SEARCHING FOR NEW LIGHT CHARGED PARTICLES IN PHOTOPRODUCTION

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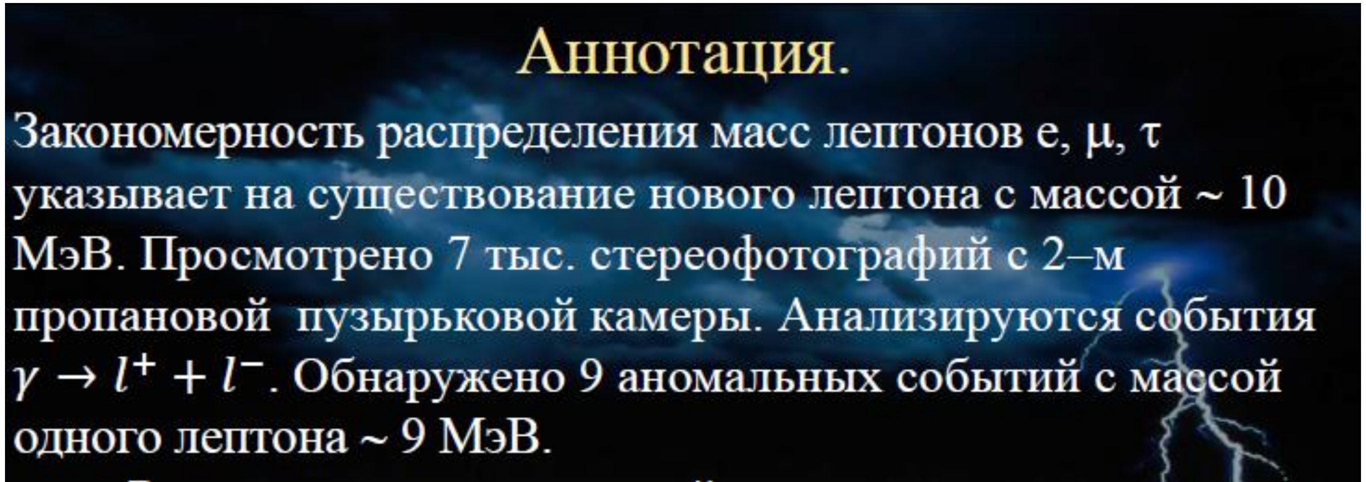
1. Motivation
2. Limitations from the muon a.m.m.
3. Earlier attempts
4. A new experiment – status and hopes

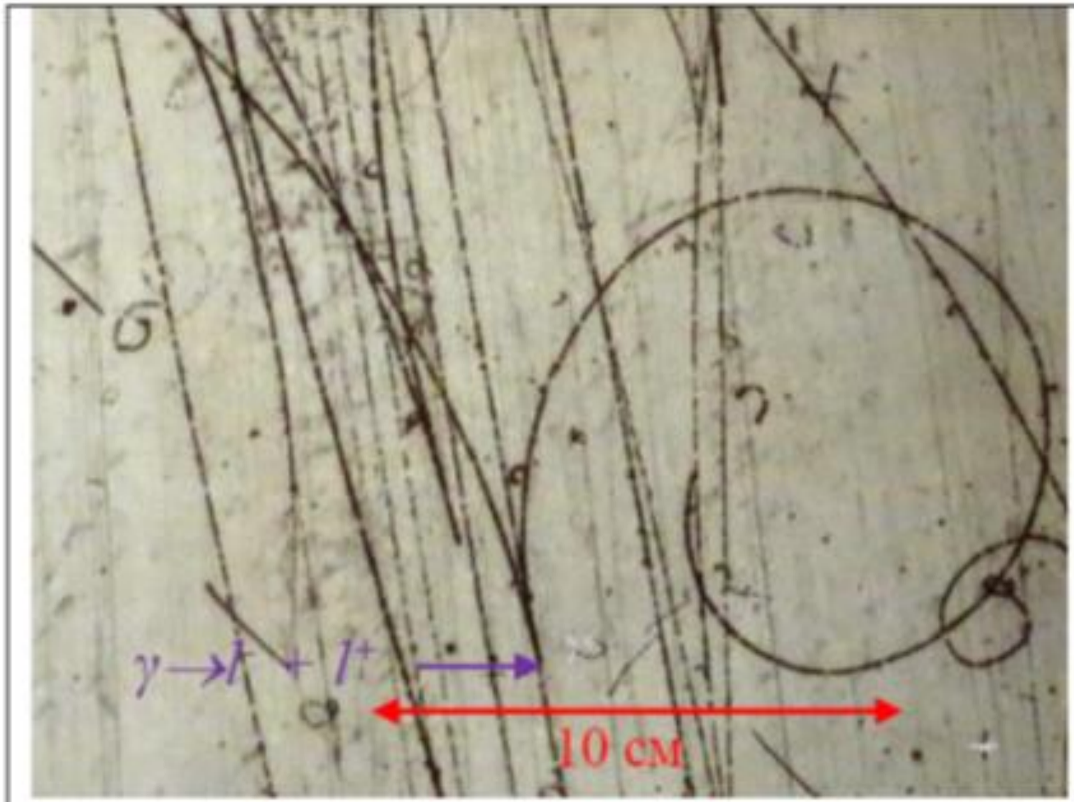
1. Motivation

Sensational data from the 2-m propane bubble chamber of JINR LHE irradiated by 10-GeV protons:

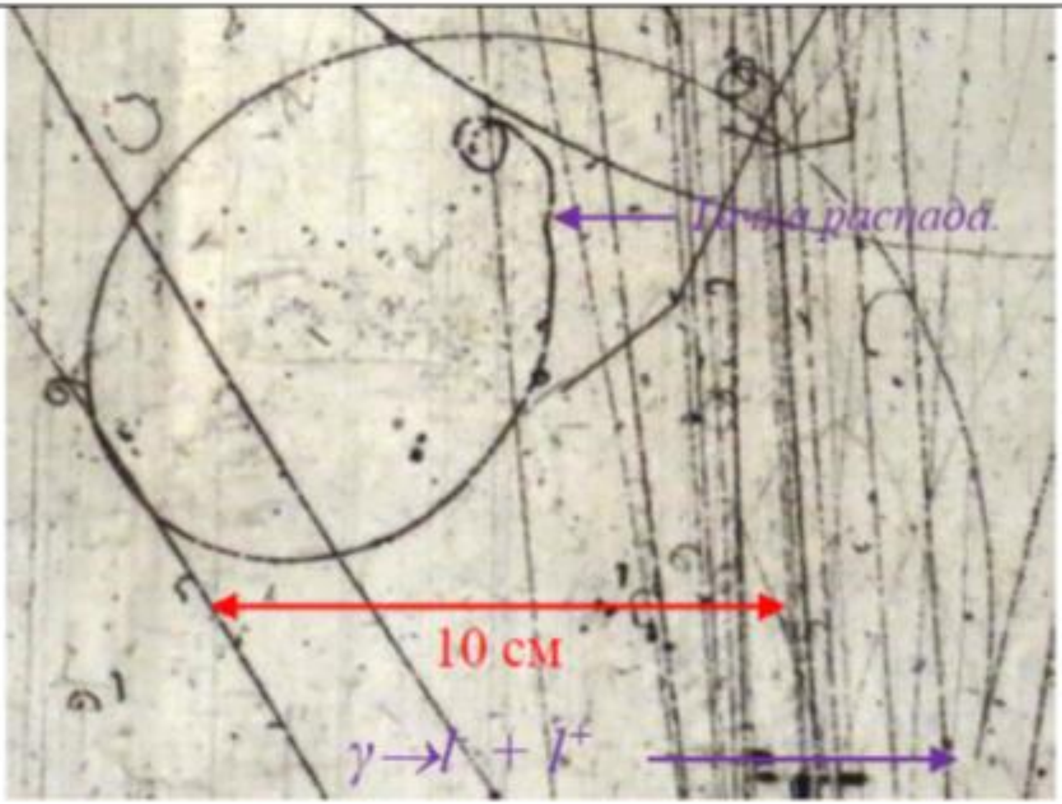
~7000 stereophotos from the chamber are viewed. Analyzed are events of $\gamma \to \ell^+ + \ell^-$, presumably formed in the matter by photons from π^0 decays.
9 anomalous events are found with the mass of a single lepton ~ 9 MeV.

