E160 SPECTROMETER DESIGN

RPC Collaboration Meeting, June 3, 2002

P. Bosted

- History
- Physical Layout
- 3D Magnet Modeling
- 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**

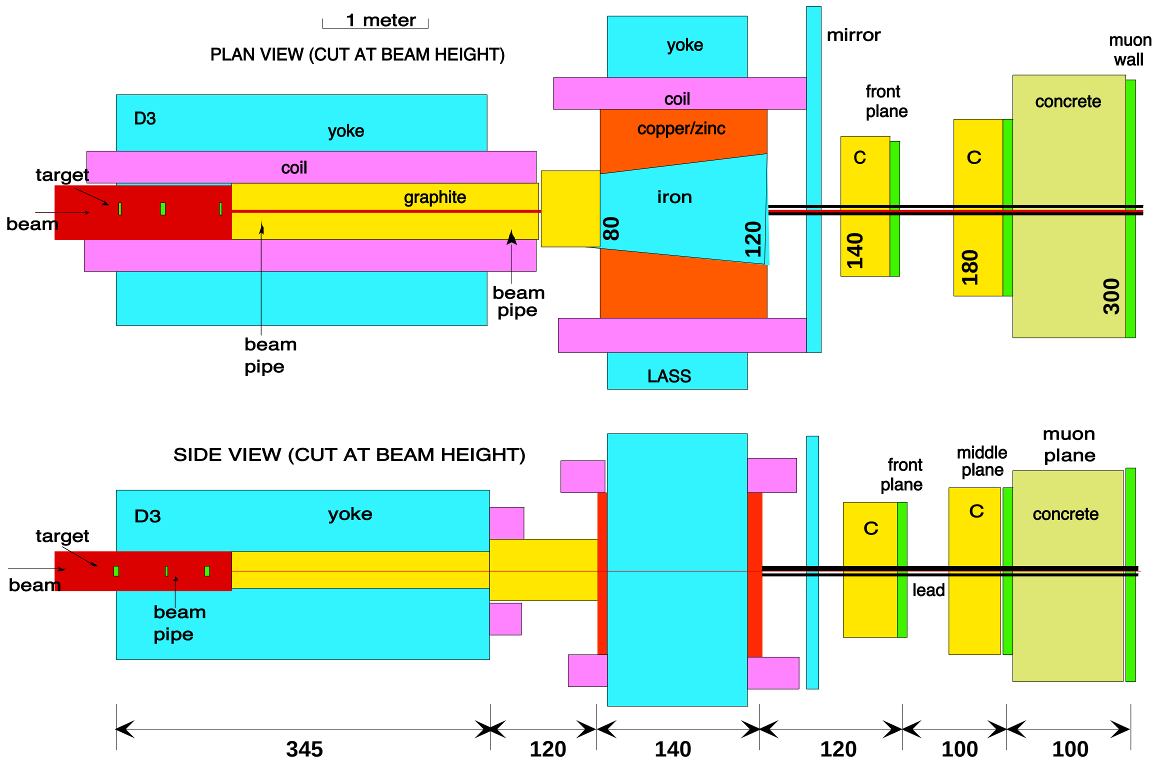
  Better resolution (3%)

  Backgrounds lower by about factor of 10

  Larger acceptance at low energy

  Can get $>$ 4x statistics than D3 only
- **3D Modeling with TOSCA and Mermaid shows higher fields in LASS: better resolution. 1.4 m slight improvement over 1.8 m.**

D3+LASS DESIGN: LAYOUT



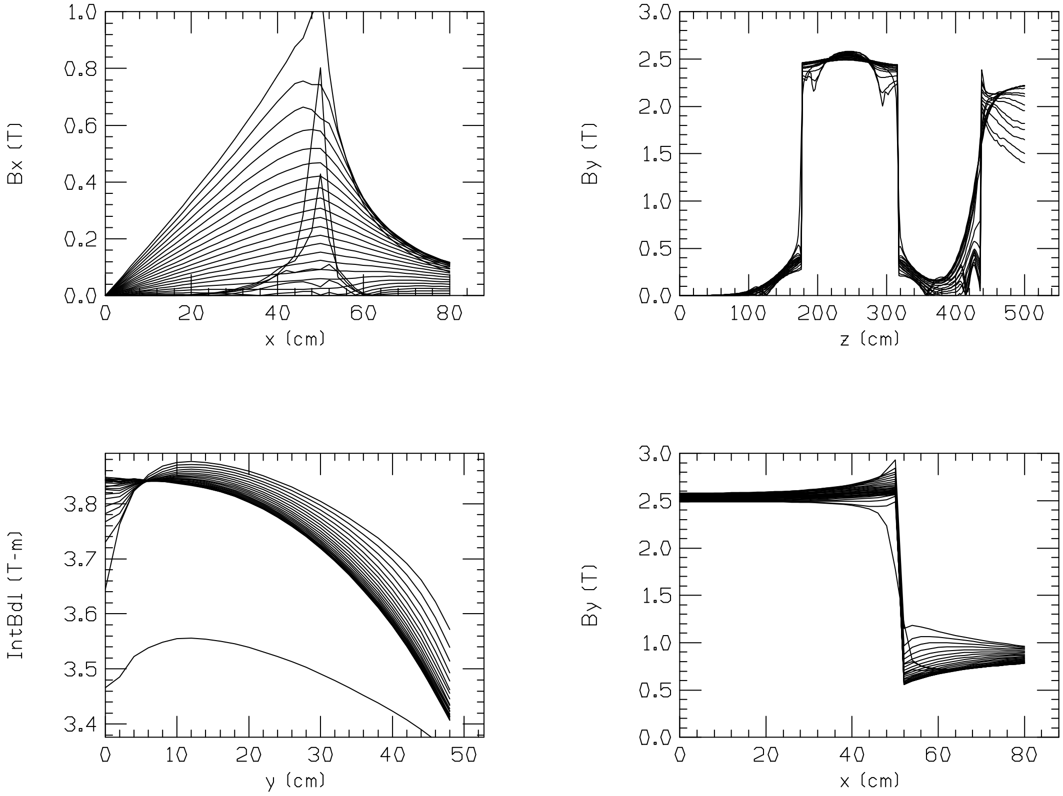
D3+LASS DESIGN: KEY FEATURES

- More integrated field compared to D3 only.
- 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. Need about 1.5 Mw of power (2700 amps).
- 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 inside D3 55 by 35 by 220 cm. Dimensions from D3 to wedge about 50 by 80 by 120 cm.
- Evacuated aluminum beam pipe inside graphite has 2 cm inner diameter, about 1 mm wall

thickness. Alignment to 0.5 mm if possible.

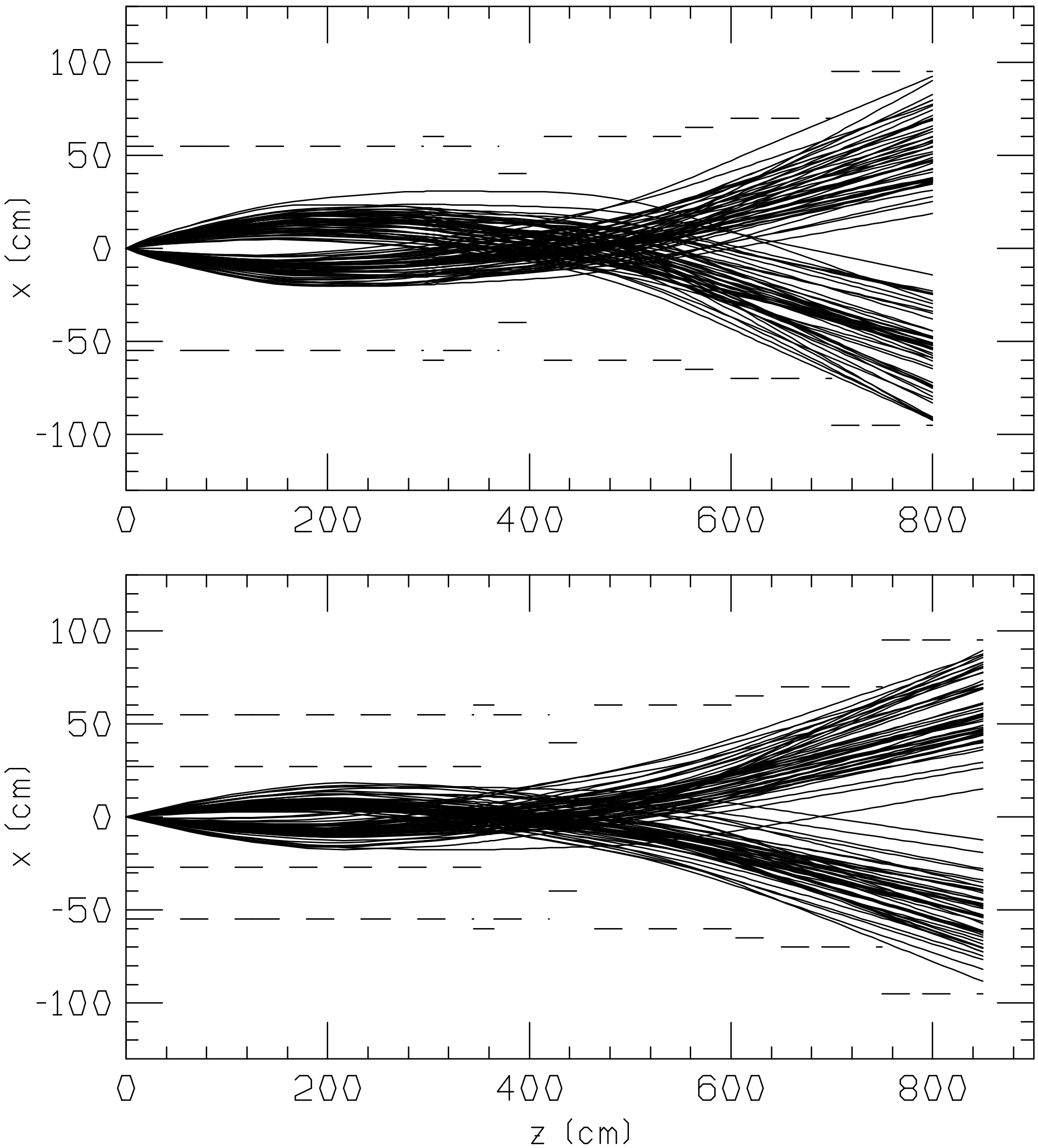
- **Gap between iron of D3 and LASS wedge set at 120 cm to allow room to work on coils.**
- **Iron wedge in LASS 140 cm long, flaring from $x = \pm 40$ cm to ± 60 cm from front to back. Height is about 1 m (fills gap), and volume is about 1.4 m^2, weight about 25Kpb.**
- **use 425 KA-turns (2700 A and about 200 V), TOSCA/Mermaid predict average of about 3.85 T-m.**
- **Need copper (or zinc or stainless steel) between wedge and LASS coils. Length 140 cm, width of each piece flares from 30 to 50 cm. Total volume is 1.1 m^3, weight about 20Kpb.**
- **Gap in iron ± 1.24 cm tall. Filled with copper except for 1 cm inner radius beam pipe.**
- **Mirror plate needed on down-beam end of LASS to minimize field in PMT's.**
- **Beam pipe beyond wedge jumps to about 3 cm radius. Surrounded by about 2 cm thickness of lead.**
- **Graphite blocks in front of front and middle hodoscope planes to reduce low energy backgrounds (each 60 cm long, ± 55 cm (± 65 cm) tall, ± 70 (± 90 cm) cm wide).**

MAGNETIC FIELDS



RAY TRACE

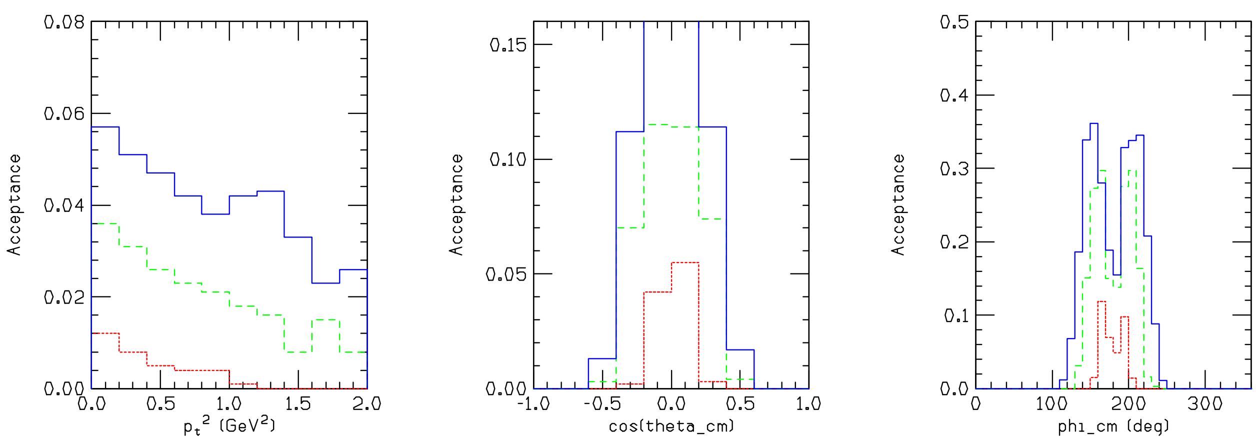
Plot shows 15 GeV (top) and 35 GeV (bottom) ray traces from top view for muon pairs from J/ψ decays.



RESOLUTION AND ACCEPTANCE

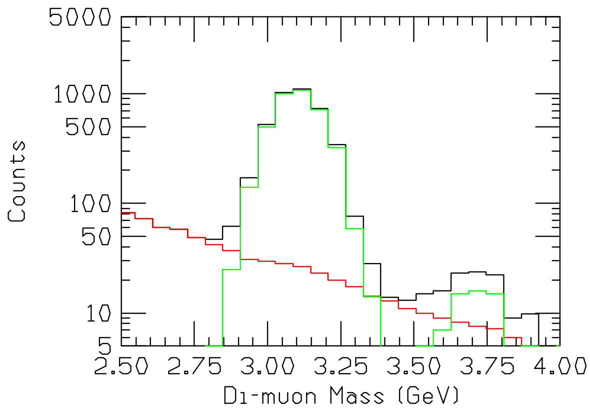
From D3SPECT. Checked get similar resolution with GEANT. Full height of detectors not used at 25/35 GeV to obtain better resolution (and less acceptance).

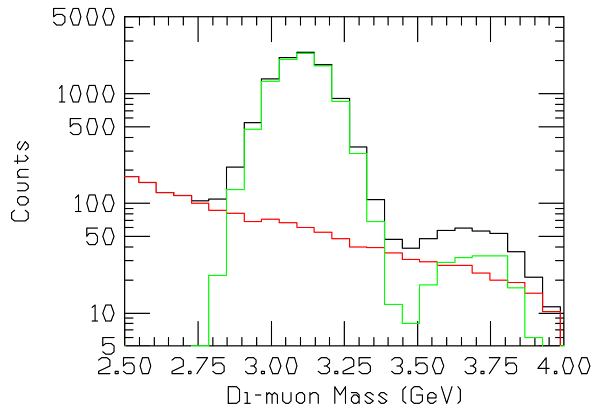
J/ψ momentum	15 GeV	25 GeV	35 GeV
Mass Resolution J/ψ (%)	3.5	2.5	2.5
Mass Resolution ψ' (GeV)	4.4	2.5	2.5
J/ψ Energy Resolution (%)	9.6	7.0	6.9
p_t Resolution (GeV)	0.12	0.11	0.12
J/ψ Acceptance	0.009	0.025	0.035
ψ' Acceptance	0.002	0.022	0.035



