B→ η' K rediscovery

13th Belle II Italian meeting
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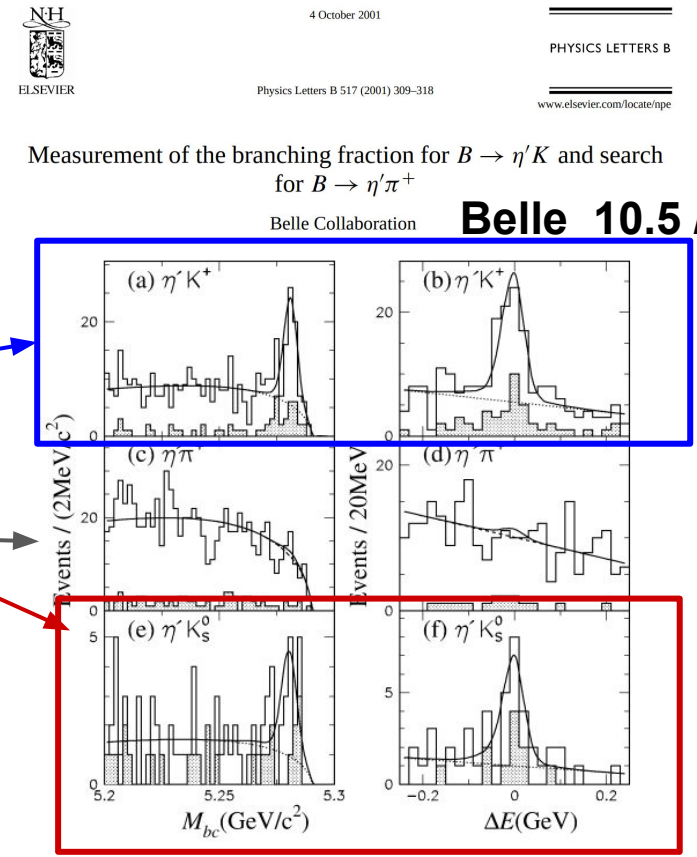
Motivation

- BR($B^0 \to \eta' K^0_S$) = (6.6 ± 0.4) × 10^{-5}
  - C_{CP} ($B^0 \to \eta' K^0$) = −0.06 ± 0.04
  - $-A_{CP}=S_{CP}$ ($B^0 \to \eta' K^0_S$) = 0.63 ± 0.06
- BR($B^+ \to \eta' K^+$) = (7.06 ± 0.25) × 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



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

Plan (last B2italia, done/today)

- Rediscover η and η' in all final states, and compare with MC expectation
- Study selection and efficiency for $B^0 \to \eta' K^0_S$ in MC
  - $\eta' \to \eta(\to \gamma\gamma)\,\pi^+\pi^-$,
  - $\eta' \to \eta(\to \pi^+\pi^-\pi^0)\,\pi^+\pi^-$, will not do
  - $\eta' \to \rho(\to \pi^+\pi^-)\,\gamma$
- Apply selection to generic Run dependent MC to check signal yield
  - Setup and 2D fit on M_{bc}-ΔE for signal extraction
- 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

Goal is ICHEP, doable
But need more work

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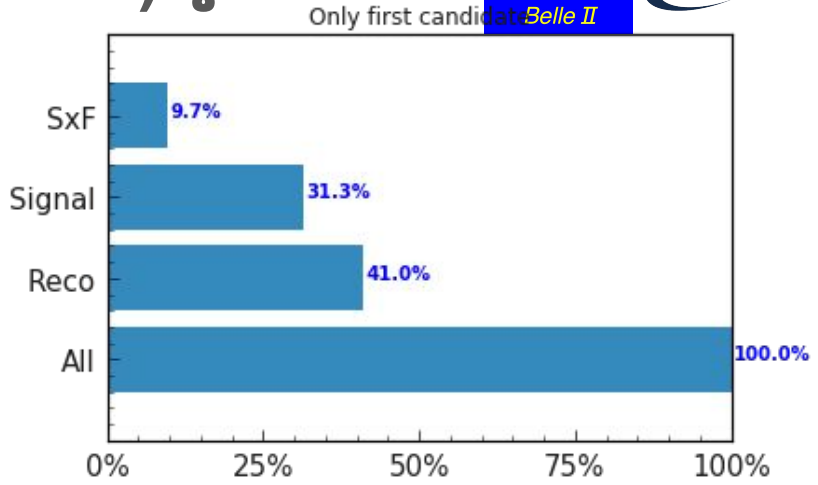
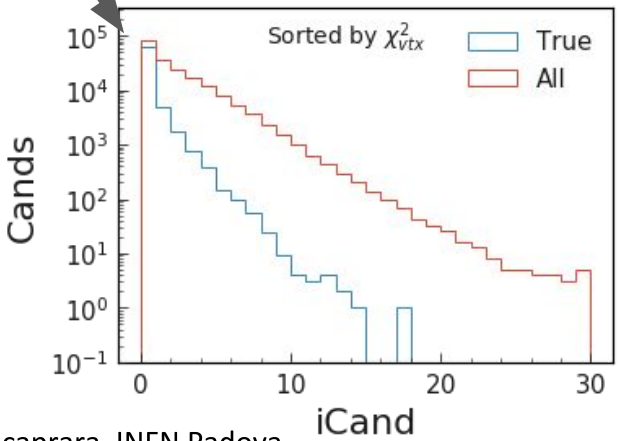
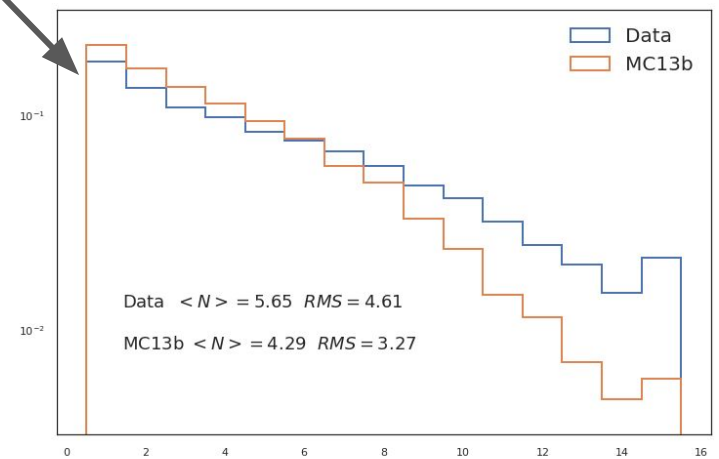
$$B \to \eta' (\to \rho(\to \pi^+\pi^-)\gamma)\, K$$

Reco Efficiency: B^+ -> η'->ρ ($\pi^+\pi^-$) γ K^+

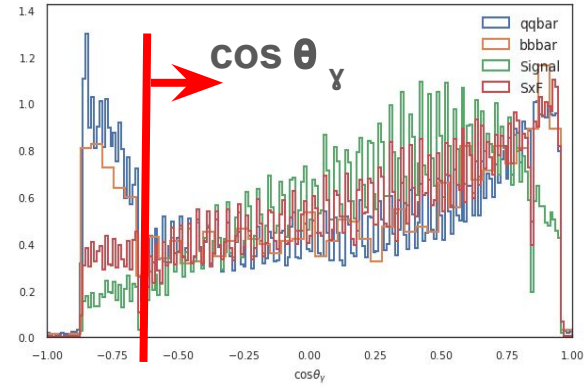
- **Eff 31.3 %**
- **SxF 9.7%**
  - Large SxF
  - Also large multiplicity
    - Different in Data and MC
- True cand have best chi2
  - **Use only first candidate**

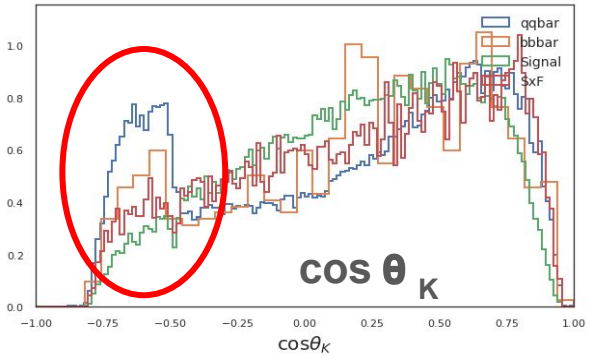


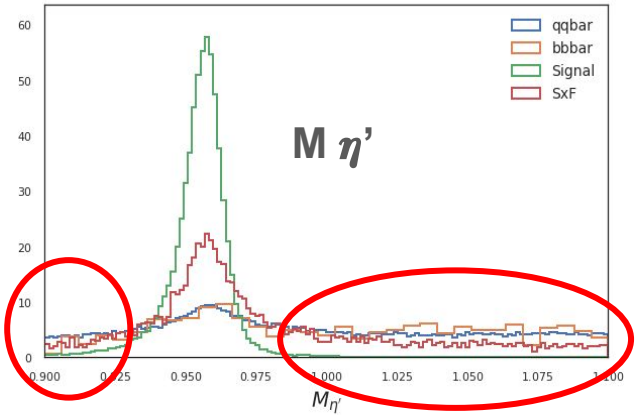




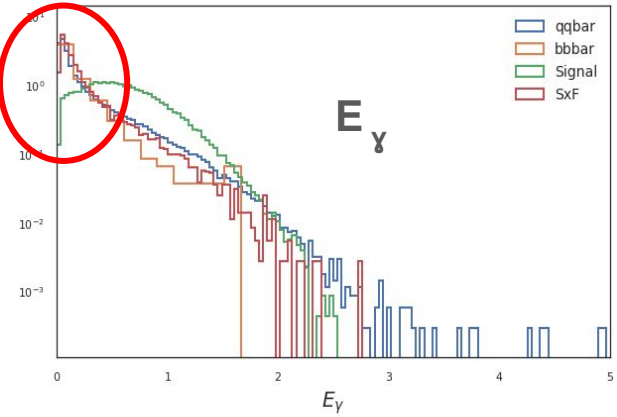
Other selections

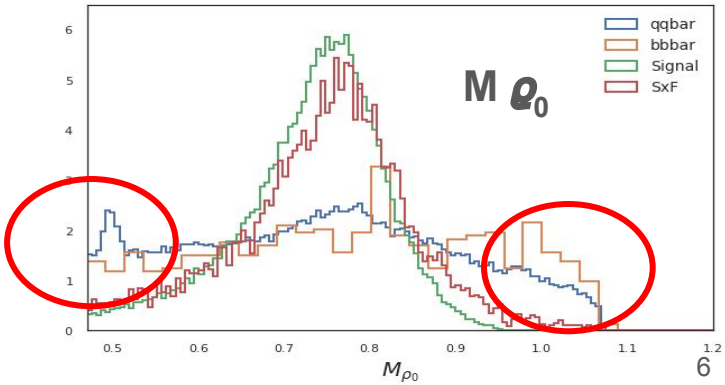




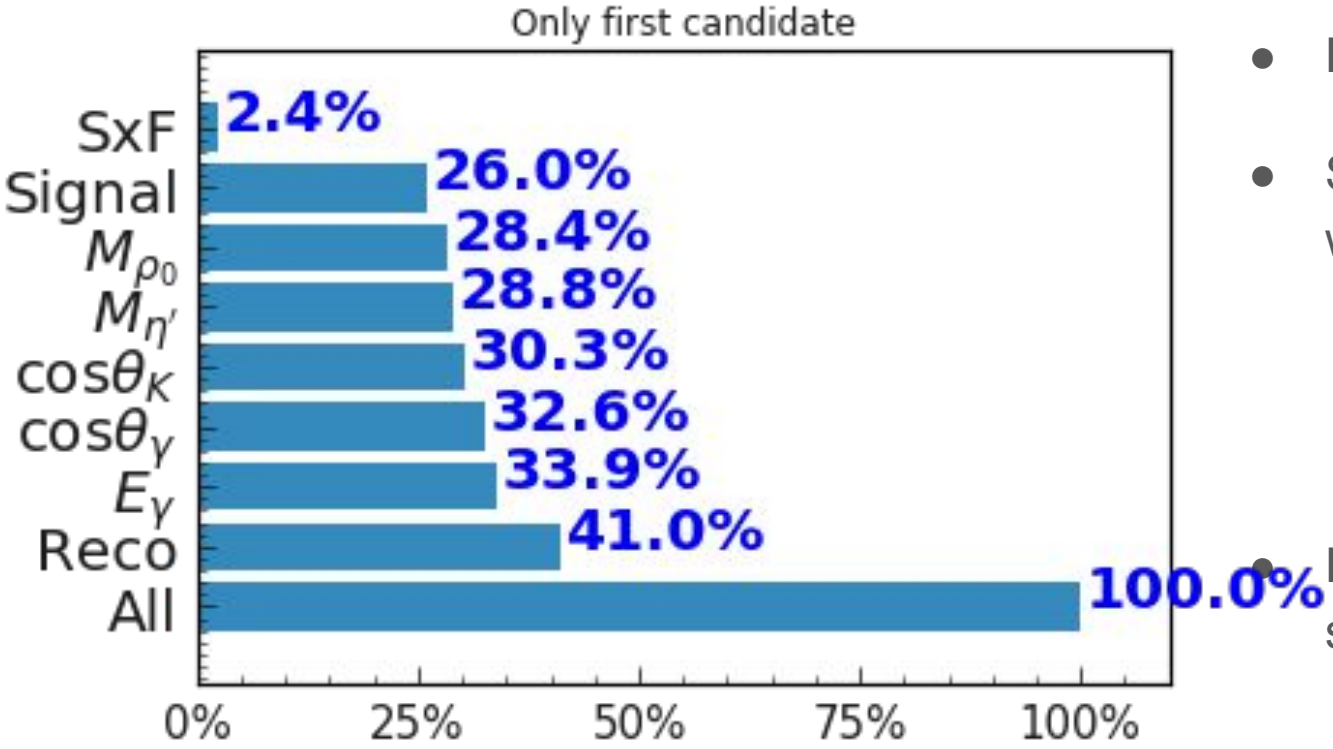


- cos θ $_{\gamma}$ > -0.64
- cos θ $_{K}$ > -0.5
- E $_{\gamma}$ >100 MeV
- M η' in [0.92-1] GeV/c^2
- M ϱ_0 in [0.51-1]GeV/c^2





