IR Ranking -
The View of HHH

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ranking criteria

- ✓ luminosity reach
- ✓ energy deposition
- ✓ beam lifetime & integrated luminosity
- ✓ chromatic aberrations
- ✓ technological difficulty:
  hardware development,
  experimental validation,
  operational implementation

our approach

- we do not rank optics solutions directly,

  but

- we first look at, and rank, the technological objects these solutions require

ranking the technological objects

technology status

development risks

performance risks

time for development, validation, & implementation

(1) state-of-the-art NbTi quadrupole magnet

- better heat transfer than present LHC triplets and/or low-gradient optics
- can sustain (factor ~3-4?) higher interaction rate
- pushed NbTi under investigation by D. Tommasini & A. Siemko
- Tom Taylor's and Oliver Bruning's talks
- no risk, available within ~5 years

(2) Nb_3Sn high-field quadrupoles

- gain in aperture or gradient >30%
- under investigation by US-LARP
- several talks (Tanaji, Ezio, Peter L., Rogelio,…)
- main risk: no long prototype yet available (expected by 2009 – impossible to predict before this date)
- could be available by 2015

(3) Nb_3Sn high-field dipole 1st magnets, e.g., open plane

- simulation studies by Ramesh Gupta, Tanaji Sen and Nikolai Mokhov
- under investigation by NED
- main risk: no funding yet available to continue NED
- prototyping cannot start before 2009
- could be available by ~2017

(4) slim NbTi quadrupole doublet

- under investigation by W. Scandale, D. Tommasini, & E. Laface
- standard technology
- main risk: integration in the experiment
- available by 2015

(5) detector-integrated dipole

- under investigation by J.-P. Koutchouk, G. Sterbini
- standard technology
- main risk: integration in the experiment
- available by 2015

(6) wire compensation of long-range beam-beam effects

- dc wire exists and already beneficial
- requires experimental check with colliding beams
- under investigation at CERN & RHIC
- main risk: jitter control for ac wire
- available now

(7) crab cavities

- being investigated by R. Calaga, J. Tuckmantel, R. Tomas, F. Caspers
- main risks: phase noise & synchronization at each IR, space
- 500 MHz crab cavities available at KEK now
- KEKB experience in 2007; if KEKB successful, consider experiment on emittance growth in hadron machine

(8) electron lens as head-on beam-beam compensator

- investigated at Tevatron
- main risks: jitter, p&e-orbit control, e- profile control, coherent or incoherent e-p interaction
- head-on compensation and benefit could be demonstrated at RHIC
- available for LHC by 2012

the above are the technological blocks from which all the proposed insertions can be constructed

guidelines for optics design

- quadrupole vs dipole first:
  quadrupole 1st needs less technological items and hence has to be preferred
- compensation of crossing:
  wires are promising and should be considered for main variants of future optics layouts;
  crab cavities only for global small-angle option
- dipoles & quadrupoles embedded in experiment:
  they can boost any future optics layout and should be investigated together with experimenters
- electron lens:
  might be considered if head-on compensation proven to be efficient at Tevatron (or RHIC)

ranking levels

common investment approach:
balance high-risk high-return ventures with low-risk guaranteed-return investments

risk: --- (very low) to +++ (very high)

return: + (low) to +++ (very high)

ranking the schemes

Low-gradient large-aperture NbTi magnets with large l*

Risk -, Return +

Quad 1st ***"pushed" NbTi***: tailored aperture & length, 2x better cooling, ~20% higher field ***Risk -, Return +***

NbTi-Nb_3Sn hybrid scheme ***Risk +, Return ++***

Quad 1st Nb_3Sn ***Risk ++, Return +++***

Quad 1st with ***detector-integrated dipole*** ***Risk ++, Return +++***

Detector-integrated quadrupole ***Risk +, Return +++***

Quad 1st ***flat beam*** ***Risk -, Return ++***

Separate-channel quad 1st Nb_3Sn or NbTi plus ***crab cavities***

Risk +++, Return +

Dipole first options with ***Nb_3Sn***

Risk +++, Return +

Pulsed or dc beam-beam compensator

Risk -, Return ++

Electron lens ***Risk +++, Return ++***

retain options with perceived lowest risk or highest return (in red)

main paths for future R&D

- further development of *“pushed” NbTi plus* *R&D of* *Nb_3Sn quadrupole 1st options*
- extend study of *detector-integrated dipoles & quadrupoles*
- optimize *long-range beam-beam compensators* & demonstrate their feasibility

combination of tools

- new low-β quadrupoles and/or Q0 ***<u>need</u>*** to be complemented by wire compensator, by D0, or by small-angle crab cavity in order to realize a significant gain in luminosity!
- D0 is efficient for much smaller β* ***<u>and</u>*** for higher beam current
- wire compensator is efficient mainly for higher beam current
- crab cavity allows for larger separation at 1st parasitic encounters if D0 is used

new parameter sets

- old Lumi’05 upgrade parameters raised concern about electron cloud or pile up
- recently we constructed several additional upgrade parameter sets, inspired by Jim Virdee, Jean-Pierre Koutchouk, and Roland Garoby
- for the new sets both electron cloud and pile up appear acceptable, and the strain is put elsewhere

LUMI'05

parameter	symbol	nominal	ultimate	12.5 ns spacing, short bunch	75 ns spacing, long bunch
transverse emittance	ε [μm]	3.75	3.75	3.75	3.75
protons per bunch	N_b [10^{11}]	1.15	1.7	1.7	6
bunch spacing	Δt [ns]	25	25	12.5	75
beam current	I [A]	0.58	0.86	1.72	1
longitudinal profile		Gauss	Gauss	Gauss	flat
rms bunch length	σ_z [cm]	7.55	7.55	3.78	14.4
beta* at IP1&5	$\beta*$ [m]	0.55	0.5	0.25	0.25
full crossing angle	θ_c [murad]	285	315	445	430
Piwinski parameter	$\theta_c\sigma_z/(2*\sigma_x*)$	0.64	0.75	0.75	2.8
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1	2.3	9.2	8.9
events per crossing		19	44	88	510
initial lumi lifetime	τ_L [h]	22	14	7.2	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	0.46	0.91	2.7	2.1
	$T_{run,opt}$ [h]	21.2	17.0	12.0	9.4
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	0.56	1.15	3.6	2.9
	$T_{run,opt}$ [h]	15.0	12.0	8.5	6.6
e-c heat SEY=1.4(1.3)	P [W/m]	1.07 (0.44)	1.04 (0.59)	13.34 (7.85)	0.26
SR heat load 4.6-20 K	P_{SR} [W/m]	0.17	0.25	0.5	0.29
image current heat	P_{IC} [W/m]	0.15	0.33	1.87	0.96
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.04 (0.38)	0.06 (0.56)	0.113 (1.13)	0.07 (0.7)
				partial wire c.	partial wire c.

+LUMI'06

parameter	symbol	ultimate	25 ns smaller β^*	25 ns large emittance	50 ns long bunch
transverse emittance	ε [μm]	3.75	3.75	7.5	3.75
protons per bunch	N_b [10^{11}]	1.7	1.7	3.4	4.9
bunch spacing	Δt [ns]	25	25	25	50
beam current	I [A]	0.86	0.86	1.72	1.22
longitudinal profile		Gauss	Gauss	Gauss	Flat
rms bunch length	σ_z [cm]	7.55	7.55	3.78	14.4
beta* at IP1&5	β^* [m]	0.5	0.08	0.25	0.25
full crossing angle	θ_c [murad]	315	100	539	381
Piwinski parameter	$\theta_c\sigma_z/(2^*\sigma_x^*)$	0.75	0.60	0.64	2.5
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	2.3	15.5	9.7	8.9
events per crossing		44	296	185	340
initial lumi lifetime	τ_L [h]	14	2.1	6.8	5.3
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	0.91	2.4	2.7	2.3
	$T_{run,opt}$ [h]	17.0	6.5	12.0	10.3
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	1.15	3.6	3.6	3.1
	$T_{run,opt}$ [h]	12.0	4.6	8.5	7.3
e-c heat SEY=1.4(1.3)	P [W/m]	1.04 (0.59)	1.04 (0.59)	2.56 (2.1)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.25	0.25	0.5	0.36
image current heat	P_{IC} [W/m]	0.33	0.33	3.74	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.06 (0.56)	0.06 (0.56)	0.11 (1.13)	0.09 (0.9)
			D0	wire comp.	wire comp.

outlook

- ✓ first ~2 years of LHC operation will clarify severity of electron cloud, long-range beam-beam & impedance etc., → determine upgrade path
- ✓ also: we need to wait for the first physics results for decision whether we can integrate elements in the detector or not
- ✓ R&D results until then will be important

- ✓ we should keep some options open!

“forward-looking baseline scenario”

we propose choosing a hybrid scheme as suggested by Tom Taylor where one (or two) quadrupole(s) per triplet is (are) made from Nb_3Sn, and the others from NbTi

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