Light Sensor selection for Cherenkov Telescope Array

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for the FPI WP of CTA

NDIP conference, July 4-8 2011, Lyon, France

Cherenkov Telescope Array

FPI WP

VHE Ground-Based γ-ray Astronomy

1. Galactic Gamma-Ray Sources:

- Supernova Remnants
- Pulsars, Pulsar Wind Nebulae
- X-Ray Binaries & Micro-quasars
- Star-Formation Regions
- The Galactic Centre

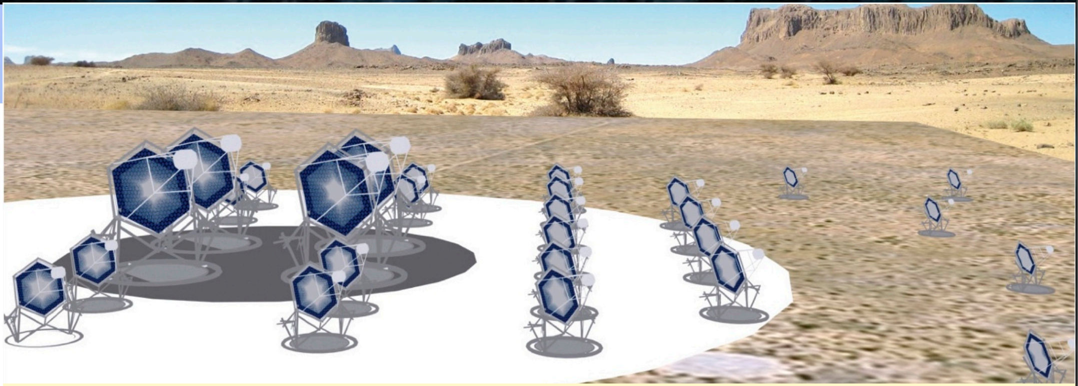
2. Extragalactic Gamma-Ray Sources:

- Active Galactic Nuclei
- Extragalactic Background Light
- Gamma-Ray Bursts
- Galaxy Clusters

3. Fundamental Physics:

- Dark Matter
- Quantum Gravity
- Charged Cosmic Rays

.... and more



CTA layout with different telescope sizes

Possible CTA sites

Cherenkov Telescope Array

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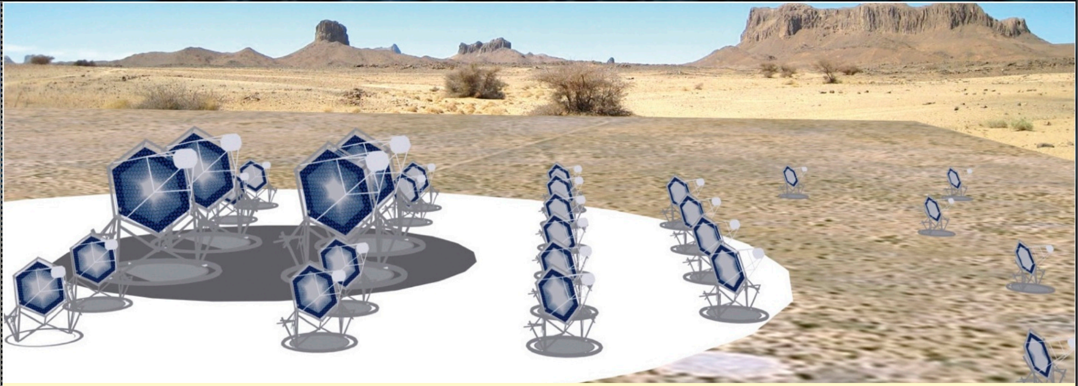
Low-Light-Level Field

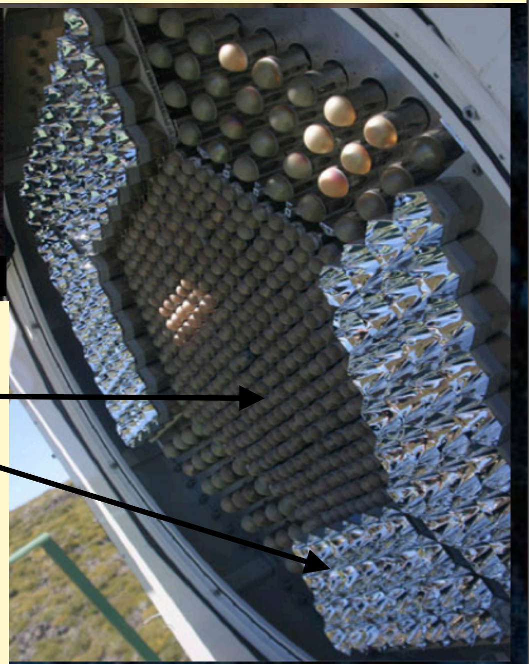
Photosensor requirements:

Total needs: >1.5 x 10^5 photosensors!

- Very high Quantum Efficiency
- Almost 100 % Collection Efficiency of photo electrons from photo cathode on the 1st dynode
- After-pulsing rate: < 0.02 % above 4 Phe (needed to lower the energy threshold)
- Pulse width: < 2 - 3 ns
- Transit Time Spread: ≤ 1.3 ns (single photo electron)
- Stabilize photo cathode to 1st dynode voltage to ~350V
- Linear Dynamic Range > 5000 photo electrons
- About 2 years ago MPI (Max Planck Instutute) started a PMT development program with Hamamatsu (Japan) and Electron Tubes Enterprises (England)



CTA layout with different telescope sizes



MAGIC I camera as example:
Photosensors
and Light Collectors
(Winstone cones)

FPI Main Parameter List
Summary by R. Mirzoyan
Original version: 16 April 2010;
Next modification: 27 May 2011
Latest modification:22 June 2011

FPI WP

Below is shown the wish list of the main parameters of the FPI work package:

PMT:

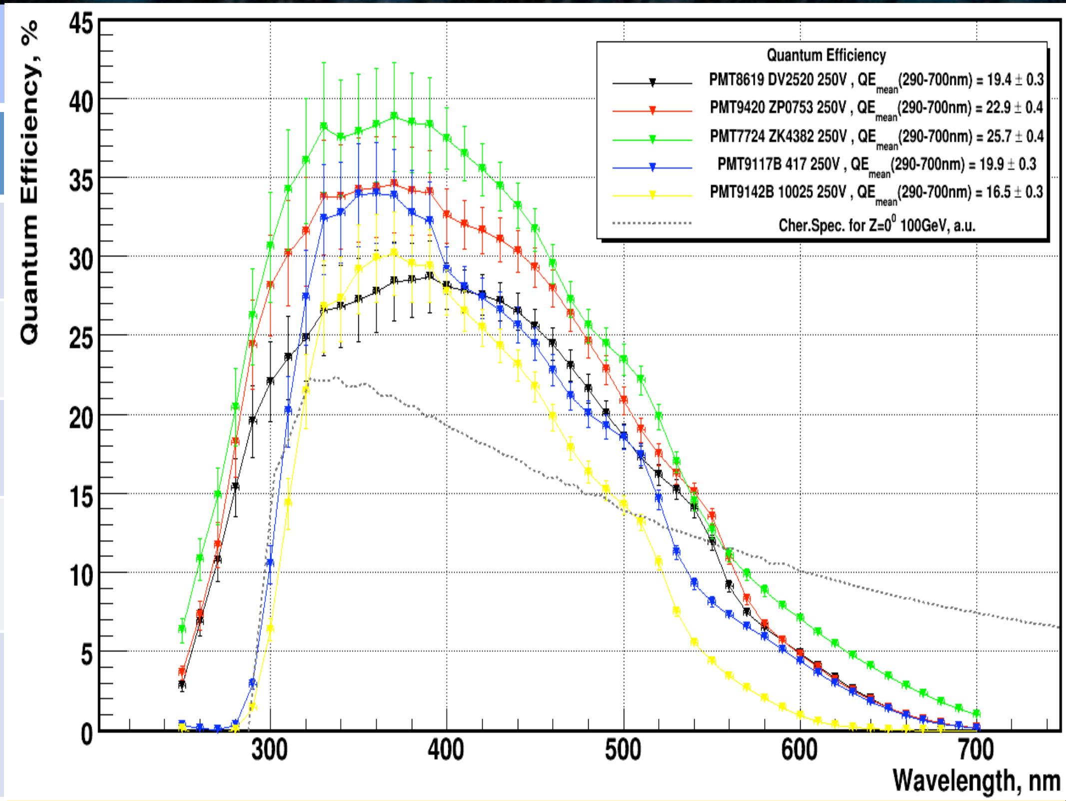
1. size:	1.5 inch
2. photo-cathode type:	super-bialkali
3. sensitivity range:	290 – 600 nm
4. peak QE on average:	35 %
5. average QE over Cherenkov spectrum	≥21 % (290-600) (without ph.e. CE)
6. variation of QE over entrance window	<10 %
7. 1st dynode ph.e. collection efficiency:	≥95 % (400 nm, 30 mm diameter)
8. photo cathode to 1st dynode HV:	≥300 V stabilized
9. 1st dynode gain:	≥ 6
10. number of dynodes:	8
11. operating gain:	$\geq 4 \times 10^4$
12. afterpulsing for threshold ≥ 4 ph.e.:	≤ 0.02 %
13. pulse width, FWHM (single ph.e.):	≤ 2.5 ns
14. transit time spread, single ph.e., rms:	1.0 – 1.3 ns acceptable (30 mm diameter)
15. single ph.e. peak/valley ratio:	≥ 1.8
16. protected from geomagnetic field:	μ-metal shield
17. dynamic range:	≥ 5000 ph.e.
18. linearity range:	≥ 5000 ph.e.
19. differential non-linearity	< 1 %

FPI WP

Evaluation of PMT

PMT candidates

Company	Type	$QE_{peak}(\lambda)$	$\langle QE \rangle_{Cher}$
Hamamatsu	8619 1“	28,7 ± 2,2 (390 nm)	19,4 ± 0,3
Hamamatsu	**9420 1,5“**	**34,6 ± 3,1 (370 nm)**	**22,9 ± 0,4**
Hamamatsu	7724 2“	38,9 ± 3,3 (370 nm)	25,7 ± 0,4
Electron Tubes	9117B 1,5“	34,0 ± 3,2 (360 nm)	19,9 ± 0,3
Electron Tubes	9142B 1,125“	30,2 ± 2,7 (370 nm)	16,5 ± 0,3



Quantum Efficiency curves.
Dashed curve: Cherenkov radiation spectrum from 50 GeV γ-shower.

Producers claim collection efficiency >90%
(direct PDE measurements still needed)

1.5 inch PMTs has been chosen as the target PMT for all 3 types of telescopes.

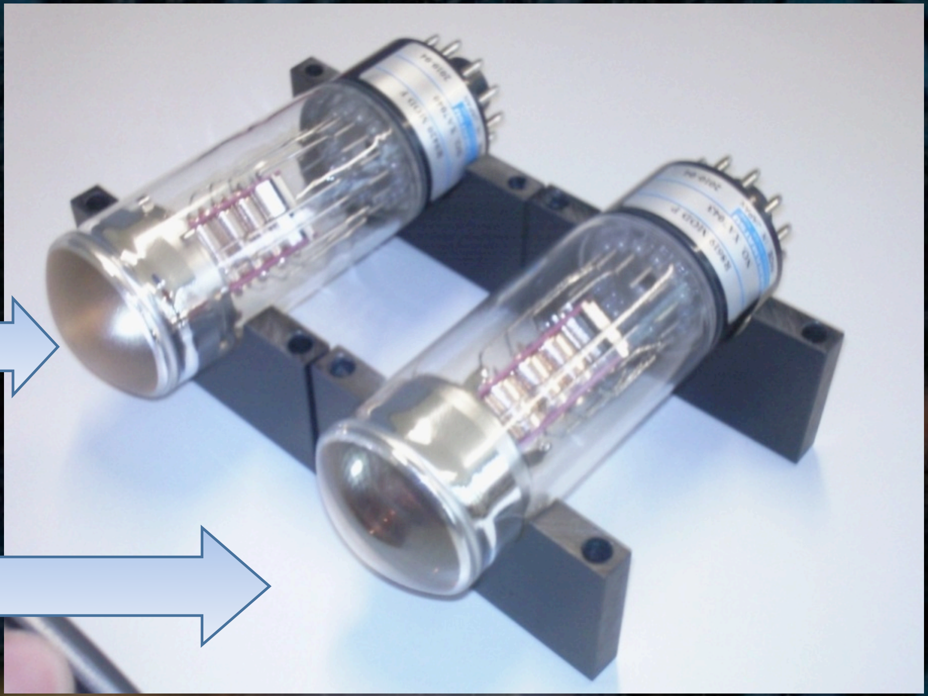
PMT candidates

Super-bialkali (SBA) 1.5' PMTs

PMT samples within MPI-Hamamatsu-ET development program :

