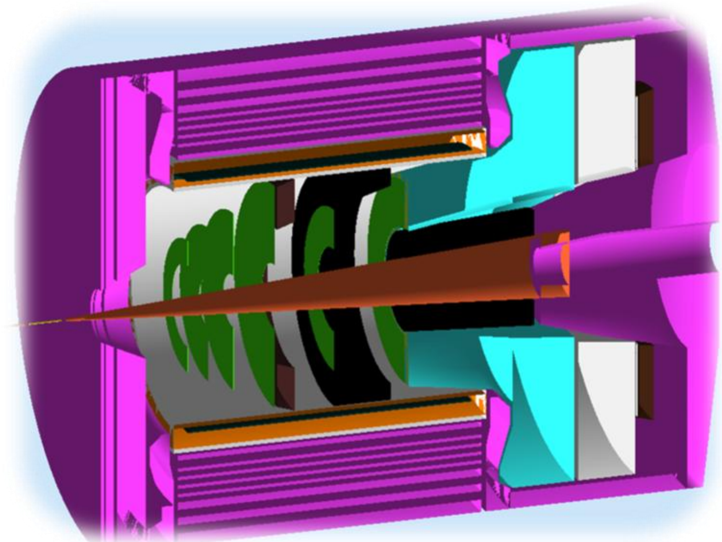
Cherenkov Detectors for SIDIS SoLID

Simona Malace, Haiyan Gao
Zein-Eddine Meziani, Eric Fuchey
Duke, Temple U.

April 13-14, 2012

Requirements

➡ Threshold Cherenkov:
- electron-pion separation (positive identification of electrons)
- pion-kaon/proton separation: positive identification of pions



SIDIS electron Cherenkov: 1.5 – 4.5 GeV

SIDIS pion Cherenkov: 2.5 – 7.5 GeV

➡ 2π coverage (SIDIS)

➡ Perform in non-negligible magnetic field environment

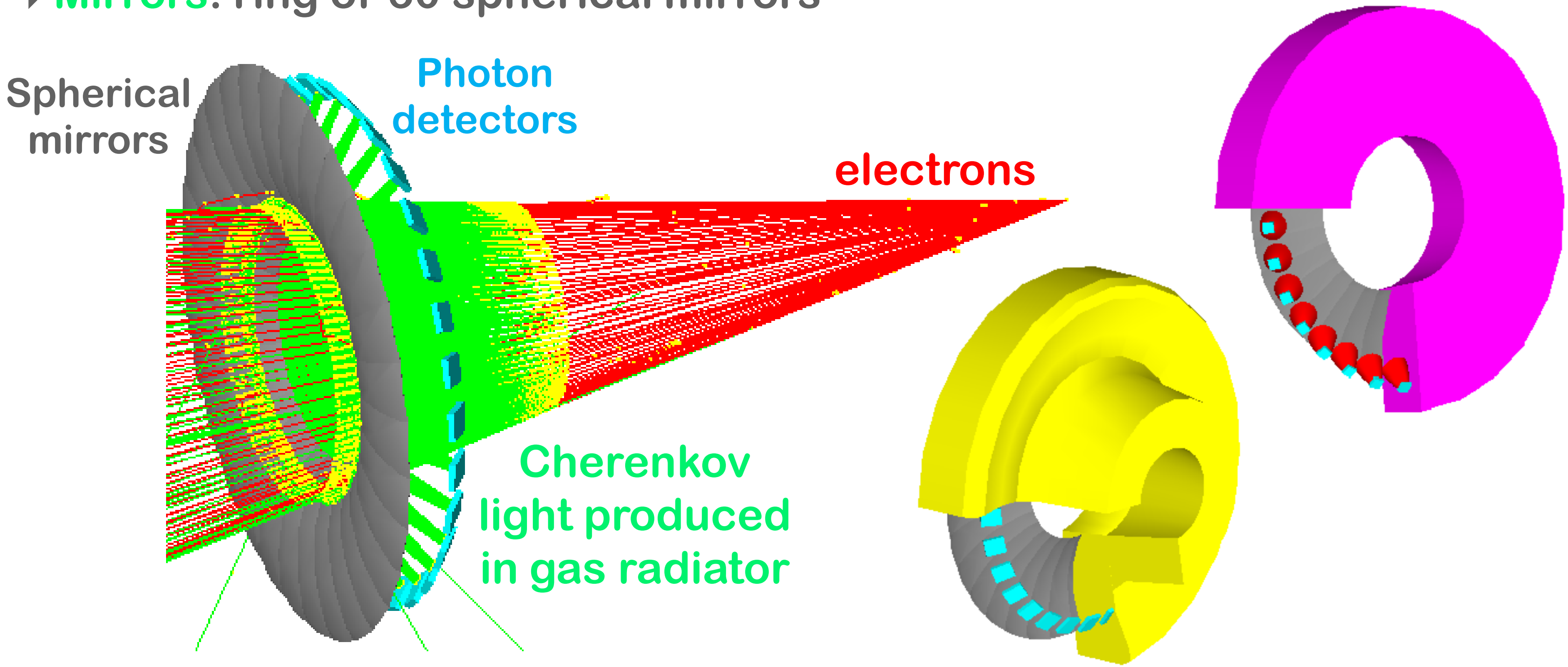
➡ Perform in non-negligible electromagnetic and hadronic background environment

➡ Simple design: cost effective, easy to install & operate

Design: Mirrors & Photon Detectors

It follows the current sector division of SoLID (as needed for PVDIS)

⇨ Mirrors: ring of 30 spherical mirrors



→ Good focusing of Cherenkov light on small size photon detectors

⇨ Photon detectors: GEMs + CsI and/or PMTs (as of now, April 2012)

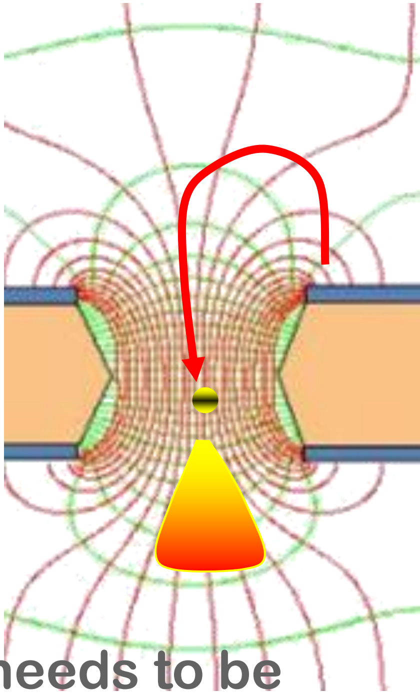
Design: Photon Detectors

➡ Photon detectors: **GEMs + CsI** (used by PHENIX)

→Insensitive to magnetic field

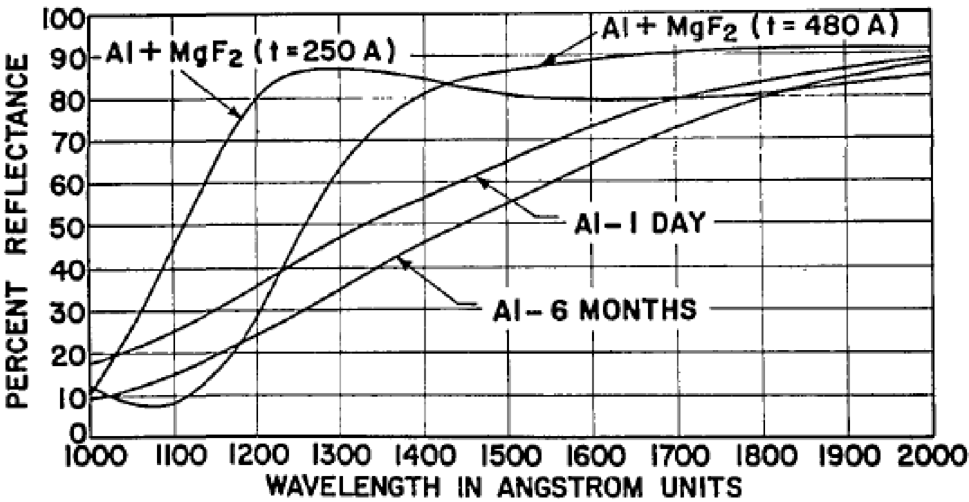
→ would be nice to back this statement with actual data

→ CsI: sensitive to deep UV light only (< 190 nm), can be degraded by humidity, intense photon flux & ion bombardment, surface contamination, radiation with neutral/charged particles



→ Gas with very good intrinsic transmittance in UV + needs to be kept pure throughout running

→ Mirrors with good reflectivity in deep UV: in theory possible, practically not necessarily the norm



→GEMs + CsI: not a vacuum device; for simplicity the Cherenkov radiator gas has to work as avalanche gas for GEMs

→Can it resolve SPE?

→ Would it work in SoLID background environment?

Design: Photon Detectors

➡ Photon detectors: **PMTs**

H8500C-03

Needs to:

→ function in SoLID magnetic field

→ be suitable for tiling: good packing density

→ resolve SPE

→ work in SoLID background environment

→ H8500C-03: typical gain (low), 1.5 x 10^{-6}, needs amplification X 100 to resolve SPE; noise could be an issue

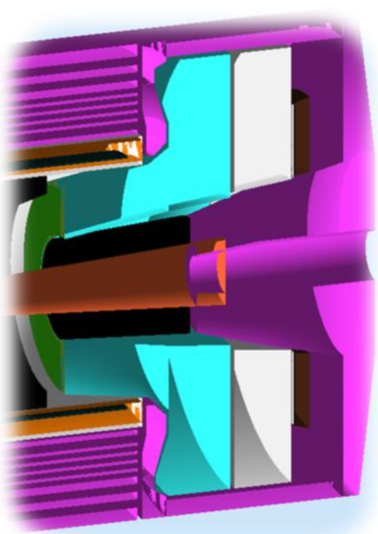
Parameter		H8500C	H8500D	H8500C-03	H8500D-0
Spectral Response		300 to 650		185 to 650	
Peak Wavelength		400			
Photocathode Material		Bialkali			
Window	Material	Borosilicate glass		UV glass	
	Thickness	1.5			
Dynode	Structure	Metal channel dynode			
	Number of Stages	12			
Number of Anode Pixels		64 (8 × 8 matrix)			
Pixel Size / Pitch at Center		5.8 × 5.8 / 6.08			
Effective Area		49 × 49			
Dimensional Outline (W × H × D)		52 × 52 × 27.4			
Packing Density (Effective Area / External Size)		89			

Electron Cherenkov: GEMs + CsI

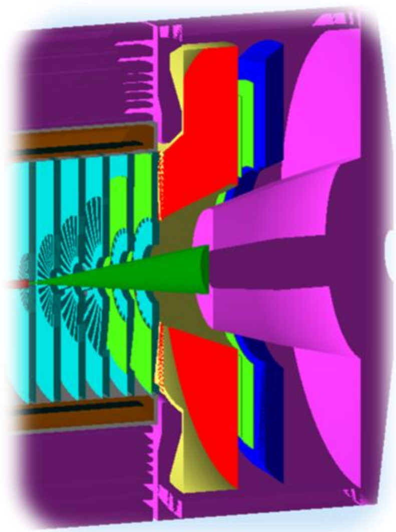
GEMs + CsI advantage: can be made of any size that SoLID might need (mirror configuration) without a dramatic increase in price per unit area

⇨ Very similar configuration possible for SIDIS and PVDIS

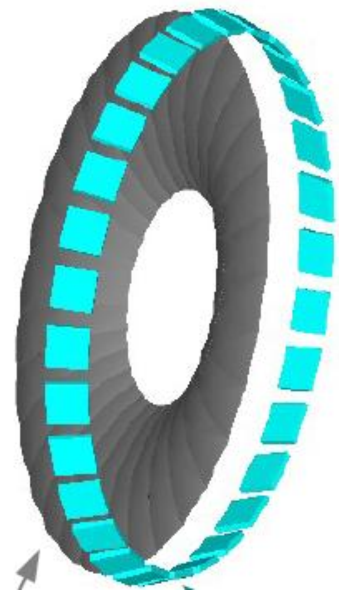
- same tank except for additional piece for SIDIS
- same mirrors, mounted at the same location
- same GEMs + CsI, mounted at different locations
- same gas: CF_4



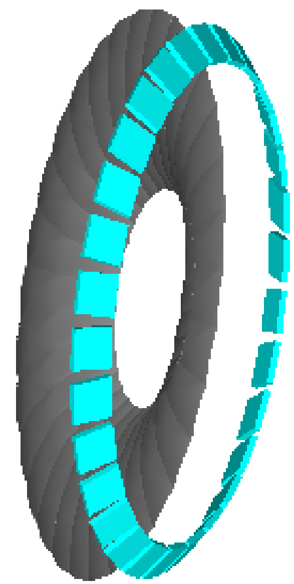
SIDIS



PVDIS



PVDIS



SIDIS

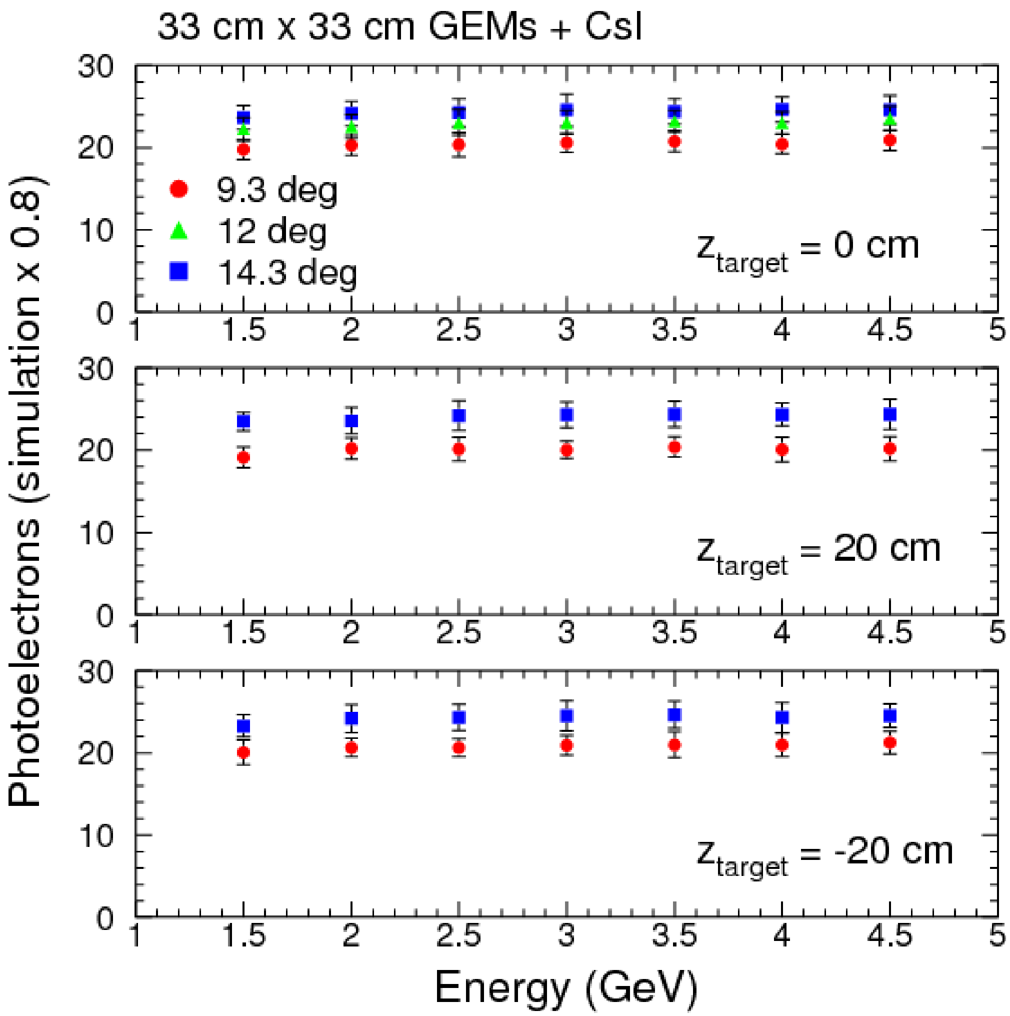
GEMs + CsI size:
33 x 33 cm^2

Mirror size:
~1.5 m X 0.4 m

Mirror position and parameters fixed by PVDIS requirements; for SIDIS the photon detector is re-positioned to maximize the collection efficiency (for SIDIS GEMs+CsI closer to the beam line – 1.96 m - than for PVDIS)

Electron Cherenkov: GEMs + CsI

➡ **Expected photoelectron yield for SIDIS: 20-25**



Gas transmittance and CsI Q.E. as measured by PHENIX

PHENIX factor: 0.516 (mesh and photocathode transparency, transport efficiency)

Safety factor: 0.8

Work in progress (simulation):

→ Estimate pion rejection factor
→ Estimate electron cut efficiency

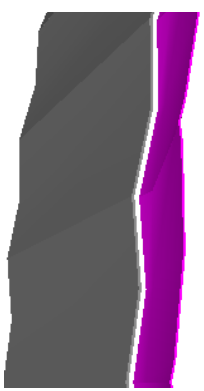
(same for the other option)

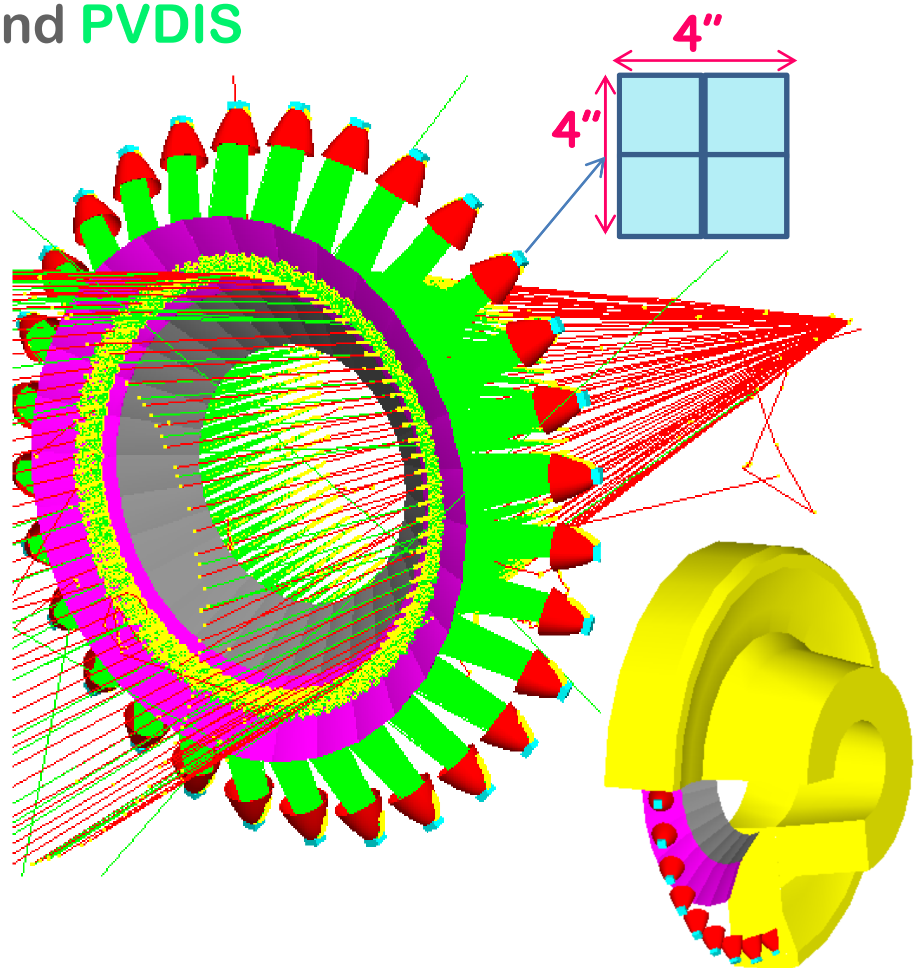
Electron Cherenkov: PMTs

H8500C-03 PMTs are expensive ($3000 per PMT if many are purchased): try to minimize number of PMTs per sector → use mirrors and cones for focusing Cherenkov light + split mirrors per sector in 2 parts with different curvatures to further reduce the light spot size (went from 9 to 4 PMTs per sector)

⇨ Different configurations for SIDIS and PVDIS

- different gas: CO_2 for SIDIS, C_4F_{10} for PVDIS
- different mirrors
- different size of PMT arrays and different (straight) cones: 4 PMTs per sector needed for SIDIS

