CLIC Workshop 2009

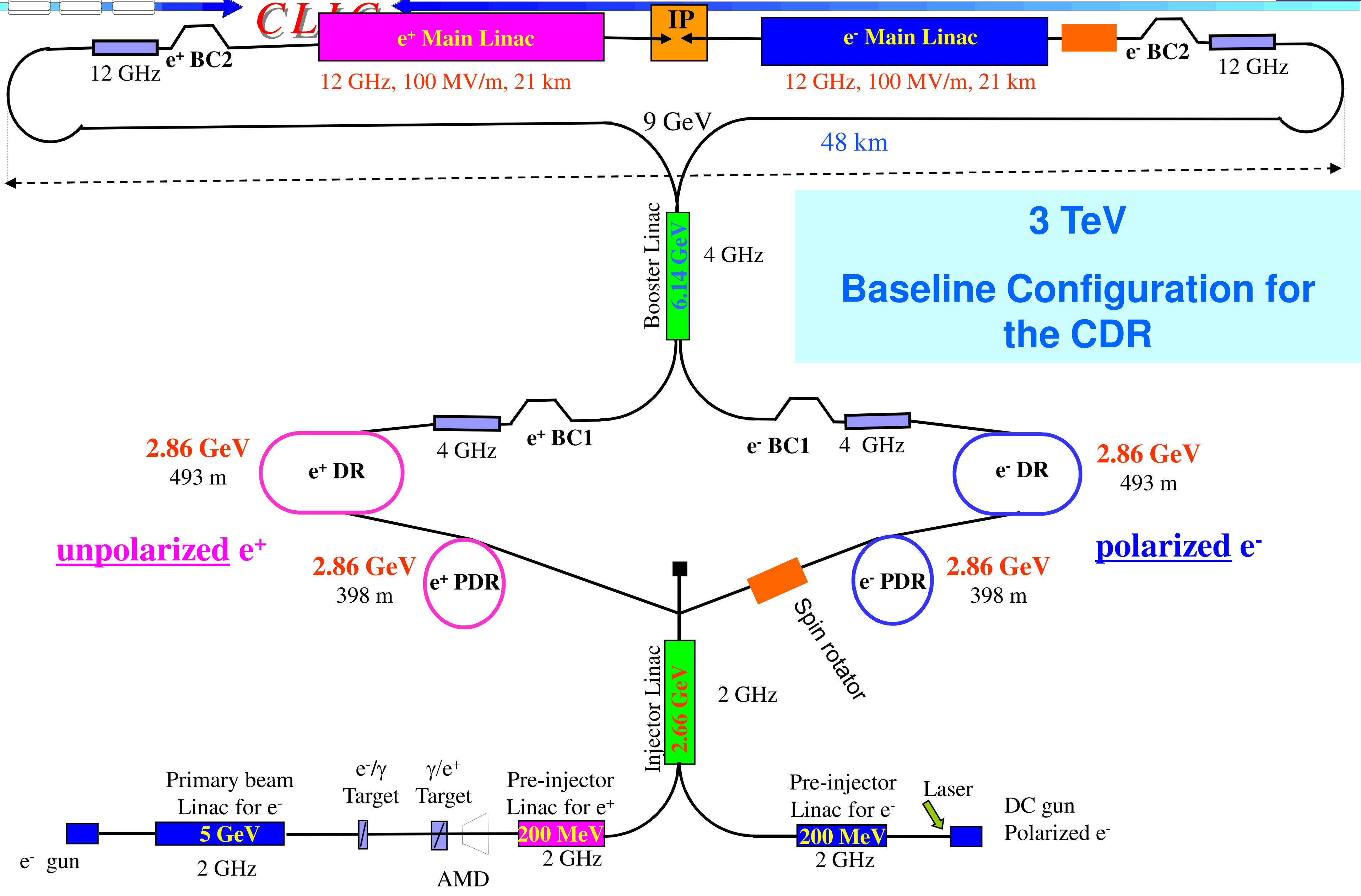
Summary of WG2
Injectors and Damping Rings

Mark Palmer

Cornell University

October 15th, 2009

CLIC Main Beam Injector Complex



3 TeV

Baseline Configuration for the CDR

Outline

- Injectors
  - ☐ Conveners:
    - Louis Rinolfi
    - Jim Clarke
    - Alessandro Variola
- Damping Rings
  - ☐ Conveners:
    - Ioannis Papaphilippou
    - Susanna Guiducci
    - Mark Palmer

Challenges for the e$^-$/e$^+$ source

Electrons

Reliable load locked gun, High voltage; Ultra-high vacuum requirements; Cathode/anode optics

Production of the full current with space charge and surface charge limits

Photocathode high polarization; High Quantum Efficiency and Long life time

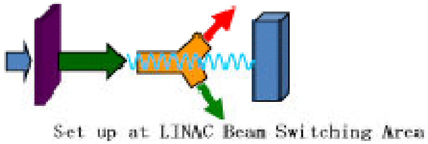
Laser frequency, Pulse length and Pulse energy.

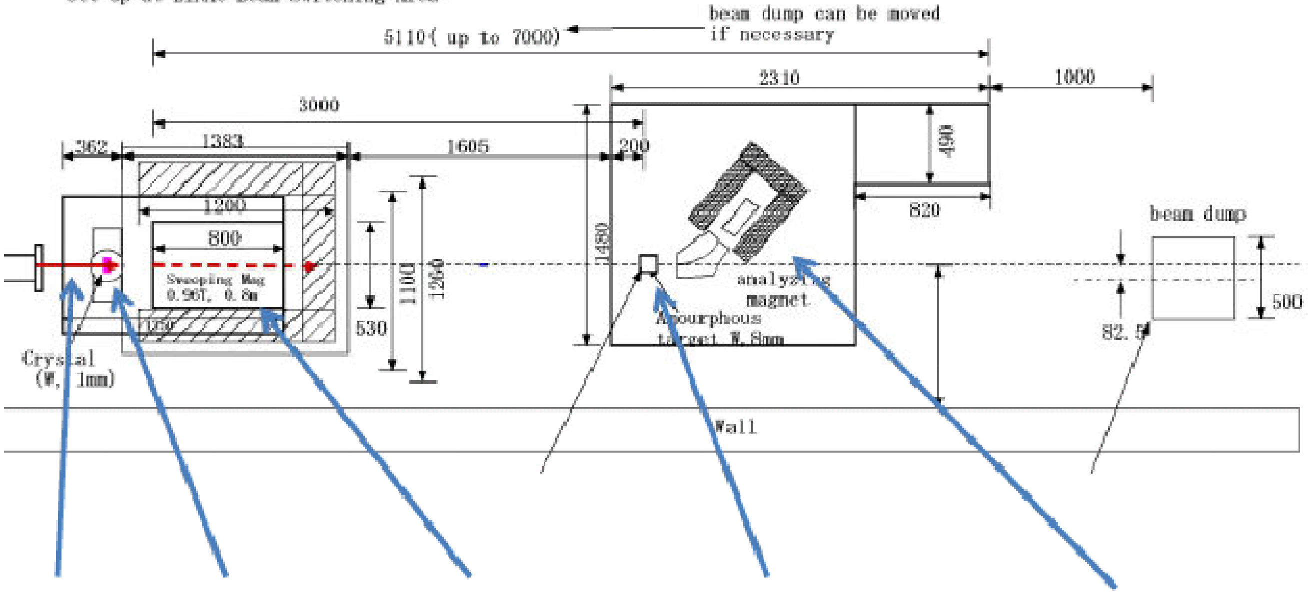
Positrons

- A single hybrid targets station or several stations to cover all the CLIC needs
- Devices for Undulator scheme (Helical undulator, collimators, dumps,…)
- Devices for Compton schemes (Optical cavities at IP, powerful laser systems,…)
- Targets issues (Heat load dynamics, beam energy deposition, shock waves, breakdown limits, activation, ….)
- Adiabatic Matching Device (AMD)
- Capture sections (Transport and collimation of large emittances, high beam loading)
- Trade off between yield, polarization and emittances
- Design and implementation of the spin rotators
- Polarization issues (Analyze systematic errors of polarization measurements)
- Efficient use of existing codes (EGS4, FLUKA, Geant4, PPS-Sim, Parmela, …)
- Integration issues for the target station (remote handling in radioactive area)
- Radioactivity issue.

KEKB hybrid source experiment

Setup





8GeV e-

1mm
W crystal

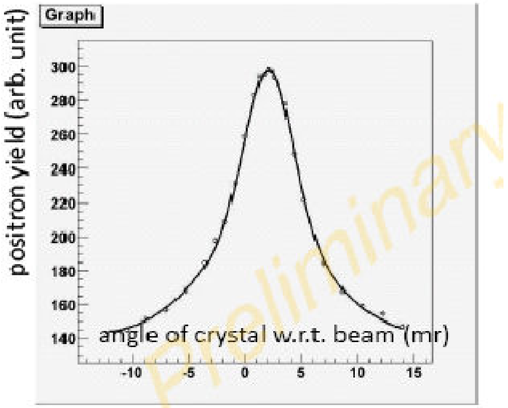
Sweeping Magnet
0.96T 0.75m

amorphous W
0.4 mm
8 mm

Analyzing magnet
5 ~ 20MeV

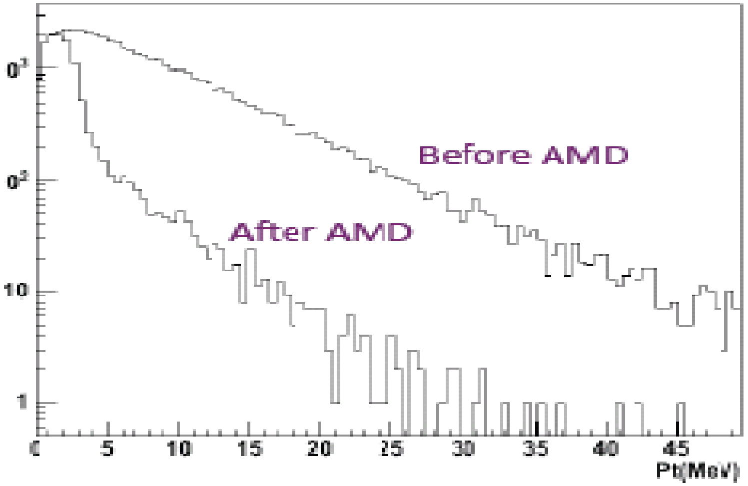
1st result

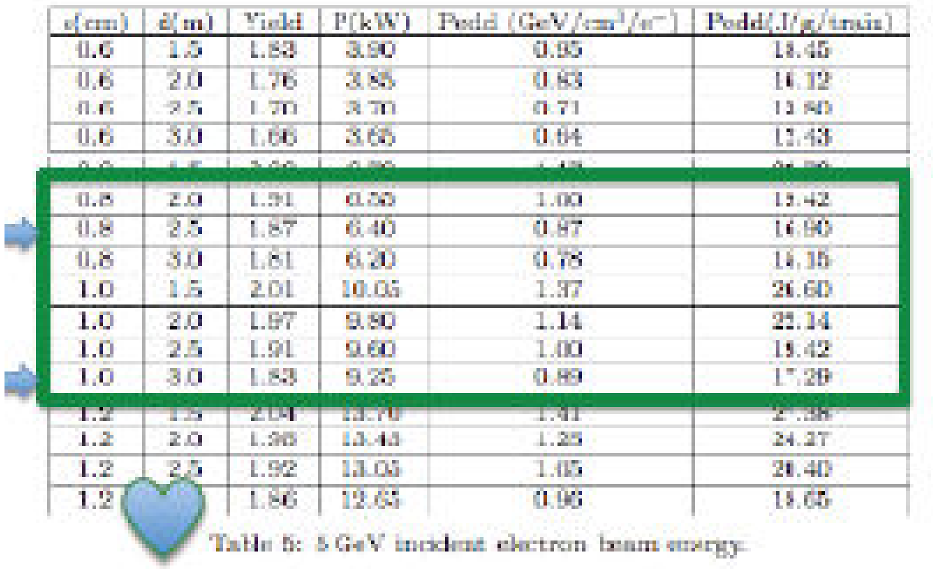
Rocking Curve



T. Takahashi

Simulation results





e(cm)	d(m)	Yield	P(kW)	Pedd $(GeV/cm^3/e^-)$	Pedd(J/g/train)
0.6	1.5	1.83	3.90	0.95	18.45
0.6	2.0	1.76	3.85	0.83	16.12
0.6	2.5	1.70	3.70	0.71	13.90
0.6	3.0	1.66	3.65	0.64	12.43
0.8	1.5	[illegible]	[illegible]	[illegible]	[illegible]
0.8	2.0	1.91	6.50	1.00	19.42
0.8	2.5	1.87	6.40	0.87	16.90
0.8	3.0	1.81	6.20	0.78	15.15
1.0	1.5	2.01	10.05	1.37	26.60
1.0	2.0	1.97	9.90	1.14	22.14
1.0	2.5	1.91	9.60	1.00	19.42
1.0	3.0	1.83	9.25	0.89	17.29
1.2	1.5	2.04	13.70	1.41	27.38
1.2	2.0	1.98	13.43	1.25	24.27
1.2	2.5	1.92	13.05	1.05	20.40
1.2	[illegible]	1.86	12.65	0.96	18.65

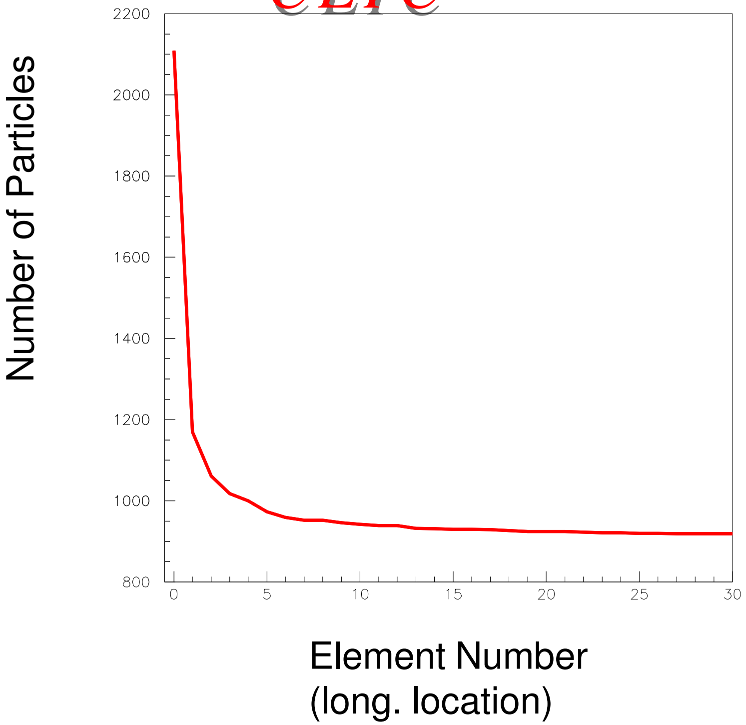
Table 5: 5 GeV incident electron beam energy.

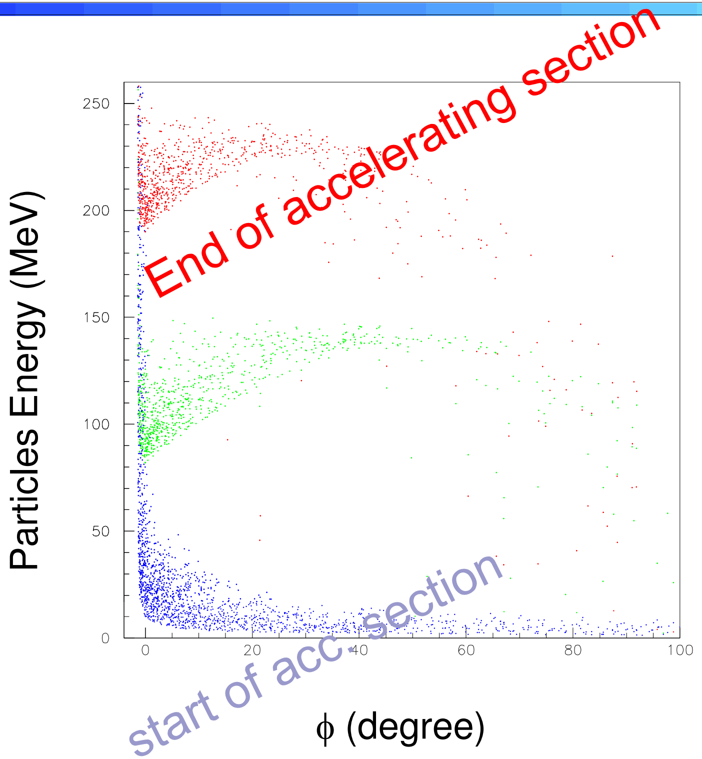
If we are looking at the optimisation of the produced yield and take into account a safety factor of 50% on the PEDD limit

1. an incident electron energy of 5 GeV
2. a distance radiator-converter of 2 – 3 meters
3. a converter thickness of 6 – 9 mm

O. Dadoun

Pre-accelerator results at 200 MeV





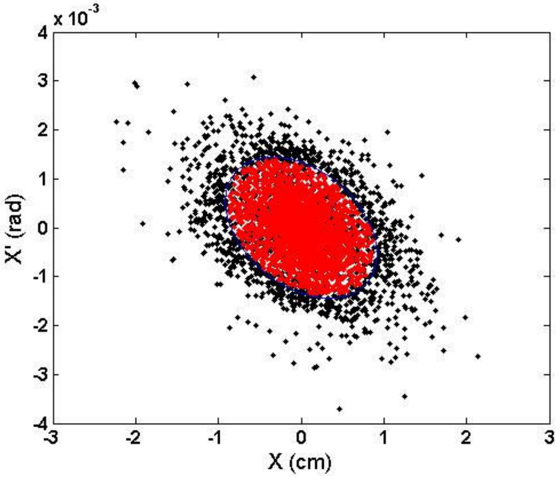
Start to end results:

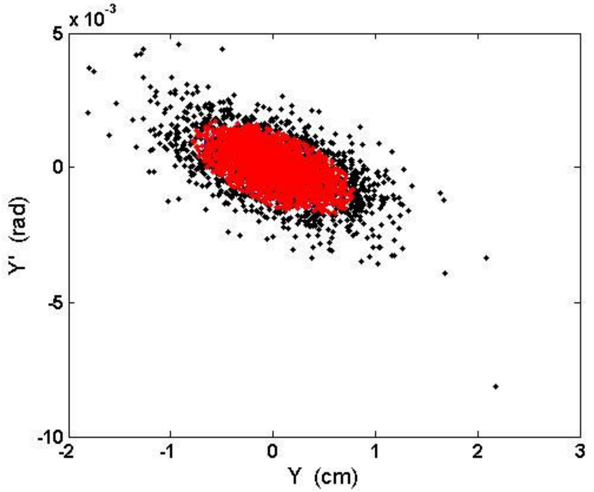
e+/e- yield	AMD yield	ACS yield	Total yield
~8.15	0.23	0.42	~ 0.8

Total yield e+/e-= 0.8 with Parmela i.e. with $7.5\ 10^9$ e- / bunch in front of crystal we get ~$6.\ 10^9$ e+ / bunch at exit of accelerating section

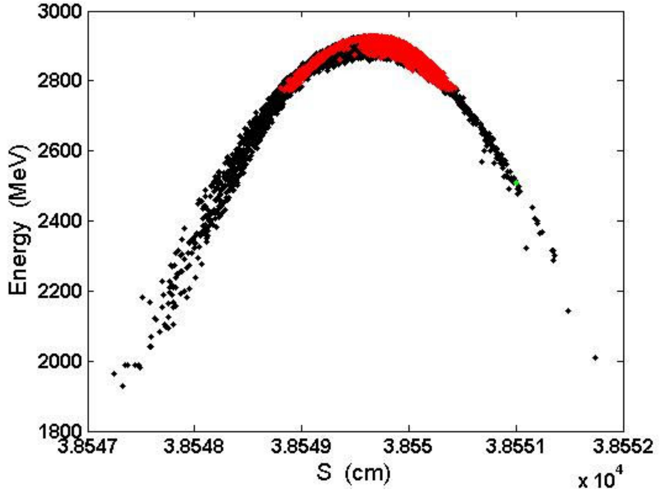
F. Poirier

Injector linac results at 2.8 GeV





To be optimized…



S cm	N. e^+	Yield e^+/e^-	$\gamma\varepsilon_x$ π mm mrad	$\gamma\varepsilon_y$ π mm mrad	<E> MeV	σ_E MeV	σ_z mm	ε_z π cm MeV
38550	4558	0.76	19804	14729	2825.1	129.5	6.2	69.5

e^+ in PDR: 2747

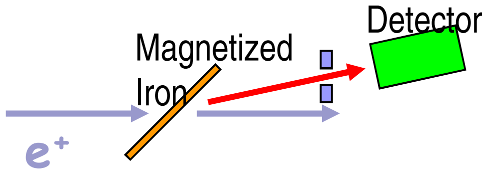
Yield e^+/e^- =0.458

For e+ capture into the PDR

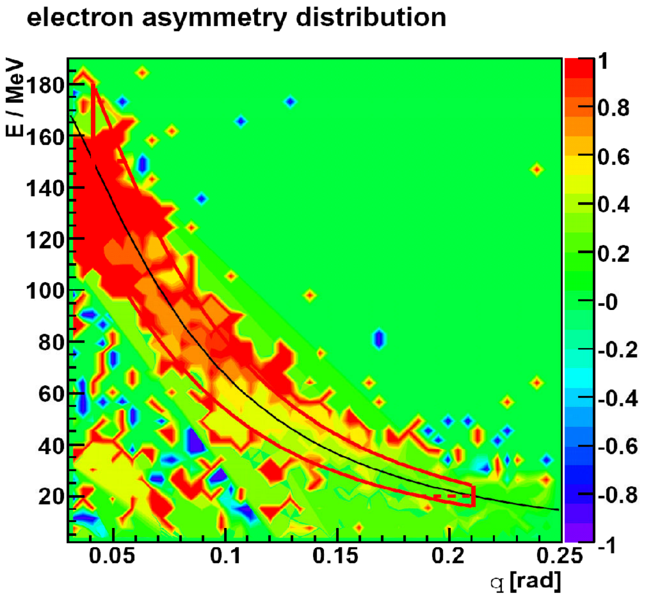
A. Vivoli

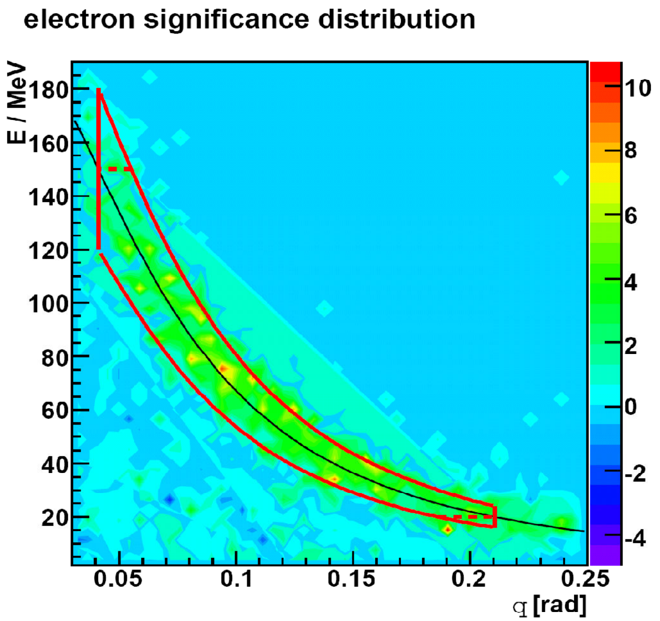
Bhabha polarimeter at 200 MeV

- G4 Simulation
  - ☐ E_{e+} 200 MeV
  - ☐ Target 30 µm Fe



$$S = \frac{A}{\Delta A} \approx \frac{n-p}{2}\sqrt{\frac{n+p}{(n+1)(p+1)}}$$



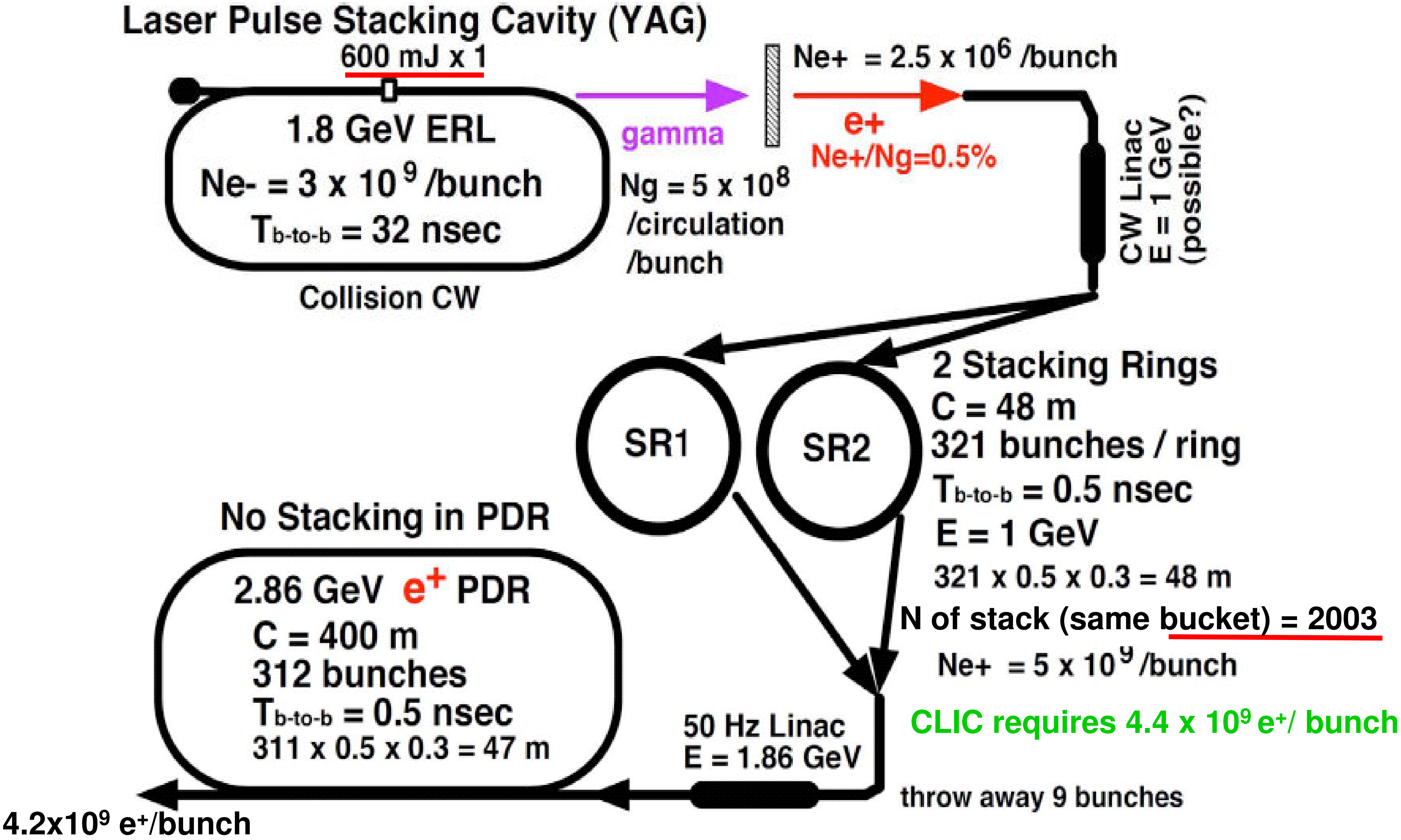


asymmetry measurement with scattered electrons

Energy range: 30 – 150 MeV

S. Riemann

CLIC Compton ERL



Laser Pulse Stacking Cavity (YAG)

600 mJ x 1

1.8 GeV ERL

Ne- = 3×10^9 /bunch

$T_{b\text{-}to\text{-}b}$ = 32 nsec

Collision CW

gamma

Ng = 5×10^8 /circulation /bunch

Ne+ = 2.5×10^6 /bunch

e+

Ne+/Ng=0.5%

CW Linac

E = 1 GeV

(possible?)

2 Stacking Rings

C = 48 m

321 bunches / ring

$T_{b\text{-}to\text{-}b}$ = 0.5 nsec

E = 1 GeV

321 x 0.5 x 0.3 = 48 m

N of stack (same bucket) = 2003

Ne+ = 5×10^9 /bunch

SR1

SR2

No Stacking in PDR

2.86 GeV e^+ PDR

C = 400 m

312 bunches

$T_{b\text{-}to\text{-}b}$ = 0.5 nsec

311 x 0.5 x 0.3 = 47 m

50 Hz Linac

E = 1.86 GeV

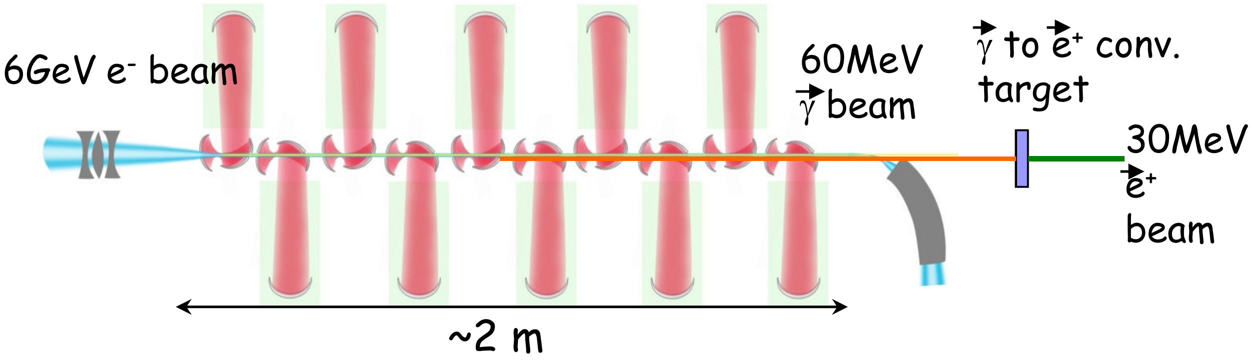
throw away 9 bunches

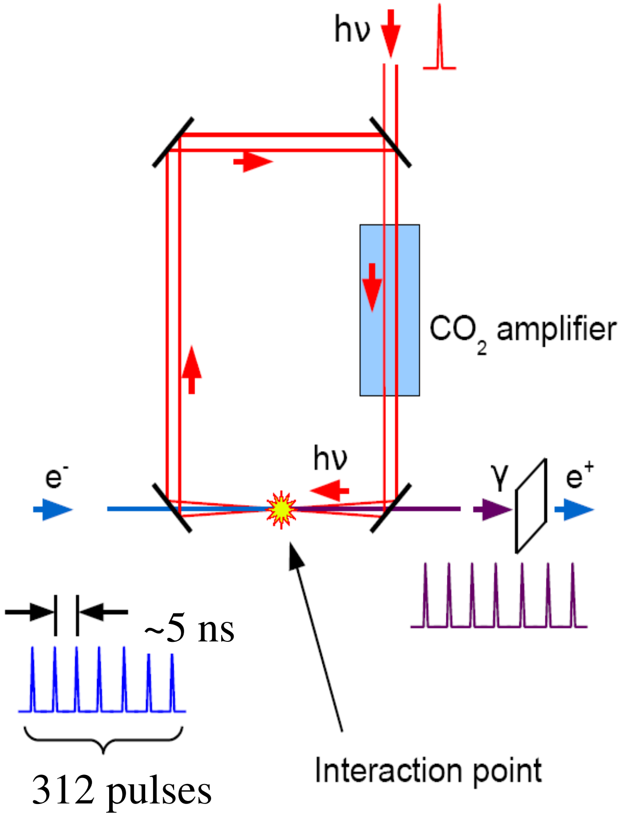
CLIC requires 4.4×10^9 e^+/ bunch

4.2×10^9 e^+/bunch

T. Omori

CLIC Compton Linac

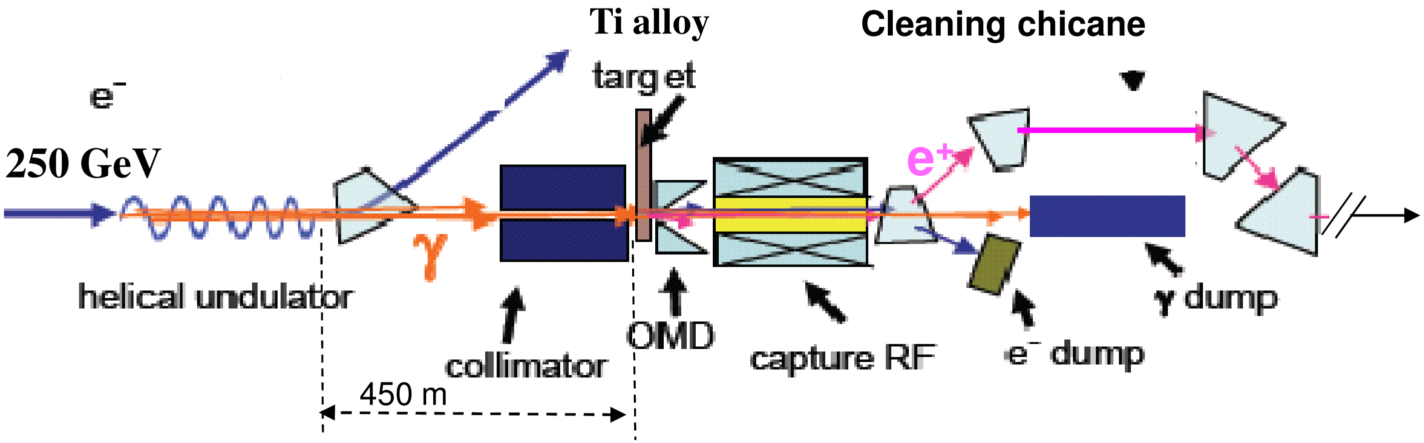


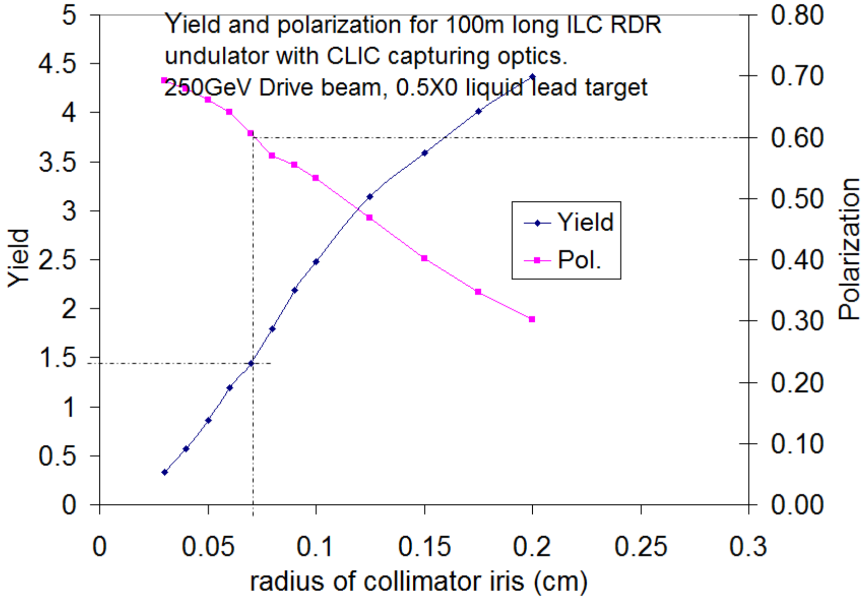


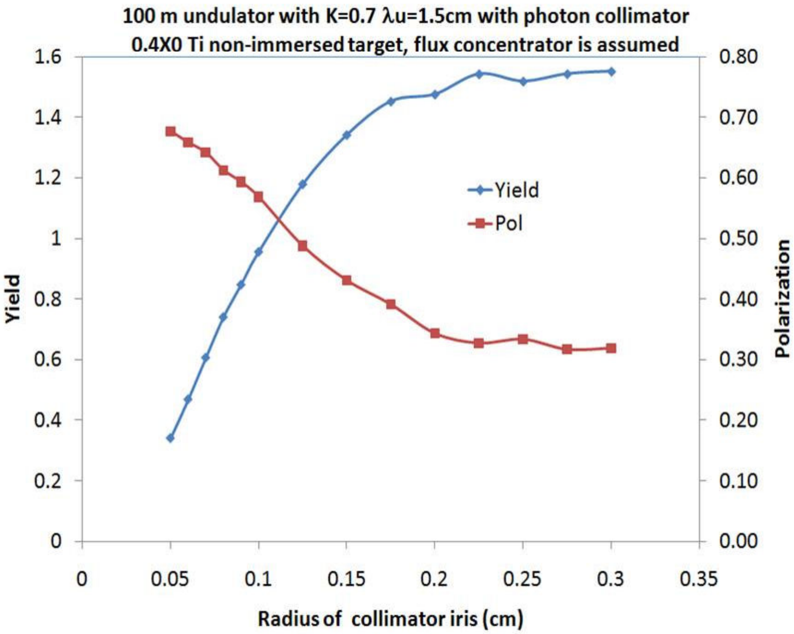
- No stacking in the PDR
- Laser system and recirculating cavity should be built and tested
- Demonstration with a test beam is required

V. Yakimenko

CLIC Undulator scheme



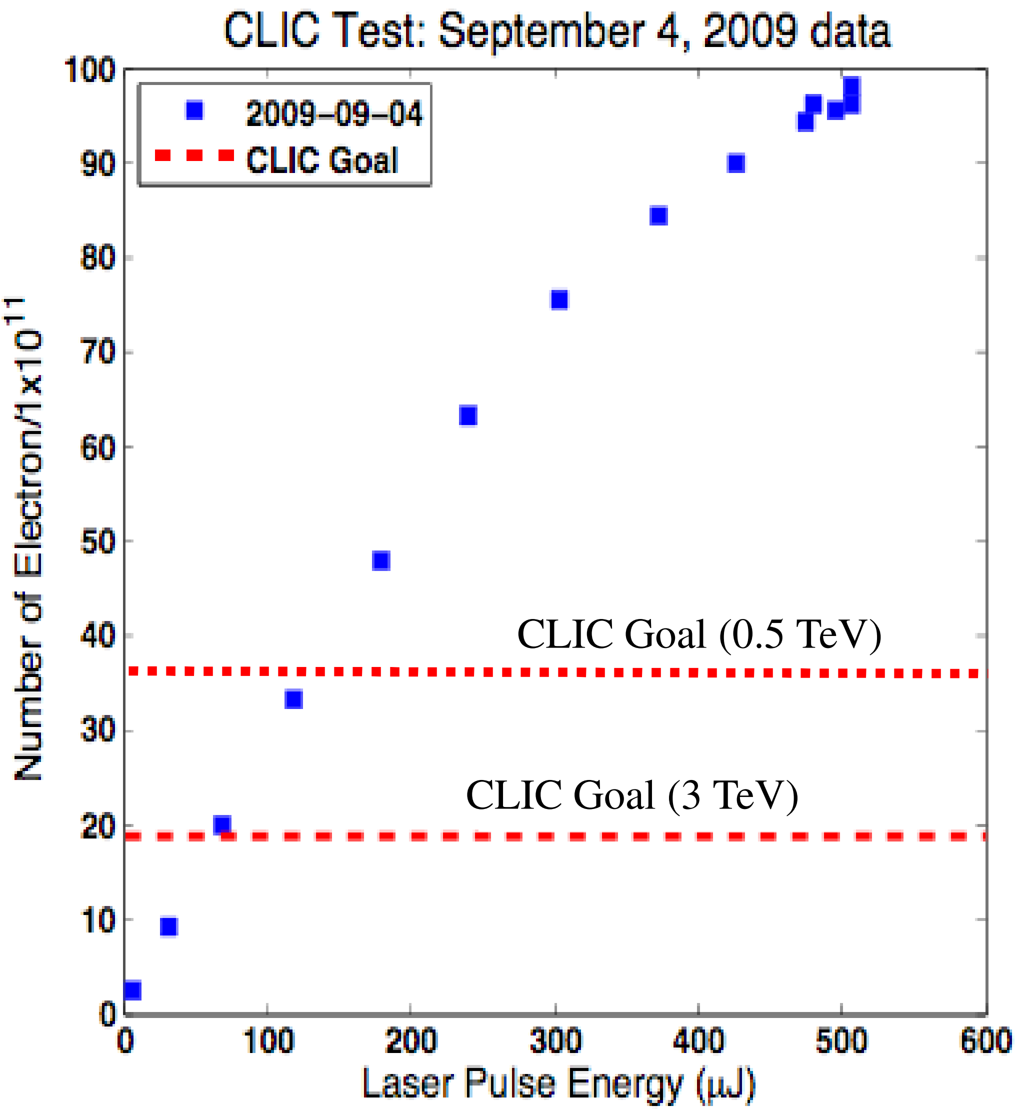




W. Gai

ANL simulations

Polarized e^- produced at SLAC



The total charge produced is a:

factor 3 above the CLIC requirement for 0.5 TeV and

factor 5 above the CLIC requirements for 3 TeV

QE ~ 0.5 - 0.7 %

The measured polarization is ~ 82 %

Major milestone

J. Sheppard

Polarized e$^-$ at JLAB

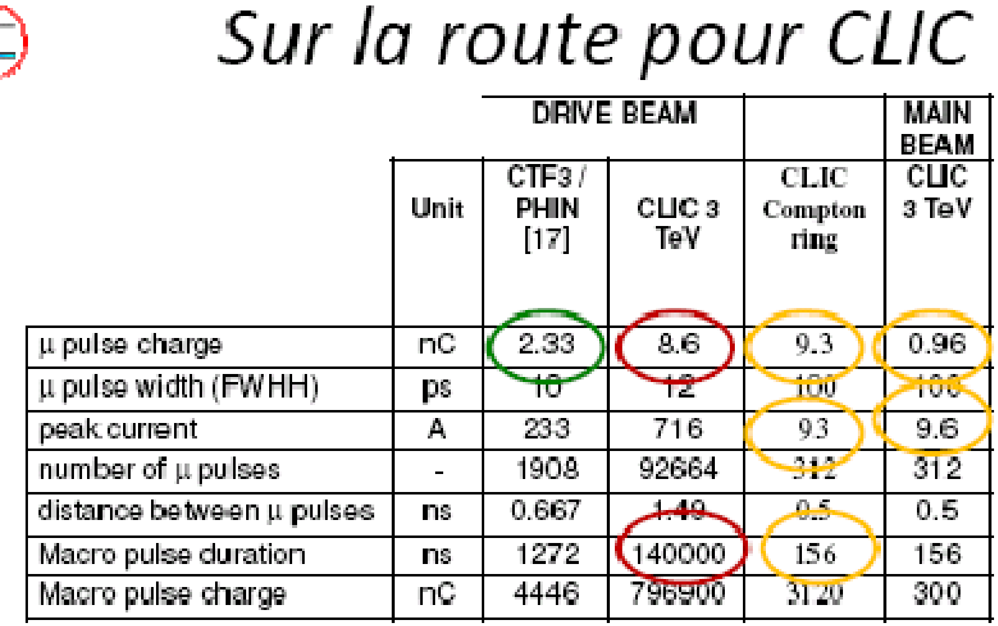
To-do List for CLIC, ILC and JLab

- Demonstrate Higher Voltage > 100kV with new inverted gun
  - 200kV for CEBAF, 350kV for ILC
  - Field emission measurements, materials and polishing techniques
  - New gun design if necessary: reduce gradient where possible, symmetric design
- Cathode/Anode Design for large laser beam
  - Uniform emittance across beam profile
  - No beam loss
- Improve Vacuum
  - NEG/ion pump limitations
  - Gauges at -13 Torr
  - Cryopumping

M. Poelker

PHIN results at CERN

PHIN = PHoto-INjector



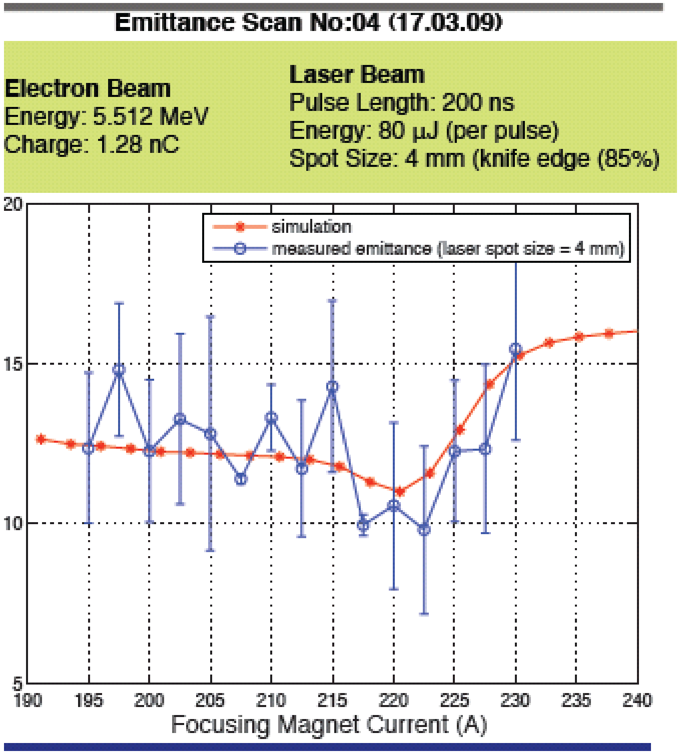
Sur la route pour CLIC

	Unit	DRIVE BEAM CTF3 / PHIN [17]	DRIVE BEAM CLIC 3 TeV	CLIC Compton ring	MAIN BEAM CLIC 3 TeV
µ pulse charge	nC	2.33	8.6	9.3	0.96
µ pulse width (FWHH)	ps	10	12	100	100
peak current	A	233	716	93	9.6
number of µ pulses	-	1908	92664	312	312
distance between µ pulses	ns	0.667	1.40	0.5	0.5
Macro pulse duration	ns	1272	140000	156	156
Macro pulse charge	nC	4446	796900	3120	300

For CTF3 drive beam more powerful amplifiers can be added to the laser

For the Compton Ring 2 GHz oscillator is feasible – More powerful amplifiers to be designed

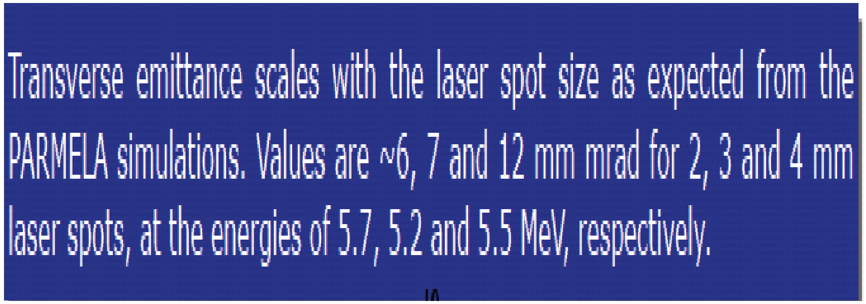
M. Petrarca



Emittance Scan No:04 (17.03.09)

Electron Beam
Energy: 5.512 MeV
Charge: 1.28 nC

Laser Beam
Pulse Length: 200 ns
Energy: 80 µJ (per pulse)
Spot Size: 4 mm (knife edge (85%)



Transverse emittance scales with the laser spot size as expected from the PARMELA simulations. Values are ~6, 7 and 12 mm mrad for 2, 3 and 4 mm laser spots, at the energies of 5.7, 5.2 and 5.5 MeV, respectively.

O. Mete

Highlights for the CDR

☺ For polarized e^-, the SLAC major milestone confirms that the desired charge can be produced

☺ For unpolarized e^+, the present simulations based on hybrid targets and the KEKB experiment provide great confidence that we can reach the requested performance with a single target station

⇨ For polarized e^+, all schemes (Compton Ring, Compton Linac, ERL, Undulator) a possible solution has been proposed but all schemes need strong R&D developments

☺ The work performed by the international collaboration working on the CLIC Injector Complex has produced important progress and should be greatly acknowledged.

CLIC DR overview

Y. Papaphilippou

- Energy increase to 2.86GeV in order to reduce collective effects (especially IBS)
- Lattice rationalisation
  - Lower magnet strengths, larger drift spaces, comfortable DA, reduced IBS
- Super conducting wiggler remain major performance item
  - Modelling and prototyping is in good progress
- Impact of collective effects revised for new parameters (no surprises)
  - IBS tracking code developed
- RF design challenging (power source, beam loading)
  - Kicker ripple specifications are challenging
- Scaled design of existing DR achieves parameters for **CLIC@500GeV**
- Collaboration with ILC very fruitful
  - E-cloud simulations and measurements in CESR-TA

Lattice version	**2007**	**2009**
Energy [GeV]	2.42	2.86
Circumference [m]	**365.21**	**493.05**
Coupling	0.0013	
Energy loss/turn [Me]	3.86	5.8
RF voltage [MV]	5.0	7.4
Natural chromaticity x / y	-103 / -136	-149 / -79
Compaction factor	8E-05	6e-5
Damping time x / s [ms]	1.53 / 0.76	1.6 / 0.8
Dynamic aperture x / y [σ_{inj}]	**±3.5 / 6**	**±12 / 50**
Number of arc cells	100	
Number of wigglers	76	
Cell /dipole length [m]	1.729/0.545	2.30 / 0.4
Bend field [T]	0.93	1.27
Bend gradient [1/m^2]	0	-1.10
Max. Quad. gradient [T/m]	**220**	**60.3**
Max. Sext. strength [T/m^2 10^3]	**80**	**6.6**
Phase advance x / z	0.58 / 0.25	0.44/0.05
Bunch population, [10^9]	4.1	
IBS growth factor	**5.4**	**1.5**
Hor. Norm. Emittance [nm.rad]	**470**	**370**
Ver. Norm. Emittance [nm.rad]	**4.3**	**4.7**
Bunch length [mm]	1.4	1.4
Longitudinal emittance [keVm]	3.5	3.8

ILC DR overview

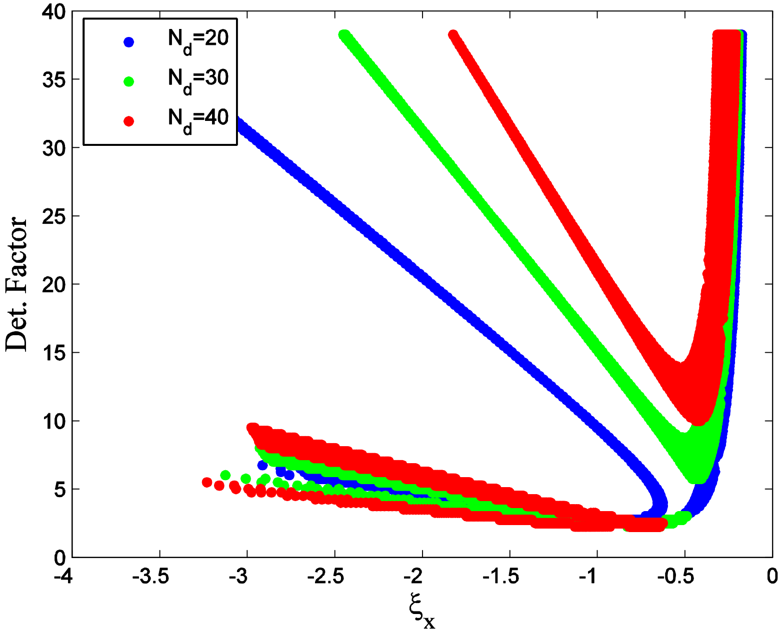
S. Guiducci

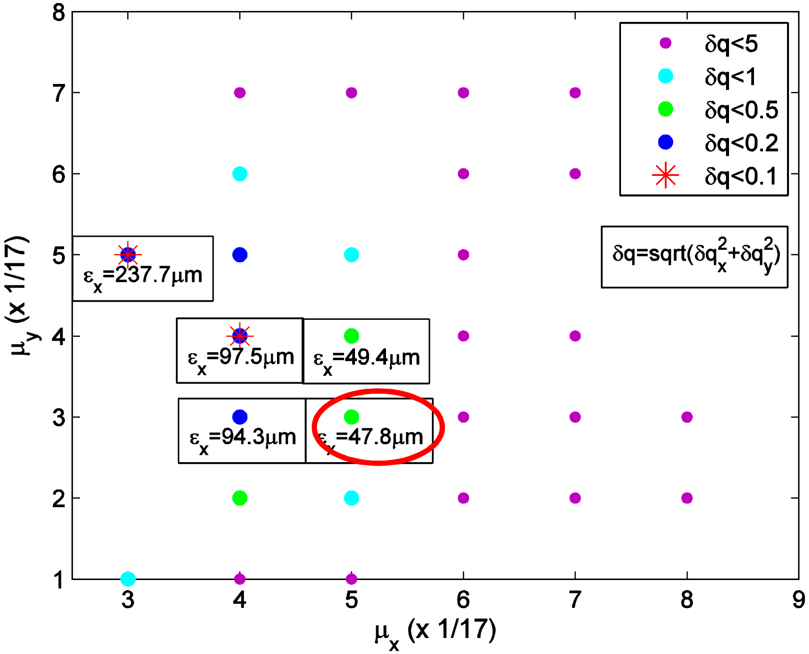
- For the ILC DR main issue is e-cloud mitigation:
  - **different under experimental study and working group to make recommendations for the DR design**
- ILC DR nominal vertical emittance (2pm) has been demonstrated at Diamond. R&D is needed:
  - **to specify alignment tolerance and stability, and diagnostics requirements and to demonstrate low emittance at nominal current, taking into account collective effects**
- For e-cloud and low emittance issues ILC and CLIC DR have common R&D objectives.
- Collaboration on some technical aspects of systems like wigglers, kickers, feedbacks could be useful.
- **January 12-15 we will have a joint ILC/CLIC DR workshop**

	ILC	CLIC
Energy (GeV)	5	2.9
Circumference (m)	3238	493
Bunch number	1300	312
N particles/bunch	$2\text{x}10^{10}$	$4.1\text{x}10^{9}$
Bunch distance (ns)	6.2	0.5
Average current (mA)	387	125
Bunch peak current (A)	25	21
Damping time τ_x (ms)	24	1.6
Emittance $\gamma\varepsilon_x$ (nm)	5300	370
Emittance $\gamma\varepsilon_x$ (nm)	20	4.7
Momentum compaction	$1.3\ \text{x}10^{-4}$	$0.6\ \text{x}10^{-4}$
Energy loss/turn (MeV)	4.4	5.8
Bunch length (mm)	6.0	1.4
RF Voltage (MV)	7.5	7.4
RF frequency (MHz)	650	2000
Natural chromaticity x/y	-100 / -63	-149 / -79

PDR design

F. Antoniou





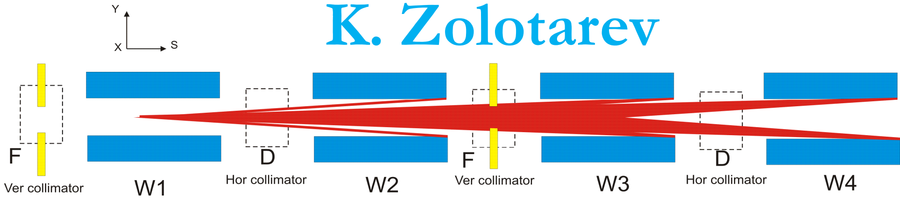
Injected Parameters	**e^-**	**e^+**
Bunch population [10^9]	4.4	6.4
Bunch length [mm]	1	10
Energy Spread [%]	0.1	8
Hor.,Ver Norm. emittance [nm]	100 x 10^3	7 x 10^6

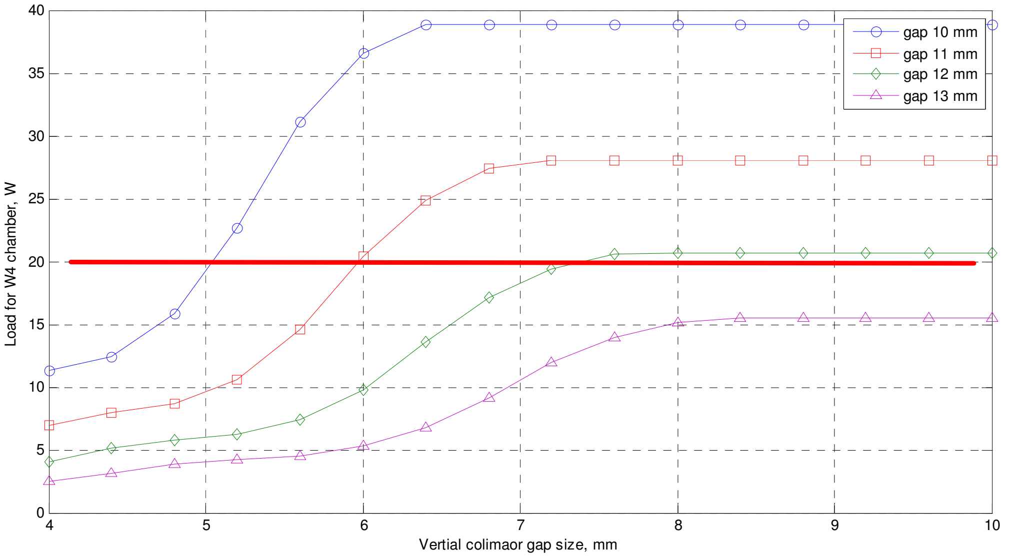
- Main **challenge:** Large input emittances especially (positrons) to be damped by orders of magnitude
- Design optimization following analytical parameterization of TME cells
  - ☐ Detuning factor larger than 2 for minimum chromaticity
- Target emittance reached with the help of conventional high-field wigglers (PETRA3)
- Non linear optimization based on phase advance scan (minimization of resonance driving terms and tune-shift with amplitude)
- PDR design ready for CDR

BINP work on CLIC DR

K. Zolotarev

- NbTi wiggler short prototype built and tested with limited performance
    - To be remeasured @ CERN for understanding limitations and decide on action plan
- Power absorption scheme established and being revised for new DR energy
- Lattice structure proposed and adopted
- New codes developed for non-linear dynamics analysis including radiation damping and space charge
- **Very important contributions of BINP to the DR design to be continued for the CDR and beyond**

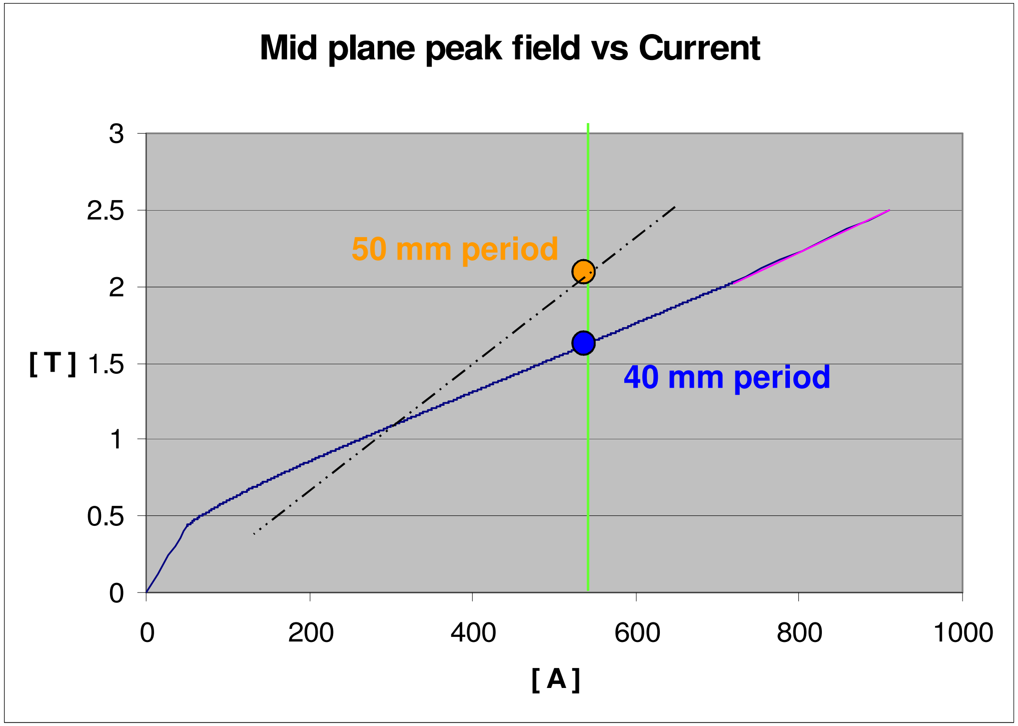




Wigglers□effect with IBS

CLIC

R. Maccaferri



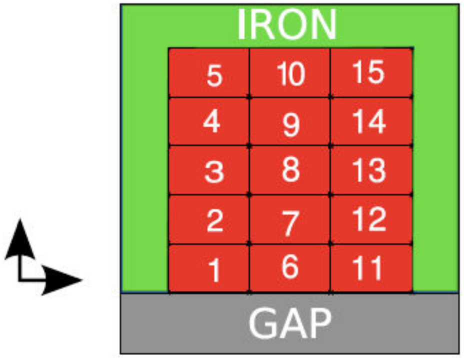
Parameters	BINP	CERN
B_{peak} [T]	2.5	2.8
λ_W [mm]	50	40
Beam aperture full gap [mm]	13	13
Conductor type	NbTi	Nb_3Sn
Operating temperature [K]	4.2	4.2

- Stronger wiggler fields and shorter wavelengths necessary to reach target emittance
- Two wiggler prototypes
  - ☐ 2.5T, 5cm period, built and currently tested by BINP
  - ☐ 2.8T, 4cm period, designed by CERN/Un. Karlsruhe
- A NbTi CERN short model **fulfills the specifications**
- More challenging wire technologies and wiggler designs are under studied at CERN and Univ. of Karlsruhe/ANKA but not yet tested.
- Final measurements from short prototypes to be expected for the CDR

Racetrack Wiggler Design

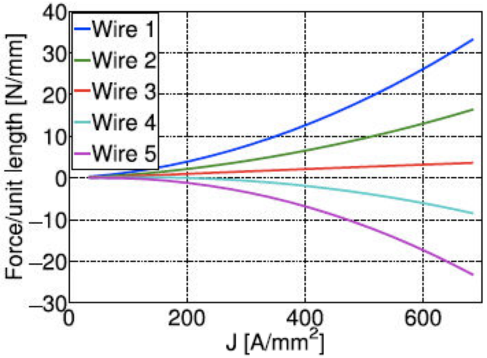
D. Schoerling

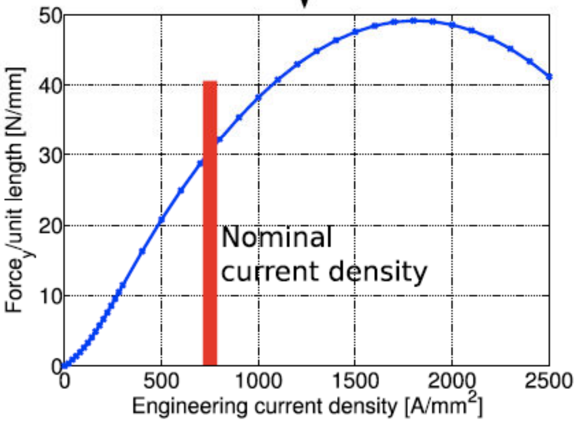
- Technical feasibility demonstrated on short model.
- NbTi wiggler is able to fulfill magnetic requirements at 50mm
- Magnetic forces can be handled, stored magnetic energy is small
- Nb_3Sn wiggler is less sensitive for beam heat load
- Different NbTi and Nb3Sn wiggler designs will be tested at CERN/Karlsruhe.

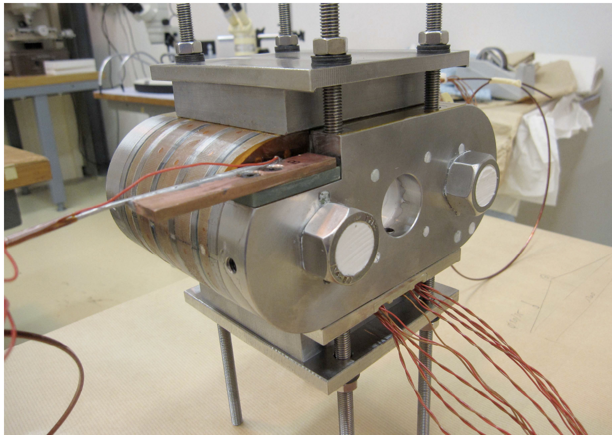


→ Forces on wire 1 to 5

Forces on wire bundle



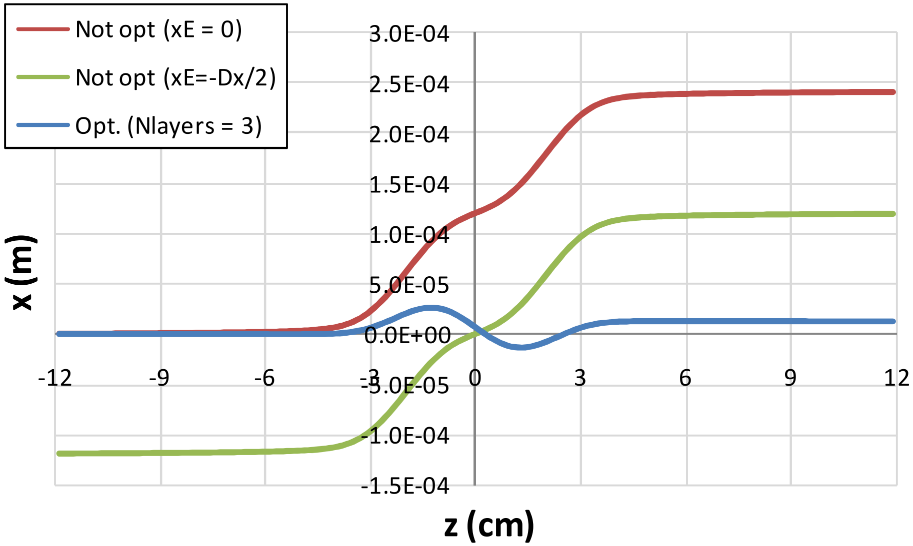


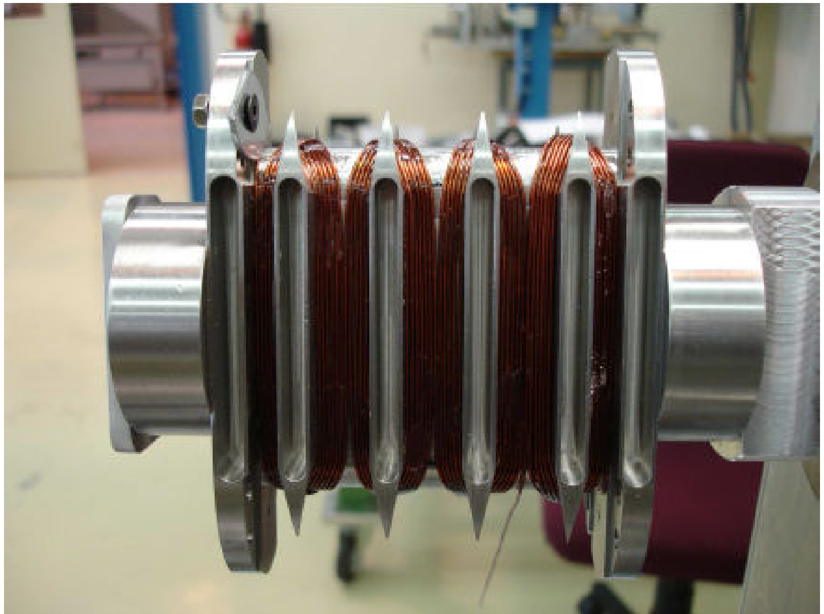


Double-Helix Wiggler

S. Bettoni

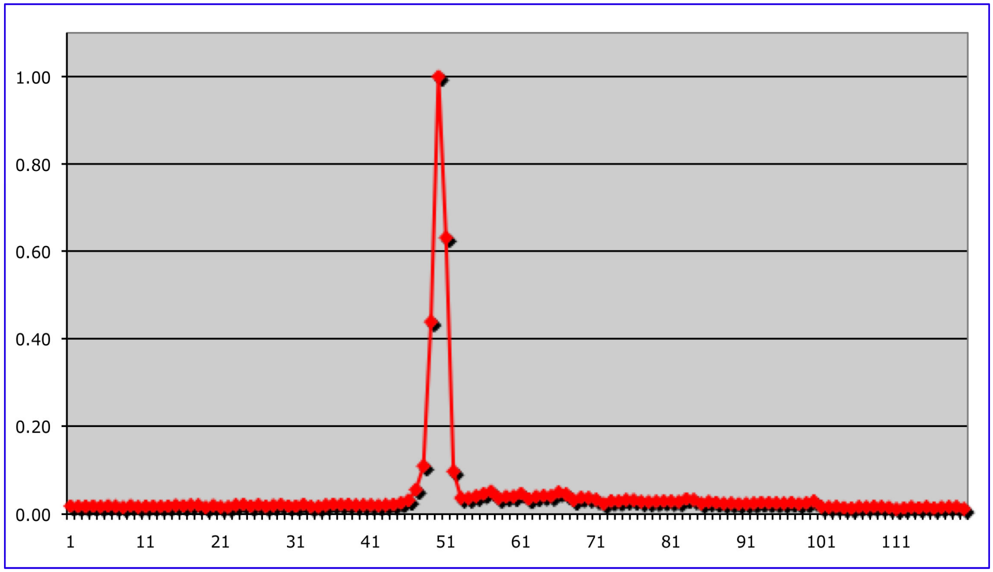
- Advantages of the double helix
    - Less quantity of conductor needed
    - Small forces on the heads
- Wire handling and winding (especially for Nb_3Sn) more tricky
- Analysis on the prototype:
    - Maximum force
    - Multipolar analysis
    - Tracking studies
    - Zeroing the integrals of motion
- Optimization of the long wiggler model is in progress

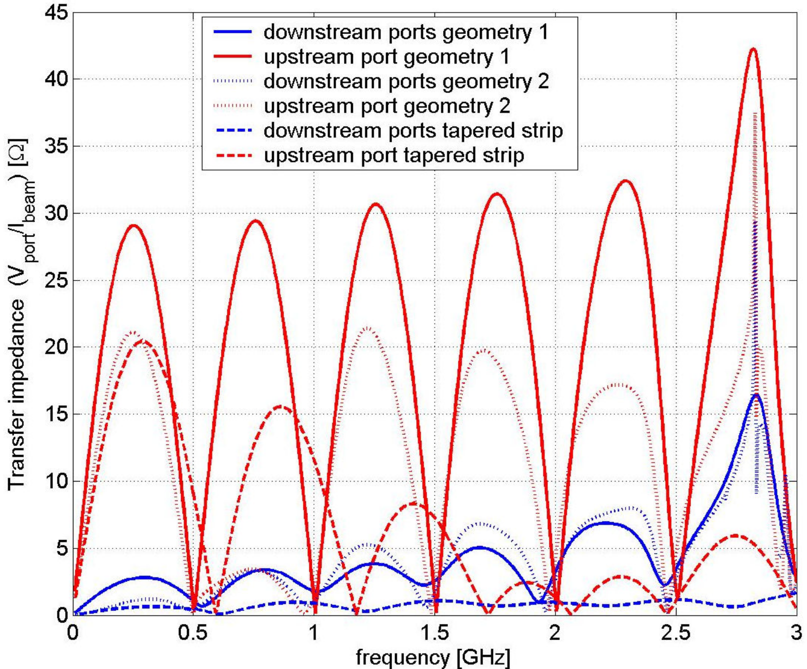




ILC kicker design

- DAFNE injection kickers, installed one year ago, work well and are very versatile devices.
- Used with both FID and old DAFNE pulsers and even as a feedback kicker!
- Reliability problems of the fast pulse generators by FID remain to be solved, (24kV units)
- A tapered stripline kicker for ATF has been designed and constructed.
- Some preliminary calculations and design considerations on the ILC kickers have been done



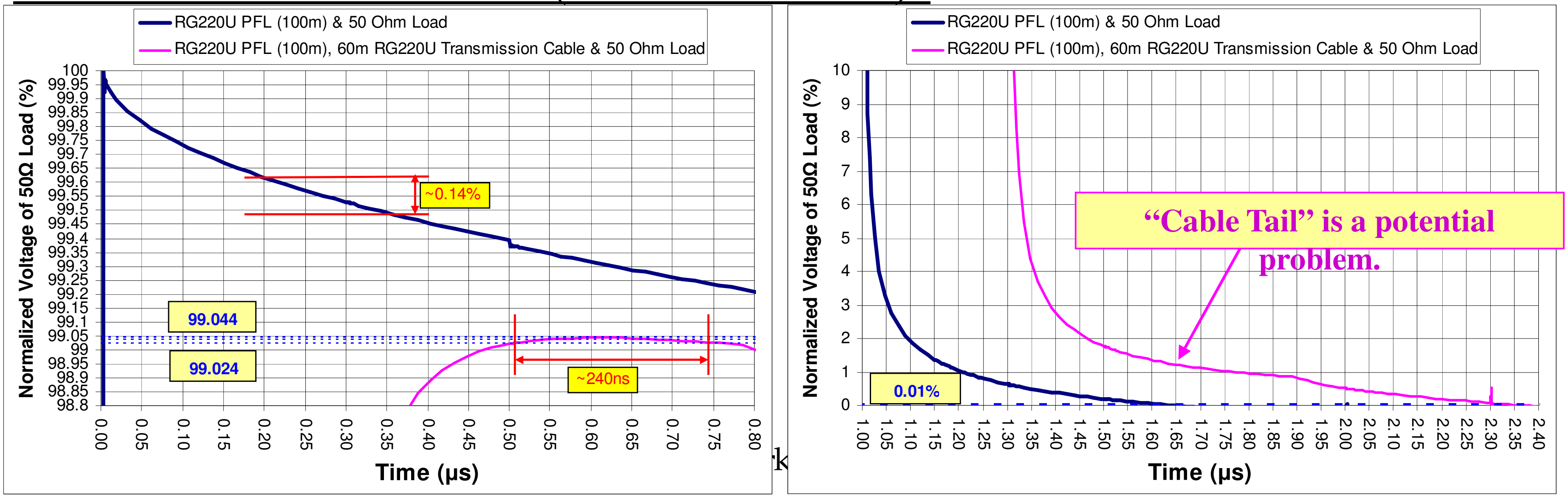


CLIC kickers

M. Barnes

1. Beam coupling impedance issues will require the use of striplines, rather than ferrite
2. Short duration pulses (fast rise and fall) are advantageous for minimizing the total duration of the pulse. Hence a multi-cell inductive adder (presently in development for ILC) may be a good choice R&D
3. Stability of DR extraction kicker (0.015% reqd.) will be a significant challenge especially because of relatively long (160ns) pulse length. R&D
4. A double kicker system relaxes the requirements for individual kickers, KEK-ATF achieved a factor of 3.3 reduction in kick jitter angle, w.r.t. a single kicker: can this be improved upon? – R&D
5. **Collaborate with ILC**

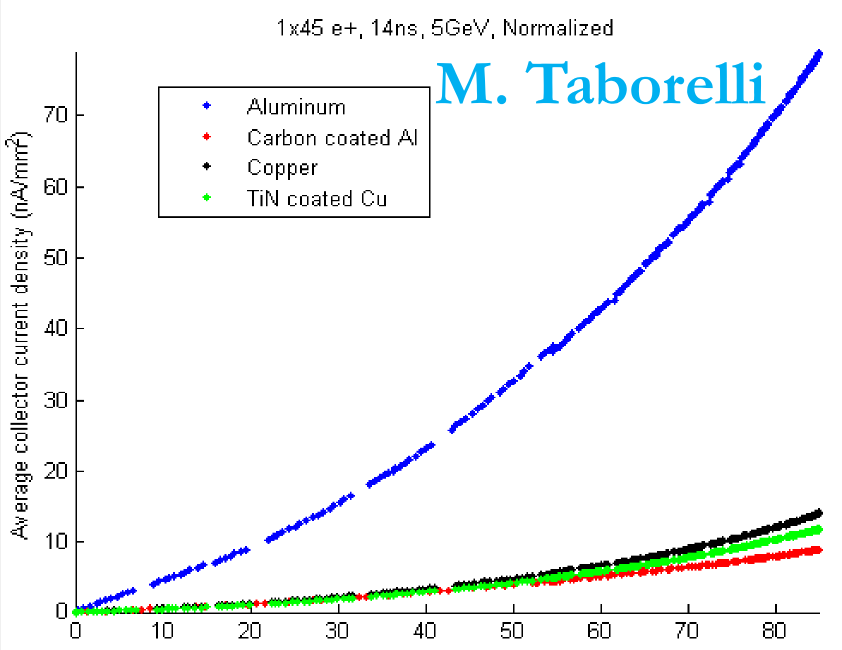
Theoretical simulations (“ideal” switch):



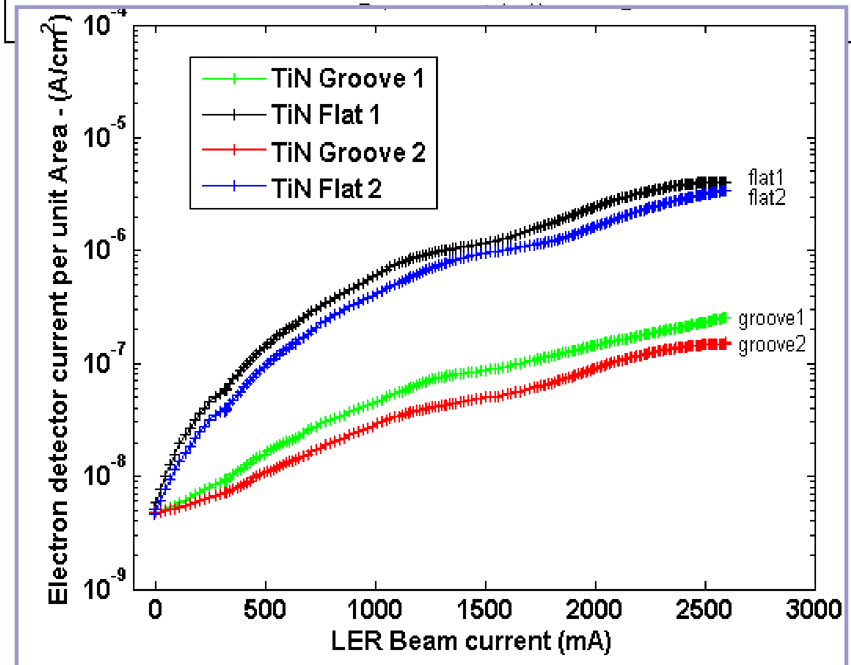
“Cable Tail” is a potential problem.

Summary of Anti-e- Cloud 2009

- TiN coating seems good with photons in conditioned state (low photoyield?)
- SEY significantly reduced when surface strongly conditioned with e-beam
- a-C coating provides SEY< 1 (2h air exposure), and below 1.3 (7 months of air exposure)
- Strong reduction of e-cloud activity on a-C coated chambers in SPS and similar results in CesrTA
- Novel diagnostic of e-cloud with microwave measurements
- Grooves show significant reduction of e-cloud in PEPII, KEKB, and CesrTA

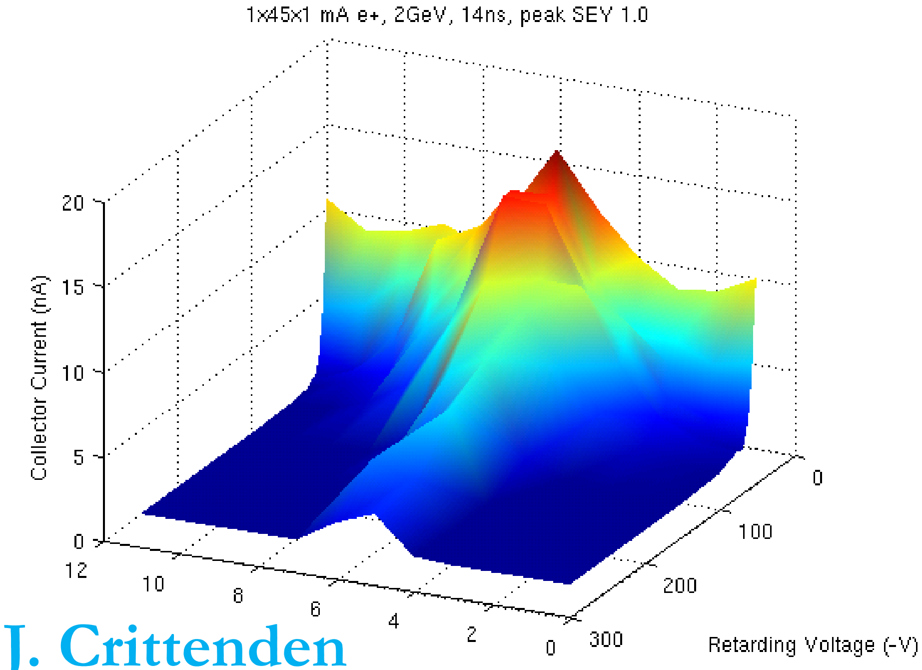


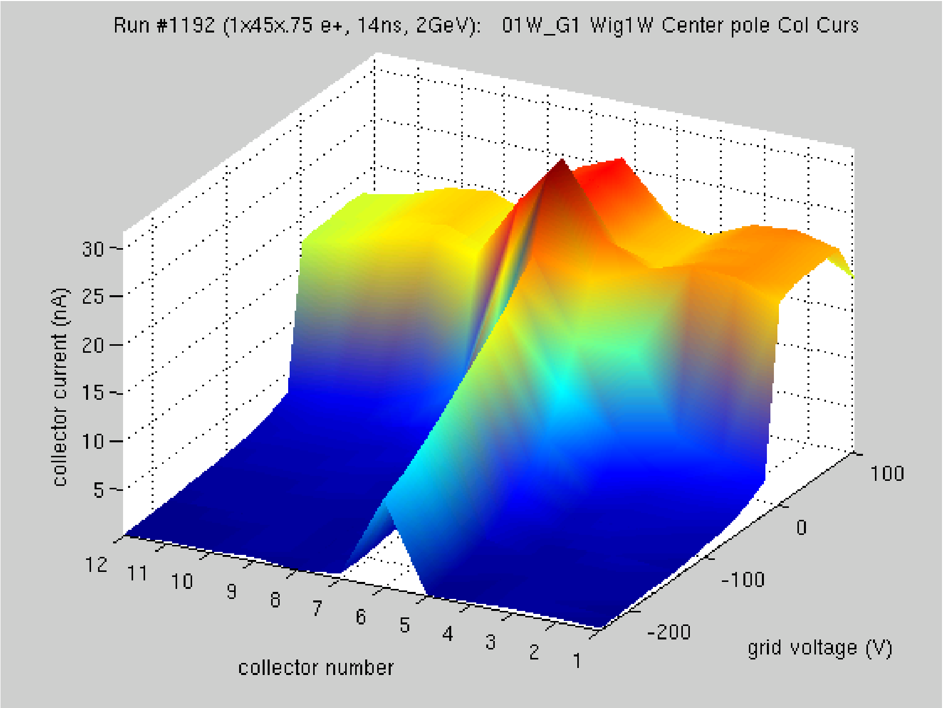
M. Taborelli



e- Cloud Simulations studies in CESRTA

- Many measurements on CesrTA are now available for validating models.
- Models for coherent tune shifts have improved significantly
- Comprehensive lattice analysis efforts are ongoing.
- The wide variety of local RFA measurements and ring-averaged tune shift data are exceeding the ability of the simulators to keep up.
- The three production runs of combined duration 100 days over the course of the coming year will greatly increase the experimental data for single and multi-bunch instabilities


1x45x1 mA e+, 2GeV, 14ns, peak SEY 1.0


Run #1192 (1x45x.75 e+, 14ns, 2GeV): 01W_G1 Wig1W Center pole Col Curs

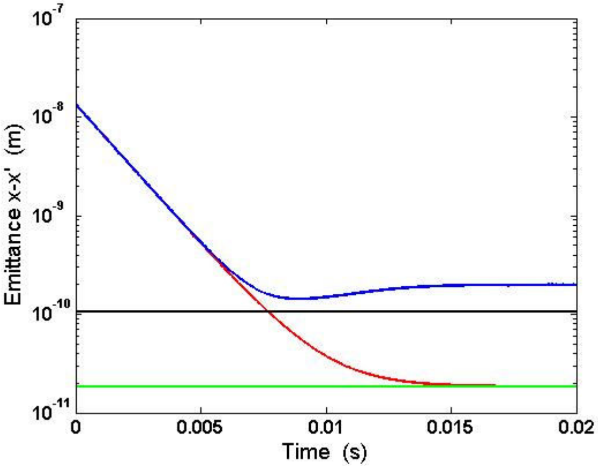
J. Crittenden

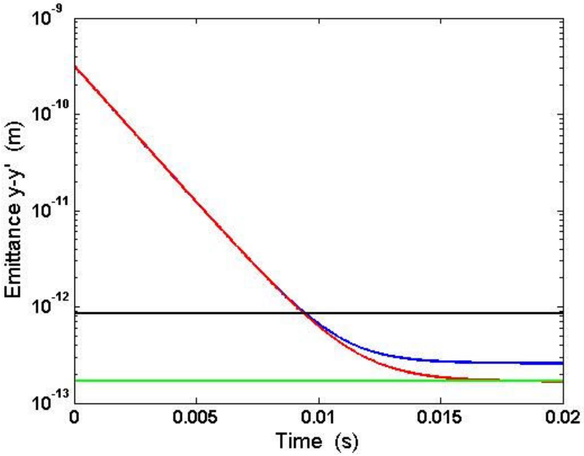
Intrabeam Scattering

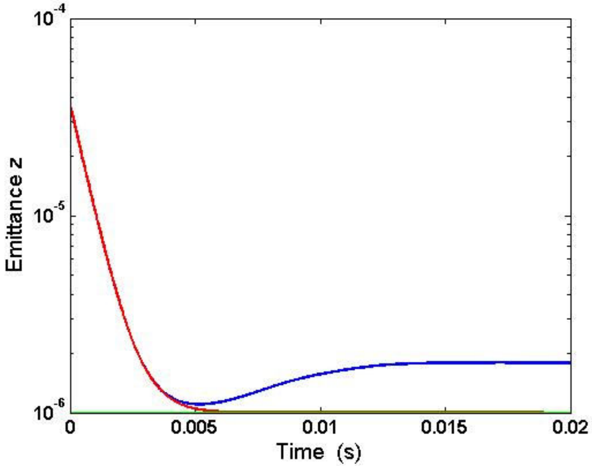
A. Vivoli

- A new code to investigate IBS effect in the CLIC damping rings is being developed:
  - Benchmarking with conventional IBS theories gave good results.
  - Calculation of the evolution of emittances gives reliable results.
  - Presence of bugs in the calculation of the distributions, not due to the IBS routine.
  - Refinements of both IBS and quantum excitation routines will be implemented.
  - Improvements for faster calculation are being studied.

- A full simulation of the current DR lattice will be performed soon.





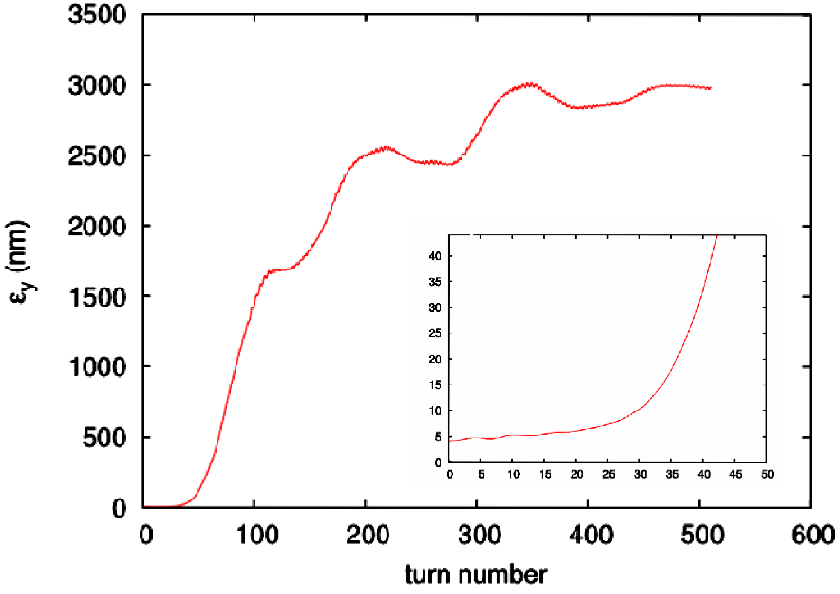


Collective effects in the DR

G. Rumolo

- Electron cloud in the e^+ DR imposes limits in PEY (99.9% of synchrotron radiation absorbed in the wigglers) and SEY (below 1.3)
  - ☐ Cured with special **chamber coatings**
- Fast ion instability in e^- DR, molecules with A>13 will be trapped (constrains vacuum pressure to around 0.1nTorr)
- Other collective effects in DR
  - ☐ Space charge (large vertical tune spread of 0.19 and 10% emittance growth)
  - ☐ Single bunch instabilities avoided with smooth impedance design (a few Ohms in longitudinal and MOhms in transverse are acceptable for stability)
  - ☐ Resistive wall coupled bunch controlled with feedback (1ms rise time calculated with head-tail)
- Studies updated with newest parameter set
- 500GeV parameters do not present significant differences
  - ☐ Increased bunch charge compensated with higher output emittances

Chambers	PEY	SEY	ρ [10^{12} e^-/m^3]
Dipole	0.000576	1.3	0.04
		1.8	2
	0.0576	1.3	7
		1.8	40
Wiggler	0.00109	1.3	0.6
	0.109	1.3	45
		1.5	70
		1.8	80



Conclusion

- Many thanks to all of the presenters
- Special Announcement -

Low Emittance Rings 2010

January 12-15, 2010

Hosted by CERN

- A conference on low emittance lepton rings (including damping rings, test facilities for linear colliders, B-factories and electron storage rings)
- Discussions of common beam dynamics and technical issues
- Organized by the joint ILC/CLIC working group on damping rings
- Aimed at strengthening the collaboration within our community

- Thank you for your attention!