

Of MICE and Muons

Daniel M. Kaplan US Spokesperson, MICE Collaboration

ILLINOIS INSTITUTE OF TECHNOLOGY

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Muon Collaboration Meeting Lawrence Berkeley Lab Feb. 14, 2005

Muon Ionization Cooling Experiment



• Goal: measure ε_N before and after cooling section to $\sigma(\varepsilon_N) = 10^{-3}$, giving $\sigma(\Delta \varepsilon_N) \approx 1\%$

<u>How is</u> $\sigma(\varepsilon) = 10^{-3}$ **achieved?**

• 5-plane 350-µm SciFi solenoidal spectrometers measure each muon before and after cooling section:



• We have
$$(\sigma_i^{meas})^2 = (\sigma_i^{true})^2 + (\sigma_i^{res})^2 \implies \sigma_i^{meas} = \sigma_i^{true} \sqrt{1 + \left(\frac{\sigma_i^{res}}{\sigma_i^{true}}\right)^2} \approx \sigma_i^{true} \left(1 + \frac{1}{2} \left(\frac{\sigma_i^{res}}{\sigma_i^{true}}\right)^2\right)$$

• Thus, for each phase-space variable *i*, must have $\frac{\sigma_i^{res}}{\sigma_i^{true}} \le \frac{1}{7} \approx 14\%$

Simulated Tracker Performance in G4MICE





• <u>Conclude</u>:

The 5 phase-space variables measured by the trackers (x, y, p_x , p_y , E) are all measured to better than 14% of the RMS of their distributions at the equilibrium emittance of the cooling section (2.5 π mm rad)

I.e., the requirement is satisfied

...but there's more to this:

Bias Correction

• "Empty-channel" simulation, before correction:



• <u>Correction scheme</u>:

$$\varepsilon_N = \frac{1}{m_\mu} \sqrt[4]{V_{4D}^{true}}$$

- For each variable *i*, the true value is $w_i = m_i \delta_i$
- Covariance matrix:

$$C_{ij} = \left\langle (\delta_i - \overline{\delta}_i)(\delta_j - \overline{\delta}_j) \right\rangle$$
$$R_{ij} = \left\langle (m_i - \overline{m}_i)(\delta_j - \overline{\delta}_j) \right\rangle$$

– Correlation matrix:

⇒Then

$$V_{4D}^{true} = V_{4D}^{meas} + R + R^T + C$$

Bias Correction (cont'd):

• <u>After correction</u>:



So far, so good! But...the crucial question:

 \rightarrow How well can this be done in practice?

• The MICE program is subdivided into a logical sequence of steps:



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MICE costs now well understood

• Detailed WBS & cost estimate prepared for recent (11/12/04) UK Cost & Schedule Review:

1	1 MICE.mpp Cost Details - draft		11.					16						-					
	31/10/2004 21:43:41	Sec.																	
Task	WBS	FC	¢FC	FC-EU	FC-US	FC-JP	FC-UK	WK	WK	WK-EU	WK-US	WK-JP	WK-UK	WK-UK	WK-EU	WK-US	WK-JP	WK-UK	Sum WK
ID	Task	£	2	¢	5	v	£	days	SY	daya	daya	days	days	SY	€	5	V.	E	E
+	MICE	12,683,675	3,725,022	e 5,367,347	\$ 5,882,680	¥ 120,141,8	£ 5,394,294	21,381.9	89,1	1,635.0	2,079.0	190.0	17,479.0	72.6)	0 1,162,840	5	0 3,840,472	4,479,45
2	Mice Integration	0		€0	\$0	¥0	E 0	1,848.0	7.3	0.0	0.0	0.0	1,848.0	7.1	1	0 0	0	0 100,800	100,80
3	MICE into Hall 5.2	0	0	e 0	8.0	¥0	6.0	768.0	3.3	0.0	0.0	0.0	768.0	3.1		0 0	5	0 0	1
4	Mice Experiment	D		€0	\$0	V0	E 0	1,080.0	4.5	0.0	0.0	0.0	1,000.0	4.5		0 0	0	0 100,800	100.80
6	Concept	. D	0	÷0	\$0	¥.0	£0	1,080.0	4.5	0.0	0.0	0.0	1,080.0	4.5		0 0	p	0 100.800	100.90
6	Nuon-Beam Line & Infrastructure	1.307,135	363,296	e 0	8.0	V.0	£ 1,307,130	2,292.7	9.6	5.0	0.0	0.0	2,288.0	9.6		0 4	1	0 464.412	464.41
7	Beam	1,152,035	336,736	€0	50	¥0	E 1,152,038	2,060.7	8.4	5.0	0.0	0.0	2,056.0	B.f		D 0	5	0 394,652	394.65
8	MICE Muon Beam Line	643,735	163,121	e 0	\$0	¥0	€ 543,735	720.5	3.0	E 0.0	0.0	0.0	721.0	3.0	1	0 0	5	0 109,892	109.89
9	Muon Solenoid	558,300	158,615	€0	\$ D	VO	£ 558,300	392 D	14	5.0	0.0	0.0	267.0	1.0		D 0		0 91,500	91.60
10	New Target	50.000	15,000	- 0	50	¥6	£ 50,000	948.2	4.0	E 0.0	0.0	0.0	949.0	4.0		0 0	5	0: 193,160	193.16
11	Hall Modifications for Beam Lines.	11,750	3,525	€ D	\$0	¥0	£ 11,750	65.0	D.3	0.0	0.0	0.0	65.0	0.2		0 0		0 19 360	19.36
12	Plant & Services a	0	6					0.0	0.0	0.0	0.0	0.0	0.0	0.0		0 0		0 0	1
15	Interiories & Salatas	58 780	17 625	e n	\$ n	¥.0	F 55 750	57.0	0.1	0.0		0.0	57.0	0.5		0 0		0 18 240	18.24
14	Beam Line Controls Intertane*	35,250	10.575	# D	50	Vô.	F 35 250	80.0	0.4	6.6	0.0	0.0	90.0	0.0		0 6		0 27 200	27.90
16	Variate Redents	49,350	14 005	en.	80	80	F 40 350	20.0	0.1			0.0	20.0	0.1	1	ñ		0 4 160	4.95
16	MICE GAD Bick north	978.765	107 539	~ 103.050	5.0	¥.	2 304 695	669.8	91			0.0	669.0	24		6 4	-	0 135 690	195.99
37	Hologan	134,000	107,000	< 100,000	80	10	£ 324 000	207.6	1.1			0.0	2000.0	1.1		0 0	-	0 28,118	24.11
40	Abaratar	195,000	97.605	-0	50	4.0	£ 105,000	1020	0.1			0.0	195.0	0.0		0 1	3	0 40,000	40.00
10	10	121,750	21,292	£ 100.050	80	80	F 45 426	20.0				0.0	120.0			0 0	2	0 47,000	
10	NUCL Indexemptions	121,785	30,339	6.100,000	50	40	E 20/0803	240.0	14			0.0	4 447 0	1.1	-	A 4	1	0 01,012	07,07
21	Hardware Distance	1,003,489	401,047	e 0	80	NO.	5, 140, 164	1,140,5			9.9	9.0	1,147.0			0 1	9	0 00000	600.00
21	Frydrogen syenen	1464,004	00,010	0	50	* w	E 149, 104	304.0	1,0	0.0		0.0	204.0	1.1		0 0	-	0 00,211	113,21
22	Hall Modifications for Milderin	88,125	25,435		80	4 W	5, 66, 125	70.0	0,1	9.9	9.0		70.0	0.3	-	2 2		0 22,400	22,40
23	Plan & Services+	497,625	149,288	€.0	\$0	¥0	£ 497,523	105.0	0.4	0.0	2 0.0	0.0	105.0	0.4		0 0	}	0 25,400	25,40
24	MICE Menocks and batery+	0		0	0			0.0		8.9	9.00	.0,0	0.0	0.0		9 9		0 0	1 100
25	MCE Support Infrastructure	270,575	81,173	€.0	\$0	¥0	E 270,575	230.5	1.1	0.0	0.0	0.0	231.0	1.1		0 0	<u> </u>	0 73,760	73,76
26	MICE Controls Interface	198,000	56,400	e 0	80	YO	£ 188,000	350.0	1/	9,9	9/9	0.0	360.0	1.1	4	8	2	0 94,400	94,40
27	MCE Vacuum Infrastructure	10,000	3,000	€0	S D	¥0	£ 10,000	7.0	0.0	0.0	0.0	0.0	7.0	D.1	<u> </u>	0 0	<u> </u>	0 1,736	1,73
28	MICE Cooling Modules	4,328,001	1,298,400	< 600,000	\$ 3,486,180	V 58,649,62	£ 1,764,62	5 5,221.7	21/	120,0	1,524.0	0.0	3,578.0	14.5		0 1,162,840		0 1,015,531	1,654,51
29	Absorber Focus Coll Modules	1,631,306	469,392	€0	\$ 320,120	¥ 58,649,62	E 1,203,500	3,313.8	13.4	0.0	0.0	0.0	3,314.0	13.0	-	0 0	D	0 944,491	244,43
30	Absorber Modules	427,896	128,342	€0	\$,320,120	¥ 58,649,62		0.0	0.0	9.0	9.0	0.0	0.0	0.1	1	0 5	P	0 0	4
31	Focus Cols	1.203.500	361,050	€0	\$0	¥0	E 1,203,500	3,115.8	13.4	0.0	0.0	0.0	3,116.0	13.0		D 0	D	0 881,131	681,13
32	AFC Integration & Installation at RAL	0	.0	€0	\$0	¥0.	£0	198.0	0.1	0.0	0.0	0.0	198.0	0.6	1	0	×	0 #3,360	63,39
33	RF Cavity & Coupling Coll	1,511,707	453,512	€0	\$ 2,751,060	VO.	0.3	1,190.9	5.0	0.0	1,191.0	0.0	0.0	D.1	1	0 878,200	×	a 0	482,57
34	RF Power Systems	890,975	267,293	e 600,000	\$.0	¥0	£ 561,125	264.0	1,1	0.0		0.0	264.0	1.1		0 (N	0 71,040	71.04
35	Magnat Power Supplies	228,043	68,413	≪0	\$415,000	¥0	£ 0	240.D	1.0	E 0.0	240.0	0.0	0.0	D.0)	D 230,400		0 0	126,60
36	Installation and Integration	D	0	e0	\$0	¥.0	60	.93.0	0,4	0.0	93.0	0.0	0.0	0.0		0 54,240	N	0 0	29.90
37	Installation and Integration - magnetic proba-	65,970	19,791	€ 100,000	\$0.	VO.	C 0 3	120.D	0.5	120.0	0.0	0.0	0.0	D.0	1	0 0	2	0 0	4
38	Detectors & Measurement	3,956,709	1,119,507	+ 3,787,813	\$ 1,569,500	¥ 50,344,17	€ 379,220	6,812.2	28.4	1,510.0	655.0	190.0	4,557.0	19.0		0 4	þ.	0 841,751	B41.75
39	Tot project	245,707	74,612	€.377,000	\$0	¥0.	0.3	D.D	0.0	0.0	0.0	0.0	0.0	D.0		0 0	P	0 0	4
40	Upstream Cherenkov	52,752	15.826	€0	\$ 96,000	¥0	£0	0.0	0,0	E 0.0	0.0	0.0	0.0	0.0		0 0	5	0 0	4
41	Downstream Cherenkov	130,884	39,265	€ 198,400	\$ D	¥0	03	D.D	0.0	0.0	0.0	0.0	0.0	0.0		D 0		0 0	1
42	Tracker Module	3.090,782	859,729	< 2,561,000	\$ 1,466.500	¥ 50,344,17	£ 379,220	4,252.2	17.3	0.0	0.0	0.0	4,252.0	17.7		0 0	6	0 768,008	768.00
43	MICE Tracker Sciencid	1,699,492	509.809	€ 2,561,000	\$0	VO	£ 10,000	D.D	0.4	0.0	0.0	0.0	0.0	0.0	1	0 0	0	0 0	
44	MICE SIFI	1,391,290	349,920	€0	\$ 1,466,500	¥ 50,844,17	£ 369,220	4,252.2	17.7	0.0	0.0	0.0	4,252.0	17.7		0 0	k.	0 768,008	768,00
45	TPG - R&D - nominal	D	0	€0	\$D	¥0	0.1	D.D	0.0	0.0	0.0	0.0	0.0	0.0	1	0 0	2	0 0	1.11.11.1
46	Calorimeter	255,752	77,026	€ 389,195	\$0	VO.	60.	0.0	0,0	0.0	0.0	0.0	0.0	0.0	1	0 0	8	0 0	
47	DAD - nominal	143.847	41.154	€ 212,218	\$ 7,000	¥0	C 0 3	1,200.D	5.0	1,200.0	0.0	0.0	0.0	D.D		0 0	0	0 0	1
48	SIM - nominal	D	ð	e0	\$0	¥0.	60	1,240.0	6.1	190.0	555.0	190.0	305.0	1.5		0 0		0 73,743	73.74
49	Detector Pert Testa - removal	D	0	€0	\$0	V0	E 0	0.0	D.O	0.0	0.0	0.0	0.0	D.f		0 0	0	0 0	
50	Installation and Integration - other	32.985	9.996	€ 50,000	\$0	¥0	60	\$20.0	0.1	120.0	0.0	0.0	0.0	0.0	1	0 0	8	0 0	1
51	Stee Controls - Industrientation & Monitoring	47.900	14,373	€ 72.622	\$0	¥O	03	396.0	1.5	0.0	0.0	0.0	396 0	1.1	1	0 0		0 95,745	95.74
52	Project Oversight	10.000	3.000	e 0	8-0	Vô.	£ 10,000	2,996.0	12.	0.0		0.0	2 996 0	12.5		0 0	2	0 902 396	802.33
53	Project Trained	1.459.637	437 893	€ 805 917	\$ 827 000	¥ 11,140,00	E 425 000	0.0	0.0	0.00	0.0	0.0	0.0	DI		0		0 0	
54	Missiones	0	φ	€0	\$0	¥0	6.0	0.0	0,0	0.0	0.0	0.0	0.0	0.0		0 0)	0 0	
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_		onex	1,82	1.516	232.829	1.			_	-						-		-	

• Hope for imminent release of £9.7M earmarked for beamline and UK contribs to Phase 1

<u>US Contributions to MICE</u>

- Originally proposed US contributions to MICE:
 - RF/Coupling-Coil (RFCC) modules
 - LH₂-absorber windows
 - Tracker assembly, photosensors & readout electronics
 - Beam Cherenkov counter
 - DAQ buffers
- 1st spectrometer solenoid recently added to list (possibly in place of 2nd RFCC module) as part of US MICE Phase 1, because Italian funding originally proposed could cause undue delay

 \rightarrow combination of long lead time plus timing of proposal to INFN

• Of agreed US contributions, RFCC modules most expensive (have large superconducting Coupling Coils, beryllium RF windows, etc.)

-1st one costs \approx \$2.2M, 2nd \approx \$1.5M

- Spectrometer solenoids come in 2nd:
 - -1st one costs \approx \$1.8M

 \Rightarrow To get to Step VI, need \approx \$5.5M in equipment funds, preferably before 2010

From whence might this come?

- Italian MICE groups now preparing proposal to INFN, due in June, to fund (*inter alia*) both spectrometer solenoids
- European MICE groups preparing "I3" proposal to EU ("Integrated Infrastructure Initiative"), due March 3
- But, fabrication of superconducting spectrometer solenoid will take about 2 years, and "MICE Avatar" schema shows 1st solenoid needed in 2007/8
- ⇒Depending on success of above proposals, keeping MICE on track may require full US expenditure as above

US MICE Funding Picture

- IIT+BNL/FNAL/LBNL/NIU/UCLA/UCR/UMiss submitted 5y US MICE Consortium NSF proposal for \$23.9M in Fall 2002 (also sent to DOE)
 - Approved! by NSF in Fall 2004 for 3 yrs @ \$100k/y
 - DOE has agreed to 3 yrs @ 300k/y

 \Rightarrow US MICE now funded by DOE + NSF @ \$400k/y

- But this is insufficient to meet above needs
- NSF Major Research Instrumentation proposal recently submitted by IIT+FNAL/LBNL for ≈ \$2M (maximum allowed) over 2 years to build solenoidal spectrometer for MICE Phase 1
- One or more NSF "Partnerships for International Research and Education" proposal(s) in the works (from UCR/NIU/UNH? TBD, subject to limit of one per institution)
 - Program limit is \$500k/y for up to 5 y
 - Might cover travel plus some personnel
 - Proposal deadline 3/10/05

Request to Muon Collaboration

As the Targetry experiment and MuCool Test Area furbishment & beamline installation wind down, could additional funds be made available for MICE by the Muon Collaboration?

US MICE Milestones

MTA

beam

done?

Tgtry

expt

done

• 1st assume favorable scenario:

FY	US MICE \$	MRI \$	Σ (non-MRI \$)	milestone	
'05	400K	1.1M	0.4M		
'06	400K	0.9M	0.8M	US MICE Phase 1 done ≈end 2006	
'07	400K		1.2M		
'08	800K		2.0M	1st RFCC done ≈end 2008	
'09	800k		2.8M		
'10	800k		3.6M	2nd RFCC done ≈end 2010	

• What if MRI proposal fails?

FY	US MICE \$	Σ\$	milestone
'05	400K	0.4M	
'06	400K	0.8M	
'07	400K	1.2M	
'08	800K	2.0M	US MICE Phase 1 done ≈end 2008
'09	800k	2.8M	
'10	800k	3.6M	1st RFCC done ≈end 2010 or 2011?

Conclusions

- US *may* be able to "hold up our end" of MICE
 - including 1st spectrometer solenoid, really it's *more* than our end, but we're not complaining
- Our ability to do so will depend on our luck with NSF proposals recently or soon to be submitted (as well as the Italian proposal to INFN and joint European MICE proposal to EU now in preparation)
- ⇒We hope to know better in ≈6 months
- Depending on degree of success of these NSF proposals, additional support of MICE by the Muon Collaboration (up to 1:1 match with NSF+DOE), starting in a few years, could play an important role