Precision Measurement of the neutron d_2

Towards the Electric χ_E and Magnetic χ_B Color Polarizabilities

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Kinematics

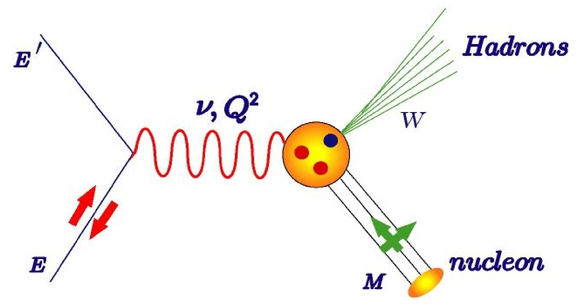
- Determine the neutron d_2 at $<Q^2>=3$ GeV² using a polarized electron beam of 4.6 and 5.7 GeV and polarized ³He target
- 13 PAC days to achieve a statistical uncertainty of $\Delta d_2^n = 5\times10^{-4}$

$$\tilde{d}_2(x,Q^2)=x^2[2g_1(x,Q^2)+3g_2(x,Q^2)]$$

$$=\frac{MQ^2}{4\alpha^2}\frac{x^2y^2}{(1-y)(2-y)}\sigma_0[(3\frac{1+(1-y)\cos(\theta)}{(1-y)\sin(\theta)}+\frac{4}{y}\tan(\frac{\theta}{2})A_\perp+(\frac{4}{y}-3)A_\parallel]$$

where,

Q^2	4-momentum transfer squared of the virtual photon.
ν	energy transfer.
θ	scattering angle.
$x=\frac{Q^2}{2M\nu}$	fraction of nucleon momentum carried by the struck quark.
$y=\frac{\nu}{E}$	fraction of the incident electron's energy that is transferred to the hadron system.



$$A_\perp=\frac{\sigma^{\downarrow\Rightarrow}-\sigma^{\uparrow\Rightarrow}}{2\sigma_0} \qquad A_\parallel=\frac{\sigma^{\downarrow\Uparrow}-\sigma^{\uparrow\Uparrow}}{2\sigma_0}$$

where

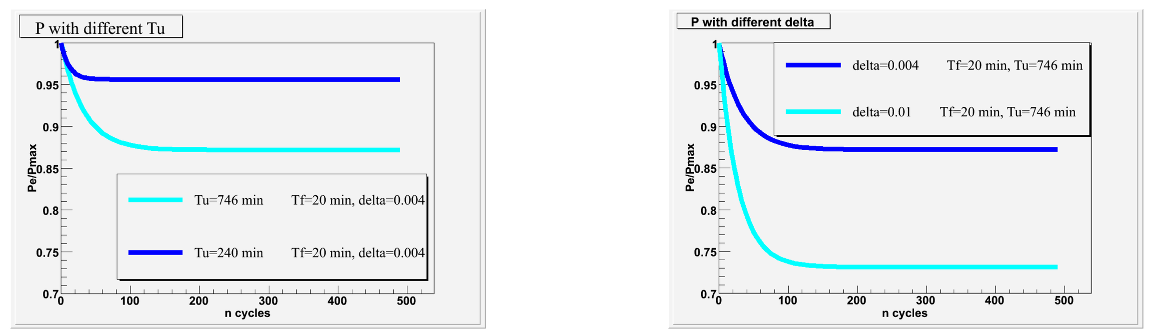
$\sigma^{\downarrow\Rightarrow}(\sigma^{\uparrow\Rightarrow})$ is the cross section for scattering off a transversely polarized target, with incident electron spin anti-perpendicular (perpendicular) to the target spin.

$\sigma^{\downarrow\Uparrow}(\sigma^{\uparrow\Uparrow})$ is the cross section for scattering off a longitudinally polarized target, with incident electron spin anti-parallel (parallel) to the target spin.

