TDCPV WG status and $B^0 \to \eta' K^0_S$ analysis)

12th Belle II Italian Meeting
16/12/2019

Stefano Lacaprara
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Outline

- **Status of TDCPV WG:**
  - B^0 lifetime measurement
  - $\sin(2\varphi_1)$ measurement from $B^0 \to J/\psi K^0_S$
    - CP-side and Tag-side Vertex studies
    - Flavour tagger validation

- **$B^0 \to \eta' K^0_S$**
  - η' in Phase III data
  - Study on MC12

$\tau(B^0)$ hadronic

Reem (IPHC Strasbourg)
BELLE2-NOTE-PH-2019-017

- No flavour tagging needed,
- Using simple Δt resolution function
  - 3 gaussian
  - Not using event per event resolution
- 6 fully reconstructed hadronic final states.
  - **In common with BToCharm WG**

- **B^0 channels** :
  - $B^0 \to D^- \rho^+$, $D^- \to K^+ \pi^- \pi^-$
  - $B^0 \to D^- \pi^+$, $D^{*-} \to D^0 \pi^-$
  - $B^0 \to D^{*-} \pi^+$,
  - $B^0 \to D^{*-} \rho^+$
  - $B^0 \to D^{*-} a1^+$

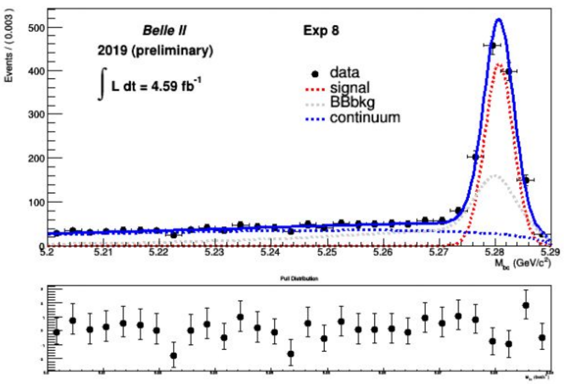
D^0 channels

$D^0 \to K^- \pi^+$
$D^0 \to K^- \pi^+ \pi^0$
$D^0 \to K^- \pi^+ \pi^+ \pi^-$

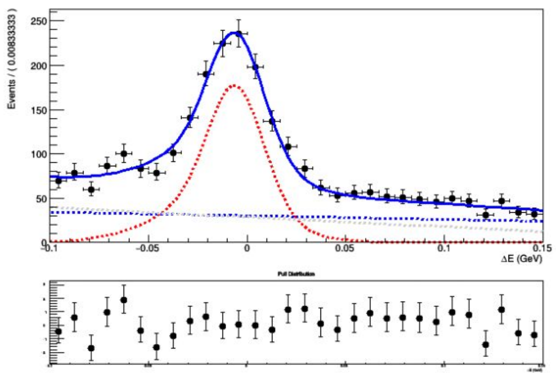
$a1^+ \to \pi^+ \pi^+ \pi^-$
$\rho^+ \to \pi^+ \pi^0$

Decay	Selection efficiency %
$B^0 \to D^- \pi^+$	20
$B^0 \to D^- \rho^+$	10
$B^0 \to D^{*-} \pi^+$	22
$B^0 \to D^{*-} \rho^+$	8
$B^0 \to D^{*-} a_1$	6.6

$B^0 \to D^- a_1^+$ excluded due to high background



Exp8 - O(1000) candidates



Lifetime extraction

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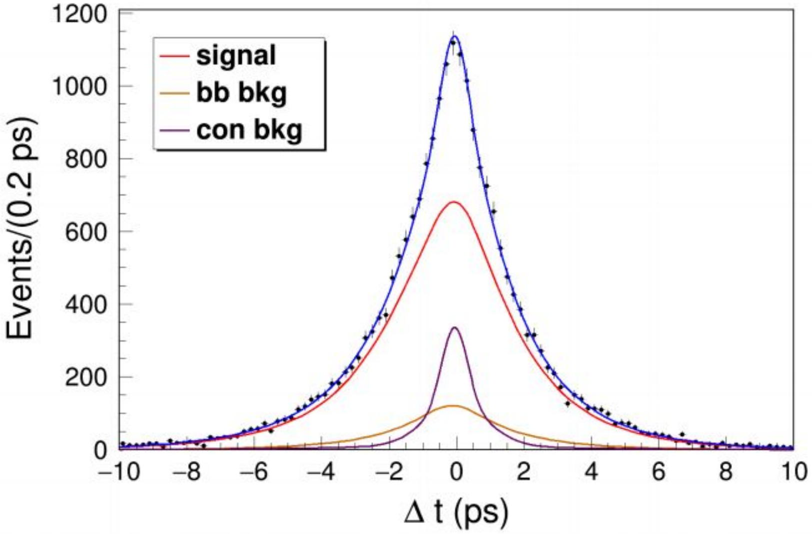
- UML fit on Δt with full pdf
  - Signal/BB/continuum
  - Fixing some parameters from MC
- Test on MC 80/fb
  - **Data stil blind**

$$\mathrm{P_{all}}(\Delta t) = f_s \boxed{\mathrm{P_{sig}}(\Delta t)} + f_{b\bar{b}}\,\mathrm{P}_{b\bar{b}}(\Delta t) + (1 - f_s - f_{\bar{b}})\,\mathrm{P_{cont}}(\Delta t).$$

$$\boxed{\mathrm{P}_{sig}(\Delta t)} = \int_{-\infty}^{+\infty} \boxed{\mathcal{P}_{th}(\Delta t')}\,\mathcal{R}_{sig}(\Delta t - \Delta t')\mathrm{d}\Delta t'.$$

$$\boxed{\mathcal{P}_{th}(\Delta t)} = \frac{1}{2\tau_B}\exp\left(-\frac{|\Delta t|}{\tau_B}\right).$$



f_{s1}	0.4 ± 0.05
μ_{s1}	-0.0091 ± 0.09
σ_{s1}	0.451
f_{s2}	0.45 ± 0.054
μ_{s2}	-0.34 ± 0.11
σ_{s2}	1.23
f_{s3}	$1 - f_{s1} - f_{s2}$
μ_{s3}	-0.8 ± 0.21
σ_{s3}	4.09
τ_{B^0}	1.52 ± 0.019

Working on systematics

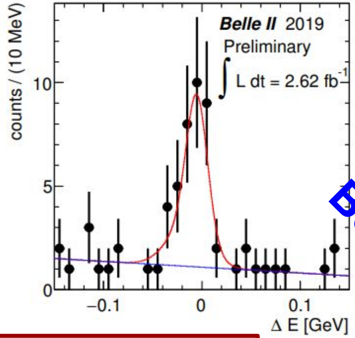
Target: Moriond

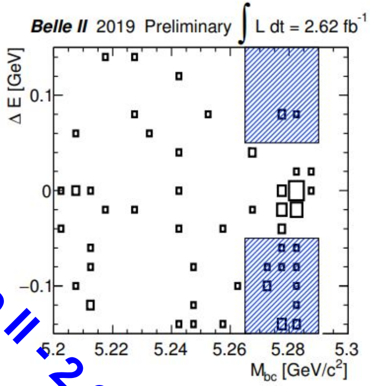
$\sin(2\varphi_1)$ measurement from $B^0 \to J/\psi K^0_S$

- Signal reconstruction is ready since this summer

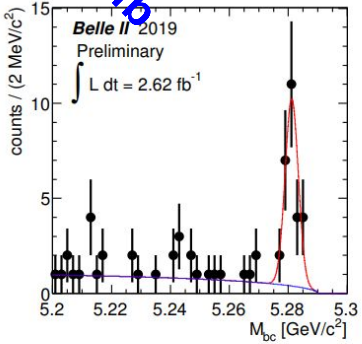
Mode	Belle II, 2019 data		Belle II, MC expectation		Belle, 2001 data [2]	
	$2.62\ \mathrm{fb}^{-1}$	$1\ \mathrm{fb}^{-1}$	$2.62\ \mathrm{fb}^{-1}$	$1\ \mathrm{fb}^{-1}$	$10.5\ \mathrm{fb}^{-1}$	$1\ \mathrm{fb}^{-1}$
$B^0 \to J/\psi K^0_S$	26.9 ± 5.2	10.3 ± 2.0	27.5	10.5	123	11.7

- Expected **O(100)** events with **10/fb**





Belle II : 2.6 /fb



VOLUME 86, NUMBER 12 PHYSICAL REVIEW LETTERS 19 MARCH 2001

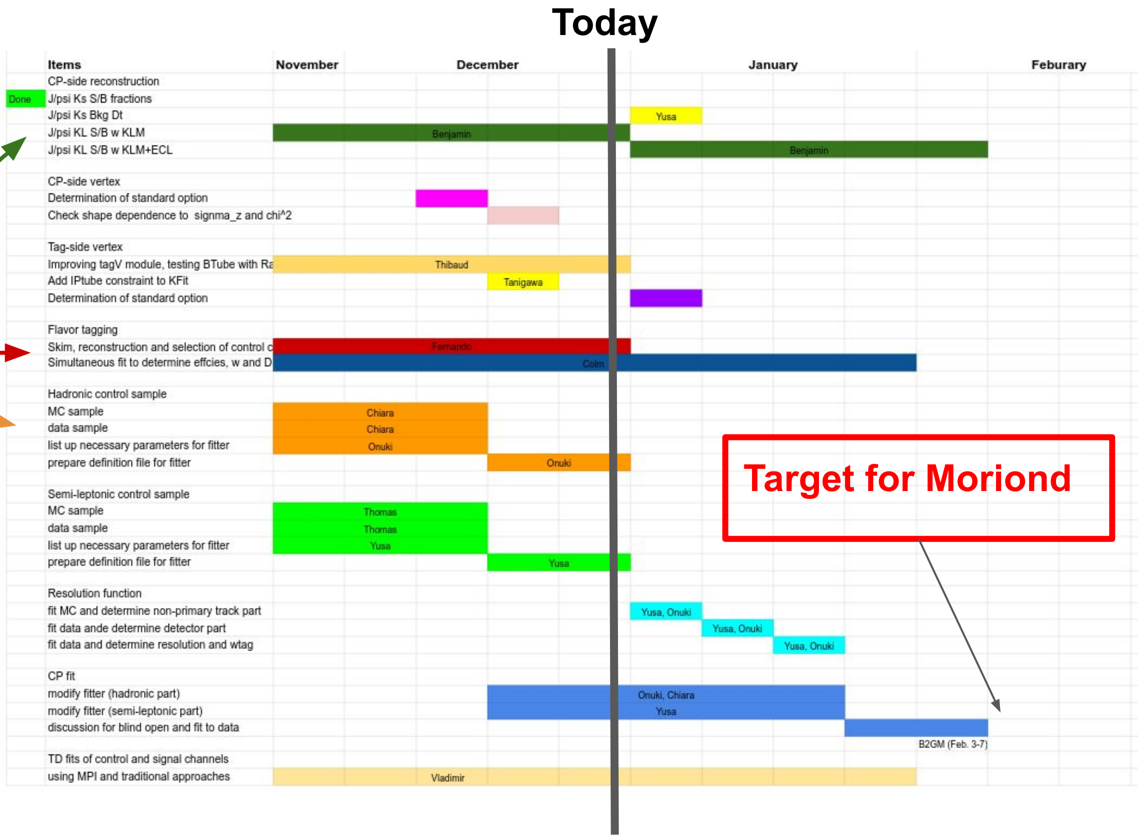
Measurement of the *CP* Violation Parameter $\sin 2\phi_1$ in B^0_d Meson Decays

A. Abashian,[44] K. Abe,[8] K. Abe,[36] I. Adachi,[8] Byoung Sup Ahn,[14] H. Aihara,[37] M. Akatsu,[19] G. Alimonti,[7] K. Aoki,[8]

We present a measurement of the standard model *CP* violation parameter $\sin 2\phi_1$ (also known as $\sin 2\beta$) based on a $10.5\ \mathrm{fb}^{-1}$ data sample collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric e^+e^- collider. One neutral B meson is reconstructed in the $J/\psi K_S$, $\psi(2S)K_S$, $\chi_{c1}K_S$, $\eta_c K_S$, $J/\psi K_L$, or $J/\psi \pi^0$ *CP*-eigenstate decay channel and the flavor of the accompanying B meson is identified from its charged particle decay products. From the asymmetry in the distribution of the time interval between the two B-meson decay points, we determine $\sin 2\phi_1 = 0.58^{+0.32}_{-0.34}(\mathrm{stat})^{+0.09}_{-0.10}(\mathrm{syst})$.

