HALL-A Upgrade

- Introduction
- MAD spectrometer
- Background simulation
- Detector system
- Infrastructure
- Physics examples
- Summary

PAC on 12 GeV
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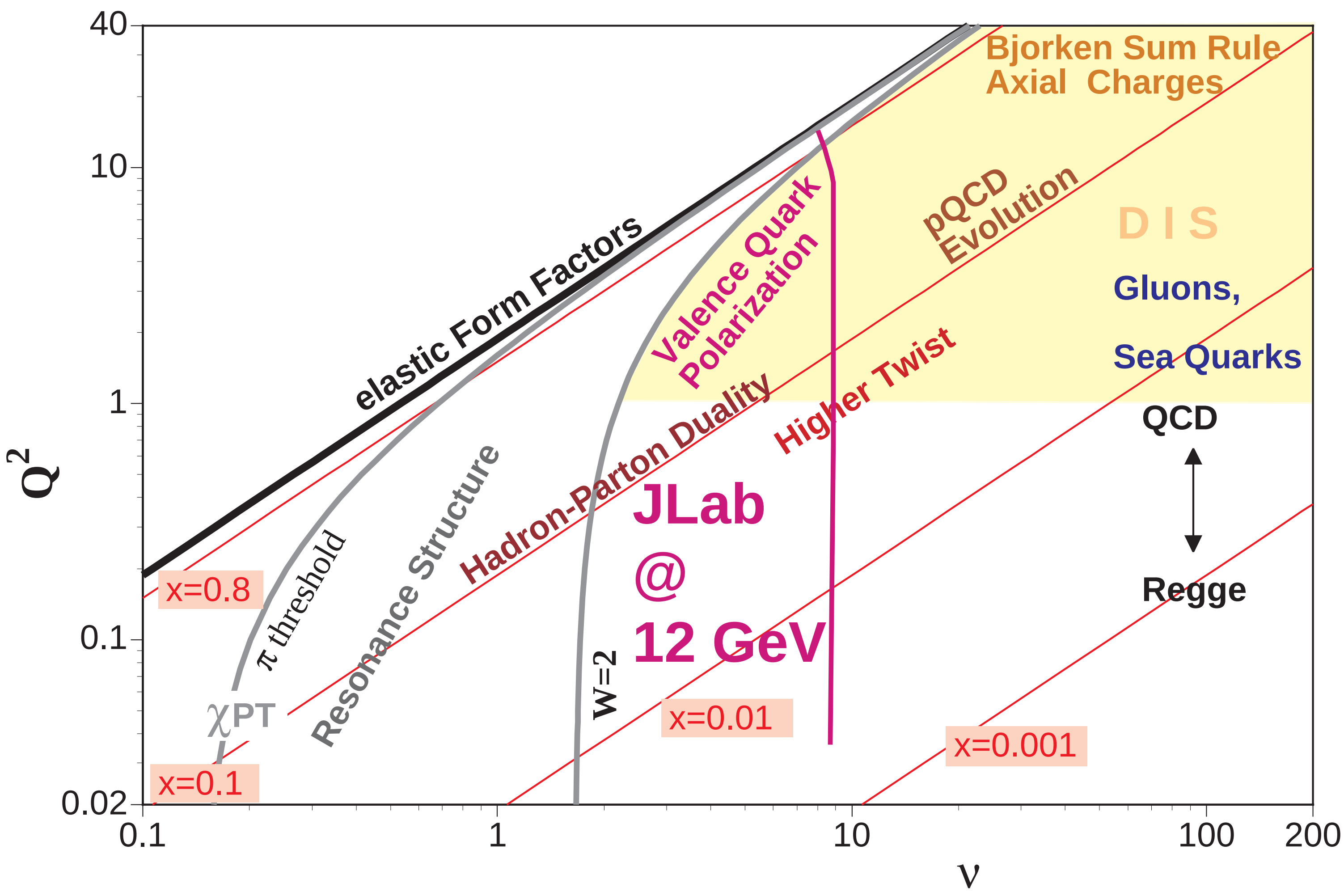
Introduction

- Initial design of Hall A upgrade focused on
  - Nucleon structure functions in valence region ($x \geq 0.5$)

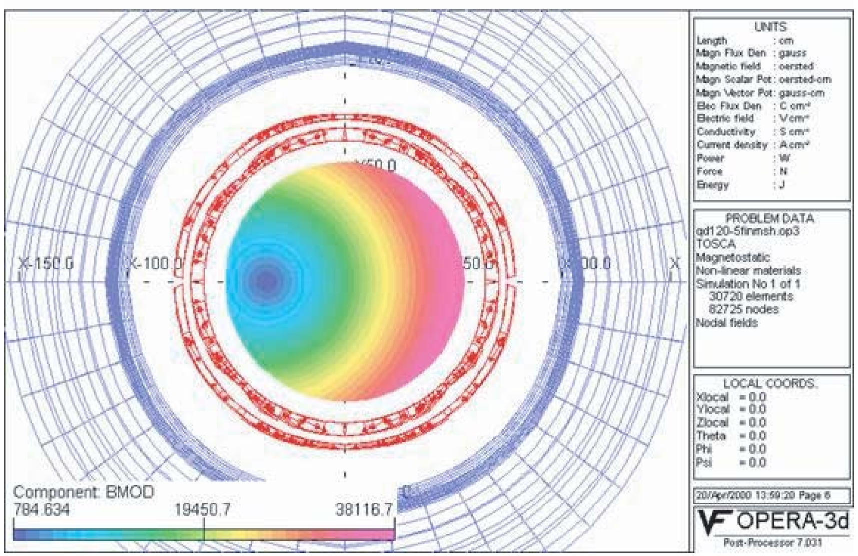
    A_1, g_2, F_2^n/F_2^p, …
- Leading to general requirements
  - ✓ High luminosity ($\geq 10^{38}$ cm^{-2} s^{-1})
  - ✓ Large acceptance in momentum and angle
  - ✓ Medium resolution ($\delta p/p \approx 10^{-3}$)
  - ✓ Intermediate excitation ($p_{max} \approx$ 6-7 GeV/c)
- Suitable candidate combined-function warm-bore SC magnets

