Summary of the MDI mini-workshop

The aim of this mini-workshop is to invite experts of MDI from very different colliders to exchange and share their experiences and knowledge with many common interests, and to promote collaborations among them. 16 - 17 January 2020.

T. Tauchi (KEK)

The HEP conference, HKUST IAS, Hong Kong, 20 January 2020

Agenda on 16 January 2020

Opening Remarks by J. Gao 高 杰 (IHEP)

Talks with 25min + 5min Q/As

Introduction : Overview of Different Colliders, J. Gao 高 杰 (IHEP)

SuperKEKB :

- Background Status and Study at Belle II, SuperKEKB, Carsten Niebuhr (DESY)
- Status of the Superconducting Final Focus Magnet at SuperKEKB, Norihito Ohuchi 大内 徳人 (KEK)
- Stability of the final focus magnets at SuperKEKB, Hiroshi Yamaoka 山岡 広 (KEK)

LEP - FCCee/CEPC :

- Lessons Learned from LEP and their Application to FCC/CEPC, Helmut Burkhardt (CERN)

CEPC :

- CEPC MDI Accelerator Issues, Sha Bai 白莎 (IHEP)
- CEPC RADIATION BACKGROUND STUDIES, Hongbo Zhu 朱 宏博 (IHEP)
- CEPC MDI SC Magnet System, Yingshun Zhu et al. 朱应顺 (IHEP)
- CEPC MDI Mechanics Issues, Haijing Wang 王 海静 (IHEP)
- CEPC MDI Detector Issues - In engineering design, Ji Quan 紀 全 (IHEP)
- CEPC Detector Overall Facilities and Hall Issues, Zhu Zian 朱 自安 (IHEP)

Agenda on 17 January 2020

Circular Colliders :

MDI issues of **BINP Super TauCharm factory**, Anton Bogomyagkov (BINP)

Overview of MDI at **FCC-ee**, Michael Koratzinos (CERN)

ILC :

(Selected) MDI Issues of ILD, Roman Pöschl (IJClab)

ILD Background Studies at ILC, Daniel Jeans (KEK)

The SiD Detector - Machine Backgrounds, Marcel Stanitzki (DESY)

ILC and Future Colliders :

Superconducting Final Focus Magnets at ILC and Future Colliders, Brett Parker (BNL)

CLIC (ILC, FCC) :

CLIC Machine Detector Interface, Philip Burrows (Oxford Univ.) , Lau Gatignon (CERN)

Stabilisation of Final Focus Magnets for CLIC and FCC, Maurizio Serluca, Laurent Brunetti (LAPP)

IP Fast Feedback Systems (FONT) at ILC and CLIC, Philip Burrows (Oxford Univ.)

Discussion on possible future collaboration :

All

Overview of Different Colliders, J. Gao 高 杰 (IHEP)

Review of some accelerator theories for colliders

Expressions of luminosity for circular and linear colliders

CC : the maximum beam beam tune shift ξ_y and the dynamic apertures

LC : $N_{\mathrm{had}},\ n_\gamma,\ \sigma_{\gamma\gamma\to\mathrm{had}}$

Historical review of e+e- circular coliders

The original idea by Rolf Wideöe in 1943

The first colliders : VEP-1 (e^-e^-) in 1963 (Novosibisk), AdA (e^+e^-) in 1963 (Orsay)

Higher energy and higher luminosity colliders in future, CEPC@China, FCCee@CERN

Historical review of e+e- linear colliders

The original idea by Maury Tigner in 1965

The first collider : SLC in 1989, born at the ICFA seminar, Fermilab, October 1978

TeV colliders in future, ILC@Japan (LCC/ICFA), CLIC@CERN

Historical review of hadron hadron circular colliders

The first colliders : ISR (pp) at CERN, 1970-1983, SPS ($\bar{\mathrm{p}}\mathrm{p}$) at CERN, 1981-1990

Future colliders : SPPC@China, FCC@CERN

Historical review of electron proton circular colliders

The first collider : HERA at DESY for 1991-2007

DOE proved EIC at BNL (CD0) in Jan. 2020

References are appended

Background Status and Study at Belle II, SuperKEKB, Carsten Niebuhr (DESY)

SuperKEKB / Belle II Commissioning since 2016

Phase 1 in 2016 w/o QCS, Belle II, Phase 2 in 2018 w/ QCS, BEAST II (background) w/o VTX

Phase 3 since 2019, Physics run w/ VTX , the peak luminosity of 1.88 x 10^{34} (design 8 x10^{35}) $cm^{-2}s^{-1}$

Major backgrounds

Single beam : "off-momentum acceptance" particles by internal scatterings in a bunch (**Touschek**, $T\frac{I_{\pm}^2}{n_b\sigma_y}$), **beam gas** ($B \cdot I_{\pm} p Z_{eff}^2$), synchrotron radiation and injection background (2x 25Hz)

Beam-beam : radiative Bhabha and two photon process

In May 2019, dominant background source from LER beam-gas (5 times more than the HER)

Data/MC ratio : O(1) for LER Touschek, O(10) for Beam-gas and
$>10^3$ for HER Touschek due to (too) small MC estimate

Collimators protect QCS and Belle II against background bursts and mitigate Touschek/Beam-gas background

Horizontal and vertical ones for Touschek and the beam gas backgrouds, respectively.

