The Large-Area Hybrid-Optics CLAS12 RICH Detector: Test of Innovative Components

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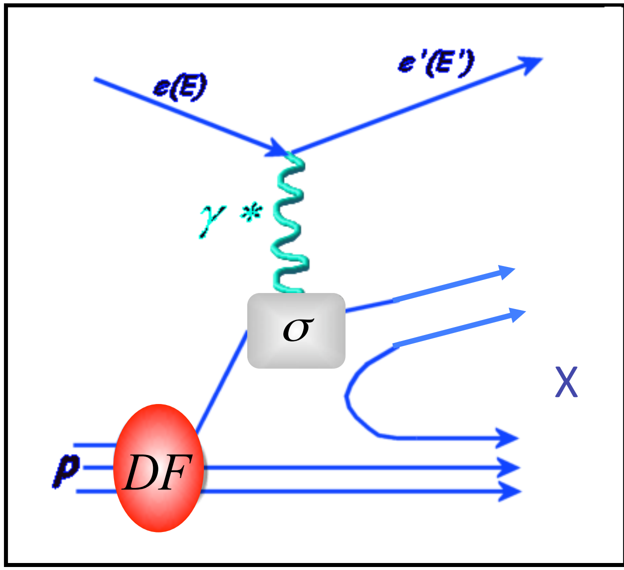
INFN Ferrara

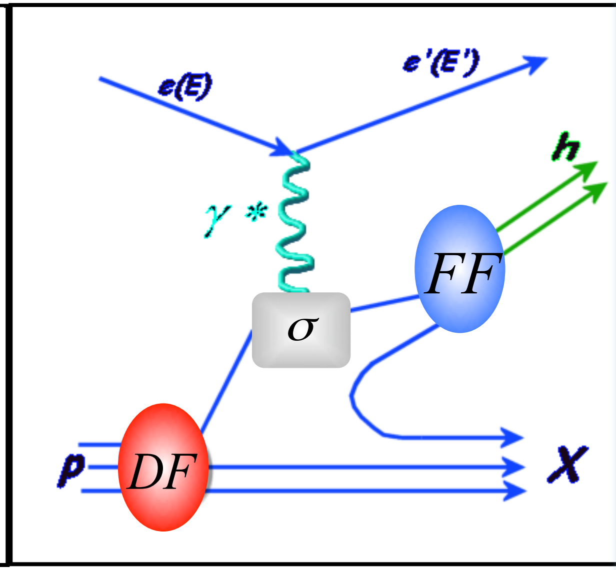
RICH 2013 Workshop, 2nd December 2013, SVC - Japan

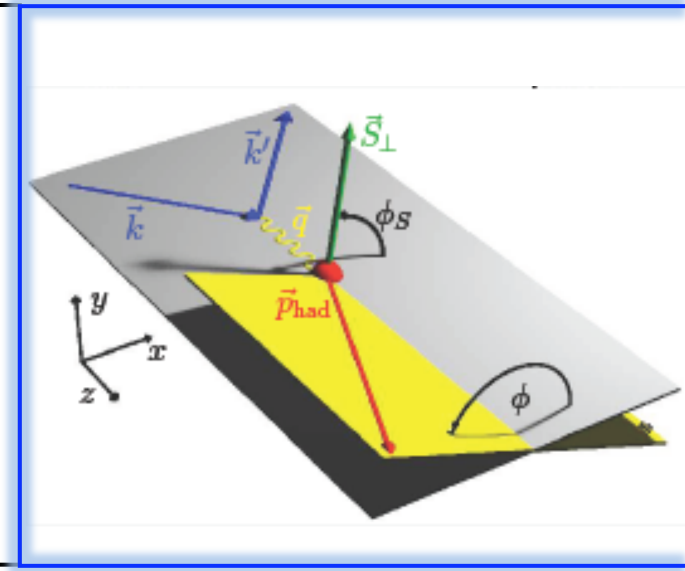
The 3D Spin Nucleon Structure

Inclusive DIS

Semi-inclusive DIS





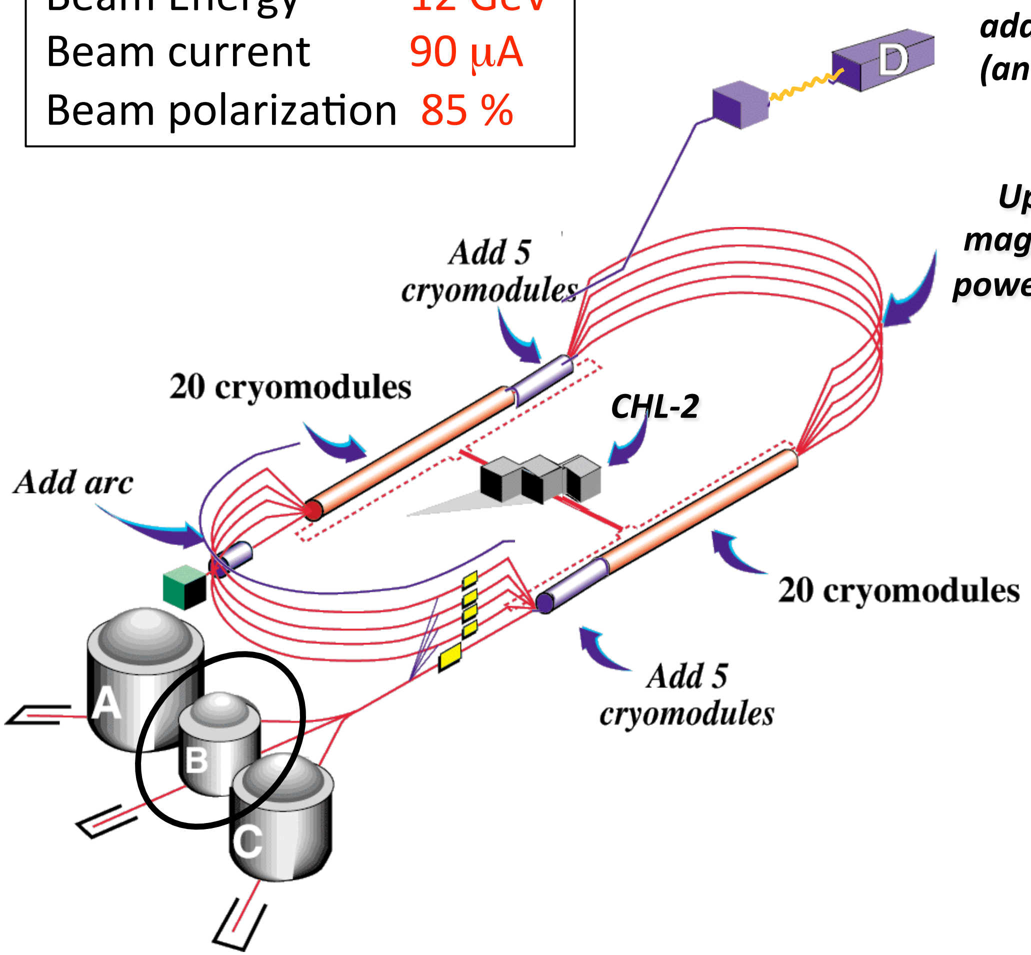


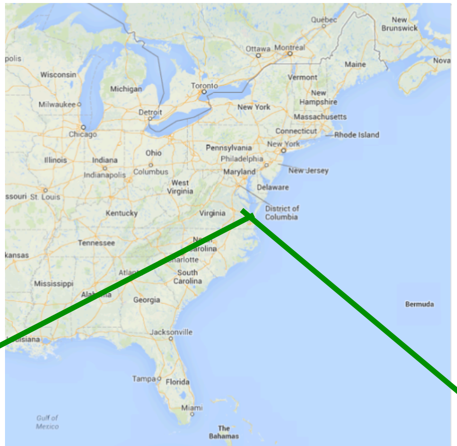
SFs (x,Q^2)	PDFs (x, Q^2) & FFs (z,Q^2)	TMDs $(x,z,P_{h\perp},\phi,\phi_S,Q^2)$
Structure functions (unpolarized, helicity)	Parton distributions	Transverse momentum dependent parton distrib.
Sum over quark charges	Flavor sensitivity	Spin-Orbit effects
$d\sigma \propto F_2\left(=\sum_q e_q^2 q(x)\right)$	$d\sigma^h \propto \sum_q e_q^2 q(x) D_q^h(z)$	$d\sigma^h \propto \sum_q e_q^2 C\left[q(x,k_T) D_q^h(z,p_T)\right]$

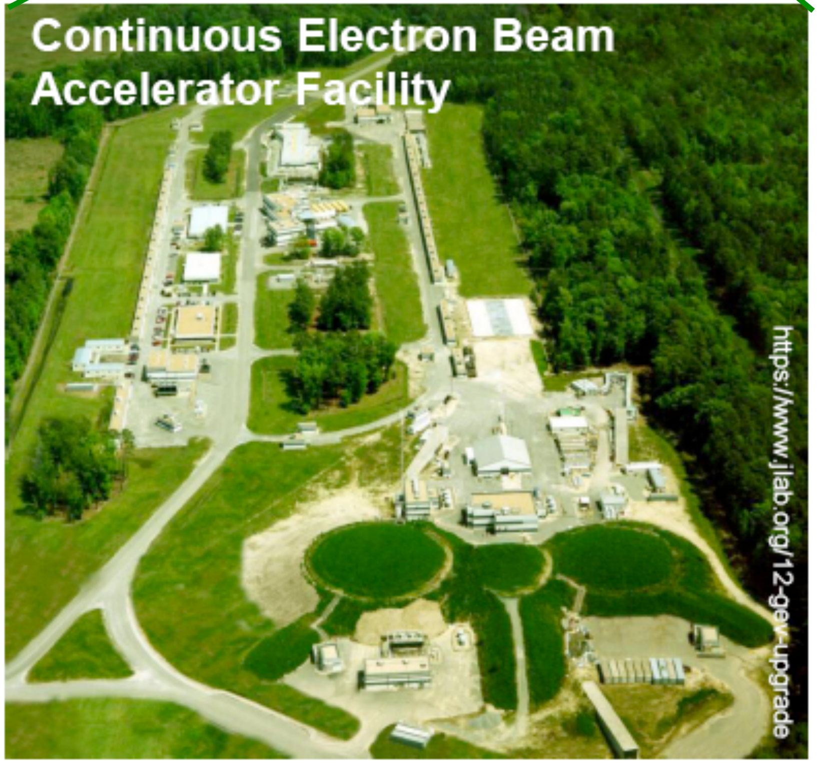
Rich and Involved phenomenology !!

CEBAF Upgrade at Jefferson Lab

Beam Energy	12 GeV
Beam current	90 μA
Beam polarization	85 %







Enhance equipment in existing halls

The CLAS12 Spectrometer

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

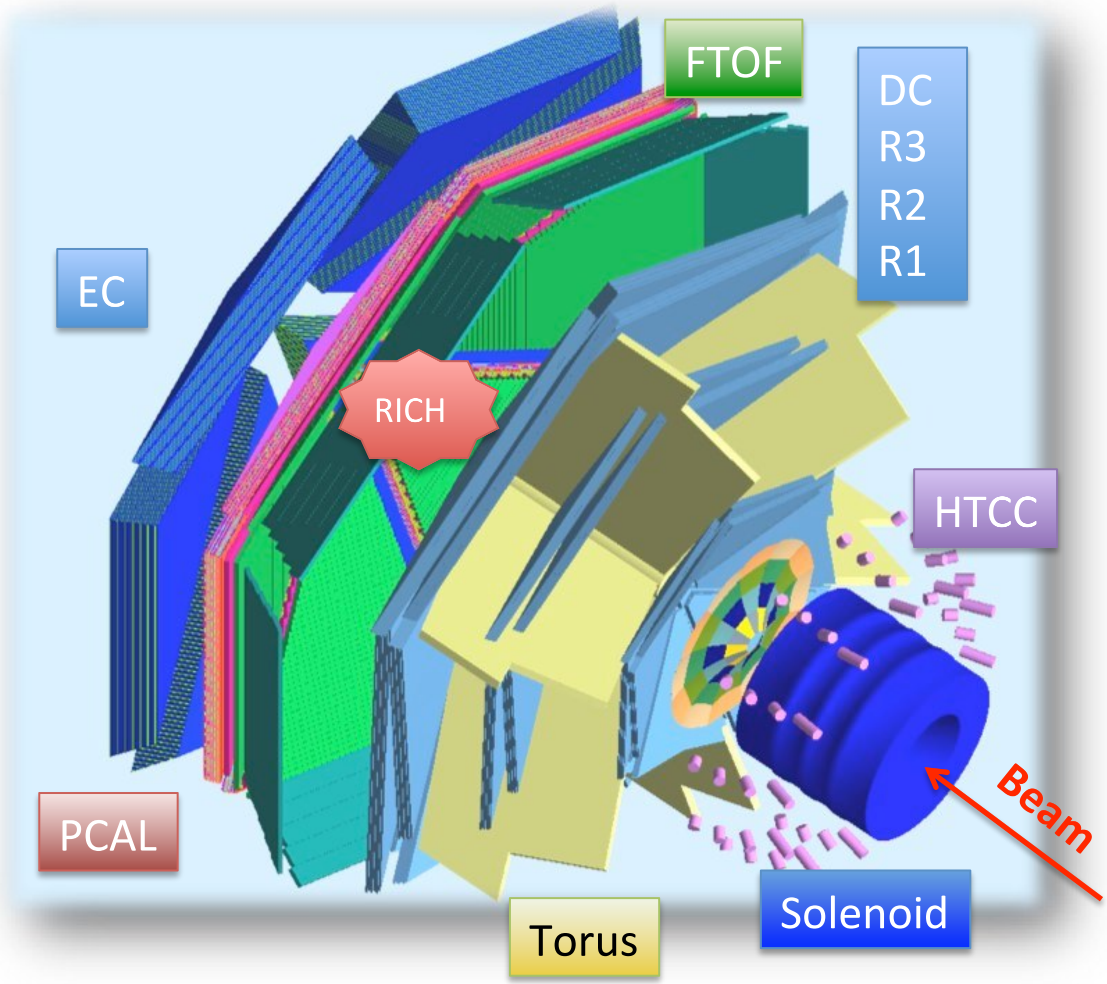
Highly polarized 12 GeV electron beam

Luminosity up to 10^{35} cm^{-2} 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.)



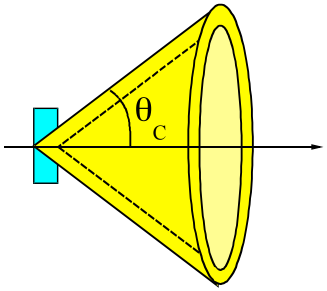
PAC30 report (2006): Measuring the kaon asymmetries is likely to be as important as pions …. The present capabilities of the present CLAS12 design are weak in this respect and should be strengthened.

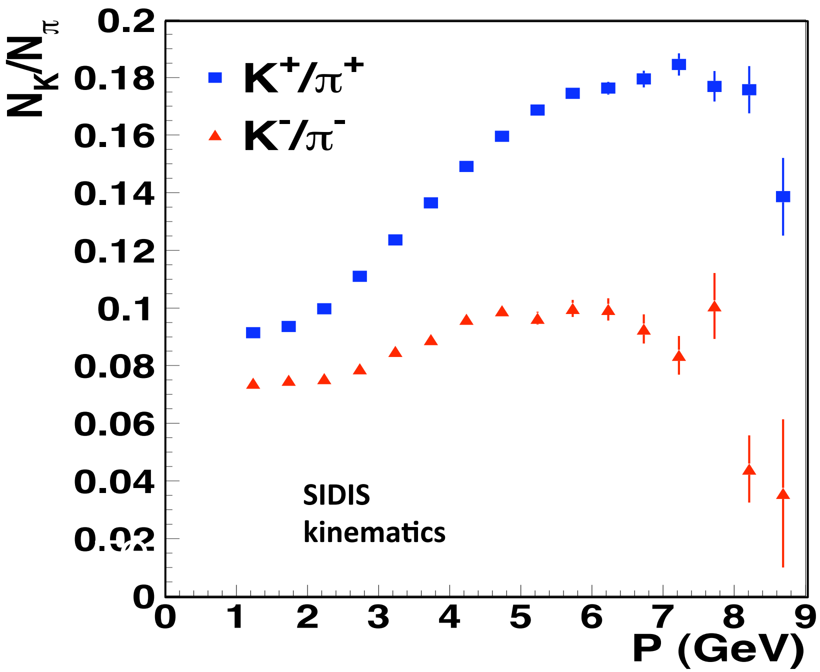
CLAS12 Momentum Range

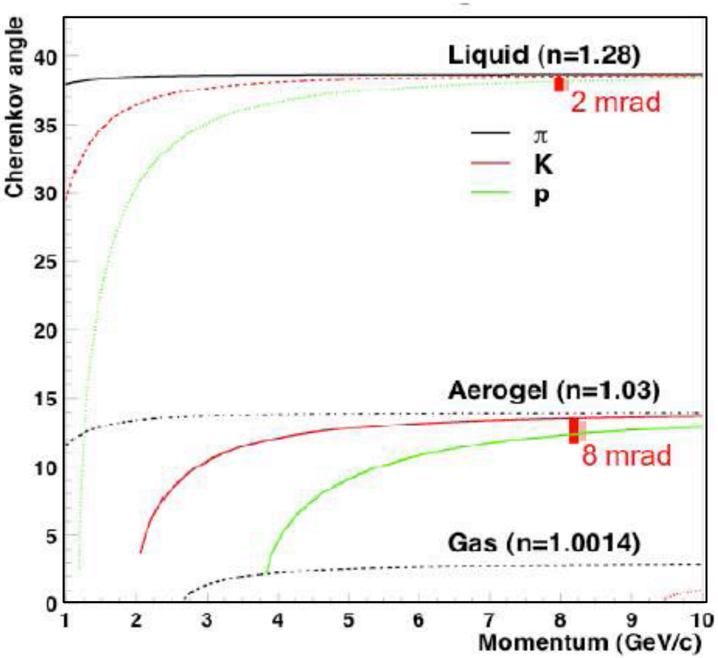
- Kaon flux 1 order of magnitude lower than π → **π rejection 1:500 required**
- **Aerogel** mandatory to separate hadrons in the 3-8 GeV/c momentum range with the required large rejection factors

  → collection of **visible Cherenkov light**

- **Use of PMTs:** challenging project, need to minimize the detector area covered with expensive photo-detectors

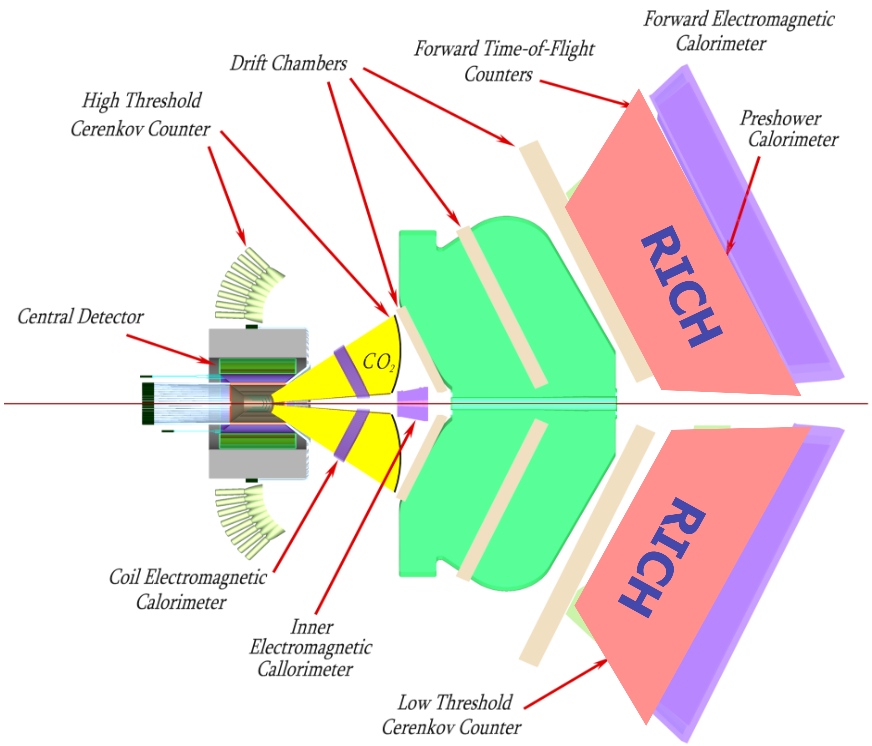






The CLAS12 RICH Project

RICH goal: π/K/p identification from 3 up to 8 GeV/c and 25 degrees
~4σ pion-kaon separation for a pion rejection factor ~ 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)

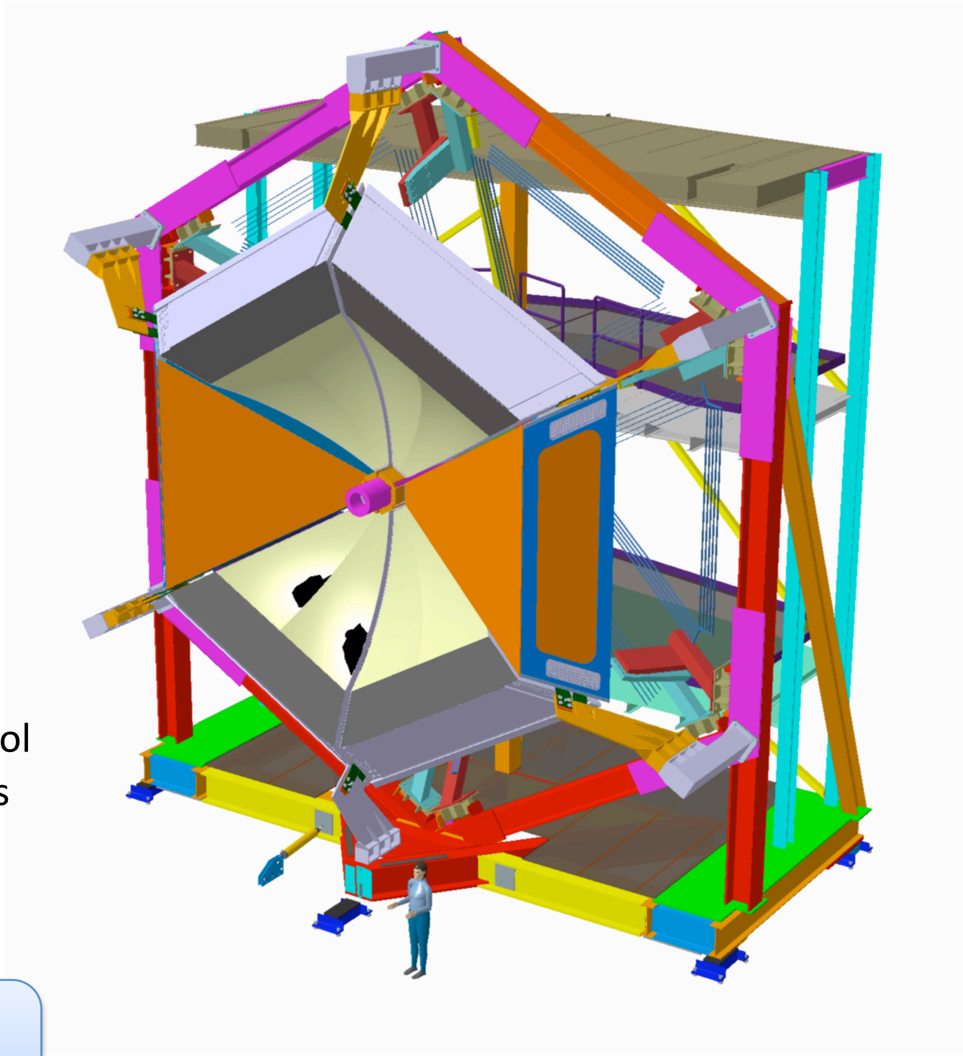
RICH Base Configuration

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)

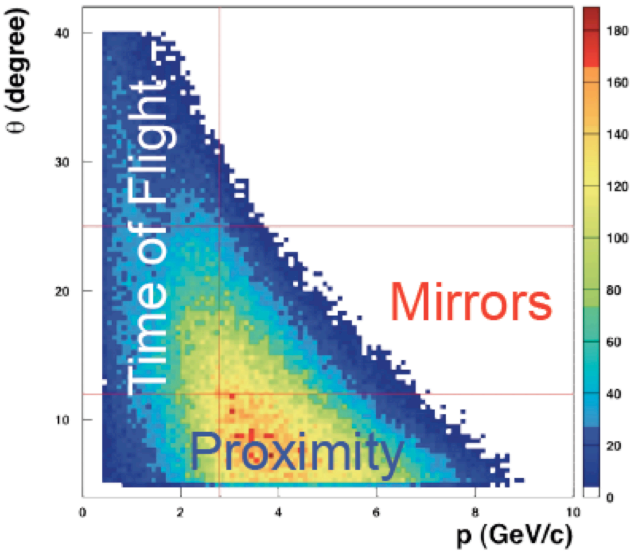
2nd sector allows:

- ✓ 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)

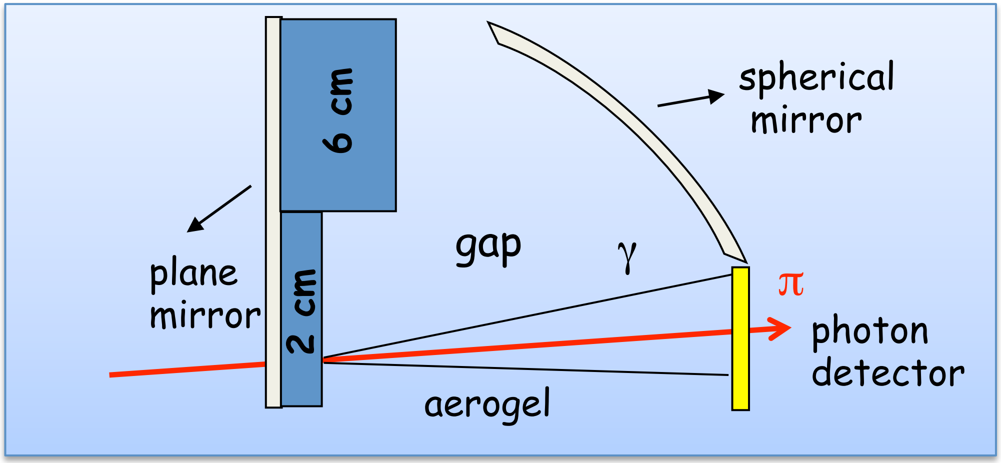


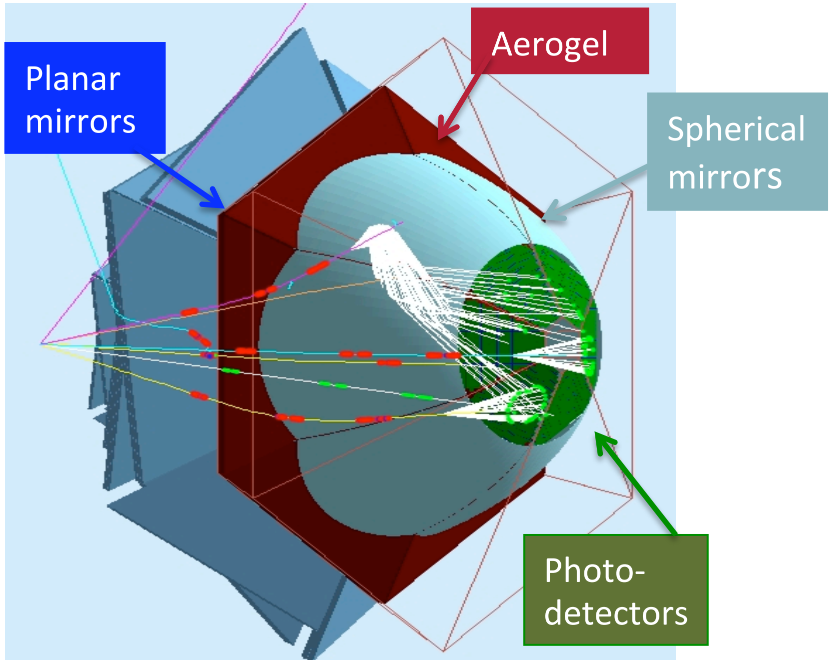
> Crucial for the study of parton dynamics related to angular momentum and spin-orbit effects with flavor sensitivity.

The Hybrid Optics Design



Direct rings/best performance for high momentum particles





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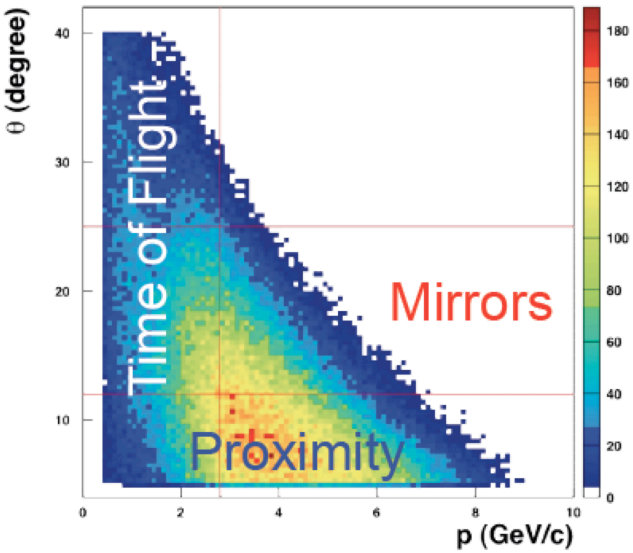

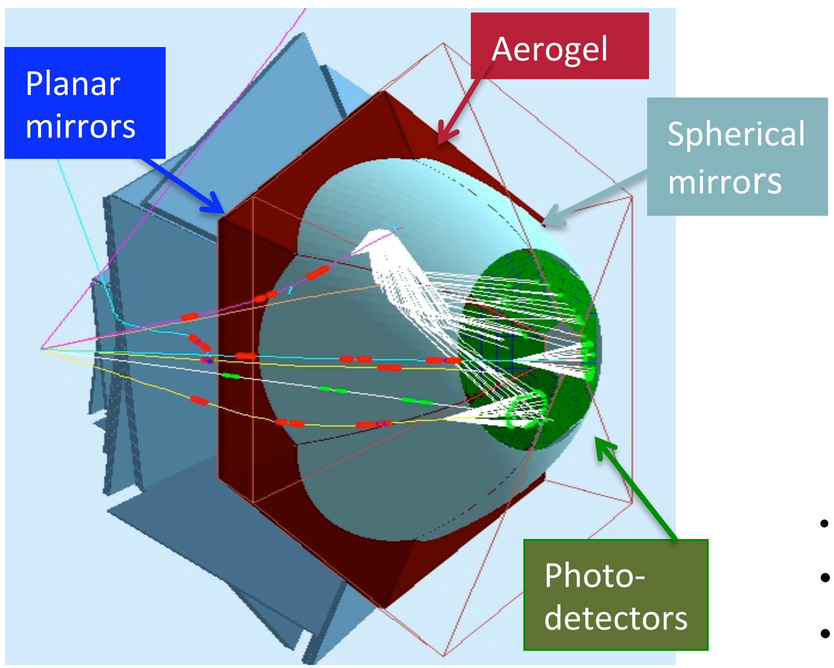

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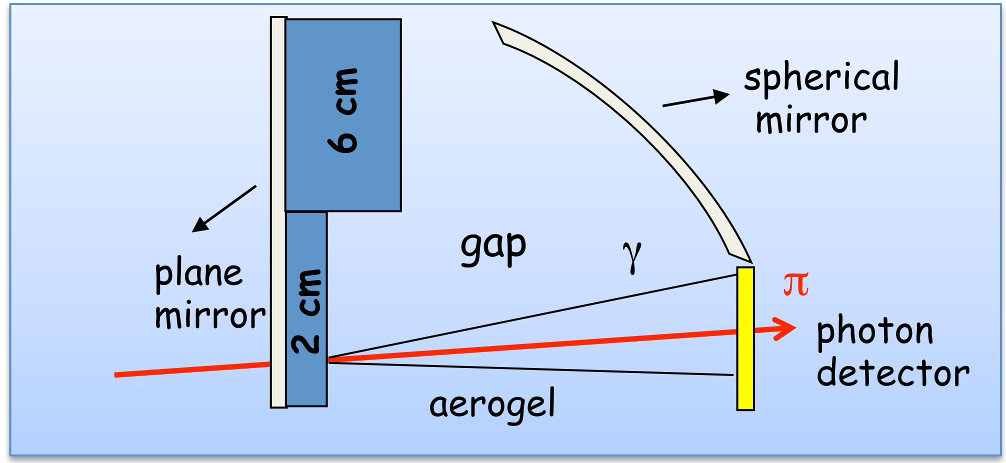
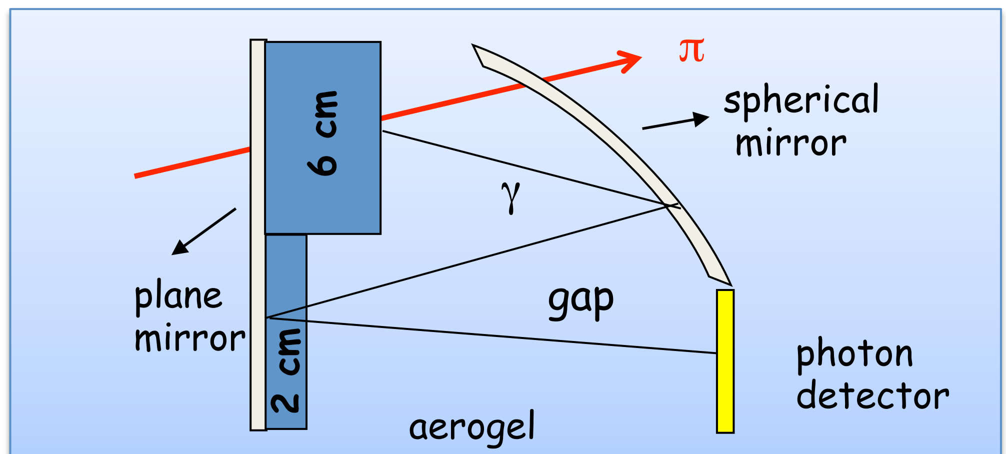
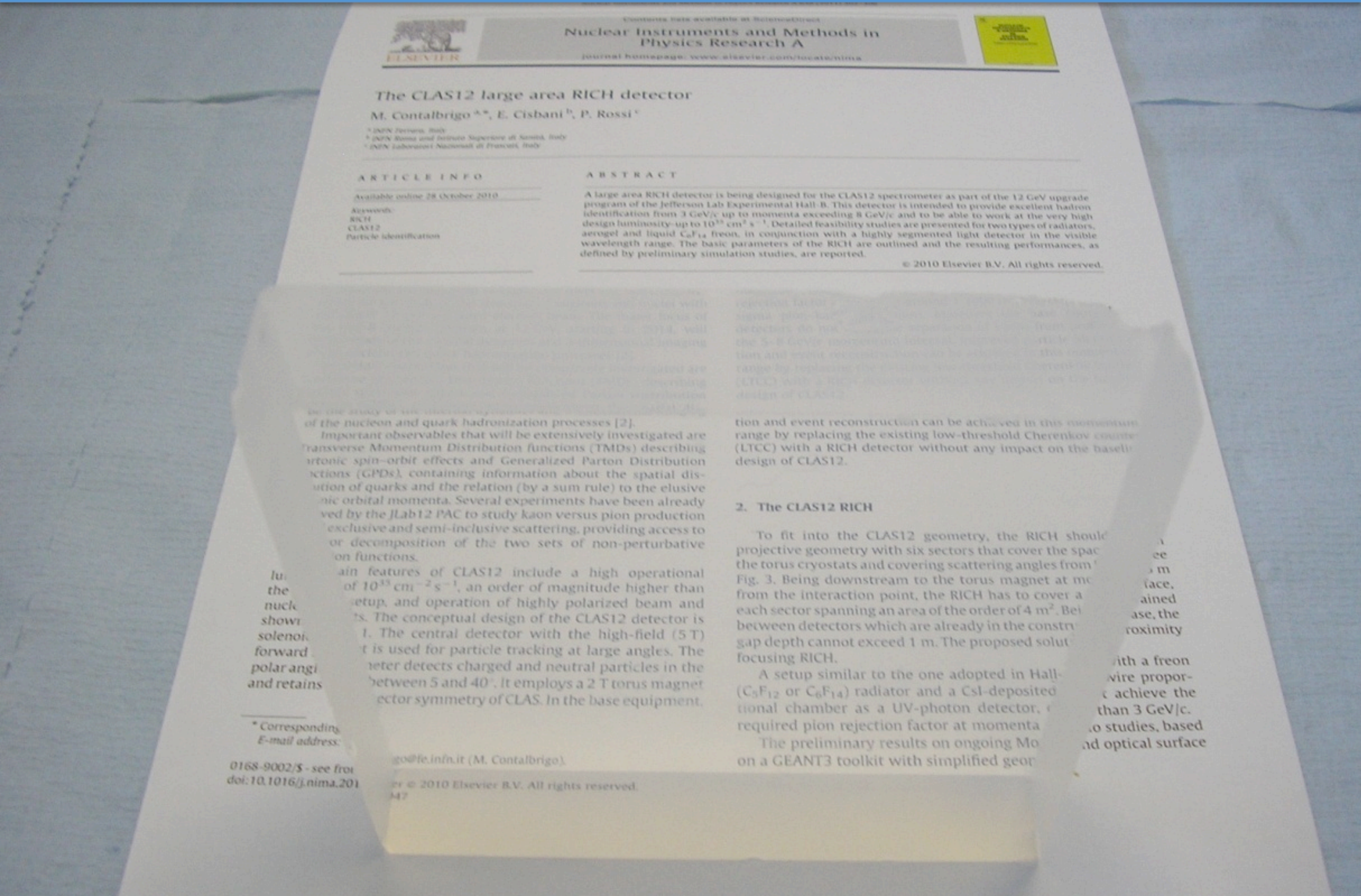


