E160 SPECTROMETER DESIGN

RPC Collaboration Meeting, January 11, 2002

P. Bosted

- **History**
- **Physical Layout**
- **Optics, Resolution, Rates**
- **Background simulations**
- **Detectors**

HISTORY

- Proposal used 2 m of alumina absorber, 29D36 and LASS dipoles. Mass resolution about 4.5% note quite good enough. Backgrounds very high.
- D3 only design had better resolution (4%) and lower backgrounds due to more alumina. Could almost achieve goal for ψ' signal, if no surprises.
- Sebastian designed 1.8 iron "wedge" in LASS for E161. Realized combining this with D3 gives

  Better resolution (3%)

  Backgrounds lower by about factor of 10

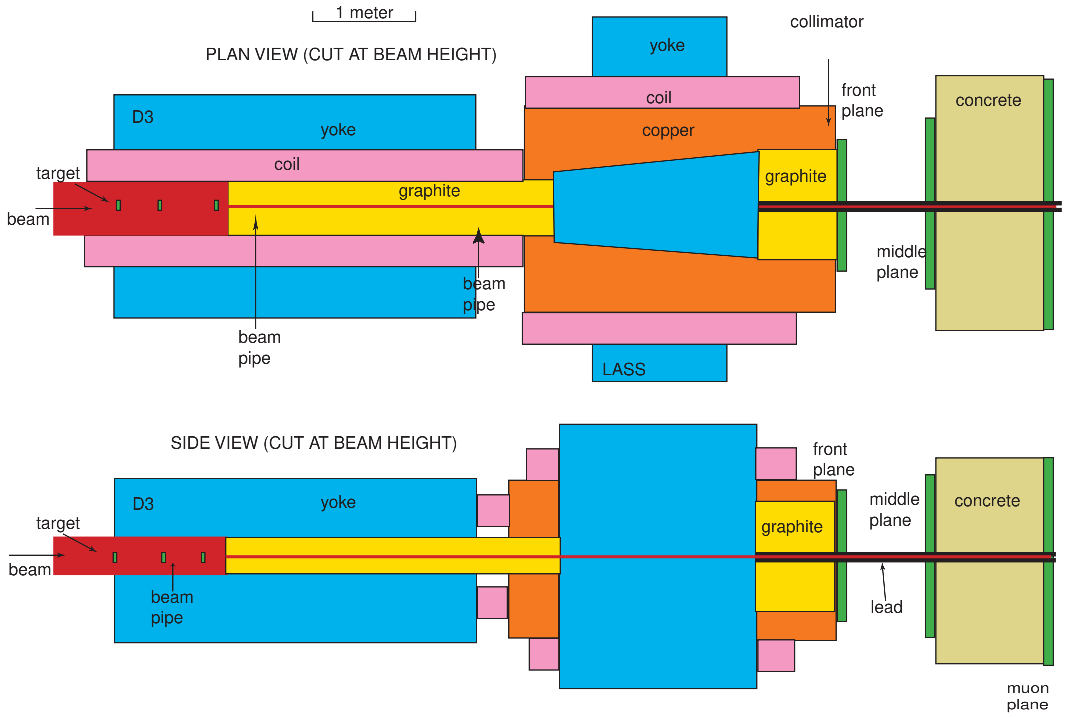
  Larger acceptance at low energy

  Can get $>$ 4x statistics than D3 only

PROBLEMS WITH D3 ONLY DESIGN

- **Multiple scattering did not include log term: this makes resolution go from 3.2% to 4.2%.**
- **Energy loss in alumina was too low (value for copper).**
- **Decays from secondary hadrons in showers were too low.**
- **Acceptance at 15 GeV very low.**
- **Taking these together, could probably achieve proposal goal for J/ψ , but ψ' error would be larger by 50% to 100%.**