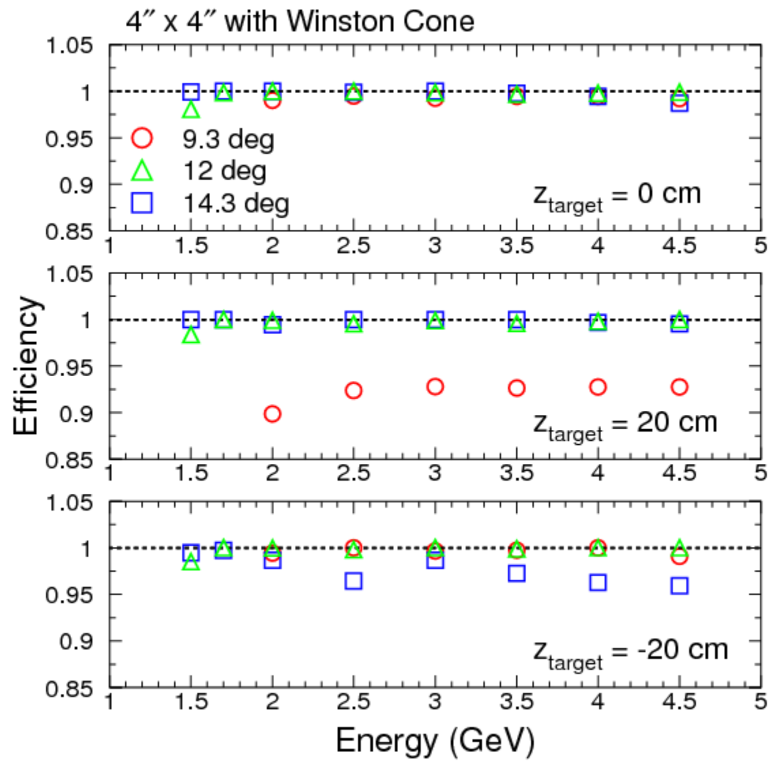


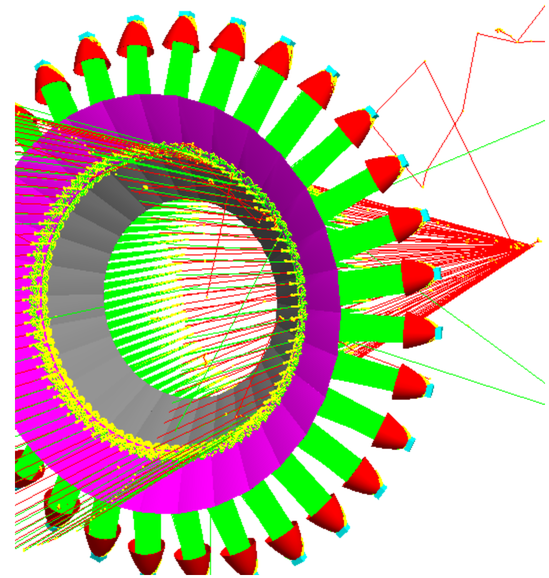


→ Make mirrors of light material (CFRP) to remove the need for double edge support for no impact on physics phase space

Electron Cherenkov: PMTs

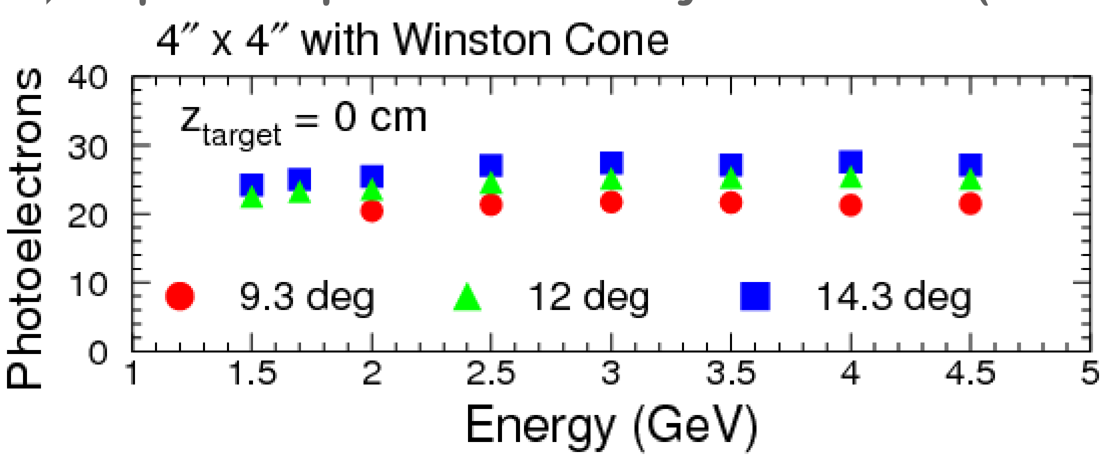
- It is possible to position the 2 parts of each mirror such that no light will be lost in the "no support needed in the middle" configuration





12 deg: cone of photons reflect on both mirrors (boundary)

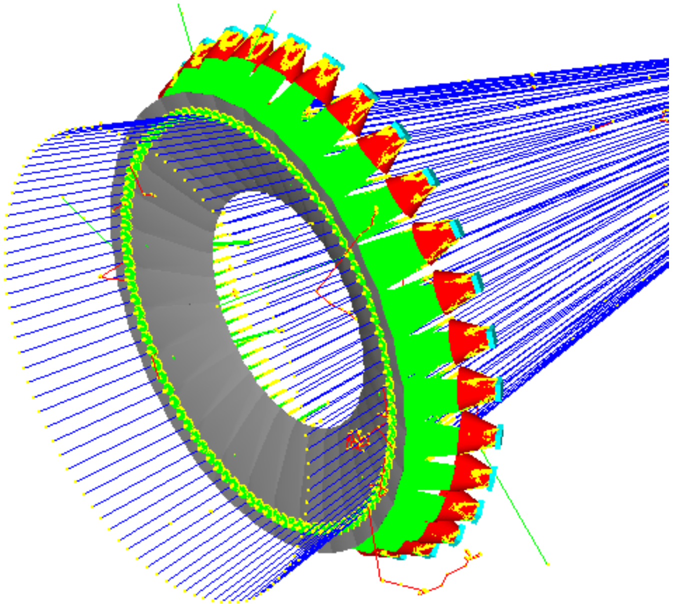
- Expected photoelectron yield: 20-25 (safety factor: 0.7)

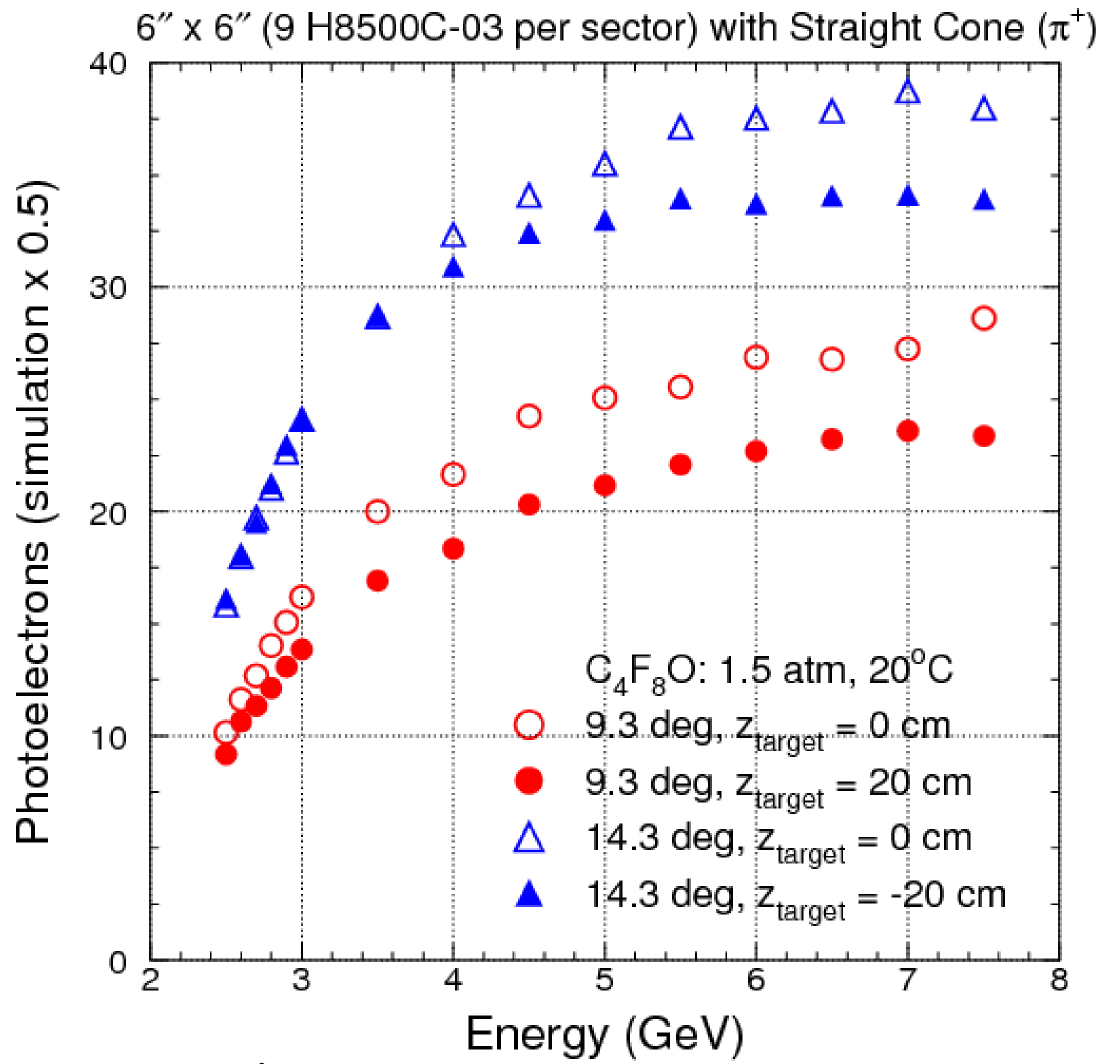


If larger photoelectron yield is needed a heavier gas like CF_4 would work as well

Pion Cherenkov: PMTs

➡ Similar design as for electron Cherenkov, the PMT option





One ring of spherical mirrors + 9 H8500C-03 PMTs per sector + straight cones + C_4F_8O at 1.5 atm and 20 C (pion threshold ~ 2 GeV)

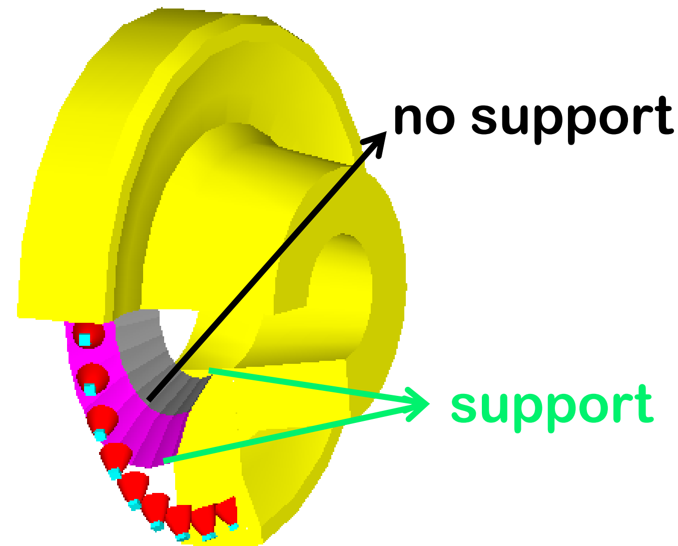
Mirrors will be kept in one piece per sector

Mirrors

➡ Electron Cherenkov, PMT option: CFRP best option right now, light enough to afford support just the inner and outer edge; one could try with glass too

➡ Electron Cherenkov, GEMs+CsI option: glass or other material (?) that would NOT absorb/retain water (CFRP would NOT work)

➡ Pion Cherenkov, PMTs: glass or CFRP



➡ Carbon fiber reinforced polymer (CFRP)

70% carbon-fiber (reinforcement material) + 30% resin (binds the fibers together)

Nuclear Instruments and Methods in Physics Research A 593 (2008) 624– 637

LHCb mirrors (made by Composite Mirror Applications, US):

→ sandwich honeycomb structure: two outer CFRP layers (1.5 mm) + core cells in-between as reinforcement

→ reflectivity with Al + MgF_2 coating: > 85% for λ > 200 nm if coated by SESO

Mirrors

➡ Quote from CMA for the pion Cherenkov mirrors

Quote #: M-00904-12
Date: 9 April 2012
Valid Until: 9 June 2012

To: Simona Malice
Jefferson Labs

Reference Documents

1) mirror_in_cherenkov_tank_1.png
2) mirror_in_cherenkov_tank_2.png
3) mirrors_for_solid_pion_cherenkov.pdf

ITEM I Description: **CFRP Composite Segmented Mirrors**

CMA Proposes to produce thirty (30) CFRP composite mirrors according to th drawings in Reference Documents 1, 2 and 3. The mirrors will be produced as thin shells (between 1 and 2mm thick) with enough stiffness to maintain their figure to a D0 spot size of less than ≤ 2mm.

Each mirror segment will be spherical with a radius of curvature of 215.389 cm. The mirror segments will be cut the shapes as shown in Reference document 3.

The mirrors will be coated with aluminum + MgF2 which exhibits ≥ 85% reflectance for a wave band of λ= 200 nm to 620 nm.

The mirrors will be mounted at 3 to 4 points on both inner and outer ends. The mounts will be adjustable in focus and will be mounted in such a way as to maintain minimal twisting.

The effort is expected to take 6 months to complete. The long lead item is the glass blank for the mandrel.

ITEM 1 Description Notes:

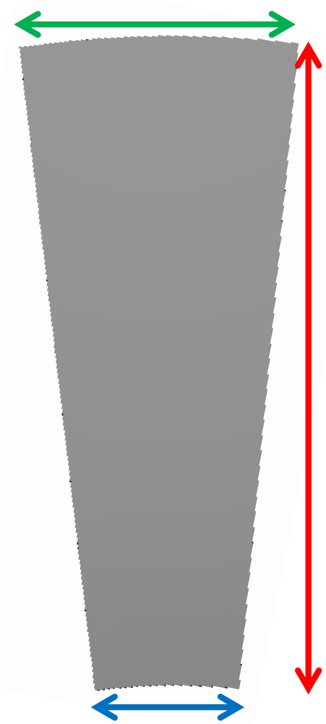
Deliverables:

1. Thirty (30) CFRP spherical mirrors with aluminum + MgF_2 coating p... mounting points.

Composite Mirror Applications

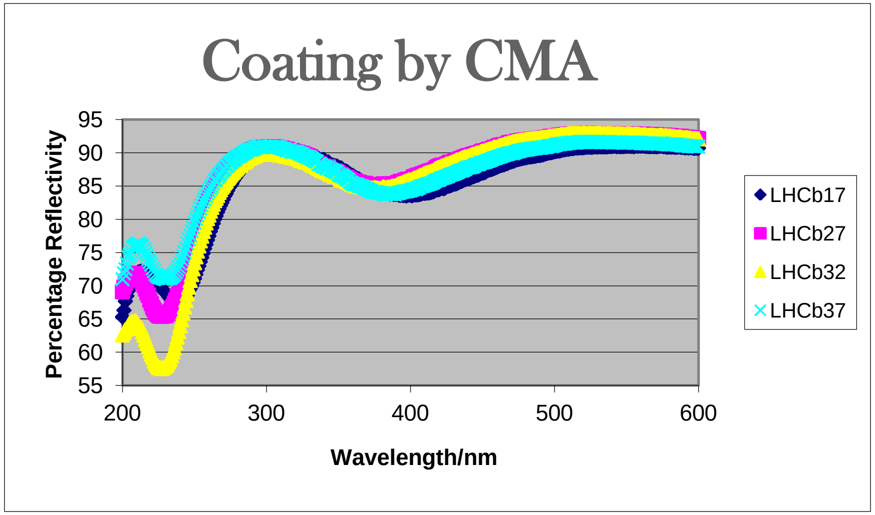
Cost Propo...
CMA Document 1...
Rev. ...

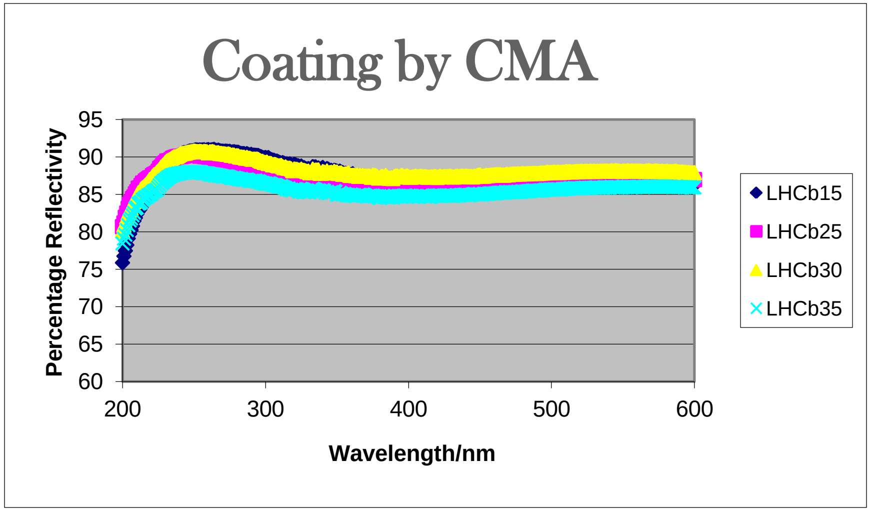
Cost:	$276,925
Shipping and Handling:	included
Delivery Schedule:	6 months from order
Terms:	30% down with Order
	20% with receipt of tooling in place, approximately month 4 of the program schedule.

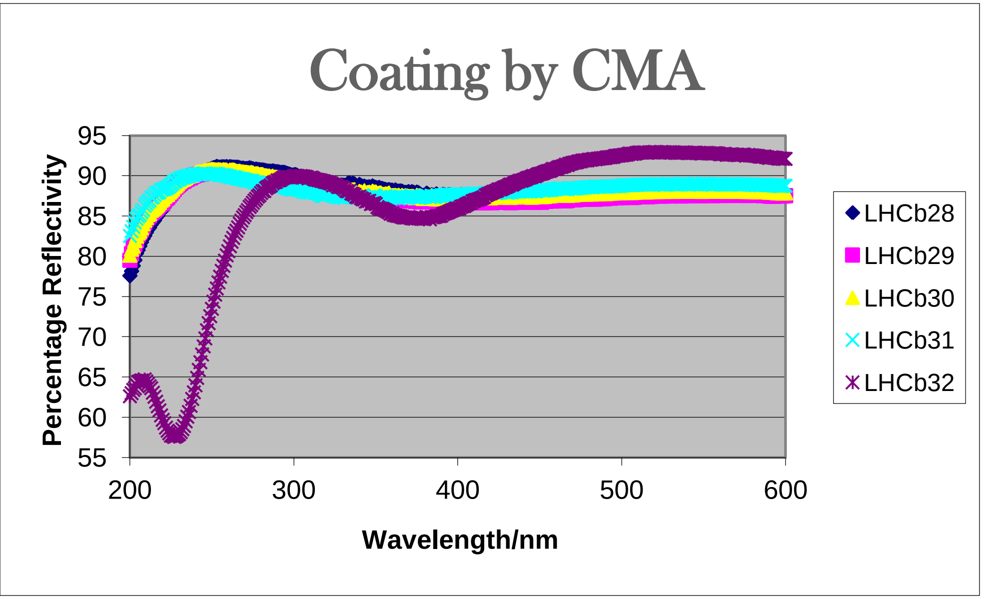


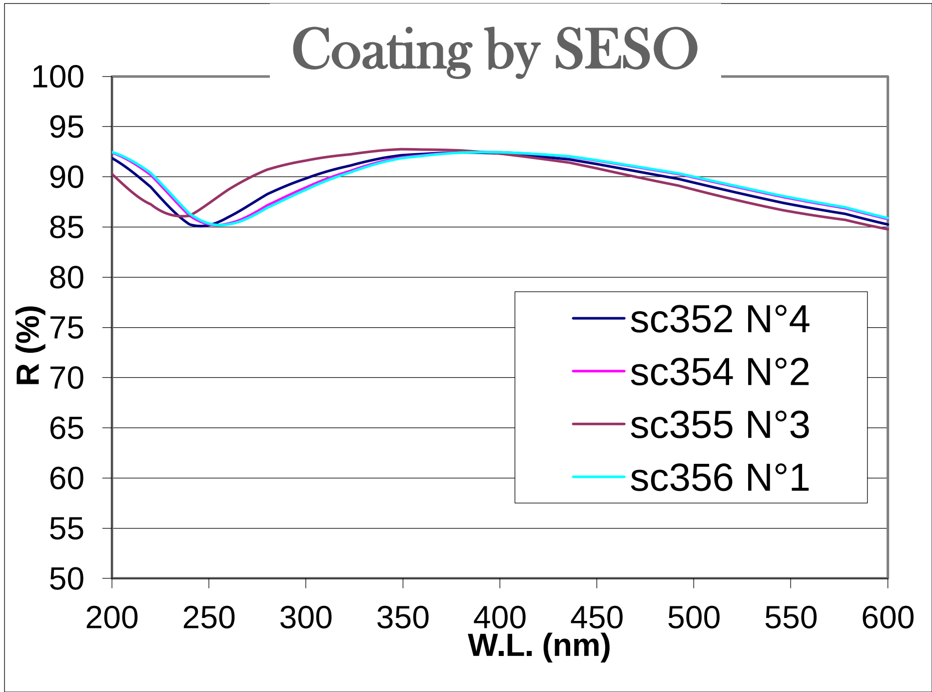
Mirrors

Quote from CMA for the pion Cherenkov mirrors: mirror reflectivity









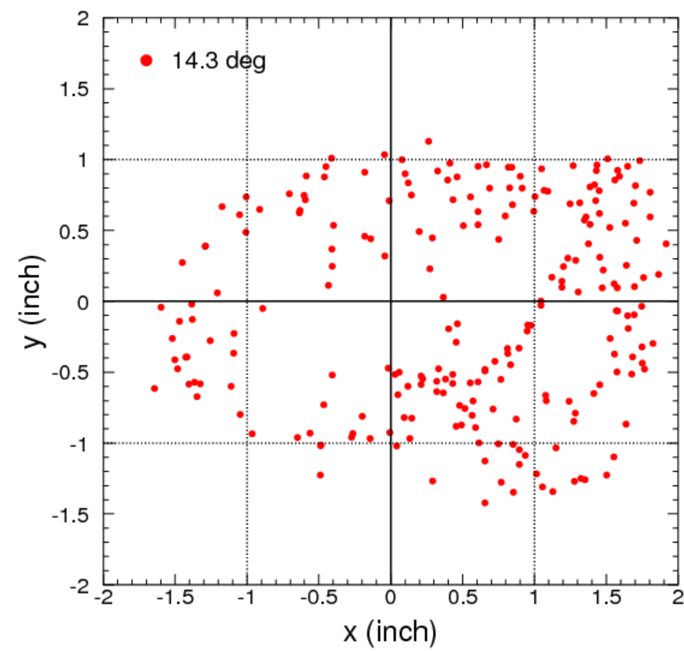
H8500C-03: Hardware Tests

➡ SPE bench tests: October 2011 – February 2012

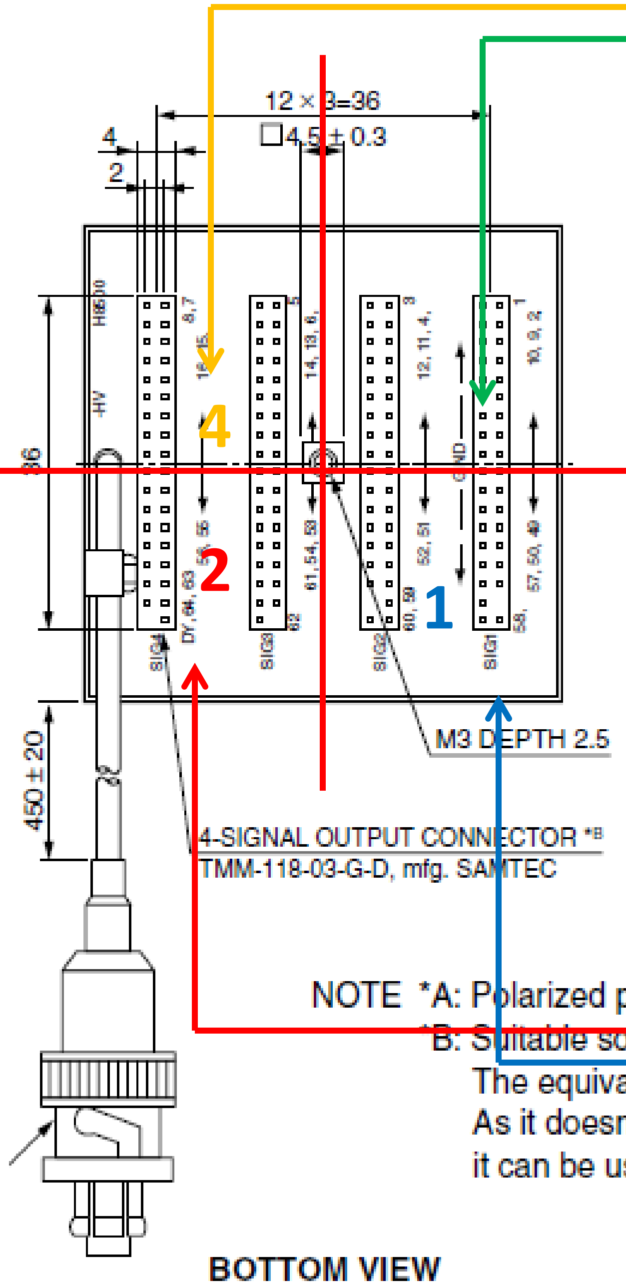
➡ the 2011 December in-beam test: “background test” to look at and compare rates on the H8500C-03 maPMT and a 5 inch Photonis tube → the 2 PMTs had very similar responses to the g_2^p commissioning environment ; rates ~ 20 kHz per $inch^2$ at the SPE level, 10 mil Carbon target, beam current < 1 μA

➡ magnetic field tests: on multi photoelectron and single photoelectron response: January 2012 – February 2012

➡ the 2012 Spring in-beam test: in progress; look at single vs coincidence rates on the maPMT



H8500C-03: Output

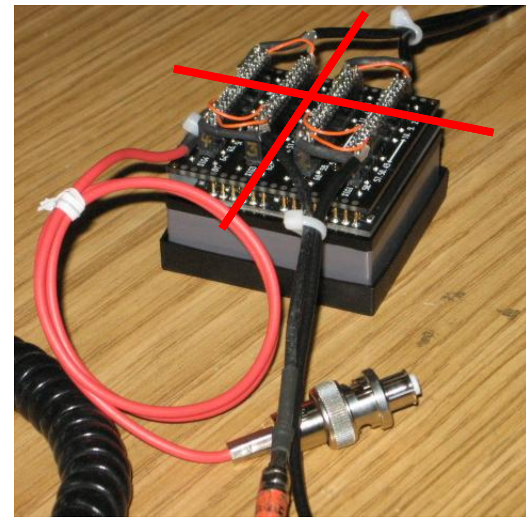


CONNECTION FOR SIGNAL CONNECTORS
(BOTTOM VIEW)

SIG4		SIG3		SIG2		SIG1	
GND	P7	GND	P5	GND	P3	GND	P1
GND	P8	GND	P6	GND	P4	GND	P2
GND	P15	GND	P13	GND	P11	GND	P9
GND	P16	GND	P14	GND	P12	GND	P10
GND	P23	GND	P21	GND	P19	GND	P17
GND	P24	GND	P22	GND	P20	GND	P18
GND	P31	GND	P29	GND	P27	GND	P25
GND	P32	GND	P30	GND	P28	GND	P26
GND	P39	GND	P37	GND	P35	GND	P33
GND	P40	GND	P38	GND	P36	GND	P34
GND	P47	GND	P45	GND	P43	GND	P41
GND	P48	GND	P46	GND	P44	GND	P42
GND	P55	GND	P53	GND	P51	GND	P49
GND	P56	GND	P54	GND	P52	GND	P50
GND	P63	GND	P61	GND	P59	GND	P57
GND	P64	GND	P62	GND	P60	GND	P58
GND	DY12	GND	GND	*A	GND	GND	*A
*A	GND	GND	*A	GND	GND	GND	GND

2 1 3

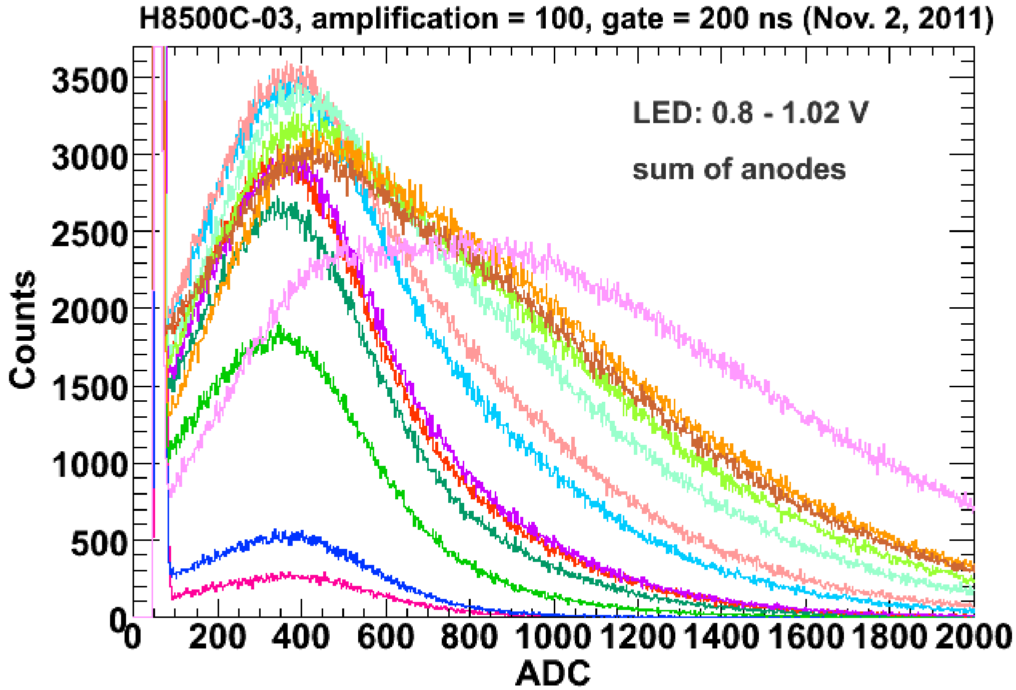
NOTE *A: Polarized position of omitted pin
*B: Suitable sockets for the signal connectors will be attache
The equivalent socket is SQT-118-01-L-D (SAMTEC).
As it doesn't have a polarized position marker,
it can be used at any positions.

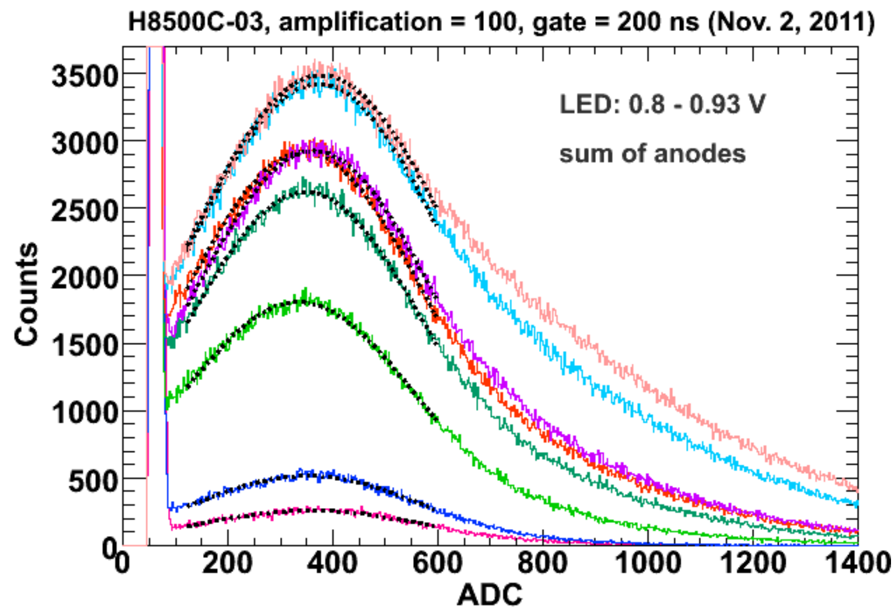


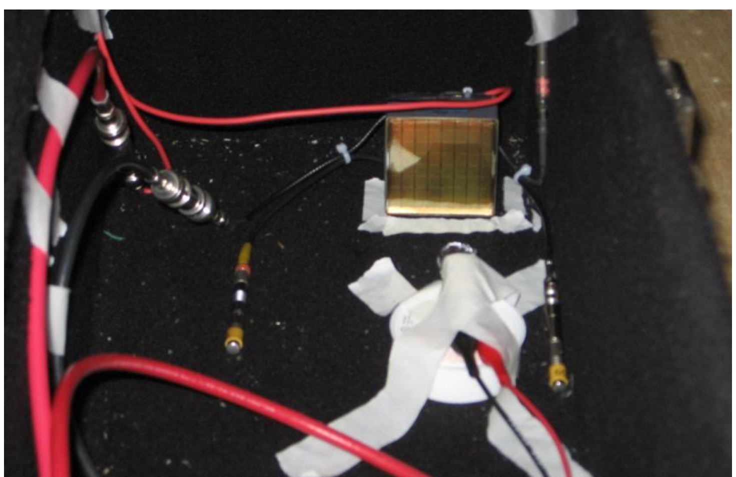
Quad division
or
Sum

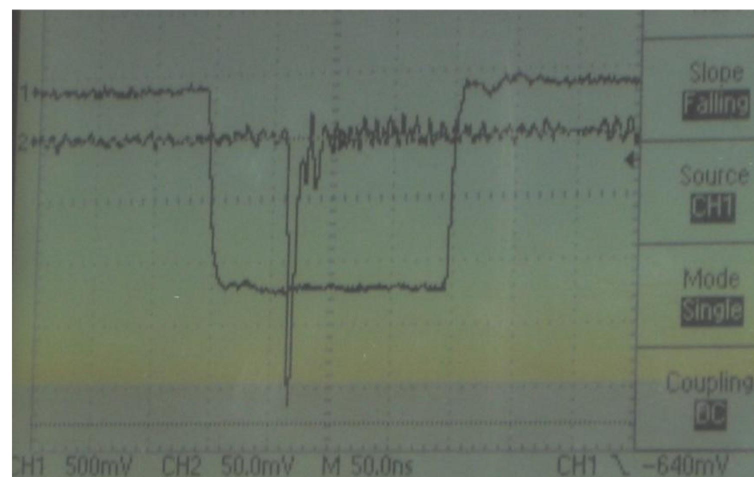
H8500C-03: Single Photoelectron

- Resolution: ~1 p.e.

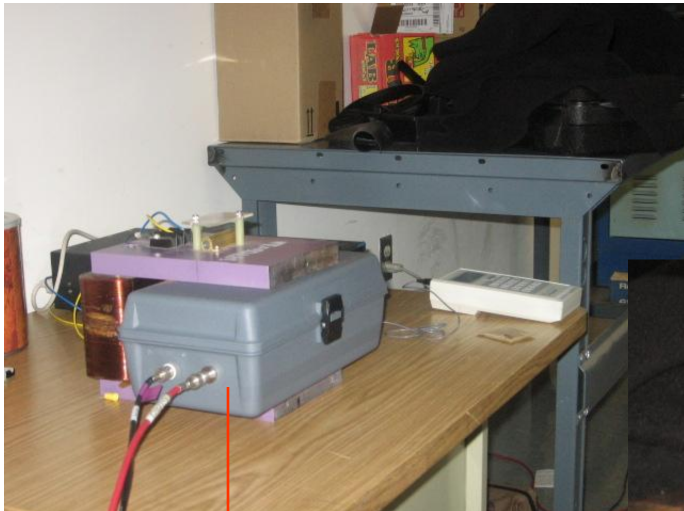


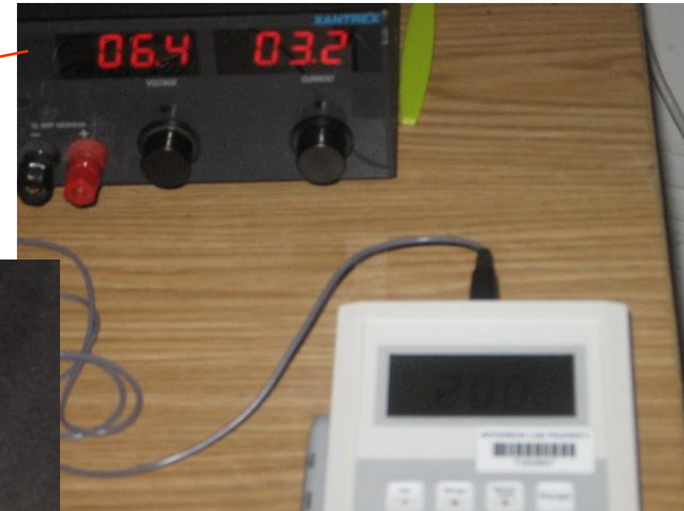






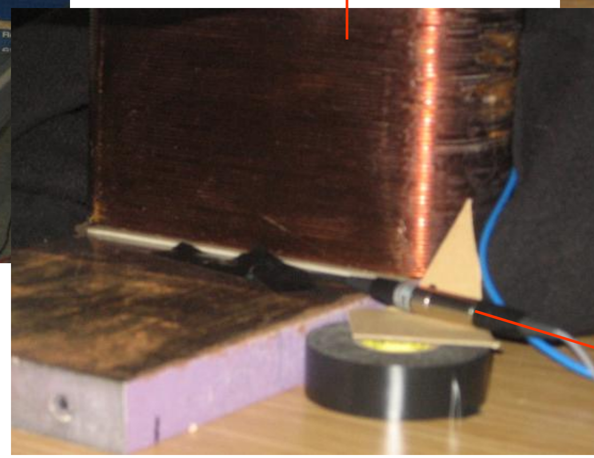
H8500C-03: Field Measurements





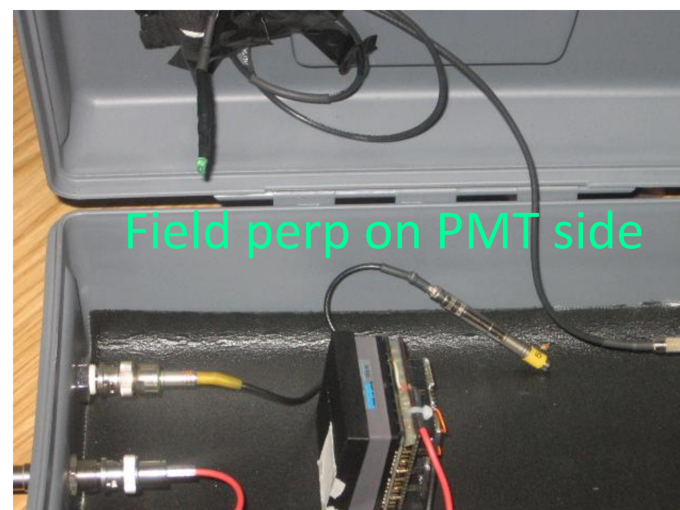
Power supply

Coil

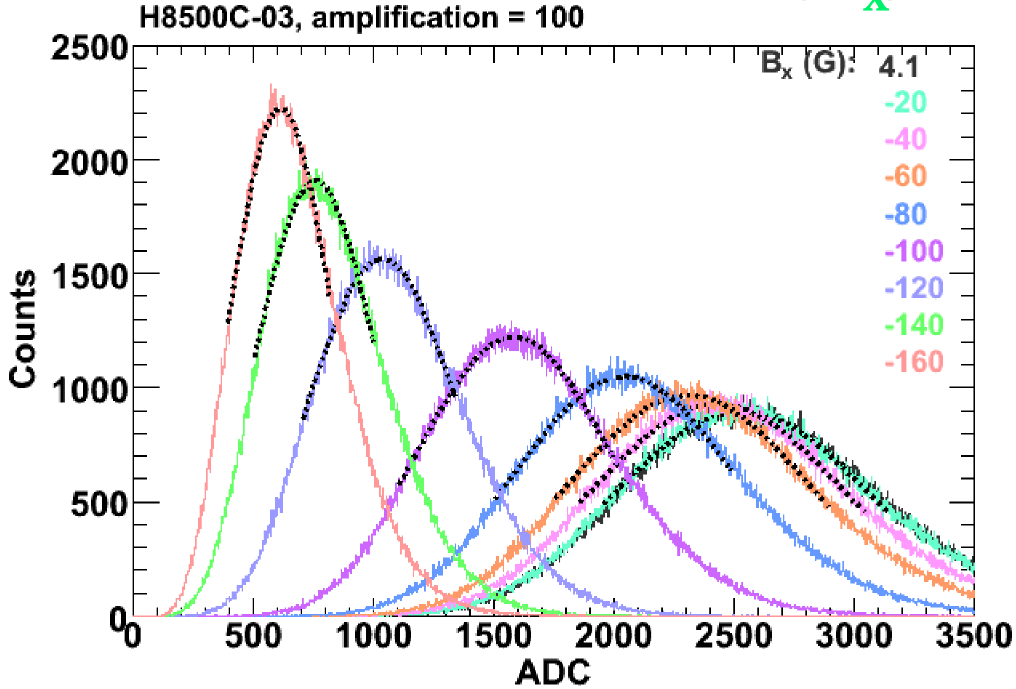


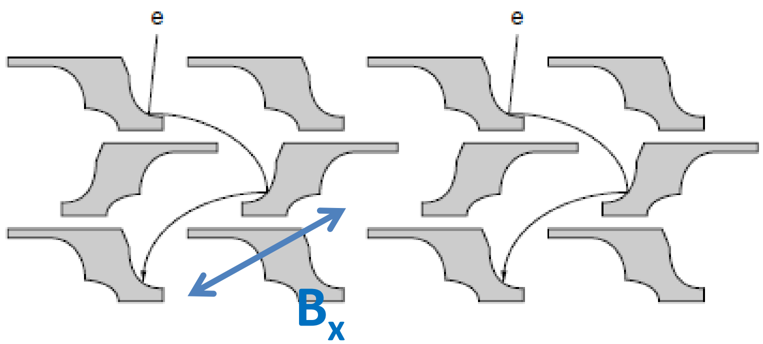
dark box inside the magnet

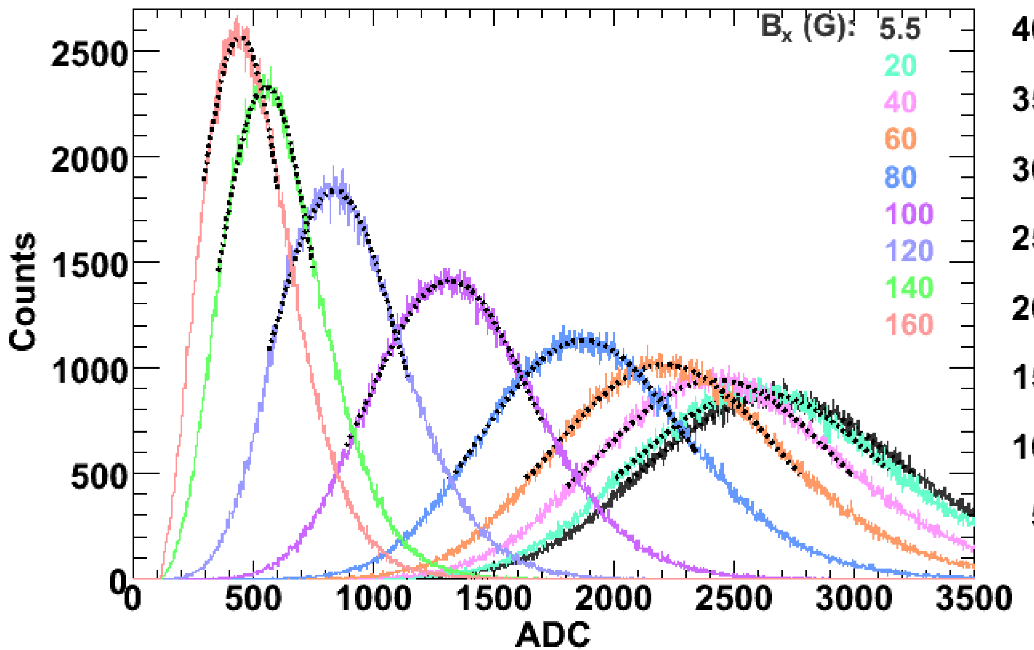
Magnetic field probe in position for field measurement

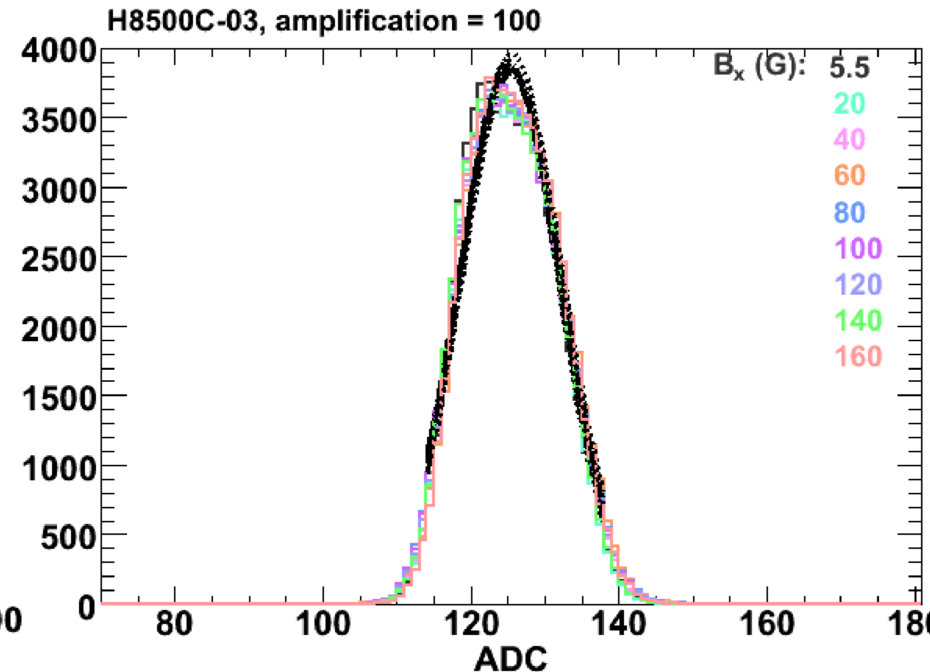


H8500C-03: Field (B_x) on Multi Photoelectrons

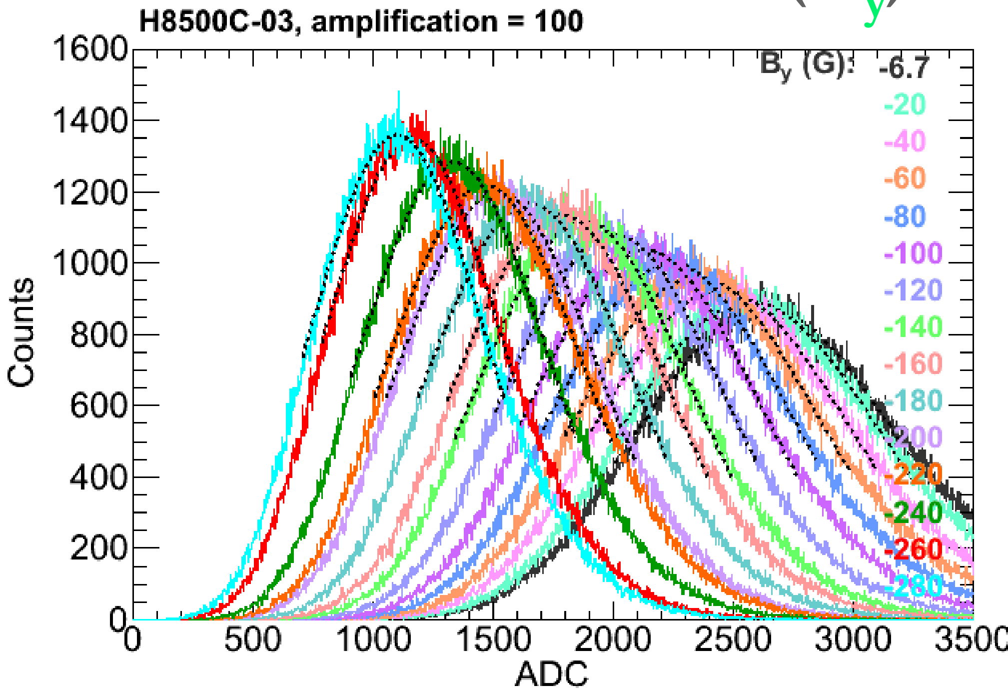


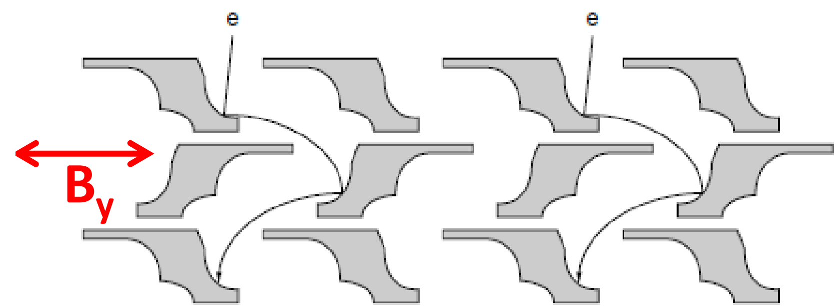


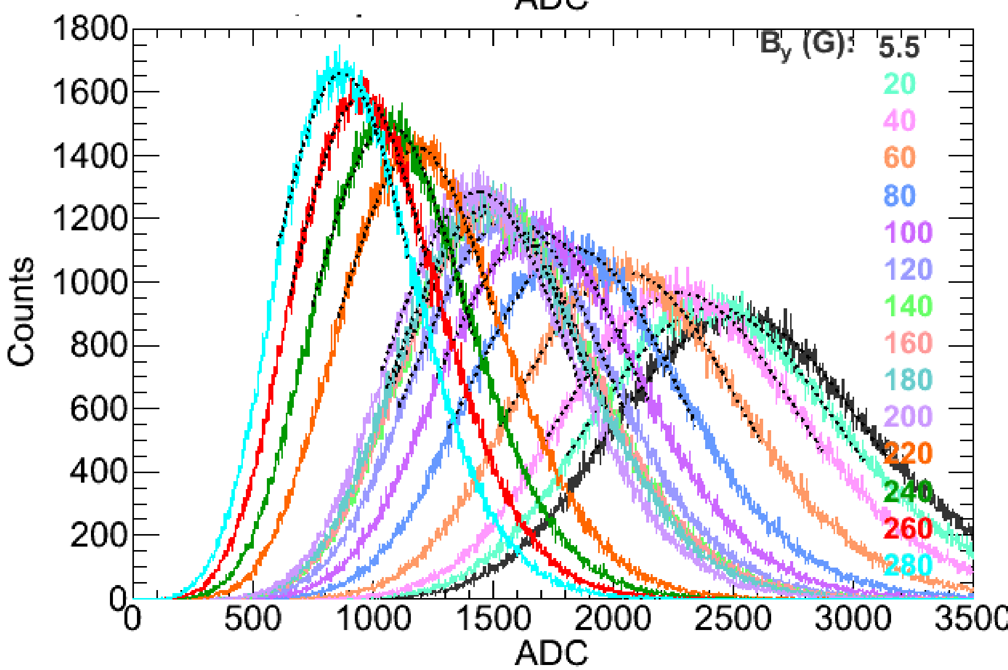


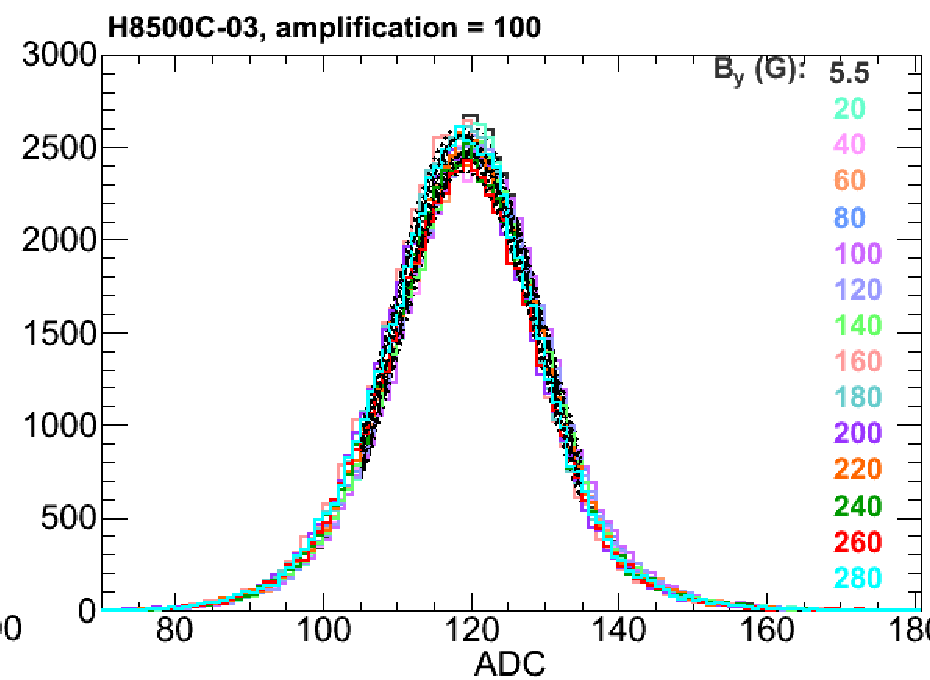


H8500C-03: Field (B_y) on Multi Photoelectrons

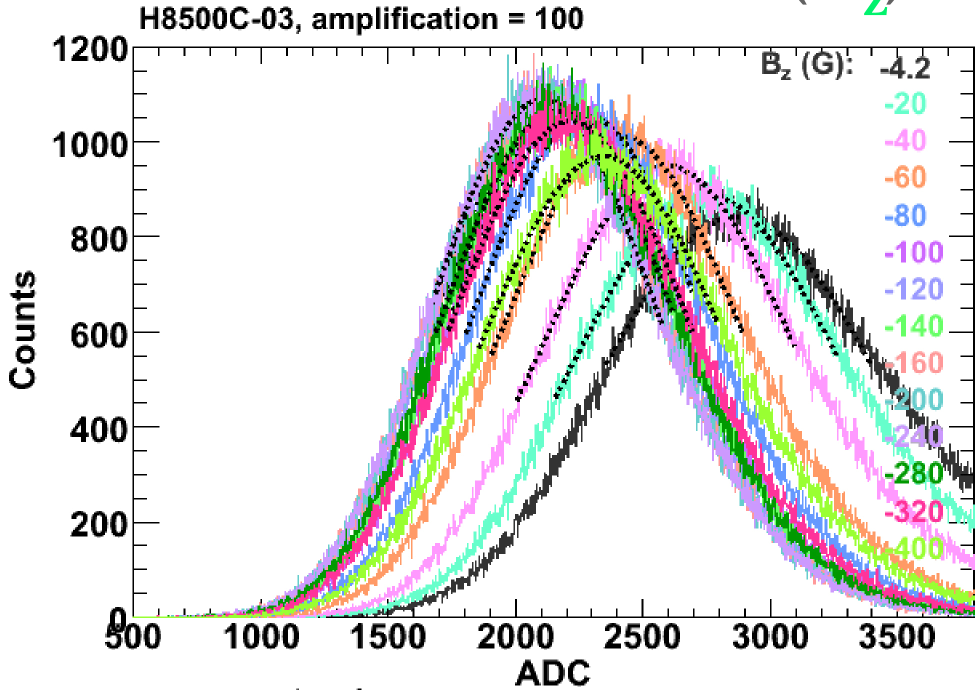


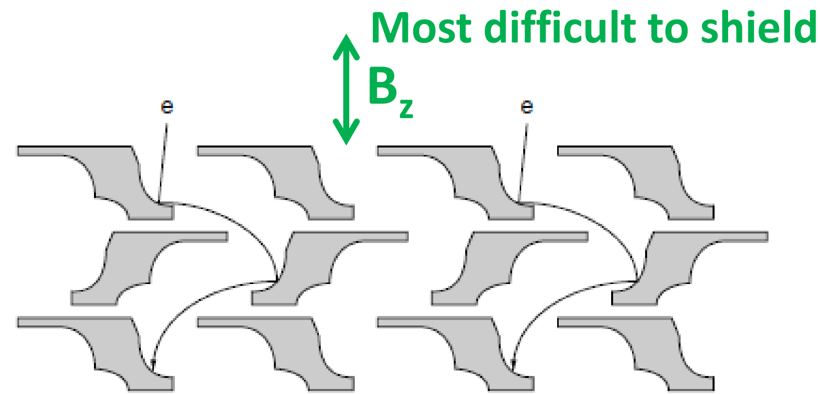


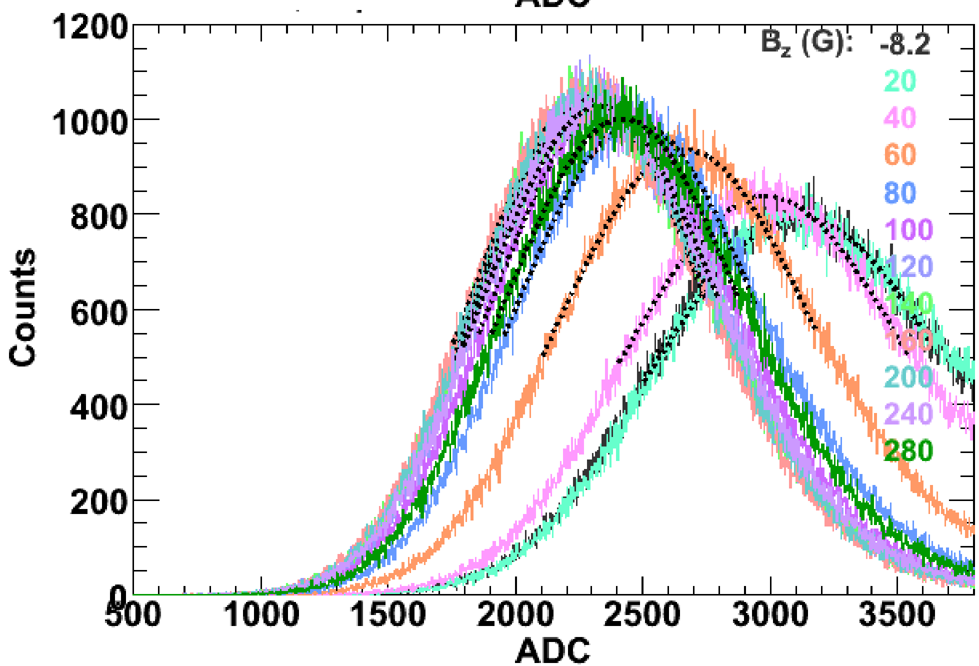


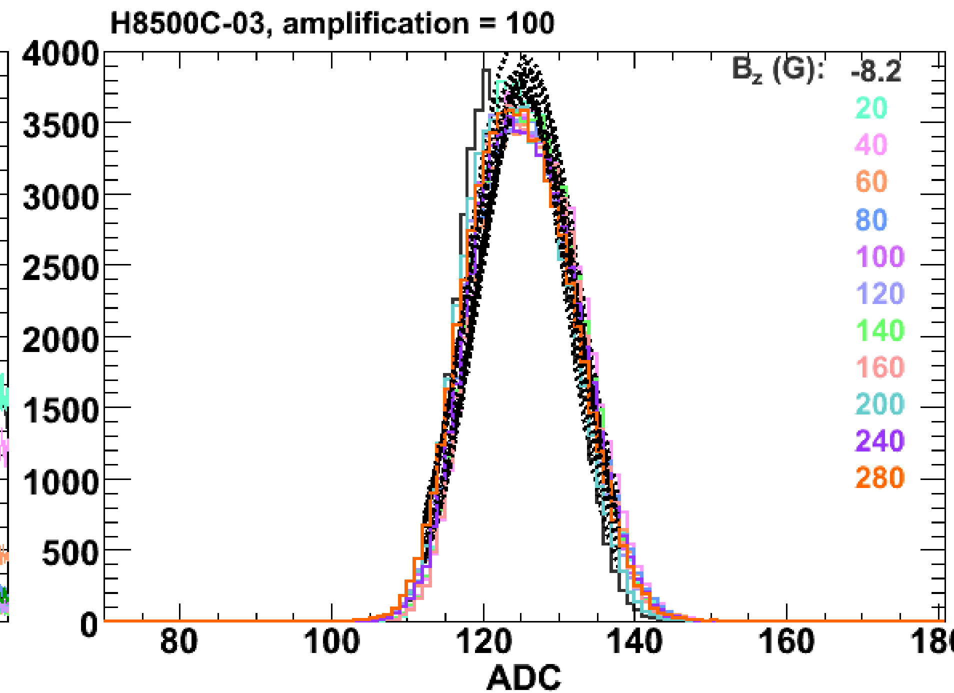


H8500C-03: Field (B_z) on Multi Photoelectrons

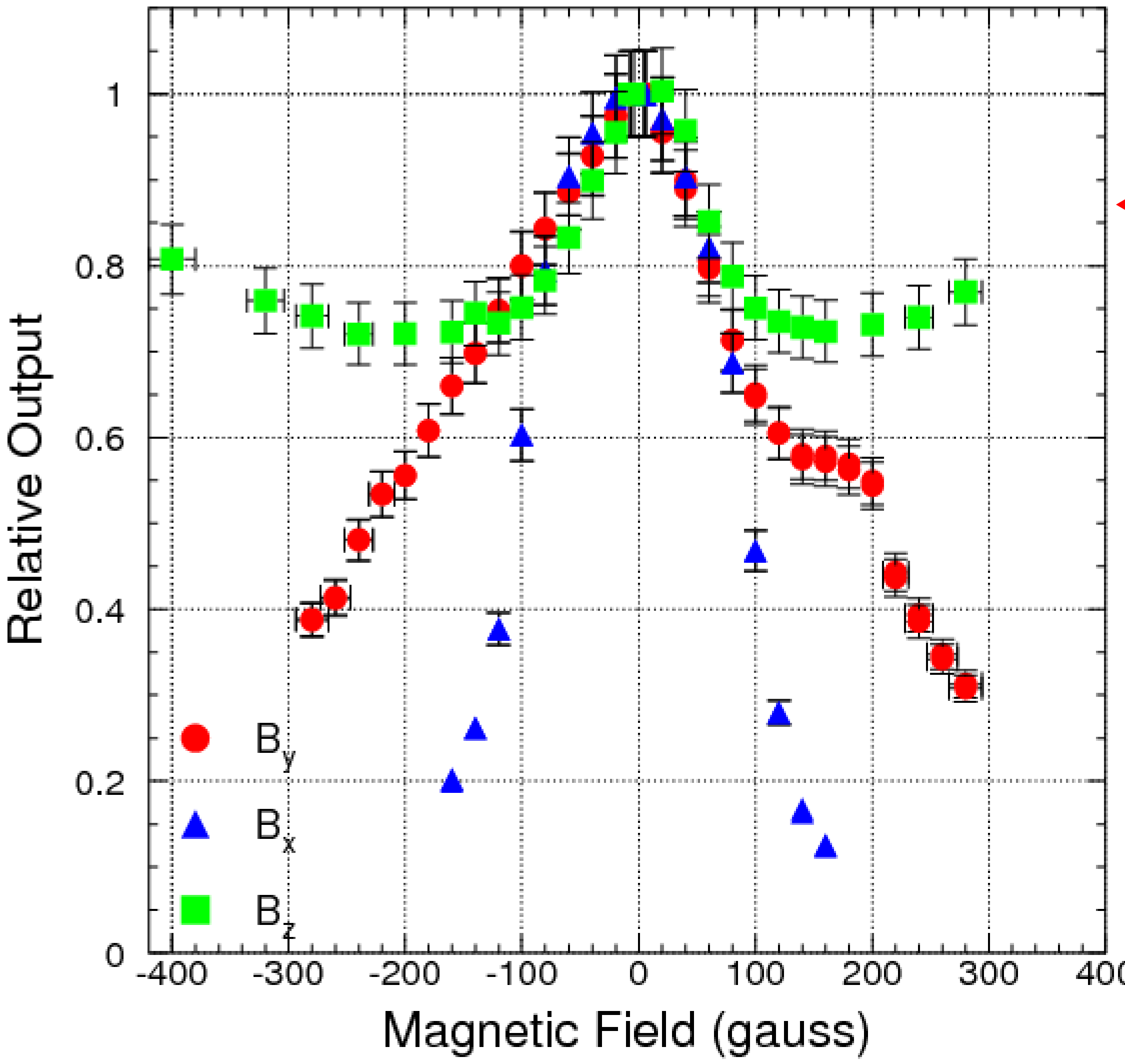


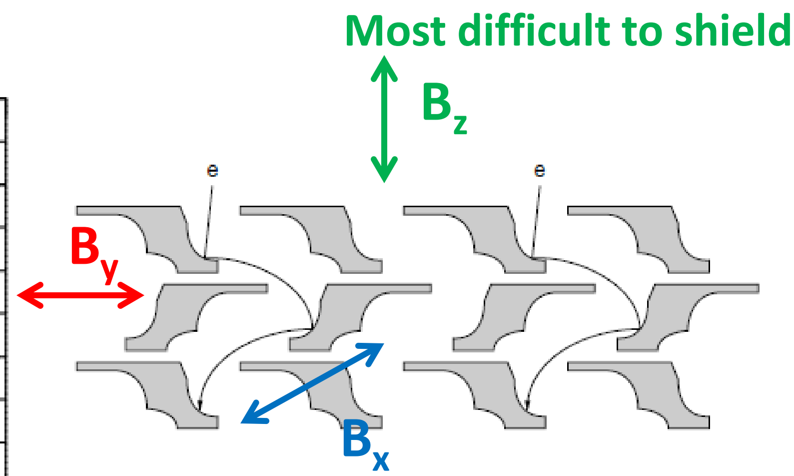






H8500C-03: Field on Multi Photoelectrons

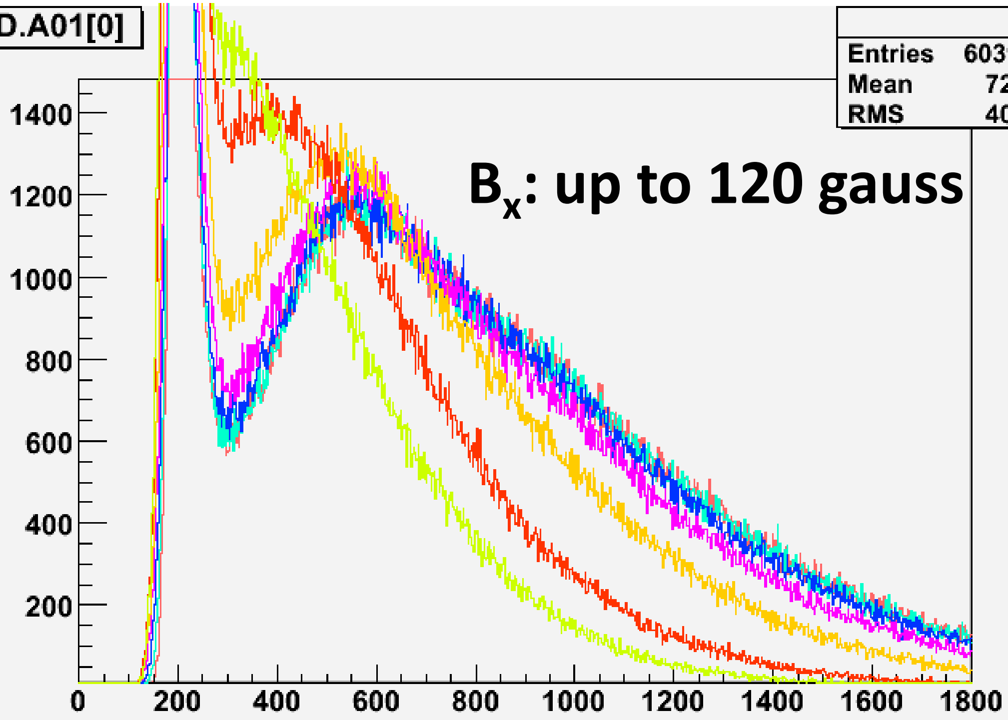




Most interesting feature: saturation of relative output with B_z

If the decrease in relative output is due to loss of gain (i.e. loss of secondary electrons on the dynode chain) it could be corrected with amplification and "superficial" shielding would be necessary

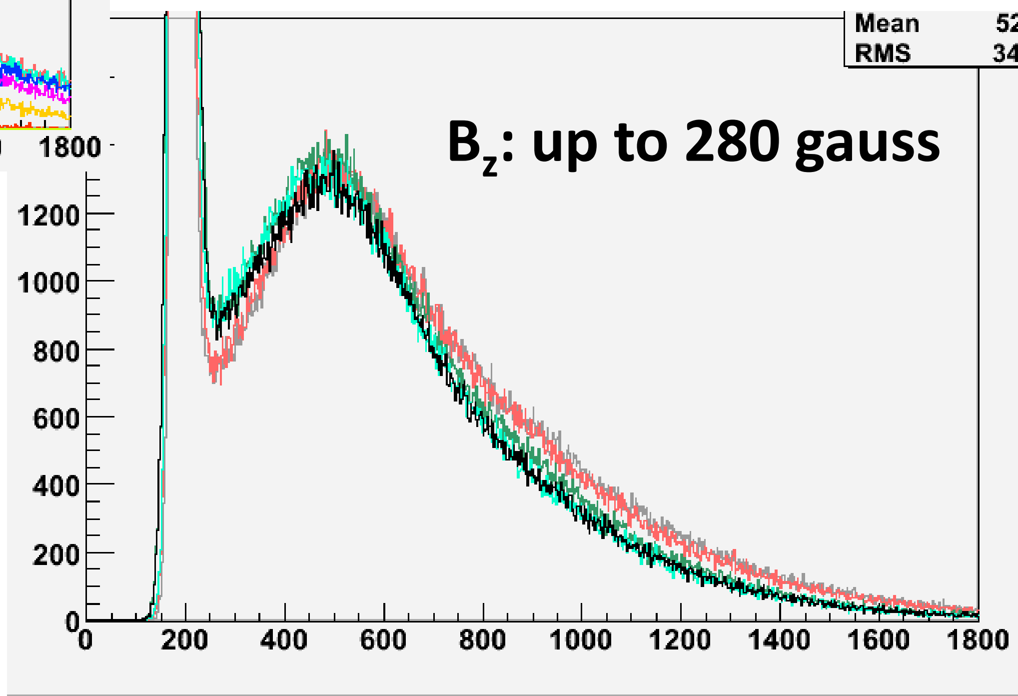
H8500C-03: Field on Single Photoelectron



To answer that question: **field impact on the SPE signal**; working on a fit to de-convolute background/signal

But it appears that there's little impact on SPE from a B_z field (need quantitative answer)

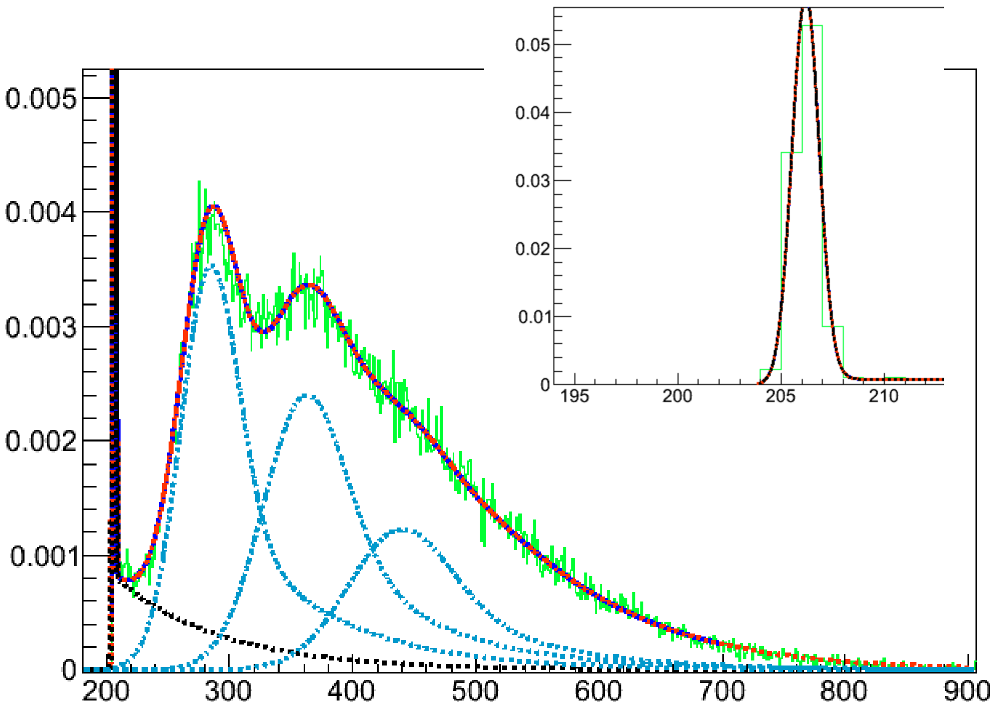
Not the case with B_x



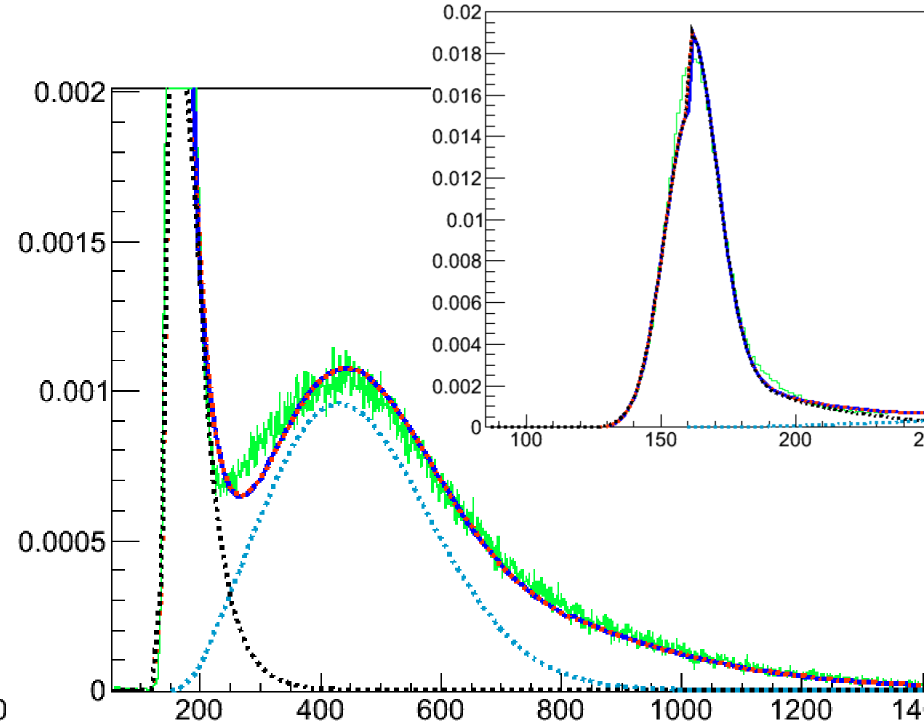
H8500C-03: Fitting Single Photoelectron Distributions

$$S_{real}(x) = \int S_{ideal}(x')B(x - x')\,dx' = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \times \left[(1 - w)G_n(x - Q_0) + wI_{G_n \otimes E}(x - Q_0)\right],$$

Works if gain off the first dynode large enough to approximate a Poisson distribution with a Gaussian one



Works for a 5 inch Photonis tube with “high” gain



Does not works for the maPMT

Looking into a more suitable functional form for the maPMT response function…

Backup Slides

Optimization of optical system

GEMs + CsI

→ Photocathode

→ GEMs

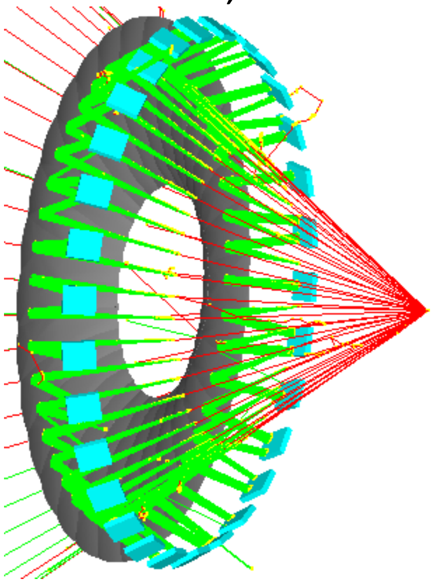
→ Gas

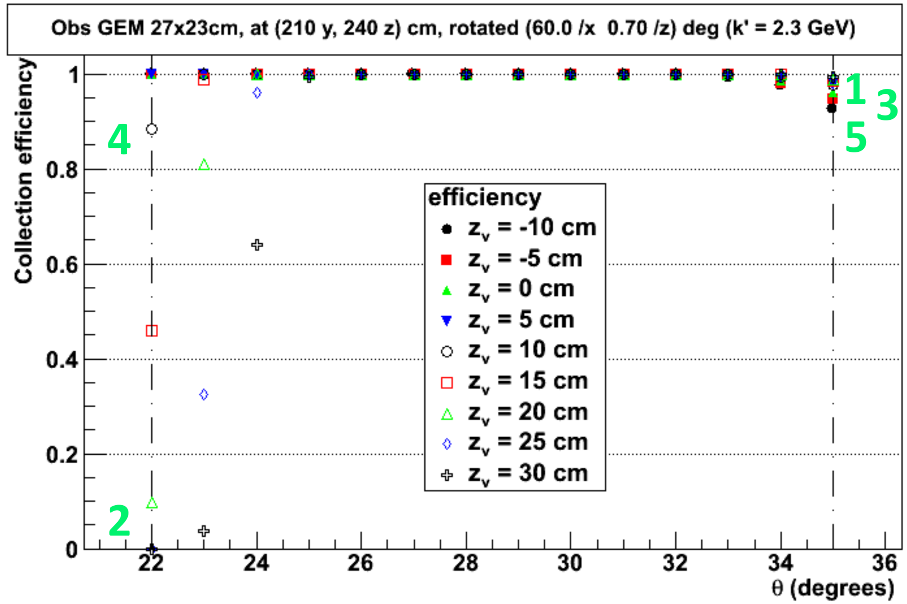
→ Mirrors

PMTs: H8500C-03

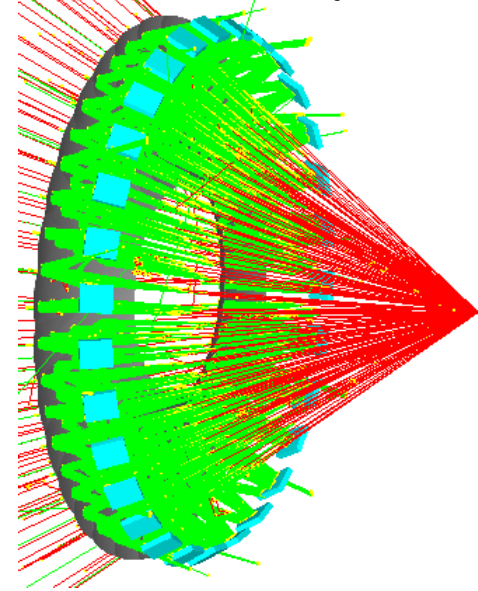
Optimization: PVDIS, GEMs + CsI

1 35, Z = +30

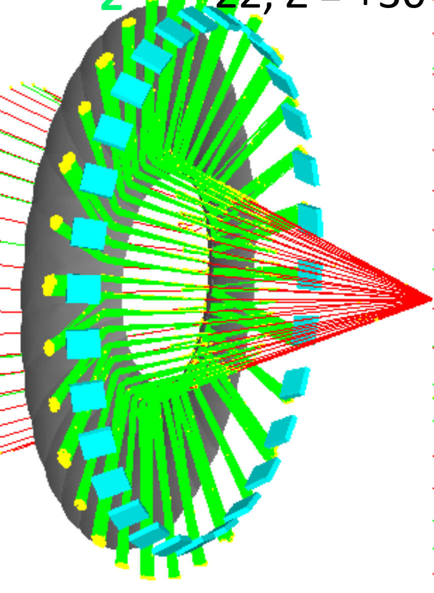




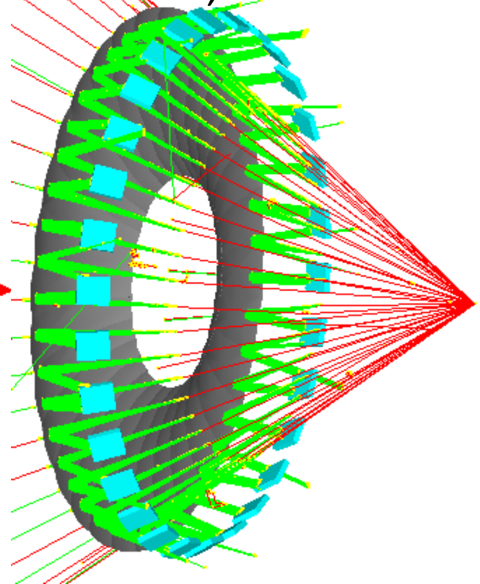
Z = 0



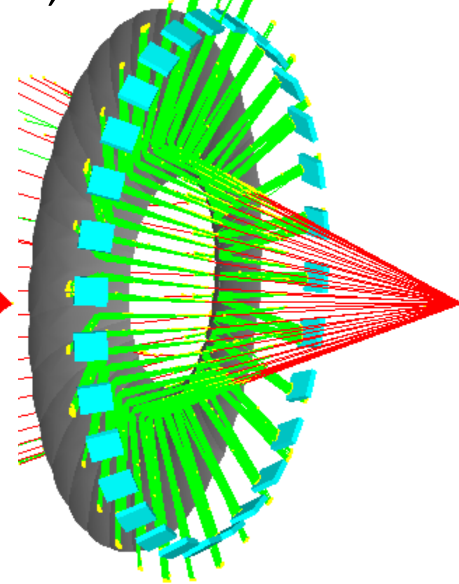
2 22, Z = +30



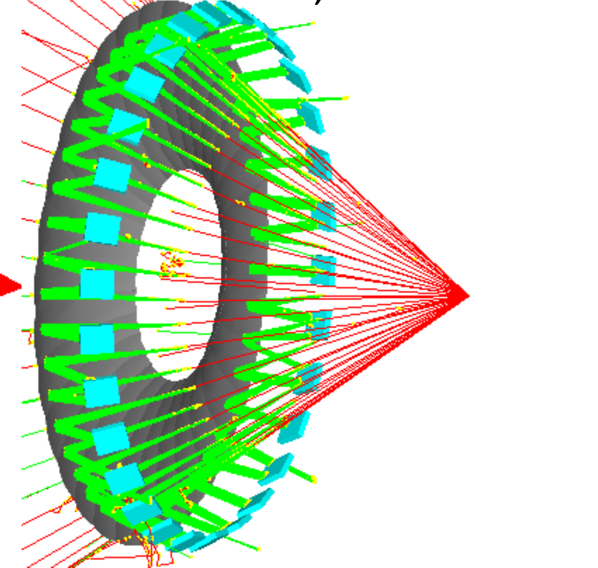
3 35, Z = -10



4 22, Z = +10

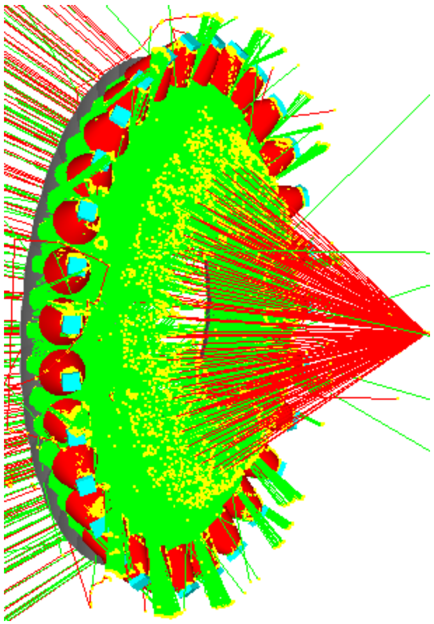


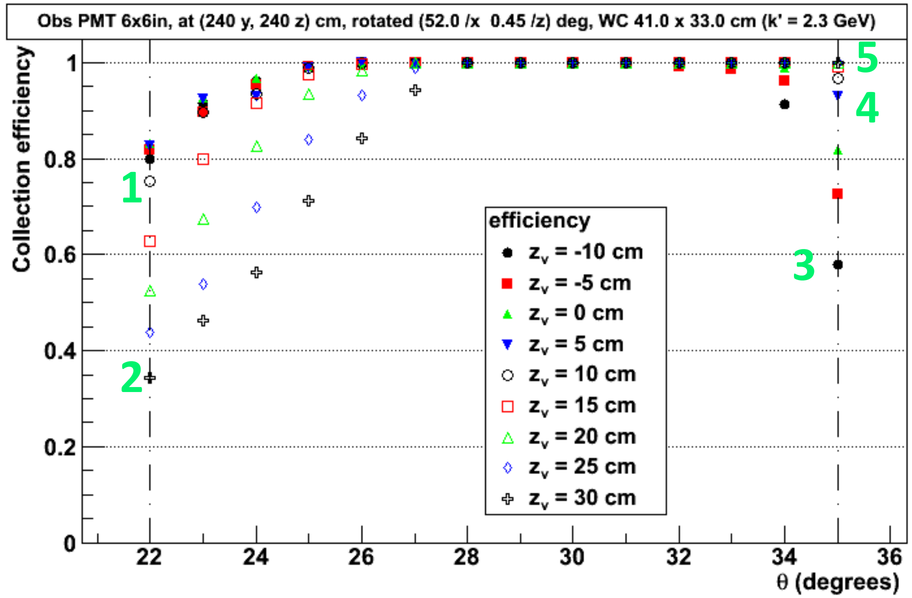
5 35, Z = +10



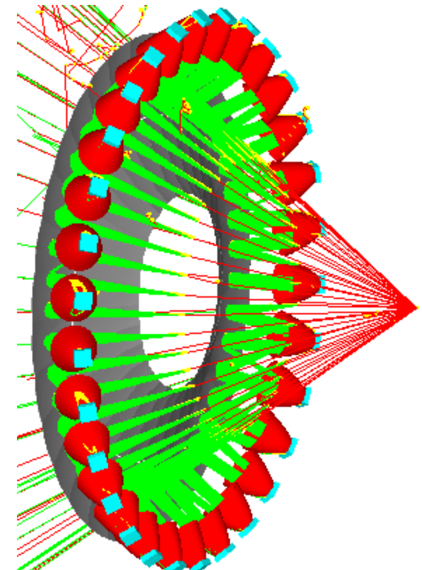
Optimization: PVDIS, PMTs

Z = +10

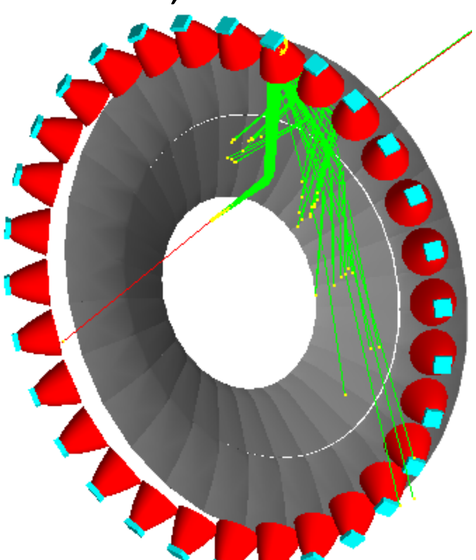




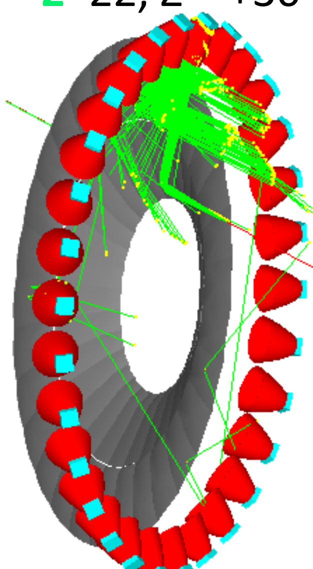
5 35, Z = +30



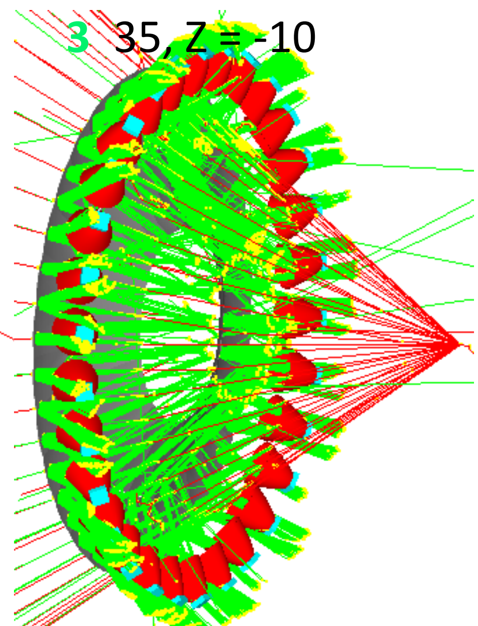
1 22, Z = +10



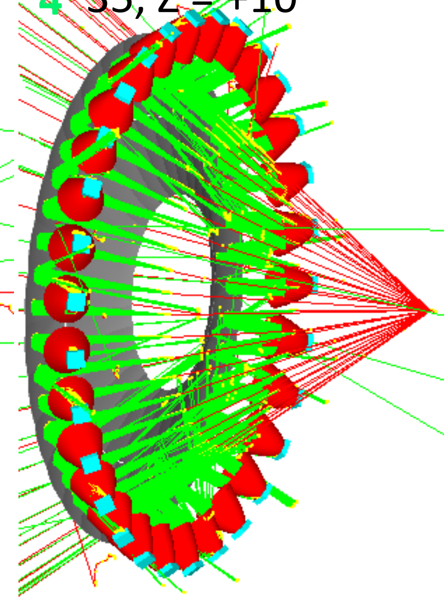
2 22, Z = +30



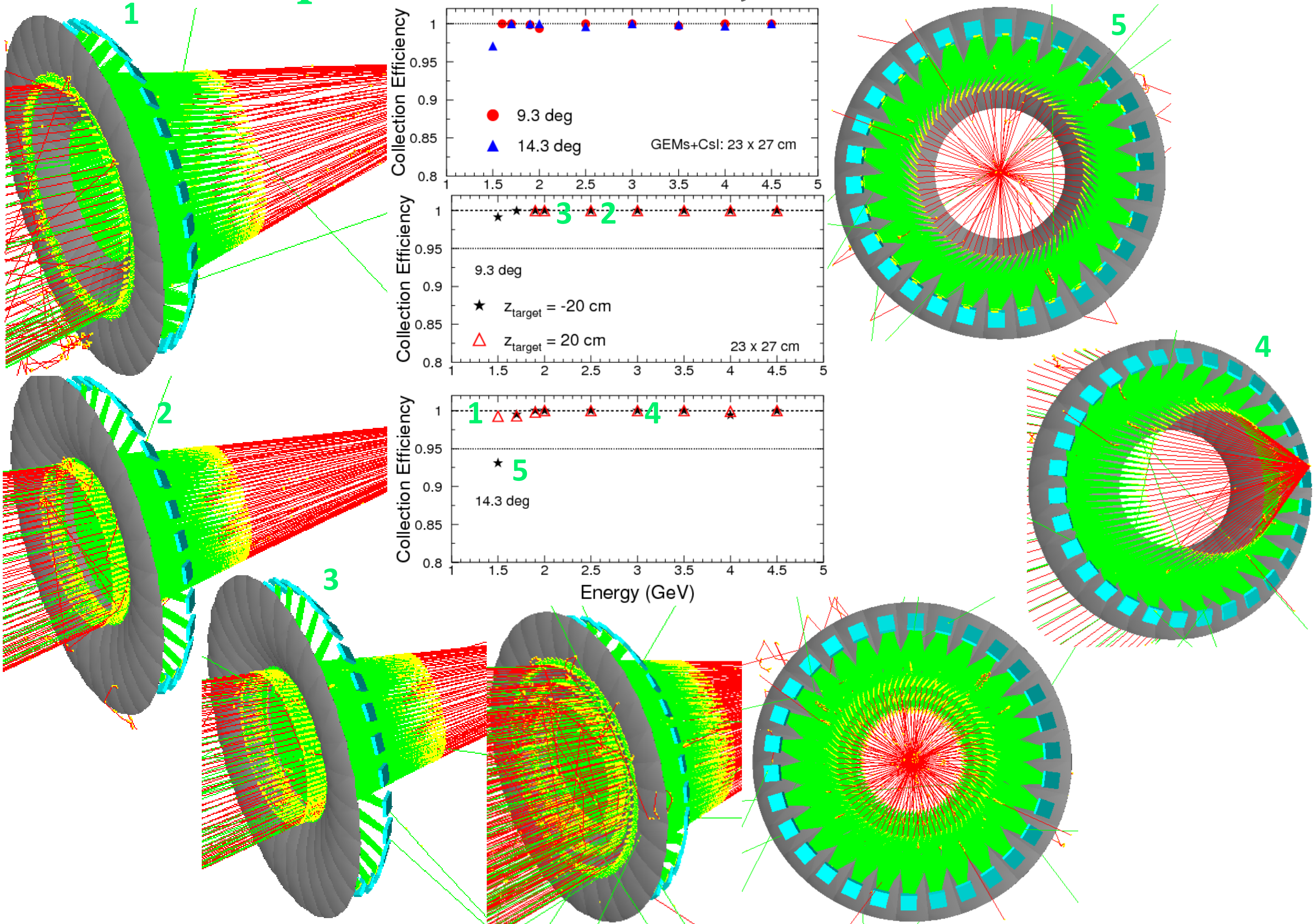
3 35, Z = -10



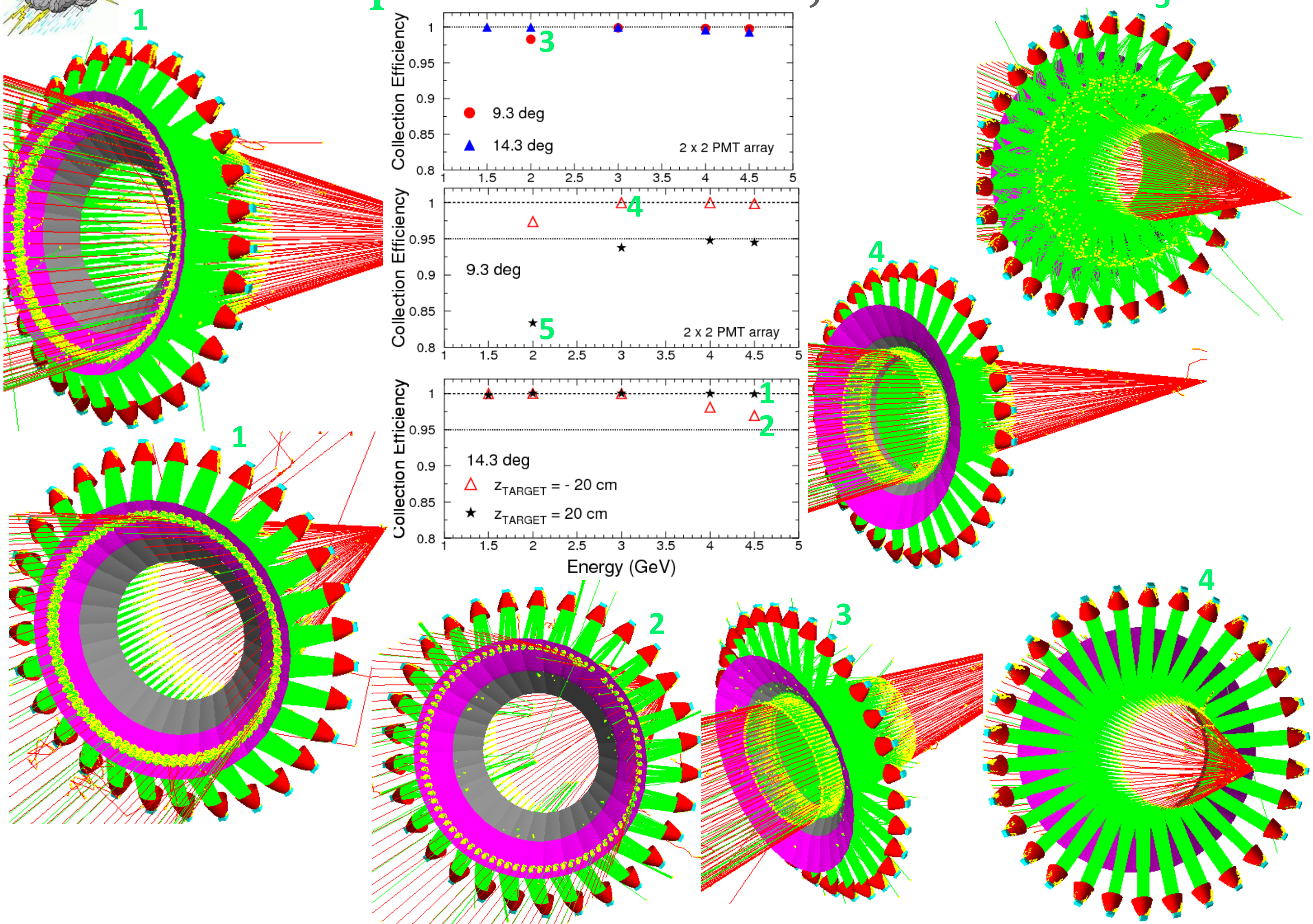
4 35, Z = +10



Optimization: SIDIS, GEMs + CsI



Optimization: SIDIS, PMTs



GEMs + CsI: Photocathode

➡ General, ~random facts about CsI: why CsI?

→ highest efficiency of solid UV photocathodes: low electron affinity & large electron escape probability

→ UV photocathode preferred over visible range ones because the latter are highly reactive to even extremely small amounts of impurities (oxygen, water)

→ typically deposited on metal substrates (or optically transparent substrates if semitransparent)

→ deposition on Cu should be avoided (Cu and CsI interact chemically): best results deposition of CsI on Cu coated with Ni or Ni/Au