INVARIANT MASS SPECTRUM AT 25 AND 35 GEV

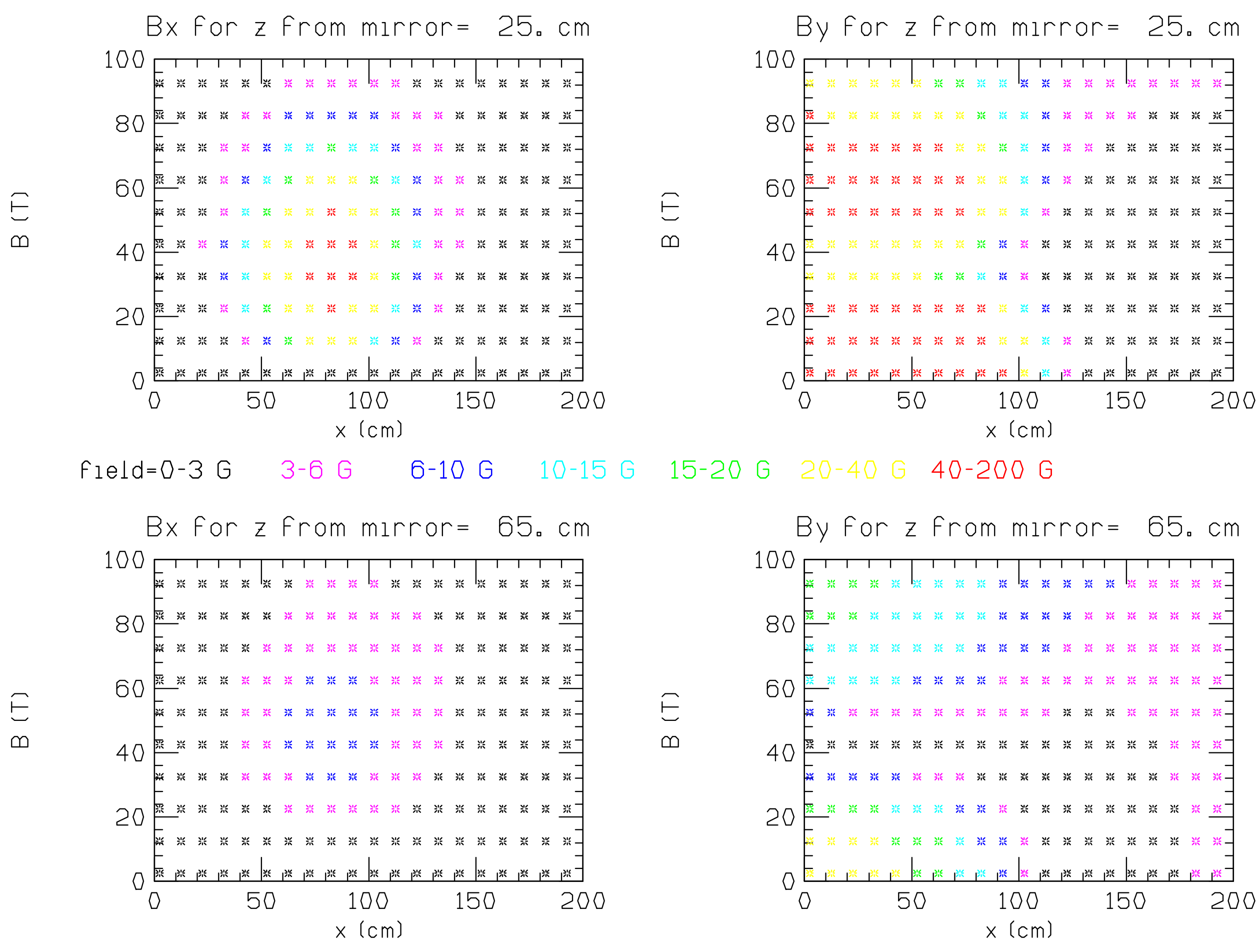
ψ' and J/ψ peaks clearly separated, even though 50x less ψ' . No acceptance for ψ' at 15 GeV. Plots include Bethe-Heitler background.





FRINGE FIELDS

TOSCA calculation shows large (> 50 G) axial fringe fields 25 cm beyond mirror plate of LASS. Moving front detectors to 65 cm reduces field to < 10 G (and detectors need to be slightly larger).