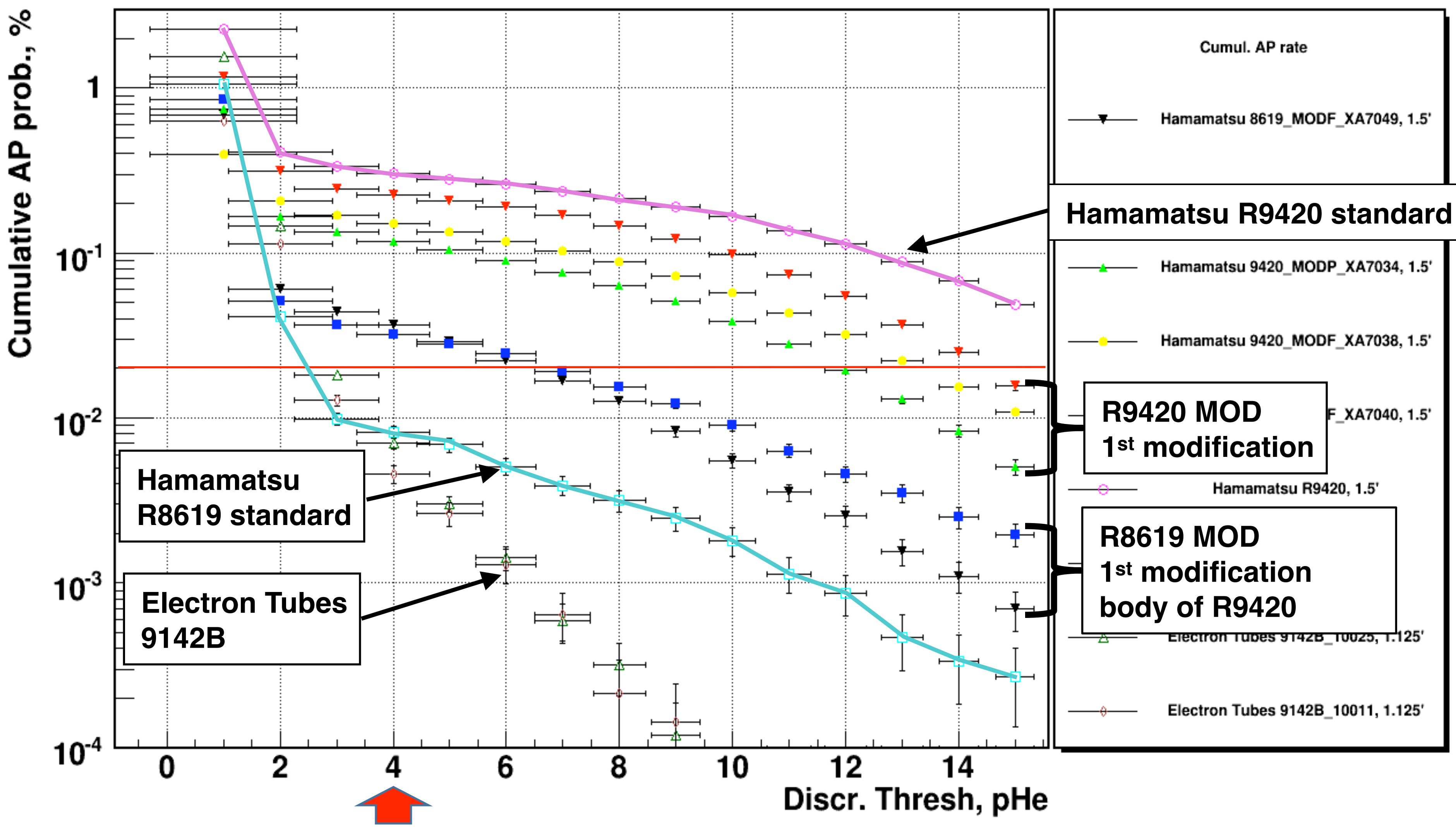
Hamamatsu R9420 modified
(convex input window shape)
(mat and polished input window types)

Hamamatsu R8619 modified
Body of R9420 but used 8619 dynode system (also two window types)



Electron Tubes 9117B

After-Pulsing measurements



Requirement for CTA: For the threshold of 4 phe P_{AP}(>4phe) ~ 0.02 % (red line)