D3+LASS DESIGN: LAYOUT



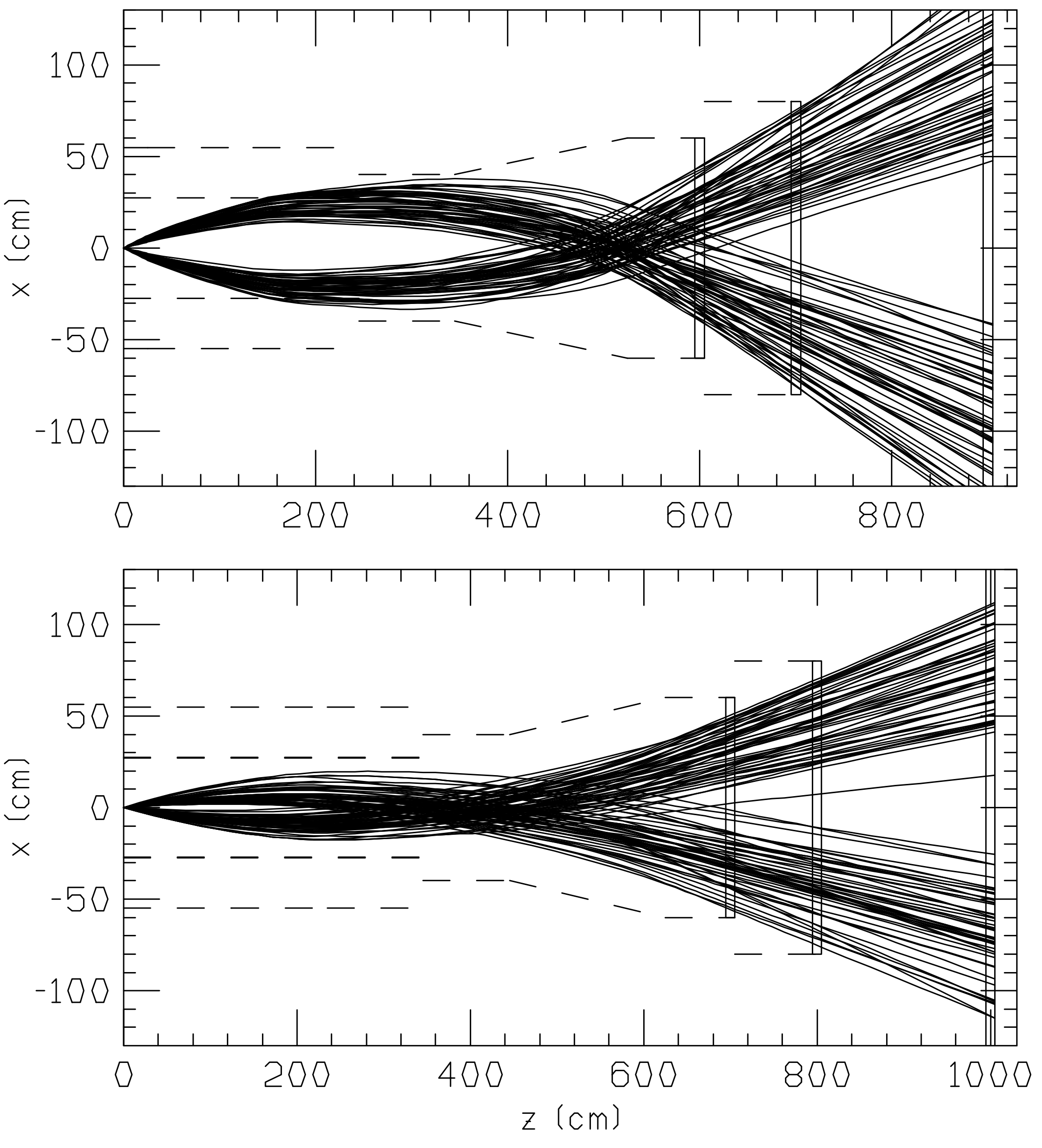
D3+LASS DESIGN: KEY FEATURES

- More integrated field
- Absorber further from target gives better resolution. More decays too, but ok since measuring two muons.
- Magnetized iron provides both bending and sufficient hadron absorption. Low cost for large acceptance.
- Target inside D3. Moves from up-beam end (35 GeV setting) to near middle (15 GeV setting). Optimizes tradeoff in acceptance versus resolution. Used 50 cm steps for 35, 25, and 15 GeV in simulations.
- Field in D3 is 22.5 kG: quickly bends low P particles into coils. Uses existing power supply, with extra power cables.
- Downstream half of D3 filled with graphite absorber ($\rho = 1.55$) to minimize decays without much multiple scattering. Graphite extends to front of "wedge". Dimensions about 35 by 55 by 220 cm.
- Evacuated aluminum beam pipe inside graphite has 1 cm diameter. Alignment to 0.5 mm if possible.

- Gap between iron of D3 and LASS wedge set at 100 cm to allow room to work on coils. Copper coils in gap augmented with extra (removable) copper to reduce muon backgrounds.
- Iron wedge in LASS 180 cm, flaring from ± 40 cm to ± 60 cm from front to back. Could be ± 50 cm in back if get more field. Assume average of 19 kG in iron.
- Need copper (or something similar) between wedge and LASS coils.
- Gap in iron ± 1 cm tall. Filled with copper except for 1 cm outer radius beam pipe.
- Mirror plate needed on down-beam end of LASS to minimize field in PMT's.
- Graphite between end of wedge and front hodoscope plane to reduce low energy backgrounds (80 cm long, ± 55 cm tall, ± 60 cm wide).
- Vacuum pipe beyond wedge assumed 1 cm inner radius. Surrounded by lead box ± 4 cm tall and ± 10 cm wide.

