

THE LARGE-AREA HYBRID-OPTICS CLAS12 RICH DETECTOR: TEST OF INNOVATIVE COMPONENTS

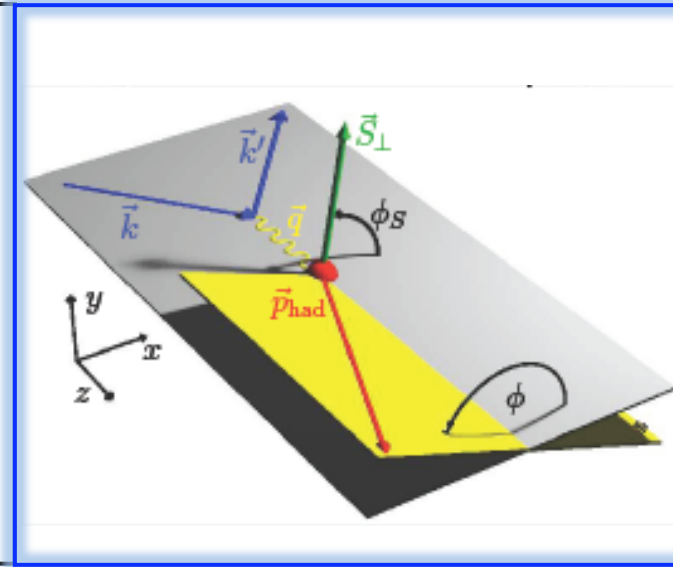
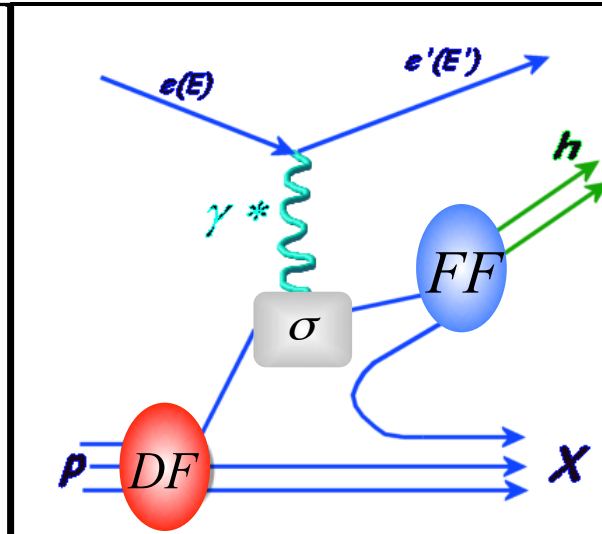
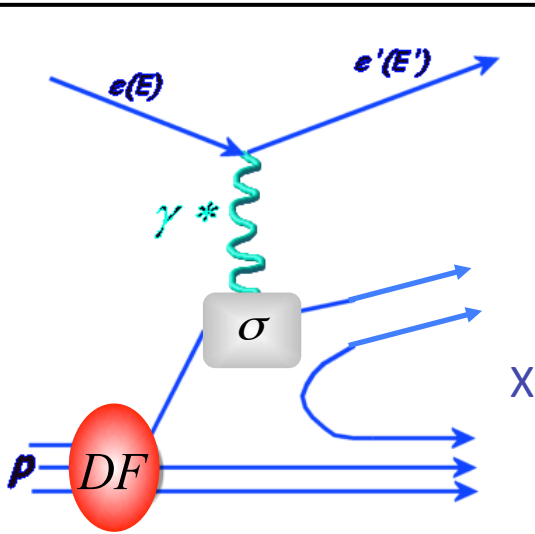
Contalbrigo Marco
INFN Ferrara

RICH 2013 Workshop, 2nd December 2013, SVC - Japan

The 3D Spin Nucleon Structure

Inclusive DIS

Semi-inclusive DIS



SFs (x, Q^2)

PDFs (x, Q^2) & FFs (z, Q^2)

TMDs ($x, z, P_{h\perp}, \phi, \phi_S, Q^2$)

Structure functions
(unpolarized, helicity)

Parton distributions

Transverse momentum
dependent parton distrib.

Sum over quark charges

Flavor sensitivity

Spin-Orbit effects

$$d\sigma \propto F_2 \left(= \sum_q e_q^2 q(x) \right)$$

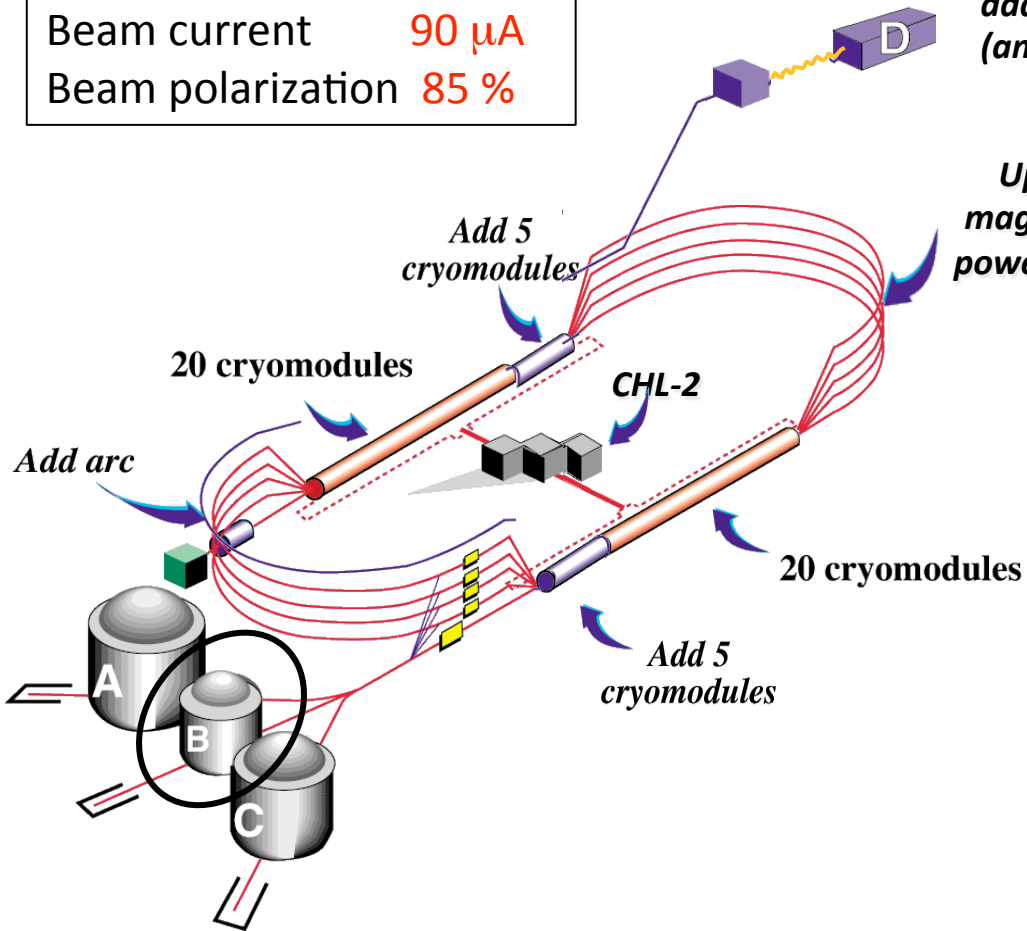
$$d\sigma^h \propto \sum_q e_q^2 q(x) D_q^h(z)$$

$$d\sigma^h \propto \sum_q e_q^2 C \left[q(x, k_T) D_q^h(z, p_T) \right]$$

Rich and Involved phenomenology !!

CEBAF Upgrade at Jefferson Lab

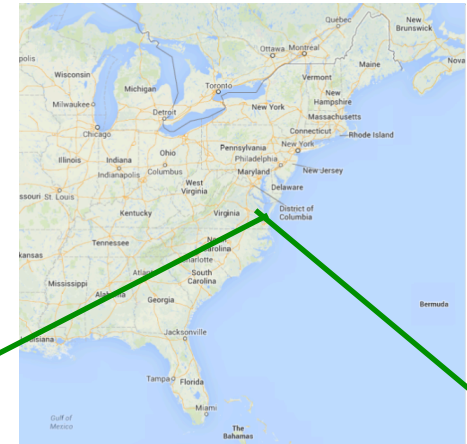
Beam Energy	12 GeV
Beam current	90 μ A
Beam polarization	85 %



**add Hall D
(and beam line)**

**Upgrade
magnets and
power supplies**

**Enhance equipment in
existing halls**



The CLAS12 Spectrometer

Ongoing upgrade of the CLAS detector.
First beam expected in 2016.

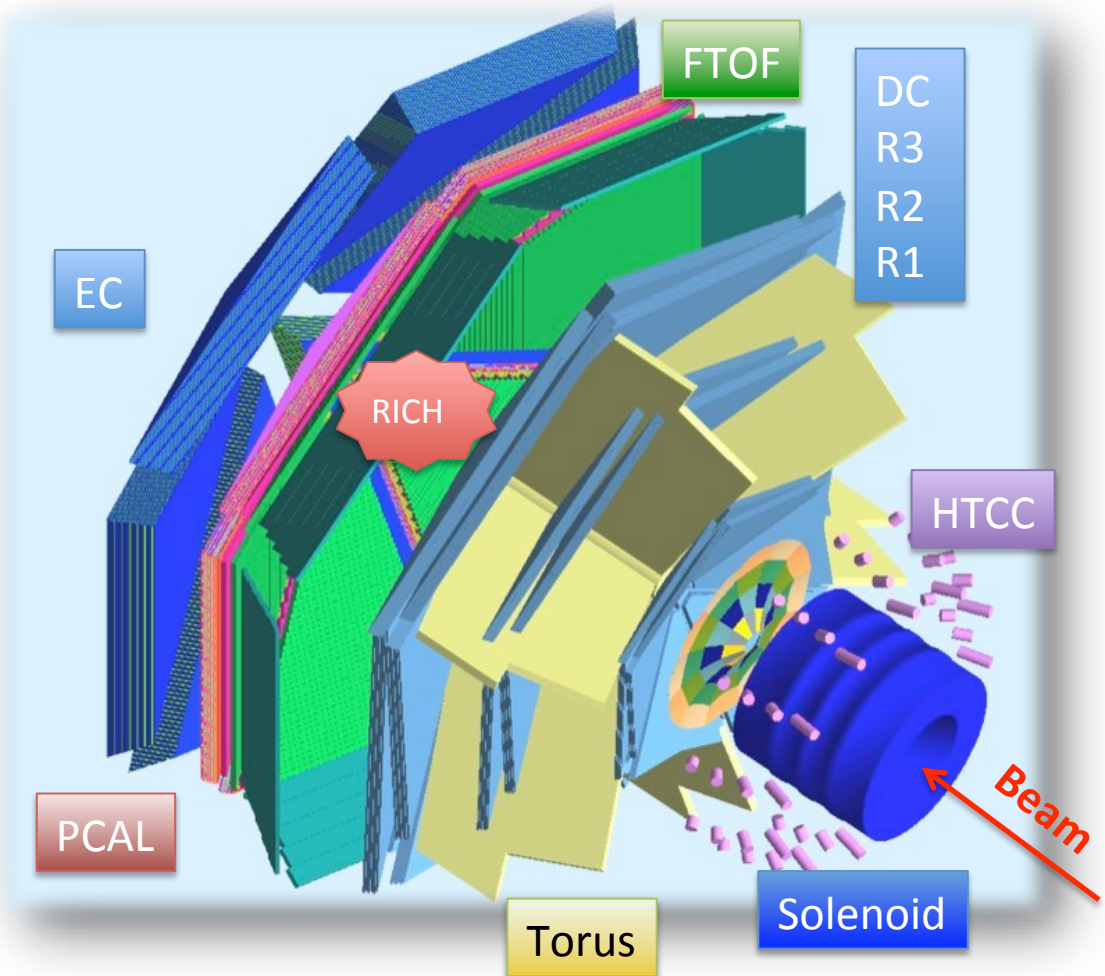
Highly polarized 12 GeV electron beam

Luminosity up to $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$

H and D polarized targets

Broad kinematic range coverage
(current to target fragmentation)

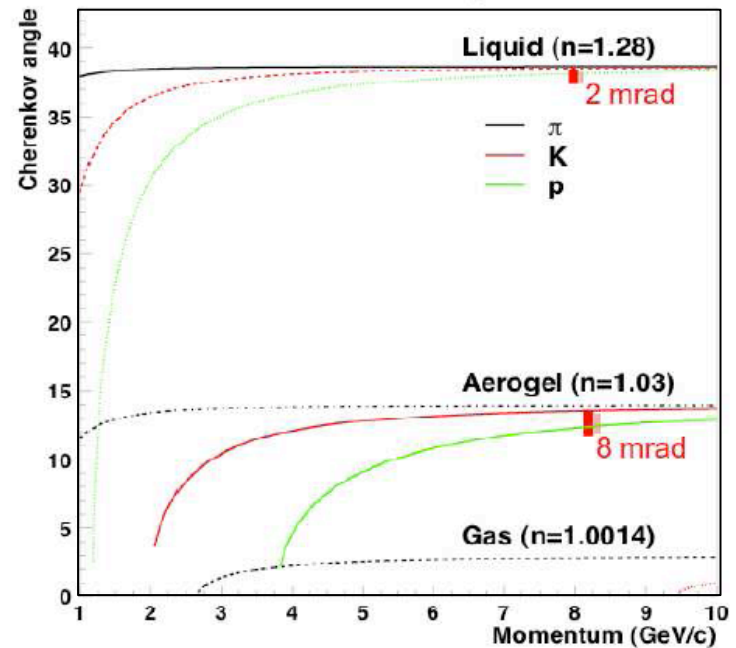
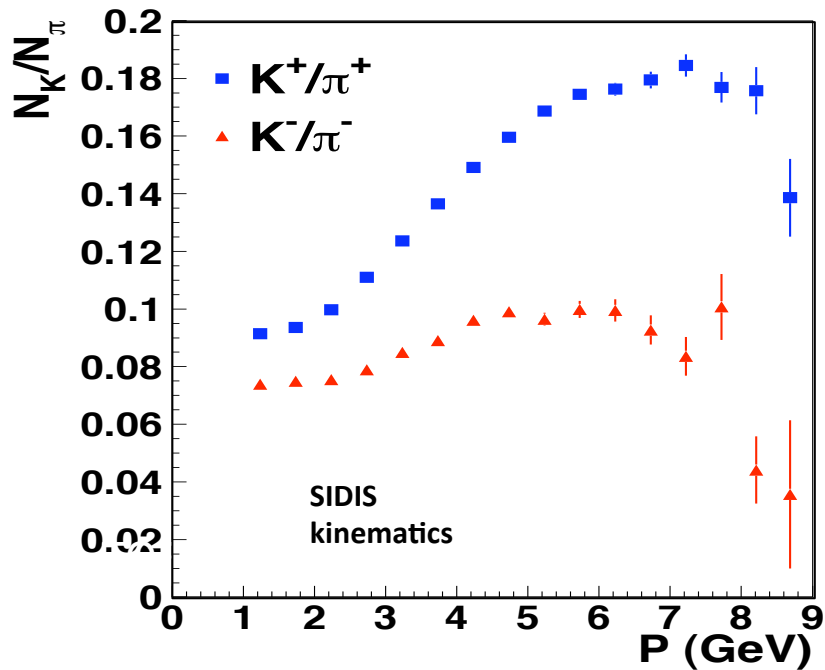
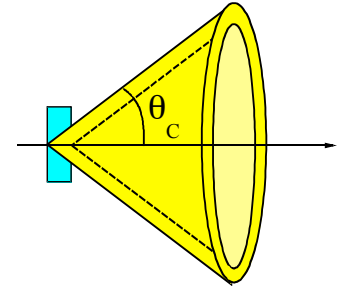
RICH: Hadron ID
for flavor separation
(common to SIDIS approved exp.)



PAC30 report (2006): Measuring the kaon asymmetries is likely to be as important as pions The present capabilities of the present CLAS12 design are weak in this respect and should be strengthened.

