On search for eV hidden photons from the Sun

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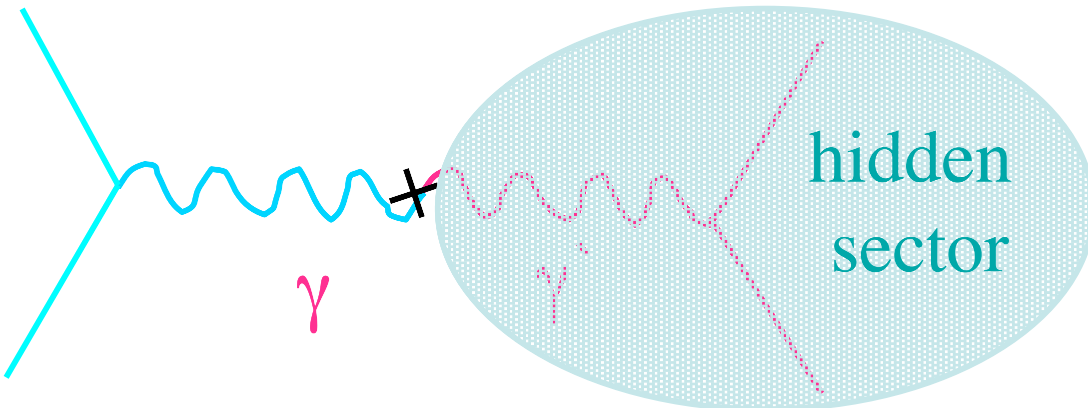
INR Moscow

First Axion Strategy Meeting
CERN, January 27, 2009

Plan

- introduction
- γ`-helioscope
- prototype
- present status

γ-γ` mixing



- Hidden sector with additional U`(1) gauge factor and a new (possibly light) $\gamma$` boson
- γ-γ` coupling $L \sim \chi F^{\mu\nu} F`_{\mu\nu}$
- γ-γ` oscillations ($m_{\gamma`} \neq 0$) Okun'82
- millicharged particles: $q=2\chi e$ ($m_{\gamma`} = 0$) Holdom'86
  - oPs - oPs` oscillations, $\chi < 3\text{x}10^{-8}$ BBN Glashow'86
  - hidden matter scattering off our matter (DAMA/LIBRA) $\chi \sim 10^{-9}$ Foot'08

γ\`-γ oscillations in vacuum

$$P_{\gamma' \to \gamma}(\omega) = 4\chi^2 \sin^2\left(\frac{\Delta q l}{2}\right)$$ - probability γ\`-γ conversion

$$\Delta q = \omega - \sqrt{\omega^2 - m_{\gamma'}^2} \approx \frac{m_{\gamma'}^2}{2\omega}$$ - momentum transfer

- if $\Delta q \, l < \pi$ coherence over l,
- probability $P \sim l^2 m_{\gamma`}^4$
- if $l >> l_{osc}$ $(\sim 1/\Delta q)$ $P \to 2\chi^2$
- e.g. $\omega \sim 1$ eV , $m_{\gamma`} \sim 10^{-4}$ eV, $l_{osc} \sim 20$ m
- vacuum is important not to dump oscillations