Especially, LER vertical collimators are essential.

Mitigation of the damage : tungusten to carbon head to reduce the deposite energy in the collimator

IP Beam pipe : Ta (Cu plated, water cool) - Be (Au plate, $1mm^t$ paraffin cool) - Ta (Cu plate, water cool)

Beam background has major impact on further progress of SuperKEKB performance

Background conditions strongly depend on optics parameters and vacuum level in the ring

At future optics with smaller β^*_y, collimator optimization will get even more difficult

β^*_y =1mm (present) to 0.3mm (design)

Transverse mode coupling (TMC) instability, smaller equivalent width, etc.

Status of the Superconducting Final Focus Magnet at SuperKEKB,

Norihito Ohuchi 大内 徳人 (KEK)

Super KEKB Interaction region (IR) :

HER(e^- beam) QC2LE,QC1LE → QC1RE,QC2RE with the horizontal crossing angle of 83mrad

LER(e^+ beam) QC2LP,QC1LP ← QC1RP,QC2RP

IR superconducting magnets, 55 in total :

8 main quadrupoles, 35 correctors(direct winding@BNL), 4 compensatie solenoids, 8 leak field cancel coils

with different magnet types with "no", permendur and iron yokes

Operation of superconducting magnets in the Phase-2 and 3 commissioning :

β^*_y =80 to 3mm in Phase-2, β^*_y = 8 to 2mm in Phase-3(2019ab), β^*_y = 2 to 1mm in Phase-3(2019c)

magnet quench events : 25 → 6 (3 by beams) → 3 (2 by beams)

The quench of the superconducting magnets are reduced drastically.

HER and LER beams were well controlled to the QCS superconducting magnets by the collimator and the beam abort system. Also,the quench detector system and the quench monitoring system are improved.

Brett's comment :it is bad to have corrector coils inside the main coils and they should only be put on the outside where they would be better protected and/or one should consider using a conductor like Nb3Sn or HTS to gain more operating margin. …a thin (maybe 1 or 1.5 mm) layer of helium inside all the coils …

Stability of the final focus magnets at SuperKEKB, Hiroshi Yamaoka 山岡 広 (KEK)

To minimize vibration of the final focus magnets (QCS);

Design rigid structure → Increase resonant frequency

Apply high damping material (M2052), whose effect was estimated in the KEKB support system.

Apply active/passive isolation system

Improvement of the QCS support system from KEKB to SuperKEKB

magnet boat/table		→	the moving stage on the precise flat floor by the self-leveling method with epoxy resin
cantilever height	2.2m	→	1.5m
QCS weight	1.5t	→	2.5t

Development of the finite element modeling and the vibration analysis

maximum deformation 2mm → 0.4mm

resonant frequency(V) 14Hz → 29Hz (22Hz meas.) , (H) 20Hz → 35Hz (25Hz meas.)

Measured results of the vertical vibration on the QCS cryostat

Integrated amplitude (f<10Hz) 300nm → 50nm (40nm calculated by the FEM)

The FEM results of difference in the vertical vibrations between QC1RP and QC1RE

25nm@25Hz and 14nm@50Hz , these results show that the luminosity loss < 5% is expected.

The QCS magnetic center vibrations will be measured by a 2,500 turn pickup coil (R&D of Japan-US collaboration).

Lessons Learned from LEP and their Application to FCC/CEPC, Helmut Burkhardt (CERN)

Bit of history of the CERN Large Electron-Positron Collider

tunneling 13/9/1983 - 8/2/1988; Operation(Z^0@LEP1, 104GeV@LEP2) for 1990-2000, dismantled for LHC

minimum β^* and maximum tune shift were limited by the need for stable low background running condition

distance IP to 1st superconducting Quadrupole (centre) L* = 3.7 m for LEP, 2.8 m FCC-ee, 23 m for LHC

Challenges for FCC, CEPC

2 rings : less evident to find collisions, need to frequently re-steer to centre collisions

Smaller beams, large crossing angle, Beamstrahlung, high power : risk of damage by heating and beam losses

Top-up injection : need for more aperture to efficiently capture beams, background spikes by losses

and lager amplitude (halo) from injection, continuously running at top maximum intensity and power

Background/Signal exchange, logging and status displays for good performance by the continuous tuning

Thermal photon scattering is the main single beam lifetime limitation in LEP, also creates off-momentum partcles

Muon backgrounds : with the beam lifetime of 200min (FCCee_Z), 2.4×10^{11} e^+,e^-/sec are lost, which generate

millions of muons/sec → avoid collimation of e^+,e^- in line of sight to experiments

Non-Gaussian tails measured by scraping with loss monitors at LEP

larger tail (>10σ_y) in the vertical plane than the horizontal tail which was reproduced by simulation

Tails from beam-beam, high chromaticity, particle scattering

Background spikes, enhanced synchrotron radiation from quadruples

Machine induced backgrounds (MIB) in LEP ~ 100 collimators to reduce MIB

Synchrotron radiation - no direct and single reflected radiation to experiments in IP region at LEP

the critical photon energies : 69, 725keV@LEP1,2 and 1.3MeV@FCC-ee

Fluorescence, specular reflection etc. are well simulated by GEANT4, now.