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After-Pulsing measurements

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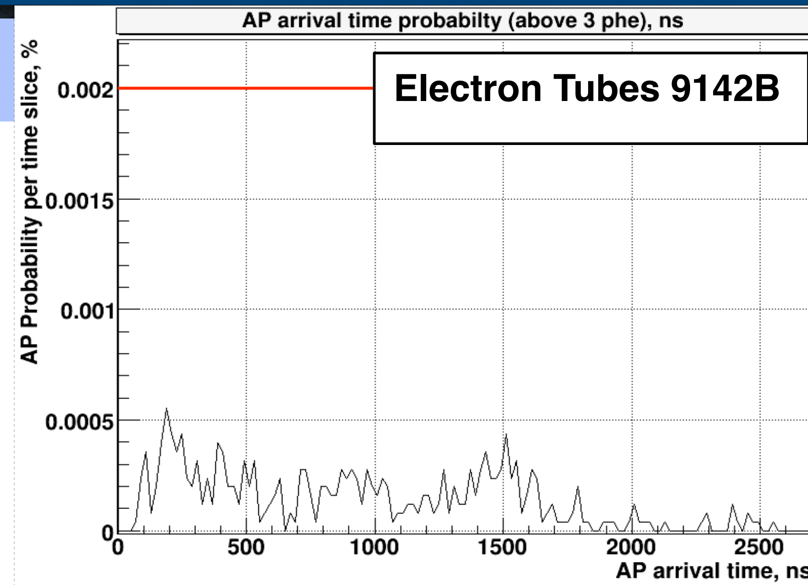
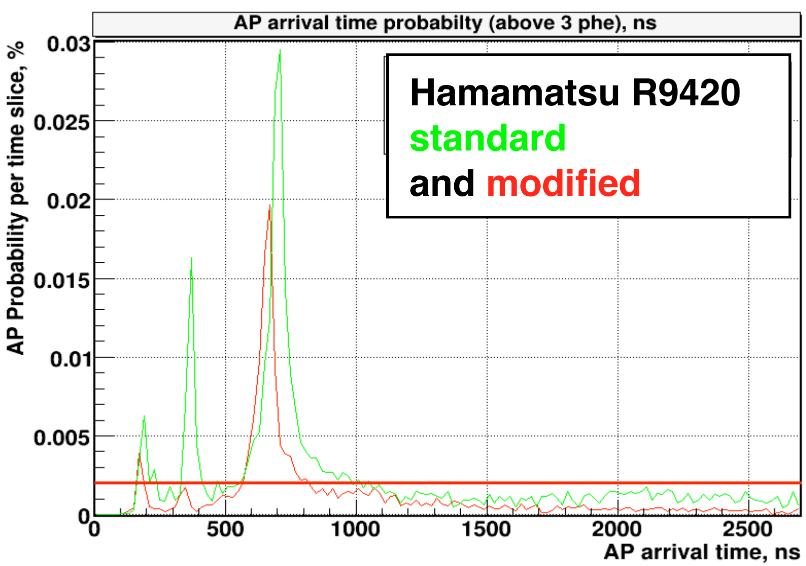
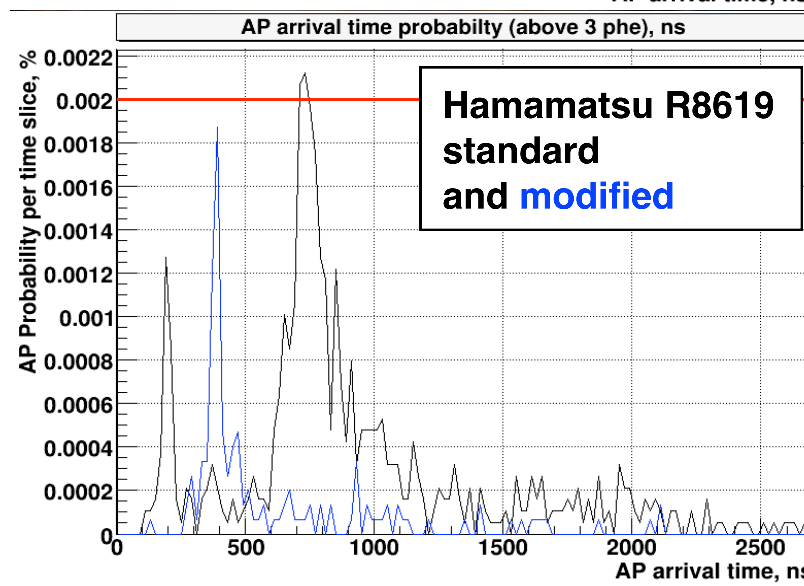
After-Pulsing sources

Sources vary for different PMTs !

- AP arrival time measurements to distinguish sources
- Peaks: ions from first dynode (H^+,$He^{+,2+}$, CH_4^+)
- Plateau caused by rest gases (low plateau = ”clean” vacuum)
- ET9142B has very low AP rate with no pronounced peaks





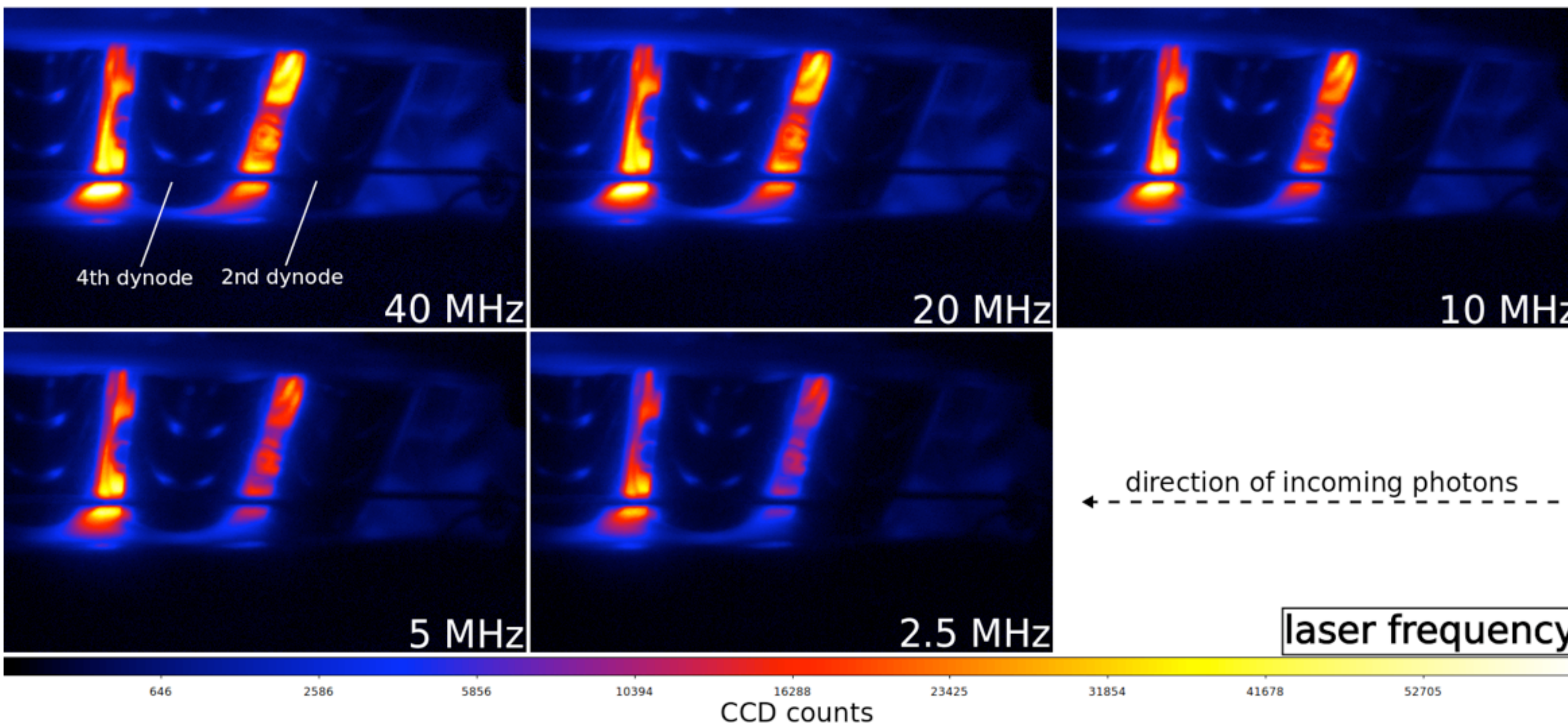


PMT glowing

Dynode system glowing

PMT irradiated by fast laser with various pulse repetition rate:

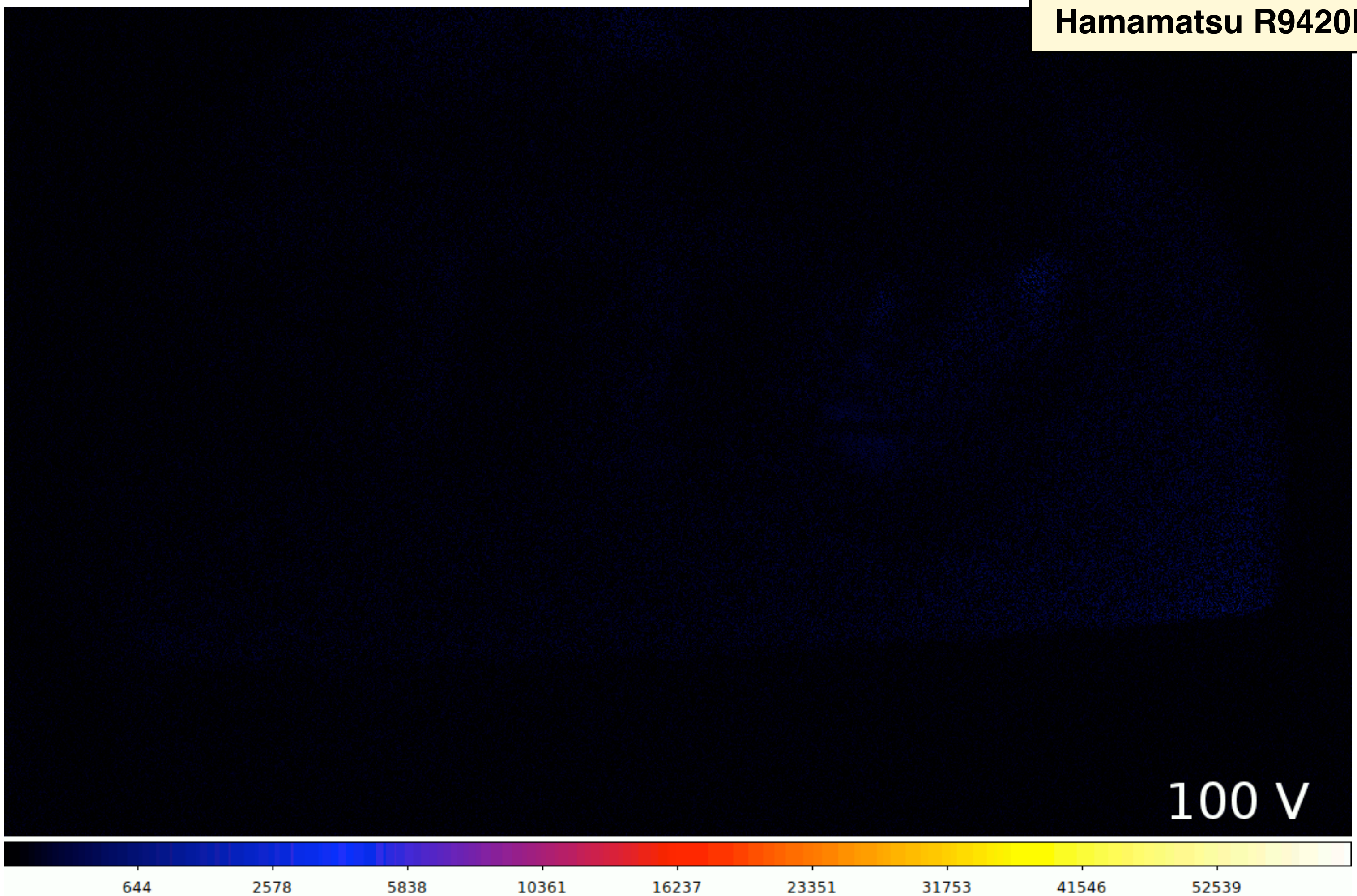
Hamamatsu R9420MOD
Exposure for every picture: 1 s



PMT glowing

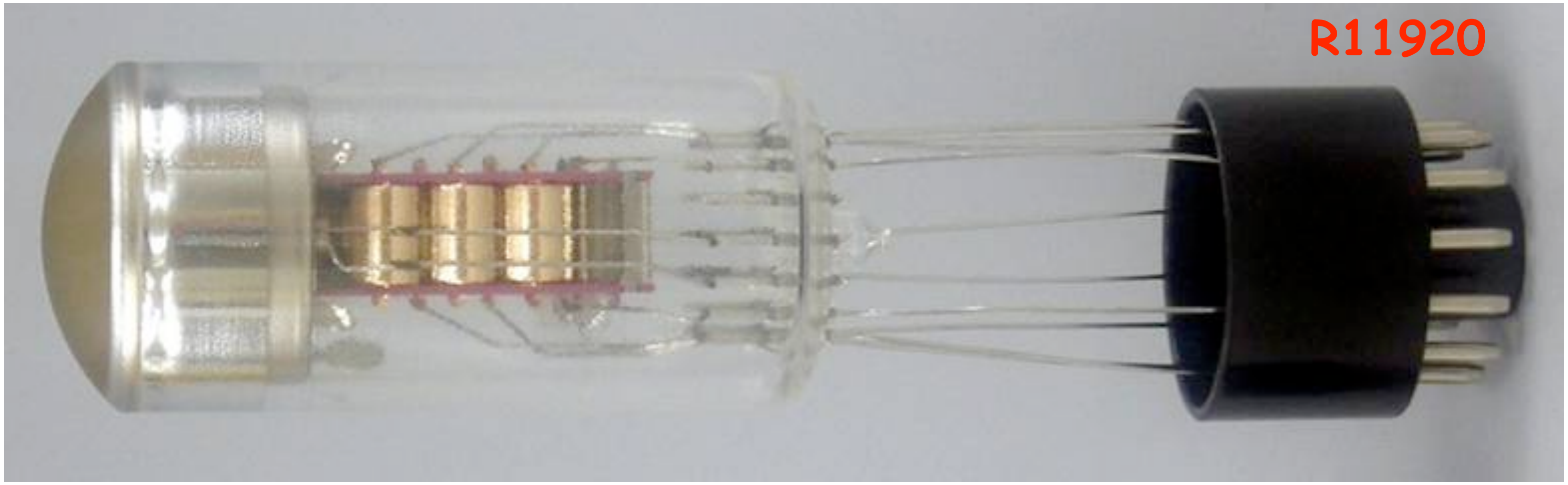
Dynode system glowing: Varying of applied voltage

