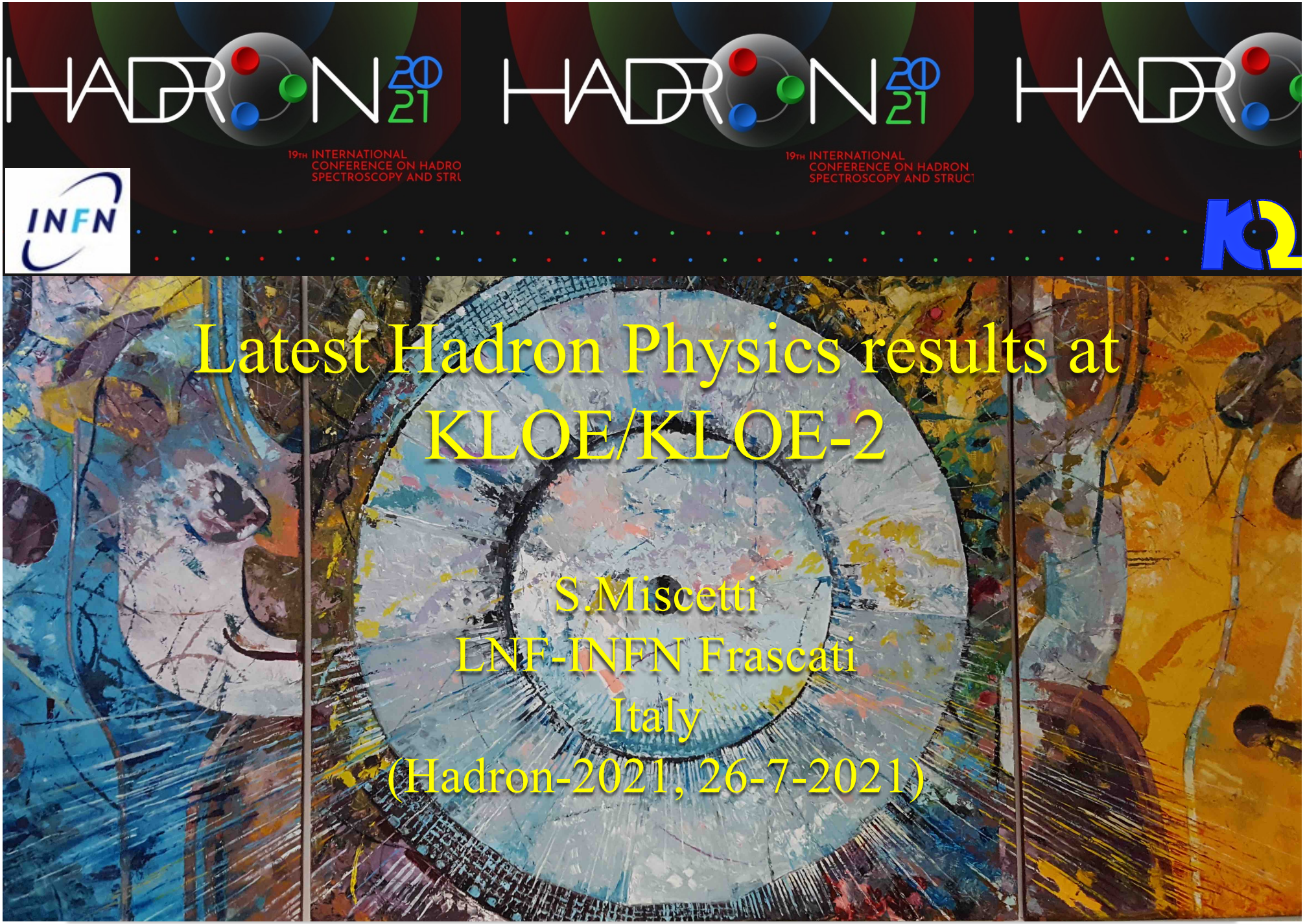


Latest Hadron Physics results at KLOE/KLOE-2

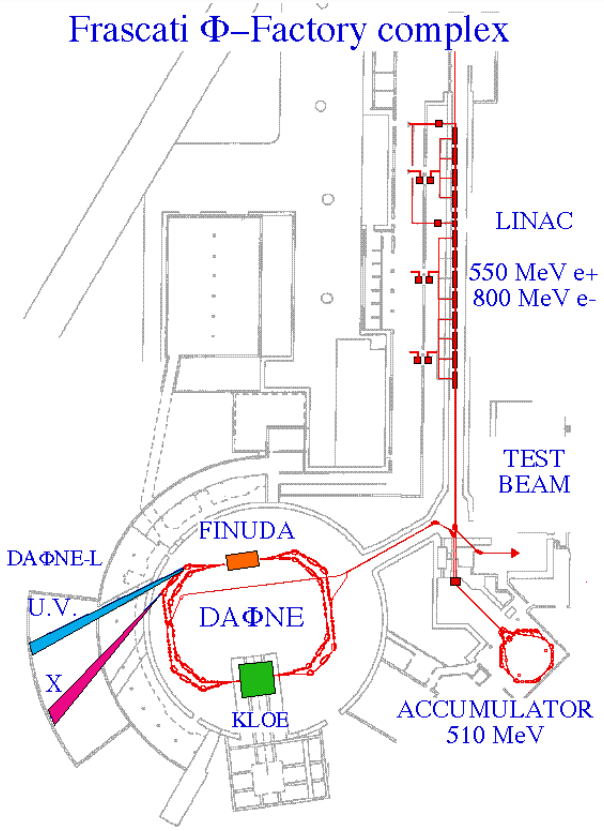
S.Miscetti
LNF-INFN Frascati
Italy

(Hadron-2021, 26-7-2021)

Talk Overview

- KLOE and KLOE-2 @ Daϕne
- Measurement of BR($\eta \rightarrow \pi^+\pi^-$)
- Search for a Leptophobic B boson
- Preliminary measurement of BR($\eta \rightarrow \pi^0\gamma\gamma$)
- Status ISR measurement of $\pi^+\pi^-\pi^0$ final state
- Status of $\gamma\gamma \rightarrow \pi^0$ measurement with low angle tagging system
- First look to $\phi \rightarrow \eta\pi^+\pi^-$ and $\phi \rightarrow \eta\mu^+\mu^-$ decays
- Conclusions

The Daϕne ϕ Factory : KLOE/KLOE-2 performance



- e+e- collider at SQRT(s) = Mphi = 1019.6 MeV
- 2 IR + 2 separate rings
- Trf = 2.7 ns with 105+105 bunches
- Continuous injection during data taking
- Crossing angle 2x12.5 mrad

Best Dafne performace with KLOE (1999-2006)

→ Lpeak = 1.5 E^{32} $cm^{-2}sec^{-1}$

→ Ltotal = 3/fb

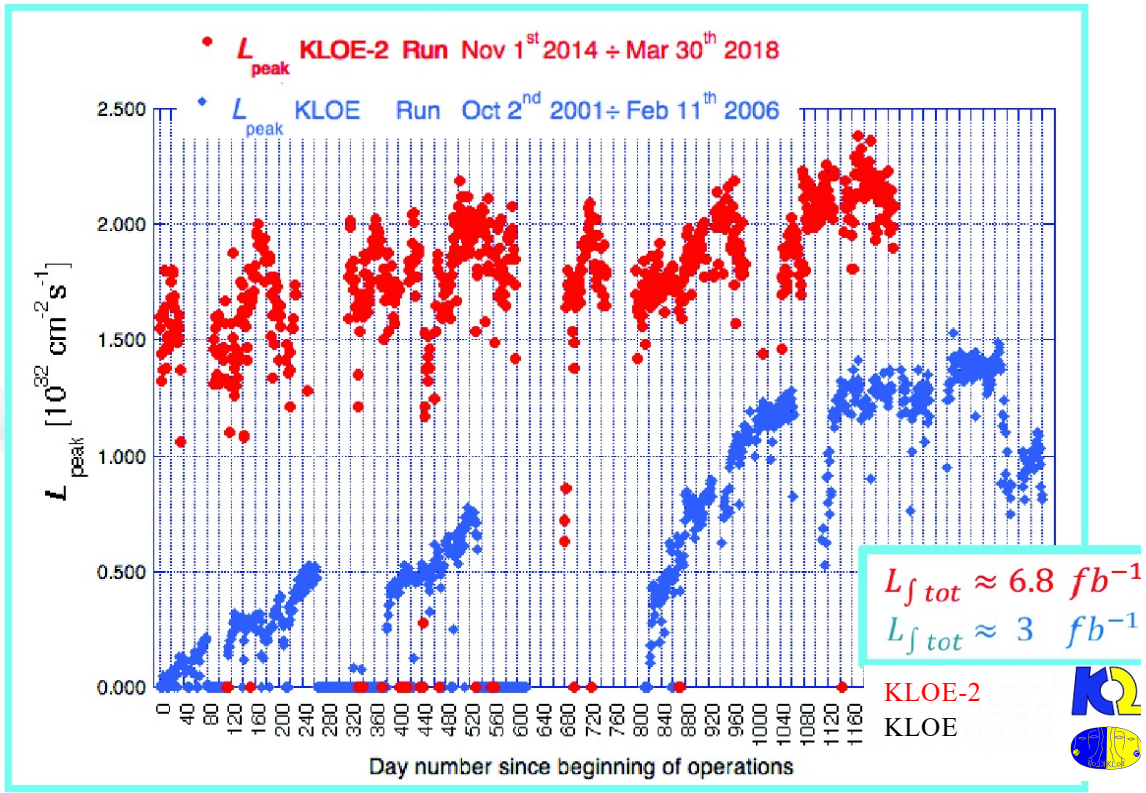
Daϕne upgrade 2012-2014

✓ new IR with large beam crossing + sextupoles for crabbed waist

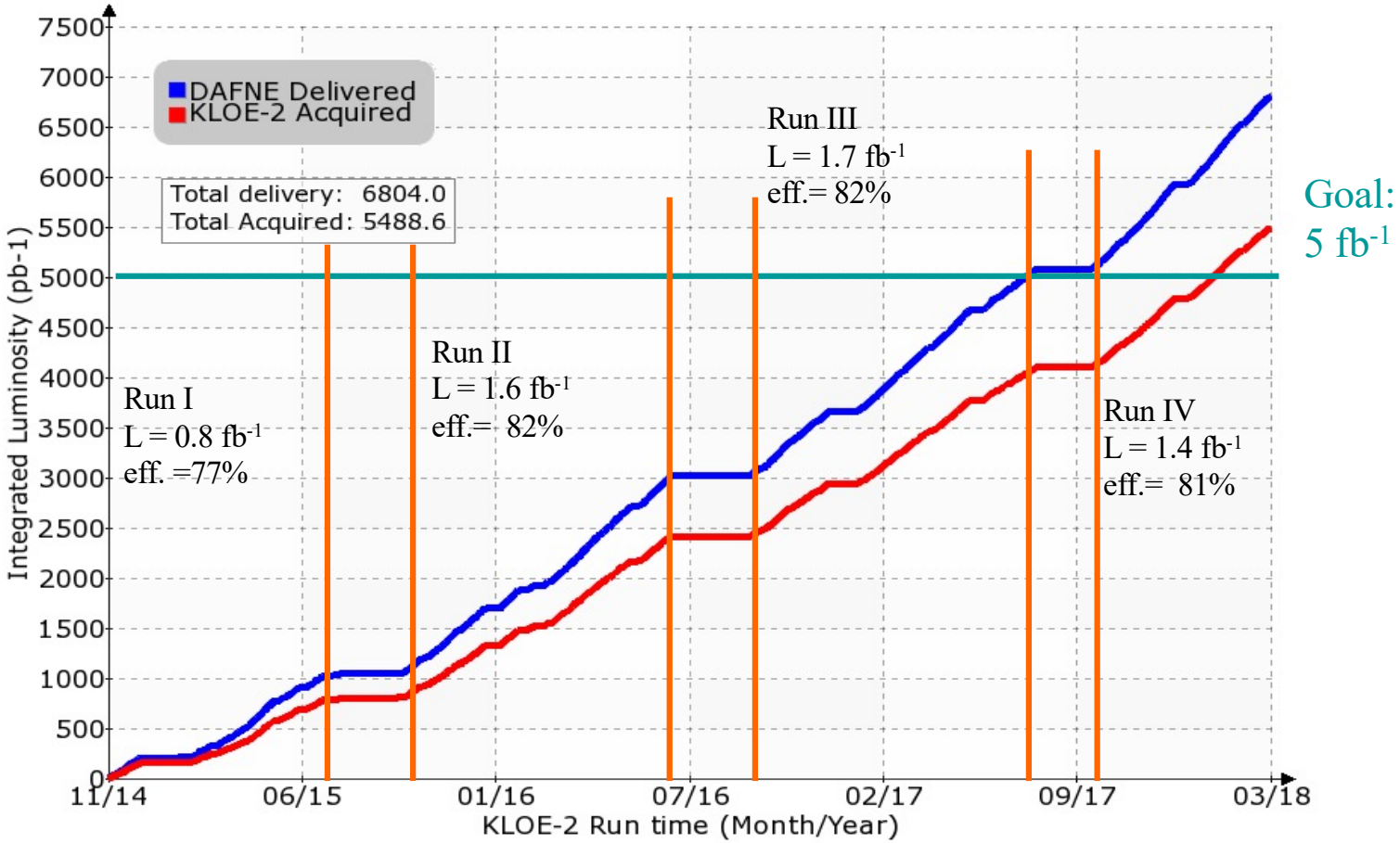
✓ 60% increase in luminosity

→ Lpeak = 2.4 E^{32} cm^{-2} sec^{-1}

→ Ltotal = 6.8 /fb



The Daϕne ϕ Factory : KLOE-2 data taking



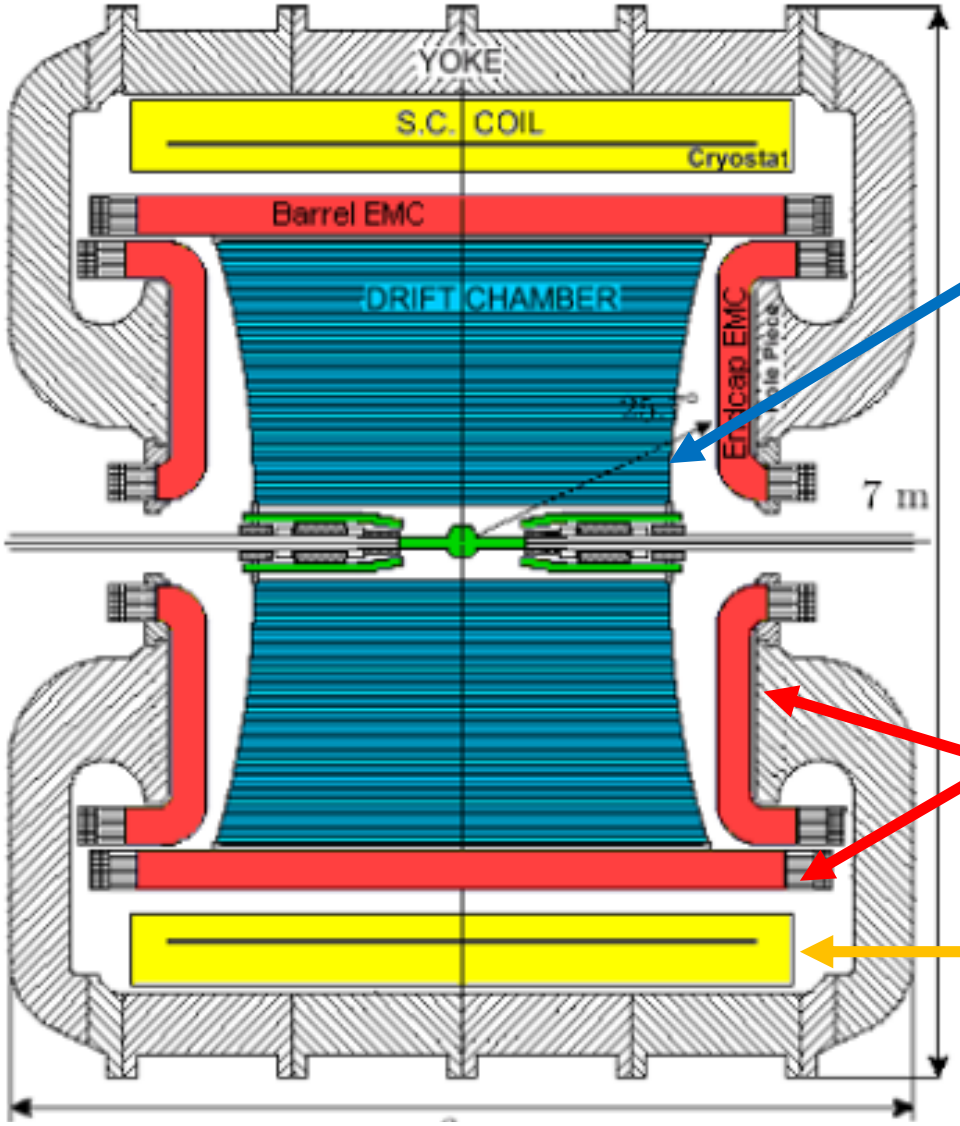
Goal: 5 fb^{-1}

KLOE-2 run: Ltot (delivered) = 6.8/fb
KLOE-2 run: Ltot (acquired) = 5.5/fb

KLOE+KLOE-2 data sample: 8/fb → 2.4 E^{10} ϕ mesons

The largest ever collected sample at the ϕ(1020) peak

KLOE detector



Drift chamber:

- Gas mixture: 90% He, 10% isobutane
- Resolutions: σ_{xy}~150μm, σ_z~2mm, $\frac{\sigma p_t}{p_t} < 0.4\%$ ($45° < \theta < 135°$), σ_v ~3mm

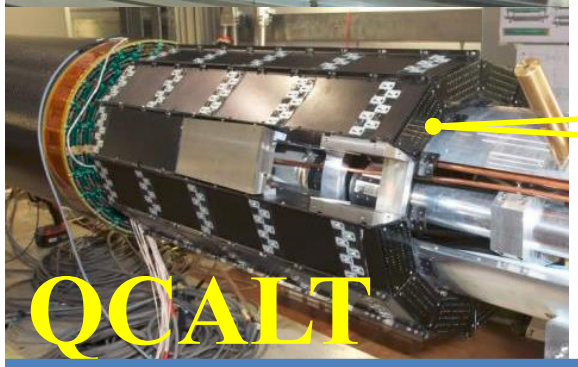
Electromagnetic calorimeter:

- Made of lead/scintillating fibers
- Covers 98% of solid angle
- Resolutions: $\frac{\sigma_E}{E} = \frac{5.7\%}{\sqrt{E(GeV)}}$,

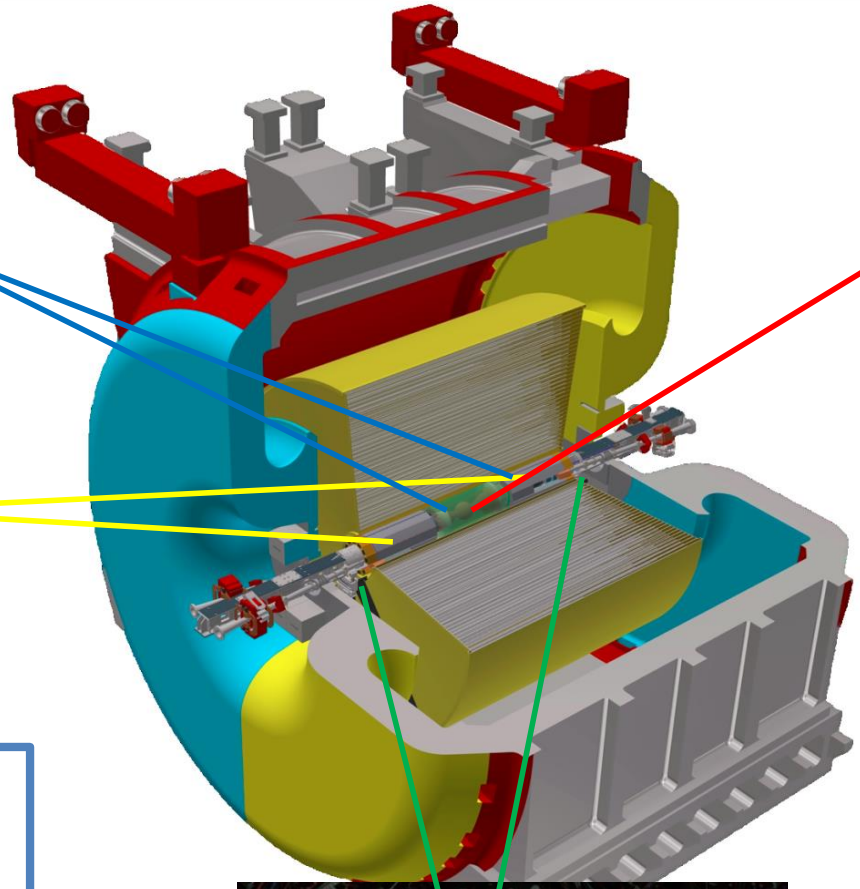
  $\sigma_T = \frac{57\ ps}{\sqrt{E(GeV)}} \oplus 140$ ps

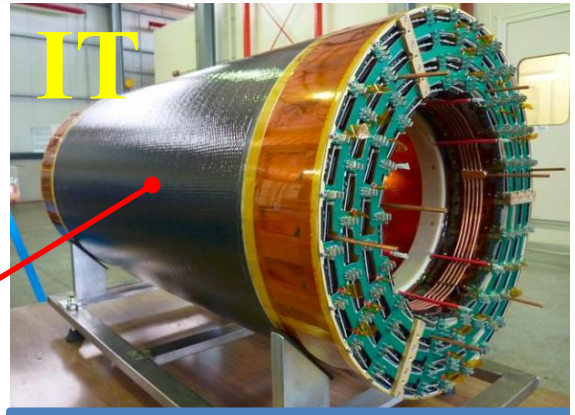
Magnetic field ~0.52 T

KLOE-2 upgrades

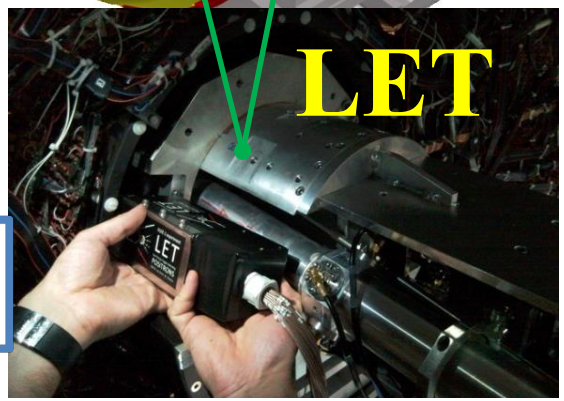


CCALT (LYSO-cristals) **& QCALT** (scintillator tiles and fibers with SiPM read-out)**:** both inside KLOE detector, to improve low polar angles acceptance for γ's & K_L decays

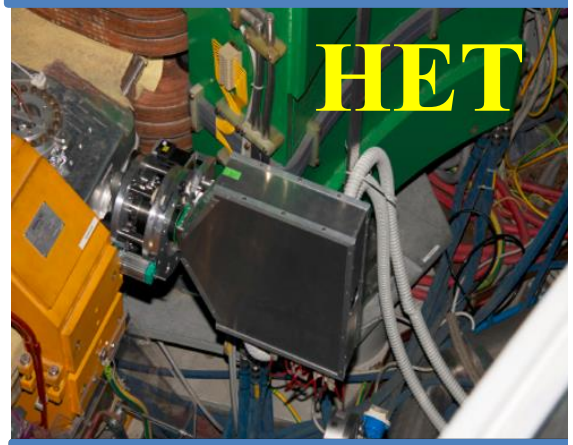




IT: 4 layers of cylindrical GEM detectors, larger acceptance for low p_t tracks, to improve vertex resolution at the Interaction Point



LET: LYSO with SiPM readout, ~1 m from the IP, γγ-physics



HET: Scintillator + PMT 11 m from the IP, γγ-physics

KLOE-2 physics

KLOE-2 coll. EPJC (2010) 68, 619
http:// agenda.infn.it/event/kloe2ws procs. EPJ WoC 166 (2018)

KAON Physics:

- CPT and QM tests with kaon interferometry
- Direct T and CPT tests using entanglement
- CP violation and CPT test:
  $K_S \to 3\pi^0$
  direct measurement of Im(ε'/ε) (lattice calc. improved)
- CKM Vus:
  K_S semileptonic decays and A_S
  (also CP and CPT test)
  $K\mu 3$ form factors, $Kl3$ radiative corrections
- χpT : $K_S \to \gamma\gamma$
- Search for rare K_S decays

Hadronic cross section

- ISR studies with 3π, 4π final states
- F_p with increased statistics
- Measurement of a_μ^{HLO} in the space-like region using Bhabha process

Dark forces:

- Improve limits on:
  Uγ associate production
  $e^+e^- \to U\gamma$, $U \to \mu\mu, \pi\pi$, ee
- Higgstrahlung
  $e^+e^- \to Uh' \to \mu^+\mu^-$ + miss. energy
- **Leptophobic B boson search**
  $\phi \to \eta B$, $B \to \pi^0\gamma$, $\eta \to \gamma\gamma$
  $\eta \to B\gamma$, $B \to \pi^0\gamma$
- Search for U invisible decays

Light meson Physics:

- **η decays,** ω decays
- Transition Form Factors
- C,P,CP violation: improve limits on
  $\eta \to \gamma\gamma\gamma$, $\pi^+\pi^-$, $\pi^0\pi^0$, $\pi^0\pi^0\gamma$
- improve $\eta \to \pi^+\pi^-e^+e^-$
- **χpT : $\eta \to \pi^0\gamma\gamma$**
- Light scalar mesons: $f_0(500)$ in $\Phi \to K_SK_S\gamma$
- **$\gamma\gamma$ Physics: $\gamma\gamma \to \pi^0$ and π^0 TFF**
- Search for axion-like particles

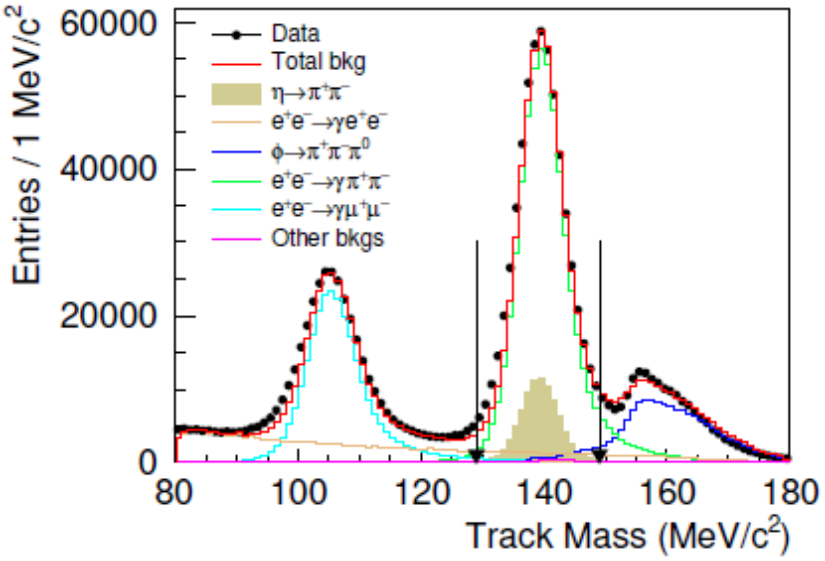
Status of $\eta \to \pi^+\pi^-$

Search for $\phi \to \eta\gamma$, $\eta \to \pi^+\pi^-$

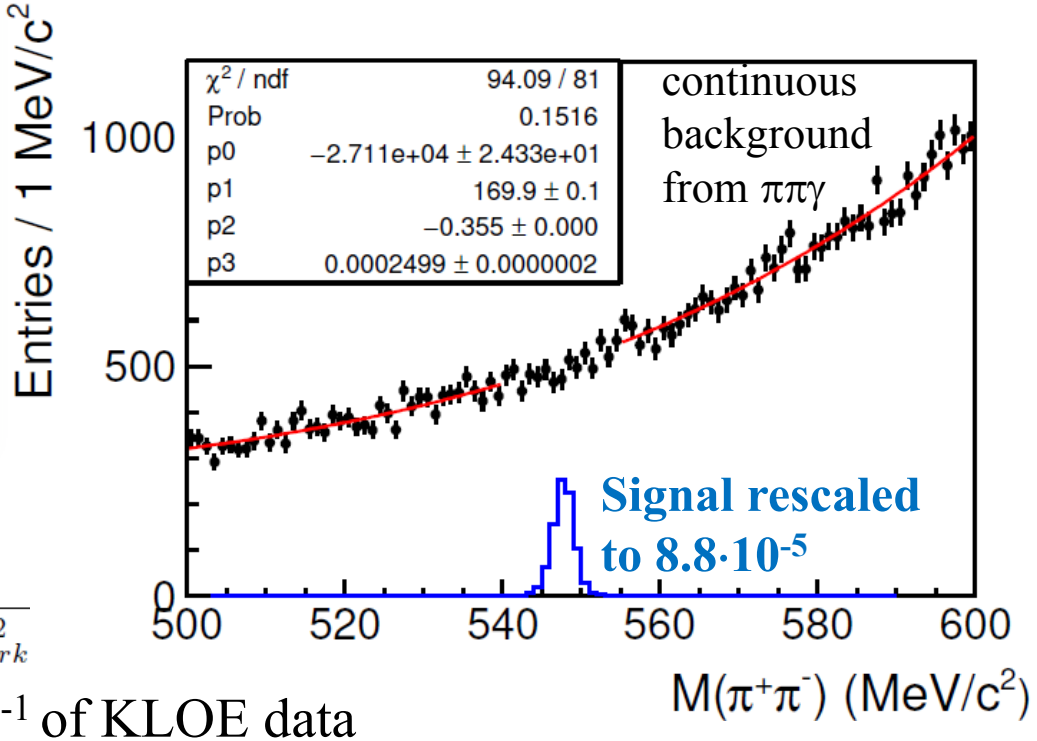
- P, CP-violating process
- In the SM the BR prediction [*Phys.ScriptaT* 99, 23 (2002)]:
  - proceed only via CPV in weak interaction $\to 10^{-27}$
  - introducing a CPV term in QCD $\to 10^{-17}$
  - allowing CPV in the extended Higgs sector $\to 10^{-15}$
- An observation of larger branching ratio would mean new source of CP violation in the strong interactions

- Previous KLOE result [*Phys.Lett.B* 606 (2005) 276] based on 0.4 fb^{-1}: $< 1.3 \cdot 10^{-5}$ @90% CL
- LHCb: $< 1.6 \cdot 10^{-5}$ @90% CL [*Phys.Lett.B* 764 (2017) 233-240]

Search for the $\phi \to \eta\gamma$, $\eta \to \pi^+\pi^-$



$$|\vec{p}_\phi - \vec{p}_1 - \vec{p}_2| = E_\phi - \sqrt{|\vec{p}_1|^2 + M^2_{trk}} - \sqrt{|\vec{p}_2|^2 + M^2_{trk}}$$



- New analysis using independent 1.6 fb^{-1} of KLOE data
- No event excess in the η region, limit extracted using CL$_s$ technique

BR($\eta \to \pi^+\pi^-$) < 4.9 · 10^{-6} @ 90% CL

- Combined with previous KLOE result: **< 4.4 · 10^{-6} @ 90% CL**

Published in JHEP10 (2020) 047

Search for Leptophobic B boson

Search for a Leptophobic B-boson – 1

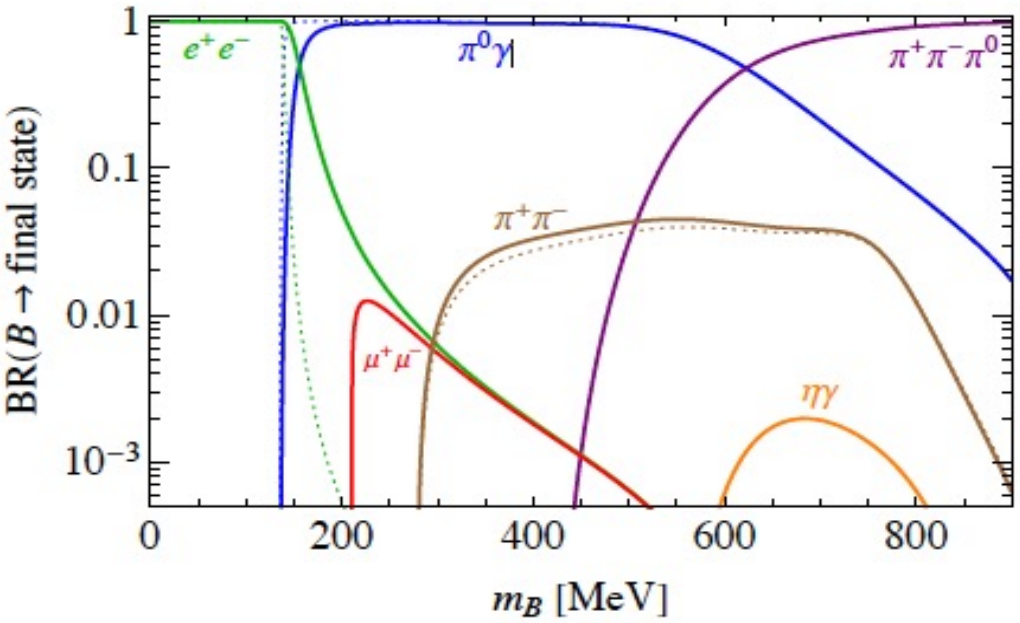
- Dark Force mediator coupled to baryon number (B-boson) with the same quantum numbers of the ω(782) ⇒ $I^G=0^-$
- Leptophobic .. i.e. it couples mostly to quarks
- Can have an impact on (g-2)mu anomaly

$$\mathcal{L} = \frac{1}{3} g_B \bar{q} \gamma^\mu q B_\mu \qquad \alpha_B = \frac{g_B^2}{4\pi} \lesssim 10^{-5} \times (m_B/100\text{MeV})$$

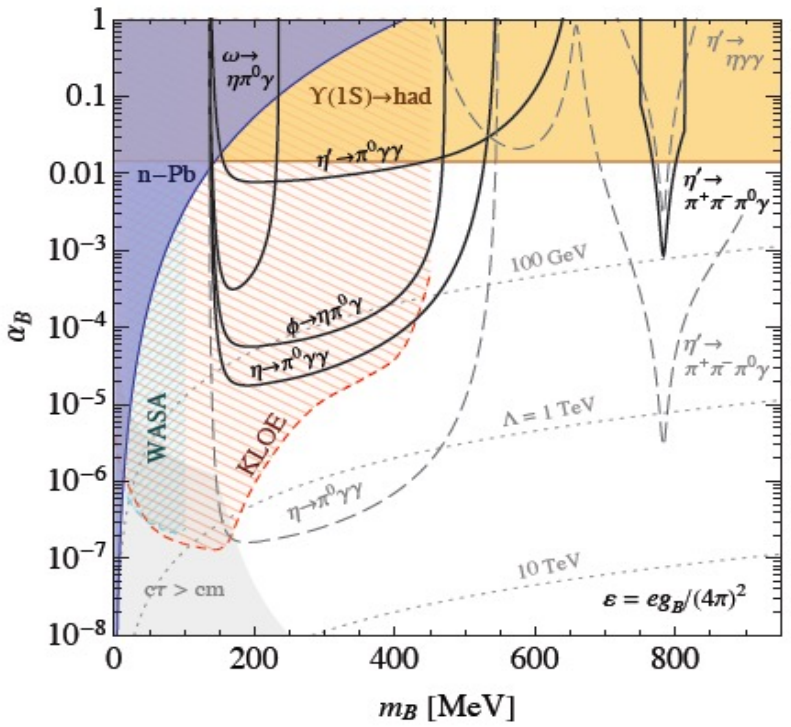
- Dominant decay channel (m_B < 600 MeV): $B \to \pi^0\gamma$
- Can be studied in:

  $\phi \to \eta B$ ➔ $\eta\,\pi^0\,\gamma$ ⇒ 5 prompt γ final state, with η and π^0 intermediate states

  $\phi \to \eta\gamma$ ➔ $\eta \to B\gamma$ ⇒ $\pi^0\,\gamma\,\gamma\,\gamma$, one π^0 intermediate state



[Tulin, PRD89(2014)114008]

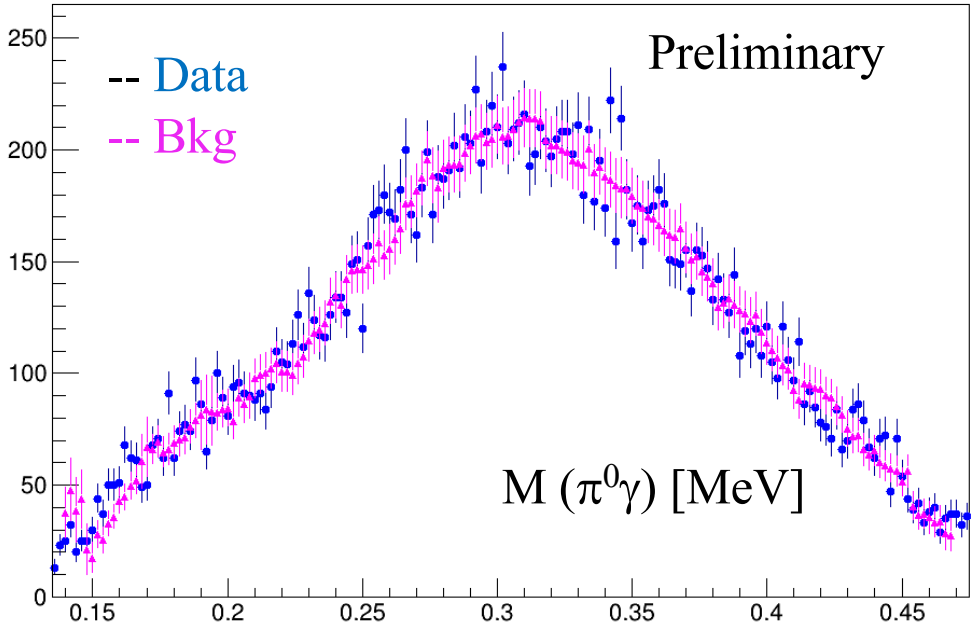


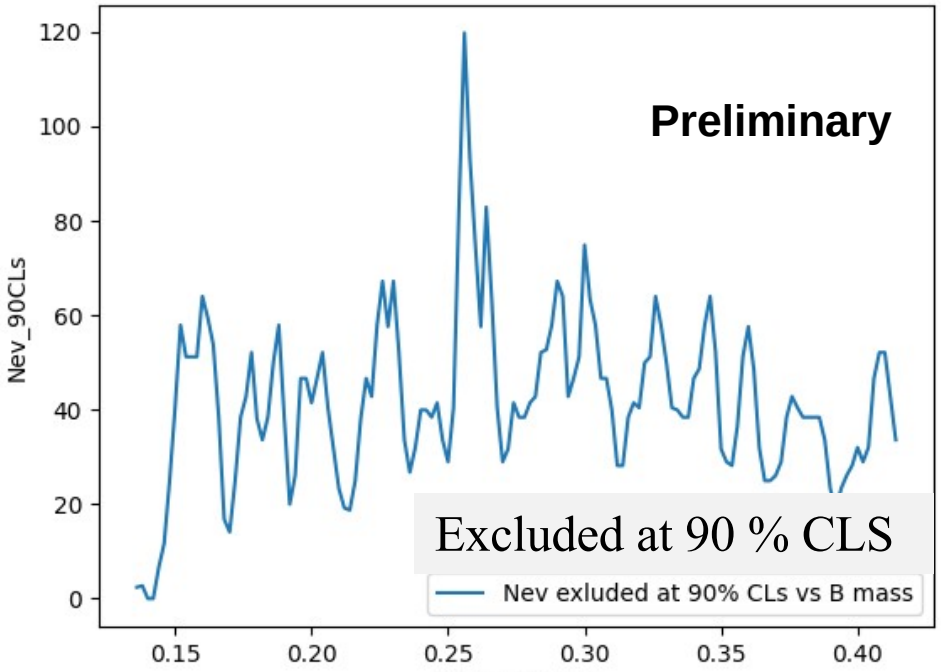
- ❑ Current constraints from phi decay comes from $\phi \to a_0\,\gamma$ KLOE measurement with 400/pb
- ❑ +KLOE A' dark photon search exclusion using BR(B➔e^+e^-) as a function of mixing parameter

Decay → / Production ↓	$B \to e^+e^-$ $m_B \sim 1-140$ MeV	$B \to \pi^0\gamma$ 140–620 MeV	$B \to \pi^+\pi^-\pi^0$ 620–1000 MeV	$B \to \eta\gamma$
$\pi^0 \to B\gamma$	$\pi^0 \to e^+e^-\gamma$	...	...	...
$\eta \to B\gamma$	$\eta \to e^+e^-\gamma$	$\eta \to \pi^0\gamma\gamma$	...	...
$\eta' \to B\gamma$	$\eta' \to e^+e^-\gamma$	$\eta' \to \pi^0\gamma\gamma$	$\eta' \to \pi^+\pi^-\pi^0\gamma$	$\eta' \to \eta\gamma\gamma$
$\omega \to \eta B$	$\omega \to \eta e^+e^-$	$\omega \to \eta\pi^0\gamma$	...	...
$\phi \to \eta B$	$\phi \to \eta e^+e^-$	$\phi \to \eta\pi^0\gamma$	...	

Search for a Leptophobic B-boson – 2

- Searched for in full KLOE stat. (1.7/fb) in 5 photon final state (η and π^0 intermediate states)
- Kinematic fit used to improve energy resolution.
- Main background comes from
  - ➔ $\phi \rightarrow a_0 \gamma \rightarrow \eta \pi^0 \gamma$
  - ➔ $\phi \rightarrow \eta\gamma \rightarrow 3 \pi^0 \gamma \rightarrow 7 \gamma$ with 2 lost or merged photons
- B-Boson expected to appear as a sharp peak in the $M(\pi^0\gamma)$ distribution
- For upper limit evaluation, background is estimated from fitting to the side-bands excluding the signal region
- Correction for reconstruction efficiency and luminosity underway to set a limit on BR
- **Expect to vastly improve existing limits on α_B .**





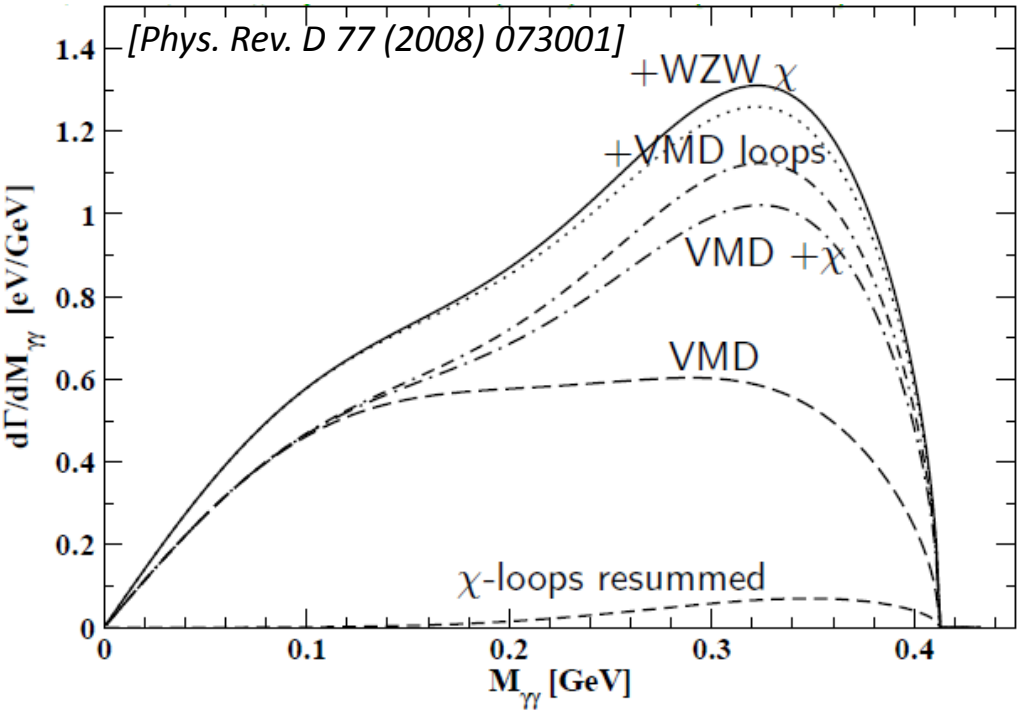
Prel. measurement of $BR(\eta \to \pi^0\gamma\gamma)$

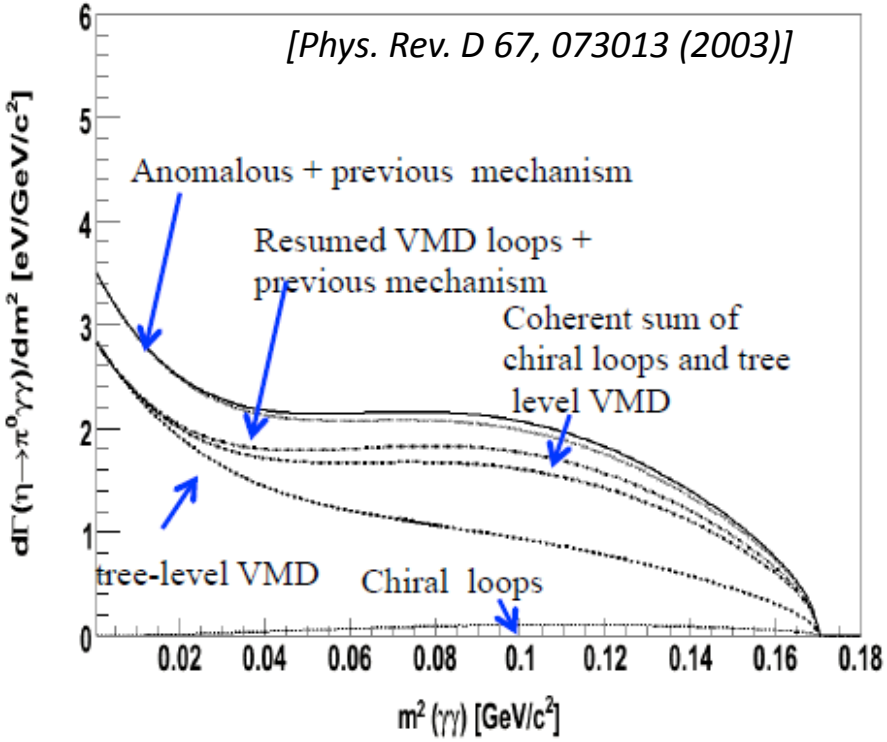
Relevance of $\phi \to \eta\gamma$, $\eta \to \pi^0\gamma\gamma$

[Ll. Ametller et al. PLB 276(1) (1984)]

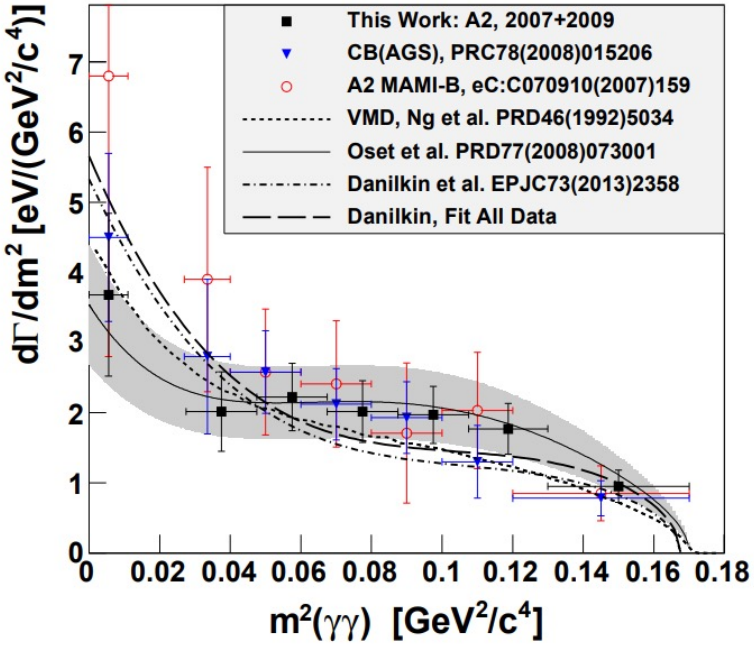
- χPT "golden mode": $O(p^2)$ null, $O(p^4)=0$ on the tree level and suppressed on 1-loop by G-parity and large kaon mass $\Rightarrow$ $O(p^6)$ are dominating

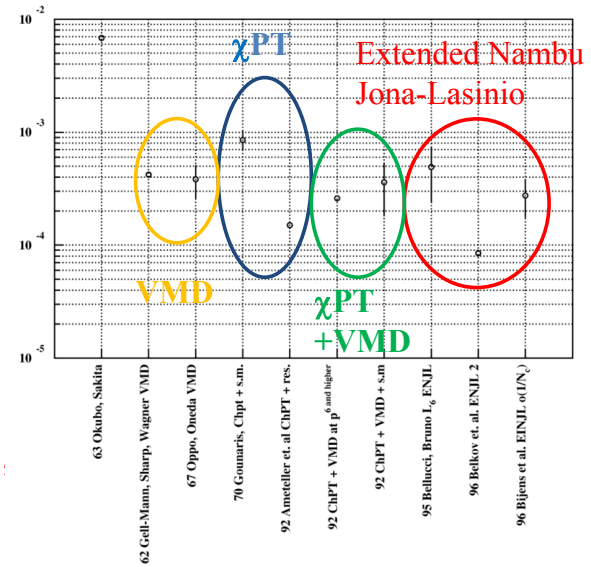
- M($\gamma\gamma$) that are not coming from π° can be used as a test of theoretical models