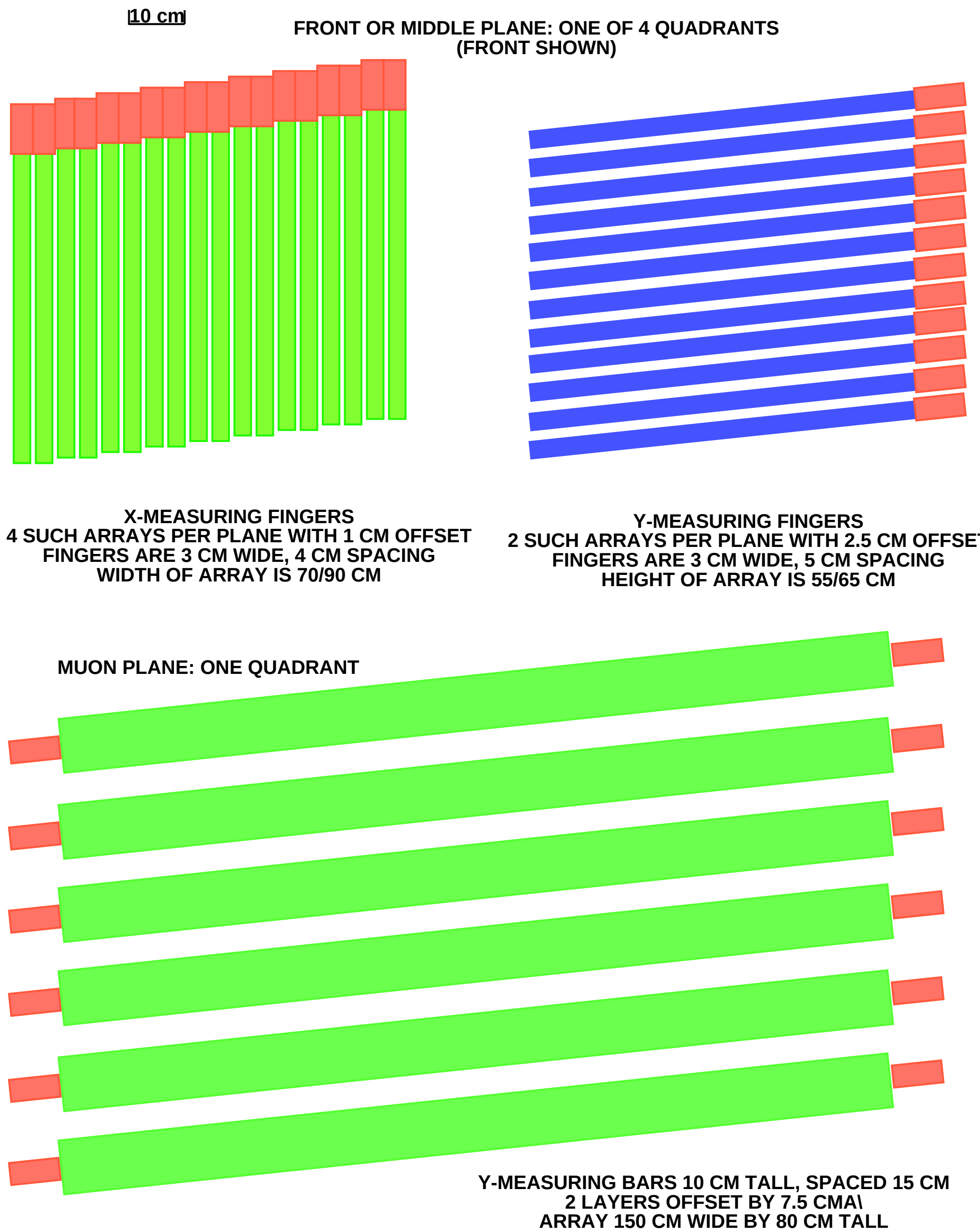


DETECTORS

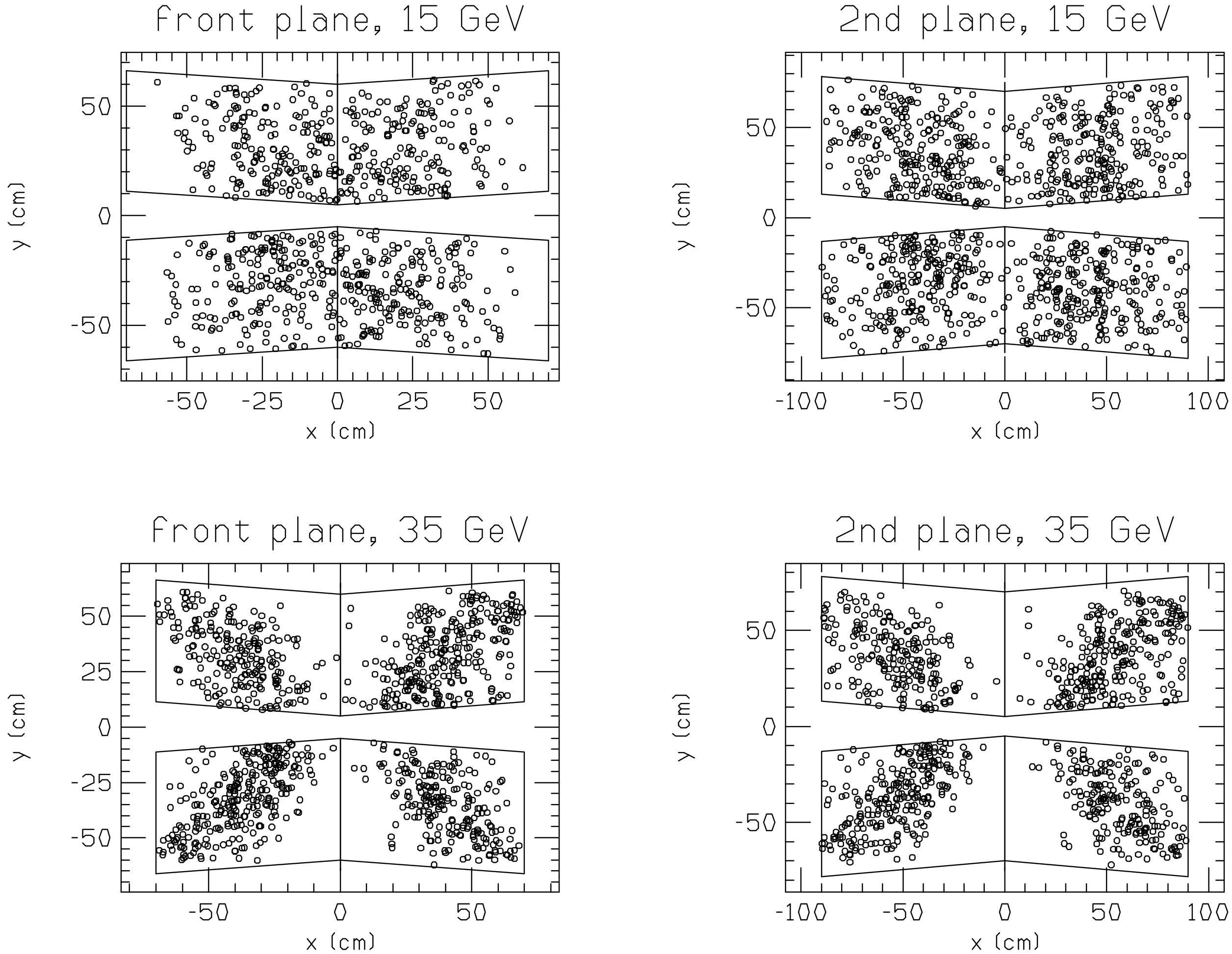
- Front and 2nd (Middle) planes used for tracking. Need x bin size 1 cm and y bin size 3 cm.
- Muon wall can have 10 cm granularity. Used for particle ID and timing. Also helps tracking.
- Separations from Wedge to Front to Middle to Muon are 120 cm, 100 cm, 100 cm respectively.
- Put 60 cm thick graphite (or similar) upbeam of Front and Middle planes to reduce sprinkle hit rates. Put 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	$\pm$70 cm	$\pm$60 cm	280	75
Middle	$\pm$90 cm	$\pm$70 cm	360	90
Muon	$\pm$150 cm	$\pm$80 cm	16	36