Solar flux of γ`

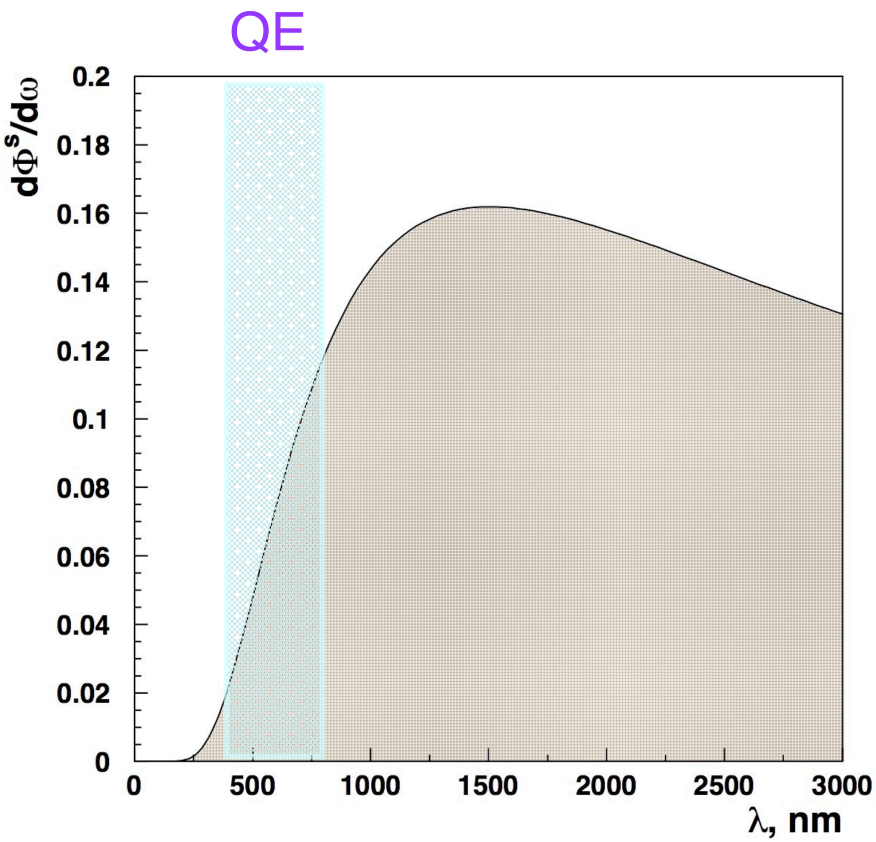
- surface γ`-flux, eV range,

T~ 5800 K (0.5 eV), max at 1 eV

$$\frac{d\Phi^s}{d\omega} \simeq \chi^2\, 4.2\times 10^{18} \frac{\omega^2}{e^{\omega/T_0}-1} \frac{1}{\mathrm{eV^3\ cm^2\ s}}\,.$$

- bulk γ`-flux, 1-5 eV range

$$\frac{d\Phi^b}{d\omega} \sim \chi^2 \left(\frac{m_{\gamma'}}{\mathrm{eV}}\right)^4 10^{32}\, \frac{1}{\mathrm{eV\ cm^2\ s}}$$

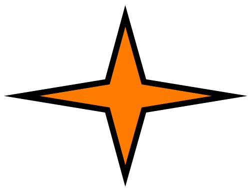


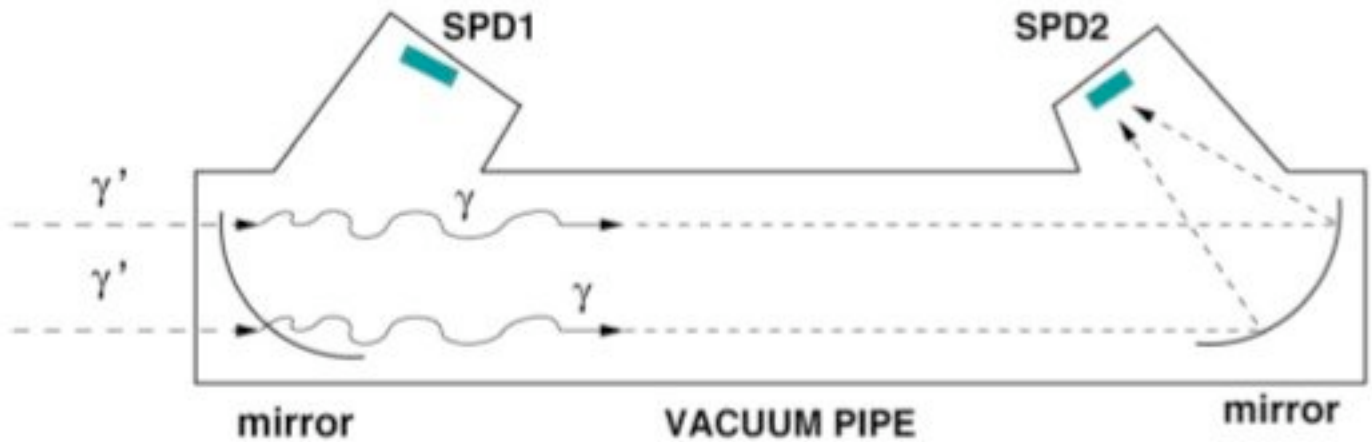
For $m_{\gamma`} < \sim 10^{-4}$ eV, $\Phi^b < \Phi^s$