Reflected rings for less demanding low momentum particles

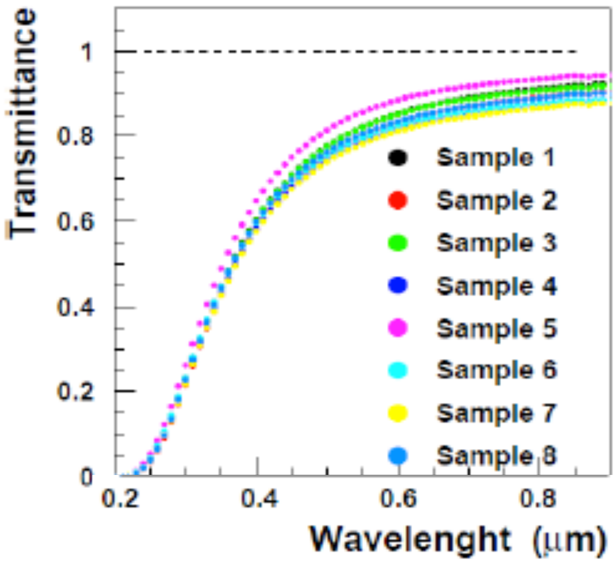


- Minimize active area (cost) to about 1 m^2
- Material budget concentrated where TOF is less effective
- Focalizing mirrors allow thick radiator for good light yield

Aerogel Radiator



Aerogel Characterization

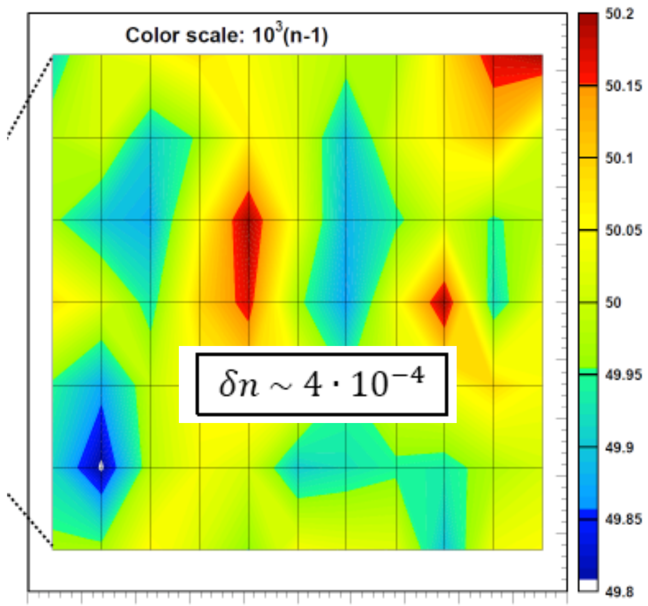


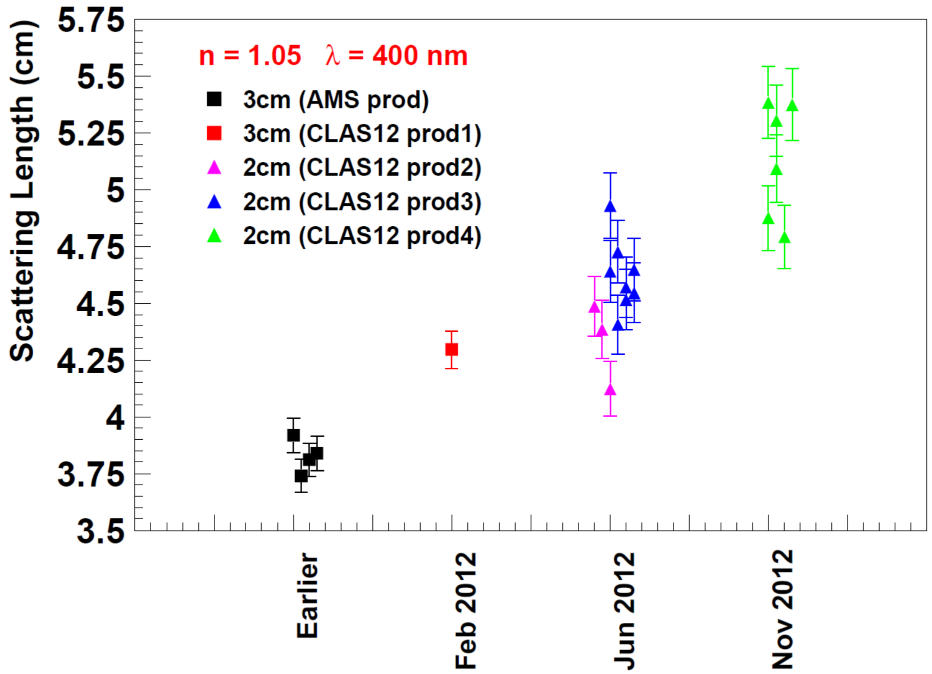
Achieved clarity for large tiles at n=1.05

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

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

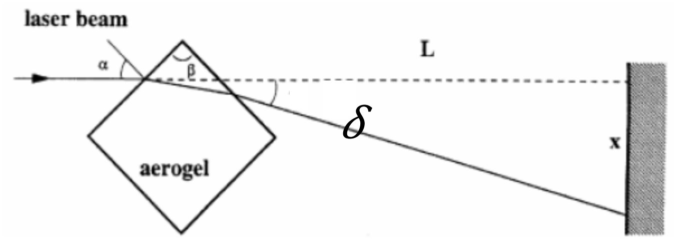
In collaboration with Budker and Boreskov Institutes of Novosibirsk

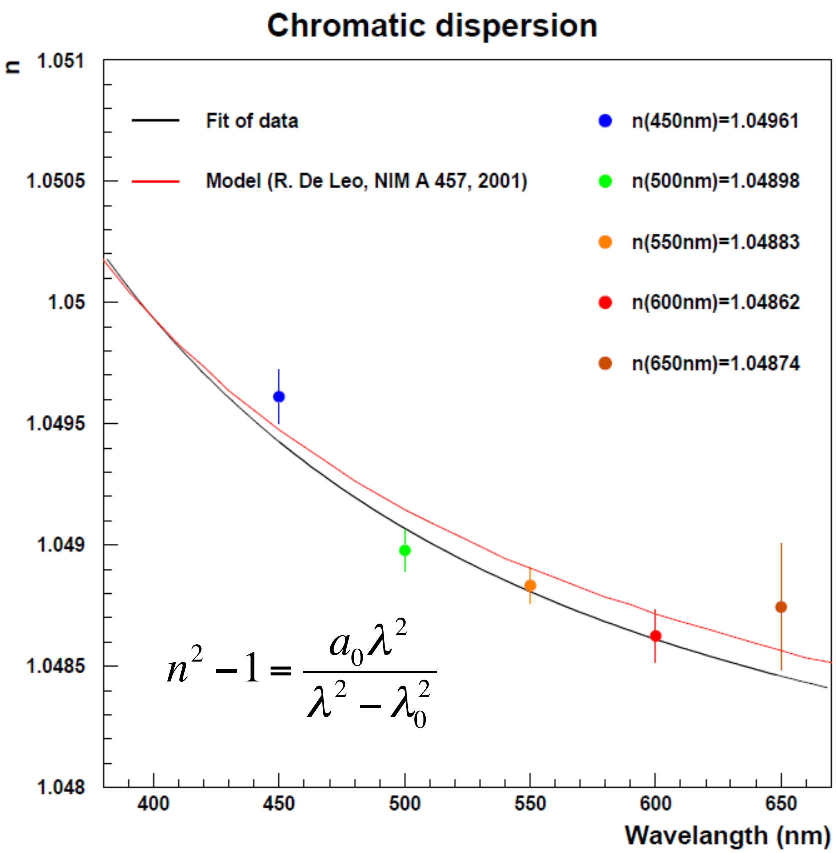




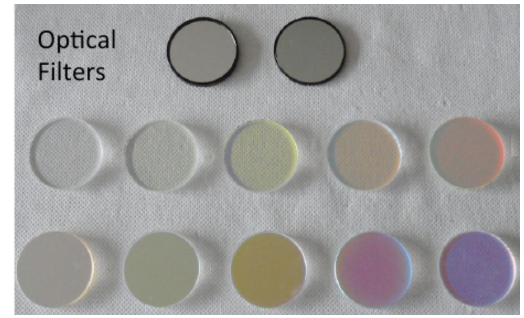
Aerogel Chromatic Dispersion

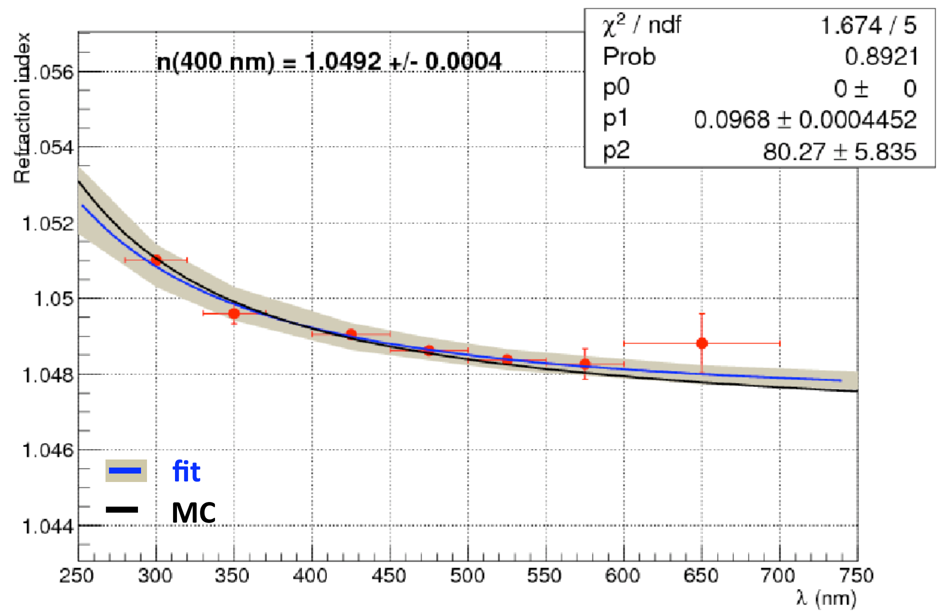
Measured by prisma method:





Measured by prototype with optical filters:





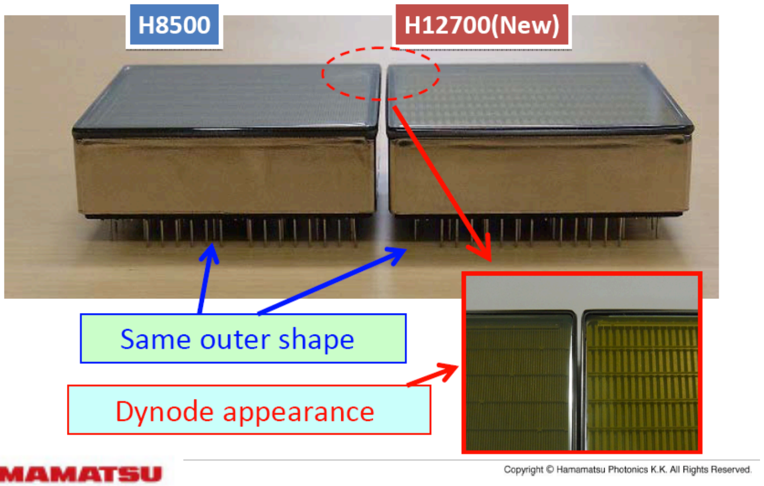
Expected value from density:

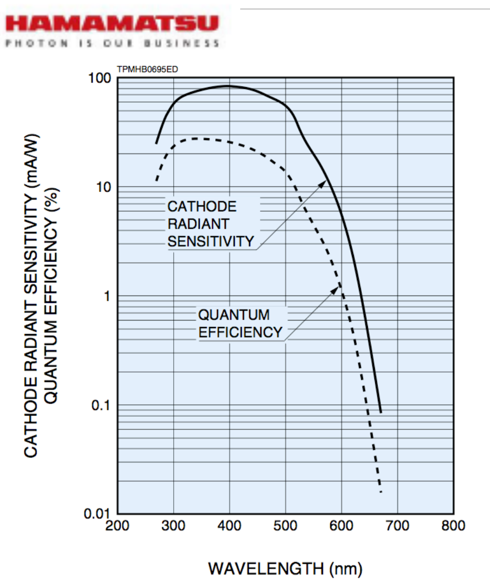
$n^2(400nm) = 1+0.438\rho$

$n(400nm) = 1.0492$

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)

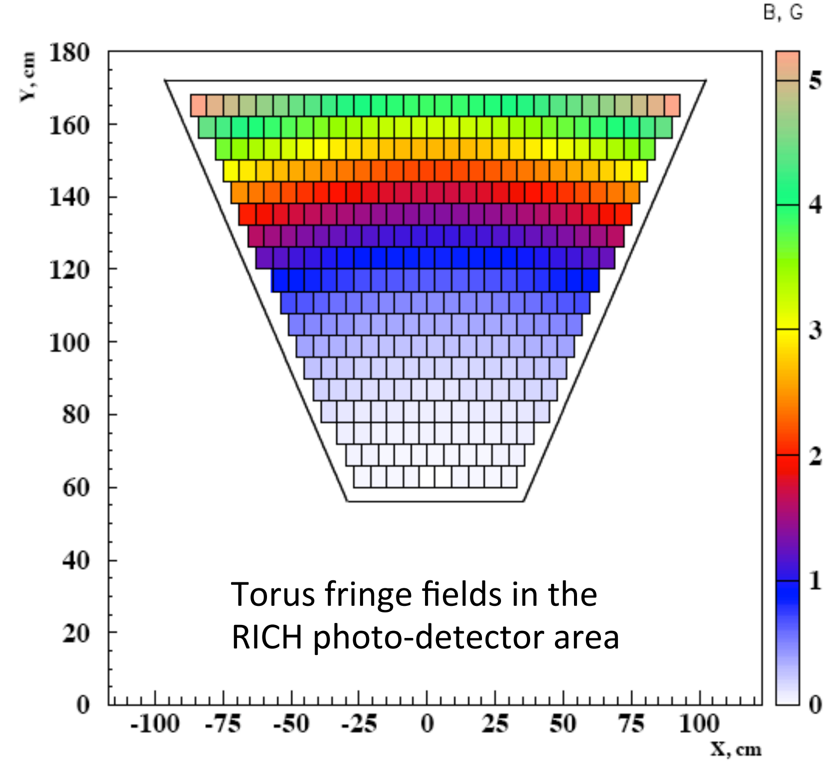




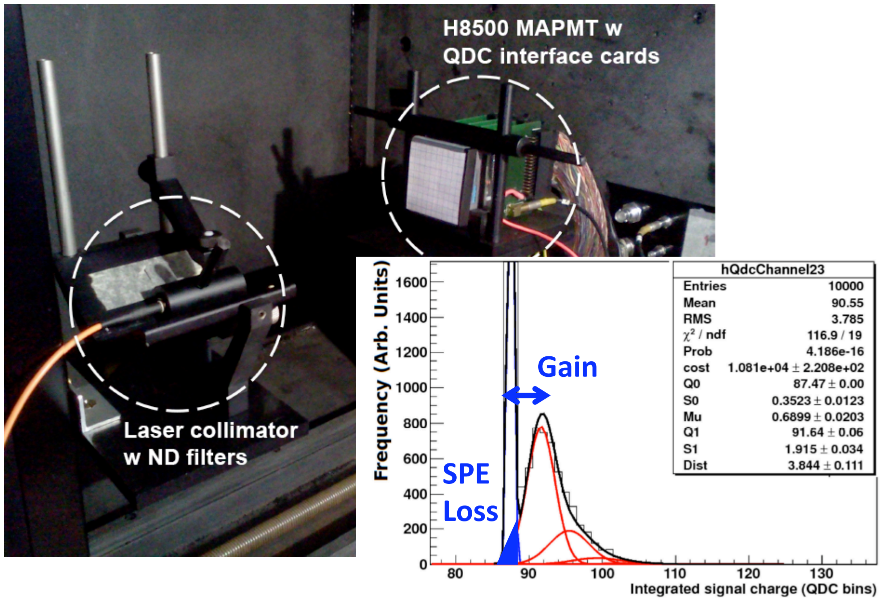
28 H8500:
- 14 with standard window (H8500C)
- 14 with UV window (H8500C-03)

2 H12700: za003 and za0014

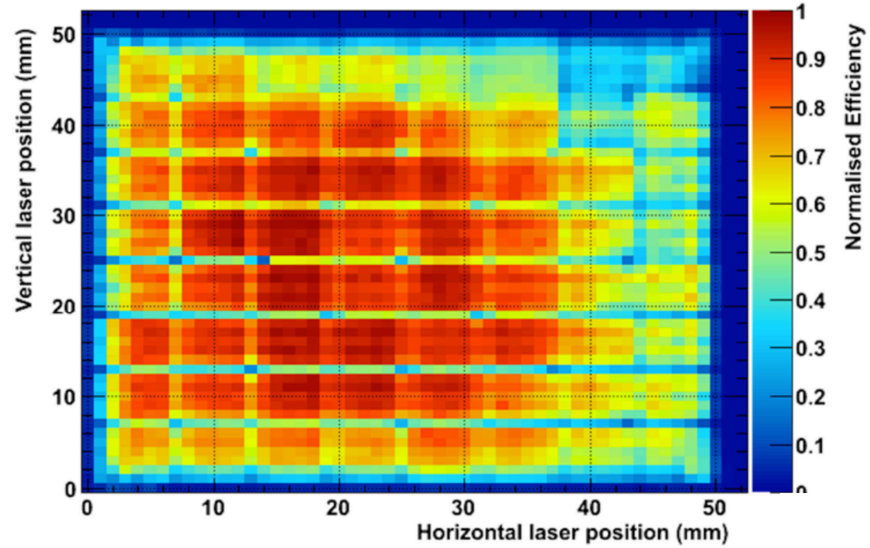
- ✓ Mature and reliable technology
- ✓ Large Area (5x5 cm^2)
- ✓ High packing density (89 %)
- ✓ 64 6x6 mm^2 pixels cost effective device
- ✓ High sensitivity on visible towards UV light
- ✓ Fast response