→ Photoemission of electrons depends on gas and electric field

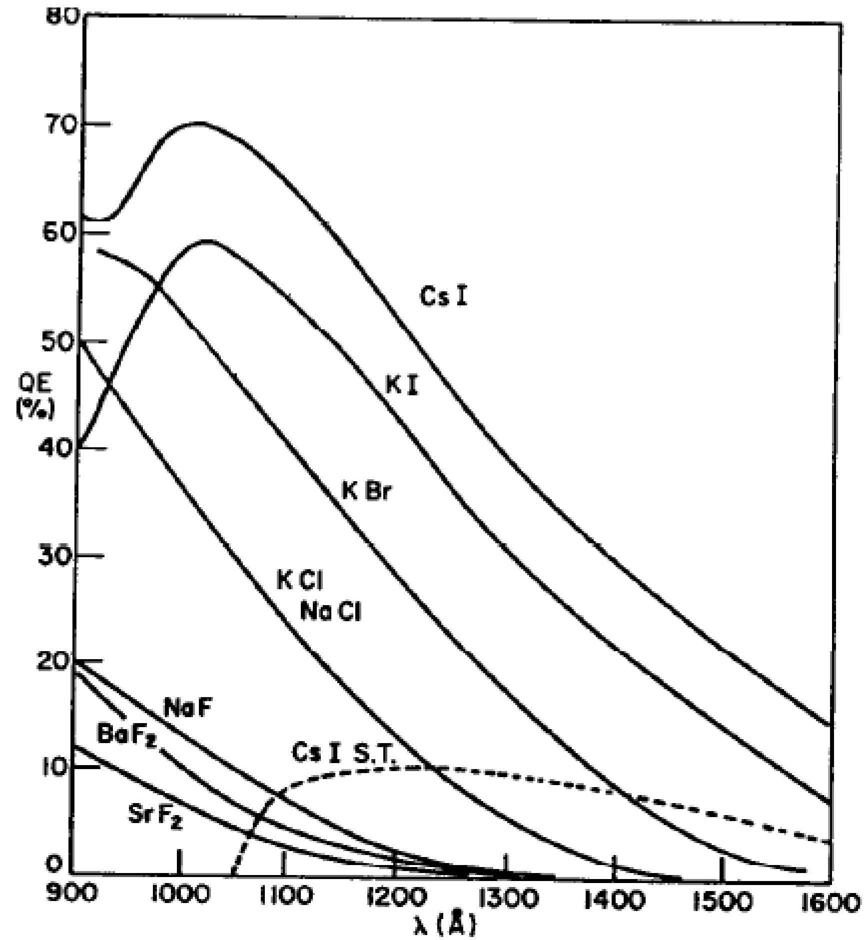


Fig. 1. Typical quantum yields versus wavelength for reflective alkali halide photocathodes. Shown for comparison is a typical quantum yield curve for a semitransparent CsI photocathode deposited on a LiF window (CsI S.T.) [2].

A. Breskin, NIM A 371 (1996) 116-136

GEMs + CsI: Photocathode

➡ **General, ~random facts about CsI: degradation because of …**

→ **humidity**: decay caused by hydrolysis
example: 50% reduction in QE after 100 min. exposure to air with 50% humidity

→ post-evaporation heat-treated photocathodes have a considerably lower decay rate when exposed to humidity ⟶

→ **intense photon flux and ion bombardment**: decay caused by dissociation of CsI molecules; iodine atoms evaporate and Cs+ with a higher e- affinity causes a reduction in QE

→ **surface contamination**

→ **radiation damage with neutral or charged particles**

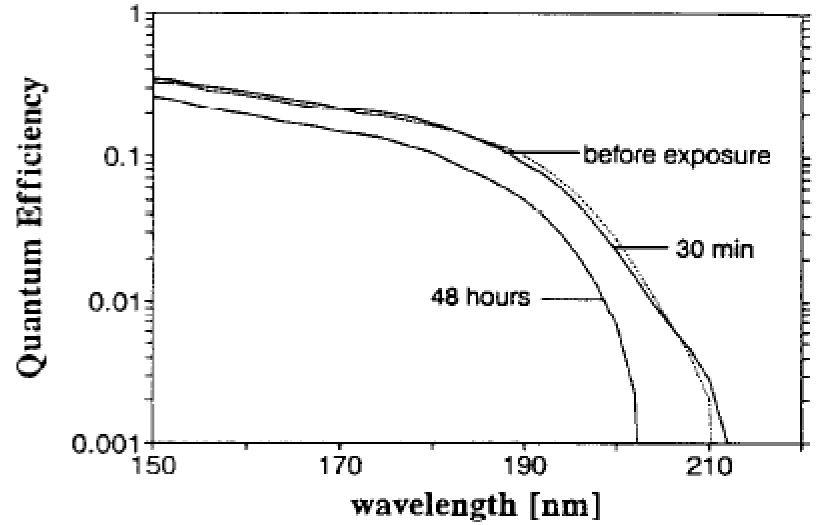
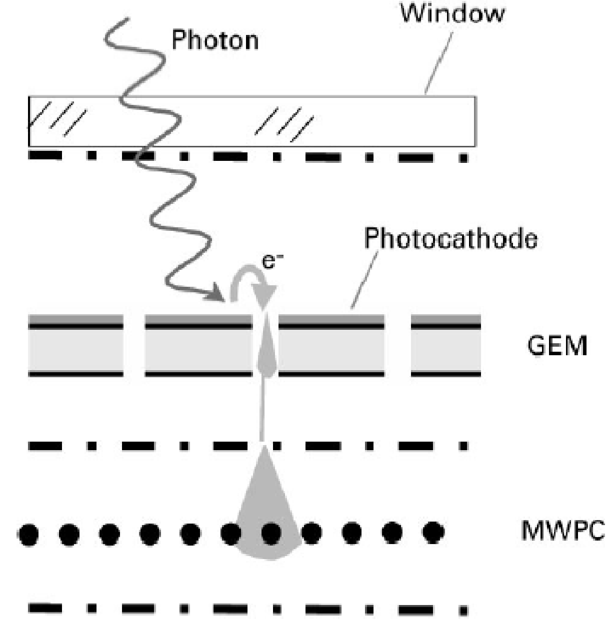


Fig. 22. The decay of the QE of CsI films evaporated on Ni/Au-coated printed circuit board under exposure to air, at a relative humidity of 35% [30].

A photon-feedback blind detector: avalanche-induced photons CANNOT reach the photocathode



A. Breskin, NIM A 371 (1996) 116-136

A. Breskin et al., NIM A 442 (2000) 58-67

GEMs + CsI: Photocathode

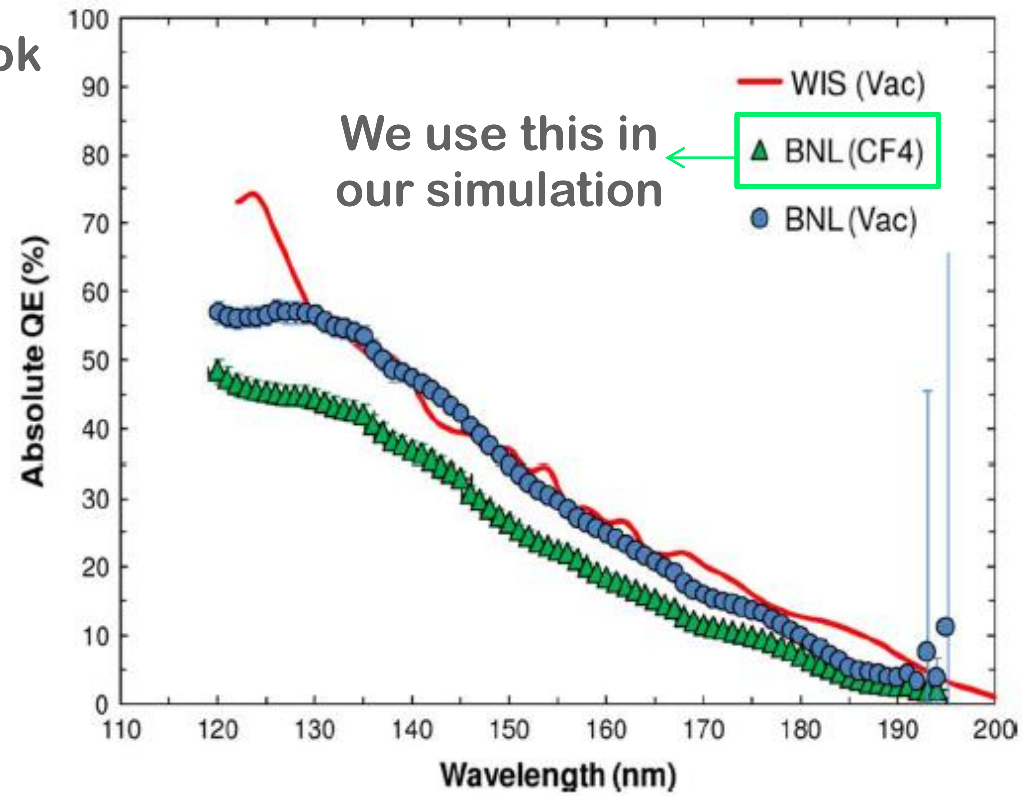
⇨ PHENIX facts on CsI: deposition, QE measurements, monitoring

→ assembly and coating: Stony Brook

GEMs assembled in clean (dust-free) and dry (H_2O < 10 ppm) environment

Au GEMs coated with CsI using evaporator; QE measured at one wavelength, 160 nm (at BNL the QE is measured from 120 nm to 200 nm)