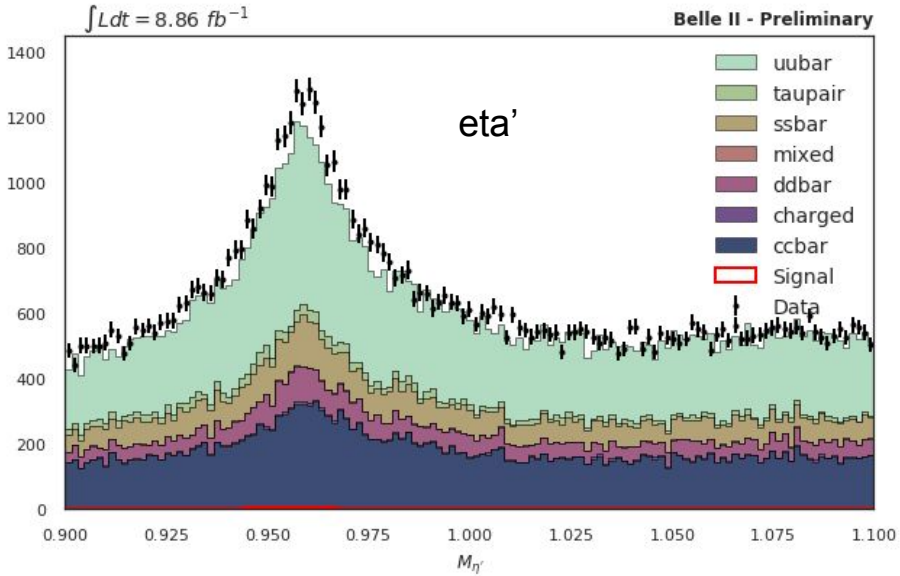
Selections efficiency

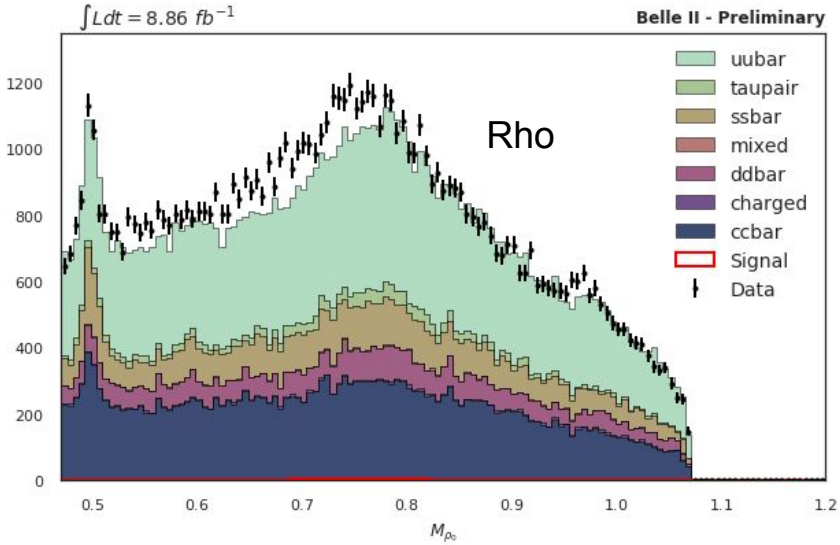


- Efficiency still good
  - **Was 31.3%**
- SxF greatly reduced with simple cuts
  - **Was 9.7%**
  - Further optimization possible: eg MVA,
  - Not sure want to do it at this stage
- Expected yield with selection:
  - **~5.5 ev /fb^{-1}**
  - ~50 ev in 8.86 fb^{-1}
- Belle: **~4.2 ev /fb-1**

WARNING: no continuum suppression cut, yet (see later)

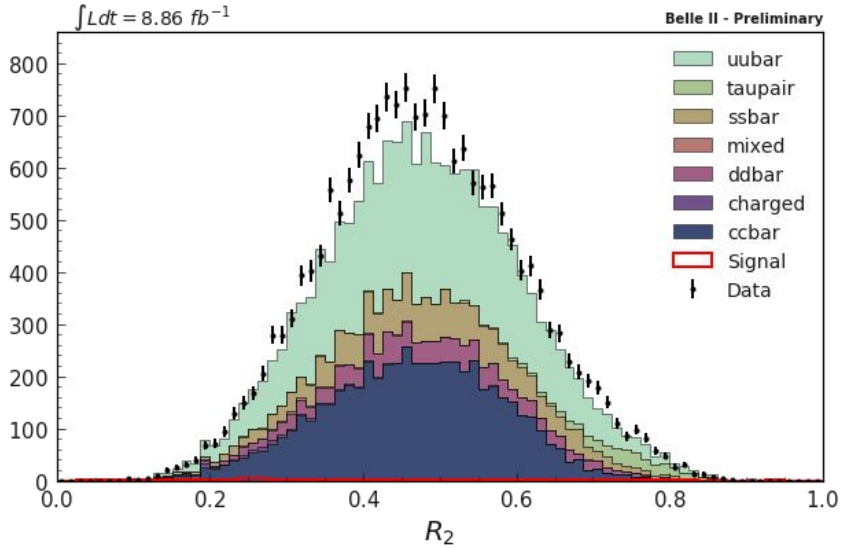
Invariant Masses

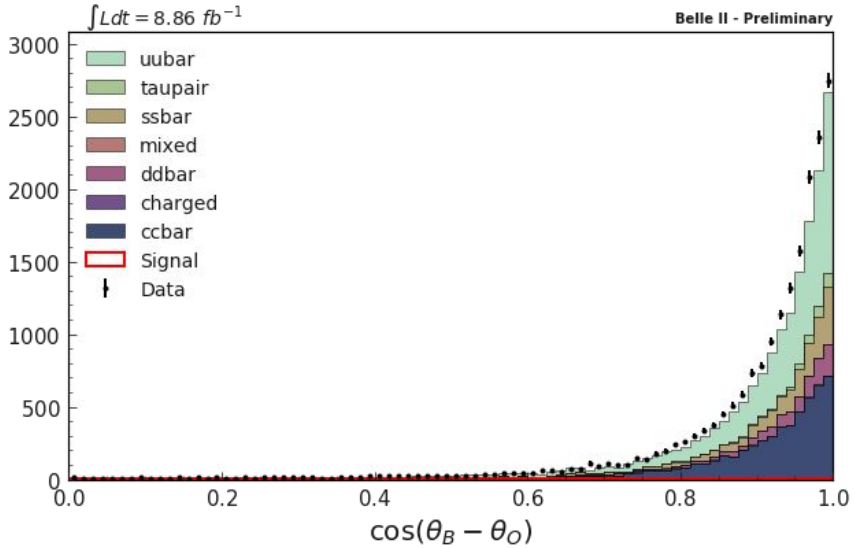




- Data - MC comparison: normalized to integrated lumi
- Plots before Mass cuts or fit constraint
  - Nice eta' peak!
- Rho mass seems shifted in data wrt to MC
  - Ks peak clearly visible, hence the Mrho cut > 0.52

Cont Suppression variables

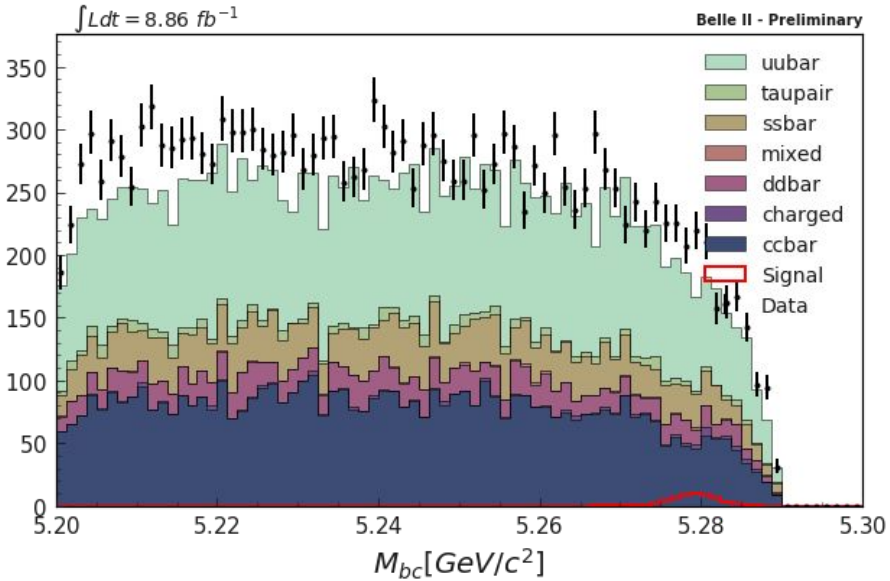


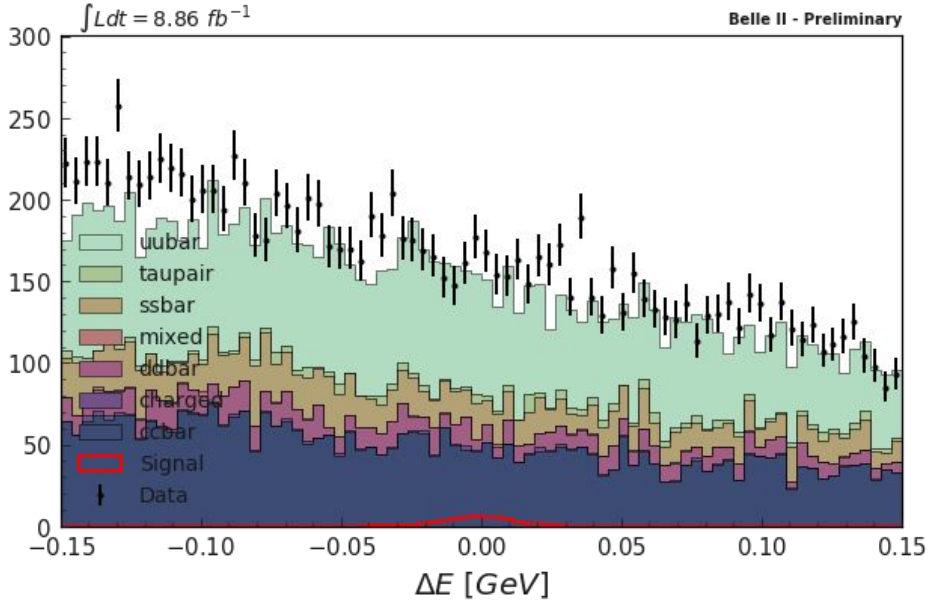


- Nice agreement MC - Data, can be used for Continuum Suppression
- Full CS using fBDT under study

$B^+ \to \eta' K^+$, $\eta' \to \rho (\pi^+\pi^-) \gamma$ Data vs MC

- Mbc and DeltaE
- No cont suppression

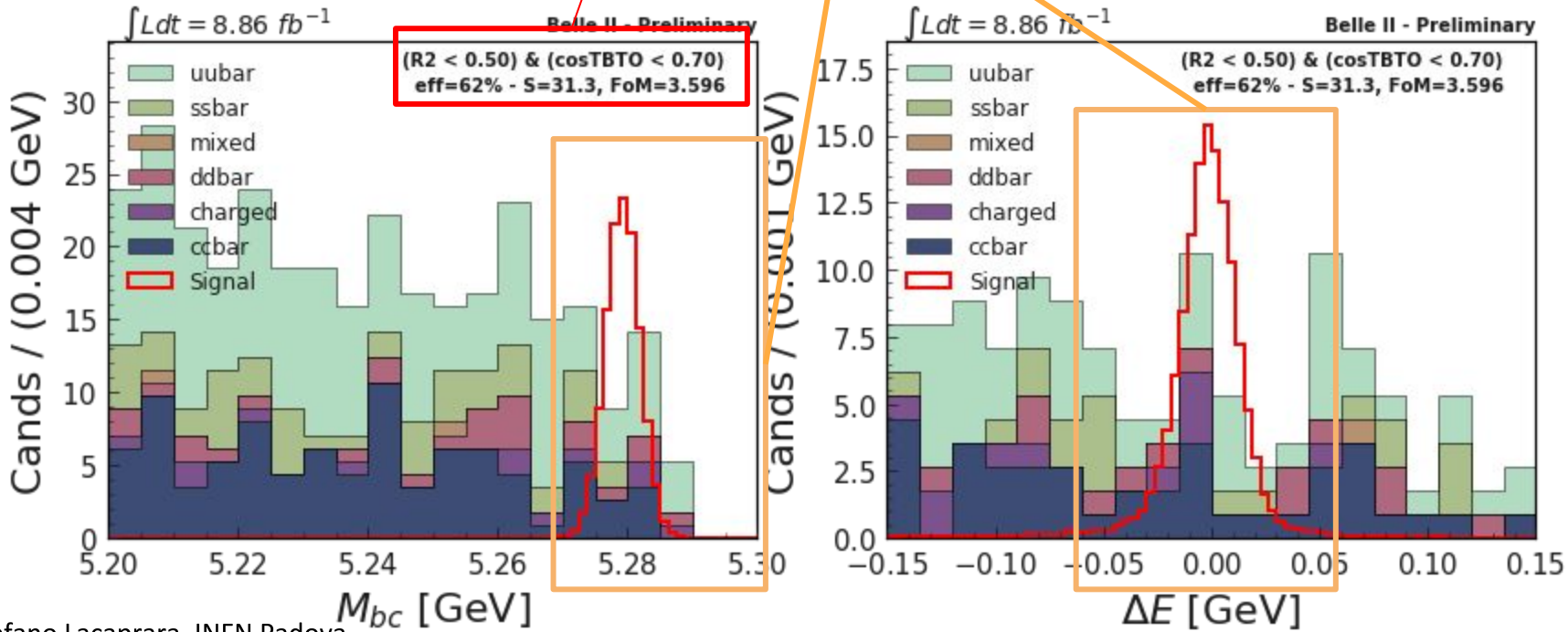




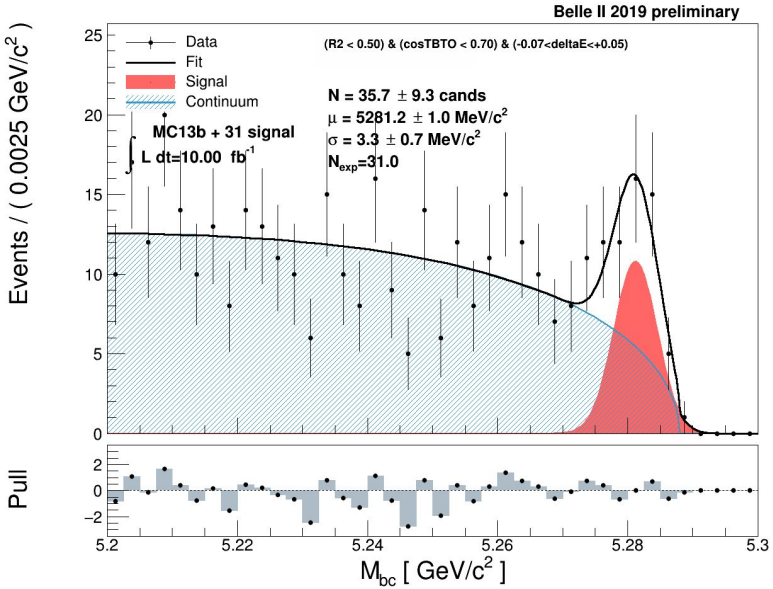
Continuum suppression

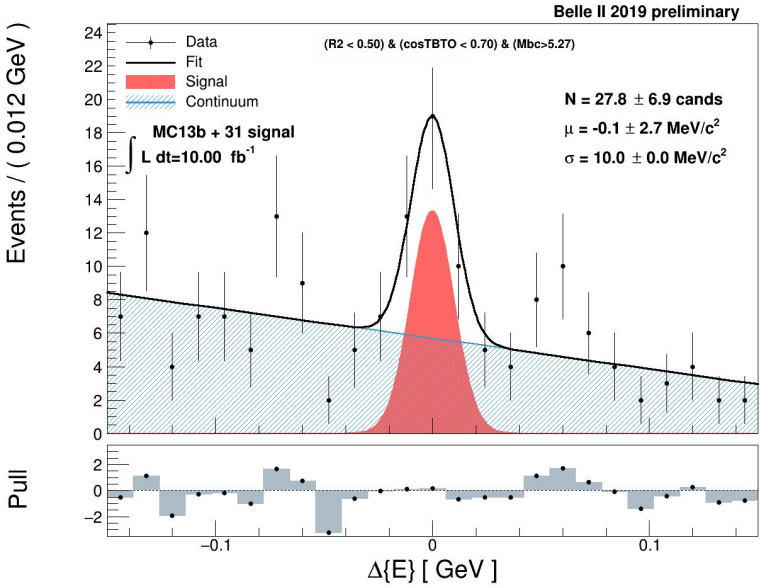
- Cont Suppression using only **R2 and cosTBTO**
- Simple optimization of S/sqrt(S+B) **in signal region**
- **R2<0.5, cosTBTO<0.7**