Hamamatsu R9420MOD



Developed CTA PMT candidate from Hamamatsu

New name: R11920-100-01



TECHNICAL INFORMATION

TENTATIVE
Feb. 2011

R11920-100-01

For Gamma-ray Telescope (CTA project), Fast time response, CC window
38mm (1.5 inch) Diameter, Super Bialkali Photocathode, 8-stage, Head-On Type

GENERAL

Parameters		Ratings	Units
Spectral Response		300 to 650	nm
Wavelength of Maximum Response		350	nm
Window	Material	Borosilicate glass	-
	Shape	Concave-Convex (R26)	-
Photocathode	Material	Super Bialkali	-
	Minimum Effective Area	30	mm dia.
Dynode Structure / Number of Stages		Linear Focused / 8	-
Base		JEDEC No.B12-43 / Flying Lead Type	-
Operating Ambient Temperature		-30 to +50	°C
Storage Temperature		-80 to +50	°C
Suitable Socket		E678-12A (option)	-

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter		Maximum Ratings	Units
Supply Voltage	Anode to Cathode	1500	V
	Cathode to 1st Dynode	300	
Average Anode Current		0.1	mA

CHARACTERISTICS (at 25 °C)

Parameters		Min.	Typ.	Max.	Unit
Cathode Sensitivity :	Luminous (2856 K)	-	100	-	μA/lm
Cathode Blue Sensitivity Index (Cs 5-58)		-	13.5	-	-
Quantum Efficiency	at peak wavelength	32	35	-	%
	from 300nm to 450nm	25	-	-	
Collection Efficiency (at 400nm)**			92		%
1st Dynode Gain		6	10		-
Anode Sensitivity :	Luminous (2856 K)	-	4	-	A/lm
Gain		-	4×10^4	-	-
Single Photon counting Peak to Vally Ratio		1.8	2.5	-	-
Anode Dark Current (after 30min storage in the darkness)		-	5	20	nA
After Pulseing (threshold 4p.e. and Gain 4×10^4 voltage)			0.05		%
Anode Pulse Rise Time**		-	2.3	-	ns
Anode Pulse Width (FWHM)**		-	-	3.0	ns
Electron Transit Time**		-	23	-	ns
Transit Time Spread (FWHM with single p.e.)**		-	-	1.3	ns
Pulse Linearity (+/-2% deviation)		15	20	-	mA
Life (50% drop in Gain)		200			C

NOTE : Anode characteristics are measured with a voltage distribution ratio and supply voltage shown below.

(** Collection Efficiency and Time response are defined with effective area of 30 mm in diameter.)

TECHNICAL INFORMATION

TENTATIVE
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VOLTAGE DIVIDER AND SUPPLY VOLTAGE

Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	P
Ratio	300V(zener diode)	1	2	1	1	1	1	2	1	

Supply Voltage: 1000 V, K: Cathode, Dy: Dynode, P: Anode

DIMENSIONAL OUTLINE AND BASING DIAGRAM

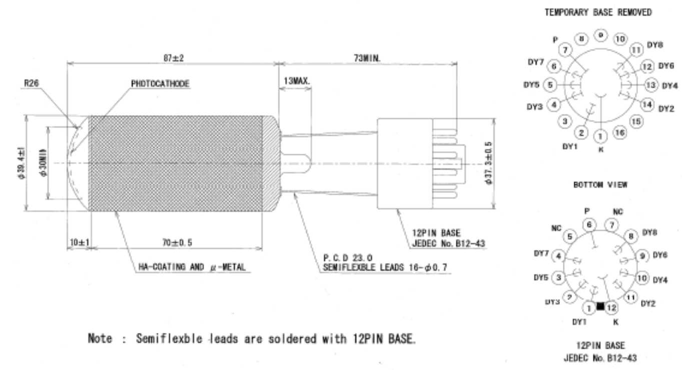

Figure 1: Dimensional Outline (Unit: mm)

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These parameteres are under improvements

25mm->20mm convex window. CE improves, TTS slightly degrades.

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FPI WP

Evaluation of SiPM

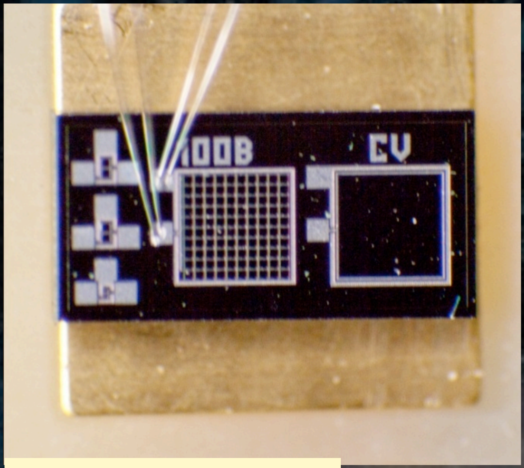
First SiPMs candidates

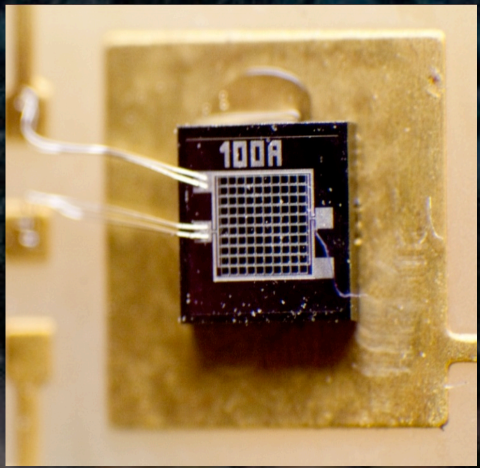
MEPhI - MPI samples:

- Different pitch (50µ, 100µ), p on n type
- Two SiPMs sizes: (1 & 3 mm²)
- Operation voltages 26V and 35V
- In total ~20 different types of SiPMs

Also tested:

- Hamamatsu MPPCs, 1& 3mm, S10362-11-50U
- Planning to test other types when available e.g. Philips, and other manufactures

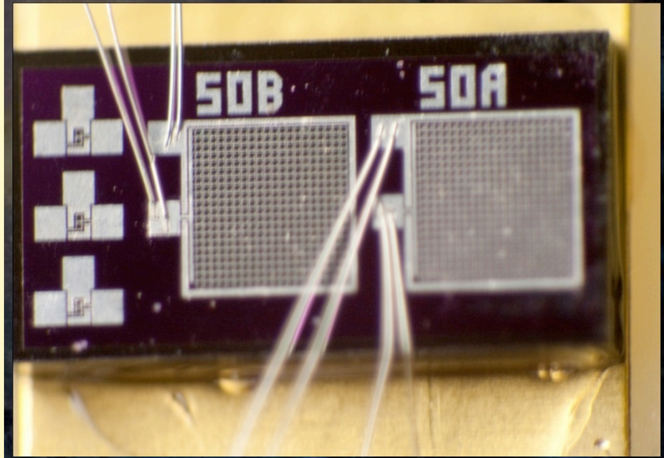




First prototypes from MEPhI:

1x1mm, 35V and 26V bias voltages. 100µ and 50µ pitch. No trenches

B, A = different geometrical efficiencies (B-high, A-lower)



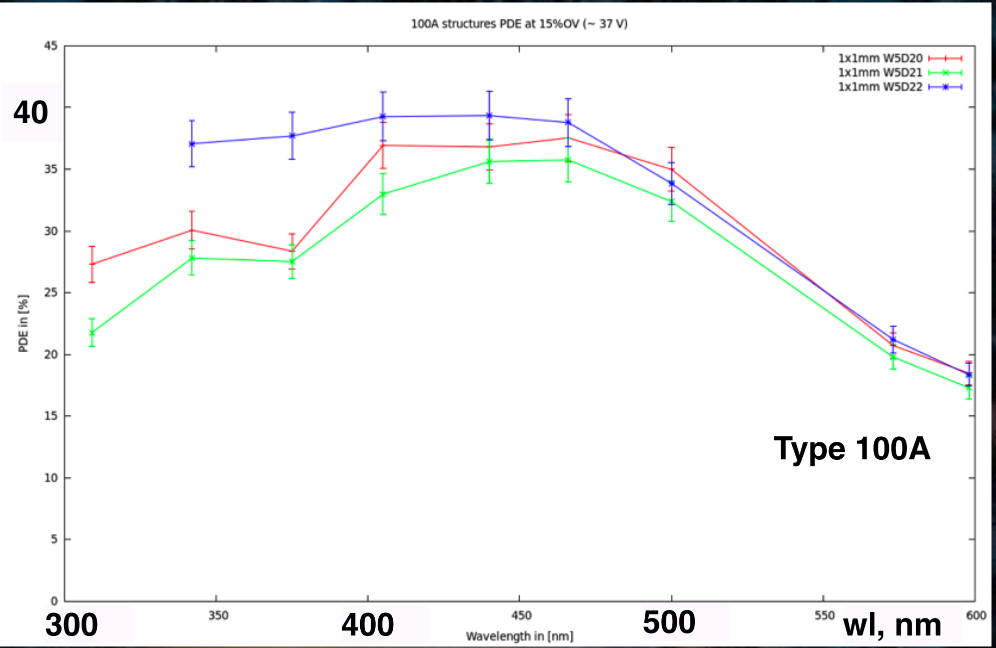
Evaluation of SiPM

Updated SiPMs candidates

Updated MEPhI - MPI (EXCELITAS) samples:

- Type 100A and 100B
- Improved PDE in UV region
- X-Talk suppression: Trenches, second p-n junction, ion implantation...
- Measurements of type A reveal samples with high (and pretty "flat") PDE:

PDE(400nm)~40% !!!



Measurement of PDE for applied over-voltage $(V-V_b)/V_b=15\%$

Updated prototypes Type 100A (U_b=37V):
Improved UV sensitivity. 1x1mm,

Evaluation of SiPM

FPI WP

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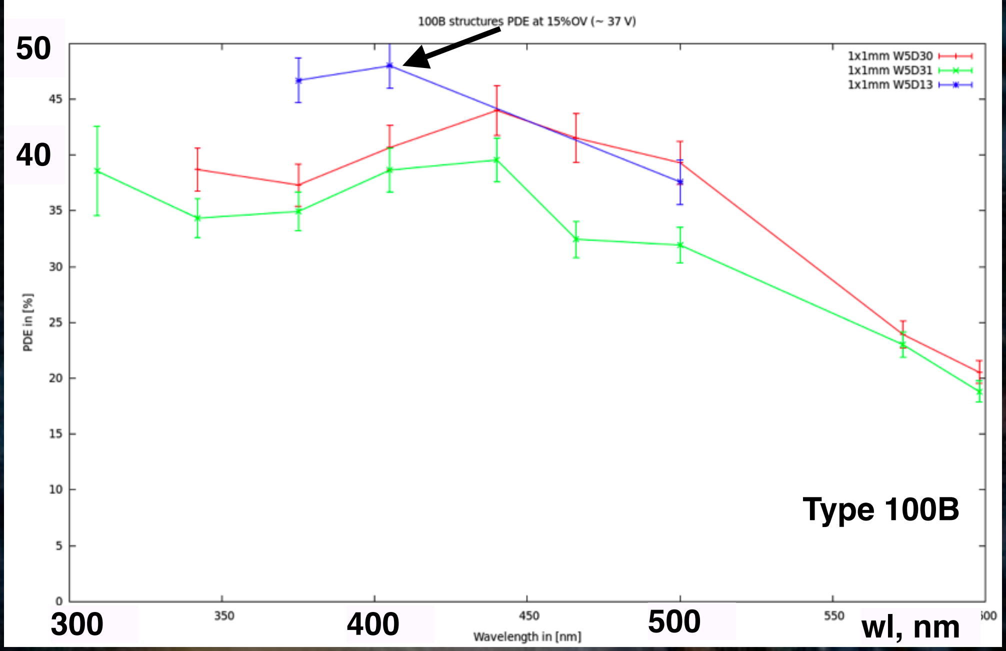
Updated SiPMs candidates

Updated MEPhI - MPI (EXCELITAS) samples:

- Type 100A and 100B
- Improved PDE in UV region
- X-Talk suppression: Trenches, second p-n junction, ion implantation...
- Measurements of type B reveal samples with high (and pretty “flat”) PDE:

PDE(400nm)~45% !!!



