Cherenkov Detectors for SoLID

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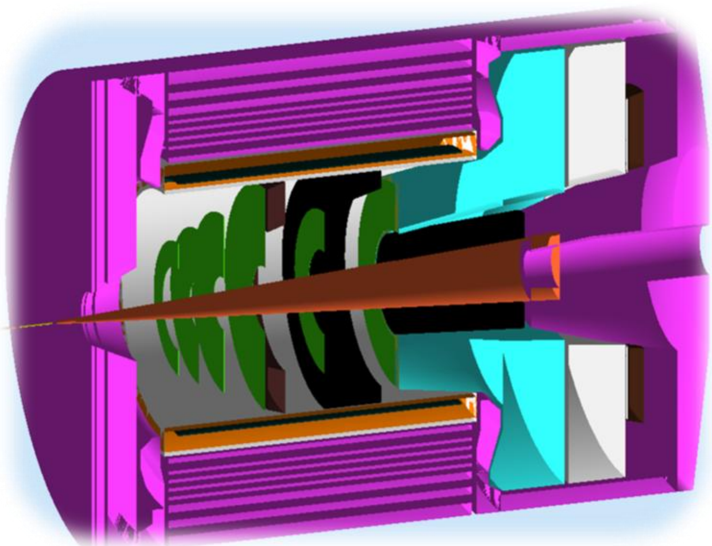
September 30th, 2011

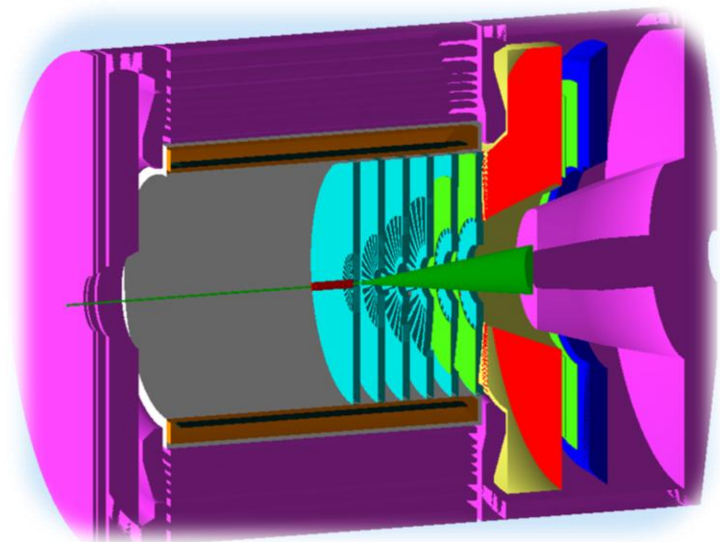
Requirements

➡ Threshold Cherenkov:
- electron-pion separation: SIDIS & PVDIS
- pion-kaon/proton separation: SIDIS

SIDIS electron Cherenkov: 1.5 – 4.5 GeV
SIDIS pion Cherenkov: 2.5 – 7.5 GeV



PVDIS Cherenkov: 2 – 3 GeV



➡ 2π coverage (SIDIS)

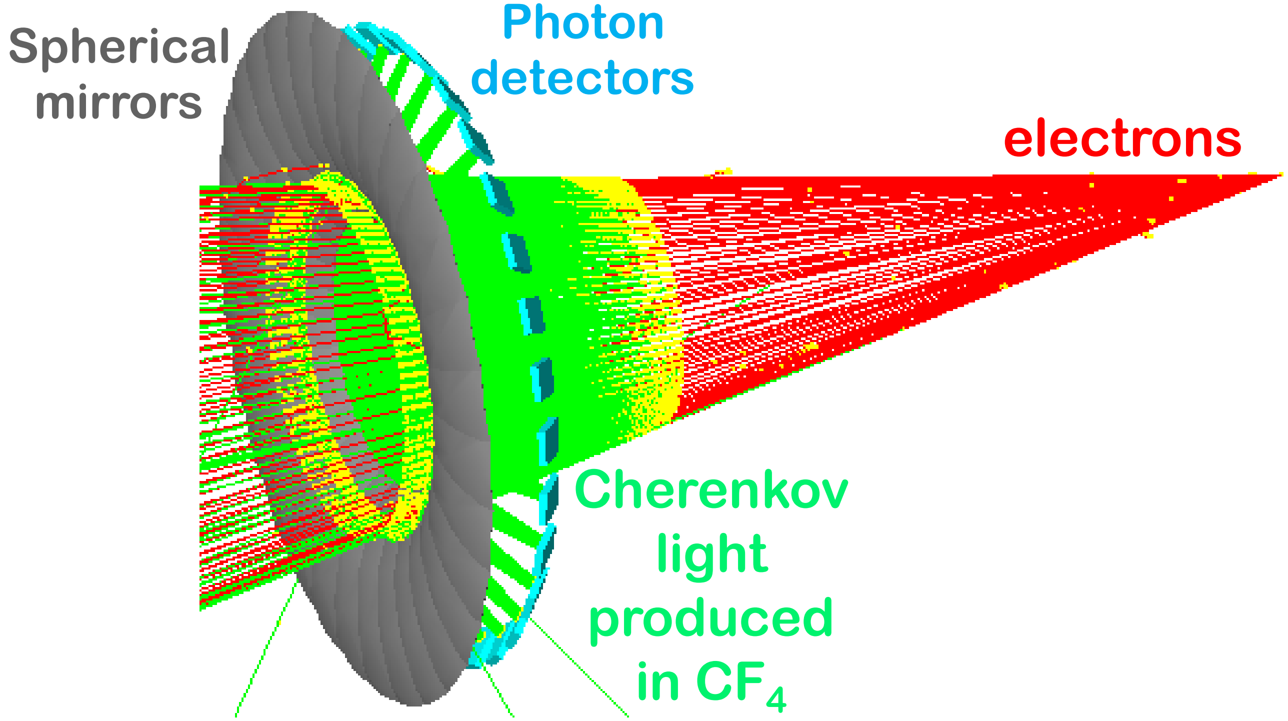
➡ Perform in non-negligible magnetic field environment

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

Design: Mirrors

It follows the current sector division of SoLID

⇨ Mirrors: ring of 30 spherical mirrors, each over 1 m long



→ Good focusing of Cherenkov light on small size photon detectors

→ Each spherical mirror will be manufactured in 2 parts (manufacturer and vacuum deposition chamber limitation)

→ We consider materials other than glass; light and rigid to remove the need for double-edge support for no impact on the physics phase space

Design: Photon Detectors

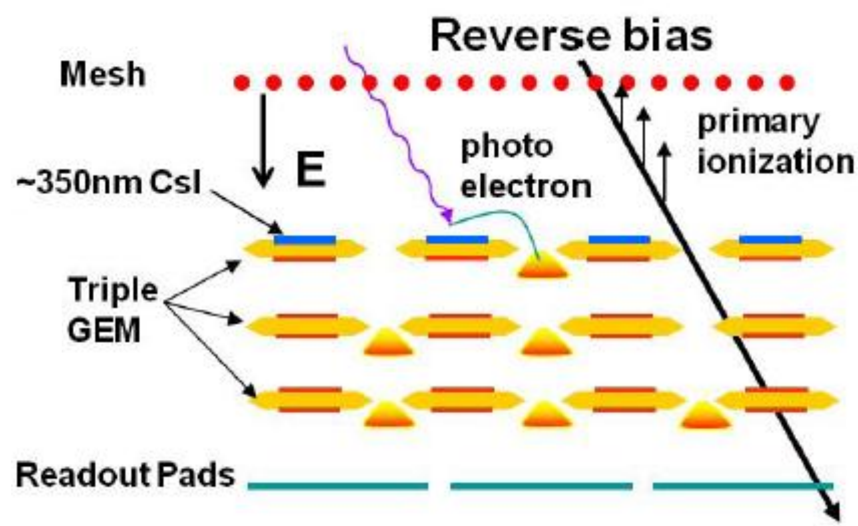
➡ **Photon detectors:**

GEMs + CsI

→ Insensitive to magnetic field

→ CsI: sensitive to deep UV light, high quantum efficiency (up to 60-70% at 110 nm)

We need:
- Pure gas transparent to UV light
- Mirrors with good reflectivity in deep UV



PMTs

→ Sensitive to magnetic field

→ Photocathodes typically sensitive to visible light mostly

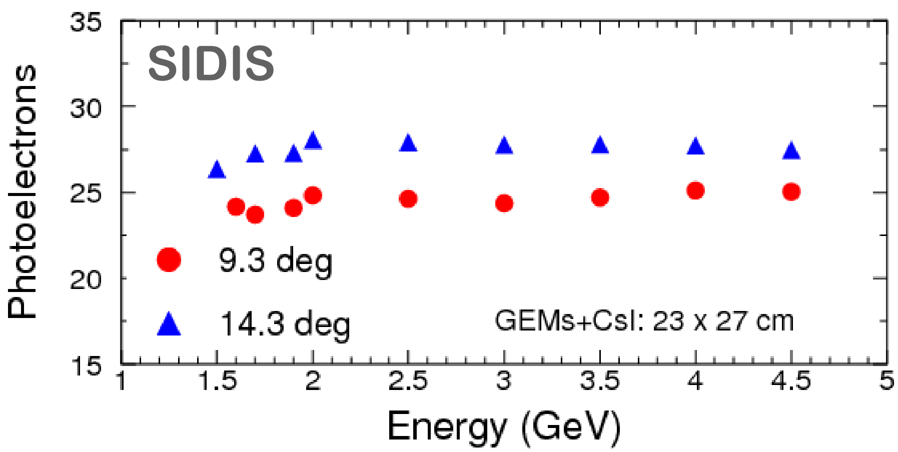
We need PMTs:
- Resistant in SoLID magnetic field
- Suitable for tilling

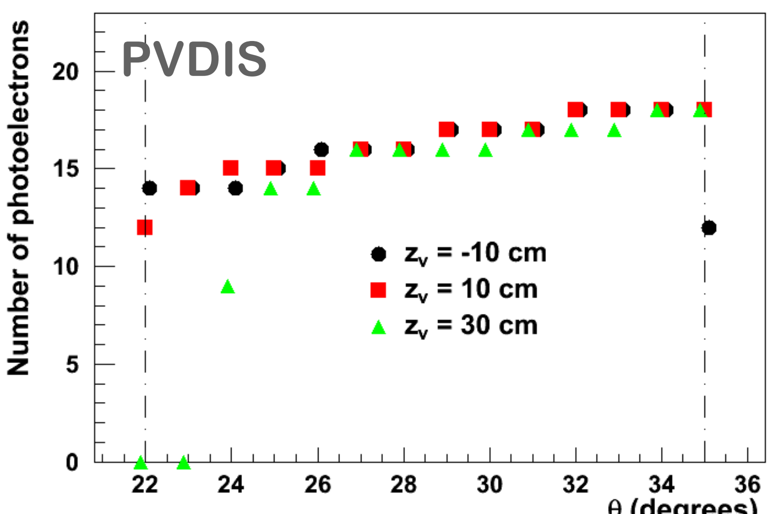
H8500C-03

Electron Cherenkov Signal: GEMs + CsI

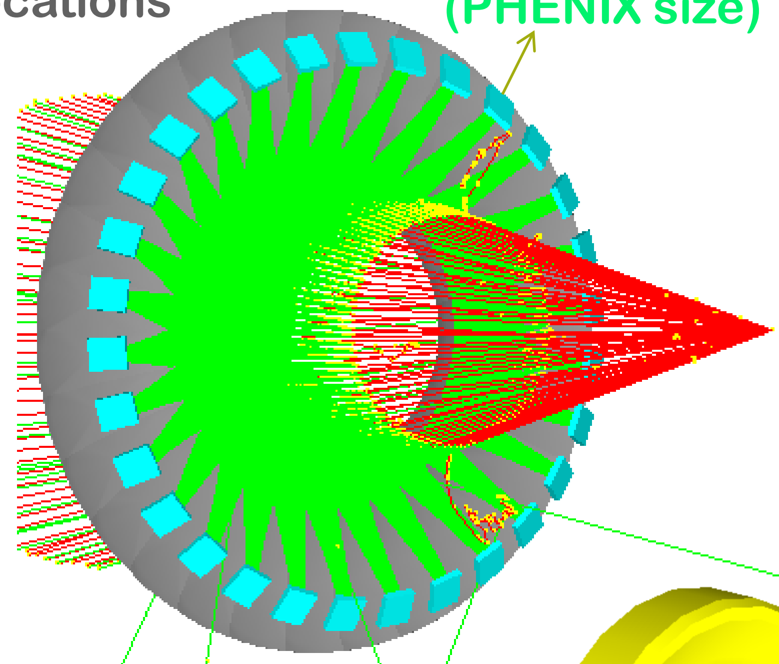
⇨ **Very similar configuration possible for SIDIS and PVDIS**

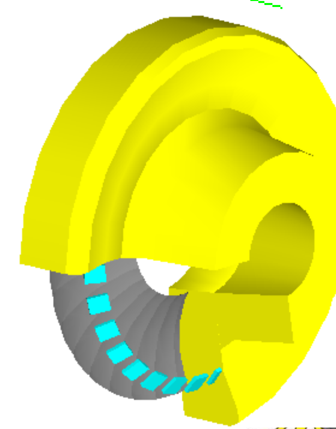
- same tank except for additional piece for SIDIS
- same mirrors, mounted at the same location
- same GEMs + CsI, mounted at different locations
- same gas: CF_4