SG, J. Redondo PLB 664(2008)180
J. Redondo, arXive: 0801.1527

γ` - helioscope

Sun



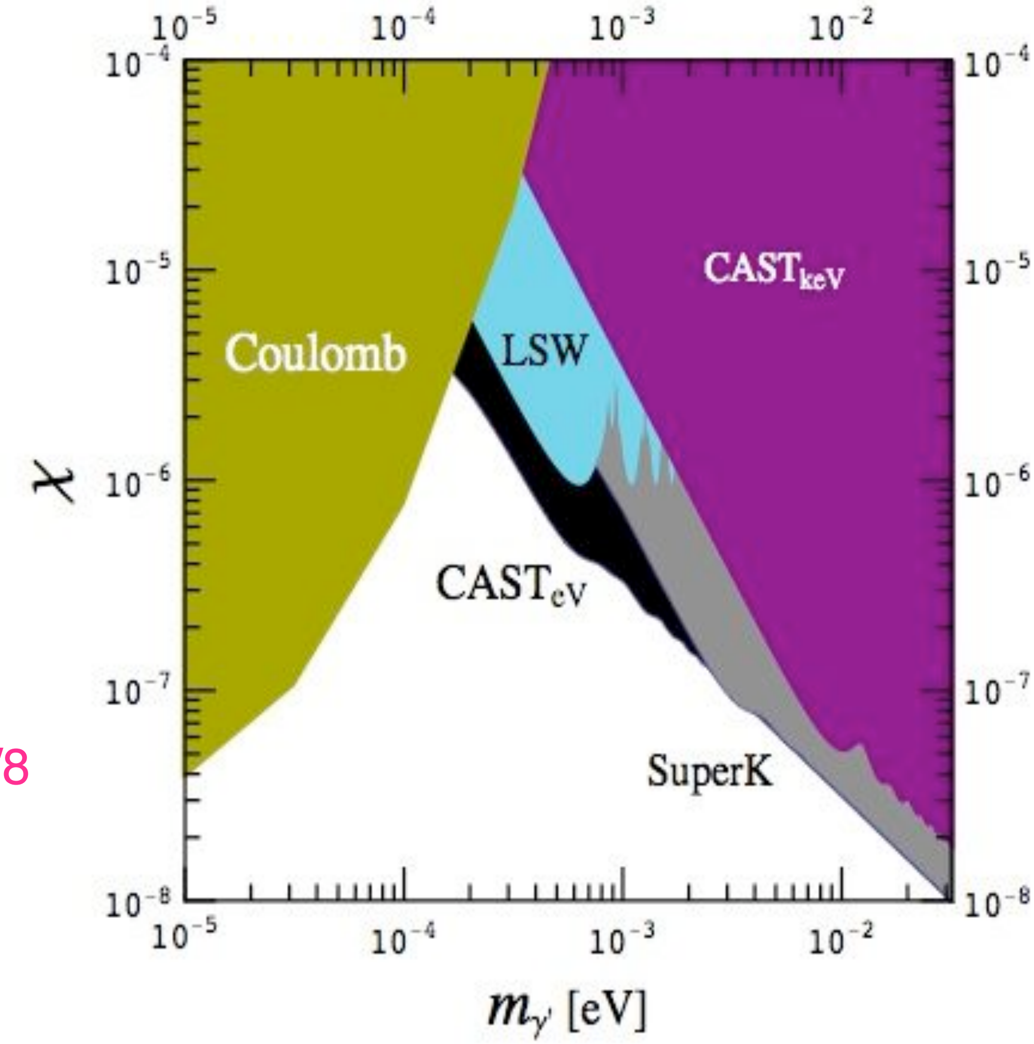


Detector components

- vacuum vessel (r, L) and pumping system
- reflective mirrors
- low noise (n) single photodetectors
- monitoring system, running time (t) ~ months
- readout electronics and DAQ

Expected results

- $2r \sim 50$ cm , $L \sim 10$ m
- $n \sim 1$ Hz
- QE ~ 25%
- reflectivity ~ 90%
- $t \sim 10^6$ s (~ 10 days)



Sensitivity in χ

$\sim r^{-172} \times L^{-1/2} \times n^{1/8} \times t^{-1/8}$

Vessel/vacuum

- Al vessel
- diam ~ 50 cm, length ~ 10 m
- weigth ~ 500 kg (?)

Cost (very prelim.):

design+ construction+ delivery (?) ~ 20 kEuro

- vacuum < 10^{-5} torr, composition?
- vessel low outgassing rate
- oil-free turbopump, speed >1000 l/s
- valve, gauges, joints, ..

requirements for photodetector (PD)

- photocathode area > ~ 1 cm^2
- spectral sensitivity 300 - 600 nm
- quantum efficiency I ~ > 25 %
- gain > ~ 10^5
- good single photoelelectron spectrum peak/vall. 10:1
- low noise level <~ 10 cps at q_{th} ~ 0.2 ph.e.
- stability of counting rate over month(s)
- sensitivity to magnetic field (B field @CAST ?)
- work in vacuum (?)
- ability to work at cryogenic temperatures(?)

