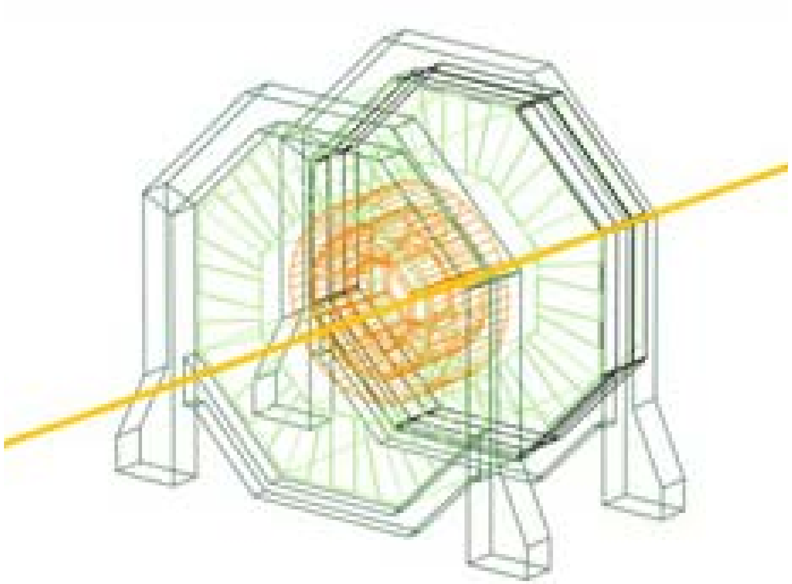
MCTF

Muon Collider Physics and Detector

'5-Year Plan and Goals'



Marcel Demarteau
Estia Eichten

Fermilab

MUTAC-09
Fermilab, April 6-8, 2009

Present Status

- The main reference document for a physics program at a muon collider is still the original Snowmass design study
  - The physics case was outlined
  - It was shown at that time that backgrounds were manageable

- This Snowmass study is in need of an update
  - There has been significant progress in the area of the accelerator design
  - New detector technologies are available
  - Physics landscape has changed with measurements from LEP, Tevatron, b-factories, ν-experiments, cosmology, …

- Teams need to be rebuild
  - to put the physics case on a up-to-date basis (see Estia Eichten's talk)
  - to synchronize the physics case and detector development with the accelerator developments,
  - to engage in a quantitative comparison in the reach of various options for a next new project

Boundary Conditions I

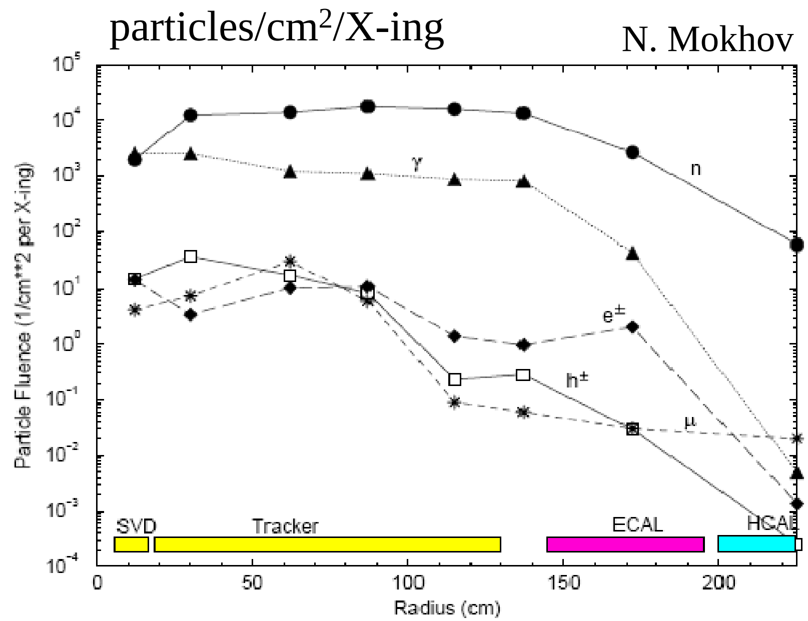
- One of the most serious technical issues in the design of a muon collider is the background arising from muon decays
  - In the 2x2 TeV muon collider, with 2×10^{12} circulating muons, 2×10^5 $\mu \to e\nu\nu$ decays occur per meter.
  - Immersed in strong magnetic fields, electromagnetic showers deposit ~2 kW/meter in the storage ring
  - Large backgrounds in the detector
- The backgrounds could spoil the physics program

Collider	*μ per bunch*	*Decays/meter*
50 × 50 GeV	4×10^{12}	2.6×10^{7}
250 × 250 GeV	2×10^{12}	2.6×10^{6}
2 × 2 TeV	2×10^{12}	3.2×10^{5}
2.5 × 2.5 TeV LEMC	1.6×10^{11}	2.0×10^{4}

MCTF

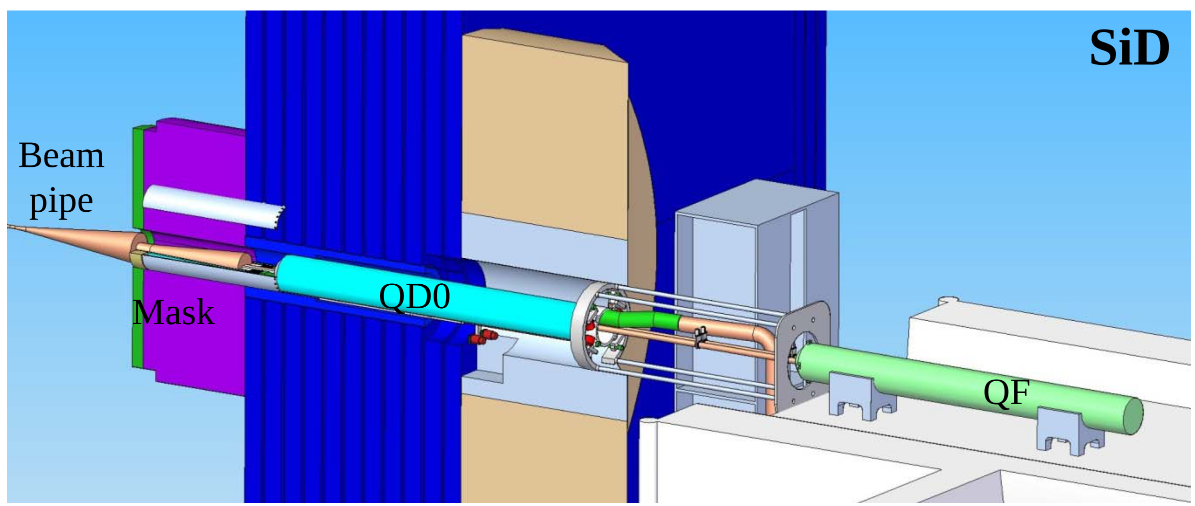
Detector Backgrounds

- Background estimate from decay muons, inside ± 1.2m central region, 2x2 TeV, for best IR configuration considered to date, with collimating spoilers and SC sweeping magnets
  - Mean decay electron of 700 GeV



- Need update with full Machine Detector Interface

- Design of beam delivery system and detector interface



Goal #1

- Have a realistic beamline design and machine detector interface in the first year
  - Determine environmental background
  - Determine machine background

- Determine realistic beam parameters such as beam polarization for both beams and beam energy spread

- Although physics will dictate what the ultimate center of mass energy will be, it will most likely not suffice to focus on one cm energy in the initial design stages. Backgrounds need to be understood (and solved) at 250x250 GeV (ILC), 750x750 GeV as well as 2x2 TeV.

Boundary Conditions II

- Premise is that μC comes online after the LHC has run its full course, including the upgrades of the LHC experiments
- Need to improve on the measurements at the LHC
  - Scenario I: Assume competition between μC and ILC/CLIC
  - Scenario II: Assume only μC and no ILC/CLIC
  - Bottom line is to compare performance of detectors (and subsequently what the physics reach is)
- Furthermore, planned experiments studying neutrino oscillations, quark/lepton flavor physics, and rare processes may also have provided insight into new physics at the Terascale
  - Nova, Double-Chooz, Daya Bay, μ2e, T2K, …
- Need to engage in a broad study of the required muon collider parameters and map the associated physics potential as a function of these parameters

Goal #2

- Determine physics program that can withstand the physics environment after ten years of running at the LHC and is competitive with an e^+e^- machine

- Determine a short list of physics processes to benchmark the performance of a μC detector

- Stimulate interest and receive input from the larger community in the physics program of the collider through a series of workshops

- Specify the minimum baseline parameters for the collider

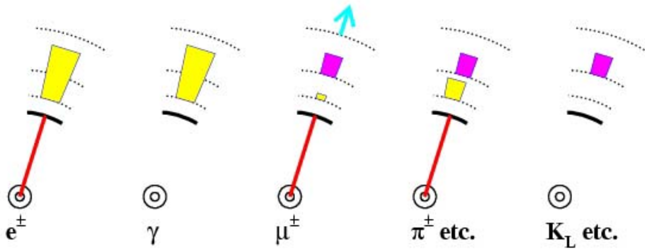
Performance Parameters

- The study of the μC physics program will guide the minimal performance parameters for the detector
- The process will be an iterative interplay between physics benchmarks and detector limitations
  - Impact parameter resolution driven by radius of inner layer of vertex detector
  - Radius of solenoid driven by technology and cost
  - Magnetic field set by cost, momentum resolution, …
  - Calorimetry most likely driven by differentiation between W and Z in the hadronic decay mode

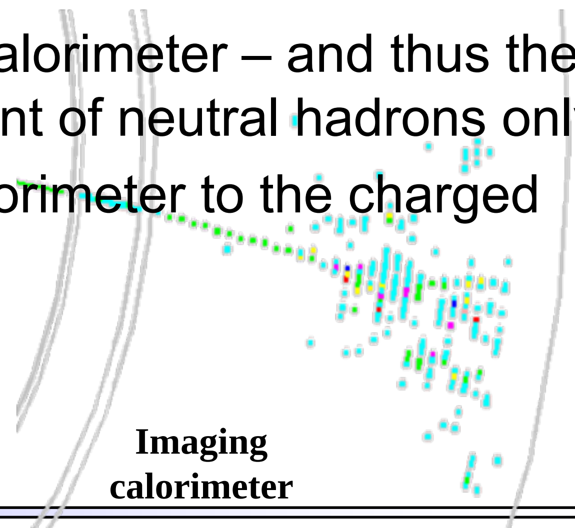
Detector	ILC	CLIC
Vertexing	$5\ \mu m \oplus \frac{10\ \mu m}{p\ \sin^{3/2}\vartheta}$	$15\ \mu m \oplus \frac{35\ \mu m}{p\ \sin^{3/2}\vartheta}$
Solenoidal Field	$B = 3\text{-}5\ T$	$B = 4\ T$
Tracking	$\frac{\delta p_T}{p_T^2} = 5 \cdot 10^{-5}$	$\frac{\delta p_T}{p_T^2} = 5 \cdot 10^{-5}$
EM Calorimeter	$\frac{\sigma_E}{E} = \frac{0.10}{\sqrt{E}} \oplus 0.01$	$\frac{\sigma_E}{E} = \frac{0.10}{\sqrt{E}} \oplus 0.01$
HAD Calorimeter	$\frac{\sigma_E}{E} = \frac{0.50}{\sqrt{E}} \oplus 0.04$	$\frac{\sigma_E}{E} = \frac{0.40}{\sqrt{E}} \oplus 0.04$
E-Flow	$\frac{\sigma(E_{jet})}{E_{jet}} = 0.03$	$\frac{\sigma(E_{jet})}{E_{jet}} = 0.03$

Particle Flow

- Major paradigm at ILC/CLIC is obtaining better energy resolution through Particle Flow Algorithms (PFA)
  - PFA: Reconstruct momenta of individual particles in jet; avoid double counting
    - Measure photons in the ECAL
    - Measure charged particles in the tracking system
    - Subtract calorimeter energy associated with charged hadrons
    - Measure neutral hadrons in the HCAL (+ ECAL)



- PFA: a brilliant idea !
- Novelty is in reducing the role of the hadron calorimeter – and thus the hadron energy resolution – to the measurement of neutral hadrons only
- Key is the proper association of hits in the calorimeter to the charged particle tracks
- Implications for the calorimetry
  - Granularity, longitudinal and transverse !
  - Sampling of the hadron calorimeter



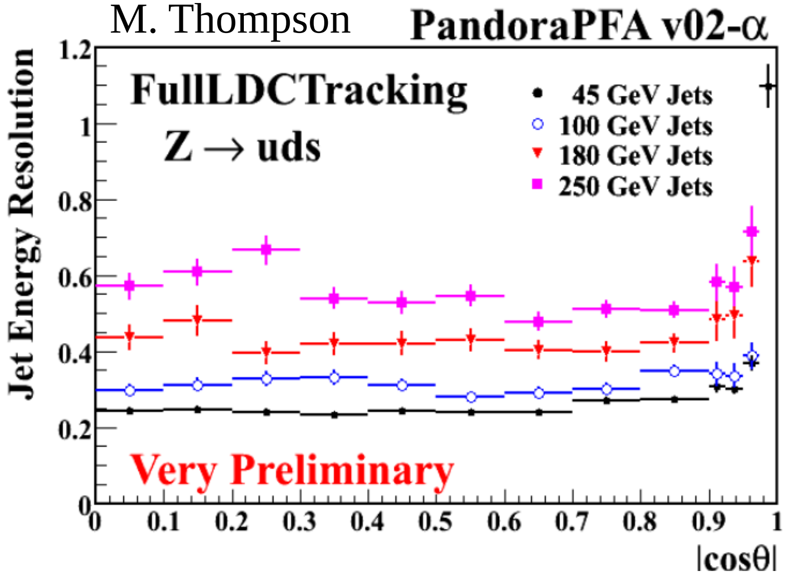
Particle Flow Viability

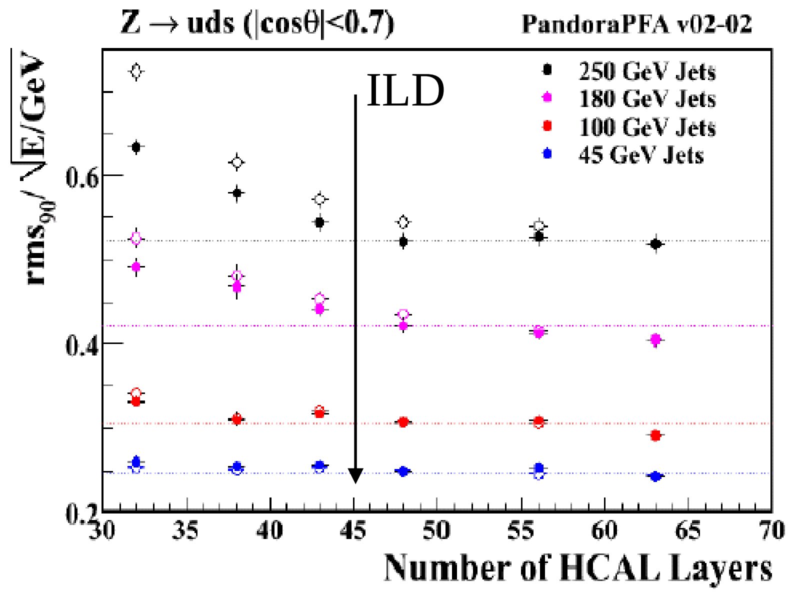
- Is PFA viable for multi-TeV collisions?
- Is PFA viable in the environment of a μC?

- Pandora PFA Performance
  - At low energies 25%/√E obtained
  - At higher energies resolution degrades
    - Performance of "conventional" good calorimeter
  - Resolution improves with increasing thickness of calorimeter at higher energies
    - Deep calorimeter needed 8λ -> 10λ

- Note: at √s = 3 TeV average parton energy is 240 GeV (averaged over all SM processes)

M. Thompson

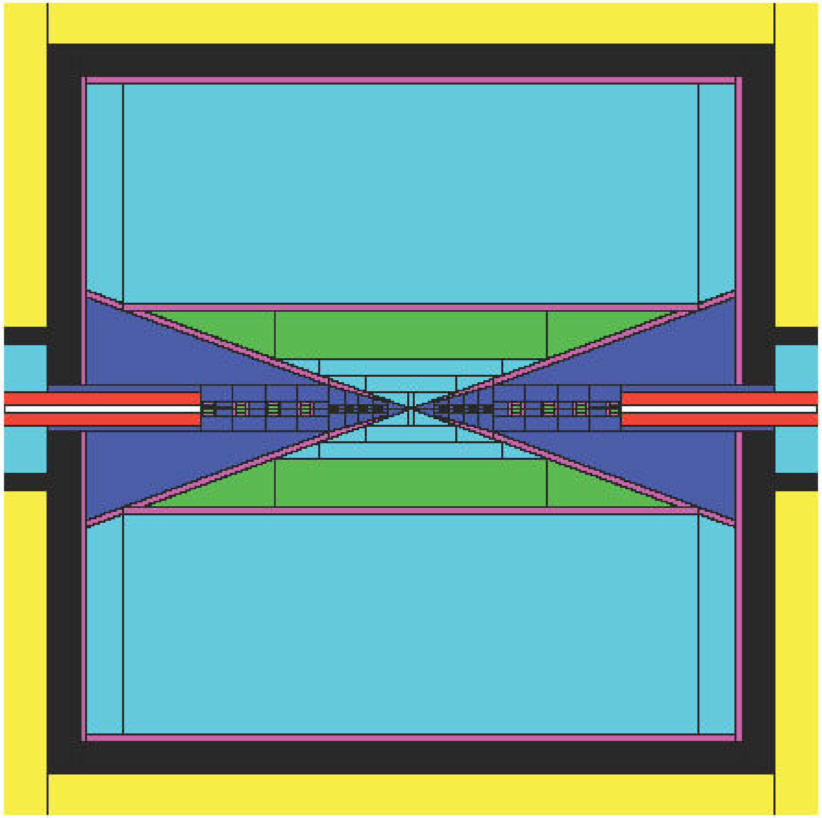




Goal #3 and #4

- Develop detector design concept for μC detector
  - Completely revisit the old Snowmass 1996
  - Special emphasis on the effect of various backgrounds

- Study physics reach through full Monte Carlo simulations of benchmark processes and compare results with physics reach of sLHC and ILC/CLIC



Boundary Conditions III

- To perform realistic benchmark studies in an efficient manner, utilizing existing tools with limited resources, it is extremely important to have a well-supported, user-friendly software platform

- Often, the lack of adequate infrastructure for software simulations is a major stumbling block for physics studies.

- Realistic studies need to include
  - Detector geometry at time of simulation and reconstruction
  - Background events with timing information
  - Beam backgrounds
  - Persistent event format
  - Set of high-level analysis tools

Goal #5

- Establish a software platform for the physics studies within a year and dedicate resources, both manpower and equipment, as needed.
  - A corollary is to decide on a programming language embraced by the experimental physics community

- Explore existing platforms and tools that have been developed and hopefully adopt one of the existing platforms

	Description	Detector	Language	IO-Format	Region
Simdet	fast Monte Carlo	TeslaTDR	Fortran	StdHep/LCIO	EU
SGV	fast Monte Carlo	simple Geometry, flexible	Fortran	None (LCIO)	EU
Lelaps	fast Monte Carlo	SiD, flexible	C++	SIO, LCIO	US
Mokka	full simulation – Geant4	TeslaTDR, LDC, flexible	C++	ASCI, LCIO	EU
Brahms-Sim	Geant3 – full simulation	TeslaTDR	Fortran	LCIO	EU
SLIC	full simulation – Geant4	SiD, flexible	C++	LCIO	US
LCDG4	full simulation – Geant4	SiD, flexible	C++	SIO, LCIO	US
Jupiter	full simulation – Geant4	JLD (GDL)	C++	Root (LCIO)	AS
Brahms-Reco	reconstruction framework (most complete)	TeslaTDR	Fortran	LCIO	EU
Marlin	reconstruction and analysis application framework	Flexible	C++	LCIO	EU
hep.lcd	reconstruction framework	SiD (flexible)	Java	SIO	US
org.lcsim	reconstruction framework (under development)	SiD (flexible)	Java	LCIO	US
Jupiter-Satelite	reconstruction and analysis	JLD (GDL)	C++	Root	AS
LCCD	Conditions Data Toolkit	All	C++	MySQL, LCIC	EU
GEAR	Geometry description	Flexible	C++ (Java?)	XML	EU
LCIO	Persistency and datamodel	All	Java, C++, Fortran	-	AS,EU,US
JAS3/WIRED	Analysis Tool / Event Display	All	Java	xml,stdhep, heprep,LCIO,	US,EU

Goal #6

- Determine areas of critical detector R&D, explore overlap with existing R&D collaborations, initiate the critical R&D
- Explore and exploit synergies with ongoing R&D efforts for other projects

Goal #7

- Obtain resources to carry out these studies
  - It has proven to be extremely difficult to attract young experimental physicists to work on projects with a timescale > 8 years. The reward structure, especially in the US, actually discourages young non-tenured physicists to work on project that do not hold the promise of data within a foreseeable future
  - Work on accelerator and detector have to proceed in parallel; funding for detector R&D is required
  - Exploitation of synergies with other projects is a must, given the limited resources

Timeline and Deliverables

- Year 1
  - Establish a realistic simulation of the Muon Collider background environment, and study the final-focus shielding design
  - Theory studies to determine the physics program; provide input to determine machine and detector parameters
  - Identify key benchmark processes
  - Setup of software framework
- Year 2
  - Define detector requirements based on physics studies and expected backgrounds; start detector design, simulation studies and identify critical detector R&D areas
- Years 3–4
  - Carry out detector R&D and simulation studies, establishing the likely detector performance.
- Year 5
  - Write the detector section of the DFSR
- Deliverables
  - A published physics report and published detector outline document
  - Software platform for realistic detector simulations including backgrounds
  - Suite of software tools for realistic simulations

Resources

	Year 1	Year 2	Year 3	Year 4	Year 5
Workshops & Travel					
M&S (K$)	0	15	15	15	15
Theory Studies					
M&S (K$)	0	10	10	15	15
Techs (FTE)	0	0.5	0.5	0.5	0.5
Post Docs (FTE)	0.2	1	1	1.5	1.5
Scientists (FTE)	0.2	0.8	0.9	1	1
Det & Bckgrd Simul.					
M&S (K$)	0	15	10	10	10
Post Docs (FTE)	0	1	1.5	2	2
Scientists (FTE)	0	1	1	1	1
Detector Development					
M&S (K$)	0	50	100	150	150
Engineers (FTE)	0	0.5	1	1	1
Post Docs (FTE)	0	0	0	0	0
Scientists (FTE)	0	0.5	0.5	0.5	0.5
M&S	**0**	**90**	**135**	**190**	**190**
FTE	0.4	5.3	6.4	7.5	7.5
SWF	**70**	**915**	**1080**	**1205**	**1205**
TOTAL	**70**	**1005**	**1215**	**1395**	**1395**

Concluding Remarks

- There is consensus that a multi-TeV lepton collider is required for full coverage of Tev-scale physics.
- The physics potential for a muon collider at $\sqrt{s} \sim 3$ TeV and integrated luminosity of 1 ab^{-1} is strong.
- A detailed updated study of the physics case for a 1.5-4.0 TeV μC is needed with a time horizon of the full run of the LHC
- Detector design studies need to proceed in parallel with accelerator studies
- Simulations of the physics performance of a μC detector under real running conditions with quantitative comparison in physics reach with other facilities should be undertaken; the steps to engage in such a process were outlined.