Target Work

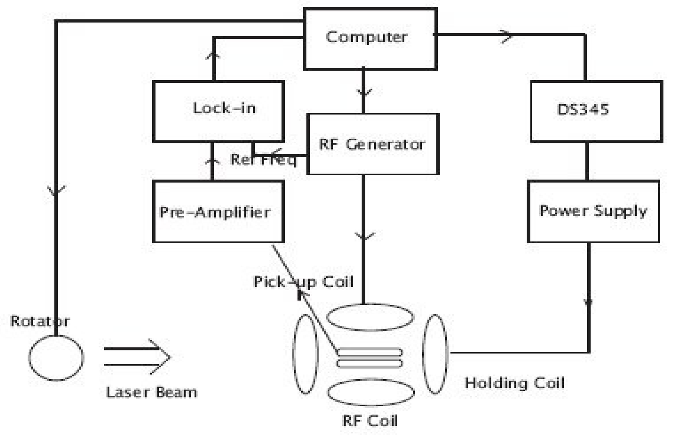
In this experiment, we will flip target spin periodically to minimize systematic uncertainty. But because there is Adiabatic Fast Passage (AFP) loss for each spin reversal, it is important to know how much target spin polarization is left after it reaches an equilibrium after many flips.

Theoretical Expectation

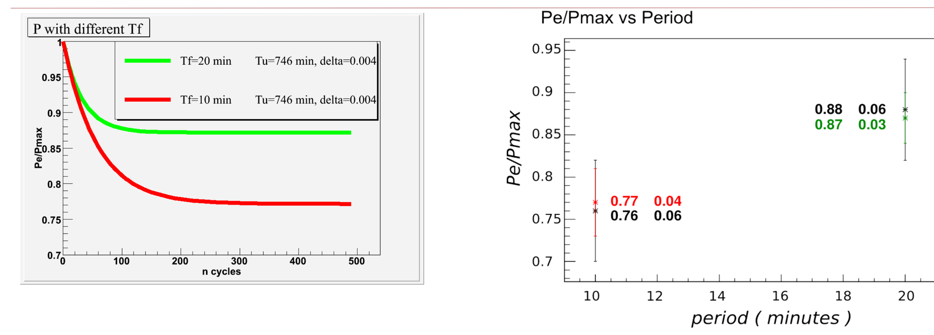


$$\frac{P_e}{P_{max}}=\frac{e^{T_f/T_u}-1}{e^{T_f/T_u}-(1-\delta)}$$

P_e	polarization at equilibrium point	T_f	period for each cycle (mins)
P_{max}	max polarization before spin-reversal	T_u	spin-up time for target
		δ	AFP loss



With holding field fixed, the RF is swept to reverse the target spin. At the same time the quarter-wave plate is rotated to change the polarization direction of the laser to continue polarizing the target.



Black: Experimental Value
Red: Theoretical Value (Tf=10 mins)
Green: Theoretical Value (Tf=20 mins)

From this test, our target group has chosen the 20 min flip period.