23 cm X 27 cm (PHENIX size)





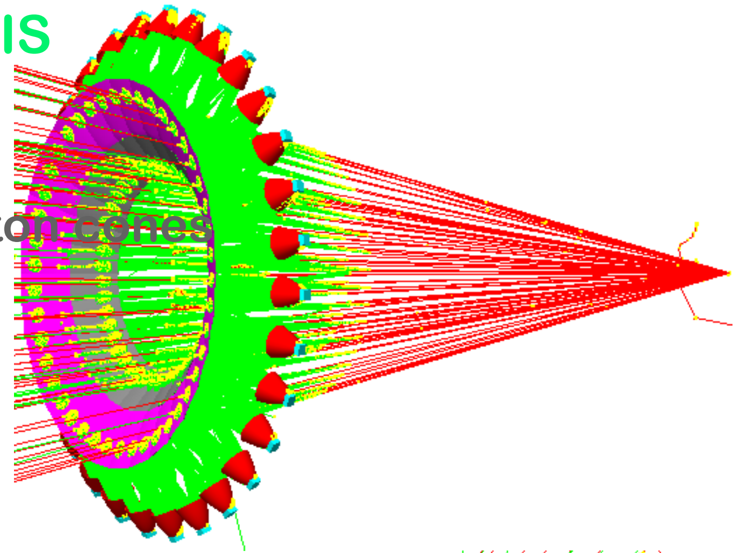
The 2 parts of each spherical mirror will have same curvature

→ Signal estimates are based on the PHENIX HBD performance

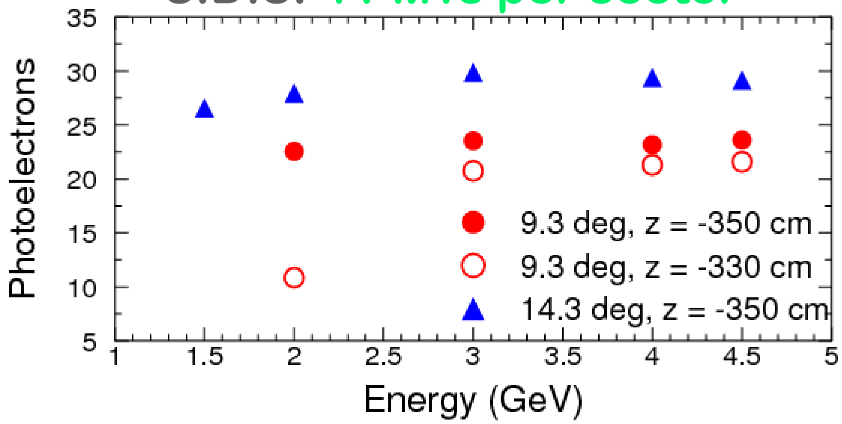
Electron Cherenkov Signal: PMTs

➡ **Different configurations for SIDIS and PVDIS**

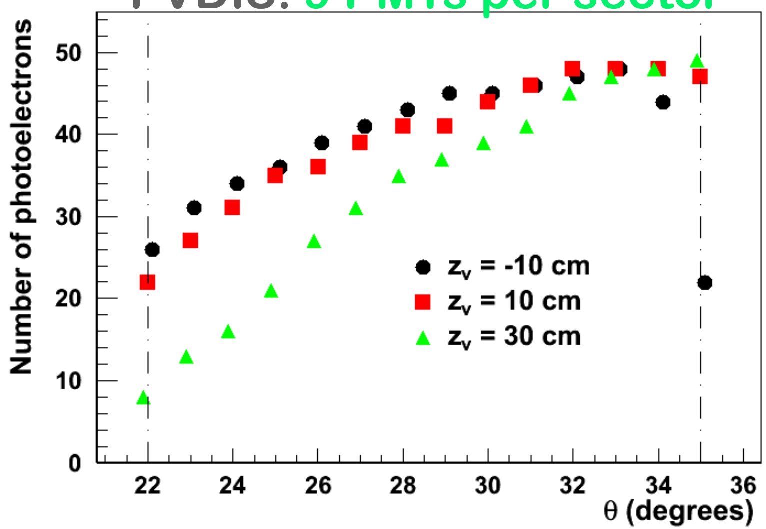
- different gas: CO_2 for SIDIS, C_4F_{10} for PVDIS
- different mirrors
- different size of PMT arrays and different Winston cones

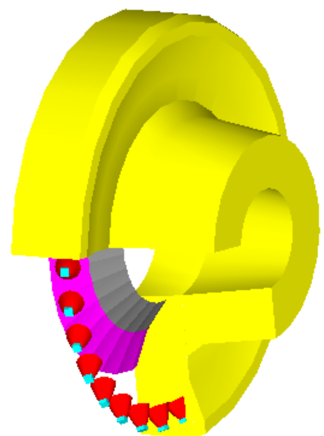


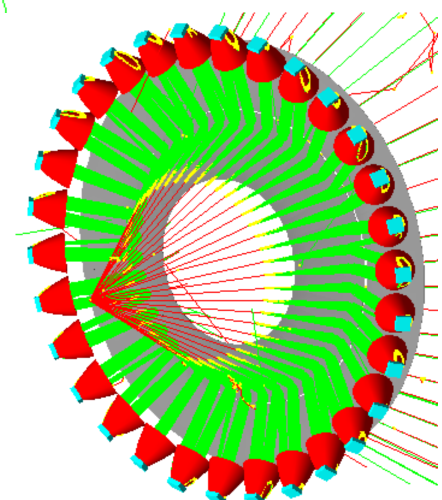
SIDIS: 4 PMTs per sector



PVDIS: 9 PMTs per sector







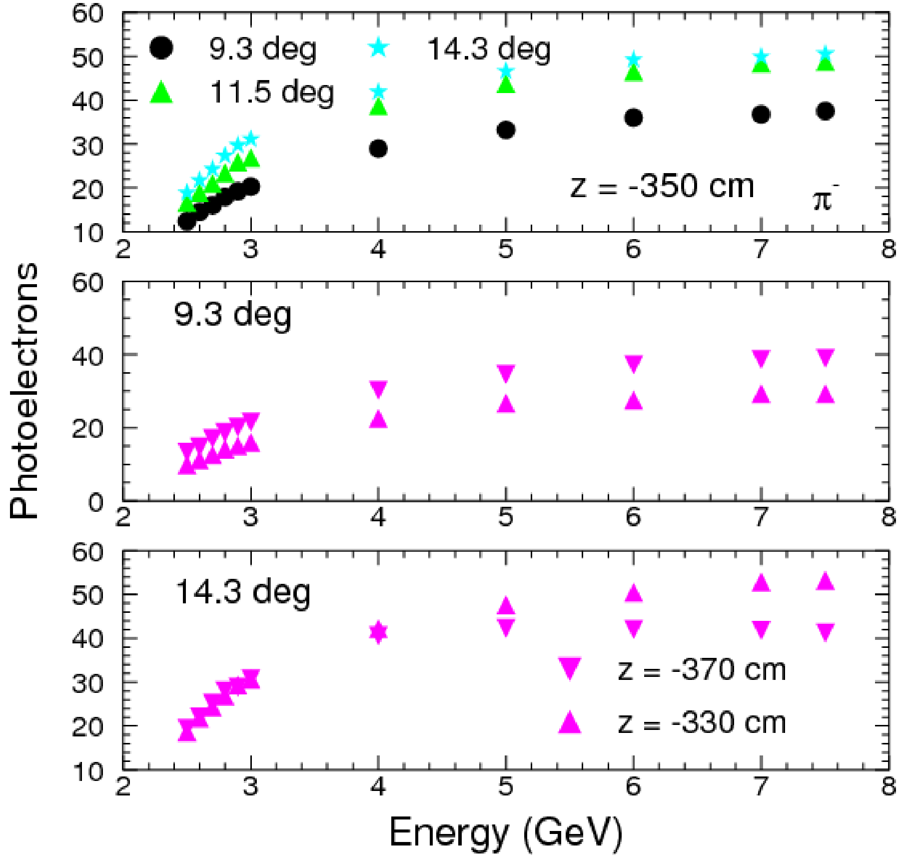
The 2 parts of each spherical mirror of different curvatures to reduce the number of PMTs per sector

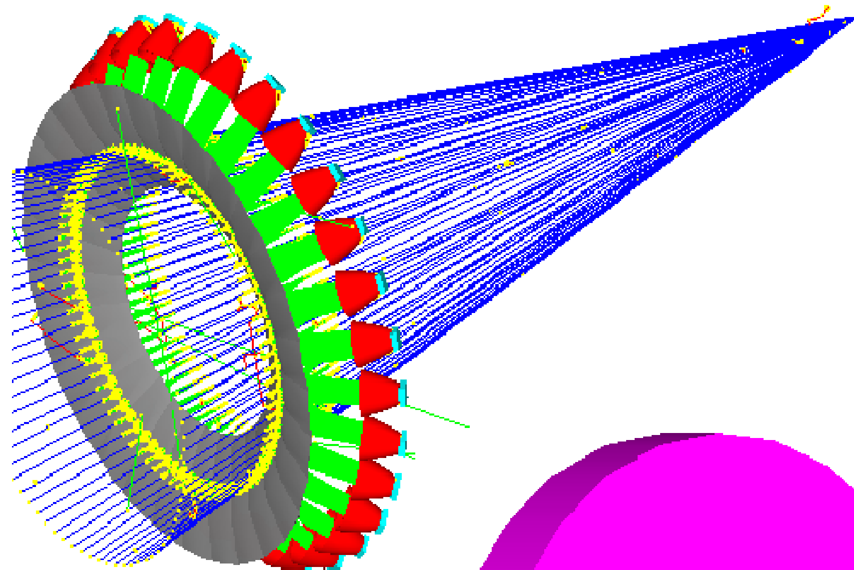
SIDIS Hadron Cherenkov Signal: PMTs

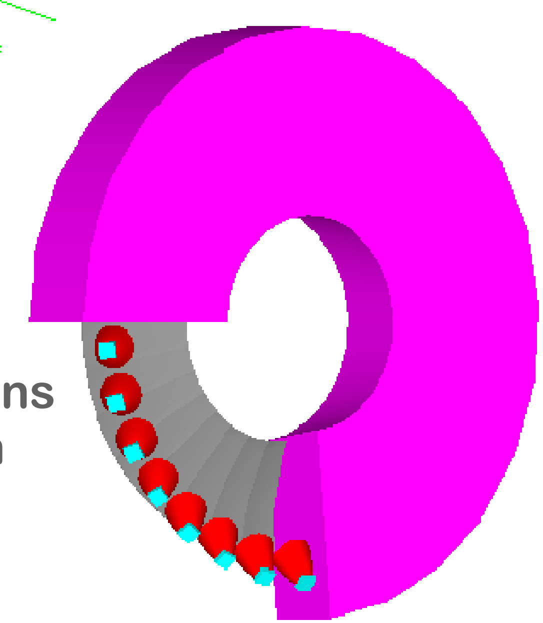
⇨ **Similar design as for SIDIS electron Cherenkov, the PMT option**

- gas: C_4F_{10}
- mirrors: parts with different curvature to reduce the number of PMTs per sector → work in progress

SIDIS: 9 PMTs per sector (for now)







Need more iterations to "finalize" design

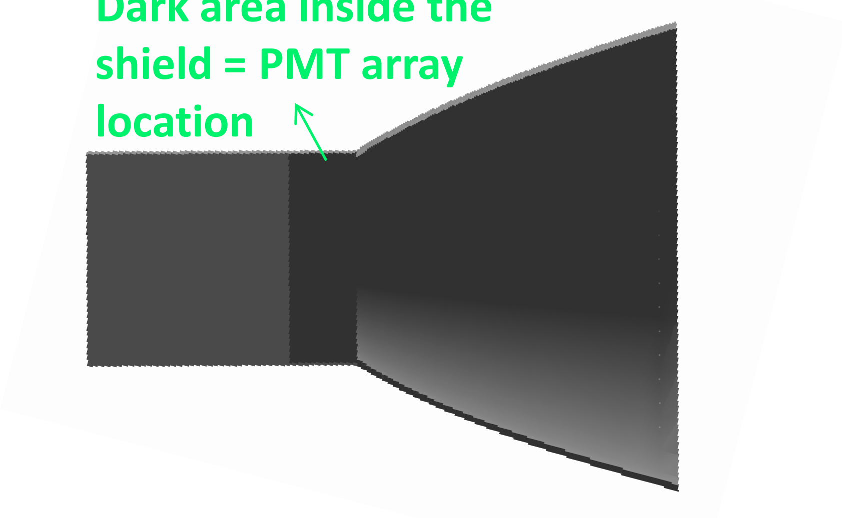
PMTs in Magnetic Field

From **H8500C** field tests at **Temple U.**

- → at 20 G (longitudinal field): < 10% signal loss
- → at 70 G: 30%

Request sent to **Amuneal for "ideal" shield** which will incorporate the Winston cones

- longitudinal component of the magnetic field from 150 G to < 20 G
- transverse component of the magnetic field from 70 G to 0 G



from 150 G / from 70 G: Estimates based on BaBar v4 field map

< 20 G / 0 G: Ideal *could be higher* though (< 50 G)

Amuneal says it's **possible** with a **2 layer shield**:

- → inner: Amumetal 0.04"
- → outer: 1008 carbon steel 1/8"
- → mylar in between 0.062"

Plans for Hardware Tests

⇨ H8500C-03 test in Hall A during g_2^p:

→ "simple" background test: PMT in dark box placed "strategically" in the hall in in-beam environment

⇨ GEMs + CsI test in Hall A during g_2^p:

In collaboration with some from the Stony Brook/BNL HBD group; interested in tests for future EIC developments

→ Phase 1 – "background response" test: one GEM + CsI unit placed in small tank with Argon gas (for example)

→ Phase 2 – "signal response" test: one GEM + CsI unit placed in tank with CF4 gas and mirror

- Need to figure out feasibility: enough counting rates where space could be available ?

