

**Acp in  $D^+ \rightarrow \eta\pi^+$ ,  $D^0 \rightarrow \eta\eta$**

**Status report**

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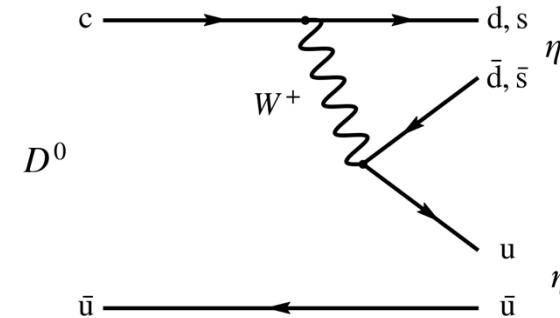
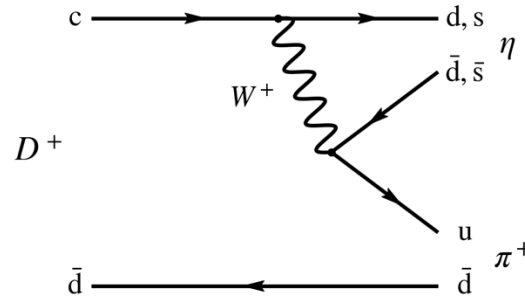
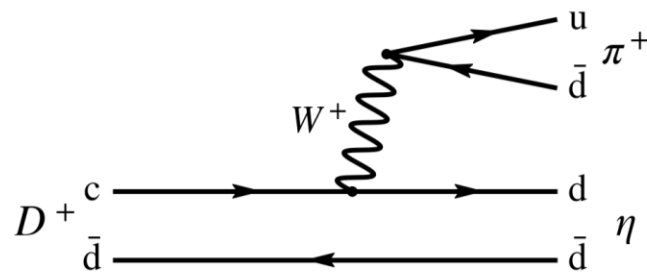
# Motivation

## Theoretical

□  $D^+ \rightarrow \eta\pi^+, D^0 \rightarrow \eta\eta$ (SCS): possible CP violation through interference of two different CKM phases,

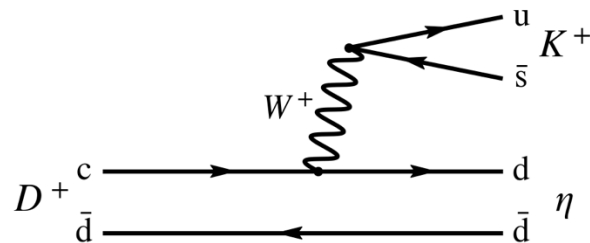
$V_{cd}V_{ud}^*$  and  $V_{cs}V_{us}^*$

- Tree diagrams



□  $D^+ \rightarrow \eta\pi^+, D^0 \rightarrow \eta\eta$ : could be used to probe U-spin sum rule (slide #18 in [ref.](#))

- Studying  $D^+ \rightarrow \eta K^+$ (DCS) is included in the plan, currently.



# Motivation

## Experimental

- ❑  $D^+ \rightarrow \eta_{3\pi}\pi^+$  studied at Belle with only 790/fb, not full data(2011, [PRL.107.221801](#))
  - Belle + Belle II expects improvement in stats. uncertainty
  - Belle: signal yields( $D^+ + D^-$ ):  $6476 \pm 110$
  
- ❑  $D^+ \rightarrow \eta h^+$  ( $h^+ = \pi^+, K^+$ ) studied twice by LHCb at 2021, 2023
  - [JHEP\(2021\)](#) :  $\eta_{e^+e^-\gamma}$ , signal yields( $D^+ + D^-$ ):  $32760 \pm 380$
  - [JHEP\(2023\)](#) :  $\eta_{\pi^+\pi^-\gamma}$ , signal yields( $D^+ + D^-$ ):  $(110.8 \pm 0.7) \cdot 10^3$
  - Totally, ~140k yields
  
- ❑  $D^0 \rightarrow \eta\eta$ : never searched in terms of CP violation
  - Br measured by BESIII(2018, [PRD.97.052005](#)), CLEO(2010, [PRD.81.052013](#)), CLEO(2008, [PhysRevD.77.092003](#))

# Analysis procedure

## $D^+ \rightarrow \eta\pi^+$ : $D^{*+}$ tag & non- $D^{*+}$ tag

- ❑  $\eta \rightarrow \gamma\gamma$  &  $\eta \rightarrow \pi^+\pi^-\pi^0$
- ❑ Separate samples according to  $D^{*+}$  tag & non- $D^{*+}$  tag
  - To use high background suppression with  $D^{*+}$  tag
- ❑ Currently, estimating signal yields by cut-based analysis
  - On-going: ML study for non  $D^{*+} \rightarrow D^+\pi^0$  tag events

- ❑ Sample: MC15ri generic
- ❑ Basf2: light-2403-persian

## $D^0 \rightarrow \eta\eta$ : $D^{*+}$ tag

- ❑  $\eta_{\gamma\gamma}\eta_{3\pi}$  &  $\eta_{\gamma\gamma}\eta_{3\pi}$  (&  $\eta_{3\pi}\eta_{3\pi}$ : low statistics)
- ❑ non- $D^{*+}$  tag
  - Not yet any planned.
  - If we don't have enough statistics, consider using CFT

# Cuts

## Pre-selection(step0)

Particles	Selection Criteria
Hard $\pi^\pm$	In CDC acceptance $dr < 1,  dz  < 3$ $\mathcal{L}_\pi > 0.6$
Normal $\pi^\pm$ in $\eta_{3\pi}$	In CDC acceptance $dr < 1,  dz  < 3$ $\mathcal{L}_\pi > 0.1$
Slow $\pi^+$	In CDC acceptance $dr < 1,  dz  < 3$
$\gamma$ of $\eta$	clusterNHits>1.5 $0.2967 < \text{clusterTheta} < 2.6180$ $E > 0.1[\text{GeV}]$
$\gamma$ of $\pi^0$	clusterNHits>1.5 $0.2967 < \text{clusterTheta} < 2.6180$ $E_{\text{forward}} > 0.05[\text{GeV}]$ or $E_{\text{barrel}} > 0.05[\text{GeV}]$ or $E_{\text{backward}} > 0.075[\text{GeV}]$
$\pi^0$	$0.120 < M[\text{GeV}] < 0.145$ kFit(mass): reject if fit fails
$\eta_{\gamma\gamma}$	$0.52 < M[\text{GeV}] < 0.57$
$\eta_{3\pi}$	$0.535 < M[\text{GeV}] < 0.57$

## Charm mesons

$D^0$	$1.6 < M(D^0)[\text{GeV}] < 2.1$ $p^* > 2\text{GeV}$
$D^{*+}$	$\Delta m < 0.160\text{GeV}$ $p^* > 2.5\text{GeV}$ Vertex TreeFit: Min(confidence level) = 0.001 IP constraint $\eta, \pi^0$ mass constraint

$\eta_{\gamma\gamma}$	$p > 0.4[\text{GeV}]$
$\eta_{3\pi}$	$p > 0.4[\text{GeV}]$
$D^+$	$1.6 < M(D^0)[\text{GeV}] < 2.1$ $p^* > 2.5\text{GeV}$ Vertex TreeFit: Min(confidence level) = 0.001 IP constraint $\eta, \pi^0$ mass constraint

## $\pi^0$ mass veto for $\eta_{\gamma\gamma}$

particles	selection criteria
$\gamma_{ROE}$	$ \text{clusterTiming}  < 200ns$ $ \frac{\text{clusterTiming}}{\text{clusterErrorTiming}}  < 2.0$ clusterNHits> 1.5 $E > 75\text{MeV}$