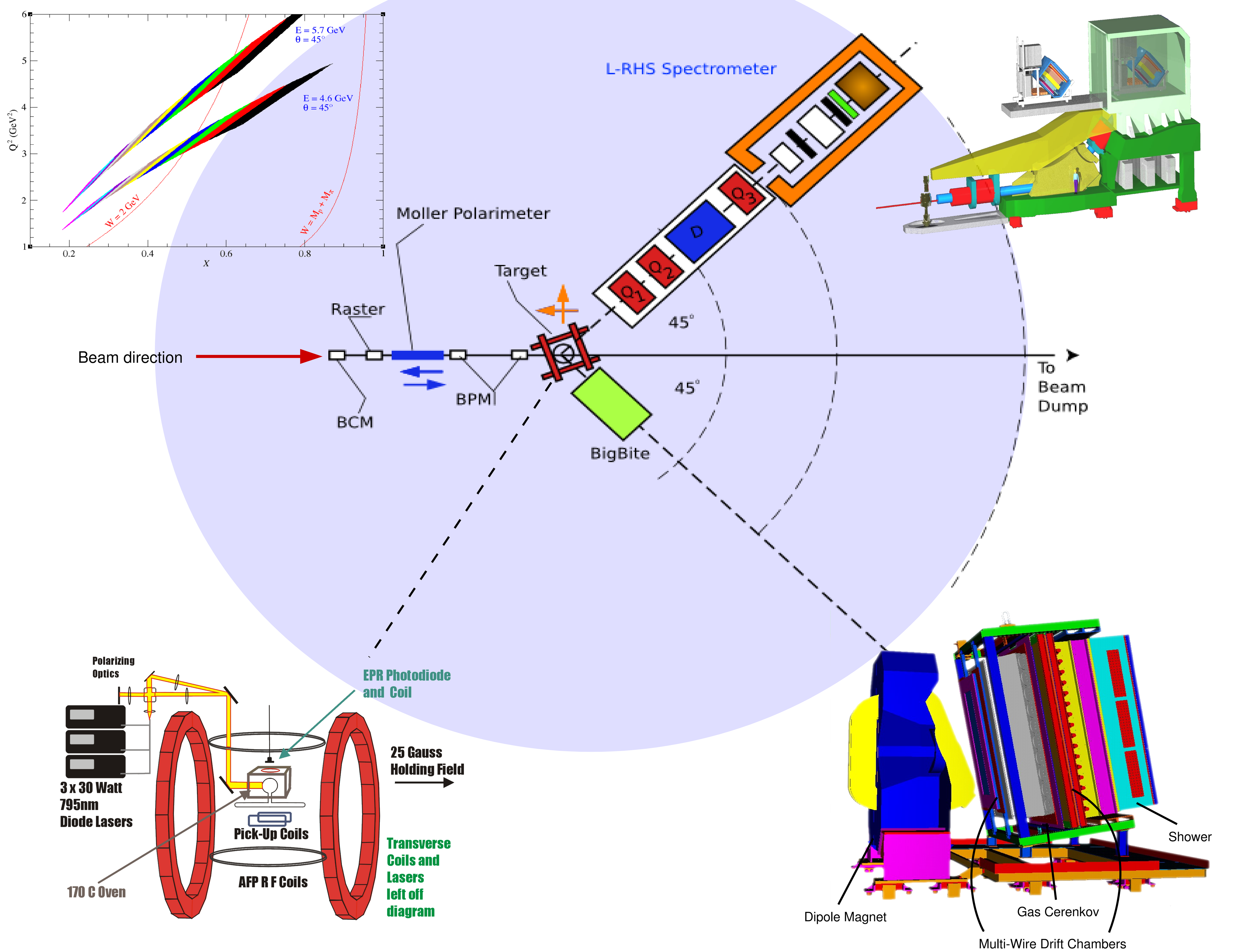
$T_f=10$ or 20 minutes $\quad T_u=746$ minutes $\quad \delta=0.004$

$$d_2^n(Q^2)=\int_0^1\tilde{d}_2(x,Q^2)dx=\int_0^1 x^2[2g_1^n(x,Q^2)+3g_2^n(x,Q^2)]dx$$