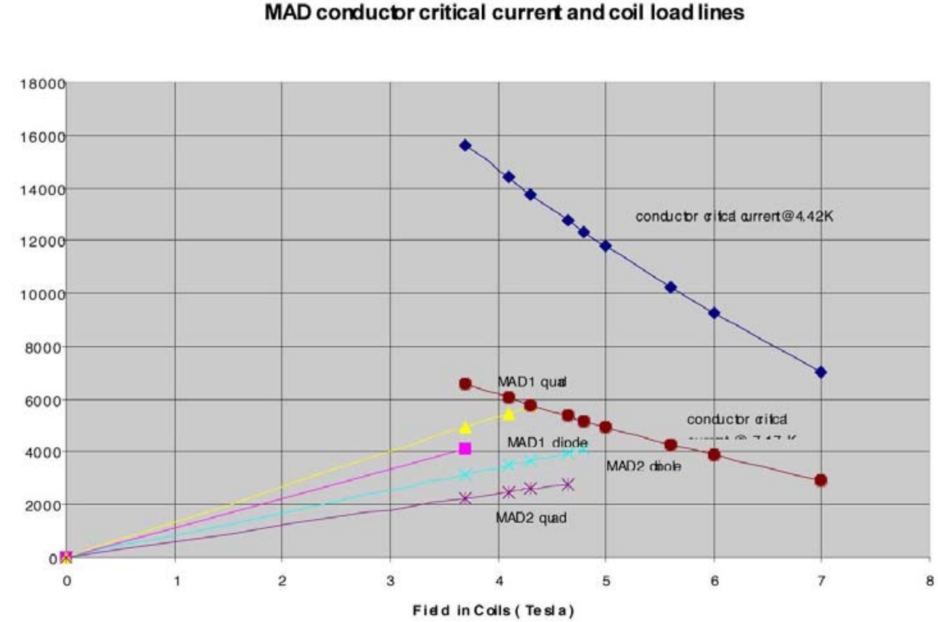
Kinematic Coverage



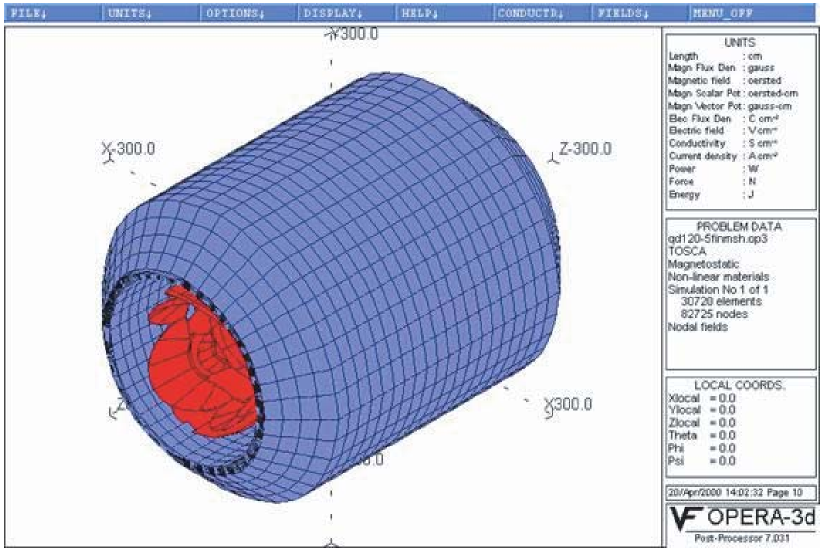
Design of MAD

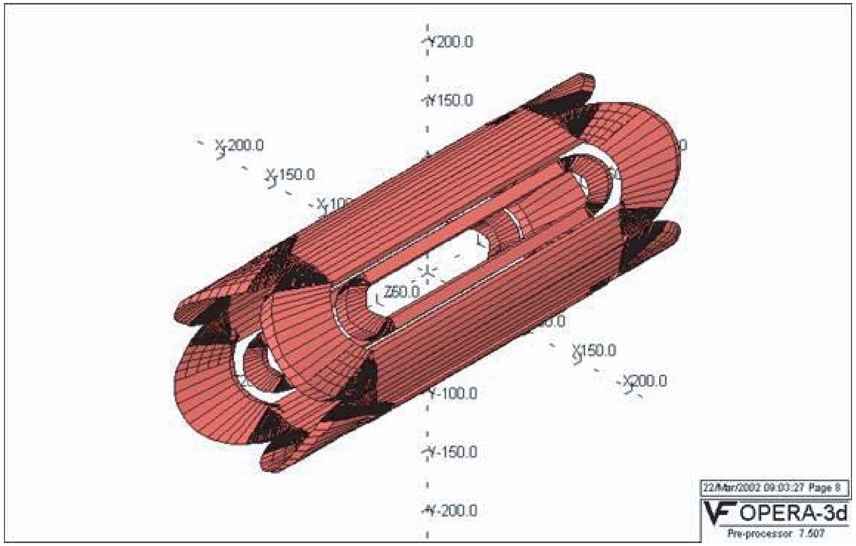
- Configuration to be optimized
  - ✓ nested (cosθ,cos2θ) coils
  - ✓ warm bore and yoke with 120 cm ID
- Resulted in 3 T dipole with 4.5 T quadrupole gradient
- Elliptical shape of yoke for closer approach to beam line

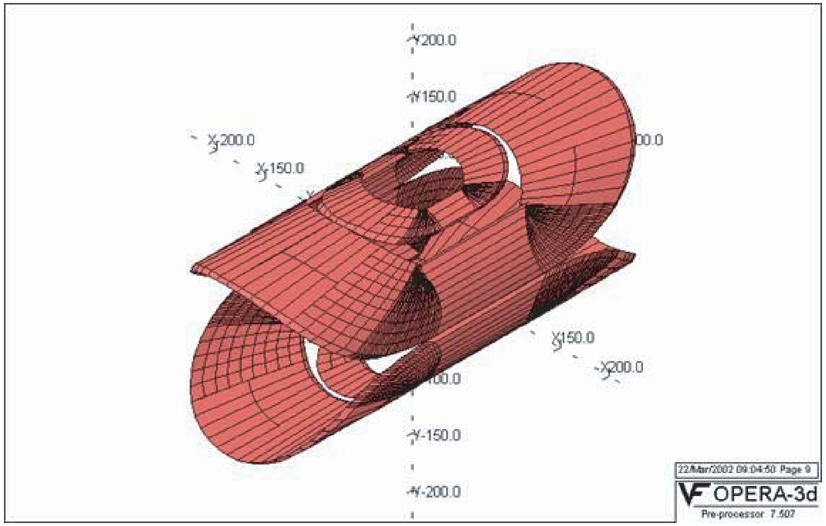


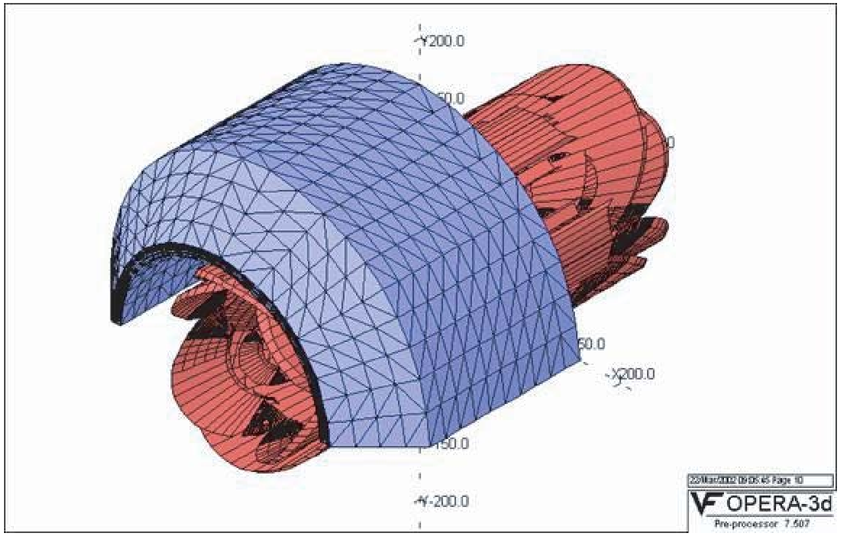


Mechanical Elements









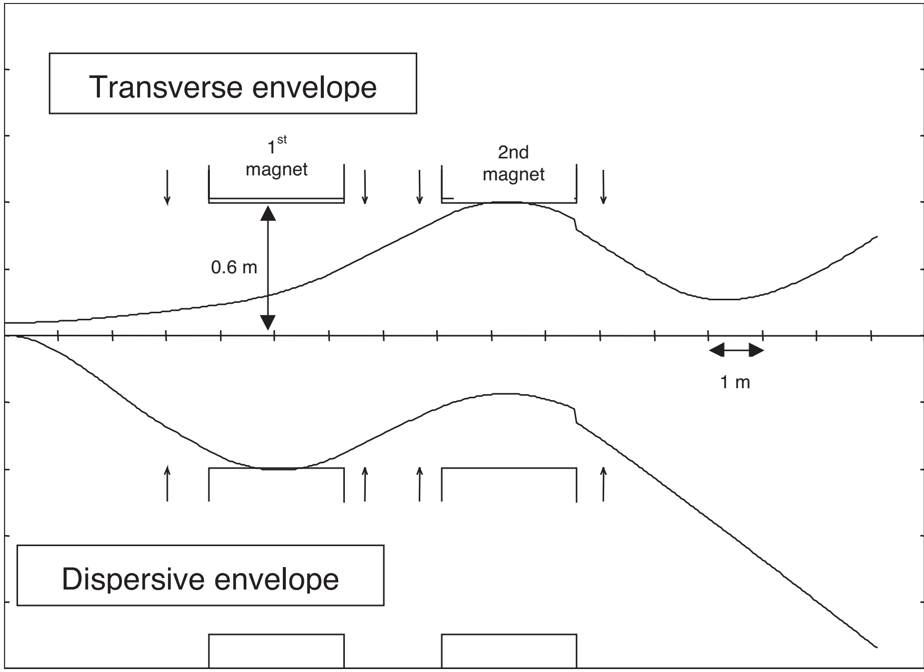
MAD Infrastructure

- Background simulation (see later) require no target-detector line-of-sight
  - ✓ Increase deflection in second magnet from 10° to 22°
- Peak field in bore -1 to 4 T in coils -2 to 5 T, acceptable forces
- Very stable cryogenics with
  - ✓ a critical temperature ≥ 7 K
  - ✓ α between 0.15 and 0.72, implying quench delayed until LHe evaporated
- Stored energy 15 and 25 MJ
- Four independent power supplies
- Total weight 2 * 250 (magnet) + 500 (shield house) ton ≈ 1000 ton
- Support requires angular and radial motion
  - ✓ no pivot mount (autocollimated laser for alignment)
  - ✓ 90° steerable wheels
- Three vacuum systems
  - ✓ cryosystem
  - ✓ spectrometer helium bag
  - ✓ gas Cerenkov

Optics Simulation

Ingredients:

- TOSCA produced field maps
- SNAKE for particle transport
- Fit transfer functions

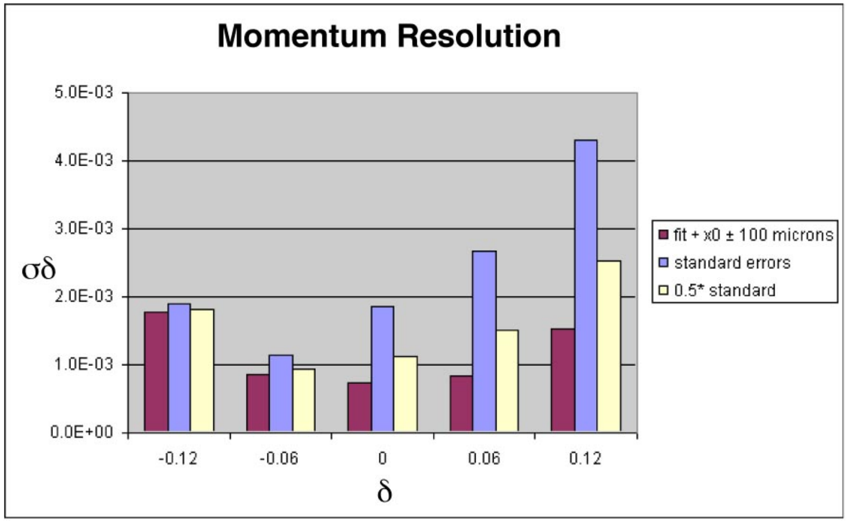


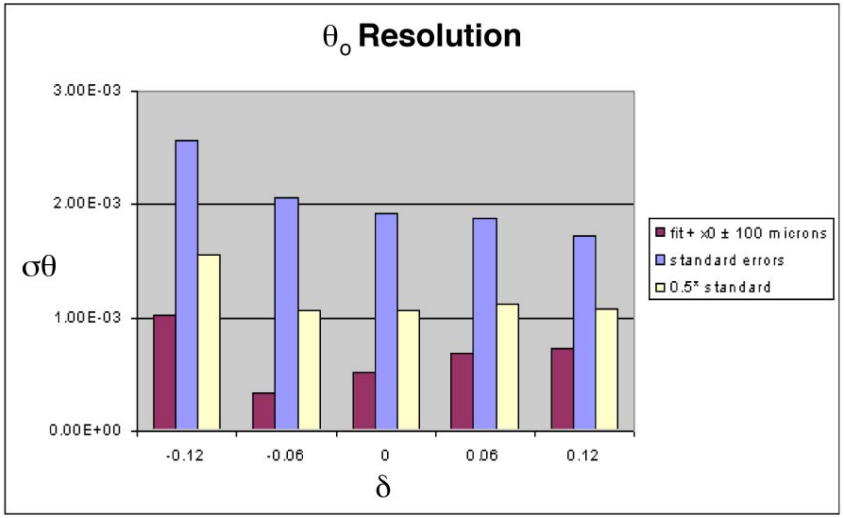
Results shown for three cases

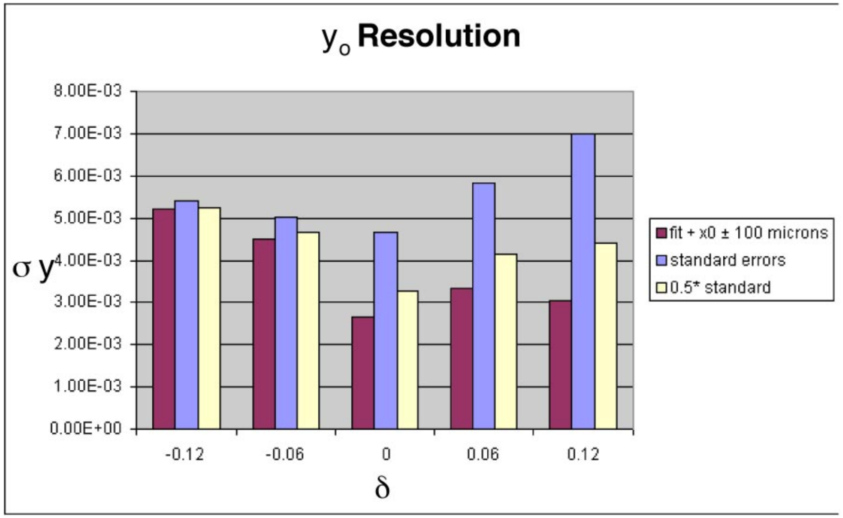
- No measurement error: understanding of optics with 200 μm beam spot
- Standard errors: $\sigma_x = \sigma_y = 100\ \mu$m and $\sigma_\theta = \sigma_\phi = 0.5$ mrad
- 0.5 * standard errors

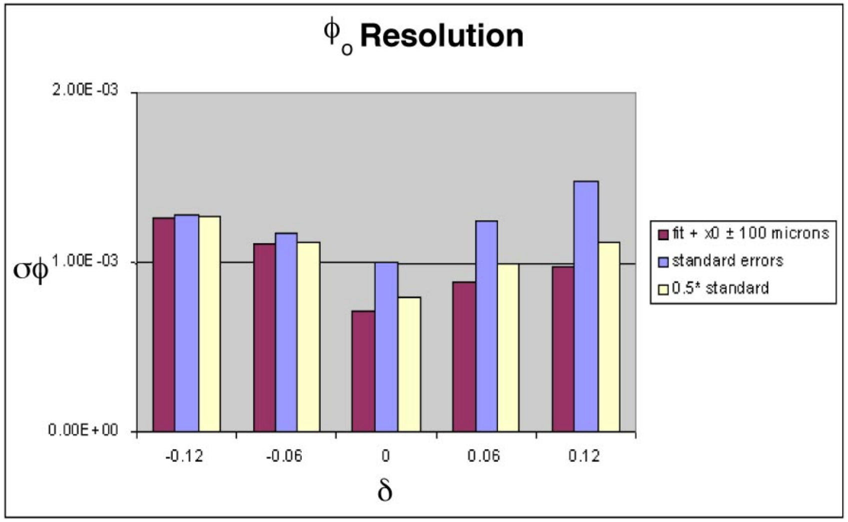
MCEEP and SIMC available for experiment simulation

Predicted Optical Performance





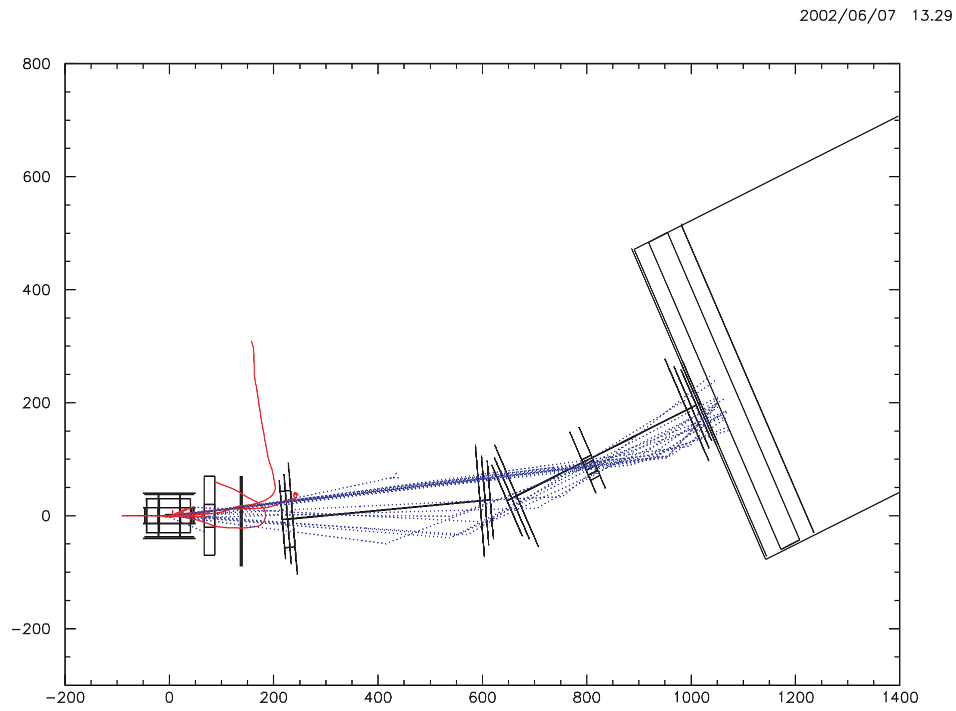




MAD Performance Summary

Spectrometer angle	35° <-> (linear interpolation) <->		12°
	acceptance	resolution(σ)	acceptance
Angular	28 msr		6 msr
horizontal	± 35 mrad	1.0 mrad	± 23 mrad
vertical	± 198 mrad	2.0 mrad	± 68 mrad
Momentum	± 15 %	0.1 %	
Target coordinate	± 6 cm @ 90°	0.26 cm	

GEANT Simulation



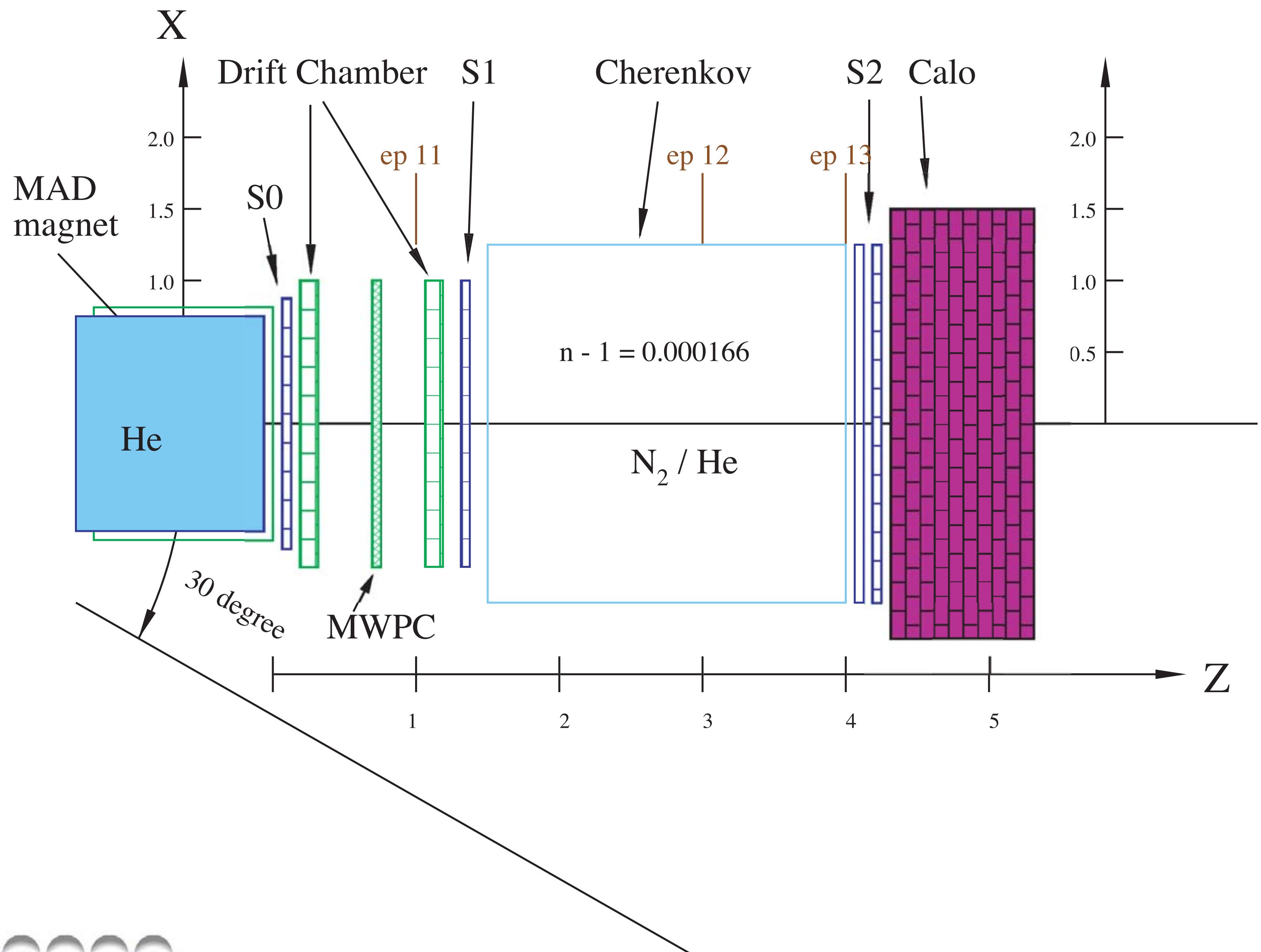
Ingredients

- EM interactions + Mott
- SNAKE field maps
- MAD configuration with
  - Target 15 cm LH2 with 180 μm thick Al window
  - Scattering chamber with 0.5 mm thick Al window
  - 2 m air
  - 100 μm plastic window
  - 5 m He

