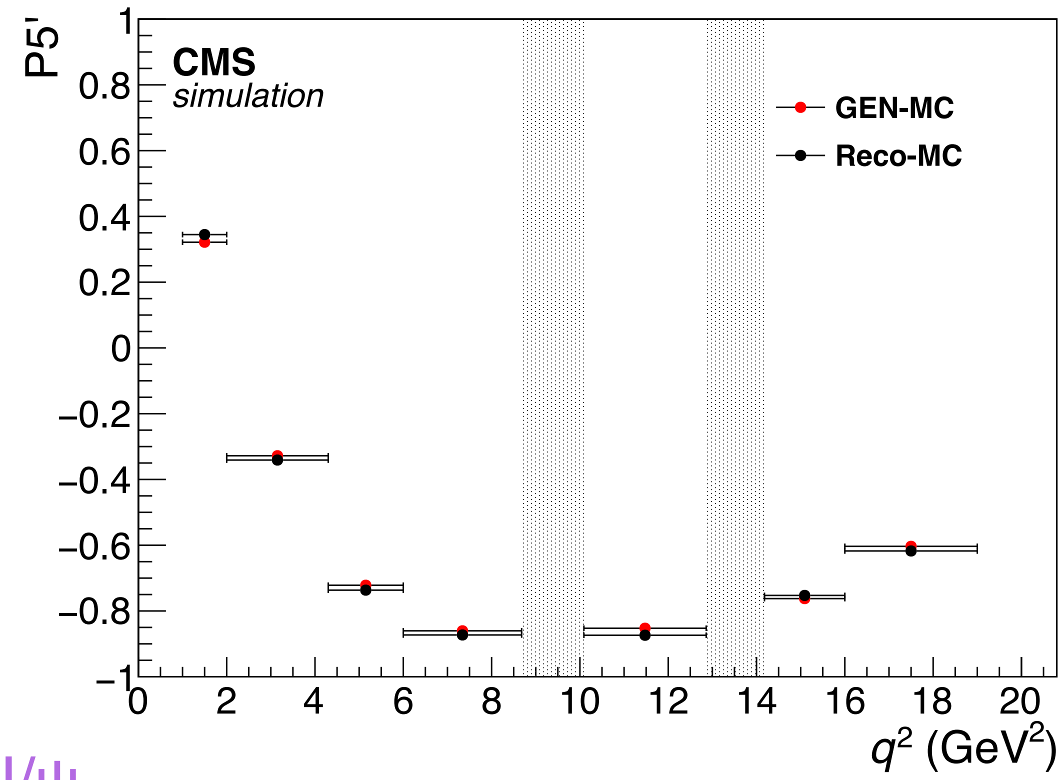
Legend ➜

- **Total fit**
- **Signal, correctly tagged events**
- **Signal, mistagged events**
- **Background**

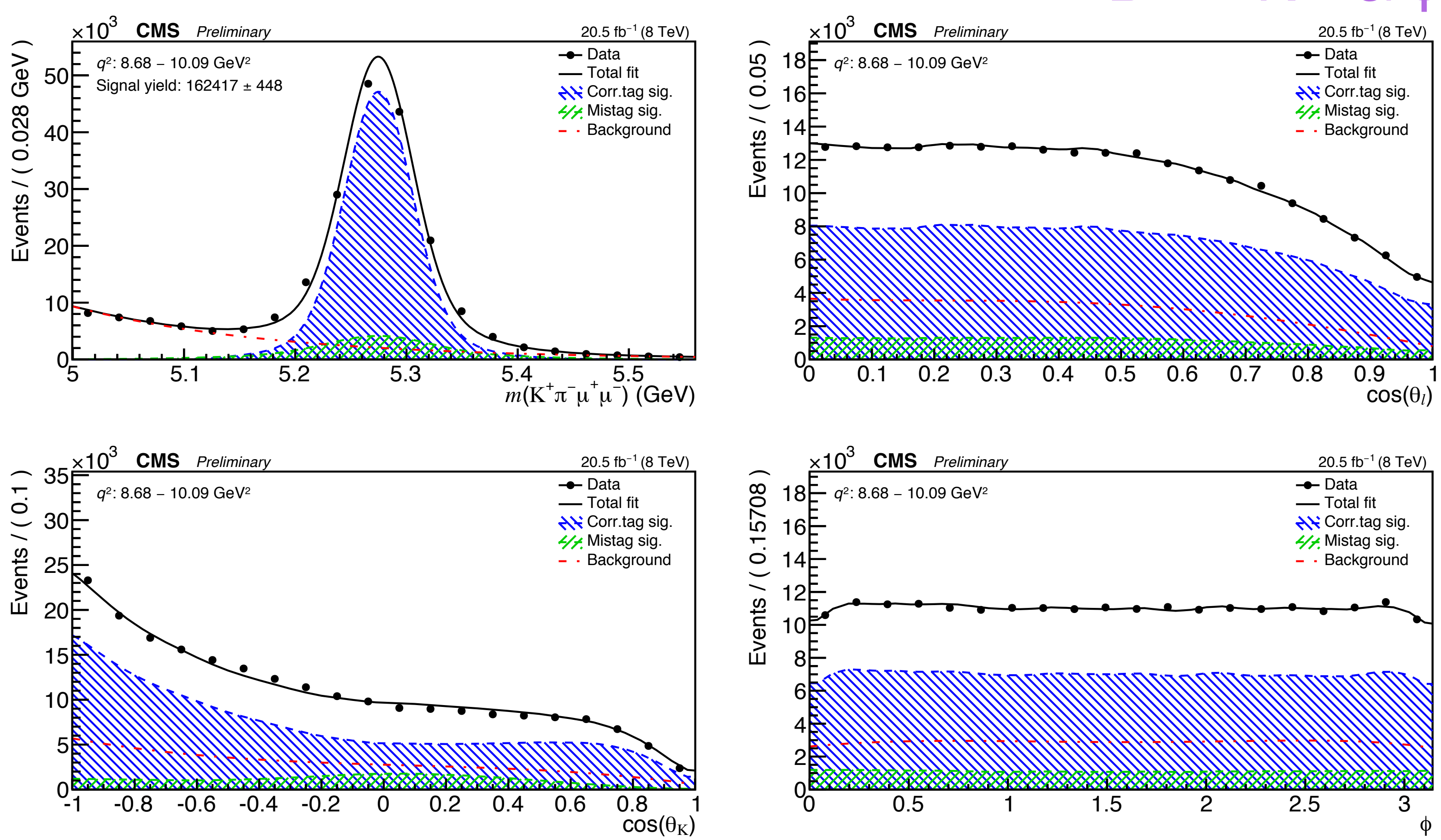
Fit validation

Several validation steps are performed with simulation:

- with statistically precise MC signal sample: compare fit results with input values to the simulation (**simulation mismodeling**)
- with 200 data-like MC signal+background samples: compare average fit results with fit to the statistically precise MC signal sample (**fit bias**)
- with pseudo-experiments



$B^0 \rightarrow K^{*0} J/\psi$



Validation with data control channels:

- Fit performed with F_L free to vary
- The difference of F_L with respect to PDG value is propagated to the signal q^2 bins as systematic uncertainty (**efficiency**)

Systematic uncertainties

Systematic uncertainty	$P_1 (10^{-3})$	$P'_5 (10^{-3})$
Simulation mismodeling	1–33	10–23
Fit bias	5–78	10–119
MC statistical uncertainty	29–73	31–112
Efficiency	17–100	5–65
$K\pi$ mistagging	8–110	6–66
Background distribution	12–70	10–51
Mass distribution	12	19
Feed-through background	4–12	3–24
F_L, F_S, A_S uncertainty propagation	0–126	0–200
Angular resolution	2–68	0.1–12
Total systematic uncertainty	60–220	70–230

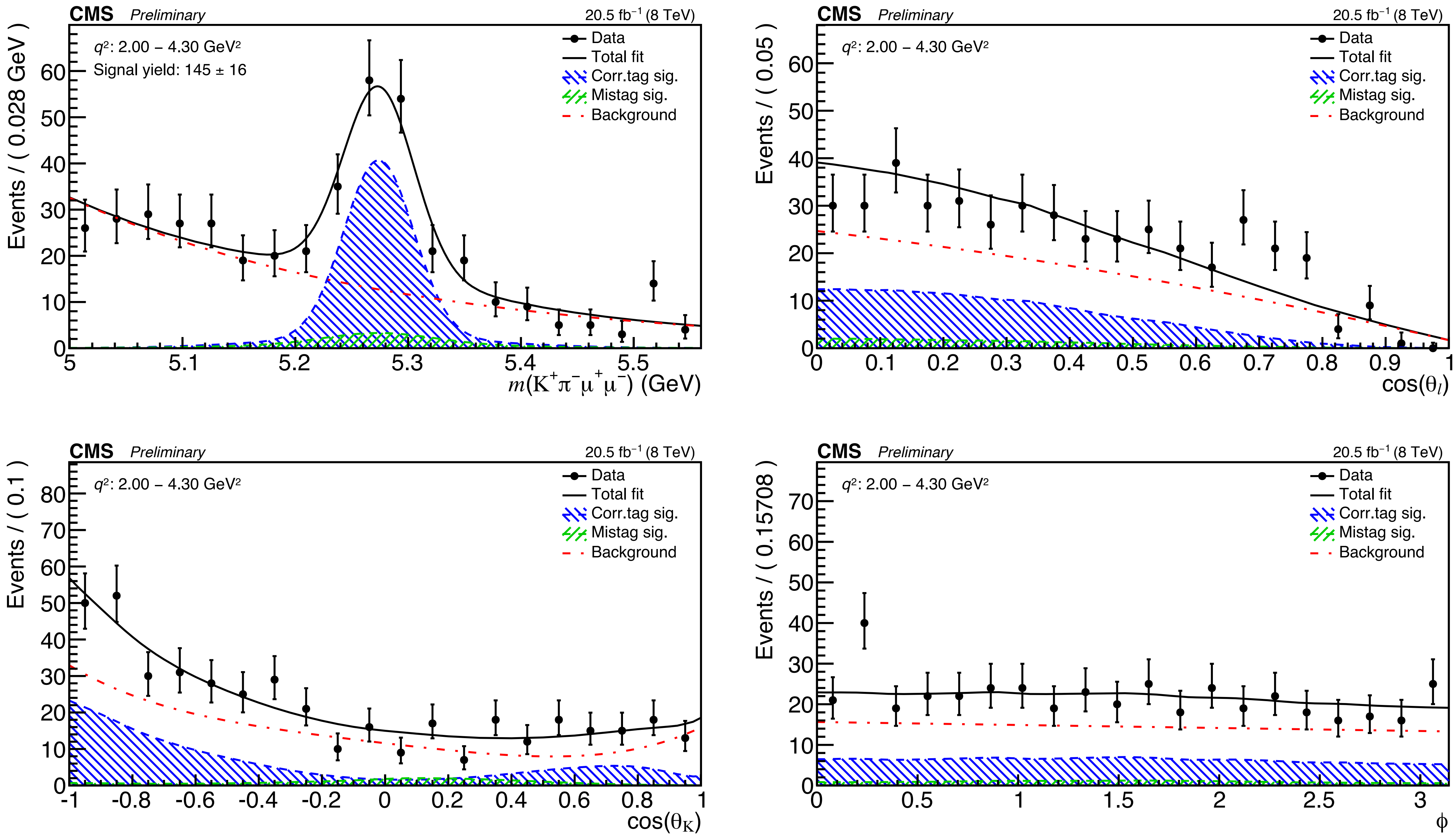
MC statistical uncertainty: fit data with 100 new efficiency distributions generated according to the simulation statistical uncertainty ➜ effect of the different efficiency functions on final result is used to estimate the systematic uncertainty

Kπ mistagging: mistag fraction free to vary in control channel $B^0 \to K^{*0}\, J/\psi$ ➜ discrepancy with respect to simulation is propagated to angular parameters