Signal Eff: 60%*26% = 16%
Belle: 14.1 %



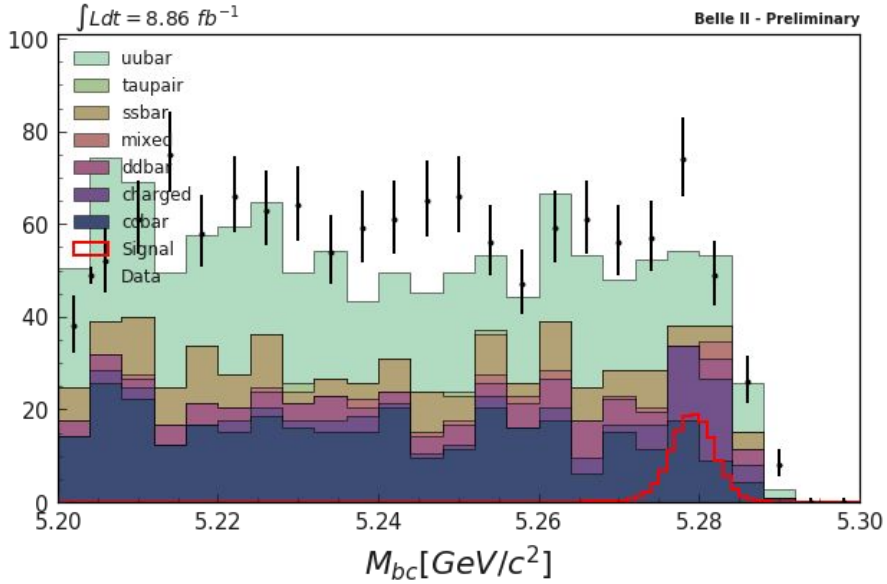
Try to fit signal: only MC + signal injection

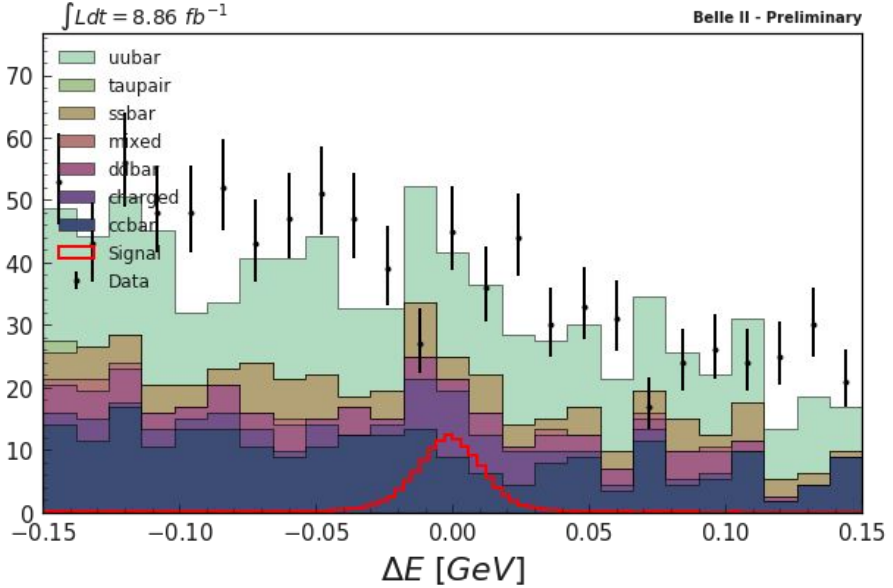




- Cut **Mbc>5.27 GeV/c²** and **-7<De<+5 MeV** in the other plot.
  - **1D plot shown (2D implemented)**
- Injected 31 events, seen 35.7+/-9 (Mbc) and 28+/-7 (De)

B^+ -> η'(->ρ ($\pi^+\pi^-$) γ) K^+ Data vs MC

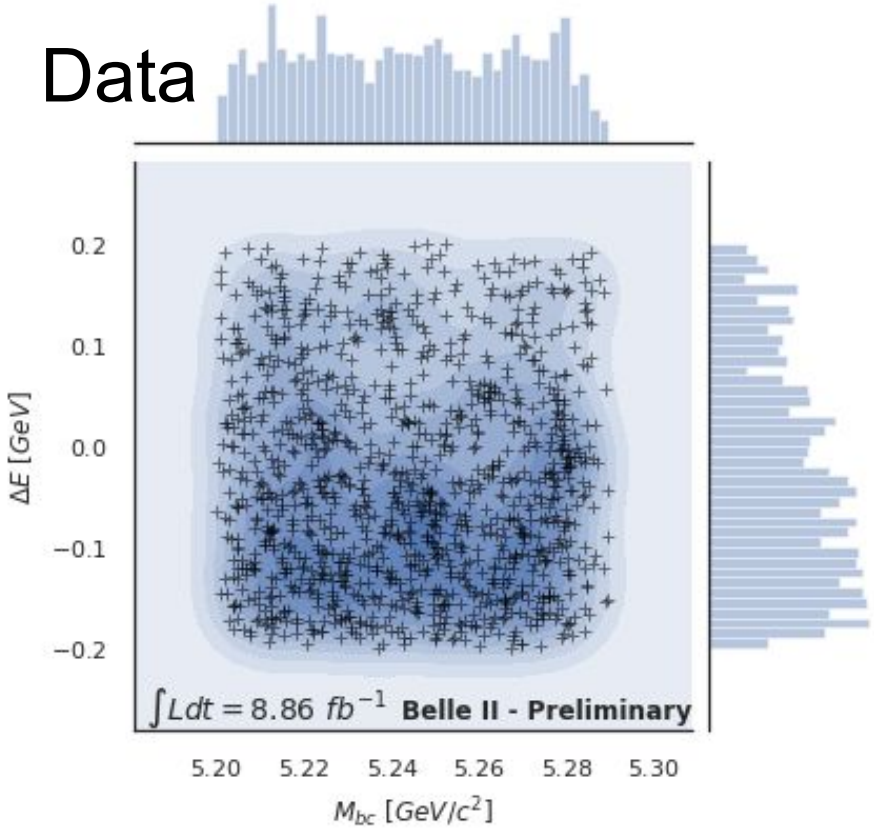




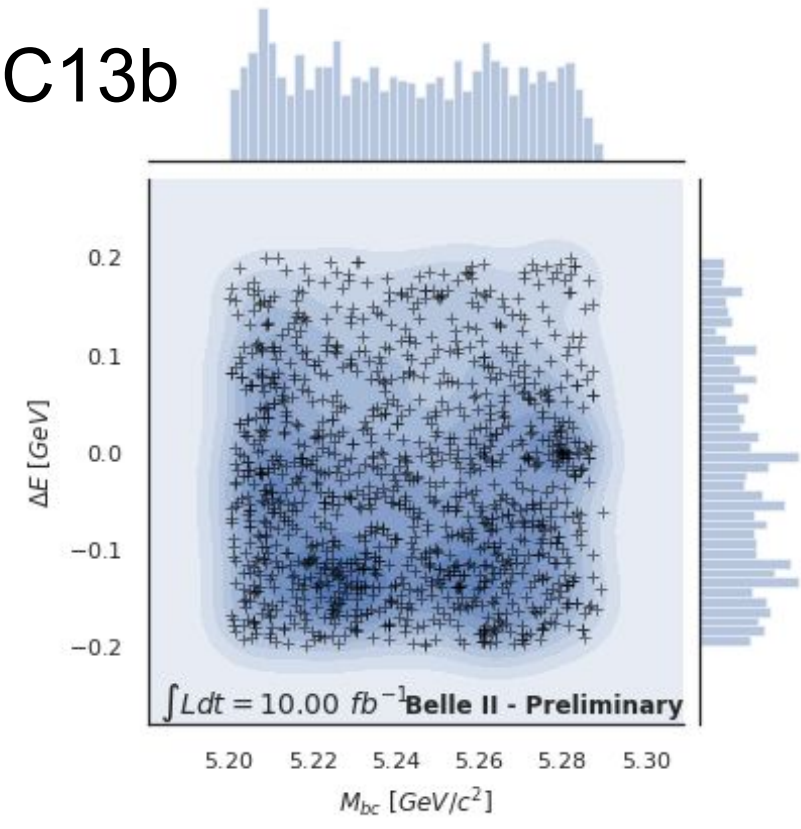
- MC13b includes signal (in charged)
  - High stat signal superimposed
- After CS selection, no selection on other variable!

DeltaE vs Mbc

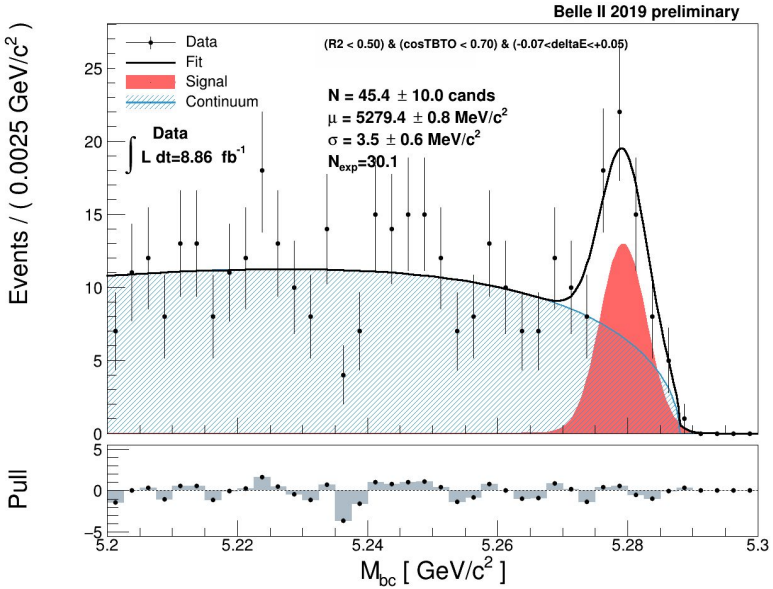
Data

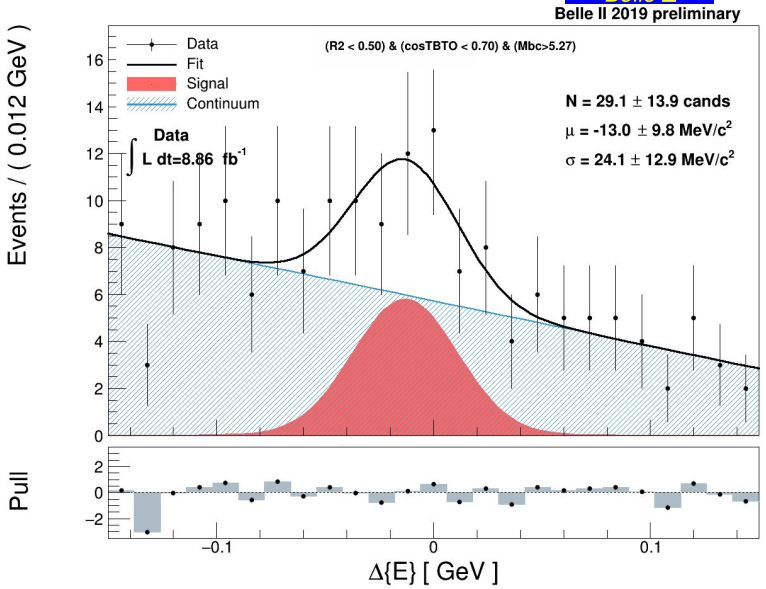


MC13b



Try to fit signal: Data



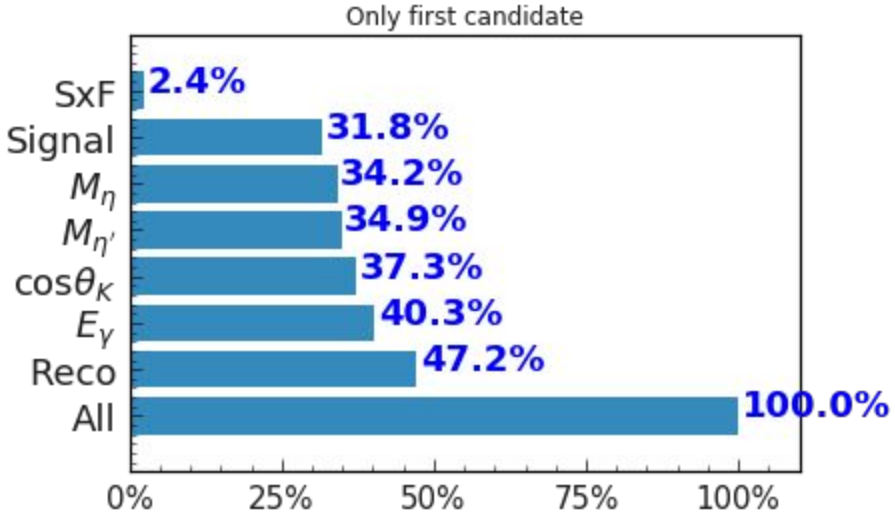


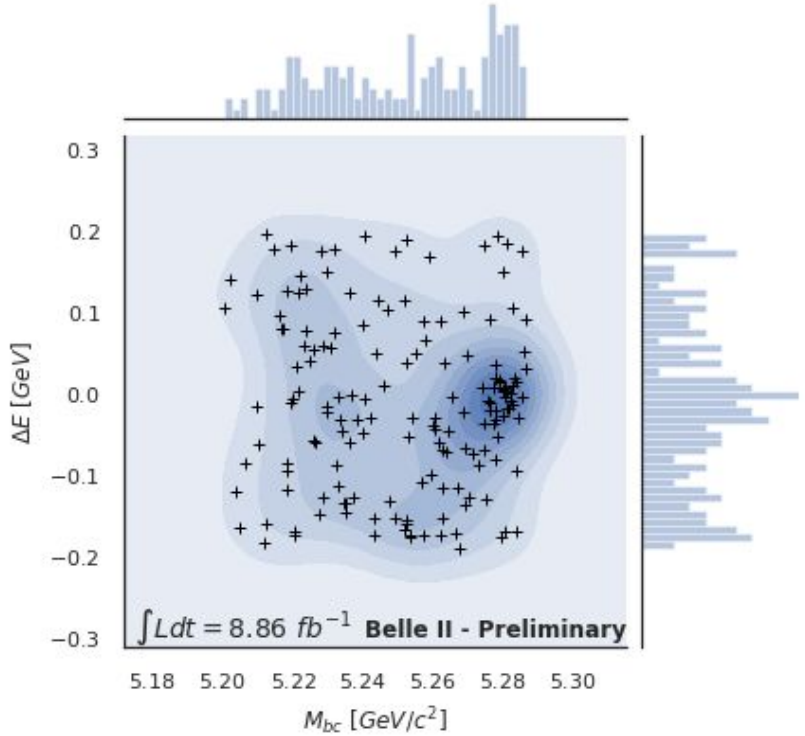
- Clear signal visible
  - Projection w/ selection on other variable
- seen 45.7+/-10 (Mbc) and 29.1.4+/-14 (De)
  - Expected: 31
- Still 1D fit: later for 2D