available PDs

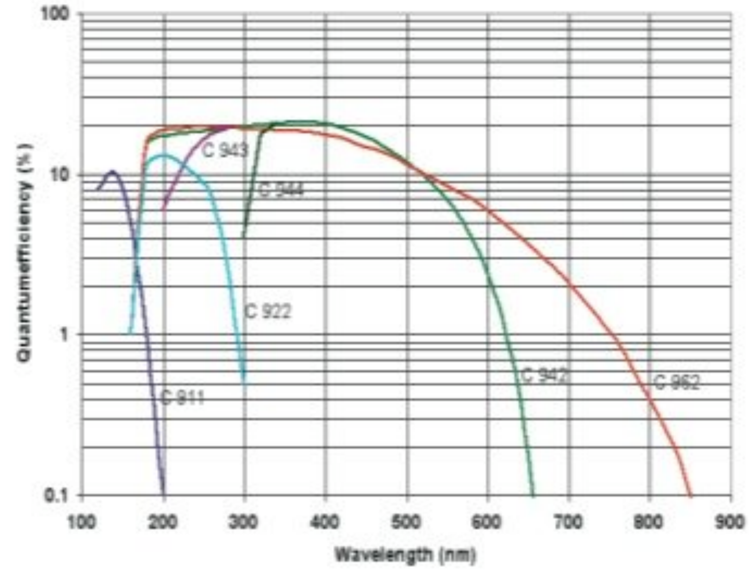
area > 1 cm^2

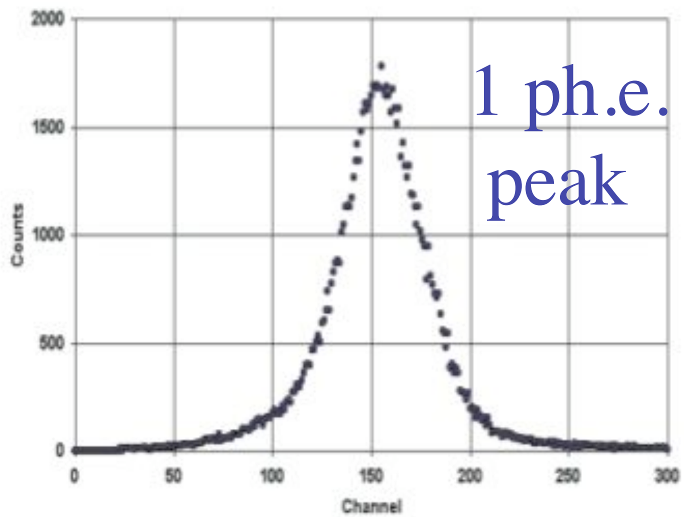
- PM - photomultiplier
- CPM - channel PM

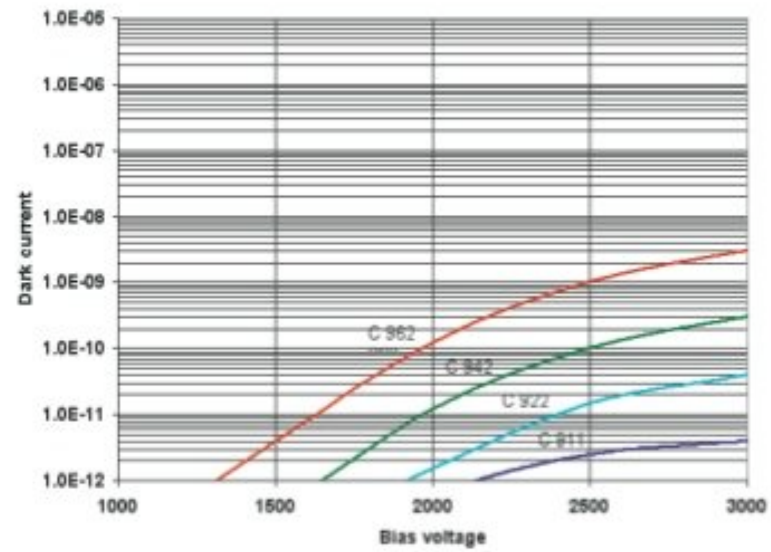
area ~ 1x1 mm^2 - 3x3 mm^2

- APD - avalanche photodiode
- SiPM - silicon PM
- MPPC - multi-pixel photon counter
- MAPD - micro-channel APD

