$B^0 \to \rho^0 \rho^0$

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Motivation

- $B \to \rho\rho$ decays ➡ CKM angle α
- Goal: Belle + Belle II measurement
- Previous measurements:
  - **Belle:** $\mathcal{B}(B^0 \to \rho^0\rho^0) = (1.02 \pm 0.30 \pm 0.15) \times 10^{-6}$

    $f_L = 0.21^{+0.18}_{-0.22} \pm 0.15$

    166 $\rho^0\rho^0$ events
  - **BaBar:** $\mathcal{B}(B^0 \to \rho^0\rho^0) = (0.92 \pm 0.32 \pm 0.14) \times 10^{-6}$

    $f_L = 0.75^{+0.11}_{-0.14} \pm 0.04$

    $S_L^{00} = 0.3 \pm 0.7 \pm 0.2$

    $C_L^{00} = 0.2 \pm 0.8 \pm 0.3$

    99 $\rho^0\rho^0$ events
  - **LHCb:** $\mathcal{B}(B^0 \to \rho^0\rho^0) = (0.94 \pm 0.17 \pm 0.09 \pm 0.06) \times 10^{-6}$

    $f_L = 0.745^{+0.0.048}_{-0.058} \pm 0.034$

    600 $\rho^0\rho^0$ events

Signal MC

- Signal MC generation:
  - Using the **mcproduzh** package for **run-independent** signal MC production

    (Exp-dependent values of beam energies are used in EvtGen)
  - basf2 release-08-01-00

```
Decay Upsilon(4S)
1.0  B0sig anti-B0sig B0 anti-B0    VSS_BMIX dm;
Enddecay
```

longitudinal ($f_L = 1$)

```
Decay B0sig
1.0  rho0 rho0    PHOTOS SVV_HELAMP    0 0 1 0 0 0;
Enddecay
CDecay anti-B0sig
```

transverse ($f_L = 0$)

```
Decay B0sig
1.0  rho0 rho0    PHOTOS SVV_HELAMP    1 0 0 0 1 0;
Enddecay
CDecay anti-B0sig
```

1×10^6 signal MC events each for

- Longitudinal ($f_L = 1$)
- Transverse ($f_L = 0$)
- PDG ($f_L = 0.71$)

In Belle rare decay file:

```
0.86e-6   rho0 rho0   PHOTOS   SVV_HELAMP   1 0 1 0 1 0;
```

Control mode signal MC:

```
1.0   rho0   anti-D0     PHOTOS SVS;
1.0   K+     pi-         PHOTOS PHSP;
```

Selections

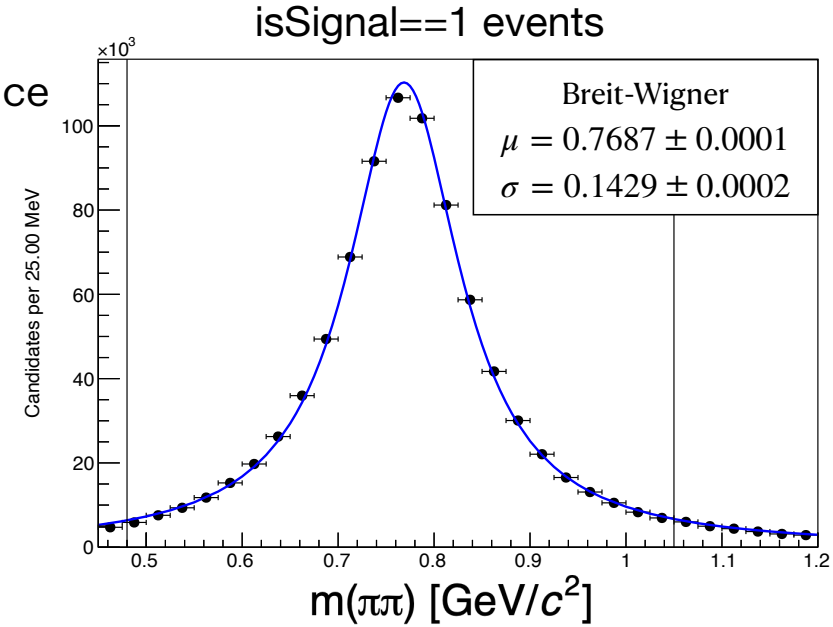
- Tracks: dr < 0.5 cm, |dz| < 2 cm, thetaInCDCAcceptance == 1, nCDCHits > 20
- ρ^0: 0.48 < $m(\pi^+\pi^-)$ < 1.05 GeV/c^2

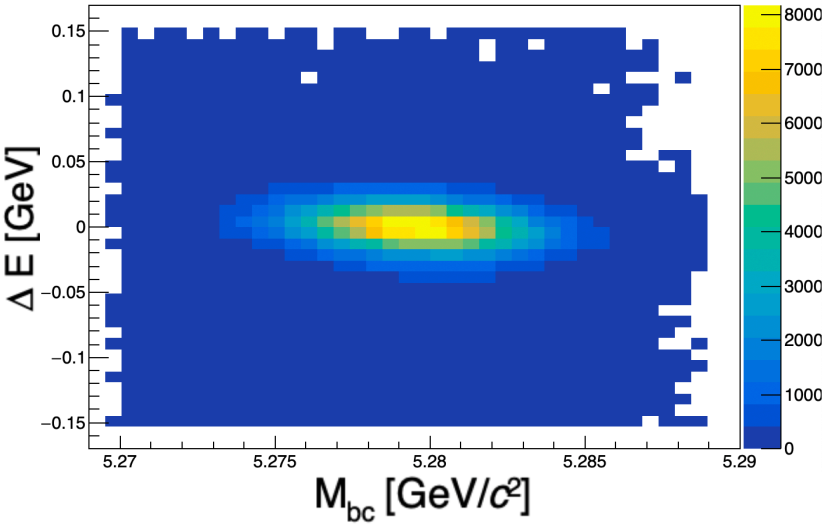
  ρ^0 candidates are randomised to avoid momentum ordering

  $m(\pi^+\pi^-)$ cut determined by fitting signal MC

  ➡ 2σ mass window
- B^0:
  - $M_{bc} > 5.27$ GeV/c^2 (reco: $M_{bc} > 5.24$ GeV/c^2)

    ➡ CS training variable
  - $|\Delta E| < 0.1$ GeV (reco: $|\Delta E| < 0.3$ GeV)
  - chiProb>0 && TagVpVal>0 && TagVNDF>0.5





Charm Vetos & PID

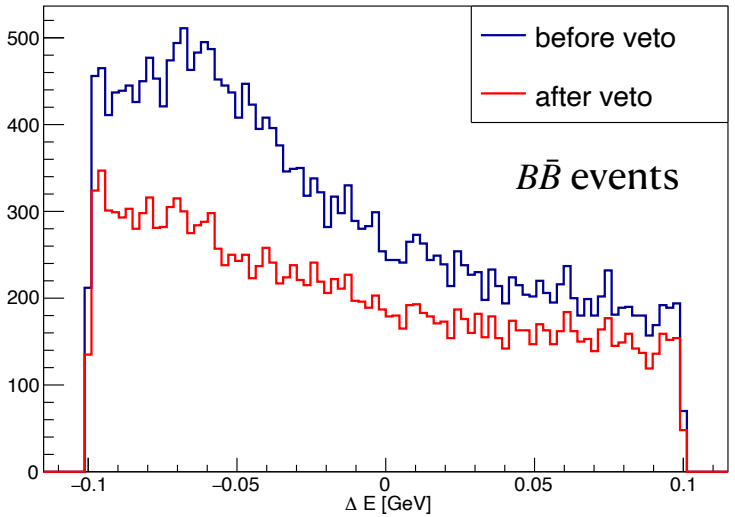
- $D^+ \to \pi^+\pi^+\pi^-, D^+ \to K^-\pi^+\pi^+, D^{*+} \to D^0\pi^+$

  $|\,m(\pi\pi\pi) - m(D)\,| < 0.012\ \mathrm{GeV}/c^2$

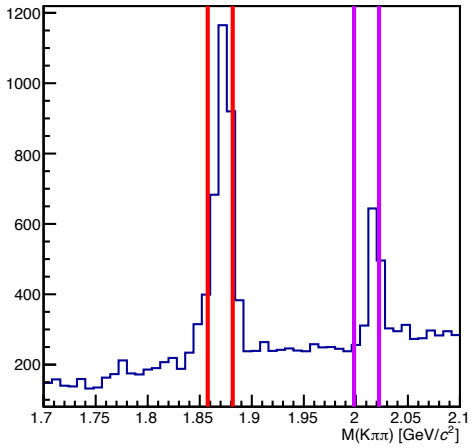
- $D^0 \to K^-\pi^+, D^0 \to \pi^+\pi^-, J/\psi \to e^+e^-, J/\psi \to \mu^+\mu^-$

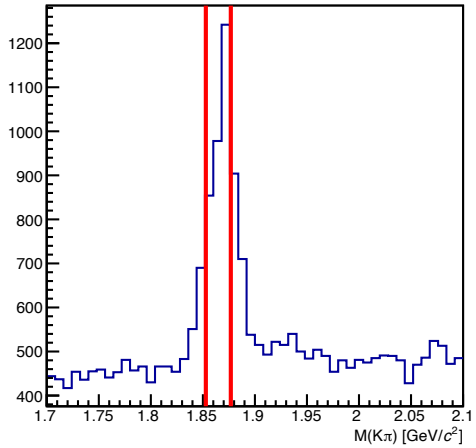
  $|\,m(\pi\pi) - m(D)\,| < 0.012\ \mathrm{GeV}/c^2$

  $|\,m(\pi\pi) - m(J/\psi)\,| < 0.036\ \mathrm{GeV}/c^2$

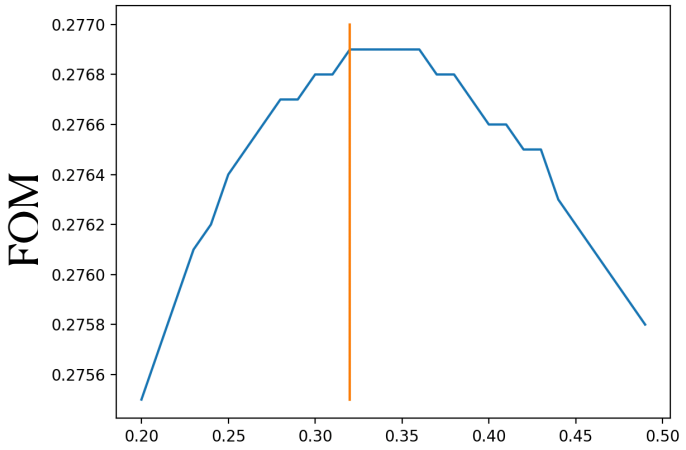


Apply 3σ window around D and J/ψ masses, performing mass swaps





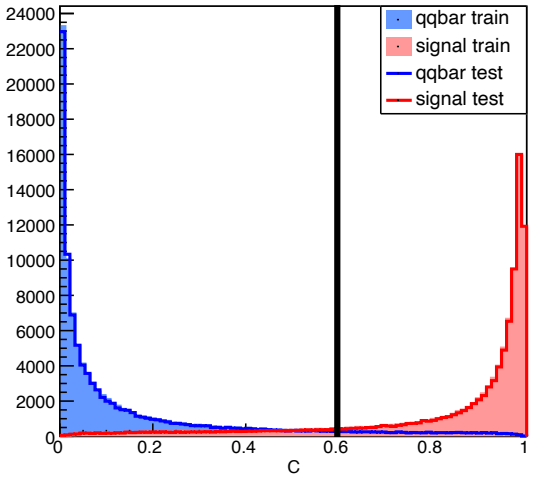
PID cut maximising FOM $= S/\sqrt{S+B}$: πK binary PID > 0.32

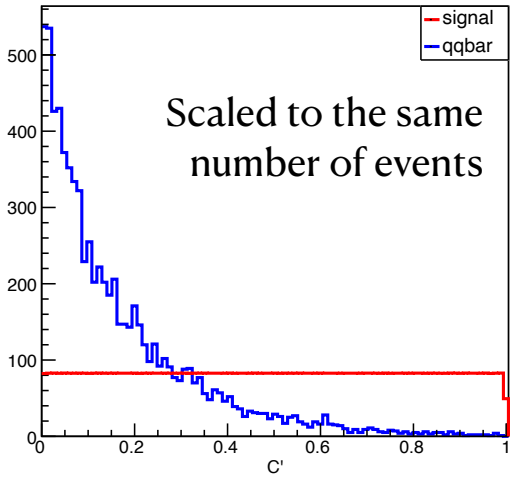


Continuum Suppression

- Train output with FBDT using 1×10^5 events for signal and qqbar each
- Training variables:

  Mbc, R2, thrustBm, thrustOm, cosTBTO, cosTBz, CMScosTheta, cosHelicityAngleMomentum, thrustAxisCosTheta, KSFWVariables, CleoConeCS





Choose $C > 0.6$ for now

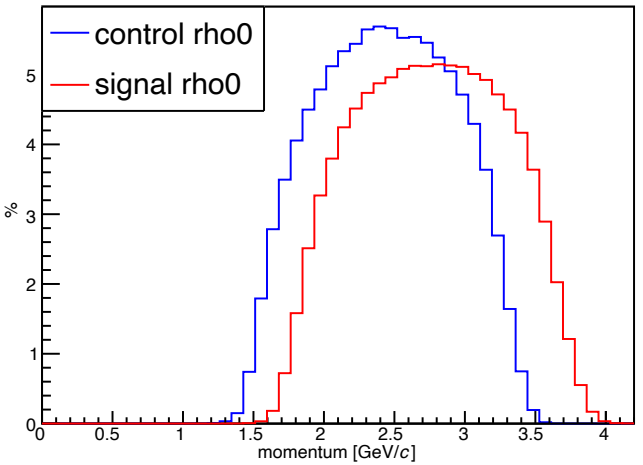
- **Best Candidate Selection**

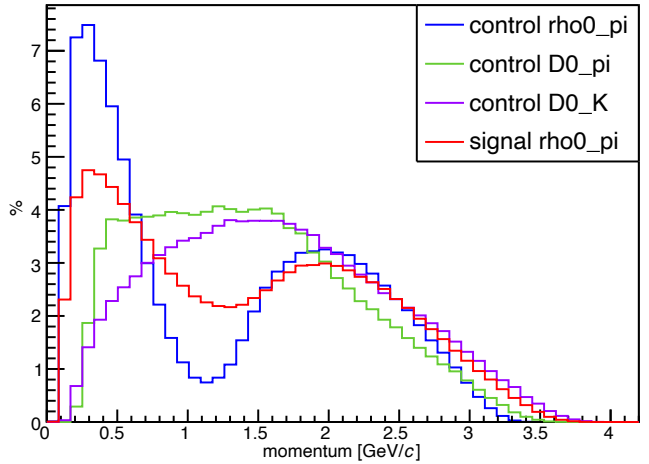
  Highest p-value of B^0 vertex fit

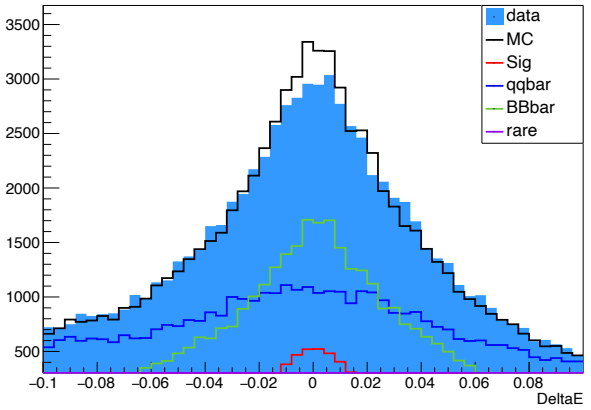
  - Signal MC multiplicity before BCS: 1.20

Control Mode

- $B^0 \to \bar{D}^0(\to K^-\pi^+)\rho^0$: should have 10 times the event as $B^0 \to \rho^0\rho^0$
  - $\mathcal{B}(B^0 \to \bar{D}^0\rho^0) = (3.21 \pm 0.21) \times 10^{-4}$
  - $\mathcal{B}(D^0 \to K^-\pi^+) = (3.947 \pm 0.030)\,\%$
  - Same selections as $B^0 \to \rho^0\rho^0$, without charm vetos, plus
    - $1.853 < m_{D^0} < 1.877\ \mathrm{GeV}/c^2$
    - Kaon binary PID > 0.32 (same as for pions)
  - Similar ρ^0, $\pi^\pm$ momentum distributions to signal
  - ΔE:

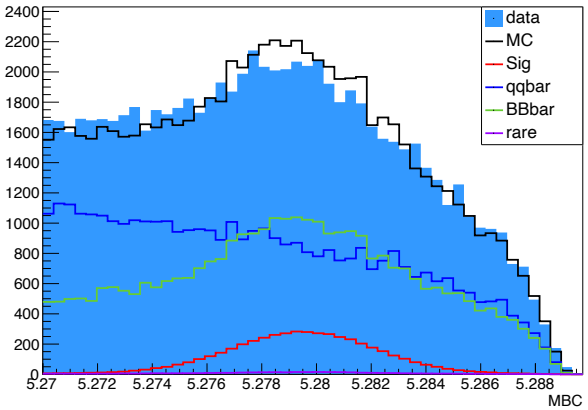


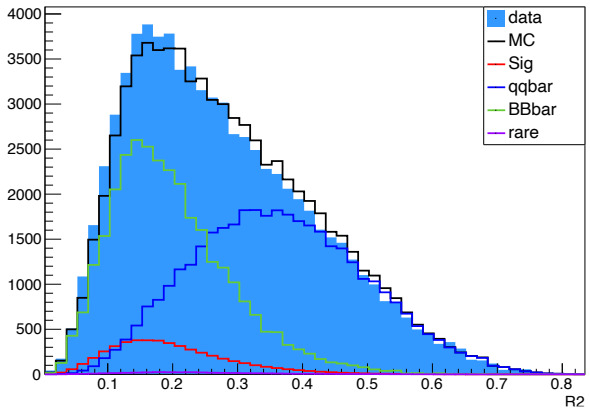


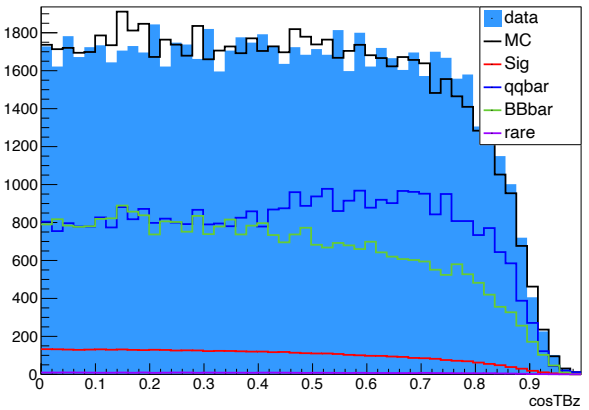


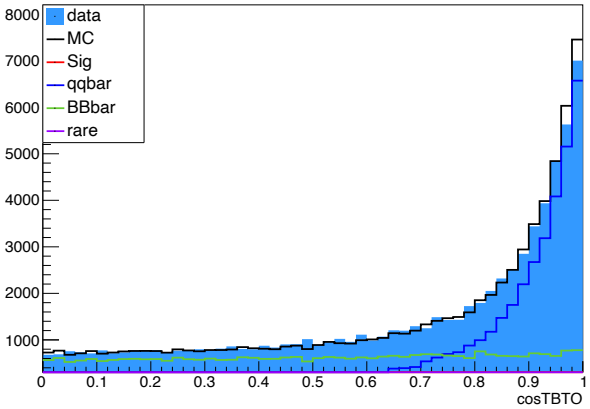
Control Mode

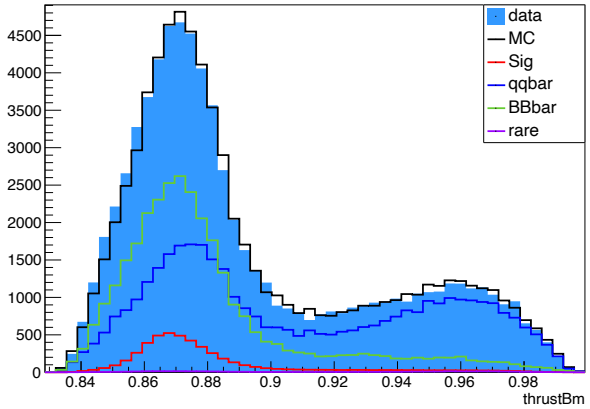
CS training variables

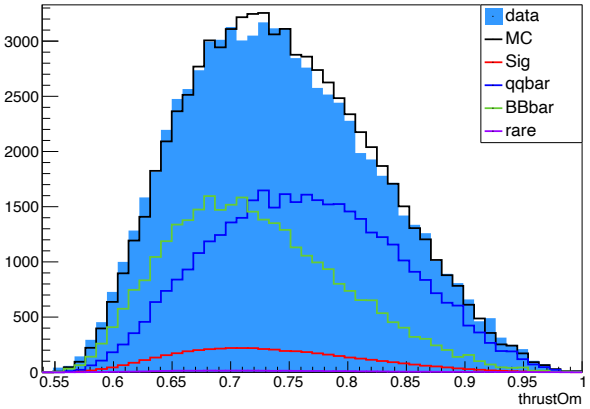












- No significant difference between simulation and data.

Control Mode

CS result

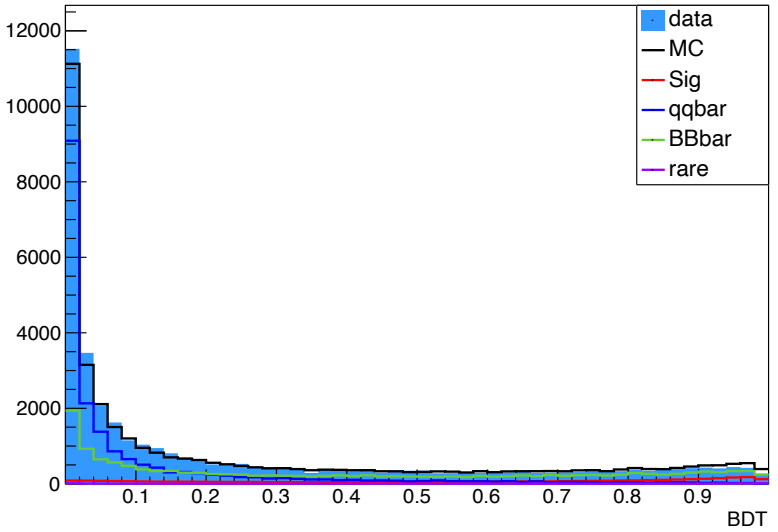
- CS output classifier
- Transformed classifier in bins of

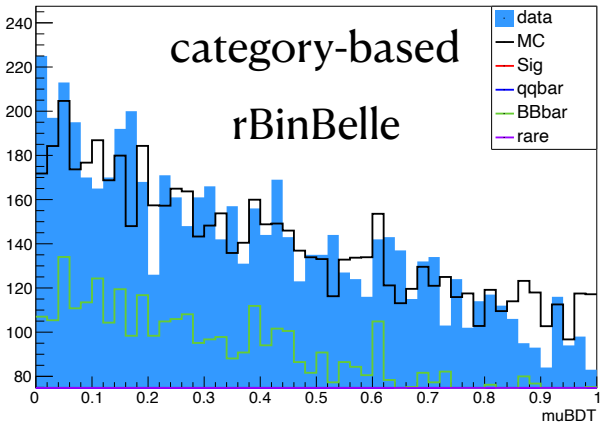
  (1) rBinBelle, category-based flavour tagger

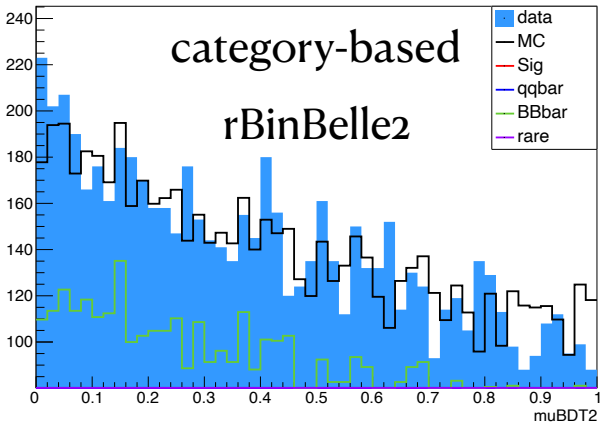
  [0 0.1 0.25 0.5 0.625 0.75 0.875 1]

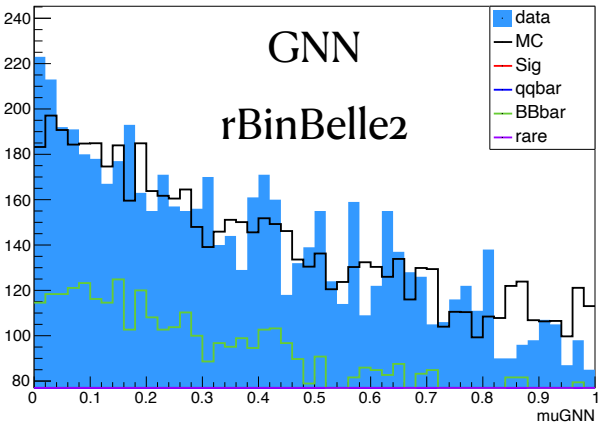
  (2) rBinBelle2, category-based and GNN favour tagger

  [0 0.1 0.25 0.45 0.6 0.725 0.875 1]







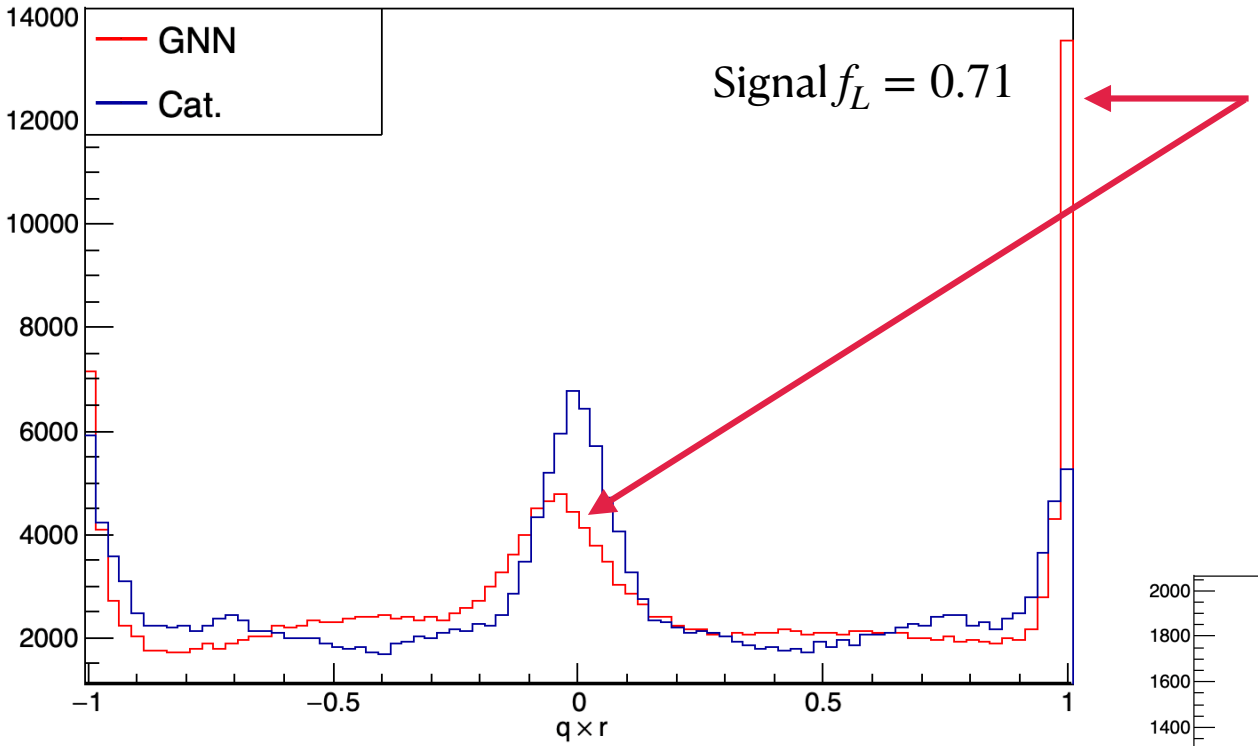


Efficiencies

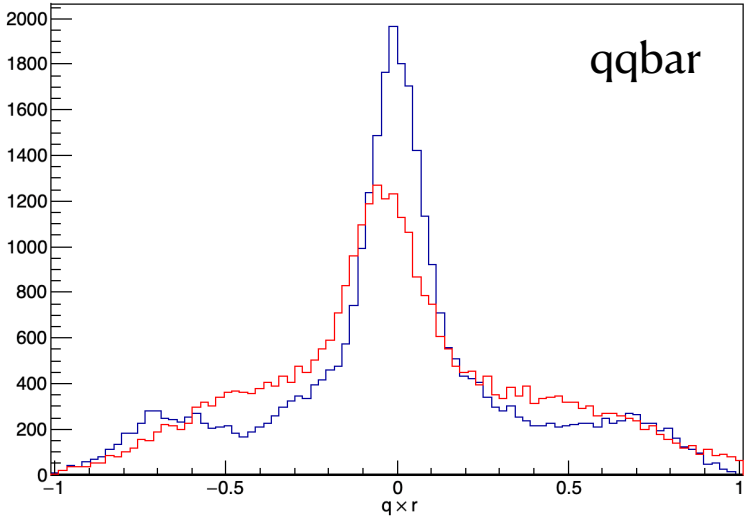
	Signal (1M events)			qqbar (692/fb)	BBbar (692/fb)	rare (711/fb x 50)
	fL = 0.71	fL = 1	fL = 0			
Reconstruction	44.92%	40.59%	56.89%	2.03%	0.18%	3.09%
m(pipi)	86.98%	86.80%	87.48%	32.94%	17.82%	24.13%
Mbc & ΔE	97.50%	97.44%	97.56%	9.90%	10.91%	22.29%
Vetos	84.15%	82.35%	87.39%	85.39%	68.24%	84.49%
PID	89.02%	91.07%	85.78%	39.74%	29.59%	36.55%
CS	85.76%	86.21%	84.19%	7.67%	44.81%	64.78%
Best candidate	87.13%	81.86%	95.21%	97.83%	96.68%	92.85%
Total	**21.32%**	**18.17%**	**29.17%**	**1.69E-05**	**3.06E-06**	**0.03%**
Expected yield for 711/fb	**154**	—	—	44090	2575	1747

Flavour Tagger

- Category-based v.s. GNN



- GNN flavour tagger result is asymmetric
- The numbers of tagged B^0 and $\bar{B}^0$ do not differ by much
- Similar result with $f_L = 1$ and $f_L = 0$ signal MC and rare
- Similar shift in central position for qqbar and BBbar



➡ Will use category-based flavour tagger for now

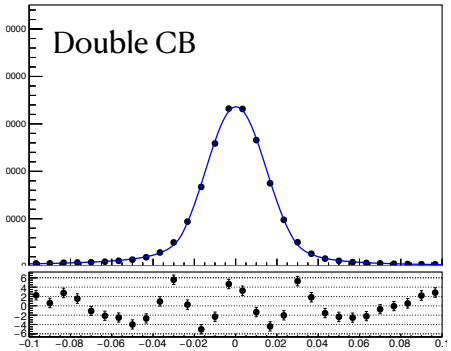
➡ CS output transformed in Belle II r-bins

Fit Models

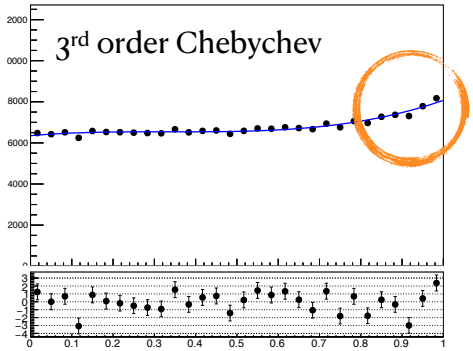
Signal

- Longitudinal

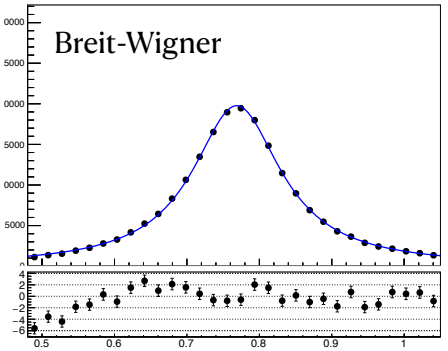
1M events



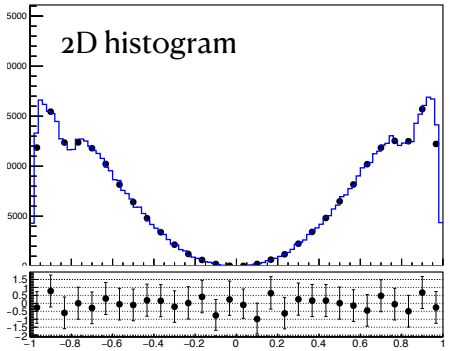
ΔE [GeV]



C'



$m(\pi\pi)$ [GeV/c^2]

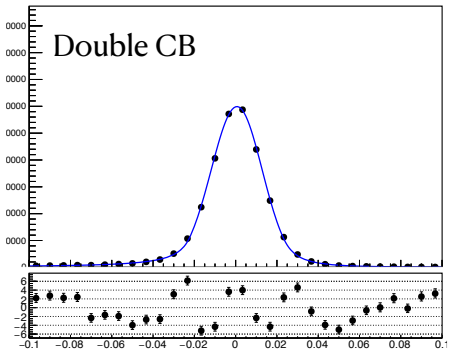


$\cos\theta_{hel}$

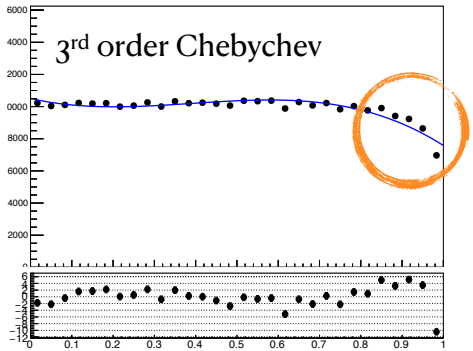
Deviation from flat distribution since transformation is based on $f_L = 0.76$ signal

- Transverse

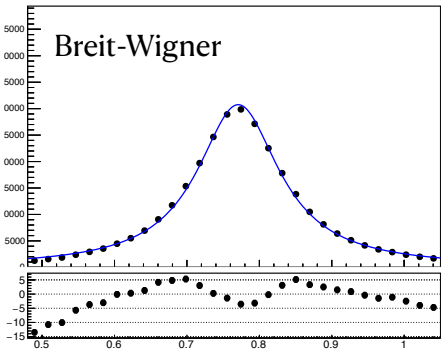
1M events



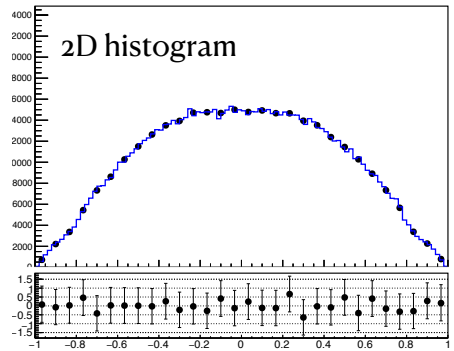
ΔE [GeV]



C'



$m(\pi\pi)$ [GeV/c^2]



