The RICH detector for CLAS12 at Jefferson Lab

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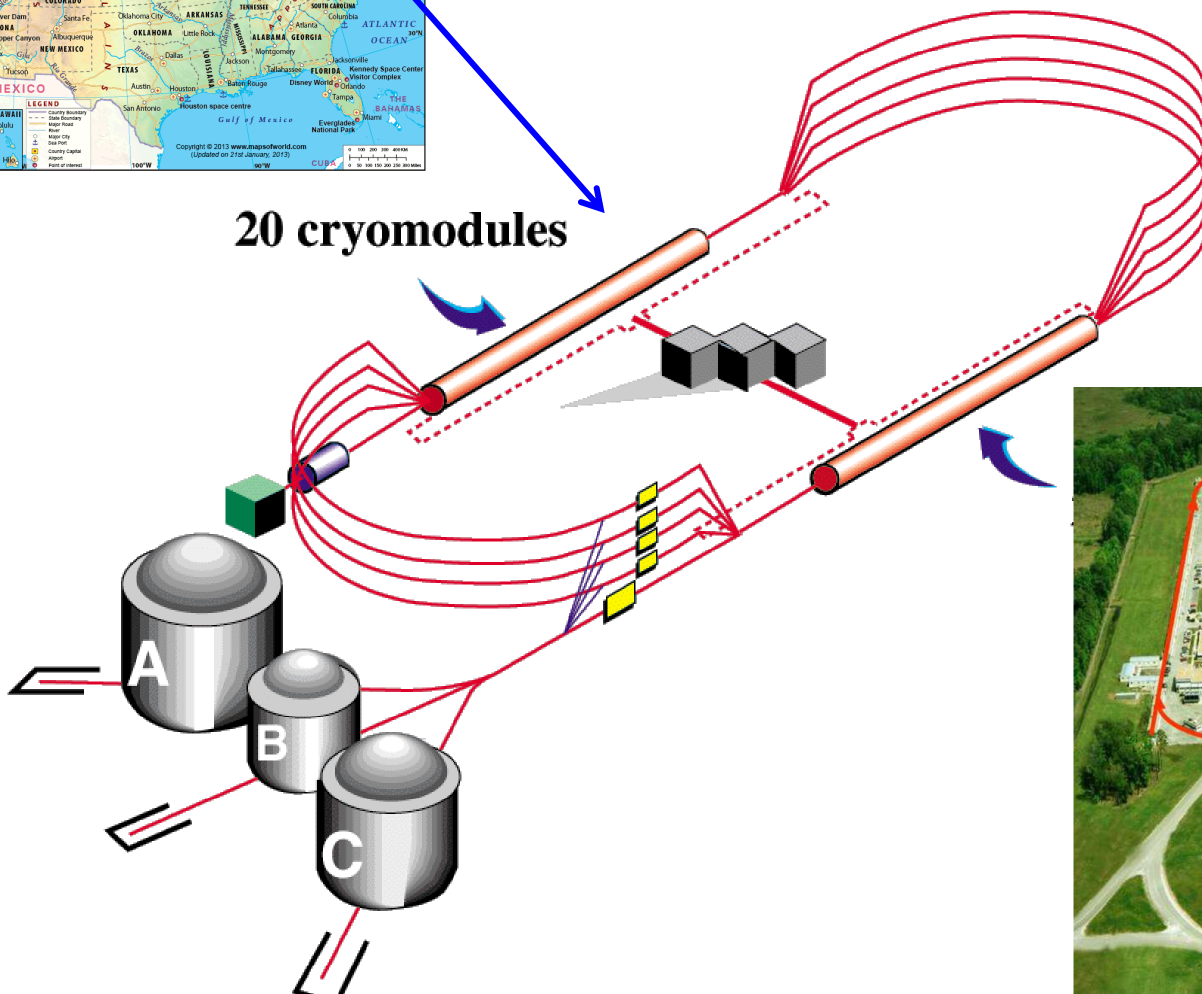
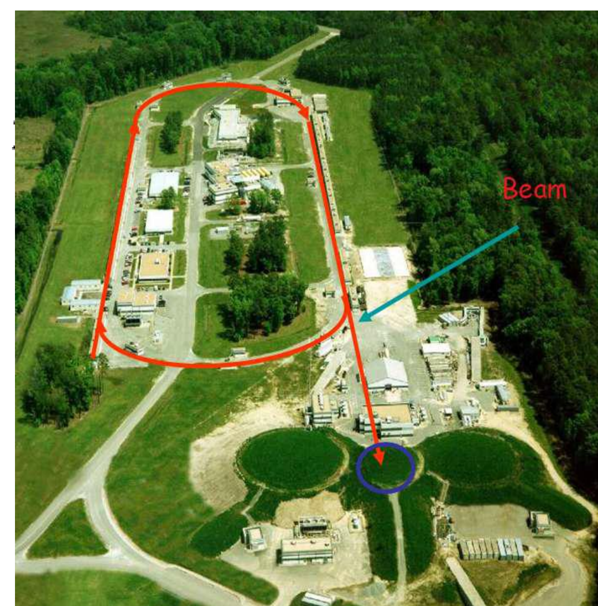
The CEBAF facility at JLab (1995-2012)

- Continuous electron beam
- Energy 0.8-5.7 GeV, Current 200μA
- polarization 85%
- delivered simultaneously to 3 Halls (A,B,C)

6 GeV CEBAF

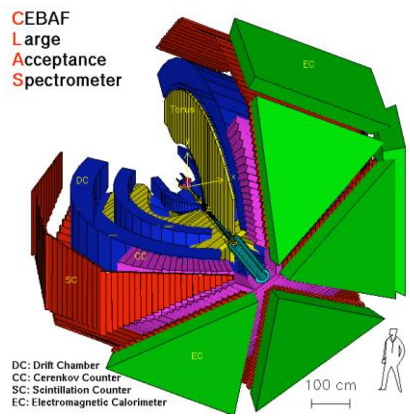




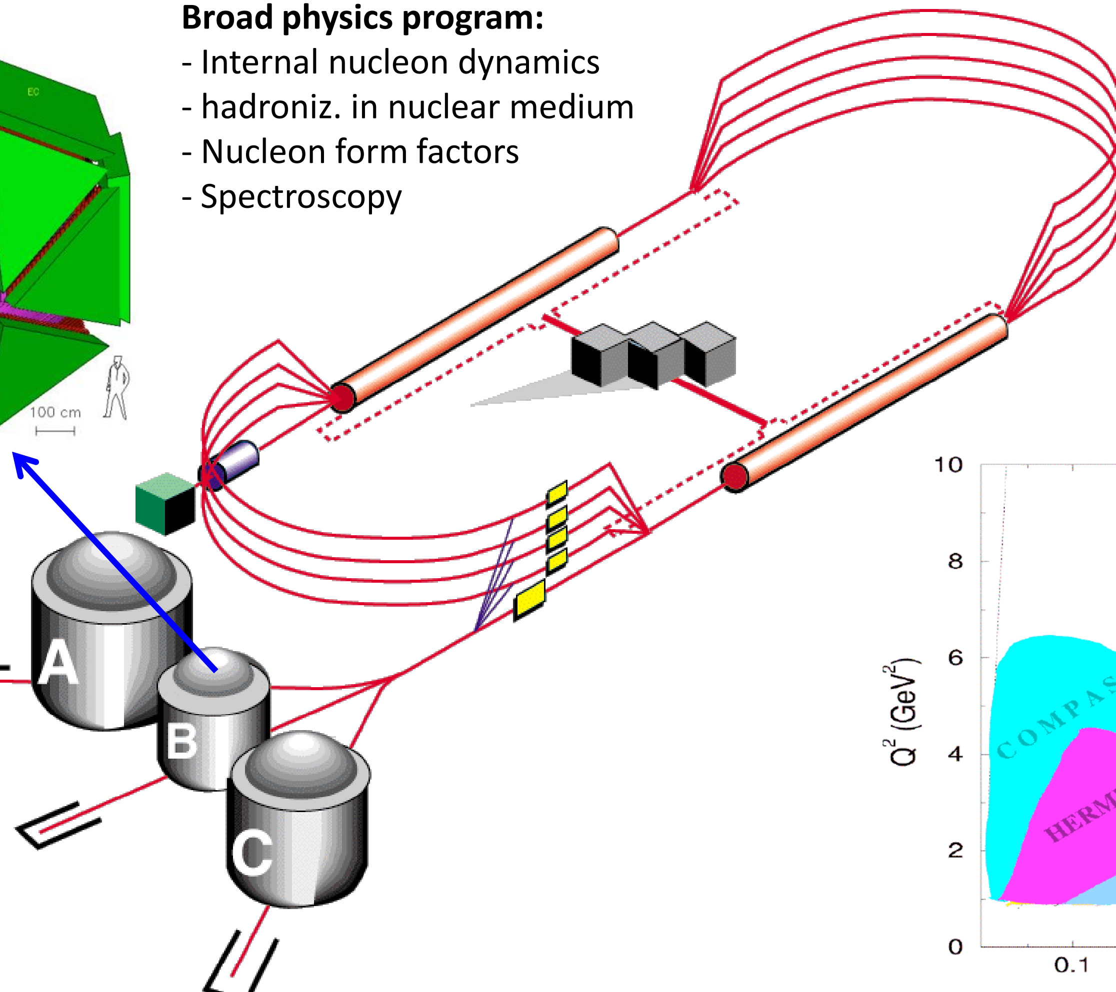
The CEBAF facility at JLab (1995-2012)

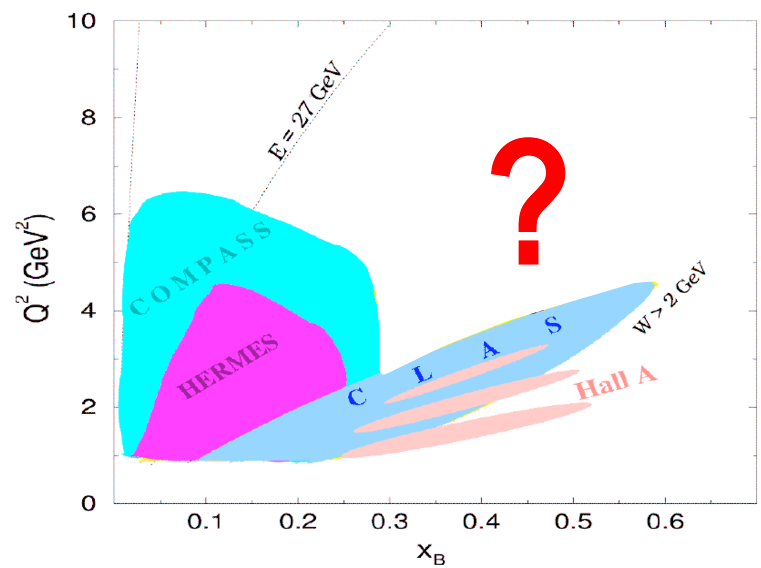
Large acceptance spectrometer dedicated to high-luminosity pol/unpol lepton scattering experiments.
Designed for multi-particle final states.

- Continuous electron beam
- Energy 0.8-5.7 GeV, Current 200μA
- polarization 85%
- delivered simultaneously to 3 Halls (A,B,C)

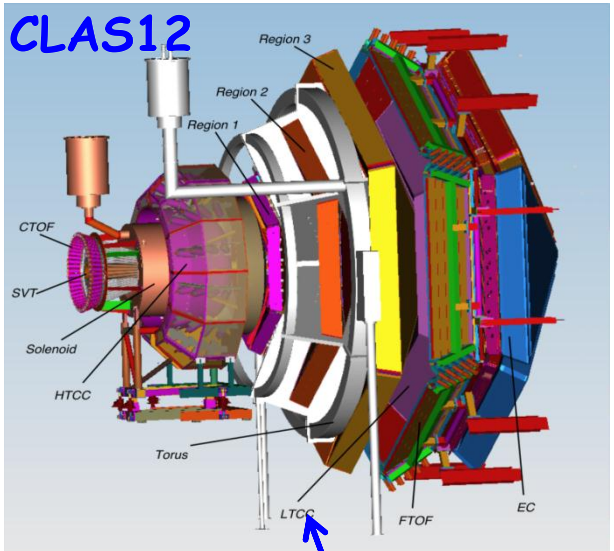


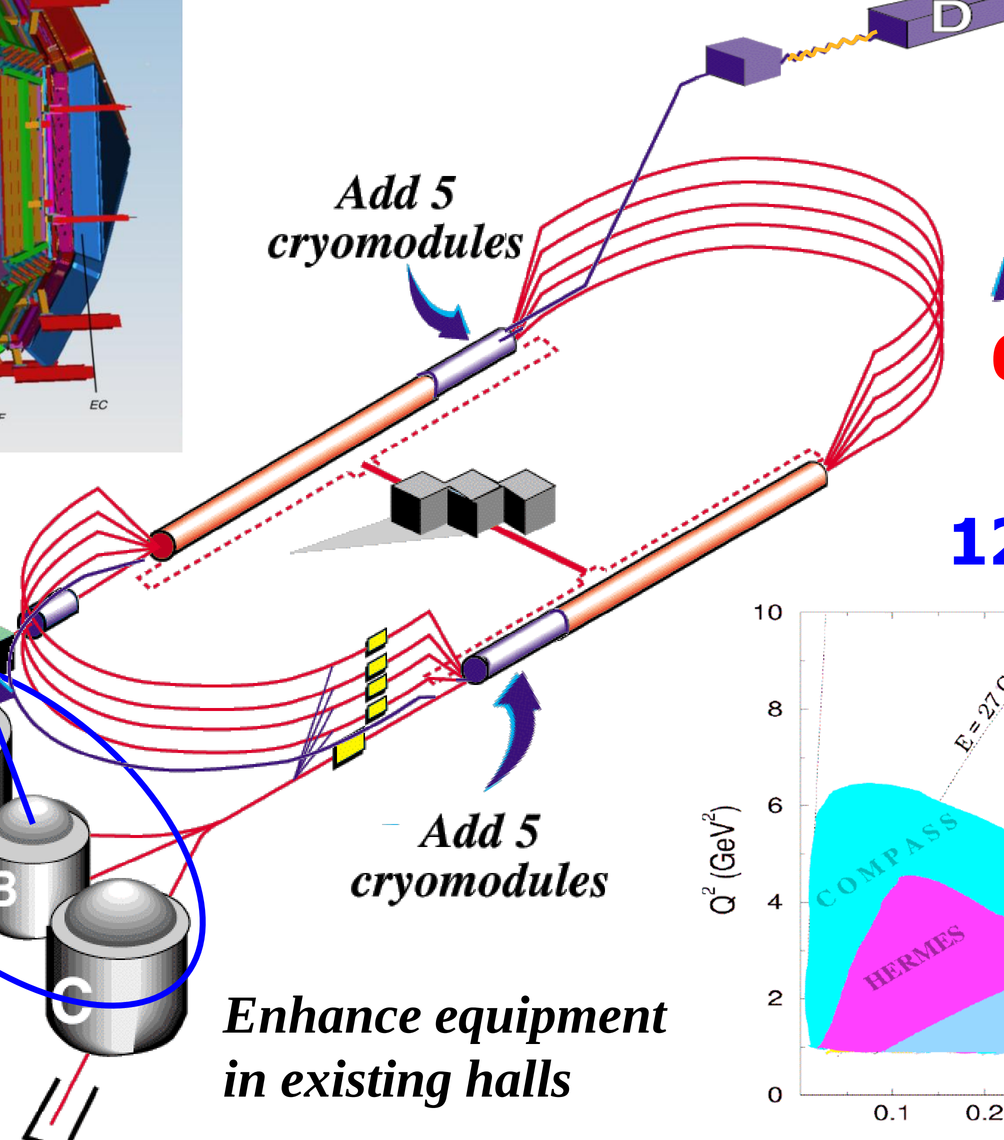
Broad physics program:
- Internal nucleon dynamics
- hadroniz. in nuclear medium
- Nucleon form factors
- Spectroscopy





The 12 GeV upgrade (2012-2015)





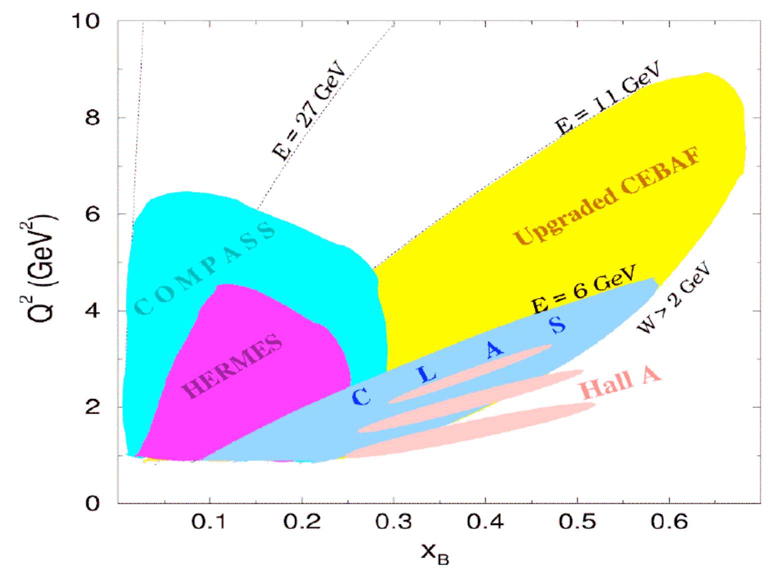
add Hall D (and beam line)

Upgrade magnets and power supplies

6 GeV CEBAF

12 GeV CEBAF

Enhance equipment in existing halls

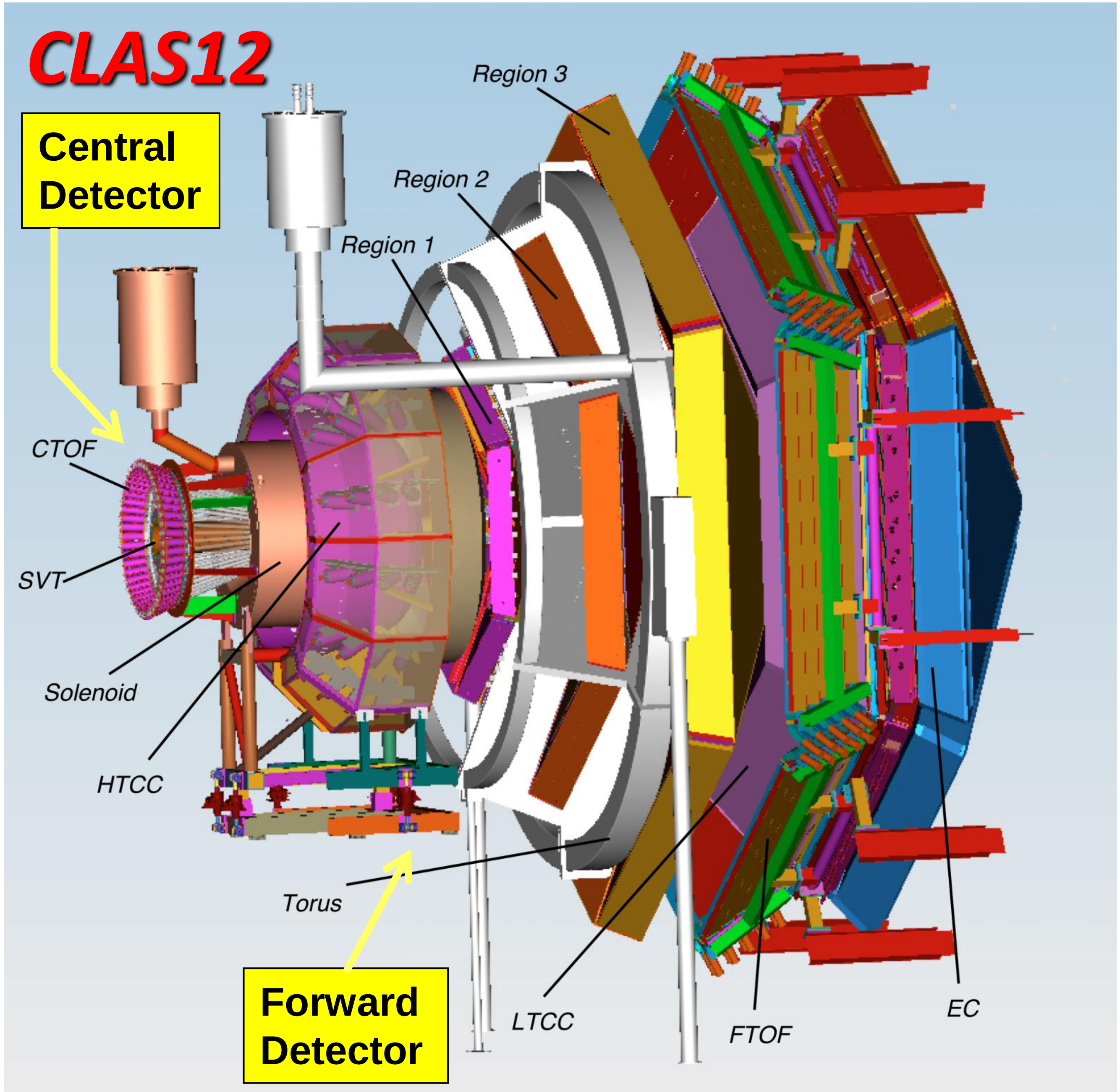


Lumi up to $10^{35}\ cm^{-2}s^{-1}$
High pol. electron beams
H and D polarized target
Wide acceptance
Very good PID

Forward spectrometer
- *TORUS magnet*
- *Forward vertex tracker*
- *HT Cherenkov Counter*
- *Drift chamber system*
- *LT Cherenkov Counter*
- *Forward ToF System*
- *Preshower calorimeter*
- *E.M. calorimeter*

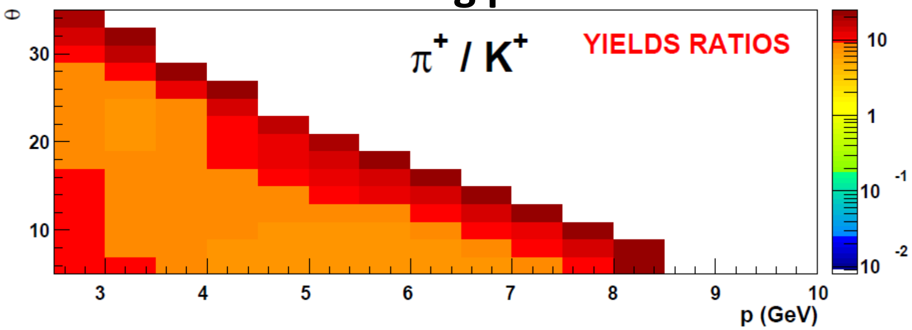
Central Detector
- *SOLENOID magnet*
- *Barrel Silicon Tracker*
- *Central Time-of-Flight*

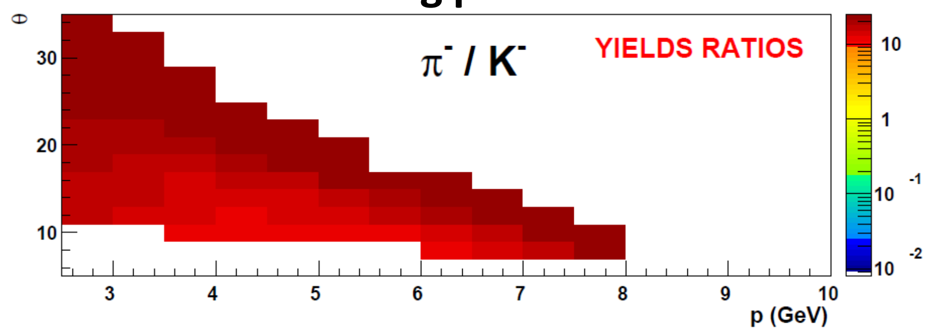
Proposed equipment
- *Small angle tagger*
- *Micromegas in CD*
- *Neutron detector in CD*
- ***RICH to replace LTCC***



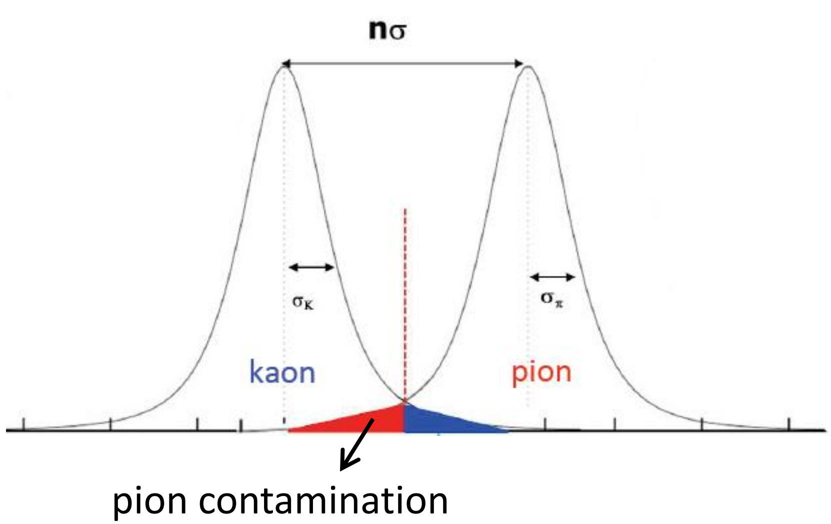
Hadron identification @ CLAS12

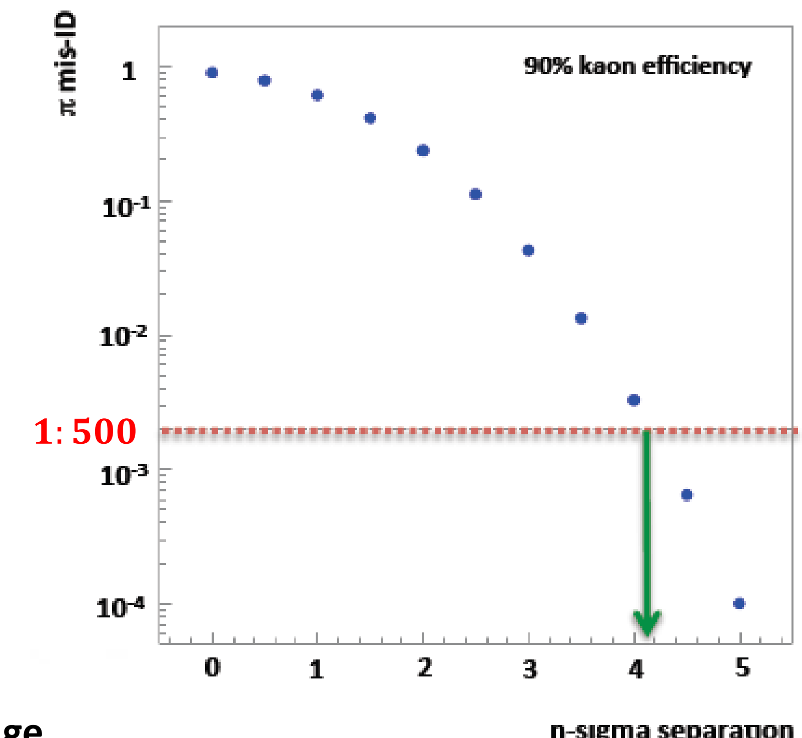
Out-bending particles / **In-bending particles**





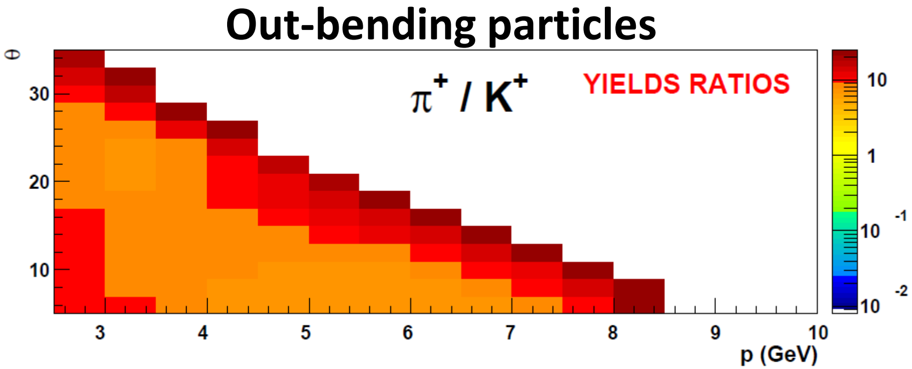
Kaon yields a factor ~ 10 smaller than pion yields

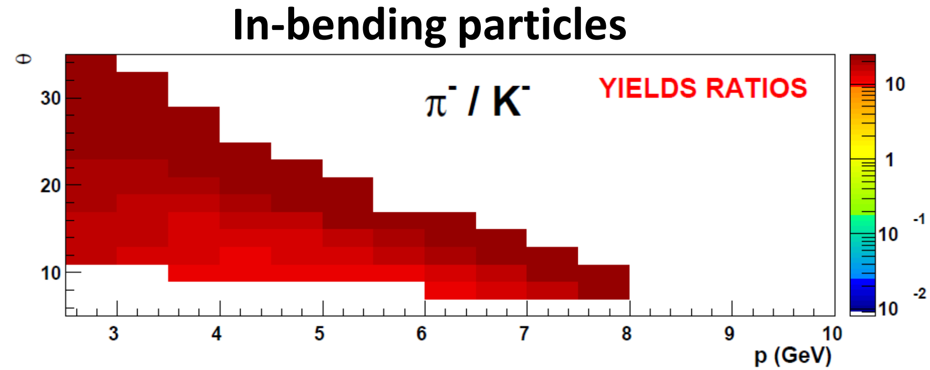


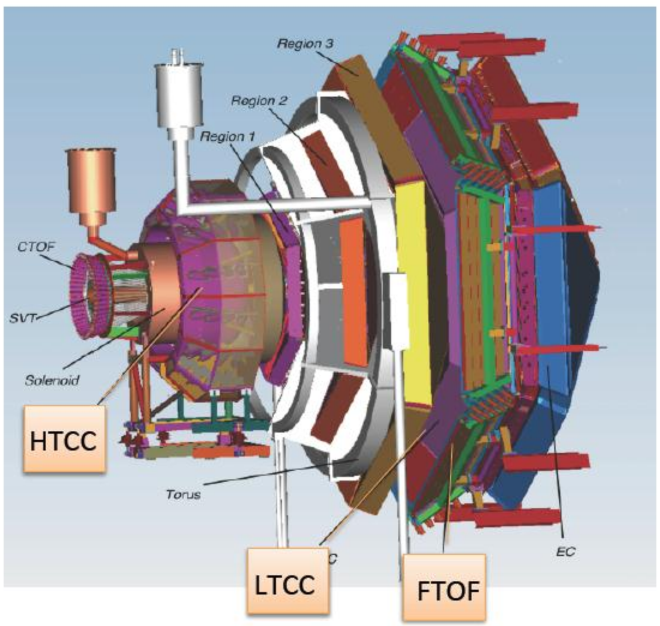


- Pion contamination at a few % level requires **rejection factor of 1:500** for a 90% kaon efficiency
- Need **4σ pion-kaon separation in full momentum range**

Hadron identification @ CLAS12







FTOF (< 3 GeV/c hadron ID):
Forward Time-of-Flight system

4σ π-K separation below 3.5 GeV

HTCC (electron ID):
High Threshold Cherenkov Counter

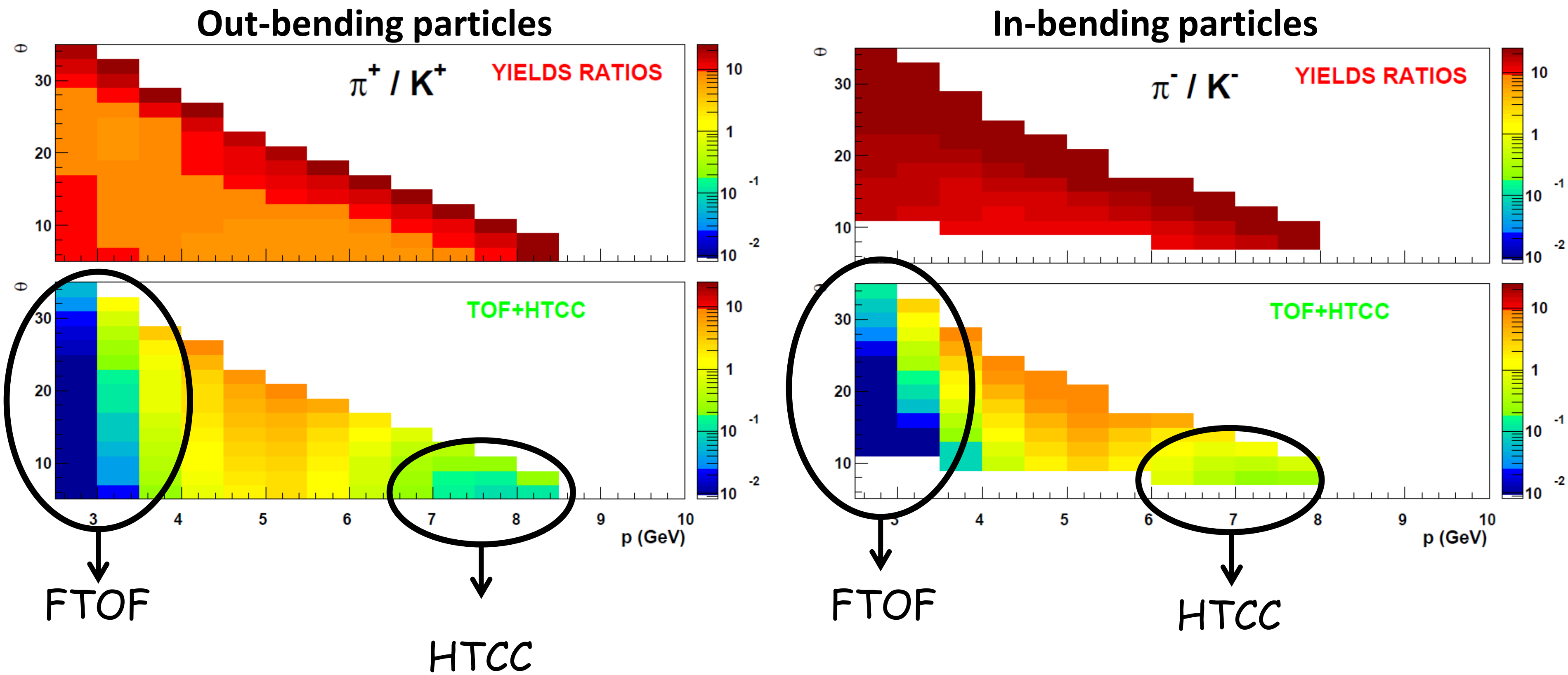
1:500 pion rejection above 7 GeV.
No K-p separation (above thresh.)

LTCC (pion ID):
Low Threshold Cherenkov Counter

1:500 pion rejection above 8 GeV.
No K-p separation (above thresh.)
Not helpful for hadron identification!

- Pion contamination at a few % level requires **rejection factor of 1:500** for a 90% kaon efficiency
- Need **4σ pion-kaon separation in full momentum range**

Hadron identification @ CLAS12



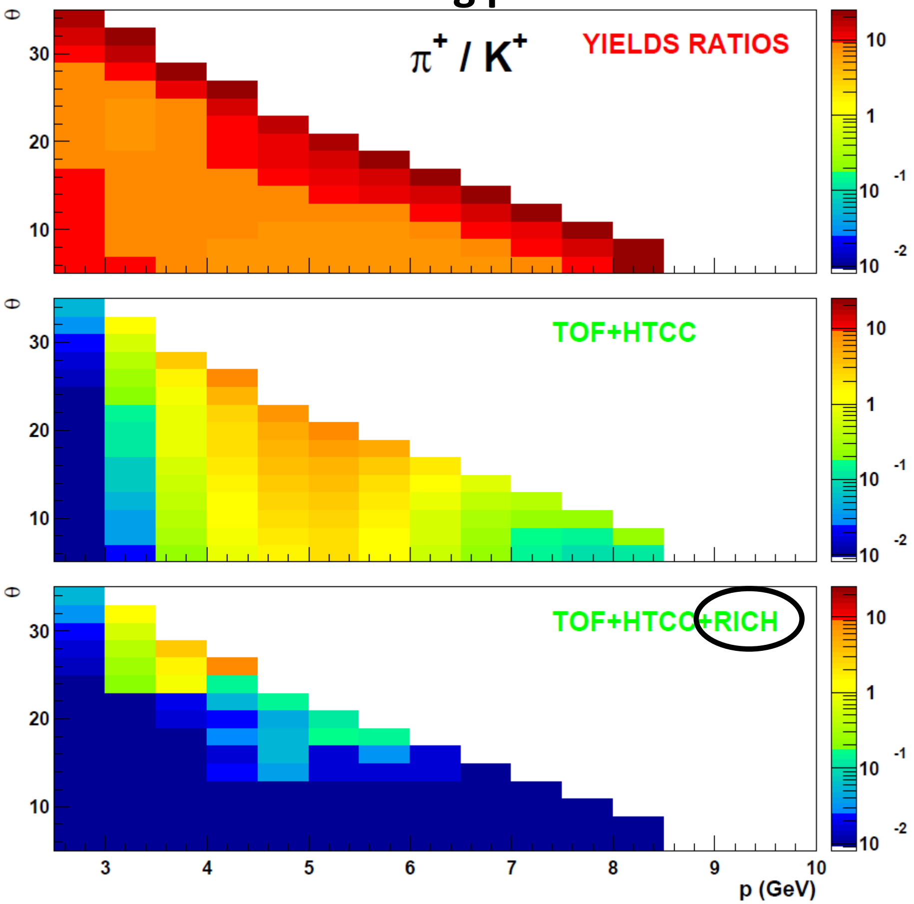
SIDIS particle flux within acceptance: **pion >> kaon in whole kinematic plane**

The PID detectors in the CLAS12 baseline (TOF, HTCC, LTCC) cannot provide efficient hadron separation in the momentum range 3-8 GeV!

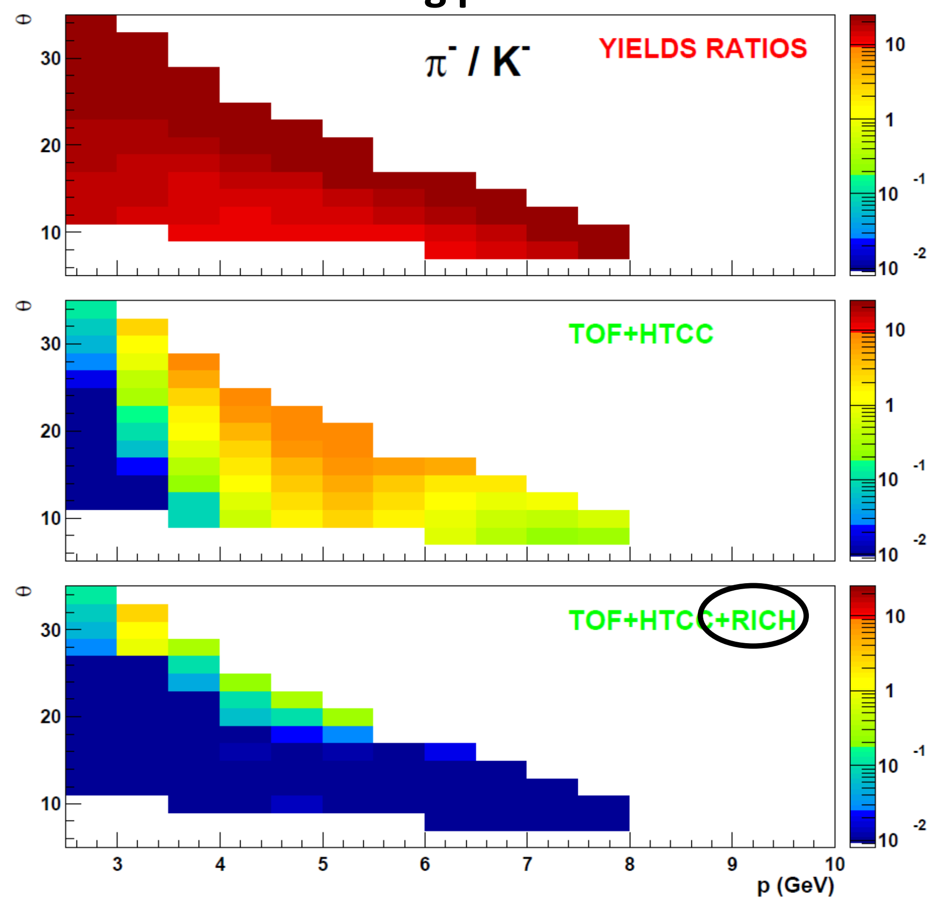
A RICH detector is mandatory for 4σ pion-kaon separation

Hadron identification @ CLAS12

Out-bending particles



In-bending particles

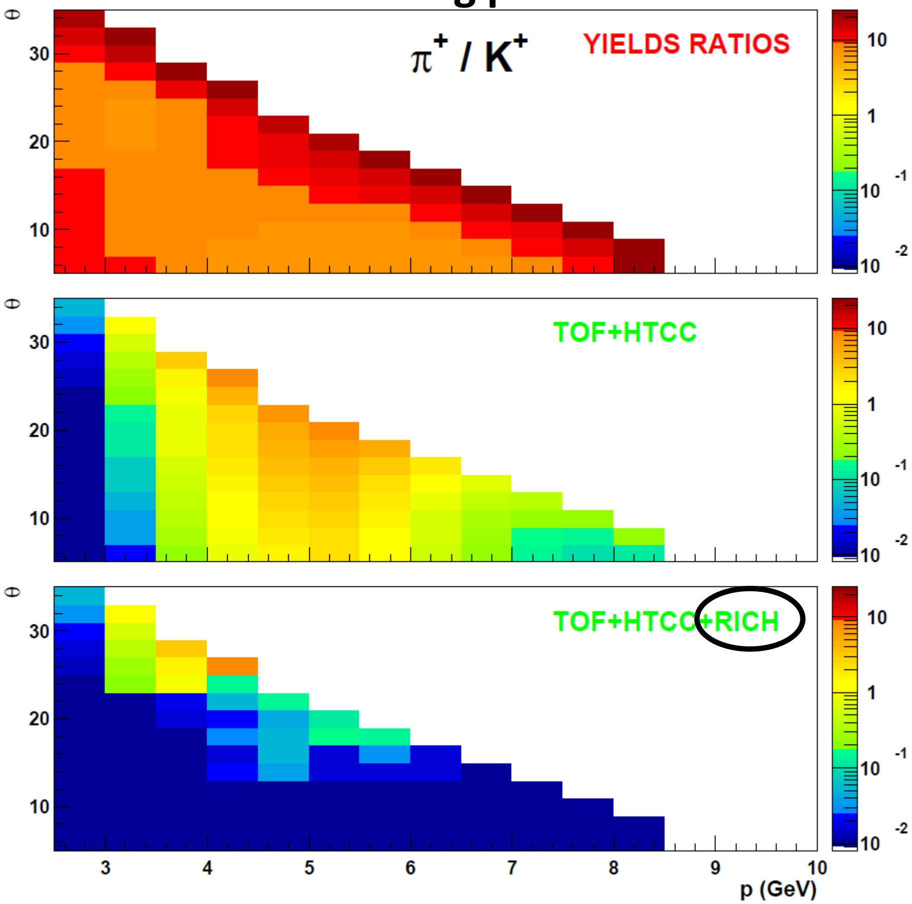


pion contamination in kaon sample from $\times 5$ to $\sim 1\%$
$\Rightarrow$ $1{:}500$ rejection factor (4σ separation) can be achived in full momentum range

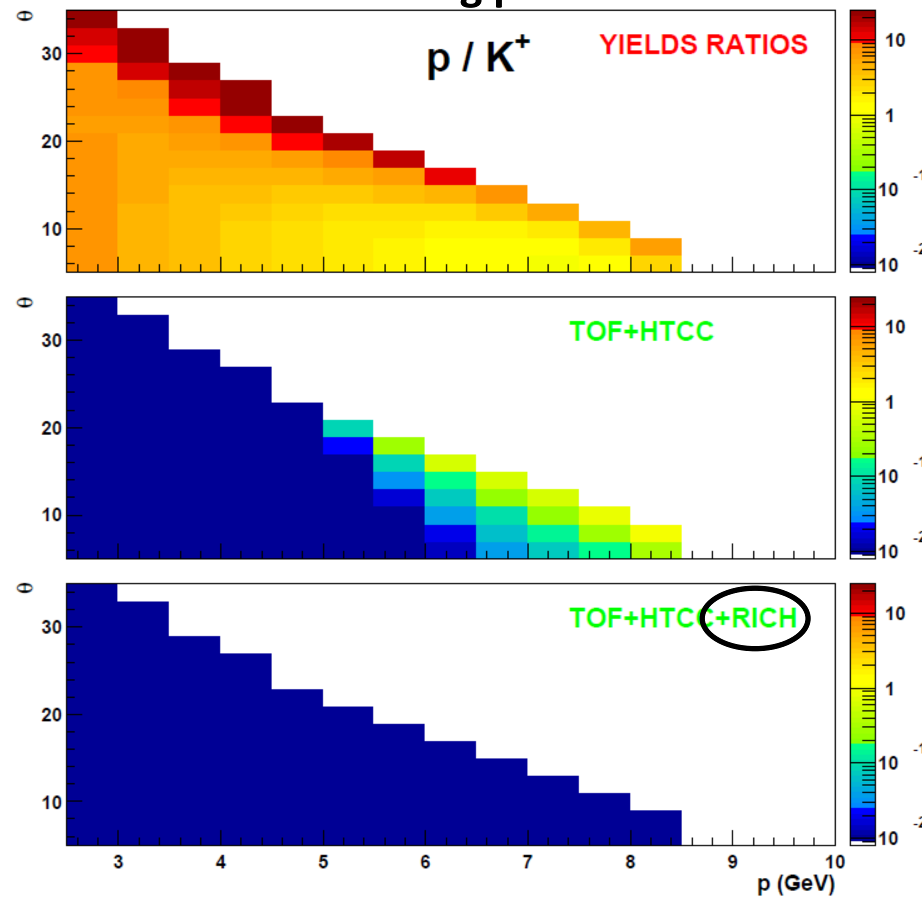
pion contamination in kaon sample from $\times\ 10$ to $\sim 1\%$
$\Rightarrow$ $1{:}1000$ rejection factor ($> 4\sigma$ separation) can be achived in full momentum range

Hadron identification @ CLAS12

Out-bending particles



Out-bending particles



pion contamination in kaon sample
from $\times 5$ to $\sim 1\%$
$\Rightarrow 1{:}500$ rejection factor (4σ separation)
can be achived in full momentum range

proton contamination in kaon sample
well under control in full range

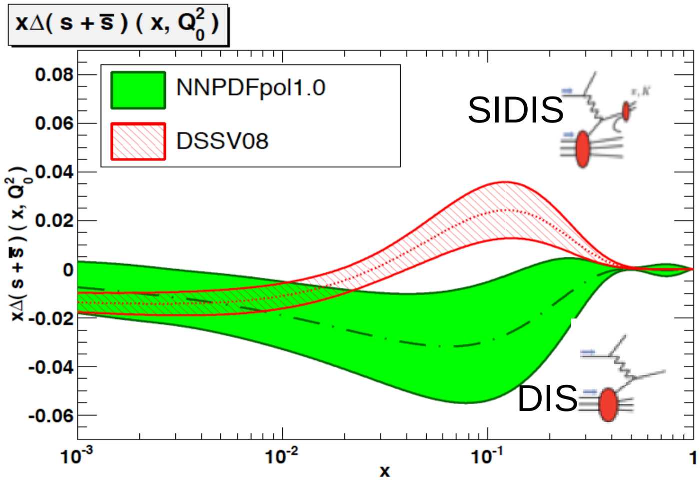
Why a RICH for CLAS12? (Physics motivations)

The addition of a RICH detector would significantly enhance the PID capabilities of CLAS12, allowing for the extraction of flavour separated information about the complex multi-dimensional nucleon structure in the poorly explored valence region.

A broad physics program will greatly benefit from clean pion-kaon separation:

- Exploring the elusive strange quark distribution in kaon production in unpolarized and polarized DIS
- Study of the flavour and kinematic dependencies of the intrinsic transverse momenta with multi-dimensional analyses of pion and kaon production in unpolarized DIS
- 3D imaging of nucleons in momentum space through extraction TMDs in SIDIS
- Study of quark propagation and hadronization in cold nuclear matter
- Study of transverse spatial distribution of gluons from hard exclusive ϕ-meson production
- Study of exotic meson configurations via tagging of strangeness-rich final states

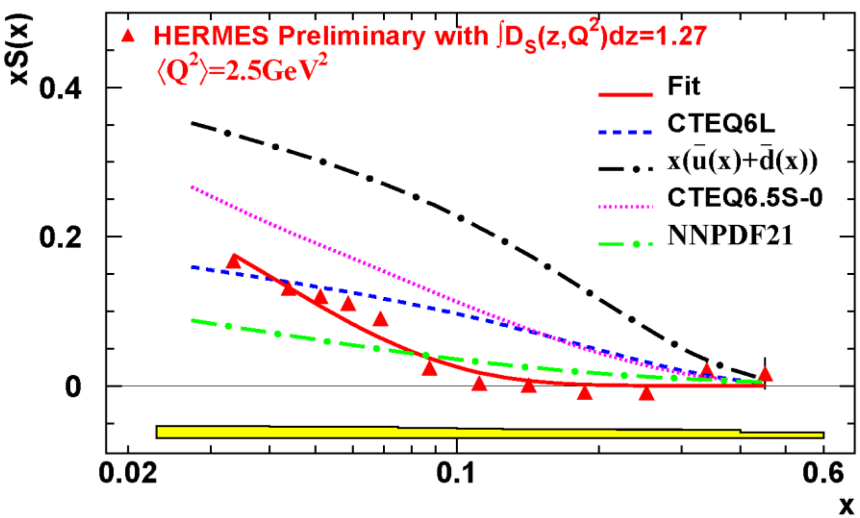
The strangeness content of the nucleon



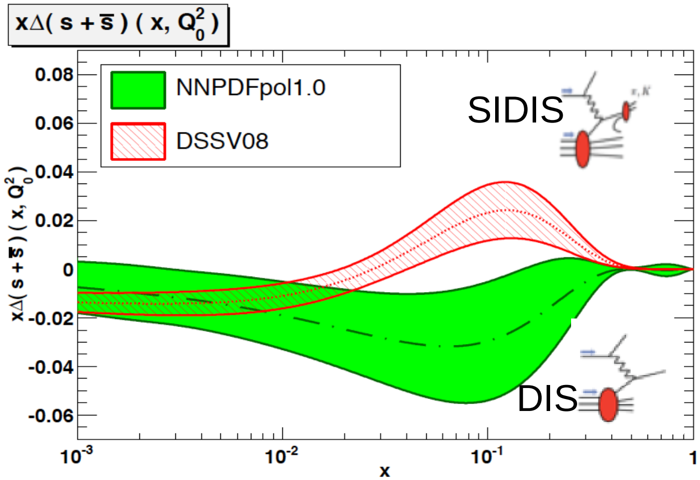
Polarized strangeness ΔS is practically unknown, even sign is not defined

Shape of HERMES $S(x)$ vs. x completely different than CTEQ6L

- $S(x) \rightarrow 0$ for $x > 0.1$ (in contrast to CTEQ6L)
- $S(x)$ substantially different than non-strange sea
- Shape of HERMES $S(x)$ results makes extraction of intrinsic strangeness very challenging



The strangeness content of the nucleon



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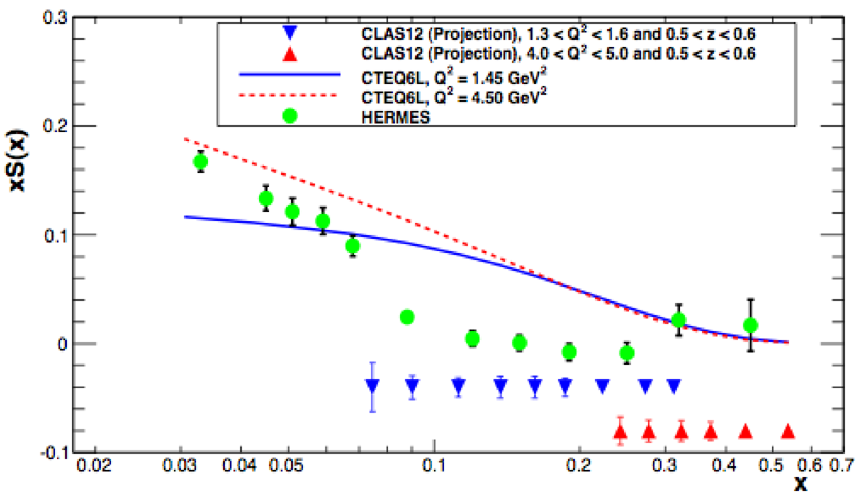
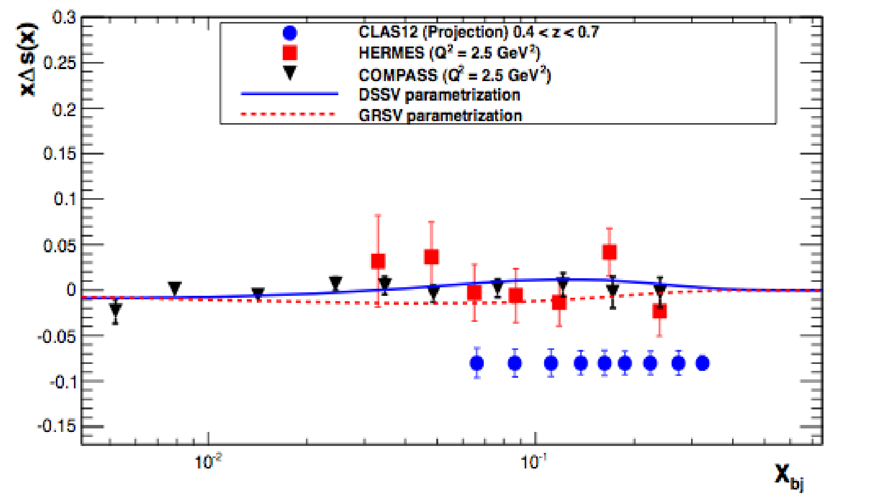




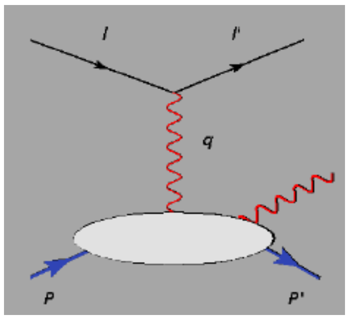
CLAS12 E12-09-007 experiment allows studies of x-dependence of strange sea distributions in wide range of kinematics, using multidimensional binning.

Measurements require good charged kaon identification in whole momentum range

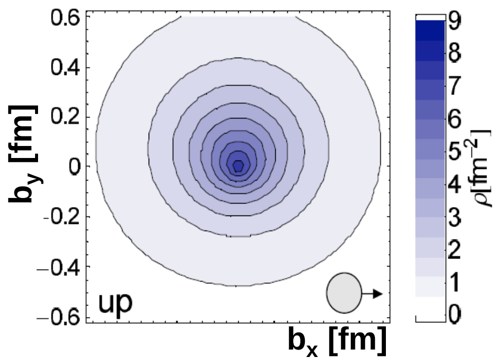
The nucleon tomography

GPDs $H(x, \xi, t)$

3D picture in coordinate space



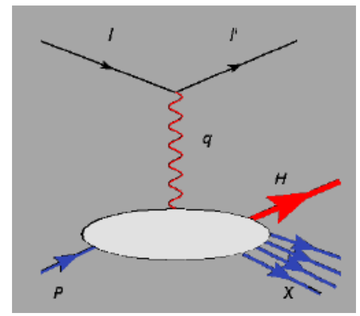
Exclusive reactions



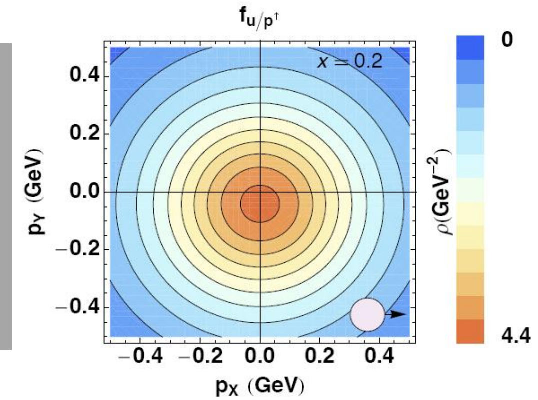
QCDSF/UKQCD, PRL 98 (07)

TMDs $f(x, p_T)$

3D picture in momentum space



Semi-inclusive DIS

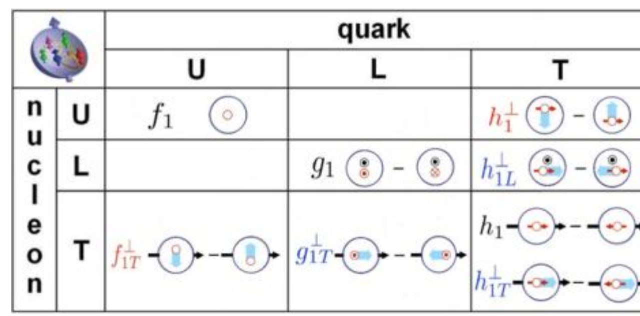


A.B., F. Conti, M. Radici, PRD78 (08)

quark (columns) / nucleon (rows)

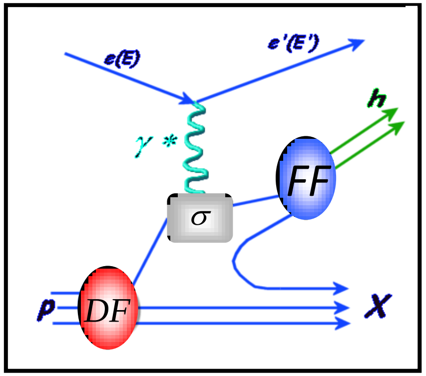
	U	L	T
U	H		$\mathcal{E}_T$
L		$\widetilde{H}$	
T	E		$H_T, \widetilde{H}_T$

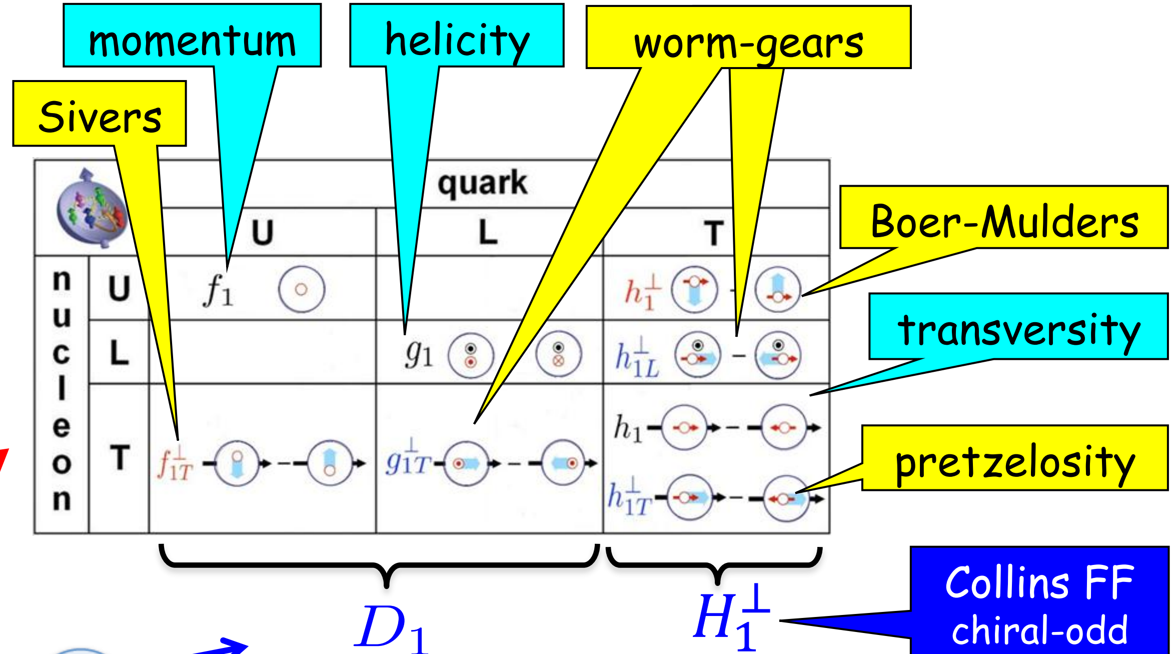
Hard exclusive **pion and kaon** production provides a unique possibility to study the chiral-odd GPDs describing spatial distributions of transversely polarized quarks.



The non-collinear structure of the nucleon: TMDs

- Describe correlations between p_T and quark or nucleon spin (**spin-orbit correlations**)
- Mostly investigated in SIDS





$$\sigma^{ep\to ehX} = \sum_q DF \otimes \sigma^{eq\to eq} \otimes FF$$

$$H_1^{\perp,u\to\pi^+} \overset{?}{\approx} H_1^{\perp,u\to K^+} \equiv H_1^{\perp,fav} \quad \text{(u-quark present)}$$

$$H_1^{\perp,u\to\pi^-} \overset{?}{\approx} H_1^{\perp,u\to K^-} \equiv H_1^{\perp,unfav} \quad \text{(u-quark not present)}$$

Assuming u-quark dominance, one would naively expect similar effects for all favored (unfavored) azimuthal moments/asymmetries for transversely polarized quarks

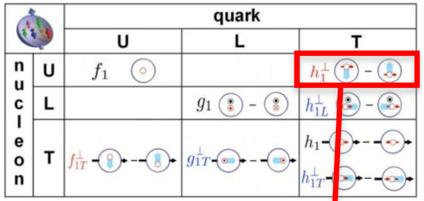
$$H_1^{\perp,u,fav} \approx -H_1^{\perp,unfav} \quad \text{(SIDIS \& } e^+e^-\text{)}$$

Expect opposite sign for azimuthal moments/asymmetries of favored unfavored hadrons for transversely polarized quarks

- Spin-azimuthal asymmetries larger for K^+ compared to π^+
- Spin-azimuthal asymmetries for K^- vs K^+ do not follow the trend of π^- vs π^+

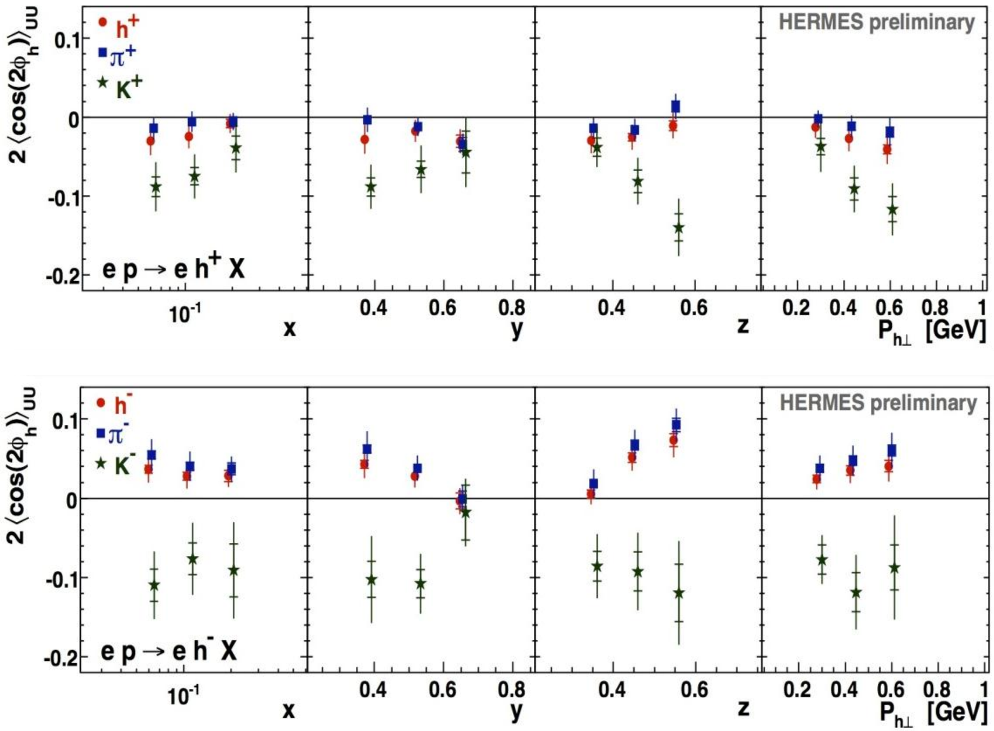
⇨ **Kaon puzzle!**

Boer-Muders effect: kaons vs pions



$h_1^{\perp} H_1^{\perp}$

A. Airapetian et al, Phys. Rev. D 87 (2013) 012010

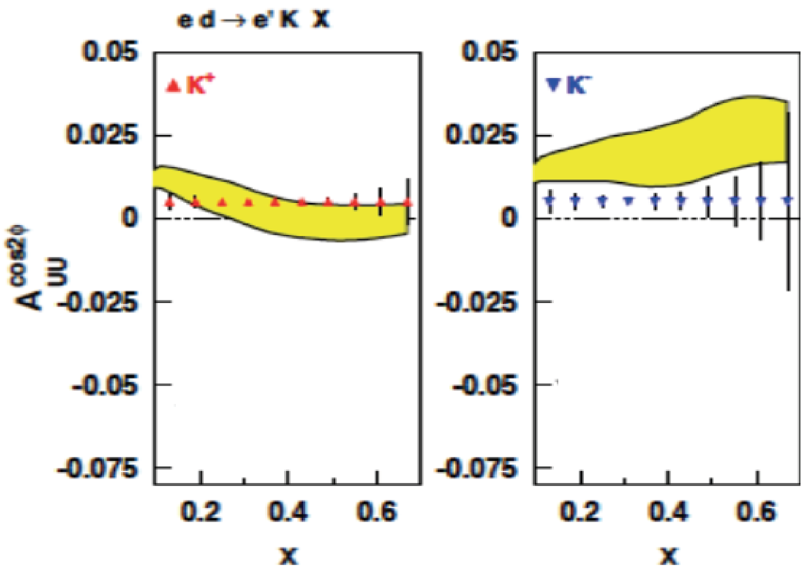


- Opposite sign for π^+/π^- consistent with opposite signs of fav/unfav Collins

- K^+/K^- amplitudes are larger than for pions, have different kinematic dependencies than pions and have same sign (inconsistent with fav/unfav Collins FF)

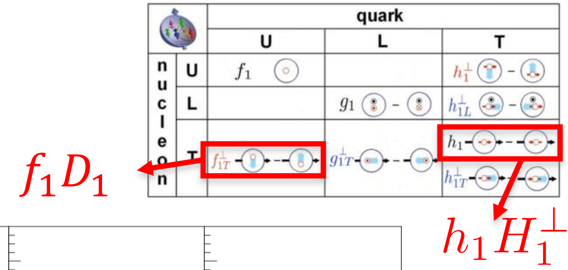
- different Collins FF for pions and kaons?

- Significant contribution from scattering off strange quarks?

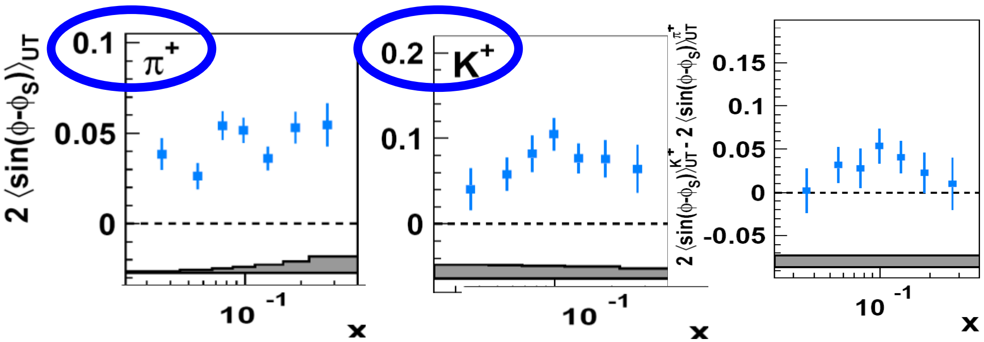


Independent, high precision measurement of Boer-Mulders asymmetry in kaon SIDIS at large x will provide complementary information on Boer-Mulders function and the Collins fragmentation functions for kaons and can shed light on the "kaon puzzle"

Sivers and Collins: kaons vs pions



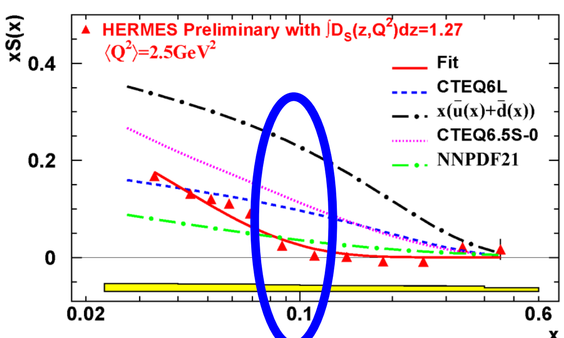
π^+/K^+ production dominated by u-quarks, but:



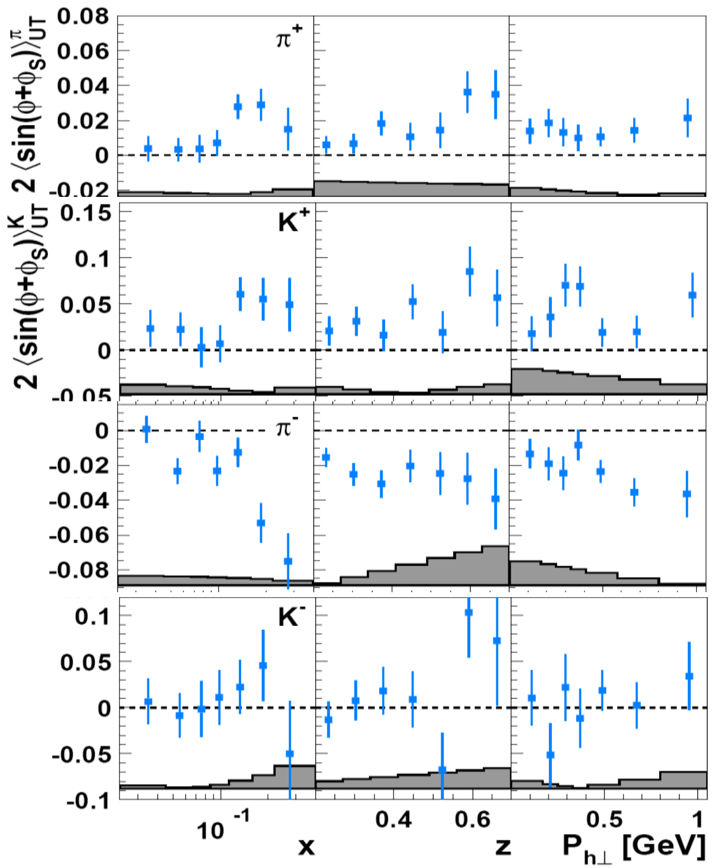
Similar observations by Compass (less pronounced)

$\pi^+ \equiv |u\bar{d}\rangle,\ K^+ \equiv |u\bar{s}\rangle\ \rightarrow$

different role of various sea quarks ?



impact of different p_T dependence of FFs in the convolution integral



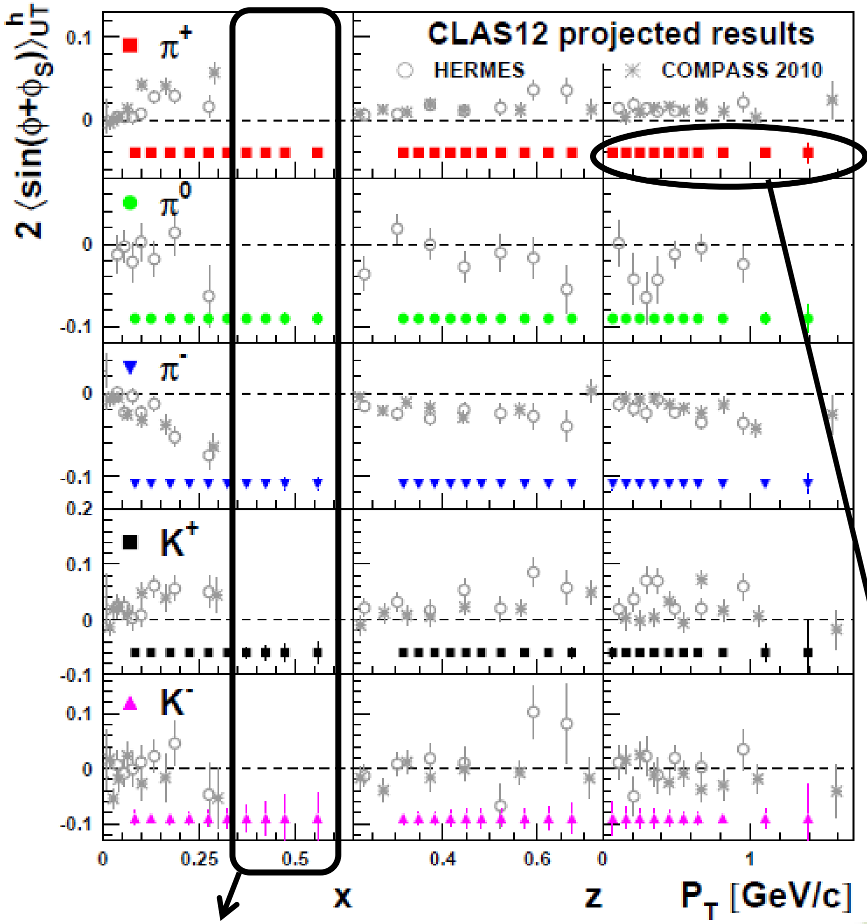
- At large x K^+ amplitude is larger than π^+

- K^- seem to have opposite sign than π^- at HERMES & BRAHMS (pp->hX) and same sign at COMPASS

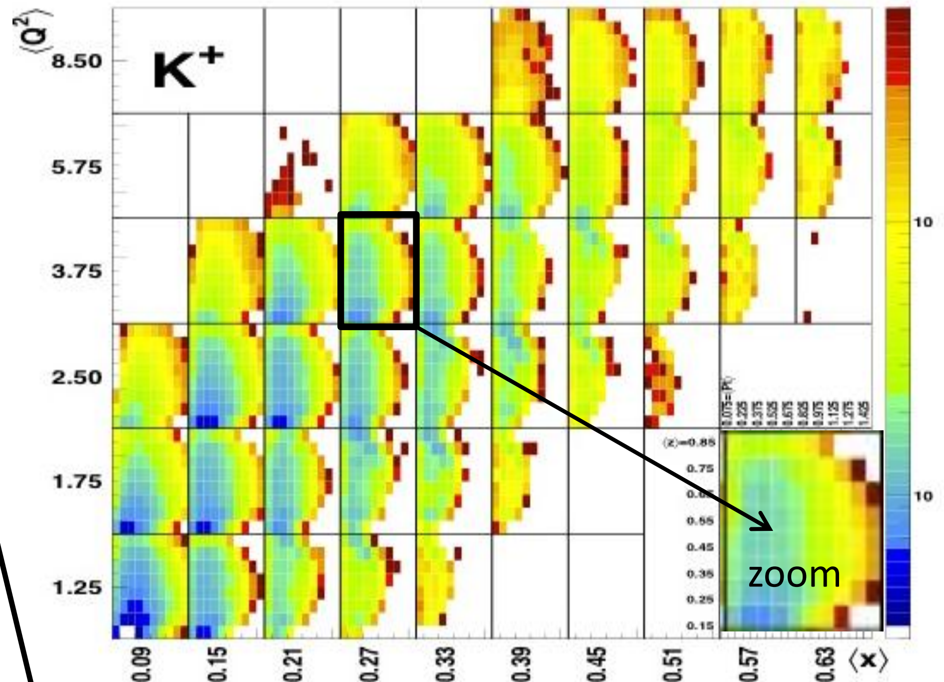
Independent high precision measurements in kaon SIDIS al large x will be crucial

Sivers and Collins asymmetries @ CLAS12

100 days @ $L = 5 \cdot 10^{33} cm^{-2} s^{-1}$, HD-Ice target (60% H pol, $f = 1/3$), RICH detector



Large statistics allows for multi-dimensional analysis with reasonable uncertainties



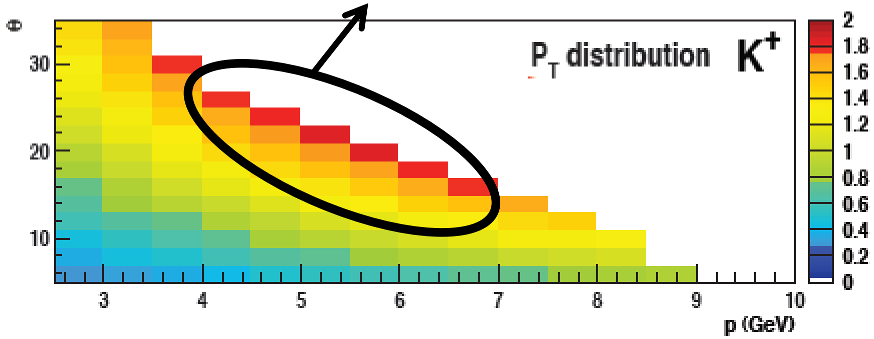
Large x important to constrain the tensor charge

High resolution and broad range in p_T to test perturb. non-perturb. transient and for Bessel function analysis

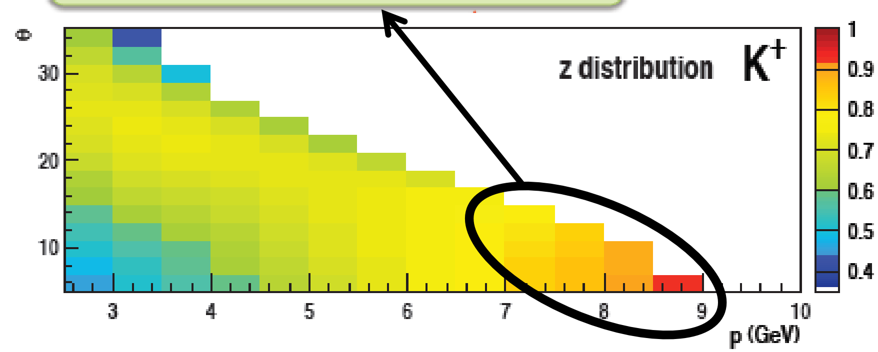
Measurement of Collins effect for kaons will shed light on the "kaon puzzle"

The RICH goals

Intermediate angular range (15-25°) important to reach high P_T values

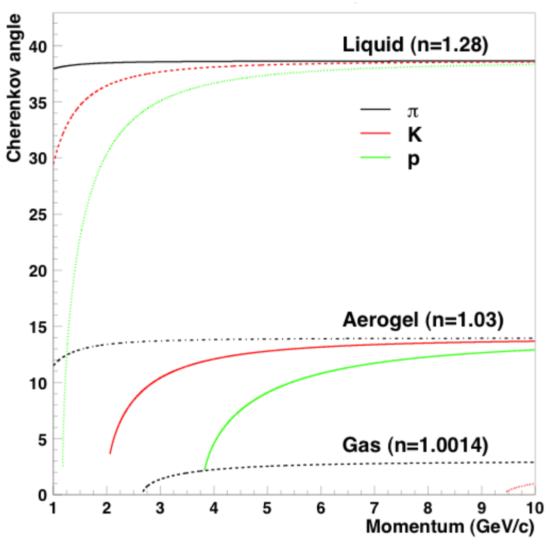


High Momentum region important as transient to hard semi-exclusive region



To reach high P_T and high z need to cover **ϑ up to $25°$ and intermediate-to-high momenta**

Requirements: 4σ pion-kaon separation (pion rejection factor 1:500) in 3-8 GeV momentum range with angular coverage in the range $5° < \vartheta < 25°$.

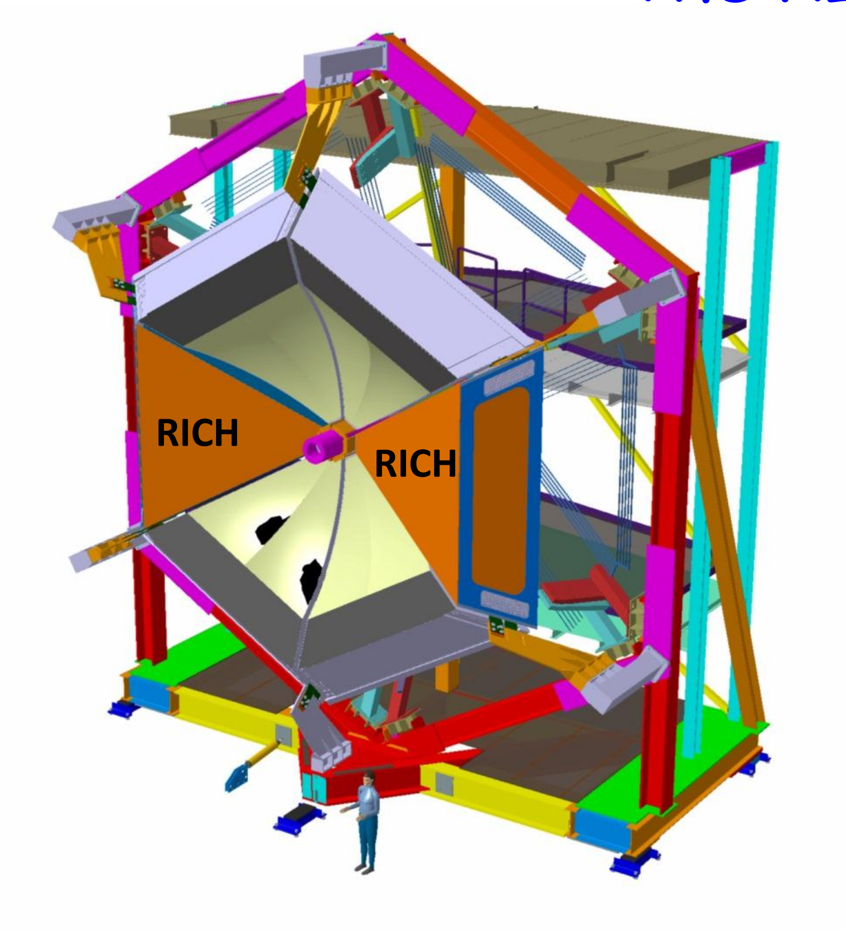


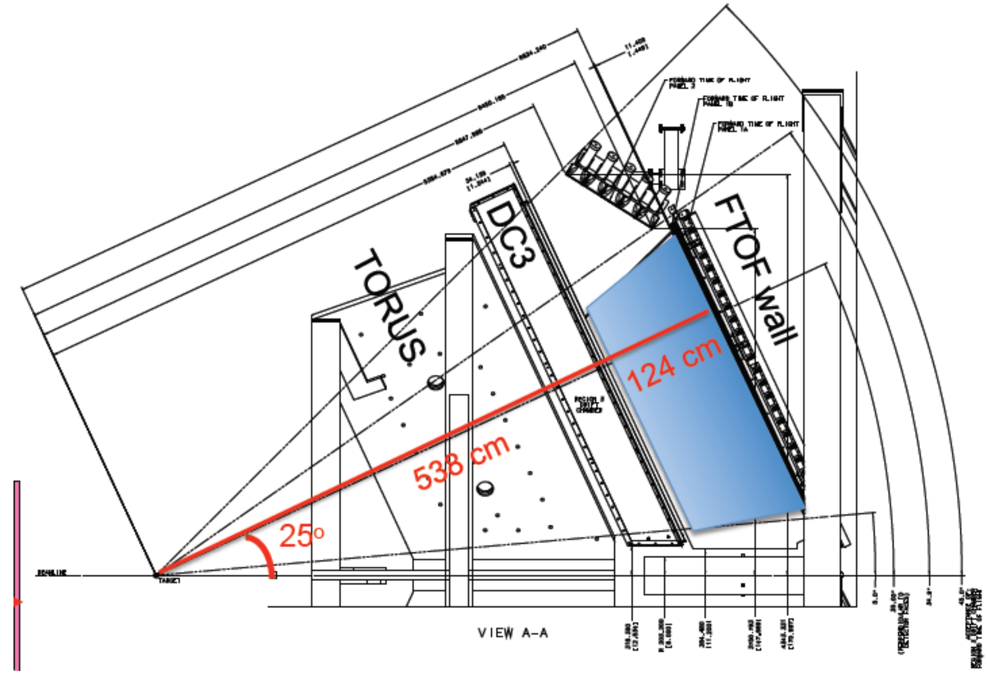
Aerogel mandatory to separate hadrons in 3-8 GeV momentum range with the required large rejection factor

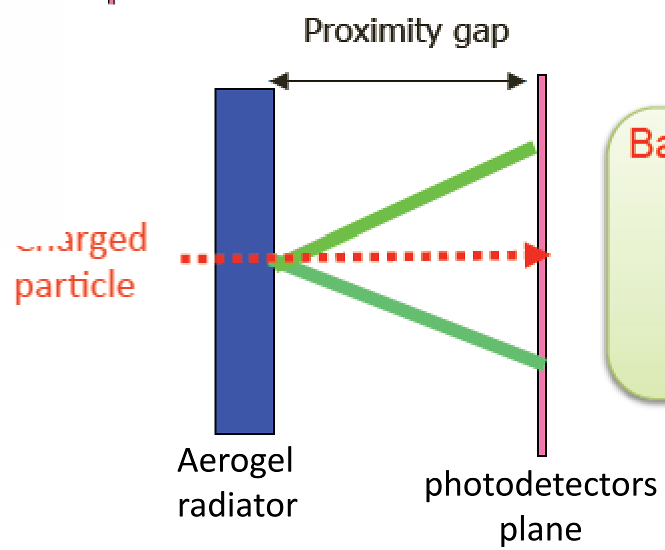
- Collection of visible Cherenkov light
- Use of PMTs

Challenge: need to minimize detector area covered with expensive photo-detectors

The RICH concept





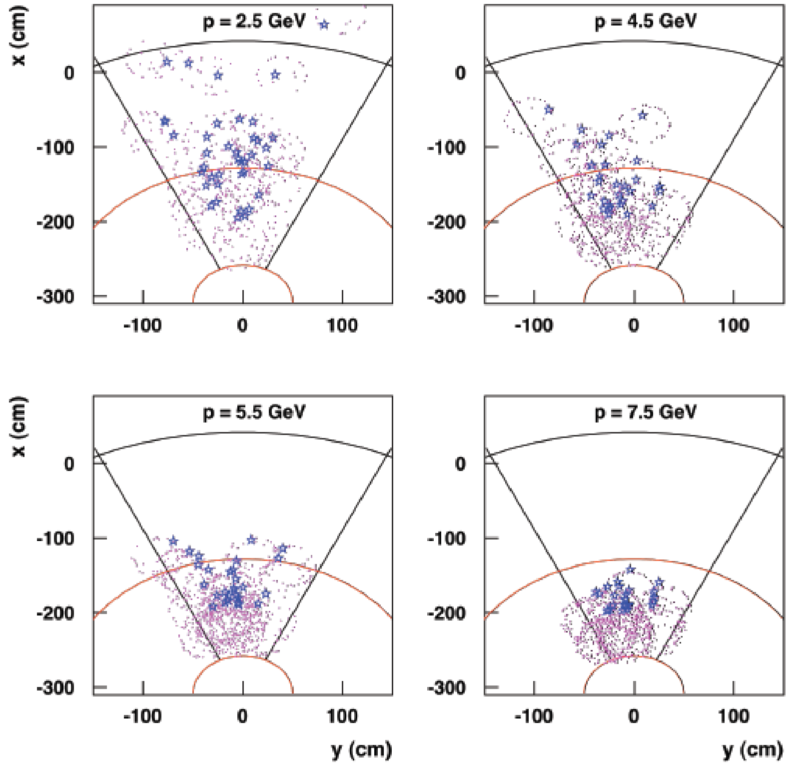


- 1st sector by the end of 2016
- 2nd++ sector(s) important for transverse target physics runs (left-right asymmetries and statistics)

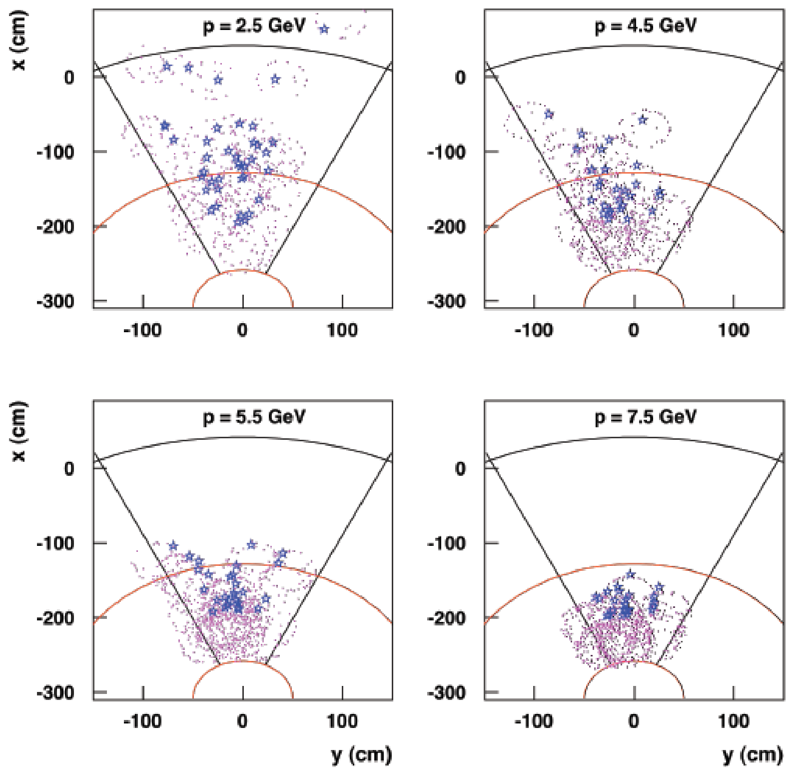
Base Numbers

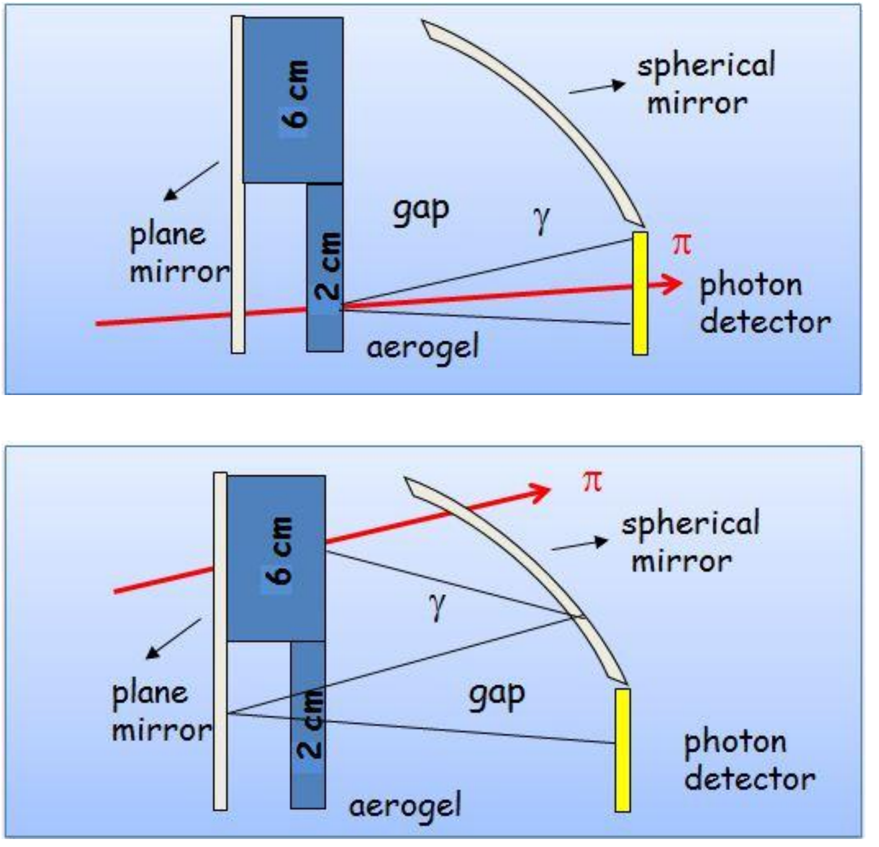
- 5 m from IP
- ~ 1 m gap
- Several m^2 surface

The RICH concept



The RICH concept

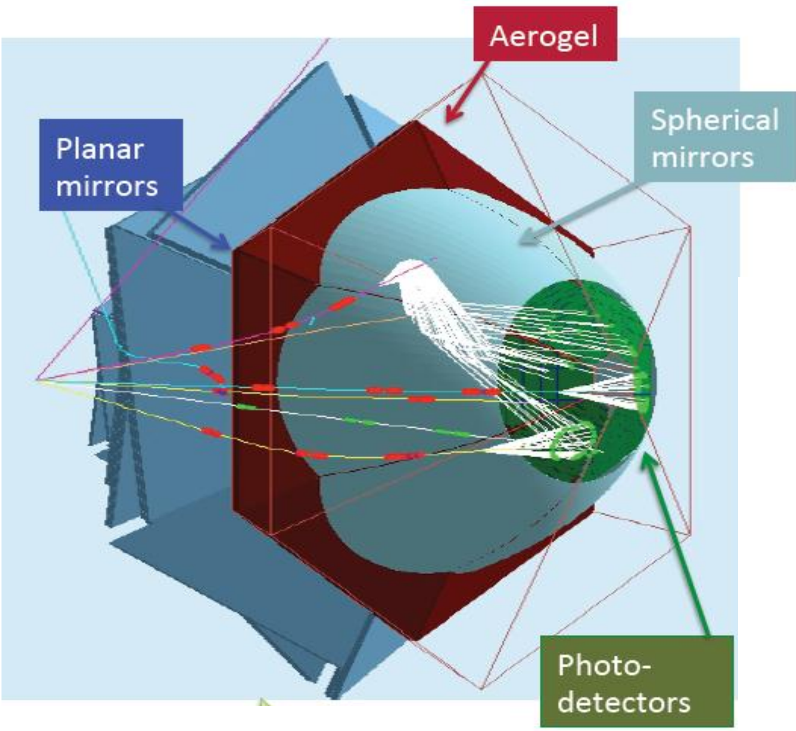


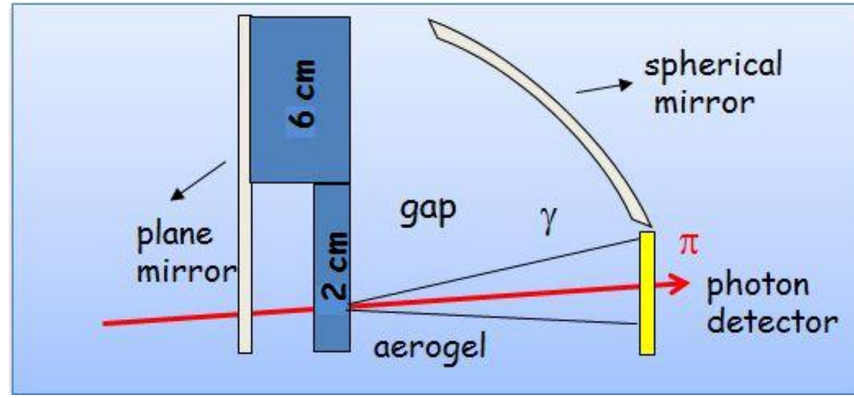


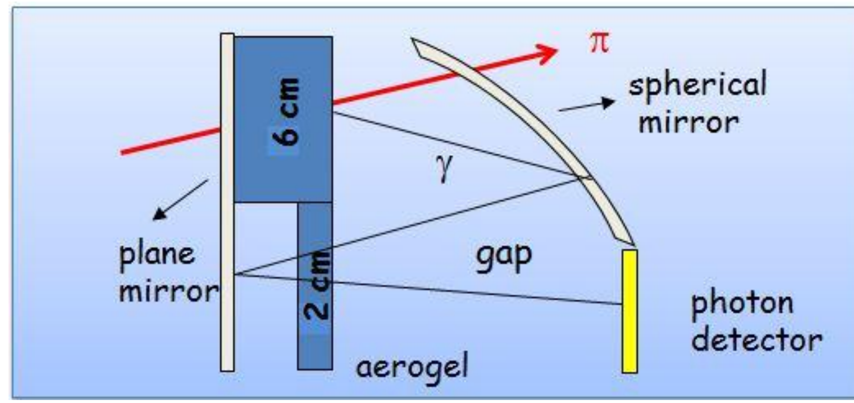
- Direct rings for forward (high momentum) particles
- Reflected rings for low momentum particles (FTOF)
- Multiple passage of Cherenkov photons in aerogel (absorption+scattering → loss of photons)
- Thicker aerogel compensates photon loss
- Focalizing mirrors reduce uncertainty of prod. point
- Metalized Carbon fiber substrate for spherical mirror
- Thin glass skin on a flat support for planar mirrors

The RICH concept

Benefits:
- instrument only forward region
- reduce active area (~1 m^2/sector)
- minimize interference with TOF system





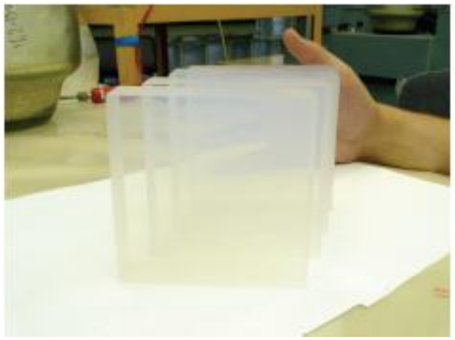


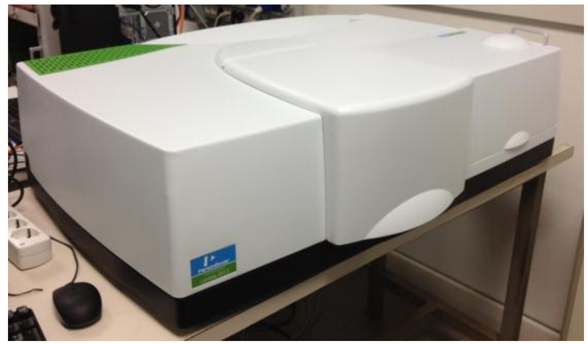
- Direct rings for forward (high momentum) particles
- Reflected rings for low momentum particles (FTOF)
- Multiple passage of Cherenkov photons in aerogel (absorption+scattering $\rightarrow$ loss of photons)
- Thicker aerogel compensates photon loss
- Focalizing mirrors reduce uncertainty of prod. point
- Metalized Carbon fiber substrate for spherical mirror
- Thin glass skin on a flat support for planar mirrors

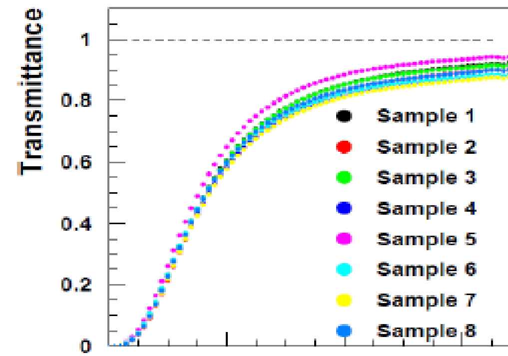
The aerogel radiator

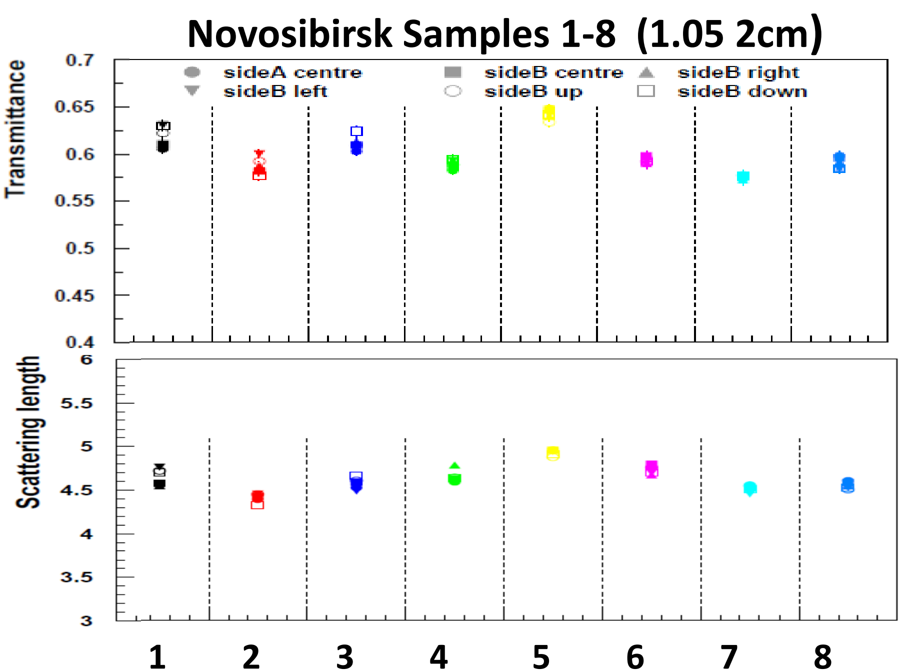
The Collaboration has developed skills and tools for the optical characterization of the aerogel radiator for the CLAS12 RICH

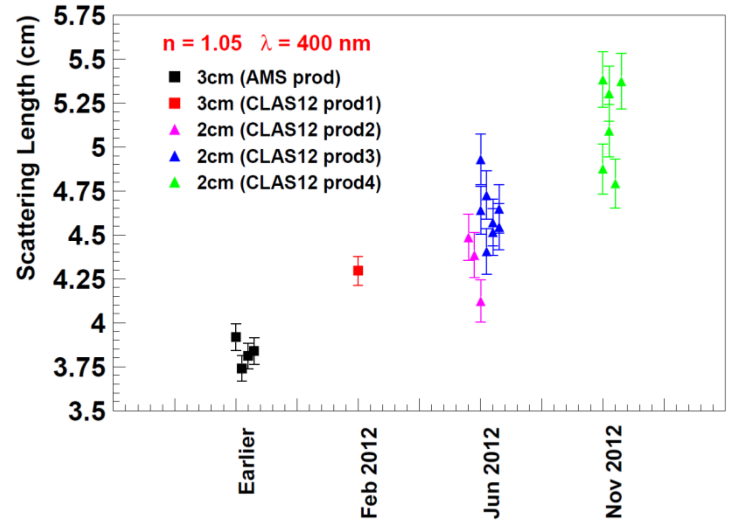
➢ Transmittance, absorption and scattering length measurements with spectrophotometer











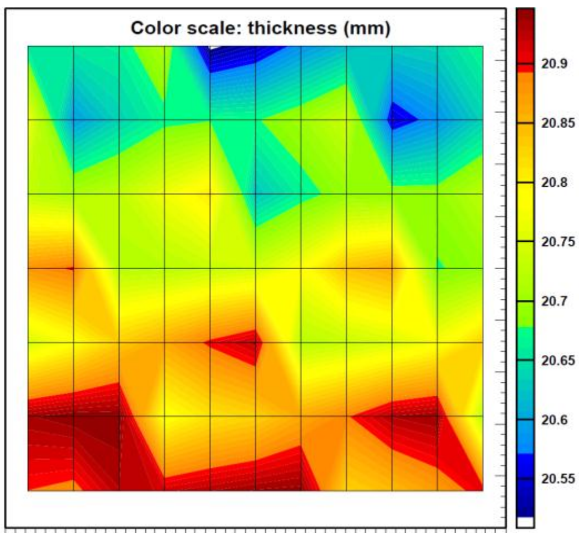
Aerogel quality significantly improved in time following the requirements of the project!

The aerogel radiator

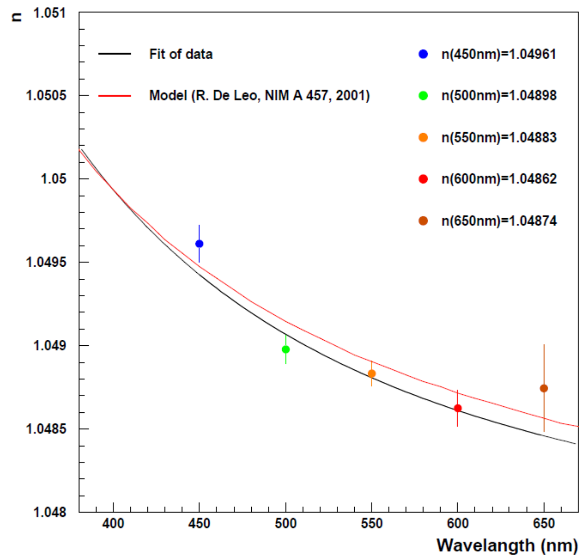
The Collaboration has developed skills and tools for the optical characterization of the aerogel radiator for the CLAS12 RICH

- Transmittance, absorption and scattering length measurements with spectrophotometer
- High precision mapping of the tiles thickness
- Measurements of refractive index and chromatic dispersion with the *prims method*.
- refractive index mapping with *gradient method*

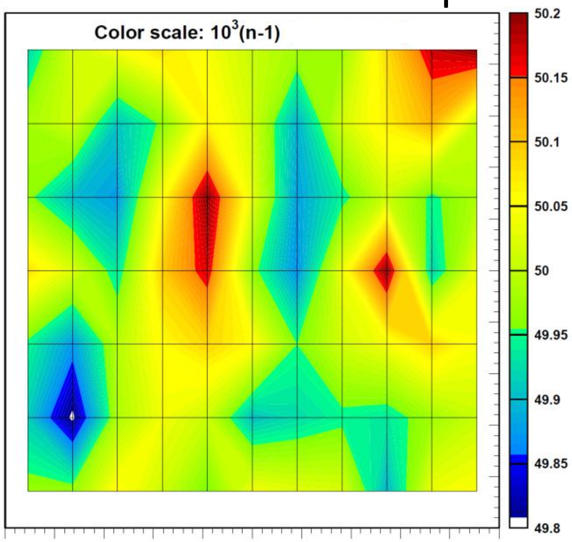
Thickness map



Chromatic dispersion



Refractive index map



The **Novosibirsk** aerogel has the highest performances (transparency, scattering length, chromatic dispersion). Novosibirsk group is reliable and has long experience (AMS, LHCb). Up to now it is the **most suitable option for the CLAS12 RICH**.

The aerogel tiles for the CLAS12 RICH:

- **Size**: $20 \times 20 \times 2\ (3)\ \ cm^3$
- **Refractive index**: 1.05
- **Clarity parameter**: $\leq 0.0050\ \ \mu m^4/cm$

The photon-detector

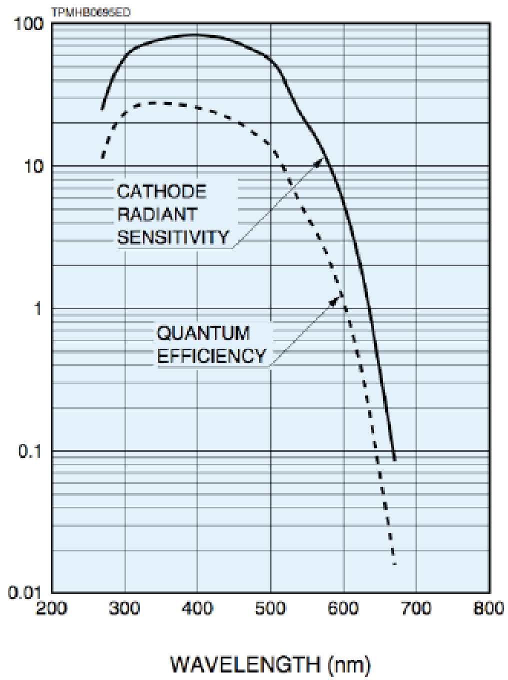
Requirements:

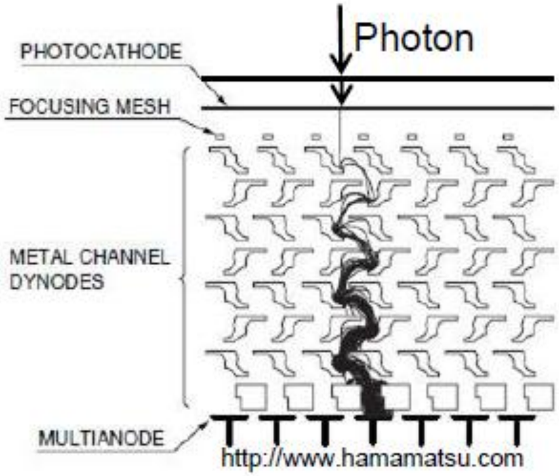
- Position sensitive
- Pixel sizes < 1cm x 1cm
- Efficient single photon detection crucial
- High packing fraction
- Sensitivity to visible light

✓ **Hamamatsu H8500 MAPMT**

MAPMT Parameter	H8500
Active Area (mm x mm)	49 x 49
Number of Pixels	64 (8 x 8)
Pixel Size (mm x mm)	5.8 x 5.8
Packing Fraction (%)	89
Range (nm)	260 - 650

MAROC3 Front-End card





SiPM are considered as an alternative for the future!