(Some) Preliminary Cost Estimates

Configuration 1:

SIDIS/PVDIS e⁻ Cherenkov
>725 K

SIDIS π Cherenkov
>1.2 M

	SIDIS/PVDIS e⁻ Cherenkov	SIDIS π Cherenkov
Mirrors	25,000	25,000
Mirror coating	100,000	100,000
PMTs	-	3,000 X 279** = 837K
Cones*	-	1,350 X 31
GEMs + CsI	200,000?	-
Gas system	200,000?	200,000?
Tank	200,000?	200,000?

Configuration 2:

SIDIS/PVDIS e⁻ Cherenkov
>1.3 M

SIDIS π Cherenkov
>1.2 M

	SIDIS/PVDIS e⁻ Cherenkov	SIDIS π Cherenkov
Mirrors	25,000 X 2	25,000
Mirror coating	100,000 X 2	100,000
PMTs	3,000 X 124 = 372 K	3,000 X 279**
Cones*	1,350 X 62 = 83.7 K	1,350 X 31 = 41.9 K
Gas system	200,000? X 2	-
Tank	200,000?	200,000?

*Cost for straight cones; Winston cones substantially more expensive

** will attempt to reduce it to 124

Summary

➡ We need **3 threshold Cherenkov** detectors for electron and pion identification (for approved **SIDIS** and **PVDIS** experiments):

→ **Design**: system of **spherical mirrors** will focus the Cherenkov light on **small-size photon detectors**

Configuration 1
<u>SIDIS/PVDIS e^- Cherenkov</u>: magnetic field insensitive **GEMs + CsI**
<u>SIDIS π Cherenkov</u>: SoLID magnetic field insensitive **PMTs (with shielding)**

Configuration 2
<u>SIDIS/PVDIS e^- Cherenkov and SIDIS π Cherenkov</u>: SoLID magnetic field insensitive **PMTs (with shielding)**

➡ Hardware tests of both photon detectors planned before the shutdown

➡ **More to do**:

→ Iterate design
→ switch to "final" magnet configuration (CLEO)
→ implement Cherenkov design in official SoLID simulation, GEMC
→ …