Conclusions

- Increase deflection by second magnet to 22° to avoid line-of-sight
- Place collimators at
  target chamber, entrance of MAD1 and centre of MAD2
- At 25° with 50 μA on 15 cm LH2 100 MHz photons with 0.7 MeV average energy

Basic Detector Package



Detector introduction

MAD Single Rates (KHz)

E_i = 11 GeV

70 uA, 15 cm LH2 target, L=3*10^{38} s^{-1}cm^{-2}

P (GeV/c)	theta=15 degree				25 degree				35 degree			
	e	pi-	pi+	p	e	pi-	pi+	p	e	pi-	pi+	p
1.5	1	780	830	360	500	290	300	290	0.1	21	120	330
3	3	90	90	170	0.4	5	100	270	0.02	0.04	130	270
4.5	4	9	70	170	0.1	0.03	30	280	--	--	--	--

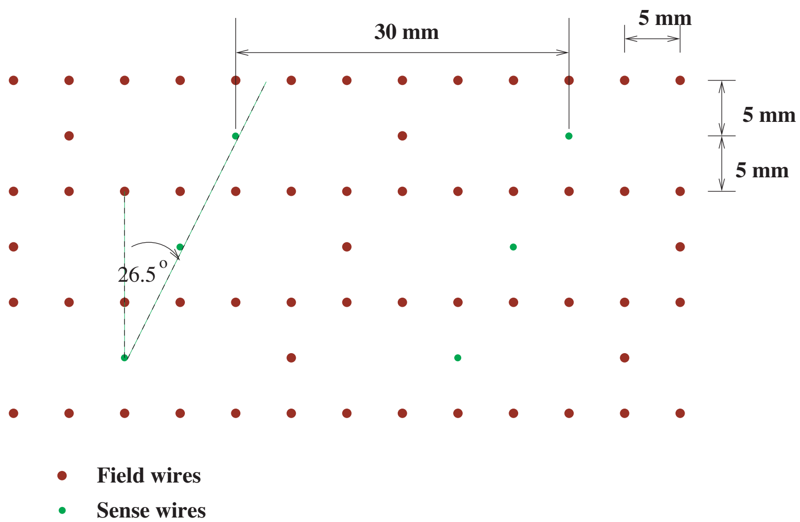
Main concerns

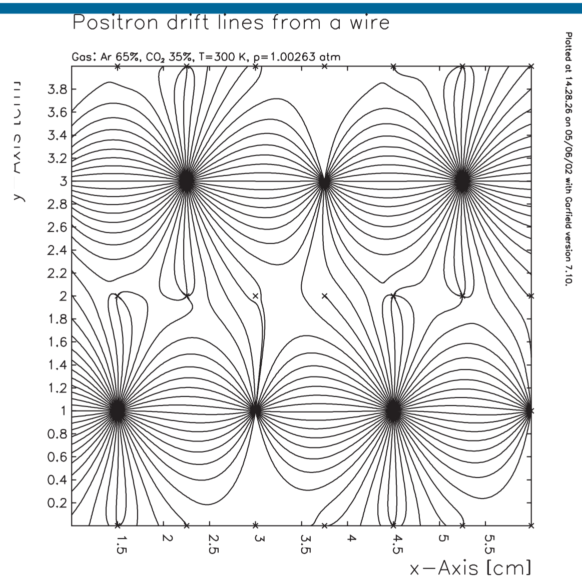
- High rate of low-energy photons
- Pion suppression

Trigger Scintillators

- Three trigger planes S0, S1 and S2(V+H)
  - ✓S0/S1 before/after driftchamber package
    0.5 m * 2 m * 0.5 cm with 1 cm overlap
  - ✓S2 two orthogonal planes just before calorimeter
    0.6 m * 2.5 m * 5 cm
  - ✓Each plane segmented in 16 paddles, read out at both ends
- Main trigger formed by S1+S2
  - ✓Timing determined by S2 (s < 150 ps)
  - ✓S0 to determine trigger efficiency
- Discriminator set to reduce soft photon background
  - ✓50 kHz/paddle in S0 and S1, 100 Hz in S2

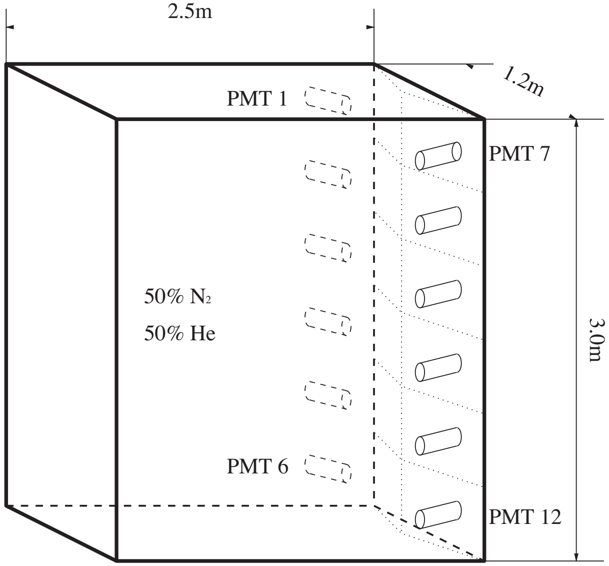
Wire Chambers

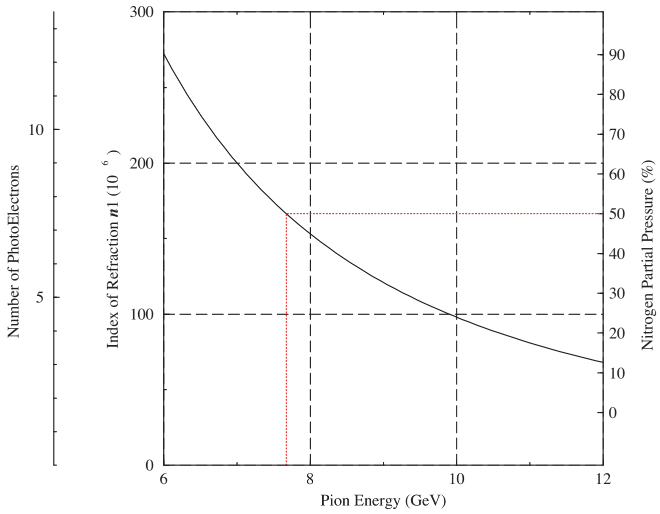


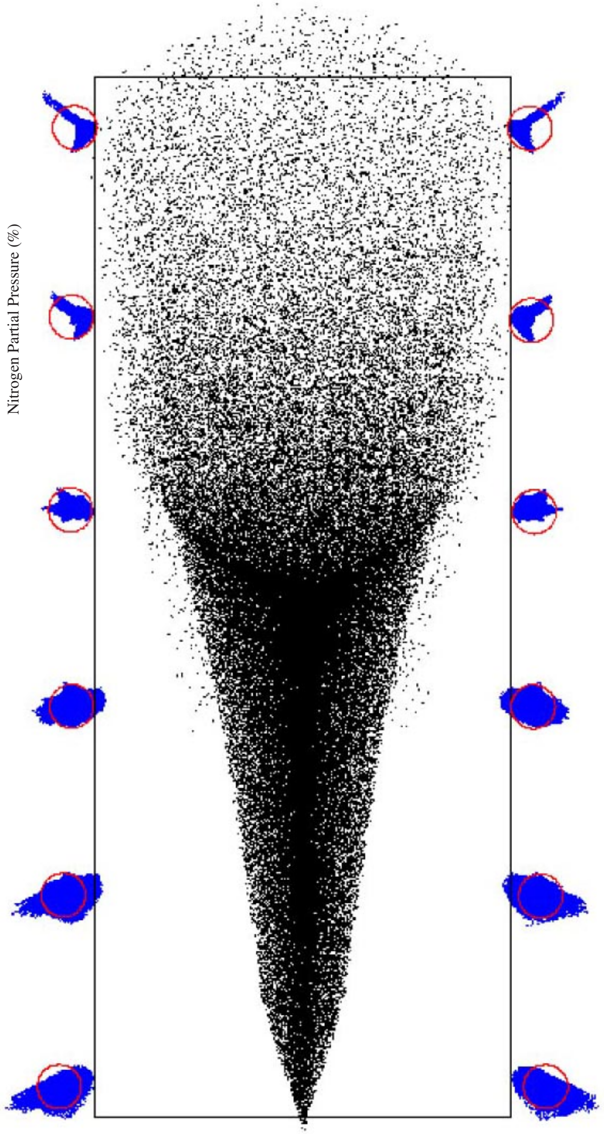


- Two drift chambers 1 m apart with standard MWPC in between
- Drift chambers
  - ✓0.6 m * 2.5 m   3 groups (u,v,x) each of four planes
  - ✓Requiring 2 out of 4 planes yields very high efficiency
  - ✓75 μm resolution, 3 mm between sense wires
  - ✓Dead time ~ 300 ns/cm/wire, negligible effect of 100 MHz soft photons
- MWPC for track selection
  - ✓3 mm wire distance

Gas Cerenkov







- Mixture of He/N_2 adjusted to optimize N_{pe}
- 12 mirrors pairwise with 1 m radius
- Winston cones for bottom 2 pairs
- Average efficiency ~98 %

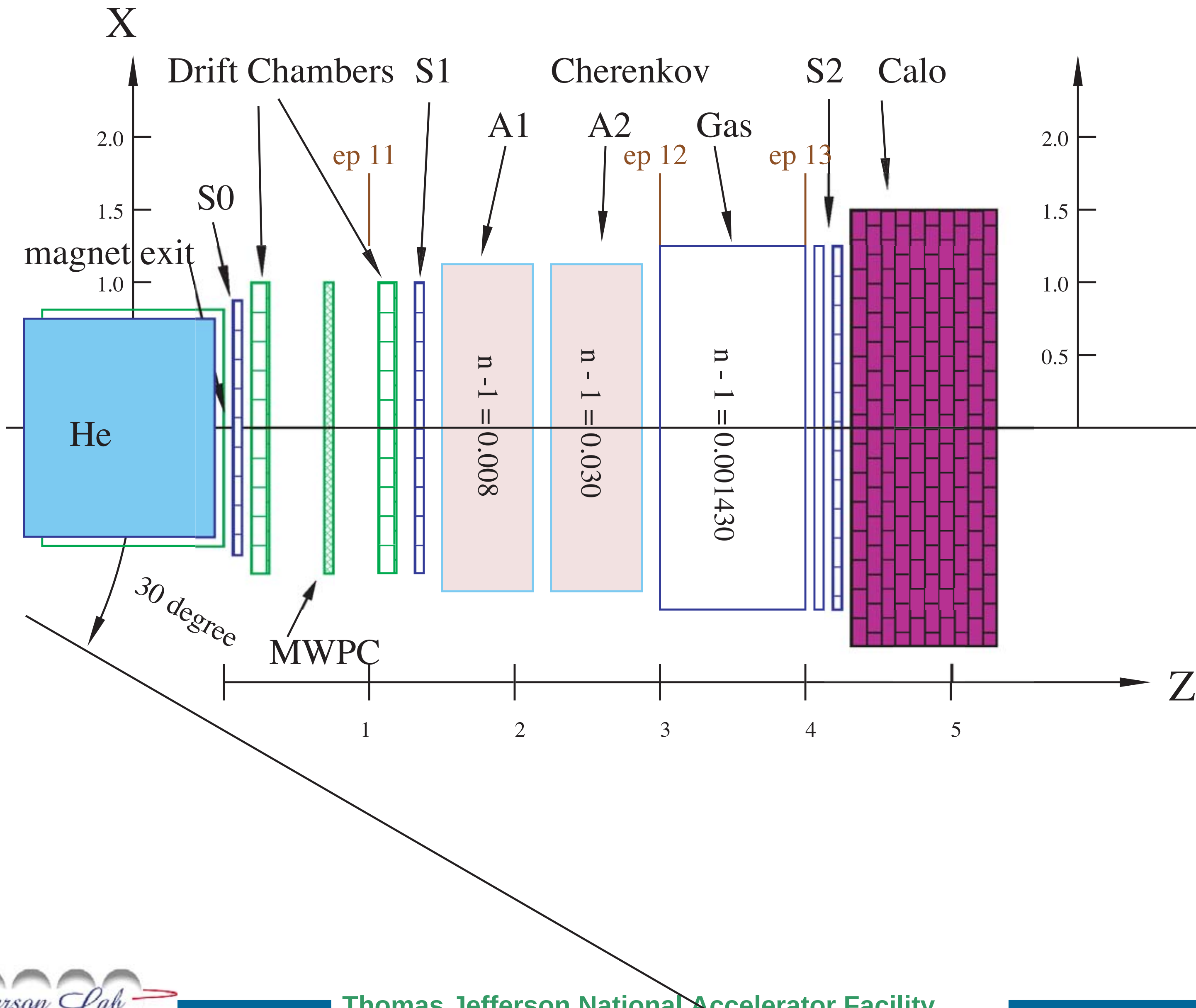
EM Calorimeter

- Main purpose pion rejection
- 3.2 m * 1 m lead(2.2 mm)-plastic(10 mm) sandwich
- Arranged in 10 cm * 100 cm strips, 22 X0 deep
- Every 5 even/odd plastic strips read out on alternate sides
- Energy resolution ~ $0.1/\sqrt{E}$
- Pion suppression e/π ~100

Data Acquisition

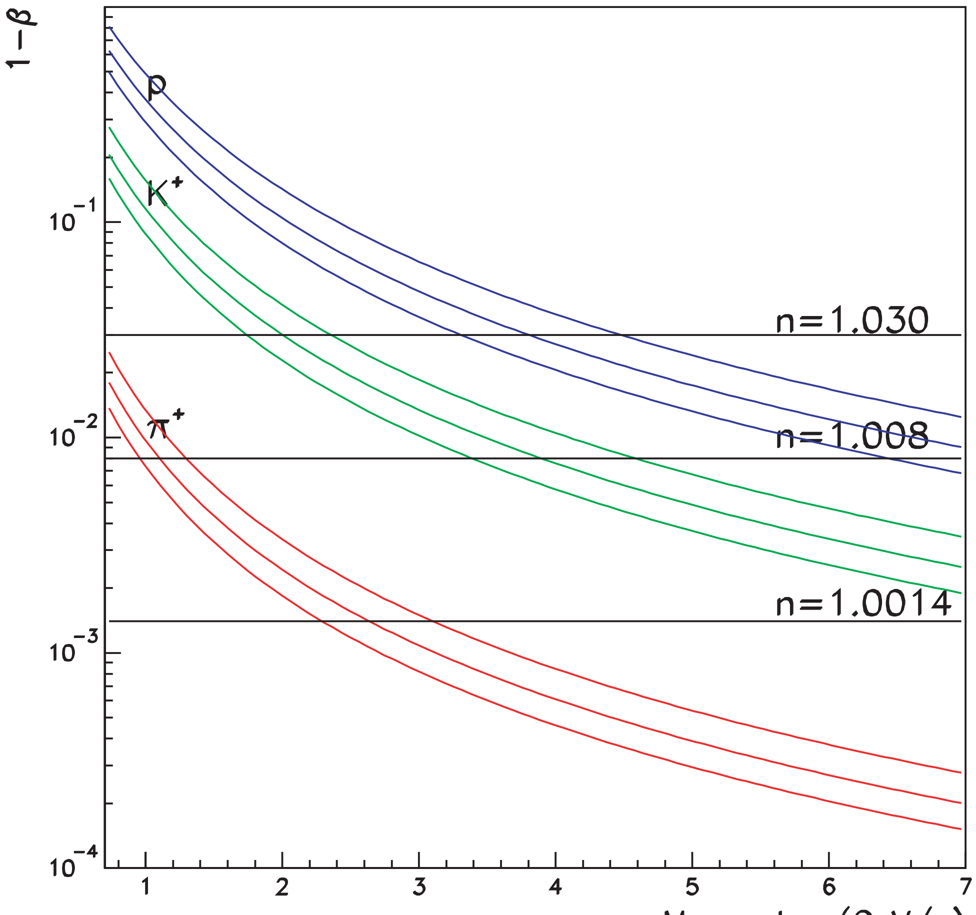
- Combination VME/NIM/CAMAC
- Flash ADC's and pipeline TDC's
- Upgrade HRS from Fastbus to VME

Hadron Extension



Particle Identification

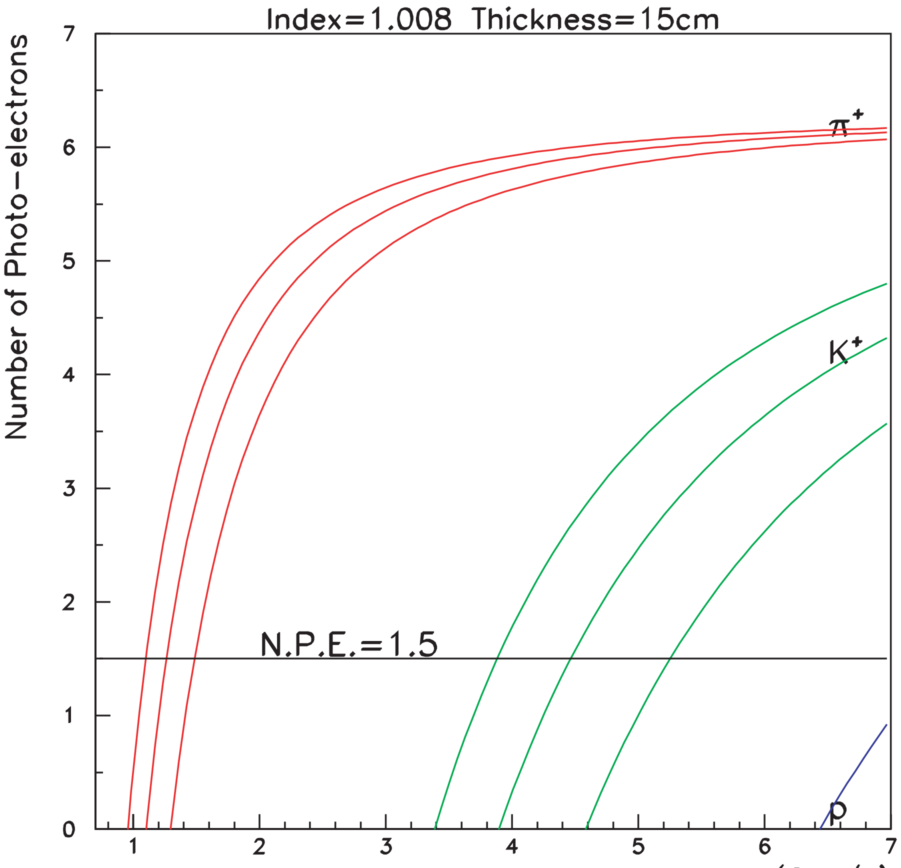
- Shorten Gas Cerenkov to 1 m
- Install two aerogel Cerenkovs with
  - ✓n = 1.008 and 1.030
- 0.6 m * 2.5 m * 15 cm
- Magnetic shield either complete box or individual PMT's
- Good identification over full momentum range