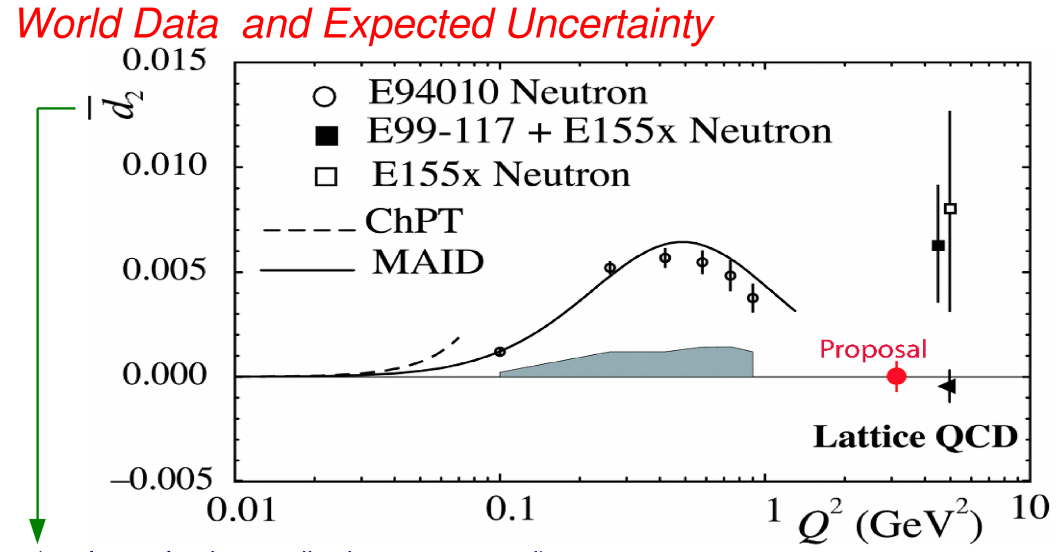
In the operator product expansion of QCD, the quantity d_2 becomes a twist-3 matrix element arising from quark-gluon interactions, making d_2 a very clean indicator of higher twist effect inside the nucleon. It also reflects the response of the color electric and magnetic fields to the spin polarization of the nucleon and is directly related to the induced color electric and magnetic polarizbilities χ_E and χ_B .

This experiment will use longitudinally polarized electrons scattering off a transversely and longitudinally polarized ^3He target in Hall A. d_2 will be extracted by combining a total cross section ($\sigma_0^{^3He}$) measurement of $\vec{^3He}(\vec{e},e')$ in the Left HRS with a simultaneous measurement of the transverse $A_\perp^{^3He}$ and the parallel asymmetries ($A_\parallel^{^3He}$) in the large-acceptance BigBite detector. The kinematics are chosen to cover a broad range in x (0.2 < x < 0.65) with 2 < Q^2 < 5 GeV² while remaining in the deep inelastic region. A new heavy gas Cerenkov detector for the BigBite is being constructed to provide the necessary background suppression in the online trigger.

We anticipate reducing the statistical uncertainty in the present value of d_2 by about a factor of four, providing a benchmark test of lattice QCD. Precision data in the large x region will also allow us to make meaningful comparisons with several theoretical models which include quark-gluon correlations and thus test our understanding of nucleon spin structure beyond the parton model in the valence quark region.

