INTENSE: particle physics experiments at the high intensity frontier, from new physics to spin-offs. A cooperative Europe – United States – Japan effort



Simone Donati



November 28<sup>th</sup>, 2022, Pisa

H2020 MSCA RISE 2018 GA 822185



## A cooperative Europe – United States – Japan effort (I)

(NORWAY) Norwegian	INTENSE BENEFICIARIES	
Europe		
AUSTRALIA - Independent State	University of Pisa	IT
Capital City     Major City     Faroe     SWEDEN     Arkhangel'sl	INGV	IT
Islands Tórchaun (DEN.)	INFN	IT
Bothnia Helsinki	CAEN Spa	IT
Rockall	Tecno In Spa	IT
(U.K.) North DENMARK Sea Riga + LAT. Moscow	Catholic University of Louvain	BE
Bellast, UNITED Sea Copenhagen & RUSSIA Vilnius Minsk	B12 Consulting	BE
Dublin isle of Leeds Hamburg BELARUS	University of Gent	BE
Birmingham Lodz * Homyel	Seems Ike	EL
Celtic Ulle ULL Frankfurt CZECH REP UK RALINE Kharkiv	University of Bern	СН
Paris* Paris* SLOVAKIA Munich Vienna + Bratislava MOLDOVA Donets'k	CERN	СН
FRANCE A n Ljubljana + Budapest Chişinau * Odesa	University of Cambridge	UK
Bay of Biscay Bordeaux Turin SAN Zagreb Bos. 82 MARINO MARINO	University of Manchester	UK
Bilbao Marseille TALLY Sarajevo Pristina Sofia Black Sea	University of Liverpool	UK
Porto	Clever Operation	FR
PORTUGAL SPAIN Valencia Bursa Ankara	Tel Aviv University	IL
Lisbon Sevilla Sevilla Sevilla Sevilla Sevilla Lisbon Sevilla	Wigner Research Center for Physics	HU
Málaga (Gibraltar(UK) Constantine TUNIS MALTA Vallatta	CIEMAT	ES
Rahat relina Oran TUNISIA Crete Nicosia SYR	University of Granada	ES
Casablanca Fès Mediterranean Sea (GR.) CYPRUS Beirut Dama		

# A cooperative Europe – United States – Japan effort (II)



INTENSE PARTNERS				
Fermi National Accelerator Laboratory	US	Nagoya University	JP	
Yale University	US	University of Tokyo	JP	
Massachusetts Institue of Technology	US	Kyushu University	JP	
		Kansai University	JP	

# Why Fermilab ? It all started a long time ago.

**Charm Experiments (I)** 



The Princeton University—Torino University—Saclay and Brookhaven National Laboratory collaboration working on E-567 has recently completed a charm search in the High Intensity Laboratory. A first-pass analysis of the data has been encouraging. Sixty  $J/\psi$  events have been reconstructed, and final analysis of the data is now in progress.

The major activities in the Broton

E567 (1978-1982) was designed to look for charmed particles production in hadron scattering, looking for the signature  $D^*+ \rightarrow D^0 \pi^+$  $\rightarrow K^-\pi^+\pi^+$ , with the caracteristic signature of a soft pion and a pair of stiffer mesons, with the kaon selected by a Cherenkov counter at trigger level. The experimental team included Val Fitch (Nobel Prize winner) and Michael Witherell (Fermilab Director in 1999-2005)



...AND WITHERELL BACK THEN In 1979, Michael Witherell was cospokesperson for E567, an early fixed-target experiment at Fermilab to study charm physics in hadronic interactions.

## **Charm Experiments at Fermilab (II)**

366

Nuclear Instruments and Methods in Physics Research A252 (1986) 366-372 North-Holland, Amsterdam

FERMILAB-Conf-87/147-E [E-400]

#### THE MICROSTRIP VERTEX DETECTOR FOR THE E687 EXPERIMENT AT TEVATRON

G. BELLINI \*, M. GIAMMARCHI \*, P.F. MANFREDI \*, D. MENASCE, L. MORONI, D. PEDRINI, S. SALA and M. VITTONE

I.N.F.N., Milano, Italy

**Charm Hadroproduction Results From Fermilab E-400**\*

P. Coteus<sup>(1)</sup>, M. Binkley<sup>(3)</sup>, F. Bossi<sup>(6)</sup>, J. Butler<sup>(3)</sup>,
J. P. Cumalat<sup>(1)</sup>, M. DiCorato<sup>(5),(6)</sup>, M. Diesburg<sup>(2)</sup>, J. Enagonio<sup>(1)</sup>,
J. Filaseta<sup>\*(2)</sup>, P. L. Frabetti<sup>(4)</sup>, I. Gaines<sup>(3)</sup>, P. Garbincius<sup>(3)</sup>,
M. Gormley<sup>(3)</sup>, J. Haggerty<sup>†(3)</sup>, D. J. Harding<sup>(3)</sup>, T. Kroc<sup>(2)</sup>,
R. Ladbury<sup>(1)</sup>, P. Lebrun<sup>(3)</sup>, P. F. Manfredi<sup>(5),(6)</sup>, J. Peoples<sup>(3)</sup>,
A. Sala<sup>(6)</sup>, C. Shipbaugh<sup>(2)</sup>, J. Slaughter<sup>\*(3)</sup>, J. Wiss<sup>(2)</sup>

<sup>(1)</sup>University of Colorado Boulder, Colorado 80303
<sup>(2)</sup>University of Illinois at Urbana-Champaign Urbana, Illinois 61801
<sup>(3)</sup>Fermi National Accelerator Laboratory

#### Batavia, Illinois 60510

<sup>(4)</sup>Universita di Bologna, Dipartimento di Fisica and LN.F.N. Bologna, Italy

> <sup>(5)</sup>Universita di Milano, Dipartimento di Fisica Milano, Italy

<sup>(6)</sup>Istituto Nazionale di Fisica Nucleare Milano, Italy

September 1987

A vertex detector has been realized to reconstruct with high efficiency the decay vertices of heavy flavours in the E687 photoproduction experiment at the FNAL Tevatron.

The vertex detector consists of 12 microstrip planes with a strip-by-strip readout. The readout electronics consists of a low noise preamplifier, an amplifier and a fast integrating ADC. All these units were developed by the INFN Milano and taylored to the actual vertex detector in order to fully exploit its intrinsic capabilities.

A test of a part of the microvertex detector has been carried out in the real experimental conditions at Fermilab during summer 1985.

Detection efficiency, charge collection and charge sharing between adjacent strips, signal to noise ratio, spurious hits, cross-talk and correlations have been extensively investigated.

A simulation program, which makes use of a purposely developed pattern recognition and of the measured performances of the

Nuclear Physics B (Proc. Suppl.) 21 (1991) 400-412 North-Holland

CHARMONIUM SPECTROSCOPY FROM P-P ANNIHILATIONS E760 COLLABORATION

Armstrong T.<sup>6</sup>, Bettoni D.<sup>2</sup>, Bharadwaj V.<sup>1</sup>, Biino C.<sup>7</sup>, Borreani G.<sup>2</sup>, Broemmelsiek D.<sup>4</sup>, Buzzo A.<sup>3</sup>, Calabrese R.<sup>2</sup>, Ceccucci A.<sup>7</sup>, Cester R.<sup>7</sup>, Church M.<sup>1</sup>, Dalpiaz P.<sup>2</sup>, Fast J.<sup>4</sup>, Ferretti-Dalpiaz P.<sup>2</sup>, Ferroni M.<sup>3</sup>, Ginsburg C.M.<sup>5</sup>, Gollwitzer K.<sup>4</sup>, Hahn A.<sup>1</sup>, Hasan A.<sup>6</sup>, Hsueh S.Y.<sup>1</sup>, Lewis R.<sup>6</sup>, Luppi E.<sup>2</sup>, Macri' M.<sup>3</sup>, Majewska A.<sup>6</sup>, Mandelkern M.<sup>4</sup>, Marchetto F.<sup>7</sup>, Marinelli M.<sup>3</sup>, Marques J.<sup>4</sup>, Marsh W.<sup>1</sup>, Martini M.<sup>2</sup>, Masuzawa M.<sup>5</sup>, Menichetti E.<sup>7</sup>, Migliori A.<sup>7</sup>, Mussa R.<sup>7</sup>, Palestini S.<sup>7</sup>, Passaggio S.<sup>3</sup>, Pastrone N.<sup>7</sup>, Patrignani C.<sup>3</sup>, Peoples Jr.J.<sup>1</sup>, Pesando L.<sup>7</sup>, Petrucci F.<sup>2</sup>, Pia M.G.<sup>3</sup>, Pordes S.<sup>1</sup>, Rapidis P.<sup>1</sup>, Ray R.<sup>5</sup>, Reid J.<sup>6</sup>, Rinaudo G.<sup>7</sup>, Rosen J.L.<sup>5</sup>, Santroni A.<sup>3</sup>, Sarmiento M.<sup>5</sup>, Savrie M.<sup>2</sup>, Schultz J.<sup>4</sup>, Seth K.<sup>5</sup>, Smith G.A.<sup>6</sup>, Tecchio L.<sup>7</sup>, Tommasini F.<sup>3</sup>, Trokenheim S.<sup>5</sup>, Weber M.<sup>4</sup>, Werkema S.<sup>1</sup>, Zhao J.L.<sup>5</sup>, Zito M.<sup>3</sup>.

Presented by M.Macri'

1 Fermi National Laboratory Batavia Illinois,

2 Ferrara University and Ferrara INFN, Italy,

- 3 Genova University and Genova INFN, Italy,
- 4 University of California at Irvine,
- 5 Northwestern University,
- 6 Pennsylvania State University,
- 7 Torino University and Torino INFN, Italy.

## **Fermilab Collider Detector Facility**



## **Observation of Top Quark Production at CDF and D0 (1995)**

VOLUME 74, NUMBER 14

PHYSICAL REVIEW LETTERS

3 April 1995

#### **CDF** Detector

![](_page_6_Picture_5.jpeg)

#### Observation of Top Quark Production in $\overline{p}p$ Collisions with the Collider Detector at Fermilab

F. Abe,<sup>14</sup> H. Akimoto,<sup>32</sup> A. Akopian,<sup>27</sup> M. G. Albrow,<sup>7</sup> S. R. Amendolia,<sup>24</sup> D. Amidei,<sup>17</sup> J. Antos,<sup>29</sup> C. Anway-Wiese,<sup>4</sup> S. Aota,<sup>32</sup> G. Apollinari,<sup>27</sup> T. Asakawa,<sup>32</sup> W. Ashmanskas,<sup>15</sup> M. Atac,<sup>7</sup> P. Auchincloss,<sup>26</sup> F. Azfar,<sup>22</sup>

J. C. Yun,<sup>7</sup> A. Zanetti,<sup>24</sup> F. Zetti,<sup>24</sup> L. Zhang,<sup>34</sup> W. Zhang,<sup>22</sup> and S. Zucchelli<sup>2</sup>

#### (CDF Collaboration)

<sup>1</sup>Argonne National Laboratory, Argonne, Illinois 60439 <sup>2</sup>Istituto Nazionale di Fisica Nucleare, University of Bologna, I-40126 Bologna, Italy Brandeis University, Waltham, Massachusetts 02254 <sup>4</sup>University of California at Los Angeles, Los Angeles, California 90024 <sup>5</sup>University of Chicago, Chicago, Illinois 60637 <sup>6</sup>Duke University, Durham, North Carolina 27708 <sup>7</sup>Fermi National Accelerator Laboratory, Batavia, Illinois 60510 <sup>8</sup>Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, I-00044 Frascati, Italy Harvard University, Cambridge, Massachusetts 02138 <sup>10</sup>Hiroshima University, Higashi-Hiroshima 724, Japan <sup>11</sup>University of Illinois, Urbana, Illinois 61801 <sup>12</sup>Institute of Particle Physics, McGill University, Montreal, Canada H3A 2T8 and University of Toronto, Toronto, Canada M5S 1A7 <sup>13</sup>The Johns Hopkins University, Baltimore, Maryland 21218 <sup>14</sup>National Laboratory for High Energy Physics (KEK), Tsukuba, Ibaraki 305, Japan <sup>15</sup>Lawrence Berkeley Laboratory, Berkeley, California 94720 <sup>16</sup>Massachusetts Institute of Technology, Cambridge, Massachusetts 02139 <sup>17</sup>University of Michigan, Ann Arbor, Michigan 48109 <sup>18</sup>Michigan State University, East Lansing, Michigan 48824 <sup>19</sup>University of New Mexico, Albuquerque, New Mexico 87131 <sup>20</sup>Osaka City University, Osaka 588, Japan <sup>21</sup>Università di Padova, Instituto Nazionale di Fisica Nucleare, Sezione di Padova. I-35131 Padova. Italy University of Pennsylvania, Philadelphia, Pennsylvania 19104 <sup>23</sup>University of Pittsburgh, Pittsburgh, Pennsylvania 15260 <sup>24</sup>Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore of Pisa, I-56100 Pisa, Italy <sup>23</sup>Purdue University, West Latavette, Indiana 4/90/ <sup>26</sup>University of Rochester, Rochester, New York 14627 <sup>27</sup>Rockefeller University, New York, New York 10021 <sup>28</sup>Rutgers University, Piscataway, New Jersey 08854 <sup>29</sup>Academia Sinica, Taipei, Taiwan 11529, Republic of China <sup>30</sup>Texas A&M University, College Station, Texas 77843 <sup>31</sup>Texas Tech University, Lubbock, Texas 79409 <sup>32</sup>University of Tsukuba, Tsukuba, Ibaraki 305, Japan <sup>33</sup>Tufts University, Medford, Massachusetts 02155 <sup>34</sup>University of Wisconsin, Madison, Wisconsin 53706 <sup>35</sup>Yale University, New Haven, Connecticut 06511 (Received 24 February 1995)

We establish the existence of the top quark using a 67 pb<sup>-1</sup> data sample of  $\overline{p}p$  collisions at  $\sqrt{s} = 1.8$  TeV collected with the Collider Detector at Fermilab (CDF). Employing techniques similar

### **CDF and D0 Collaborations have spanned the Globe**

![](_page_7_Figure_1.jpeg)

# Today and the future, Muon Campus, Short Baseline Neutrino Program and Deep Underground Neutrino Experiment

![](_page_8_Figure_1.jpeg)

Czech Republic, Finland, France, Georgia, Germany, Greece, Hungary, Israel, Italy, Netherlands, Poland, Portugal, Romania, Russia, Serbia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom

# Fermilab Village, a good place to be (crucial after a 10-hour flight)

![](_page_9_Picture_1.jpeg)

# **Elementary particles & fundamental interactions**

![](_page_10_Figure_1.jpeg)

# **INTENSE: Exploring the Intensity Frontier**

![](_page_11_Figure_1.jpeg)

# Exploiting a European (Lar-TPC) Technology at Fermilab To solve neutrino mysteries

![](_page_12_Figure_1.jpeg)

with the help of an interactive map on Fermilab's website.

# Short-Baseline Neutrino Program (SBN) Deep Underground Neutrino Experiment (DUNE) at Fermilab

![](_page_13_Figure_1.jpeg)

# The muon-to-electron-conversion (Mu2e) experiment at Fermilab

Search for Charged Lepton Flavor Violation (CLFV) through the coherent conversion:

 $\mu^{-}$  + Al  $\rightarrow$  e<sup>-</sup> + Al

- Low momentum μ<sup>-</sup> beam (< 100 MeV/c)
- High intensity pulsed rate

   10<sup>10</sup> μ<sup>-</sup> /s stopped on Al target
- Stopped  $\mu^{\scriptscriptstyle \rm T}$  captured in atomic orbits
  - Cascade in the 1s state (fs)

![](_page_14_Figure_7.jpeg)

Decay in OrbitMuon Capture(BR=39%)(BR=61%) $\sqrt{2^7}Al$  $\sqrt{2^7}Al$ BackgroundNormalization

<u>Mu2e goal:</u> improve by a factor 10<sup>4</sup> the world's best sensitivity (SINDRUM II\*) on:

$$R_{\mu e} = \frac{\Gamma(\mu^- + N \rightarrow e^- + N)}{\Gamma(\mu^- + N \rightarrow \text{all captures})}$$

down to a Single Event Sensitivity of 3 x  $10^{-17}$ . SM prediction <  $10^{-49} - 10^{-52}$ , any observation would be a clear evidence of New Physics.

\*W. Bertl et al., Eur. Phys. J. C47, 337 (2006)

# The Mu2e muon beamline

![](_page_15_Figure_1.jpeg)

#### **Production Solenoid:**

8 GeV protons strike tungsten target producing mostly pions Graded B field reflects low momentum particles downstream

### **Transport Solenoid:**

Select low momentum negative muons (+antiproton absorber)

### **Detector Solenoid:**

Capture muons on Al target, absorber reduces proton background Graded B field focuses electrons in tracker fiducial volume Tracker/Calorimeter measure particles momentum/energy

# **Muography:** imaging method with cosmic-ray radiation (I)

![](_page_16_Figure_1.jpeg)

# **Muography:** imaging method with cosmic-ray radiation (II)

![](_page_17_Figure_1.jpeg)

# Network Organization: Management Board / Scientific Board

MANAGEMENT BOARD				
Simone Donati	UNIPI	Michele Weber	UBERN	
Giovanni Macedonio	INGV	Sandro Palestini	CERN	
Franco Spinella	INFN	Melissa Uchida	UCAMB	
Alessandro Iovene	CAEN	Mark Lancaster	UMAN	
Lucio Amato	TECNO IN	<b>Constantinos Andreopoulos</b>	ULIV	
Andrea Giammanco	UCLOUVAIN	Radia Sia	CLEVER	
Michel Herquet	<b>B12 CONSULTING</b>	Eliezer Piasetzki	TAU	
Mychael Tytgat	UGENT	Dezso Varga	WIGNER	
Amanda Soukoulia	SEEMS Ike	Ines Gil Botella	CIEMAT	
		Antonio Bueno Villar	UGRA	
Chair: Simone Donati				

	WORK PACKAGE	LEAD BENEFICIARY	SCIENTIFIC BOARD	
WP1	Neutrino Detectors	University of Bern	M.Weber (UNIBE), G.Raselli (INFN), A.Fava (FNAL)	
WP2	Neutrino Physics: event reconstruction tools	University of Cambridge	L.Whitehead (UNICAM), A.Menegolli (INFN)	
WP3	Neutrino Physics: data analysis	INFN	D.Gibin (INFN), A.Szeic (UNIMAN), E.Piasetzky (TAU)	
WP4	CLFV Experiments	University of Manchester	M.Lancaster (UNIMAN), E.Pedreschi (INFN), F.Spinella (INFN)	
WP5	Muography	Catholic University of Louvain	A.Giammanco (UCL), M.Tytgat (UGENT), G.Macedonio (INGV)	
WP6	<b>Dissemination and Outreach</b>	INFN	C.Vignoli (INFN)	
WP7	Transfero of Knowledge	INFN	C.Vignoli (INFN), R.Sia (CLEVER), M.Tytgat (UGENT)	
WP8	Management	University of Pisa	S.Donati (UNIPI)	
			Chair: Daniele Gibin	

## Implementation

	Planned MP	Started MP	<b>Executed MP</b>	Started/Planned %	Executed/Planned %	
UNIPI	14	5.34	5.34	38	38	
UCL	8	2.83	2.83	35	35	
INGV	3	0	0			
CAEN	10	4.47	2.47	45	25	
SEEMS	6	0	0			3 PM Planned for early 2023
UBERN	32	20.99	17.66	66	55	
UCAMBR	16	1.00	0.60	6	4	
CLEVER	18	6.40	6.40	36	36	
TAU	18	3.00	1.93	17	11	
TECNO	2	0	0			
CERN	24	19.33	15.12	81	63	
INFN	160	55,57	48.44	35	31	
UGENT	9	2.00	0.80	22	9	
UMAN	84	24.00	23.07	29	28	
WIGNER	6	3.66	3.66	61	61	
CIEMAT	10	3.00	1.26	30	13	
UGR	18	0	0			6+2+1+1 PM Planned for 2023
ULIV	22	0	0			9+8 PM Planned for 2023
	460	151.59	131.35	33	29	

![](_page_20_Figure_0.jpeg)

# **MidTerm Review Meeting - Agenda**

		Welcome - Introduction		
_	WP8	Management	Simone Donati	
+	WP1	Neutrino Detectors	Alberto Guglielmi	-
+			Michele Weber	-
+	WP2	Neutrino physics: event reconstruction tools	Daniele Gibin	-
+	WP3	Neutrino physics: data analysis	Melissa Uchida	-
+			Christian Farnese	-
		Coffee Break		-
Τ				
	WP4	Charged Lepton Flavour Violation	Mark Lancaster	
	WP5	Muography	Andrea Giammanco	
	WP6	Dissemination and Outreach	Chiara Vignoli	
	WP7	Transfer of Knowledge	Filippo Varanini	
			Michael Tytgat	
_				
_		Lunch		
+		Departs from Coconded Decorders		
+		Reports from Seconded Reserchers	All	
+		Tea Break		-
+				$\vdash$
		Virtual Tour of ICARUS at Fermilab	Angela Fava & Friends	$\square$
				1