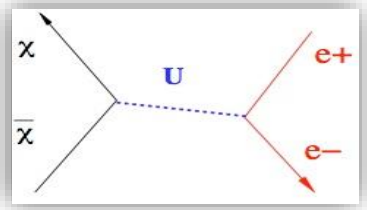
SEARCH FOR PHYSICS BEYOND THE SM IN MESON DECAYS WITH WASA DETECTOR.

Damian Pszczel

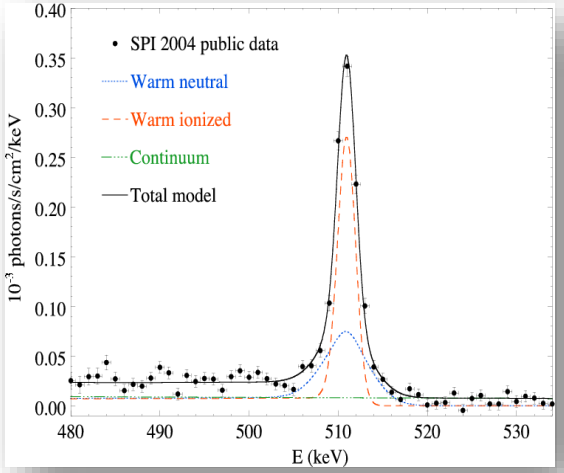
ASTROPHYSICAL OBSERVATIONS (COSMIC RAYS)

- Nature of dark matter?
  - WIMPS
  - Axions
  - Sterile neutrinos
  - …

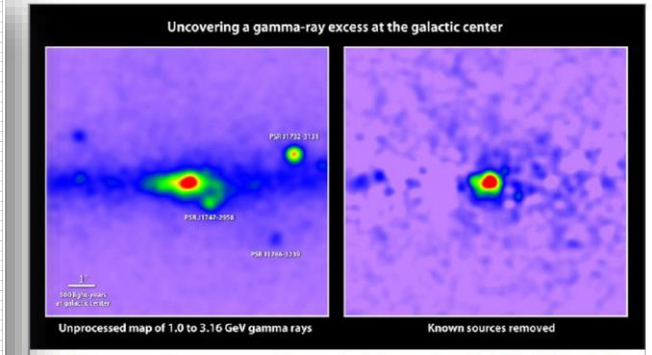
Dark sector with „dark force": new particles do not couple directly to SM, but interact through „portals"



Possible explanation of some astrophysical anomalies SPI/INTEGRAL, PAMELA, AMS, FERMI-LAT, HESS, ATIC



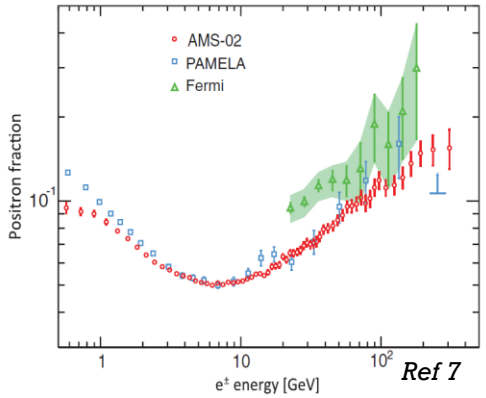
Ref 5



At left is a map of gamma rays with energies between 1 and 3.16 GeV detected in the galactic center by Fermi's LAT; red indicates the greatest number. Prominent pulsars are labeled. Removing all known gamma-ray sources (right) reveals excess emission that may arise from dark matter annihilations.

Credit: T. Linden, Univ. of Chicago

Ref 6



Ref 7

DARK PHOTON

- New „Dark" gauge symmetry leaves the SM particles unchanged. The associated gauge boson U, with mass M_U, could couple to SM through the kinetic small mixing term in the Lagrangian:

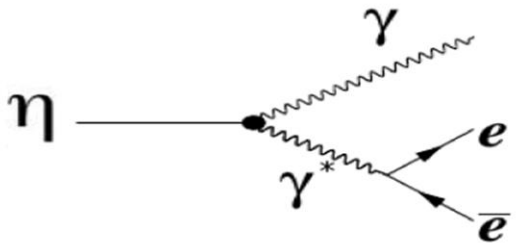
$$\mathbf{L_{mix} = \tfrac{1}{2}\, \varepsilon\, F_{\mu\nu}^{QED}\, F^{\mu\nu}_{DARK}}$$

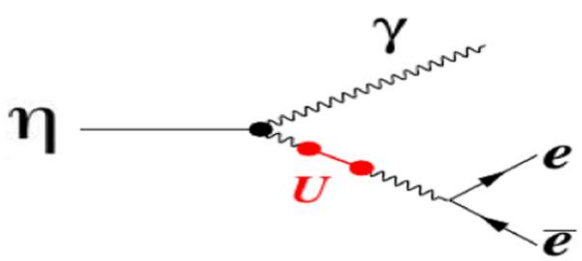
- The dark mediator is called the dark photon

  since it can mix with a photon in all processes

$\gamma_D = U = A'$

- $\mathbf{M_U} < 2$ GeV

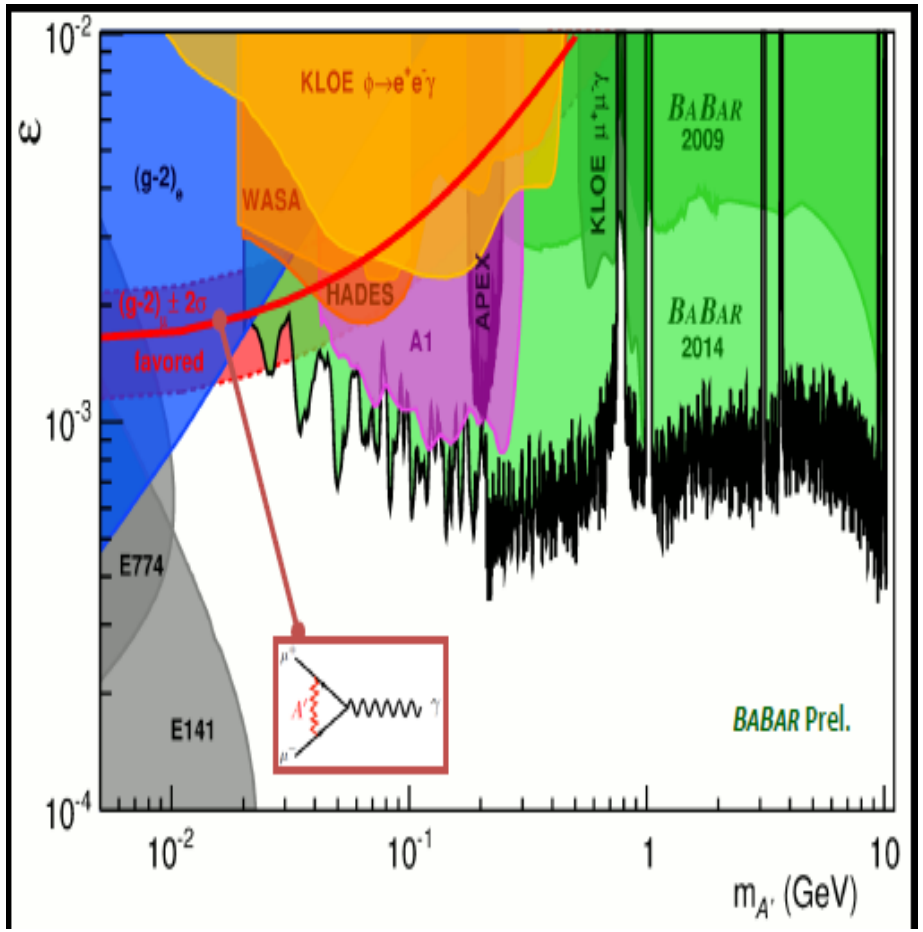




DARK PHOTON

- We can search for its signature in Dalitz decays of mesons
- $\pi^0 \rightarrow e^+e^-\gamma$ analysis with WASA detector published
- New analysis in $\eta \rightarrow e^+e^-\gamma$ channel: $M_\eta > M_\pi$
- Invariant mass of e^+e^- spectrum!
- Mean life-time: $\tau_U \cong \frac{3}{\alpha \epsilon^2 M_U} = 3 \cdot 10^5 yr \cdot \frac{10\ MeV}{M_U} \cdot \frac{10^{-35}}{\alpha \epsilon^2}$

For example, if $\epsilon^2 > 10^{-6}$,
M_U = 100 MeV/c^2 then $\tau_U \propto 10^{-14}$ s and U mean free path less than 1 mm