(V.A. Nikitin, JINR, Dubna, May 2017)





Positive lepton



Negative lepton, decays with emitting electron

Mass of the particle is found through curvature of the trajectory and range

At every point of the trajectory in the magnetic field $B \approx 1.5$ T

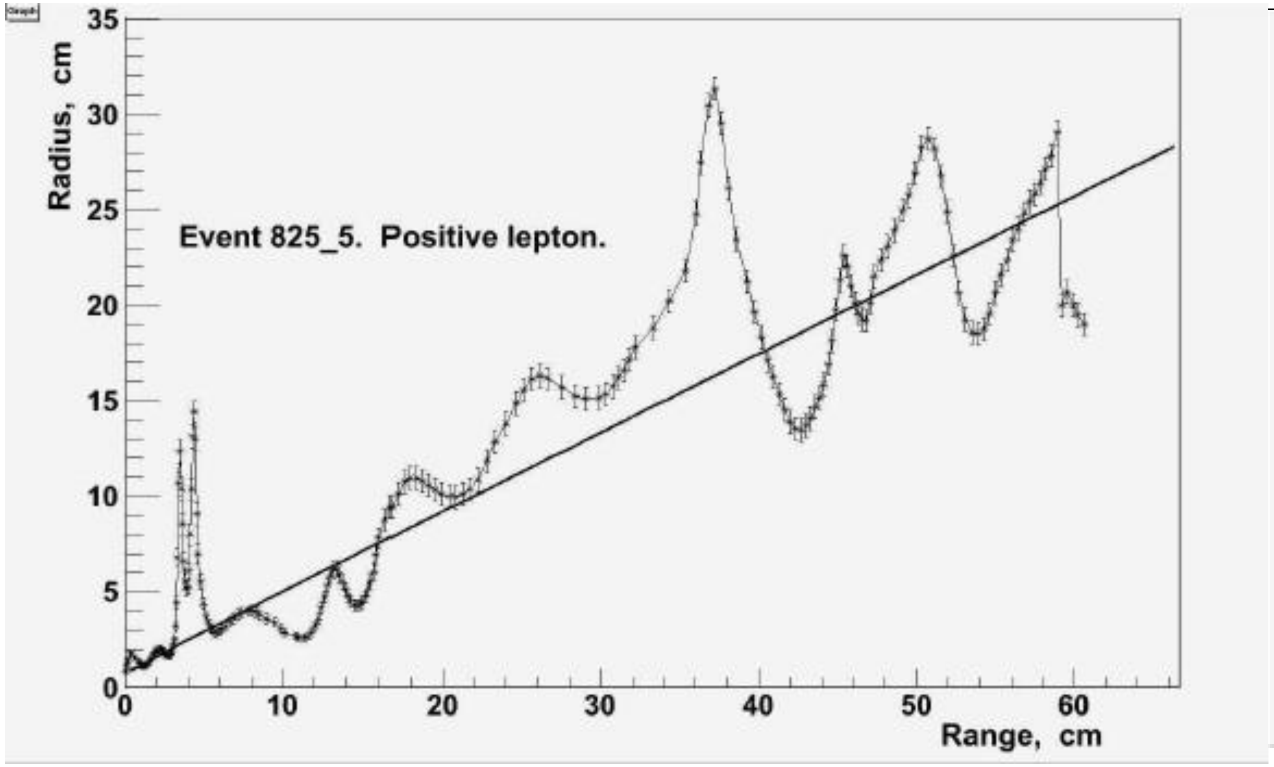
$$p = (e/c)\,B\,R$$

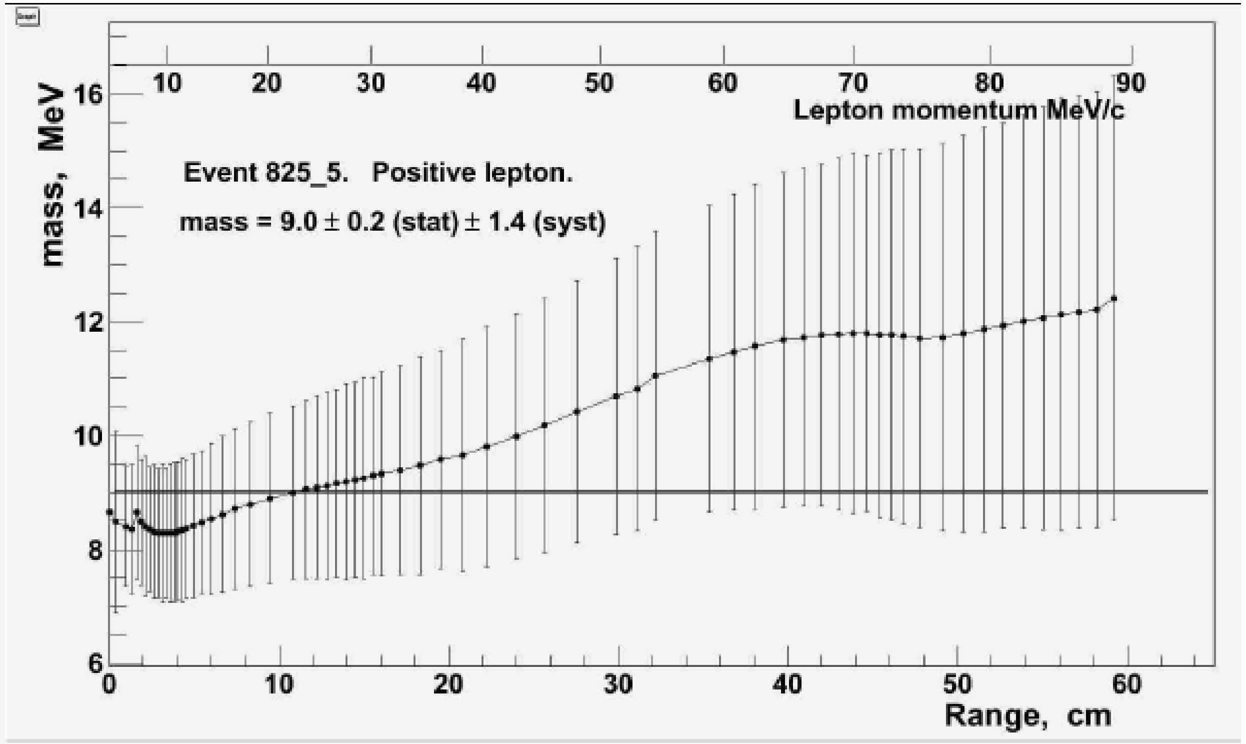
$$p^2 = E^2 - m^2 \quad \rightarrow \quad dp/dx = (1/\beta)\ dE/dx$$

$$\text{Mass} \quad m = p\,/\,(\beta\gamma)$$

The energy is found instead through the range

$$l(E_k, m) = c1\frac{E_k^2}{E_k^{c2} + m}$$





V.A. Nikitin: parameters of found anomalous tracks

mass MeV	range, cm	range g/cm2	momentum MeV/c	charge	
11,4	20	10	35	-	
9,2	44	22	58	-	decay
11,4	24	12	38	+	decay
7,5	26	13	42	+	
8,9	26	13	40	+	
8,1	35	18	50	-	
7,4	25	13	45	-	
10,3	49	25	88	-	
9,0	63	32	95	+	

$\langle m \rangle = 9.4 \pm 2$ MeV

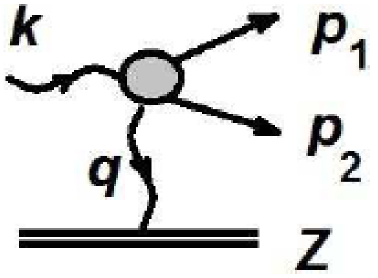
Sum of all track lengths = 312 cm and 2 decays are seen.
One may expect to have twice as much at the lepton momentum ~20 MeV/c
hence with the average length (“length of life”) ~ 70 cm ($\rightarrow$ size of the set up!)