Measurement of PDE for applied over-voltage $(U-U_b)/U_b=15\%$

Updated prototypes Type 100B (U_b=37V):
Improved UV sensitivity. 1x1mm,

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Evaluation of SiPM

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Updated SiPMs candidates

Updated MEPhI - MPI (EXCELITAS) samples:

- Type 100A and 100B
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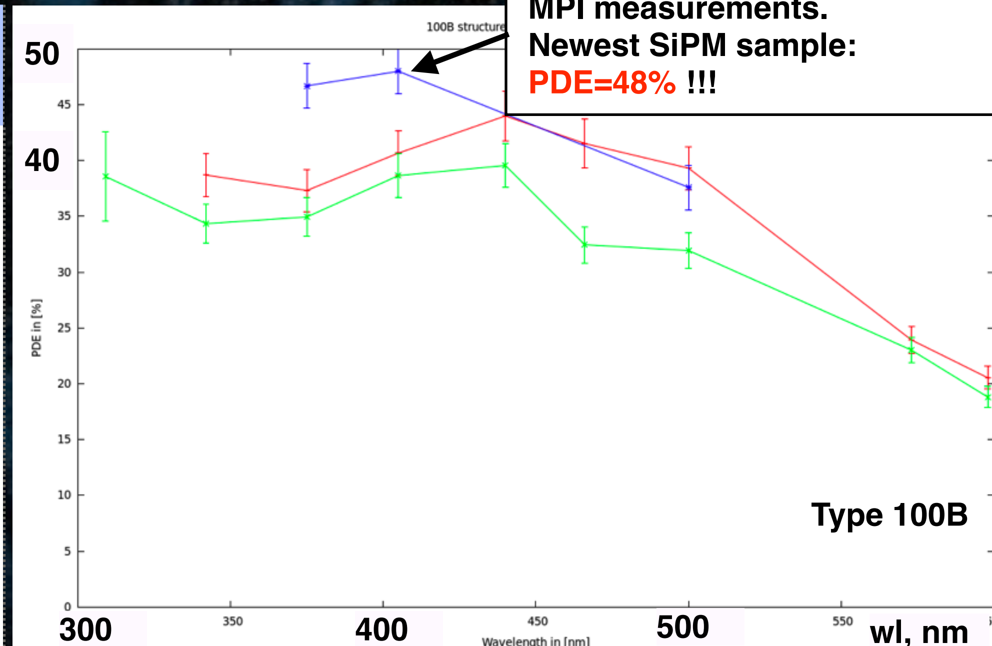
PDE(400nm)~45% !!!

MPI measurements.
Newest SiPM sample:
PDE=48% !!!



Measurement of PDE for applied over-voltage $(U-U_b)/U_b=15\%$

Updated prototypes Type 100B (U_b=37V):
Improved UV sensitivity. 1x1mm,

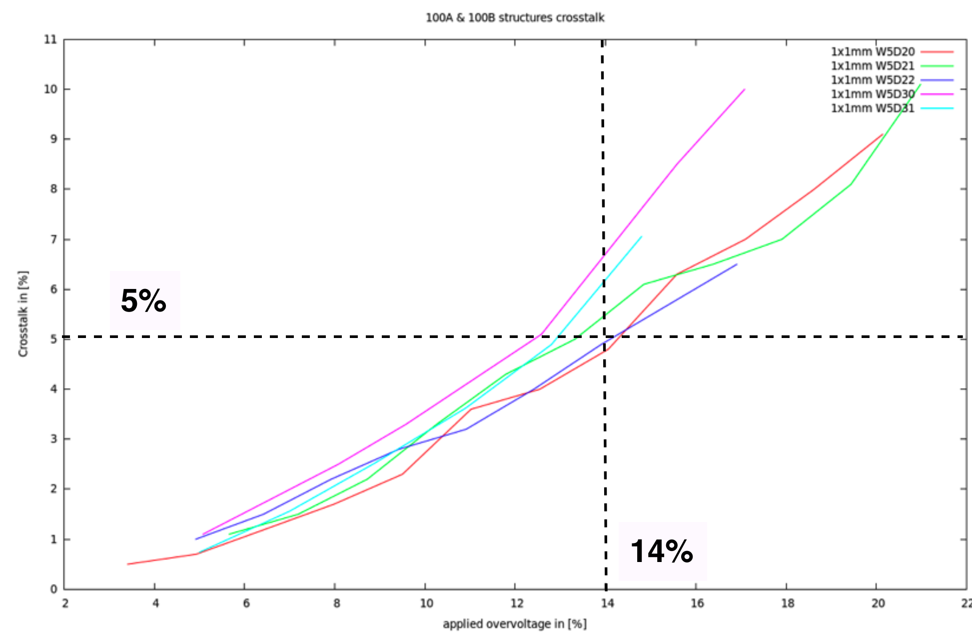
Evaluation of SiPM

Updated SiPMs candidates

Updated MEPhI - MPI (EXCELITAS) samples:

- Type 100A and 100B
- Improved PDE in UV region
- X-Talk suppression: Trenches, second p-n junction, ion implantation...
- Cross-talk measurements: Very low crosstalk of

$P_{X\text{-}talk}(\Delta U/U_b=14\%) \sim 5\%$!!!



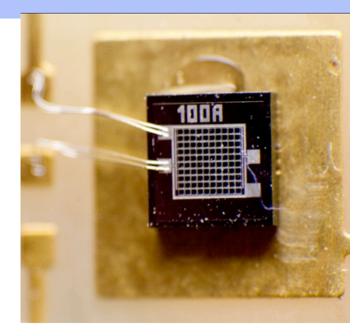
Optical cross-talk versus over-voltage $(U-U_b)/U_b$
(PDE saturates at 10-15% over-voltage)

Updated prototypes Type 100B (U_b=37V):
Improved UV sensitivity. 1x1mm, Optical trenches introduced

Summary

PMTs:

SiPMs:



- One may assume that it could make sense to start using SiPMs in our telescopes once their efficiency will exceed the PDE of PMTs by 1.5-2 times at comparable costs.
- SiPMs are becoming serious sensor candidates for the CTA project: PDE ($\Delta U/U_b$=0.15) ~ 50% reached for low cross-talk $P_{X\text{-talk}}$($\Delta U/U_b$=0.14) ~ 5% !
- Intending to evaluate all new SiPM candidate sensors
- We believe in a few years one can have high quality SiPMs from several manufacturers that can be used also in our project.

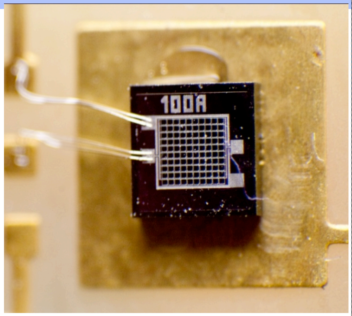
Summary

FPI WP

PMTs:

- PMT development for the needs of CTA is in progress
- Already now the PMTs of Hamamatsu came rather close to the specified target parameter values: peak PDE ~32%, After-pulsing slightly above 0.02%.
- Next two years further optimization of PMTs from both Hamamatsu and Electron Tubes Enterprises (Some financial support from CTA is foreseen)
- Design and tests of PMT-based pixels and clusters of 7-pixels

SiPMs:



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