Progress in the development of a S-RETGEM-based detector for an early forest fire warning system

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Violent forest and bush fires in South Europe, Australia, USA and other countries worldwide bring in danger human lifes, destroy properties, damage the environment

The probability of fires in forests and fields is steadily increasing owing to climate changes and human activities.

The lost of forest due to the fire in Europe in the period of 1971-2000

(from J. Goldammer et al, presented at the International Conference ”Fire and emergency safety”, October 202 , Bulgaria)

Country	Time period	Average number of fires	Total area burned, ha
Albania	1981-2000	667	21456
Algeria	1979-1997	812	37037
Bulgaria	1978-1990 1991-2000	95 318	572 11242
Cyprus	1991-1999	20	777
Croatia	1990-1997	259	10000
France	1991-2000	5589	17832
Greece	**1990-2000**	**4502**	**55988**
Israel	1990-1997	959	5984
Italy	1990-1999	111163	118576
Lebanon	1996-1999	147	2129
Morocco	1960-1999	n.a.	2856
Portugal	1990-1997	20019	97175
Romania	1990-1997	102	355
Slovenia	1991-1996	89	643
Spain	1990-1999	18105	159935
Turkey	1990-1997	1973	11696

Summary: Europe, up to 10,000 km^2 of vegetation are destroyed by fire every year, and up to 100,000 km^2 in North America and Russia.

Du to the scale and the danger forest fires classified as a planetary disaster

The most important in fight with the forest fire is <u>its early identification</u>

What is considering/ exists?

- Satellites:Multifunctional satellites such as NOAA and Landsat with CCD- and IR-cameras on board can observe large areas with moderate time and spatial resolution.
- Spy Airplanes (visible images)\IR sensors
- Watch towers :CCD or image intensifiers monitors operating in IER and visible region of spectra

IR detecors(4.4micr)

Laser scattering

- Heat sensors
- Combination of these methods

A short review of these methods…

Satellites are very expensive, they observe limited areas, cannot detect small fires. …Clouds is another problem

Spy airplanes with visible and IR

In the USA, Canada, Russia, Finland, and other countries with large forest areas an early warning system is planned to be based on aircraft patrolling with visible , but mainly IR-cameras is used.

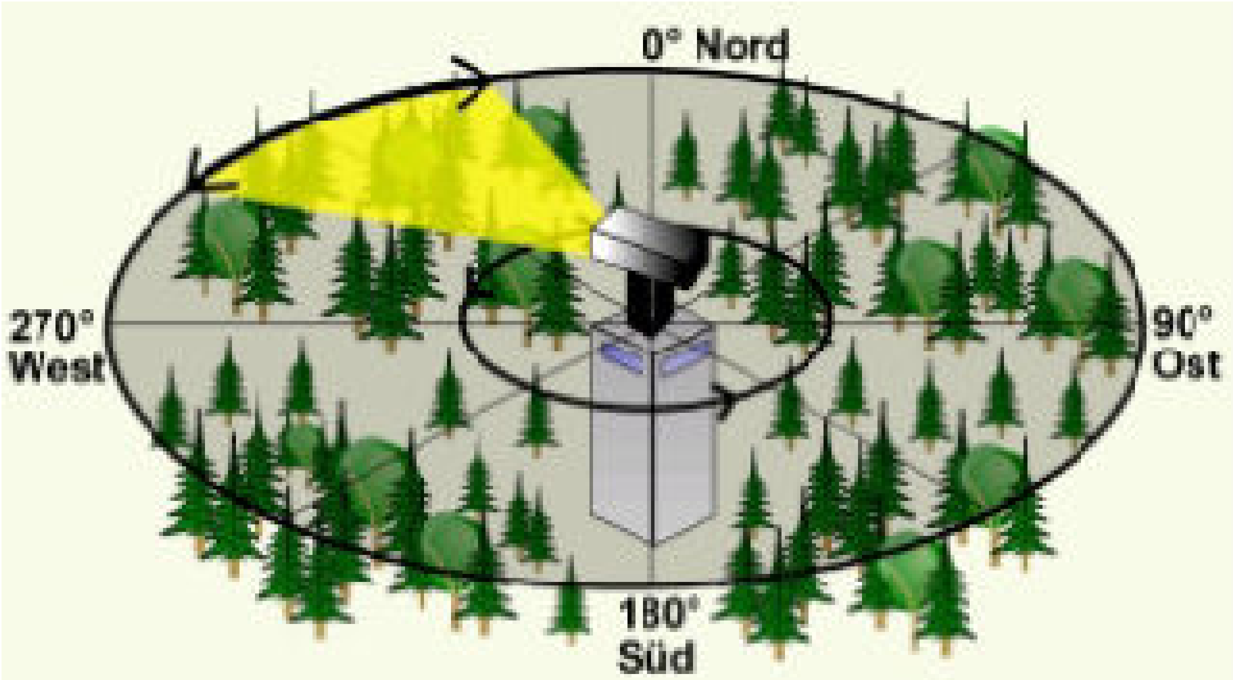
However, this is expensive to operate if quick detection is mandatory

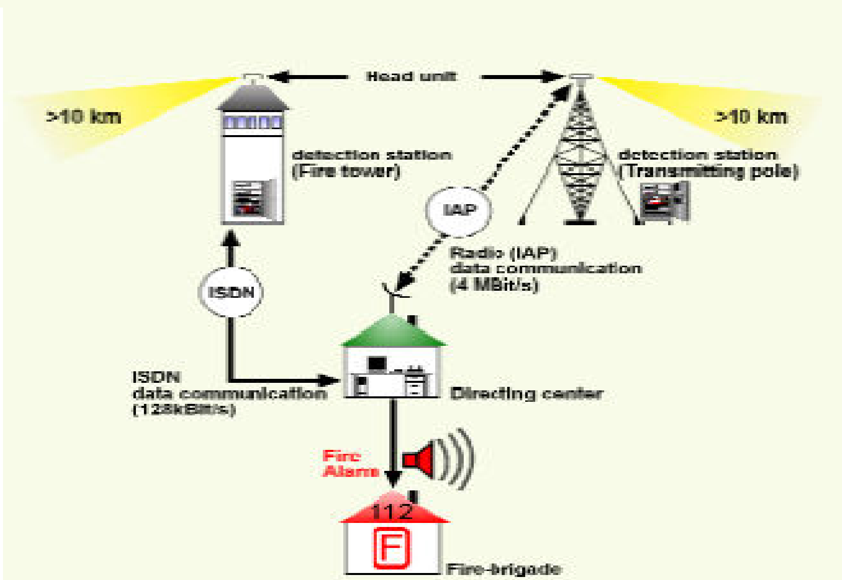
Watch tower approach

The state's Forestry Department erected a 40-foot forest fire watch tower on the summit of Harts Hill in the spring of 1913 to replace a similar tower on Bear Hill. The four-cornered steel framed tower was supported by four strong steel posts firmly cemented into the ledge at the summit of the hill. The lookout was another seven to eight feet higher, bringing the total height of the structure to nearly 50 feet, or 285 feet above sea level. The forest fire watch tower had glass windows on all four sides that provided an unobstructed view for several miles in all directions, 'as far as the western part of the state and the southern part of New Hampshire.' The first watchman was Henry Fay, the firefighter with the longest years of service. He was selected for the job, and paid, by the state Forestry Department. His equipmen t consisted of powerful glasses, a chart of the country 'round about,' a range finder and a telephone number (512-M). If he spotted a fire, he called the nearest fire department or fire warden. It was reported that he would be able to see a fire 10 to 15 miles away, and when he 'gained complete familiarity with his apparatus, could place it as close as 100 to 200 feet.' The Town voted in 1912 to pay $350 for public access to the tower. An iron stairway at the northwest corner was built so that ladies would not be 'inconvenienced.' On May 1913, over 400 people took advan tage of the public opening." -- Text from calendar by Jayne M. D'Onofrio.

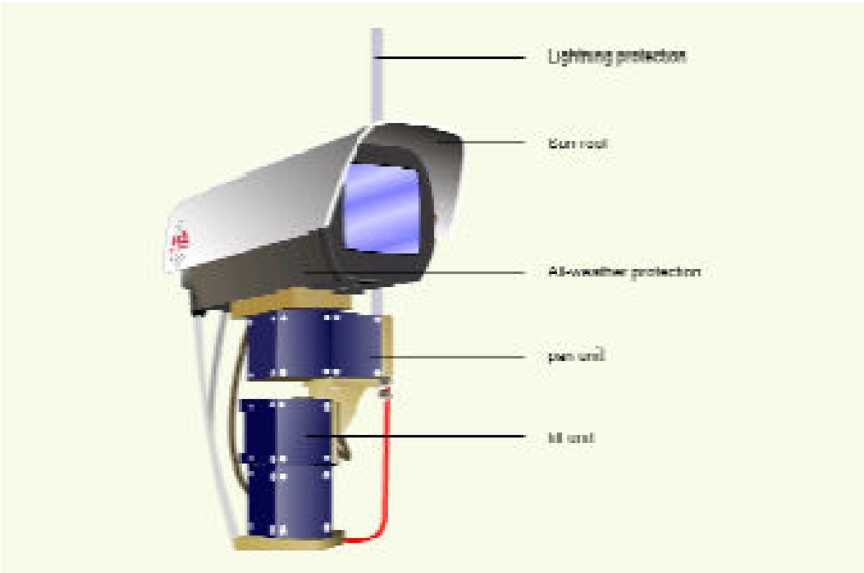
Harts Hill forest fire watch tower, 1913 picture

Modern approach:





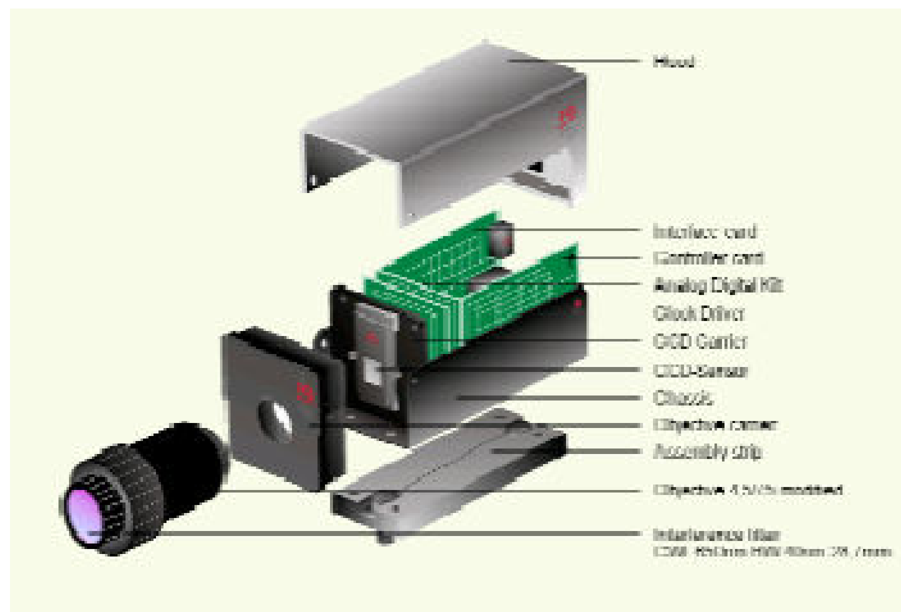
Already functioning in Germany
and will be soon installed in Russia



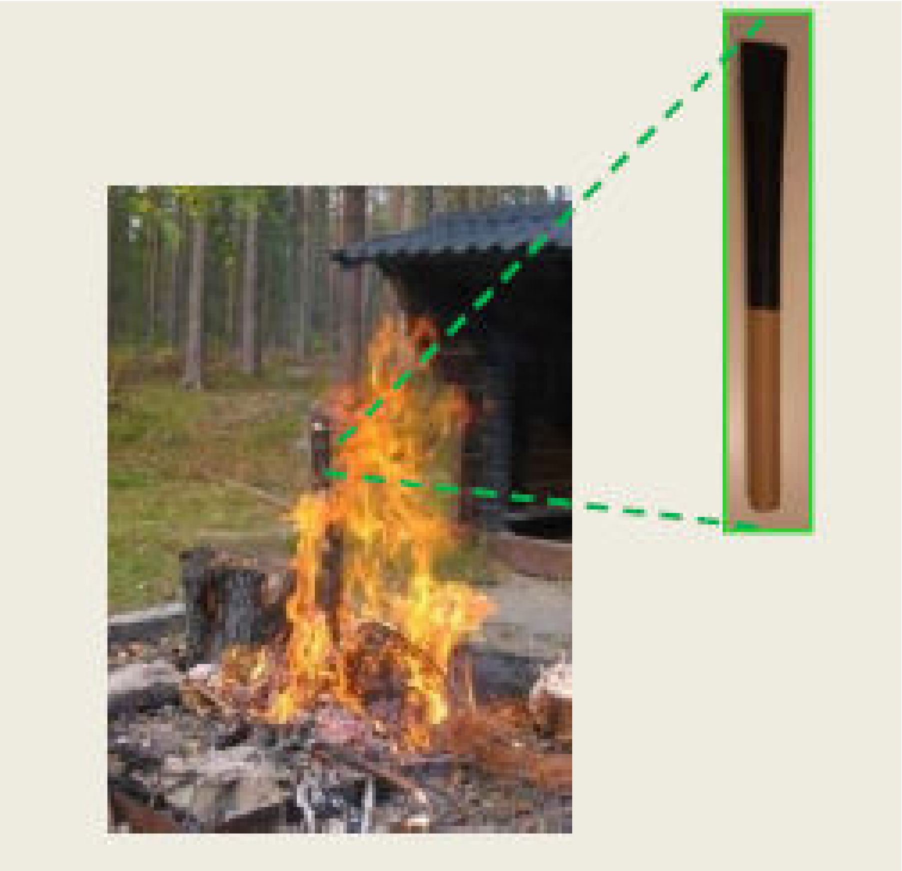
Smoke detection within the visible spectral region is especially important in densely wooded forests, as open flames (which IR-sensors respond to) give alarm too late. Furthermore, cameras provide the operator in the control center with expressive images and hence make it easier for him to evaluate the situation.

650 nm (CWL) and 400(HW)nm.
Can identify 10x10x10m^3
smoke on ~10km

The entire system is very expensive



Heat sensors (Swedish company)



Very cheap (~10Euro), but should be placed each 5-10m, so the <u>total price is high</u>

Our suggestion- for early fire detection use high-sensitivity UV gaseous detectors

Requirements for these detectors
(and for any stationary forest fire detectors)

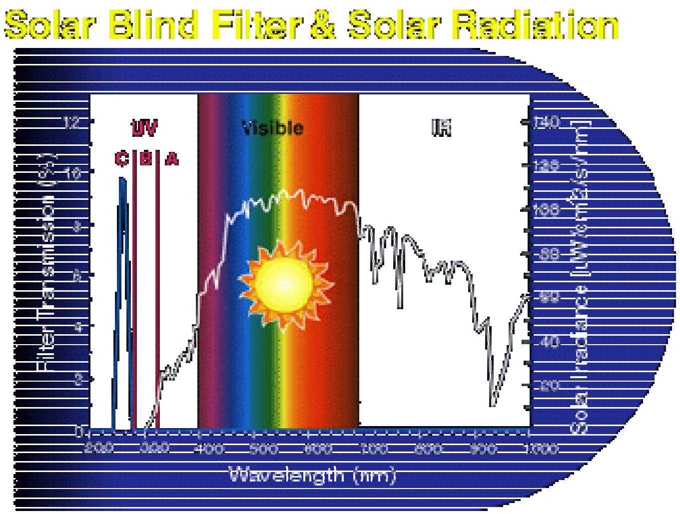
Low price
High sensitivity to flames
Insensitivity to <u>direct</u> sunlight
Low power consumption

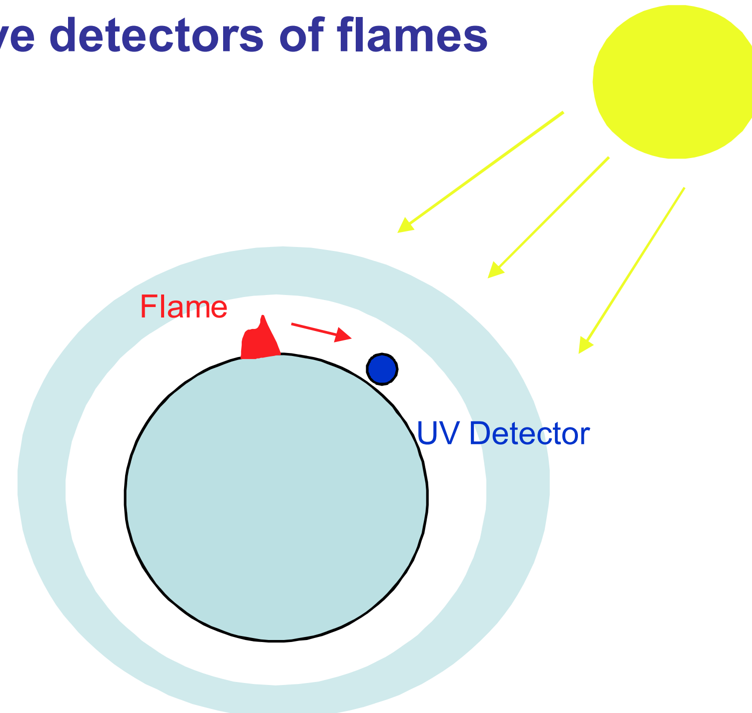
There are commercial UV detectors of flame, but their sensitivity is insufficient for the forest fire detection

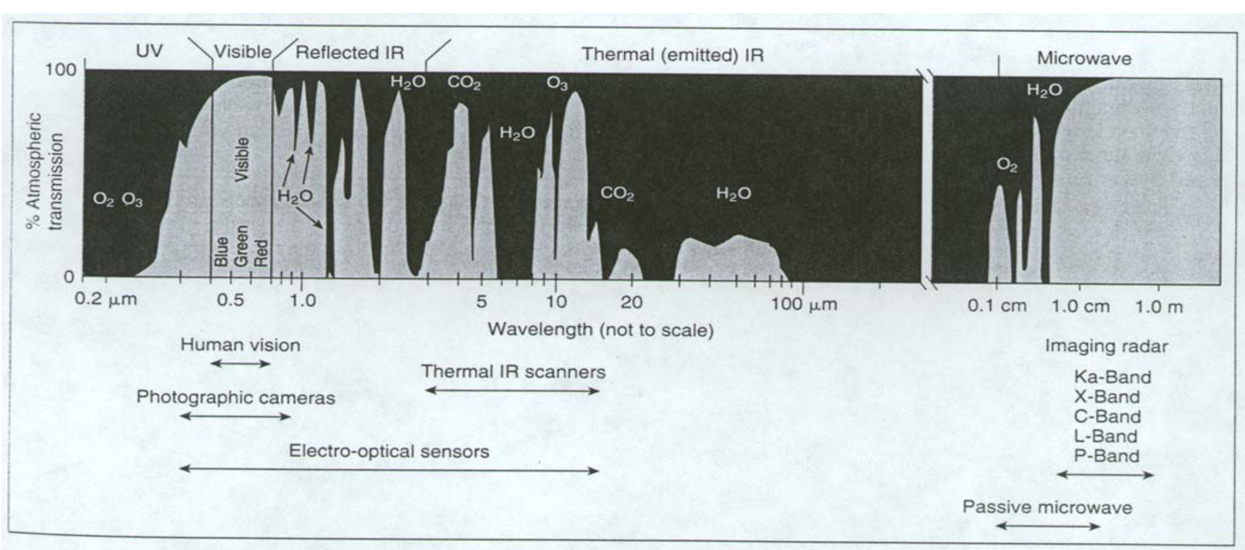
EU standard:
The highest sensitivity
Class 1: ~30x30x30cm^3 flame
on ~20m in 20sec

An example of the class one detectors is Hamamatsu UVtron

The basic idea of the UV sensitive detectors of flames



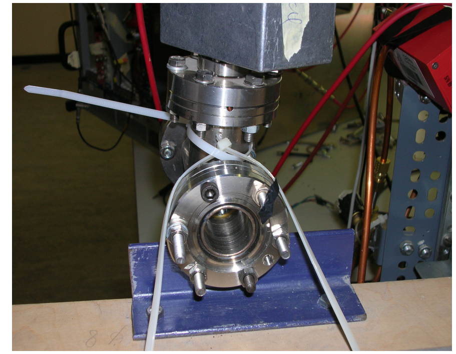




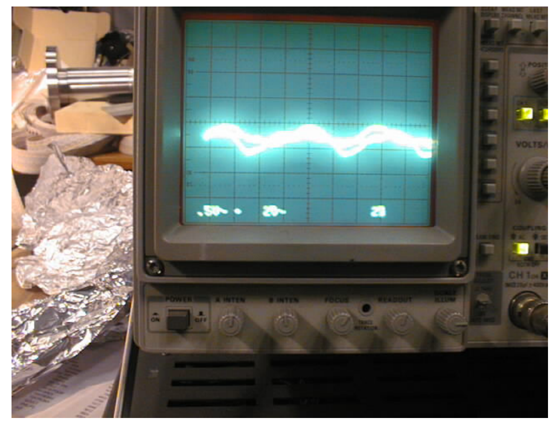
Ozone layer in upper atmosphere blocks the sun radiation in the range 185-260 nm, however on the ground level the atmosphere is transparent in this spectral interval

So a UV detector, sensitive only in the interval 185-260nm is able to detect a UV radiation from the flame, but at the same time is insensitive to the Sun radiation

For several years we are persuing a gaseous detector approach for flame detection: photosensitive avalanche detectors operating in photon counting mode



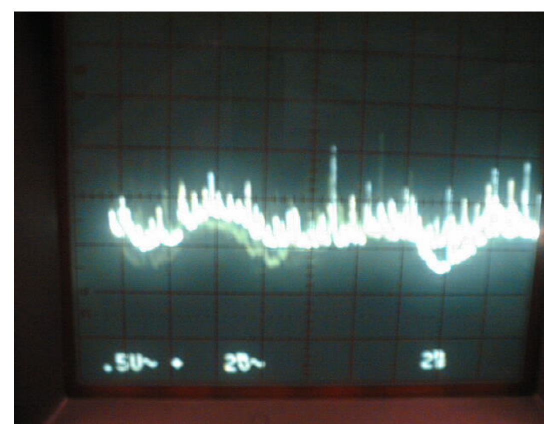
Laboratory prototype



Background in a fully illuminated room (usual+ halogen lamps)

First step-laboratory prototypes. They were
1000 time more sensitive than the class 1commercial detectors.
Can operate in illuminated area

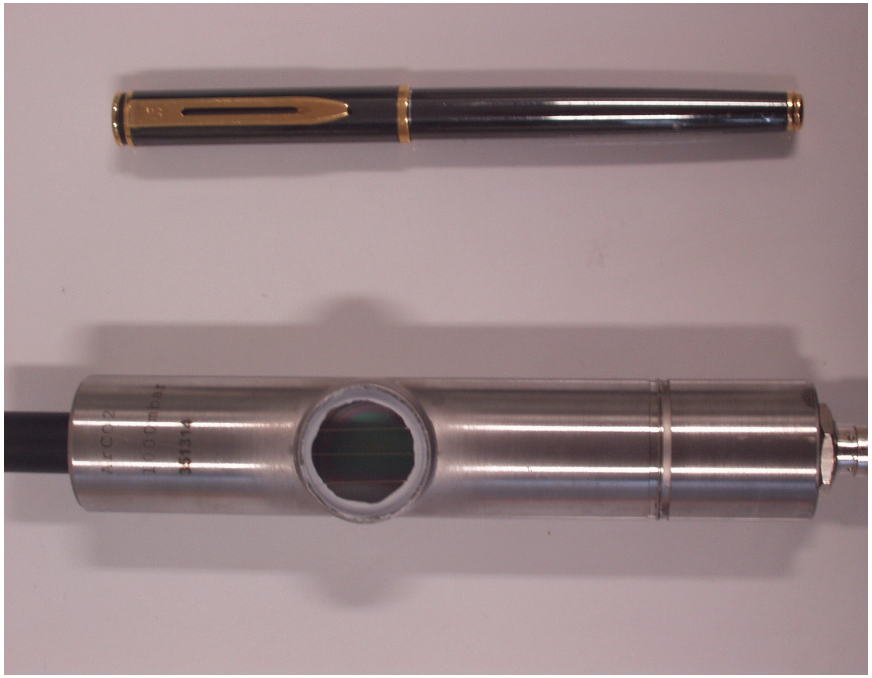
Candle in a fully illuminated room

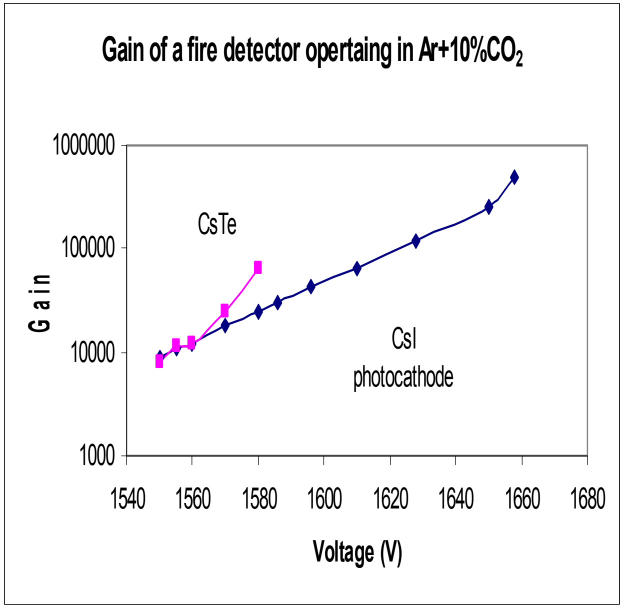


This success triggered our attempts to install contacts with companies and commercialize the detectors

Indoor Detector of Flames and Sparks

(a sealed single-wire counter with CsI pc)

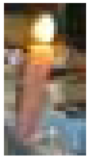




(In collaboration with Oxford Intsr and Reagent, Moscow)

The detector is able to operate in fully illuminated rooms

Comparison between our and Hamamatsu UV fire detector



Three UV detectors of fire were compared using the same candle flame:
1.Hamamatsu R2868
2.Our laboratory prototype
3.Our industrial prototype.