Quantum numbers of the "anomalous lepton"

Decays are seen $\ell \to e + ?$ i.e. $\ell \to e + \nu$ or $\ell \to e + \gamma$

Simplest possibilities for spin of ℓ :
spin = 0
spin = ½
spin = 1

Due to their electric charge, pairs $\ell^+ \ell^-$ can be produced by photons on nuclei through the Bethe-Heitler mechanism (pair production in the nuclear Coulomb field)



Relatively small cross section

$$\sigma(\ell^+ \ell^-) / \sigma(e^+e^-) \sim (m_e / m_\ell)^2 \sim 1/400$$

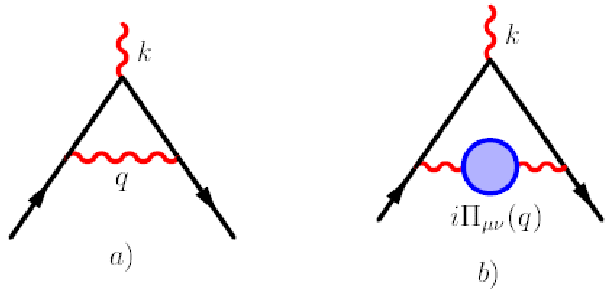
might be the reason why such pairs are not easily seen in every day experiments ???

2. Standard model and limitations on $\ell^{+} + \ell^{-}$ from the muon a.m.m.

Almost no space in SM for additional particles !

PDG-2018

$$\boldsymbol{a = \frac{g-2}{2} = a^{\mathrm{QED}} + a^{\mathrm{EW}} + a^{\mathrm{hadr}}}$$



$$a^{\mathrm{exp}} = \left(\frac{g-2}{2}\right)^{\mathrm{exp}} = 0.001\ 165\ 920\ 91\ (54_{\mathrm{stat}})\ (33_{\mathrm{sys}})$$

$$a^{\mathrm{SM}} = \left(\frac{g-2}{2}\right)^{\mathrm{SM}} = 0.001\ 165\ 918\ 23\ (1_{\mathrm{weak}})\ (34_{\mathrm{LO\,hadr}})\ (26_{\mathrm{NLO\,hadr}})$$

$$a^{\mathrm{QED}} = \left(\frac{\alpha}{2\pi}\right) + 0.765857425(17)\left(\frac{\alpha}{\pi}\right)^2 + 24.05050996(32)\left(\frac{\alpha}{\pi}\right)^3 + 130.8796(63)\left(\frac{\alpha}{\pi}\right)^4 + 753.3(1.0)\left(\frac{\alpha}{\pi}\right)^5 + \ldots = 0.001\ 165\ 847\ 19$$

$a^{\mathrm{hadr}}[\mathrm{LO}] = 0.000\ 000\ 069\ 31(34)$ ← **Here might be anomalous leptons**

$$\Delta a = a^{\mathrm{exp}} - a^{\mathrm{SM}} = (2.68 \pm 0.63_{\mathrm{exp}} \pm 0.43_{\mathrm{th}}) \times 10^{-9}$$

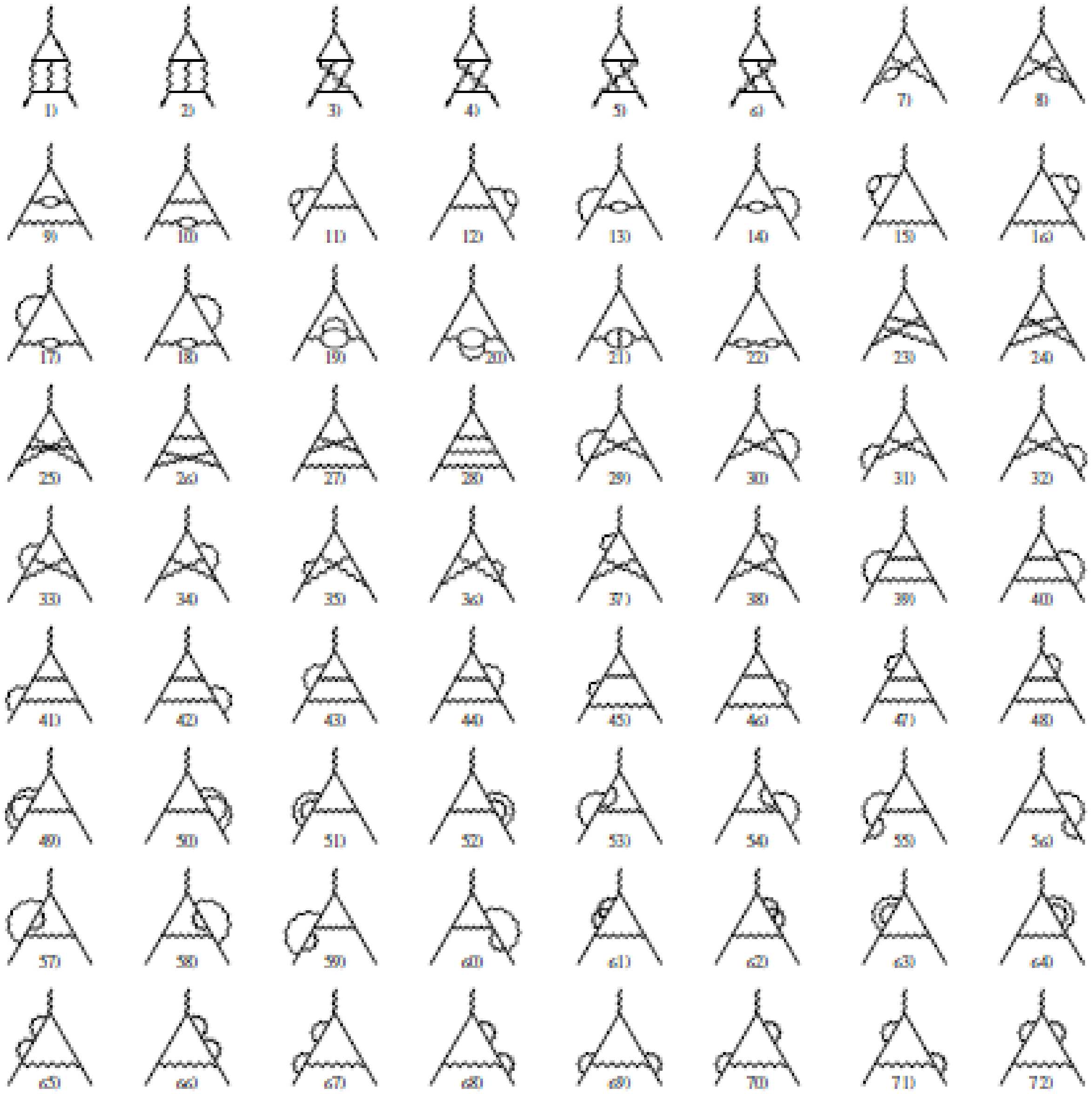
Complexity of the calculation:
Kinoshita group (borrowed from A. Nyffeler)

Pure QED (for electron)
1-loop 1 diagram
2-loop 7 diagrams
3-loop 72 diagrams
4-loop 891 diagrams
5-loop 12672 diagrams

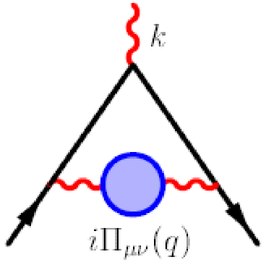
Electroweak
1-loop 3 diagrams
2-loop 1678 diagrams

Hadrons

Light-by-light scattering



2a. Contribution of anomalous leptons to a.m.m. (“hadron”)



$$\Pi_{\mu\nu} = (q_\mu q_\nu - q^2 g_{\mu\nu})\Pi(q^2)$$

$$\frac{-i}{q^2} \to \frac{-i}{q^2} + \frac{-i}{q^2}\, iq^2\Pi\, \frac{-i}{q^2} + \ldots = \frac{-i}{q^2(1-\Pi)}, \qquad \Pi(0) = 0$$

$$\text{a.m.m.} = \int \frac{d^4q}{(2\pi)^4}\, \frac{q^2\Pi}{q^2\; q^2}\, (\Gamma S \Gamma S \Gamma)$$

Unsubtracted dispersion relation is usually applied:

$$\text{If } \Pi(t)/t \to 0 \text{ at } t \to \infty \qquad \frac{\Pi(q^2)}{q^2} = \frac{1}{\pi}\int \frac{\operatorname{Im}\Pi(t)}{t}\, \frac{dt}{t - q^2 - i0}$$

Then

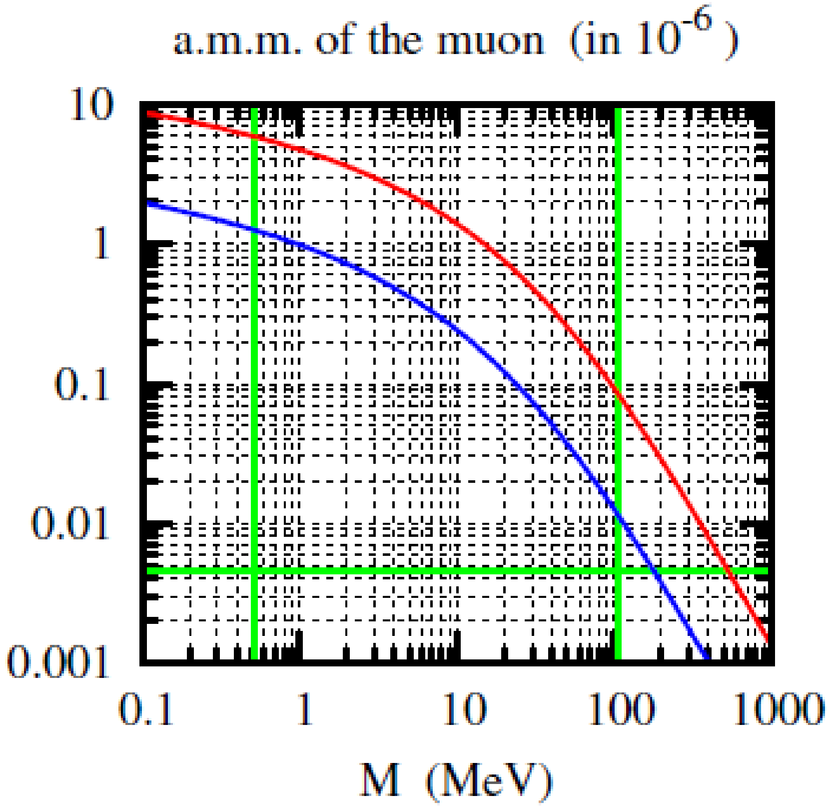
$$\text{a.m.m.} = \frac{1}{\pi}\int \frac{\operatorname{Im}\Pi(t)}{t}\, K(t)\, dt \qquad K(t) = \frac{\alpha}{\pi}\int_0^1 \frac{x^2(1-x)\, dx}{x^2 + (t/m_\mu^2)(1-x)}$$

Polarization operator and contributions of $\ell^+ + \ell^-$ to the muon a.m.m.

$$\text{spin } 0: \quad \mathrm{Im}\,\Pi(t) = \frac{\alpha}{12}\Big(1 - \frac{4M^2}{t}\Big)^{3/2}$$

$$\text{spin } 1/2: \quad \mathrm{Im}\,\Pi(t) = \frac{\alpha}{3}\Big(1 - \frac{4M^2}{t}\Big)^{1/2}\Big(1 + \frac{2M^2}{t}\Big)$$

$$\text{spin } 1: \quad \mathrm{Im}\,\Pi(t) = \frac{\alpha}{12}\Big(1 - \frac{4M^2}{t}\Big)^{3/2}\Big(3 + \frac{t}{M^2}\Big)$$



Blue = spin 0
Red = spin ½

Available space from (Exp – SM) < 4.2×10^{-9} (within 2σ)
Hence the limits on the "lepton" mass M:

Spin of $\ell = 0$ M > 190 MeV
Spin of $\ell = ½$ M > 550 MeV
(update of Dedenko, Domogatsky, Zheleznykh, Petrunkin. 1973)

Special case: spin 1.

Integral is divergent (since effective theory with vector particles is not renormalizable).

So the contribution to a.m.m. depends on high momenta
where the used effective vertices and interactions (actually it was the Proca theory)
may not work for evaluation of the polarization operator…

Additional information on the polarization operator at high energies is needed
($\Rightarrow$ need a further analysis)

Conclusion is that

1) “anomalous leptons” of the mass of order 9 MeV cannot be scalar or spinor particles.
2) the option of vector particles is not fully excluded by the muon a.m.m.
3) so, a direct check that such particles are not produced in photoproduction makes sense.

3. An early experiment on photoproduction of “anomalous leptons” (LPI, synchrotron S-25, 265 MeV. 1959)

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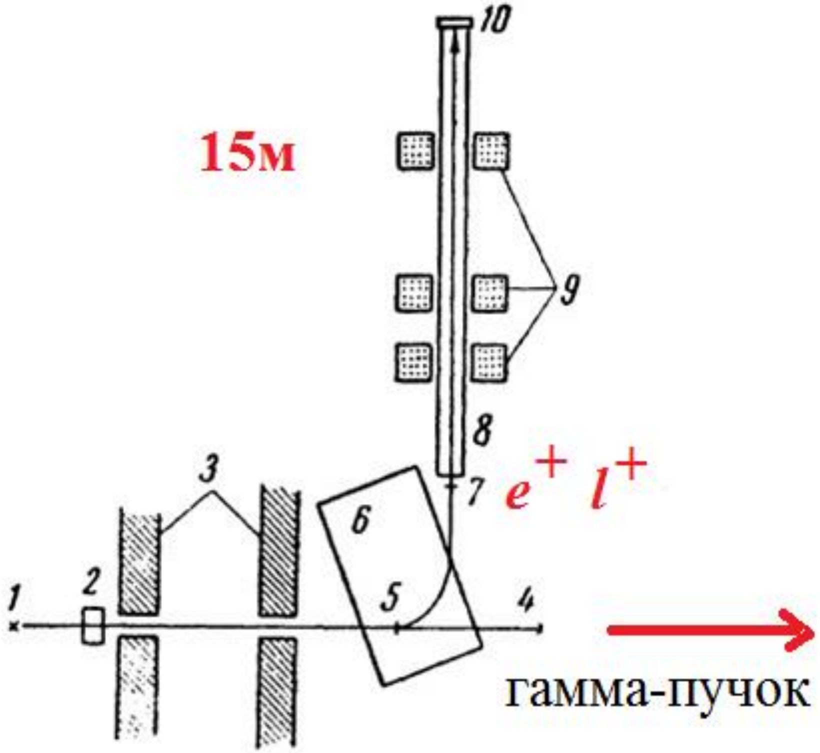
ПОИСКИ ЧАСТИЦ С МАССАМИ ОТ 6 ДО 25 ЭЛЕКТРОННЫХ МАСС

А. С. Белоусов, С. В. Русаков, Е. И. Тамм, П. А. Черенков

Описываются эксперименты, поставленные с целью выяснить, генерируются ли γ-квантами частицы с массами M от 6 до 25 электронных масс с сечениями, следующими из электромагнитной теории образования пар. Для этой цели, с помощью быстрых схем совпадений, измерялось время пролета частицами с заданным импульсом расстояния между двумя сцинтилляционными счетчиками. Частицы генерировались в свинцовой мишени, помещенной в пучок тормозного излучения синхротрона. Сравнивались рассчитанные теоретически и полученные экспериментально скорости счета совпадений для параметров установки, отвечающих регистрации частиц с ожидаемой массой. В каждой серии опытов измерялось также отношение скорости счета электронов к скорости счета фона. Полученные результаты показывают, что под действием γ-квантов частицы с единичным зарядом, спином $^1/_2$ и массами от 6 до 25 m_e не образуются с сечениями, следующими из электромагнитной теории.



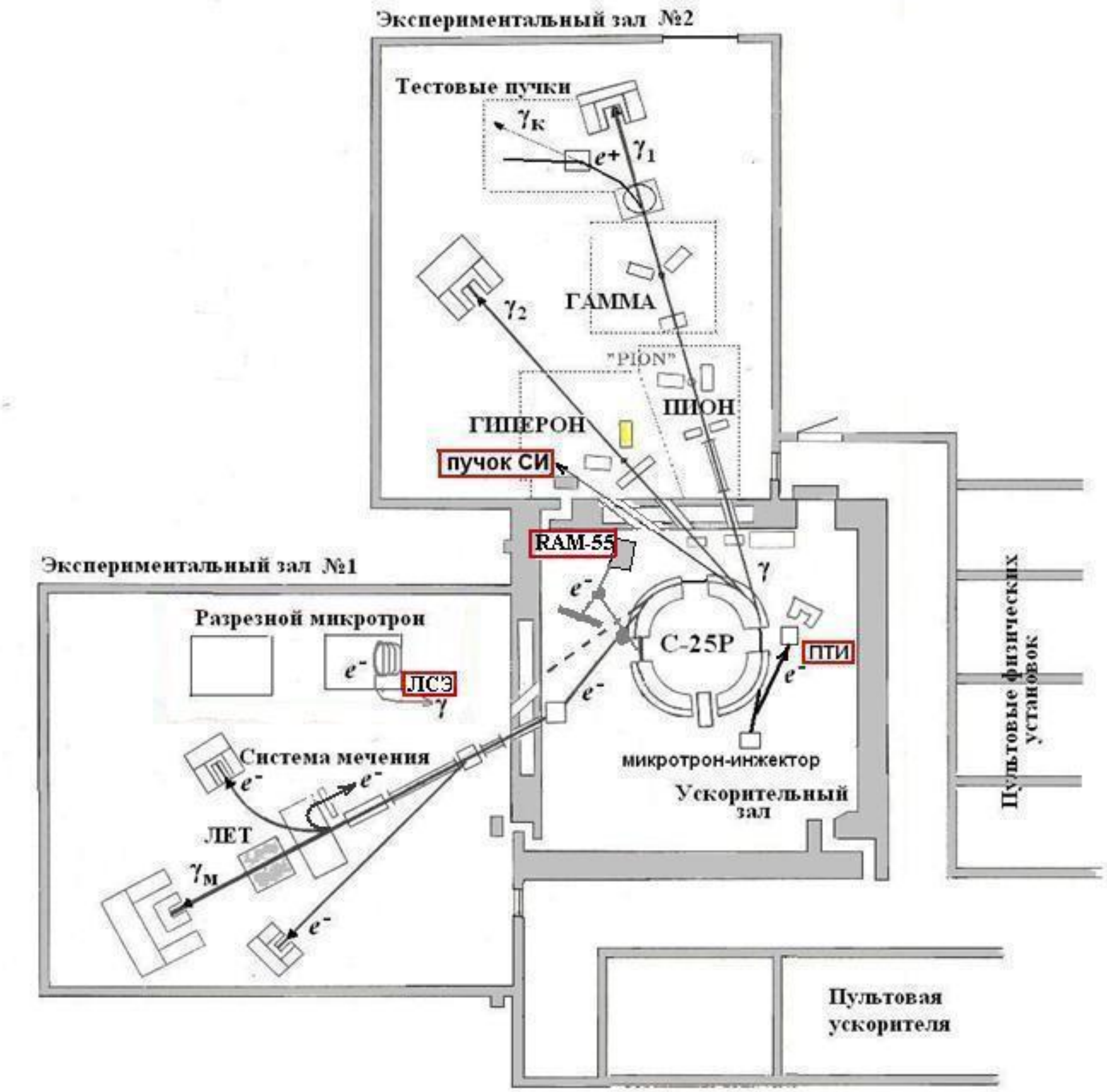
Геометрия опыта: *1* — мишень синхротрона, *2* — мониторная камера, *3* — свинцовые коллиматоры, *4* — направление пучка тормозного излучения, *5* — свинцовая мишень, *6* — магнит, *7* — сцинтилляционный счетчик, *8*—вакуумная труба, *9* — фокусирующие линзы, *10* — сцинтилляционный счетчик

4. Present experiment:
photoproduction of lepton pairs at the bremsstrahlung photon beam

LPI electron synchrotron
C-25R in Troitsk
in the energy regime
up to 300 (500) MeV.

Identification:
TOF, magnetic field,
NaI

Aim: among particles
with selected
momentum identify
slower (heavier) ones.



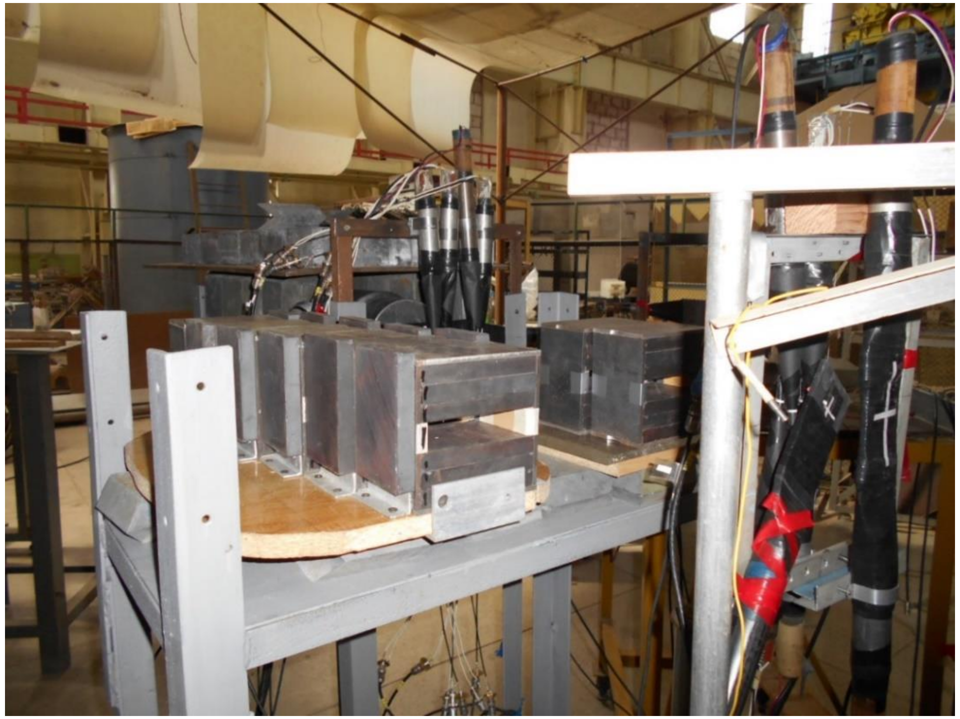
синхротрон
γ до ~850 МэВ
e⁻ до ~650 МэВ
γ СИ (ВУФ, МР)

микротроны
e⁻ 7-11 МэВ
e⁻ 7-35 МэВ

γ ЛСЭ (терагерц)

Synchrotron S-25R

and Exp Hall-2 with the setup on the left side.

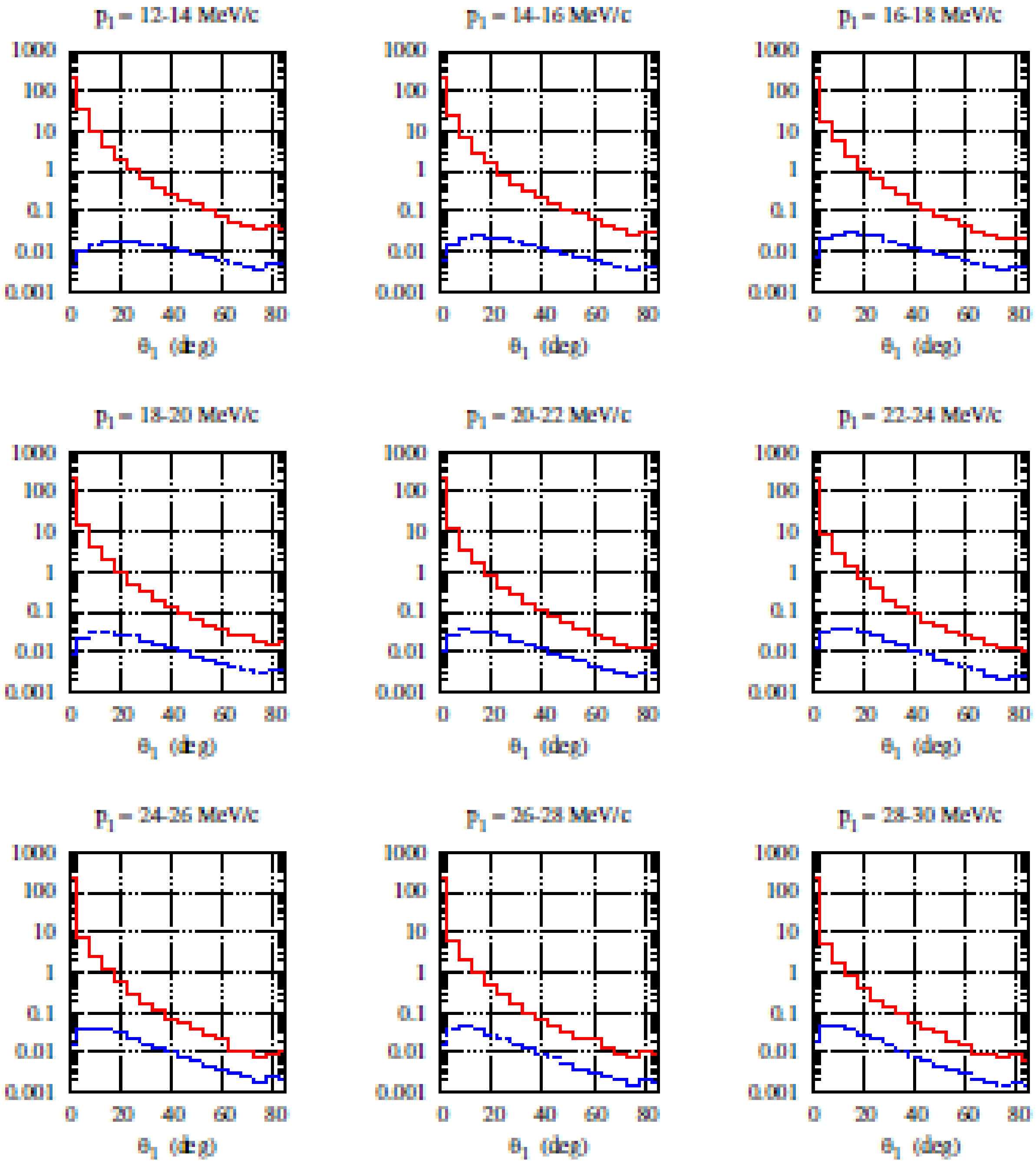


Special kinematics

1) Produced e+e- pairs are mainly emitted at forward angles, whereas heavier “leptons” have bigger angles.

Example of simulation of yields of e+e- and 9-MeV leptons (of spin ½) produced by 300 MeV bremsstrahlung photon beam (10^8 photons/sec) off a 1mm copper target.
Red cures = electrons,
Blue curves = 9-MeV “leptons”.

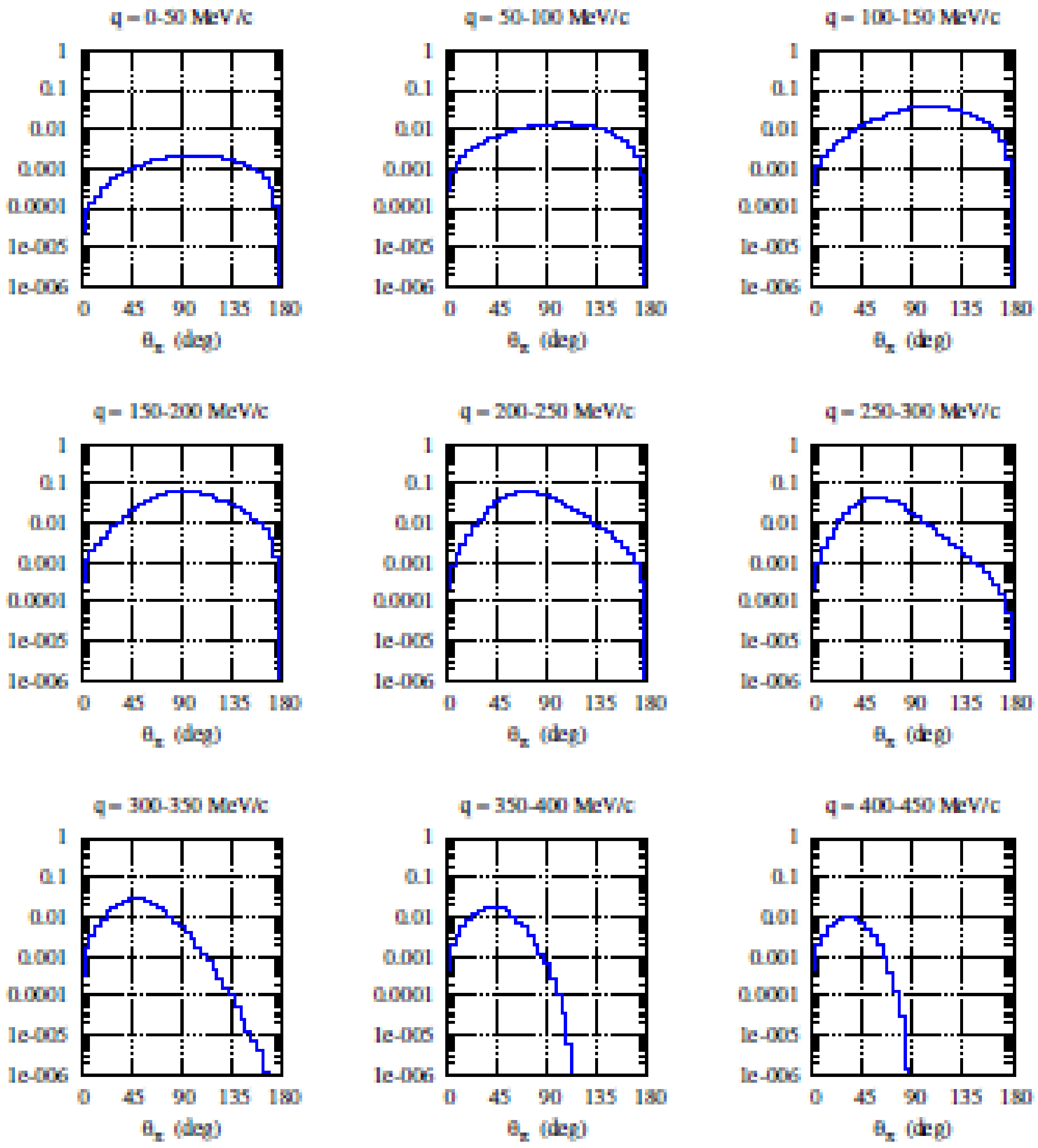
At medium angles “leptons”/electrons ~ 10%.