F_L, F_S, and A_S uncertainty propagation:

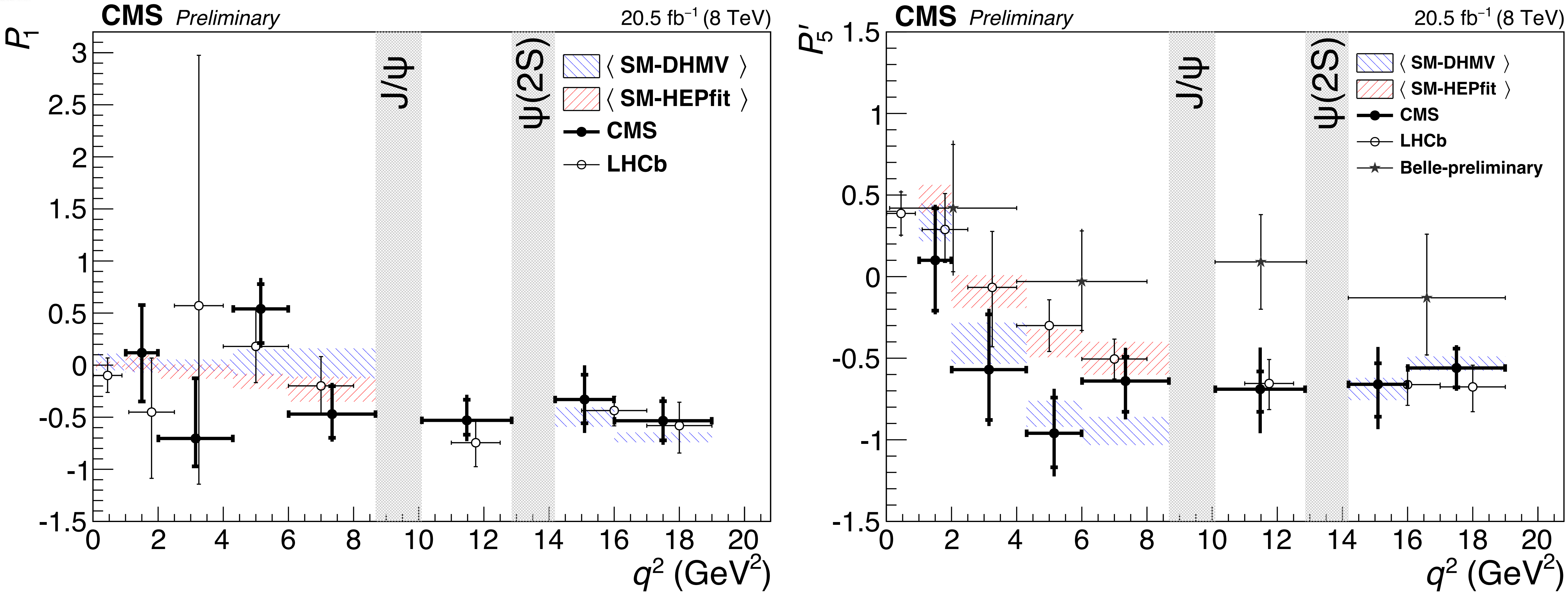
- Generate a statistically precise, $O(100 \times \text{data})$, pseudo-experiments (one per q^2 bin)
- Fit with all 6 angular parameters free to vary
- Fit with F_L, F_S, and A_S fixed
- Ratio of uncertainties between free and partially-fixed fit is used to compute the systematic uncertainty

Preliminary results: 2nd q^2 bin



<u>Representative fit results</u>: vertical bars give the statistical uncertainties, horizontal bars the bin width (fits to all other q^2 bins are in backup slides)

Preliminary results



- Inner vertical bars ➜ statistical uncertainty
- Outer vertical bars ➜ total uncertainty
- Horizontal bars ➜ bin widths

- Statistical uncertainty is the dominant contribution but in 5th and 6th q^2 bins were it is comparable to systematic uncertainty