CPM photomultiplier 1



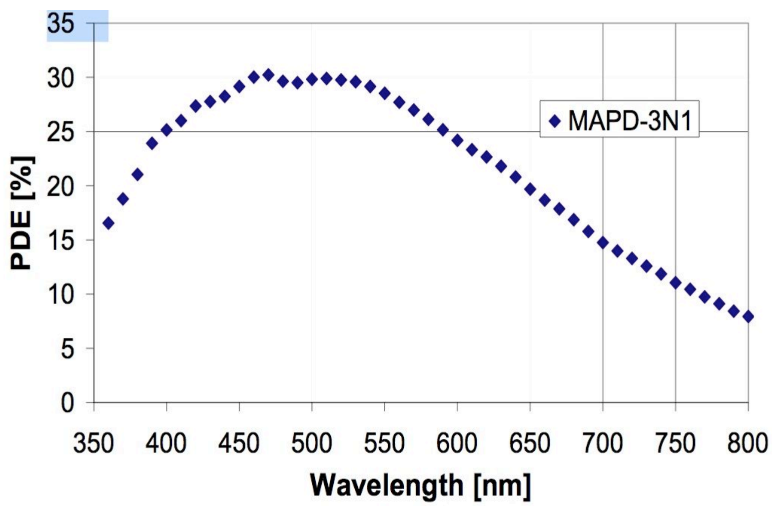


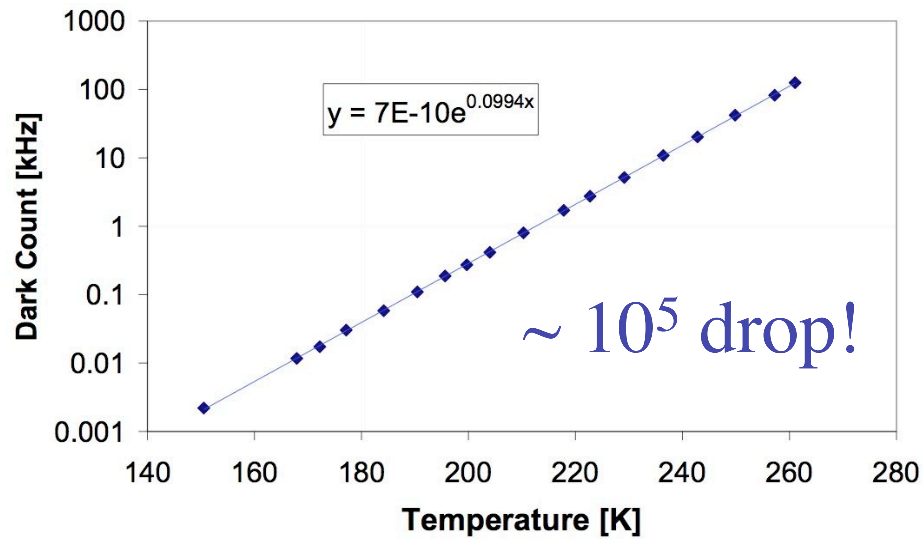


CPM photomultiplier 2

Type	C 911	C 922*	C 942	C 943	C 944	C 962
Spectral response (nm)	115-200	165-320	165-650	185-650	300-650	165-850
Photocathode material	CsI	CsTe	Bialkali	Bialkali	Bialkali	Multialkali
Min. useful area (mm)	5	5	5	5	5	5
Window material	MgF_2	Quartz	Quartz	UV-glass	Boro	Quartz
Electron multiplication		Channel Electron Multiplier				
Supply voltage (V)		2400 (max. 3000V)				
Current amplification	5×10^7	5×10^7	5×10^7	5×10^7	5×10^7	5×10^7
Anode sensitivity *@ 140 nm (A/W)* *@ 200 nm (A/W)* *@ 400 nm (A/W)*	6×10^5	1×10^6	3×10^6	3×10^6	3×10^6	3×10^6
Dark current (pA)	2	10	80	80	80	800
Bias current (µA)	50	50	50	50	50	50
Max. anode current		10% of bias current (max. 30 sec)				
Response time *Rise time (ns)* *Pulse width/FWHM (ns)*	3 6	3 6	3 6	3 6	3 6	3 6
Special Types for Photon Counting **Type**	**C 911P**	**C 922P***	**C 942P**	**C 943P**	**C 944P**	**C 962P**
Supply voltage (V)		3000 (max. 3000V)				
Single photo electron gain	3×10^8	3×10^8	3×10^8	3×10^8	3×10^8	3×10^8
Dark counts (cps)	0.1	1	10	10	10	100
Peak to valley	10:1	10:1	10:1	10:1	10:1	10:1
Max. ambient temp. (°C)	50	50	50	50	50	50
* Preliminary						

