Status and Updates for BBLR compensation

HS – 16-7-2015
HL-PLC

With contributions from:
S. Fartoukh, A. Rossi, R.Steinhagen (GSI), R.Veness, R.Jones, S. Redaelli, G. Tranquille, T.Lefevre, Y.Papaphillipou, G.Stancari(FNAL), A.Valishev (FNAL)

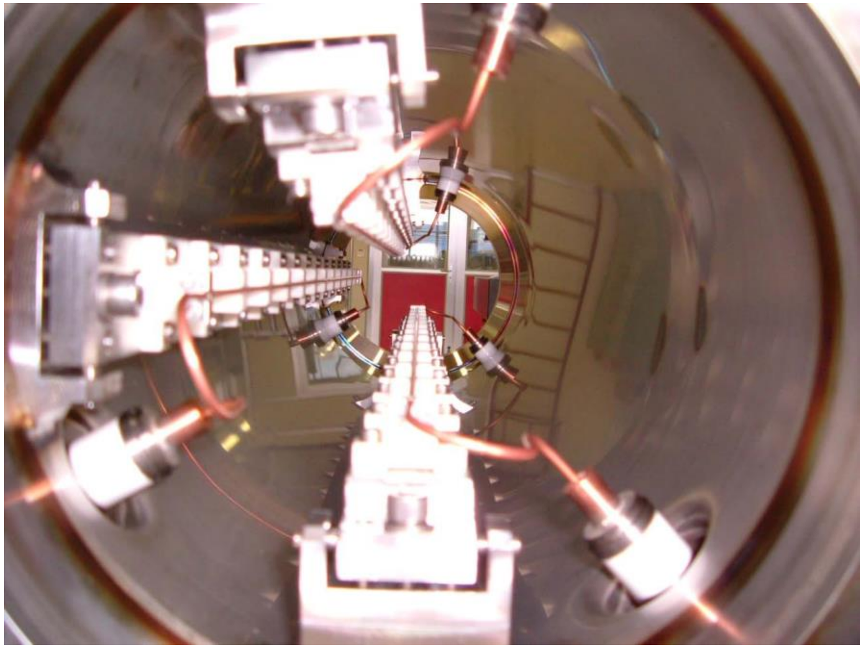
Outline

- Demonstrators
  - news on SPS wires
  - news on LHC “wire in jaw collimators”
  - related instrumentation
- R&D on actuators for HL-operation
  - wires
  - e-lens beam
    - test-stand
    - R&D (overlap monitor, higher current, pulsed beam)
- Integration/optimal location

Demonstrators

- Work consists of simulations, a workshop in December 2015, SPS experiments in 2015, LHC experiments in 2017/2018
  - simulations: Y.Papaphilipou et al, A.Valishev et al.
  Aim: simulate possible beam observables with/without compensation, specify necessary instruments performance
  - workshop: details still to be defined; December 2015
  aim: bring about 10 people from simulations together with about 10 instrumentation experts…see what is possible
  - SPS experiments: next slide
  - LHC experiments: following slides
- Aim of this work is to have end of the year 2018 enough experimental evidence such that BBLR compensation becomes a “construction option” for HL-LHC.

Wires in the SPS



- Installation “reanimated”
- Only one power converter left, needs access to change cabling. Remote polarity switch. Installation can be cycled in any SPS cycle.
- Cooling water circuit verified and operational
- Vacuum integrity verified
- Remote motorization does not work for the moment….need to steer the beam.
- Will be used for parasitic MDs, basically for code benchmarking.

News on “Wire in jaw” collimators

- 4 “wire in jaw“ collimators ordered from CINEL. Design finished in late 2014. Delivery expected in spring 2016, followed by qualification tests. Installation now scheduled for WS 2016/2017

- 2 configuration options:
1) full compensation of one beam: 1 collimator L&R in IP1 & IP5
2) compensation of both beams on the ingoing or outgoing side
= 2 collimators on the same side in IP1 & IP5

-Planned MD experiments: weak-strong regime
- one beam (with BBLR compensators and new instrumentation): single bunch plus witness bunch; other beam: at least enough bunches to have full LRBB on both sides
- can envisage to do experiments at injection energy
- The “two bunches only” operation will allow to go maximum close to the weak beam (7…9 sigma), which puts the wire at (10…12) sigma.

→ prepare for option 1: integration: A.Rossi

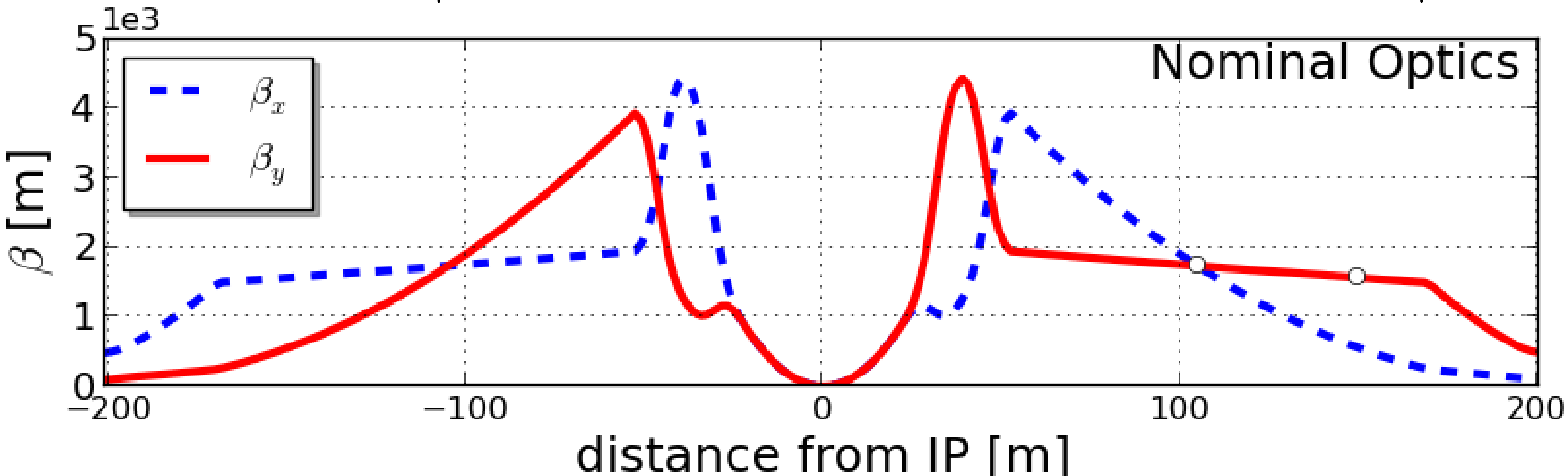
-Simulations ongoing for observables

- Workshop on “BBLR compensation: Simulations and Observation”:
First week in December 2015, Lyon, 2 days, by invitation only.

Two wires/IP/beam

- Locality of the compensation
  - Wire should be as close as possible to the LR encounters (~π/2 from IP)
- Integrated current can be reduced for the same correction reach
- Powered independently to fit the LR integrated kick on either side
  - Optics anti-symmetry imposes anti-symmetric resonance driving terms excitation left and right of the IP

$$\mathcal{H}_{n_x,n_y} \propto \left| \int_0^C \frac{b_n}{r_W^n} \beta_x^{n_x/2} \beta_y^{n_y/2} e^{i(n_x\mu_x + n_y\mu_y)} ds \right|$$



Related instrumentation: coronagraph

- collaboration agreement signed with KEK (T.Mitsuhashi et al.) for the design and construction of a coronagraph in the LHC

= 2 D transverse profile measurements for the beam halo
→ principle next two slides

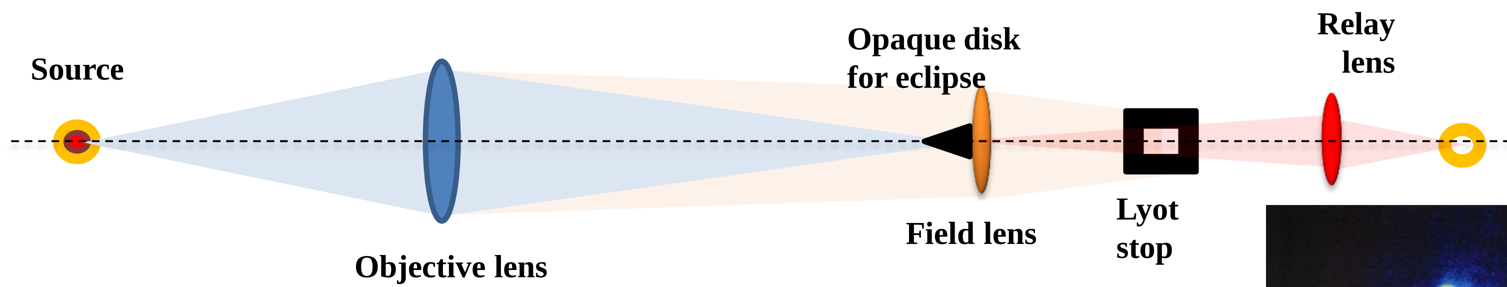
- schedule:
design and procurement of components, lab tests: 2015
Modifications of synchrotron light telescope (of one beam): WS 2015/2016
commissioning of coronagraph during 2016

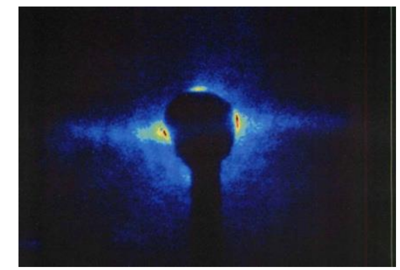
- question to answer:

- trade-off to be made between demagnification of telescope (physical space, size and quality of lenses, cost) and scientific usage