Backup Slides

Optimization of optical system

GEMs + CsI

→ Photocathode

→ GEMs

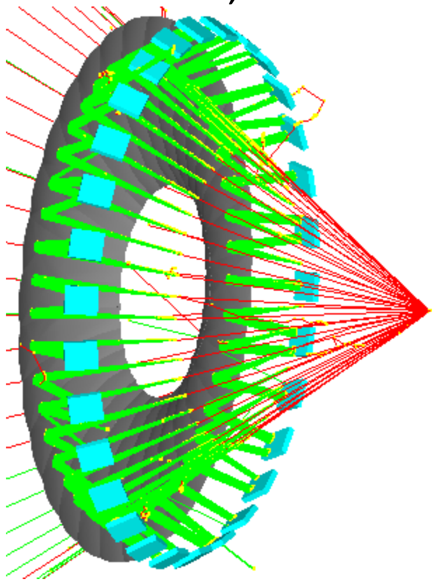
→ Gas

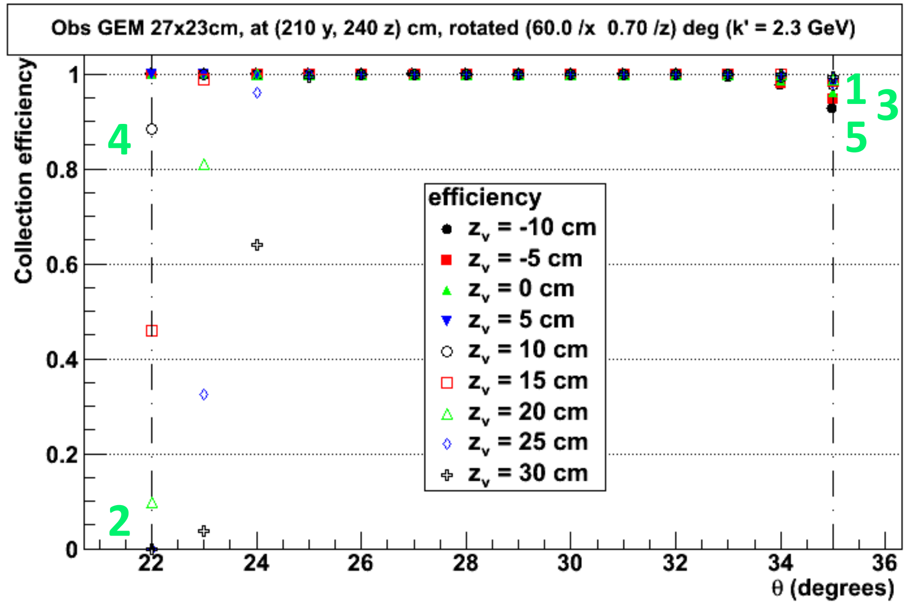
→ Mirrors

PMTs: H8500C-03

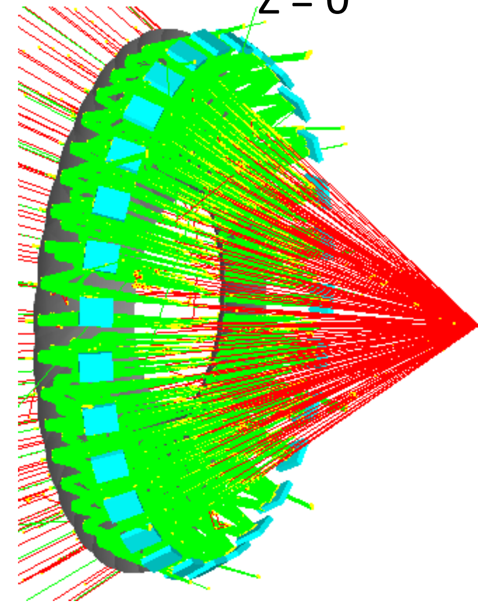
Optimization: PVDIS, GEMs + CsI

1 35, Z = +30

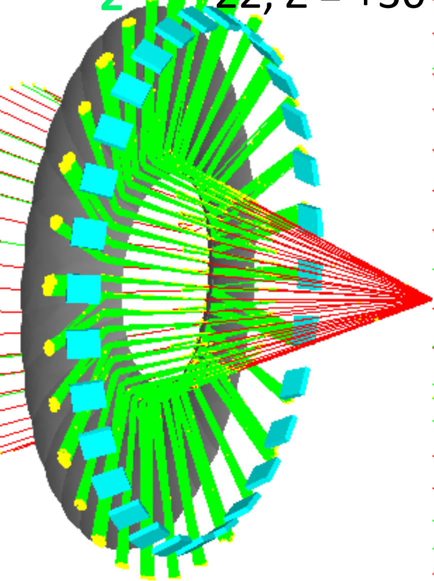




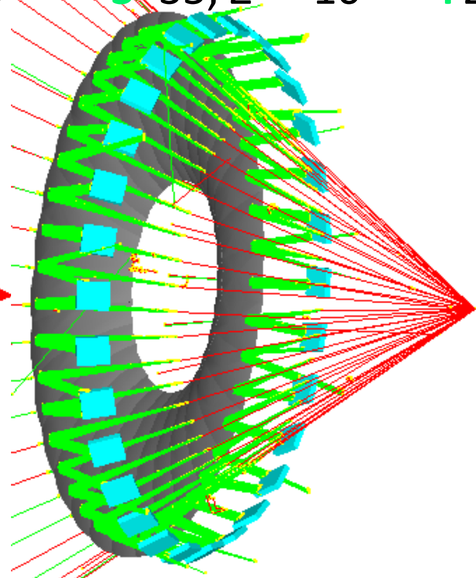
Z = 0



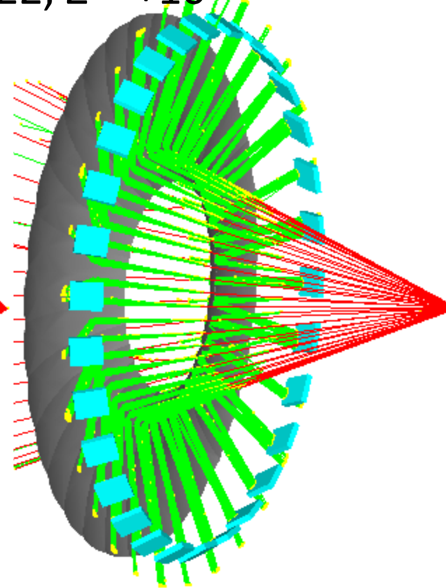
2 22, Z = +30



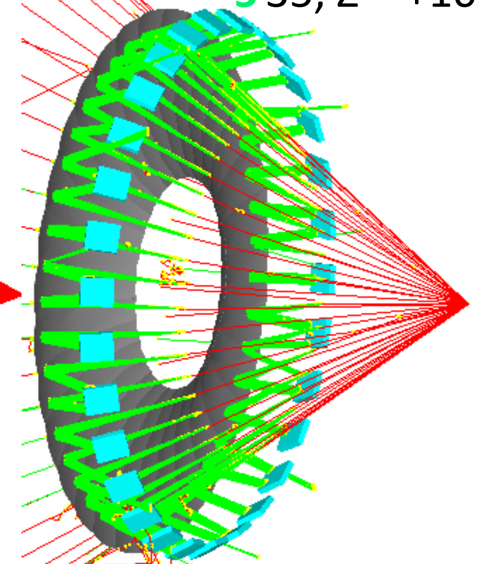
3 35, Z = -10



4 22, Z = +10

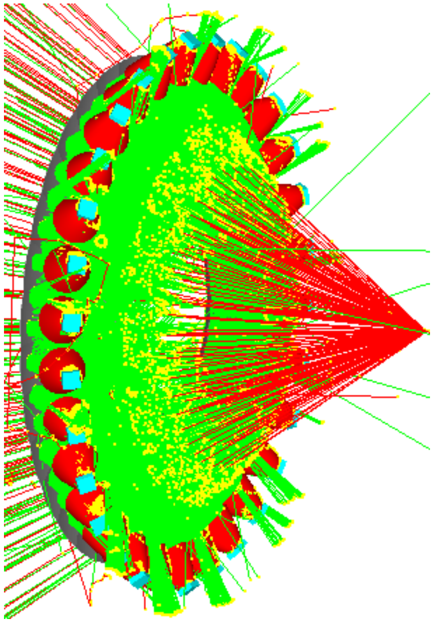


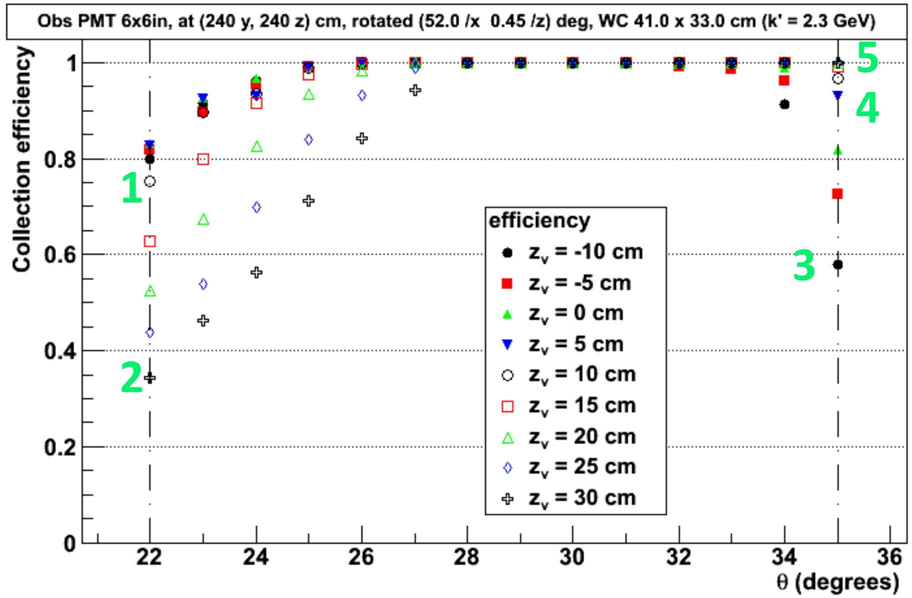
5 35, Z = +10



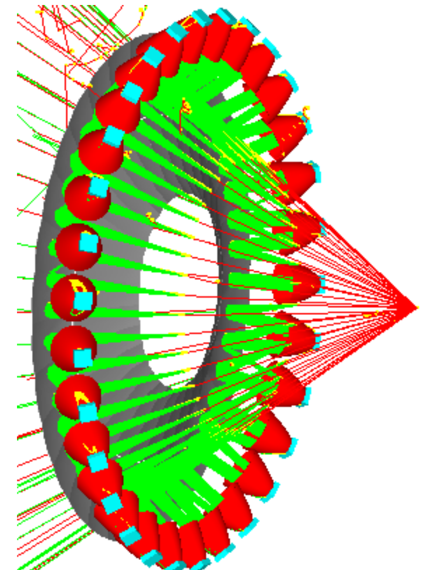
Optimization: PVDIS, PMTs

Z = +10

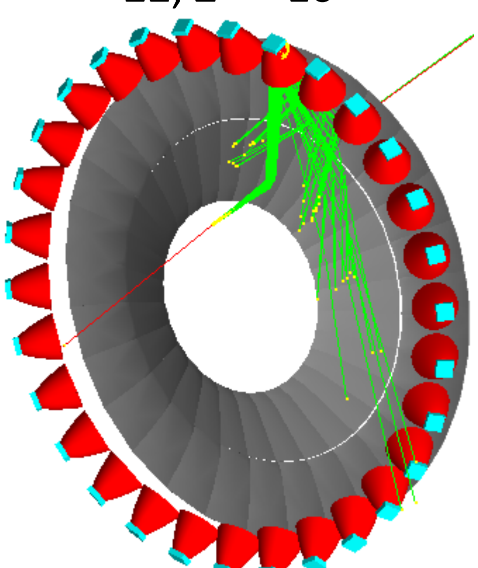




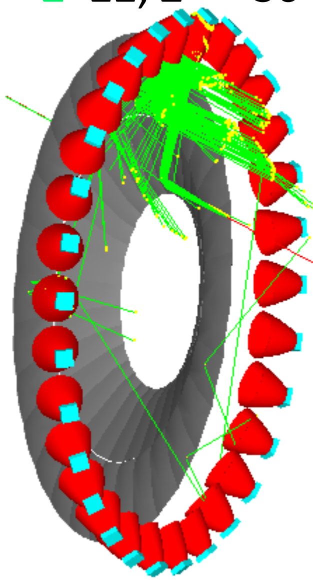
5 35, Z = +30



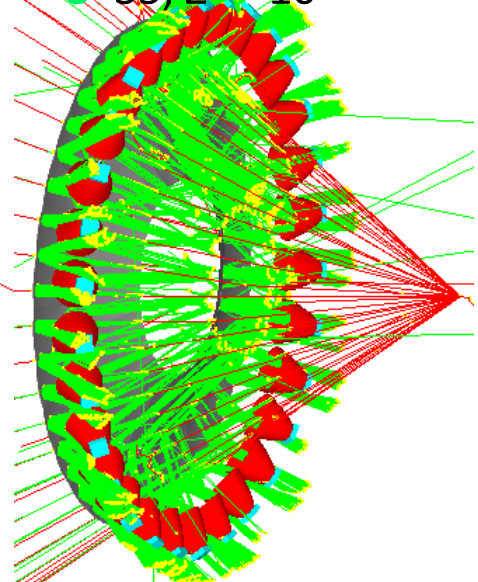
1 22, Z = +10



2 22, Z = +30



3 35, Z = -10



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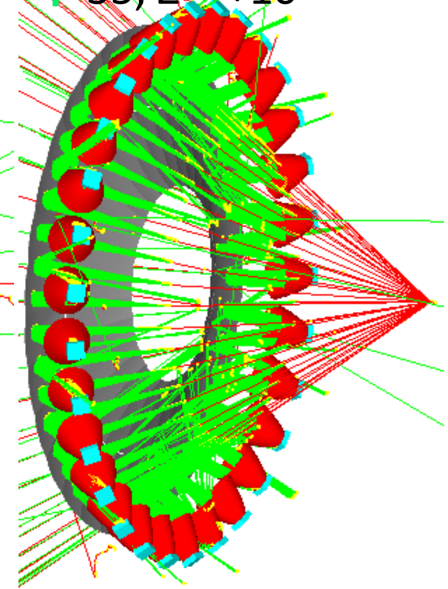
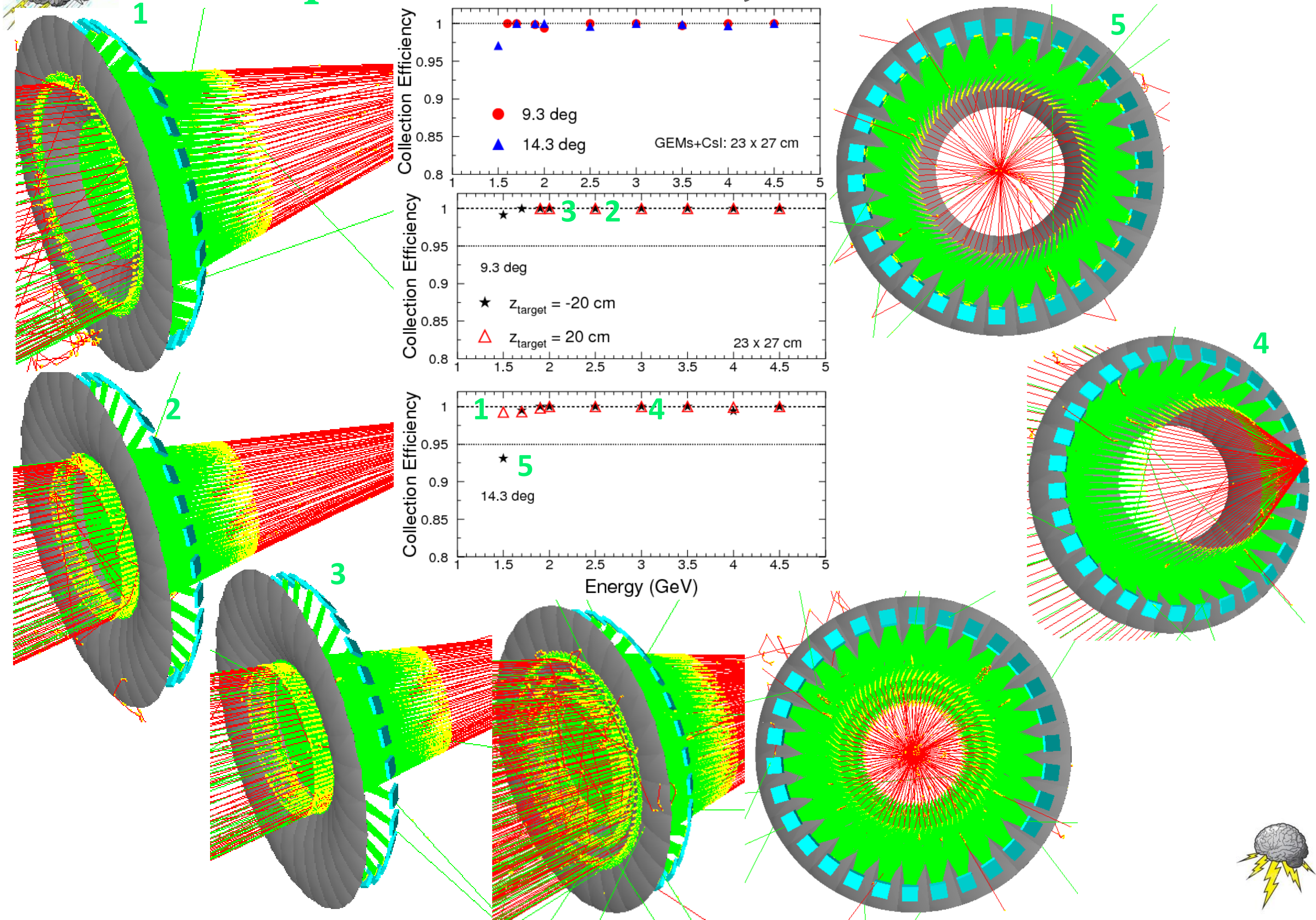


Optimization: SIDIS, GEMs + CsI



Optimization: SIDIS, PMTs

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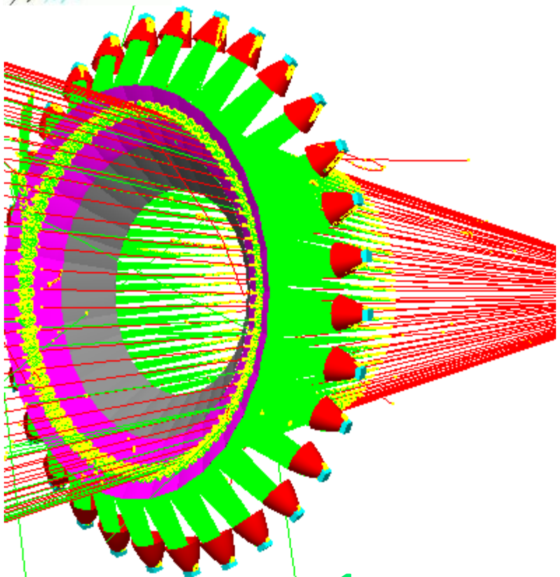

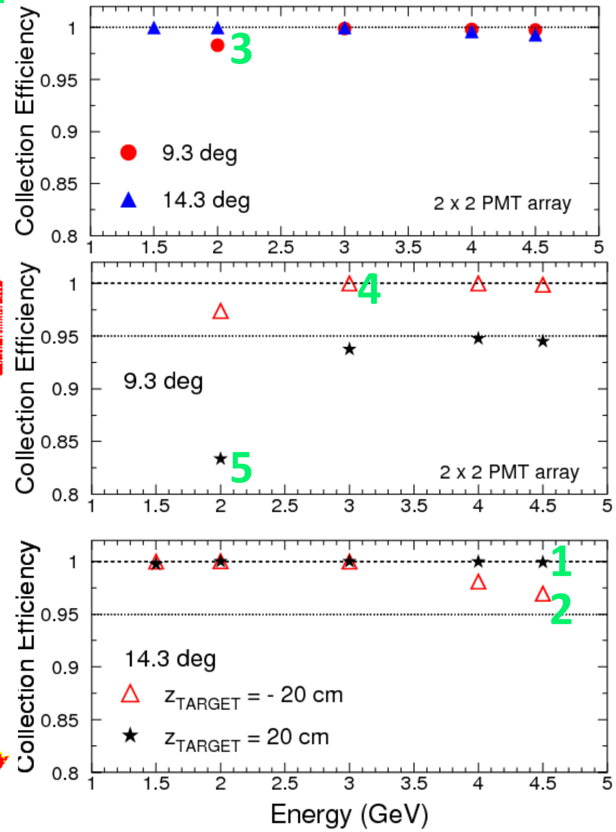

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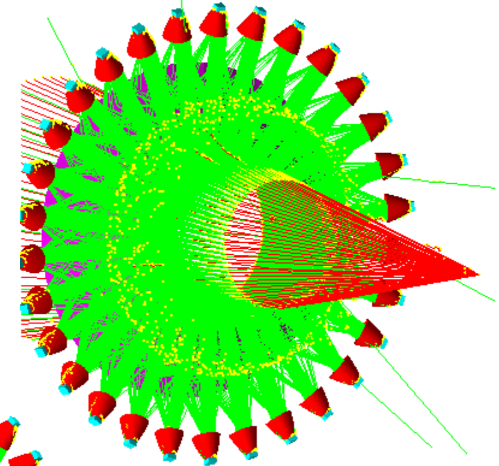

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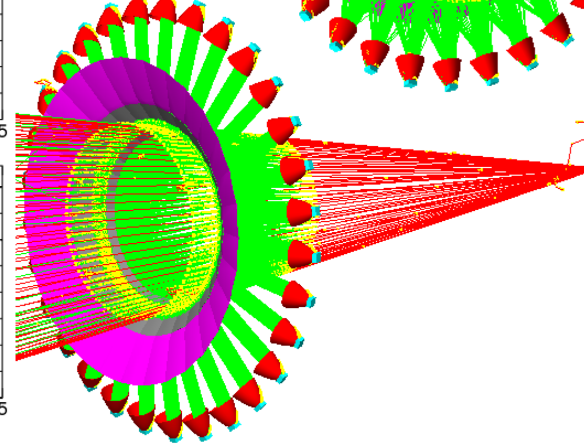

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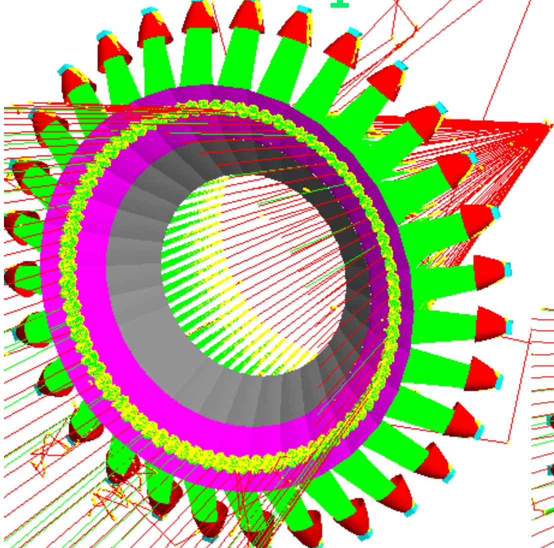

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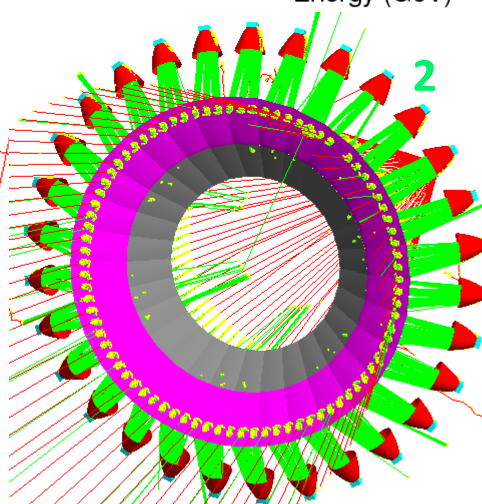

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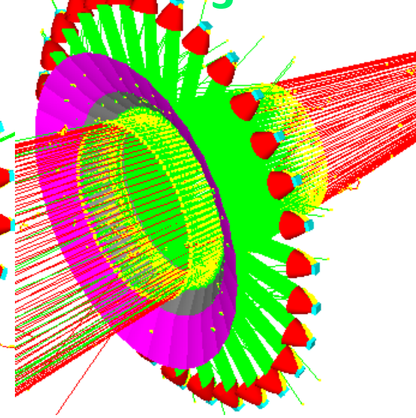

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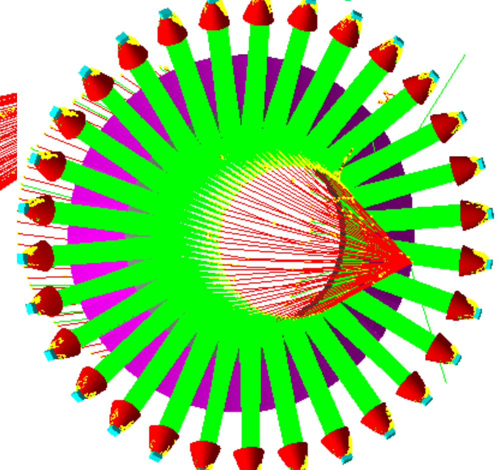


GEMs + CsI: Photocathode

➡ 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

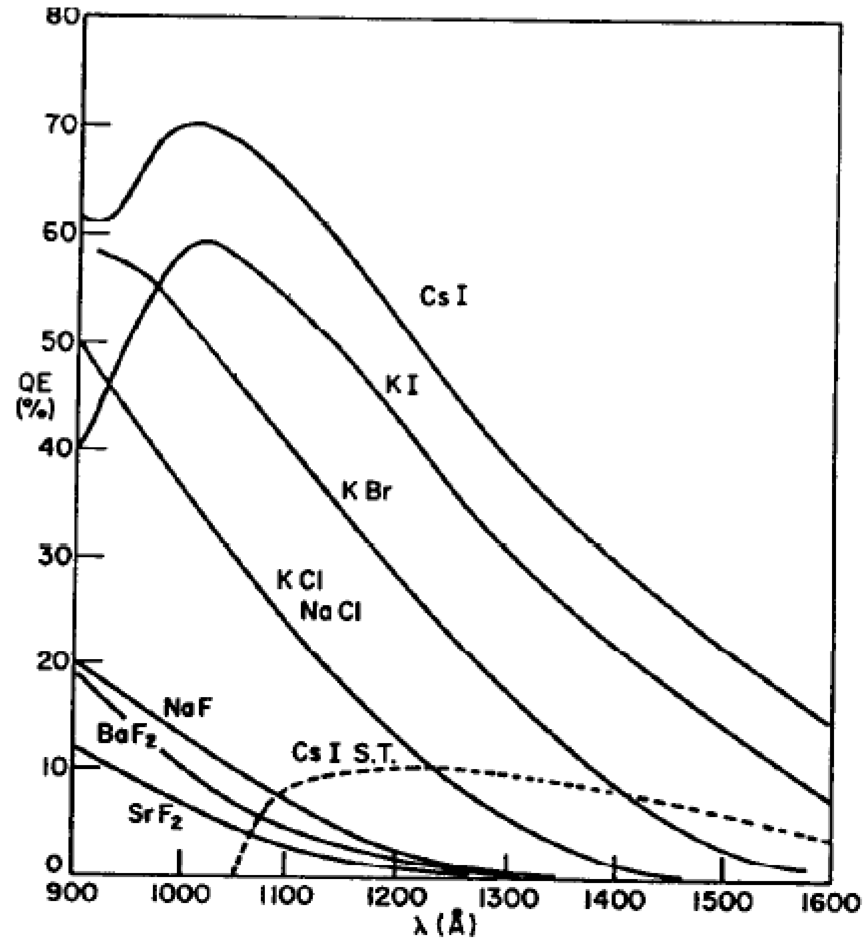


Fig. 1. Typical quantum yields versus wavelength for reflective alkali halide photocathodes. Shown for comparison is a typical quantum yield curve for a semitransparent CsI photocathode deposited on a LiF window (CsI S.T.) [2].

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 →

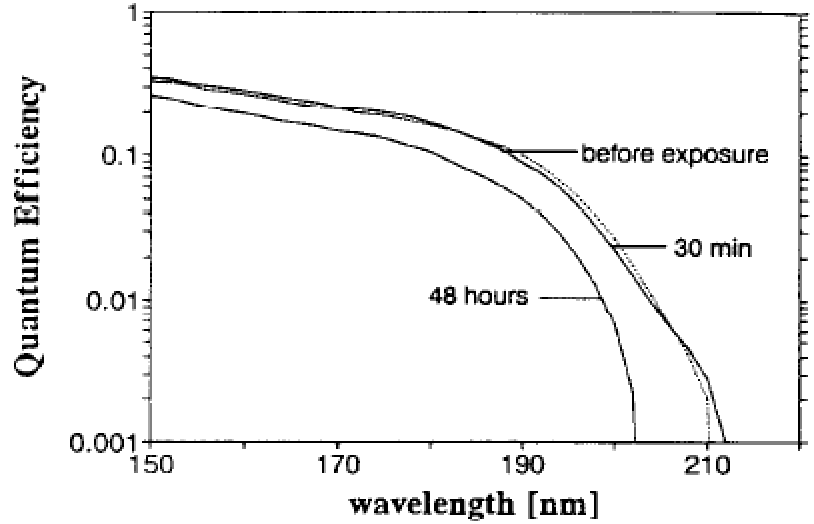


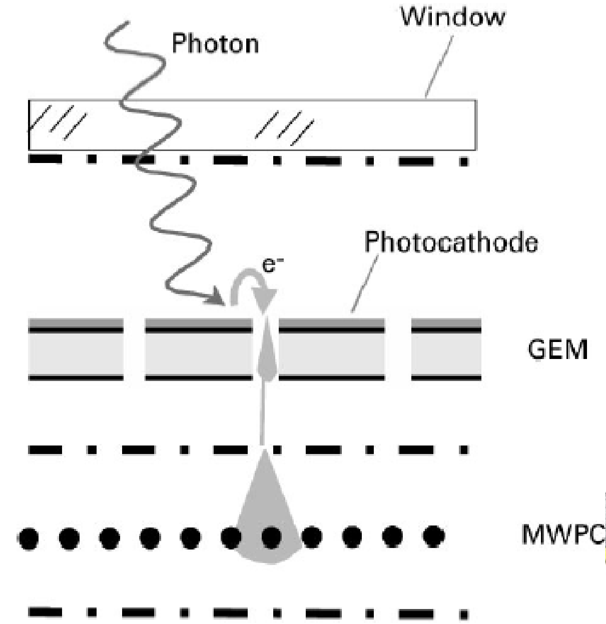
Fig. 22. The decay of the QE of CsI films evaporated on Ni/Au-coated printed circuit board under exposure to air, at a relative humidity of 35% [30].

→ 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

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

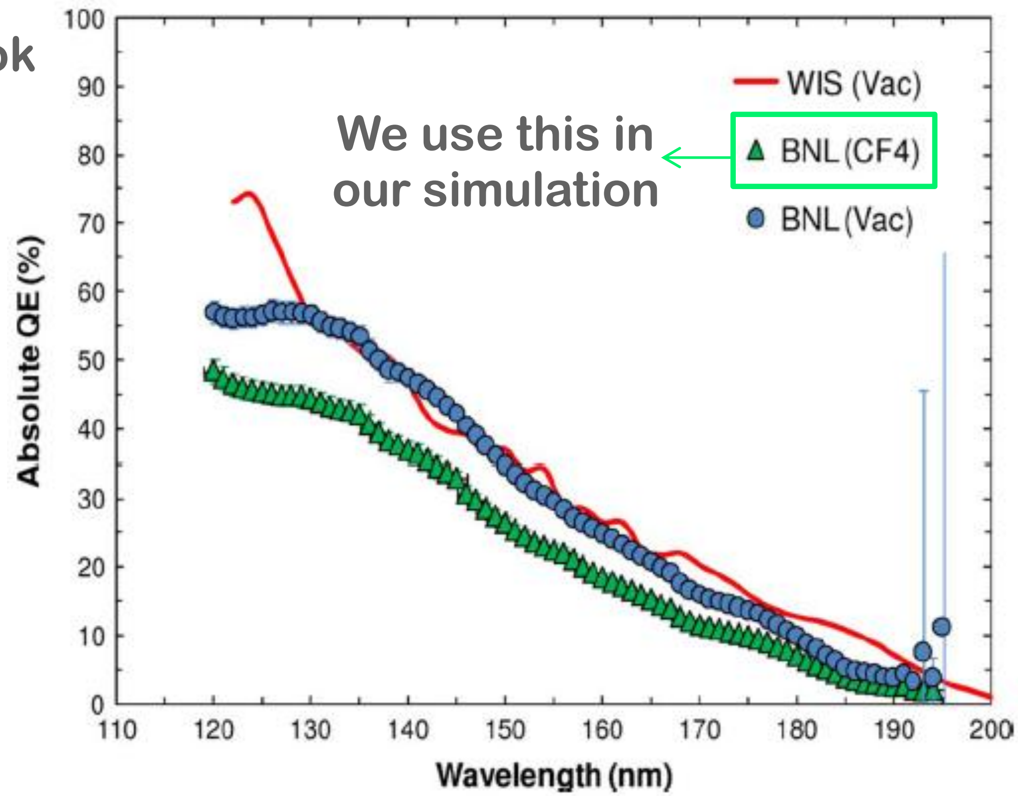
⇨ PHENIX facts on CsI: deposition, QE measurements, monitoring

→ 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



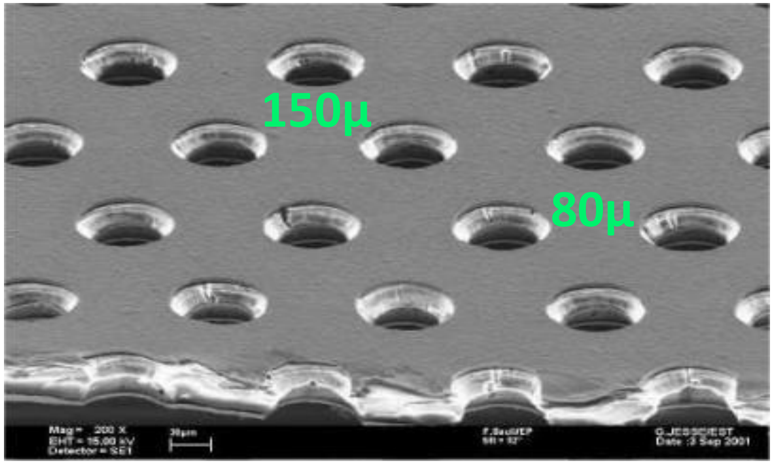
→ relative measurements of CsI QE performed periodically during PHENIX to check for possible degradation (special device needed)

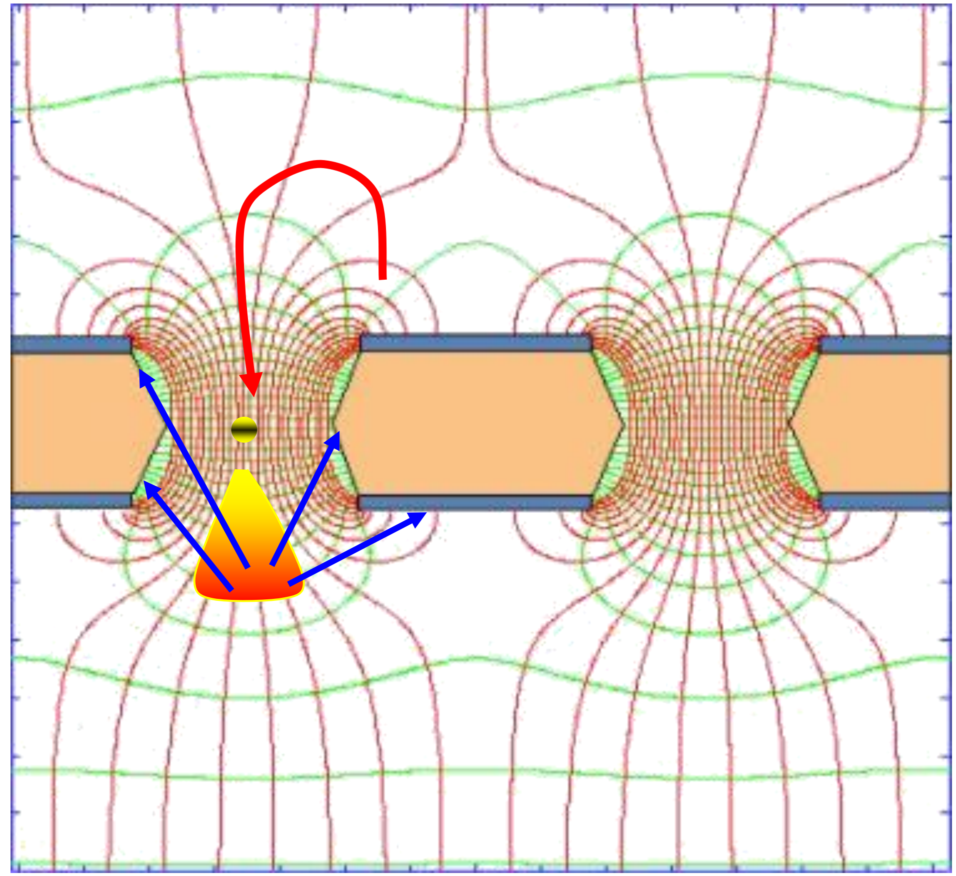
arXiv:1103.4277v1 [physics.ins-det] 22 Mar 2011