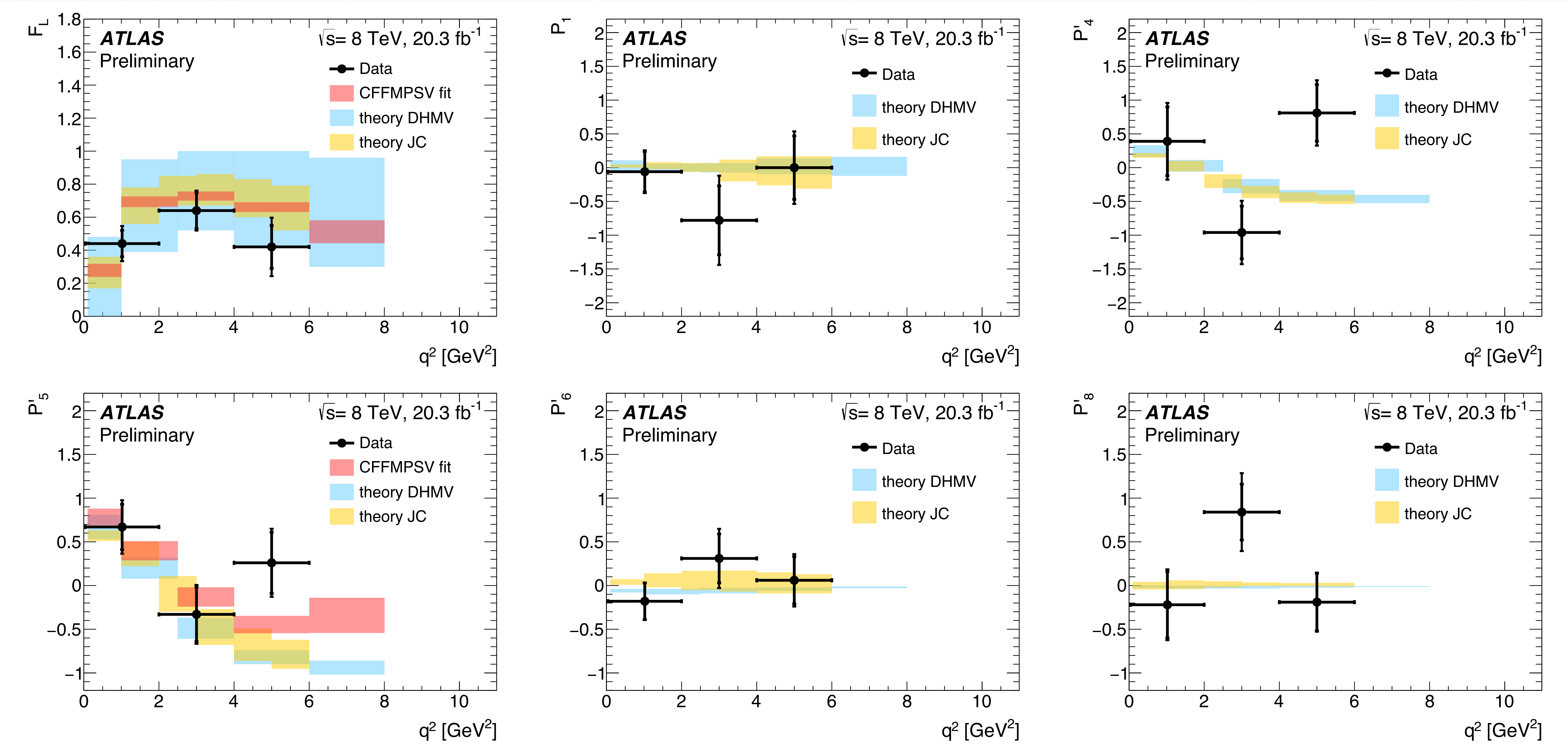
- **SM-DHMV** is computed using soft form factors in conjunction with parametrized power corrections, and with the hadronic charm-loop contribution derived from calculations
- **SM-HEPfit** uses full QCD computation of the form factors and derives the hadronic contribution from LHCb data

- LHCb: *JHEP 02 (2016) 104*
- Belle-preliminary: *arXiv:1612.05014*
- SM-DHMV: *JHEP 01 (2013) 048, JHEP 05 (2013) 137*
- SM-HEPfit: *JHEP 06 (2016) 116, arXiv:1611.04338*

ATLAS-CONF-2017-023

Angular analysis results on $B_d \to K^* \mu^+ \mu^-$

- Results are compatible with theoretical calculations & fits:

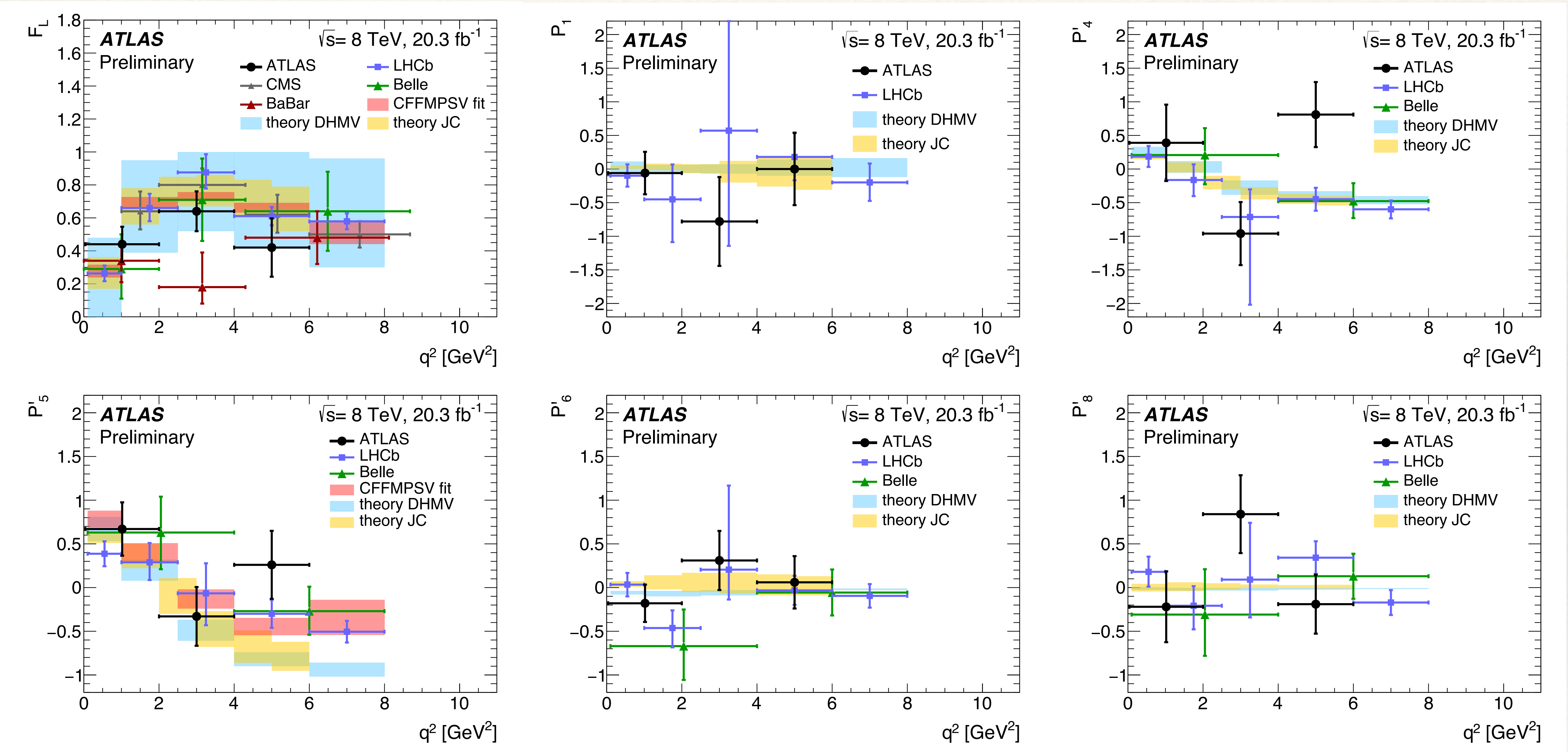


CFFMPSV: Ciuchini et al.; JHEP **06** (2016) 116; arXiv:1611.04338.
DMVH: Decotes-Genon et al.; JHEP **01** (2013) 048; JHEP **05** (2013) 137; JHEP **12** (2014) 125.
JC: Jäger-Camalich; JHEP **05** (2013) 043; Phys. Rev. **D93** (2016) 014028.

