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ACCELERATOR PROSPECTS FOR PHOTON–PHOTON PHYSICS *

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ABSTRACT

This paper provides an overview of the accelerators in the world where two-photon physics could be carried out in the future. The list includes facilities where two-photon physics is already an integral part of the scientific program but also mentions some other machines where initiating new programs may be possible.

1. Introduction

The next round of two photon experiments will be at machines with much higher luminosity than has ever been available. There are many different kinds of machine, so it is convenient to group them in three different categories:

1. Upgrades of the present generation of machines.
2. The new generation of high-luminosity factories.
3. Future linear colliders.

These options will be addressed separately in the sections which follow.

Before beginning, I should add a disclaimer. I will only be addressing technical possibilities. It should not be assumed that the laboratories which operate the machines discussed here have plans for a two-photon physics program. Any prospective users will have to go and ask permission themselves!

2. Upgrades of Present Machines

2.1 CESR

The present luminosity of CESR is 2.3×10^{32} cm^{-2} s^{-1} at beam energies of 5.3 GeV and last year an integrated luminosity of 1.2 fb^{-1} was achieved.[1]. Two-photon physics is already part of the present CESR/CLEO program:

- Two-photon coupling of charmonia $\eta_c, \chi_{c0}, \chi_{c2}$
- Light meson spectroscopy with emphasis on all-neutral states:
  - ◊ The 2γ coupling of a_0 (980)
  - ◊ Glue content of glueball candidates
- $\gamma\gamma \Rightarrow \pi^+ \pi^-, K^+K^-, p\bar{p}$ (a qcd test)

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The NSF recently decided not to support Cornell's proposal for a dedicated asymmetric B Factory before 1997. The CESR group will now be concentrating all of their efforts towards improving the luminosity and doing as much B Physics as possible before an asymmetric B Factory comes on-line. By the end of 1994, the luminosity will approach or exceed 5×10^{32} cm^{-2} s^{-1} and will continue to rise in the years after that. This will be achieved by incorporating the techniques that were originally developed for the asymmetric B Factory proposal.[2]

It is unclear how large a part two-photon physics will play in the future experimental program. Those experiments that can be done without requiring special triggers can obviously go ahead. It seems rather unlikely that specialized two-photon experiments will be allowed to interfere with the primary goal of B physics.

There is a second Interaction Region in CESR. Is it likely to be available for a small, dedicated two photon experiment? The estimated luminosity gain for CLEO due to running with a single Interaction Region is a factor 2.2. This is due to the fact that the beam-beam effects of the two Interaction Regions are additive, and it is not possible to optimize the running conditions for both Interaction Regions simultaneously. It is highly unlikely that returning to running two Interaction Regions in CESR is an option.

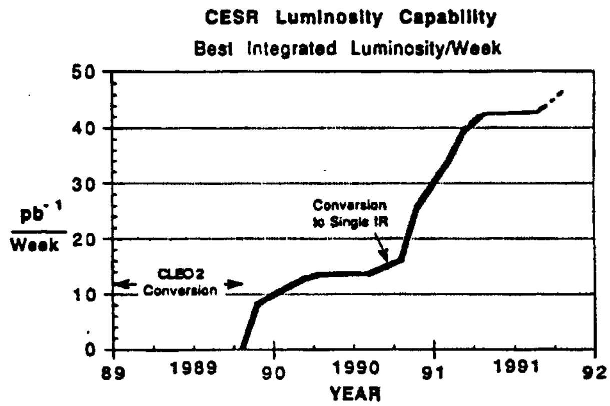

Figure 1. CESR integrated luminosity per week

2.2 SLC

SLC should continue operation at least until the end of 1993 and not beyond 1996.[3] The main thrust of the program is to collide polarized electrons with unpolarized positrons and two-photon physics will only be possible parasitically. The only new opportunity for two-photon physics at SLC would be using back-scattered lasers, which would be the world's first high energy photon-photon collider with a luminosity $\sim10^{29}$ cm^{-2} s^{-1} (see Tim Barklow's paper in this conference).

However, when SLC stops operation for high energy physics, the Arcs and Final Focus are scheduled to be decommissioned so that head-on collisions would no longer be possible. There is not a big window of opportunity, and a photon-photon collider is not currently part of SLAC's scientific program. It seems unlikely that this is a viable option in the present economic climate.

2.3 Final Focus Test Beam (FFTB) at SLAC

The FFTB will be commissioned next year and will be running a few months a year for the next few years.[4] It will be used primarily for machine studies related to the next generation of linear colliders. The possibility of doing QED studies using a laser is already being explored (see Jim Spencer's paper in this conference). Since this is a rather low cost experiment, there seems to be a good chance that it will go ahead. There seems to be little opportunity of doing any other high energy physics experiments at the FFTB.

2.4 LEP

The present luminosity of LEP[5] at 2×47 GeV is 1.1×10^{31} cm^{-2} s^{-1}. and last year the integrated luminosity was 16 pb^{-1}. Approximately the same luminosity was obtained in each of the four interaction regions. The present operating mode of LEP is to use four bunches colliding in the four detectors and separated in the other four straight sections. This year, a "pretzel" scheme (as pioneered at CESR) will be used to try to increase the luminosity. Initially eight bunches will be used to try to double the luminosity. The maximum number of bunches that could eventually be used is 36, but this will take some time to develop (the diagnostics must be upgraded to enable the two beams to be observed separately).

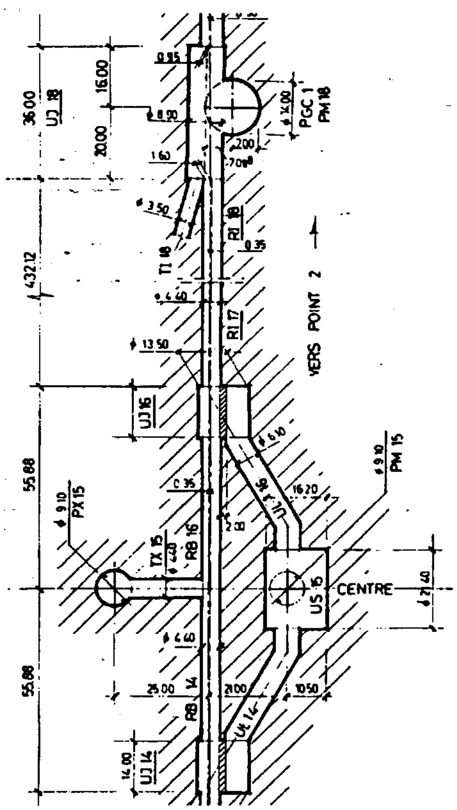

Figure 2. Layout of IR1 in LEP.

There are four additional Interaction Regions in LEP. Could one of these be made available for a small, dedicated two-photon experiment? This is less unlikely than CESR. Two small experiments already are approved and have been installed in the additional straight sections: a monopole search and a single bremsstrahlung detector. However, when collisions occurred in six places in LEP, the beam–beam effect was enhanced and the beams were more unstable. The additional experiments were only given data towards the end of a run when the currents were low. In addition, the beta values are sixteen times greater than in the standard interaction regions, and there is no beam-centering diagnostic—both effects drastically reduce the maximum luminosity attainable.

The maximum luminosity obtained in these additional Interaction Regions was about 3×10^{29} cm^{-2} s^{-1}, but for a small dedicated two-photon experiment, the forward direction is fairly empty, and measuring at small angles should more than offset the low luminosity and low availability. The preferred location would be in IR1 which is wider than the other areas and would probably allow installation of a small-angle detector without requiring civil engineering. Will CERN welcome a proposal for a dedicated two-photon experiment? Since these experimental areas are currently being assigned to LHC experiments, it is unlikely but maybe not impossible.

2.5 HERA

HERA has already obtained colliding beams with single bunches.[6] The DESY group is to be congratulated on this impressive achievement! The main thrust over the next few months will be to increase the number of bunches up to a nominal value of 210, bringing up the luminosity accordingly. Since HERA is the first e–p collider in the world, and is about to start experiments in a completely new physics regime, interest in two-photon physics is initially likely to be low, but there is still one empty interaction region,and an intelligent proposal for a small dedicated experiment might not be rejected.

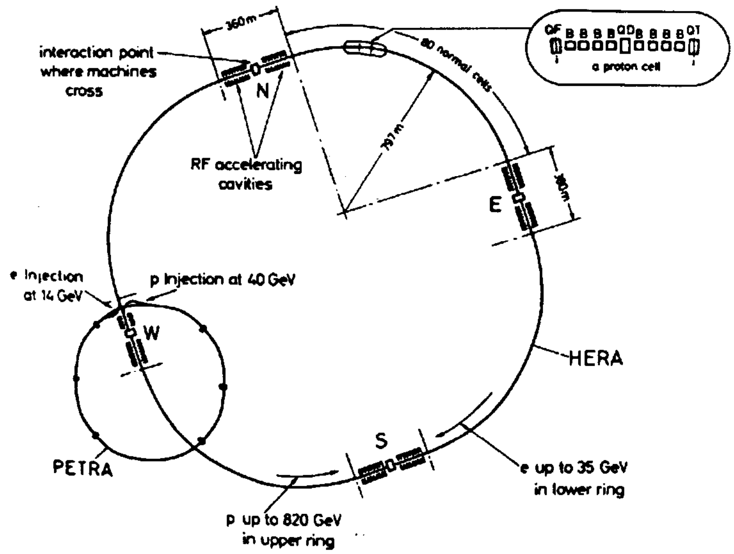

Figure 3. Layout of the HERA Ring

2.6 PETRA

PETRA has not run for high energy physics since 1986 and is now being used as part of the injector chain for HERA.[7] Some of the RF cavities and power sources have been transferred from PETRA to HERA, so the top energy in PETRA is only 14 GeV.

Later, PETRA could conceivably become available for a small-scale dedicated experiment, but this will take a fair amount of rebuilding and will be a hard sell. The kind of experiment that would be least invasive would be to use the PETRA electron beam for single pass collisions with photons from a laser or FEL, but it is not clear that DESY has the operations staff to run PETRA as a collider in addition to DORIS and HERA.

2.7 DORIS

DORIS is still being used for high energy physics experiments (Argus), as well as for synchrotron radiation.[8] The integrated luminosity is already suffering from not having an on-demand injector. The long term future of DORIS as a high energy physics machine will depend on the success of the next run. The most likely scenario in the long term is that the synchrotron light users will take over the whole machine, the fate of most high energy physics machines!

2.8 TRISTAN

The present luminosity of TRISTAN is 1.4×10^{31} cm^{-2} s^{-1} at beam energies of 32 GeV.[9] KEK has decided to convert TRISTAN into a synchrotron light source in the mid-nineties. Opportunities for a new physics proposal on TRISTAN in the near future seem very limited. The official KEK laboratory program calls for construction of a

B Factory and continuing research on the JLC (Japanese Linear Collider). These machines will be addressed in later sections.

2.9 BEPC (Beijing)

The luminosity reached by BEPC is 2.6×10^{31} cm^{-2} s^{-1} at 1.65 GeV per beam.[10] Operation at 3.1 GeV center-of-mass energy will continue for some time at one IR with a detector (BES). The north area is at present unused, and plans are under way to separate the beams there to try to increase the luminosity at the detector. Other upgrades planned are to try to increase the reliability (actually, 60% of scheduled time is available for experimentation—already a rather impressive number), and to decrease the beta function at the interaction point by installing a mini-β insertion.

Given the excellent operation of this facility, it would be worth while exploring the possibility of a small-scale second detector. The north area could be a good candidate for a dedicated two-photon experiment that should enjoy a rather high integrated luminosity which could offset the low beam energy. The Chinese have already demonstrated their willingness to accept foreign collaborators, and I am sure that they would react positively to the idea of an additional experiment.

3. Factories

3.1 Asymmetric $\bar{B}$ Factories.

Many laboratories carried out design studies of B Factories. The CERN-PSI proposal[11] is currently in abeyance, as it is unlikely that funds will be available if LHC goes ahead on the expected timetable. Similarly, the DESY proposal[12] is not being actively pursued, since all of DESY's resources are being devoted to commissioning HERA. The present thinking is that a linear collider would be preferred over a B Factory as DESY's next project. In Europe, there is still an ECFA working group on B Factories, so that a proposal could be reactivated if the political and financial climates change.

As mentioned above, the construction of a dedicated, asymmetric B Factory, CESR-B, at Cornell has been set back until at least 1997 due to funding problems. However, the upgrades which will be applied to CESR to increase the luminosity would be a central part of the CESR-B project. The experience gained from operating superconducting cavities with high beam power, and the use of a crossing angle and crab cavities would enable the Cornell group to reactivate their proposal very quickly. At that time, the proposal would be reinforced by the confidence obtained from operational experience with new techniques that are untested now. All of the B Factory proposals would profit from this experience, which should be strongly encouraged.

Novosibirsk is still proposing an asymmetric B Factory,[13] and theoretical studies are continuing. The project will be funded after the Φ Factory which, given the present economic climate in Russia, makes any estimate of the timetable for this machine unreliable. Such a machine seems unlikely this decade.

This leaves two proposals which are still active.

3.1.1 Asymmetric B Factory at KEK

The KEK proposal originally called for a totally new, 1273 meter ring in a new tunnel.[14] This proposal, which required new civil construction, was not acceptable to Monbusho at that time. An acceptable set of parameters with two new rings in the TRISTAN tunnel is still being sought (this is technically very difficult, as the circumference is really too large). Design work is now concentrating on a dedicated ring of \mbox{1200–1300} meter circumference,[15] in the belief that the political context is changing. A two stage project is envisaged. The first stage is designed for a luminosity of 2×10^{33} cm^{-2} s^{-1}, would later be upgraded to 10^{34} cm^{-2} s^{-1} as a second stage. Other details of the proposed Japanese B Factory, in particular the IR region, are not yet well defined.

The Japanese high energy physics community is very supportive of the B Factory, and it is reasonable to assume that some version of the proposal will go ahead. A request for funding will be submitted, most likely in 1994, and construction would take about five years. There is little difference in total cost or construction time between the version in the TRISTAN tunnel and a totally new facility and the peak luminosity should also be similar. The availability of the facility for physics is liable to be higher in the dedicated tunnel, as access for repair would suffer from fewer constraints.

3.1.2 PEP-II (SLAC, LBL & LLNL)

The PEP-II project is the most advanced in the approval process, although it is not yet approved. A Conceptual Design Report has been written,[16] and the DOE has reviewed the proposal in detail and endorsed it. An active R&D program has already demonstrated that the design choices were valid. Burt Richter, in his presentation to the 1992 HEPAP Subpanel on the US Program of High Energy Physics Research, proposed building PEP-II out of the present SLAC budget by redirecting priorities.[4] The report of the Subpanel[17] endorsed PEP-II, and recommended approval to begin construction in 1996 in a funding scenario with constant budget (adjusted for inflation). If more money were available, construction could begin as early as 1994, but if the HEP budget falls then PEP-II would not be funded before 1997. At the time of writing, the DOE funding profile is still unclear; nevertheless, it is reasonable to plan for an Asymmetric B Factory at SLAC sometime this decade.

Table 1. PEP-II Interaction Region Parameters

Beam energies	9 GeV, 3.1 GeV
Design luminosity	3×10^{33} cm^{-2} s^{-1}
Bunch separation	4.2 ns
Detector coverage	90%

The extremely high luminosity would probably offset the difficulty in observing small angles. At present, only one IR is foreseen—a second IR is not excluded by the site, but is not as easy to implement as in a single ring machine because of the need to bring the two beams into collision. Since construction funds will be tight, a proposal for a second IR would probably need to provide money for the additional machine components, as well as for the detector (i.e., come with a checkbook).

3.2 Tau-Charm Factory

The Spanish government is proposing to build a Tau-Charm Factory,[18] probably sited in Seville, Andalusia (other provinces are also interested). The Spanish government is prepared to put up most of the cost, and the provincial government most of the rest. The Spanish government has officially requested the assistance of CERN in the construction phase and in the operation phase, and this is still being negotiated. A decision is likely in June 1992, but the project is sufficiently far advanced that it is reasonable to be planning for a Tau-Charm factory in Spain.

Table 2 . Tau–Charm Factory Interaction Region Parameters

Beam energies	2 ×2 GeV (Max 2×2.5 GeV)
Design luminosity	10^{33} cm^{-2} s^{-1}
Bunch separation	40 ns
Detector coverage	99.7%

The extremely high luminosity, combined with the high angle coverage, makes this an attractive machine. However, it is likely that a detailed examination of lost particles in the detector would show that the smallest angles are problematical. Any experiment, particularly a two-photon experiment at small angles, would therefore need to make a careful evaluation of the background conditions. At present, only one IR is foreseen; a second IR is not excluded by the design, but is left as an option for a future upgrade. If there were to be a viable proposal to do two-photon physics at this machine, I am certain that your participation would be encouraged.