Results are summarized in the table below:

Hamamatsu R2868		Our industrial prototype		Our lab. prototype	
Distance (m)	Mean number of counts per 10sec	Distance (m	Mean number of counts per 10sec	Distance (m	Mean number of counts per 10sec
1		1	81579		
1,1	583				
2,5	99				
3	76	3	9015	3	87574
4,5	28				
10	6	10	811	10	7902
20					
30		30	92	30	876

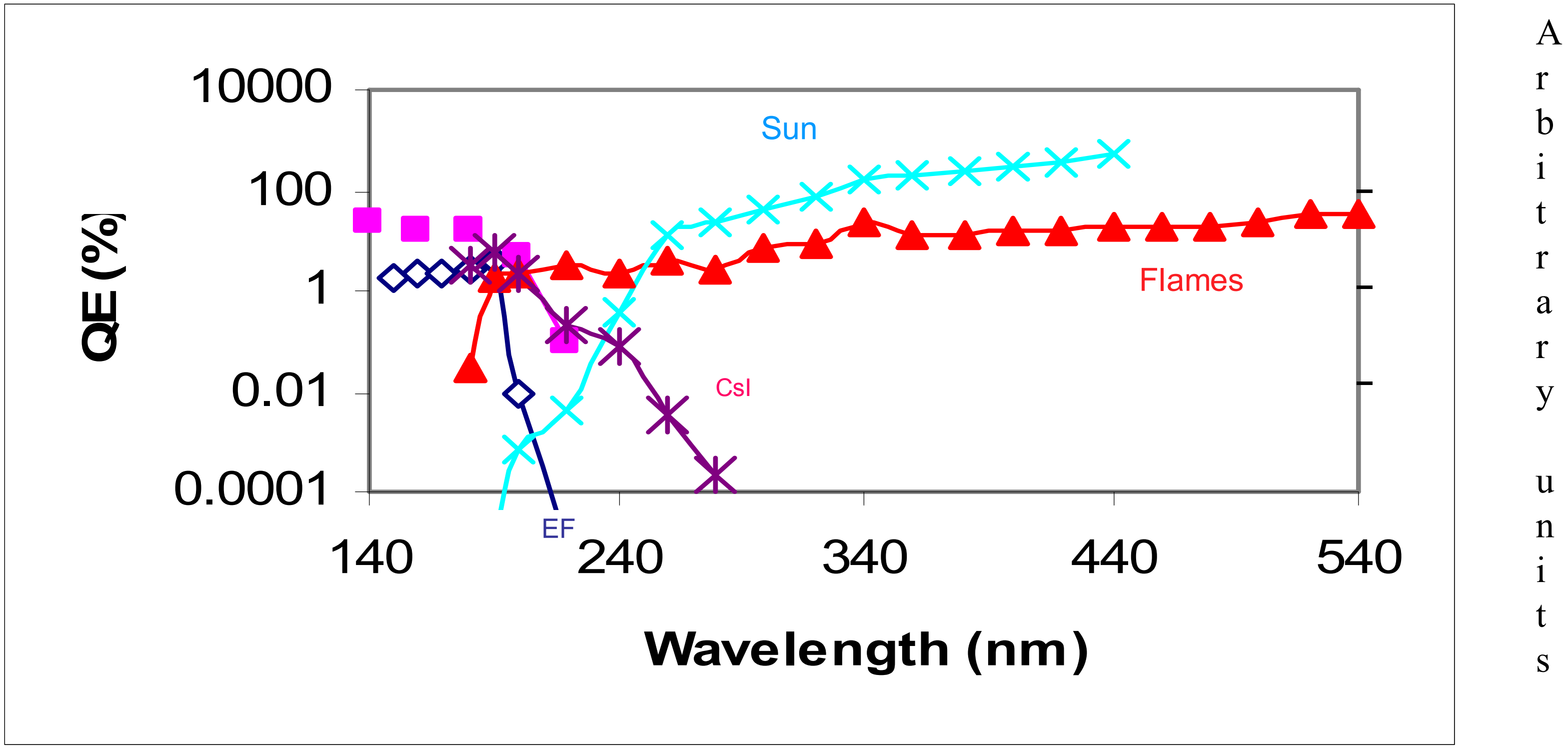
Conclusion:
Our lab prototype is ~1152 and our industrial prototype is~ 118 times more sensitive than Hamamatsu R2868.

A lesson we learned: the Sun radiation is so strong that high sensitivity *solid-based pc* detectors can operate in direct sunlight conditions *only in combination with filters*

↓

This means an attenuation is at least on a factor of 10 at the peak of the transparency

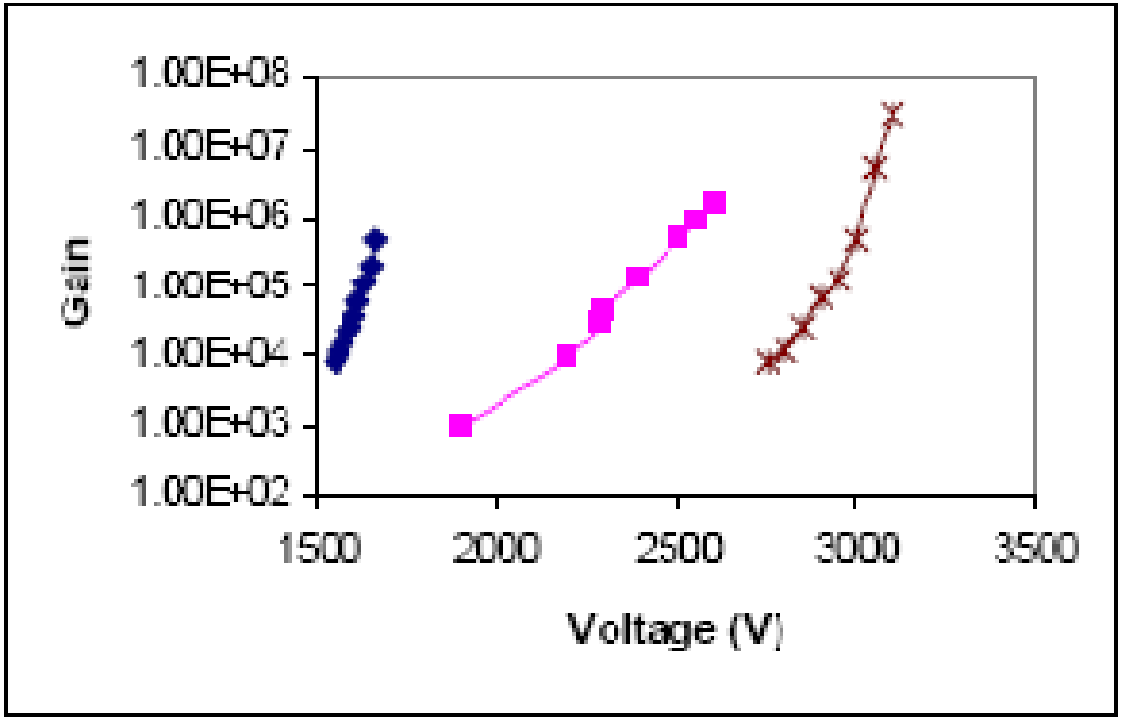
Results of measurements the CsI and Ethylferrocene QE (%) and spectrum of flame and the sun (arbitrary units)



Conclusion: all high-sensitivity solid photocathodes have a “tail” of sensitivity in long wavelengths. In contrast, gaseous photocathodes have a sharp cut off at $E_v>E_i$

The use of photosensitive gases (TMAE and EF) instead of solid photocathodes is the best solution

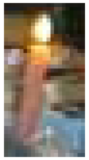
Detectors filled with photosensitive vapours can operate without any filters and in photon counting mode



EF-based detectors can easily operate at gains of10^6 or more

Fig. 6. Gain vs. voltage for some of our detectors: blue rhombus sealed single-wire counter with the CsI photocathode and with a diameter of the cathode cylinder of 20 mm (gas mixture Ar+10%CO_2), rose square- wire counter with the CsI photocathode with a diameter of the cathode cylinder of 30 mm(gas mixture Ar+10%CH_4), brown star-gain for the single wire- counter filled with EF vapers (gas mixture Ar+15%CO_2).

Comparison of TMAE and EF detectors(20°C) with the 1st class flame detectors



Hamamatsu R2868		Our TMAE detector at 23°C		Our EF detector at 25°C	
Distance (m)	Mean number of counts per 10sec: N_H	Mean number of counts per 10sec: N_{tmae}	Ratio N_{tmae}/N_H	Mean number of counts per 10sec: N_{ef}	Ratio N_{ef}/N_H
1,1	583	690747	1.18×10^3	75613	1.3×10^2
3	76	91013	1.19×10^3	11052	1.4×10^2
10	6	7820	1.30×10^3	643	1.1×10^2
30	0.1	873	8×10^3	68	6×10^2
85		51		4	

A note: we have a working prototype at CERN; those who are interested are welcome to see it in operation!

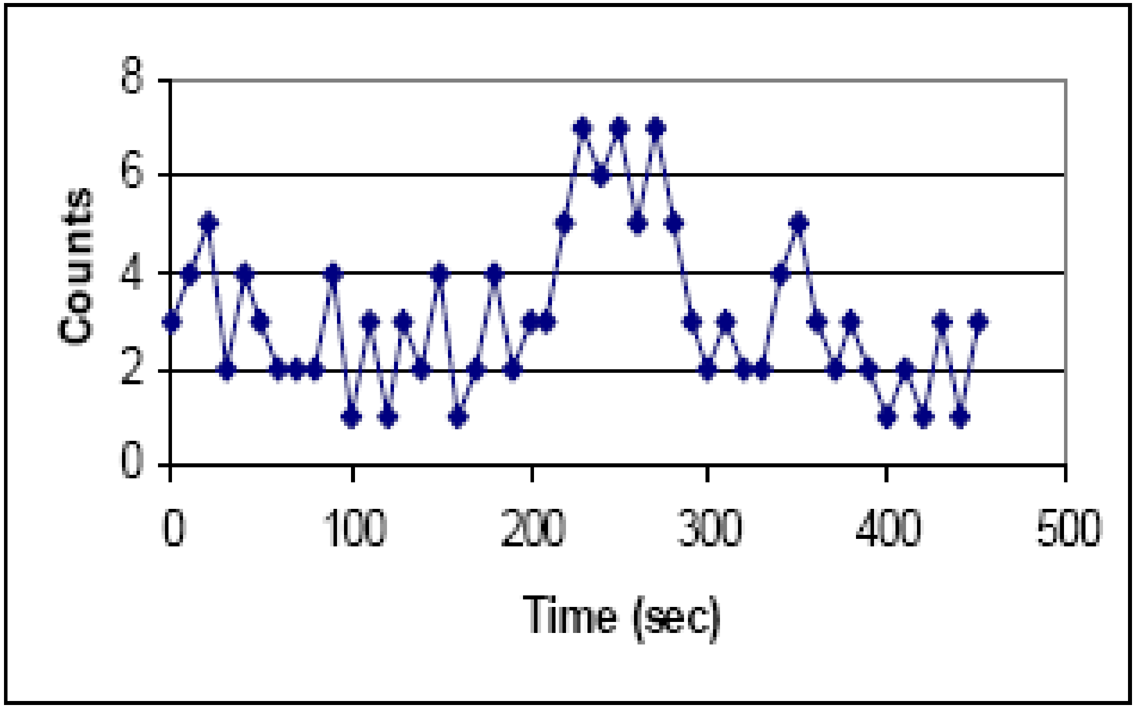


Fig. 10. Counts measured from the sealed gaseous detector filled with EF vapors (V=3 kV) in direct sunlight conditions. At the time interval 220-280 sec an alcohol fire (~5 x 5 x 5cm^3) was placed 30 m away from the detector. One can see that the counting rate almost doubled.