ATLAS-CONF-2017-023

Angular analysis results on $B_d \to K^* \mu^+ \mu^-$

- Results are compatible with theoretical calculations & fits:



CFFMPSV: Ciuchini et al.; JHEP **06** (2016) 116; arXiv:1611.04338.

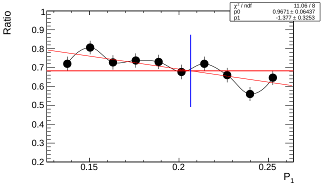
DMVH: Decotes-Genon et al.; JHEP **01** (2013) 048; JHEP **05** (2013) 137; JHEP **12** (2014) 125.

JC: Jäger-Camalich; JHEP **05** (2013) 043; Phys. Rev. **D93** (2016) 014028.

Additional stuff

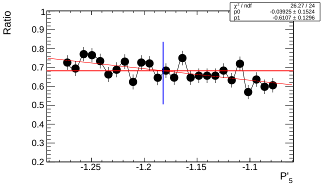
Additional or backup slides

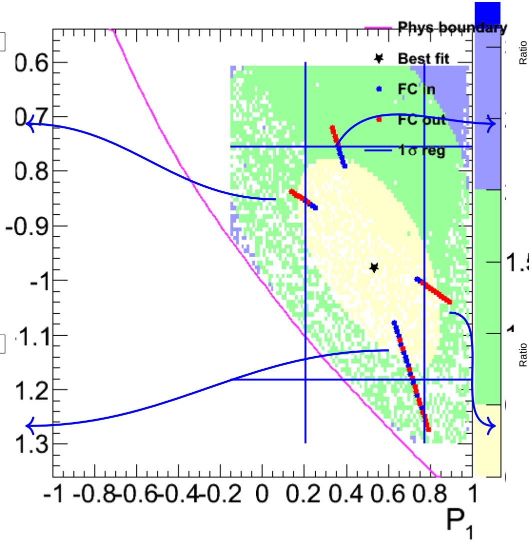
Bin 2 NEW

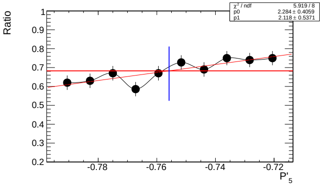


Done

Done

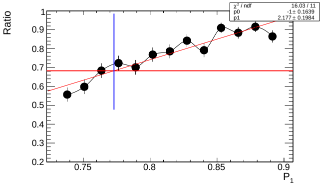




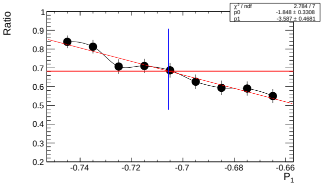


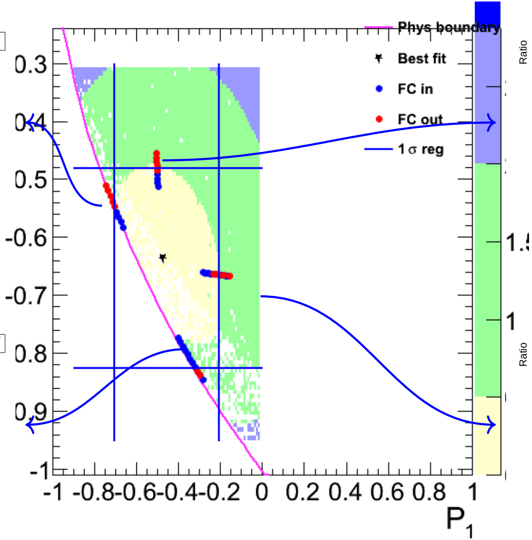
Done

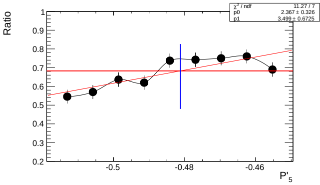
Done



Bin 3 NEW

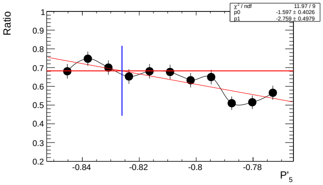