Relevance of $\phi \to \eta\gamma$, $\eta \to \pi^0\gamma\gamma$



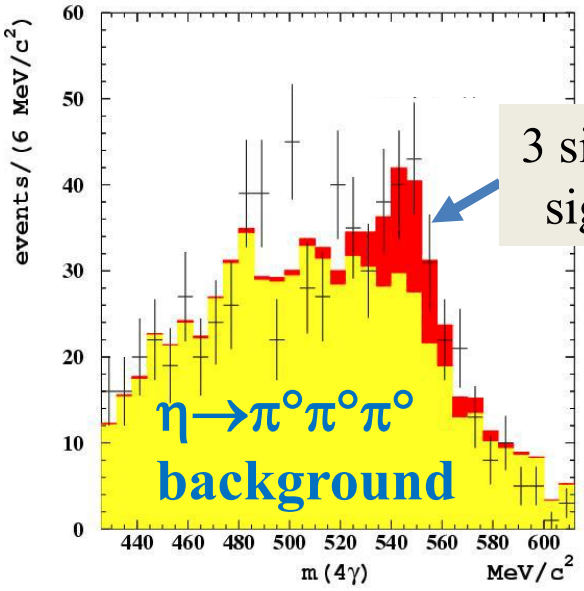


BR = $(22.1 \pm 2.4 \pm 4.7)\times10^{-5}$ CB@AGS (2008)

BR = $(25.2\pm2.5)\times10^{-5}$ CB@MAMI (2014)

Old KLOE preliminary: $(8.4\pm2.7\pm1.4)\times10^{-5}$

(L = 450 pb^{-1} ~ 70 signal events)



3 sigma signal significance

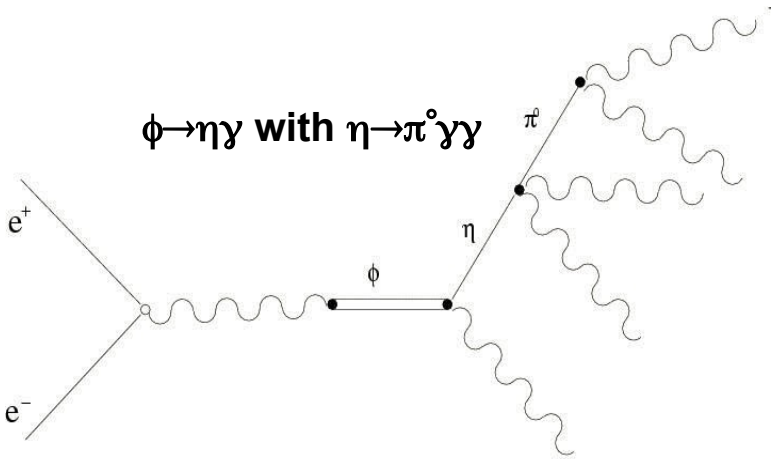
Most recent Theory evaluation

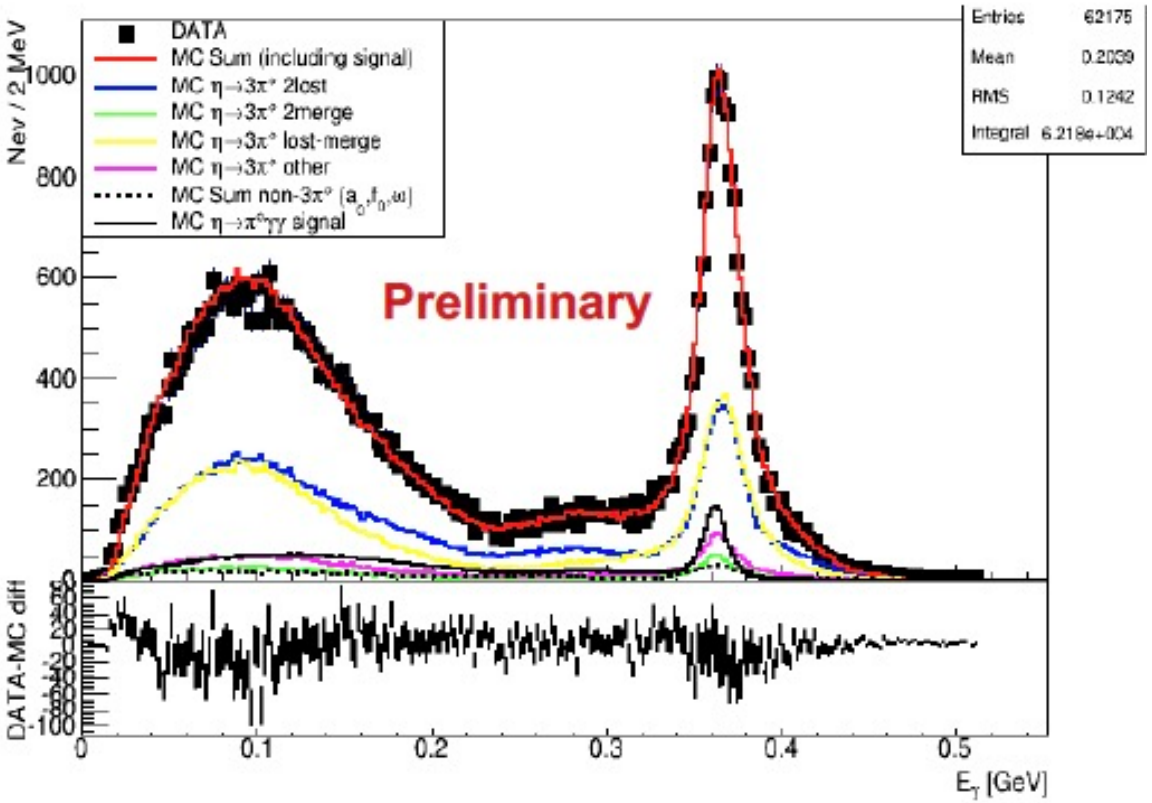
R.Escribano et al. PRD 102 (2020) 034026

BR=$1.35(8)\times10^{-4}$

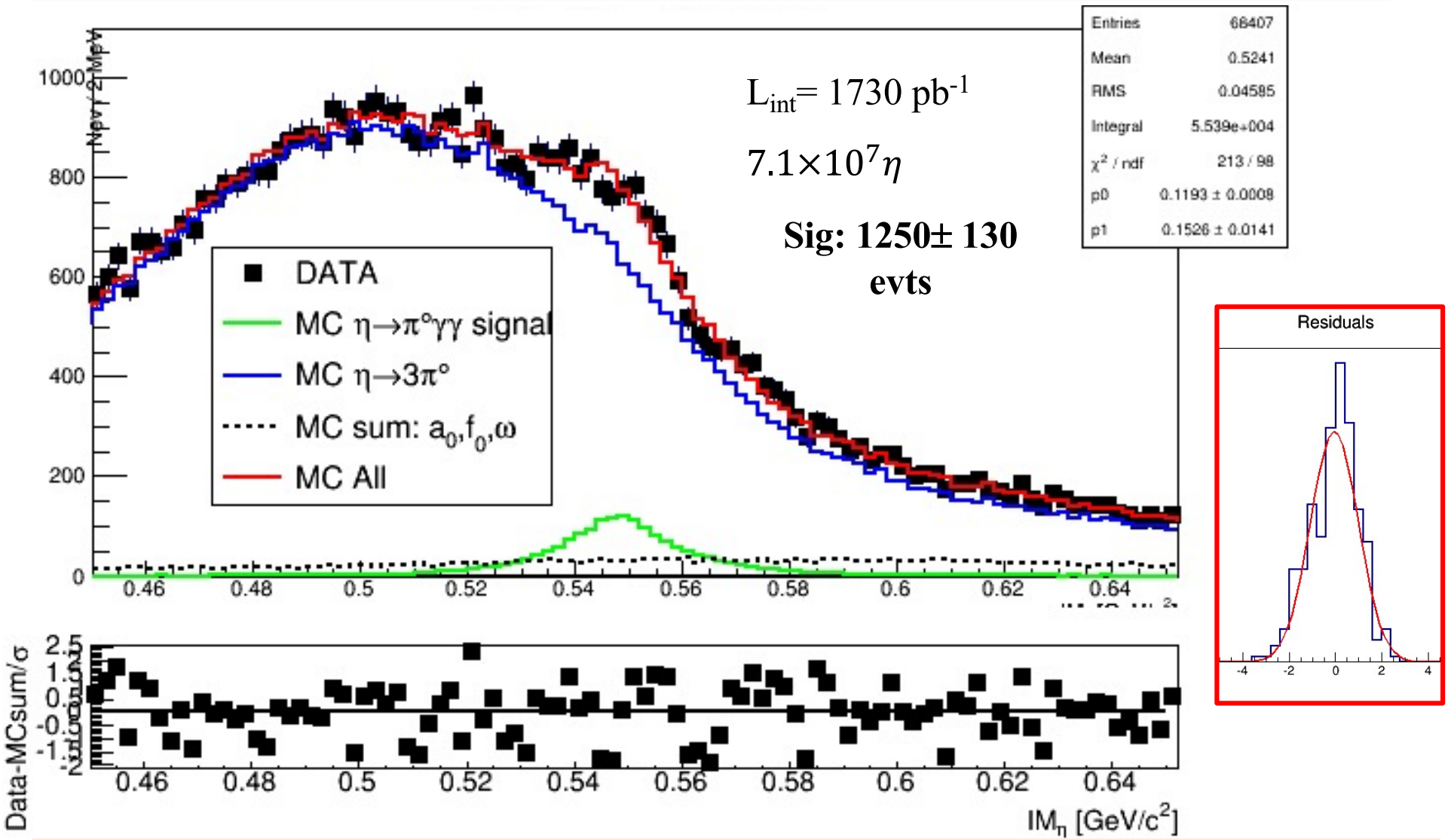
$\phi \to \eta\gamma$, with $\eta \to \pi^0\gamma\gamma$ new analysis strategy

- **A new analysis of KLOE data carried out using x4 larger data sample (~ 1.7/fb)**
- Similar strategy to the prompt analysis of the B-Boson
- Energy resolution of all variables improved by means of a kinematic fit
- Kinematic fit with constraints on η and π^0 masses used to reject a0
- Two π^0 events removed to suppress ϕ and ω
- TMVA-BDT based rejection for $\eta \to 3\pi^0$ merging cases using cluster shapes as an input





$KLOE$: $\eta \to \pi^0\gamma\gamma$ signal



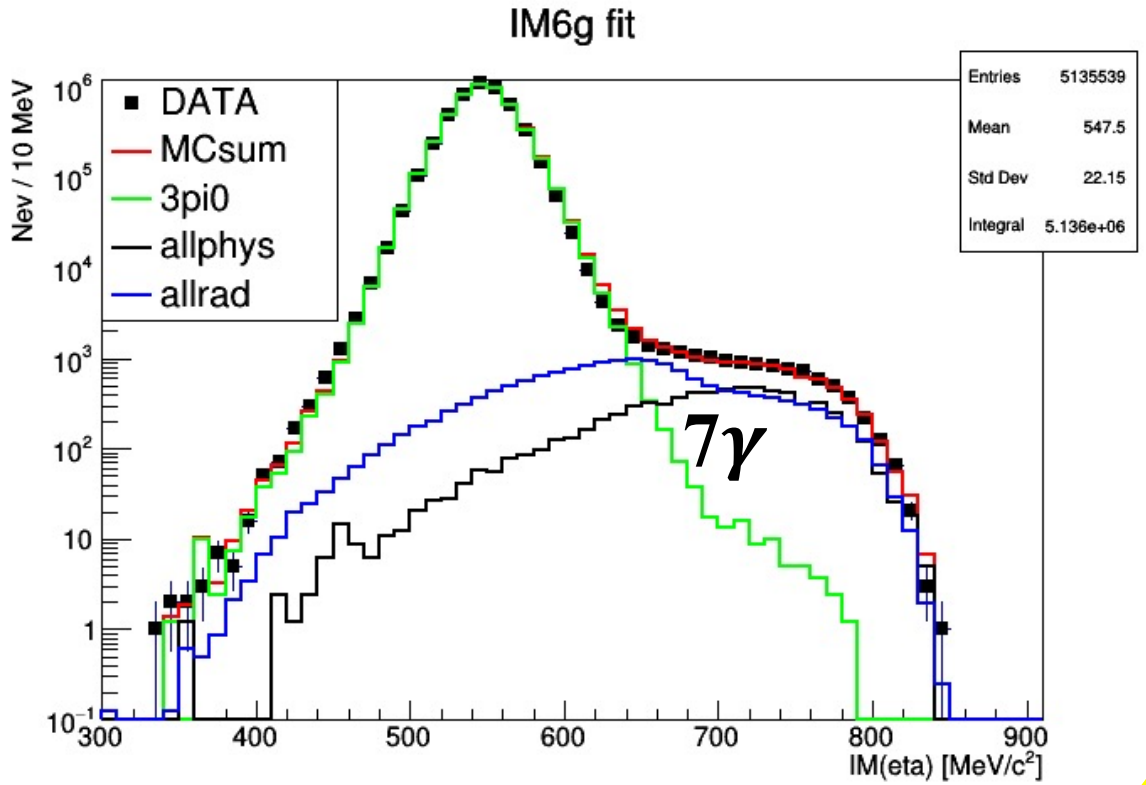
L_{int}= 1730 pb^{-1}

$7.1\times10^7\eta$

Sig: 1250± 130 evts

Great agreement of data-MC sum of S+all background components. Residuals have pull sigma=1
Clear evidence of the signal (S/B~0.1) ~ 20% efficiency
10% stat. error i.e. 3 times better than previous KLOE study

BR normalization: counting $\eta \to 3\pi^0$



$$\frac{BR(\eta \to \pi^\circ \gamma\gamma)}{BR(\eta \to 3\pi^\circ)} = \frac{N_S/\varepsilon_S}{N_{3\pi^\circ}/\varepsilon_{3\pi^\circ}}$$

$$BR = (1.23 \pm 0.14_{stat}) \times 10^{-4}$$

Preliminary KLOE result:

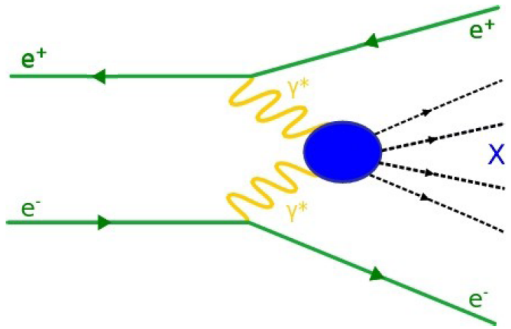
- Normalization based on very stable counting of 7 photons events.
- few % stability on the counting if integrating 6-8 photon events
- **In agreement with latest theory calculation and with old KLOE preliminary (1.3 sig)**
- **Work on systematics is well progressed (Kin fit, TVMA, Chi2 cut)**
- **Work on M(gg) spectrum is also on-going**

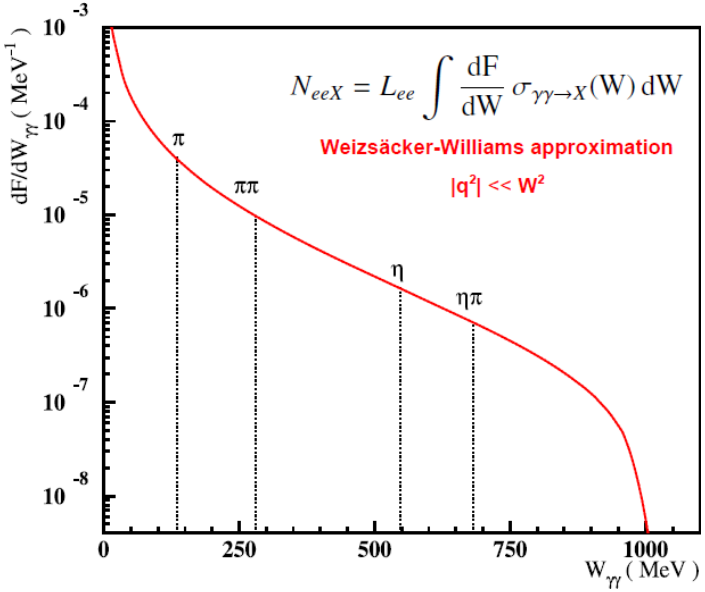
Status of $\gamma\gamma \rightarrow \pi^0$

$\gamma\gamma$ Physics at KLOE-2

$$e^+e^- \to e^+e^-\gamma^\star\gamma^\star \to e^+e^-X$$

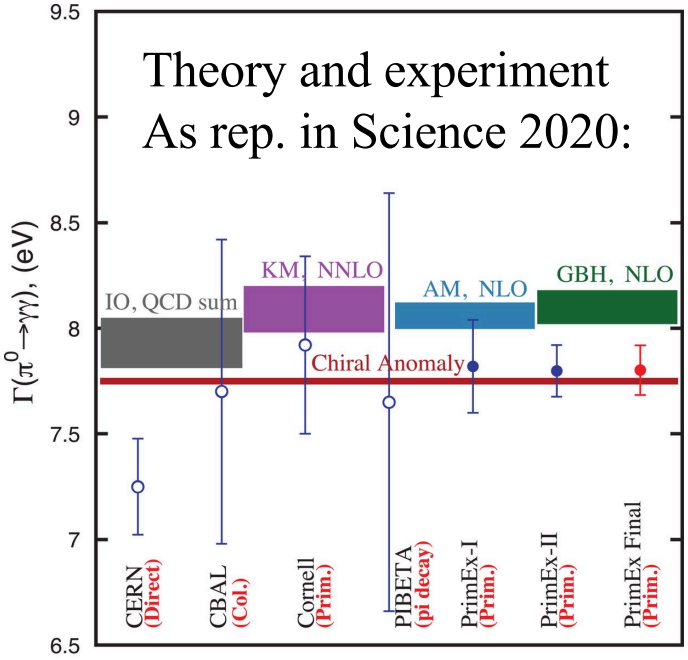
for quasi-real photons $J^{PC}(X) = \{0^{\pm,+}, 2^{\pm,+}\}$
$\to X = \{\pi^0, \pi\pi, \eta\}$





