CLIC Detector studies
status + plans

Contents:

- Introduction to CLIC accelerator

- 2004 CLIC Study group report: "Physics at the CLIC Multi-TeV Linear Collider"

- CERN participation in Linear Collider R&D (EUDET, DevDet)

- ILC-CLIC collaboration
CLIC basic features

High acceleration gradient: > 100 MV/m
- “Compact” collider – total length < 50 km at 3 TeV
- Normal conducting acceleration structures at high frequency

Two-Beam Acceleration Scheme
- Cost effective, efficient
- Simple tunnel, no active elements
- Modular, easy energy upgrade in stages

Drive beam - 95 A, 240 ns from 2.4 GeV to 240 MeV
12 GHz – 64 MW
100 MV/m

Main beam – 1 A, 156 ns from 9 GeV to 1.5 TeV
4.5 m diameter
CLIC layout

CLIC overall layout

3 TeV

Drive Beam Generation Complex

Main Beam Generation Complex

326 klystrons
33 MW, 139 µs
drive beam accelerator
2.37 GeV, 1.0 GHz

326 klystrons
33 MW, 139 µs
drive beam accelerator
2.37 GeV, 1.0 GHz

combiner rings
Circumferences
delay loop 80.3 m
CR1 160.6 m
CR2 481.8 m

booster linac,
9 GeV, 2 GHz

TA
R = 120 m
245 m

BC2
245 m

e⁻ main linac, 12 GHz, 100 MV/m,
21 km

245 m

BC2

IP1

drive beam accelerator
2.37 GeV, 1.0 GHz

CR2

CR2

CR1

CR1

delay loop

delay loop

TA
R = 120 m

21 km

48 km

245 m

2.4 GeV

e⁻ DR

365 m

e⁻ DR

365 m

e⁺ DR

365 m

e⁺ DR

365 m

e⁺ injector, 2.4 GeV

e⁻ injector,
2.4 GeV

Lucie Linssen, Krakow FCAL meeting 6/5/2008 slide 3
## CLIC main parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center-of-mass energy</td>
<td>3 TeV</td>
</tr>
<tr>
<td>Peak Luminosity</td>
<td>$7 \times 10^{34}$ cm$^{-2}$ s$^{-1}$</td>
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<tr>
<td>Peak luminosity (in 1% of energy)</td>
<td>$2 \times 10^{34}$ cm$^{-2}$ s$^{-1}$</td>
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<tr>
<td>Repetition rate</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Loaded accelerating gradient</td>
<td>100 MV/m</td>
</tr>
<tr>
<td>Main linac RF frequency</td>
<td>12 GHz</td>
</tr>
<tr>
<td>Overall two-linac length</td>
<td>42 km</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>$3.72 \times 10^9$</td>
</tr>
<tr>
<td>Bunch separation</td>
<td>0.5 ns</td>
</tr>
<tr>
<td>Beam pulse duration</td>
<td>156 ns</td>
</tr>
<tr>
<td>Beam power/beam</td>
<td>14 MWatts</td>
</tr>
<tr>
<td>Hor./vert. normalized emittance</td>
<td>660 / 20 nm rad</td>
</tr>
<tr>
<td>Hor./vert. IP beam size bef. pinch</td>
<td>40 / ~1 nm</td>
</tr>
<tr>
<td>Total site length</td>
<td>48 km</td>
</tr>
<tr>
<td>Total power consumption</td>
<td>322 MW</td>
</tr>
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</table>

Luminosity and Background Values

<table>
<thead>
<tr>
<th></th>
<th>CLIC</th>
<th>CLIC</th>
<th>CLIC</th>
<th>ILC</th>
<th>NLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{rms}}$</td>
<td>$[\text{TeV}]$</td>
<td>0.5</td>
<td>1.0</td>
<td>3.0</td>
<td>0.5</td>
</tr>
<tr>
<td>$f_{\text{rep}}$</td>
<td>$[\text{Hz}]$</td>
<td>100</td>
<td>50</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>$N$</td>
<td>$[10^9]$</td>
<td>3.7</td>
<td>3.7</td>
<td>3.7</td>
<td>20</td>
</tr>
<tr>
<td>$\epsilon_y$</td>
<td>$[\text{nm}]$</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>$L_{\text{total}}$</td>
<td>$10^{34}\text{cm}^{-2}\text{s}^{-1}$</td>
<td>2.2</td>
<td>2.2</td>
<td>5.9</td>
<td>2.0</td>
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<tr>
<td>$L_{0.01}$</td>
<td>$10^{34}\text{cm}^{-2}\text{s}^{-1}$</td>
<td>1.4</td>
<td>1.1</td>
<td>2.0</td>
<td>1.45</td>
</tr>
<tr>
<td>$n_\gamma$</td>
<td>1.2</td>
<td>1.5</td>
<td>2.2</td>
<td>1.30</td>
<td>1.26</td>
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<tr>
<td>$\Delta E/E$</td>
<td>0.08</td>
<td>0.15</td>
<td>0.29</td>
<td>0.024</td>
<td>0.046</td>
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<tr>
<td>$N_{\text{coh}}$</td>
<td>$10^5$</td>
<td>0.03</td>
<td>37.0</td>
<td>$3.8 \times 10^3$</td>
<td>—</td>
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<tr>
<td>$E_{\text{coh}}$</td>
<td>$10^2\text{TeV}$</td>
<td>0.5</td>
<td>1080</td>
<td>$2.6 \times 10^5$</td>
<td>—</td>
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<tr>
<td>$n_{\text{incoh}}$</td>
<td>$10^6$</td>
<td>0.05</td>
<td>0.12</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>$E_{\text{incoh}}$</td>
<td>$[10^6\text{GeV}]$</td>
<td>0.28</td>
<td>2.0</td>
<td>22.4</td>
<td>0.2</td>
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<tr>
<td>$n_{\perp}$</td>
<td>12.5</td>
<td>17.1</td>
<td>45</td>
<td>28</td>
<td>12</td>
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<tr>
<td>$n_{\text{had}}$</td>
<td>0.14</td>
<td>0.56</td>
<td>2.7</td>
<td>0.12</td>
<td>0.1</td>
</tr>
</tbody>
</table>

- Target is to have about one beamstrahlung photon per beam particle
  - similar effect to initial state radiation
  \[ \Rightarrow \text{average energy loss is larger in CLIC than ILC} \]
- Note: shorter bunches increase the photon energy but not the number
Time structure of the beam

Train repetition rate 50 (100) Hz

CLIC

1 train = 312 bunches 0.5 nsec apart

ILC

⇒ 5 Hz 1 train ~2820 bunches ~337 ns apart

Experimenting at CLIC similar to the “NLC”

Time stamping!

Lucie Linssen, Krakow FCAL meeting 6/5/2008
CLIC links, workshops and time-line

CLIC website:
http://clic-study.web.cern.ch/CLIC-Study/

CLIC07 workshop, October 2007
http://cern.ch/CLIC07Workshop

CLIC08 workshop, October 14-17 2008

CLIC CDR foreseen for 2010
CLIC TDR foreseen for 2014

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## Detector Specifications

**CLIC Report 2004:**
Starting point: the TESLA TDR detector adapted to CLIC environment

- Detailed studies performed for previous CLIC parameters
- Update with new CLIC parameters is underway
- Greater need for time-stamping of events
- No significant physics difference found previously between NLC and TESLA at sub-TeV energies
- None expected between old and new multi-TeV parameters

<table>
<thead>
<tr>
<th>Detector</th>
<th>CLIC</th>
</tr>
</thead>
</table>
| Vertexing         | $15 \mu m \oplus \frac{35 \mu m GeV/c}{\sin^{3/2} \theta}$  
|                   | $15 \mu m \oplus \frac{35 \mu m GeV/c}{\sin^{5/2} \theta}$ |
| Solenoidal Field  | $B = 4 T$                                         |
| Tracking          | $\frac{\delta p}{p^2} = 5 \times 10^{-5}$         |
| E.m. Calorimeter  | $\frac{\delta E}{E (GeV)} = 0.10 \frac{1}{\sqrt{E}} \oplus 0.01$ |
| Had. Calorimeter  | $\frac{\delta E}{E (GeV)} = 0.40 \frac{1}{\sqrt{E}} \oplus 0.04$ |
| $\mu$ Detector    | Instrumented Fe yoke                             |
|                   | $\frac{\delta p}{p} \simeq 30\%$ at 100 GeV/c    |
| Energy Flow       | $\frac{\delta E}{E (GeV)} \simeq 0.3 \frac{1}{\sqrt{E}}$ |
| Acceptance mask   | $|\cos \theta| < 0.98$                           |
|                   | 120 mrad                                          |
| beampipe          | 3 cm                                              |
| small angle tagger| $\theta_{min} = 40$ mrad                         |
CERN participation in LC: EUDET 2006-2009

- MICELEC: microelectronics user support
- VALSIM: optimisation of hadronization process in GEANT4
- Magnet: magnetic field map of PCMAG magnet at DESY test beam
- Timepix: development of pixel chip for TPC pixelised readout
- TPC electronics: development of TPC pad readout (aiming for combined analog/digital readout fitting behind 1×4 mm² pads)
PCMAG field map campaign at DESY 2007

TPC pad readout, programmable amplifier 130 nm technology

Timepix chip
CERN contribution to LC tasks in FP7 proposal DevDet

http://project-fp7-detectors.web.cern.ch/project-FP7-detectors/Default.htm

- Test beam for combined linear collider slice tests (providing beam, large magnet, general infrastructures etc.)

- Continued support for TPC electronics

- Participation in Project office for linear collider detectors (engineering tools for project office; design support for test beam set-up)

- Test-case of LC project tools on CLIC forward region example (together with DESY and ILC forward study teams)

- Software tools (geometry and reconstruction tools)

- Microelectronics user support
CLIC-ILC Collaboration?

• Following visit of Barry @ CERN (Nov 07)

  Independently of US/UK financial crisis,
  but even more desirable now

• CLIC-ILC Collaboration meeting (Feb 08)
  http://indico.cern.ch/conferenceDisplay.py?confId=27435

• GDE/ACFA Meeting at Sendai/Japan (March 08)
  http://www.awa.tohoku.ac.jp/TILC08/
Subjects with strong synergy

1. Civil Engineering and Conventional Facilities
3. Detectors
4. Cost and Schedule
5. Beam Dynamics & Beam Simulations including Low Emittance Transport
The recent CLIC-ILC meeting at CERN is an example of optimizing resources

- We all agree on a common goal: the need to build a lepton collider after LHC
  -> Constructive competitiveness?

There are mutual benefits to be expected by improving the connections between the two projects:

- CERN expertise on large detectors
- MDI experts sharing common work (already happening)
- CLIC benefiting from our well advanced tools to design a detector concept
- ILC concepts tried at ECM >> 500 GeV
  -> ILC concepts to designate contacts to help CLIC
# ILC-CLIC working groups

<table>
<thead>
<tr>
<th>ILC-CLIC working groups</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topic</strong></td>
<td><strong>Conveners</strong></td>
</tr>
<tr>
<td>Civil Engineering and Conventional Facilities (CFS)</td>
<td>Claude Hauviller (CERN), John Osborne (CERN), Vic Kuchler (FNAL)</td>
</tr>
<tr>
<td>Beam Delivery Systems and Machine Detector Interface</td>
<td>Brett Parker (BNL), Daniel Schulte (CERN), Andrei Seryi (SLAC), Emmanuel Tsesmelis (CERN)</td>
</tr>
<tr>
<td>Detectors</td>
<td>Lucie Linssen (CERN), Francois Richard (LAL), Dieter Schlatter (CERN), Sakue Yamada (KEK)</td>
</tr>
<tr>
<td>Cost &amp; Schedule</td>
<td>John Carwardine (ANL), Katy Foraz (CERN), Peter Garbincius (FNAL), Tetsuo Shidara (KEK), Sylvain Weisz (CERN)</td>
</tr>
<tr>
<td>Beam Dynamics</td>
<td>Andrea Latina (FNAL), Kiyoshi Kubo (KEK), Daniel Schulte (CERN), Nick Walker (DESY)</td>
</tr>
</tbody>
</table>

First working group meeting, 13/5/2008

Lucie Linssen, Krakow FCAL meeting 6/5/2008
Topics for CLIC-ILC Detector R&D

Summary: Detectors from meeting 8 Feb 08:

1) Define a CLIC detector concept at 3 TeV.
   (update of 2004 CLIC Study) based on ILC detector concepts.

2) Detector simulations
   - Simulation tools to be used by ILC and CLIC (WWS software panel)
   - Validation ILC detector options for CLIC at high energy, different time structure and different backgrounds
   - 1 TeV benchmark studies to provide overlap
   - compare performance using defined benchmark physics processes
     (e.g. WW/ZZ separation)
3) **EUDET /DEVDET** (infrastructure for LC detector R&D, with associated non-EU groups)
   - microelectronic tools
   - 3D interconnect technologies (for integrated solid state detectors)
   - simulation and reconstruction tools
   - combined test with magnet and LC sub-detectors

4) **TPC**
   - TPC performance at high energies (>500 GeV).
   - TPC read out electronics

5) **Calorimetry**
   - Dual Readout Calorimetry (feasible at LC?)

6) **General**
   - increased CLIC participation in future ECFA workshops (2008 Warsaw) on LC detectors
• General layout and integration
  – Common meeting/review required
  – Common engineering tools for detector design in preparation (DESY, CERN, IN2P3, FP7)
• Background and luminosity studies
  – Strengthen support
• Masking system
  – Constraints on vertex detector
• Detector field
  – Need a field for CLIC
• Magnet design
• Common simulation tools for detector studies
  – Need to review what is available
• Low angle calorimeters
• Beam pipe design (LHC)
• Vacuum etc. (LHC)
• Common simulation tools
  – BDSIM
    • Integration into GEANT?
  – FLUKA (CERN)
  – Halo and tail generation (CERN)
  – Common formats etc

• Study of machine induced background
  – In particular, neutrons, muons and synchrotron radiation
  – Mitigation strategies
    • e.g. tunnel fillers against muons

• Study of beam-beam background and luminosity spectrum
• LAPP, Oxford, CERN, FP7, BNL, SLAC, …
  – Other please join
• Low-noise design
  – Noise level measurements (DESY, CERN)
    • Among others, measurements at LHC
  – Component design
• Mechanical design of quadrupole support
• Final quadrupole design
• Stabilization feedback design
  – Sensors
  – Actuators
  – Interferometers
Experimental Area Integration
(from summary 8/2/2008)

- Common definitions
- Infra-structure
  - Work is quite generic
    - No large differences expected for CLIC detector to some ILC detector
    - Collaboration has started
    - LHC expertise
- Push-pull
  - Is an option for both projects
  - A collaboration has started
  - Brings ILC/CLIC/LHC expertise
- Crossing angle
  - Investigate requirements
  - Then study benefits to find a common crossing angle
Push-Pull studies for two detectors
Conclusions

• CLIC physics/detector studies are starting again
• Many similarities with ILC detector studies
• Good exchange and collaboration with ILC experts is fundamental and is underway.....

thank you
Spare slides

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Prospects for Scientific Activities over the Period 2012 - 2016

To be decided in 2010-2011 in light of first physics results from LHC, and designed and R&D results from the previous years. This programme could most probably comprise:

- An LHC luminosity increase requiring a new injector (SPL and PS).
  The total cost of the investment over 6 years (2011-2016: 1000-1200 MCHF + a staff of 200-300 per year. Total budget: ~200-250 MCHF per year.

- Preparation of a Technical Design for the CLIC programme, for a possible construction decision in 2016 after the LHC upgrade (depending on the ILC future).
  Total CERN M + P contribution + ~250 MCHF + 1000-1200 FTE over 6 years.

- Enhanced infrastructure consolidation: 30 MCHF + 40 FTEs from 2011.

NB: Over the period 2012-2016. Effective participation of CERN in another large programme (ILC or a neutrino factory) will not be possible within the expected resources if positive decisions taken on LHC upgrade and CLIC Technical Design. This situation could totally change if none of the above programmes is approved or if a new, more ambitious level of activities and support is envisaged in the European framework.
Two Beam Module

Two Beam HW & Int. WG

20760 modules
71460 power production structures PETS (drive beam)
143010 accelerating structures (main beam)
CLIC Standard Two Beam Module
Single CLIC tunnel with alcoves for drive beam return loops and dumps
Major revision of CLIC parameters made 2007
(final parameter optimization still ongoing)

Basic changes

30 GHz -> 12 GHz RF frequency

close to old NLC frequency (11.424 GHz)
easier to adapt NLC work and experience
lower frequency allows more relaxed alignment tolerances

150 MV/m -> 100 MV/m

reduces breakdown rate and surface damages in RF accelerating structures

50 km long LINAC allows 2 x 1.5 TeV = 3 TeV CM energy (was 5 TeV)

0.5 ns bunch spacing, 312 bunches (= 156 ns bunch trains), 50 Hz (3 TeV)

optimized for maximum luminosity
was subject of various changes in the past: 0.667 ns -> 0.267 ns -> 0.667 ns -> 0.5 ns

Aim for feasibility and conceptual design report in 2010
# CLIC parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>CLIC 3 TeV</th>
<th>CLIC 1 TeV</th>
<th>CLIC 0.5 TeV</th>
<th>ILC 0.5 TeV</th>
<th>NLC 0.5 TeV</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of mass energy</td>
<td>$E_{cm}$</td>
<td>3000</td>
<td>1000</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>GeV</td>
</tr>
<tr>
<td>Main Linac RF Frequency</td>
<td>$f_{RF}$</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>1.3</td>
<td>12</td>
<td>GHz</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$L$</td>
<td>5.9</td>
<td>2.25</td>
<td>2.24</td>
<td>2</td>
<td>2</td>
<td>$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$</td>
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<tr>
<td>Luminosity (in 1% of energy)</td>
<td>$L_{99%}$</td>
<td>2</td>
<td>1.08</td>
<td>1.36</td>
<td></td>
<td></td>
<td>$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$</td>
</tr>
<tr>
<td>Linac repetition rate</td>
<td>$f_{rep}$</td>
<td>50</td>
<td>50</td>
<td>100</td>
<td>5</td>
<td>120</td>
<td>Hz</td>
</tr>
<tr>
<td>No. of particles / bunch</td>
<td>$N_b$</td>
<td>3.72</td>
<td>3.72</td>
<td>3.72</td>
<td>20</td>
<td>7.5</td>
<td>$10^9$</td>
</tr>
<tr>
<td>No. of bunches / pulse</td>
<td>$k_b$</td>
<td>312</td>
<td>312</td>
<td>312</td>
<td>2670</td>
<td>192</td>
<td></td>
</tr>
<tr>
<td>No. of drive beam sectors / linac</td>
<td>$N_{unit}$</td>
<td>24</td>
<td>8</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td></td>
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<tr>
<td>Overall two linac length</td>
<td>$l_{linac}$</td>
<td>41.7</td>
<td>13.9</td>
<td>6.9</td>
<td>22</td>
<td>14</td>
<td>km</td>
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<tr>
<td>Proposed site length</td>
<td>$l_{tot}$</td>
<td>47.9</td>
<td>20.1</td>
<td>13.2</td>
<td>31</td>
<td>32</td>
<td>km</td>
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<tr>
<td>DB Pulse length (total train)</td>
<td>$t_t$</td>
<td>139</td>
<td>46</td>
<td>23</td>
<td>-</td>
<td>-</td>
<td>$\mu$s</td>
</tr>
<tr>
<td>Beam power / beam</td>
<td>$P_b$</td>
<td>14</td>
<td>4.6</td>
<td>4.6</td>
<td>10.8</td>
<td>6.9</td>
<td>MW</td>
</tr>
<tr>
<td>Wall-plug power to beam efficiency</td>
<td>$r_{wp} \cdot r_f$</td>
<td>8.7</td>
<td>6.1</td>
<td>6.1</td>
<td>9.4</td>
<td>7.1</td>
<td>%</td>
</tr>
<tr>
<td>Total site AC power</td>
<td>$P_{tot}$</td>
<td>322</td>
<td>~150</td>
<td>~150</td>
<td>230</td>
<td>195</td>
<td>MW</td>
</tr>
</tbody>
</table>
3x more energy loss due to beamstrahlung at CLIC w.r.t. ILC

unavoidable at Linear Colliders in general: small beam sizes -> large beamstrahlung

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>CLIC 3 TeV</th>
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<th>ILC 0.5 TeV</th>
<th>NLC 0.5 TeV</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse horizontal emittance</td>
<td>$\gamma_{e_x}$</td>
<td>660</td>
<td>660</td>
<td>660</td>
<td>8000</td>
<td>3600</td>
<td>nm rad</td>
</tr>
<tr>
<td>Transverse vertical emittance</td>
<td>$\gamma_{e_y}$</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>nm rad</td>
</tr>
<tr>
<td>Nominal horizontal IP beta function</td>
<td>$\beta^*_x$</td>
<td>4</td>
<td>20</td>
<td>15</td>
<td>20</td>
<td>8</td>
<td>mm</td>
</tr>
<tr>
<td>Nominal vertical IP beta function</td>
<td>$\beta^*_y$</td>
<td>0.09</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4</td>
<td>0.11</td>
<td>mm</td>
</tr>
<tr>
<td>Horizontal IP beam size before pinch</td>
<td>$\alpha_x$</td>
<td>40</td>
<td>142</td>
<td>640</td>
<td>243</td>
<td></td>
<td>nm</td>
</tr>
<tr>
<td>Vertical IP beam size before pinch</td>
<td>$\alpha_y$</td>
<td>1</td>
<td>2</td>
<td>5.7</td>
<td>3</td>
<td></td>
<td>nm</td>
</tr>
<tr>
<td>Beamstrahlung energy loss</td>
<td>$\delta_B$</td>
<td>29</td>
<td>11</td>
<td>7</td>
<td>2.4</td>
<td>5.4</td>
<td>%</td>
</tr>
<tr>
<td>No. of photons / electron</td>
<td>$\eta_y$</td>
<td>2.2</td>
<td>1.2</td>
<td>1.1</td>
<td>1.32</td>
<td>1.3</td>
<td>-</td>
</tr>
<tr>
<td>No. of pairs ($p_T^{\text{min}}=20\text{MeV/c}, \tilde{I}_{\text{min}}=0.2$)</td>
<td>$N_{\text{pairs}}$</td>
<td>45</td>
<td>17.1</td>
<td>11.5</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>No. of coherent pairs</td>
<td>$N_{\text{coh}}$</td>
<td>38</td>
<td>0.07</td>
<td>0.0001</td>
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<td>$10^7$</td>
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<tr>
<td>No. of incoherent pairs</td>
<td>$N_{\text{incoh}}$</td>
<td>0.44</td>
<td>0.09</td>
<td>0.05</td>
<td></td>
<td></td>
<td>$10^5$</td>
</tr>
<tr>
<td>Hadronic events / crossing</td>
<td>$N_{\text{hadron}}$</td>
<td>3.23</td>
<td>0.29</td>
<td>0.1</td>
<td></td>
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<td>-</td>
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