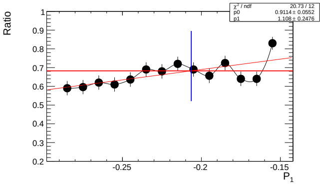


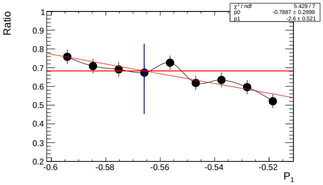


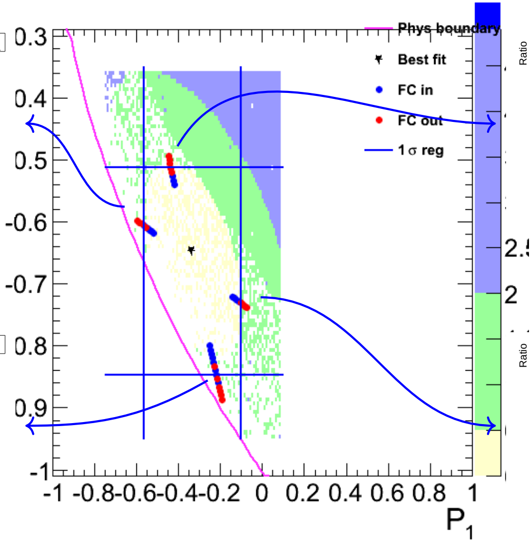
Done
Done

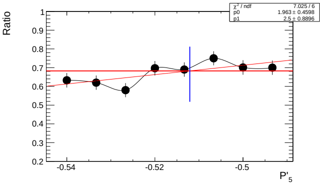
Done
Done





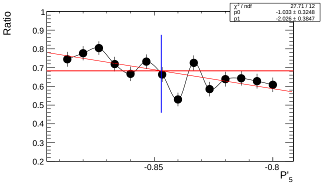


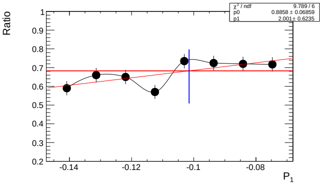




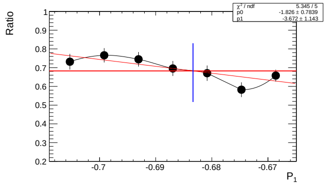
Done
Done

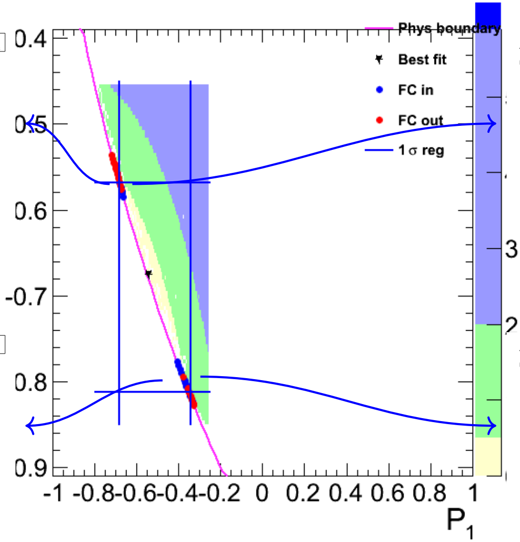
Done
No

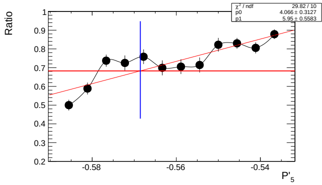




Bin 5 NEW

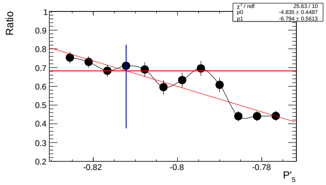


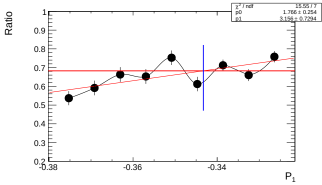




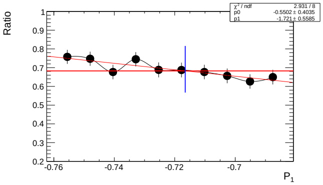
Done
Done

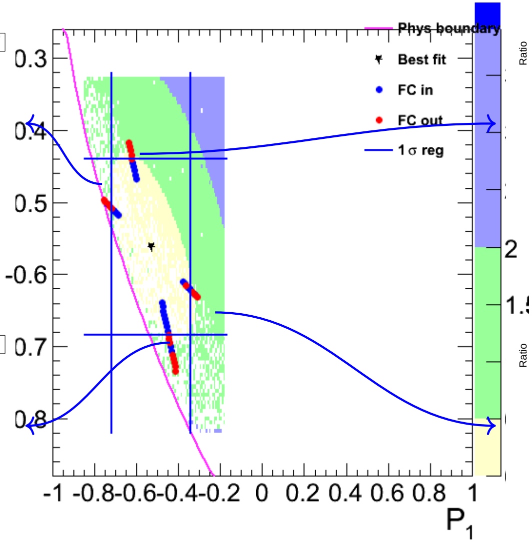
Done
Done

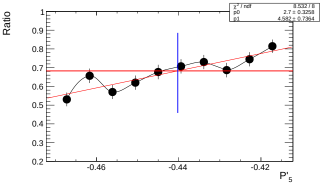




Bin 8 NEW





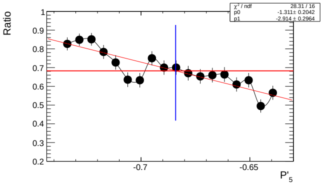


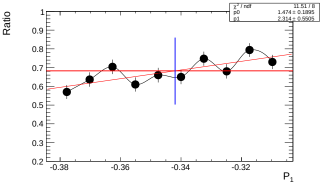
Done

Done

Done

Done





Proposed solution: “Custom MINOS”

Proposed solution (“Custom MINOS”)