Physics Goals of tagging low-angle scattered e+/e- in KLOE-2

- Precise measurement of the $\Gamma(\pi^0 \to \gamma\gamma)$ with collider method (i.e. as CBAL, ASG)
  → Aiming at few % precision
- Measurement of the FF for $q^2 < 0.001$ GeV^2



Low angle Tagging system in KLOE – 2: HET

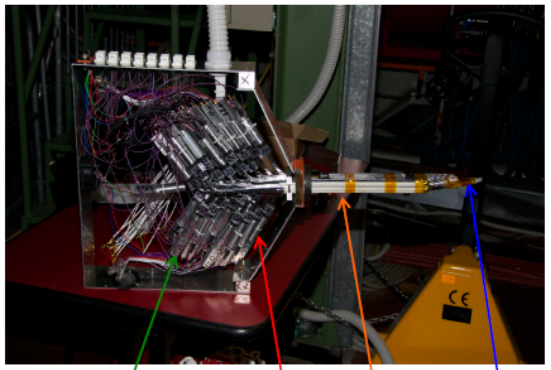
- **HET (High Energy Tagging) stations located 11 m away from IP** after the first Bending dipole of DaΦne acting as a momentum Spectrometer for the scattered leptons

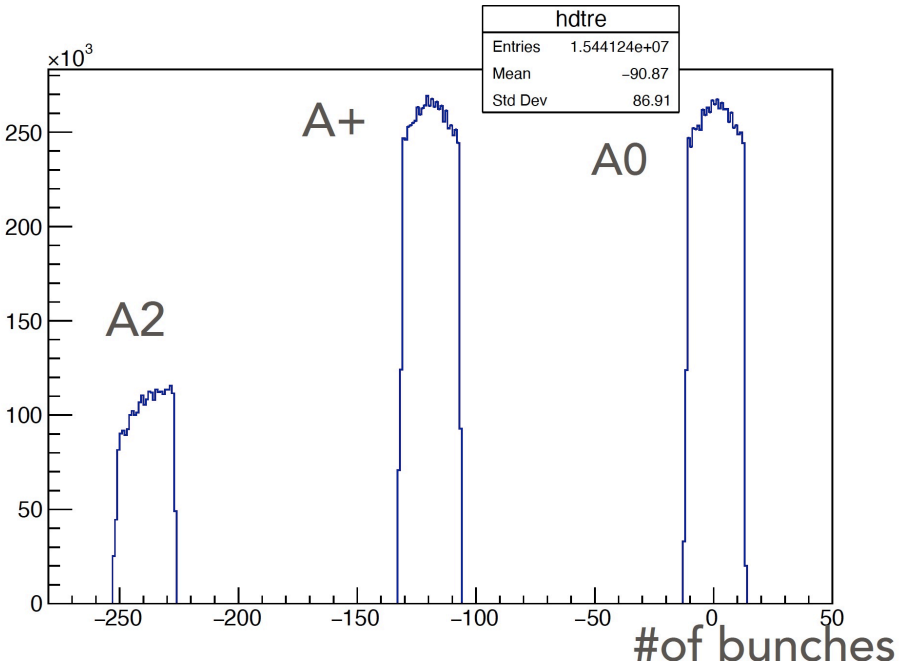
- **HET acquisition syncronized w.r.t. the KLOE DAQ with DaΦne** (each 325 ns) and the KLOE trigger. The HET acquisition window corresponds to 2.5 DaΦne revolutions recorded when a KLOE trigger is asserted

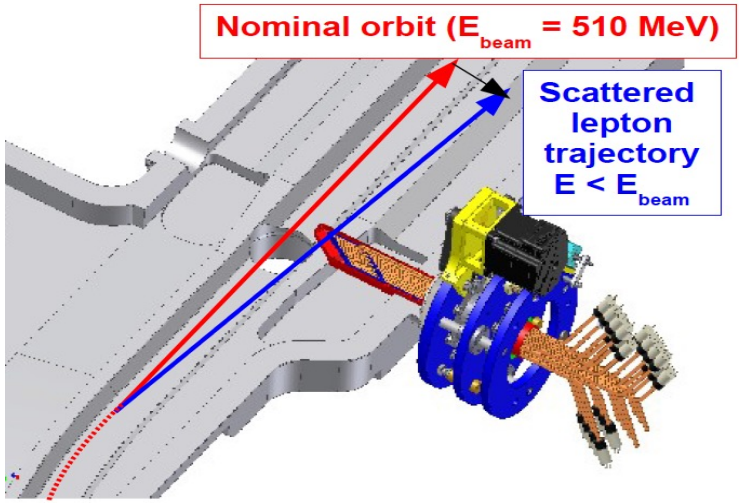
- **Analysis is based on the accidental pure (A0/A2) samples** used for background modeling with respect to the accidental + **HET*KLOE coincidences (A+ sample)**

HET: Scintillator hodoscope with 28 plastic scintillators in Roman Pots

$\sigma_\theta \sim 2,5\text{mrad}, \sigma_r \sim 5\text{mm}, \sigma_t \sim 500(1)\text{ps}$







Status of $\gamma\gamma \rightarrow \pi^0$ search with 1.5/fb (1)

- ❑ reconstruction of 3 fb^{-1} completed
- ❑ Here we present only 2017-2018 data surviving our DQM

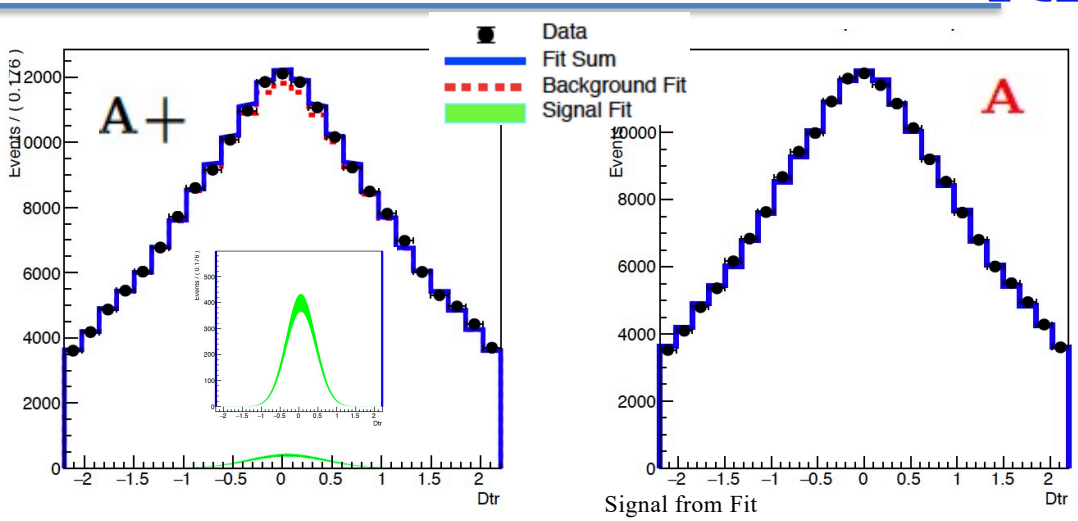
❑ **Single-arm selection established**

- 2 photon sample associated to the same bunch crossing
- Selected bunch crossing, and, independently selected HET signal, in a time window of 40 ns around the KLOE trigger

❑ **Simultaneous fits of A+/A samples**

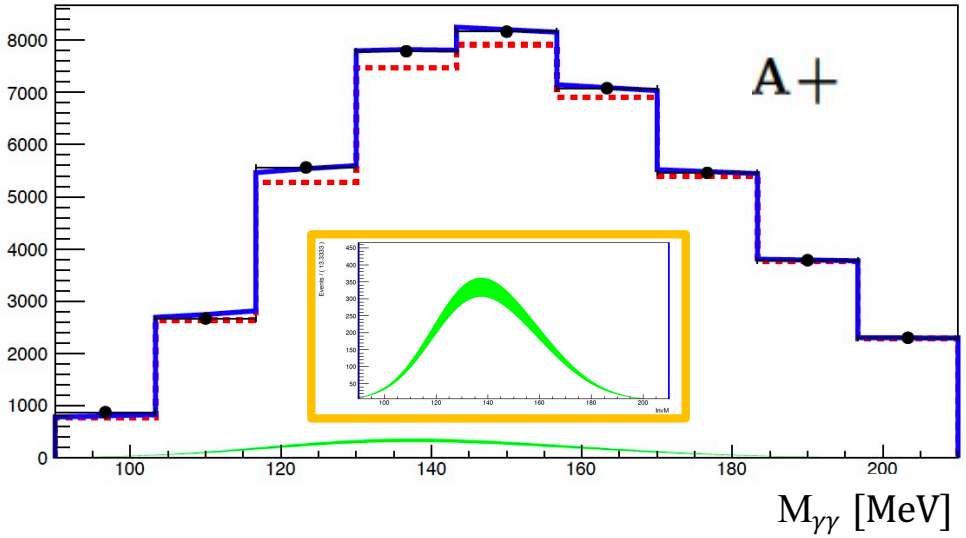
Fit to accidental−pure samples used to constrain the

- number of accidentals in A+
- Time coincidence window : 4 bunch crossings

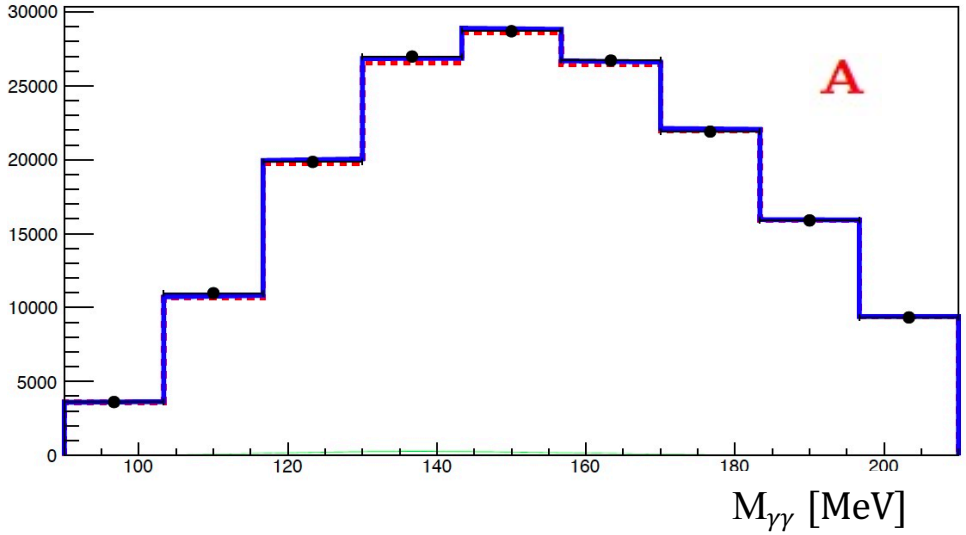


- Accidental pure sample (A) used to model background pdf
- Signal pdfs by Ekhara simulation, control samples and BDSIM transport of the leptons through the beam line.
- Acceptance extracted using low angle radiative Bhabha cross section measurements .. in progress

$\Delta T_{\gamma\gamma} - \Delta R_{\gamma\gamma}/c < 0.3$ ns

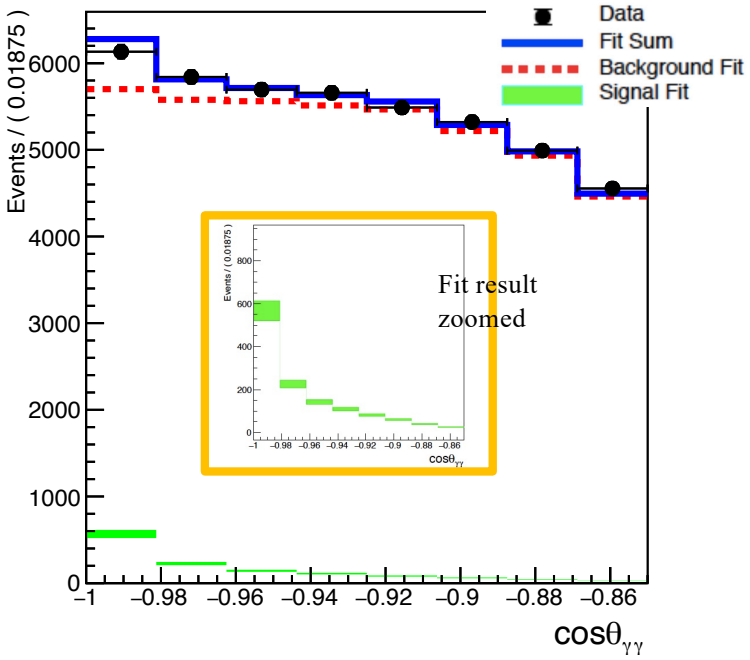


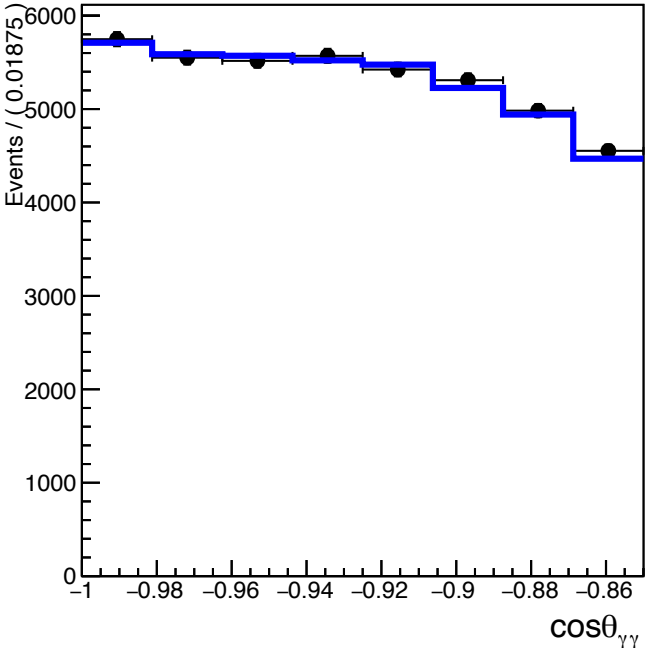
$\Delta T_{\gamma\gamma} - \Delta R_{\gamma\gamma}/c > 0.3$ ns

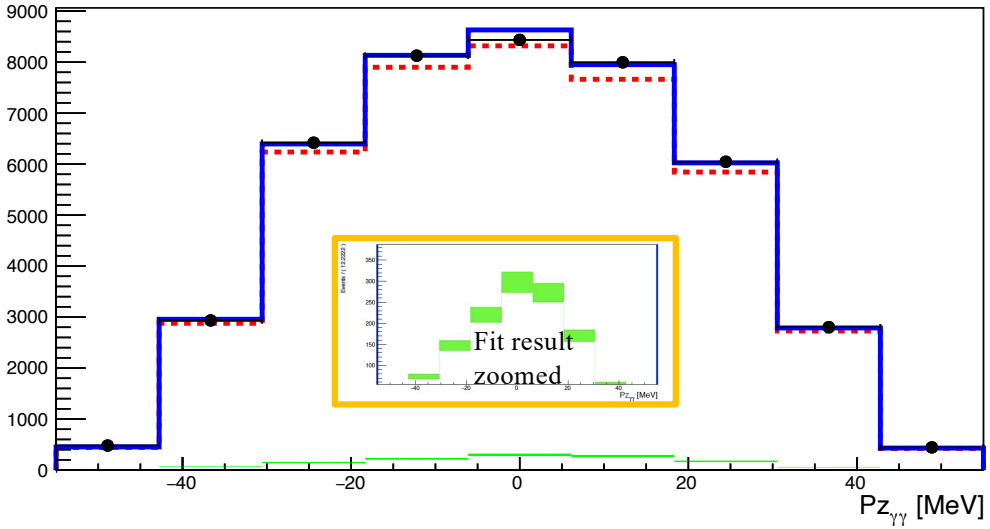


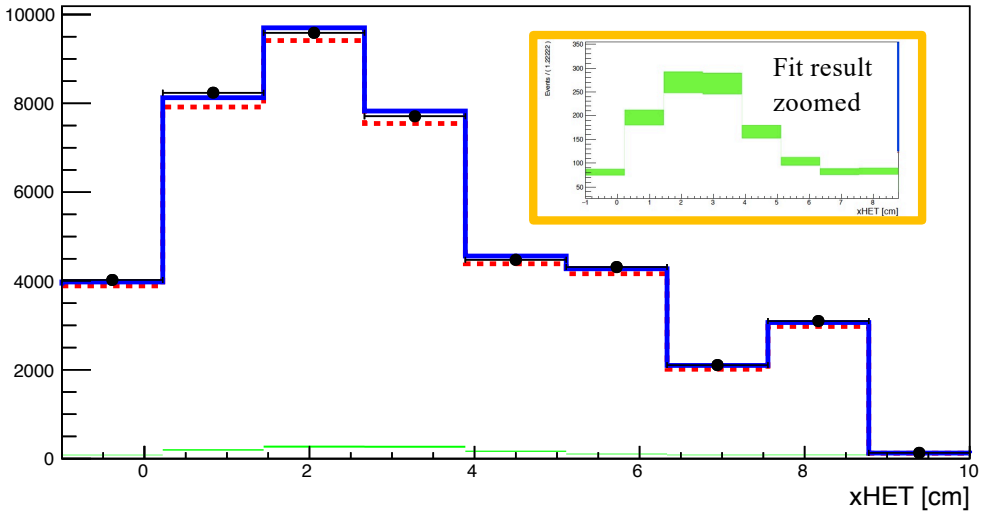
Status of $\gamma\gamma \to \pi^0$ search with 1.5/fb (2)