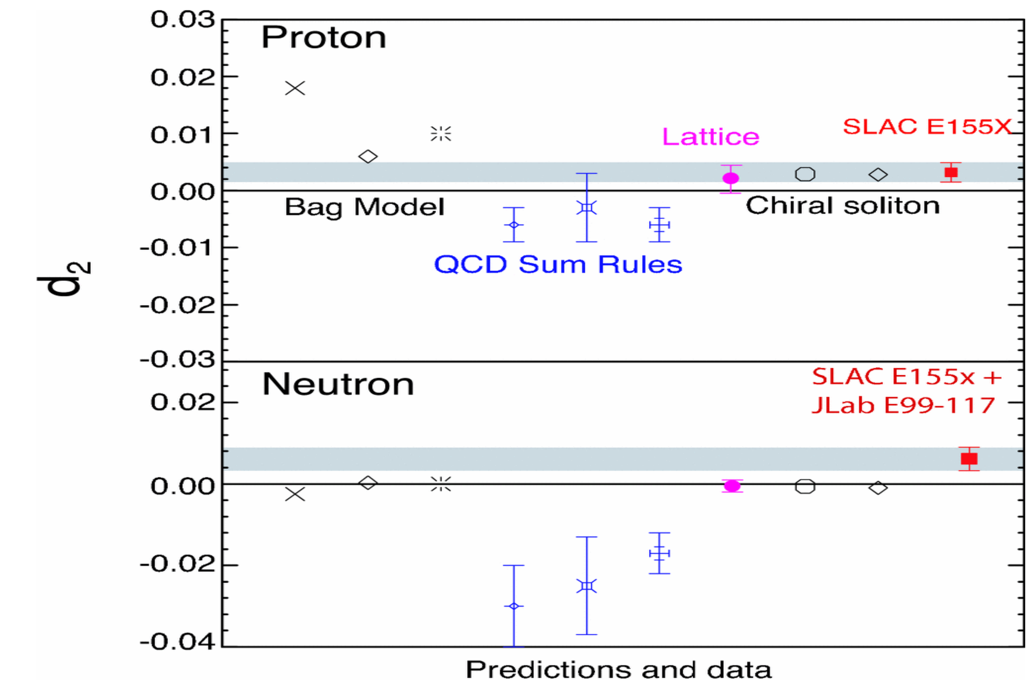


World Data and Expected Uncertainty



(nucleon elastic contribution suppressed)

Model Evaluation



Gas Cerenkov Design

- MC background simulation by Degtyarenko et al. (tested in Halls A and C)
- Online cuts include:
  - BB magnet sweeps particles with p < 200 MeV/c
  - GeN BB trigger: shower+pre-shower (Total energy)
  - 3—5 p.e. threshold on Cerenkov
- Total estimated trigger rate (GeN trig + Cerenkov): 2—5 kHz

Online triggers

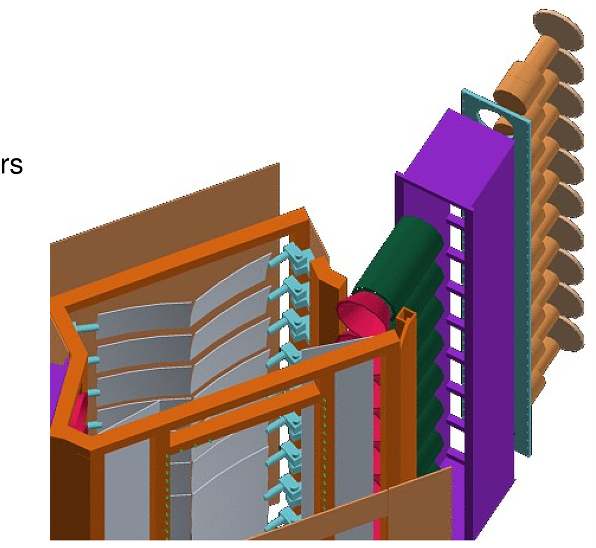
$e-$	$2-5$ kHz
$e+$	<1 kHz

Removed via online cuts

$\pi-$	90 kHz
$\pi+$	90 kHz
p	50 kHz
n	50 kHz

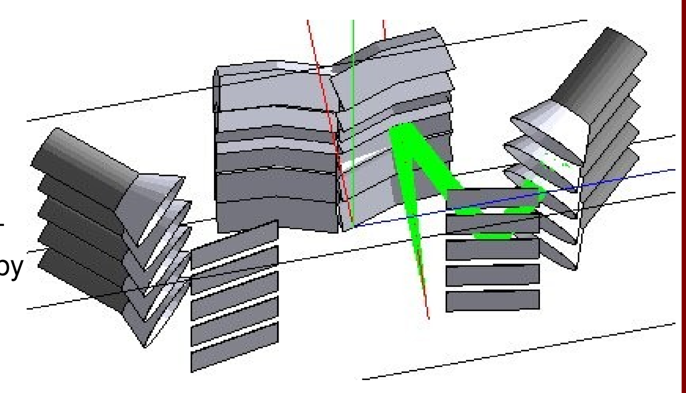
Dimension: 200cm x 60cm x 60cm
- sandwiched between wire chambers

Radiator gas: C_4F_{10}
- n= 1.0015
- π threshold: 2.51 GeV/c
- ~25 photo-electrons / 40 cm electron track



>98% efficient with 3-4 p.e. Threshold
- negligible pion contamination
- **minimum** π/e rejection ratio 500:1 online (probably better)

Geant4 ray trace Simulation done by H.Yao.
This simulation matches an independent ray trace simulation done by B.Sawatzky



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