Much of the work is on details, MDI - IR design particularly important,

simulation, beam-dynamics, background — benchmarked with LEP and e^+e^- factories, stimulating and profiting from further hardware / technology developments

CEPC MDI Accelerator Issues, Sha Bai 白莎 (IHEP)

MDI layout (about ±7m long from the IP) and IR design :

The detector solenoid magnet of 3T, 7.6m length. All accelerator components in $\cos\theta < 0.993$ ($\theta < 0.118$)

The horizontal crossing angle is 33mrad and L*= 2.2m.

The beam stay clear (BSC) : $BSC_x = \pm 18\sigma_x + 3mm$ for injection and $BSC_y = \pm 22\sigma_y + 3mm$ for beam lifetime

IR SC magnets physics design parameters :

QD0a/QD0b : 1.5m length, 77.5T/m, apertures 10.16 - 22.03 mm(H), 15.13-17.46mm(V)

QF1 : 2m length, 63.4T/m, apertures 23.64-30.91mm(H), 16.79-14.01(V), L*(QF1)=5.51m

Solenoid compensation :

$\int B_z ds$ (z<2.12m) ～0， B_z <300 Gauss at z > 2.12m with skew quadrupole coils

Synchrotron radiation :

Last bend :12.5W@Lumical-QDa, 0.75W@QDa,0.9W@QDb,6.3W@QDa-QDb,1.78W@QF1,19.6W@QDb-QF1

also estimated under the extreme conditions of offsets of -2mrad,+0.115mrad(angle), ± 5mm (position).

Critical energy (H/V in keV) : 458.7/271.2@QDa, 657.9/361.5@QDb, 428.3/613.5@QF1

From the solenoid combined field, no SR hit on the Be IP pipe and hit on the beam pipe at 213.5m from IP.

Beam loss in IR : 218bunches at 2997Hz, 1.5×10^{11}/bunch, L=5.2 x $10^{34}cm^{-2}s^{-1}$

Thermal photon scattering, beam gas scattering, beamstrahlung, radiative Bhabha scattering

Beam loss reduced to very low level with collimators for RBB and BS. IR vacuum of 3 x 10^{-10} torr

Collimator design :

Beam stay clear, impedence control, phase between the pair collimators, put in large dispersion region

SR from the upstream bending magnet in the ARC can contribute to the heat load of the collimators.

HOM absorber :

HOM, 10GHz, ~3kW, trapped mode at the crotch point (z~±700mm)

HOM absorber: inner surface of the beam pipe is grooved and coated with absorbing material,

and the outer surface of the beam pipe is water cooled.

IP BPM : two 4 button electrodes BPM at ± 80cm from the IP in the double pipe part, in front of Lumcal.

CEPC RADIATION BACKGROUND STUDIES, Hongbo Zhu 朱 宏博 (IHEP)

Interaction Region Layout ：

Based on the CDR design (to be optimized) , e.g. a single QD0 (2m long, 136T/m)

Radiation Backgrounds, important inputs to the detector (+machine) designs ：

beam-induced or luminosity related radiation backgrounds

Synchrotron radiation : BDSim to transport beam (core + halo) from the last dipole to the interaction region and record the particles hitting the central beryllium beam pipe (± 7cm from IP).

Careful mask design, the tip shape and high Z material(Au chosen, 0.6mm^t) for SR from the last bend

3 locations at |Z|= 1.51,1.93 and 4.2m → Photons/bunch hitting the central beam pipe from 80, 000 to 250.

Beamstrahlung/pair production : generated with GuineaPig

Background expressed by hit density, total ionizing dose (TID) and non-ionizing energy loss (NIEL)

With a safety factor of 10;

pairs: 2.26 hits cm^{-2} BX^{-1}, 591.14 KRad yr^{-1}, 1.11×10^{12} $n_{eq}cm^{-2}yr^{-1}$@VTX 1st layer , Higgs factory (E_{cm}=240GeV)

Off-Energy beam particles (radiative Bhabha, beam gas, thermal photon scattering etc.) :

2 sets of collimators placed, but not sufficient yet, optimaization is needed

RB and beam gas, thermal photon backgrounds generated by BBBrem and a costomized code, respectively, then particles were tracked with SAD, hit map in the vertex detector (with the collimators) is calculated.

The beam gas backgrounds dominates 368.37 cm^{-2} BX^{-1} at the VTX 1st layer, at 10^{-7} Pa vacuum pressure

VERIFICATION WITH BEPC II/BES III for simulation tools and analysis procedures :

Decomposition of background components as the SuperKEKB (C. Niebuhr's talk), the experimental steps were proposed as well as the vacuum pressure degradation test in the beam pipe at the BSRF end station.

From experiences at LEP and SuperKEKB, 10-20 collimaters may be needed per IP.

Suggestions in discussion :

Backgroud study is also needed for the quench protection.

More frequent communication with accelerator MDI group is needed for the accelerator design is advanced.