DETECTOR CONCEPTUAL DESIGN

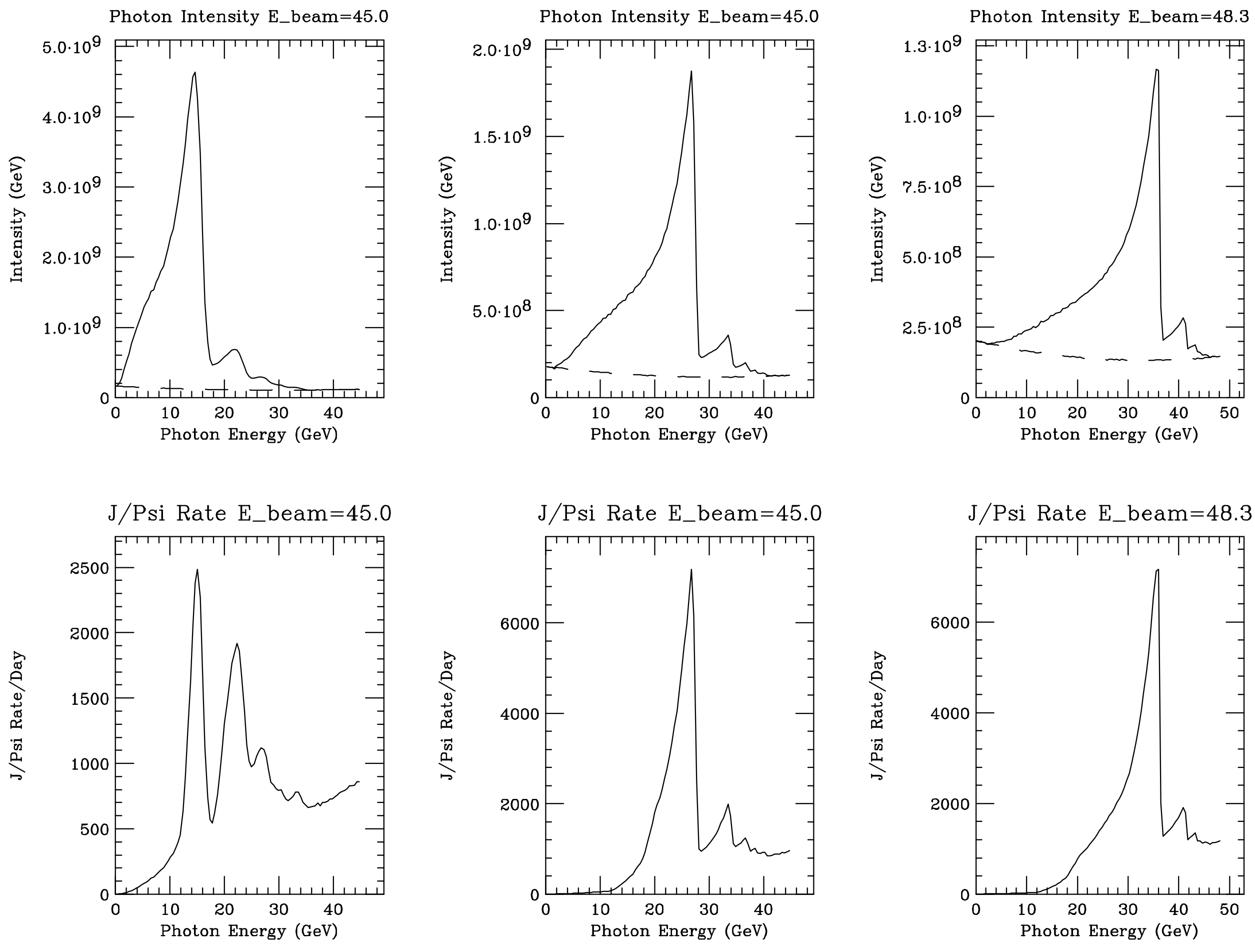


COUNTS vrs x/y AT DETECTORS



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	10K	30K	30K
ψ' goal per target	-	1000	1000
days (at 100% efficiency)	4	5	10

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 least possible days, and keep rates in hodoscope fingers at level of < 2 hit/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). Mainly get muons from pi/K decays (up to 10/spill, almost all rejected with p_t cut). Get about 0.5 sprinkle hits/finger/spill.**

- **Hadronic background from 25 GeV spectrum:**

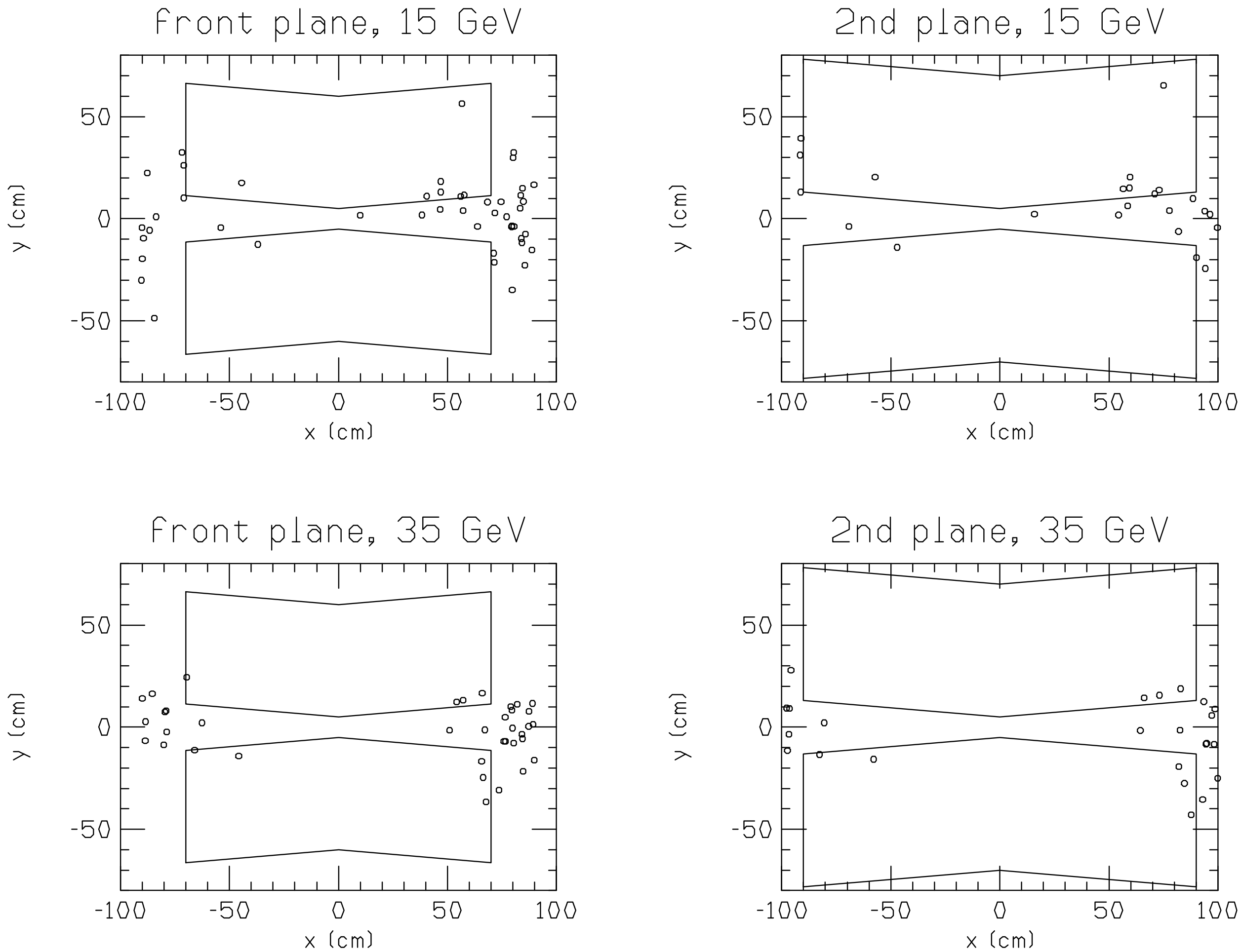
	Front		2nd Plane		
particle	**hits**	$< E >$	**hits**	$< E >$	**tracks**
elec+pos	**10**	**0.049**	**5**	**0.111**	**0**
muons	**11**	**8.268**	**10**	**9.445**	**9**
pions	**2**	**0.332**	**0**	**0.000**	**0**
protons	**7**	**0.184**	**0**	**0.000**	**0**