- $M_{\gamma\gamma}$, $\cos\theta_{\gamma\gamma}$ with a signal enriched cut ($\Delta T_{\gamma\gamma}-\Delta R_{\gamma\gamma}/c < 0.3$ ns) simultaneously fit
- Pz vs plastic position (xHET) correlation included in the fit.
- checks of simultated signal and fit results ongoing







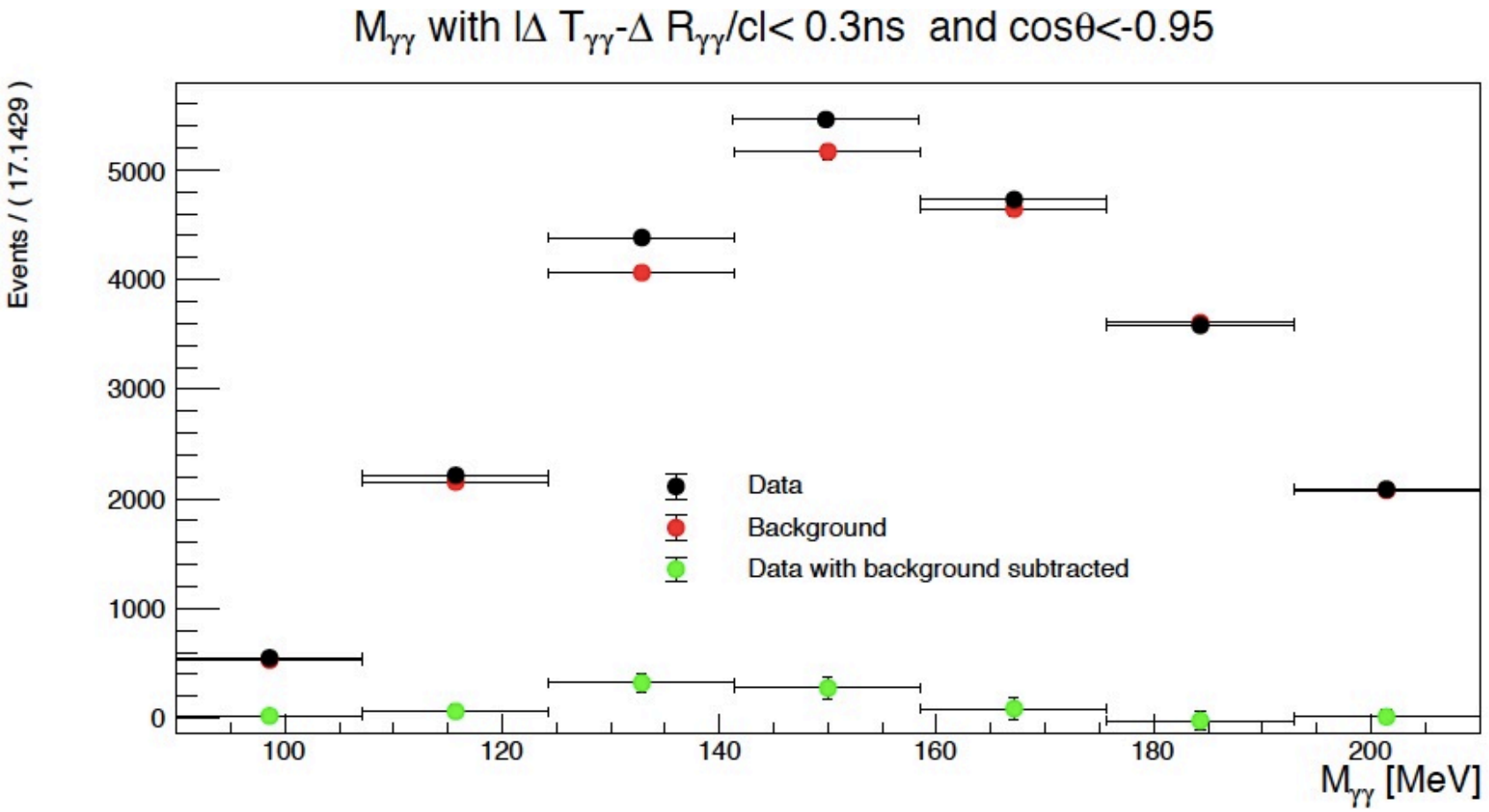


Status of $\gamma\gamma \to \pi^0$ search with 1.5/fb (3)

- **8% precision on signal reached with ~ 1.5 fb^{-1}** (2017-18 data)
- Now performing calibration of the other samples

➔ Investigating effect of kinematic fit procedure on reconstructed variables

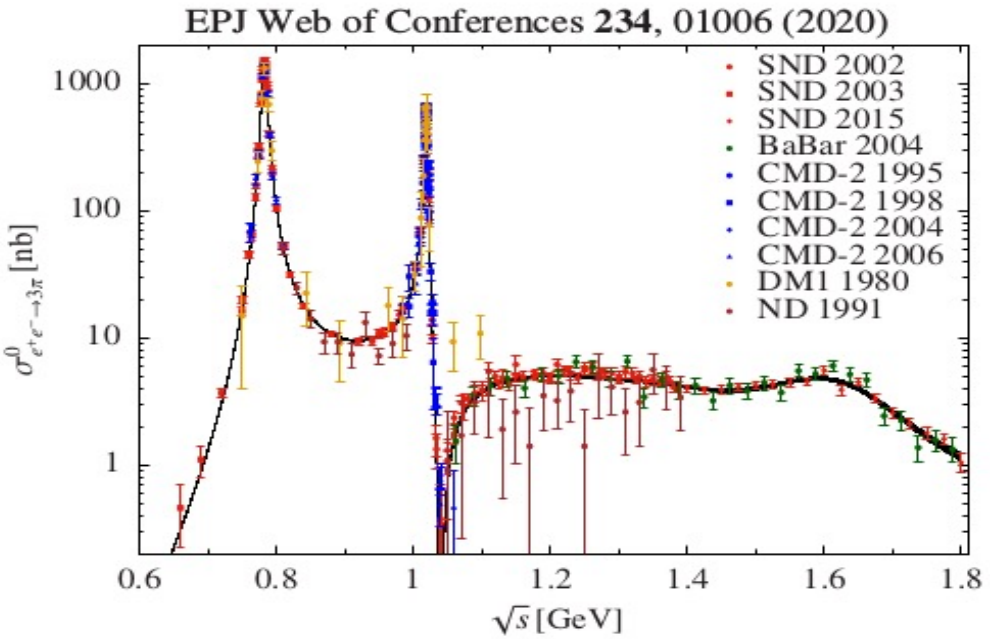
➔ Example of «iper-selected» events shown below

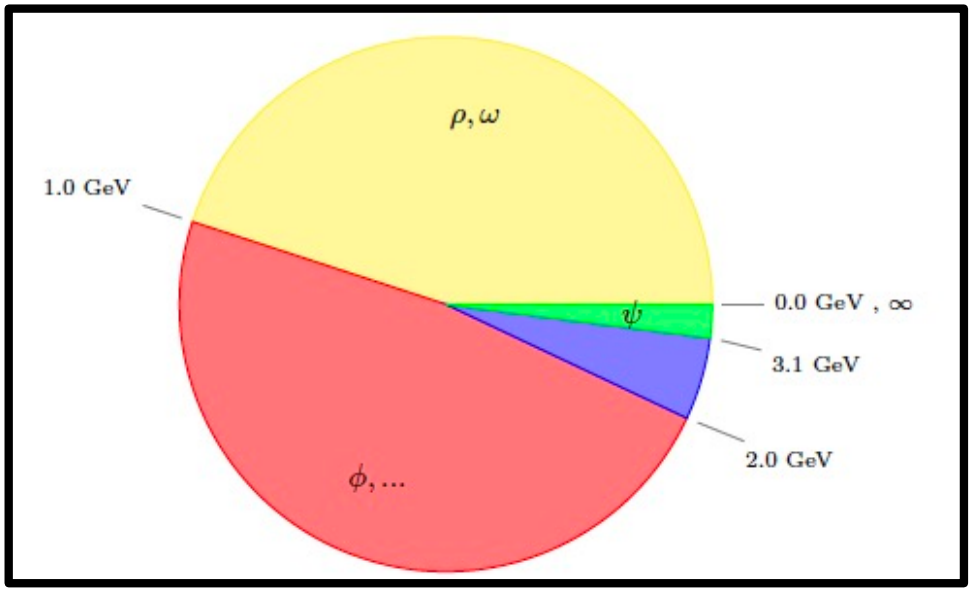


Status of ISR production of $\pi^+ \pi^- \pi^0$

3π channel with ISR return (1)

- 3π channel represents the second largest contribution on a_μ^{HVP} at the leading order, both in absolute values and uncertainties.
- Current cross section measurement of $e^+e^- \to 3\pi$ comes from CMD-2/SND measurement with energy scan and by Babar/BES with ISR technique.
- For SQRT(s) < Mϕ, this measurement is feasible using ISR technique in KLOE/KLOE-2
- Improve lack of ISR data samples in low energy region, complementary results to direct energy scans





Further physics goals:

- ✓ to extract the peak cross section of the process $e^+e^- \to V \to 3\pi$, involving vector resonances $V = \varphi, \omega$ and to measure cross section of non-resonant process $e^+e^- \to \gamma \to 3\pi$
- ✓ to measure product of branching fractions $B(\omega \to e^+e^-) \times B(\omega \to 3\pi)$

3π channel with ISR return (2)

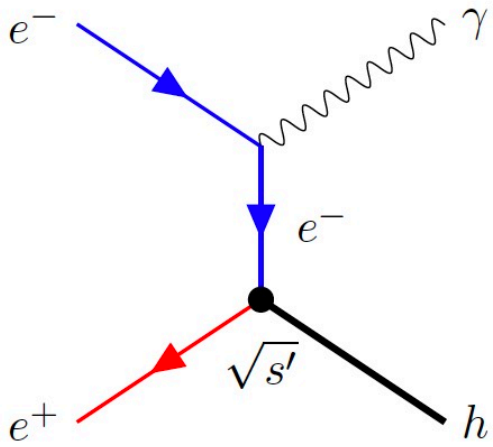
In KLOE we can use 246/pb off-peak and 1.7/fb on-peak

- **Sample used: 1.7/fb on-peak**
- MC signal generated with PHOKHARA 5

Event selection:

- **At least two tracks** with opposite curvature
- **Three neutral clusters** with:
  - $|\cos\theta|<0.92$, Eclu >15 MeV,
  - Tclu-Rclu/c < min $(2,5\sigma_t)$ ns
- Two tracks with opposite curvature that are extrapolated inside a cylinder with

  $r = \sqrt{x^2 + y^2} < 4$ cm and $|z|< 10$ cm



$e^+e^- \rightarrow hadrons + \gamma$

Additional selections:

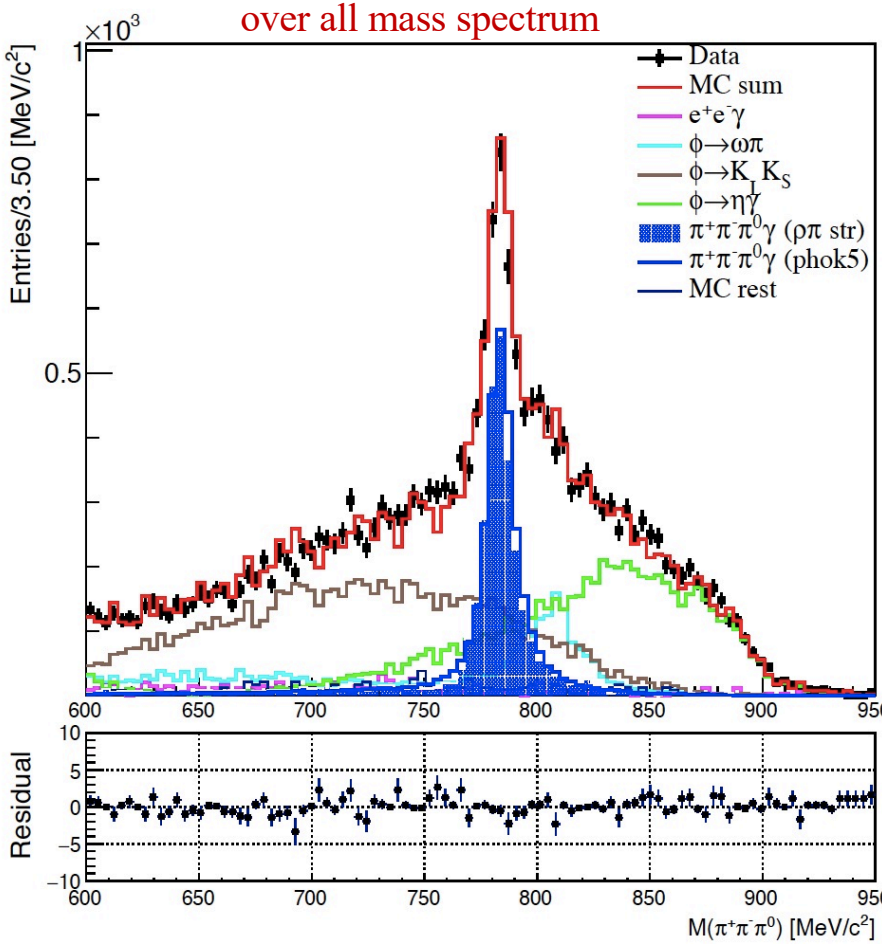
- Kinematic fit with seven constraints
  $\chi^2_{7C} < 26$ rejects Kaons
- $\cos\gamma\gamma < 140°$ to reject Bhabhas
- $E_\gamma < 207$ MeV to reject $\rho\pi$

$$E_\gamma = |\bar{p}_{\pi+} + \bar{p}_{\pi-}| - \left(\sqrt{s} - \sqrt{m_\pi^2 + p_{\pi-}^2} - \sqrt{m_\pi^2 + p_{\pi+}^2}\right)$$

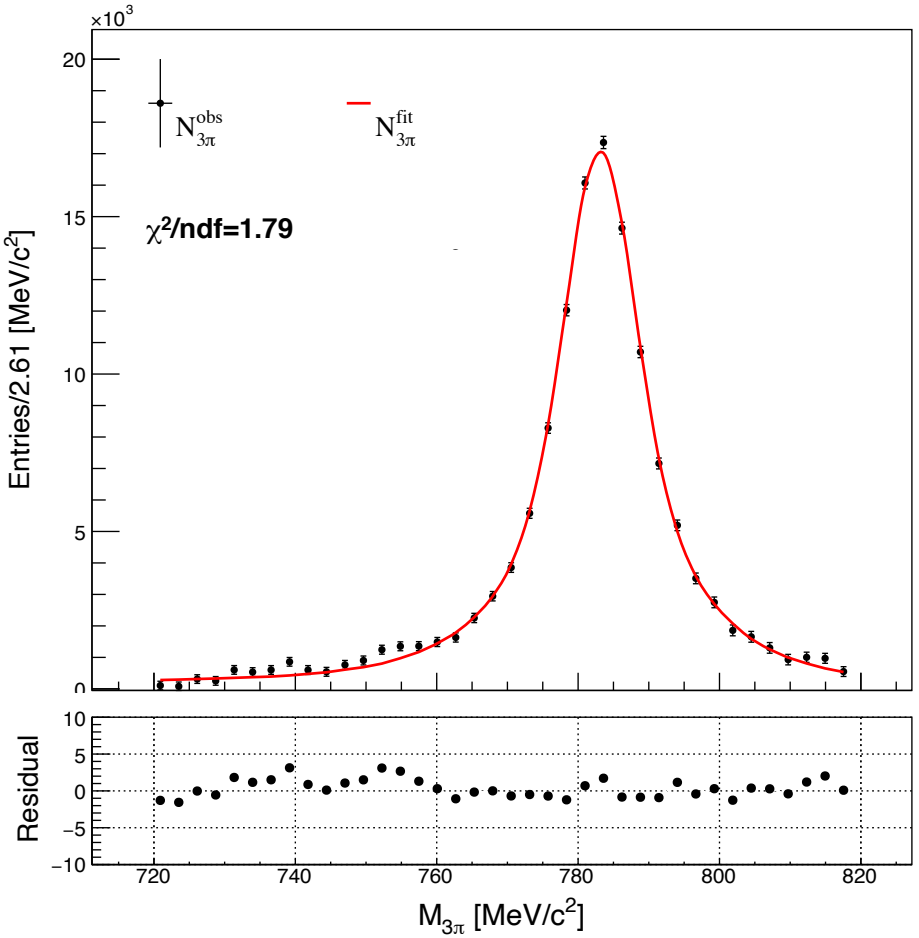
$$\beta_\pi < f_\beta\,(M_{2\pi})$$

3π channel with ISR return (3)

