Physics Study of ILC Machine Baseline Design

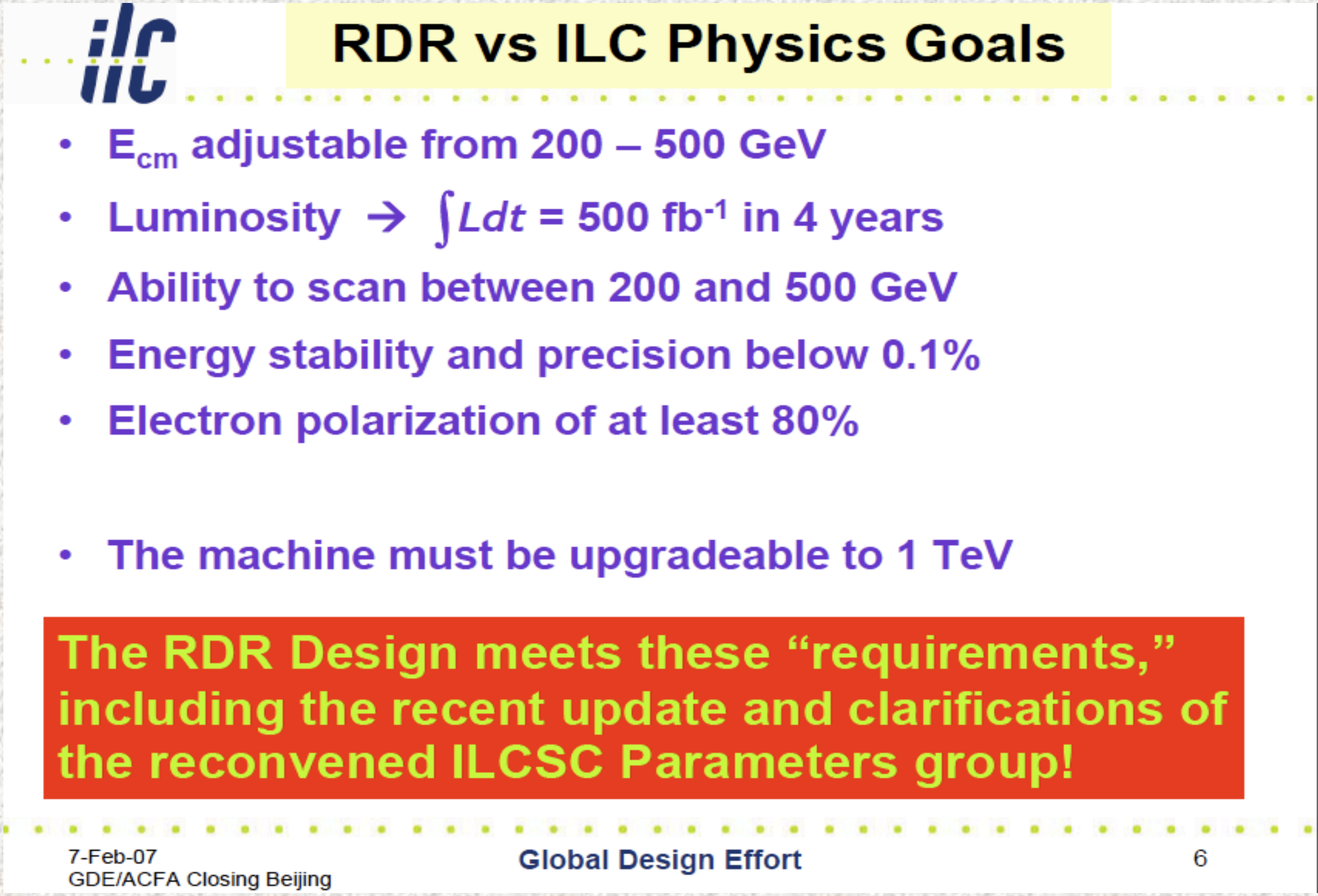
Jim Brau

November 15, 2010

ILC Scope

ILCSC “scope document” specifies the requirements, including emphasis on importance of variable energy operation, with good luminosity performance

- Top could be special messenger; 350 GeV scan!
- Polarization very powerful probe!



RDR vs ILC Physics Goals

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

- The machine must be upgradeable to 1 TeV

The RDR Design meets these “requirements,” including the recent update and clarifications of the reconvened ILCSC Parameters group!

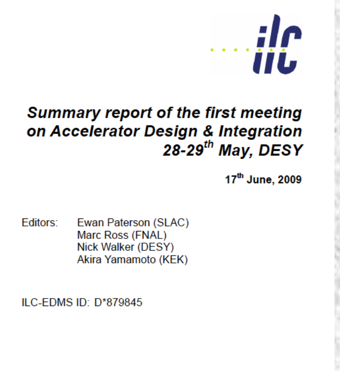
7-Feb-07
GDE/ACFA Closing Beijing

Global Design Effort

6

ILC Design Evolution


international linear collider
Reference Design Report
Accelerator
August 2007
ILC-REPORT-2007-001


Summary report of the first meeting on Accelerator Design & Integration 28-29th May, DESY

17th June, 2009

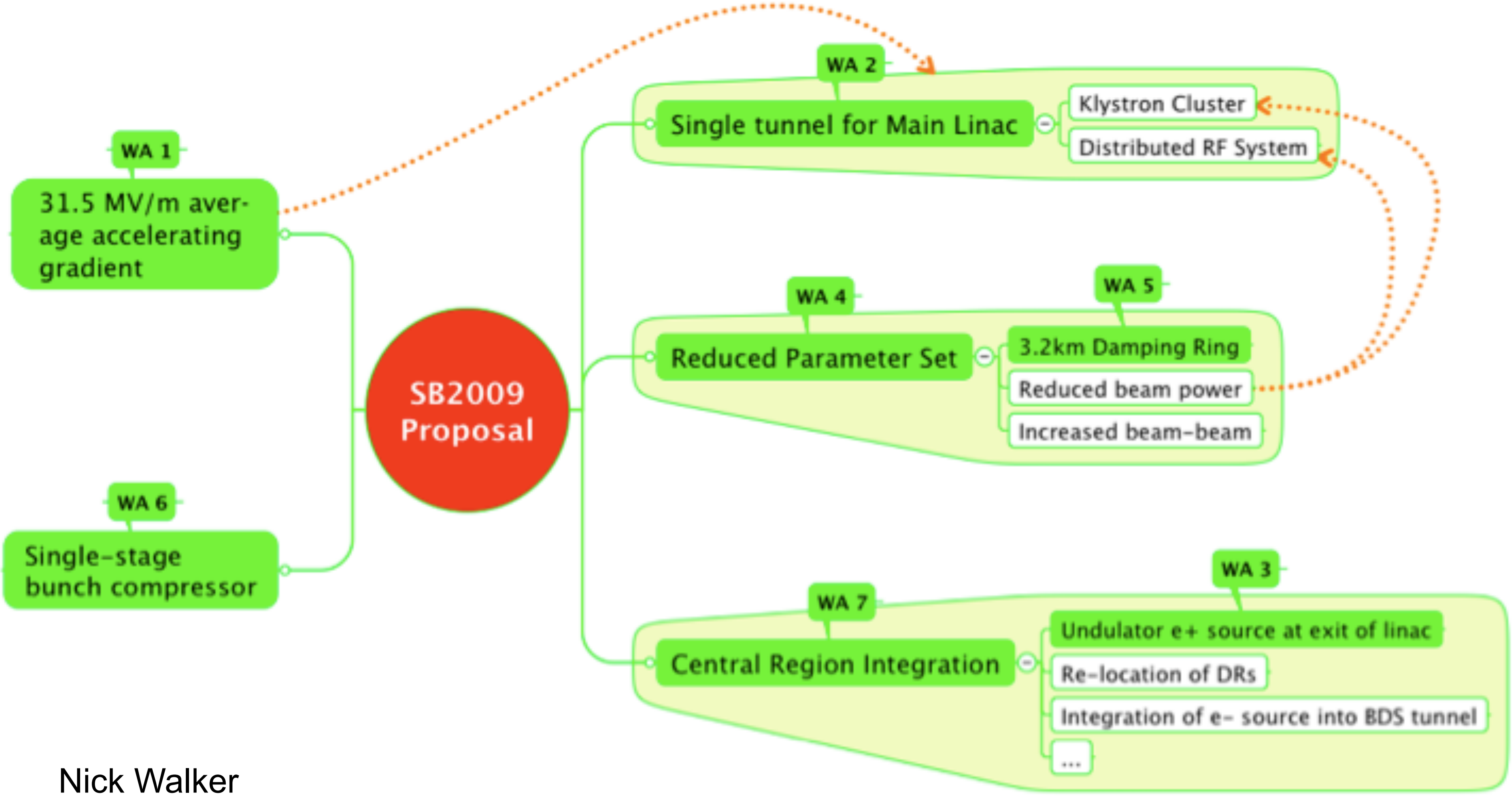
Editors: Ewan Paterson (SLAC)
Marc Ross (FNAL)
Nick Walker (DESY)
Akira Yamamoto (KEK)

ILC-EDMS ID: D*879845

- Reference Design Report (RDR) – 2007
  - First detailed technical snapshot, defining in detail the technical parameters and components to guide the development of the worldwide R&D program
- SB2009
  - Proposed set of changes to the baseline aimed at optimizing ILC design for cost, performance and risk.
  - Physics impact studied and commented on by Physics and Detectors Study Group*
- New ILC Design and Parameters
  - Response to study group's reaction to reduced low energy luminosity – a modified design with new parameters

* T. Barklow, M. Berggren, J. Brau, K. Buesser, K. Fujii, N. Graf, J. Hewett, T. Markiewicz, T. Maruyama, D. Miller, A. Miyamoto, Y. Okada, M. Thomson, G. Weiglein

SB2009 Themes



Nick Walker

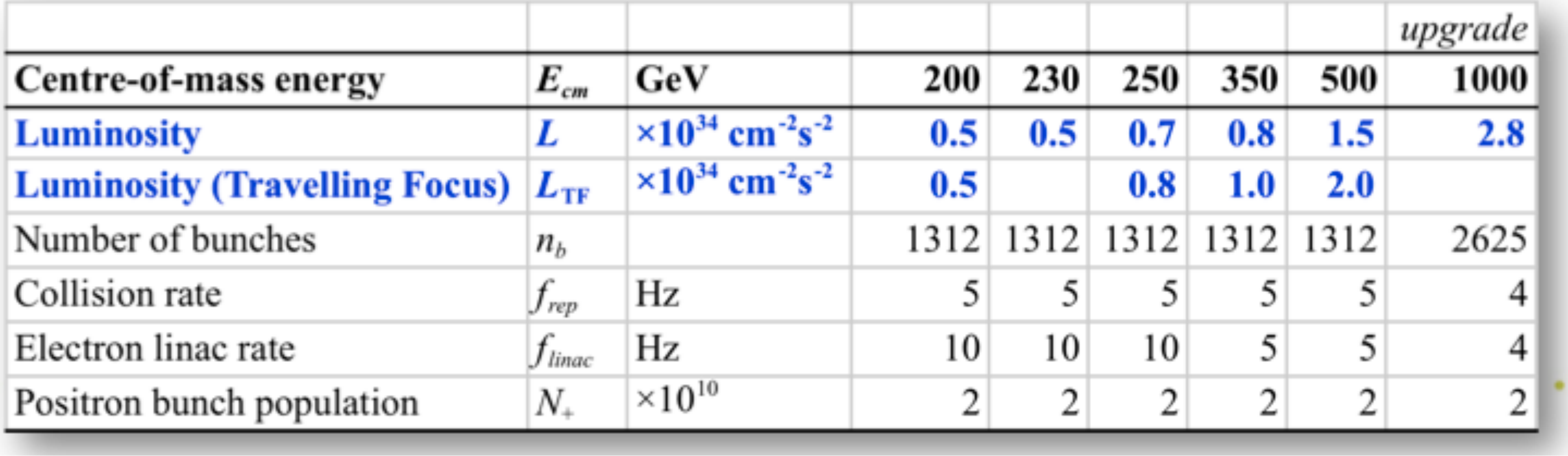
Baseline Assessment -2, Themes

Jan 18-21 @ SLAC

- **Reduction of # bunches (2625 → 1312)**
  - Reduced beam power → reduced RF
  - Smaller damping rings (6.4 km → 3.2 km)
  - Regain luminosity via stronger focusing at IP

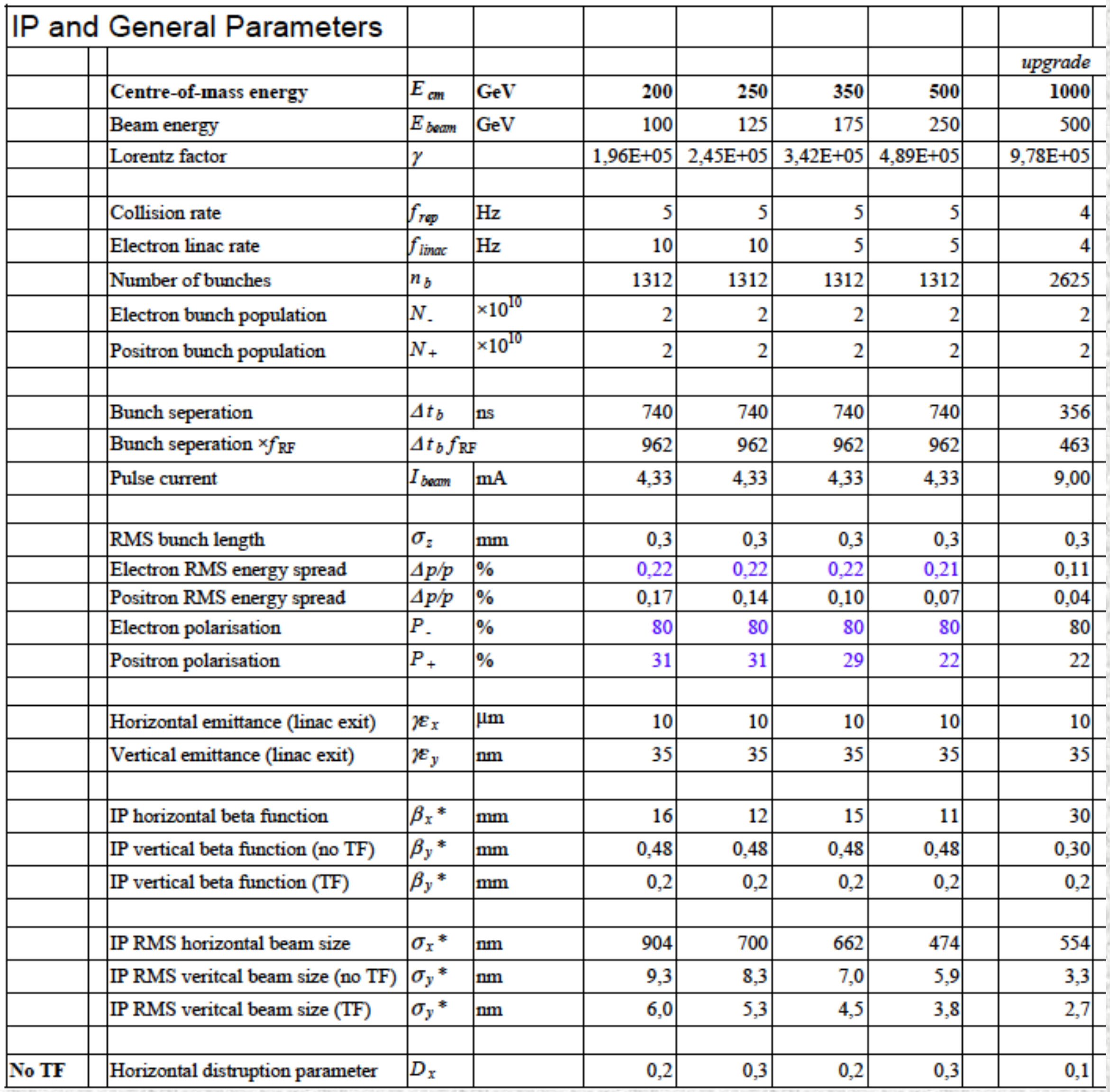
- **Re-location of e+ source to end on Main Linac**
  - Better integration (central campus) – higher overhead (at 500 GeV running) ⇒ reduced risk
  - Issues of running for Ecm < 300 GeV

Nick Walker



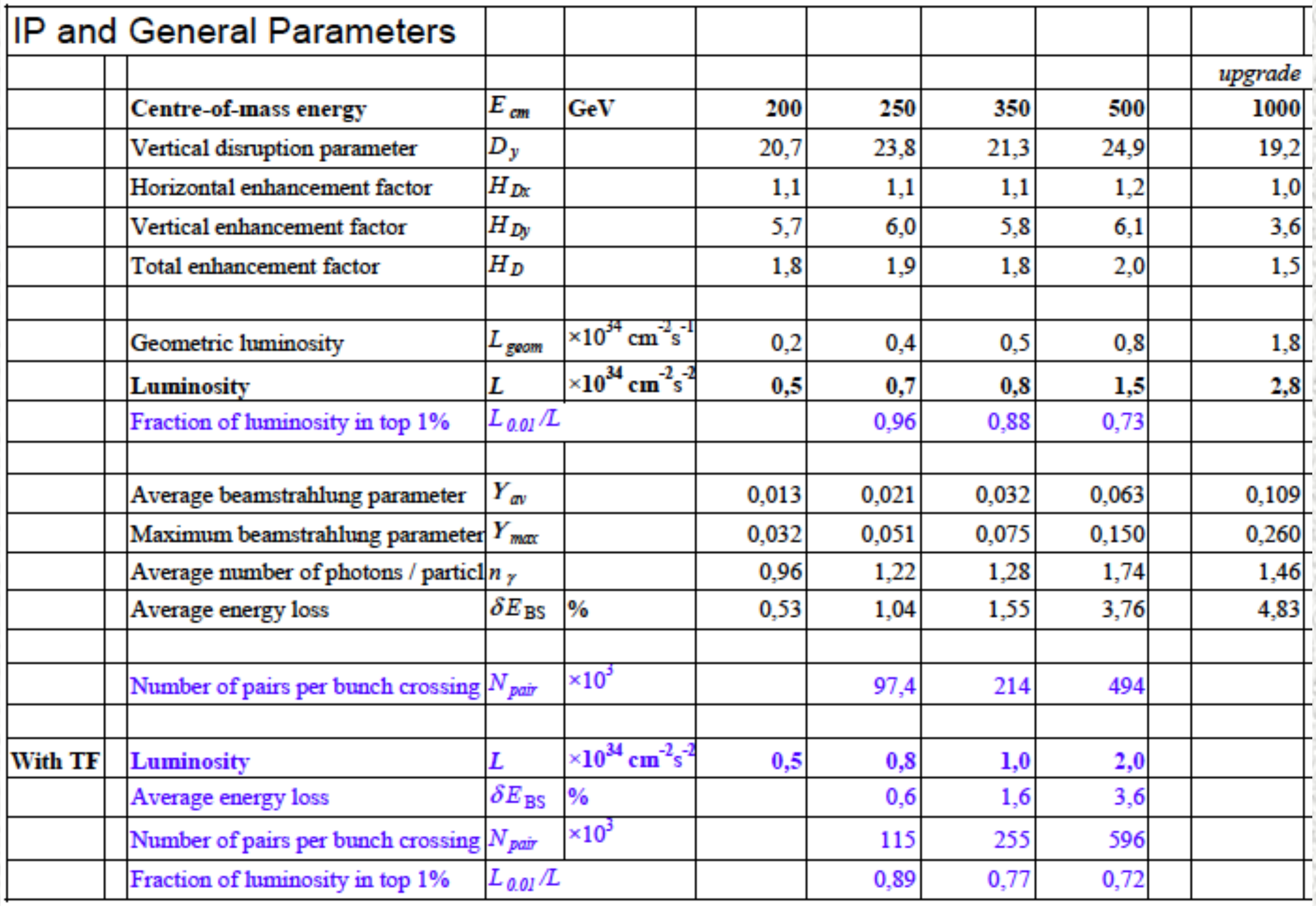
								upgrade
Centre-of-mass energy	E_{cm}	**GeV**	**200**	**230**	**250**	**350**	**500**	**1000**
Luminosity	L	$\times 10^{34}\ \mathrm{cm^{-2}s^{-2}}$	**0.5**	**0.5**	**0.7**	**0.8**	**1.5**	**2.8**
Luminosity (Travelling Focus)	L_{TF}	$\times 10^{34}\ \mathrm{cm^{-2}s^{-2}}$	**0.5**		**0.8**	**1.0**	**2.0**	
Number of bunches	n_b		1312	1312	1312	1312	1312	2625
Collision rate	f_{rep}	Hz	5	5	5	5	5	4
Electron linac rate	f_{linac}	Hz	10	10	10	5	5	4
Positron bunch population	N_+	$\times 10^{10}$	2	2	2	2	2	2

Recently Updated ILC Machine Parameters



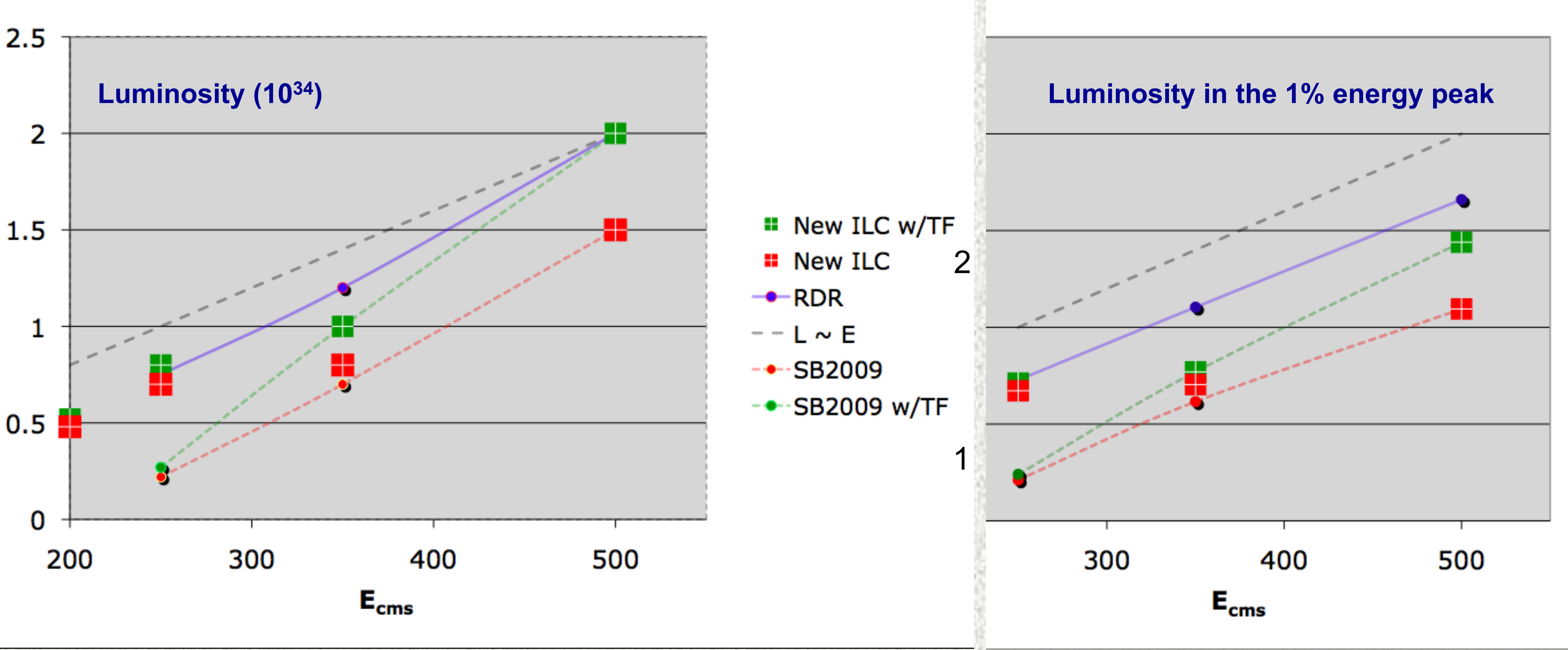
IP and General Parameters									
									upgrade
	Centre-of-mass energy	E_{cm}	**GeV**	**200**	**250**	**350**	**500**		**1000**
	Beam energy	E_{beam}	GeV	100	125	175	250		500
	Lorentz factor	γ		1,96E+05	2,45E+05	3,42E+05	4,89E+05		9,78E+05
	Collision rate	f_{rep}	Hz	5	5	5	5		4
	Electron linac rate	f_{linac}	Hz	10	10	5	5		4
	Number of bunches	n_b		1312	1312	1312	1312		2625
	Electron bunch population	N_-	$\times 10^{10}$	2	2	2	2		2
	Positron bunch population	N_+	$\times 10^{10}$	2	2	2	2		2
	Bunch seperation	Δt_b	ns	740	740	740	740		356
	Bunch seperation $\times f_{RF}$	$\Delta t_b f_{RF}$		962	962	962	962		463
	Pulse current	I_{beam}	mA	4,33	4,33	4,33	4,33		9,00
	RMS bunch length	σ_z	mm	0,3	0,3	0,3	0,3		0,3
	Electron RMS energy spread	$\Delta p/p$	%	0,22	0,22	0,22	0,21		0,11
	Positron RMS energy spread	$\Delta p/p$	%	0,17	0,14	0,10	0,07		0,04
	Electron polarisation	P_-	%	80	80	80	80		80
	Positron polarisation	P_+	%	31	31	29	22		22
	Horizontal emittance (linac exit)	$\gamma\varepsilon_x$	µm	10	10	10	10		10
	Vertical emittance (linac exit)	$\gamma\varepsilon_y$	nm	35	35	35	35		35
	IP horizontal beta function	$\beta_x{}^*$	mm	16	12	15	11		30
	IP vertical beta function (no TF)	$\beta_y{}^*$	mm	0,48	0,48	0,48	0,48		0,30
	IP vertical beta function (TF)	$\beta_y{}^*$	mm	0,2	0,2	0,2	0,2		0,2
	IP RMS horizontal beam size	$\sigma_x{}^*$	nm	904	700	662	474		554
	IP RMS veritcal beam size (no TF)	$\sigma_y{}^*$	nm	9,3	8,3	7,0	5,9		3,3
	IP RMS veritcal beam size (TF)	$\sigma_y{}^*$	nm	6,0	5,3	4,5	3,8		2,7
No TF	Horizontal distruption parameter	D_x		0,2	0,3	0,2	0,3		0,1

Recently Updated ILC Machine Parameters (cont.)



IP and General Parameters										
										upgrade
		Centre-of-mass energy	E_{cm}	**GeV**	**200**	**250**	**350**	**500**		**1000**
		Vertical disruption parameter	D_y		20,7	23,8	21,3	24,9		19,2
		Horizontal enhancement factor	H_{Dx}		1,1	1,1	1,1	1,2		1,0
		Vertical enhancement factor	H_{Dy}		5,7	6,0	5,8	6,1		3,6
		Total enhancement factor	H_D		1,8	1,9	1,8	2,0		1,5
		Geometric luminosity	L_{geom}	$\times10^{34}$ cm^{-2}s^{-1}	0,2	0,4	0,5	0,8		1,8
		Luminosity	L	$\times10^{34}$ cm^{-2}s^{-2}	**0,5**	**0,7**	**0,8**	**1,5**		**2,8**
		Fraction of luminosity in top 1%	$L_{0.01}/L$			0,96	0,88	0,73		
		Average beamstrahlung parameter	Υ_{av}		0,013	0,021	0,032	0,063		0,109
		Maximum beamstrahlung parameter	Υ_{max}		0,032	0,051	0,075	0,150		0,260
		Average number of photons / particl	n_γ		0,96	1,22	1,28	1,74		1,46
		Average energy loss	δE_{BS}	%	0,53	1,04	1,55	3,76		4,83
		Number of pairs per bunch crossing	N_{pair}	$\times10^3$		97,4	214	494		
With TF		**Luminosity**	L	$\times10^{34}$ cm^{-2}s^{-2}	**0,5**	**0,8**	**1,0**	**2,0**		
		Average energy loss	δE_{BS}	%		0,6	1,6	3,6		
		Number of pairs per bunch crossing	N_{pair}	$\times10^3$		115	255	596		
		Fraction of luminosity in top 1%	$L_{0.01}/L$			0,89	0,77	0,72		

Recently Updated ILC Machine Parameters



TF = traveling focus

Physics and Detector Studies of New ILC Parameters

- **Effects which have been studied**
  - Luminosity at low E_{cms}
  - Effective luminosity due to Beamstrahlung losses
  - Machine backgrounds – Takashi Maruyama
- **Physics processes studied to assess impact**

  $e^+e^- \to Z\,h \to \mu^+\,\mu^-$ Higgs
  - Higgs mass – Hengne Li
  - Higgs cross section – Hengne Li
  - Higgs branching ratios - Hiroaki Ono at ECFA IWLC

  Stau detection (forward electron vetoes) – Mikael Berggren et al.

  Low mass SUSY scenarios study – Paul Grannis
  - Snowmass SM2 benchmark
    - (m_0 = 100 GeV, $m_{1/2}$ = 250 GeV, tan β = 10, A_0 = 0, and sign μ = +) - similar to SPS1a point

Higgs threshold spin analysis

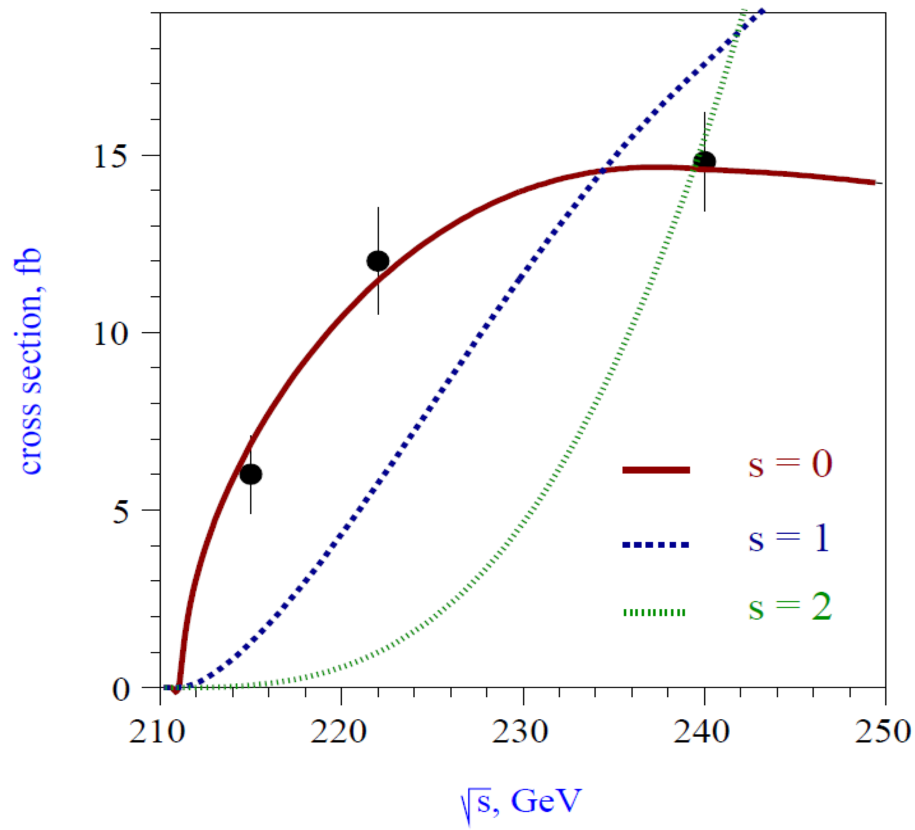


FIGURE 2. The cross sections determined at $\sqrt{s}$ = 215, 222 and 240 GeV (dots) and the predictions for s=0 (full line), s=1 (dashed line) and s=2 (dotted line).

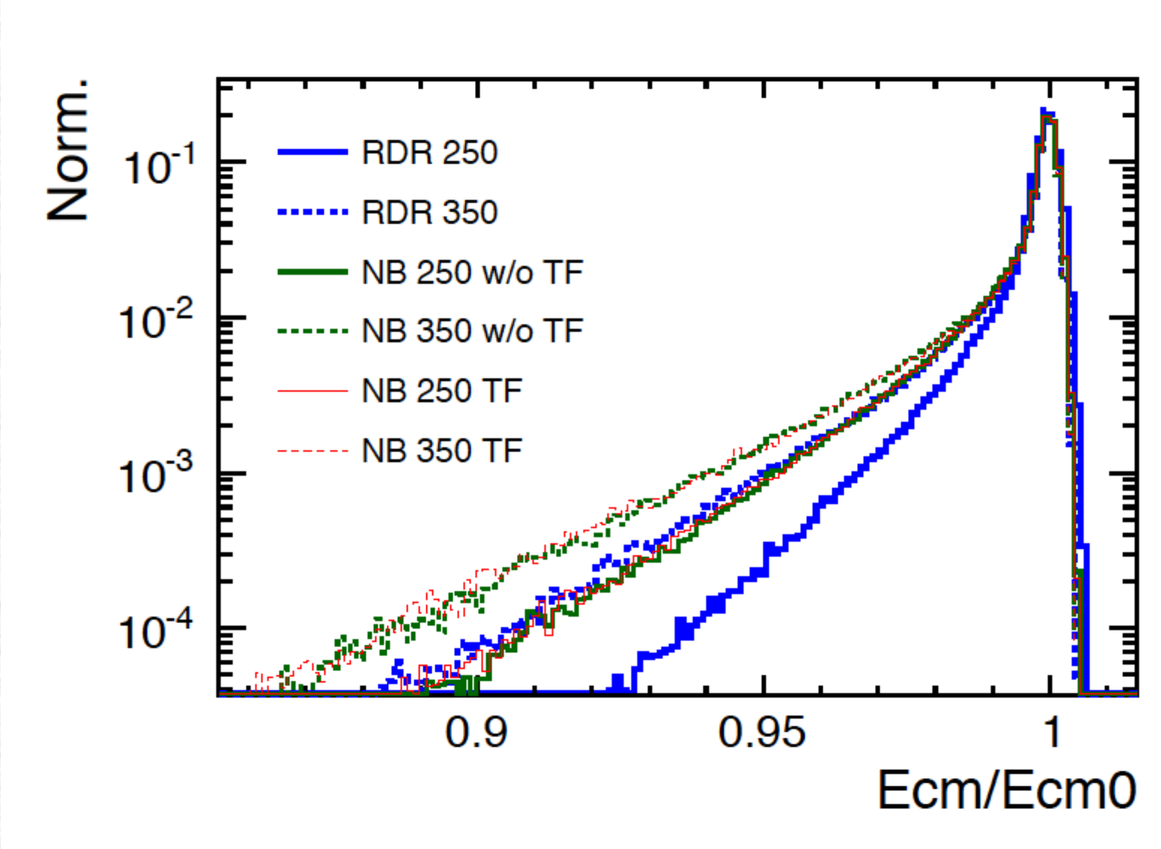
20 fb^{-1} at each energy point

This is an example of the need for good low energy luminosity

hep-ph/0302113 Dova, Garcia-Abia and Lohmann

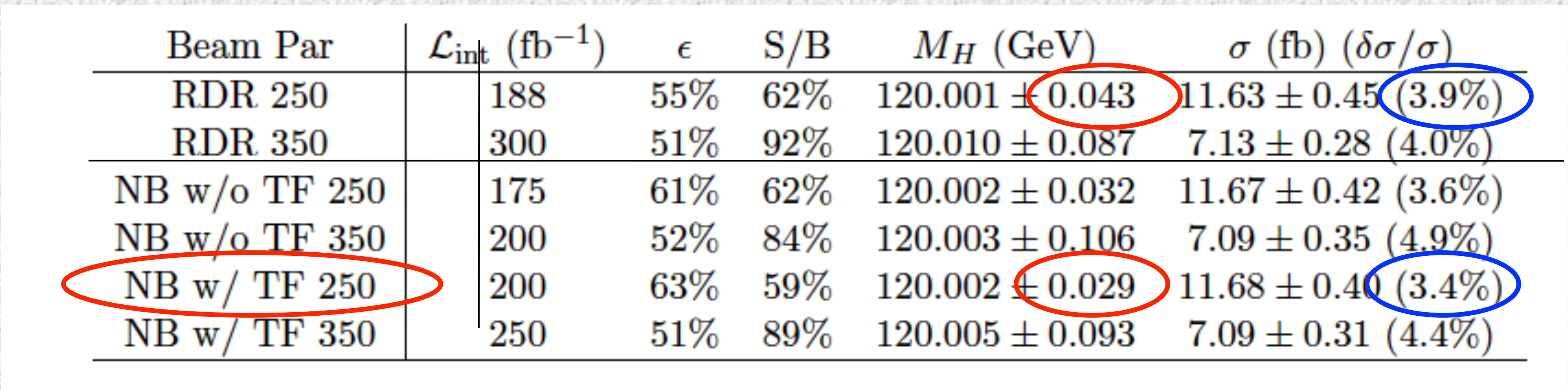
Higgs Mass and Cross Section

- Higgs measurements are best done at E_{cm}=250 GeV
- New Study of Higgs Recoil Mass compares new machine parameters with RDR, and operation @ 350 GeV - Hegne Li



Hengne Li

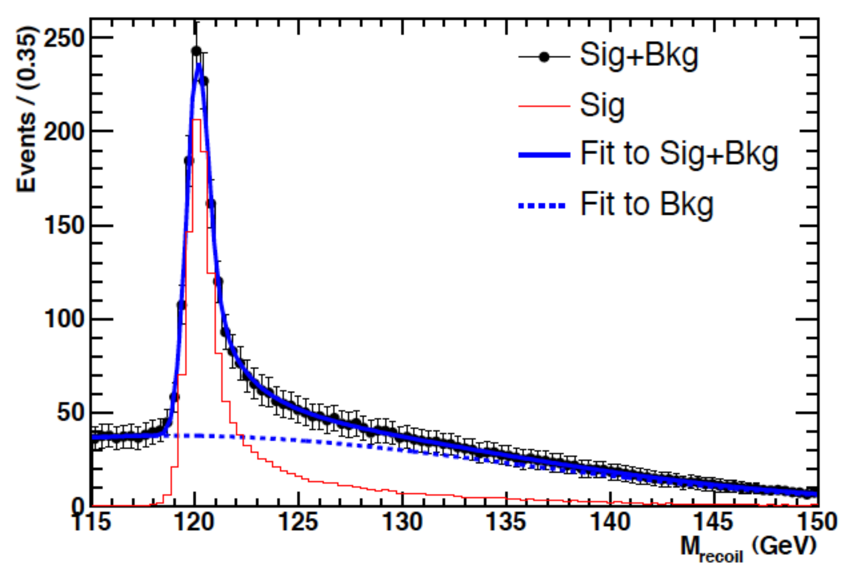
Higgs Mass and Cross Section



Beam Par	$\mathcal{L}_{\text{int}}$ (fb^{-1})	ϵ	S/B	M_H (GeV)	σ (fb) ($\delta\sigma/\sigma$)
RDR 250	188	55%	62%	120.001 ± 0.043	11.63 ± 0.45 (3.9%)
RDR 350	300	51%	92%	120.010 ± 0.087	7.13 ± 0.28 (4.0%)
NB w/o TF 250	175	61%	62%	120.002 ± 0.032	11.67 ± 0.42 (3.6%)
NB w/o TF 350	200	52%	84%	120.003 ± 0.106	7.09 ± 0.35 (4.9%)
NB w/ TF 250	200	63%	59%	120.002 ± 0.029	11.68 ± 0.40 (3.4%)
NB w/ TF 350	250	51%	89%	120.005 ± 0.093	7.09 ± 0.31 (4.4%)

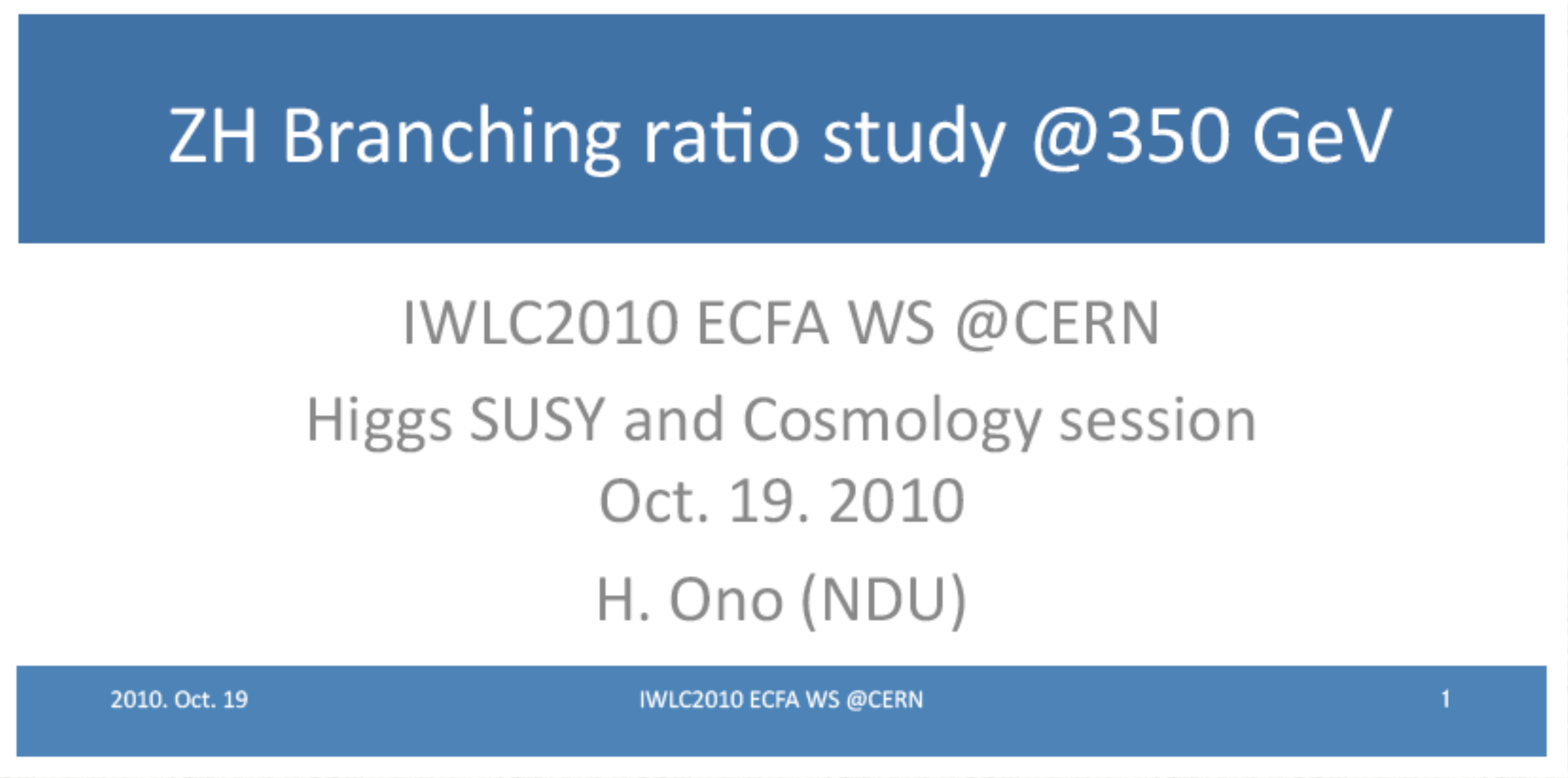
Coupling precision (cross section) better
with new parameters than RDR

Higgs precision improvements:
δM: 43 MeV → 29 MeV (wTF)
δσ: 3.9% → 3.4% (wTF)



Higgs Branching Ratios

- Study in progress
- Preliminary results presented in Geneva



ZH Branching ratio study @350 GeV

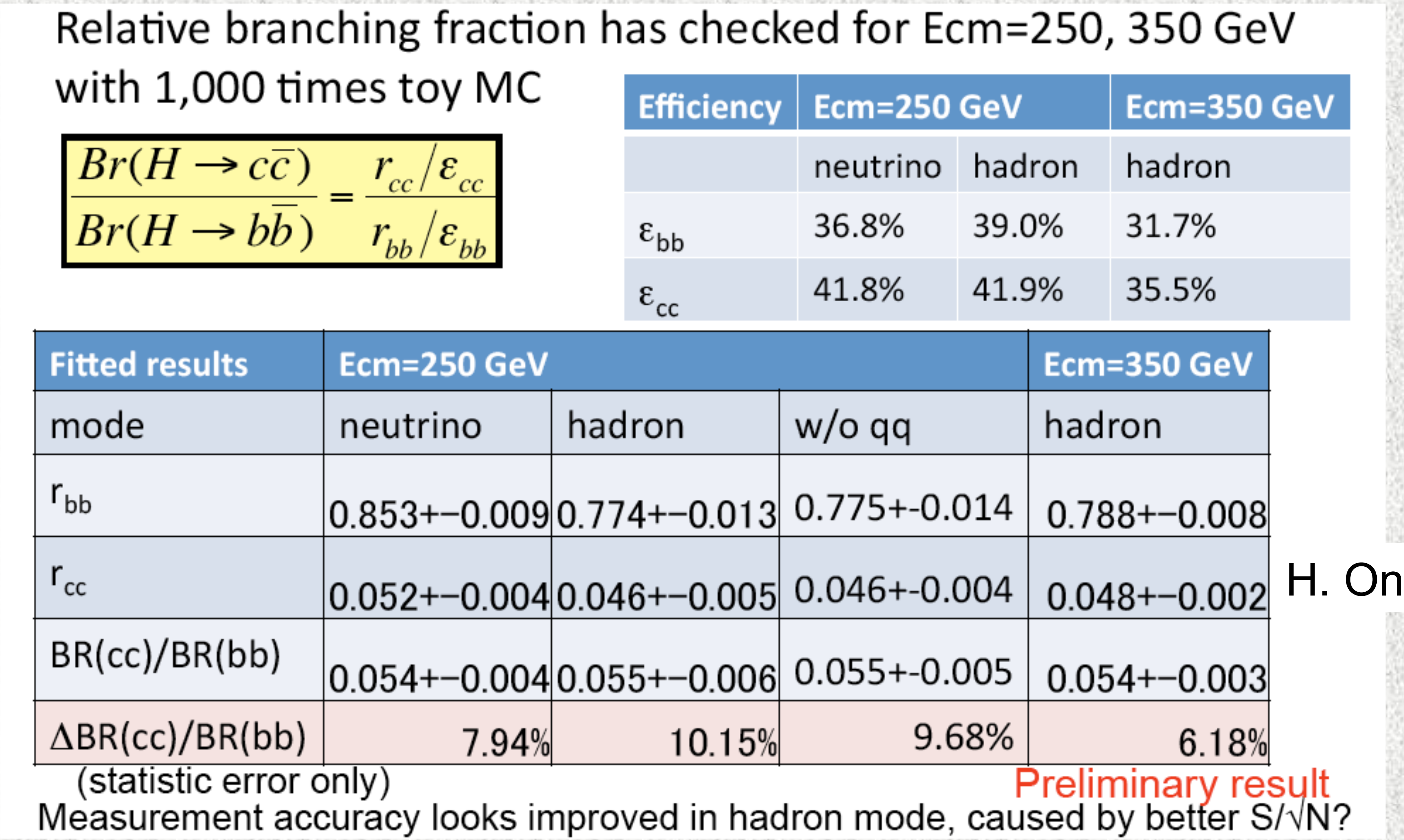
IWLC2010 ECFA WS @CERN

Higgs SUSY and Cosmology session
Oct. 19. 2010

H. Ono (NDU)

2010. Oct. 19 IWLC2010 ECFA WS @CERN 1

Higgs Branching Ratios



Relative branching fraction has checked for Ecm=250, 350 GeV with 1,000 times toy MC

$$\boxed{\frac{Br(H \to c\bar{c})}{Br(H \to b\bar{b})} = \frac{r_{cc}/\varepsilon_{cc}}{r_{bb}/\varepsilon_{bb}}}$$

Efficiency	Ecm=250 GeV		Ecm=350 GeV
	neutrino	hadron	hadron
ε_{bb}	36.8%	39.0%	31.7%
ε_{cc}	41.8%	41.9%	35.5%

Fitted results	Ecm=250 GeV			Ecm=350 GeV
mode	neutrino	hadron	w/o qq	hadron
r_{bb}	0.853+−0.009	0.774+−0.013	0.775+-0.014	0.788+−0.008
r_{cc}	0.052+−0.004	0.046+−0.005	0.046+-0.004	0.048+−0.002
BR(cc)/BR(bb)	0.054+−0.004	0.055+−0.006	0.055+-0.005	0.054+−0.003
ΔBR(cc)/BR(bb)	7.94%	10.15%	9.68%	6.18%

(statistic error only)

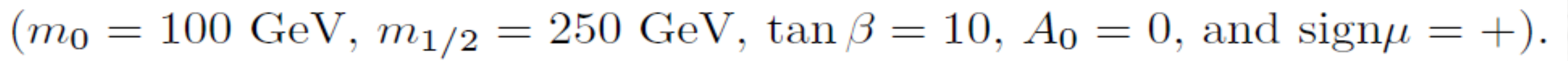
Preliminary result

Measurement accuracy looks improved in hadron mode, caused by better S/√N?

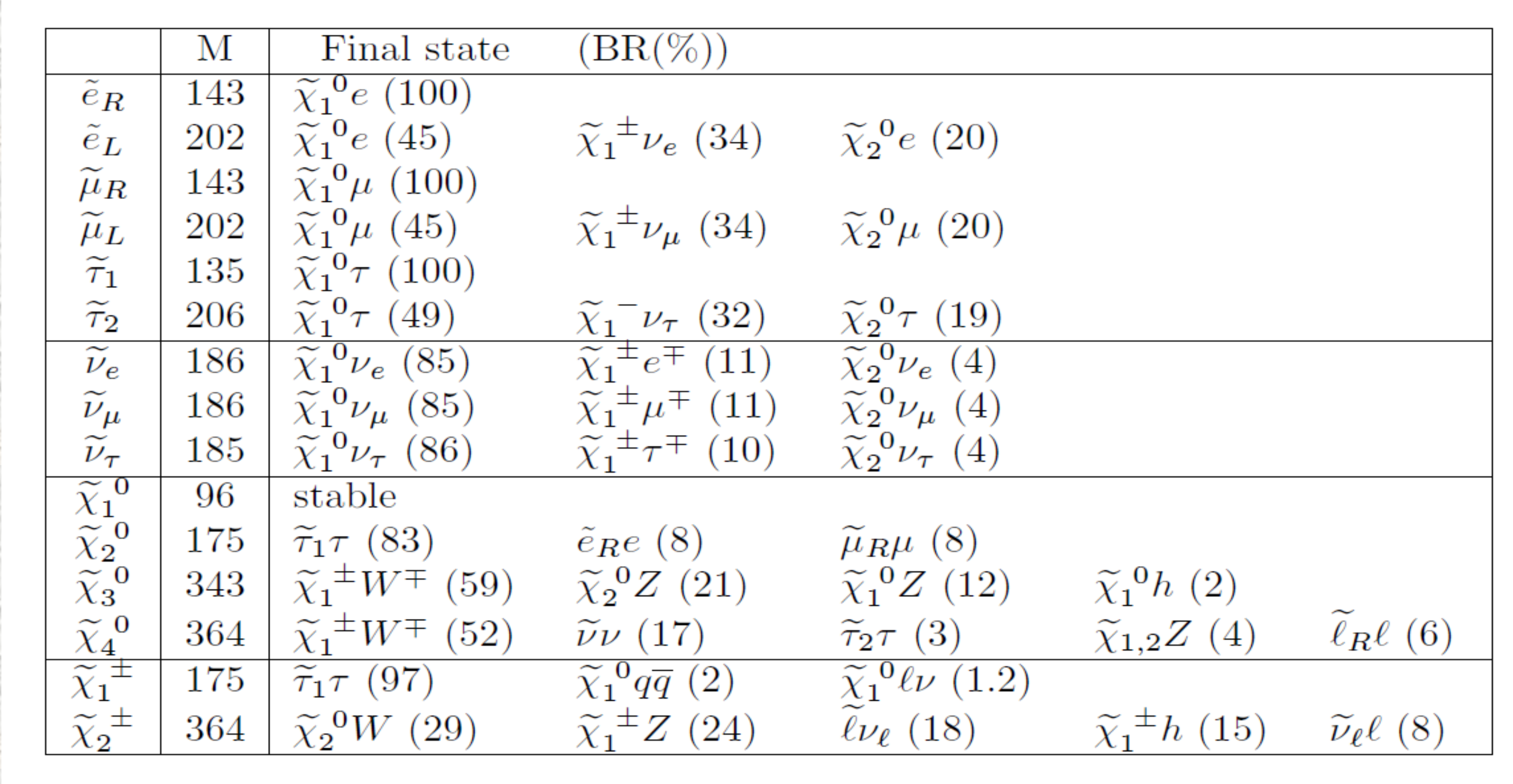
H. Ono

Low mass SUSY scenarios study

- Study of Snowmass SM2 point (~ SPS1a point)
  - hep-ex/0211002v1, P. Grannis

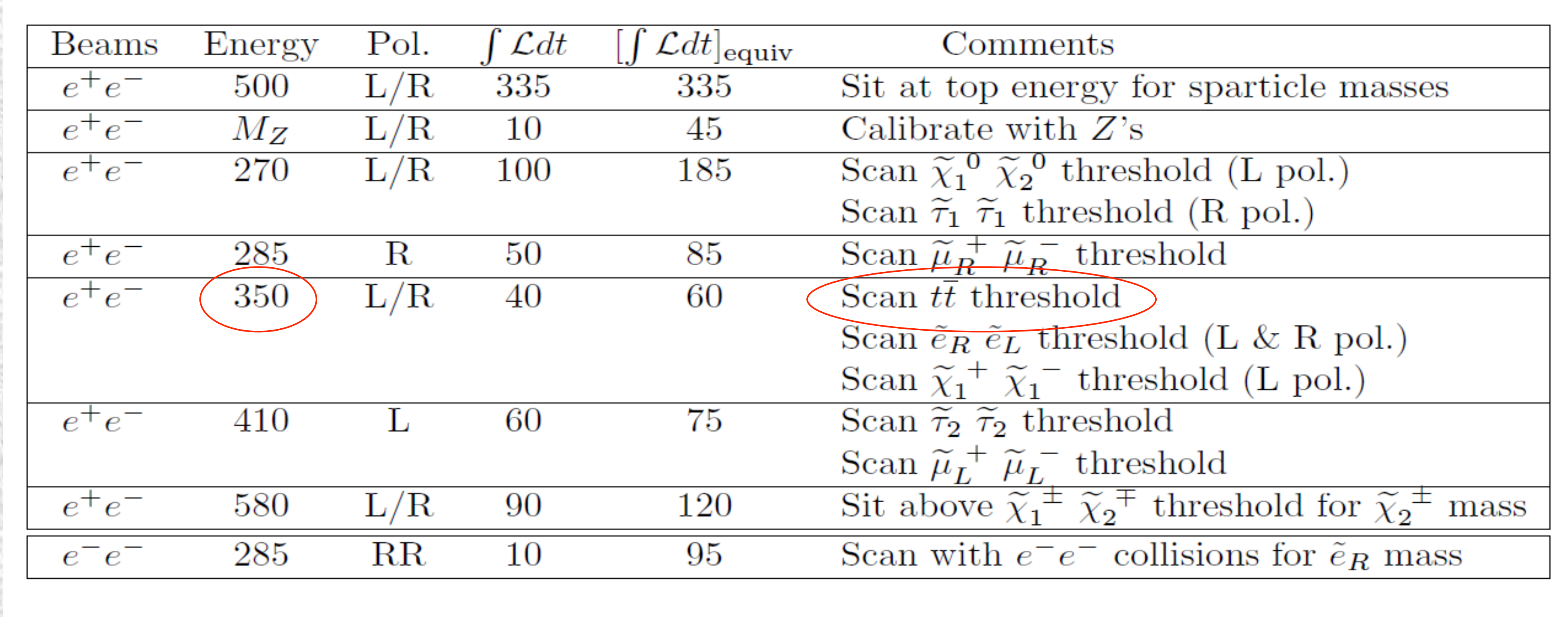


$(m_0 = 100\ \text{GeV},\ m_{1/2} = 250\ \text{GeV},\ \tan\beta = 10,\ A_0 = 0, \text{ and sign}\mu = +).$



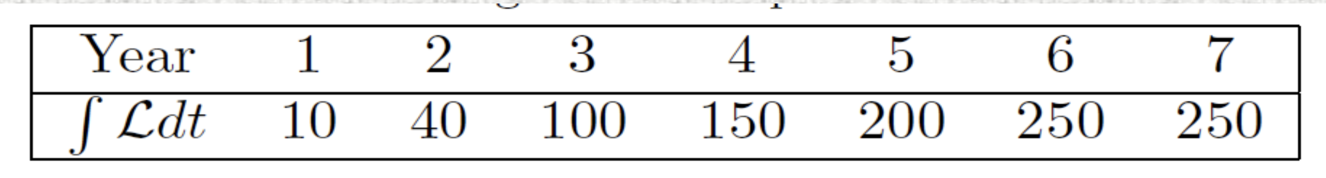
	M	Final state	(BR(%))			
$\tilde{e}_R$	143	$\widetilde{\chi}_1{}^0 e$ (100)				
$\tilde{e}_L$	202	$\widetilde{\chi}_1{}^0 e$ (45)	$\widetilde{\chi}_1{}^\pm \nu_e$ (34)	$\widetilde{\chi}_2{}^0 e$ (20)		
$\widetilde{\mu}_R$	143	$\widetilde{\chi}_1{}^0 \mu$ (100)				
$\widetilde{\mu}_L$	202	$\widetilde{\chi}_1{}^0 \mu$ (45)	$\widetilde{\chi}_1{}^\pm \nu_\mu$ (34)	$\widetilde{\chi}_2{}^0 \mu$ (20)		
$\widetilde{\tau}_1$	135	$\widetilde{\chi}_1{}^0 \tau$ (100)				
$\widetilde{\tau}_2$	206	$\widetilde{\chi}_1{}^0 \tau$ (49)	$\widetilde{\chi}_1{}^- \nu_\tau$ (32)	$\widetilde{\chi}_2{}^0 \tau$ (19)		
$\widetilde{\nu}_e$	186	$\widetilde{\chi}_1{}^0 \nu_e$ (85)	$\widetilde{\chi}_1{}^\pm e^\mp$ (11)	$\widetilde{\chi}_2{}^0 \nu_e$ (4)		
$\widetilde{\nu}_\mu$	186	$\widetilde{\chi}_1{}^0 \nu_\mu$ (85)	$\widetilde{\chi}_1{}^\pm \mu^\mp$ (11)	$\widetilde{\chi}_2{}^0 \nu_\mu$ (4)		
$\widetilde{\nu}_\tau$	185	$\widetilde{\chi}_1{}^0 \nu_\tau$ (86)	$\widetilde{\chi}_1{}^\pm \tau^\mp$ (10)	$\widetilde{\chi}_2{}^0 \nu_\tau$ (4)		
$\widetilde{\chi}_1{}^0$	96	stable				
$\widetilde{\chi}_2{}^0$	175	$\widetilde{\tau}_1 \tau$ (83)	$\tilde{e}_R e$ (8)	$\widetilde{\mu}_R \mu$ (8)		
$\widetilde{\chi}_3{}^0$	343	$\widetilde{\chi}_1{}^\pm W^\mp$ (59)	$\widetilde{\chi}_2{}^0 Z$ (21)	$\widetilde{\chi}_1{}^0 Z$ (12)	$\widetilde{\chi}_1{}^0 h$ (2)	
$\widetilde{\chi}_4{}^0$	364	$\widetilde{\chi}_1{}^\pm W^\mp$ (52)	$\widetilde{\nu}\nu$ (17)	$\widetilde{\tau}_2 \tau$ (3)	$\widetilde{\chi}_{1,2} Z$ (4)	$\widetilde{\ell}_R \ell$ (6)
$\widetilde{\chi}_1{}^\pm$	175	$\widetilde{\tau}_1 \tau$ (97)	$\widetilde{\chi}_1{}^0 q\bar{q}$ (2)	$\widetilde{\chi}_1{}^0 \ell\nu$ (1.2)		
$\widetilde{\chi}_2{}^\pm$	364	$\widetilde{\chi}_2{}^0 W$ (29)	$\widetilde{\chi}_1{}^\pm Z$ (24)	$\widetilde{\ell}\nu_\ell$ (18)	$\widetilde{\chi}_1{}^\pm h$ (15)	$\widetilde{\nu}_\ell \ell$ (8)

Low mass SUSY scenarios run allocations



Beams	Energy	Pol.	$\int \mathcal{L}dt$	$[\int \mathcal{L}dt]_{\text{equiv}}$	Comments
e^+e^-	500	L/R	335	335	Sit at top energy for sparticle masses
e^+e^-	M_Z	L/R	10	45	Calibrate with Z's
e^+e^-	270	L/R	100	185	Scan $\widetilde{\chi}_1{}^0\ \widetilde{\chi}_2{}^0$ threshold (L pol.) Scan $\widetilde{\tau}_1\ \widetilde{\tau}_1$ threshold (R pol.)
e^+e^-	285	R	50	85	Scan $\widetilde{\mu}_R{}^+\ \widetilde{\mu}_R{}^-$ threshold
e^+e^-	350	L/R	40	60	Scan $t\bar{t}$ threshold Scan $\tilde{e}_R\ \tilde{e}_L$ threshold (L & R pol.) Scan $\widetilde{\chi}_1{}^+\ \widetilde{\chi}_1{}^-$ threshold (L pol.)
e^+e^-	410	L	60	75	Scan $\widetilde{\tau}_2\ \widetilde{\tau}_2$ threshold Scan $\widetilde{\mu}_L{}^+\ \widetilde{\mu}_L{}^-$ threshold
e^+e^-	580	L/R	90	120	Sit above $\widetilde{\chi}_1{}^\pm\ \widetilde{\chi}_2{}^\mp$ threshold for $\widetilde{\chi}_2{}^\pm$ mass
e^-e^-	285	RR	10	95	Scan with e^-e^- collisions for $\tilde{e}_R$ mass

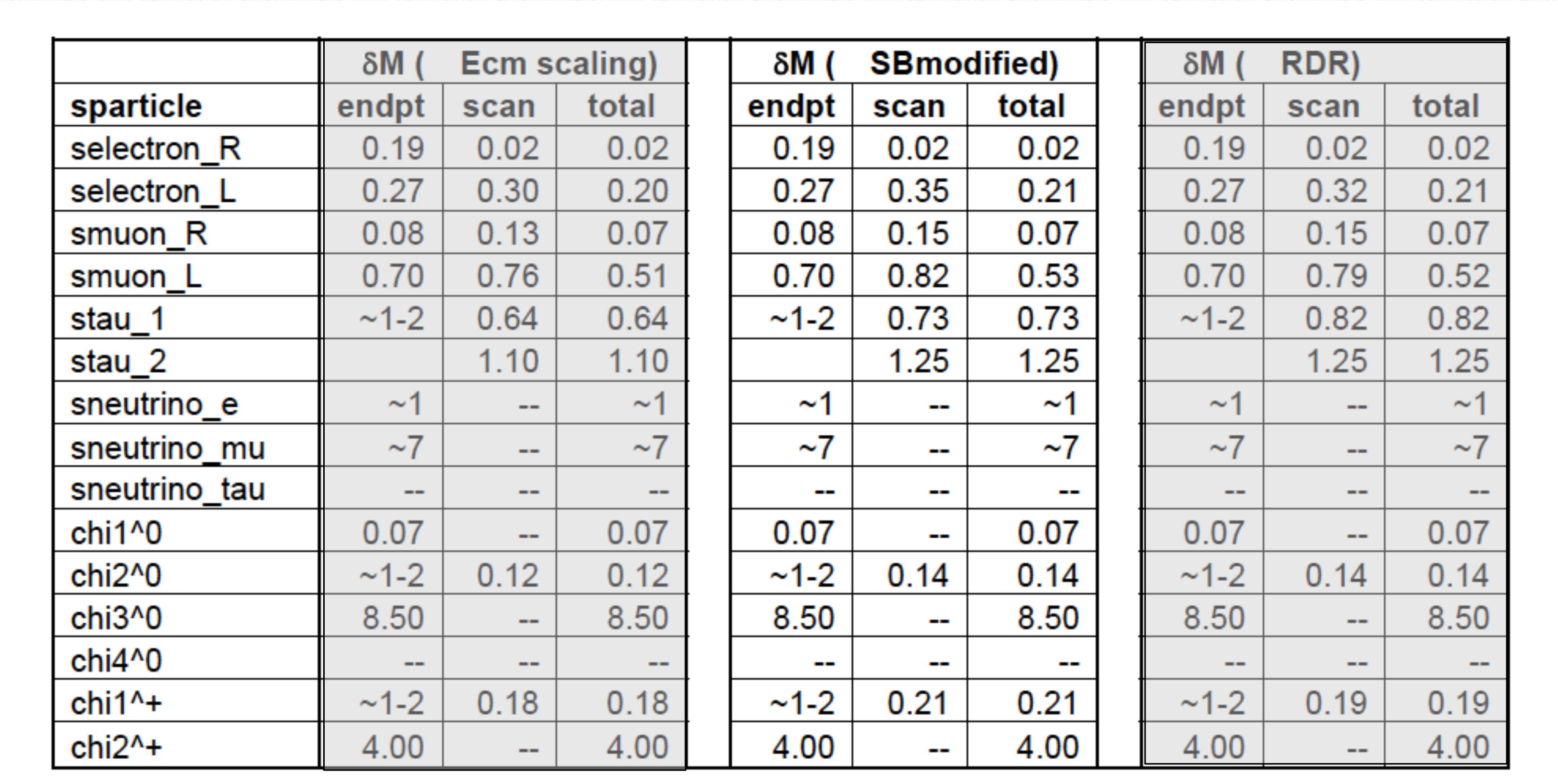
hep-ex/0211002v1, P. Grannis



Year	1	2	3	4	5	6	7
$\int \mathcal{L}dt$	10	40	100	150	200	250	250

~1000 fb^{-1} equivalent luminosity (scaled by L ~ E) required to achieve physics program

Low mass SUSY scenarios run allocations

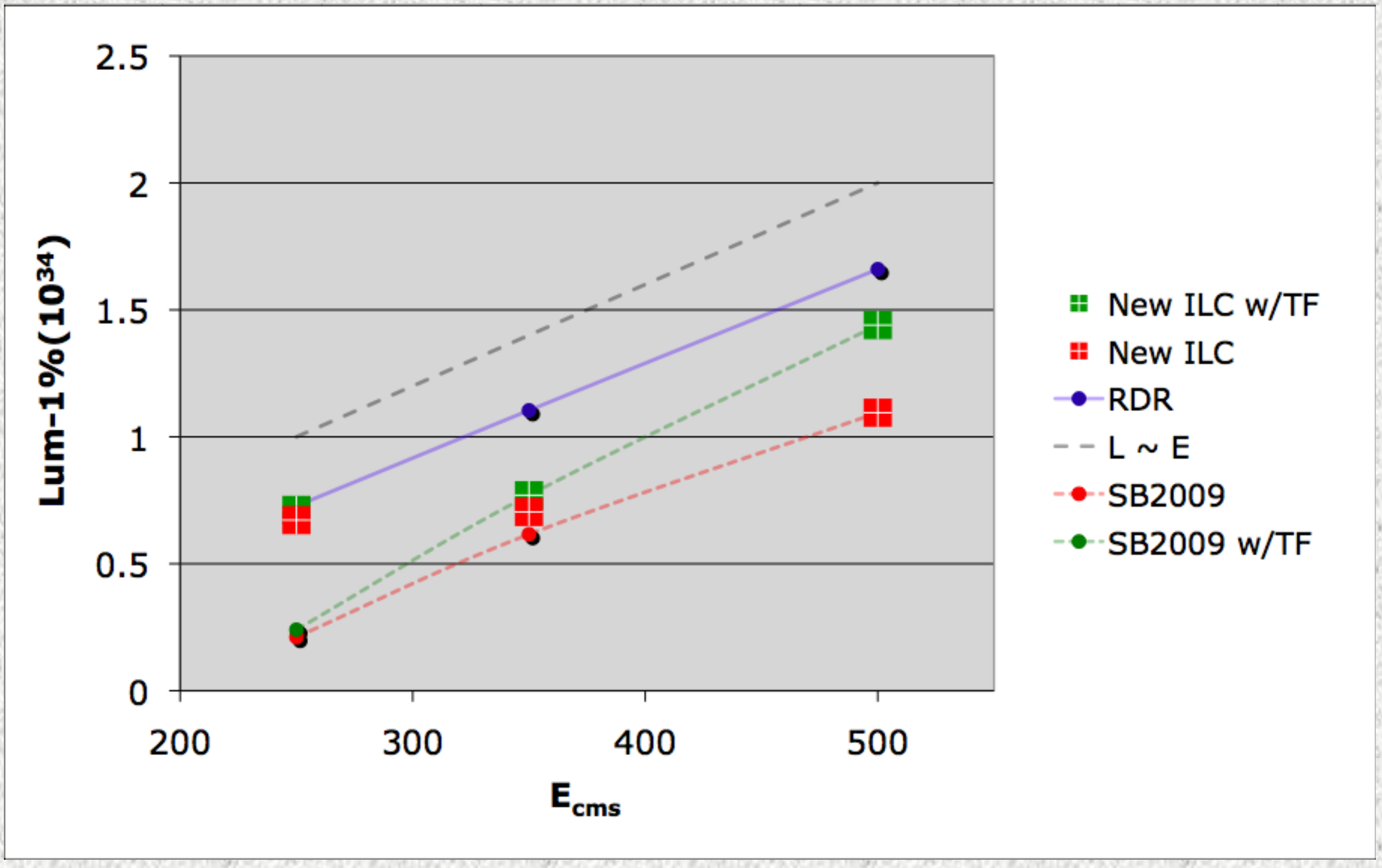


	δM (Ecm scaling)			δM (SBmodified)			δM (RDR)		
sparticle	endpt	scan	total	**endpt**	**scan**	**total**	endpt	scan	total
selectron_R	0.19	0.02	0.02	0.19	0.02	0.02	0.19	0.02	0.02
selectron_L	0.27	0.30	0.20	0.27	0.35	0.21	0.27	0.32	0.21
smuon_R	0.08	0.13	0.07	0.08	0.15	0.07	0.08	0.15	0.07
smuon_L	0.70	0.76	0.51	0.70	0.82	0.53	0.70	0.79	0.52
stau_1	~1-2	0.64	0.64	~1-2	0.73	0.73	~1-2	0.82	0.82
stau_2		1.10	1.10		1.25	1.25		1.25	1.25
sneutrino_e	~1	--	~1	~1	--	~1	~1	--	~1
sneutrino_mu	~7	--	~7	~7	--	~7	~7	--	~7
sneutrino_tau	--	--	--	--	--	--	--	--	--
chi1^0	0.07	--	0.07	0.07	--	0.07	0.07	--	0.07
chi2^0	~1-2	0.12	0.12	~1-2	0.14	0.14	~1-2	0.14	0.14
chi3^0	8.50	--	8.50	8.50	--	8.50	8.50	--	8.50
chi4^0	--	--	--	--	--	--	--	--	--
chi1^+	~1-2	0.18	0.18	~1-2	0.21	0.21	~1-2	0.19	0.19
chi2^+	4.00	--	4.00	4.00	--	4.00	4.00	--	4.00

sparticle mass precision expected in the RDR and SBmodified parameter sets differ little from those with the Ecm luminosity scaling.

P. Grannis, Oct. 28, 2010

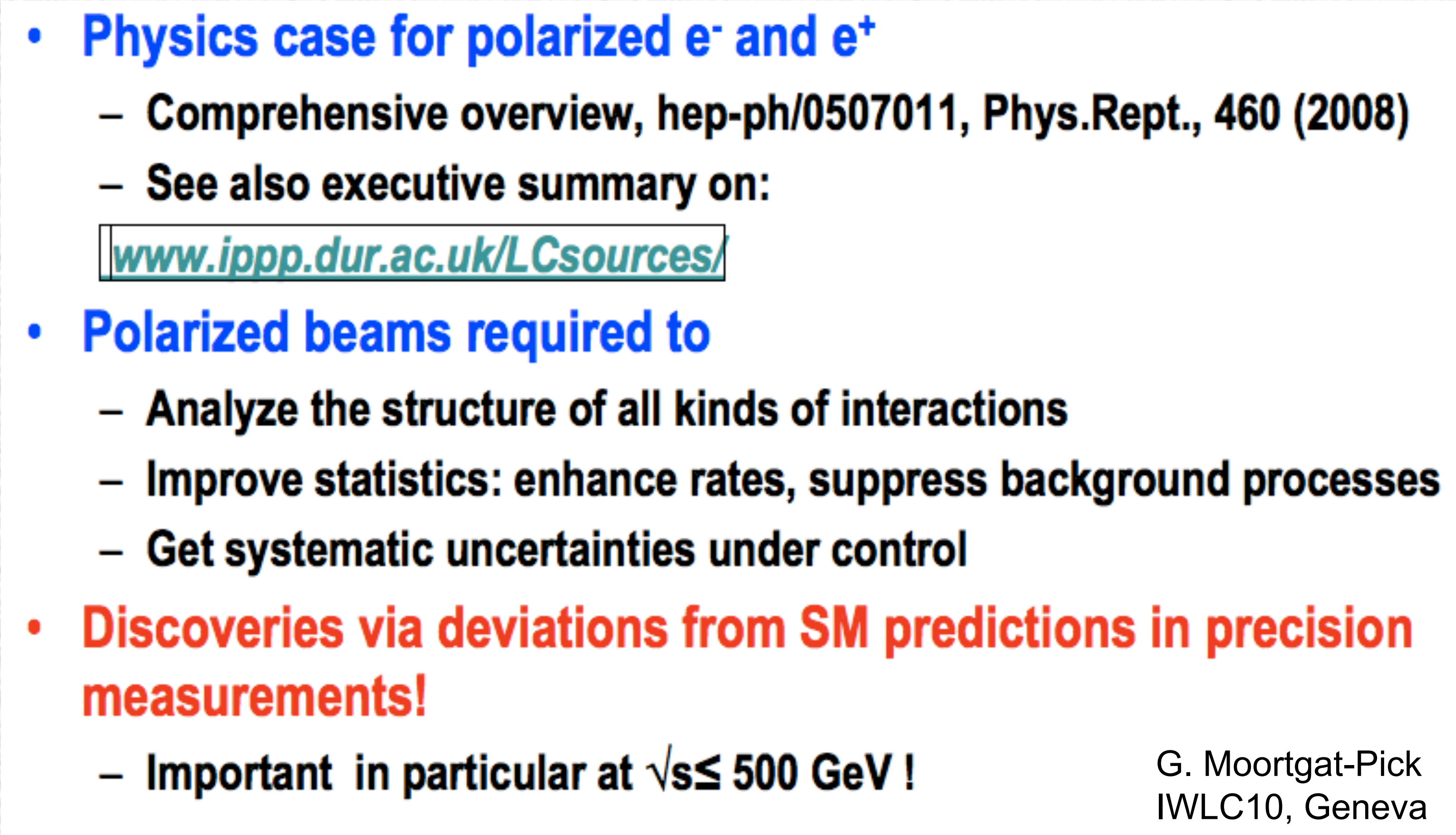
Physics Without Traveling Focus



- Loss of luminosity at highest energies
  - Impact needs to be quantified

Positron Polarization

	250 GeV	350 GeV	500 GeV
Positron Polarization	31%	29%	22%

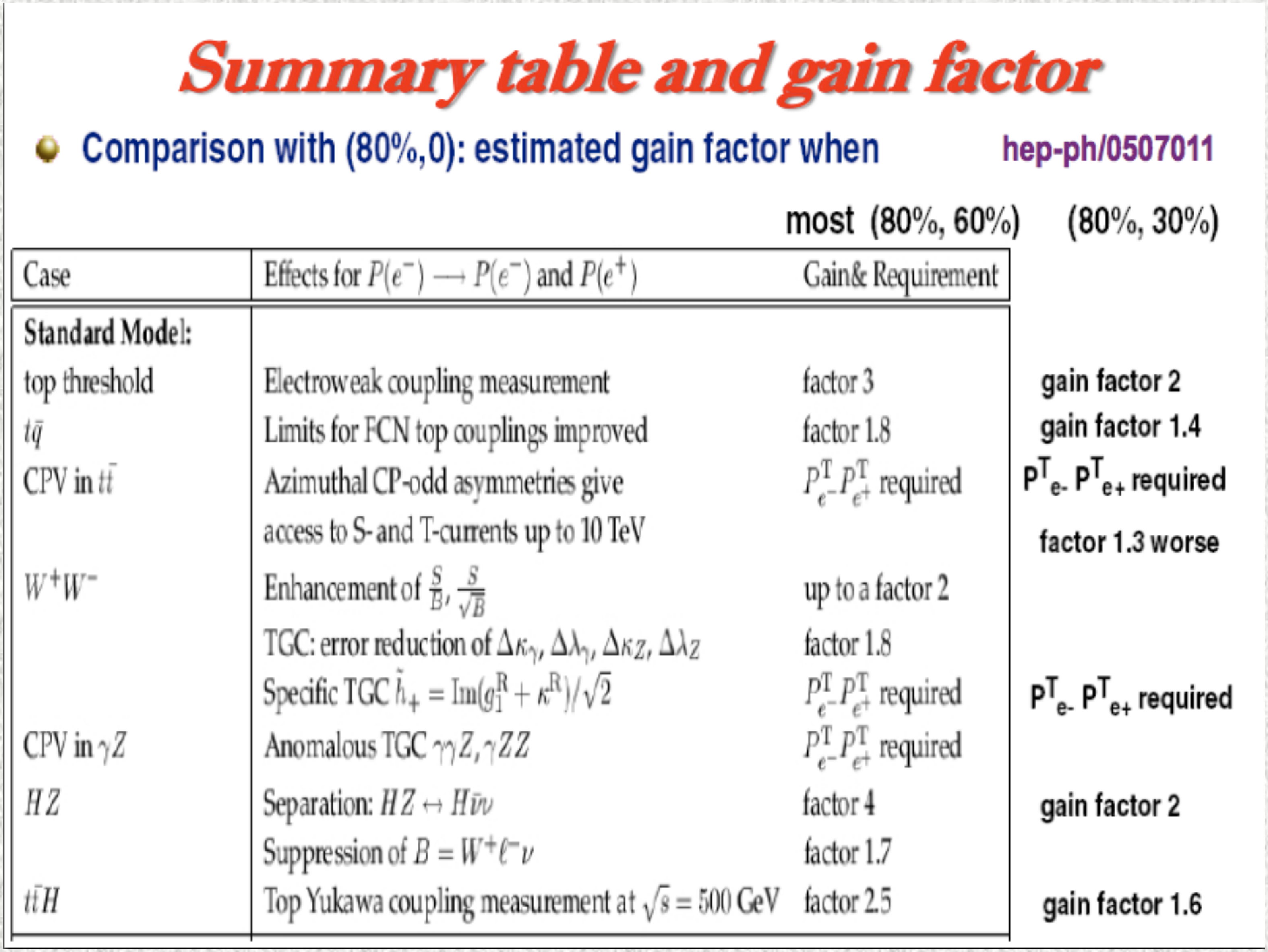


- Physics case for polarized e$^-$ and e$^+$
  - Comprehensive overview, hep-ph/0507011, Phys.Rept., 460 (2008)
  - See also executive summary on:

  www.ippp.dur.ac.uk/LCsources/
- Polarized beams required to
  - Analyze the structure of all kinds of interactions
  - Improve statistics: enhance rates, suppress background processes
  - Get systematic uncertainties under control
- Discoveries via deviations from SM predictions in precision measurements!
  - Important in particular at $\sqrt{s} \leq 500$ GeV !

G. Moortgat-Pick
IWLC10, Geneva

Positron Polarization



Summary table and gain factor

- Comparison with (80%,0): estimated gain factor when

hep-ph/0507011

most (80%, 60%) (80%, 30%)

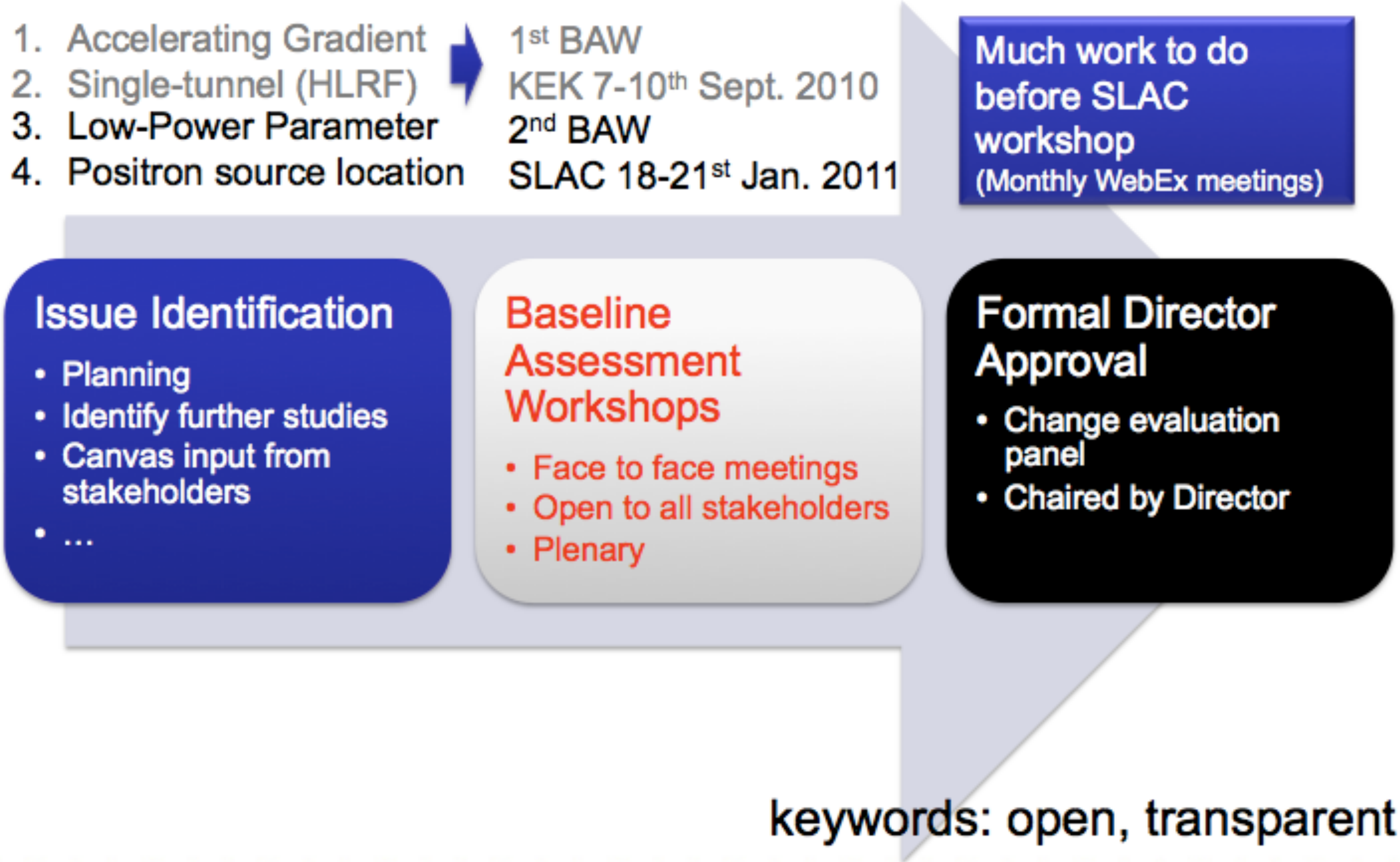
Case	Effects for $P(e^-) \longrightarrow P(e^-)$ and $P(e^+)$	Gain& Requirement	
Standard Model:			
top threshold	Electroweak coupling measurement	factor 3	**gain factor 2**
$t\bar{q}$	Limits for FCN top couplings improved	factor 1.8	**gain factor 1.4**
CPV in $t\bar{t}$	Azimuthal CP-odd asymmetries give	$P^T_{e^-} P^T_{e^+}$ required	**P^T_{e-} P^T_{e+} required**
	access to S- and T-currents up to 10 TeV		**factor 1.3 worse**
W^+W^-	Enhancement of $\frac{S}{B}, \frac{S}{\sqrt{B}}$	up to a factor 2	
	TGC: error reduction of $\Delta\kappa_\gamma, \Delta\lambda_\gamma, \Delta\kappa_Z, \Delta\lambda_Z$	factor 1.8	
	Specific TGC $\tilde{h}_+ = \mathrm{Im}(g_1^R + \kappa^R)/\sqrt{2}$	$P^T_{e^-} P^T_{e^+}$ required	**P^T_{e-} P^T_{e+} required**
CPV in γZ	Anomalous TGC $\gamma\gamma Z, \gamma ZZ$	$P^T_{e^-} P^T_{e^+}$ required	
HZ	Separation: $HZ \leftrightarrow H\bar{\nu}\nu$	factor 4	**gain factor 2**
	Suppression of $B = W^+\ell^-\nu$	factor 1.7	
$t\bar{t}H$	Top Yukawa coupling measurement at $\sqrt{s} = 500$ GeV	factor 2.5	**gain factor 1.6**

G. Moortgat-Pick
IWLC10, Geneva

TLCC Process: BAW2

1. Accelerating Gradient
2. Single-tunnel (HLRF)
3. Low-Power Parameter
4. Positron source location

1st BAW
KEK 7-10th Sept. 2010
2nd BAW
SLAC 18-21st Jan. 2011



Much work to do before SLAC workshop
(Monthly WebEx meetings)

Issue Identification

- Planning
- Identify further studies
- Canvas input from stakeholders
- …

Baseline Assessment Workshops

- Face to face meetings
- Open to all stakeholders
- Plenary

Formal Director Approval

- Change evaluation panel
- Chaired by Director

keywords: open, transparent

Nick Walker

BAW-2 Issues

Travelling Focus

- More detailed simulations required
- Stability issues → impact on feedback and tolerances
- considered higher-risk option
- Inclusion not a cost issue

some studies just starting

10Hz Operation (Low E_{cm})

- Positron damping ring 50% duty cycle
- RF solution still required (this workshop)
- Understanding cost impact (1.9% TPC)
- Other emerging options (high-field undulator)

IWLC10 – solutions exist

Upgrade / Risk-Mitigation

- Understand scenarios for re-establishing RDR bunch number
- Cost impact (mostly CFS)
- Considered either as possible luminosity upgrade or risk-mitigation (GDE PAC)

Physics impact ↔ Working with Physics & Detector groups as part of the TLCC process

Nick Walker

Summary

- The New Baseline Machine Parameters are being studied by the physics and detectors SB2009 Working Group
  - Beamstrahlung losses
  - Machine backgrounds
  - Higgs mass, cross section, & branching ratios
  - Stau detection
  - Low mass SUSY scenario (an example)
  - Polarization
- The improvement in the low energy luminosity performance over the past year appears to have significantly restored physics potential of the ILC design
- We assume traveling focus will be implemented
  - Without it, the main impact would be at the highest energies (~25% loss of luminosity)