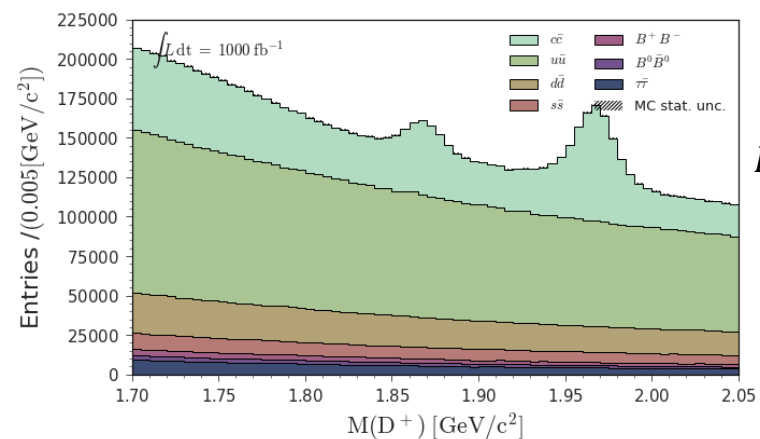
particles	selection criteria
$ M(\gamma\gamma_{ROE}) - m_{\pi^0} $	$> 0.011\text{GeV}/c^2$

## $D^{*+}$ tag for $D^+$

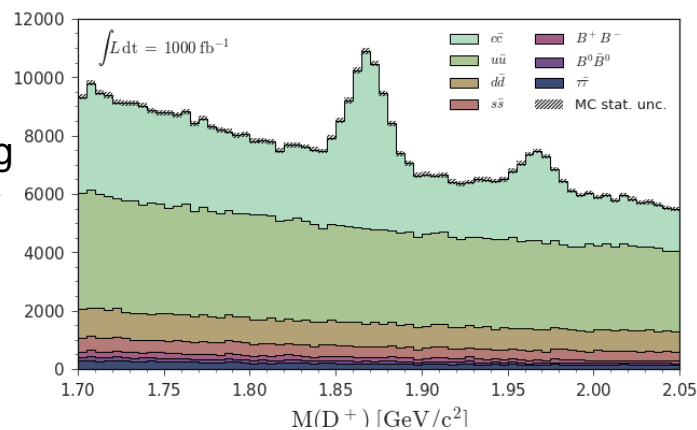
$\gamma$ for slow $\pi^0$	$ \text{clusterTiming}  < 200ns$ $ \frac{\text{clusterTiming}}{\text{clusterErrorTiming}}  < 2.0$ clusterNHits> 1.5 $E_{\text{forward}} > 0.025[\text{GeV}]$ or $E_{\text{barrel}} > 0.025[\text{GeV}]$ or $E_{\text{backward}} > 0.040[\text{GeV}]$
slow $\pi^0$	$0.105 < M[\text{GeV}] < 0.150$ $p > 0.1\text{GeV}$
$D^{*+}$	$0.138 < \Delta m[\text{GeV}] < 0.143$ choose lowest $ M(D^{*+}) - m(D^{*+}) $

# $D^+ \rightarrow \eta_{\gamma\gamma} \pi^+$ (step1)

## From pre-selection(step0)

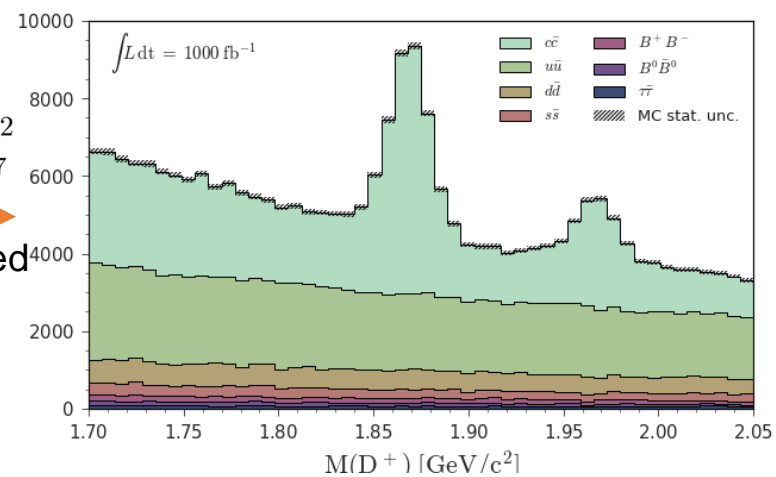


D\*+ tag

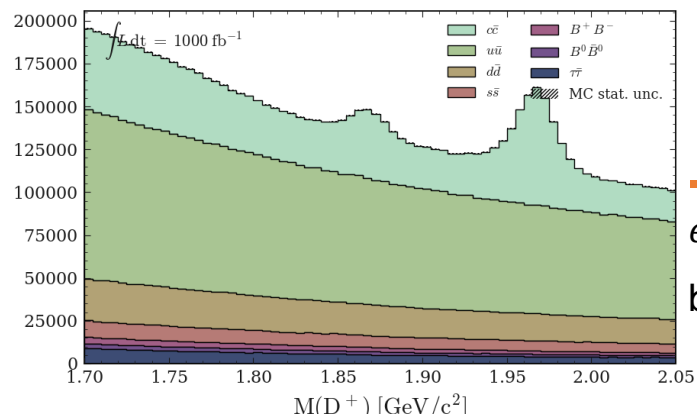


$\eta_{\gamma\gamma}$

$|\Delta\phi(\gamma_1, \gamma_2)| < 2$   
 $\angle(\gamma_1, \gamma_2) < 1.7$   
ε decreased  
by 6%

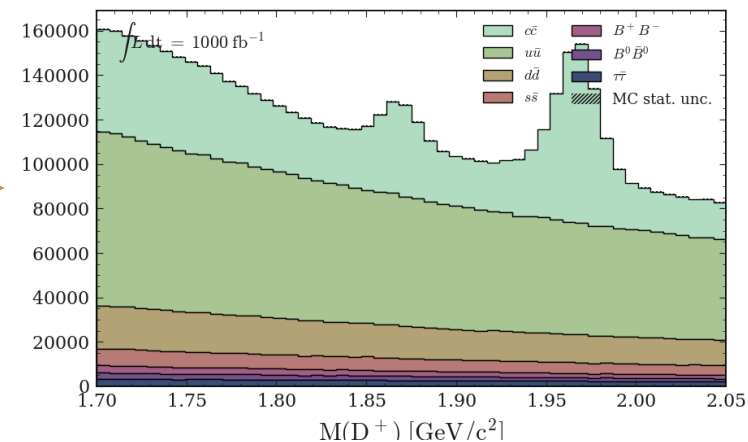


D\*+ not tagged



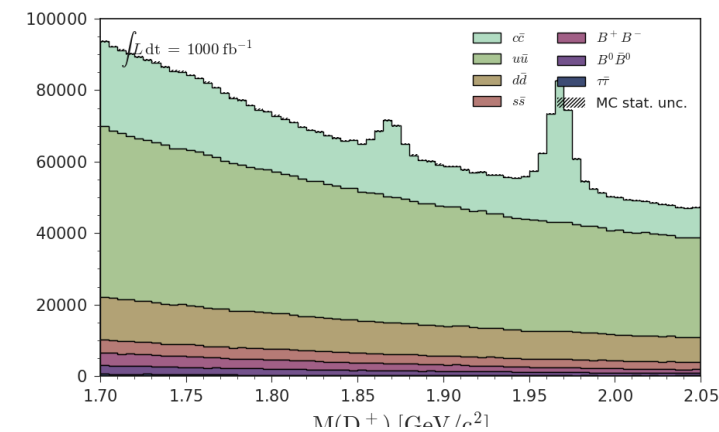
$\eta_{\gamma\gamma}$

$|\Delta\phi(\gamma_1, \gamma_2)| < 2$   
 $\angle(\gamma_1, \gamma_2) < 1.7$   
ε decreased  
by 6%