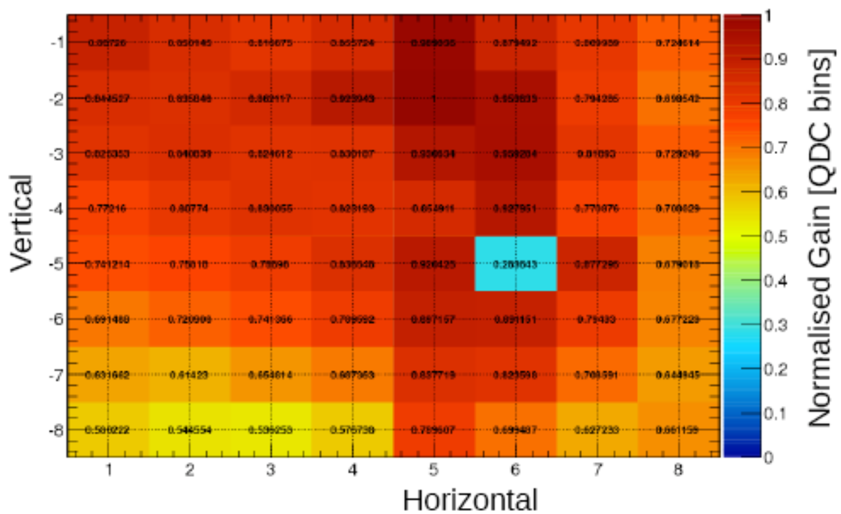
MA-PMT Gain Map



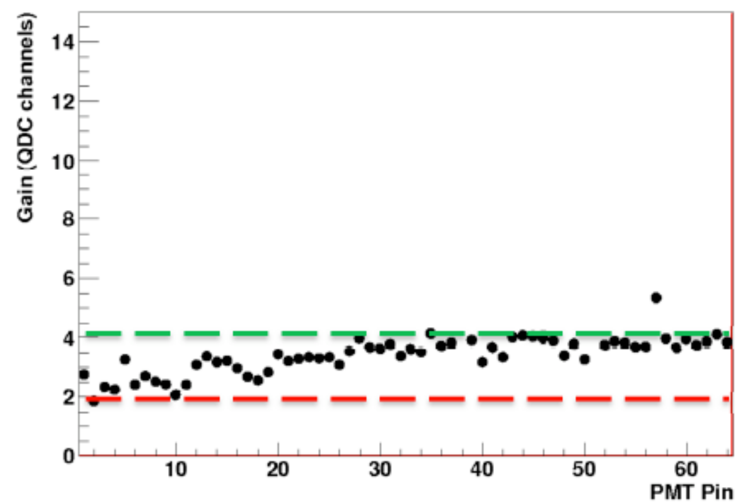
H8500



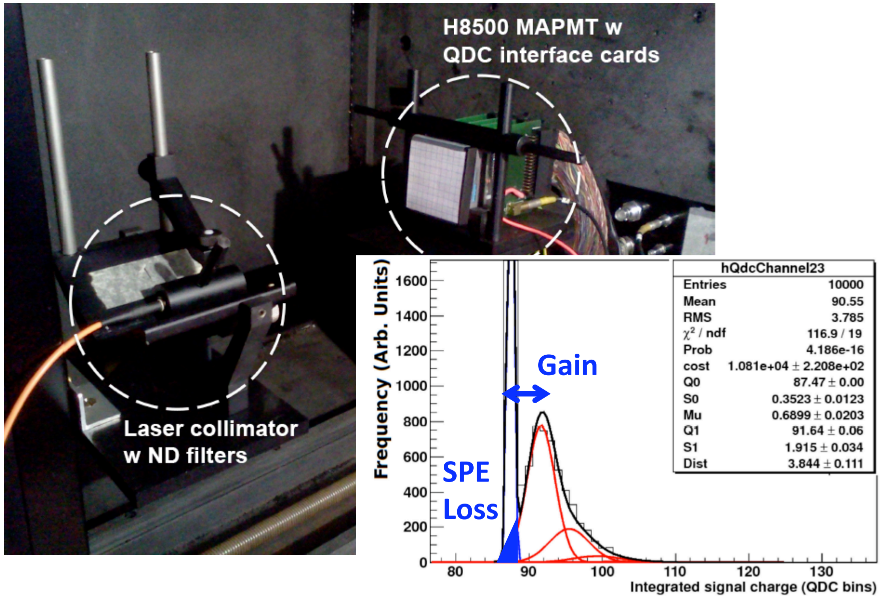
H12700 1:2 gain variation

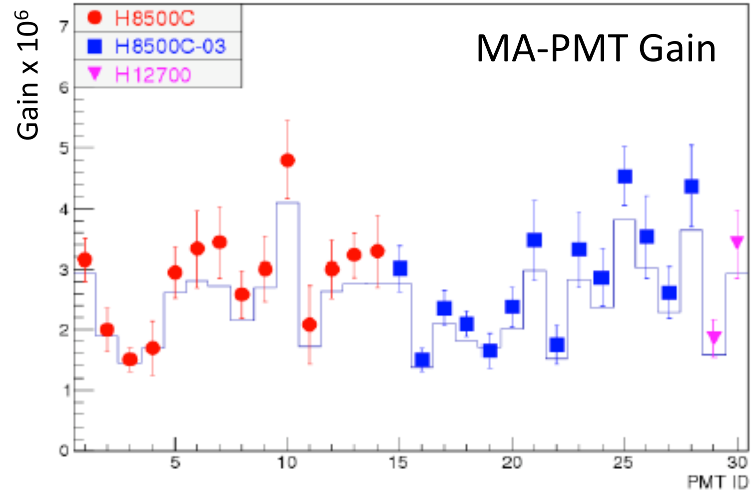


Pixel Gain: 1:2 variation can be easily compensated by the read-out electronics



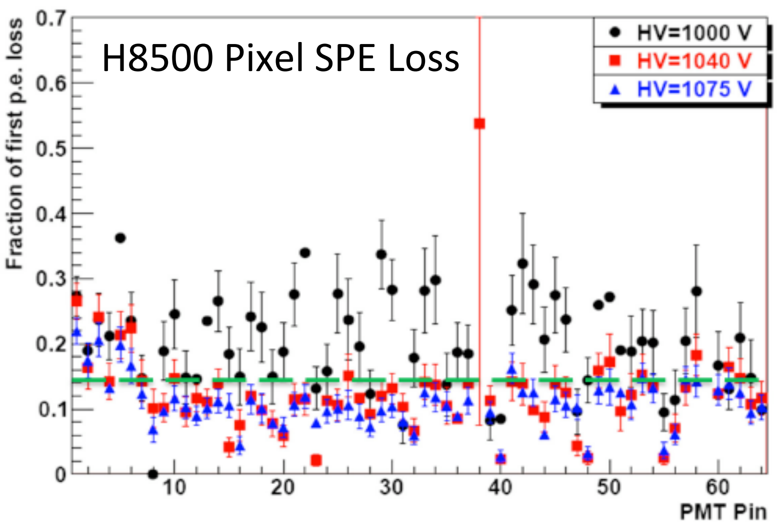
MA-PMT SPE Loss

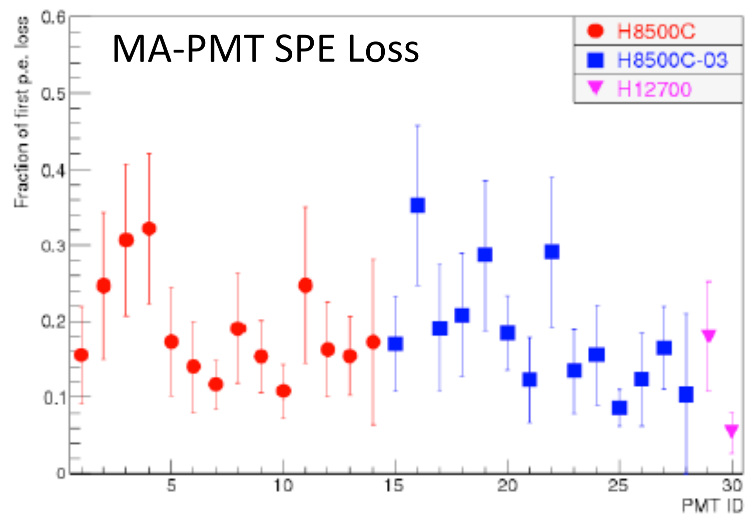




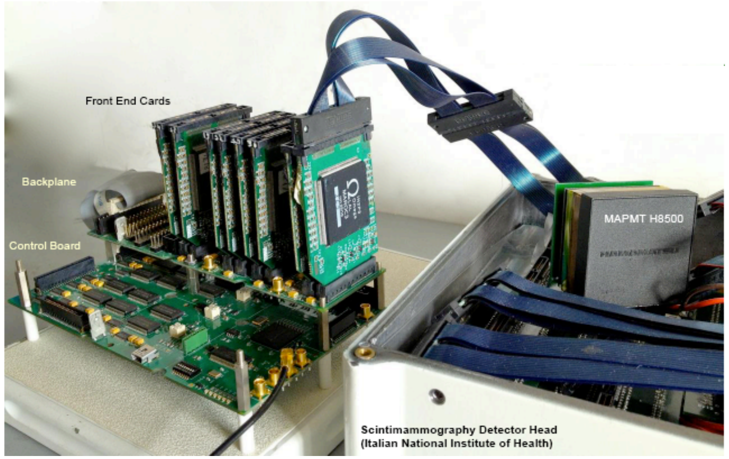
SPE loss limited to ~15% above 1040V and almost uniform over 28 MA-PMTs

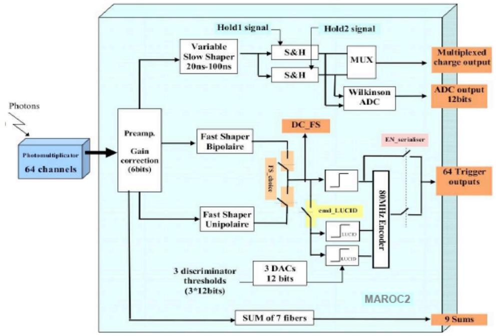
H12700 features a ~30 % better SPE resolution than H8500 at similar gain