CEPC MDI SC Magnet System, Yingshun Zhu et al. 朱应顺 (IHEP)

Overview of CEPC MDI SC magnets : L*=2.2m and the horizontal crossing angle of 33mrad

CDR designs of QD0/QF1, 136/110 T/m, 2/1.48m length, located in the 3T solenoid field

anti-solenoids before QD0, outside QD0 and QF1 are needed.

QD0 w/ or w/o iron yokes and QF1 with iron yokes and anti-solenoid coils are in the same cryostat.

Iron-free design of final focus QD0 :

two layers cos2 θ quadrupole coil using NbTi Rutherford cable without iron yoke, 2510A @4.2K

Two layers of shield coil is introduced outside the quadrupole coil to improve the field quality

Integrated field harmonics with shield coil $< 3\times10^{-4}$.

Coil inner/outer radius = 20/26.5mm, beam pipe inner/outer radius = 10/13mm

Collar outer radius = 31.5mm, shield coil outer radius =33.5mm

QD0 design with iron core :

Iron core in the middle part is shared by the two apertures (**novel design**)

The field harmonics w/ field crosstalk between the two apertures is smaller than 0.5×10^{-4}

The excitation current can be reduced, i.e. 2060A @4.2K

Design of QD0 short model magnet with 0.5m length (near IP side) : First trial in China

Verification of the design with two apertures w/ iron yoke, mastering the cryogenic testing technique and for the development of long QD0 model

FEM stress analysis was completed and no influence of the 3T solenoid with anti-solenoid was calculated.

The physical design of QD0 short model magnet passed the experts review in July 2019.

Design of superconducting quadrupole magnet QF1 :

The design is similar to the QD0 with iron yoke with the negligibly small effect of the cross talk.

Design of superconducting anti-solenoid :

The anti-solenoid is divided into a total of 29 sections with different inner coil diameters (B_{max}=7T).

To reduce the length of the cryostat, the sections after QF1region will be operated at room-temperature.

CEPC MDI Mechanics Issues, Haijing Wang 王 海靜 (IHEP)

Overview : Detector layout of CDR design, where the iron yoke length = 9.6m

First vacuum pump@±6.5m and the remote vacuum connection@70cm

Preliminary installation scenario :

The IP chamber and detectors(VTX,SIT,FTD) are assembled and aligned.

Pre-alignment of SC magnet with the cryostat in working condition, then install BPM, HOM absorber, RVC.

Move the SC magnet to working location, then connect the flanges following the alignment

Finish the connection and alignment for both sides, install the yoke walls

Two key issues: the vacuum leak rate < 2.7x 10^{-11}Pa m^3/s and the alignment error: ≤30μm

One concern issue : the distance from yoke boundary to connection location (m) = 6.1m → 3.8m

The current design is based on the shortest version (3.8m), while needs to be discussed further.

Remote vacuum connection (RVC) methods :

RVC similar to SuperKEKB as baseline, and studying other schemes at the same time.

Option-1 : Long tools of spline flange, spline gear ((ϕ264mm x 223mm) and bellows, locking gear, pneumatic annular, limit pin, long tools and support

Option-2 : Inlatable seal design (ϕ112mm x 120mm) @CSNS but limited leak rate < 10^{-7}Pa m^3/s with improbvements of precise maching of sealing membrane and flange, different material of sealing membrane and flange, usinf edge sealing intead of membrane sealing

Common issue : all exceeds the requirement of cosθ<0.993, **so Lumical move to IP assembly ?**

Support system of SC magnets :

The current design of cryostat is 5 m long with18 mm thick stainless walls, about 2 tons in total.

The FEM analysis results: 190μm maximum deformation in downward for the about 3.6m cantilever support , also 48μm / ℃ of the environmental temperature. So, **No clear solution right now !**

CEPC MDI Detector Issues - In engineering design, Ji Quan 紀 全 (IHEP)

General introduction :

Detector of CDR design, where the iron yoke length = 12.02m ← 9.6m

The connection part between spectrometer and accelerator is accelerator vacuum tube

Accelerator components must access through 5310 - 1400(beam pipe@detector) - 5310mm from both sides within $\cos\theta < 0.993$

Interface requirements and structural design :

Barrel yoke (dodecagon) with helical arrangement with 3180t and the FEM result of 0.6mm deformation

End yoke with strengthening ribs with 1165t has the max. deformation of 2.08mm due to the magnetic force

So, design parameters of yoke provided according to magnetic field requirements, can meet the strength and stiffness requirements of spectrometer design

Beampipe of 1400mm length equiped with the veterx detector and Lumcal($<\phi$153mm)

Carbon fiber cylinder (a) , Gas enlarge channel (b),

The central Be pipe (c, paraffin), The extending Al pipe (d, water)

An optional choice: pillow seal for RVC, It consists of two flanges connected by inflatable dual bellows.

e.g. A leak-rate of 1.3×10^{-11}Pa m^3/s@JPARC,RIKEN meets the vacuum design requirements of beam pipe.

Can thin-walled beryllium pipe support the inflation pressure of pillow seal?

The FEM results show that In general, the beam pipe is safe under pressure of 0.3MPa at both ends.