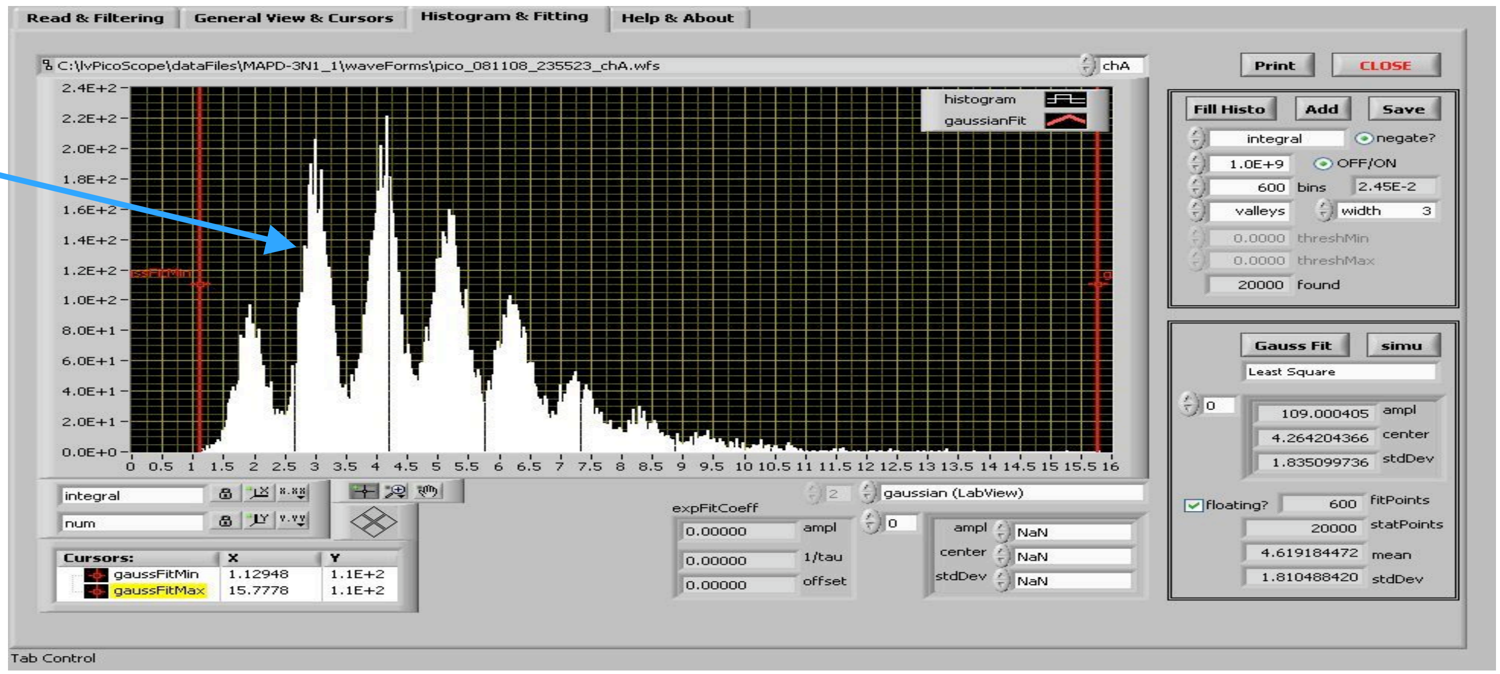
MAPD