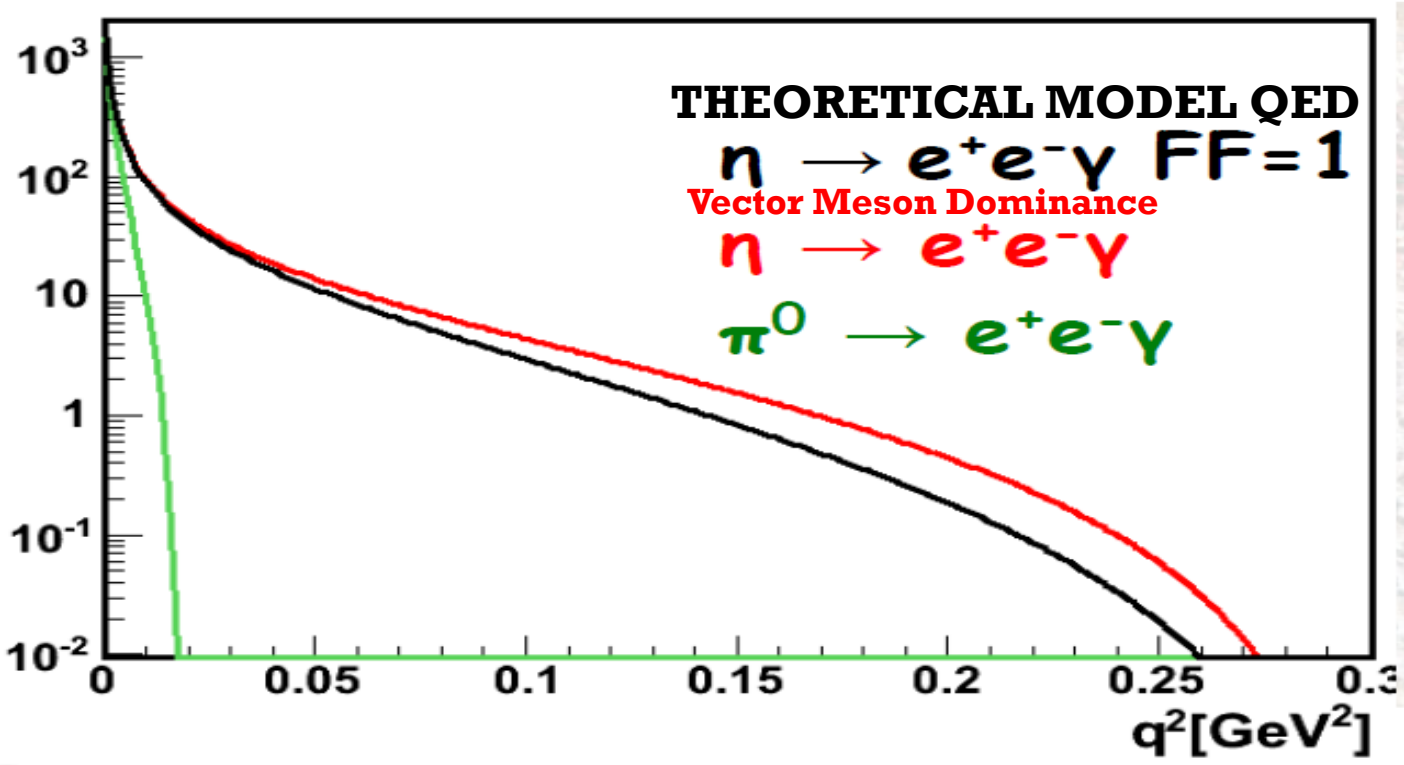


Ref 14

INVARIANT MASS OF LEPTON PAIR

- $\eta \to e^+e^-\gamma$ larger mass range than $\pi^0 \to e^+e^-\gamma$
- Unfortunately – lower statistics ($\sigma_{pp\to pp\eta} << \sigma_{pp\to pp\pi}$)

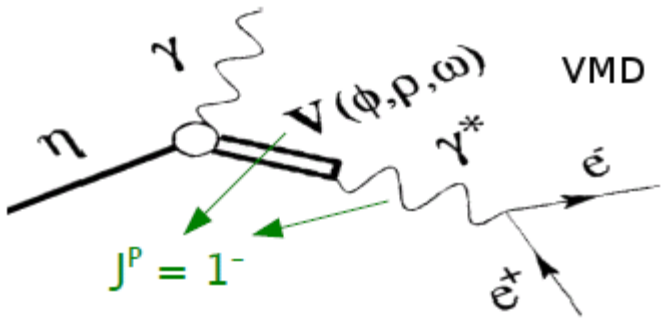
  μb << mb



Ref 16

$$\frac{d\Gamma(P \to \ell^+\ell^-\gamma)}{dq^2\Gamma_{\gamma\gamma}} = \frac{2\alpha}{3\pi}\frac{1}{q^2}\sqrt{1-\frac{4m_\ell^2}{q^2}}\left(1+\frac{2m_\ell^2}{q^2}\right)\left(1-\frac{q^2}{M_P^2}\right)^3 |F_P(q^2,0)|^2$$

Landsberg 1985



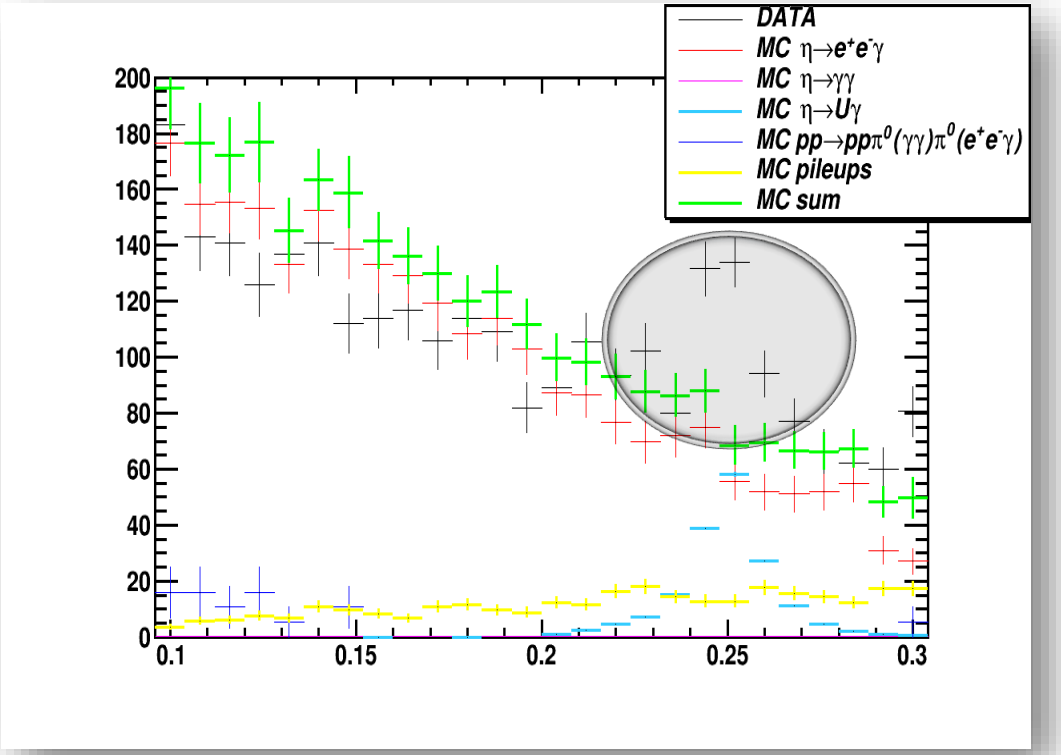
Ref 17

- Transition form factor fit:

  $F^2(q^2)=(1-q^2/\Lambda^2)^{-2}$

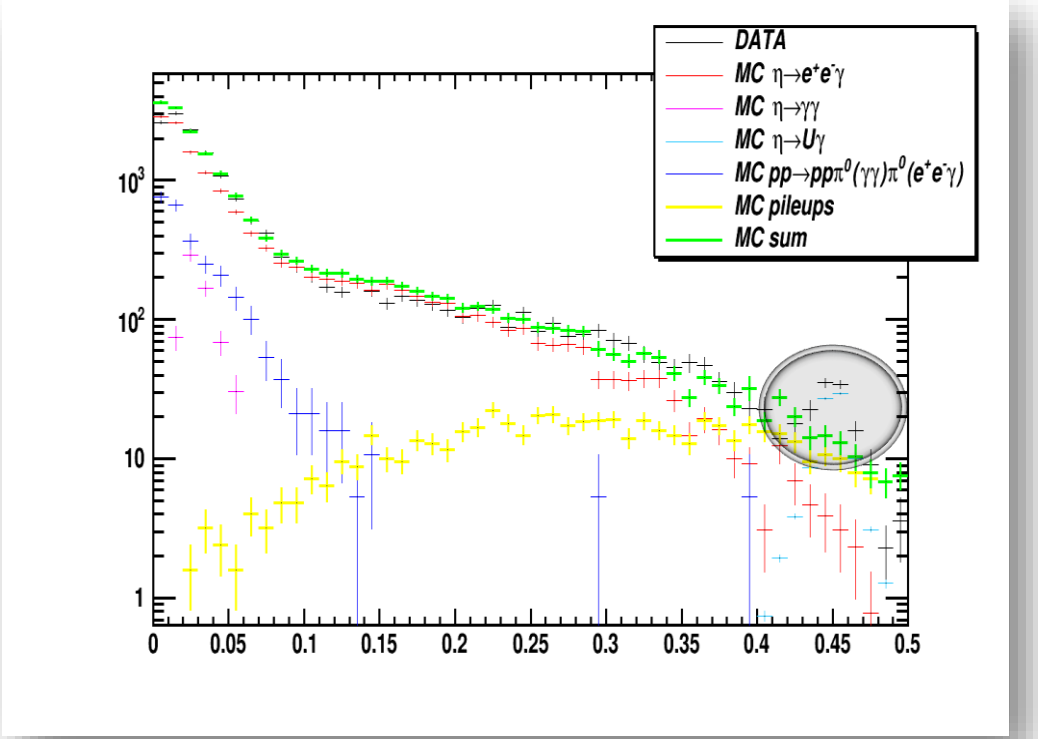
SIMULATION OF SIGNAL SIGNATURE

BR = 10^{-4}
M = 250 MeV/c^2



Invariant mass of e^+e^- [GeV/c^2]