Next step :

Determine the vacuum connection structure of the accelerator vacuum tube and the beam pipe as soon as possible. (It affects the progress of follow-up work)

CEPC Detector Overall Facilities and Hall Issues, Zhu Zian 朱 自安 (IHEP)

Design points :

Under groud experimental hall, surface facilities, detector assembly, utilities, magnetic field leakage, radiations, scheduling, cost performance etc.

Two IPs/detectors of CEPC :

Baseline detector : LTS solenoid (3T, ϕ7.2m x 7.4m,NbTi,4K) outside the calorimeters, TPC

IDEA detector : HTS solenoid (2T, ϕ4m x 6m,YBCO,4K) inside the calorimeters, Silicon tracker, thinner yoke

Stray magnetic field distribution :

Magnetic straf field of the baseline(CDR) detector, 50Gaus@20.6m(R),25.5m(Z),

and 28Gauss@the booster ring where the accelerator magnets must be shielded.

Cavern & Shaft :

Main cavern (30Hx30Wx40Lm^3) experimental hall, 20 and 300t cranes, a ϕ16m shaft ,1,000t gantry crane

Auxiliary cavern (18Hx18Wx80Lm^3) detector service, electronics, power supplies, cryogenics system etc. with a ϕ9m service shat and a ϕ6m personnel access shaft.

Procedure of large piece down to cavern :

Biggest and heavy part, the fully assembled and tested solenoid, to be lowered. After landing, only moving longitudinally. A temporarily/middle yoke ring pre-assembled together with the solenoid, weight about 800 tons. To be optimized and improved with yoke assembly procedure

Ground building :

Magnet assembly hall, cryogenics hall with helium gas tank, gantry crane, sub-detectors assembling and testing hall providing additional advantage of rehearsing the risky operations, water cooling station, gas station and power supply

Next steps :

detailled procedures of piping, cabling, connection between underground and ground facilities and many together with progress of the detector design.

MDI issues of BINP Super TauCharm factory, Anton Bogomyagkov (BINP)

Parameters : The beam energy from 1 to 3GeV, circumference 478.092m

E_{beam}=3GeV, I=7 $\times 10^{10}$/bunch, β^*_x=50mm, β^*_y=0.5mm, ε_x=10.9nm, κ=0.5%, σ_z=10mm, 290bunches

2θ=60mrad, single IP, luminosity=1.1 $\times 10^{35} cm^{-2}s^{-1}$, (σ^*_x =20μm, σ^*_y=165nm), L*=0.905m

MDI area : All accelerator equipment should be **inside 175 mrad cone**

Region 1: FF quadrupoles, solenoids, correctors, flanges, bellows, RVC, HOM absorbers...

Region 2: solenoid nonlinear fringe fields, a need for screening and correction

FF vacuum chamber: Be-tube(±150mm, ϕ30mm, cooled), Y-chamber(cooled), BPMs)

Cryostat with FF magnets : Compensating coil, QD0 100T/m, 200mm length, correction coils,
QF1 45T/m, 300mm length with screening solenoid

FF quadrupole : iron yoke double aperture SC :

No field cross-talk between apertures but no additional coils for symmetry required

prototype made

Vacuum chamber : design and testing for the thermal load of 100W/m

From room temperature beam chamber to cryogenic temperature magnet

Minimizes the number of bellows, high-frequency contacts, cold-warm transitions,
simplifies removal of the heat

Remote vacuum connector (RVC) : R&D with successful result, leak rate < 1 $\times 10^{-10}$ mbar(10^{-8}Pa) L/s

Assembling with and without RVC as SuperKEKB/Belle II and DAΦNE/KLOE, respectively

DAΦNE/KLOE like assembling w/o RVC is proposed

Two type of compensation coils, i.e. cylindrical and elliptical shapes :

Cylindrical layout provides insufficient vertical emittance blow up (23 pm)

Elliptical layout has no emittance blow up

Both schemes fit inside the 175 mrad cone

Elliptical schemes has smaller fields in the quadrupoles area and more compact but more complicated

Overview of MDI at FCC-ee, Michael Koratzinos (CERN)

Introduction : Definition of MDI and its importance with some specifics for the circular colliders

Requirements at the IP, FCCee, which should be realized with technical solutions :

1. Accelerator magnetic elements **< 110mrad**; 2. Integrated field seen by the beam = 0

3. Small vertical emmittance growth due to fringe fields; 4. FFQ in a zero-field; 5. Field errors of FFQ < 1×10^{-4}

Solutions : 4. Screening solenoids; 3. Compensating solenoid; 5. Two **CCT**-FFQs; 2. OK by tuning

Baseline solutions/designs, L*=2.2m and the horizontal crossing angle of 30mrad:

Luminometer in front of the magnetic elements, i.e. the compensating solenoid at 2m form IP

FFQ located in the integrated solenoid field < 50mTm surrounded by the screening solenoid

The detector solenoid field, 2T or 3T with respect to the emittance blow up $\Delta \varepsilon_y \propto B_{det}^5$:

The emittance blow up from 2IPs is 0.4pm at 2T, it is 3pm at 3T (the budget 1pm). Luminosity→ 1/1.7

Final focus quadrupole with a canted-cosine theta (CCT) design, iron-free also :

All the requrement are satisfied ! CCT consists of two layers of helical coils to cancel out the solenoid fields

"the multipole mix is a local property of the magnet, which can vary along its length. This is not possible with a traditional design. "

QC1L 100T/m,1.2m length, 40mm aperture (fits the warm water-cooled beam pipe of inner diameter 30mm)

the integrated multipoles of < 0.1 units of 10^{-4}. The edge effects can be compensated by the first two turns.

