Drive Beam Complex
(a few topics)

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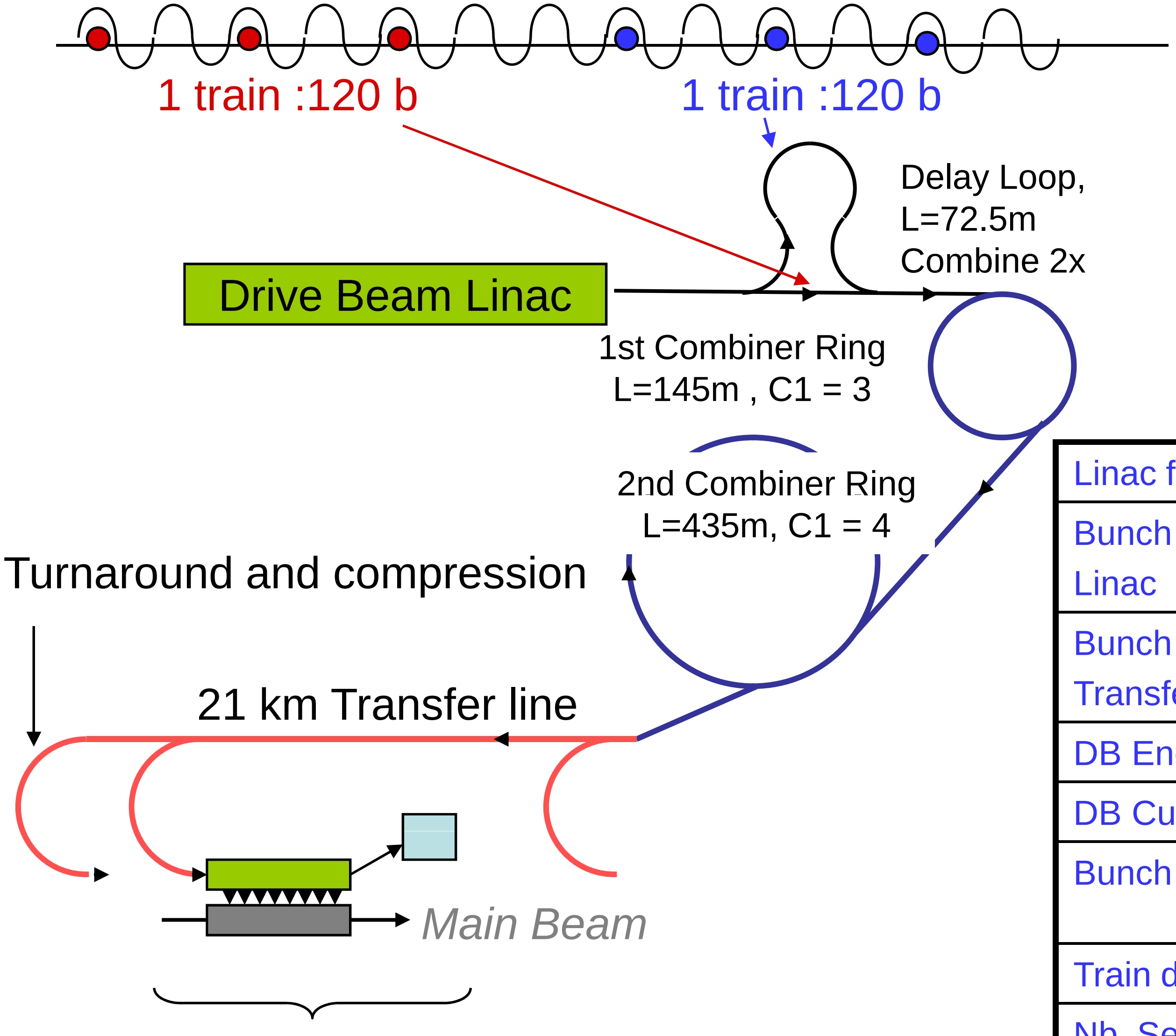
Clic Workshop , 16 Oct 2007

Outline

- DB complex schematic
- Turn-around and compression : see F. Stulle
- Long transfer line
- Combiner rings : Synchrotron radiation
- Open studies

Drive Beam schematic



1 train :120 b

1 train :120 b

Delay Loop,
L=72.5m
Combine 2x

Drive Beam Linac

1st Combiner Ring
L=145m , C1 = 3

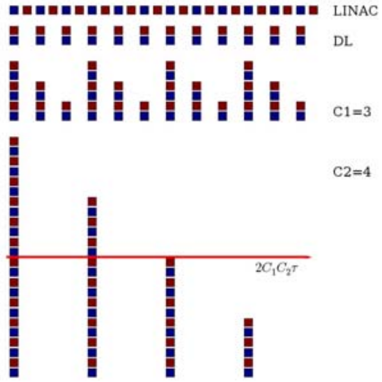
2nd Combiner Ring
L=435m, C1 = 4

Turnaround and compression

21 km Transfer line

Main Beam

Decelerator + Dump



Linac frequency	1	GHz
Bunch frequency Linac	0.5	GHz
Bunch frequency Transfer Line	12	GHz
DB Energy	2.37	GeV
DB Current	**101**	A
Bunch population	5.2 10^{10}	-
Train duration	241	ns
Nb. Sectors in TL	24	-
Repetition frequency	50	Hz

Long transfer line

- Straight 21km long line (twice)
- Need optimisation for performance and cost
- Specify vacuum requirements
- Specify magnet requirements

FODO optimisation

Number of cells $N = \frac{L_0}{\hat{\beta}} \frac{1+\sin\frac{\mu}{2}}{\sin\mu}$

Total magnet power $A_p(\hat{\beta},\mu) = \frac{4L_0}{\hat{\beta}} \frac{(1+\sin\frac{\mu}{2})^3}{\sin\mu\cos^2\frac{\mu}{2}}$

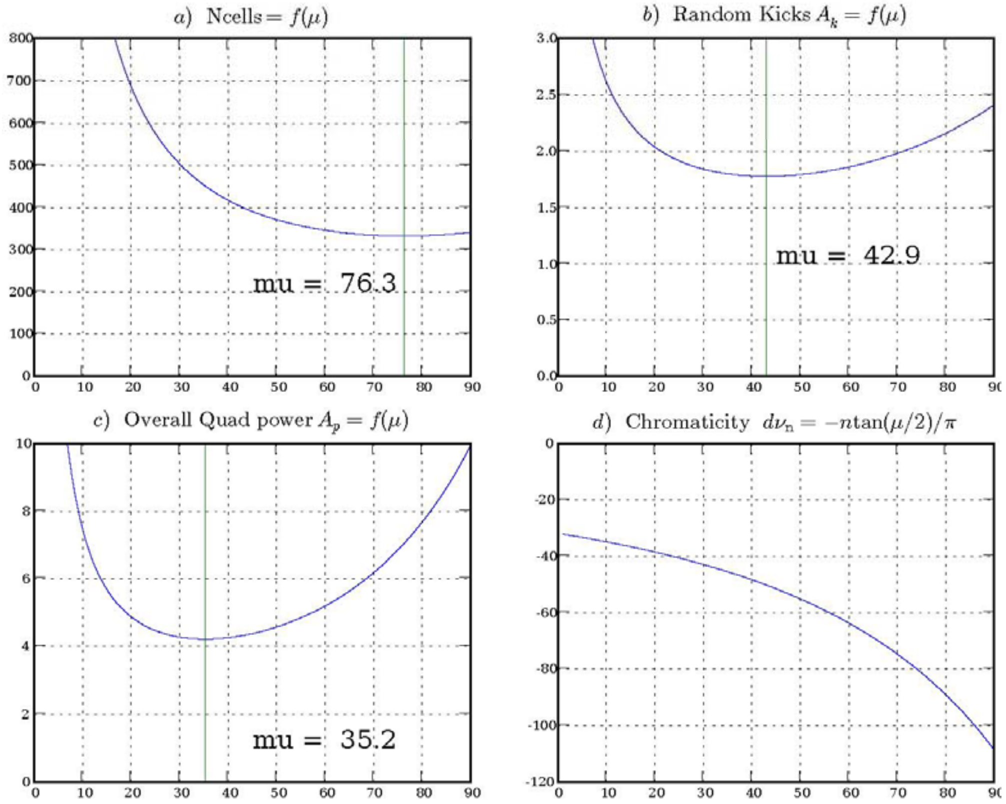
kick by random quadrupole displacement

$$\frac{\Delta_x}{\sigma_\beta} = \frac{2(1+\sin\frac{\mu}{2})}{\hat{\beta}\cos\frac{\mu}{2}} \sqrt{\frac{L_0}{\epsilon\sin\mu}}\delta_x = \frac{2(1+\sin\frac{\mu}{2})}{\cos\frac{\mu}{2}\sin^{1/2}\mu} \frac{1}{\hat{\beta}} \sqrt{\frac{L_0}{\epsilon}}$$

Chromaticity $C = -\frac{L_0}{2\pi\hat{\beta}} \frac{1+\sin\frac{\mu}{2}}{\cos\frac{\mu}{2}}$

These functions all factorise :

$f(\hat{\beta},\mu) = g(\hat{\beta})\, h(\mu)$



Further calculations : with $\mu = 45^0$ and $\varepsilon = 2\ 10^{-8}$ m

Optimise β_{max} depending on

the choice of magnet technology

Chromatic effects

- Kicks from random Quad misalignment
  - → Δ/σ_β ($dx = 10^{-4}$ m , L_0 = 21 km) = 1.7
- Detuning $\Delta\nu$ ($\delta p = 0.02$) =~ 1.0

→Beam fully filamented

- Static solution : chromatic correction, need
  - Sextupoles
  - A dispersion wave (D=~ 0.5 m) made with dipoles at the entrance of the line, to be closed at the entrance of every turnaround

Operability : better use static solutions if possible at reasonable price

Vacuum and ion issues

- The electron beam ionises the residual gas
- Electrons are repelled rapidly (light objects)
- Ions are attracted (or focused) by the beam and can be trapped inside (so called ‘neutralisation’ of the beam’)

→ induces tune-shift & tune spread

Mean free path for electrons to produce a ion : $\lambda = \frac{1}{\rho_{\mathrm{gas}}\sigma_{\mathrm{ion}}}$

$$\rho_{\mathrm{lin,ion,train}} = \frac{p_{\mathrm{Torr}} N_{\mathrm{e,train}}}{\lambda_0}$$

$$\mathrm{CO},\ \mathrm{pressure\ 1Torr} : \lambda_0 = 0.16\ \mathrm{m}$$

With ‘standard’ pressure (no getter, no bake-out)
One DB train , Ne = 1.78^{e}14, p=10^{-8} T : ρ_{lit} = 1.11^{e}7 ion/m

Ion effects - I

- Trapping condition : $A_{\mathrm{trap}} \geq \frac{N_{\mathrm{e}} r_p \, \Delta L}{4\sigma_\beta^2}$
  - Atomic numbers > A_{trap} are trapped
  - Inside train, Ne = 5^e10, ΔL = 2.5^e-2 m

    A_{trap} = 1.3^e-4 → CO is trapped
  - Train-train, Ne = 1.8^e14, ΔL = 1500 m

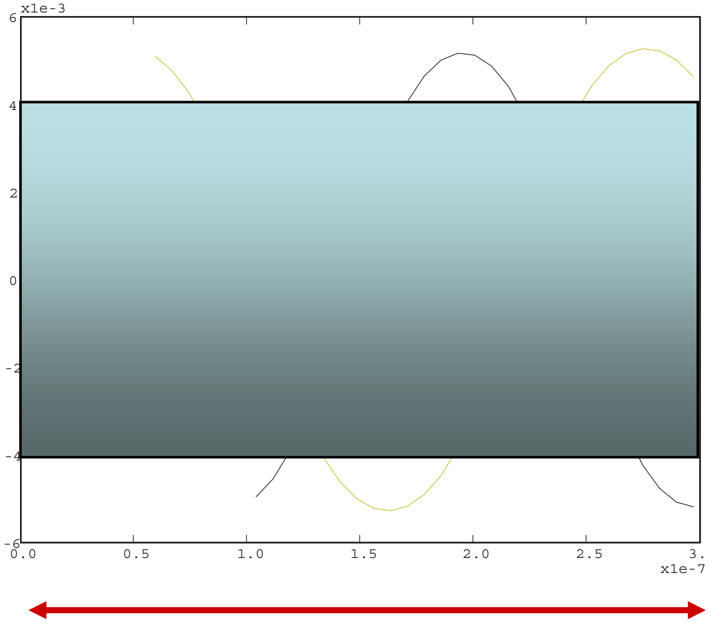
    A_{trap} = 4^e5 → CO fully untrapped

Coherent tune-shift : $\Delta\nu = C \frac{\beta_\beta r_0 \rho_{\mathrm{lit}} L_{\mathrm{ML}}}{8\pi\gamma\sigma_\beta^2}$

C = 1 for same ion and beam profile, not the case see below

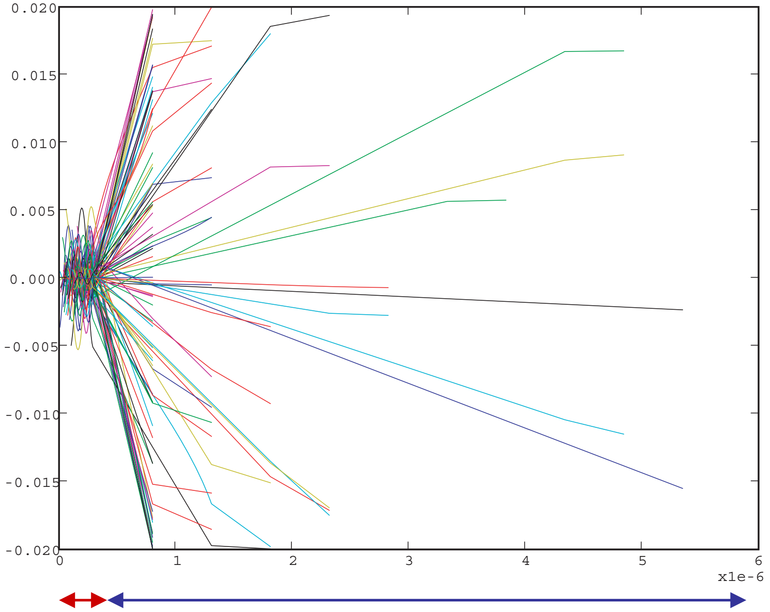
Ion effects - II

X [m]



Train length Time [s]

X [m]

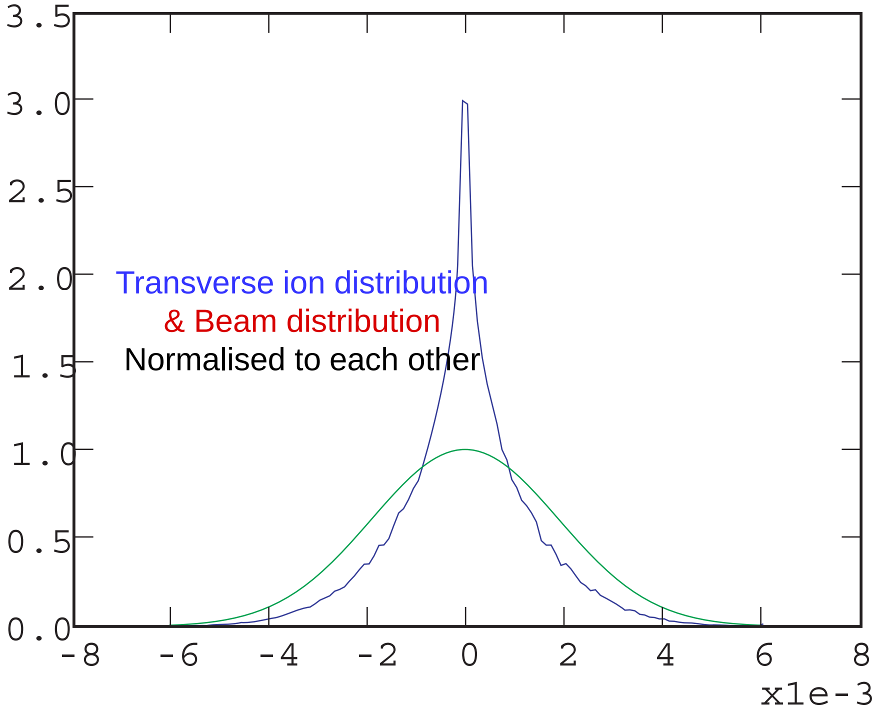


Train

Gap

Time [s]

Ion effects - III



- Ratio at peak C =~ 3
- $\Delta\nu$ =~ 0.45 at 10^{-8} Torr
  - Between head and trail of train
  - Between small and large (> σ_β) amplitude
- No more clear if the description coherent/incoherent tune shift applies

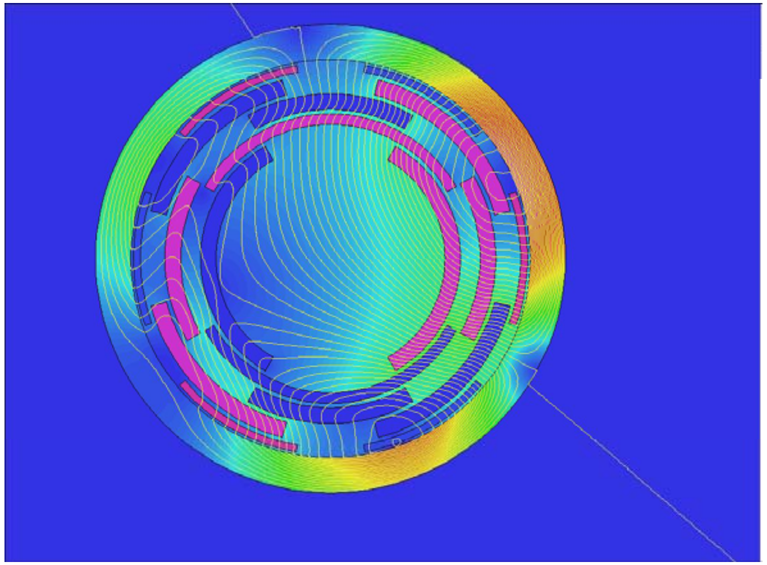
This would require a more sophisticated treatment
But, anyway obviously too large to avoid filamentation
→ 'standard' 10^{-8} Torr not adequate
→ Need 10-100 times better (getter + bake-out)

Magnets

- Need
  - Quadrupoles with G l_q = 0.25 T/m x
  - Sextupoles
  - Orbit correctors
- The small power needed allows to consider ‘cos(nθ)’_magnets, all in one yoke
  - Compact and light, adequate for installation at the ceiling of the tunnel
- (Option :
  - permanent magnet for ~90% of the Quad GL
  - powered trim Q + S + B as above)

A combined magnet for the long TL - I

Low fields allows for ‘cos(nϕ)’ design



This exemple contains : Bh, Bv, Q, Qs, S

Borrowed (w/o permission) from P.Belochitskii, T.Eriksson and T. Zickler, CERN/AT/MEL/2007/TZ, oct 2007)

- Need
  - Q with GL = 0.25 Tm/m
  - B h & v for orbit correction
  - S for chromatic correction
  - Useful radius : 25 mm
- First pass Ansys for Q :
  - r_Q_coil_in = 30mm
  - I=30 A, nI=330 Aturn
  - wire 9mm^2
- Get (to be refined) :

Yoke diameter	150	mm
Weight	80	kg
Quad power	40	W
B + S power	<50	W

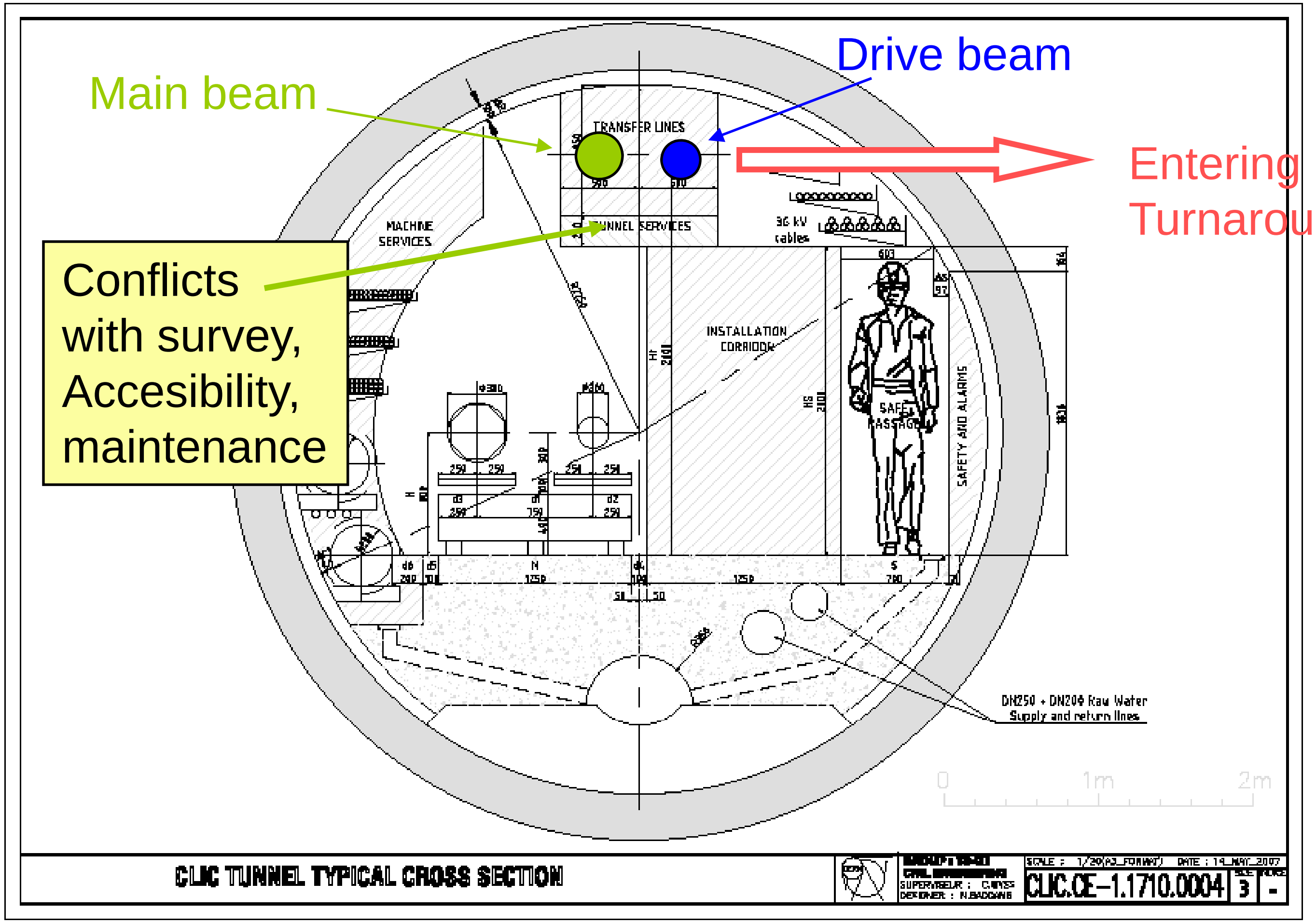
Many thanks to M. Bajko for expertise and advice

A combined magnet for the long TL - II

- Compact monolithic & low-weight object, for ceiling installation
- Thin power and cooling lines
- Remains to work-out :
  - Detailed design, body field errors
  - Compensation of end-field errors
  - Powering (I vs. V …)
  - Cooling (air, water)
  - Overall engineering (reliabilty, cost, …)

L = 0.5m
F = 0.15m
M < 100kg
P < 100W

Main tunnel cross-section



Main beam

Drive beam

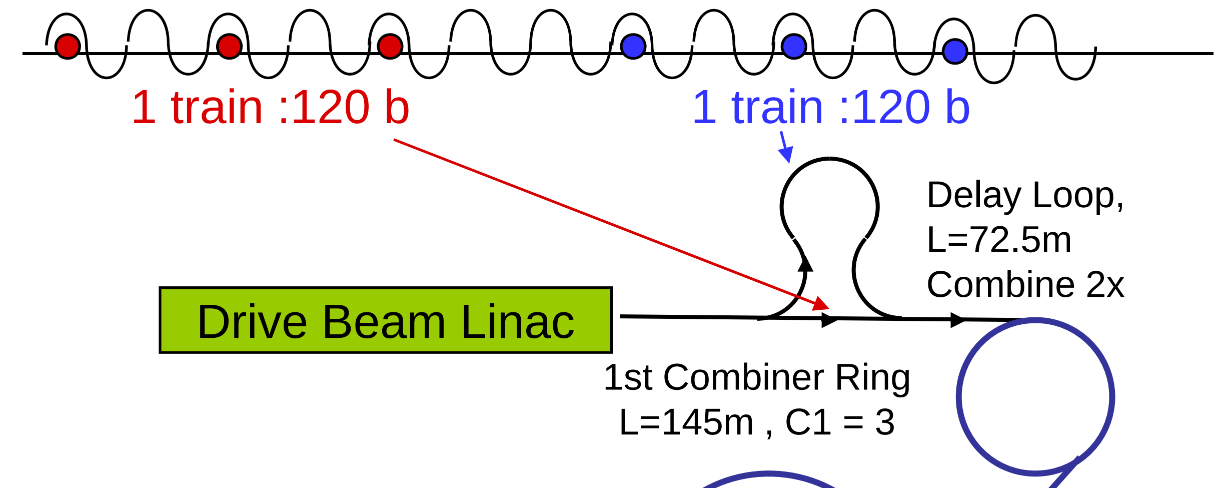
Entering Turnaround

Conflicts with survey, Accesibility, maintenance

Combiner rings

- Synchrotron radiation issues
- Open studies

Drive Beam schematic



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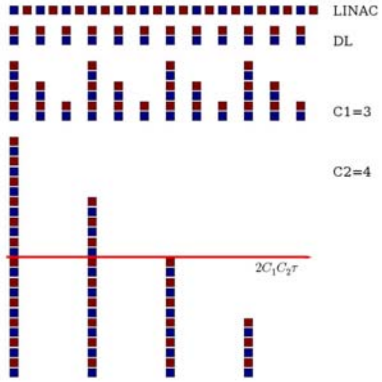

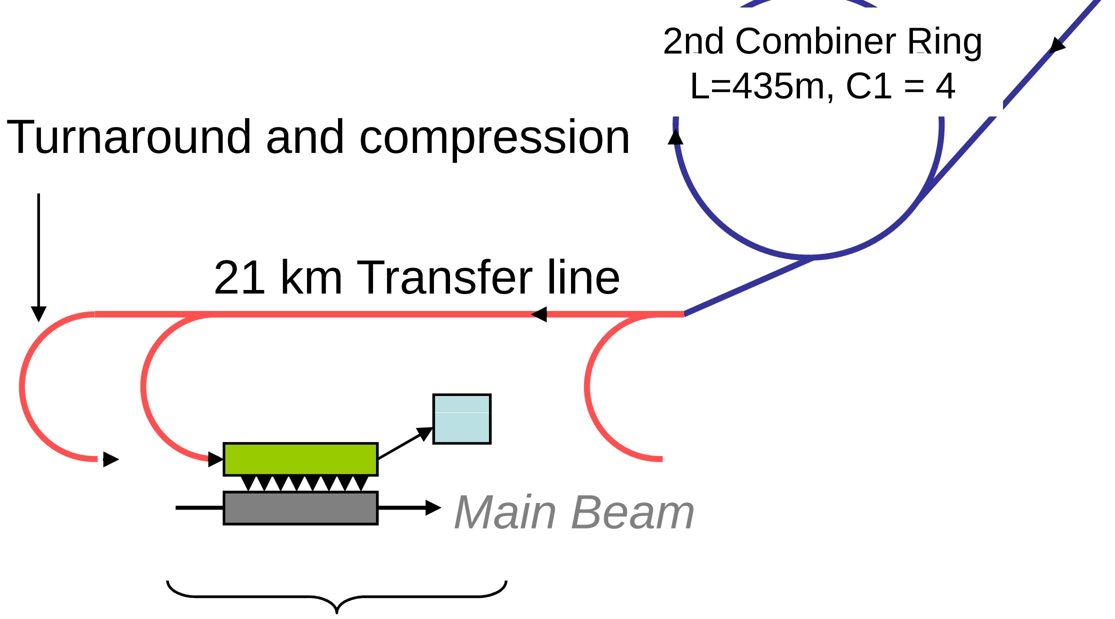

2nd Combiner Ring
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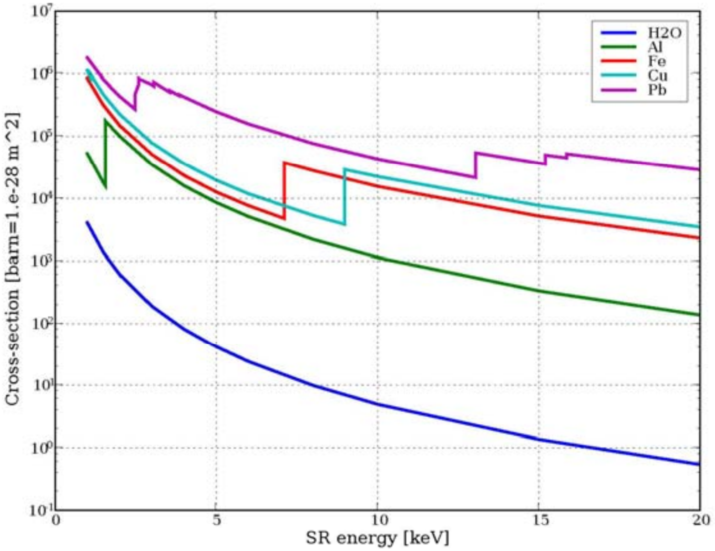
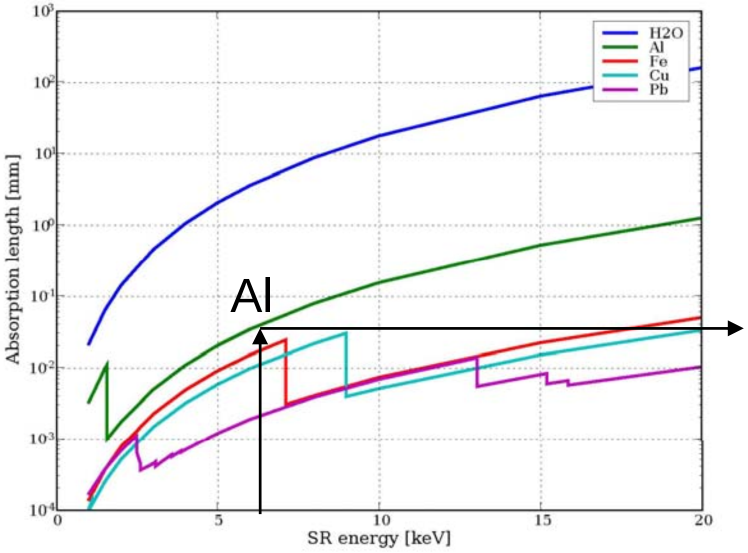
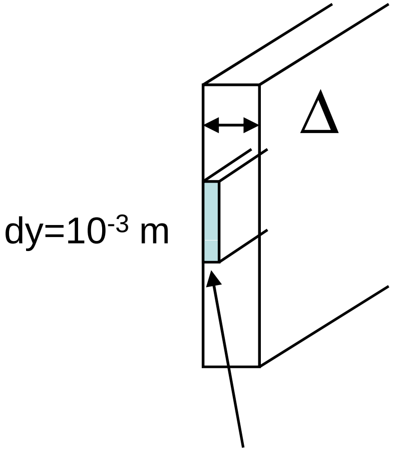
SR issues - I



C1		
Bending radius	**5**	**m**
dE/E per turn	**$1.2\ 10^{-5}$**	**-**
Power/m	**1050**	**W/m**
Photon energy	**6.3**	**KeV**
Photon rate	**$1.04\ 10^{18}$**	**1/m/s**





Heated volume over dz=1m:
$V = dz\ dy\ (dx_{abs}^2 + d_{diff}^2)^{1/2}$

$d_{diff} \sim= (2Dt)^{1/2}$

6 KeV : $dx_{abs} = \alpha_{impact} \times 5\ 10^{-5} = 10^{-5}$ m

SR issues - II

C1		
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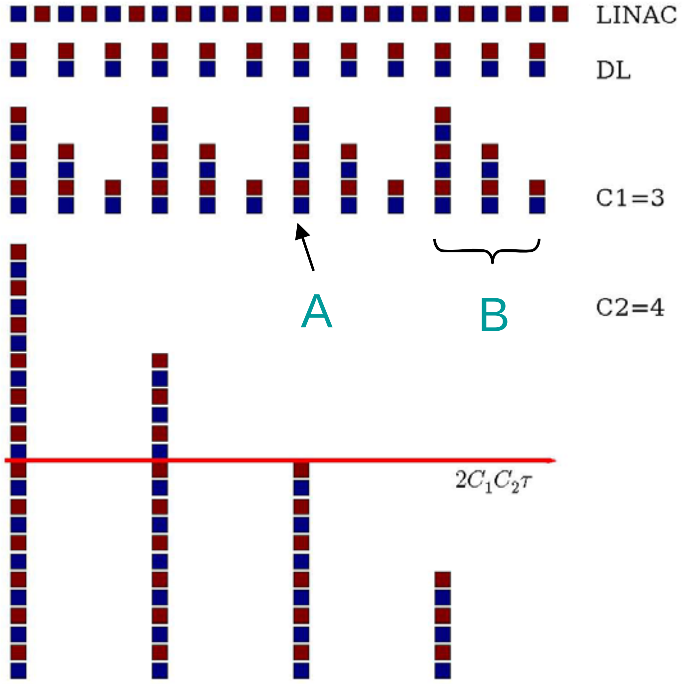

$t = 2NC_1C_2\tau$

Pulse duration	tau	2.41E-07
C1		3
C2		4
Sectors	N	24
Aluminium		
Heat cap.	C	2.24E+06
Heat cond.	K	2.21E+02
Haet diff.	D	9.87E-05
Impact surface	S	1.00E-03

Fast adiabatic heat deposition / per magnet

Case	Q [J]	t [s]	x [m]	d [m]	V [m-3]	DT [K]
A	0.11	2.41E-07	1.00E-05	6.90E-06	1.21E-08	**4.0**
B	0.22	1.45E-06	1.00E-05	1.19E-05	1.56E-08	**6.2**
C	20.89	1.39E-04	1.00E-05	1.17E-04	1.17E-07	**79.4**

Steady heat transfer across vacuum chamber thickness,

Repetition rate	f	50	Hz
Per magnet			
Power	P [W]	1044	
Temp gradient : gradT=P/(SK)	[K/m]	4.73E+03	
Chamber thick.	x [m]	0.001	
Delta T = x gradT	[K]	4.7	

Very simple calculation, and bending radius may change

SR issues - III

- Crude SR steady and adiabatic indicate:
  - SR is absorbed in a thin inner layer of the vacuum chamber
  - Transient temperature rise of the order $\Delta T = 80 \pm ?$ K at repetition frequency f=50Hz
  - Good vacuum requires getter at room temperature …

DL+CR1+CR2+TLs = 2.5km including multi-turn
→ ~1/10th of long TL, but vacuum can be degraded

- → Precise time-dependent thermal, mechanical and vacuum model needed

- Coherent synchrotron radiation can most likely be screened with adequately ajusted vertical aperture → marginal addition to SR (need precise calculation)

ESRF : I=100mA, E=6GeV, Power=3kW/m, E_γ=20KeV, λ=1mm

C1 : I_{av}=58mA, E=2.4GeV, Power=1.0kW/m, $E\gamma$=6KeV, λ=0.05mm

(Fully-) Open studies for Delay Loop and Combiner rings

- Linear optics to be built for
  - Synchronous and chromatic-corrected rings
  - Then sensitivity/robustness studies
    - Tune variations → synchronicity errors
    - Tune error, β-beating → emittance growth

0.1mm average radial Error → dz = 0.63 mm

- Source of errors
  - EM collective effects (25→100A in four turns)
  - Ions production
    - Δν growing along trains + instabilities ?

- Coordinated studies with vacuum design experts

- → Lot of studies, expertise welcome

Summary

- Long transfer line:
  - reasonably comfortable
  - But need good (getter+bake-out) vacuum
- Delay loop and Combiner rings
  - SR issues : worrying problems
  - Optics studies : entirely open area
- Turnaround and compression:
  - good optics exists (F. Stulle)
  - Integration to be fully reviewed (discussed in session ‘2-beam integration’)