B->η’ K, η’->η (γγ) $\pi^+\pi^-$

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

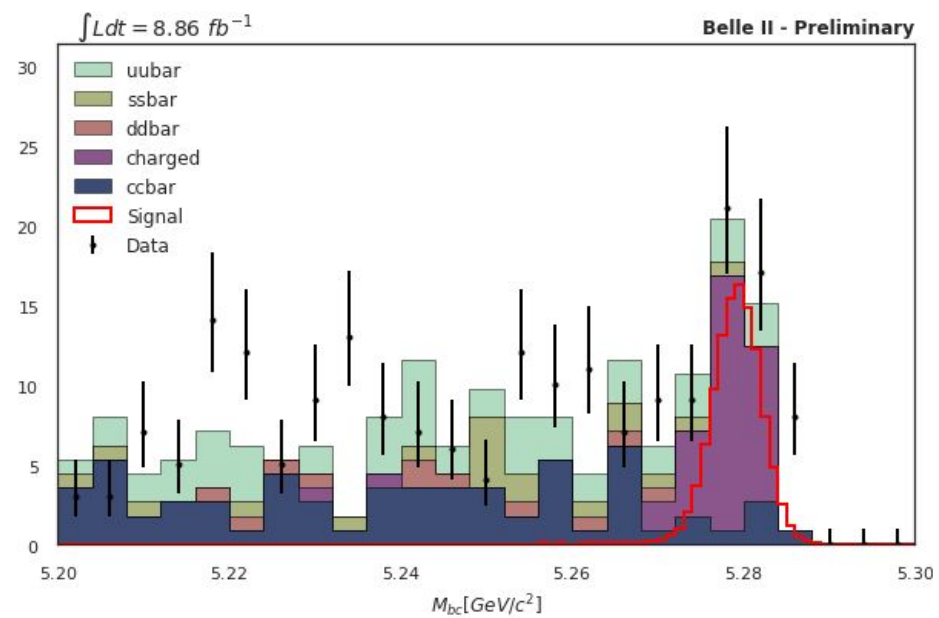
- Simple signal selection
  - Signal eff 32% (40% reconstruction only)
  - SxF 2.4 (vs 7.1 %)
  - **w/ CS** eff: 32 * 0.75 = **24%**
  - **Belle was 22%**

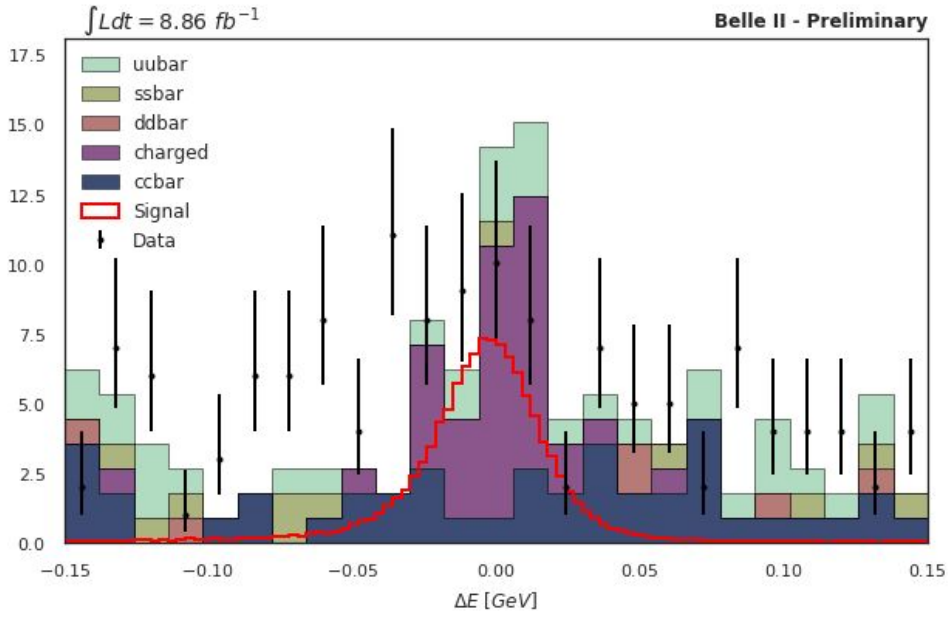




- **Low Background**
- Tested with MC w/ signal inection
- And MC w/o signal removal

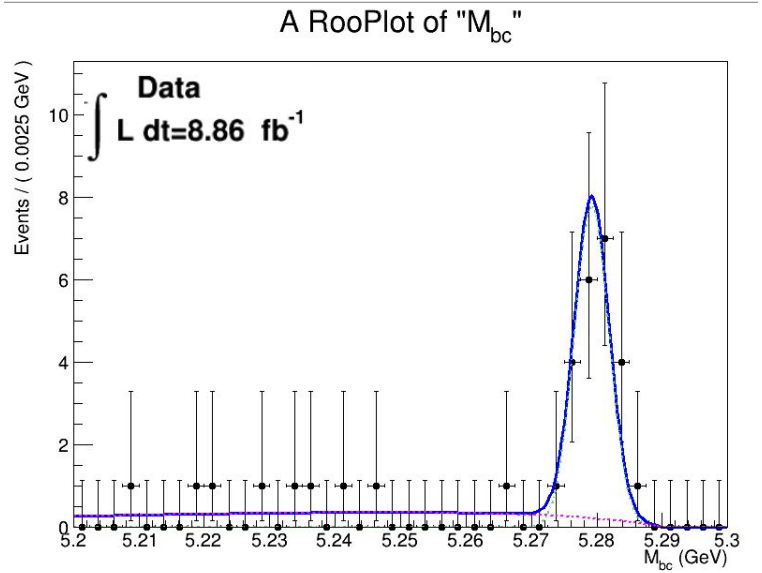
$B^+ \to \eta' (\to \eta (\gamma\gamma) \pi^+\pi^-) K^+$

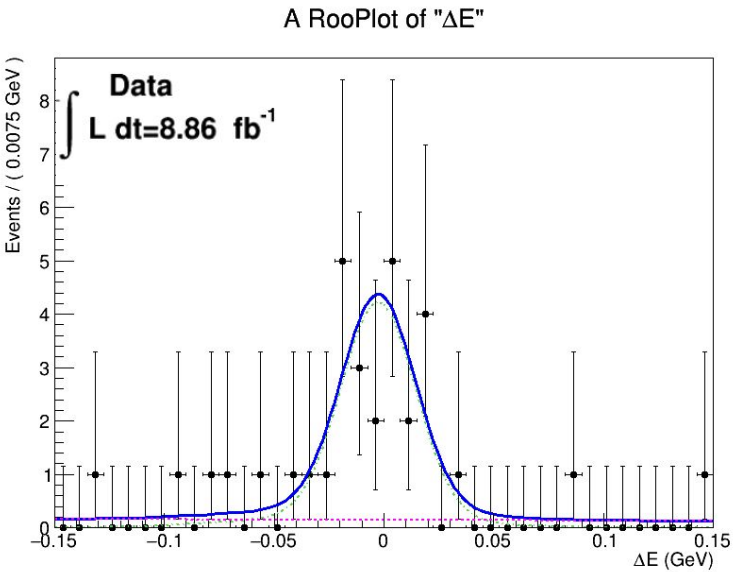




Data vs MC with expected signal

B^+ -> η' (->η (γγ) $\pi^+\pi^-$) K^+ 2D FIT

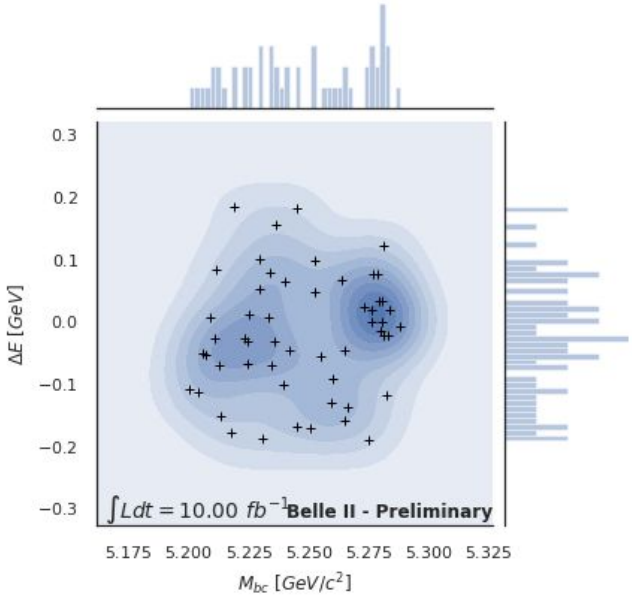


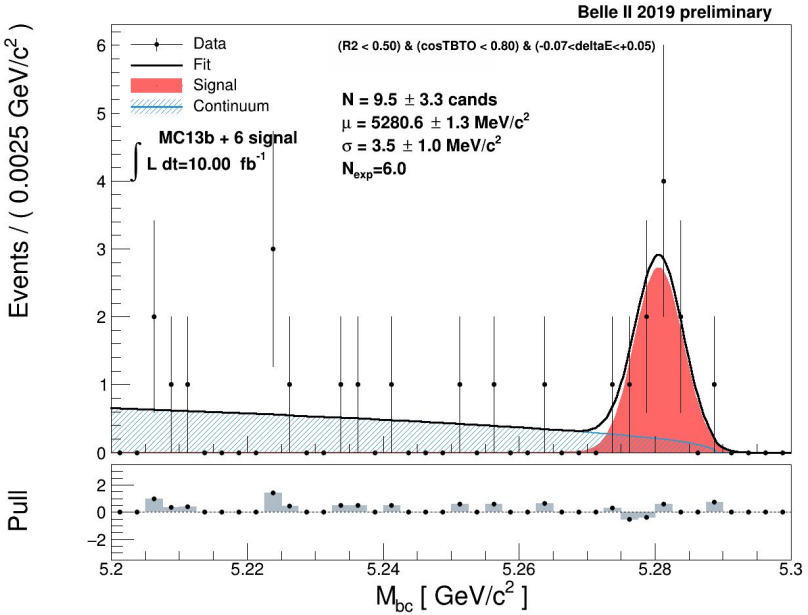


- 2D fit for Mbc and DeltaE
  - **Fit result: 29.0 +/- 10 evevents**
  - **Expected 31 events**
- Fit on MC and Toy studies (injected 10-100) looks good

$B_0 \to \eta' K_s,\ \eta' \to \eta\,(\gamma\gamma)\ \pi^+\pi^-$

Expected signal (MC + injection)





- Small signal yield with current lumi
  - but very low background
- Closure test ok: **injected 6, fit 9.5 +/- 3.3**

B->eta' K expected yield

- Expected signal 8.8 /fb (Run2019).
  -

	η'->η (γγ) $\pi^+\pi^-$	η'->ρ ($\pi^+\pi^-$) γ	**Total**
B^+->η' K^+	113 - **30**	190 - **31**	300 - **58**
B^0->η' K_s	36.4 - **5.5**	61.4 - **10**	100 - **16**

Belle with 10.4 /fb

Mode	N_S
$\eta'_{\eta\pi\pi} K^+$	$28.9^{+6.5}_{-5.7}$
$\eta'_{\rho\gamma} K^+$	$42.5^{+9.1}_{-8.3}$
$\eta'_{\eta\pi\pi} \pi^+$	$0.0^{+1.2}_{-0.0}$
$\eta'_{\rho\gamma} \pi^+$	$0.0^{+5.6}_{-0.0}$
$\eta'_{\eta\pi\pi} K^0$	$6.4^{+3.4}_{-2.7}$
$\eta'_{\rho\gamma} K^0$	$10.1^{+4.4}_{-3.6}$

- Expected ~same yield with less integrated luminosity
- For **ICHEP** ∫Ldt~40-70 /fb -> **yield x 5-10**

Conclusion and outlook

- Plan:
  - **Rediscovery aimed for ICHEP (summer 2020)**
  - Signal selection done (almost)
  - Data MC comparison ok
  - Fit in place and working well
    - Improve CS using fBDT
  - Move to proc11
    - Add prompt(bucket9 + …) for exp12
  - Use more MC
  - Documentation[1]
- Stay blind for neutral states.

[1] **Hofstadter's Law**: It always takes longer than you expect, even when you take into account Hofstadter's Law.