# $D^+ \rightarrow \eta \pi^+ \pi^- \pi^0 \pi^+$ (step1)

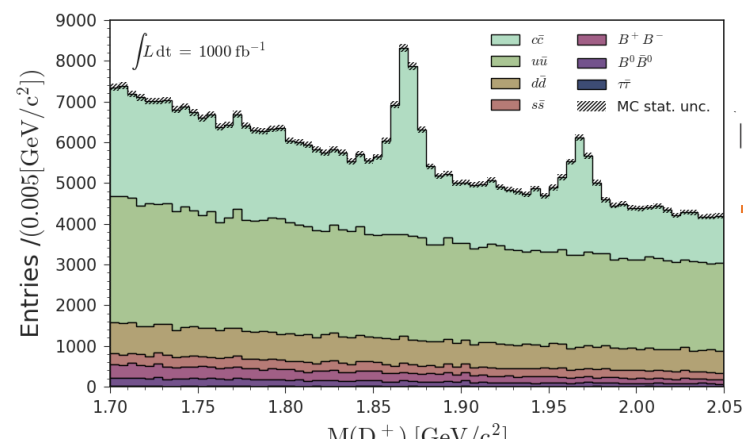
From pre-selection (step0)



$D^{*+}$  tag



$D^{*+}$  not tagged

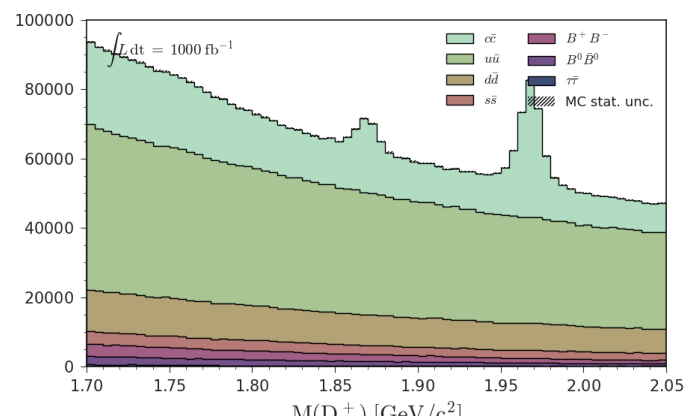


$\pi^0$

$$|\Delta\phi(\gamma_1, \gamma_2)| < 1.5$$

$$\langle \gamma_1, \gamma_2 \rangle < 1.4$$

$\epsilon$  decreased  
by 5%

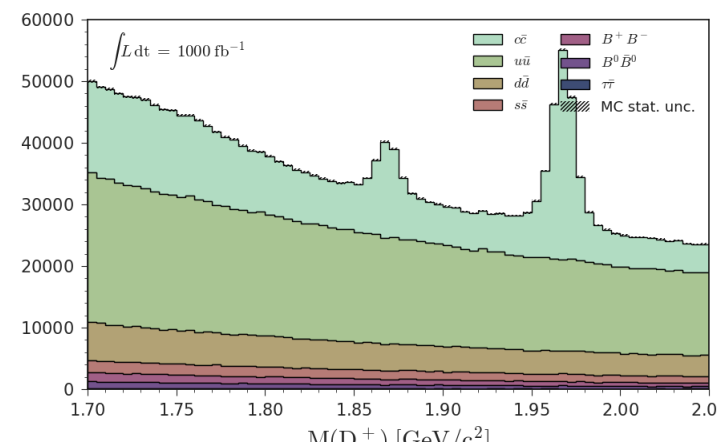
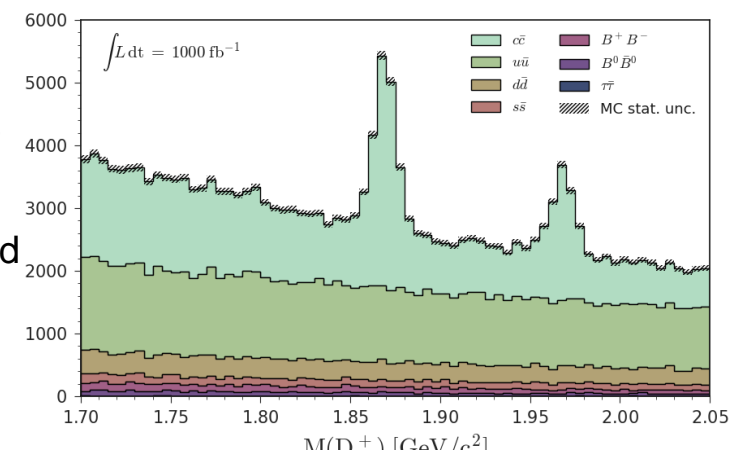


$\pi^0$

$$|\Delta\phi(\gamma_1, \gamma_2)| < 1.5$$

$$\langle \gamma_1, \gamma_2 \rangle < 1.4$$

$\epsilon$  decreased  
by 5%



# Cut optimization(step2, tagged)

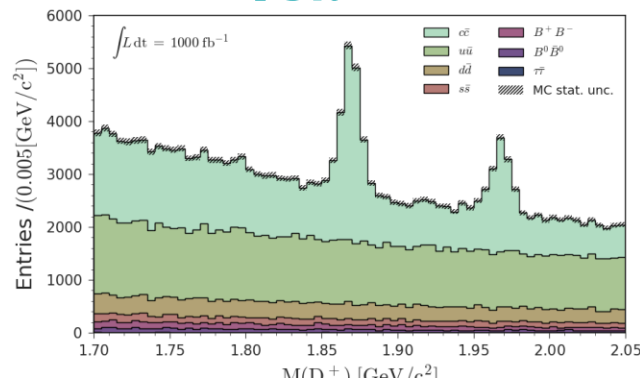
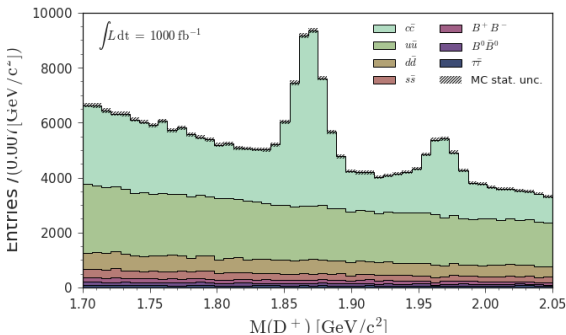
- $\cos \theta_{xy}$   
Cosine of angle between p and vertex vector  
(vector connecting IP and fitted vertex)