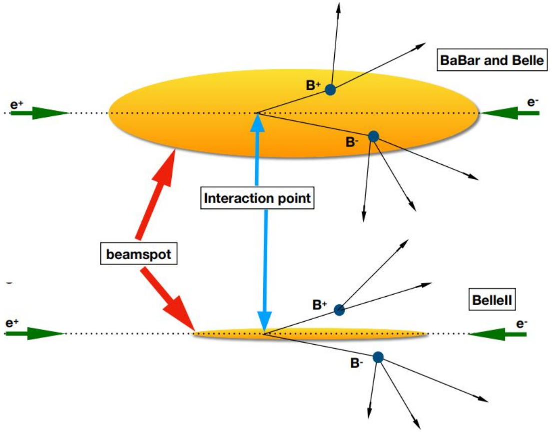
Preparation and test of analysis tools

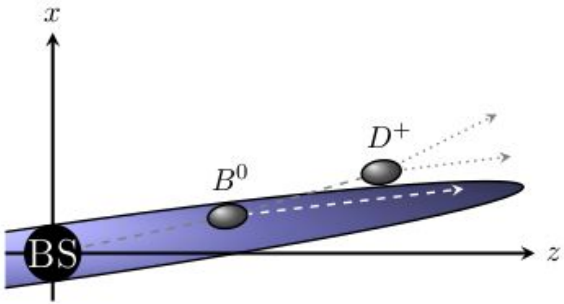
- Δt measurement, control samples, wrong tag fraction, Δt resolution
- A plan with work sharing is in place, involving many people and groups
- Italian contribution:
  - **Fernando**
    - FlavourTagger
  - **Benjamin**:
    - B^0 -> J/psi K_L
    - Hard for winter conf maybe?
  - **Chiara** (now J)
    - Had control sample

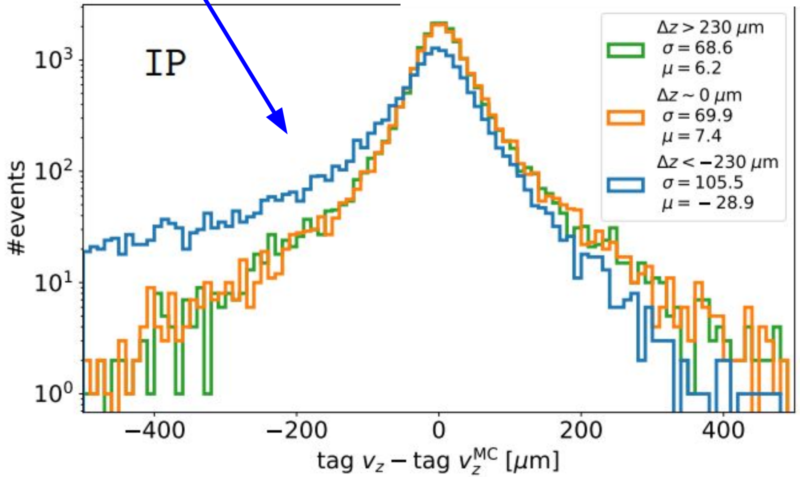


Tag Vertex issues

- Current algo is TagV, based internally on RAVE (CMS).
  - Lack of developers for TagV and no support for RAVE
    - Investigating use of KFit in place of RAVE
  - **Personpower needed, you are welcome to join!**
- Due to nano beam, the IP constraint is tricky to use
  - IP constraint is wrong if B flies long time
  - Using IP constraint can bias the Tag Vertex Z residuals
  - Elongating along B boost better but not yet perfect







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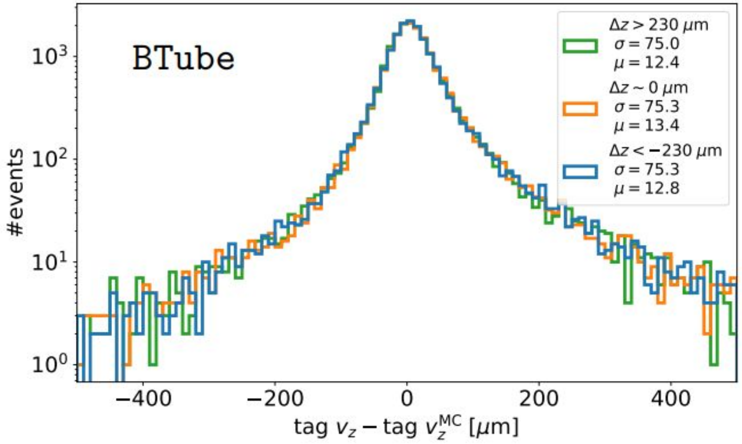
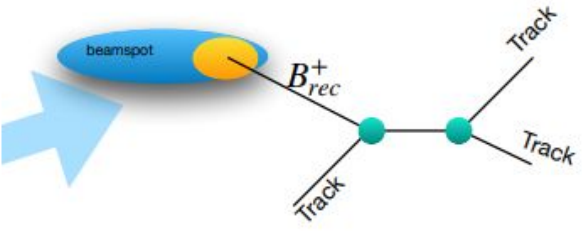
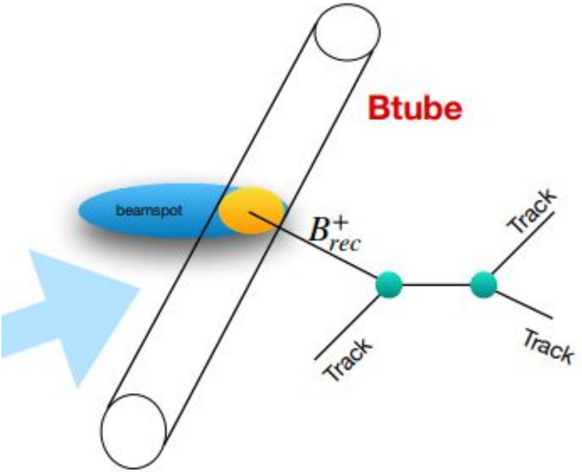
Tag Vertex Fit

Sourav (Tel Aviv),
Thibaud (MPI)

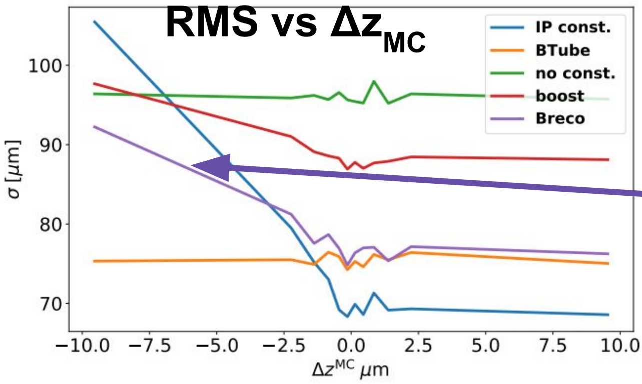
- **Btube** constraint
- Propagate B_{sig} to beamspot
  - Get the vertex of both B
  - Compute flight direction of B_{TAG}
  - Use the tube as a constraint on tag side
  - https://agira.desy.de/browse/BIIANA-120

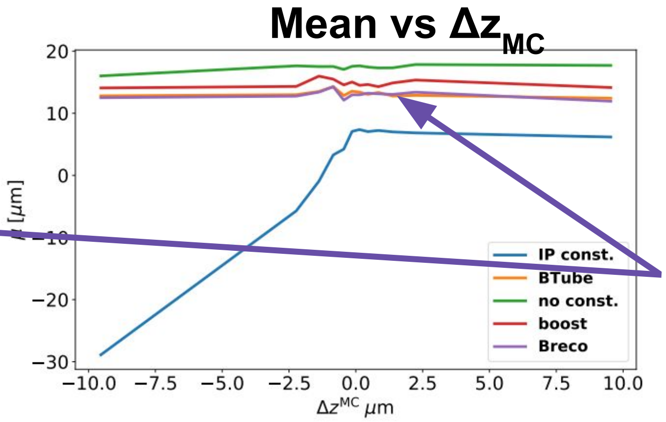




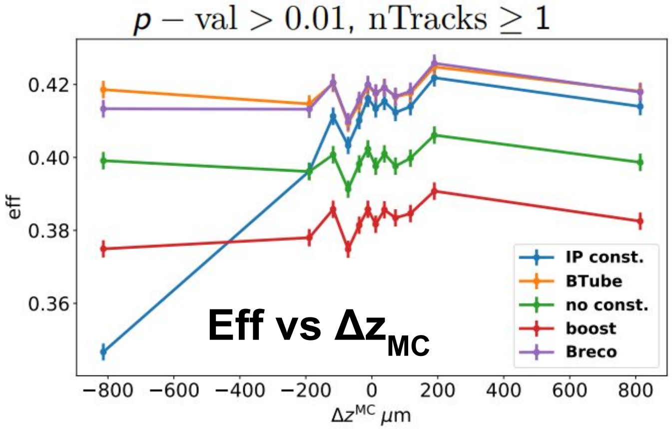


Btube vs other constraint





- RMS and mean vs Δz_{MC} for various constraint
- **Breco** is the actual standard de-facto



- Efficiency vs Δz_{MC} : as good as Breco
- Btube has no (or little) bias vs Δz_{MC}
- **Next step is test with KFit in place of RAVE**
- Test on data: fit mixing and lifetime

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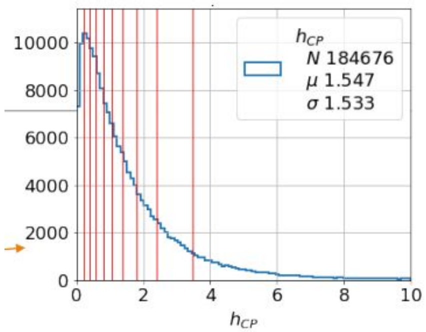
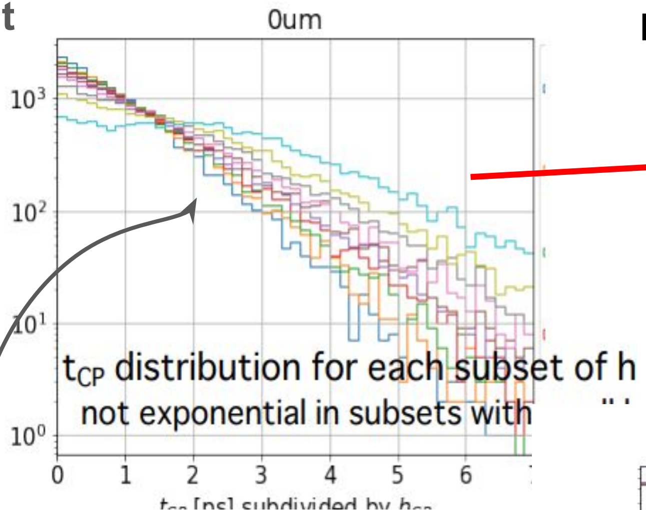
CP-side vertex: IP constraint w/ KFit

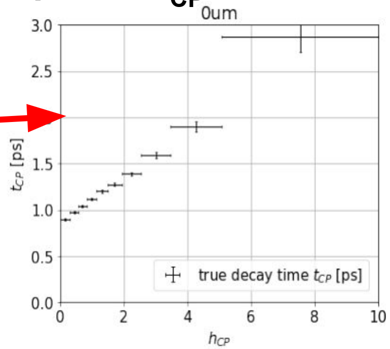
Tanigawa-san Tokyo

- **Similar issue on CP-side vertex fit**
- Study in bin of $h_{CP} = \chi^2/NDoF$

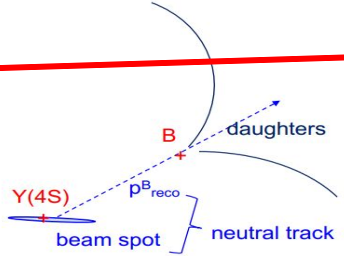


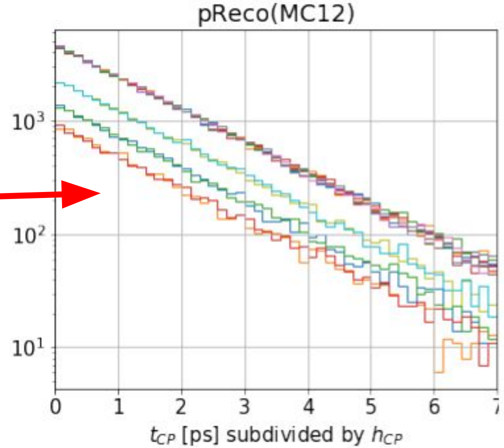


Exp fit to t_{CP} distribution



- strong correlation between t and h
  - **τ depends on h_{CP}!**
- **Solution: event-by-event tube constraint**
  - Require fully reconstructed B^0 **P_{RECO} Tube**
  - **Similar to Btune, but for CP side**