Good data-MC agreement reached over all mass spectrum



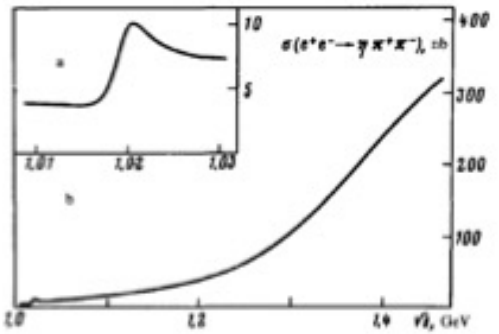
Extraction of 3π cross section in the ω region in progress:



- Data fit with a single BW convoluted with the ISR radiator and a mass resolution smearing function
- Large improvement on fit quality with better mass resolution description (2 gaussians) ➔**Still improveable**
- **Errors on fit parameters are excellent (** 10-50 keV on Γ and Mass and % on Bee*B3π)
- Analysis of systematics on analysis cuts, background subraction still on-going
- Theory fit model being refined

First look for the $\phi \rightarrow \eta\pi^+\pi^-$ and $\phi \rightarrow \eta\mu^+\mu^-$ decays

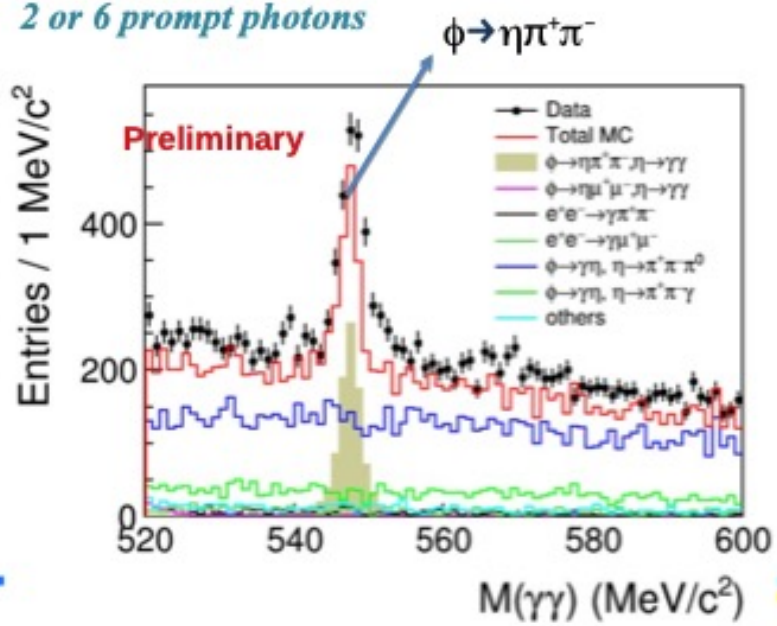
- In VMD model, $e^+e^- \rightarrow \eta\pi^+\pi^-$ is proceed via ρ resonances, mainly via $\rho\eta$ intermediate state. KLOE/KLOE-2 data allow to measure the line shape around ϕ
- $\phi \rightarrow \eta\pi^+\pi^-$ violates the OZI rule and G-parity, VMD predicts the Br~ 0.35×10^{-6}. Br<1.8×10^{-5} @ 90% CL @ CMD-2 PLB491(2000)81
- The same sample can be also used to search for the Dalitz decay $\phi \rightarrow \eta\mu^+\mu^-$, Br<$0.94\times10^{-5}$ @ 90% CL @ CMD-2 PLB501(2001)191

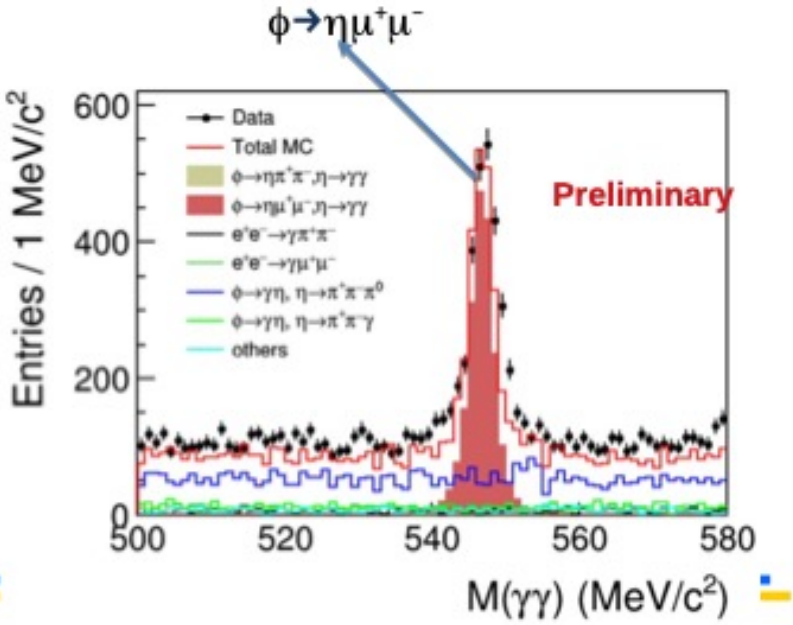


With ~700 pb^{-1} KLOE data, analysis procedure for $\phi \rightarrow \eta\pi^+\pi^-$ and $\eta\mu^+\mu^-$ is established:

- *$\eta \rightarrow \gamma\gamma/\pi^0\pi^0\pi^0$*
- *2 charged tracks*
- *2 or 6 prompt photons*

clear $\phi \rightarrow \eta\pi^+\pi^-$ and $\eta\mu^+\mu^-$ signals





Conclusions

- The KLOE and KLOE-2 experiment have collected a total of 8/fb of high quality data for both Kaon Physics and **low energy hadrons**

- We have published **the world best limit on $\eta \to \pi^+\pi^-$** using the whole KLOE data sample reaching the limit **BR < $4.9E^{-6}$**, 3 times better than previous one

- We are studying 5 photon final state to set the world best limit on the **leptophobic B-Boson searching for the decay chain $\phi \to \eta B$, $B \to \pi^0\gamma$**
  ➔ same 5 photon sample is used to **study the golden Chi-pt process $\phi \to \eta\gamma$, $\eta \to \pi 0\gamma\gamma$**
  Our preliminary BR is ~1/2 of previous best measurements and in agreement with the most recent theory calculation

- We are using π^0's produced with $\gamma\gamma$-fusion and tagged with our low angle tagging system to determine the $\Gamma(\pi^0 \to \gamma\gamma)$ of this process. **8% stat. error reached on the first 1.5/fb**

- **A clean signal of 3π final state in the ω region through ISR method is established.** Statistical determination of the parameters looks very promising.

- We have observed for the first time, **clean signals for $\phi \to \eta\pi^+\pi^-$ and $\phi \to \eta\mu^+\mu^-$ decays**

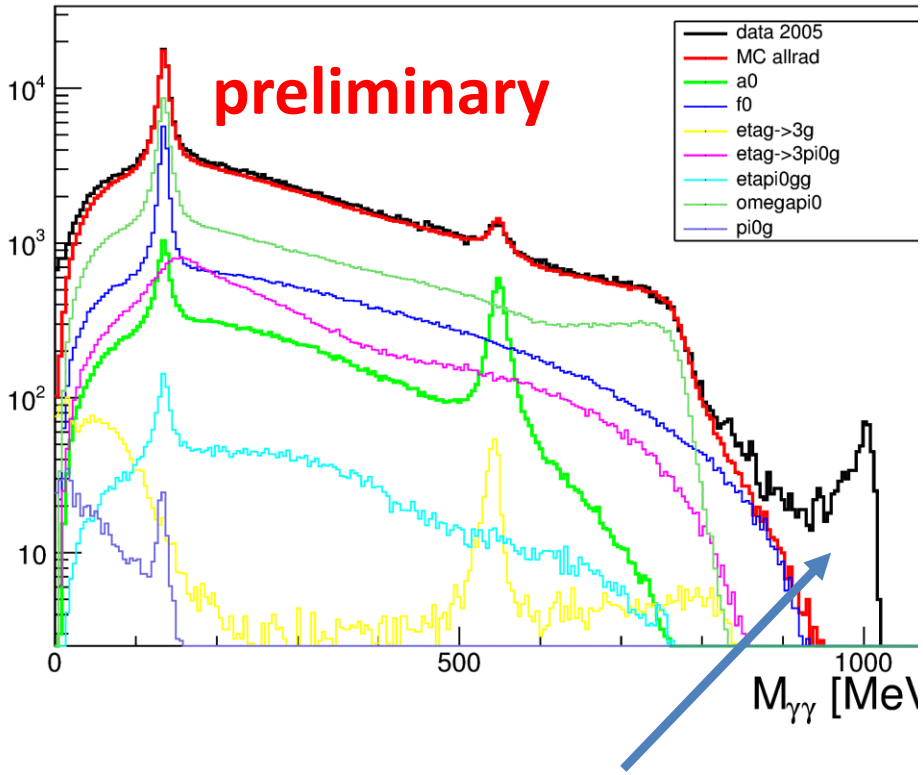
- Working hard to complete all of these items. **Stay tuned**

Additional material

$B \to \pi^\circ\gamma$ in $\phi \to B\eta$ channel

- Study on 1.7 fb^{-1} of KLOE data
- 5 prompt photons in the final state:
  - $\phi \to \eta B \to \eta(\gamma\gamma)\pi^\circ(\gamma\gamma)\gamma \to 5\gamma$
- Main background coming from: $\phi \to (a_0 \to \eta\pi^\circ)\gamma$ and $\phi \to (\eta \to 3\pi^\circ)\gamma$ with lost or merged photons
- Kinematic fit to improve resolution

M(2γ) after kinematic fit correction



$e^+e^- \to \gamma\gamma$ events not in the MC

Low angle radiative Bhabhas cross section measurement

Motivation: infer HET $A \times \varepsilon$ with high precision

$P_0 = (1 - p_b)^N$

P_0: probability to have no signal in the HET

p_b: probability per bunch crossing to register one radiative Bhabha with the HET, linearly increasing with luminosity (L $[10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}]$)

N: number of bunches considered in the measurement (N=22)

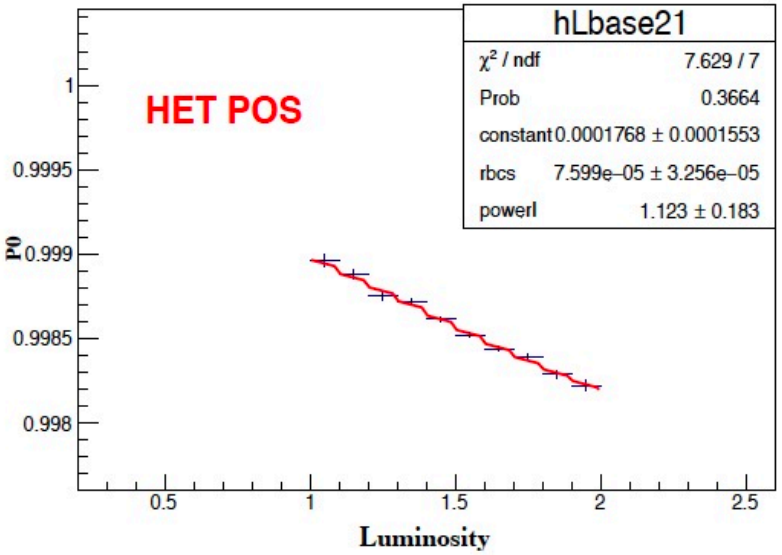
Data analyzed per bin of circulating DAFNE currents ($I_{e,p}$ [A]) and per HET channel

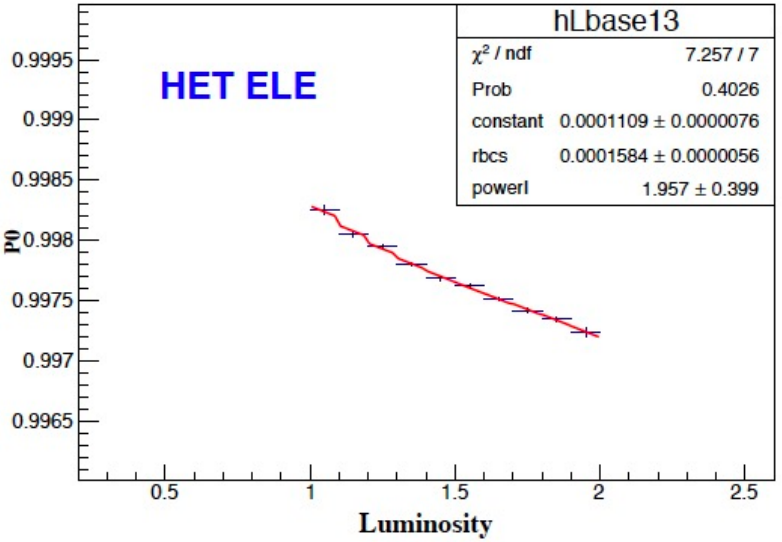
Measured probability $p = p_b \times (T_{bunch}/10\,ns)$

$A' \times \sigma_{Bha}$ estimated by a fit to P_0 as a function of L measured by KLOE with Large Angle Bhabha

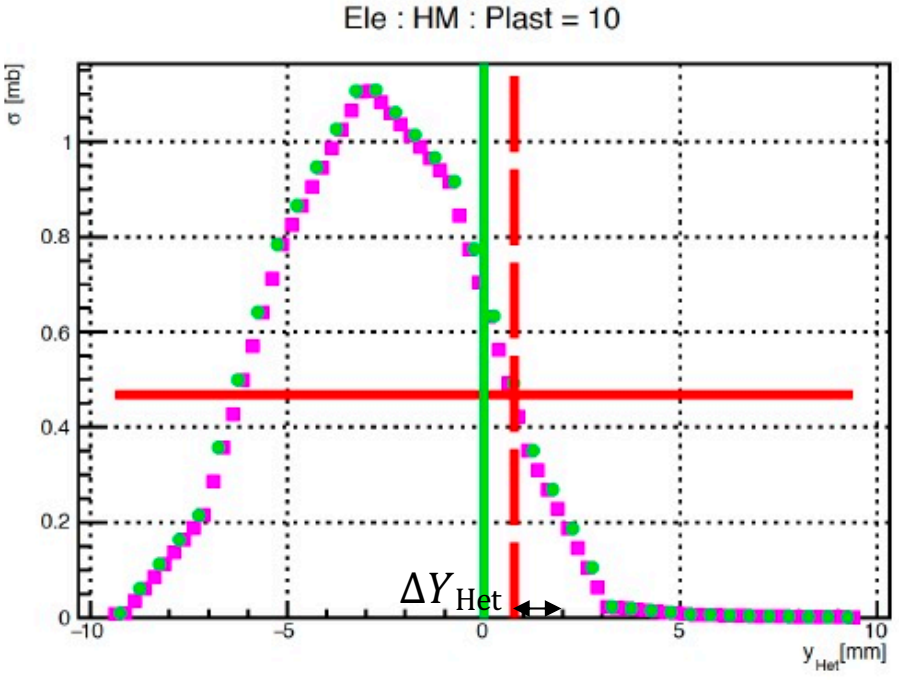
Fit function: $(1 - p)^N$,
$p = K + A' \times \sigma_{Bha} \times L$, $K = \alpha \times I_{e,p}^{\beta}$

Reference period: Oct17-Dec17





σ (X_{HET}, Y_{HET}), Bbbrem vs Ekhara



Magenta squares: BBBrem $\sigma(Y_{Het})$ (small binning)

Green circles: BBBrem $\sigma(Y_{Het})$ (large binning)

