

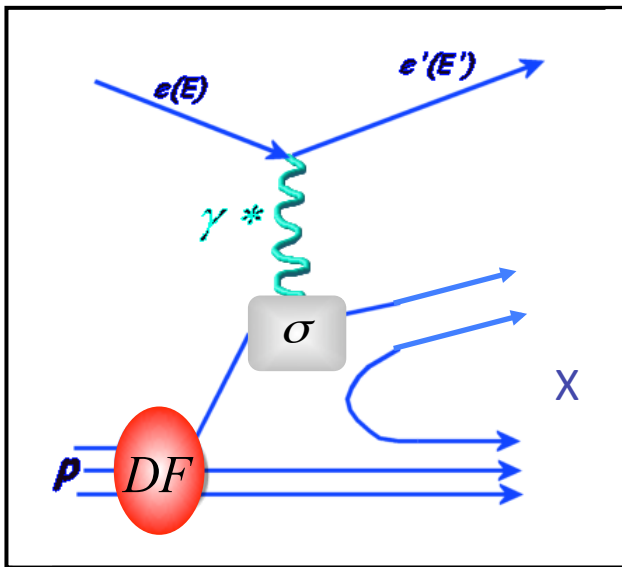
THE LARGE AREA CLAS12 RING-IMAGING CHERENKOV DETECTOR

Contalbrigo Marco
INFN Ferrara

14th ICATPP Conference, 25th September 2013

The 3D Spin Nucleon Structure

Inclusive DIS



SFs (x, Q^2)

Structure functions
(unpolarized, helicity)

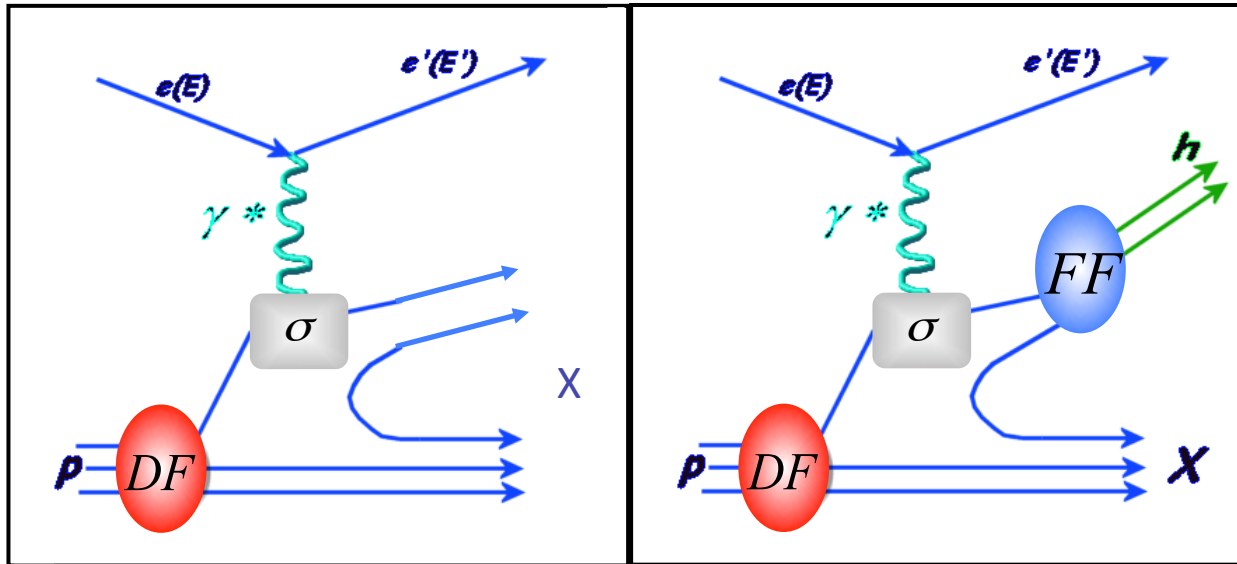
Sum over quark charges

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

The 3D Spin Nucleon Structure

Inclusive DIS

Semi-inclusive DIS



SFs (x, Q^2)

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

Structure functions
(unpolarized, helicity)

Parton distributions

Sum over quark charges

Flavor sensitivity

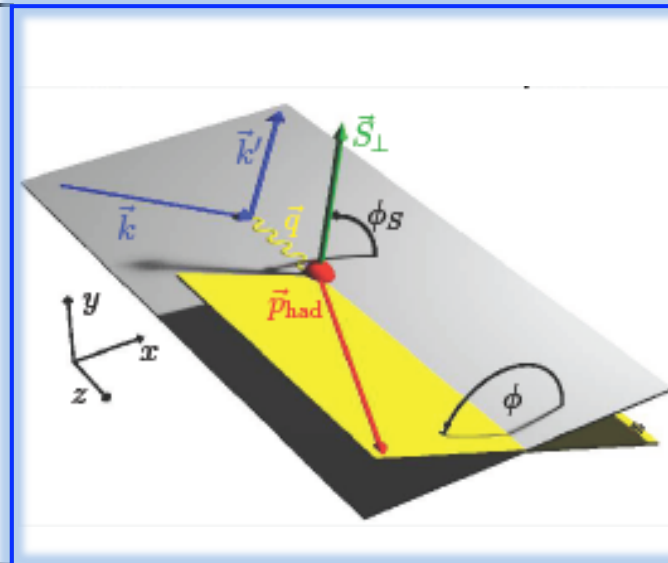
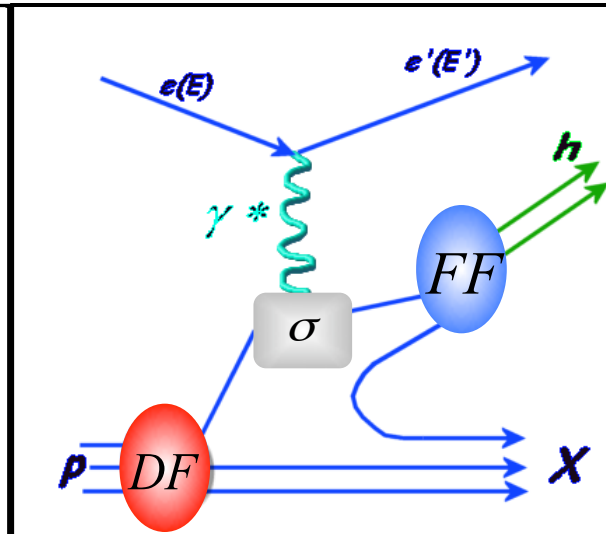
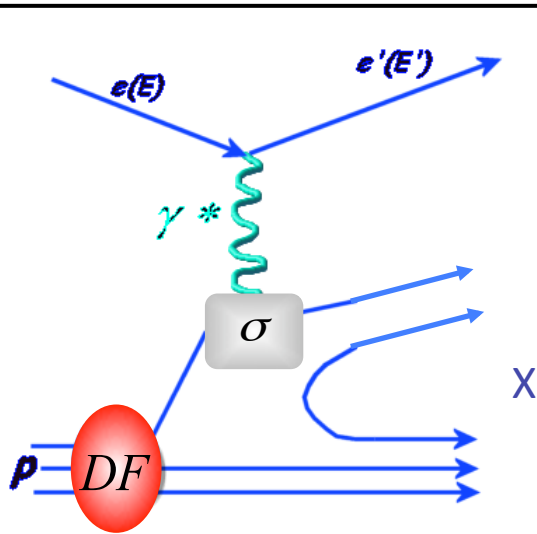
$$d\sigma \propto F_2 \left(= \sum_q e_q^2 q(x) \right)$$

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

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

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

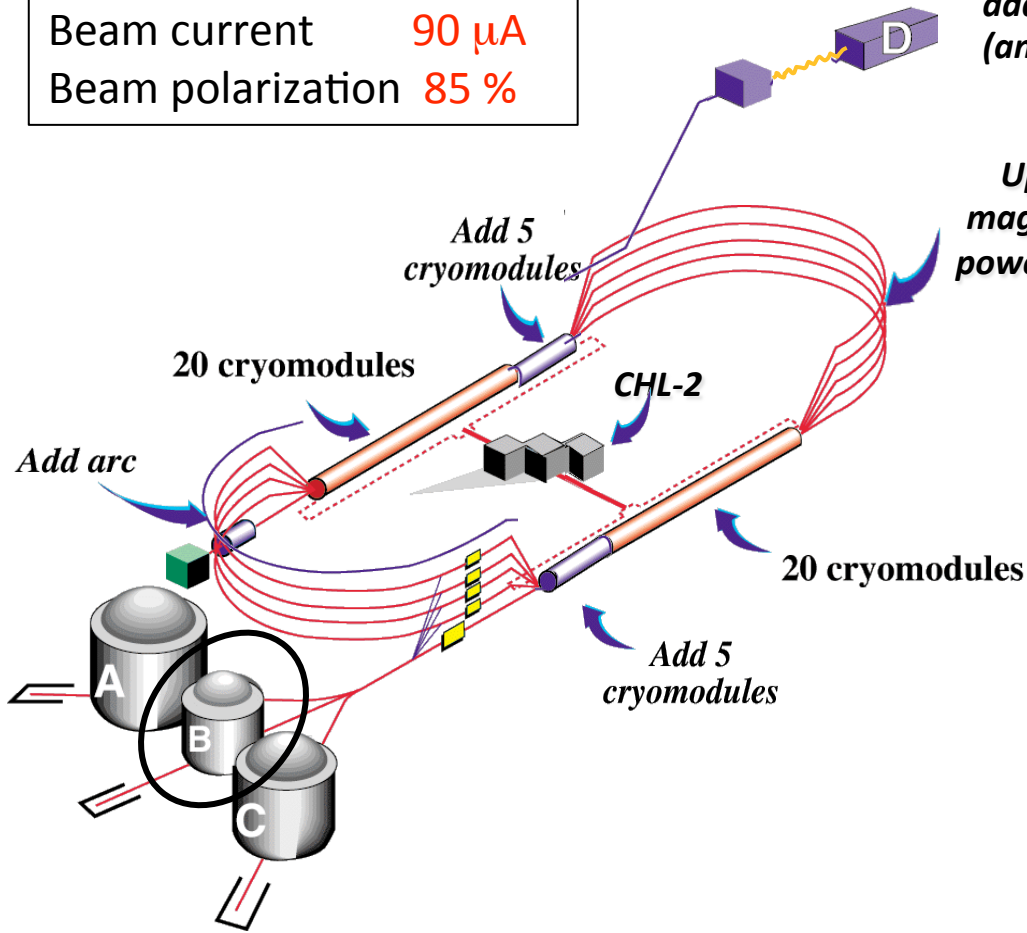
$$d\sigma^h \propto \sum_q e_q^2 q(x) D_q^h(z)$$

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

Rich and Involved phenomenology !!

CEBAF Upgrade at Jefferson Lab

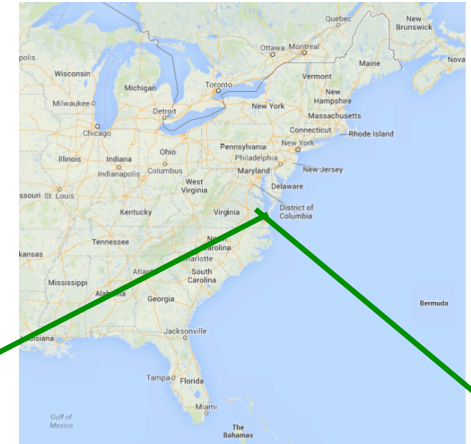
Beam Energy	12 GeV
Beam current	90 μ A
Beam polarization	85 %



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

**Upgrade
magnets and
power supplies**

**Enhance equipment in
existing halls**



**Continuous Electron Beam
Accelerator Facility**

<https://www.jlab.org/12-gev-upgrade>

The CLAS12 Spectrometer

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

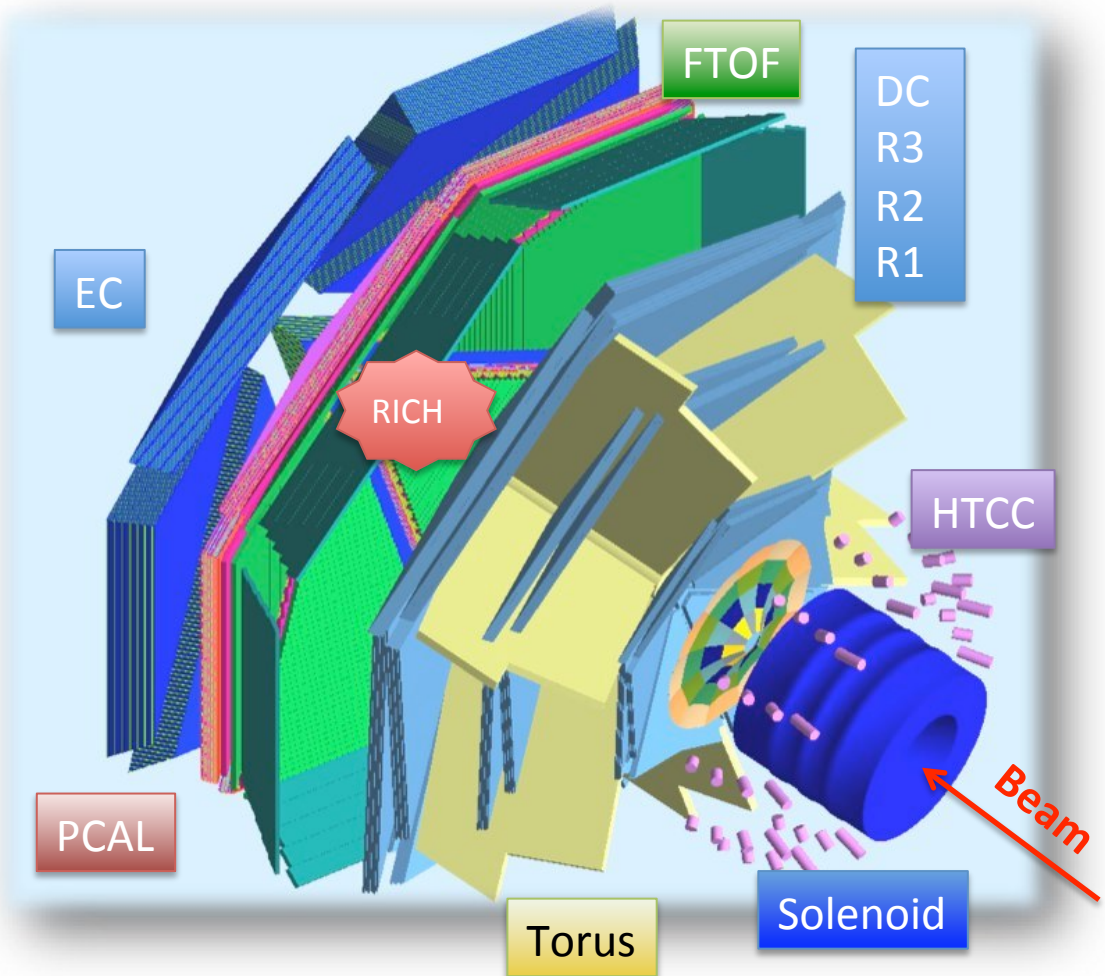
Highly polarized 12 GeV electron beam

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

H and D polarized targets

Broad kinematic range coverage
(current to target fragmentation)

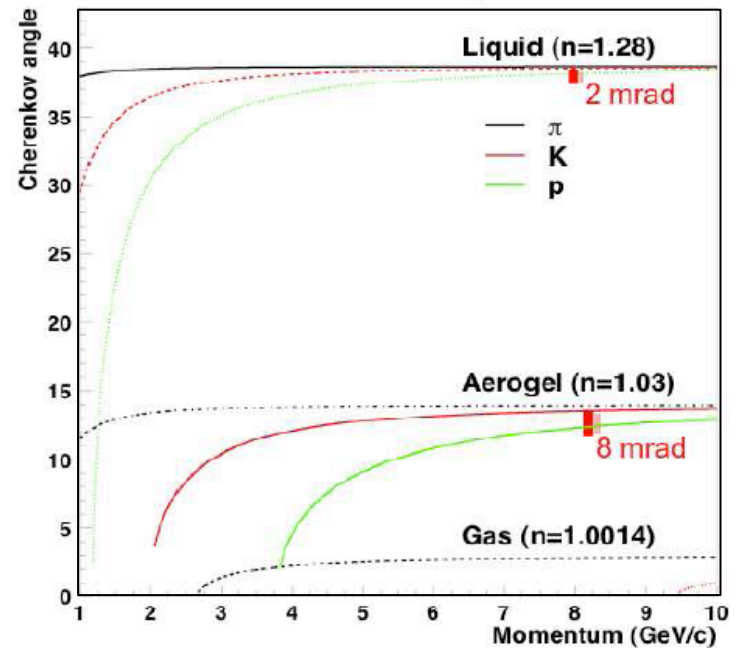
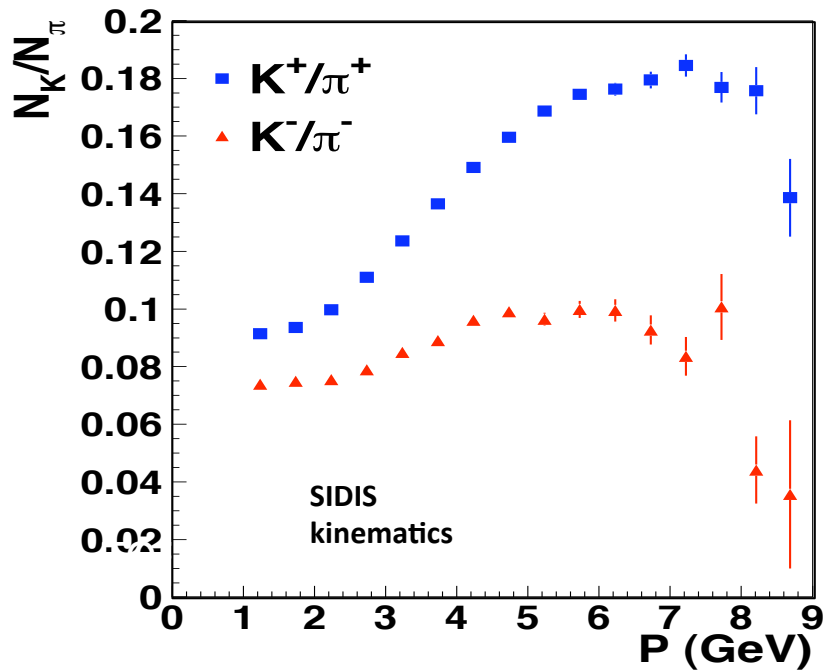
RICH: Hadron ID
for flavor separation
(common to SIDIS approved exp.)



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.

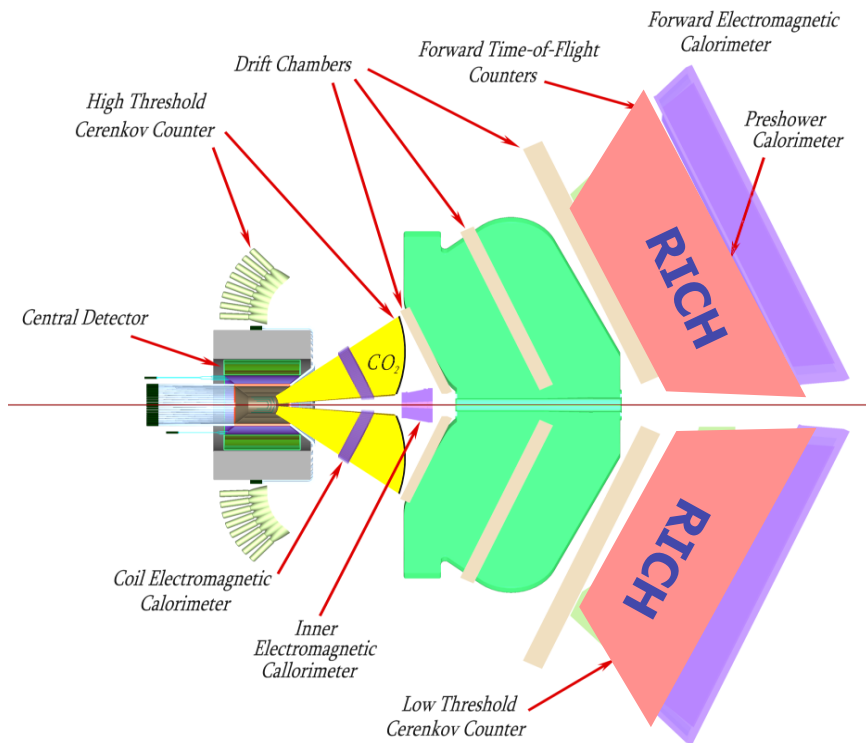
CLAS12 Momentum Range

- ◆ 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
 - \rightarrow collection of **visible Cherenkov light**
- ◆ **Use of PMTs:** challenging project, need to minimize detector area covered with expensive photodetectors



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

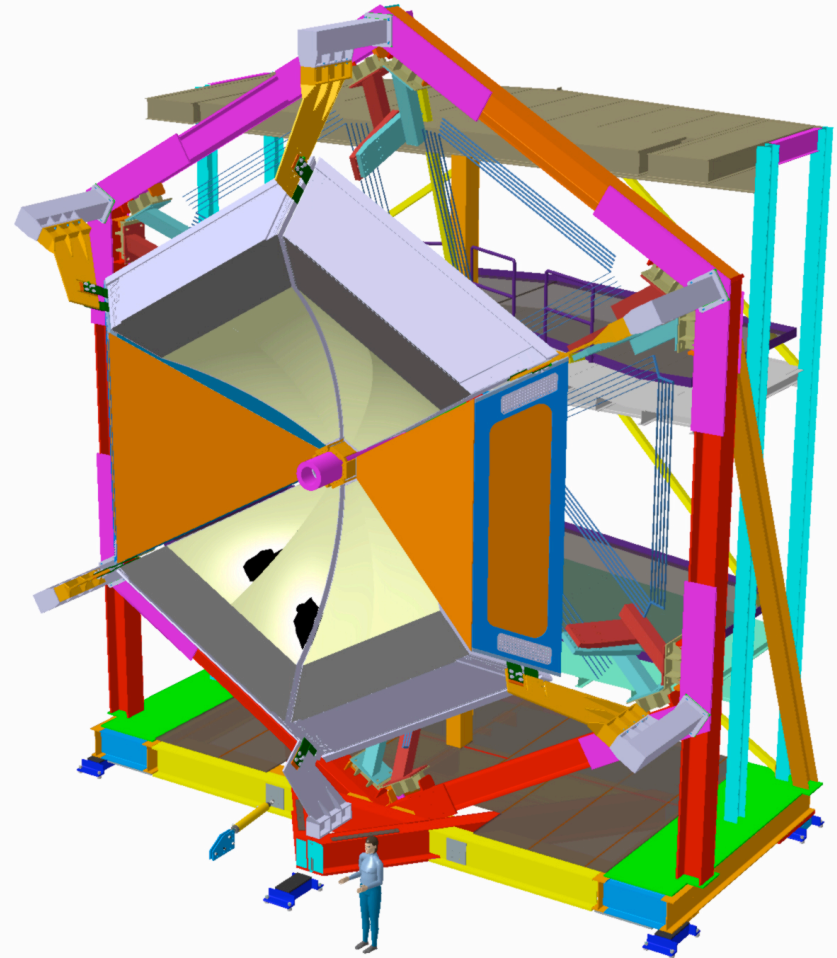
1st sector allows:

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

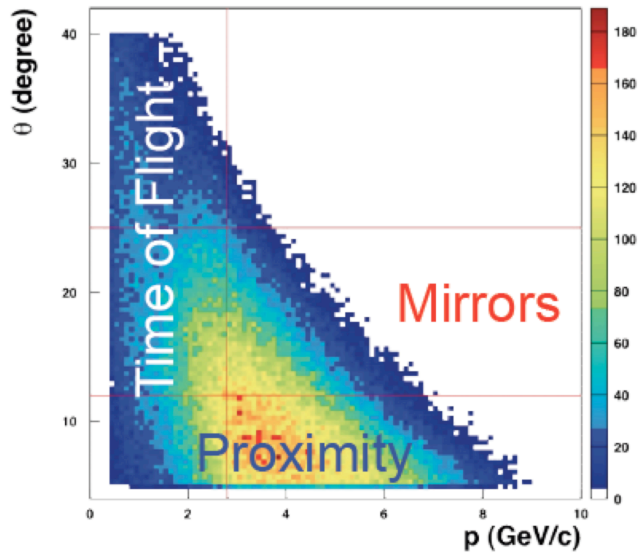
2nd sector allows:

- ✓ 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)

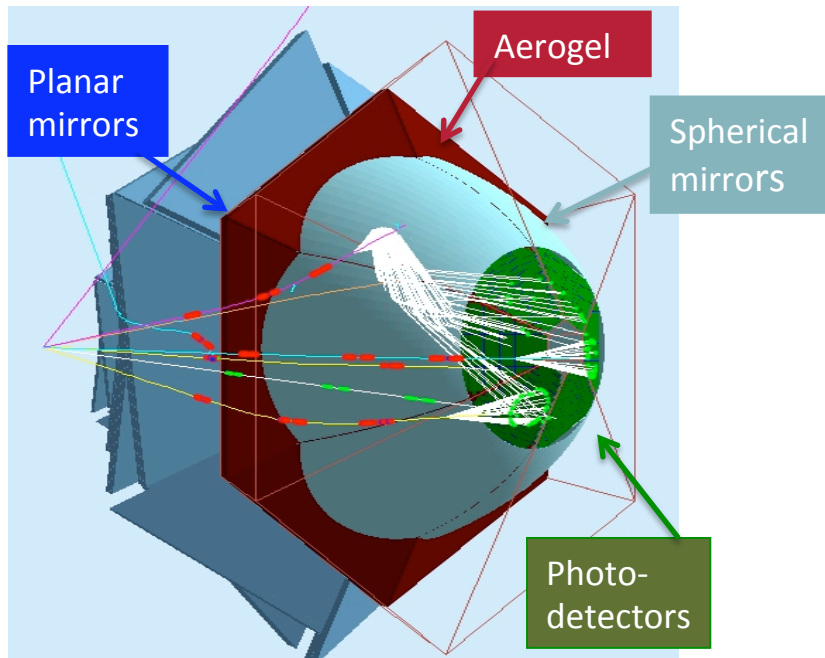
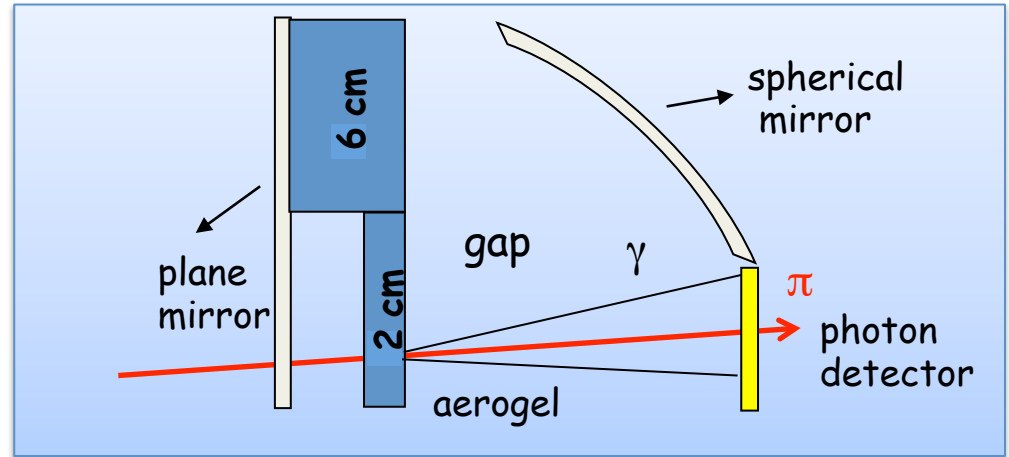
Crucial for the study of parton dynamics related to angular momentum and spin-orbit effects with flavor sensitivity.



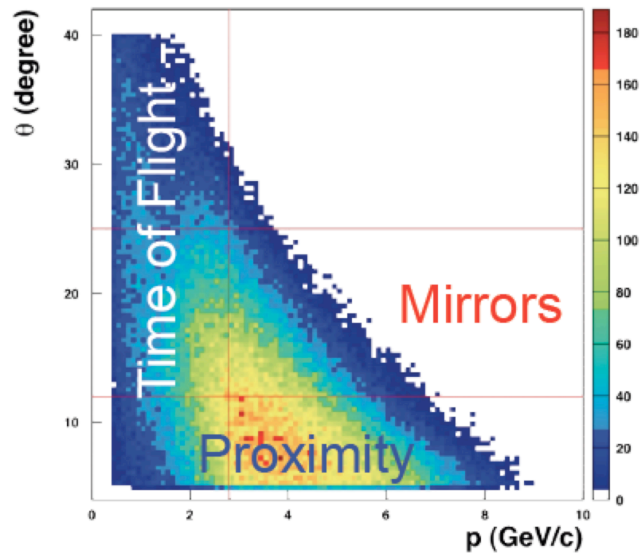
The Hybrid Optics Design



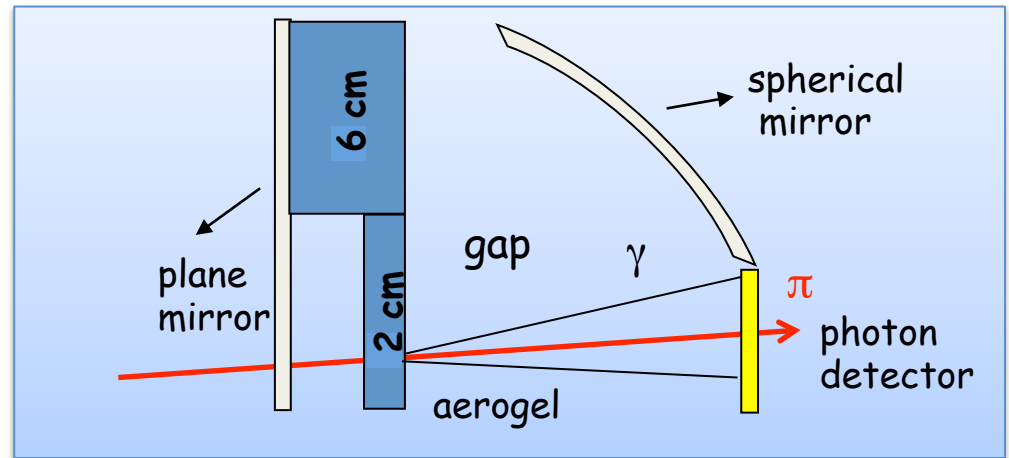
Direct rings/best performance for high momentum particles



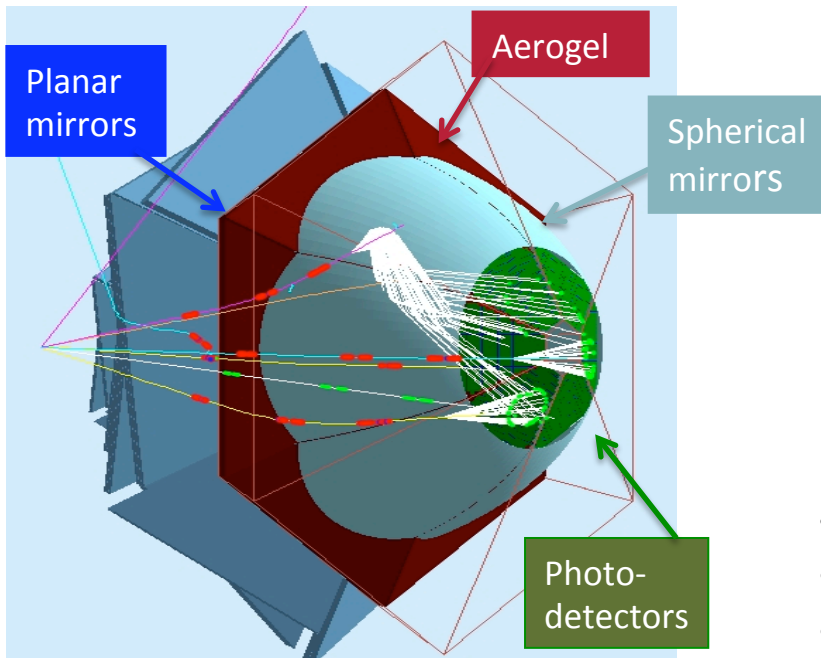
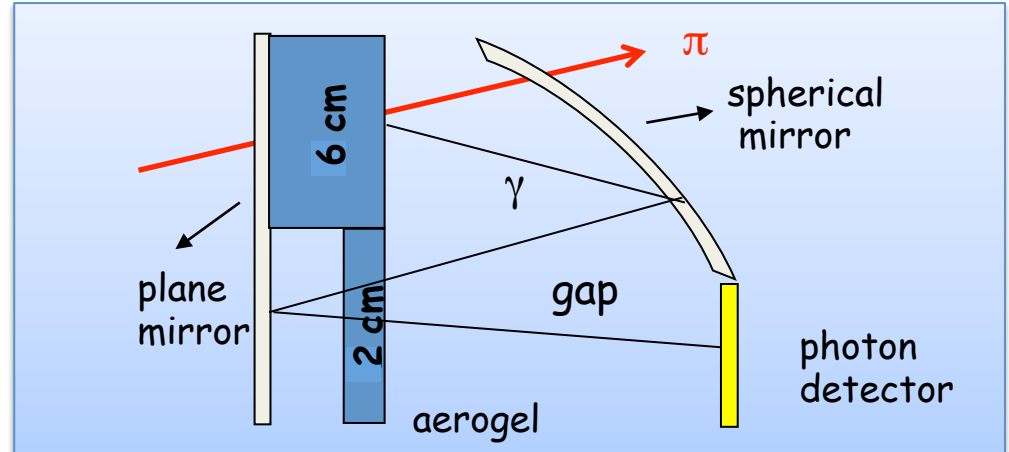
The Hybrid Optics Design



Direct rings/best performance for high momentum particles

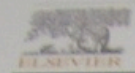


Reflected rings for less demanding low momentum particles



- Minimize active area (cost)
- 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

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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.

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...with ... The main focus of ... 2014, will ... imaging ... are ... describing ... distribution ... study of the structure ...

of the nucleon and quark hadronization processes [2].

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 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 large area RICH detector detects charged and neutral particles in the momentum range between 5 and 40 GeV/c. It employs a 2 T torus magnet with a dipole symmetry of CLAS. In the base equipment,

...rejection factor ... the 5–8 GeV/c momentum interval ... range by replacing the existing low-threshold Cherenkov counter (LTCC) with a RICH detector ... design of CLAS12.

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

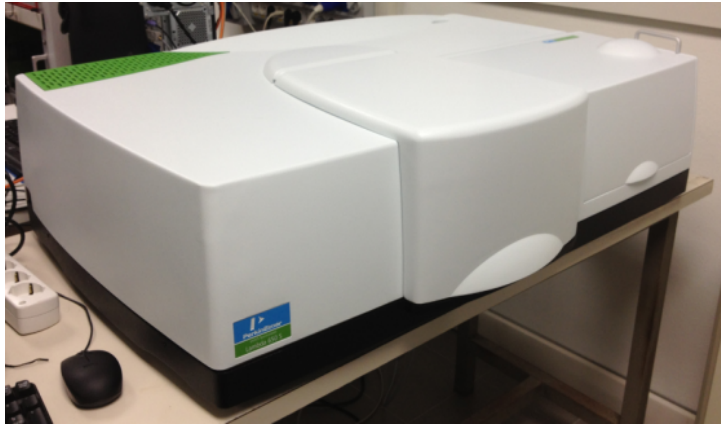
To fit into the CLAS12 geometry, the RICH should have a projective geometry with six sectors that cover the space between the torus cryostats and covering scattering angles from 0° to 180° . Fig. 3. Being downstream to the torus magnet at the interaction point, the RICH has to cover a large area each sector spanning an area of the order of 4 m^2 . Between detectors which are already in the construction, the gap depth cannot exceed 1 m. The proposed solution is a solenoidal focusing RICH.

A setup similar to the one adopted in Hall-B (C₅F₁₂ or C₆F₁₄) radiator and a CsI-deposited on a cylindrical chamber as a UV-photon detector, 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

Aerogel Transmittance

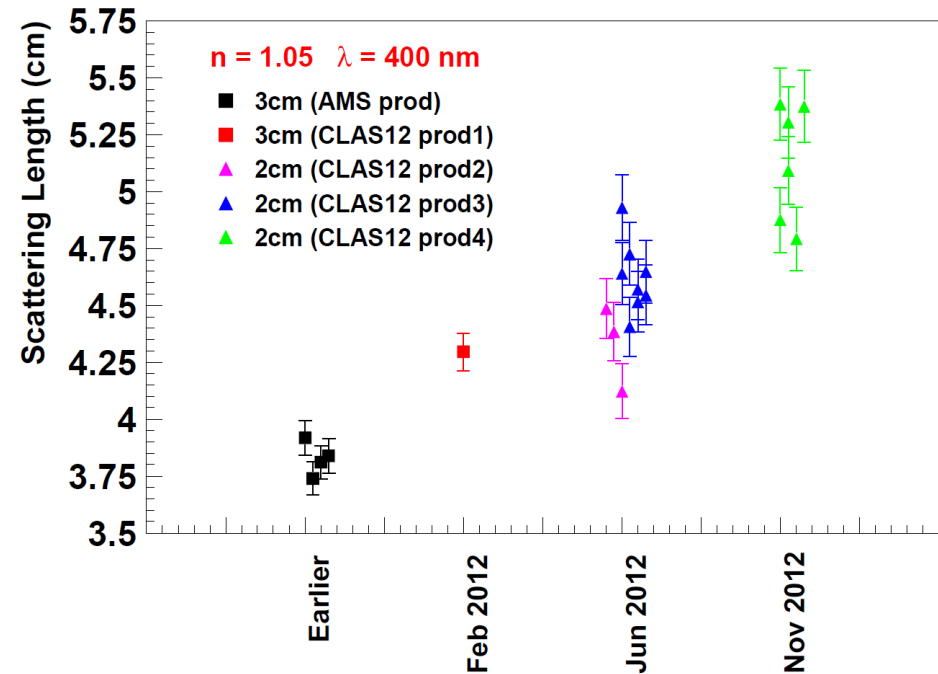
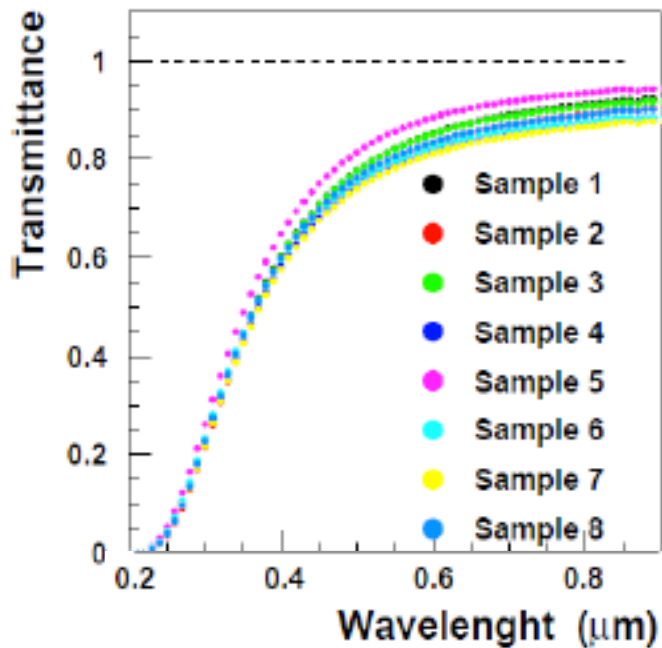


Achieved clarity for large tiles at $n=1.05$

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

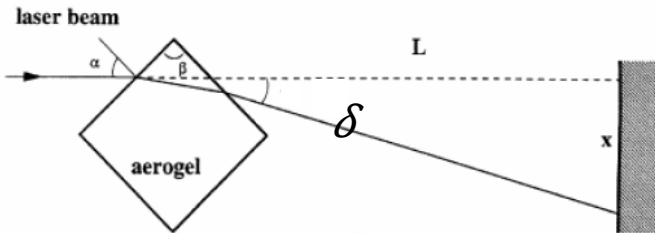
(LHCB has $0.0064 \mu\text{m}^4 \text{ cm}^{-1}$ for $n=1.03$)

In collaboration with Budker and Boreskov
Institutes of Novosibirsk

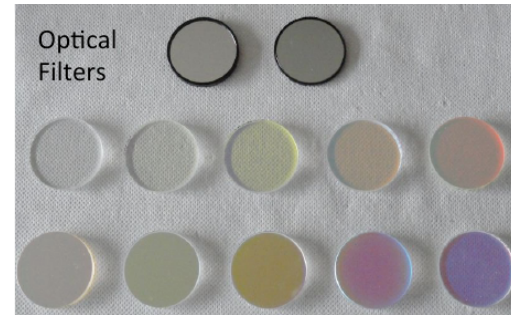


Aerogel Chromatic Dispersion

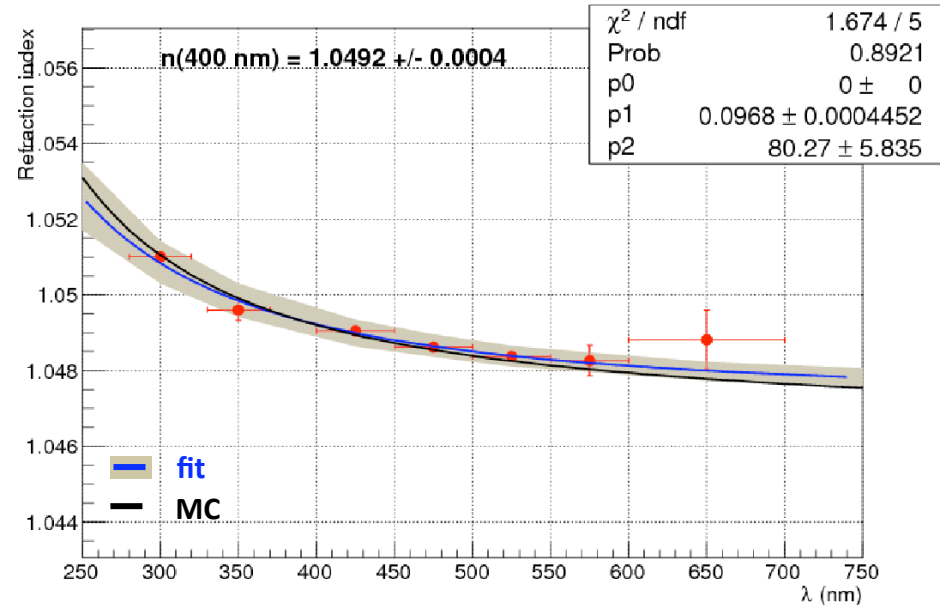
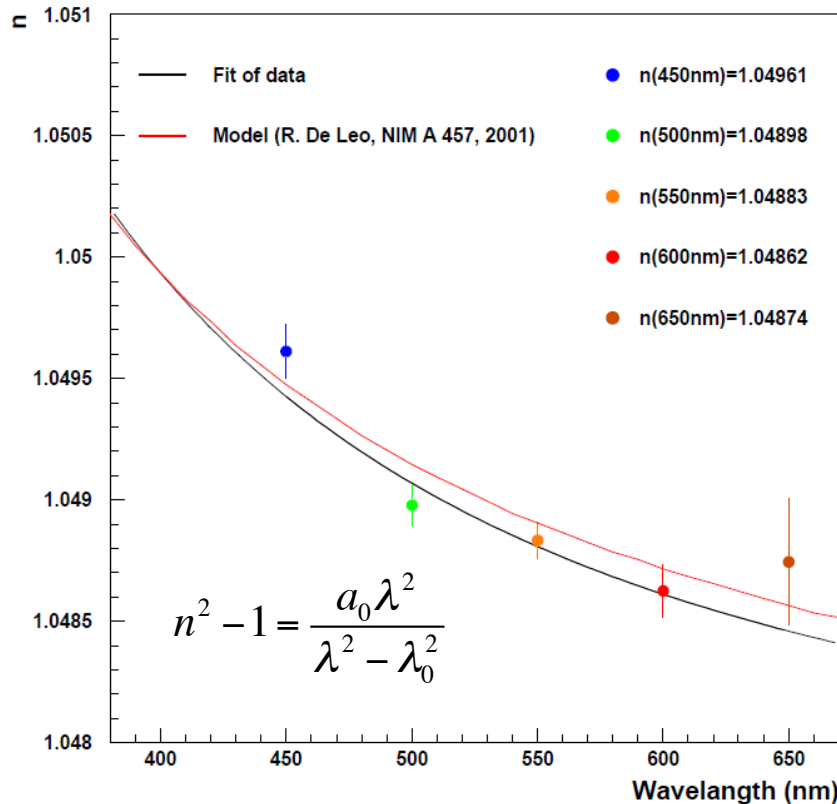
Measured by prisma method:



Measured by prototype with optical filters:



Chromatic dispersion



Expected value from density:

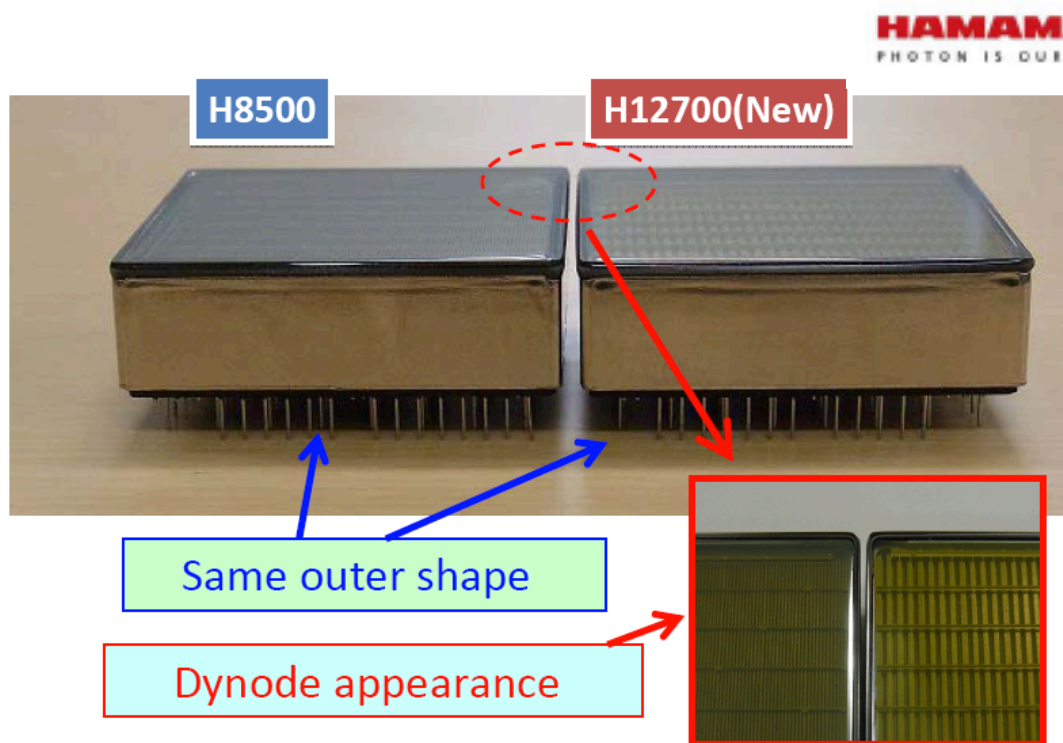
$$n^2(400\text{nm}) = 1 + 0.438\rho$$

$$n(400\text{nm}) = 1.0492$$

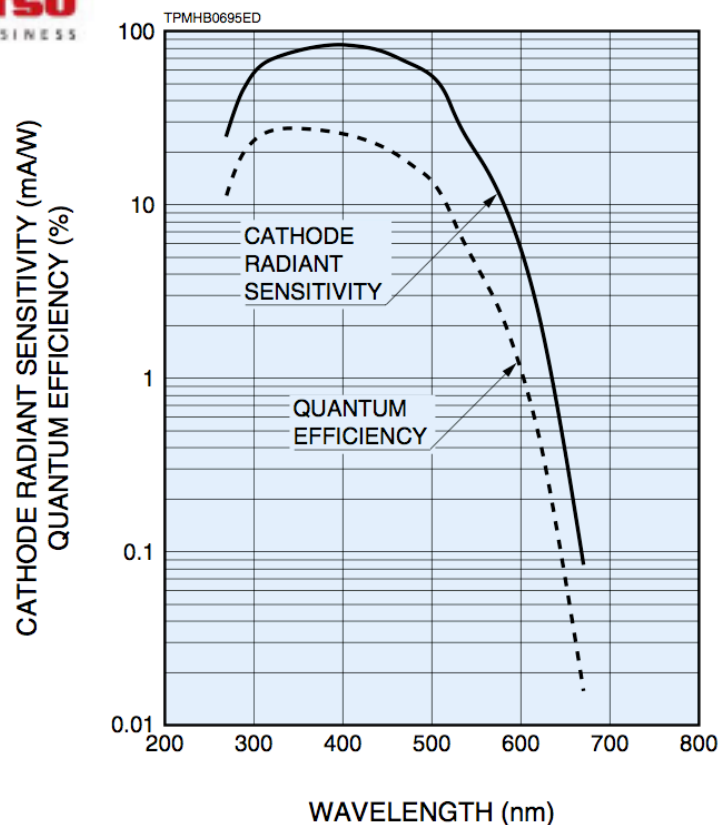
Photon Detectors: MA-PMT

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

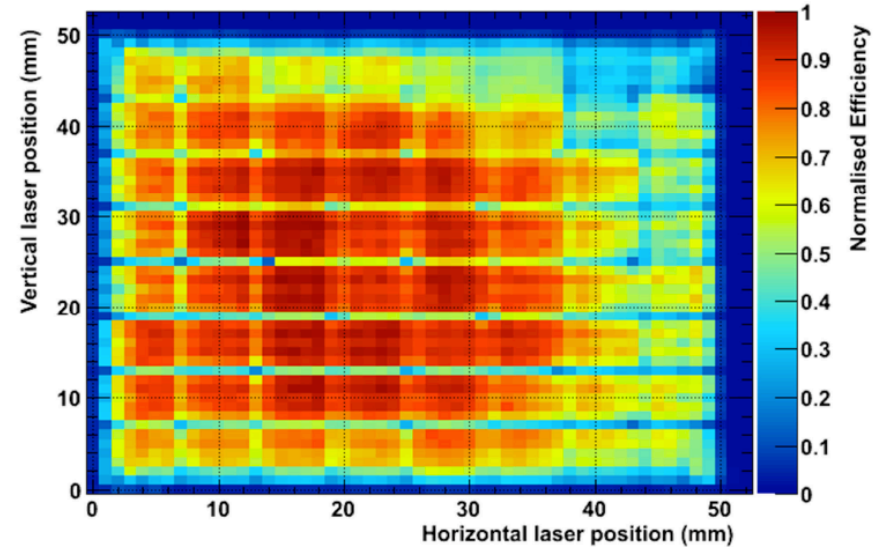
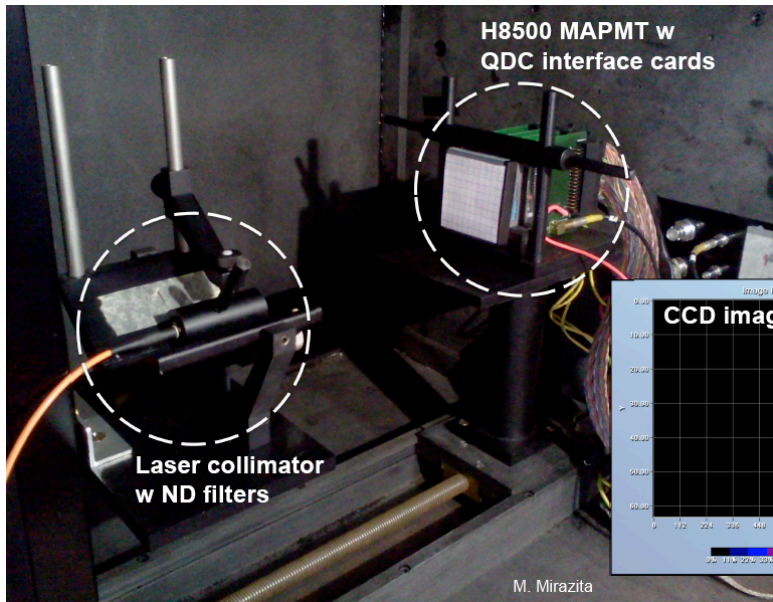
- ✓ Mature and reliable technology
- ✓ Large Area ($5 \times 5 \text{ cm}^2$)
- ✓ High packing density (89 %)
- ✓ 64 $6 \times 6 \text{ mm}^2$ pixels cost effective device
- ✓ High sensitivity on visible towards UV light
- ✓ Fast response



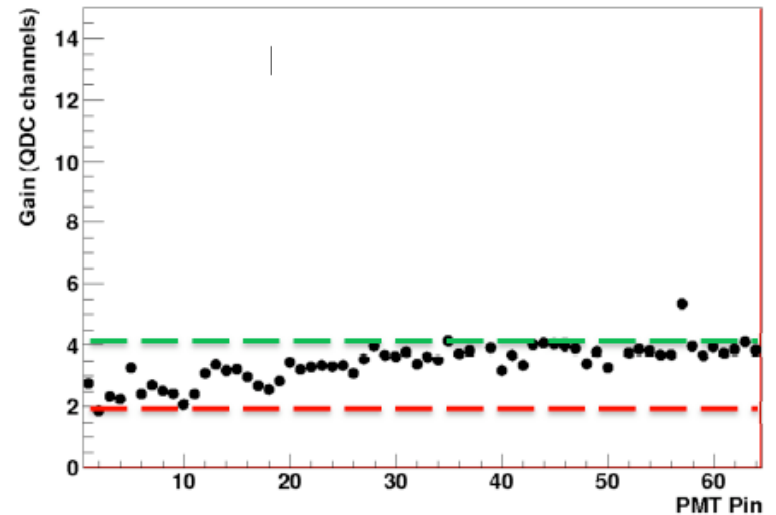
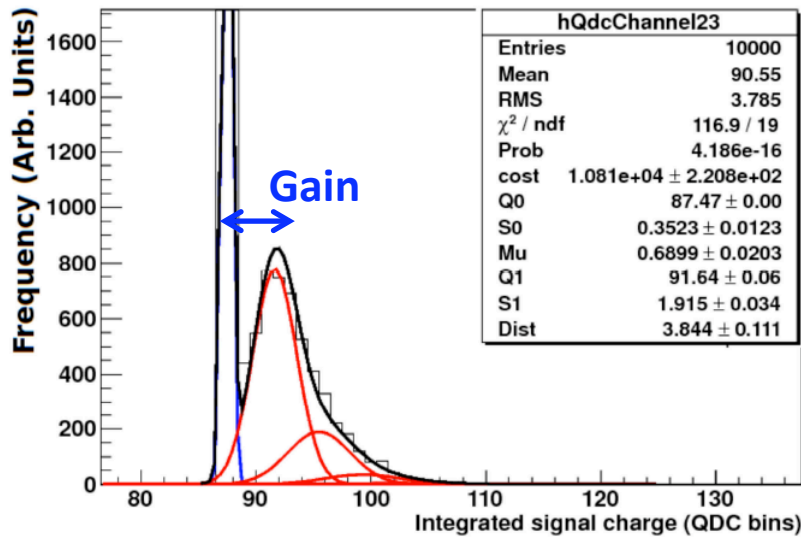
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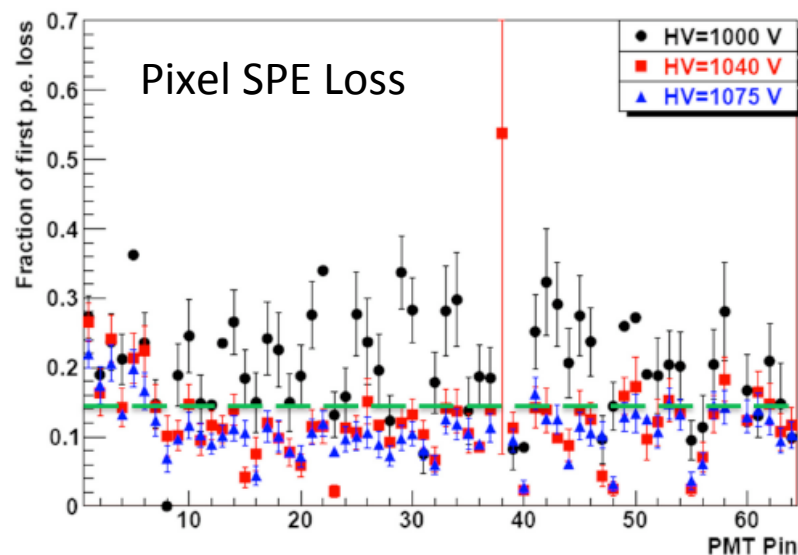
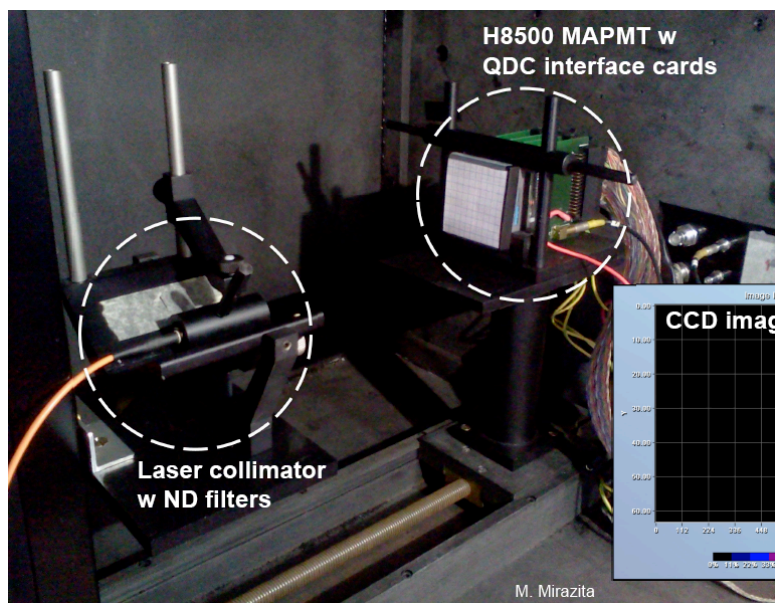
MA-PMT Gain Map



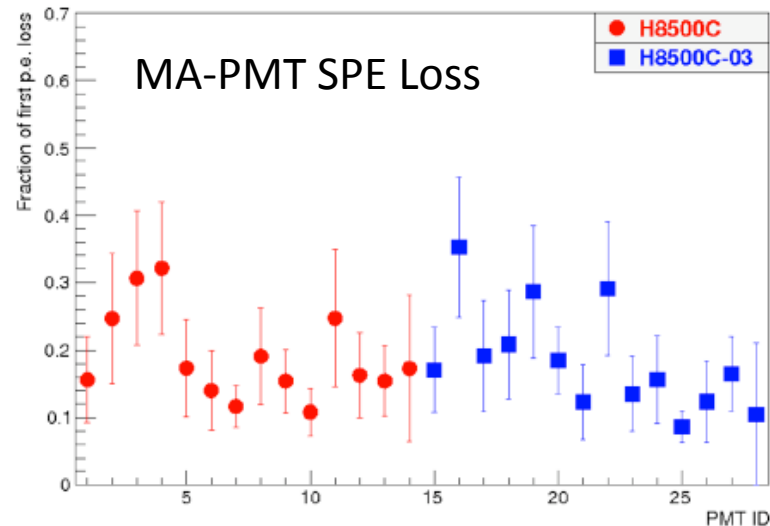
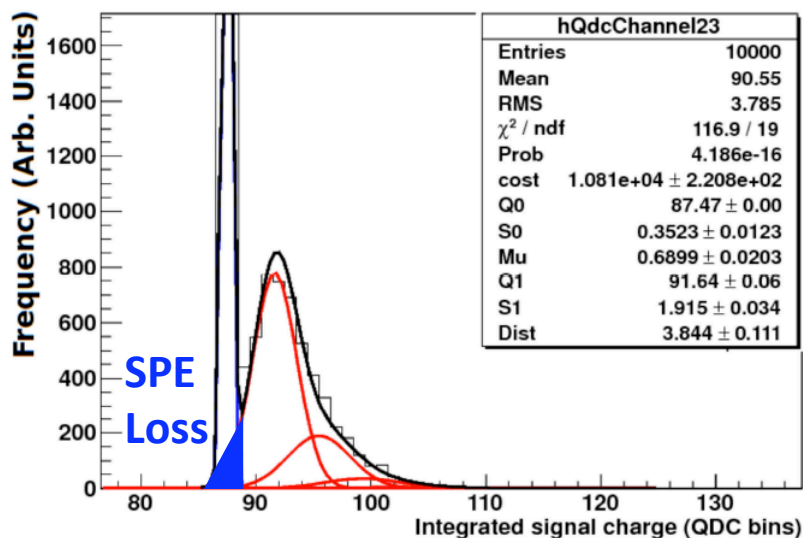
Pixel Gain: 1:2 variation can be easily compensated by the read-out electronics



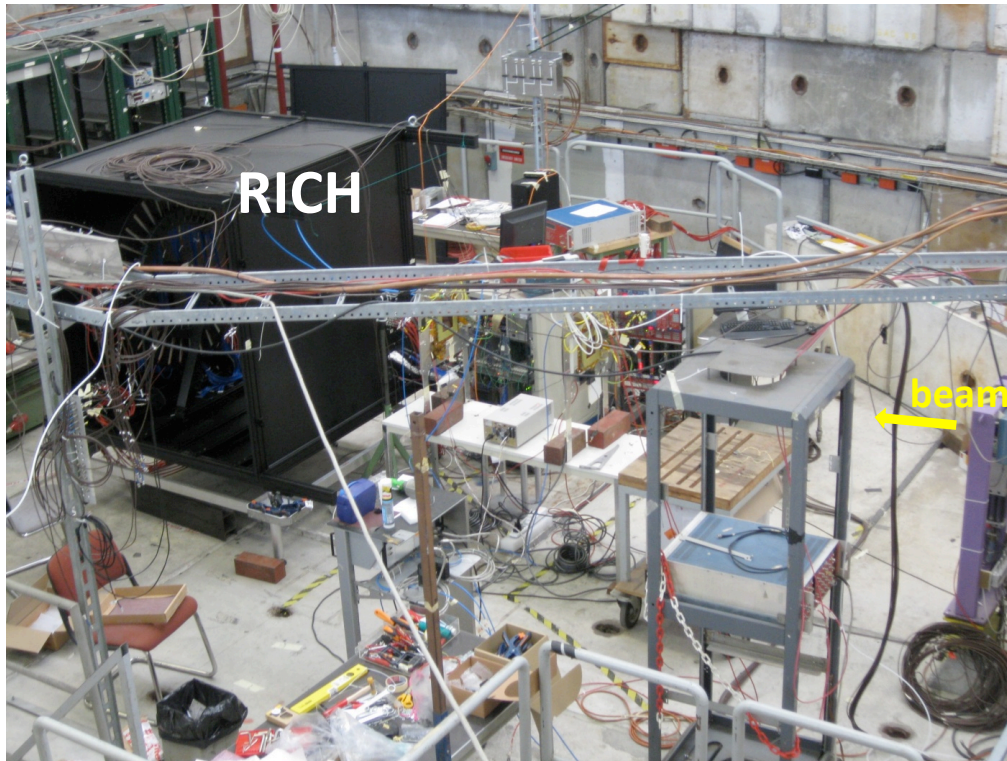
MA-PMT SPE Loss



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

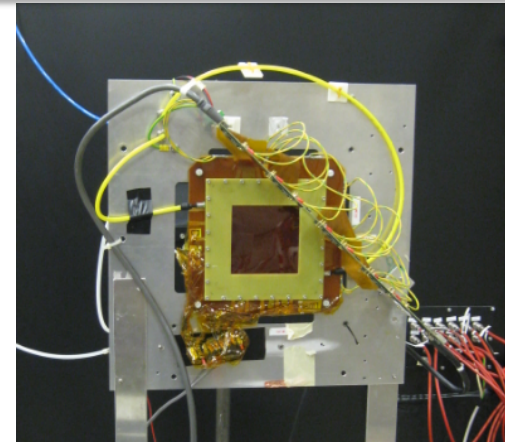


RHIC Prototype at CERN-T9



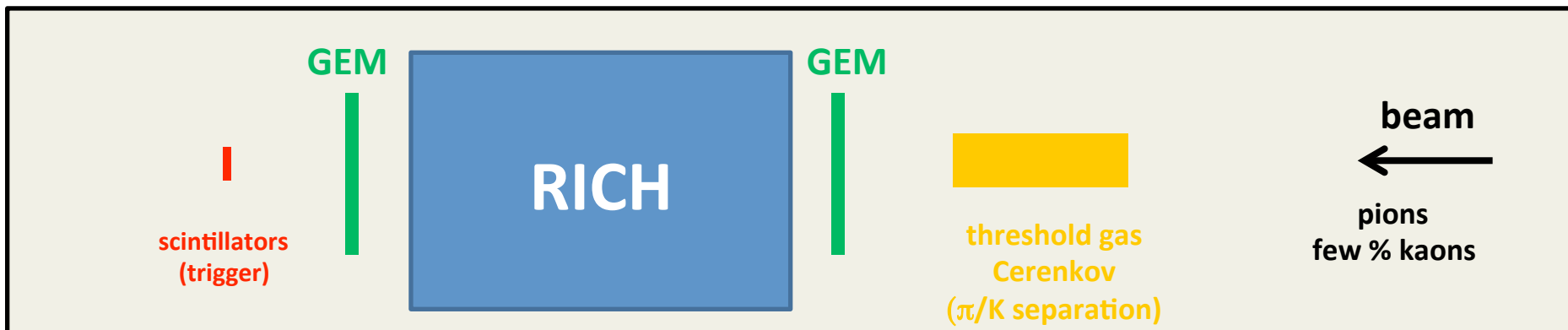
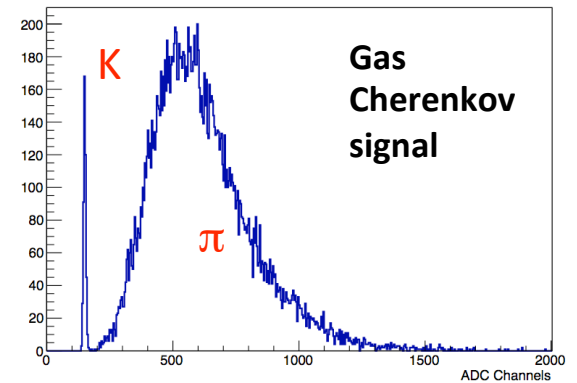
RICH

beam

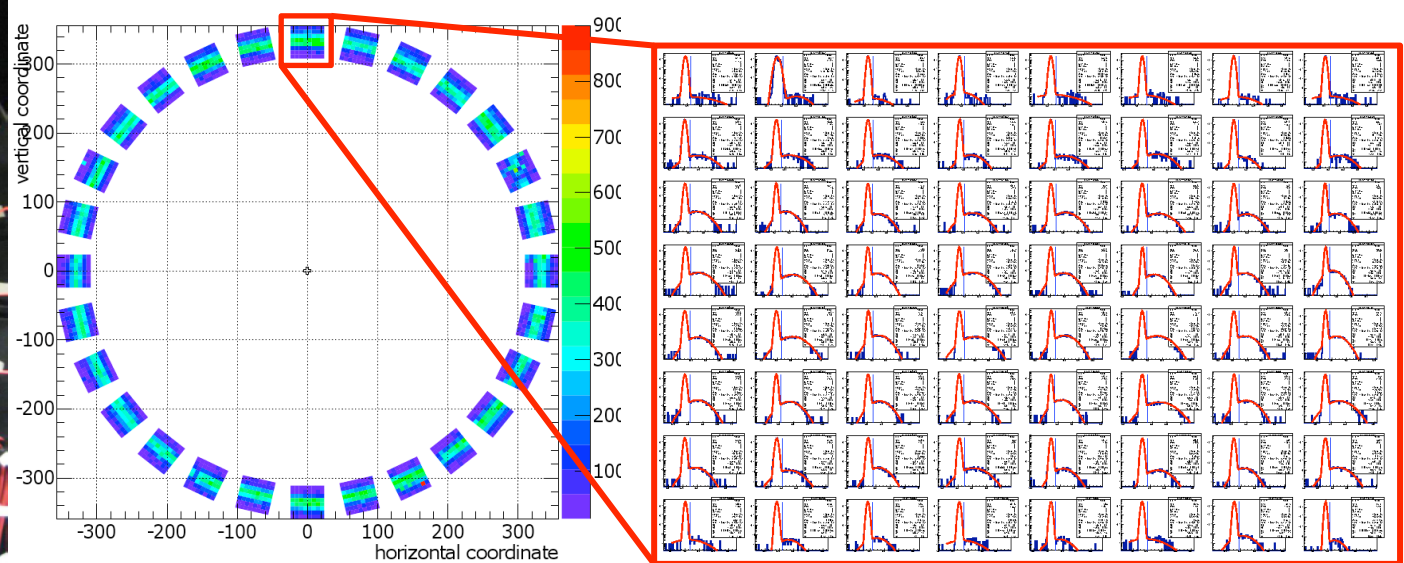
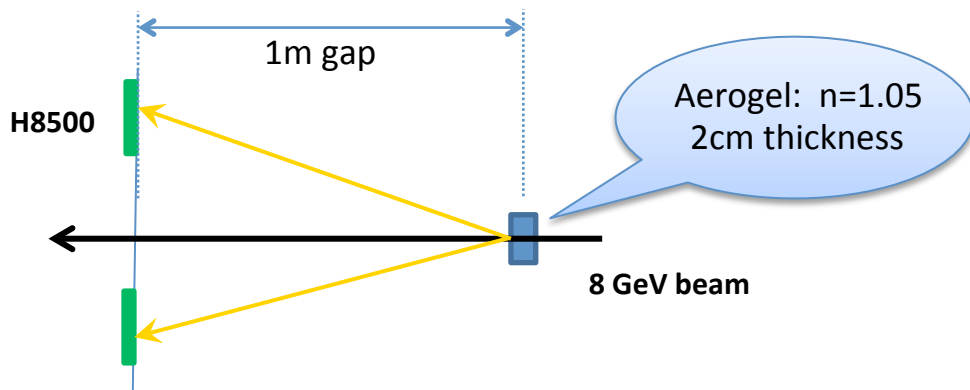


GEM chamber layout

Cerenkov ADC

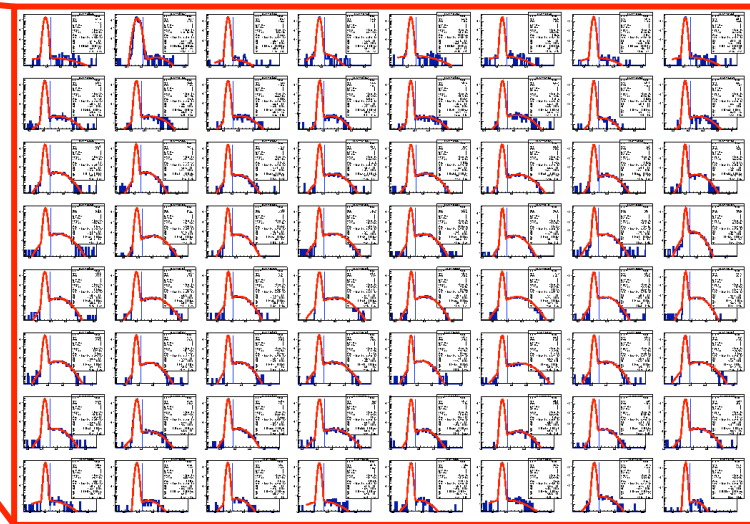
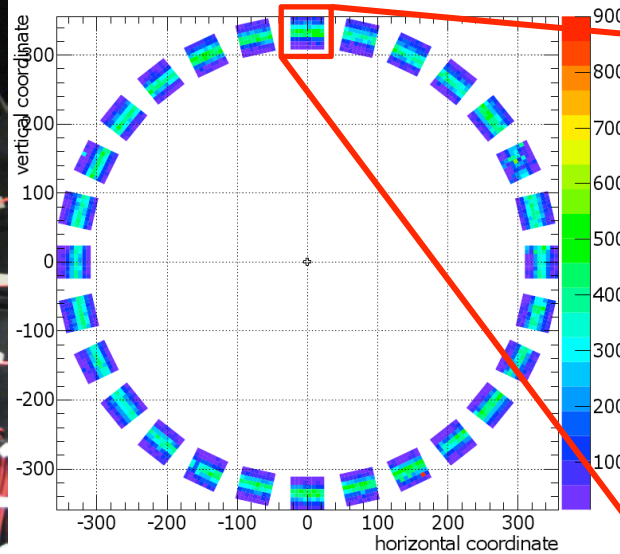
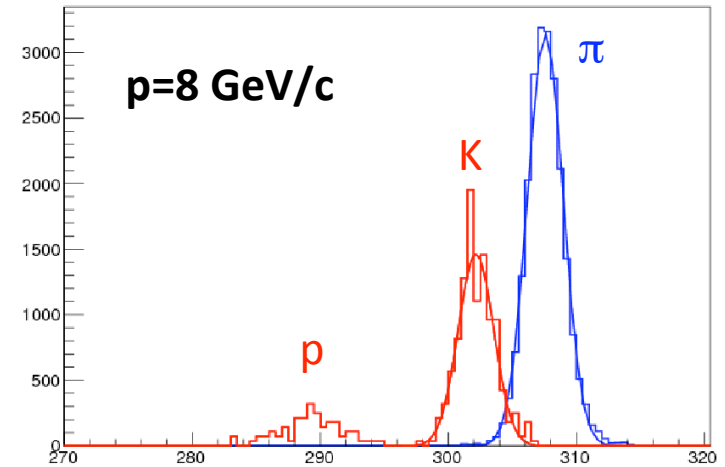
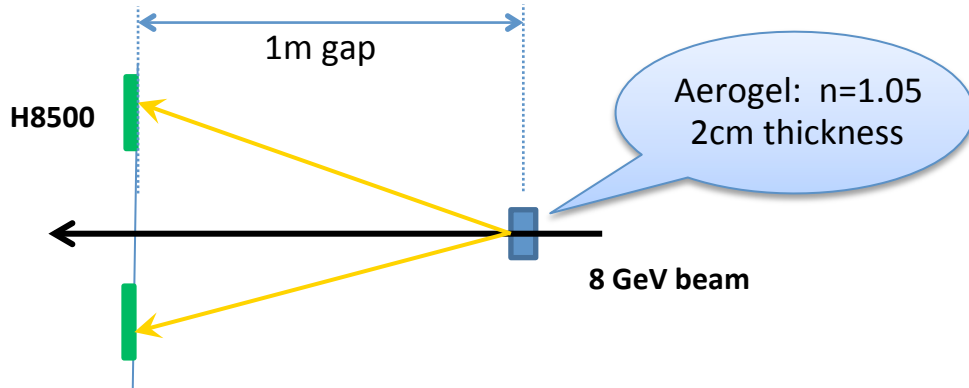


RHIC Prototype: Direct Light Case

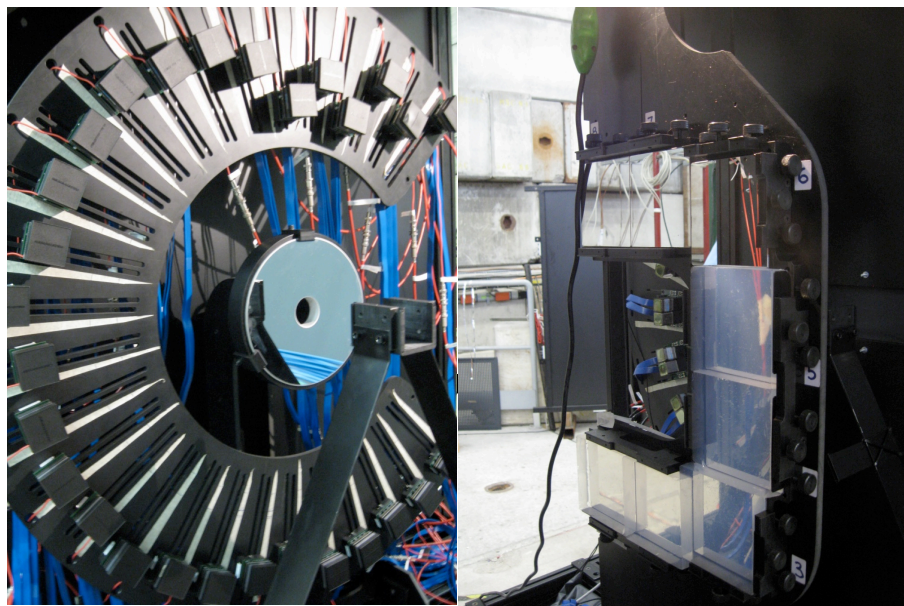
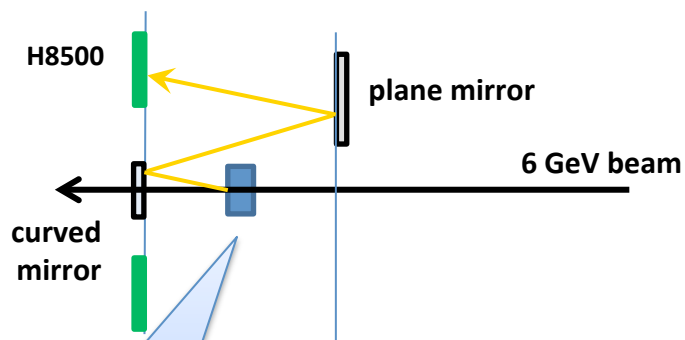


RHIC Prototype: Direct Light Case

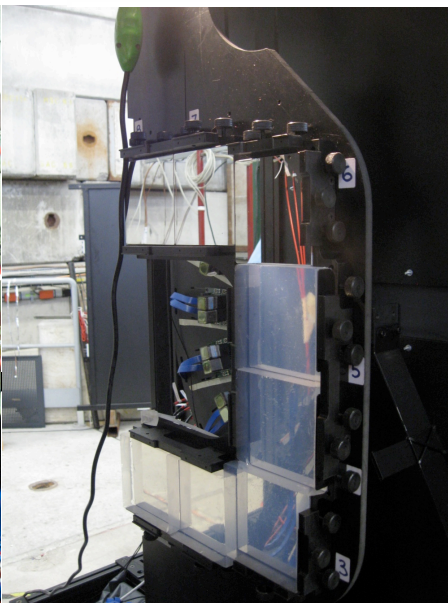
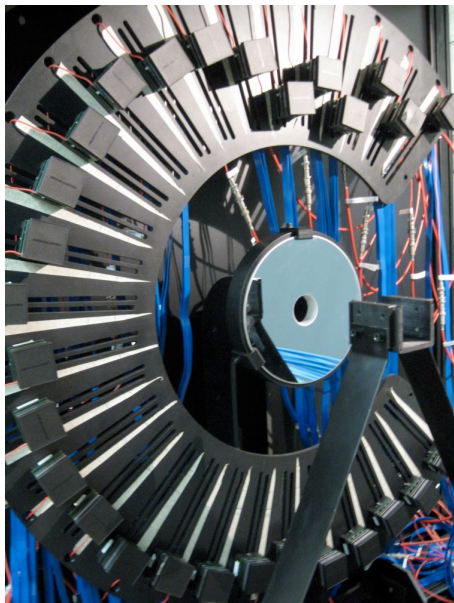
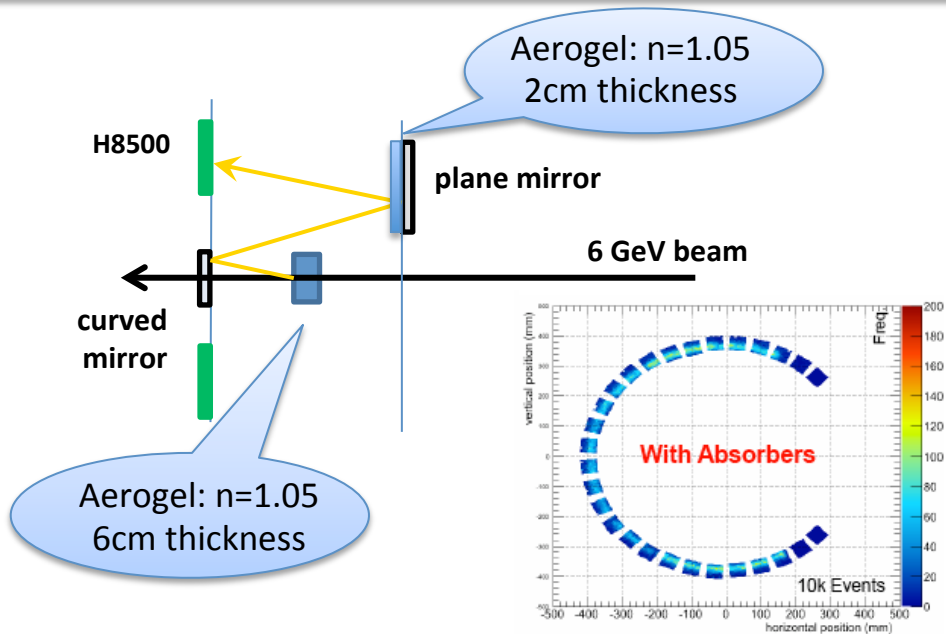
Clear hadron separation up to the CLAS12 maximum momentum



RHIC Prototype: Reflected Light Case

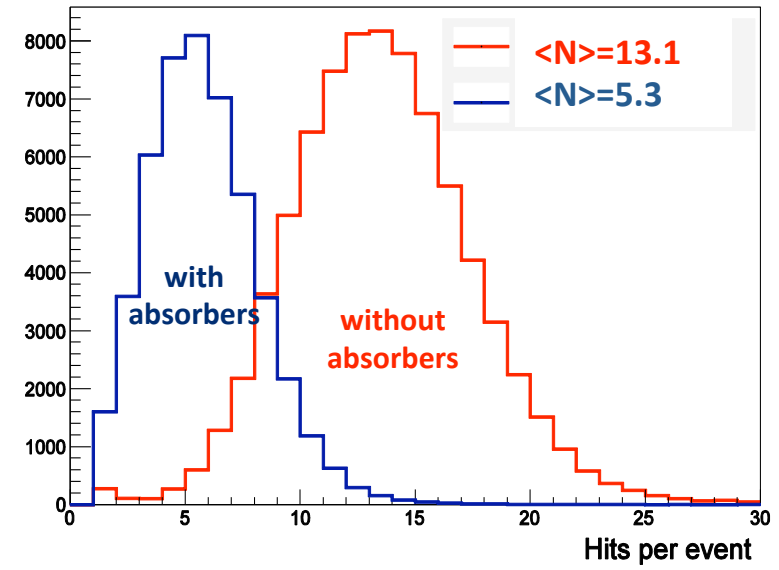
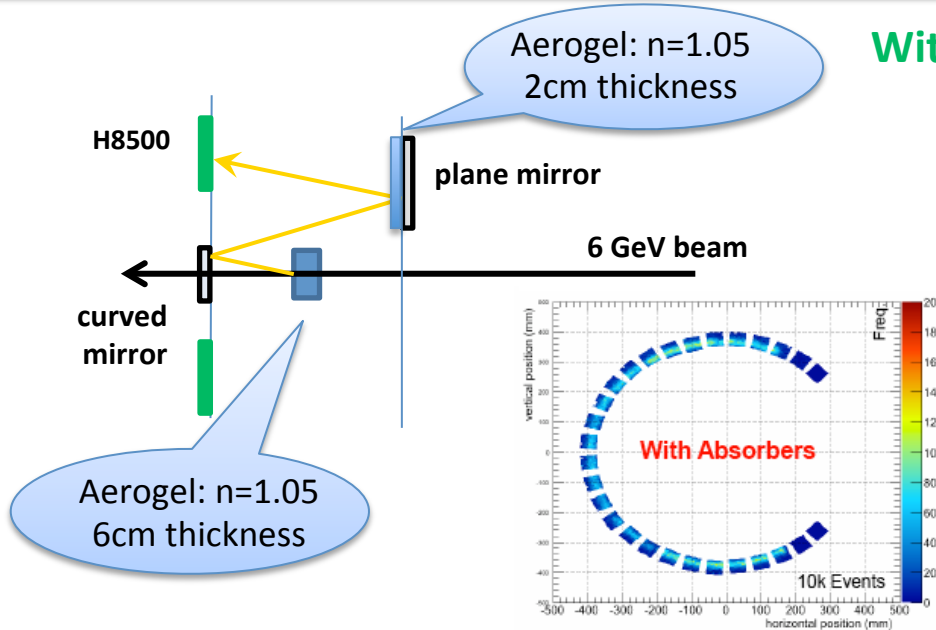


RHIC Prototype: Reflected Light Case

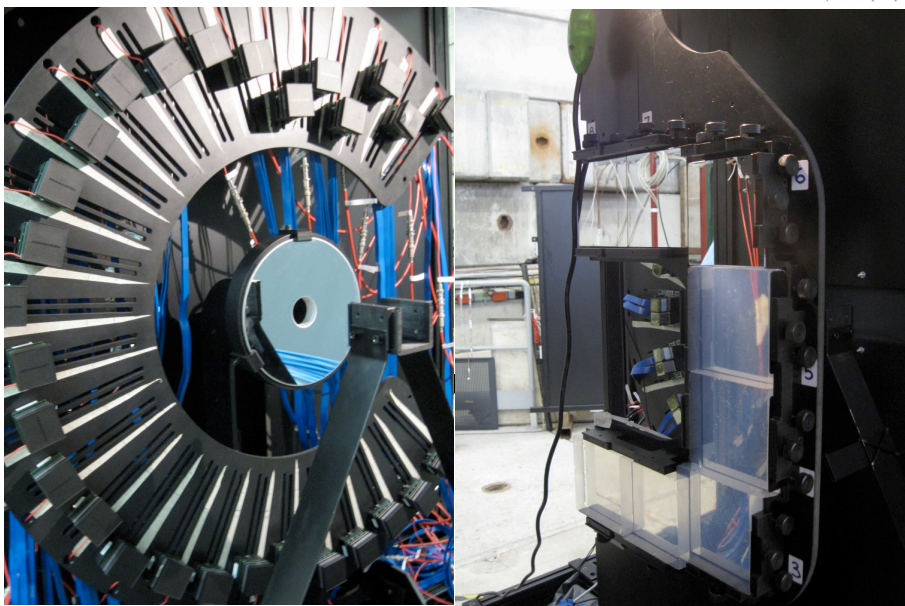
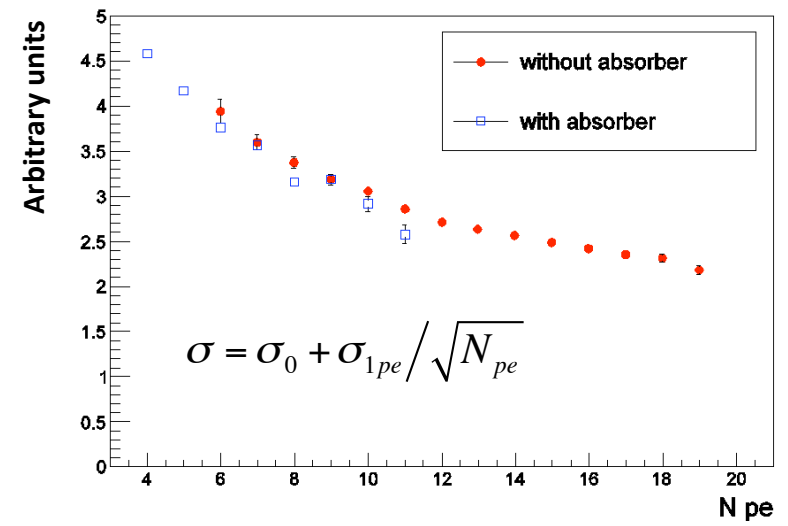


RHIC Prototype: Reflected Light Case

With absorbers: sizeable fraction of light survives



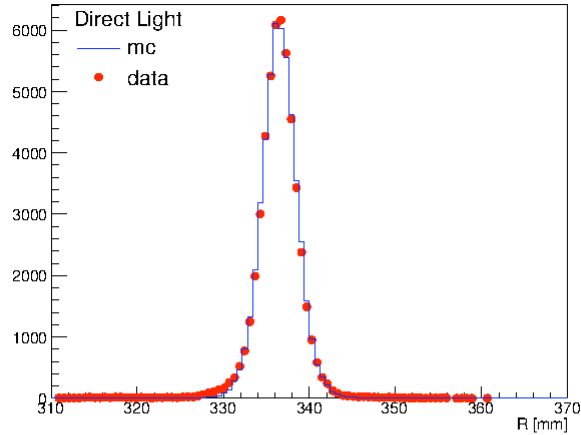
and resolution is not significantly degraded



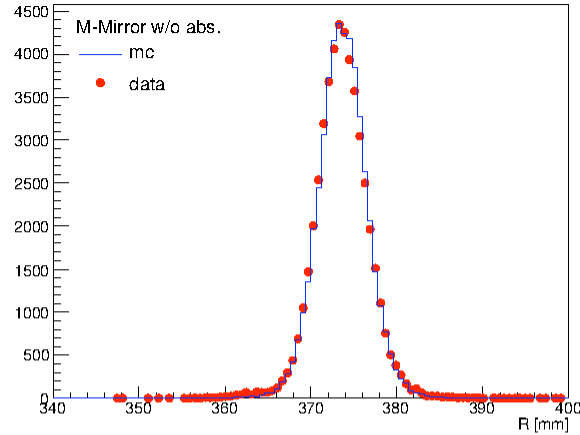
RICH Simulations

reflected light setup

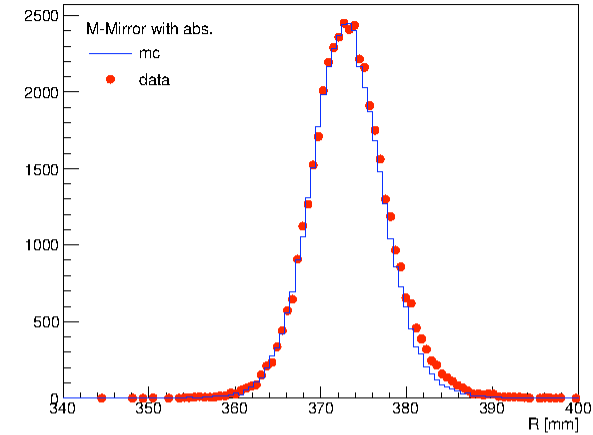
direct light setup



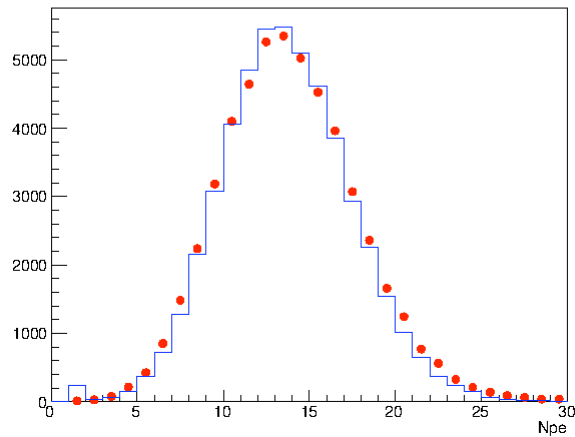
without absorbers



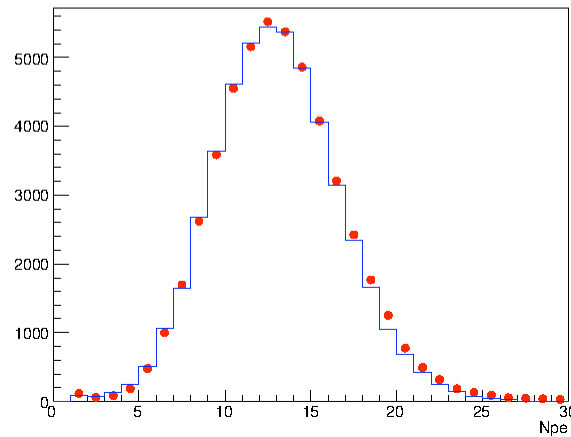
with absorbers



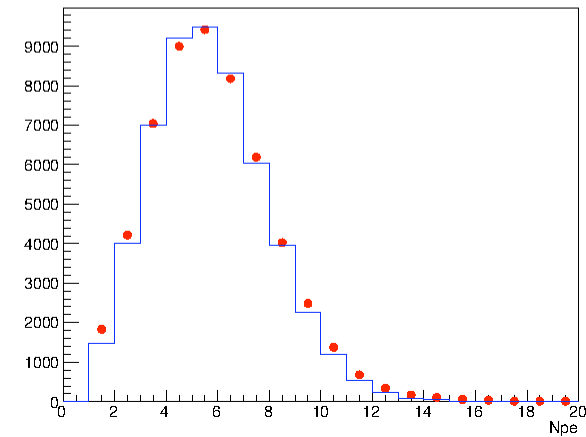
Number of photo-electrons



Number of photo-electrons



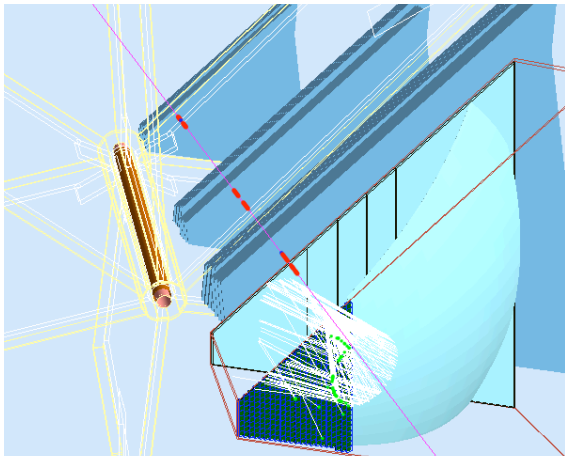
Number of photo-electrons



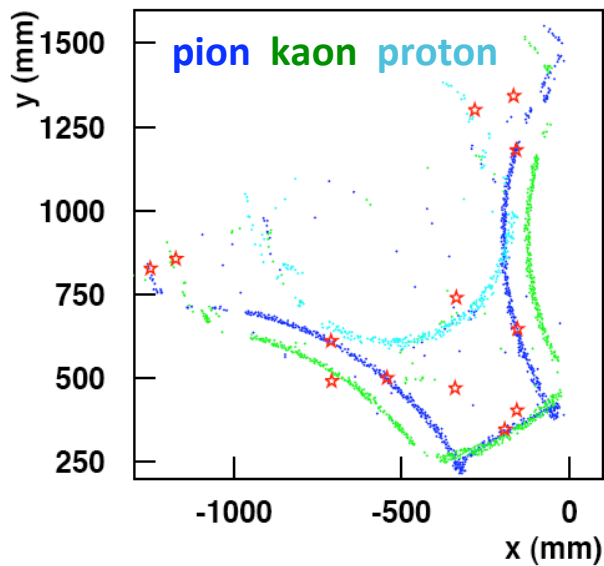
Based on measured optical characteristics and validated with RICH prototype data

The CLAS12 Hadron ID

One charged particle per sector in average:

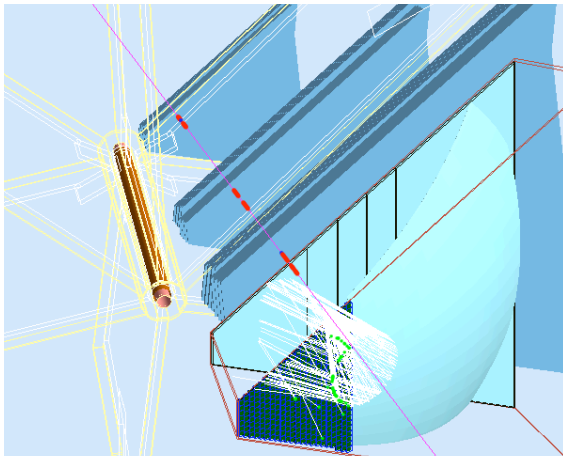


Non trivial RICH light patten due to reflections:
patter recognition and likelihood ID required

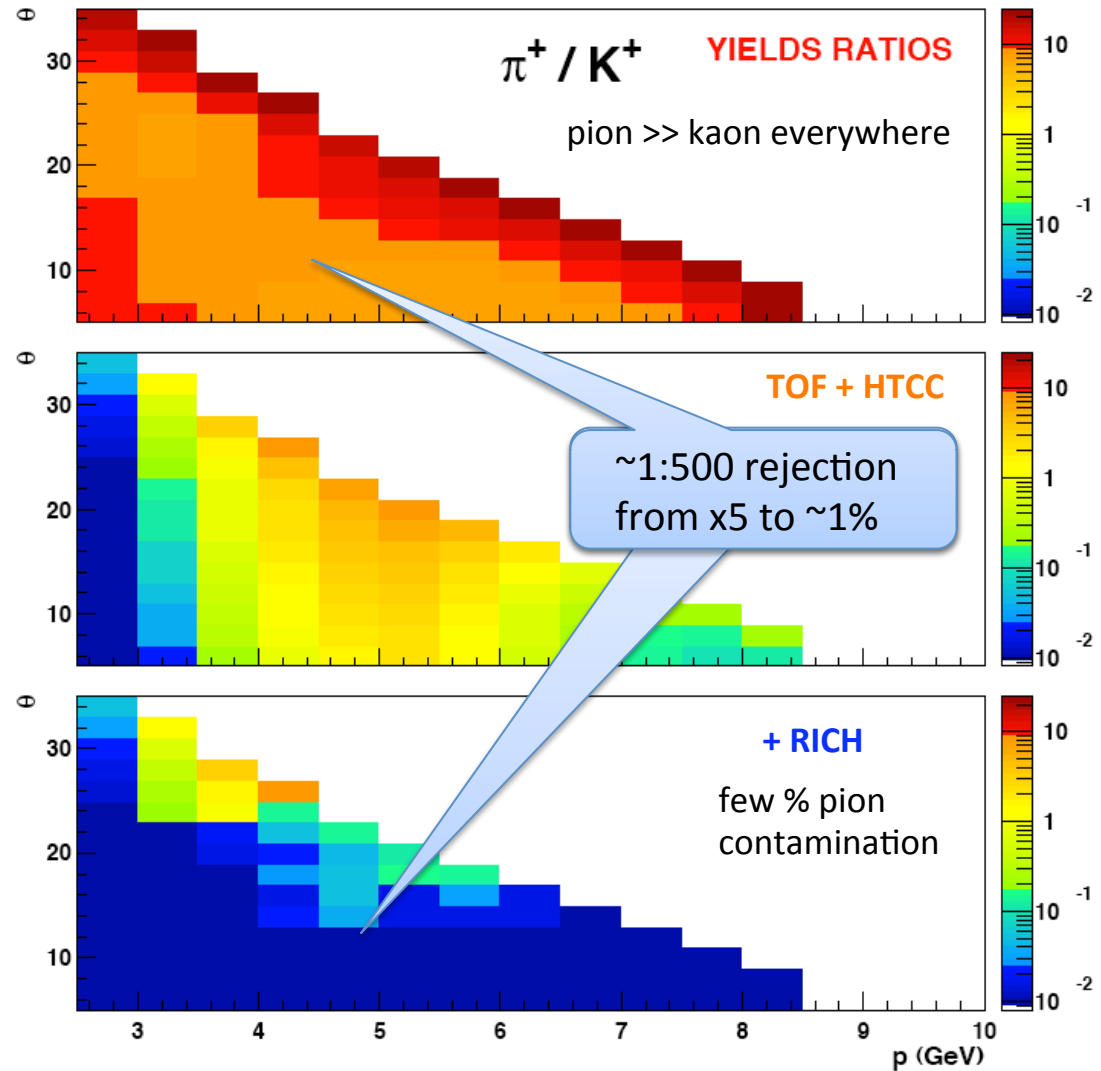
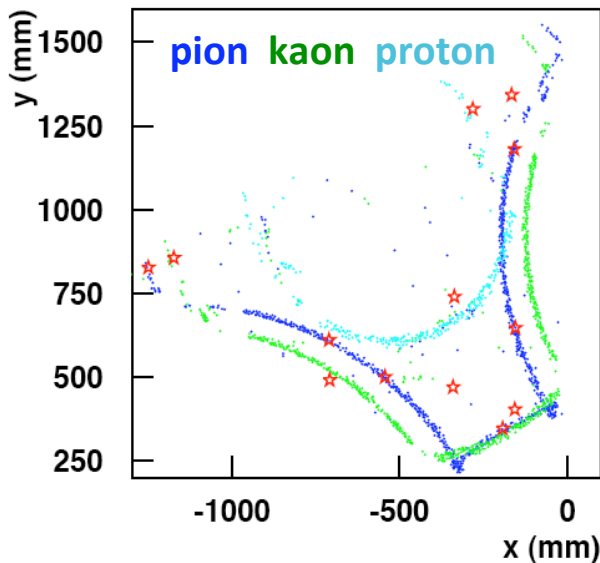


The CLAS12 Hadron ID

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%

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

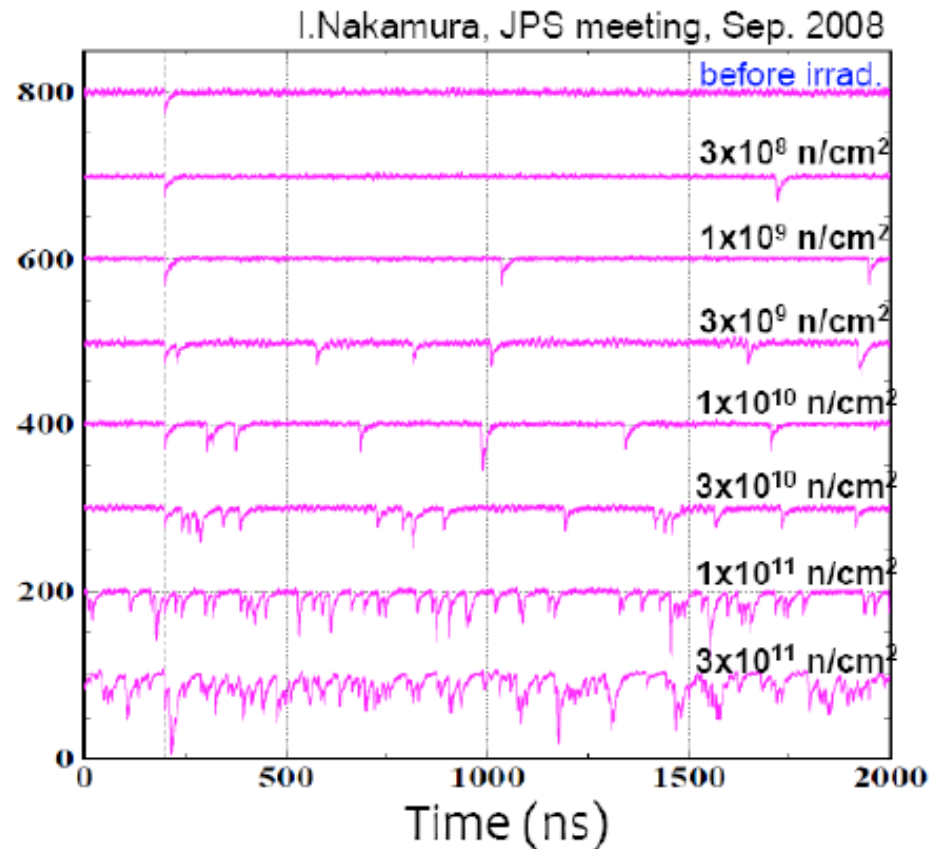
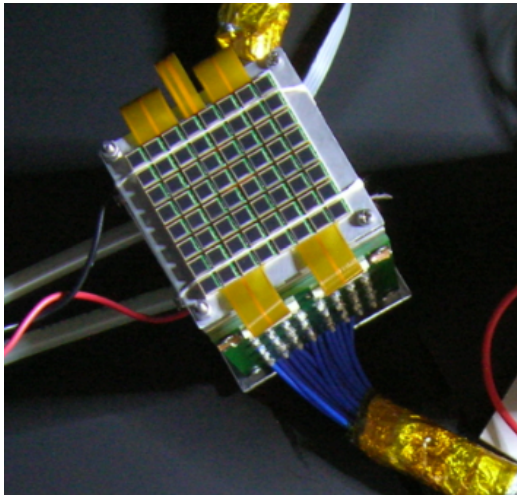
GOAL: 1st sector ready by the end of 2016

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

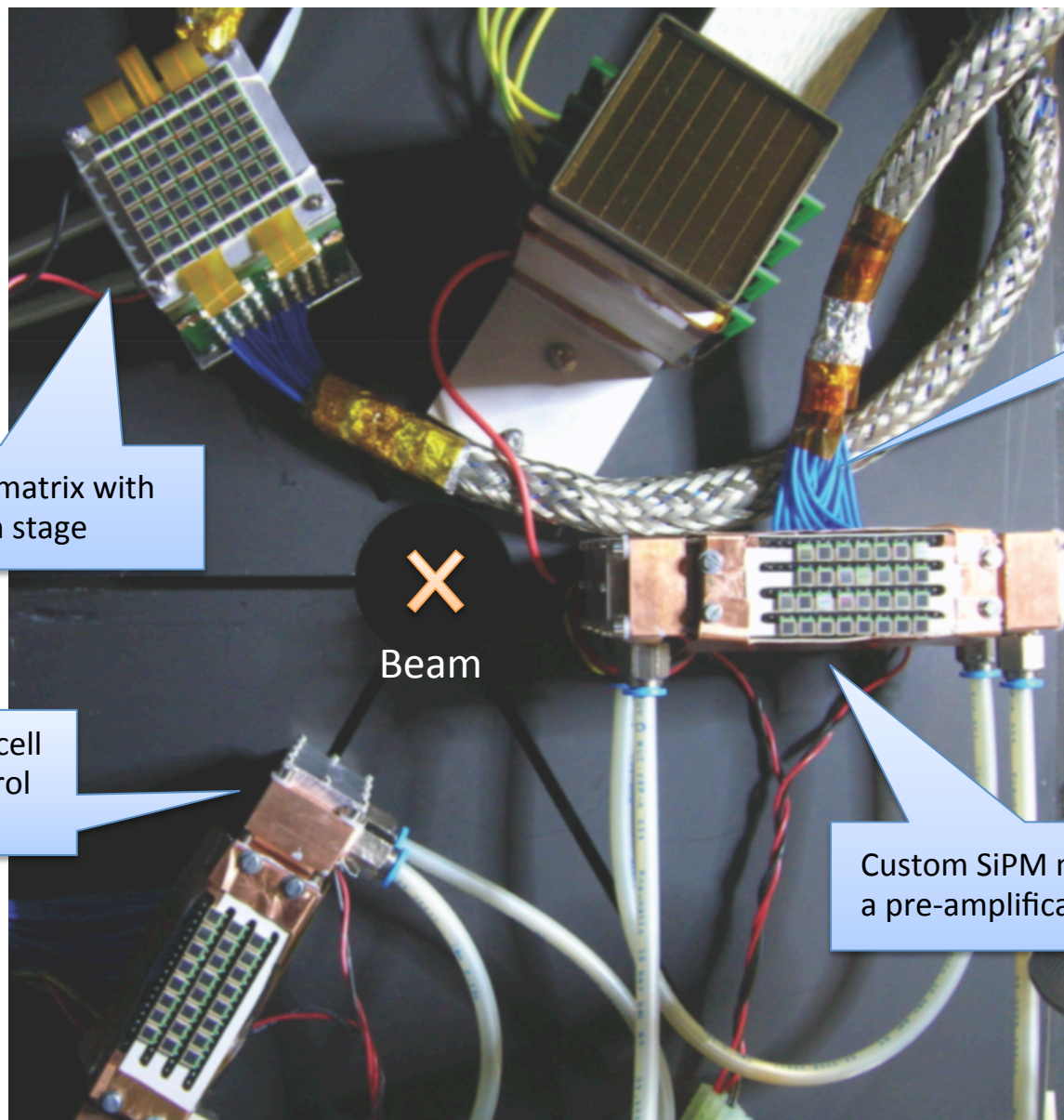
Expected fluence @ LHCb-2:
1 year \rightarrow 6 10^{11} n/cm²



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

The SiPM Test Prototype



Commercial SiPM matrix with a pre-amplification stage

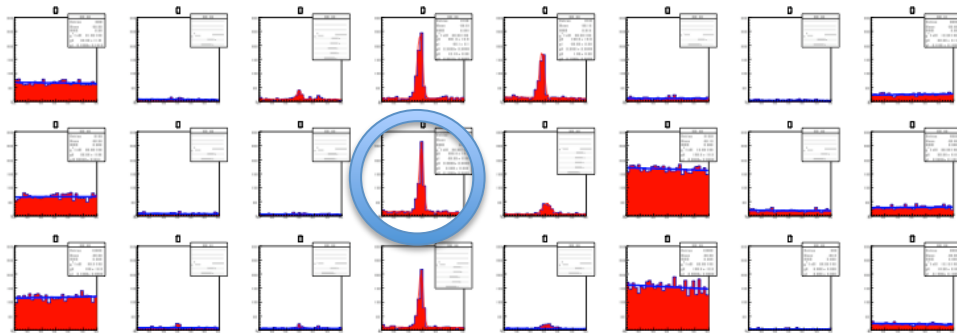
1.5 m coaxial cables to the electronics

X
Beam

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

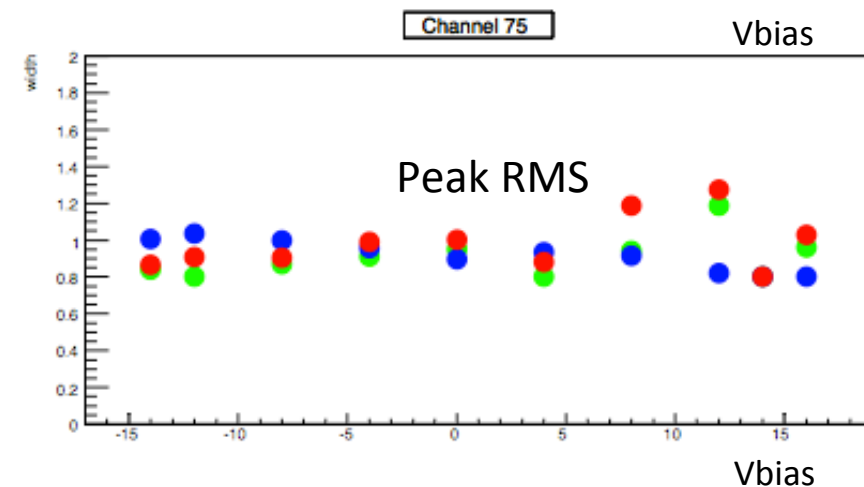
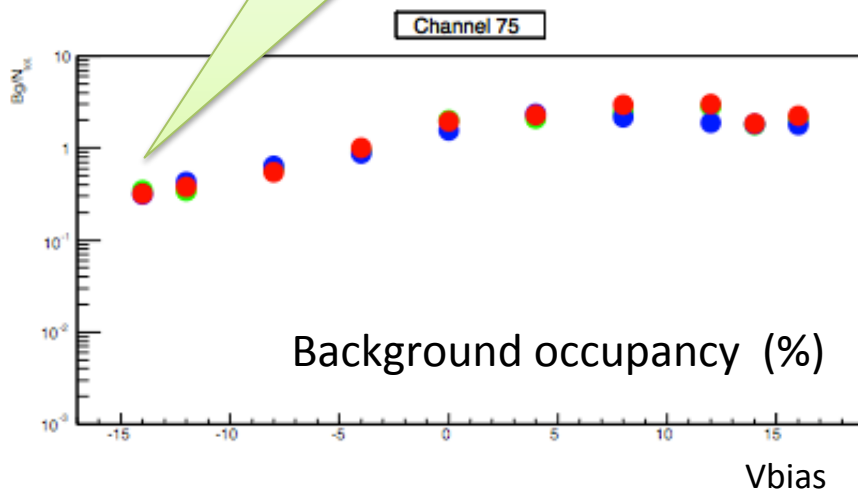
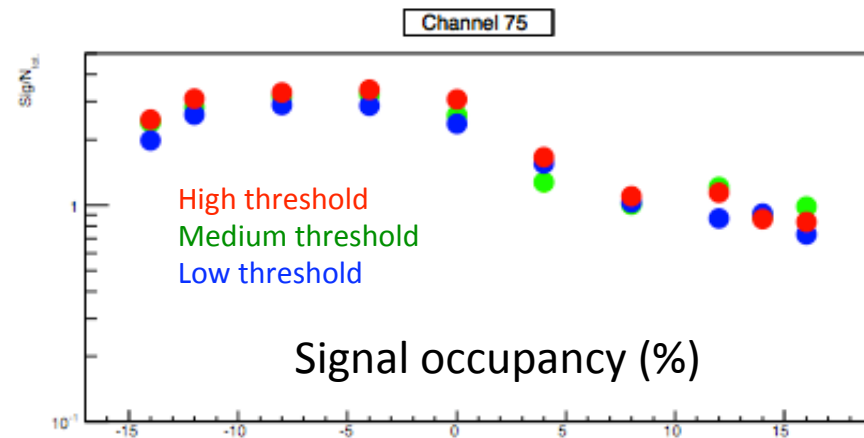
Custom SiPM matrices with a pre-amplification stage

The Custom SiPM Matrix @ +25°



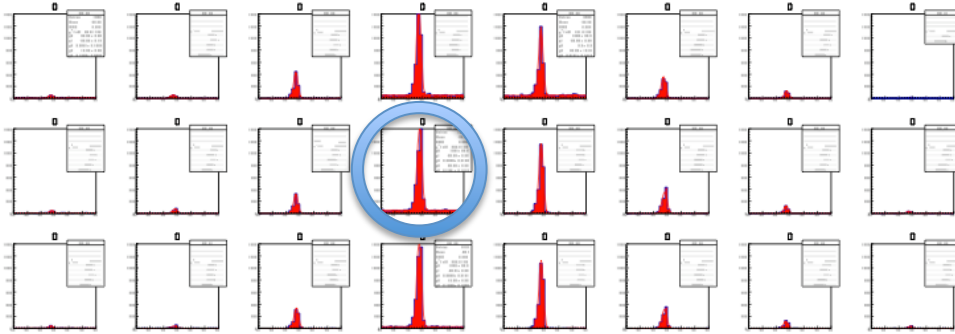
Equalization of the single SiPM is critical

10^{-3} level is challenging



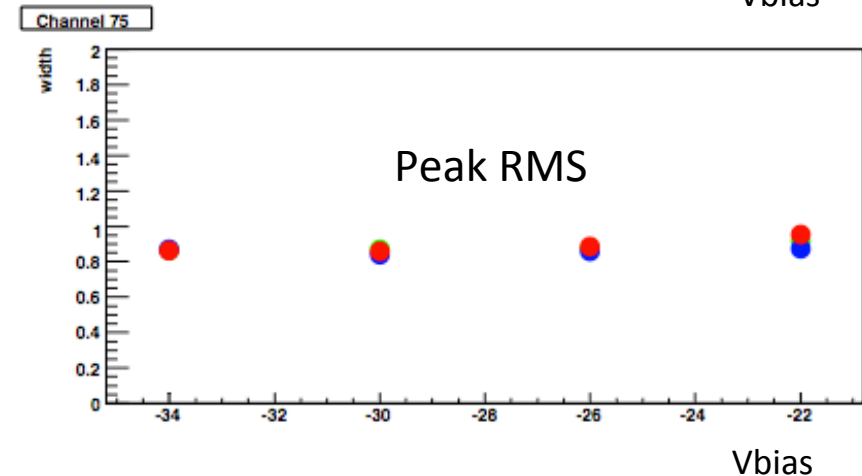
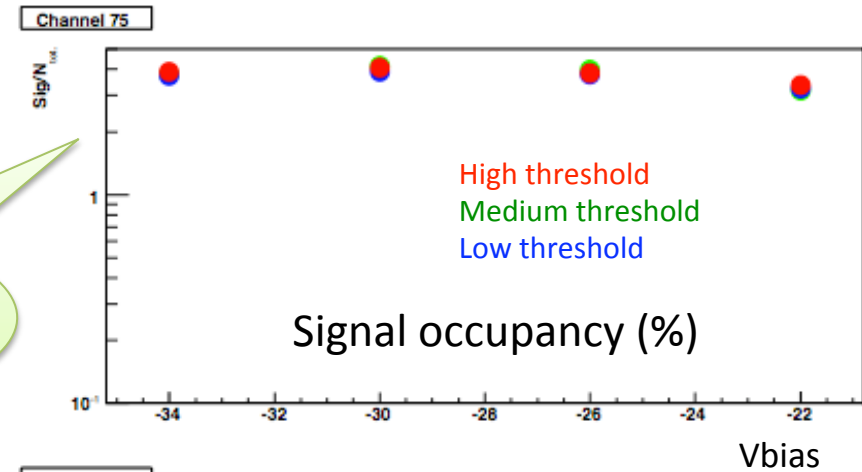
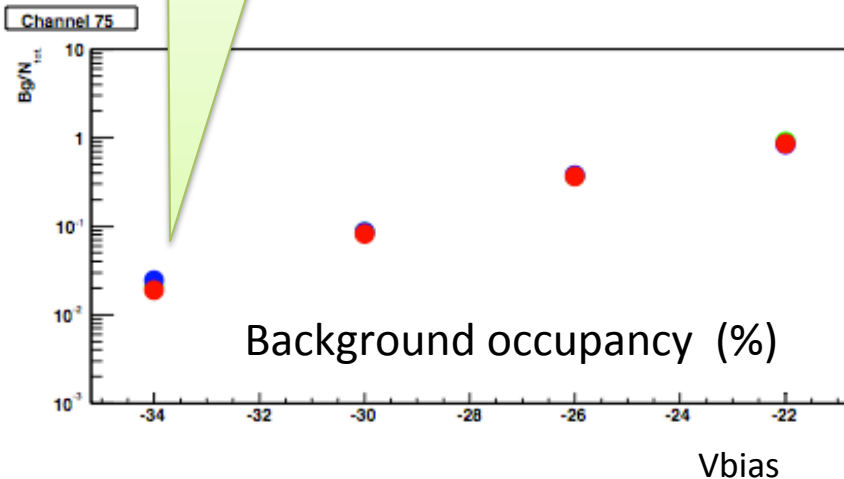
The Custom SiPM Matrix@-25°

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



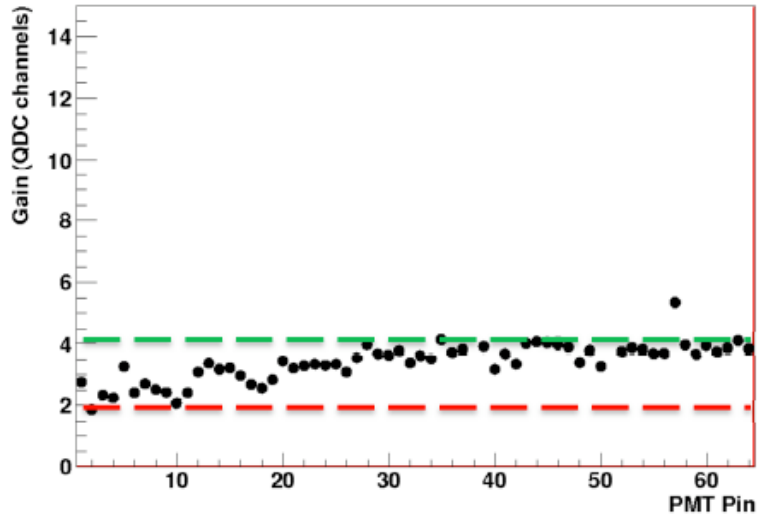
In a +/- 3 ns window
Comparable with H8500

Largely insensitivity to
Vbias and discriminator
threshold

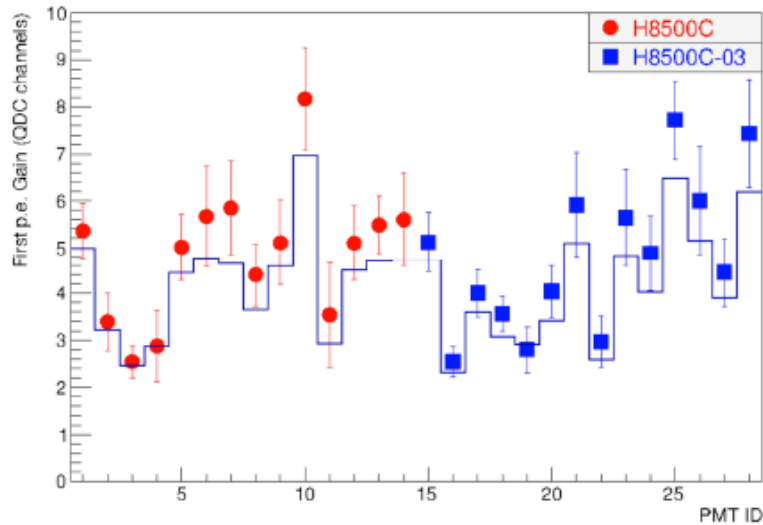


MA-PMT Gain Map

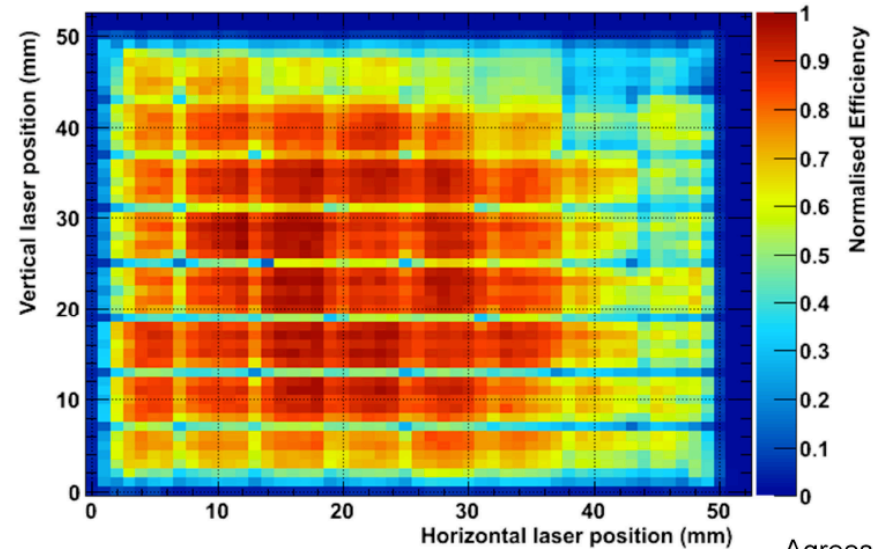
Pixel Gain:



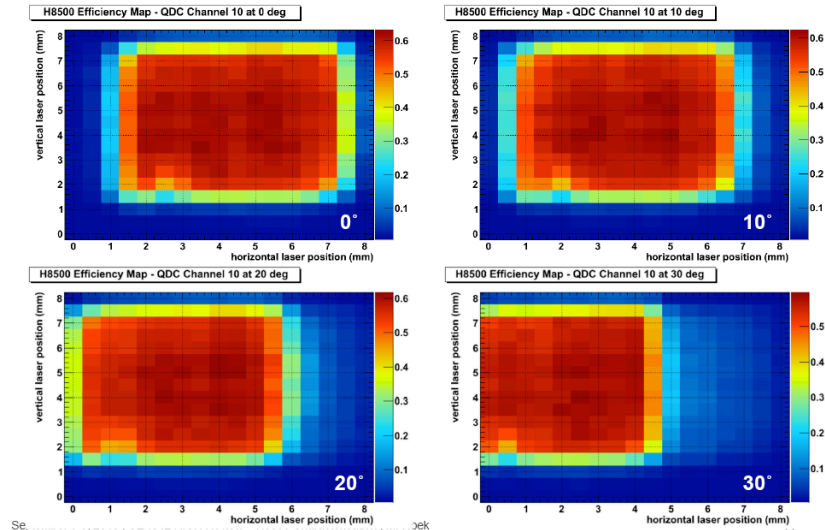
PMT average gain:



Efficiency Map:

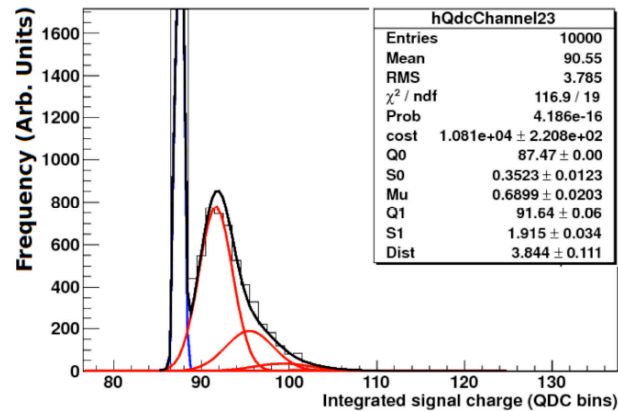


Incident angle scan:



MA-PMT Efficiency and X-talk

~ 15% SPE Loss :



~ 3% Cross-Talk:

