INITIAL DESIGN OF A FAST HYBRID PHOTODETECTOR BASED ON THE RPC STRUCTURE

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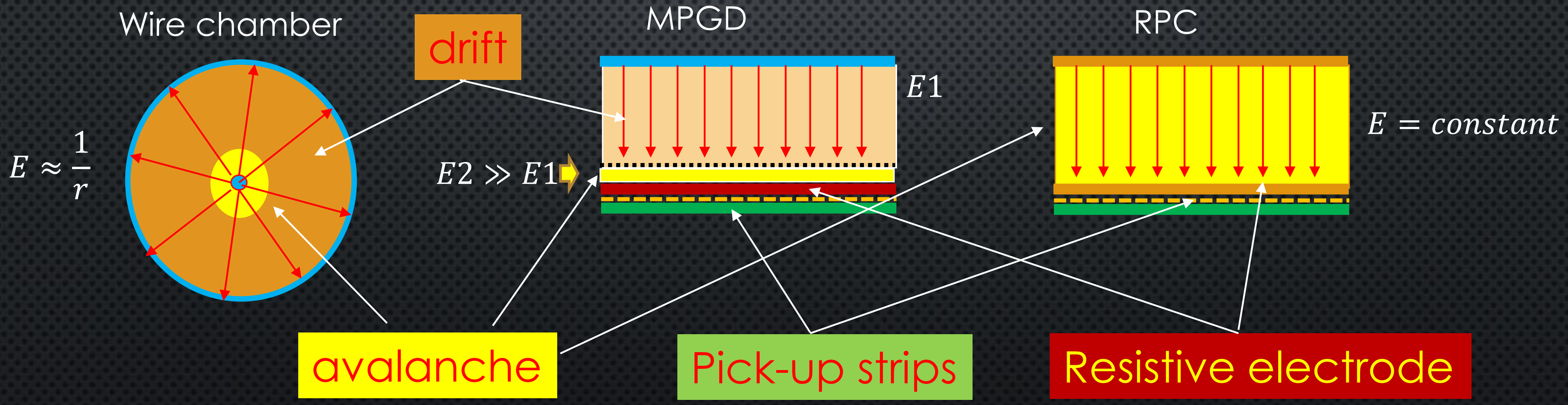
BASIC PRINCIPLES OF GASEOUS DETECTORS

- ALL GASEOUS DETECTORS DESIGNED FOR MUONS SHARE THE SAME BASE PRINCIPLE:
  - A GASEOUS TARGET THICK ENOUGH FOR A MIP TO RELEASE A SUFFICIENT PRIMARY IONIZATION
  - AN ELECTRIC FIELD SUFFICIENTLY STRONG TO START AN AVALANCHE MULTIPLICATION
  - A SEGMENTED PICK-UP ELECTRODE TO READOUT THE SIGNAL AND EXTRACT A SPACE-TIME INFORMATION



RPC STRENGTH VS. WEAKNESS DIAGRAM

Continuous resistive electrode structure

Simple and robust construction

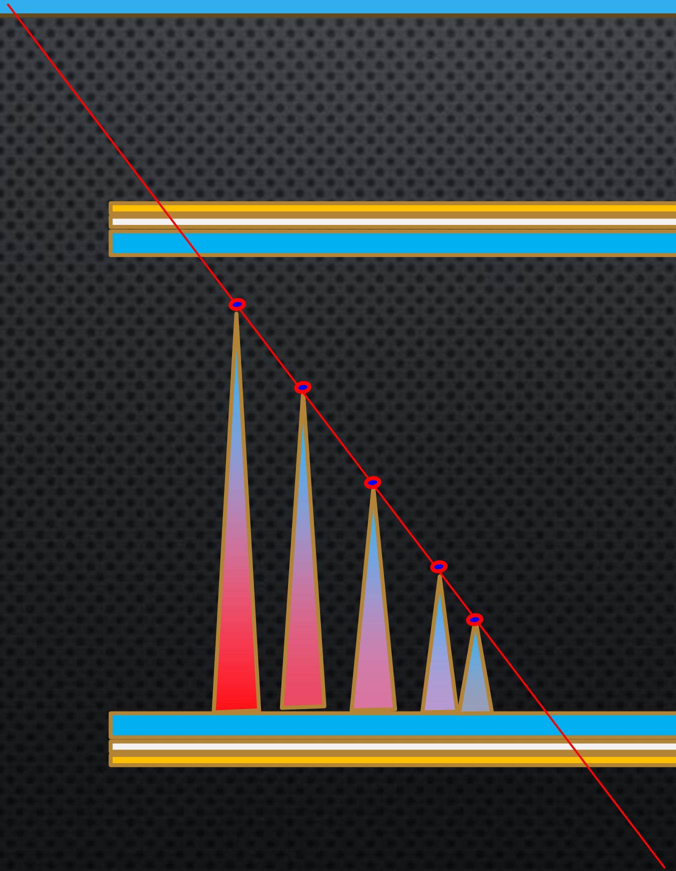
Spark free

Low cost

Easy to scale single module dimension to a few m^2 at constant unit cost and complexity

