Steve Geer
December 1997

Workshop on Physics at the First Muon Collider & Front–End of a Muon Collider: A Brief Summary

- Workshop at Fermilab, Nov. 6–9
  More than 200 people participated

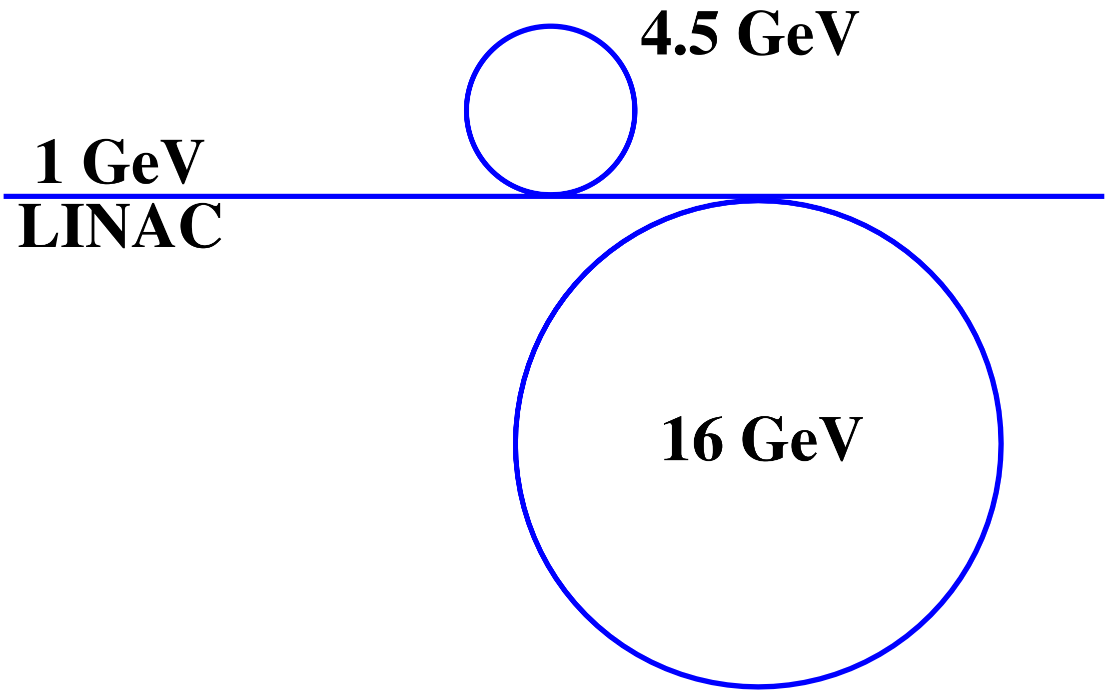
- 9 Working Groups:
  - Accelerator
  - Low Energy Hadron Physics
  - Neutrino Physics
  - Deep Inelastic Scattering
  - Low Energy Muon Physics
  - Higgs & Z Factories at the FMC
  - SUSY at the FMC
  - Stong Dynamics at the FMC
  - Top Factory at the FMC

Enormous amount of material

Place Holder
FMC sited at Fermilab

Accelerator Working Group

- Concentrated on a few critical issues in proton driver design for a Fermilab source with 10^{14} protons per pulse at 15 Hz:



- RF system design

  Longitudinal space charge effects

  Short few ns bunches

  Instability issues

Bob Noble

Encouraging progress

Proton Source Parameters for the Workshop

Based on Summer Study –> *S.D. Holmes et al, Fermilab TM*–2021

	Step 1		Step 2	Step 3
	Scenario 1	Scenario 2		
Linac				
Kinetic Energy (MeV)	400	1000	1000	1000
Momentum Spread (95% FW)	1	1	1	1
Current (mA)	45	67.1	112	328.5
Pulse Length (μs)	0.75	0.75	0.75	0.75
H^- per pulse	1×10^{13}	1.5×10^{13}	2.5×10^{13}	1×10^{14}
Repetition Rate (Hz)	15	15	15	15
Pre–Booster				
Extraction Kinetic Energy (GeV)				4.5
Momentum Spread (95% HW)				0.5%
Circumference (m)				180.6
Protons per bunch				5×10^{13}
Number of Bunches				2
Repetition Rate (Hz)				15
Extracted bunch length (ns)				21
Transverse Emittance (mm–mr)				200π
Longitudinal Emittance (eV–sec)				1.8
Booster				
Extraction Kinetic Energy (GeV)	16	8	16	16
Momentum Spread (95% HW)	< 0.1%	< 0.1%	< 0.1%	1.2%
Crcumference (m)	474.2	474.2	474.2	474.2
Protons per Bunch	1.2×10^{11}	1.8×10^{11}	3.0×10^{11}	5×10^{13}
Number of Bunches	84	84	84	2
Repetition Rate (Hz)	15	15	15	15
Extracted bunch length (ns)	4.9	4.9	4.9	2.3
Transverse Emittance (mm–mr)	50π	30π	50π	240π
Longitudinal Emittance (eV–sec)	2.2	1.8	1.8	4.0

–> 1.5×10^{15} protons/sec at 16 GeV/c

Compared with effectively a few x 10^{12} protons/sec at 8 GeV/c from BOOSTER now.

Physics with Low Energy Hadrons

- Can inject a factor of 3–4 more into Main Injector –> direct benefit to MI physics program ... Kaons, neutrinos (see later), antiproton production, ...
- The most extensive low energy hadron physics that would benefit seems to be the Kaon physics program. For example searches for rare decays:

$K^+ \to \pi^+\nu\bar{\nu}$	$K^0 \to \pi^0\nu\bar{\nu}$	Windows on physics beyond the Standard Model
$K_S \to \pi^0 e^+ e^-$	$K \to \pi\mu e$	
$K_L \to \mu e$	etc ...	

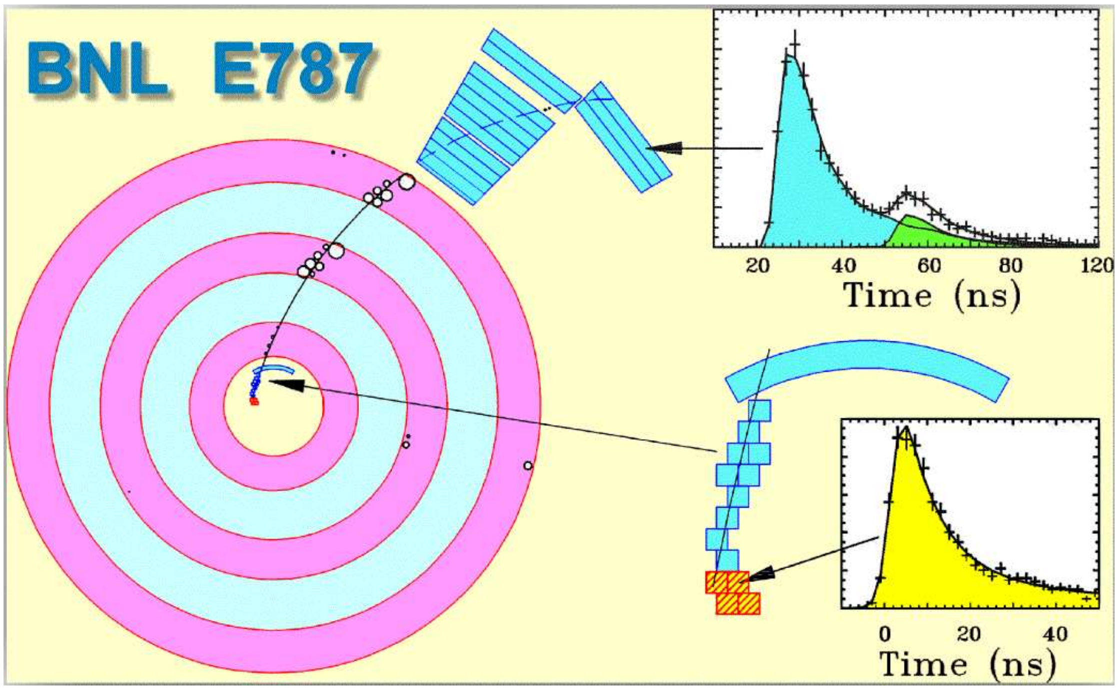
- Depending on what previous experiments had been run (MI, AGS′, JHF) the FEMC would enable improvements in sensitivity from a few –> x10.

	AGS	AGS′	MI	JHF	FEMC
p (GeV/c)	25	25	120	50	16
Duty factor	0.33	0.27	0.33	0.16	0.90
Tera–p / sec	20	30	10	60	400
K_L sensitivity	26	40	100	150	325
Stopped K^+	12	18	8	47	210

- Needs a stretcher ring –> duty factor 90%.