Flavor tagger validation

Fernando (TS)
Colm (IPMU)

- Use fully-hadronic **self-tagged B^0 decay**
- **Use Time Integrated PDF**
  - signal flavour α flavour and tag-side β, χ_d B meson mixing

$$\mathcal{P}^{\mathrm{Obs}}_{\alpha\beta} = \frac{\varepsilon}{2}[1 - \alpha\beta(\alpha \cdot \Delta w + (1 - 2w) \cdot (1 - 2\chi_d))]$$

- **From fit get: ε_i, w_i, Δw_i**
  - for i=1,7 bins (r=|1-2w|)
- Closure test on MC ok
- Working toward a full fit

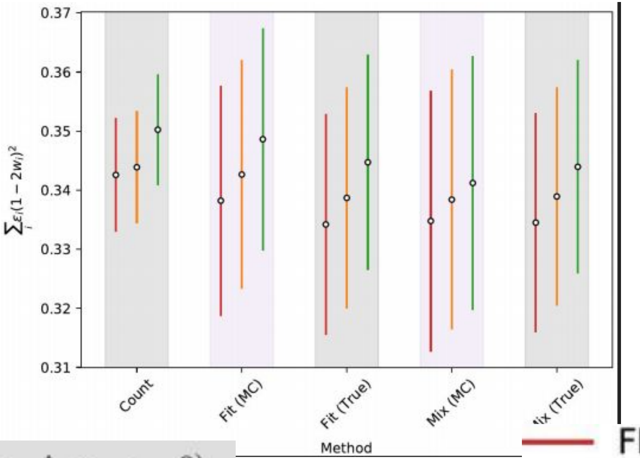
$$\mathcal{P}_{\mathrm{Sig}} = \mathcal{P}(\Delta E) \times \mathcal{P}(M_{bc}|\Delta E) \times \mathcal{P}(\varepsilon, w, \Delta w, \alpha, \beta)$$

Control Samples (same as $\tau(B^0)$)

1	$B^+ \to \bar{D}^0 \pi^+$
2	$B^+ \to \bar{D}^0 \rho^+$
3	$B^+ \to \bar{D}^{*0} \pi^+$
4	$B^+ \to \bar{D}^{*0} \rho^+$
5	$B^+ \to \bar{D}^{*0} a_1^+$

1	$D^+ \to K^- \pi^+ \pi^+$
2	$D^+ \to K^0_S \pi^+$
3	$D^+ \to K^0_S \pi^+ \pi^0$
4	$D^+ \to K^- \pi^+ \pi^+ \pi^0$

Plus neutral modes



Status of $B^0 \to \eta' K^0_S$

- η' in phase 3
- $\eta' \to \eta(\to \gamma\gamma)\,\pi^+\pi^-$ in MC12

Introduction

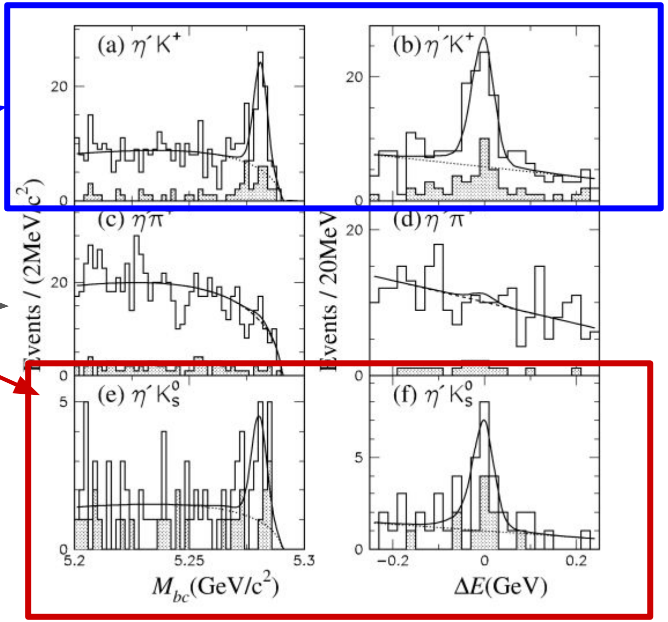
- $BR(B^0 \to \eta' K^0_S) = (\, 6.6 \pm 0.4\,) \times 10^{-5}$
    - $C_{CP}\,(B^0 \to \eta' K^0\,) = -0.06 \pm 0.04$
    - $-A_{CP}=S_{CP}\,(B^0 \to \eta' K^0_S\,) = 0.63 \pm 0.06$
- $BR(B^+ \to \eta' K^+) = (7.06 \pm 0.25\,) \times 10^{-5}$
- Can it be seen with 10/fb?
    - **It was done at Belle,** both for:
        - B^+: $BR=(79^{+12}_{-11} \pm 8) \times 10^{-6}$
        - B^0 : $BR=(55^{+19}_{-16} \pm 9) \times 10^{-6}$
        - Limit for $B^0 \to \eta' \pi^+$
- Final states used at Belle
    - $\eta' \to \rho(\to \pi^+\pi^-)\,\gamma$ (42/10 ev B^+/B^0)
    - $\eta' \to \eta(\to \gamma\gamma)\,\pi^+\pi^-$ (29/6 ev)
    - $\eta' \to \eta(\to \pi^+\pi^-\pi^0)\,\pi^+\pi^-$ not used

4 October 2001
PHYSICS LETTERS B
ELSEVIER
Physics Letters B 517 (2001) 309–318
www.elsevier.com/locate/npe

Measurement of the branching fraction for $B \to \eta' K$ and search for $B \to \eta' \pi^+$

Belle Collaboration

Belle 10.5 /fb



Shaded $\eta' \to \eta\pi\pi$, white all (including $\eta' \to \rho\gamma$)

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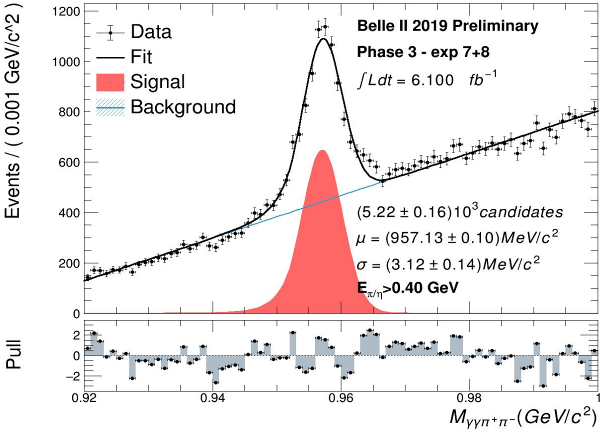
Plan (today)

- Rediscover η and η' in all final states, and compare with MC expectation
- Study selection and efficiency for $B^0 \rightarrow \eta' K^0_S$ in MC
  - $\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\, \pi^+\pi^-$,
  - $\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\, \pi^+\pi^-$,
  - $\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\, \gamma$
- Apply selection to generic Run dependent MC to check signal yield
  - Setup and 2D fit on M_{bc}-ΔE for signal extraction (not today but ready)
- Study Data continuum and side bands for background assessment
- **Repeat for B^+**
- Document everything
- Finalize selection for Data
  - Review process toward unblinding
- Systematics and unblinding

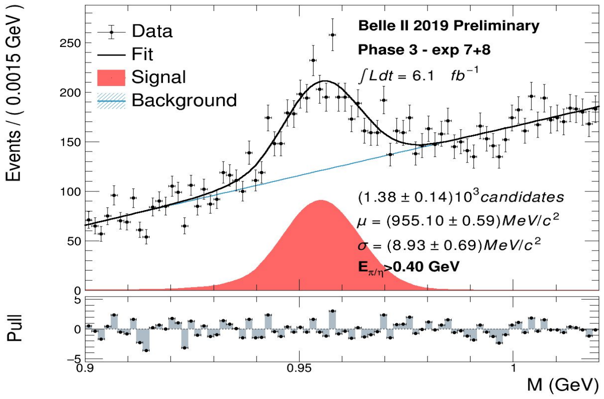
A lot of work still needed, hard for Moriond

η' rediscovery in phase3 (and 2)

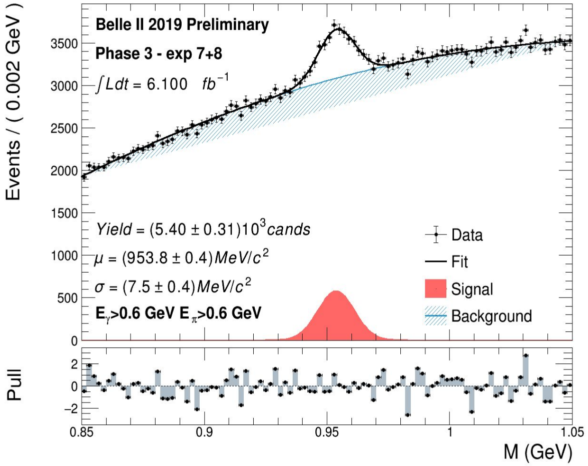
$\eta' \to \eta(\to\gamma\gamma)\,\pi^+\pi^-$



$\eta' \to \eta(\to\pi^+\pi^-\pi^0)\,\pi^+\pi^-$



$\eta' \to \rho(\to\pi^+\pi^-)\,\gamma$



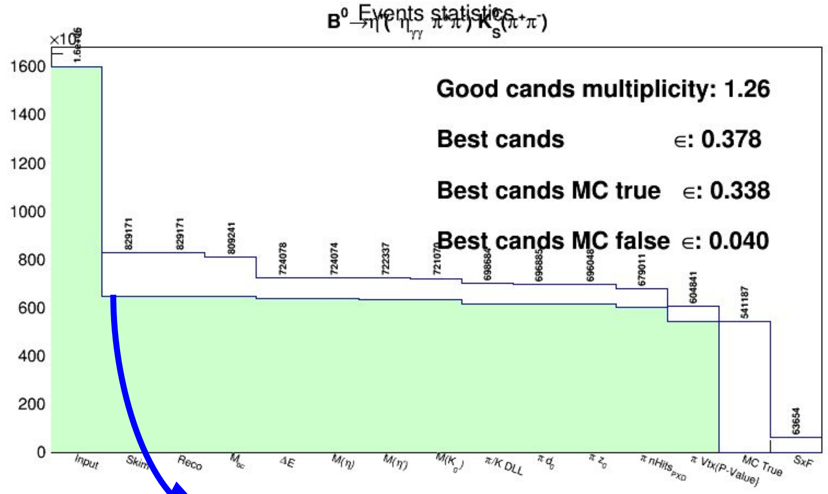
- $\pi^0 \to\gamma\gamma$, $\eta \to\gamma\gamma$, $\eta \to\pi^+\pi^-\pi^0$ and phase2 in backup
- For $\rho(\to\pi^+\pi^-)\,\gamma$ applied a π^0 veto: S/B improved
  - TreeFitter w/ mass constraint on η/π^0, not on ρ
- Very good agreement with MC: peak position, width, and yield
- At Belle width: **2.7 vs 3.12 MeV ($\gamma\gamma\pi^+\pi^-$) and 8.8 vs 7.5 MeV ($\rho\gamma$)**

BELLE2-NOTE-PH-2018-038

Efficiency $B^0 \to \eta'(\to \eta(\to \gamma\gamma)\, \pi^+\pi^-) K^0_S(\to \pi^+\pi^-)$

- Signal efficiency and SxF varied a lot depending:
  - MC campaign (simulated beam background)
  - Basf2 release (issue and improvement on reconstruction, mostly tracking and vertexing)

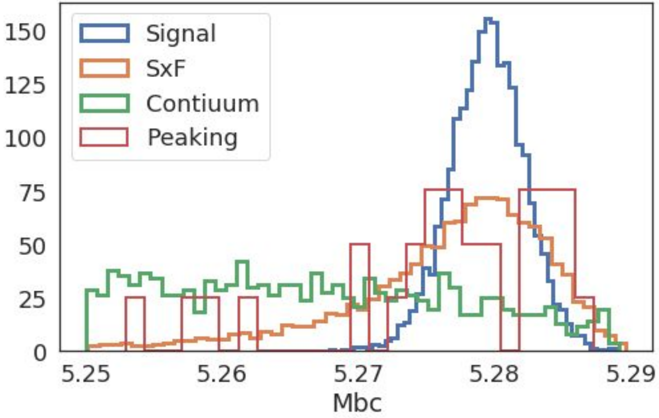
MC Campaign/Release	Efficiency	SxF
MC7/Rel-09 (B2TIP)	23 %	3.8 %
MC9/Rel-02	22 %	6.7 %
MC10/Rel-02	11 %	3.5 %
MC12b/Rel-03	19 %	4.5 %
MC12b/Rel-04	**37 %**	**9.3 %**
“ Best Cand -SxF BDT	**34 %**	**4.0 %**