Prototype testbeams

CERN PS East Area, T9 beam test area (Jul-Aug 2012 and Nov-Dec 2012):

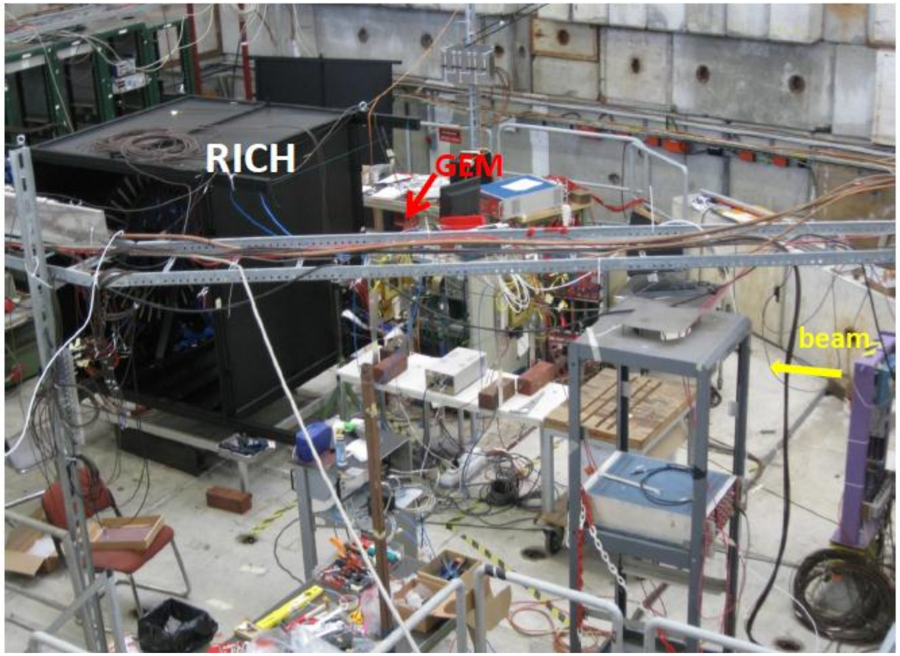
A large-scale prototype has been build to test the various features of the CLAS12 RICH (both direct and reflected light configurations)

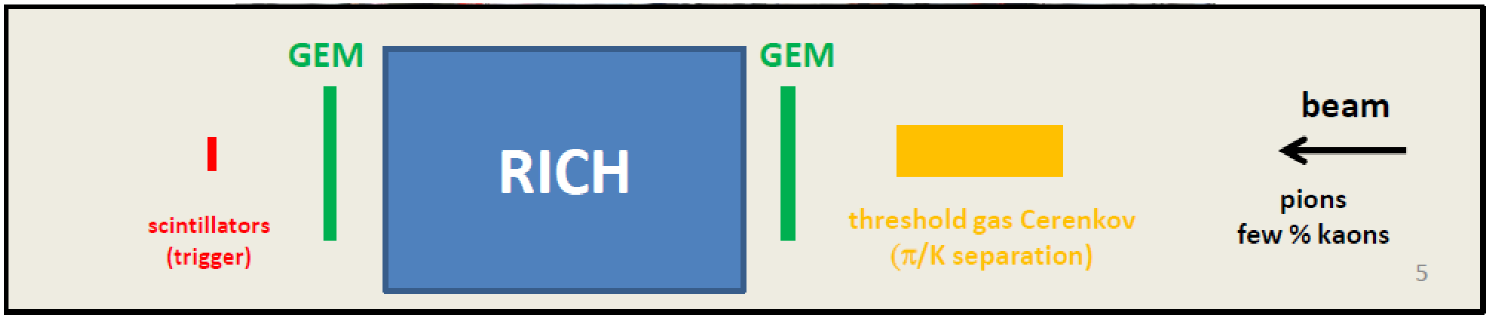
Testbeams allowed to study effects which are not easy to simulate: aerogel characteristics, mirror reflectivity, photon detection, etc

Prototype test-beam extremely usefull to validate MC simulation for CLAS12 RICH

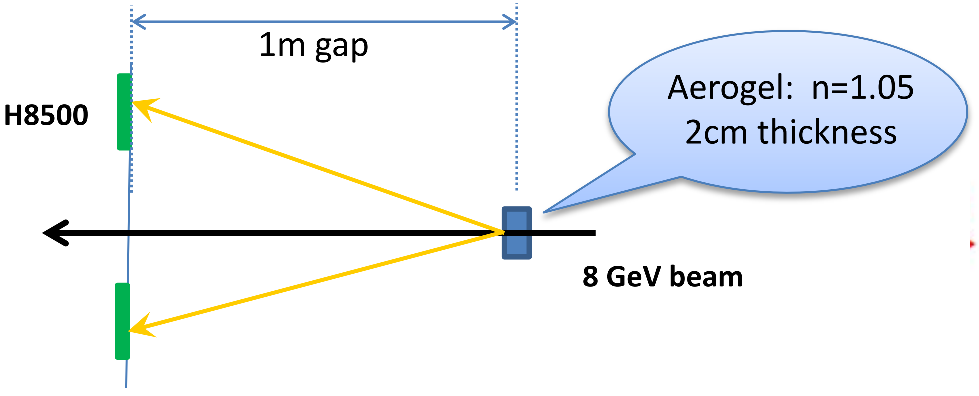
Testbeams:

- Negative polarity; momenta 6,7,8 GeV/c
- At 8GeV/c, π:K = 60:1





Prototype testbeams



Similar to CLAS12 RICH configuration

MAPMTs:

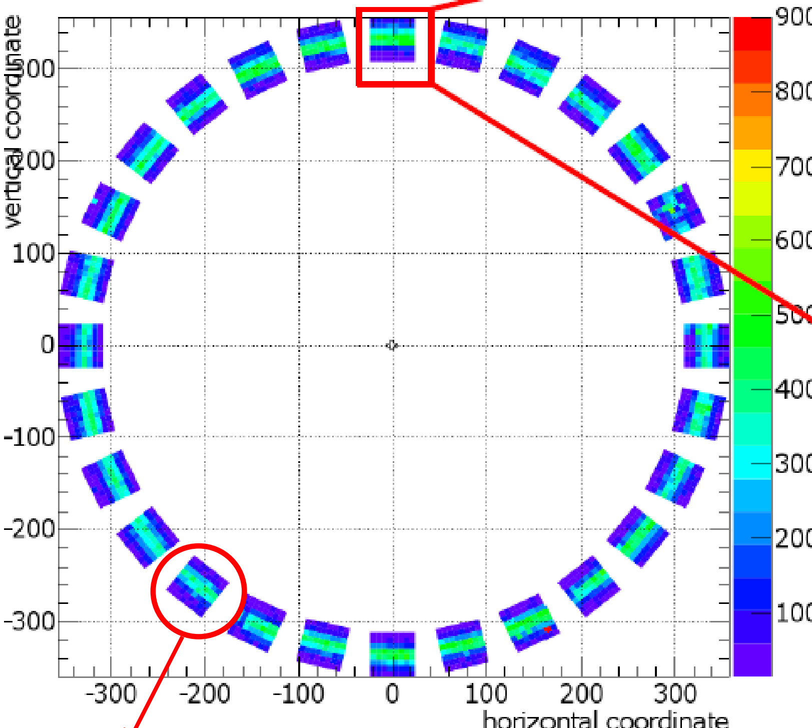
- 28 **H8500** MAPMTs (14 normal, 14 UV-extended windows)
- Readout **MAROC3** electronics (ADC)

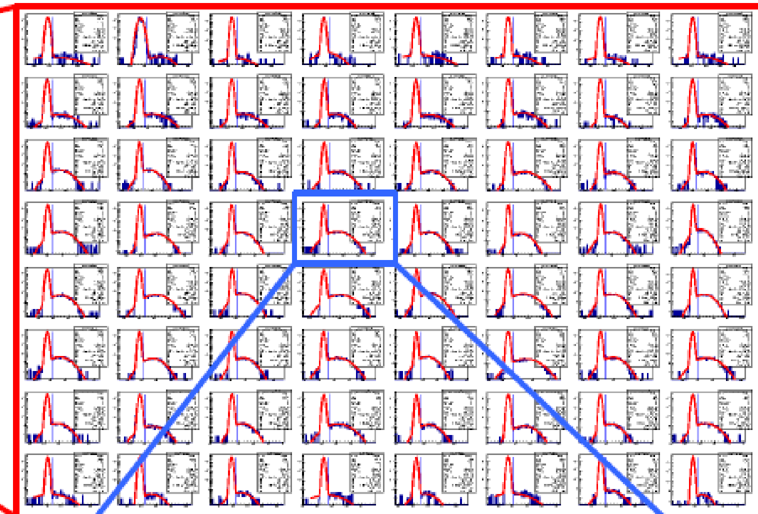
Aerogel:

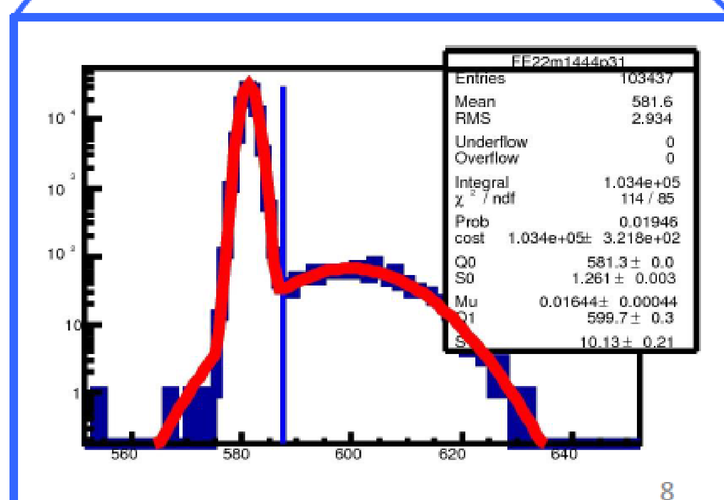
- **Novosibirsk,** varying n, t, transparencies
- Transparency monitored – laser and photodiode

Prototype testbeams

On-line event display

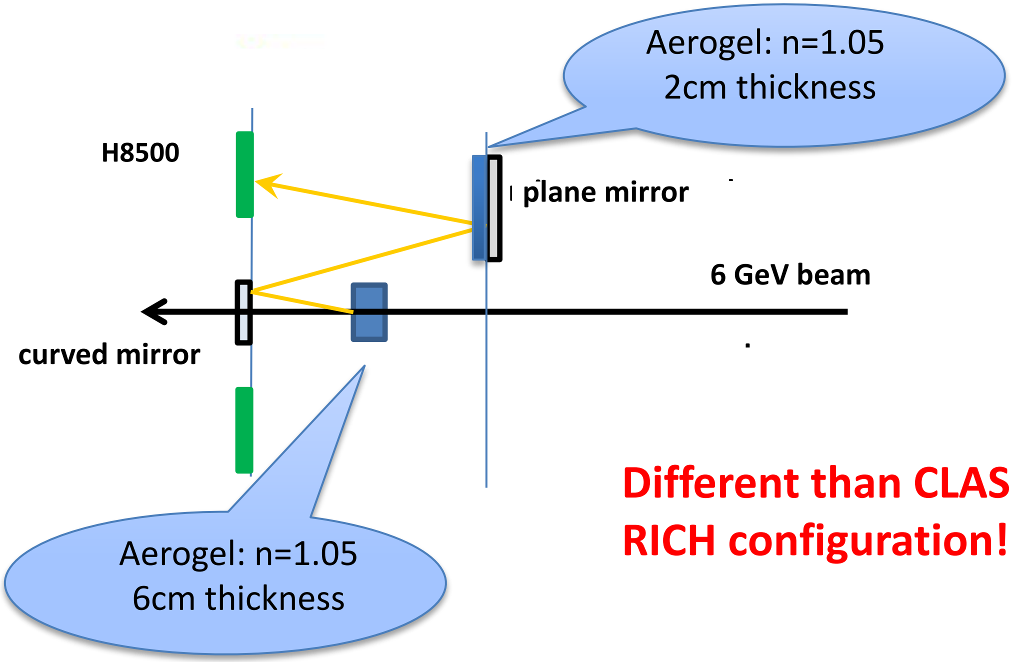






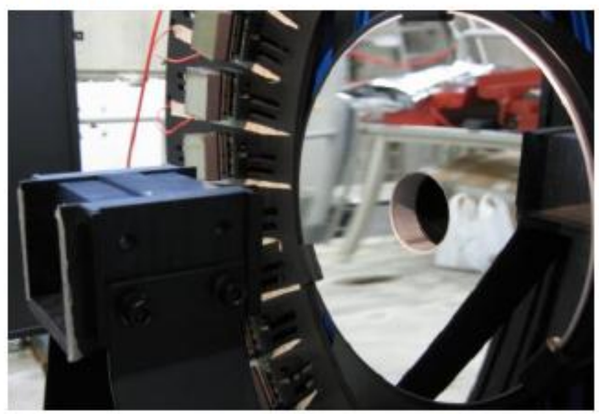
ADC spectra

Prototype testbeams



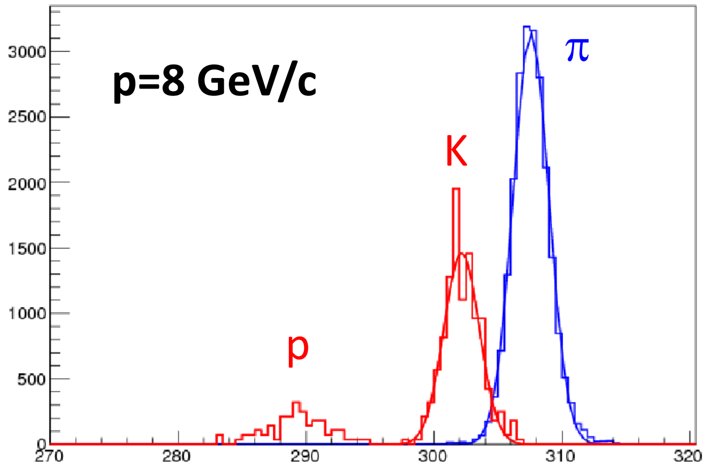
Different than CLAS12 RICH configuration!

- **Absorbers**: Novosibirsk, CERN AMS samples
- n=1.05, t=2cm, varying transparency



Prototype testbeams: preliminary results

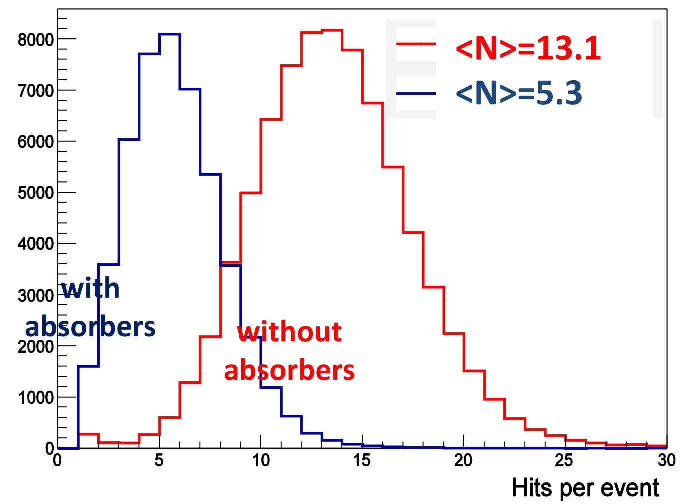
Direct light configuration

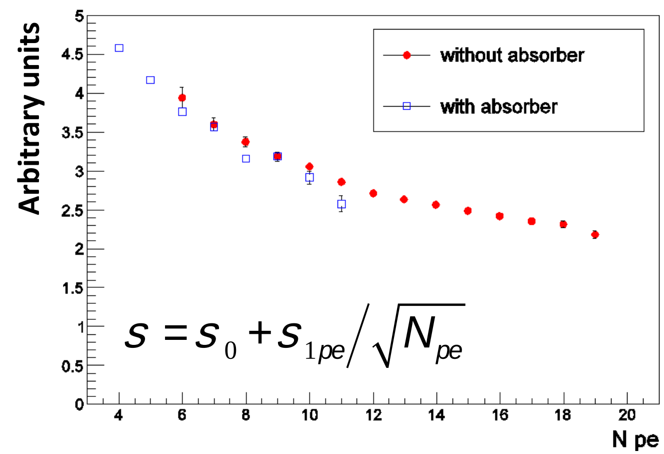


Clear hadron separation up to the CLAS12 maximum momentum

Data analysis in progress

Reflected light configuration





sizeable fraction of light survives
resolution is not significantly degraded

Conclusions

The 3D mapping of the nucleon structure in both momentum and coordinate space is a major focus of the hadron physics community and constitutes a mileston in the physics program of the JLab 12 GeV upgrade.

The addition of a RICH detector would significantly enhance the PID capabilities of CLAS12, allowing for the extraction of flavour separated information about the complex multi-dimensional nucleon structure in the poorly explored valence region.

A non-conventional geometry will allow to reduce costs and limit impact on other detectors

MC simulations suggest a 4σ pion-kaon separation in 3-8 GeV momentum range

Test-beams on a prototype performed at CERN and LNF. Data are being analyzed.

A wide International collaboration is involved in the various aspects of the project

1^{st} RICH module ready by end of 2016

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)