D3 DESIGN: RAY TRACE

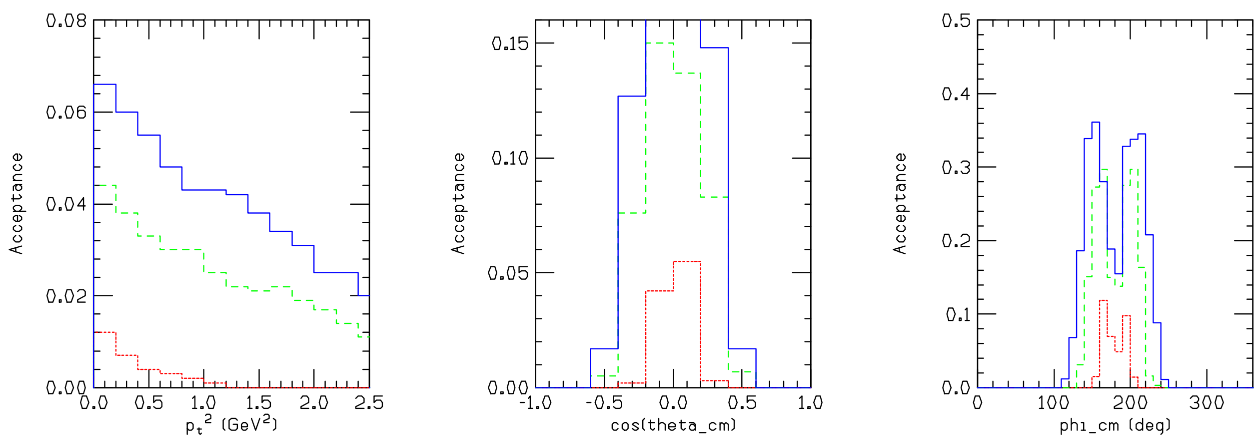
Plot shows 15 GeV (top) and 35 GeV (bottom) ray traces from top view.



RESOLUTION AND ACCEPTANCE

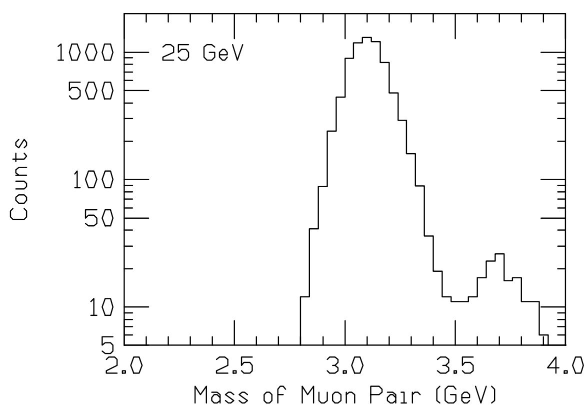
From D3SPECT. Checked get same resolution with GEANT.

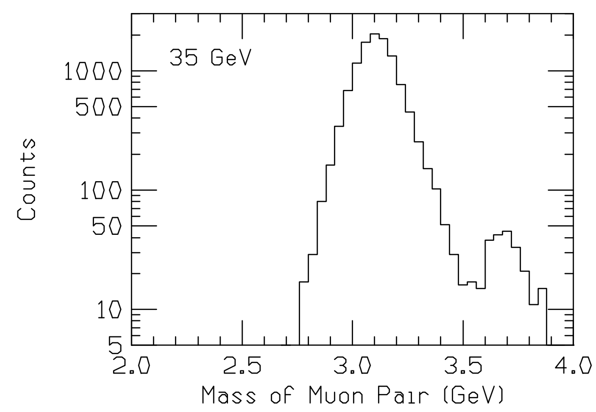
J/ψ momentum	15 GeV	25 GeV	35 GeV
Mass Resolution J/ψ (%)	3.5	3.0	3.4
Mass Resolution ψ' (GeV)	7.6	3.5	3.9
ψ Energy Resolution (%)	10.7	8.3	8.6
p_t Resolution (GeV)	0.12	0.12	0.14
J/ψ Acceptance	0.0087	0.040	0.059
ψ' Acceptance	0.002	0.038	0.068



INVARIANT MASS SPECTRUM AT 25 AND 35 GEV

ψ' and J/ψ peaks clearly separated, even though 50x less ψ' . No acceptance from ψ' at 15 GeV. Plots don't include Bethe-Heitler background.