3.3 Phi Factories

There are three Phi factories in different stages of approval. Since the beam energy is low, the possibility of doing interesting two-photon physics is probably limited. Nevertheless, at least one of these machines (DAΦNE) is funded and is being built, so it is well worth considering the possibilities. The designs of the three machines are totally different in concept and differ in size by more than a factor of five.

Table 3 . Phi Factory Interaction Region Parameters			
	DAΦNE	Novosibirsk	SMC
Beam energies	2 ×0.5 GeV	2 ×0.5 GeV	2 ×0.5 GeV
Circumference	94.6 m	35.2 m	17.4 m
Design luminosity	10^{32} cm^{-2}s^{-1}	10^{33} cm^{-2}s^{-1}	2 ×10^{32} cm^{-2}s^{-1}
Target luminosity	5×10^{32} cm^{-2} s^{-1}	5 ×10^{33} cm^{-2} s^{-1}	10^{33} cm^{-2} s^{-1}
Bunch separation	2.7–10.7 ns	117 ns	58 ns
Detector coverage	Not yet fixed	Not yet fixed	Not yet fixed

3.3.1 DAΦNE at INFN, Frascati

DAΦNE[19] is an approved, fully funded project to be completed in 1995. The design is based on two rings colliding in two interaction regions and separated horizontally elsewhere. A letter of intent for one interaction region has been received from the KLOE Collaboration (spokesman, Paolo Franzini). At the time of writing, this is the only active collaboration. Two other groups have expressed interest in a smaller detector for the second interaction region (spokesmen, Giorgi and Bressani). If you want to join, run don't walk.

3.3.2 Phi Factory at Novosibirsk

Conditions in Russia are desperate—but not hopeless. The INP has secured the contract for building the Low Energy Booster Magnets for the SSC. They hope that such contracts will permit them to go ahead with their own Phi Factory. This is a very clever design[20] using a figure-of-eight geometry, which only permits one interaction region, and therefore only one detector. The design is fairly far ahead, and engineering studies are also well in hand. Our colleagues in Russia are going through hard times, and I am sure that the INP group would welcome any offer of collaboration.

3.3.3 UCLA Phi Factory Superconducting Mini-Collider (SMC)

UCLA is proposing a novel design for a Phi Factory,[21] and is actively seeking pro-ject approval. The proposal is based on the idea of making the orbits of parti-cles with different energies almost equal, a Quasi-Isochronous Ring (QIR). This permits the bunch length to be very short, so the beta function at the Inter-action Region can be small. The high luminosity can therefore be obtained with smaller currents. There is only one Interaction Region and therefore only one detector. The project is still in the early stages of the approval process and the HEPAP

Subpanel did not strongly endorse the proposal, as they judged that the high energy physics interest did not warrant an additional machine (since DAΦNE is going ahead). This conclusion will make it extremely difficult to obtain DOE funds for the machine, but the UCLA group is likely to seek alternative sources of funding for this interesting machine of novel conception.

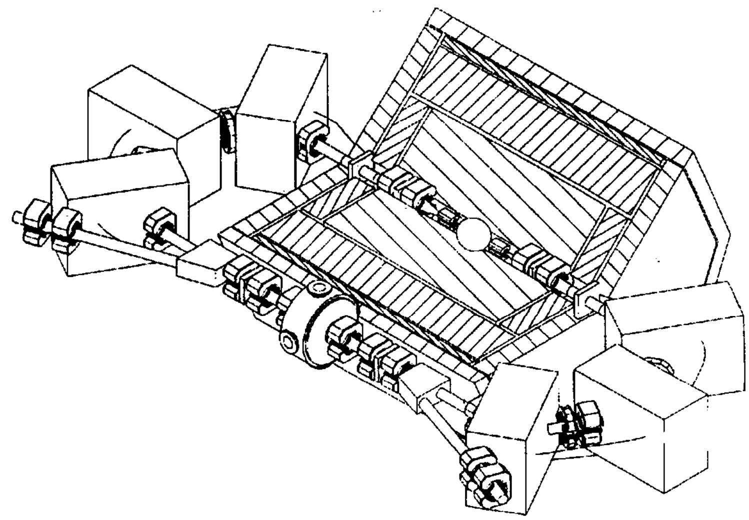

Figure 4 Schematic of the proposed SMC at UCLA.