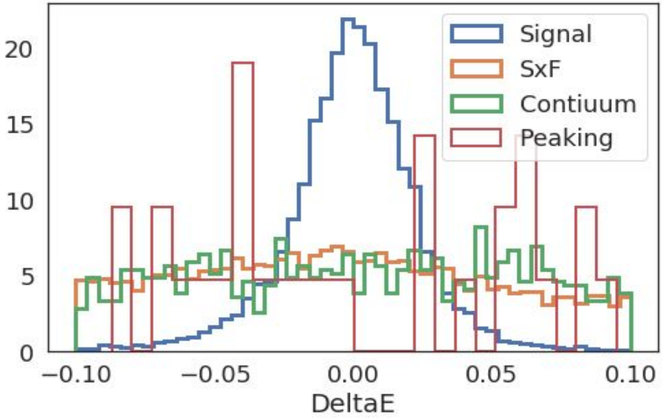


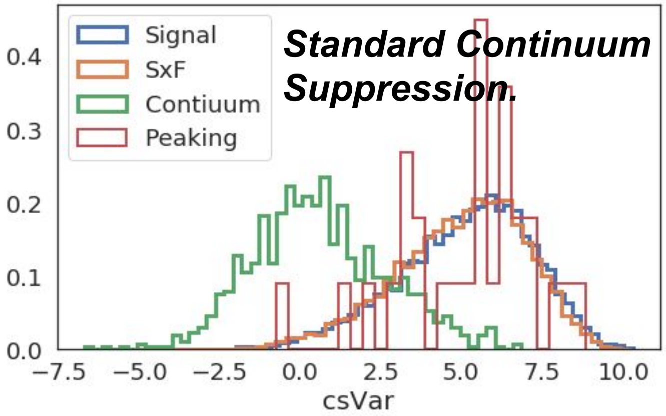
Most ε drop from reconstruction

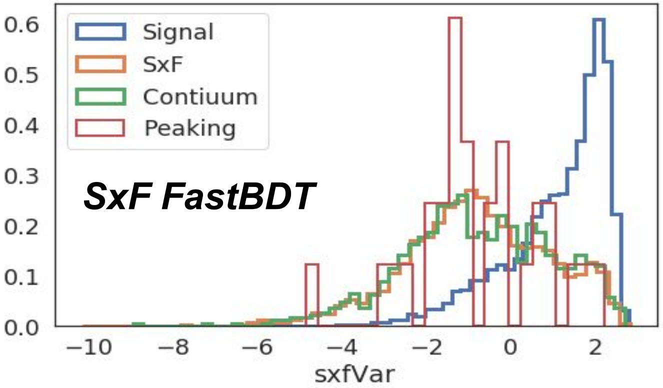
Optimized for Efficiency, not (yet) for SxF suppression.
Just using old (B2TIP) cuts, including SxF BDT (see backup)

Pdf: Signal - SxF - Bkg - BB

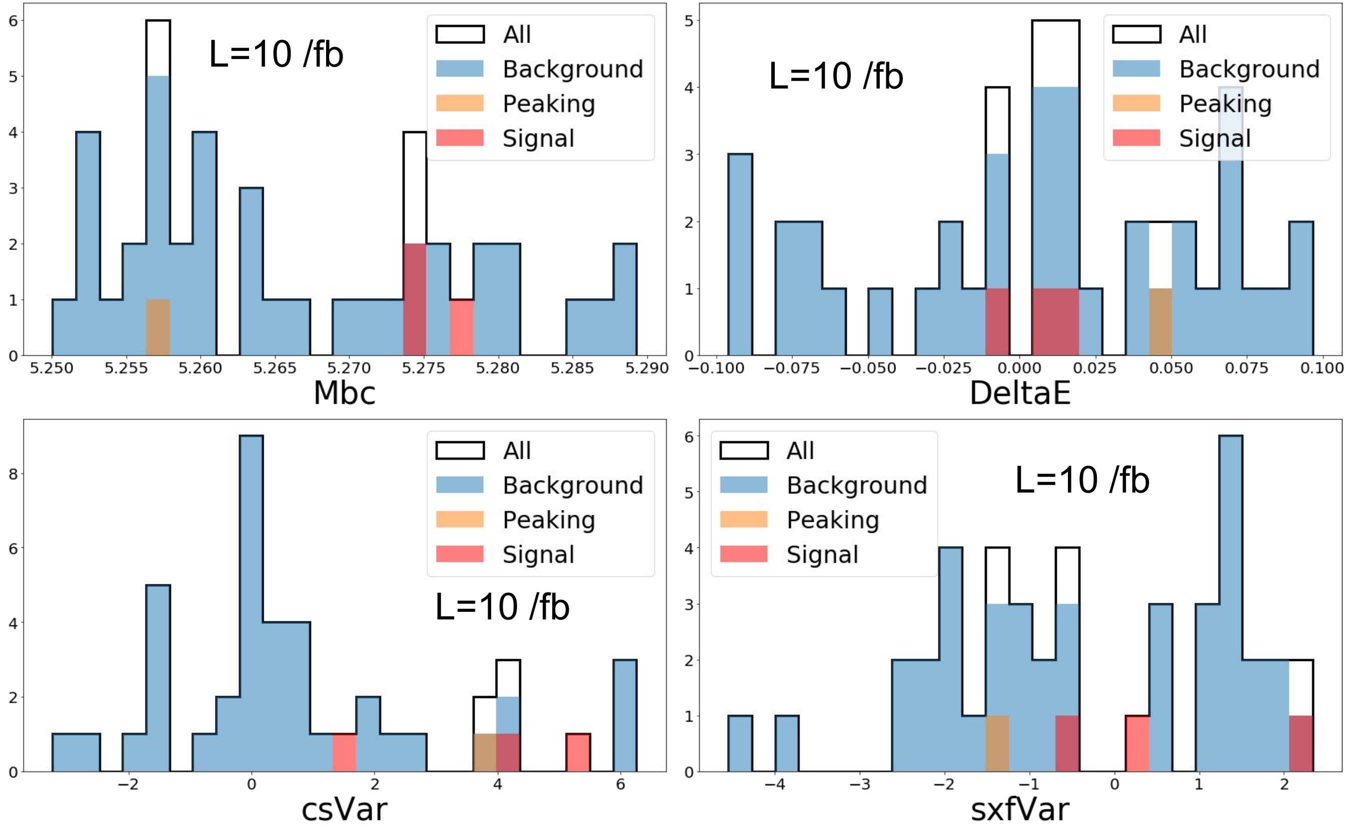








Test on Run Dependent MC12d



Continuum (+τ) + BBar
L = 10 /fb

DS	Exp'd	Seen
Signal	~10	3
Bkg	~100	40
BB	~3	1

A quick test, much to be understood yet.

Data still blind
Will look at SB and continuum

Summary

- TDCPV WG plan for Moriond
  - B^0 lifetime with hadronic modes
  - First TD B0 $\rightarrow K^0_S J/\psi$ measurement
- Rediscovery of hadronic penguin $B^0 \rightarrow \eta' K^0_S$
  - Very good η' signal seen on data
  - Very good efficiency with release 4
  - First test on Run dependent MC
  - Difficult for Moriond
    - Short timescale and personpower issue: will try anyway.

Backup

AS REQUESTED, I FIT MY PRESENTATION ON ONE POWERPOINT SLIDE.
I HAD TO USE ALL OF THE WHITE SPACE, BUT I THINK IT WAS WORTH IT TO FIT EVERYTHING ON ONE PAGE.
IT'S ACTUALLY ONLY ONE BULLET POINT, BUT IT'S A LONG ONE.
www.dilbert.com

B^0 lifetime measurement

- Measurement of B meson lifetimes with hadronic decay final states
  - **Phase III data,**
  - IPHC Strasbourg, Reem Rasheed et al
    - BELLE2-NOTE-PH-2019-017
    - Status: in review by conveeners, soon to go to RC
- No flavour tagging needed, simple Dt resolution function
  - 6 fully reconstructed hadronic final states. **In common with BToCharm WG**

- **B^0 channels** :
  - $B^0 \to D^- \rho^+$, $D^- \to K^+ \pi^- \pi^-$
  - $B^0 \to D^- \pi^+$, $D^{*-} \to D^0 \pi^-$
  - $B^0 \to D^{*-} \pi^+$,
  - $B^0 \to D^{*-} \rho^+$
  - $B^0 \to D^{*-} a1^+$

D^0 channels

$D^0 \to K^- \pi^+$
$D^0 \to K^- \pi^+ \pi^0$
$D^0 \to K^- \pi^+ \pi^+ \pi^-$

$a1^+ \to \pi^+ \pi^+ \pi^-$
$\rho^+ \to \pi^+ \pi^0$

Decay	Selection efficiency %	σ_{effe}(statistical) %
$B^0 \to D^- \pi^+$	20	0.04
$B^0 \to D^- \rho^+$	10	0.03
$B^0 \to D^{*-} \pi^+$	22	0.043
$B^0 \to D^{*-} \rho^+$	8	0.025
$B^0 \to D^{*-} a_1$	6.6	0.019

B^0-> D^- a_1^+ excluded due to hig background

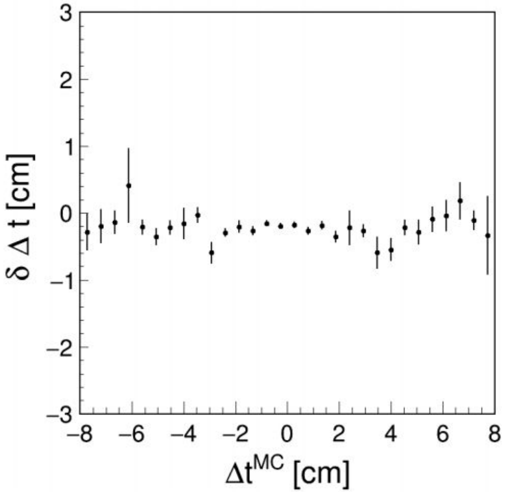
Δt model and fit (MC only)

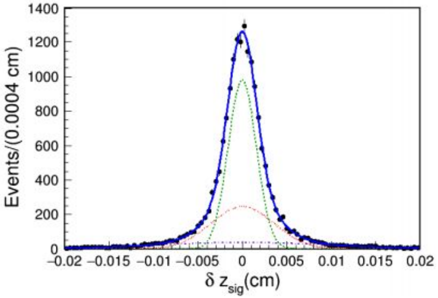
- Convolution of physics
- And resolution function

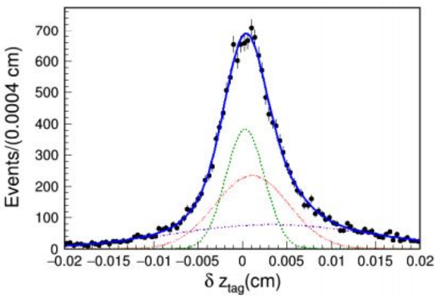
$$\mathcal{P}_{th}(\Delta t) = \frac{1}{2\tau_B} \exp\left(-\frac{|\Delta t|}{\tau_B}\right).$$

$$\mathrm{P}_{sig}(\Delta t) = \int_{-\infty}^{+\infty} \mathcal{P}_{th}(\Delta t')\, \mathcal{R}_{sig}(\Delta t - \Delta t')\mathrm{d}\Delta t'.$$

- Not using the event-based uncertainty
  - No dependency of Δz residual on Δt_{MC}
- Simplified model:
  - triple gaussian separately for signal and tag side
  - For signal, continuum, BB