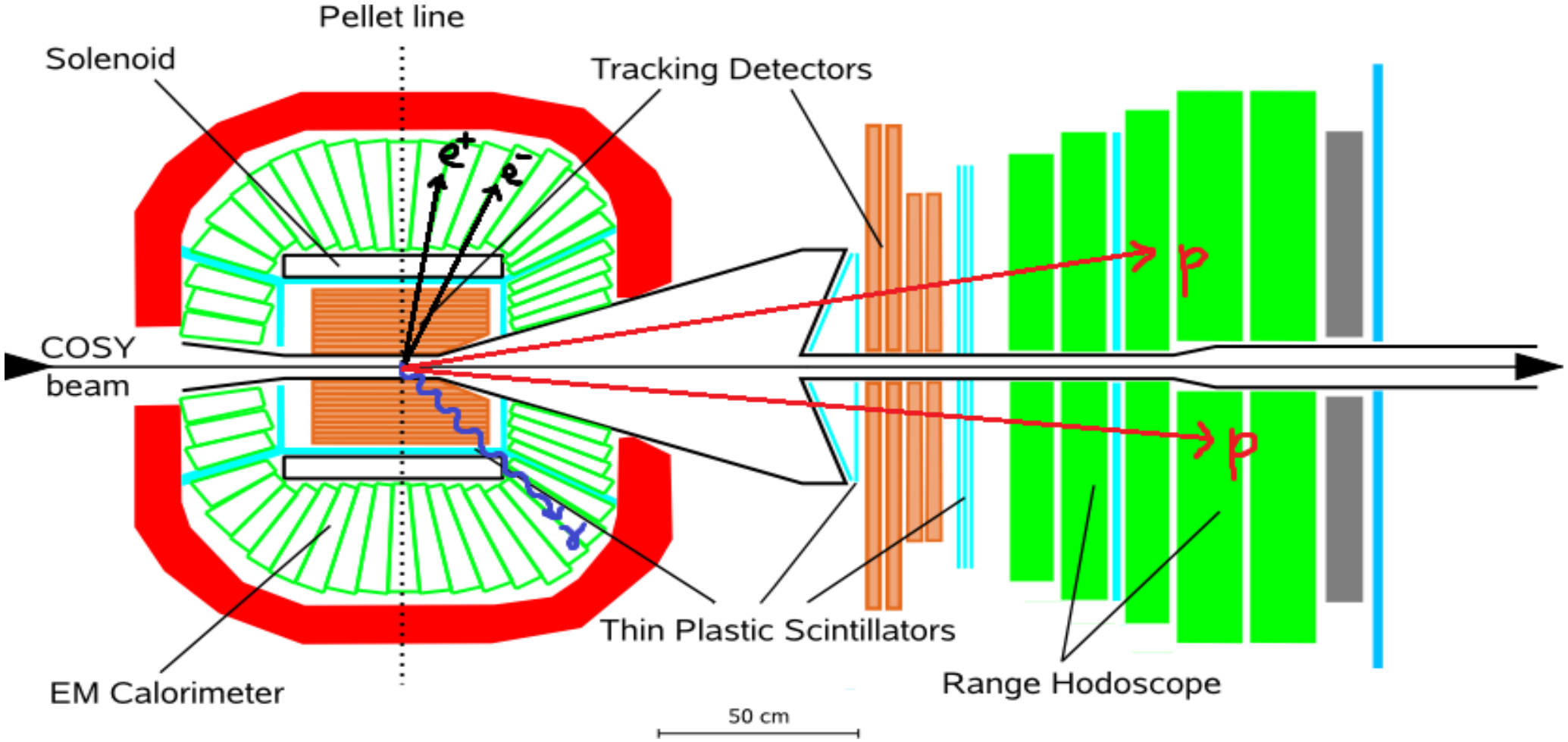
BR = 10^{-5}
M = 450 MeV/c^2



Invariant mass of e^+e^- [GeV/c^2]

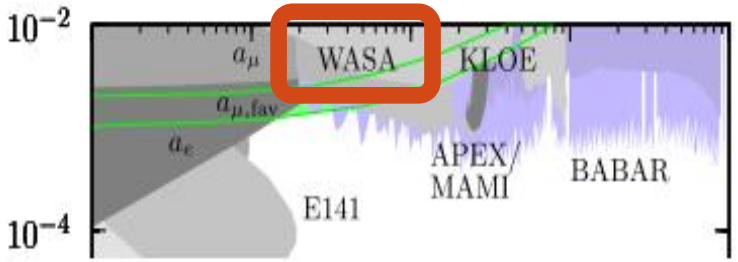
WASA-AT-COSY EXPERIMENT

pp→ppη[→ e+e-γ] @ 1.4 GeV

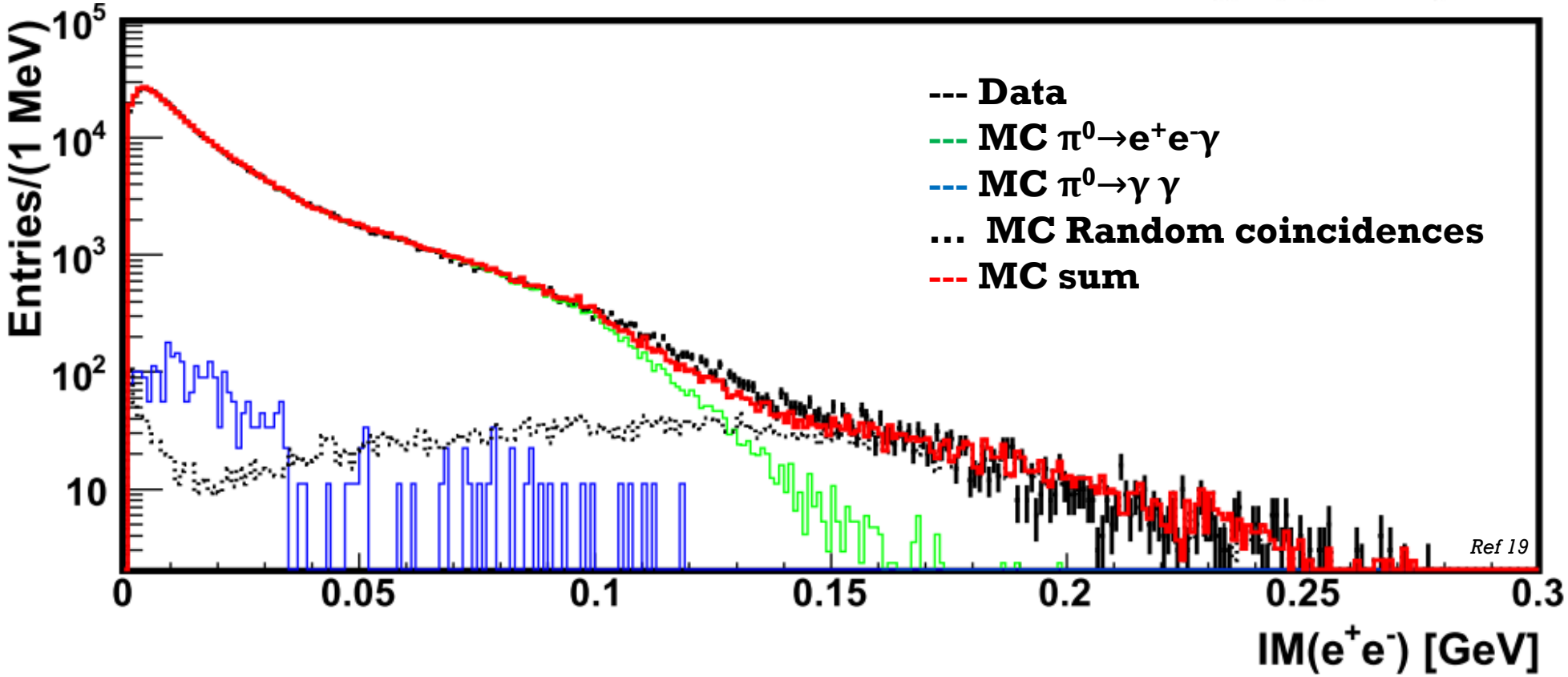


$\pi^0 \to e^+e^-\gamma$ CHANNEL γ_{dark} - γ_{sm} COUPLING PARAMETER UPPER LIMIT

- **$\pi^0 \to e^+e^-\gamma$ channel** : *Phys.Lett. B726 (2013) 187-193*
- *MonteCarlo(Background + Signal) ≈ Data*



Ref 18



DATA SET

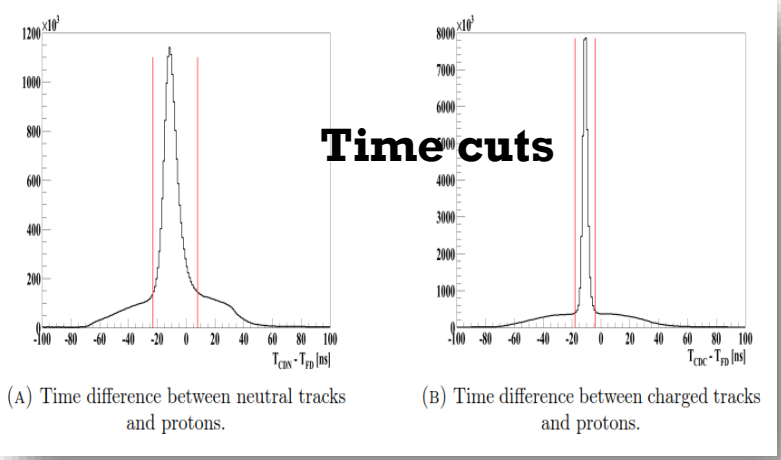
- PP collision @ 1.4 GeV
- 2012 Feb-Apr (6-7 weeks of data taking) ~100 TB of data
- Initial selection („preselection”):
  - Trigger system based on clusters in Central Detector
  - Tracks in Forward Detector >= 2 (Energy, time and PID)
  - Hits in Drift Chamber >= 14 (at least two trakcs with signals from 7 MDC layers)
  - Charged clusters in CD thin plastic scintillators >= 2
- ~100 10^6 η

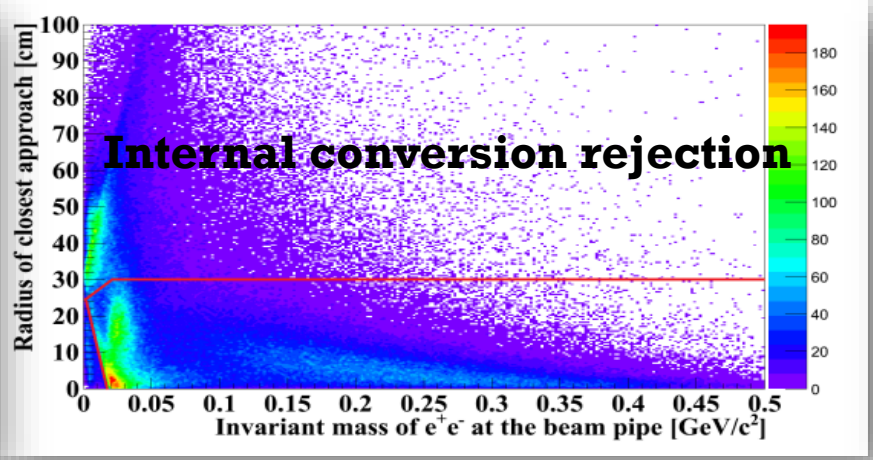
SELECTION OF $\eta \rightarrow e^+e^-\gamma$ CHANNEL

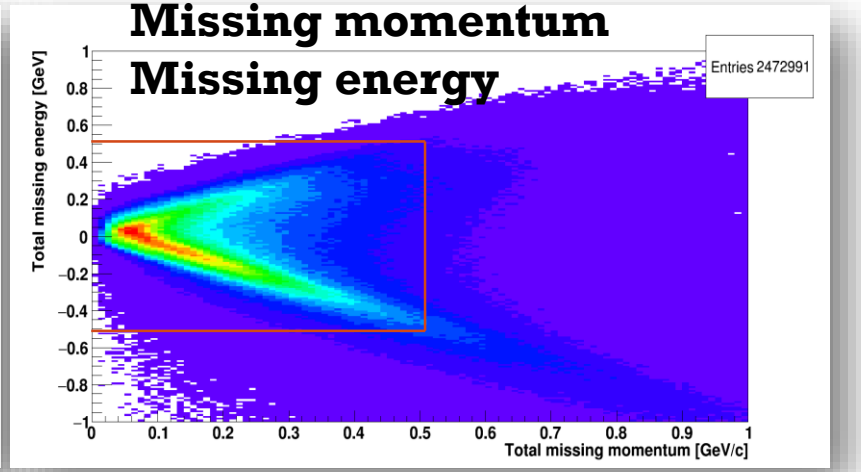
1. Time information (CD Charged, CD Neutral, Forward)
2. Particle identification (Edep vs charge*momentum)
3. Rejection of internal conversion of photons ($CA_\perp$ vs IM_{ee} on the beam tube)
4. Total missing Energy, Total missing mass, Total missing momentum
5. Angular information (η_θ, γ^*-γ in η_{RF})
6. Missing mass of two protons (530-570 MeV/c^2)
7. Invariant mass of $e^+e^-\gamma$ (450-650 MeV/c^2)

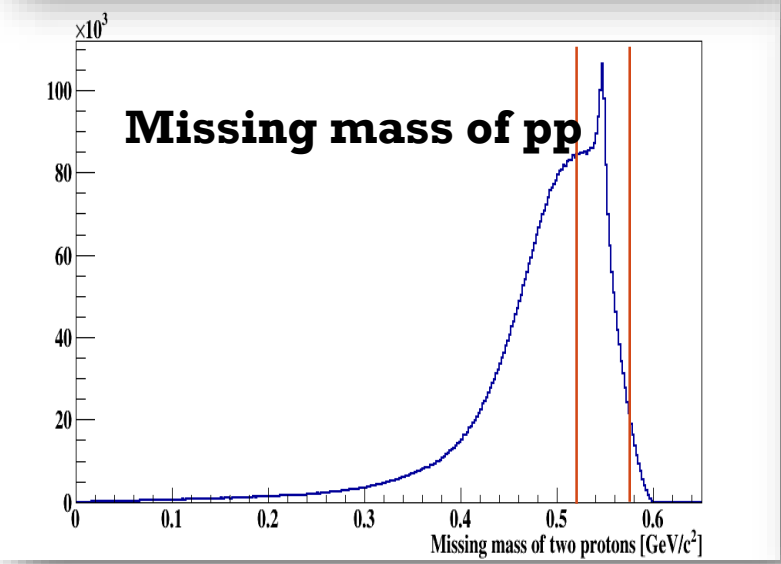
SELECTION OF $\eta \to e^+e^-\gamma$ CHANNEL

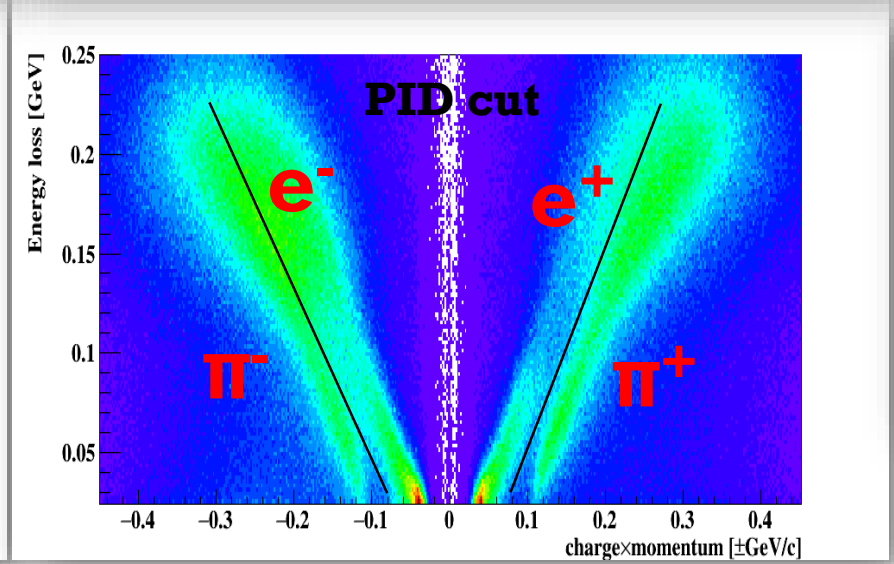
My analysis of pp→ppη[→ e+e-γ] @ 1.4 GeV

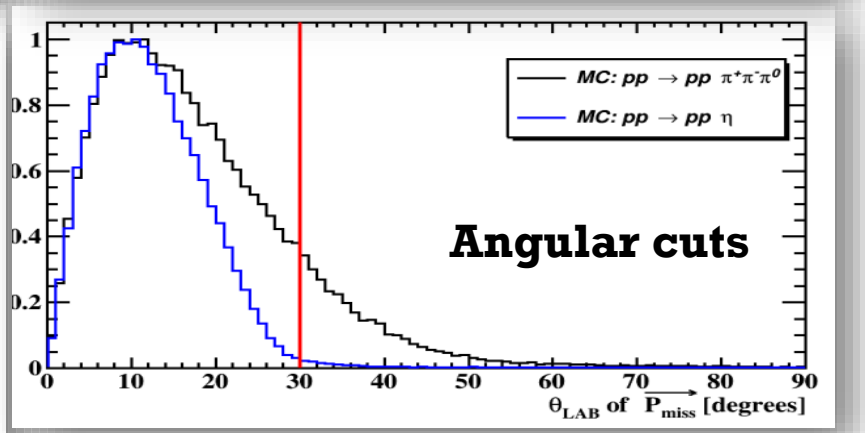






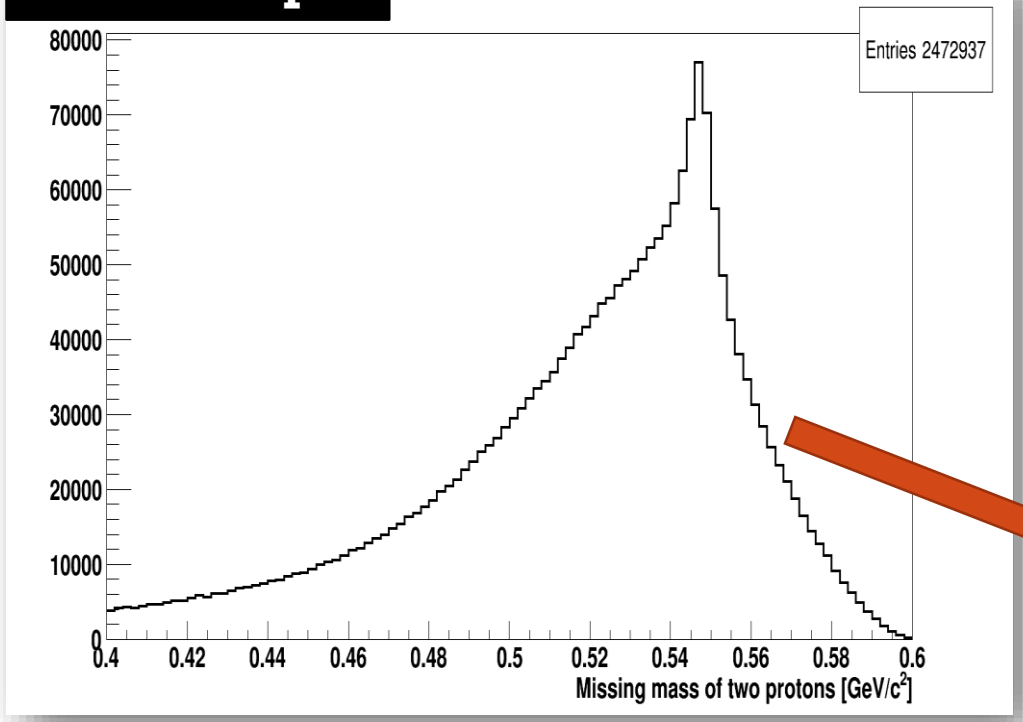






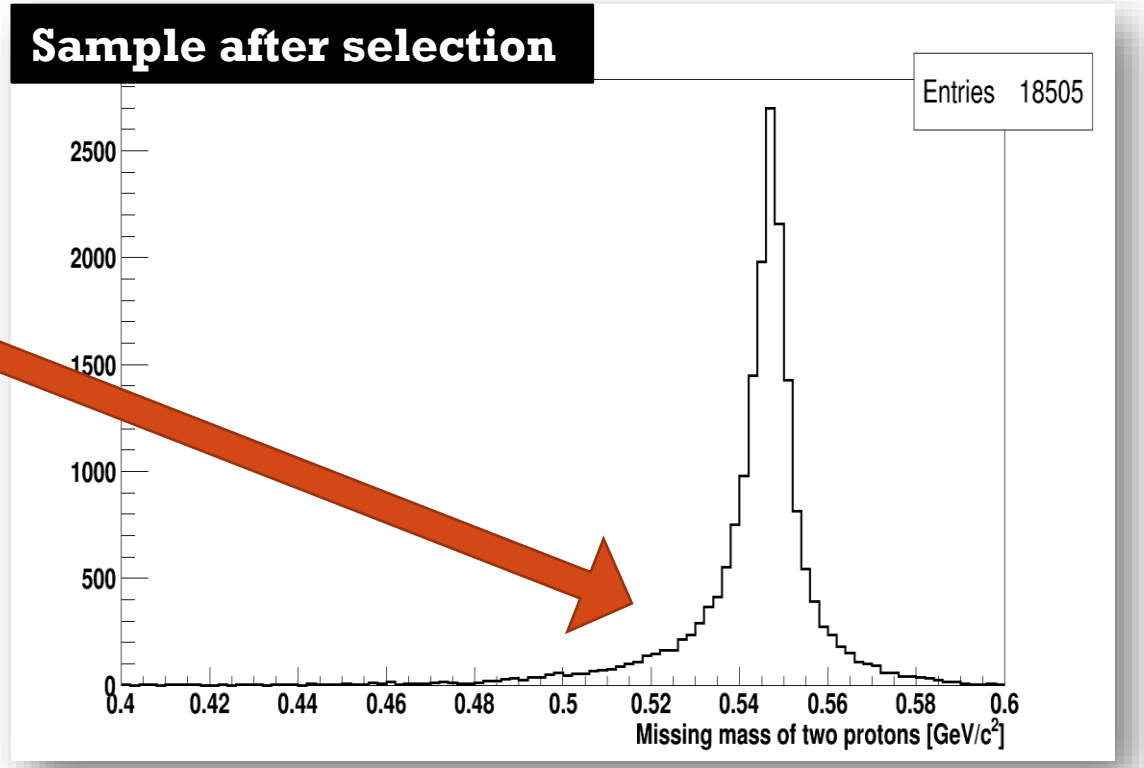
TAGGING OF η IN WASA-AT-COSY

Initial sample



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

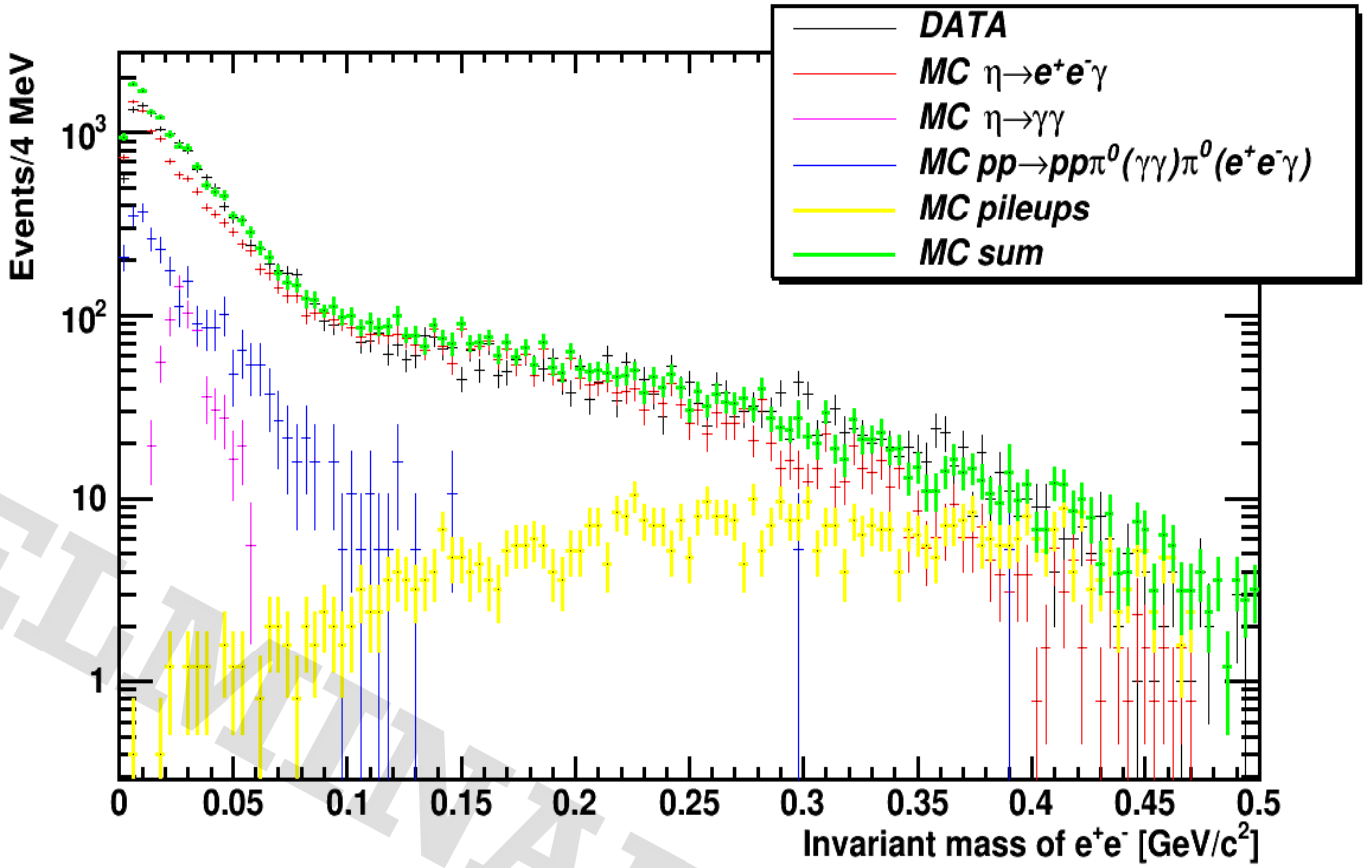
Sample after selection



SELECTION OF $\eta \to e^+e^-\gamma$ CHANNEL

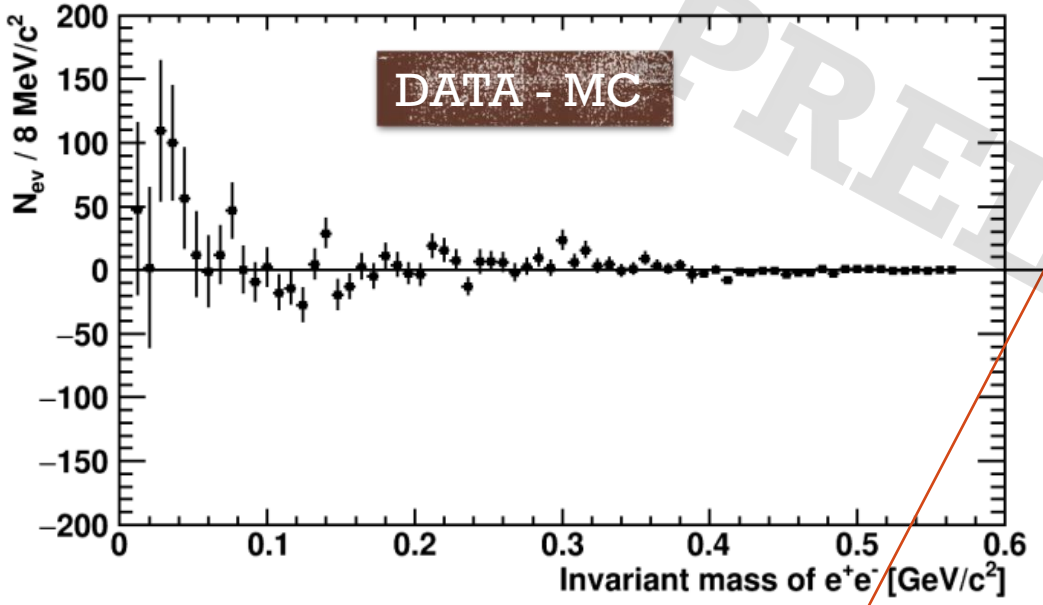
- Acces to higher masses:

  $M_\eta = 0.547\ GeV/c^2$
- ~15 000 $\eta \to e^+e\text{-}\gamma$
- no signal observed → upper limit

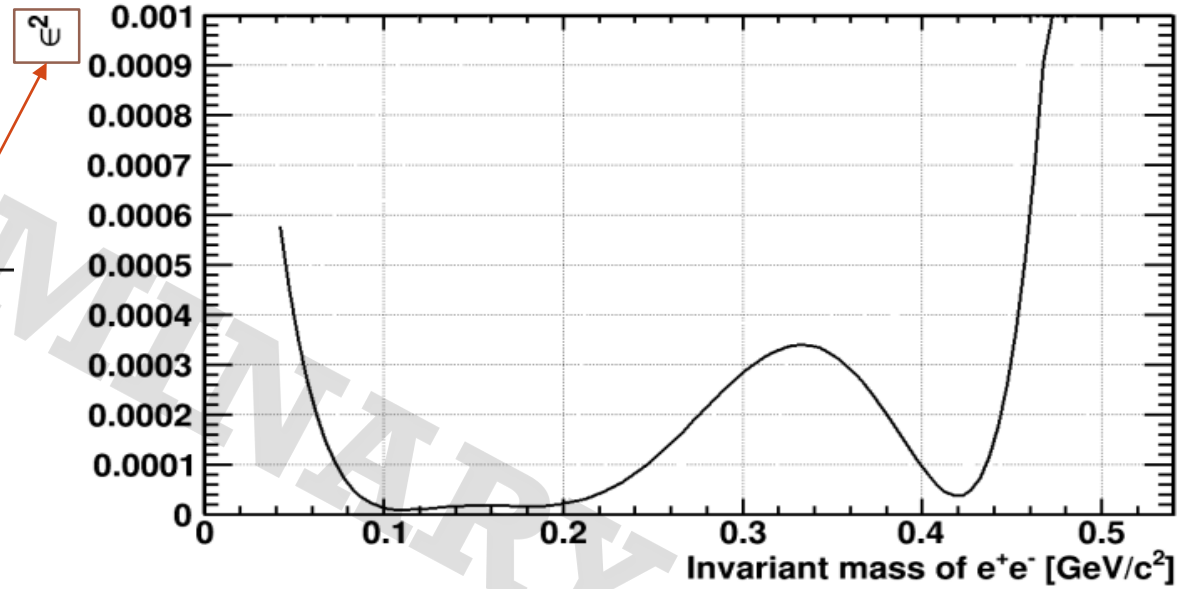


PRELIMINARY

γ_{dark} - γ_{sm} COUPLING PARAMETER UPPER LIMIT



90 % CL limit



PRELIMINARY

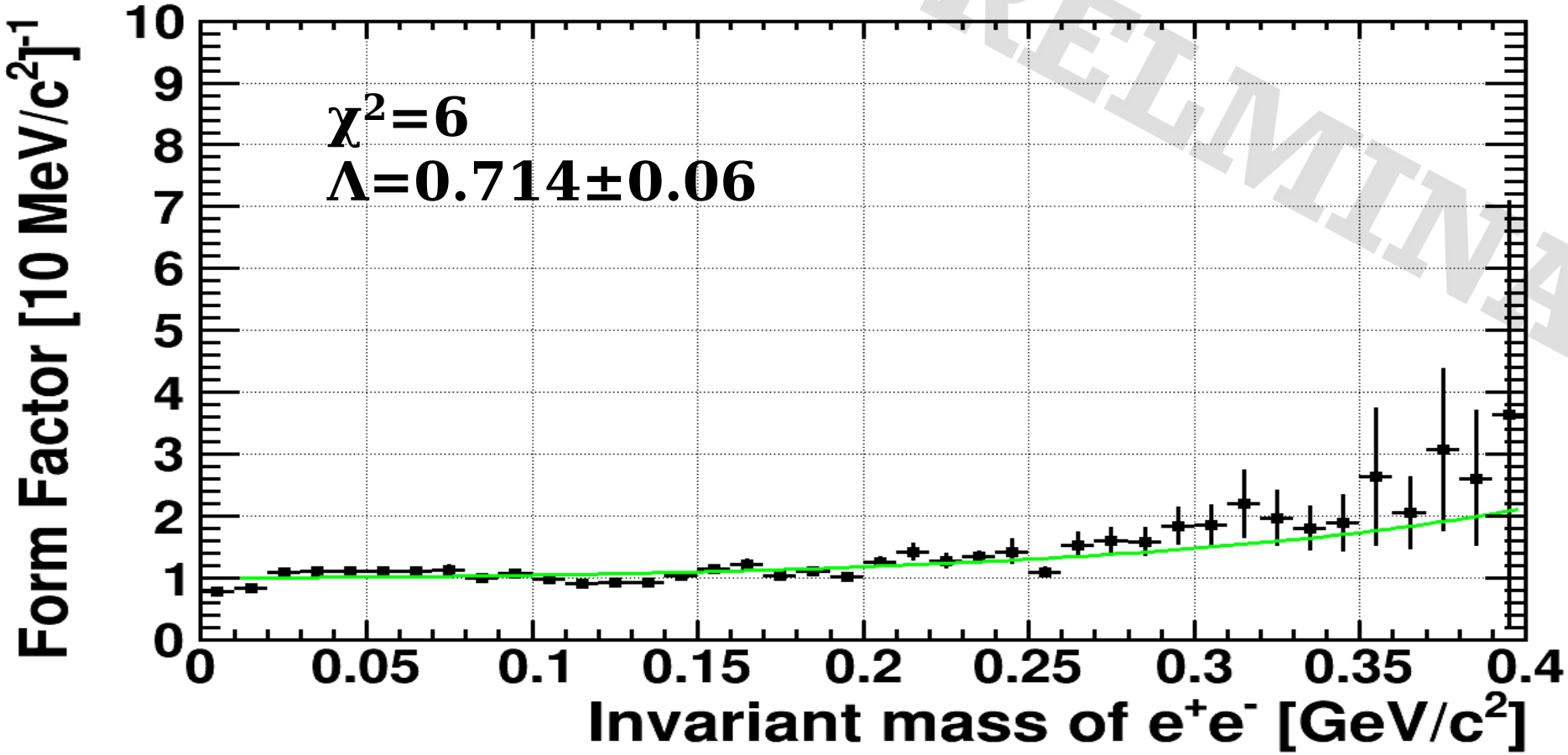
$N_{ev} = \beta \cdot (\eta \rightarrow \gamma\, \gamma_{DARK})$ + SM background

γ_{DARK} contribution

FORM FACTOR EXTRACTION: „DIRECT" SELECTION

- Transition form factor fit:

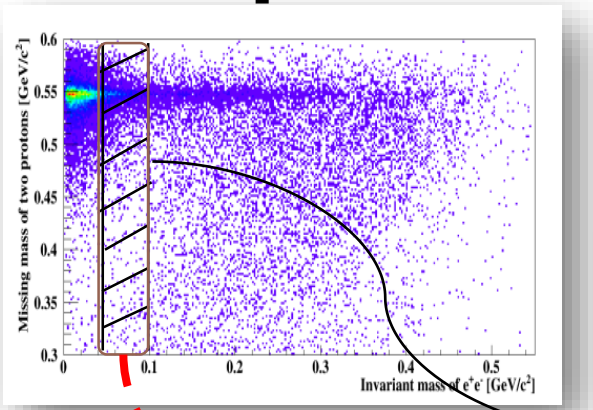
  $F^2(q^2)=(1-q^2/\Lambda^2)^{-2}$



PRELIMINARY

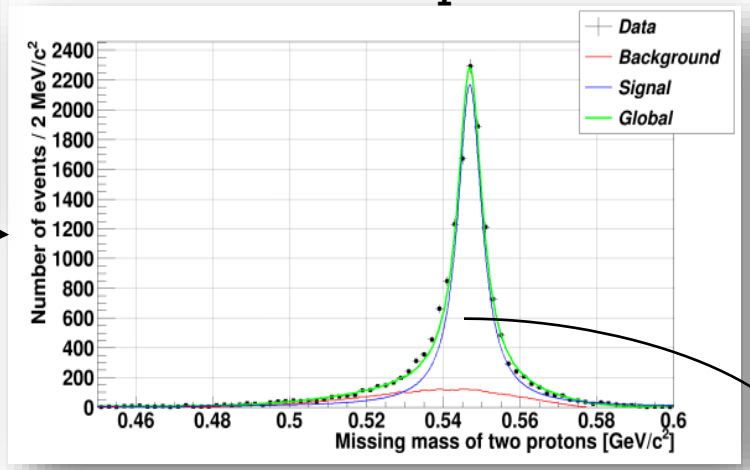
FORM FACTOR EXTRACTION: NON-η BACKGROUND FITTING PROCEDURE

MM2p vs IMee



Data Fit = signal + background

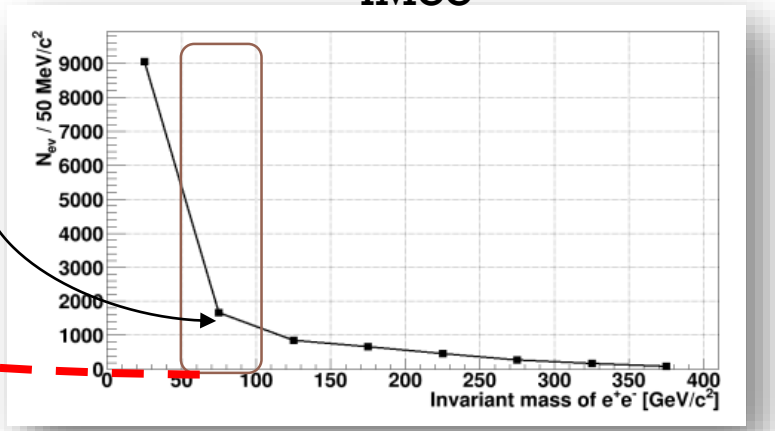
MM2p



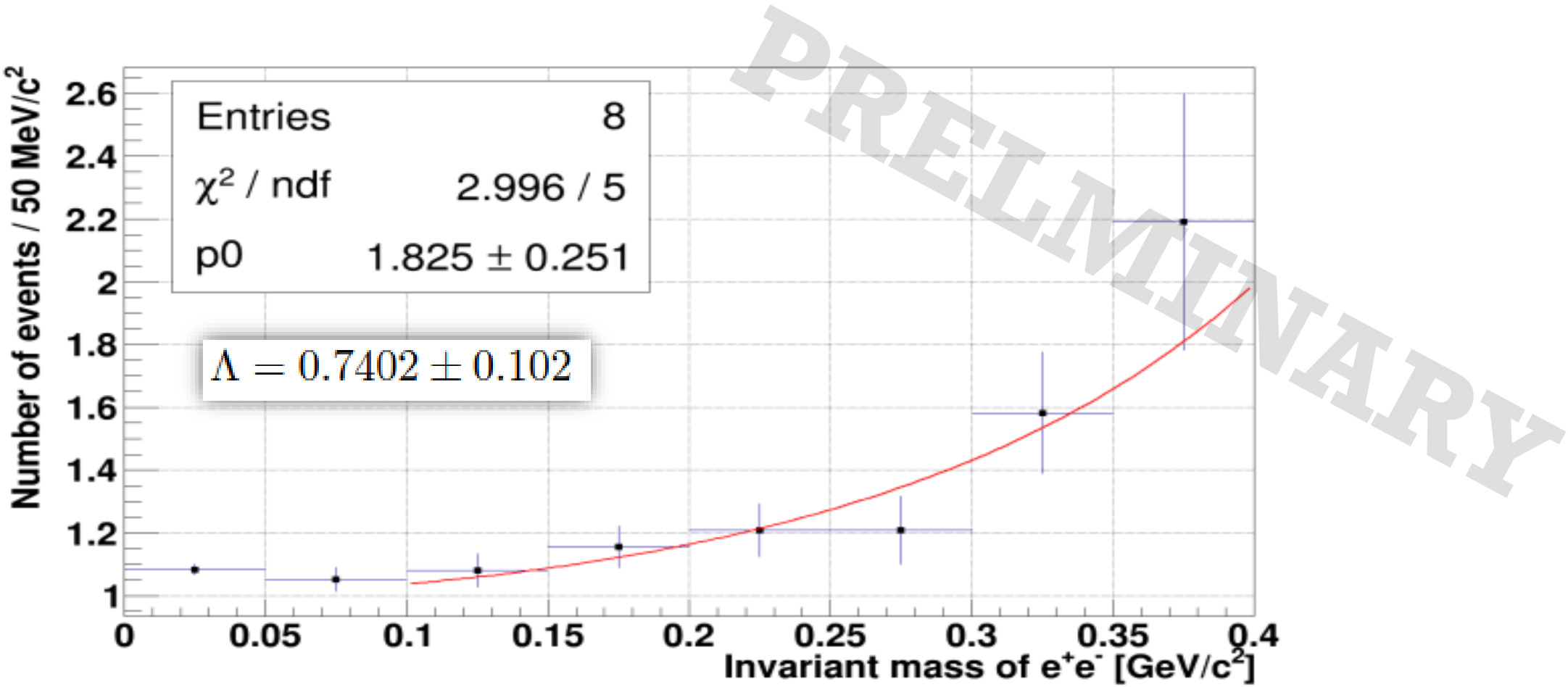
MM2p projection for a given IMee bin

Integral of fitted signal = bin content on IMee histogram

IMee



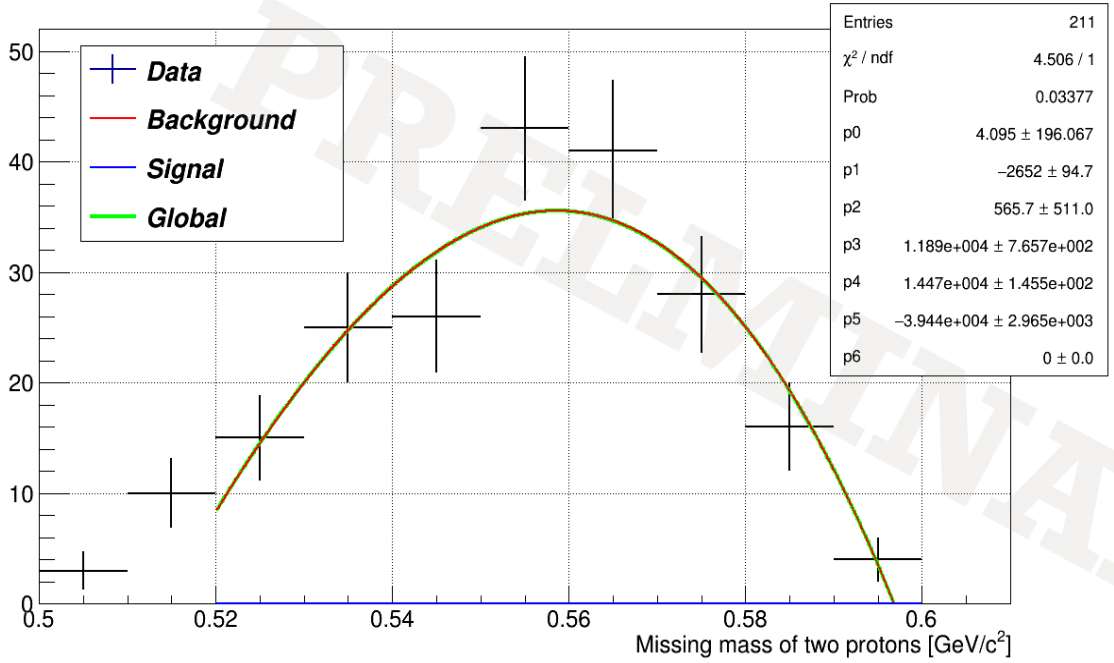
FORM FACTOR EXTRACTION: NON-η BACKGROUND FITTING PROCEDURE



$\eta \rightarrow e^+e^-$ CHANNEL

- Based on Marcin Berłowski PhD thesis analysis with larger statistics
- New criteria on particle times and new identification
- Signal content consistent with zero – new upper limit on BR (to be released soon)

$3\text{-}4 \times 10^{-6}$



EXT NO.	PARAMETER NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	4.09542e+000	1.96067e+002	-6.73171e-001	9.69296e-005
2	p1	-2.65224e+003	9.46843e+001	3.91555e-001	4.77615e-005
3	p2	5.65714e+002	5.11039e+002	1.90644e+000	2.80142e-005
4	p3	1.18920e+004	7.65701e+002	2.78039e+000	1.75146e-005
5	p4	1.44660e+004	1.45518e+002	3.33390e-001	1.02912e-005
6	p5	-3.94350e+004	2.96525e+003	-1.16778e+001	4.93460e-006
7	p6	0.00000e+000	3.83304e-002	-1.98835e-009** at limit **	
8	p7	5.47000e-001	fixed		
9	p8	1.60000e-002	fixed		

PRELIMINARY

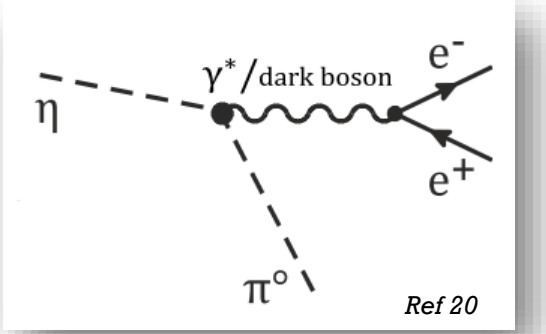
$\eta \to \pi^0 e^+ e^-$ CHANNEL

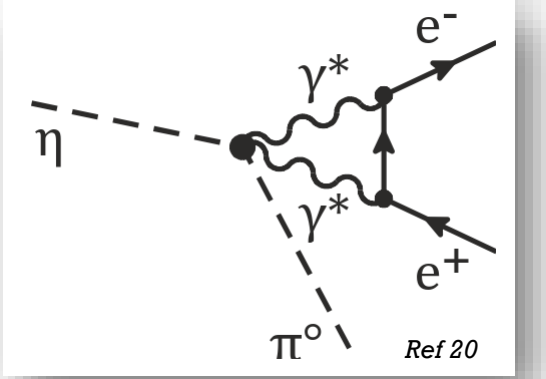
- $\eta \to \pi^0 \gamma^* \gamma^* \to \pi^0 e^+ e^-$ would conserve C-parity

$C(\pi^0\gamma^*\gamma^*) = C(\pi^0)\cdot C(\gamma^*)\cdot C(\gamma^*) = (+1)\cdot(-1)\cdot(-1) = +1 = +1 = C(\eta)$

- Expected theoretical BR($\eta \to \pi^0 \gamma^*\gamma^* \to \pi^0 e^+ e^-$) ~ $10^{-9} - 10^{-12}$
- $\eta \to \pi^0 \gamma^* \to \pi^0 e^+ e^-$ would violate C-parity:

$C(\pi^0\gamma^*) = C(\pi^0)\cdot C(\gamma^*) = (+1)\cdot(-1) = -1 \neq +1 = C(\eta)$





- Current experimental limit: BR($\eta \to \pi^0 e^+ e^-$) < $4\cdot 10^{-5}$ (90% CL)

  4 orders of magnitude between experimental limit and SM expectation → room for physics beyond SM

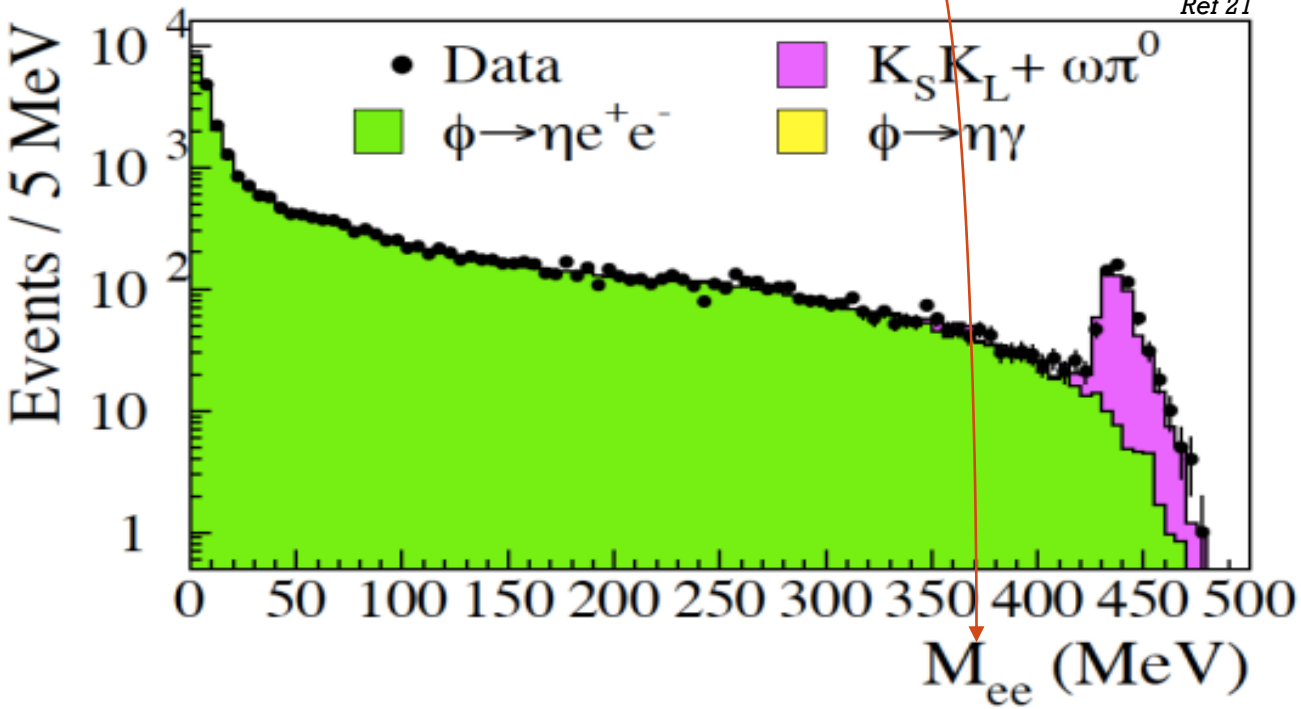
- WASA-at-COSY preliminary limit (IMee>100 MeV/c^2):

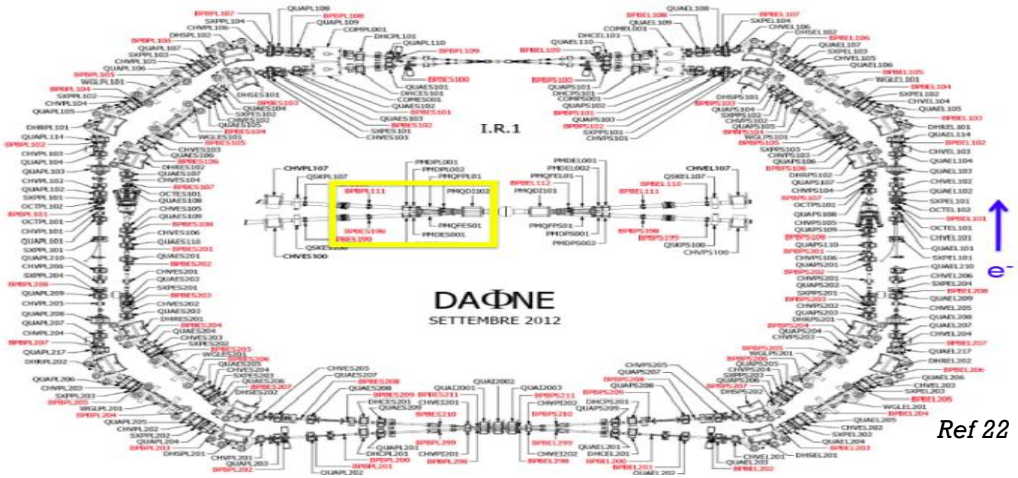
  BR($\eta \to \pi^0 e^+ e^-$) < $2\cdot 10^{-5}$ (90% CL)

OTHER EXPERIMENTS LOOKING FOR DARK BOSONS

KLOE@DAΦNE

- e^+e^- collider in Frascati (Italy)
- Dark higgs h' → UU → 4l, 4π, 2l+2π
- Dark photon in $e^+e^- \rightarrow \eta e^+e^-$





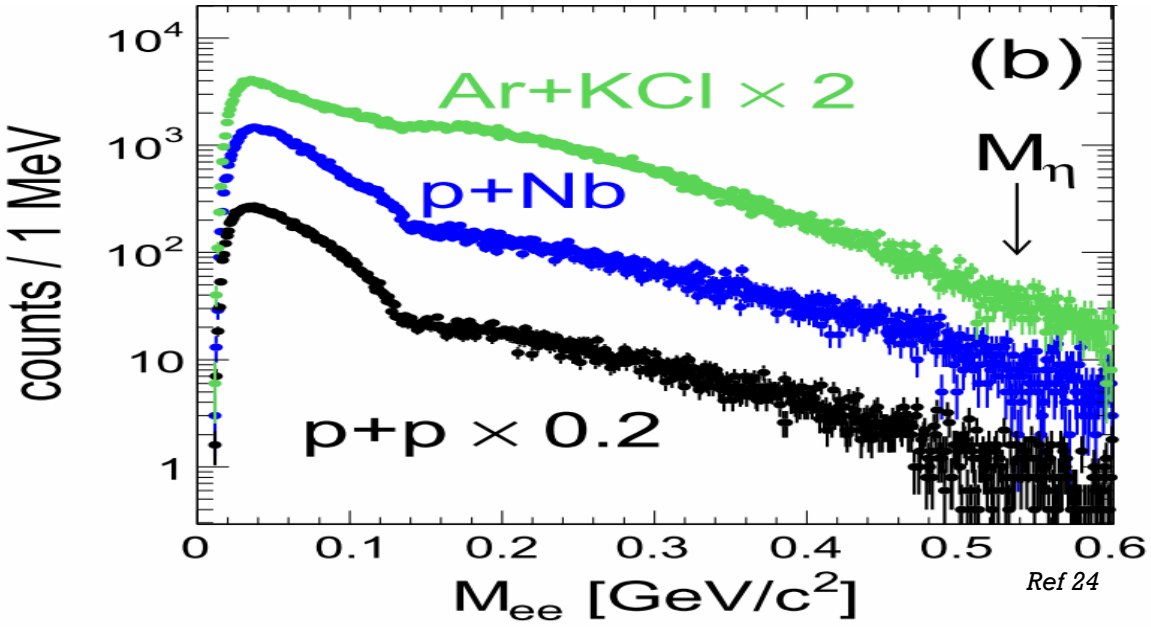
Ref 22

Ref 22

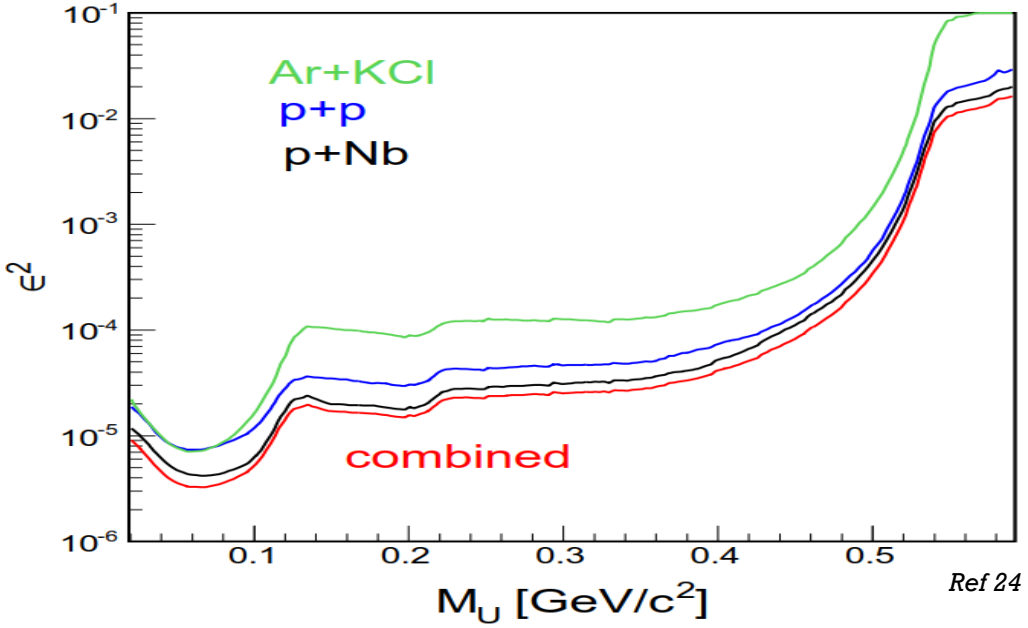
OTHER EXPERIMENTS LOOKING FOR DARK BOSONS

HADES (High Acceptance Dielectron Spectrometer)

- Collisions between heavy-ion beam (p/Ar) and target (p/Nb/KCl)
- Dark photon in inclusive measurement of e^+e^- pairs



Ref 24



Ref 24

OTHER EXPERIMENTS LOOKING FOR DARK BOSONS

JLAB (Newport News, VA)

- CEBAF (Continuous Electron Beam Accelerator Facility)

→ e^- @ 12 GeV beam

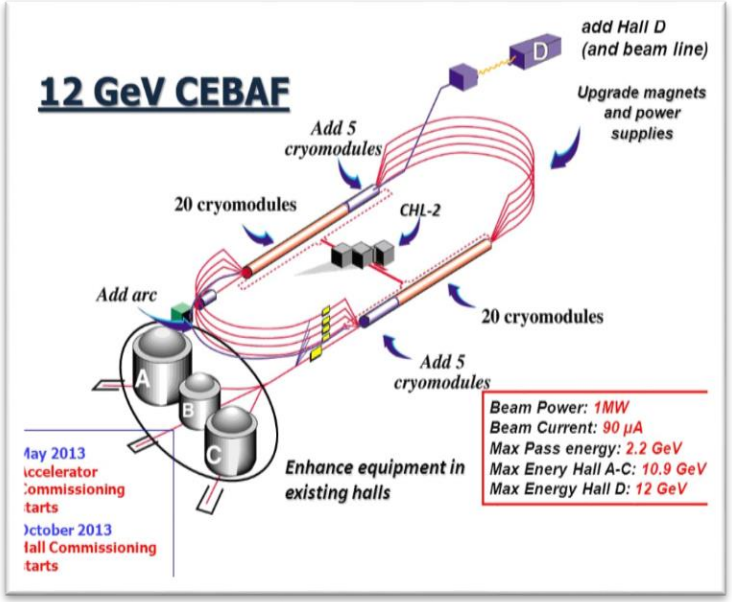
- HPS (Heavy Photon Search)

→ e^- on tungstene foil target

- Displaced decay vertex

→ smaller ϵ values

M_U: 20-500 MeV/c^2



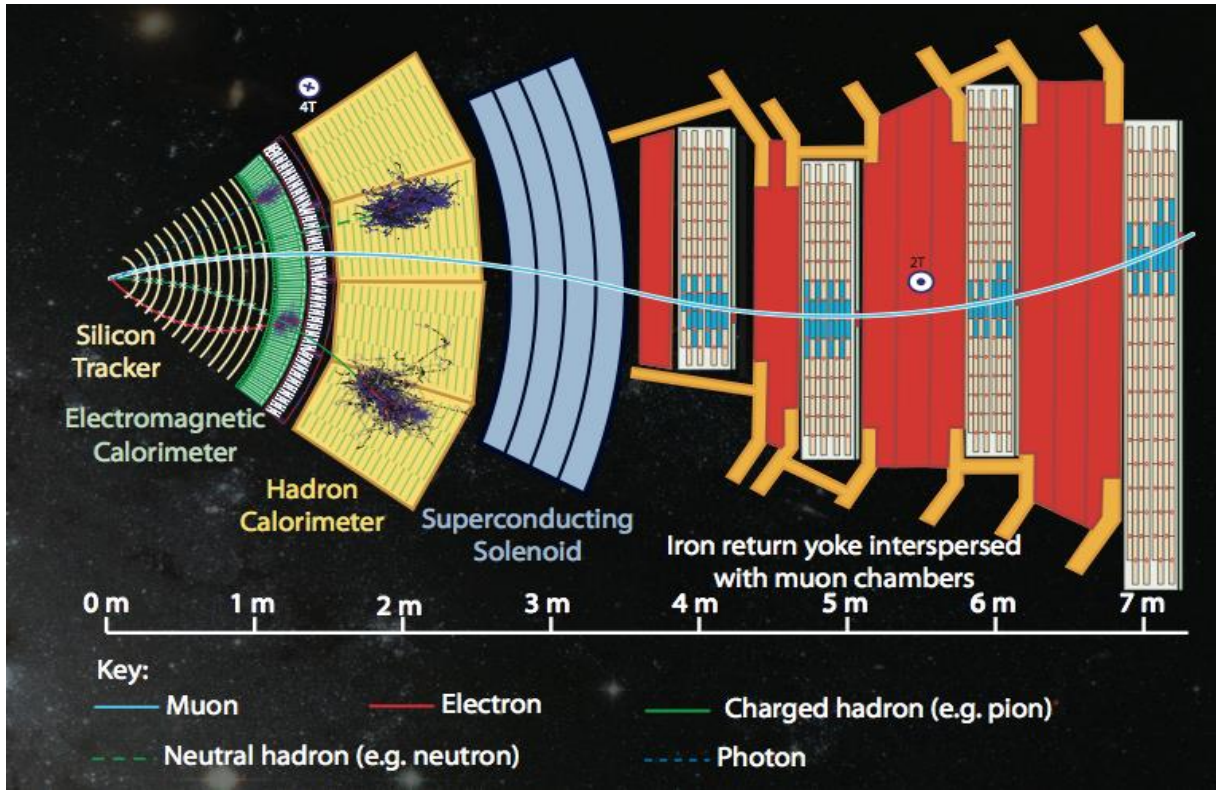
Ref 25

Ref 25

OTHER EXPERIMENTS LOOKING FOR DARK BOSONS

LHC

- Mainly focused on heavier WIMPS (related to SUSY models)
- But also: $\gamma_D \rightarrow 2\mu$ in CMS
- Beam dumps (longer mean lifetime) – The Rare Decays and Dark Matter Experiment @ SPS
- LHCb, ATLAS,…



Ref 26

SUMMARY AND OUTLOOK

- Extraction of η transition form factor and (ϵ, M_U) upper limit from $\eta \rightarrow e^+e^-\gamma$ analysis (very soon)
- Extraction of BR limit on $\eta \rightarrow e^+e^-$ (very soon)

- Extraction of the π^0 transition form factor
- Merging of data sets (2008 and 2012)
- Search for dark bosons in $\eta \rightarrow \pi^0 e+e-$ (exclusive measurements)
- Unseen decays of the dark photon f.e. $\eta \rightarrow \gamma + X$, $\eta \rightarrow e+e- + X$

THANK YOU

Ref 27

REFERENCES

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