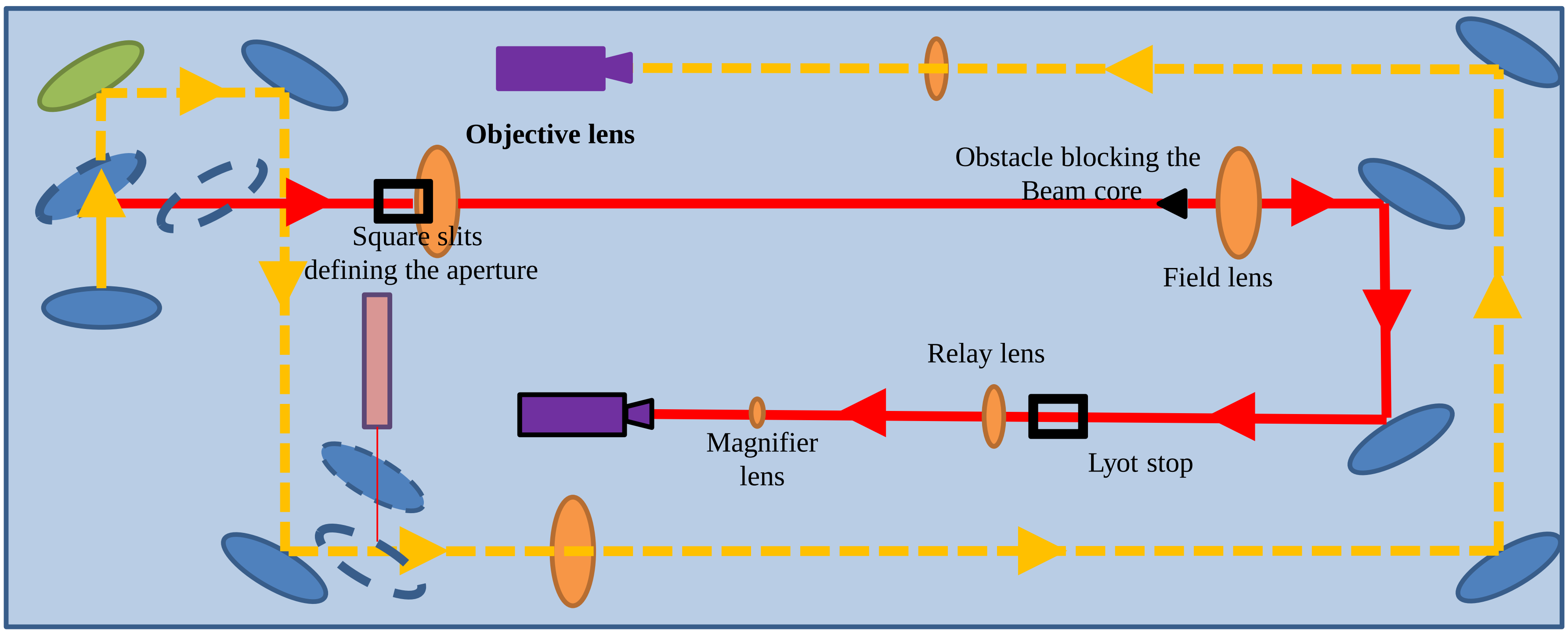
Present design: contrast between core peak and visible halo: 10^{-4} (only)

Coronagraph for beam halo measurement

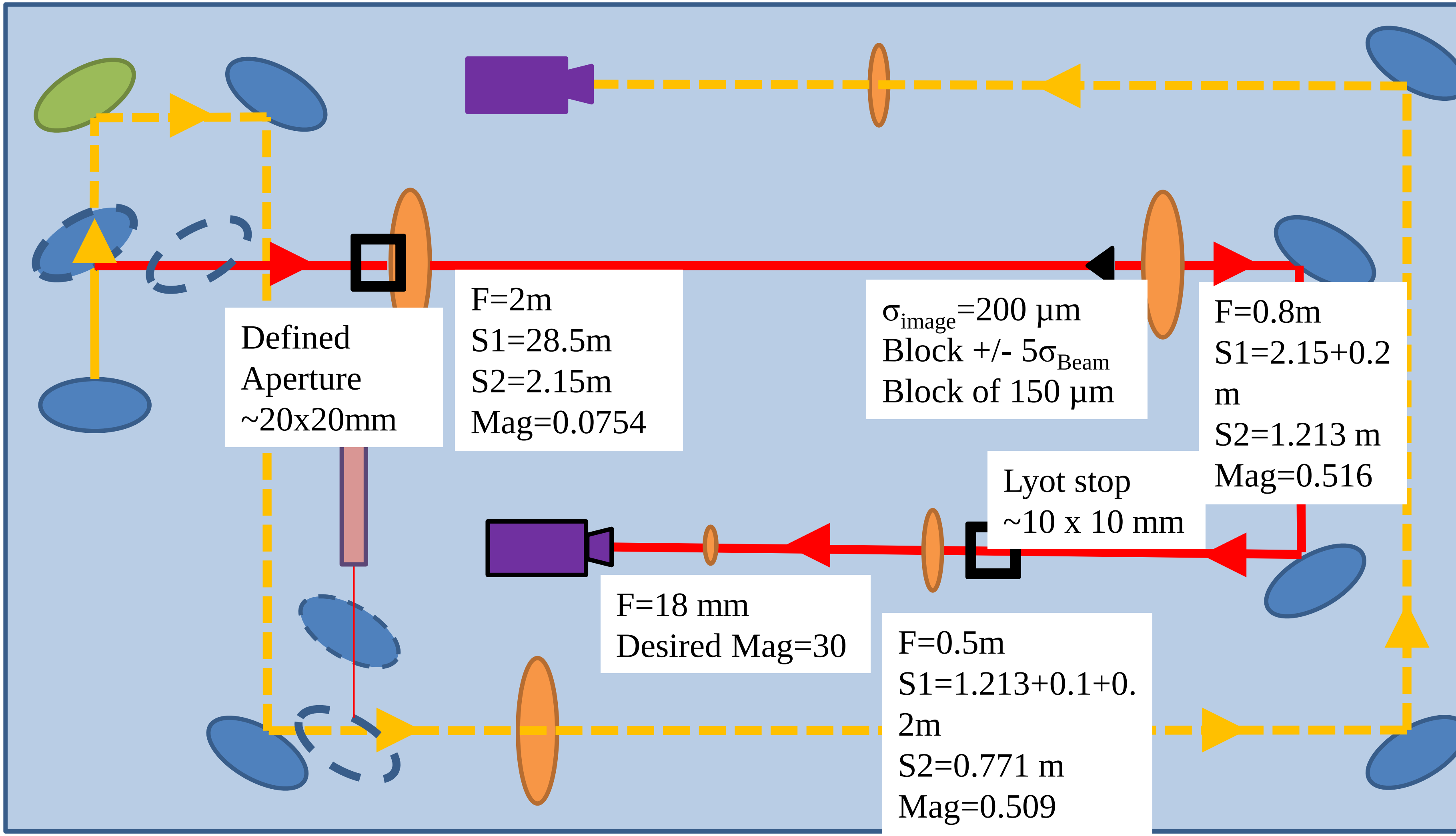




Setup of the coronagraph at B1



Optical design



Total Size needed is 5.2 m

Achieving 2.26 final Mag fitting on camera measurable halo +/-10 sigma (after the not wanted 5 sigma)

Other new instrumentation

- Waiting for progress on tune spectra, BTFs (T.Pieloni et al.)
- High dynamic range camera for direct observation of halo: Collaboration set up with A.Fisher (SLAC)… moving slowly
- BGV (beam gas vertex): with enough integration time could be used for halo measurements as well:
  - wait for commissioning results for nominal profile, then assess sources for backgrounds at the 10^{-5} level.

"New" activities on physical wire actuator

- In general: Any physical wire needs to be operated in the shadow of the tertiary collimators and has to comply to machine protection requirements.
- review proposal of Amalia Ballarino (2008!) to use HTS wire
- More detailed study of field distribution:

$$c_{pq}^{LR} \propto \sum_{k \in LR} \frac{\beta_{x,k}^{|p|/2} \beta_{y,k}^{|q|/2}}{d_{bb,k}^{|p|+|q|}}$$

Taken from S.Fartoukh's presentation

We want to approximate the above sum of LRBB interactions by a single multipole kick with a 1/r shape.

Can we not see if a field shape like r^(alpha); (alpha ~ -1) is not a better approximation and if a mechanically more stable geometry than a wire (sheet, cross, triangle….) can satisfy this new field requirement and the cooling needs?

→ have foreseen a small study with A.Patapenka under the supervision of M.Barnes using the OPERA tool. Need support for this from ABP…

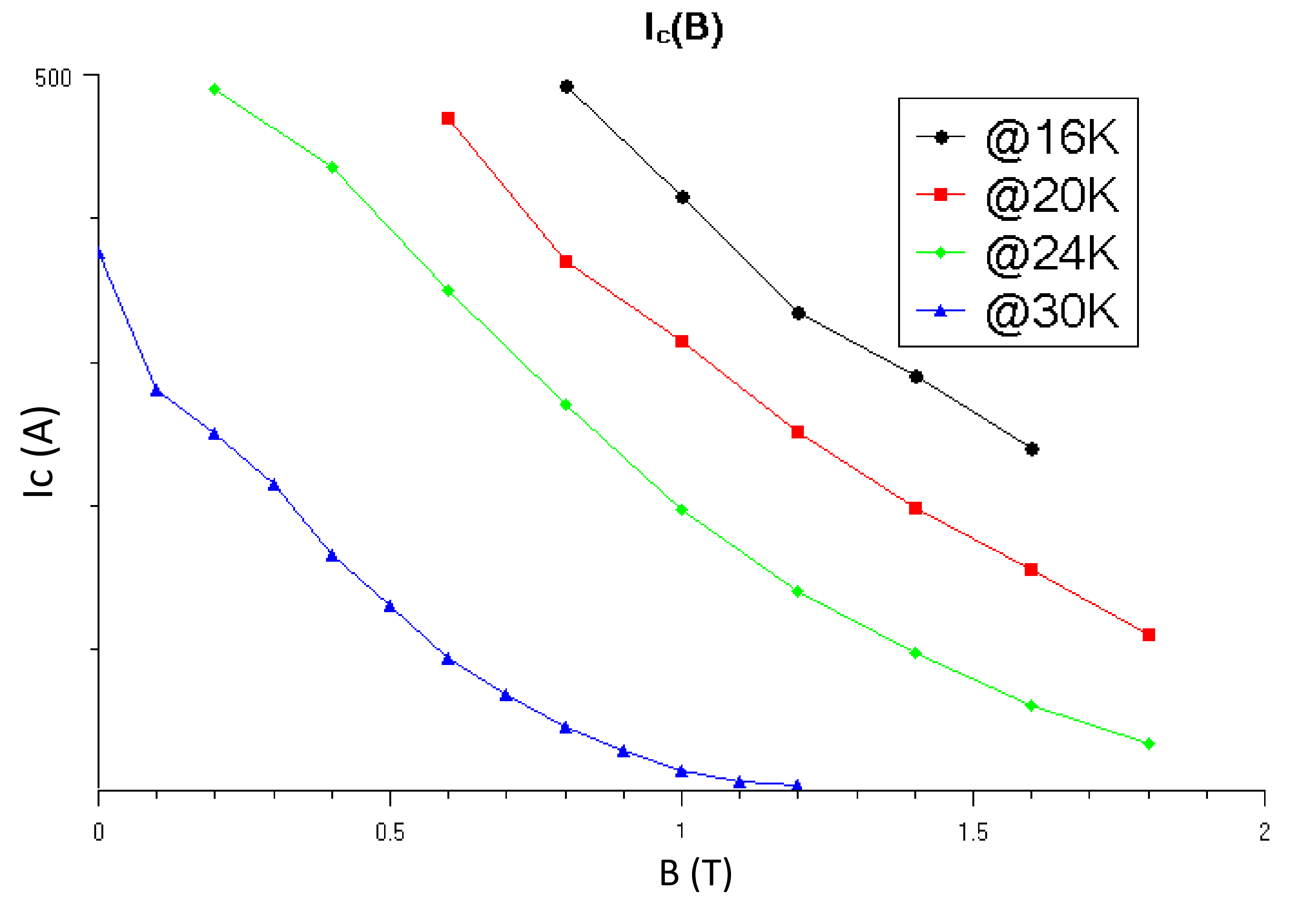
Possible HTS wire implementation

Amalia Ballarino

Care HHH Working Meeting
LHC beam-beam effects and beam-beam interaction
CERN, 28th August 2008

