CLIC Energy Scan

D. Schulte for the CLIC team

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Luminosity and Background Values

		CLIC	CLIC	ILC
E_{cms}	[TeV]	0.5	3.0	0.5
f_{rep}	[Hz]	50	50	5
f_{RF}	[GHz]	12	12	1.3
G_{RF}	[MV/m]	80	100	31.5
n_b		354	312	2625
Δt	[ns]	0.5	0.5	369
N	$[10^9]$	6.8	3.7	20
σ_x	[nm]	202	40	655
σ_y	[nm]	2.26	1	5.7
ϵ_x	[μm]	2.4	0.66	10
ϵ_y	[nm]	25	20	40
$\mathcal{L}_{total}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	2.3	5.9	2.0
$\mathcal{L}_{0.01}$	$[10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	1.4	2.0	1.45

Energy Scans

- Request to run 3TeV CLIC at lower energies
  - with high luminosity
- Energy scans can be large or small
- Scans over a few percent will be handled by tuning the final quadrupole field and adjusting the main linac average gradient
  - preferred is reduction of gradient towrds the end
- But the experiment want to also go to significantly lower energies
  - no concrete description of needs available
  - but from discussions preliminary discussions
    energy will be change for some months
  - $\Rightarrow$ can do *some* hardware modifications
- I will focus on the large change in energy

Options to Change Beam Energy

1) Extraction at low energy

- but need extraction and bypass lines

- compromises fill factor and tunnel design or requires significant hardware intervention

2) Remove the end of the linac

- go down from $3\,\mathrm{TeV}$ by removing the end of the linac

- one way option

⇒ For both of these solutions charge remains unchanged

3) We use a lower gradient ($G = G_0 E/E_0$)

- constant gradient along the linac

⇒ charge needs to be proportional to gradient

4) We reduce the gradient in a part of the linac

- higher gradient initially

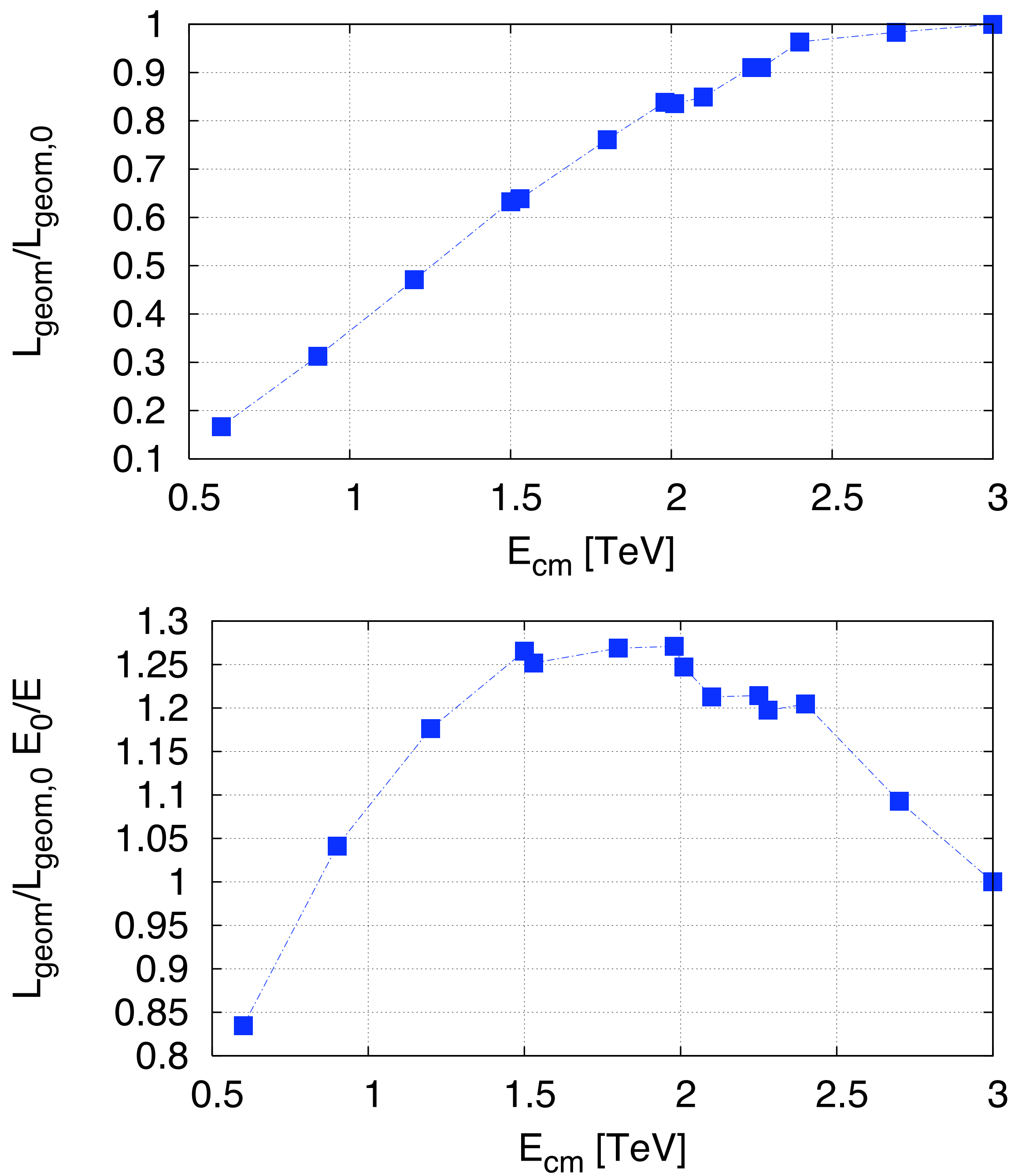
⇒ charge can be reduced almost proportional to gradient

Luminosity for Constant Charge

- Use Rogelio's $3\,\mathrm{TeV}$ BDS
- Applies to 1+2
- BDS magnetic fields scaled
  - final double needs to be exchanged for changes of more than $\approx 10\%$
- Geometric luminosity (for constant charge) does not decrease linearly

⇒ Need to understand reason

- could be improvement of BDS performance due to reduce radiation at lower energy



Gradient and Bunch Charge

- Applies to option 3 and somewhat to 4
- Scaling $N/N_0 = G/G_0$ and $\sigma_z = \mathrm{const}$ keep the relative energy spread $\delta(s)$ constant
- We require BNS damping for beam stability

$$\delta(s) \approx \beta_1^2(s) \frac{Ne^2 W_\perp}{E(s)}$$

- Emittance growth due to dispersive imperfections scales as

$$\Delta\epsilon_y \propto \left(\frac{\sigma_E}{E}\Delta y\right)^2$$

$\Rightarrow$ independent of G, for our scaling

- Emittance growth due to wake fields scales as

$$\Delta\epsilon_y \propto \left(\frac{NW_\perp(2\sigma_z)}{E}\Delta y\right)^2 E$$

$\Rightarrow$ improves with smaller G, for our scaling

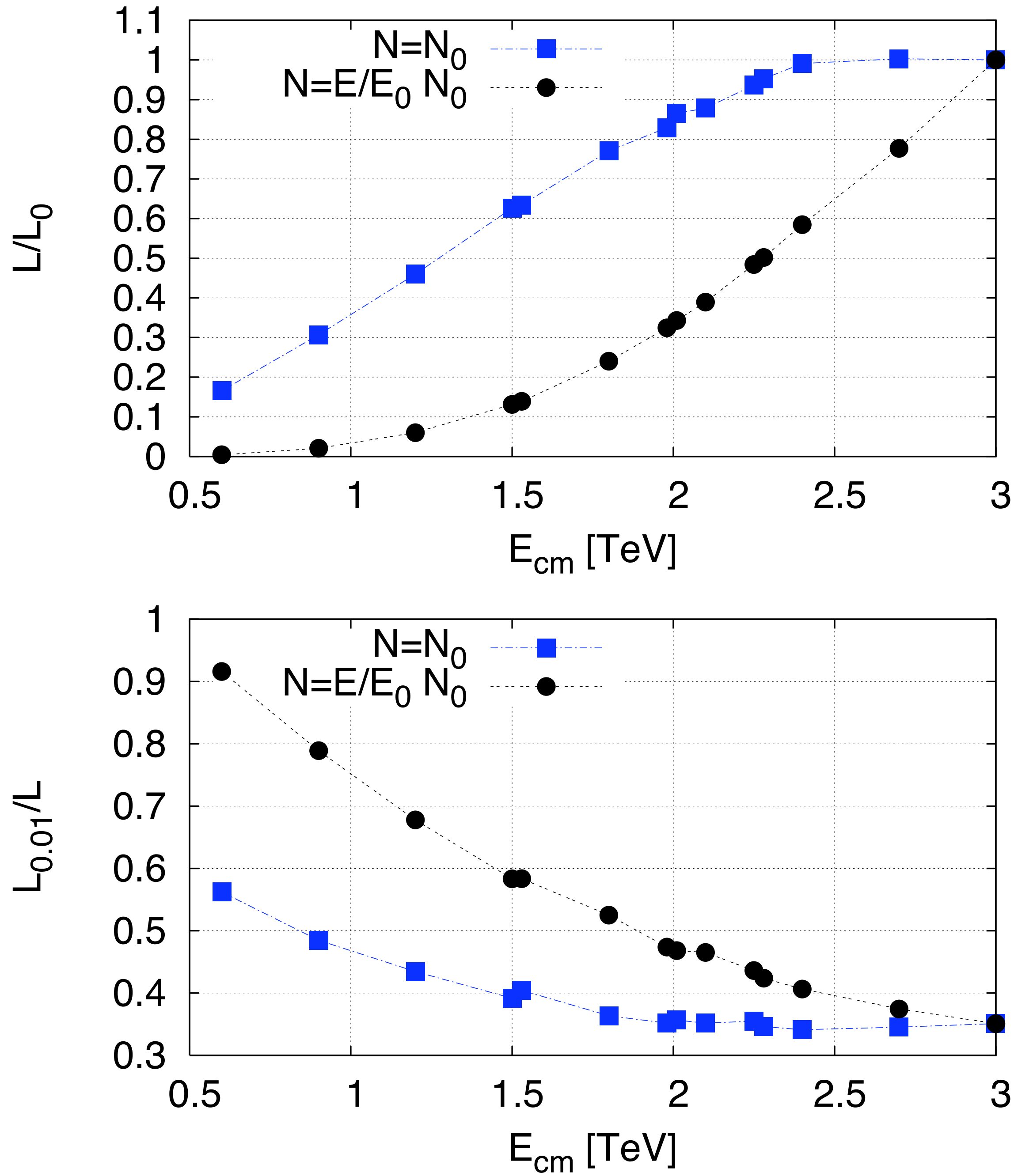
- Same scaling works in BDS if collimation geometry remains constant
  - could maybe improve for lower energies as final doublet aperture can increase (R. Tomas)

Total Luminosity with Gradient Change

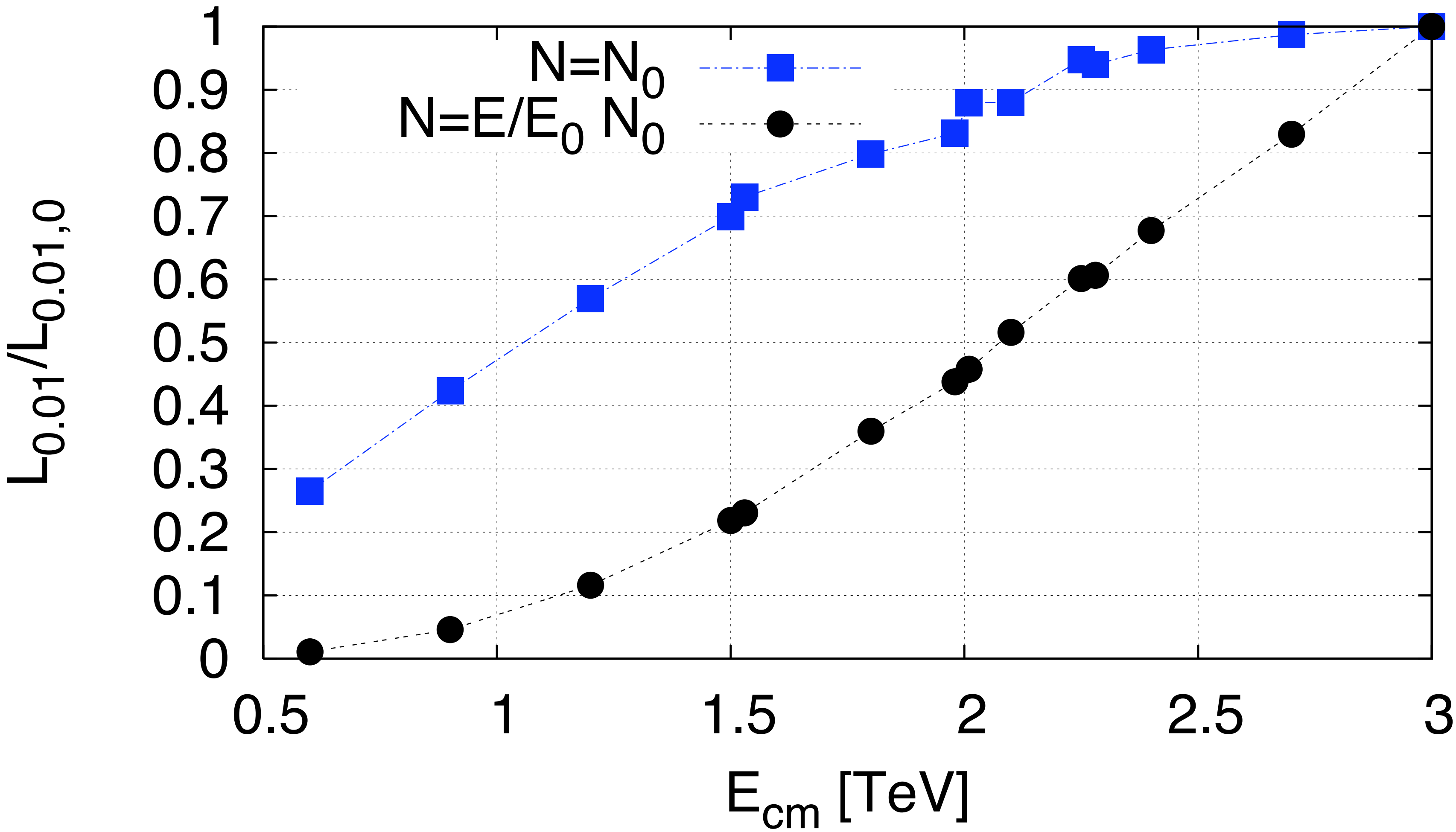
- Significant luminosity loss due to charge reduction

$\Rightarrow$ Need to compensate

- Spectrum improves with lower energy
  - in particular for reduced charge



Luminosity in Peak with Gradient Change



Strategies for 3)

- One can attempt to mitigate the luminosity loss by

  a) Changing structure design to increase bunch charge for $3\,\mathrm{TeV}$

  - less luminosity loss for lower energies
  - but need to compromise $3\,\mathrm{TeV}$ performance
  - first indication is that this would be serious (A. Grudiev)

  b) Increasing repetition frequency of drive beam

  - but what about beam dynamics and klystrons

  c) Increasing pulse length

  - but pulse length is built into the geometry of CLIC

  any combination of a+b+c

- Will look at 3b and 3c
- The disadvantage of 4) is that none of these ideas can be applied

Gradient Reduction

- The gradient is reduced by reducing the drive beam current via

  I) reducing the bunch charge

  II) reducing the number of bunches per unit time and their charge

  III) using the on/off mechanism

- We will neglect III) as it is would be mainly used for fine-tuning and does not help to recover luminosity

- Changing the beam energy only on one side does not help to recover luminosity, the loss as a function of $\sqrt{s}$ is slightly larger than for symmetric changes

  - impacts physics

Change of Repetition Frequency (3b)

- For reduced beam current, power in DBA is
  - for constant final energy

$$\frac{P_{RF}}{P_{RF,0}} = \left(\frac{1+\frac{I}{I_0}}{2}\right)^2$$

  - for $E/E_0 = I/I_0$

$$\frac{P_{RF}}{P_{RF,0}} = \left(\frac{I}{I_0}\right)^2$$

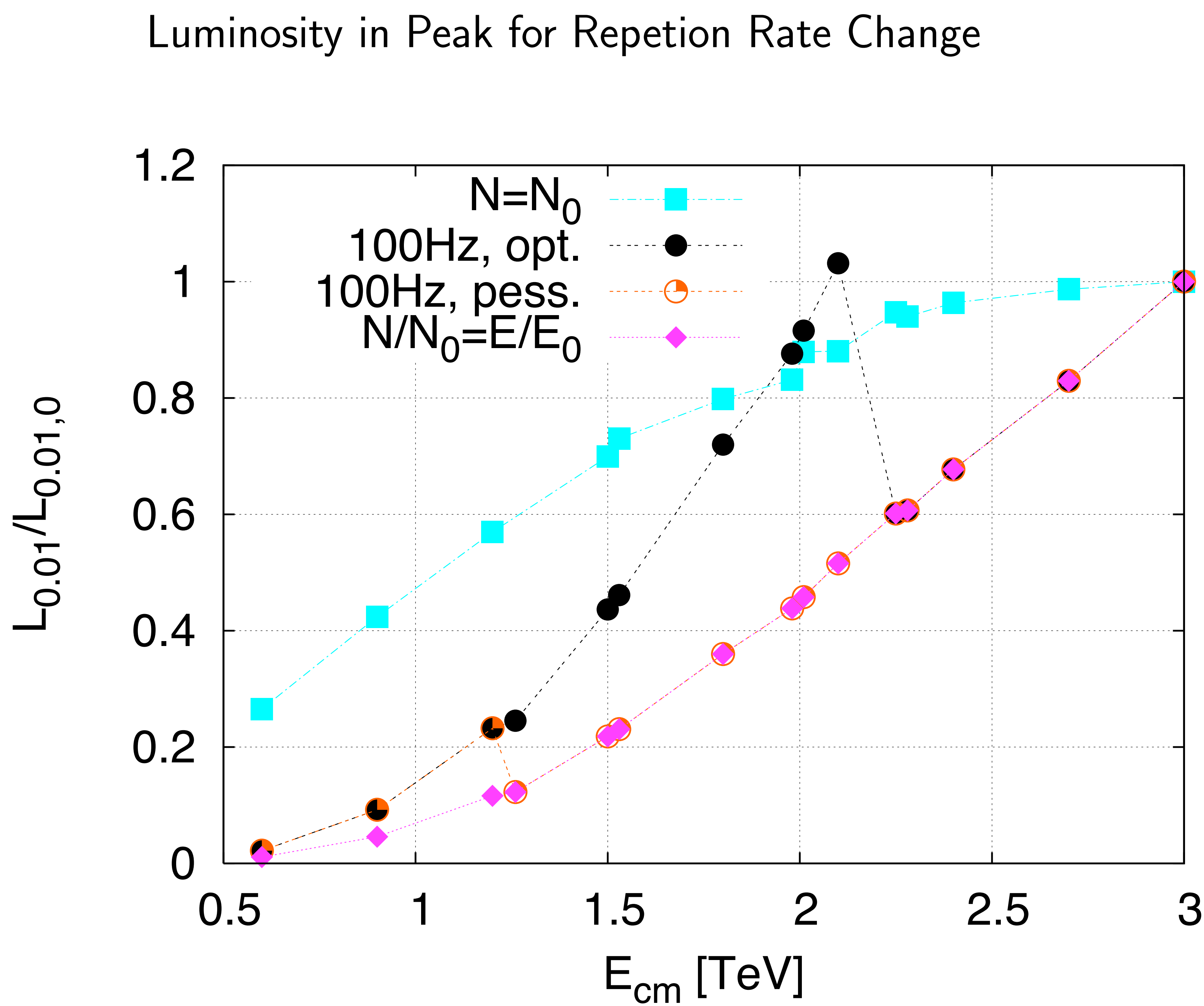
- In principle could hope to increase repetition frequency up to

$$f_{rep} = f_{rep,0}\left(\frac{G_0}{G}\right)^2 \frac{\eta}{\eta_0}$$

- Issues are reduced efficiency of klystrons at lower power and wish to stay at multiples of $50\,\mathrm{Hz}$
  - but could combine two klystrons and use interleaved pusling at low energy

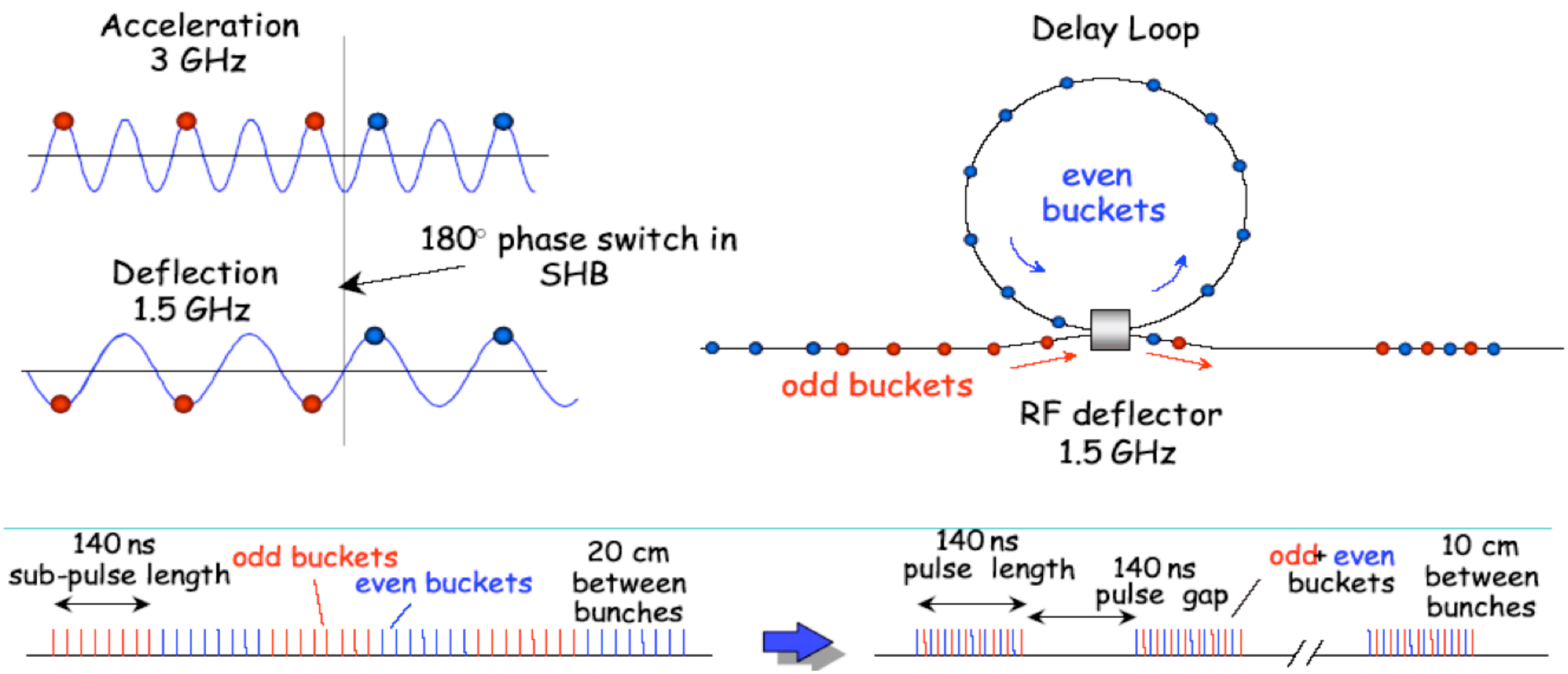
  $\Rightarrow 100\,\mathrm{Hz}$ at $I = 0.7I_0$, $E = 0.7E_0$

- Further study is needed on RF and beam



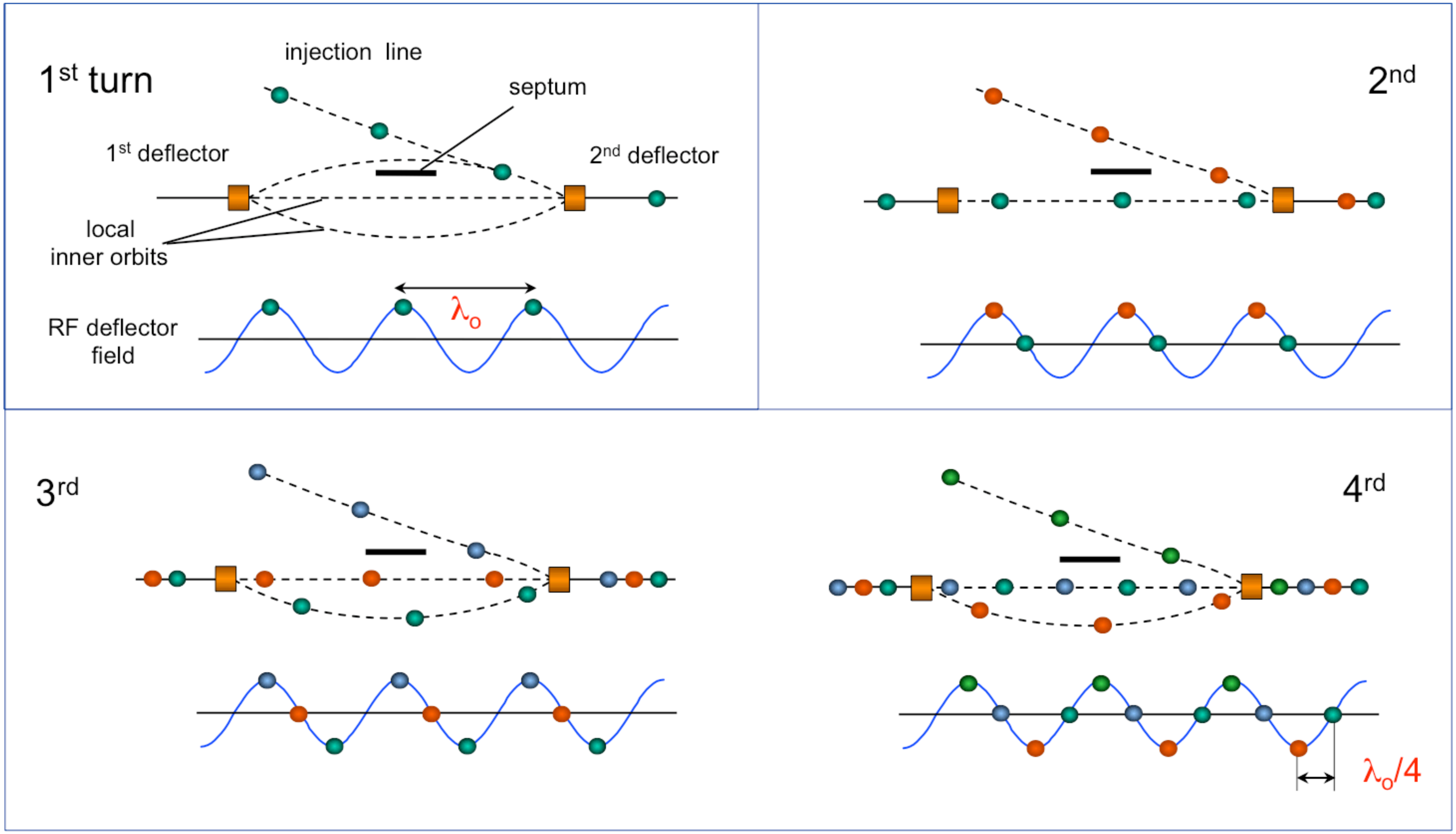
Luminosity in Peak for Repetion Rate Change
N=N0
100Hz, opt.
100Hz, pess.
N/N0=E/E0
L0.01/L0.01,0
Ecm [TeV]
0
0.2
0.4
0.6
0.8
1
1.2
0.5
1
1.5
2
2.5
3

Delay Loop

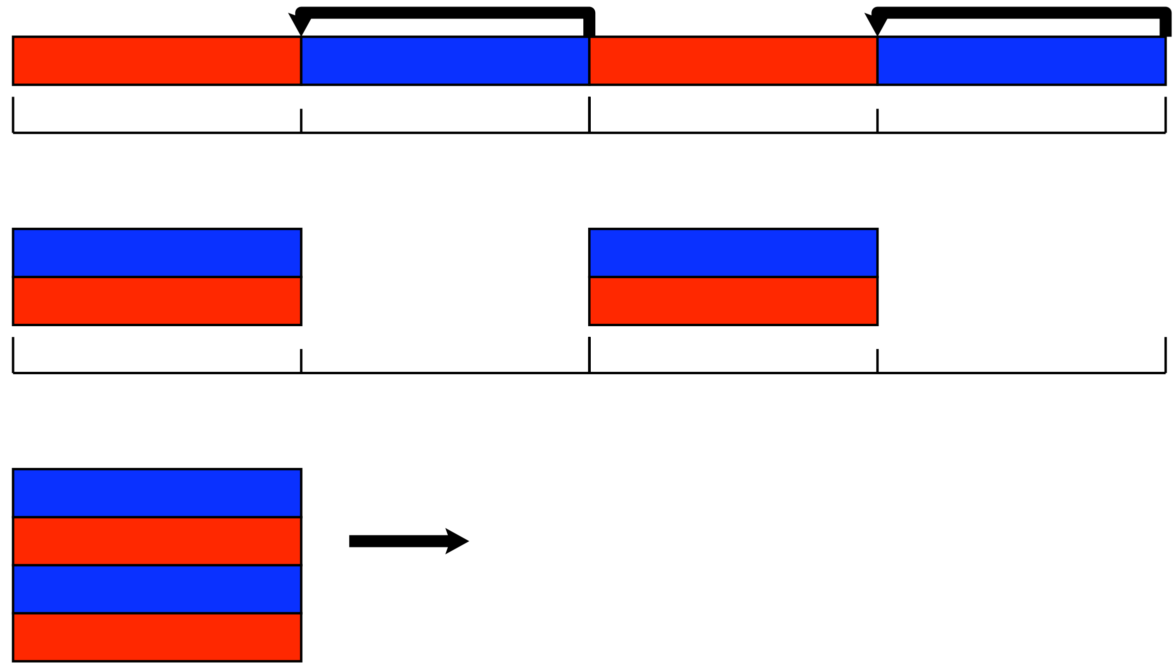


Acceleration
3 GHz
Deflection
1.5 GHz
180° phase switch in
SHB
Delay Loop
even
buckets
odd buckets
RF deflector
1.5 GHz
140 ns
sub-pulse length
odd buckets
even buckets
20 cm
between
bunches
140 ns
pulse length
140 ns
pulse gap
odd+ even
buckets
10 cm
between
bunches

Combiner Rings



Pulse Length (3bIII)



- The pulse length is defined by the geometry of the accelerator

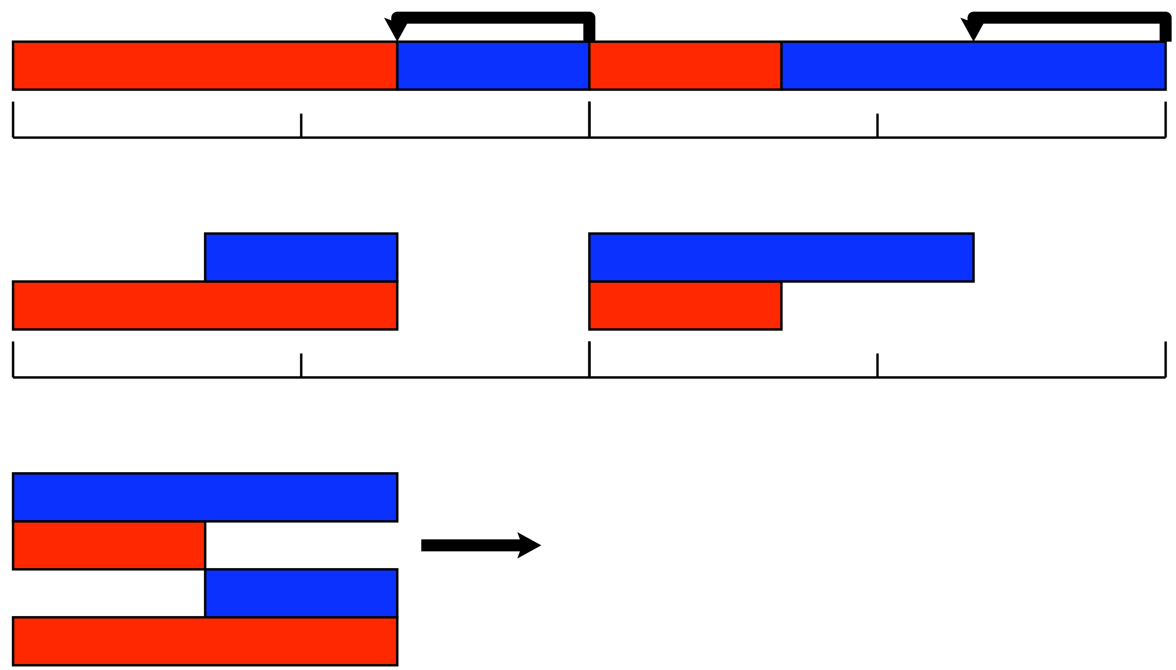
  $\Rightarrow$ cannot change it arbitrarily

Pulse Length

- Well, some bird triggered an idea
  - With small modification of delay loop we can change the combination factor and increase the pulse length
  - Can accept longer pulses in main linac since the power is lower
    - strongest constraint from temperatur $P\sqrt{\tau} \leq P_0\sqrt{\tau_0}$
  - For $G/G_0 \leq 3/4$ can use upper scheme

  $\Rightarrow$ $80\,\mathrm{ns}$ longer pulse

  $\Rightarrow$ 160 extra bunches per train



Pulse Length (cont.)

- For $G/G_0 \leq 2/3$ can use upper scheme

  $\Rightarrow$ $120\,\mathrm{ns}$ longer pulse

  $\Rightarrow$ 240 extra bunches per train

- For $G/G_0 \leq 1/2$ can use lower scheme

  - need to modifiy first combiner ring

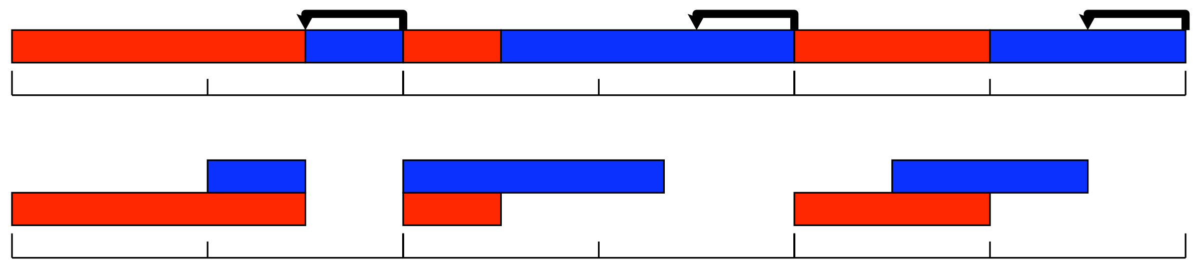
  - would need larger combiner ring with two pulses as baseline

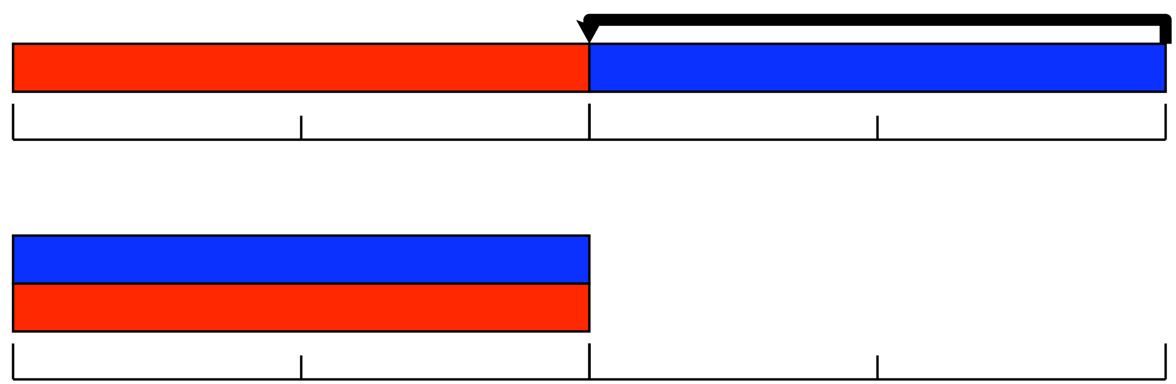
  $\Rightarrow$ $240\,\mathrm{ns}$ longer pulse

  $\Rightarrow$ 480 extra bunches per train

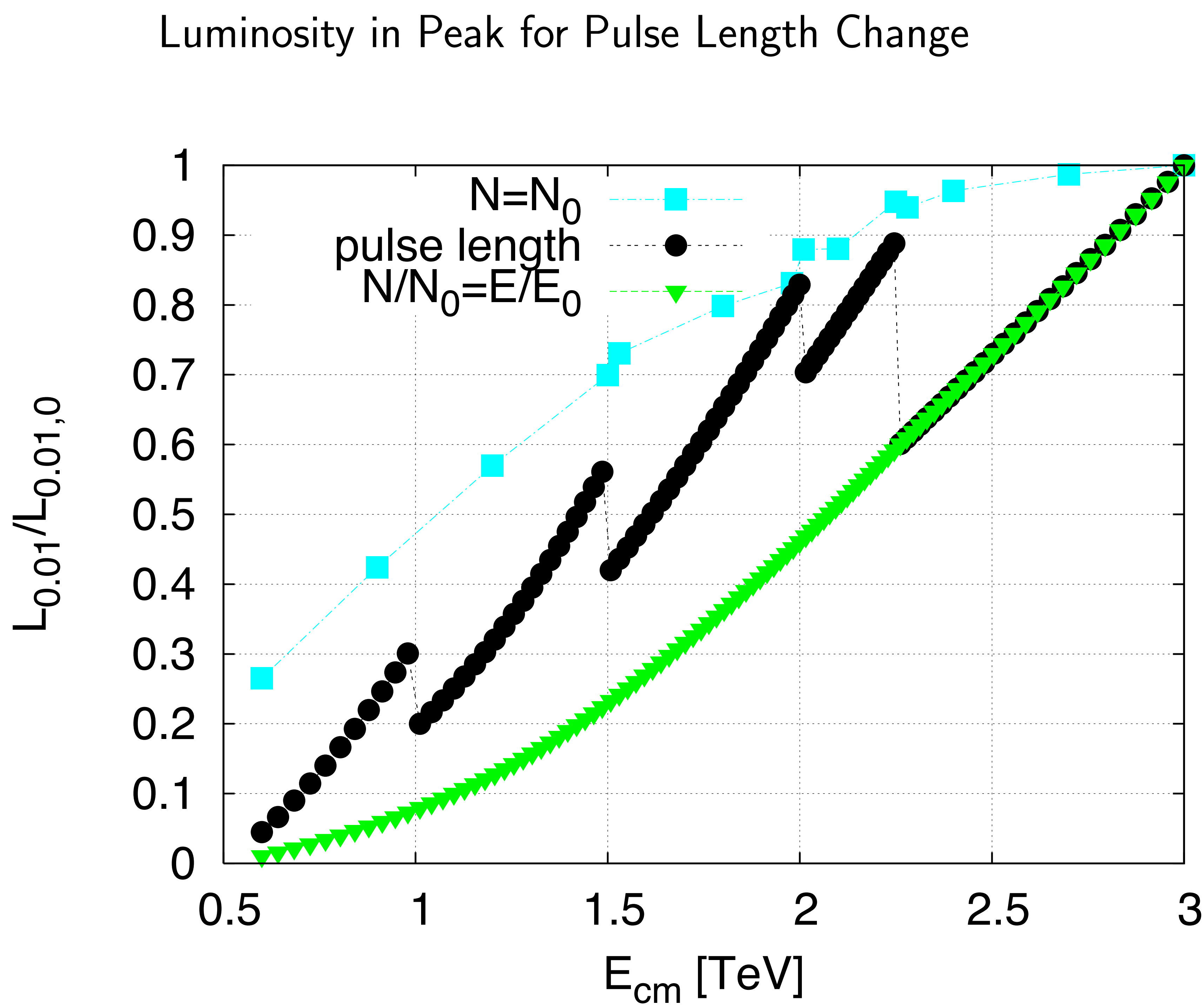
- For $G/G_0 \leq 3/8$ and $G/G_0 \leq 1/3$ similar solutions can be used

  - up to 1280 bunches at $1/3$ of the charge

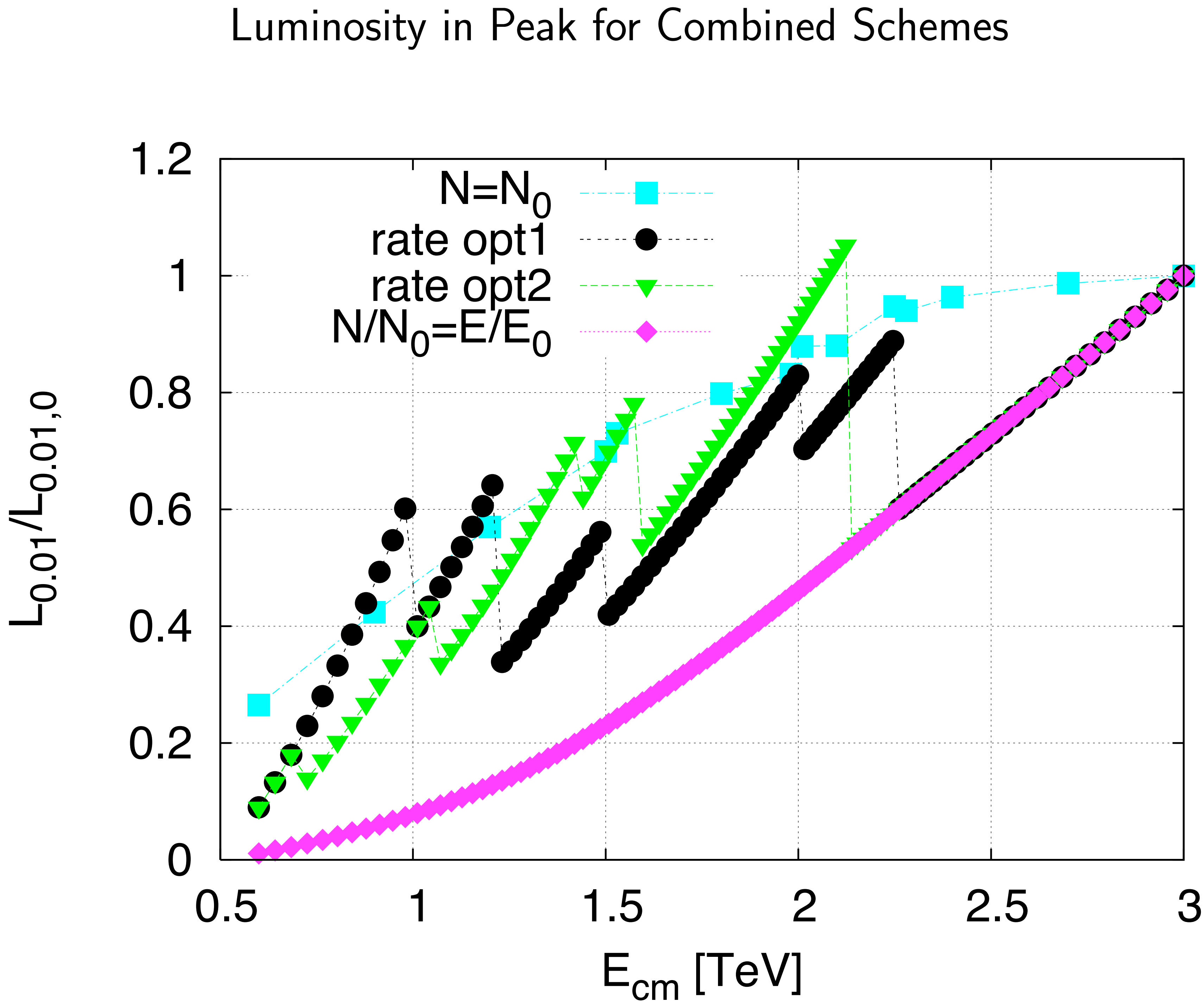




- Other options should be investigated



Luminosity in Peak for Pulse Length Change
N=N0
pulse length
N/N0=E/E0
L0.01/L0.01,0
Ecm [TeV]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.5
1
1.5
2
2.5
3


Luminosity in Peak for Combined Schemes
N=N0
rate opt1
rate opt2
N/N0=E/E0
L0.01/L0.01,0
Ecm [TeV]
0
0.2
0.4
0.6
0.8
1
1.2
0.5
1
1.5
2
2.5
3

Conclusion

- Different options of energy scan exist
  - option 3 (gradient reduction) appears a good strategy
- The single bunch luminosity loss could pontentially be compensated in part by
  - higher repetition frequency
  - longer pulses
- Longer pulses appear feasible with minor modifications to the CLIC layout
- More studies need to be performed to verify that no issues exist
- Design impact
  - make all sub-system compatible with 100Hz
  - make all sub-sustem compatible with longer pulses
- Other improvements may be possible (e.g. BDS)

Reserve

Drive Beam Acceleration (3b)

- Constant final energy

  $\Rightarrow$ some beam dynamics issues improve (some maybe worse) relative apertures remain the same

- Final energy scaled as the current

  $\Rightarrow$ beam dynamics issues remain the same relative apertures become worse

- Effective gradient in DBA

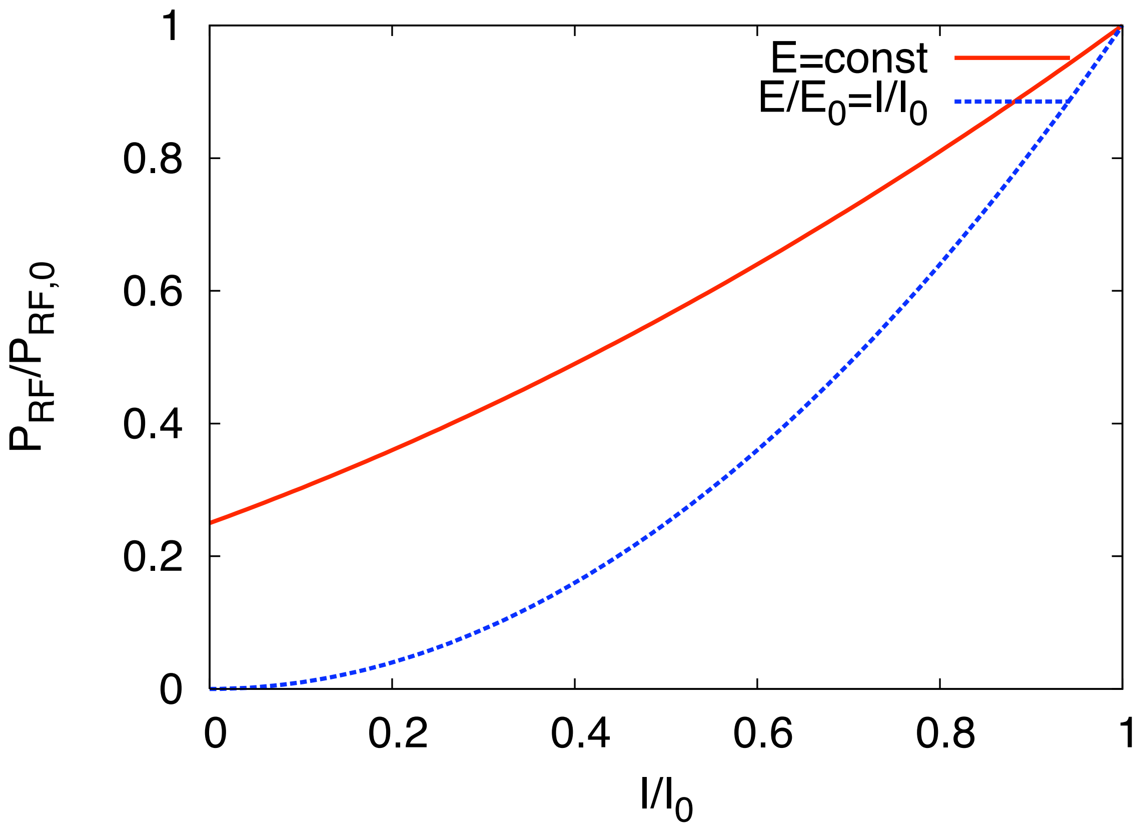
$$\frac{G}{G_0} = 2\sqrt{\frac{P_{RF}}{P_{RF,0}}} - \frac{I}{I_0}$$

- For constant final energy

$$\frac{P_{RF}}{P_{RF,0}} = \left(\frac{1+\frac{I}{I_0}}{2}\right)^2$$

- For $E/E_0 = I/I_0$

$$\frac{P_{RF}}{P_{RF,0}} = \left(\frac{I}{I_0}\right)^2$$



Comments on Klystron Power and Pulse Rate

- In principle could hope to increase repetition frequency up to

$$f_{rep} = f_{rep,0} \left(\frac{G_0}{G}\right)^2 \frac{\eta}{\eta_0}$$

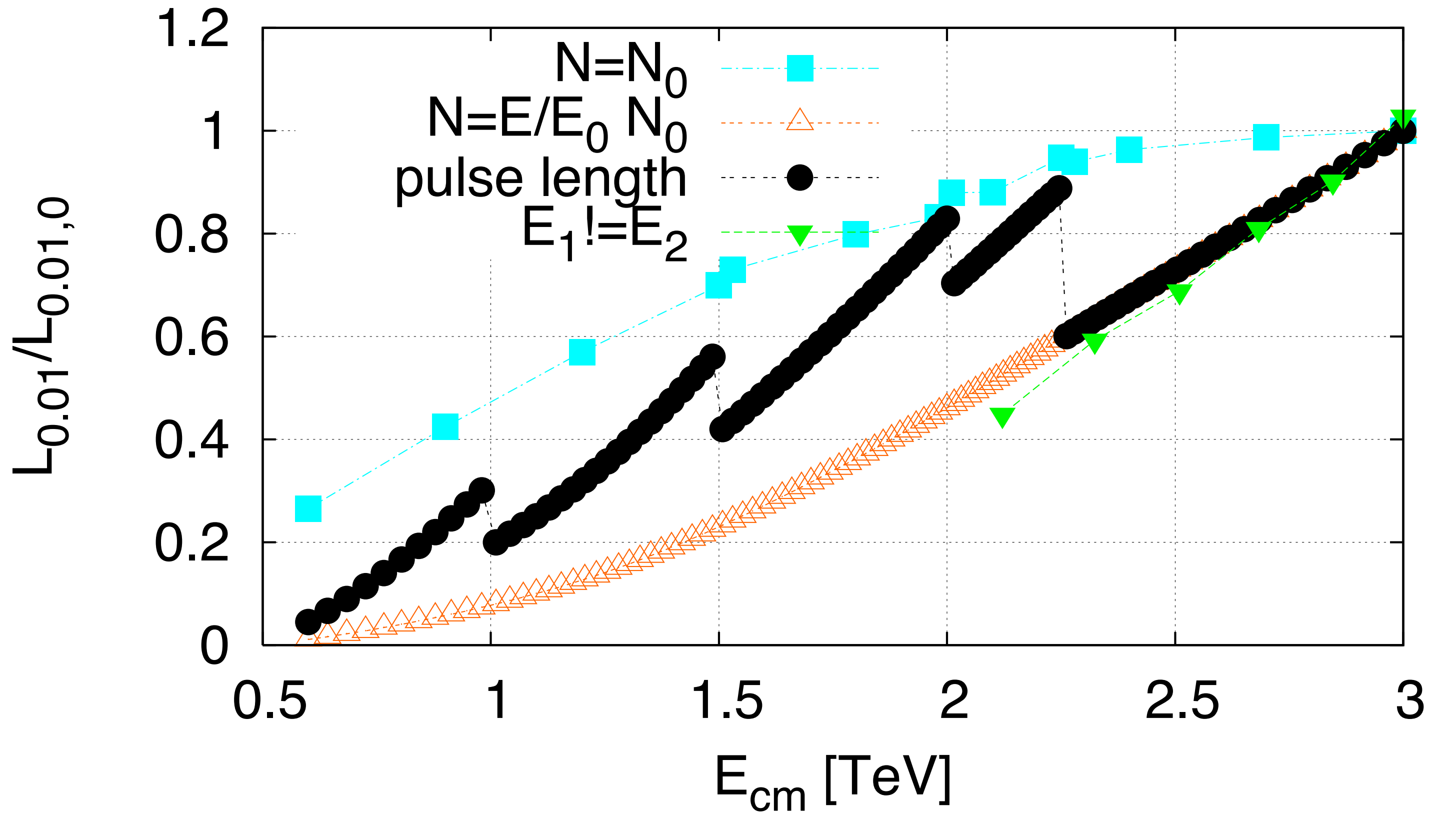
- But klystron efficiency goes down for lower output power
- But should only run at multiples of 50 Hz
- Igor Syratchev estimates that we can expect to run at 120Hz at a quarter of the nominal output power

  $\Rightarrow$ does not work if we run with full drive beam energy

  $\Rightarrow$ could give factor two at 1.5 GeV if drive beam energy is reduced

- Could improve this by
  - new klystron design (Erk, Igor)
  - combination of power of pairs of klystron (Alexej G.)
  - but needs exploration (Erk et al.)
- Also need to check that we can achieve stable beam
- Maybe best guess is that we divide power by two with no loss
- Note: you want to power all drive beam accelerating structures

Side Remark: Different Beam Energies



⇒ Luminosity loss is slightly faster than for balanced collisions

⇒ There is no obvious strategy to recover any luminosity

⇒ Physics would only be willing to accept energy imbalance, if the machine had a strong advantage (L. Linssen)

Options and Issues I

- Try to improve BDS at lower energies (could mainly help for 3+4)

1) Extract beams into bypass line

- choice of extraction energies
- design of extraction system (length?)
- bypass design and integration

⇒ extraction systems would need to be significant and compromise fill factor

⇒ does not look too promising

2) Remove end of the linac

⇒ strategy for physics and machine

⇒ does not look promising at all

Options and Issues II

- Include the impact of lower bunch charges on damping ring emittances (for 3+4)

- some impact in the horizontal plane

3) Run at lower gradient

- I) Use structure with larger a/λ to increase bunch charge

  ⇒ redo optimisation

  a) Reduce drive bunch charge current and energy and increase klystron frequency

  ⇒ study klystron options

  b) Increase pulse length

  - Electron and positron main beam are accelerated with one booster linac RF pulse
    - ⇒ slightly larger esistive wall wakefield effects
    - ⇒ need larger distance in booster linac 3 TeV
  - Similar problem for injector linac
  - Check implication of missing bunches on
    - ⇒ drive beam dynamics, beam loading compensation and beam phase stability
  - other issues

- need to identify highest acceptable average current

⇒ looks promising

Options and Issues III

- 4) Use of high gradient in beginning of linac

  ⇒ needs study but not likely to yield any improvement, reduces other luminosity recovery strategies

  ⇒ not too promising option

Drive Beam Accelerator