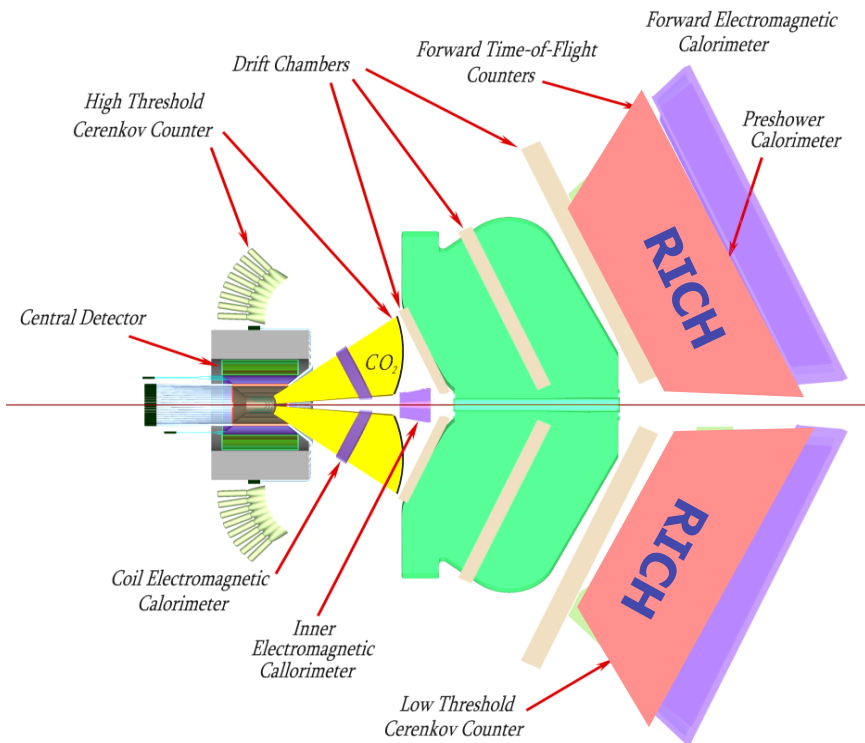
CLAS12 Momentum Range

- ◆ Kaon flux 1 order of magnitude lower than $\pi \rightarrow \pi$ rejection 1:500 required
- ◆ **Aerogel** mandatory to separate hadrons in the 3-8 GeV/c momentum range with the required large rejection factors
- collection of **visible Cherenkov light**
- ◆ **Use of PMTs:** challenging project, need to minimize the detector area covered with expensive photo-detectors



The CLAS12 RICH Project

RICH goal: $\pi/K/p$ identification from 3 up to 8 GeV/c and 25 degrees
 $\sim 4\sigma$ pion-kaon separation for a pion rejection factor $\sim 1:500$



INSTITUTIONS
INFN (Italy) Bari, Ferrara, Genova, L.Frascati, Roma/ISS
Jefferson Lab (Newport News, USA)
Argonne National Lab (Argonne, USA)
Duquesne University (Pittsburgh, USA)
Glasgow University (Glasgow, UK)
J. Gutenberg Universitat Mainz (Mainz, Germany)
Kyungpook National University, (Daegu, Korea)
University of Connecticut (Storrs, USA)
UTFSM (Valparaiso, Chile)

RICH Base Configuration

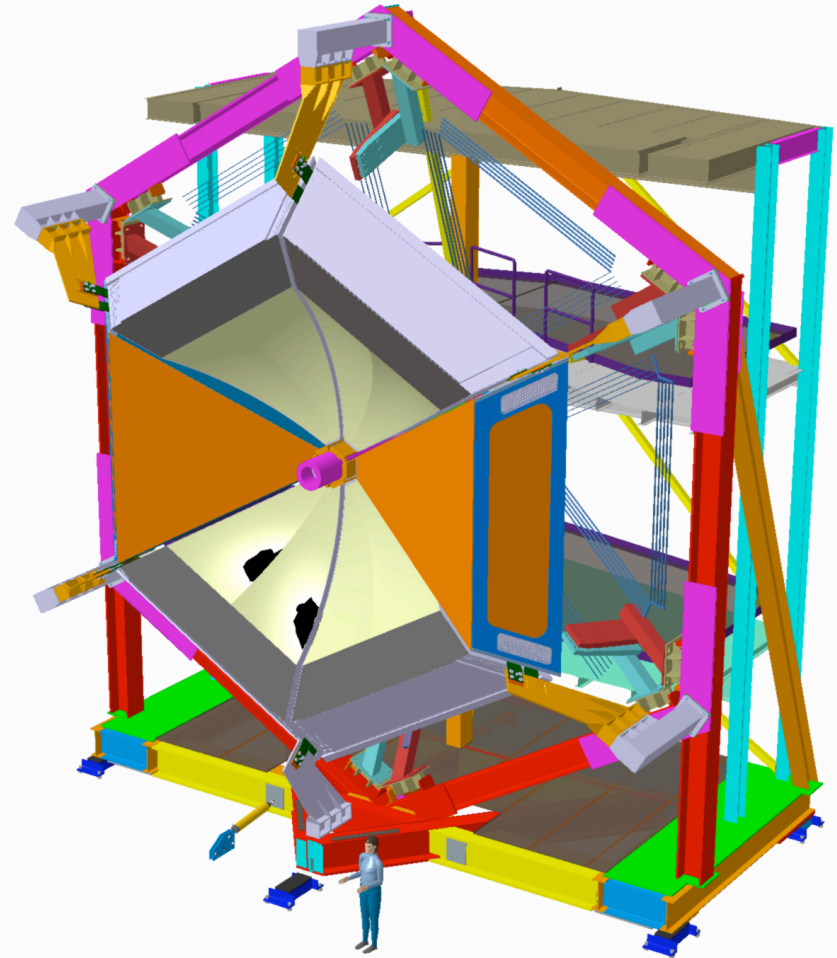
1st sector allows:

- ✓ to start physics with un-polarized and longitudinal polarized target
- ✓ full coverage of the relevant azimuthal angle ϕ (w.r.t virtual photon)

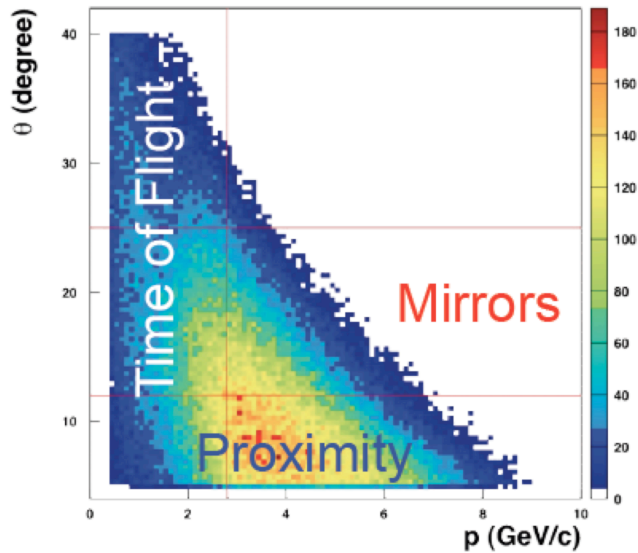
2nd sector allows:

- ✓ to extend the kinematical coverage into the most interesting regions (high- Q^2 and high- P_T)
- ✓ the symmetric arrangement needed to control systematic effects in precision measurements with polarized targets (i.e. double ratio method)

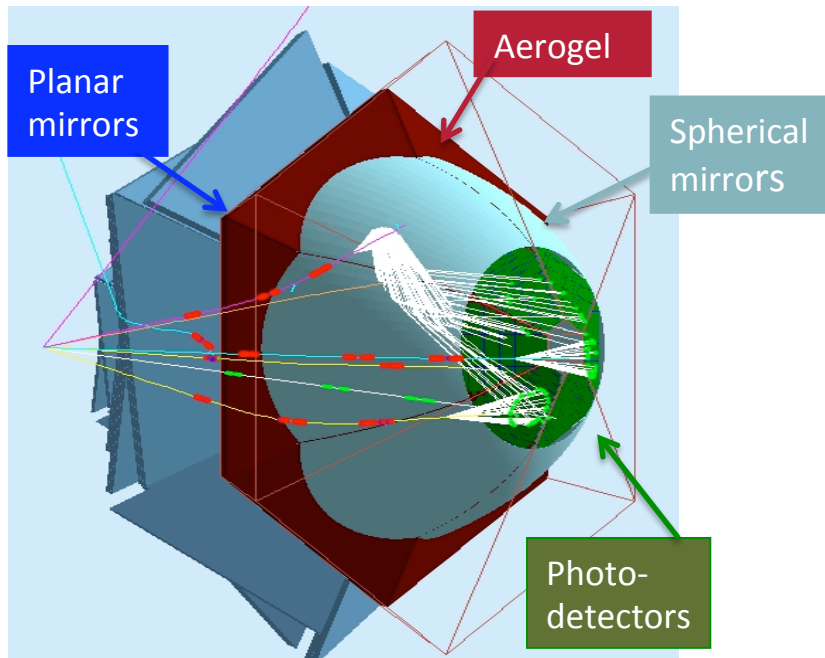
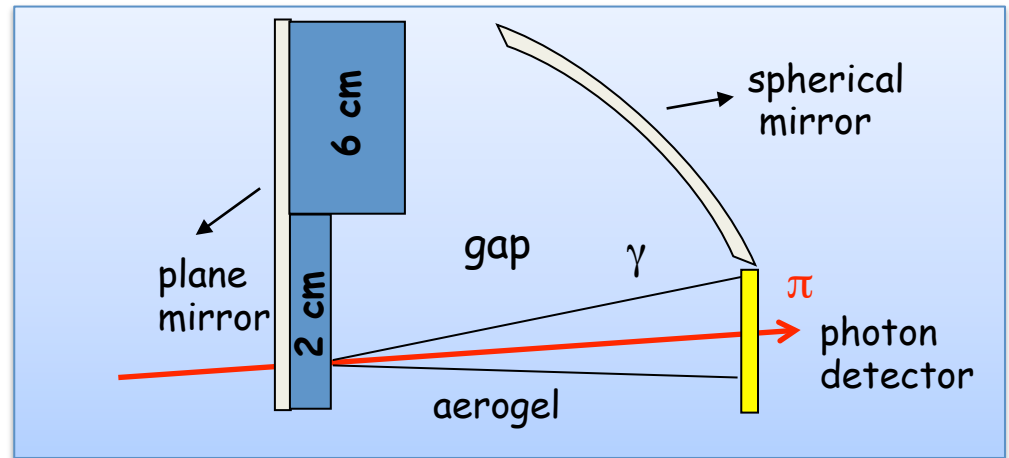
Crucial for the study of parton dynamics related to angular momentum and spin-orbit effects with flavor sensitivity.



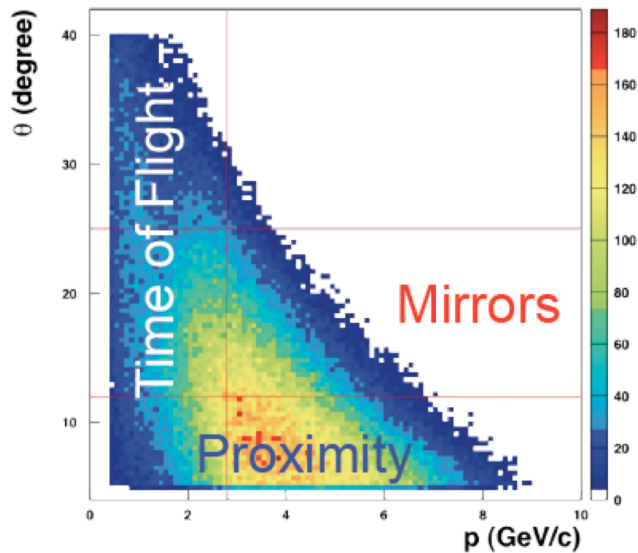
The Hybrid Optics Design



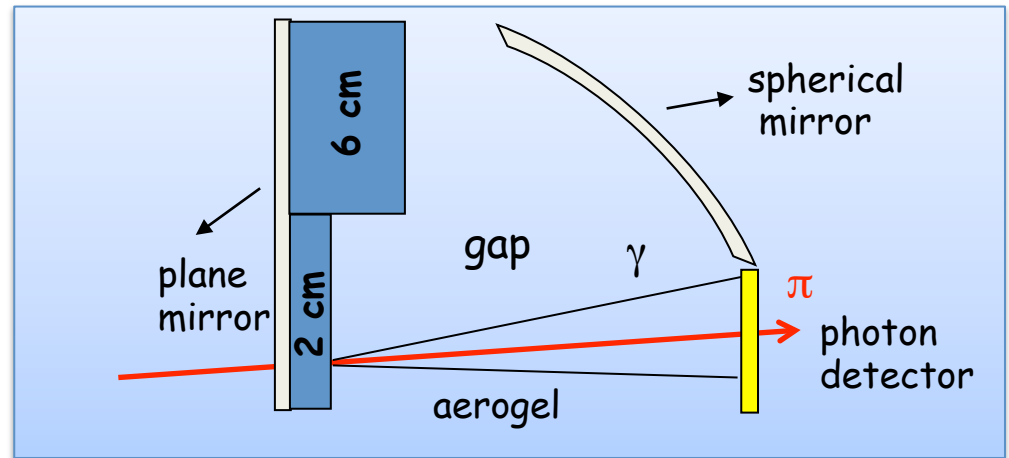
Direct rings/best performance for high momentum particles



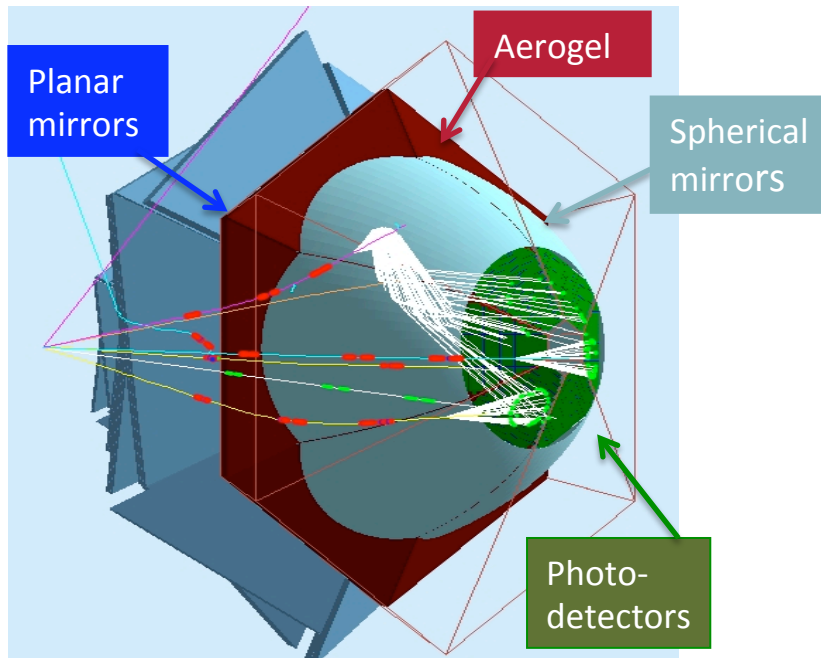
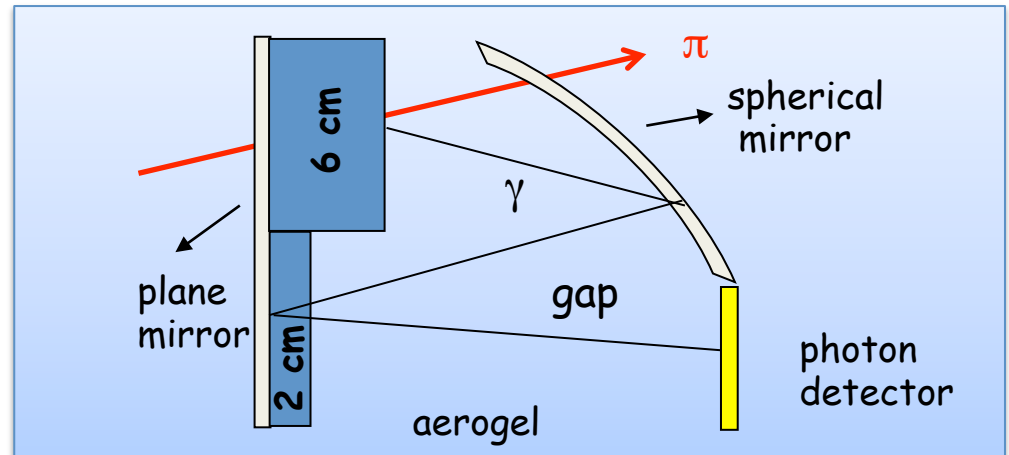
The Hybrid Optics Design



Direct rings/best performance for high momentum particles



Reflected rings for less demanding low momentum particles



- Minimize active area (cost) to about 1 m^2
- Material budget concentrated where TOF is less effective
- Focalizing mirrors allow thick radiator for good light yield

Aerogel Radiator



The CLAS12 large area RICH detector

M. Contalbrigo^{a,*}, E. Cisbani^b, P. Rossi^c

^a INFN Ferrara, Italy
^b INFN Roma and Istituto Superiore di Sanità, Italy
^c INFN Laboratori Nazionali di Frascati, Italy

ARTICLE INFO

Available online 28 October 2010

Keywords:
RICH
CLAS12
Particle identification

ABSTRACT

A large area RICH detector is being designed for the CLAS12 spectrometer as part of the 12 GeV upgrade program of the Jefferson Lab Experimental Hall-B. This detector is intended to provide excellent hadron identification from 3 GeV/c up to momenta exceeding 8 GeV/c and to be able to work at the very high design luminosity up to $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. Detailed feasibility studies are presented for two types of radiators, aerogel and liquid C_6F_{14} freon, in conjunction with a highly segmented light detector in the visible wavelength range. The basic parameters of the RICH are outlined and the resulting performances, as defined by preliminary simulation studies, are reported.

© 2010 Elsevier B.V. All rights reserved.

The study of the structure of nucleons and nuclei with the help of the high-resolution spectrometers at CLAS12, will allow us to investigate the structure of nucleons and nuclei in the non-perturbative regime of QCD. The main focus of the CLAS12 program is the study of the structure of nucleons and nuclei in the non-perturbative regime of QCD. The main focus of the CLAS12 program is the study of the structure of nucleons and nuclei in the non-perturbative regime of QCD.

Important observables that will be extensively investigated are transverse Momentum Distribution functions (TMDs) describing partonic spin-orbit effects and Generalized Parton Distribution functions (GPDs), containing information about the spatial distribution of quarks and the relation (by a sum rule) to the elusive orbital momenta. Several experiments have been already performed by the JLab12 PAC to study kaon versus pion production in exclusive and semi-inclusive scattering, providing access to the decomposition of the two sets of non-perturbative wave functions.

Main features of CLAS12 include a high operational design luminosity of $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, an order of magnitude higher than CLAS, and operation of highly polarized beam and target. The conceptual design of the CLAS12 detector is shown in Fig. 1. The central detector with the high-field (5 T) torus magnet is used for particle tracking at large angles. The CLAS12 detector detects charged and neutral particles in the angular range between 5 and 40° . It employs a 2 T torus magnet with a detector symmetry of CLAS. In the base equipment, the CLAS12 detector is designed to operate with a freon radiator and a CsI-deposited radiator.

The CLAS12 detector is designed to operate with a freon radiator and a CsI-deposited radiator. The CLAS12 detector is designed to operate with a freon radiator and a CsI-deposited radiator. The CLAS12 detector is designed to operate with a freon radiator and a CsI-deposited radiator.

tion and event reconstruction can be achieved in this momentum range by replacing the existing low-threshold Cherenkov counter (LTCC) with a RICH detector without any impact on the baseline design of CLAS12.

2. The CLAS12 RICH

To fit into the CLAS12 geometry, the RICH should have a projective geometry with six sectors that cover the space between the torus cryostats and covering scattering angles from 5° to 40° . Fig. 3. Being downstream to the torus magnet at the interaction point, the RICH has to cover a large area each sector spanning an area of the order of 4 m^2 . Between the CLAS12 detectors which are already in the construction, the gap depth cannot exceed 1 m. The proposed solution is a segmented RICH.

A setup similar to the one adopted in Hall-B (CLAS12) with a C_6F_{14} radiator and a CsI-deposited radiator is required pion rejection factor at momenta between 3 and 8 GeV/c.