Gaseous target and multiplication coincide

prompt avalanche → high time resolution and efficiency



- Cluster number and depth
- Cluster size fluctuations
- Multiplication fluctuations

Very wide avalanche charge range and high <Q>

- High operating current
- transition to streamer
- limitation to rate capability

Implications:

- challenging electronics
- “low” resistivity electrodes
- electronegative gases

MPGD STRENGTH VS. WEAKNESS

Micro-pattern electrode

Industrially printable

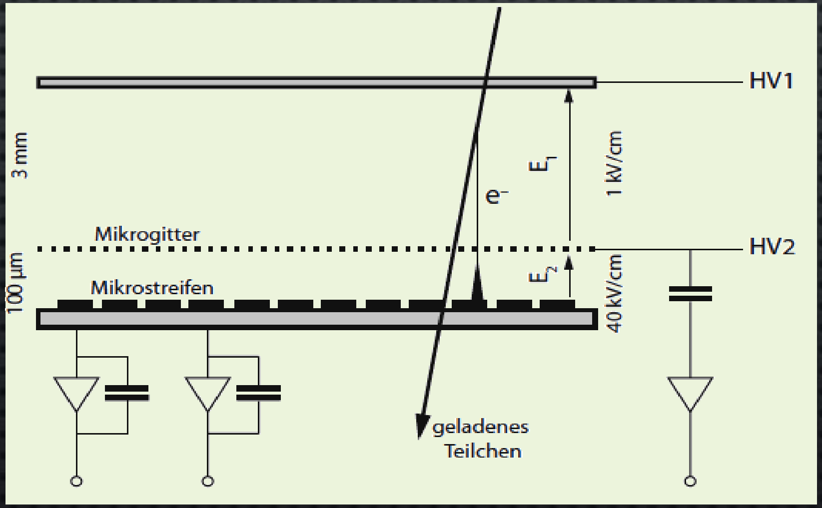
Expensive and difficult to build

Module dimension scale-up to a few m^2 is challenging

Spark safe just with resistive layers on the anodic readout strips

Gaseous target and multiplication separated

delayed avalanche → modest time resolution



Multiplication space is the same for all the avalanches

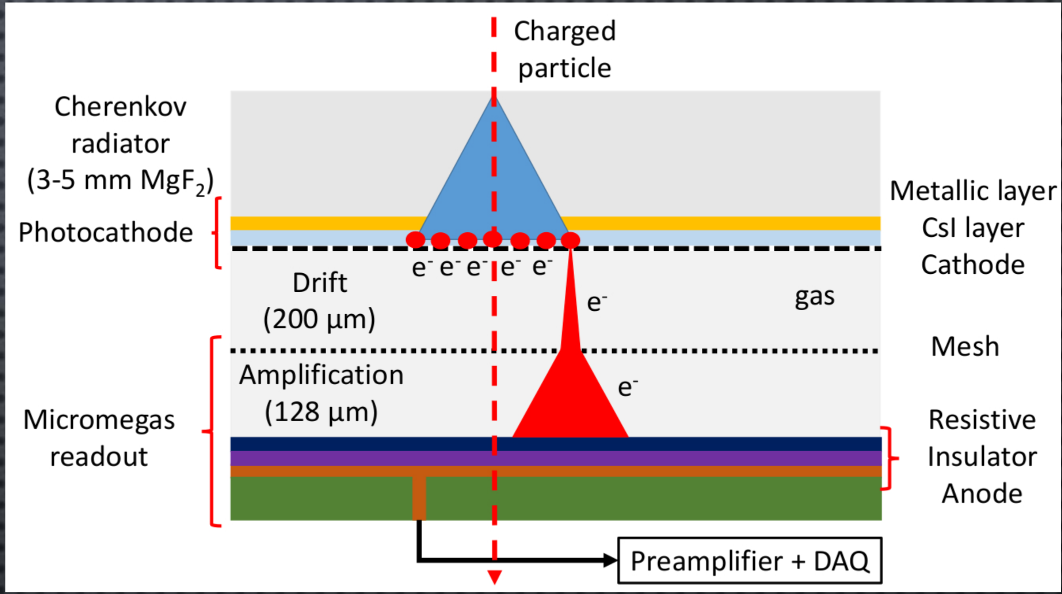
Reduced spread avalanche charge distribution