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

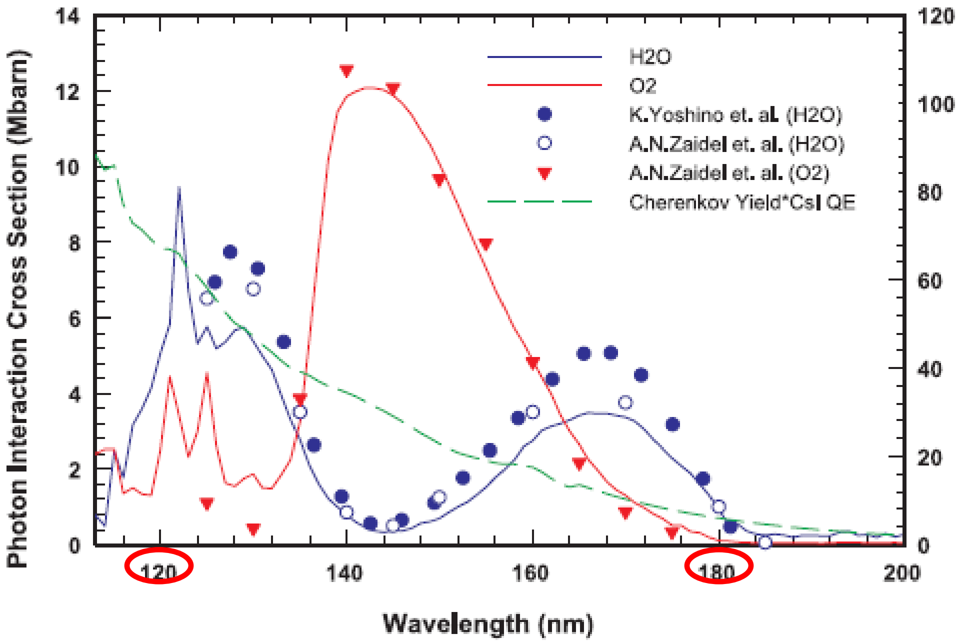
Makes it insensitive to magnetic field

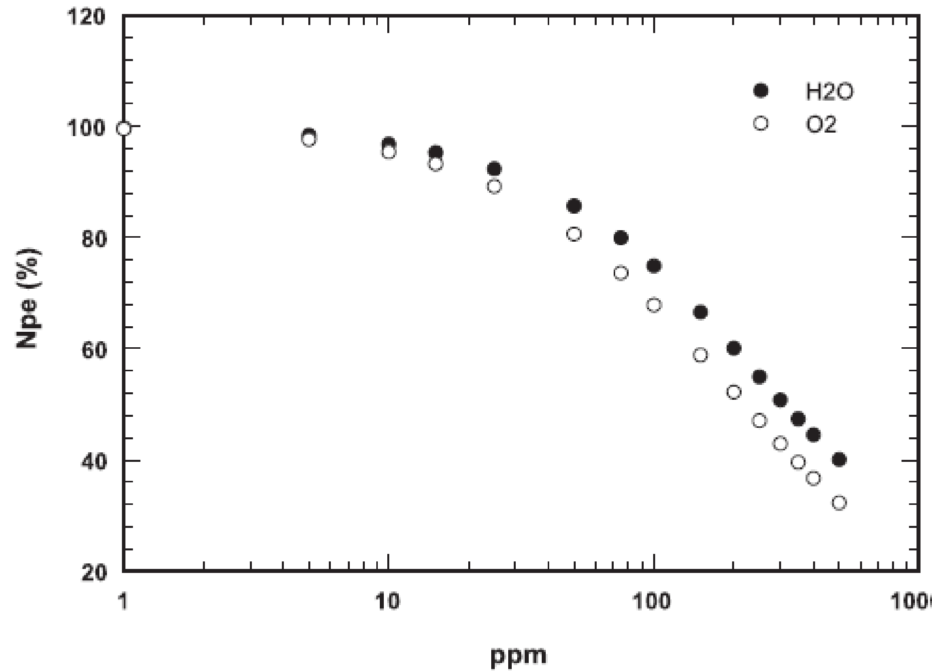
Deposition of photocathode on the first layer of GEM makes it photon-feedback blind: avalanche-induced photons CANNOT reach the photocathode

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

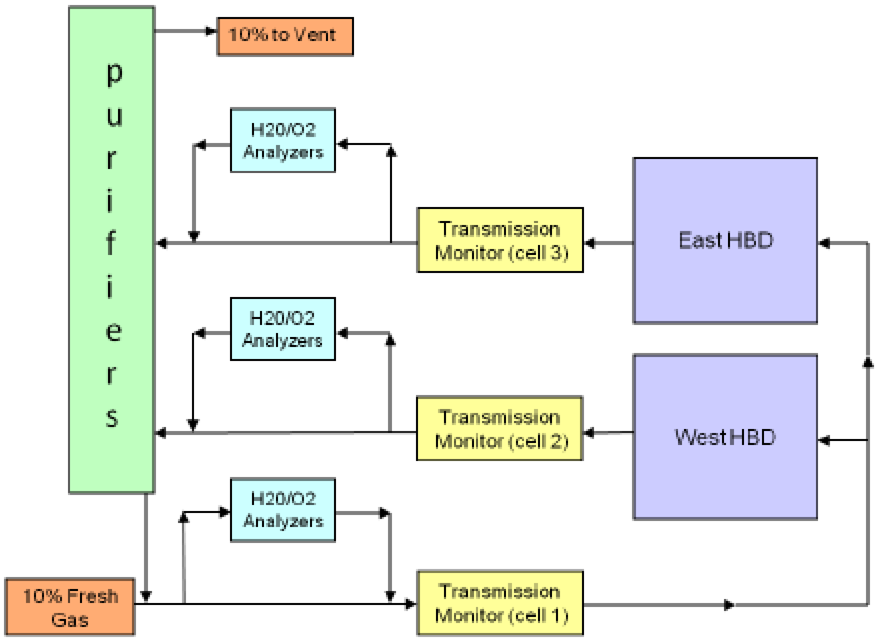
• PHENIX had an independent monitoring system to detect low levels of contamination

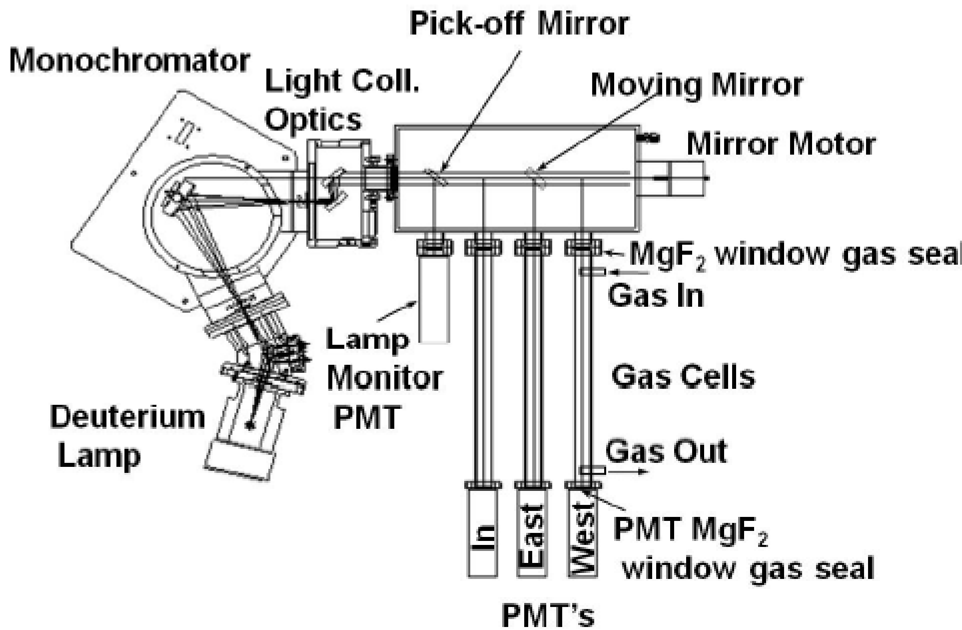
arXiv:1103.4277v1 [physics.ins-det] 22 Mar 2011

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

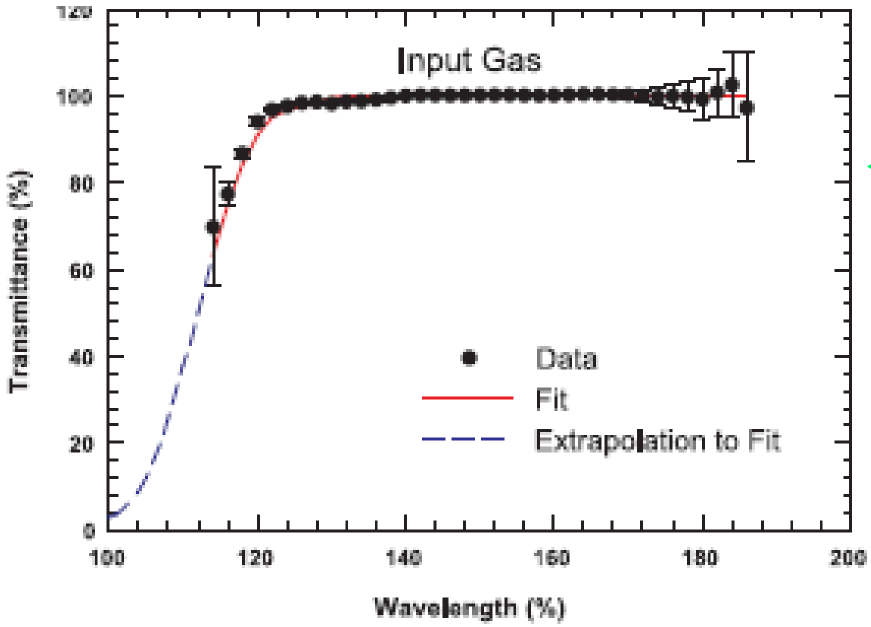
- Gas transmittance monitor system used by **PHENIX** to measure impurities at the few ppm level

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

GEMs + CsI: Gas

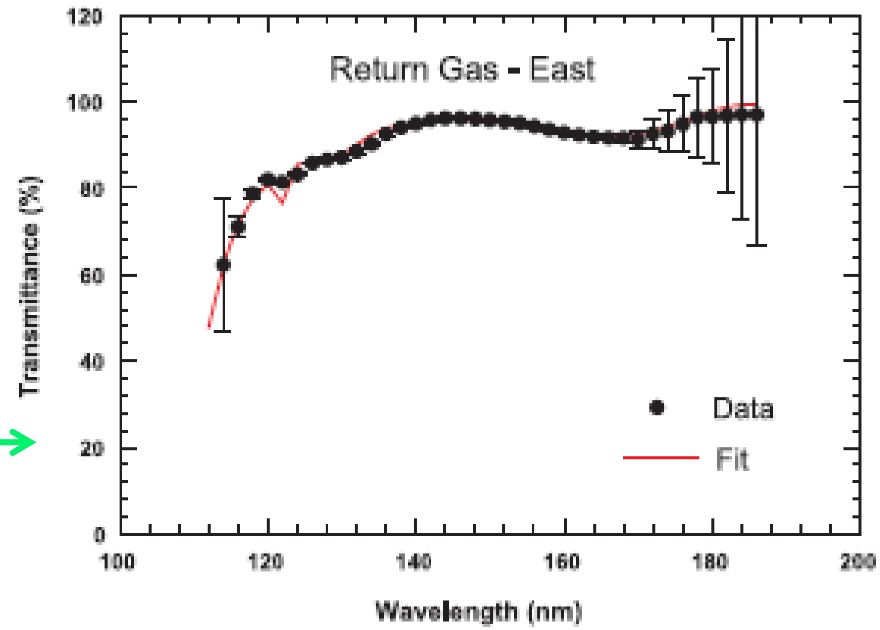
⟹ Need a gas transparent to deep UV light: CF_4

- 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**

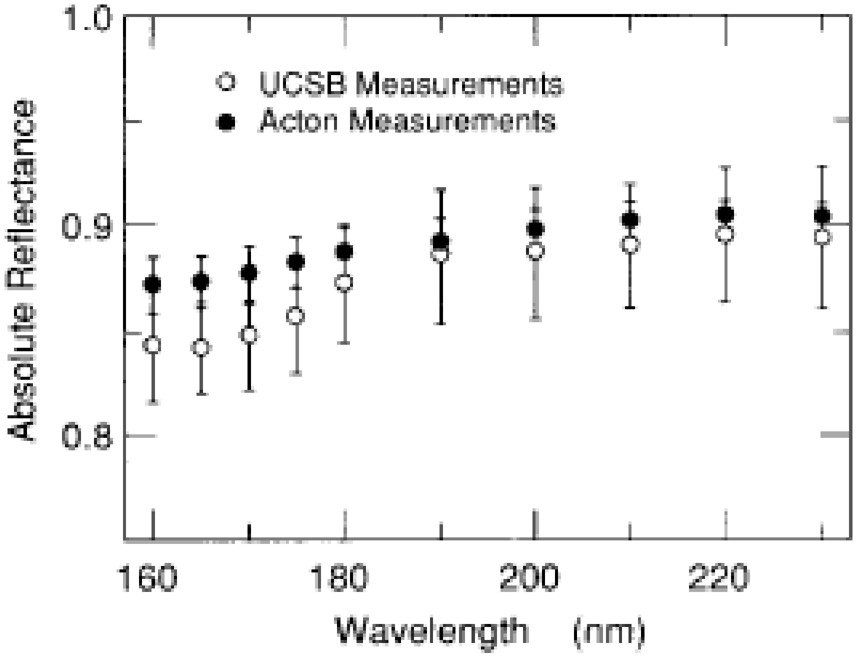


Fig. 8. Results of the reflectivity measurement of the witness coupons for all 430 mirrors at Acton Corp. and UCSB for the light at wavelengths 160–230 nm.