$$D^+ \rightarrow \eta_{\gamma\gamma} \pi^+$$

$$D^+ \rightarrow \eta_{3\pi} \pi^+$$

- $\epsilon$  decreased by 31%

- $\epsilon$  decreased by 34%

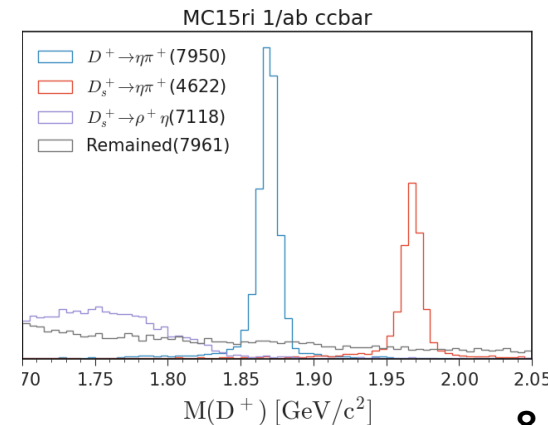
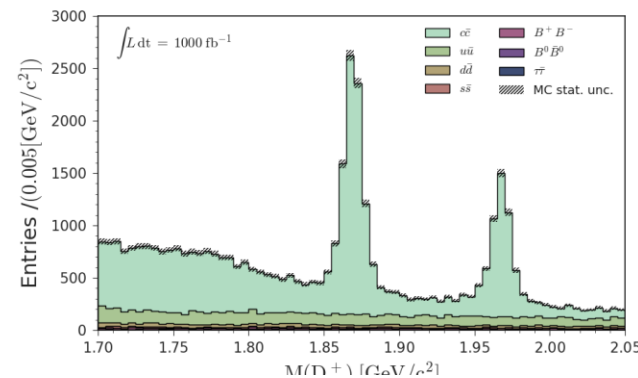
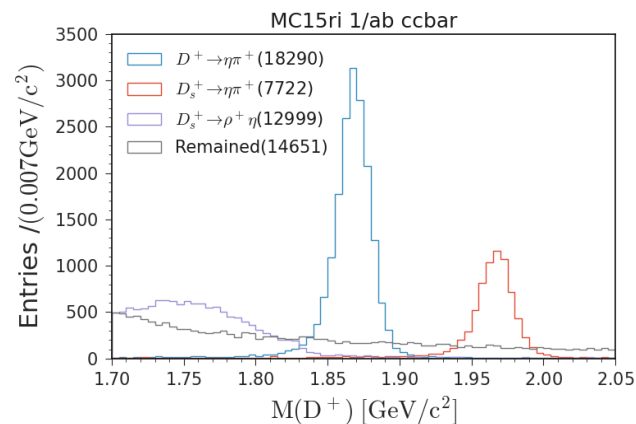
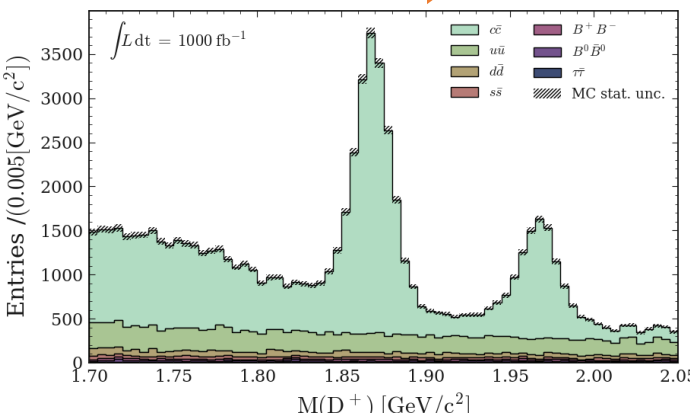


□ Optimized cuts in  $1.78 < M(D^+) < 1.95$

- $\cos \theta_{xy} > 0.99964 (\theta_{xy} < 1.5^\circ)$
- $p(\eta) > 1.14 \text{ GeV}$
- $p(\pi^+) > 0.48 \text{ GeV}$

□ Optimized cuts in  $1.80 < M(D^+) < 1.94$

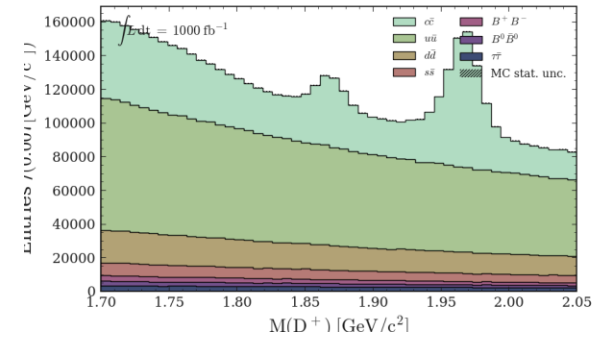
- $\cos \theta_{xy} > 0.9995 (\theta_{xy} < 1.8^\circ)$
- $p(\eta) > 0.98 \text{ GeV}$
- $p(\pi^+) > 0.49 \text{ GeV}$





# Cut optimization(step2, non-tagged)

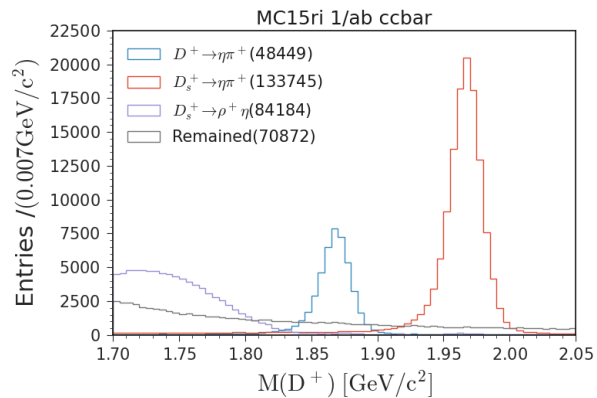
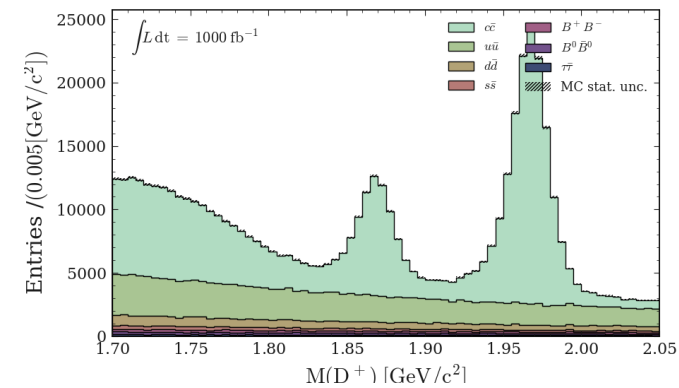
$$D^+ \rightarrow \eta_{\gamma\gamma} \pi^+$$



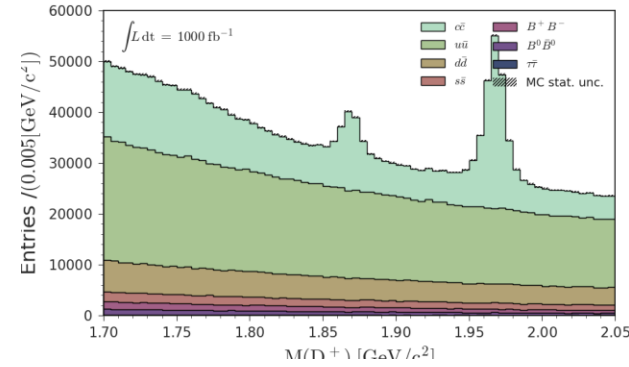
- $\epsilon$  decreased by 45%

Optimized cuts in  $1.78 < M(D^+) < 1.95$

- $\cos \theta_{xy} > 0.99930 (\theta_{xy} < 2.14^\circ)$
- $p(\eta) > 1.24 \text{ GeV}$
- $p(\pi^+) > 0.63 \text{ GeV}$



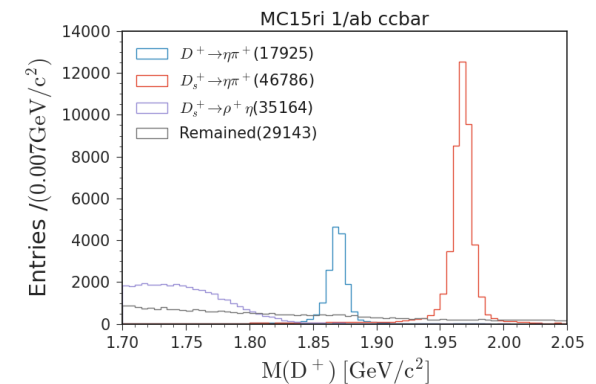
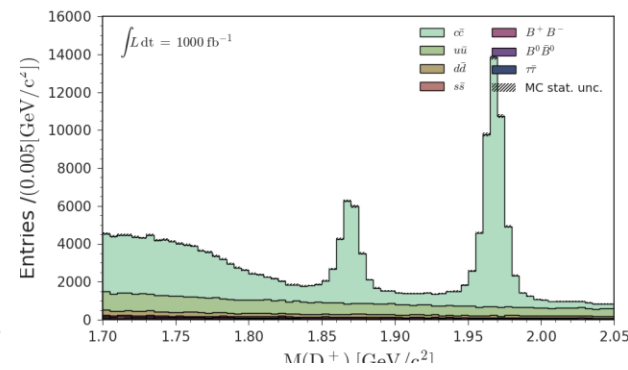
$$D^+ \rightarrow \eta_{3\pi} \pi^+$$