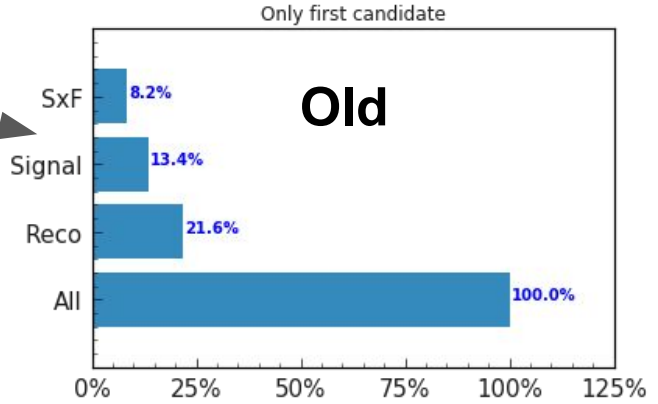
Backup

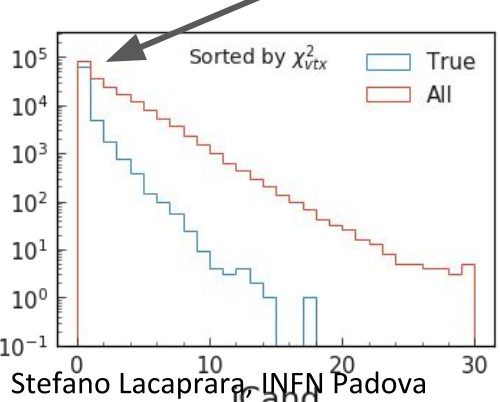
Introduction

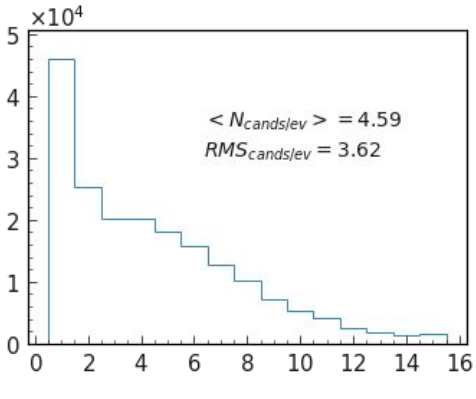
- Technicalities:
  - Release light-1912-icarus
  - Data: proc10 + bucket8 8.86 /fb
  - MC:
    - Signal MC13a
    - Background MC13b run dependent 10 /fb
- Channels: **B -> η' K**
  - **η'** (-> **η**(->**γγ**)**ππ**) and **η'** (-> ***ρ***(->**ππ**)**γ**) **K**
  - Both for $\mathbf{B^+}$**-> … K**$^+$ and $\mathbf{B^0}$**-> … K**^0_s
- Will mostly concentrate on $\mathbf{B^+}$ -> **η'** (-> ***ρ***(->**ππ**)**γ**) K^+

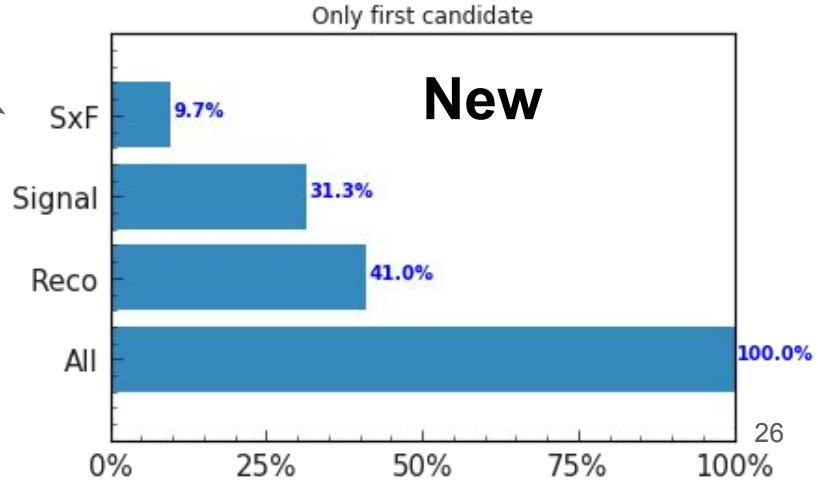
Efficiency: B^+ -> η'->ρ ($\pi^+\pi^-$) γ K^+

- Low eff reported two week ago.
- Fixed a bug in pi0 veto
  - I was vetoing all events with an additional γ in RoE, regardless to M
- **Eff 31.3 %** (was 13.4 %)
- **SxF 9.7%**
  - Large SxF
  - Also large multiplicity
- True cand had best chi2



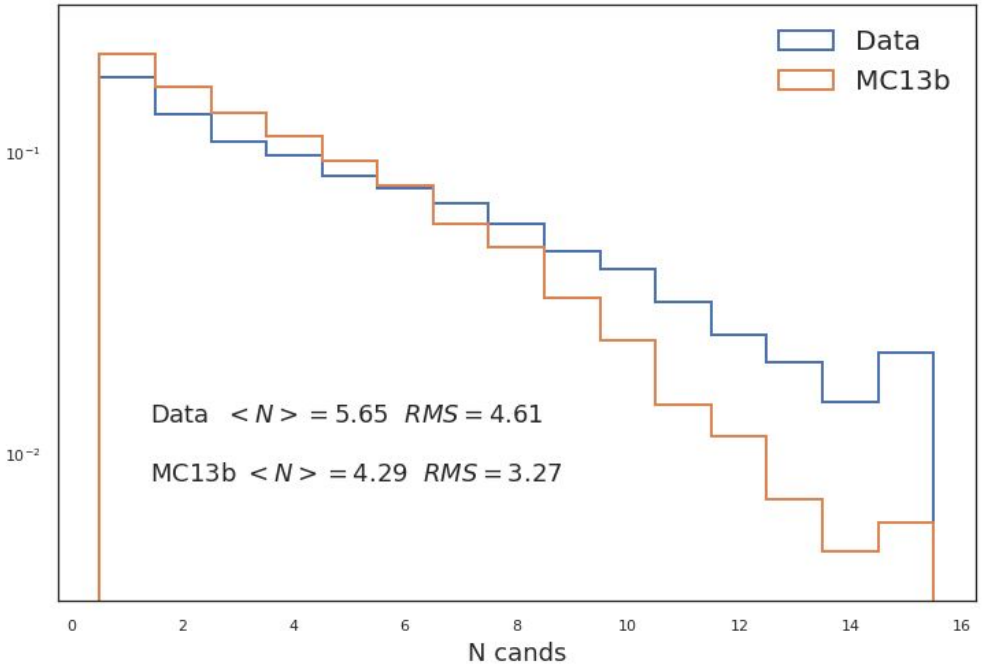


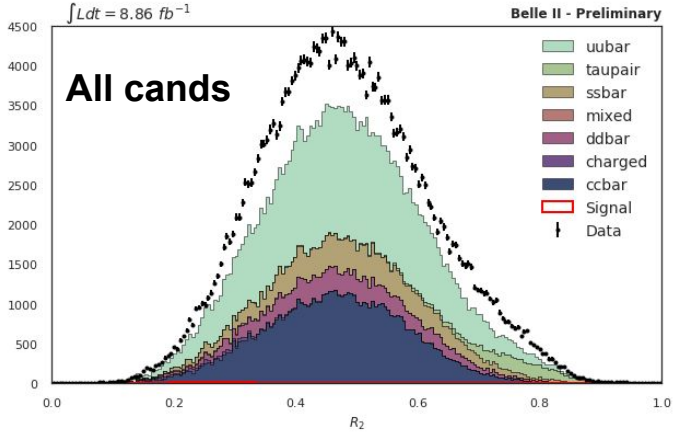


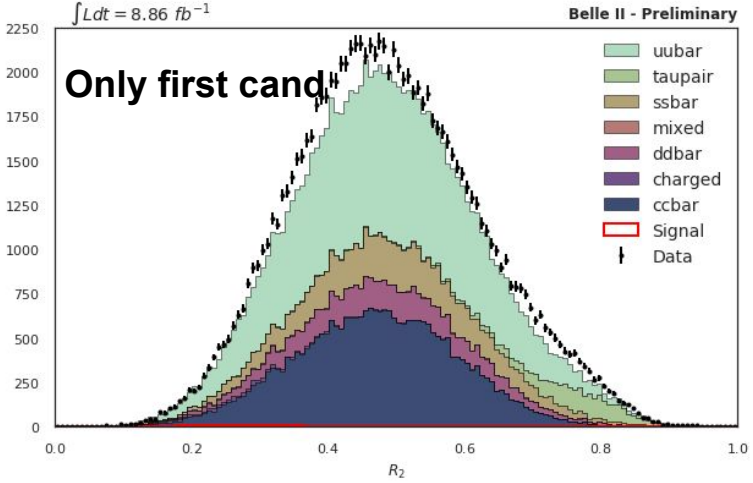


Data/MC comparison

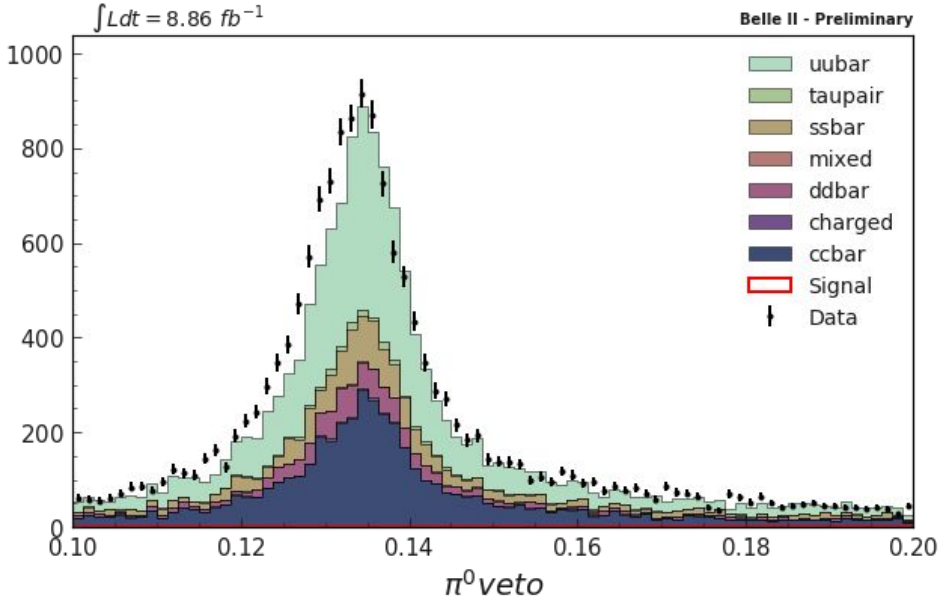
- Normalization problem when using all candidates
- Average cands/ev different in Data/MC
- Using only first candidate better but not yet perfect

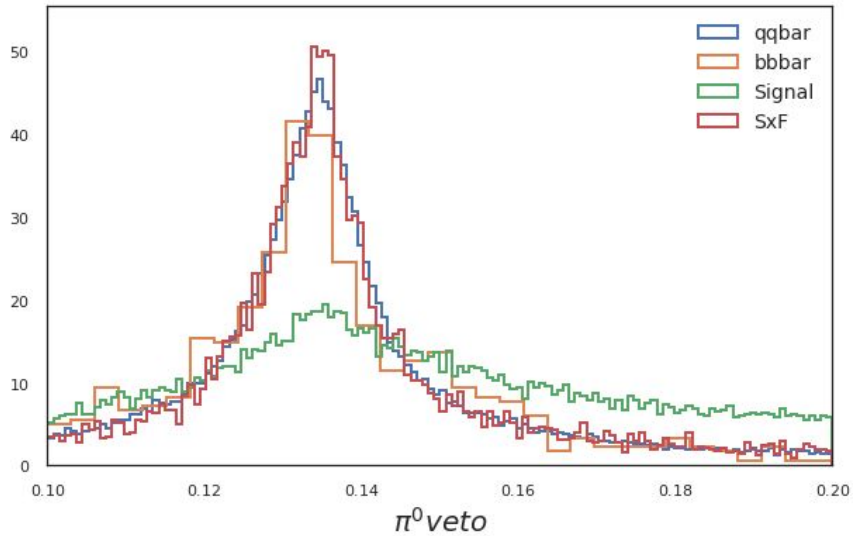






Pi0 veto

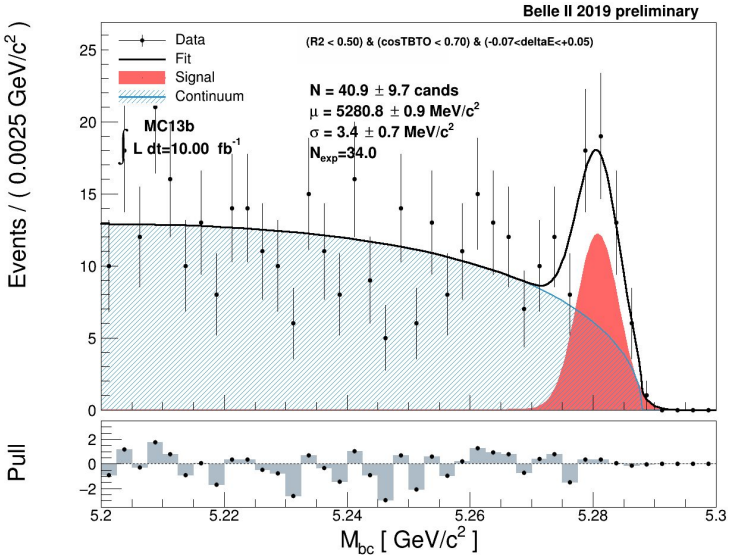


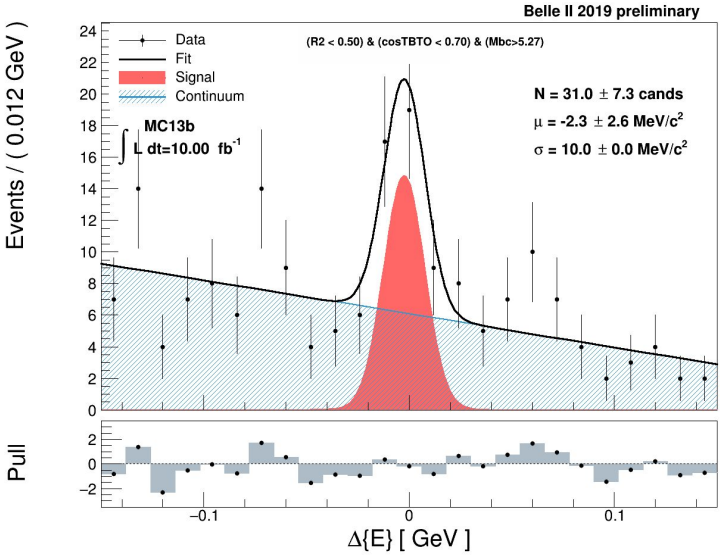


- Pi0 veto mass peak shifted in Data wrt to MC

- Significant signal loss if cut on pi0veto.
- No cut applied.
- Accumulation of signal close to Mpdg due to selection of pi0 veto

