Nuclear medium studies using DIS experiments with CLAS/CLAS12 at JLab, present and future

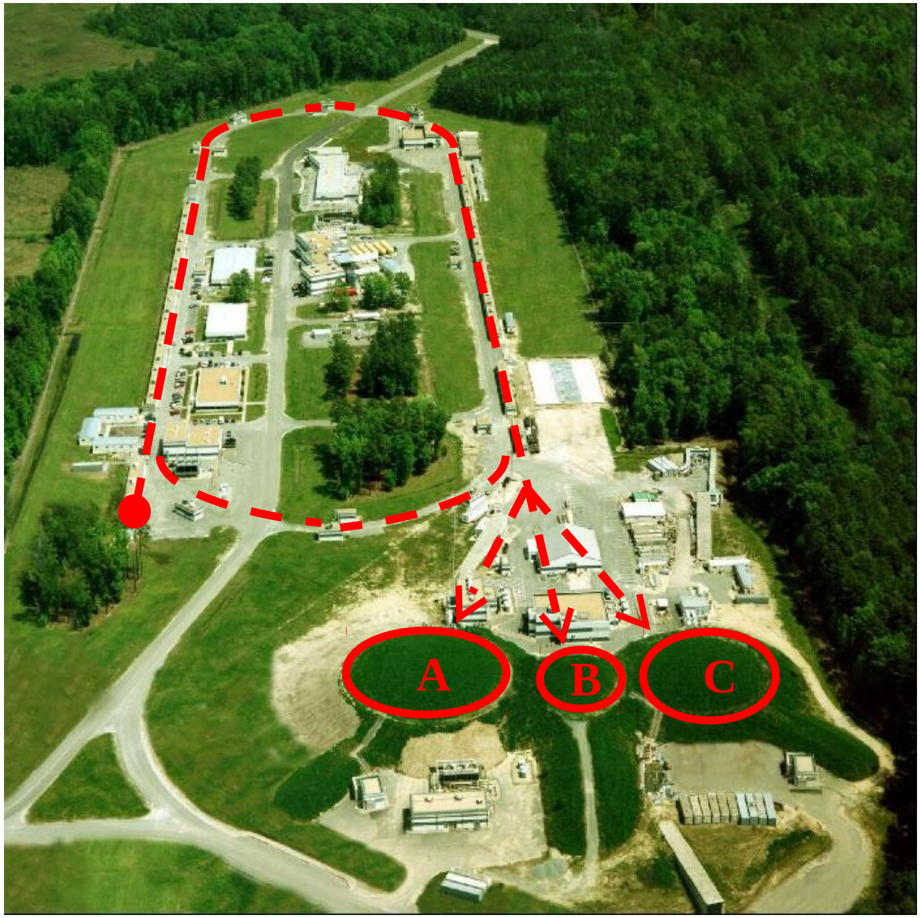
Hayk Hakobyan
Universidad Técnica Federico Santa Maria

DIS 2018, Kobe, Japan
April, 2018

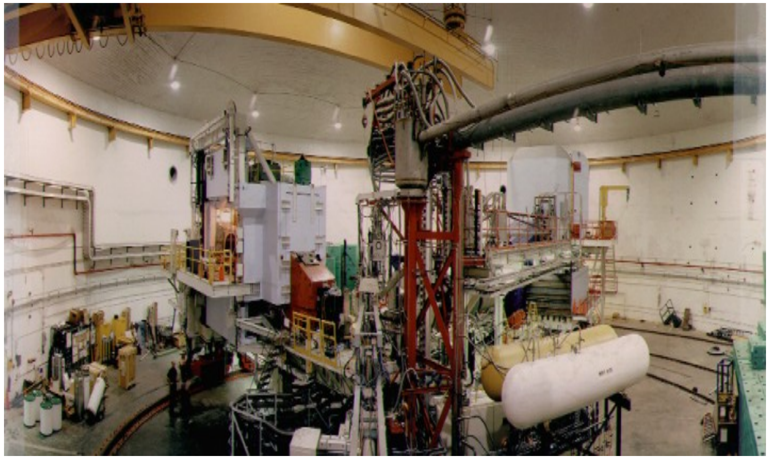
Thomas Jefferson National Accelerator Facility (Jefferson Lab / JLab)

Jefferson Lab

International community of 2000 users, which studies the matter as a structure of quarks and gluons

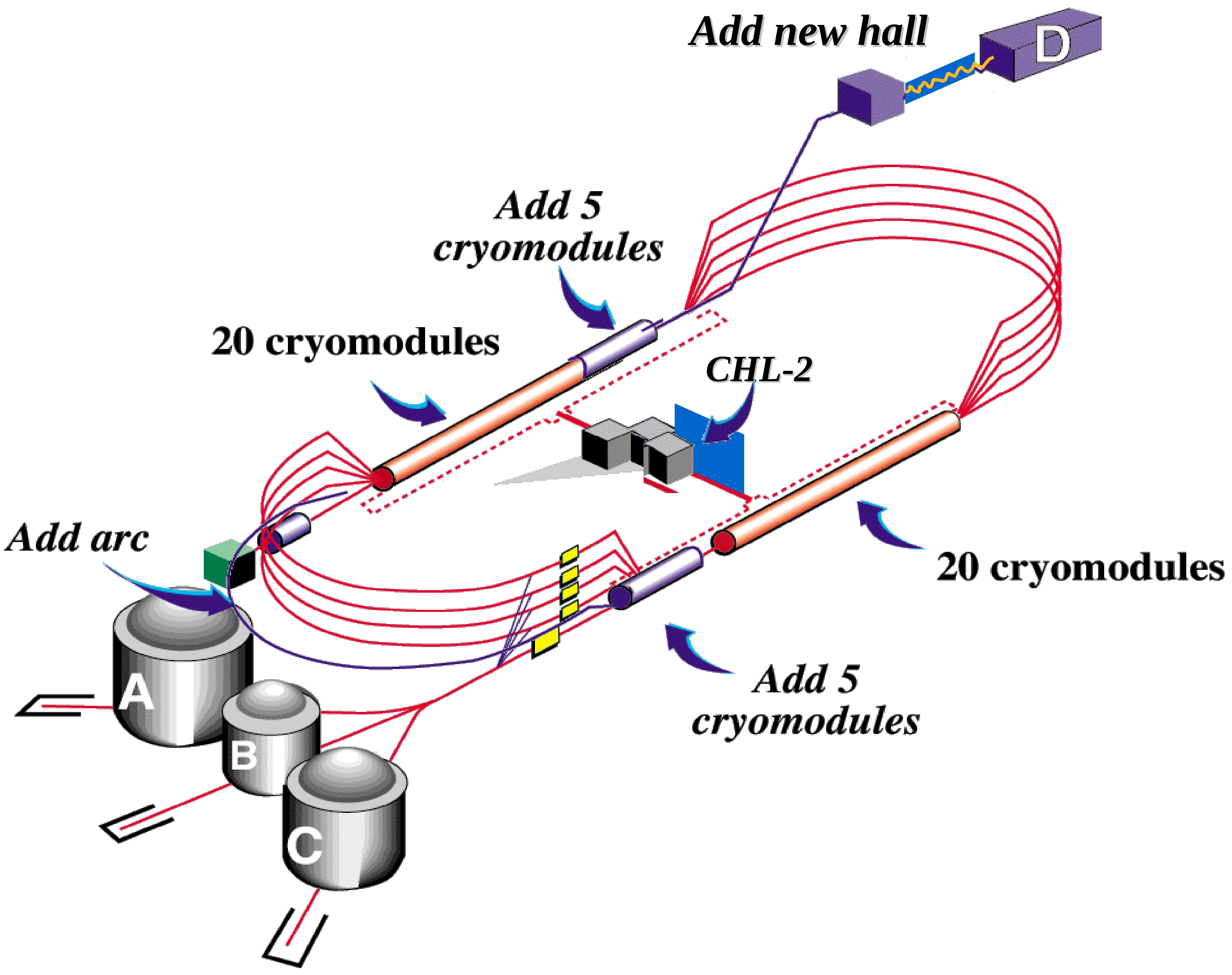


Based on superconductivity, CEBAF accelerator produces a high quality electron beam with 100% duty factor, now with energies up to 12 GeV.

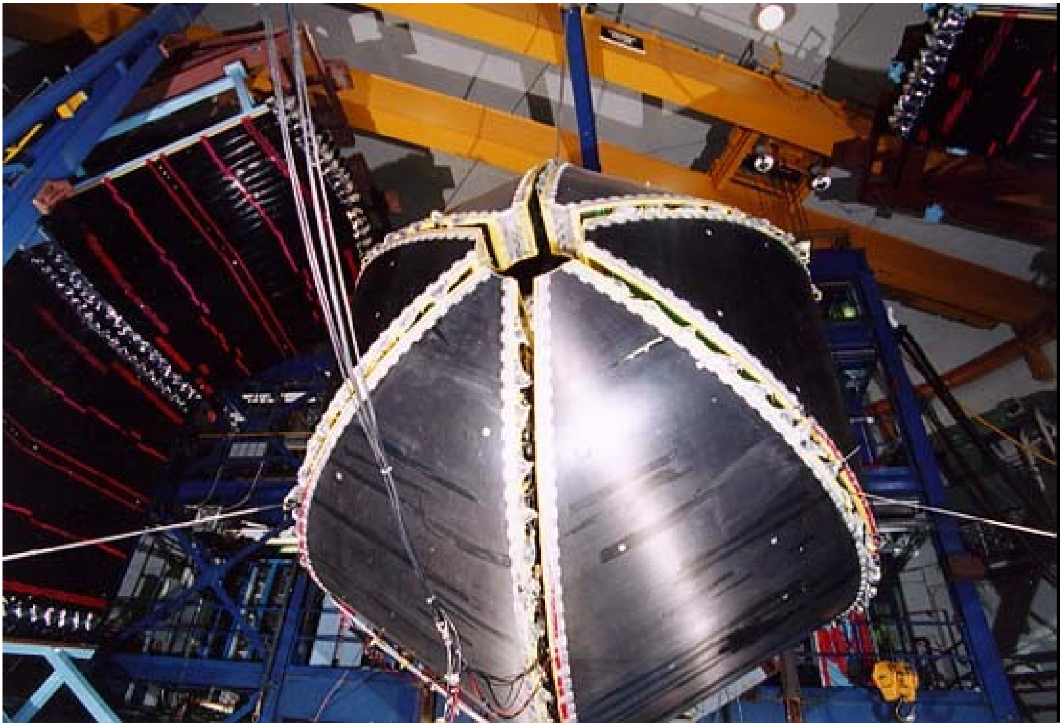


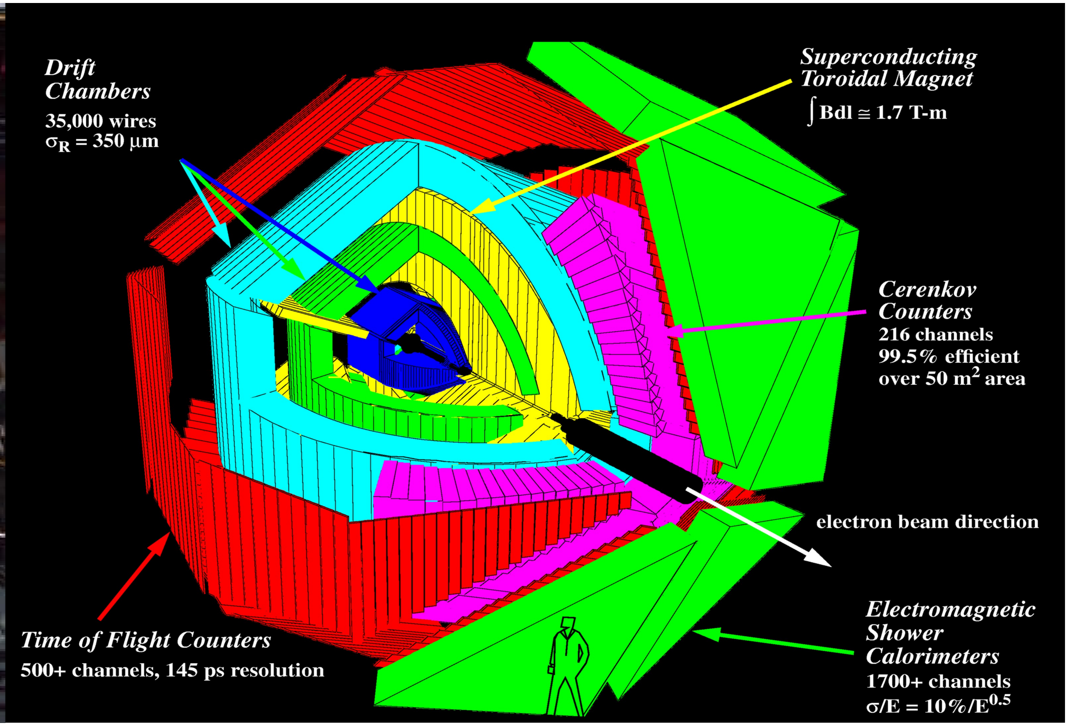
The unique design of the CEBAF accelerator permits simultaneous delivary of a high quality electron beam to four experimental halls.

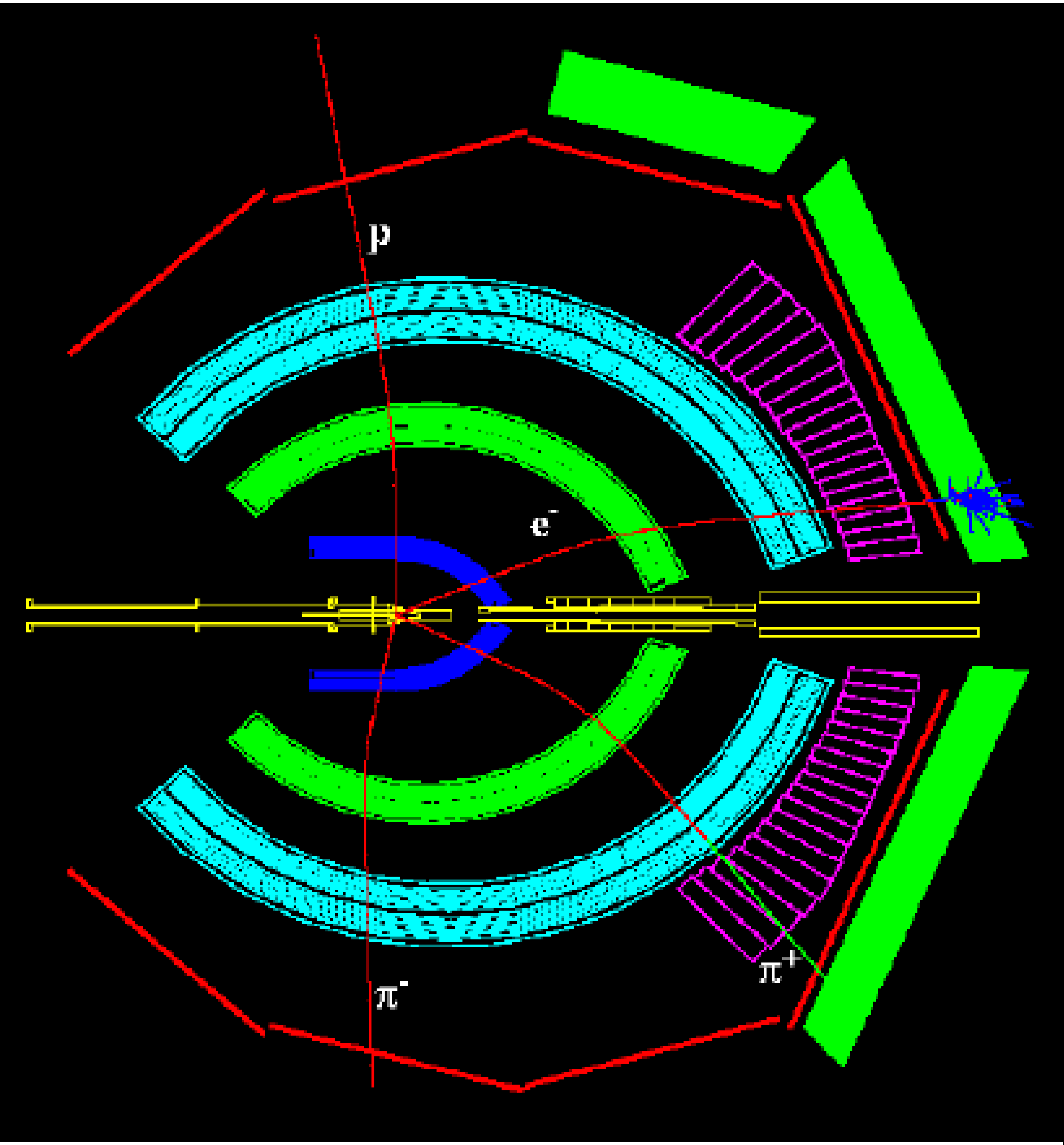
The CEBAF upgrade from 6 GeV to 12 GeV



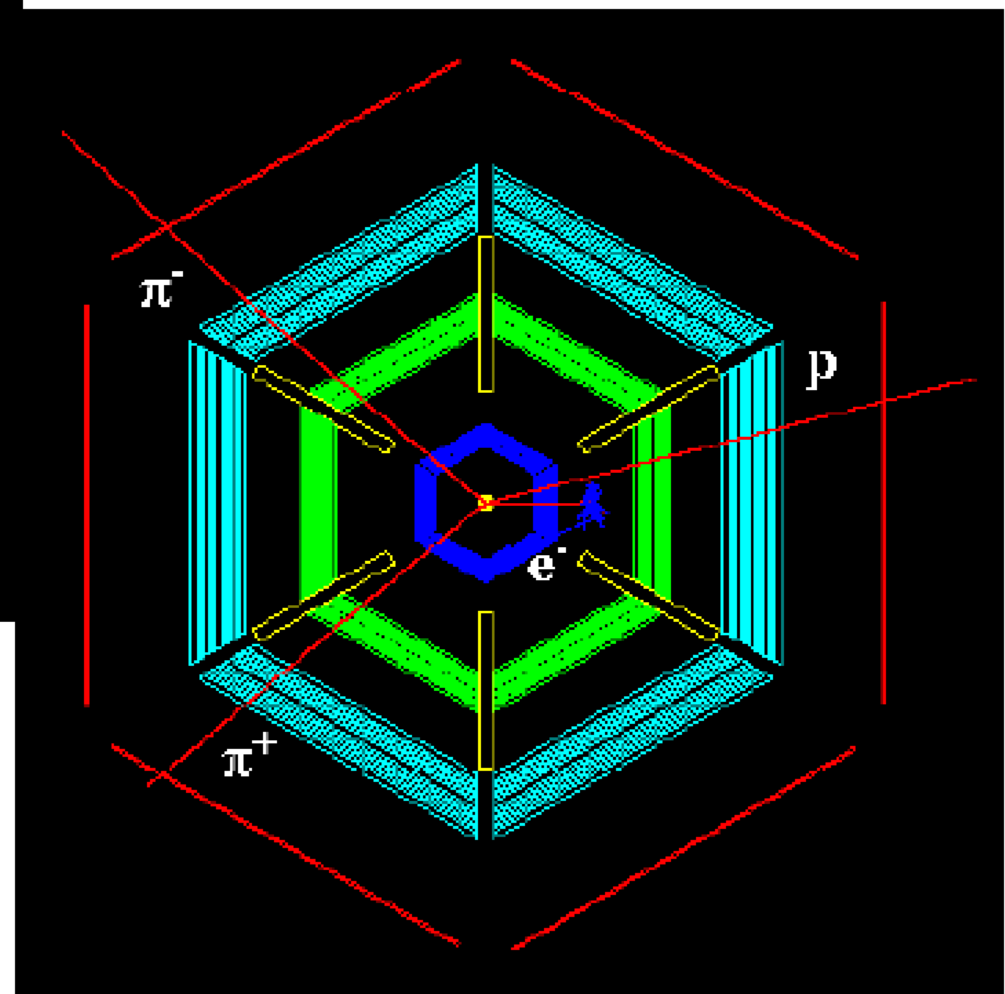
Experimental Hall B with CLAS





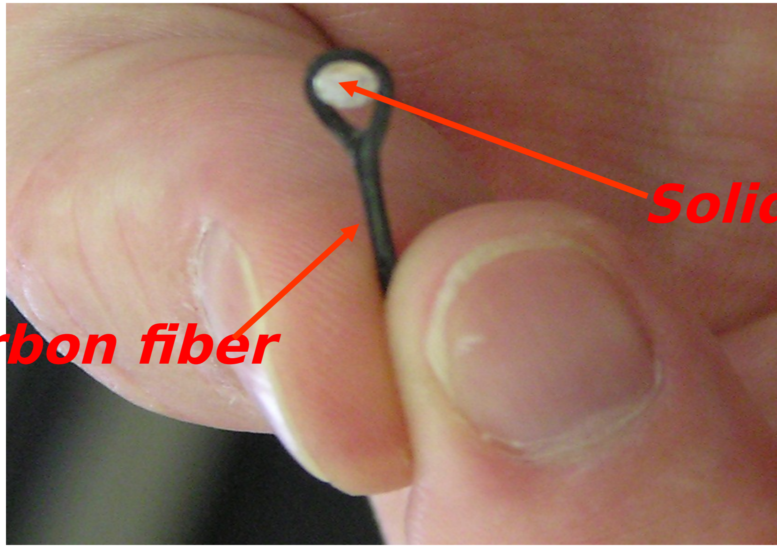


- Charged particle angles 8° - 144°
- Neutral particle angles 8° - 70°
- Momentum resolution ~0.5% (charged)
- Angular resolution ~0.5 mr (charged)
- Identification of p, π^+/π^-, K^+/K^-, e^-/e^+



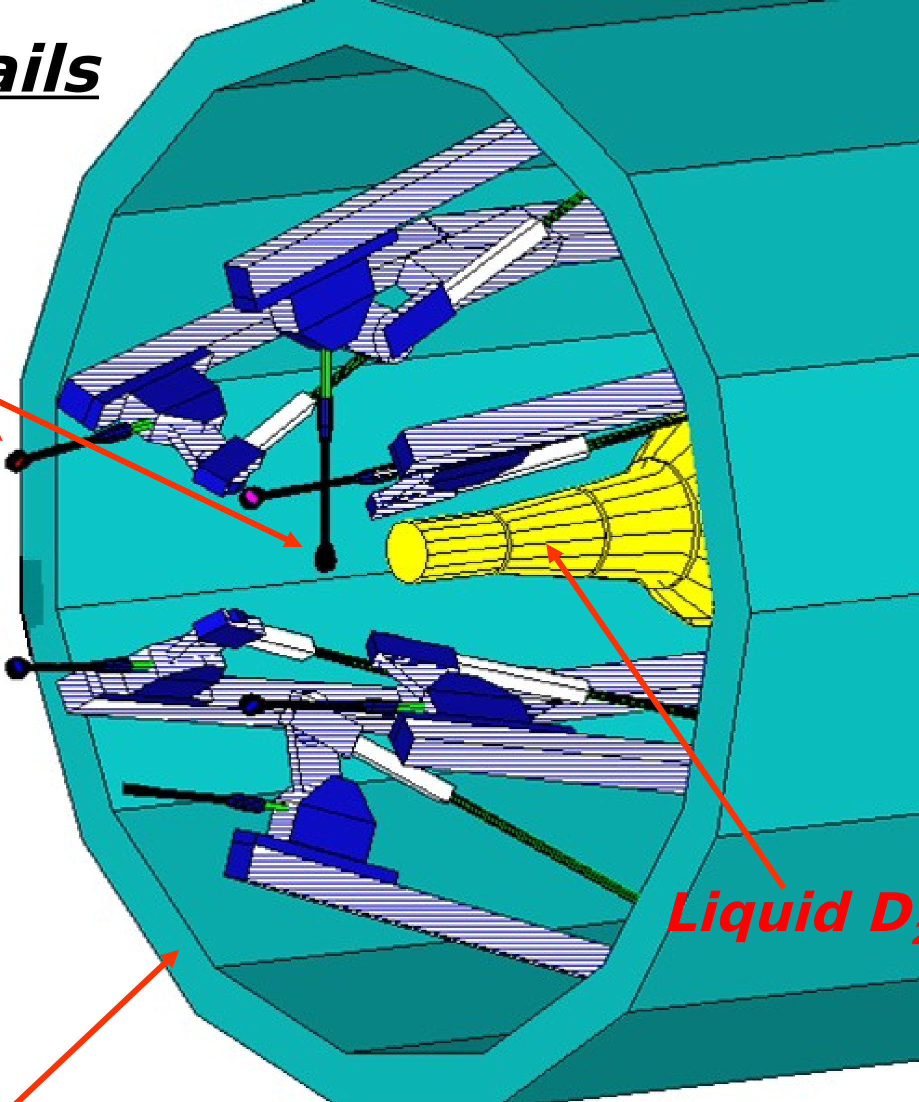
CLAS Eg2 experimental target

Experimental details



Solid target

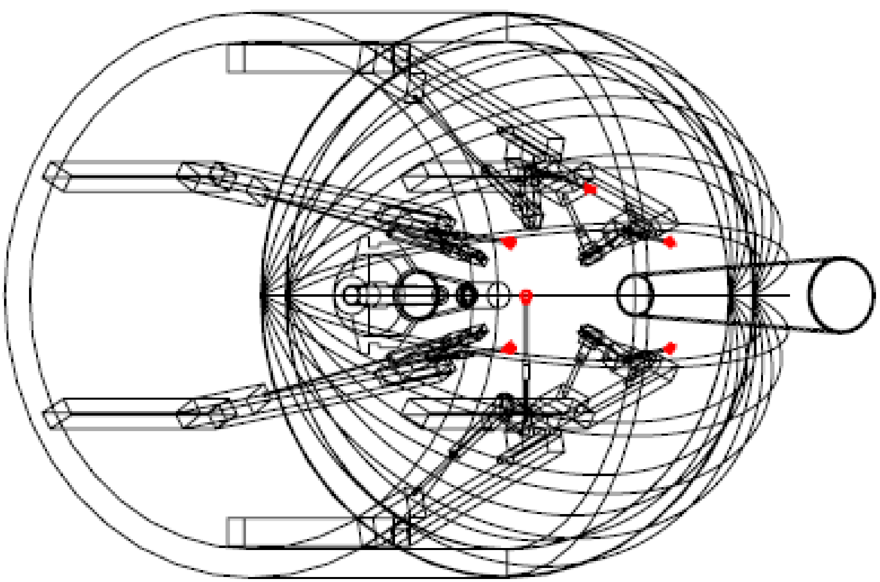
Carbon fiber



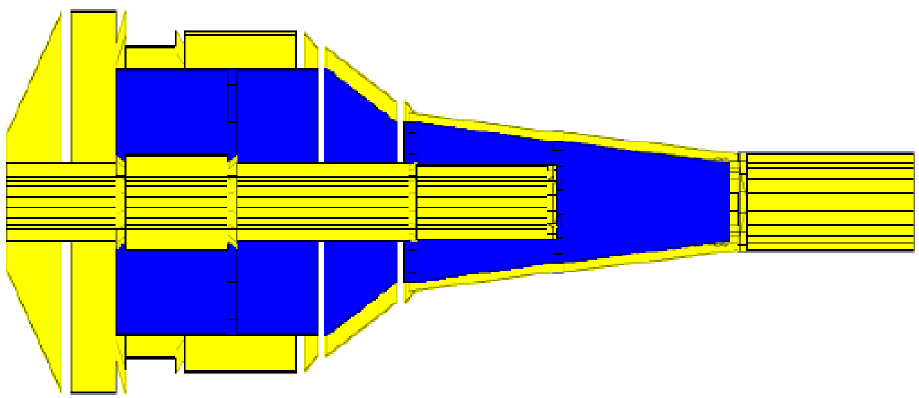
Liquid D_2

Rohacell foam scattering chamber

EG2 Experiment target in GEANT3
Solid (C, Al, Fe, Sn, Pb) target simultaneously
with deuterium target



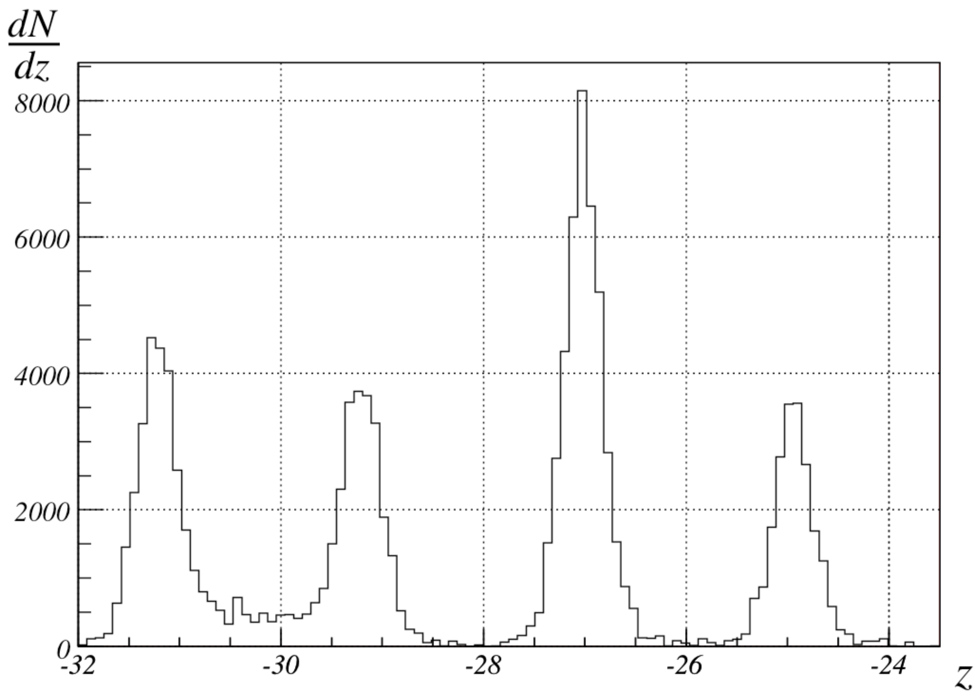
H. Hakobyan, W. Brooks et al, Nucl. Instrum. and Meth. A592:218-223, 2008.



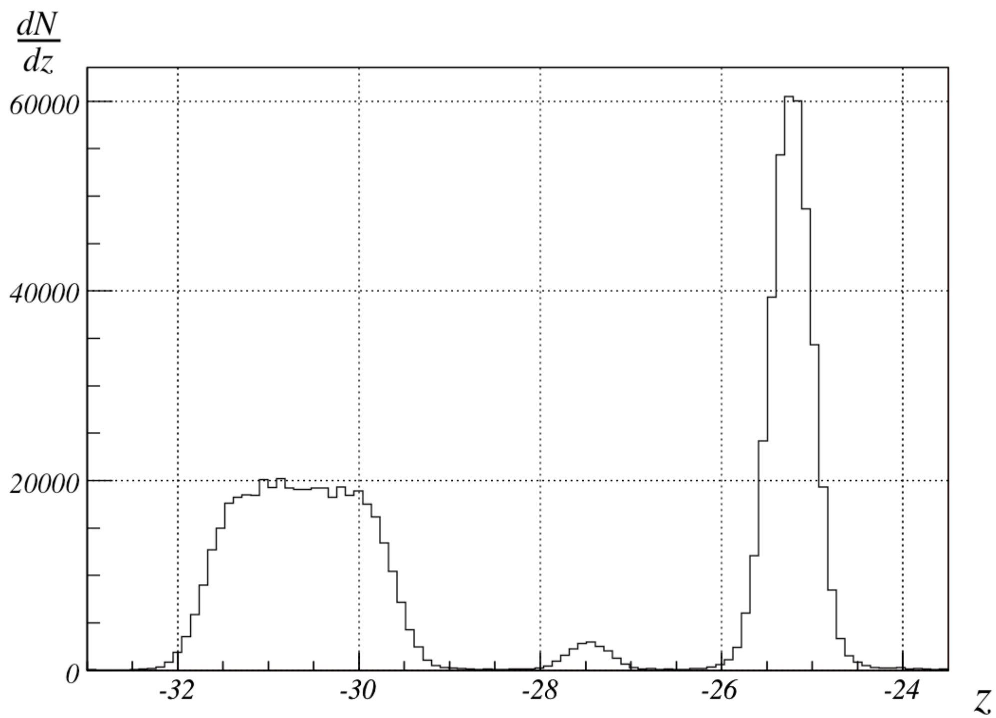
D_2 cell in GEANT

Real CLAS data

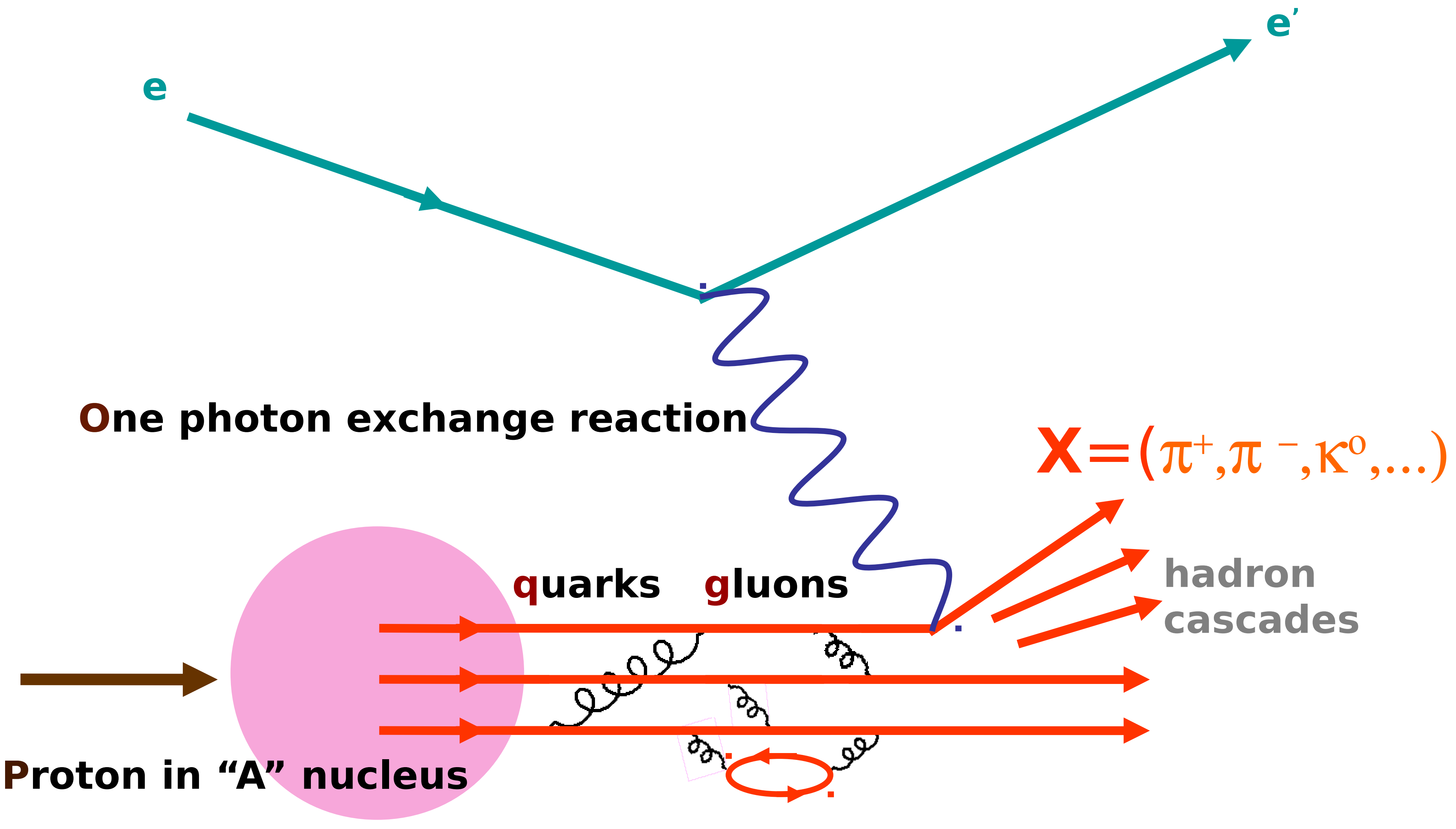
Liquid target empty



Liquid target full



Schematic diagram of semi-inclusive Deep Inelastic Scattering of a lepton off a nucleon



Sturdies performed with CLAS Eg2 double-target

- Nuclear Hadronization
- Color transparency
- Short range nuclear correlations
- Two hadron correlations
- EMC effect measurements
- Hadronic structure function measurements in nuclei
- Etc.

Talk by Taisiya Mineeva tomorrow at 12:20,
"Hadronization in Semi-Inclusive DIS from CLAS at JLab"

Some results of π^+ and η (Eta - first time shown) hadronization studies

Experimental Variables

ν – energy transferred by the electron, = initial energy of struck quark, (2 ~ 4.5) GeV here

Q probe, (1 ~ 4) GeV^2 here

z_h =t is carried by hadron; $0<z_h<1$

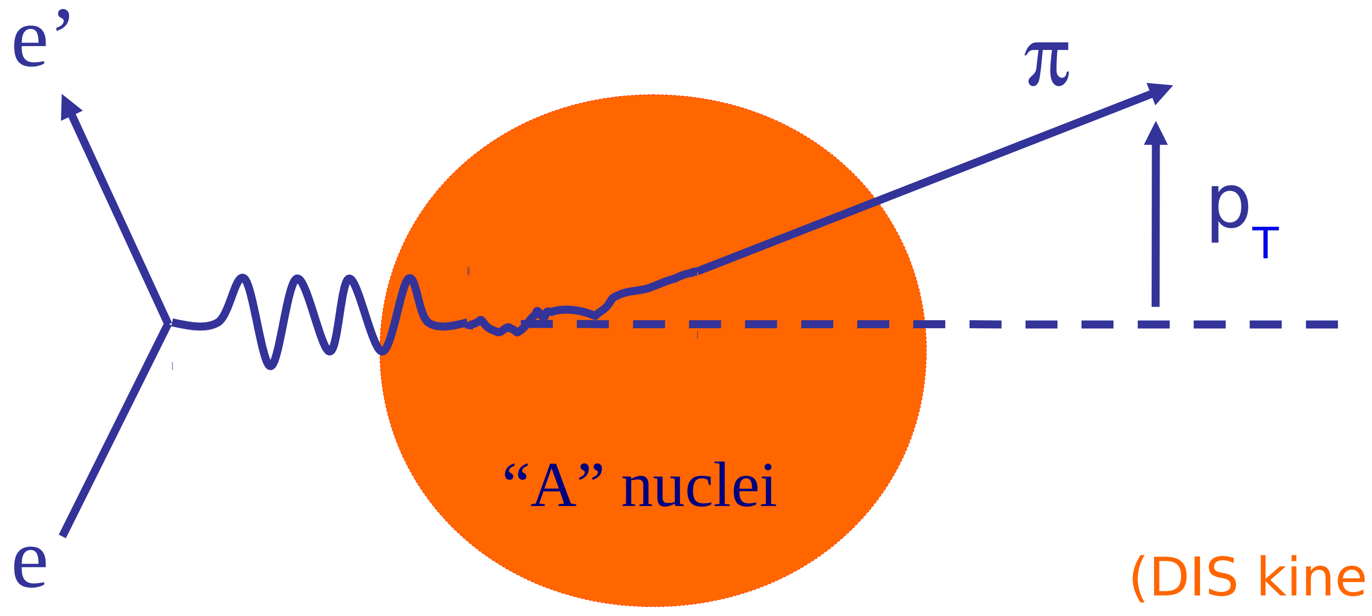
P_T – hadron momentum transverse to virtual photon direction

Φ – hadron azimuthal angle to virtual photon direction

E_{BEAM}=5 GeV (CLAS)

Experimental observables

Transverse momentum broadening: $\Delta p_T^2 = p_T^2(A) - p_T^2(^2H)$

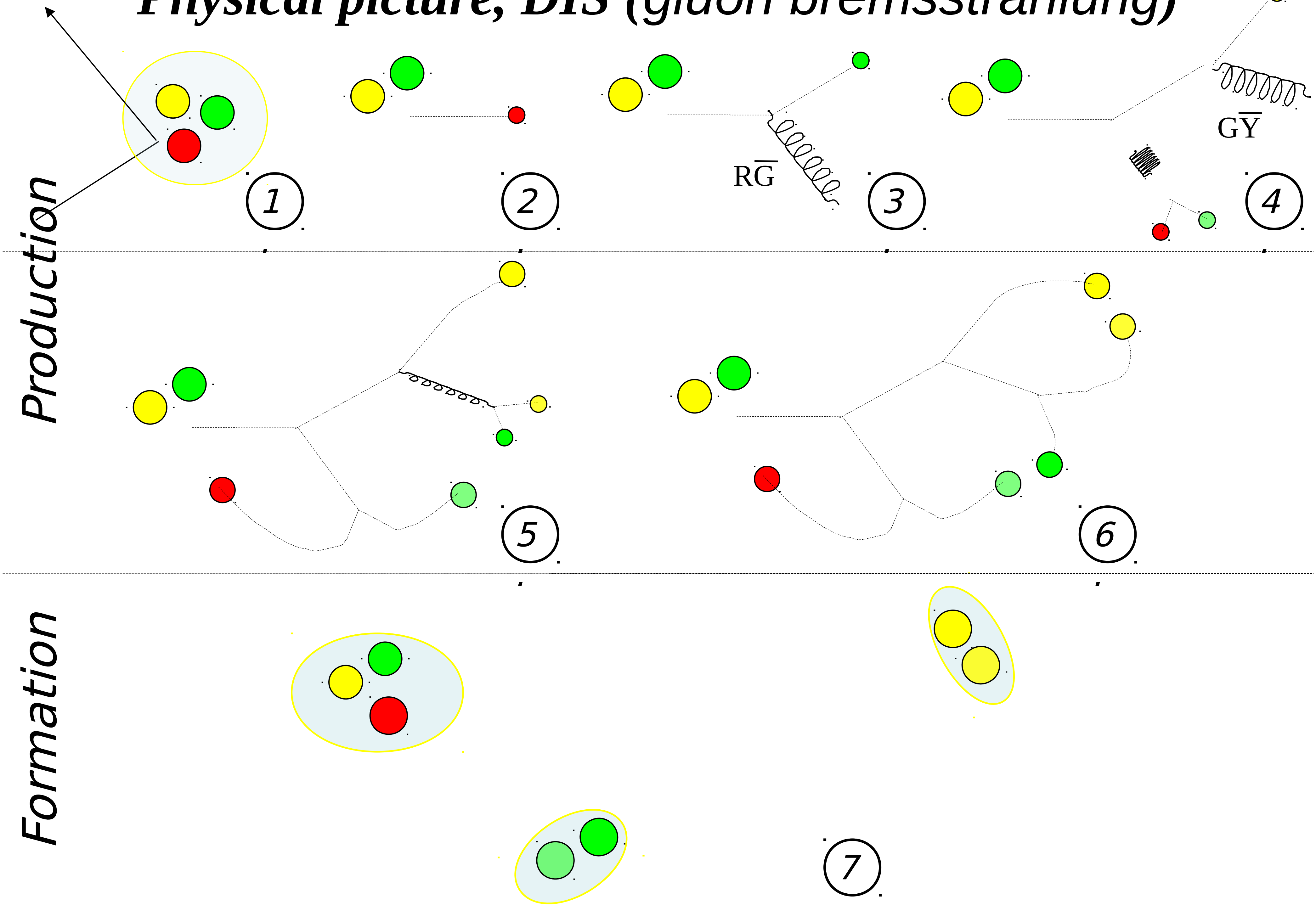


(DIS kinematics)

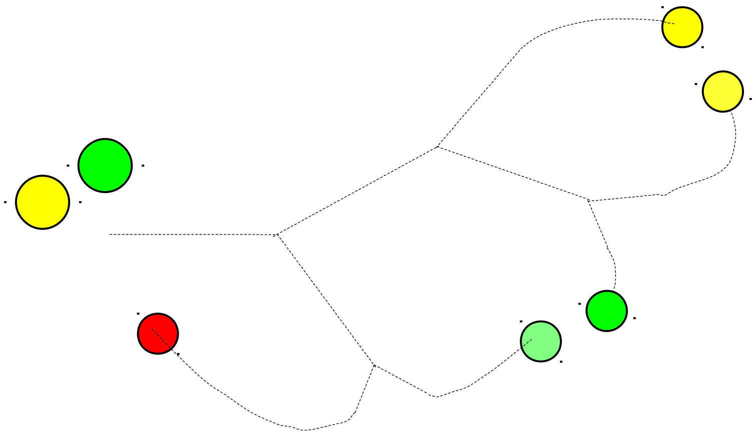
Hadronic multiplicity ratio:

$$R_M^h(z,\nu,p_T^2,Q^2,\phi) = \frac{\left\{ \dfrac{N_h^{DIS}(z,\nu,p_T^2,Q^2,\phi)}{N_e^{DIS}(\nu,Q^2)} \right\}_A}{\left\{ \dfrac{N_h^{DIS}(z,\nu,p_T^2,Q^2,\phi)}{N_e^{DIS}(\nu,Q^2)} \right\}_D}$$

Physical picture, DIS *(gluon bremsstrahlung)*



Kopeliovich, Nemchik, Predazzi, Hayashigaki, Nuclear Physics A 740 (2004) 211–245



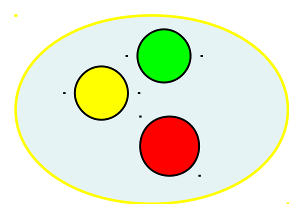
Two distinct dynamical stages, each with characteristic time scale

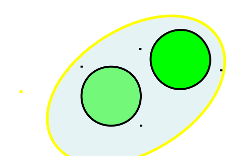
Production time t_p

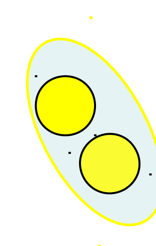
Time during which quark emits gluons is deconfined. Signaled by medium-stimulated energy loss via gluon emission: (p_T broadening)

Formation time t_f

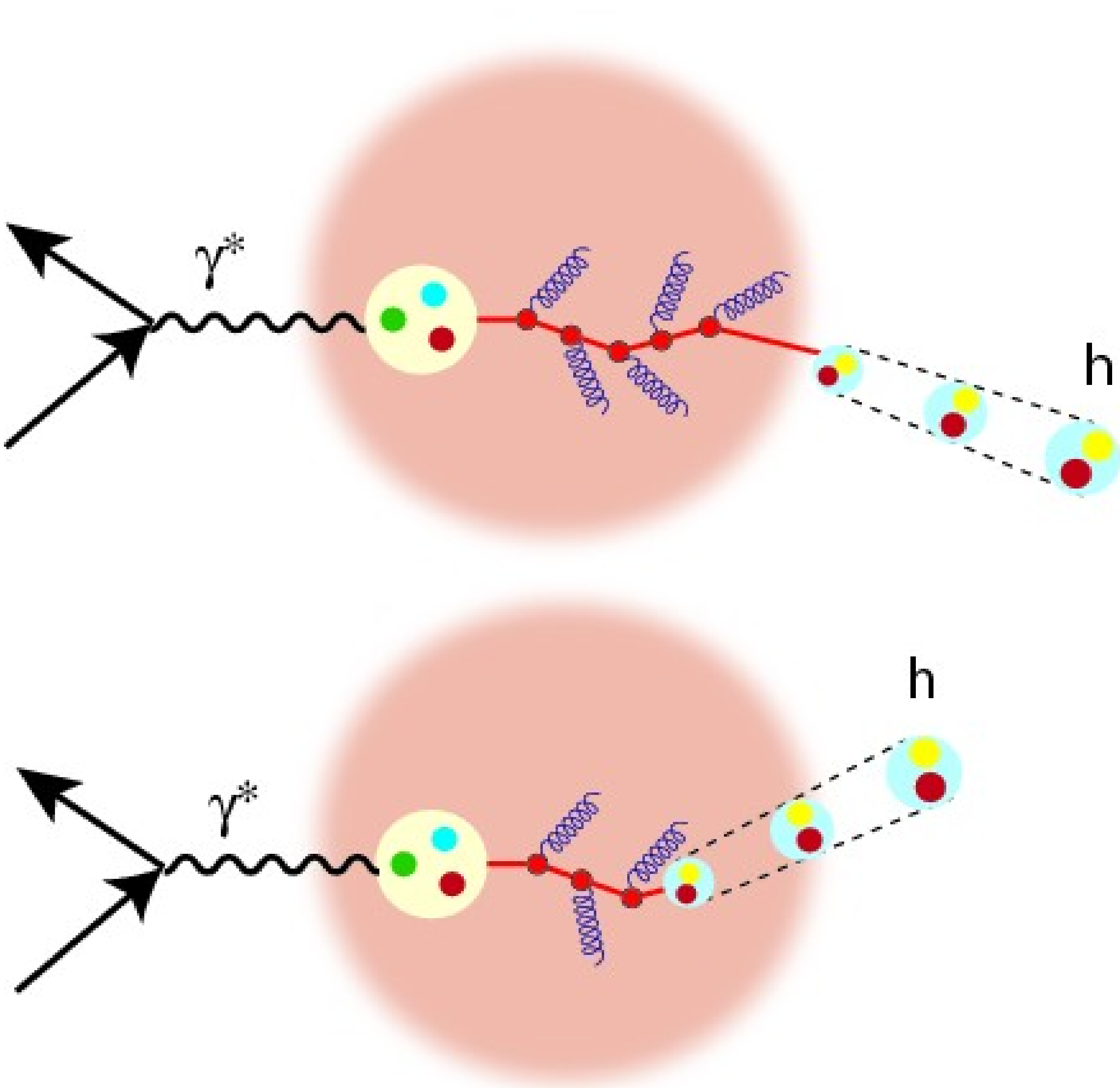
Time required to form color field of hadron Signaled by interactions with known hadron cross sections No gluon emission (Hadron attenuation)

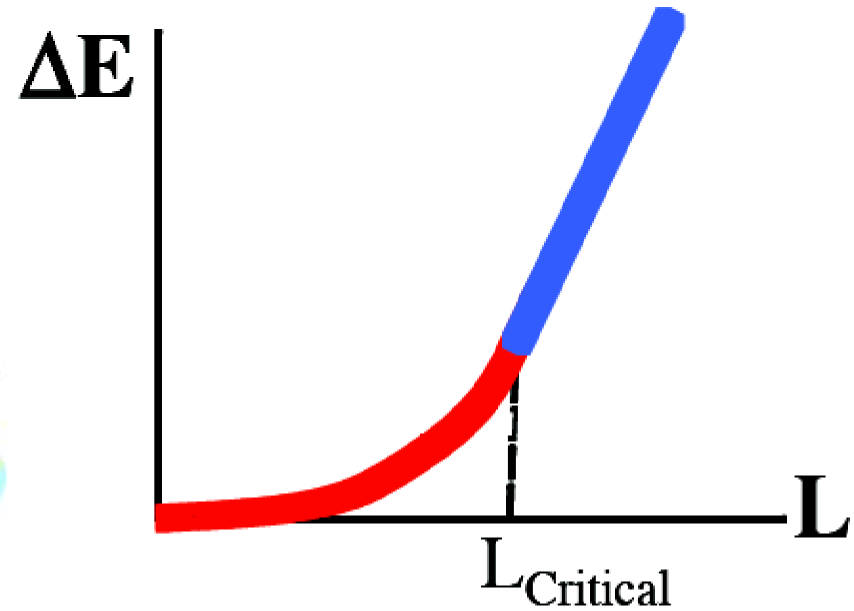






The production and formation of the final hadron, ¿inside or outside?





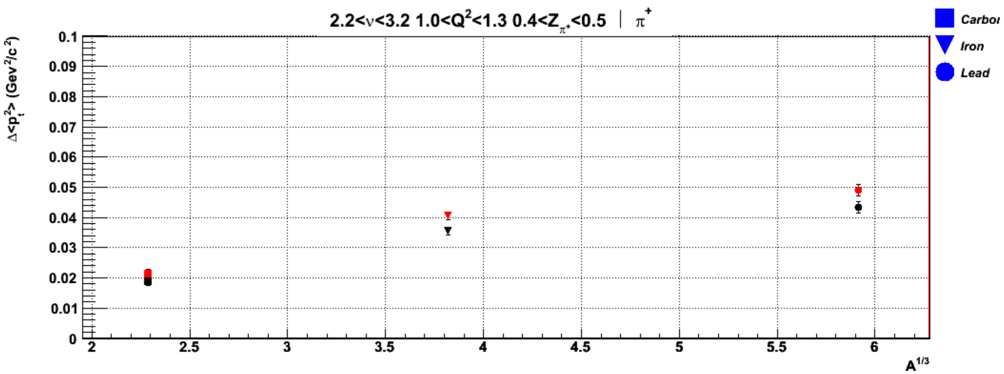
$$-\frac{dE}{dx} \propto L \qquad L < L_{Critical}$$

$$-\frac{dE}{dx} \propto \sqrt{E} \qquad L > L_{Critical}$$

$$-\frac{dE}{dx} = \frac{\alpha_s N_c}{4} \Delta k_T^2$$

Baier, Schiff, Zakharov, Annu. Rev. Nucl. Part. Sci. 2000. 50:37-69

Transverse momentum dependence on 1/3 of nuclear mass number (all together in 24 kinematical region)

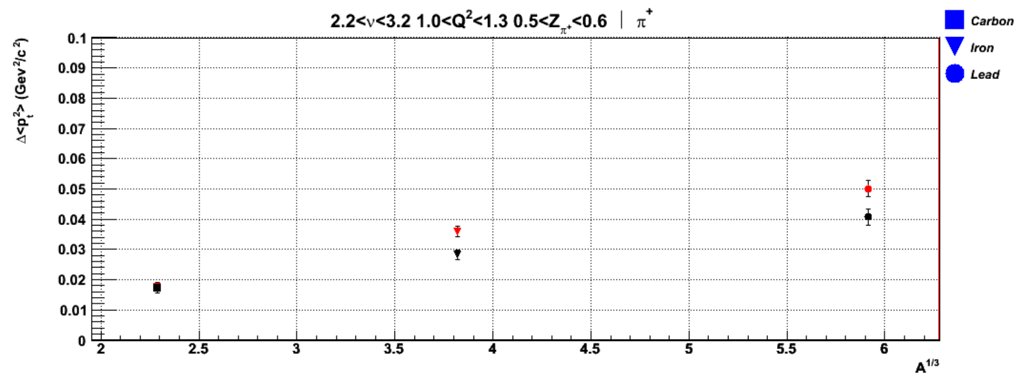


C_{mean}=0.0214 Fe_{mean}=0.0404 Pb_{mean}=0.0490

C_{err}=0.0013 Fe_{err}=0.0012 Pb_{err}=0.0019

Corrected data

C_{mean}=0.0189 Fe_{mean}=0.0355 Pb_{mean}=0.0434

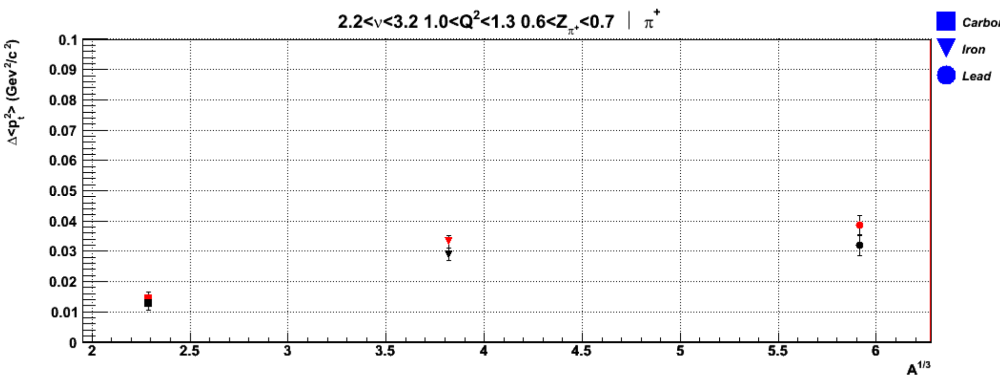


C_{mean}=0.0174 Fe_{mean}=0.0359 Pb_{mean}=0.0501

C_{err}=0.0018 Fe_{err}=0.0017 Pb_{err}=0.0027

Corrected data

C_{mean}=0.0173 Fe_{mean}=0.0282 Pb_{mean}=0.0407

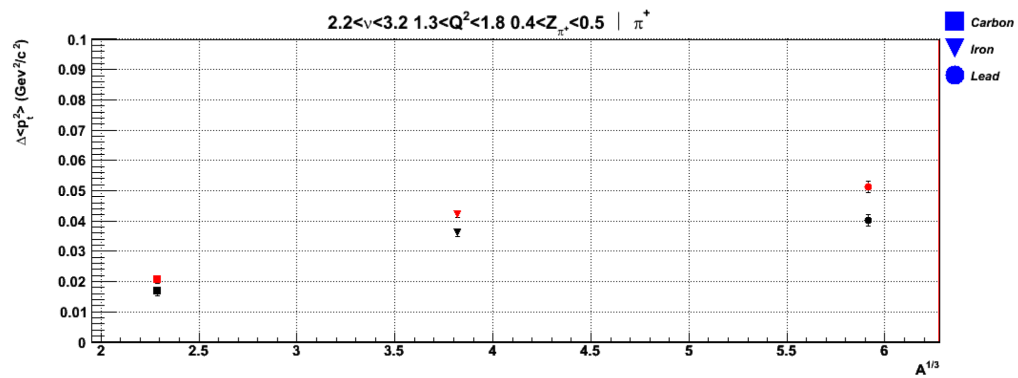


C_{mean}=0.0144 Fe_{mean}=0.0333 Pb_{mean}=0.0385

C_{err}=0.0023 Fe_{err}=0.0021 Pb_{err}=0.0034

Corrected data

C_{mean}=0.0129 Fe_{mean}=0.0290 Pb_{mean}=0.0320



C_{mean}=0.0206 Fe_{mean}=0.0422 Pb_{mean}=0.0512

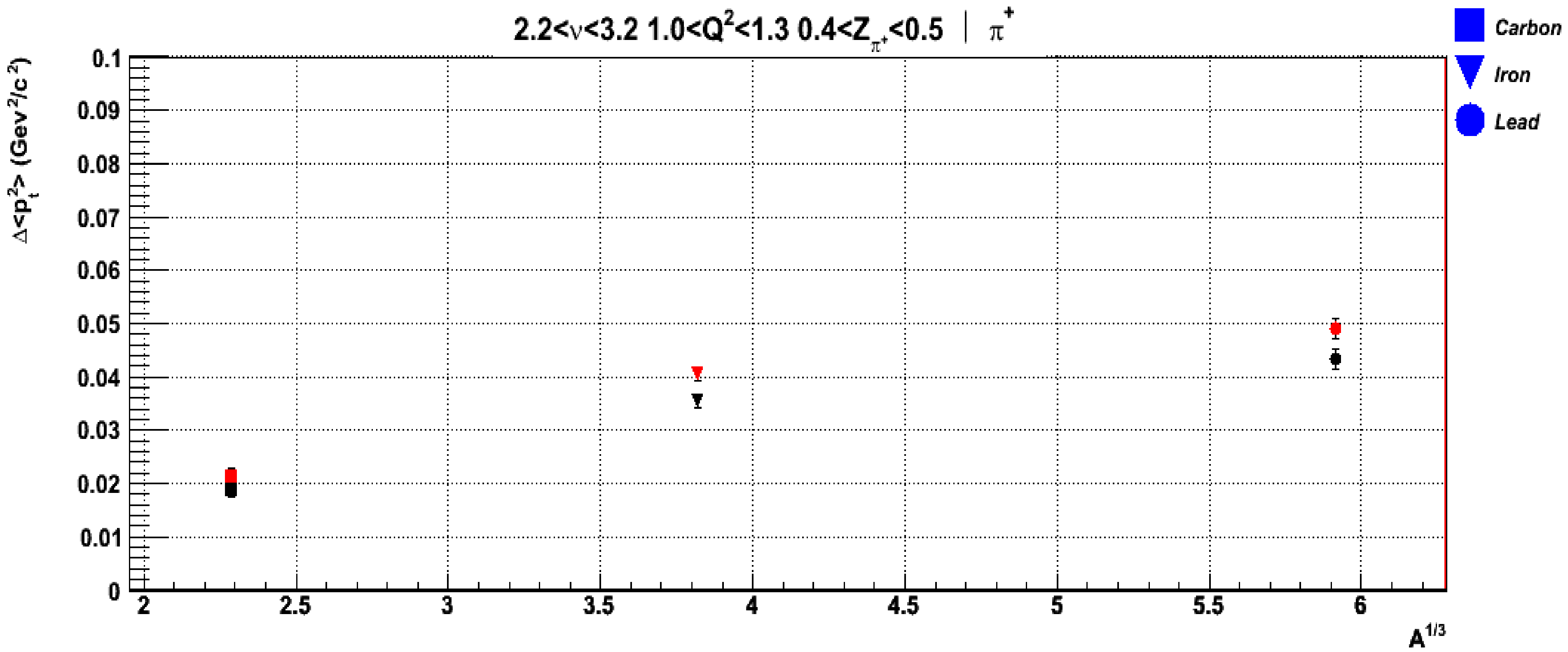
C_{err}=0.0013 Fe_{err}=0.0012 Pb_{err}=0.0019

Corrected data

C_{mean}=0.0167 Fe_{mean}=0.0360 Pb_{mean}=0.0403

Acceptance correcion less than 14 %

Transverse momentum dependence on 1/3 of nuclear mass number (all together in 24 kinematical region)



C_{mean}=0.0214 Fe_{mean}=0.0404 Pb_{mean}=0.0490

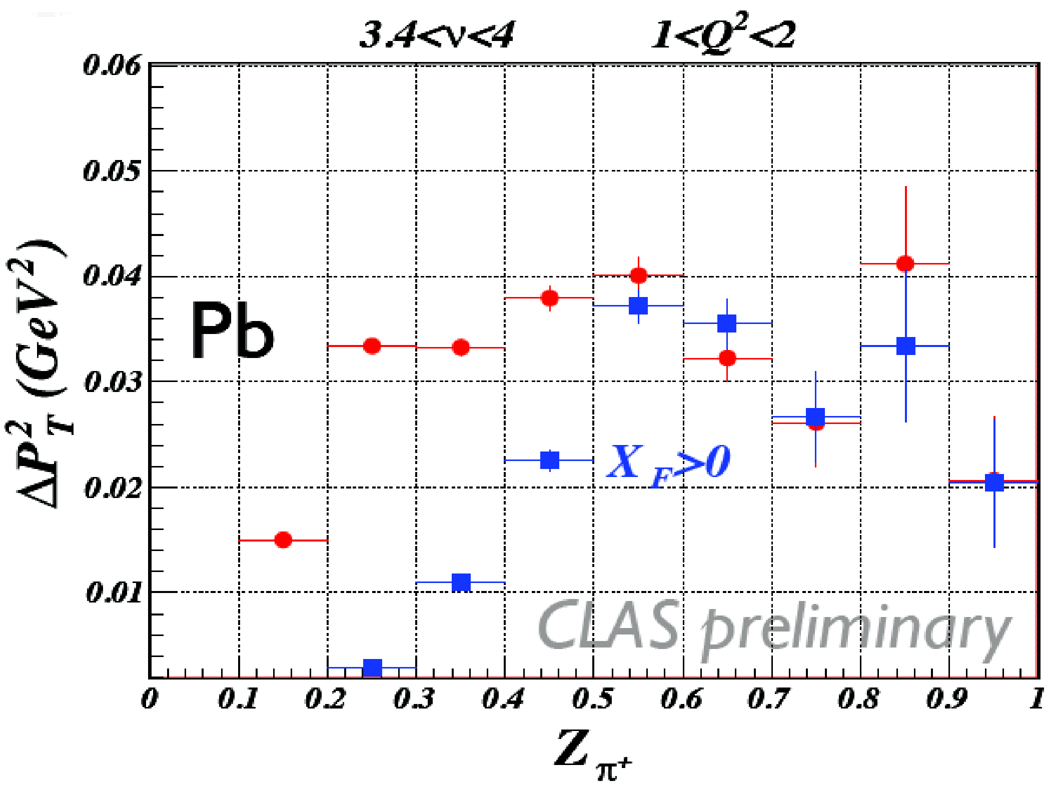
C_{err}=0.0013 Fe_{err}=0.0012 Pb_{err}=0.0019

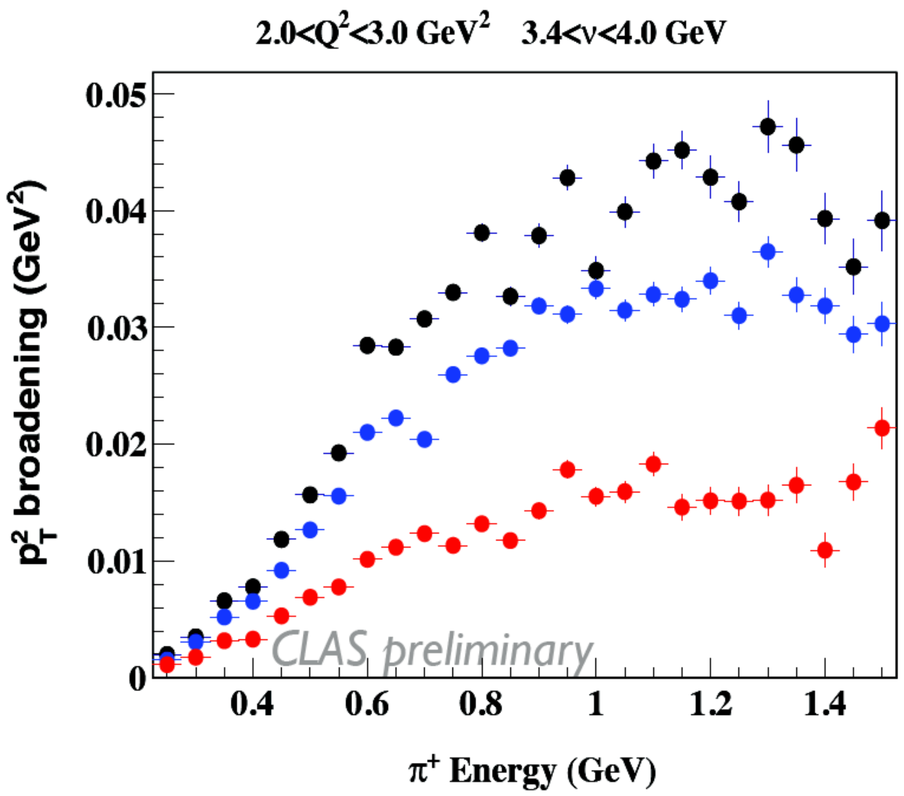
Corrected data

C_{mean}=0.0189 Fe_{mean}=0.0355 Pb_{mean}=0.0434

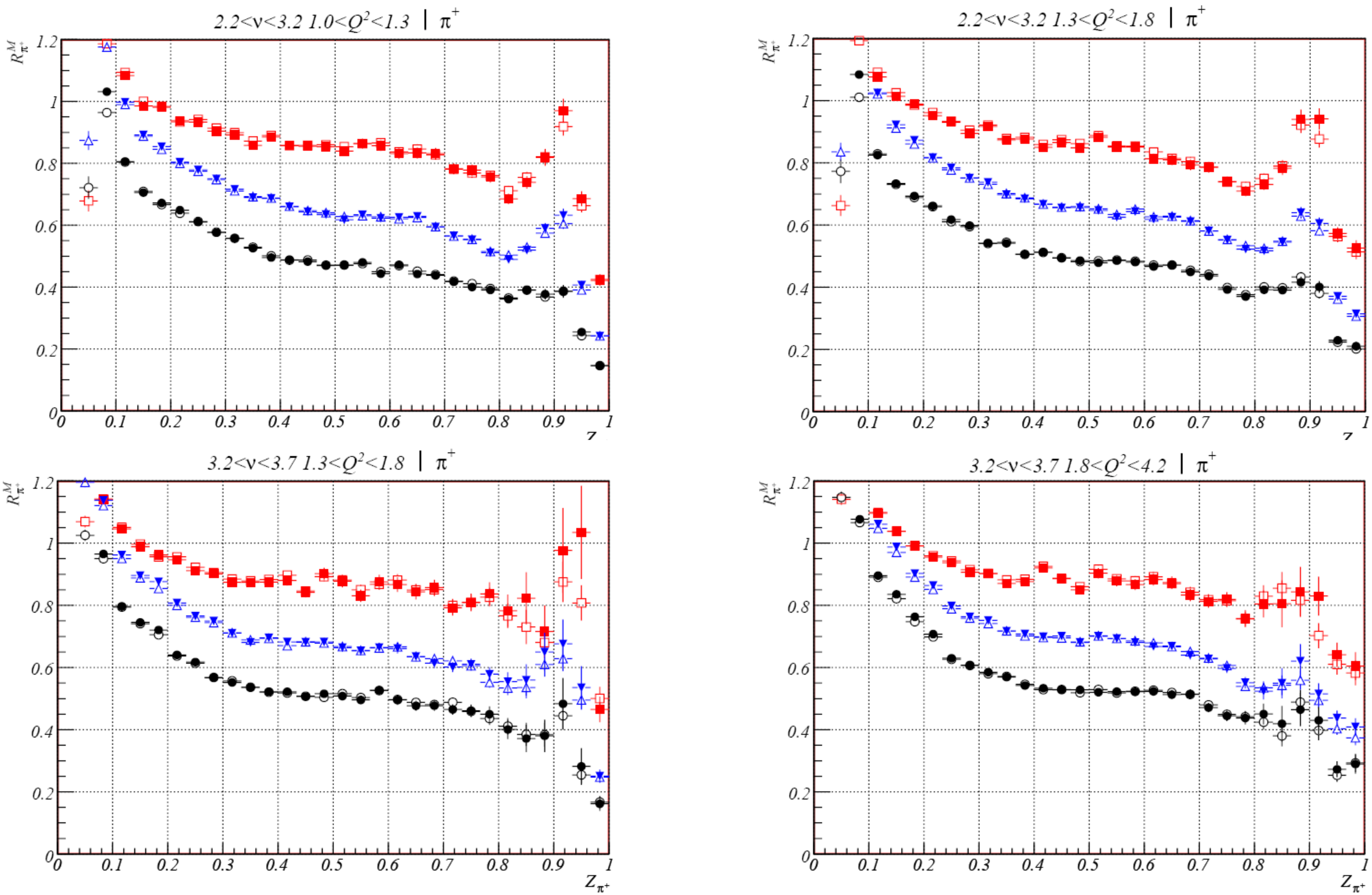
Acceptance correcion less than 14 %

Z and energy dependence of transverse momentum broadening for π^+

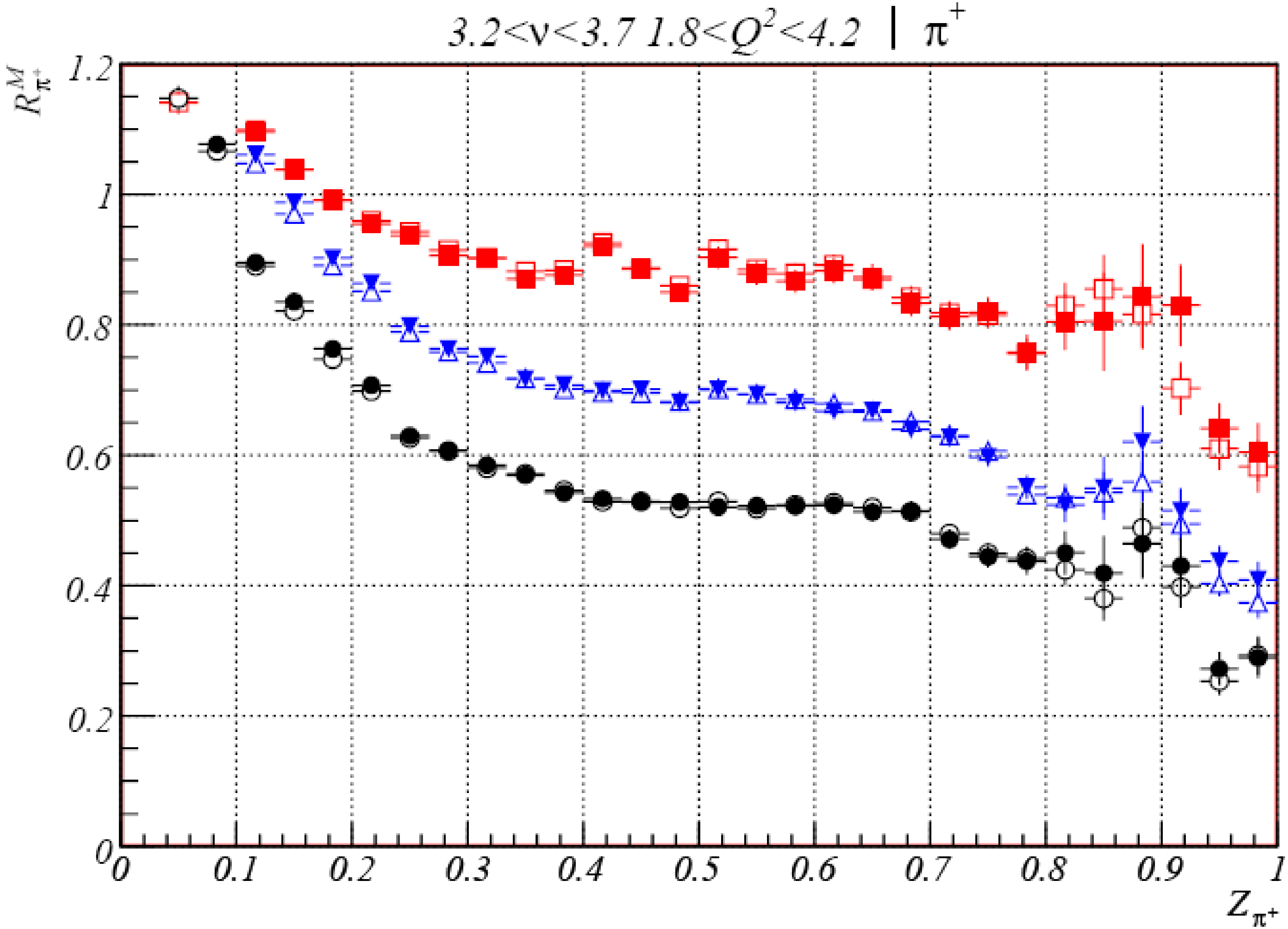




Hadronic multiplicity ratio dependence on z in different kinematical regions



Hadronic multiplicity ratio dependence on z in different kinematical regions



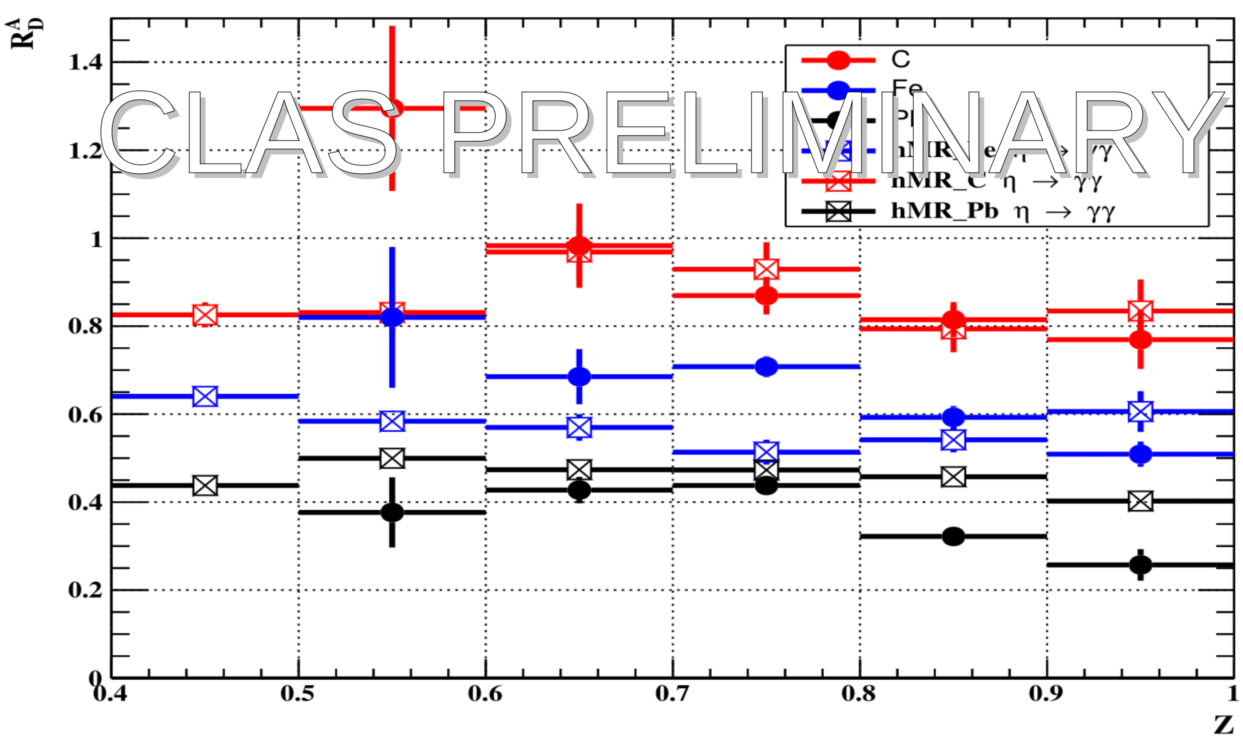
Eta particle contains strange quarks!

π^0 DECAY MODES	Fraction (Γ_i/Γ)
2γ	(98.823 ± 0.034) %
$e^+ e^- \gamma$	(1.174 ± 0.035) %

η DECAY MODES	Fraction (Γ_i/Γ)
Neutral modes	
neutral modes	(72.12 ± 0.34) %
2γ	(39.41 ± 0.20) %
$3\pi^0$	(32.68 ± 0.23) %
Charged modes	
charged modes	(28.10 ± 0.34) %
$\pi^+\pi^-\pi^0$	(22.92 ± 0.28) %
$\pi^+\pi^-\gamma$	(4.22 ± 0.08) %

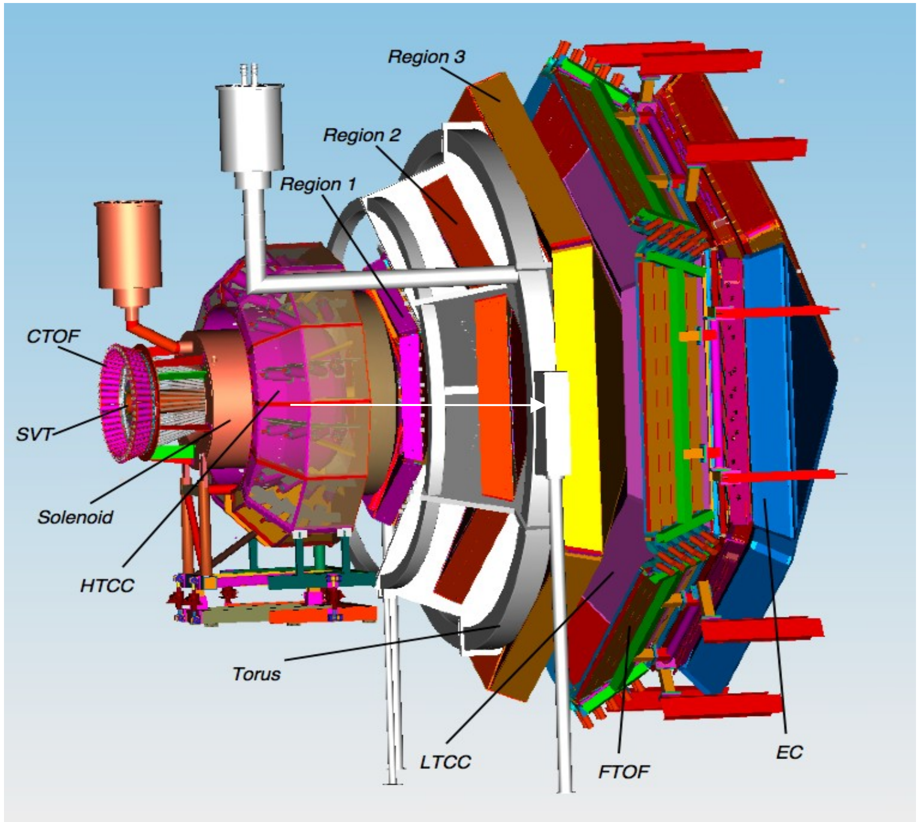
By Orlando Soto

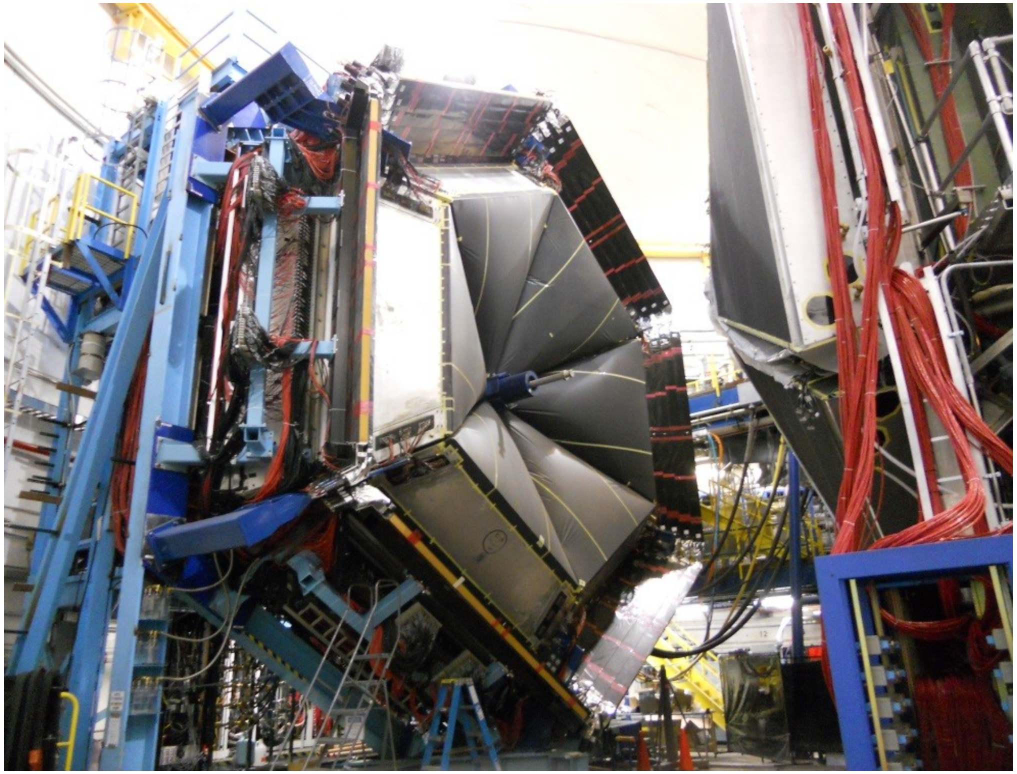
Multiplicity Ratio $\eta \rightarrow \pi^+\pi^-\pi^0$ / $\eta \rightarrow \gamma\ \gamma$



Experiments with CLAS12

CLAS12





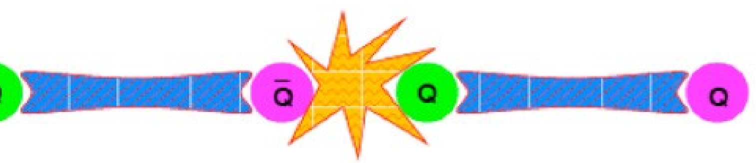
$L=10^{35}\ cm^{-2}s^{-1}$

The internal structure of nucleons ($E=mc^2$)

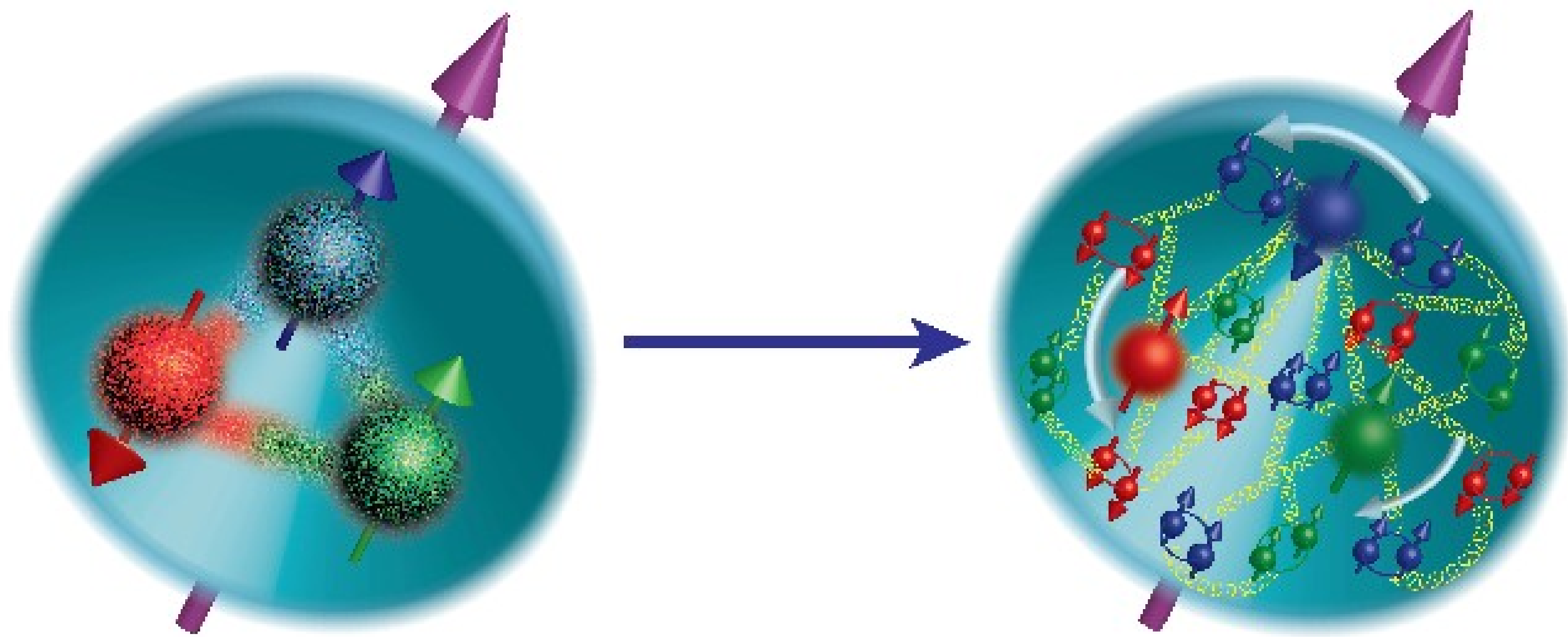
Uncertainty principle
$\Delta P * \Delta X < h$
(parton kinetic energy)

Spin and Angular Momentum
Resonances
(proton, Spin-1/2) (Delta resonance, Spin=3/2)

Confinement
Color flux tube (or strings)



Hadronization



A frontier program in the hadron physics

• Will allow to obtain the tridimensional images of a nucleon, revealing some aspects about hidden dynamics of its internal structure (GPDs and TMDs).

• **Will complete our understanding about the transition between hadrons and quarks/gluons of nucleons (hadronization, color transparency, etc).**

• Will be possible in the definitive form to confirm the existence of the exotic mesons, predicted by QCD as a result of the confinement of quarks.

• Moreover, will give some low energy proofs for the existence of the physics beyond Standard Model, complementing this way the measurements on higher energy scale.

Hadrons in CLAS12

hadron	$c\tau$	mass (GeV)	flavor content	detection channel	Production rate per 1k DIS events
π^0	25 nm	0.13	$u\bar{u}d\bar{d}$	$\gamma\gamma$	1100
π^+	7.8 m	0.14	$u\bar{d}$	direct	1000
π^-	7.8 m	0.14	$d\bar{u}$	direct	1000
η	0.17 nm	0.55	$u\bar{u}d\bar{d}s\bar{s}$	$\gamma\gamma$	120
ω	23 fm	0.78	$u\bar{u}d\bar{d}s\bar{s}$	$\pi^+\pi^-\pi^0$	170
η'	0.98 pm	0.96	$u\bar{u}d\bar{d}s\bar{s}$	$\pi^+\pi^-\eta$	27
ϕ	44 fm	1.0	$u\bar{u}d\bar{d}s\bar{s}$	K^+K^-	0.8
$f1$	8 fm	1.3	$u\bar{u}d\bar{d}s\bar{s}$	$\pi\pi\pi\pi$	-
K^+	3.7 m	0.49	$u\bar{s}$	direct	75
K^-	3.7 m	0.49	$\bar{u}s$	direct	25
K^0	27 mm	0.50	$d\bar{s}$	$\pi^+\pi^-$	42
p	stable	0.94	ud	direct	530
$\bar{p}$	stable	0.94	$\bar{u}\bar{d}$	direct	3
Λ	79 mm	1.1	uds	$p\pi^-$	72
$\Lambda(1520)$	13 fm	1.5	uds	$p\pi^-$	-
Σ^+	24 mm	1.2	us	$p\pi^0$	6
Σ^0	22 pm	1.2	uds	$\Lambda\gamma$	11
Ξ^0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ξ^-	49 mm	1.3	[illegible]	$\Lambda\pi$	0.9

With new Eg2 target, designed and built in UTFSM

Extreme Conditions for the New Target

- High Vacuum (6x10E-6 mbar) → low gas loads materials
- Magnetic Field (5 Tesla) → Non-magnetic materials
- Cryotarget (30 °K) → Low temperature resistant
- Radiation Hardness
- Reduced space

The problem to solve is to generate precise movement (to exchange targets) in these extreme conditions.

Types of Solid Targets

Properties of the solid targets

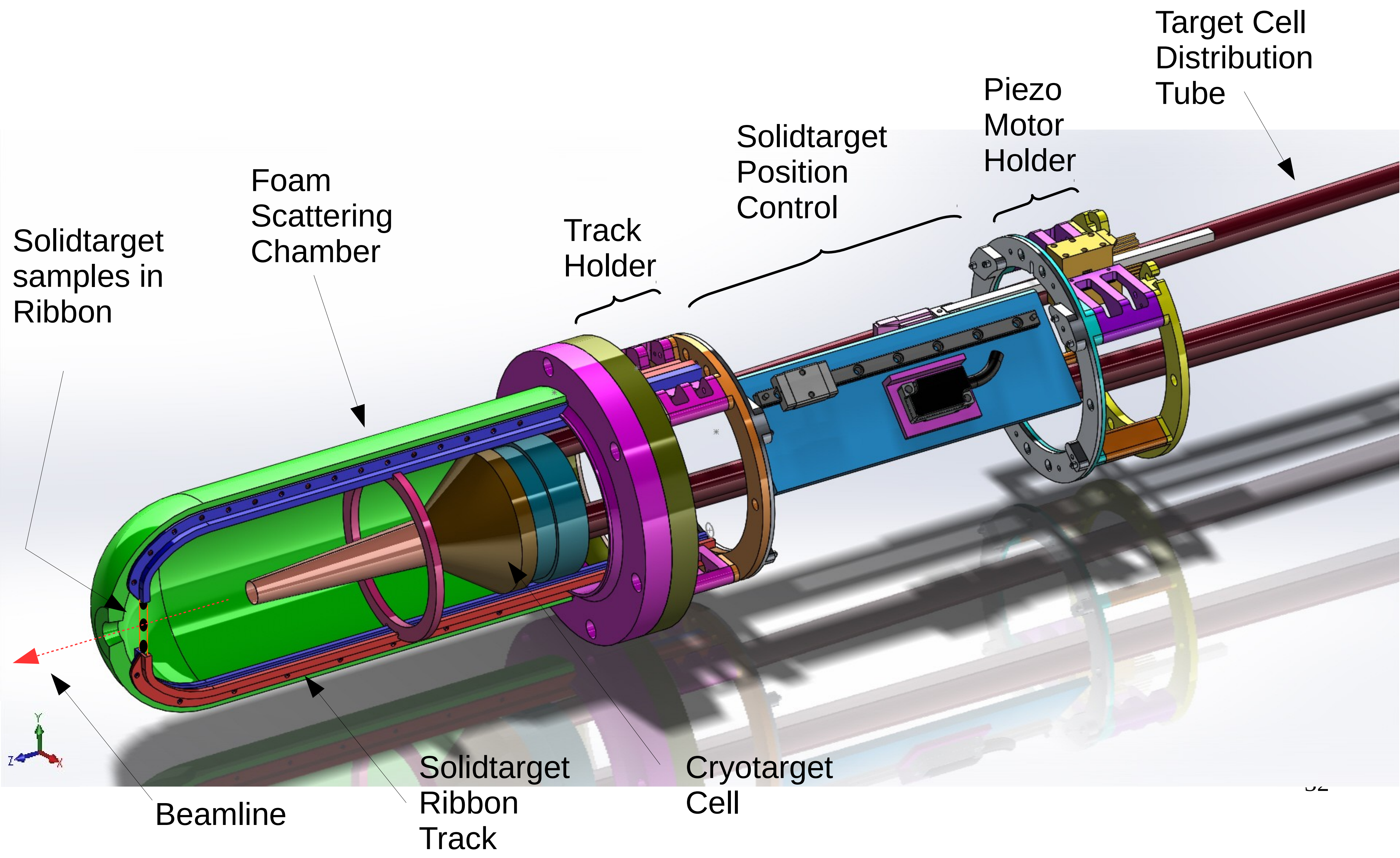
Target	Longitudinal thickness			Transverse thickness
	Dimension	Areal density (g/cm^2)	Radiation lengths	Areal density (g/cm^2)
Carbon	1.7 mm	0.38	0.009	0.33
Thin Aluminum	15 µm	0.00	0.000	0.41
Thick Aluminum	0.58 mm	0.16	0.007	0.41
Iron	0.40 mm	0.31	0.023	1.2
Tin	0.31 mm	0.23	0.026	1.1
Lead	0.14 mm	0.16	0.025	1.7

- Diameter: 3 mm

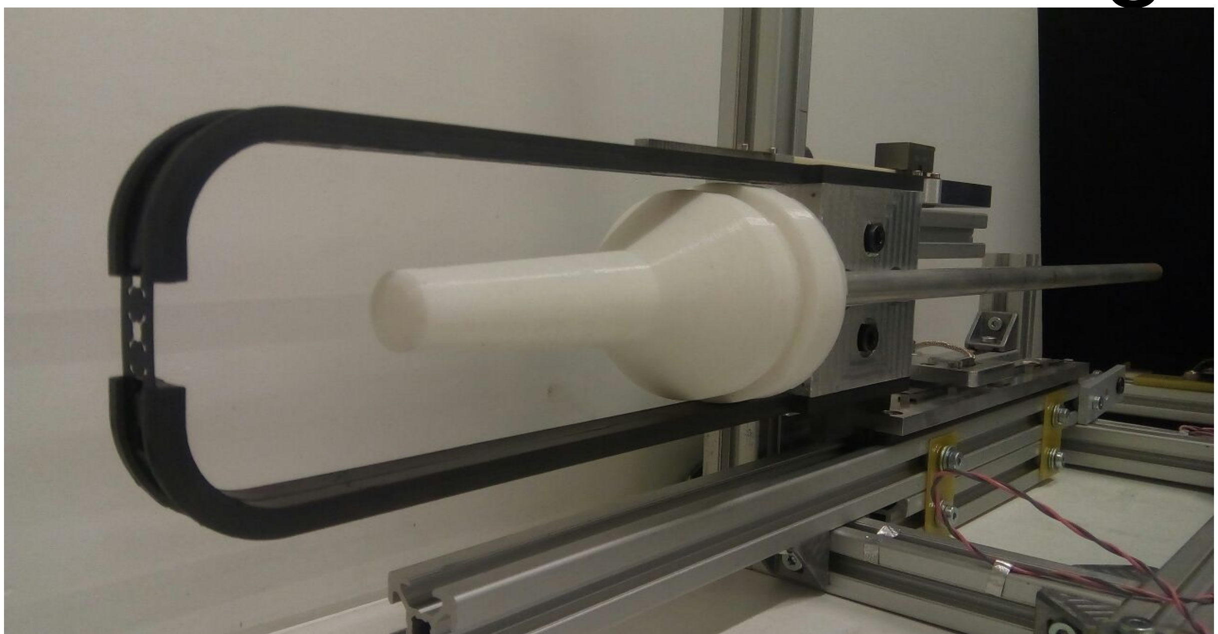
New targets types will include: 4He, C, O, Ar, Pb and others. Unfortunately no Fe.

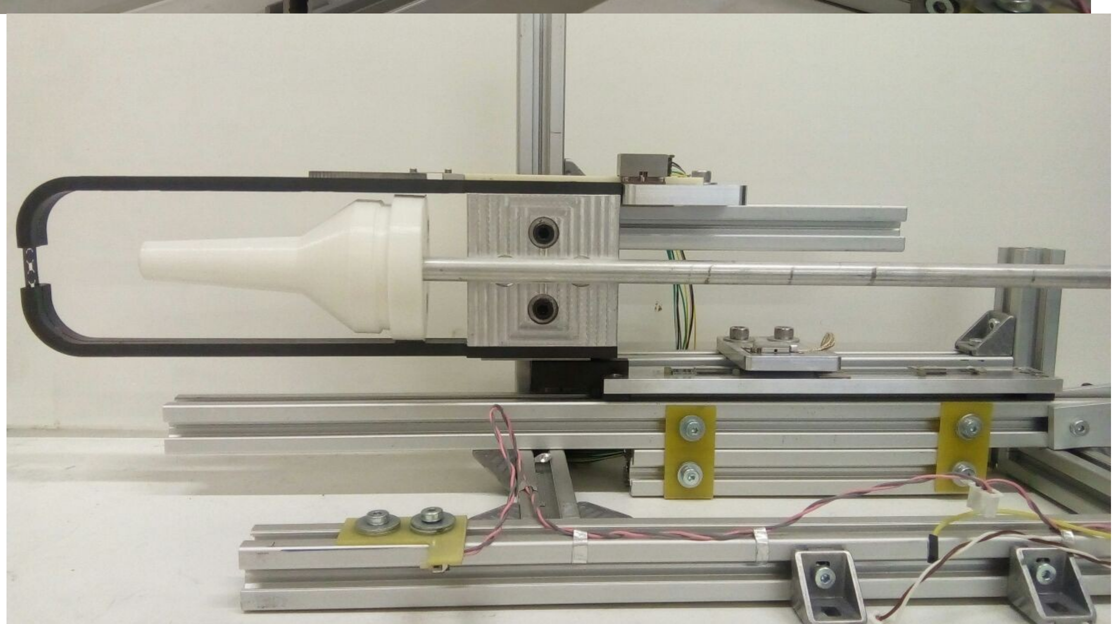
Materials for Cryocell fabrication

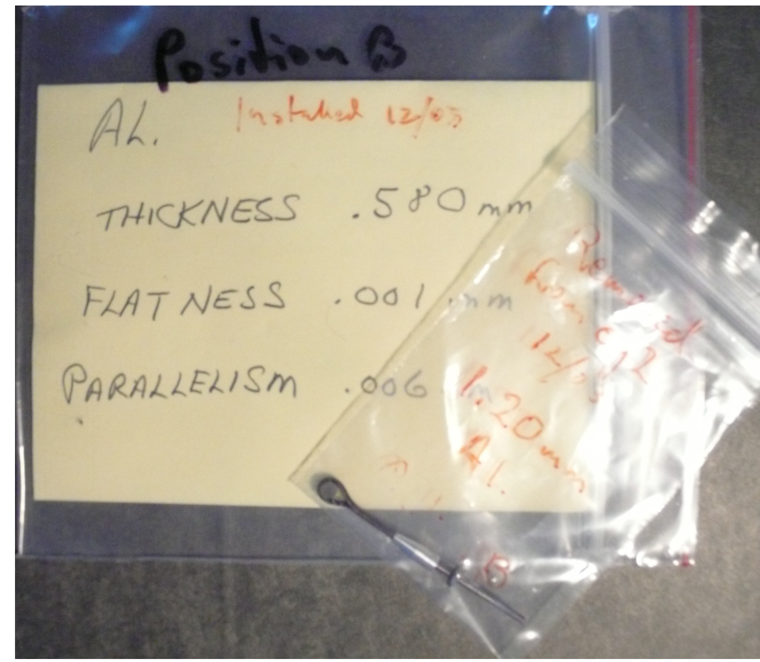
Full Assembly



Solid Target
1:1 working model







Tests to perform

- Develop a control system for the movement precision and the mechanical robustness (in UTFSM)
- Test the target in the vacuum (in UTFSM)
- Test the target in the vacuum and high magnetic field (in JLab)

Mechanical Calibration

- Solid target Position Compensation
- Displacement of parts
- Foam Scattering Chamber seal

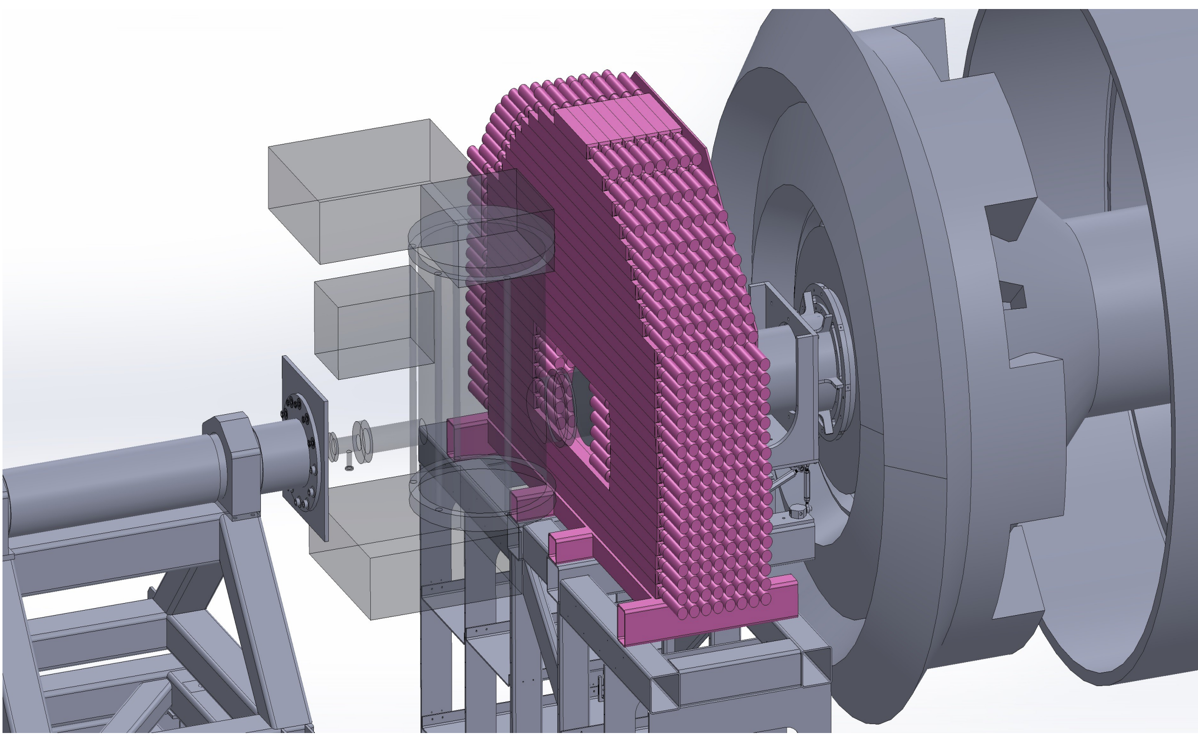
f()

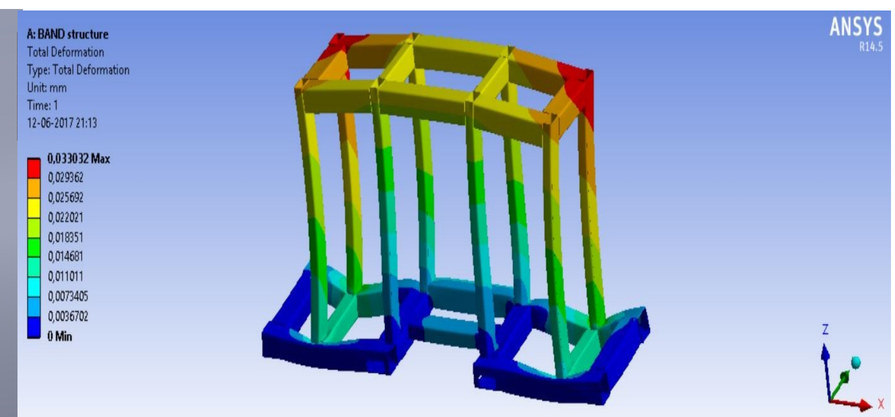
- Temperature operation
- Vacuum operation
- Magnetic field operation

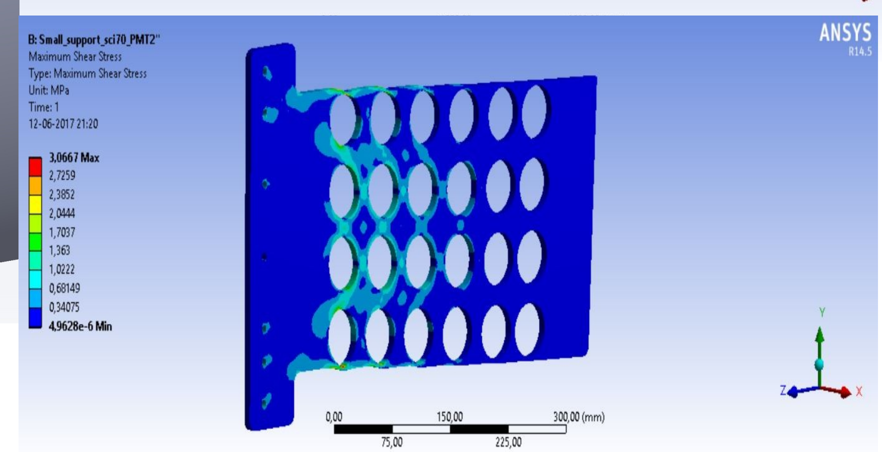
BAND (Back Angle Neutron Detector)

(Mechanical design by Iñaki Vega, Milan Ungerer)

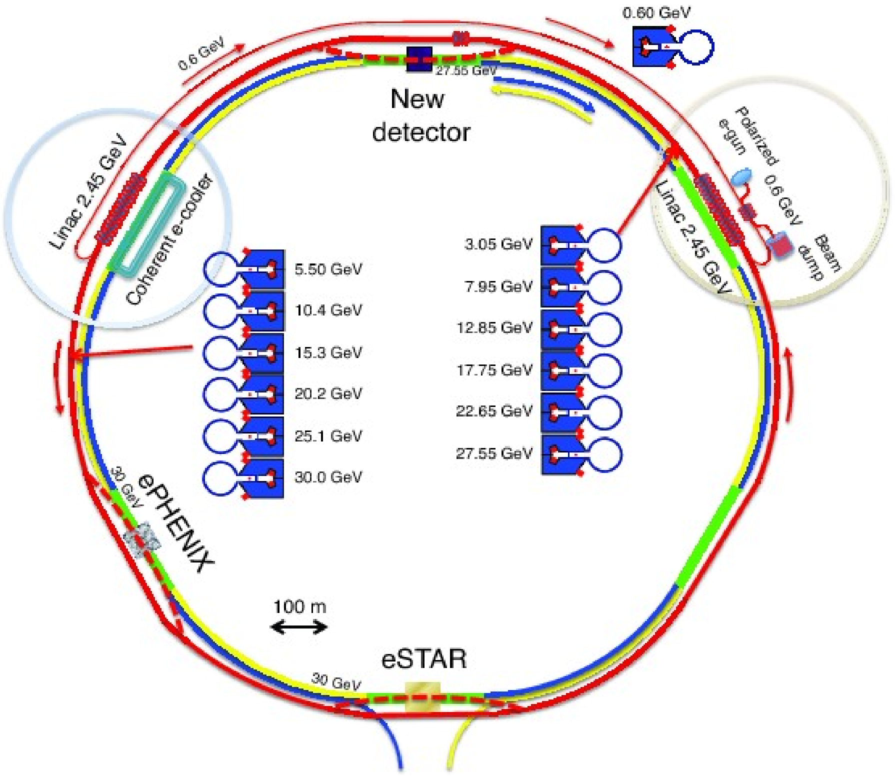
With colleagues from MIT, TAU & ODU

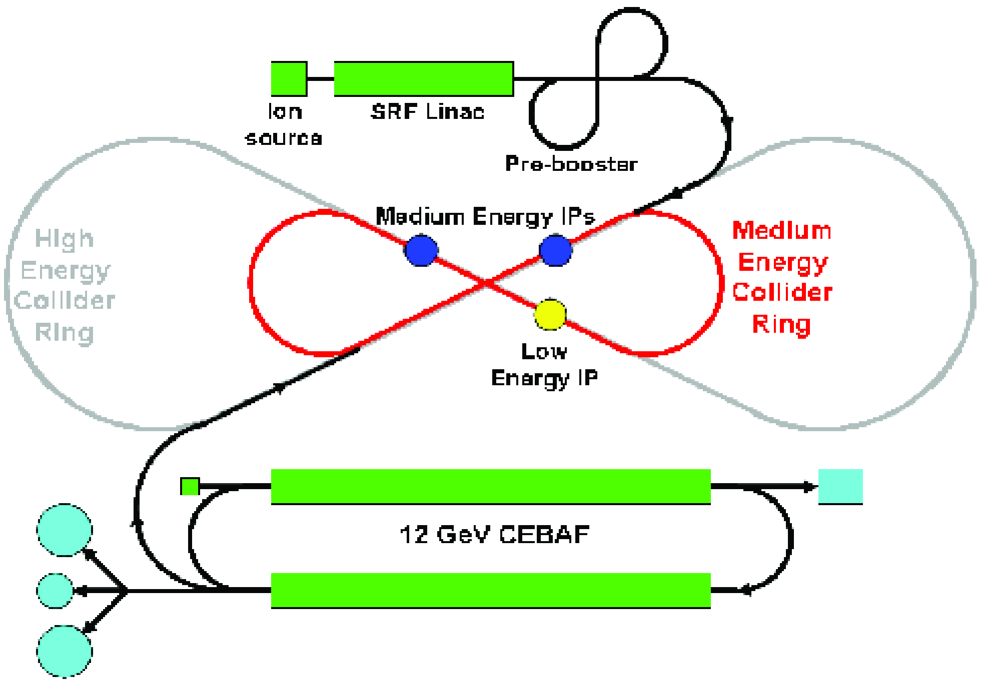






EIC (Electron-Ion collider)





RHIC **JLab**

Conclusions!

CLAS experiment with double target opened a large spectra of studies like:

- Nuclear Hadronization
- Color transparency
- Short range nuclear correlations
- Two hadron correlations
- EMC effect measurements
- Hadronic structure function measurements in nuclei
- Etc.

More is coming with new CLAS12 and new double target!