- $\epsilon$  decreased by 43%

Optimized cuts in  $1.80 < M(D^+) < 1.94$

- $\cos \theta_{xy} > 0.99967 (\theta_{xy} < 1.47^\circ)$
- $p(\eta) > 1.11 \text{ GeV}$
- $p(\pi^+) > 0.61 \text{ GeV}$



# Estimation of signal yields

- Fitting is not done yet. Will do fit using simultaneous fit( $D^+ + D^-$ )
- Let's estimate signal yields by counting

Belle II: Nsig events(Topoana, <b>counting</b> )	$D^+ \rightarrow \eta_{\gamma\gamma}\pi^+$	$D^+ \rightarrow \eta_{3\pi}\pi^+$
Tagged, 1/ab	$18290 \pm 135.2$	$7950 \pm 89.2$
Non-tagged, 1/ab	$48449 \pm 220.1$	$17925 \pm 133.9$
Expected Nsig events in Run1(426/fb)	$28430 \pm 168.6$	$11023 \pm 105.0$

Previous results(fitted error)	$D^+ \rightarrow \eta_{e^+e^-\gamma}\pi^+$	$D^+ \rightarrow \eta_{\pi^+\pi^-\gamma}\pi^+$	$D^+ \rightarrow \eta_{3\pi}\pi^+$
LHCb(2021), 6/fb ( <a href="#">ref.</a> )	$32760 \pm 380$		
LHCb(2023), 6/fb ( <a href="#">ref.</a> )		$(110.8 \pm 0.7) \cdot 10^3$	
Belle(2011), 791/fb ( <a href="#">ref.</a> )			$6476 \pm 110$

# Estimation of signal yields

- Still there would be room to improve yields. Trying to improve with MVA.

## Belle II MC: pre-selection

Nsig true signal events after pre-selection (MC matched, counting)	$D^+ \rightarrow \eta_{\gamma\gamma}\pi^+$	$D^+ \rightarrow \eta_{3\pi}\pi^+$
Tagged, 1/ab	$22922 \pm 151$	$9681 \pm 98$
Non-tagged, 1/ab	$93102 \pm 305$	$31525 \pm 178$
Total: expected Nsig in Run1(426/fb)	$116024 \pm 341$	$41206 \pm 203$

Non tagged: signal efficiency  
decreased significantly  
cut based study

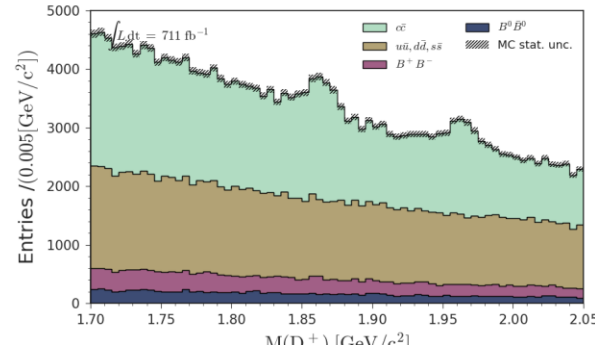
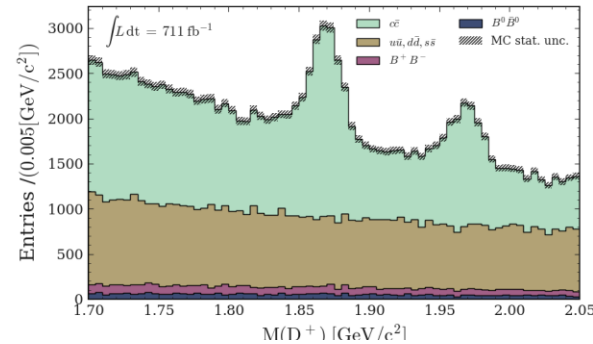
Belle + Belle II?

# Estimation of signal yields

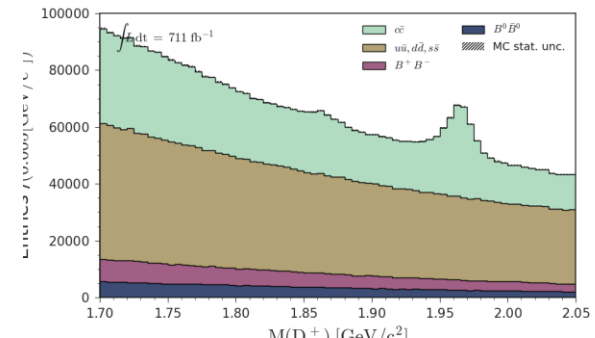
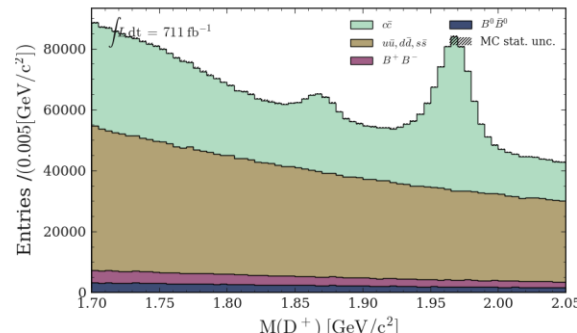
Belle MC: pre-selection (detail will be in later report)

Belle: Nsig true events after pre-selection (MC matched, counting)	$D^+ \rightarrow \eta_{\gamma\gamma}\pi^+$	$D^+ \rightarrow \eta_{3\pi}\pi^+$
Tagged in $\Upsilon(4S)$ MC(711/fb)	7815 $\pm$ 88	3668 $\pm$ 61
Non-tagged in $\Upsilon(4S)$ MC(711/fb)	43214 $\pm$ 208	17692 $\pm$ 133
Total in $\Upsilon(4S)$ MC(711/fb)	51029 $\pm$ 226	21360 $\pm$ 146
Expected Nsig true events in full data (943/fb)	67680 $\pm$ 260	28330 $\pm$ 168

• Tag

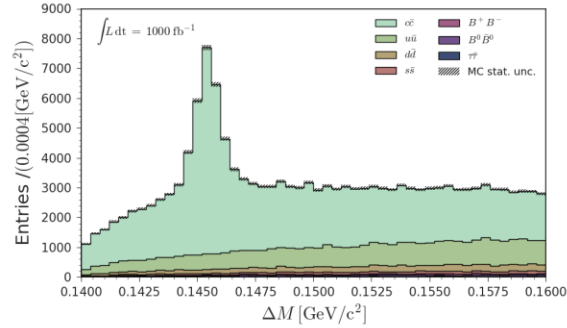
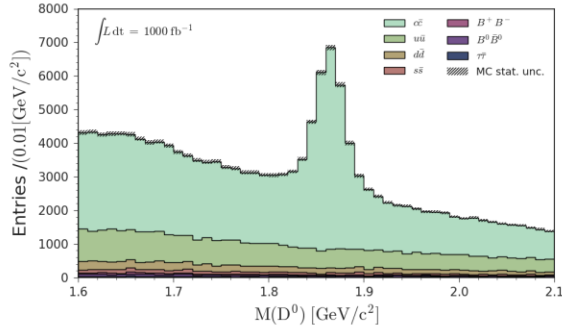


• Non-tagged

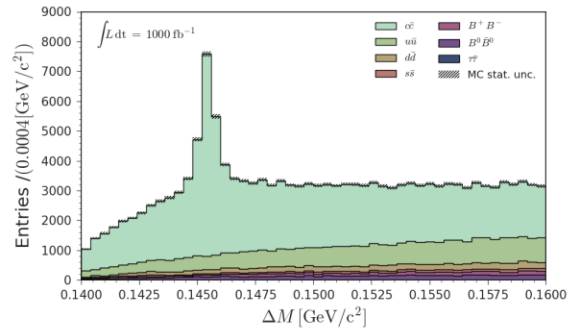
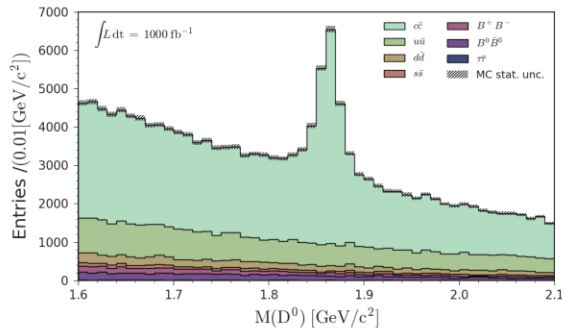


# $D^0 \rightarrow \eta\eta$ distribution after pre-selection

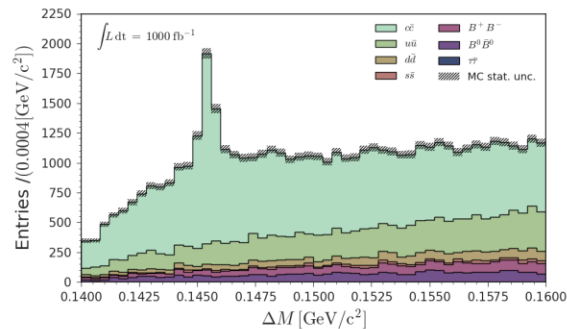
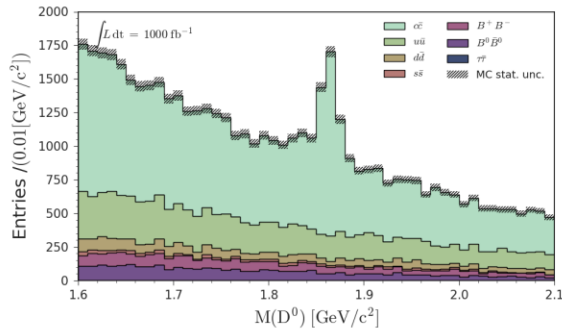
$D^0 \rightarrow \eta_{\gamma\gamma}\eta_{\gamma\gamma}$



$D^0 \rightarrow \eta_{\gamma\gamma}\eta_{3\pi}$



$D^0 \rightarrow \eta_{3\pi}\eta_{3\pi}$



Particles	Selection Criteria
Hard $\pi^\pm$	In CDC acceptance $dr < 1,  dz  < 3$ $\mathcal{L}_\pi > 0.6$
Normal $\pi^\pm$ in $\eta_{3\pi}$	In CDC acceptance $dr < 1,  dz  < 3$ $\mathcal{L}_\pi > 0.1$
Slow $\pi^+$	In CDC acceptance $dr < 1,  dz  < 3$
$\gamma$ of $\eta$	clusterNHits > 1.5 $0.2967 < \text{clusterTheta} < 2.6180$ $E > 0.1[\text{GeV}]$
$\gamma$ of $\pi^0$	clusterNHits > 1.5 $0.2967 < \text{clusterTheta} < 2.6180$ $E_{\text{forward}} > 0.05[\text{GeV}]$ or $E_{\text{barrel}} > 0.05[\text{GeV}]$ or $E_{\text{backward}} > 0.075[\text{GeV}]$
$\pi^0$	$0.120 < M[\text{GeV}] < 0.145$ kFit(mass): reject if fit fails
$\eta_{\gamma\gamma}$	$0.52 < M[\text{GeV}] < 0.57$
$\eta_{3\pi}$	$0.535 < M[\text{GeV}] < 0.57$

# Summary and plans

## $D^+ \rightarrow \eta\pi^+$

- ❑ Belle II: using MC15ri samples
  - Estimate signal yields by cut-based analysis
- ❑ Belle: using b2bii, 4S MC samples
  - Estimate naive signal yields(by pre-selection)
- ❑ Plans
  - MVA study
  - Extract expected stats. uncertainty

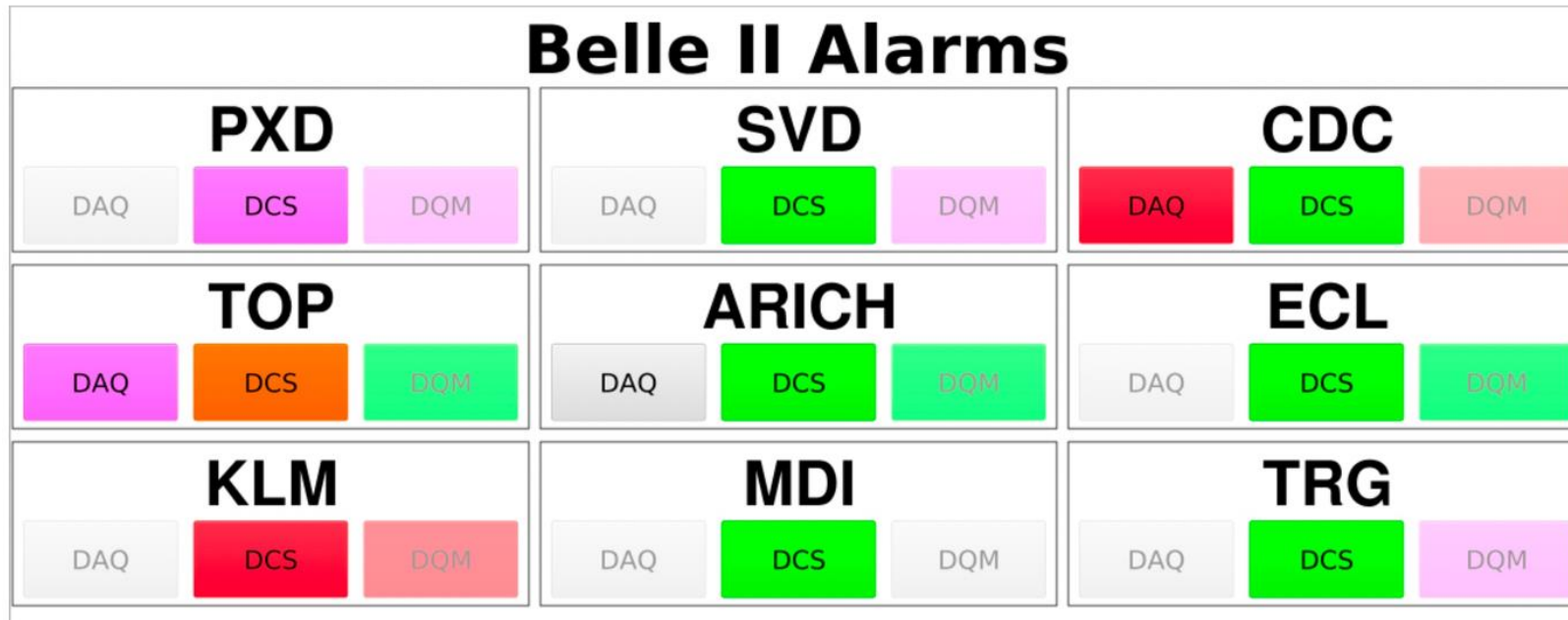
## $D^0 \rightarrow \eta\eta$

- ❑ Have seen peak of signals at Belle II MC in  $\eta_{\gamma\gamma}\eta_{3\pi}$  &  $\eta_{\gamma\gamma}\eta_{3\pi}$  &  $\eta_{3\pi}\eta_{3\pi}$
- ❑ Plans
  - Focus on  $D^+ \rightarrow \eta\pi^+$  first
  - No detailed plans yet

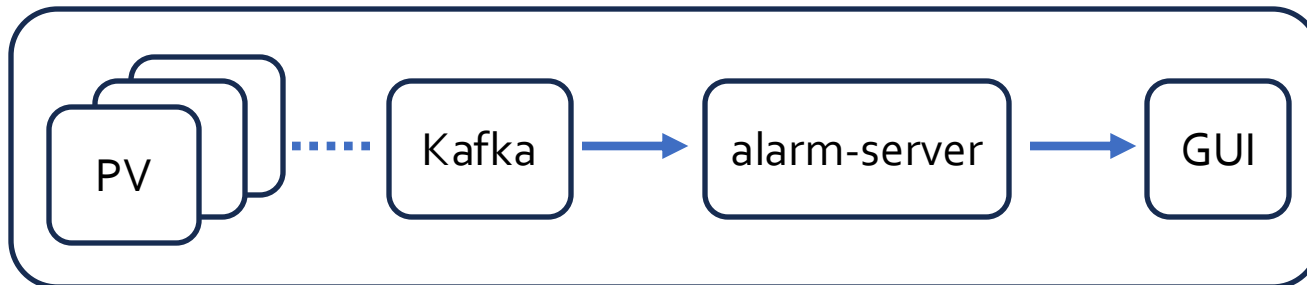
# Service tasks I

## DAQ alarm system

- First central alarm system among sub-detectors



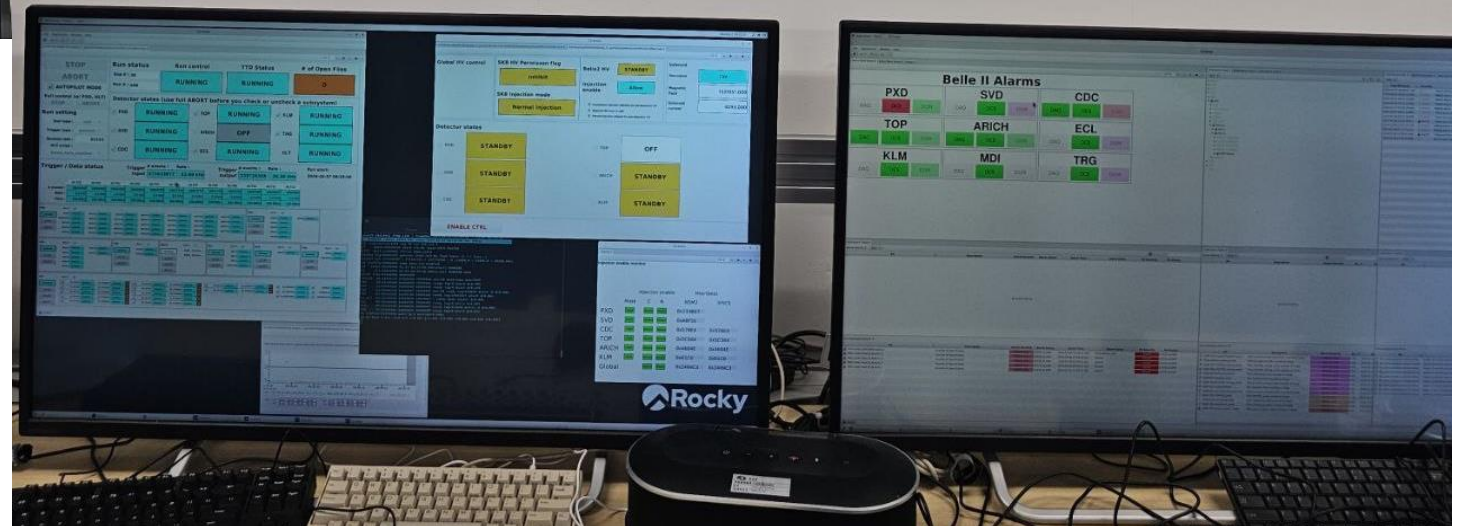
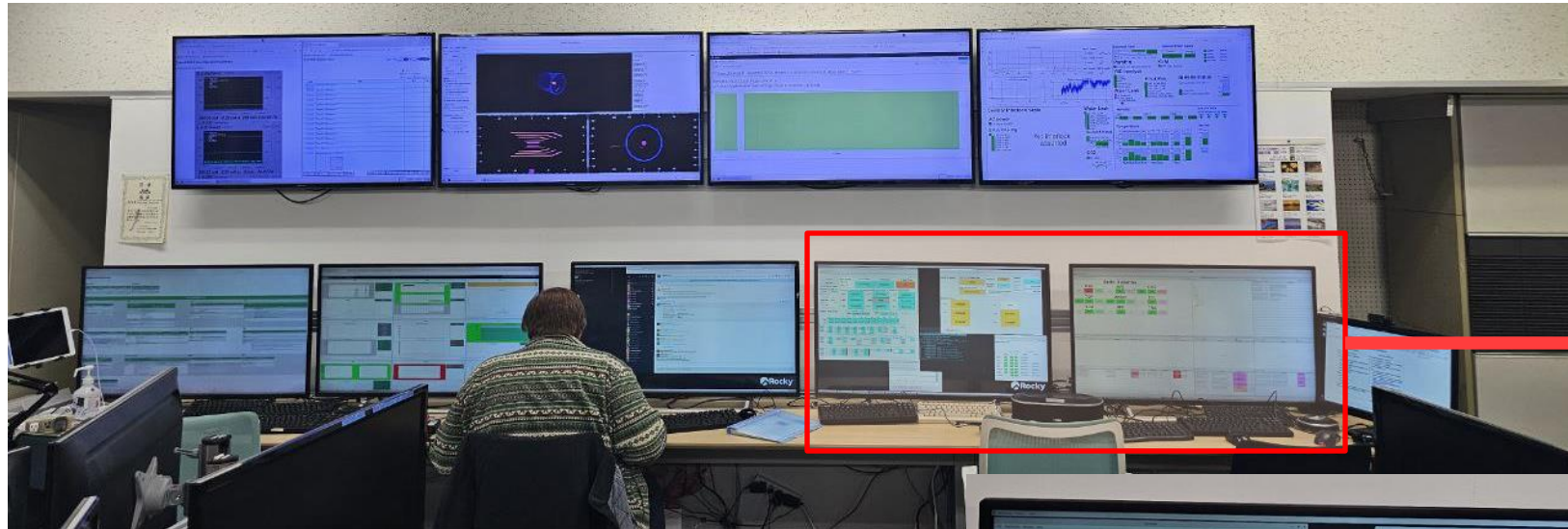
DAQ network



# Service tasks I

## DAQ alarm system

- Control room





# Service tasks II

## Charm Physics Group Data Production & Skim liaison

- Each physics group have a liaison
- Main roles: data production and skim
  - Validate and transfer requests of signal MC samples  
(Charm mesons, baryons decays)
  - Manage skims according to analysts' requests

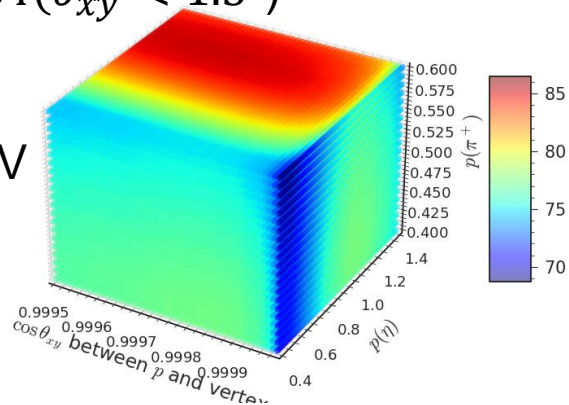
**Backup**

# Cut optimization(tag)

$$D^+ \rightarrow \eta_{\gamma\gamma} \pi^+$$

Optimized cuts

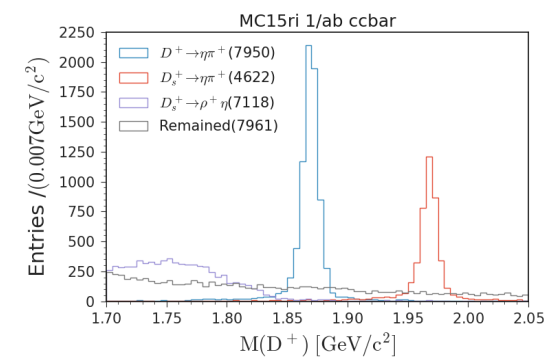
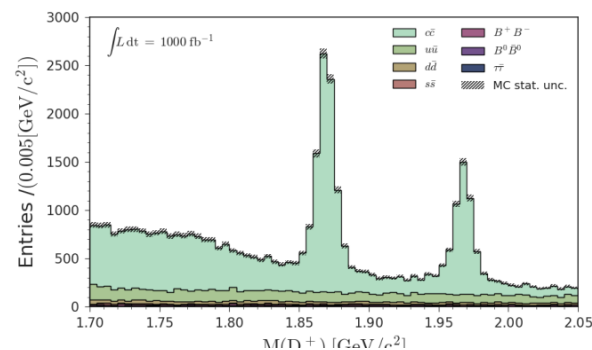
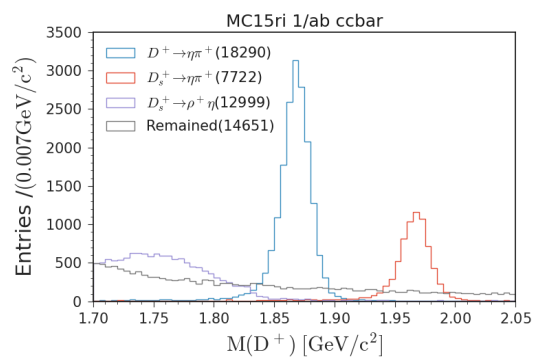
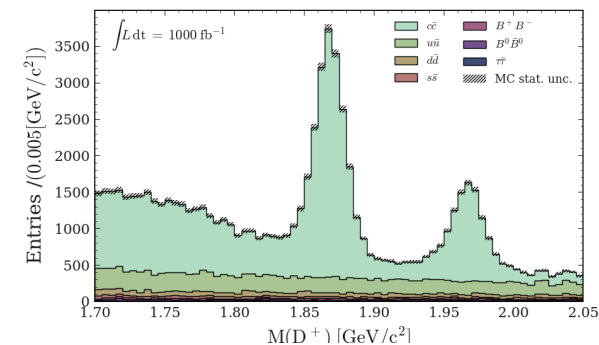
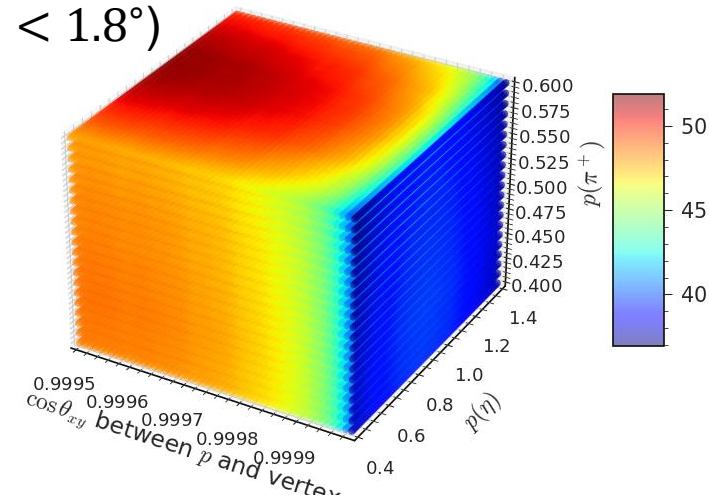
- $\cos \theta_{xy} > 0.99964 (\theta_{xy} < 1.5^\circ)$
- $p(\eta) > 1.14 \text{ GeV}$
- $p(\pi^+) > 0.48 \text{ GeV}$



$$D^+ \rightarrow \eta_{3\pi} \pi^+$$

Optimized cuts

- $\cos \theta_{xy} > 0.9995 (\theta_{xy} < 1.8^\circ)$
- $p(\eta) > 0.98 \text{ GeV}$
- $p(\pi^+) > 0.49 \text{ GeV}$

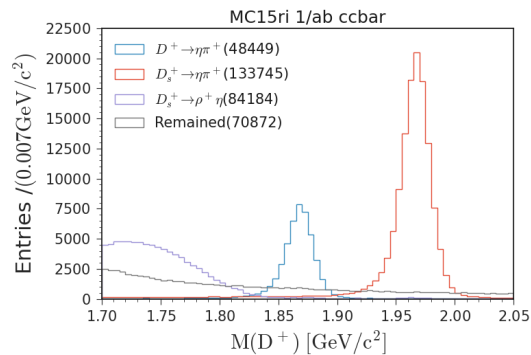
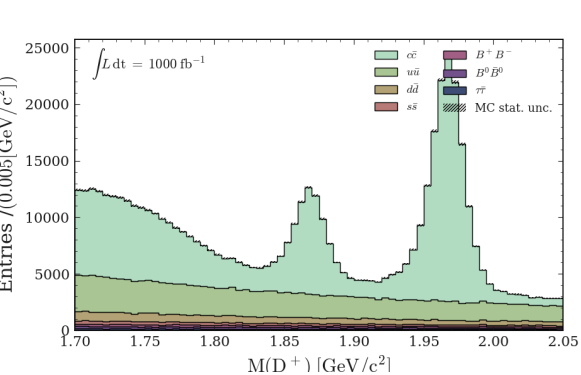
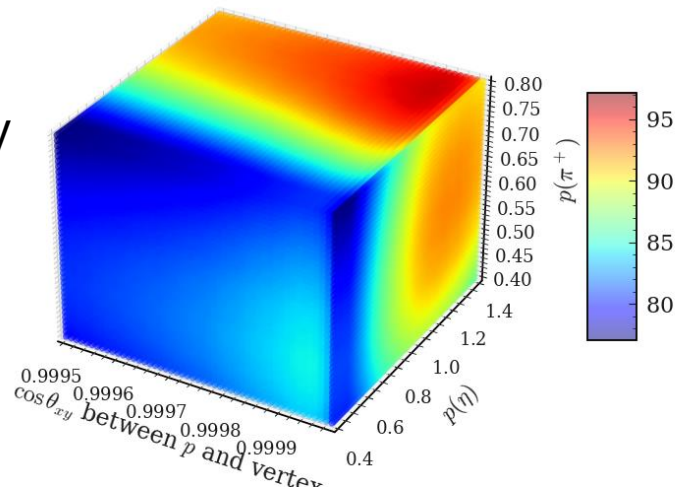


# Cut optimization(non-tag)

$$D^+ \rightarrow \eta_{\gamma\gamma}\pi^+$$

Optimized cuts

- $\cos \theta_{xy} > 0.99930 (\theta_{xy} < 2.14^\circ)$
- $p(\eta) > 1.24\text{GeV}$
- $p(\pi^+) > 0.63\text{GeV}$



$$D^+ \rightarrow \eta_{3\pi}\pi^+$$

Optimized cuts

- $\cos \theta_{xy} > 0.99967 (\theta_{xy} < 1.47^\circ)$
- $p(\eta) > 1.11\text{GeV}$
- $p(\pi^+) > 0.61\text{GeV}$