Low gain per cluster and average <Q>

- rate capability > 100 kHz/cm^2
- No need of electronegative gases

MICROMEGAS HYBRID GASEOUS PHOTO DETECTOR

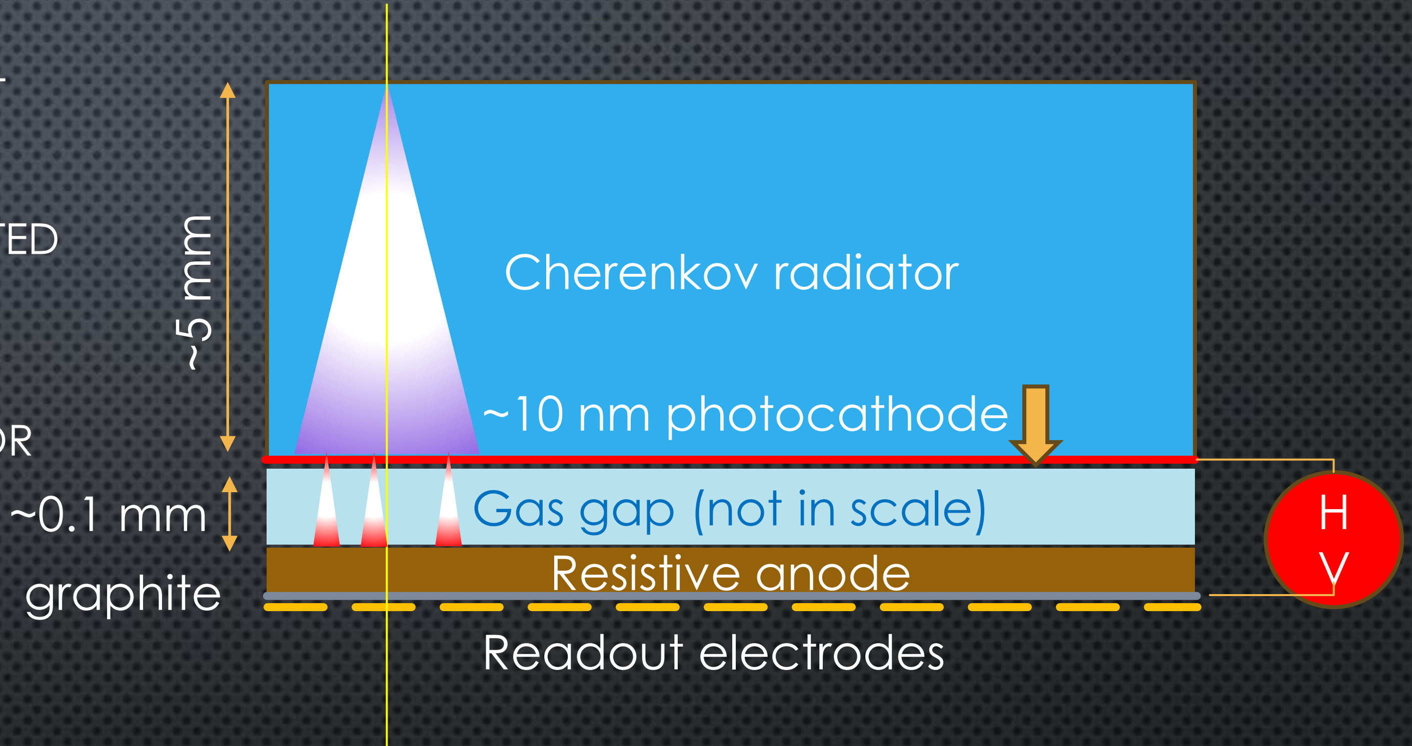
- CREATING A HYBRID STRUCTURE BETWEEN A GASEOUS DETECTOR AND A PHOTO-DETECTOR HAS BEEN RECENTLY PROPOSED TO OVERCOME SOME OF THE PROBLEMS HIGHLIGHTED FOR THE MICROMEGAS
- PICOSEC DETECTOR
- THE CONCEPT IS BASED SEPARATING THE FUNCTIONS:
  - A CHERENKOV RADIATOR COUPLED WITH A PHOTOCATHODE PROVIDES PRIMARY ELECTRONS IN THE GAS ALL AT THE SAME DISTANCE FROM THE ANODE
  - THE GASEOUS DETECTOR HAS THE FUNCTION TO AMPLIFY THE PRIMARY ELECTRON SIGNAL



- THE ADVANTAGE FOR MICROMEGAS IS JUST TO SUPPRESS THE DRIFT TIME FLUCTUATIONS OF THE ELECTRONS, IMPROVING THE TIME RESOLUTION, IN PRINCIPLE TO THE TENS OF PS
- THE DRIFT SPACE IS REDUCED (BUT NOT ELIMINATED) AND STILL USED AS A FIRST STAGE AMPLIFICATION GAP
- A LEGITIMATE QUESTION IS WHY NOT REMOVING THE MESH AND OBTAINING AN RPC LIKE STRUCTURE?

