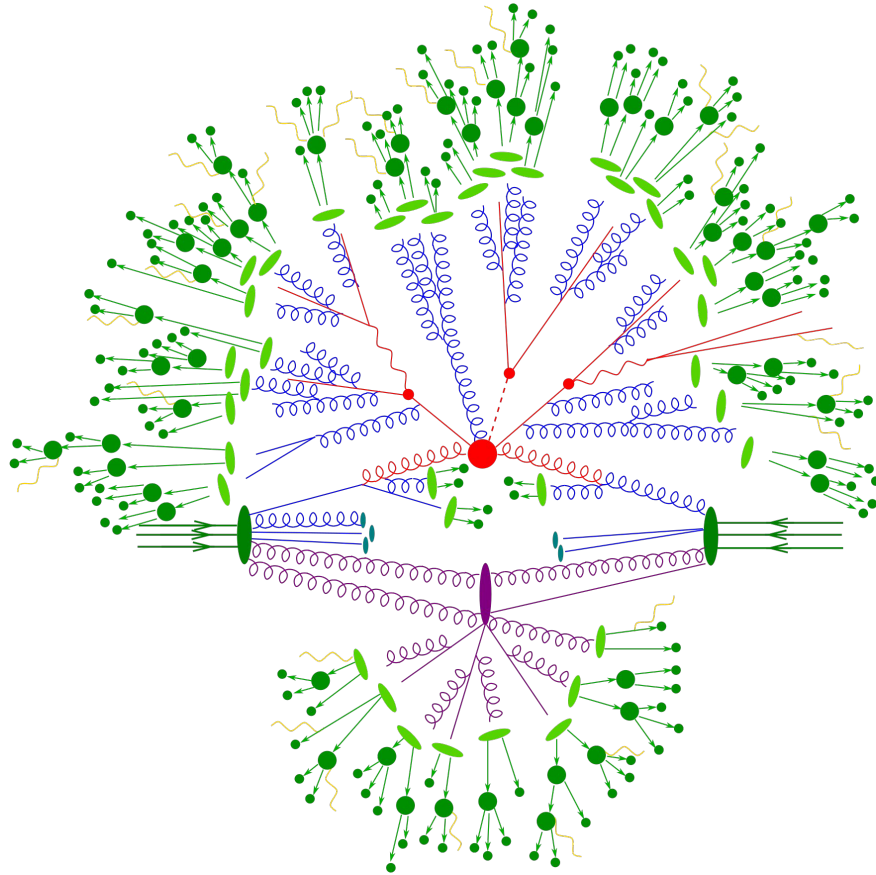




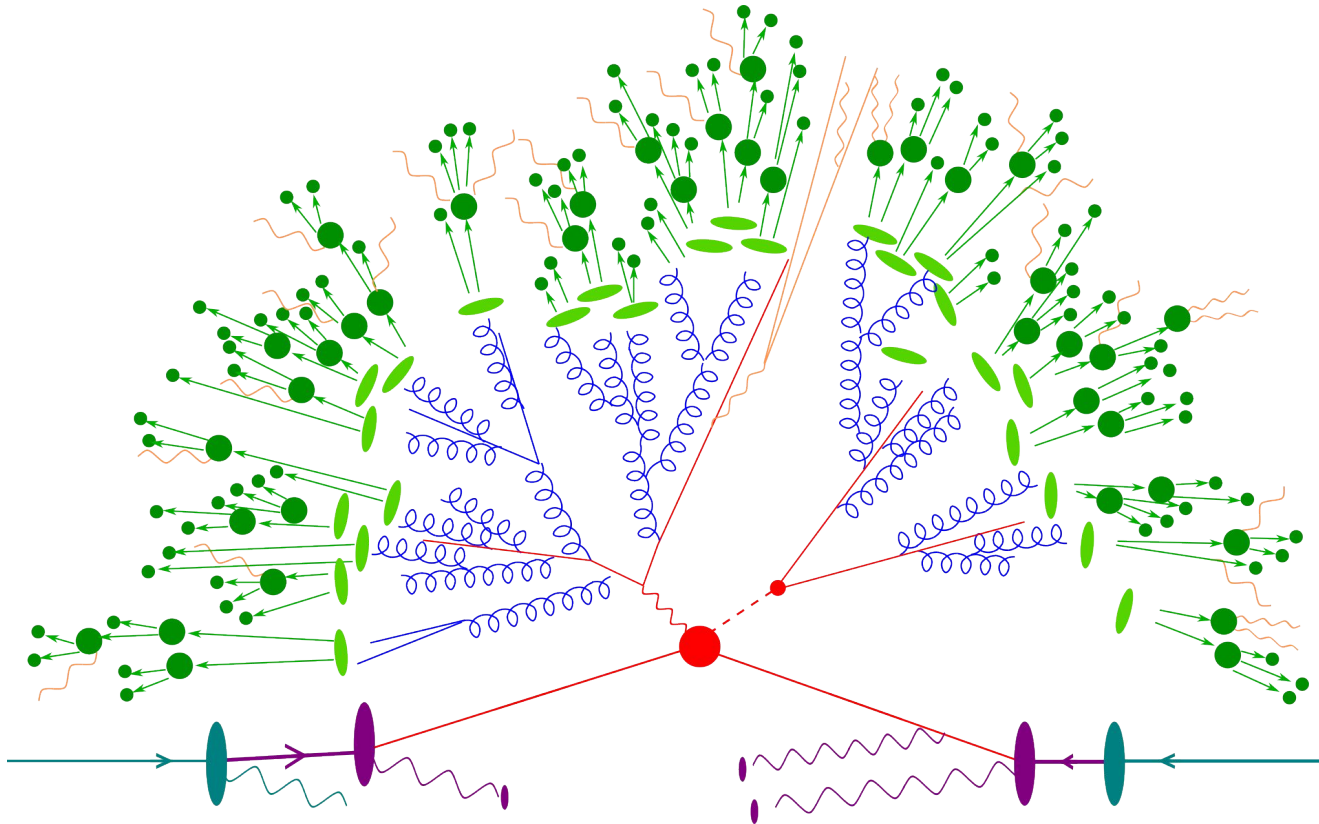
The new Sherpa 3.0 event generator

Alan Price*, Lois Flower
on behalf of the Sherpa collaboration



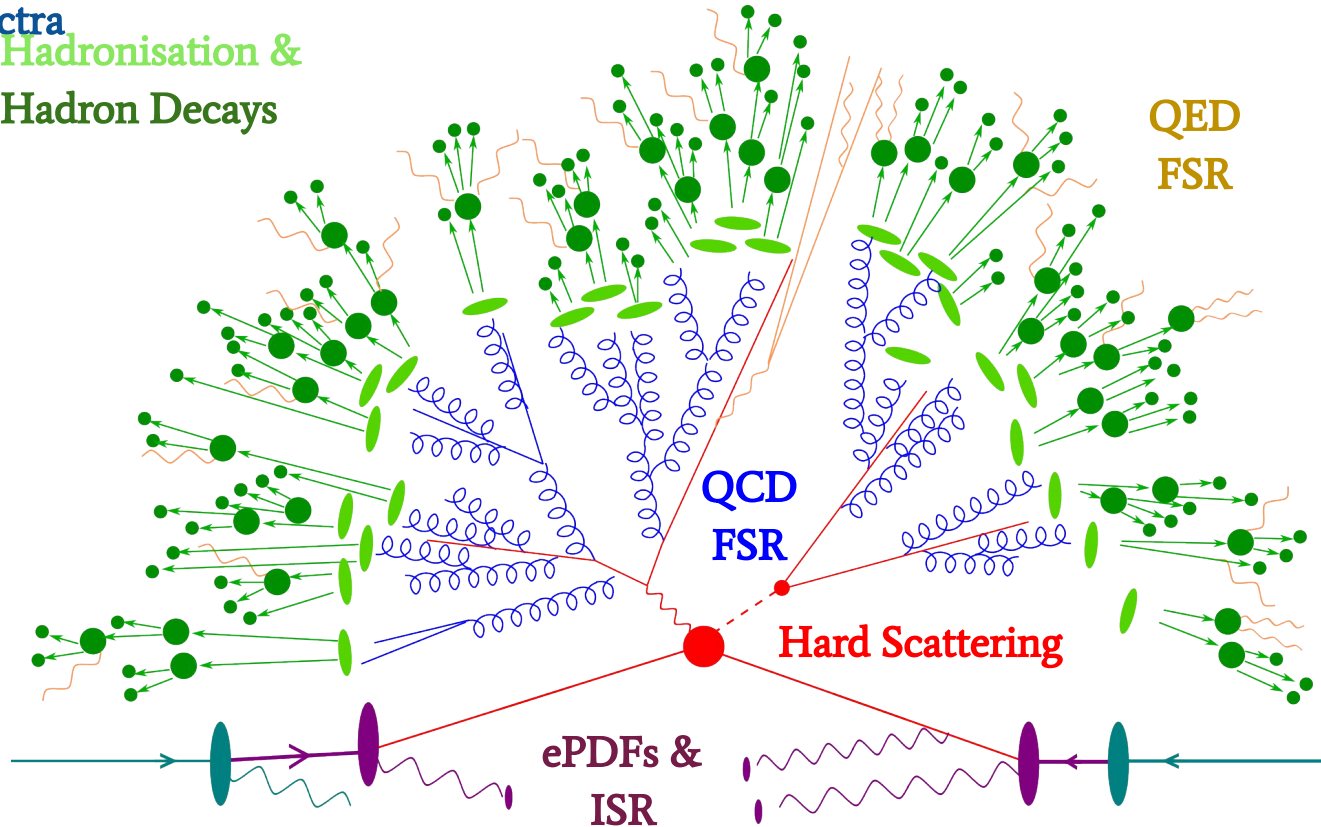


Monte Carlo event generators for LC



Beam spectra

Hadronisation &
Hadron Decays



<https://sherpa-team.gitlab.io/>

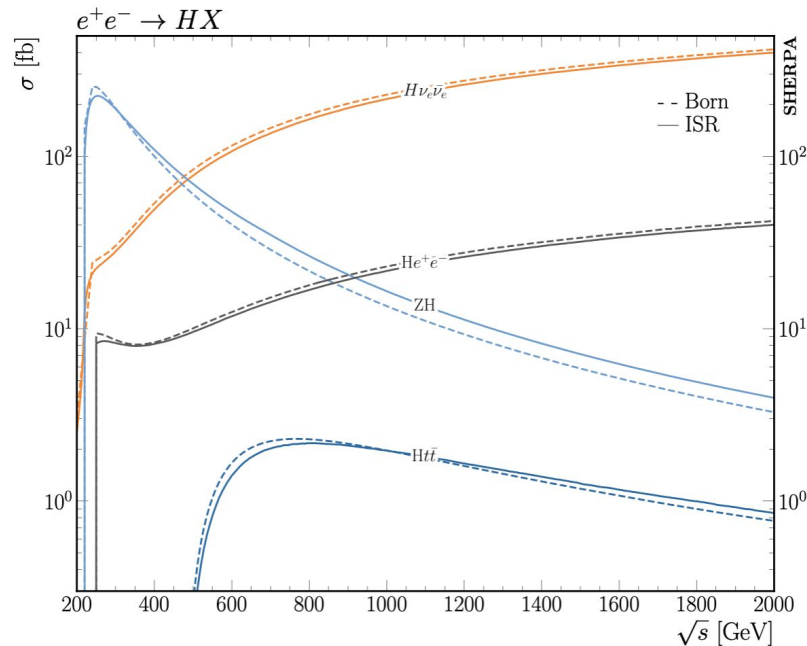


Condensing the work of the last >5 years

- new physics features
- more intuitive user interface
- more efficient CPU footprint
- modern build system
- comprehensive validation suite

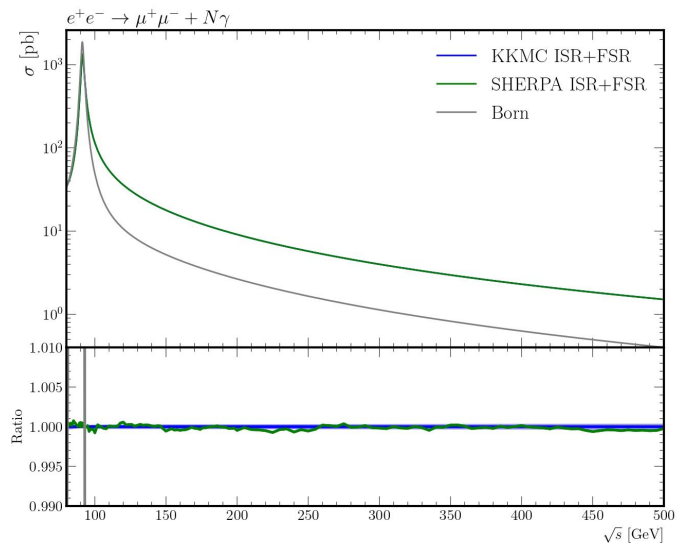
New in Sherpa 3.0: Real photon emissions in the initial state! [[Krauss, Schönherr, Price 2022](#)]

- Extension of Sherpa YFS module for soft photon resummation in final state [[Krauss, Schönherr 2008](#)]
- Supplemented with collinear logs up to $O(\alpha^3 L^3)$
- Complete treatment of multi-photon kinematics: Explicit photons, no simplified electron PDF
- Matching to full NLO EW complete [[Krauss, Price 2021](#)]
- NNLO Matching underway

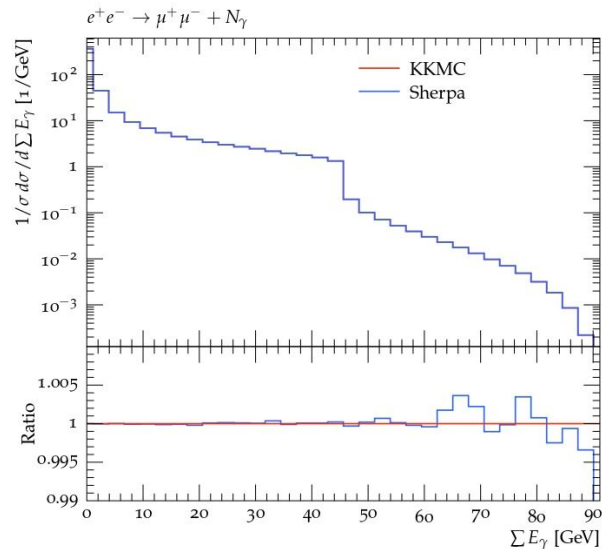


KKMC: LEP Era YFS MC for $e^+e^- \rightarrow f\bar{f}$

Comput.Phys.Comm. 130 (2000) 260-325



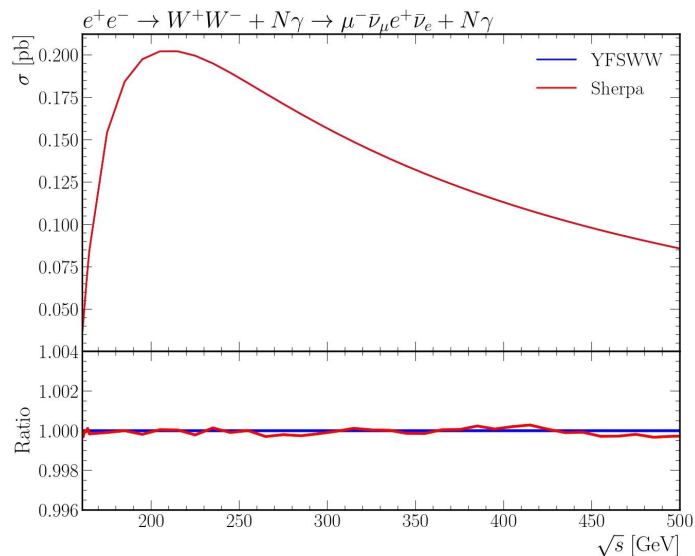
Superb agreement in σ
over a range of $\sqrt{s}$



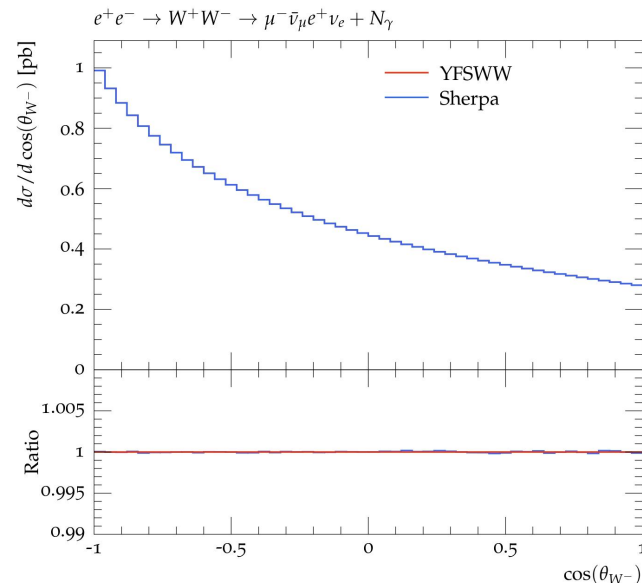
Excellent agreement in
the photon kinematics

YFSWW: LEP Era YFS MC for $e^+e^- \rightarrow WW$

Comput.Phys.Commun. 140 (2001) 475-512



Superb agreement in σ
over a range of $\sqrt{s}$



Excellent agreement in
the W kinematics

[Flower, Schönherr 2023]

Yennie-Frautschi-Suura soft-photon resummation does not include $\gamma \rightarrow f^+ f^-$ corrections which enter at $\mathcal{O}(\alpha^2)$

Yennie, Frautschi, Suura '61; Krauss, Schönherr '08

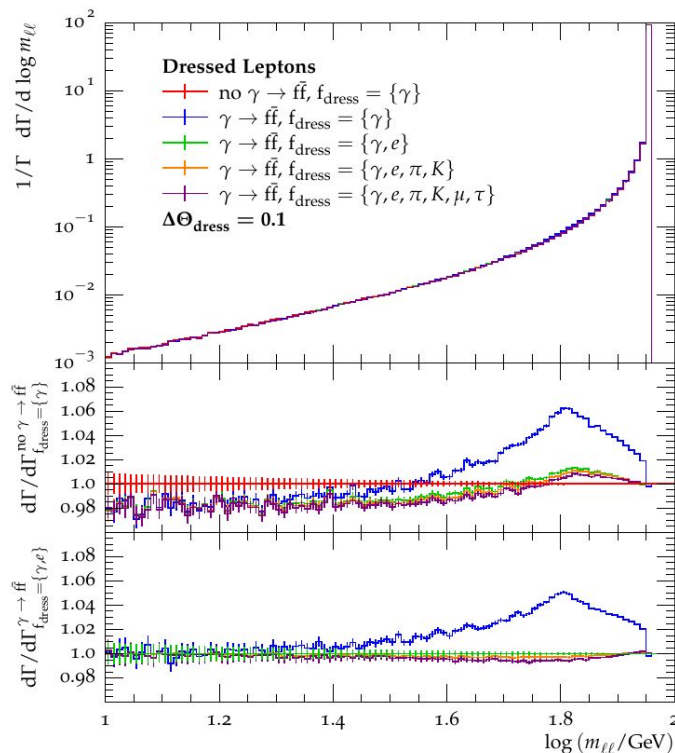
Collinear QED evolution:

- reconstruct starting scale of every photon
 - evolve in parton shower picture until every photon virtuality drops below $4m_e^2$
- ⇒ effect only corrections beyond YFS resummation

Dressing algorithm:

- lepton dressing ambiguous beyond photon FSR
- include secondary flavours?
if yes, some, or all?
- depending on dressing algorithm, more or less energy may be recombined into dressed lepton

$$Z \rightarrow e^+ e^-$$



Connection with
QED ISR
underway!
[Flower, Price]

- Available in one of Sherpa's ME generators (AMEGIC)
 - Recently resurrected for Sherpa 3
- Reweight the ME with pol factor (1+P),(1-P)
- Validated against Madgraph/Whizard
- Automatically included in YFS: Soft photons blind to spin!

BEAMS:

– 11

– -11

POLARIZATIONS:

BEAM_1: 0.3

BEAM_2: -0.8

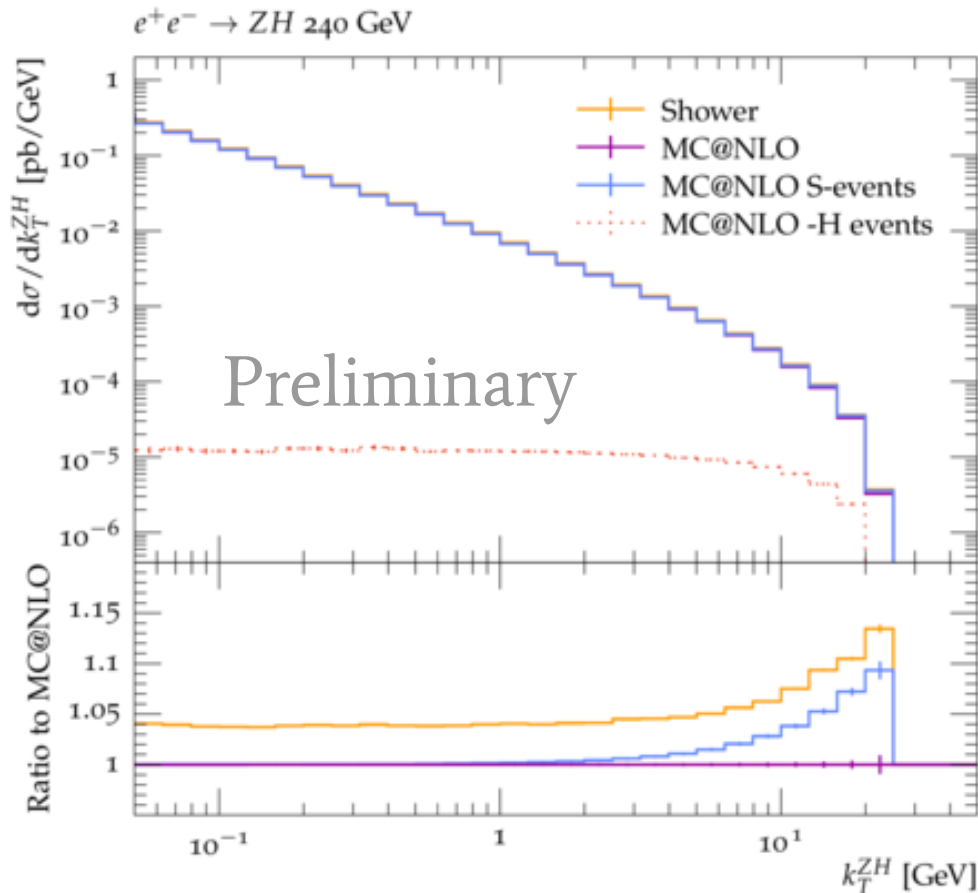
$P_{e^-} \ P_{e^+} \ %$	MadGraph	Sherpa
0 0	2100.0(0.72)	2099.5(0.09)
0 60	1825.0(0.63)	1824.1(0.08)
0 80	1733.0(0.66)	1732.3(0.08)
0 -60	2375.0(0.67)	2375.0(0.11)
0 -80	2466.0(0.72)	2466.9(0.11)
60 0	2375.0(0.67)	2375.0(0.11)
60 60	1344.0(0.46)	1343.7(0.06)
60 80	1000.0(0.35)	1000.0(0.04)
60 -60	3406.0(0.97)	3406.4(0.15)
60 -80	3749.0(1.11)	3750.1(0.17)
80 0	2466.0(0.72)	2466.9(0.11)
80 60	1184.0(0.36)	1183.6(0.05)
80 80	756.0(0.26)	755.8(0.03)
80 -60	3749.0(1.11)	3750.1(0.17)
80 -80	4177.0(1.24)	4177.9(0.18)

Table 1: Polarized cross-section for $e^+e^- \rightarrow \mu^+\mu^-$ at 91.2 GeV. The results are quoted in fb.

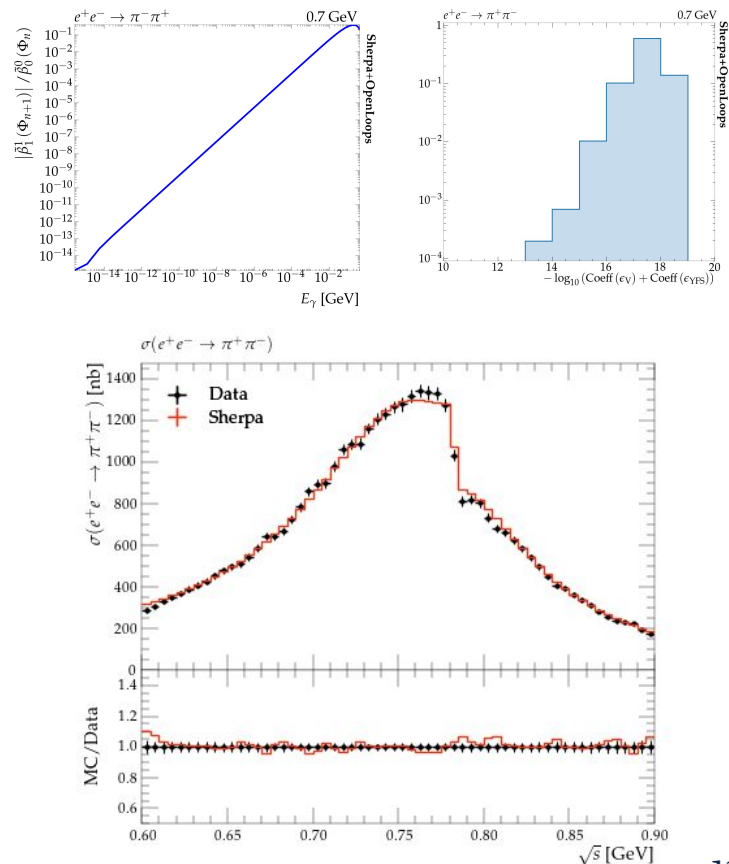
$P_{e^-} \ P_{e^+} \ %$	MadGraph	Sherpa
0 0	0.2402	0.2402
0 60	0.2086	0.2086
0 80	0.1981	0.1981
0 -60	0.2718	0.2718
0 -80	0.2823	0.2823
60 0	0.2086	0.2086
60 60	0.1537	0.1537
60 80	0.1144	0.1144
60 -60	0.3899	0.3898
60 -80	0.4292	0.4292
80 0	0.1981	0.1981
80 60	0.1354	0.1354
80 80	0.08647	0.0865
80 -60	0.4292	0.4292
80 -80	0.4782	0.4781

Table 1: Polarized cross-section for $e^+e^- \rightarrow HZ$ at 250 GeV. The results are quoted in fb.

- ▶ Automated matching of NLO EW and QED parton shower
- ▶ FSR validated against YFS
- ▶ TBP: validation against FO
- ▶ In progress: validation against initial-state YFS
- ▶ Method is extremely general, many applications to be studied
- ▶ Planned public release 3.x



- LO pion production easily combined with YFS or structure function
- Matching to complete NLO done [A.P, F. Krauss]
 - Extension to NNLO underway [S. Delorme, J. Gluza, A.P, N.Salone, A. Siodmok]
- $e^+e^- \rightarrow 2\pi$ can be combined with QED parton shower for ISR and FSR (scalar splitting functions) [L. Flower]
- Extension to matched NLO+PS fairly trivial to build on fixed-order NLO
- New Flexible **Form-Factor**
- Interface to **alphaQED**
- Additional Final states are being added e.g Kaons, Protons....



- ▶ Sherpa 3.0.2 released
 - Download and information on Sherpa homepage:
<https://sherpa-team.gitlab.io/>
 - New user interface (YAML language)
Give it a try!
- ▶ Sherpa's LHC expertise carries over to low-energy e+e-
 - Additionally dedicated developments
- ▶ NEW: automated YFS for state-of-the-art QED corrections [Alan Price]
- ▶ NEW: photon $\rightarrow$ lepton splittings in YFS [Lois Flower]



```
EVENT_GENERATION_MODE: Weighted
BEAMS: [11,-11]
BEAM_ENERGIES: 1.02/2

ME_GENERATORS: [Comix, Recola]

PROCESSES:
- 11 -11 -> 13 -13:
  Order:
    EW: 2
    QCD: 0

YFS:
  BETA: 1
  MODE: ISR
  IR_CUTOFF: 1e-6

PARTICLE_DATA:
  11:
    Massive: 1
    Mass: 0.0005109989500
  13:
    Massive: 1
    Mass: 0.1056583755
```

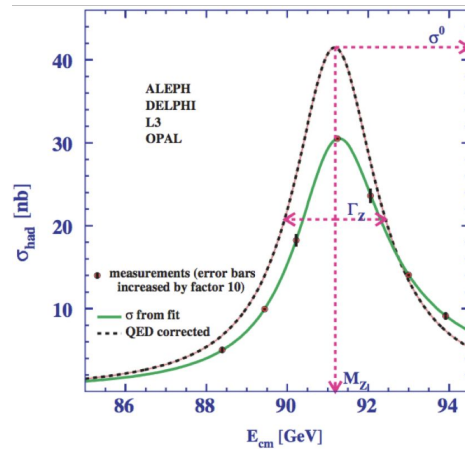


Backup

- Factor 2-100 improvement in the measurement of EWPOs
- 0.1% errors which could be ignored at LEP will be dominant at future e+e- machines
- On the theoretical side this translates into a much more sophisticated modelling
 - Fixed Order Improvements**

Observable	Where from	Current (LEP)	FCC (stat.)	FCC (syst.)	Now FCC
M_Z [MeV]	Z linesh. [32]	$91187.5 \pm 2.1\{0.3\}$	0.005	0.1	3
Γ_Z [MeV]	Z linesh. [32]	$2495.2 \pm 2.1\{0.2\}$	0.008	0.1	2
$R_l^Z = \Gamma_h/\Gamma_l$	$\sigma(M_Z)$ [33]	$20.767 \pm 0.025\{0.012\}$	$6 \cdot 10^{-5}$	$1 \cdot 10^{-3}$	12
σ_{had}^0 [nb]	σ_{had}^0 [32]	$41.541 \pm 0.037\{0.025\}$	$0.1 \cdot 10^{-3}$	$4 \cdot 10^{-3}$	6
N_ν	$\sigma(M_Z)$ [32]	$2.984 \pm 0.008\{0.006\}$	$5 \cdot 10^{-6}$	$1 \cdot 10^{-3}$	6
N_ν	$Z\gamma$ [34]	$2.69 \pm 0.15\{0.06\}$	$0.8 \cdot 10^{-3}$	$< 10^{-3}$	60
$\sin^2 \theta_W^{\text{eff}} \times 10^5$	$A_{FB}^{\text{lept.}}$ [33]	$23099 \pm 53\{28\}$	0.3	0.5	55
$\sin^2 \theta_W^{\text{eff}} \times 10^5$	$\langle \mathcal{P}_r \rangle, A_{FB}^{\text{pol}, \tau}$ [32]	$23159 \pm 41\{12\}$	0.6	< 0.6	20
M_W [MeV]	ADLO [35]	$80376 \pm 33\{6\}$	0.5	0.3	12
$A_{FB, \mu}^{M_Z \pm 3.5 \text{ GeV}}$	$\frac{d\sigma}{d\cos\theta}$ [32]	$\pm 0.020\{0.001\}$	$1.0 \cdot 10^{-5}$	$0.3 \cdot 10^{-5}$	100

[Jadach, Skrzypek, Eur. Phys. J. C79(2019)]



$$d\sigma(L, \hat{L}) = \alpha^k \sum_n \alpha^n \sum_{i=0}^{\infty} \sum_{j=0}^{\infty} \hat{\sigma}_{n,i,j} L^i \hat{L}^j$$

$$\hat{L} = \log\left(\frac{Q^2}{E_\gamma^2}\right) \quad L = \log\left(\frac{Q^2}{m_e^2}\right)$$

Soft Log

Collinear Log

- ▶ Dream of phenomenologists or experimentalists:
From a model's Lagrangian $L \rightarrow$ simulated event samples
- ▶ Important ingredient: UFO standard to automatically transfer Feynman rules (from FeynRules, SARAH, ...) into event generators
- ▶ Sherpa interface available for a while
[[Höche, Kuttimalai, Schumann, FS 2014](#)]
 - New in Sherpa 3.0.0: UFO 2.0 interface with more flexibility, e.g. with form factors
 - Automatic decay tables/chains
 - Spin correlations
 - Effective field theories (SMEFT, HEFT) via UFO model