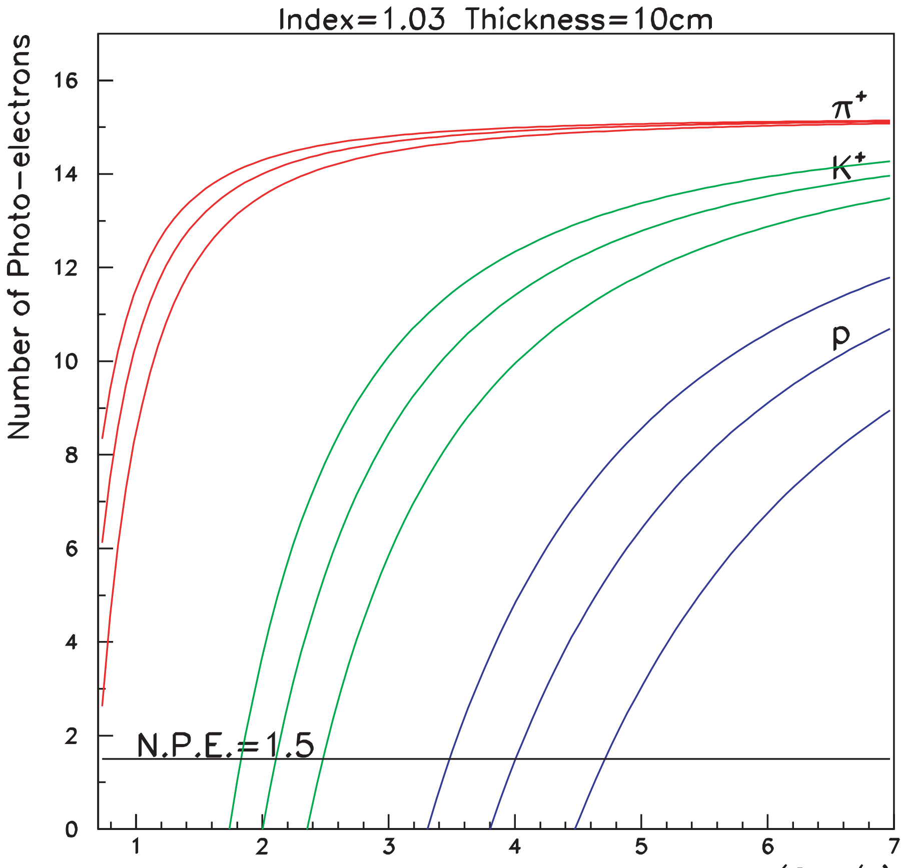
(a)

Index	p_π (GeV/c)	p_K (GeV/c)	p_p (GeV/c)
1.030	0.58	2.06	3.92
1.008	1.11	3.93	7.46
1.0014	2.61	9.24	17.6

Particle Identification (cont.)



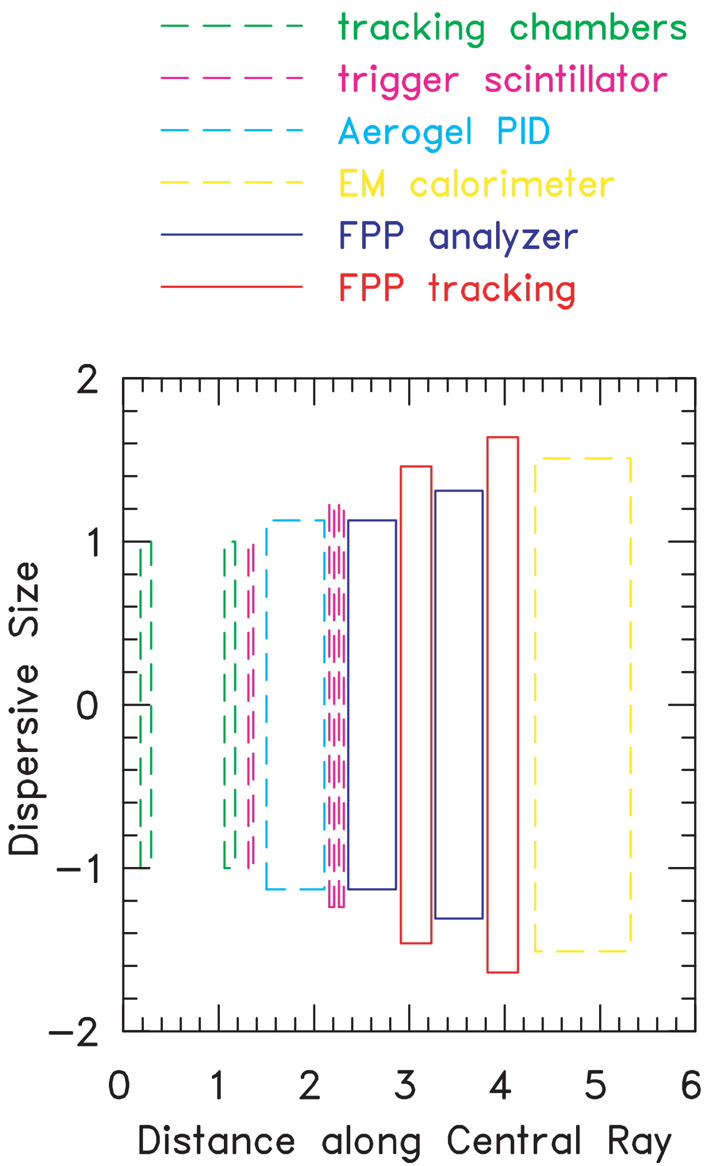
(c)



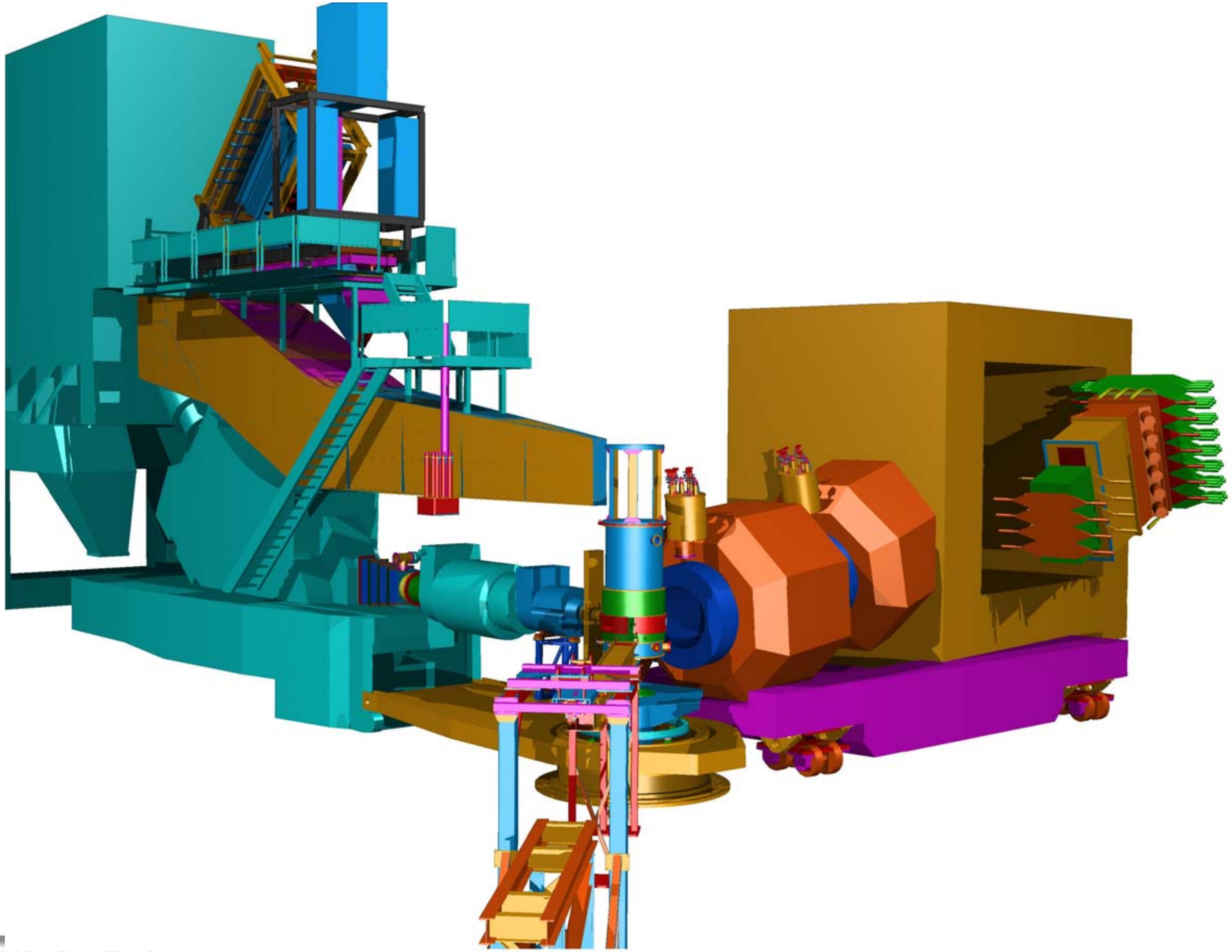
(d)

Focal Plane Polarimeter

- Double CH2 analyzer
  - ✓ Each 2 m * 3.5 m * 0.5 m (~% ton!)
- Tracking 2.5 m * 4 m
  - ✓ 4 multilayer straw chambers
  - ✓ 2 cm drift cel
- Use aerogel for π^+ rejection



Overview of MAD and HRS



Calorimeter

- Calorimeter on floor successful for photon/electron detection
  in coincidence experiments (e,e'pγ or e,e'X)
- Existing A/C calorimeter
  1700 lead-glass blocks 4 * 4 * 40 cm^3
- Improved version
  - ✓ Use PbF2
    - Higher density -> better energy resolution
    - Higher refractive index -> lower e^- threshold
    - Enhanced UV transmission
    - Lower critical energy -> less e^+e^- pairs
  - ✓ 1296 elements 26 * 26 * 200 mm^3

Beam Line

- Beam emittance deteriorates factor 2 (longitudinal) to 10 (transverse)
- Little effect on quality of data, no need for significant modifications
- Arc dipoles modified from C- to H-yoke

- Energy measurement
  - ✓ ARC measurement requires remapping of all dipoles
  - ✓ EP instrument only useable up to 6 GeV

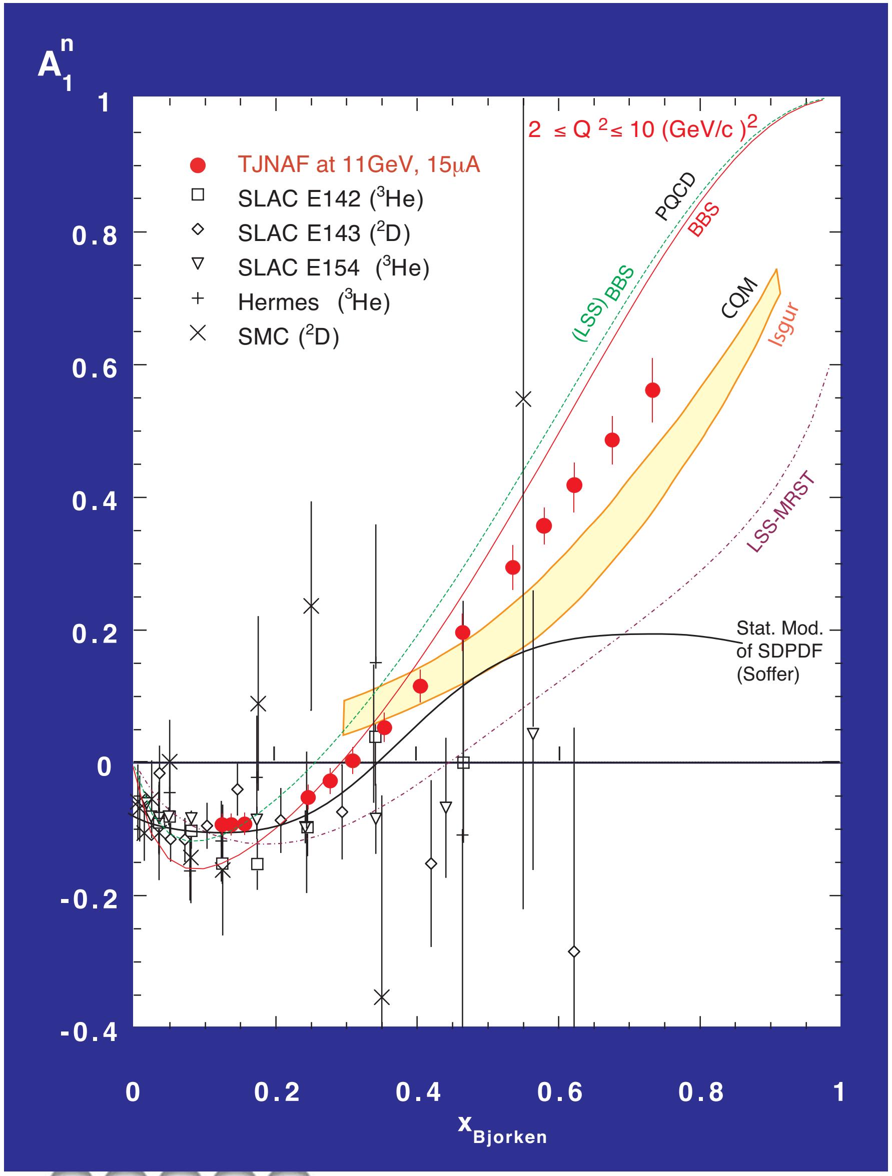
  - ✓ Beam polarimeters
    - Møller reduce dipole bend angle from 11° to 7°
      add quadrupole
    - Compton lift beam line by 8 cm

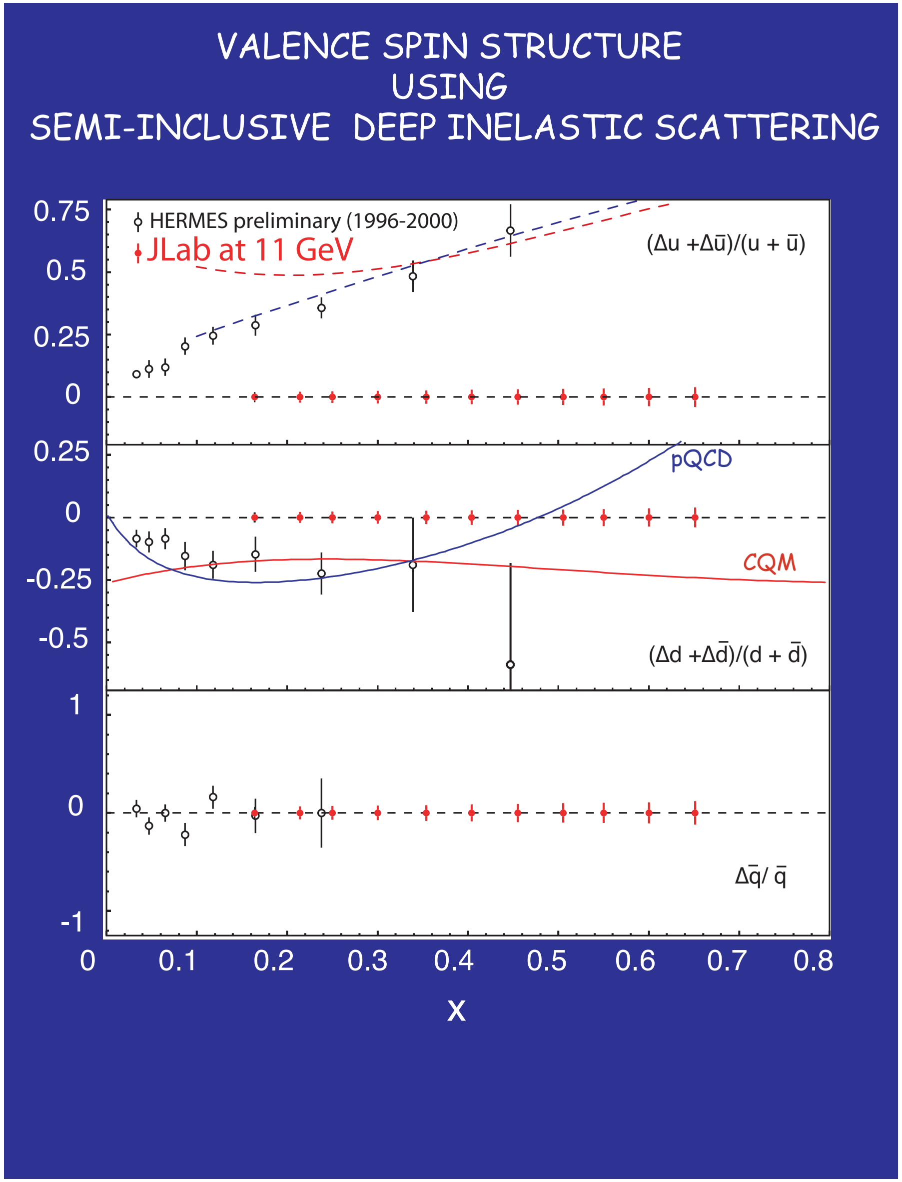
Research Program

Experimental Requirements for MAD

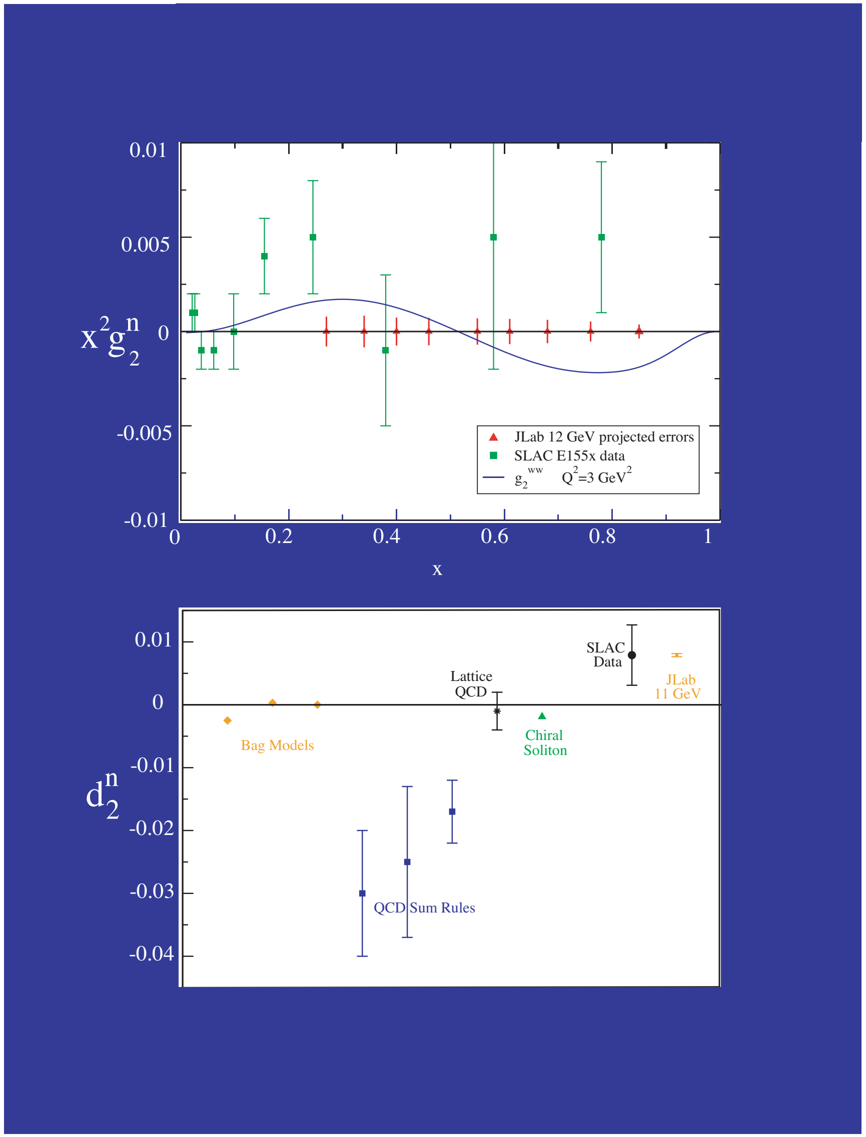
No.	Exp's	Pmax (GeV/c)	Angle (degrees)	Acc(angle) (msr)	Acc(mom) (%)	Res(mom) (%)	Res(ang) H, V(mr)	Luminos-ity (10^37)	e or h?
1	d/u (3H/3He)*	6	15-30	15-30	30	0.3	1-3	10	e
2	A1n,g1n	6-7	15-30	15-30	30	0.3	2-3	0.1	e
3	g2n	6	15-30	15-30	30	0.3	2-3	0.1	e
4	A1p,g1p	6-7	15-30	15-30	30	0.3	2-3	0.01	e
5	spin duality	6-7	12-25	12-25	30	0.3	2-3	0.1	e
6	g1 at high E	6-7	12	12	30	0.3	1-3	0.1	e
7	DIS-Parity	6-7	12-15	12-15	30	0.3	1-3	100	e
8	semi-pi+/pi-	6	15-25	15-25	30	0.3	2-3	5	e
9	d_bar/u_bar	6	15-25	15-25	30	0.3	2-3	40	e
10	delta_u, d, s	6	15-25	15-25	30	0.3	2-3	0.1	e
11	transversity	6	15-38	15-30	30	0.3	2-3	0.1	e
12	pi struc. fun.	3	15-22	15-25	30	0.3	2-3	0.1	e
13	charm	6-7	12-15	12-15	30	0.3	1-3	40	e
14	hadronization	6	12-30	12-30	30	0.3	2-3	40	e
15	x>1	7	12-60	12-30	30	0.2	1-3	40	e
16	Gen	6	15-20	15-20	30	0.3	2-3	0.1	e
17	Gep/Gmp	7-8*	15-35	15-30	30	0.3	2-3	40	p, FPP
16	CT (e,e'p)	7-8*	15-35	15-30	30	0.3	2-3	40	p
17	CT with FPP	7	15-40	15-30	30	0.3	2-3	10	p, FPP
18	CT in pion prod	6	12-30	12-30	30	0.3	2-3	20	pi
19	pi+- photoprod	6	12-30	12-30	30	0.3	2-3	20	pi
20	pi0 photoprod	7	12-90	12-30	30	0.3	2-3	20	p, FPP
21	KLambda	6	12-90	12-30	30	0.3	2-3	20	p
22	gamma-d	4	20-40	20-30	30	0.3	2-3	20	p, FPP

Neutron (Proton) Spin Structure A1

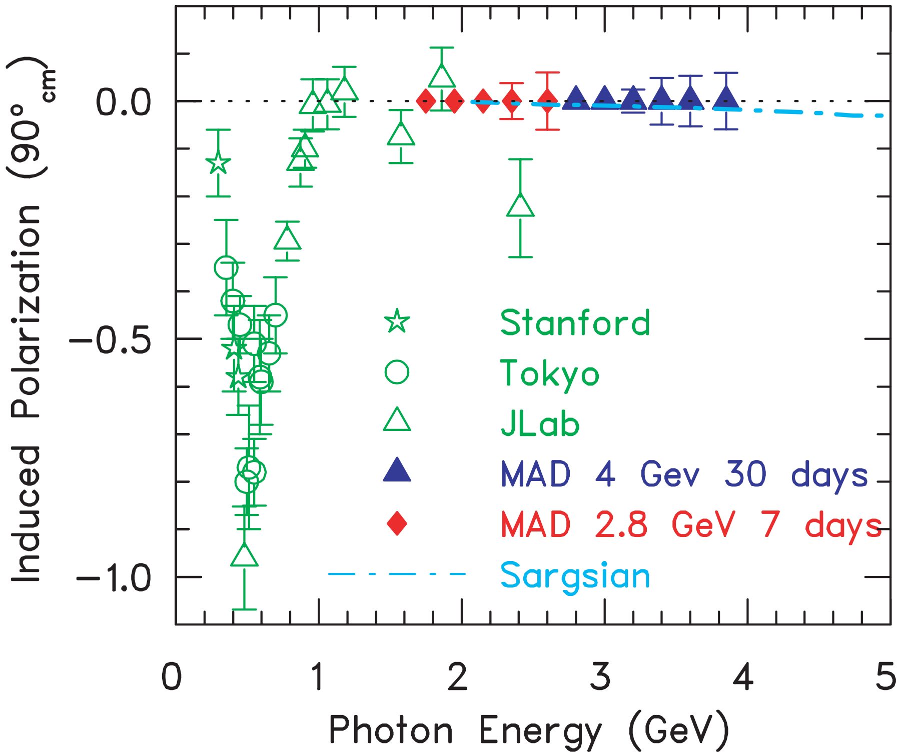


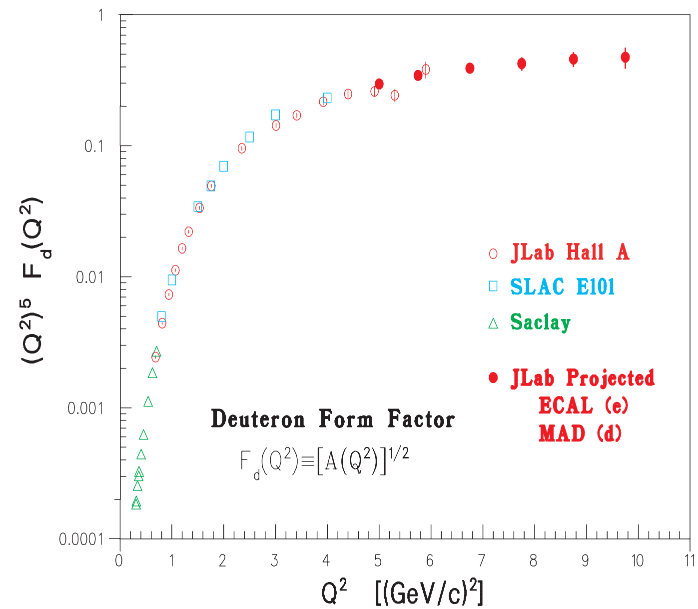


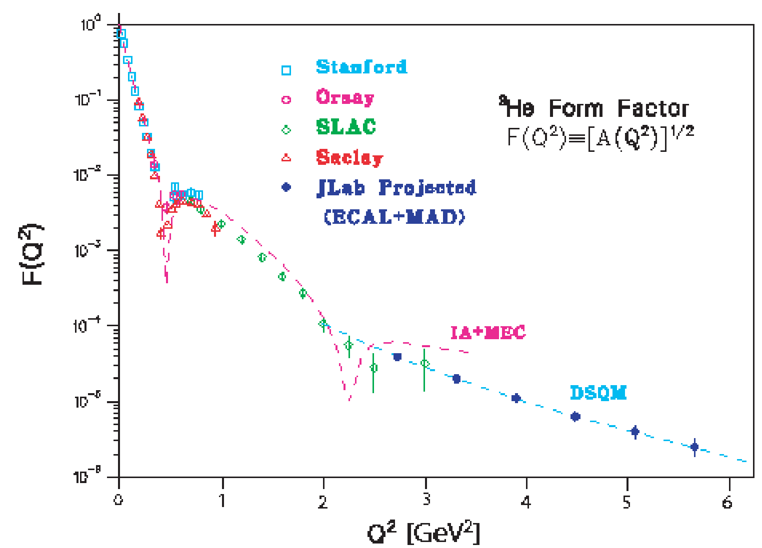
Neutron (Proton) Spin Structure g2



Few-Body Systems







Summary

- MAD design has met all specifications
  Large acceptance
    - ✓ angle 30 msr
    - ✓ momentum 30 %

  Medium resolution
    - ✓ angle few mrad
    - ✓ momentum 10^{-3}

- MAD with HRS and ECAL provides versatile and powerful instrumentation for large variety of experiments