MgB_2 conductor: electrical properties

Ex-situ, 1.1 mm Φ MgB_2 wire (Columbus)

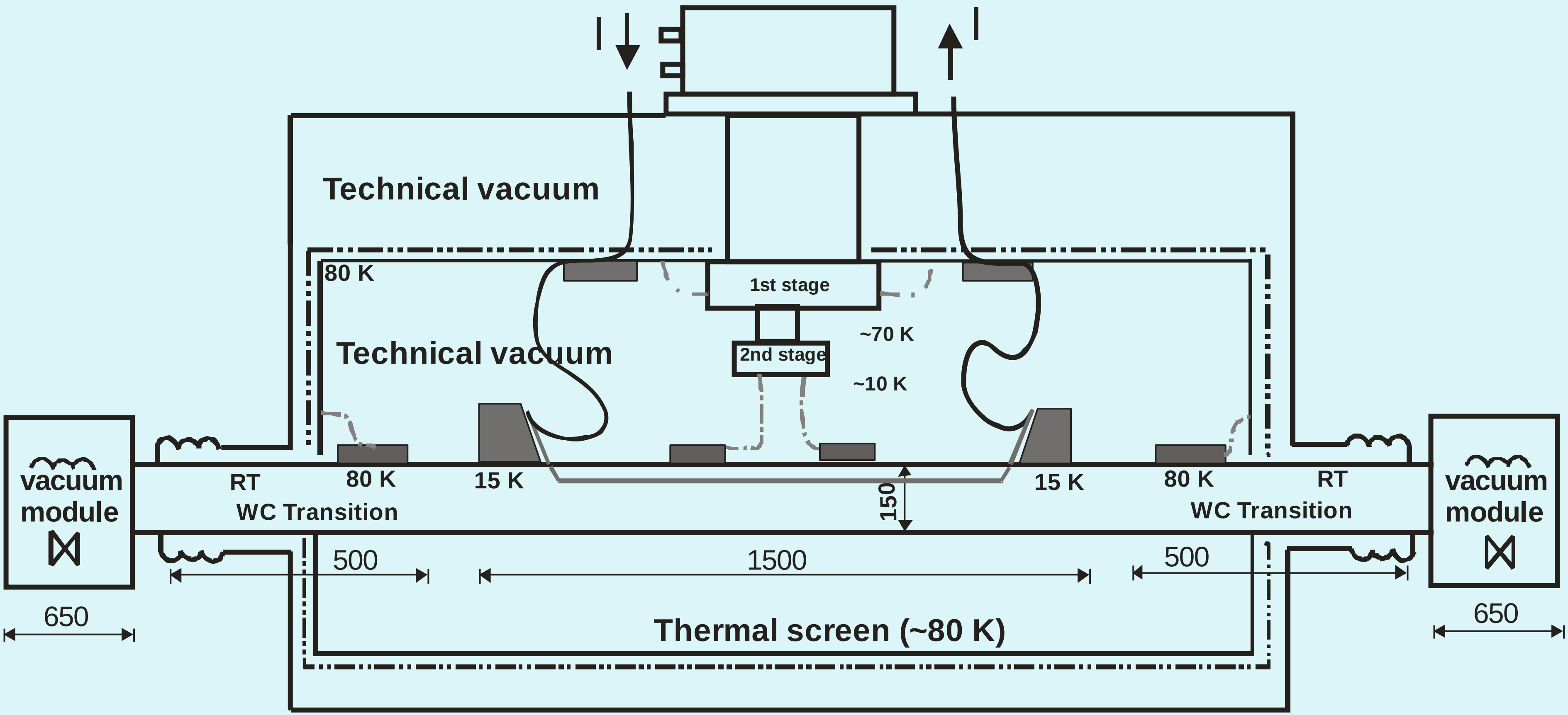


Measurements performed by Columbus in July 2008

Ic(24 K, 0.4T)=436 A. J_{ce}=357 A/mm^2
Measured at CERN an Ic ~ 800 A (4.2 K, 1.5 T)

$Rb_{min} \sim 100\ R_{wire}$

Cryostat around cold beam pipe

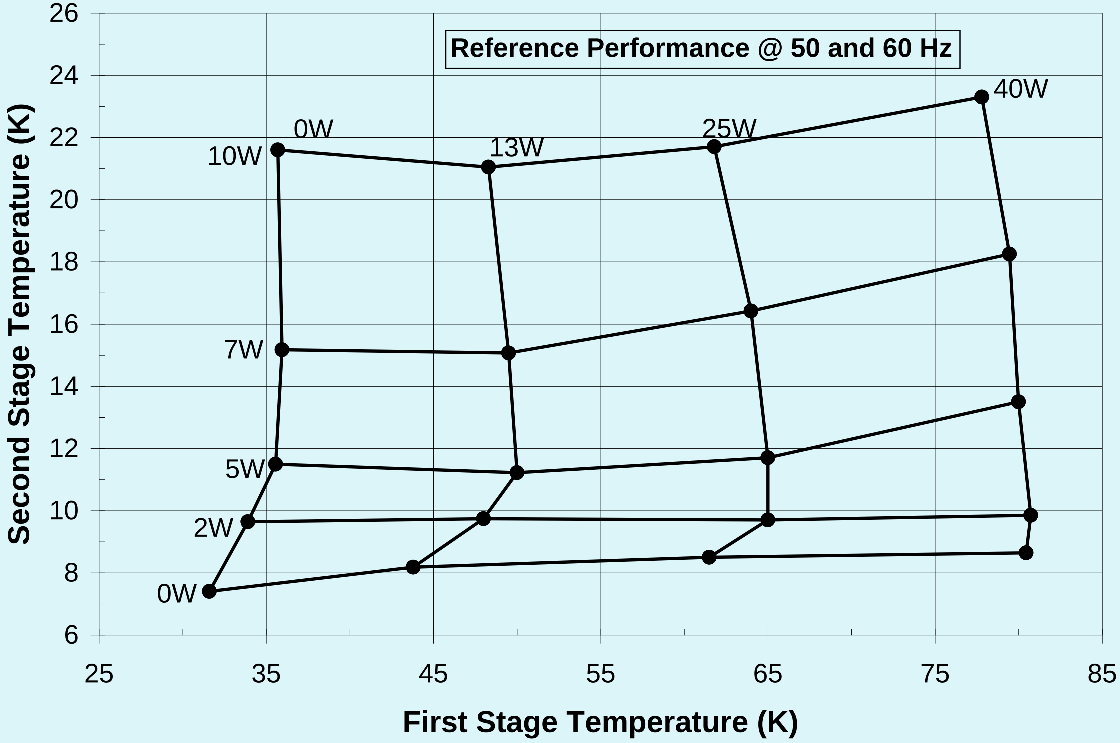


LTOT ~4 m (including vacuum modules)
Lcryostat ~2.5 m
HTOT ~1.2 m

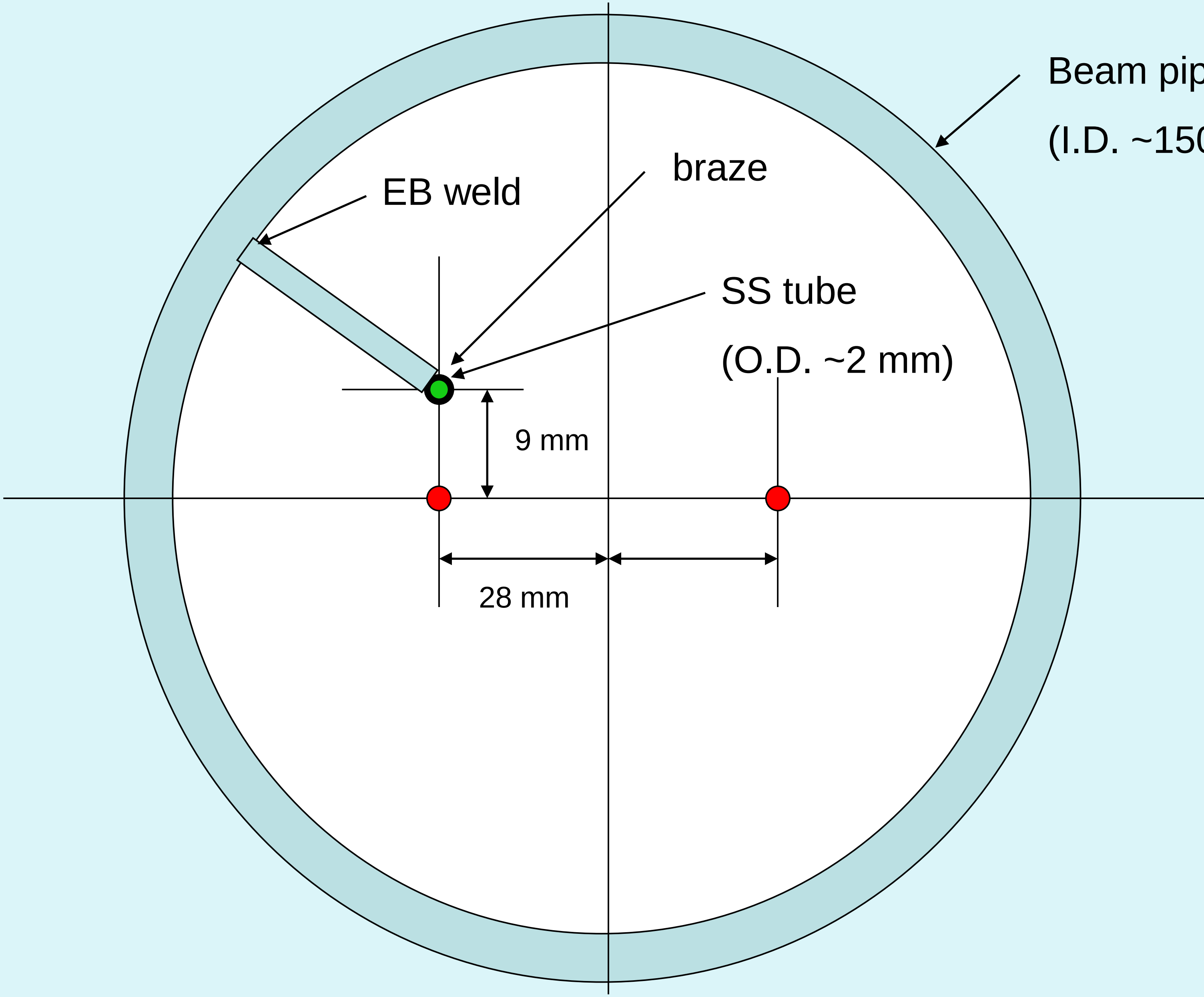
A. Ballarino

Two-stage Pulse Tube cryocooler

Cryomech, 40 W @ 80 K, 8 W @ 20 K- 0 W @ 8 K



Conductor support structure – cross-section



-The resistivity of copper (RRR=120) at 20 K is $\sim 1.3 \cdot 10^{-10}\ \Omega$ m – about 100 times lower than at room temperature

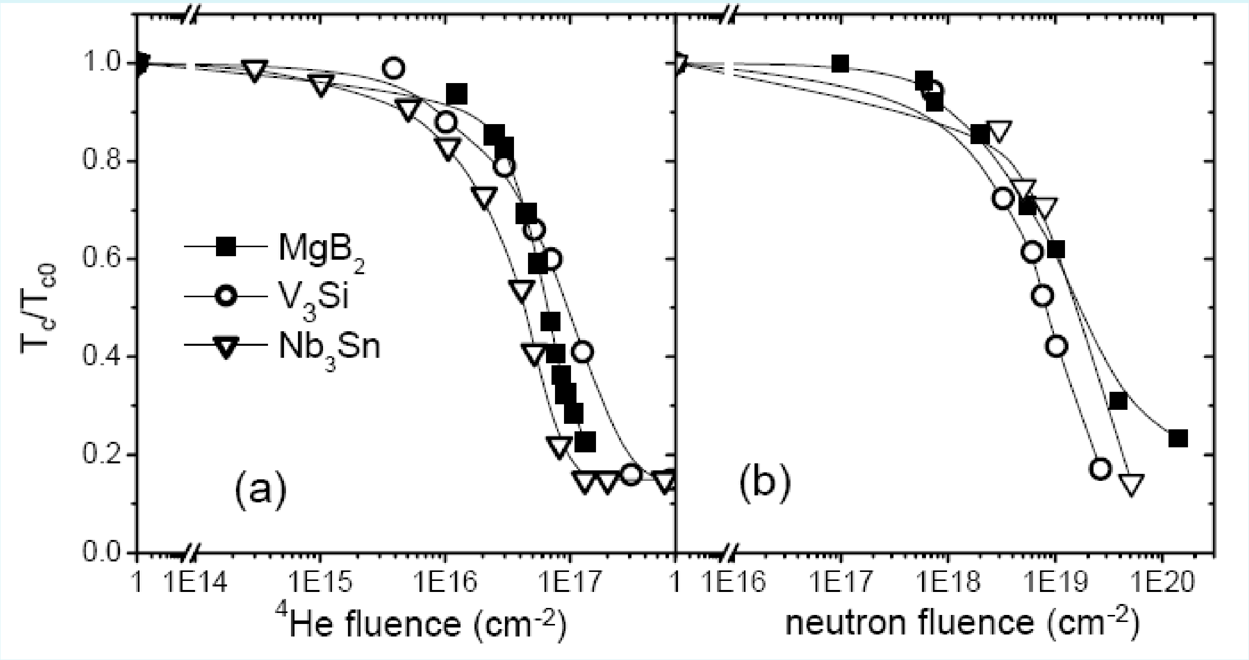
-A copper wire (RRR=120) of about 0.9 mm^2 cross section ($\Phi \sim 1$ mm) would dissipate about 1 W when transporting 80 A in dc mode at 20 K

-At this stage, it may be interesting to consider also the copper wire option (the cryostat, the integration and assembly procedures, and the size of the stainless steel tube would not change –the MgB_2 conductor has a diameter of 1.1 mm)

Open points

-Heat losses from the beam ?
In the present proposal, the MgB_2 conductor operates with a temperature margin of about 10 K

-Radiation in the area where the MgB2 is integrated ?
The radiation resistance properties of MgB2 seems to be good – similar to Nb_3Sn. Neutron irradiation tests were done at very high fluences (up to $3.9 \cdot 10^{19}$ $n \cdot cm^{-2}$, INFM and University of Genova). Up to fluences of $1 \cdot 10^{18}$ $n \cdot cm^{-2}$ no degradation of Tc was observed



My conclusions (HS):

- Already in 2008 Amalia concluded that a HTS wire integrated into the vacuum is feasible.
- The specific resistance of copper at cryogenic temperature is 100 times lower than at room temperature.
  Even a copper tube cooled with liquid helium would do it!!!
- In the meantime the cryocoolers and the HTS material has improved.
- In contrary to the 2008 proposal the mechanical design has to be reviewed and made “movable”.
- The impact of the beam on the wire has to be studied.
- The impedance police will have to say a word…

- Last not least:
  I would like to propose the construction of a prototype, which is compatible with an installation into the LHC during LS2!

Electrostatic compensation?

Using a charged wire at some high voltage also a 1/r field can be generated (the vacuum tube behind the wire needs a cylindrical shape)

Stephane Fartoukh has "quickly" calculated the required voltages:

→ *About 60 kV over 1 m…not impossible*

→ *cannot easily be pulsed at MHz frequencies*

→ *difficult geometry*

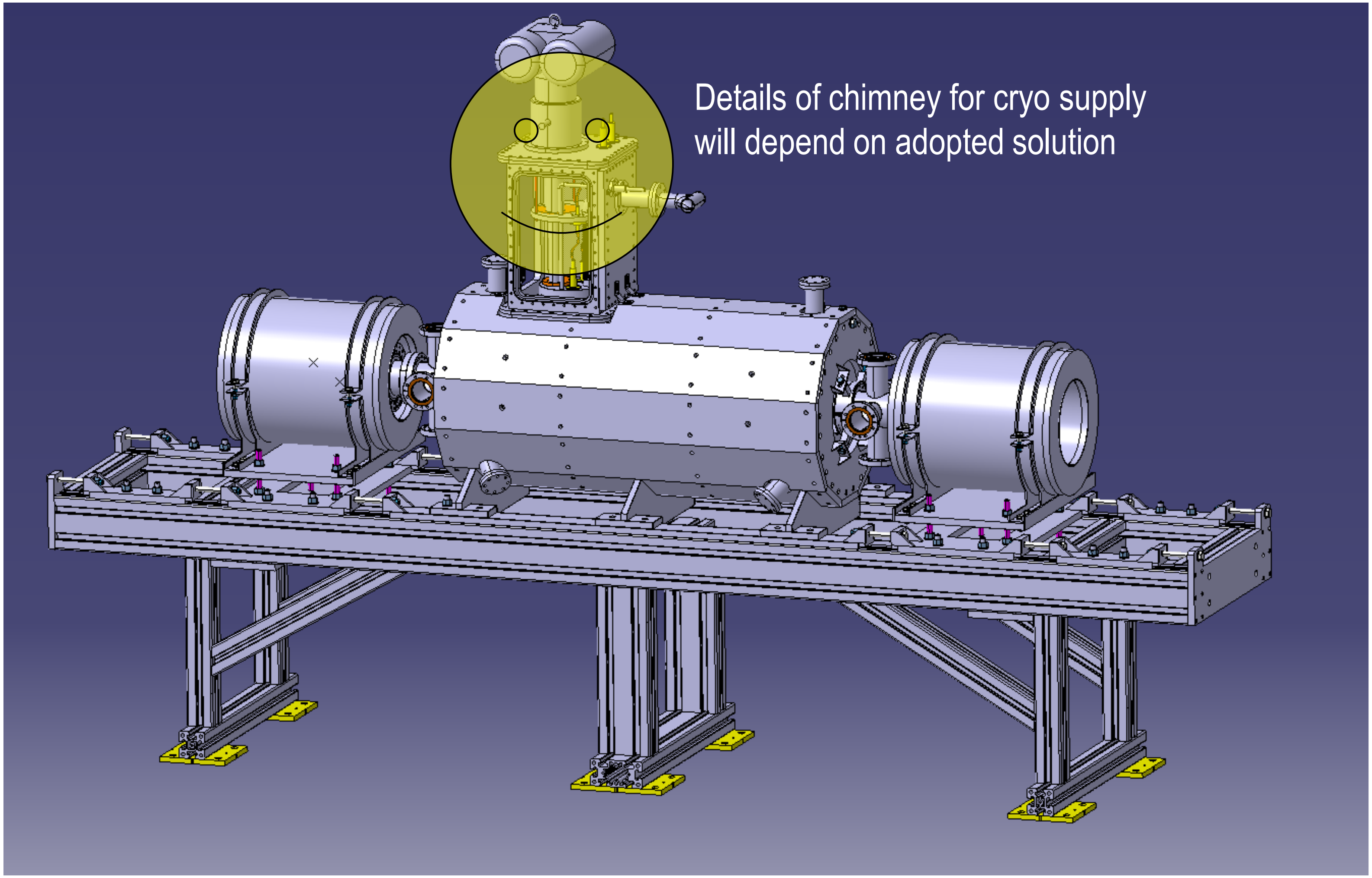
→ *What will the beam do with the wire?*

→ *Not Followed up for the moment*

E-lens as BBLR actuator

- *No machine protection issues, can be as close to beam as wanted*
- *But:*
  - integration issues are at least as difficult as for a physical wire
  - needs about 60 Am kick strength
  → 4 times more current than achieved (for 3m interaction length)
  - needs R&D for pulsing
  - e-beam has a Gaussian shape (transverse). Does this effect the efficiency of compensation? → need ABP support
  - Propose a test stand at CERN for above R&D including related instrumentation (overlap monitor (=mainly for Halo collimation with hollow e-beam)
  - test stand issues (next slides):
  design of a 1m long prototype SC solenoid (D.Perini et al.):
  no import of TEL-2 from the US
  cryogenic supply for SC solenoid (S.Claudet et al.)
  R&D details (R.Veness, I. Syratchev, P.Forck (GSI), A.Jeff (Liverpool University) et al.

1m long SC solenoid prototype (D.Perini et al.)



Prototype details

- *1m long SC solenoid with max. field of 6 T*
- *Expected cryoload < 4 W*
- *Inner (warm) bore diameter: 154 mm*
- *Straight design (no 60 degree bends)*
- *Constructed inhouse (i.e. coil in house, components bought inhouse, final assembly: closeby industry)*
- *Ready next summer (summer 2016)*
- *Provided with it: 2 small (warm) solenoids for source and collector; workbench*
- *Responsibility of BE-BI: inside vacuum chamber (source interface; BPMs, BCT, clearing electrodes, overlap monitor, collector):*
  Responsibility: R.Veness (BE-BI-ML)
  → *confirmation of required inner bore diameter by September 2015*
  → *Design and construction for autumn 2016*

Study of a possible test station for new e-lens

S. Claudet, TE-CRG

July 2015

Content

- Requirements
- Alternatives evaluated
- Presentation of BA7 proposal
- Cost & Schedule rough estimates for BA7
- Summary

Requirements

- General considerations:
  - No longer recovered item from Fermilab
  - Short model to be built by TE-MSC (incl. tests at SM18) and used for RnD according to below test program
  - If validated, long model to be built for LHC-P4 (tested at SM18)
- Interfaces:
  - About 1 x 5 m2 plus diagnostics & electronics
  - Target 5W@4.5K, 70K shielded
- Test program:
  - Few months each year, exact program to be confirmed
  - 2 to 3 years of RnD for possible halo collimator for LHC-P4
  - Up to 7 years total for possible BBLR for P1/P5

Alternatives evaluated

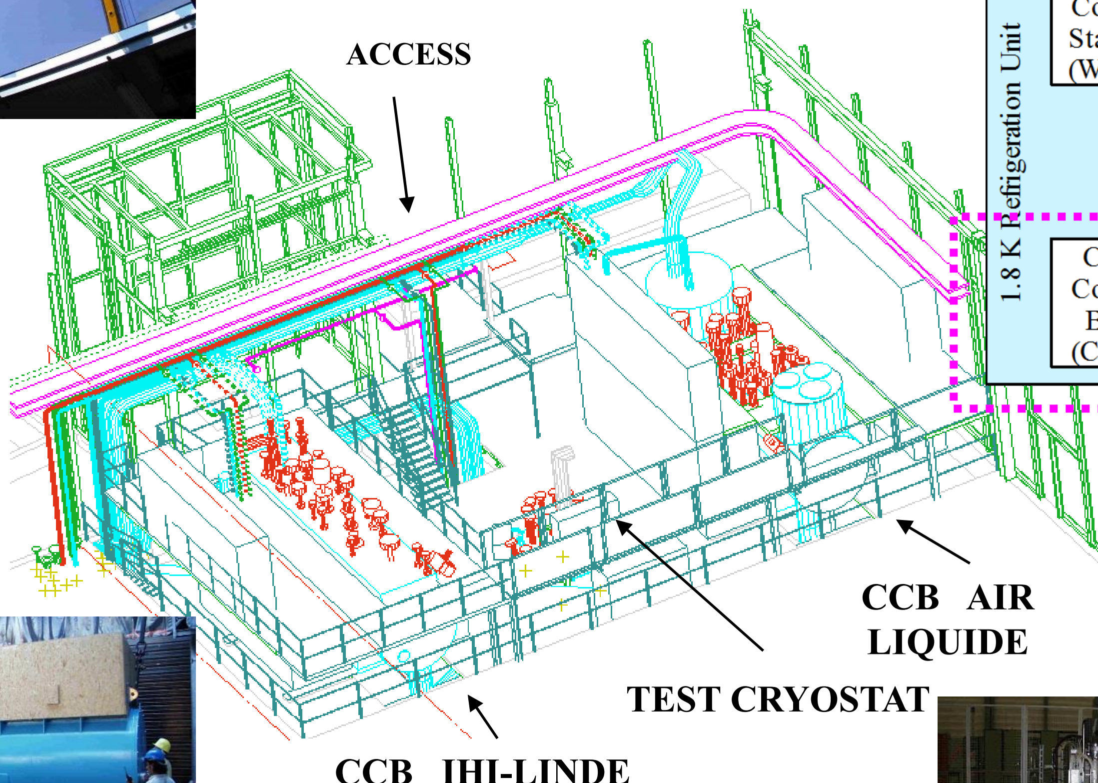
- B236 (no cryo, but BI instrumentation there)

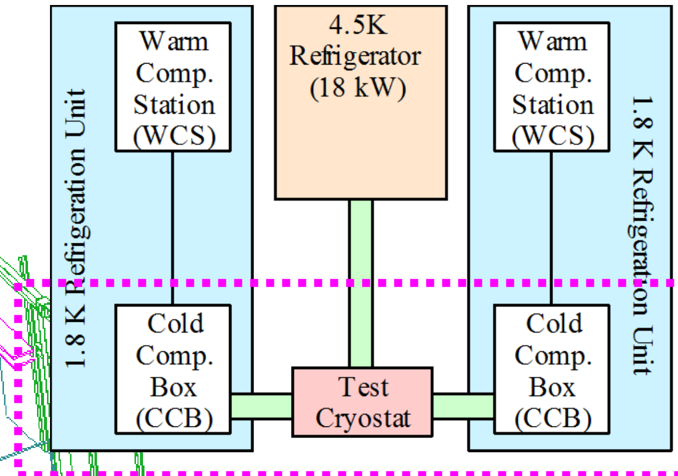
  Too high heat loads for cryo-coolers, too much integrated consumption not to recover helium, and too long distance to install a recovery pipe towards B165 central Liquefier
- SM18: no space for so long test period, only qualification of sc magnet
- P8-CAST: Too large refrigerator, and will CAST stop one day?
- North Area ex-Bloc4: Too large refrigerator, and all to be restored
- BA7: future re-liquefaction of LHe storage tanks
  - Adapted refrigerator capacity for e-lens during Run’s, and compatible during LS’s for both needs

  => Best candidate identified so far

Former qualification of LHC 1.8K units at BA7

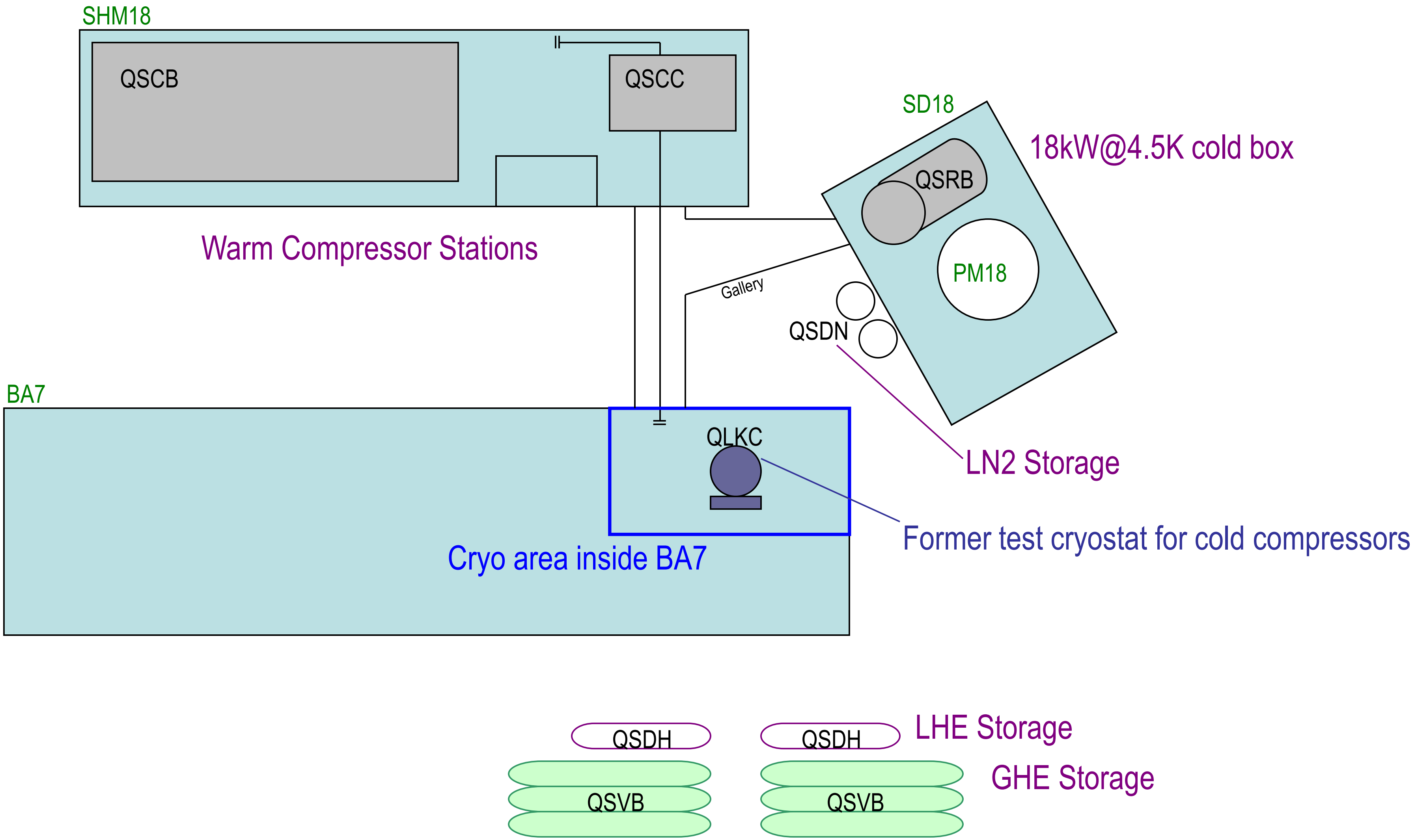
(2001-2003)





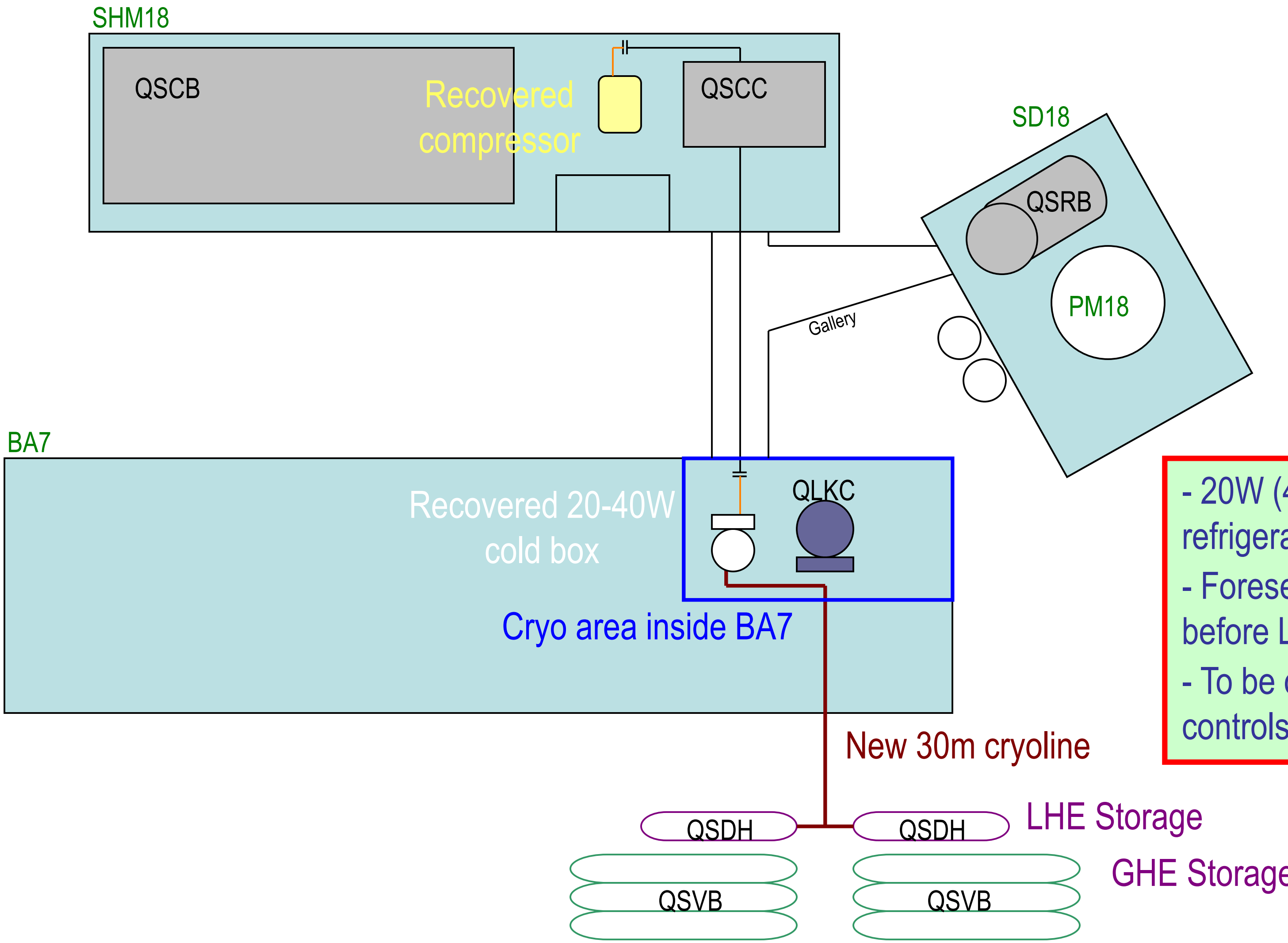
Zone 1.8, existing Cryo equipments

All operated for LHC (sector 12)



Helium management during LS

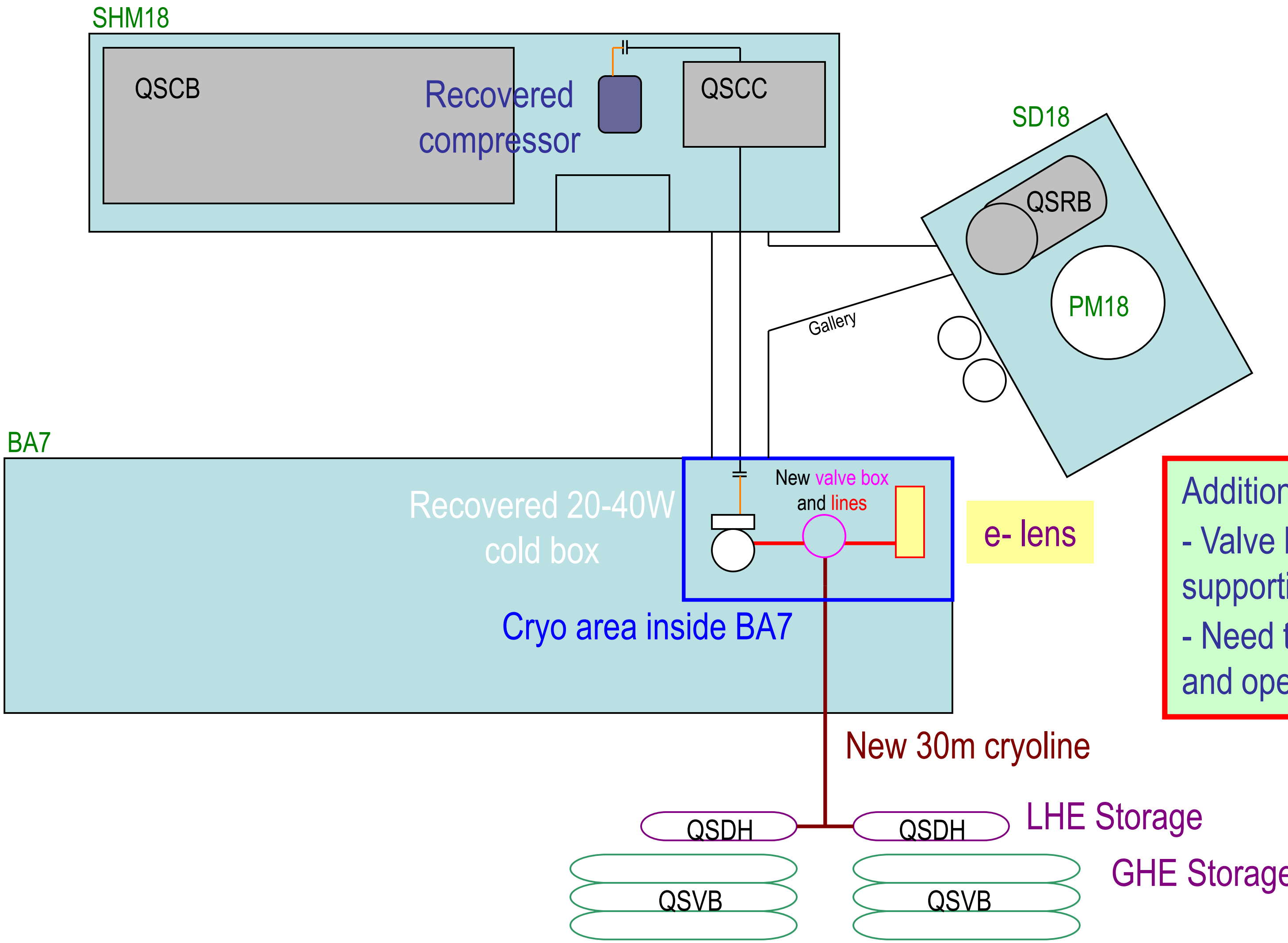
Wish to minimise the external storage by re-liquefying the boil-off



- 20W (40W with LN2) refrigerator almost new
- Foreseen to be operational before LS2
- To be done: Checks, piping, controls, new cryoline

Considering now Helium-LS AND e- lens

Wish to minimise the additional work required



Additional work:
- Valve box, small cryo lines, supporting structures
- Need to be ready end'16, and operated for e-lens

Summary (of Serge Claudet)

- The best way identified so far to support the extensive tests of the new e- lens project is at BA7, coupled with an installation already foreseen by the cryogenic group
- Only the marginal installation costs will have to be bared by the e- lens project, and moderate operation cost to run the installation
- This infrastructure should be operational by end of 2016, with solution to be found for engineering resources mid'15 to mid'16 for valve box and lines


CERN

6m deep hole below future teststand

R&D on e-lens prototype

- Increase in electron beam current
  Presently a "copy" of the Tevatrun gun is designed and constructed at CERN. This will import the know-how to CERN. For reasons of scheduling the first tests of this gun will be done on the test-stand at Fermilab (2016)
  After these tests a new design (larger surface, higher voltages…) will be made in order to increase the e-beam current….no further action for the moment.

- Modulation of electron beam current (next slides)
  a) small modulation at 10-3 (even 10-4) level at several 100 MHz in order to make a simple BPM work (button monitors)→ high frequency modulation electrode
  b) modulation of entire current
  (CERN interest: PACMAN bunches; GSI interest: Space charge compensation)
  ….presently thinking to enter into a collaboration with a Russian institute (CLIC initiative by Igor Syratchev): High efficiency High power klystron
  → in addition to the pulsed waveform of the modulator the electron beam in the klystron will be switched ON/OFF during the rise/fall times of the HV pulse

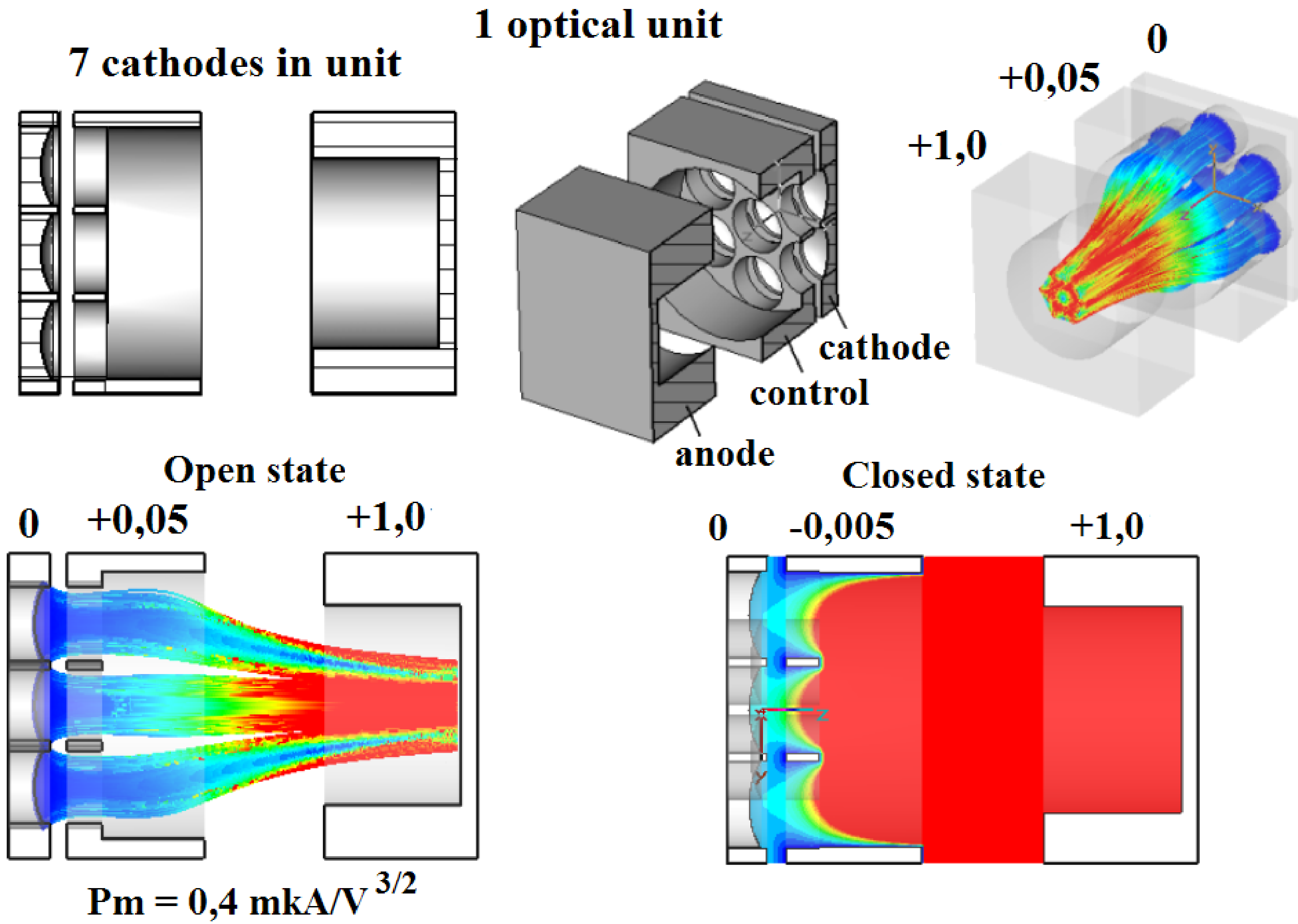
- Overlap monitor (overnext slides)

Development of the gun with low control voltage for 1,5 MW, 0,8 GHz HEKCW klystron

I.A. Guzilov

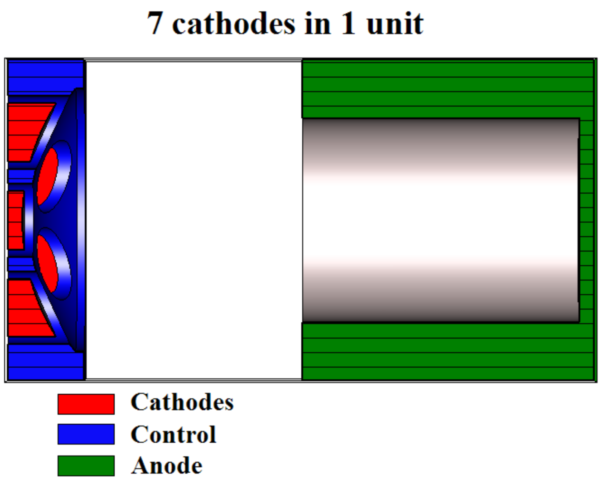
JSC "Vacuum device's basic technologies", Moscow, Vvedenskogo str., 3-1, RUSSIAN FEDERATION, email: *iag@bk.ru*

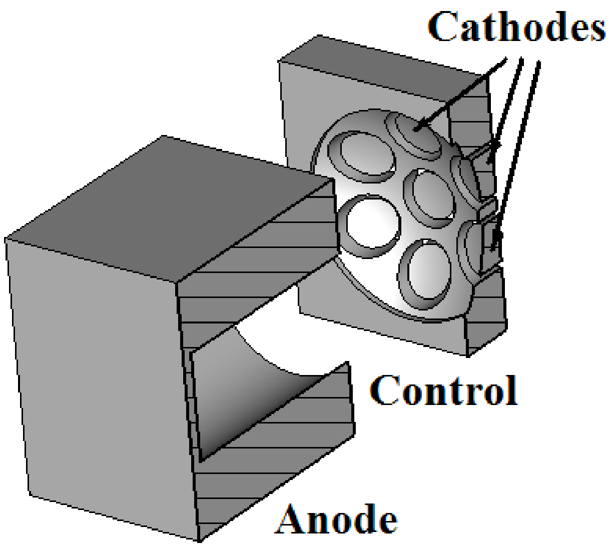
Way to drastically reduce the control voltage - Optics with multi-beam gate electrode
1. Control by positive potential

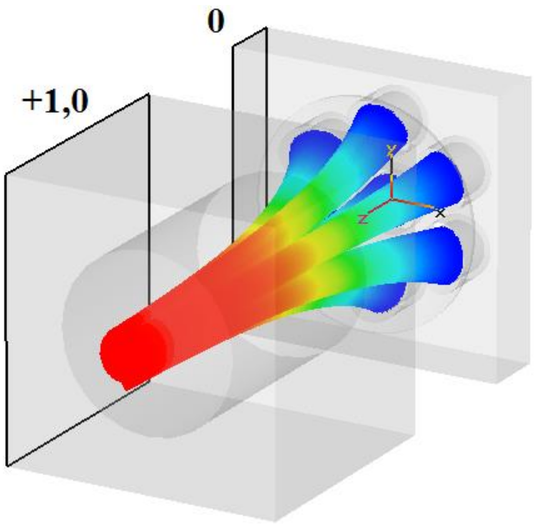


The amplitude of the control voltage is 5,5% for Pm=0,4

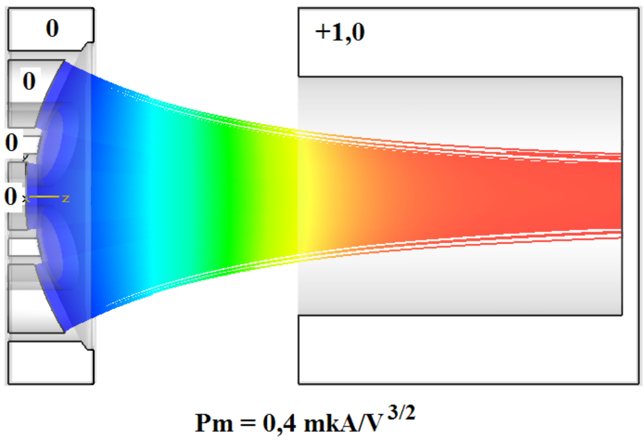
Optics with multi-beam gate electrode
2. Control by negative potential



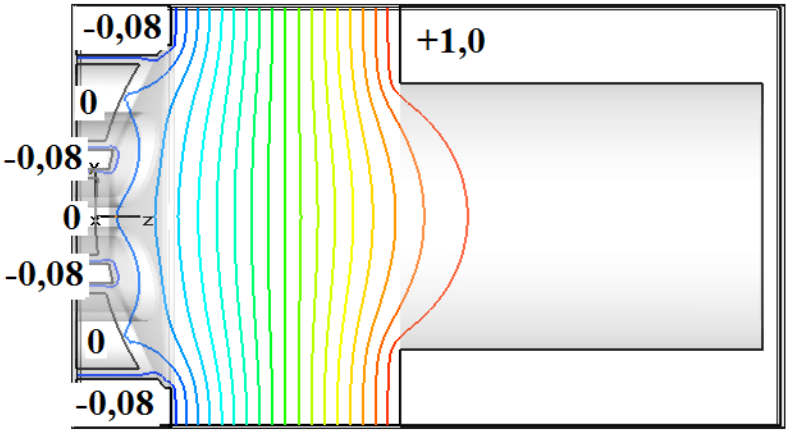




Open state



Closed state



The amplitude of the control voltage is 8% for Pm=0,4

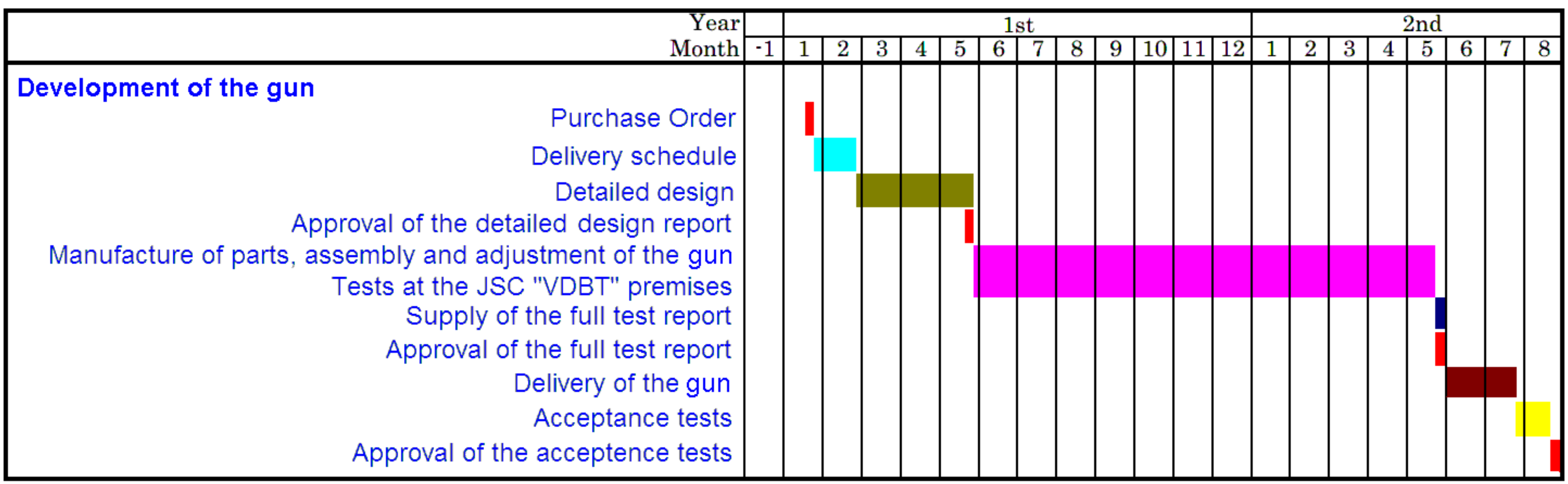
Technical requirements for the gun

1. Cathode unit of the gun has several separated cathodes
2. Control electrode should be chosen from 2 variants
   (var 1 - positive potential during pulse, var 2 - zero potential during pulse)
3. Diameter of channel in anode is 16 mm, the length of the channel is no less, then 150 mm
4. The cooling of the collector is air, average power in collector is no more, then 200 W
5. Cathode voltage 40 kV (Uc)
6. Cathode pulse current 2,7 A (Ic)
7. Amplitude of control voltage < 10 % Uc.
8. Collector pulse current > 98 % Ic.
9. Current density on the cathode < 2,5 A/cm^2

Milestones

Development of the gun with low control voltage

JSC "Vacuum device's basic technologies"
Research dept.

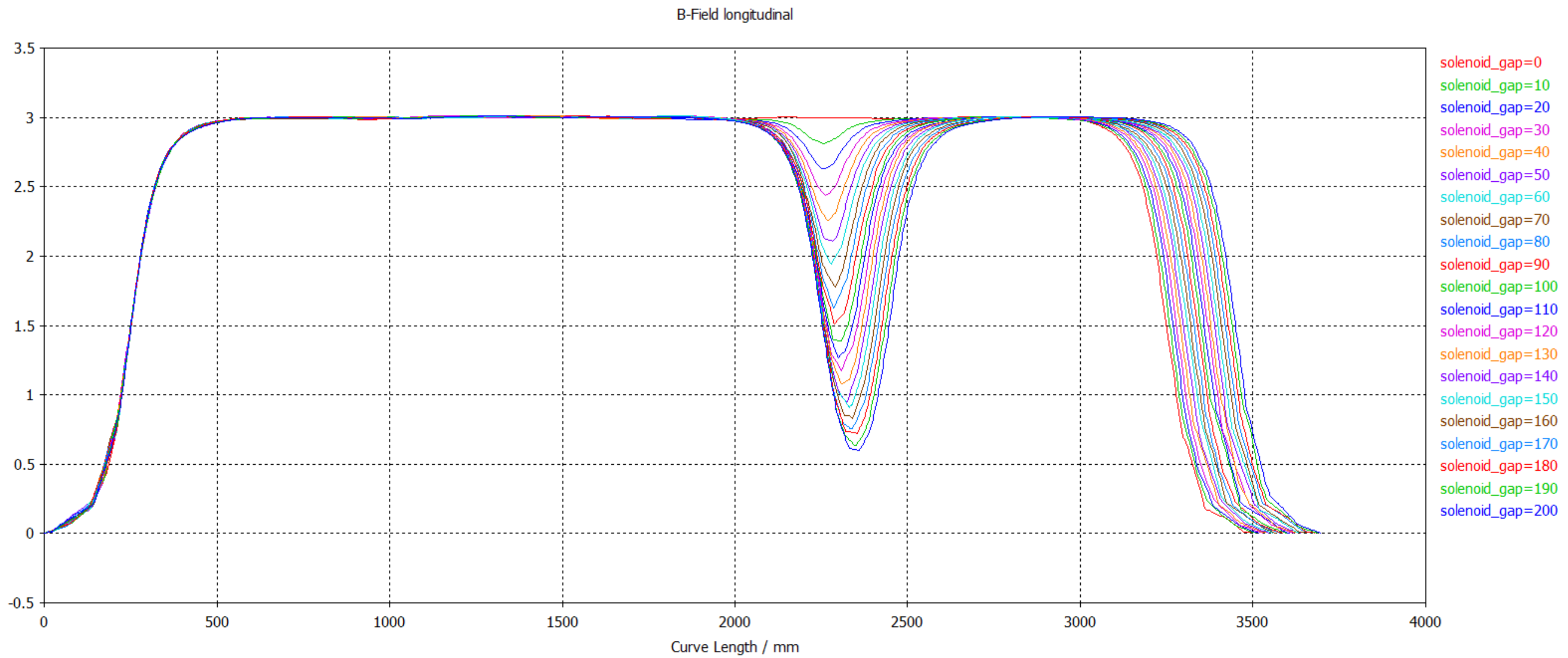


Overlap Monitor R&D

Overlap Monitor: = 2D transverse profile monitor close to the overlap region of proton and electron beam (predominantly for Halo collimation)

- Collaboration set up with Liverpool university for such a monitor using a thin gas jet as target (10-6 gas pressure of N2) and N2 fluorescence for observation
- Test stand available in Liverpool; still this year observation of fluorescence there with a low energy electron beam
- Contribution of GSI (P.Forck): Using different spectral lines of fluorescence to distinguish between proton beam and electron beam
- Integration of a new (slim design of monitor) into CERN test-stand later
- Considering installation of test monitor first in Linac4 in order to study proton signal
- Looks promising in simulations; only “problem”: monitor too big to be installed inside SC solenoid…measured electron beam profile does not have the same size as in the overlap region.

Magnetic field



- Field on axis with two solenoids of 2m and 1m
- First solenoid starts at z=250mm
- Gap in mm shown on right
- Simulated for solenoid field=3T but should scale linearly
- Very simplistic, ignores gun & collector solenoids, bends, beam pipe and other components.

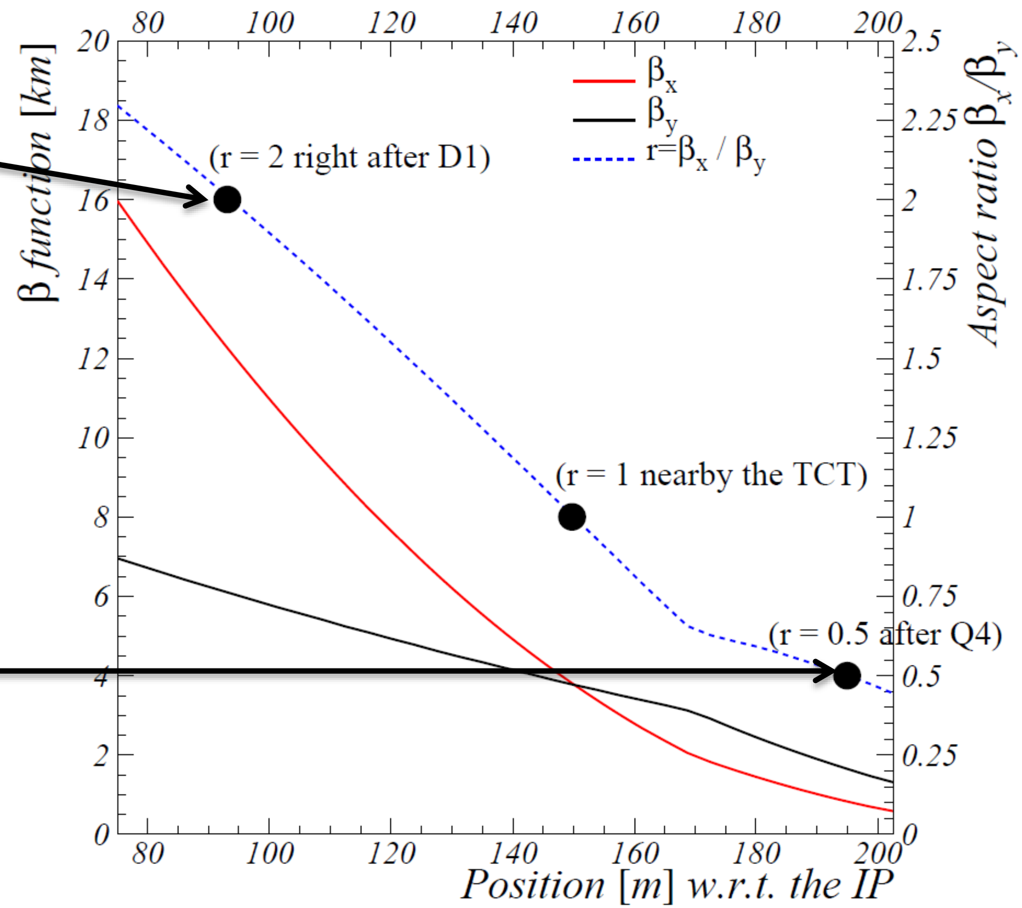
BBLR Integration (HL optics; A.Rossi)

- For years the assumption has been that the optimum location of BBLR compensation is a equal betas (next to TCTs)
- In a recent study S.Fartoukh has shown that almost optimum compensation of all multipoles is at betax/betay = 0.5 or betax/betay =2
- A. Rossi has looked in detail at possible locations with these beta ratios

BBLR locations (plot taken from S.Fartoukh)

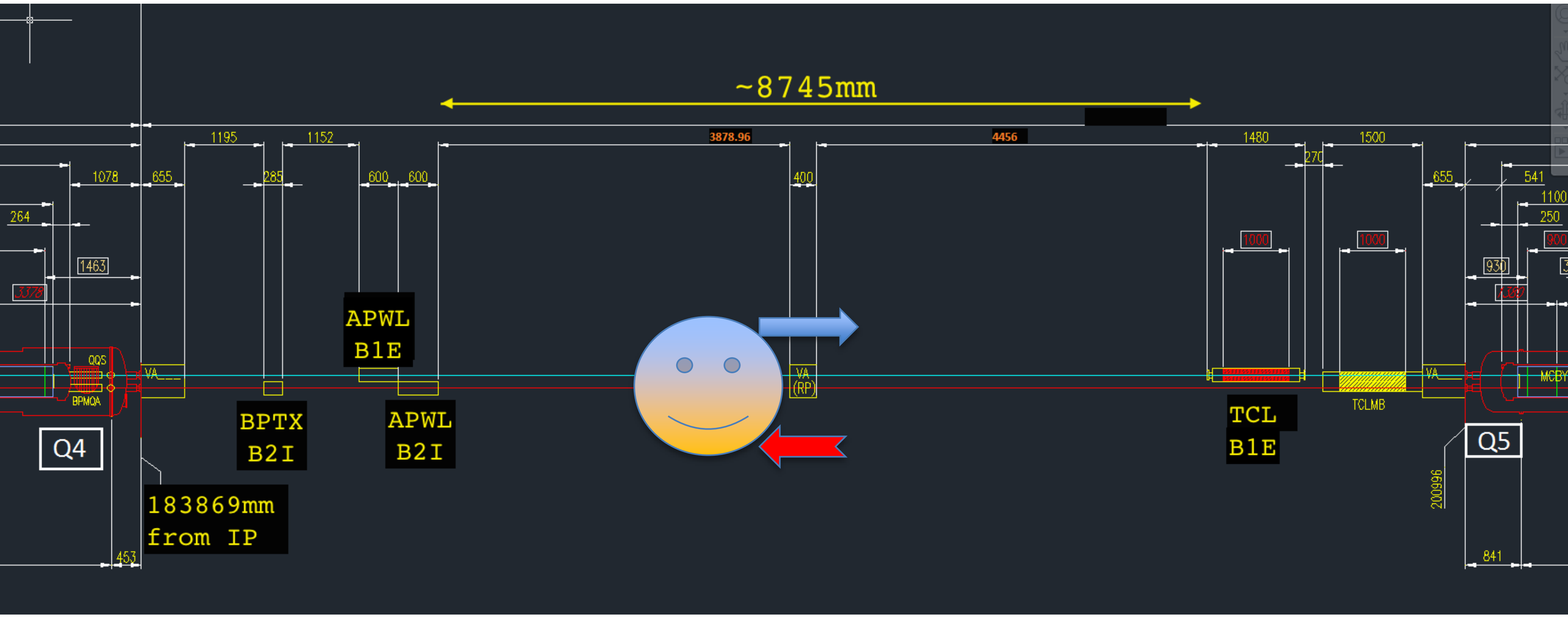
$\beta_x/\beta_y \approx 2$ at ~ 90m from IP
Single beam pipe

$\beta_x/\beta_y \approx 0.5$ at ~ 190m
Between Q4 and Q5



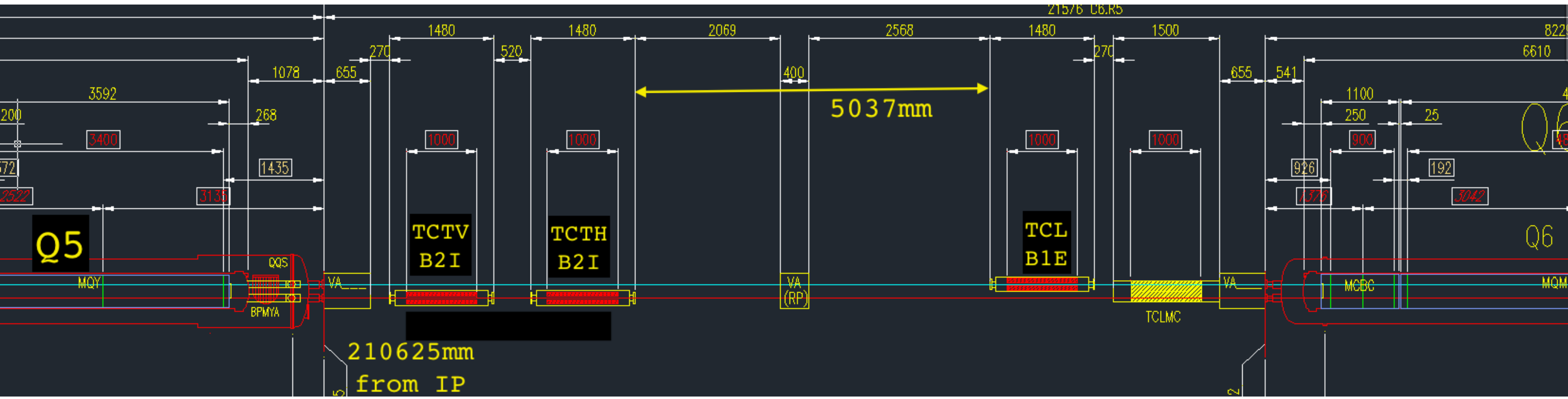
Q4-Q5:

HL-LHC v1.2 (still under study)



optic version (still under study).

Q5-Q6:
HL-LHC v1.2 (still under study)



Summary

- Progress on wire demonstrators in the SPS and the LHC
- Important workshop scheduled for first week of December in Lyon; people interested please contact me.
- Comprehensive program established for R&D on possible BBLR actuators for HL-scheme
  - physical wires
  - e-lenses
- Test stand definition for e-lens test stand complete
- Cost estimate available for whole program; will be presented in EATSMB next Monday
- E-lens on its way to be proposed as Eucard3 JRA