4. Future Linear Colliders

The relevant unit of time for the next generation of linear colliders is a decade. The most optimistic scenario would aim to start a 2×250 GeV linear collider in about three years, with construction taking about five years. In the US, competition with the SSC would make funding for a totally American linear collider unlikely before the late nineties. In Europe, LHC will probably have the same effect. There is now a wide spread conviction that the next linear collider must be truly international, both for technical and financial reasons, and this is an area of accelerator research which is extremely active. So far, all of the proposals have concentrated on electron–positron collisions, rather than electron–photon or photon–photon interactions.

There are several different linear collider approaches, which I have roughly categorized below. In all of these proposals, large numbers of events from beamstrahlung interactions will be produced, and the proposals are not all equally suitable for two-photon physics nor for making a photon–photon collider. Since the Thursday morning session of this conference is devoted entirely to Linear Colliders, the discussion here will be limited to an overview of the parameters of the different proposals. Interested readers should examine the proposals in more detail and make their opinions known. This could help clarify the future direction of the machine studies.

4.1. Conventional—copper cavities at DESY/Darmstadt[22] and Superconducting cavities at TESLA[23]

These machines are based on trying to extrapolate existing technology. These proposals have the least technical uncertainty, but because the accelerating gradients are modest, they require long structures. The proposals have large number of bunches per pulse, and the transverse beam dimensions are relatively large.

Table 4 Overview of Future Linear Colliders *							
	Energy GeV	Gradient MeV/m	RF Frequency GHz	Bunch Charge $\times 10^9$	Bunches per Pulse	Repetition Rate Hz	Beam Size V×H nm
DESY/ Darmstadt	2×250	**17**	3.0	7	172	50	35×316
TESLA	2×250	**25**	1.5	40	400	20	101×640
NLC (SLAC)	2×250	50	**11.4**	10	10	120	3.4×612
JLC (KEK)	2×250	40	**11.4**	9	20	200	2.7×300
Novosibirsk / Protvino	2×500	100	14.3	**100**	1	200	7×1000
CERN	2×250	80	30	5	1	**1700**	12×60
*Disclaimer: parameters change almost daily; these are indicative.							

4.2 High Frequency RF— NLC at SLAC[24] and JLC at KEK[25]

These machines use an extremely high RF frequency (11.4 GHz) in order to obtain high accelerating gradients. These machines are characterized by extremely small transverse dimensions of the beam.

4.3 High Bunch Current—Novosibirsk / Protvino[24]

This proposal is based on the idea of trying to extract the maximum amount of RF energy from the structure to maximize the efficiency. Accordingly, the bunch currents are extremely high and the transverse beam dimensions are large. The repetition rate is very low.

4.4 High Repetition Rate—CLIC at CERN[26]

This proposal uses superconducting cavities at low frequency (350 MHz) to accelerate a drive beam, which in turn is used to accelerate the main beam at a very high frequency (30 MHz). The use of superconducting cavities leads to an extremely large number of bunches with extremely small transverse dimensions.

5. Summary

All of the new generation of colliders (both upgrades of existing machines and new facilities) need high luminosity, and triggers will be extremely selective to prevent the detector from being swamped. Two-photon physics will tend to be treated as background, and triggers will exclude much of the the data. Two different kinds of opportunities for two-photon physics will be available:

(1) as part of a large detector, where the triggering is such that parasitic operation is not excluded by the primary physics goal;

(2) as dedicated experiments that can be mounted in special IR regions. Clearly, the smaller and cheaper the proposal, the easier it will be to get funded.

A dedicated facility for two-photon physics seems a long way off. Nevertheless, one idea that was proposed during the conference was for a dedicated linear photon-photon collider to study charmonium states. This would involve two accelerated electron beams and two photon beams (possibly from the same FEL). Such a facility could also provide a test bed for linear accelerator technology. This idea seems worth more detailed study.

There seem to be no lack of opportunities for two-photon physics. However, it will require a considerable amount of ingenuity to obtain funding in the difficult years ahead, and this will probably impose collaboration between interested physicists on a scale that has not been typical of the field in the past.

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