

η and η' meson rediscovery (plus f_0)

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Light meson in Belle II - Phase II

- goal of this work is to rediscover η and η' particles in Phase2 data
- JIRA ticket is **BIIPH2-62**
- General strategy is:
 - ▶ Define selection based on MC - phase II
 - ▶ test selection on large DataChallenge dataset (inclusive MC w/o MC truth)
 - ▶ run on Data Phase2 (exp3, Prod6)

This presentation

Collect the work done so far

particle list

- ✓ $\pi^0 \rightarrow \gamma\gamma$ (backup)
- ✓ $\rho \rightarrow \pi^+\pi^-$
- ✓ $f_0(975) \rightarrow \pi^+\pi^-$
- ✓ $K_S^0 \rightarrow \pi^+\pi^-$ (backup)
- ✓ $\phi \rightarrow K^+K^-$ (backup)
- ✓ $\eta \rightarrow \gamma\gamma$
- ✓ $\eta \rightarrow \pi^+\pi^-\pi^0$
- ✓ $\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$
- ✓ $\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$
- ✗ $\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$

- MC phase II
 - ▶ $c\bar{c}$ events
 - ▶ Warning: non inclusive MC
 - ▶ BGx0: prodID 2218
 - ▶ BGx1: prodID 2264
- Data
 - ▶ exp3, Prod6, skim Hadron $[[nTracksLE \geq 3] \text{ and } [Bhabha2Trk == 0]]$
 - ▶ Runs: 529:5613: Lumi: 491.5 pb^{-1}
 - ▶ Also Prod6 available for comparison:
 - ★ exp3, Prod5, skim Hadron $[[nTracksLE \geq 3] \text{ and } [Bhabha2Trk == 0]]$
 - ★ Runs: 529:5613: Lumi: 472 pb^{-1}
- Data Challenge - MC phase 3
 - ▶ skim TDCPV (ProdID 5142)
 - ▶ N events (post skim) 59830371
 - ▶ Confluence page

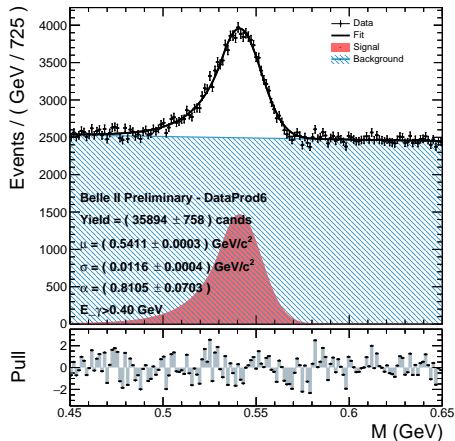
- git repo: `ssh://git@stash.desy.de:7999/~lacaprar/etaprime.git`
- `etaprime/Jupiter`
- Ntuple processing in `EtaProcessing.py`
- and in `EtaPrimeProcessing.py`
- analysis in `Pi0|Eta|EtaPrime....ipynb`
- Code is a messy shape, in case you want to reuse it, you might want to ask me

Selection:

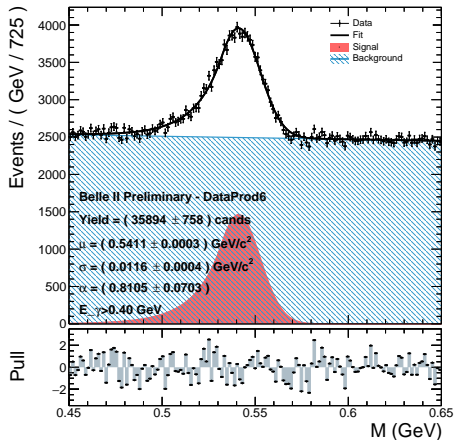
- gamma:pi0 from `stdPhotons`
 - ▶ $0.296706 < \theta_\gamma < 2.61799$
 - ▶ $|\text{clusterTiming}| < \text{clusterErrorTiming}$ or $E > 0.1 \text{ GeV}$
 - ▶ $E_1/E_9 > 0.3$ or $E > 0.1 \text{ GeV}$
- $50 \text{ MeV} < E_\gamma < 6 \text{ GeV}$
- $E_9/E_{25} > 0.75$
- Cluster: $N_{\text{hits}} > 5$, $E_9/E_{21} > 0.95$
- Varing $E_\gamma > 300 - 500 \text{ MeV}$

UML Fit with CristalBall + Chebychev[1]

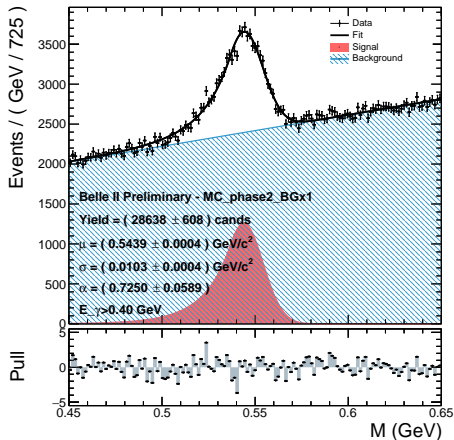
Invariant Mass plot for Data Prod6, 500 nb^{-1}



Data - Phase 2

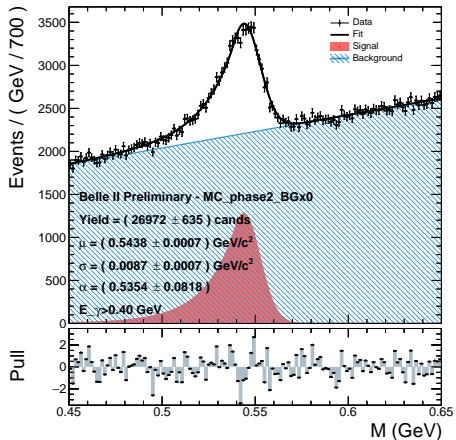


Montecarlo - Phase 2 BGx1

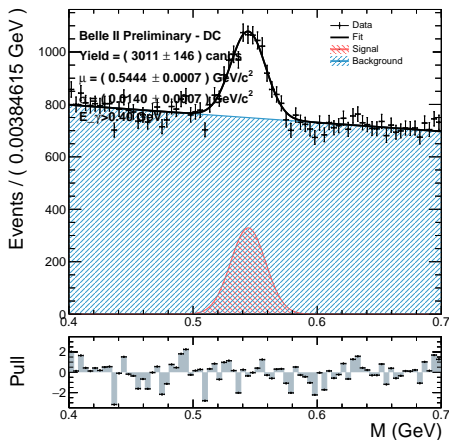


$\Delta\mu \sim 2 \text{ MeV}$, $\Delta\sigma \sim 1 \text{ MeV}$. **Warning:** MC only $c\bar{c}$ bkg shape different

BGx0 MC Phase 2



BGx1 MC Phase 3 Data Challenge



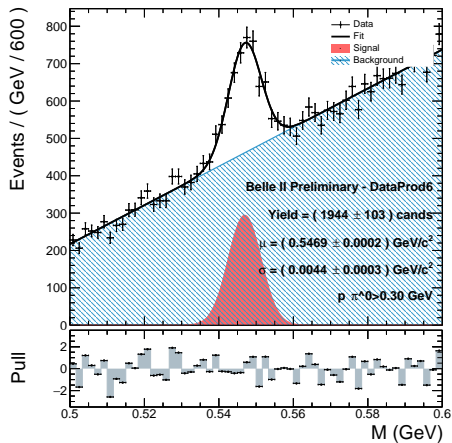
Ph2: BGx1 σ 10.3 MeV vs BGx0 8.7 MeV vs Ph3-BGx1 14 MeV

Selection:

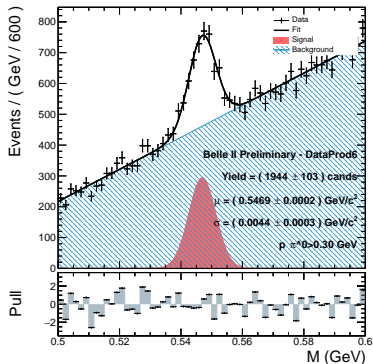
- $\pi^0 \rightarrow \gamma\gamma$
 - ▶ $|clusterTiming| < clusterErrorTiming$ or $E > 0.1$ GeV
 - ▶ $50 \text{ MeV} < E_\gamma < 6$ GeV
 - ▶ Cluster: $N_{hits} > 1.5$, $E_9/E_{21} > 0.9$
 - ▶ $100 < M_{\gamma\gamma} < 150$ MeV
 - ▶ $p_{\pi^0} > 300$ MeV
- π^\pm
 - ▶ $|d_0(\pi)| < 2$ cm, $|z_0(\pi)| < 4$ cm
 - ▶ $PionID > 0.5$, $KaonID < 0.5$
 - ▶ $0.296706 < \theta_\gamma < 2.61799$
- $p_\eta > 100$ MeV
- VertexFit for decay chain (mass constrained for π^0)

UML Fit with Gauss + Chebychev[1]

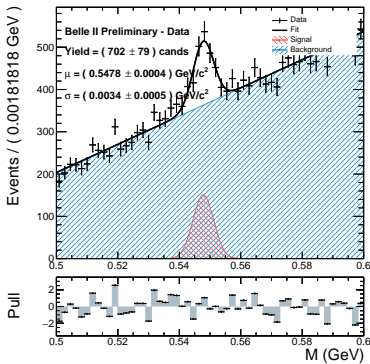
Invariant Mass plot for Data Prod6, 500 nb^{-1}



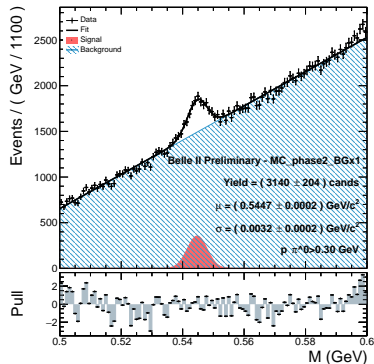
Data - Phase 2 - Prod6



Data - Phase 2 - Prod5



Montecarlo - Phase 2 BGx1

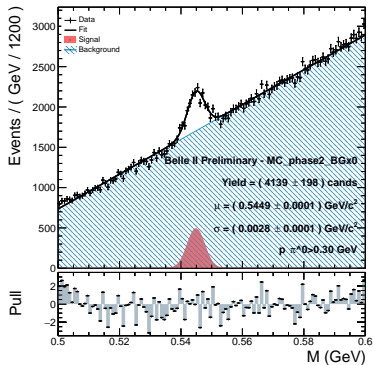


Peak on MC ~ 2 MeV higher than data. Width significantly larger on Data (4.4 vs 3.2 MeV).

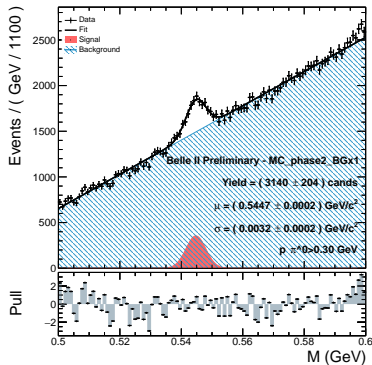
S/B very different (MC only $c\bar{c}$)

Prod6 $\sigma \sim 3.4$ MeV vs 3.2 on Prod5 (not full stat)

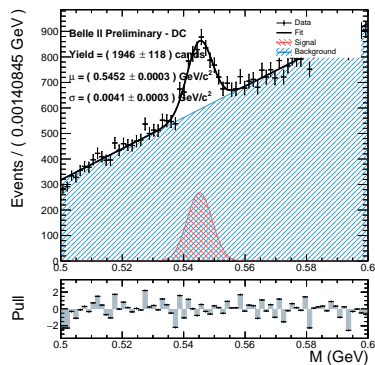
MC - Phase 2 BGx0



MC - Phase 2 BGx1



MC - Phase 3 BGx1 - Data Challenge



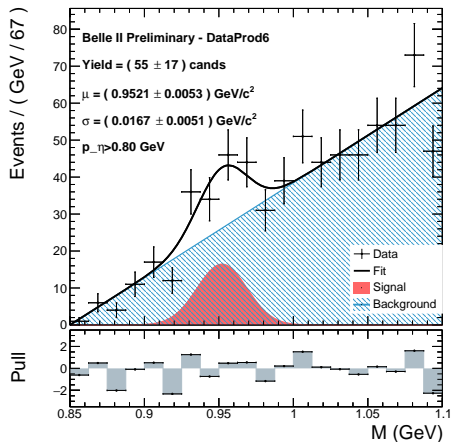
Width increases from 2.8 to 3.2 MeV with BGx1
 On Ph3 (DC) $\sigma \sim 4.1 \text{ MeV}$, and S/B more similar to that of data.