The CsI coated GEMs are then transferred and assembled inside a glovebox



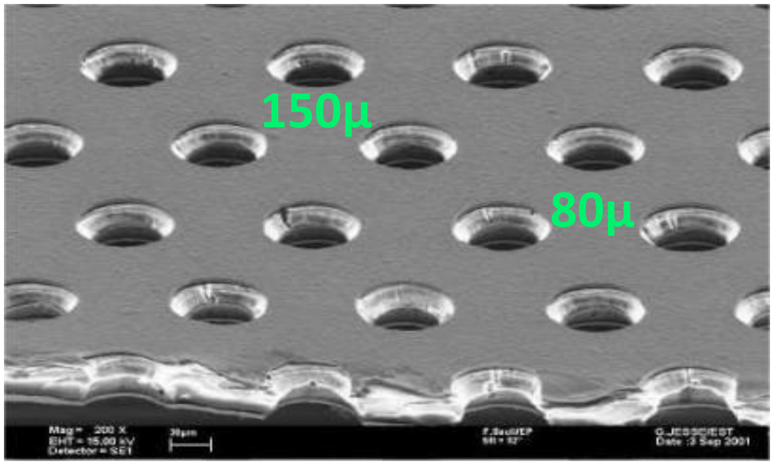
→ relative measurements of CsI QE performed periodically during PHENIX to check for possible degradation (special device needed)

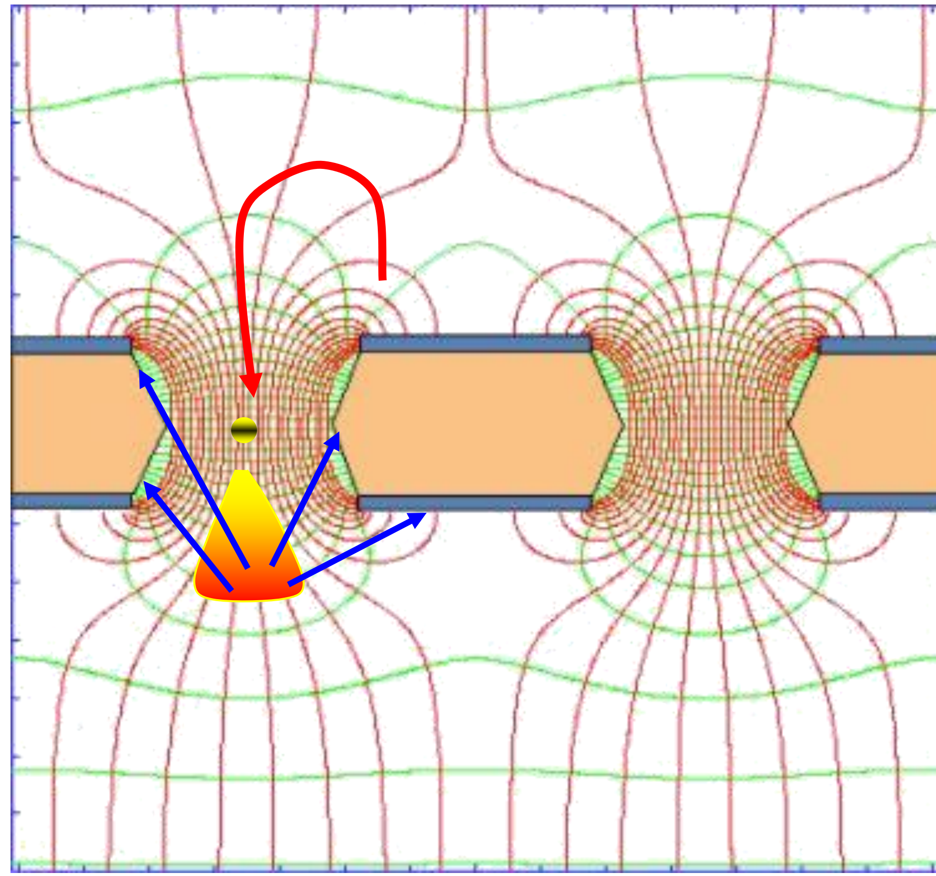
arXiv:1103.4277v1 [physics.ins-det] 22 Mar 2011

B. Azmoun *et al.*, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 56, NO. 3, JUNE 2009

GEMs + CsI: GEMs

➡ GEMs: pictures from Tom Hemmick





→ HV creates very strong field such that the avalanche develops inside the holes

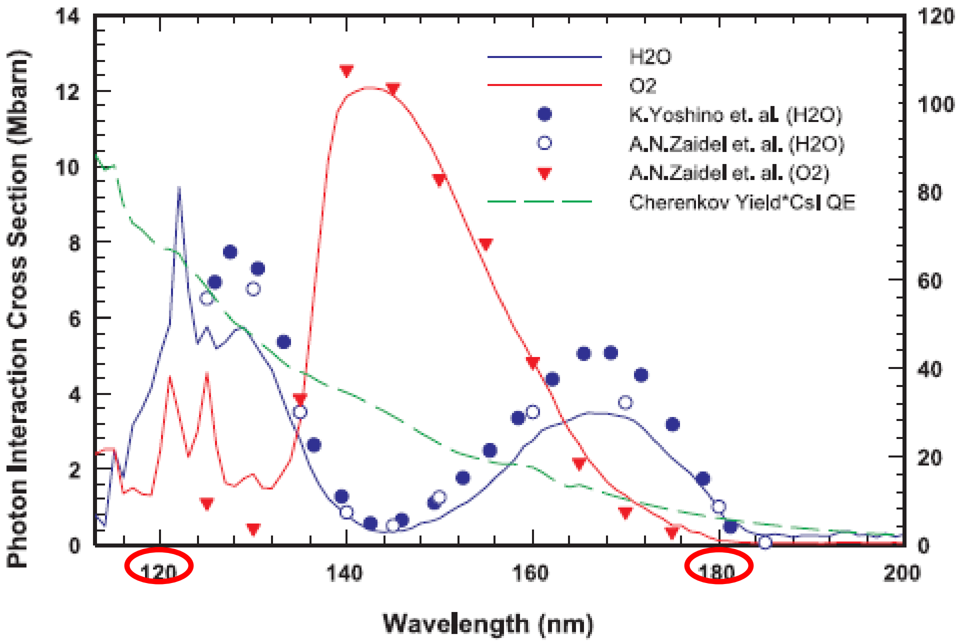
Makes it insensitive to magnetic field

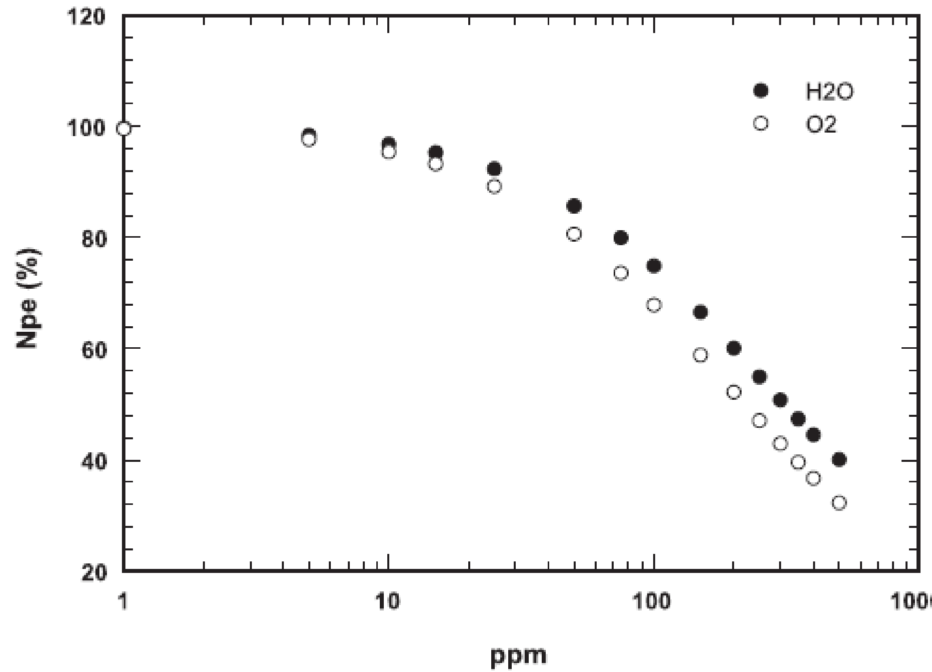
Deposition of photocathode on the first layer of GEM makes it photon-feedback blind: avalanche-induced photons CANNOT reach the photocathode

GEMs + CsI: Gas

➡ Need a gas transparent to deep UV light: CF_4

- The gas purity is very important: impurities can affect the gas transmittance (and photocathode performance)





Water and Oxygen: strong absorption peaks for Cherenkov light where CsI is sensitive (< 200 nm)

Small levels of either impurity => loss of photons and therefore loss of photoelectrons

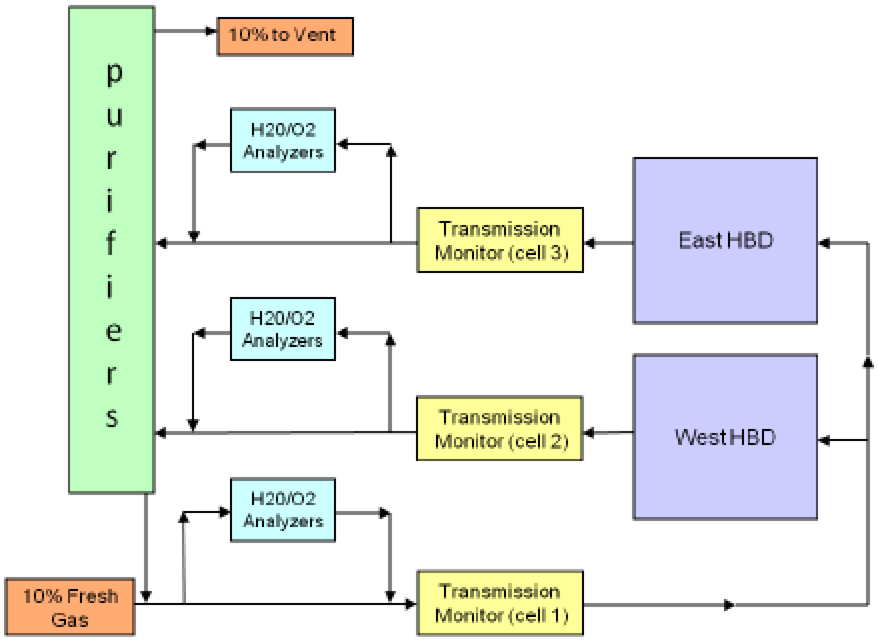
- PHENIX had an independent monitoring system to detect low levels of contamination

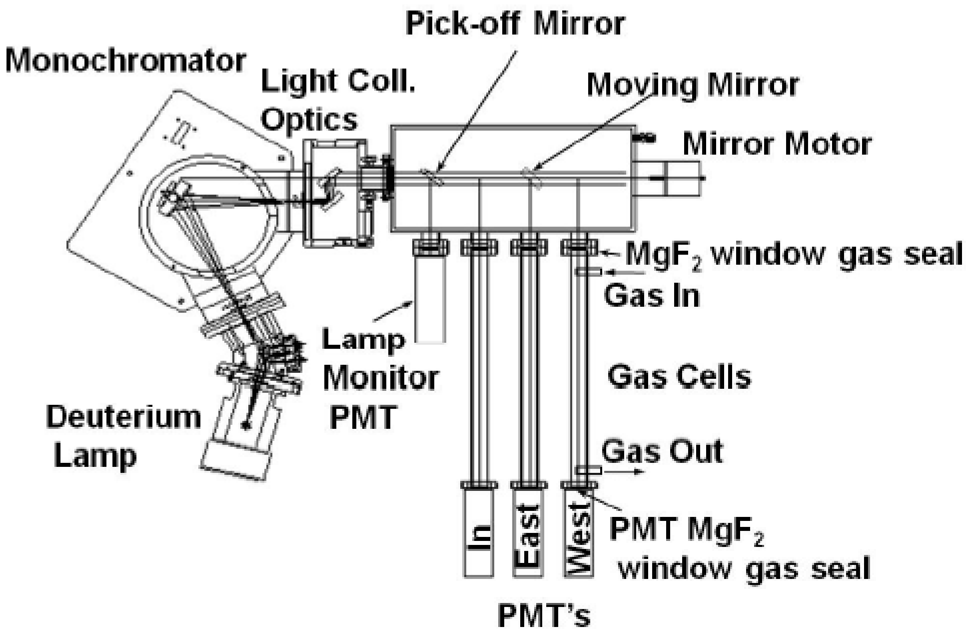
arXiv:1103.4277v1 [physics.ins-det] 22 Mar 2011

GEMs + CsI: Gas

➡ Need a gas transparent to deep UV light: CF_4

- The gas purity is very important: impurities can affect the gas transmittance (and photocathode performance)





- PHENIX recirculating gas system used to supply and monitor pure CF_4 gas

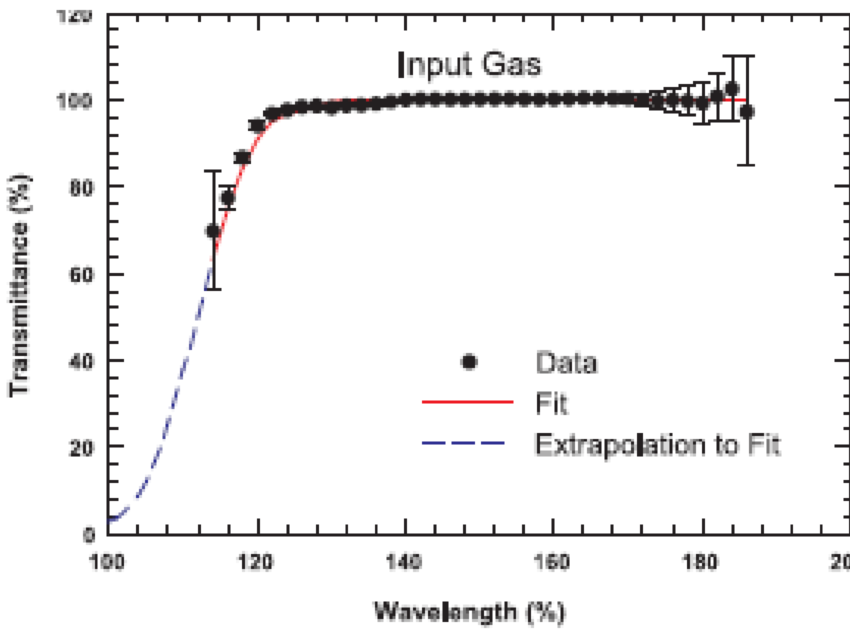
- Gas transmittance monitor system used by PHENIX to measure impurities at the few ppm level

arXiv:1103.4277v1 [physics.ins-det] 22 Mar 2011

GEMs + CsI: Gas

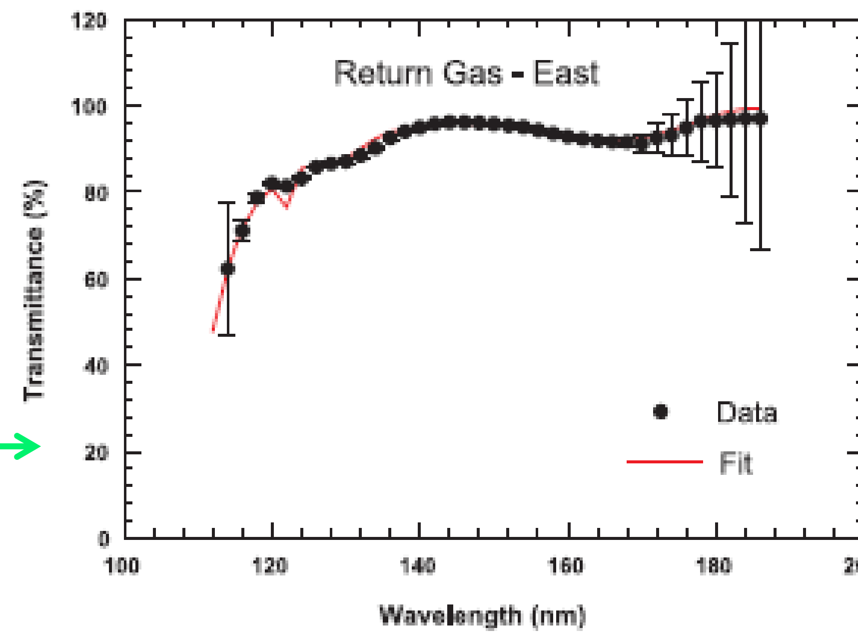
➡ Need a gas transparent to deep UV light: CF_4

- The gas purity is very important: impurities can affect the gas transmittance (and photocathode performance)



Very good purity of the input gas: < 2 ppm impurities (water and oxygen)

The output gas: 20-30 ppm water and 2-3 ppm oxygen impurities



- Throughout PHENIX run: < 5% loss of photoelectrons because of gas impurities

arXiv:1103.4277v1 [physics.ins-det] 22 Mar 2011

GEMs + CsI: Mirrors

➡ We need mirrors with good reflectivity in deep UV

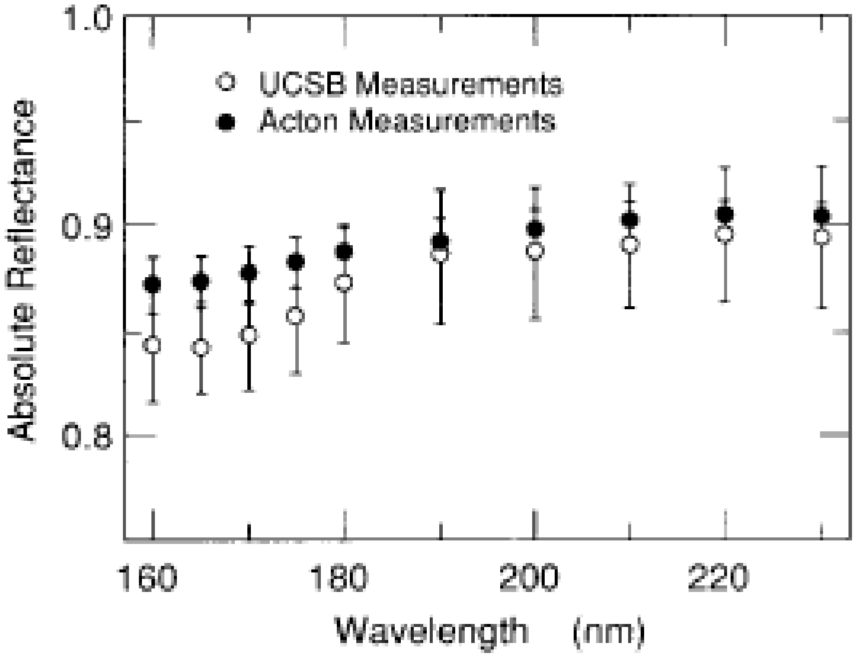


Fig. 8. Results of the reflectivity measurement of the witness coupons for all 430 mirrors at Acton Corp. and UCSB for the light at wavelengths 160–230 nm.

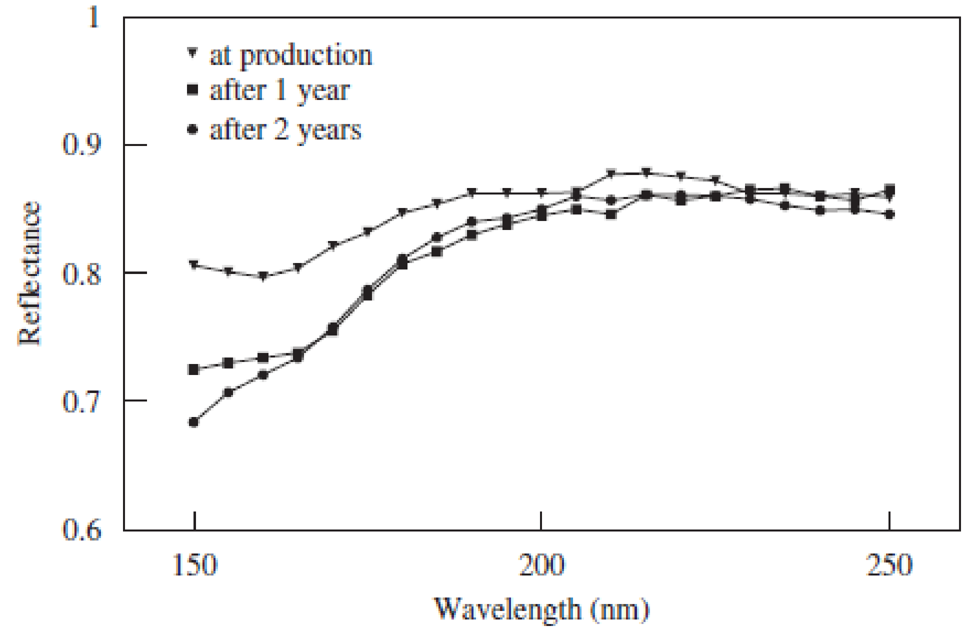


Fig. 36. Measured reflectance for a typical mirror piece. The measurements have been performed shortly after production, 1 and 2 years later.

