Vector Boson Scattering at Lepton Colliders

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HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Motivation for Vector Boson Scattering

Physics potential of Vector Boson Scattering:

1. Precision test of the electroweak SM at high energies
2. The Higgs Mechanism at work
3. Anomalous Higgs couplings (beyond branching ratios)
4. New Higgs-sector physics: the Higgs Portal
   - Extra Higgses
   - Resonances excited by VBF
   - Strong interactions, continuum, compositeness, top quarks
   - New final states (Dark Matter ?)

Requirements / Benefits at High-Energy Lepton colliders $s \gtrsim 1\ \text{TeV}^2$

1. High energy: $s \gtrsim 1\ \text{TeV}^2$
2. Well-defined initial state: electroweak production (small theory errors)
3. High precision, triggerless operation: complete coverage of final states
4. Separation of spin, isospin, CP quantum number
5. Discriminating power even on (some) light quark flavors

Deviations as EFT — Dim 8 Operators

Motivated by SMEFT:

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \left[\frac{c_i^{(5)}}{\Lambda} \mathcal{O}_i^{(5)} + \frac{c_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \frac{c_i^{(7)}}{\Lambda^3} \mathcal{O}_i^{(7)} + \frac{c_i^{(8)}}{\Lambda^4} \mathcal{O}_i^{(8)} + \dots \right]$$

S. Weinberg, 1979 — Buchmüller/Wyler, 1986

Grzadkowski/Iskrzysnki/Misiak/Rosiek, 2010

Eboli/Gonzalez-Garcia/Mizukoshi, 2006

Alboteanu/Kilian/JRR, 2008 — Kilian/Ohl/JRR/Sekulla, 2014

Longitudinal operators

$$\mathcal{L}_{S,0} = F_{S,0} \mathrm{tr}\left[(\mathbf{D}_\mu \mathbf{H})^\dagger (\mathbf{D}_\nu \mathbf{H})\right] \mathrm{tr}\left[(\mathbf{D}^\mu \mathbf{H})^\dagger (\mathbf{D}^\nu \mathbf{H})\right]$$

$$\mathcal{L}_{S,1} = F_{S,1} \mathrm{tr}\left[(\mathbf{D}_\mu \mathbf{H})^\dagger (\mathbf{D}^\mu \mathbf{H})\right] \mathrm{tr}\left[(\mathbf{D}_\nu \mathbf{H})^\dagger (\mathbf{D}^\nu \mathbf{H})\right]$$

Mixed operators

$$\mathcal{L}_{M,0} = -g^2 F_{M_0} \mathrm{tr}\left[(\mathbf{D}_\mu \mathbf{H})^\dagger (\mathbf{D}^\mu \mathbf{H})\right] \mathrm{tr}\left[\mathbf{W}_{\nu\rho}\mathbf{W}^{\nu\rho}\right]$$

$$\mathcal{L}_{M,1} = -g^2 F_{M_1} \mathrm{tr}\left[(\mathbf{D}_\mu \mathbf{H})^\dagger (\mathbf{D}^\rho \mathbf{H})\right] \mathrm{tr}\left[\mathbf{W}_{\nu\rho}\mathbf{W}^{\nu\mu}\right]$$

$$\mathcal{L}_{M,2} = -g'^2 F_{M_2} \mathrm{tr}\left[(\mathbf{D}_\mu \mathbf{H})^\dagger (\mathbf{D}^\mu \mathbf{H})\right] \mathrm{tr}\left[\mathbf{B}_{\nu\rho}\mathbf{B}^{\nu\rho}\right]$$

$$\mathcal{L}_{M,3} = -g'^2 F_{M_3} \mathrm{tr}\left[(\mathbf{D}_\mu \mathbf{H})^\dagger (\mathbf{D}^\rho \mathbf{H})\right] \mathrm{tr}\left[\mathbf{B}_{\nu\rho}\mathbf{B}^{\nu\mu}\right]$$

$$\mathcal{L}_{M,4} = -g g' F_{M_4} \mathrm{tr}\left[(\mathbf{D}_\mu \mathbf{H})^\dagger \mathbf{W}_{\nu\rho} (\mathbf{D}^\mu \mathbf{H}) \mathbf{B}^{\nu\rho}\right],$$

$$\mathcal{L}_{M,5} = -g g' F_{M_5} \mathrm{tr}\left[(\mathbf{D}_\mu \mathbf{H})^\dagger \mathbf{W}_{\nu\rho} (\mathbf{D}^\rho \mathbf{H}) \mathbf{B}^{\nu\mu}\right],$$

$$\mathcal{L}_{M,7} = -g^2 F_{M_7} \mathrm{tr}\left[(\mathbf{D}_\mu \mathbf{H})^\dagger \mathbf{W}_{\nu\rho} \mathbf{W}^{\nu\mu} (\mathbf{D}^\rho \mathbf{H})\right];$$

Transversal operators

$$\mathcal{L}_{T,0} = g^4 F_{T_0} \mathrm{tr}\left[\mathbf{W}_{\mu\nu}\mathbf{W}^{\mu\nu}\right] \mathrm{tr}\left[\mathbf{W}_{\alpha\beta}\mathbf{W}^{\alpha\beta}\right],$$

$$\mathcal{L}_{T,1} = g^4 F_{T_1} \mathrm{tr}\left[\mathbf{W}_{\alpha\nu}\mathbf{W}^{\mu\beta}\right] \mathrm{tr}\left[\mathbf{W}_{\mu\beta}\mathbf{W}^{\alpha\nu}\right],$$

$$\mathcal{L}_{T,2} = g^4 F_{T_2} \mathrm{tr}\left[\mathbf{W}_{\alpha\mu}\mathbf{W}^{\mu\beta}\right] \mathrm{tr}\left[\mathbf{W}_{\beta\nu}\mathbf{W}^{\nu\alpha}\right],$$

$$\mathcal{L}_{T,5} = g^2 g'^2 F_{T_5} \mathrm{tr}\left[\mathbf{W}_{\mu\nu}\mathbf{W}^{\mu\nu}\right] \mathrm{tr}\left[\mathbf{B}_{\alpha\beta}\mathbf{B}^{\alpha\beta}\right],$$

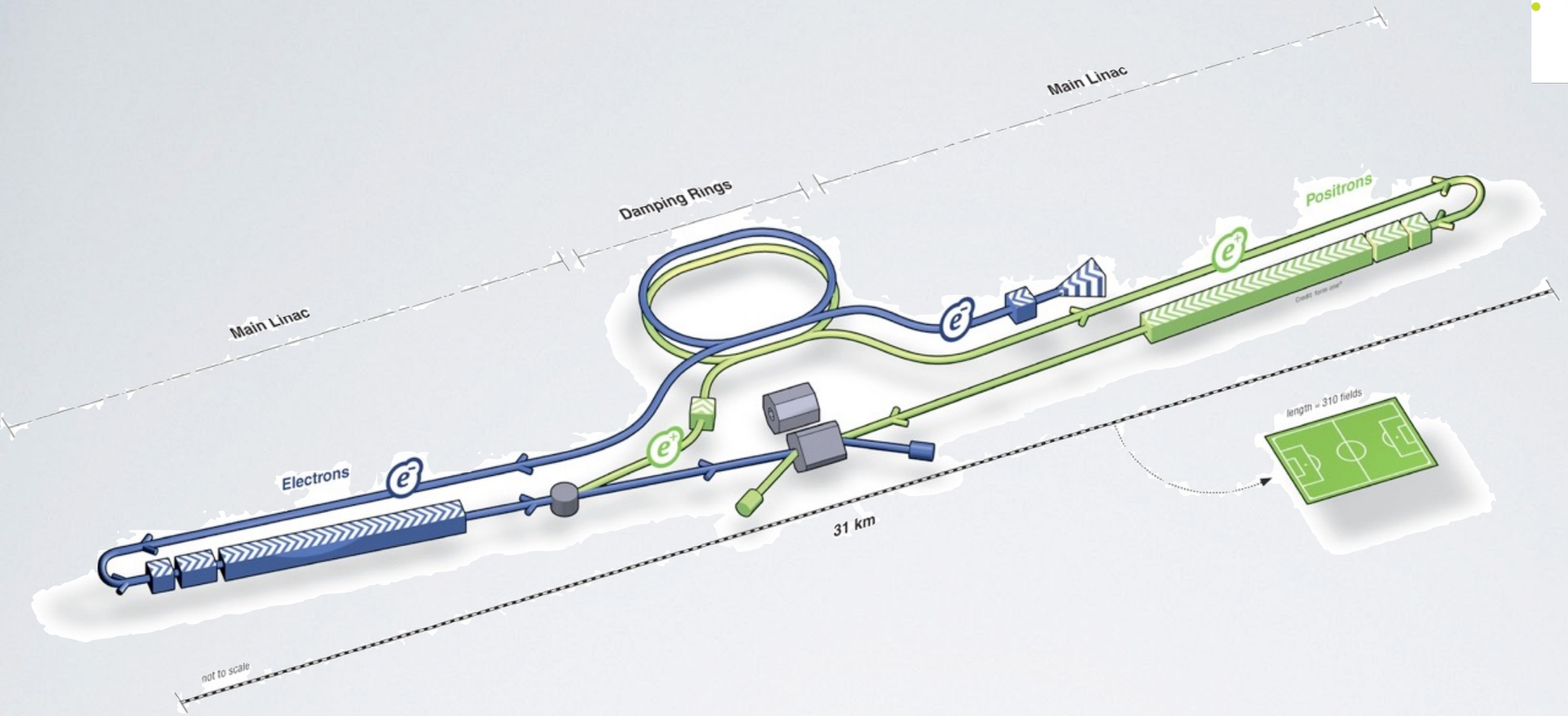
$$\mathcal{L}_{T,6} = g^2 g'^2 F_{T_6} \mathrm{tr}\left[\mathbf{W}_{\alpha\nu}\mathbf{W}^{\mu\beta}\right] \mathrm{tr}\left[\mathbf{B}_{\mu\beta}\mathbf{B}^{\alpha\nu}\right],$$

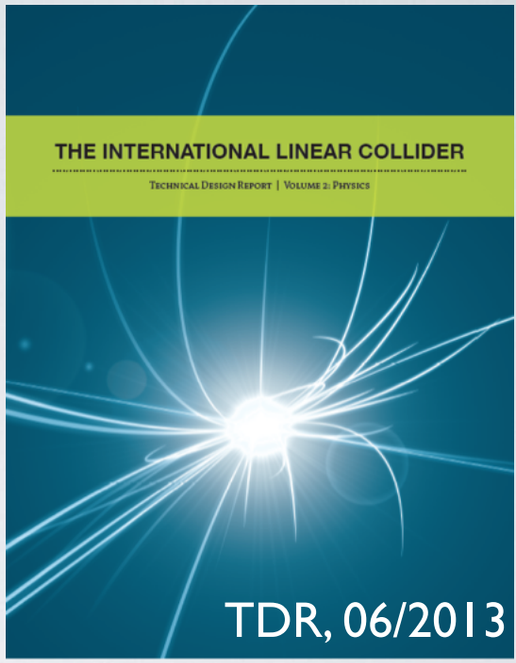
$$\mathcal{L}_{T,7} = g^2 g'^2 F_{T_7} \mathrm{tr}\left[\mathbf{W}_{\alpha\mu}\mathbf{W}^{\mu\beta}\right] \mathrm{tr}\left[\mathbf{B}_{\beta\nu}\mathbf{B}^{\nu\alpha}\right],$$

$$\mathcal{L}_{T,8} = g'^4 F_{T_8} \mathrm{tr}\left[\mathbf{B}_{\mu\nu}\mathbf{B}^{\mu\nu}\right] \mathrm{tr}\left[\mathbf{B}_{\alpha\beta}\mathbf{B}^{\alpha\beta}\right],$$

$$\mathcal{L}_{T,9} = g'^4 F_{T_9} \mathrm{tr}\left[\mathbf{B}_{\alpha\mu}\mathbf{B}^{\mu\beta}\right] \mathrm{tr}\left[\mathbf{B}_{\beta\nu}\mathbf{B}^{\nu\alpha}\right].$$

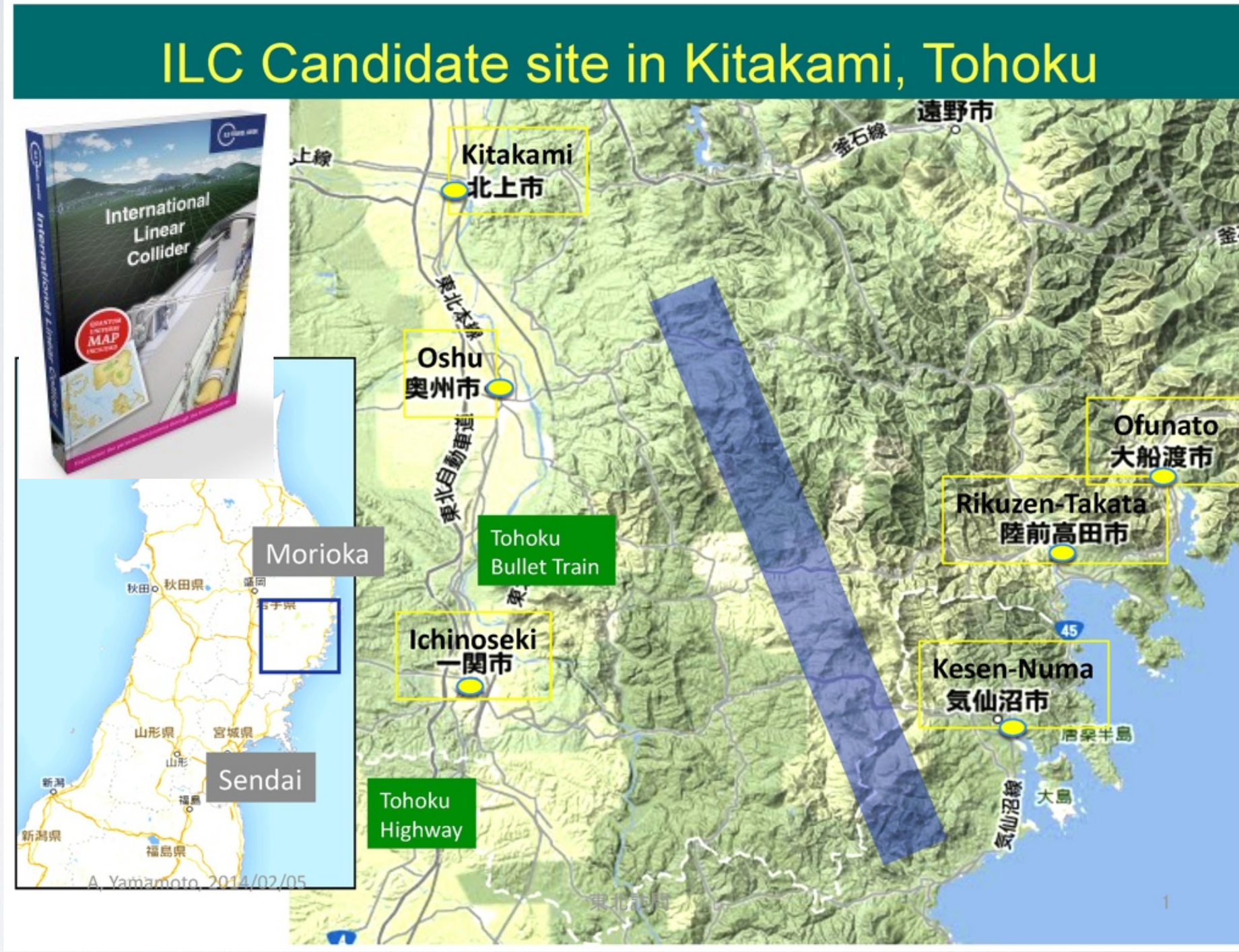
ILC — 250–500 GeV e^+e^- Collider





- e^+e^- collider, 20.5–31 km length, c.m. energy: 250–500 GeV (tunable) [Upgrade: 1 TeV]
- Integrated Luminosity: 250/fb/yr [> 500/fb/yr]
- Based on superconducting RF cavities (31.5 MV/m design, 35 MV/m goal, 41–45 MV/m max.)
- Two detectors/experiments ILD & SiD (shared interaction point)
- Concurrent running with LHC high-luminosity phase
- MEXT (Japanese Ministry of Science & Education): 3 expert committees (Physics, TDR, HR)
- Extremely positive evaluation of TDR, cost estimate and physics case
- Decision most likely in time for European strategy update [end 2018]

ILC at Kitakami-Chi 北上市



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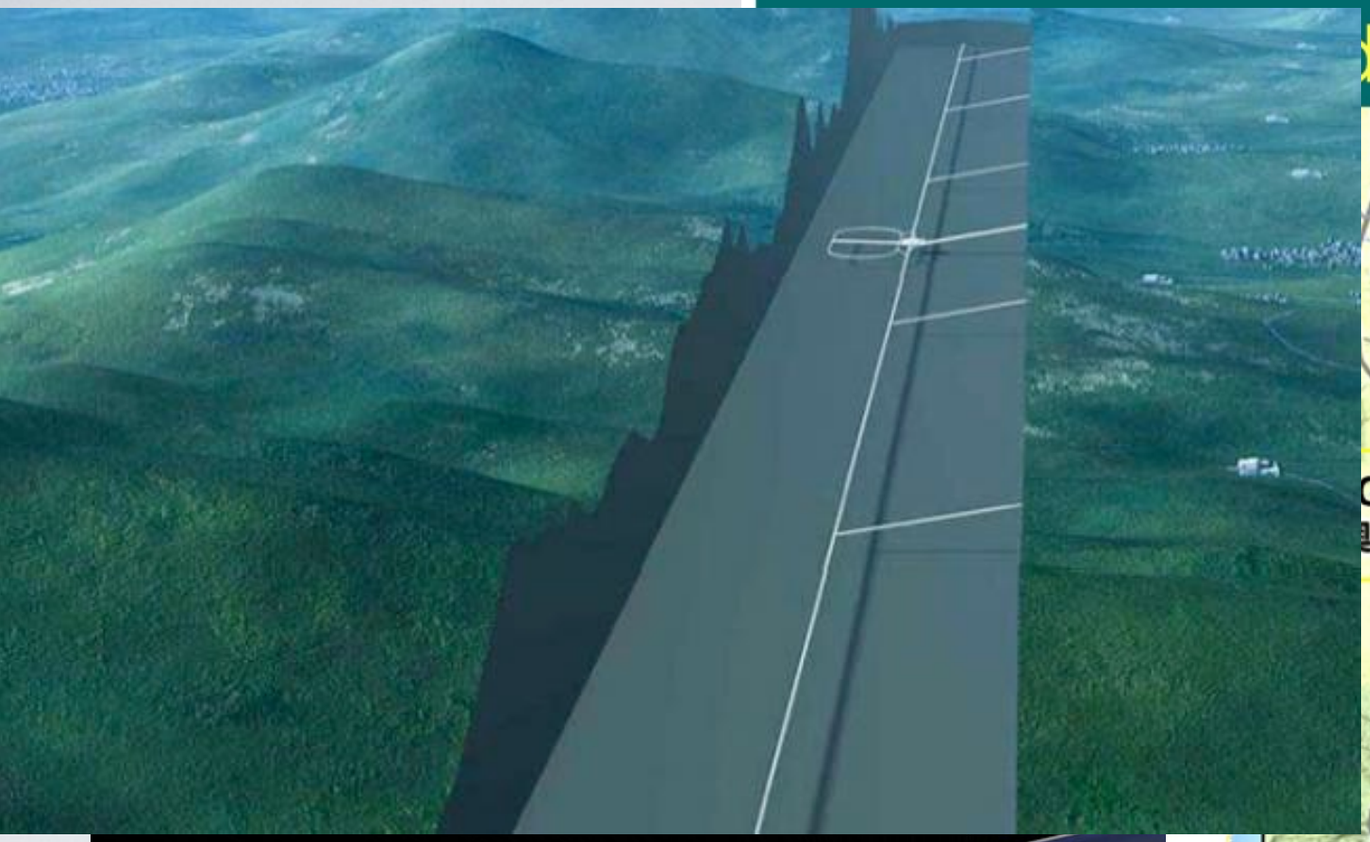
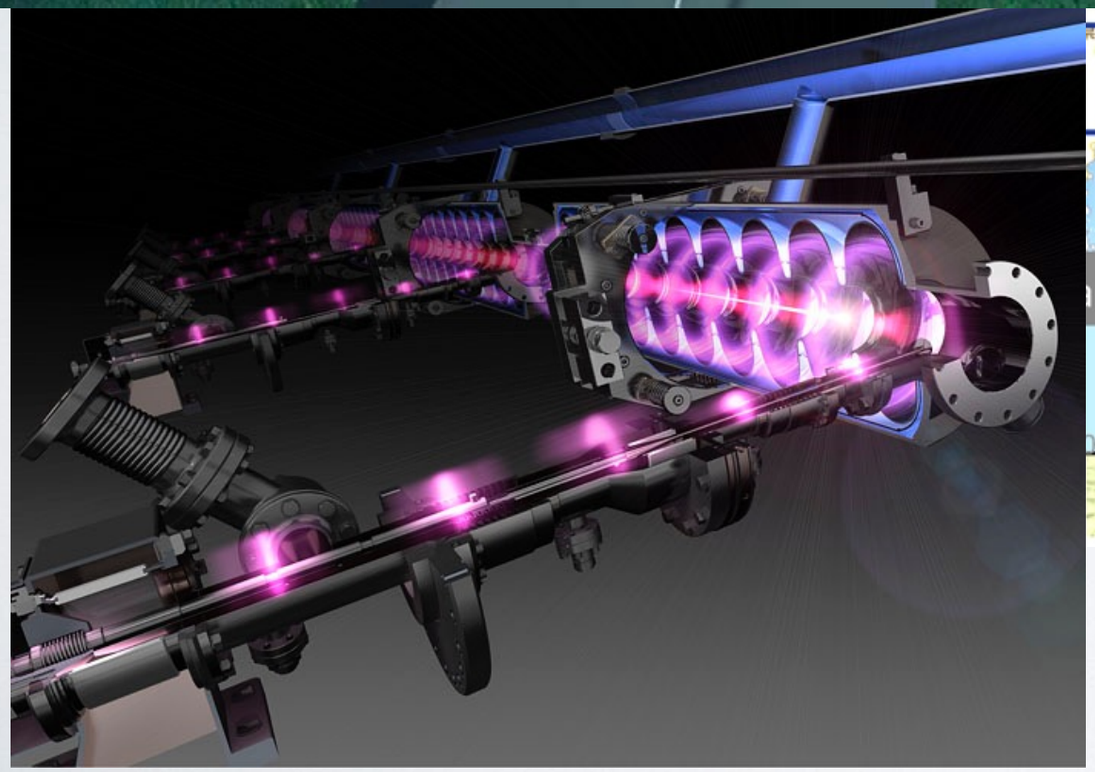
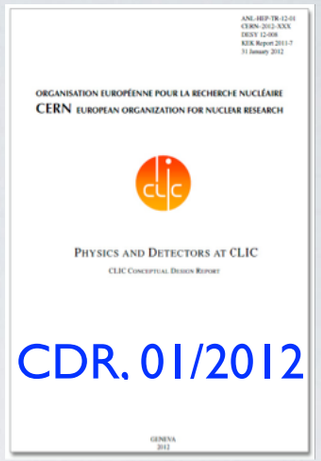
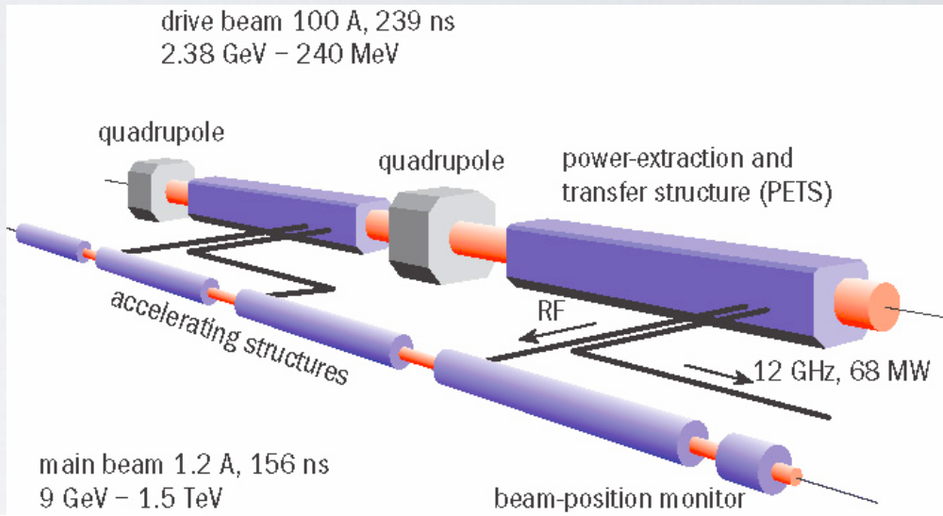


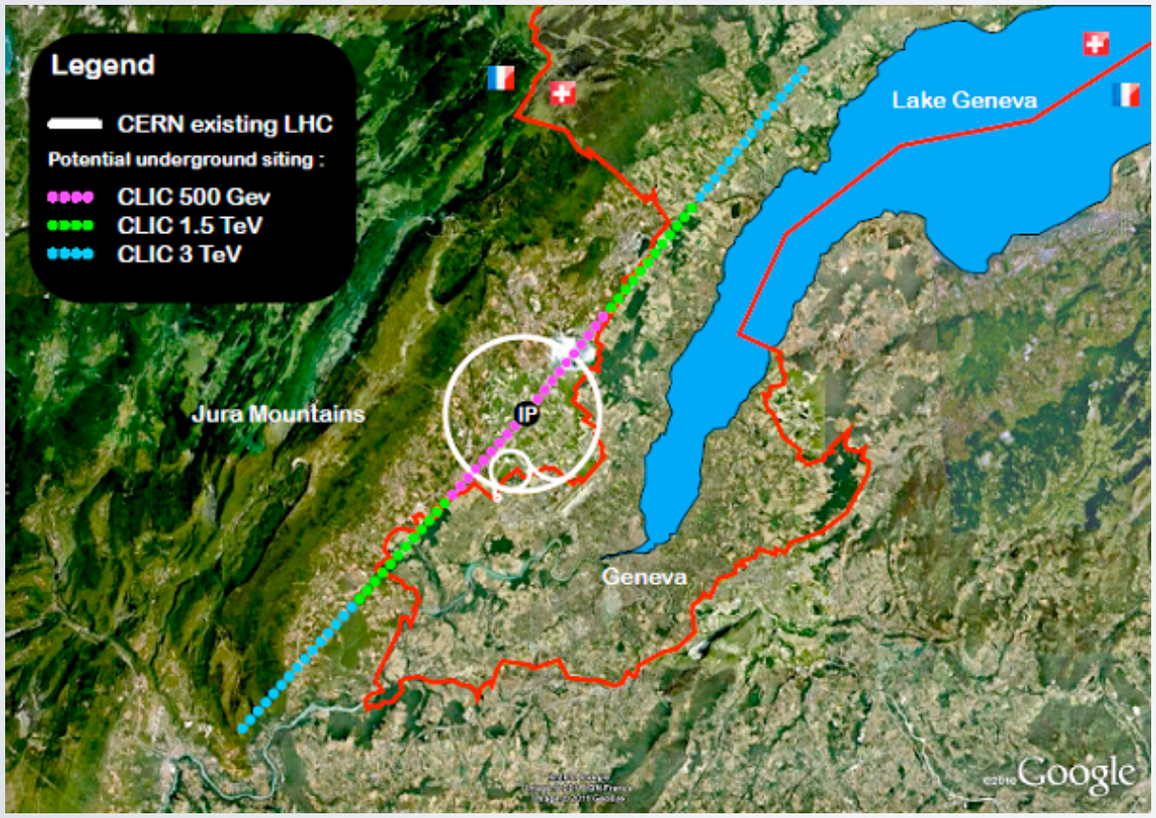


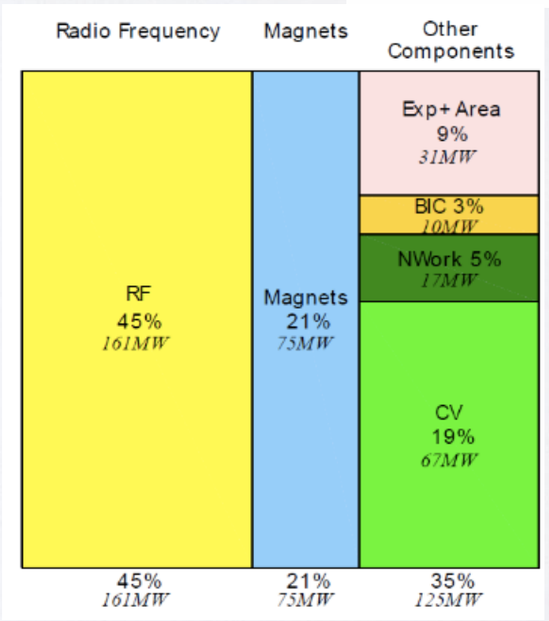
CLIC — 1500–3000 GeV e^+e^- Collider

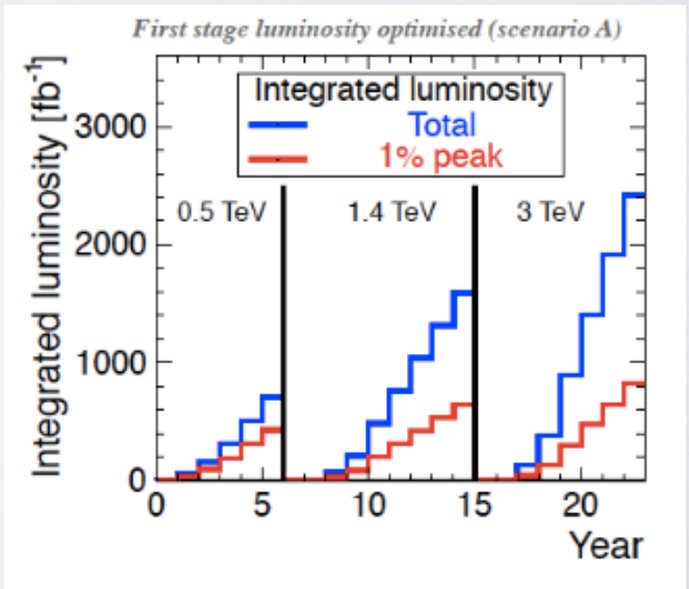
- Normalconducting RF cavities: drive beam with ca. 100 MV/m
- Conceptual Design Report (CDR): [01/2012]
- Linear tunnel of ca. 30-50 km at CERN
- "pre-TDR" for European Strategy update end of 2018
- staged approach: 380/500 GeV, 1400 GeV, 3000 GeV
- Main challenge I: large scale test facility → CLEAR 0.22 GeV
- Main challenge II: power consumption (590 MW @ 3 TeV)
- Only presently feasible multi-TeV option for e+e-











Setup of ILC / CLIC

(HE-)ILC: energies & staging

- [E_1 = 0.25 TeV, $\mathscr{L}_{\text{int}}$ = 2,000 fb^{-1}]
- [E_2 = 0.35 TeV, $\mathscr{L}_{\text{int}}$ = 200 fb^{-1}]
- ⋮ E_3 = 0.5 TeV, $\mathscr{L}_{\text{int}}$ = 4,000 fb^{-1} ⋮
- E_4 = 1.0 TeV, $\mathscr{L}_{\text{int}}$ = 8,000 fb^{-1}

Initial state polarization: 80% e^- , ≳30% e^+

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CLIC: energies & staging

- [E_1 = 0.35/0.38 TeV, $\mathscr{L}_{\text{int}}$ = 100+500 fb^{-1}]
- E_2 = 1.5 TeV, $\mathscr{L}_{\text{int}}$ = 1,500 fb^{-1}
- E_3 = 3.0 TeV, $\mathscr{L}_{\text{int}}$ = 3,000 fb^{-1}

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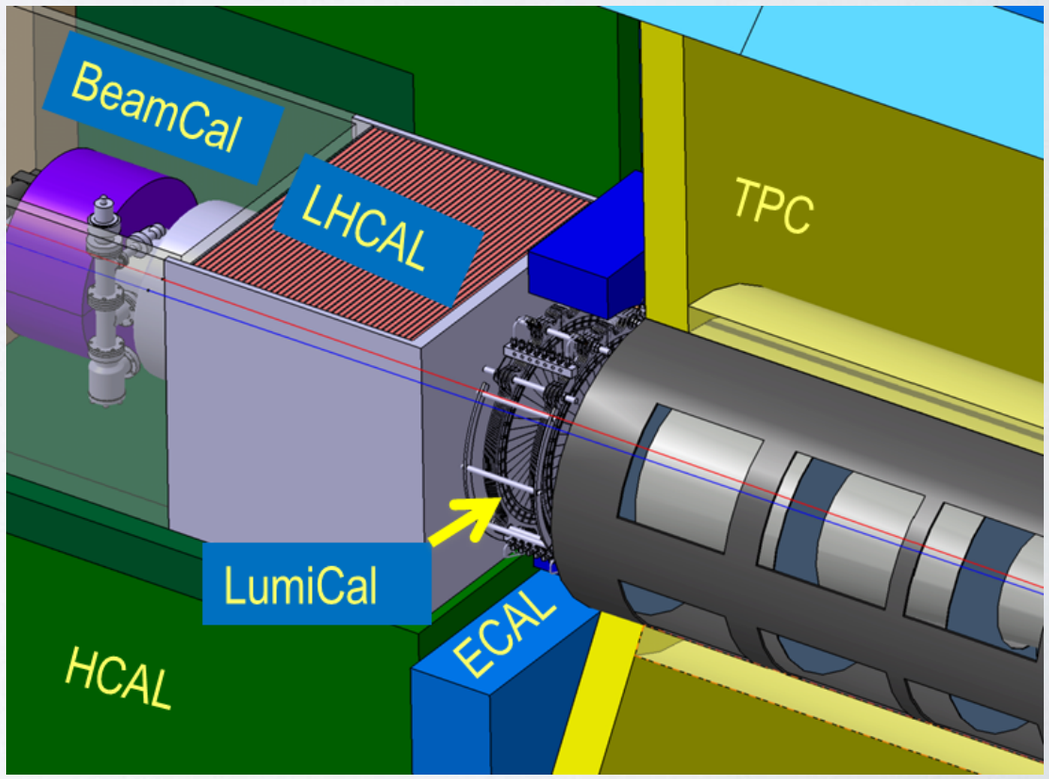
Low angle coverage

M. Idzik: A.Phys. Pol. B46 (2015) 1297

- LumiCal: 38 — 110 mrad
- BeamCal: 15 — 38 mrad



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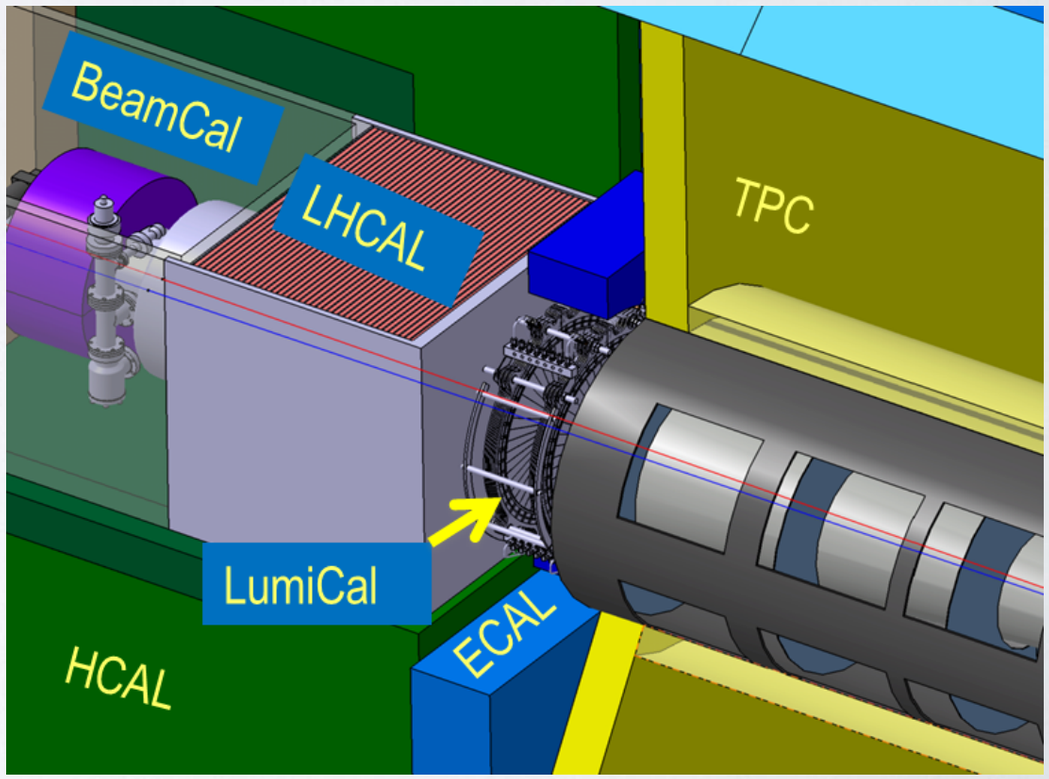
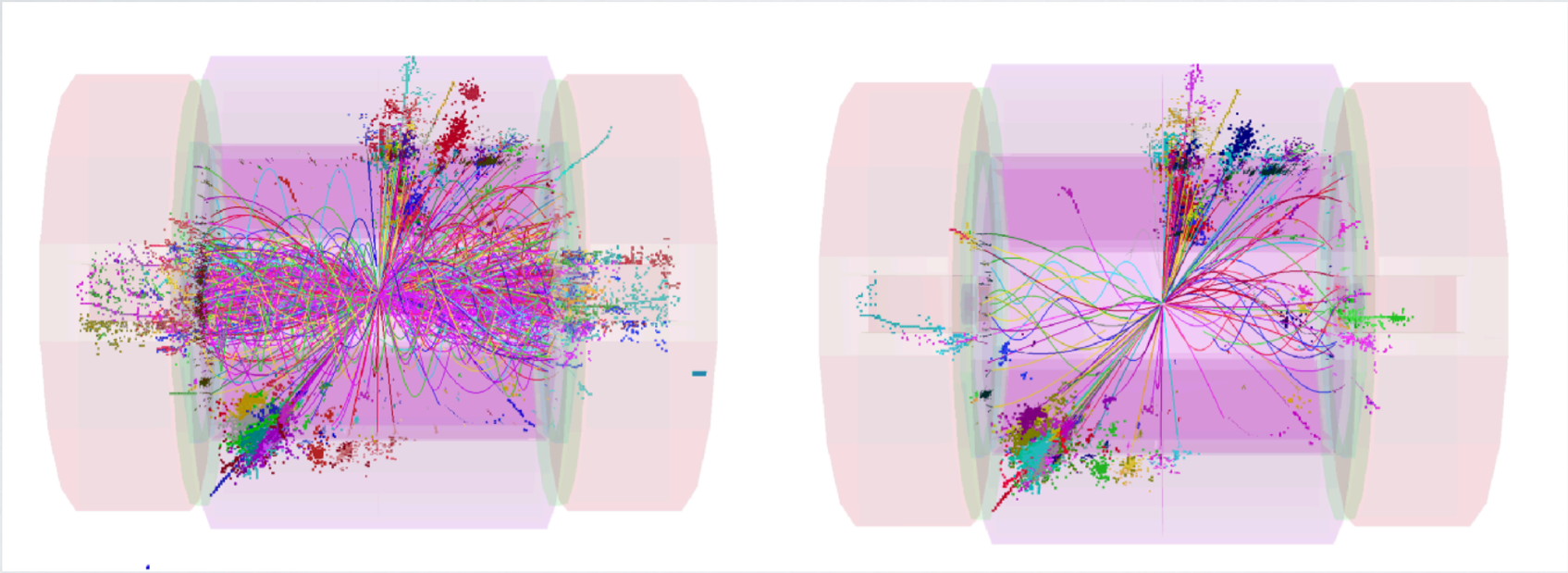
can go down to 15 mrad, i.e. $\eta \approx 4.9$



Identification of hadronic *W* / *Z*

J. S. Marshal / A. Münnich / M.A.Thomson , arXiv: 1209.4039

Particle Flow Algorithm (PFA) allows very good particle ID for ILD detector



Tight PFO removes photon-induced background from 1.2 TeV to 100 GeV

→ cf. Talk by Jakob Meyer

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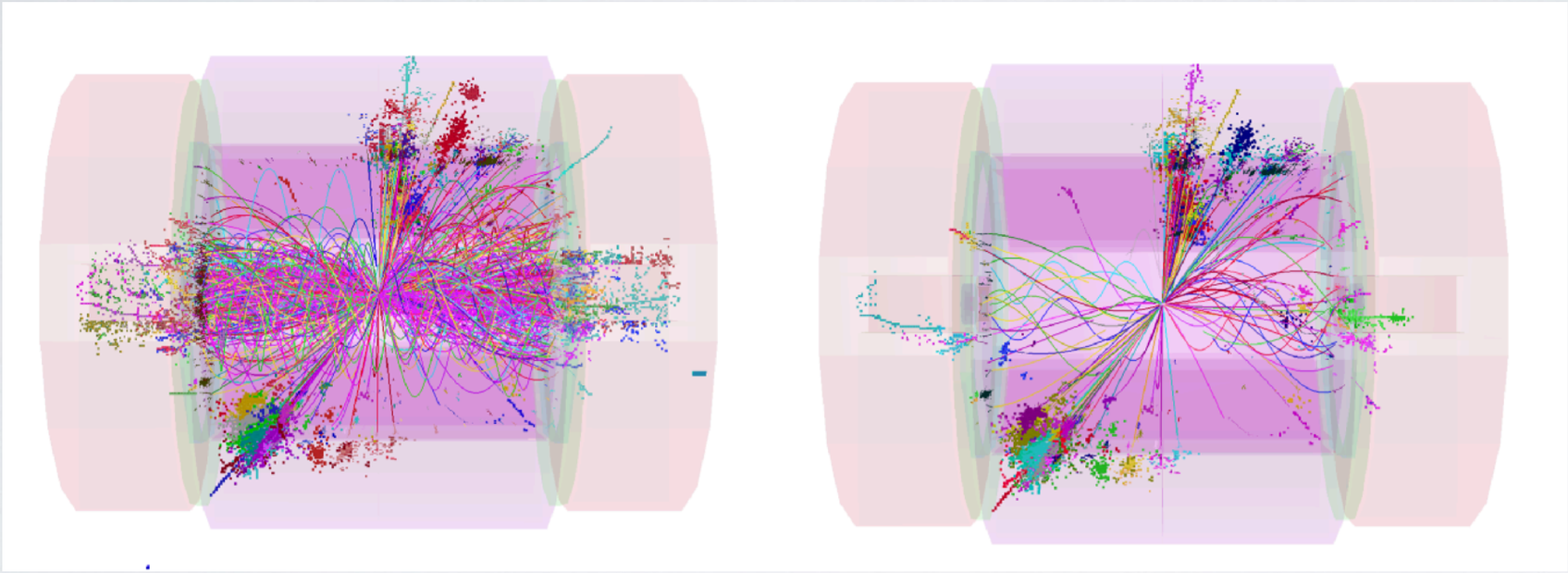

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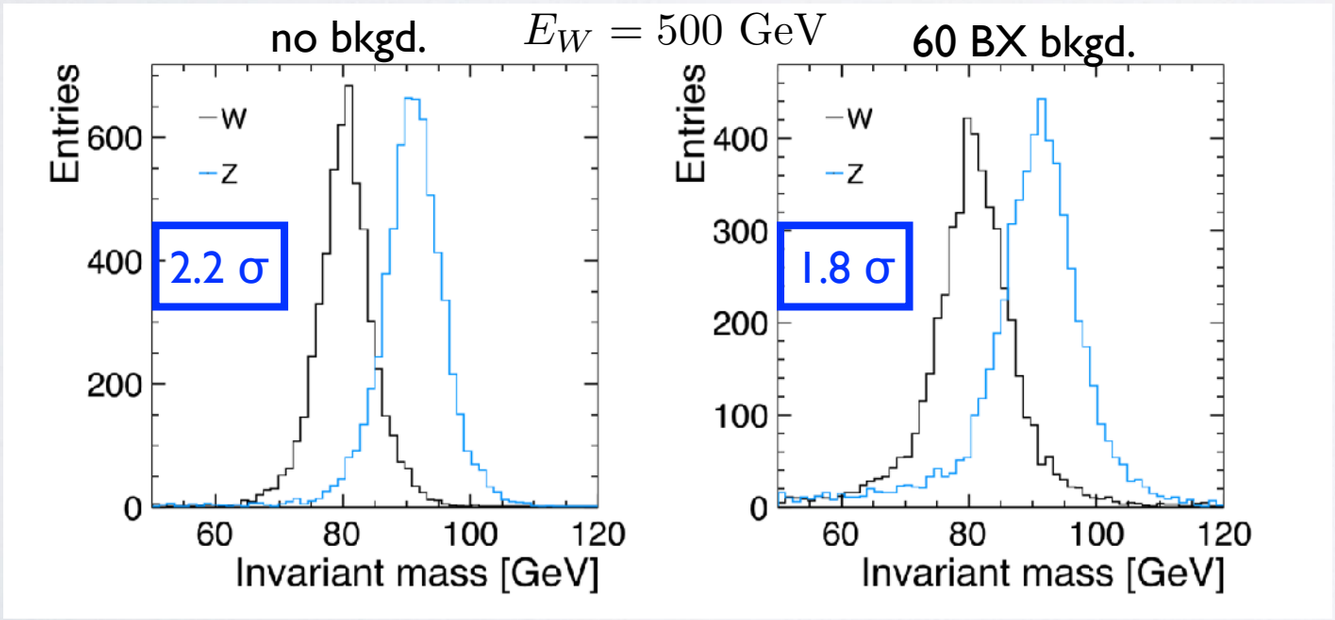

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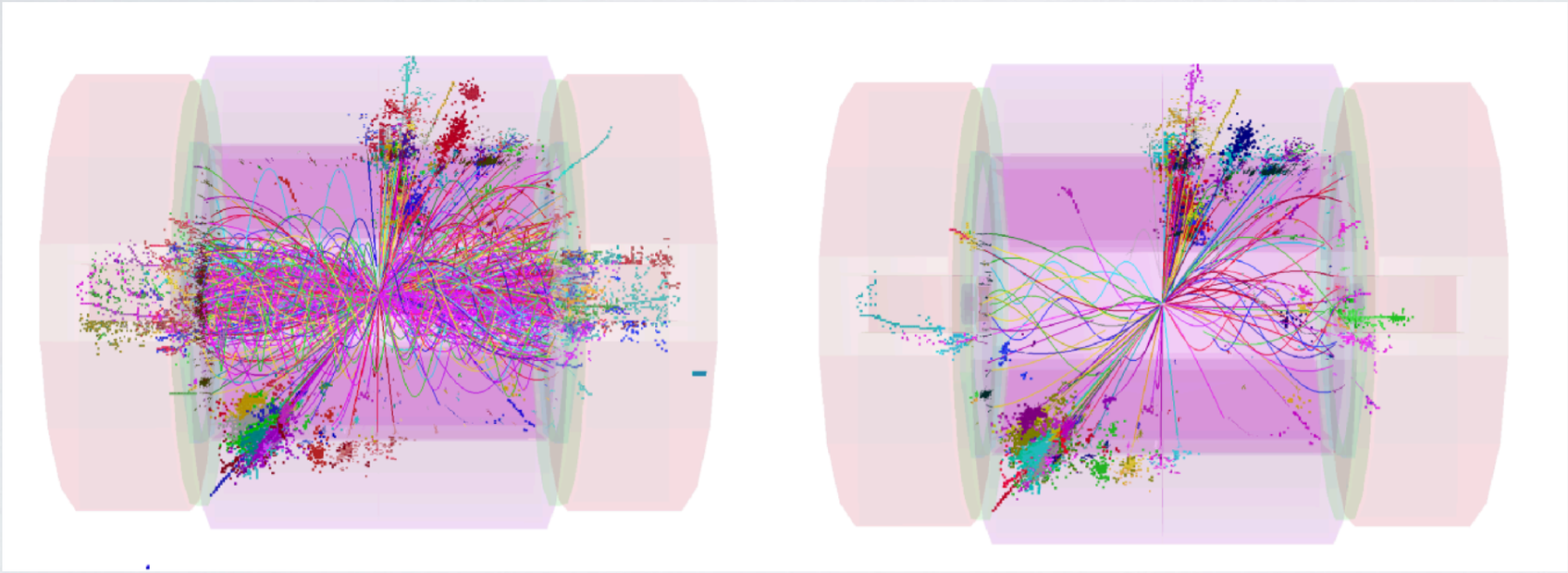

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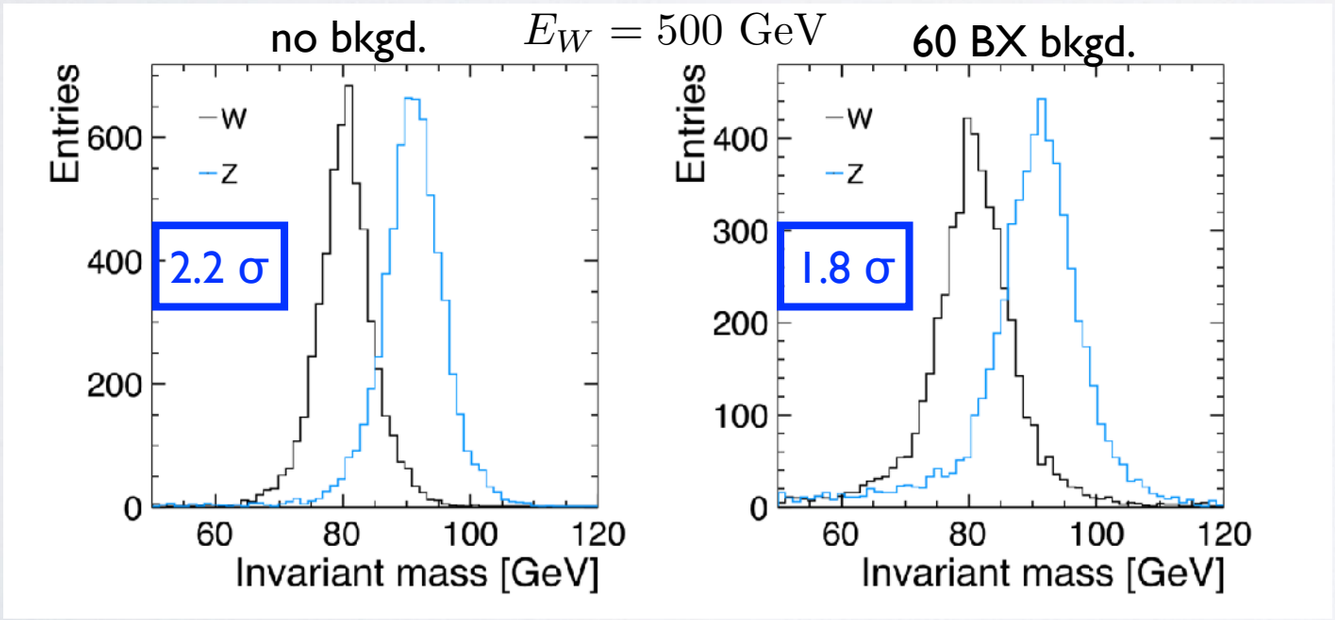
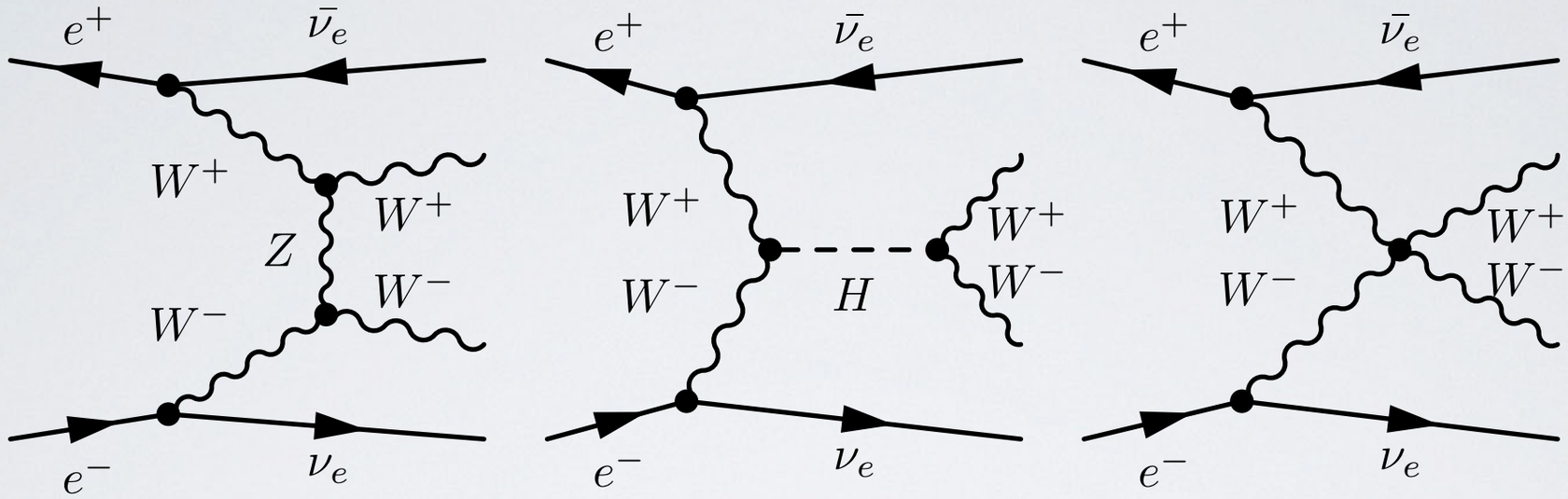


- *W*/*Z* discrimination: 88% efficiency
- With γ-induced bkgd: 71 — 79 %

→ cf. Talk by Jakob Meyer

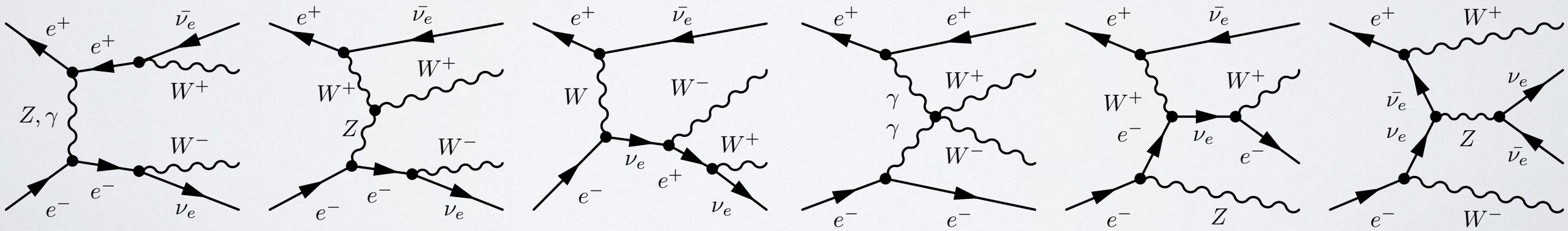
Vector Boson Scattering in $e^+ e^-$

Signal process: triple gauge couplings, Higgs-*V*-*V* couplings, quartic gauge couplings



same for *WZ* and *ZZ* , using all *W*/*Z* decays, particularly *W*/*Z* →*jj*

Background: difermions with EW radiation, single *W*, tribosons, radiative dibosons etc.



Overview Literatur: VBS in e^+e^- / e^-e^-

- Gunion/Tofighi-Niaki, PRD36 (1987) 2671: full MEs for VBS (*WW*) and heavy Higgs production [0.5, 1, 2 TeV]
- Gunion/Tofighi-Niaki, PRD38 (1988) 1433: same for *ZZ* final states [0.5, 1, 2 TeV]
- Barger/Cheung/Han/Phillips, PRD52 (1995) 3815: measurements of *WW*/*ZZ* ratios [1.5 – 2 TeV]
- Dominici, Riv.Nuo.Cim.20 (1997) 1: access to parameters of EW chiral Lagrangian in *WW* VBS [1.5 TeV]
- Denner/Dittmaier/Hahn, PRD56 (1997) 117: EW corrections to $ZZ \to ZZ$
- Denner/Hahn, NPB525 (1998) 27: EW corrections to $WW \to WW$
- Han/He/Yuan, PLB422 (1998) 294: interplay of *WW* VBS and *WWZ*/*ZZZ* production [0.5, 0.8, 1, 1.6 TeV]
- Boos/He/Kilian/Pukhov/Yuan/Zerwas, PRD57 (1998) 1553: EW chiral Lagrangian (strong EW) [1.6 TeV]
- Boos/He/Kilian/Pukhov/Yuan/Zerwas, PRD61 (2000) 077901: strong EW: *ZZ*/W^-W^- channels [1.6 TeV]
- Kilian, Int.J.Mod.Phys.A15 (2000) 2387: strong EW in e^-e^- [1 TeV]
- Linear Collider Physics Ressource Book 2001, Part 3: Studies of Exotic and SM Physics [hep-ex/0106057]
- Chierici/Rosati/Kobel, LC-PHSM-2001-038 : experimental study for strong EW [0.18–0.8 TeV]
- Rosati, CERN-THESIS-2002-083 : experimental study for strong EW [0.18–0.8 TeV]
- Beyer/Kilian/Krstonošić/Mönig/JRR/Schmidt/Schröder, EPJC48 (2006) 353: α parameters, VBS+VVV [1 TeV]
- Accomando/Denner/Pozzorini, JHEP 0703 (2007) 078: EW Sudakov logarithms in VBS [3 TeV]
- Liebler/Moortgat-Pick/Weiglein, JHEP 1506 (2015) 093: moff-shell Higgs effects in ee $\to$ $\nu\nu$*WW* [0.25 – 1 TeV]
- Fleper/Kilian/JRR/Sekulla, EPJC77.2 (2017) 120: VBS for SMEFT with dim 8 / simplified models [1, 1.4, 3 TeV]

VBS in $e^+ e^-$: SM rates and Backgrounds (I)

Experimentally: study all processes that lead to VBS–like signatures [1 TeV]:

Vector-Boson Scattering

Triboson Production

Vector-Boson Scattering / Radiative Bhabha

Top [pair] production

Diboson Production

Single W Production

Radiative Z Production

QCD Di-/Multijets

Process	Subprocess	σ [fb]
$e^+e^- \to \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	$W^+W^- \to W^+W^-$	23.19
$e^+e^- \to \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	$W^+W^- \to ZZ$	7.624
$e^+e^- \to \nu\bar{\nu}q\bar{q}q\bar{q}$	$V \to VVV$	9.344
$e^+e^- \to \nu e q\bar{q}q\bar{q}$	$WZ \to WZ$	132.3
$e^+e^- \to e^+e^- q\bar{q}q\bar{q}$	$ZZ \to ZZ$	2.09
$e^+e^- \to e^+e^- q\bar{q}q\bar{q}$	$ZZ \to W^+W^-$	414.
$e^+e^- \to b\bar{b}X$	$e^+e^- \to t\bar{t}$	331.768
$e^+e^- \to q\bar{q}q\bar{q}$	$e^+e^- \to W^+W^-$	3560.108
$e^+e^- \to q\bar{q}q\bar{q}$	$e^+e^- \to ZZ$	173.221
$e^+e^- \to e\nu q\bar{q}$	$e^+e^- \to e\nu W$	279.588
$e^+e^- \to e^+e^- q\bar{q}$	$e^+e^- \to e^+e^- Z$	134.935
$e^+e^- \to X$	$e^+e^- \to q\bar{q}$	1637.405

[80% e^-, 40% e^+ polarization]

[Beyer/Kilian/Krstonošić/Mönig/JRR/Schmidt/Schröder, EPJC48 (2006) 353]

VBS in e^+e^- : SM rates and Backgrounds (II)

Process	1400 GeV	3000 GeV	Factor
$W^+W^-\nu\bar{\nu}$	47.1	132	1
$W^+W^-e^+e^-$	1570	3820	1
$W^\pm Ze^\mp\nu$	138	408	0.136
ZZe^+e^-	3.78	4.70	0.019
$W^+W^-(Z\to\nu\bar{\nu})$	11.7	9.35	1
$ZZ\nu\bar{\nu}$	15.7	57.5	1
ZZe^+e^-	3.78	4.70	1
$W^\pm Ze^\mp\nu$	138	408	0.136
$W^+W^-e^+e^-$	1570	3820	0.019
$ZZ(Z\to\nu\bar{\nu})$	0.484	0.237	1

Total cross sections [fb], no cuts

Mismatched hadronic vector bosons

Triboson background

[80% e^-, 0% e^+ polarization]

Fleper/Kilian/JRR/Sekulla: 1607.03030

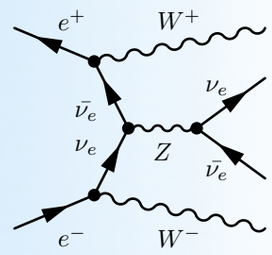
- ☑ Signal cross sections rise factor 3–4 from 1.4 to 3 TeV
- ☑ Mistagging from *W/Z* conversions in hadronic bosons: severe for *WZ* scattering
- ☑ Irreducible backgrounds from tribosons (Gauge invariance connects full processes)

VBS in $e^+ e^-$: Selection / isolation cuts

Cuts for 1 TeV ILC — 1.4 TeV CLIC — 3 TeV CLIC

Suppression of background from Z → $\nu\nu$, W^+W^- , and QCD 4-jet production

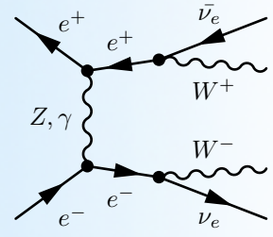
$M_{inv}(\bar{\nu}\nu) > 150\,\text{GeV}$ $M_{inv}(\bar{\nu}\nu) > 175\,\text{GeV}$ $M_{inv}(\bar{\nu}\nu) > 230\,\text{GeV}$



Suppression of background from t–channel exchange in subprocess

$p_{\perp,W/Z} > 150\,\text{GeV}$ $p_{\perp,W/Z} > 180\,\text{GeV}$ $p_{\perp,W/Z} > 300\,\text{GeV}$

$|\cos\theta(W/Z)| < 0.8$ $|\cos\theta(W/Z)| < 0.8$ $|\cos\theta(W/Z)| < 0.8$

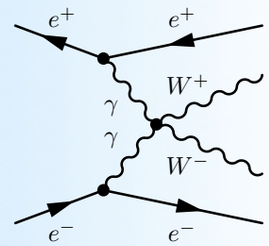


Suppression of $\gamma\gamma$–fusion induced backgrounds

$p_\perp(WW) > 45\,\text{GeV}$ $p_\perp(WW) > 50\,\text{GeV}$ $p_\perp(WW) > 100\,\text{GeV}$

$p_\perp(ZZ) > 40\,\text{GeV}$ $p_\perp(ZZ) > 40\,\text{GeV}$ $p_\perp(ZZ) > 60\,\text{GeV}$

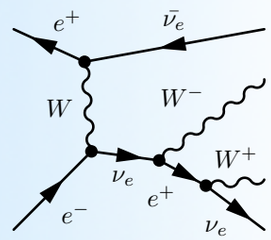
$\theta(e) > 15\,\text{mrad}$ $\theta(e) > 15\,\text{mrad}$ $\theta(e) > 15\,\text{mrad}$



Suppression of non-scattering vector boson processes [i.e. massive EW radiation]

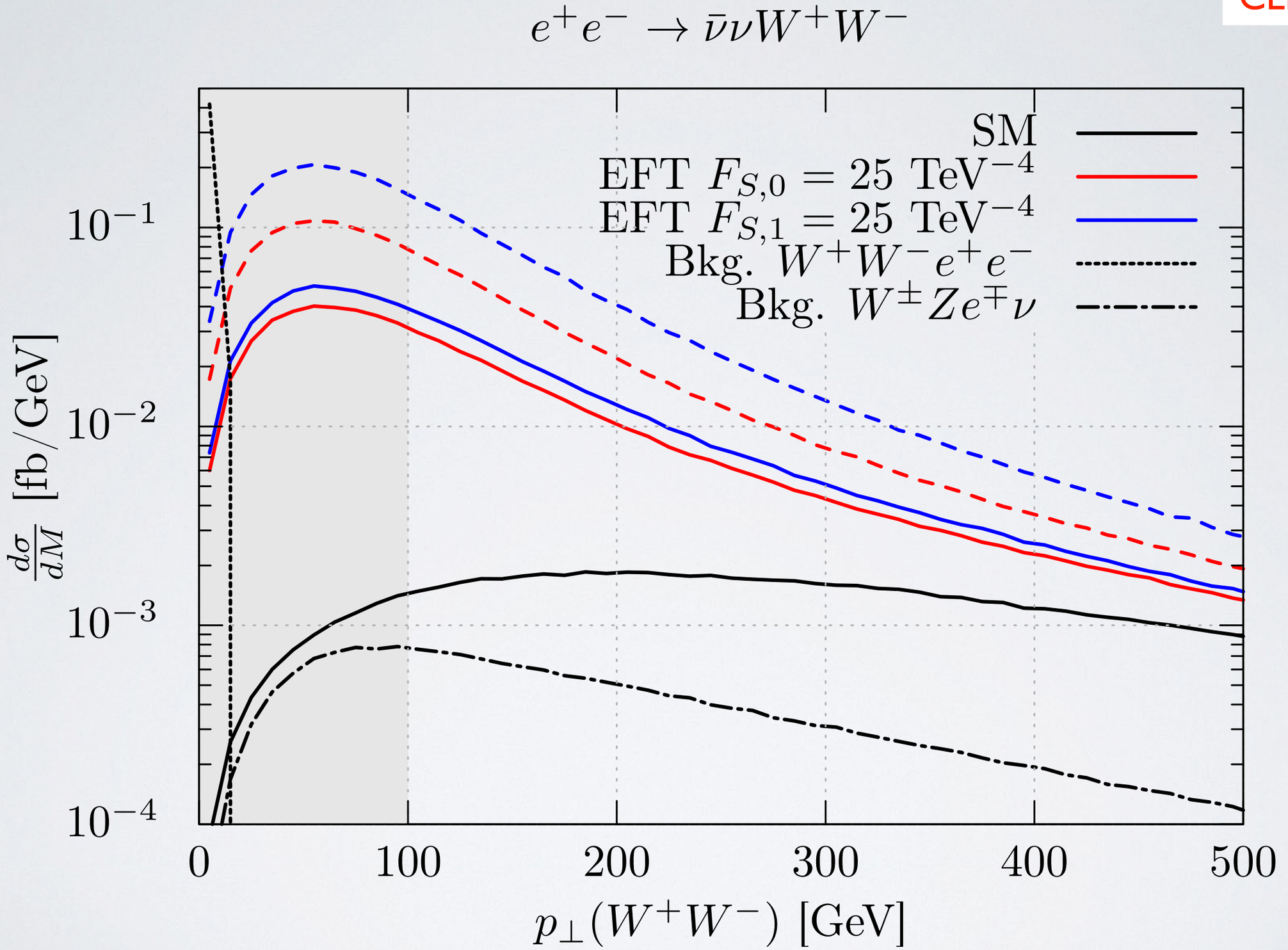
$M_{inv}^{WW} \in [575, 800]\,\text{GeV}$ $M_{inv}^{WW} \in [800, 1175]\,\text{GeV}$ $M_{inv}^{WW} \in [900, 1900]\,\text{GeV}$

$M_{inv}^{ZZ} \in [600, 800]\,\text{GeV}$ $M_{inv}^{ZZ} \in [800, 1175]\,\text{GeV}$ $M_{inv}^{ZZ} \in [850, 1900]\,\text{GeV}$



Longitudinal Vector Boson Scattering in $e^+ e^-$

CLIC 3 TeV



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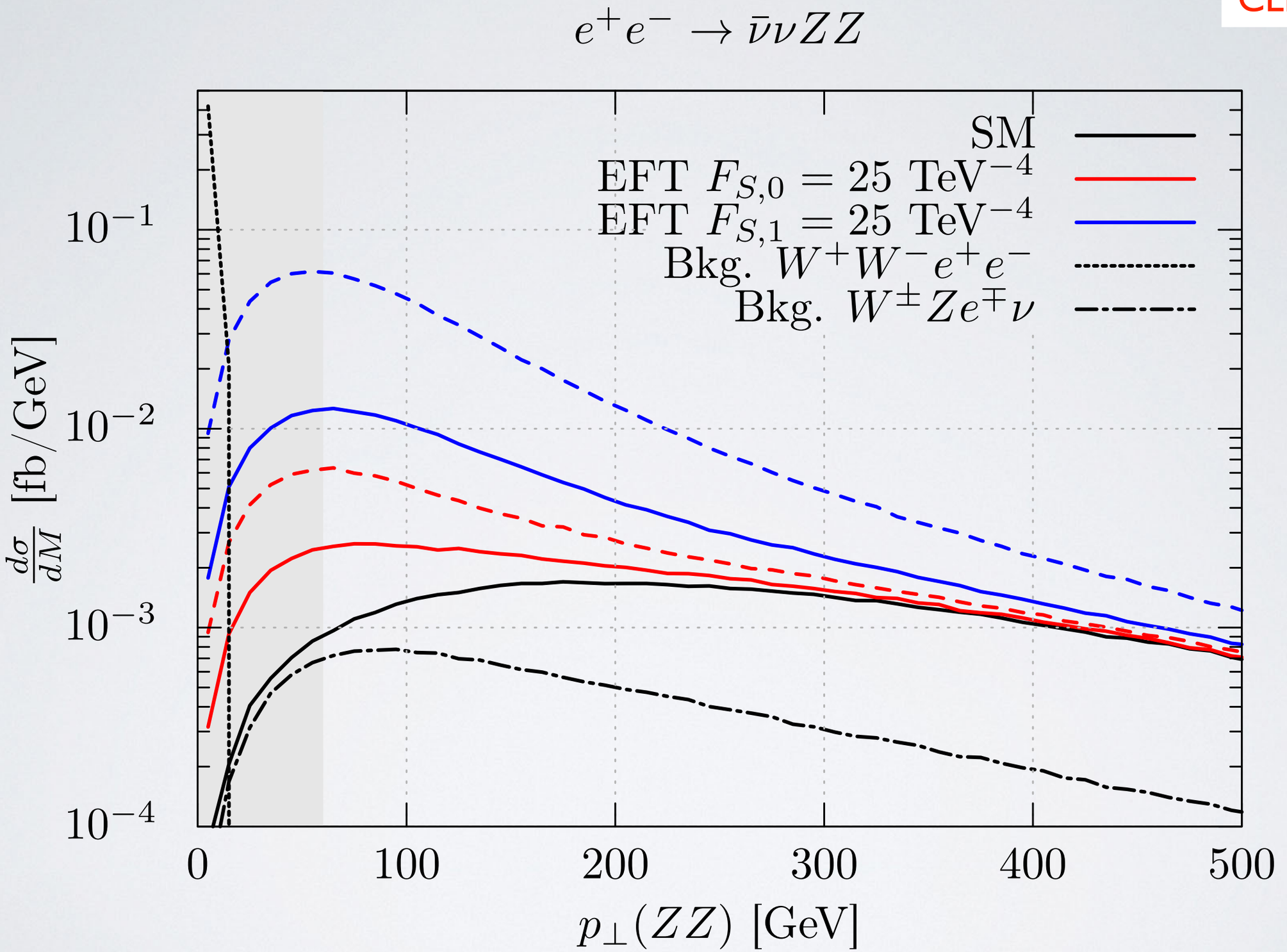
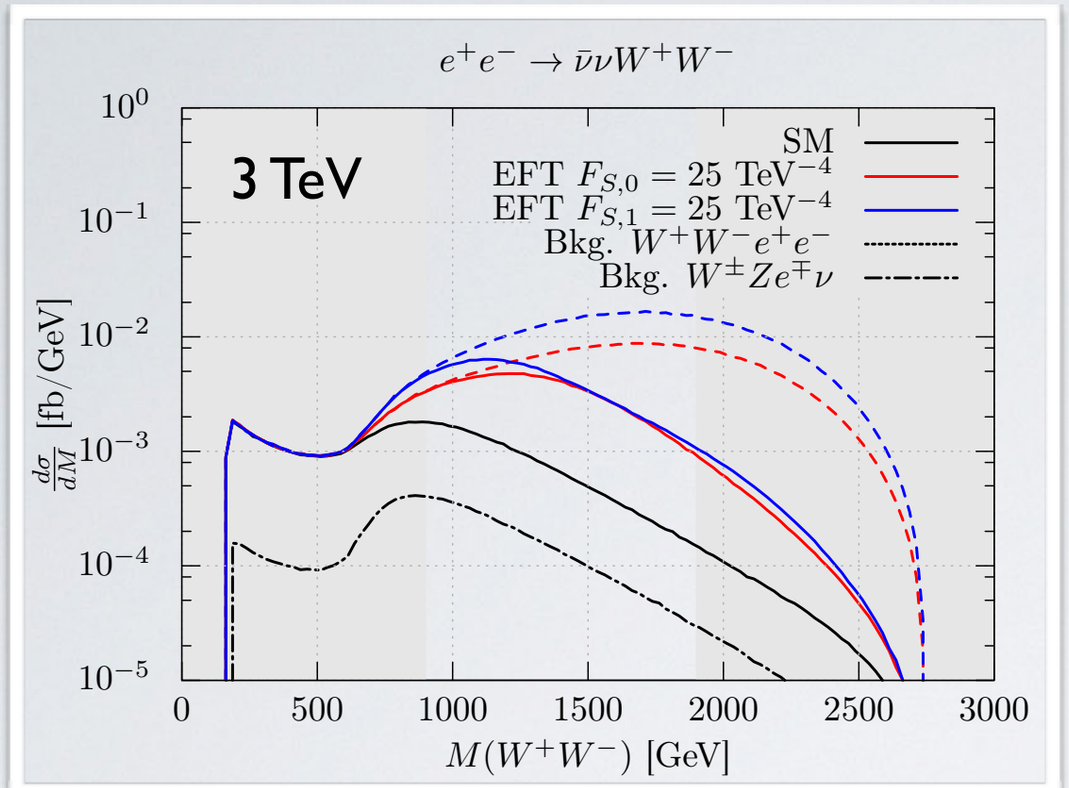
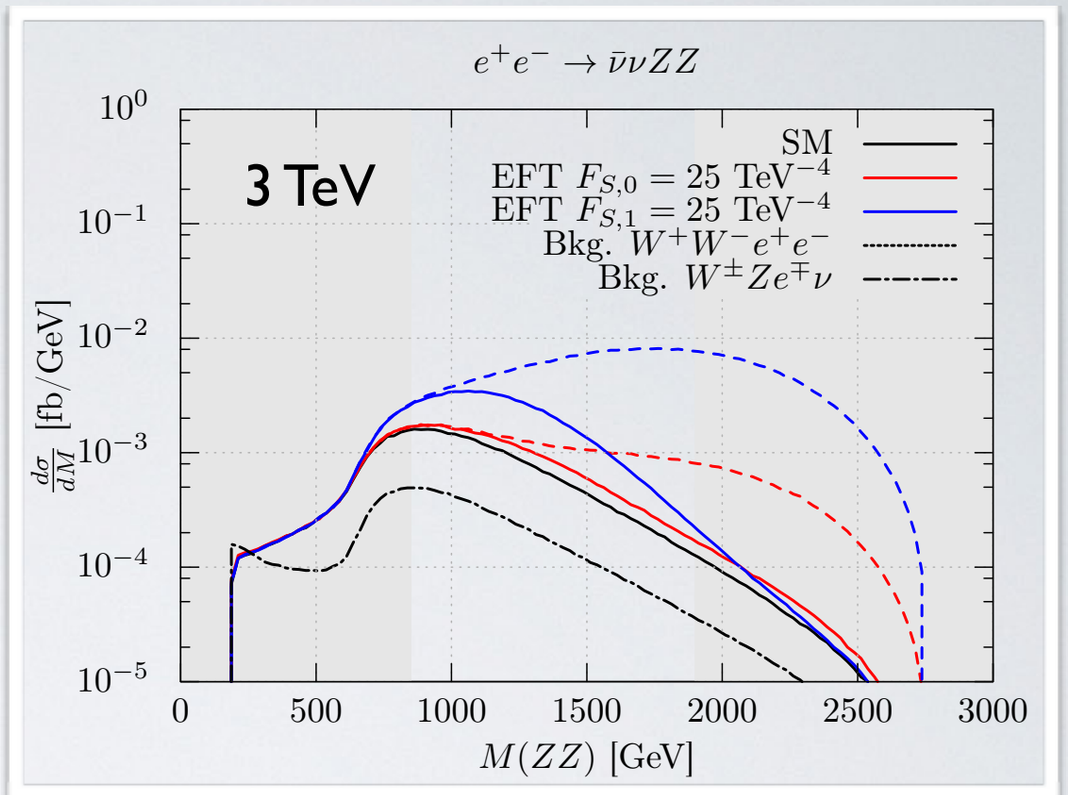
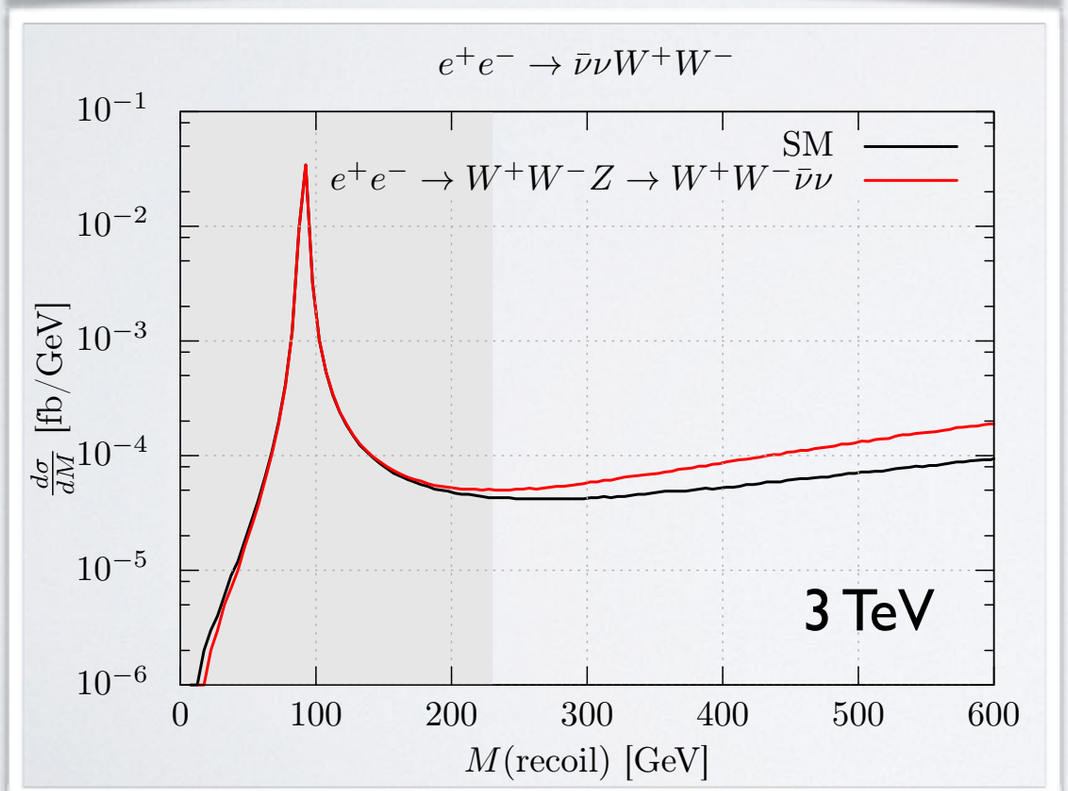
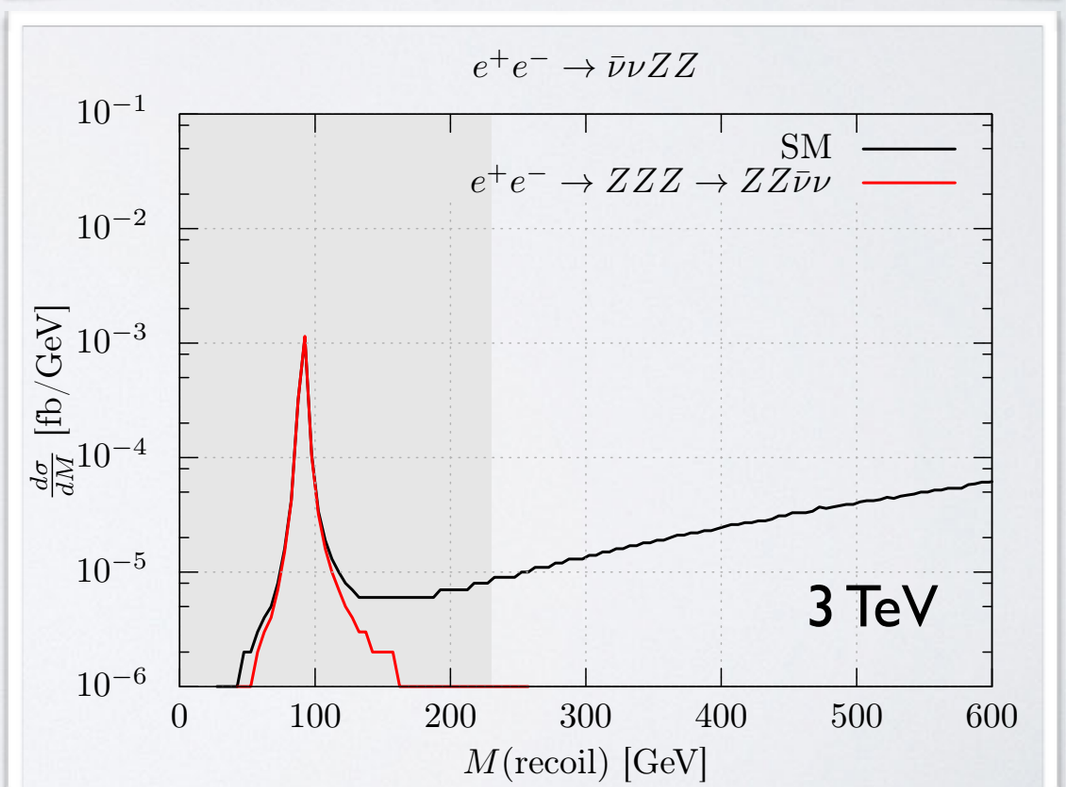


Separability of signal and triboson backgrounds









VBS in $e^+ e^-$: SM rates and Backgrounds (III)

Fleper/Kilian/JRR/Sekulla: 1607.03030

Process	1400 GeV	3000 GeV	Factor
$W^+W^-\nu\bar{\nu}$	0.119	0.790	1
$W^+W^-e^+e^-$	0.000	0.000	1
$W^\pm Ze^\mp\nu$	0.269	1.200	0.136
ZZe^+e^-	0.000	0.000	0.019
$W^+W^-(Z\to\nu\bar{\nu})$	0.039	0.610	1
$ZZ\nu\bar{\nu}$	0.084	0.790	1
ZZe^+e^-	0.000	0.000	1
$W^\pm Ze^\mp\nu$	0.288	1.593	0.136
$W^+W^-e^+e^-$	0.000	0.000	0.019
$ZZ(Z\to\nu\bar{\nu})$	0.000	0.000	1

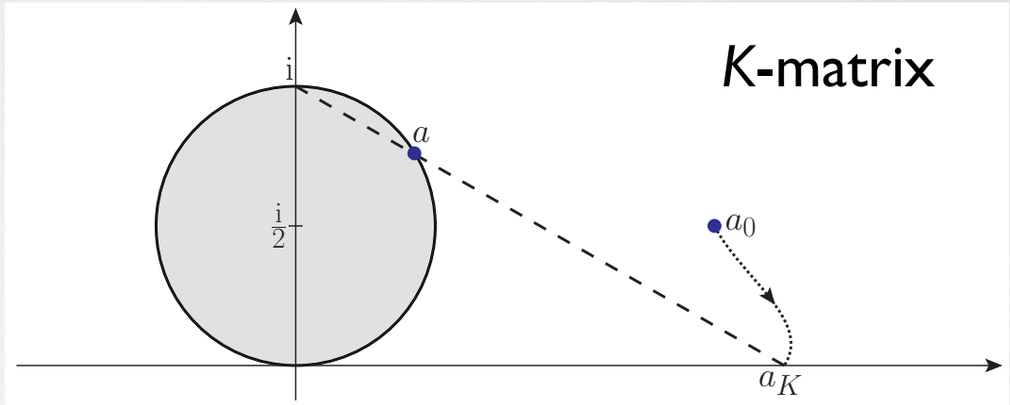
Total cross sections [fb], all cuts

MC error are ≈ 1% on average

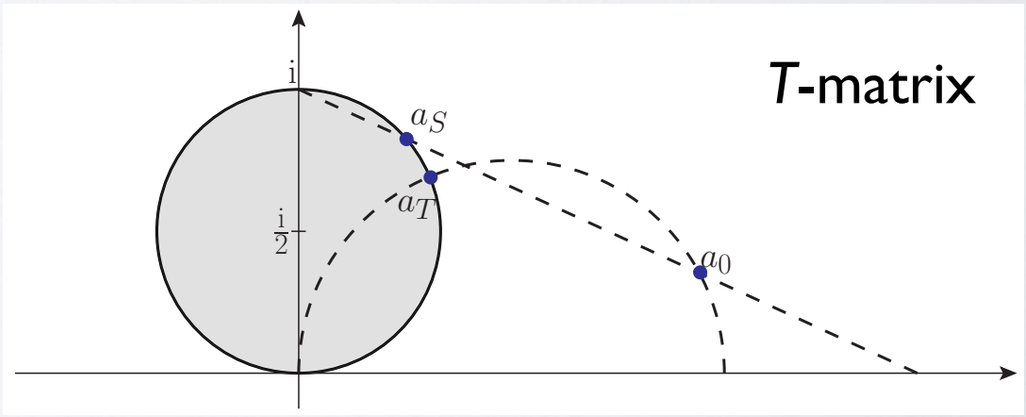
Quick remark on validity and unitarization

- EFT only valid for energy scales well below new degrees of freedom
- Higher-dimensional operators: amplitudes rise with energy
- Highest sensitivity from highest energies
- High-energy regime could lead to unphysical results
- Truncate reach ("event clipping")
- Measurement only in low-energy bins
- Unitarization procedure
- *K*-matrix: Stereographic projection to Argand circle
- … is partial resummation of perturbative series
- Problem for amplitudes with intrinsic imaginary part (e.g. resonances)
- *T*-matrix: Thales circle construction [Kilian/Ohl/JRR/Sekulla 2014]
- Identical to *K*-matrix for real amplitudes
- Does not rely on perturbative description

$$S = \frac{1+iK/2}{1-iK/2} \qquad a_K(s) = \frac{a(s)}{1-\mathrm{i}a(s)}$$

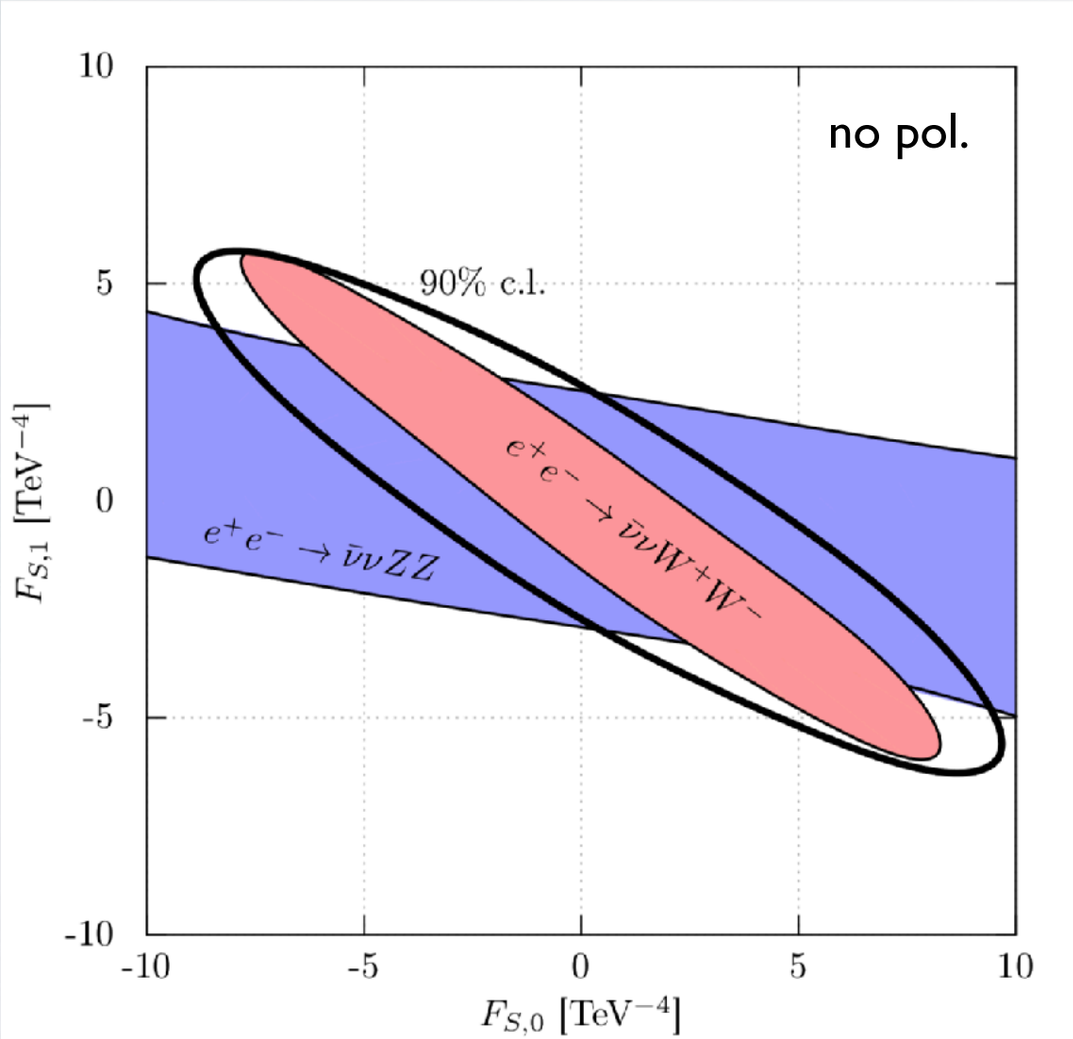


$$\left|a - \frac{a_K}{2}\right| = \frac{a_K}{2} \quad \Rightarrow \quad a = \frac{1}{\mathrm{Re}\left(\frac{1}{a_0}\right) - \mathrm{i}}$$



Exclusion sensitivities

Continuum model matched to low-energy SMEFT with two Dim 8-coefficients at 3 TeV, 2 ab^{-1}



- All cuts have been applied
- Detector efficiencies are included
- All cross sections use *T*-matrix unitarization

Fleper/Kilian/JRR/Sekulla: 1607.03030

→ cf. Talk by Jakob Meyer

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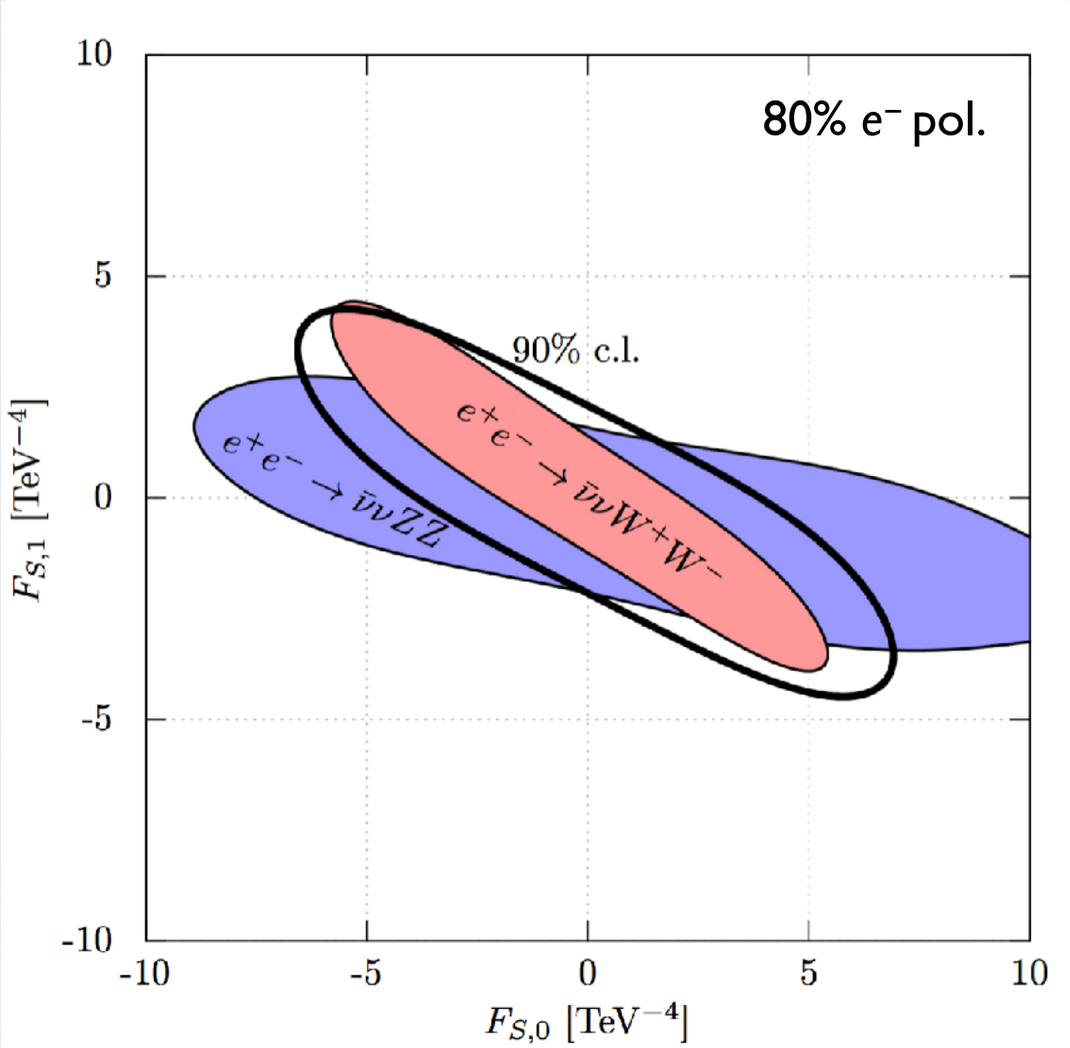

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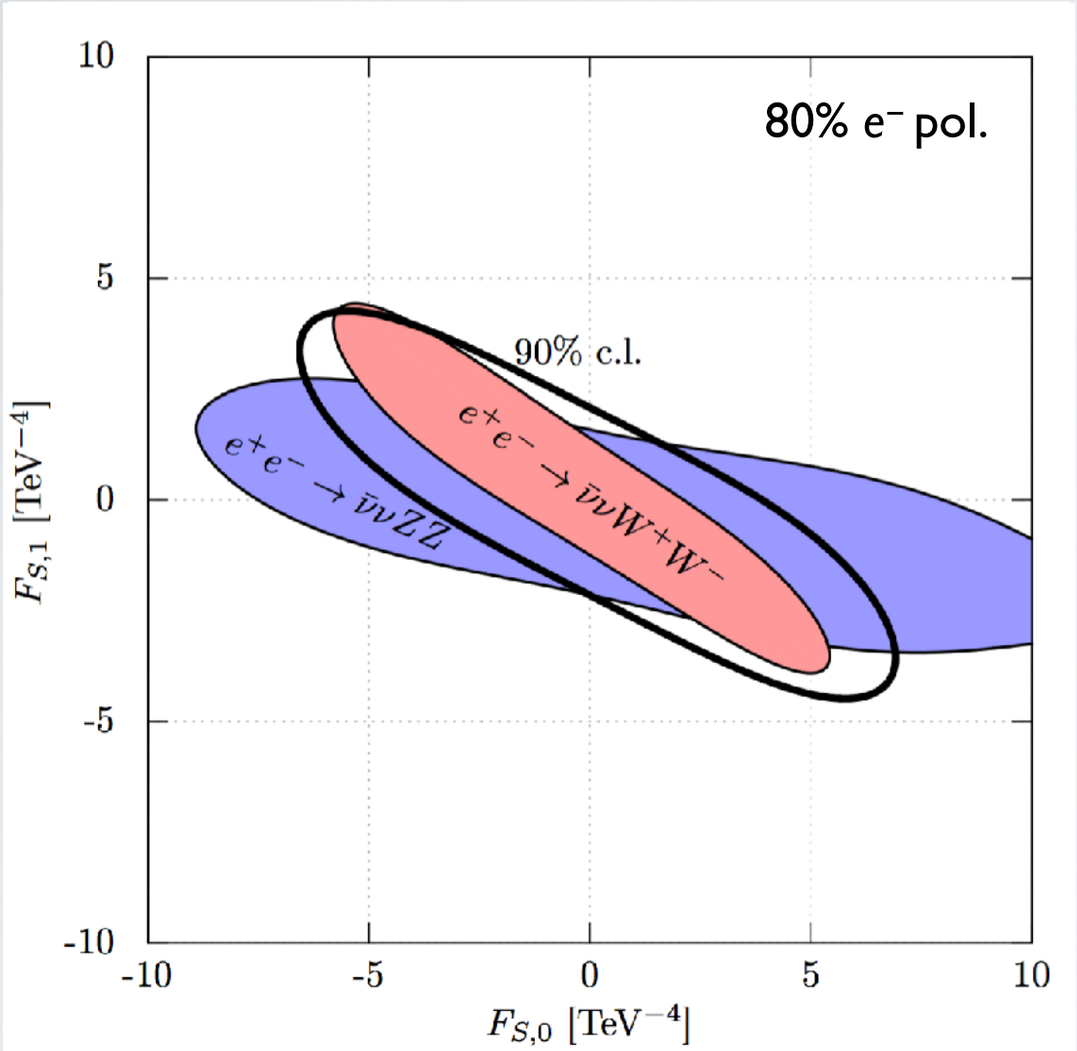

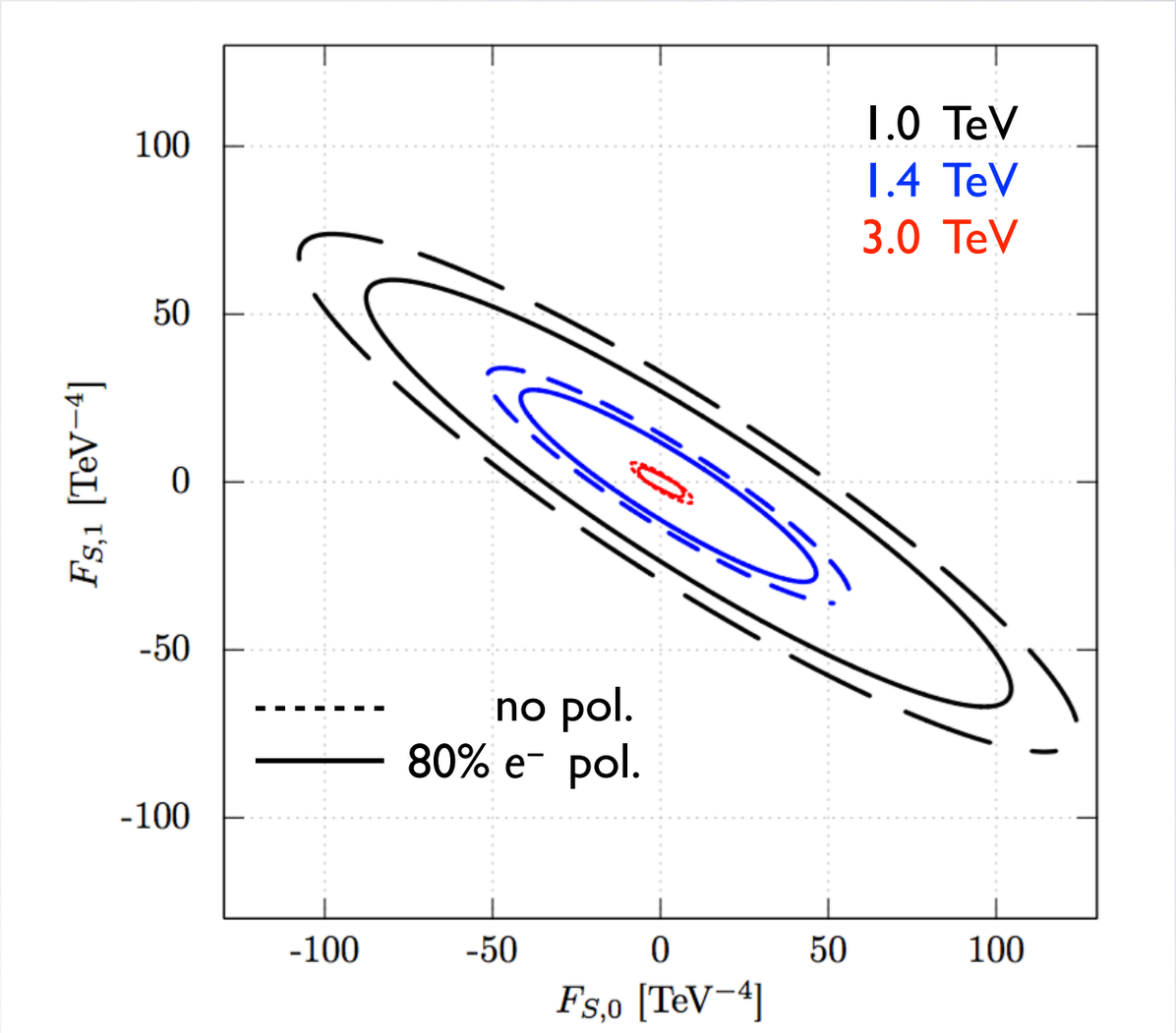

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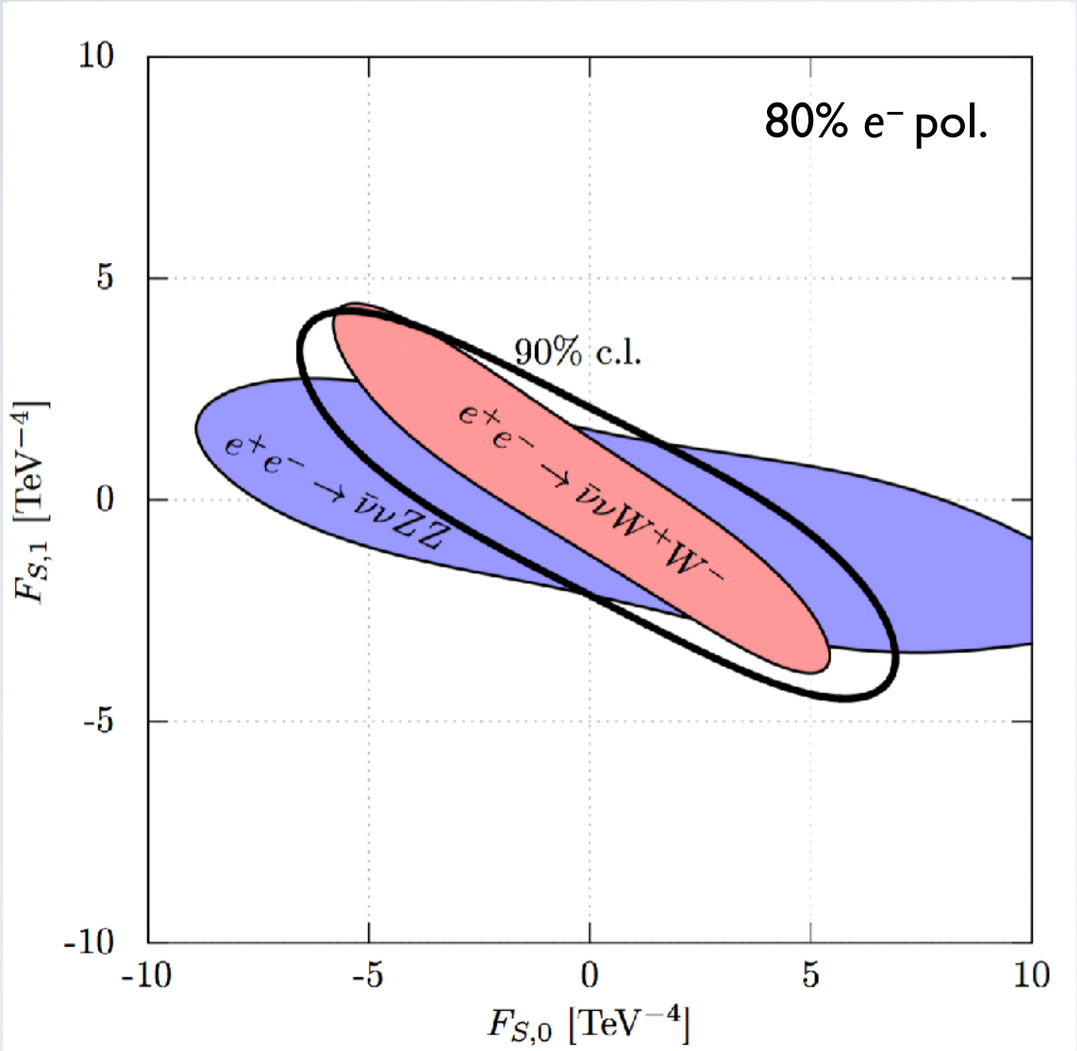

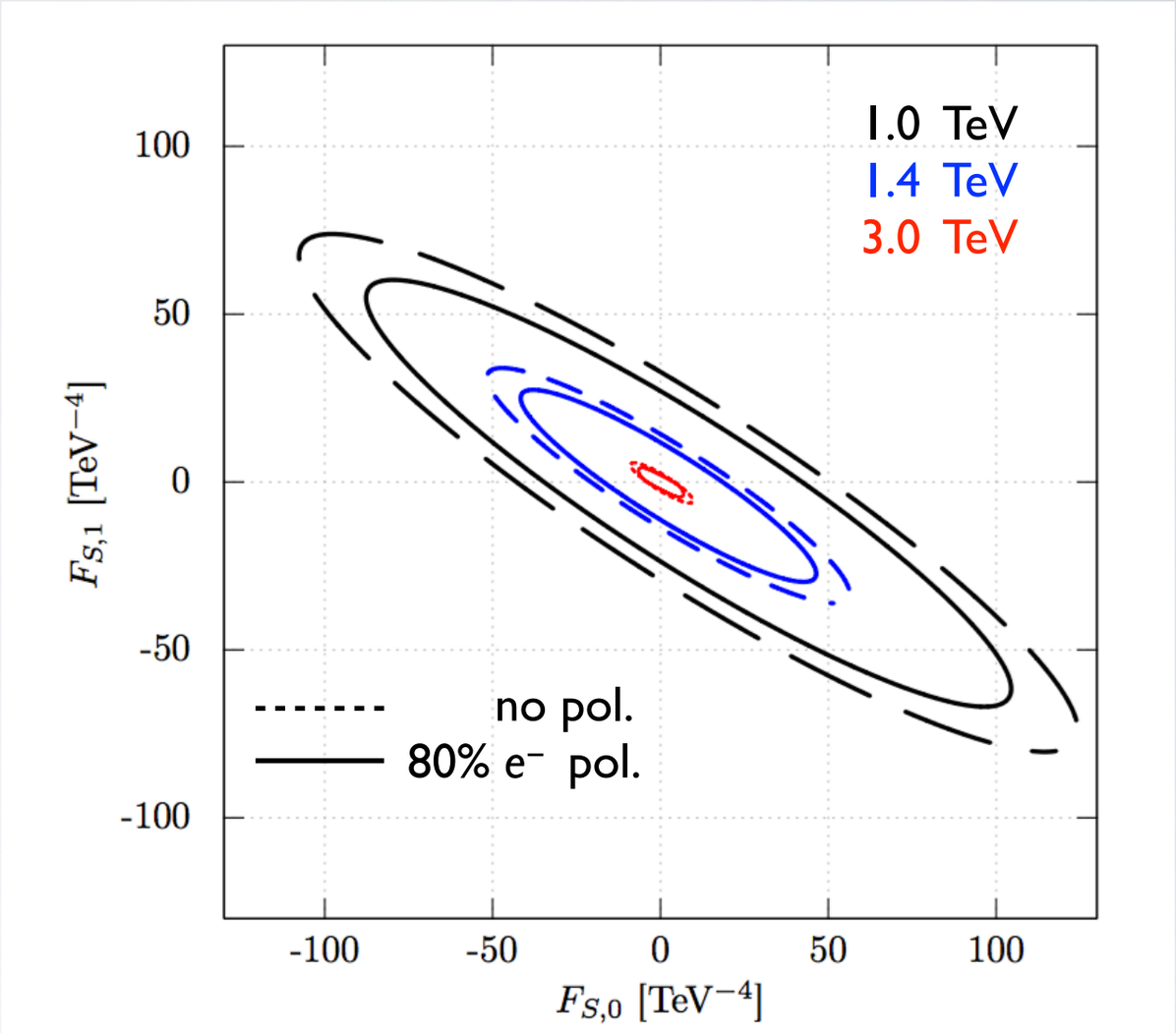

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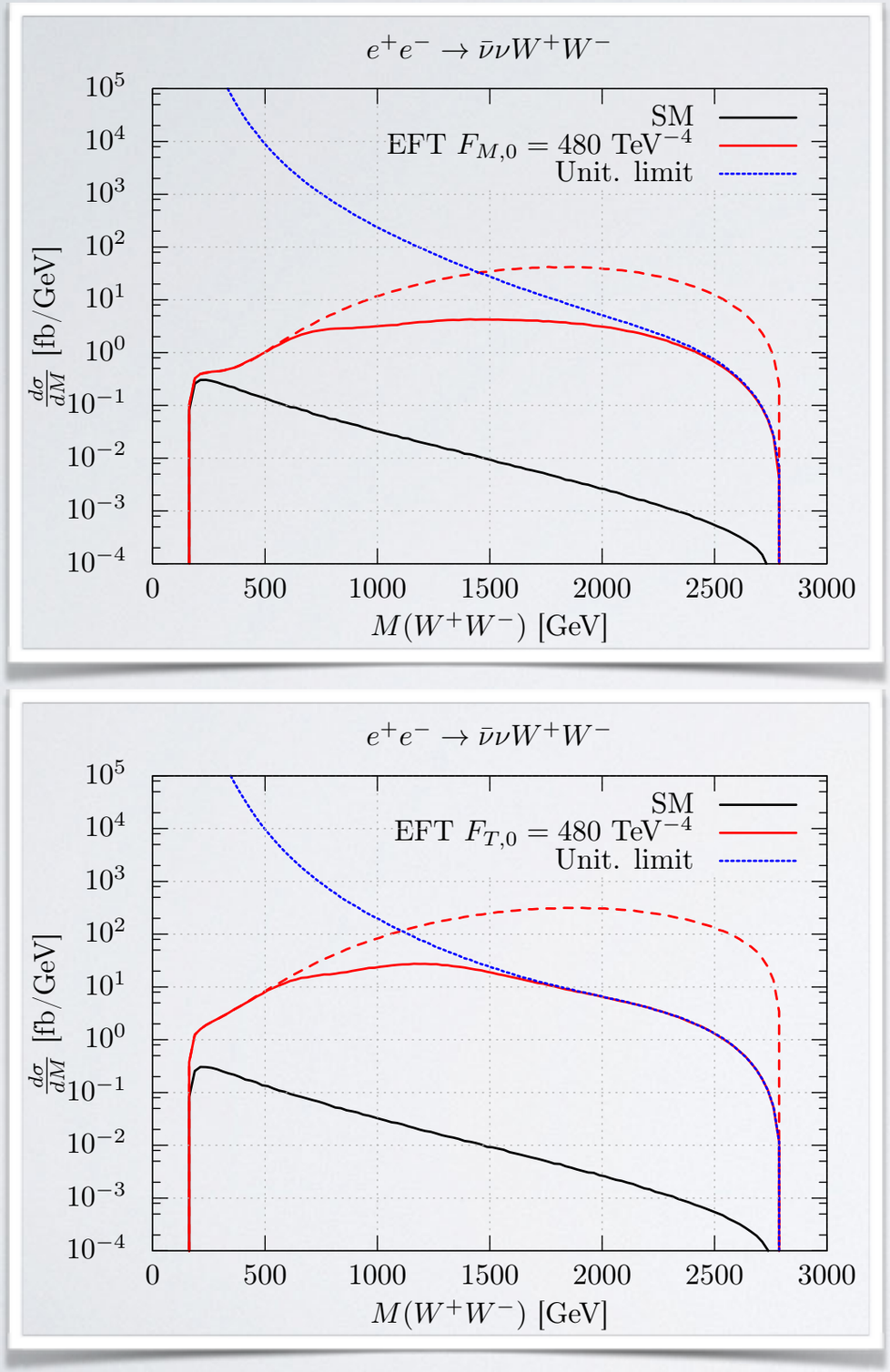
Fleper/Kilian/JRR/Sekulla: 1607.03030

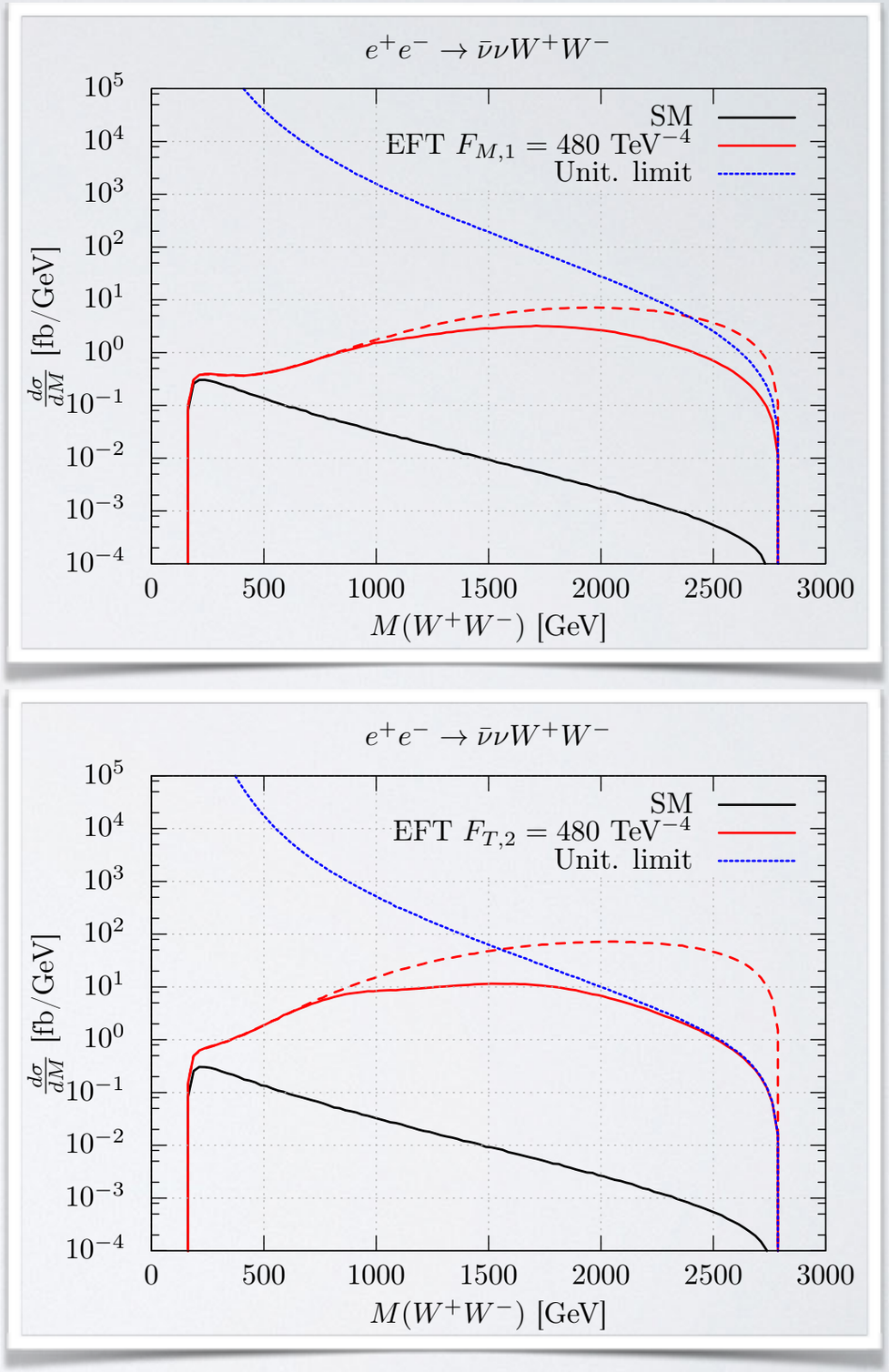
- Confirmed by full simulation [CLICdp]

→ cf. Talk by Jakob Meyer

SMEFT dim. 8: longitudinal vs. mixed operators

$e^+e^- \to \nu\bar{\nu}W^+W^-$ LT op. (upper panel), T operators (lower panel); continuum, no cuts





3 TeV

Simplified Models & New Resonances

- Rise of amplitude / anomalous coupling: Taylor expansion below a resonance
- Resonances might be in direct reach of LHC
- EFT framework EW-restored regime: $SU(2)_L \times SU(2)_R$, $SU(2)_L \times U(1)_Y$ gauged
- Include EFT operators in addition (more resonances, continuum contribution)
- Apply *T*-matrix unitarization beyond resonance ("UV-incomplete" model)

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Consider four simple cases (resonances)

- Isoscalar scalar (neutral)
- Isotensor scalar (5 states: ++, +, 0, –, – –)
- Isoscalar tensor (neutral)
- Isotensor tensor (5 states)

	isoscalar	isotensor
scalar	σ^0	$\phi_t^{--}, \phi_t^-, \phi_t^0, \phi_t^+, \phi_t^{++}$ $\phi_v^-, \phi_v^0, \phi_v^+$ ϕ_s^0
tensor	f^0	$\begin{pmatrix} X_t^{--}, X_t^-, X_t^0, X_t^+, X_t^{++} \\ X_v^-, X_v^0, X_v^+ \\ X_s^0 \end{pmatrix}$
...	...	...

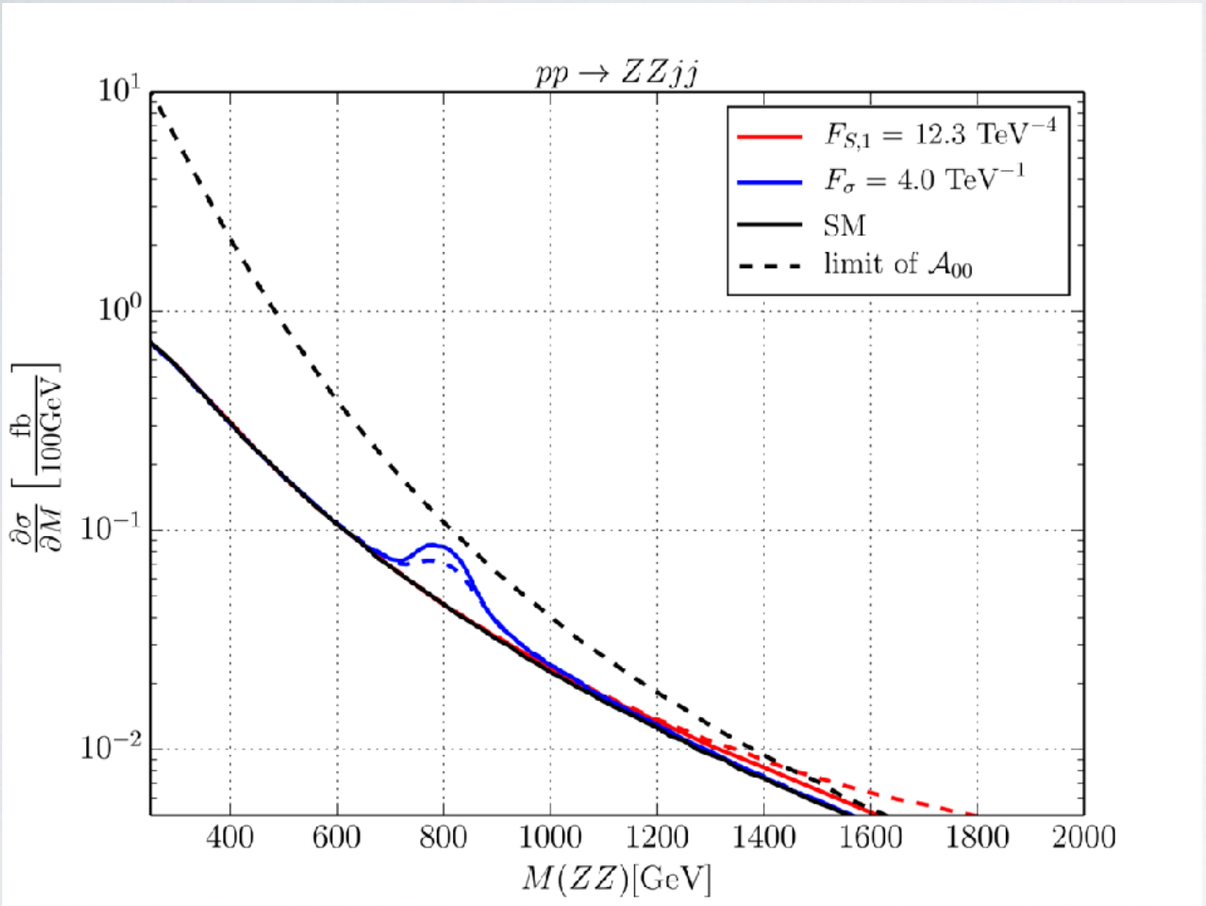
Spin 1 has different physics (mixing with *W*/*Z*)

$$32\pi\Gamma/M^5$$

	σ	ϕ	f	X
$F_{S,0}$	$\frac{1}{2}$	2	15	5
$F_{S,1}$	–	$-\frac{1}{2}$	-5	-35

Simplified Models: New Resonances in VBS

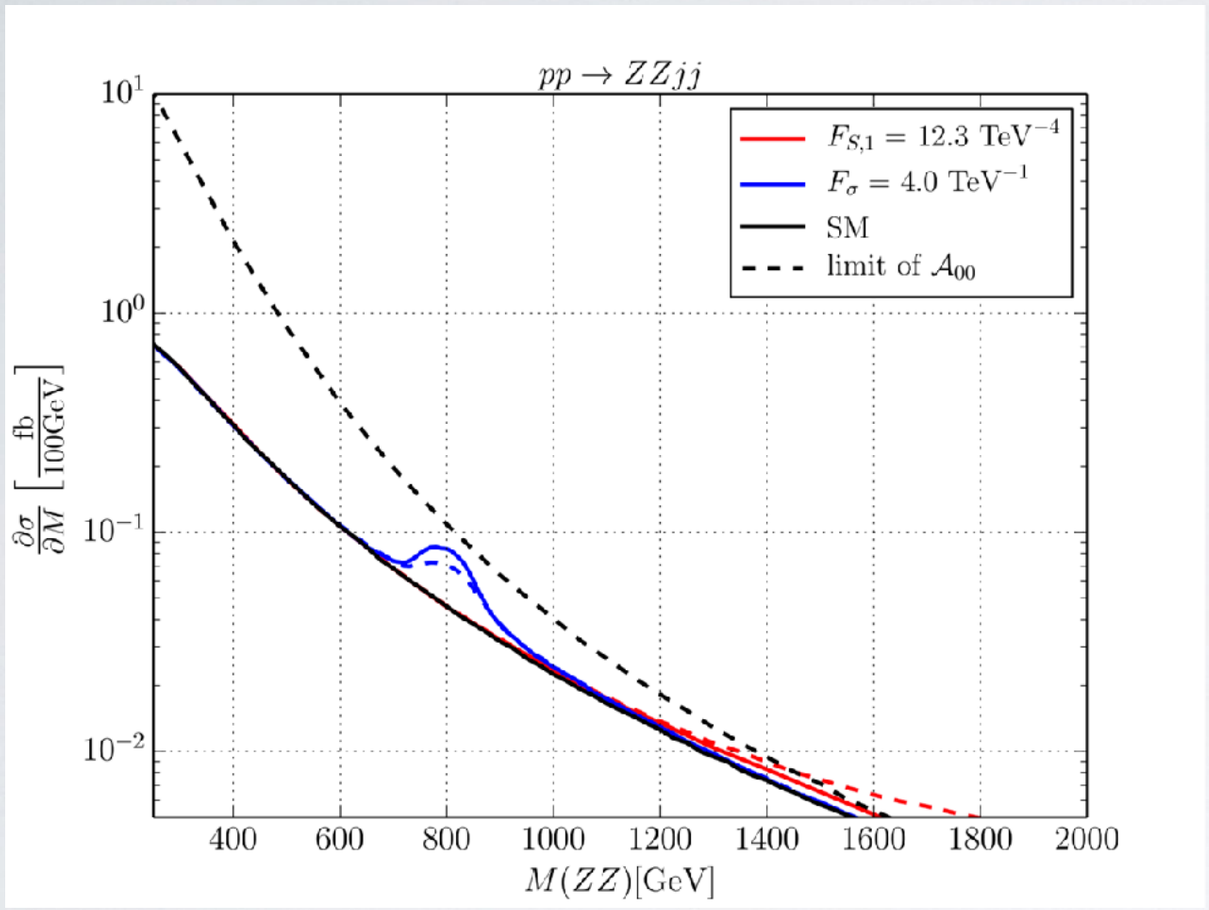
Comparison: Isoscalar scalar resonance , with cuts



LHC (14 TeV)

Simplified Models: New Resonances in VBS

Comparison: Isoscalar scalar resonance , with cuts



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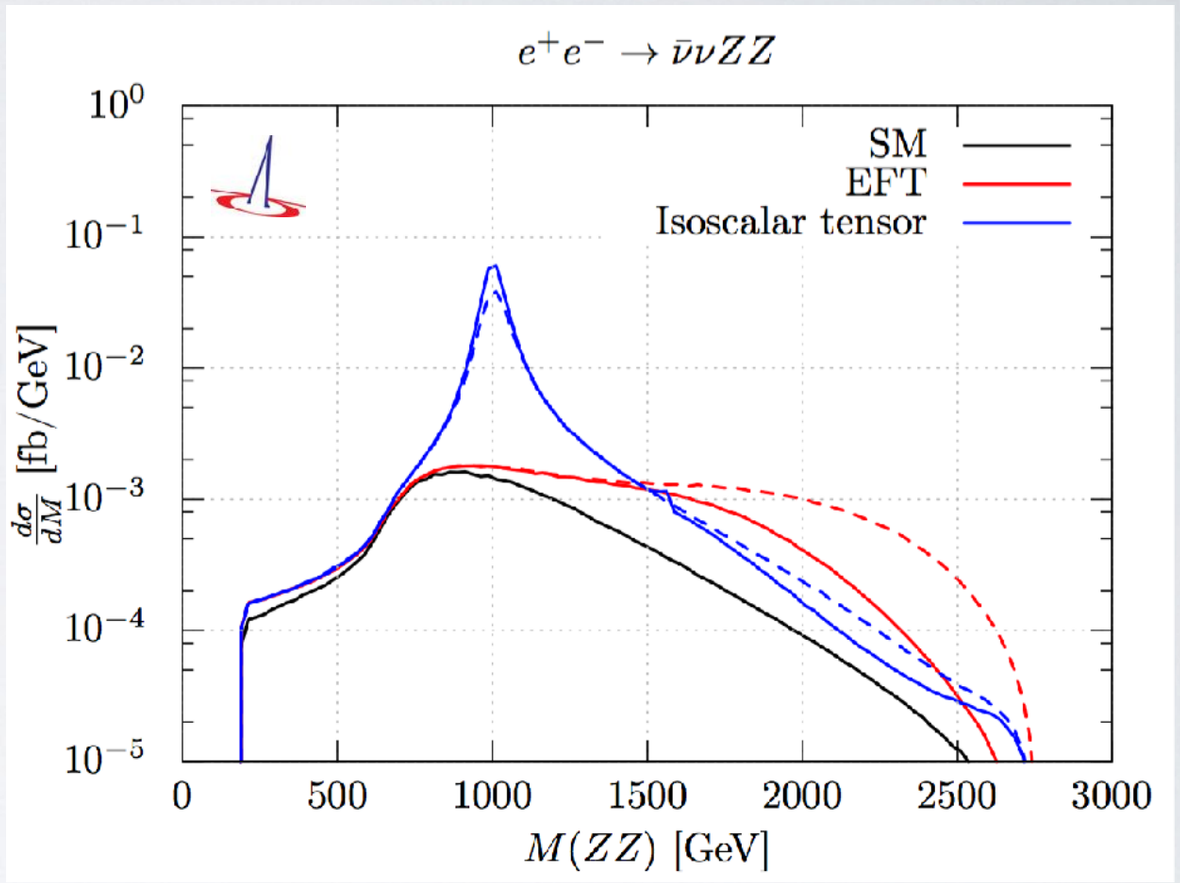

CLIC (3 TeV)

Detour: VB scattering into Top Quarks

$W^+W^- \to t\bar{t}$ as a probe for the top Yukawa coupling (SM vs. e.g. fermiophobic Higgs)

[Grojean/Panico/Wulzer, *wip*]

[Kilian/Kreher, *wip*]

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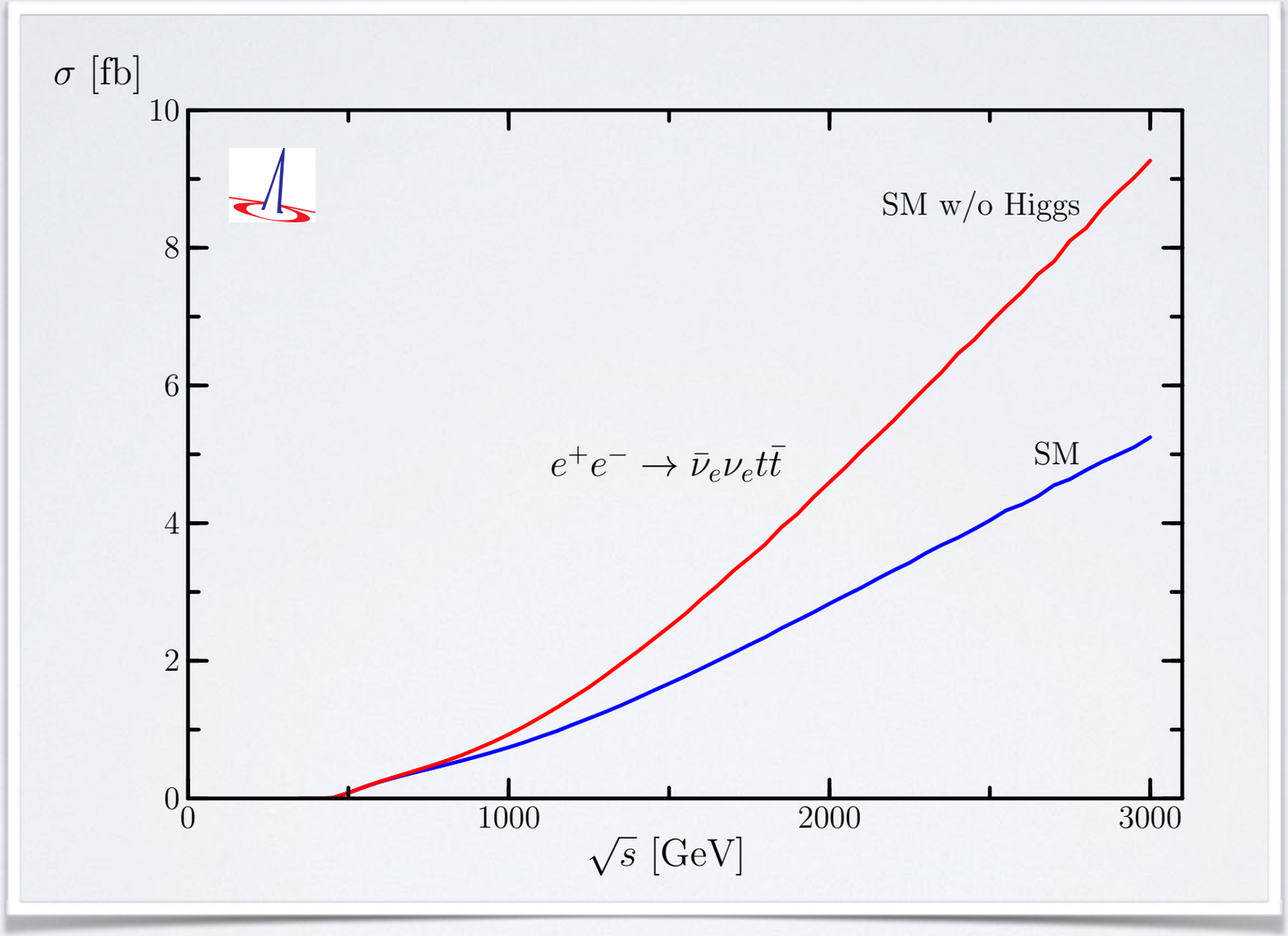


The ultimate VBS measurement

- Ultimate machines: plasma-driven e^+e^- accelerators
- ALEGRO: Advanced LinEar collider study GROup M. E. Peskin, Fukuoka 05/2018
- RF cavities: 50 MV/m, Drive beam: 100-150 MV/m
- Dielectric Laser (DLA): 1 GV/m , Plasema Wakefield (PWFA): 10–100 GV/m
- Idea for linear ultra-high energy e^+e^- collider: 10 TeV / 30 TeV / 50 TeV
- Problem: needed peak luminosity: $10^{36}\,cm^{-2}\,s^{-1}$, beam power: 50 MW (?), size: $\approx$ 1 x 1 nm^2
- Beam spectrum: only fraction will be in highest bin, non-linear regime
- Effectively becomes a photon collider: $\gamma\gamma \to W^+W^-$ quite favorable

- VBS cross sections tremendous: 0.8 pb [30 TeV] → 1.1 pb [50 TeV]
- Regime of EW radiation [VBS is just EW parton scattering]:

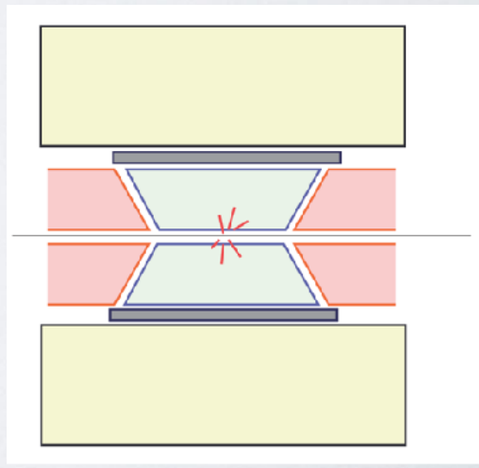
  W radiation probability: $2 \times \frac{\alpha_w}{\pi} \log^2 \frac{\sqrt{s}}{m_W} \sim 0.44$

- SM heavy flavor: macroscopic lifetimes *b*: 40 cm *c*: 20 cm τ : 70 cm
- Detector concepts might be relatively simple:

  no precision vertex detector needed,

  ca. 1 m tracking volume + high-granularity calorimeter

ALIC detector concept, [courtesy: J.-P. Tiang]



Conclusions & Outlook

- Linear Electron-Positron Colliders can reach very high energy
- Massive analysis power: no triggers, well-defined initial states, polarization
- Fully hadronic final states available in VBS
- Hence: invariant mass of diboson system is fully reconstructable

cf. talk by Michał Szleper

- Gauge invariance: VBS and tribosons cannot be disentangled in signal model
- Fiducial volumes: cuts can massively enrich VBS component
- Theory challenges: precision predictions, EW corrections, Sudakov logarithms
- Experimental challenges: hadronic *W*/*Z* discrimination in TeV regime
- Studies of L, LT, T (longitudinal / mixed / transversal) [dim-8] operators
- Validity of EFT: energy range, violation of perturbative unitarity, unitarization
- Beyond SMEFT: simplified models with new resonances

- Ultimate VBS measurement might be in plasma-driven 10-50 TeV e^+e^-

6th Workshop on Multi-Boson Interactions

August 28-30, 2018

U. Michigan, Ann Arbor

1. TU Dresden
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3. DESY
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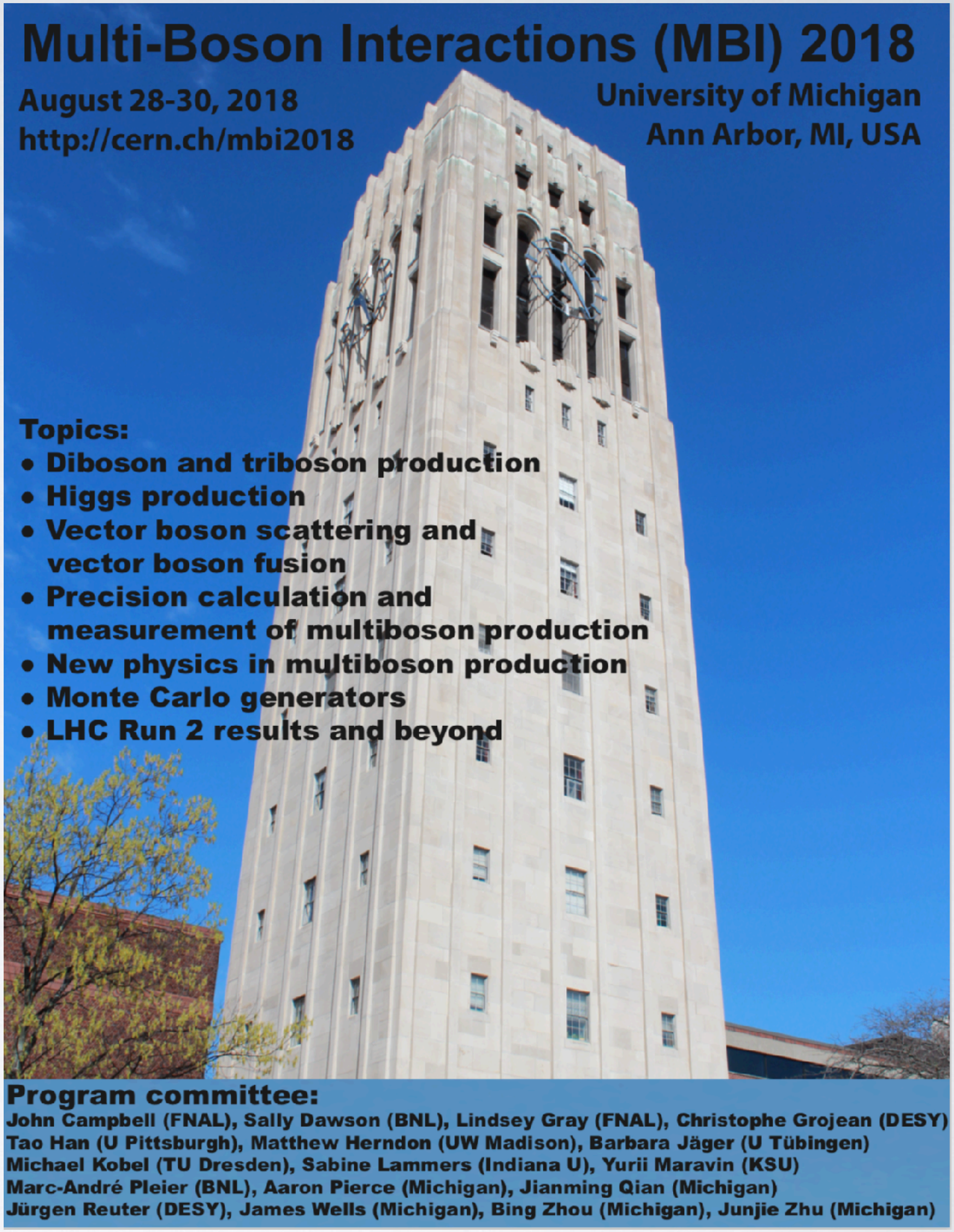
5. KIT Karlsruhe
6. **U. of Michigan — Ann Arbor**



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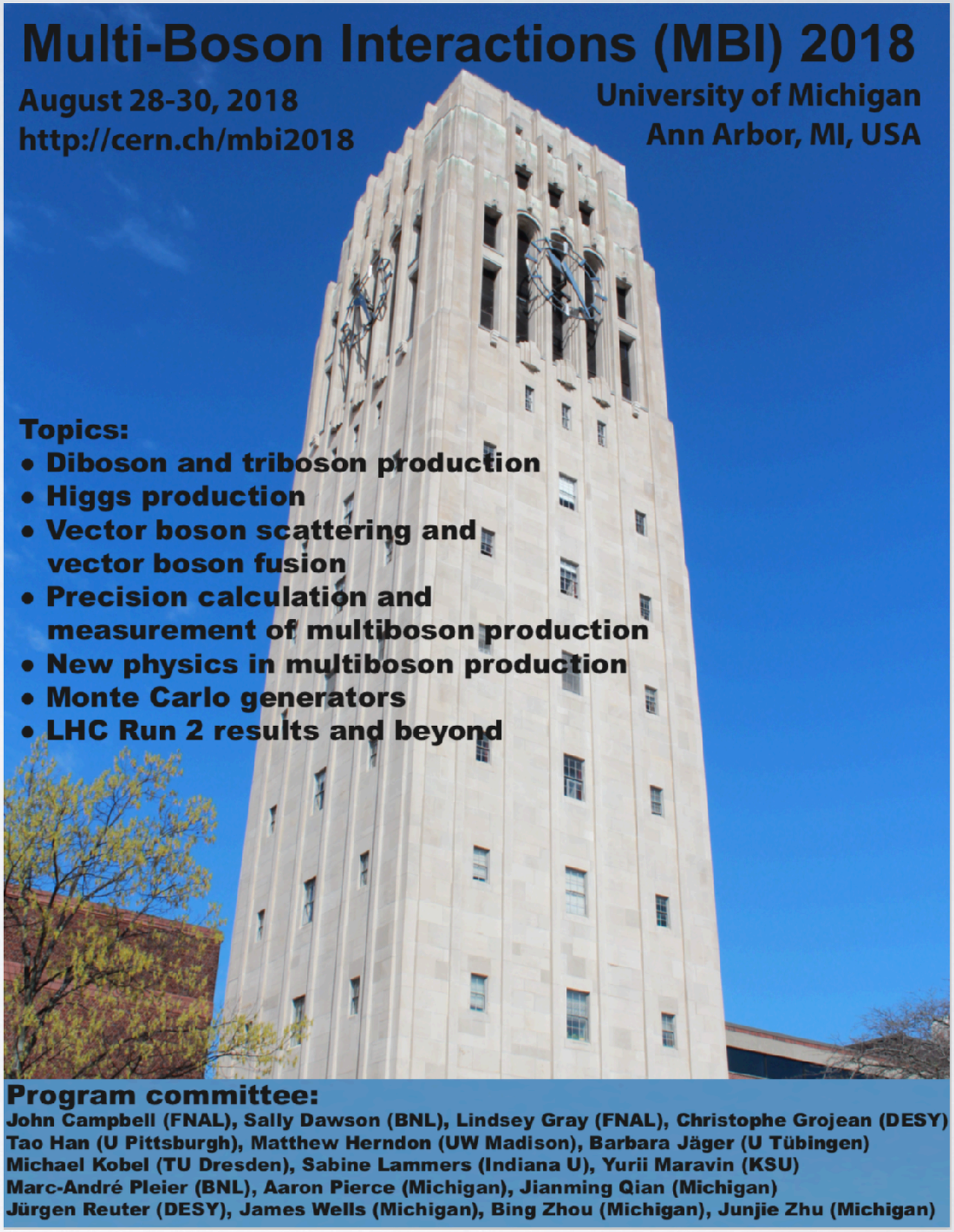
Looking for a (European) host for 7th MBI in 2019 !