E160 SPECTROMETER DESIGN

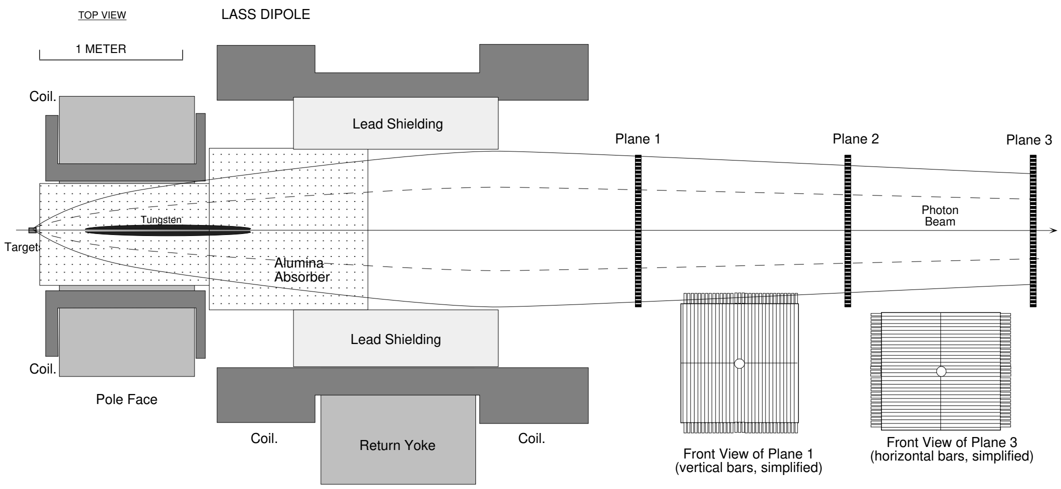
E160 Project Review, August 9, 2001

P. Bosted

- Problems with Proposal Design
- (How LASS design can be improved)
- (Muon Telescope)
- D3 Design: Physical Layout
- D3 Design: Optics, Resolution, Rates
- D3 Design:Background simulations

PROPOSAL DESIGN

- Uses 2 m of alumina absorber, 29D36 and LASS dipoles.
- Mass resolution about 4.5%, p_t resolution 0.14 GeV, z resolution 5%: all right at limit.
- Acceptance (35 GeV) about 0.3 with R_e cut.



PROBLEMS WITH PROPOSAL DESIGN

- **Proposal assumed ψ' /jpsi cross section ratio 0.3: really 0.15 (world average from 50 to 1000 GeV, consistent no E dependence).**
- **Hadronic punch-through rates in alumina were under-estimated by factor of about 3. Now using detailed PYTHIA simulations to generate hadronic events, rather than simply one pion per NI.**
- **No statistical dilution factor for BH subtraction was taken into account.**
- **Taking these together, and assuming detector limited to 80 charged particles/spill (already high!), find we are about factor 15 below physics goal for ψ' (and factor of three for J/ψ).**
- **Punch-through rate decreases rapidly with thickness as shown on next page: would like to run near "knee" where mostly muons left (or 3.5 m of alumina).**

PUNCH-THROUGH RATES IN ALUMINA

Filled diamonds are muons, circles other charged, squares all charged particles. Similar plots were made for other materials by Piotr.

HOW TO FIX PROPOSAL DESIGN

- Different absorber (i.e. Be or C) doesn't help.
- Can gain factor 50 in luminosity if make alumina thicker (i.e. 3.5 m).
- But, proposal tracking scheme (target point plus two planes after LASS dipole) gives mass resolution $> 6\%$: no good for ψ' .
- Need about factor 1.6 more integrated B field to get back to 4% mass resolution: cannot see how to get this with LASS coil geometry.
- Can recover 4% mass resolution by moving LASS dipole back, and putting extra tracking layer in front of magnetic field.
- Now system 6 m long, so acceptance about 0.12 (down factor of 4). Overall, gain factor 10 in luminosity: experiment feasible again.

- **Main difficulty: detector granularity in all three planes must be < 2.5 mm in x (or $\sigma_x <$ 0.7 mm). Now tracking without using target point. Need approximately 6000 to 8000 detector channels each with good timing: probably scintillating. fiber. Would need to share channels to common PMT/electronics to make affordable. Detectors would be in several kG field.**

MUON RANGE TELESCOPE

- Put absorber near "knee", then measure opening angle of muons with position.
- Followed by about 40 layers of iron interspersed with detectors. See where particle lost to get range. Rokni calculations and actual experience say 5% momentum resolution possible up to 10 GeV (may be worse at 30 GeV).
- Mass resolution of 4.4% (C absorber) to 4.9% (alumina) (a little above our limit).
- Acceptance $\approx 50\%$ for $E_J > 25$ GeV.
- Size needed is huge: rectangle about 5 m by 5 m by 30 m, or 3 million pounds of iron, > 400 m^2 of detector surface. Rough cost estimate is $> \$3,000,000$
- Not good for E161 unless iron magnetized, detectors have fine granularity for measuring sign of muon. (Volume for E161 would be about 1/4).
- Does not take advantage of point target: better suited to neutrino detection.
- Can any existing detector be borrowed?

ABSORBER CHOICE, RESOLUTIONS

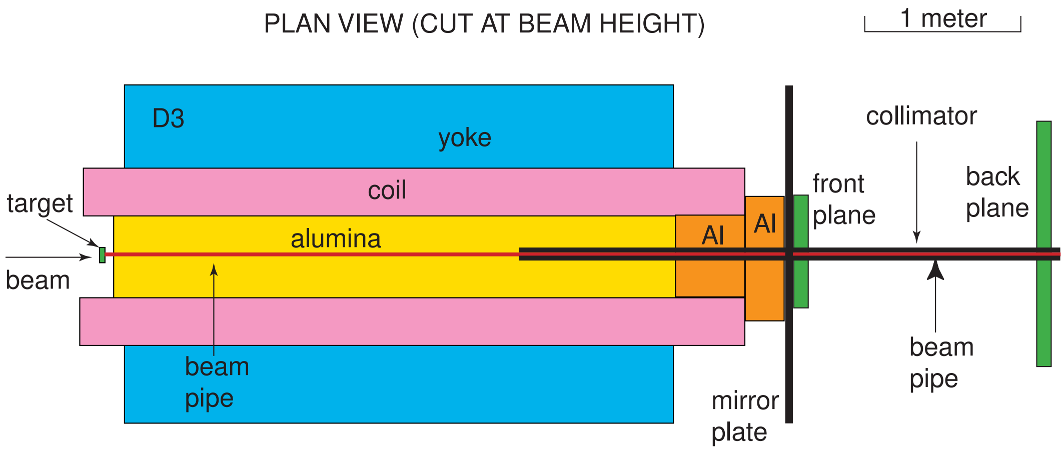
For various materials, the length in meters and r.l. of the material that matches the "knee" condition; number particles emerging is for 25,000 nuclear interactions; invariant mass resolutions that would be obtained from:

- **a) θ resolution from absorber alone (no magnetic field);**
- **b) same as a) but P resolution from an iron range telescope;**
- **c) same as a) but P resolution from tracking in LASS dipole;**
- **d) absorber immersed in constant 23 kG.**

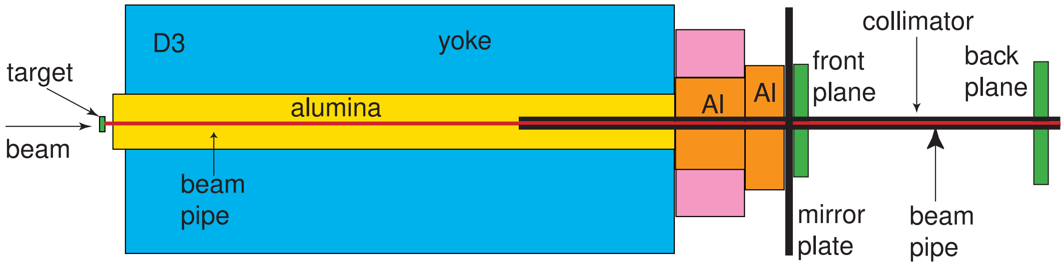
Material	density	Knee	Knee	Part.	Res (a)	Res (b)	Res (c)	Res (d)
Be	1.87	10 m	28 rl	100	2.6%	4.3%	4.0%	2.3%
C	2.20	6 m	32 rl	60	2.6%	4.4%	4.0%	2.2%
Al_2O_3	3.60	3.5 m	48 rl	50	3.1%	4.9%	4.0%	3.2%
Al	2.70	5 m	56rl	80	3.6%	5.0%	4.4%	2.9%
Cu	8.96	2.0 m	140 rl	10	5.7%	6.5%	6.0%	11%

D3 DESIGN

PLAN VIEW (CUT AT BEAM HEIGHT)



SIDE VIEW (CUT AT BEAM HEIGHT)



D3 DESIGN

- Studies show immersing absorber in constant 23 kG magnetic field gives better mass resolution than any other method, because both angle, momentum resolution improved (see case d) previous page).
- Need large, long, high field magnet. Best choice at SLAC (by far) is E158 D2 or D3 (B81, B82 in 8 GeV spectrometer). Opening 55 cm wide, 35 cm tall (flared at end), 345 cm long.
- Backgrounds also reduced (high field sweeps away low energy charged particles).
- Design has target position only 15 cm from D3 yoke (to maximize acceptance).
- D3 filled with alumina absorber.
- 80 cm drift to first detector plane: drift filled with aluminum absorber. 1.5 m drift in air to second detector plane. 75 cm drift to "muon" plane (with iron or copper between to absorb pions and protons).

- Summary of hadron filter materials:

z-range	x	y	material	weight
5-360 cm	±27.4 cm	±17.4 cm	alumina	2400 kg
360-410 cm	±27.4 cm	±30 cm	aluminum	440 kg
410-440 cm	±40.0 cm	±40 cm	aluminum	520 kg

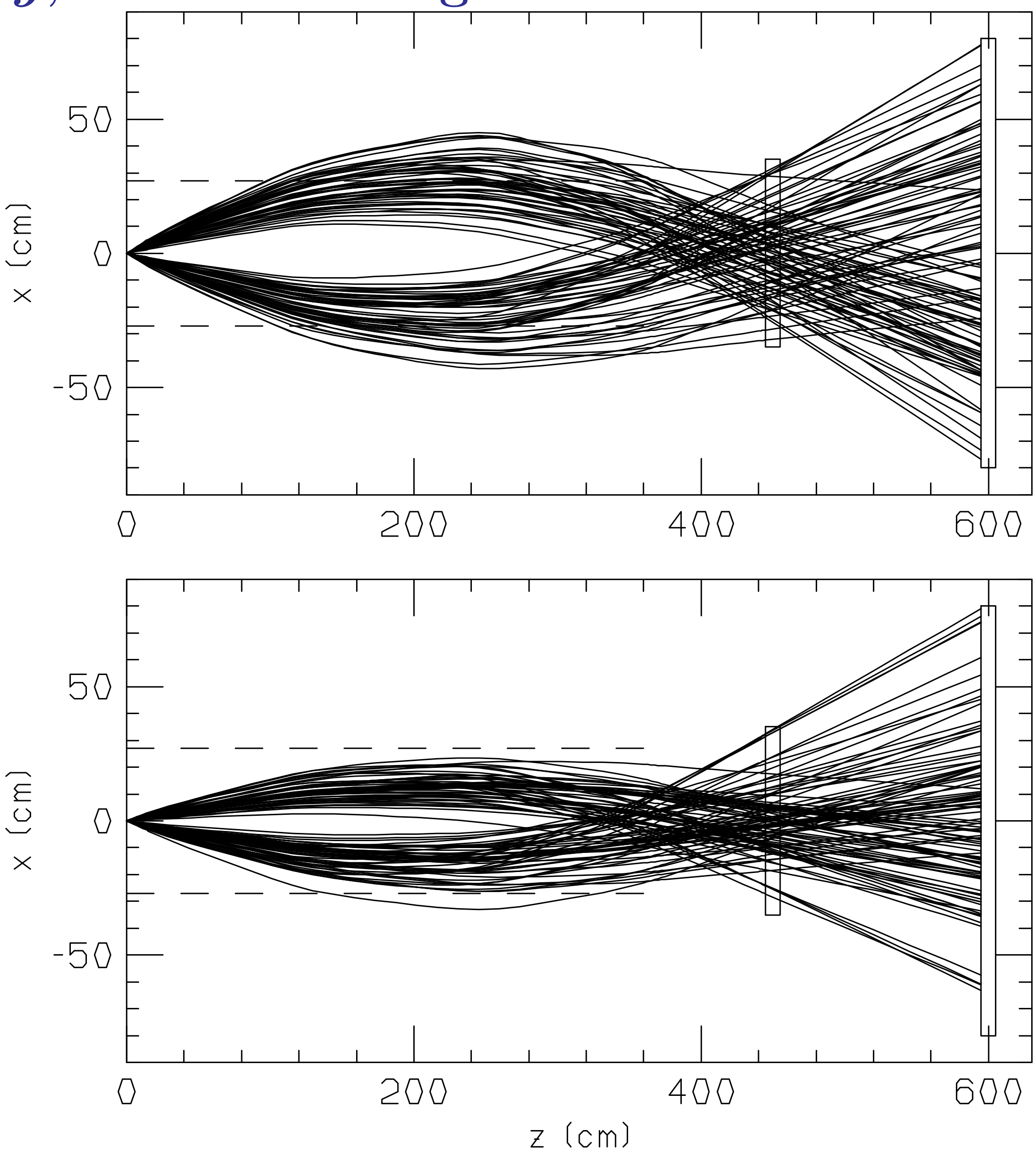
- At 15 GeV, resolution requirements looser, allow muons to pass through 30 cm wide copper coils (field drops linearly with distance into coil).
- Small beam pipe inside (1.7 cm diameter). Surrounded by tungsten for $z > 2.5$ m to reduce backgrounds.
- Summary of tangsten absrober pieces:

z-range	x	y	volume	weight
260-360 cm	±5.0 cm	±2.6 cm	4900 cm^3	88 kg
360-420 cm	±5.0 cm	±3.5 cm	5400 cm^3	100 kg
420-580 cm	±5.0 cm	±4.4 cm	13700 cm^3	250 kg

- **Acceptance about factor two lower than revised LASS design, but backgrounds lower by factor of two also: figure of merit same within error of estimate.**
- **Much easier setup (uses D3 in current location). Detector requirements much more manageable (similar to original proposal).**

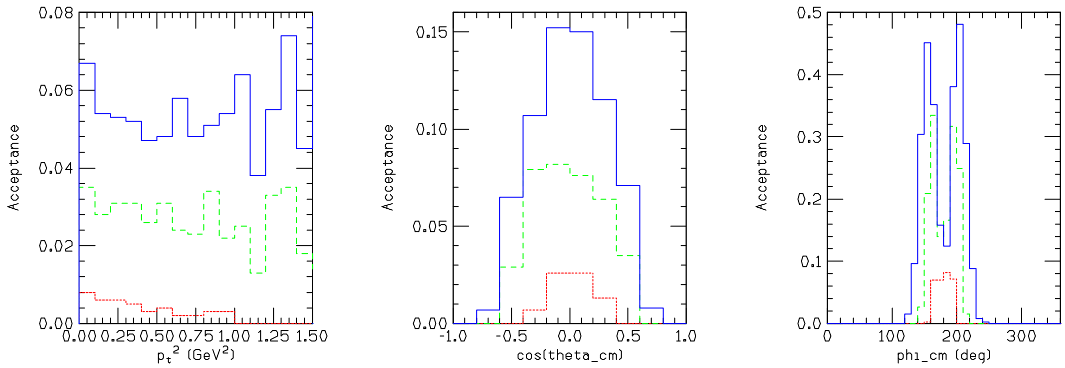
D3 DESIGN: RAY TRACE

Plot shows 15 GeV (top) and 35 GeV (bottom) ray traces from top view. In y, maximum angle is about 0.05 rad.

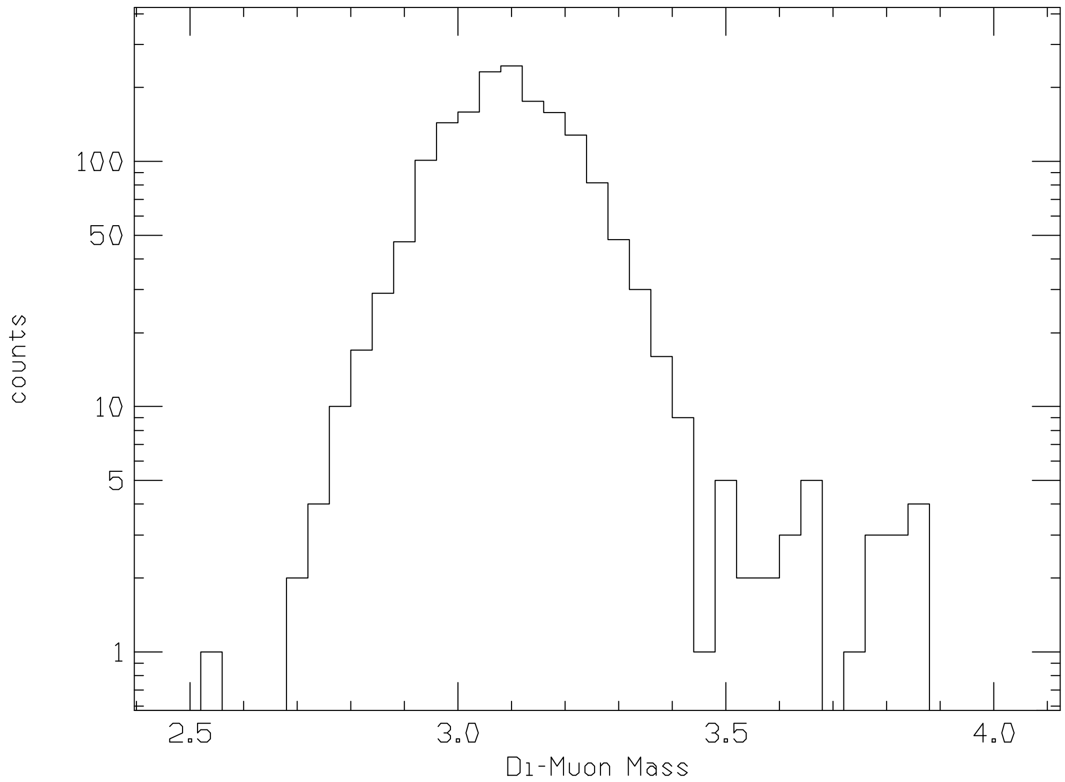


RESOLUTION AND ACCEPTANCE

J/ψ momentum	15 GeV	25 GeV	35 GeV
Mass Resolution J/ψ (%)	4.4	4.2	4.0
Mass Resolution ψ' (%)	4.0	4.3	3.9
J/ψ Energy Resolution (%)	8.6	6.3	5.7
p_t Resolution (GeV)	0.16	0.12	0.12
J/ψ Acceptance	0.0058	0.0297	0.0559
ψ' Acceptance	0.002	0.028	0.043

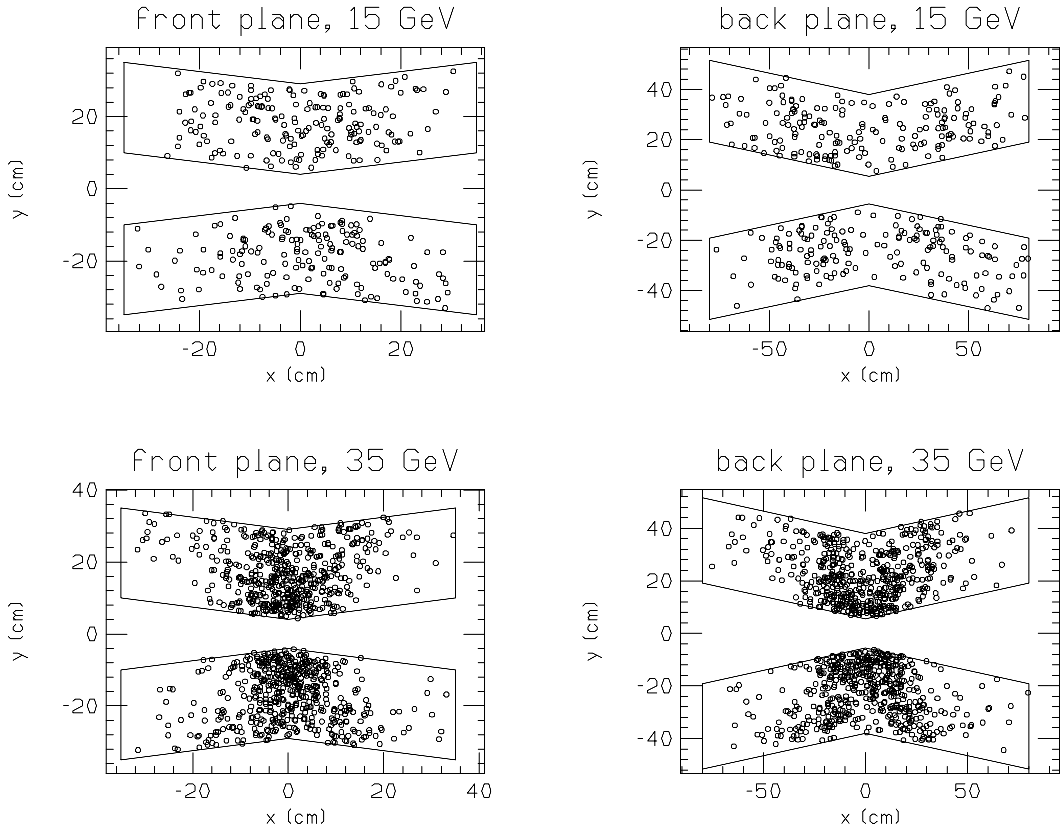


INVARIANT MASS SPECTRUM AT 35 GEV



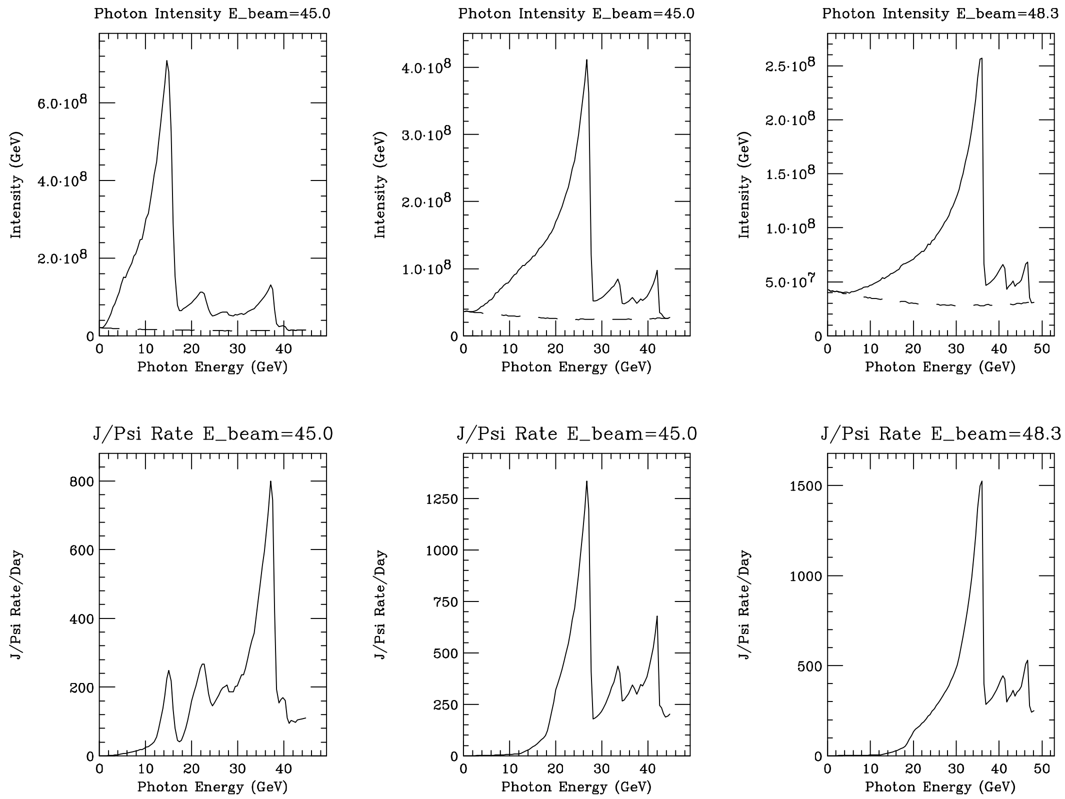
COUNTS vrs x/y AT DETECTORS

Top plot for 15 GeV, bottom plots for 35 GeV.



COUNT RATES

Top plots are photon intensity, bottom plots are quasi-elastic J/ψ rates per day for 1 gm/cm^2 target.



COUNT RATES

Electron Energy (GeV)	45.0	45.0	48.3
Electron Current (10^{10}/spill)	5.0	5.0	5.0
Peak Photon Energy (GeV)	14.8	26.5	35.2
Collimator Radius (mm)	1.0	1.5	1.5
Diamond thickness (r.l.)	0.0040	0.0040	0.0040
Diamond angle (μrad)	305	888	1590
$k > 2.5$ GeV Photons/spill	1.1×10^9	5.8×10^8	3.8×10^8
Linear Polarization at Peak	0.91	0.68	0.47
J/psi/day total	16757.	26382.	27876.
J/psi/day in Peak	1003.	8299.	9900.
J/psi goal per target	3000.	30000.	30000.
$/psi'$ goal per target	-	600.	600.
days (at 100% efficiency)	6.0	14.5	12.1

BACKGROUND RATES IN DETECTORS

- Big effort gone into simulation of all physics processes that can make hits in detectors.
- Iterated on design values (beam flux, absorber thickness, acceptance, etc.) to simultaneously reach physics goals in 30 ideal days, and keep rates in array of 1000 hodoscope fingers at level of few hits/spill/finger, and < 10 tracks/spill.
- GEANT used to simulate spectrometer: various models used to generate input rays for the 5 main backgrounds.
- Hadronic backgrounds calculated with PYTHIA. Typically 100,000 particles leave target per spill. Mostly pions, kaons, and photons. Relatively large angles. Calculated for Be (thickest target). This is largest source of sprinkle hits (about 1/finger/spill) and track candidates (hit both front and back plane, but not usually "muon" plane) at 8/spill (most easily rejected with geometrical cuts and requiring "muon" plane).

- **Hadronic background from 15 GeV spectrum:**

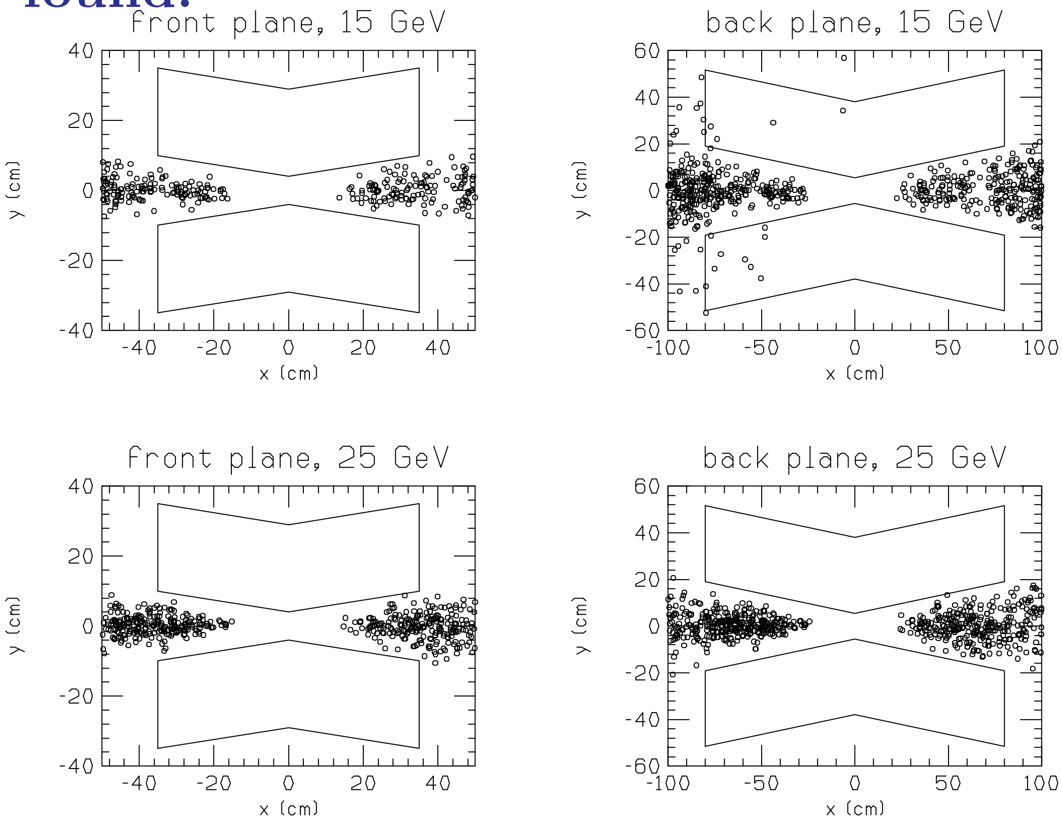
	Front		Back		
particle	**hits**	$< E >$	**hits**	$< E >$	**tracks**
electrons	**17**	**0.223**	**12**	**0.311**	**3**
muons	**3**	**1.436**	**34**	**1.855**	**2**
pions	**8**	**2.618**	**5**	**1.959**	**3**
protons	**60**	**0.014**	**8**	**0.023**	**1**
neutrons	**310**	**0.022**	**118**	**0.036**	**33**
photons	**194**	**0.010**	**152**	**0.013**	**37**

- **Background from photons that Compton scatter in target, Calculated for Be (thickest) target, get several thousand photons per spill. Result in about 0.2 sprinkle hits/finger/spill. No tracks. Tungsten collimator is crucial. Sometimes get "showers", rather than isolated sprinkle hits.**

- **Primakov π^0 production calculated from lead (highest Z^2) target yields about 5000 photons per spill. Results in about 0.2 sprinkle hits/finger/spill. No tracks.**

- **Background from e^+/e^- pairs produced in lead (highest r.l.) target, based on statistics of 1/100 spill. Observed < 0.1 sprinkle hits/spill. Collimator design crucial: rates very high with no W collimator.**

- Background from Bethe-Heitler muons pairs, calculated using Tsai formulas for coherent, quasi-elastic, and inelastic. About 2,000 produced/spill (lead target), at typical small angles m_μ/k. Most pass between top and bottom detectors planes, but occasionally a low momentum muon hits the back plane. No tracks found.



- **Bottom line: About 1 sprinkle hit per detector element per spill and order of 10 tracks/spill. Similar to E155: should work o.k.**

		15 GeV Flux		25 GeV Flux	
Process	Particles	Front	Back	Front	Back
Hadronic	e, π, p	1.0	0.5	1.0	0.5
Compton	e^-/e^+	0.3	0.2	0.2	0.1
Primakov	e^-/e^+	0.3	0.2	0.2	0.1
e^-/e^+ Pairs	e^-/e^+	< 0.2	< 0.1	< 0.2	< 0.1
Total		1.6	0.9	1.4	0.7

- **Future work: a) determine if any other significant background processes; b) do complete tracking simulation to determine efficiency and purity of J/ψ reconstruction in presence of backgrounds.**