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

	Front		2nd Plane		
particle	**hits**	$< E >$	**hits**	$< E >$	**tracks**
electrons	**8**	**0.015**	**5**	**0.008**	**0**
muons	**4**	**17.778**	**4**	**13.238**	**3**
pions	**2**	**0.941**	**2**	**1.287**	**0**
protons	**5**	**0.084**	**1**	**0.393**	**0**

- **These GEANT muon rates about factor 1.5 higher than D3SPECT, which does not generate real hadronic showers (assumes hadron is "gone" after 150 gm/cm^2.**

DECAY MUON COUNTS vrs x/y AT DETECTORS

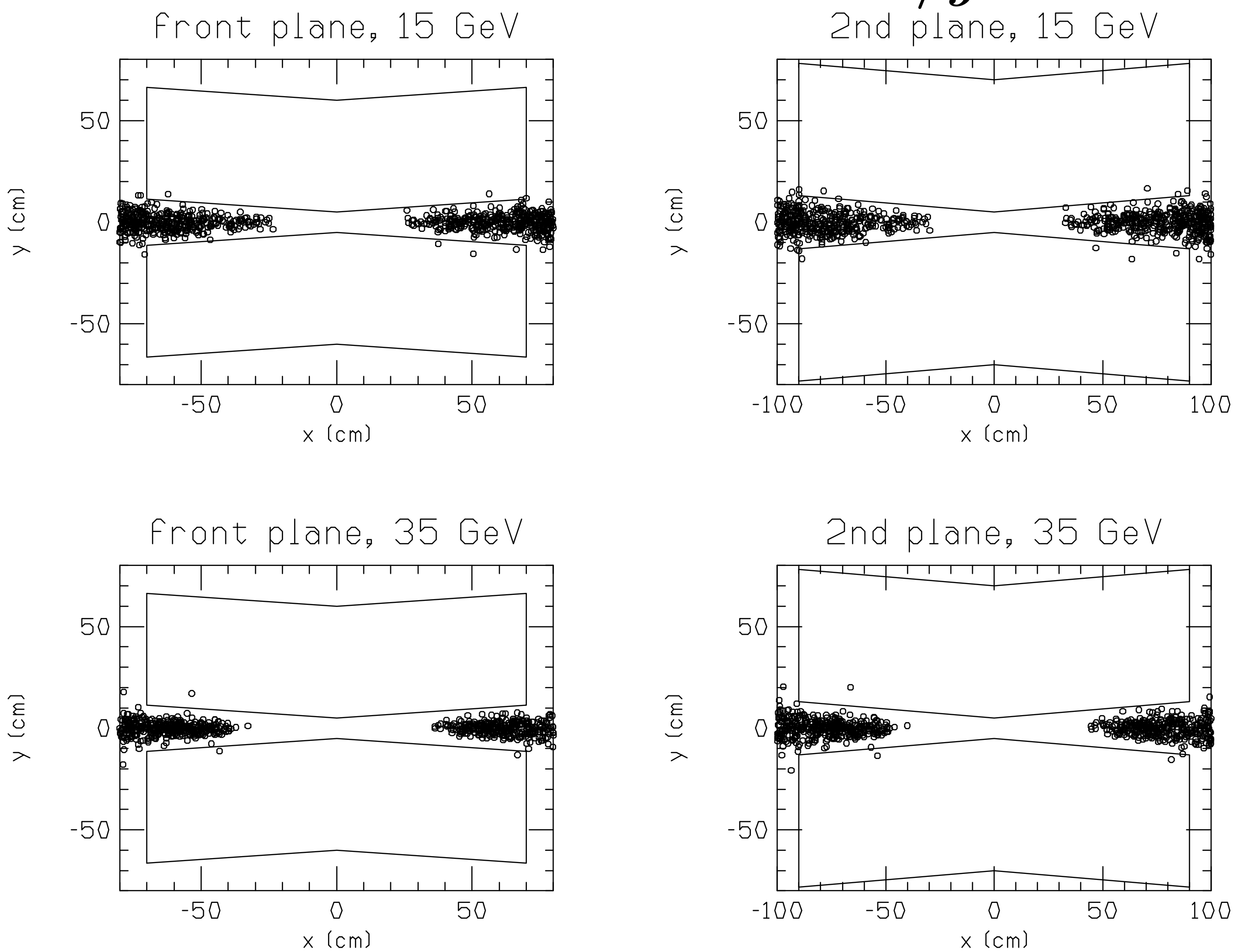


- **Background from photons that Compton scatter in target, Calculated for Be (thickest) target, get order of 10,000 photons per spill. Result in < 0.2 sprinkle hits/finger/spill. No tracks. Lead collimator and graphite after LASS are crucial. Sometimes get "showers", rather than isolated sprinkle hits.**
- **Primakov π^0 production calculated from lead (highest Z^2) target yields about 25,000 photons per spill. Results in < 0.1 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.**