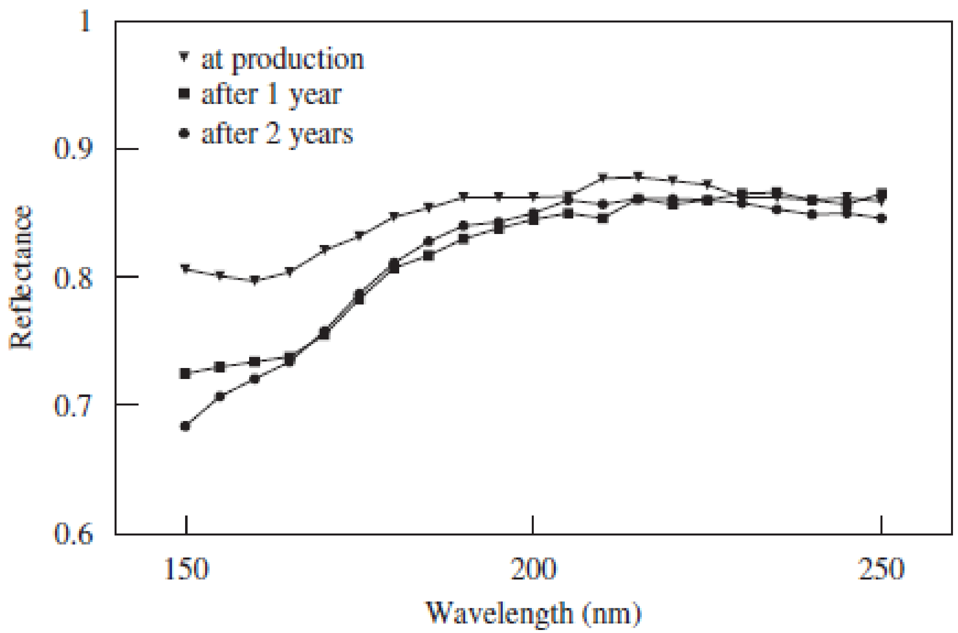


Fig. 36. Measured reflectance for a typical mirror piece. The measurements have been performed shortly after production, 1 and 2 years later.

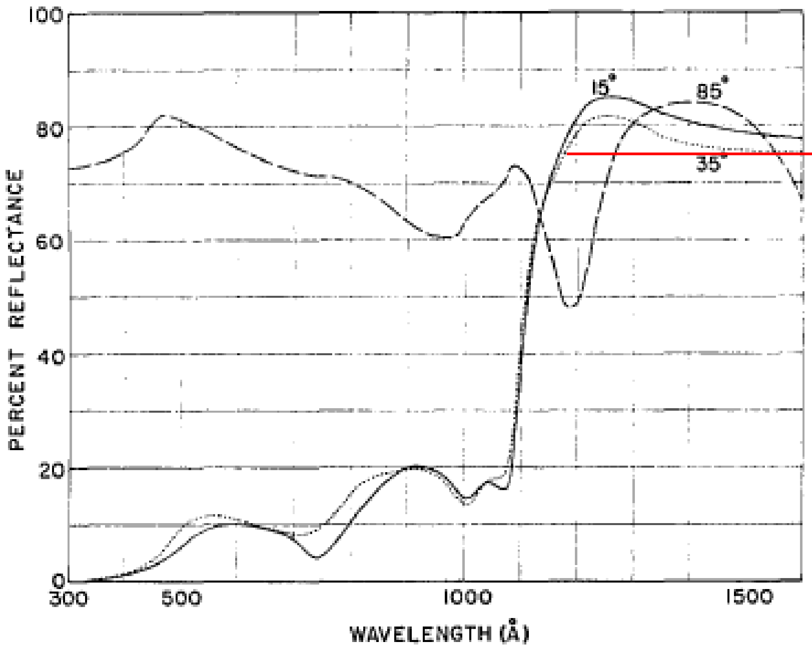
Nuclear Instruments and Methods in Physics Research A300 (1991) 501-510

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.

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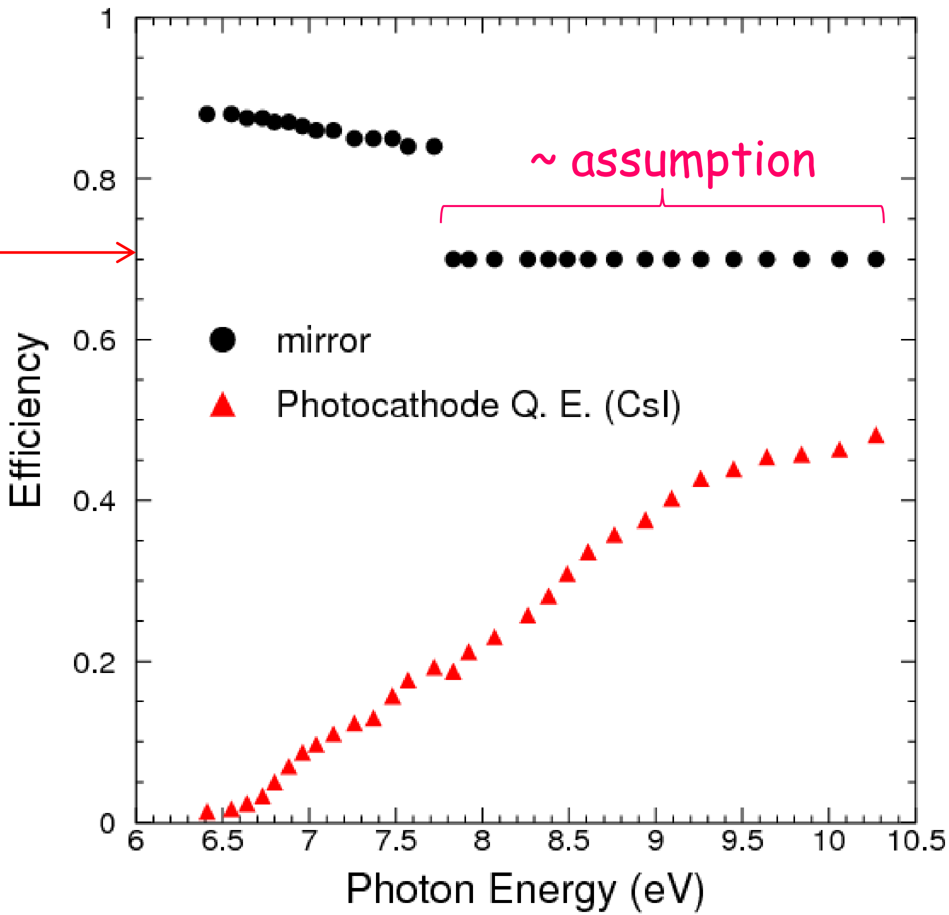
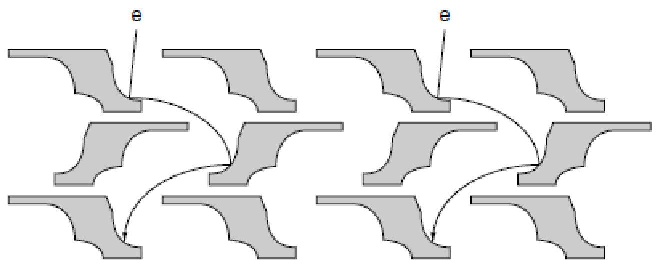


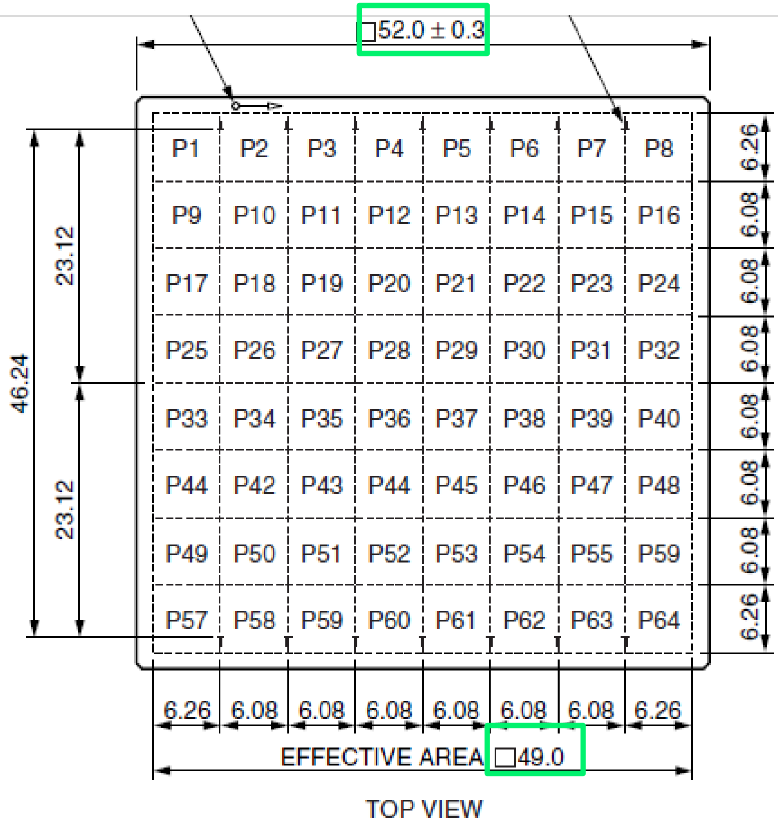
We use this in our simulation

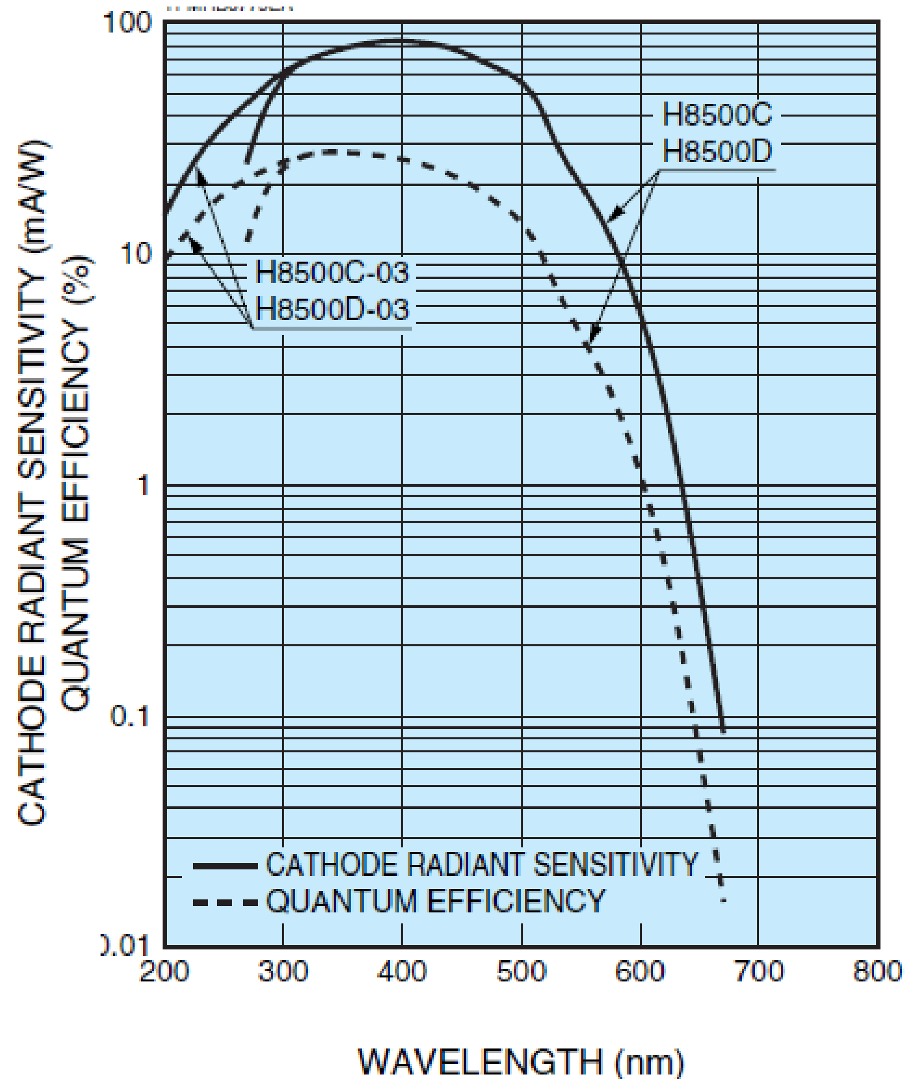
PMT: H8500C-03

- Hamamatsu specifications:
  - → Metal channel dynode structure



  - → 64-channel multianode

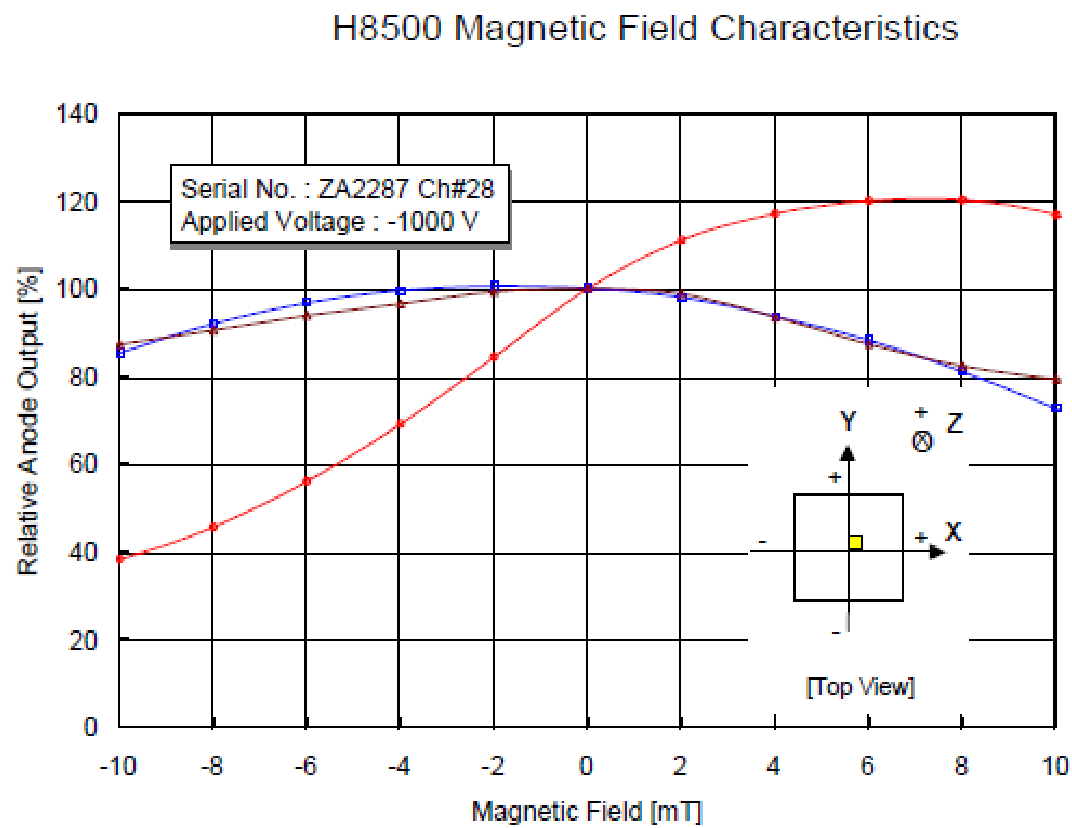


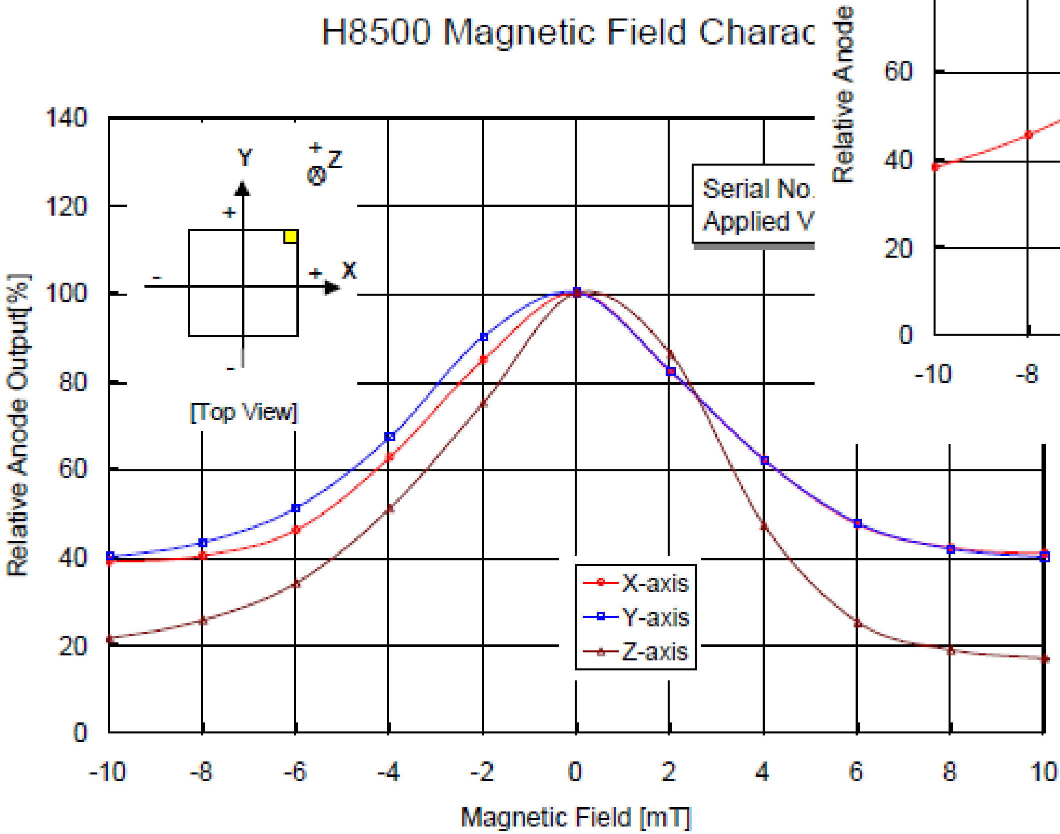


→ spectral response: 185-650 nm with UV glass

PMT: H8500C-03

➡ Hamamatsu specifications:



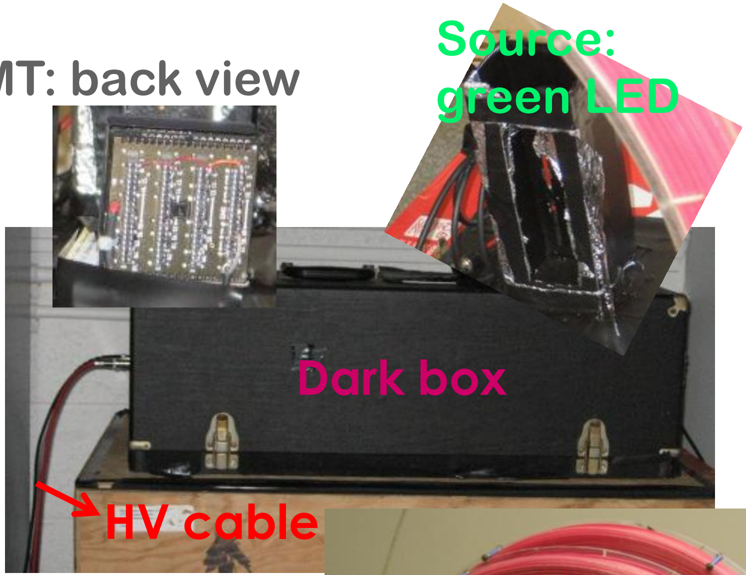


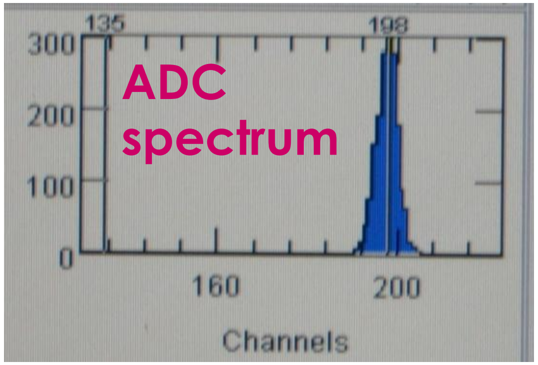
PMT: H8500C-03

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

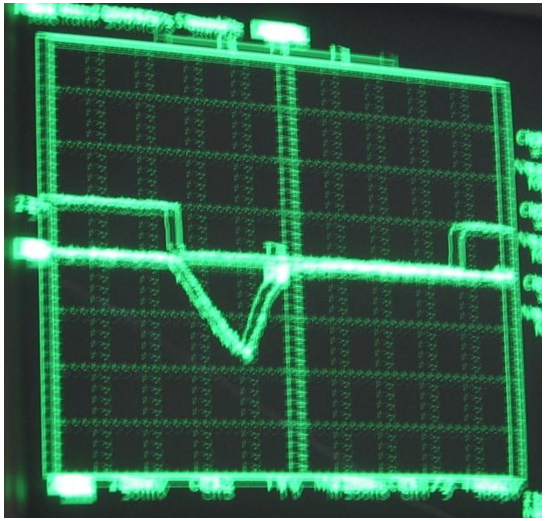
→ We tested H8500C (H8500C-03 expected to have similar response in magnetic field)

PMT: back view





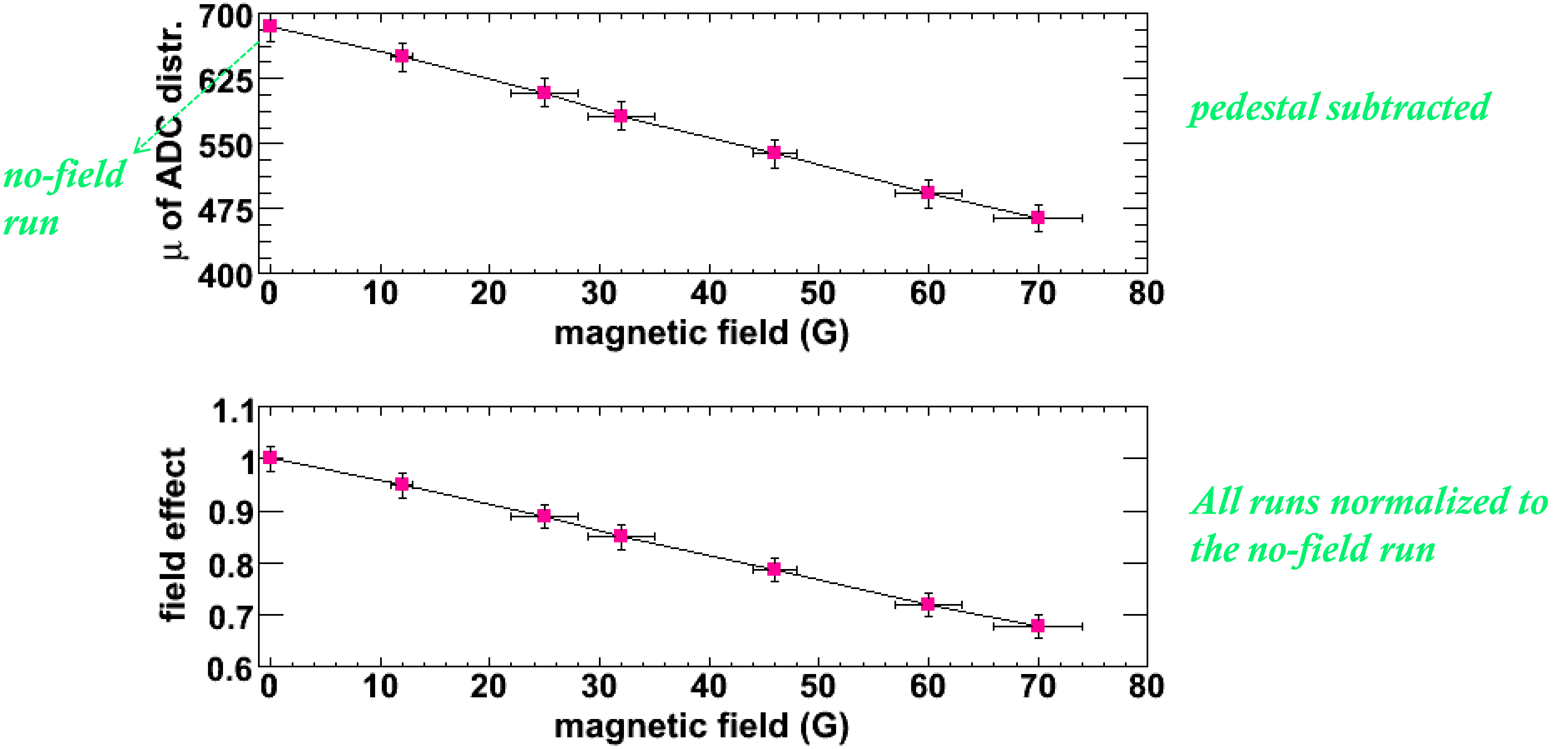
coils



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

PMT: H8500C-03

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



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