Selection:

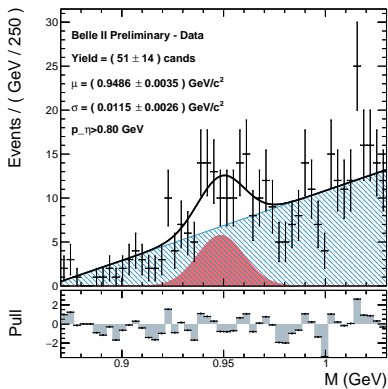
- $\eta \rightarrow \gamma\gamma$
 - ▶ $E_9/E_{25} > 0.75$
 - ▶ Cluster: $N_{hits} > 5, E_9/E_{21} > 0.93$
 - ▶ $E_\gamma > 400$ MeV
 - ▶ $0.52 < M_{\gamma\gamma} < 0.56$ GeV
 - ▶ $p_\eta > 800$ MeV
- π^\pm
 - ▶ $|d_0(\pi)| < 2$ cm, $|z_0(\pi)| < 4$ cm
 - ▶ $PionID > 0.5, KaonID < 0.5$
 - ▶ $p_\pi > 400$ MeV
- VertexFit with $\eta \rightarrow \gamma\gamma$ mass constrained

UML Fit with Gauss + Chebychev[1]
maybe a signal

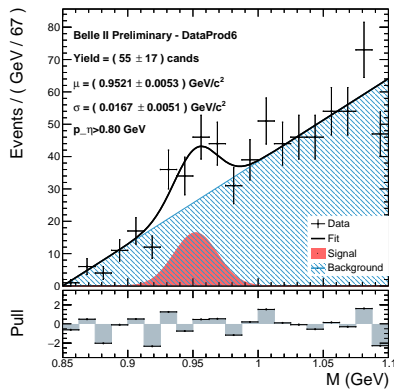
Invariant Mass plot for Data Prod6, 500 nb^{-1}



Data - Phase 2 -Prod5

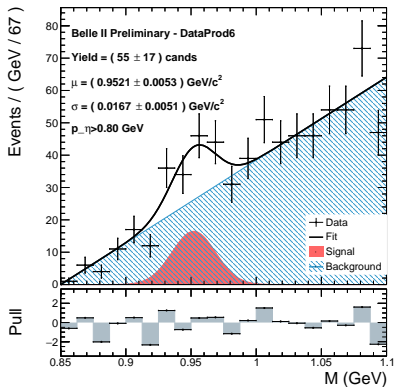


Data - Phase II - Prod6

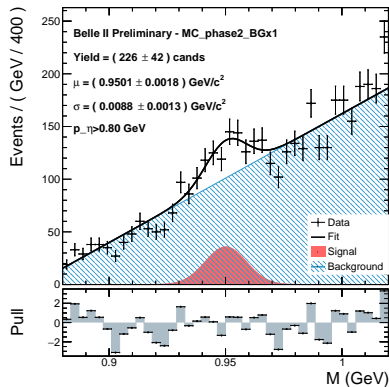


Maybe is a signal. Visible also in Prod5, width smaller.
 Fit is rather unstable and statistics - if any - small

Data - Phase 2

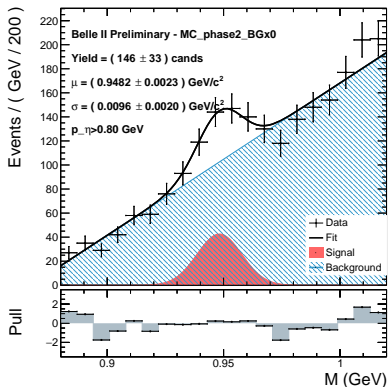


Montecarlo - Phase 2 BGx1

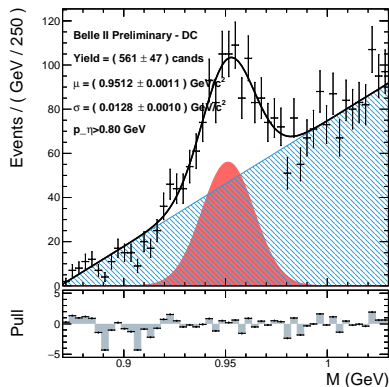


Maybe is a signal. "Peak" position is $\Delta \sim 2 \text{ MeV}$, $\sigma \sim 17 \text{ MeV}$ is larger than MC (9 MeV)

Montecarlo - Phase 2 BGx0



Montecarlo - Phase 3 BGx1 - Data Challenge



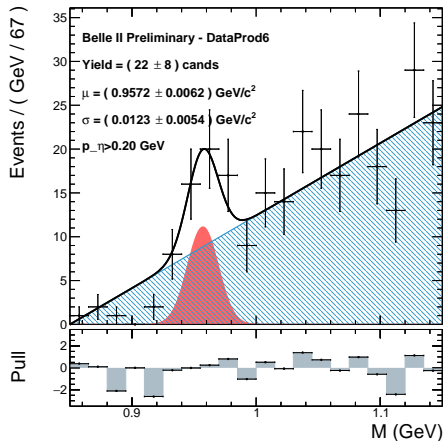
Nicer peak in MC phase2 BGx0 and in Data Challenge

Selection:

- $\pi^0 \rightarrow \gamma\gamma$
 - ▶ Cluster: $N_{hits} > 5$, $E_9/E_{21} > 0.91$
 - ▶ $E_\gamma > 50$ MeV
 - ▶ $125 < M_{\pi^0} < 150$ MeV
 - ▶ $p_{\pi^0} > 100$ MeV
- π^\pm
 - ▶ $|d_0(\pi)| < 2$ cm, $|z_0(\pi)| < 4$ cm
 - ▶ $PionID > 0.5$, $KaonID < 0.5$
 - ▶ $p_\pi > 100$ MeV
- η
 - ▶ $510 < M_\eta < 590$ MeV
 - ▶ $p_\eta > 200$ MeV
- VertexFit with π^0, η mass constrained

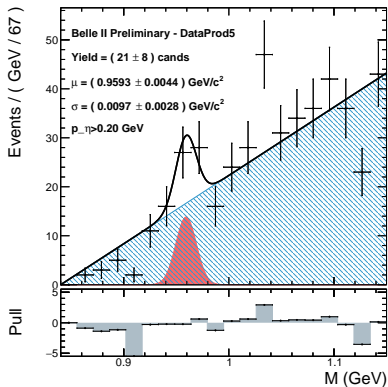
UML Fit with Gauss + Chebychev[1]

Invariant Mass plot for Data Prod6, 500 nb^{-1}

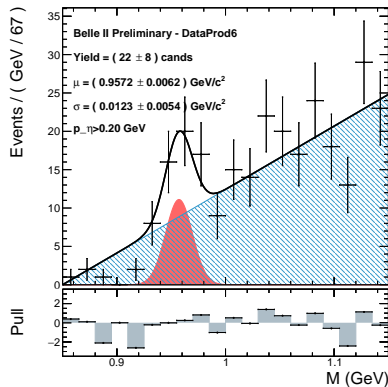


maybe, very maybe ...