Try to fit signal: only MC (with its bb signal)



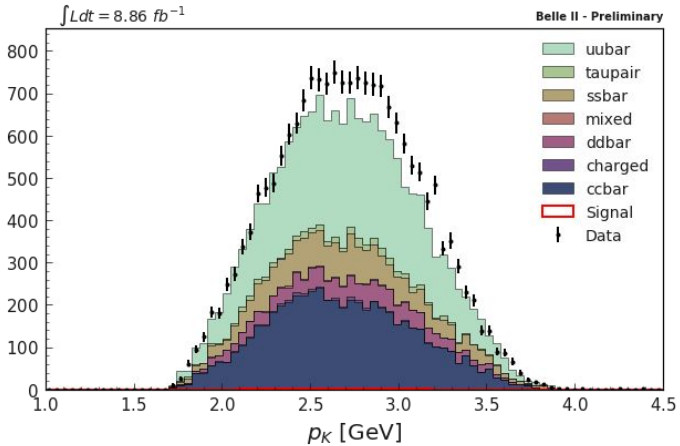


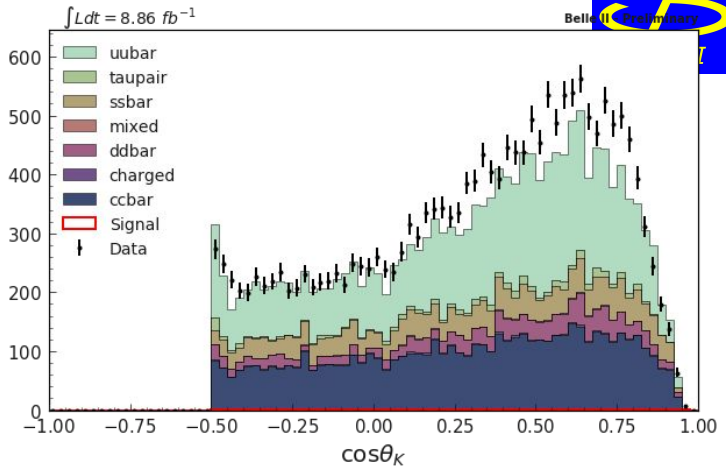
- Previously removed signal from generic BB
  - **Now use MC as data: signal not removed**
- There are 34 candidates in 10/fb of MC13b (expected 31 w/ CS cuts)
- Seen 41+/-10 (Mbc) and 31+/-7 (De)

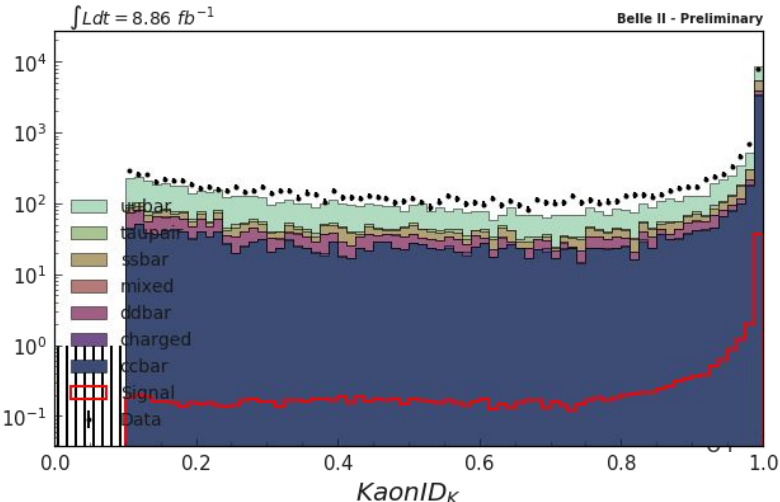
Data - MC comparison

- Start comparing reconstructed quantities for Data and MC
- General idea is to apply selection only on variables that are well modelled by MC
- Start with rectangular cuts, MVA selection will follow later
  - MC: using qq-bar (udsc)
  - bb-bar generic (mixed and charged)
    - For background only study exclude signal from charged (or mixed)
    - Using `reconstructMCdecay(...)`
    - Count #signal events to use MC13b as “data-(not-so-)challenge”
  - Use larger signal MC to model signal and SxF
- All normalized to data integrated luminosity

Data MC comparison K



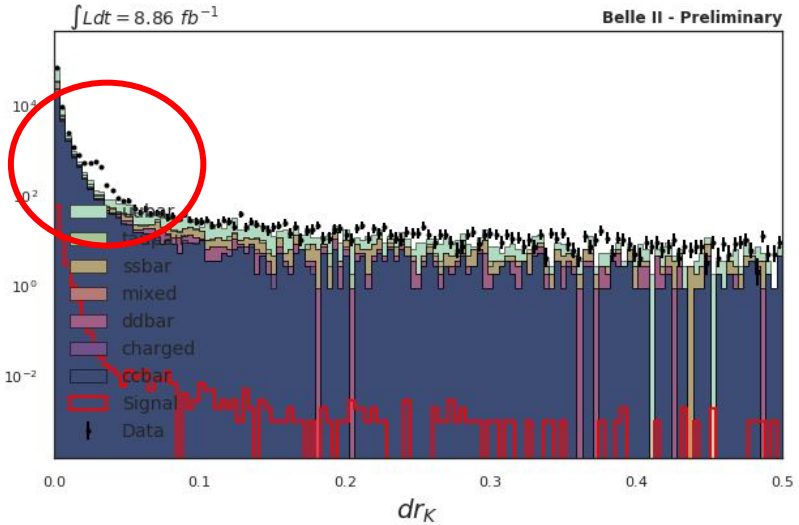


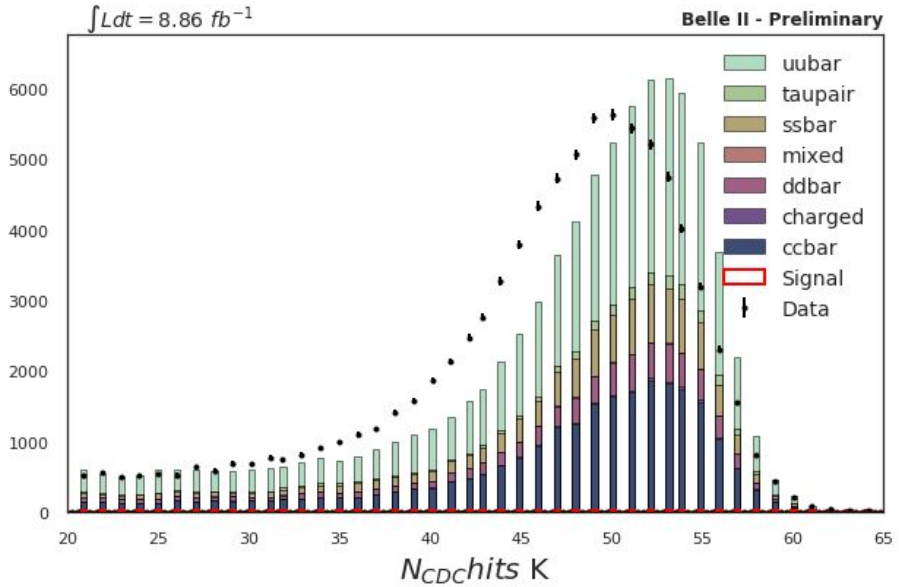


- Using Loose K^+
- Overall normalization is better, not perfect
- Shape decent, but not perfect as well

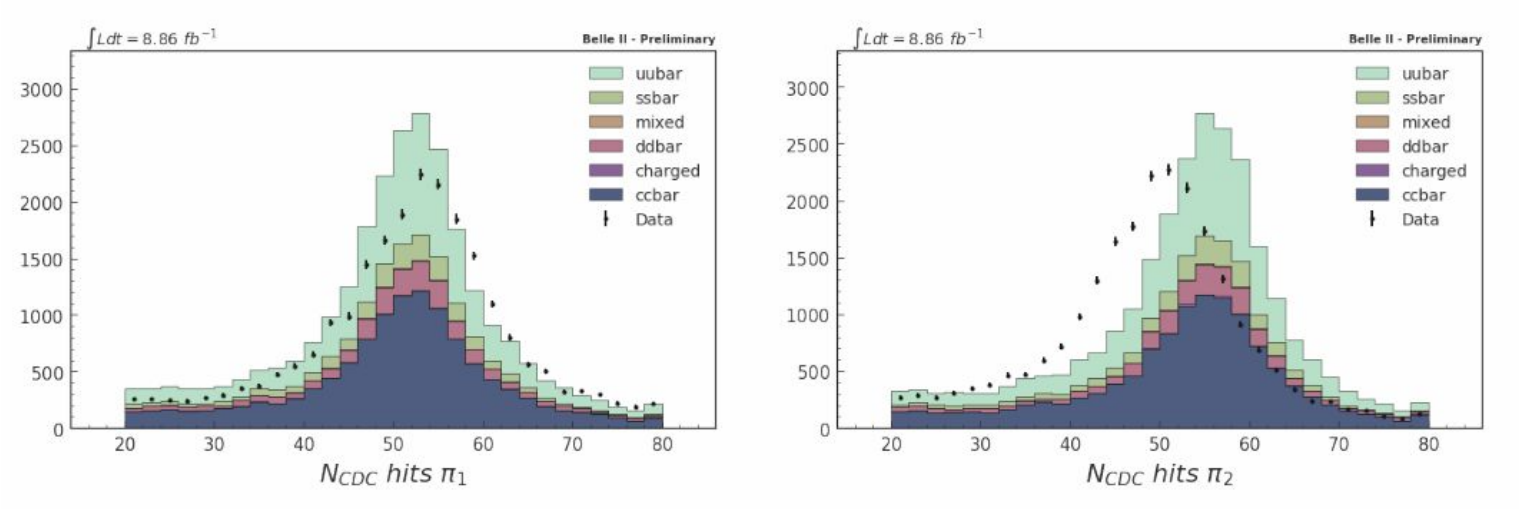
K dr and N CDC hits

- Data has peak at dr~50 um. Seen also for pions from eta'->eta pi pi decay
- Significant difference on N CDC hits
- For pion, also between pi+ and pi- from eta' -> eta pi+ pi- decay



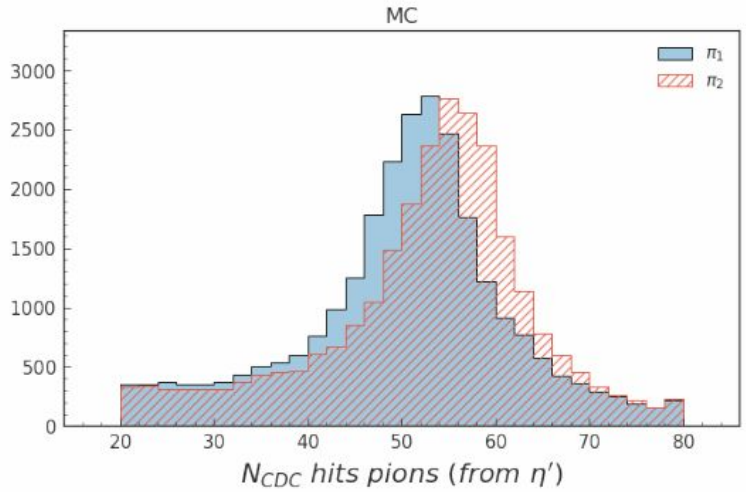


N CDC hits for pion eta'->eta pipi

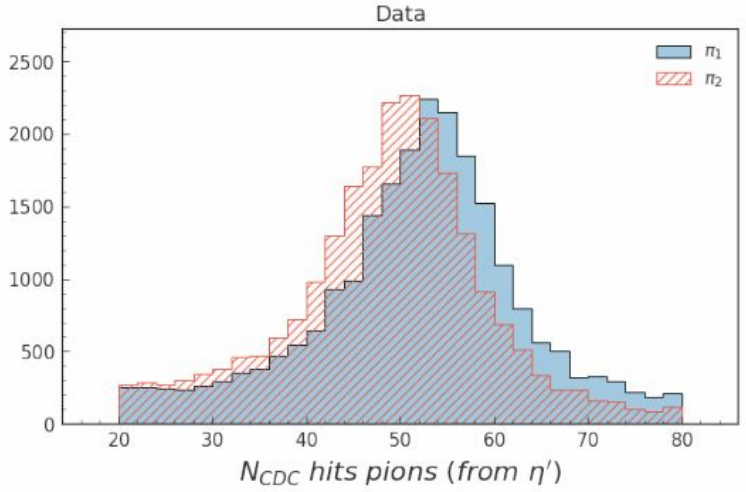


- Disagreement between data and MC
- And also between the two pions pi1=pi+ pi2=pi-
  - Is this a charge related asymmetry? Is it known?