The preliminary results on ongoing Monte Carlo studies, based on a GEANT3 toolkit with simplified geometry and optical surface

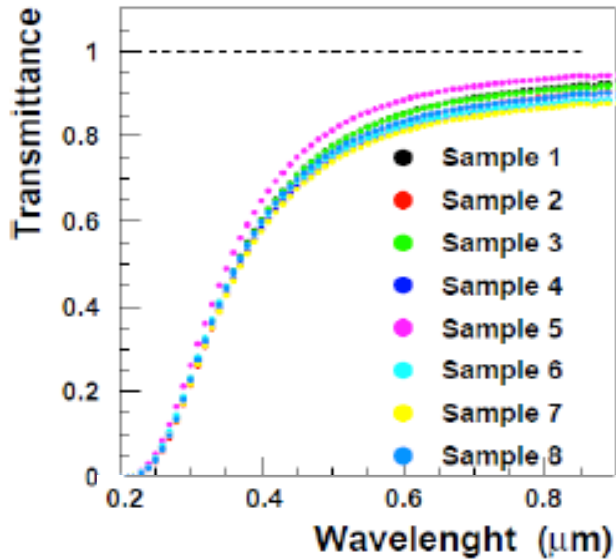
* Corresponding author.
E-mail address: mcontal@fe.infn.it

0168-9002/\$ - see front matter
doi:10.1016/j.nima.2010.10.147

mcontal@fe.infn.it (M. Contalbrigo).

© 2010 Elsevier B.V. All rights reserved.
147

Aerogel Characterization

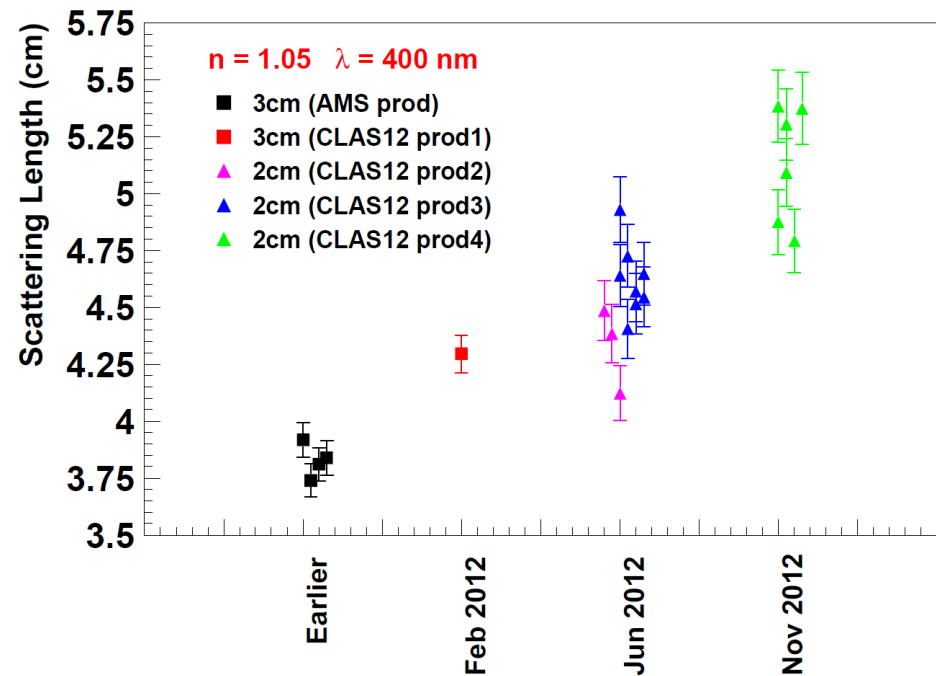
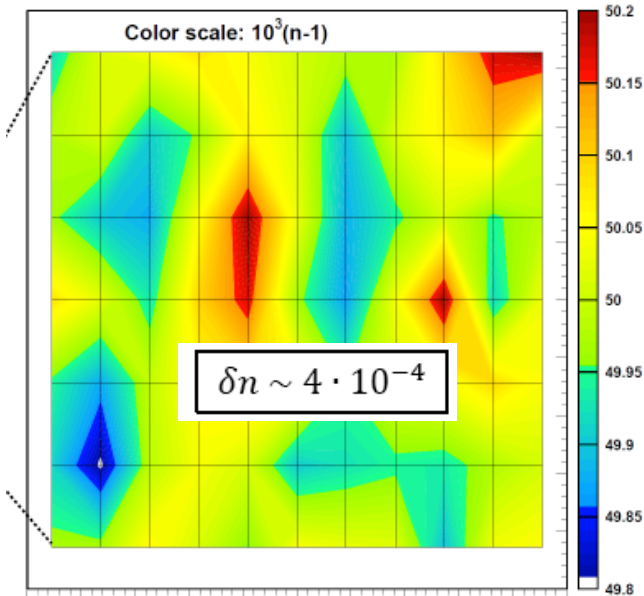


Achieved clarity for large tiles at $n=1.05$

$$\sim 0.00050 \mu\text{m}^4 \text{ cm}^{-1}$$

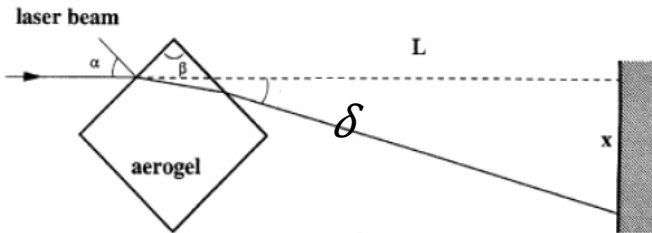
(LHCb has $0.0064 \mu\text{m}^4 \text{ cm}^{-1}$ for $n=1.03$)

In collaboration with Budker and Boreskov
Institutes of Novosibirsk

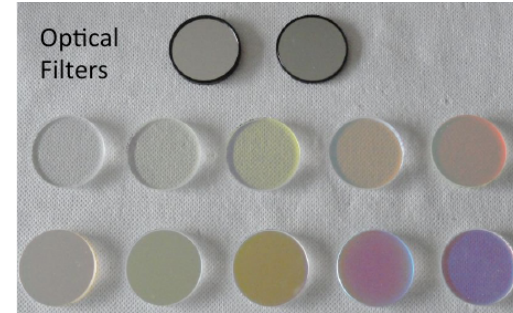


Aerogel Chromatic Dispersion

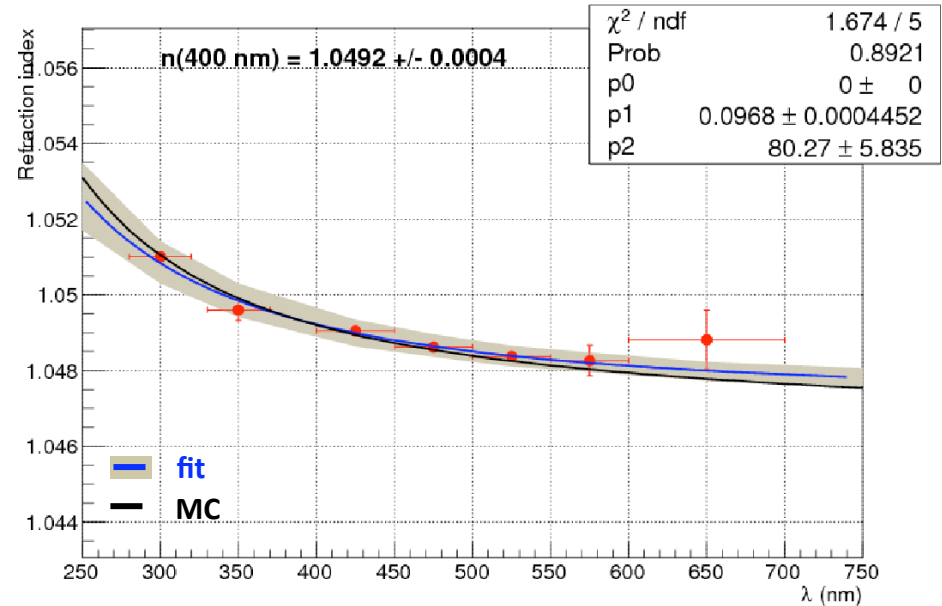
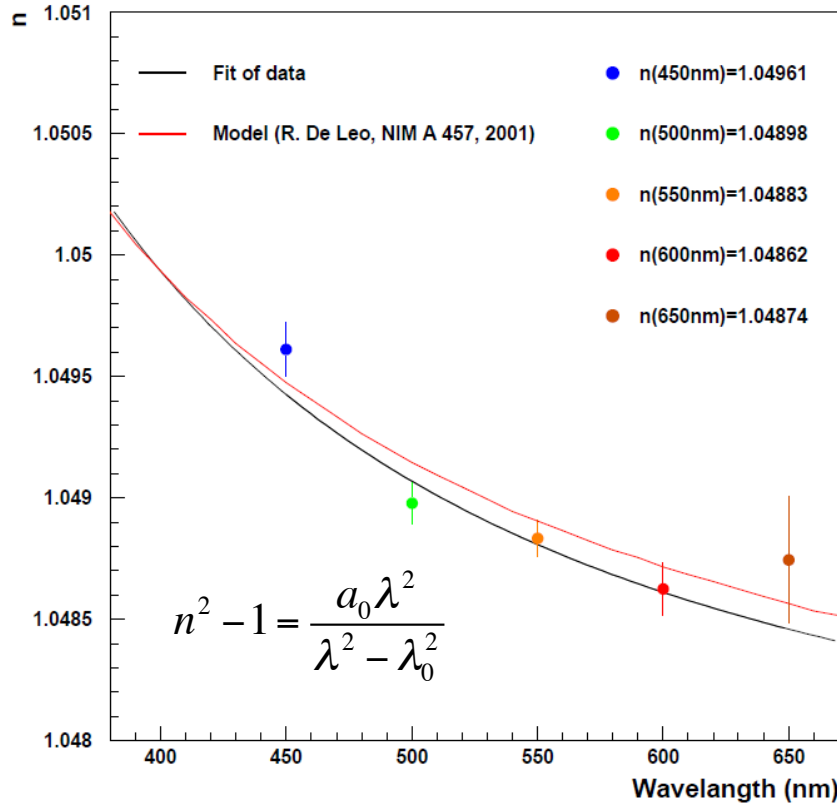
Measured by prisma method:



Measured by prototype with optical filters:



Chromatic dispersion

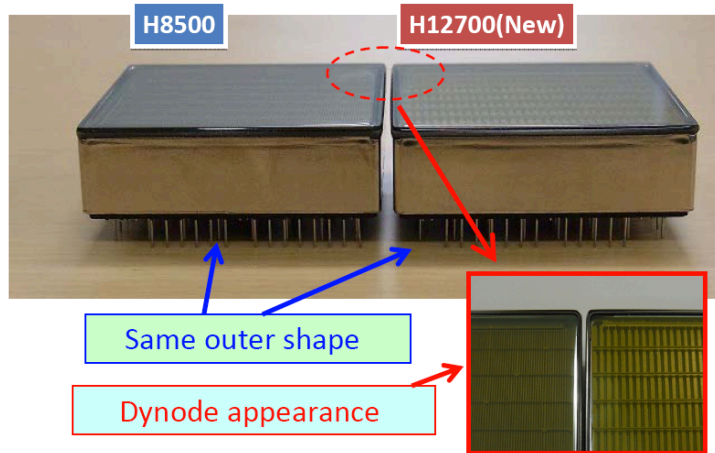


Expected value from density:
 $n^2(400\text{nm}) = 1 + 0.438\rho$
 $n(400\text{nm}) = 1.0492$

Photon Detectors: MA-PMT

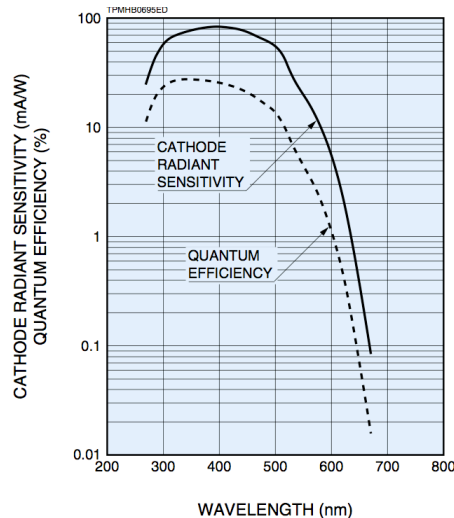
The only option to keep the schedule is the use of multi-anode photomultipliers (we consider the promising SiPM technology as the alternative)

- ✓ Mature and reliable technology
- ✓ Large Area ($5 \times 5 \text{ cm}^2$)
- ✓ High packing density (89 %)
- ✓ 64 $6 \times 6 \text{ mm}^2$ pixels cost effective device
- ✓ High sensitivity on visible towards UV light
- ✓ Fast response

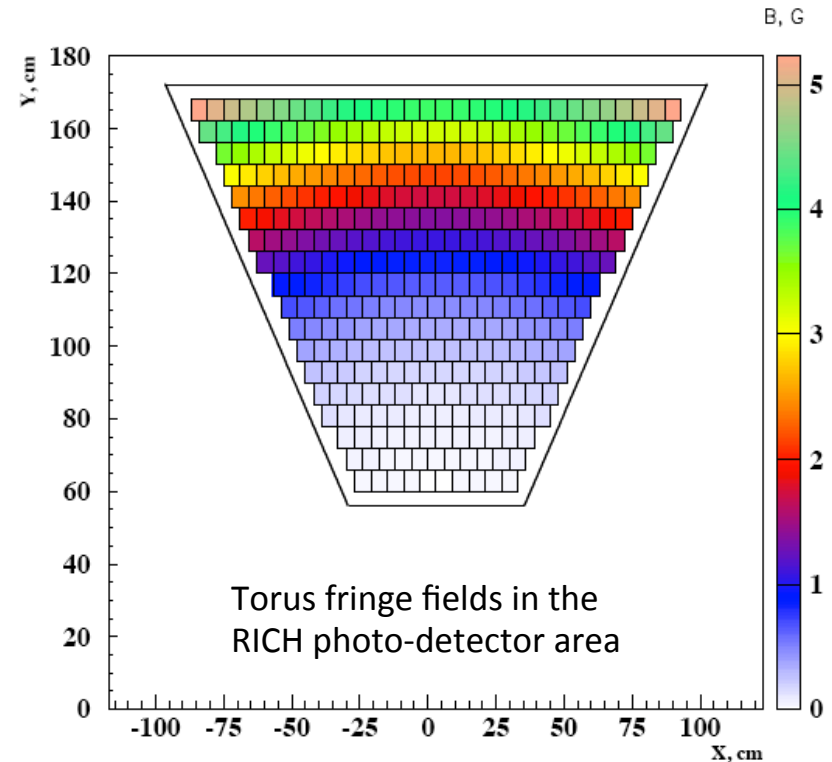


HAMAMATSU
PHOTON IS OUR BUSINESS

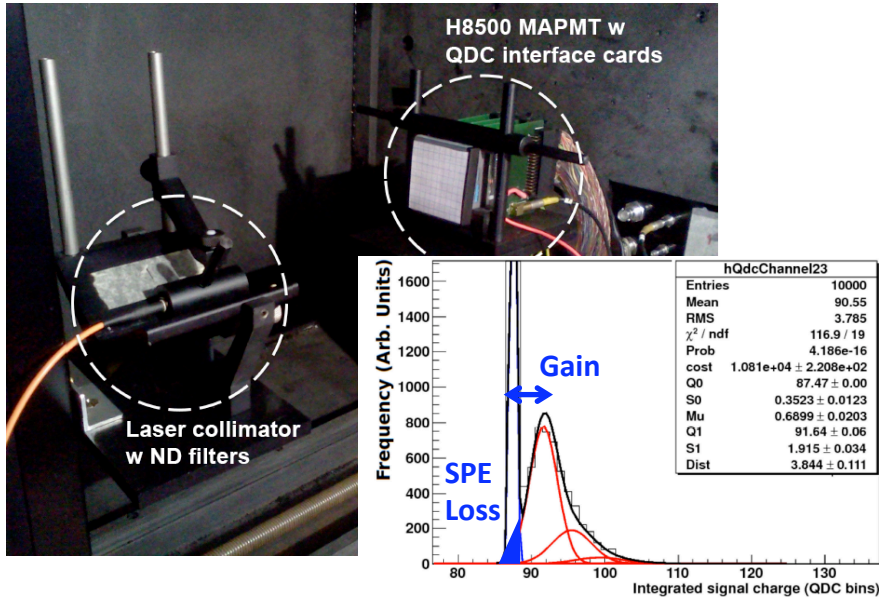
Copyright © Hamamatsu Photonics K.K. All Rights Reserved.



