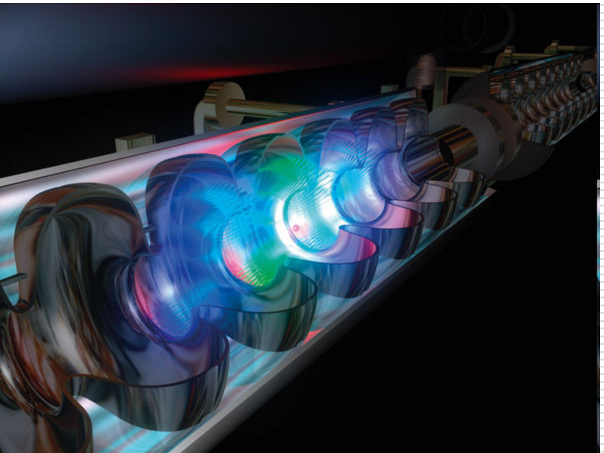
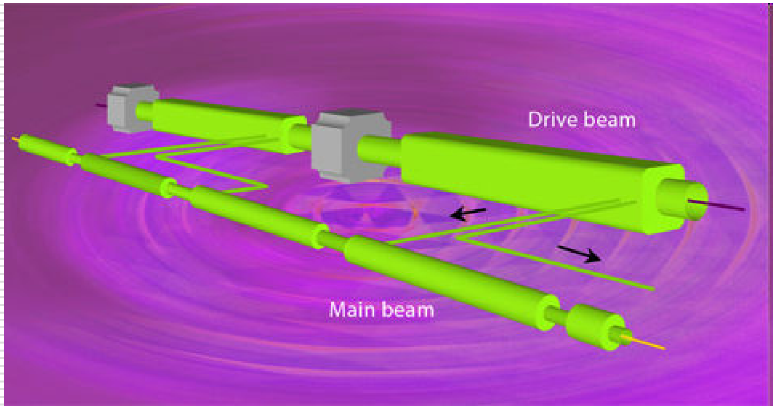
international linear collider

Future colliders: physics motivations

CERN Summer Student Lecture Programme

F. Richard LAL/Orsay





Introduction

- Particle physics requires long term planning
- LHC has taken >20 years (reminder: first workshop on LHC was 1984. . .)
- Satellite expts also very long: Planck Surveyor (CMB), just launched, planned since 1992
- Since a long time there is an international consensus that the next large HEP machine should be an **e+e- linear collider LC**
- Basic questions:
- Which type of linear collider ?
- For which physics ?
- Why do we need a machine beyond LHC ?

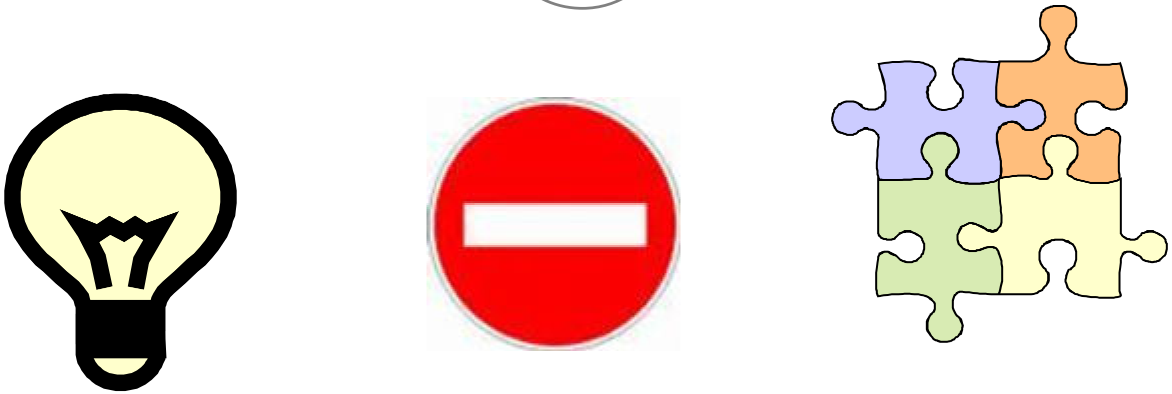
The standard view BSM

- From LEP/SLC/TeVatron compelling arguments (precision measurements PM) to expect a **light Higgs** within SM or its SUSY extension MSSM
- A LC is ideal to study the properties of a light Higgs
- MSSM passes remarkably PM offering full calculability
- In particular it allows to extrapolate the weak/em/strong couplings to an **unification** scale without very large quantum corrections to the Higgs mass
- It is fair to say that the model is not predictive on flavours in particular fermion masses hierarchies and CP violation
- A basic input to decide the energy of a LC is missing: what are the masses of the **lightest SUSY particles** (charginos, neutralinos, sleptons) best studied at LC ?

Alternates

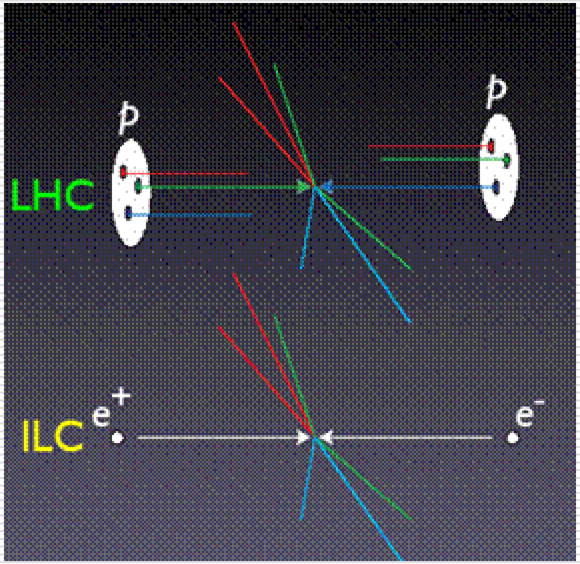
- Other views have emerged allowing for very different pictures: **Composite Higgs** and even Higgless
- They often are linked to **extra dimensions**
- Eminent role of top physics in this view: it could also be composite like the Higgs
- In the language of extra dimensions Kaluza Klein bosons couple preferentially to Higgs and top quarks generating large deviations in **top** couplings
- A LC measuring top and Higgs couplings with excellent accuracies is ideally well suited to observe these effects

Higgs boson ?

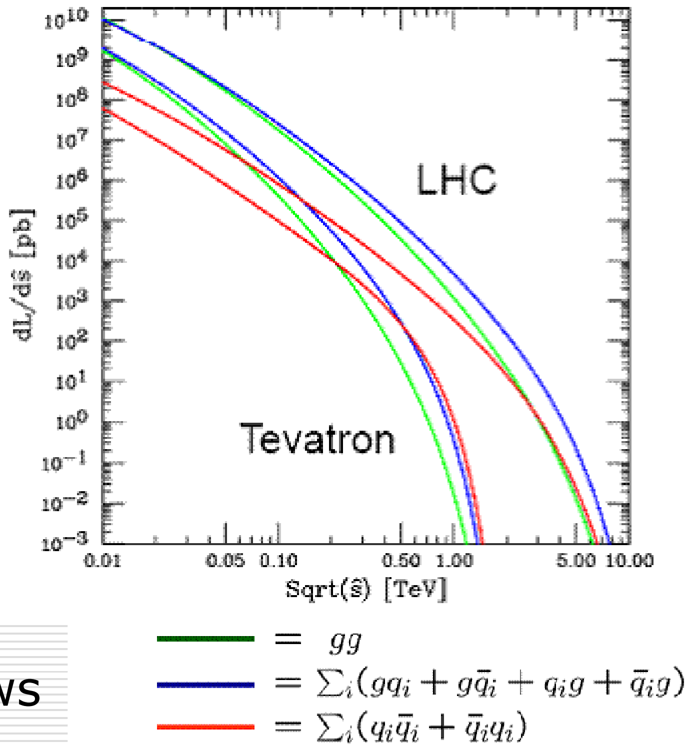


Elementary scalar	Absent	Composite
Minimal SUSY	Strong interactions	SI but ~ to ND>4
ZH guaranteed	New resonances ?	Affects H and top quark
SUSY masses ?	> 1 TeV	ZH top pairs at ILC

Major differences LHC/LC



- LC with a well defined initial state and energy gives precise masses e.g. Z/W at LEP (also true for sparticles)
- LC has **polarised** electrons essential to test **SU(2)L⊕U(1)** see SLC vs LEP

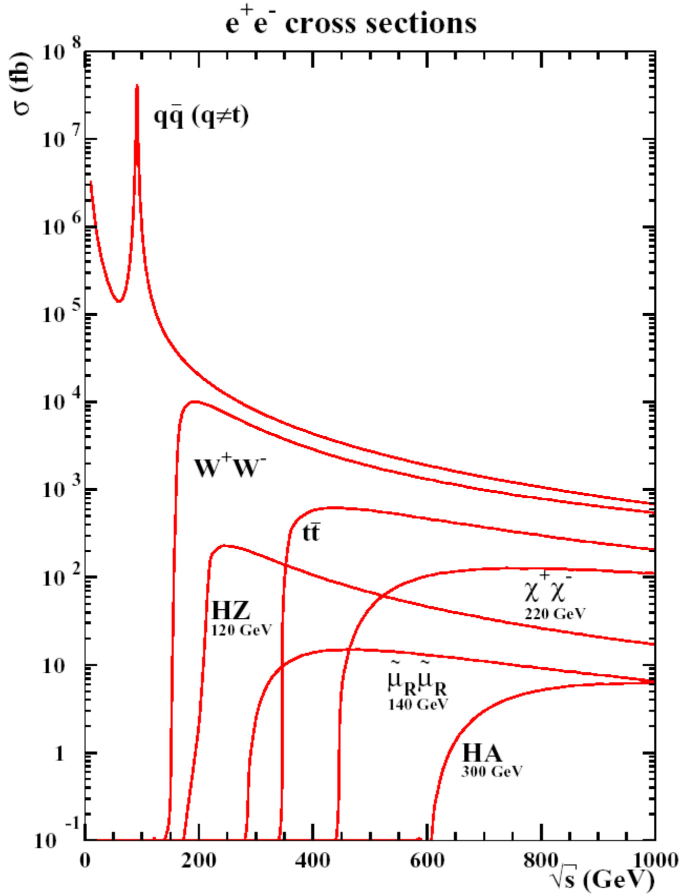


Huston, Campbell, S (2007)

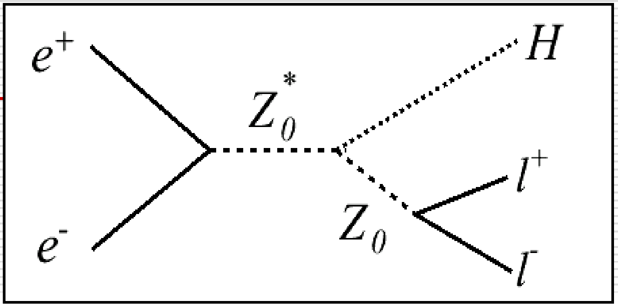
- Accurate **luminosity** + absence of trigger allows very clean unbiased determination of cross sections with accuracies well below 1%
- In a hadron machine with PDF+QCD corrections (α_s/α_{em}) accuracies ~10%

Democratic Production

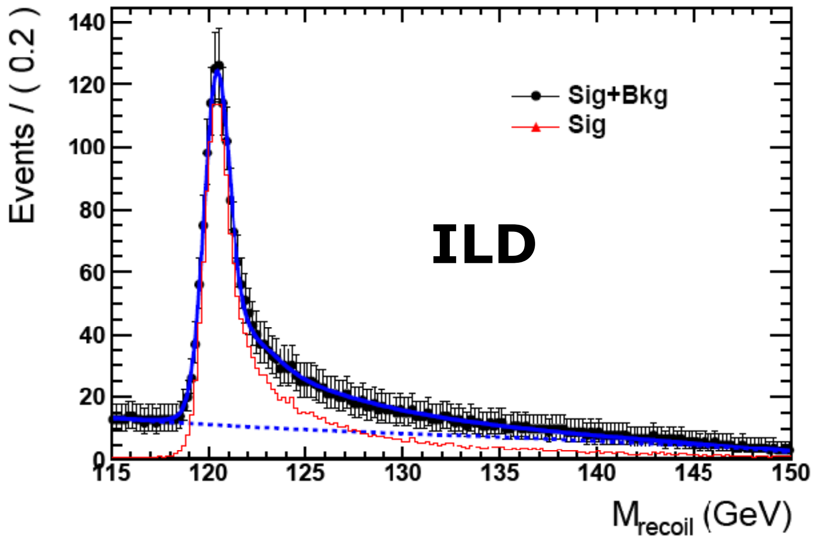
- All processes have similar cross section
- **HZ** the 'gold plated' process comes out very cleanly and allows to measure Higgs BR at %
- **Top** quarks reconstructed with low background
- **Charginos** can be studied in great detail



ee->Z*->HZ



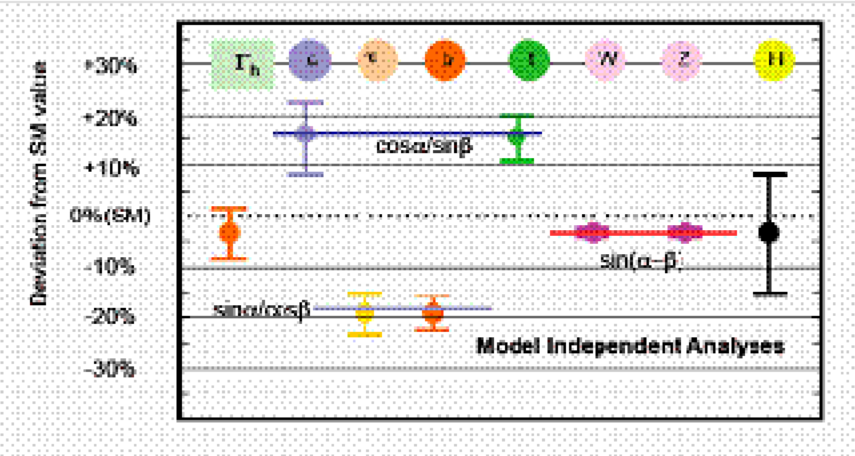
- The recoil mass technique with Z->μ+μ- gives a very clean signal
- Works even if H decays into invisible or complex modes
- ZZH coupling constant determined to 1%
- In the SM case most BR ratios known 10 times more precisely than at LHC



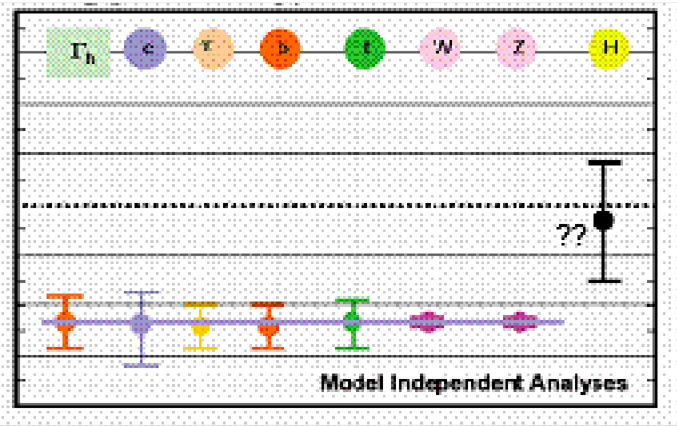
Why so precise ?

Deviations from SM

(By S. Yamashita)



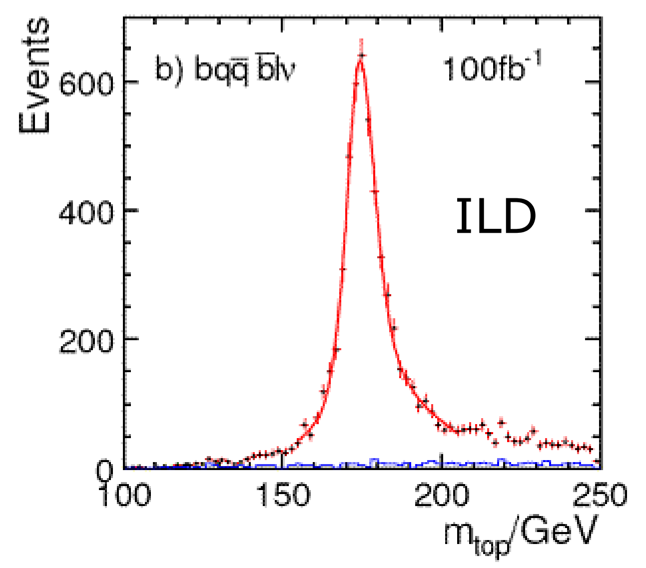
SUSY
(2 Higgs Doublet Model)

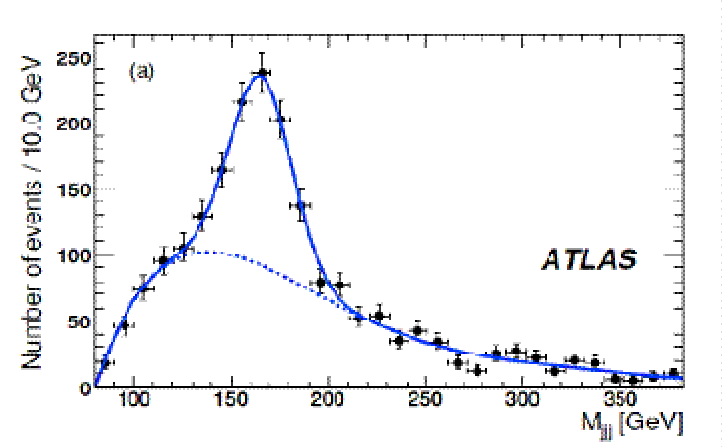


Extra dimension
(Higgs-radion mixing)

Top physics

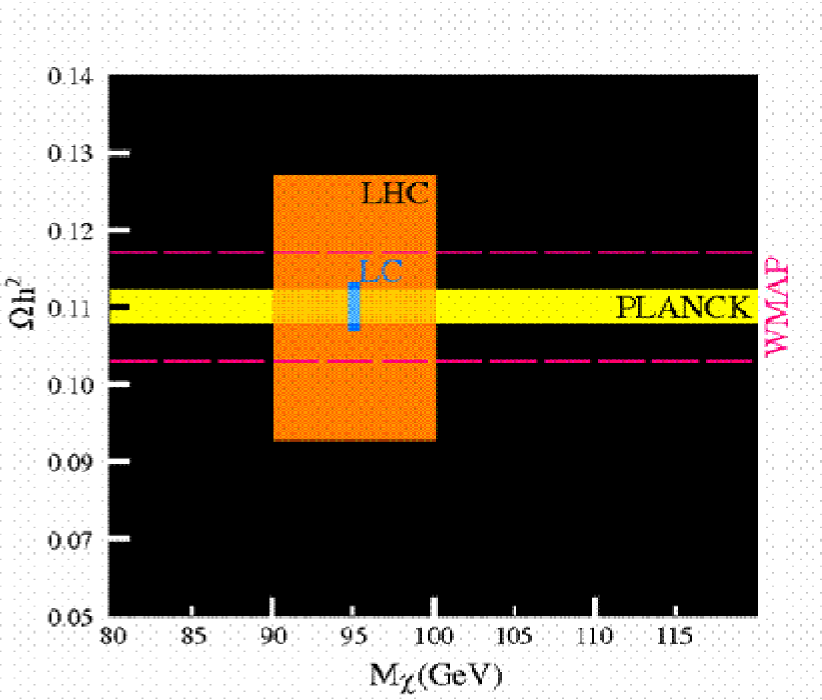
- LC 1 pb, LHC 1nb but with larger uncertainties
- Very good s/b at ILC and energy conservation allows to reconstruct modes with a neutrino
- Mt and Γt with 50 MeV error, 0.4% on cross section
- Polarisation allows to separate tR and tL (extra dimensions)





Dark matter & SUSY

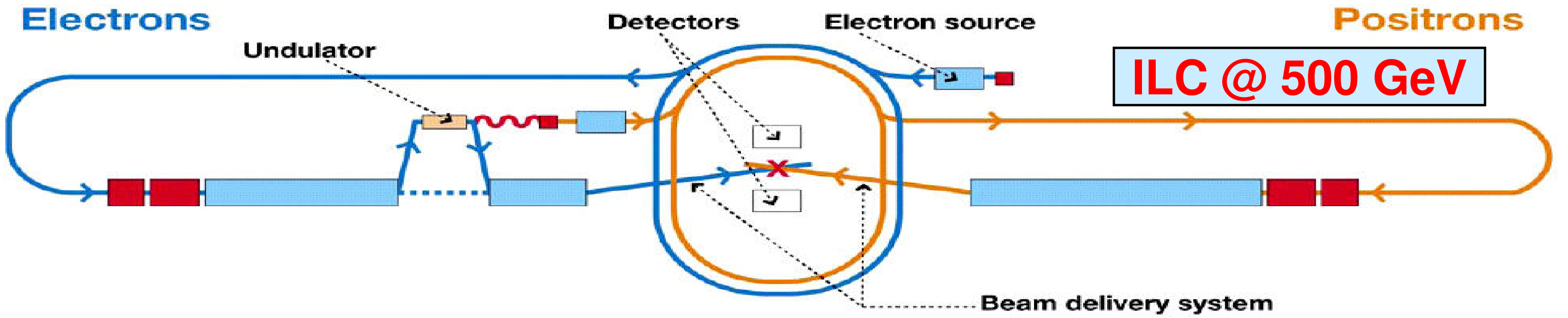
- ☐ With LHC+LC it is possible to reach sufficient accuracy on the predicted dark matter to match cosmological observations
- ☐ Do they coincide ?



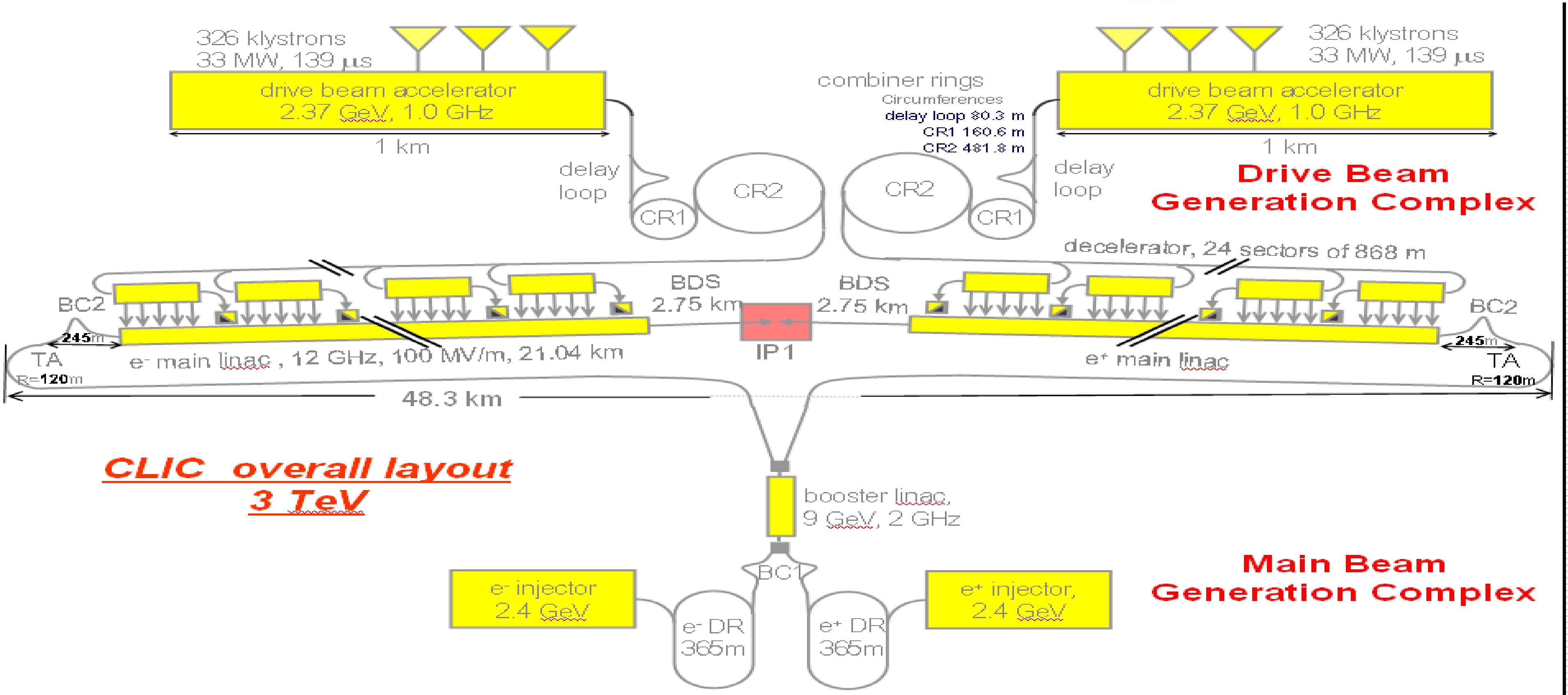
How to go from LEP/SLC to the next LC

- Not possible to recycle bunches like in circular machines (LEP) and SLC luminosity needs a 10000 increase
- Use very intense beams with focussing 1000 smaller than SLC (improving **emittance**)
- Requires large damping rings (multi-bunch)
- Large power needed in such machines -> crucial is **η=Beampower/Plug power**
- Bunch separation is an issue for detectors
- Standard way like SLC: klystron+ modulators with low η
- Two ways:
- ILC supraconductive linac allowing large bunch time separation
- CLIC a two beam accelerator with high gradient

CLIC and ILC layouts



ILC @ 500 GeV



Drive Beam Generation Complex

CLIC overall layout 3 TeV

Main Beam Generation Complex

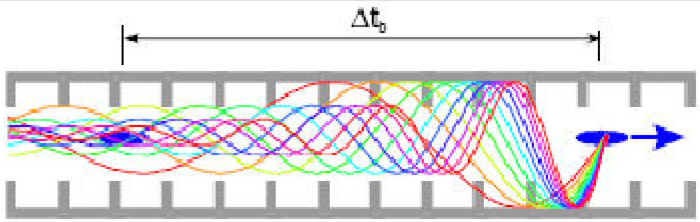
Some parameters

$$L \sim \eta \frac{P_{\text{electrical}}}{E_{CM}} \sqrt{\frac{\delta_E}{\varepsilon_{n,y}}} H_D$$

Type	LEP200	SLC100	ILC500	CLIC500
Vertical size nm	4000	700	5.7	2.3
Total P MW	65	50	216	129.4
Wall plug transf %			9.4	7.4
Luminosity 10^{31} $cm^{-2}s^{-1}$	5	0.2	1500	1400
Interval between bunches ns	>>>	>>>	176	0.5
Polarisation %	No	80	>80	>80
Gradient MV/m	8	17	31.5	100

- ILC and CLIC intend to start at 500 GeV
- ILC is upgradable, with present technology, at 1 TeV
- CLIC could reach 3 TeV but with ~constant luminosity (same δ)

CLIC



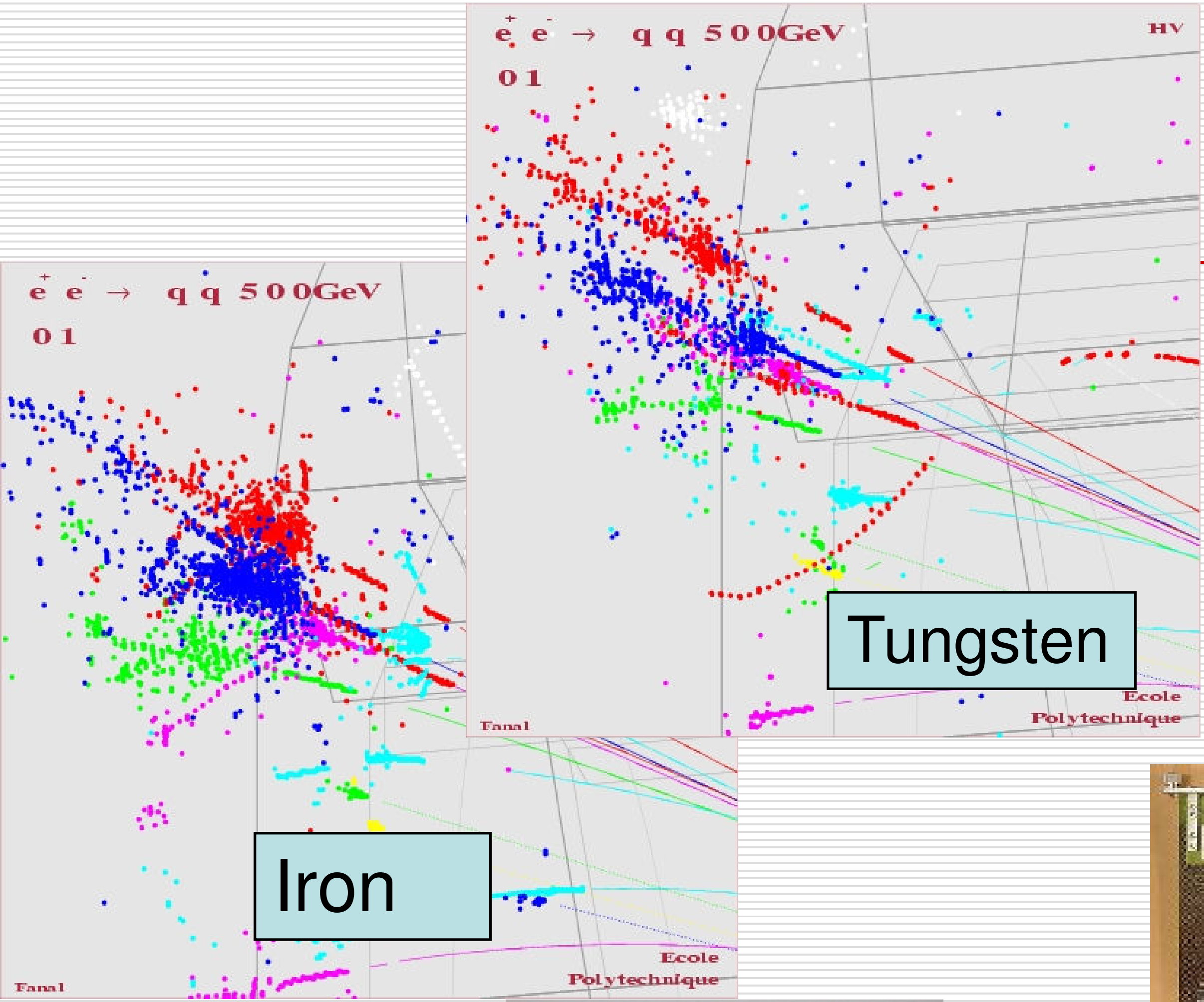
- ☐ Higher gradient at CLIC -> shorter machine reaching higher energies
- ☐ CLIC has tight requirements on alignment due to wake fields (frequency x10) and beam size at IP
- ☐ CLIC has to demonstrate its feasibility with the test station CTF3
- ☐ Both machines have in common several critical R&Ds e.g. on positron generation
- ☐ Several methods are developed to generate large flux of photons which are then converted into e+e-
- ☐ These photons can be polarized transmitting their polarisation to positrons

Detectors for LC

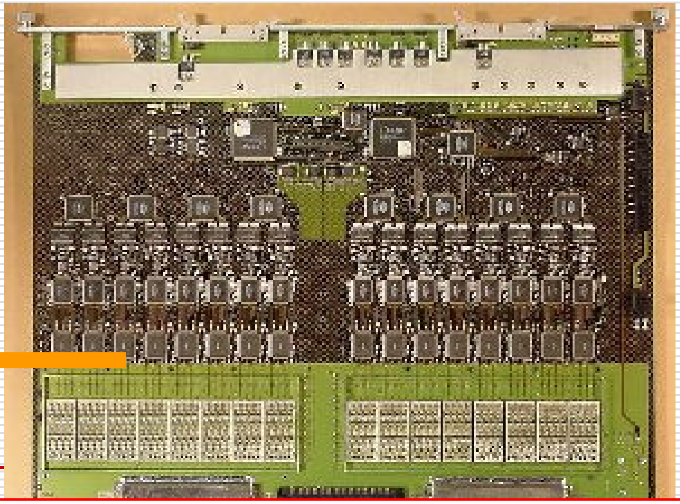
- Can work with improved performances /LHC
- Open trigger with no bias on new physics
- Higher quality of b/c tagging (low radiation)
- Reconstruct separately charged and neutral particles (PFLOW) possible with high granularity calorimeters
- These detectors are challenging: need to reconstruct complex final states with multijets: ttH has 8 jets -> full solid angle coverage essential
- A major difference with LEP: only one detector can take data at a given time

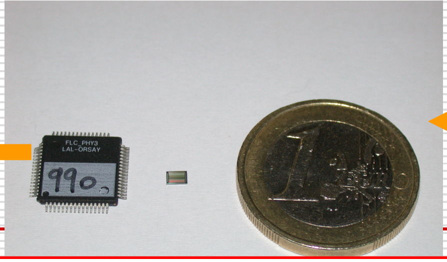
  -> concept of push-pull

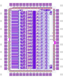
JETS



- High granularity+high density (SiW)
- µelectronics integrated inside calorimeters
- Possible with new technology+power pulsing
- Requires R&D





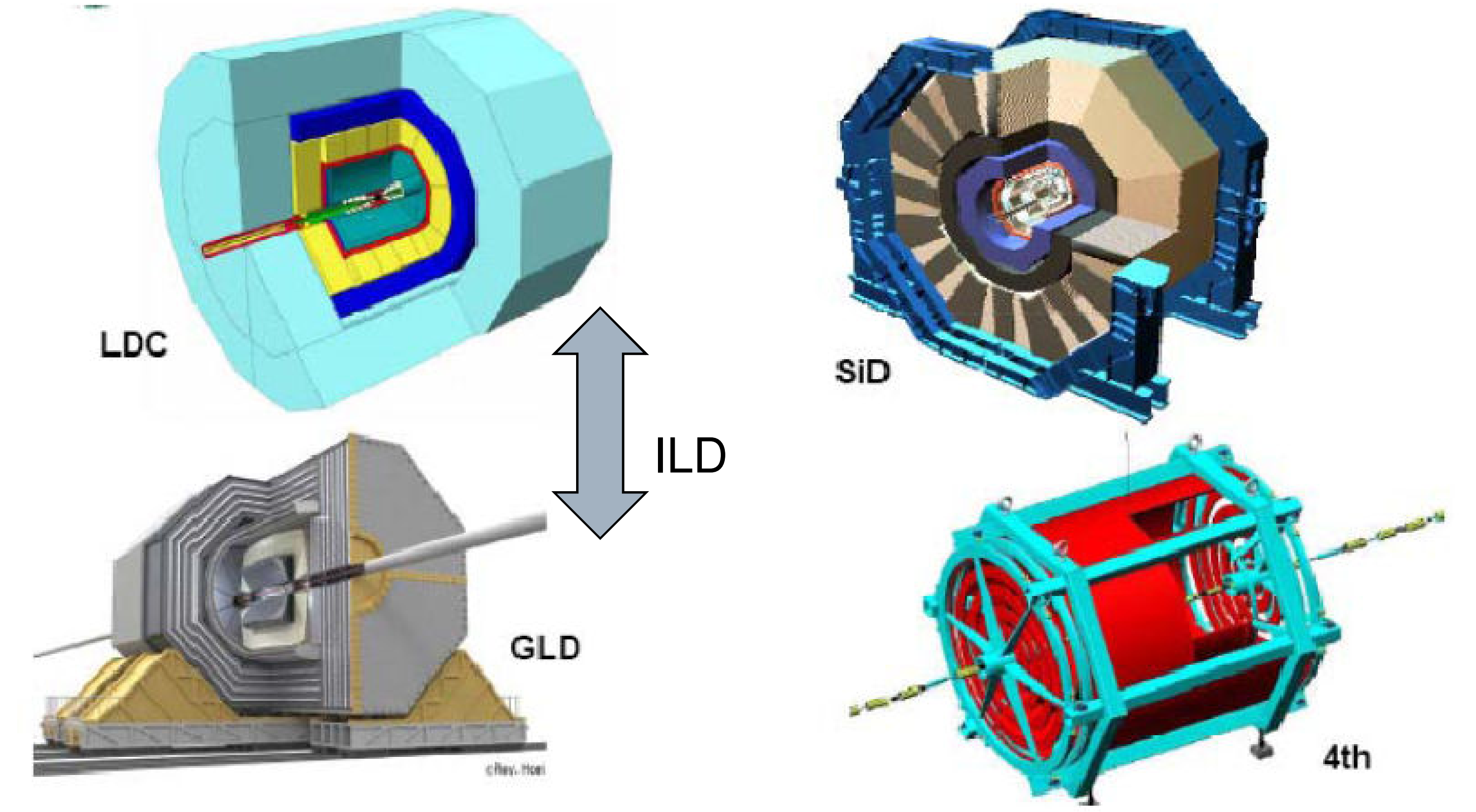


ILC : **100µW/ch**

Physics Proto. 18ch 10*10mm **5mW/ch**

ATLAS LAr FEB 128ch 400*500mm **1 W/ch**

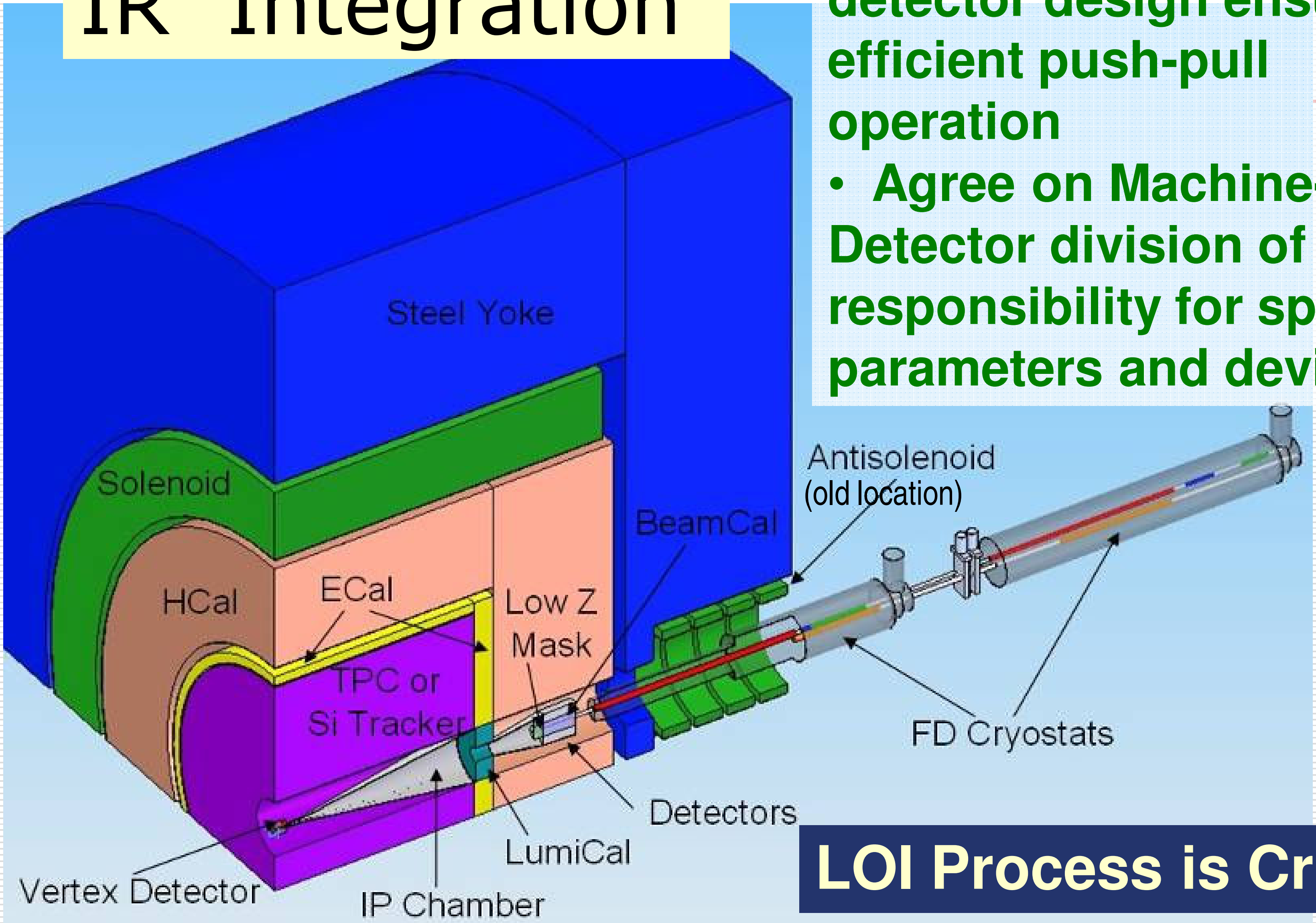
Detectors for ILC (~1000 physicists and Engineers)



IR Integration

CHALLENGES:

- Optimize IR and detector design ensuring efficient push-pull operation
- Agree on Machine-Detector division of responsibility for space, parameters and devices

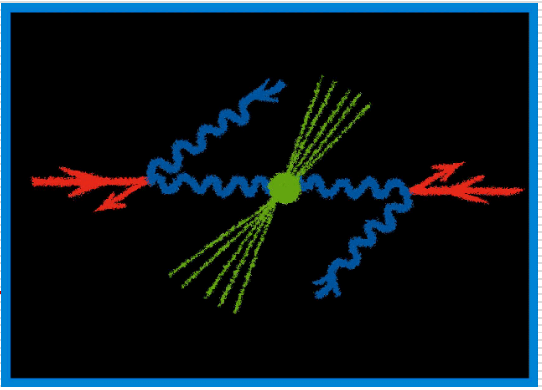


LOI Process is Crucial

Where are we ?

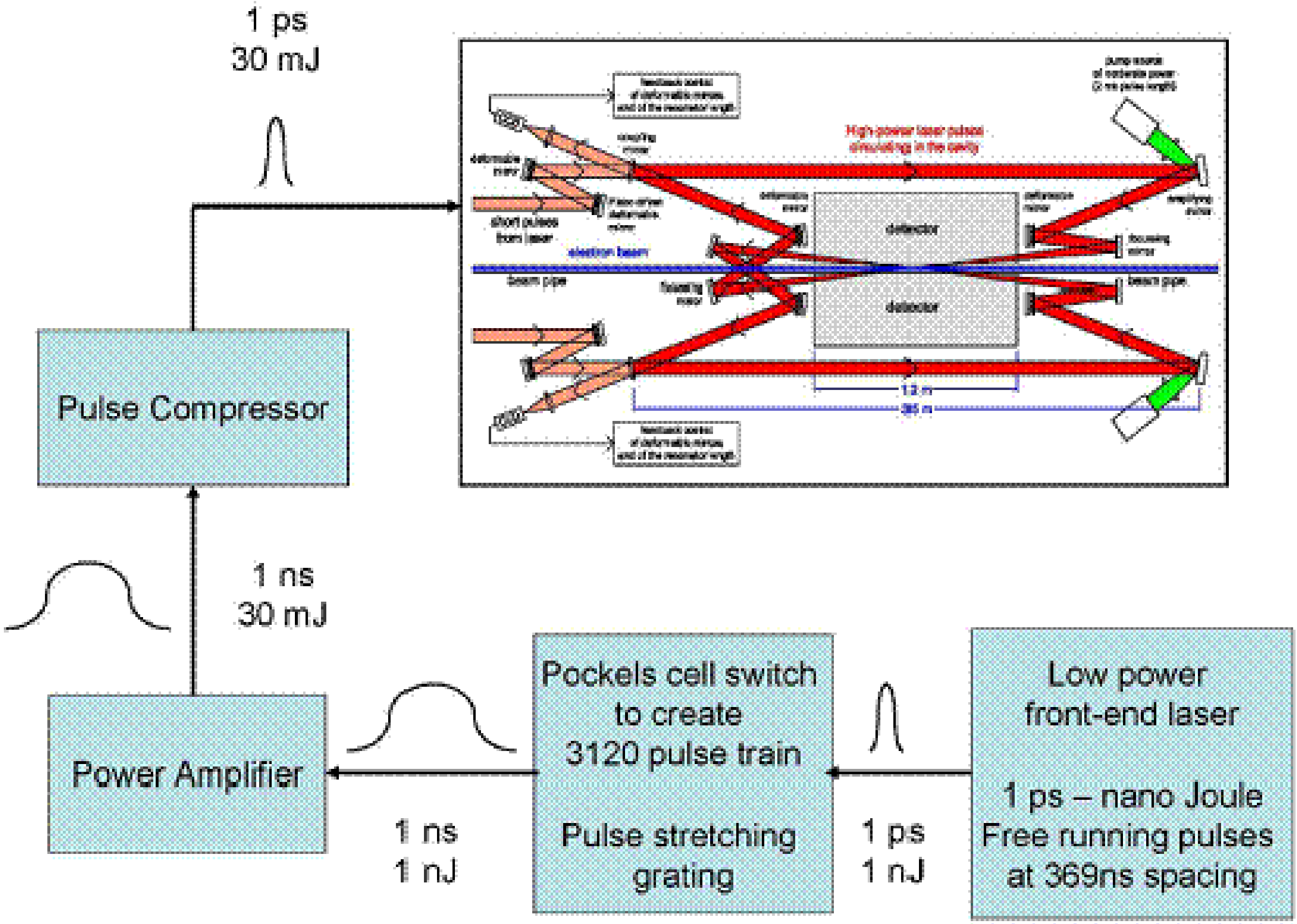
- ILC is developed internationally after a choice of technology by an international panel ITRP 2004
- A TDR is expected in 2012 for the machine (CLIC not before 2015)
- ILC relies on a well developed technology used to build an XFEL in DESY but with higher gradients ~+25% (underway)
- A baseline design study for detectors with detailed interfacing to the machine
- Will need a demonstrator: ready ~2013
- ILC has few options: Gigaz (which requires polarised positrons to cope with the accuracies) and a $\gamma\gamma$ collider

Option



- $\gamma\gamma$ collider
- Laser beams (eV energy) scatter onto incident electron beams ~100 GeV are transformed into photon beams carrying 80% of the electron energy
- Challenging lasers given the high repetition rate
- Laser pulses stored in cavities and re-used
- Higgs couples to two photons and can be directly produced
- $\gamma\gamma$ -> h/H/A while ee->Zh and HA

Set up



1 ps
30 mJ

Pulse Compressor

1 ns
30 mJ

Power Amplifier

1 ns
1 nJ

Pockels cell switch
to create
3120 pulse train

Pulse stretching
grating

1 ps
1 nJ

Low power
front-end laser

1 ps – nano Joule
Free running pulses
at 369ns spacing

Where do we go ?

- Initial view was that we need a LC irrespective of LHC results since LC is optimal for a light Higgs
- 500 GeV sufficient (Higgs+top physics)
- Time has past, our ideas have evolved on what could be BSM (composite, noHiggs, heavy Higgs)
- Present idea:

  - Wait for LHC (and Tevatron) results to decide

  - Get ready in 2012 (on all essential aspects) to propose a project to the funding authorities

HEP strategy

- Connect CLIC and ILC efforts to avoid duplication and potentially damaging competition
- Prepare for major challenges: technical (industrialisation 16000 SC cavities), financial (~6 B$), political with a worldwide machine (LHC different, ~ITER ?) OCDE, ESFRI
- ILC and CLIC projects intend to address these problems
- Present uncertainties justify an open scenario
- However ILC is ready to go while it will take longer to complete the CLIC project

Apologies

- Other projects are also on the print board
- s-LHC for x10 Luminosity very advanced
- LHeC to send electrons on protons from LHC
- μ-collider revived at Fermilab
- Laser and beam plasma acceleration > 1 GV/m progressing fast but with limited η

In conclusion

- The HEP community has developped a consistent and worldwide strategy to construct an e+e- LC
- A viable project, ILC, can be presented to the governments end of 2012
- A final decision (ILC/CLIC) will depend on the physics results from LHC

Z′

LHC :

- up to ~5 TeV direct observation

- up to ~2 TeV identif.

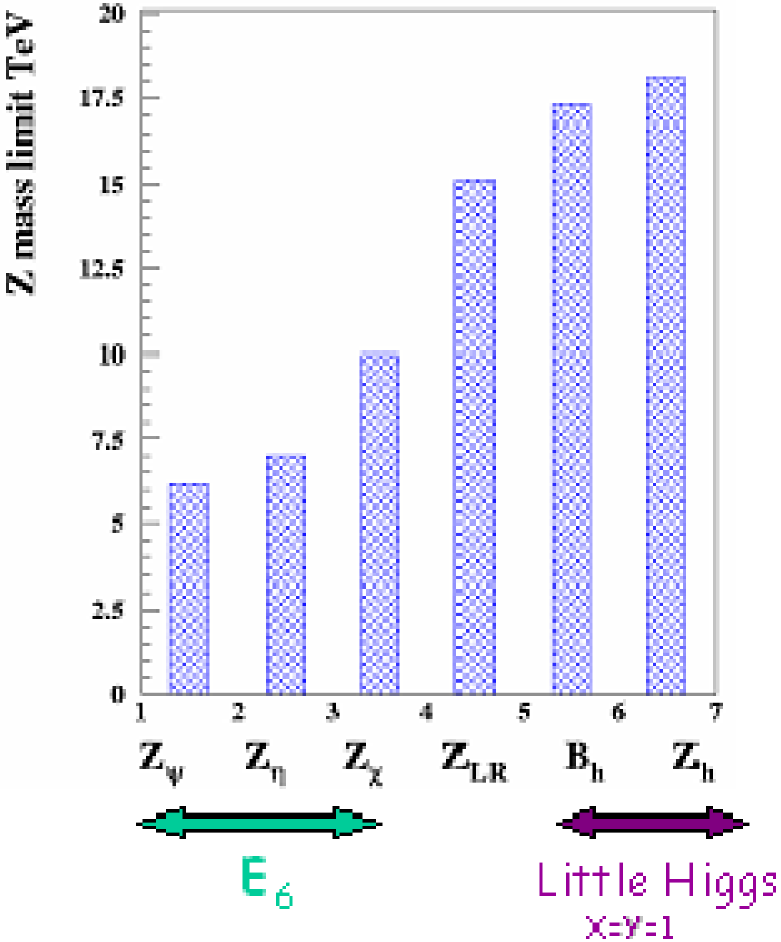
- LC can :

- discriminate between models up to ≥ 5 TeV

- predict MZ′ with a relative accuracy

< (MZ′/10TeV)²

< 25 % at 5 TeV



1 TeV 1 ab-1

CLIC 3 TeV main parameters

Center-of-mass energy	CLIC conserv.	CLIC Nominal
Total (Peak 1%) luminosity	1.5(0.73)10^{34}	5.9(2.0)·10^{34}
Repetition rate (Hz)	50	
Loaded accel. gradient MV/m	100	
Main linac RF frequency GHz	12 (NC)	
Bunch charge10^9	3.72	
Bunch separation ns	0.5	
Beam pulse duration (ns)	156	
Beam power/linac (MWatts)	14	
Hor./vert. norm. emitt (10^{-6}/10^{-9})	3 / 40	2.4 / 25
Hor/Vert FF focusing (mm)	10/0.4	8/0.1
Hor./vert. IP beam size (nm)	83 / 2.0	40 / 1.0
Soft Hadronic event at IP	0.57	2.7
Coherent pairs/crossing at IP	5 10^7	3.8 10^8
BDS length (km)	2.75	
Total site length (km)	48.3	
Wall plug to beam transfer eff.	6.8%	
Total power consumption (MW)	415	

LC 500 GeV Main parameters

Center-of-mass energy	ILC	CLIC Conserv.	CLIC Nominal
Total (Peak 1%) luminosity	$2.0(1.5)\cdot10^{34}$	$0.9(0.6)\cdot10^{34}$	$2.3(1.4)\cdot10^{34}$
Repetition rate (Hz)	5	50	
Loaded accel. gradient MV/m	33.5	80	
Main linac RF frequency GHz	1.3 (SC)	12 (NC)	
Bunch charge10^9	20	6.8	
Bunch separation ns	176	0.5	
Beam pulse duration (ns)	1000	177	
Beam power/linac (MWatts)	10.2	4.9	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	10/40	3 / 40	2.4 / 25
Hor/Vert FF focusing (mm)	20/0.4	10/0.4	8/0.1
Hor./vert. IP beam size (nm)	640/5.7	248 / 5.7	202/ 2.3
Soft Hadronic event at IP	0.12	0.07	0.19
Coherent pairs/crossing at IP	10?	10	100
BDS length (km)	2.23 (1 TeV)	1.87	
Total site length (km)	31	13.0	
Wall plug to beam transfer eff.	9.4%	7.5%	
Total power consumption MW	216	129.4	