ISMD2023, Gyöngyös, Hungary, Aug 20-26,2023

QED meson description of the anomalous particles at ~17 and ~38 MeV

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I Introduction

- The report of anomalous soft photons, at ISMD 2009, Gomel, Belarus
- The Schwinger confinement mechanism implies a light q and $\bar{q}$ interacting in QED are confined in (1+1)D, as a QED meson in (1+1)D
- The QED meson in (1+1)D can represent a physical QED meson in (3+1)D when the radius of the flux tube in (3+1)D is properly taken into account

II Such a theory predicts for light quarks with two flavors

isoscalar and isovector mesons at ~17MeV and ~38 MeV

III Anomalous particles at ~17 & ~38 MeV were subsequently observed by ATOMKI and DUBNA

IV Conclusions: promising experimental evidence, pending confirmations, important implications

CYWong,PRC81,064903(2010);arxiv:1001.1691
CYWong,JHEP2020(8),165;arxiv:2001.04864
CYWong,EPJA58,100(2020);arxiv:2010.13948
CYWong,FrontPhys18,64401(2023),arxiv:2208.09920
CYWong & A.Koshelkin,arxiv:2111.14933

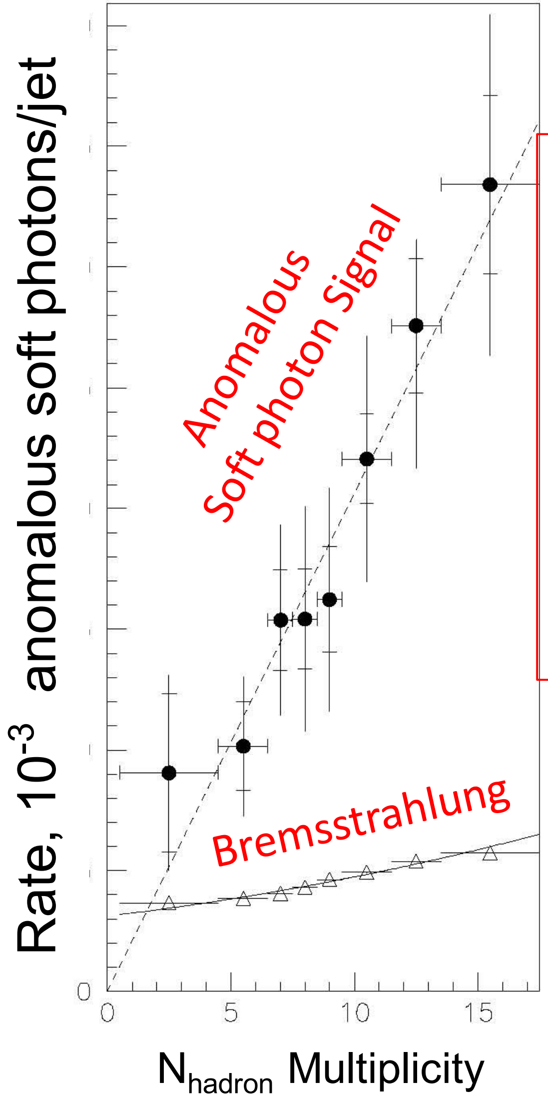
Anomalous soft photons (excess e+e-) are always produced whenever hadrons are produced. They are not produced when hadrons are not produced.

Experiment	**Collision Energy**	**Photon pT**	**Photon/Brems Ratio**
Exclusive measurements with knowledge of all particle momenta to determine bremmstrahlung contributions			
K^+ p, CERN WA27,BEBC(1984)	**70 GeV/c**	**PT < 60 MeV/c**	**4.0 ± 0.8**
K^+ p, CERN NA22, EHS (1993) **π^+ p, CERN NA22, EHS (1997)**	**250 GeV/c** **250 GeV/c**	**PT < 40 MeV/c** **PT < 40 MeV/c**	**6.4 ± 1.6** **6.9 ± 1.3**
π^- p , CERN WA83,OMEGA(1997)	**280 GeV/c**	**PT < 10 MeV/c**	**7.9 ± 1.4**
π^- p , CERN WA91,OMEGA(2002)	**280 GeV/c**	**PT < 20 MeV/c**	**5.3 ± 0.9**
p p , CERN WA102,OMEGA(2002)	**450 GeV/c**	**PT < 20 MeV/c**	**4.1 ± 0.8**
e+e-→hadrons CERN DELPHI(2010) with hadron production	**~91 GeV (CM)**	**PT < 60 MeV/c**	**~4.0**
e+e- →μ+μ- CERN DELPHI(2008) with no hadron production	**~91 GeV (CM)**	**PT < 60 MeV/c**	**~1.0**

(Table compiled by V. Perepelitsa, ISMD 2009, Gomel, Belarus)

e+e- annihilation at Z0 decay (~ 91 GeV)

DELPHI (EPJ 2010) arXiv:1004.1587

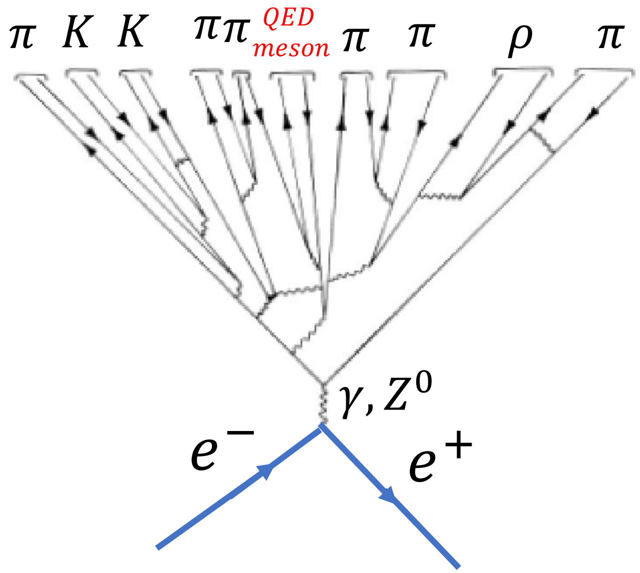


Anomalous soft photon yield is proportional to the hadron yield.

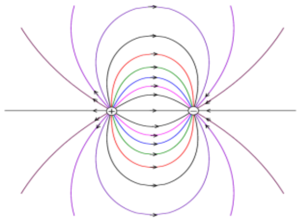
All theoretical models up to 2009 failed !

QED mesons as the source of anomalous soft photons

CYWongPRC81,064903(2010),arxiv:1001.1691



Schwinger confinement mechanism in QED in $(1+1)$D (static viewpoint)

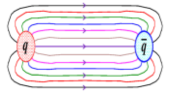


q and $\bar q$ in (3+1)D

In (3+1)D, the electric field lines of force extend to infinity, and a q and $\bar q$ is de-confined.

The potential is $V_{q\bar q}(r_{q\bar q}) = -\frac{g_{4D}^2}{4\pi|\overrightarrow{r_q}-\overrightarrow{r_{\bar q}}|} = -\frac{\alpha_{4D}}{|\overrightarrow{r_q}-\overrightarrow{r_{\bar q}}|}$, $\alpha_{4D} = \frac{g_{4D}^2}{4\pi} = \frac{1}{137}$,

g_{4D} is the QED coupling constant in (3+1)D and g_{4D} is dimensionless.



q and $\bar q$ in a fluxtube in (3+1)D

If the electric field lines of force in (3+1)D can be bundled together into a flux tube, which can be idealized as a string in (1+1)D, then

$$V_{q\bar q}(x_{q\bar q}) = \frac{g_{2D}^2}{2}|x_q - x_{\bar q}|,$$ and a q and $\bar q$ will be confined.

q and $\bar q$ in a string in (1+1)D

Schwinger showed in 1962 that a massless fermion and an antifermion, interacting in QED in (1+1)D, are confined as a neutral boson with a mass

$$m = \frac{g_{2D}}{\sqrt{\pi}}$$

where g_{2D} is the QED coupling constant in (1+1)D and g_{2D} has the dimension of a mass.

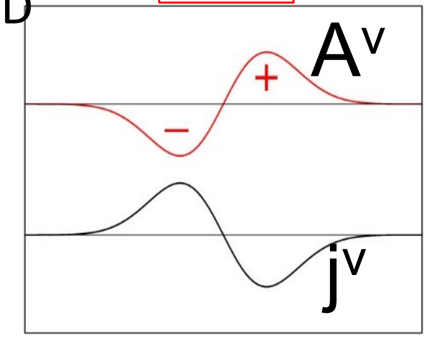
Light quarks are approximately massless and they interact in QED.

We can apply the Schwinger confinement mechanism to light quarks to infer that a light q and $\bar q$ interacting in QED in (1+1)D are confined as a QED meson in (1+1)D.

Schwinger confinement mechanism in QED in (1+1)D, (dynamical viewpoint)

See Chapter6,CYWong'Intro.toHigh-EnergyHeavy-IonCollisions'

QED



- Consider the vacuum of completely filled states of massless quarks below the Dirac sea in (1+1)D
- Introduce an external QED gauge field A^ν acting on the quark field ψ

Dirac eq. $$\gamma_\nu(p^\nu\text{-}g_{2D}A^\nu)\psi = 0$$

- Solution of ψ generates *an induced current*, $j^\nu = \bar{\psi}\gamma^\nu\psi$,

(1) $$j^\nu = -\frac{g_{2D}}{\pi}\left(A^\nu - \partial^\nu \frac{1}{\partial^\lambda\partial_\lambda}\partial_\mu A^\mu\right), \quad \text{gauge-invariant under } (A^\nu)' = A^\nu - \partial^\nu\Lambda$$

This second term needed to maintain gauge invariance

- The induced current j^ν generates a new gauge field $\tilde{A}^\nu$

(2) Maxwell eq. $$\partial_\mu F^{\mu\nu} = \partial_\mu(\partial^\mu\tilde{A}^\nu - \partial^\nu\tilde{A}^\mu) = g_{2D}\, j^\nu$$

- Stable collective motion of is possible when $\tilde{A}^\nu = A^\nu$,

$$A^\nu \xrightarrow{\text{Dirac eq.}} j^\nu \xrightarrow{\text{Maxwell eq.}} \tilde{A}^\nu \rightarrow j^\nu \rightarrow A^\nu \rightarrow j^\nu \rightarrow \cdots \qquad (A\ j\ A\ \text{ self-consistent non-linearity})$$

- When $\tilde{A}^\nu = A^\nu$, Eqs. (1) and (2) are the same as

(3) $$\partial_\mu\partial^\mu A^\nu + \frac{(g_{2D})^2}{\pi}A^\nu = 0$$

(4) $$\partial_\mu\partial^\mu j^\nu + \frac{(g_{2D})^2}{\pi}j^\nu = 0$$

- Eqs. (3) and (4) are the Klein-Gordon equation for a stable boson, QED meson in (1+1)D, with a mass

$$m = \frac{g_{2D}}{\sqrt{\pi}}$$

Two equivalent views of a QED meson (or a QCD meson) in (1+1)D

- **Fundamental quantum field theory viewpoint:**

  A meson is a localized, stable, collective, space-time variation of the quark current j^ν and the gauge field A^ν in a many-body quark-(gauge field) fluid.