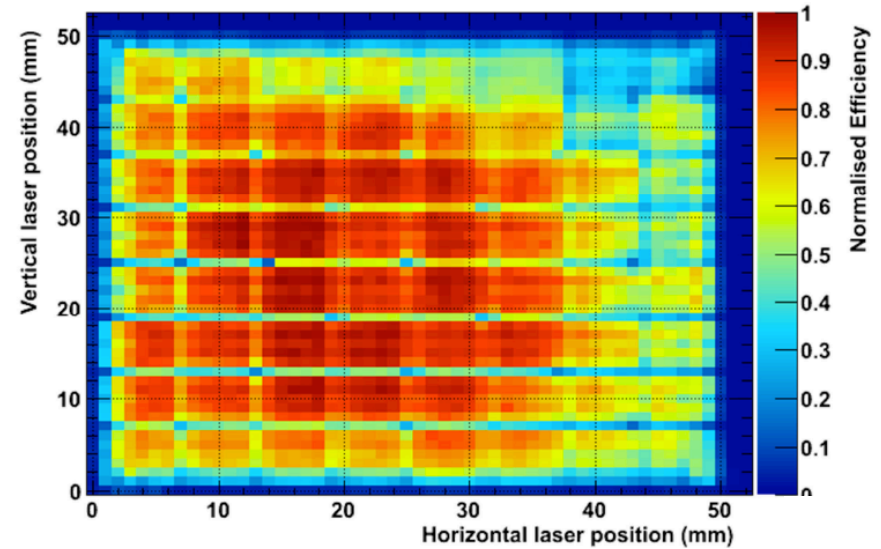
28 H8500:
 14 with standard window (H8500C)
 14 with UV window (H8500C-03)
 2 H12700:
 za003 and za0014



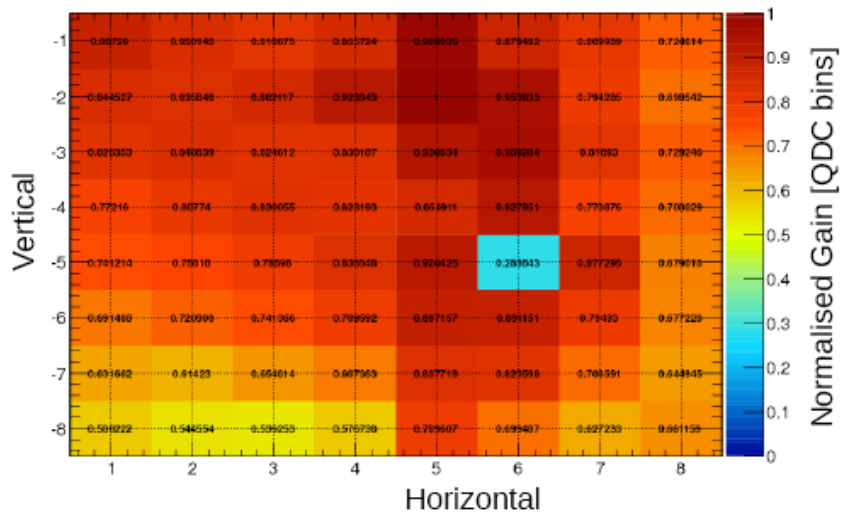
MA-PMT Gain Map



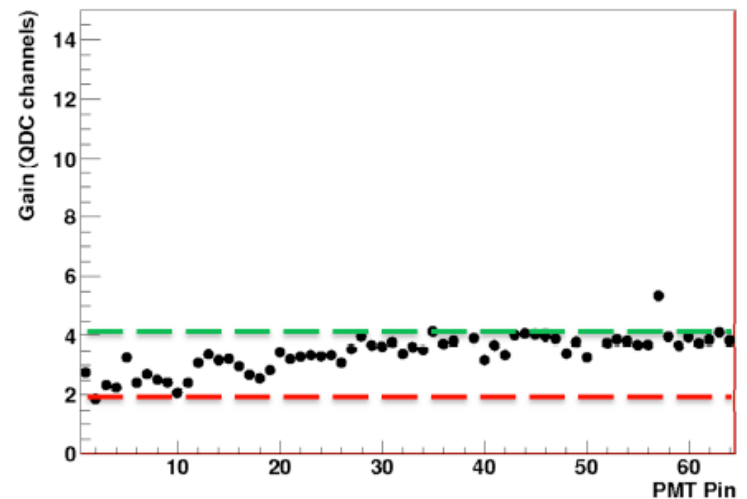
H8500



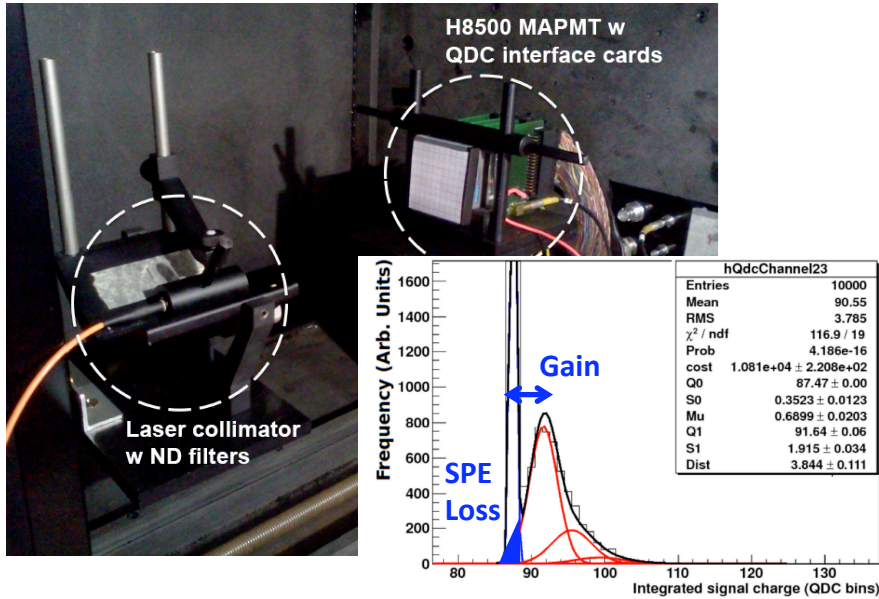
H12700 1:2 gain variation



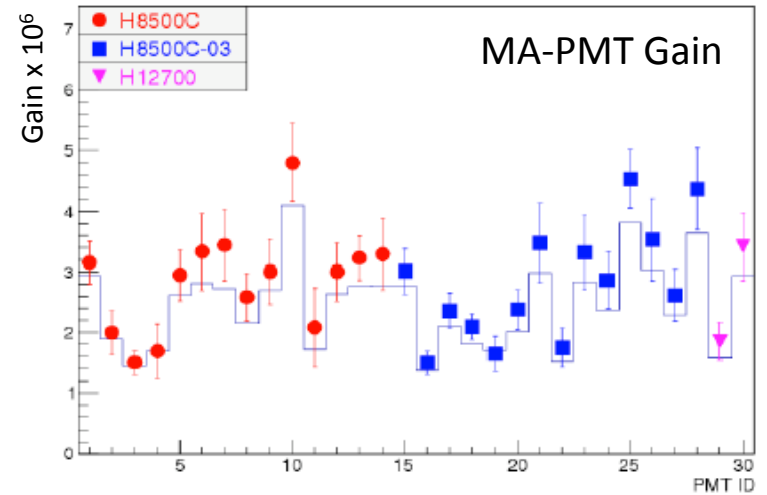
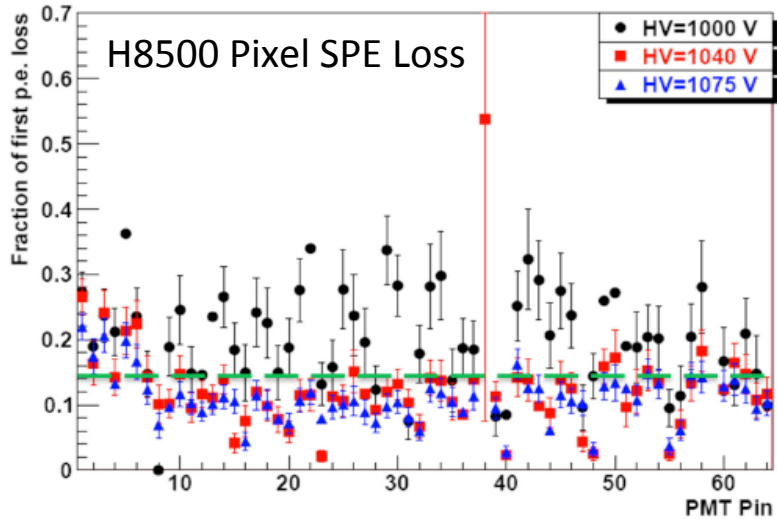
Pixel Gain: 1:2 variation can be easily compensated by the read-out electronics



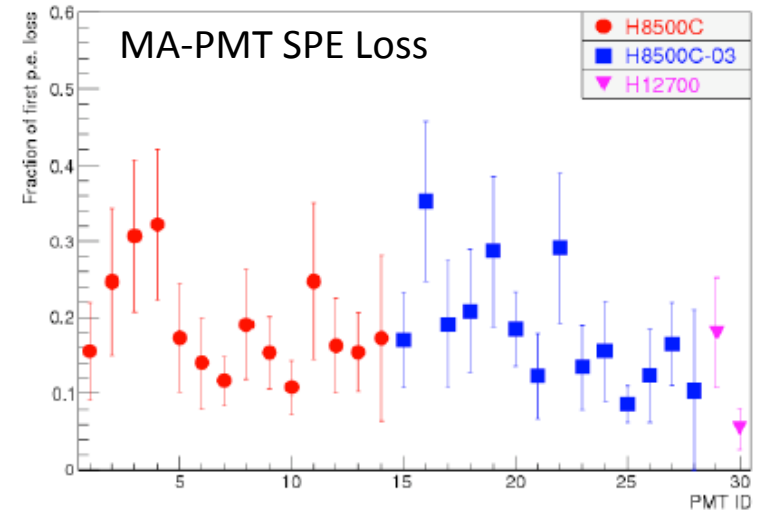
MA-PMT SPE LOSS



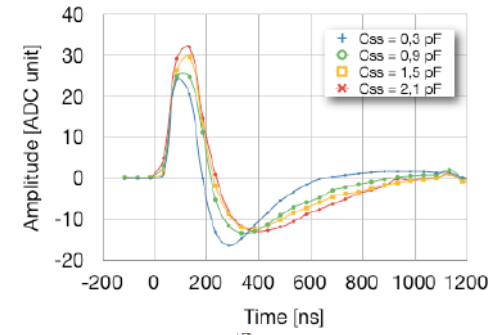
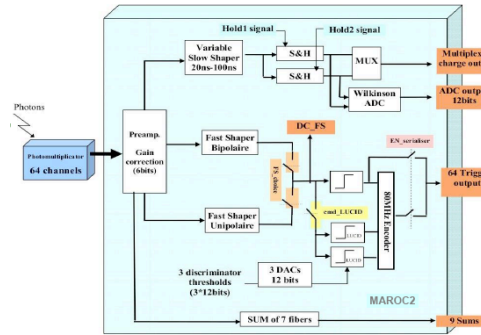
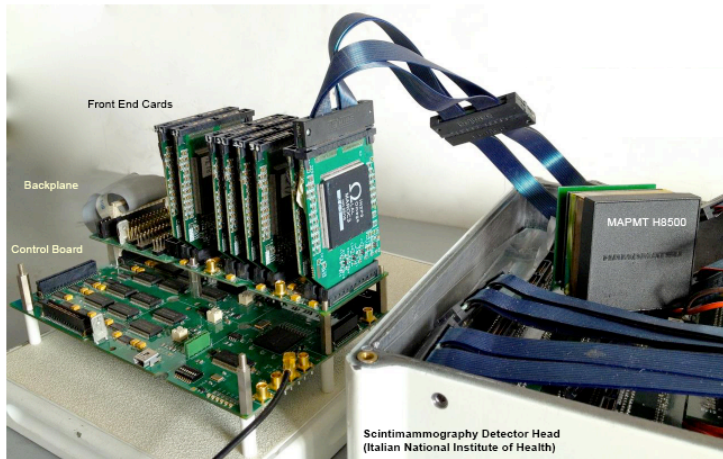
SPE loss limited to ~15% above 1040V and almost uniform over 28 MA-PMTs



H12700 features a ~30 % better SPE resolution than H8500 at similar gain

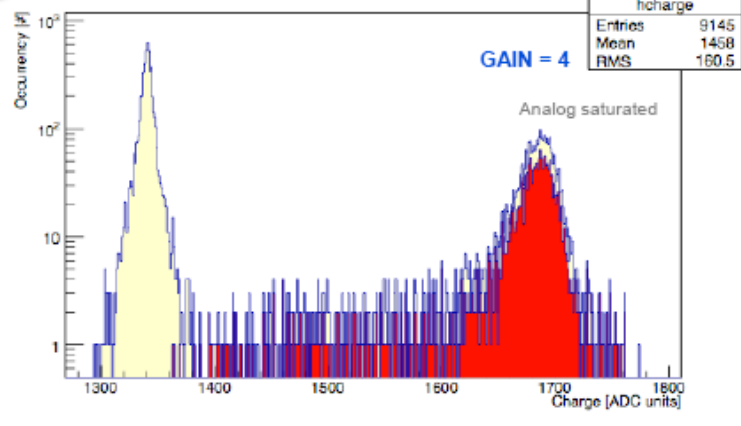
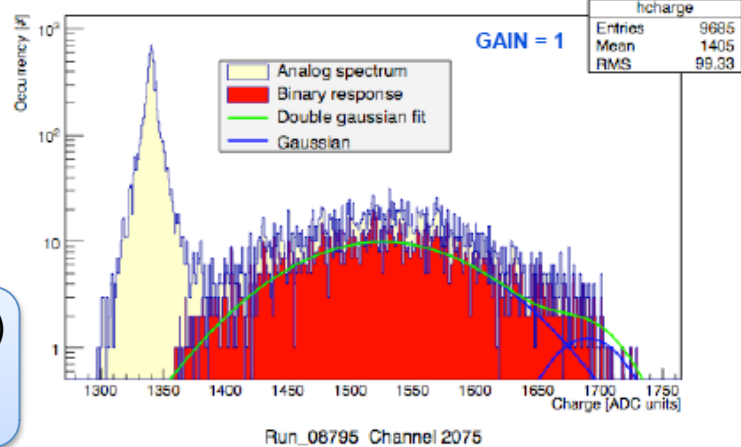
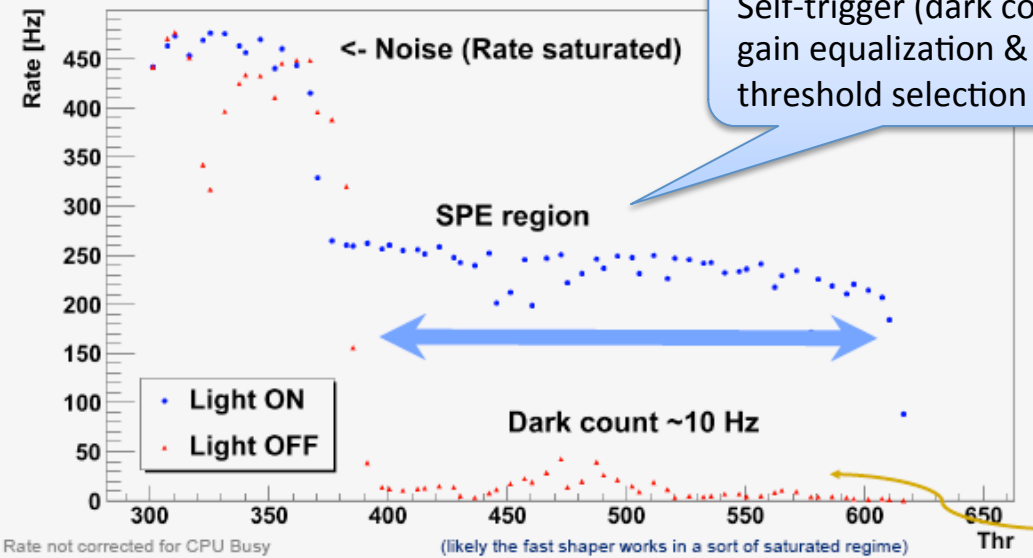


MAROC3 Front-End Electronics

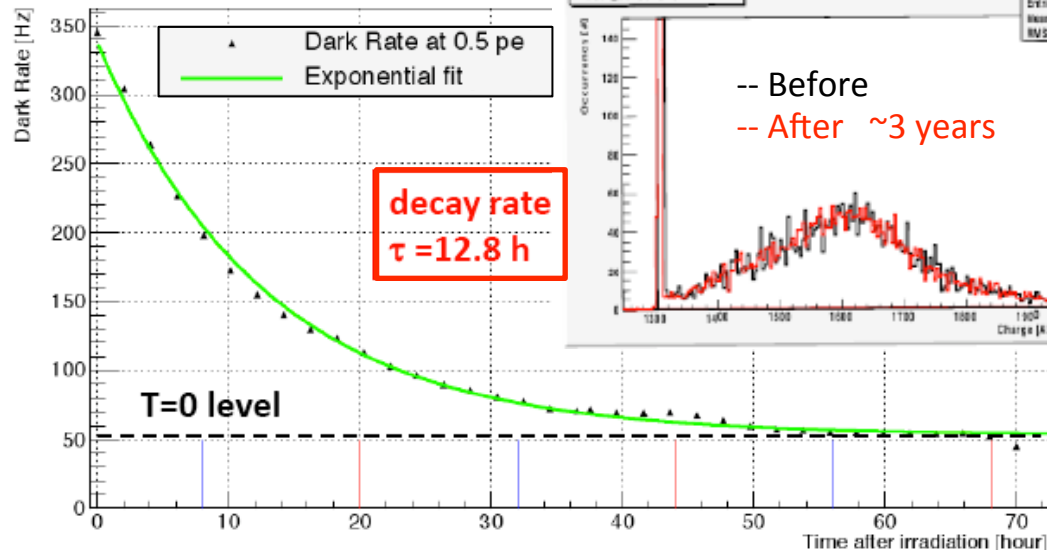


Multiplexed analog output
64 binary outputs with time jitter ~300 ps

Digital Rate vs Thr / Internal Trigger

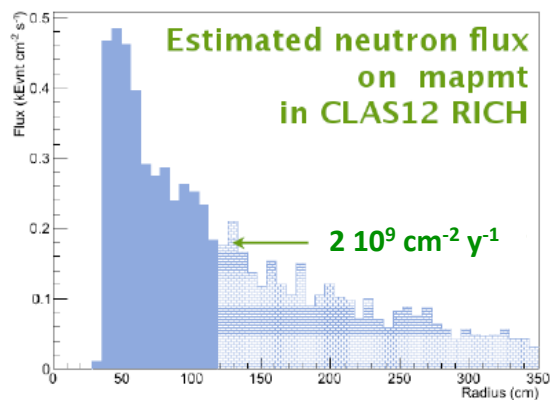


Neutron Irradiation Tests



Neutrons produced isotropically through
 $d(230\text{keV}) t \rightarrow n \alpha$
 α particles measured to monitor the intensity