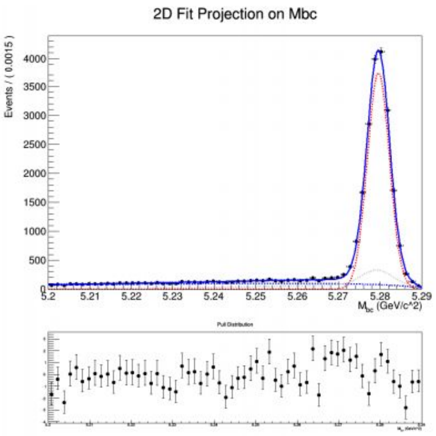


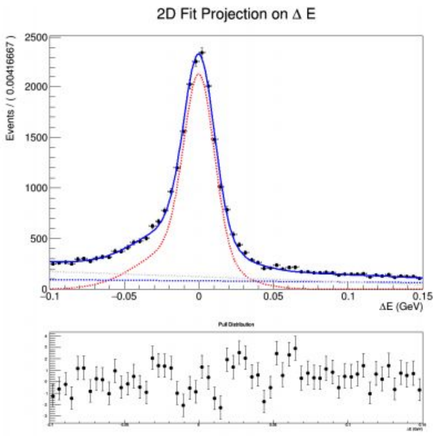




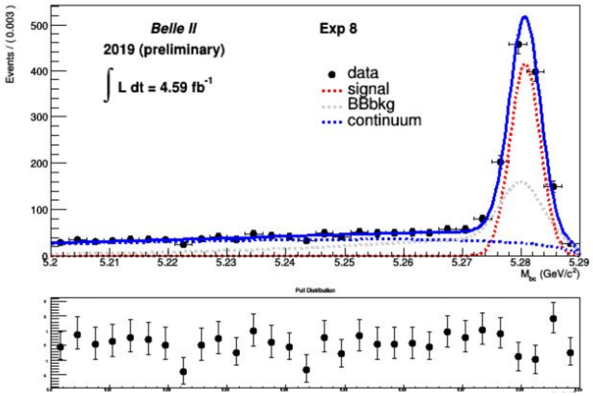
Signal in MC and Data

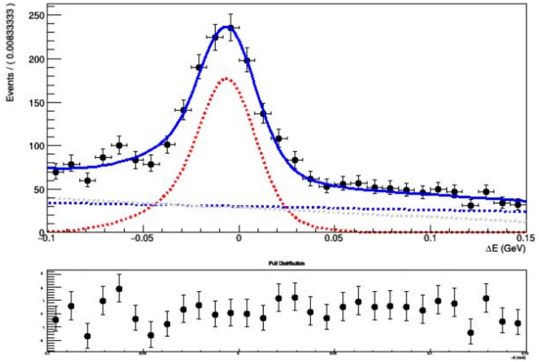
- 2D fit on Mbc and DE with signal, BB, and continuum contribution





- In data (exp8 only), O(1000) candidates
- Clean signal
  - f_{sig}~53% in signal region (0.4 for MC)





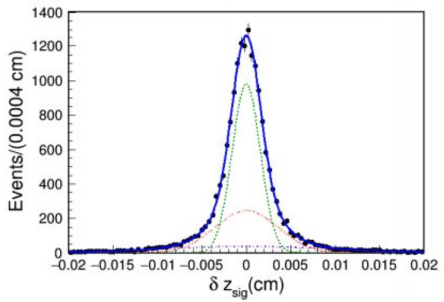
Δt model and fit (MC only)

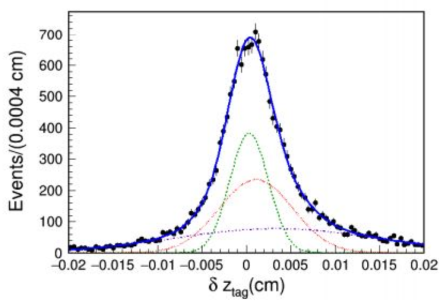
- Convolution of physics
- And resolution function

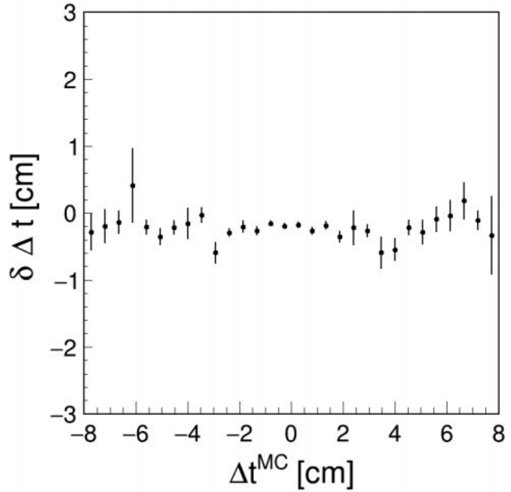
$$\mathcal{P}_{th}(\Delta t) = \frac{1}{2\tau_B} \exp\left(-\frac{|\Delta t|}{\tau_B}\right).$$

$$\mathrm{P}_{sig}(\Delta t) = \int_{-\infty}^{+\infty} \mathcal{P}_{th}(\Delta t') \, \mathcal{R}_{sig}(\Delta t - \Delta t') \mathrm{d}\Delta t'.$$

- Not using the event-based uncertainty
  - No dependency of Δz residual on Δt_{MC}
- Simplified model:
  - triple gaussian separately for signal and tag side
  - For signal, continuum, BB







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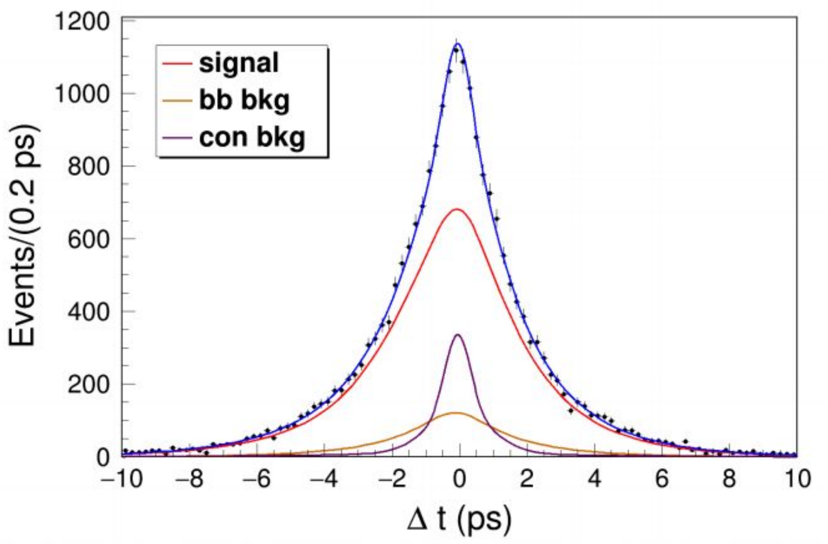
Lifetime extraction

- UML fit on Δt with full pdf
  - Fixing some parameters from MC
- Test on MC 80/fb
  - **Data stil blind**

$$\mathrm{P}_{\mathrm{all}}(\Delta t) = f_s\,\mathrm{P}_{\mathrm{sig}}(\Delta t) + f_{b\bar{b}}\,\mathrm{P}_{b\bar{b}}(\Delta t) + (1 - f_s - f_{\bar{b}})\,\mathrm{P}_{\mathrm{cont}}(\Delta t).$$

$$\mathrm{P}_{sig}(\Delta t) = \int_{-\infty}^{+\infty} \mathcal{P}_{th}(\Delta t')\,\mathcal{R}_{sig}(\Delta t - \Delta t')\mathrm{d}\Delta t'.$$

$$\mathcal{R}_{sig}(\Delta t) = f_{s1}\,\mathcal{N}(\Delta t;\ \mu_{s1}, \sigma_{s1}) + f_{s2}\,\mathcal{N}(\Delta t;\ \mu_{s2}, \sigma_{s2}) + (1 - f_{s1} - f_{s2})\,\mathcal{N}(\Delta t;\ \mu_{s3}, \sigma_{s3})(4)$$



f_{s1}	0.4 ± 0.05
μ_{s1}	-0.0091 ± 0.09
σ_{s1}	0.451
f_{s2}	0.45 ± 0.054
μ_{s2}	-0.34 ± 0.11
σ_{s2}	1.23
f_{s3}	$1 - f_{s1} - f_{s2}$
μ_{s3}	-0.8 ± 0.21
σ_{s3}	4.09
τ_{B^0}	1.52 ± 0.019

Working on systematics

Target: Moriond

Flavor tagger validation

Fernando (TS)
Colm (IPMU)

- Use fully-hadronic **self-tagged B^0 decay**
- **Use Time Integrated PDF**
  - signal flavour **α** flavour and tag-side **β**

$$\mathcal{P}^{\mathrm{Obs}}_{\alpha\beta} = \frac{\varepsilon}{2}[1 - \alpha\beta(\alpha \cdot \Delta w + (1-2w)\cdot(1-2\chi_d))]$$

- **ε** Tagging efficiency
- w wrong tag probability
- Δw (B vs Bbar w)
- **α** flavour of signal side B (self tagged)
- **β** flavour of tag side B (flavour tagger)
- χ_d B meson mixing
- **From fit get: $\varepsilon_i, w_i, \Delta w_i$**
  - for i=1,7 bins (r=|1-2w|)

Control Samples (same as $\tau(B^0)$)

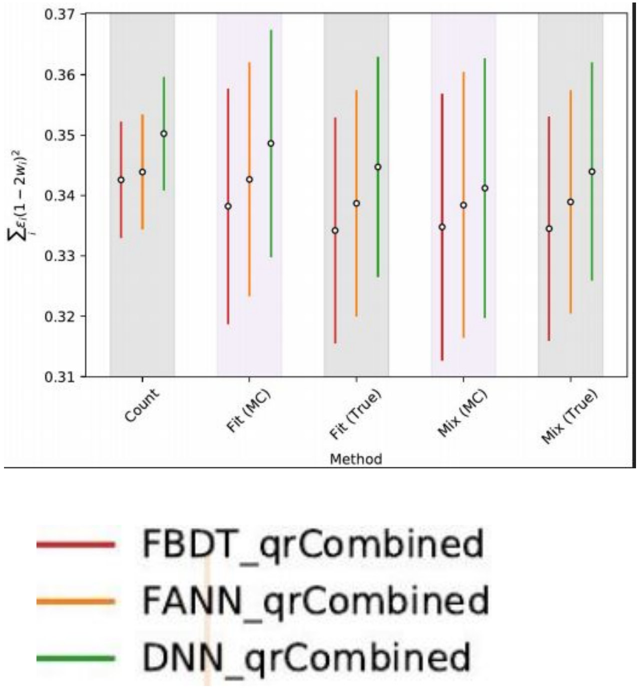
1	$B^+ \to \bar{D}^0 \pi^+$
2	$B^+ \to \bar{D}^0 \rho^+$
3	$B^+ \to \bar{D}^{*0} \pi^+$
4	$B^+ \to \bar{D}^{*0} \rho^+$
5	$B^+ \to \bar{D}^{*0} a_1^+$

1	$D^+ \to K^- \pi^+ \pi^+$
2	$D^+ \to K^0_S \pi^+$
3	$D^+ \to K^0_S \pi^+ \pi^0$
4	$D^+ \to K^- \pi^+ \pi^+ \pi^0$

Plus neutral modes

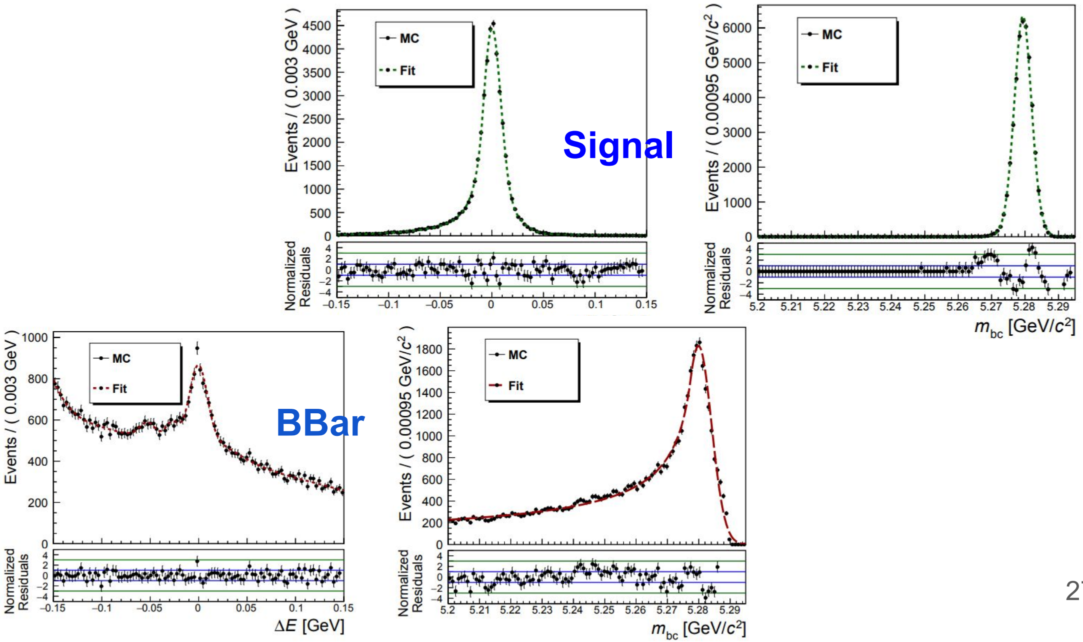
Results on MC: total effective eff

On MC: testing fit machinery
Also $\boldsymbol{\varepsilon}_i, w_i, \Delta w_i$ measured
Good match with MC truth



Write 2D fit for with components for signal, continuum and BBar

$$\mathcal{P}_{\mathrm{Sig}} = \mathcal{P}(\Delta E) \times \mathcal{P}(M_{bc}|\Delta E) \times \mathcal{P}(\varepsilon, w, \Delta w, \alpha, \beta)$$



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MPI fit method

- UML fit for TDCPV assumes that Δt resolution is independent on measured parameters and efficiency uniform in Δt, Δt_{true}. What if not.
- Reweight MC sample to get pdf of each event, instead of a analytic common pdf (eg tri-gaussian)
  - MC/Data discrepancy are cured by smearing MC quantities $\Delta t'_{rec} = \Delta t_{rec} + G(\alpha \cdot \delta(\Delta t_{rec}))$
    - α can be extracted from the fit
  - Use control sample (no CPV) to get α (smearing factor) from data
- Same fit to extract $\tau(B^0)$ $\tau(B^+)$, δm, S, and w_i, Δw_i, as well as smearing factor
  - Tested on MC12b (MC vs MC, no smearing needed not found)
  - And Belle w/ B2BII
  - Strong correlation τ - α

	S	$\tau(ps)$	$\delta m(ps^{-1})$	α_{smear}
assistive MC	0.69	1.535	0.502	
Belle data $J/\psi(\mu\mu)K^0_S$				
1 *par. MPI TDCPV*	0.595 ± 0.042	1.525 (*fixed*)	0.507 (*fixed*)	
3 *par. MPI TDCPV*	0.586 ± 0.042	1.641 ± 0.030	0.543 ± 0.039	
4 *par. MPI TDCPV*	0.621 ± 0.046	1.536 ± 0.049	0.554 ± 0.041	0.71 ± 0.13
PRL (2012) $J/\psi K^0_S$	0.670 ± 0.029	1.525 (*fixed*)	0.507 (*fixed*)	

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Final states considered (Belle)

- $\eta' \to \eta\pi^+\pi^-$: BR=42.6%
  - $\eta \to \gamma\gamma$: BR=38.41%
  - $\eta \to \pi^+\pi^-\pi^0$:BR=22.94%
- $\eta' \to \rho(\to\pi^+\pi^-)\gamma$: BR=28.9%
  - Including non resonant $\pi^+\pi^-\gamma$
- $K^0_S \to \pi^+\pi^-$: BR=69.2 %

Mode	N_S	Σ	$\epsilon(\%)$	$\epsilon B_s(\%)$	$BF(10^{-6})$
$\eta'_{\eta\pi\pi}K^+$	$28.9^{+6.5}_{-5.7}$	9.4	21.7	3.78	69^{+15}_{-14}
$\eta'_{\rho\gamma}K^+$	$42.5^{+9.1}_{-8.3}$	7.5	14.2	4.18	92^{+20}_{-18}
$\eta'_{\eta\pi\pi}\pi^+$	$0.0^{+1.2}_{-0.0}$	0.0	23.7	4.11	–
$\eta'_{\rho\gamma}\pi^+$	$0.0^{+5.6}_{-0.0}$	0.0	15.4	4.55	–
$\eta'_{\eta\pi\pi}K^0$	$6.4^{+3.4}_{-2.7}$	3.5	20.8	1.25	46^{+25}_{-20}
$\eta'_{\rho\gamma}K^0$	$10.1^{+4.4}_{-3.6}$	4.0	11.5	1.16	79^{+34}_{-28}

In Belle, most of signal comes from

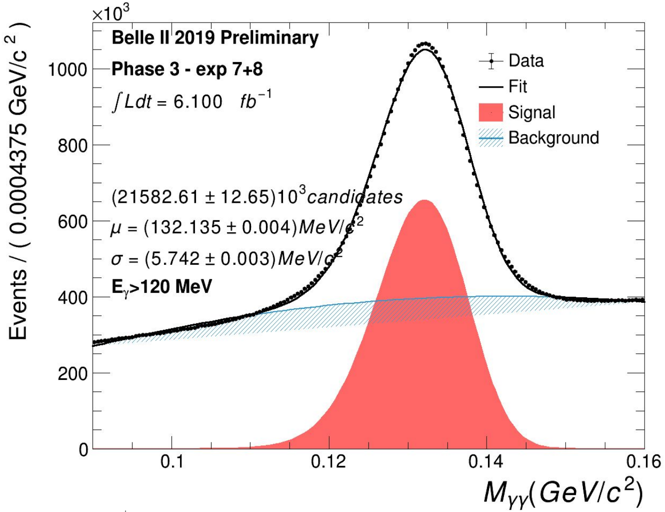
- $\eta' \to \rho(\to\pi^+\pi^-)\gamma$

$\eta \to \pi^+\pi^-\pi^0$ was not used in this analysis, only $\eta \to \gamma\gamma$

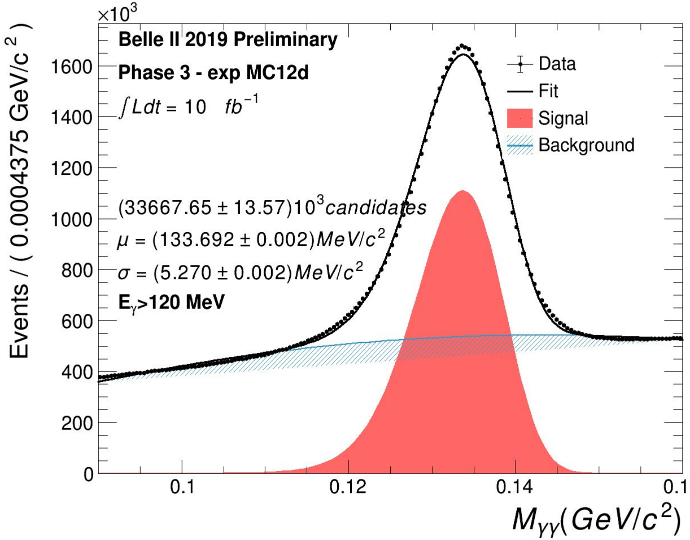
$\pi^0 \rightarrow \gamma\gamma$

- γ in CDC volume
- N_{hits}>1.5
- E_9/E_{21}>0.9
- E_γ>120 MeV

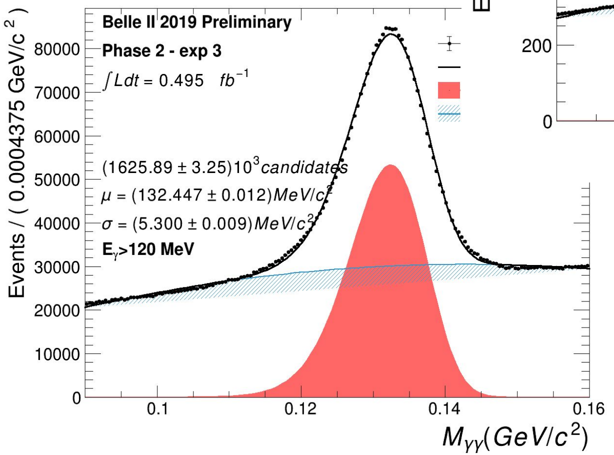
Phase 3



Run Dep MC12d

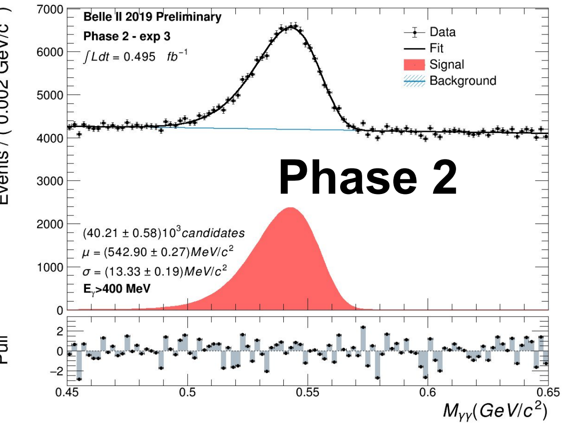


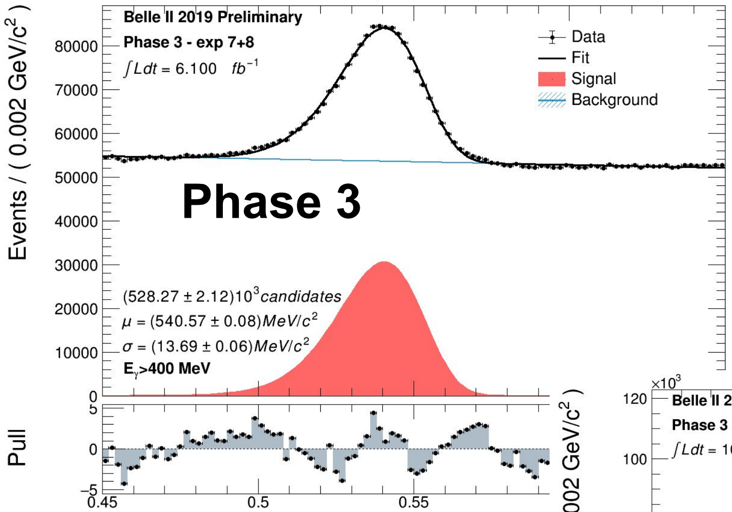
Phase 2

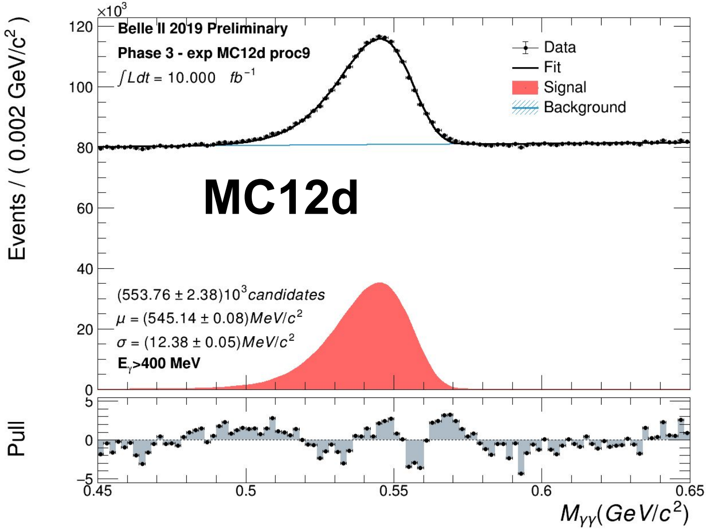


- Fit Novosibirsk + chebichev(2)
- Peak Shift 1 MeV between Data and MC12d
- Width 5.3 vs 5.7 vs 5.3 (phase 2, 3, MC)