- **Phenomenological, approximate two-body viewpoint:**

  A meson is a bound state of a valence quark and a valence antiquark interacting with a phenomenological effective confining interaction, as an approximate open-string two-body problem.

Can a $q\bar{q}$ meson in (1+1)D represent a physical $q\bar{q}$ meson in (3+1)D ?

- In (3+1)D, the flux tube has a structure with a transverse radius R_T, the coupling constant g_{4D} is dimensionless.
- In (1+1)D, the open string has no structure, but the coupling constant g_{2D} has the dimension of a mass.
- In going from (3+1)D → (1+1)D, the information on the flux tube radius R_T in (3+1)D is encoded in the coupling constant g_{2D} in (1+1)D,

$$\boxed{(g_{2D})^2 = \frac{1}{\pi R_T^2}(g_{4D})^2}$$

C.Y.Wong,PRC80,054917(2009)[arxiv:0903.38790]
C.Y.Wong,PRC81,064903(2010)[arxiv:1001.1691]

- A flux tube in (3+1)D can be idealized as a string in (1+1)D.
- The string in (1+1)D can be restored back to the original physical flux tube in (3+1)D by the above relation.

- We obtain for a physical QED meson in QED in (3+1)D, $m_{QED}^2 = \frac{4\alpha_{4D}^{QED}}{\pi R_{T,QED}^2}$.

For a physical QCD meson in QCD in (3+1)D, $m_{QCD}^2 = \frac{4\alpha_{4D}^{QCD}}{\pi R_{T,QCD}^2}$ in the quasi-Abelian Approximation of QCD.

- If the flux tube radius R_T is an intrinsic property of the quark, then

$$\frac{(QCD\ meson\ mass\ m_{QCD})}{(QED\ meson\ mass\ m_{QED})} = \sqrt{\frac{\alpha_{4D}^{QCD}}{\alpha_{4D}^{QED}}} \approx \sqrt{\frac{0.7}{1/137}} \approx 10 \approx \frac{(hundreds\ MeV)}{(tens\ MeV)}, \quad \text{and} \quad \frac{(QCD\ meson\ linear\ length)}{(QED\ meson\ linear\ length)} \approx \frac{1}{10}$$

There are <u>serious objections</u> to the proposed concepts of confined $q\bar{q}$ QED mesons in (3+1)D.

Debate between the Wise Guy (大智) and the Old Fool (愚公)

Wise Guy
DaZhi(大智）
raises
objections :

- Quarks interact in QCD and QED simultaneously.
- When quarks oscillates, the color charges and electric charges also oscillate simultaneously.
- Stable collective QED excitations of quarks cannot occur without the QCD interactions.

Old Fool
YuGong(愚公)
replies:

- Quark current $j^\nu$and gauge field A^ν are not single-element quantities. They are 3×3 color matrices.
- They have 9 elements which breaks up into color-octet subgroup and color-singlet subgroup
- In the space-time arena, each j^ν and A^ν subgroup can generate separate stable collective excitations.
- There can be localized, stable QCD excitations in the color-octet j^ν and A^ν to lead to π^0,η,η',...
- There can also be localized, stable QED excitations in the color-singlet j^ν and A^ν to lead to X17, E38,...

Debate between the Wise Guy (大智) and the Old Fool (愚公) (contd)

Wise Guy DaZhi(大智) raises objections :

- Is it ever possible for a quark and antiquark be produced and interact in QED alone?

Old Fool YuGong(愚公) replies:

- q and $\bar{q}$ exist only when they are confined and bound
- Confined and bound states arise non-perturbatively
- A light q and $\bar{q}$ pair can be produced for example by $e^{+} + e^{-} \rightarrow q + \bar{q}$ at energies $\sqrt{s}(q\bar{q})$,

$$m_q + m_{\bar{q}} < \sqrt{s}\,(q\bar{q}) < m_\pi$$

- Below $\sqrt{s}\,(q\bar{q}) < m_\pi$, the q and $\bar{q}$ can interact non-perturbatively only through the QED interaction, as the non-perturbative QCD interaction will lead to confined and bound QCD mesons with $m_{q\bar{q}} = \sqrt{s}\,(q\bar{q}) \geq m_\pi$

Debate between the Wise Guy (大智) and the Old Fool (愚公) (contd)

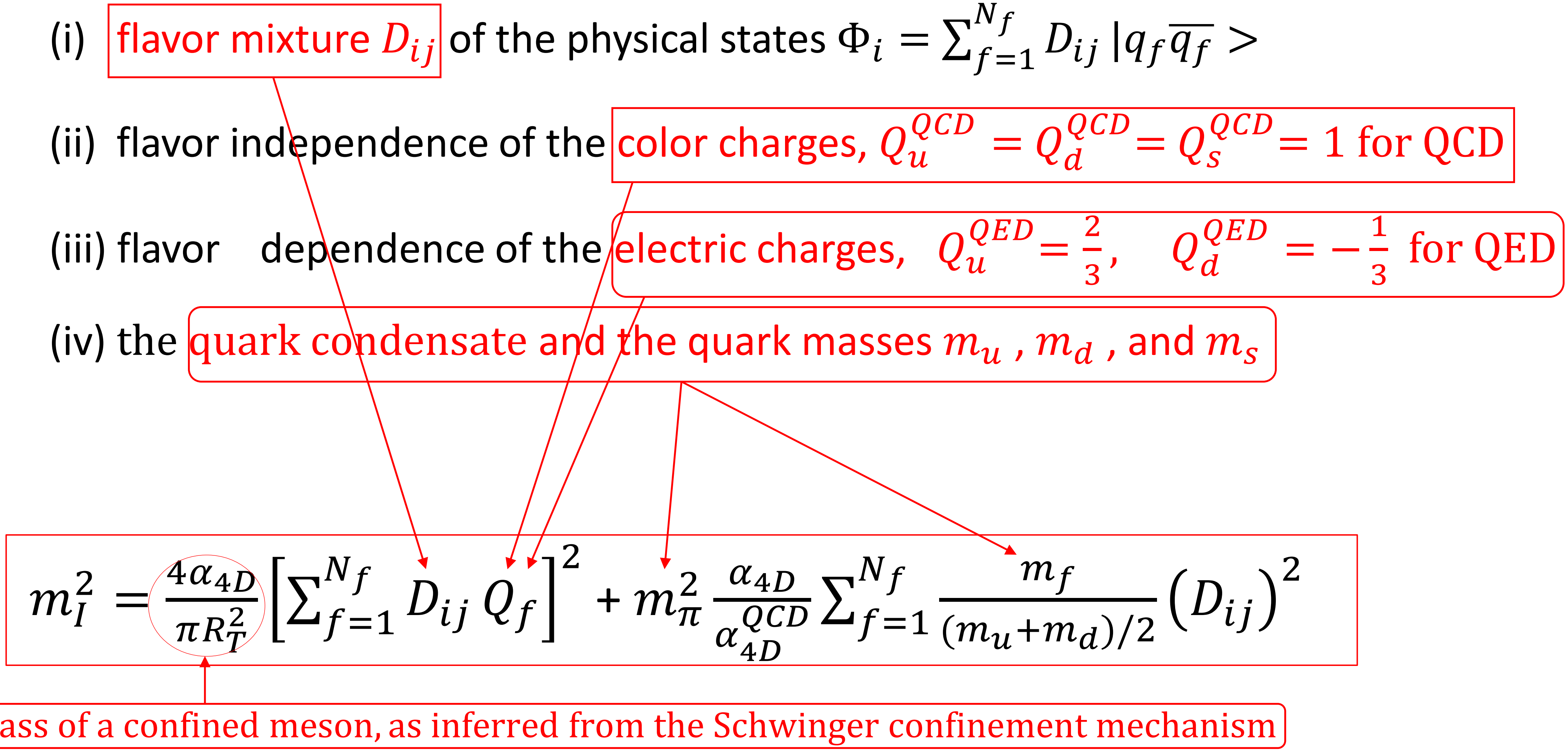
Wise Guy
DaZhi(大智）
raises
objections :

- Only non-Abelian QCD interactions can confine quarks
- The Abelian QED interaction does not confine electrons and positrons, so the QED interaction does not confine quarks and antiquarks
- Lattice gauge calculations showed that a quark and an antiqurk is deconfined in compact QED in (3+1)D.

Old Fool
YuGong(愚公)
replies:

- Light quarks (and antiquarks) as massless fermions are confined in QED in 1+1D (Schwinger,1962)
- Confined $q\bar{q}$ in QED in 1+1D can be taken as idealization of confined $q\bar{q}$ in QED in 3+1D in a flux tube
- Present-day lattice calculations for quarks in compact QED in (3+1)D may not be definitive because they do not include the Schwinger confinement effect of dynamical quarks
- Polyakov showed that fermions are confined in compact QED in (2+1)D which can be longitudinally stretched into a flux tube -- for the Schwinger (1+1)D confinement mechanism to be operative
- The open-string description of QCD+QED mesons gives correct π^0, η, η', X17, E38 masses (JHEP 08(2020)165, arxiv:2001.04864)

For quantitative descriptions of QCD and QED mesons, we must take into account



(i) flavor mixture D_{ij} of the physical states $\Phi_i = \sum_{f=1}^{N_f} D_{ij} \, |q_f \overline{q_f} >$

(ii) flavor independence of the color charges, $Q_u^{QCD} = Q_d^{QCD} = Q_s^{QCD} = 1$ for QCD

(iii) flavor dependence of the electric charges, $Q_u^{QED} = \frac{2}{3}$, $Q_d^{QED} = -\frac{1}{3}$ for QED

(iv) the quark condensate and the quark masses m_u , m_d , and m_s

$$m_I^2 = \frac{4\alpha_{4D}}{\pi R_T^2} \left[\sum_{f=1}^{N_f} D_{ij} \, Q_f \right]^2 + m_\pi^2 \frac{\alpha_{4D}}{\alpha_{4D}^{QCD}} \sum_{f=1}^{N_f} \frac{m_f}{(m_u+m_d)/2} \left(D_{ij} \right)^2$$

the mass of a confined meson, as inferred from the Schwinger confinement mechanism

Procedure to calculate the QED meson masses

- We input the pion mass m_π .
- We fit the η and η' masses, and obtain $\alpha_{4D}^{QCD} = 0.68$ and $R_T = 0.4$ fm.
- We assume that the flux tube radii are the same for QCD and QED mesons and extrapolate from QCD meson masses to QED mesons masses with $\alpha_{4D}^{QED} = \frac{1}{137}$.
- We obtained $m_{I=0}^{QED} = 16.9$ MeV

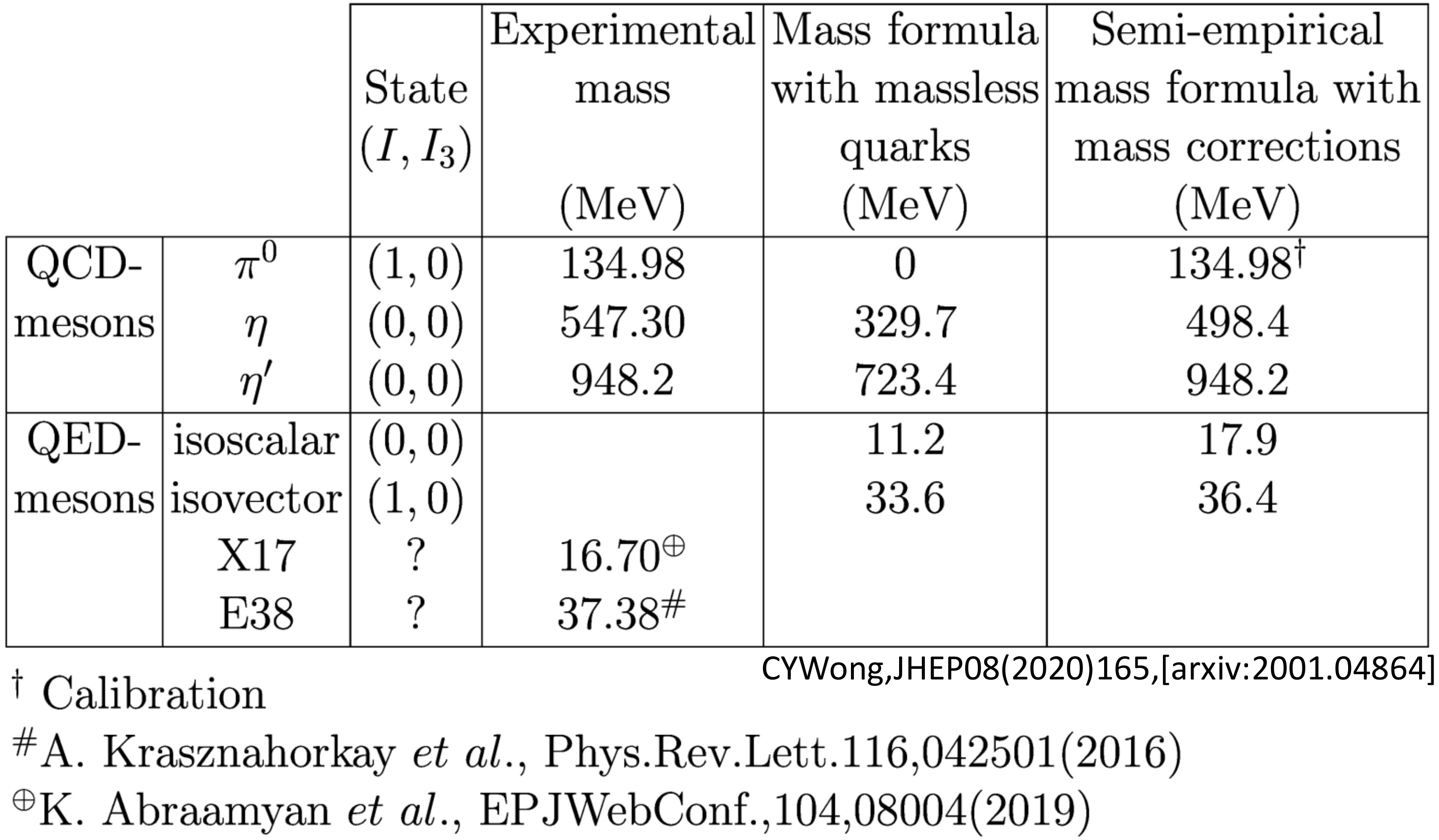
$$m_{I=1}^{QED} = 36.4 \text{ MeV}$$

QCD mesons with 3 flavors and QCD mesons with 2 flavors in detail

$$\boxed{m_I^2 = \frac{4\alpha_{4D}}{\pi R_T^2}\left[\sum_{f=1}^{N_f} D_{ij}\, Q_f\right]^2 + m_\pi^2 \frac{\alpha_{4D}}{\alpha_{4D}^{QCD}} \sum_{f=1}^{N_f} \frac{m_f}{(m_u+m_d)/2}\left(D_{ij}\right)^2 ,}$$

for the physical state $\Phi_i = \sum_{f=1}^{N_f} D_{ij} |q_f\, \overline{q_f} >$,

with D_{ij} and m_f from PDG Tables, $R_T = 0.4$ fm, $\alpha_{4D}^{QCD} = 0.68$, $\alpha_{4D}^{QED} = \frac{1}{137}$.



		State (I, I_3)	Experimental mass (MeV)	Mass formula with massless quarks (MeV)	Semi-empirical mass formula with mass corrections (MeV)
QCD-mesons	π^0	$(1, 0)$	134.98	0	$134.98^\dagger$
	η	$(0, 0)$	547.30	329.7	498.4
	η'	$(0, 0)$	948.2	723.4	948.2
QED-mesons	isoscalar	$(0, 0)$		11.2	17.9
	isovector	$(1, 0)$		33.6	36.4
	X17	?	$16.70^\oplus$		
	E38	?	$37.38^\#$		

CYWong,JHEP08(2020)165,[arxiv:2001.04864]

† Calibration

$^\#$A. Krasznahorkay *et al.*, Phys.Rev.Lett.116,042501(2016)

$^\oplus$K. Abraamyan *et al.*, EPJWebConf.,104,08004(2019)

QCD mesons & QED mesons are reasonable concepts!

QED and QCD meson masses with 2 flavor in detail

$$\Phi_{I=0,I_3=0}=\frac{1}{\sqrt{2}}(|u\bar{u}> + |d\bar{d}>)$$

$$\Phi_{I=1,I_3=0}=\frac{1}{\sqrt{2}}(|u\bar{u}> - |d\bar{d}>)$$

$$m_I^2 = \frac{4\alpha_{4D}}{\pi R_T^2}\left[\frac{Q_u+(-1)^I Q_d}{\sqrt{2}}\right]^2 + m_\pi^2 \frac{\alpha_{4D}}{\alpha_{4D}^{QCD}}$$

Effective charge = $\frac{Q_u+(-1)^I Q_d}{\sqrt{2}}$

$Q_u^{QCD} = Q_d^{QCD} = 1$

$Q_u^{QED} = 2/3, \quad Q_d^{QED} = -1/3$

$R_T = 0.4$ fm, $\alpha_{4D}^{QCD}=0.68, \quad \alpha_{4D}^{QED}=\frac{1}{137}$

Effective charge

$I = 0, \quad I_3=0$

QCD: $\frac{1+1}{\sqrt{2}}$

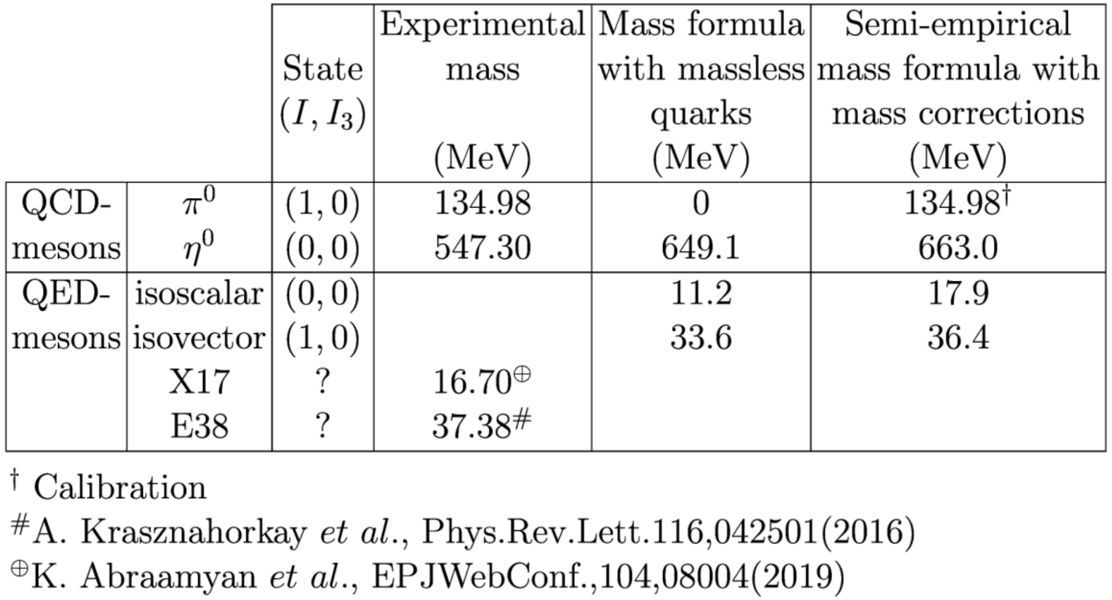
QED: $\frac{1}{\sqrt{2}}\left[\left(\frac{2}{3}\right)+\left(-\frac{1}{3}\right)\right]$

Effective charge

$I = 1, \quad I_3=0$

QCD: $\frac{1-1}{\sqrt{2}}$

QED: $\frac{1}{\sqrt{2}}\left[\left(\frac{2}{3}\right)-\left(-\frac{1}{3}\right)\right]$



		State (I, I_3)	Experimental mass (MeV)	Mass formula with massless quarks (MeV)	Semi-empirical mass formula with mass corrections (MeV)
QCD-mesons	π^0	$(1,0)$	134.98	0	$134.98^\dagger$
	η^0	$(0,0)$	547.30	649.1	663.0
QED-mesons	isoscalar	$(0,0)$		11.2	17.9
	isovector	$(1,0)$		33.6	36.4
	X17	?	$16.70^\oplus$		
	E38	?	$37.38^\#$		

† Calibration

A. Krasznahorkay *et al.*, Phys.Rev.Lett.116,042501(2016)

⊕ K. Abraamyan *et al.*, EPJWebConf.,104,08004(2019)

CYWong,PRC81,064903(2010),[arxiv:1001.1691]
CYWong,JHEP08(2020)165,[arxiv:2001.04864

Confrontation of theoretical QED meson predictions with experiment

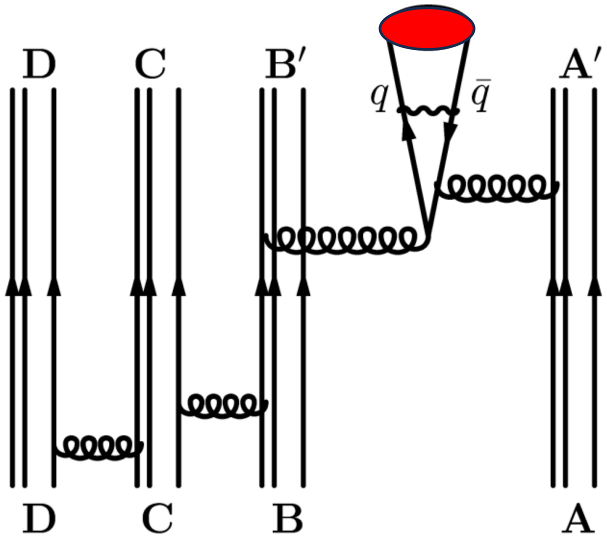
We need

(1) to produce QED mesons

(2) to detect QED mesons by their decays

(3) and measure the invariant mass of the decay products

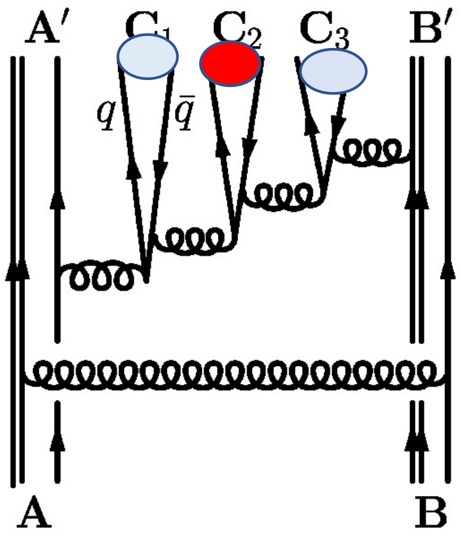
QCD meson (○) and QED mesons (●) can be produced by producing $q\bar{q}$ pairs at the approriate energies in hadron-hadron colliisons



(a)

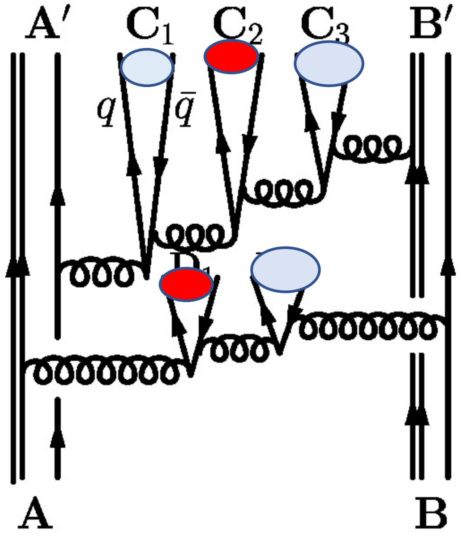
(i) Low excitation energies below pion mass threshold (ATOMKI experiments)

(ii) Peripheral high-energy parton-parton collisions



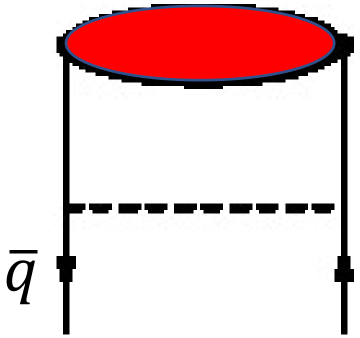
(b)

Intermediate energy hadron-hadron and nucleus-nucleus collisions above pion mass threshold (Anomalous soft photons, Dubna experiments.)



(c)

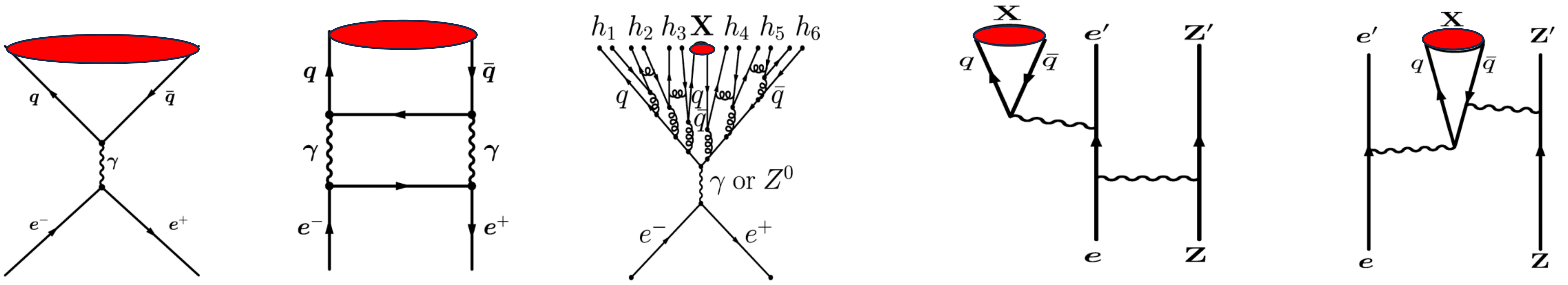
High energies central AA Collisions (RHIC and LHC experiments)



(d)

Coalescence during deconfinement-to confinement QGP phase transition in high energies central AA collisions (RHIC & LHC experiments)

QCD meson and QED mesons can also be produced in in $e^+ - e^-$ anninihiations and bremsstrahlung-type processes



(a) (b) (c) (d) (e)

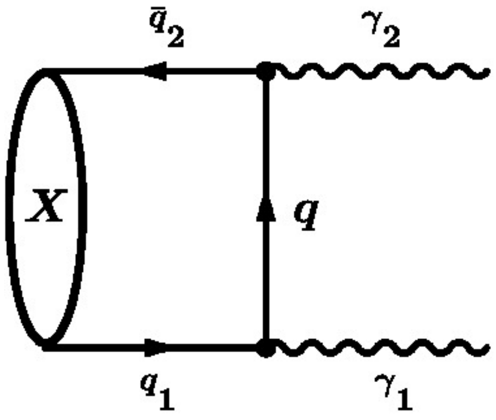
QED meson production by low-energy e^+e^- annihilation below pion mass threshold, $\sqrt{s_{e^+e^-}} \le m_\pi$ (inverse ATOMKI experiment)

QED meson production by high-energy e^+e^- annihilation (DELPHI,PADME experiments,…)

QED meson production by electron-nucleus bremsstrahlung-type reactions (JLAB experiment,…)

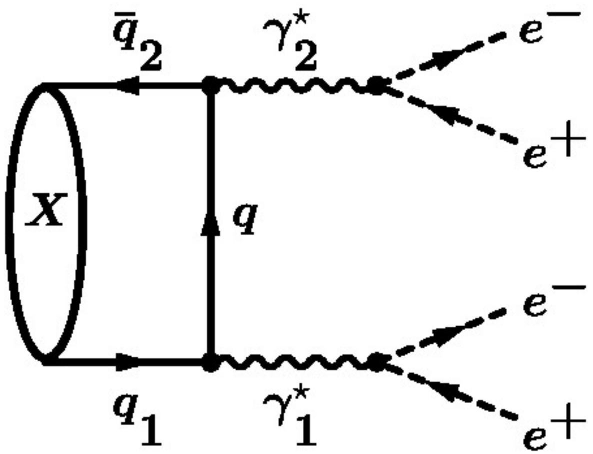
How QED meson decays ?
What are their decay products?

QED mesons can be detected by (a) $\gamma\gamma$, (b) $\gamma^*\gamma^*$, and (c) e^+e^-



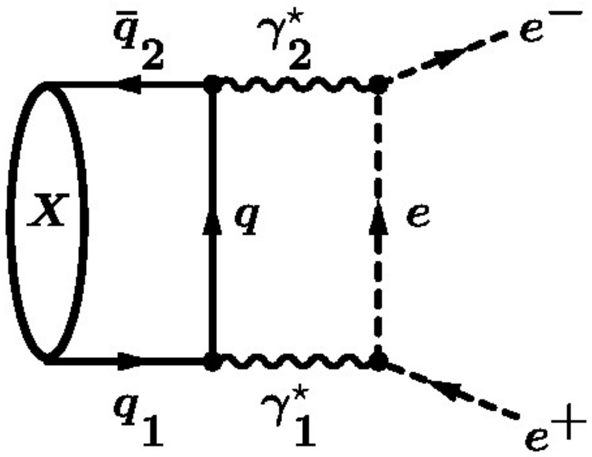
(a)

Detection using the invariant mass of two real photons
-- Dubna



(b)

Detection using the invariant mass of two virtual photons
-- RHIC?



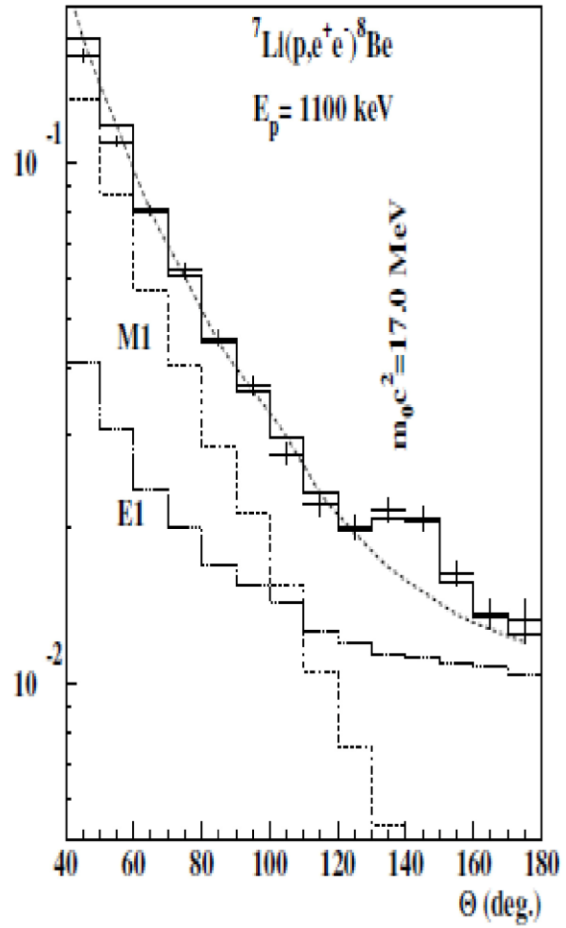
(c)

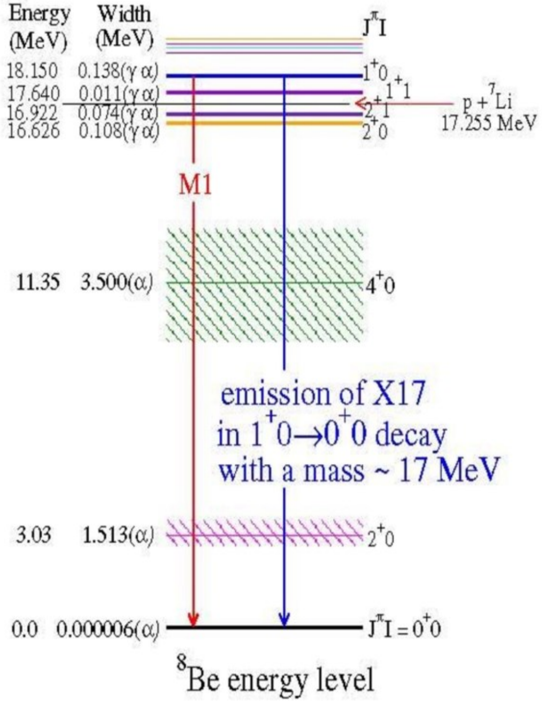
Detection using invariant mass of e^+e^-
-- ATOMKI
Excess e^+e^- -- anomalous soft photons

Experimental observations of anomalous particles at ∼17 and ∼38 MeV

Observation of X17 in the decay of ^{8}Be* by ATOMKI (2016)

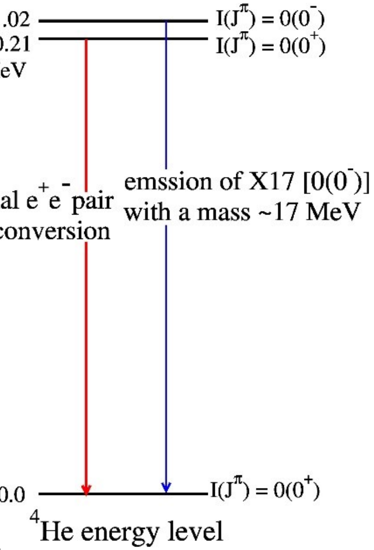
Krasznahorkay et al PRL116,042501 (2016)