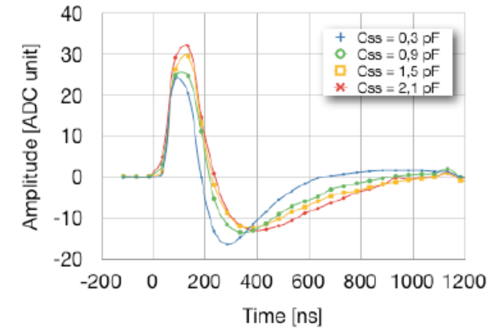


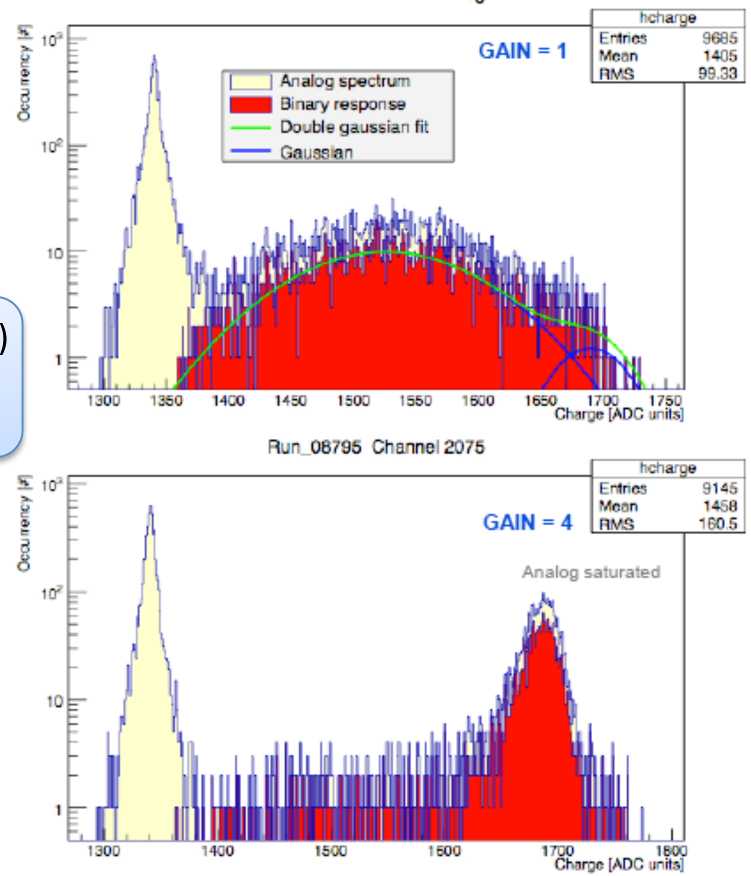


MAROC3 Front-End Electronics

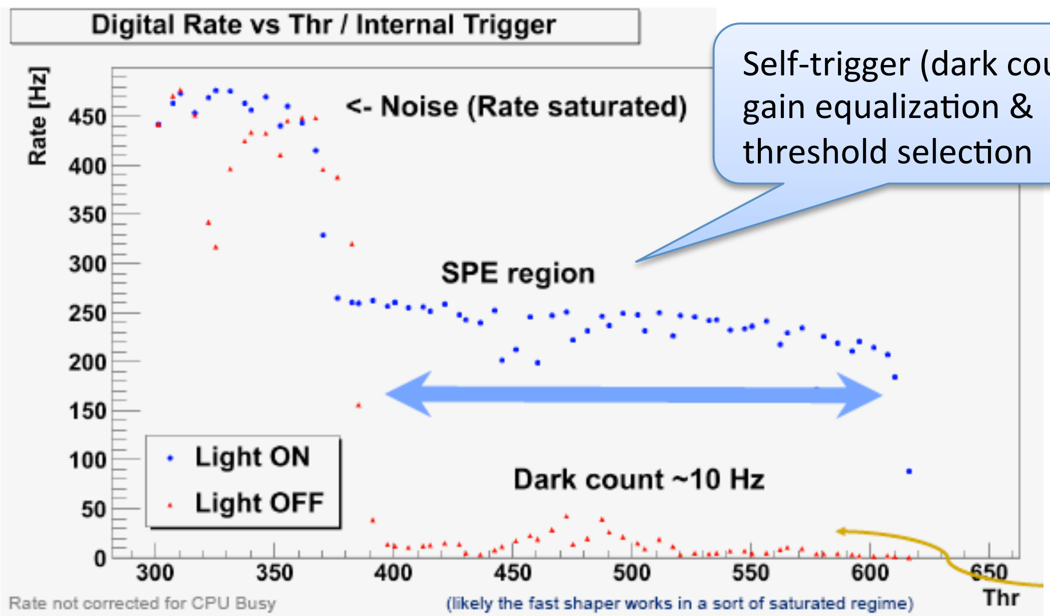






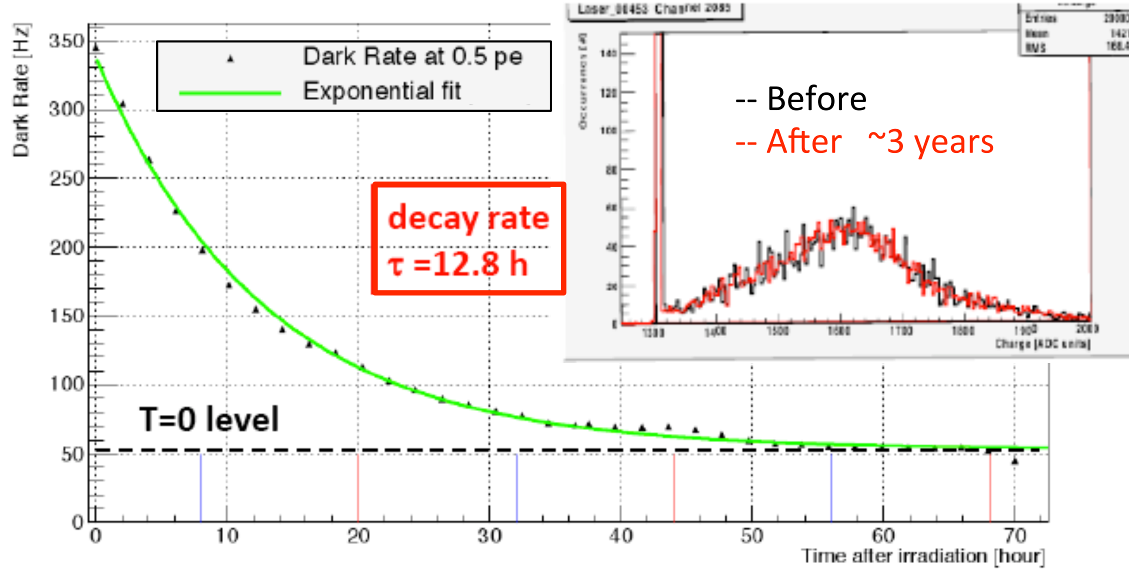


Multiplexed analog output
64 binary outputs with time jitter ~300 ps



Self-trigger (dark counts) gain equalization & threshold selection

Neutron Irradiation Tests



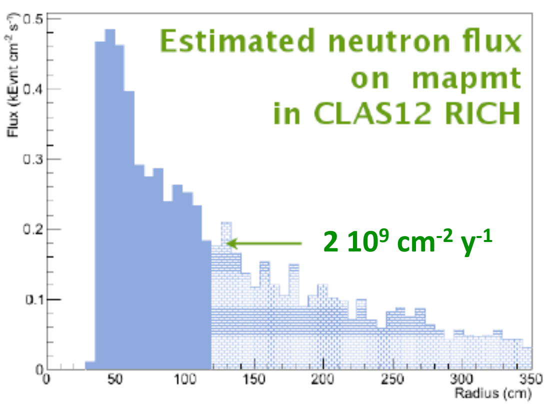
Neutrons produced isotropically through

d(230keV) t → n α

α particles measured to monitor the intensity

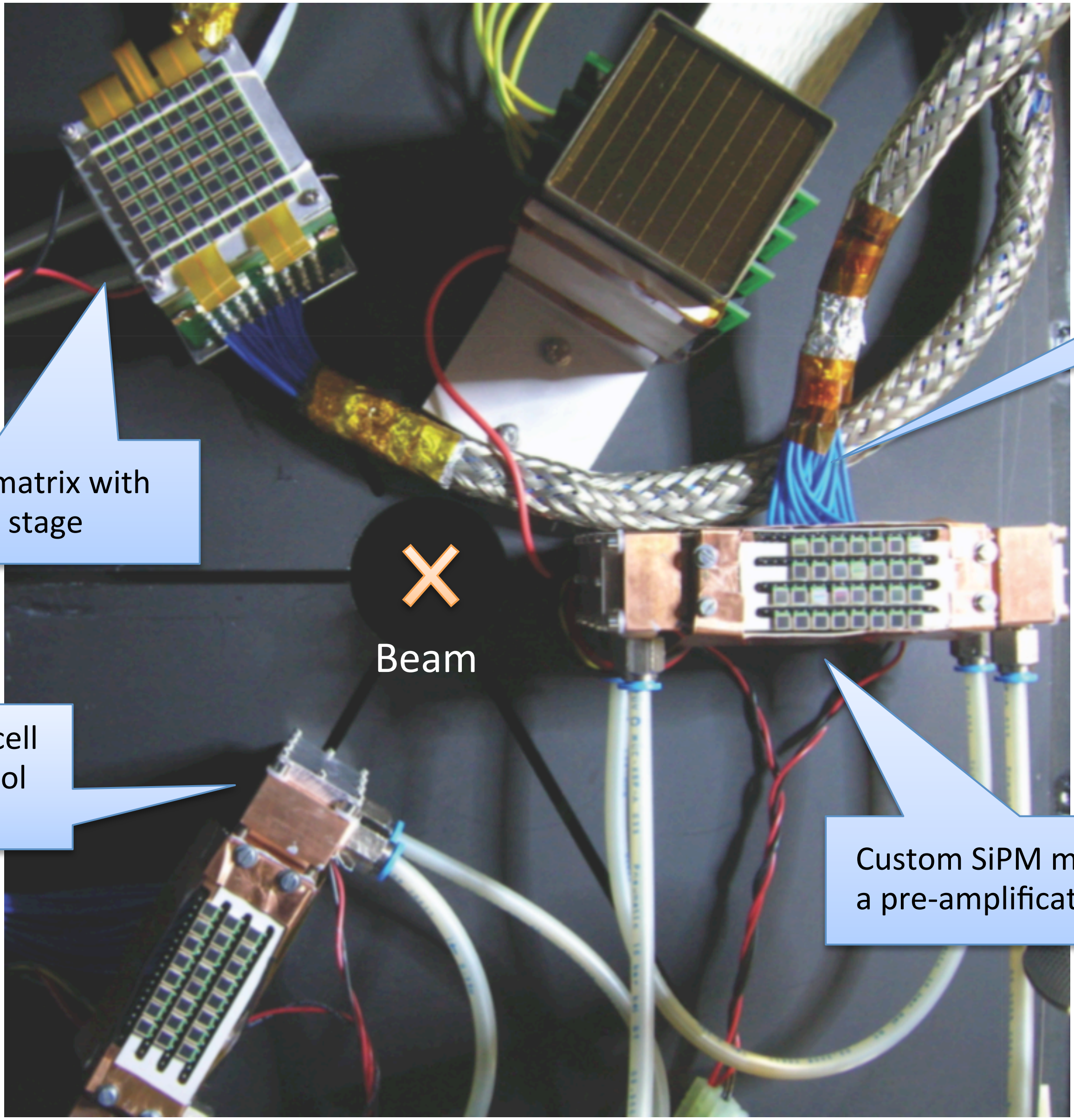
- max flux 10^{11} s^{-1} in 4π
- max neutron energy 14.6 MeV

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



	Name	Irrad.	spread	Average	
UV	L14U2	Yes	0.3%	92.13 ± 0.12	no effect
	L14U	No	0.2%	92.39 ± 0.07	
non-UV	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



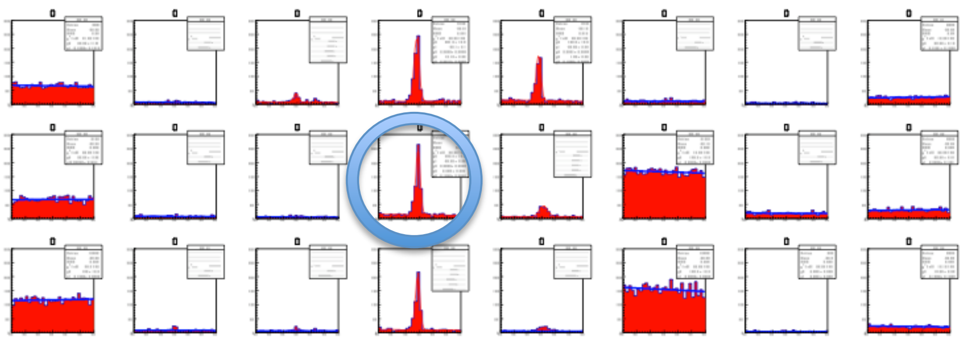
Commercial SiPM matrix with a pre-amplification stage

1.5 m coaxial cables to the electronics

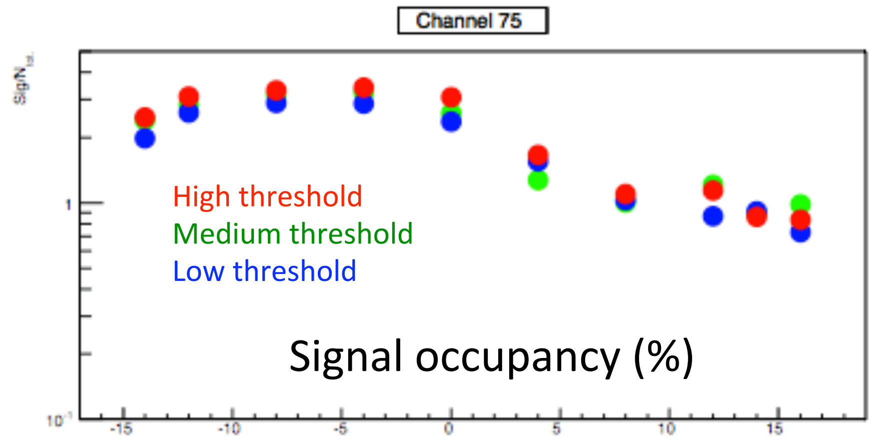
Water-cooled Peltier cell for temperature control [-25 : +25 Celsius]

Custom SiPM matrices with a pre-amplification stage

The Custom SiPM Matrix @ +25°

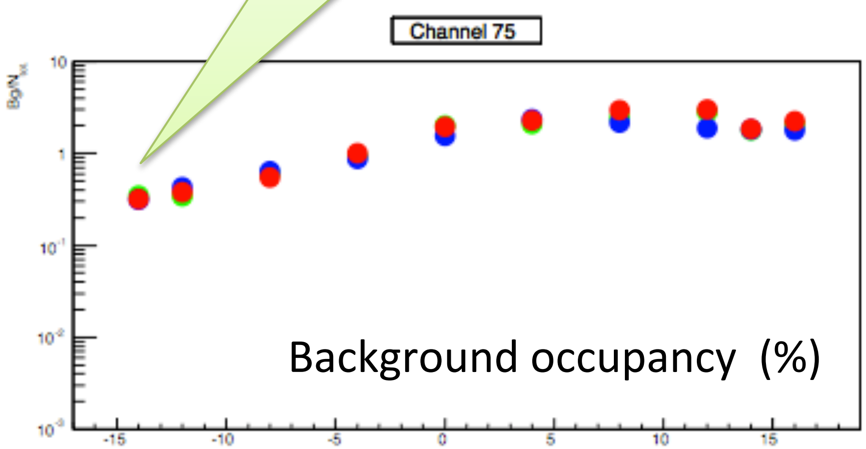


Equalization of the single SiPM is critical

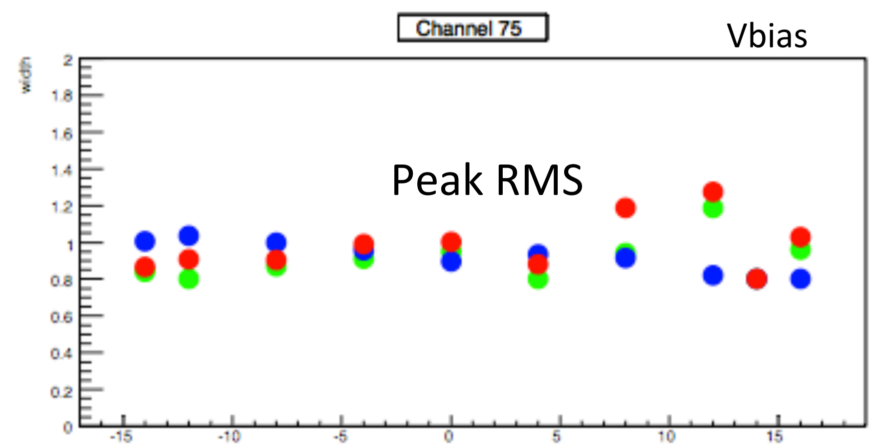


10⁻³ level is challenging

Vbias



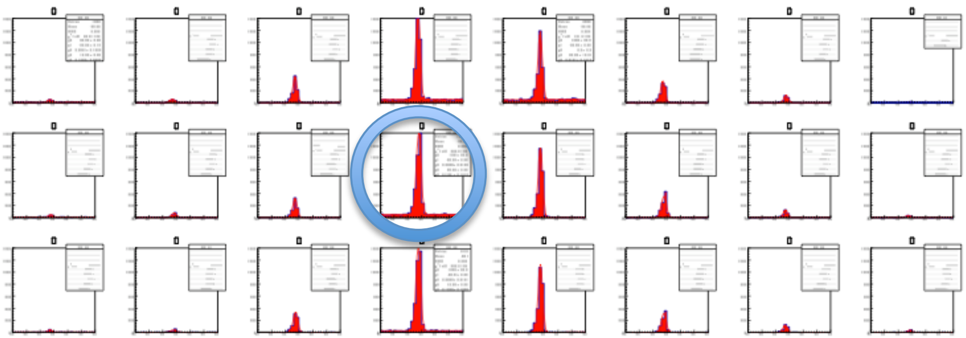
Vbias

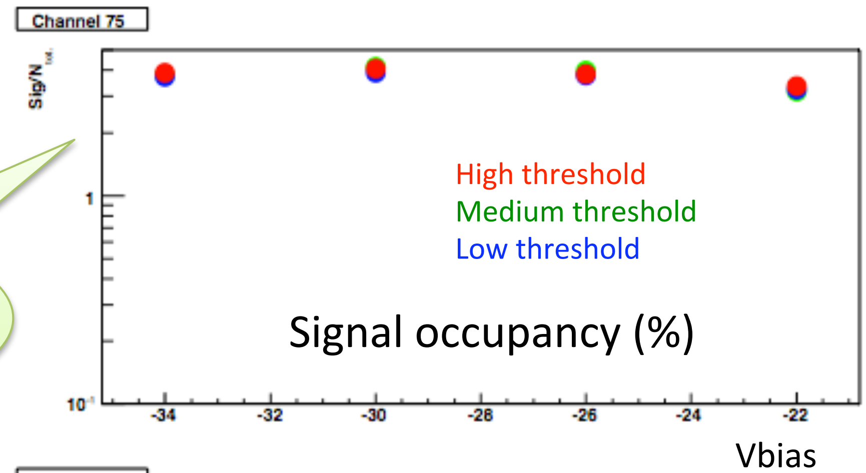


Vbias

The Custom SiPM Matrix@-25°

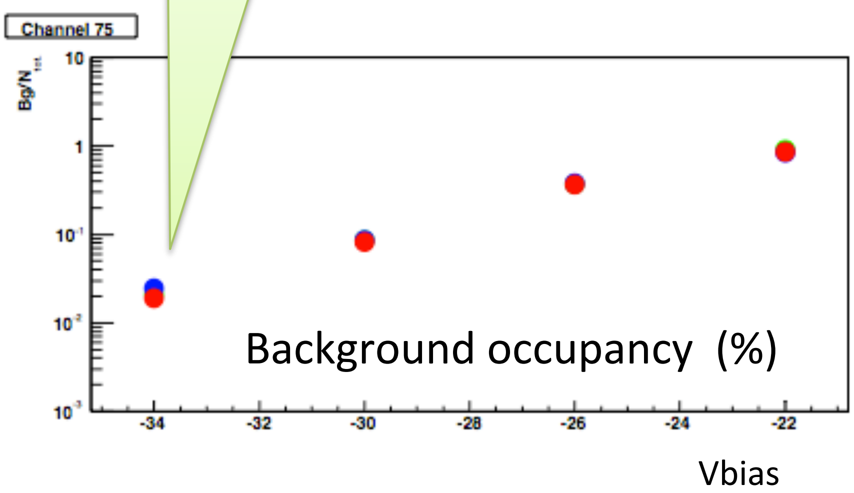
For a 12 cm radius Cherenkov cone and a 3 mm SiPM pixel, an occupancy of 4 % corresponds to about 24 p.e.

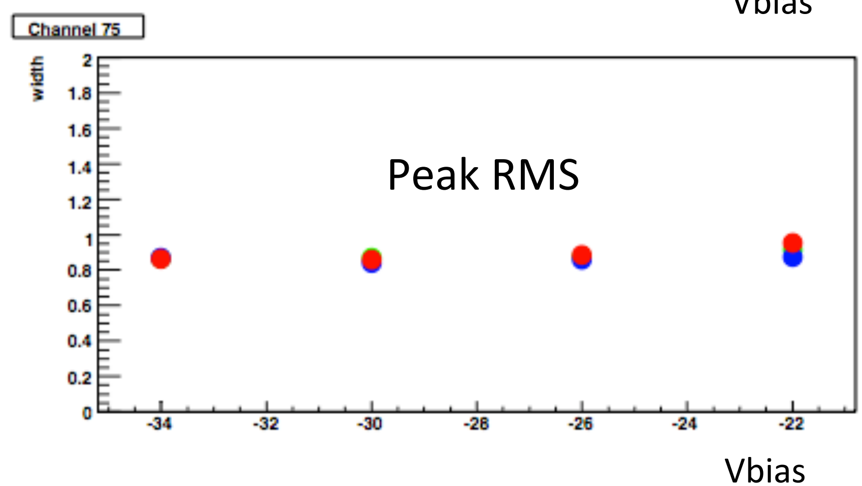




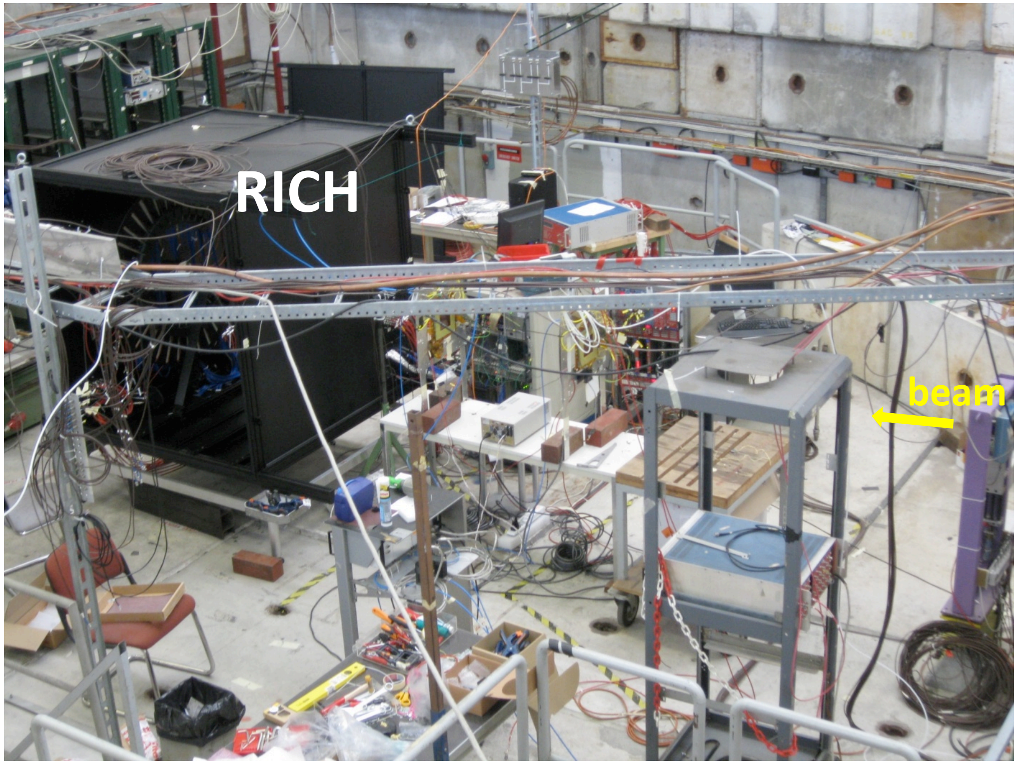
In a +/- 3 ns window
Comparable with H8500

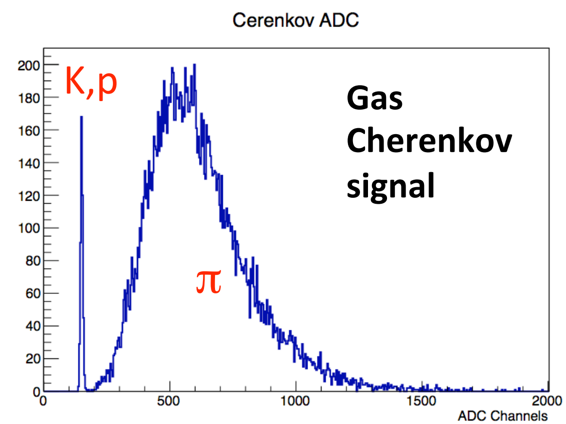
Largely insensitivity to Vbias and discriminator threshold