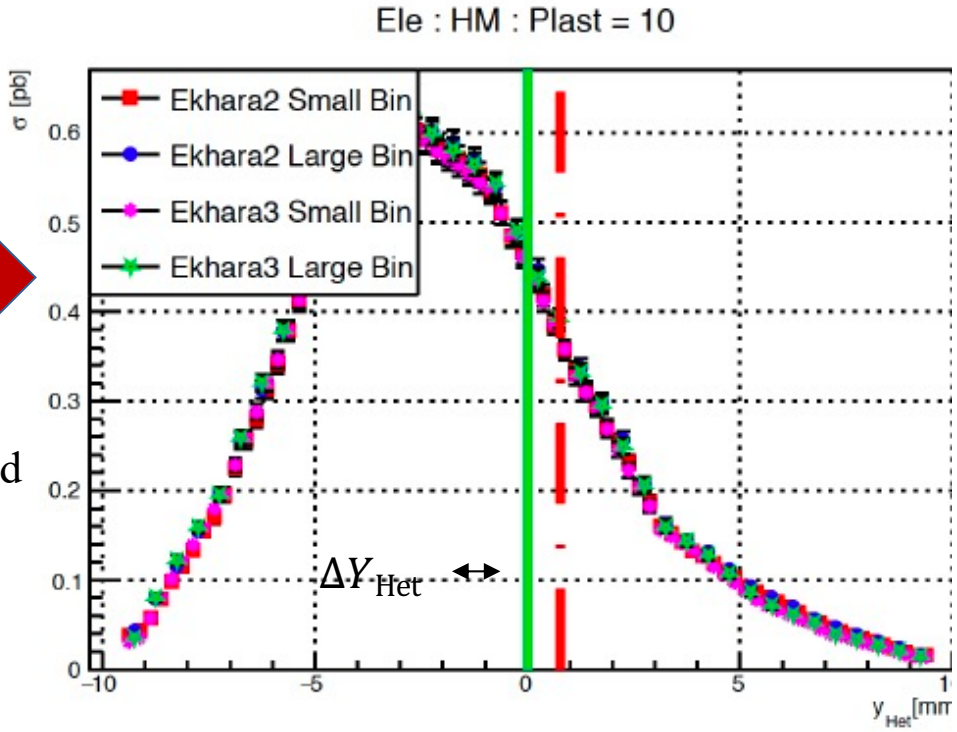
Vertical green line: Plastic design position

Horizontal red line: $A' \times \sigma_{Bha}$ measureme

Vertical dashed red line: Plastic position from $A' \times \sigma_{Bha}$ measurement

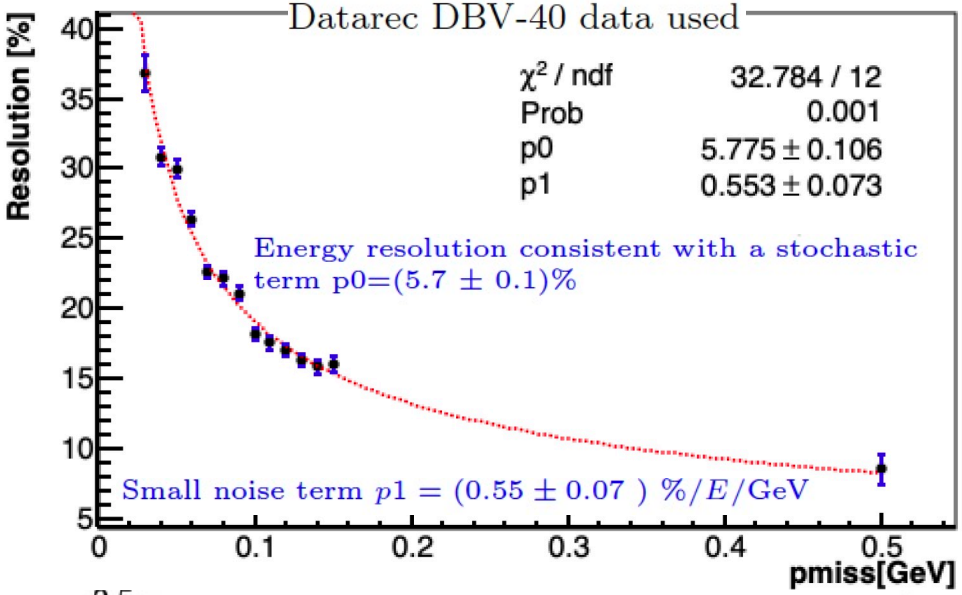
Vertical green line: Plastic design position

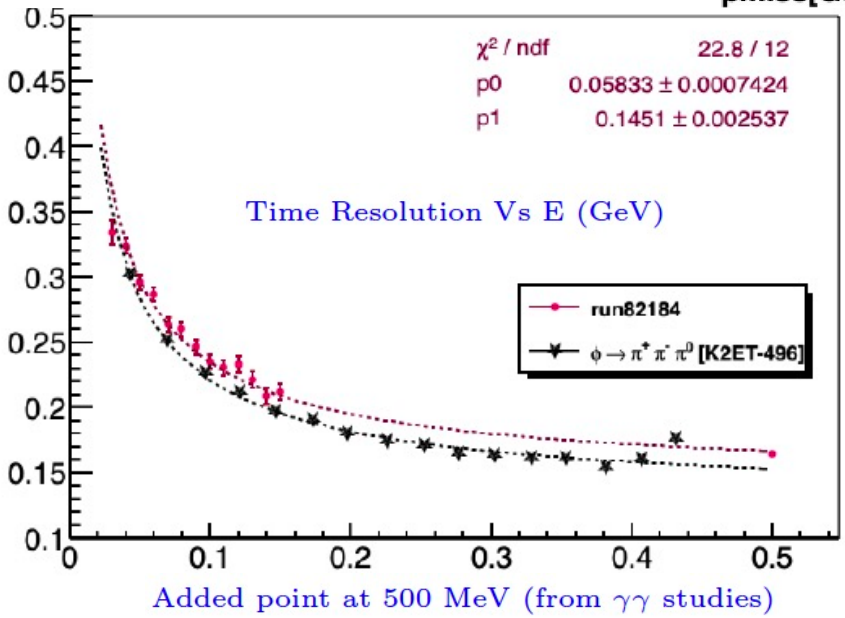
Vertical dashed red line: Plastic position from $A' \times \sigma_{Bha}$ measurement

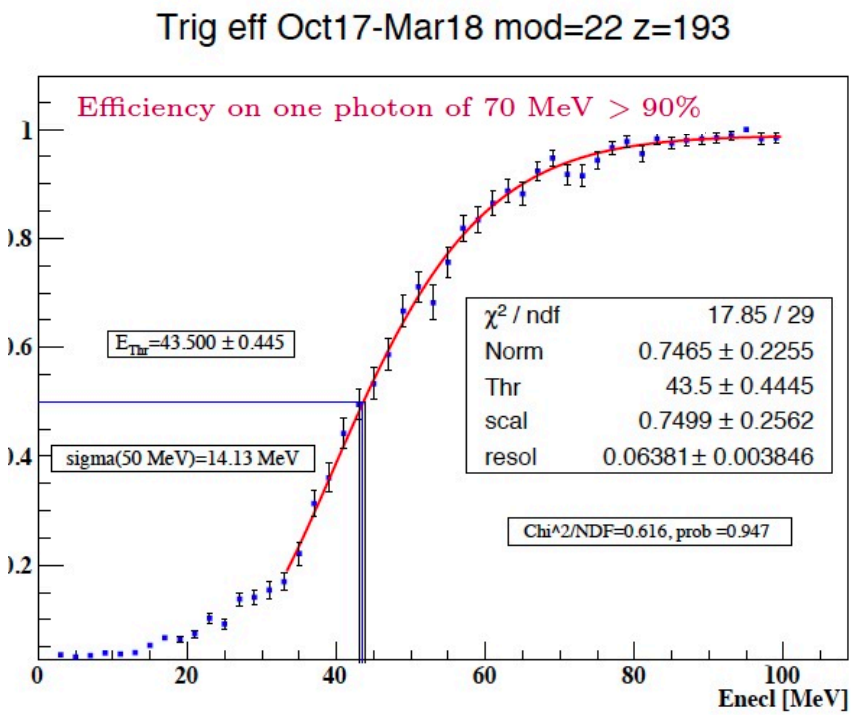


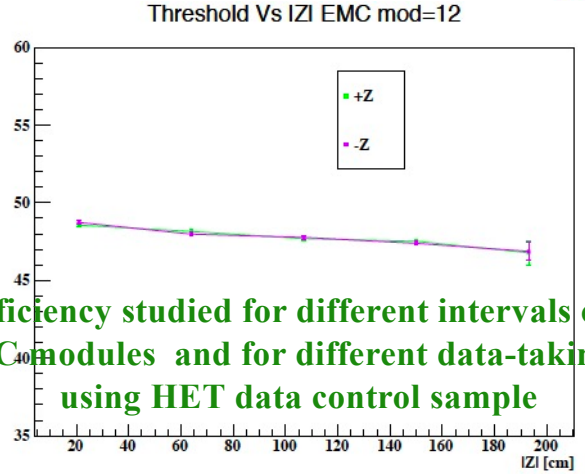
1. Average Y_{HET} shits derived for each data taking period from low angle Bhabha cross section measurement per channel
2. A final global shift for each station is then included in the simulation of the π^0 signal (red line)

EMC Resolution and Trigger efficiency using radiative Bhabhas control samples

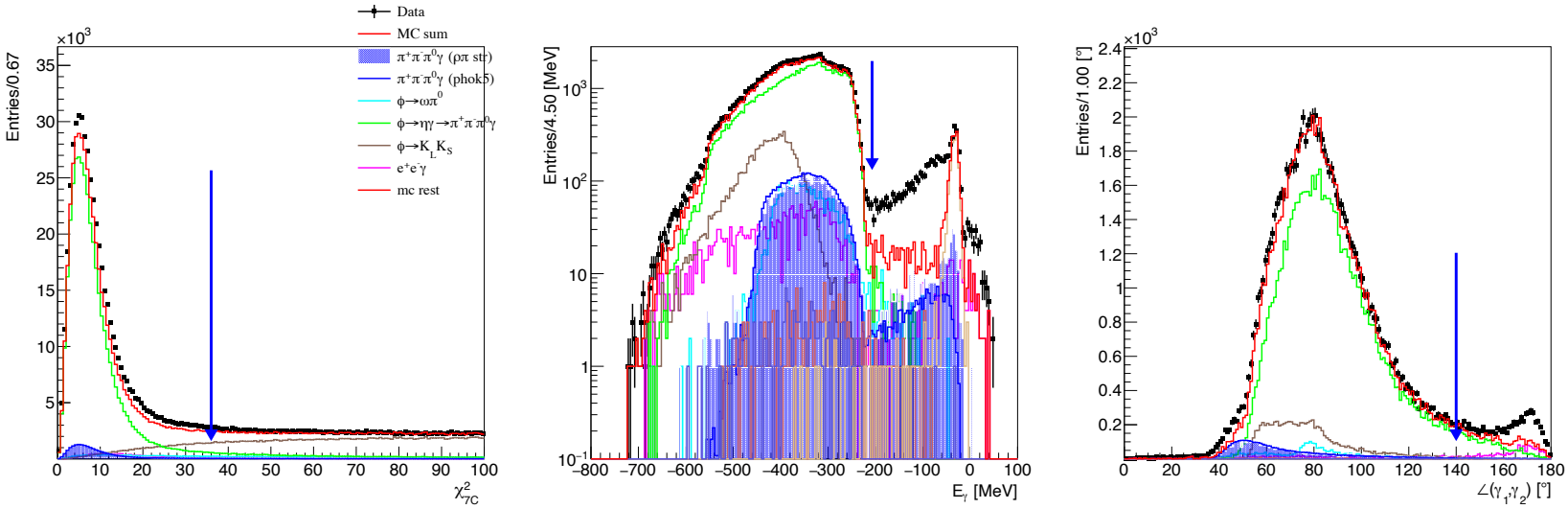




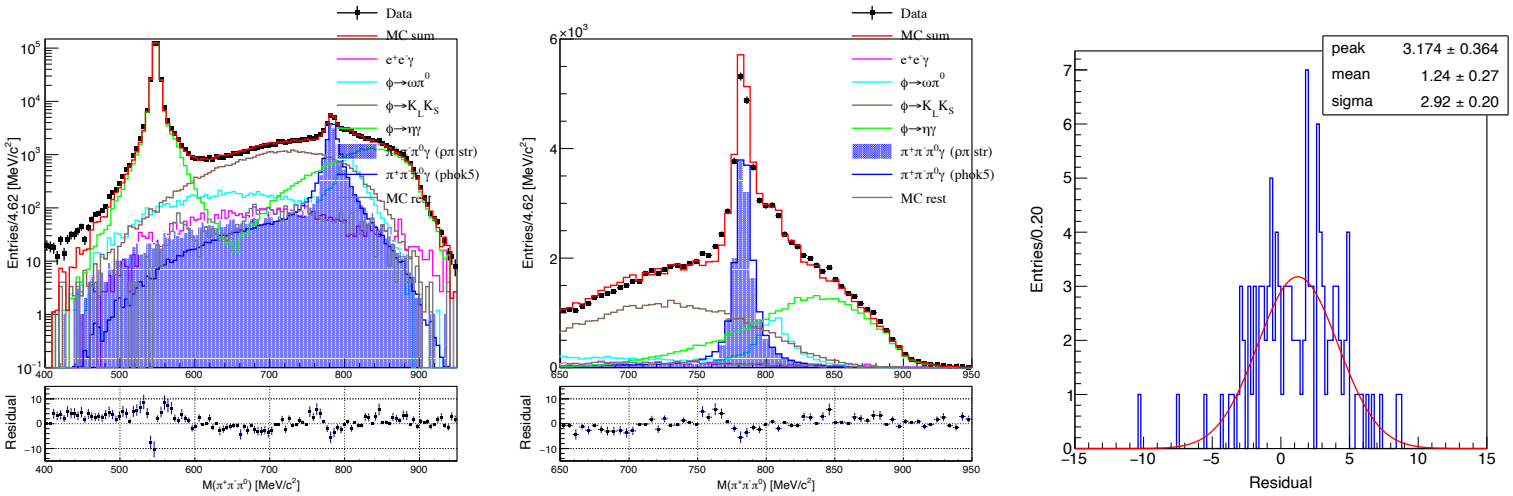




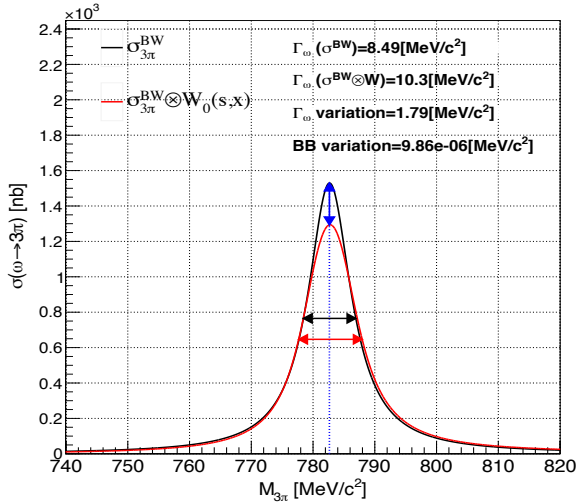
Trigger efficiency studied for different intervals of |Zcl|, for all 24 EMC modules and for different data-taking periods using HET data control sample



Left: Chi-square distribution after pre-selections. Middle: Photon energy distribution after the χ^2_{7C} cut. Right Opening angle distribution after χ^2_{7C} and E_γ cuts. Arrows: Nominal



Left: Invariant mass $M_{3\pi}$ after the scaling. Middle: Enlarged in omega region. Right: Residual distribution after the scaling.



Normalized Breit-Wigner line shape in omega-mass region (Black). Effective line shape distorted by the ISR photon emission (Red).

Breit-Wigner resonance

- Narrow resonances: J/ψ, ϕ and ω
  $\sigma_{3\pi}^{\rm BW}(s') = \frac{12\pi}{M_V^2}\frac{s'}{(s'-M_V^2)^2+M_V^2\Gamma_V^2}\Gamma_{ee}\Gamma_{3\pi}$
- ISR distorted visible cross section.
  $m = \sqrt{s(1-x)}$.

Determine $\Delta\Gamma$ and $\Delta\mathscr{B}\mathscr{B}$

$\sigma_{3\pi}^{\rm BW}\otimes W_0(s,x)$ in small mass interval $\Delta M_{3\pi}$,
$N_{3\pi}^{\rm teo} = \mathcal{L}_{\rm int}\sigma_{3\pi}^{\rm vis} \approx L_{\rm ISR}\sigma_{3\pi}^{\rm BW}$, where

$$\sigma_{3\pi}^{\rm vis} \approx \int_0^{x_{\rm max}} \varepsilon(s,x)W_0(s,x)\sigma_{3\pi}^{\rm BW}(s(1-x))dx,$$

resulting

$$\sigma_{3\pi}^{\rm vis}(\Gamma,\mathscr{B}\mathscr{B}) \rightarrow \sigma_{3\pi}^{\rm BW}(\Gamma_{\rm BW}+\Delta\Gamma,\mathscr{B}\mathscr{B}_{\rm BW}+\Delta\mathscr{B}\mathscr{B})$$