FF prototype :

CCT is a relatively new idea in magnet design, and never one has been built with compensation.

→ the FCC FF quad prototype project, the first prototype was made and just in time for Chistmas 2019!

There was **a warning message from SuperKEKB (K.Oide, 26/6/2019)**;

"The final quads and solenoids must be robust enough against beam losses. Esp. thin corrector windings. …"

LumiCal : W+Si sandwich: 3.5 mm W + Si sensors in 1 mm gaps, 25 bayers ($25X_0$), 1074 < z < 1190 mm

Beampipe, HOM absorbers, BPM, remote flange, bellows :

FF quads assembly in thin cryostat using a stiff skelton for θ<110mrad,and the cantilever support (4.37m)

(Selected) MDI Issues of ILD, Roman Pöschl **(IJClab)**

Introduction : ILC project, Physics program(Z to 1TeV), Detector requrements, ILC250 status

Requirements at the IP for the pushpull operation of two detectors:

Self-shielding against radiations and the stray magnetic field of < 50Gauss at the garage position (15m apart)

The detector is very hermetic covering down to θ=5mrad (BeamCal is the most forward detector).

Beams : Train of ~1msec at 5Hz, 1 train=1312 x 554ns, 2 x10^{10}/bunch, σ_Z=300μm, Pol.e^-/e^+=80/30%

The horizontal crossing angle of 14mrad, L*=4.1m common for the two detectors, QD0 inside of the detector with QD0EX1(extraction) and SD0(sextupole) for the local chromaticity correction scheme

QD0 : Superconducting, actively shielded so no compensating solenoid by Brett's design

Study of development of vacuum since the TDR, especially L*= 4.4m → 4.1m :

Effects of the vacuum pumps(120L/s) removal were studied; 20 times worse but recovered by NEG coating

Beam gas background much smaller than pair induced background, so even 100nTorr can be tolerable.

ILD solenoid magnet, iron yoke : 3.5T and can be up to 4.5T

Thinner yoke for the cost reduction, -20%@60cm iron off, -50%@2m iron off , but the radiation ?

increasing stray fields 93Gauss@15m 1,000Gauss@15m→ 50Gauss w/ shielding wall

Anti-DID (max. 360 Gauss dipole field) integrated in the solenoid to reduce backgrounds :

The magnetic fields are aligned to the out-going/extracting beam together with low-energy pair particles

Power pulsing operation for the detector electronics :

Electronics switched on during > ~1ms of ILC bunch train and data acquisition while bias currents shut down between bunch trains. Mastering of technology is essential for operation of ILC detectors

Total power consumptions are 982kW underground and 2450kW on surface (current estimations)

Cabling scheme :

Extraction of cables from the inner detectors with minimum gaps and for opening endcaps without disconneting the cables , the locations of patchpanels are important in very limited spaces.

ILD Background Studies at ILC, Daniel Jeans (KEK)

Introduction of ILD detector : large (TDR baseline) and Small option

TPC, the vertex detector of silicon pixels surrounded by silicon strips, calorimeters (FCAL, ECAL, HCAL)

Beamstrahlung : Low energy incoherent pairs are generated by the beam beam interactions.

The high p_T tail can directly reach the inner detectors, and the vast majority have low p_T and “follow” the B-field lines. Some of them hit the BeamCal then generate the seconday backgrounds

The anti-DID field (field in x-direction) is rather complex system.

Is it needed ? How big is its effect on detector backgrounds ?

Simulate beamstrahlung pairs at ILC-250 with ILD Geant4-based simulation :

Using the detailed field maps of the 3T solenoid/yoke, with and without anti-DID field, where the use of anti-DID better centres distribution on outgoing beampipe and reduces total energy deposit

“Direct” hits by particles directly coming from IP and the seconday particles, which are distingushed by the hit time in the simulation, “early” and “late” for the direct and the seconday backgrounds

The VTX hits : the anti-DID reduces “late” hits by 1/3 ~ 1/4 in all the layers, 40% reduction in total hits

THe TPC hits : according to TPC experts, this looks manageable.

(TPC is sensitive to the back-scattered Xrays also.)

we have not yet concluded if we need anti-DID, but we have information with which to decide...

Beamline muons : Muon production and transportation are simulated by L. Keller, G. White @ SLAC.

Muons are produced at the upstream collimators by hitting the **halo** particles in the beam of **0.1%** assumed.

They are reduced by 5 toroidal spolilers (ϕ1.4m x 5m) w/ or w/o a muon wall (5.2x5x5m^3).

Question: is the muon wall needed ?

Results : a few muons per bunch crossing seems manageable, ~ 4/BX w/ 5 donut spoilers (no muon wall)

The muon wall probably not needed from an event reconstruction standpoint.