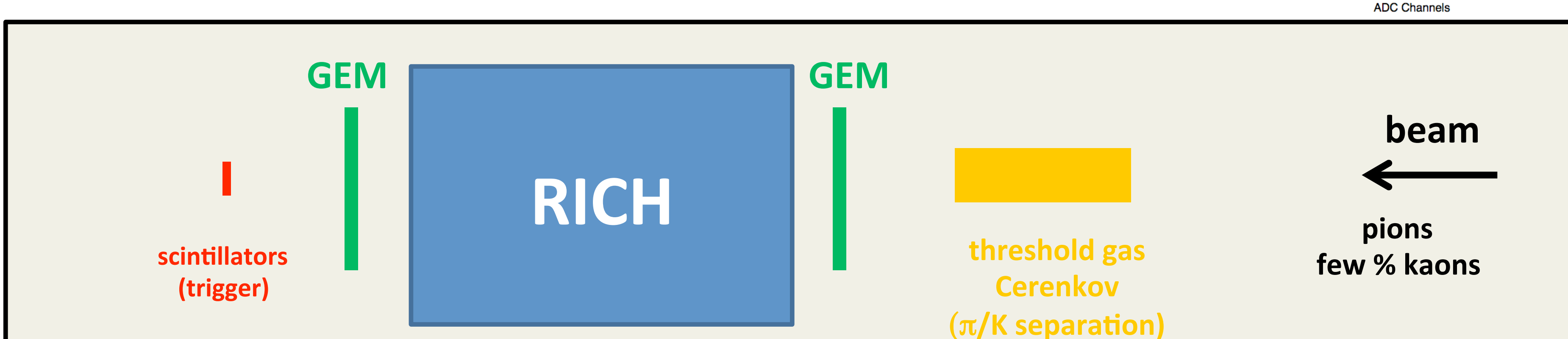




RHIC Prototype at CERN-T9







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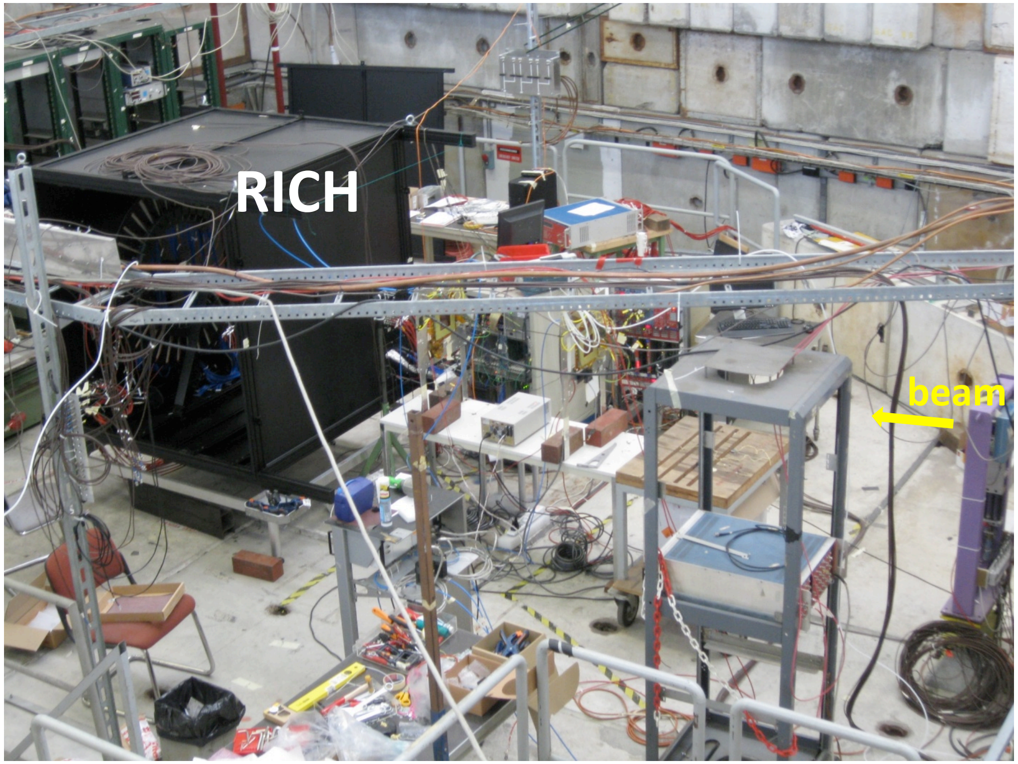
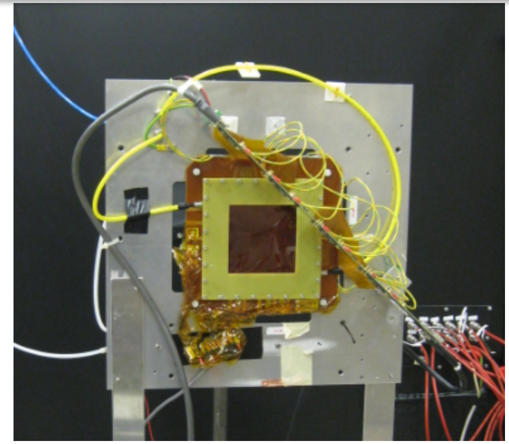
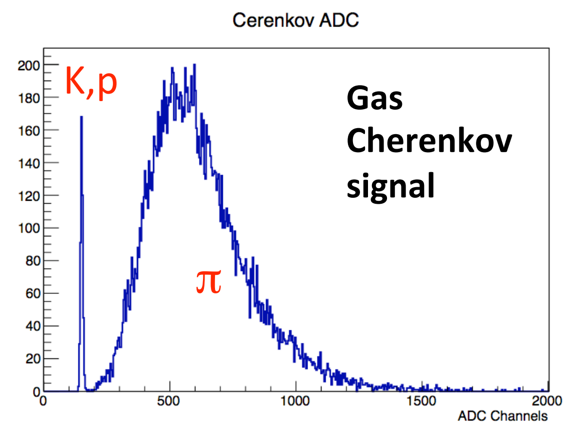
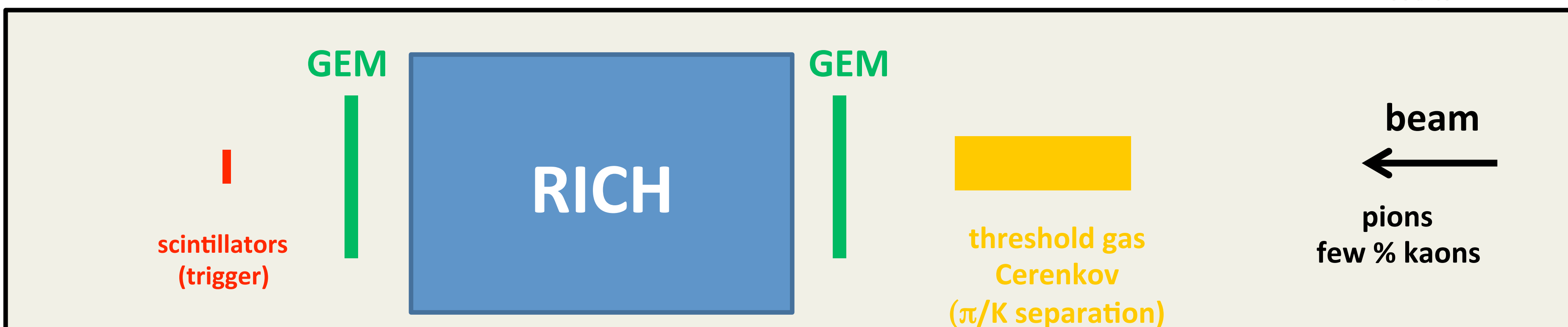


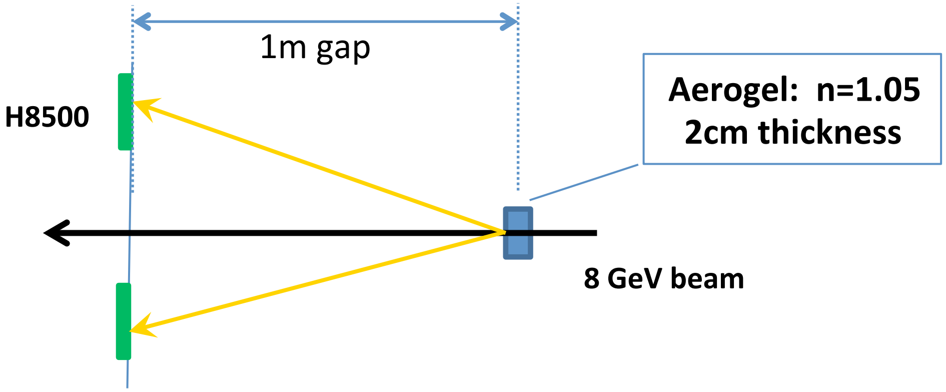


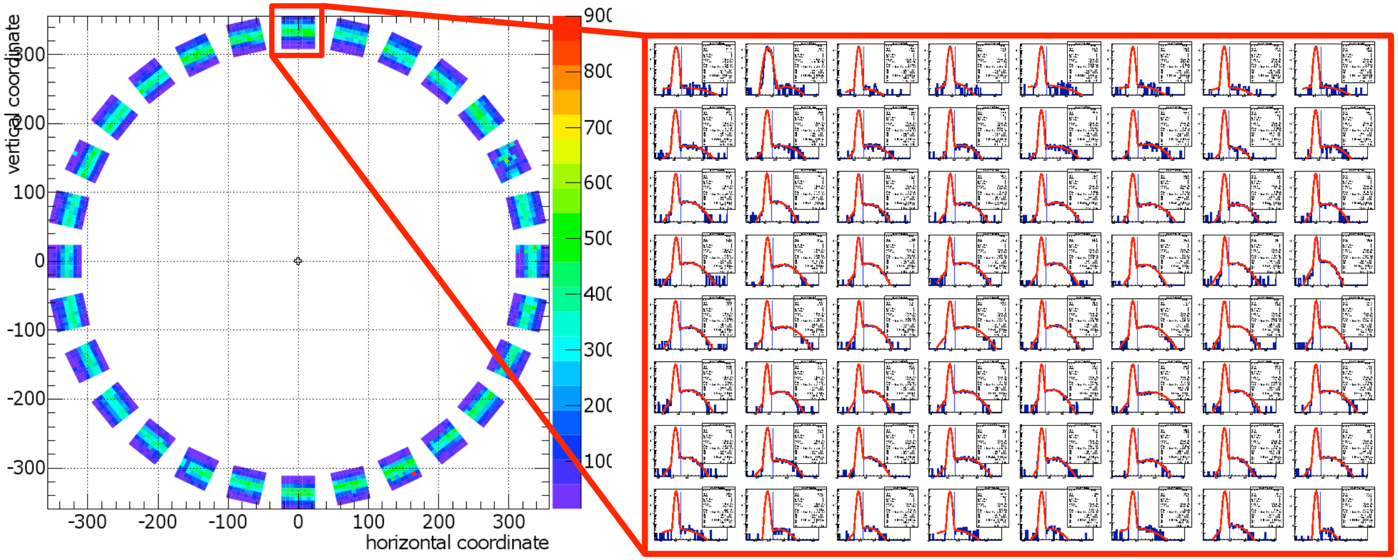
GEM chamber layout



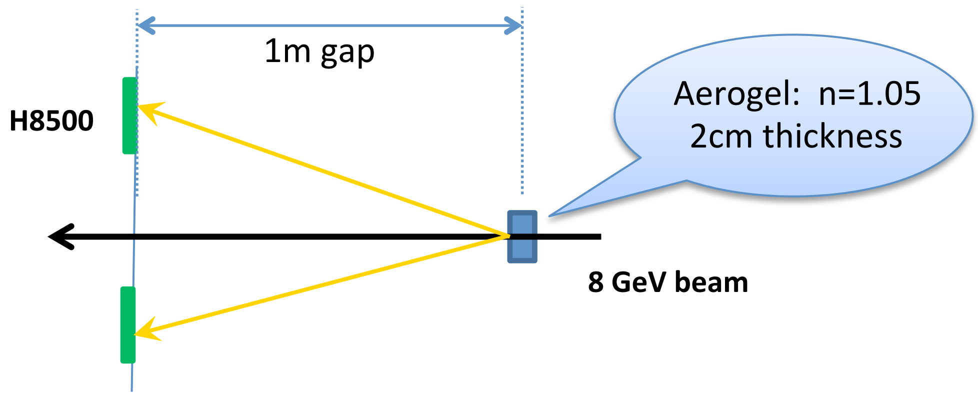


RHIC Prototype: Direct Light Case

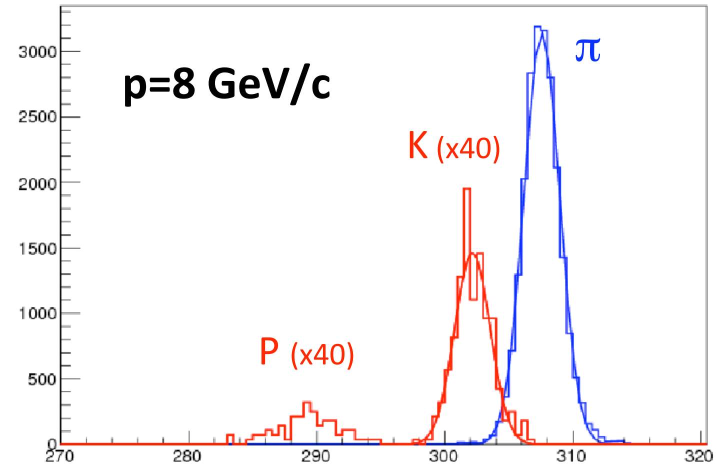


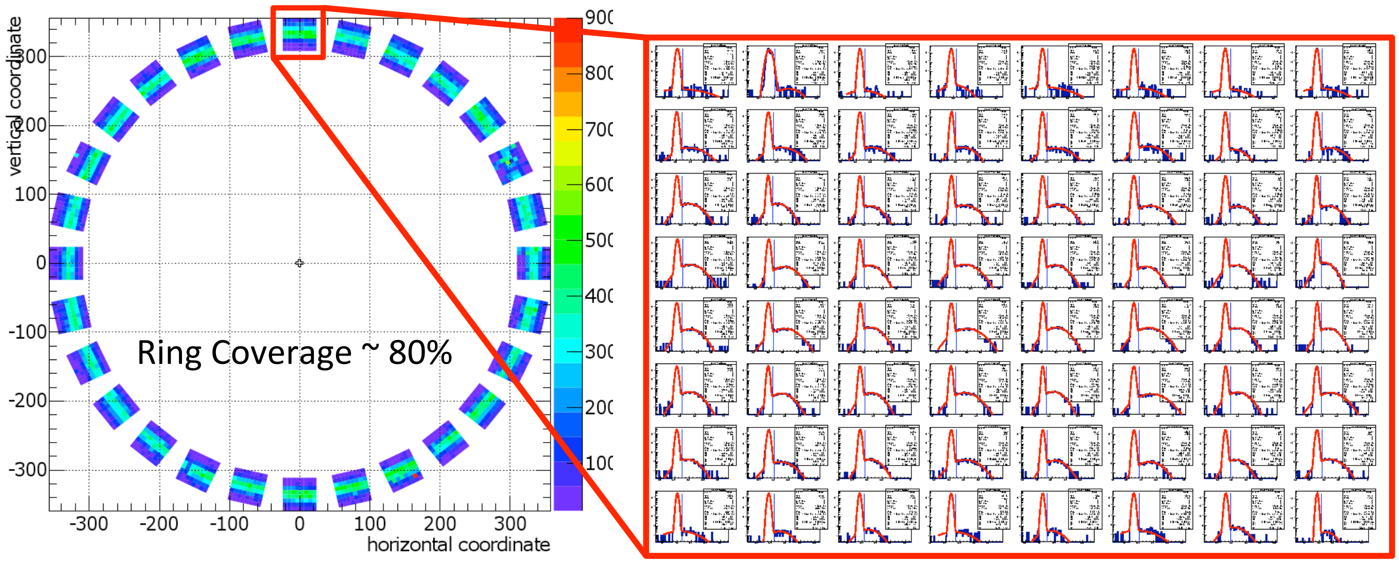


RHIC Prototype: Direct Light Case

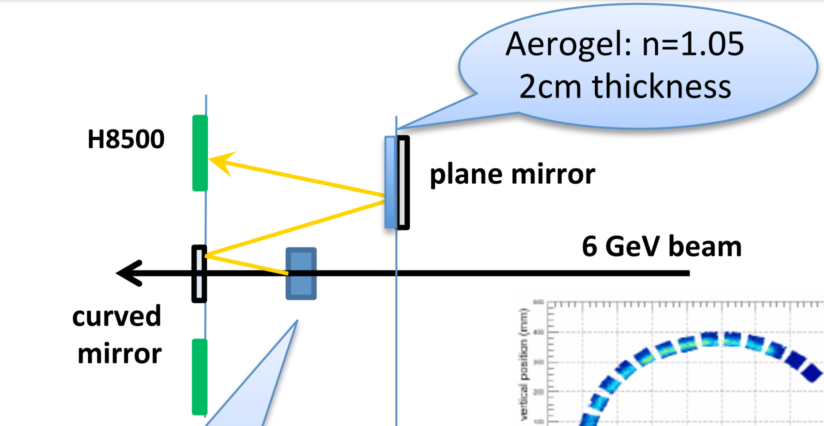


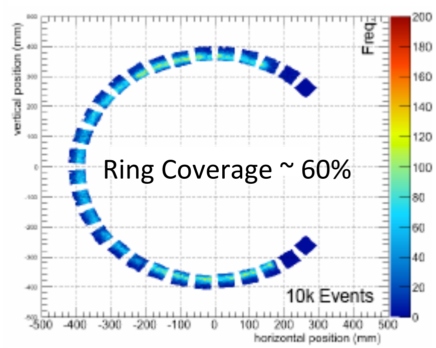
Clear hadron separation up to the CLAS12 maximum momentum