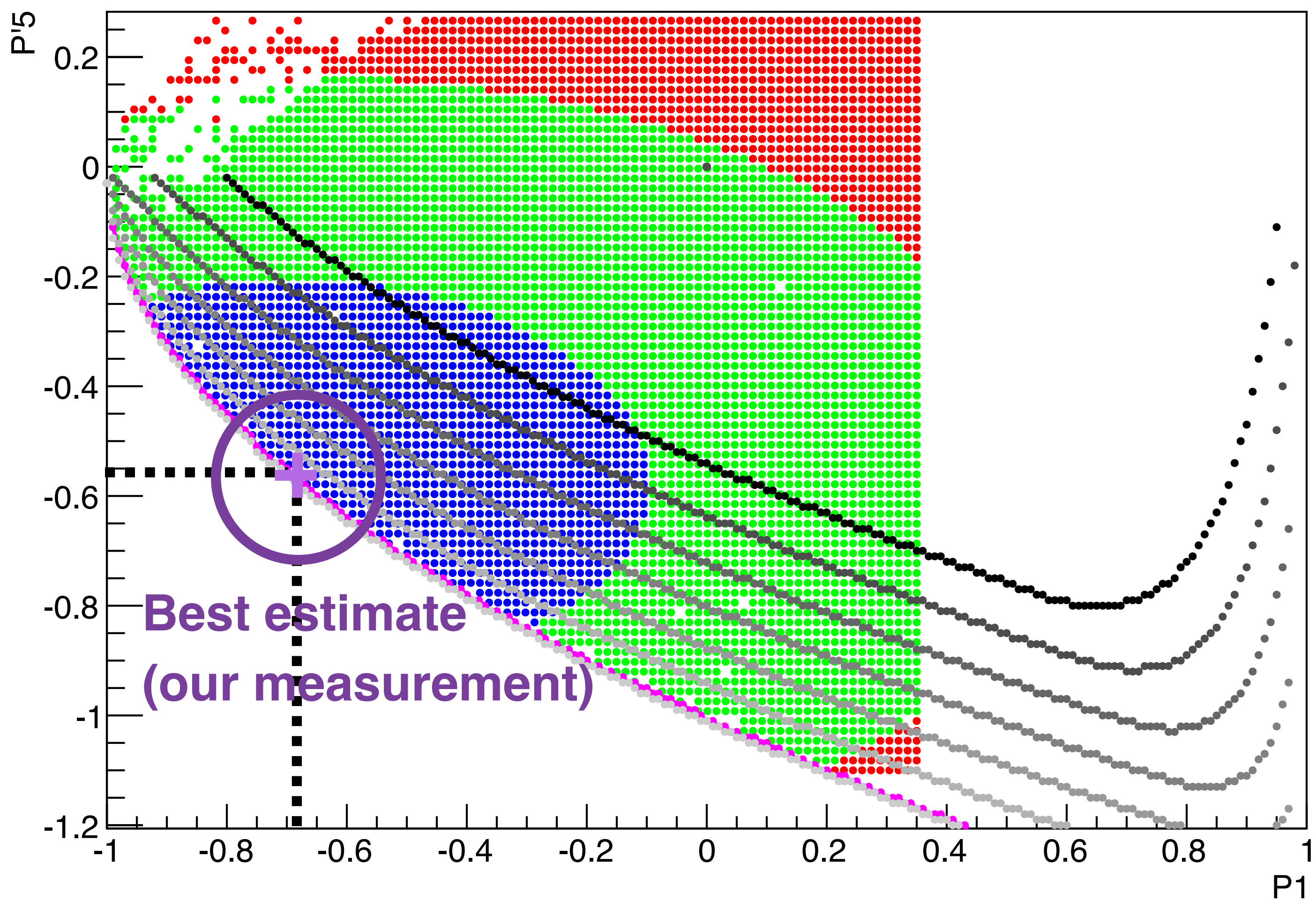
1. Discretise the P_1-P_5’ domain
2. Maximise the likelihood for $\mathbf{Y_S}$, $\mathbf{Y_B}$ an $\mathbf{A^5_s}$ at each point of the P_1-P_5’ domain
3. Best estimate of P_1 and P_5’: point in the P_1-P_5’ domain with maximal likelihood

4. Fit likelihood distribution on the P_1-P_5’ domain at point **2.** with a 2D gaussian
5. Find the contour at ΔNLL = 0.5 of the 2D gaussian in the physical domain

6. Statistical uncertainties: projection of the contour on the P_1 and P5’ axis

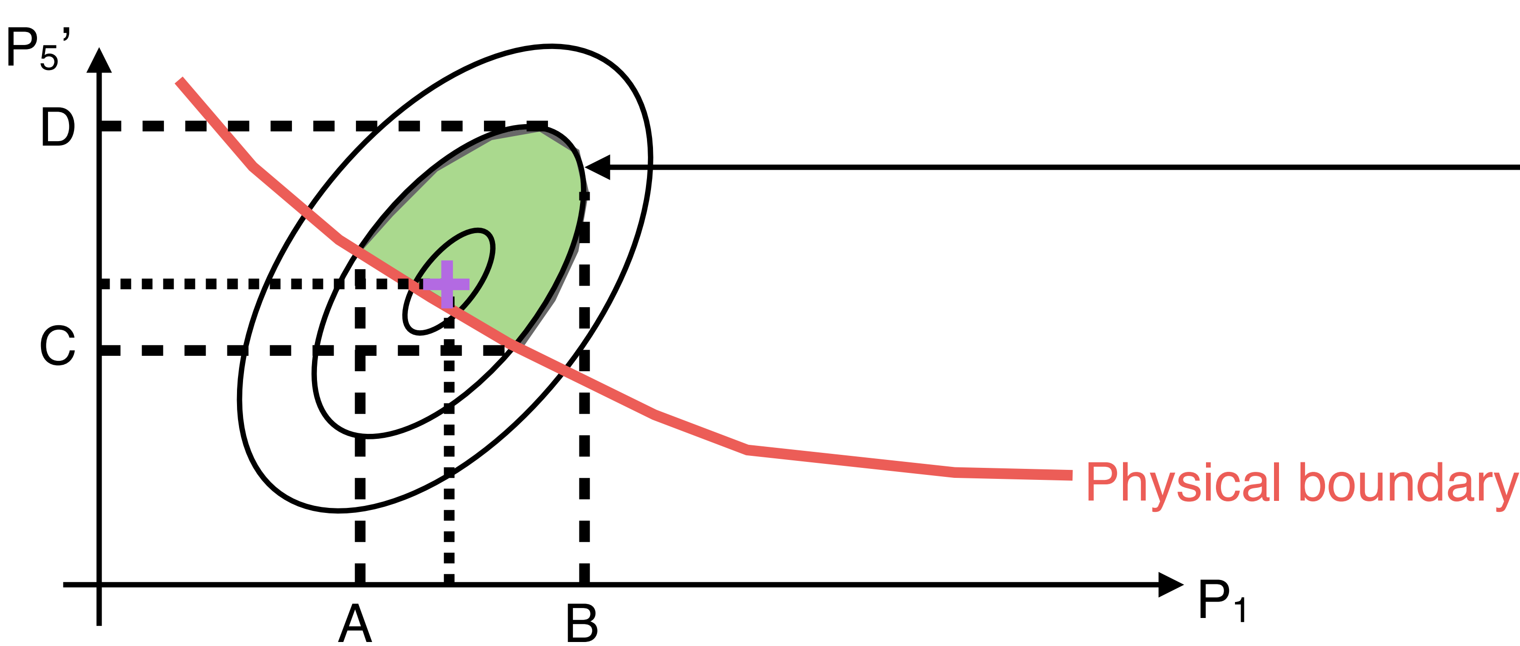
Justification for this method: it is well known that for a “well behaving” likelihood (*e.g.* not too skewed) the projection of ΔNLL = 0.5 contour on both axis defines 68% confidence intervals

Alternative proposed solution: bin 1



Coloured region only meant to give a feeling about negative log likelihood (NLL) gradient

- blue = span 0 to 1/2 ΔNLL
- green = span 0.5 to 2 ΔNLL



- Fit coloured region with 2D gaussian
- Find contour at 0.5 ΔNLL of 2D gaussian in physical domain
- Project the contour on the P1 and P5' axis to find statistical uncertainty

Alternative proposed solution: "Hybrid frequentist-bayesian"

Proposed solution: "Hybrid frequentist-bayesian"

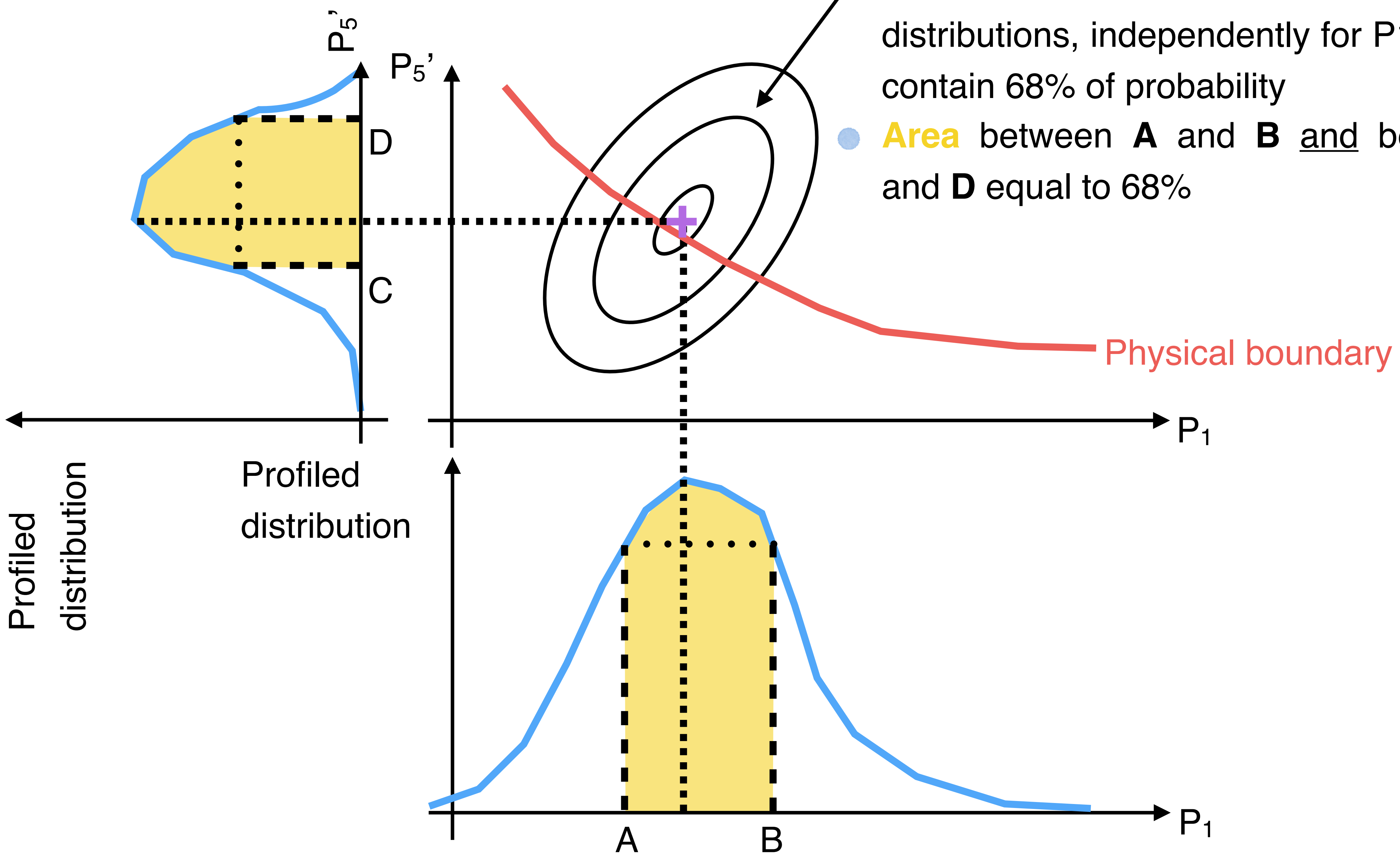
1. Discretise the P_1-P_5' domain
2. Maximise the likelihood for $\mathbf{Y_S}$, $\mathbf{Y_B}$ an $\mathbf{A^5_s}$ at each point of the P_1-P_5' domain
3. Best estimate of P_1 and P_5': point in the P_1-P_5' domain with maximal likelihood

4. Fit likelihood distribution on the P_1-P_5' domain at point **2.** with a 2D gaussian
5. Normalise the 2D gaussian to 1 in the physical domain

6. Statistical uncertainties: define intervals in which the profiled distributions, independently for P_1 and P_5', contain 68% of probability

Justification for this method: we apply the bayesian theorem to both the 1D profiled likelihood

Alternative proposed solution: bin 1



- Fit coloured region with 2D gaussian
- Normalise 2D gaussian to 1 in physical domain
- Define intervals in which the profiled distributions, independently for P1 and P5', contain 68% of probability
- Area between **A** and **B** <u>and</u> between **C** and **D** equal to 68%