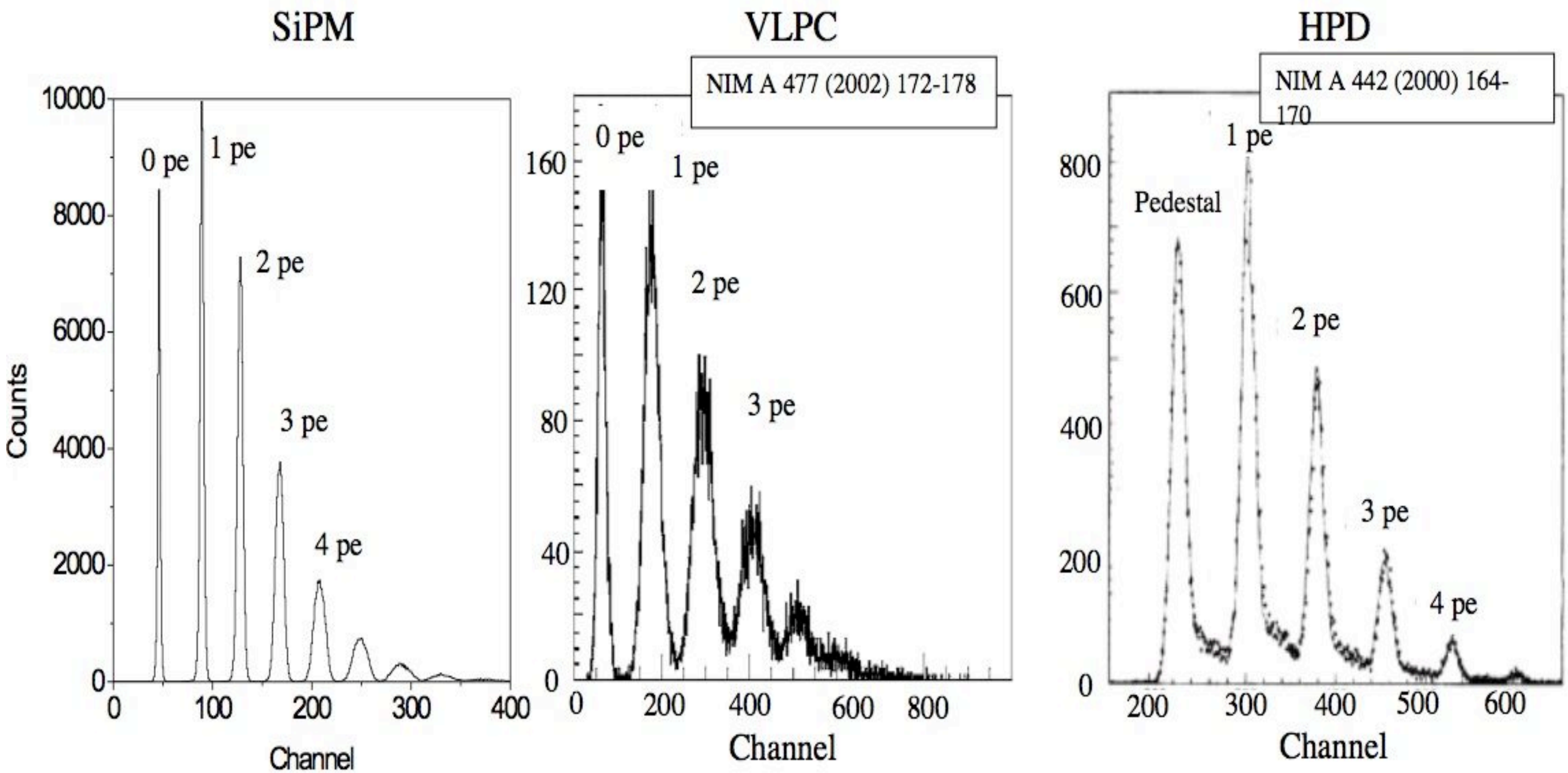


~ 10^5 drop!