$\eta \rightarrow \gamma\gamma$

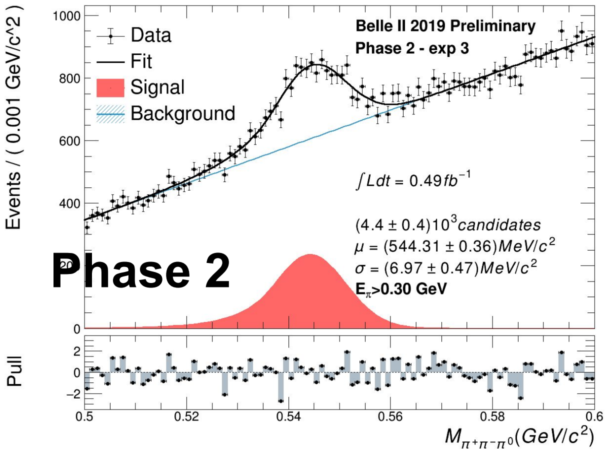


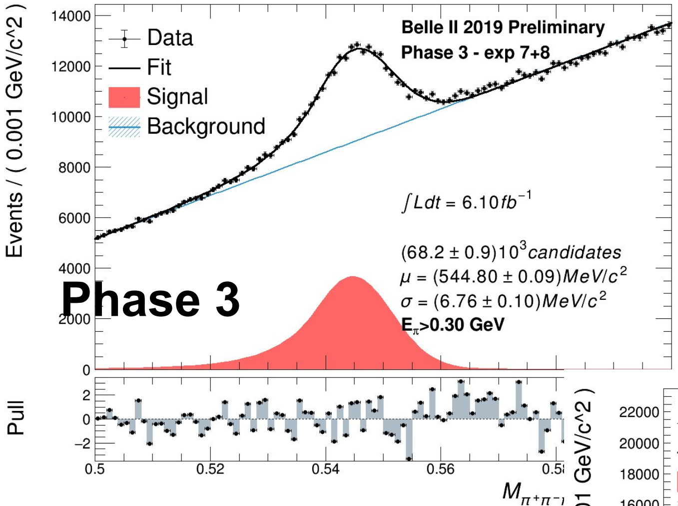


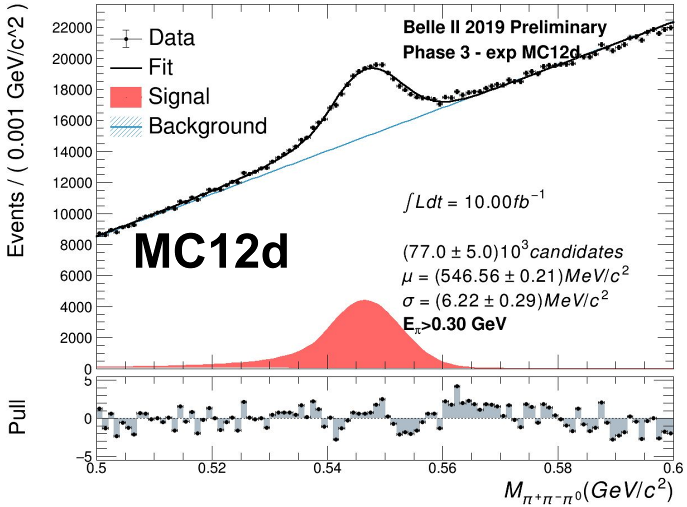


- Same cut as for $\pi^0 \rightarrow \gamma\gamma$
  - E_γ>400 MeV
- Peak: +5 MeV in MC phase3
- Width : 13 vs 14 vs 12.5 MeV (phase2, 3, MC12d)
  - At Belle (10.5 /fb)
  - $\eta \rightarrow \gamma\gamma$ width was 12 MeV/c^2

$\eta \rightarrow \pi^+\pi^-\pi^0$

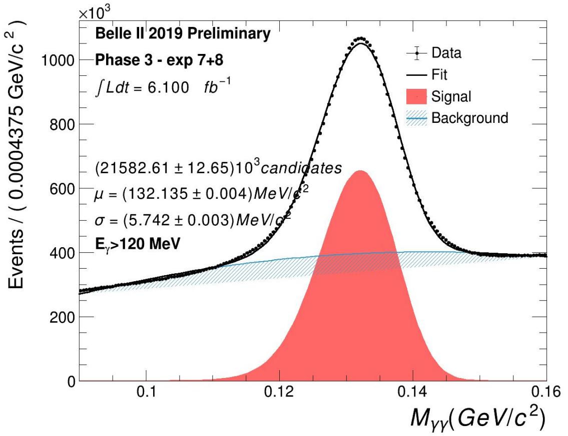


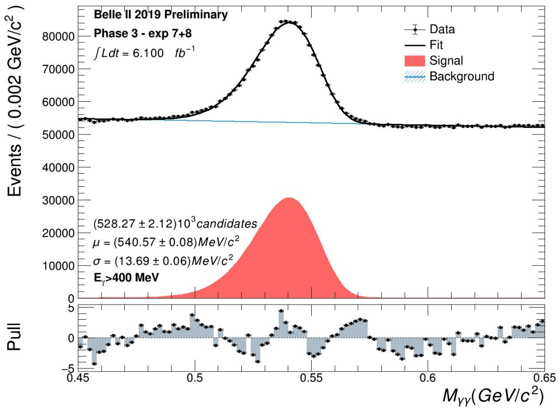


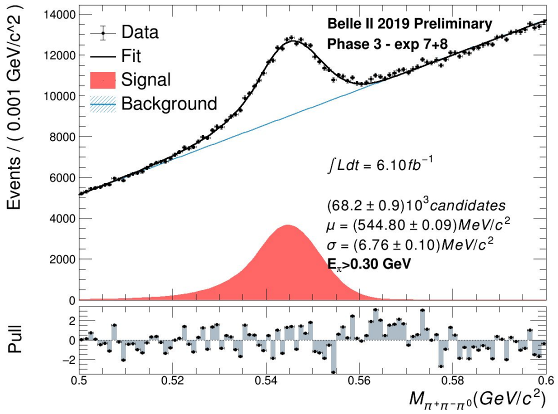


- $\pi^0 \rightarrow \gamma\gamma$
  - E_γ>200 MeV, 110<$m_{\pi 0}$<150 MeV,
- $\pi^{+/-}$: P(□^{2})>10^{-4}, dr<0.5 cm, |dz|<2 cm
- **p(π^{0+-})>300 MeV**
- TreeFitter, π^0 mass constraint
- Peak: +2 MeV in MC phase3
- Width : 7 vs 7 vs 6.4 MeV (phase2, 3, MC12d)
  - Not used at Belle (10.5 /fb)

$\pi^0 \to \gamma\gamma$ $\eta \to \gamma\gamma$ $\eta \to \pi^+\pi^-\pi^0$

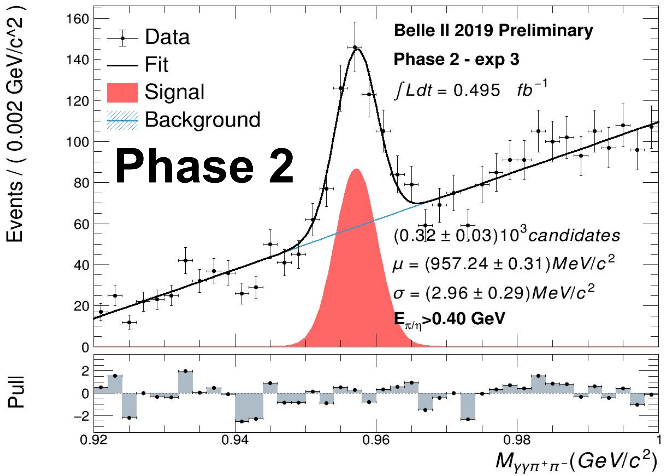


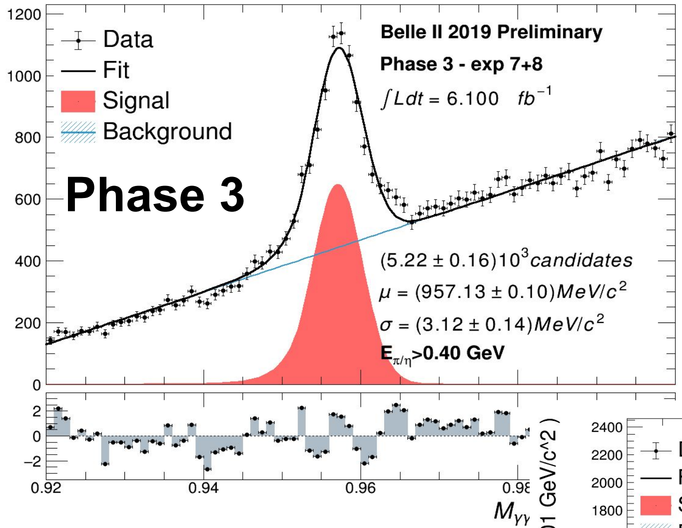


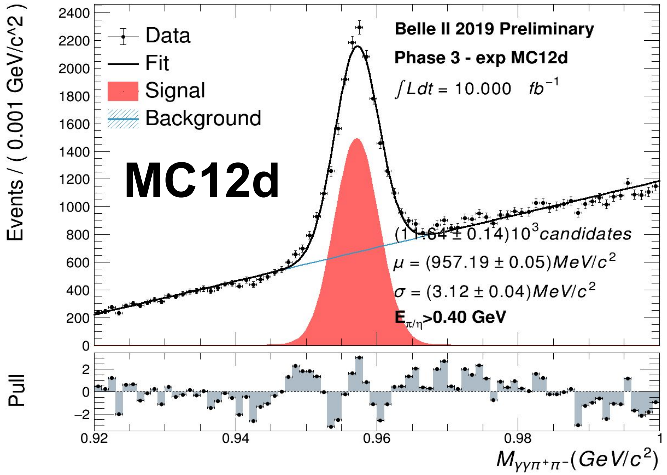


- Good signal also in Phase2 (see backup)
- Good agreement with MC12d MC (run dependent)
  - For position, width, and yield
  - **Width for $\eta \to \gamma\gamma$ at Belle 12 MeV (Belle2 13.9 MeV)**

$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\, \pi^+\pi^-$

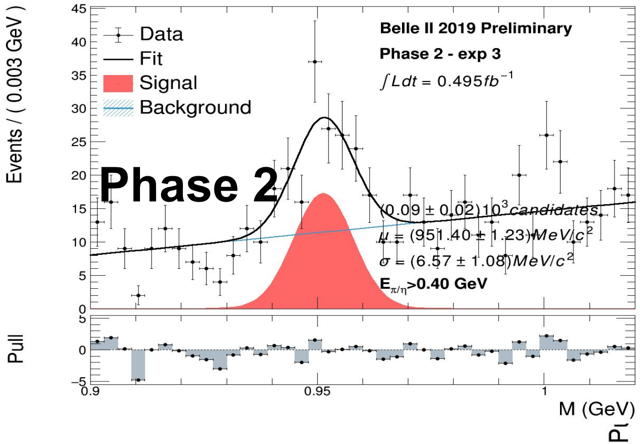


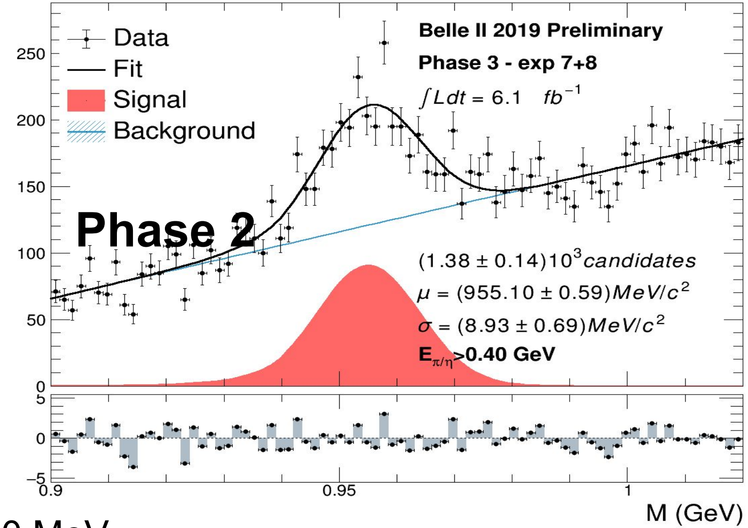




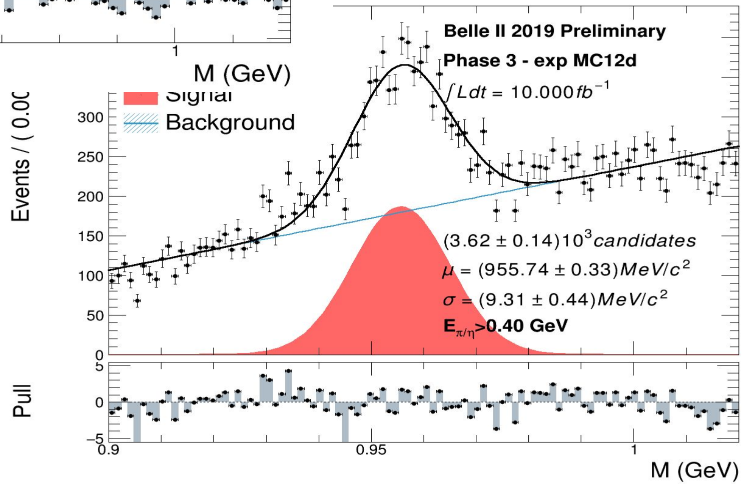
- γ and $\pi^{+/-}$ as before
  - $480 < M_\eta < 580$ MeV, $E_\gamma > 400$ MeV
- **p(π/η)>400 MeV**
- TreeFitter with η mass constraint
- Peak: same in data and MC
- Width : 3.0 vs 3.1 vs 3.1 (phase2, 3, MC12d)
  - at Belle (10.5 /fb), width was 2.7 MeV

$\eta' \to \eta(\to \pi^+\pi^-\pi^0)\ \pi^+\pi^-$



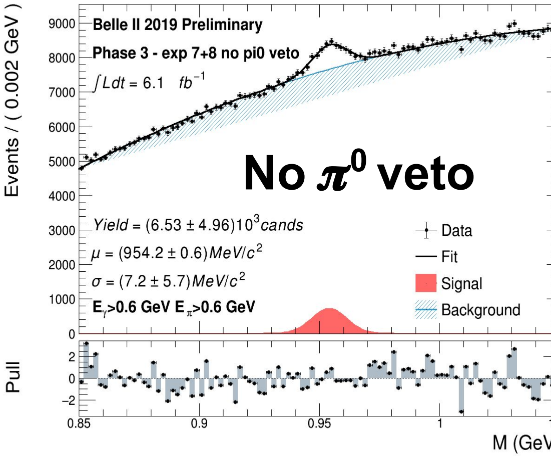


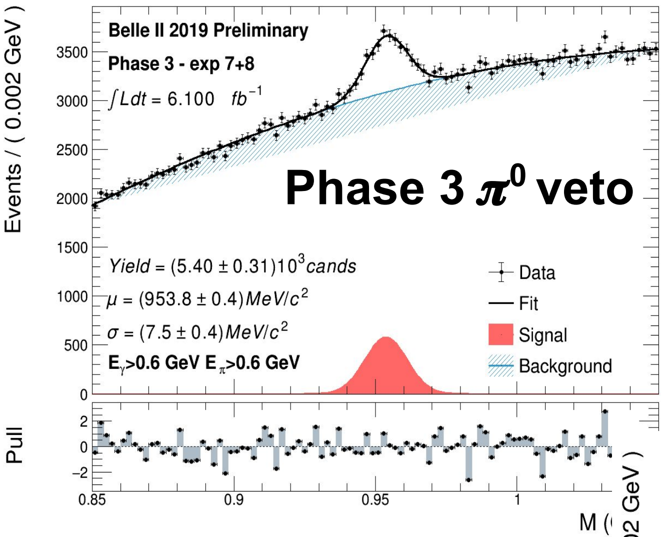
MC12d

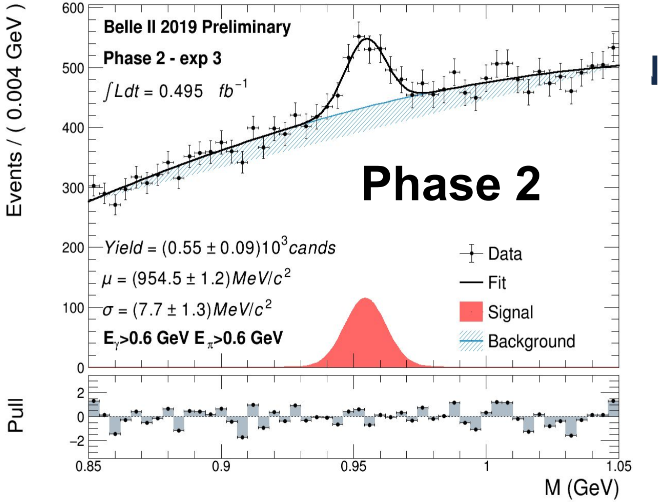


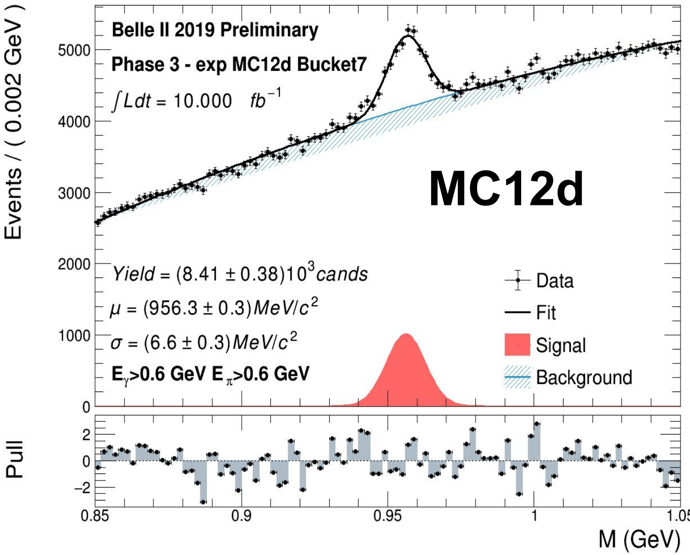
- γ and $\pi^{+/-}$ as before
  - 510<M_η<580 MeV, E_π>400 MeV
- **p(π/η)>400 MeV**
- TreeFitter with η and π^0 mass constraint
- Peak: same in data and MC (lower in phase 2)
- Width : 6.6 vs 8.9 vs 9.3 (phase2, 3, MC12d)
  - Not used at Belle (10.5 /fb)
- Yield (/fb) ($3\pi/2\gamma$)~0.23/0.85 ~ 0.27 - BR($3\pi/2\gamma$)=0.6
  - **$\varepsilon(3\pi/2\gamma)$~0.5**

$\eta' \to \rho(\to \pi^+\pi^-)$





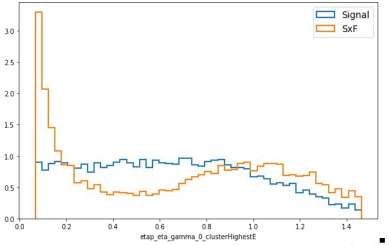


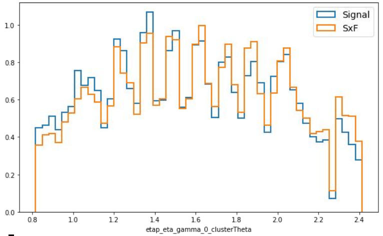


- γ and $\pi^{+/-}$ as before
  - **p(π/γ)>600 MeV**
  - **π^0 veto**: no γ in ROE with 120<$M_{\gamma\gamma}$<145 MeV
- TreeFitter: without ρ mass constraint (large res)
- Peak: +3 MeV in MC
- Width : 7.7 vs 7.5 vs 6.6 (phase2, 3, MC12d)
  - At Belle (10.5 /fb) 8.8 MeV
- Yield (/fb) ($\rho\gamma/2\gamma2\pi$)~0.85/0.85 ~ 1 - BR($\rho\gamma/2\gamma2\pi$)=2.3
  - **$\varepsilon(3\pi/2\gamma)$~0.4**

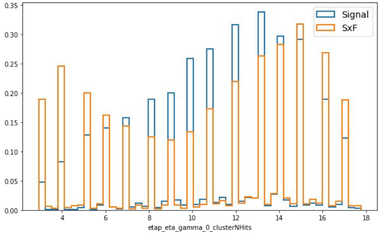
SxF Mitigation: fastBDT

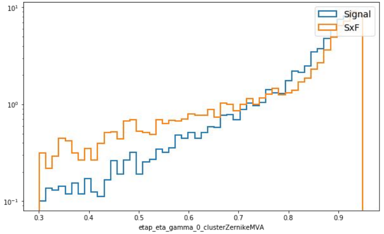
Almost 100% of SxF from $\eta(\rightarrow\gamma\gamma)$.

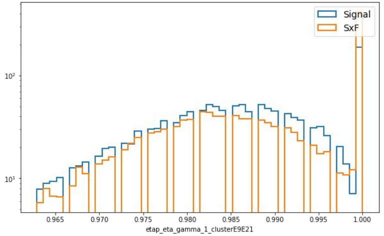


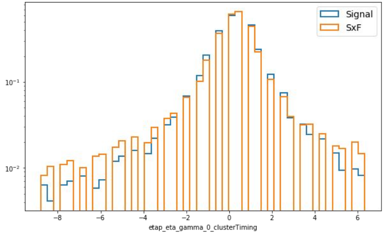


γ variables

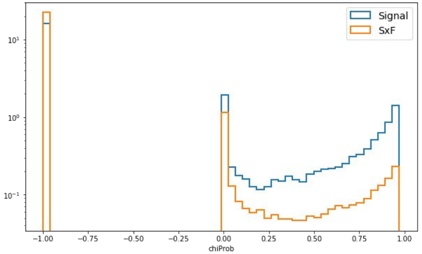


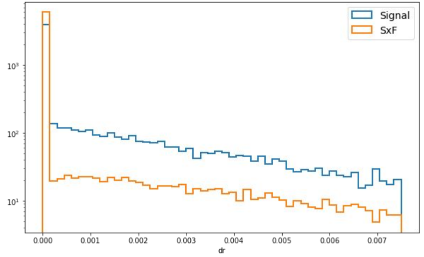


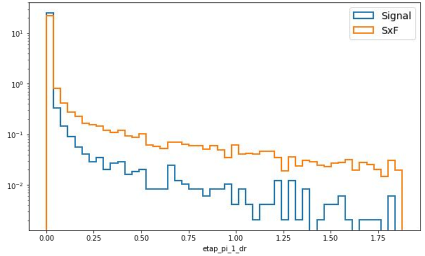




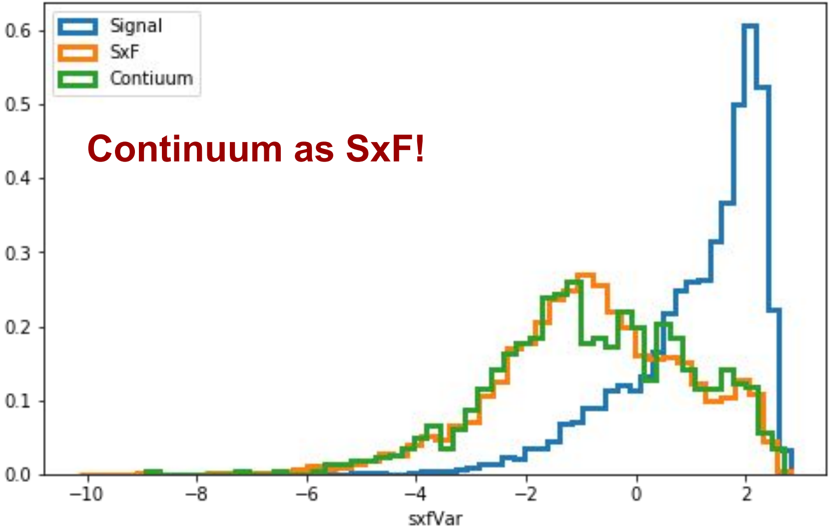
η' vertex variables



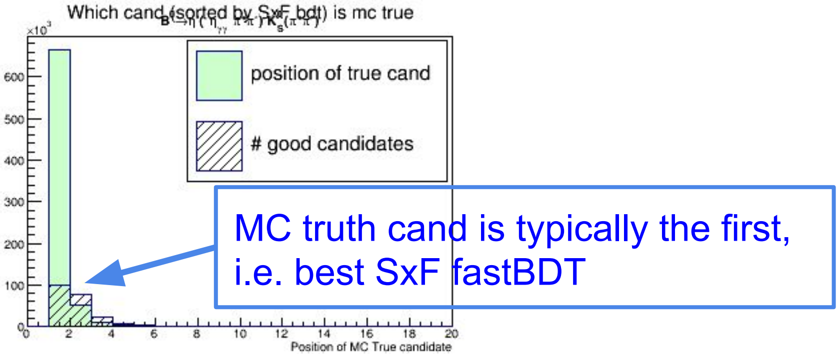


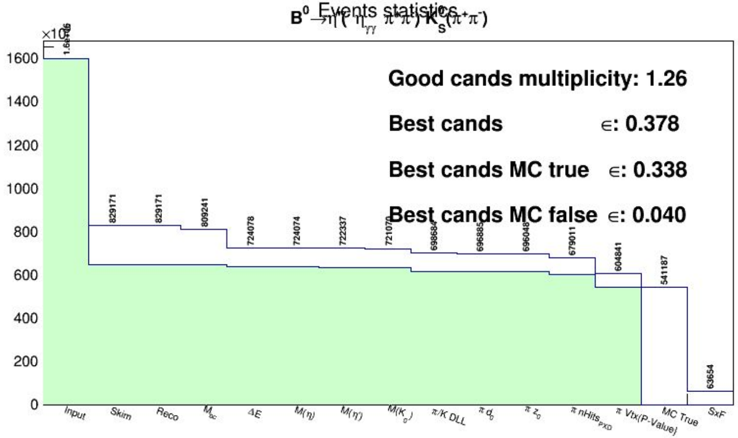


SxF FastBDT output



Sorting Candidates by SxF FastBDT





Selection	Efficiency	SxF
All candidates	37.0 %	9.3%
Best cand (SxF FBDT)	**33.8 %**	**4.0 %**

Need toys to understand which is better

Correlation (for signal)

Correlation M_{bc} **vs** ΔE **0.13**: know issue

Cont suppression ok

ΔE **vs SxF** symmetric correlation

M_{bc} **vs SxF** small **0.09**