- max flux 10^{11} s^{-1} in 4π
- max neutron energy 14.6 MeV

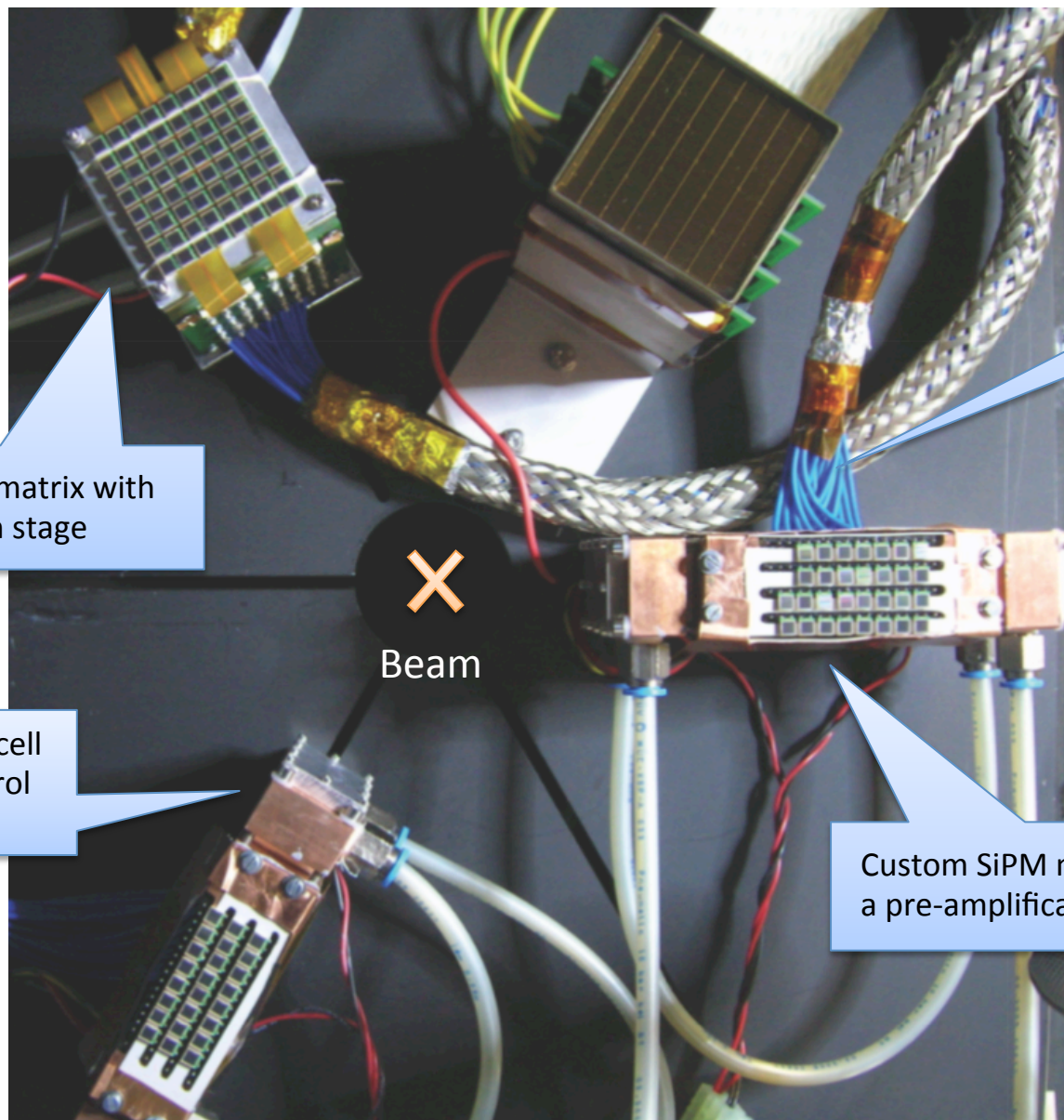


UV
 non-UV

No long-term effect on MA-PMT or MAROC3, null or negligible effect on specific components after ~ 20 years

Name	Irrad.	spread	Average	
L14U2	Yes	0.3%	92.13 ± 0.12	no effect
L14U	No	0.2%	92.39 ± 0.07	
L141	Yes	1.4%	89.31 ± 0.53	-2.8%
L14	No	0.2%	92.09 ± 0.09	
Lucite S.	Yes	1.2%	89.37 ± 0.48	-1.3%
Lucite L.	No	0.5%	90.65 ± 0.20	

The SiPM Test Prototype



Commercial SiPM matrix with a pre-amplification stage

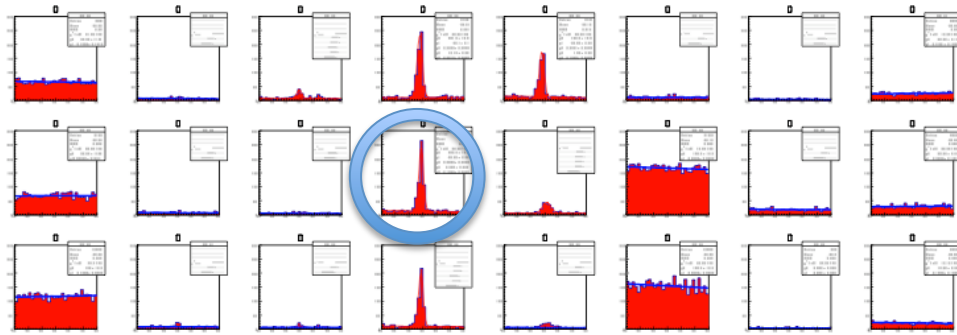
1.5 m coaxial cables to the electronics

X
Beam

Water-cooled Peltier cell for temperature control [-25 : +25 Celsius]

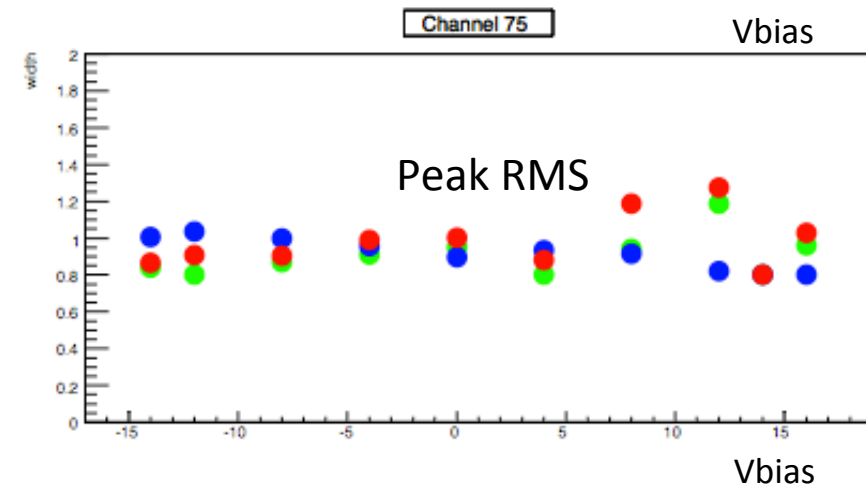
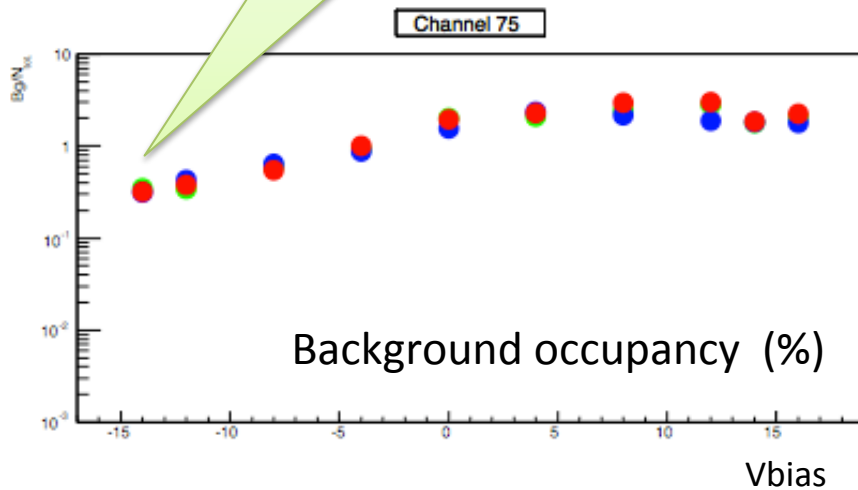
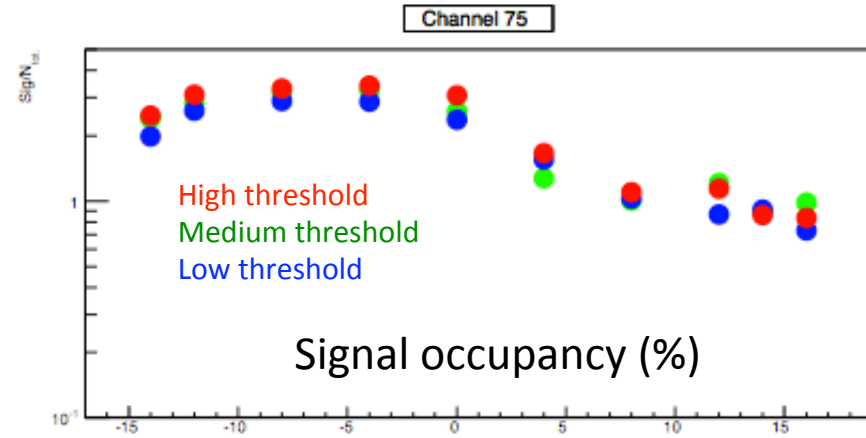
Custom SiPM matrices with a pre-amplification stage

The Custom SiPM Matrix @ +25°



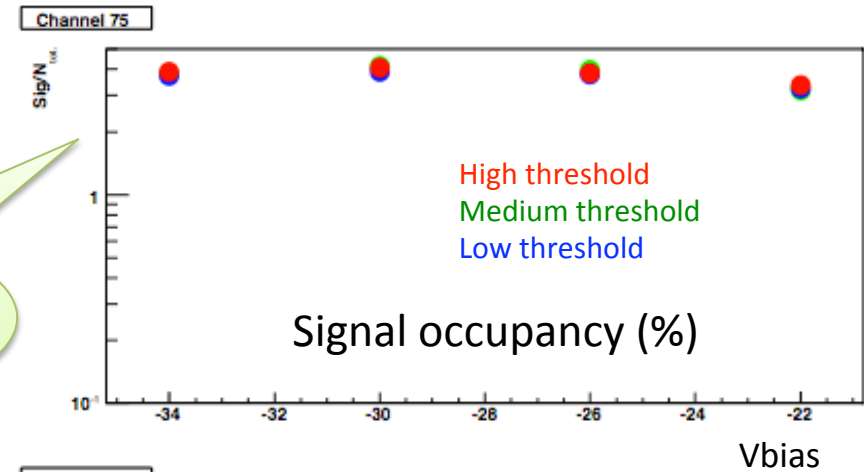
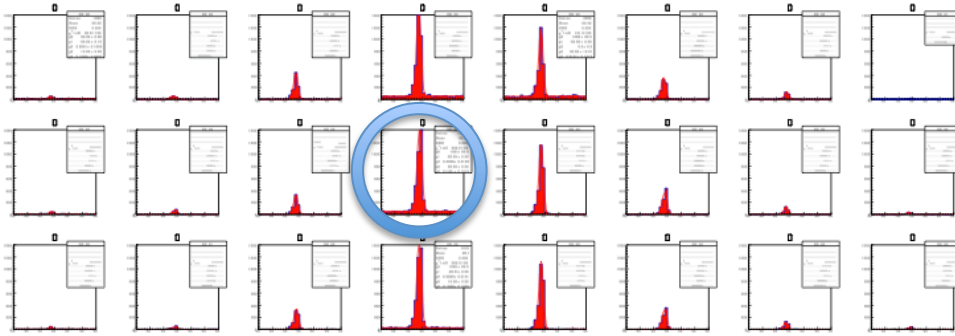
Equalization of the single SiPM is critical

10^{-3} level is challenging



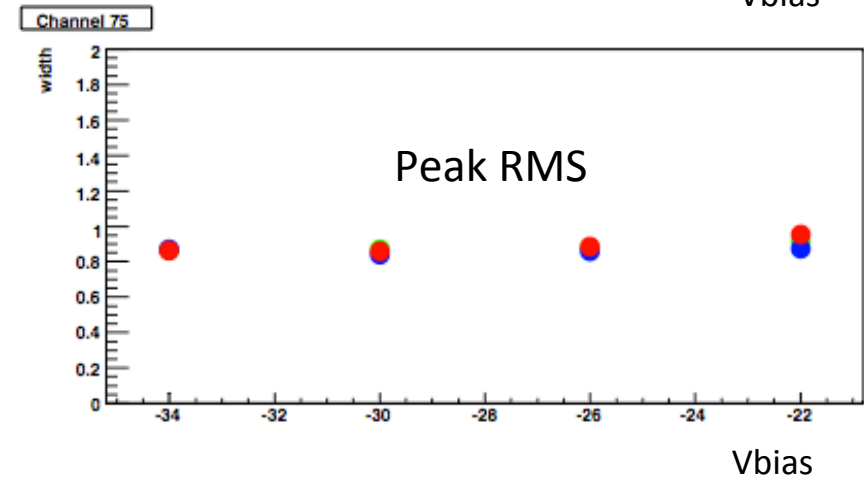
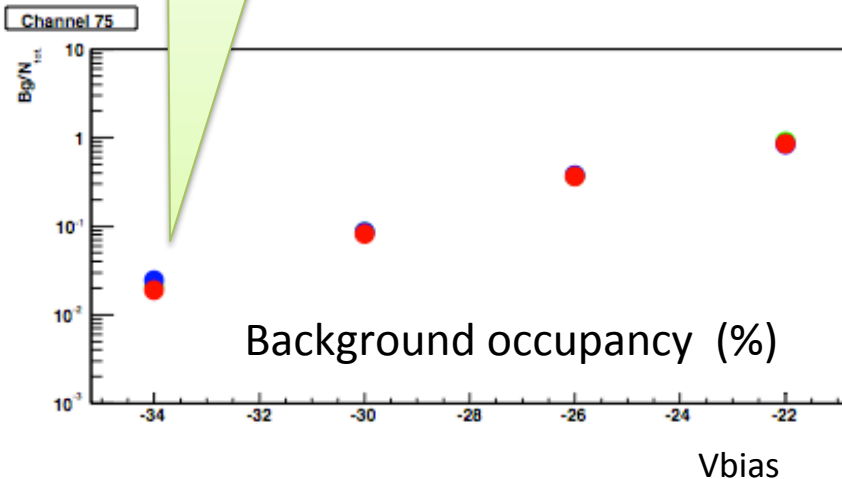
The Custom SiPM Matrix@-25°

For a 12 cm radius Cherenkov cone and a 3 mm SiPM pixel, an occupancy of 4 % corresponds to about 24 p.e.

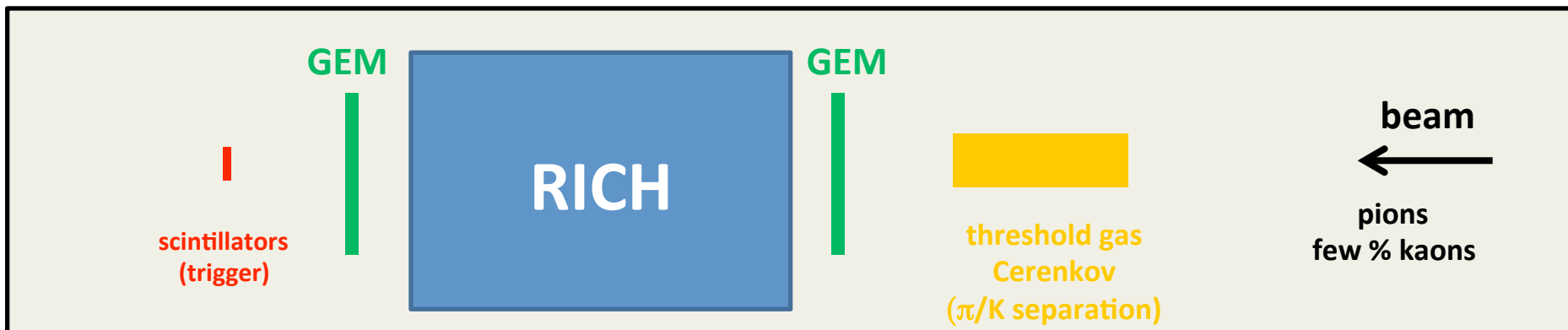
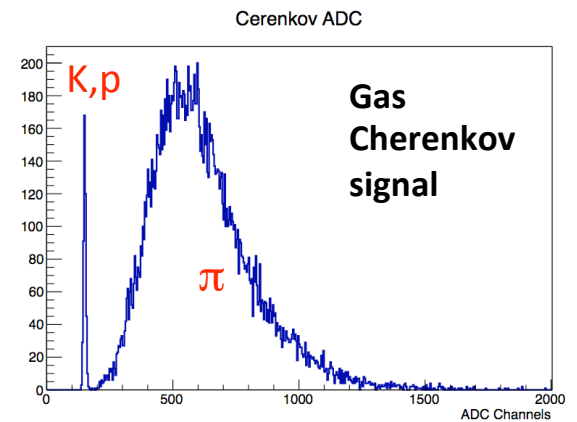
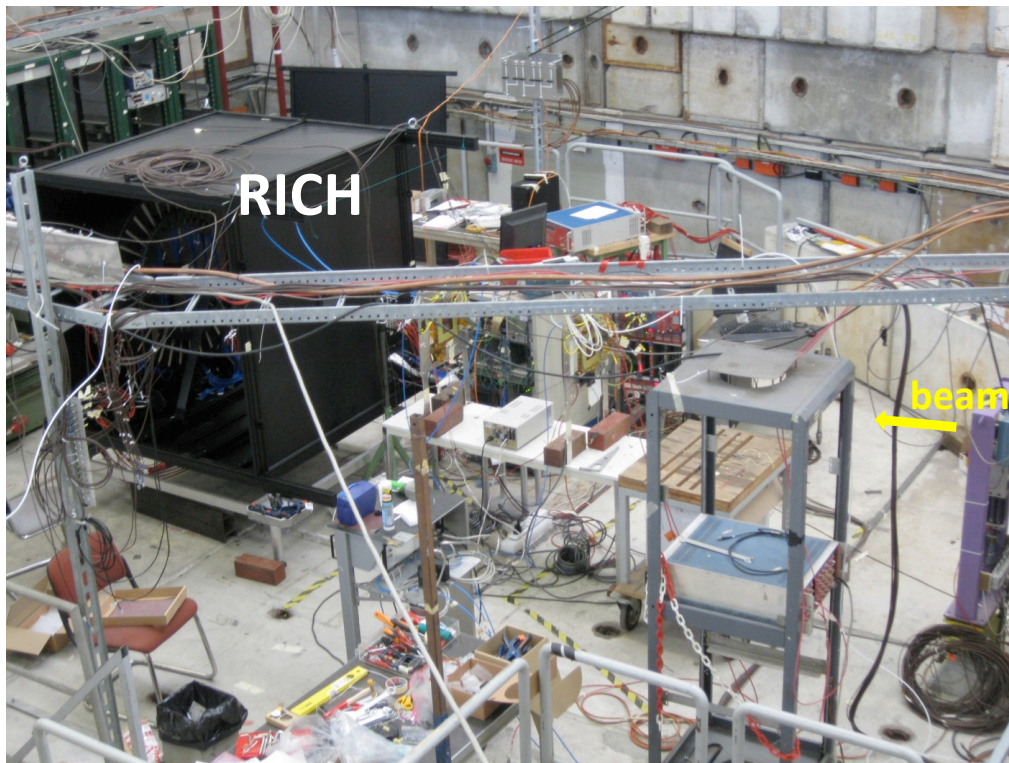