PROPOSAL OF A RESISTIVE PLATE PHOTO-DETECTOR

- ONE OF THE ADVANTAGES OF HAVING ALL THE PRIMARY ELECTRONS AT THE SAME DISTANCE FROM THE ANODE (LIMITING THE AVALANCHE FLUCTUATIONS) IS NOT EXPLOITED BY MMGAS SINCE THE MESH ALREADY PROVIDES IT REDUNDANTLY
- THE INTRODUCTION OF THE PHOTO-DETECTOR FUNCTION IN RPCS CONVERSELY WOULD HAVE A HUGE IMPACT:
  - REDUCES THE LARGE MULTIPLICATION FLUCTUATIONS ACHIEVING THE SAME ADVANTAGES OF MICRO-PATTERNS DETECTORS → HIGH RATE AND NO NEED OF F GASES…
  - A SINGLE MICRO GAP OF $\sim 100\ \mu m$ WOULD BE SUFFICIENT FOR ACHIEVING FULL EFFICIENCY AND TENS OF PS TIME RESOLUTION
  - THE MICRO-MESH IS NOT NECESSARY



Common challenges of this detectors

- Photocathodes known for having high yield (e.g. CsI), can be quicky oxidized if exposed, moreover are fragile to the ion bombing
- Robust photocathodes have lower yield so there is a problem of reaching a sufficient S/N

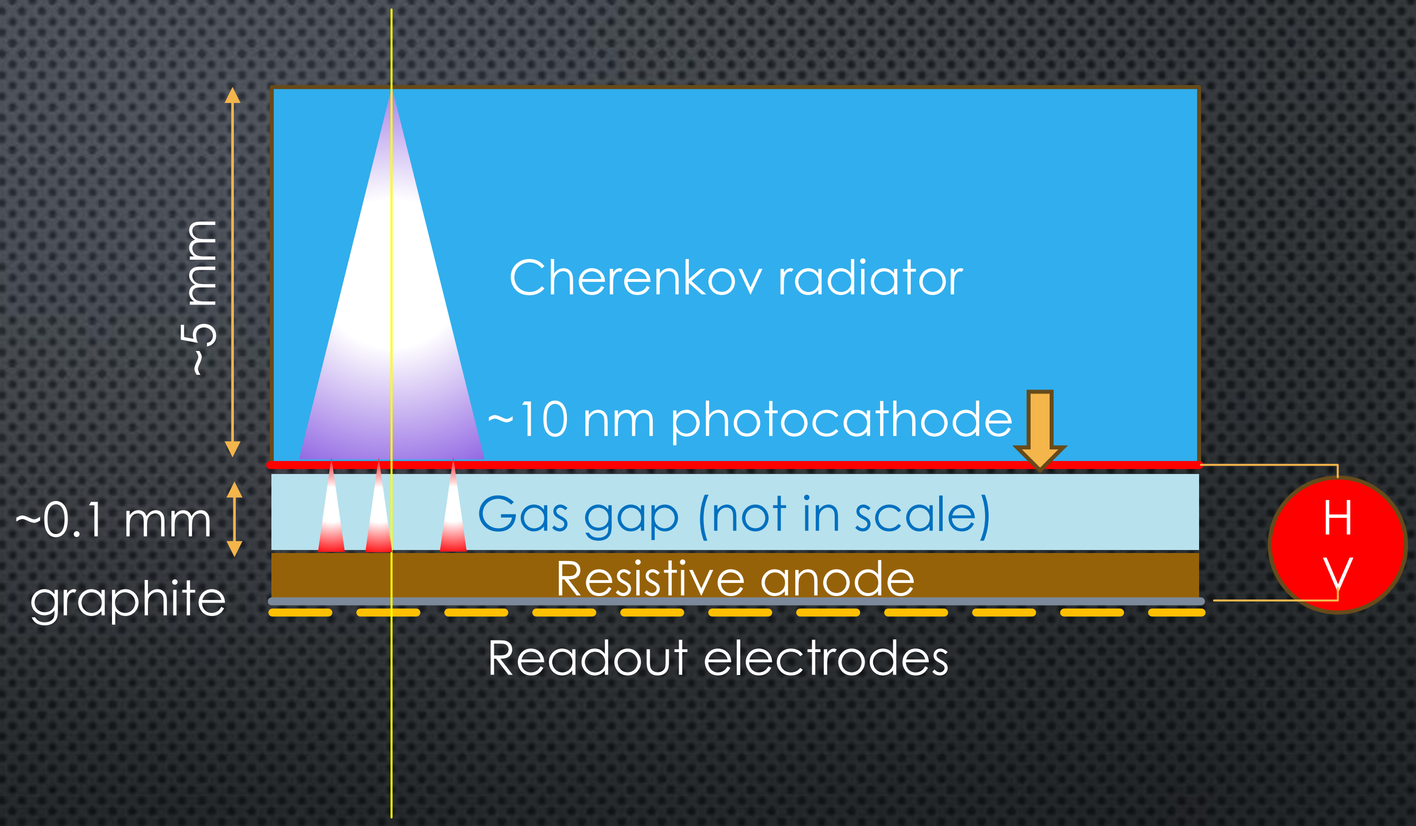
HYBRID RPC DETECTOR DESIGN CONCEPT

Radiator: UV effective but industrially available in large plates

Select a robust photocathode accepting its limited yield

3 average photo-electrons are the minimum for a good efficiency 1-P(0) ≈ 95%

The requisite is of course to be efficient with a single photo-electron



Use of chemically stable gases (Ar, CO_2…) avoiding all the known related RPC problems with F-gases and to preserve the photocathode

Limit the avalanche size to the strict minimum onsets by the FE electronics

The result to be checked with specific performance and longevity test

FE VS. GAS GAPS: ESTIMATION OF THE AVALANCHE

Expected state of the art FE → noise = 1000 e- RMS (working on halving it…)

Threshold on the injected signal → 5000 e- RMS

Assuming to lose a factor 40 on the induction → avalanche geometry x Ramo x readout strip

2*10^5 electrons for the minimum detectable signal

Rough assumptions on charge distribution for saturated avalanches

- mode ≈ average ≈ 3 x minimum
- The maximum ≈ 3 x average
- Close to gaussian + small tails

Gas gap optimization parameters:

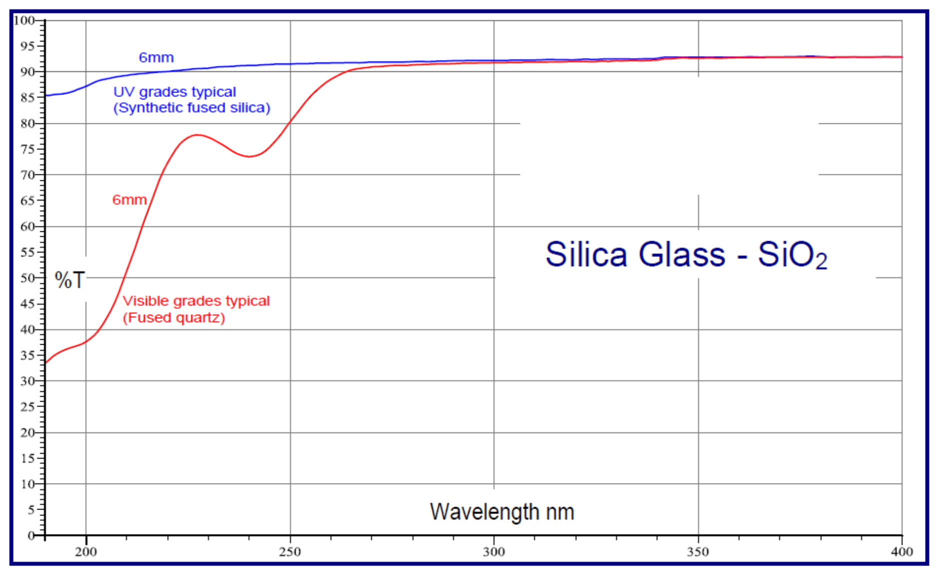
- As small as possible to achieve saturation with proportionally fewer electrons → 0.1 mm
- Deep saturation also increases the induction efficiency
- Pay attention to the Ramo related charge reduction → thin anode
- The saturation performance and the charge distribution is expected to be better since all electrons start at the same point and there are no Landau fluctuations