→ probably good idea to reserve space for it in case of future need (e.g. unexpectedly large backgrounds...)

→ should be taken into account for estimating detector data rates

The SiD Detector - Machine Backgrounds, Marcel Stanitzki (DESY)

Introduction of ILC Accelerator and SiD detector : ILC250, the double the bunch number option
ILC Bunch Train Structure has huge Impact on the Detector design, triggerless readout, buffering on front-end&Readout after the last bunch and the power pulsing, saving of a factor 100→No Active cooling

SiD : Compact high-field design (5T solenoid), All-Silicon tracking for robustness against backgrounds based on SLD experiences, at a linear collider every bunch train is like the first turn in a synchrotron (J.Brau)

SiD MDI : The proximitry of the vertex detector to the IP is constrained by the beam parameters.
beam pipe, LumiCal, PolyC mask, BeamCal, BPMs, QD0, IP feedback kicker and the support tube

Sources of backgrounds : From beamstrahlung to neutrons
e^+e^- pairs (GuineaPig), muons from the collimators(MuCarlo), neutrons from the main beam dump(FLUKA)
All studies have used full detector simulation of SiD with Geant4-based.

Pair Background :
IP beam pipe designed for the envelope which changes with the beam energy, 250GeV is much more relaxed than 500GeV. It is good time to think about vertex detector upgrade, different beam pipe at enegy upgrade.

Results : SiD Default "4 hits per cell per train"(buffer) was considered a good compromise between performance and complexity . Doubling the bunch number (luminosity upgrade), it has impact on detector design, mainly electronics increasing the buffer depth to fulfill the fraction of dead cells < 10^{-4}.

Muon Halo : first observed in SLD and unavoidable at a linac → shielding, timing
Number of hits are calculated for cases of "5 spoilers" and "5 spoilers + wall" at ILC250, ILC500.
Muons traverse SiD from left to right (Δt~40ns), many muons are "slow" spiraling in the magnetic field creating hits, but **overall occupany due to muons is never even getting close to 10^{-4}.**

Neutrons from the Beam Dump : The "hottest spot" of the ILC at ± 350m from IP
Results of timing and occupancy , the fraction of dead cells < 10^{-4} with the buffer depth of 4.

The way forward :
After a green light, repeat the studies with a close-to-final MDI design incl. shielding, pacman, vibration …

Superconducting Final Focus Magnets at ILC and Future Colliders, Brett Parker (BNL)

IR Magnet and MDI Lessons from Previous Work :

"IR Magnets" includes Final Focus quadrupoles, Beam Separation Dipoles, Solenoids/Anti-solenoids, Corrector Magnets and External Field Cancel Coils.

HERA-II / BEPC-II IR Magnets and MDI:

The design of interface between the cold mass and the warm part is very important, rigid support v.s. heat load, movement of the magnetic center etc. in cooling and enegetic operations. (e.g. passing forces and torques from cold-to-warm supports)

ILC Final Focus Magnets and MDI :

Because the present ILC QD0 assumes 1.9K superfluid cooling (for the least vibration, but never tested), the QD0 cryostat has an additional 4K conduction cooled heat shield; the extra radial space this requires is not wasted as it allows a larger outer solenoid coil to balance the axial force generated by the inner anti-solenoid coil. a force neutral anti-solenoid coil is added. also, (anti) DID concept come out.

SuperKEKB IR Corrector Magnets and Cancel Coils :

With 35 correction coils and 8 cancel coils we sometimes hear this referred to as a "complicated system" . But having to dead reckon multiple, stringent, magnetic field magnet production requirements can itself be quite costly (i.e. require a lot of contingency to guarantee performance and no errors... the known unknowns) and brings its own risk (... the unknown unknowns). "It is bad to have corrector coils inside the main coils."

Future : BNL Electron-Ion Collider (EIC) IR Magnets :

We are half way in a BNL funded (LDRD) project to wind and test a dual helical tapered quadrupole coil (**CCT**) to locally adjust the quadrupole strength which could also be used to add local admixtures of other field harmonic components.

Future : CERN FCC-ee IR Magnets :

Dual helical coil winding is now a key IR magnet technology. We will continue to find synergies between future IR design work: ILC, CLIC, EIC, FCC-ee, FCC-eh/LHeC, CEPC and more!

CLIC Machine Detector Interface, Philip Burrows (Oxford Univ.) , Lau Gatignon (CERN)

Quick reminder: what is MDI :

The Machine Detector Interface must ensure optimum luminosity for the experiment(s) with minimal backgrounds and includes the local environment and infrastructure. It integrates the post-collision line.

CDR : L*=3.5m, 2 detectors with push pull operation, the experimental hall accomodates them.

Changes to detector model :

Single detetor, i.e. no push-pull of two detectors, but this does remain an option

L*=6m QD0 in the tunnel , which has the major implications for MDI , the same crossing angle of 20mrad

Changes to MDI :

Cavern layout : Detector opening not on IP

Luminosity and tuning :

Both beam optics with L*=3.5m and 6m were studied icluding the beam tuning, the latter luminosity is about 15% less than the former. However, it is better for the stabilization of FFQ (QD0).

Stabilisation : CLIC specification (displacement of the QD0 final focus) : 0.20 nm RMS@4Hz

Results of control (autumn 2016) with LAPP active foot + 1 LAPP vibrations sensor : 0.25 nm RMS@4Hz

IP feedback system demonstrated

Some other implications :

Beam line sectorisation scheme was proposed, which looks simpler and well separated between the detector and the accelerator elements.

A new detector model with L* = 6 m has been evaluated and this is now the new baseline for CLIC.

Stabilisation of Final Focus Magnets for CLIC and FCC, Maurizio Serluca, Laurent Brunetti (LAPP)

INTRODUCTION : Successful operation of future colliders requires advanced vibration analysis and control, e.g. preserve the very low emittance along the beamline at LC and minimize emittance dilution both for the nano-meter beams.

Vibration control for CLIC : Spec. : Beam offset < 0.2 nm RMS at IP

Active control with the developed sensors : Results of control (autumn 2016) with LAPP active foot + 1 LAPP vibrations sensor : 0.25 nm RMS@4Hz, where only 1 sensor in feedback.

From the demonstration to a large scale experiment, a large actuator must be developed for CLIC.

Accelerator Test Facility: ATF2 : 1.3GeV electron beam, σ_z=37nm (design), 40nm achieved

The passive stabiization of the final doublet manets on the stiff table was demonstrated, i.e. the relative motion between shintake monitor and final doublets of [4 – 6] nm RMS @ 0.1Hz (vertical axis) .

Also, the feedforward system was tested with14 GM sensors on the magnets at the beamline. Jitter reduction around 10-20% due to very unstable run conditions and strong jitter at the injection of the extraction line

SuperKEKB : Real-time vibration measurements system installed on both sides of BELLE II with LAL,KEK

To study the correlation between measured luminosity and vibrations : 24 hour monitoring gives indications about time and frequency of disturbances that helps in the research of the vibration sources (Dec. 2019)

Analysis of the common aspects with FCC-ee : FFQ support by the 4.37m long cantilever

Within the FCC-ee MDI collaboration we are reviewing the main steps towards the study of vibrations and stabilisation for FCC-ee, including active and/or passive control, IP feedback with respect to the interest frequency range and global (beam) tracking simulation to identify the specifications.

IP Fast Feedback Systems (FONT) at ILC and CLIC, Philip Burrows (Oxford Univ.)

Introduction and IP FB system concept :

IP feedback system has been optimized for the beam parameters, especially the time structure of bunch train of ILC and CLIC, which are 1,300bunches/500ns-sepration and 300bunches/0.5ns-sep., respectively.

The feedback latency, current technology must be O(100ns), digital@ILC and O(10ns), analog@CLIC.

FB hardware should be close to IP (especially for CLIC !) for the speed of light of 30cm/ns.

Two systems, one on each side of IP, allow for redundancy.

ILC IP FB design status : ILC TDR (2013)

IP beam position feedback: beam position correction up to ± 300 nm vertical at IP

IP beam angle feedback: hardware located few 100 metres upstream, very similar to position FB, less critical

Bunch-by-bunch luminosity signal (from 'BEAMCAL')

FB BPM in front of QD0 and FB kicker just behind of QD0/SD0

CLIC IP FB design status : CLIC CDR (2012)

NB : primary method for control of beam collision overlap is via vibration isolation of the FF magnets, and dynamic correction of residual component motions

IP beam position feedback: beam position correction up to ± 50 nm vertical at IP within a train (157ns)

More realistic engineering design in development

FB BPM and kicker are located just behind the BeamCal

FONT prototype systems performance : Stripline BPM resolution of 0.3μm (latency, drive power)

ILC prototype: FONT4 at KEK/ATF was verified the basic performance satisfication (150ns, < 300 nm)

CLIC prototype: FONT3 at KEK/ATF was verified the basic performance satisfication (13ns, < 50nm)

Outstanding technical issues :

Component designs need to be optimised for tight spatial environments, cabling, operation in large, spatially-varying B-field , further studies of radiation environment, lectronics location, rad hardness, shielding and RF interference between beam and FB electronics and also between kicker and detector etc. .

Discussion on possible future collaboration :

We could successfully exchange MDI issues of SuperKEKB, CEPC, SuperTauCharm factory, FCCee, ILC, CLIC and BNL-EIC. We found a lot of common issues such as superconducting final focus magnets, beam induced backgrouds, mechanical integration, solenoid compensation schemes, beam pipe design, forces and torques management . It is very nice to know current issues at various colliders. Also, we could communicate with experimentalists and accelerator physicists, altough they work separately on a daily basis. This workshop place is rather good since many of us leave from their own universities, institutes and we could concentrate in the mini-workshop.

The MDI is a meeting place for experimentalists and accelerator physicists to discuss on realization of future colliders in the energy and luminosity frontiers. Since investment of future collider is huge, all of them can not be realized, even a single collider is diffiult to be realized. It is very important to have an international collabortion through common issues such as MDI for us to participate in such a collider with actual contributions as much as possible in future.

There is a suggestion to continue this kind of activity, i.e. MDI mini-workshop by inviting young generations from experimental and accelerator fields. The HKUST IAS seems to be a good place if finantial support is available at least for local expenses to students.