



Tests of fundamental symmetries in the η meson decays

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- CP and C tests with η meson
- Rare decays $\pi^0, \eta \rightarrow e^+e^-$
- Experiments:
 - KLOE-2 at DaΦne (Frascati, Italy)
 - WASA-at-COSY (Jülich, Germany)
 - Crystal Ball at MAMI (Mainz, Germany)



Tests of discrete symmetries in η decays

- C invariance in em interactions of hadrons

Bernstein,Feinberg, Lee PR139,B1650,1965

- π^0, η C,CP eigenstate
- all first order processes suppressed
- π^0, η abundantly produced:
 $\pi^- p \rightarrow n \eta$ (BNL); $\gamma p \rightarrow p \eta$ (MAMI,ELSA)
 $pp \rightarrow pp \pi^0, \eta$ (COSY)
 $e^+ e^- \rightarrow \phi \rightarrow \eta \gamma$ (DAΦNE)
- η : complementary (flavor conserving) to K_L decays

⇒ Rare decays

⇒ Symmetries of the decay distributions



- $\eta \rightarrow \pi\pi$

- predictions:

Jarlskog, Shabalin PRD52,248;PRD52,6327

$$BR(CKM) \leq 2 \times 10^{-27} (G_F^2 \sin^2 \theta_C + \text{dynamical suppr.})$$

$$BR(QCD\theta) \leq 3 \times 10^{-17} \text{ (from } d_n\text{)}$$

$$BR(ExtrHiggs) \leq 1.2 \times 10^{-15}$$

- $\text{Exp } BR(\eta \rightarrow \pi^+\pi^-) \leq 1.3 \times 10^{-5}$

KLOE PLB606,276(05)

- $\text{Exp } BR(\eta \rightarrow \pi^0\pi^0) \leq 3.5 \times 10^{-4}$

GAMS YF70,693(07)

Background from direct 2π production

- $\eta \rightarrow 4\pi^0$

$$BR \leq 6.9 \times 10^{-7}$$

CBall(BNL) PRL 84,4802

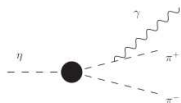
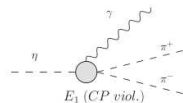
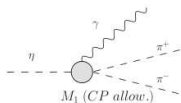


CP test in $\eta \rightarrow \pi^+ \pi^- e^+ e^-$

- $\eta \rightarrow \pi^+ \pi^- \gamma^{(*)}$ (γ polarization)

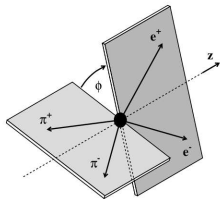
Geng, Ng, Wu MPL A17:1489(02)

- not constrained by d_n



- Angle between decay planes in $\eta \rightarrow \pi^+ \pi^- e^+ e^-$

Gao MPL A17:1583(02)



$$A \equiv \frac{N(0 < \phi < 90) - N(90 < \phi < 180)}{N(0 < \phi < 180)}$$

$$A \leq 0.02 \text{ (from } \eta \rightarrow \pi^+ \pi^- \text{)}$$

$$A = (-0.6 \pm 2.5 \pm 1.8) \times 10^{-2}$$

KLOE PLB675,283(09)



η decays: Tests of C invariance

- final states with odd $\# \gamma$ C-violating

$$BR(\eta \rightarrow 3\gamma) < 1.6 \times 10^{-5}$$

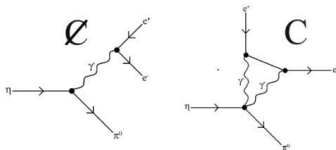
KLOE PLB591,49

$$BR(\eta \rightarrow \pi^0 \pi^0 \gamma) < 5 \times 10^{-4}$$

$$BR(\eta \rightarrow \pi^0 \pi^0 \pi^0 \gamma) < 6 \times 10^{-5}$$

CBall(BNL) PRL94,041601

- $\eta \rightarrow e^+ e^- \pi^0$



- $BR < 4 \times 10^{-5}$

PLB59,99(75)

- Test C up to $BR \approx 10^{-8}$ (decay via $\pi^0 \gamma^* \gamma^*$)

⇒ analysis WASA-at-COSY



η decays: Tests of fundamental symmetries

η

$$I^G(J^{PC}) = 0^+(0^-+)$$

Mass $m = 547.853 \pm 0.024$ MeV

Full width $\Gamma = 1.30 \pm 0.07$ keV

C-nonconserving decay parameters

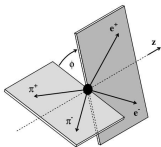
$$\pi^+\pi^-\pi^0 \quad \text{left-right asymmetry} = (0.09^{+0.11}_{-0.12}) \times 10^{-2}$$

$$\pi^+\pi^-\pi^0 \quad \text{sextant asymmetry} = (0.12^{+0.10}_{-0.11}) \times 10^{-2}$$

$$\pi^+\pi^-\pi^0 \quad \text{quadrant asymmetry} = (-0.09 \pm 0.09) \times 10^{-2}$$

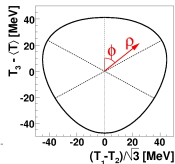
$$\pi^+\pi^-\gamma \quad \text{left-right asymmetry} = (0.9 \pm 0.4) \times 10^{-2}$$

$$\pi^+\pi^-\gamma \quad \beta \text{ (D-wave)} = -0.02 \pm 0.07 \quad (S = 1.3)$$



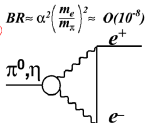
CP-nonconserving decay parameters

$$\pi^+\pi^-e^+e^- \text{ decay-plane asymmetry } A_\phi = (-0.6 \pm 3.1) \times 10^{-2}$$



Charge conjugation (C), Parity (P), Charge conjugation $\times$ Parity (CP), or Lepton Family number (LF) violating modes

$\pi^0\gamma$	C	< 9	$\times 10^{-5}$	CL=90%	257
$\pi^+\pi^-$	P,CP	< 1.3	$\times 10^{-5}$	CL=90%	236
$2\pi^0$	P,CP	< 3.5	$\times 10^{-4}$	CL=90%	238
$2\pi^0\gamma$	C	< 5	$\times 10^{-4}$	CL=90%	238
$3\pi^0\gamma$	C	< 6	$\times 10^{-5}$	CL=90%	179
3γ	C	< 1.6	$\times 10^{-5}$	CL=90%	274
$4\pi^0$	P,CP	< 6.9	$\times 10^{-7}$	CL=90%	40
$\pi^0e^+e^-$	C	[f] < 4	$\times 10^{-5}$	CL=90%	257
$\pi^0\mu^+\mu^-$	C	[f] < 5	$\times 10^{-6}$	CL=90%	210
$\mu^+e^- + \mu^-e^+$	LF	< 6	$\times 10^{-6}$	CL=90%	264

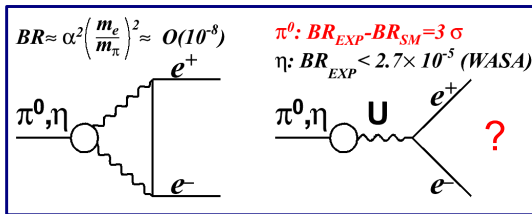


- $$BR_{\text{no-rad}}(\pi^0 \rightarrow e^+e^-) = (7.48 \pm 0.29_{\text{stat}} \pm 0.25_{\text{syst}}) \times 10^{-8}$$

PRD75:012004(07)



Rare decays $\pi^0, \eta \rightarrow e^+ e^-$



- $BR(exp) = (7.48 \pm 0.29_{stat} \pm 0.25_{syst}) \times 10^{-8}$
- $BR(SM) = (6.23 \pm 0.09) \times 10^{-8}$

Dorokhov PRD75:114007(07)

$\Rightarrow 3\sigma$ excess

- $\eta \rightarrow \mu^+ \mu^- \quad 5.8 \pm 0.8 \times 10^{-6} \quad (UB \ 4.3 \times 10^{-6})$
- $\eta \rightarrow e^+ e^- < 2.7 \times 10^{-5} \quad 90\% \text{ CL} \quad (UB \ 1.8 \times 10^{-9})$

CELSIUS/WASA PRD77:032004(08)

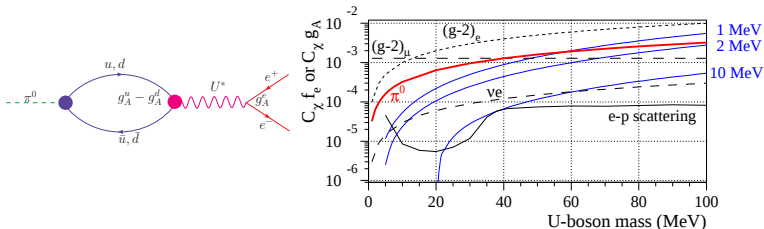
$\Rightarrow$ Sensitive to new interactions



MeV (light) Dark Matter

- Neutral scalar χ , $m_\chi \sim 1 - 10\text{MeV}$
- $\chi\chi \rightarrow e^+e^- \Rightarrow 511\text{keV}$ line from galactic center
- χ annihilation: vector boson U , $m_U \sim 10 - 100\text{MeV}$

Boehm,Fayet NPB683,2004;Kahn et al. PRD78:115002(08)



NMSSM Higgs

- $\pi^0 \rightarrow e^+e^-$ mediated via CP-odd Higgs boson A_1^0
- $\mathcal{B}(\pi^0 \rightarrow e^+e^-)$ constrain NMSSM parameter space

Chang,Yang,PLB676:88(09)



$\pi^0, \eta \rightarrow e^+e^-$ planned experiments

- $\pi^0 \rightarrow e^+e^-$:
- WASA-at-COSY test run (2010):
 $pp \rightarrow pp\pi^0$ $T_p = 0.55$ GeV (1.3 mb)
below $pp \rightarrow pp\pi^+\pi^-$ threshold
reconstructed $\pi^0 \rightarrow e^+e^-\gamma$ 9/s (total 4.5×10^6)
- $\eta \rightarrow e^+e^-$:
- WASA-at-COSY $pp \rightarrow pp\eta$
- Goal improve BR limit, feasibility
background $\eta \rightarrow e^+e^-\gamma, pp \rightarrow pp\pi^+\pi^-, \dots$



Sources of the mesons

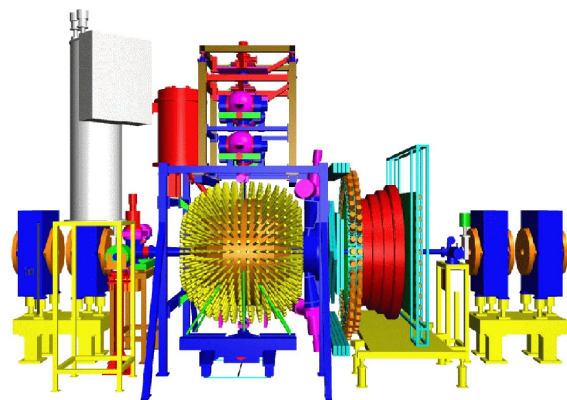
- WASA: $pd \rightarrow {}^3\text{He}\eta$ $10 \eta/s$ $3 \times 10^7 \eta$ decays
- WASA: $pp \rightarrow pp\eta$ $\geq 100 \eta/s$ $> 10^8 \eta$ decays
- WASA: $pp \rightarrow pp\pi^0$ $\approx 2500 \pi^0/s$ $\approx 10^9 \pi^0$ decays
- Crystal Ball: $\gamma p \rightarrow p\eta$ $3 \times 10^7 \eta$
- KLOE: $e^+e^- \rightarrow \phi \rightarrow \eta\gamma$ $> 10^8 \eta/\text{year}$



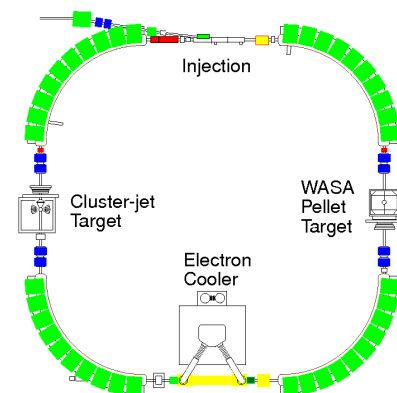
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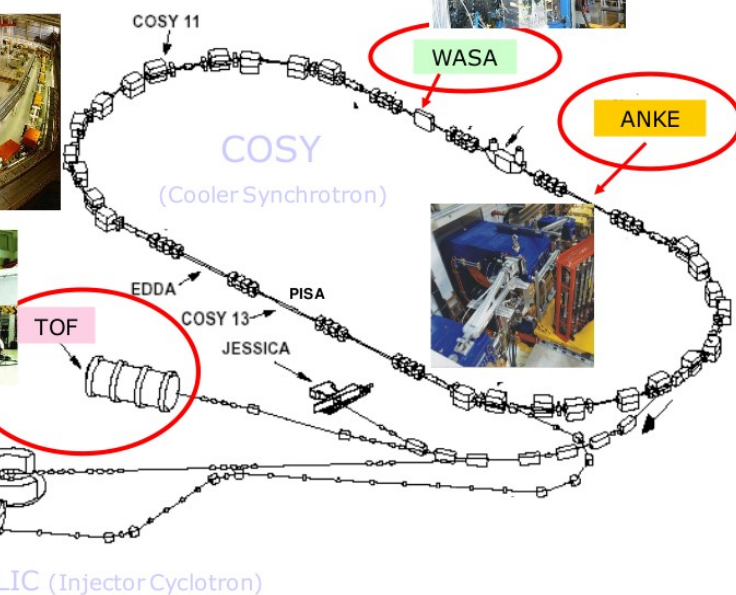
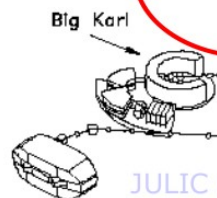
WASA Proposal 1987: key experiments: $\pi^0, \eta \rightarrow e^+e^-$



CELSIUS <2005

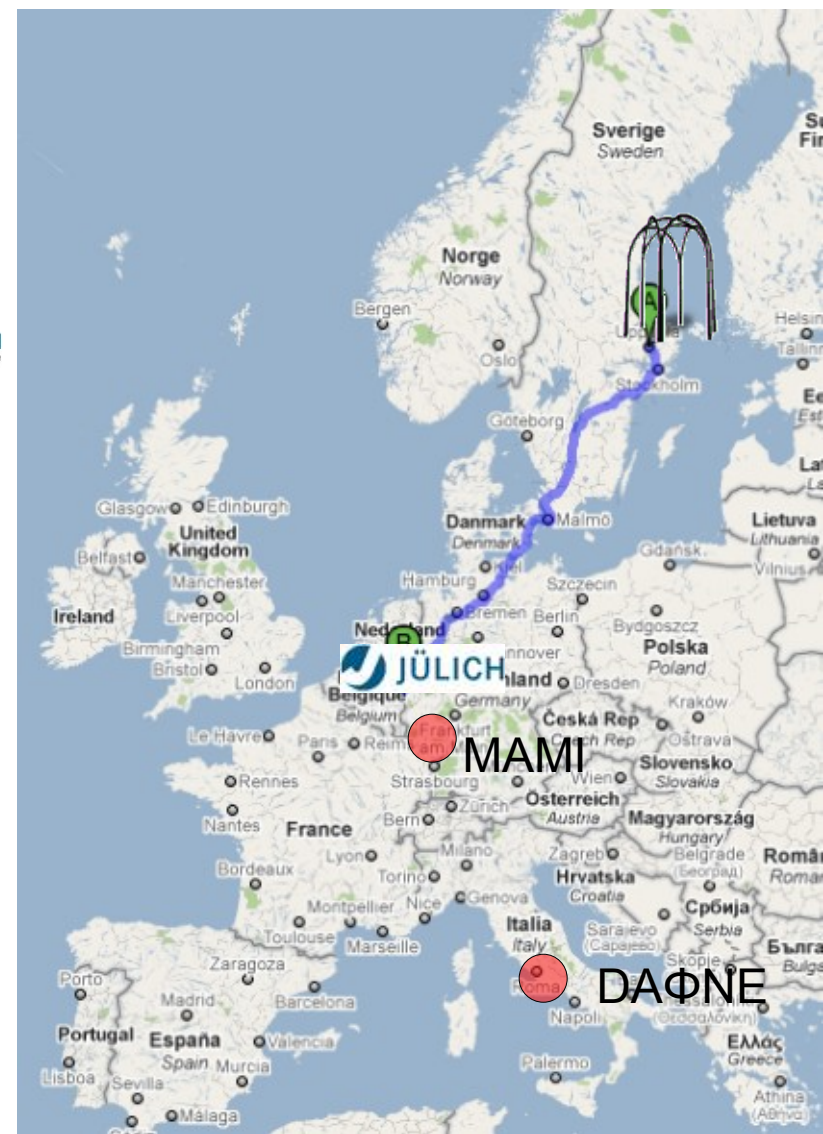


COSY >2007



Schematic overview COSY Facility (FZ-Jülich)

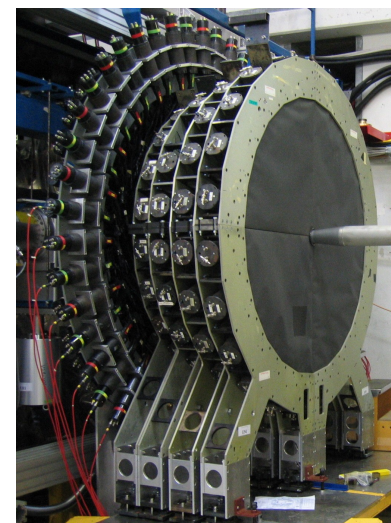
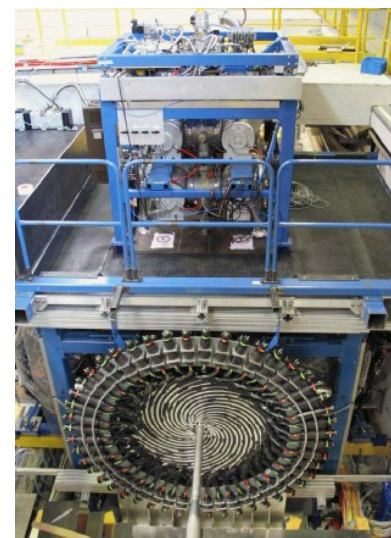
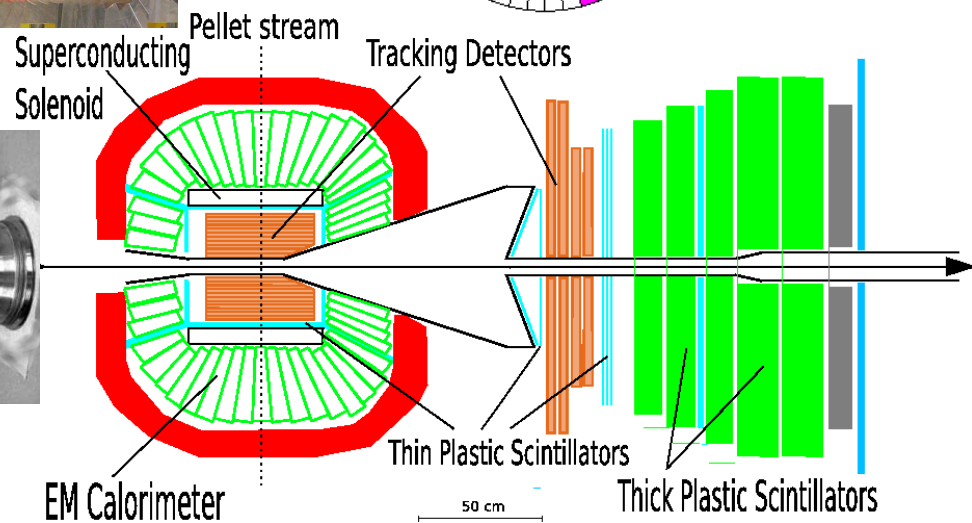
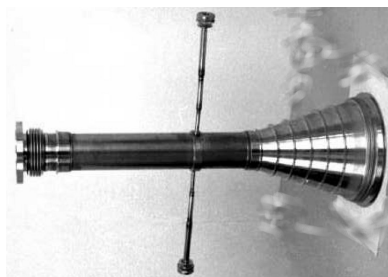
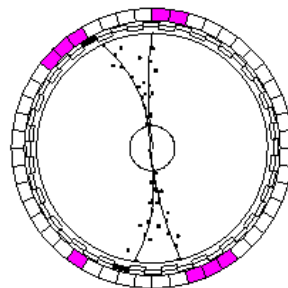
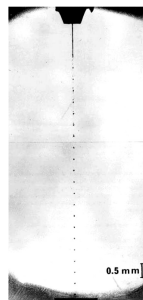
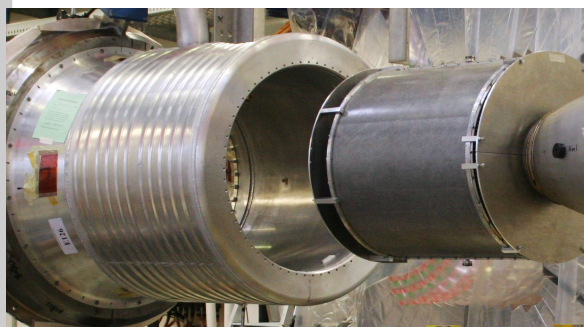
Recent results from Experiments at COSY, HADRON2009, 4/12/09



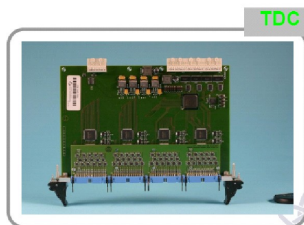


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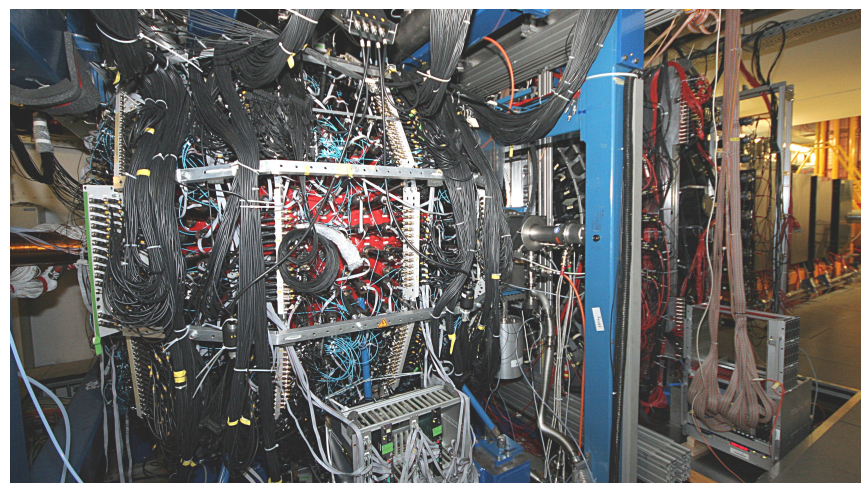
WASA detector



QDC



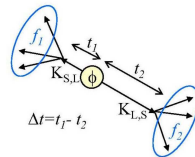
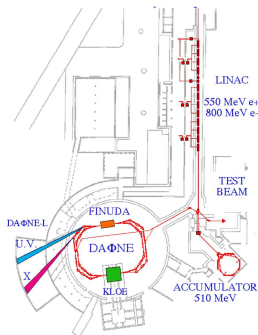
TDC



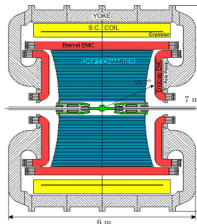
NIM A594,339



DAΦNE: e^+e^- collider $\sqrt{s}=M_\phi=1020 \text{ MeV}$



Built in the late 90's, KLOE is a multi purpose apparatus, optimised to maximise the detection efficiency for K_L decays

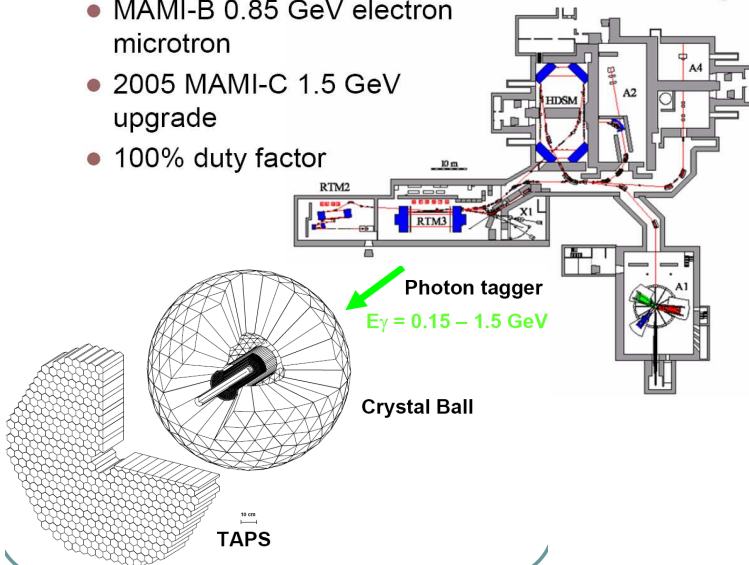


- ❖ **Superconducting coil** $B = 0.52 \text{ T}$
- ❖ **Be beam pipe** (0.5 mm thick), spherical 10 cm radius
- ❖ **Electromagnetic calorimeter**
Lead/scintillating fibers (1 mm $\varnothing$) 4880 PMT's, 15 X_0
- ❖ **Drift chamber**
(4 m $\varnothing \times 3.3 \text{ m}$) 90% He + 10% IsoB, CF frame, 12582 stereo, single sense wire, "almost squared" cells
- ❖ **Quadrupole calorimeter**



Crystal Ball at Mainz

- MAMI-B 0.85 GeV electron microtron
- 2005 MAMI-C 1.5 GeV upgrade
- 100% duty factor





Summary and outlook

- KLOE-2: starting new data campaign

[arXiv:1003.3868](https://arxiv.org/abs/1003.3868)

www.lnf.infn.it/kloe2

- WASA-at-COSY: $> 10^8$ η data sample being analyzed

nucl-ex/0411038, [NIMA594:339](https://nima.594.339)

www.fz-juelich.de/ikp/wasa

- PrimeNet/MesonNet: EU Network for light neutral meson physics

www.fz-juelich.de/ikp/primenet