N CDC hits for pion eta'->eta pipi

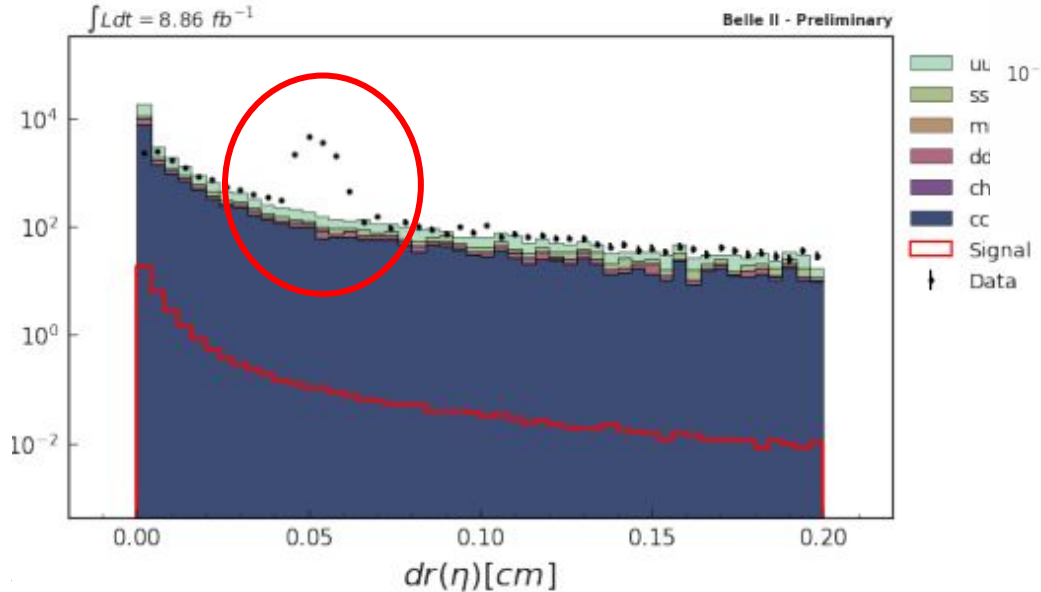


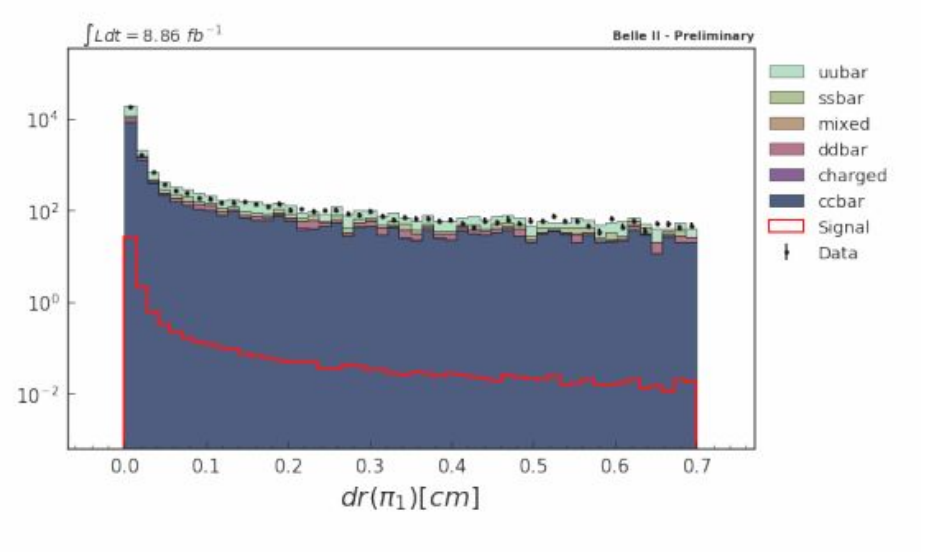
- N_{CDC} different for pi+ and pi-
- But in different way in Data and MC
- Same for pions from K_s



Dr for eta' and pi (in eta'->eta pi+ pi-)

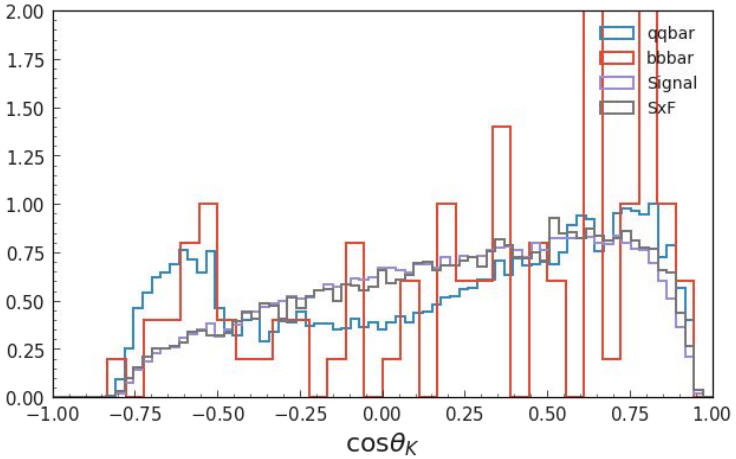
- **dr= transverse distance in respect to IP**
- Do I have a problem with IP in data?
- Should I get dr wrt Beam Spot?
- ipConstraint=True in TreeFit?

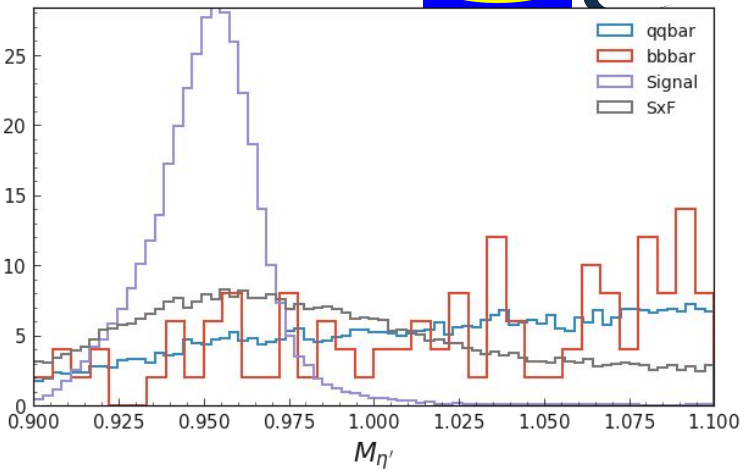


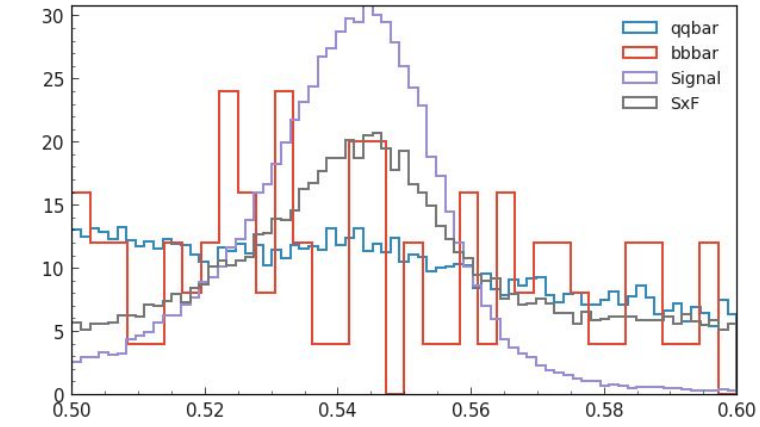


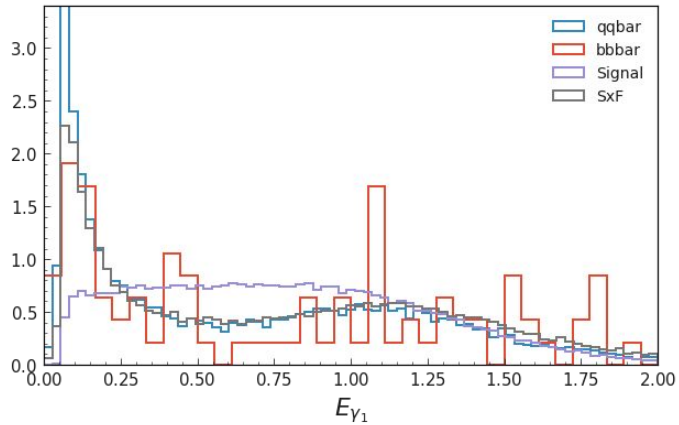

```
vx.treeFit("B+:ch3",
conf_level=-1, ipConstraint=True,
updateAllDaughters=True,
massConstraint=[331],
path=my_path)
```

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

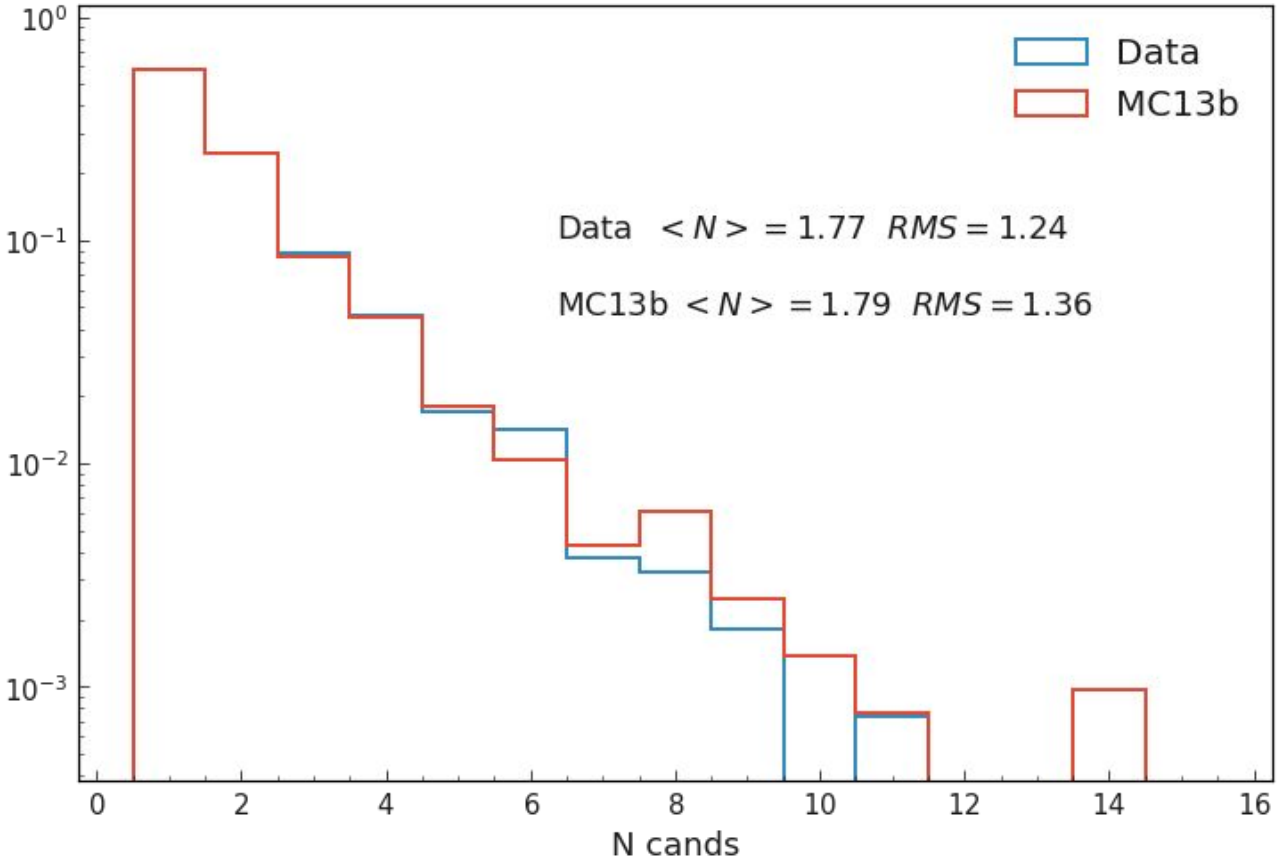




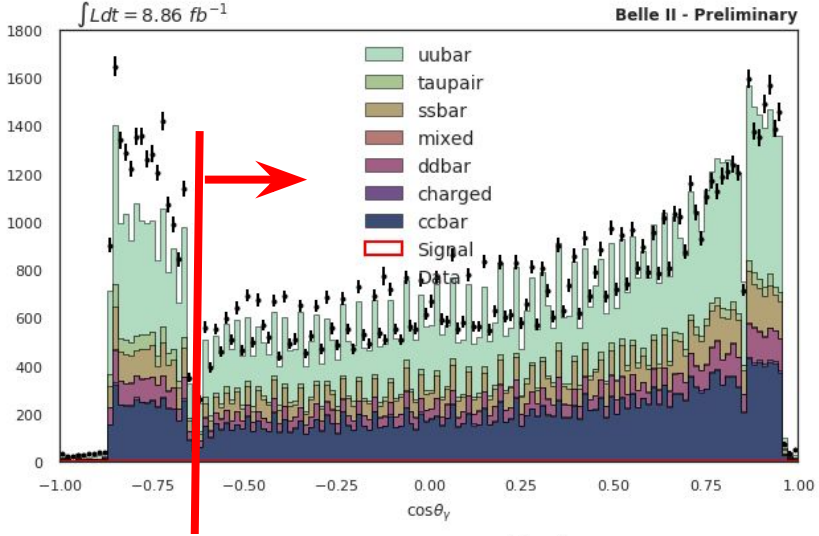




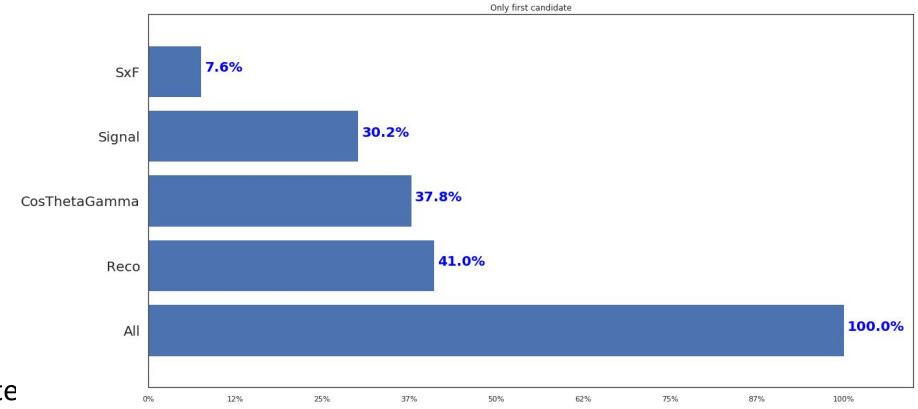
$B^+ \to \eta' (\to \eta (\gamma\gamma) \pi^+\pi^-) K^+$

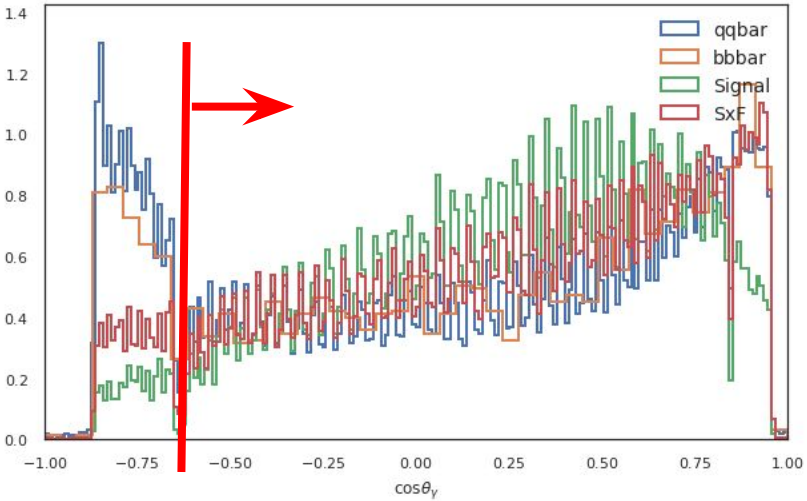


Gamma CosTheta



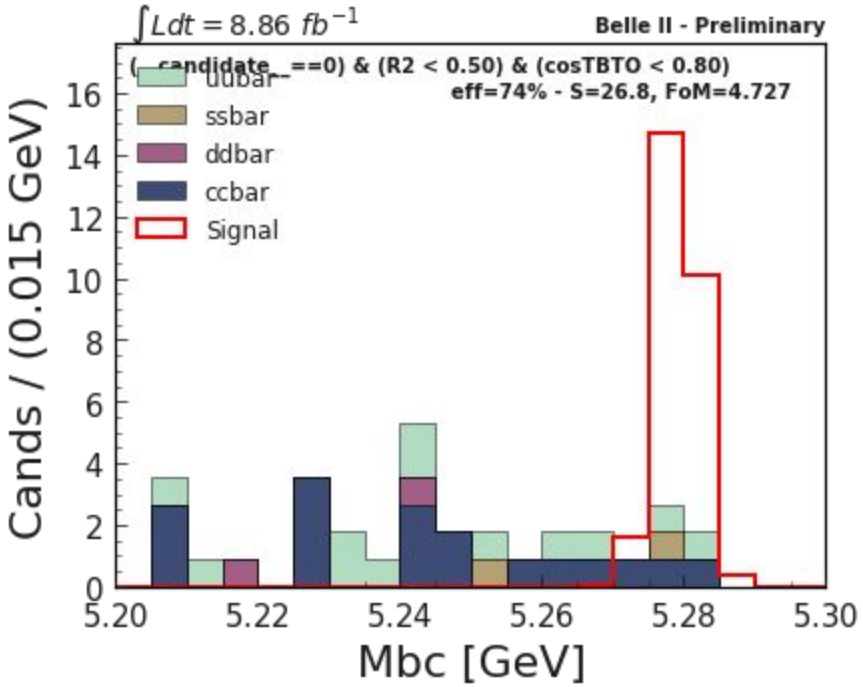
- Most of excess in data is for backward gamma
- Also a place where the background and SxF is large (and signal small)
- Cut **cosThetaGamma>-0.64**
- **Small eff loss (41 -> 37.8%)**

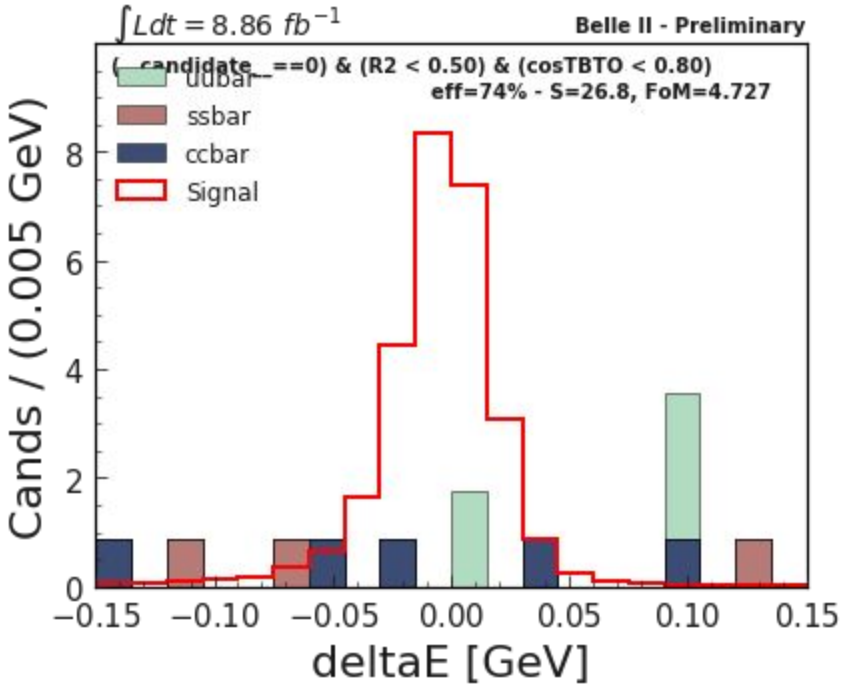




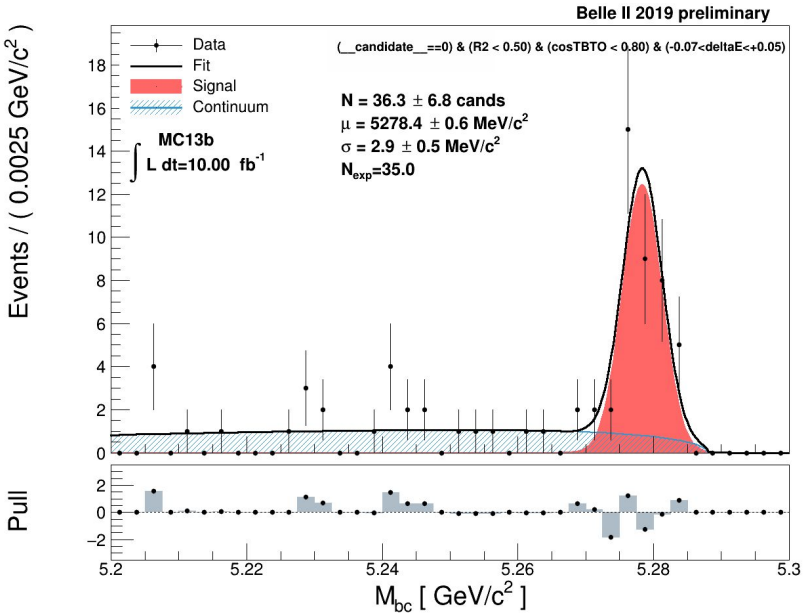
Ste

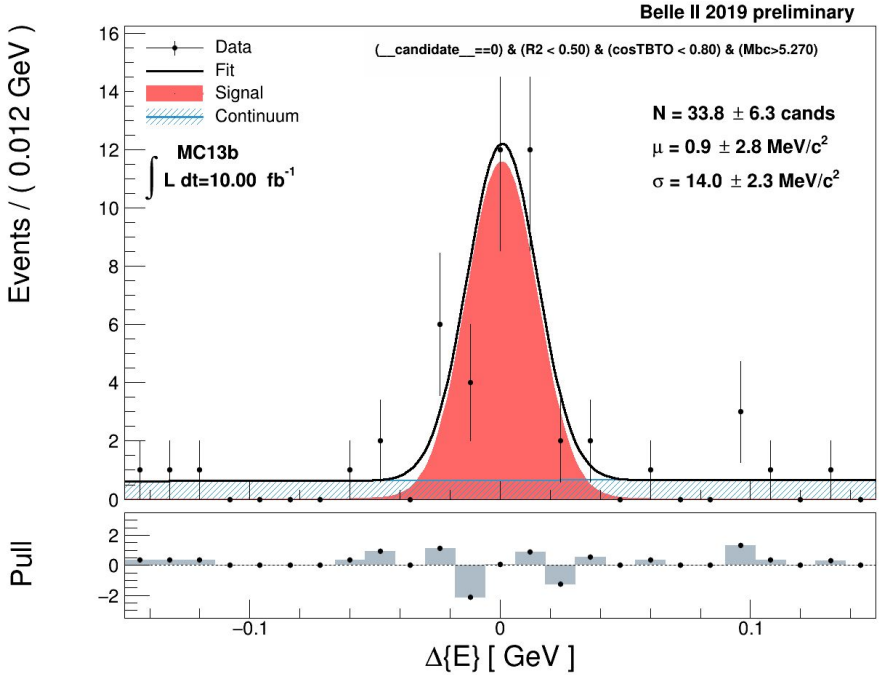
$B^+ \to \eta' (\to \eta (\gamma\gamma) \pi^+\pi^-) K^+$



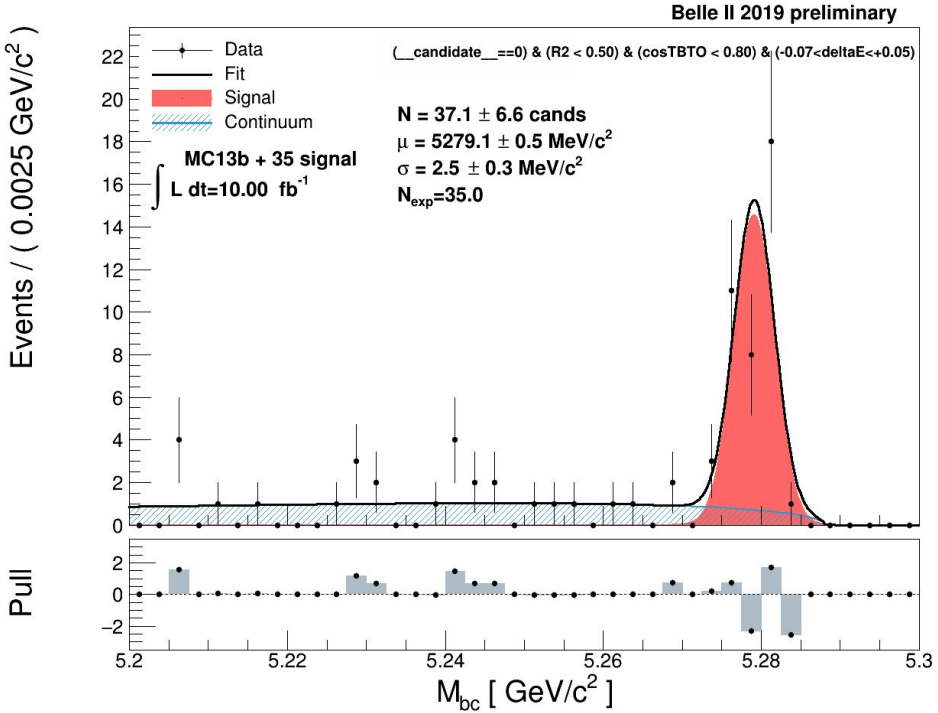


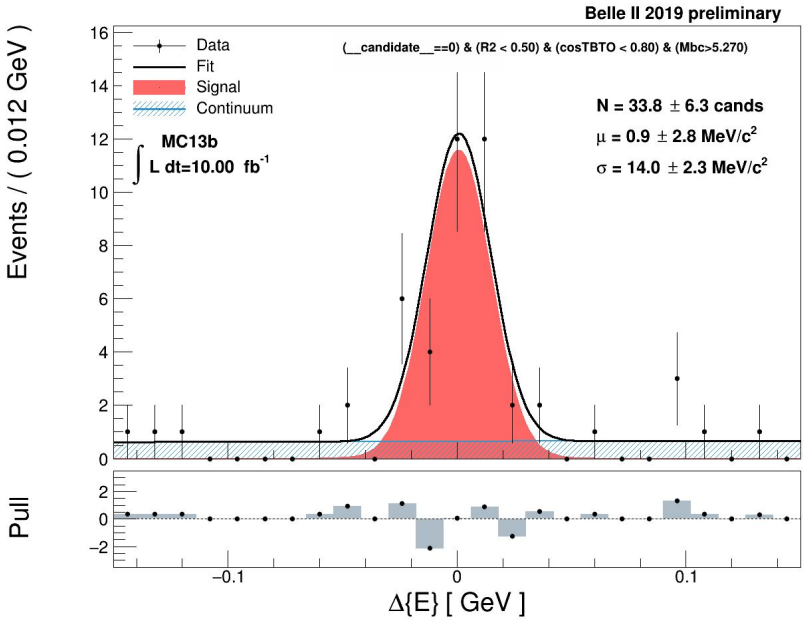
$B^+ \to \eta' (\to \eta (\gamma\gamma) \pi^+\pi^-) K^+$



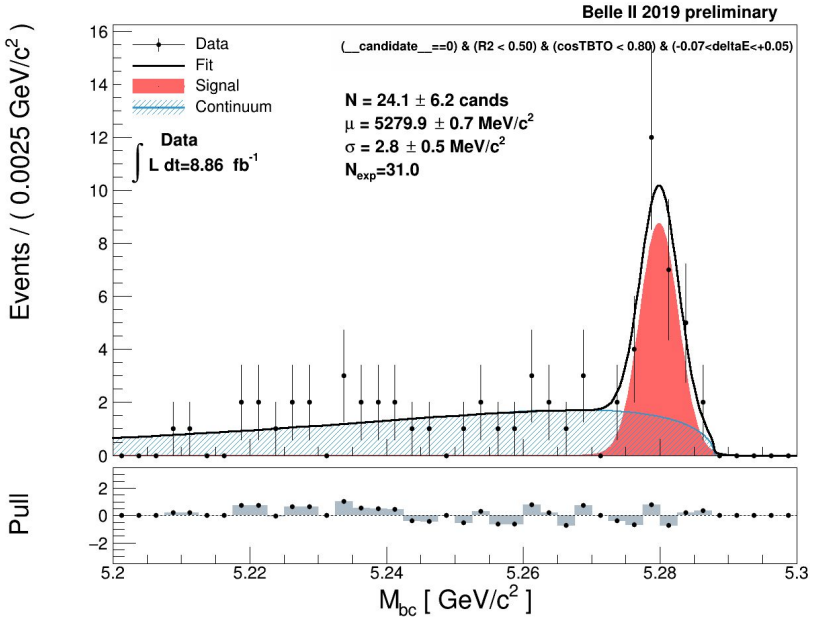


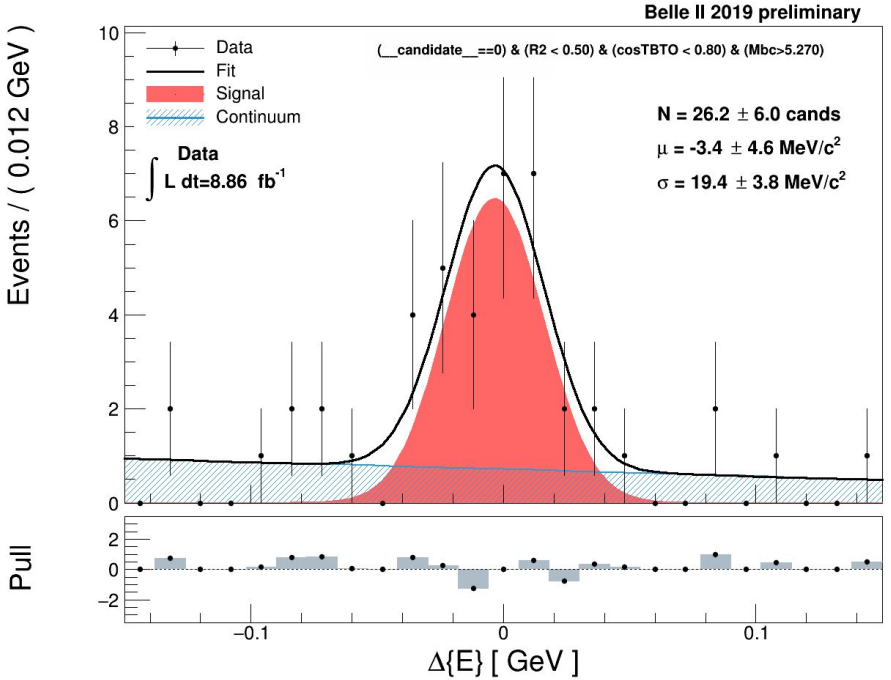
$B^+ \to \eta' (\to \eta (\gamma\gamma) \pi^+\pi^-) K^+$





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





Toys studies