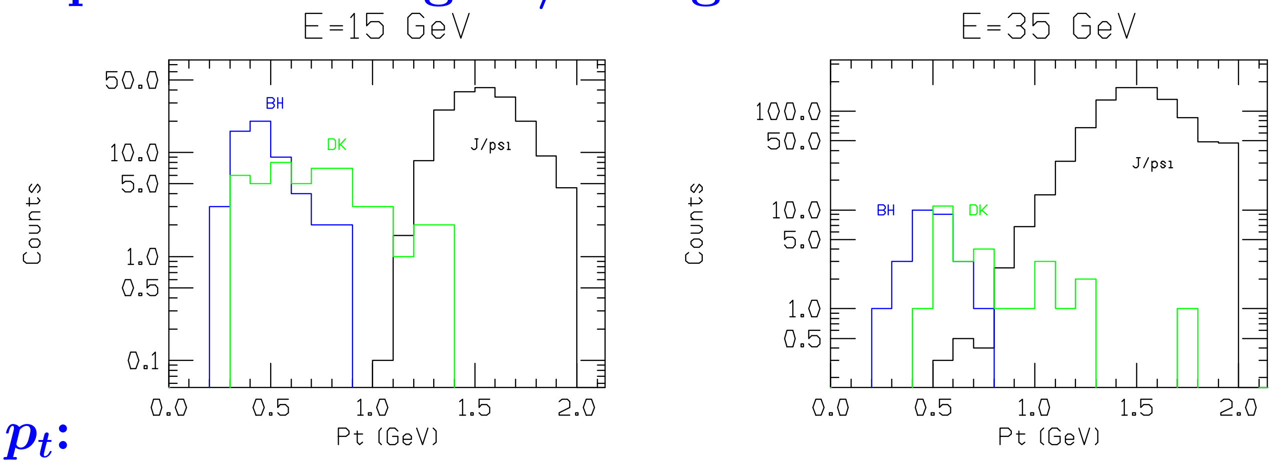
- **Background from Bethe-Heitler muons pairs, calculated using Tsai formulas for coherent, quasi-elastic, and inelastic. About 4,000 produced/spill (0.12 r.l. lead target), at typical small angles m_μ/k. Most pass between top and bottom detectors planes, but get several hits/spill in front/middle hodoscopes, and a few tracks/spill. The muon rates are highest for the 15 GeV setting. Most will be eliminated with p_t cut. When B.H. rates highest, hadron decays lowest, so total is roughly independent of target.**

	Front		2nd Plane		
E_ψ	hits	$< E >$	hits	$< E >$	tracks
15	17.8	14.948	23.9	12.886	14.6
25	13.1	17.568	18.2	15.825	11.4
35	7.8	22.572	10.7	18.397	6.6

ETHE-HEITLER MUON COUNTS vrs x/y AT DETECTOR



Separation of signal/background muons with p_t:



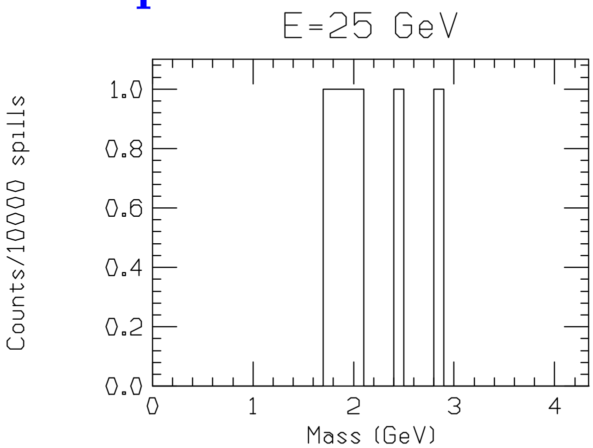
- **Bottom line: About 1 sprinkle hit per detector element per spill and order of 10 tracks/spill. Lower than E155: should work o.k., especially considering have four independent quadrants.**

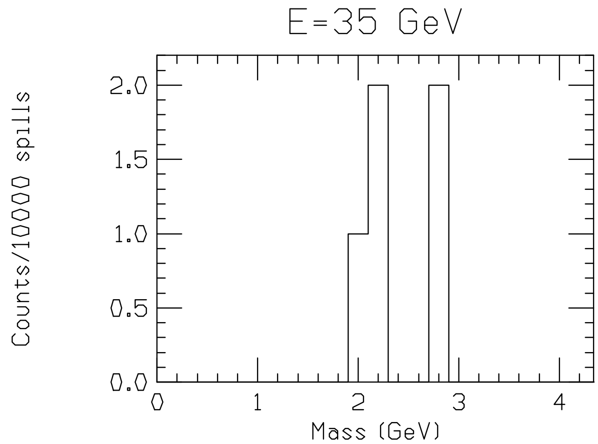
ACCIDENTAL RATE

- 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 up to 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, with cuts that p_t each muon must be > 0.8 GeV and $0.7 < p_1/p_2 < 1.3$ (keeps most ψ' events). Except 2 ψ' for this spectrum.





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 4 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 (for example, GEANT doesn't treat neutrons very well).
- **Overall, spectrometer design works nicely.**