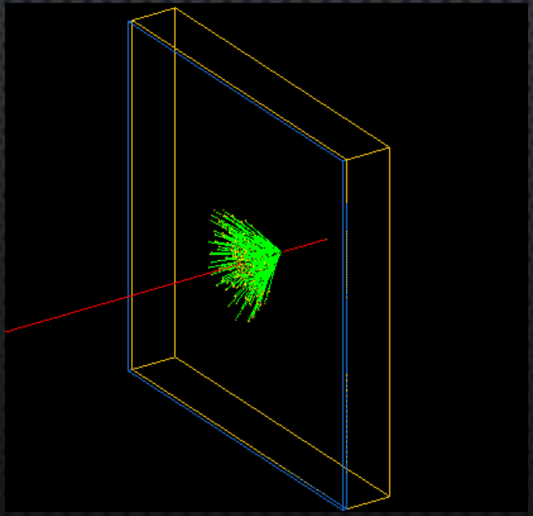
Expected average charge:~ 0.1 pC
30 times better of the single gap state of the art → 300 kHz/cm^2

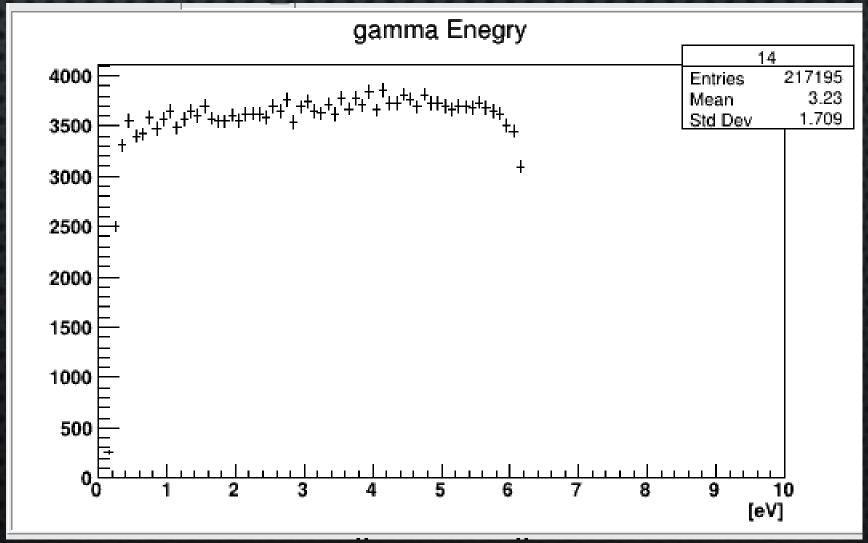
Worsening of FE performance proportionally reflects on <Q>
FE performance is key for success

Estimation of the radiator performance

- The radiator should have a stable refraction index and transparency to the UV in the highest possible wavelength range
- Compatibly with cost and upscaling of the dimensions…
- A good candidate is fused quartz instead of optical grade glass, but one should test all the cases…
- The thickness is of the order of few mm, and can be optimized
- A simulation performed in G4 has been setup to study and optimize the various steps







- Average 217 photons generated by one thousand 10 GeV muon impinging on 5 mm of silica glass
- Only the upper part of the spectrum is useful for the PE effect

CHOICE OF THE PHOTO-CATHODE MATERIAL

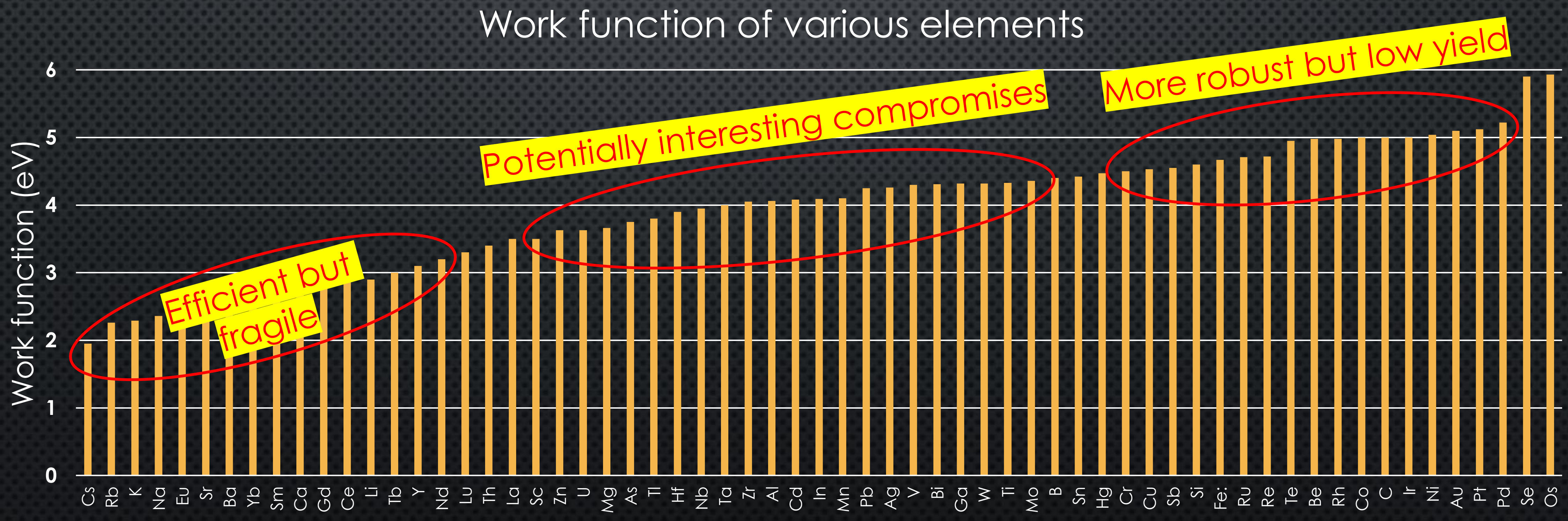
The choice of the photocathode is one of the most crucial points