Pion background

This is background of charged
pions produced off the copper
target at angles of order 40 deg.

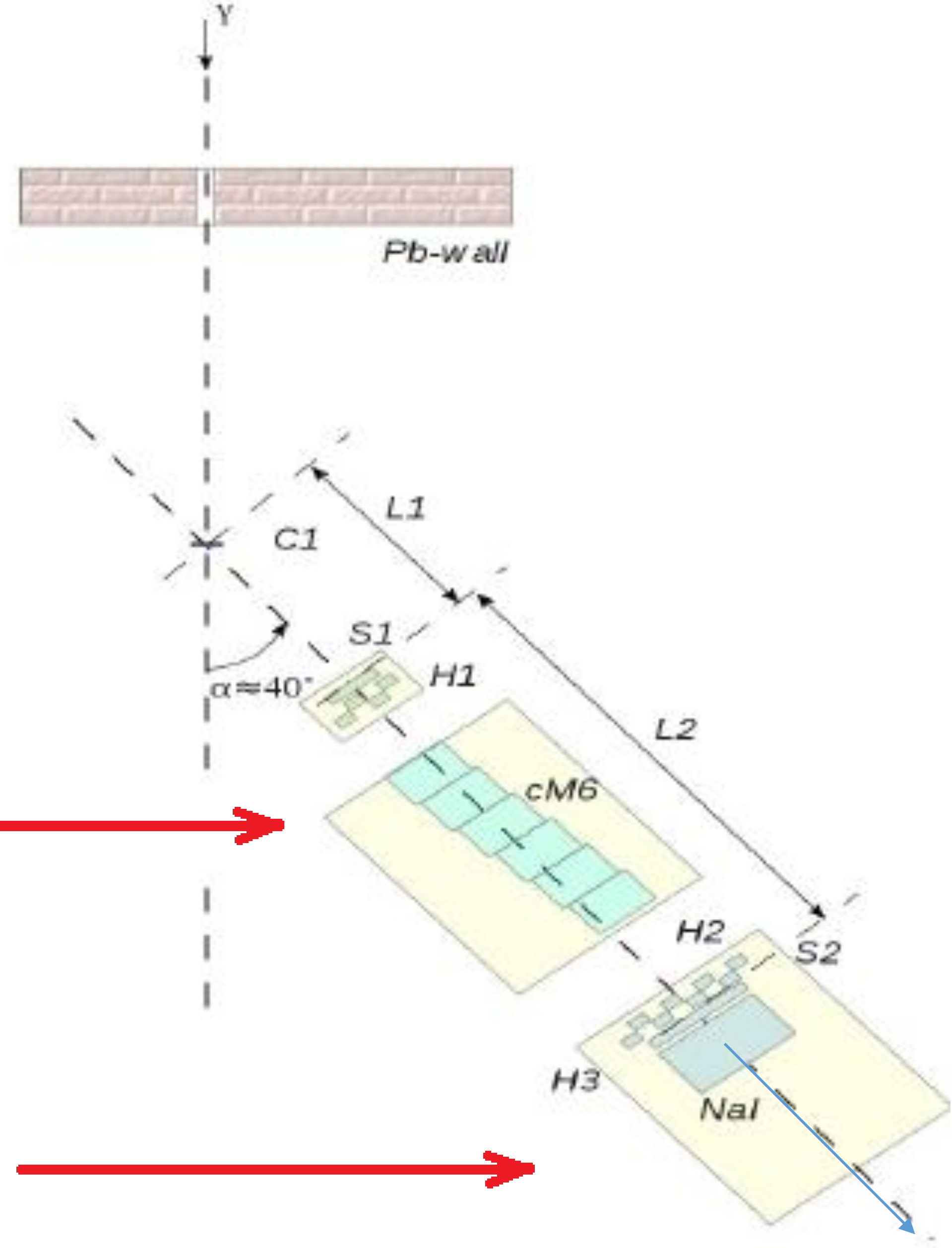
Here is an estimate in the Fermi gas model.
The simulation predicts that the fraction of
soft pions with momenta below 50 MeV/c
Is not large and the pion background
Is less than the expected yield of
heavy leptons.



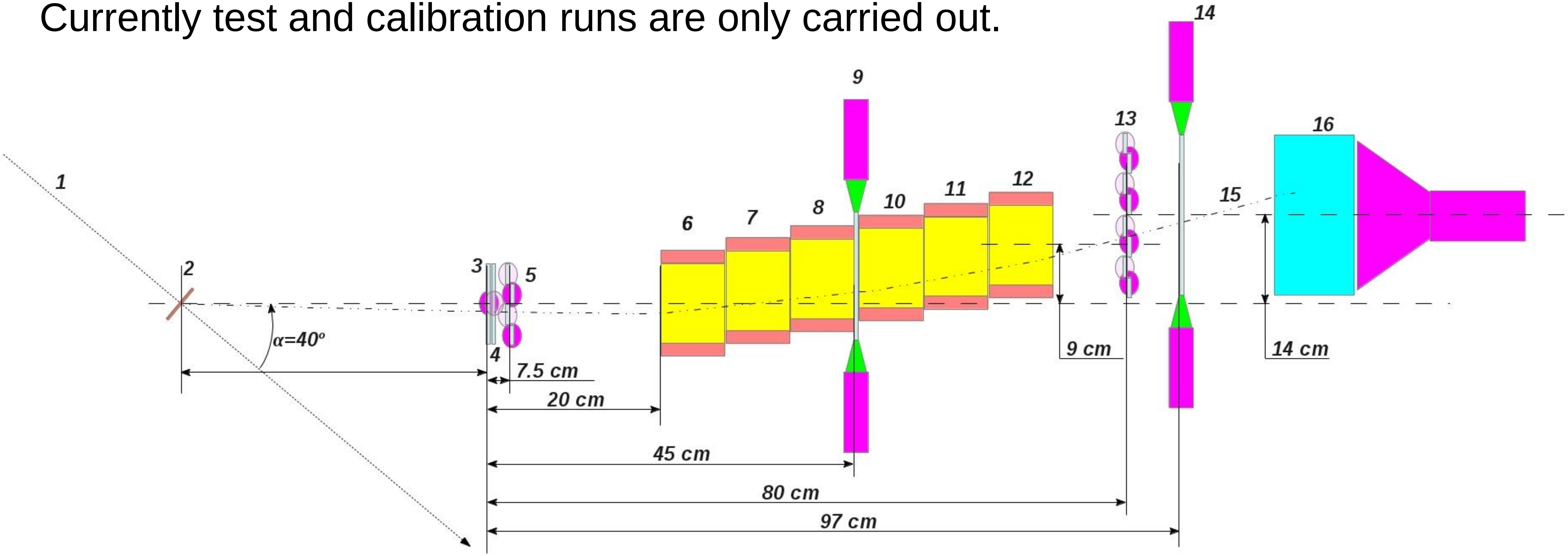
The layout of a very simple experimental setup.
The detector arm is set at 40 deg with respect to the photon beam.

Magnetic field of 1.6 kGs is made of permanent magnets. It is optimized to trace positive-charge particles with the momenta near 20 MeV/c.
(Such a low momentum Is chosen in order to have a better TOF discrimination of positrons and heavier particles

NaI of $\varnothing 20 \times 10$ cm is used to select particles having (at the same momentum) lesser kinetic energy.
The setup includes start/stop counters and coordinate hodoscopes.



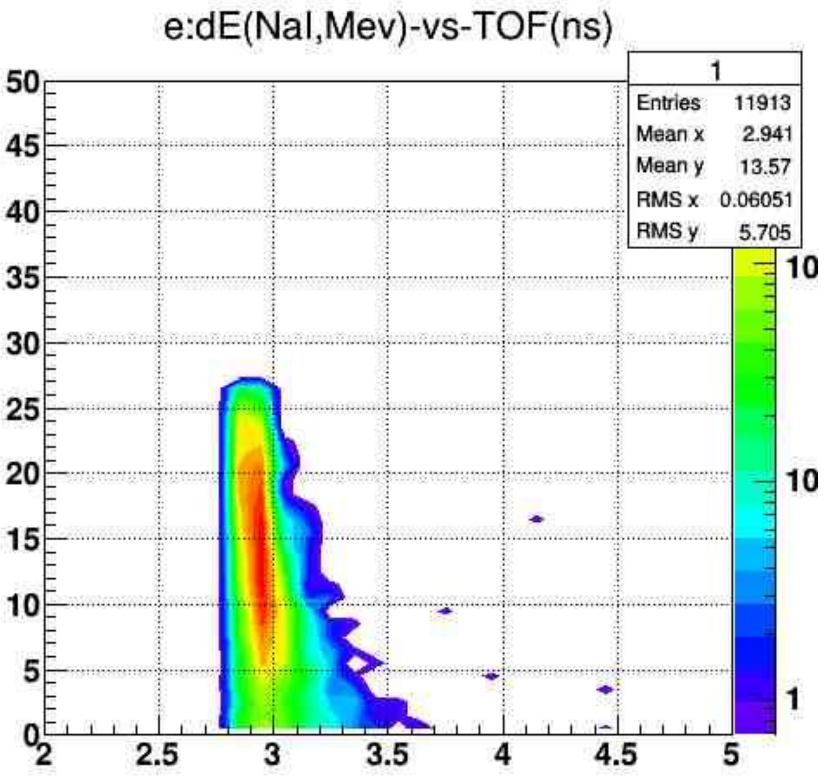
The setup as of September 2018.
Unfortunately we don't have yet final results to the moment to show.
Currently test and calibration runs are only carried out.

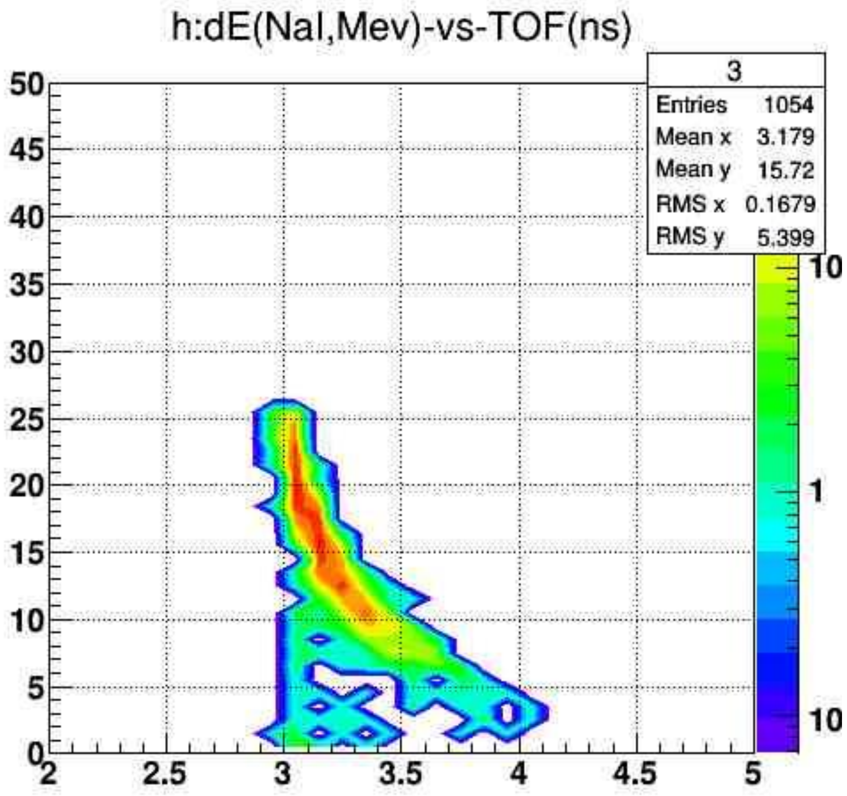


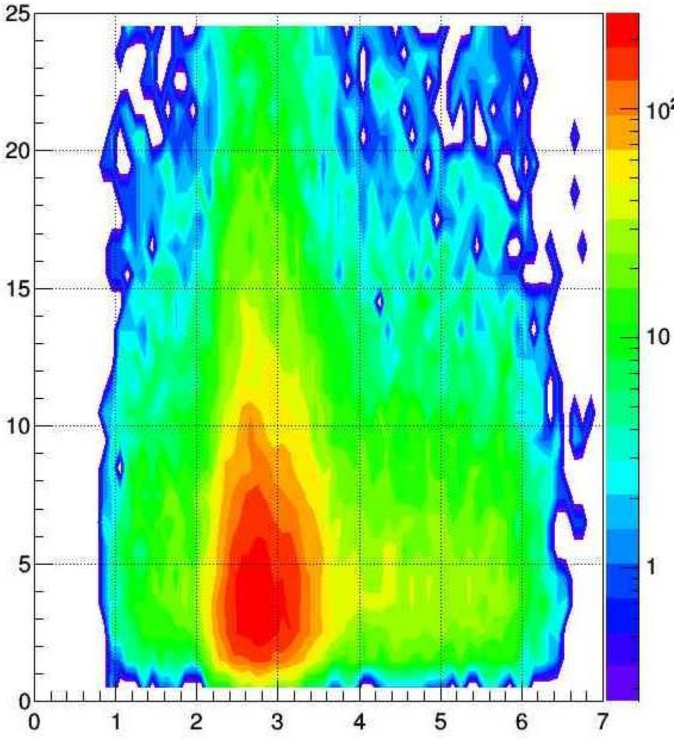
2 - copper convertor 1x50x50 mm^3. 3,9,14 – TOF start/stop (5mm thick).
5,13 – coordinate hodoscopes. 16 - NaI
15 – trajectory of a 15 MeV/c particle

Energy losses ΔE (MeV) in NaI
vs TOF (ns) [S1-S2 = 85cm]

TOF = 2.8 ns for β=1.
Electrons (left) and heavy leptons (center). Simulations vs test run







Conclusion

The experiment on searching for pair $\ell^+ \ell^-$ photoproduction s under way.

Everything is working (including the synchrotron itself). The setup is improved to reduce backgrounds…

Chances to find new physics are minimal but –

we hope to establish at least better (more reliable) limits
for “heavy” particle photoproduction cross sections
in comparison with older experiments…