X17 particle observed in decay of ^{4}He* at Atomki

Krasznahorkay et al, PRC104,044003(2021) arxiv:2104.10075



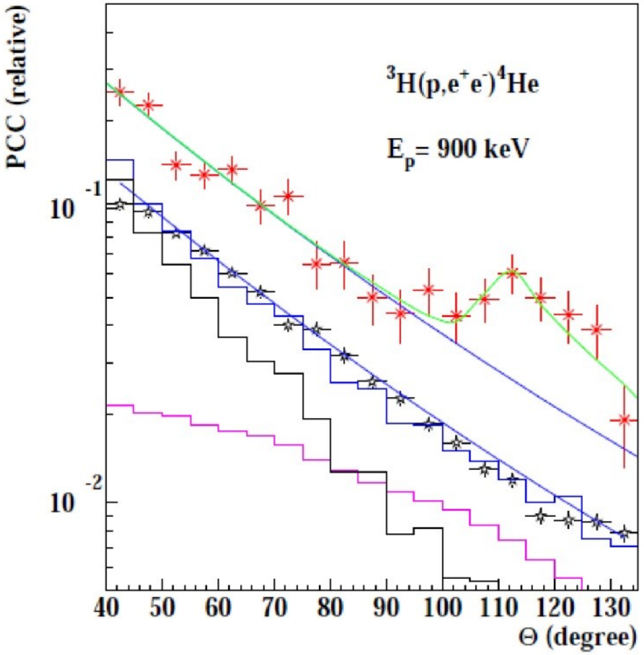


FIG. 2. *Angular correlations for the e^+e^- pairs measured the $^3H(p,\gamma)^4He$ reaction at the E_p=900 keV.*

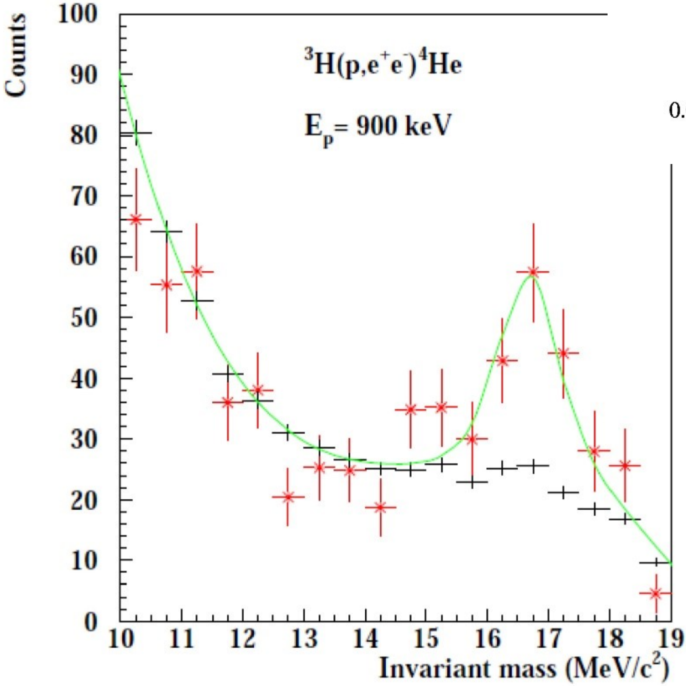
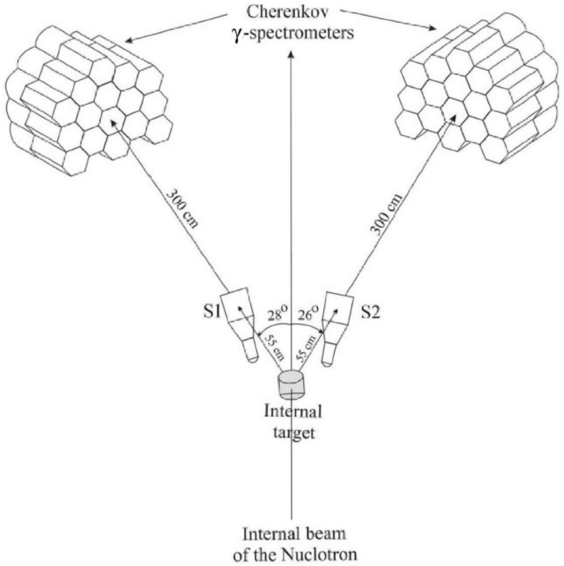
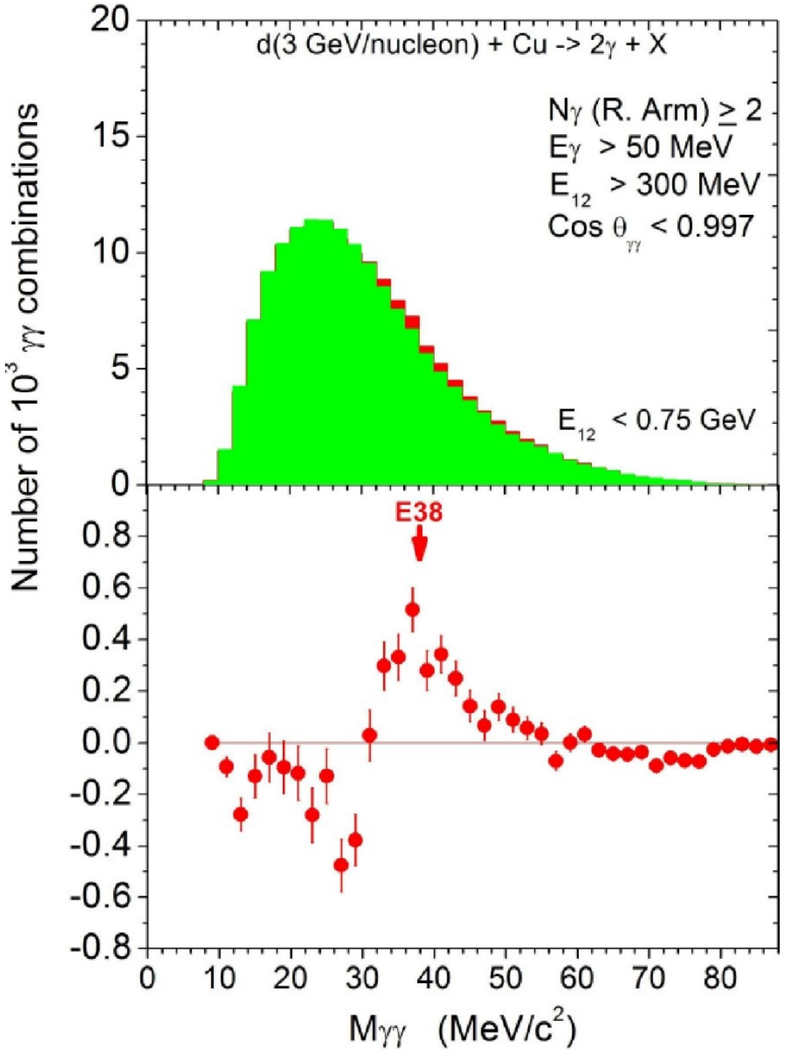


FIG. 3. *Invariant mass distribution derived for the 20.49 MeV transition in ^4He.*

Observation of the E38 boson at Dubna



Abraamyan et al. arxiv:1208.3829(2012)
EPJWebConf204,08004(2019)



Other hints of anomalous particles in regions of many tens of MeV

(i) Anomalous soft photons (excess e^+e^-) in high-energy hadron-hadron and e^+e^- annihaltions, with $p_T < 60$ MeV/c^2

(ii) COMPASS hadron-hadron collisions, with $\gamma\gamma$ invariant mass at $\sim$17 and $\sim$38 MeV

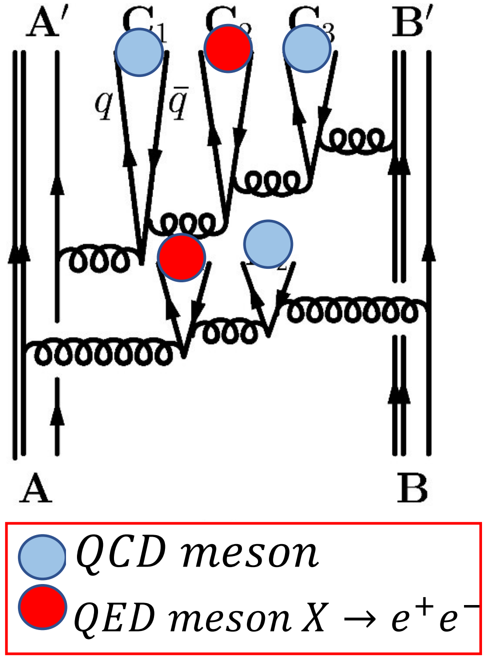
(iii) Pb collisions on Photographic Emulsion at RHIC, with e^+e^- invariant mass at $\sim$18 MeV

(iv) CMS anomalous low-mass diphoton structure at $\sim$40 MeV in Pb-Pb collisions at LHC

(v) ALICE pPb collisions, $\gamma\gamma$ invariant mass at $\sim$50 MeV.

Anomalous soft photons (excess e+e-) are always produced whenever hadrons are produced. They are not produced when hadrons are not produced.

Experiment	Collision Energy	Photon pT	Photon/Brems Ratio
Exclusive measurements with knowledge of all particle momenta to determine bremmstrahlung contributions			
K^+ p, CERN WA27,BEBC(1984)	**70 GeV/c**	**p_T < 60 MeV/c**	**4.0 ± 0.8**
K^+ p, CERN NA22, EHS (1993) **π^+ p, CERN NA22, EHS (1997)**	**250 GeV/c** **250 GeV/c**	**p_T < 40 MeV/c** **p_T < 40 MeV/c**	**6.4 ± 1.6** **6.9 ± 1.3**
π^- p , CERN WA83,OMEGA(1997)	**280 GeV/c**	**p_T < 10 MeV/c**	**7.9 ± 1.4**
π^- p , CERN WA91,OMEGA(2002)	**280 GeV/c**	**p_T < 20 MeV/c**	**5.3 ± 0.9**
p p , CERN WA102,OMEGA(2002)	**450 GeV/c**	**p_T < 20 MeV/c**	**4.1 ± 0.8**
e+e-→hadrons CERN DELPHI(2010) with hadron production	**~91 GeV (CM)**	**p_T < 60 MeV/c**	**~4.0**
e+e- →μ+μ- CERN DELPHI(2008) with no hadron production	**~91 GeV (CM)**	**p_T < 60 MeV/c**	**~1.0**

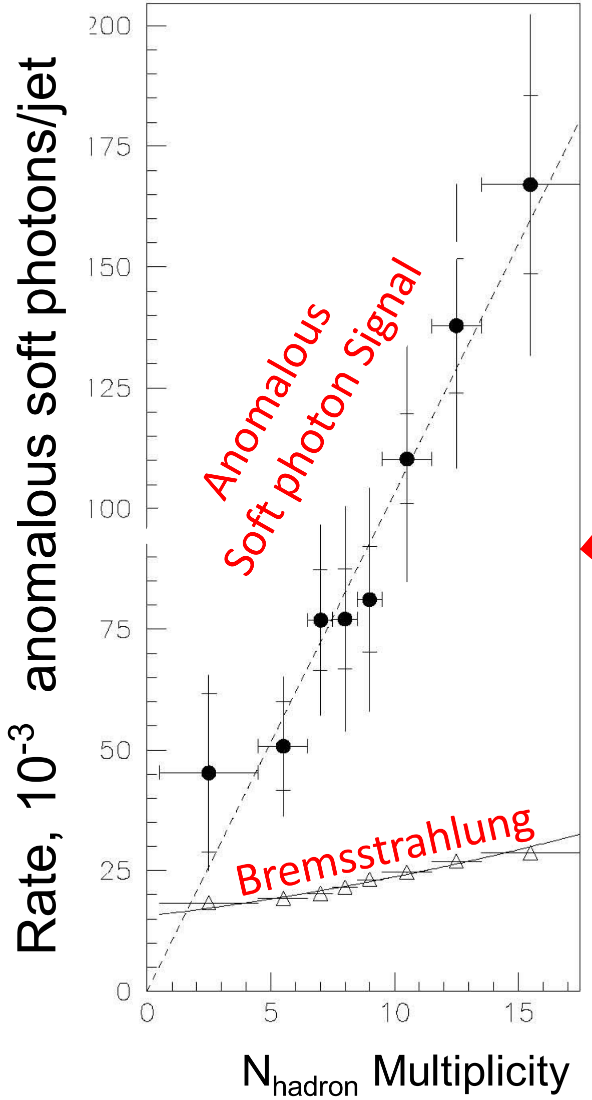


(Table compiled by V. Perepelitsa, 2009)

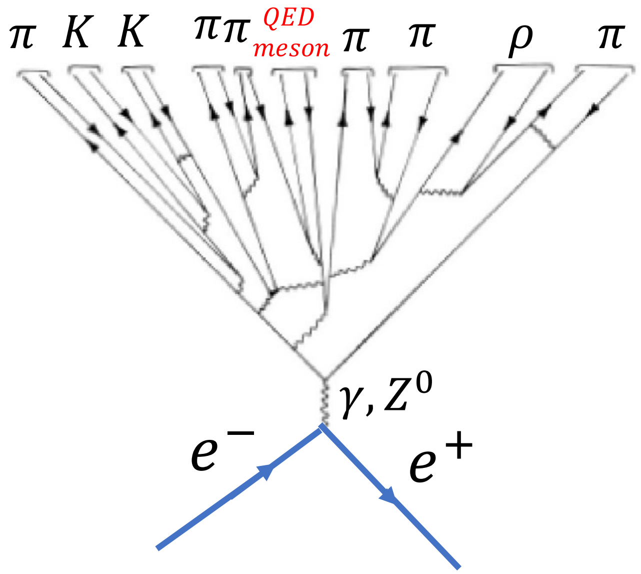
Anomalous soft photon yield is proportional to the hadron yield

e+e- annihilation at Z0 decay (~ 91 GeV)

DELPHI (EPJ 2010) arXiv:1004.1587

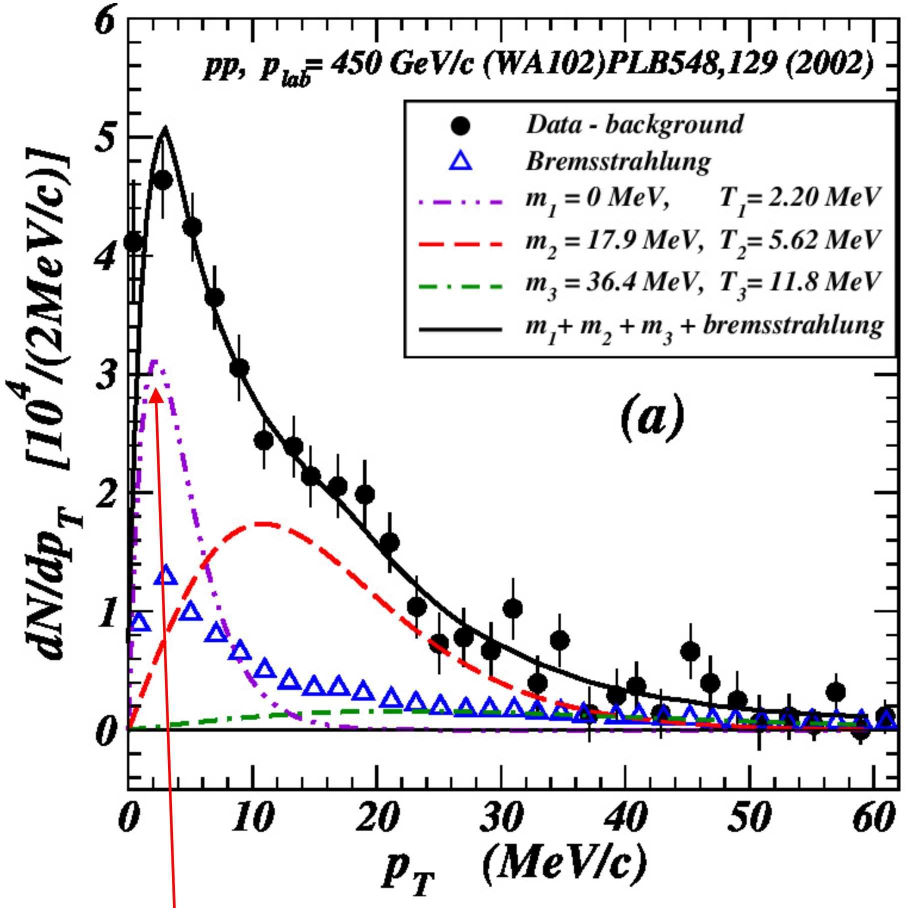


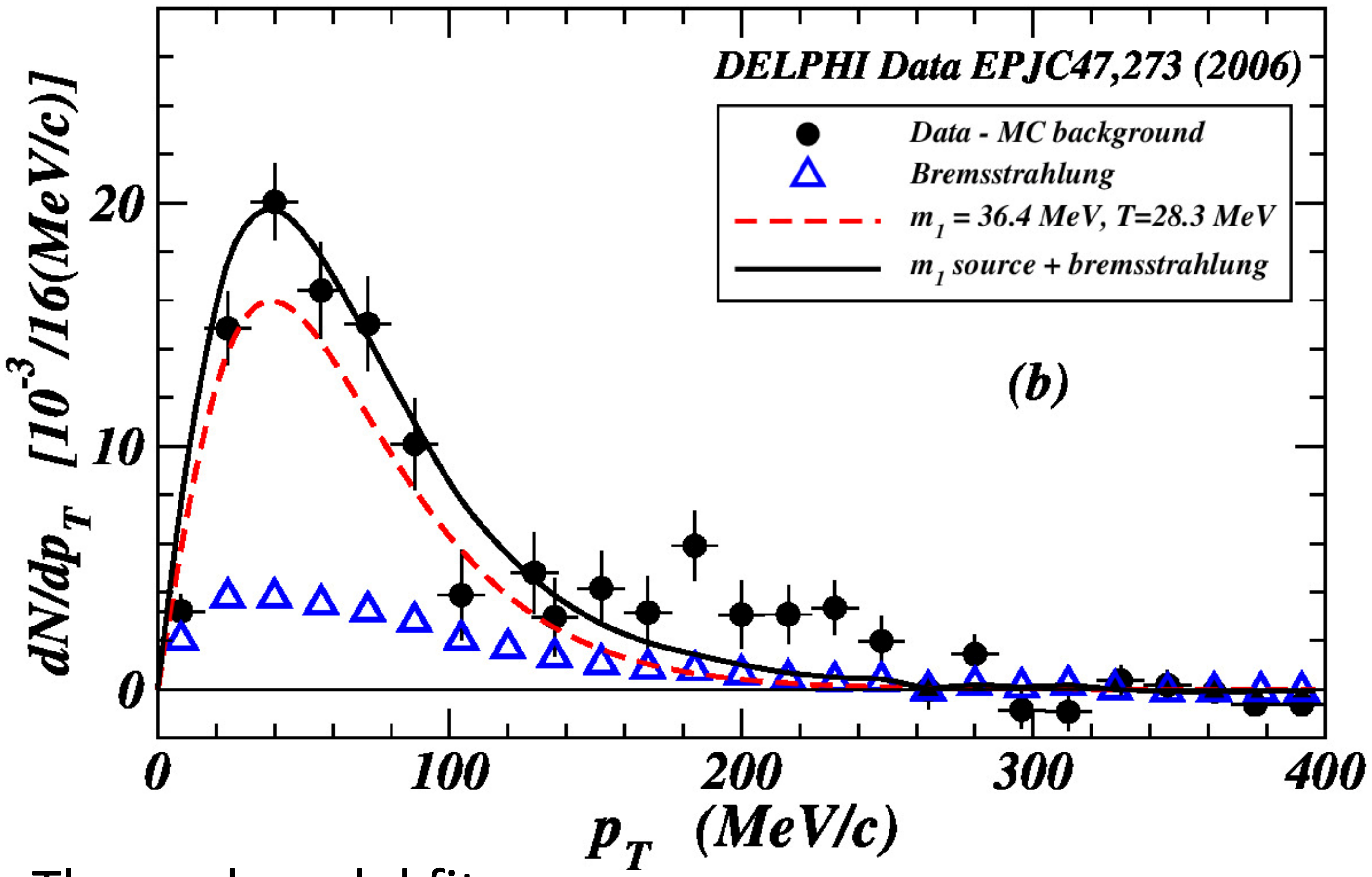
$$\frac{\text{Number of anomalous soft photons}}{\text{Number of produced hadrons}} \approx \frac{150 \times 10^{-3}}{15} \approx \frac{1}{100}$$



Anomalous soft photons (ASP) and QCD mesons arise likely from similar $q\bar{q}$ production mechanisms

pT spectrum of anomalous soft photons (ASP) suggests boson masses of ~18 and ~36 MeV



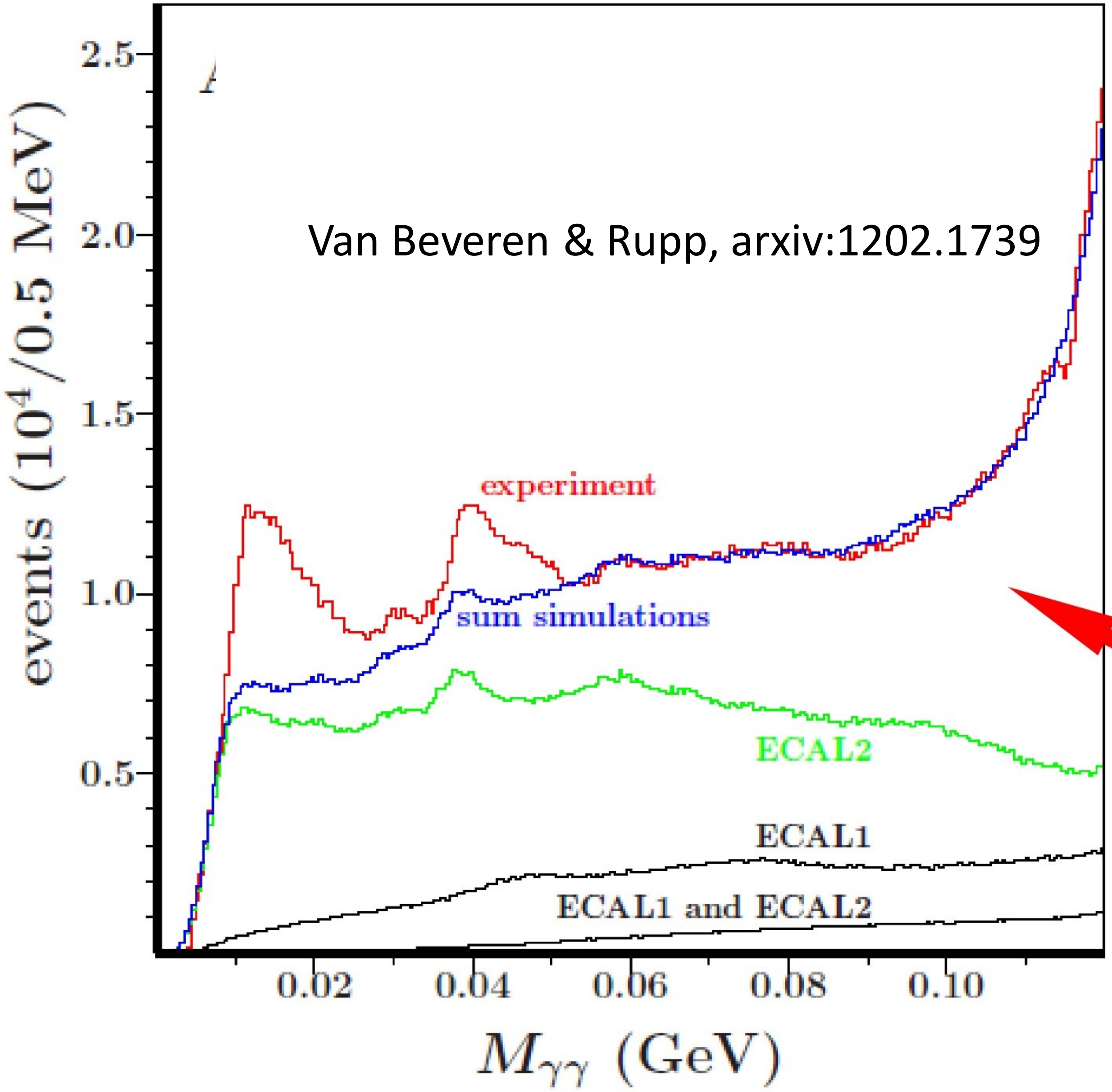


Suggests the production of real photons from the decay of the anomalous soft photons

Thermal model fit:

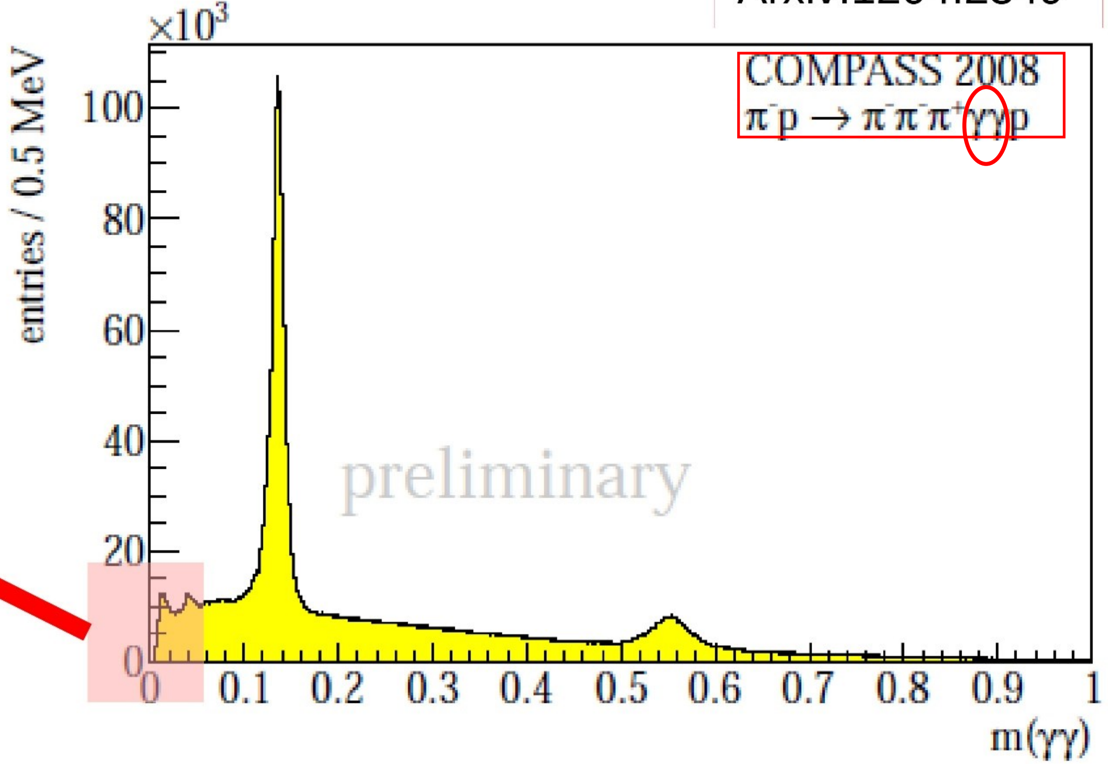
$$\frac{dN}{p_T dp_T} = \sum_{i=1}^{3} A_i e^{-\sqrt{m^2+p_T{}^2}/T_i}$$

CYWong,JHEP08(2020)165,[arxiv:2001.04864]



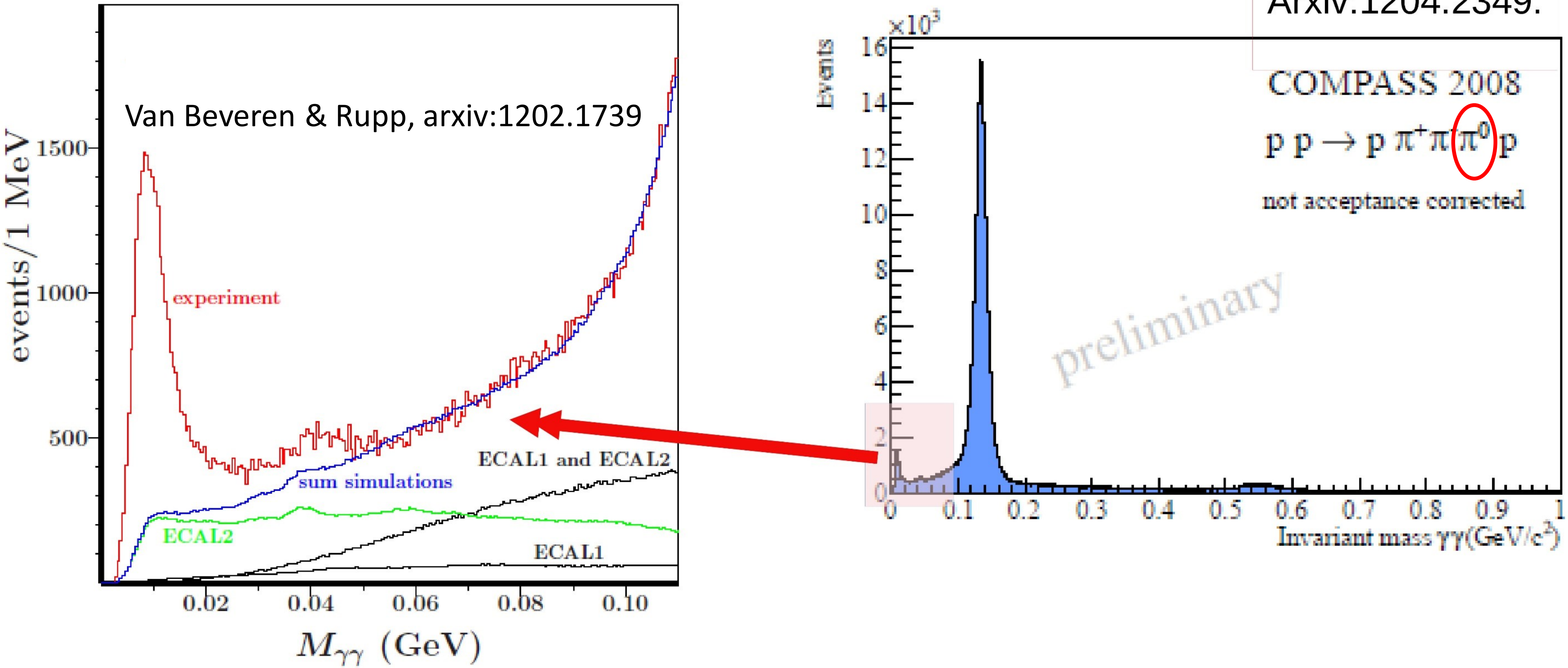
Van Beveren & Rupp, arxiv:1202.1739

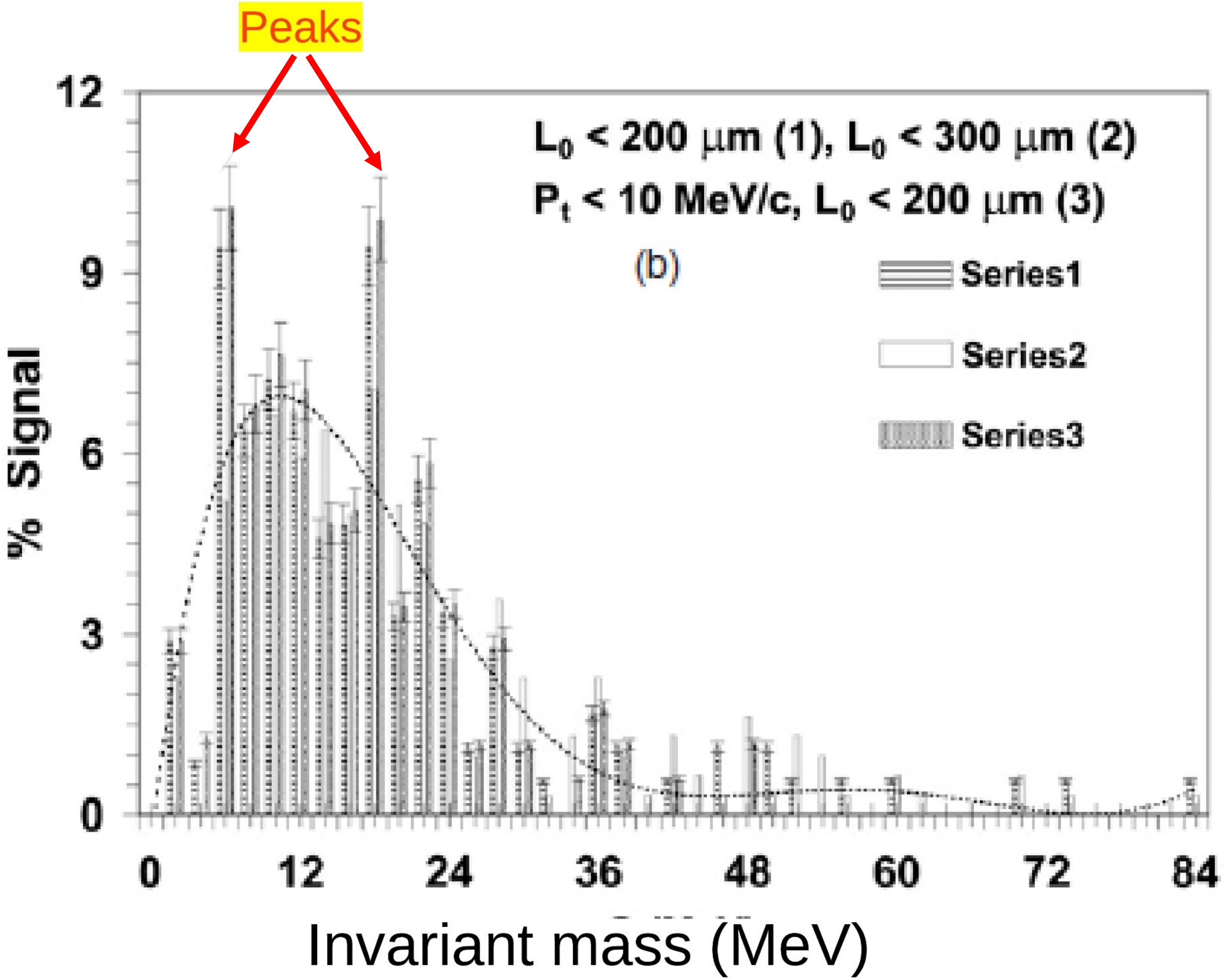
Bernhard et.al
Arxiv:1204.2349



Van Beveren & Rupp, arxiv:1202.1739

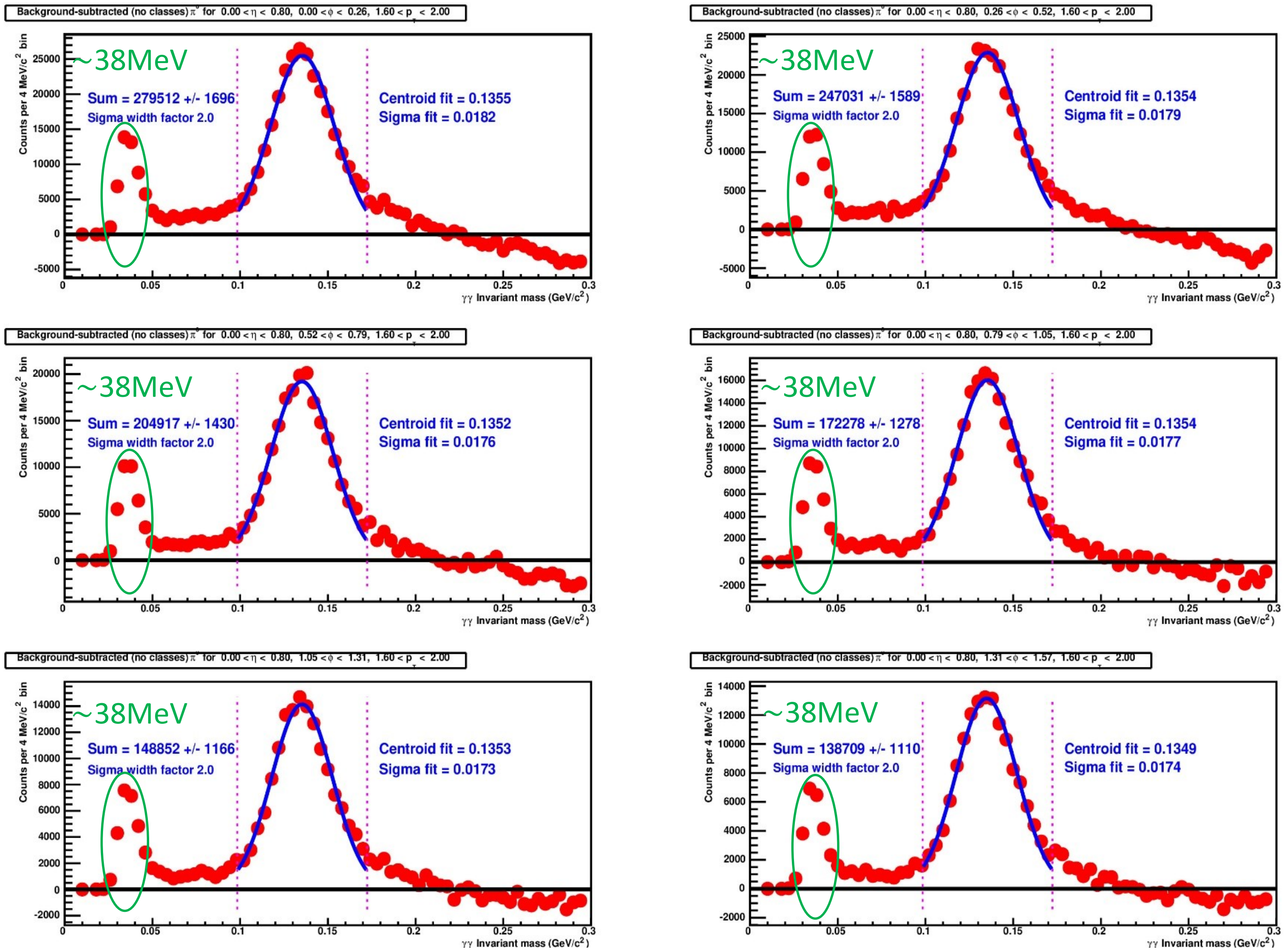
Bernhard et.al
Arxiv:1204.2349.





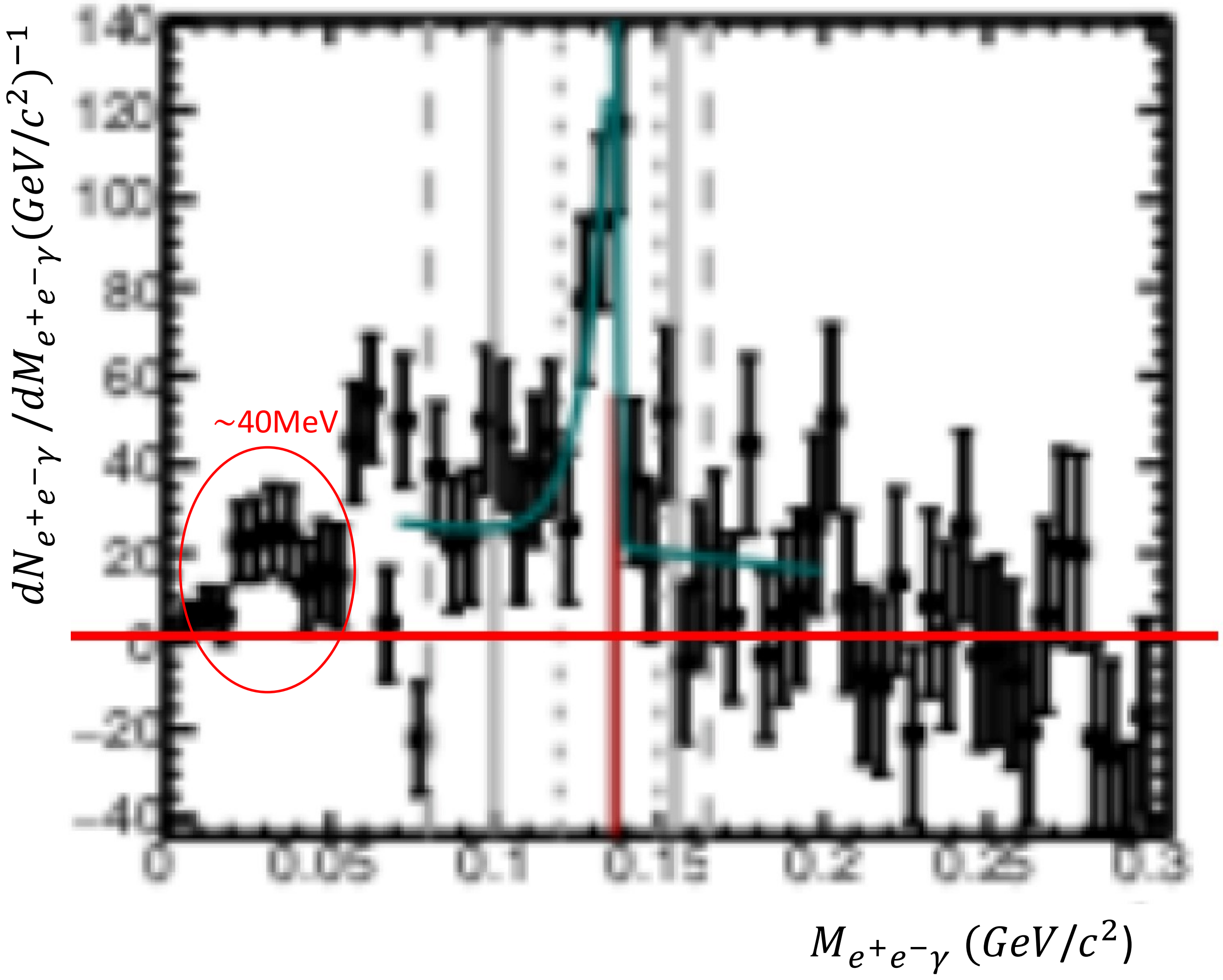
Jain & Singh
J.Phys.G134,129(2007)

Pb Beam at 160A GeV
on photographic emulsion



Background-subtracted spectrum of diphoton invariant mass $M_{\gamma\gamma}$ in 6 angular bins with respect to the event plane for CMS PbPb collisions at $\sqrt{s_{NN}}$ =2.76 TeV in the 40-50% centrality, with 1.6< p_T<2 GeV/c.
(From B. A. Snook, Ph.D. Thesis, Vanderbilt University, 2014, Fig. 5.8)

0.60 GeV/c < $p_T < 0.7$ GeV/c



ALICE pPb at $\sqrt{s_{NN}}$ =5.02 TeV

From P G. Zamora, Ph.D. Thesis, Univ. Complutense de Madrid, 2017

ATOMKI and Dubna experiments provide promising evidence for QED mesons, pending future confirmations.

Implications of possible existence of the QED mesons in (3+1)D

1. There will be a new family of QED-confined $q\bar{q}$ composite particles, which are complex in nature, with additional degrees of freedom in spin-spin, spin-orbit, collective vibrations, collective rotations, flavor admixtures, molecular states, …
2. Confinement occurs for q and $\bar{q}$ not only in QCD but also in QED
3. Confinement may be an intrinsic property of the quarks. If so, a quark and an antiquarks interact with weak and gravitational interactions may lead to confined $q\bar{q}$ composite particles.
4. The QED interaction between a quark and an antiquark may be predominantly linear with a small Coulomb 1/r component, attractive for electric charges of opposite signs, and repulsive for the same sign. In such a case, there may be a stable d-u-d QED neutron, whereas the corresponding u-d-u QED proton is unstable. The QED neutron may be a good candidate for dark matter.

CONCLUSIONS

1. Theoretical predictions and experimental observations point to the possible existence of QED mesons, pending further confirmations.

2. The existence of QED mesons, if confirmed, will has important implications on the fundamental properties of quarks and their QED interactions.