In a +/- 3 ns window
Comparable with H8500

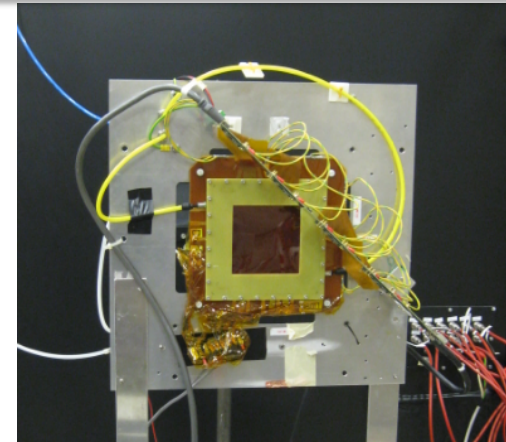
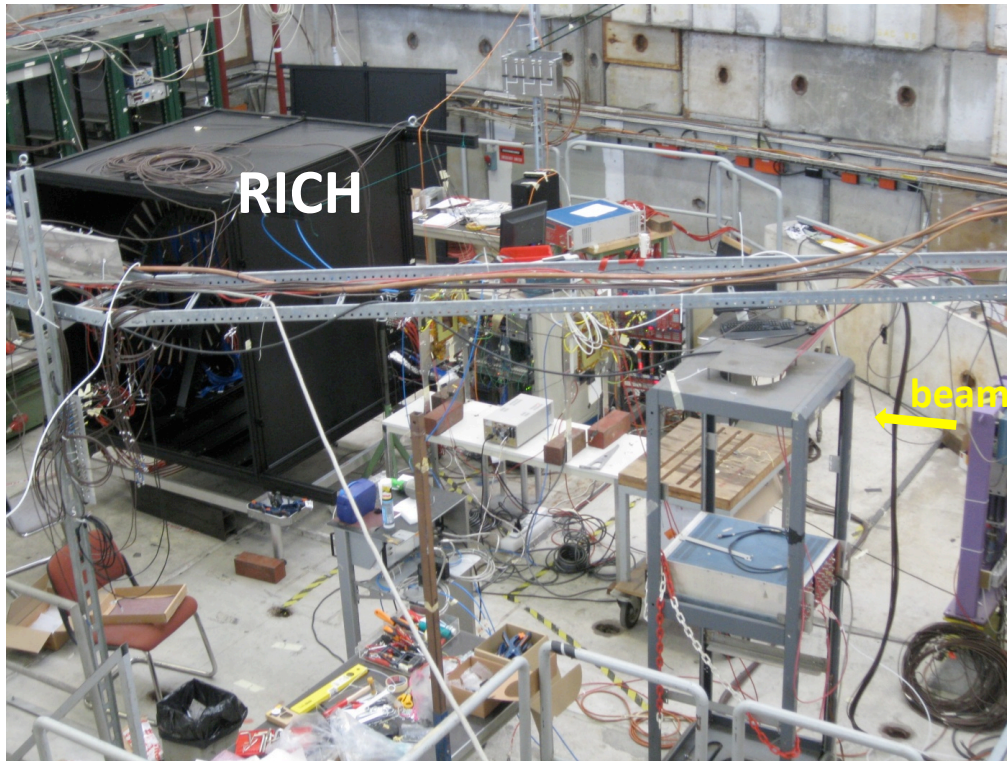
Largely insensitivity to
Vbias and discriminator
threshold



RHIC Prototype at CERN-T9

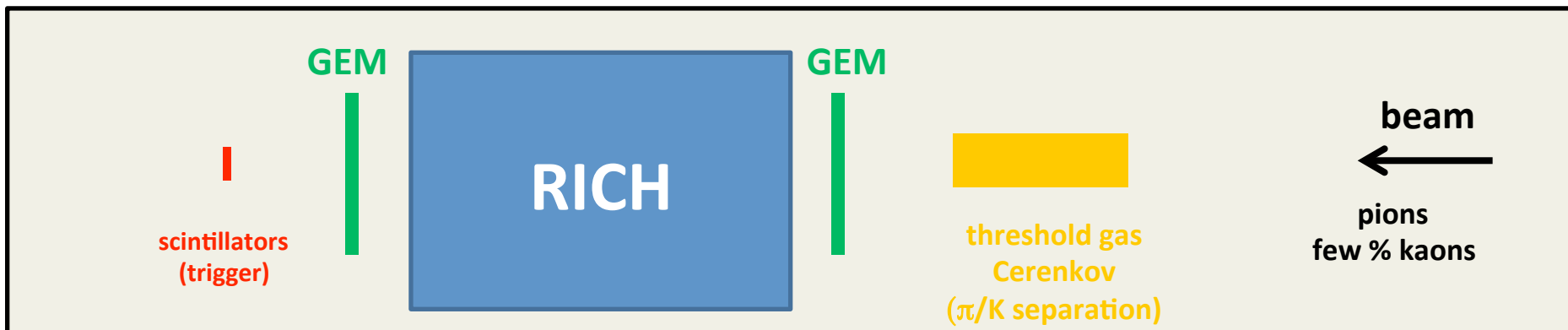
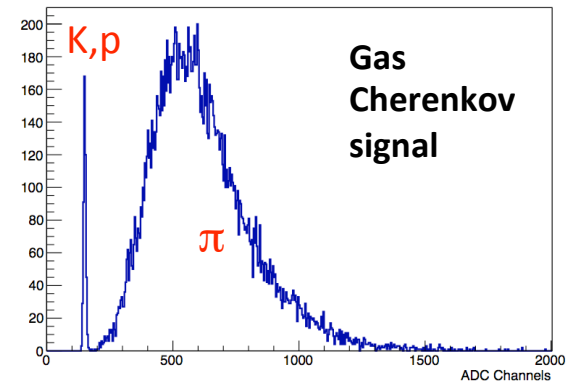


RHIC Prototype at CERN-T9

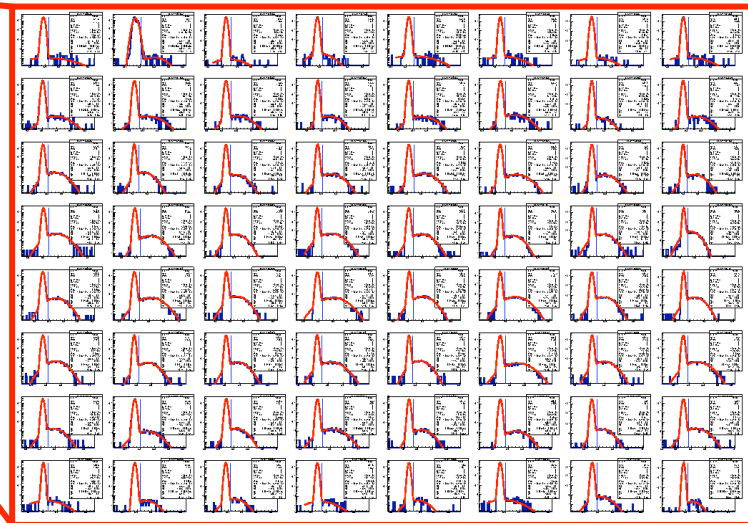
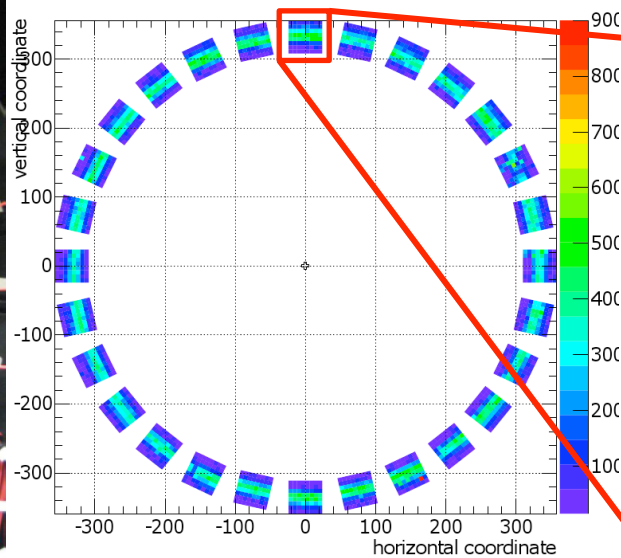
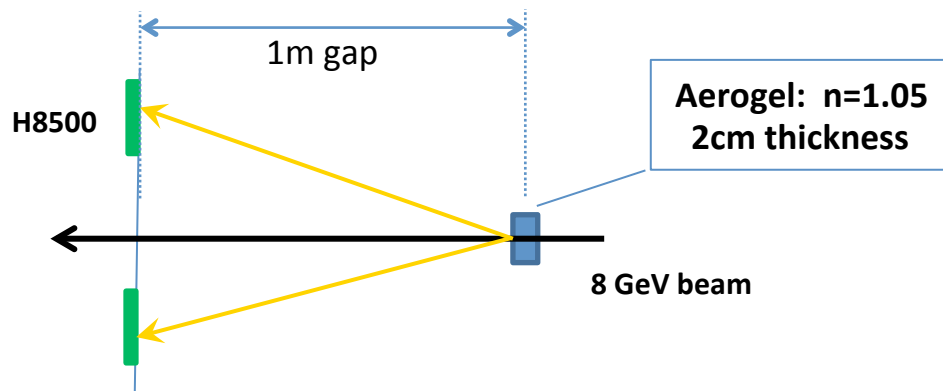


GEM chamber layout

Cerenkov ADC

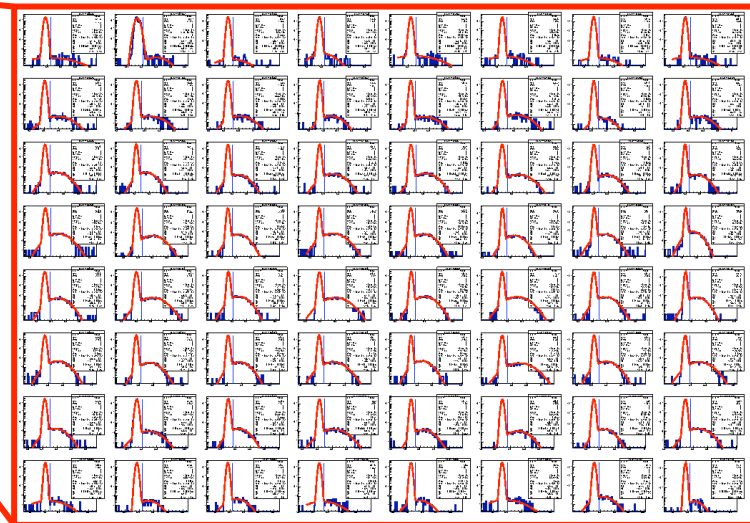
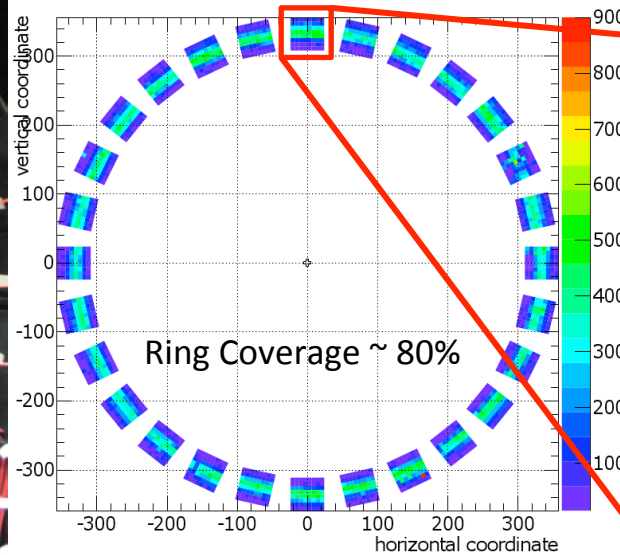
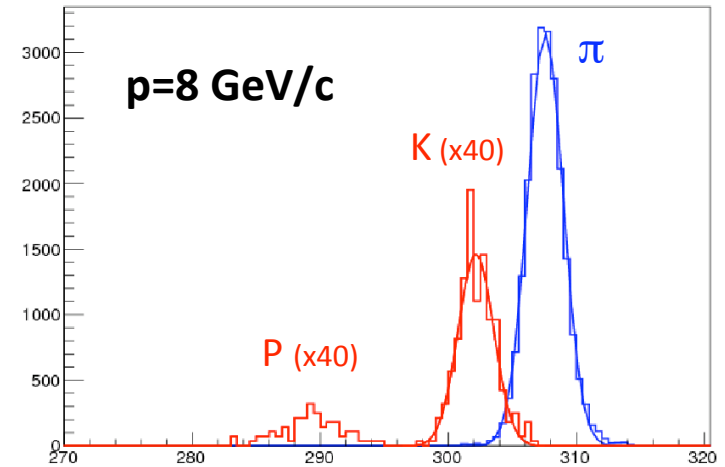
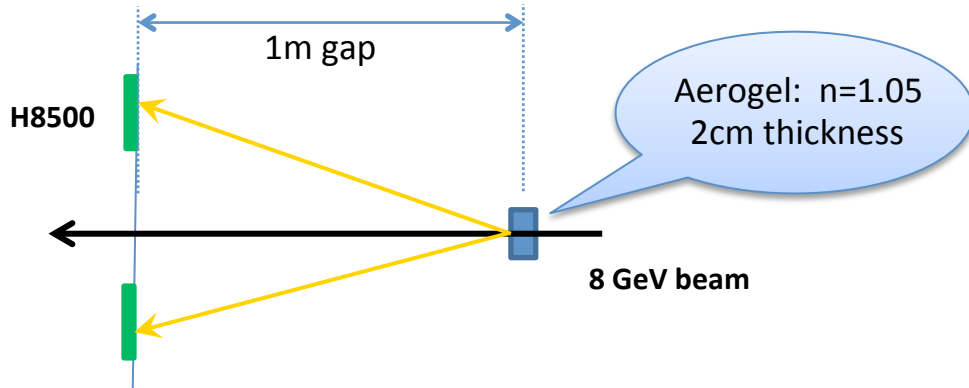


RHIC Prototype: Direct Light Case

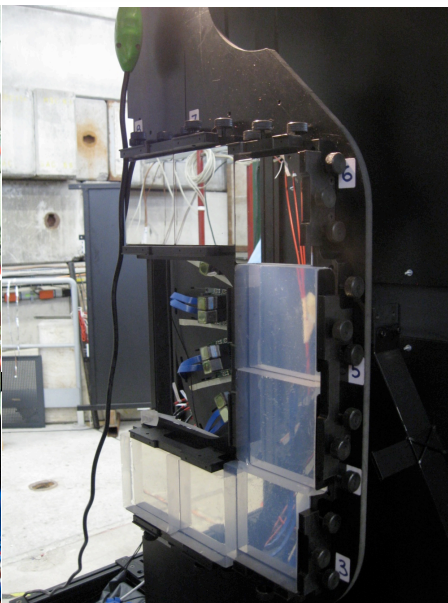
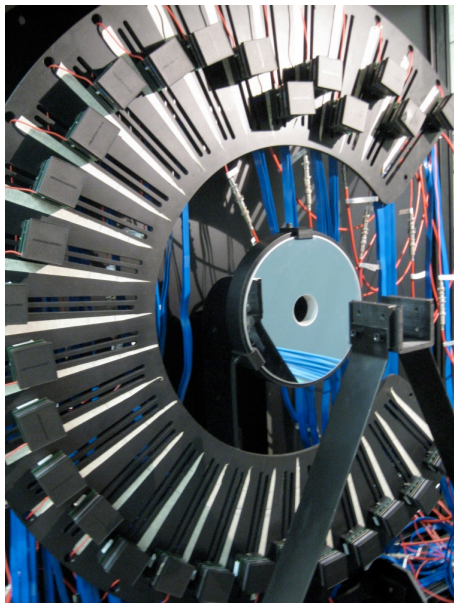
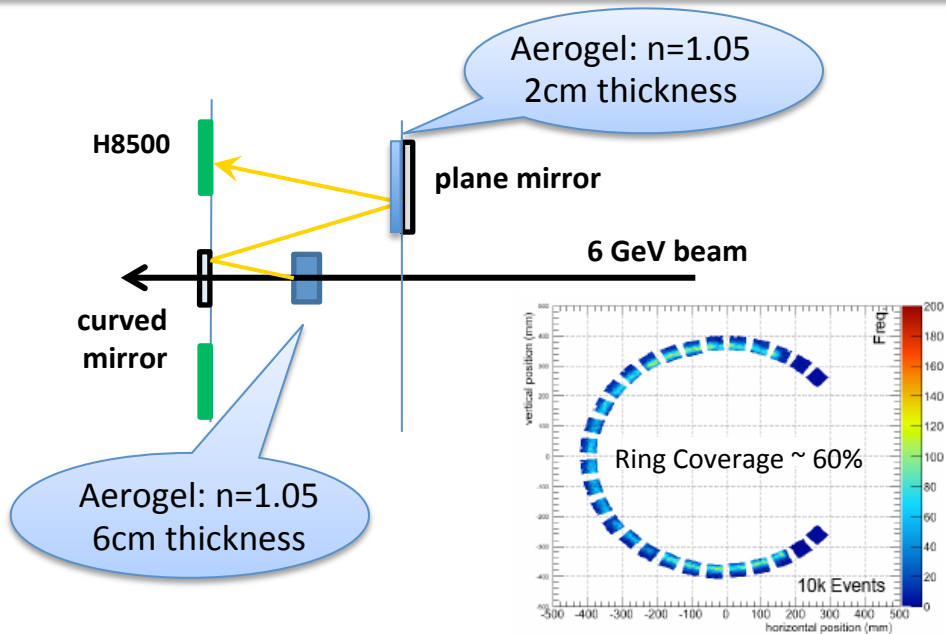


