

*LARP*

**US LHC Accelerator Research Program**

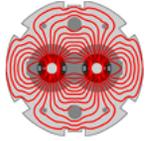
*bnl - fnal - lbnl - slac*

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LHC Commissioning & Upgrades

as part of LARP Accelerator Systems

Vladimir Shiltsev FNAL/AD



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# LARP Technical Scope

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Letter from Joint Oversight Group (DOE and NSF):

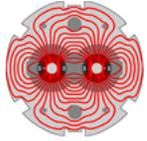
“ The research program should be planned to make optimal use of the infrastructure and expertise within participating US National Laboratories and should be worked out with CERBN on the basis of mutual interest.

The planned research could be expected to include:

participation in beam commissioning and ongoing optimization of beam parameters;

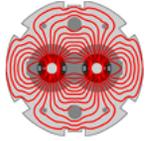
beam experiments, including construction of specialized instrumentation, aimed at both improved LHC performance and fundamental beam physics questions

design and development of equipment for improvements to the LHC, such as 2<sup>nd</sup> generation IR quads and advanced instrumentation.”



# LHC Technical Challenges

	Tevatron [March '06]	LHC ["nominal"]
Luminosity [ $\text{cm}^{-2} \text{s}^{-1}$ ]	1.7e32	100e32
Magnet style	1-in-1	2-in-1
Beam-beam tunes shift	0.025	0.010
# of bunches	36	2,808
Beam stored energy [MJ]	1	366
B-field stored energy [MJ]	300	10,600
Chromaticity snapback $dQ'$	$\sim 40$	$\sim 100$
Tolerable loss on ramp	$\sim 2-4\%$	$\sim 0.01-0.1\%$



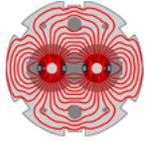
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# Host Lab

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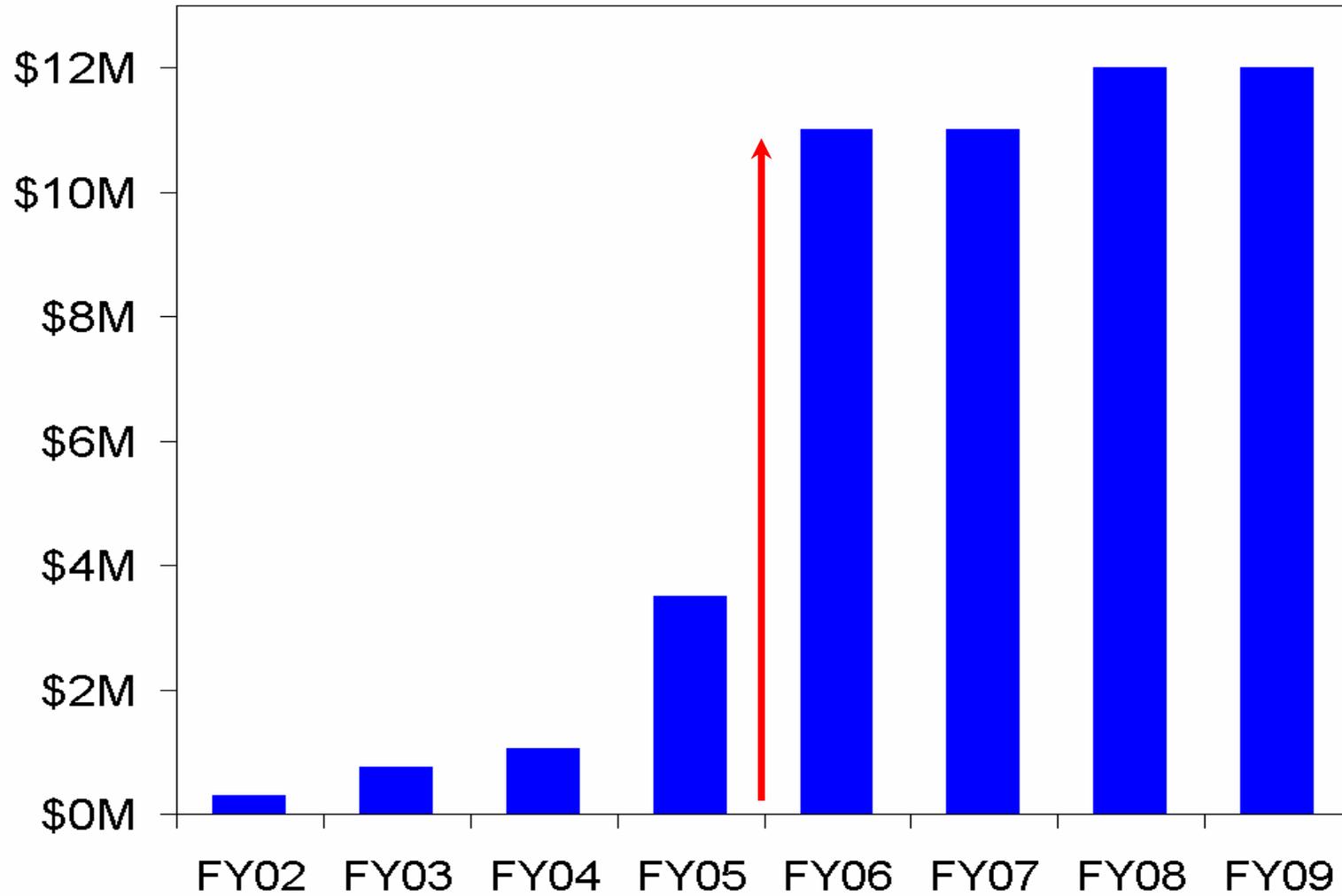
Letter from Joint Oversight Group (DOE and NSF) to FNAL Director:

“ Accordingly we request that Fermilab serve as Host Laboratory for US participation in these aspects of the Research Program, consistent with the International Agreement and its Accelerator Protocol.”



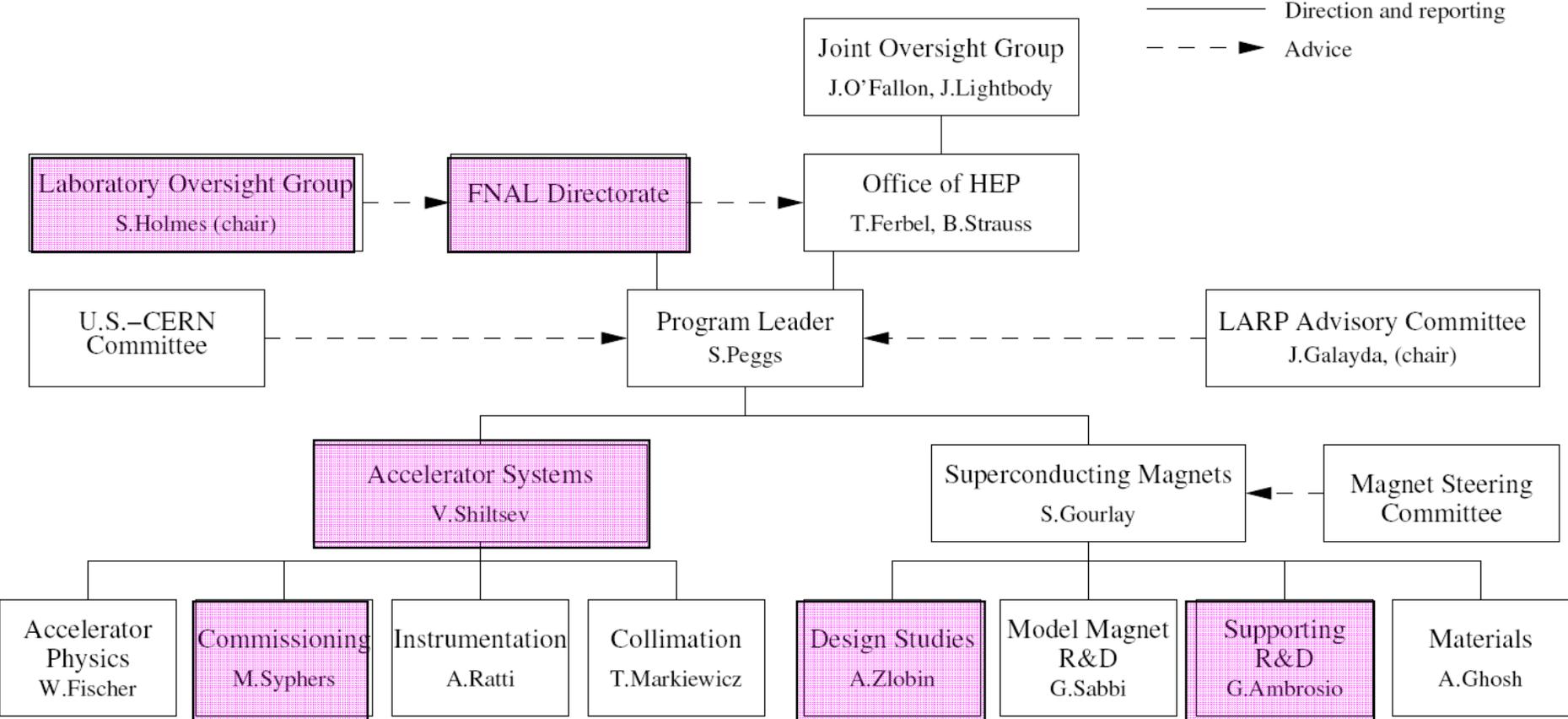
**LARP**

# Budget Scope



# US LHC Accelerator Research Program (LARP) Organization Chart

January 5, 2006



LARPAC: J.Galayda (chair), A.Chao, A.Devred, J.Minervini, C.Rode, A.Seryi, K.Wittenburg, A.Yamamoto

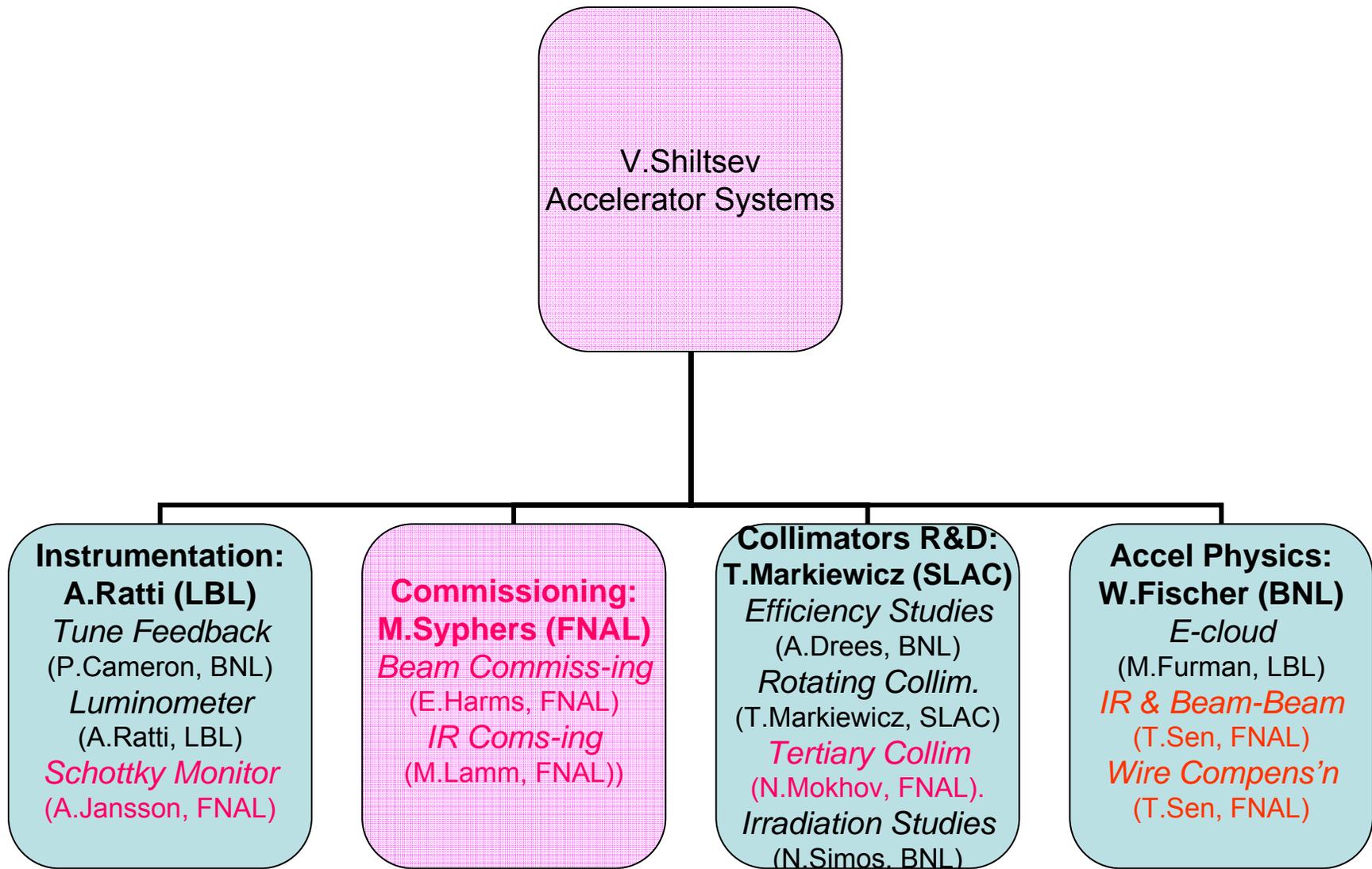
LOG: S.Holmes (chair), P.Drell, S.Ozaki, J.Siegrist

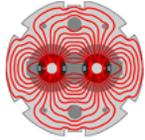
MSC: S.Gourlay, G.Ambrosio, A.Ghosh, M.Lamm, G.Sabbi, P.Wanderer, A.Zlobin

US-CERN Comm: L.Evans, R.Assmann, R.Bailey, P.Bryant, P.Lebrun, R.Ostojic, L.Rossi, F.Ruggiero, R.Saban, H.Schmickler  
S.Holmes, S.Gourlay, M.Harrison, J.Kerby, P.Limon, S.Peggs, T.Raubenheimer, V.Shiltsev, J.Siegrist, V.Yarba



# Accelerator Systems Org Chart

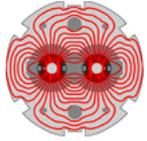




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# FY06 Accelerator Systems Budget

Mar 31, 2006			Total	Labor+MTSC			
WBS				BNL	FNAL	LBNL	SLAC
US LHC Accelerator Research Program			11000	3264	3300	4086	350
1	<b>Accelerator Systems</b>	<b>Shiltsev</b>	<b>3684</b>	<b>875</b>	<b>1200</b>	<b>1309</b>	<b>300</b>
1.1	<b>Instrumentation</b>	<b>Ratti</b>	<b>1635</b>	<b>450</b>	<b>250</b>	<b>935</b>	<b>0</b>
1.1.1	Phase I						
1.1.1.1	Tune feedback	Cameron	430	405	25		
1.1.1.2	Luminometer	Ratti	960	25		935	
1.1.1.4	Schottky monitor	Jansson	245	20	225		
1.2	<b>Commissioning</b>	<b>Syphers</b>	<b>879</b>	<b>65</b>	<b>670</b>	<b>144</b>	<b>0</b>
1.2.1	Phase I						
1.2.1.1	Beam Commissioning	Harms	335	35	300		
1.2.1.2	Interaction Region Commissioning	Lamm	501	30	335	136	
1.2.1.3	Hardware Commissioning	Lamm	43		35	8	
1.3	<b>Collimation</b>	<b>Markiewicz</b>	<b>500</b>	<b>150</b>	<b>50</b>	<b>0</b>	<b>300</b>
1.3.1	Phase I						
1.3.1.1	Cleaning efficiency studies	Drees	50	50			
1.3.2	Phase II						
1.3.2.1	Rotating Collimator R&D	Markiewicz	320		20		300
1.3.2.2	Tertiary collimator study	Mokhov	30		30		
1.3.2.3	Irradiation studies	Simos	100	100			
1.4	<b>Accelerator Physics</b>	<b>Fischer</b>	<b>670</b>	<b>210</b>	<b>230</b>	<b>230</b>	<b>0</b>
1.4.1	Studies						
1.4.1.1	Electron Cloud	Furman	200	50		150	
1.4.1.2	Interaction Regions & Beam-Beam	Sen	260	0	180	80	
1.4.1.3	Beam-Beam wires	Sen	210	160	50		

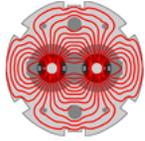


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# FY'06

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- All tasks involve multiple labs
- Matrix organization across multiple labs is not without its challenges
- Good communications and a lot of travel are necessary
- All “direction and reporting” mechanisms are now in place
- First year of the big funding step from ~3M\$ to 11M\$

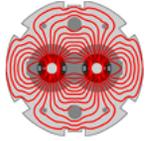


# Accelerator Division activities

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- **Instrumentation**
  - TuneTracker and Tune Feedback in Tevatron and RHIC
  - 4.8GHz Schottky monitor design
- **Commissioning**
  - Hardware commissioning
  - Beam commissioning
  - LHC@FNAL, communication and documentation
- **Collimation**
  - Tertiary collimators to protect detectors
- **IR Design, Beam-beam and Energy Deposition**
  - Beam-beam simulations and experiment at RHIC
  - Wire compensation device design and tests
  - Quad-first and Dipole-first upgrade optics

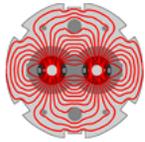


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# Accelerator Division Efforts

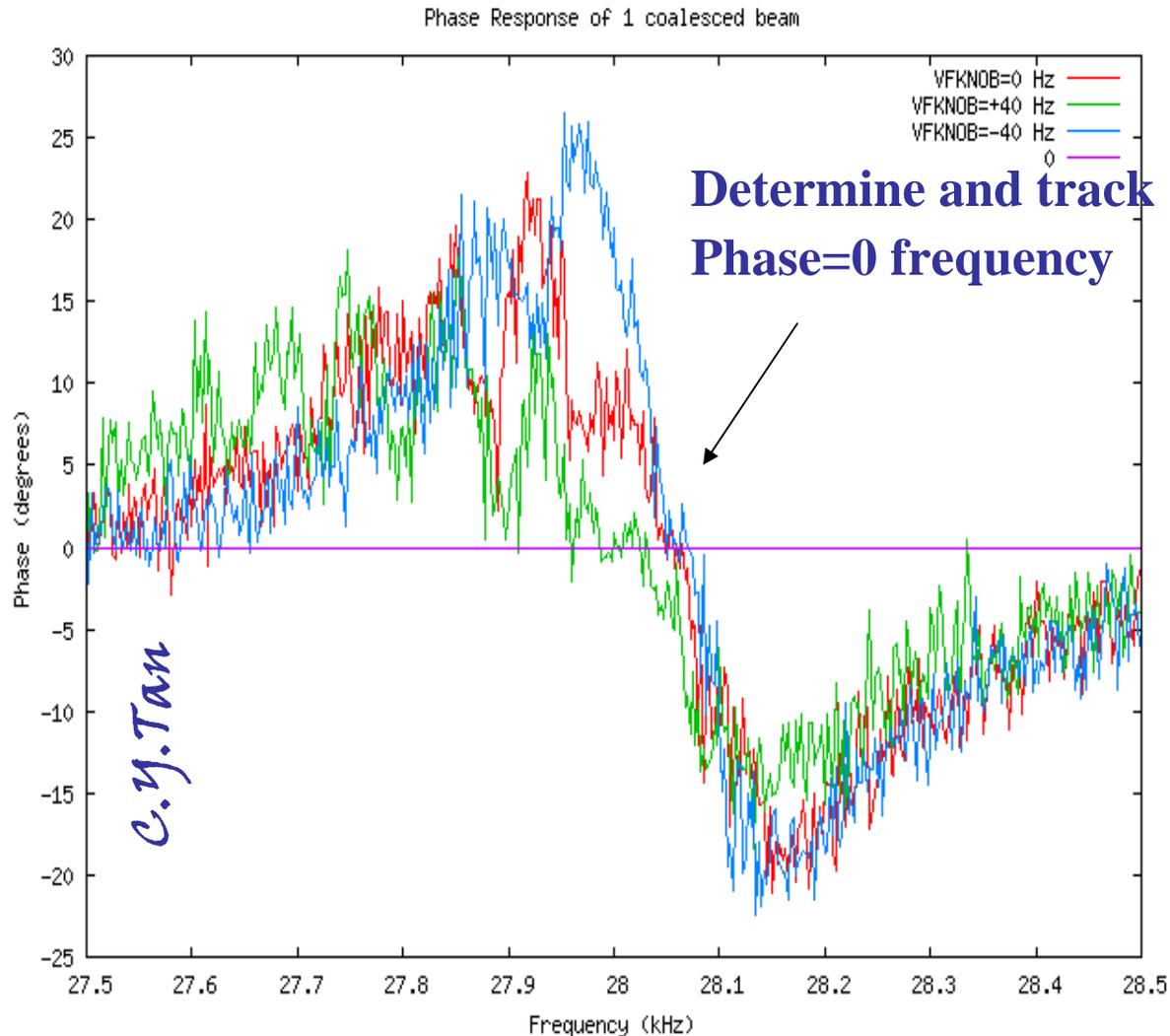
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- FY'06 budget 0.9M\$
- Current effort:
  - 17 people:
    - 7 Engineers and Designers
    - 3 Post-docs and guest scientists
    - 7 Physicists
  - Total ~5.5FTE
- Oct'06: 1 person scheduled to start 1 yr term to do LHC generic hardware commissioning

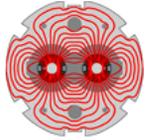


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# Fast Tevatron Tune Tracker

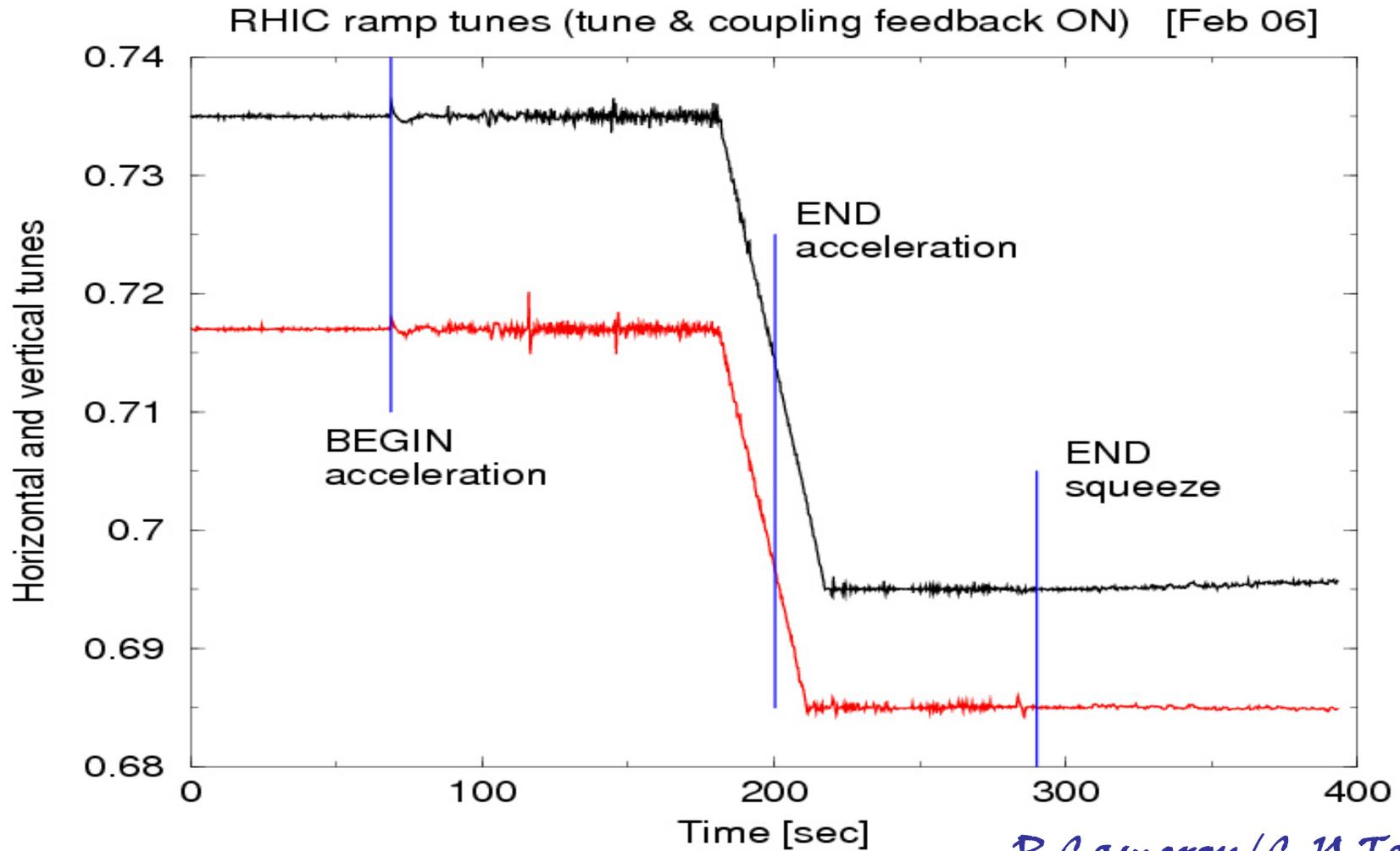


- Beam is lightly excited over a frequency range around  $f_{\text{betatron}}$
- Zero phase response frequency declared =  $Q$
- Accuracy in  $Q \sim 0.0001$
- Very fast method (3Hz)
  - Works on every Tev ramp and in LB squeeze
- Change  $dP/P$  and determine  $Q'$ 
  - Stat accuracy  $\sim 0.2$
  - Syst error  $\sim 0.5$  unit

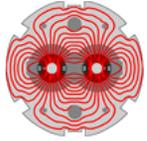


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# TCFB on RHIC ramp



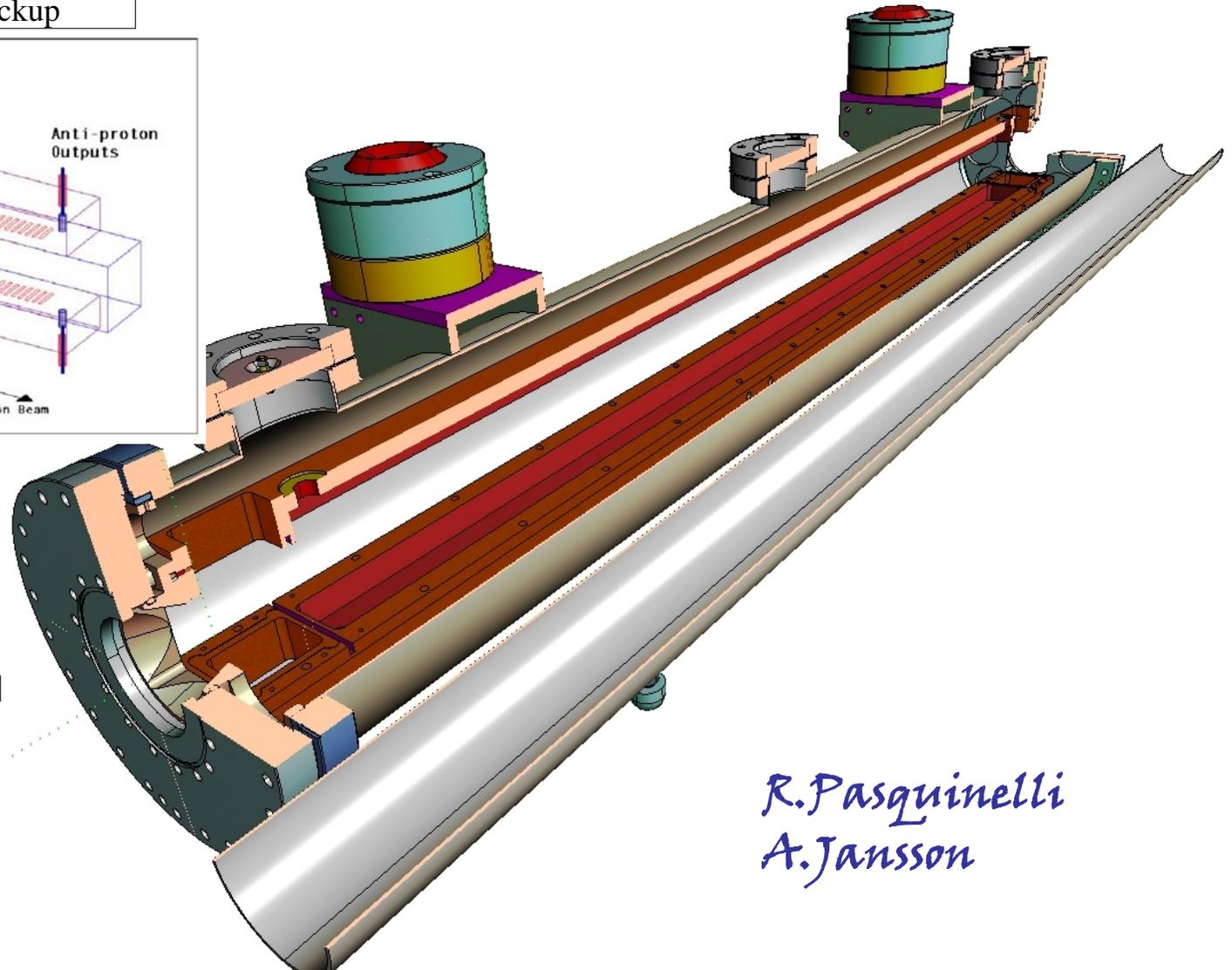
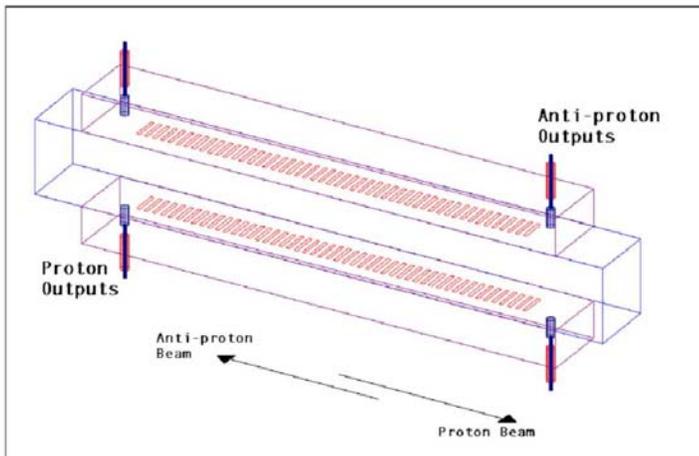
*P. Cameron/C.Y. Tan*



# LHC 4.8 GHz Schottky Design

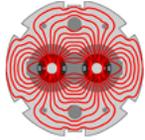
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Slotted Waveguide Pickup



- Remarkable Progress:
  - Final drawings ready for CERN inspection
  - Final Design Review 06/19/06 at CERN

*R. Pasquinelli  
A. Jansson*

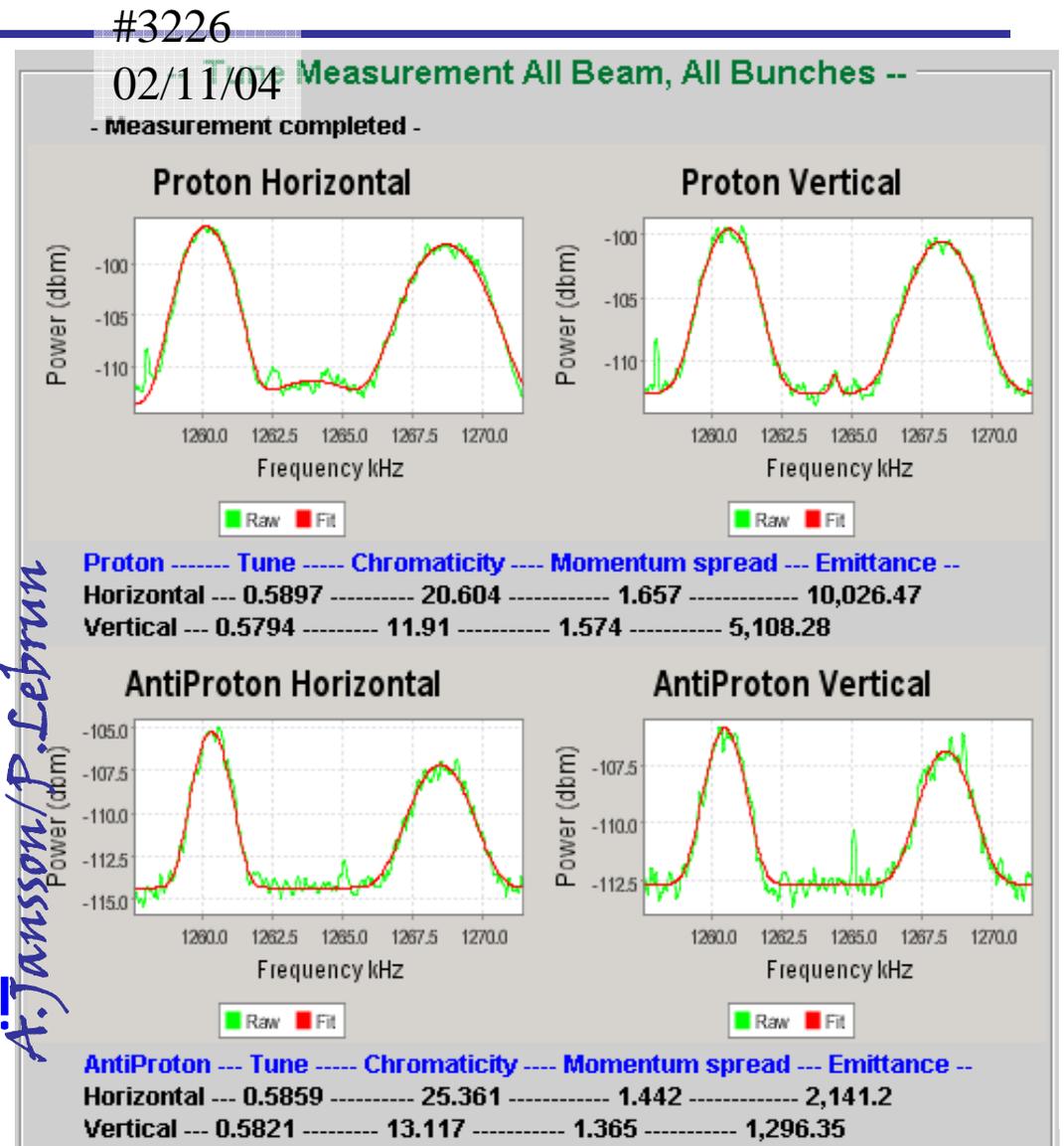


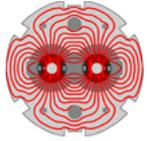
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# 1.7GHz Schottky Spectra

- Q and 1-Q lines are seen
- Fit gives:
  - Betatron frequency (accuracy  $\sim 0.001$ )
  - $dP/P \propto$  sum of two widths
  - $C_{vh} \propto$  difference of two widths
  - Emittance  $\propto$  area under the peaks
- For each bunch!  
... non-invasive!

A. Jansson / P. Lebrun

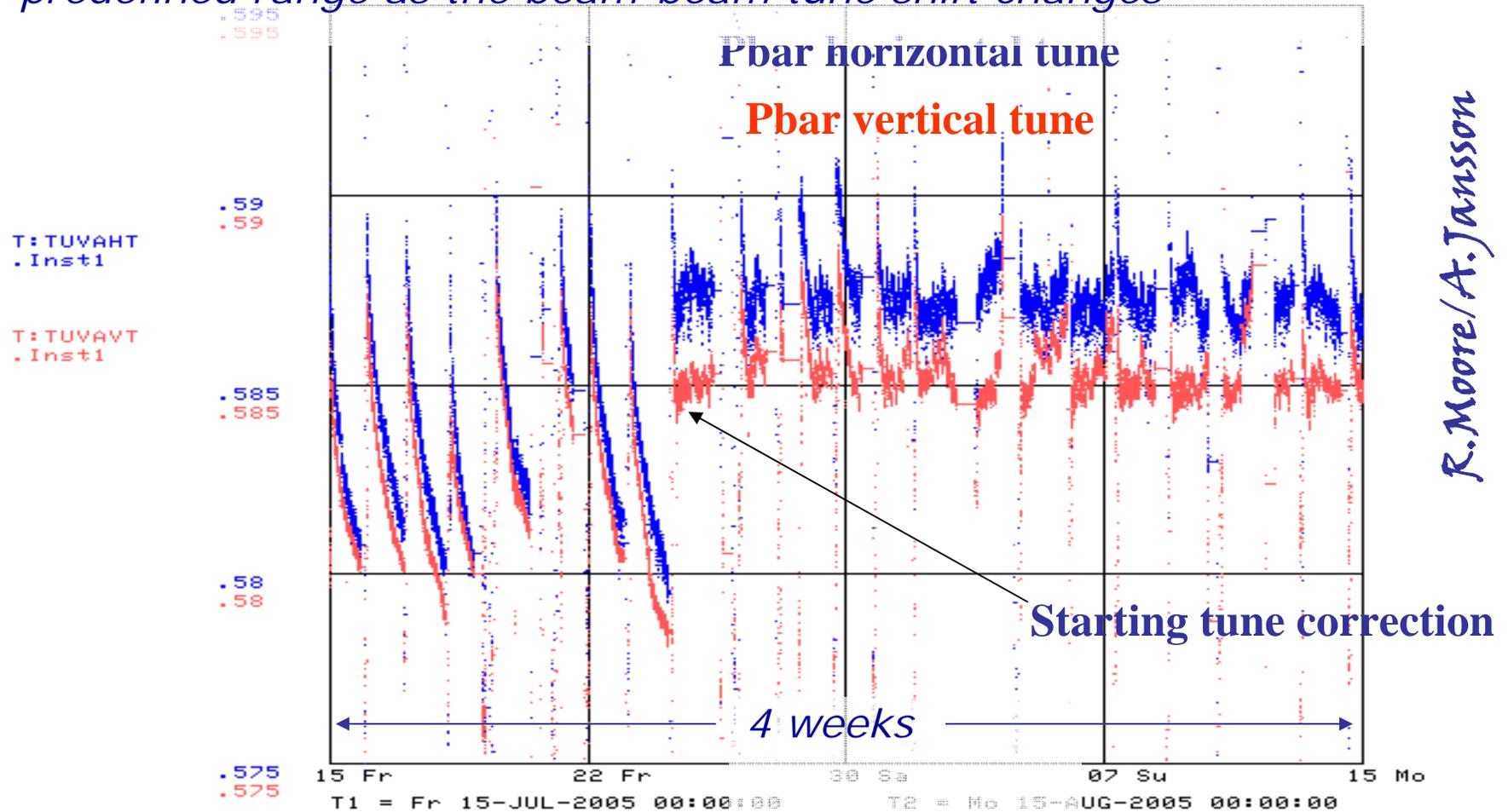




# Tevatron Tune Stabilization

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- Operators use 1.7 GHz Schottky data to keep  $p\bar{p}$  tunes within a predefined range as the beam-beam tune shift changes





# LARP Hardware Commissioning Tasks

## Installation Oversight

Since DOE Review Last Fall:

- First USLHC String (Q1-Q3/Feedbox/D1) transported to tunnel
- LARP Oversight and technology transfer for USLHC interconnects
- Transportation and Installation of Second IR quad/DFBX/D1 on going.
- Limited LARP oversight planned for all US deliverable installations

*M. L. Amin*



Photos from Jan 2006 IR 8L installation

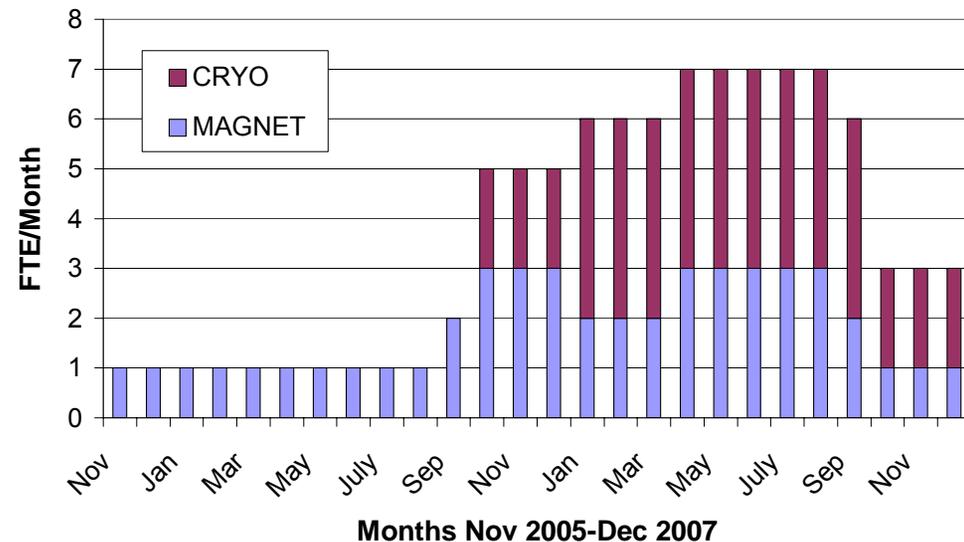


# LARP Hardware Commissioning Tasks

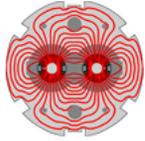
## Commissioning of US Deliverables and General HC

- LARP commissioners receive “Project Associate” status, join a CERN group (AT/ACR or AT/MEL) for nominally one year and contribute to the groups general HC responsibilities as well as US deliverables.
- Short term HC support from US experts as needed
- One commissioner stationed at CERN now. 3-4 additional to follow in the fall of 2006.
- Peak participation coincides with anticipated peak commissioning period FY07.

Proposed Profile for LARP Hardware Commissioners



*M. Syphers/M. Lamm*



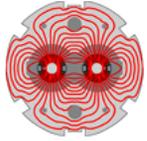
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# Beam Commissioning Status

- Several US visitors to CERN in January/February 06
  - Nearly continuous presence for ~6 weeks
  - Chamonix workshop
  - Beam Commissioning logistics
  - Software
  - CCC opening
  - get to know LHC beam principals
- Informal review of LHC Beam Commissioning structure completed  
(~13 people are currently being considered )
- Beam Commissioning 'Expression of Interest'  
(circulated in all 4 Labs)
- Refining areas of involvement, beginning to assign names/share with CERN counterparts
- Gearing up for LARP presence during SPS running, more so for Sector test
- Details presented in Poster Session



*E. Harms/M. Syphers*



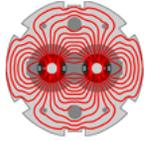
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# LHC@FNAL Status

- Committee's work complete
- Endorsement received from
  - Fermilab Directorate
  - Affected Fermilab Divisions/Sections (AD, PPD, CD, FESS)
  - LARP management
  - CMS management
- Construction plans in development
- Funds set aside/awaiting DOE approval
- Center planned to be open in September 2006
- More detail in Breakout session

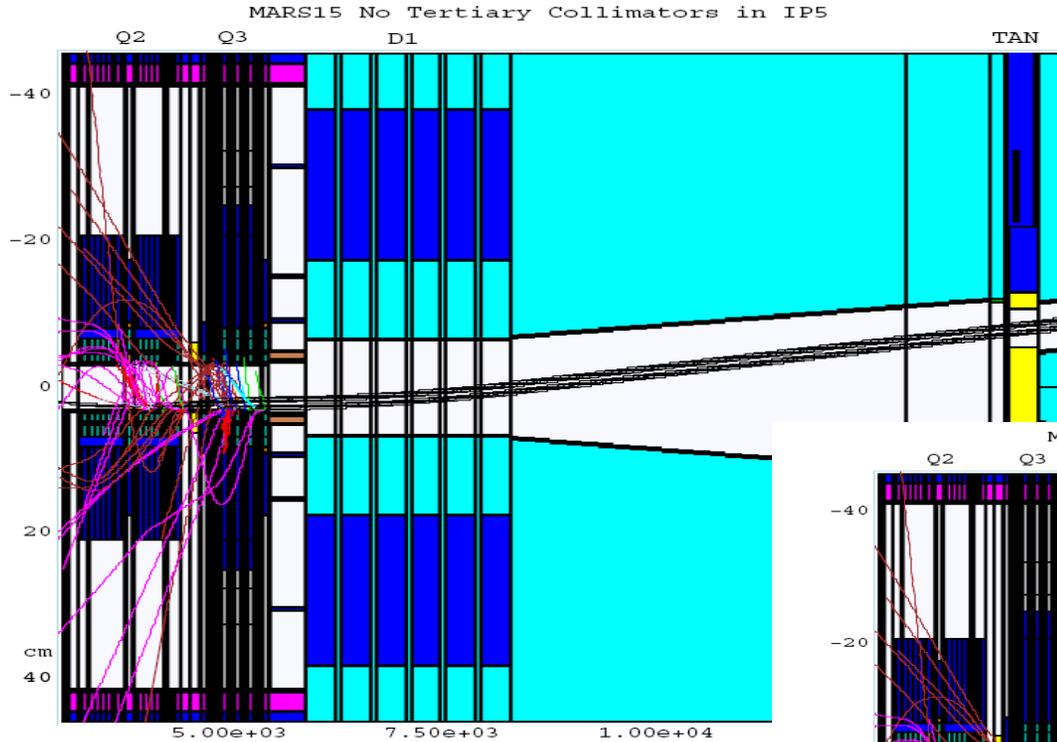


*E. Harms/E. Gotschalk*

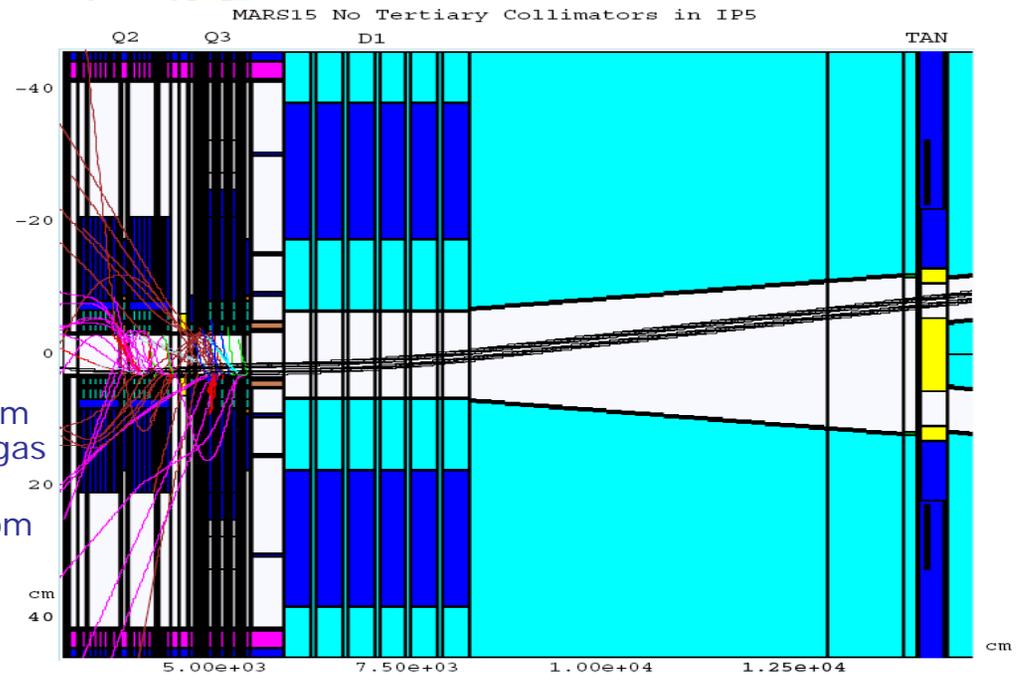


# TERTIARY Collimators at CMS

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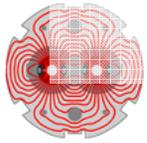


*N. Mokhov/M. Monville*



Particle tracks  $E > 10$  GeV for a few 7-TeV protons at

- Simulations of Detector protection against beam losses at secondary collimators, due to beam-gas and unsynchronized aborts
- Two 1m long copper jaws H,V at 7-8 sigma from beam, 145 m from IP



# RHIC long-range beam-beam compensator design

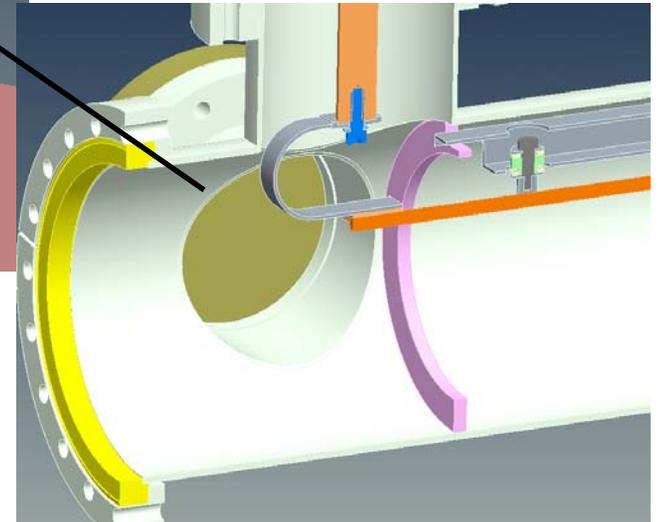
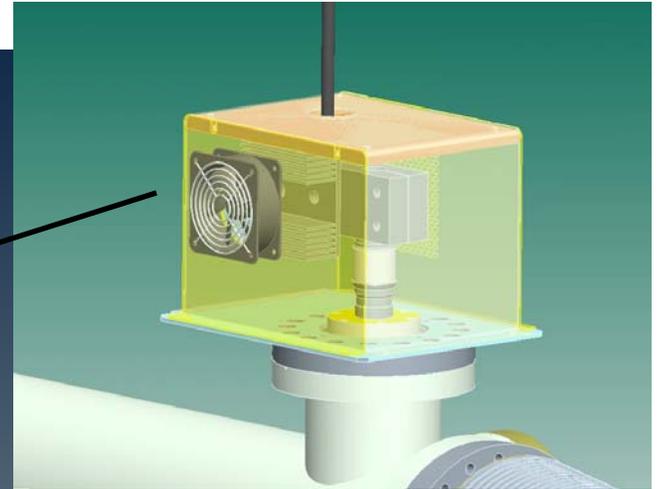
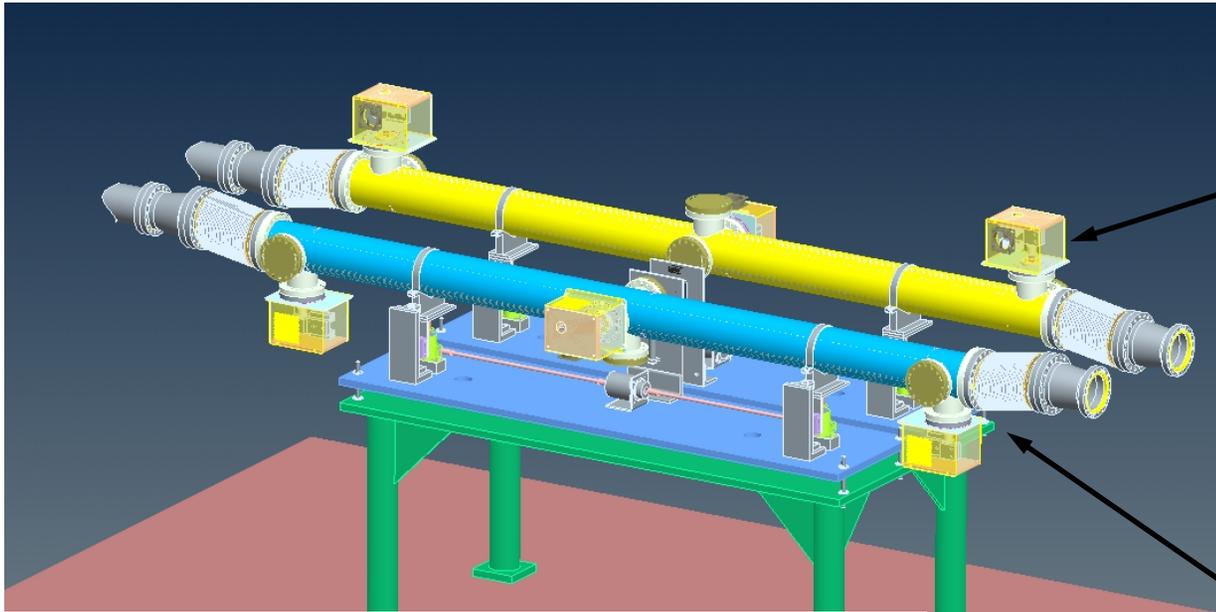
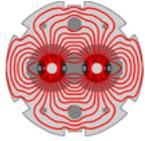


Table 3: Main parameters for RHIC long-range beam-beam compensators.

quantity	unit	value	comment
integrated strength ( $IL$ ), single interaction	Am	9.6	
maximum integrated strength ( $IL$ ) <sub>max</sub>	Am	125	
length of wire $L$	m	2.5	
radius of wire $r$	mm	3.5	
number of heat sinks $n$	...	3	at both ends and in middle
electrical resistivity $\rho_e$	$\Omega\text{m}$	$1.72 \times 10^{-8}$	Cu (at 20°C)
heat conductivity $\lambda$	$\text{Wm}^{-1}\text{K}^{-1}$	384	Cu (at 20°C)
density $\rho_g$	$\text{kg/m}^3$	$8.96 \times 10^3$	Cu (at 20°C)
thermal expansion coefficient	$\text{K}^{-1}$	$1.68 \times 10^{-5}$	Cu (0 to 100°C)
melting temperature	K	1083	Cu
radius of existing beam pipe $r_p$	mm	60	
current in wire $I$ , single interaction	A	3.8	
maximum current in wire $I_{max}$	A	50	
electric resistance $R$	$\text{m}\Omega$	1.12	
maximum voltage $U_{max}$	mV	55.9	
maximum dissipated power $P_{max}$	W	2.8	
maximum temperature change $\Delta T_{max}$	K	15	
maximum change in length $\Delta L_{max}$	mm	0.4	
vertical position range	mm	65	
vertical position range	$\sigma_y$	10.6	for $\gamma = 107$ , $\beta^* = 1$ m, and $\epsilon_n = 20$ mm-mrad
weight of wire $G$	kg	0.9	

*T.Sen/W.Fischer*

In CY06 – construct and install a wire compensator in RHIC, downstr. of Q3 in IR6



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## Beam-beam experiments, simulations

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- **RHIC beam-beam experiments in April 2006**

Motivation: Test of wire compensation in 2007

Determine if a single parasitic at top energy causes beam losses that need to be compensated. Similar experiment done last year at injection energy - found strong effects at separations  $\leq 6\sigma$ .

2 experiments done so far – April 5<sup>th</sup>, April 12<sup>th</sup>

- **Beam-beam simulations of 2006 experiments**

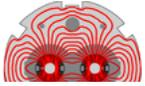
Motivation: Tests and improvements of codes, predictions of observations in 2006 and of wire compensation

Four groups

FNAL: V. Ranjbar, T. Sen; SLAC: A. Kabel; LBL: J. Qiang;  
University of Kansas: J. Shi

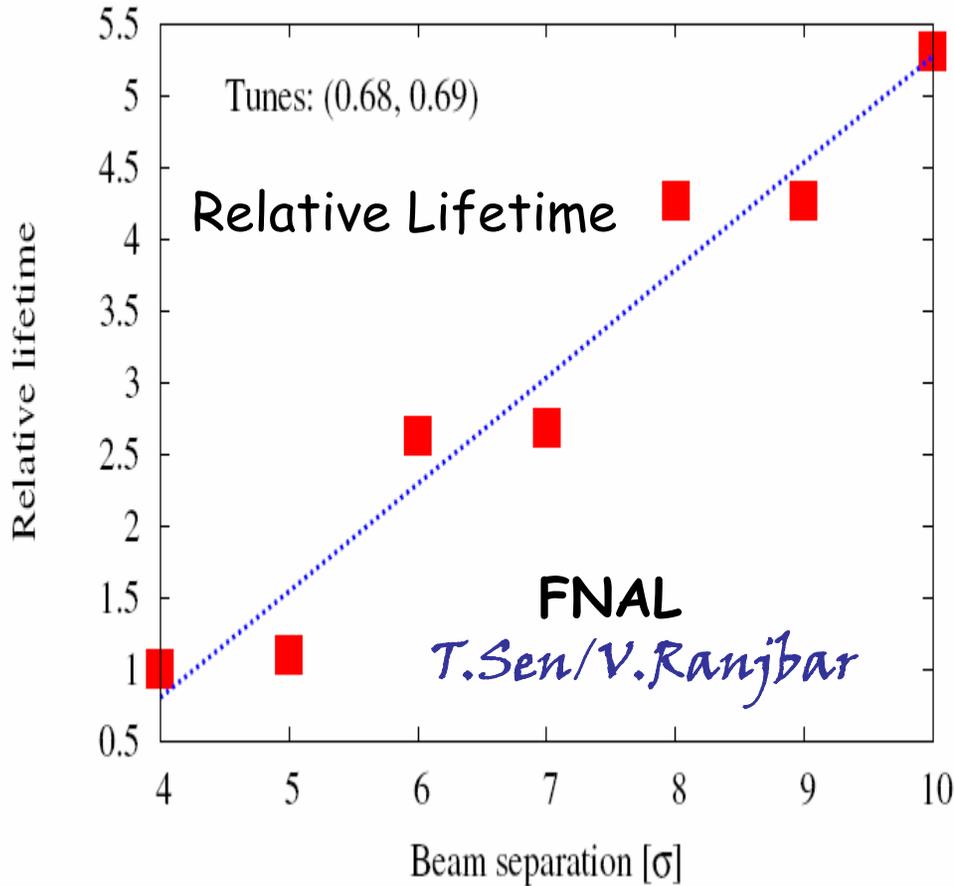
Website: <http://www-ap.fnal.gov/~tsen/RHIC>

for information exchange and results

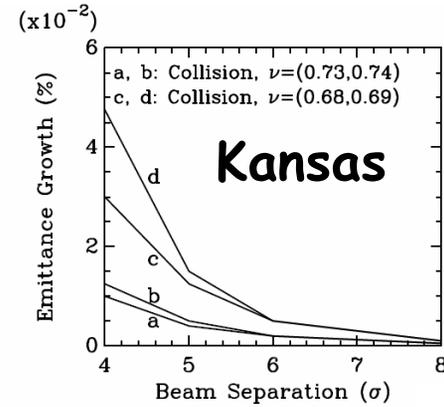


# Beam-beam simulation results

Relative lifetimes from BBSIM vs beam separation

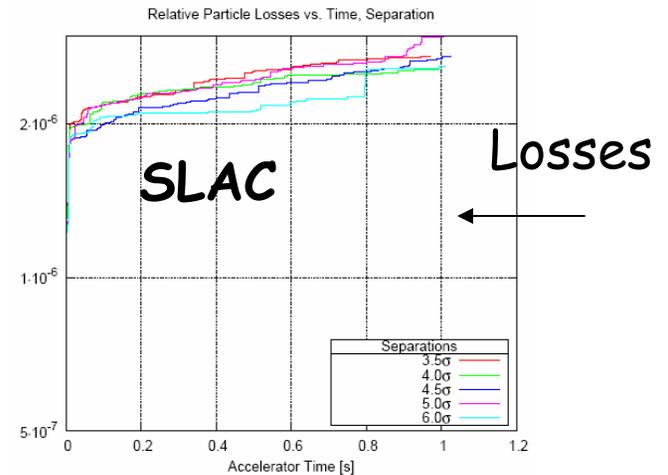
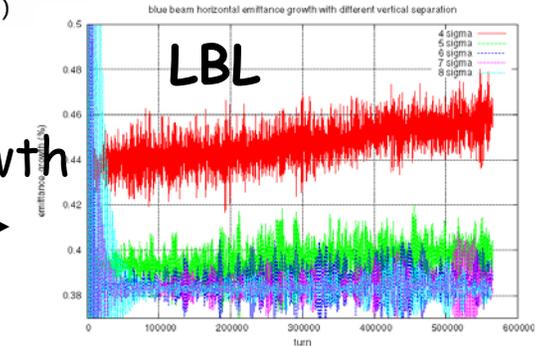


BBSIM (VR, TS) simulations for lifetime show a **linear dependence on separation**

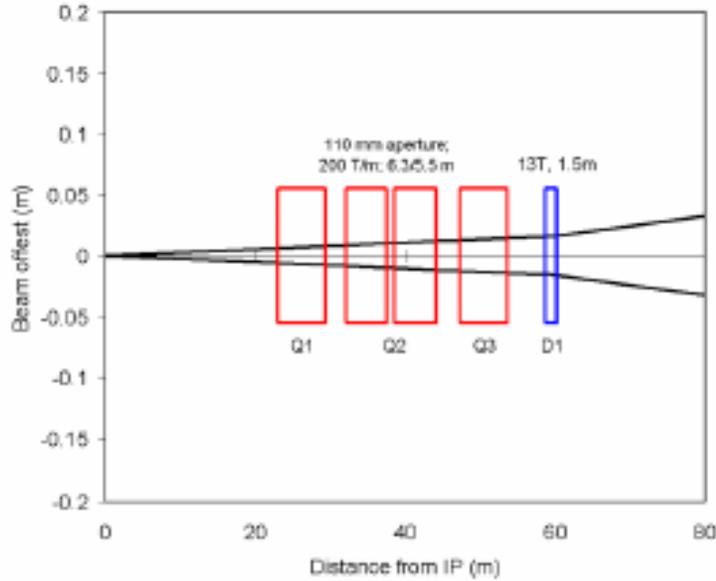


No sextupoles

Emittance growth



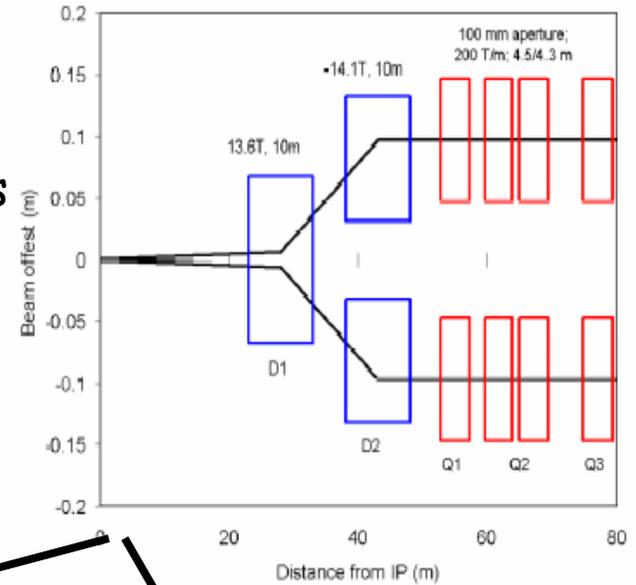
# IR Layouts



Baseline Layout  
 Quads first  
Too many parasitics

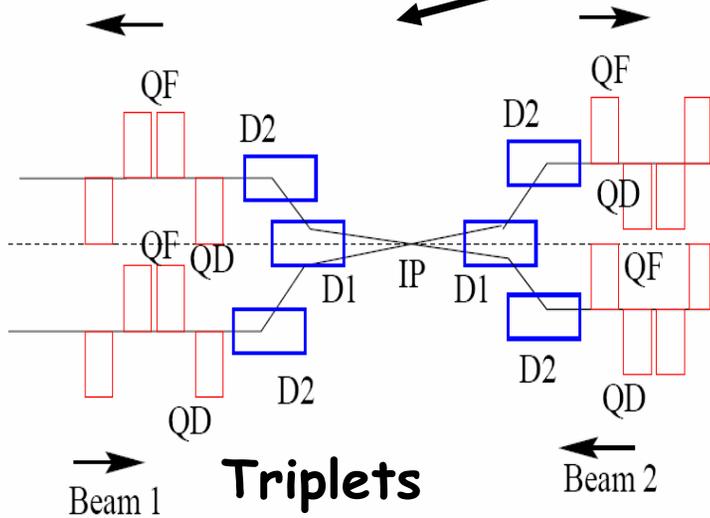


Dipoles first layout

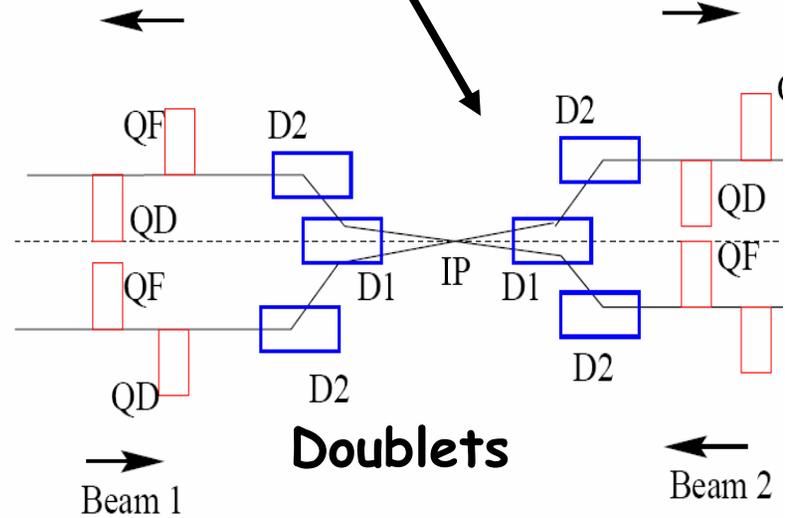


Early separation  
 but ...

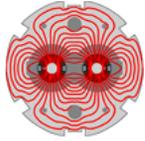
*J. Johnstone/T. Sen*



Dipole first layout: triplet focusing



Dipole first layout: doublet focusing

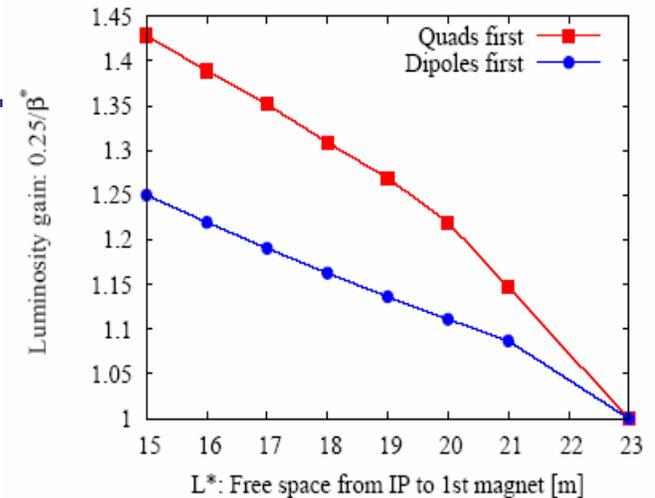


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# IR Optics Issues

## IR Magnet apertures and fields

	Pole tip field [T]	Aperture [mm]
Quads 1 <sup>st</sup>	10	101
Dipoles 1 <sup>st</sup> : triplets	11	107
Dipoles 1 <sup>st</sup> : doublets	10	104



## Energy Deposition

Major issue in all optics, but dipole designs more challenging.

## Beam-beam interactions

Demonstration of wire compensation would favor quads 1<sup>st</sup>.

## Chromaticity and Nonlinear Correctors

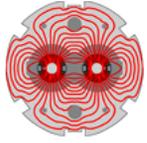
Corrector strengths lower with quads 1<sup>st</sup> but independent control of 2 beams with dipoles 1<sup>st</sup>.

## Luminosity gain with lower L\*

Larger gain with quads 1<sup>st</sup>.

## Flux jumps in IR magnets

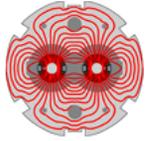
Chromaticity jumps small (~2 units) with  $\Delta b_3 = 1$  in both optics if spurious dispersion in IR is controlled to ~1cm at IP. Nonlinear effects need to be studied



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# BackUp Slides

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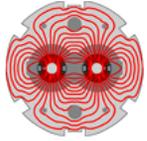


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# Communication/Coordination

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- **Communication within LARP:**
  - VideoConf of all AS L2s+Steve ~once/mos
  - One-on-one meetings (site visits, reviews, etc) ~once/qrtr
  - Collaboration meetings ~twice/year
- **Communication with CERN**
  - First “long-termers” (P.Limon et al)
  - Visits (HC, BC, Instr, etc) >1/mos
  - Workshops (e.g. TAN) and reviews (e.g. RC) ~once/qrtr
  - US-CERN meetings ~ once/yr
- **LARP Doc DB is functioning:**
  - ~250 docs uploaded from Oct'05-Apr'06

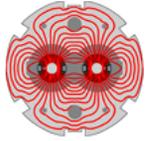


*LARP*

# New Initiatives

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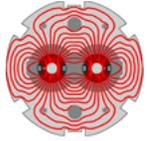
- AC dipole
- dB/B measurements
- Crystal collimation
- Super-SyncLite
- e-lenses for Head-on B-B Compensation
- Crab cavities
- 1.5TeV Injector in LHC tunnel LER-LHC
- Optical Stochastic Cooling



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# Counting ...





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# Long Range Beam-Beam

SPS :  $\tau \sim d^5$

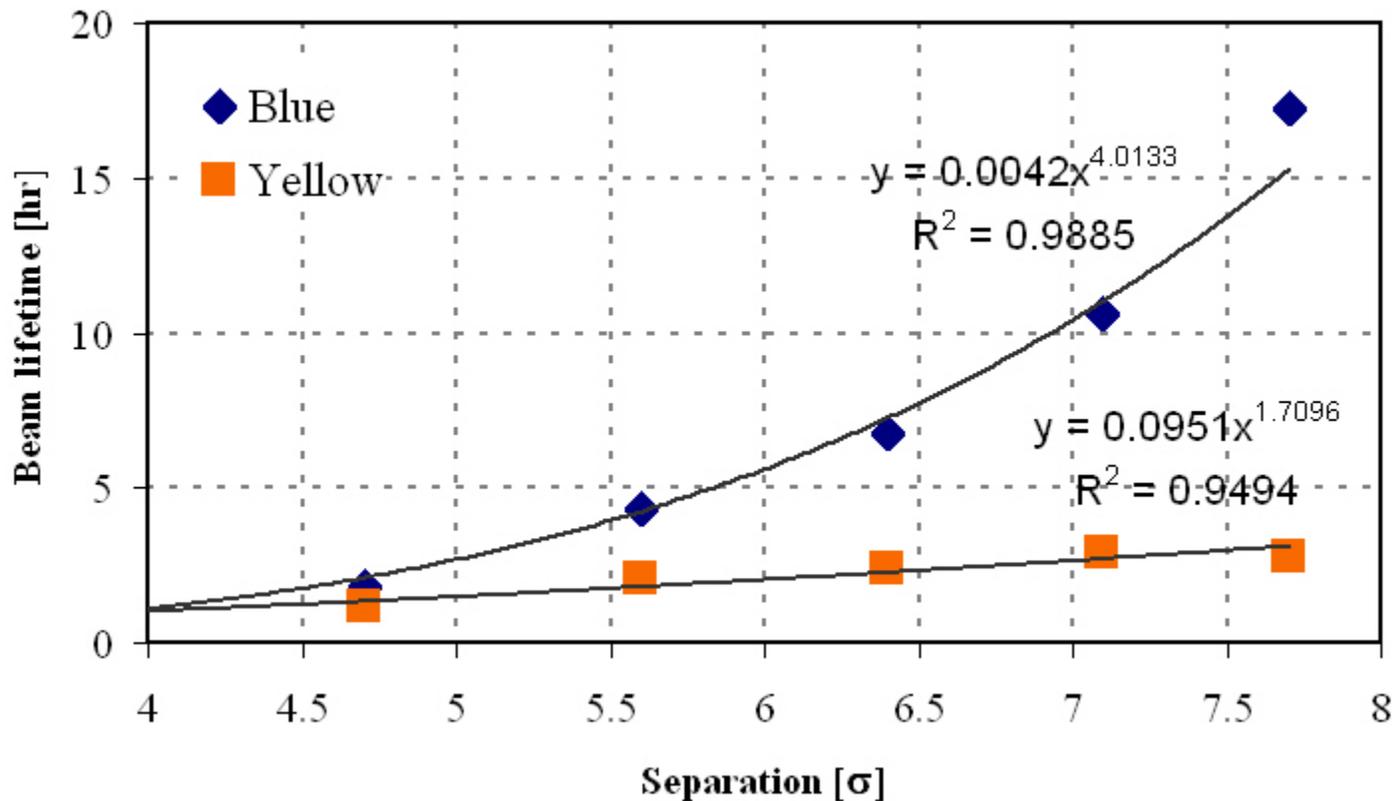
[measured 11/09/04]

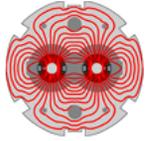
Tevatron:  $\tau \sim d^3$

[measured in HEP stores, TEL]

RHIC :  $\tau \sim d^4$  or  $d^2$

[measured 04/28/05, scan 4]

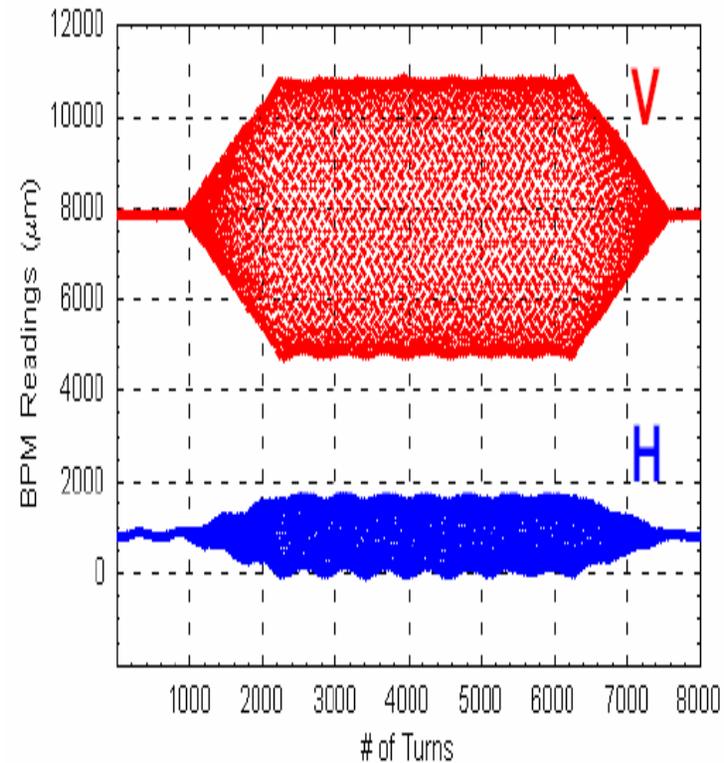




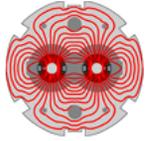
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# AC dipole

- Recent results from the Tevatron
- Collaboration formed including Fermilab, BNL and CERN.
- Formal proposal for LHC at this meeting



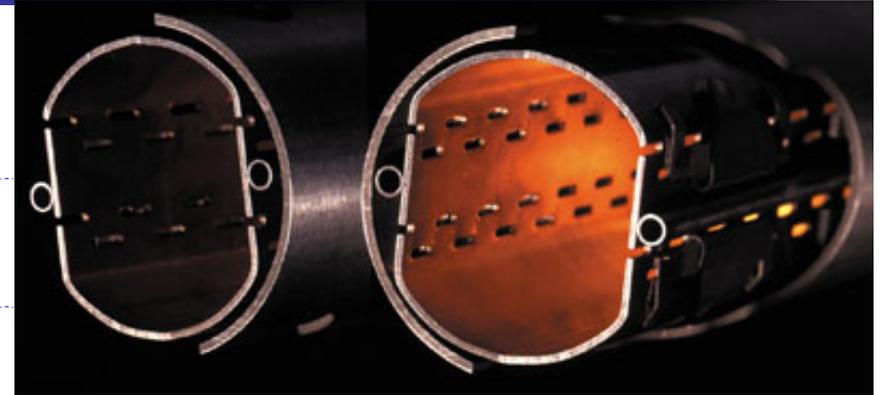
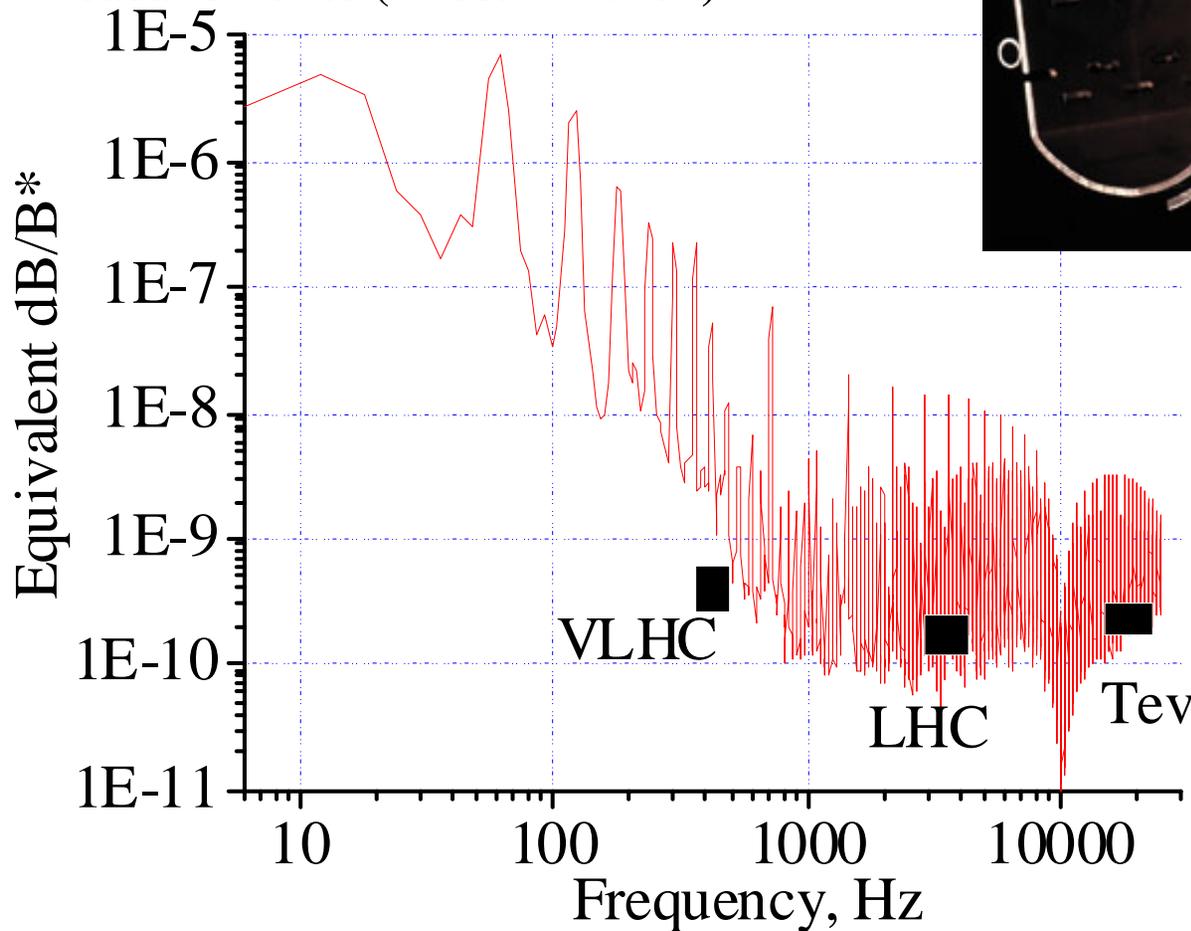
**First AC dipole data in the Tevatron**



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# New Initiatives: dB/B Fluctuations

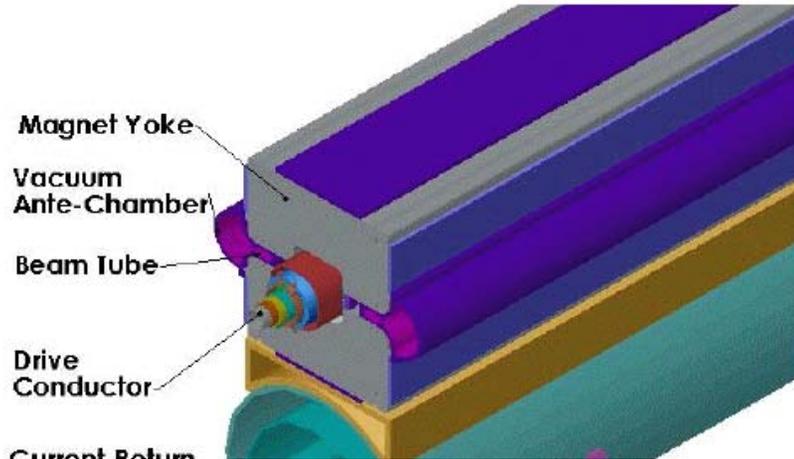
Tevatron Stand-Alone Dipole measurements (Proc. PAC'01)



LHC screen: light and feels 20 K He flow turbulence; B-flux is constant at 3kHz  $\rightarrow$  dB/B  $\sim$  dR/R  $\rightarrow$  need dR < 1A to blow horizontal emittance

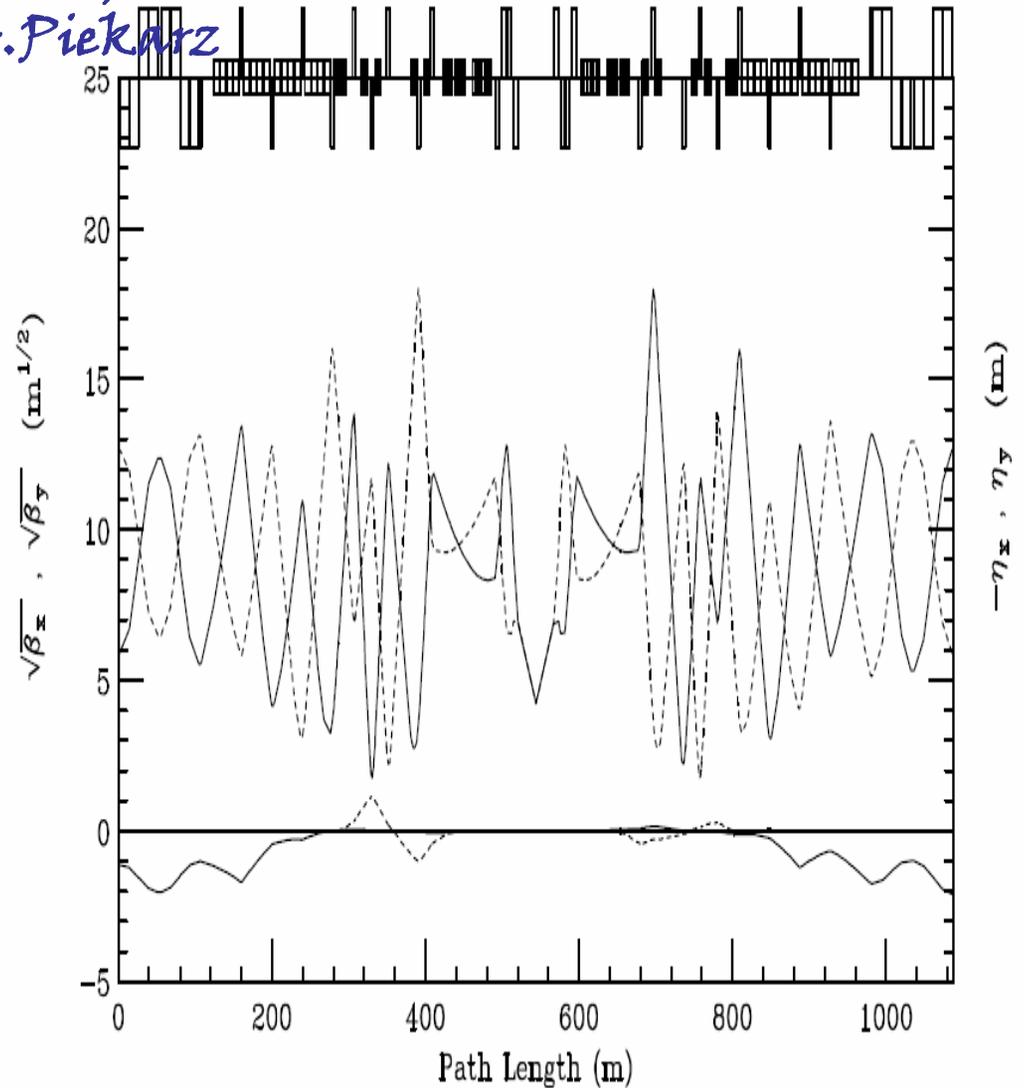
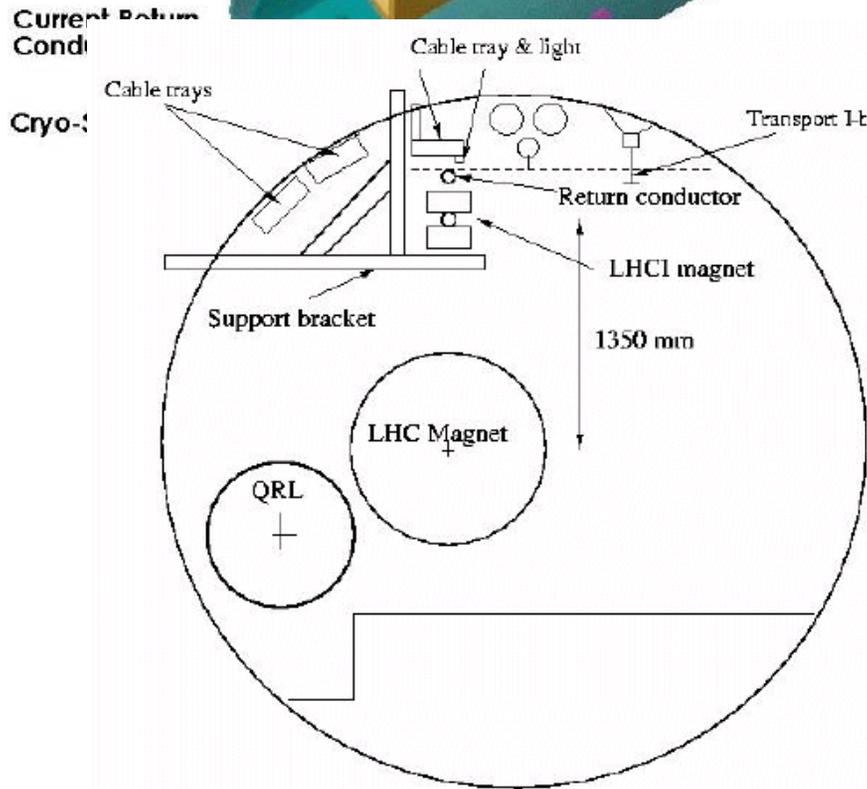
Can be measured at CERN MMF and in Tev

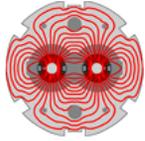
# 1.5 TeV SuperFerric Injector in LHC tunnel



J. Johnstone  
 T. Sen,  
 H. Piekarz

LHC-I Optics @ IR1/5 :  $\beta^* = 18.00\text{m}$



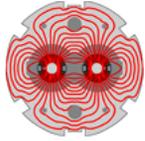


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# AD ManPower

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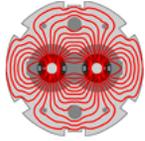
Quantity	FTE	Amount	Fringe	Burdened Cost	Transaction Source	Job Name
856.88	5.22	42,481.43	25,055.55	67,536.98		APPLICATIONS PHYSICIST Total
739.96	4.54	39,069.36	23,043.11	62,112.47		APPLIED SCIENTIST Total
331.40	2.00	12,780.71	7,538.06	20,318.77		ASSOCIATE SCIENTIST Total
322.20	1.93	9,493.09	5,599.02	15,092.11		DESIGNER Total
644.08	3.96	35,650.03	21,026.39	56,676.42		ENGINEER Total
254.40	1.56	9,412.14	5,551.28	14,963.42		ENGINEERING ASSOCIATE Total
167.32	1.02	7,663.80	4,520.11	12,183.91		ENGINEERING PHYSICIST Total
281.28	1.77	9,813.86	5,788.21	15,602.07		GUEST SCIENTIST Total
405.36	2.41	11,838.04	6,982.08	18,820.12		RESEARCH ASSOCIATE Total
1482.16	9.05	73,093.26	43,110.40	116,203.66		SCIENTIST Total
65.28	0.42	2055.04	1,212.06	3,267.10		TECHNICAL SPECIALIST Total
5550.32	33.9	253350.76	149,426.28	402,777.04		Grand Total



**LARP**

# AD Man-Power

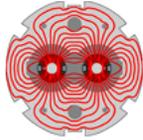
Task Number	Quantity	FTE	Amount	Fringe	Burdened Cost
20.12.1.1.9 Total	404.08	2.41	20,434.50	12,052.27	32,486.77
20.29.1.1.9 Total	1276.60	7.96	61,575.06	36,316.97	97,892.03
31.1.1.1.1 Total	303.32	1.84	11,678.19	6,887.80	18,565.99
31.1.1.1.4 Total	1311.32	8.02	57,528.95	33,930.57	91,459.52
31.1.2.1.1 Total	404.28	2.48	20,531.28	12,109.35	32,640.63
31.1.3.2.2 Total	217.68	1.36	11,853.43	6,991.15	18,844.58
31.1.4.1.2 Total	651.28	3.91	32,461.29	19,145.67	51,606.96
31.1.4.1.3 Total	576.96	3.37	20,966.69	12,366.15	33,332.84
31.2.1.3.3 Total	404.8	2.55	16321.37	9,626.34	25,947.71
<b>Grand Total</b>	<b>5550.32</b>	<b>33.9</b>	<b>253350.76</b>	<b>149,426.28</b>	<b>402,777.04</b>



**LARP**

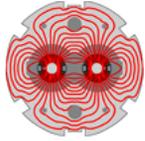
# AD Man-Power

Period	Quantity	FTE	Amount	Fringe	Burdened Cost
<b>OCT05-06 Total</b>	514.28	3.06	25,865.54	15,255.50	41,121.04
<b>NOV05-06 Total</b>	494.72	3.09	23,998.58	14,154.36	38,152.94
<b>DEC05-06 Total</b>	759.80	5.00	33,807.95	19,939.93	53,747.88
<b>JAN-06 Total</b>	921.72	5.76	42,026.15	24,787.02	66,813.17
<b>FEB-06 Total</b>	879.76	5.50	42,544.91	25,092.99	67,637.90
<b>MAR-06 Total</b>	1097.88	5.97	43,948.71	25,920.95	69,869.66
<b>APR-06 Total</b>	882.16	5.51	41,158.92	24,275.53	65,434.45
<b>Grand Total</b>	5550.32	33.9	253,350.76	149,426.28	402,777.04



**LARP**

PROJ #	TASK #	TASK DESCRIPTION	EXP CATEGORY	OBL BUD	YTD OBL	YTD ACT
20	20.12.1.1.9	AD-LARP: US LHC ACCELERATOR RESEARCH PROGRAM	Materials & Services	0	0	0
			Total	0	0	0
	20.12.1.1.9	AD-LARP: US LHC ACCELERATOR RESEARCH PROGRAM	Personnel Costs	32	32	32
	20.29.1.1.9	LARP: US LHC ACCELERATOR RESEARCH PROGRAM		199	98	98
			Total	232	130	130
31	31.1.1.1.1	Tune Feedback	Materials & Services	0	4	0
			Total	0	4	0
	31.1.1.1.1	Tune Feedback	Overhead	0	6	6
	31.1.1.1.4	Schottky Monitor		0	28	28
	31.1.2.1.1	Beam Commissioning		0	10	10
	31.1.3.2.2	Tertiary Collimator Study		0	6	6
	31.1.4.1.2	Interaction Regions & Beam-Beam		0	16	16
	31.1.4.1.3	Beam-Beam Wires		0	10	10
	31.2.1.3.3	Radiation Heat Deposition		0	8	8
			Total	0	84	84
	31.1.1.1.1	Tune Feedback	Personnel Costs	0	19	19
	31.1.1.1.4	Schottky Monitor		0	91	91
	31.1.2.1.1	Beam Commissioning		0	33	33
	31.1.3.2.2	Tertiary Collimator Study		0	19	19
	31.1.4.1.2	Interaction Regions & Beam-Beam		0	52	52
	31.1.4.1.3	Beam-Beam Wires		0	33	33
	31.2.1.3.3	Radiation Heat Deposition		0	26	26
			Total	0	272	272
Total				232	492	488



**LARP**

## DoE Reviews

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- “The review committee was very pleased with the presentations on beam instrumentation and accelerator physics. In addition, they found the idea of participation in the development of a remote control room a very interesting possibility for enhancing interactions with CERN from afar via the Fermilab project “LHC@FNAL”.
- Plans for commissioning of LHC hardware are already being implemented, with the first U.S. staff member (Peter Limon) already stationed at CERN. It was reported by management that U.S. laboratories will provide staffing for this effort, and, in fact, FNAL has committed seven persons to this task. LARP and CERN will cover costs of travel and additional living expenses in the Geneva area.
- Finally, the committee again emphasized its displeasure with the lack of formality in dealings of LARP, and strongly recommended a more effective bookkeeping system for managing expenses and progress on all active tasks, and a person who would be responsible for implementing such a system”.