- As robust as possible
- With the highest possible quantum yield

Two competing requirements

Useful photon energy available range is limited to about $7\ eV$

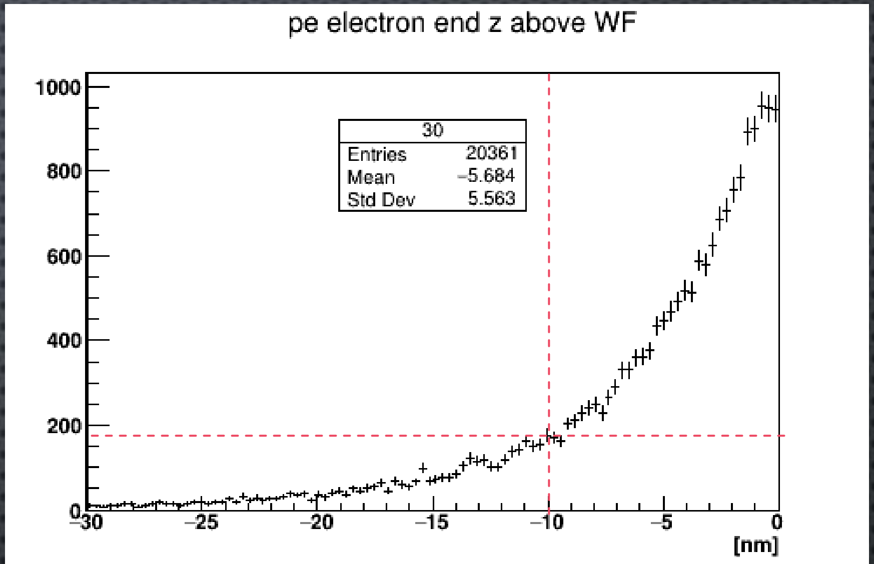
- An electron is emitted in the vacuum if after being kicked by the photon it arrives in proximity of the surface with a kE > of the work function
- W.F. is the work to extract an electron from the surface to vacuum and depends on the material type



SIMULATION OF THE PHOTO-CATHODE

VERY EARLY SIMULATION RESULTS SHOWING THAT THE WORK STARTED…

- FIRST TEST PERFORMED WITH ZR (W.F.=4 EV)
- SHOWING THE ELECTRONS WITH KE > W.F. VS. THE PHOTOCATHODE DEPTH, FOR 100 EVENTS
- IT SEEMS THAT THE OPTIMAL THICKNESS IS IN THE RANGE OF VERY FEW NM…
- VERY CLOSE TO THE EXPERIMENTAL VALUE REPORTED BY MMGAS FOR AL (HAVING A VERY CLOSE WF)



- MANY OPTIONS TO EXPLORE NOT ONLY INDIVIDUAL ELEMENTS BUT ALSO CRYSTALS AND NANOMATERIALS OR COMBINATIONS OF THEM
- PICOSEC ALREADY EXPLORED SEVERAL OPTIONS SHOWING THE OVERALL FEASIBILITY

No.	MgF_2 (mm)	Photocathode	$N_{p.e.}$
1	3	5.5 nm Cr + 18 nm CsI	10.4 ± 0.4
2			9.0 ± 0.1
3			9.9 ± 0.4
4	3	5.5 nm Cr + 36 nm CsI (*)	6.43 ± 0.11
5	3	3 nm Cr + 18 nm CsI (*)	8.41 ± 0.24
6	3	6.5 nm Al + 18 nm CsI (*)	8.40 ± 0.24
7	3	Cr + CsI + LiF	<1.0
8	3	Cr + CsI + MgF_2	3.55 ± 0.08
9	3	20 nm Cr (*)	0.66 ± 0.13
10	3	6 nm Al	1.69 ± 0.02
11	5	10 nm Cr (*)	2.15 ± 0.05
12	5	10 nm Al	2.20 ± 0.05