RHIC Prototype: Direct Light Case

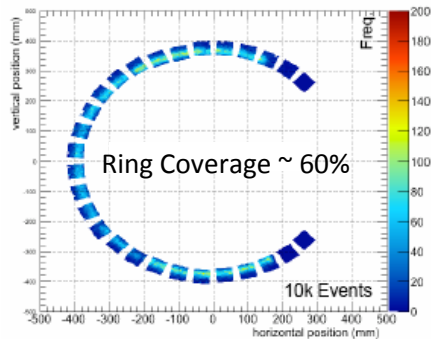
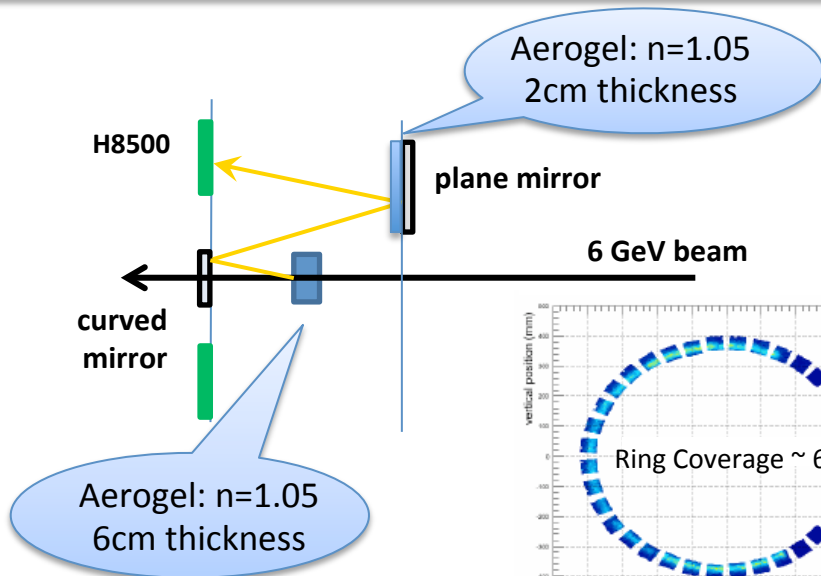
Clear hadron separation up to the CLAS12 maximum momentum



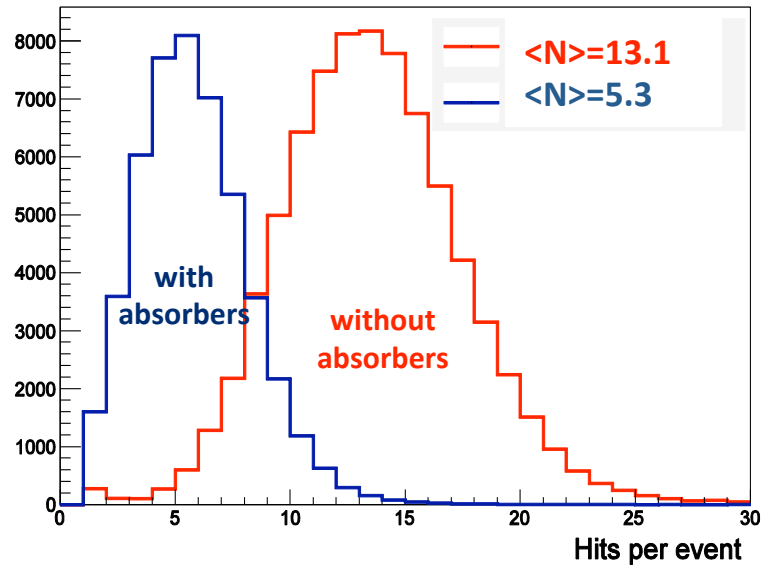
RHIC Prototype: Reflected Light Case



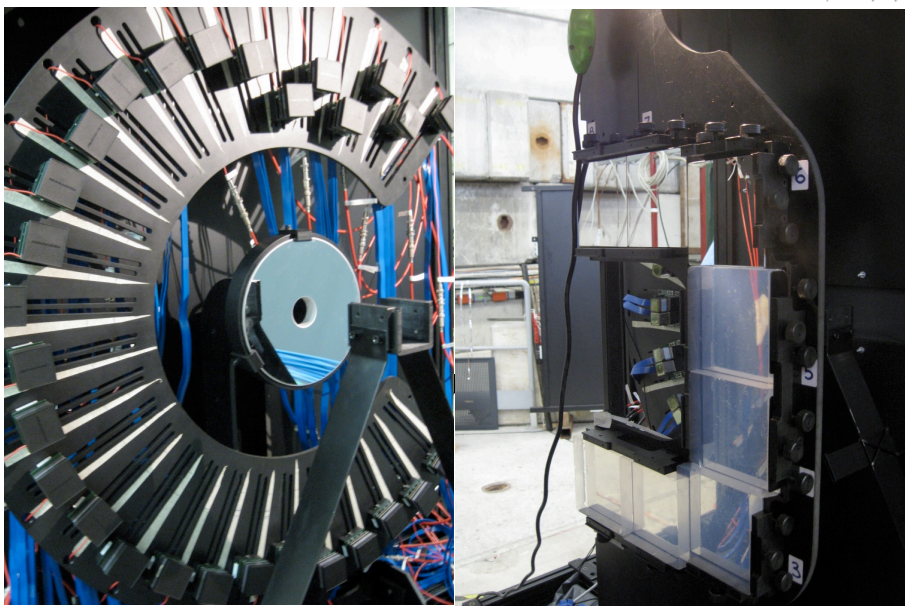
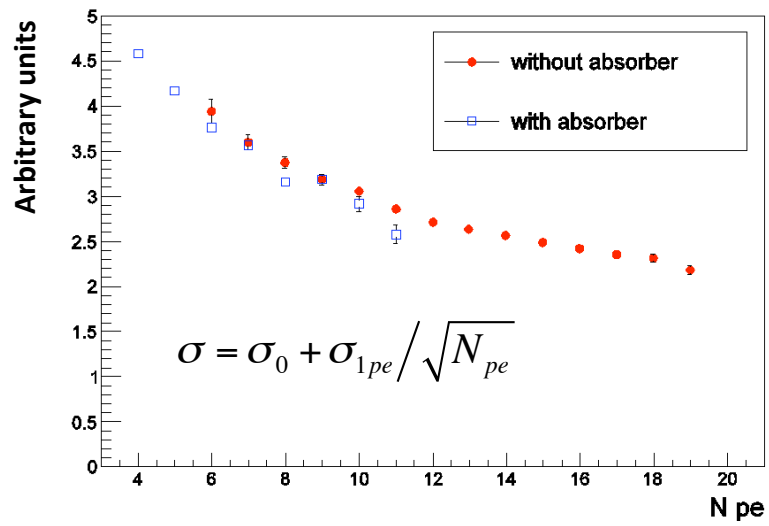
RHIC Prototype: Reflected Light Case



With absorbers: sizeable fraction of light survives



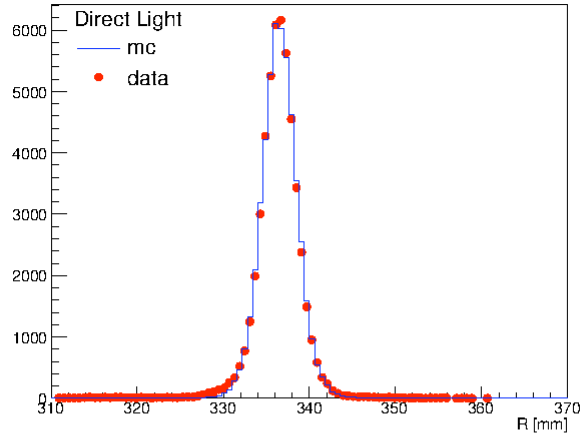
and resolution is not significantly degraded



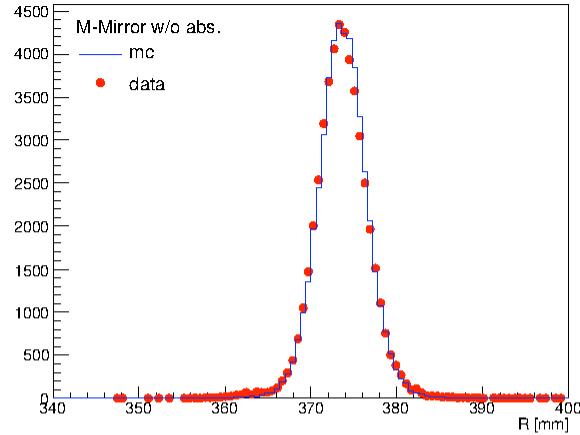
RICH Simulations

reflected light setup

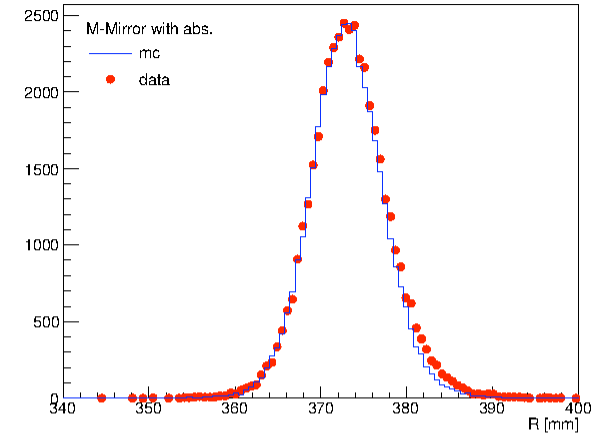
direct light setup



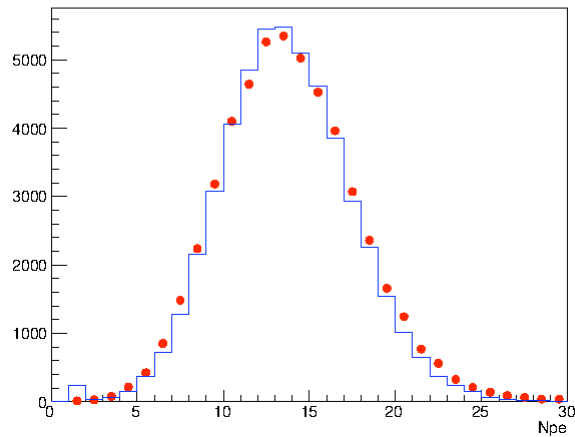
without absorbers



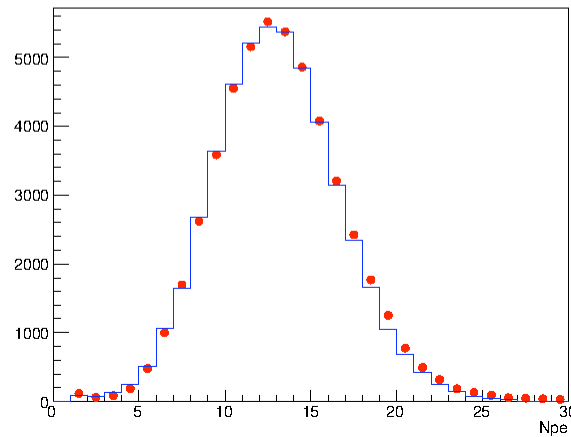
with absorbers



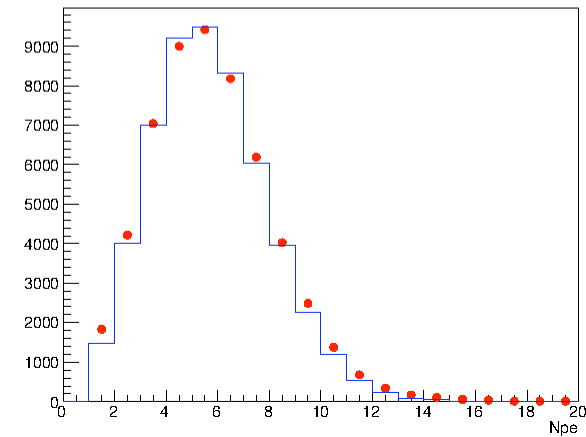
Number of photo-electrons



Number of photo-electrons



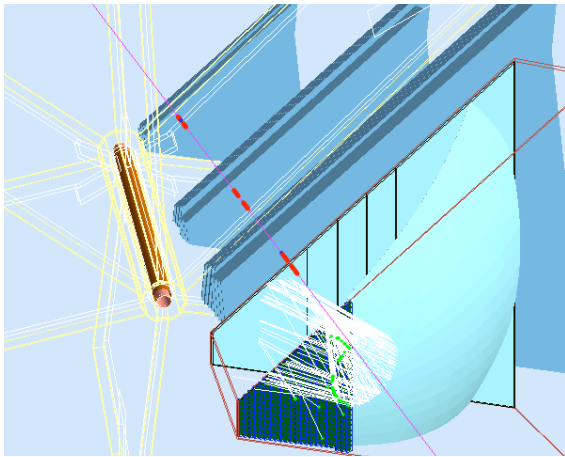
Number of photo-electrons



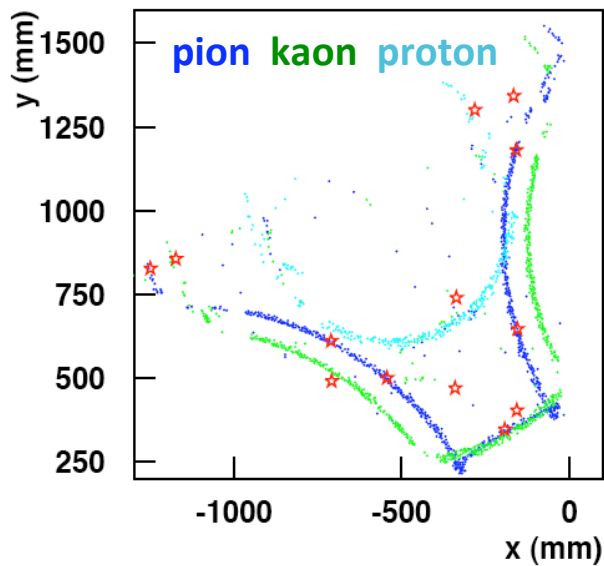
Based on measured optical characteristics and validated with RICH prototype data

The CLAS12 Hadron ID

One charged particle per sector in average:

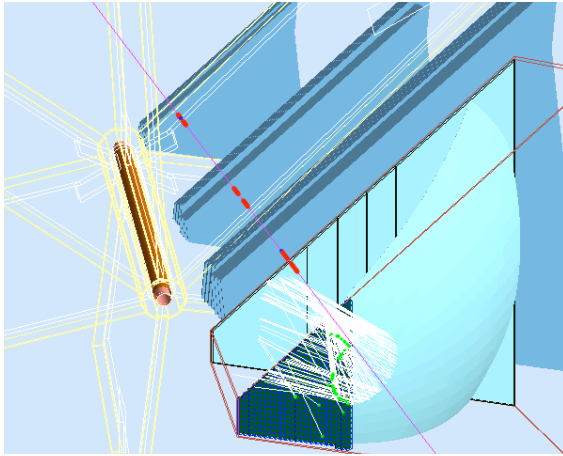


Non trivial RICH light patten due to reflections:
patter recognition and likelihood ID required

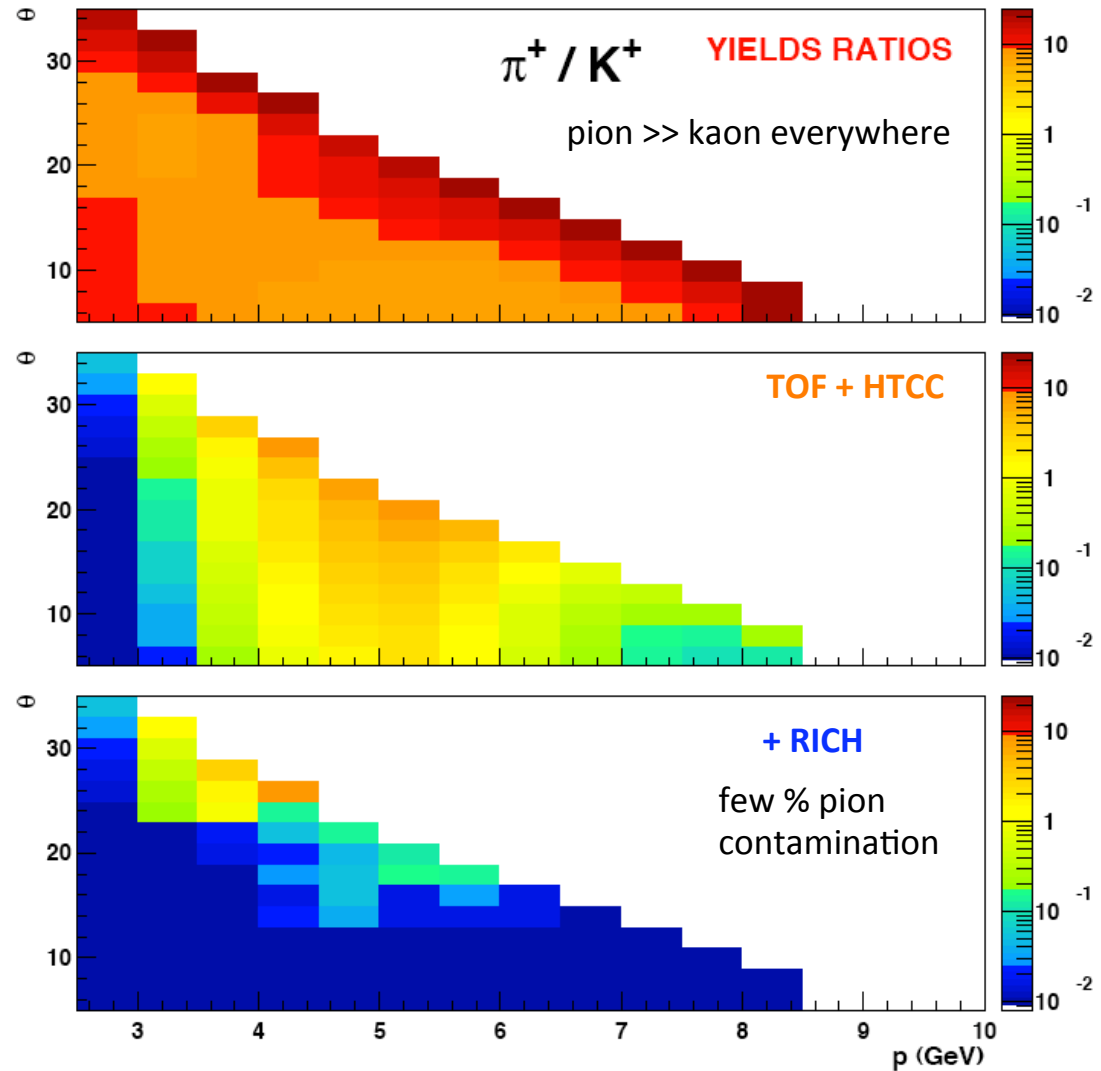
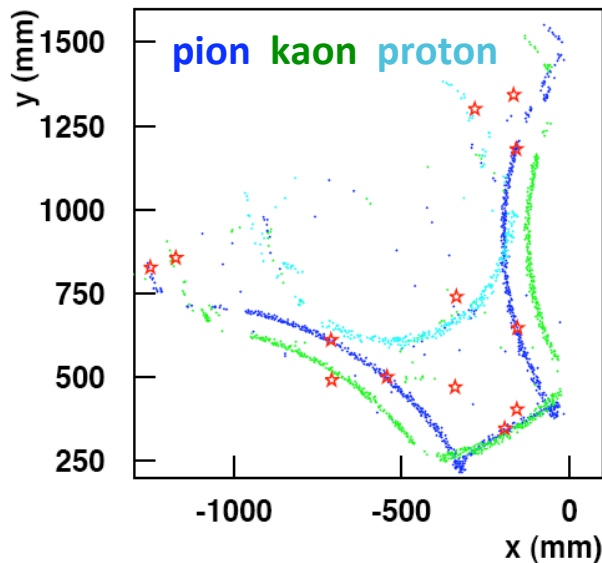


The CLAS12 Hadron ID

One charged particle per sector in average:



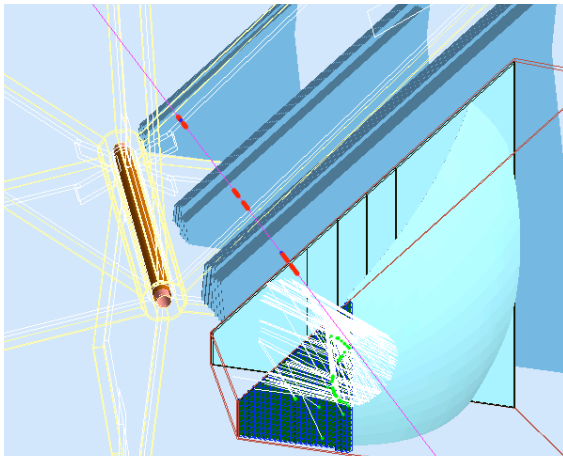
Non trivial RICH light patten due to reflections:
patter recognition and likelihood ID required



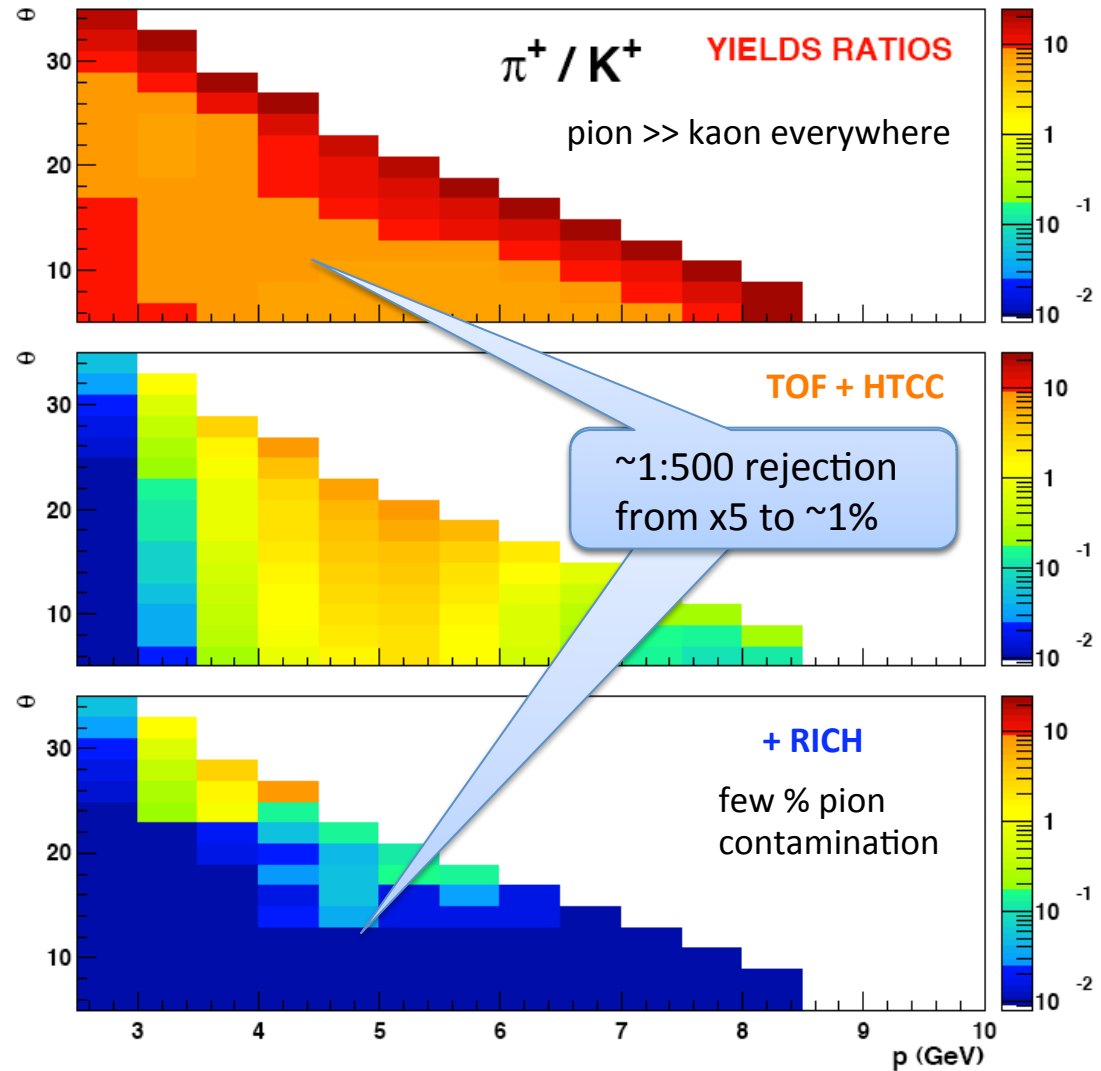
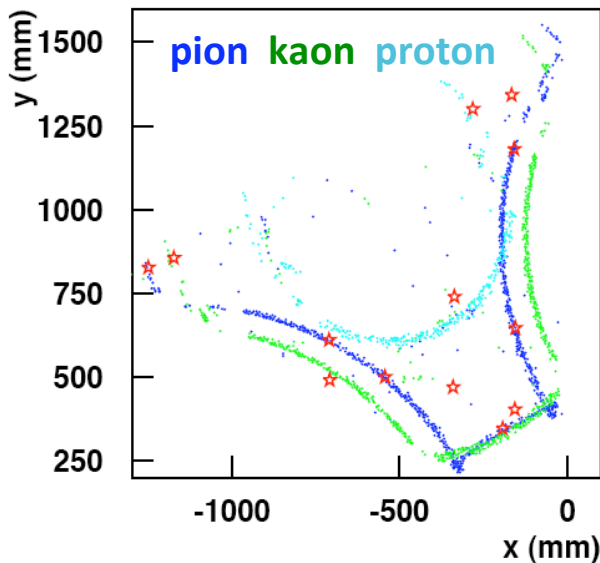
Even with a not yet optimized tuning of pattern recognition and likelihood ID, the π contamination is of the order of 1%

The CLAS12 Hadron ID

One charged particle per sector in average:



Non trivial RICH light patten due to reflections:
patter recognition and likelihood ID required



Even with a not yet optimized tuning of pattern recognition and likelihood ID, the π contamination is of the order of 1%

RICH Project Landscape

- 2010: ✓ Concept of Design and Technology
- 2011: ✓ Tests of components and small prototype
- 2012: ✓ Extensive tests with large-scale prototype
- 2013:
 - ✓ June: Technical Review
 - ✓ August: TDR
 - ✓ September: Project Review with DOE

Starting the construction phase

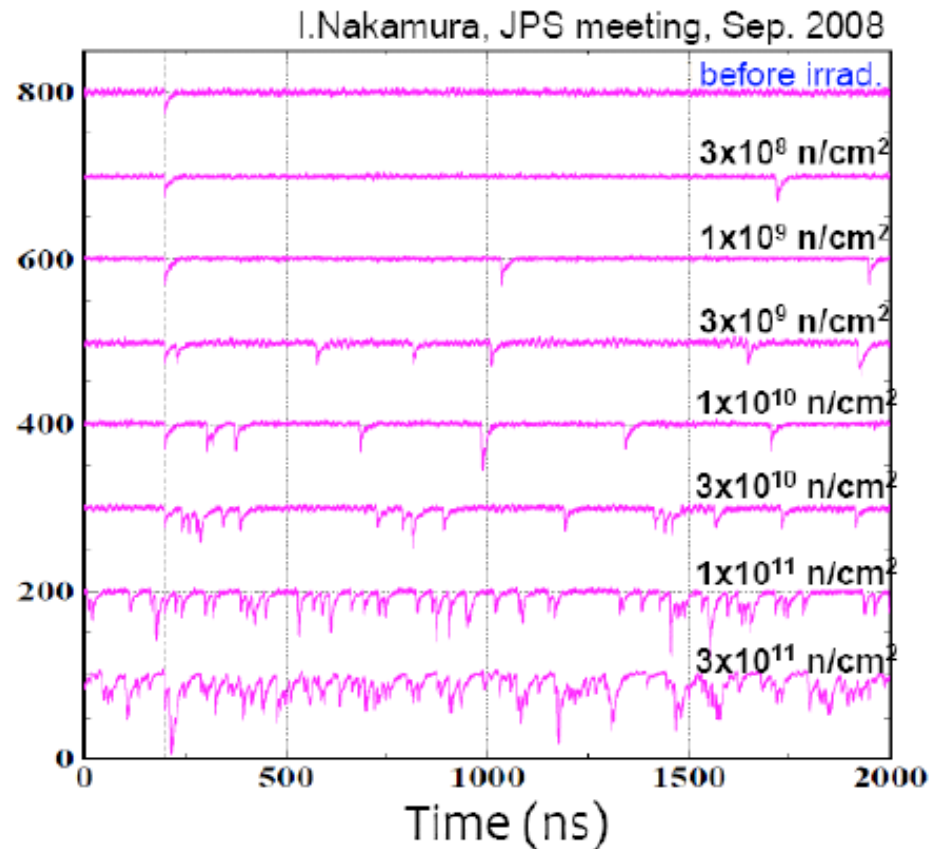
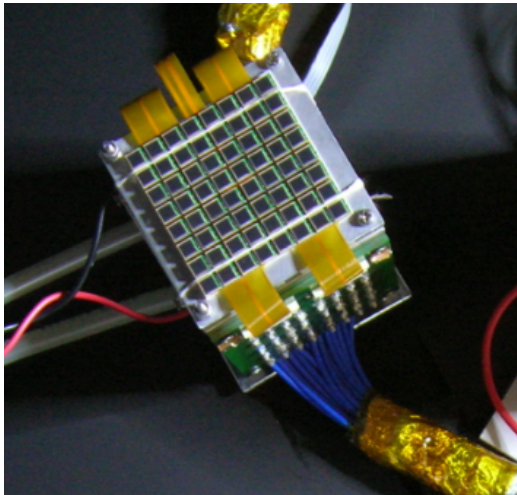
GOAL: 1st sector ready by the end of 2016

Photon Detectors: SiPM

Measured fluence @ Belle:
90/fb \rightarrow 1-10 10^9 n/cm²

Expected fluence @ Belle-2:
50/ab \rightarrow 2-20 10^{11} n/cm²

Expected fluence @ LHCb-2:
1 year \rightarrow 6 10^{11} n/cm²

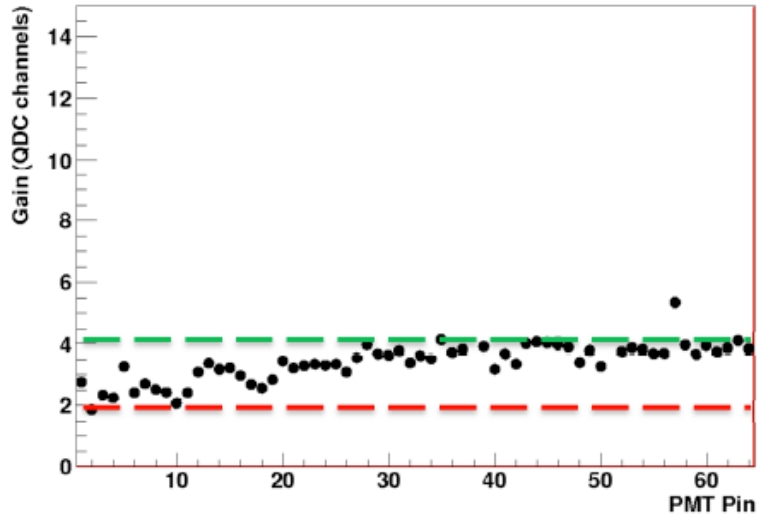


Fluence at CLAS12 allows the use of SiPM for future upgrades:

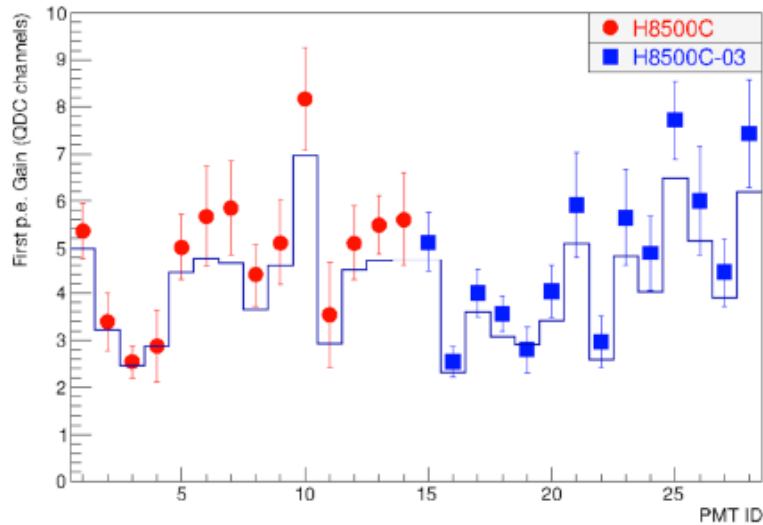
- ✓ fast development in performances (dark count \sim 1 MHz for 3x3 mm² devices)
- ✓ fast reduction in price (already comparable with MA-PMTs over 1 m²)
- ✓ require dedicated R&D for electronics and cooling

MA-PMT Gain Map

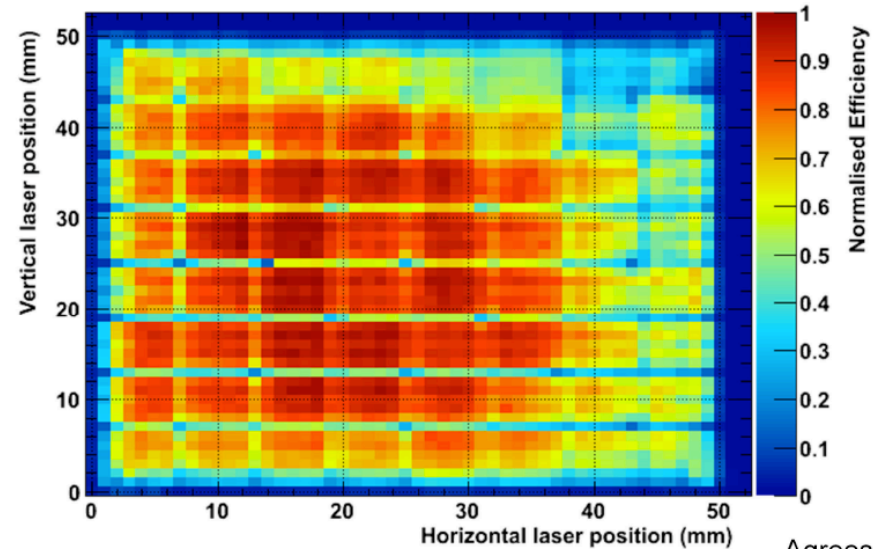
Pixel Gain:



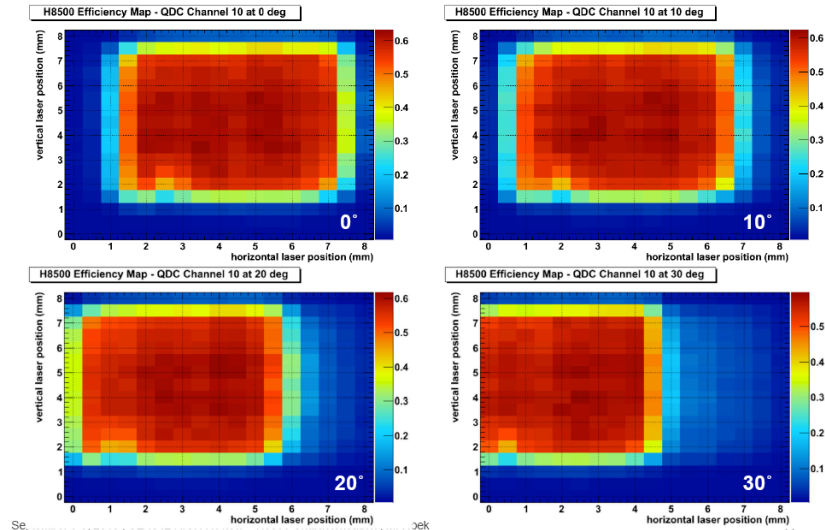
PMT average gain:



Efficiency Map:

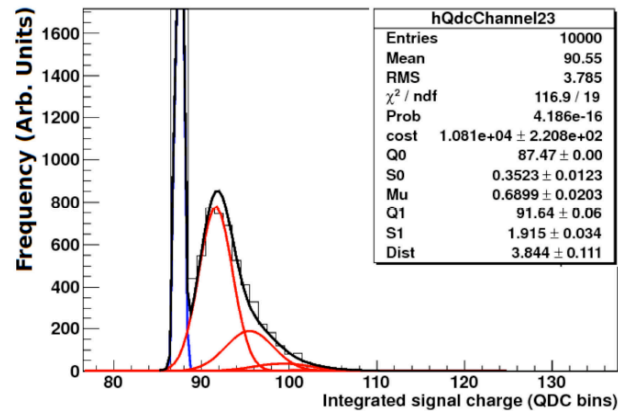


Incident angle scan:



MA-PMT Efficiency and X-talk

~ 15% SPE Loss :



~ 3% Cross-Talk:

