ATTIVITA' FERRARA

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\+ **Aram Movsisyan** (INFN fellowship per stranieri)

JLab12, 16 Aprile 2012

Attivita' Ferrara

- **Proposal of SIDIS experiments**
  - ✓ *With hadron ID (RICH)   A-, B+ approved*
  - * *With transverse target (HD-Ice)   C2*
  - * *Dihadron + DVCS channels*

- **HD-Ice target magnet configuration**
  - ✓ *Magnetic stability*
  - ✓ *Moeller background*
  - ✓ *Acceptance*
  - * *Quench protection*

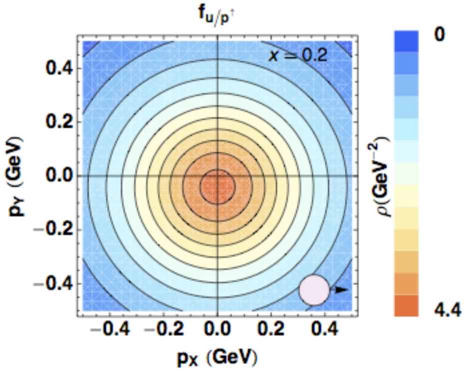
- **RHIC (GEANT4-based) simulation + reconstruction available**
  - ✓ *Detailed geometry*
  - ✓ *Optical effects (mirror reflectivity)*
  - ✓ *Digitalization*
  - ✓ *Background (Rayligh)*
  - ✓ *Likelihood based on direct ray-tracing*
  - * *Validation of the preliminary results ongoing*
  - * *Optimal compromise to be found*
- **RHIC prototype**
- **Aerogel Characterization**
- **SiPM for Cherenkov light detection**

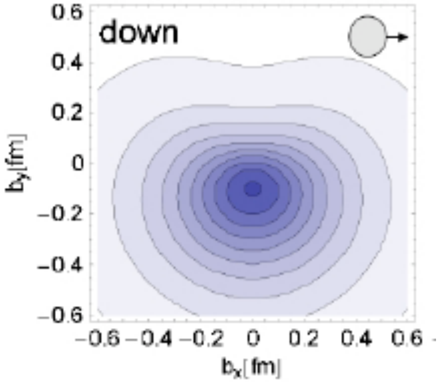
Nucleon 3D structure with SIDIS & exclusive experiments

Quantum phase-space distributions of quarks

$W_p^q(x,k_T,r)$ “Mother” Wigner distributions

Probability to find a quark q in a nucleon P with a certain polarization in a position r & momentum k





$$\begin{tikzcd}
 & W_p^q(x,k_T,r) \arrow[dl, "d^3r"'] \arrow[dr, "d^2k_T\ (FT)"] & \\
\text{TMD PDFs: } f_p^u(x,k_T),\ldots \arrow[dr, "d^2k_T"'] & & \text{GPDs: } H_p^u(x,\xi,t),\ \ldots \arrow[dl, "\xi=0{,}t=0"] \\
 & \text{PDFs } f_p^u(x),\ldots &
\end{tikzcd}$$

TMD PDFs: $f_p^u(x,k_T)$,…

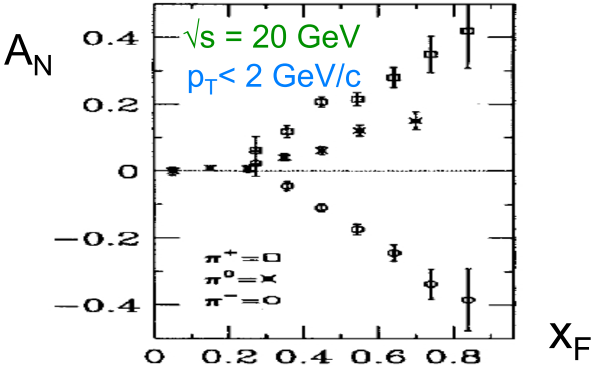
Semi-inclusive measurements
Momentum transfer to quark
Direct info about momentum distribution

GPDs: $H_p^u(x,\xi,t)$, …

Exclusive Measurements
Momentum transfer to target
Direct info about spatial distribution

PDFs $f_p^u(x)$,…

May explain SSA



LOI 11-105
Exclusive Physics: DVCS
with Transverse Target

May solve
proton spin puzzle

$$J_q = \frac{1}{2}\Delta\Sigma + L_q = \lim_{t\to 0}\int_{-1}^{1} dx\ x\ \left[H(x,\zeta,t) + E(x,\zeta,t)\right]$$

Leading Twist TMDs

Quark polarisation

Nucleon polarisation

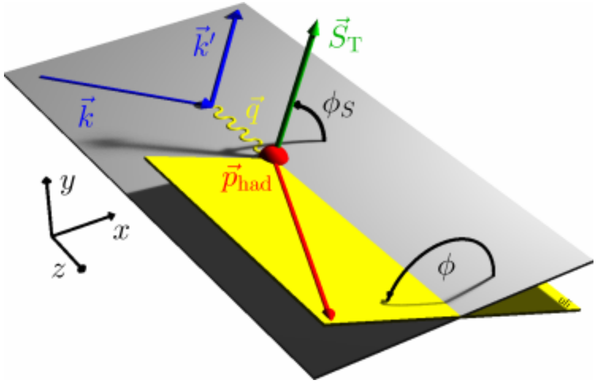
	U	L	T
U	f_1 *Number Density*		$h_1^\perp$ *Boer Mulders*
L		g_1 *Helicity*	$h_{1L}^\perp$ *Worm-gear*
T	$f_{1T}^\perp$ *Sivers*	$g_{1T}^\perp$ *Worm-gear*	h_1 *Transversity* $h_{1T}^\perp$ *Pretzelosity*

E12-09-007
Quark number and helicities

E12-06-112
E12-09-008
Boer-Mulders for pions and kaons

E12-07-107
E12-09-009
Spin-effects for pions and kaons

PR12-11-111
TT proposal



CLAS12 has access to all of them through specific azimuthal modulations (ϕ, ϕ_S) of the cross-section thanks to the polarized beam and target

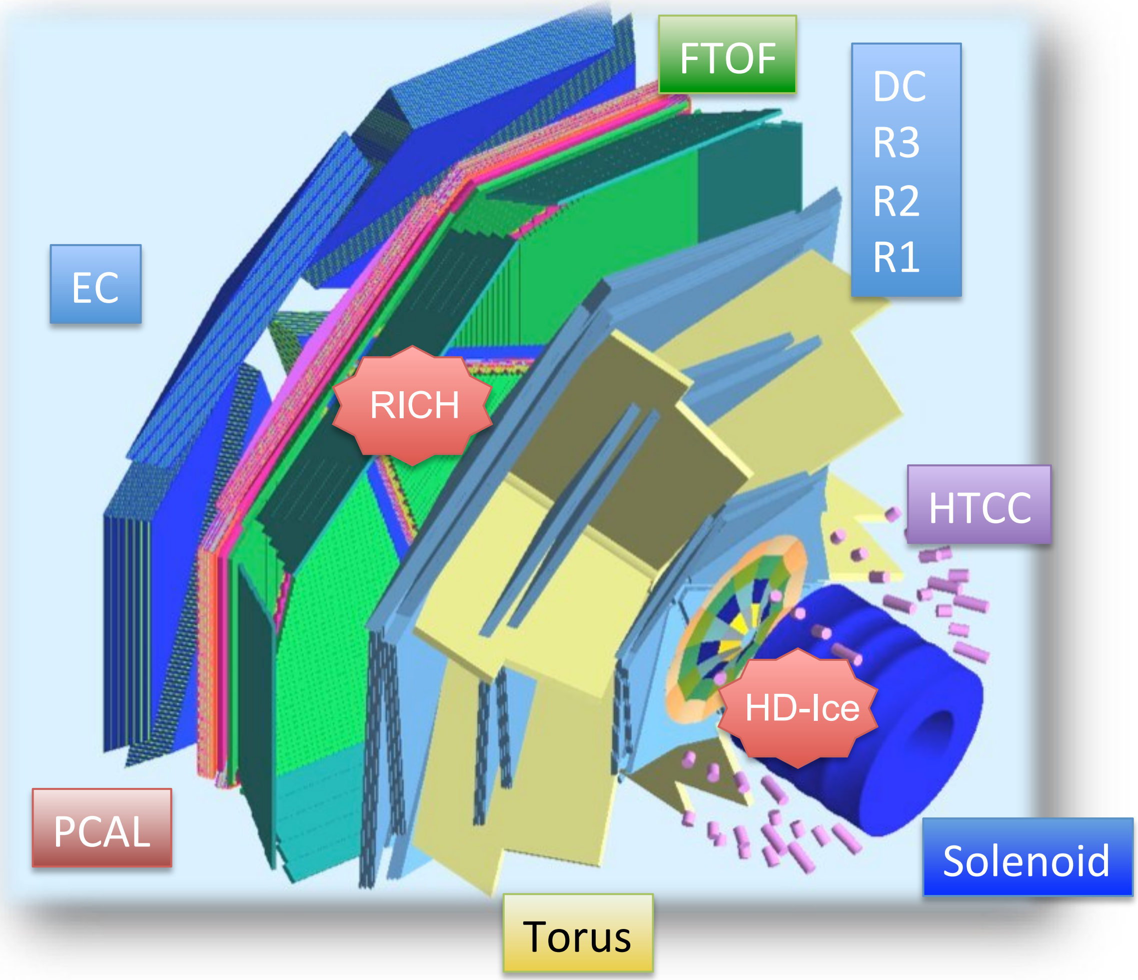
The CLAS12 Spectrometer

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

Highly polarized electron beam

H and D polarized targets

Broad kinematic range coverage (current to target fragmentation)



HD-Ice: Transverse Target new concept
(commission with CLAS at 6 GeV common to LOI 11-105)

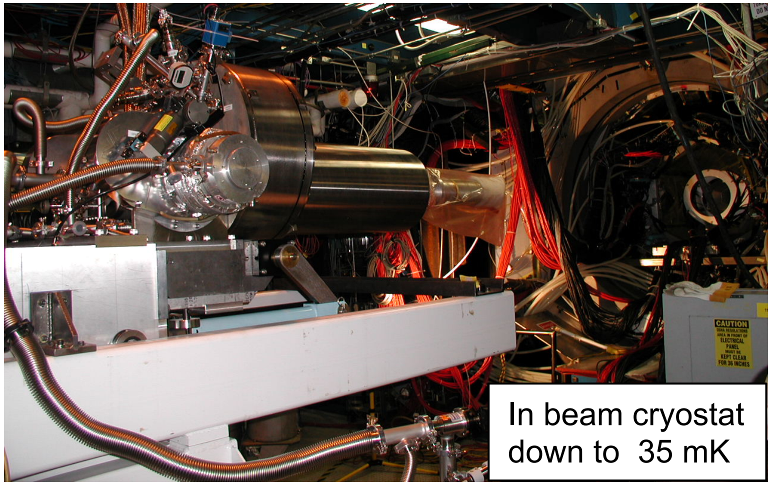
RICH: Hadron ID for flavor separation
(common to SIDIS approved exp.)

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.

HD-Ice
Holding Magnet

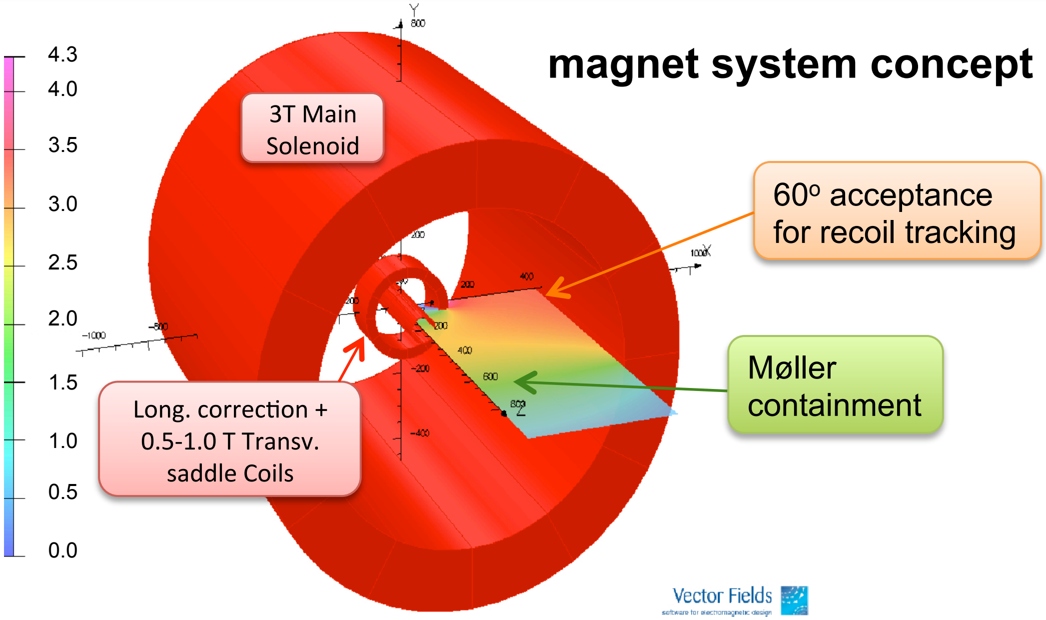
Transversely Polarized HD-Ice Target

Up to 75% H and 40 % D polarization independently controlled



In beam cryostat down to 35 mK

magnet system concept



3T Main Solenoid

60º acceptance for recoil tracking

Møller containment

Long. correction + 0.5-1.0 T Transv. saddle Coils

HD-Ice target vs standard nuclear targets

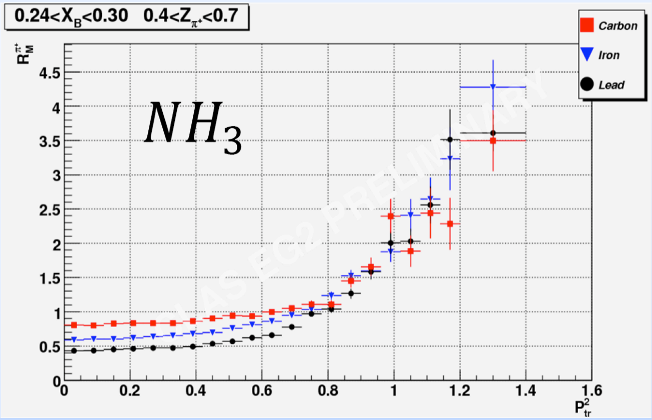
Advantages:

- ➢ Minimize nuclear background

  small dilution and nuclear effets at large p_T

- ➢ Weak holding field (BdL ≤ 0.1 Tm)

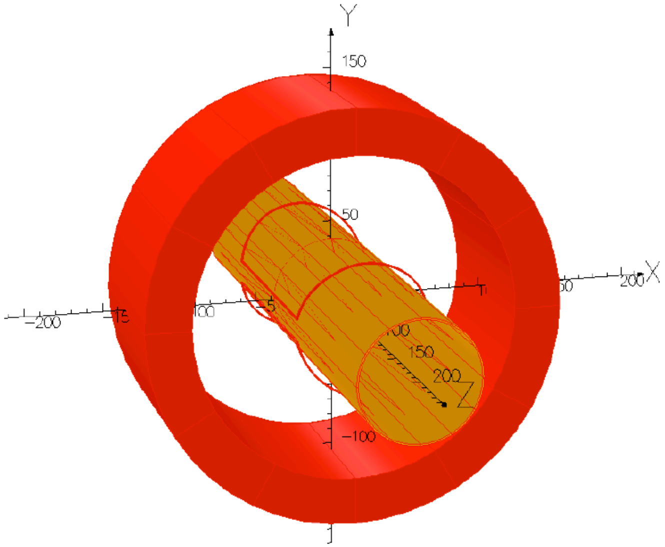
  wide acceptance, negligible beam deflection, viable field inversion

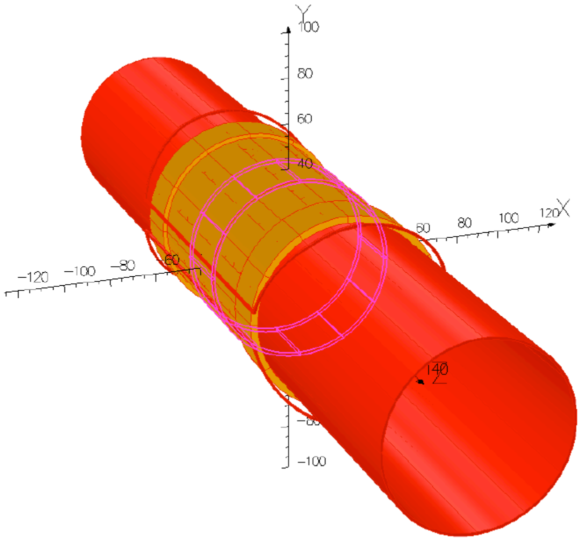


Disadvantages:

- ➢ Very long polarizing times (months)
- ➢ Need to demonstrate that can remain polarized for long periods with an electron beam: as consevative approach we consider 1/10 of full luminosity (compensated by better dilution)

The alternatives

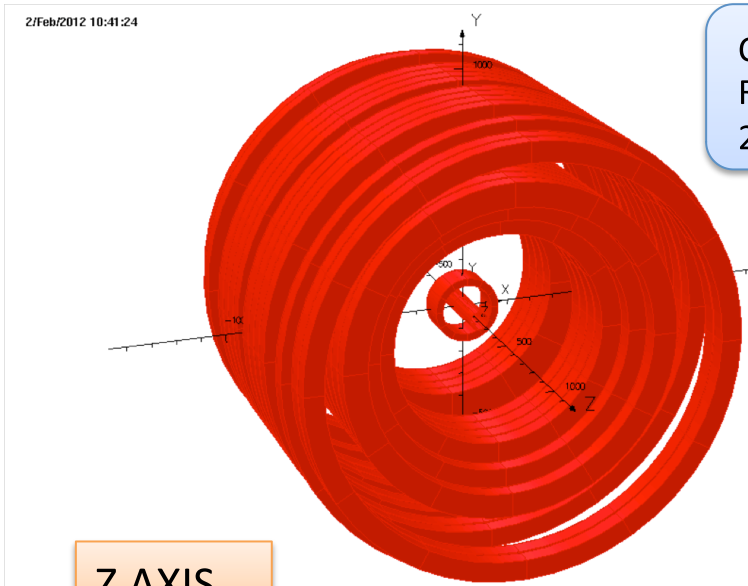




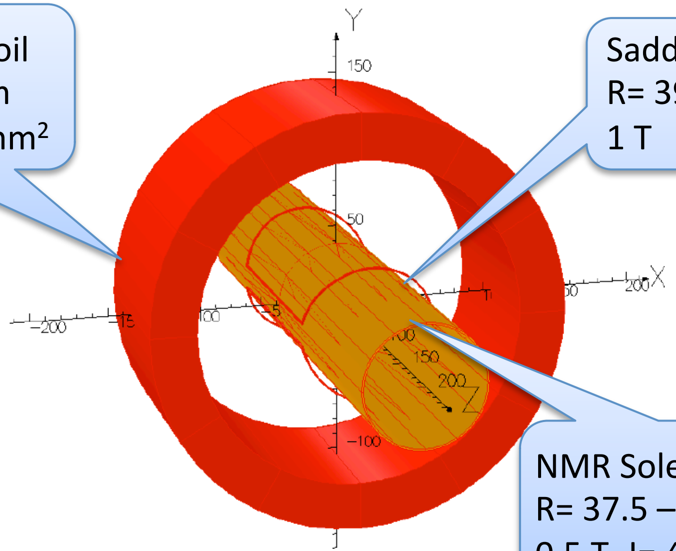
- **N80:**
  - ✔ *High Field for high Lumi*
  - ✔ *Decouple from Hdice cryostat*
  - ✔ *Short target*
  - ✔ *Mechanical challenge*

- **N101:**
  - ✔ *Mild Field for low Lumi*
  - ✔ *Light structure*
  - ✔ *Long target*
  - ✔ *Material budget*

TT magnet N80



Vector Fields
software for electromagnetic design

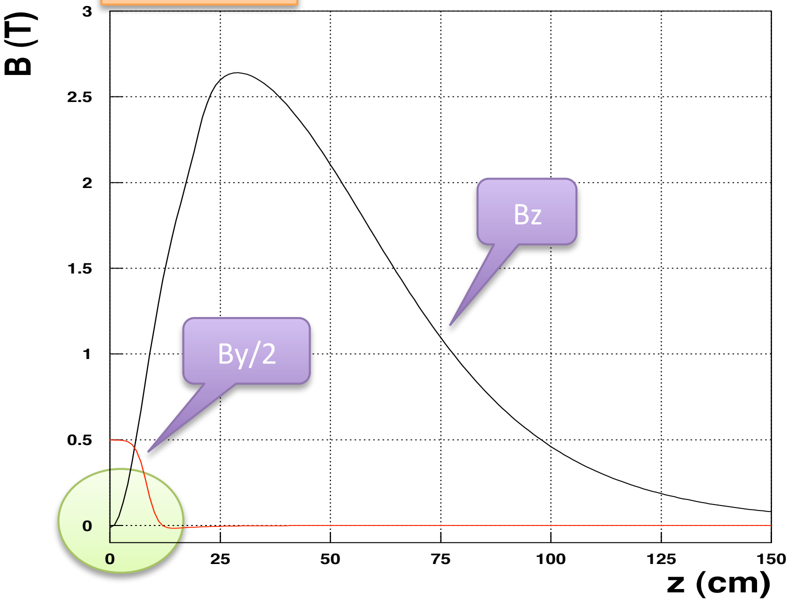


Compensating Coil
R= 105 – 135 mm
2.5 T J= 148 A/mm^2

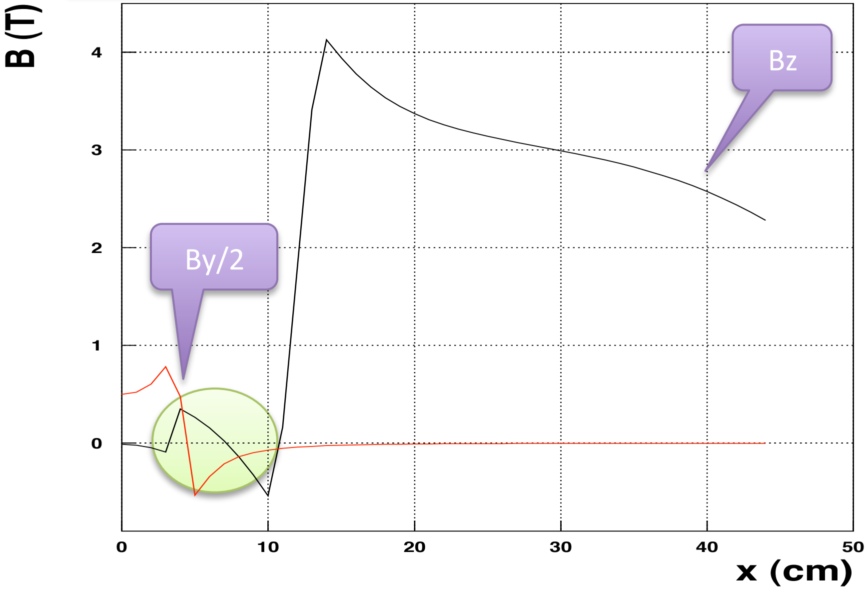
Saddle Coil
R= 39 mm
1 T

NMR Solenoid
R= 37.5 – 38.5 mm
0.5 T J= 400 A/mm^2

Z AXIS

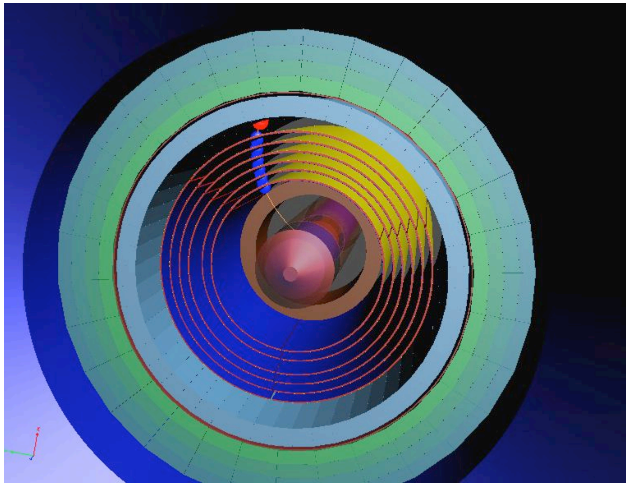


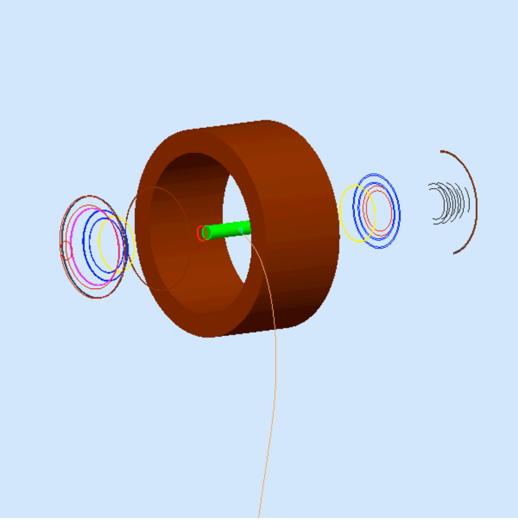
X AXIS



TT-N80 Performances

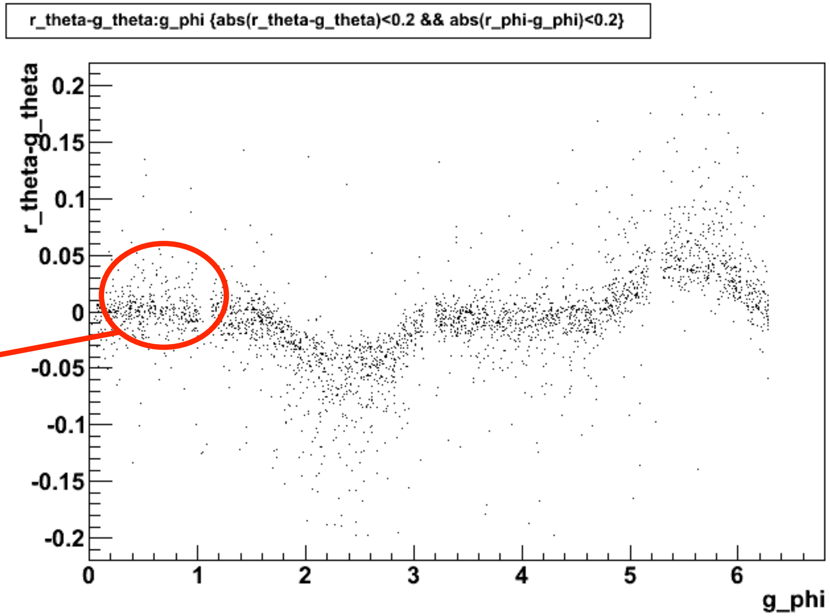
- Massive coil
- 60º acceptance from cell center
- Untouched forward acceptance



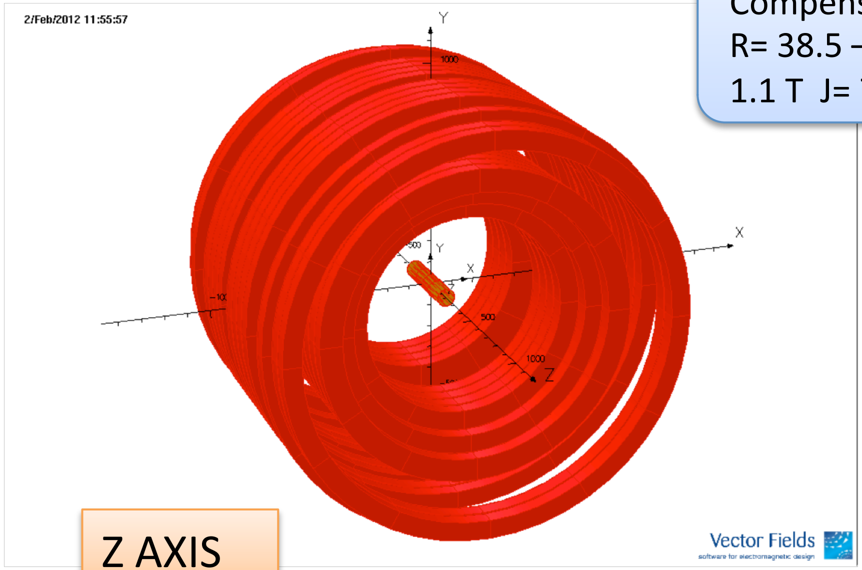


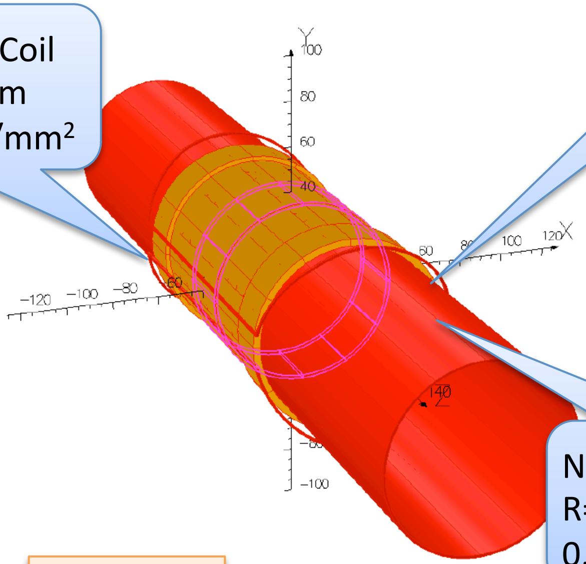
Thanks to Sebastien Procureur

- Momentum resolution ~ 10%
  versus 6 % with standard setup
- Theta resoultion ~ 8 mrad
  versus ~ 7 mrad with standard setup



TT magnet N101



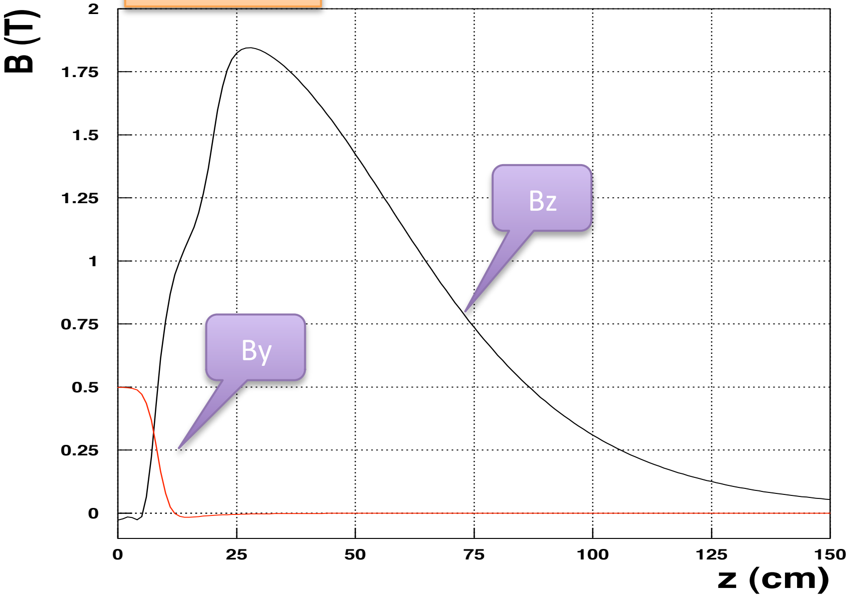


Compensating Coil
R= 38.5 – 40 mm
1.1 T J= 730 A/mm^2

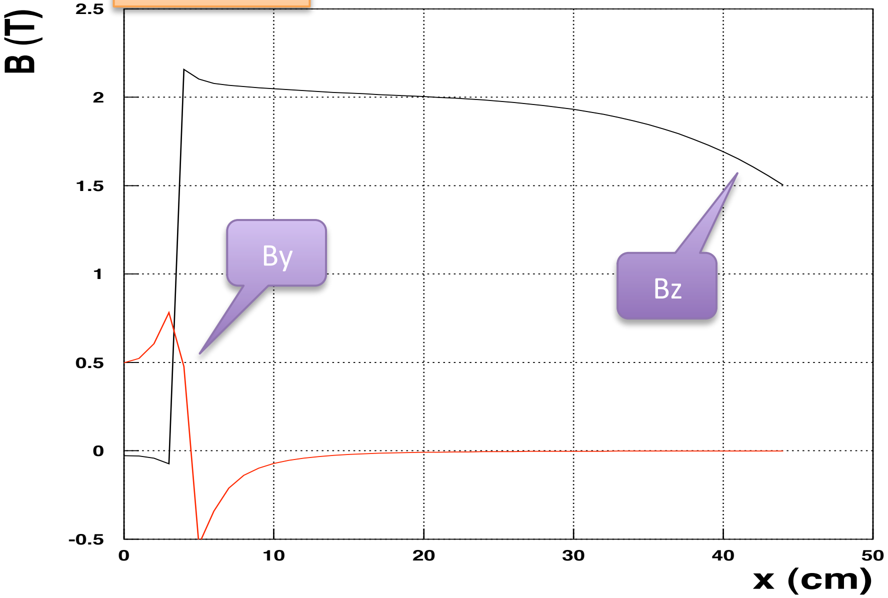
Saddle Coil
R= 39 mm
0.5 T

NMR Solenoid
R= 37.5 – 38.5 mm
0.9 T J= 730 A/mm^2

Z AXIS

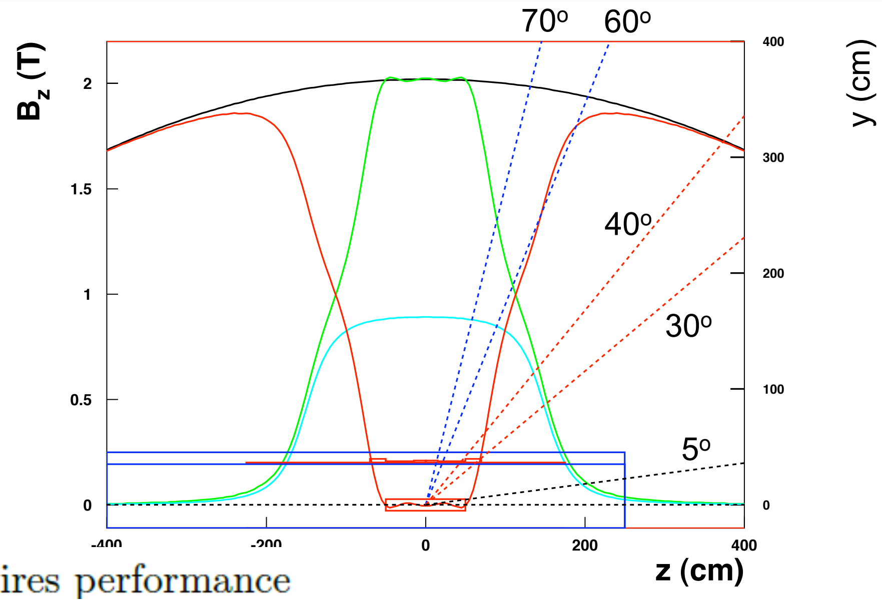


X AXIS

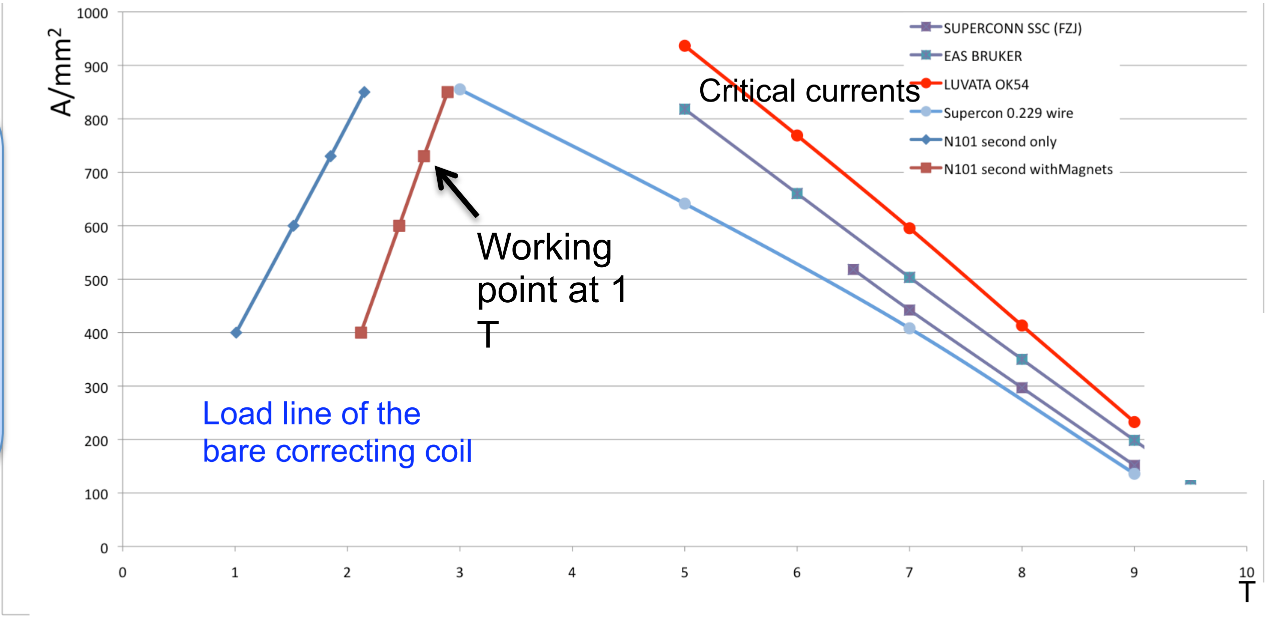


TT-N101 Case

- ❖ Good compensation (homogeneity)
- ❖ Untouched forward acceptance
- ❖ Material budget at large angles
  - ~ 4 mm from 30 to 40 degrees
  - ~ 2 mm above 40 degrees