Because such detectors are much more sensitive than the commercial one, they can used for the forest fires warning systems

From our point of view detectors with photosensitive vapors are ready for this application

↓

However, there is a practical problem: –nowadays it is not easy to find a company able to manufacture sealed single wire counters

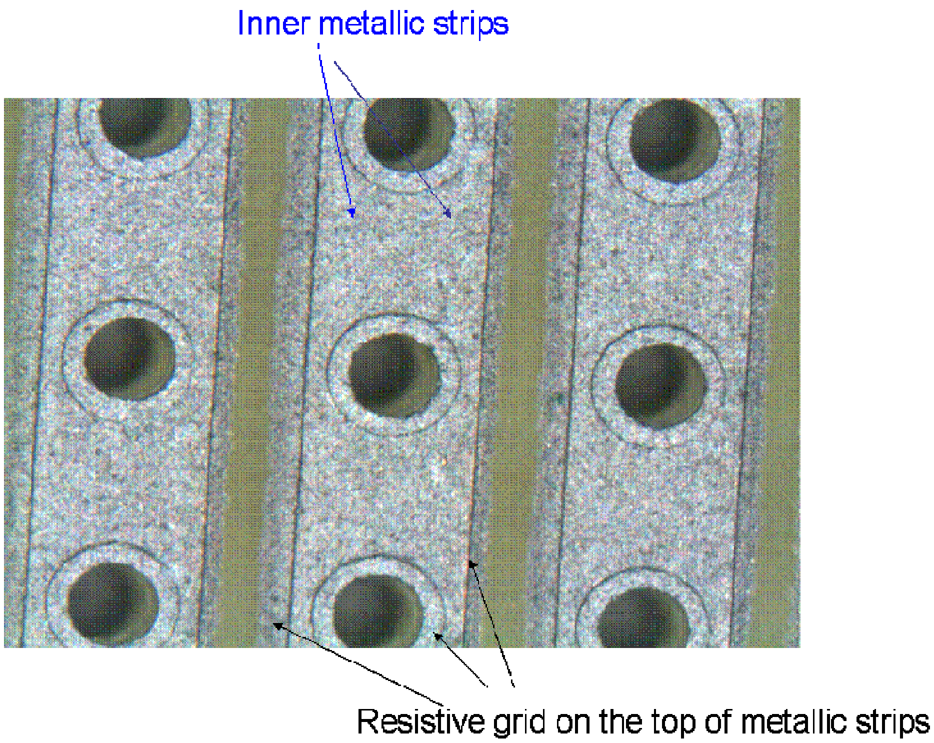
↓

In the past the single-wire counter were very cheap.
The high price comes from the fact that now there is no anymore production lines

↓

This is why we start developing GEM-type flame detectors.
The best solution is the use of S-RETGEMs:
they are spark-protected,
position –sensitive,
today is much easier to manufacture them than wire-type detectors

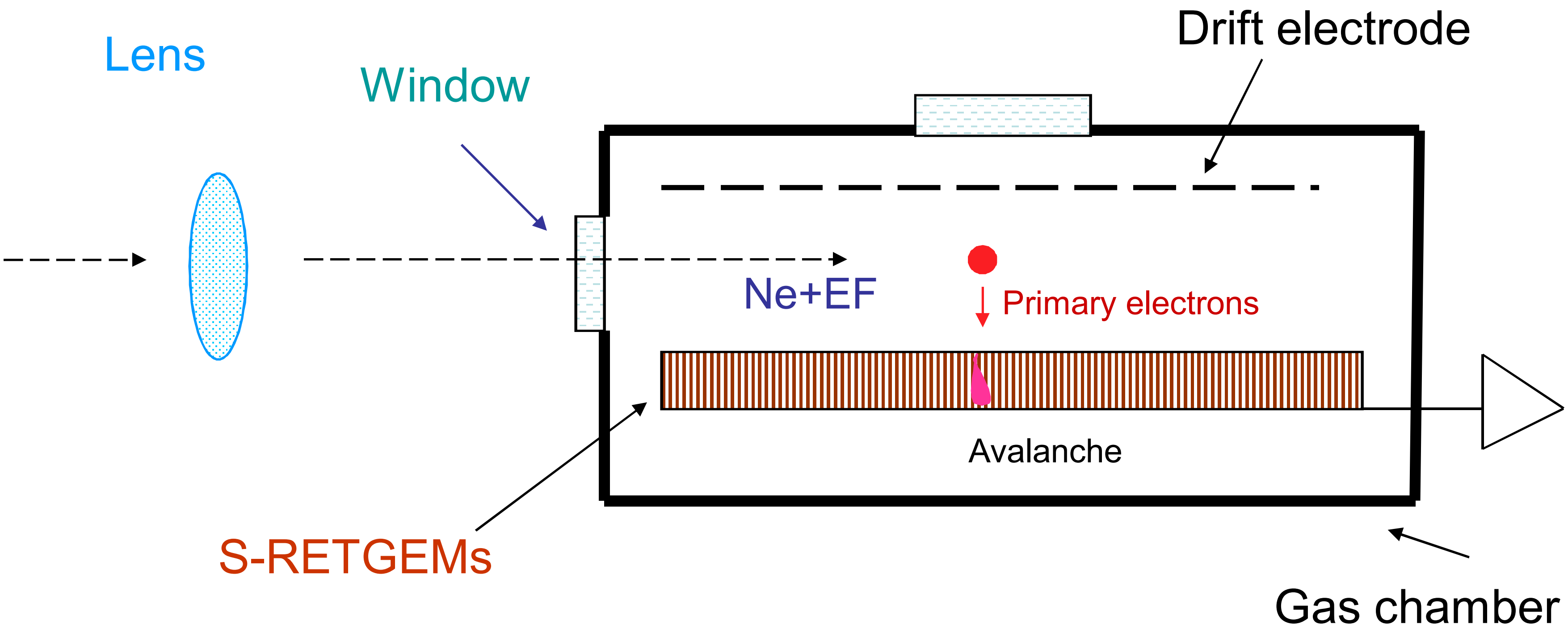
S-RETGEM detector filled with Ne* and EF

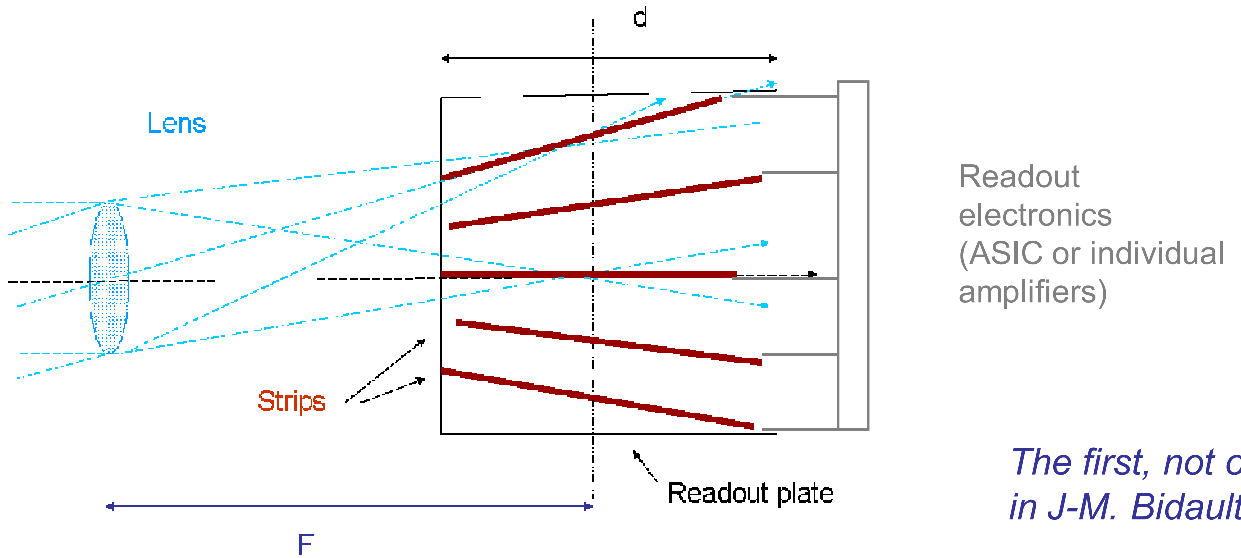


A photo of S-RETGEM developed in R. Olivera Workshop
(see Di Mauro et al, report at the IEEE Nucl. Sci, Dresden, 2008)

S-RETGEM flame detector operating in St. Etienne

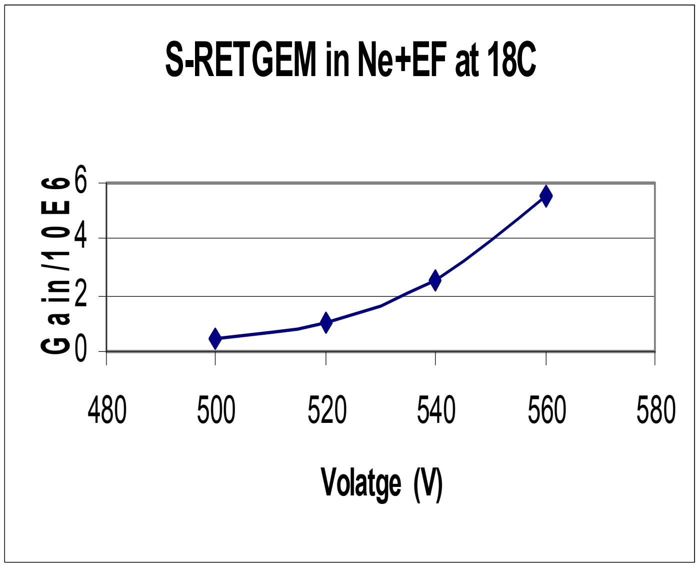
*About unique properties if Ne one can learn from the talk of M. Cortesi et al at this Workshop





The first, not optimized, prototype is described in J-M. Bidault et al, NIM A580, 2007, 1036

The main feature of Ne –very high gains, thus one step of multiplication is sufficient



EF "stabilize" the mixture, so the detector can be sealed

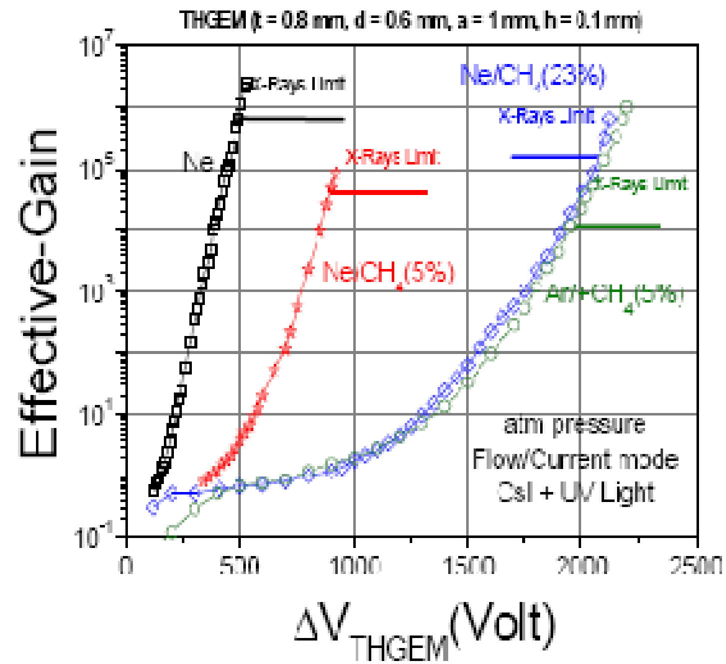


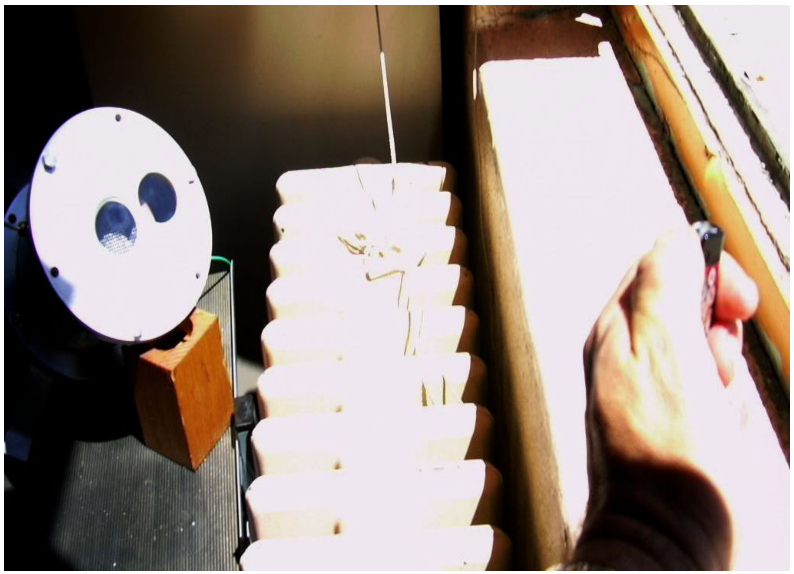
Figure 4. Effective-gain curves obtained in the single-THGEM detector of Fig. 1, with single UV photons (CsI photocathode; E_{drift} = 0) in Ne, Ne/CH_4 mixtures and in Ar/CH_4 (95:5). The maximum effective gain reached in each gas, in the same detector, with 9 keV (Cu-K_α) X-rays is also shown (E_{drift} = 0.2 kV/cm). THGEM geometry: t = 0.8 mm, d = 0.6 mm, a = 1 mm, h = 0.1 mm.

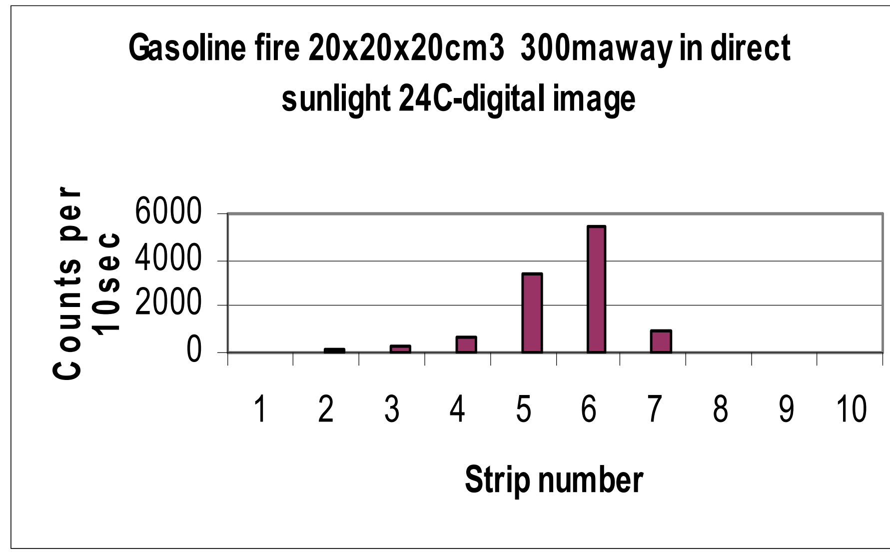
For more details see: *M. Cortes et al.*, *arXiv:0905.2916*

Unique properties of this detector:

One step of multiplication only
No readout plate
Spark-proved
Position-sensitive
Insensitive to direct sun light

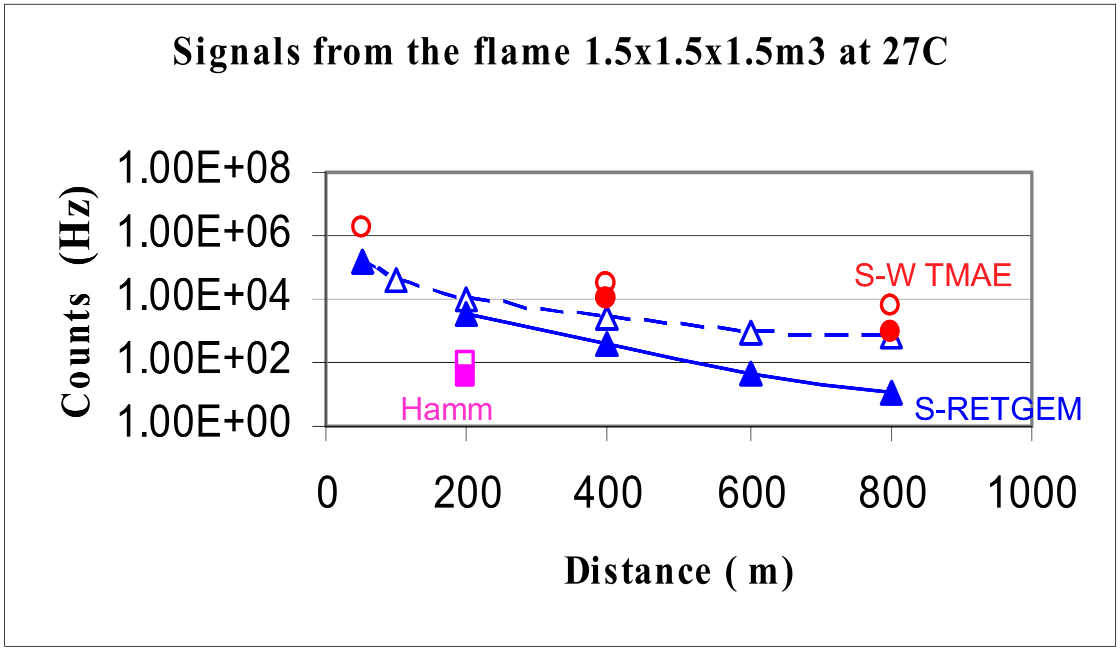
Operation in direct sunlight and imaging capability-are extremely important





This why S-RETGEMs are essential

The most important data-long distance tests:

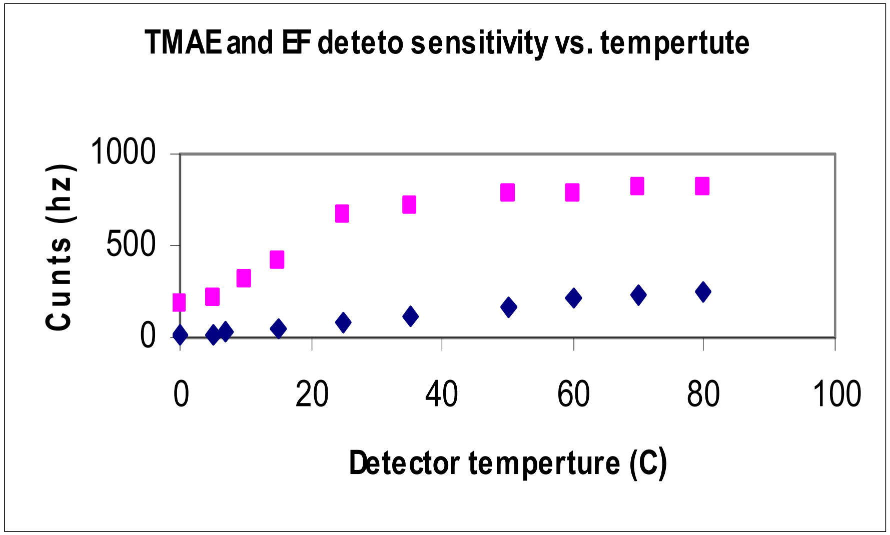


Open symbols-calculations
Filled symbols-measurements

Air absorption: mean free pass for active photons in the case of EF~250m
In the case of TMAE ~400m
Estimations based on these data show that with EF 5x5x5m^3 fire will give 20Hz at 1,5km.With increasing the recording time to 100 sec even higher sensitivity can be reached

The main conclusion: our detectors can detect flames at large distance

Vapors filling optimization:



Liquid drop was introduced

So, if detectors are heated (by the sun radiation, for example), their sensitivity
and gain increases, but the operational conditions (in digital mode) practically do not change

Tests by companies requests: air-filled gaseous detectors

The idea:

to study reaction on gas leak

To make them even more simple and cheaper

(G. Charpak loves this idea !)

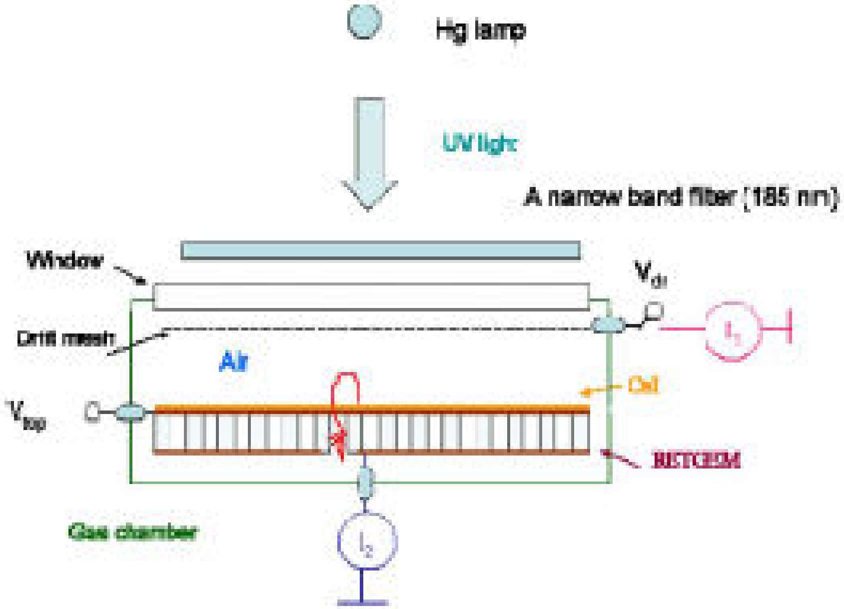


Fig. 10. Schematic drawing of the experimental setup for study o RETGEMs combined with CsI photocathodes in air.

Gas gain: $A=I_2/I_{1\ sat}$

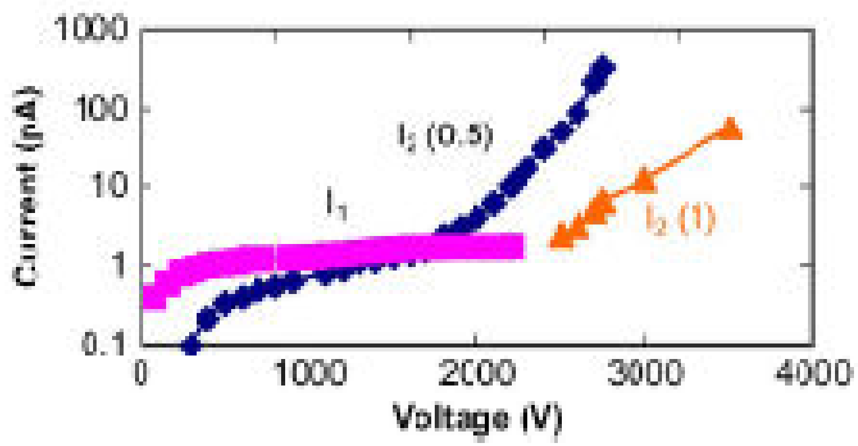


Fig. 11. Photocurrent produced by an Hg lamp versus applied voltage measured from the drift mesh I_1 (the mesh was grounded via the picoammeter and the negative voltage was applied to the RETGEM top electrode) and from the bottom electrode of the RETGEM I_2 (as function of the negative voltage applied to the top RETGEM electrode; in this measurement, the voltage on the drift electrode was kept constant and equal to – 1 kV). The values in brackets indicate the RETGEM thickness.

G. Charpak et al, IEEE Nucl. Sci., 55, (2008) 1657

Physics of operation in air

$n = n_o \exp(-\int \eta dx)$

↓

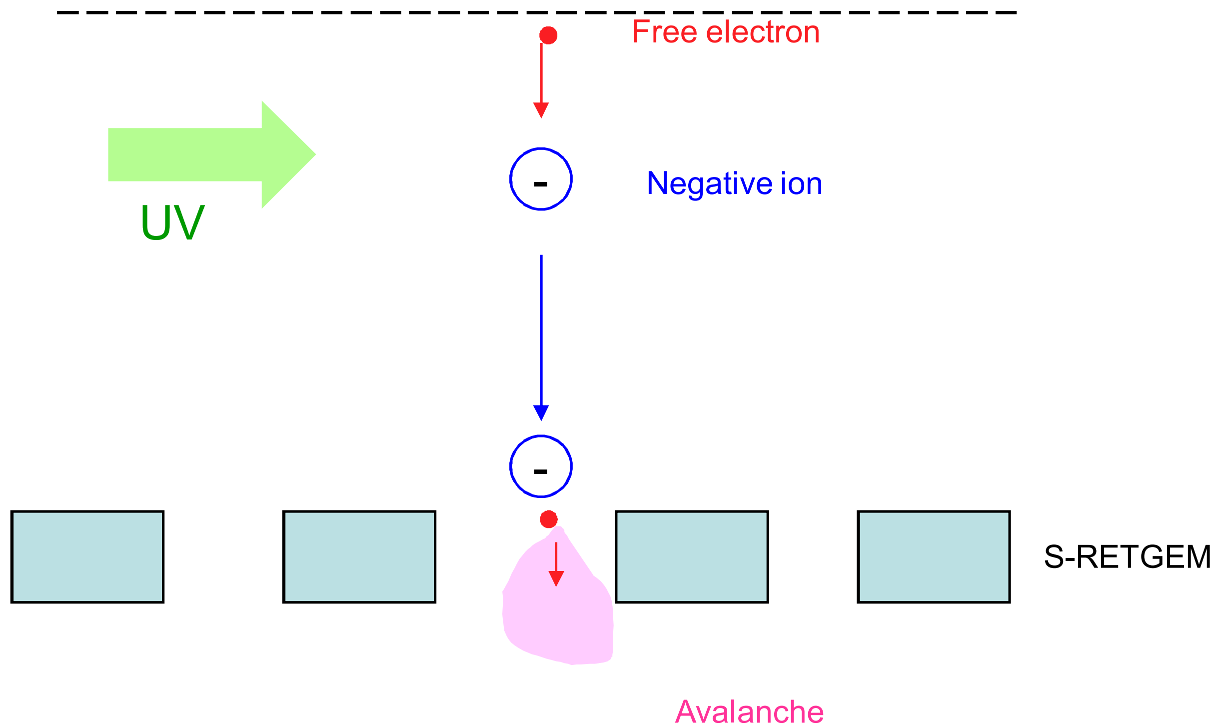
$(A_s = \mathrm{Exp}[\int(\alpha - \eta)dx)$

↓

Detachment due to the multiplication

↓

$A_L = \mathrm{Exp}[\int(\alpha + \alpha^*)dx$



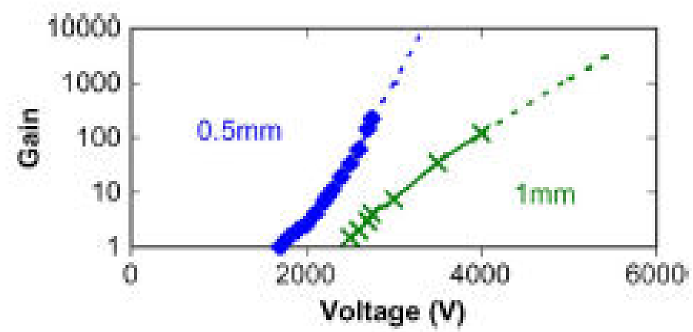


Fig. 12. Gain versus voltage across RETGEM calculated from the data presented in Fig. 11.

All looks very exotic, but there are TPCs prototypes operating in electronegative gases

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Negative ion drift and diffusion in a TPC near 1 bar

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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GEM operation in negative ion drift gas mixtures

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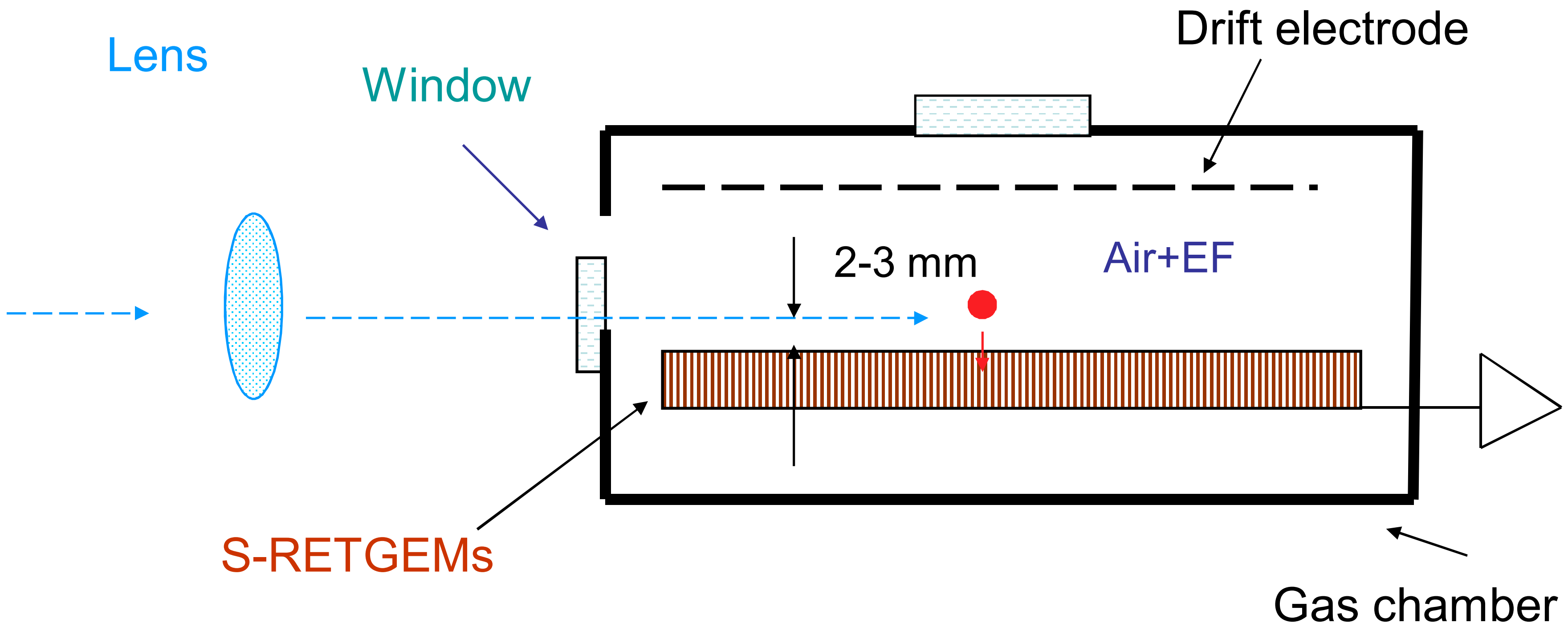


The main advantages of the new detector:

- Line beam close to S-RETGEM- high survival probability
- one step-simplification - no losses of avalanche electrons due to attachment in the transfer region
- no extraction- no losses of avalanche electrons in the collection region- **this is why S-RETGEMs are essential!**

Due to these features our presents detector is much better than the earlier version described in *J-M. Bidault et al, NIM A580, 2007, 1036*

Calculation of the electron survival probability: $n=n0\exp(-\int \eta dx)$ for a single-wire counter

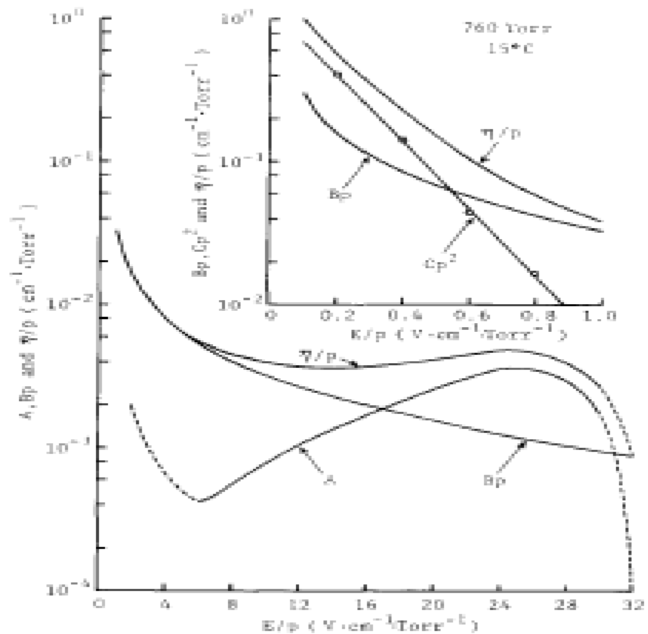


Fig. 1. Attachment coefficients as a function of E/p in air at atmospheric pressure. A, Bp, Cp^2 and η/p represent, respectively, the dissociative, three-body four-body and total attachment coefficients per unit pressure.

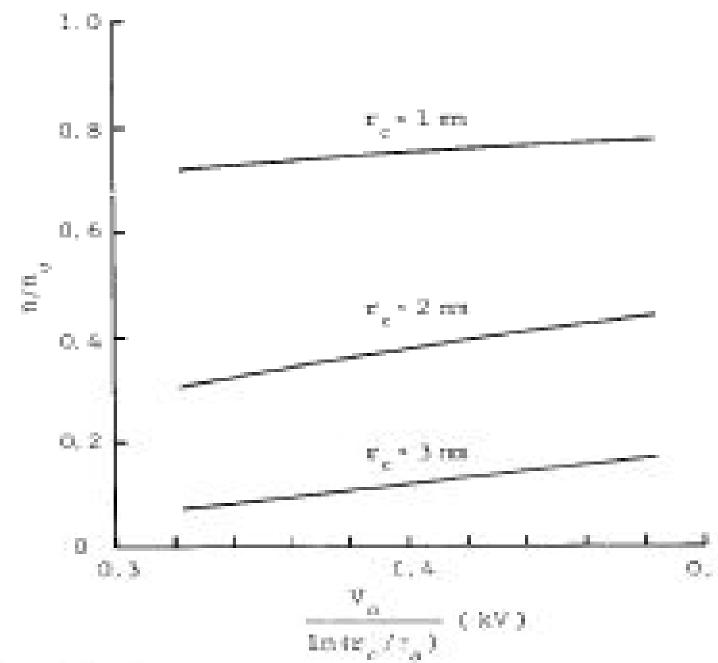
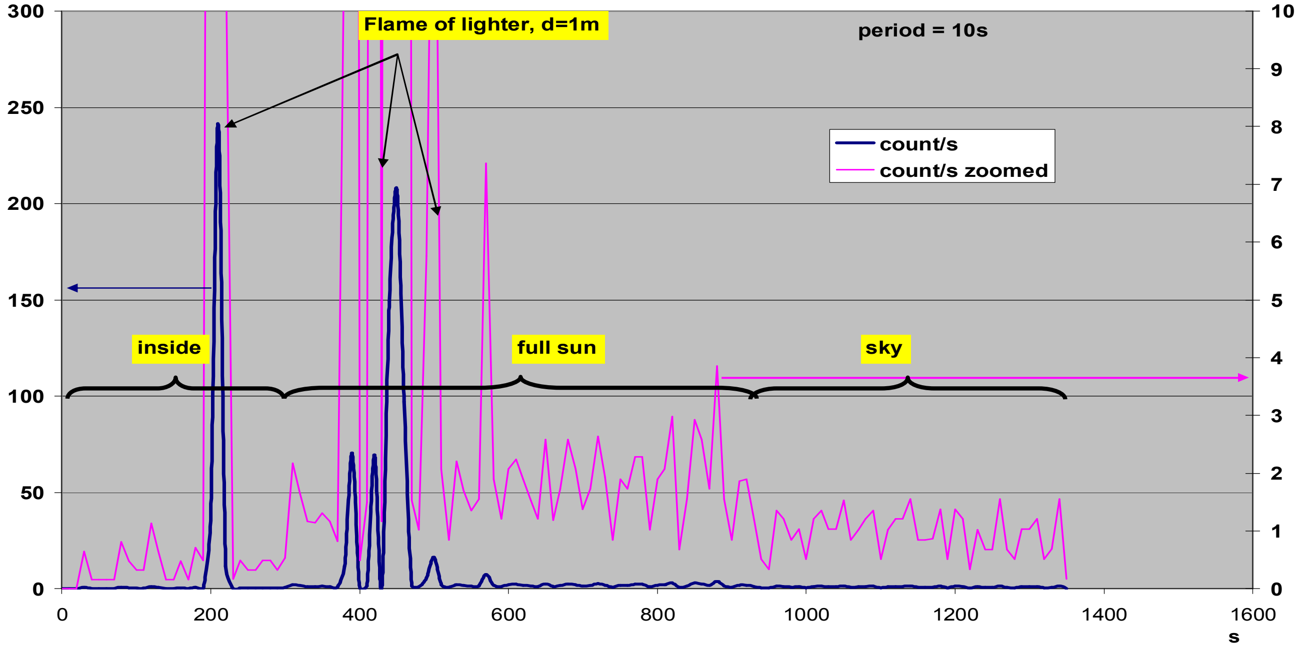


Fig. 2. Electron surviving probability n/n_0 as a function of $V_0/\ln(r_c/r_a)$. $r_a = 25$ μm, $p = 760$ Torr.

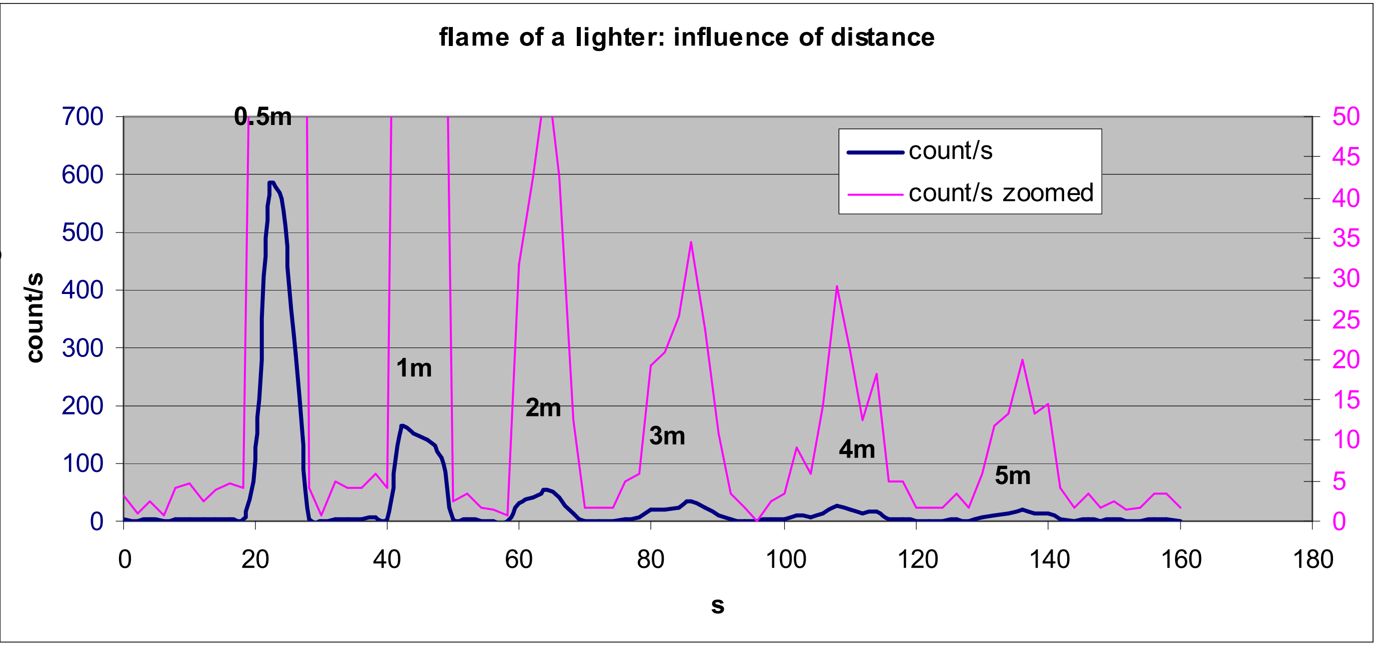
P.A. Chaterlon et al., Proc.Phys. Soc 85 (1965) 355,
J. Dutton et al., Proc. Phy.Soc, 82 (1963) 581
G.C. Hurst et al.,Phy. Rev 114(1959) 116

Test of RETGEM detectors with EF vapours



18C,

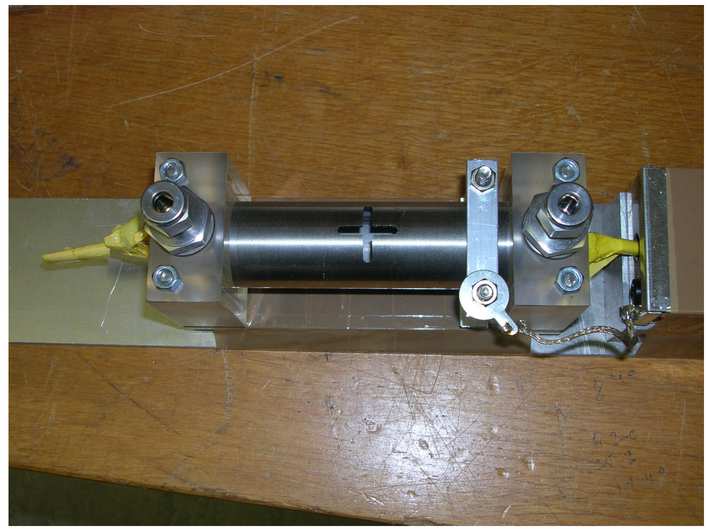
No lens, no beam collimation

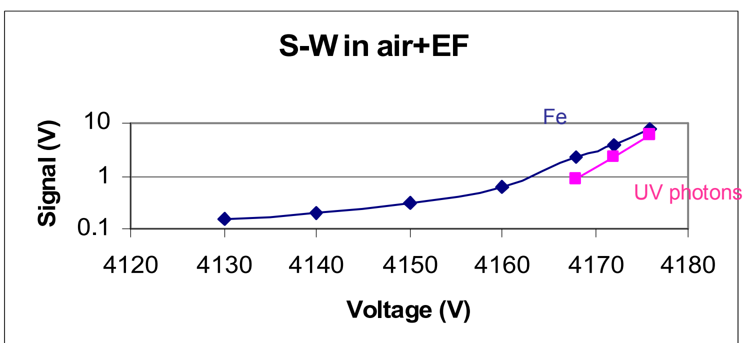


20 times more sensitive Than Hamamatsu (calibration with candle), so can catch 1,5x1.5x1,5 m5 fire on a distance of ~500m

After a great success with air filled S-RETGEM we made tests for a “fun” with single wire detector operating in air single wire in air

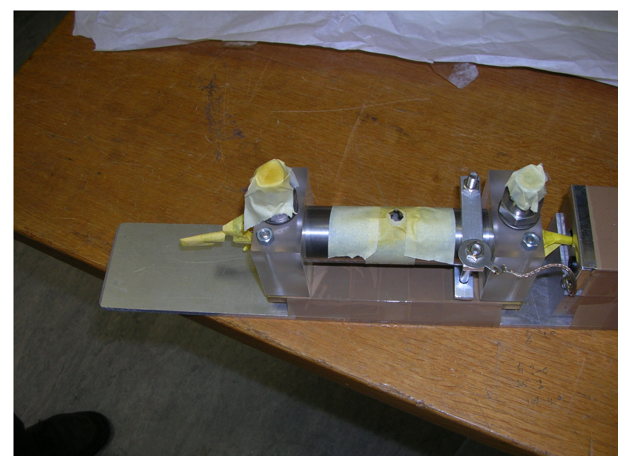
It is not tight, filled with EF (a drop inside).
However, several months of operation in air,
10 times less compared to EF +Ar,
but still 10 time higher than Hamamatsu





We see <u>single</u> photoelectrons!

We never heard about something similar!



Mastering S-W counters (after success with air+EF):

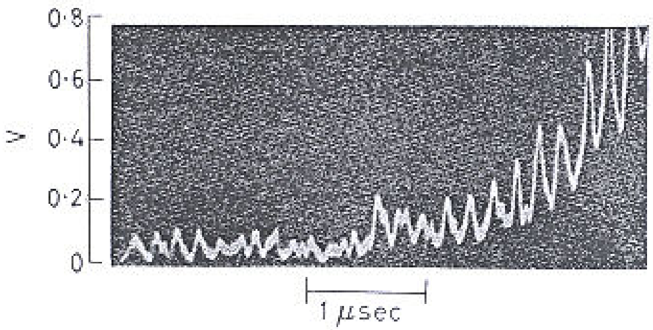
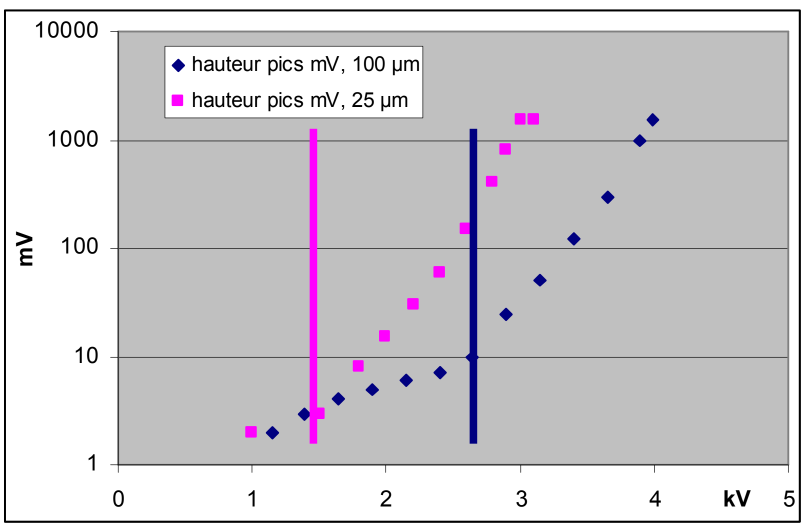
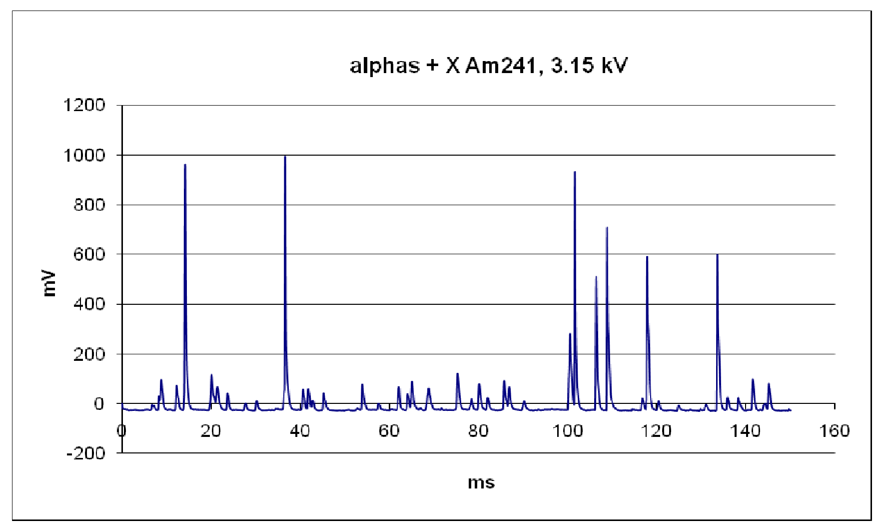


Figure 5.22. Series of avalanches in room air at U_{stat}, which lead to breakdown; $E/p = 37{\cdot}7$, $p_{20} = 760$ Torr, $d = 2{\cdot}5$ cm. The growth of the current in generations can be observed up to current amplitudes ten times higher than the mean amplitude reproduced here[43]

It is generally accepted that S-W counters do not work stably in air die to feedabcks

After our studied of their operation
and feedback suppression
we were able to run the S-W counters at high gains even without EF





G. Charpak et al., paper in preparation

Prototypes vs. “price – sensitivity” considerations:

Detector	Price (Euro)	Sensitivity (Ham. units)
Hamamatsu	**80**	**1**
Sealed single wire	120-150	1000
Seaed S-RETGEM (Ne+EF)	100	100
Sealed S-RETGEM, ps-sens	150	100
S- RETGEM in air	80	25
S-W filled with air	40-70	10

Current relations with companies:

Oxford Instr
Fine secure (France)
DIEHL (Germany)
Tensor (Russia)
DT sensors, Switzerland

DIEHL…


Our product range

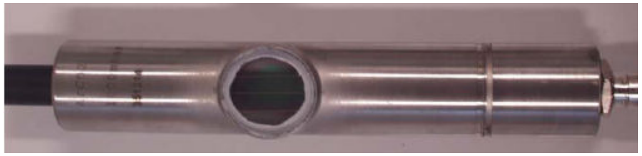
Our products comprise high quality semi-finished products for the worldwide automotive, electronic and sanitation industries as well as electronic controls for the large European home appliance and heater manufacturers. In the field of defense systems, including guided missiles, intelligent ammunition, tank tracks and vehicle maintenance, Diehl is one of the most important suppliers of the German Army and NATO forces. As for avionics, the company develops and produces systems and sub-systems for the leading aircraft manufacturers of the world. In the field of Metering we develop and manufacture flow meters and offer solutions for the transfer and the analyses of all energy consumption data.

DTSensors – Sensors

UV Flame Detectors (Class 1)

- ✓ Best Wildfire Detectors
- ✓ Detects cigarette lighter from 30m

CERN Supersensitive Flame Detectors



- ✓ Unique in the world.
- ✓ Invented in CERN for internal use
- ✓ 1000 times the sensitivity of Class 1
- ✓ Milliseconds reaction time

A slight from: *Proposal to Greece government, 2009*

DTSensors – Sensors

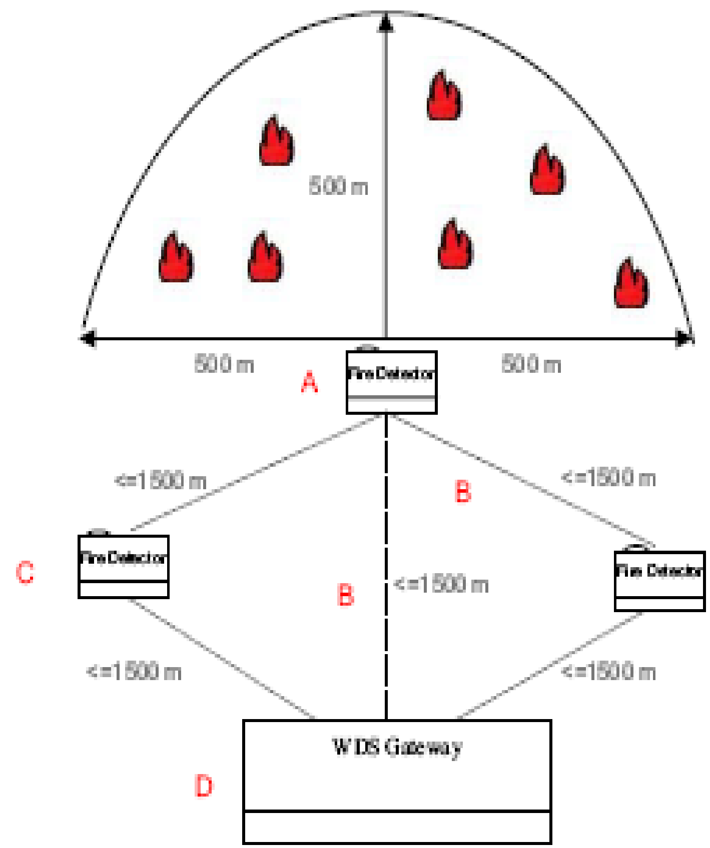
At present can detect a flame 2x2x2 m^2 on a distance of 200m

From: *Proposal to Greece government, 2009*

Proposal to the Greece government:

to install such system
in open/sensitive areas

WDS - Fire Detection Architecture



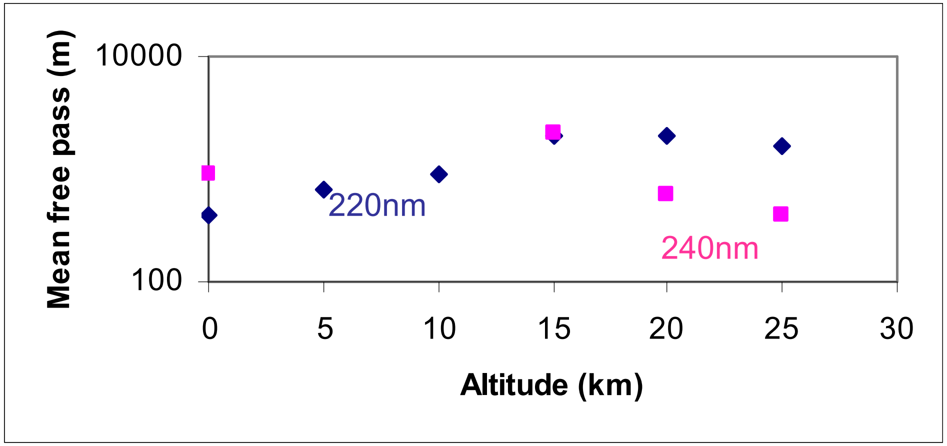
A. Every fire detector has been tested to detect 20cm flame in 500m within 180° (Line Of Sight)
B. A node (fire detector of meteo box) should communicate with either another node or directly with the gateway. The distance should not exceed 1500m.
C. A node may use another node (hops) to connect to the gateway. The maximum number of hops till a node reaches the gateway should not exceed the 10 nodes (gateway and initial node included).
D. The segment of nodes controlled by a gateway should not exceed the 50 devices.

Conclusions

- For the early forest fire detection we suggest using a new GEM-based position-sensitive UV detector of flames and sparks.
- Preliminary investigation showed that sensitivity of this detector is 100-1000 higher than that of any commercially available UV flame detector.
- Due to the high sensitivity, good timing characteristics and the position resolution the new detector can be used to survey large areas and thus can replace in a cost efficient way several conventional detectors performing the same task.
- For the forest fire detection they should be installed on towers in troubleshooting area (bushes and open areas)
- Also can be used on planes

● ● ● Probably the best will be to use a smart combination of all methods: air plane, stationary CCD, UV…

Air transmission at high altitudes:

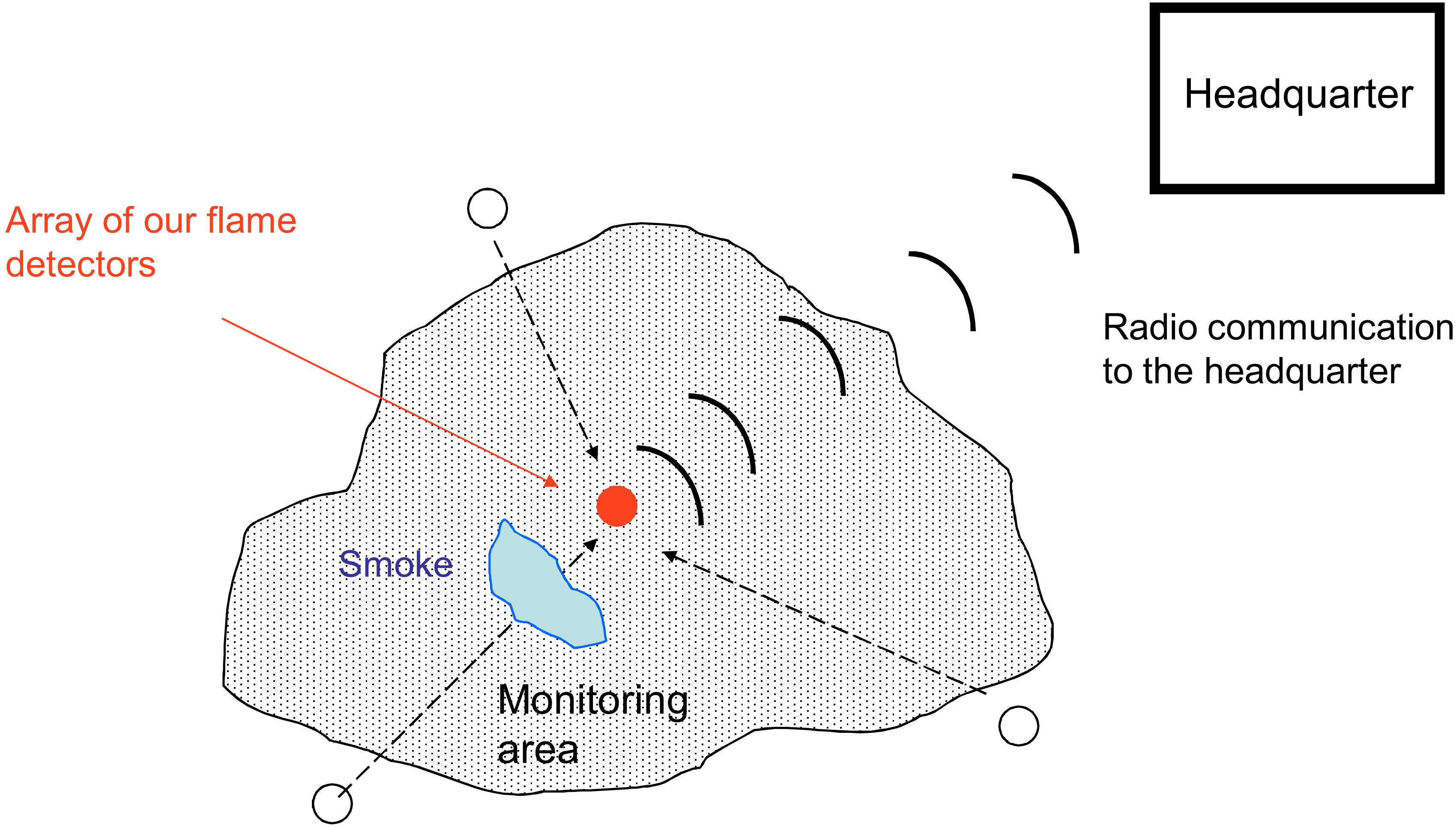


At 10-15km the UV photons mean free pass increases to km

TMAE -filled gaseous detectors were already successfully used for UV imaging air Cherenkov telescopes

(see pioneering works of A. Menzione et al)

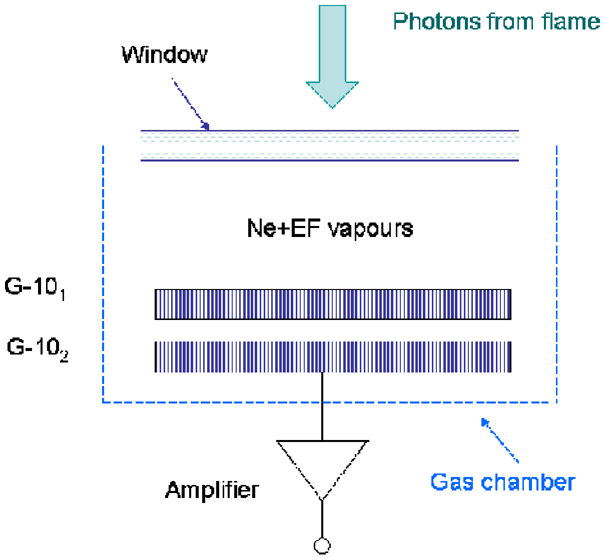
A project in progress: in combination with compact pulsed UV sources the detector will also be able to detect smoke and dangerous gases.

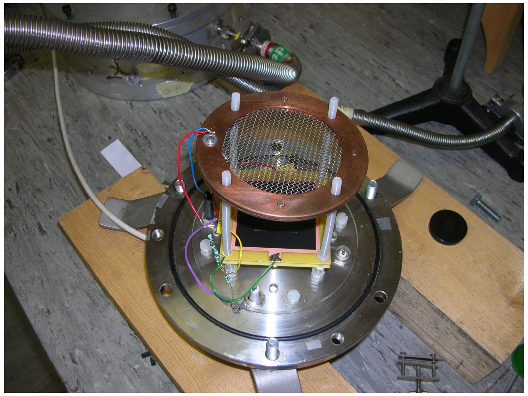


Network of pulsed UV sources

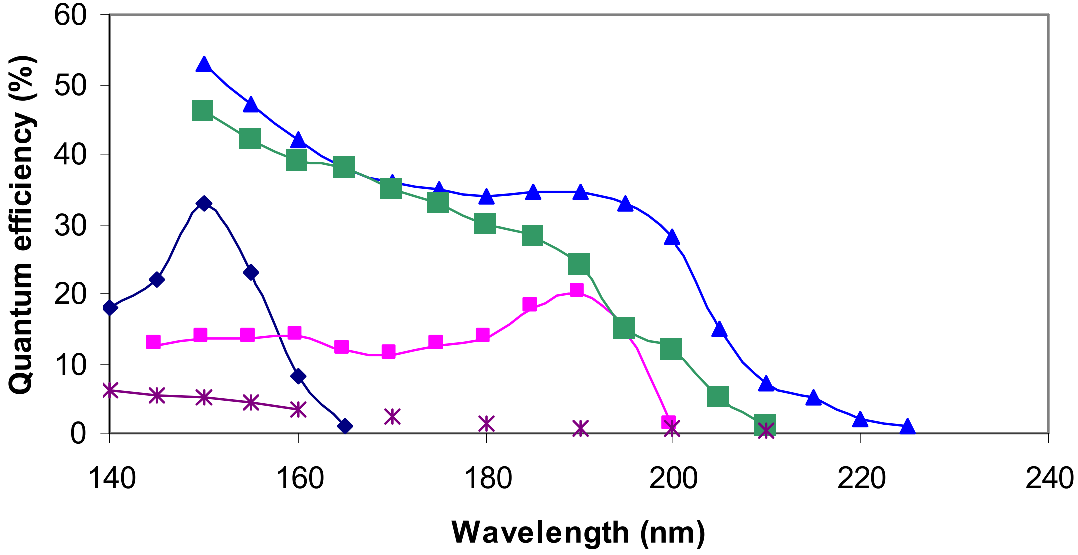
Backups

RETGEM-based detectors





Comparison of quantum efficiencies of the most commonly used solid photocathodes and photosensitive gases



- CuI (A ~10^6)
- CsI (A~10^4)
- TMAE (A~10^5)
- EF (A~10^6)
- TMA/TEA (A~10^6)

C

C

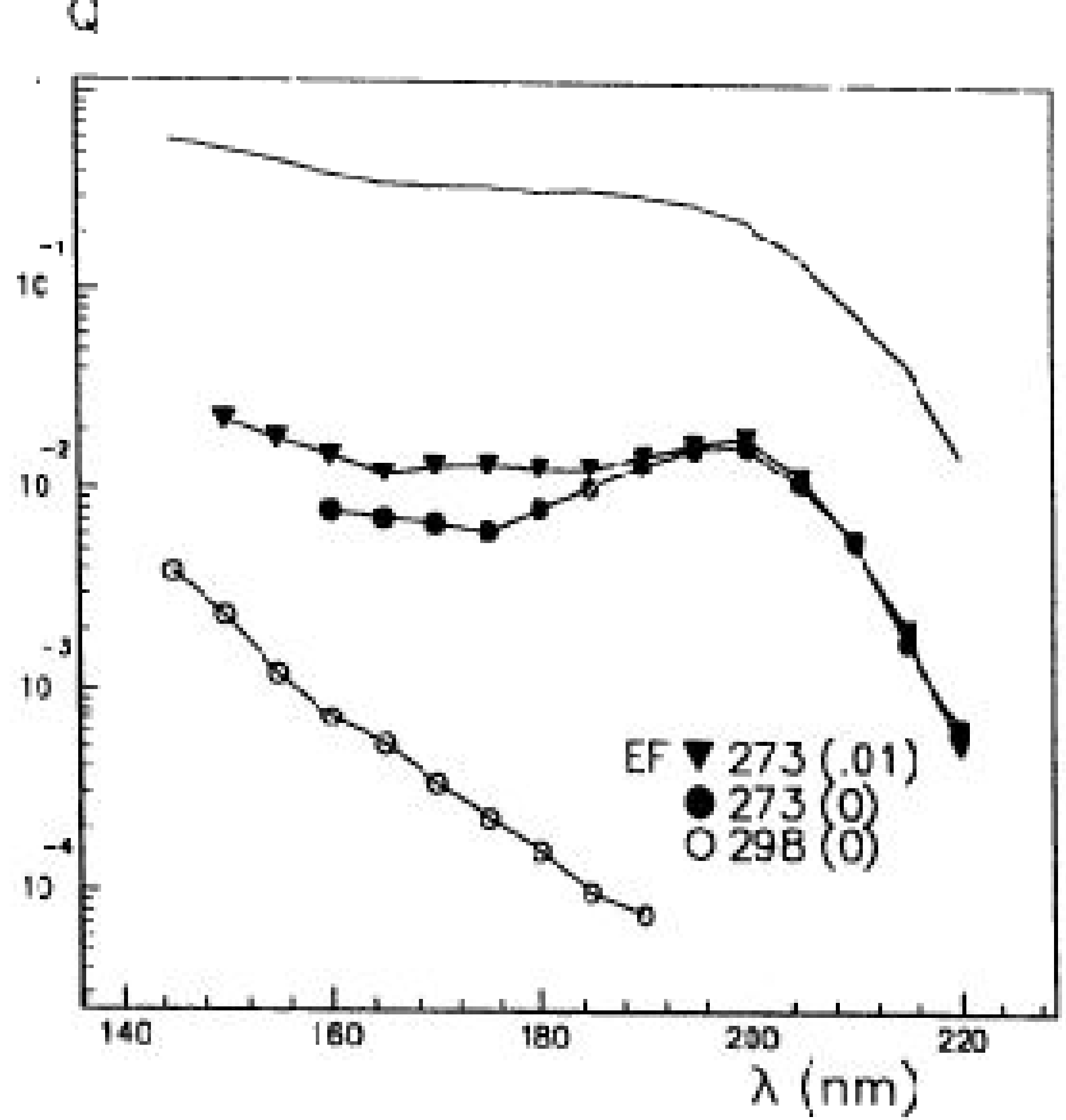


Fig. 13. The measured quantum yields Q versus the photon wavelength λ of the stainless-steel cathode with an adsorbed ethyl ferrocene (EF) film. The labelling gives the photocathode temperature (K), followed by the TMAE partial pressure (Torr) in brackets. The solid line without data points is the TMAE gas-phase quantum efficiency.