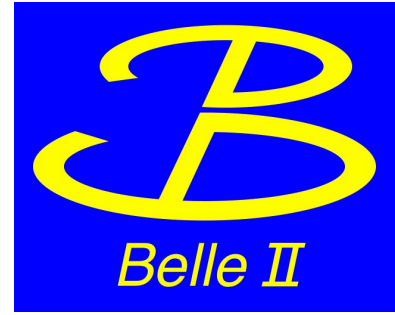# $D^{\pm} \rightarrow K^0_S \omega \pi^{\pm}$ with Belle II

DESY 2022 Summer Student project
Matilde Carminati, University of Pisa
Supervisor: Daniel Pitzl

Super KEKB:

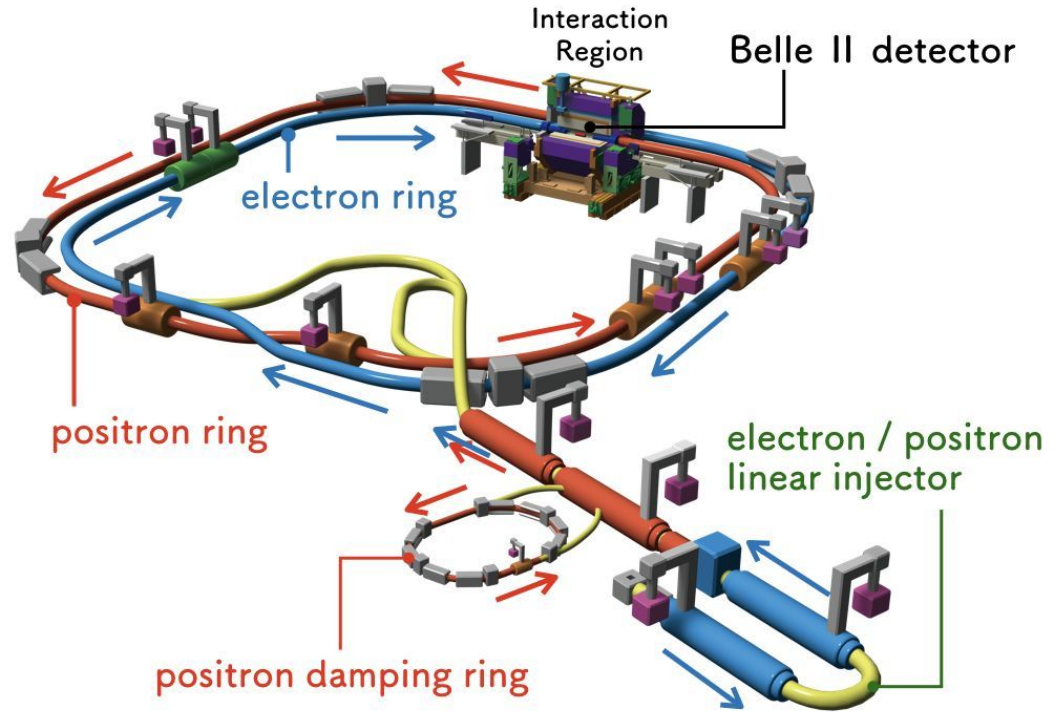asymmetric e⁺e⁻ collider

in Japan

operating since 2019

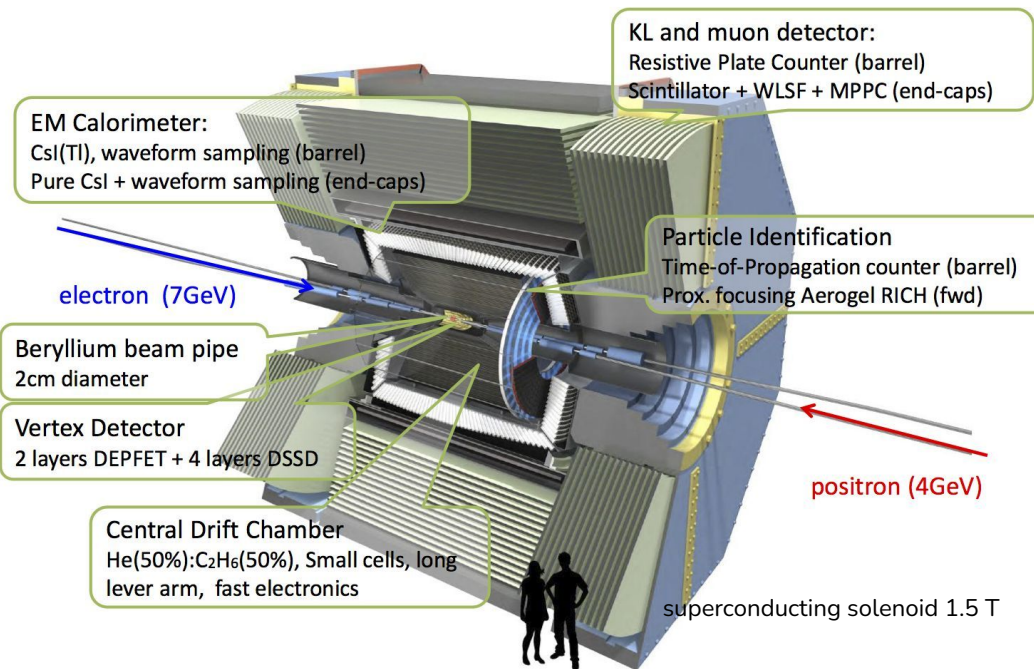with 4+7 GeV at the

Y(4S) resonance,

producing pairs of B

mesons as well as charm

and tau particles
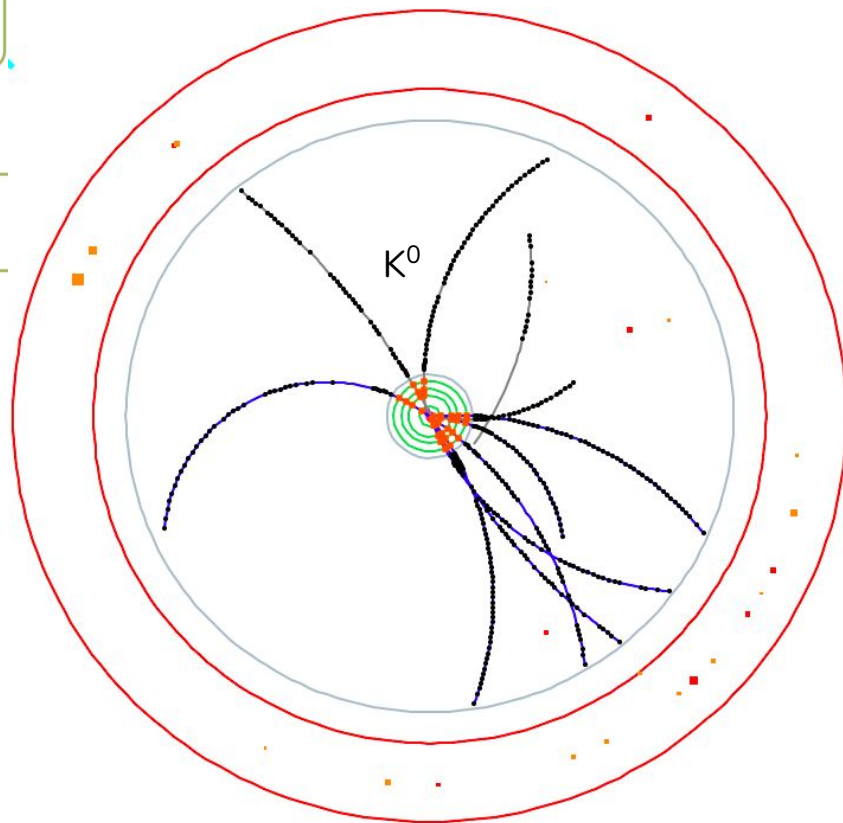

Integrated luminosity: 204 fb⁻¹
(2020-2021)

Belle II Detector

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

KL and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)

electron (7GeV)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

positron (4GeV)

Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long
lever arm, fast electronics

superconducting solenoid 1.5 T

K^0 candidate

K^0

2022 PDG table **for D⁺**

K⁰_Sπ⁺ω is missing

K⁰_Sω is also an important channel in charmless B decays with evidence for CP violation seen by Belle

$K^0_S \pi^+ \eta$		$(1.31 \pm 0.05) \%$
$K^0_S \pi^+ \eta'(958)$		$(1.90 \pm 0.21) \times 10^{-3}$
$K^- 2\pi^+ \pi^0$	$[ll]$	$(6.25 \pm 0.18) \%$
$K^0_S 2\pi^+ \pi^-$	$[ll]$	$(3.10 \pm 0.09) \%$
$K^- 2\pi^+ \eta$		$(1.35 \pm 0.12) \times 10^{-3}$
$K^0_S \pi^+ \pi^0 \eta$		$(1.22 \pm 0.25) \times 10^{-3}$
$K^- 3\pi^+ \pi^-$	$[jj]$	$(5.7 \pm 0.5) \times 10^{-3}$
$\overline{K}^*(892)^0 2\pi^+ \pi^-,$ $\overline{K}^*(892)^0 \to K^- \pi^+$		$(1.2 \pm 0.4) \times 10^{-3}$
$\overline{K}^*(892)^0 \rho^0 \pi^+,$ $\overline{K}^*(892)^0 \to K^- \pi^+$		$(2.3 \pm 0.4) \times 10^{-3}$
$\overline{K}^*(892)^0 a_1(1260)^+$	$[nn]$	$(9.3 \pm 1.9) \times 10^{-3}$
$K^- \rho^0 2\pi^+$		$(1.72 \pm 0.28) \times 10^{-3}$
$K^- 3\pi^+ \pi^-$ nonresonant		$(4.0 \pm 2.9) \times 10^{-4}$
$K^+ 2K^0_S$		$(2.54 \pm 0.13) \times 10^{-3}$
$K^+ K^- K^0_S \pi^+$		$(2.4 \pm 0.5) \times 10^{-4}$