1 ph.e. peak



Single ph.e. peak

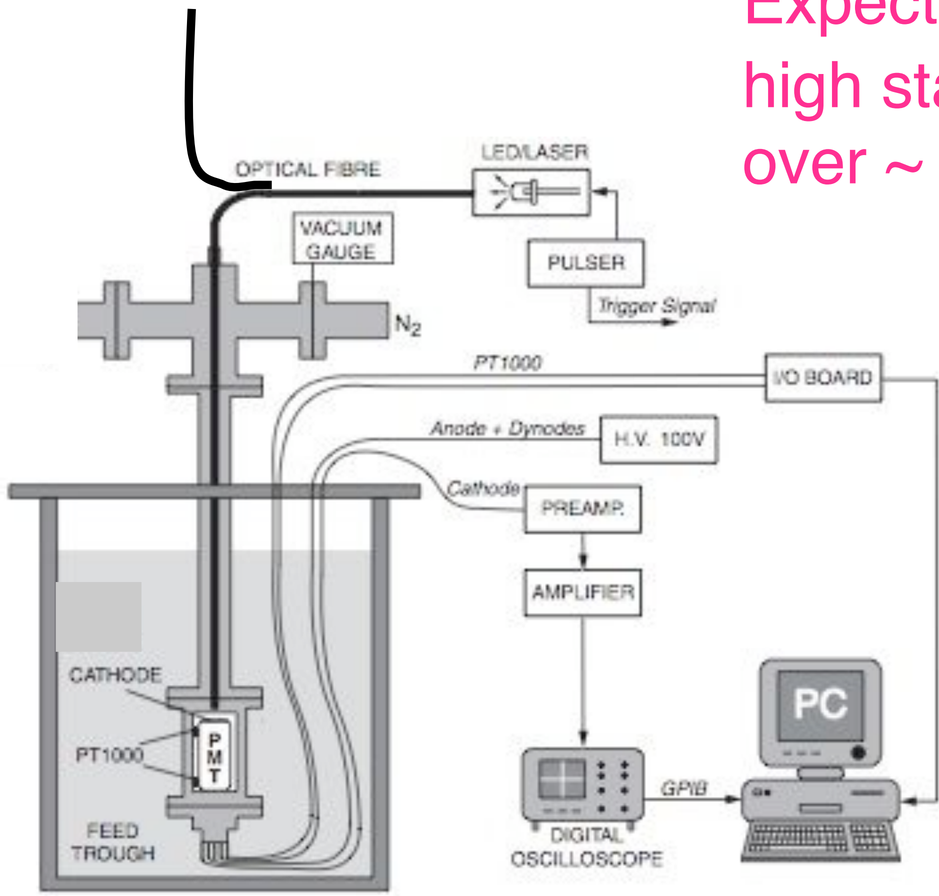


Photodetectors summary

Photo detect.	Area cm^2	Gain	Spectr. Sensit., nm	QE, %, max	Noise, Hz, Tr ~ 0.3 ph.e.	$\Delta g/g$ ~ 1% ΔT ΔV	SER, fwhm %	Cost Euro
PM	>1	10^8	250-650	~25	< 10 Hz T~ 77 K	10^o, 3 10^{-4}	~ 50	500-1500
CPM	~1	10^8	200-850	28	< 10 Hz T~ 300 K	?	~ 20	~ 700
APD	~ 0.1	10^4	400-750	>60	?	0.3^o,1.10^{-4}		~ 50
SiPM	0.01 pixel	2 10^6	400-650	>40	10^5 T~ 300K	2.5^o,10^{-3}	~20	~200
MAPD	~ 0.1	7 10^4	350-900	>25	1-10 Hz Crio. T	?	~25	~100
MPPC	0.1	10^6	350-700	>25	?	?	~25	~200

Monitoring system

to detector



Reference PD

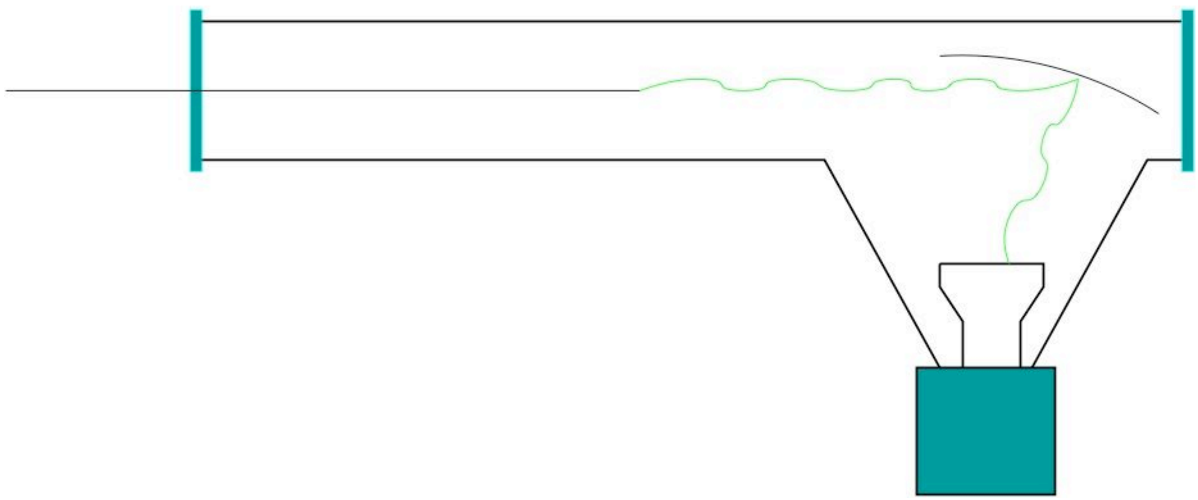
Expected $\Delta n_{\gamma`}$ / noise < ~ 10^{-3}
high stability of noise counting rate over ~ monthes required

Monitoring of stability of
- gain,
- threshold,
- QE,
- optical system
- …….

- reference PMT
- LED
- Am-241 alfa source

stability ~ 10^{-3}

Prototype: used beam Cherenkov counter?



Present status and plans

- INR group have sent request for funding in 2009
  A. Belov, SG, engineer/mechanician,
  vessel, vacuum, PD, DAQ, ..

- P. Nedelec group (Lyon U.) is interested
  in photodetector studying (MacFly),
  request for funding
  Could start tests in Lyon. Monitoring(?)
  Electronics.

- Yu. Musienko (INR & North.Univ) -
  help in tests of photodetectors at CERN