L Sohl et al 2019 J. Phys.: Conf. Ser. 1312 012012

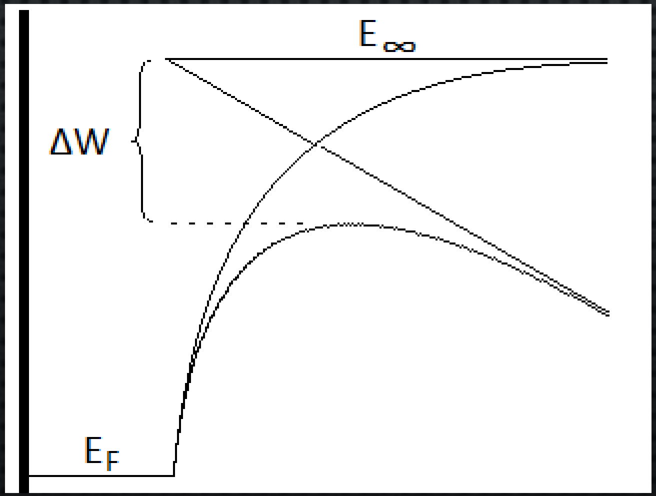
THE SCHOTTKY EFFECT – A STRATEGICAL ADVANTAGE

SCHOTTKY EFFECT DEFINITION: THE SCHOTTKY EFFECT IS A PHENOMENON THAT REDUCES THE ENERGY REQUIRED TO REMOVE ELECTRONS FROM A SOLID SURFACE IN A VACUUM WHEN AN ELECTRIC FIELD IS APPLIED.

ELECTRIC FIELD'S ROLE: AN ELECTRIC FIELD LOWERS THE BARRIER FOR ELECTRON ESCAPE, ENHANCING THE ELECTRON EMISSION BY REDUCING THE WORK FUNCTION.

$$J(F,T,W) = A_G T^2 e^{\frac{-(W-\Delta W)}{kT}}$$

$$\Delta W = \sqrt{\frac{{q_e}^3 F}{4\pi\epsilon_0}},$$



ADVANTAGE FOR RPCS: THE RPCS STRUCTURE WOULD HAVE NATURALLY AN INTERESTINGLY HIGH E APPLIED TO THE PHOTOCATHODE OF THE ORDER OF 10 MV/M

POTENTIALLY INTERESTING FOR RCC: THE FIELD AT THE INNER RADIUS IS HIGHER THAN THE ONE OF RPCS AND FURTHER ENHANCEMENT IS OFFERED BY THE PRESSURIZATION

A PRIORI ESTIMATION OF THE EFFECT IN EFFECTIVELY LOWERING THE W.F. IT IS VERY DIFFICULT, SINCE THE CLASSIC FORMULA DO NOT TAKE IN TO ACCOUNT THE SURFACE NANO-STRUCTURES WHICH CAN ENHANCE THE EFFECT ALSO BY 1 ORDER OF MAGNITUDE

A ROUGH ESTIMATION INDICATES AN EFFECT OF THE ORDER OF 0.2 - 0.4 EV

WRAP UP AND CONCLUSIONS

- THE PRESENT PROPOSAL ILLUSTRATES THE INITIAL DESIGN OF A NEW HYBRID DETECTOR
- THE PRIMARY TARGET FUNCTION IS ABSOLVED BY AN APPROPRIATE PHOTODETECTOR
- THE SIGNAL AMPLIFICATION IS PERFORMED BY AN RPC-LIKE STRUCTURE AS IN FASHION OF A LARGE AREA POSITION SENSITIVE PHOTOMULTIPLIER…
- THIS FUNCTION SPLITTING CAN REMOVE SEVERAL LIMITATION OF CLASSIC RPCS: F-GASES, AVALANCHE CHARGE SPREAD, NECESSITY OF MULTIGAPS FOR PS TIMING AND ACCESSING THE HIGH RATE RANGE OF GASEOUS DETECTORS
- RETAINING THE POWERFULLY SCALABLE ARCHITECTURE OF CLASSIC RPCS…
- THIS STRATEGY ALSO PROPOSED FOR MMGAS SHOWS ITS BEST WITH RPCS
- A SIMULATION HAS BEEN SETUP, SHOWING THAT THE QUANTUM YIELD IS CONSISTENT WITH THE EXPERIMENTAL RESULTS OBTAINED FOR MMGAS SIMILAR APPLICATION
- KEY FOR SUCCESS ARE MICRO GAP, STRONG FIELD AND VERY SENSITIVE FE…