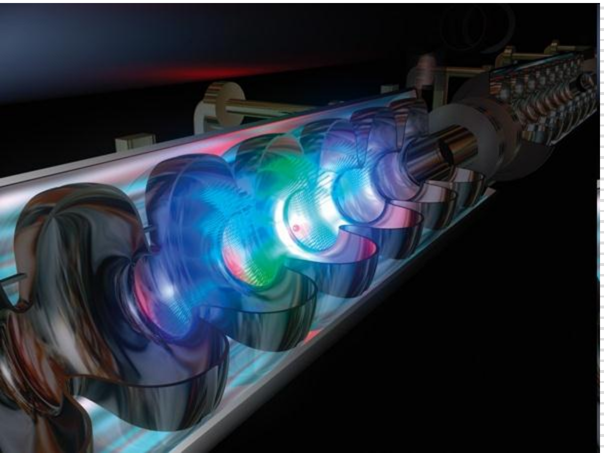
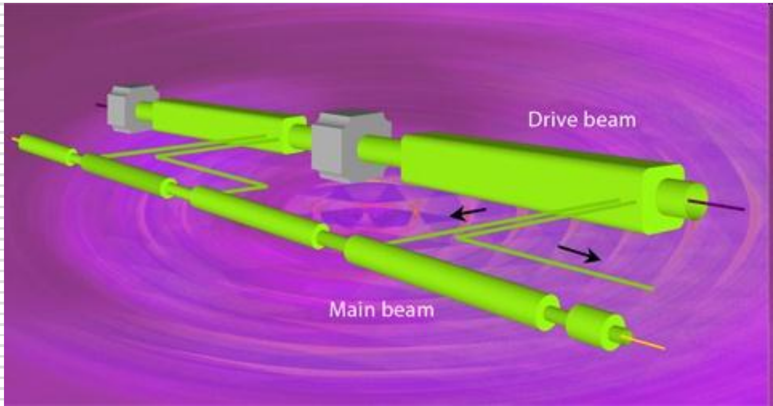
international linear collider

Future colliders: physics motivations

CERN Summer Student Lecture Programme

F. Richard LAL/Orsay





Introduction

- There is a wide consensus that lepton colliders are indispensable tools for HEP, in complement to hadron colliders, and that the next facility should be a e+e- linear collider
- For more than 10 years a worldwide R&D effort took place to provide a valid project for a e+e- LC
- LHC (after Tevatron) is exploring BSM physics and should give us the critical inputs to decide on the parameters of a future lepton collider
- While the SM is our solid baseline there exist a variety of scenarios with contrasted consequences on the choice of parameters for a future LC
- Europe will have a strategy discussion on the future of HEP during next year

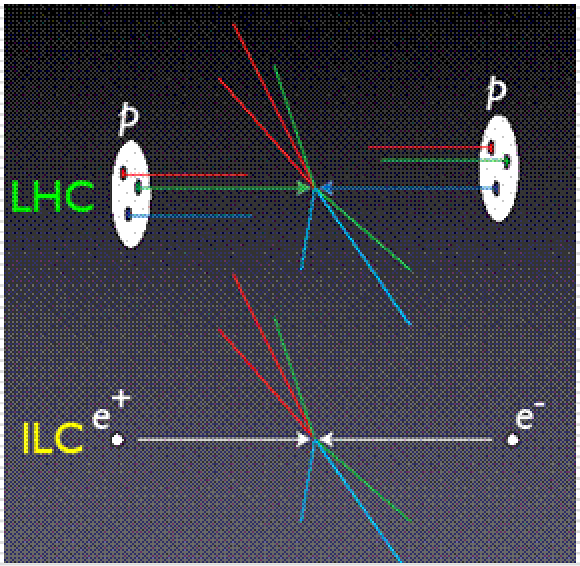
The standard view BSM

- From LEP/SLC/TeVatron compelling arguments (precision measurements PM) to expect a **light Higgs <150 GeV** within SM or most of 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 **colorless SUSY particles** (charginos, neutralinos, sleptons) best studied at LC ?

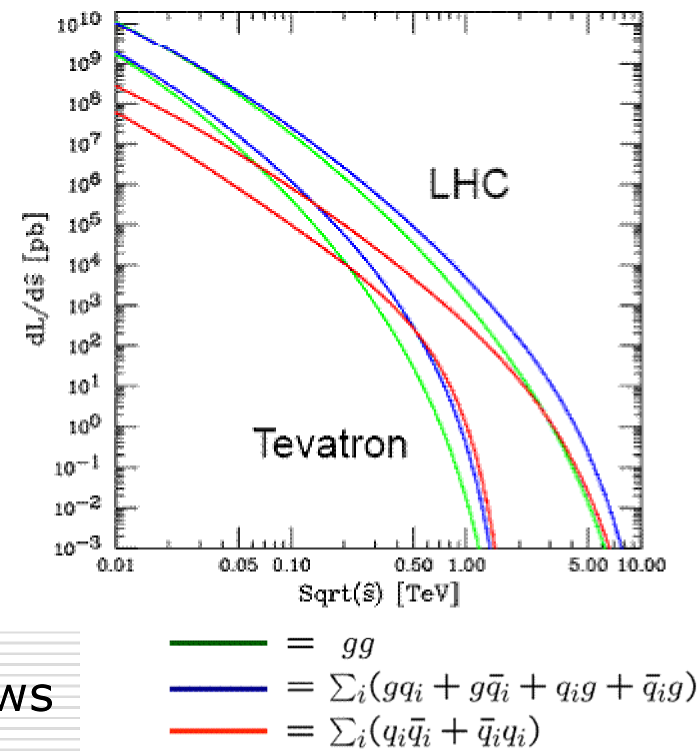
Alternates

- Other views have emerged allowing for very different pictures: **Composite Higgs** and even **Higgsless**
- They often are linked to **extra dimensions**
- Eminent role of **top physics** in this view: it could also be composite like the Higgs
- These models also predict large deviation in $\mathbf{W_L W_L}$ couplings which can be precisely studied in e+e-
- In the language of extra dimensions Kaluza Klein bosons couple preferentially to Higgs, top quarks and $W_L W_L$ generating large deviations in couplings to Z boson
- A LC measuring top, Higgs and WW couplings with excellent accuracies is ideally well suited to observe these effects

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

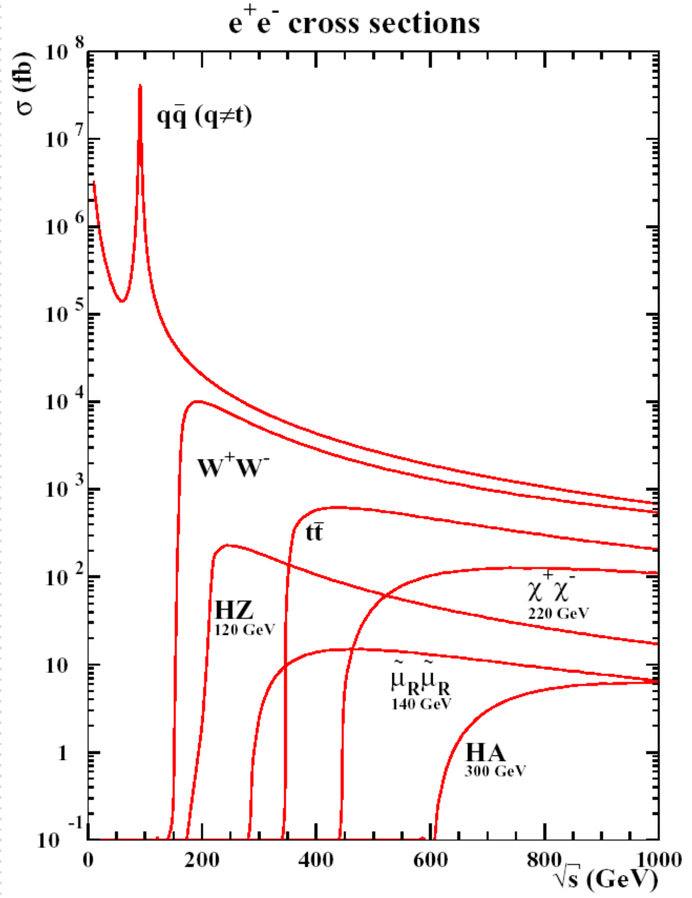


Huston, Campbell, S (2007)

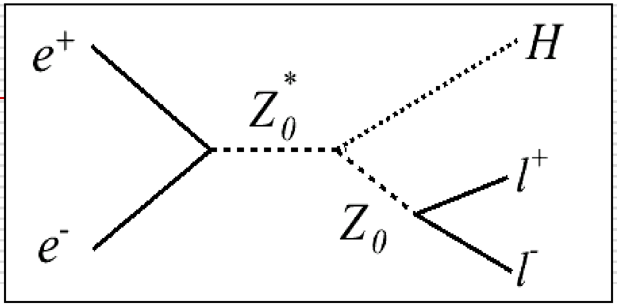
- Accurate **luminosity** + absence of trigger allows very clean unbiased determination of cross sections with accuracies well below 1%
- In a hadron machine with PDF+QCD corrections (**α_s/α_{em}**) accuracies ~10%

Democratic Production

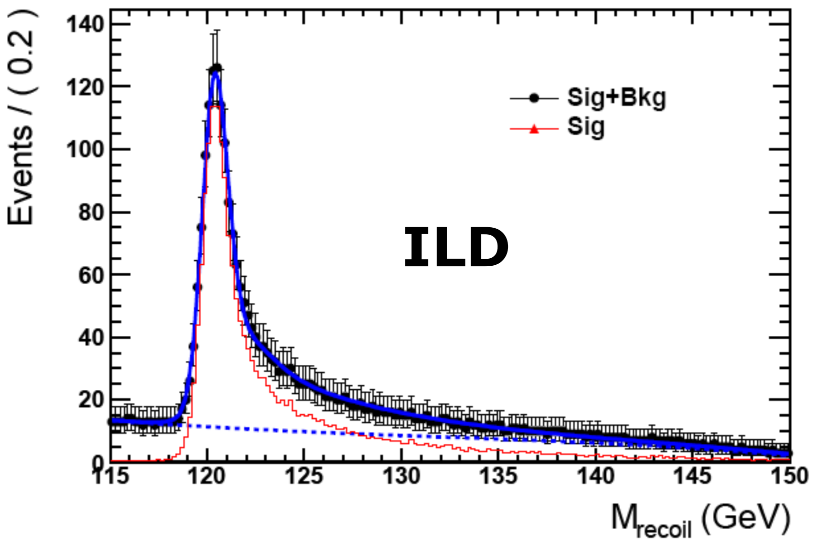
- All processes have similar cross section
- **HZ** the 'gold plated' process comes out very cleanly and allows to measure Higgs BR at %
- For comparison this channel has s/b~1/1000 at TeVatron
- **Top** quarks are reconstructed with low background
- **Charginos** can be studied in great detail



ee->Z*->HZ

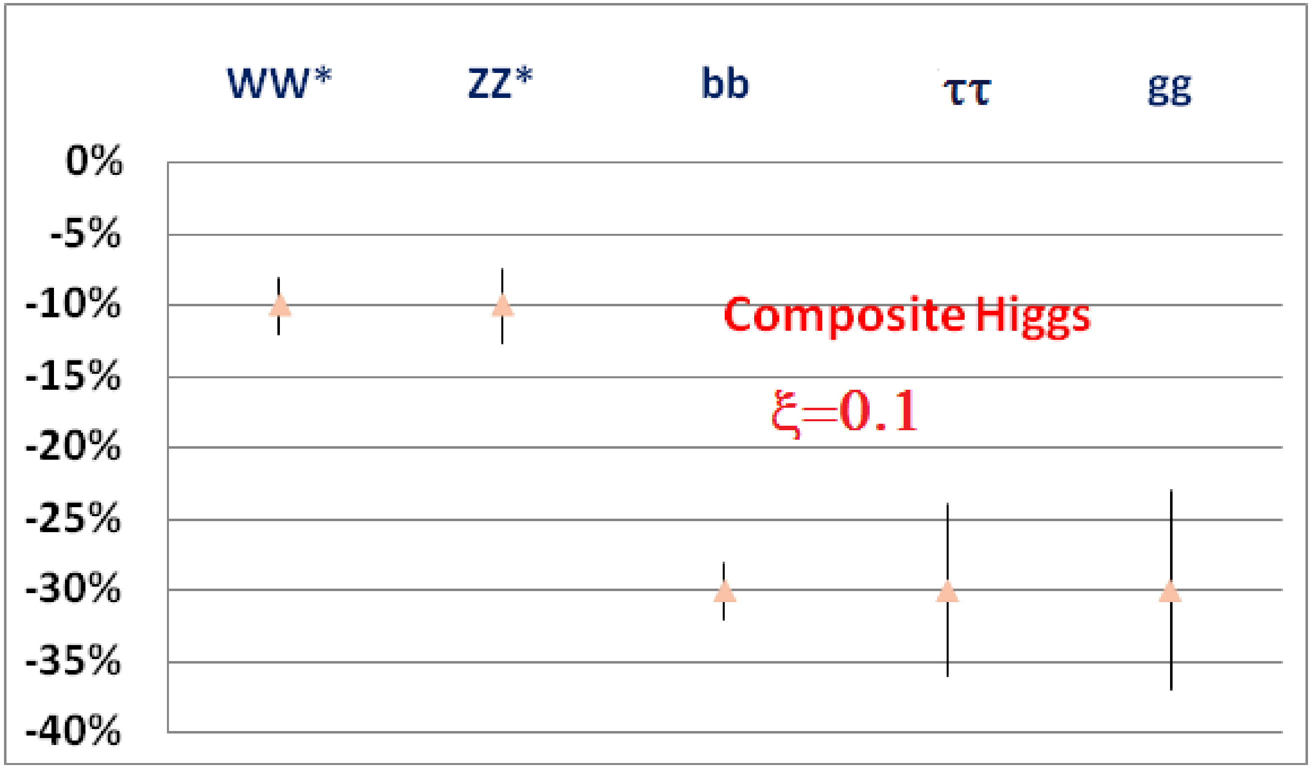


- The recoil mass technique with Z->μ+μ- gives a very clean & robust signal
- Works even if H decays into **invisible** or **complex** modes
- ZZH coupling constant determined to 1%
- In the SM case most BR ratios known 10 times more precisely than at LHC



Why so precise ?

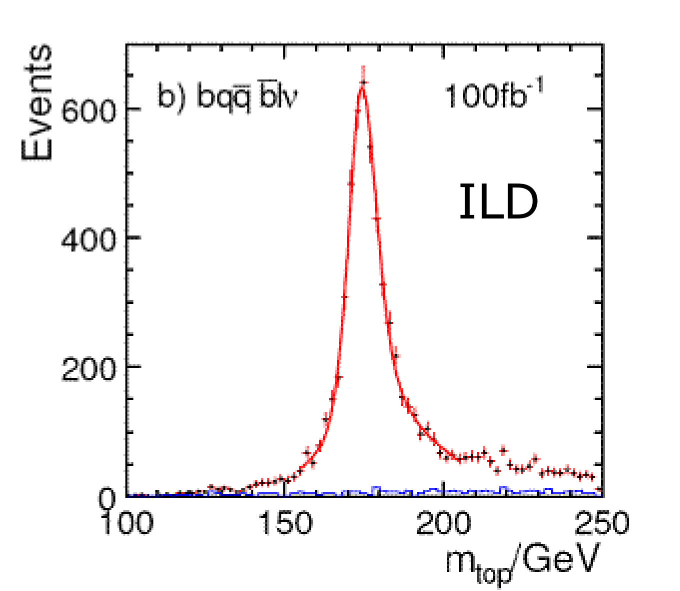
Deviations on SM widths for Mh=140 GeV

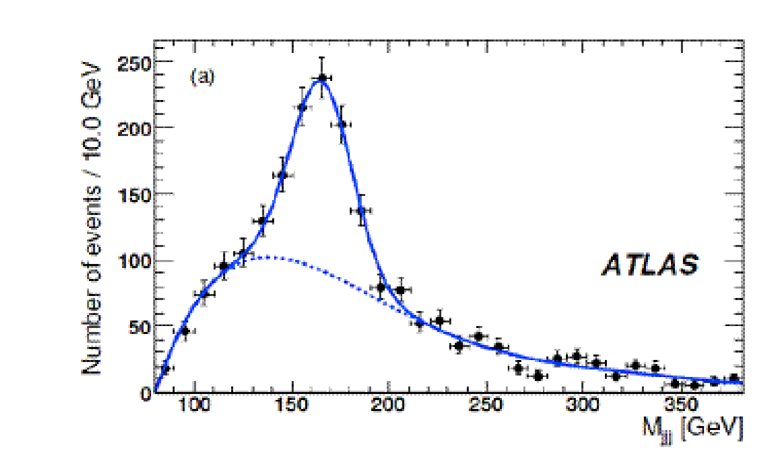


G. Giudice et al hep-ph/0703164

Top physics

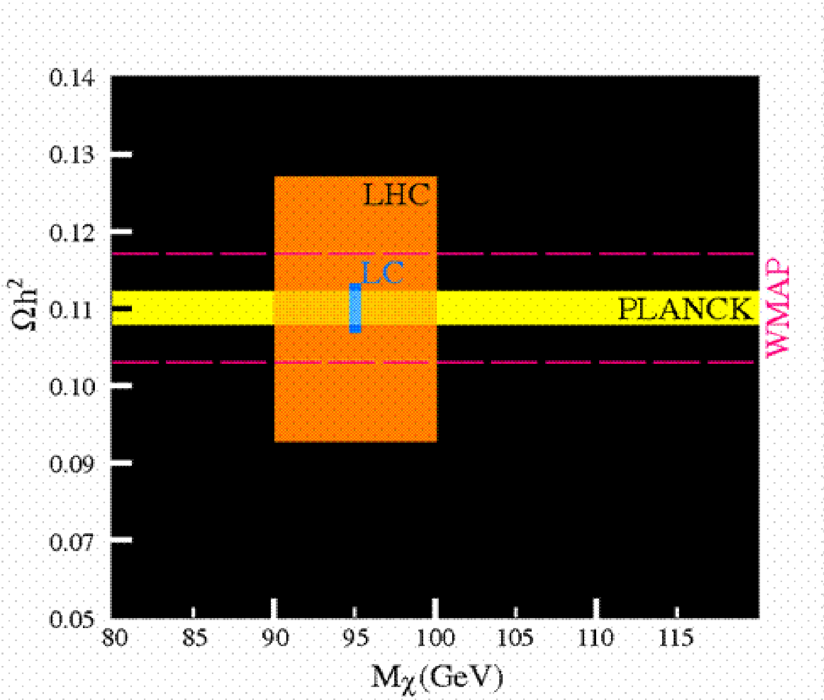
- LC 1 pb, LHC 1nb but dominated by gluon-gluon
- Very good s/b at ILC and energy/momentum conservation allows to reconstruct modes with a neutrino
- Mt and Γt with ~50 MeV error, 0.4% on cross section
- LC unique to measure tR and tL Z couplings at % (ND>4) using polarization (LHC > 10 times worse)





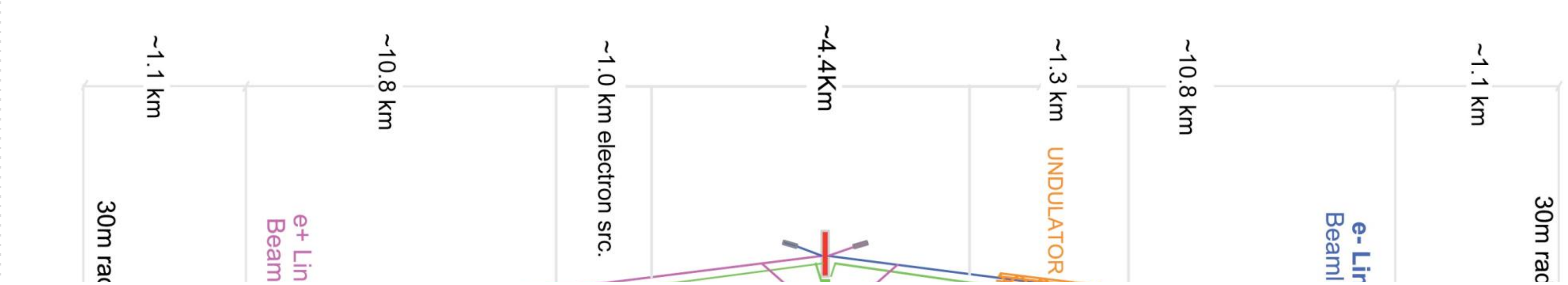
Dark matter & SUSY

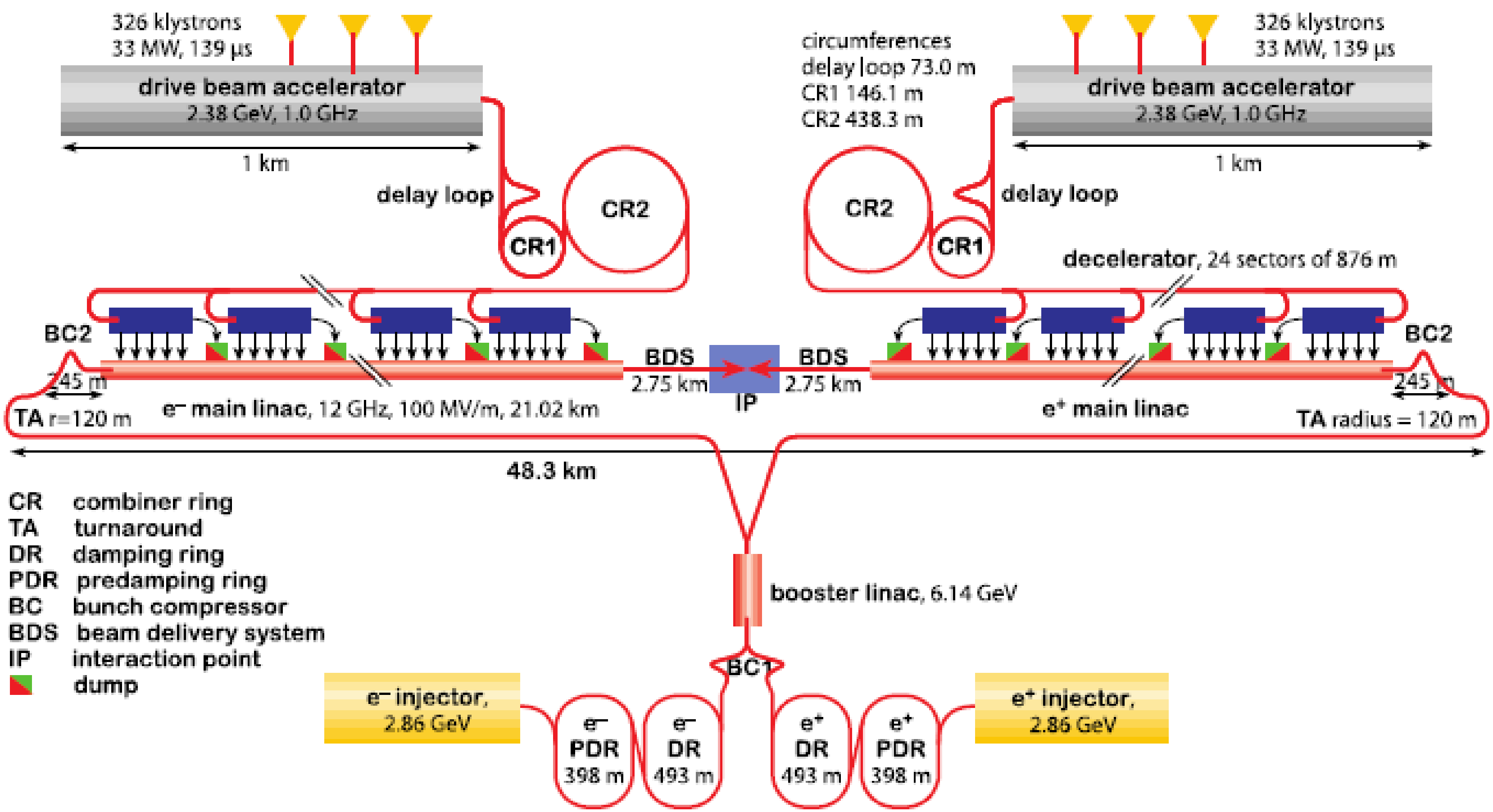
- Is possible to reach sufficient accuracy on the predicted dark matter to match cosmological observations ?
- LC provides the best accuracy
- Do they coincide ?



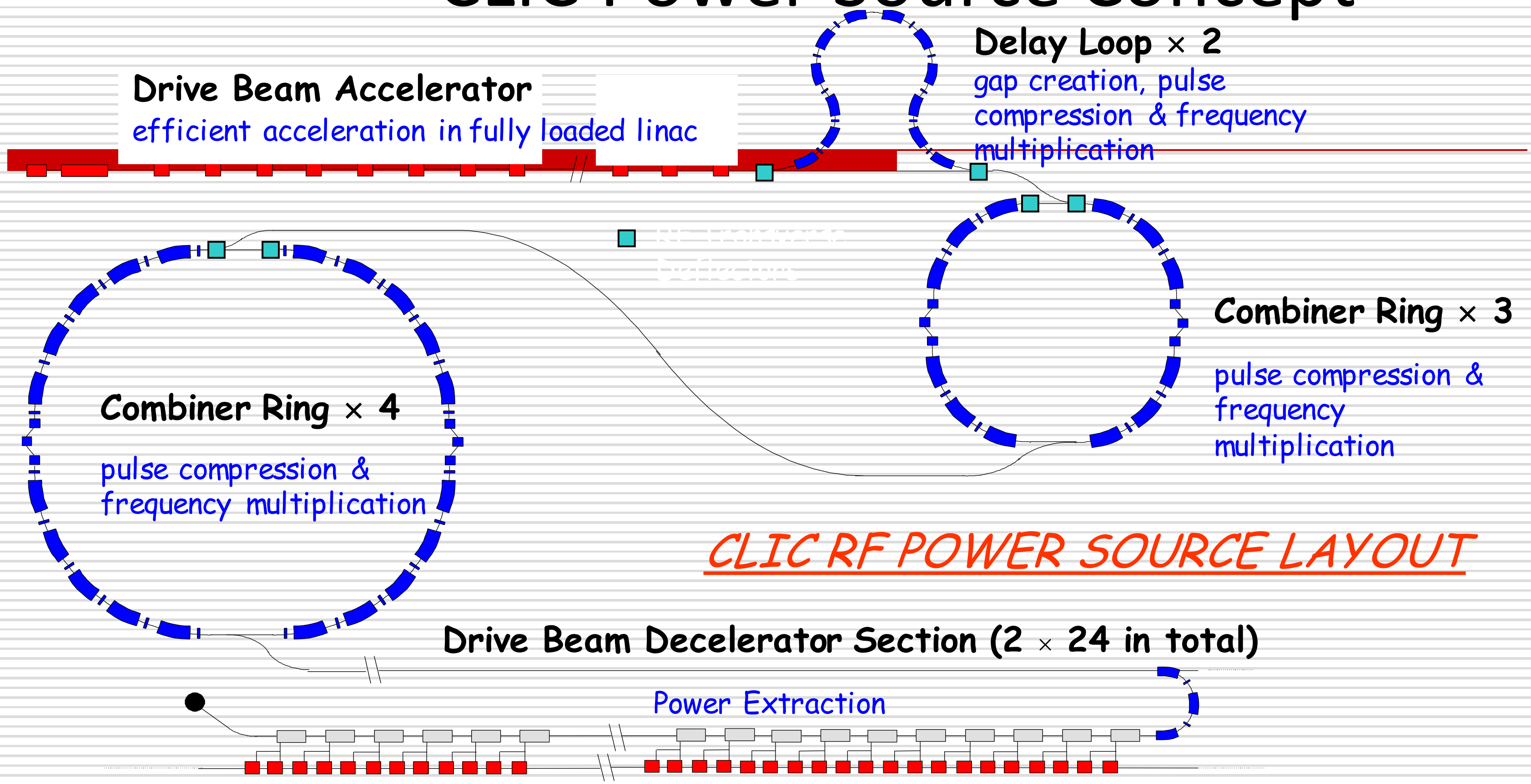
How to go from LEP/SLC to the next LC

- It is not possible to use **circular machines** (LEP) due to SR
- 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: warm cavities, klystron+ modulators with low η
- Two other ways:
- ILC **supraconductive** (2^0 Kelvin) linac allowing long bunch with good bunch separation but moderate gradient
- CLIC **a two beam accelerator** with higher gradient but <ns bunch separation

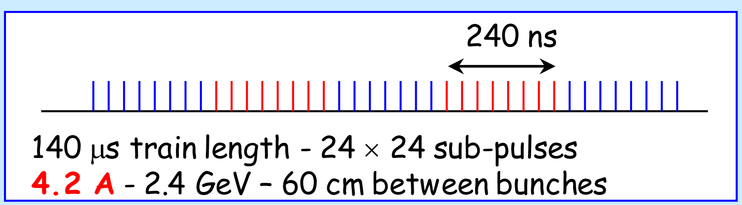

~1.1 km
~10.8 km
~1.0 km electron src.
~4.4Km
~1.3 km
UNDULATOR
~10.8 km
~1.1 km


326 klystrons
33 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
1 km
delay loop
CR2
CR1
circumferences
delay loop 73.0 m
CR1 146.1 m
CR2 438.3 m
326 klystrons
33 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
1 km
delay loop
CR2
CR1
decelerator, 24 sectors of 876 m
BC2
245 m
TA r=120 m
e⁻ main linac, 12 GHz, 100 MV/m, 21.02 km
BDS
2.75 km
IP
BDS
2.75 km
e⁺ main linac
BC2
245 m
TA radius = 120 m
48.3 km
CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump
booster linac, 6.14 GeV
BC1
e⁻ injector,
2.86 GeV
e⁻
PDR
398 m
e⁻
DR
493 m
e⁺
DR
493 m
e⁺
PDR
398 m
e⁺ injector,
2.86 GeV

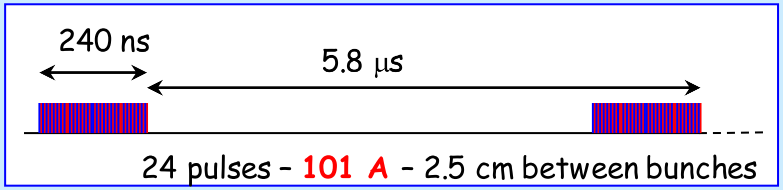
CLIC Power Source Concept



Drive beam time structure - initial



Drive beam time structure - final



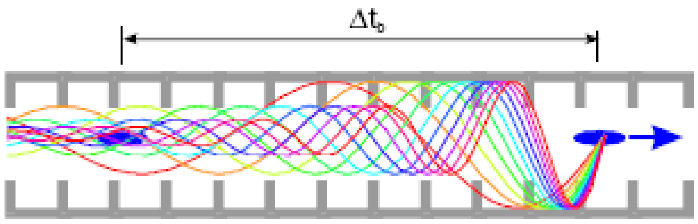
Some parameters

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

Type	LEP200	SLC100	ILC500	CLIC500
Vertical size nm	4000	700	5.7	2.3
Total P MW	65	50	216	240
Wall plug transf η %			9.4	4.1
Luminosity 10^{31} $cm^{-2}s^{-1}$	5	0.2	1500	1400
Interval between bunches ns	>>>	>>>	738	0.5
Polarisation %	No	80	>80	>80
Gradient MV/m	8	17	31.5	80

- 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 560 MW ~constant luminosity (same δE)

CLIC/ILC

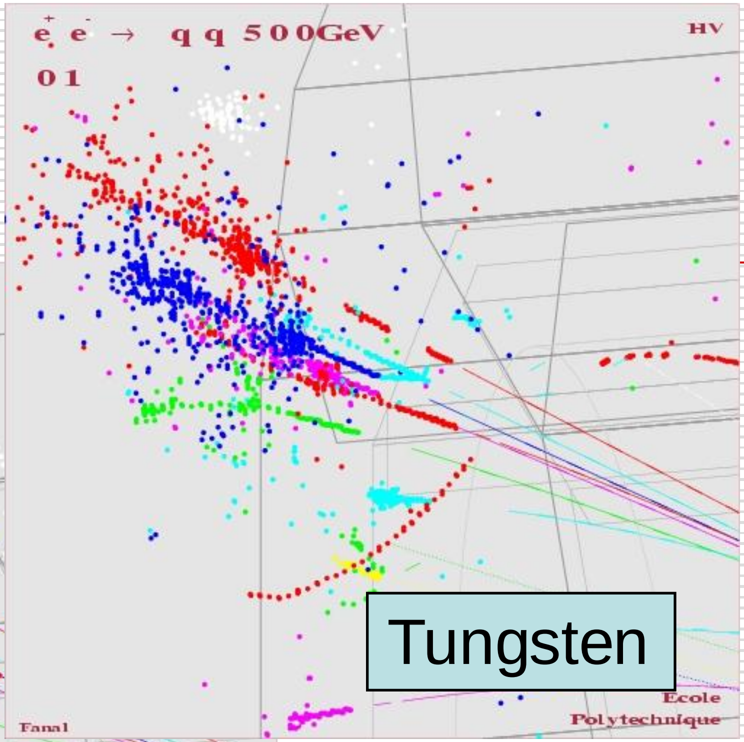


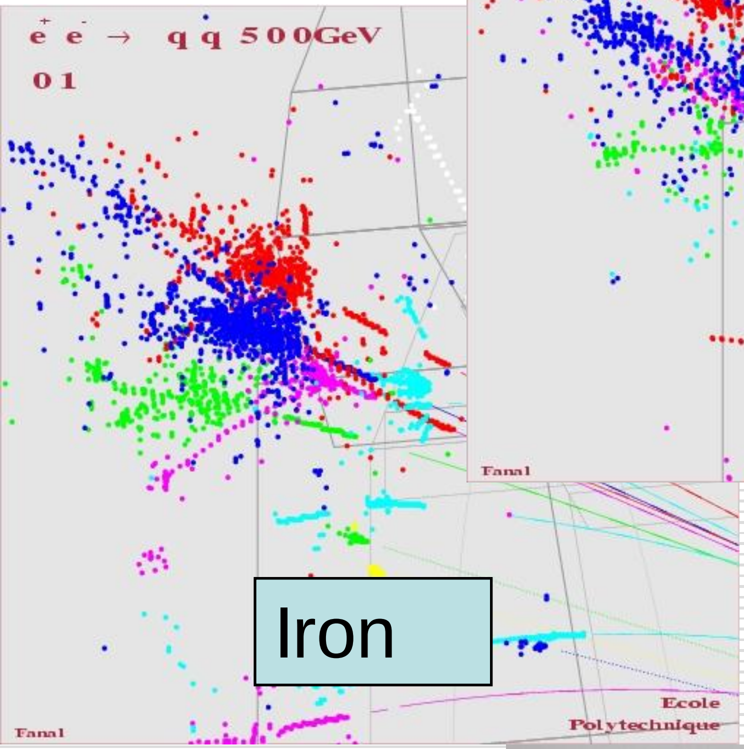
- Higher **gradient** at CLIC -> shorter machine reaching higher energies: 13 km instead of 30 km at 500 GeV
- CLIC has tight requirements on alignment due to wake fields (**frequency** x10) and beam size at IP
- CLIC is demonstrating its **feasibility** with the test station CTF3 (D. Schulte)
- Feasibility of ILC is based on various R&D efforts and test stations in the 3 regions in particular XFEL at DESY using the same technology
- Both machines have in common several critical R&Ds (damping rings, beam delivery, generation of positrons etc...)
- Both machines need to be able to run at **low energy** to allow for energy scans at threshods (HZ,tt,SUSY particles)

Detectors for LC

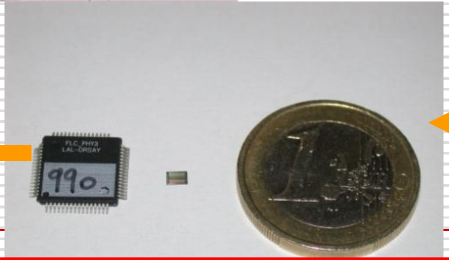
- Improved performances /LEP/LHC
- Open trigger with no bias on new physics
- Higher quality of **b/c tagging** (factor 10)
- Reconstruct separately charged and neutral particles (**PFLOW**) possible with high **granularity** calorimeters
- These detectors are challenging: need to reconstruct complex 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**

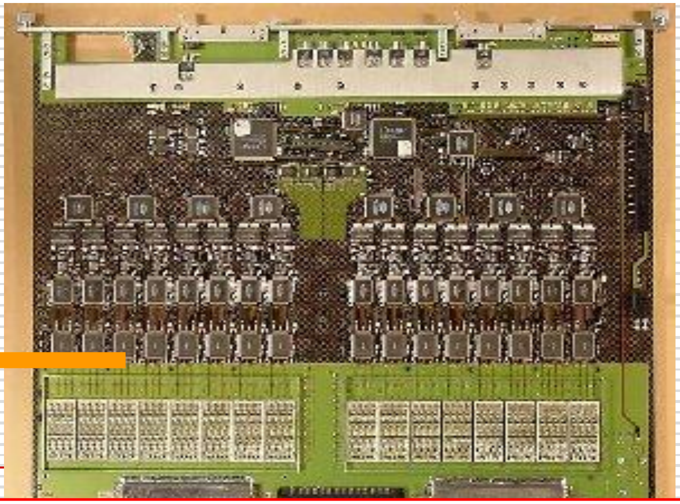
JETS





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





ILC : **100µW/ch**

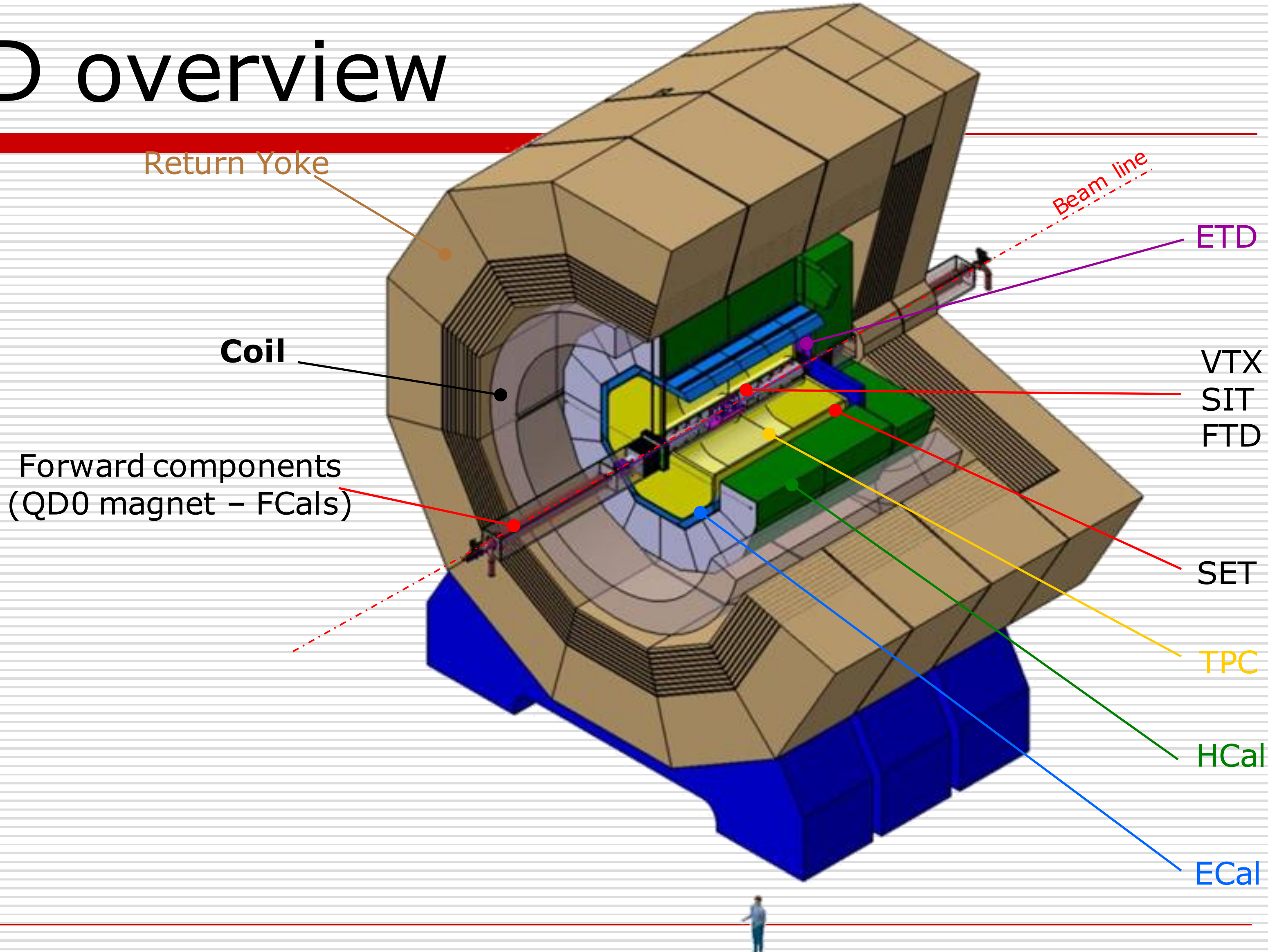
Physics Proto. 18ch 10*10mm **5mW/ch**

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

ILD & SiD

- Two detector concepts, SiD and ILD, have been selected by an international panel
- These detectors have demonstrated their ability to perform LC physics at 500 GeV
- There is an intense ongoing R&D effort (1000 engineers and physicists) to reach a realistic design and costing by end of 2012
- The same concepts, with appropriate changes in size, are tested for CLIC and 1st indications are very promising

ILD overview



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 will produce a CDR by end of 2011
- ILC relies on a well proven technology used to build an XFEL in DESY but with higher gradients ~+25% (underway)
- A detailed baseline design for detectors with interfacing to the machine will be completed by end 2012
- ILC has few options: Gigaz (which requires polarised positrons to cope with the accuracies) and a $\gamma\gamma$ collider

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

What happens at LHC ?

The New York Times

- LHC has gathered >1 fb-1 at 7 TeV
- LHC should soon provide an essential answer: Is there a light Higgs <150 GeV as predicted by SM (and SUSY extensions)
- First indications from LHC at **HEP 2011**, Mh~140 GeV
- Encouraging to go for a 500 GeV LC
- So far there are no other indications but rather severe limits on SUSY, Z'/W' but this is based on small statistics 1fb-1/3000fb-1

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
- A major discussion will take place in 2012 to update the **European strategy** in HEP

Apologies

- Other projects are also on the print board
- Doubling the energy of LHC (>2030) with an aggressive R&D on SC dipoles
- LHeC to send electrons on protons from LHC (following HERA at DESY)
- MultiteV μ-collider revived at Fermilab in conjuction to the neutrino beam program
- 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 technology and physics results from LHC
- Watch for the European strategy discussion in 2012
- Watch for LHC results

BACK UP SLIDES

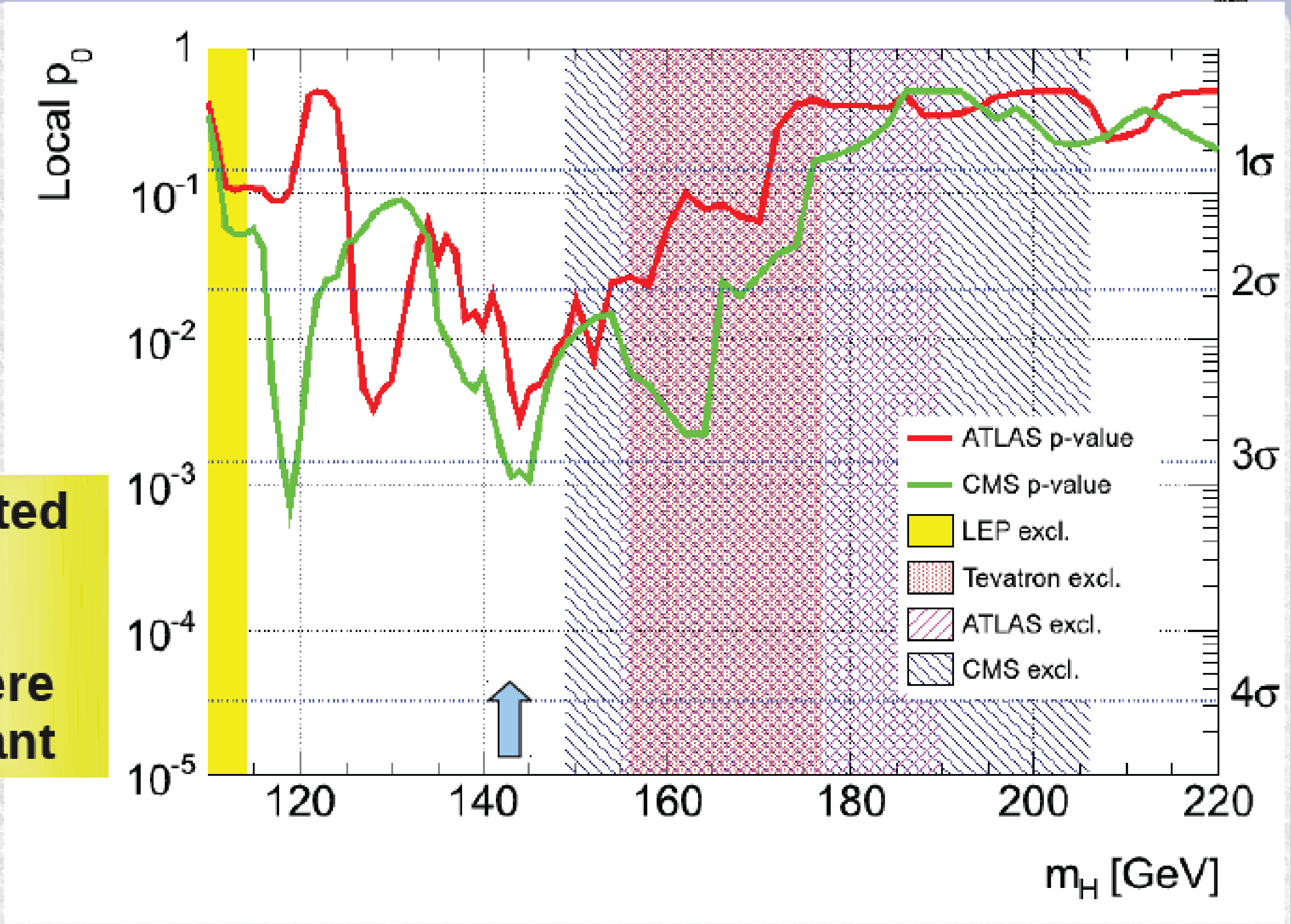
CLIC main parameters

Centre-of-mass energy	500 GeV	3 TeV
Total (Peak 1%) luminosity	$2.3(1.4)\cdot10^{34}$	$5.9(2.0)\cdot10^{34}$
Total site length (km)	13.0	48.3
Loaded accel. gradient (MV/m)	80	100
Main linac RF frequency (GHz)	12	
Beam power/beam (MW)	4.9	14
Bunch charge (10^9 e+/-)	6.8	3.72
Bunch separation (ns)	0.5	
Beam pulse duration (ns)	177	156
Repetition rate (Hz)	50	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)	4.8/25	0.66/20
Hor./vert. IP beam size (nm)	202 / 2.3	40 / 1
Hadronic events/crossing at IP	0.19	2.7
Coherent pairs at IP	100	$3.8\ 10^8$
Wall plug to beam transfer eff	4.1%	5.0%
Total power consumption (MW)	240	560

ILC parameters

	Centre-of-mass energy	E_{cm}	GeV	200	230	250	350	500	upgrade 1000
	Collision rate	f_{rep}	Hz	5	5	5	5	5	4
	Electron linac rate	f_{linac}	Hz	10	10	10	5	5	4
	Number of bunches	n_b		1312	1312	1312	1312	1312	2625
	Electron bunch population	N_-	$\times 10^{10}$	2	2	2	2	2	2
	Positron bunch population	N_+	$\times 10^{10}$	2	2	2	2	2	2
	Main Linac average gradient	G_{av}	MV/m	12.6	14.5	15.8	22.1	31.5	>31.5
	RMS bunch length	σ_z	mm	0.3	0.3	0.3	0.3	0.3	0.3
	Electron RMS energy spread	$\Delta p/p$	%	0.22	0.22	0.22	0.22	0.21	0.11
	Positron RMS energy spread	$\Delta p/p$	%	0.17	0.15	0.14	0.10	0.07	0.04
	Electron polarisation	P_-	%	80	80	80	80	80	80
	Positron polarisation	P_+	%	31	31	31	29	22	22
	IP RMS horizontal beam size	σ_x^*	nm	904	843	700	662	474	554
	IP RMS veritcal beam size	σ_y^*	nm	9.3	8.6	8.3	7.0	5.9	3.3
	Luminosity	L	$\times 10^{34}$ cm^{-2}s^{-1}	**0.47**	**0.54**	**0.71**	**0.86**	**1.49**	**2.70**
	Fraction of luminosity in top 1%	$L_{0.01}/L$		92.2%	89.8%	84.1%	79.3%	62.5%	63.5%
	Average energy loss	δE_{BS}		0.61%	0.78%	1.23%	1.75%	4.30%	4.86%
Using	IP RMS veritcal beam size	σ_y^*	nm	6.0	5.6	5.3	4.5	3.8	2.7
Traveling	**Luminosity**	L	$\times 10^{34}$ cm^{-2}s^{-1}	**0.64**	**0.73**	**0.97**	**1.17**	**2.05**	**3.39**
Focus	Fraction of luminosity in top 1%	$L_{0.01}/L$		91.6%	89.0%	83.0%	77.9%	60.8%	62.3%
	Average energy loss	δE_{BS}		0.61%	0.79%	1.26%	1.78%	4.33%	4.85%

P-values at low mass



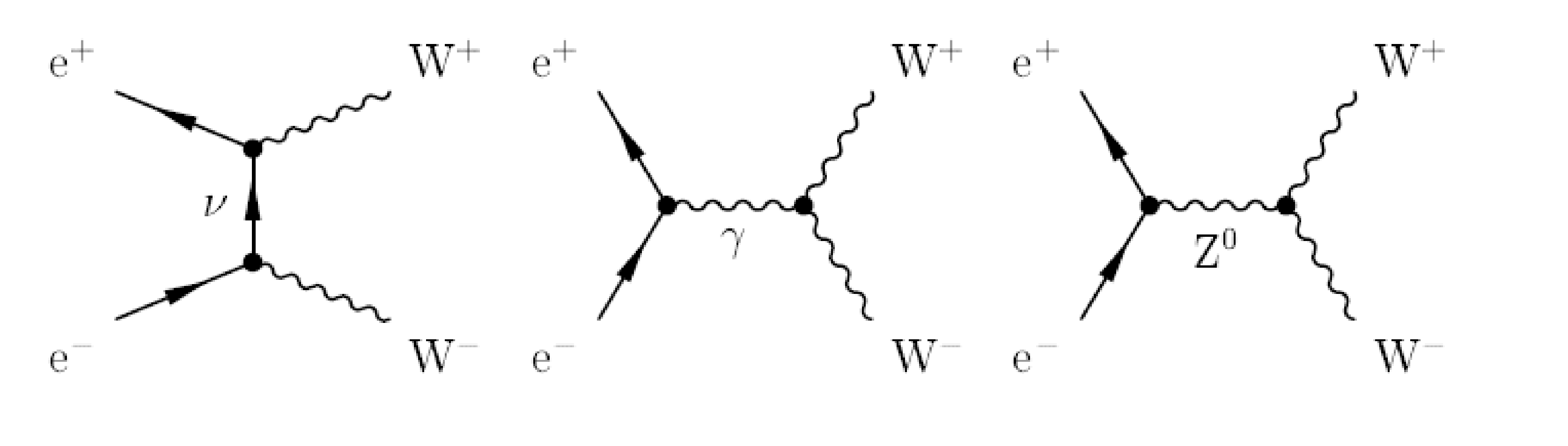
Some correlated uncertainties

Look-elsewhere effect important

Specific role of WW

- Before W gets a mass through EWSB, W like the photon has only transverse polarizations and $W_T W_T$ interactions are well behaved at high energies
- After EWSB, it gets a longitudinal polarization and $W_L W_L$ gives a divergent interaction in the absence of a Higgs boson
- Therefore studying e+e-> $W_L W_L$ can be of uttermost importance to investigate the EWSB mechanism
- Unfortunately e+e-> $W_L W_L$ is 2 orders smaller than the uninteresting $W_T W_T$ terms due no neutrino exchange
- Electron POLARIZATION should allow to solve this problem
- With e-R there is no neutrino exchange and $W_L W_L$ is easy to isolate
- Clearly unique potential of lepton colliders

Role of polarisation



No coupling
to e-R

Z′

LHC :

- up to ~5 TeV direct observation

- up to ~2 TeV identif.

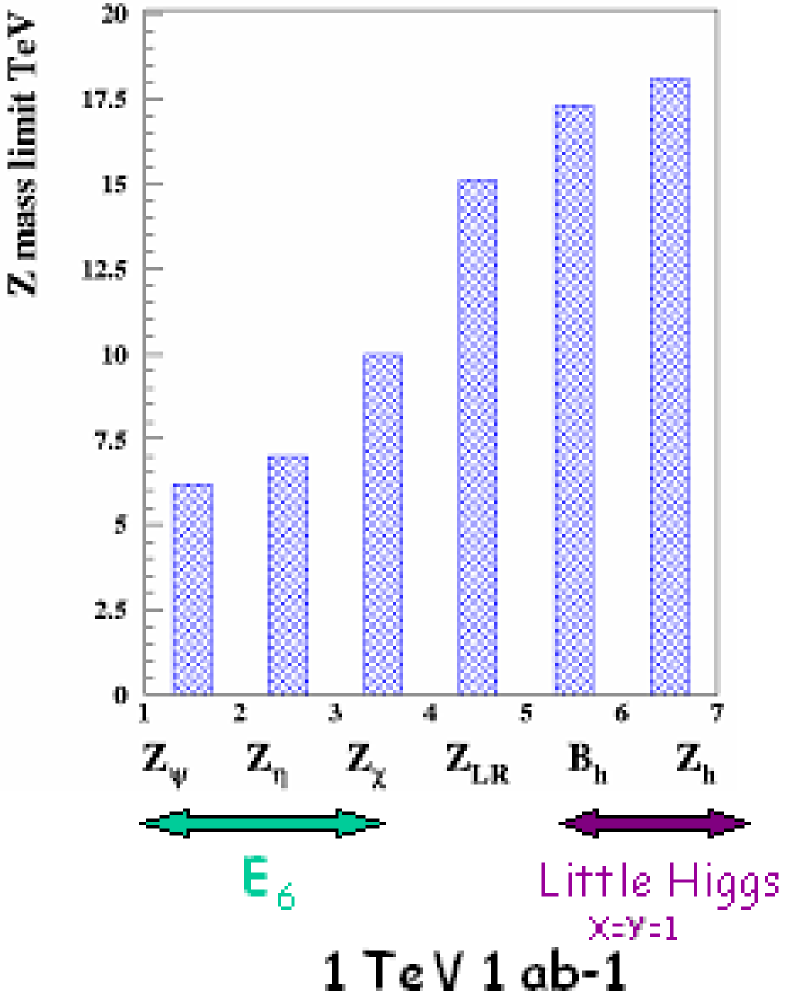
• LC can :

- discriminate between models up to ≥ 5 TeV

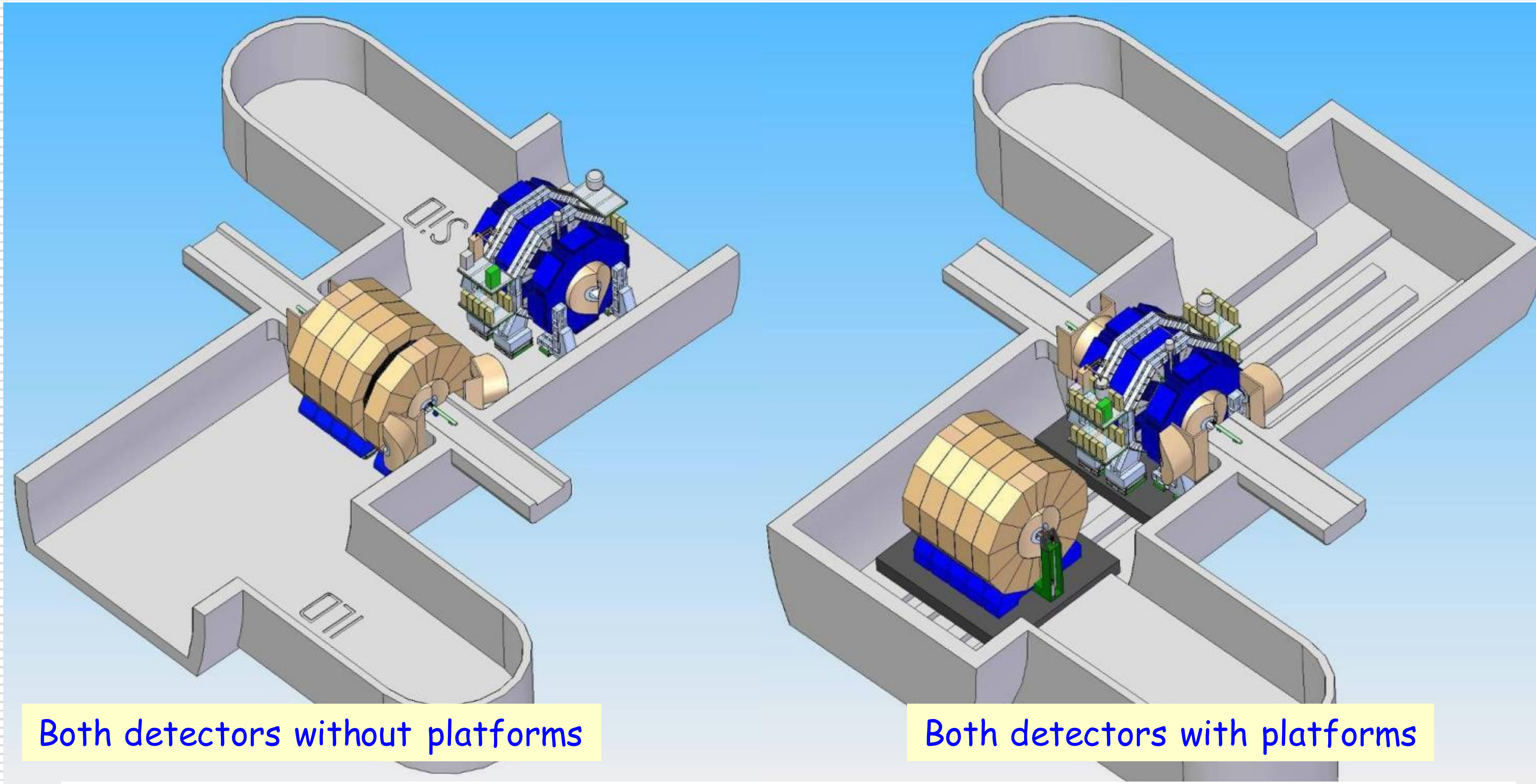
- predict MZ′ with a relative accuracy

$< (MZ'/10\,TeV)^2$

< 25 % at 5 TeV



Push – Pull Detector Concept

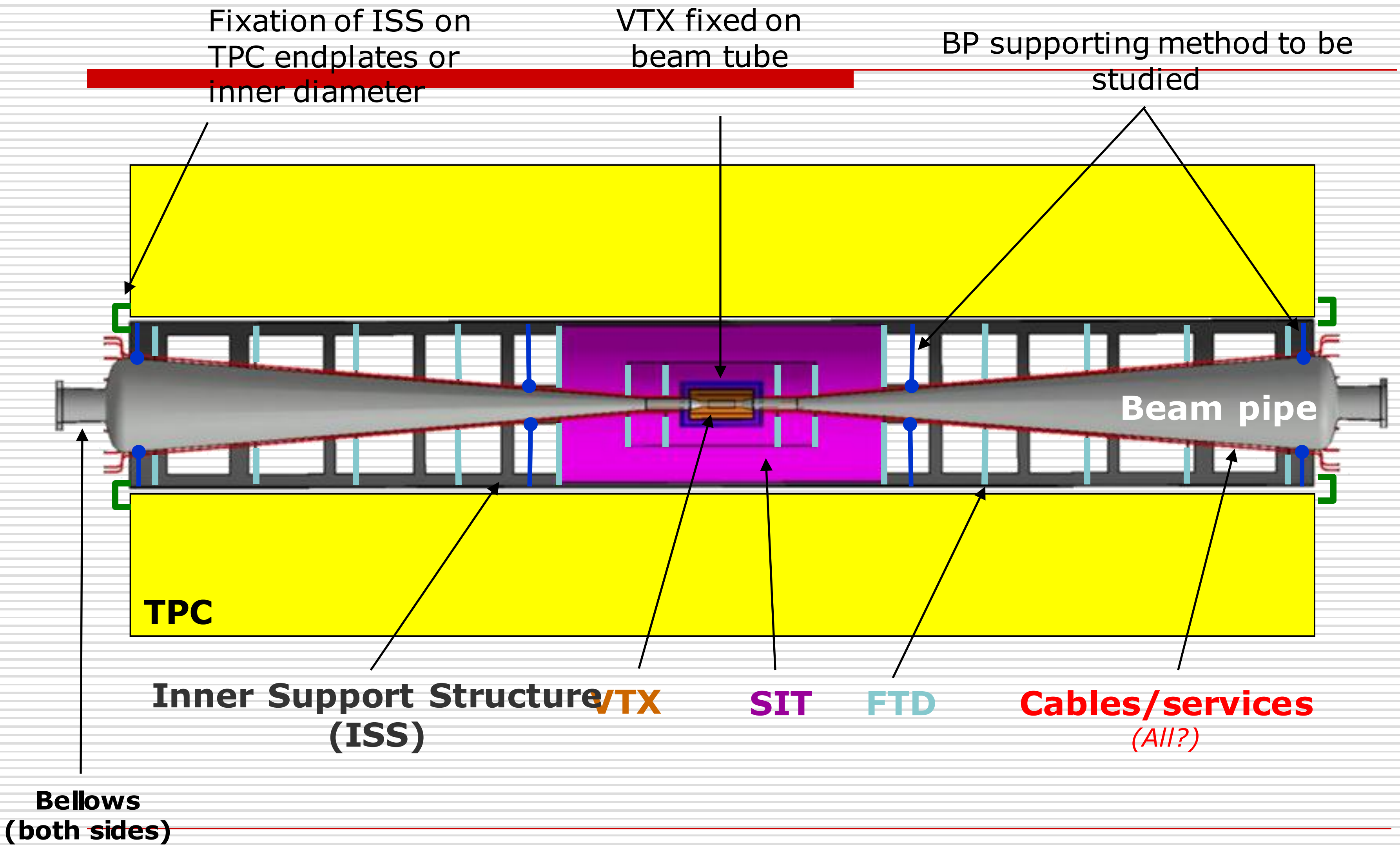


Both detectors without platforms

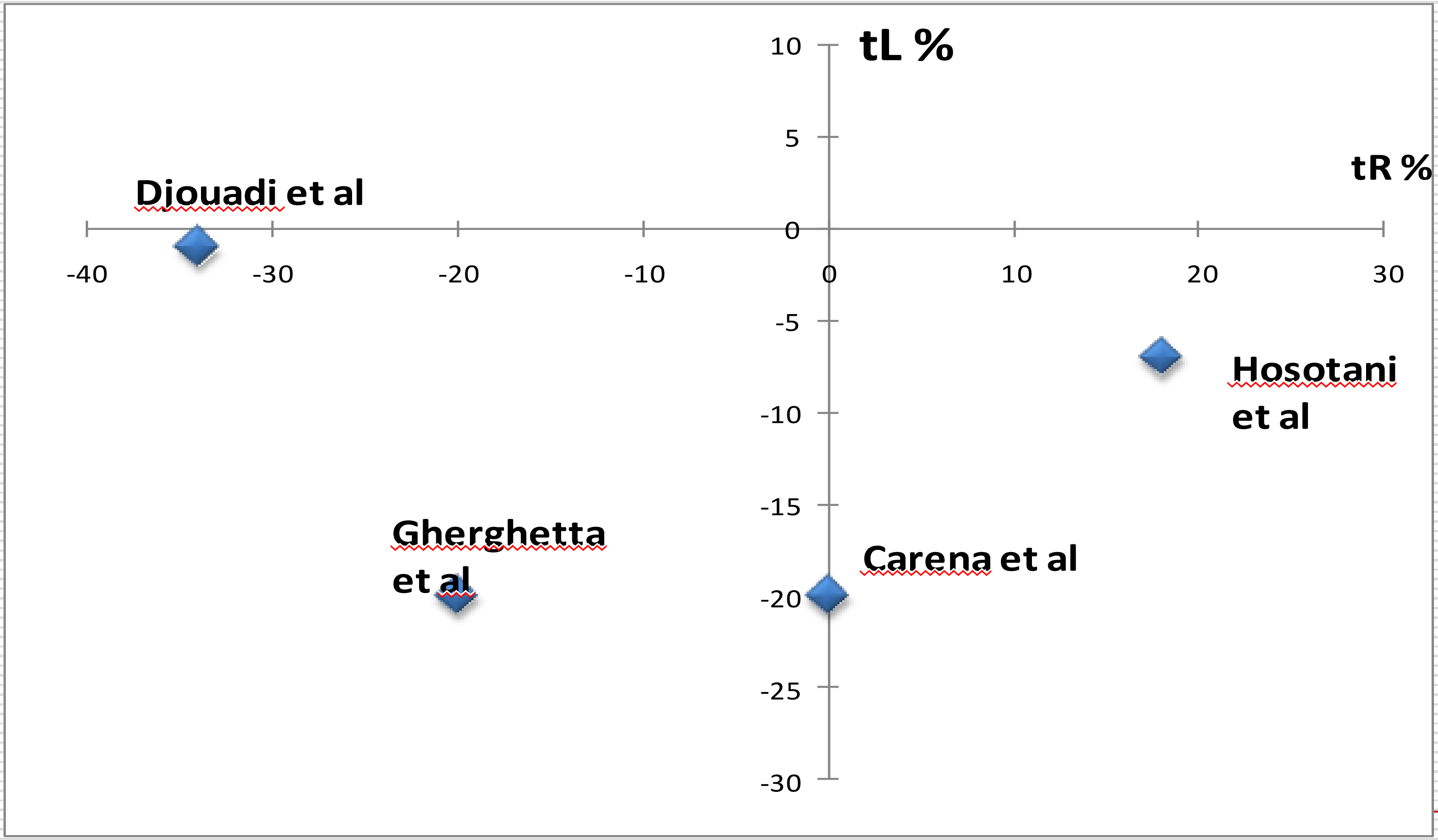
Both detectors with platforms

- Vibration stability will be one of the major criteria in eventual selection of a motion system design

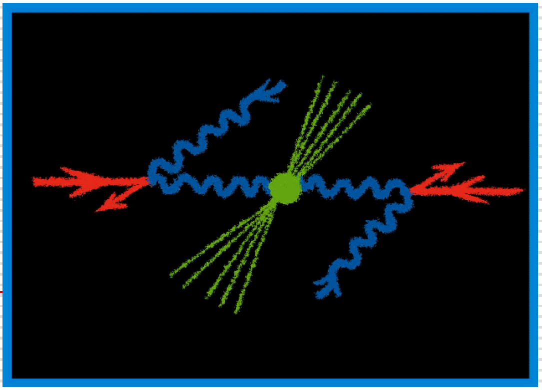
Inner region - reminder



Top couplings to Z in the Randall Sundrum model

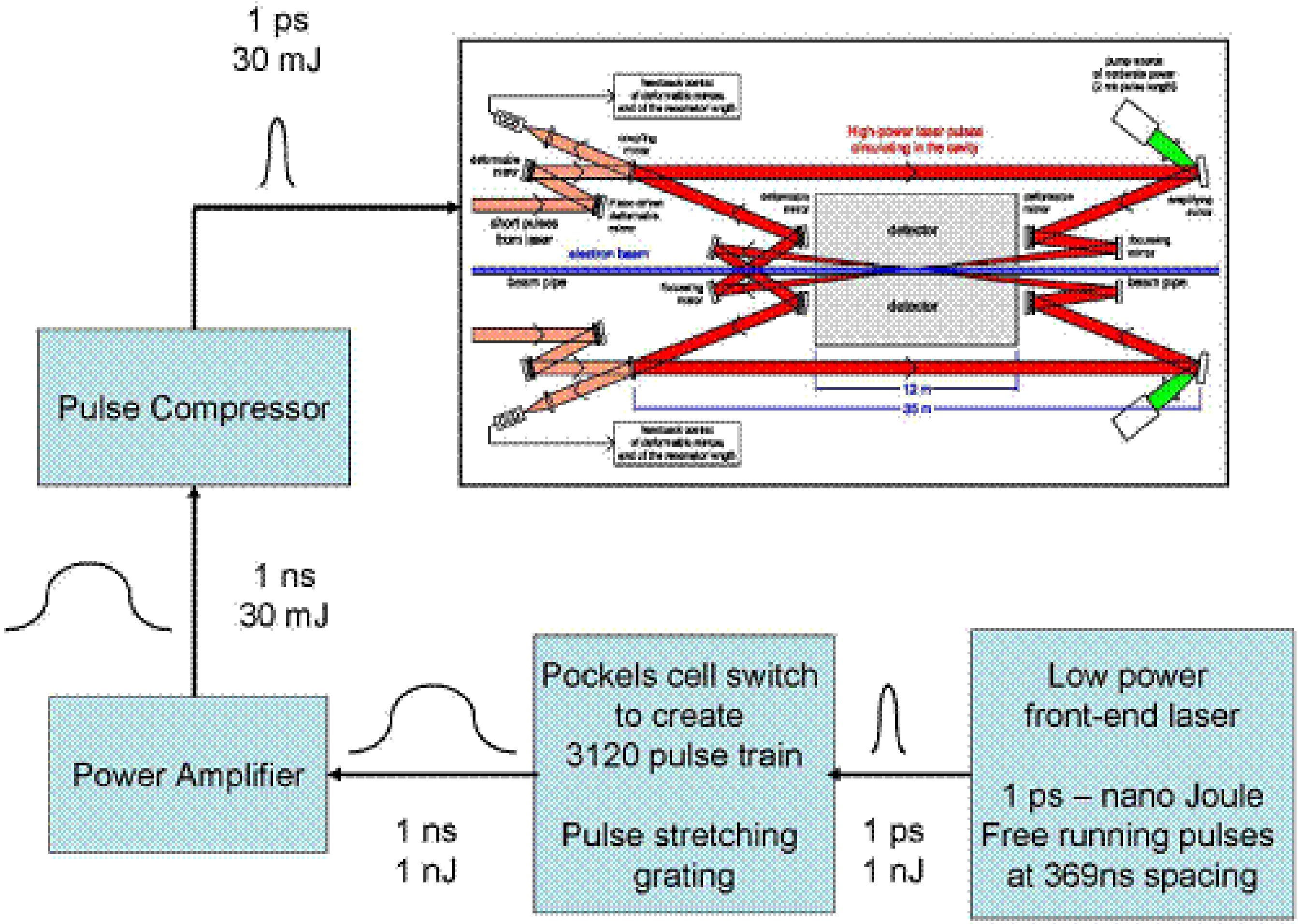


Option



- γγ 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
- γγ -> 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