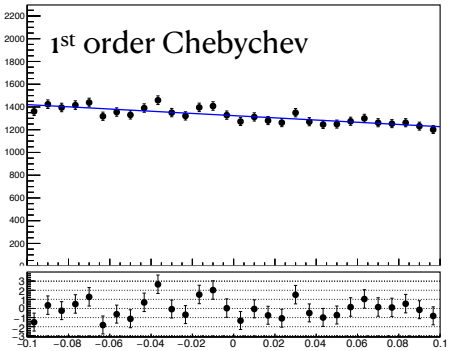
$\cos\theta_{hel}$

Fit Models

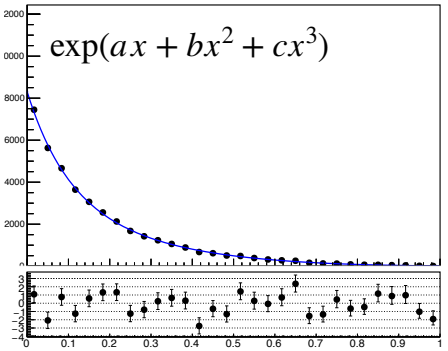
qqbar & BBbar

- qqbar

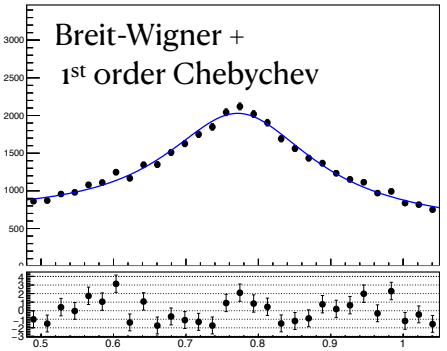
692/fb



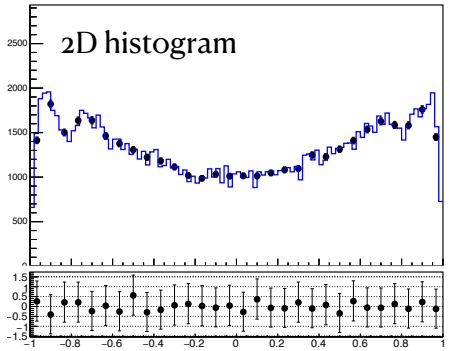
ΔE [GeV]



C'



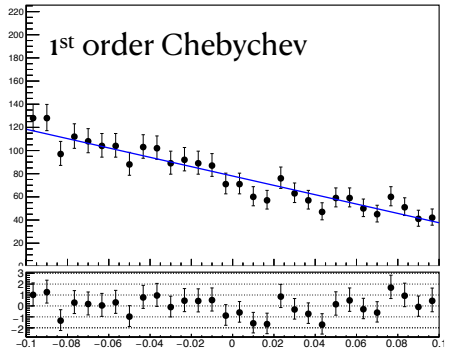
$m(\pi\pi)$ [GeV/c^2]



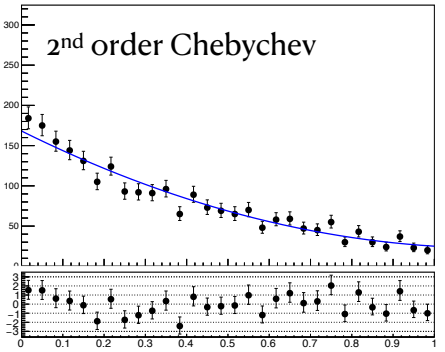
$\cos\theta_{hel}$

- BBbar

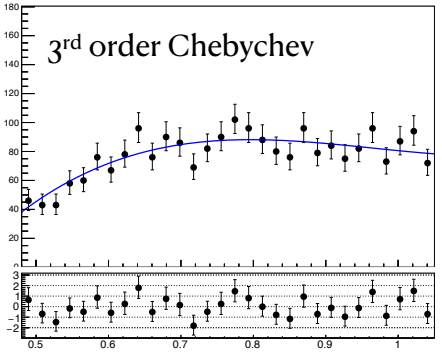
692/fb



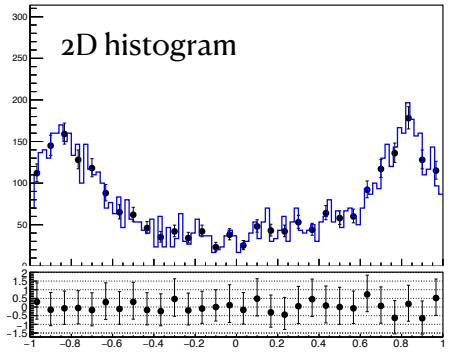
ΔE [GeV]



C'



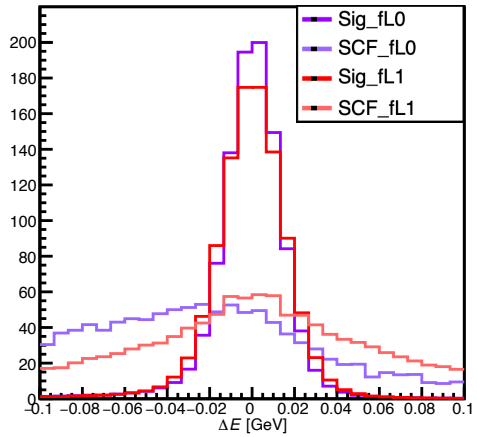
$m(\pi\pi)$ [GeV/c^2]

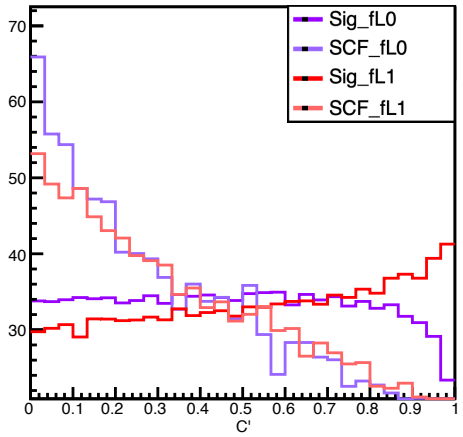


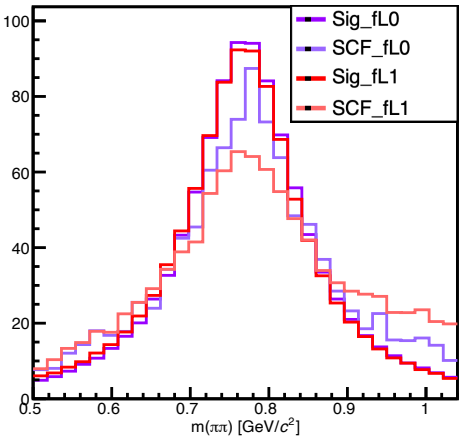
$\cos\theta_{hel}$

Fit Models

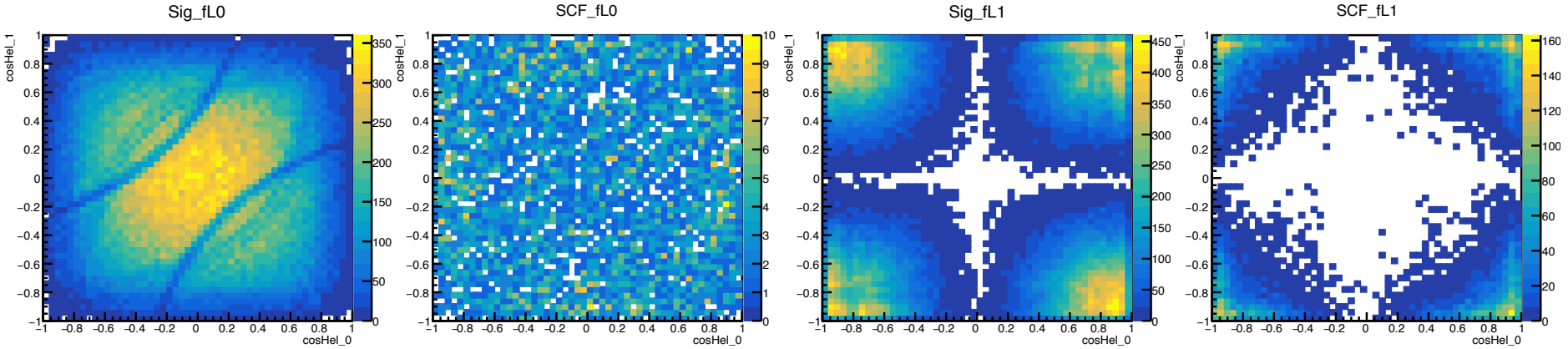
Self-cross-feed







Scaled to the same number of events



✳ SCF included in signal component in fit, ratio fixed to signal MC

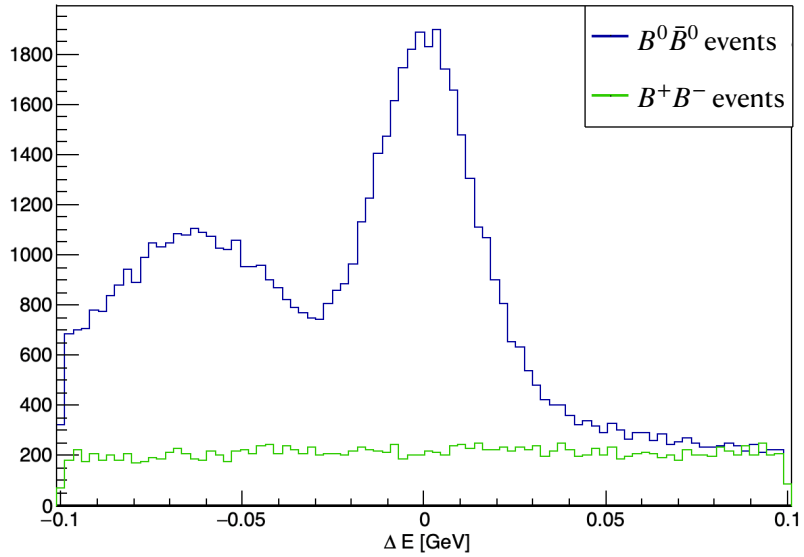
- 10.66% in $f_L = 1$ signal MC
- 1.98 % in $f_L = 0$ signal MC

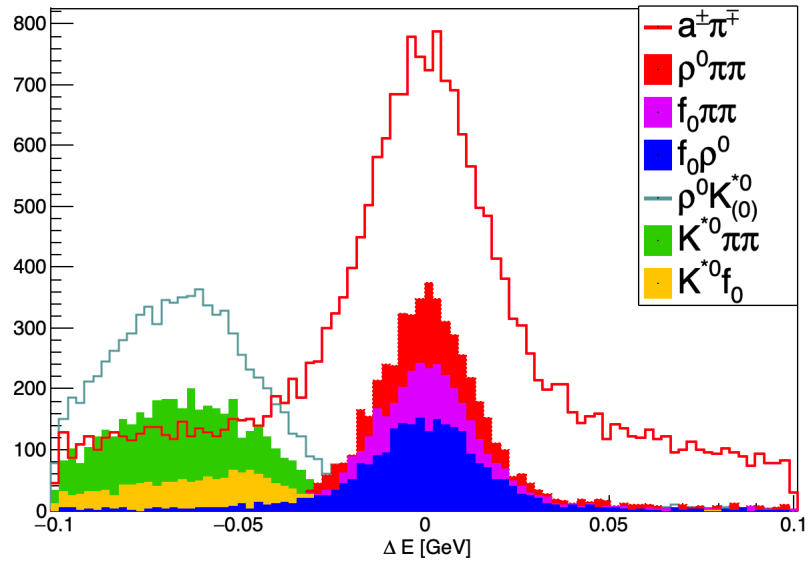
Rare background

(711/fb)*50

- Peaking at $\Delta E \approx 0$ (same final state)
  - $B^0 \to a_1^{\pm}\pi^{\mp}$
  - $B^0 \to \rho^0\pi^+\pi^-$
  - $B^0 \to f_0\rho^0$
  - $B^0 \to f_0\pi^+\pi^-$
- Peaking at $\Delta E < 0$
  - $B^0 \to \rho^0 K^{*0}, B^0 \to \rho^0 K_0^{*0}$
  - $B^0 \to K^{*0}\pi^+\pi^-$
  - $B^0 \to K^{*0} f_0$

Model the peaking background separately and include the rest into $B\bar{B}$ background.





Summary

- $B^0 \to \rho^0\rho^0$ analysis for Belle
- Final state selection and continuum suppression could be further optimised
- GFlat flavour tagger for Belle?
- Signal modelling of C' does not look very good
- Study rare B decay backgrounds