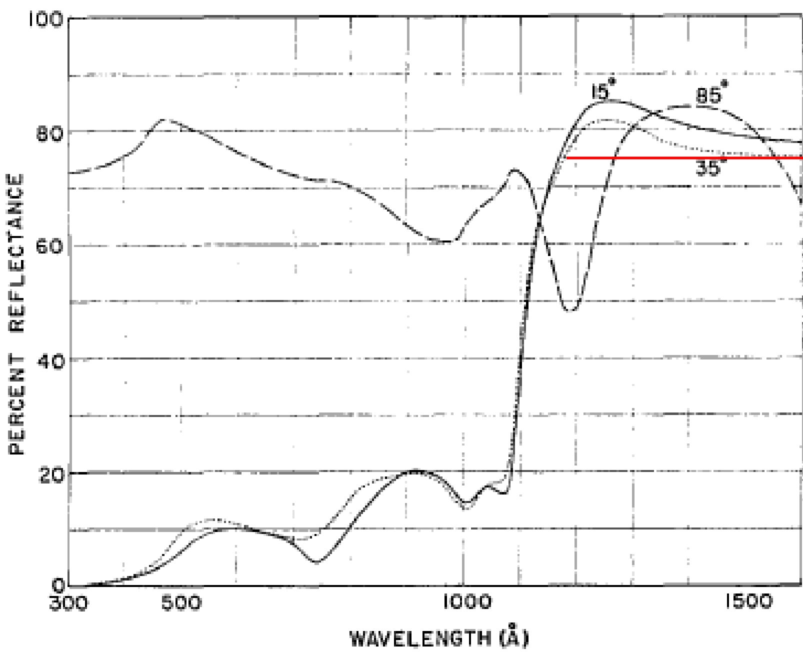
Nuclear Instruments and Methods in Physics Research A300 (1991) 501-510

P. Abbon et al. , Nuclear Instruments and Methods in Physics Research A 577 (2007) 455–518

cutoff at 150 nm from quartz window

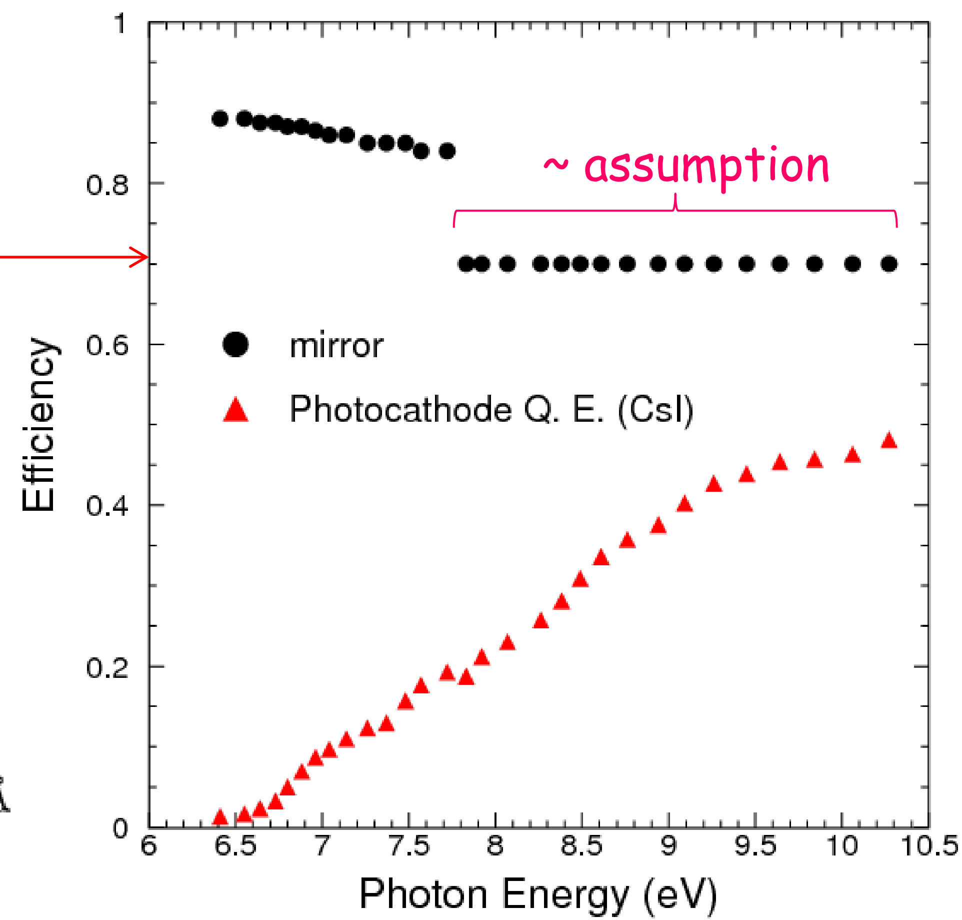
GEMs + CsI: Mirrors

➡ We need mirrors with good reflectivity in deep UV



Measured reflectance of an Al + MgF_2 mirror from 300 Å to 1600 Å. The MgF_2 thickness is 250 Å.

March 1971 / Vol. 10, No. 3 / APPLIED OPTICS

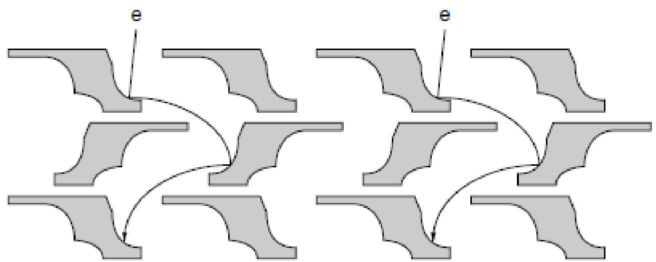


We use this in our simulation

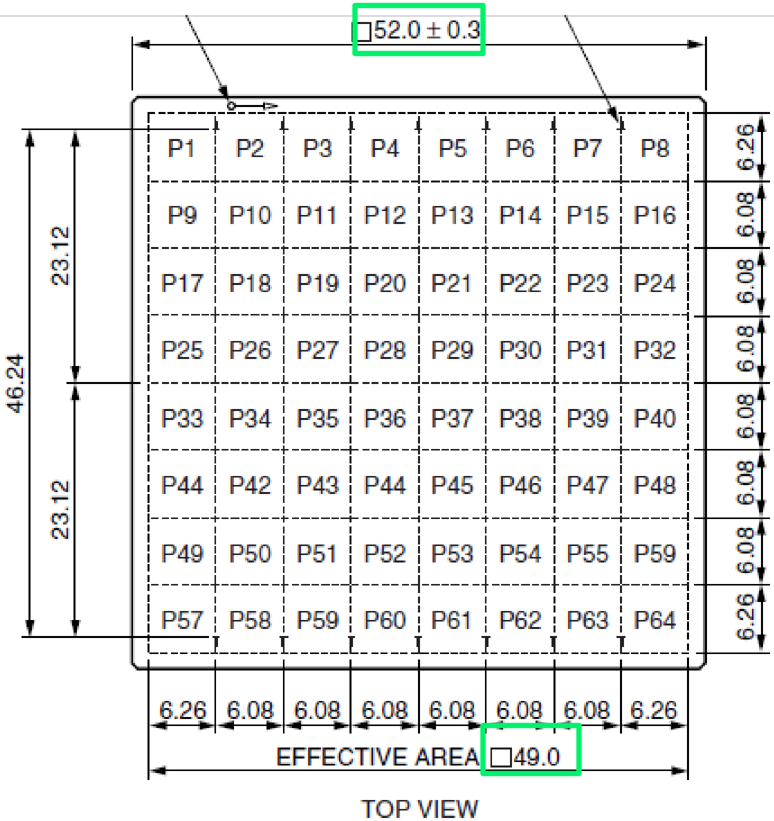
PMT: H8500C-03

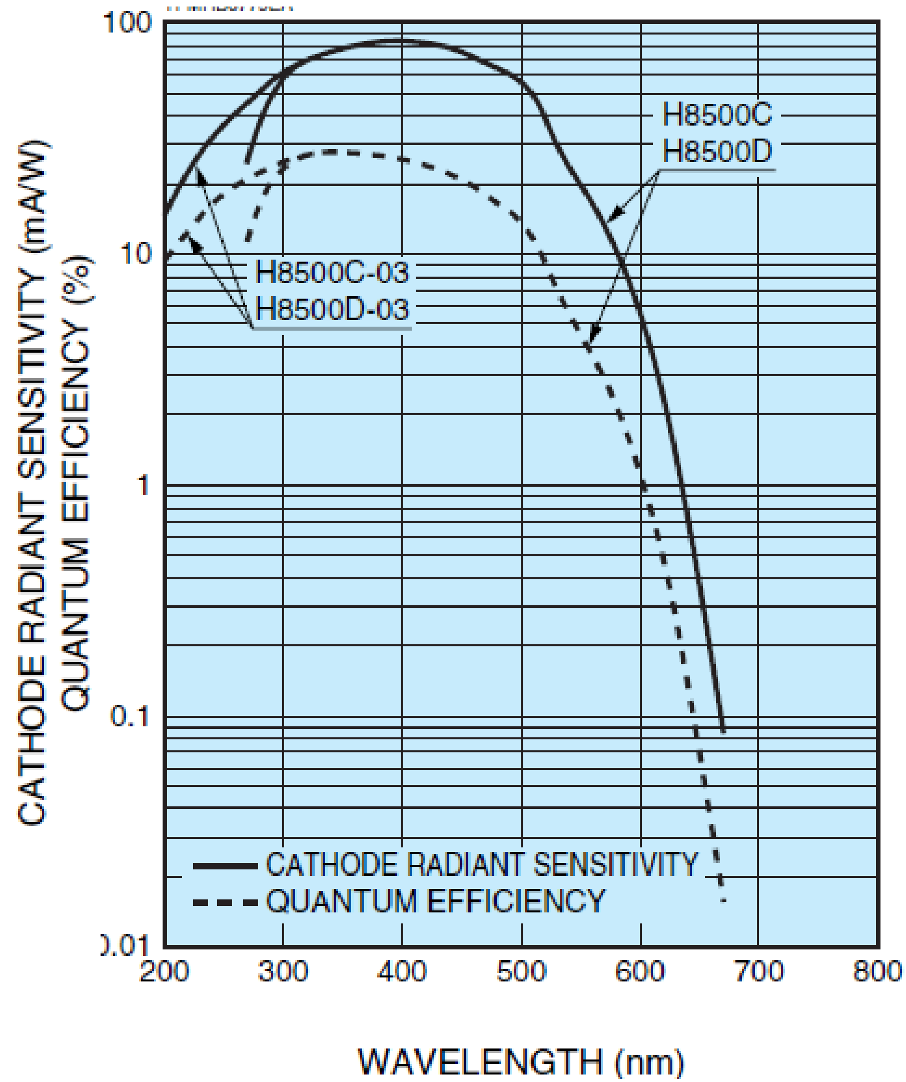
➡ Hamamatsu specifications:

→ Metal channel dynode structure



→ 64-channel multianode

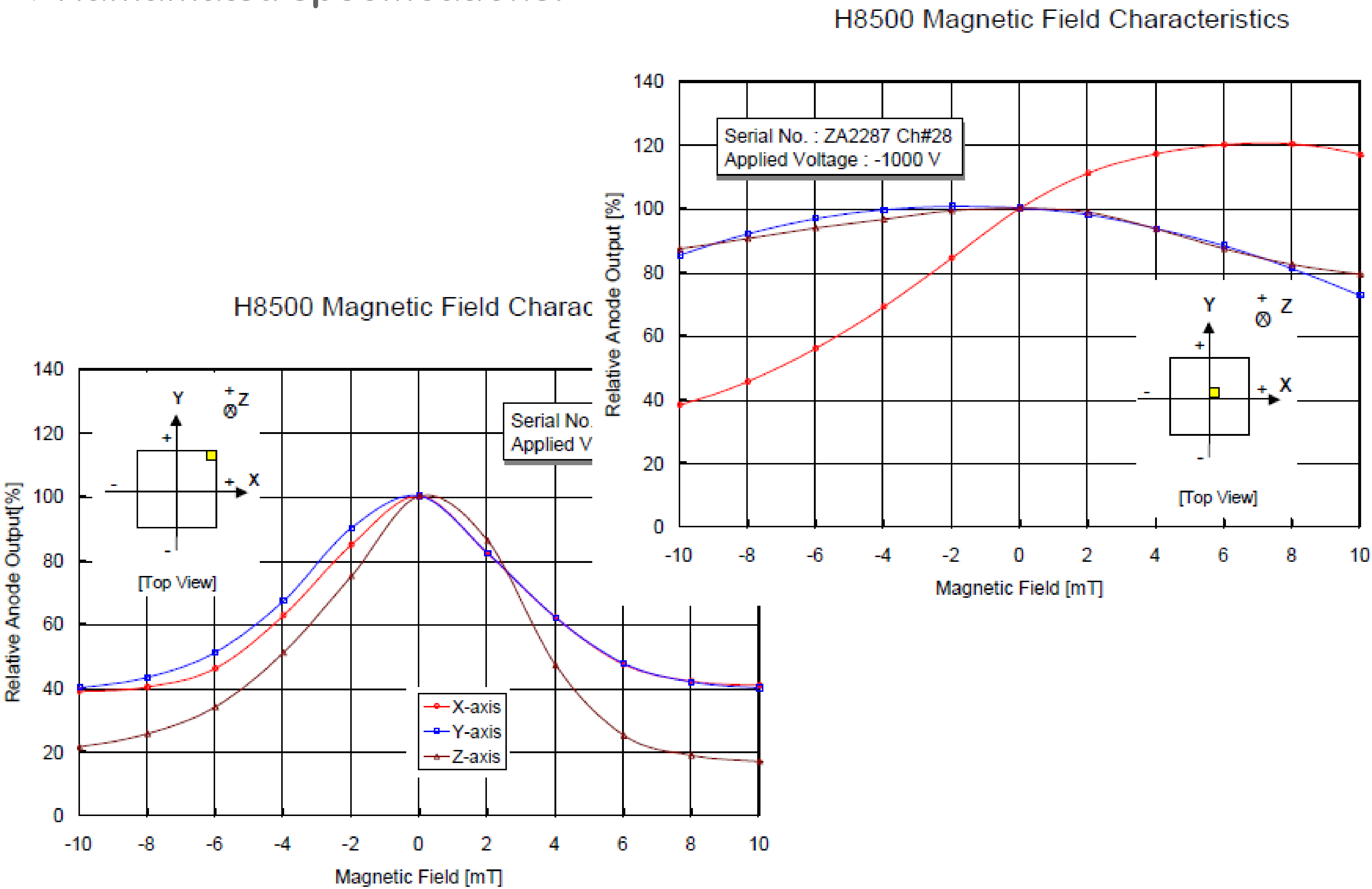




→ spectral response: 185-650 nm with UV glass

PMT: H8500C-03

➡ Hamamatsu specifications:

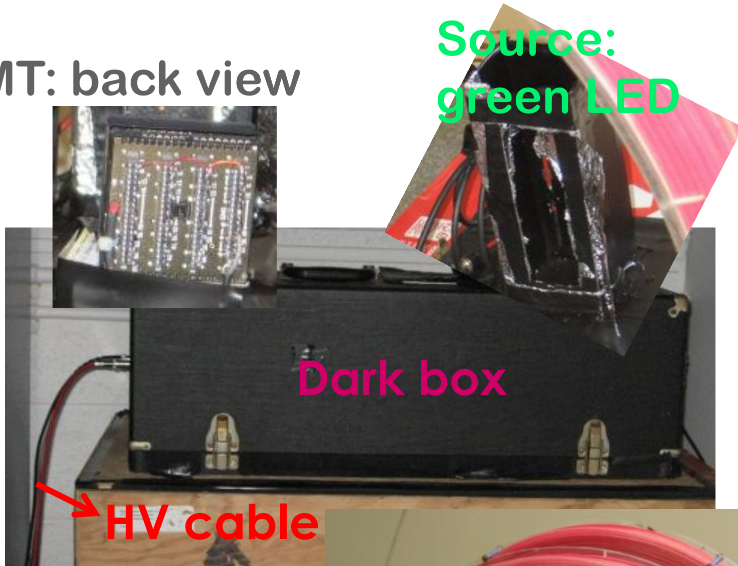


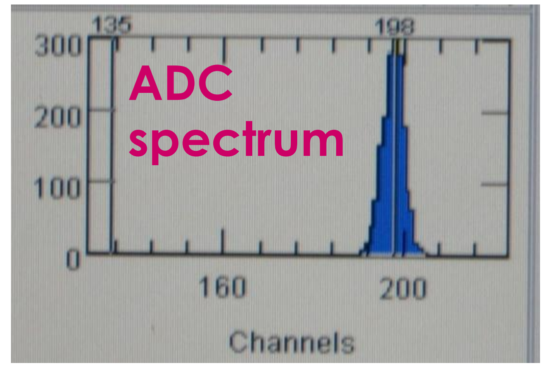
PMT: H8500C-03

H8500C magnetic field tests at Temple U.: July 18-22, 2011

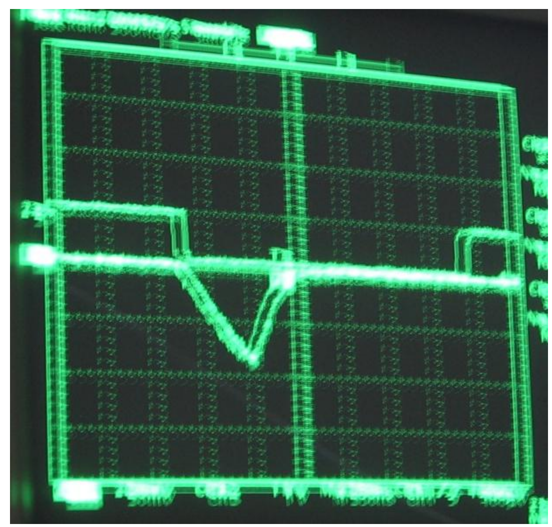
→ We tested H8500C (H8500C-03 expected to have similar response in magnetic field)

PMT: back view





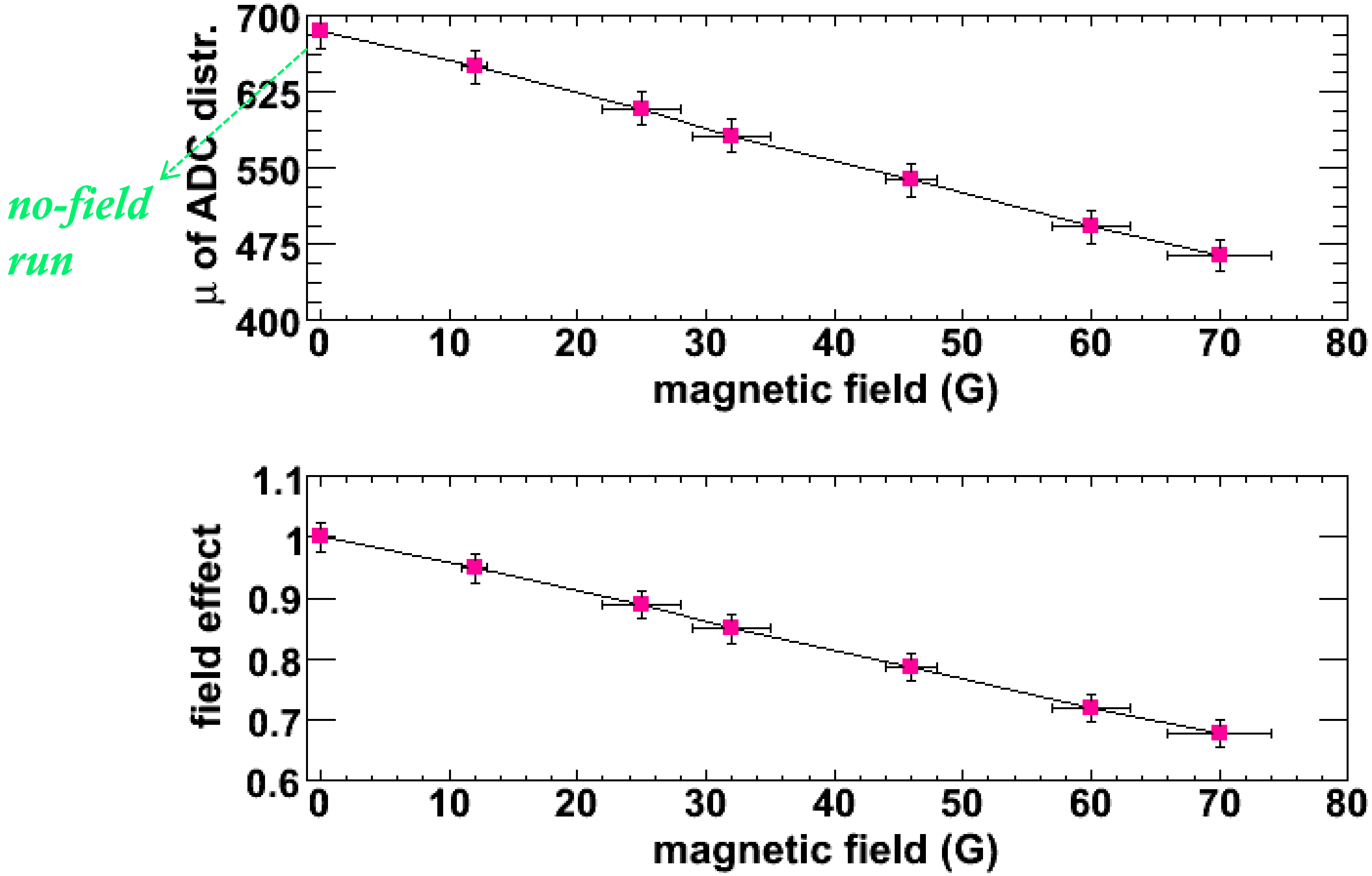
coils



For our tests we "read" the sum of all anodes

PMT: H8500C-03

➡ H8500C magnetic field tests at Temple U.: July 18-22, 2011



pedestal subtracted

All runs normalized to the no-field run

→ The PMT experiences "only" a 30% signal reduction at 70 G (not bad!)