Load lines and wires performance



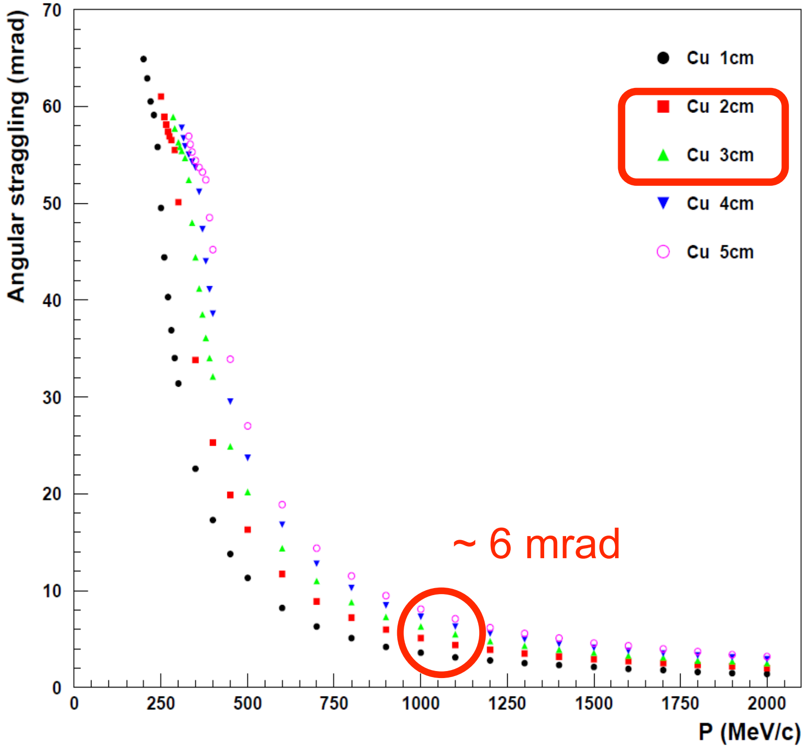
Critical currents

Working point at 1 T

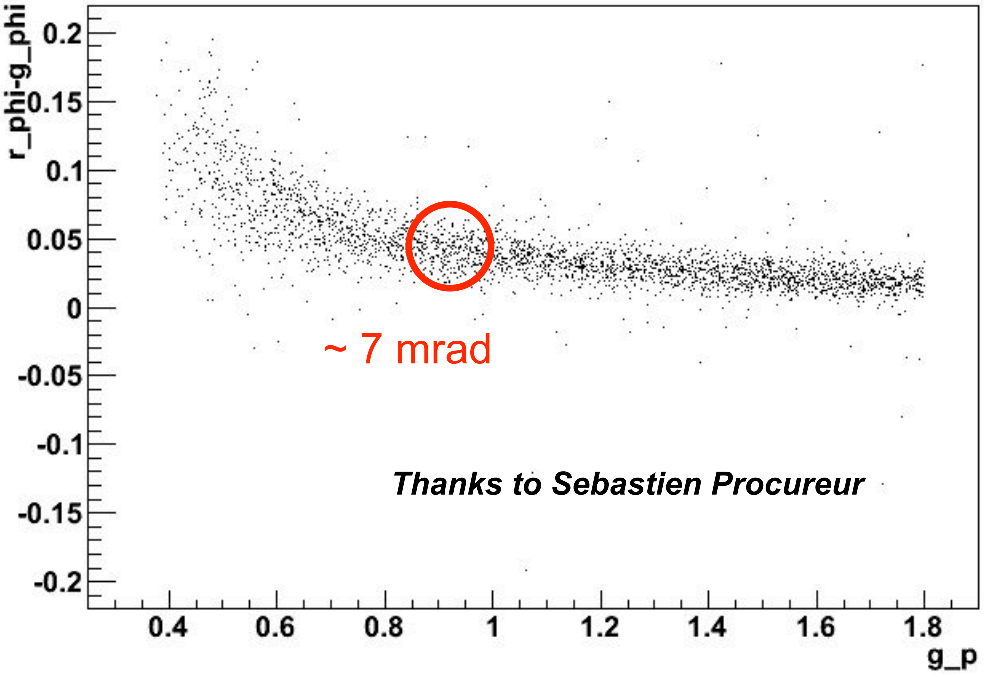
Load line of the bare correcting coil

- ❖ Close to safety margin for standard SC wires
- ❖ Quenching (T < 160 K):
  - 0.3-0.35 wire
  - L = 0.12 H
  - dump resistance 12 Ohm
  - current 82 A

Moeller background

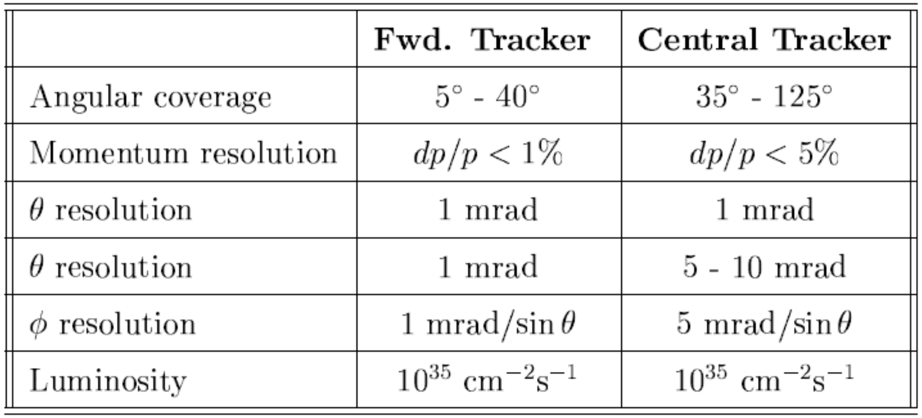


~ 6 mrad



~ 7 mrad

Thanks to Sebastien Procureur



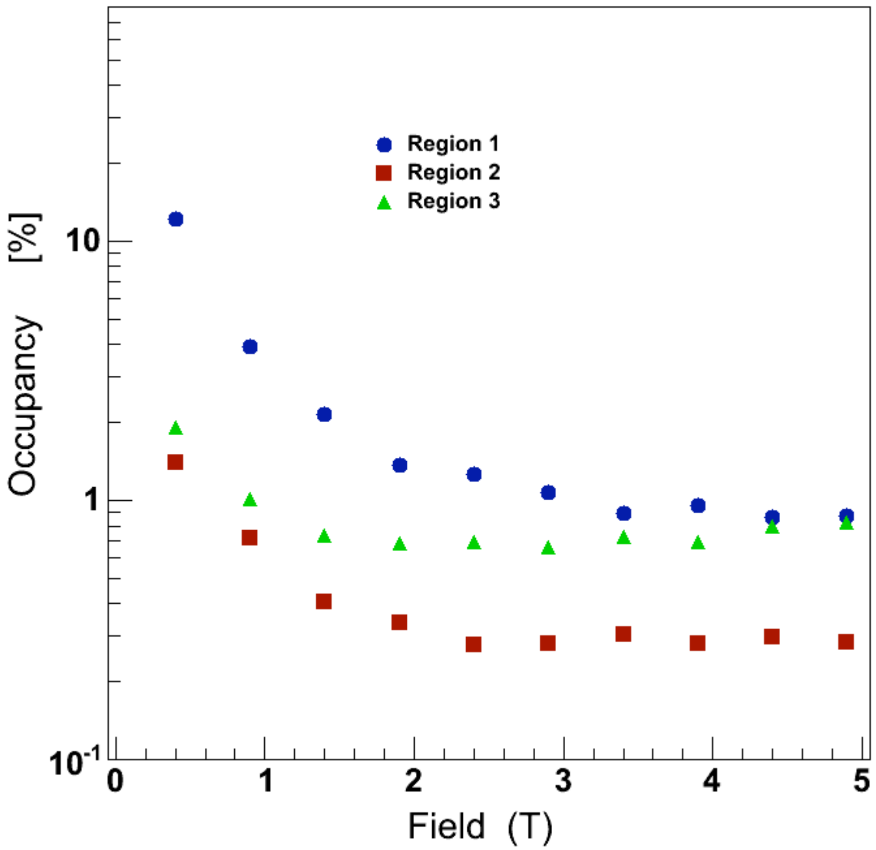
	Fwd. Tracker	Central Tracker
Angular coverage	5° - 40°	35° - 125°
Momentum resolution	$dp/p < 1\%$	$dp/p < 5\%$
θ resolution	1 mrad	1 mrad
θ resolution	1 mrad	5 - 10 mrad
ϕ resolution	1 mrad/$\sin\theta$	5 mrad/$\sin\theta$
Luminosity	10^{35} cm^{-2}s^{-1}	10^{35} cm^{-2}s^{-1}

Table 2.1: General specifications for `CLAS12` tracking.

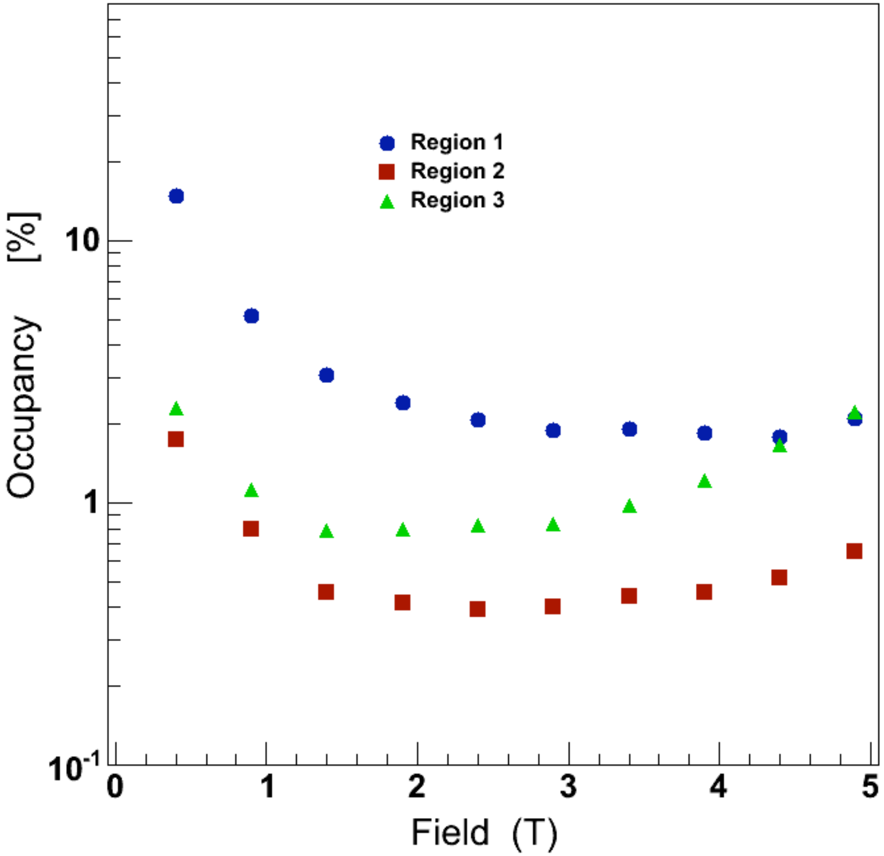
Moeller background

Drift Chamber Occupancy

HD N80



HD N101



Attivita' RICH

Aerogel provides in principle a good pion/kaon separation up to 8 GeV/c

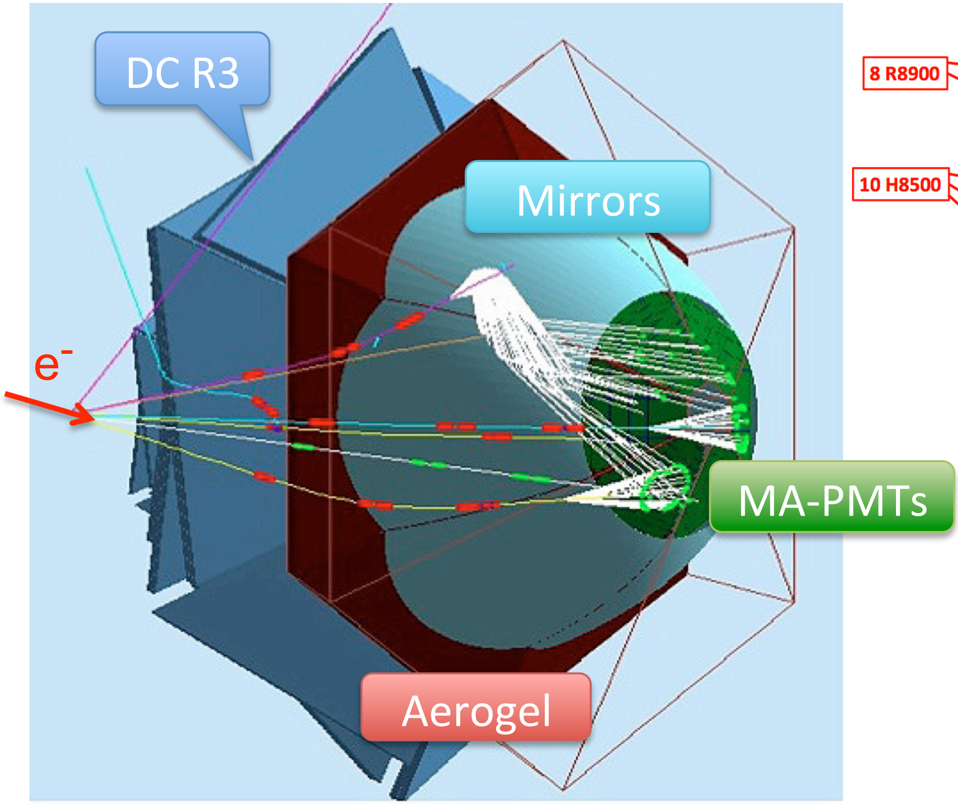
- **GEMC (GEANT4-based) simulation + reconstruction available**
  - ✔ *Detailed geometry (aerogel in tiles)*
  - ✔ *Optical effects (mirror reflectivity and quality)*
  - ✔ *Digitalization*
  - ✔ *Background (Rayligh)*
  - ✔ *Realistic components characteristics*
  - ✔ *Likelihood based on direct ray-tracing*
  - * *Validation of the preliminary results ongoing*
  - * ***Optimal compromise to be found***

- **Aerogel Characterization**
  - ✔ *Transmittance & Reflection*
  - ✔ *Dispersion*

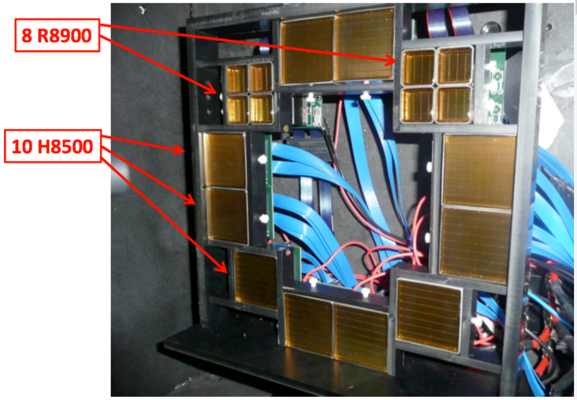
- **Proof of principle with a realistic prototype:**
  - * ***Performances at upper momentum limit (up to 8 GeV/c)***
  - * ***Double reflection concept***
  - * ***Hardware components***
  - * ***SiPM option***

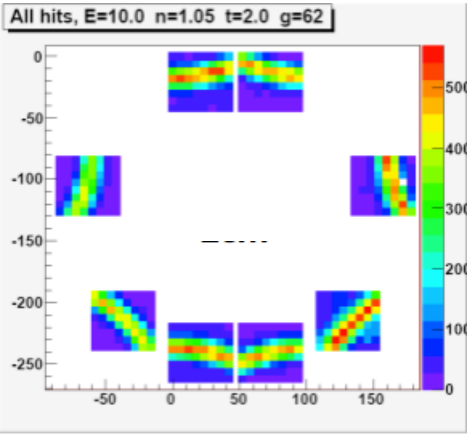
RICH
SIMULATIONS

The RICH Detector



Test beam results at CERN, July 2011





Simulation of n=1.05 aerogel + H8500:

≥ 10 p.e. for direct rings

(confirmed by preliminary test-beam results)

≥ 5 p.e. for reflected rings

≥ 500 pion rejection factor @ 99% kaon eff.

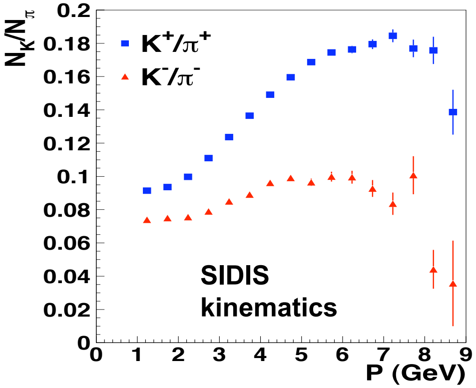
RICH goal:

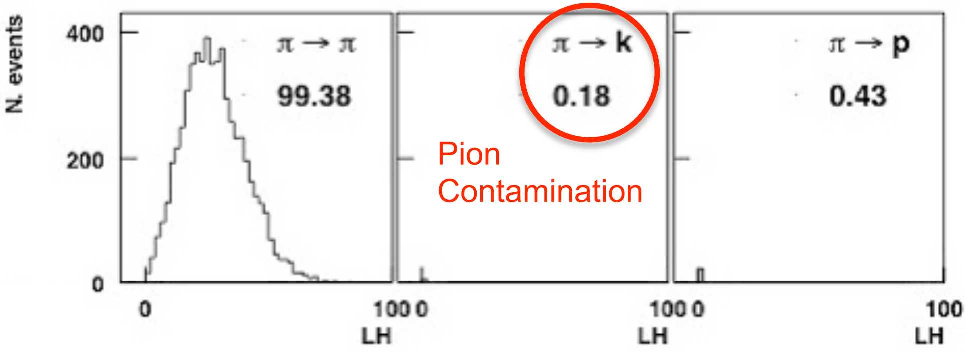
π/K/p separation

of **4-5 σ @ 8 GeV/c**

for a pion rejection

factor **1:1000**





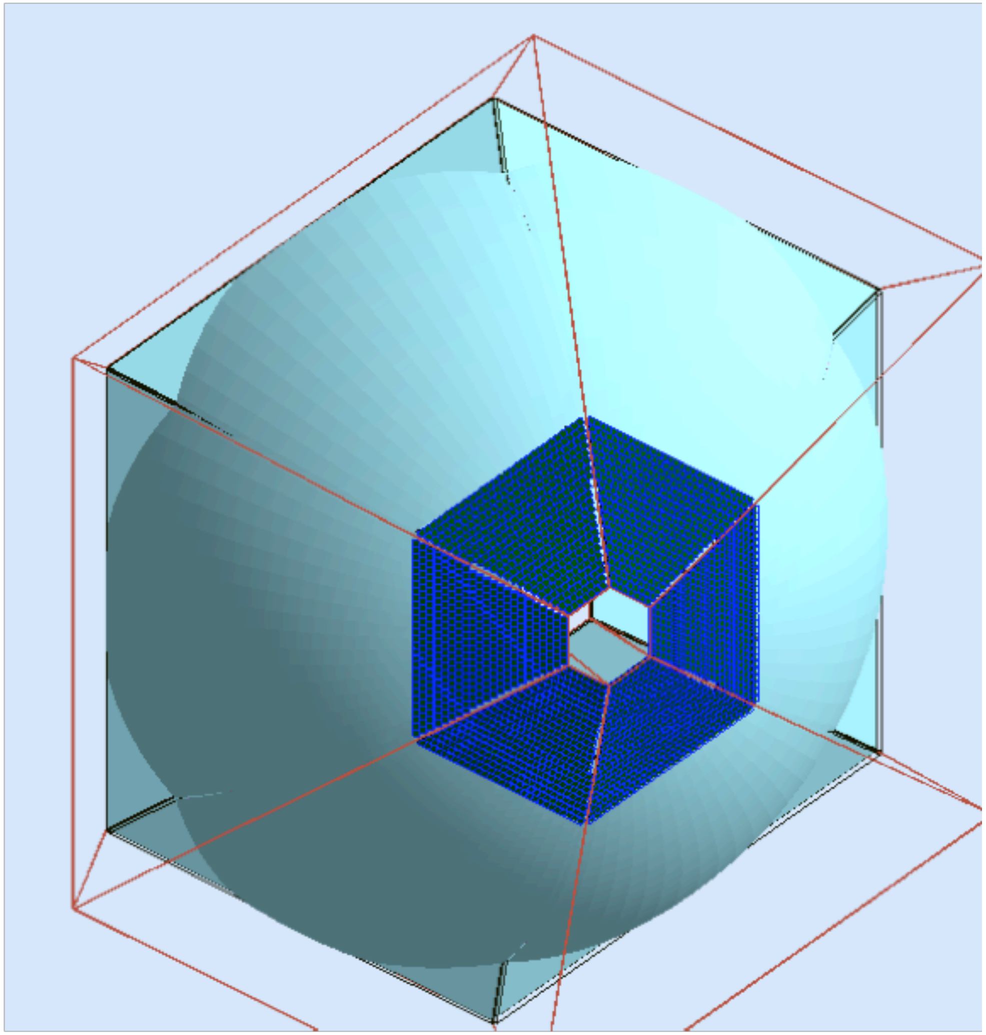
Pion Contamination

Standard set-up

Geometry:

rich_build_radtrap_mirror35_default.pl

On the Jlab GEMC database



Validation:

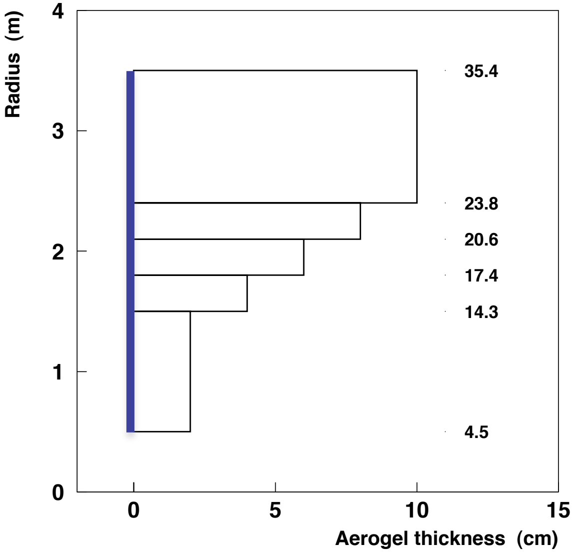
- ✔ handle of MA-PMT copies
- ✔ volume overlaps
- ✔ refine materials (to match aerogel transmission)
- ☐ user friendly layout

Average N p.e.: NBA ?

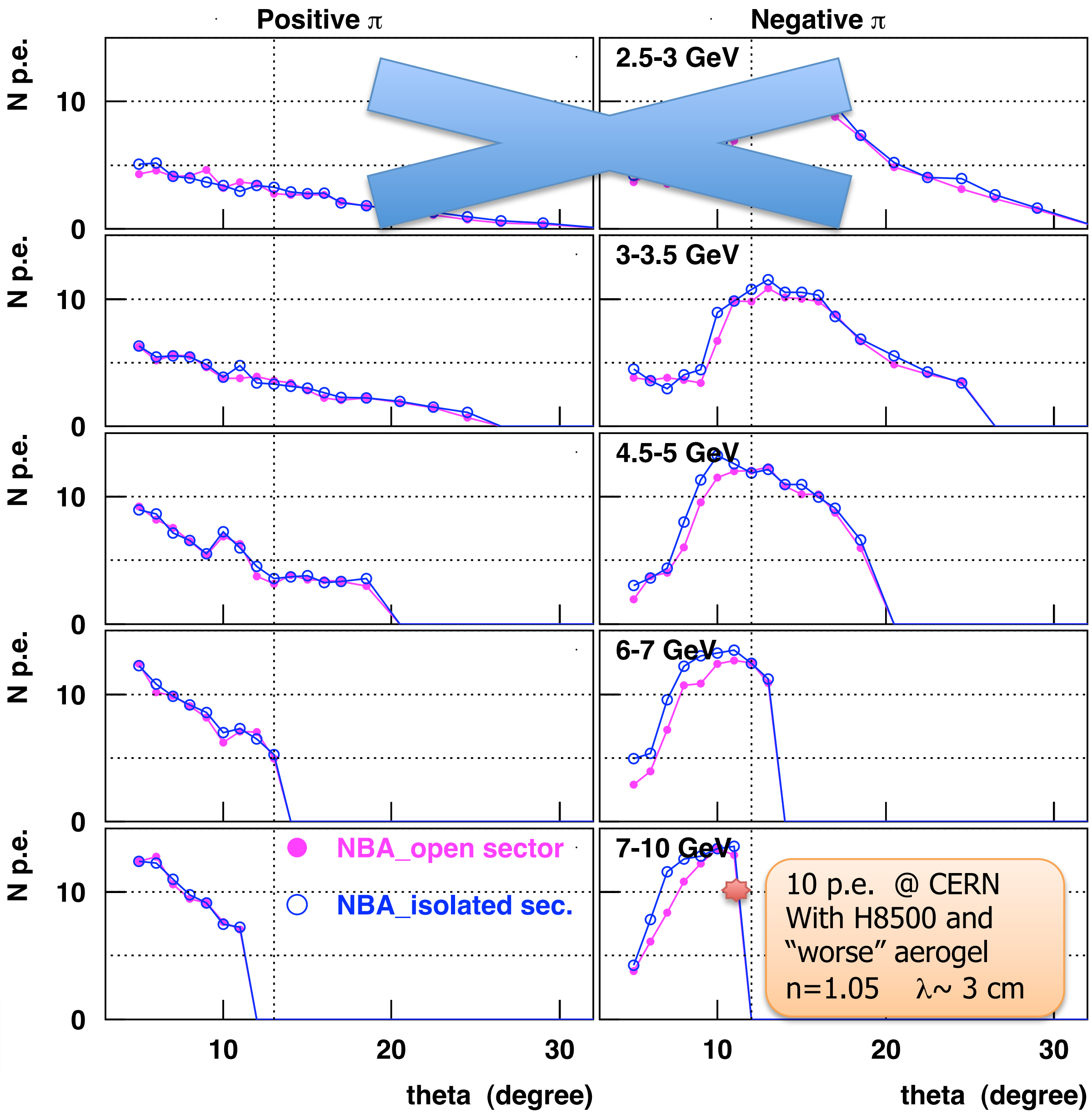
Aerogel:
- n=1.05, λ=5.5 cm
- thick. increasing with radius: 2-4-6-8-10 cm

Mirror: 14° - 35°
- 90% reflectivity

MA-PMTs: H8500 eff=0.65

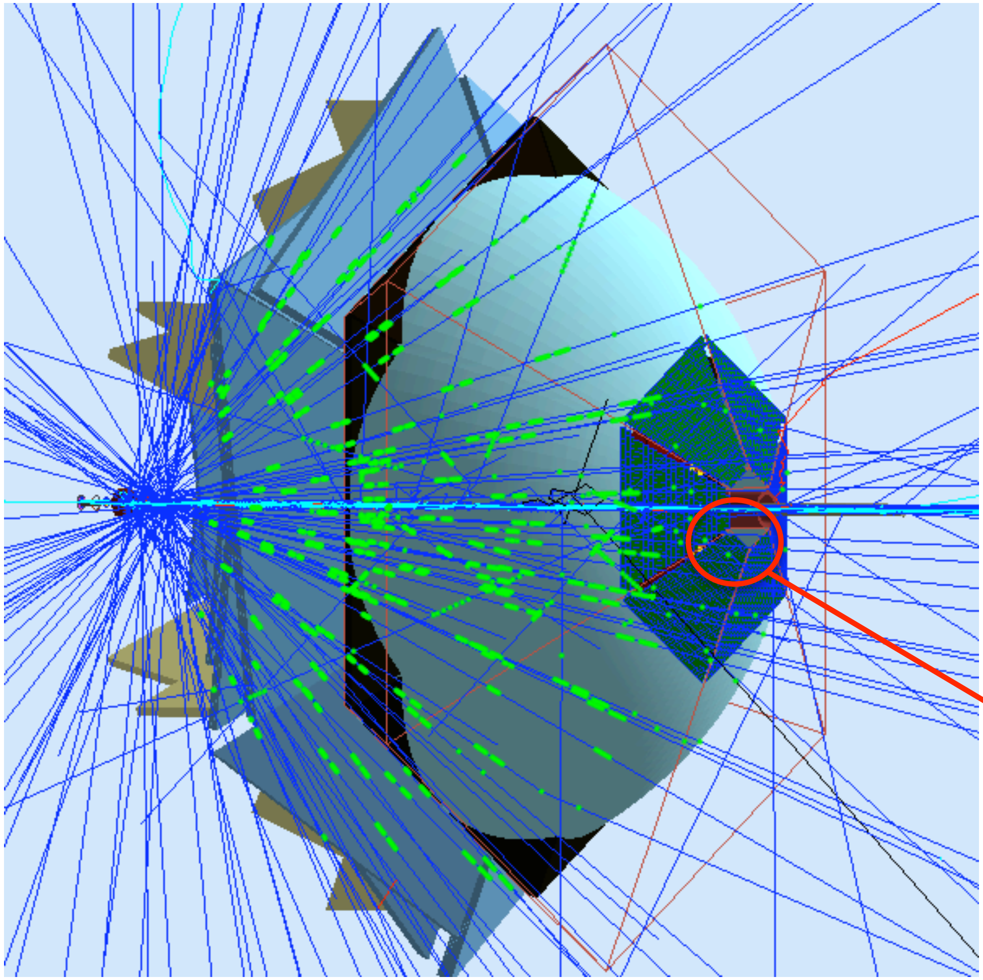


Minor difference on the number,
Major on the hit pattern



10 p.e. @ CERN
With H8500 and
"worse" aerogel
n=1.05 λ~ 3 cm

The RICH Background



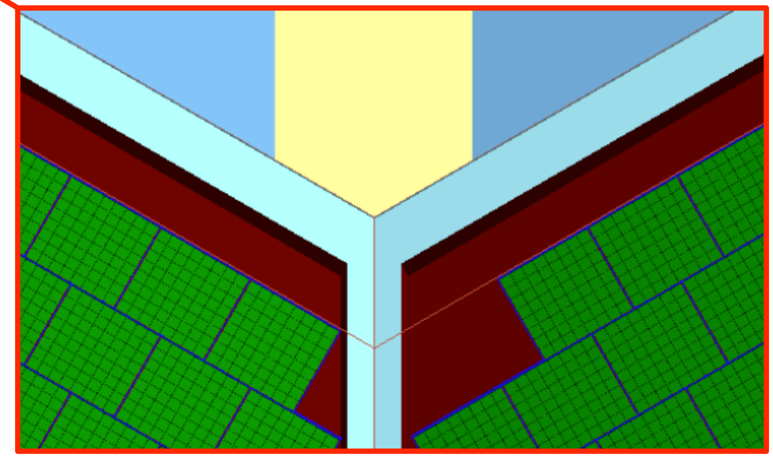
Major source of backgrounds

Photons conversions into the aerogel producing Cerenkov light

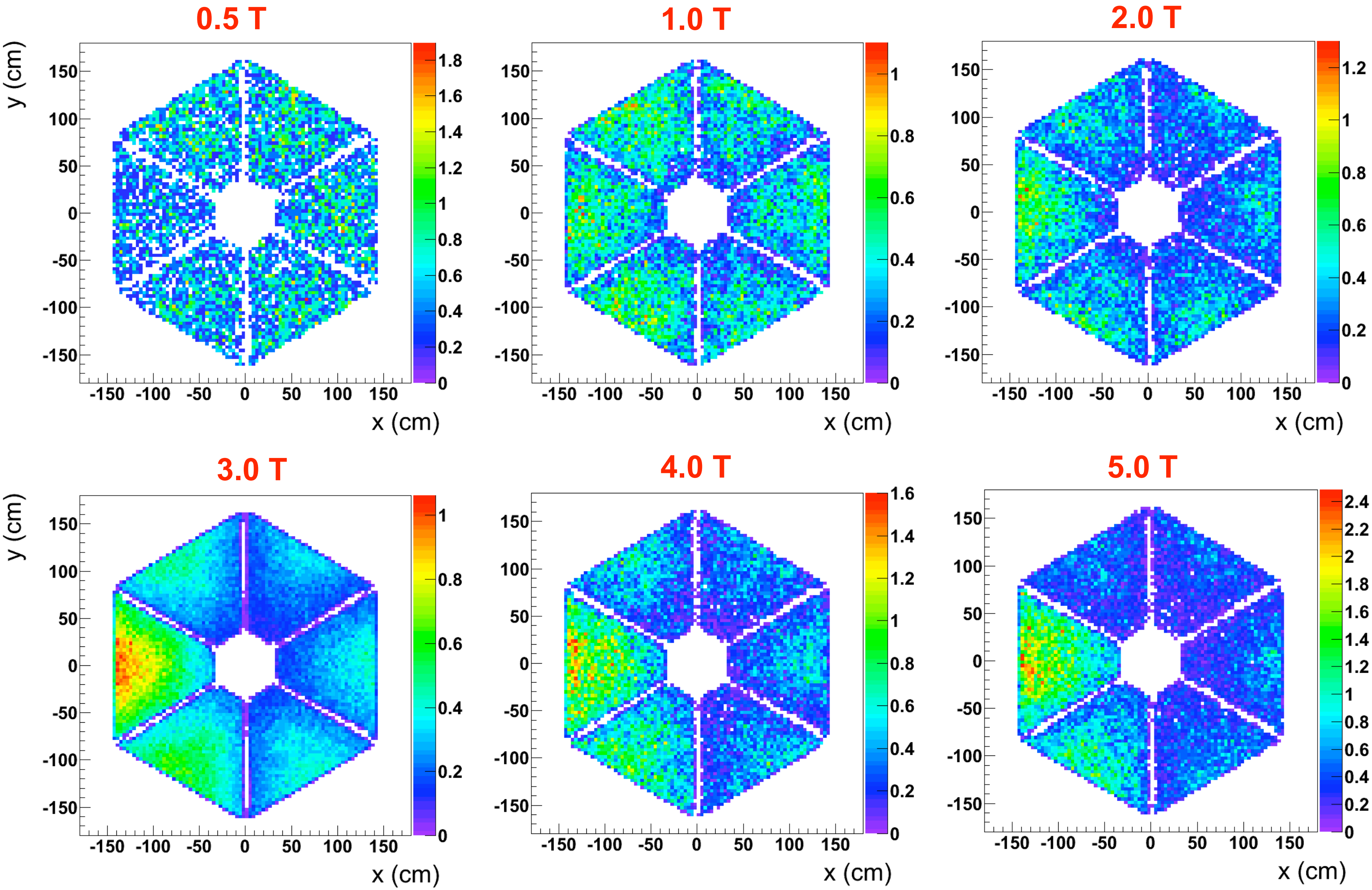
MAPMT definition

H8500 geometry

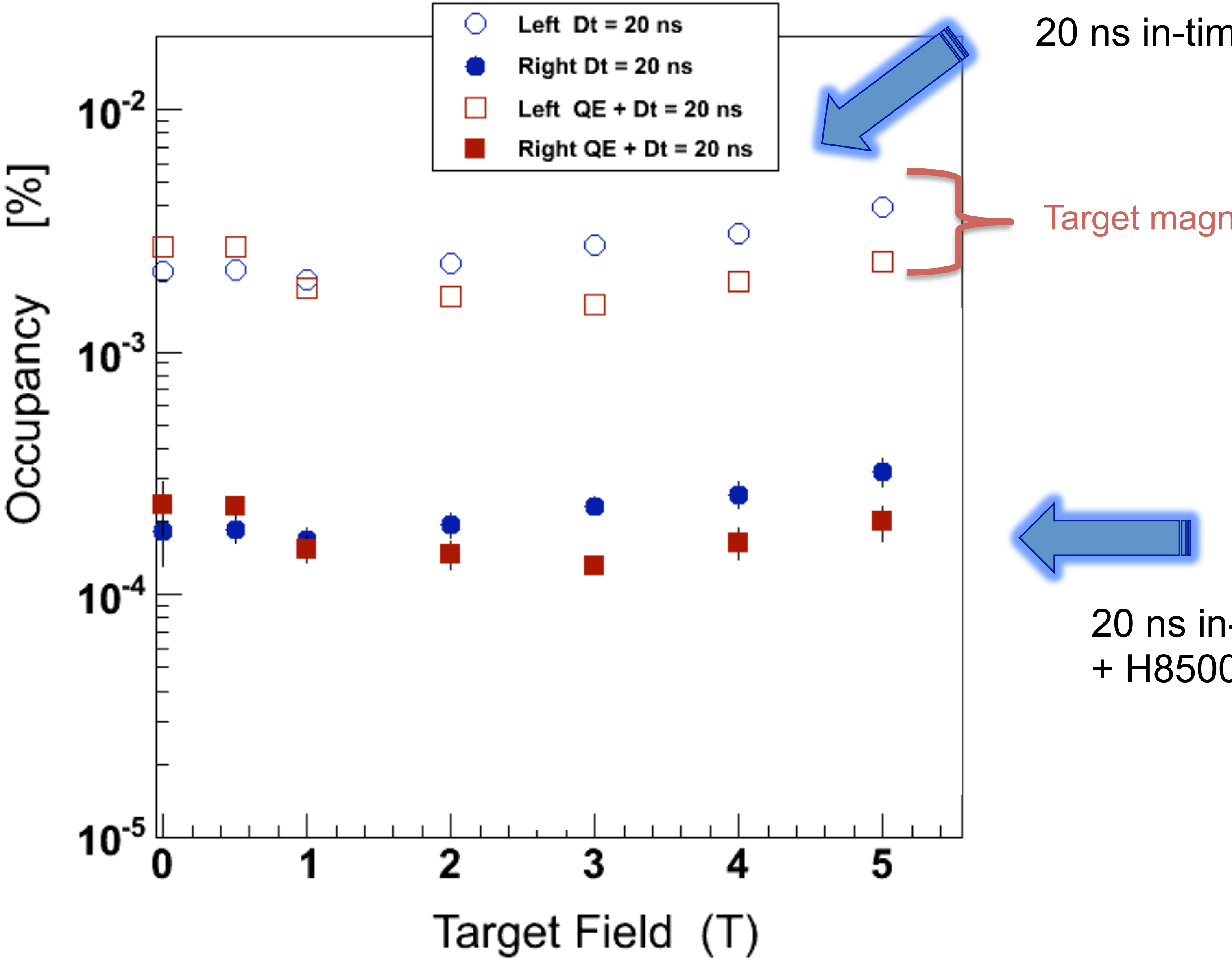
Not optimized pixel definition



The RICH Hit Probability



The RICH Occupancy @ $L=10^{34}$

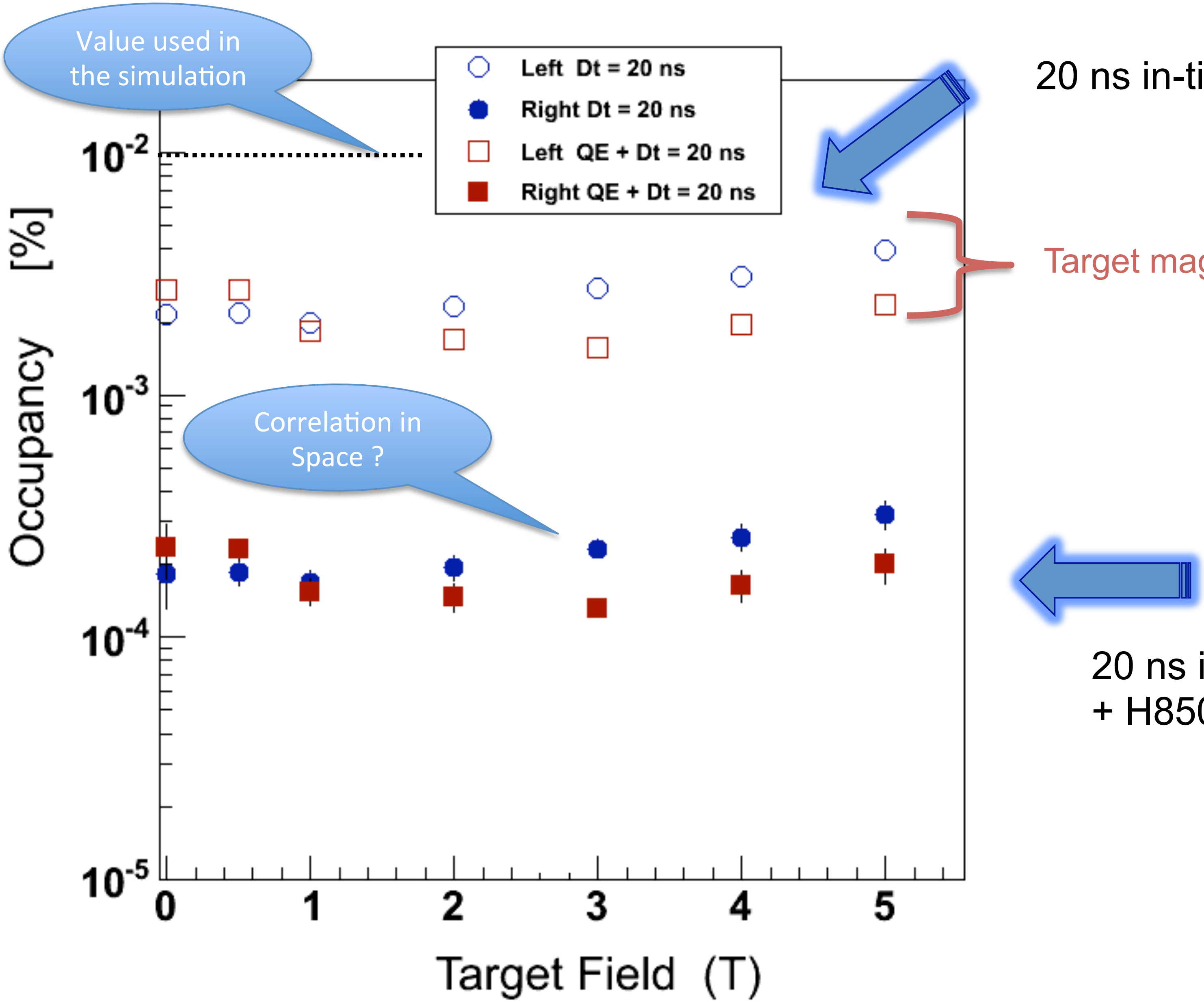


20 ns in-time window

Target magnet torque

20 ns in-time window
+ H8500 Q.E.

The RICH Occupancy @ L=10^{34}



20 ns in-time window

Target magnet torque

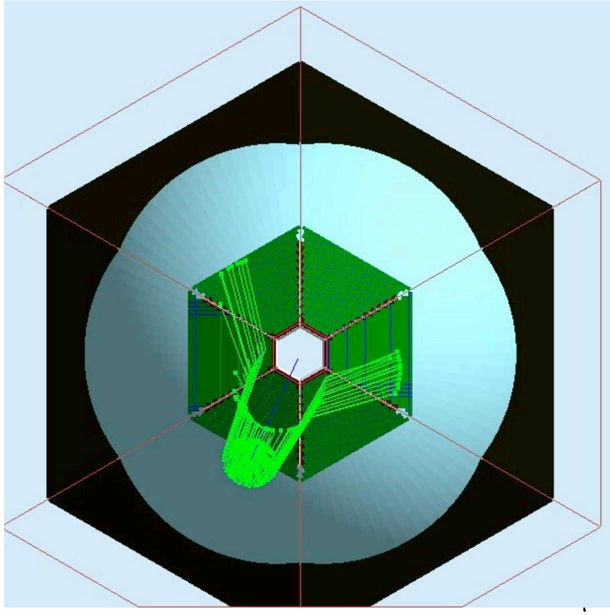
20 ns in-time window
+ H8500 Q.E.

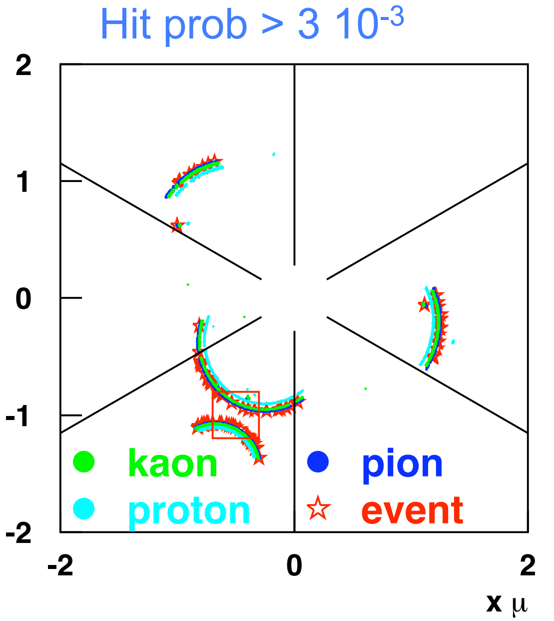
The pattern recongnition

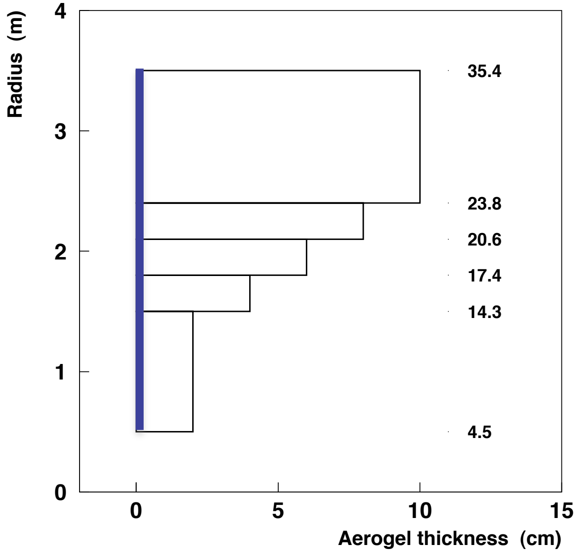
200 trials per point

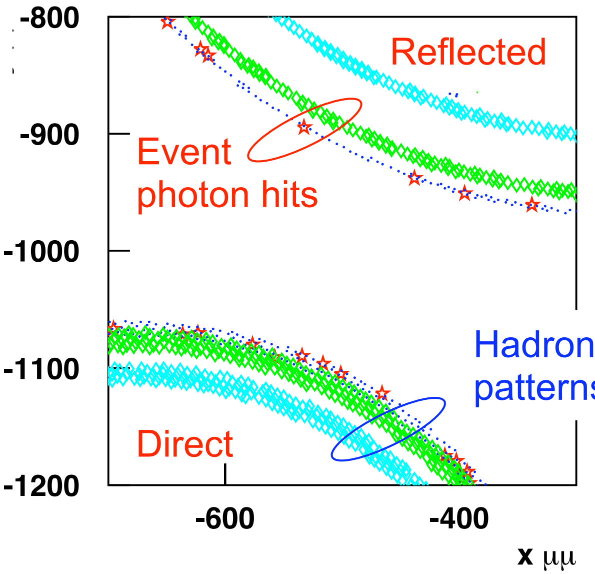
Aerogel:
- n=1.06
- thick. increasing with radius: 2-4-6-8-10 cm

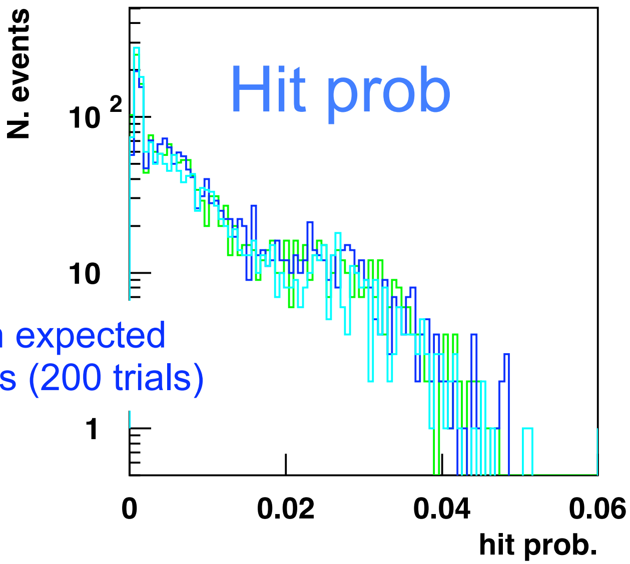
Mirror: 14° - 25°
MA-PMTs: UBA











The likelihood

For a given track t and particle hypothesis h $(= \pi, K, p)$ use **direct ray tracing** for a large number of generated photons to determine the **hit probability for each PMT**

The **measured hit pattern** is compared to the hit **probability densities** for the different hypotheses through a likelihood function:

$$L^{(h,t)} = \Sigma_i log[P^{(h,t)}_{PMT}(i)C_{PMT}(i) + \overline{P}^{(h,t)}_{PMT}(i)(1 - C_{PMT}(i))]$$

(the hypothesis that maximizes $\mathbf{L^{(h,t)}}$ is assumed to be true)

$C_{PMT}(i)$ is the hit pattern from data
= 1 if the ith PMT is hit
= 0 if the ith PMT is not hit

$P^{(h,t)}_{PMT}(i)$ is the probability of a hit given the kinematics of track t and hypothesis h

$$P^{(h,t)}_{PMT}(i) = 1 - exp(-\frac{N^{(h,t)}(i)}{\Sigma_i N^{(h,t)}(i)} n^{(h,t)} - B(i))$$

$\overline{P}^{(h,t)}_{PMT}(i) = 1 - P^{(h,t)}_{(PMT)}$ is the probability of no hit

$n^{(h,t)}$ is the total number of expected PMT hits

$B(i)$ is a background term (assumed to be 10^{-4}, fine with prelim. studies)

The goodness parameter

For a given track t and particle hypothesis h $(=\pi, K, p)$ use **direct ray tracing** for a large number of generated photons to determine the **hit probability for each PMT**

The **measured hit pattern** is compared to the hit **probability densities** for the different hypotheses through a likelihood function:

$$L^{(h,t)} = \Sigma_i log[P^{(h,t)}_{PMT}(i) C_{PMT}(i) + \overline{P}^{(h,t)}_{PMT}(i)(1 - C_{PMT}(i))]$$

Sum on all PMTs: it depends on the total number of readout channels and the background level

$$LH = L^{(h,t)} - L^{(h,t)}_{MIN}$$

L minimum: no signal, hits where only background is expected

$$R_{QP} = 1 - \frac{LH^{2st}}{LH^{1st}}$$

Quality parameter:

0 ambiguity → 1 good ID

LH performances for outbending particles

Aerogel:
- n=1.05, λ=5.5 cm
- thick. increasing with radius: 2-4-6-8-10 cm

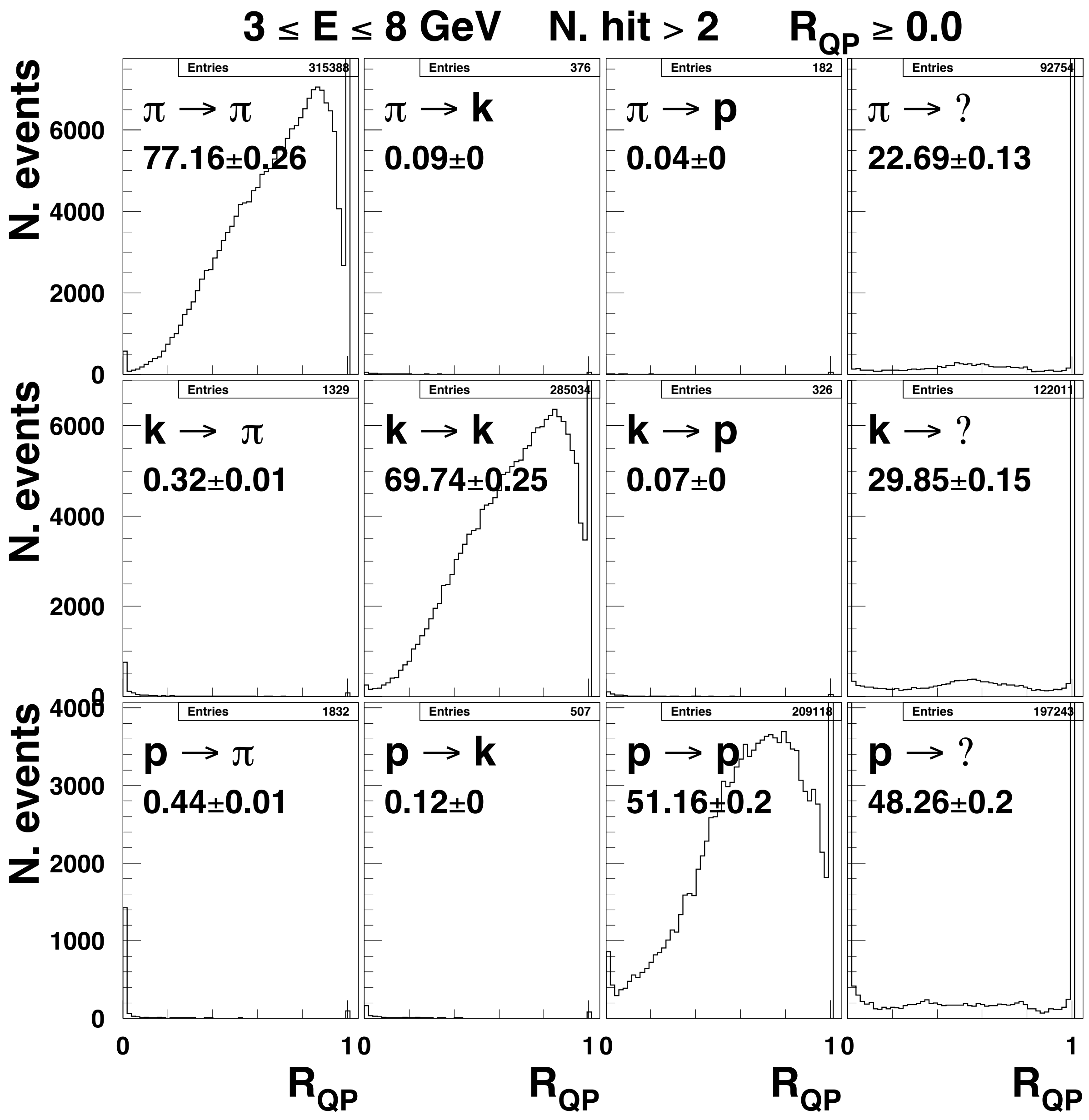
Mirror: 14° - 35°
- 90% reflectivity

MA-PMTs: H8500 eff=0.65

Contamination ~ few per mill

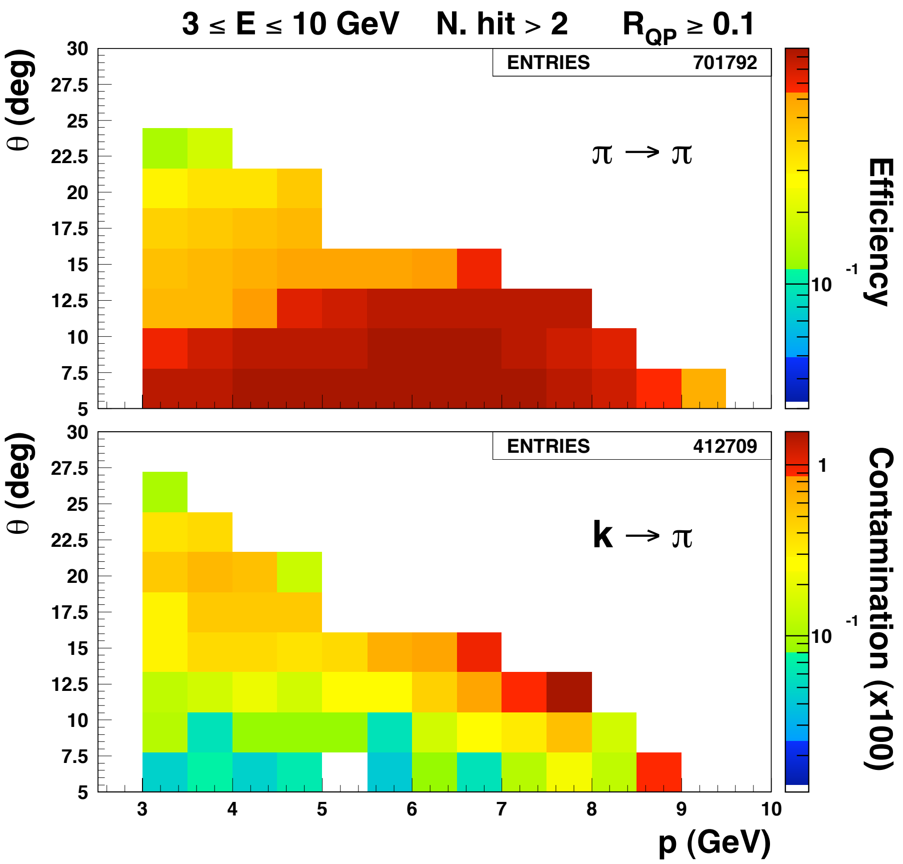
Efficiency ~ 70 % for kaons

Identification quality:
in average good

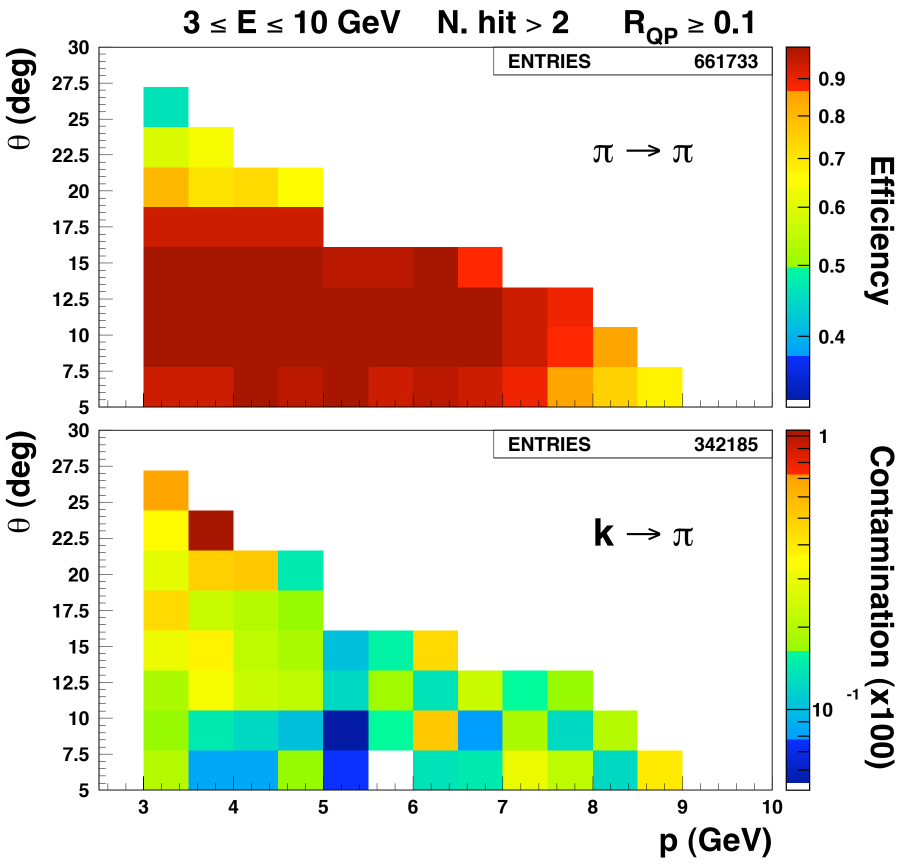


LH performances in 2D

OUT-bending (positives)



IN-bending (negatives)



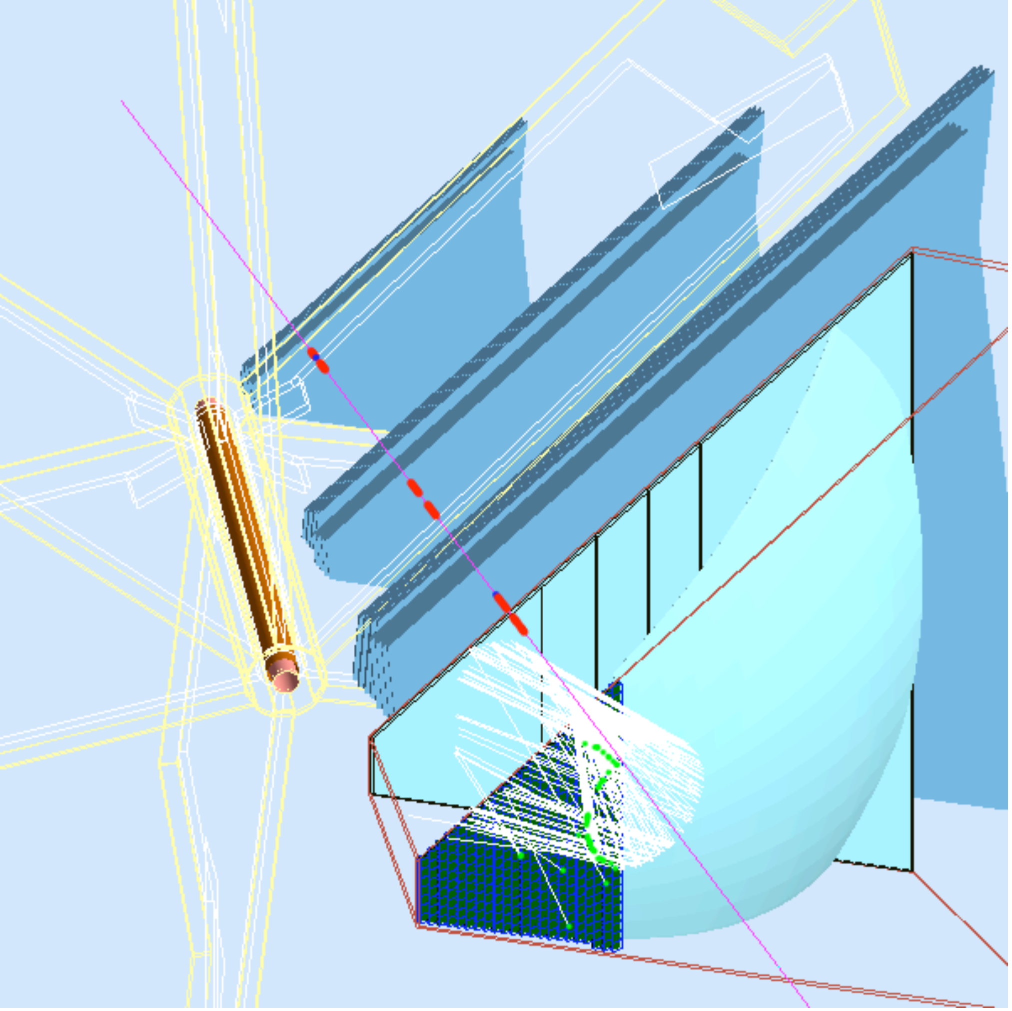
RICH
PROTOTYPE

Prototype for standard set-up

Geometry:

rich_build_radtrap_mirror35_default.pl

On the Jlab GEMC database



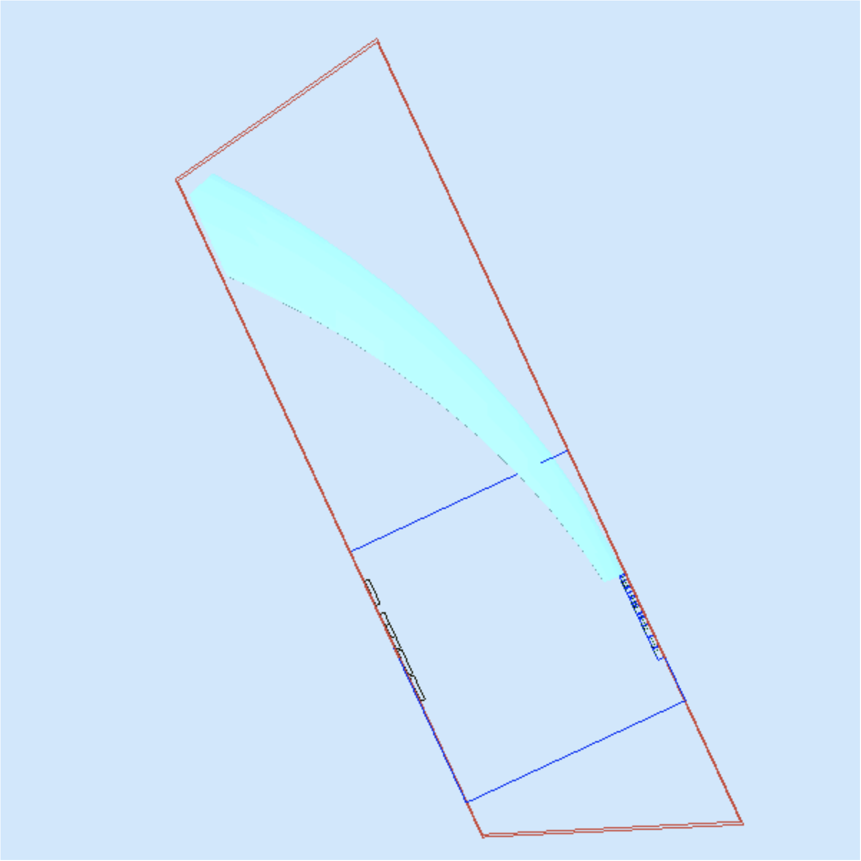
Only one isolated sector

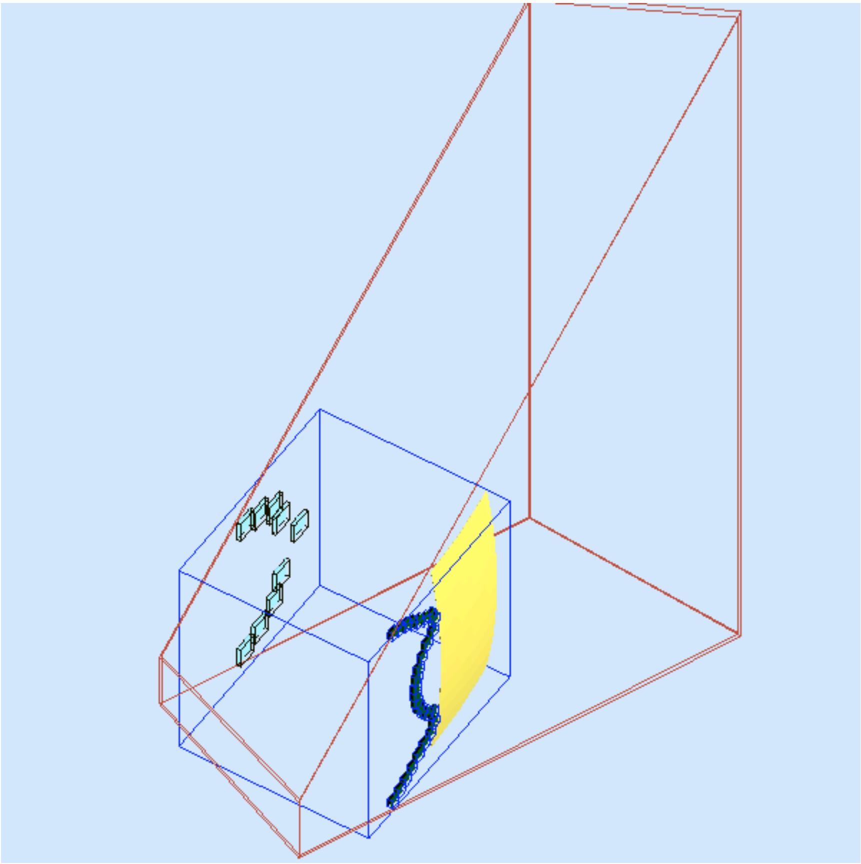
No magnetic field

Aerogel & PMTs as in CLAS12

Prototype geometry

Geometry as close as possible to the CLAS12 RICH design



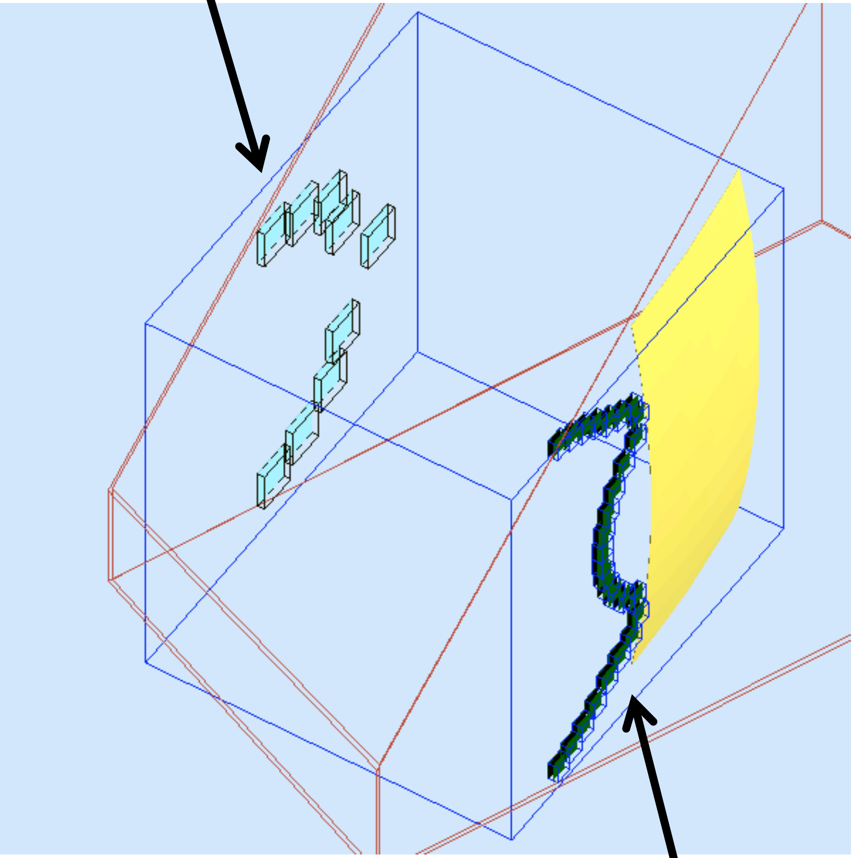


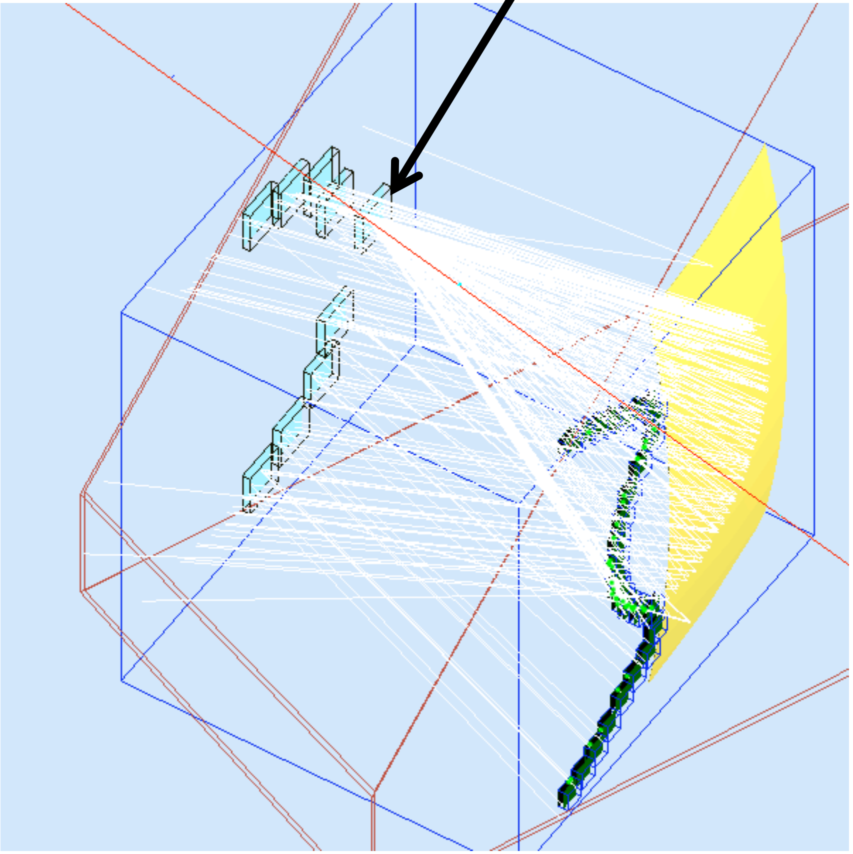
Same gap
Same mirror (portion of)

Prototype geometry

8 Plane mirror + aerogel sandwiches

1 thick radiator

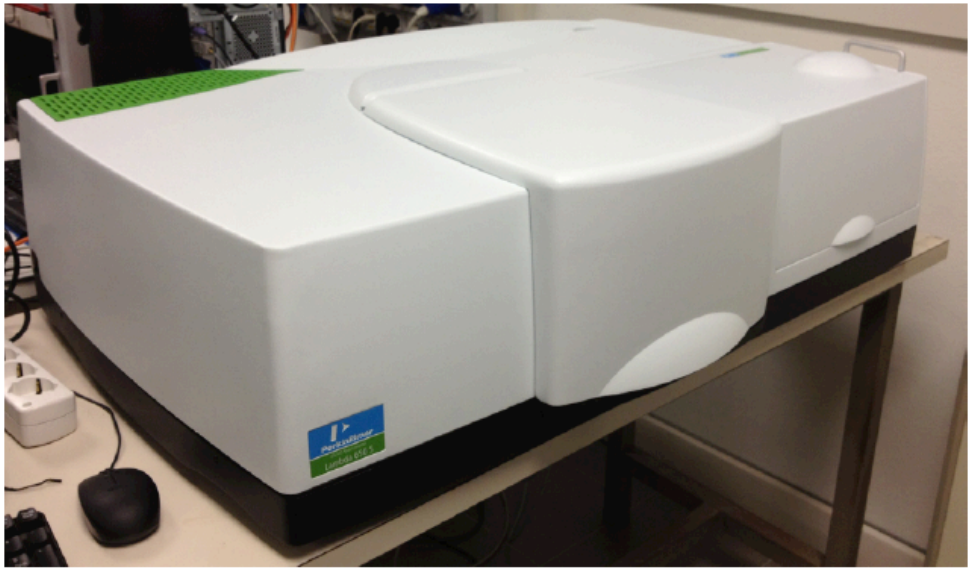




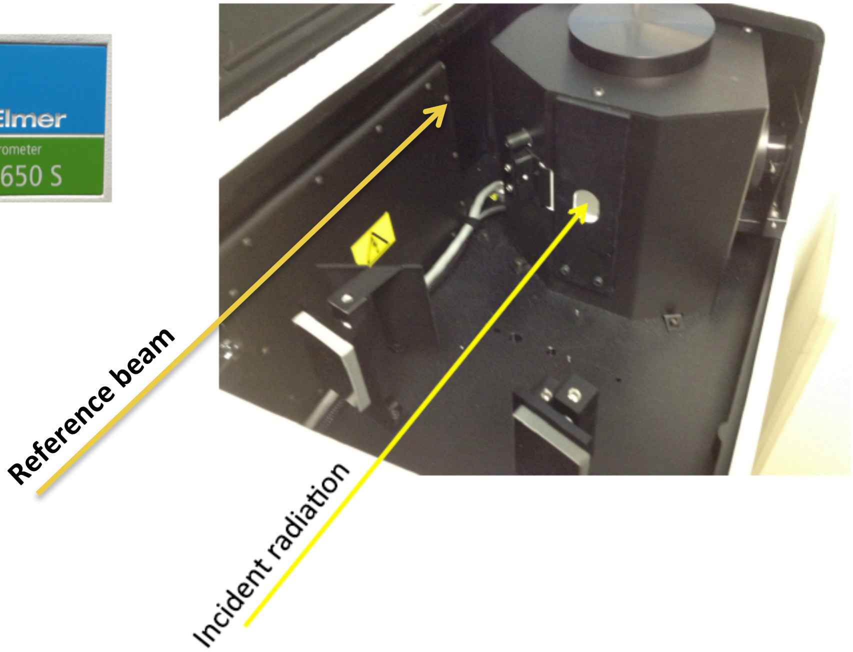
28 MA-PMTs

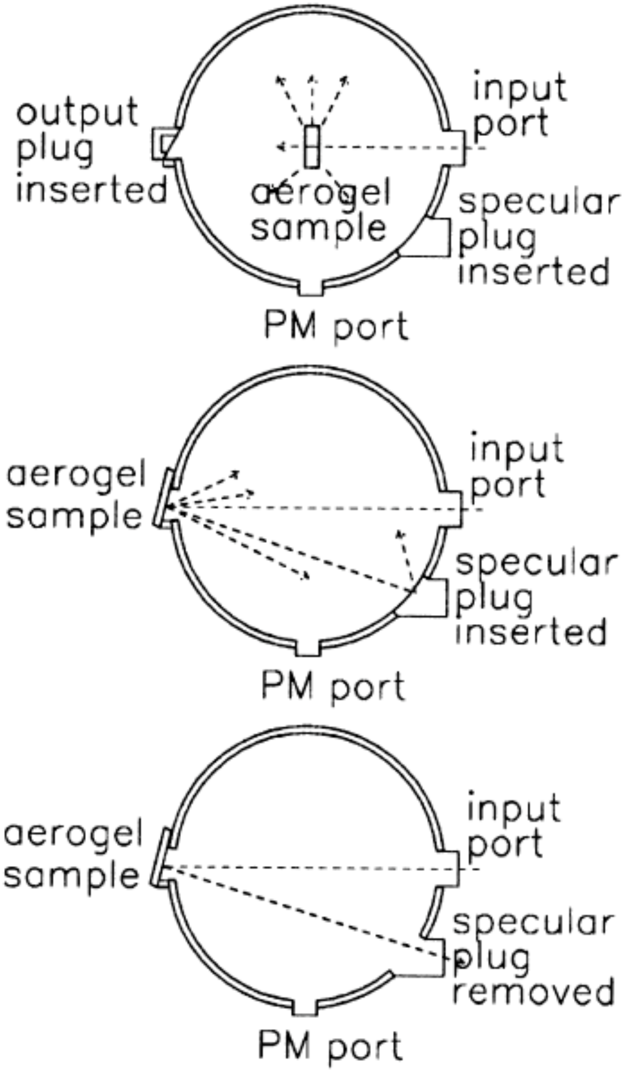
Aerogel Characterization

Aerogel characterization



PerkinElmer
UV/VIS Spectrometer
Lambda 650 S





Aerogel characterization

Basic formalism

Transmittance

Hunt formula

$$T = e^{-\frac{t}{\Lambda_{tot}}} = e^{-t\left(\frac{1}{\Lambda_A}+\frac{1}{\Lambda_S}\right)} = e^{-\frac{t}{\Lambda_A}} \cdot e^{-\frac{t}{\Lambda_S}} = A \cdot e^{-\frac{Ct}{\lambda^4}}$$

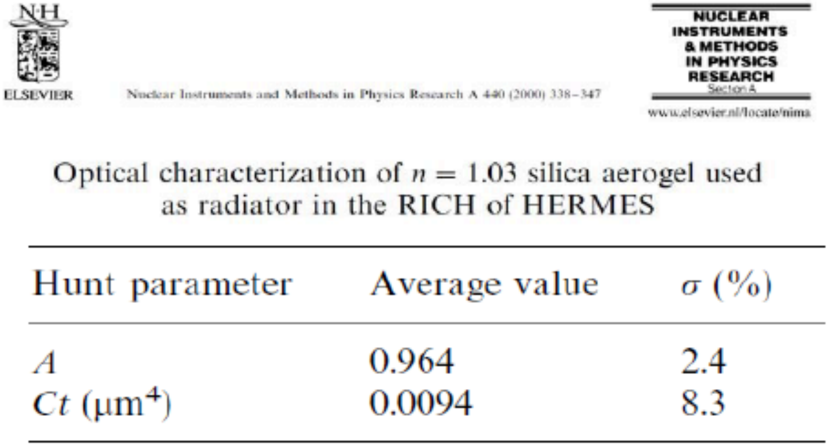
$$A = TF = e^{-\frac{t}{\Lambda_A}} \Longrightarrow$$

Transflectance

$\Lambda_A = \frac{-t}{lnA}$ **Absorption length**

$\Lambda_S = \frac{\lambda^4}{Ct} t$ **Scattering length**

Procedure: measure $T(\lambda) \rightarrow$ fit with Hunt formula $\rightarrow$ extract Λ_A and Λ_S



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Nuclear Instruments and Methods in Physics Research A 440 (2000) 338–347

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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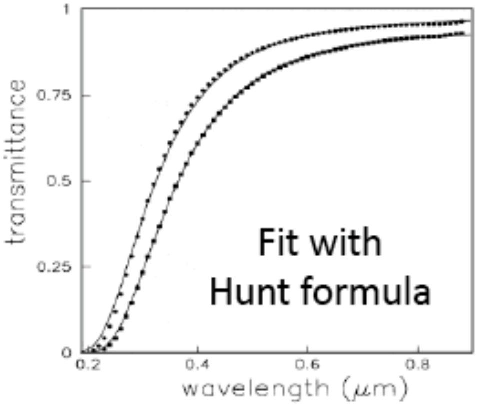
Optical characterization of $n = 1.03$ silica aerogel used as radiator in the RICH of HERMES

Hunt parameter	Average value	σ (%)
A	0.964	2.4
Ct (μm^4)	0.0094	8.3



Fit with Hunt formula

Aerogel characterization

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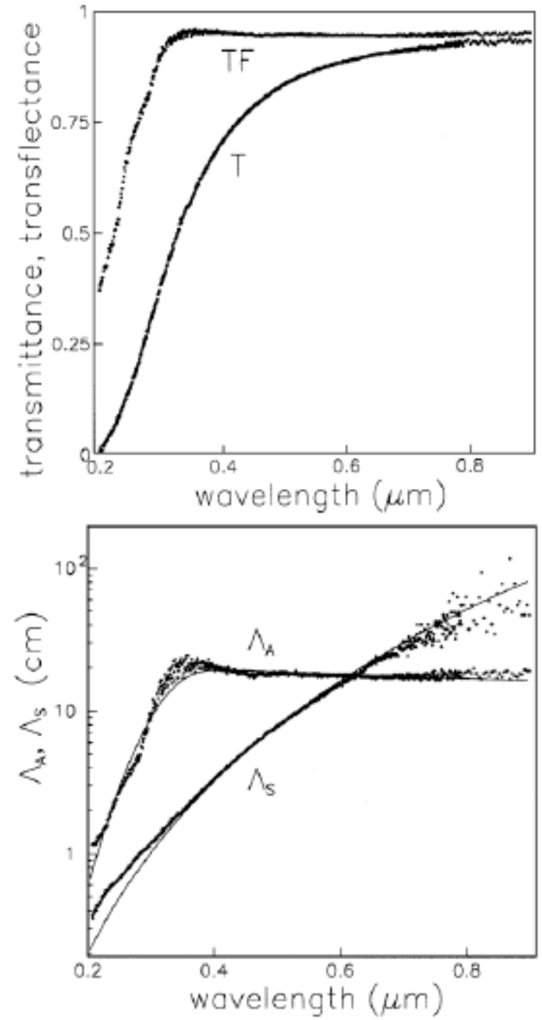
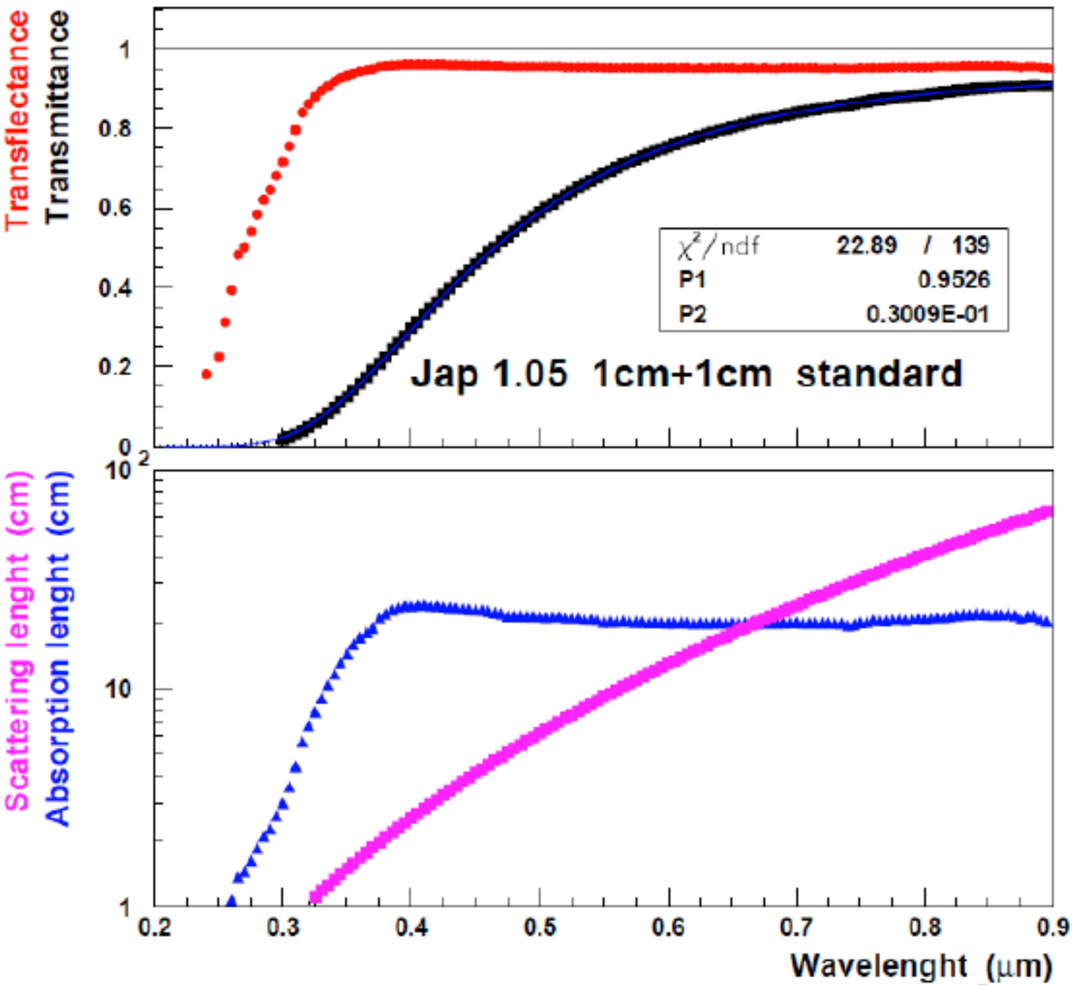
Nuclear Instruments and Methods in Physics Research A 440 (2000) 338–347

NUCLEAR
INSTRUMENTS
& METHODS
IN PHYSICS
RESEARCH
Section A

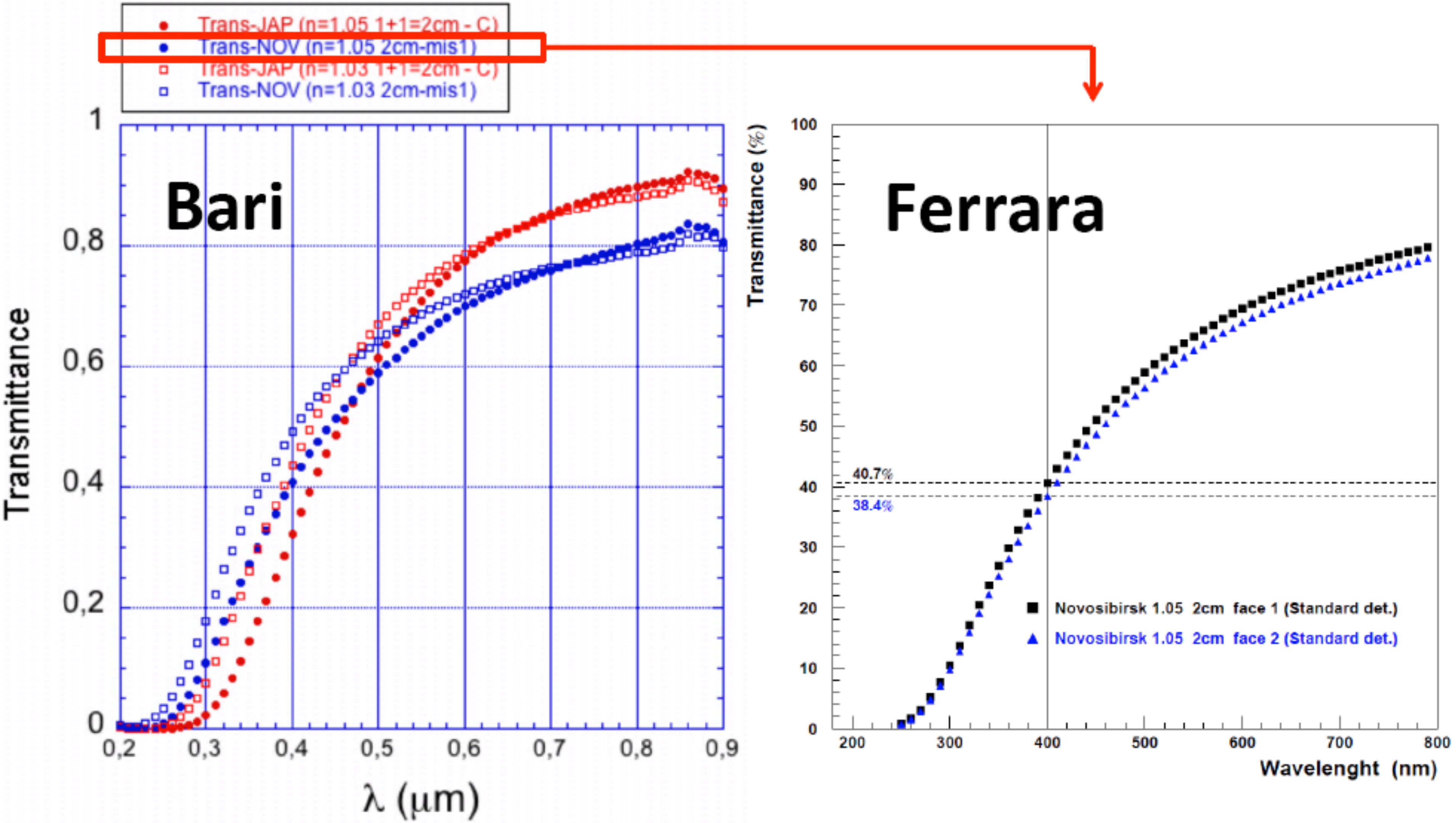
Optical characterization of $n = 1.03$ silica aerogel used as radiator in the RICH of HERMES



Ferrara measurements



Aerogel characterization



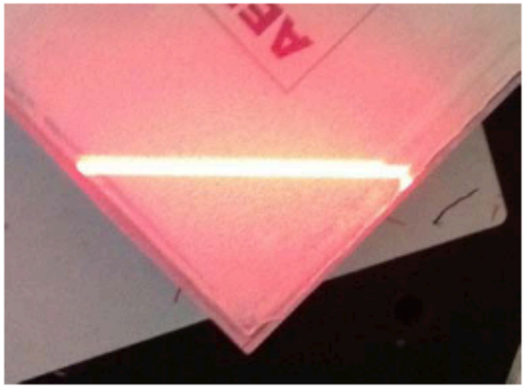
The two measurements are consistent:

- T≈ 40% at λ=400 nm
- T≈ 80% at λ=800 nm

Aerogel characterization

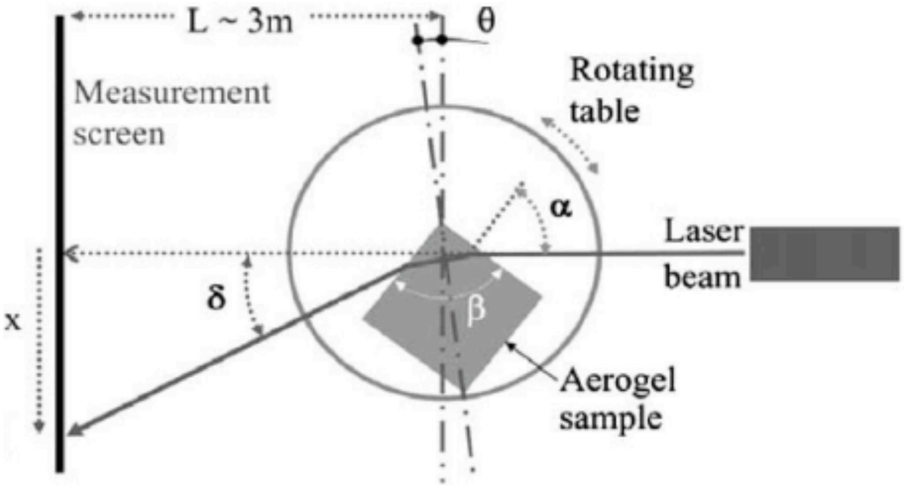
The "standard prism" method

- The adjacent sides of the aerogel tile form a prism
- Measure the deviation of a laser beam passing through the aerogel tile edges
- The position of the laser beam spot is measured on a screen placed downstream



- The aerogel refractive index *n* can be determined by fitting the angular distribution of the spots of the refracted beam with the **Snell-Descartes law:**

$$\delta = \alpha - \beta + \arcsin\left\{ n \cdot \sin\left[\beta - \arcsin\left(\frac{\sin\alpha}{n} \right) \right] \right\}$$



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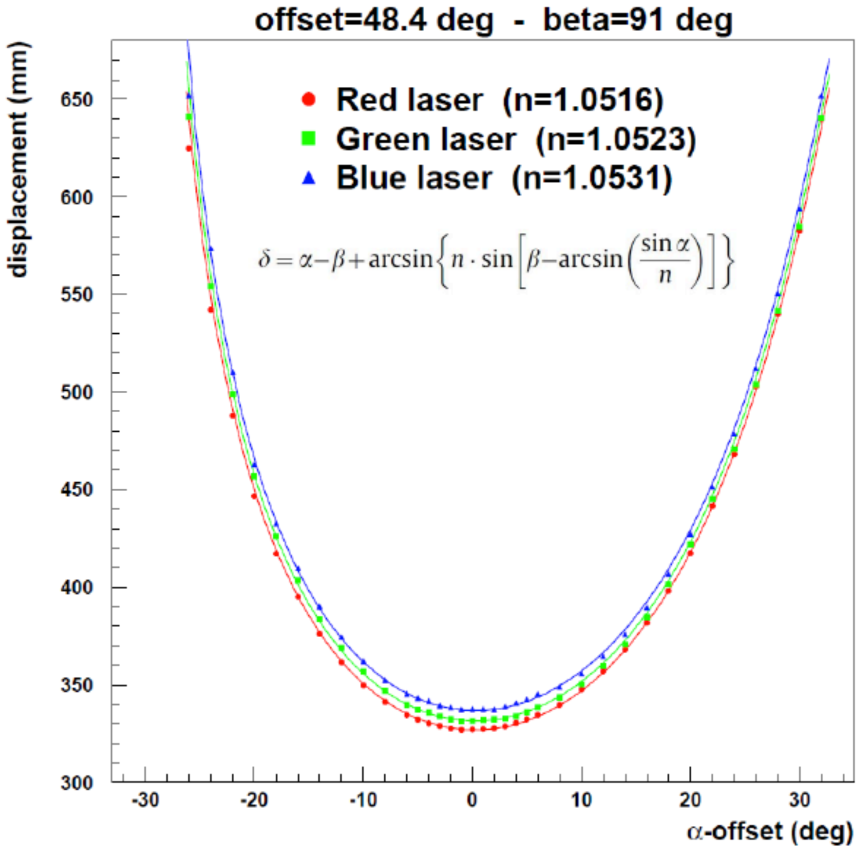
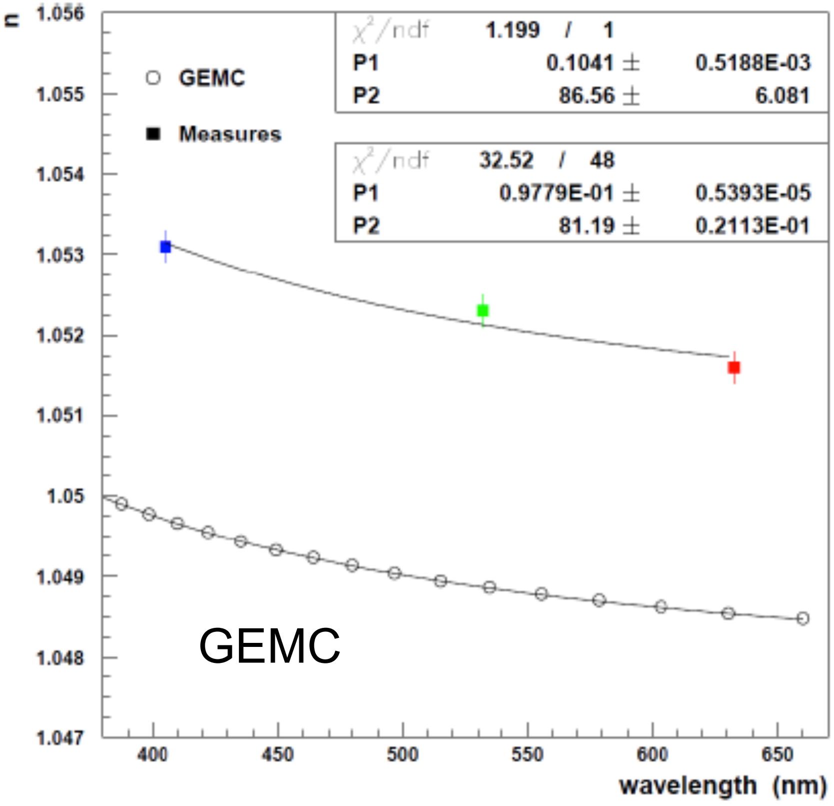
Aerogel characterization

The dispersion law

$$n^2(\lambda) - 1 = \frac{a_0\lambda^2}{\lambda^2 - {\lambda_0}^2} \Rightarrow n(\lambda) = \sqrt{1 + \frac{P_1\lambda^2}{\lambda^2 - {P_2}^2}}$$





~ 0.003 oofset but same trend !

Silicon PhotoMultipliers

The SiPM alternative

- MA-PMTs are an almost plug and play device good to accomplish one sector before CLAS12 starts physics measurements

Major issues

- Their material budget, cost and magnetic field sensitivity limit the alternatives for better detector configurations

- **Cost:**
  - ✓ *Reduce active area*
  - ✓ *Operate with cheaper devices*

- **Average number of photoelectrons:**
  - ✓ *Increase quantum efficiency*
  - ✓ *Move QE peak toward green*
  - ✓ *Change configuration*

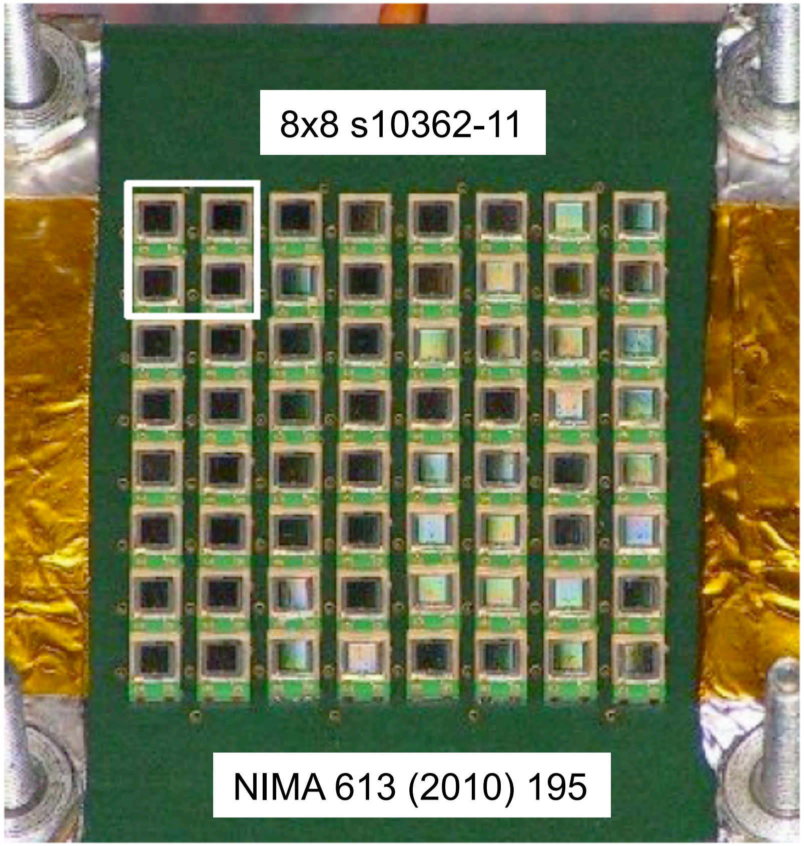
SiPM might offer a cheaper and more efficient solution expecially in a longer time perspective for the other sectors

- Important to test them before the TDR write-up

SiPM: Plans

Test feasibility of the single photon detection in the CLAS12 framework

- **Use 3x3 mm devices to cope with large area and 50P or 100P to maximize fill factor**
- **Works with 8x8 MPPC modules to mimic the H8500 layout (modularity and direct comparison of performances)**



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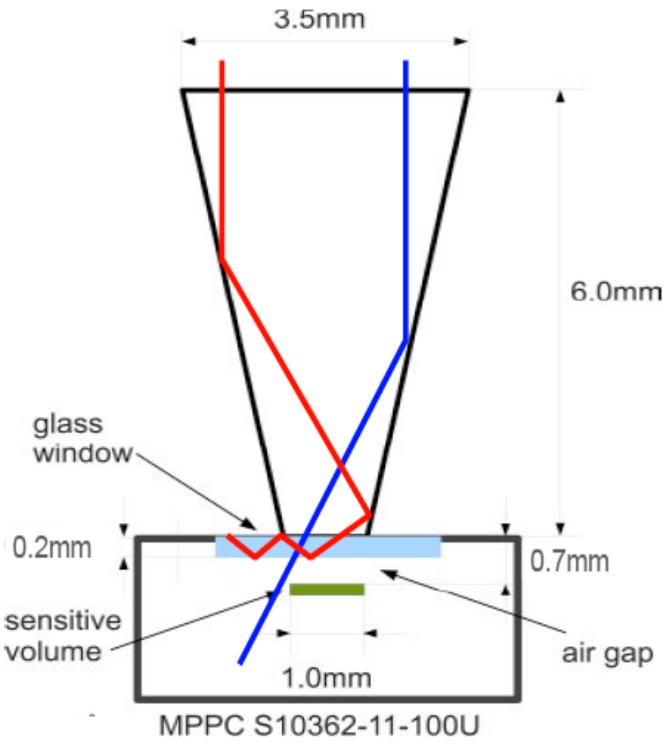
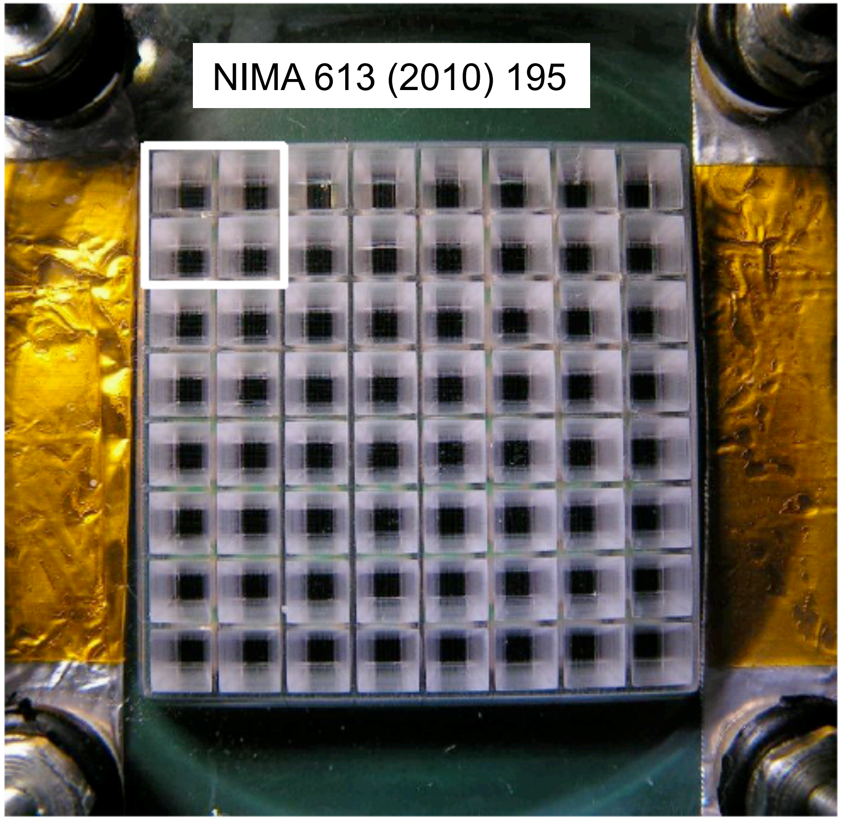
SiPM: Plans

Test feasibility of the single photon detection in the CLAS12 framework

- **Test light collectors to improve signal over background ratio and reduce number of channels**

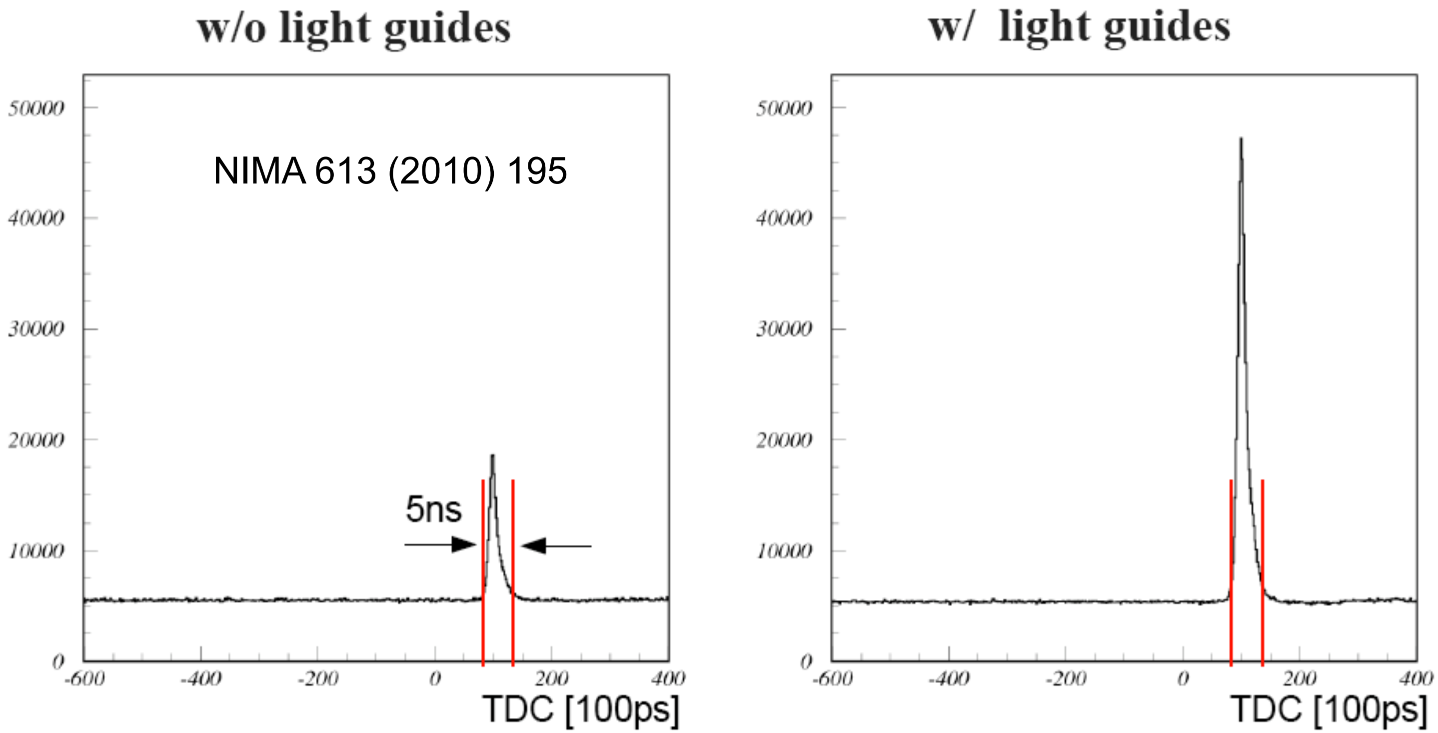




SiPM: Plans

Test feasibility of the single photon detection in the CLAS12 framework

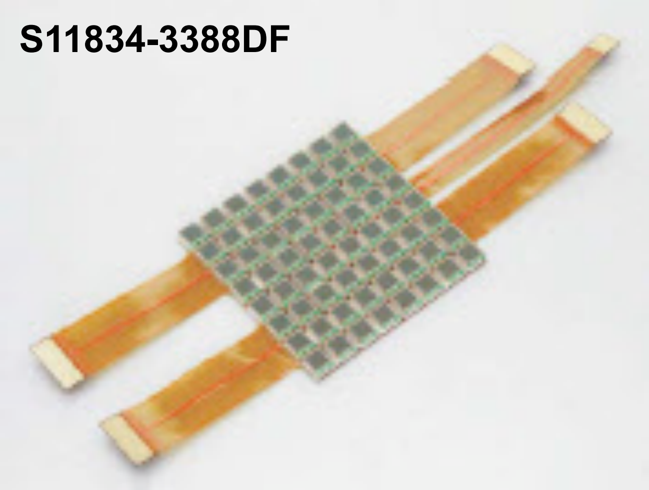
- **Control the dark-count rate**
  - ✔ *Fast electronic and narrow time coincidence*
  - ✔ *Detailed analysis of single-photon signal shape*
  - ✔ *Look for low dark-count rate devices*
  - ✔ *Control in temperature*



SiPM: Plans

Test feasibility of the single photon detection in the CLAS12 framework

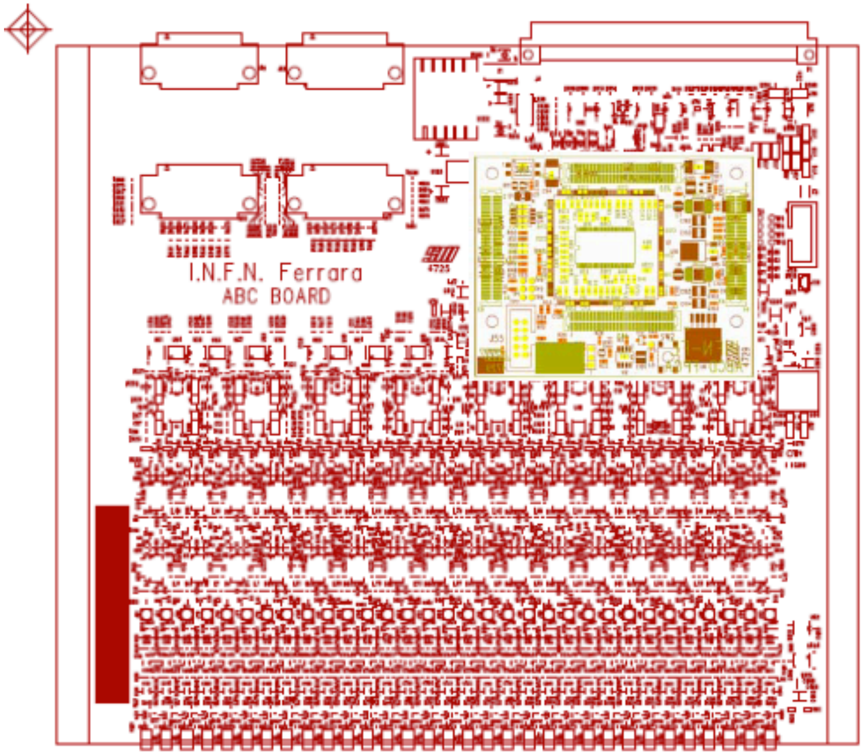
- **Limit the cost**
- **Await cost-effective solutions and for SiPM price reduction with time**



SiPM: Front-End electronic

Start with the board developed in Ferrara for SuperB

- 32 channels
- Programmable bias voltage for each channel
- Programmable discriminating threshold for each channel
- Time resolution dominated by the signal rise-time variations
  (goal: keep it of the order of 1 ns)
- Digital output to TDC as standard
- Analogic output to sampling digitalizer for background studies



"IFR_ABCD" mother board

Attivita' Ferrara

- **Proposal of SIDIS experiments**
  - ✔ *With hadron ID (RICH)   A-, B+ approved*
  - * *With transverse target (HD-Ice)   C2*
  - * *Dihadron + DVCS channels*

- **HD-Ice target magnet configuration**
  - ✔ *Magnetic stability*
  - ✔ *Moeller background*
  - ✔ *Acceptance*
  - * *Quench protection*

- **RHIC (GEANT4-based) simulation + reconstruction available**
  - ✔ *Detailed geometry*
  - ✔ *Optical effects (mirror reflectivity)*
  - ✔ *Digitalization*
  - ✔ *Background (Rayligh)*
  - ✔ *Likelihood based on direct ray-tracing*
  - * *Validation of the preliminary results ongoing*
  - * *Optimal compromise to be found*
- **RHIC prototype**
- **Aerogel Characterization**
- **SiPM for Cherenkov light detection**

Nucleon 3D structure with SIDIS & exclusive experiments