Data - Phase 2 Prod5

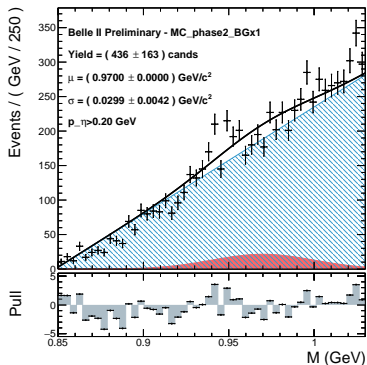


Data - Phase 2 Prod6

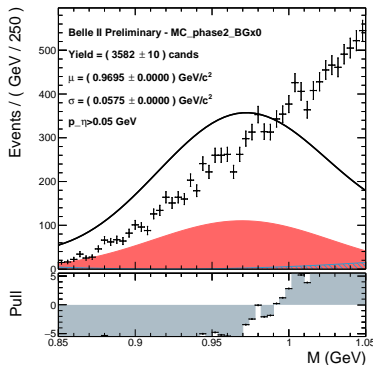


Very maybe both in Prod5 and Prod6

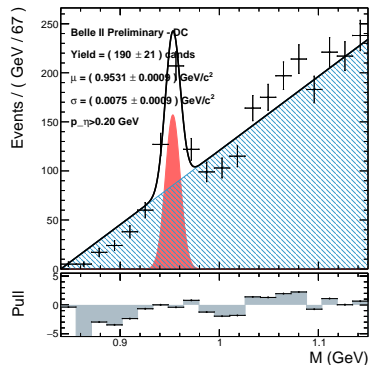
Montecarlo - Phase 2 - BGx1



Montecarlo - Phase 2 - BGx0



Montecarlo - Phase 3 - BGx1



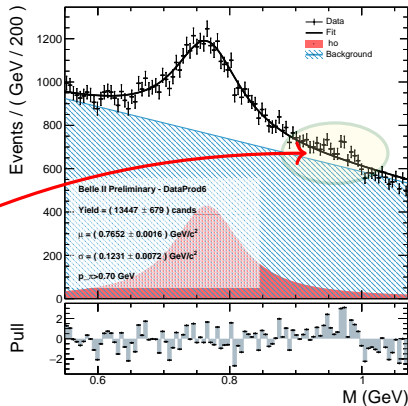
Almost no signal in the MC - ph2 (even before the cuts, MC truth) Wrong MC sample?
 Ok for DC, quite narrow ($\sigma \sim 7.5 \text{ MeV}$ vs 12.8 MeV for $\gamma\gamma$) also 200 $\eta'_{3\pi}$ vs 560 $\eta'_{\gamma\gamma}$
 to de understood

Selection:

- stdPi (good)
 - ▶ $0.296706 < \theta_\pi < 2.61799$
 - ▶ $|d_0(\pi)| < 2 \text{ cm}$
 - ▶ $|z_0(\pi)| < 4 \text{ cm}$
 - ▶ $PionID > 0.5$
- $KaonID < 0.5$
- $NHits_{CDC} > 15$
- $p_\pi > 0.3 \text{ GeV}$

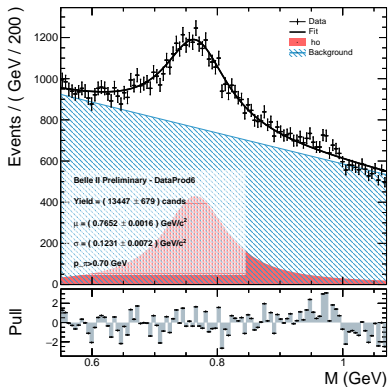
UML Fit with Breit-Wigner + Chebychev[1]

Invariant Mass plot for Data Prod6, 500 nb^{-1}

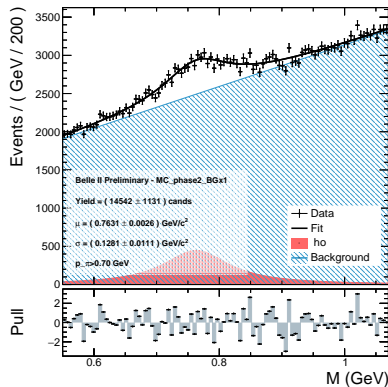


Hint of $f_0 \rightarrow \pi^+ \pi^-$ at $M_{\pi^+ \pi^-} \approx 0.98 \text{ GeV}$?

Data - Phase 2

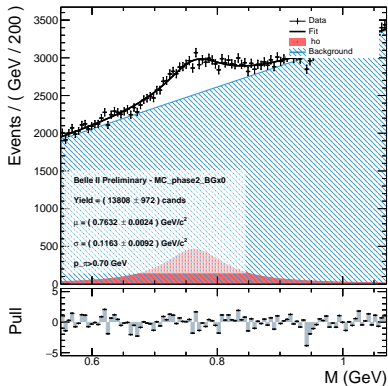


Montecarlo - Phase 2 BGx1

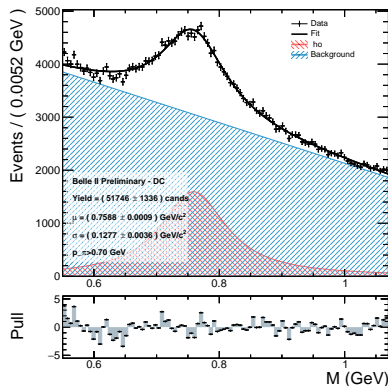


All seems fine: large intrinsic width. PDG 150 MeV, my fit 125 MeV)

Montecarlo - Phase 2 BGx0



Data Challenge - Montecarlo



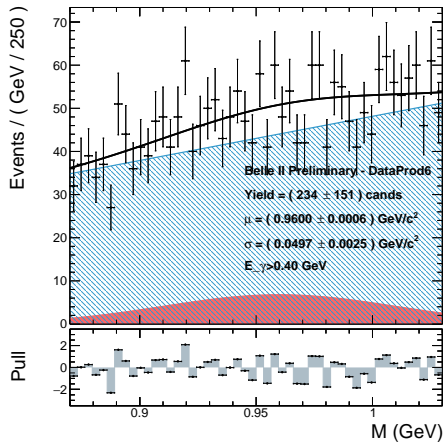
Background on DC similar to that of Data, no $f_0(975)$ (not simulated)

Selection:

- $\rho \rightarrow \pi^+\pi^-$
 - ▶ $PionID > 0.5$, $KaonID < 0.5$
 - ▶ $p_\pi > 0.4$ GeV
 - ▶ $0.470 < M_\rho < 1.07$ GeV before fit
 - ▶ $.73 < M_\rho < 0.8$ GeV after fit
- γ
 - ▶ gamma:pi0 from stdPhotons
 - ▶ Cluster: $N_{hits} > 5$, $E_9/E_{21} > 0.95$
 - ▶ $E_\gamma > 100$ MeV
 - ▶ **Pi0Veto**
 - * $|M_{\gamma\gamma} - M_{\pi^0}| > 20$ MeV with the γ from ROE with $M_{\gamma\gamma}$ closest to M_{π^0} **and**
 - * $N < 2$ γ in ROE with $|M_{\gamma\gamma} - M_{\pi^0}| < 20$ MeV
- VertexFit with ρ mass constrained

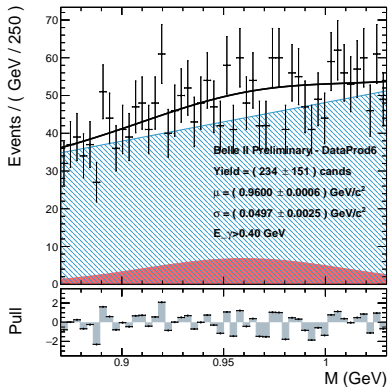
UML Fit with Gauss + Chebychev[1]

Invariant Mass plot for Data Prod6, 500 nb^{-1}

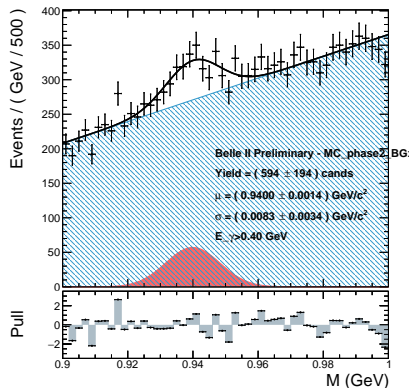


Nope (yet)

Data Prod6 - Phase 2



Montecarlo phase 2 BGx1



Good signal in MC phase 2. More work needed on Data

- Some η and η' final states rediscovered on Data
- agreement with MC is decent, not perfect
- still things to understand both in MC and Data
- all seen also in Data Challenge MC
- Belle 2 note in preparation

Light meson rediscovered

- ✓ $\pi^0 \rightarrow \gamma\gamma$
- ✓ $\rho \rightarrow \pi^+\pi^-$
- ✓ $f_0(975) \rightarrow \pi^+\pi^-$ **new**
- ✓ $K_S^0 \rightarrow \pi^+\pi^-$
- ✓ $\phi \rightarrow K^+K^-$
- ✓ $\eta \rightarrow \gamma\gamma$ **already seen w/ lower stat**
- ✓ $\eta \rightarrow \pi^+\pi^-\pi^0$ **new**
- ✓ $\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$ **new**
- ✓ $\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$ **new**
- ✗ $\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$ **working**

Additional or backup slides

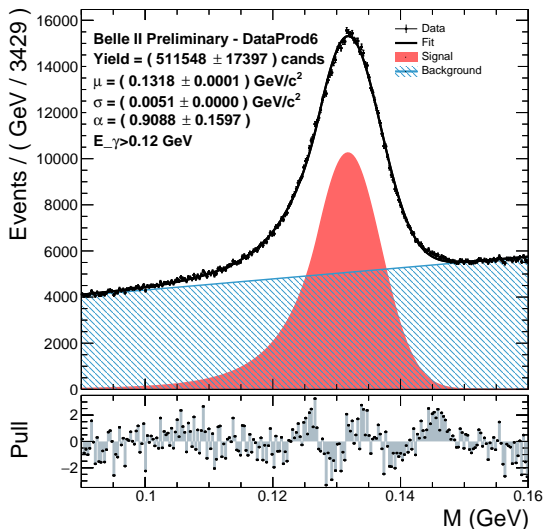
- $BR(\eta' \rightarrow \eta \pi^+ \pi^-) = 0.429$
 - ▶ $BR(\eta \rightarrow \gamma\gamma) = 0.3941$
 - ▶ $BR(\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-) = 0.169$
 - ▶ $BR(\eta \rightarrow \pi^+\pi^-\pi^0) = 0.3268$
 - ▶ $BR(\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-) = 0.140$
- $BR(\eta' \rightarrow \rho\gamma) = 0.291$
 - ▶ $BR(\rho \rightarrow \pi^+\pi^-) = 1$

Selection:

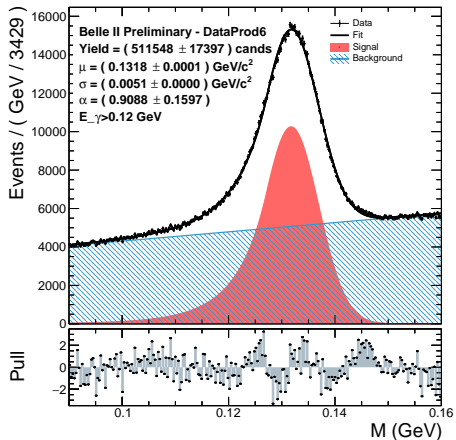
- `gamma:pi0` from `stdPhotons`
 - ▶ $0.296706 < \theta_\gamma < 2.61799$
 - ▶ $|clusterTiming| < clusterErrorTiming$
or $E > 0.1$ GeV
 - ▶ $E_1/E_9 > 0.3$ or $E > 0.1$ GeV
- $50 \text{ MeV} < E_\gamma < 6 \text{ GeV}$
- $E_9/E_{25} > 0.75$
- Cluster: $N_{hits} > 1.5$, $E_9/E_{21} > 0.9$
- Varing $E_\gamma > 60 - 160 \text{ MeV}$

UML Fit with CristalBall + Chebychev[1]

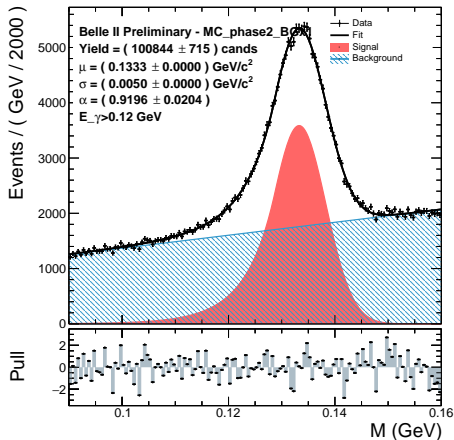
Invariant Mass plot for Data Prod6, $\sim 200 \text{ nb}^{-1}$



Data - Phase 2 Prod 6

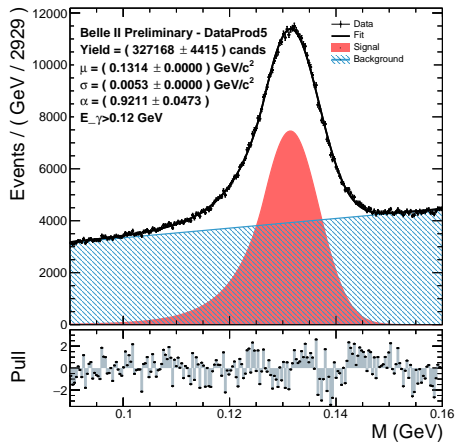


Montecarlo - Phase 2 BGx1

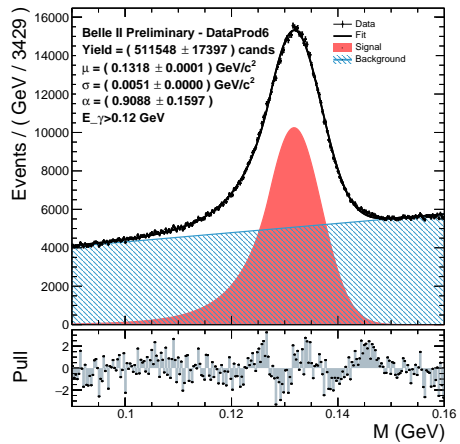


Nice agreement on σ , on MC peak is a bit shifted wrt Data

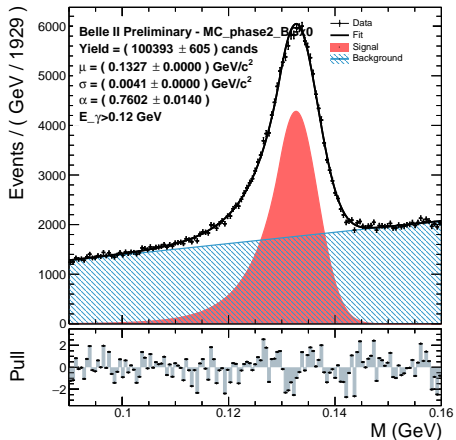
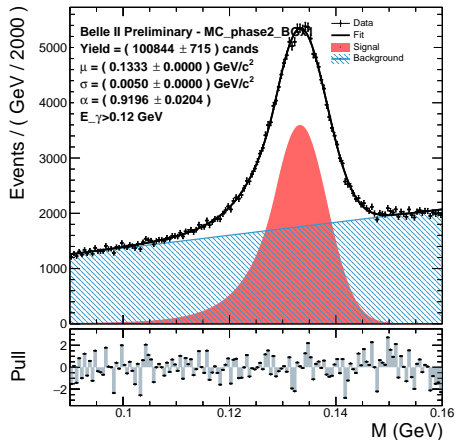
Data - Phase 2 Prod 5



Data - Phase 2 Prod 6

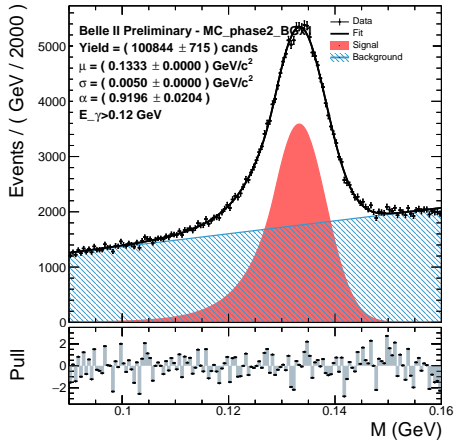


Peak position unchanged ($\Delta \sim 0.4 \text{ MeV}$), width: Prod6 5.1 MeV, Prod5 5.3 MeV, so 4% improvement.

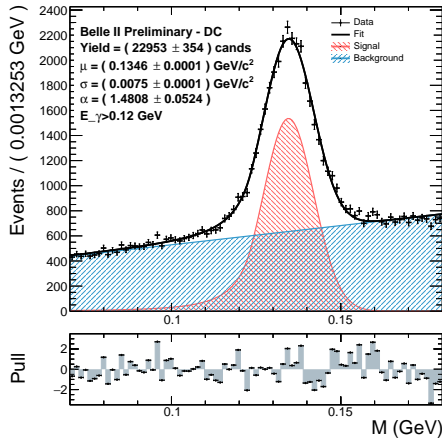
MC - Phase 2 BGx0

MC - Phase 2 BGx1


Peak position shift by 1 MeV, width increase by 1 MeV

MC - Phase 2 BGx1



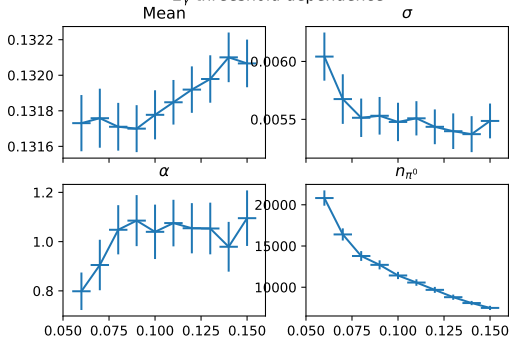
Data Challenge - Phase 3 BGx1



Peak position shift further by 1 MeV, width increase from 5.3 to 7.5 MeV

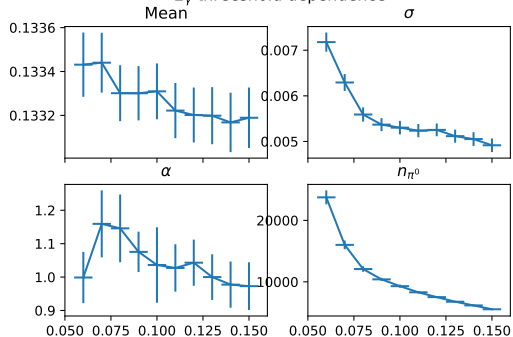
Data Prod5- Phase 2

E_{γ} threshold dependence



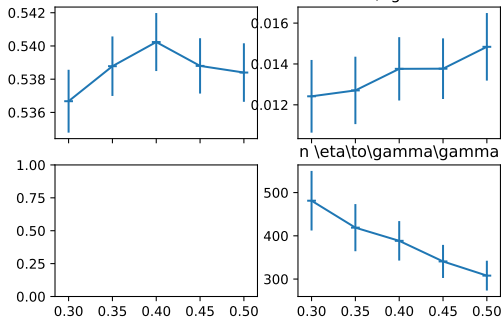
Montecarlo - Phase 2 BGx1

E_{γ} threshold dependence



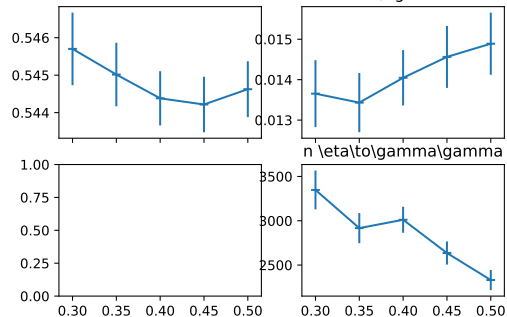
Data - Phase 2

E_γ threshold dependence
Mean



Data Challenge - Montecarlo

E_γ threshold dependence
Mean

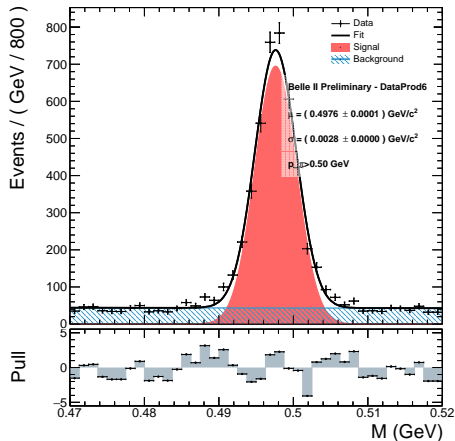


Selection:

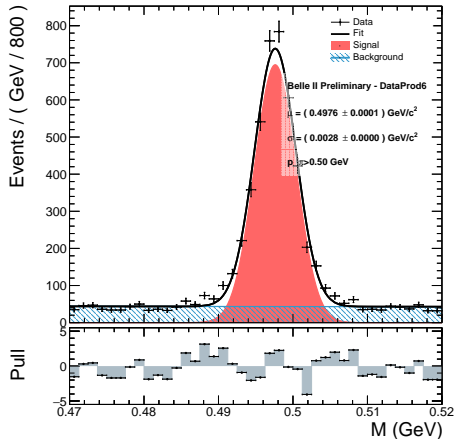
- stdPi (good)
 - ▶ $0.296706 < \theta_\pi < 2.61799$
 - ▶ $|d_0(\pi)| < 2 \text{ cm}$
 - ▶ $|z_0(\pi)| < 4 \text{ cm}$
 - ▶ $PionID > 0.5, KaonID < 0.5$
- or $p < 0.5 \text{ dr} > 0.05, dz < 0.8, \cos \Delta\phi > 0.955$
- or $0.5 < p < 1.5 \text{ dr} > 0.03, dz < 1.8, \cos \Delta\phi > 0.995$
- or $p > 1.5 \text{ dr} > 0.02, dz < 2.8, \cos \Delta\phi > 0.9955$
- $NHits_{CDC} > 15$ (and $NHits_{SVD} = 0$ for DC)
- $p_\pi > 0.3 - 1.3 \text{ GeV}$

UML Fit with Gauss + Chebychev[1]

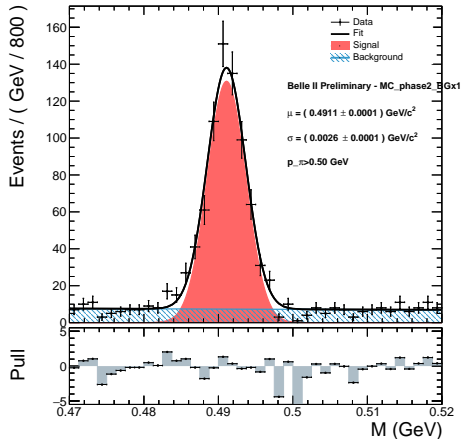
Invariant Mass plot for Data Prod6, 500 nb^{-1}



Data - Phase 2

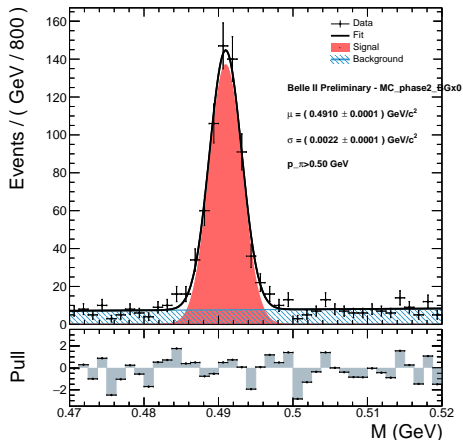


Montecarlo - Phase 2 BGx1

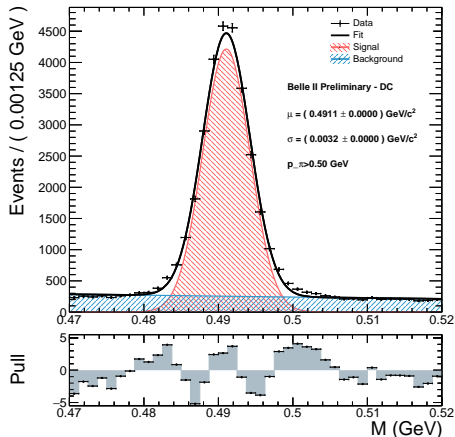


Significan shift in peak position, width similar (large on Data)

Montecarlo - Phase 2 BGx0



Montecarlo - Phase 3 Data Challenge



Peak shift not due to BGx1, only larger width. DC BGx1 has even larger width.

Selection:

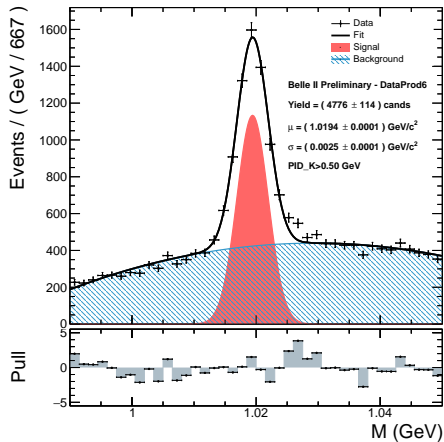
- stdK(good)

- ▶ $0.296706 < \theta_\pi < 2.61799$
- ▶ $|d_0(\pi)| < 2 \text{ cm}$
- ▶ $|z_0(\pi)| < 4 \text{ cm}$
- ▶ $PionID < 0.5$
- ▶ $KaonID > 0.5$
- ▶ $NHits_{CDC} > 15$

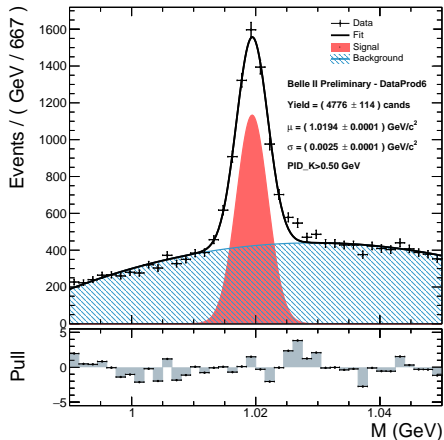
- $p_K > 0.3 \text{ GeV}$

UML Fit with Gauss + Chebychev[1]

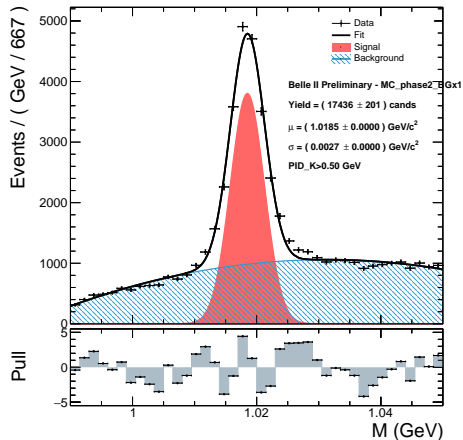
Invariant Mass plot for Data Prod6, 500 nb^{-1}



Data - Phase 2

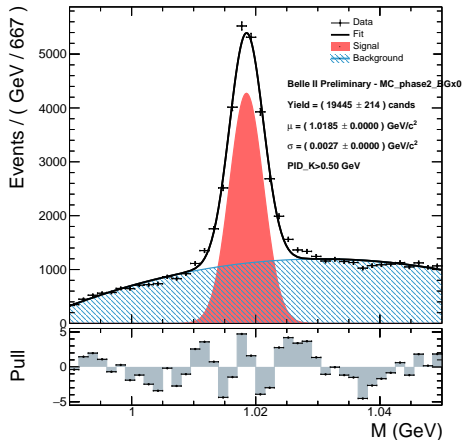


Montecarlo - Phase 2 BGx1

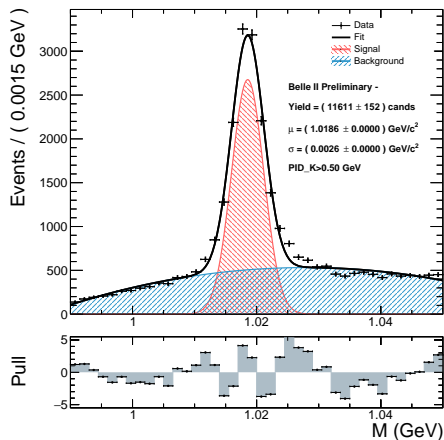


Peak position 1 MeV higher on Data than MC, width slightly smaller in Data

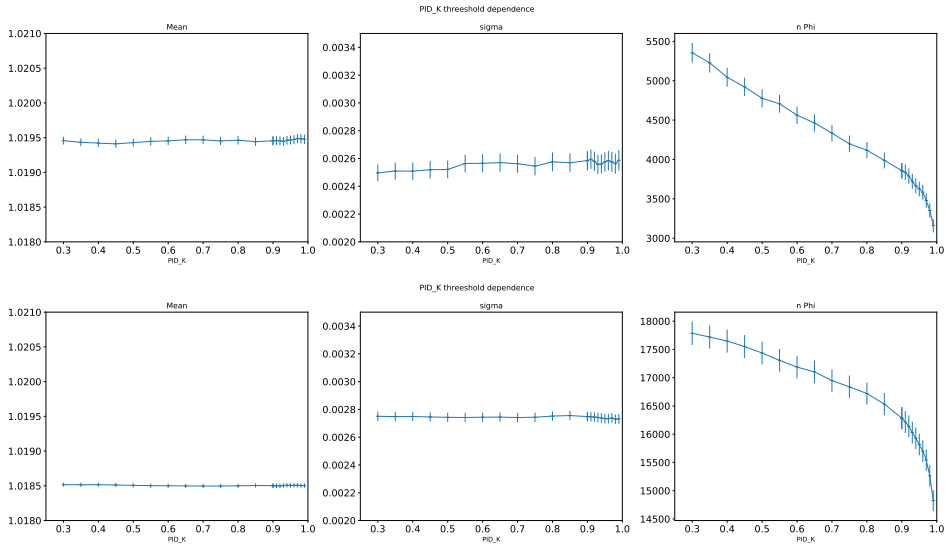
Montecarlo - Phase 2 BGx0



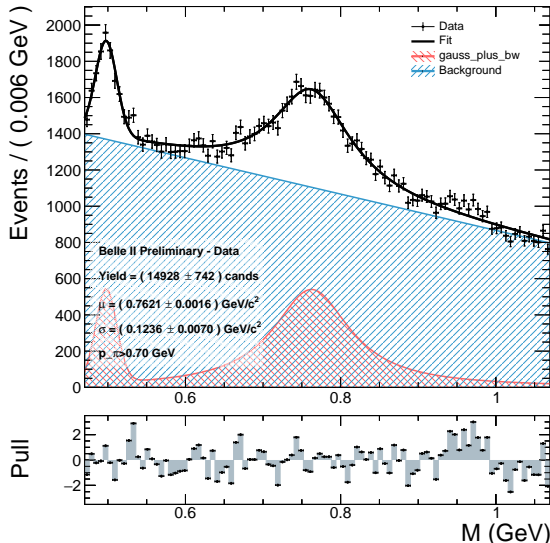
Montecarlo - Phase 3 BGx1 - Data Challenge



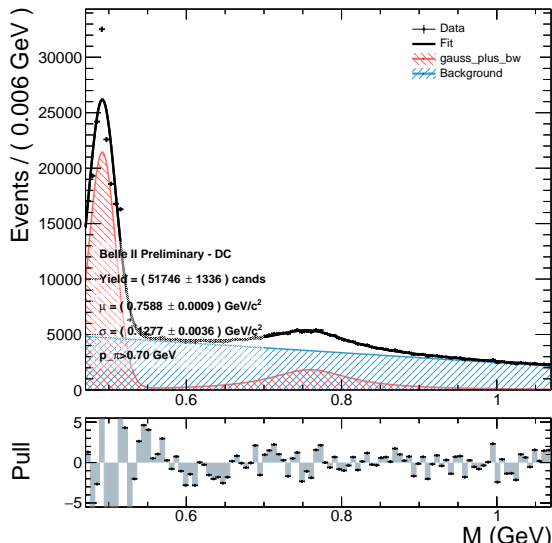
Phase 3 BGx1 better than Phase 2 BGx1 ?



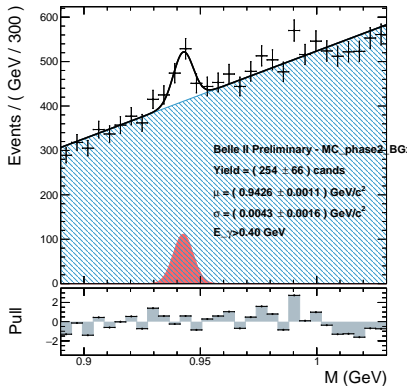
Data - Phase 2



Data Challenge - Montecarlo



Montecarlo phase 2 BGx0



Montecarlo phase 3 BGx1 Data Challenge