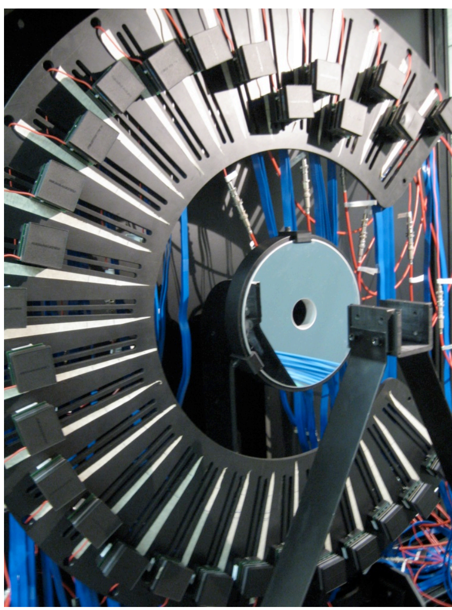


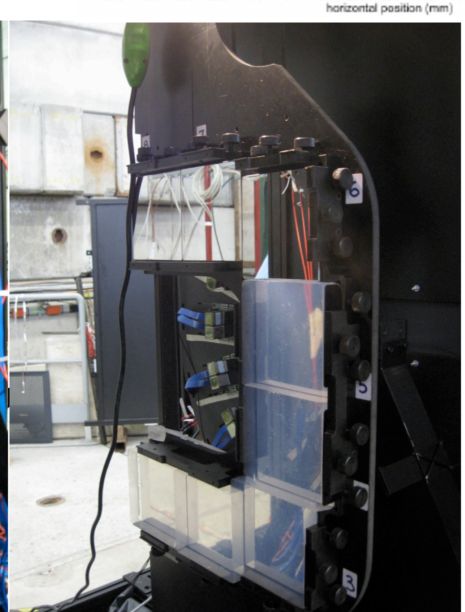


RHIC Prototype: Reflected Light Case

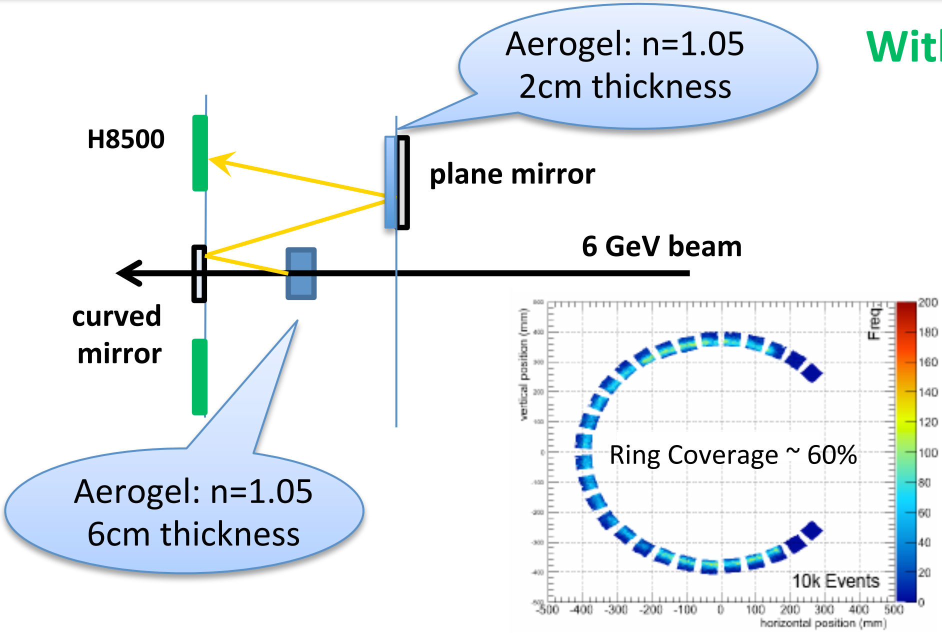




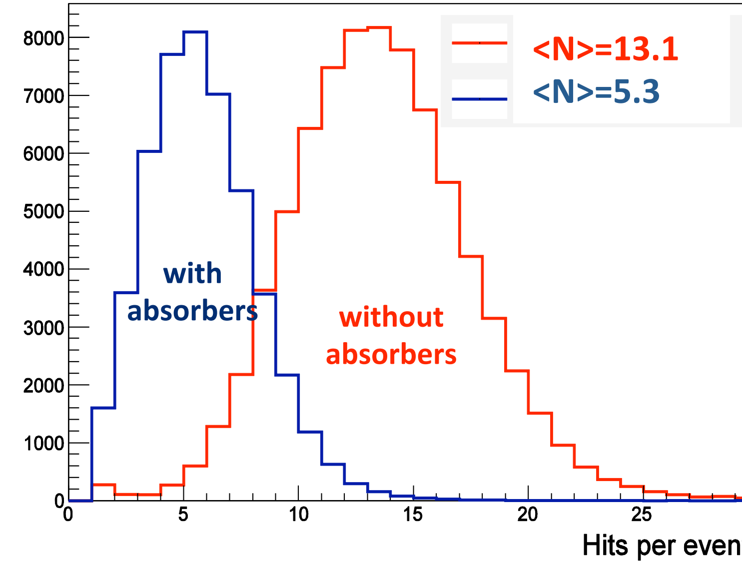


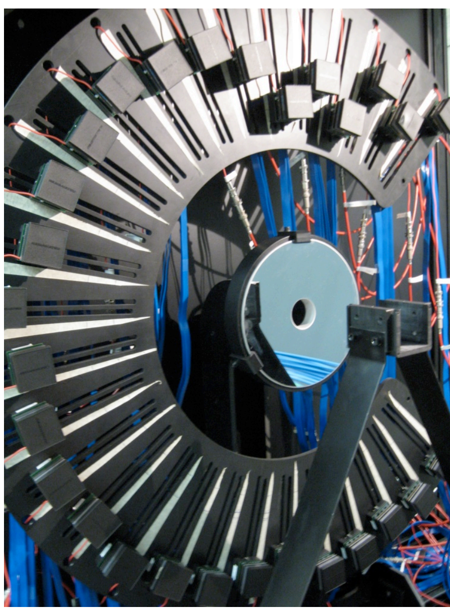


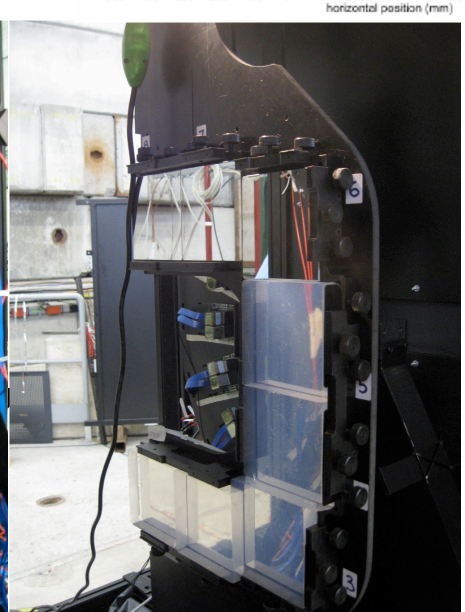
RHIC Prototype: Reflected Light Case



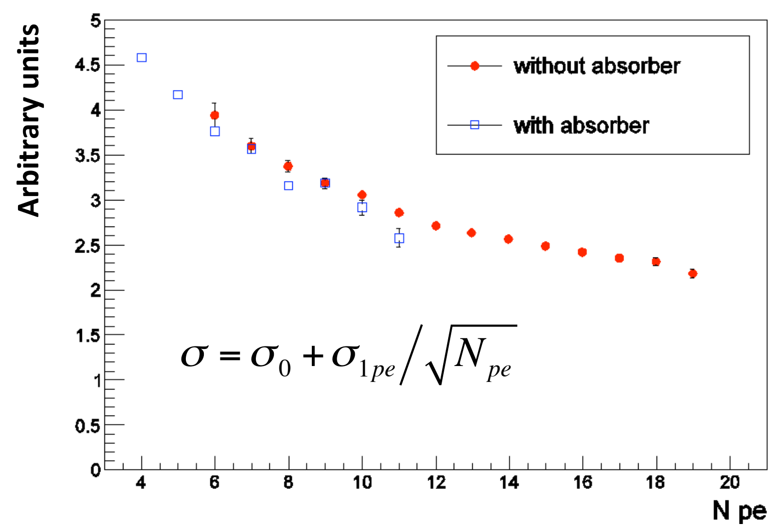
With absorbers: sizeable fraction of light survives







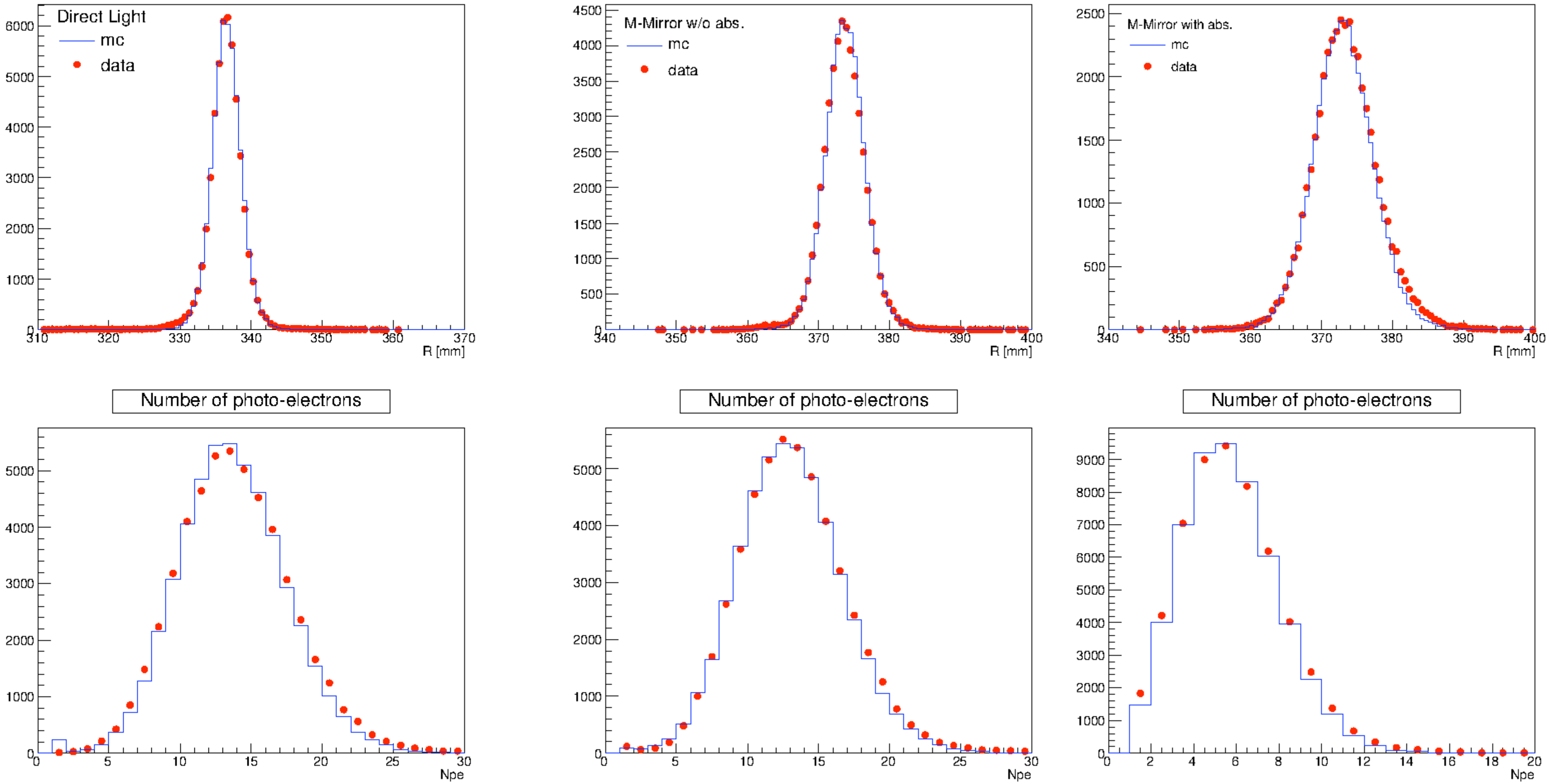
and resolution is not significantly degraded



RICH Simulations

reflected light setup

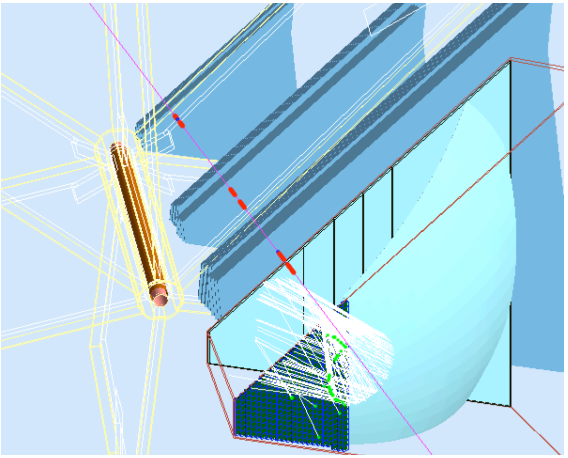
direct light setup | **without absorbers** | **with absorbers**



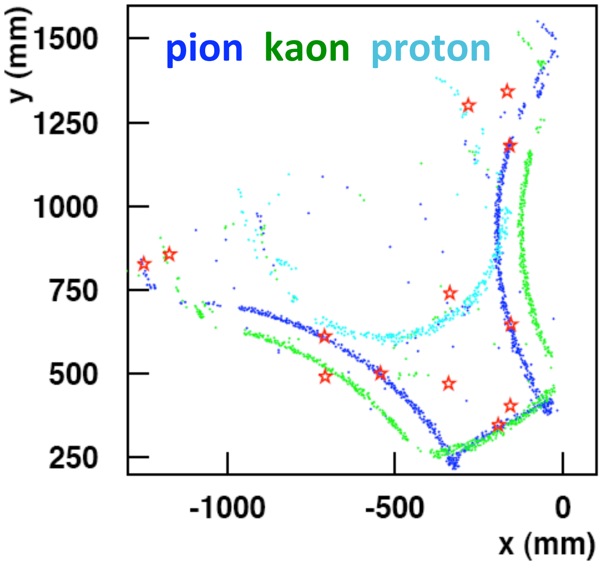
Based on measured optical characteristics and validated with RICH prototype data

The CLAS12 Hadron ID

One charged particle per sector in average:

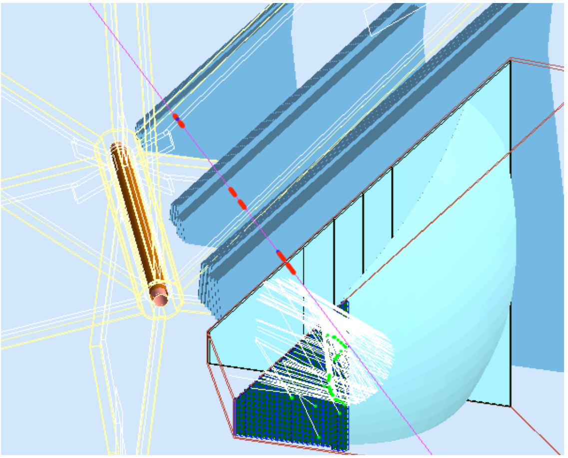


Non trivial RICH light patter due to reflections:
patter recognition and likelihood ID required



The CLAS12 Hadron ID

One charged particle per sector in average:



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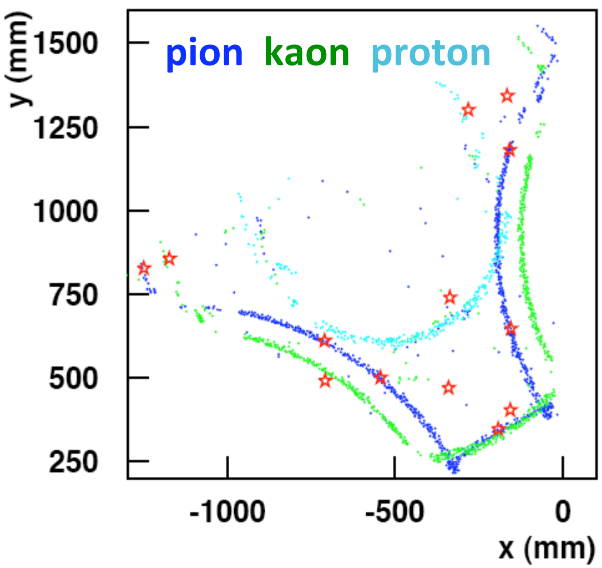
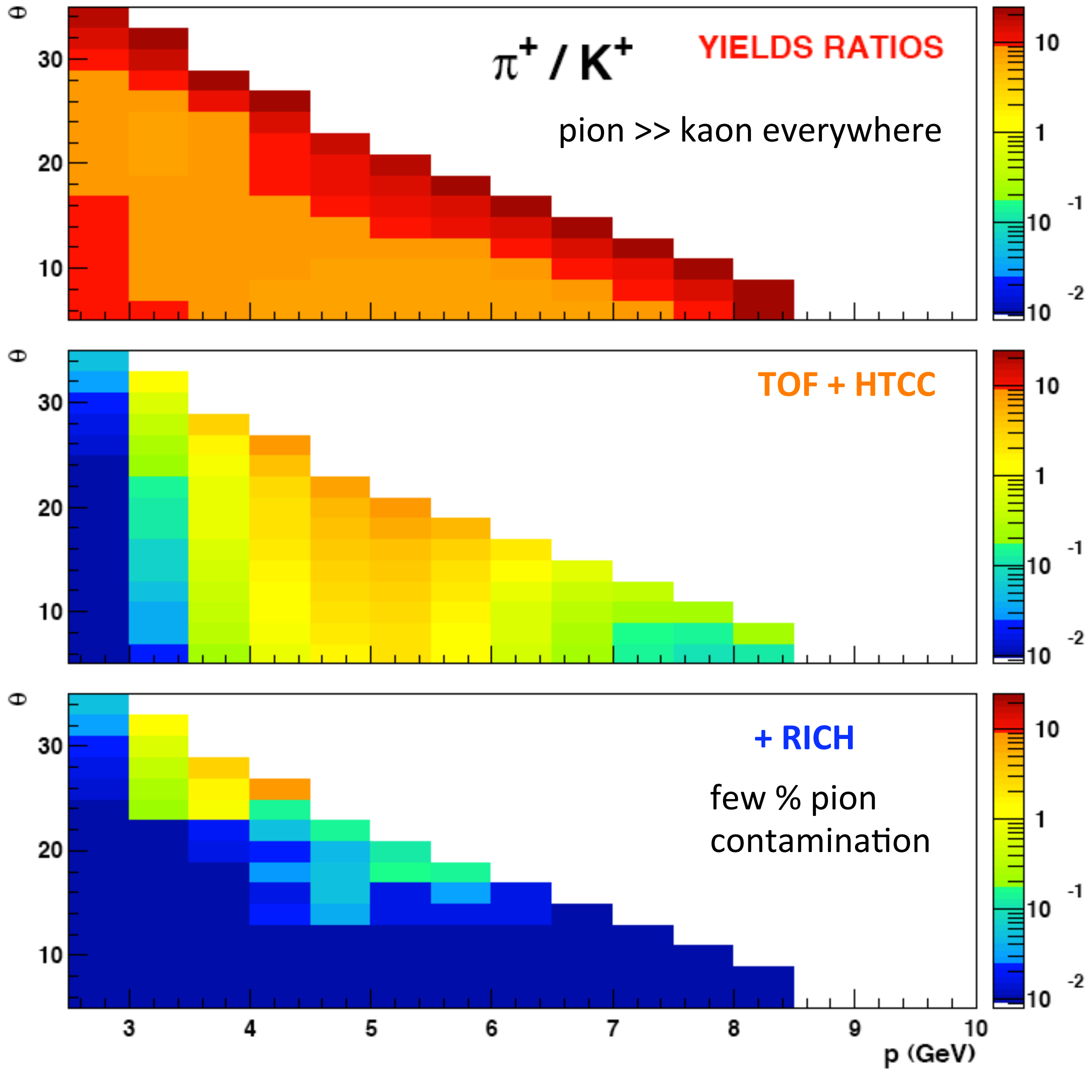
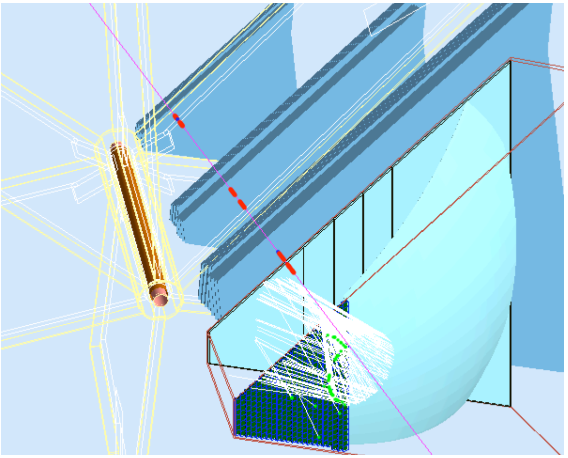