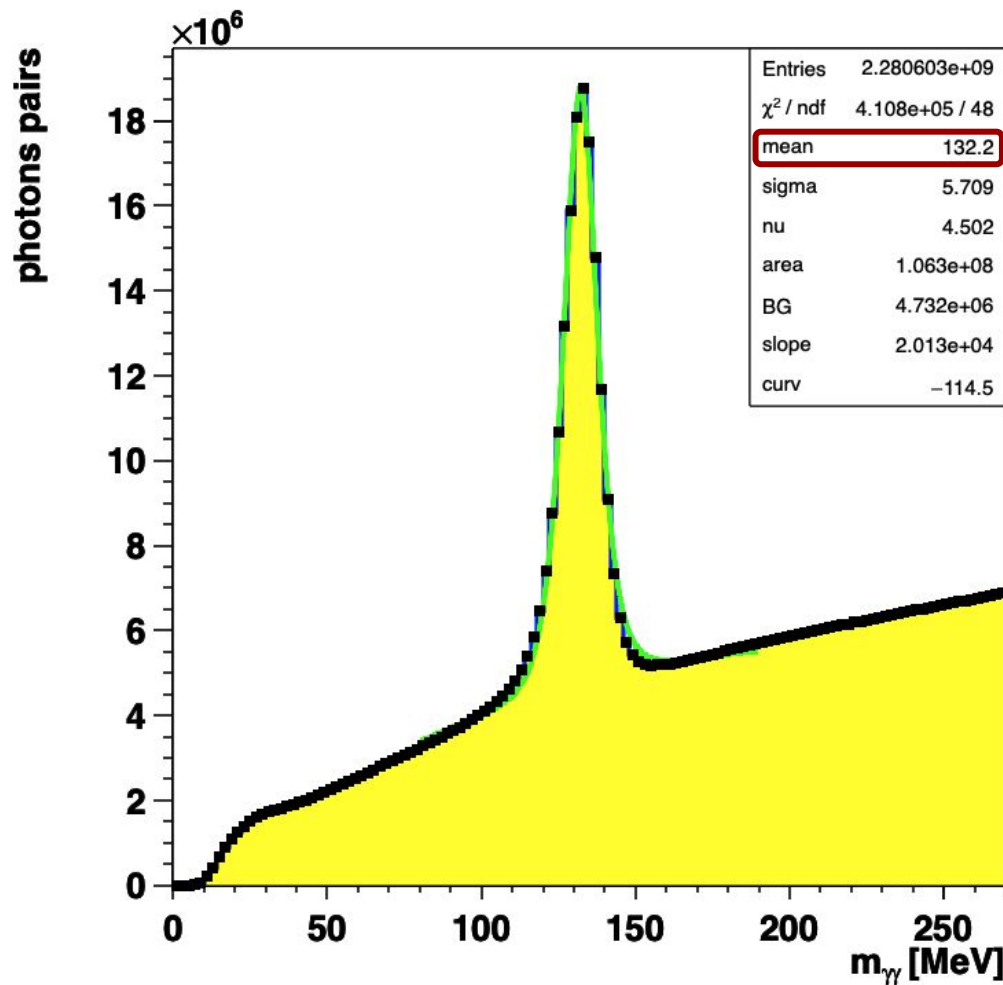# K$^0_S \to \pi^+\pi^-$ selection

❖ 2 oppositely charged pion tracks

❖ displaced from the beam

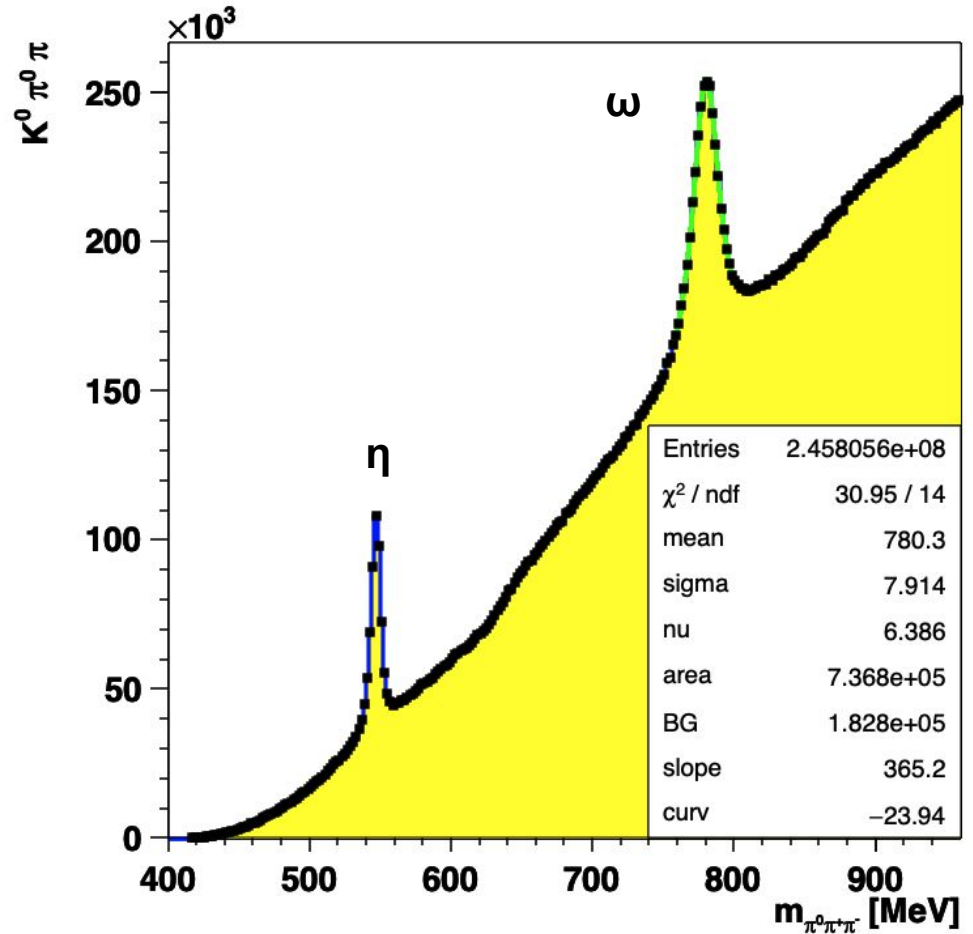❖ intersecting in the xy plane

❖ match in z at the intersection point

Entries	2.17755e+08
χ^2 / ndf	4.519e+04 / 73
mean	498
sigma	1.881
nu	1.674
area	1.194e+08
BG	3.261e+05
slope	−884.2
curv	−367.8
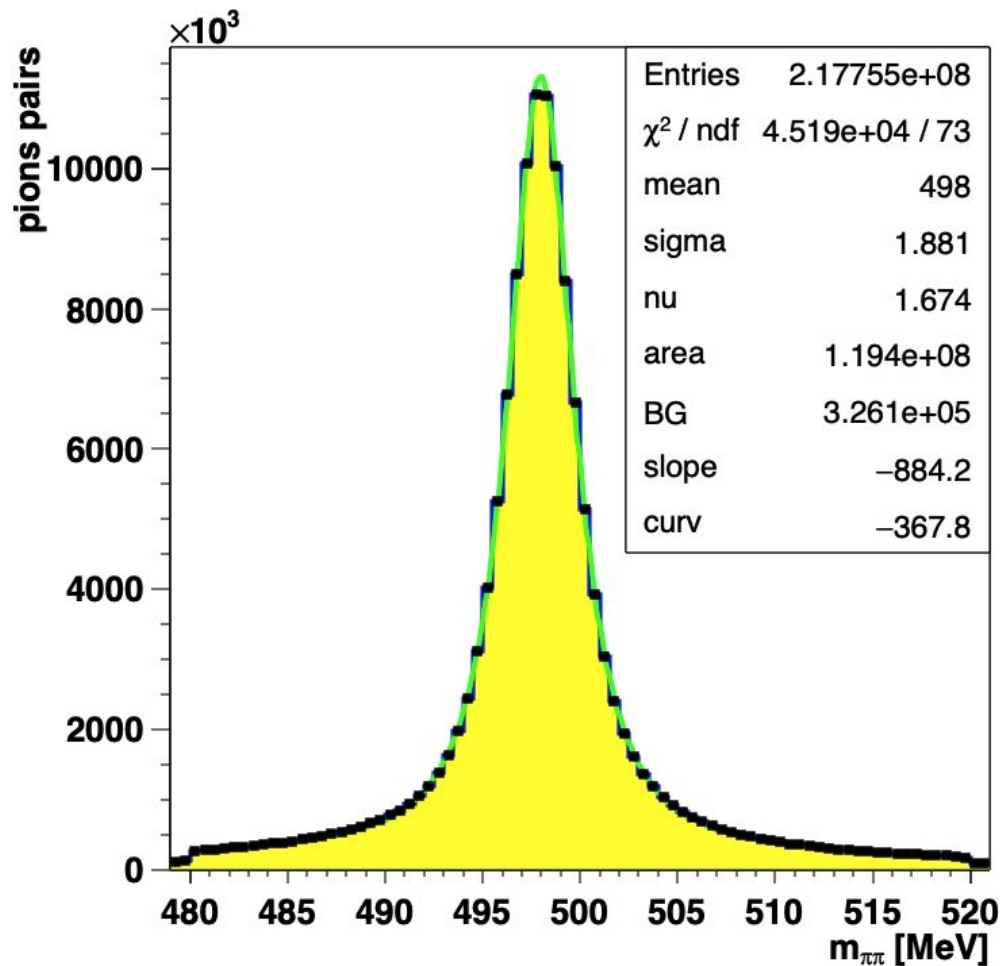
π⁰→γγ selection

❖ 2 ECL clusters without tracks pointing to them

❖ cluster shape consistent with electromagnetic shower

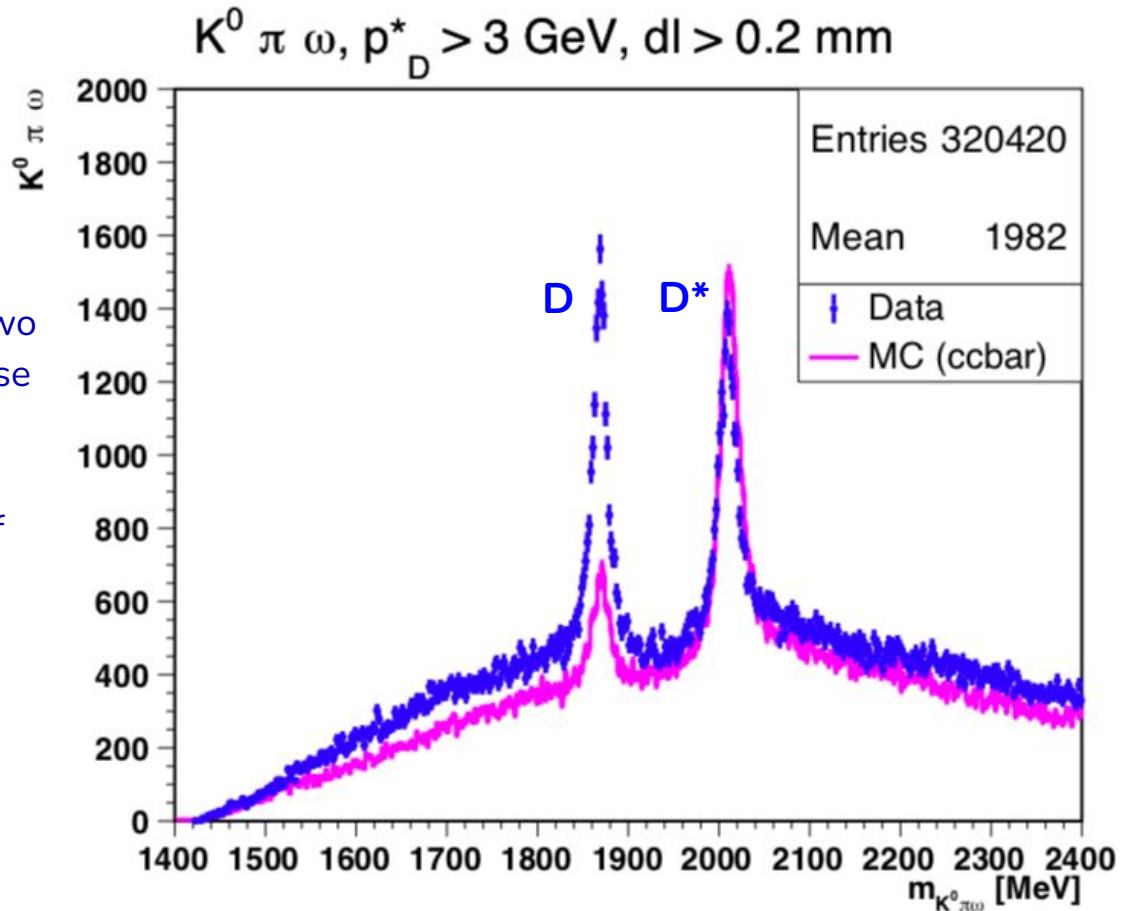❖ the mass is slightly below PDG (135 MeV) but has a better resolution (5.7 MeV)

Entries	2.280603e+09
χ² / ndf	4.108e+05 / 48
mean	132.2
sigma	5.709
nu	4.502
area	1.063e+08
BG	4.732e+06
slope	2.013e+04
curv	−114.5

ω → π⁺π⁻π⁰ selection

❖ π^0 and 2 oppositely charged pion tracks

❖ ω mass peak at 780 MeV (η at 548 MeV)

D→K⁰ωπ

❖ K⁰, ω and one pion track

❖ vertex fit for 3 charged pions (two from ω) and cut on the transverse decay length from the beam

❖ p* is momentum in the center of momentum frame

❖ D⁺ signal at 1870 MeV in data (much smaller signal in simulation)

❖ (also observe D* → D⁰π with D⁰ → K⁰ω at 2010 MeV)

$K^0 \pi \omega$, p^*_D > 3 GeV, dl > 0.2 mm

Entries 320420
Mean 1982

Data
MC (ccbar)

D   D*

Measurement of a branching fraction

Production rate: $N = \sigma_{D^+} \, L \, A \, \varepsilon \, B$

for signal and reference channel(s)

σ = production cross section
L = luminosity
A = detector and selection acceptance (cuts)
ε = detection efficiency
B = branching fraction

assuming good generator and good detector simulation:
$(\sigma_{D^+} \, A \, \varepsilon \, B)^{ref}_{data} = (\sigma_{D^+} \, A \, \varepsilon \, B)^{ref}_{sim}$

$$\Rightarrow \frac{N^{ref}_{data}}{N^{ref}_{sim}} = \frac{L_{data}}{L_{sim}}$$

the same for the signal channel, but now we assume:
$(\sigma_{D^+} \, A \, \varepsilon)^{sig}_{data} = (\sigma_{D^+} \, A \, \varepsilon)^{sig}_{sim}$

$$\Rightarrow \frac{N^{sig}_{data}}{N^{sig}_{sim}} = \frac{L_{data}}{L_{sim}} \frac{B^{sig}_{data}}{B^{sig}_{sim}}$$

Belle II event generator:
$B^{sig}_{sim}(D \to K^0_S \pi \omega) = 0.19255\%$

$$\frac{B^{sig}_{data}}{B^{sig}_{sim}} = \frac{N^{sig}_{data}}{N^{sig}_{sim}} \Big/ \frac{N^{ref}_{data}}{N^{ref}_{sim}}$$

Reference channels

$$\Delta m = m_{K^0 \pi^0 \pi} - m_{K^0 \pi^0}$$

D* → K⁰ωπ

Entries	37900
χ^2 / ndf	337.4 / 243
mean	145.5
sigma	0.4059
nu	1.796
area	2.595e+04
BG	33.29
slope	2.825
curv	−0.1202

D* → K⁰π⁰π

Entries	144879
χ^2 / ndf	596.6 / 243
mean	145.5
sigma	0.4491
nu	2.063
area	8.71e+04
BG	164.4
slope	12.67
curv	−0.527
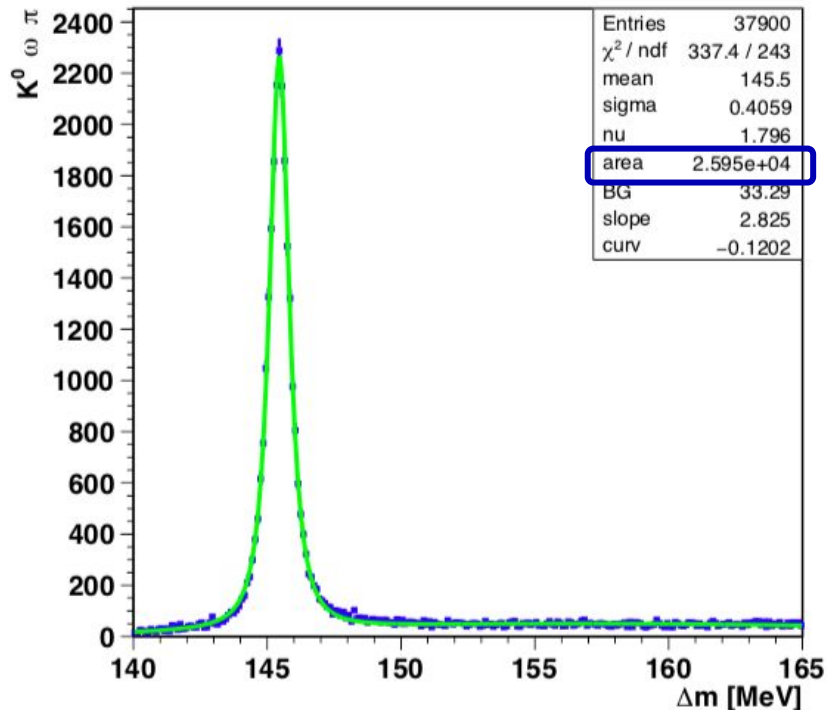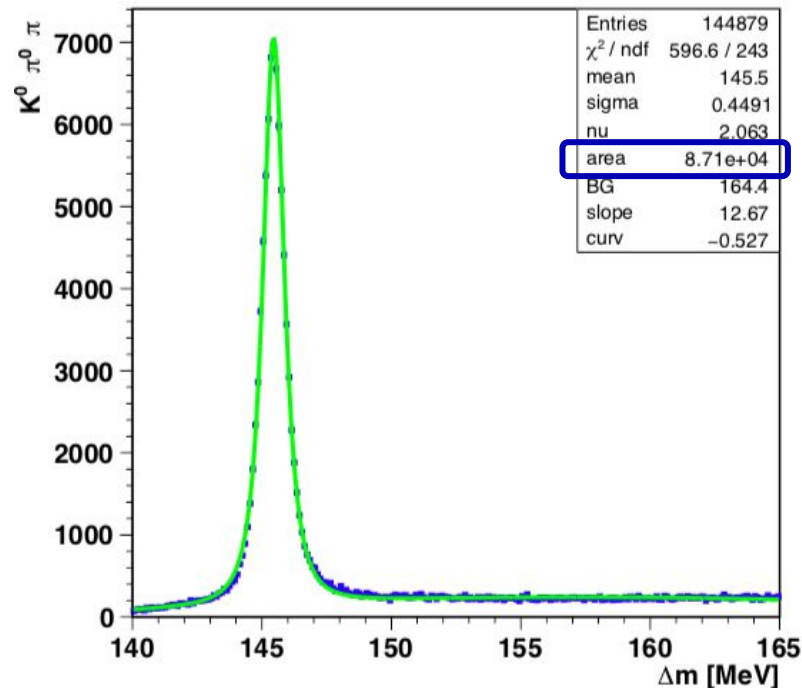
Direct charm reference channels

$D \rightarrow K^0 \pi^0 \pi$

Entries	4875878
χ^2 / ndf	3406 / 114
mean	1864
sigma	12.73
nu	3.082
area	2.271e+05
BG	4514
slope	−5.704

$D^0 \rightarrow K^0 \pi^0$

Entries	1.459354e+07
χ^2 / ndf	1872 / 233
mean	1855
sigma	18.13
nu	6.279
area	2.452e+05
BG	6420
slope	−13.52
curv	0.01464

$D^0 \rightarrow K^0 \omega$

Entries	2583975
χ^2 / ndf	527.3 / 193
mean	1863
sigma	8.855
nu	2.957
area	1.179e+05
BG	3231
slope	−7.112
curv	0.003924
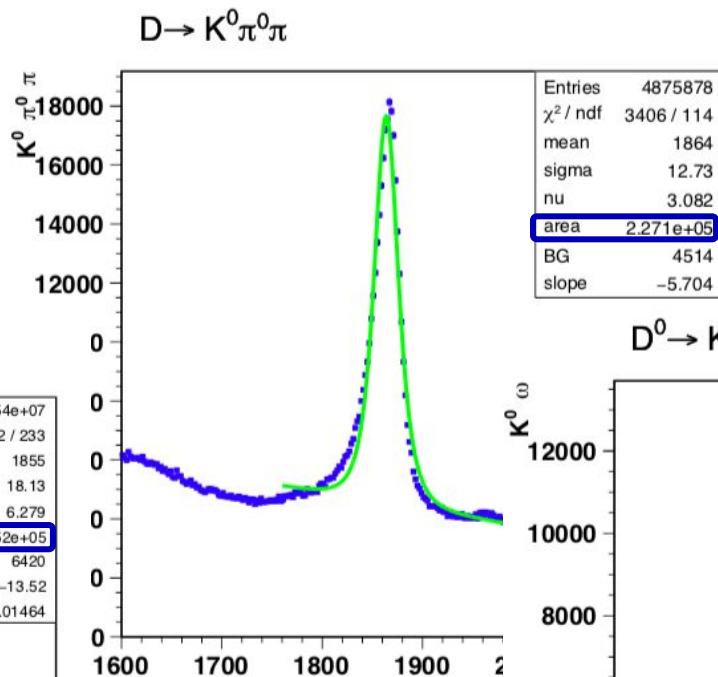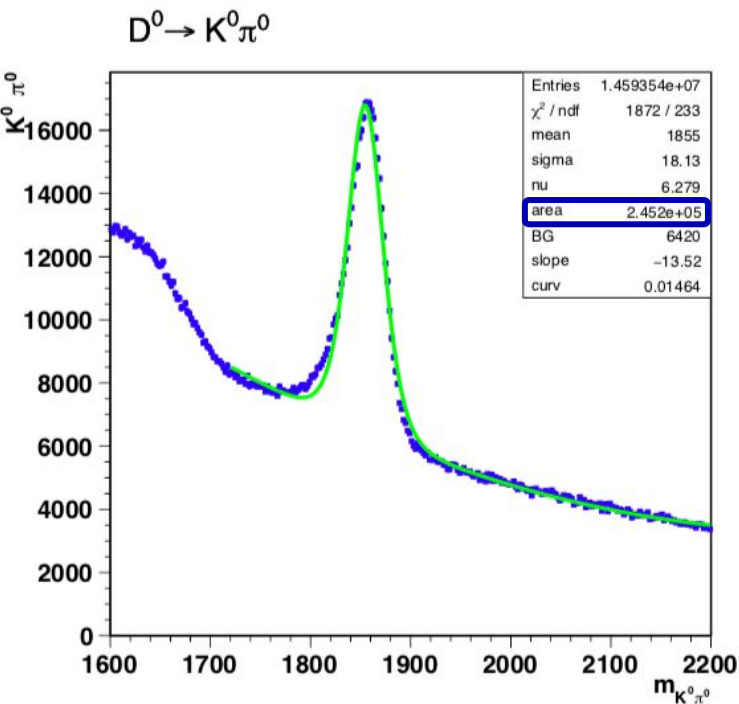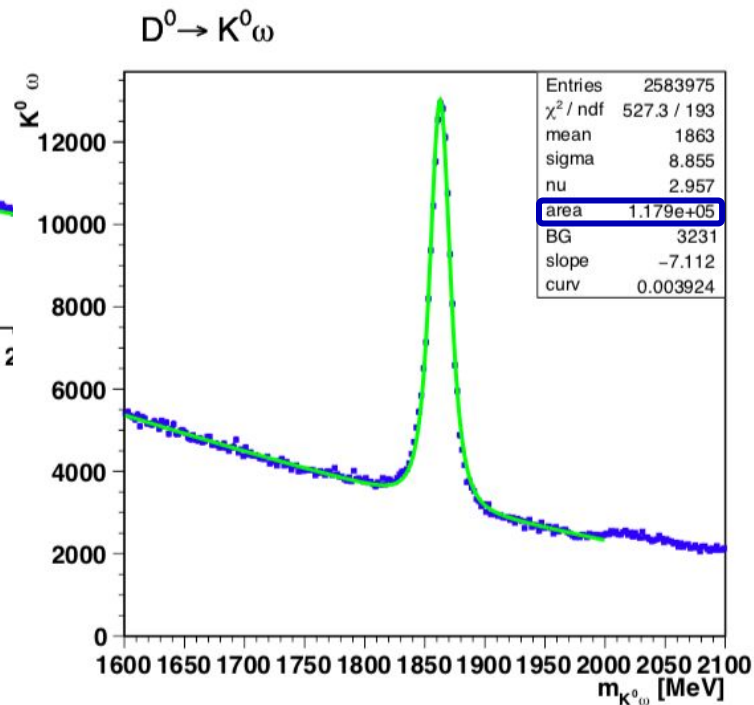
Background reduction
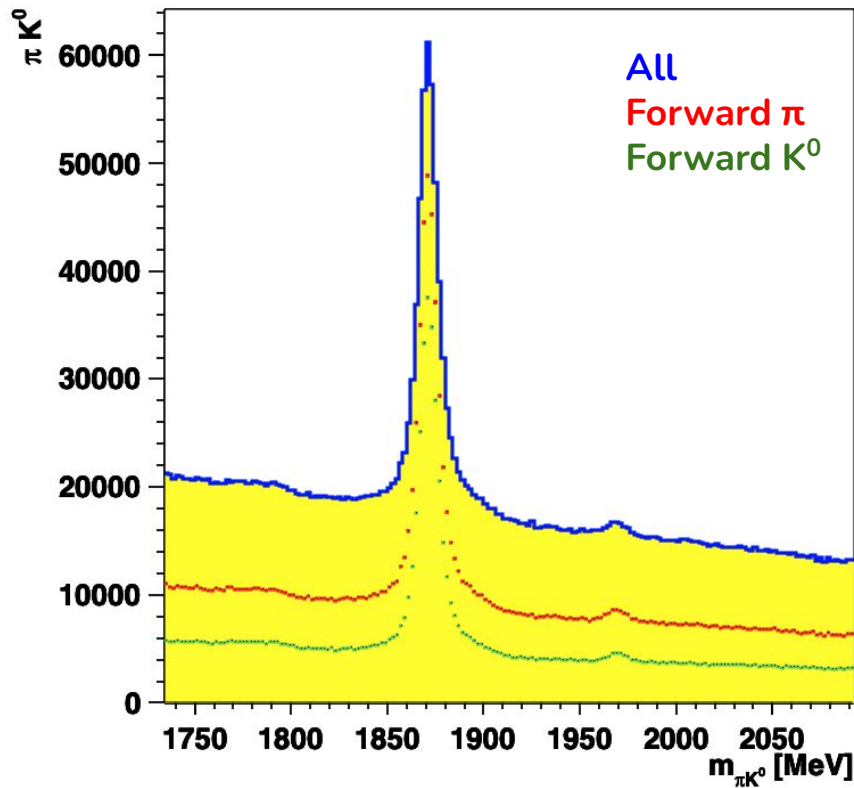
Signed impact parameter:

$\beta < \pi/2 \to \delta = +|\delta|$ **keep**

$\alpha > \pi/2 \to \delta = -|\delta|$ **reject**

D^+ decay length: 0.3 mm
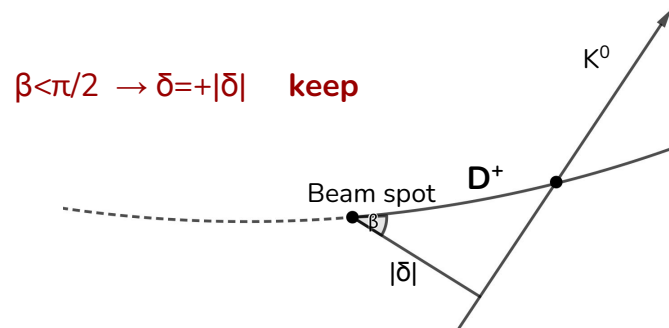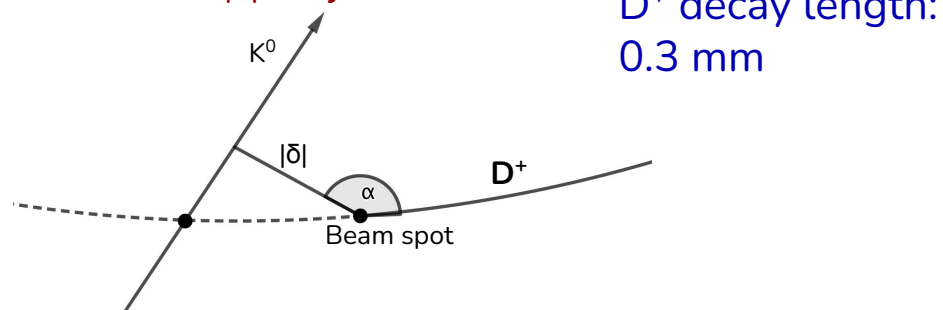
Systematic variations from cuts

signal cuts	peak area data [10^3]	peak area MC [10^3]	Data/MC	Stability
p*>2.5, dl>0.2	16.1±0.9	8.9±0.7	1.80±0.17	1.15±0.14
p* > 3.5, dl>0.2	8.0±0.5	4.22±0.25	1.88±0.16	1.10±0.13
p* > 3, dl>0.2	**13.5±0.9**	**6.54±0.34**	**2.07±0.17**	**1.00±0.11**
p* > 3, dl>0.1	16.7±1.3	8.2±0.6	2.03±0.22	1.02±0.14
p* > 3, dl>0.3	11.1±0.6	5.7±0.4	1.94±0.17	1.07±0.13

Systematic variations from reference channels

Channel	peak area data [10^3]	peak area MC [10^3]	data / MC
ref D → $K^0_S\pi^0\pi$	227.1±1.3	379.6±2.2	L = 0.598±0.005
ref D^0 → $K^0_S\omega$	117.9±0.8	221.0±0.9	L = 0.533±0.004
ref D^0 → $K^0_S\pi^0$	245.2±1.3	442.6±1.2	L = 0.554±0.003
ref D* → $K^0_S\pi^0\pi$	227.1±1.3	379.6±2.2	L = 0.598±0.005
ref D* → $K^0_S\omega\pi$	25.95±0.21	57.1±0.3	L = 0.454±0.004

$$B^{sig}_{data} = \frac{N^{sig}_{data}}{N^{sig}_{sim}} \frac{B^{sig}_{sim}}{L}$$

Belle II event generator:
$B^{sig}_{sim}(D \to K^0_S \pi \omega) = 0.19255\%$

$B^{sig}_{data}(D \to K^0_S \pi \omega) = (0.79 \pm 0.03(\text{stat}) \pm 0.12(\text{syst}))\%$

7-body decay
chain:
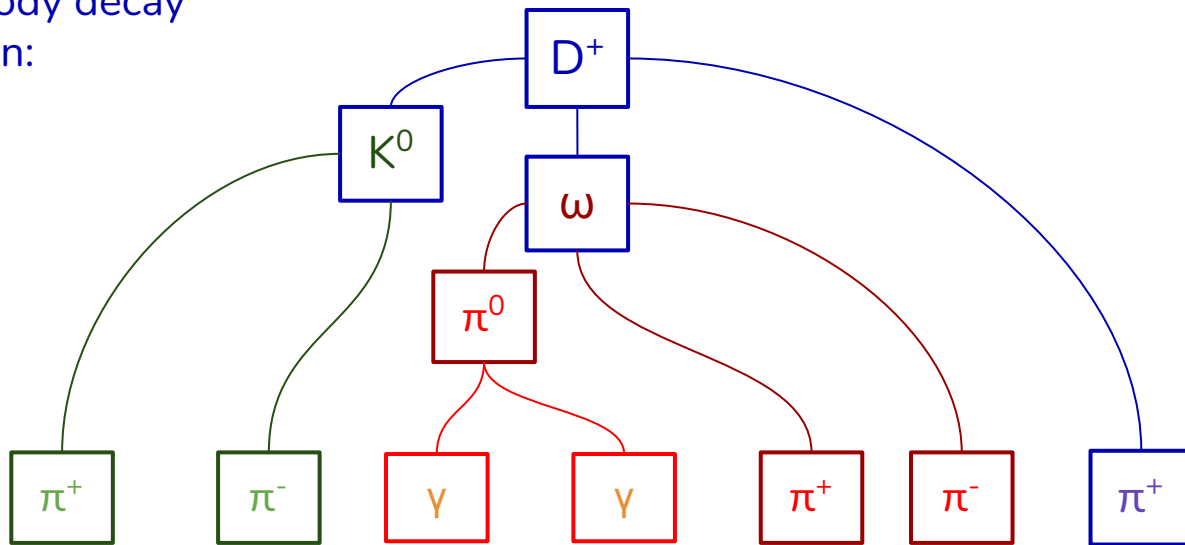
from luminosity   12.9%
from cut on dl   3.4%
from cut on p^*_D 7.3%
(relative uncertainties)

Thank you for the attention.
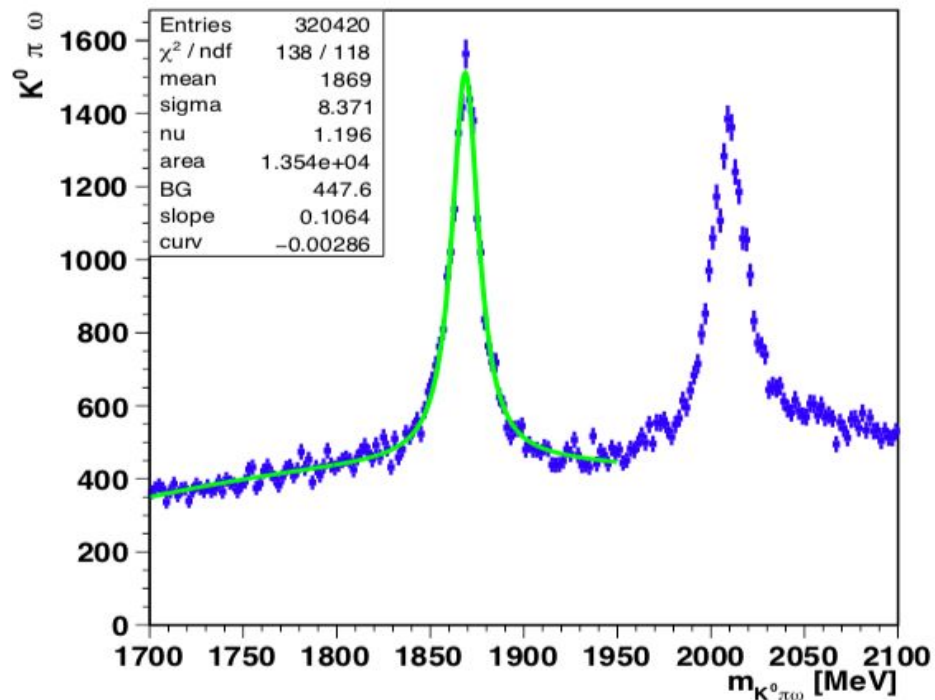
Backup slides

Belle II detector:

- ❖ vertex detector (pixels and strips)
- ❖ central drift chamber
- ❖ TOP and ARICH for particle identification
- ❖ electromagnetic calorimeter ECL
- ❖ superconducting solenoid magnet
- ❖ muon detector KLM
- ❖ trigger and DAQ system
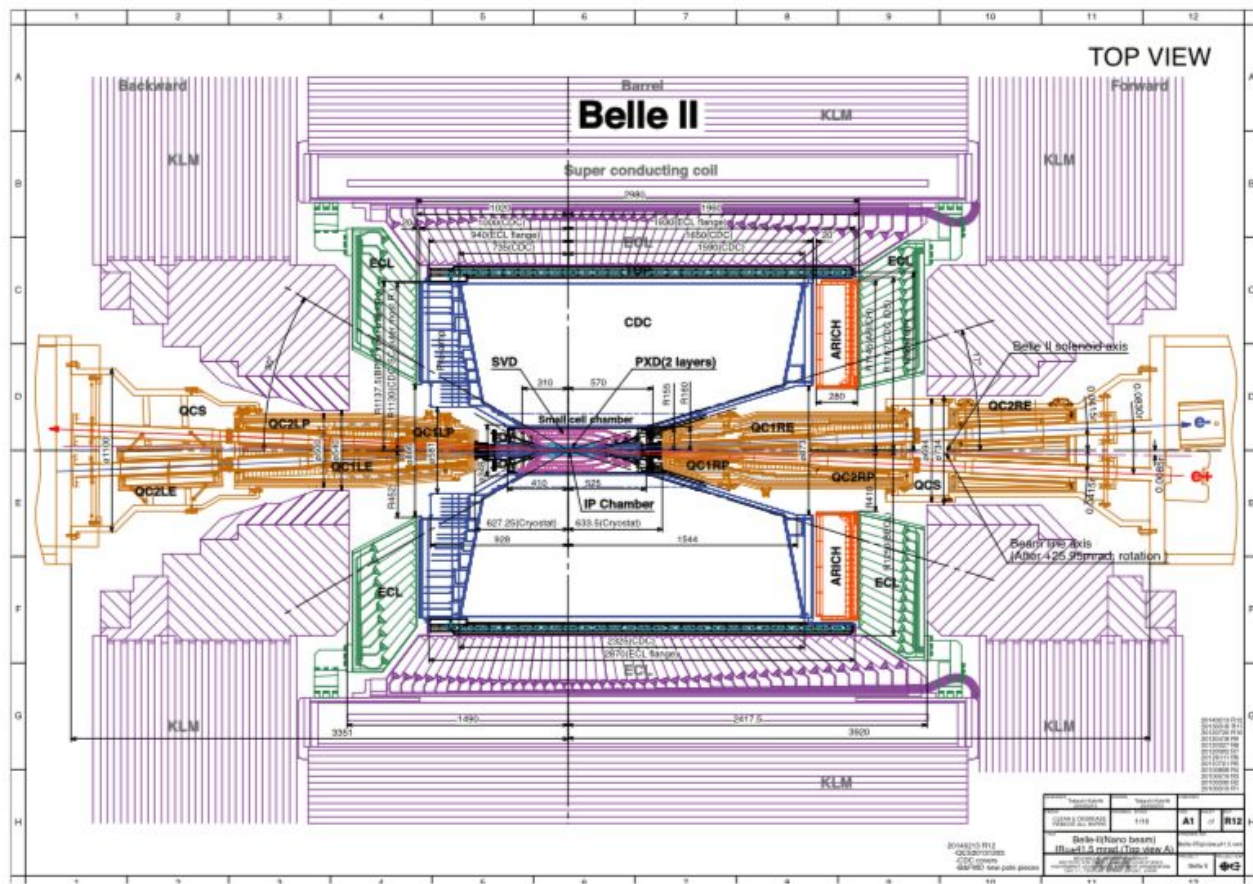
Experiment number	Recorded integrated luminosity [fb^{-1}]
12 (2020)	63.58
14 (2020)	15.90
16-18 (2021)	124.17

$D^+ \rightarrow K^0 \omega \pi$ in data and simulation
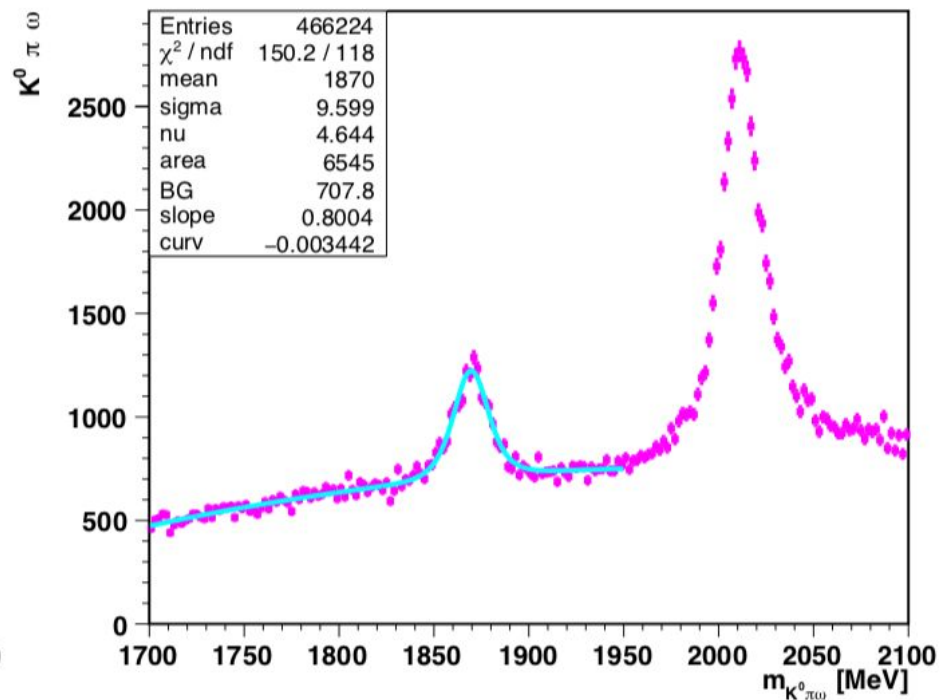
Related channel D→K⁰ηπ

BF measured by BES III in 2020 not yet included in MC14rd

$K^0 \pi \eta$, $p^*_D > 2.5$ GeV, dl > 0.2 mm

Entries 153103

Mean 1824

Data
MC (ccbar)

Tue Aug 30 16:08:28 2022
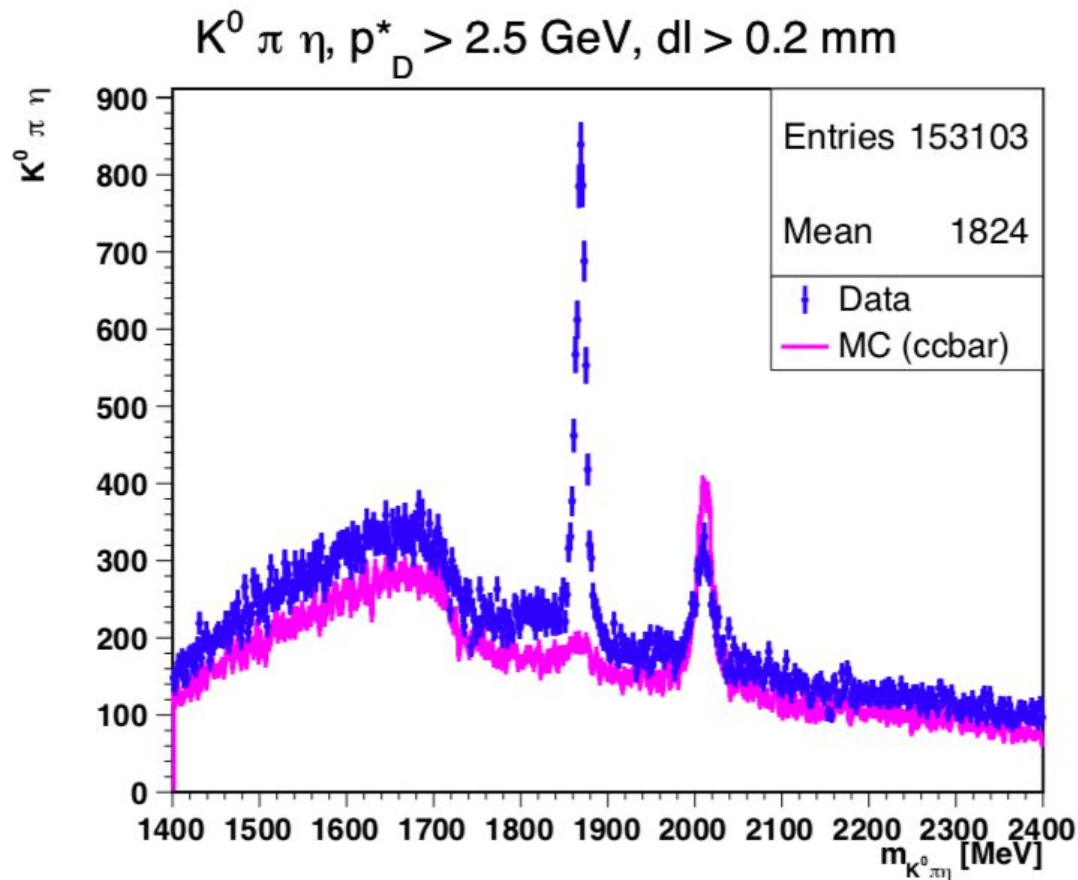
Reference channel $D^0 \rightarrow K^0\pi^0$

A_{peak} = (239.2±1.1)10³

$\pi^0 K^0$, p* > 2.5 GeV, forward K^0

Entries	1.459354e+07
Mean	1961
χ^2 / ndf	2371 / 343
mean	1855
sigma	18.05
nu	8.114
area	2.392e+05
BG	6499
slope	−12.71
curv	0.01021

Mon Aug 29 12:11:05 2022

Reference channel D→K⁰π⁰π
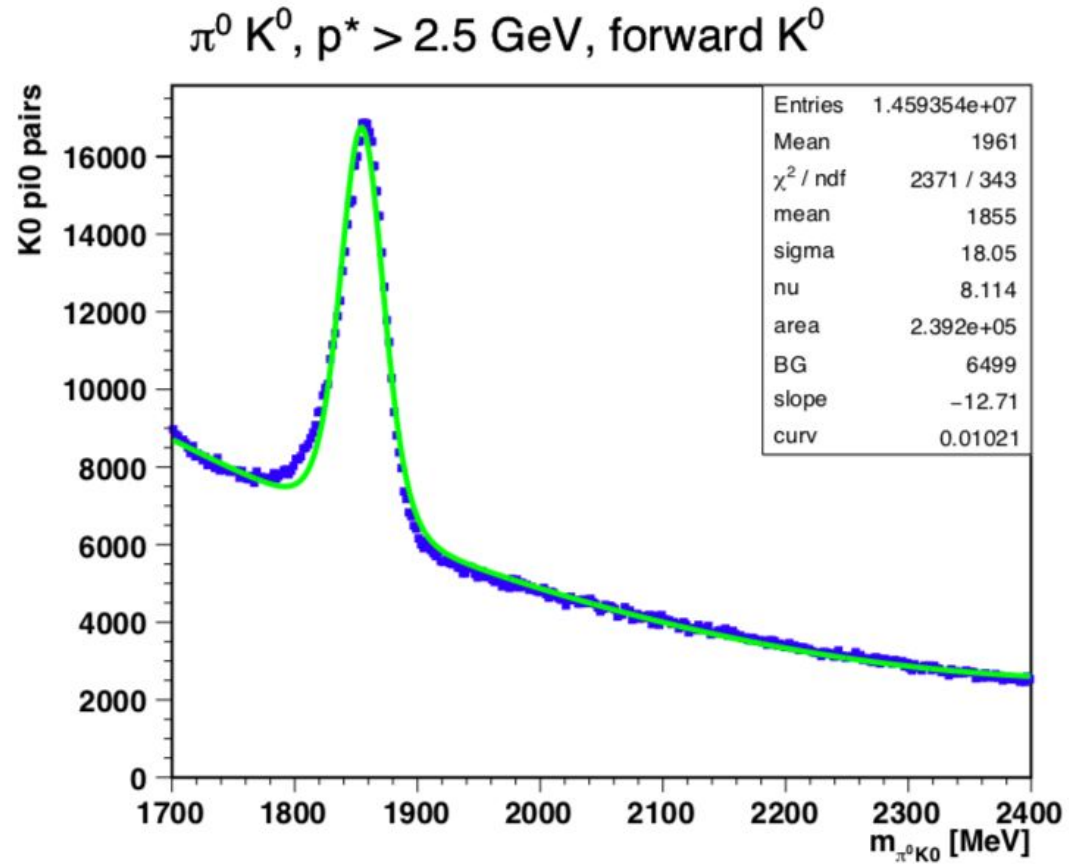
Reference channel
$D \rightarrow K^0 \pi^0 \pi$

$A_{peak} = (229.9 \pm 1.0)10^3$

$\pi^0 K^0 \pi$, $p^* > 2.5$ GeV, $E_\gamma > 0.11$ GeV

Entries	4875878
Mean	2001
χ^2 / ndf	5850 / 343
mean	1864
sigma	12.9
nu	3.076
area	2.299e+05
BG	4458
slope	−2.527
curv	7.129e−05

Mon Aug 29 12:11:05 2022
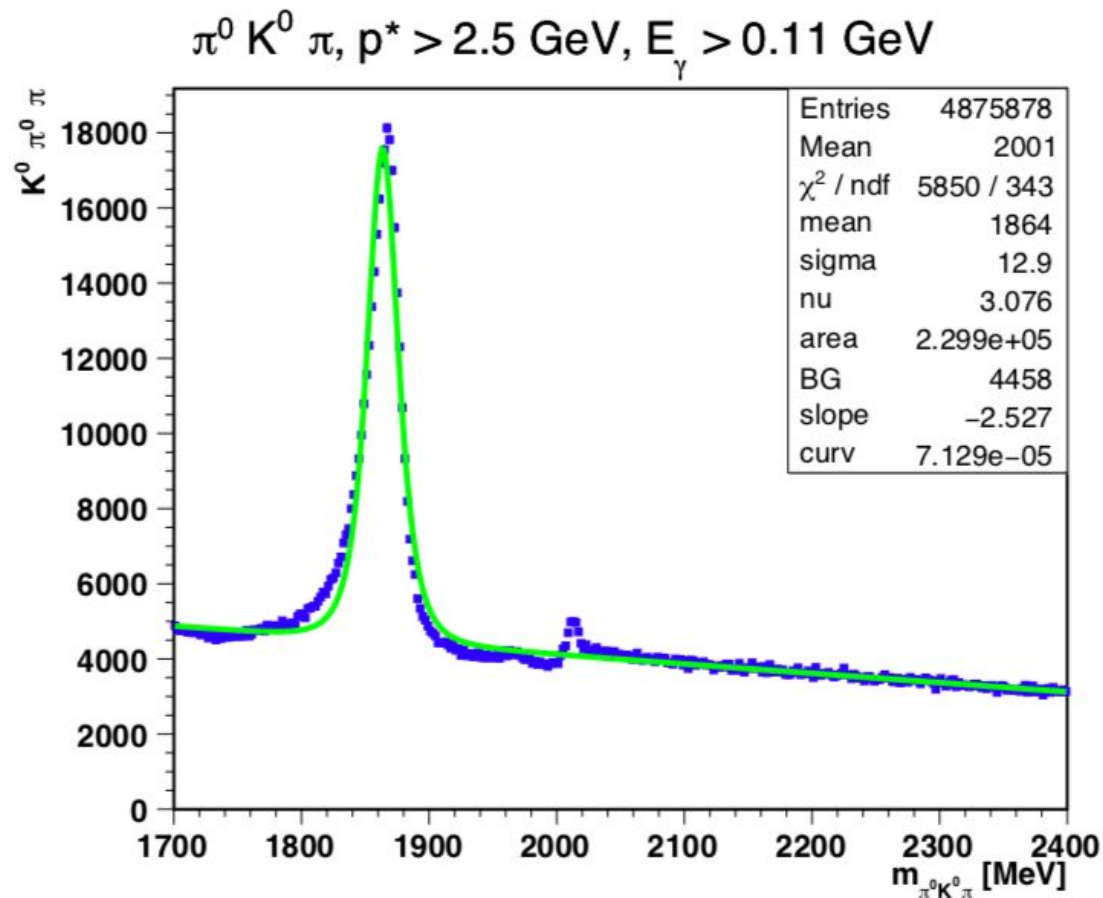
Reference channel $D^0 \rightarrow K^0\omega$

$A_{peak} = (115.2 \pm 0.7)10^3$

$K^0 \omega$, $p^*_D > 2.5$ GeV, $E_\gamma > 110$ MeV

Entries	2583975
Mean	1756
χ^2 / ndf	1113 / 293
mean	1863
sigma	8.849
nu	3.518
area	1.152e+05
BG	3271
slope	−6.379
curv	0.0049

$m_{K^0\omega}$ [MeV]

Mon Aug 29 12:11:05 2022
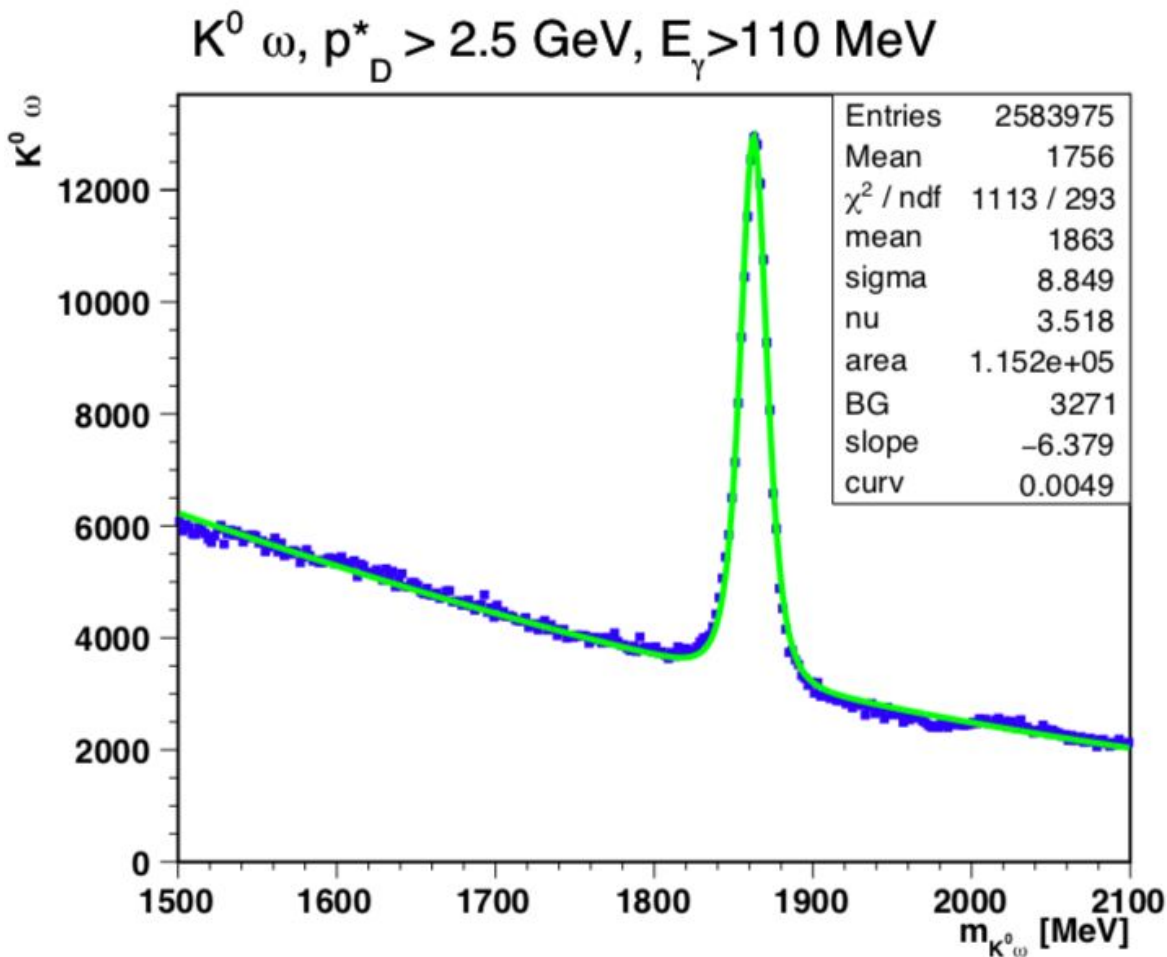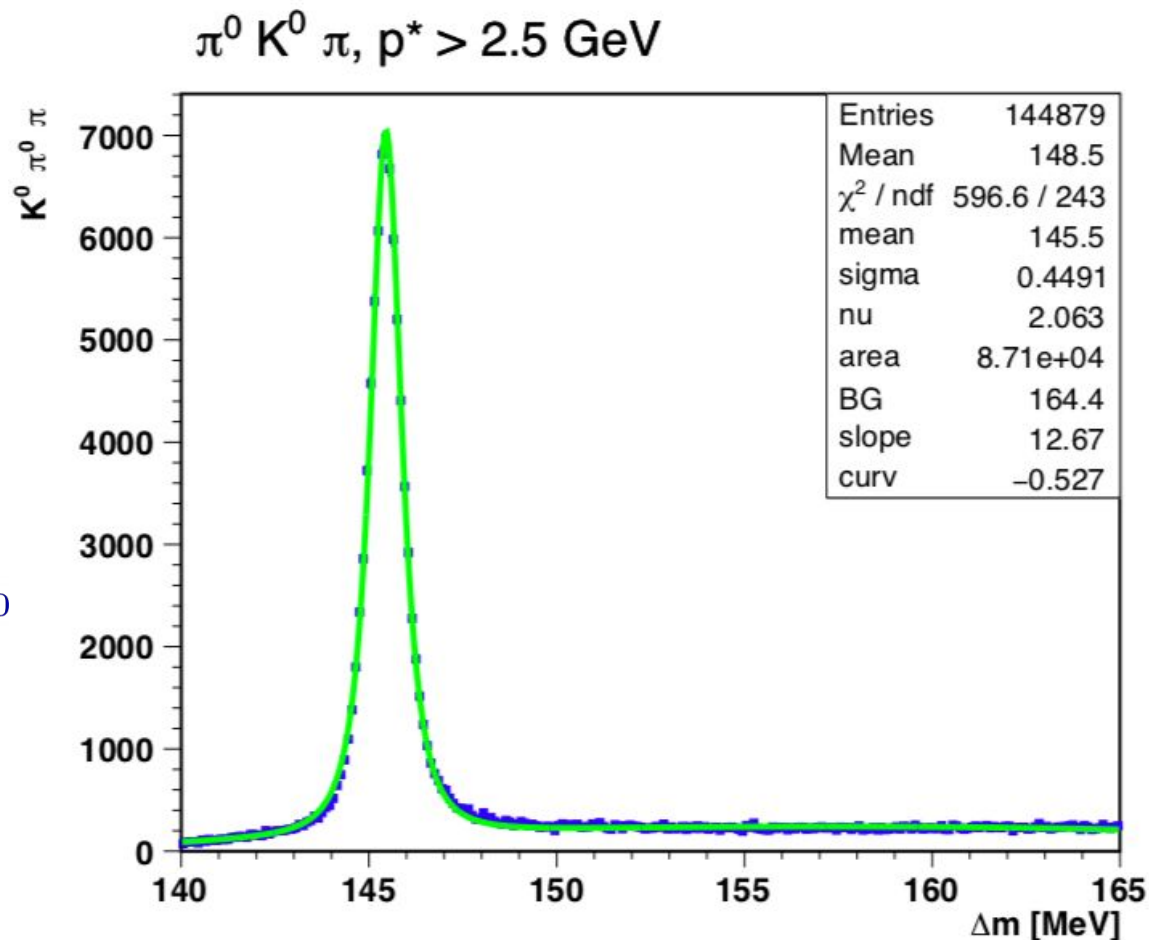
Reference channel
$D^* \to K^0 \pi^0 \pi$

$A_{peak} = (87.1 \pm 0.4)10^3$

$$\Delta m = m_{K^0 \pi^0 \pi} - m_{K^0 \pi^0}$$

$\pi^0 K^0 \pi$, $p^* > 2.5$ GeV
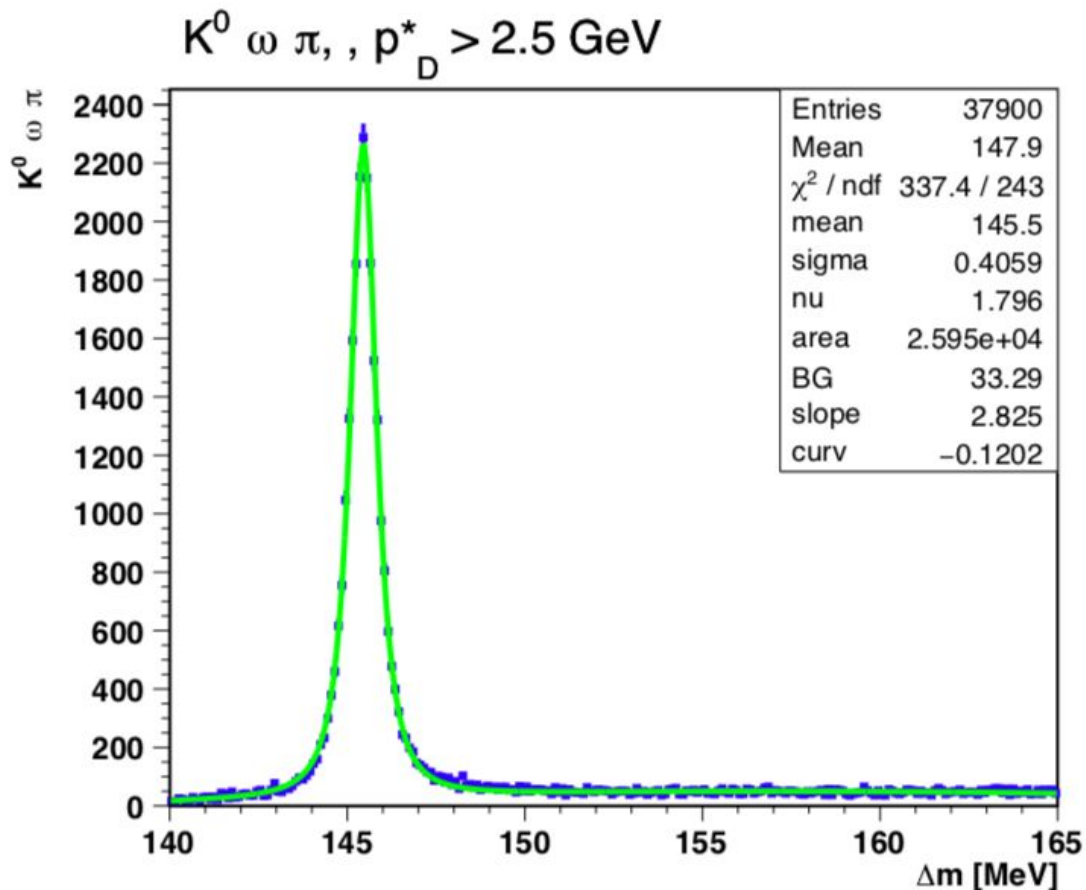
Entries	144879
Mean	148.5
χ^2 / ndf	596.6 / 243
mean	145.5
sigma	0.4491
nu	2.063
area	8.71e+04
BG	164.4
slope	12.67
curv	−0.527

Mon Aug 29 12:11:05 2022

Reference channel
$D^* \to K^0\omega\pi$

$A_{peak} = (25.95\pm0.21)10^3$

$$\Delta m = m_{K^0\omega\pi} - m_{K^0\omega}$$

$K^0\omega\pi$, , $p^*_D > 2.5$ GeV

Entries	37900
Mean	147.9
χ^2 / ndf	337.4 / 243
mean	145.5
sigma	0.4059
nu	1.796
area	2.595e+04
BG	33.29
slope	2.825
curv	−0.1202

Mon Aug 29 12:11:05 2022

$D \to K^0 \omega \pi$ branching fraction

Reference channel	Data/MC for $D^+ \to K^0_S \omega \pi$	BF ($D^+ \to K^0_S \omega \pi$) [%]
$D \to K^0_S \pi^0 \pi$	3.46±0.28	0.67±0.05
$D^0 \to K^0_S \omega$	3.88±0.32	0.75±0.06
$D^0 \to K^0_S \pi^0$	3.73±0.30	0.72±0.06
$D^* \to K^0_S \pi^0 \pi$	4.4±0.4	0.84±0.07
$D^* \to K^0_S \omega \pi$	4.6±0.4	0.88±0.07