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- **Standard Model: BR = $(9.1 \pm 3.8) \times 10^{-11}$**

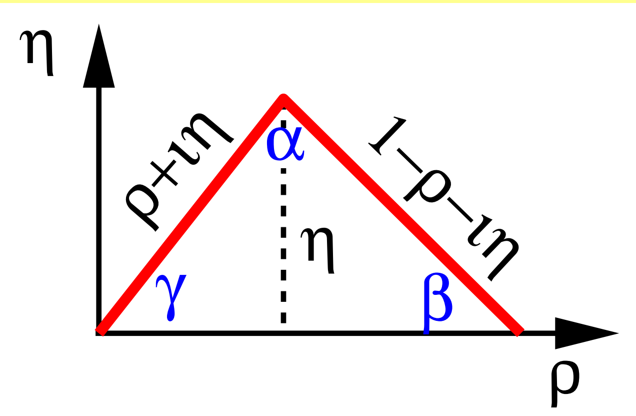


1 event seen

$\rightarrow$ BR = $(42^{+97}_{-35}) \times 10^{-11}$

New physics or statistical fluctuation ?

- **Current goals (AGS2000 & KAMI) $\rightarrow \pm 15\%$**

- 

W. Marciano

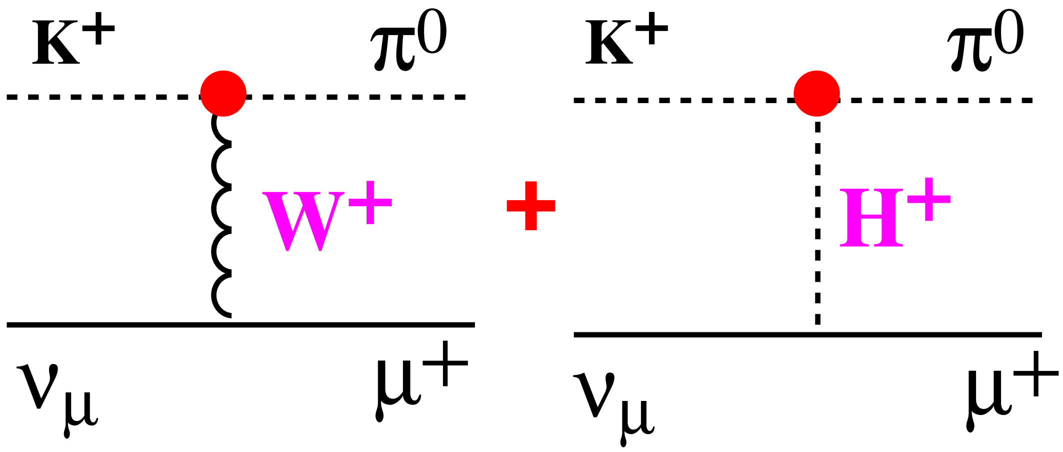
FMC Front–End

BR $\rightarrow \pm 4\%$

$\rightarrow \Delta\eta/\eta \sim \pm 0.02$!

- **Also additional x 3 in MI would help KAMI ... note Experiments hard ... probably need both stopped K^+ and decay in flight techniques**

$K^+ \to \pi^0 \mu^+ \nu$ T–Violating μ Polarization



W. Marciano

New Physics

~~CP~~ Interference

(Multi–Higgs)

$$P_\mu^T = \hat{s}_\mu \cdot (\hat{p}_\mu \times \hat{p}_\pi)$$

T violating

- **KEK E246 –> 9×10^{-4}**
- **Proposal for AGS2000 experiment –> 1.3×10^{-4}.**
- **At Front–End MC –> 10^{-5} ?**

K_S , $K_L \to \pi^+\pi^-$ Interference

- **Produce almost pure K^0 beam using rf separated K^+ beam and charge exchange. Measure amplitude versus proper time t :**

$$\text{Interference} \sim \; 2D\,|\eta|\cos(\Delta m t - \phi_{+-})\exp(-t/2\tau_S)$$

- **CPT experiment at MI –> $\Delta m/m < 4 \times 10^{-20}$ Plank scale CPT test ... would benefit from x(3–4) more protons in MI.**
- **Lower energy experiment at FEMC also possible. The K_S yield/proton for 25 GeV K_S/120 GeV p similar to 6 GeV K_S / 16 GeV p !**

Physics with Low Energy Hadrons: Summary

- **There is an extensive Kaon−physics program that could be pursued at the Front−End of a muon collider, which could provide experiments with a factor of a few – 10 more Kaons than will be available in the next few years.**

- **The physics motivation for rare−Kaon decay physics is likely to remain strong in the future −> window on physics beyond the LHC scale.**

- **In addition to an extensive K−physics program, there are also many hadronic physics topics looking for a home. The ones considered at the workshop were:**

  Proton exclusive scattering and polarization
  Proton & antiproton forward scattering
  Proton form−factors
  Hypernuclear physics
  Baryon spectroscopy
  Rare η decays and symmetry tests
  Light quark spectroscopy
  Charmonium spectroscopy
  Exotic meson and glueball searches

Neutrino Physics

- Exploit intense muon source to produce very intense neutrino/antineutrino beams.

- The resulting beams are qualitatively better than conventional beams from meson decays.

Precisely known flavor content:

$\mu^- \rightarrow \nu_\mu + \bar{\nu}_e + e^-$ **and** $\mu^+ \rightarrow \bar{\nu}_\mu + \nu_e + e^+$

Great for $\nu_e - \nu_x$ oscillations (including $\nu_e - \nu_\tau$) !

Great for $\nu_x - \nu_\tau$ oscillations (No $D_S \rightarrow \nu_\tau$ in beam !)

Great for $\nu_\mu - \nu_e$ oscillations (No ν_e in ν_μ beam !)

Precisely known fluxes and differential distributions:

$$\nu_\mu : \quad \frac{dn}{dx\,d\Omega} = \frac{1}{4\pi}\left[2x^2(3-2x) \mp 2x^2(1-2x)\mathcal{P}\cos\theta\right]$$

$$\nu_e : \quad \frac{dn}{dx\,d\Omega} = \frac{1}{4\pi}\left[12x^2(1-x) \mp 12x^2(1-x)\mathcal{P}\cos\theta\right]$$

where $x = 2E_\nu/m_\mu$, θ is the angle between the neutrino and the muon spin, and $\mathcal{P}$ is the muon polarization.

Neutrino Beam Options

- **Use collider straight sections** (*Bruce King*)
- **Use Recirculating Linear Acceltrs** (*Chuck Ankenbrandt*).

Neutrino Beam Pulses from Recirculating LINACs

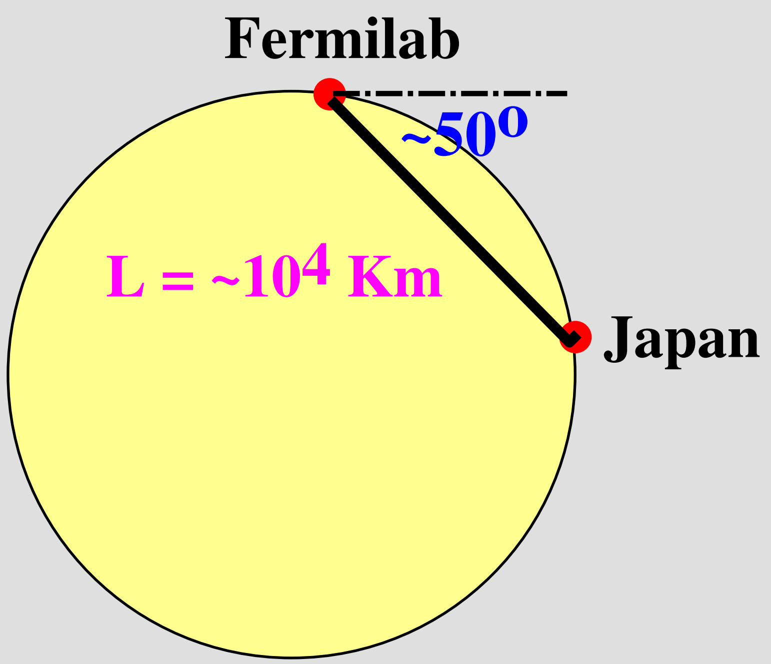
	Turn Number											
	1	2	3	4	5	6	7	8	9	10	11	12
RLA 1												
E_μ(start) (GeV)	1.0	1.96	2.92	3.88	4.84	5.8	6.76	7.72	8.68	9.64		
E_μ(end) (GeV)	1.48	2.44	3.4	4.36	5.32	6.28	7.24	8.2	9.16			
$\langle E_\mu \rangle$ (GeV)	1.24	2.2	3.16	4.12	5.08	6.04	7.0	7.96	8.92			
$\langle\gamma\rangle$	11.7	20.8	29.9	39.0	48.1	57.2	66.3	75.3	84.4			
$\gamma c\tau$ (km)	7.72	13.7	19.7	25.7	31.7	37.8	43.8	49.6	55.7			
f_{decay}=100m/$\gamma c\tau$ (%)	1.3	0.73	0.51	0.39	0.32	0.26	0.23	0.20	0.18			
N_{decay}/bunch (x10^{10})	6.5	3.7	2.6	2.0	1.6	1.3	1.2	1.0	0.9			
N_{decay}/year (x10^{18})	9.8	5.5	3.8	2.9	2.4	2.0	1.7	1.5	1.4			
RLA 2												
E_μ(start) (GeV)	9.6	15.1	20.6	26.1	31.6	37.1	42.6	48.1	53.6	59.1	64.6	70.1
E_μ(end) (GeV)	12.4	17.9	29.4	28.9	34.4	39.9	45.4	50.9	56.4	61.9	67.4	
$\langle E_\mu \rangle$ (GeV)	11.0	16.5	22.0	27.5	33.0	38.5	44.0	49.5	55.0	60.5	66.0	
$\langle\gamma\rangle$	104	156	208	260	312	364	416	469	521	573	625	
$\gamma c\tau$ (km)	68.7	100	140	170	210	240	270	310	340	380	410	
f_{decay}=300m/$\gamma c\tau$ (%)	0.44	0.30	0.21	0.18	0.14	0.13	0.11	0.097	0.088	0.079	0.073	
N_{decay}/bunch (x10^{10})	2.0	1.4	0.97	0.83	0.64	0.60	0.51	0.45	0.40	0.36	0.34	
N_{decay}/year (x10^{18})	3.0	2.1	1.5	1.2	0.96	0.90	0.77	0.68	0.60	0.54	0.51	
RLA 3												
E_μ(start) (GeV)	70	85	100	115	130	145	160	175	190	205	220	235
E_μ(end) (GeV)	77.5	92.5	108	123	138	153	168	183	198	213	228	243
$\langle E_\mu \rangle$ (GeV)	73.8	88.8	104	119	134	149	164	179	194	209	224	239
$\langle\gamma\rangle$	698	840	982	1124	1266	1408	1550	1692	1834	1976	2118	2260
$\gamma c\tau$ (km)	460	550	650	740	840	930	1000	1100	1200	1300	1400	1500
f_{decay}=533m/$\gamma c\tau$ (%)	0.12	0.10	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04
N_{decay}/bunch (x10^{10})	0.52	0.42	0.35	0.31	0.27	0.25	0.23	0.21	0.19	0.18	0.16	0.15
N_{decay}/year (x10^{18})	0.78	0.63	0.53	0.46	0.41	0.37	0.34	0.31	0.28	0.26	0.25	0.23

RLA neutrino pulses ... workshop parameters (*Steve Geer*)

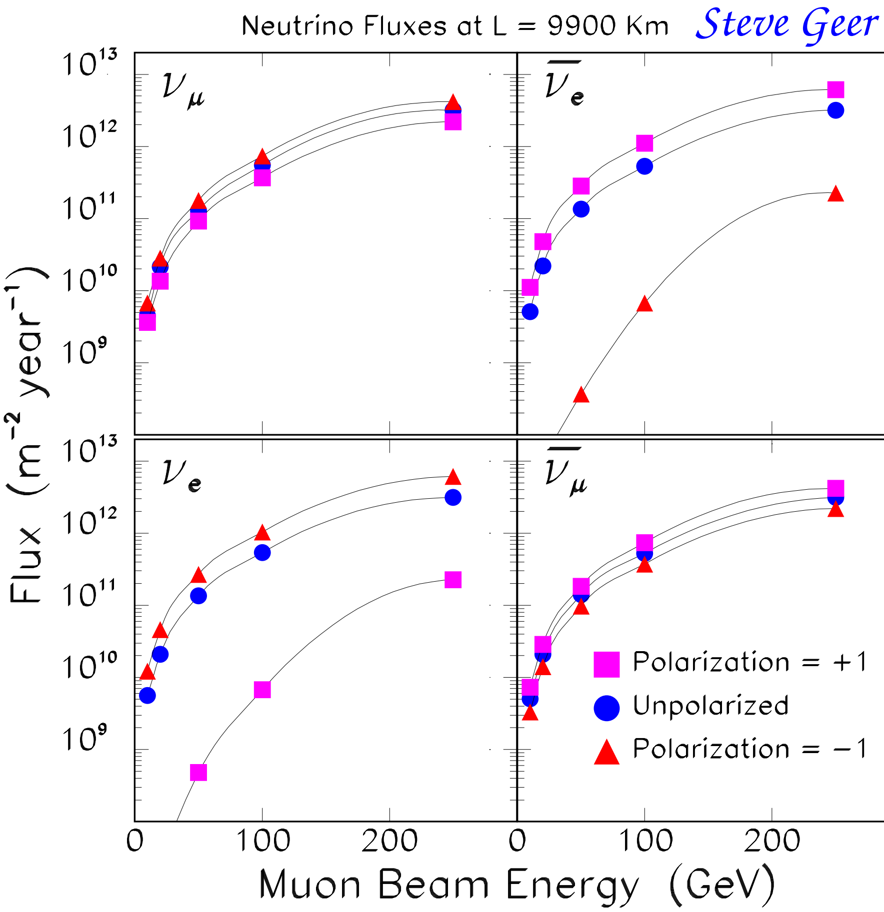
- **Build special storage ring with long straight section e.g. Straight section = arc length –> 25% of muons decay in right direction** (*Steve Geer*)

With 7.5 x 10^{20} μ^+ (or μ^-) per year, can get O(10^{20}) neutrinos/yr produced in the straight section.

Neutrino Fluxes: Fermilab –> Japan



E_ν (GeV)	L/E Km/GeV
10	1000
20	500
30	330
40	250
50	200

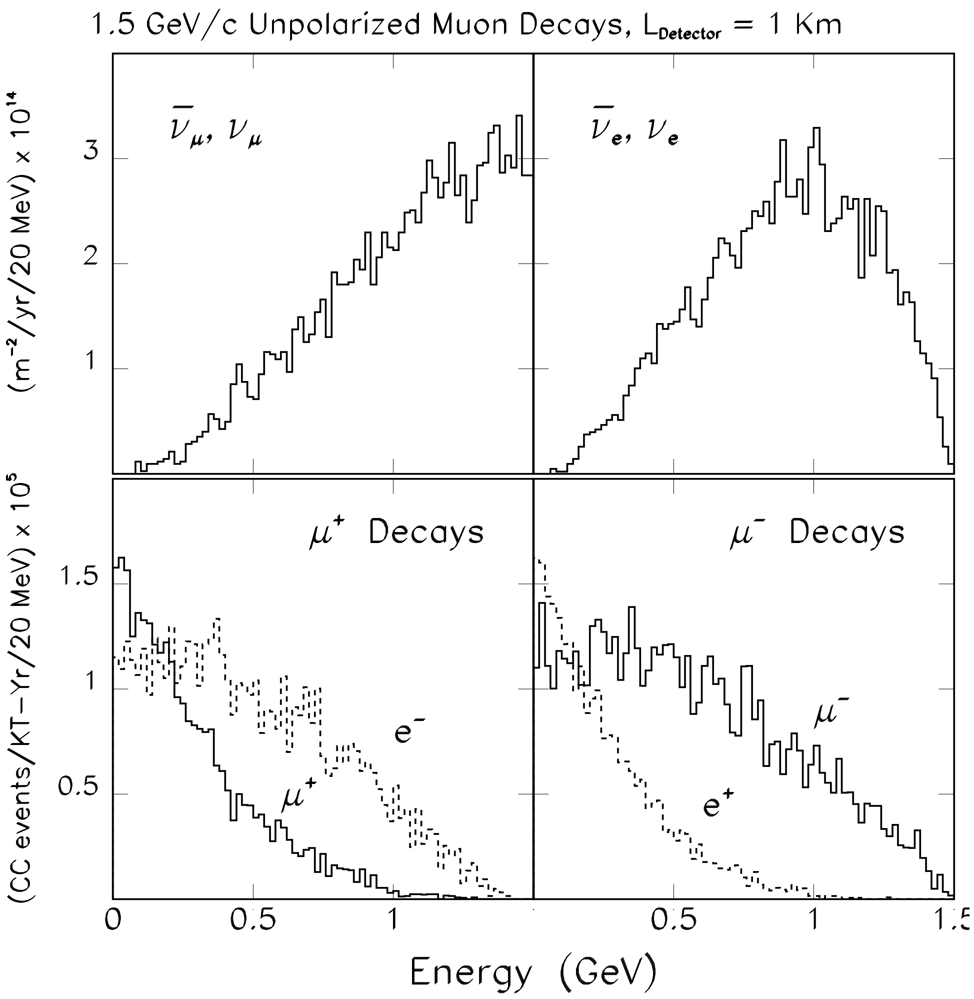


Example: for a 20 GeV initial muon beam the fluxes in Japan are a few x 10^{10} neutrinos per m^2 per year.

For fluxes at Soudan, multiply by 183 –> about 10 x currently forseen MINOS fluxes !

Low Energy Short Baseline Scenario

- Consider a **1.5 GeV/c muon beam** stored in a ring with a straight section pointing at an experiment 1 Km away:

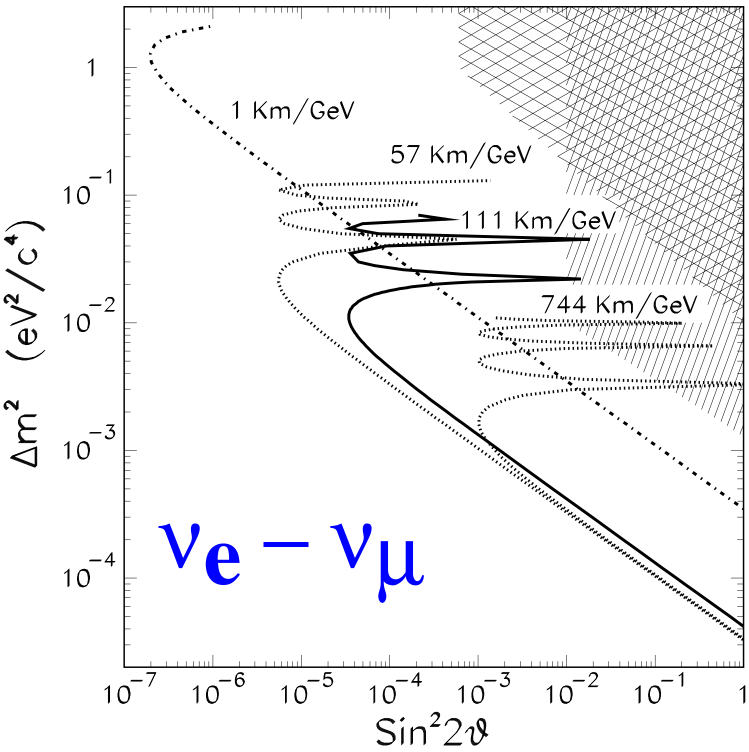


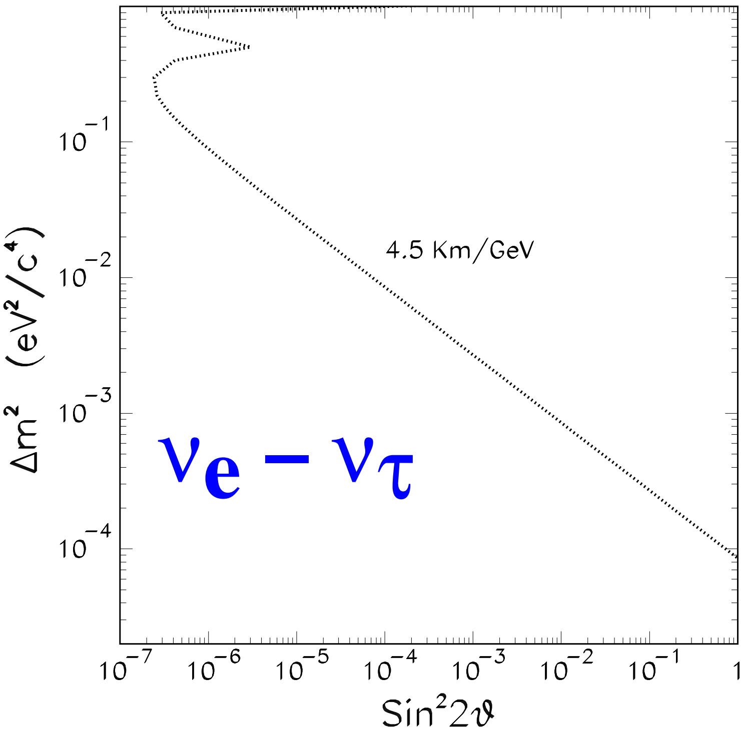
- 1.4×10^{16} ν_e m^{-2} yr^{-1}
- 1.4×10^{16} ν_μ m^{-2} yr^{-1}
- 6×10^{6} ν CC interactions KT^{-1} yr^{-1}
- 3×10^{6} $\bar{\nu}$ CC interactions KT^{-1} yr^{-1}

$$P = \sin^2 2\theta \, \sin^2(1.27\, \Delta m^2\, L/E)$$

Single Event Sensitivity Contours in ($\sin^2 2\theta$, Δm^2)–plane

Steve Geer: Fermilab–PUB/97–389

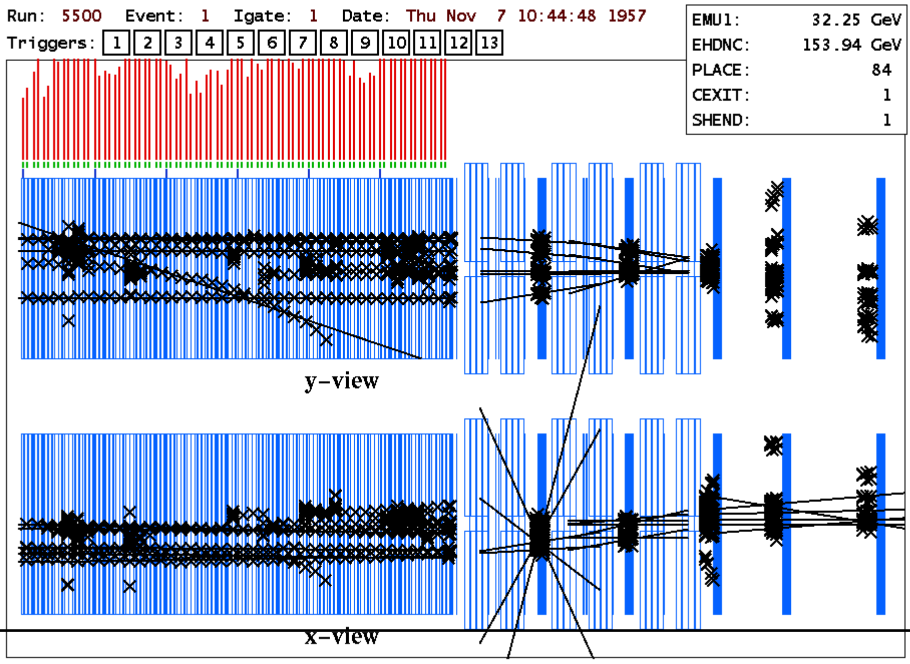




Search for wrong–sign μ

- **Hatched = MINOS**
- **Cross–hatched = MiniBooNE**
- **L/<E> = 1 km/GeV**
  1 km baseline
  E_μ = 1.5 GeV
- **L/<E> = 57 km/GeV**
  Fermilab–Soudan
  E_μ = 20 GeV
- **L/<E> = 111 km/GeV**
  Fermilab–Soudan
  E_μ = 10 GeV
- **L/<E> = 744 km/GeV**
  Fermilab–Kamioka
  E_μ = 20 GeV
- **L/<E> = 4.5 km/GeV**
  Fermilab–Soudan
  E_μ = 250 GeV

Deep Inelastic Scattering



Kevin McFarland

Simulation of NuTeV (CCFR) exposed to 1 turn 600m downstream of RLA3 (250 GeV muon decays)

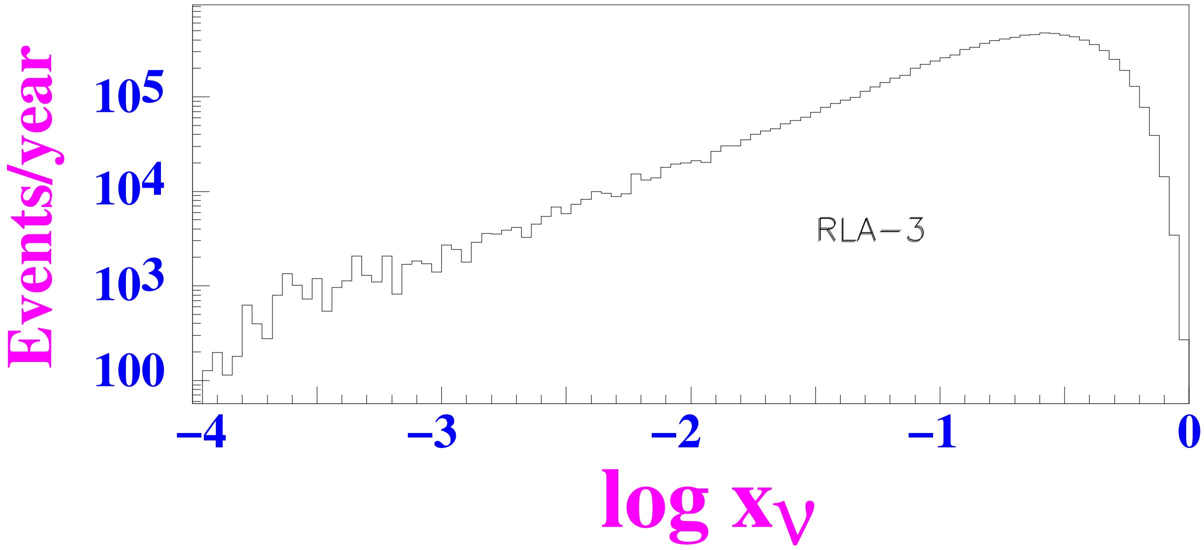
Multiple neutrino interactions (+ a bunch of muons)

- **Factor of 1000 more than present $\nu_\mu N$ rates !**
- **Beam spot small (90% ν within 40cm)**
- **Can use small precision detectors:**

Emulsion: (*Reay*)
H_2 Target + Č + CAL + μ (*B. King*)
Scint. target + CAL + μ range (*K. McFarland*)
Bubble Chamber at 15 Hz (*H. Schellman*)

- **With special purpose 250 GeV ring –> 800 000 ν interactions / year in a 10 kg detector** (*S. Geer*) **so why not use Si Pixel target ?**

νN DIS Physics



D. Harris & *K. McFarland*

900 kg
3m x 3m
target

- RLA−3 (250 GeV muons) −> 1 m long LH_2 target −> ~10 million events/year ... dont need a heavy target so can measure proton structure directly !
- $\sin^2\theta_W$: NC/CC ratio −> statistical error = 0.2%. Main systematic from charm production ... measure it !! Estimate can get to $\Delta \sin^2\theta_W$ < 0.5% −> ΔM_W ~ 20−50 MeV.
- Charm production: 1 m long LH_2 target −> 100 000 reconstruced events / year −> $|V_{dc}|^2$, s, $\bar{s}$.
- Spin physics (where does the proton spin come from ?). Look for polarization of, for example, strange sea quarks.
- B−Physics: $\nu_\mu u \to \mu^+ b$: 20 events/year/ 3 m H_2 −> $|V_{ub}|^2$ ... for more statistics −> dedicated ring ?

Low Energy Muon Physics

Potentially an extensive experimental physics program but for many experiments the challenge comes from the instantaneous rate .... so the bunch structure is critical.

Exp.	Process	Topic
Rare Decays	μ+Z –> e+Z μ –> eγ μ –> eee	Lepton flavor viol SM test GUT, SUSY, ...
μ decay	lifetime spectrum	G_F, SM test SM test
g–2 Muon EDM	g–2 EDM	SM test P–, T–violation
Muonic atoms	μ^+e μp $\mu\mu$?	QED test EW Interference P–, T–violation
μ capture	μHe_3 μp μd μZ	low energy QCD SM test medium effects
T violation	μZ	SM test

Example: Lepton Flavor Violation

Place Holder
lfv versus year

- Want to get to, for example:
  BR(μ –> e γ) < 10^{-14} , or BR(μN –> eN) < 10^{-16}

  –> Probes for leptoquarks, Higgs boson effects, contact interactions etc ... e.g. Λ_c > 3000 TeV !

- Typically experiments want to maximize useful muon flux, whilst minimizing instantaneous rate:

Wrong time structure for cooling channel

- So either find a way of delivering muons DC or CW or ....

  - Find experiments that can use short intense muon pulses with low duty factor ...
    Muon EDM may be an example but it requires polarization (50% ?).

  - Find experiments that can use the muons before the cooling (large phase–space) .... in which case we can consider a DC or CW source .... example: MECO μ –> e conversion experiment.

- Is there a strong low energy muon physics program at the Front–End of a muon collider ? Needs work !

First Muon Collider: Workshop Parameters

	Low Energy		Medium Energy	Top Factory	Higher Energy
	Narrow σ_p	Broad σ_p			
$\sqrt{s}$ (GeV)	100	100	200	350	500
beam energy (GeV)	50	50	100	175	250
σ_p/p	3×10^{-5}	1×10^{-3}	1×10^{-3}	1×10^{-3}	1×10^{-3}
muons per bunch	3×10^{12}	3×10^{12}	2×10^{12}	2×10^{12}	2×10^{12}
number of bunches	1	1	2	2	2
repetition rate (Hz)	15	15	15	15	15
norm. $\varepsilon_{\perp}$ (mm–mr)	297π	85π	67π	56π	50π
Collider Circum (m)	380	380	700	864	1000
f_{rev} (Hz)	7.9×10^5	7.9×10^5	4.3×10^5	3.5×10^5	3.0×10^5
turns/lifetime	820	820	890	1260	1560
β^* (cm)	13	4	3	2.6	2.3
σ_z (cm)	13	4	3	2.6	2.3
σ_r (μm)	286	85	47	30	22
$\mathcal{L}_{peak}$ (cm^{-2} s^{-1})	6×10^{32}	7×10^{33}	6×10^{33}	1×10^{34}	2×10^{34}
$\mathcal{L}_{av}$ (cm^{-2} s^{-1})	5×10^{30}	6×10^{31}	1×10^{32}	3×10^{32}	7×10^{32}

Z^0 Factory

- LEP Z–pole era is over. To be worthwhile, a 2nd generation Z–factory (muon collider) would need to make 10^8 Z / year –> $\mathcal{L} = 2 \times 10^{32}\ cm^{-2}\ s^{-1}$

- This luminosity seems out of reach of present design study parameters. Never–the–less, consider physics program if $\mathcal{L} = 2 \times 10^{32}\ cm^{-2}\ s^{-1}$ could be achieved.

$Sin^2\theta_W$: Discrepancy (LEP vs SLD) likely to remain.
If muon polarization = 45%, then with 10 million Zs A_{LR} –> $\delta(Sin^2\theta_W) < 10^{-4}$ ... this would be great. Note: $\Delta(Sin^2\theta_W) = 15 \times 10^{-4}$ as m_H = 60 GeV –> 1000 GeV.

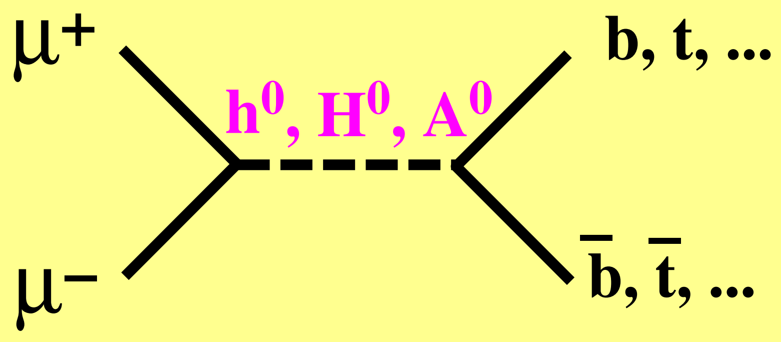
Γ_Z: Presently $\Gamma_Z = 2.4948 \pm 0.0020 \pm 0.0015$(energy). With continuos energy calibration (spin precession) & more statistics –> $\delta < 0.0003$.

$R_l = \Gamma_{had}/\Gamma_l$: Presently $R_l = 20.775 \pm 0.0025$
–> $\alpha_s = 0.124 \pm 0.004 \pm 0.002$ (theory, m_H).
Improve statistics by 10 –> $\delta(\alpha_s) < 0.001$.

R_b, Michel parameters in τ decays, B_S oscillation, rare B decays, ...

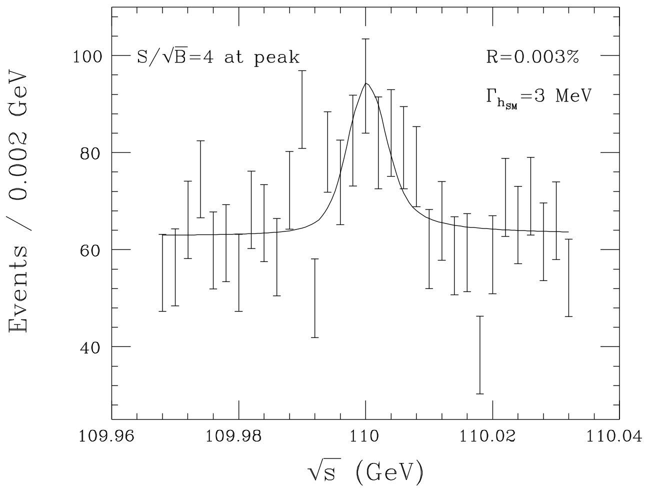
- ISSUES: Luminosity measurement (needs work), polarization (45% ?), LUMINOSITY !

Higgs Factory



The Jewel in the Crown !

Jack Gunion & V. Barger



Assume:

Center–of–mass energy spread R = 0.003%

A priori know from LHC:
m_h = 110 GeV ± 100 MeV

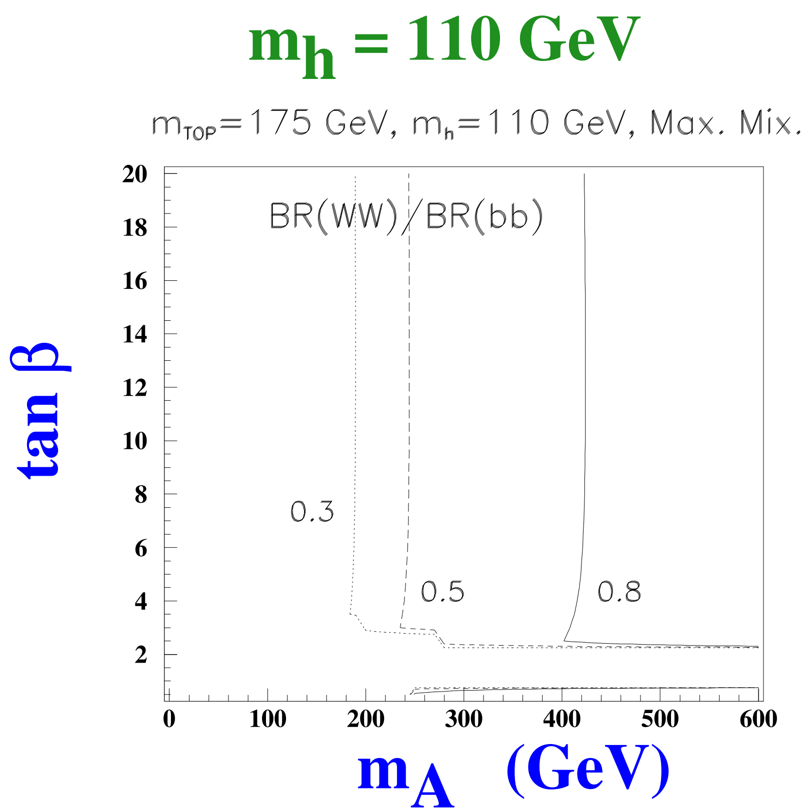
–> 3 years at 0.05 fb^{-1}/yr

Once m_h known to 1 MeV, make a 3 point scan:

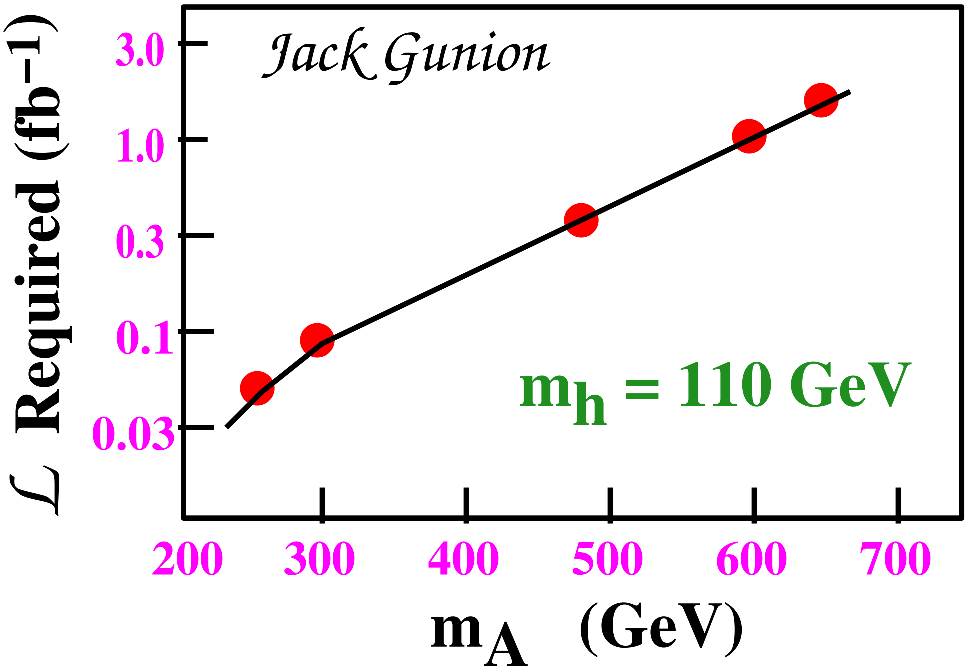
Γ_h^{tot} : 16%	**$\Delta m_h \sim$ 0.1 MeV**
$\sigma\cdot BR(b\bar{b})$: 3%	**$\Delta\Gamma_h \sim$ 0.5 MeV**
$\sigma\cdot BR(WW^*)$: 15%	

–> 8 years of running at 5 x 10^{30} cm^{-2} s^{-1}

- **A factor of 3 more luminosity than workshop parameters would make a big difference !**



- Note: For SM $BR(WW)/BR(b\bar{b}) = 1$
- Can distinguish between SM and MSSM over large region of parameter space.
- S−channel + Zh data −> sensitivity up to $M_A \sim 600$ GeV



Luminosity needed for a 3σ discovery using BR(WW)/BR(bb) etc.

In the same way that the $Sp\bar{p}S$ collider discovered the Z^0 & LEP/SLC milked the precision Z^0 physics, it could be that the LHC (or TEV33) discover the Higgs and the FMC milks the precision Higgs physics.

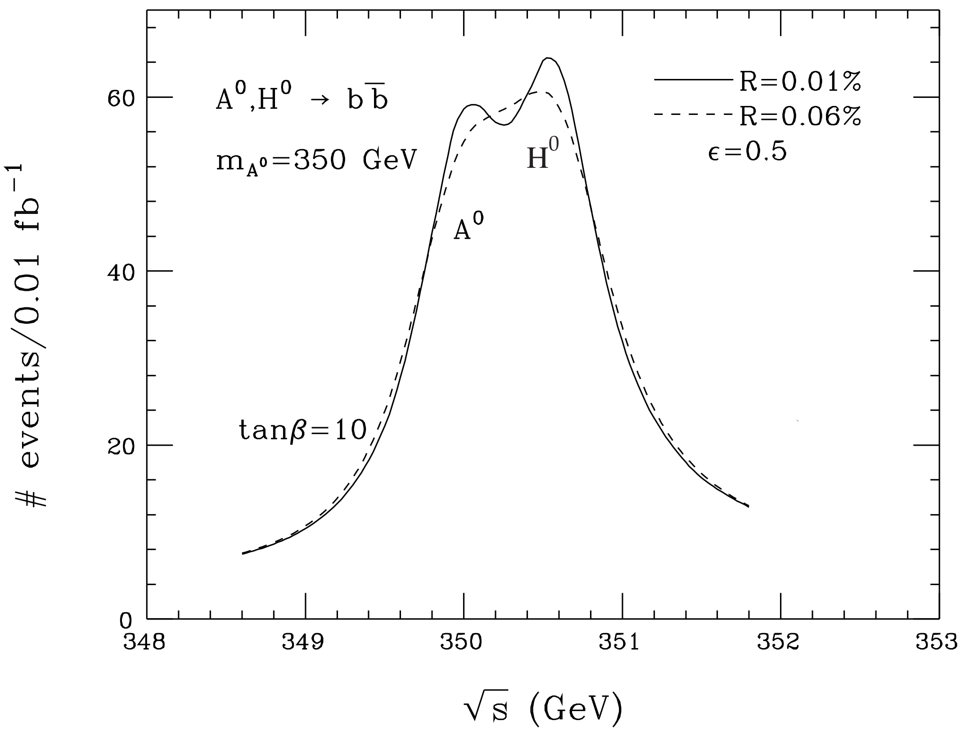
SUSY Physics

- There are > 100 SUSY–breaking parameters (Milles [1984], Haber & Kane [1985]) and MANY models.

- To uniquely determine which model describes reality (if any) will require the observation of all (?) of the sparticles, and many precision meas–urements ... & will take more than one machine.

- The Higgs sector is a vital piece of the picture (h^0, H^0, A^0, $H^\pm$) –> compelling case for an FMC.

- H^0 and A^0 widths broader than h^0. Beam energy spread of 0.1% may be adequate for scan.

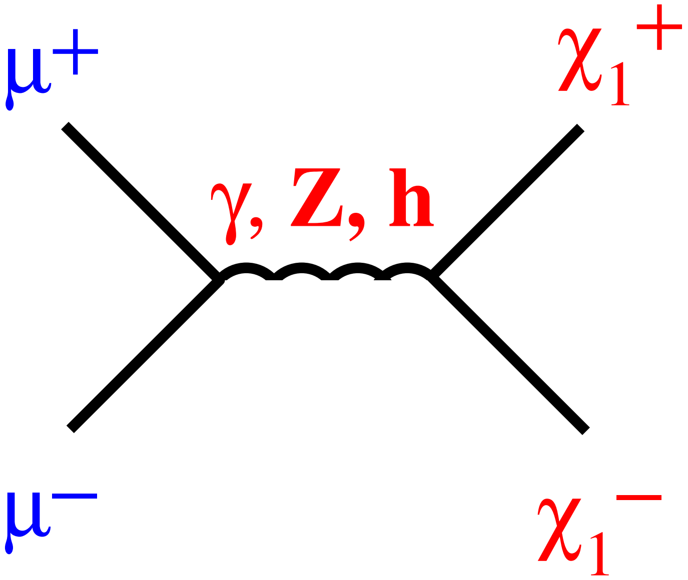


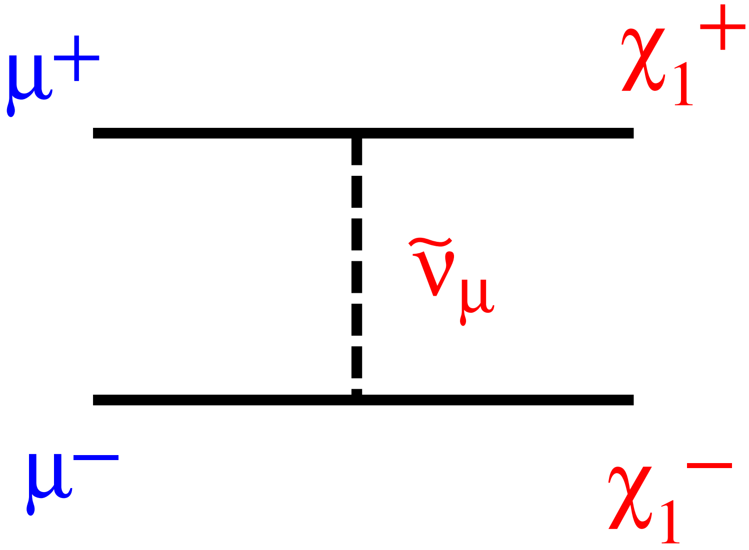
In mSUGRA with large m_A:

$m_A \sim m_{H^0} \sim m_{H^\pm}$

at large tan β ... only an S–channel scan may allow separation of A & H^0

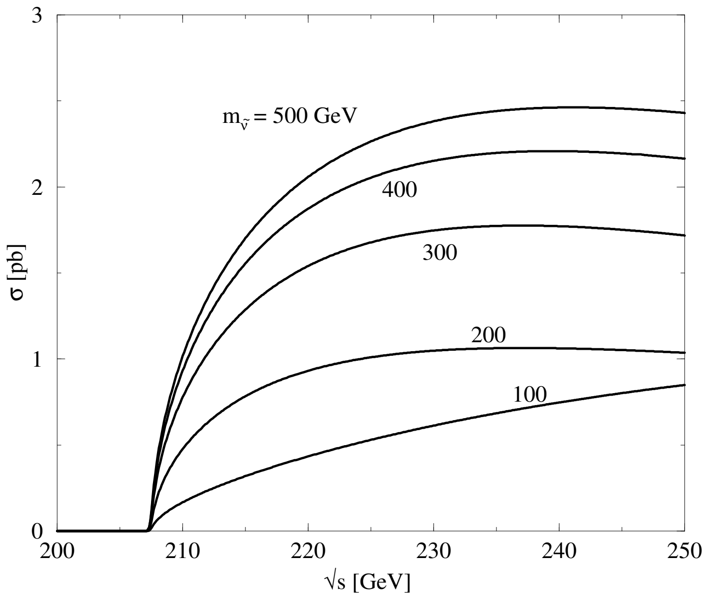
Charginos





- $\chi_1^+ \to f\,\bar{f}'\ \chi_1^0$ ... look for 4 jets + $\cancel{E}_T$

V. Barger



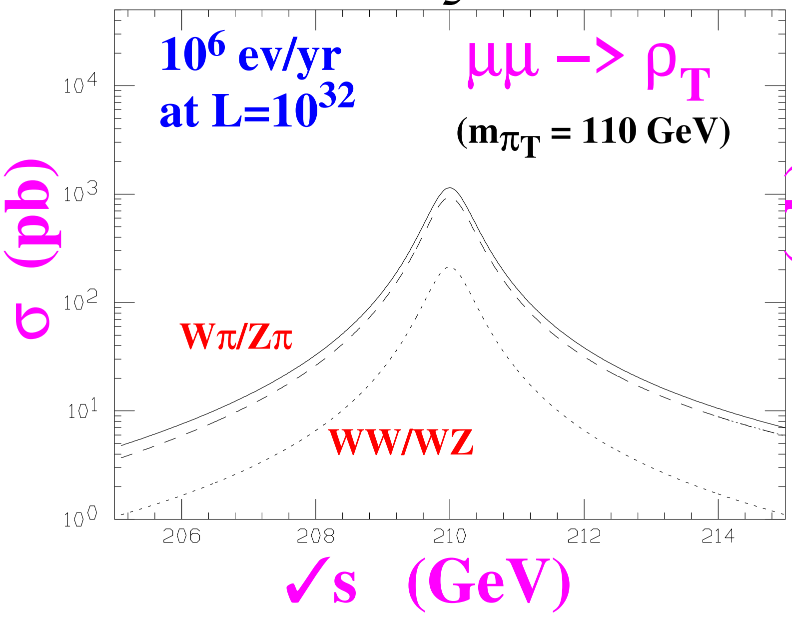
- **σ depends on $m_{\chi_1^+}$ and $m_{\tilde{\nu}_\mu}$ –> infer $m_{\tilde{\nu}_\mu}$**
- **Polarization can be used to turn off ν_μ contribution**

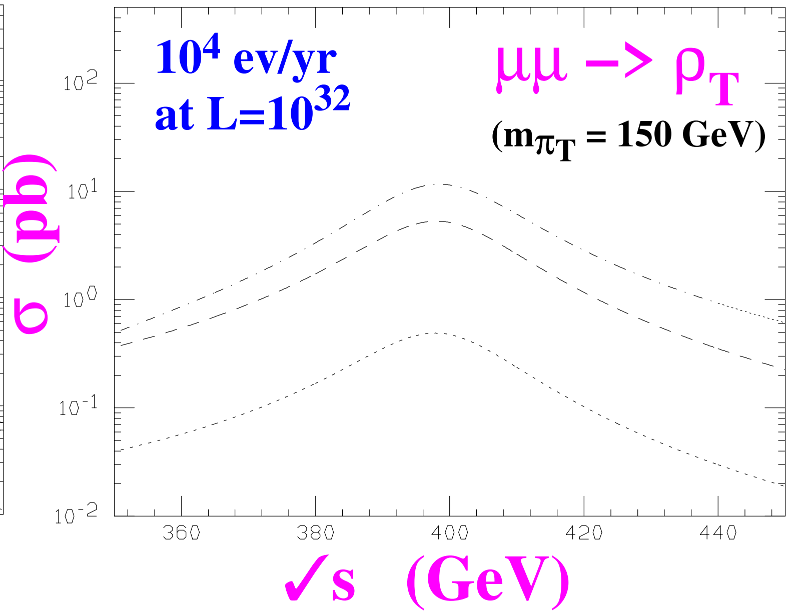
- *Final Remark:* **If we live in a SUSY world some sparticles may well be at the TeV scale .... sooner or later we will want a multi–TeV collider !**

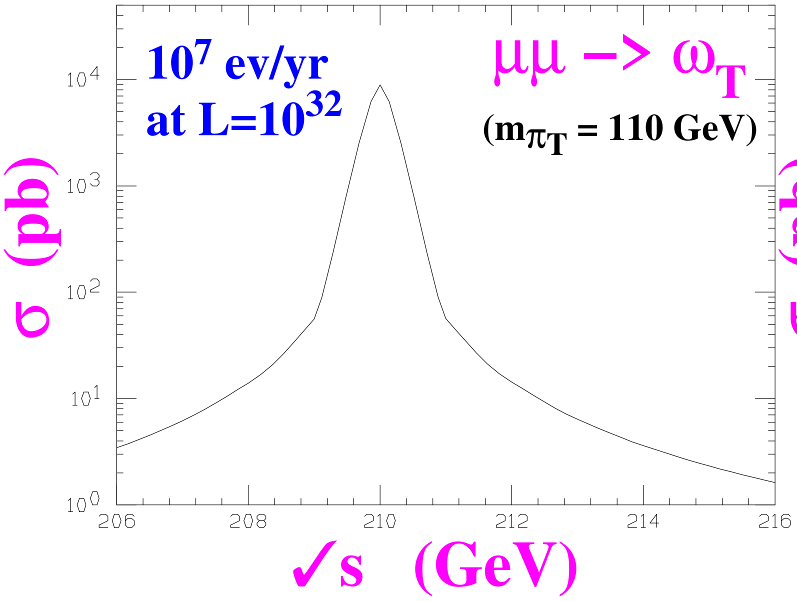
Strong Electroweak Sector

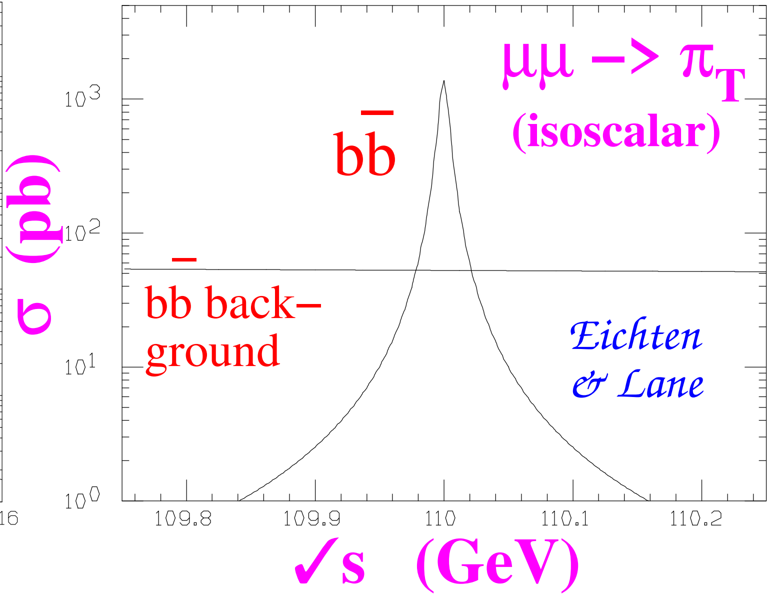
- Technihadrons low enough in mass to be produced at the FMC will probably be first seen at TEV33 ... or if not, at the LHC. Need precision measurements of masses, widths, BRs, study ρ,ω interference, etc.

John Wolmesely







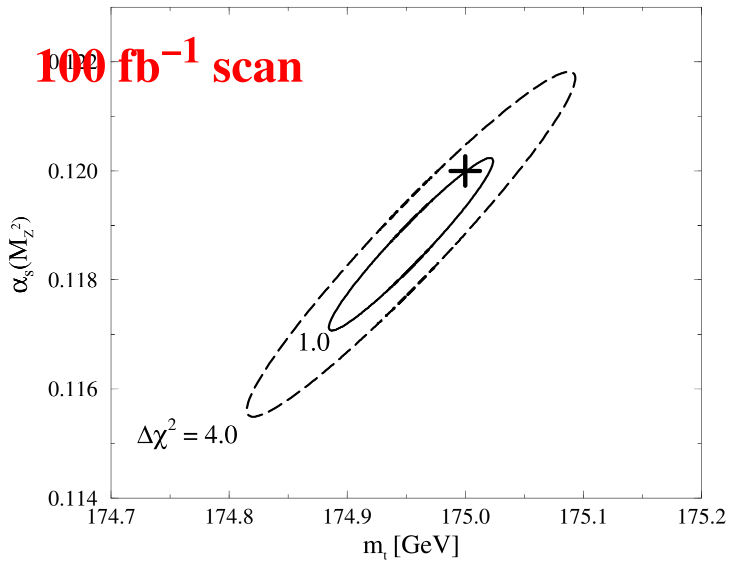


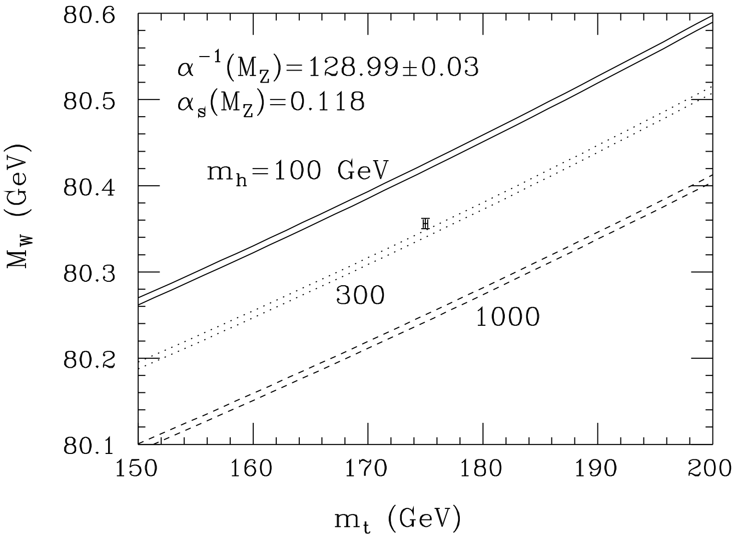
- If no light Higgs boson exists then EW gauge bosons develop strong interactions at the 1–2 TeV scale –> 3–4 TeV muon collider needed.

Top Factory

- Precise m_W & m_t measurements test radiative structure of SM –> look for new physics. Important if nothing new found at TeV33/LHC

Barger, Berger, Gunion, Han





- Threshold $t\bar{t}$ production –> m_t, m_H, $|V_{tb}|^2$, α_s

- Example: 10 fb^{-1} scan
  (3 yrs at 3 x 10^{32} cm^{-2} s^{-1})

  Δm_t ~ 200 MeV

- Can check consistency of SM with Higgs Boson

- Theoretical uncertainties:

  Deftn pole mass (*M. Smith*)
  NNLO correctns (*A. Hoang*)
  Final state interactions
  Final state gluons (*L. Orr*)

- Can also search for anomalous top couplings (polariz–ation would enhance capability) & new particles in production ($\mu\mu$ –> X –> $t\bar{t}$, $\mu\mu$ –> H –> $\bar{t}c + \bar{c}t$) and decay (e.g. t –> H^+b).

Summary: Workshop Conclusions

- There is an enormous amount of Front–End physics to think about ! The neutrino physics possibilities look great ! Can we invent low energy muon experiments that match the Front–End bunch structure .... or a way to make the bunch structure match the experiments ?
- There is a strong cutting–edge physics program at the FMC in almost any scenario. If a Higgs–like object is discovered at TeV33/LHC an FMC Higgs factory would be GREAT ! If nothing is found at TeV33/LHC, precision m_W and m_t studies very desirable (–> top factory) and eventually a multi–TeV muon collider would be needed !
- Some things that were identified as important and/or need of more work:

◆ We cant afford to give up any luminosity ... in fact a factor of 3 more luminosity than given in workshop parameters seems plausible and is VERY desirable !

◆ How well can we measure the luminosity ?

◆ What B–tagging efficiency can we expect ? ...
i.e. more work on detector/backgrounds needed !

◆ What polarization can we really achieve ?
(vs luminosity).

Score Card

Rating	Topic	Comments
*	Low Energy Hadrons	Adiabatic continuation of Kaon program
?	Low Energy Muons	Bunch structure ? More work needed.
*** ***	Neutrinos–Oscillations Neutrinos – DIS	Exciting qualitative & quantitative improvement
☆☆☆☆	Higgs Factory	Jewel in the crown !
☆☆	SUSY	Higgs sector compelling & precision spectroscopy
☆☆	SEWS	Precision spectroscopy
☆	Top Factory	Important if TeV33/LHC find nothing
†	Z Factory	Need higher luminosity than presently forseen

Muon Source Parameters for the Workshop

Parameters of muon bunches downstream of the ionization cooling channel

	Narrow σ_p	Broad σ_p
muons per bunch	5×10^{12}	5×10^{12}
μ^+ bunches per cycle	1	1
μ^- bunches per cycle	1	1
momentum (MeV/c)	200	200
σ_p/p	5%	10%
bunch length (cm)	1.5	10
normalized $\varepsilon_\perp$ (mm–mr)	$200\ \pi$	$60\ \pi$
repetition rate (Hz)	15	15
μ^+ per year (10^7 secs)	7.5×10^{20}	7.5×10^{20}
μ^- per year (10^7 secs)	7.5×10^{20}	7.5×10^{20}

- $7.5 \times 10^{20}\ \mu^{\pm}$ / year $\longrightarrow$

$7.5 \times 10^{20}\ \nu_e$ / year $7.5 \times 10^{20}\ \bar{\nu}_e$ / year

$7.5 \times 10^{20}\ \nu_\mu$ / year $7.5 \times 10^{20}\ \bar{\nu}_\mu$ / year

DIS at a μp Collider

$\sqrt{s}$ (GeV)	894
proton energy (GeV)	1000
protons per bunch	1.25×10^{12}
number of proton bunches	4
proton norm. $\varepsilon_\perp$ (mm–mr)	12.5π
proton β^* (cm)	15
proton beam–beam shift	0.02
muon energy (GeV)	200
muons per bunch	2×10^{12}
number of bunches	4
muon norm. $\varepsilon_\perp$ (mm–mr)	50π
muon β^* (cm)	7.5
muon σ_r (μm)	40
muon storage turns	2000
muon beam–beam shift	0.026
repetition rate (Hz)	15
$\mathcal{L}_{av}$ (cm^{-2} s^{-1})	1.3×10^{33}

Workshop μ–p collider parameters

V. Shiltzev, Fermilab–Conf–97/114

- Very low x physics looks hard if shielding cones prevent measurements at very small angles.
- High–Q^2 physics looks very interesting:

Sensitivity (95% CL) to Scalar Leptoquark Couplings for E_{CM} = 1 TeV, 10 fb^{-1} –>

M_{LQ} (GeV)	HERA–95	HERA–2005	μp
100	1.5×10^{-2}	2×10^{-3}	1.5×10^{-3}
150	2.5×10^{-2}	4×10^{-3}	2×10^{-3}
200	7.0×10^{-2}	1×10^{-2}	2×10^{-3}
250	2.5×10^{-1}	4×10^{-2}	2×10^{-3}
500			5×10^{-3}
800			3×10^{-2}

- Detector/backgrounds need careful study