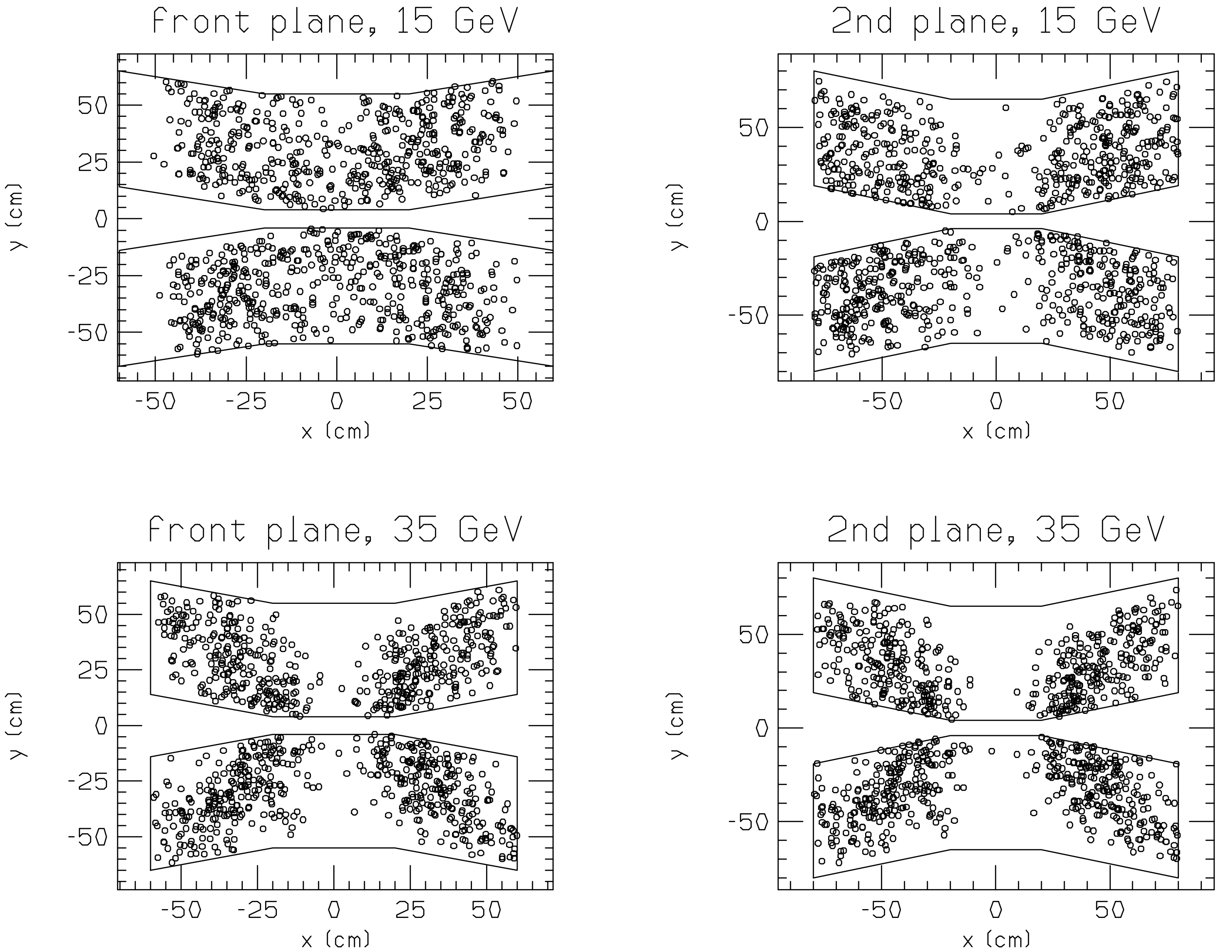


DETECTORS

- Front and 2nd (Middle) planes used for tracking. Need x bin size 0.8 (1.2) cm for central (outer) x regions and y bin size < 2.54 cm.
- Muon wall can have 10 cm granularity. Used for particle ID and timing. Also helps tracking.
- Separations from Wedge to Front to Middle to Muon are 80 cm, 100 cm, 200 cm respectively.
- Graphite between Wedge and Front. Concrete between Middle and Muon.
- "Chevron" geometry is equivalent to p_T cut: eliminates most muon backgrounds.

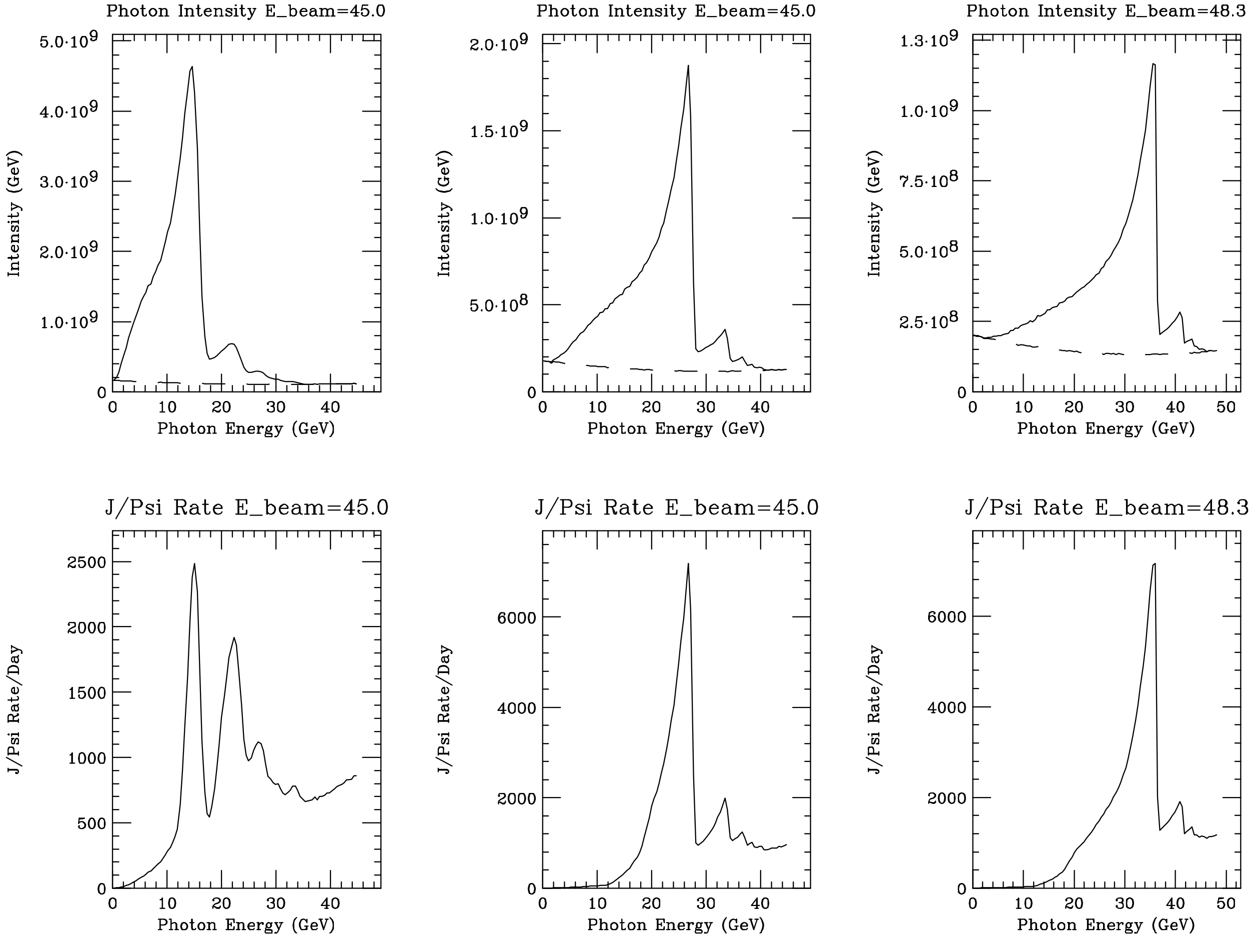
Layer	x	y	x fingers	y fingers
Front	± 60 cm	± 55 cm	240	80
Middle	± 80 cm	± 65 cm	320	100
Muon	± 150 cm	± 80 cm	16	36

COUNTS vrs x/y AT DETECTORS



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

Now using 6x higher flux of photons than with D3 only, with no extra peaks at high k.

Electron Energy (GeV)	45.0	45.0	48.3
Electron Current (10^{10}/spill)	5.0	5.0	5.0
$k > 2.5$ GeV Photons/spill	8.3×10^9	2.8×10^9	1.8×10^9
Peak Photon Energy (GeV)	14.8	26.5	35.2
Diamond angle (μrad)	305	888	1587
C37 opening (mm)	± 2	± 2	± 2
Photon Beam Power (kW)	1.7	0.9	0.7
Diamond thickness (mm)	1.5	1.5	1.5
Linear Polarization	0.91	0.68	0.47
J/ψ/day total	78K	124K	132K
J/ψ/day in Peak	11K	45K	48K
J/ψ goal per target	7K	30K	30K
J/ψ goal per target	-	600	600
days (at 100% efficiency)	2.6	2.6	2.5

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 8 ideal days, and keep rates in hodoscope fingers at level of < 0.3 hits/spill/finger, and < 10 tracks/spill.
- GEANT and D3SPECT used to simulate spectrometer: various models used to generate input rays for the 5 main backgrounds.
- Hadronic backgrounds calculated with PYTHIA. Typically 500,000 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 (average 0.2/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:**

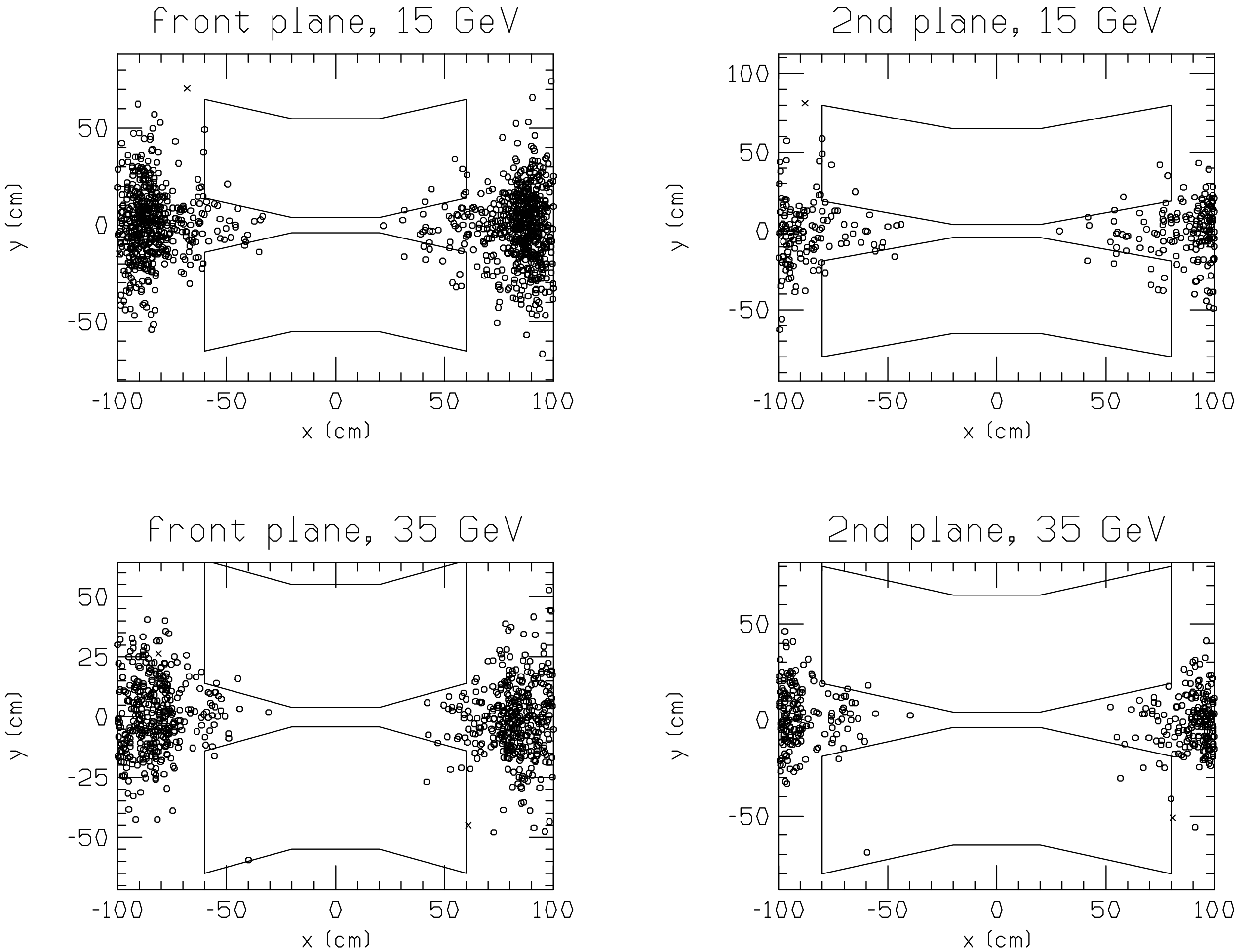
	Front		2nd	Plane	
particle	hits	$< E >$	hits	$< E >$	tracks
electrons	4	0.167	1	0.024	1
muons	5	7.717	4	6.738	4
pions	5	0.295	2	0.387	2
protons	7	1.023	9	0.383	4
neutrons	27	0.220	17	0.191	15
photons	9	0.126	5	0.036	1

- **Hadronic background from 35 GeV spectrum:**

	Front		2nd	Plane	
particle	hits	$< E >$	hits	$< E >$	tracks
electrons	3	0.201	2	0.029	1
muons	6	4.778	7	4.238	6
pions	5	0.941	1	0.087	1
protons	10	0.794	6	0.893	6
neutrons	26	0.227	14	0.256	10
photons	9	0.107	5	0.115	4

- **These GEANT muon rates about factor two higher than D3SPECT, which does not generate real hadronic showers (assumes hadron is “gone” after 100 gm/cm^2.**

DECAY MUON COUNTS vrs x/y AT DETECTORS

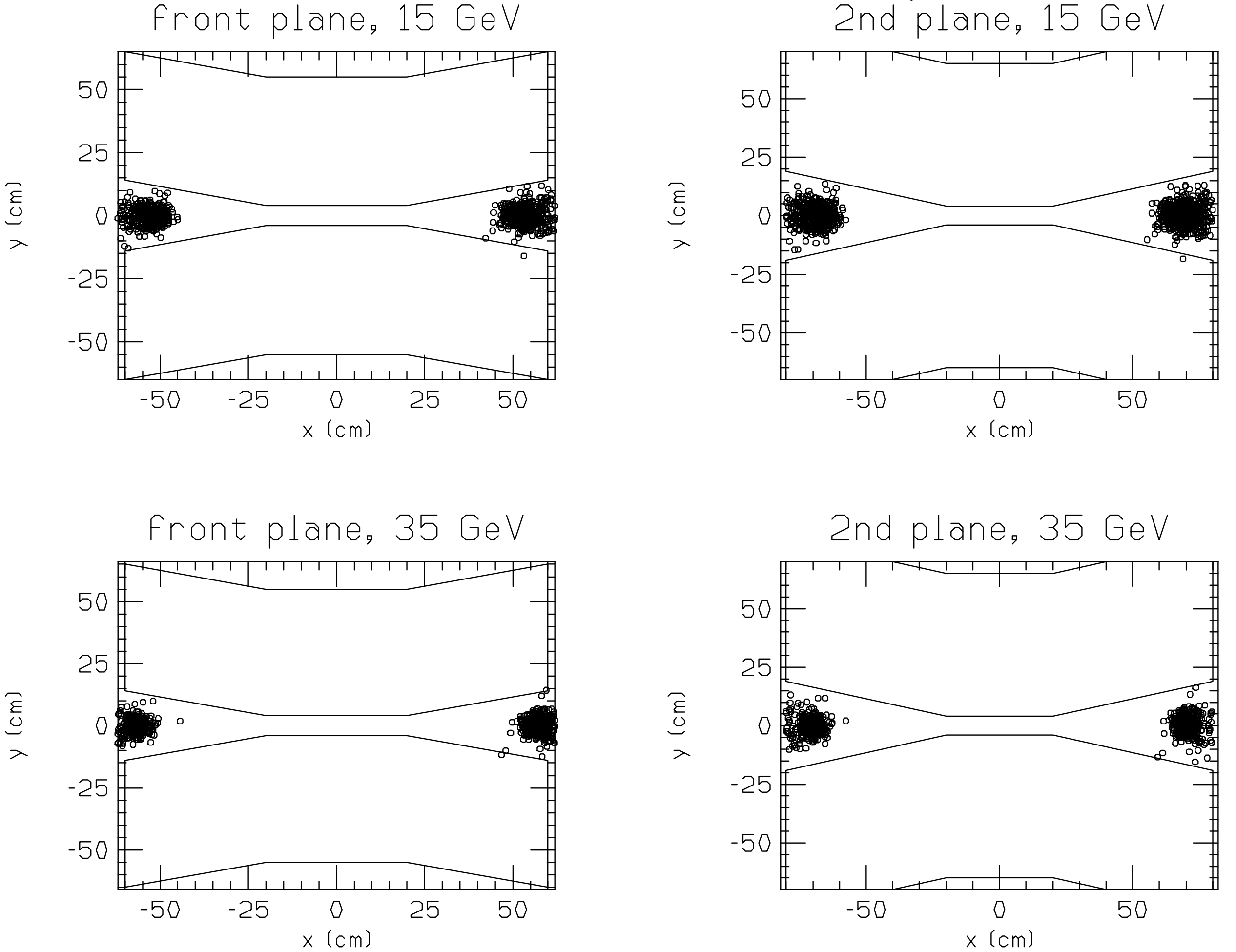


- Background from photons that Compton scatter in target, Calculated for Be (thickest) target, get order of 10,000 photons per spill. Result in < 0.03 sprinkle hits/finger/spill. No tracks. Lead collimator and graphite after LASS are crucial. Sometimes get "showers", rather than isolated sprinkle hits.
- Primakov π^0 production calculated from lead (highest Z^2) target yields about 25,000 photons per spill. Results in < 0.03 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. Found no sprinkle hits or tracks. Electrons all swept into > 100 r.l. of copper/graphite. Some muons will be produced in e.m. showers: these will mostly be low momentum and in horizontal plane, and miss detectors.

- **Background from Bethe-Heitler muons pairs, calculated using Tsai formulas for coherent, quasi-elastic, and inelastic. About 4,000 produced/spill (0.12 r.l. lead target), at typical small angles m_μ/k. Most pass between top and bottom detectors planes, but get several hits/spill in front/middle hodoscopes, and a few tracks/spill. The muon rates are highest for the 15 GeV setting.**

	Front		2nd Plane		
E_ψ	hits	$< E >$	hits	$< E >$	tracks
15	3.8	14.948	6.9	9.886	2.9
25	2.1	12.568	2.2	11.825	1.4
35	1.3	22.572	2.7	12.397	1.1

BETHE-HEITLER MUON COUNTS vrs x/y AT DETECTORS



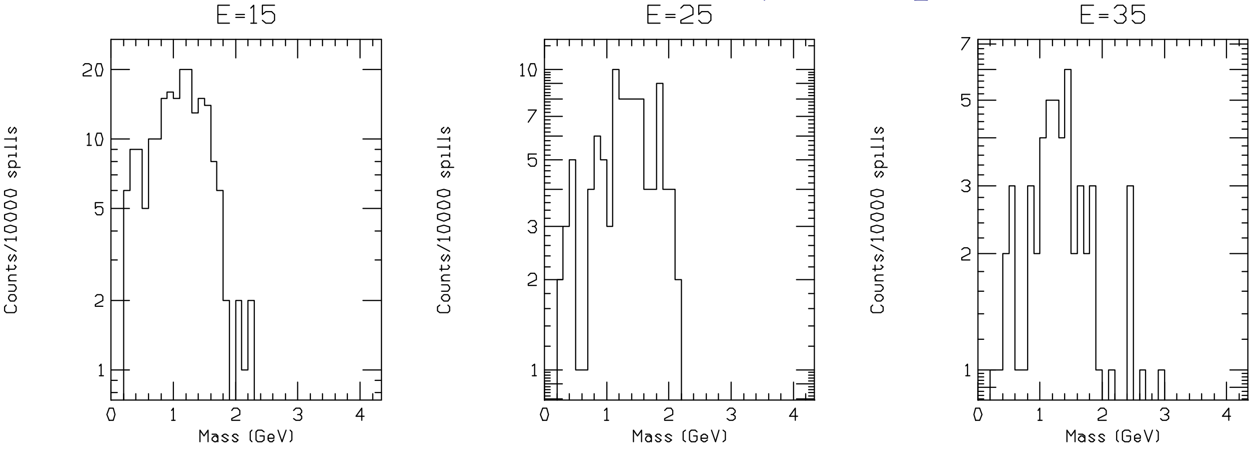
- Bottom line: About 0.2 sprinkle hit per detector element per spill and order of 5 (10) tracks/spill with (without) “muon” plane. Lower than E155: should work o.k.

ACCIDENTAL RATE

- **Accidental coincidences can make background under mass peaks: main worry in the small ψ' peak, where expected rate is about 0.0002/spill.**
- **Calculated rate/spill vrs di-muon mass for opposite sign muons from pi, K decays (not including decays of secondaries), Bethe-Heitler, open charm, ρ and ϕ decays.**
- **Assumed 3 nsec time window and 300 nsec long pulses.**
- **Find < 0.00002 events/spill with $M > 3.5$ GeV (no events found). Realistic rate could be 5x higher due to muons from secondary hadrons, but don't have enough statistics from GEANT to evaluate accurately. Could start to be comparable to ψ' rate.**
- **Crucial to have good coincidence timing.**
- **Crucial to have particle ID ("muon plane") so pion, proton, and electron tracks not included in randoms.**

ACCIDENTAL MASS SPECTRA

Count rates are for 10,000 spills.



IMPLICATIONS

- Lower background rates means maybe optimal to use 0.2 r.l. for high Z targets (rather than 0.12 r.l.).
- Should be able to run close to maximum luminosity possible with coherent brem. beam.
- DAQ rate now lower: less than 1 kB/spill. Even with factor 3 safety margin, still lower than previous design. Would anything change in DAQ project?
- Higher count rate of good particles will allow more time

  for systematic studies (different target thicknesses, etc.),

  more ψ' statistics,

  more values of Z,

  and a cushion against under-estimated backgrounds.
- Overall, very happy with new spectrometer design.