Flavour-tagged time-dependent analysis of the $B^0 \to K_S^0 \eta'$ decay with Run2 + Run3 data

B2EtapKs + Bs2Kspipi + B2Kpipi0 + Bs2KsKs joint meeting

Pio Francesco Varrella - 08-09-2026

Fit to get acceptance shape

$$f_{tanh}(t,\vec{p})[RooBDecay(\ldots,1.0,1.0,0.0,0.0,\ldots)\otimes G(0,0.05)]$$

analytical form

with tanh

$$e^{-\Gamma t}\left[cosh\left(\frac{\Delta\Gamma t}{2}\right)+A_f sinh\left(\frac{\Delta\Gamma t}{2}\right)\right]$$

t<p_{10}

$$p_0[1+p_1 tanh(p_2(t-p_3))+p_4 tanh(p_5(t-p_6)+p_7(t-p_6)^2+p_8(t-p_6)^3)] \longrightarrow p_0[1+p_1 tanh(p_2(t-p_3))+p_4 tanh(p_5(t-p_6)+p_7(t-p_{11})^2+p_8(t-p_{12})^3)]$$

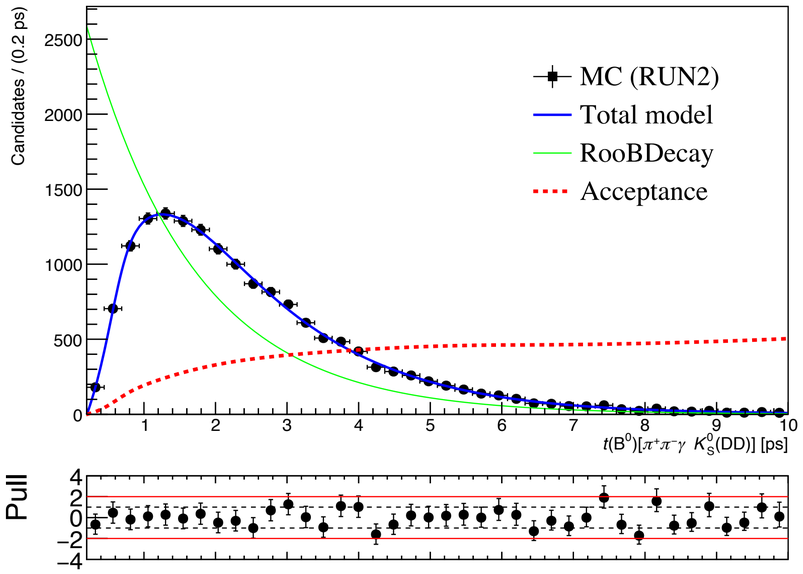
t>p_{10}

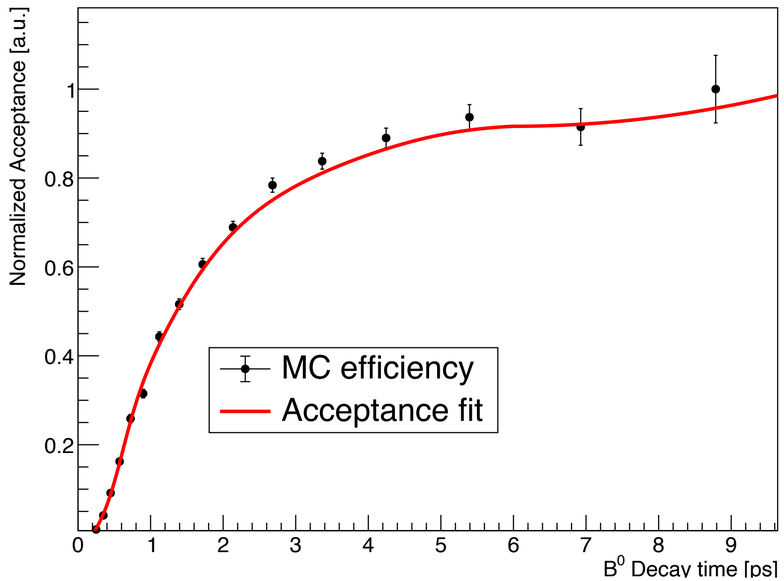
$$p_0\left[[1+p_1 tanh(p_2(p_{10}-p_3))+p_4 tanh(p_5(p_{10}-p_6)+p_7(p_{10}-p_6)^2+p_8(p_{10}-p_6)^3)][1+p_9(t-p_{10}^2)]\right]$$

$$p_0\left[[1+p_1 tanh(p_2(p_{10}-p_3))+p_4 tanh(p_5(p_{10}-p_6)+p_7(p_{10}-p_{11})^2+p_8(p_{10}-p_{12})^3)][1+p_9(t-p_{10}^2)]\right]$$

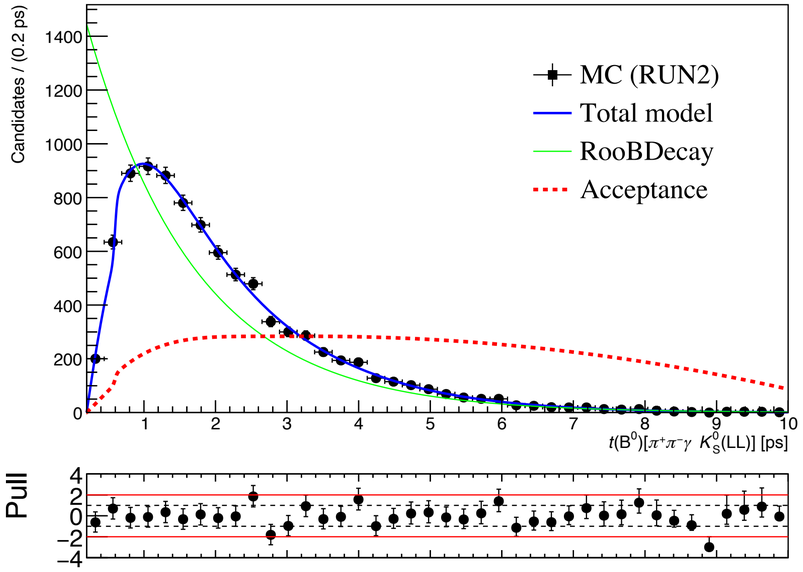
Fit to (TM) Signal MC to get decay-time acceptance

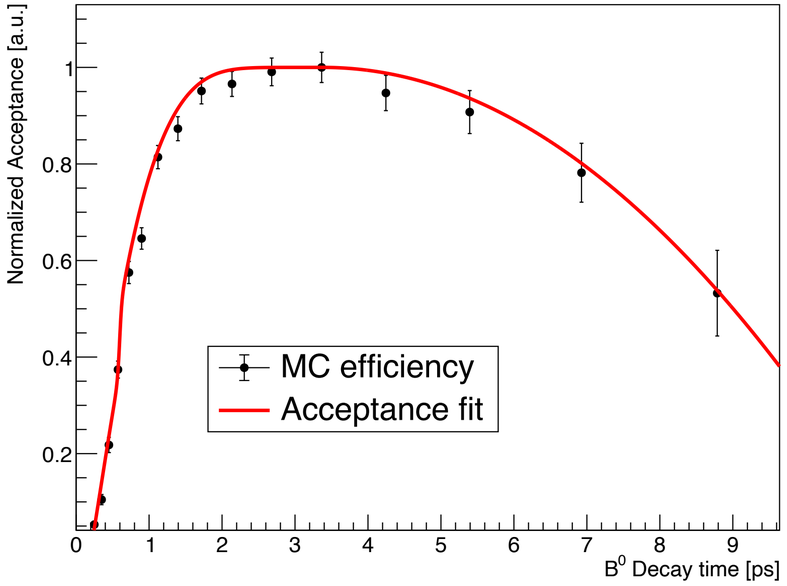
1g DD





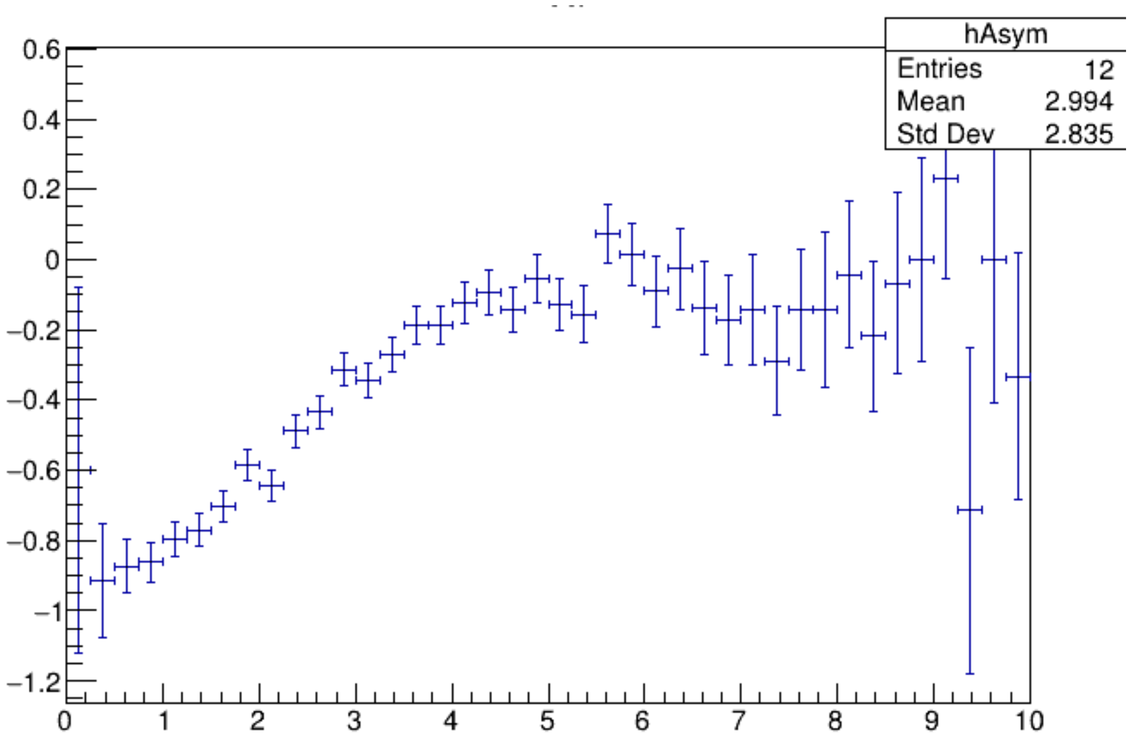
1g LL



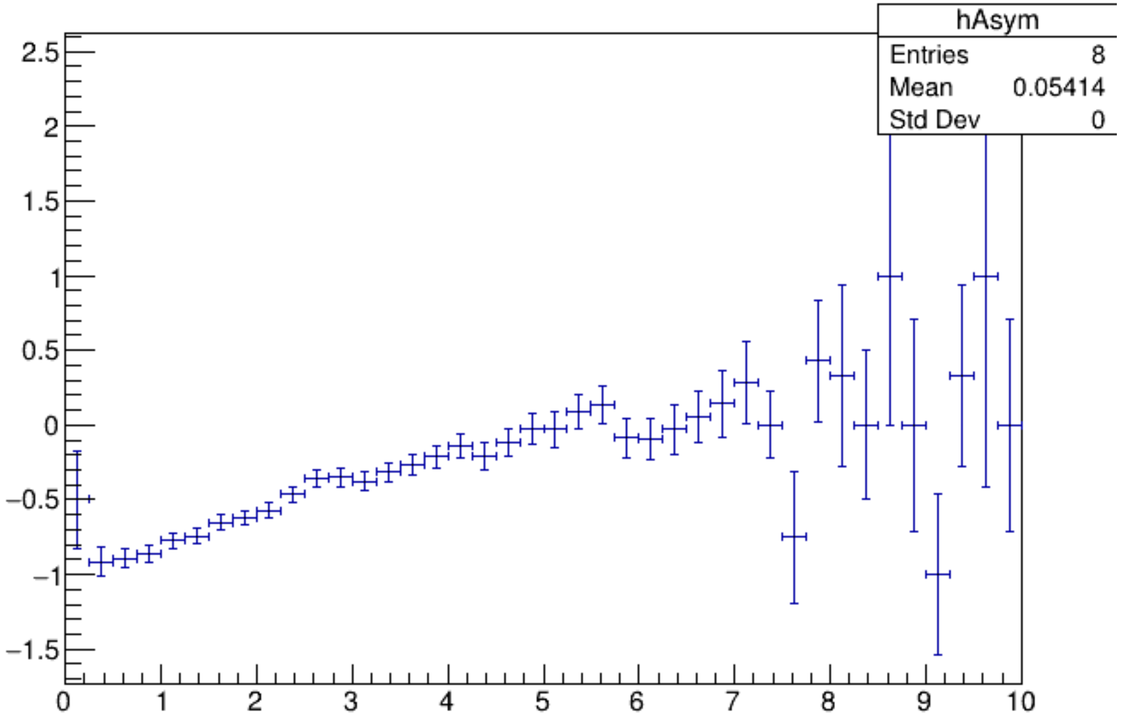


And 2g's ? Bug in decfile giving a non-zero CP asymmetry for NoCPV MC

2g DD



2g LL



Plots show the CP asymmetry of NoCPV (Sig) MC in function of decay-time

→ Ready MR to correct problem in buggy decfile

Fit to test Signal Model

$$\epsilon_{MC}(t)[RooBDecay(\ldots, fcosh, fsinh, fcos, fsin, \ldots) \otimes G(0,0.05)]$$

fixed from

previous fit

$$q = +1(-1)\ for\ B0_TRUEID = 511(-511)$$

$$\omega = 0 = \bar{\omega}$$

$$fcosh = \delta_{q,1}(1 - \omega + \bar{\omega}) + \delta_{q,-1}(1 + \omega - \bar{\omega})$$

$$fcos = -C[\delta_{q,1}(1 - \omega - \bar{\omega}) - \delta_{q,-1}(1 - \omega - \bar{\omega})]$$

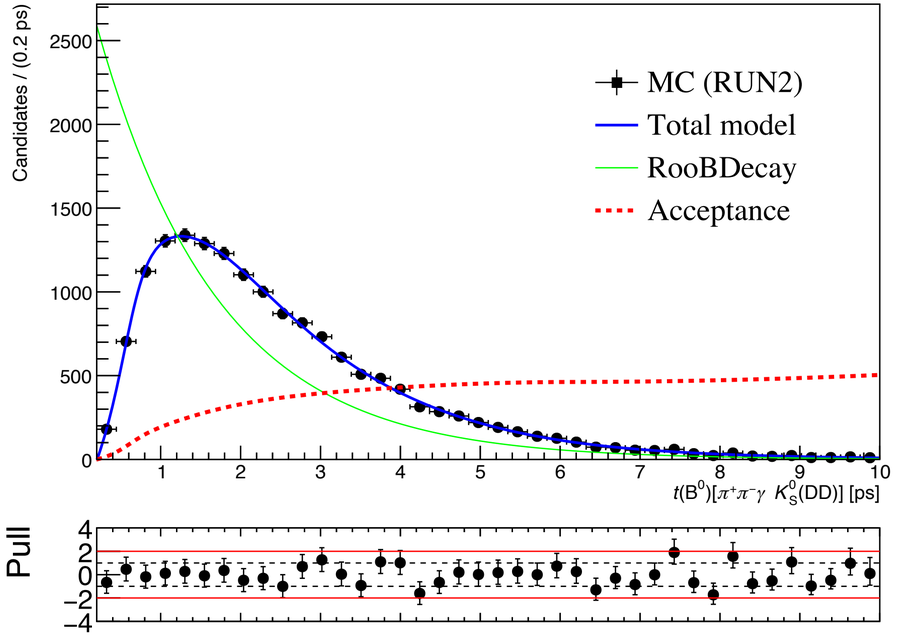
$$fsinh = -D[\delta_{q,1}(1 - \omega + \bar{\omega}) + \delta_{q,-1}(1 + \omega - \bar{\omega})]$$

$$fsin = -S[\delta_{q,1}(1 - \omega - \bar{\omega}) - \delta_{q,-1}(1 - \omega - \bar{\omega})]$$

Fit to (TM) Signal MC with complete model

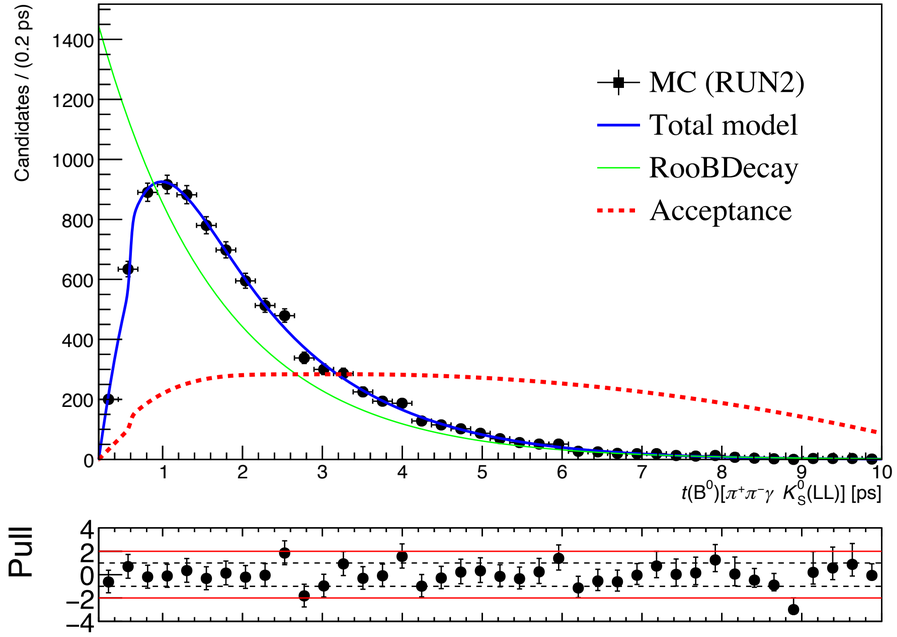
1g DD

$C = -0.029 \pm 0.03 \quad S = 0.003 \pm 0.02$



1g LL

$C = +0.06 \pm 0.03 \quad S = 0.009 \pm 0.02$



- **CovMatrix Quality: 3**
- **Fit status: 0**
- **Edm:** $\in [10^{-8}, 10^{-5}]$

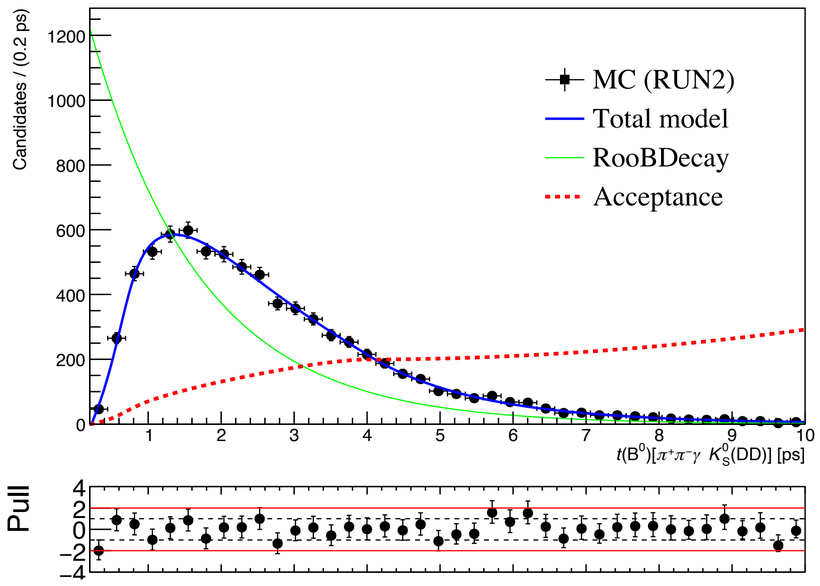
C and S not compatible with 0 for 2g's

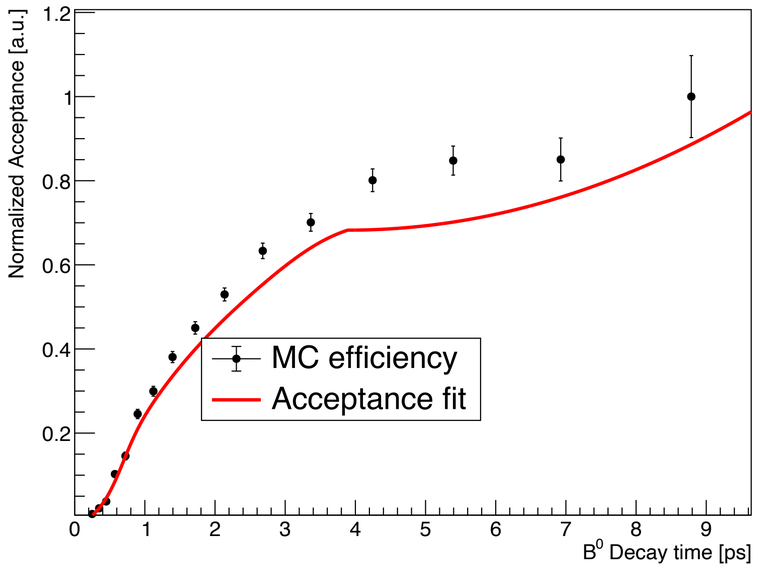
↓

Acceptance gets affected by decfile issue

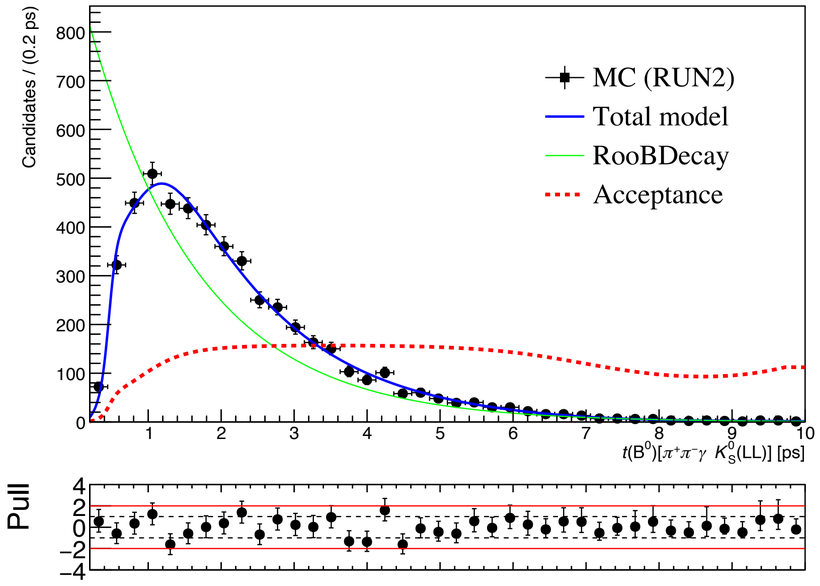
Fit to (TM) Signal MC with CPV to get decay-time acceptance

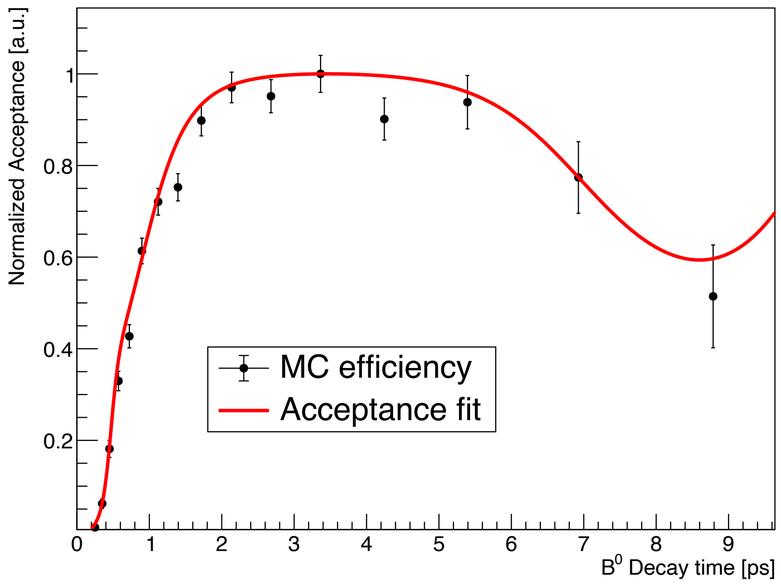
1g DD





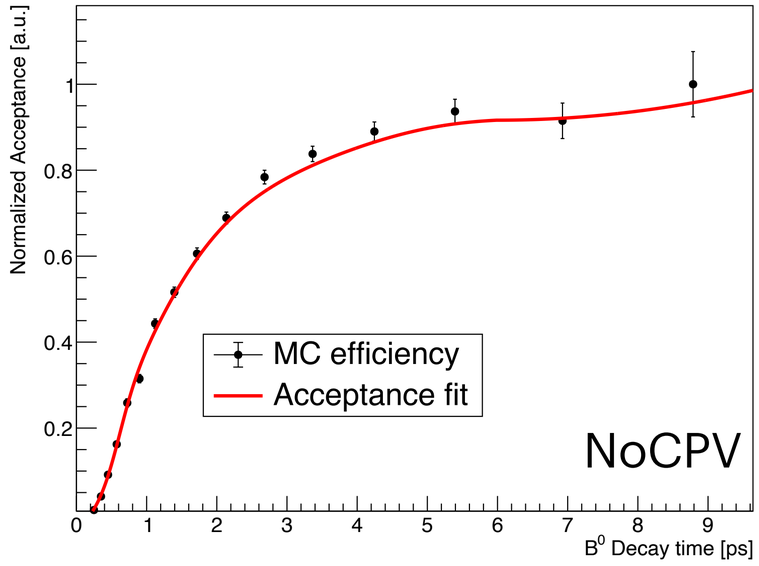
1g LL

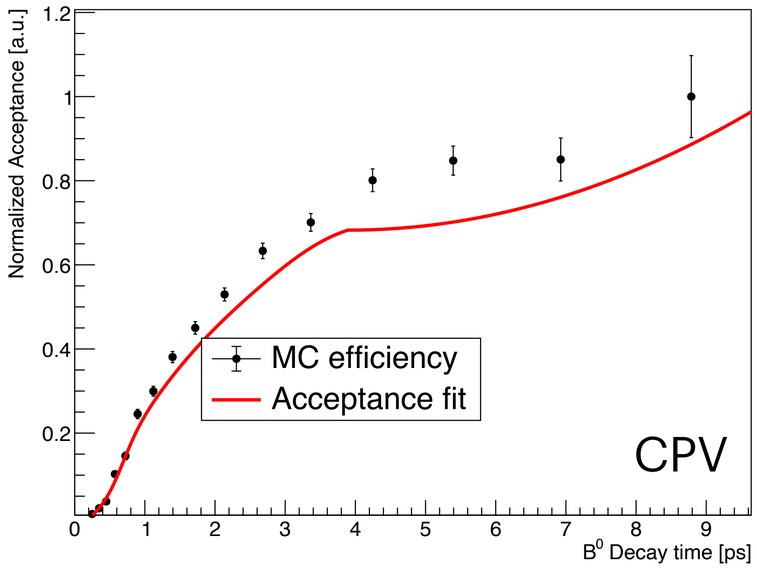




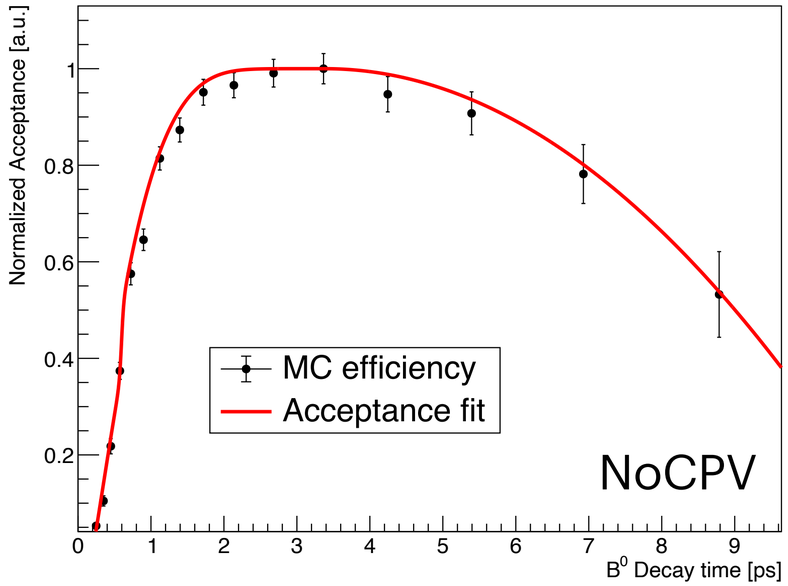
Comparison of acceptance shapes for 1g's from NoCVP to CPV MC

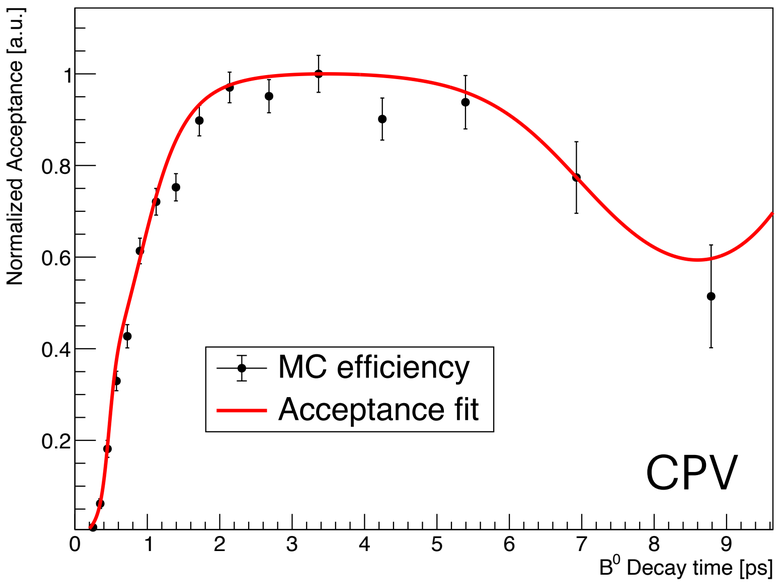
1g DD





1g LL





CPV values: comparison between generation and fit

$$\Delta m_d = 0.5065 \qquad \frac{\Delta\Gamma}{\Gamma} = 0 \qquad \left|\frac{q}{p}\right| = 1 \qquad arg\left(\frac{q}{p}\right) = +0.681553212$$

$$|A_f| = 0.951189731 \qquad arg(A_f) = 0 \qquad |\bar{A}_f| = 1 \qquad arg(\bar{A}_f) = 0$$

$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f} = \left|\frac{q}{p}\right| e^{i\cdot arg(q/p)} |\bar{A}_f| e^{i\cdot arg(\bar{A}_f)} \cdot \frac{1}{A_f} e^{-i\cdot A_f} = \frac{e^{i\cdot arg(q/p)}}{|A_f|}$$

$$\left(\begin{array}{c} |\lambda_f| = \dfrac{1}{|A_f|} \\ arg(\lambda_f) = arg(q/p) \end{array} \right.$$

$$S_f = \frac{2Im(\lambda_f)}{1+|\lambda_f|^2} = \frac{2\cdot|\lambda_f|\cdot sin(arg(\lambda_f))}{1+|\lambda_f|^2} = 0.01188 \qquad C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} = -0.04999$$

$$D_f = \frac{2Re(\lambda_f)}{1+|\lambda_f|^2} = \frac{2\cdot|\lambda_f|\cdot cos(arg(\lambda_f))}{1+|\lambda_f|^2} = 0.99867$$

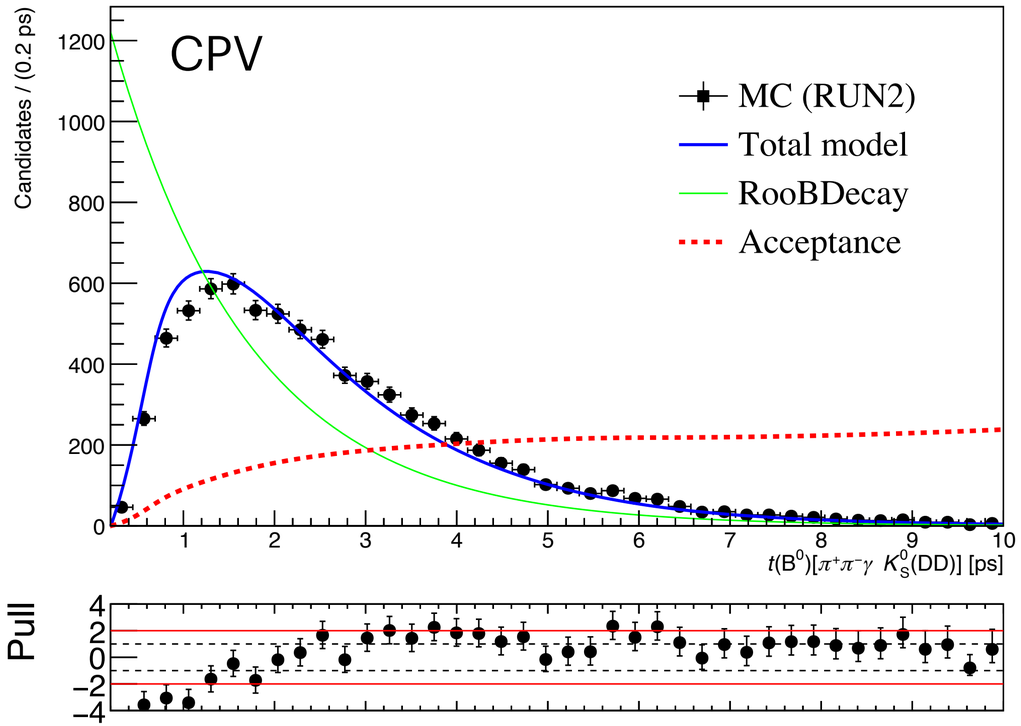
"CP violating parameters set to 2020 HFLAV averages"

Fit to (TM) Signal MC with CPV to test Signal model

$S_f = 0.01188$ $C_f = -0.04999$ $D_f = 0.99867$

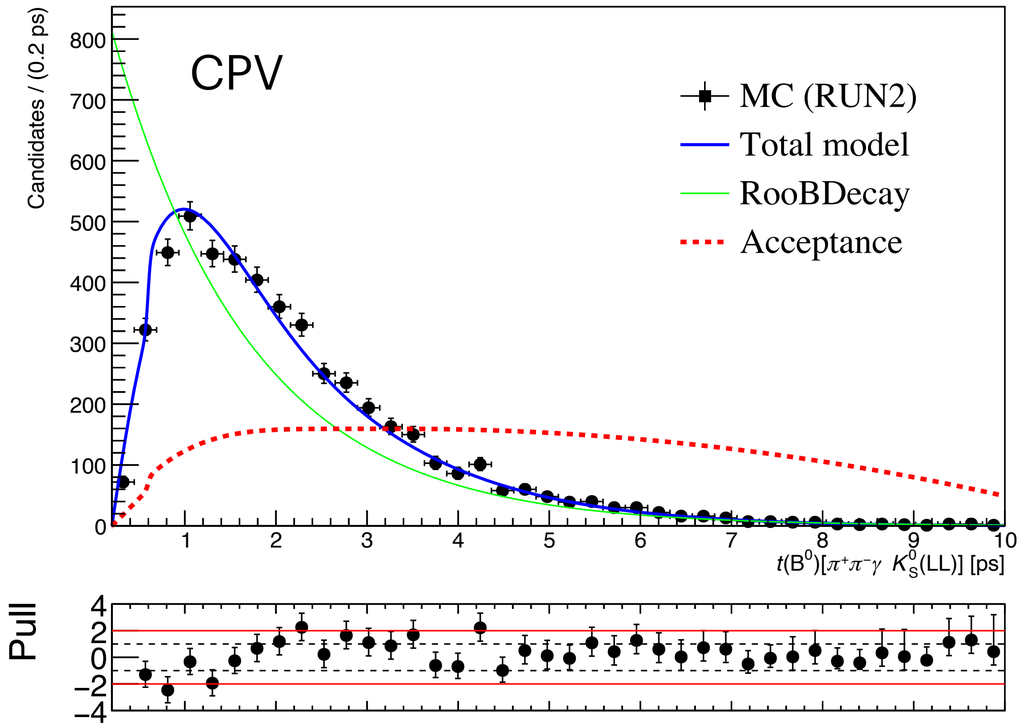
1g DD

$S = 0.24 \pm 0.02$ $C = -0.60 \pm 0.02$ $D = -0.48 \pm 1$



1g LL

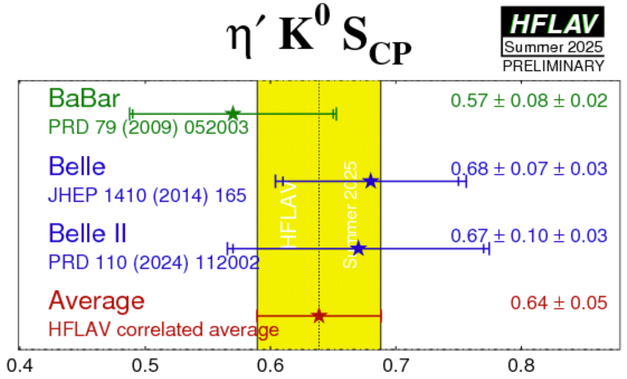
$S = 0.39 \pm 0.03$ $C = -0.41 \pm 0.03$ $D = -0.48 \pm 1$

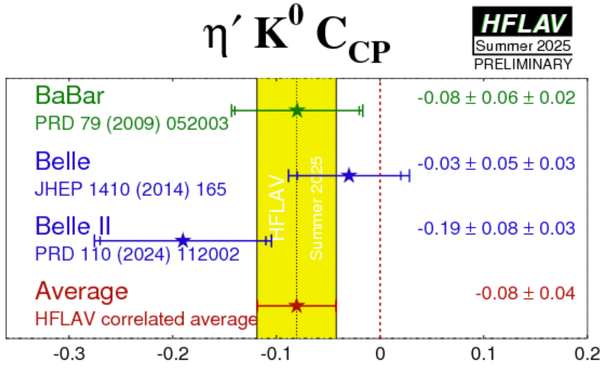


Fit to (TM) Signal MC with CPV using another code

$S_f = 0.01188$ $C_f = -0.04999$ $D_f = 0.99867$

1g DD	$S = -0.68 \pm 0.12$	$C = -0.27 \pm 0.01$	$D = -0.49 \pm 0.49$
1g LL	$S = -0.68 \pm 0.12$	$C = -0.27 \pm 0.01$	$D = -0.49 \pm 0.49$
2g DD	$S = -0.68 \pm 0.12$	$C = -0.27 \pm 0.02$	$D = -0.49 \pm 0.49$
2g LL	$S = -0.68 \pm 0.12$	$C = -0.27 \pm 0.02$	$D = -0.49 \pm 0.49$





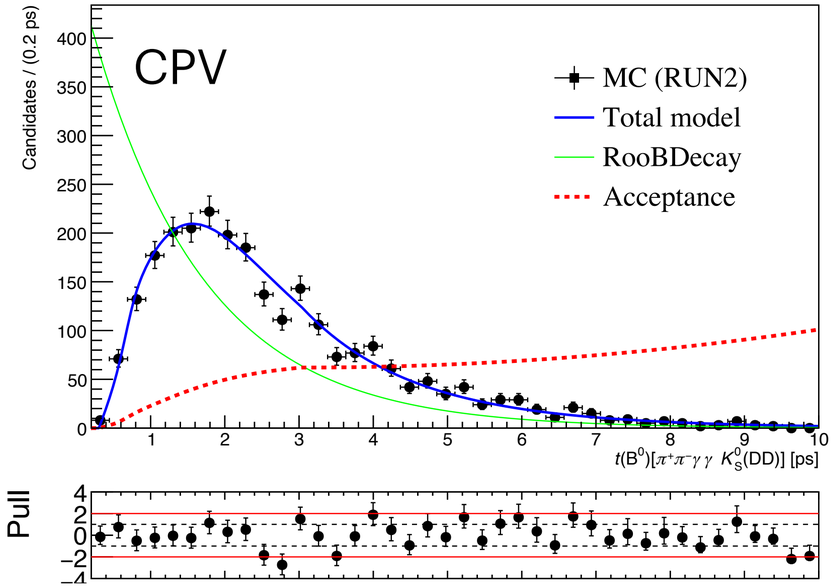
HFLAV 2021 results

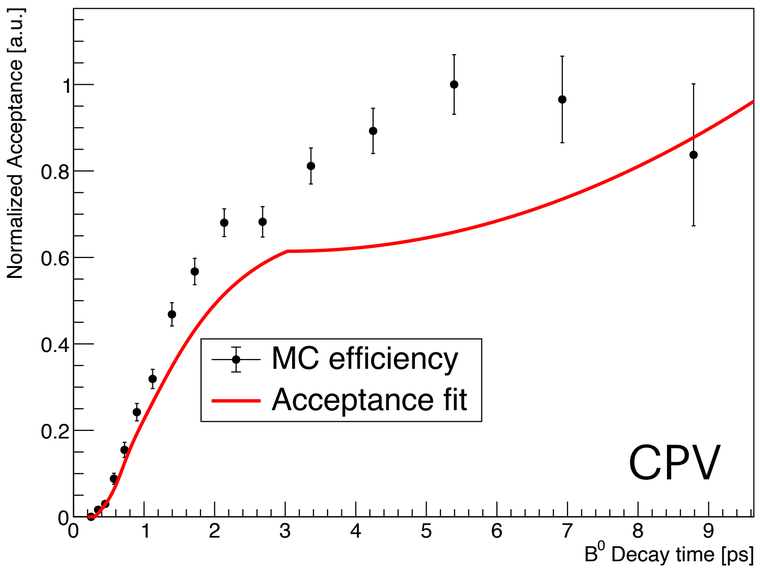
			$\eta' K^0$	
BABAR	[381]	467M	$0.57 \pm 0.08 \pm 0.02$	$-0.08 \pm 0.06 \pm 0.02$
Belle	[382]	772M	$0.68 \pm 0.07 \pm 0.03$	$-0.03 \pm 0.05 \pm 0.03$
Average			0.63 ± 0.06	-0.05 ± 0.04
Confidence level			0.53 (0.6σ)	

What about 2g's ?

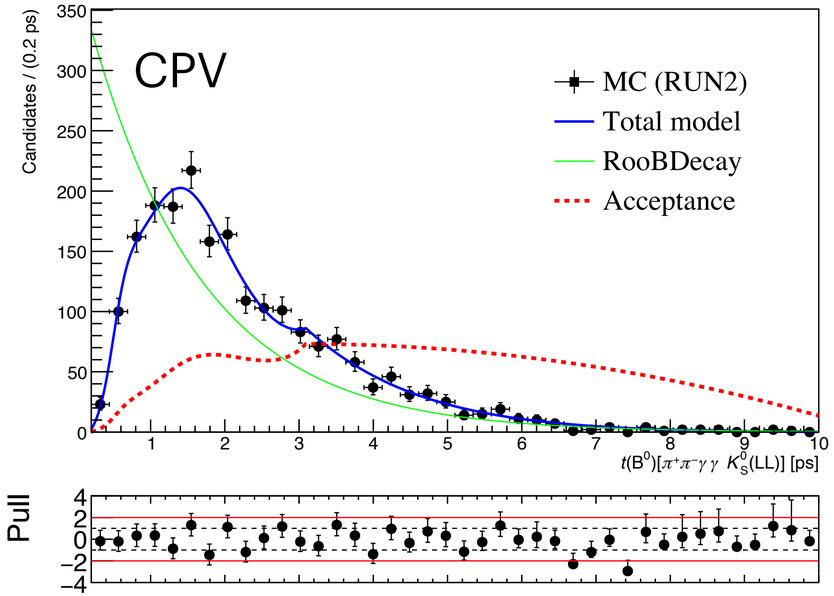
Fit to (TM) Signal MC with CPV to get decay-time acceptance

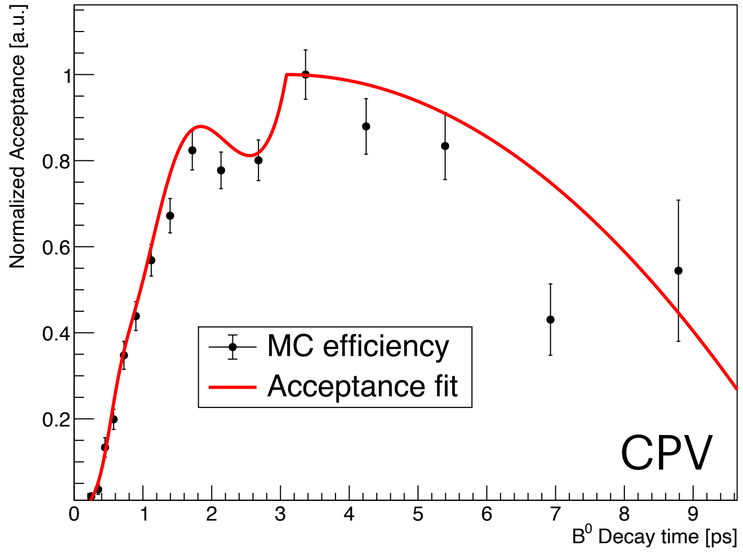
2g DD





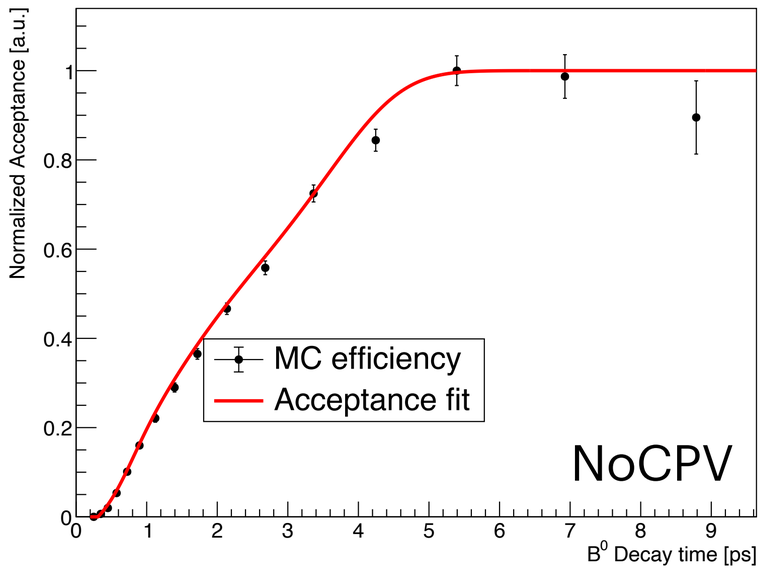
2g LL

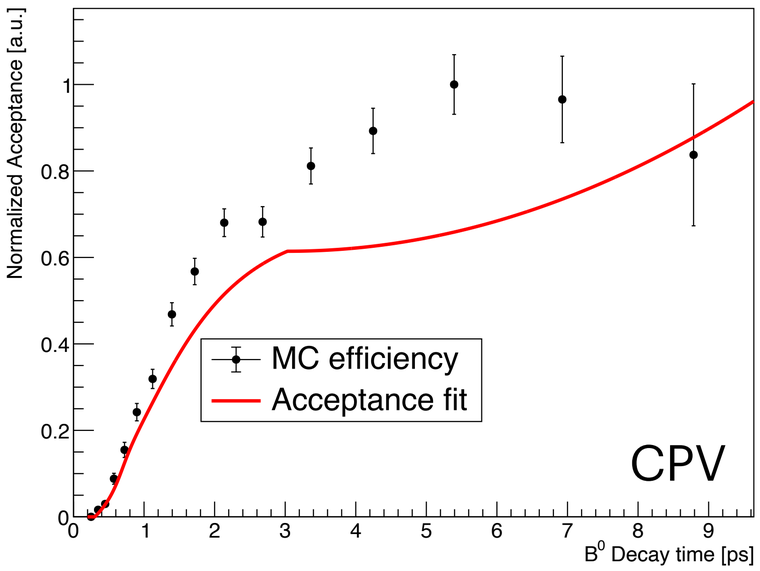




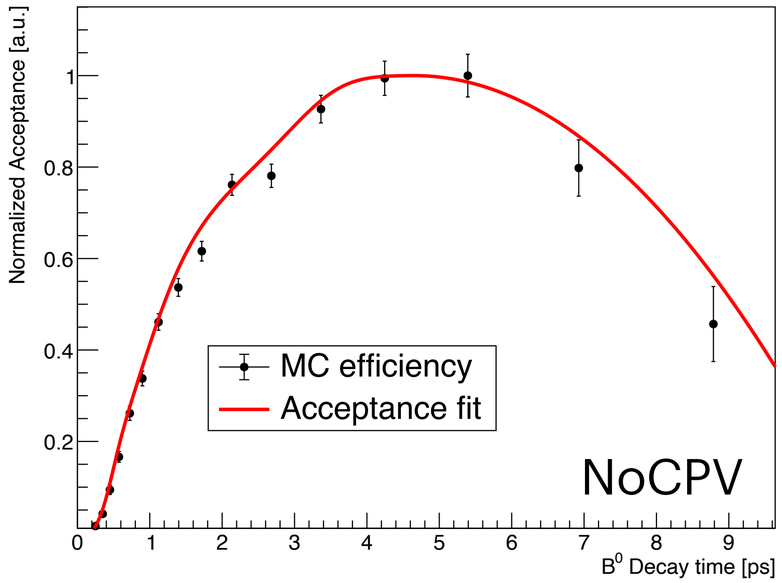
Comparison of acceptance shapes for 2g's from NoCVP to CPV MC

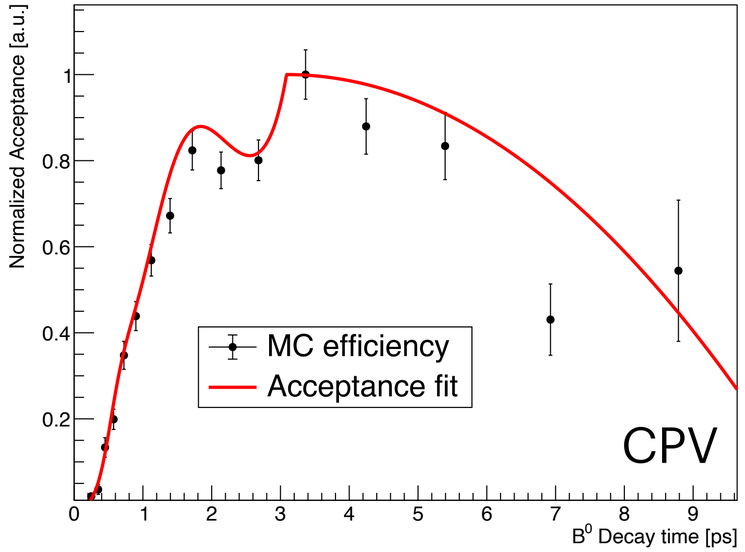
2g DD





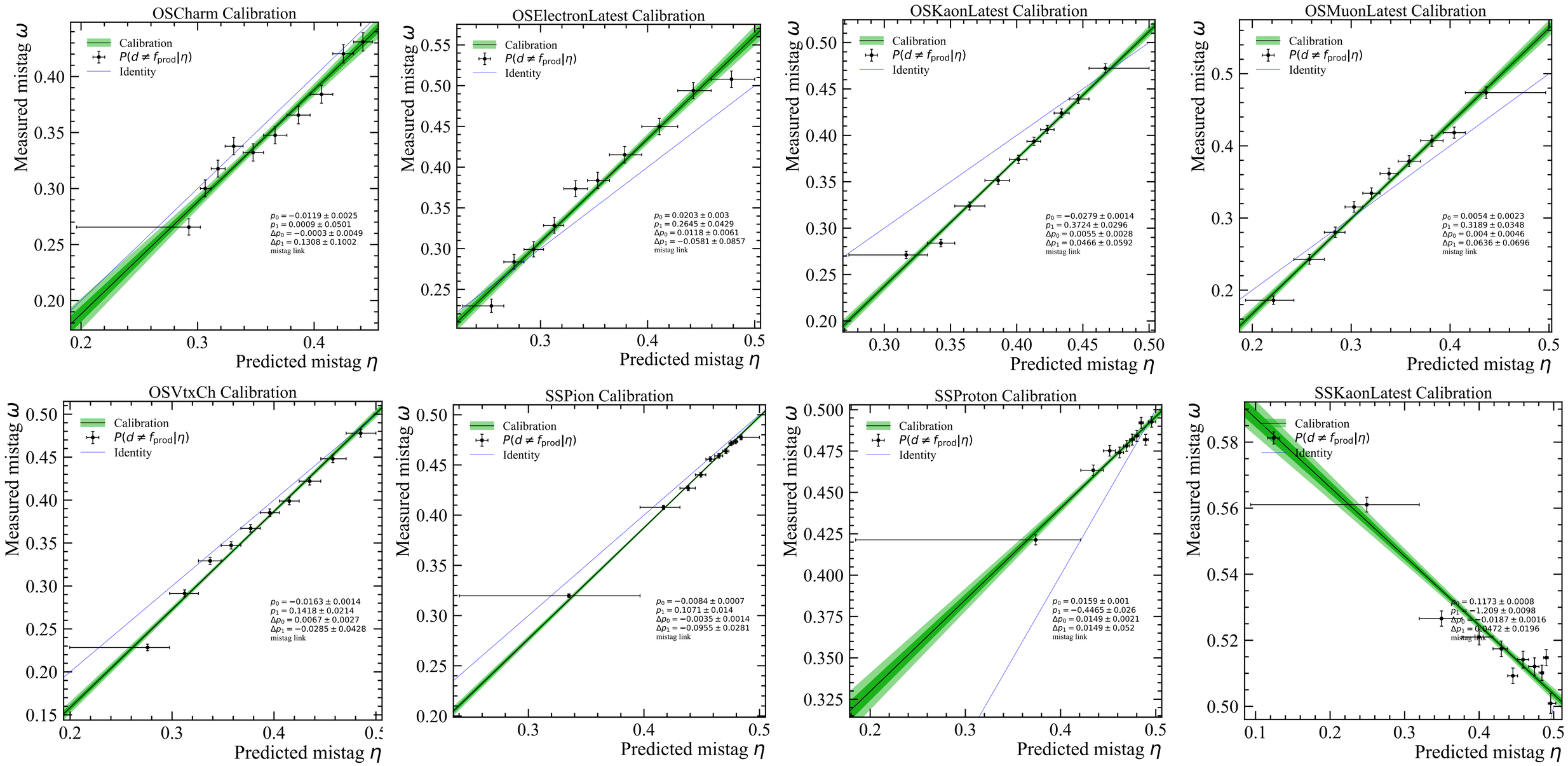
2g LL



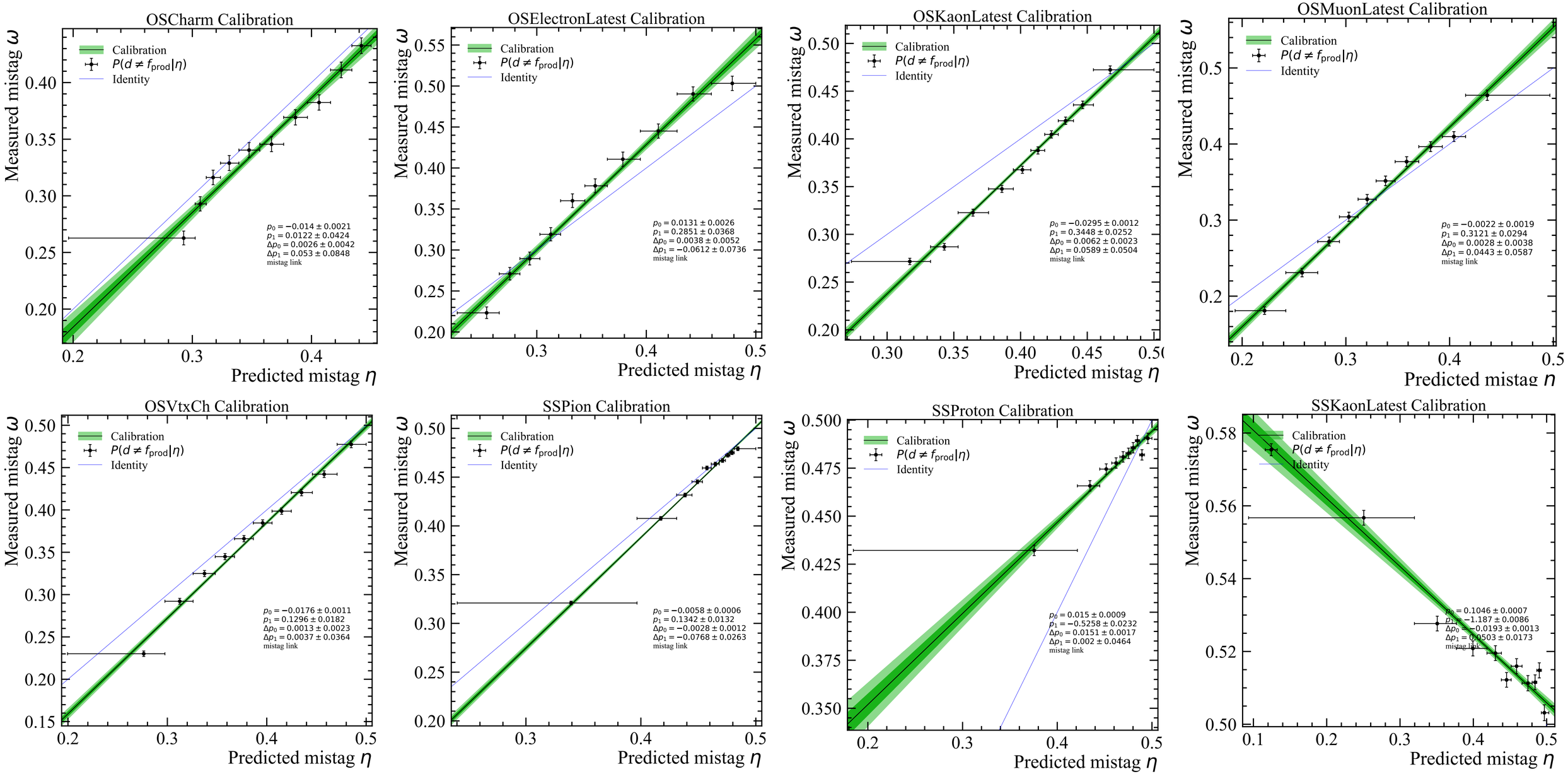


Let’s go on with Flavour Tagging calibration

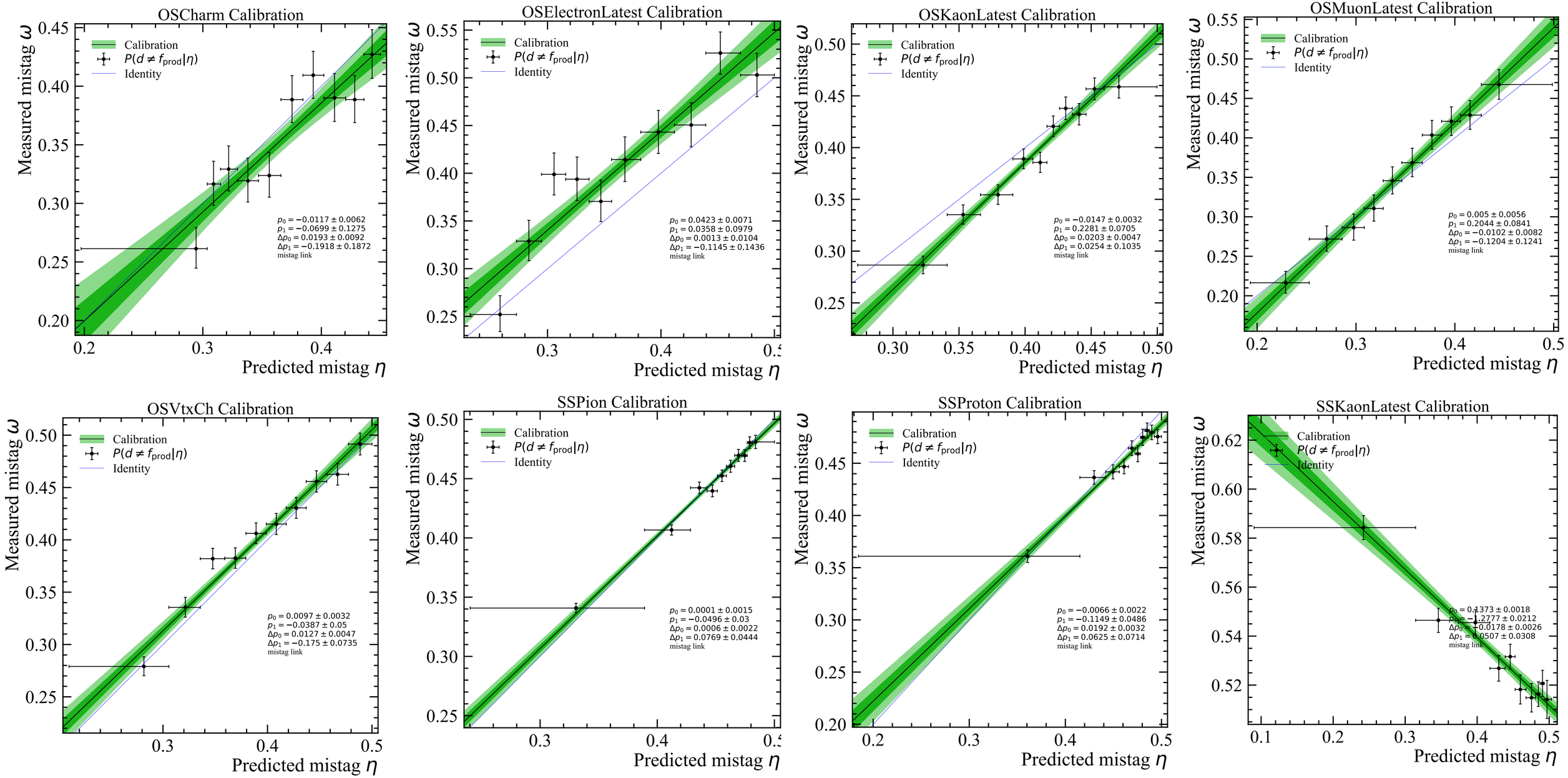
Calibration curves for 1g DD simulation



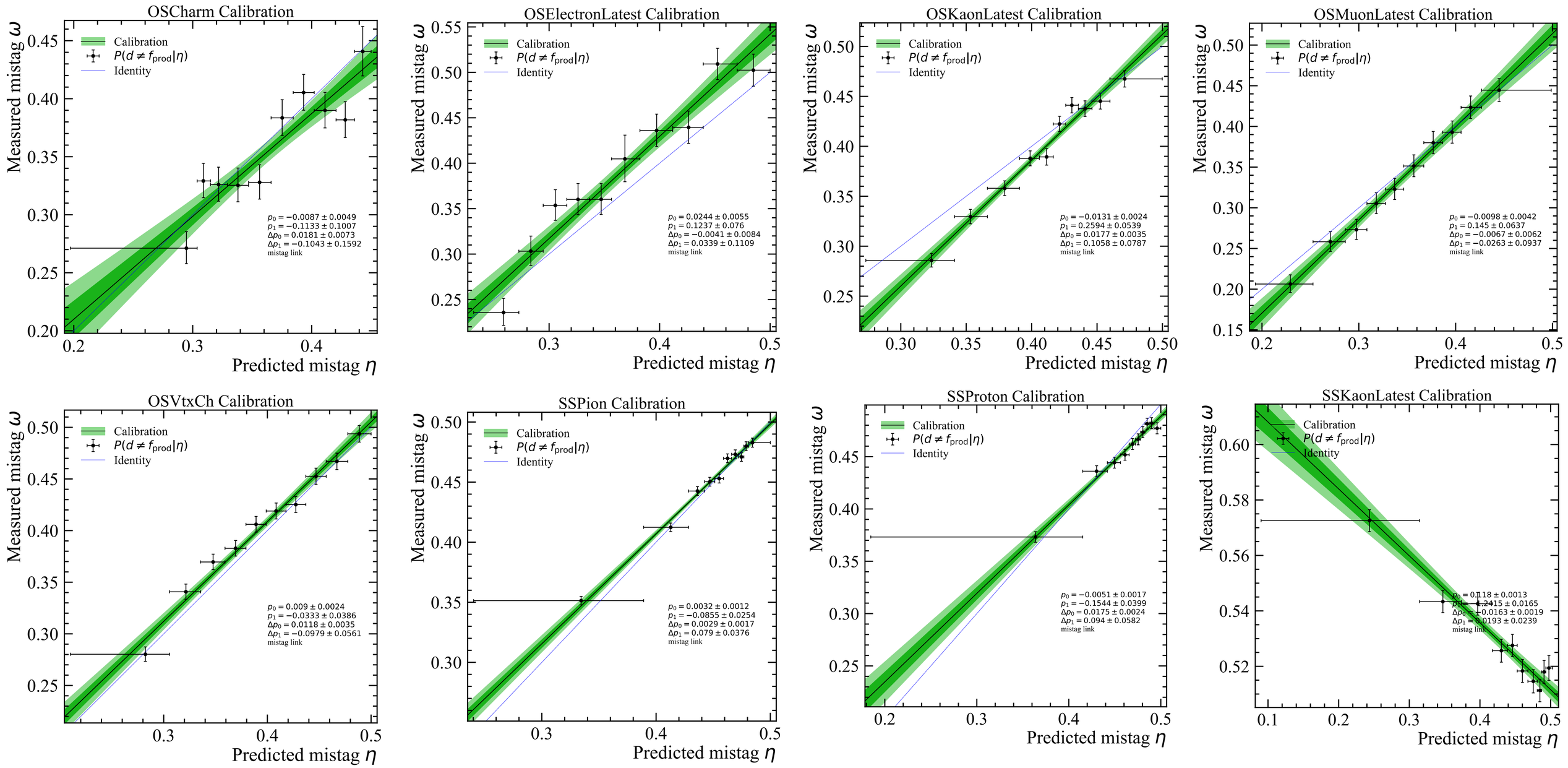
Calibration curves for 1g LL simulation



Calibration curves for 1g DD data



Calibration curves for 1g LL data



Taggers performances

1g DD simulation

Tagger	Tagging efficiency [%]	Effective tagging efficiency [%]
OSCharm	6.11 ± 0.03	0.615 ± 0.003
OSElectronLatest	3.64 ± 0.02	0.398 ± 0.003
OSKaonLatest	19.39 ± 0.05	1.653 ± 0.006
OSMuonLatest	6.65 ± 0.03	0.937 ± 0.006
OSVtxCh	20.11 ± 0.05	1.826 ± 0.006
SSKaonLatest	0	0
SSPion	79.18 ± 0.05	2.427 ± 0.006
SSProton	37.48 ± 0.06	0.1964 ± 0.0008
OS combination	38.26 ± 0.06	3.844 ± 0.010
SS combination	84.26 ± 0.05	2.566 ± 0.006

1g DD data

Tagger	Tagging efficiency [%]	Effective tagging efficiency [%]
OSCharm	4.77 ± 0.04	0.451 ± 0.005
OSElectronLatest	3.36 ± 0.04	0.232 ± 0.003
OSKaonLatest	18.46 ± 0.08	1.174 ± 0.007
OSMuonLatest	5.86 ± 0.05	0.718 ± 0.007
OSVtxCh	18.08 ± 0.08	1.018 ± 0.006
SSKaonLatest	0	0
SSPion	83.61 ± 0.08	2.180 ± 0.007
SSProton	38.6 ± 0.1	0.719 ± 0.004
OS combination	34.95 ± 0.10	2.60 ± 0.01
SS combination	88.04 ± 0.07	2.799 ± 0.009

1g LL simulation

Tagger	Tagging efficiency [%]	Effective tagging efficiency [%]
OSCharm	6.00 ± 0.03	0.617 ± 0.003
OSElectronLatest	3.48 ± 0.02	0.404 ± 0.003
OSKaonLatest	19.19 ± 0.04	1.614 ± 0.005
OSMuonLatest	6.58 ± 0.03	0.966 ± 0.005
OSVtxCh	19.74 ± 0.04	1.806 ± 0.005
SSKaonLatest	0	0
SSPion	78.87 ± 0.04	1.822 ± 0.004
SSProton	39.97 ± 0.05	0.1417 ± 0.0005
OS combination	37.85 ± 0.05	3.843 ± 0.009
SS combination	84.38 ± 0.04	1.927 ± 0.005

1g LL data

Tagger	Tagging efficiency [%]	Effective tagging efficiency [%]
OSCharm	4.57 ± 0.03	0.406 ± 0.003
OSElectronLatest	3.20 ± 0.03	0.272 ± 0.003
OSKaonLatest	18.39 ± 0.06	1.074 ± 0.005
OSMuonLatest	5.75 ± 0.04	0.770 ± 0.006
OSVtxCh	17.79 ± 0.06	0.970 ± 0.005
SSKaonLatest	0	0
SSPion	83.59 ± 0.06	1.432 ± 0.004
SSProton	41.06 ± 0.08	0.540 ± 0.003
OS combination	34.79 ± 0.07	2.572 ± 0.010
SS combination	88.27 ± 0.05	1.913 ± 0.005

Backup

Run 2

Simultaneous fit to mass - decay time

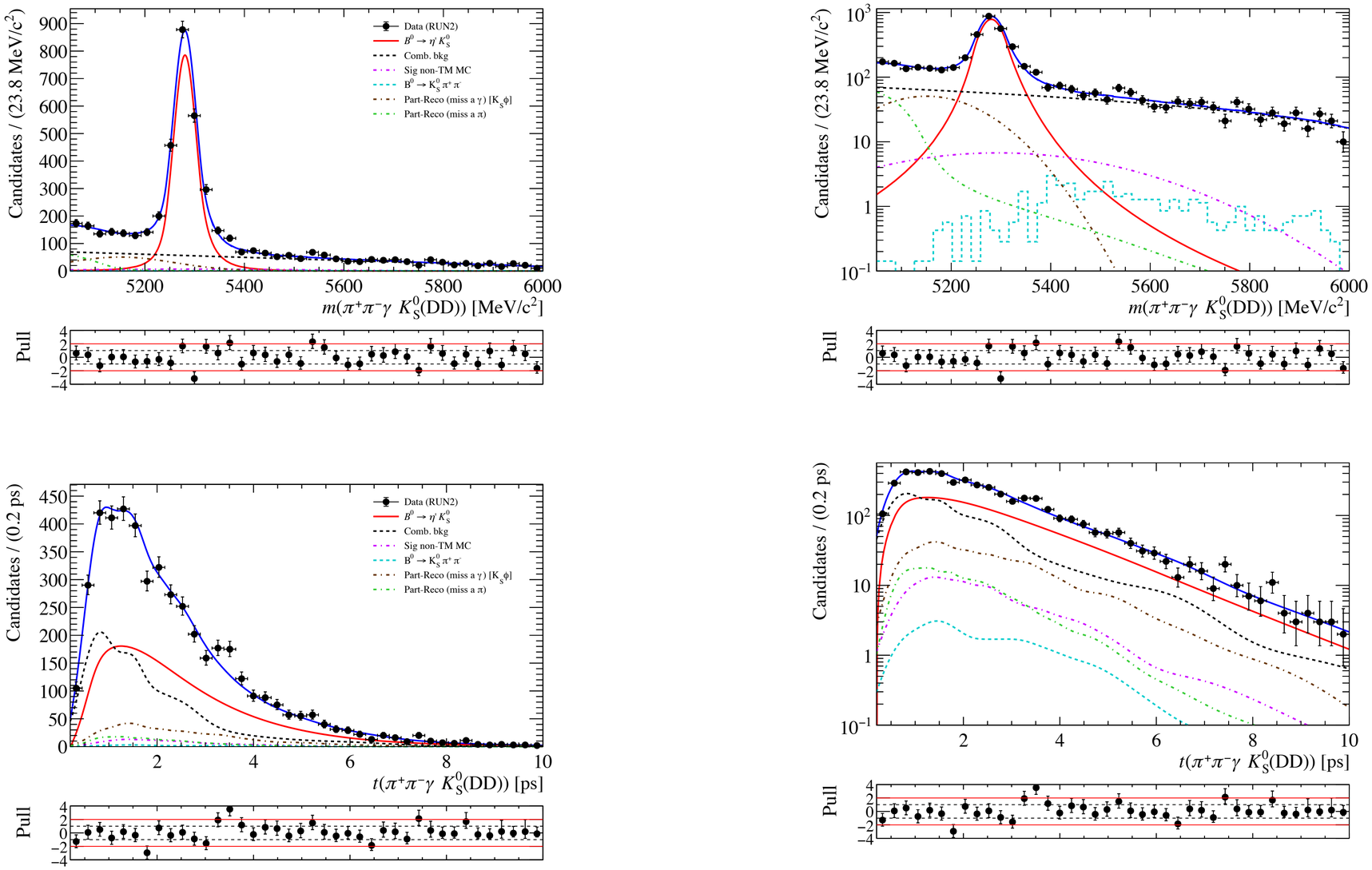
Preliminary one to set and test machinery

- No tagging info is included (neither data or bkg components)
- Not a CP fit as fcosh, fsinh, fcos and fsin are fixed respectively to 1.0, 1.0, 0.0, 0.0

Simultaneous (mass, decay time) fit to Run2 data with No Tagging and No CPV observables

1g DD

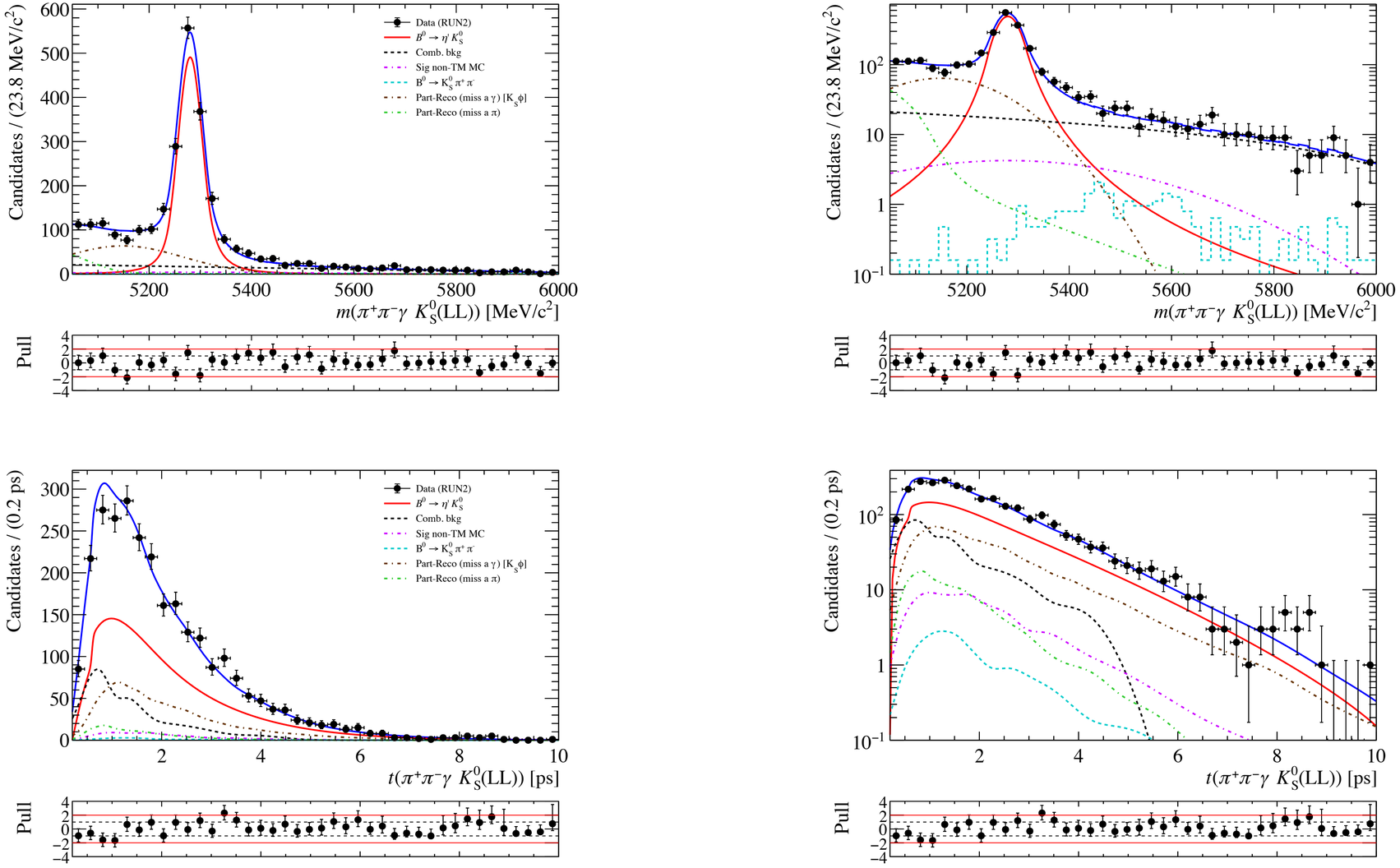
Good quality fit



Simultaneous (mass, decay time) fit to Run2 data with No Tagging and No CPV observables

1g LL

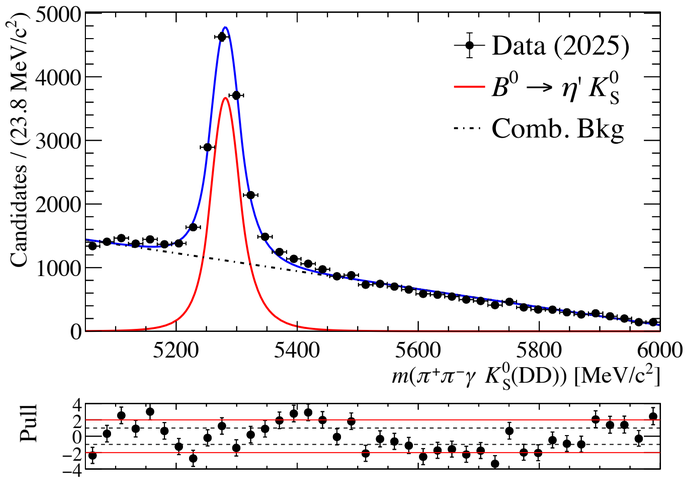
Good quality fit



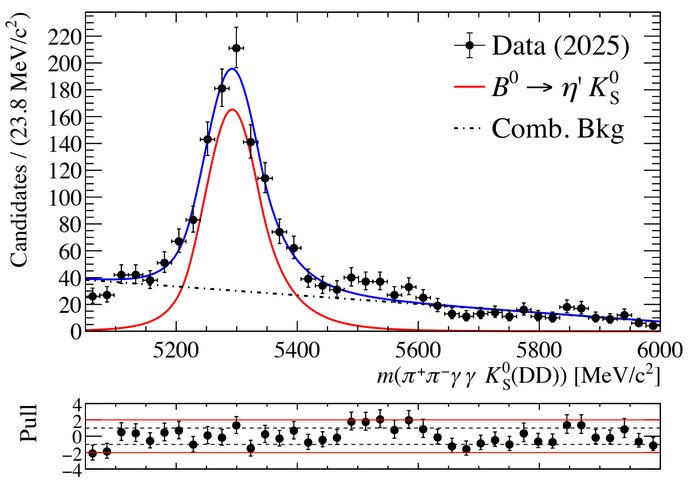
Run 3 (2025)

Preliminary 2025 sample B^0 mass fit with XGBoost selection

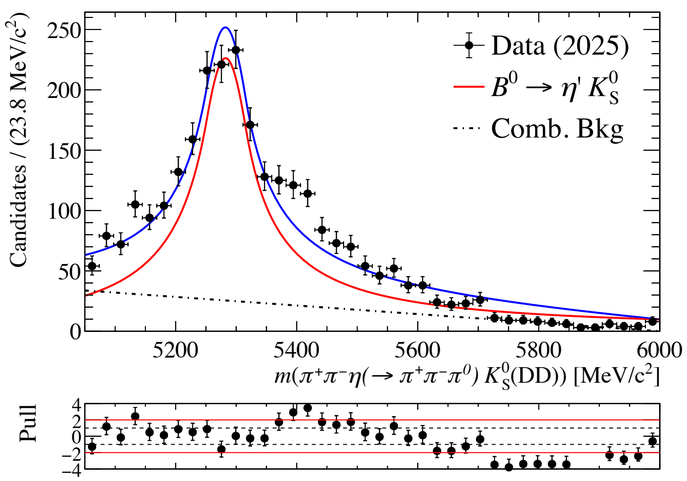
1g DD



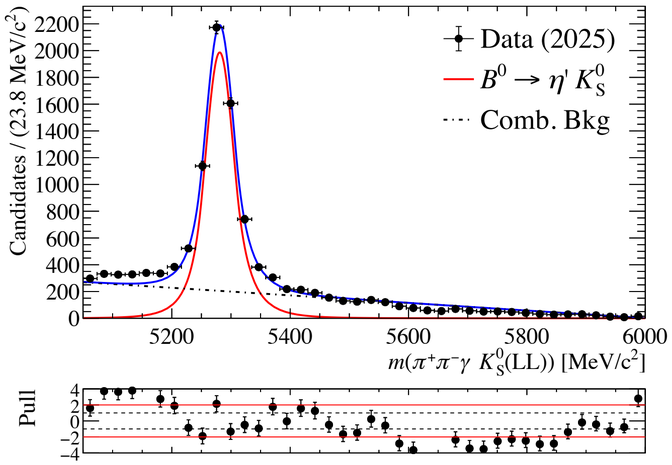
2g DD



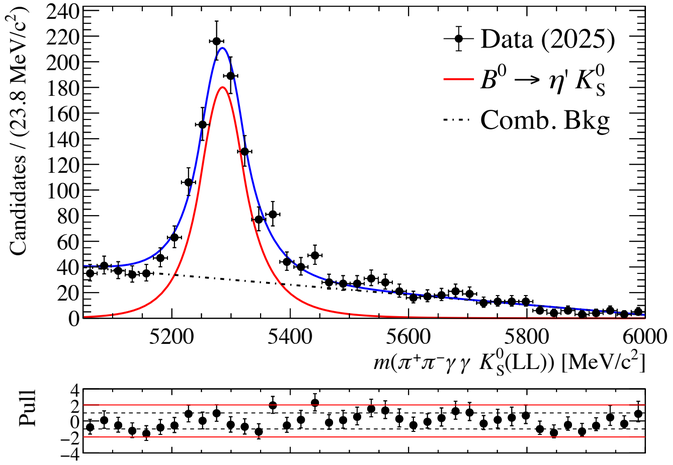
Resolved DD



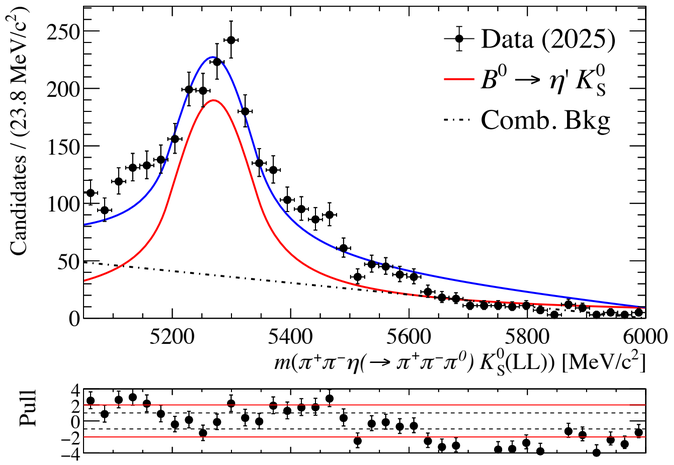
1g LL



2g LL



Resolved LL



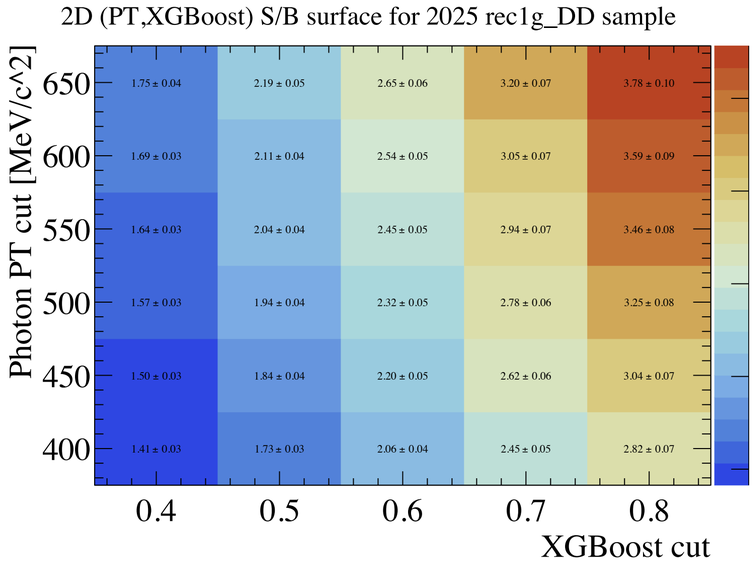
2D (XGBoost, PT) $\frac{S}{B}$ scan for 2025 data

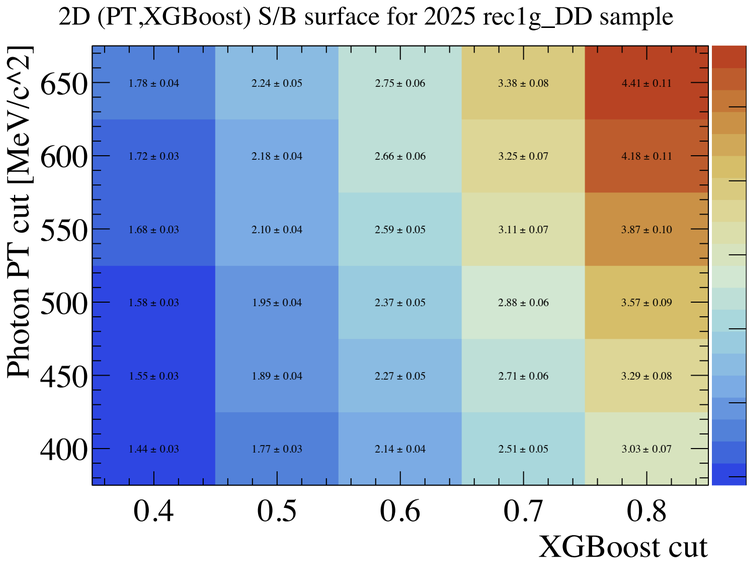
$P_T(\gamma) > 650\ MeV/c^2$

PT cut after

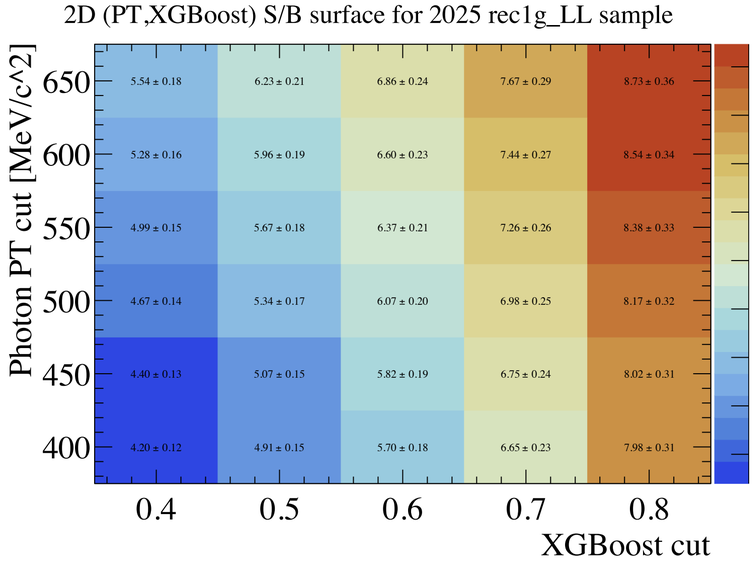
PT cut before

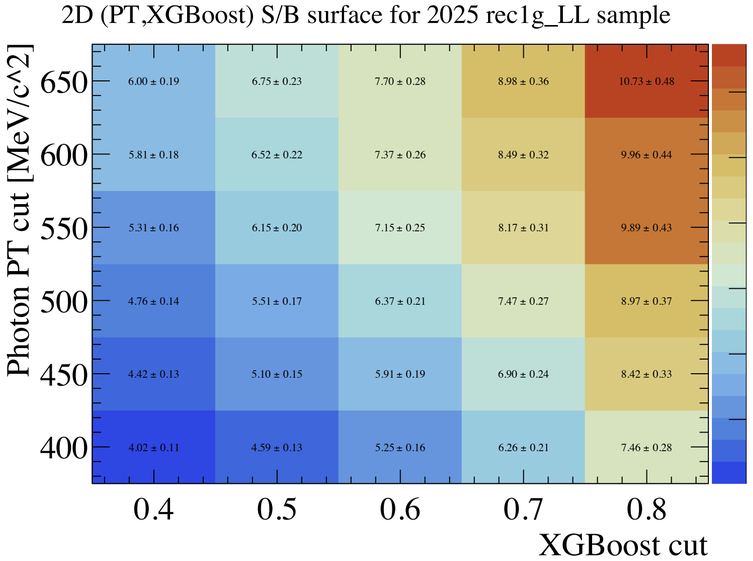
1g DD





1g LL





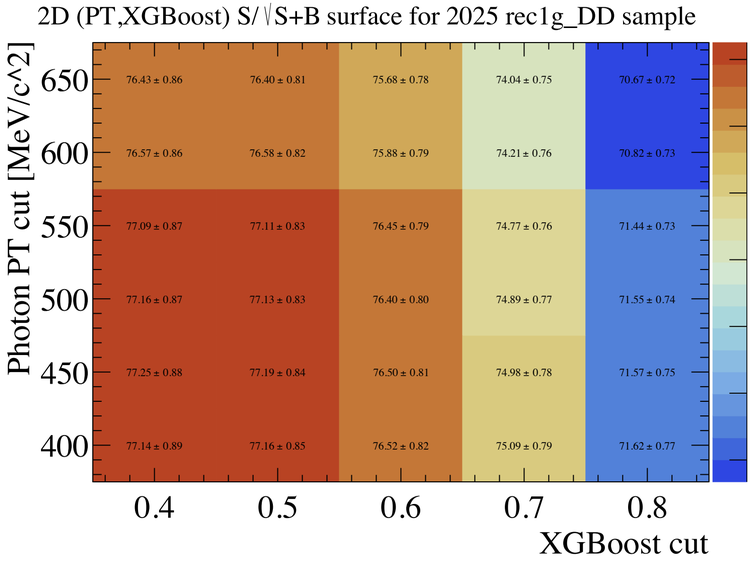
2D (XGBoost, PT) $\frac{S}{\sqrt{S+B}}$ scan for 2025 data

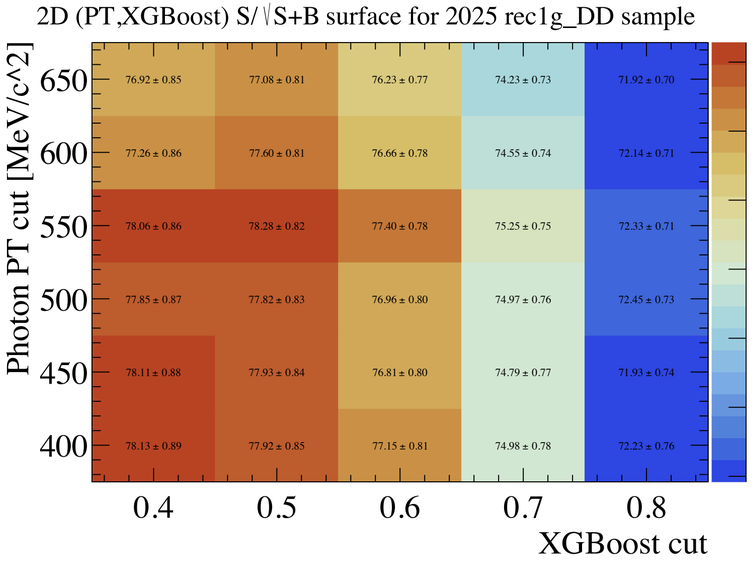
$XGB > +0.4$

PT cut after

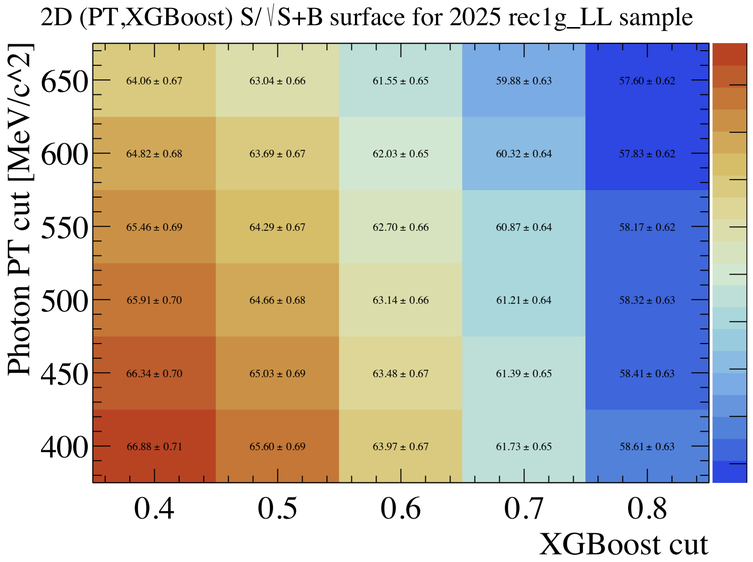
PT cut before

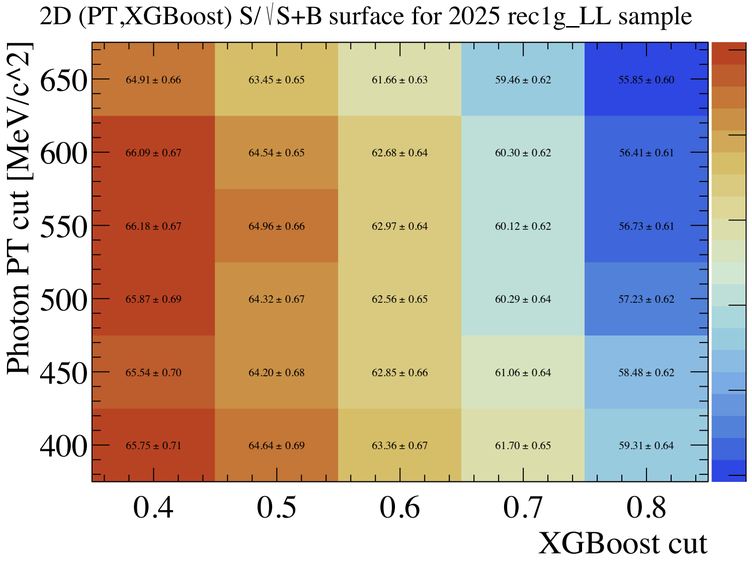
1g DD





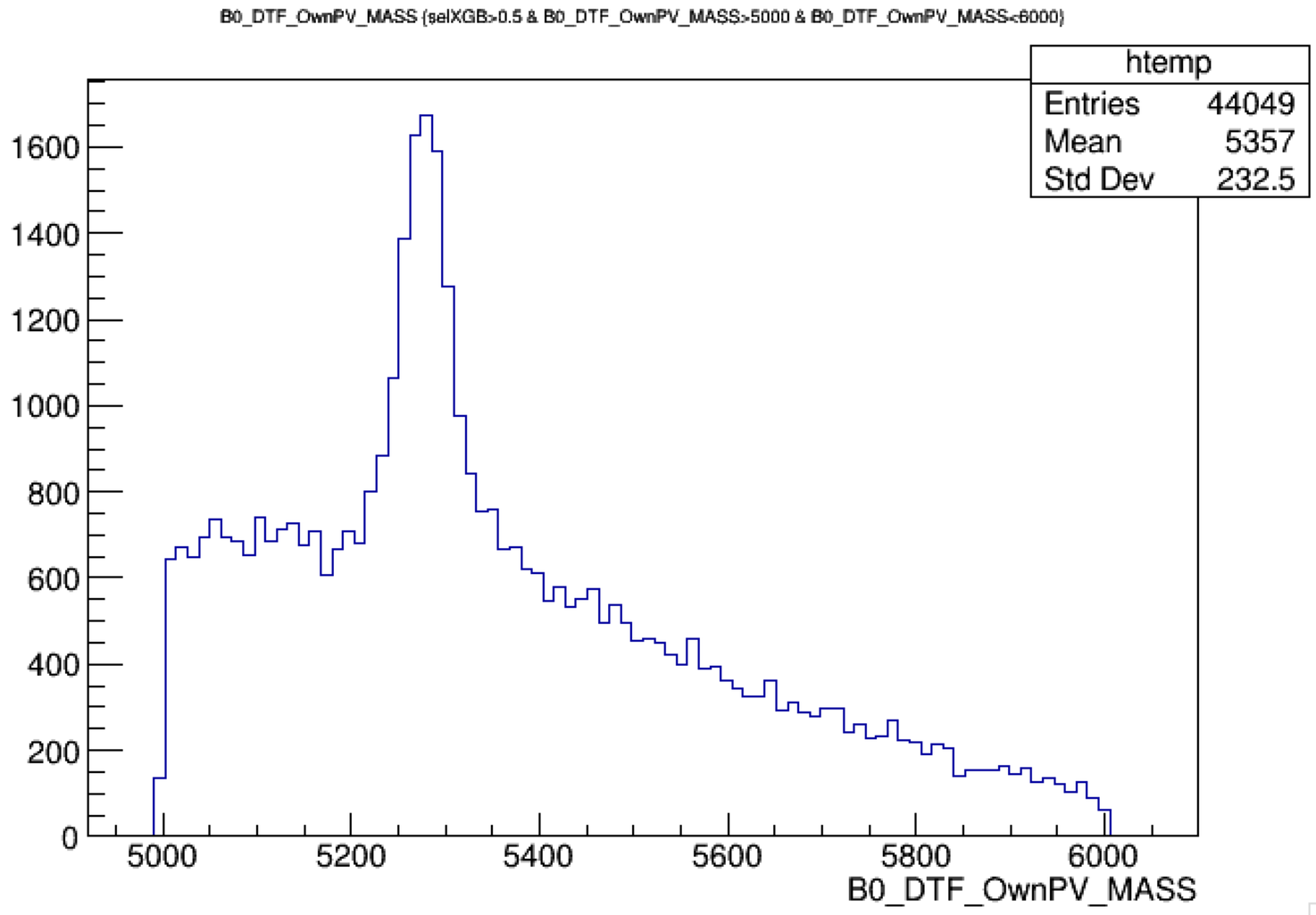
1g LL





Run 3 (2026)

First preliminary look to 2026 data B^0 mass



XGBoost > 0.5

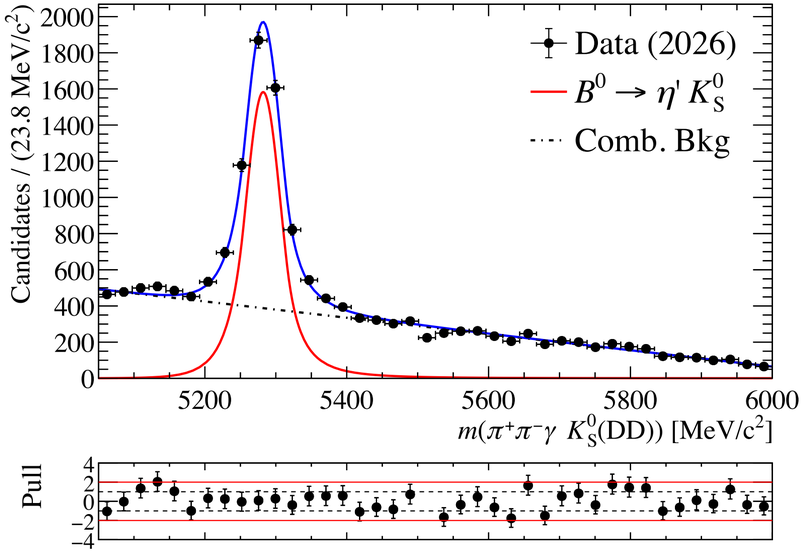
Used XGBoost method trained with 2025 data and Sig MC as no 2026 simulation available yet

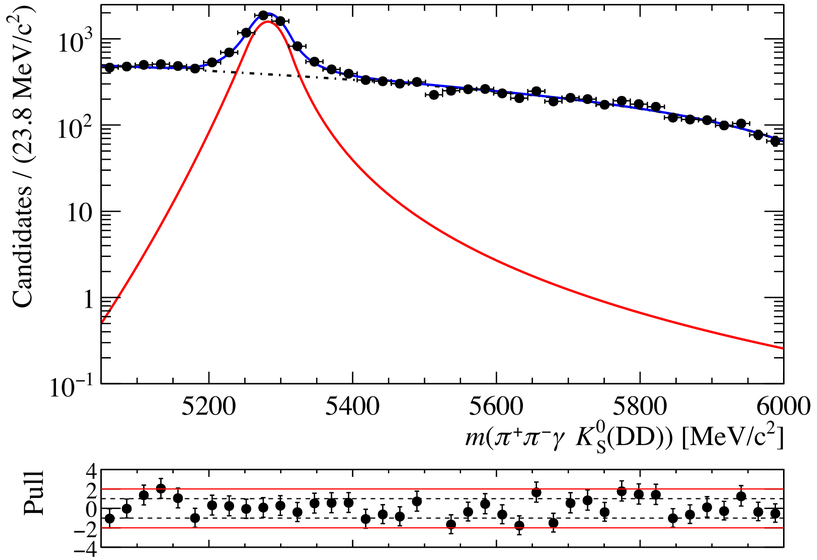
Preliminary 2026 data B^0 mass fit and comparison to 2025 one

1g DD

2026

XGB > +0.4 & $P_T(\gamma) > 650\ MeV/c^2$



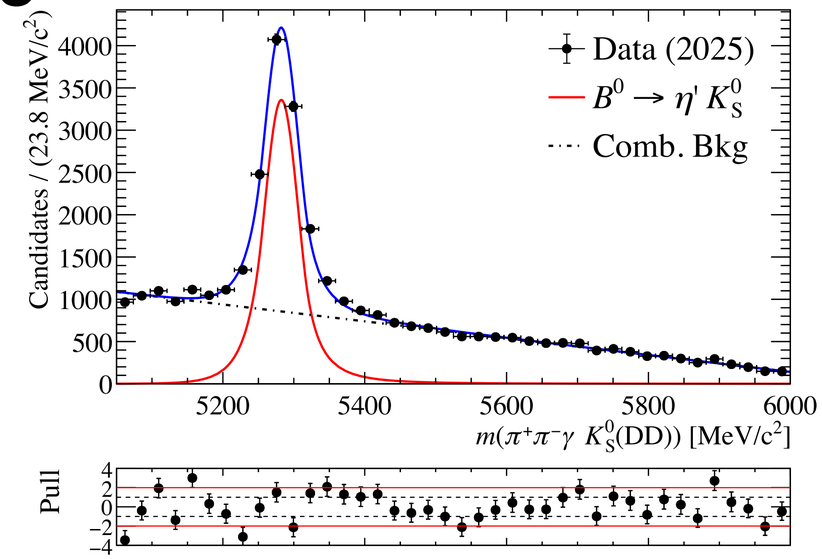


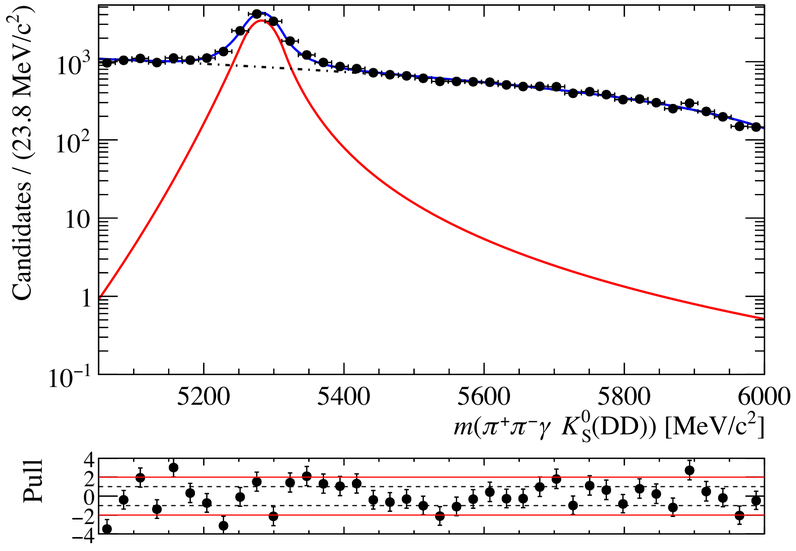
N(Sig) = 4 779 ± 106

N(Comb)= 11 132± 132

σ(Data) = 24.7 ± 0.7

2025





N(Sig) = 9 933 ± 153

N(Comb)= 24 559 ± 195

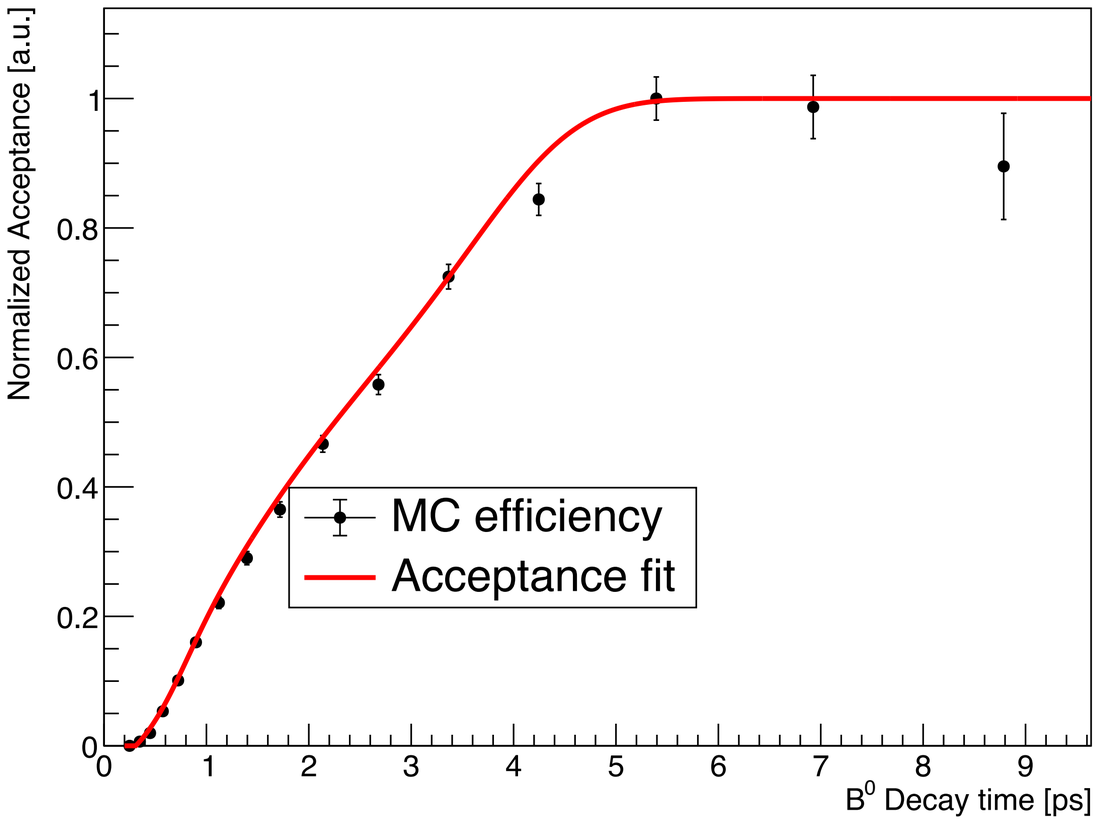
σ(Data) = 24.2 ± 0.5

σ(MC) = 19.5 ± 0.5

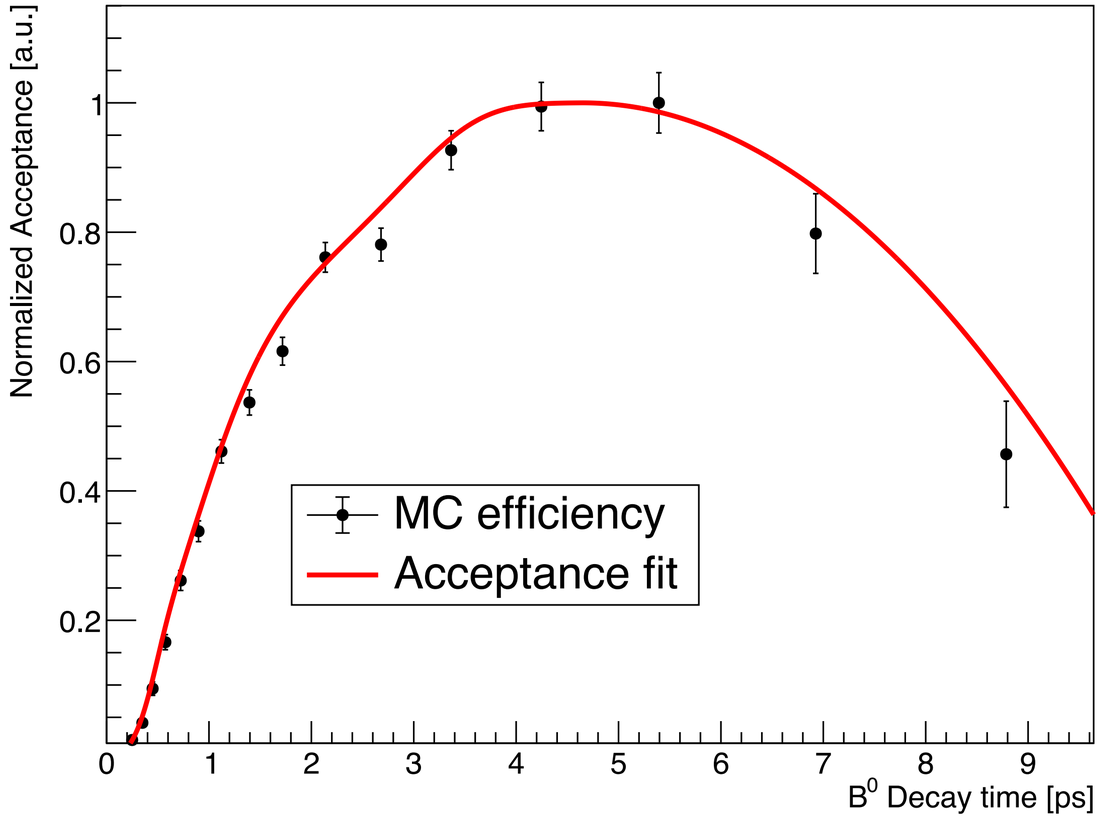
Extra

Decay-time acceptances for 2g's final states

2g DD

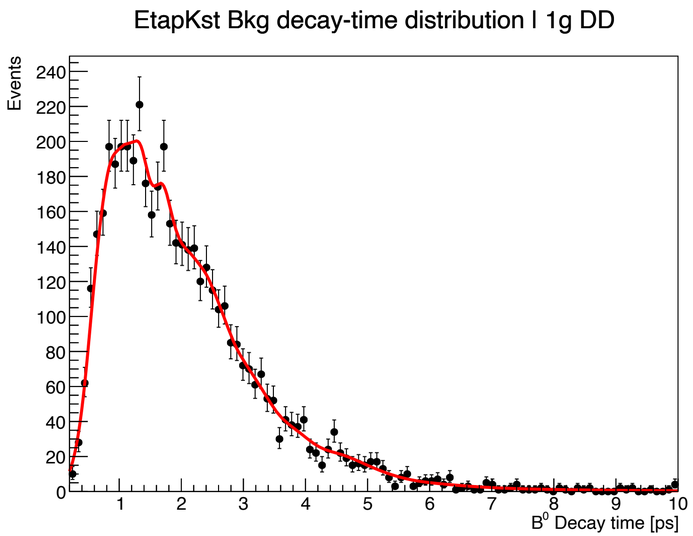


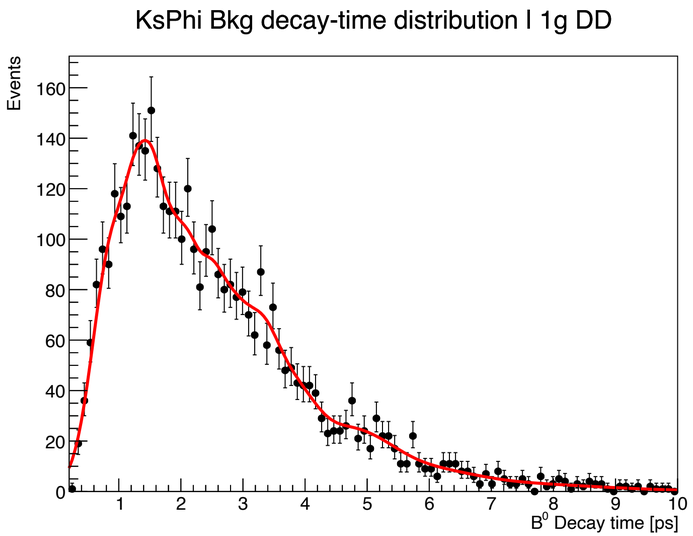
2g LL

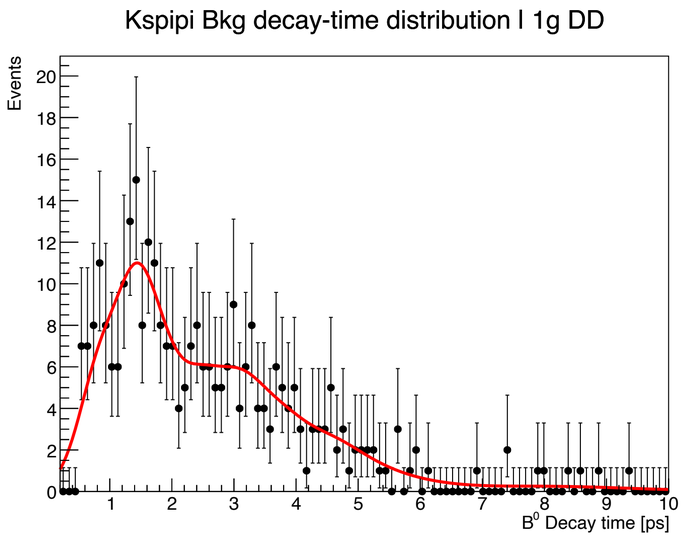
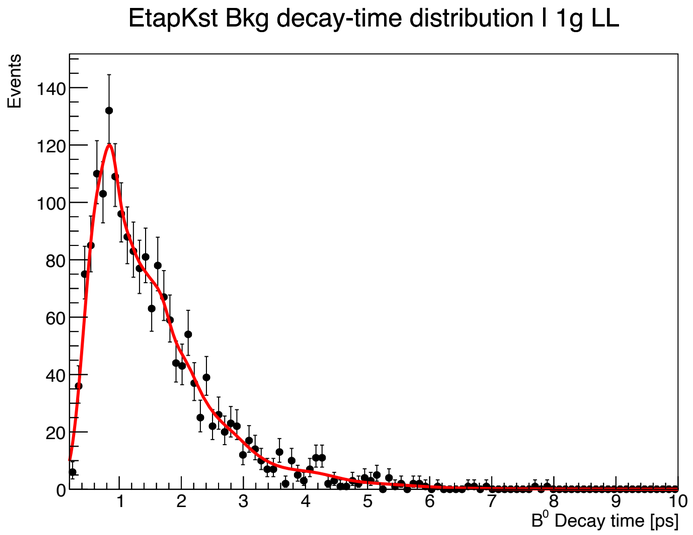
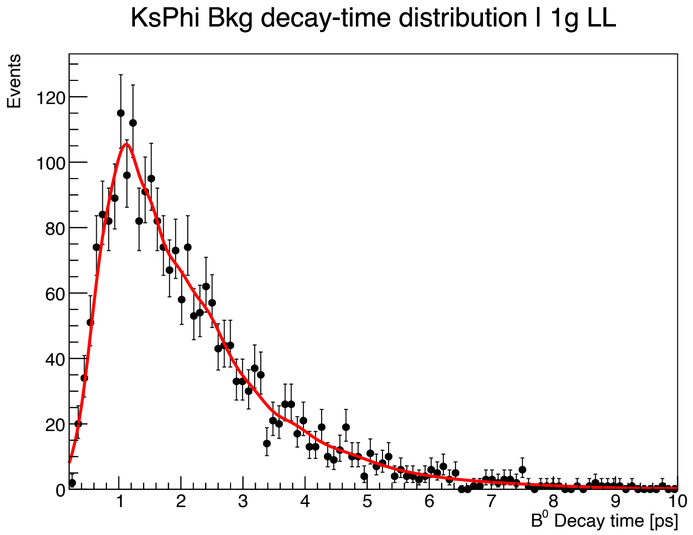
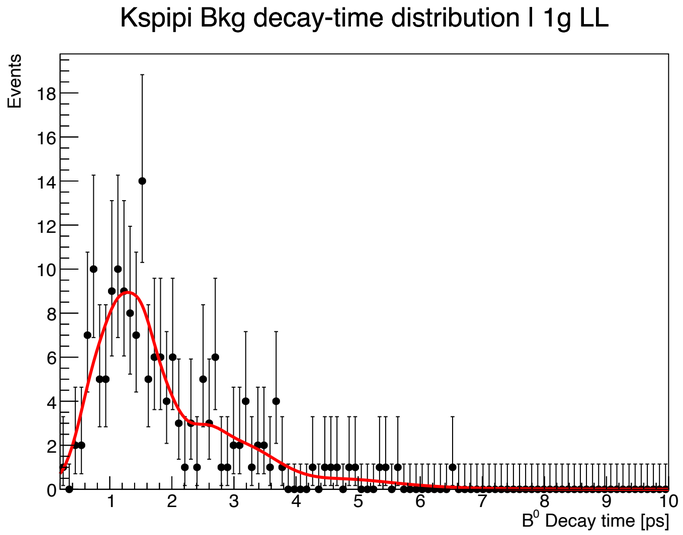


Bkg MCs decay-time distributions from KDE templates

1g DD







1g LL