Even with a not yet optimized tuning of pattern recognition and likelihood ID, the π contamination is of the order of 1%

The CLAS12 Hadron ID

One charged particle per sector in average:



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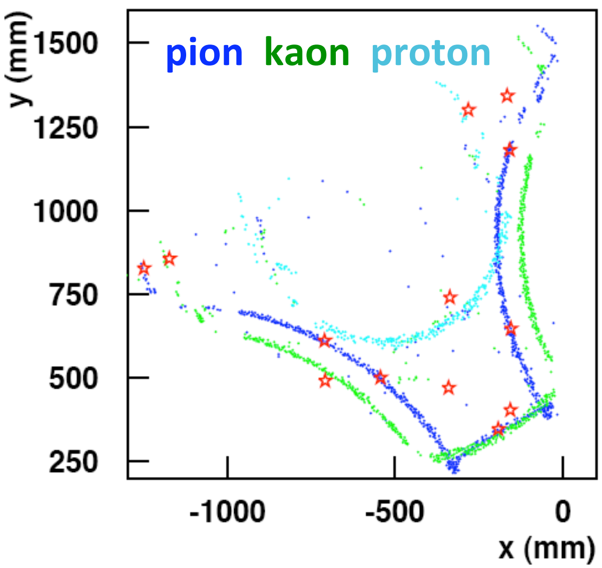
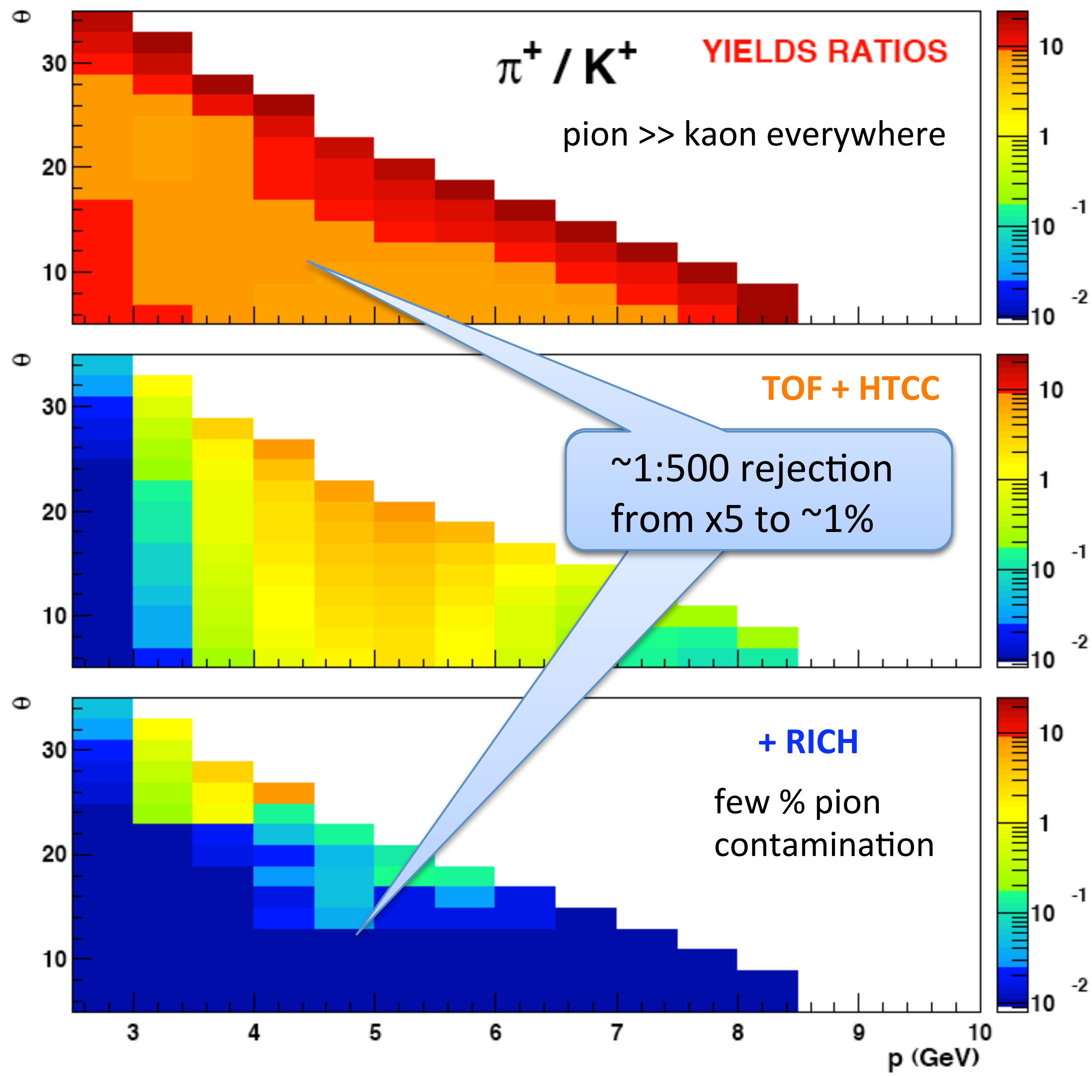




Even with a not yet optimized tuning of pattern recognition and likelihood ID, the π contamination is of the order of 1%

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

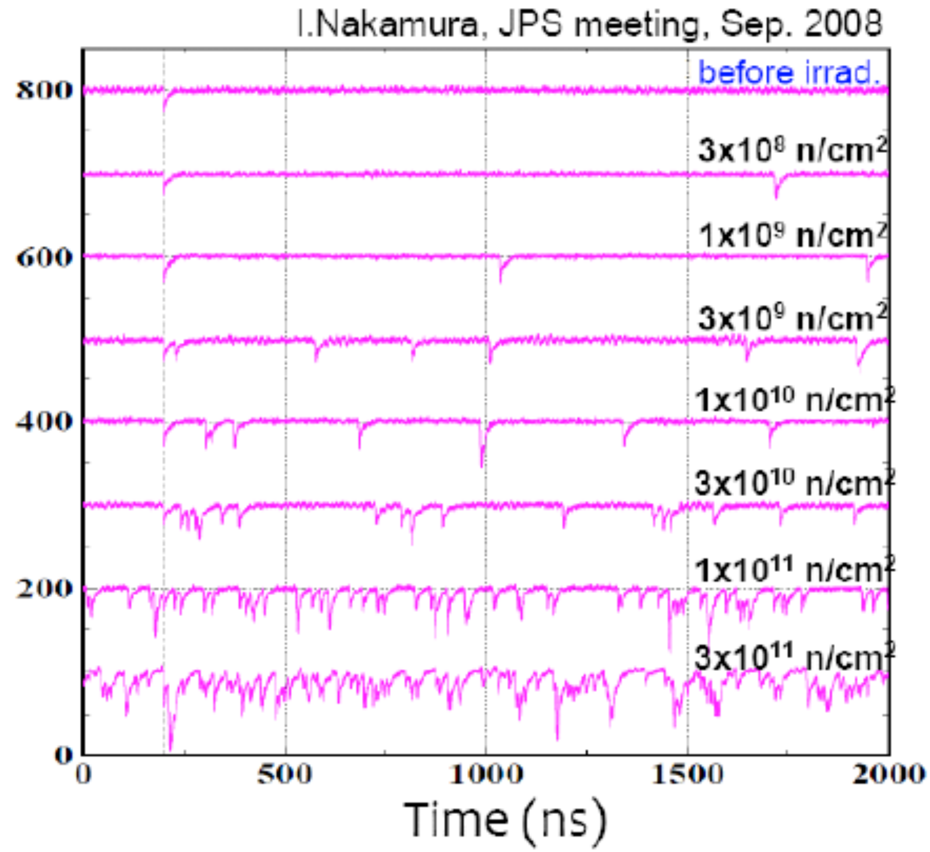
GOAL: 1st sector ready by the end of 2016

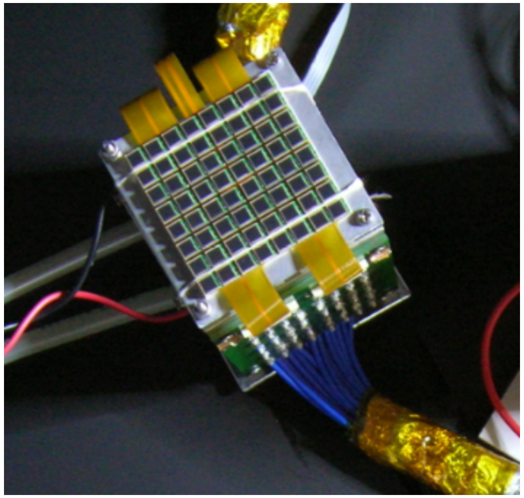
Photon Detectors: SiPM

Measured fluence @ Belle:
90/fb → 1-10 10^9 n/cm^2

Expected fluence @ Belle-2:
50/ab → 2-20 10^{11} n/cm^2

Expected fluence @ LHCB-2:
1 year → 6 10^{11} n/cm^2





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

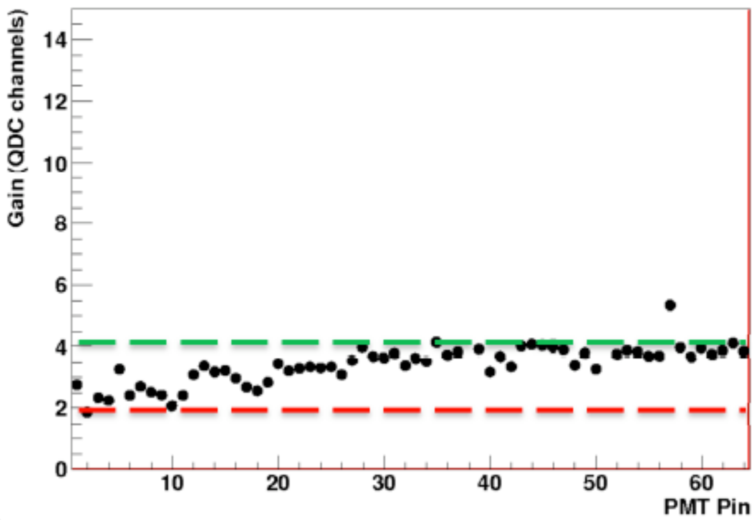
✓ fast develop in performances (dark count ~ 1 Mhz for 3x3 mm^2 devices)

✓ fast reduction in price (already comparable with MA-PMTs over 1 m^2)

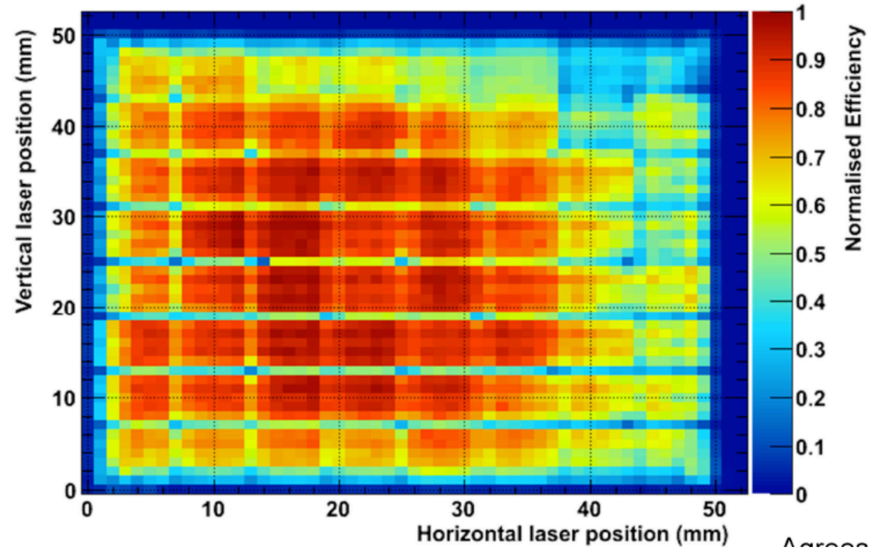
✗ require dedicated R&D for electronics and cooling

MA-PMT Gain Map

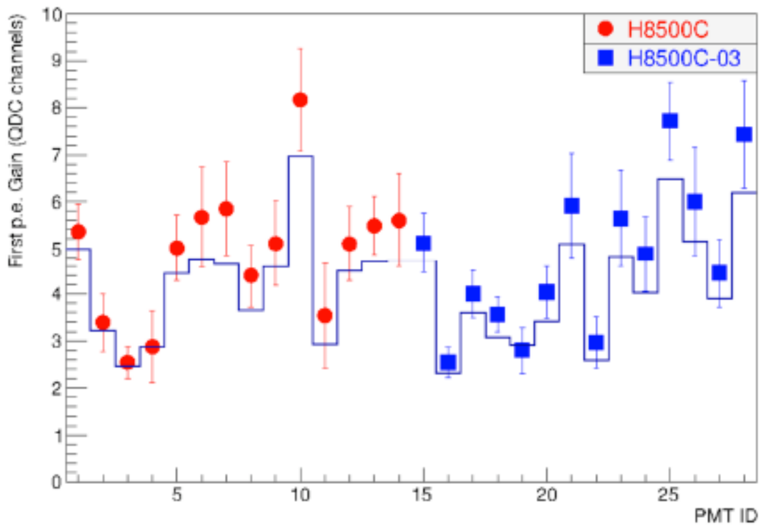
Pixel Gain:



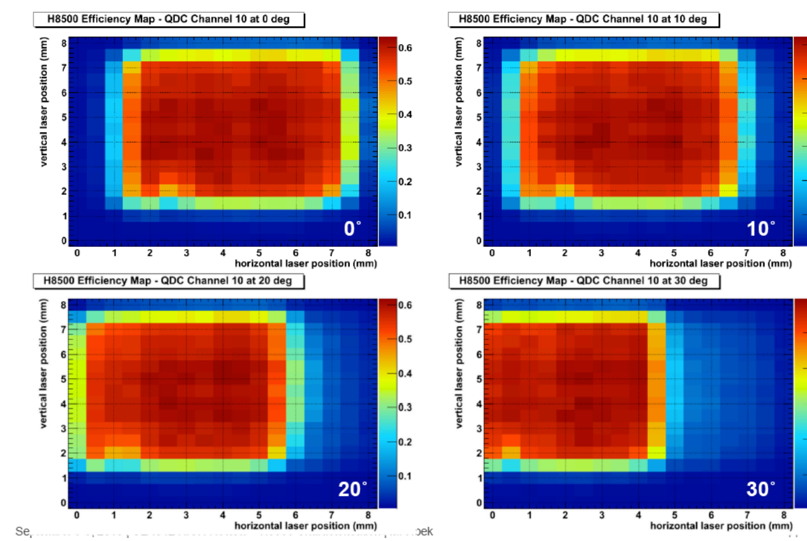
Efficiency Map:



PMT average gain:

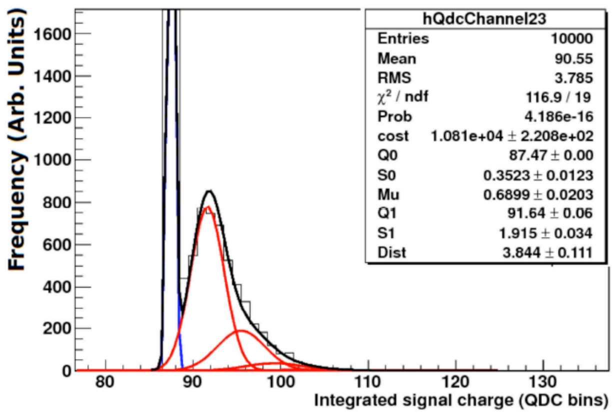


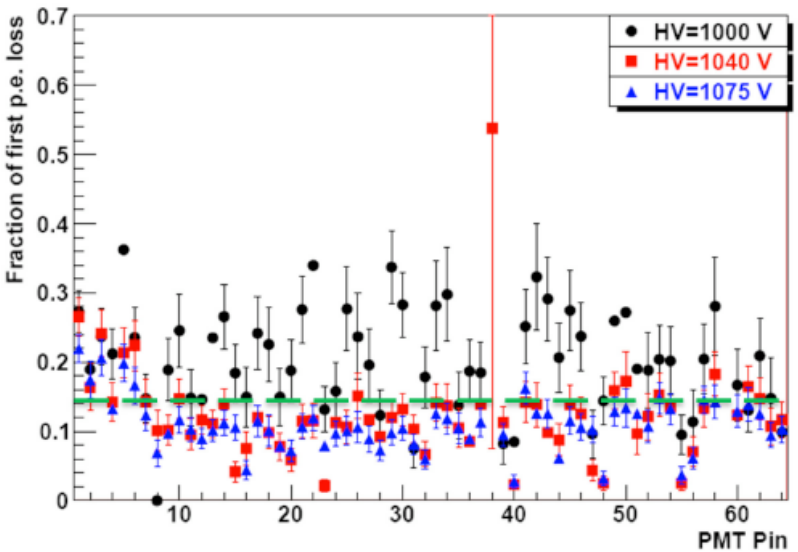
Incident angle scan:



MA-PMT Efficiency and X-talk

~ 15% SPE Loss :





~ 3% Cross-Talk: