New Methods for Precision Luminosity at Higgs Factories

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For PALOOZA '24

April 13, 2024

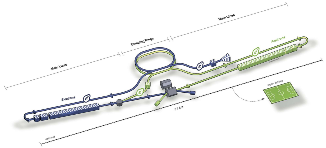
Contents

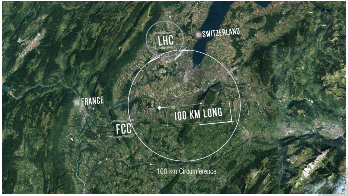
Higgs Factories

- **Why Higgs Factory?**
- We want to precisely measure more Higgs bosons! (also top quarks)
- **Doesn't the LHC do this?**
- Not precisely!
- See LHC disagreement with other experiments (W mass etc.)
- Hadron colliders prefer low energy (< 100 GeV), **NOT** $\sqrt{s}$
- Lepton colliders prefer CoM energy, aka $\sqrt{s}$
- **What is a Higgs Factory?**
- e^+e^- or $\mu^+\mu^-$ collider operating at ZH threshold
- Usually $\sqrt{s} \approx 250$ GeV
- **Why ZH?**
- High cross-section and can be precisely measured

Higgs Factories

- **What/where?**
- Future Circular Collider (FCC) in Geneva
- International Linear Collider (ILC) in Japan
- International Linear Collider (ILC) at FermiLab
- Compact Linear Collider (CLiC) in Geneva
- Cool Copper Collider (C^3) in USA (SLAC?)
- Circular Electron Positron Collider (CEPC) in China



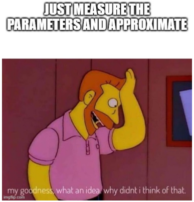


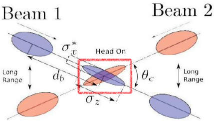
The Scope of This Talk

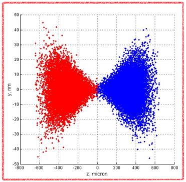
- **What are we doing**
- Counting particles!
- **???It's that simple???**
  $\longrightarrow$
- "Counting in Colliders"
  is Luminosity
- **What is luminosity?**
- Density of particles where your beams collide , $N = L\sigma$

The Scope of This Talk

- **Why can't we just know this?**
- Gaussian beam approximation +Machine parameters??



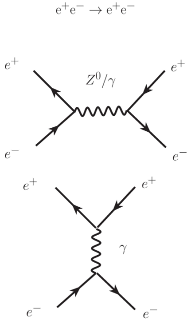




- $L_{ep} =$ $N_e N_p f \left[2\pi\sqrt{(\sigma_{z,p}^2+\sigma_{z,e}^2)(\sigma_{x,p}^2+\sigma_{y,p}^2+\sigma_{x,e}^2+\sigma_{y,e}^2)}\right]^{-1}$
- It isn't that simple.

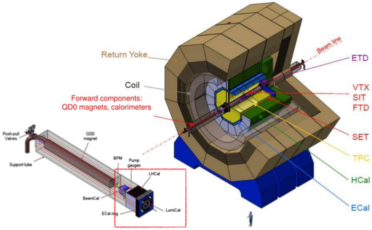
Luminosity from Counting Bhabhas

- **How do we usually do it?**
- Measure a well-known process. Bhabhas!



Measuring Bhabhas

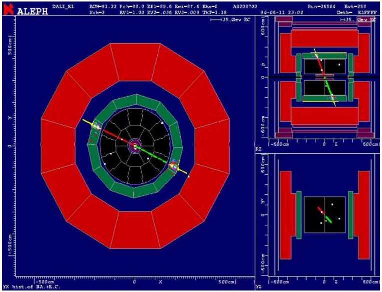
- **How?**
- e^+e^- in detector with following:
- Back-to-back acolinearity: $\theta_{ac} \approx 0$
- Back-to-back acoplanarity: $\phi_{ap} \approx 0$
- Both near beam energy $E_{\pm} \approx \frac{\sqrt{s}}{2}$
- **Where?**
- Low mass t-channel
  $\rightarrow$ Small angle, $\theta < 0.2$ rad
  $\rightarrow$ Forward calorimeter



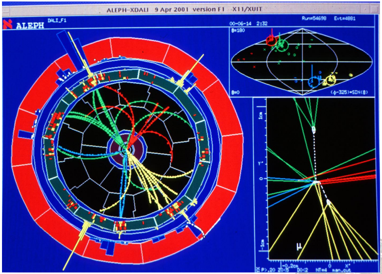
Counting Bhabhas

- **What does this look like?**
- Look at LEP events ...

- Wide-angle (electroweak) Bhabha at ALEPH (LEP)



- (for comparison) ZH at ALEPH (LEP)



Counting Bhabhas

- **What affects this measurement?**
- See OPAL's table ... Also, theory uncertainty on Bhabhas

Uncertainty	section	93 -2	93 pk	93 +2	94a	94b	94c	95 -2	95	95 +2
Radial Metrology	2.3									
uncorrelated		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
correlated		1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Radial Thermal	2.3.2									
uncorrelated		0.06	0.00	0.06	0.09	0.11	0.11	0.25	0.25	0.25
correlated		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Inner Anchor	4.1.4									
uncorrelated		0.23	0.23	0.23	0.23	0.23	0.23	0.58	0.58	0.58
correlated		1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36
Outer Anchor	4.1.4									
uncorrelated		0.13	0.13	0.13	0.13	0.13	0.13	0.28	0.28	0.28
correlated		0.31	0.31	0.31	0.31	0.31	0.31	0.30	0.30	0.30
Z Metrology	2.4									
uncorrelated		0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.37	0.37
correlated		0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Background	5									
uncorrelated		0.76	0.76	0.76	0.75	0.75	0.75	0.76	0.76	0.76
correlated		0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Trigger	6									
uncorrelated		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
correlated		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Wagon Tagger	6									
uncorrelated		0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02
correlated		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total External ($\Delta\epsilon_{\rm ext}$)										
uncorrelated		0.81	0.81	0.81	0.80	0.80	0.81	1.10	1.10	1.10
correlated		2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16
Energy	4.3									
uncorrelated		0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
correlated		1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
Beam parameters	7									
uncorrelated		0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
correlated		0.57	0.57	0.57	0.57	0.57	0.57	0.76	0.76	0.76
Radial resolution	8									
uncorrelated		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
correlated		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Acollinearity bias	8									
uncorrelated		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
correlated		0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Azimuthal resolution	8									
uncorrelated		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
correlated		0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Clustering	8									
uncorrelated		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
correlated		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$\Delta R - \Delta\Theta$ cut difference	9.3									
uncorrelated		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
correlated		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M.C. statistics	8									
uncorrelated		0.29	0.27	0.29	0.33	0.13	0.25	0.36	0.34	0.32
correlated		0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Total Simulation ($\Delta\epsilon_{\rm sim}$)										

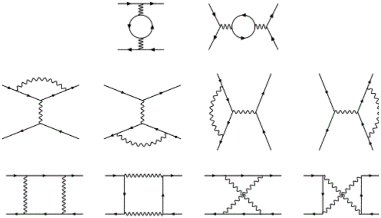
Event purity
"SNR"

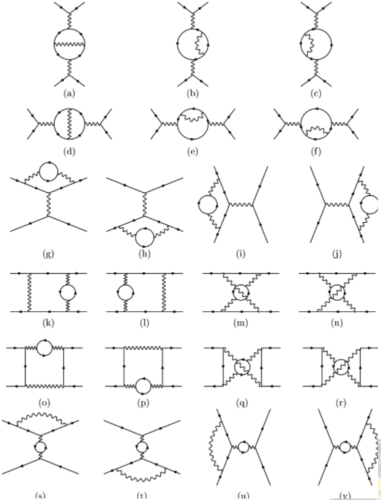
Energy res. ,
energy calibration

Spatial res. ,
detector acceptance

Bhabha Theory Uncertainty

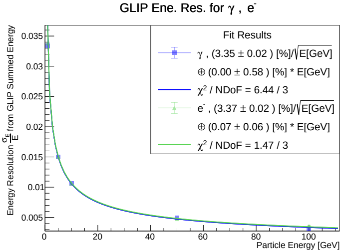
- **What is it?**
- About 5×10^{-4}. Need 5×10^{-5}
- ...but this worked at LEP???
- More corrections at higher energies
- Some of these can have W,Z,H

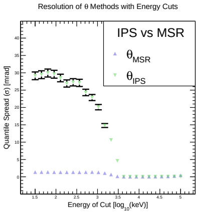


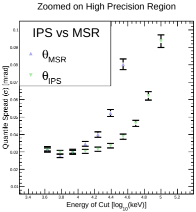


Bhabhas Detector Design

- **Are our detectors good enough?**
- Currently, no.
- Need $< 100\ \mu$rad θ res.
- Need $<$ 1 GeV Energy res.
- Solution? Thesis work on new forward calorimeter (GLIP)





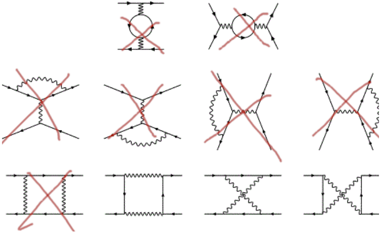


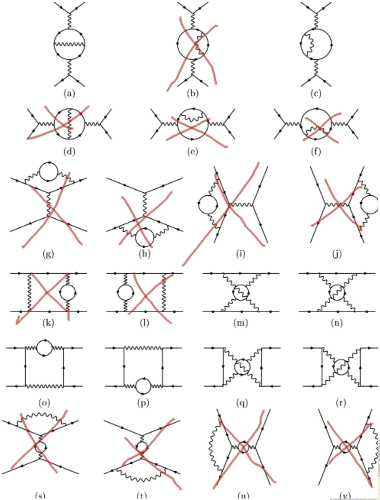
Bhabhas are good then?

- Maybe, if I complete my thesis AND
- A theorist improves theory uncertainty on Bhabha σ
- However, there are other factors that are complicated that make Bhabhas problematic
- What else is there?
- DiGammas $e^+e^- \to \gamma\gamma$?

Counting DiGammas: Theory

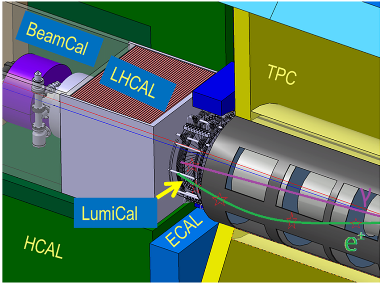
- **What about theory?**
- Less theory corrections because no $\gamma\gamma\gamma$ or $\gamma\gamma\gamma\gamma$ vertices





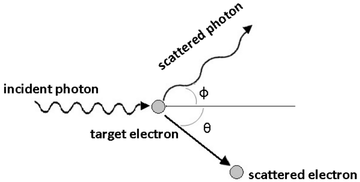
Counting DiGammas: Measurement

- **What affects measurement?**
- Essentially same as Bhabha's ...
- Less "complicated" factors
- No hits before calorimeter
- No bending of direction from Mag. field, beam pipe
- But less data (4000x less events)

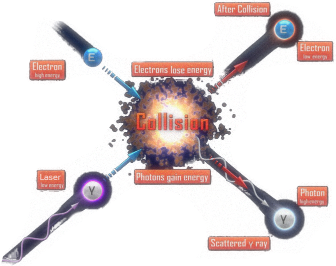


Luminosity Desires

- Luminosity dreams:
  What do we want?
  - Simpler theory calculations
  - Simpler event topologies (like gamma rays)
  - Lots of statistics
  - Can be precisely measured
- Simplest electron scattering measurement?
- Probably Compton scattering
- Cross-section $\approx 10000000\times$ Bhabha



...what if both particles are beams, not just the photons?
What if we had ...
... 3 BEAMS?



3Beam Math pt1: Control Variates

- We need to do some math homework first...
- **What are control variates?**
- DV μ that **can't measure well** but **its important**
- DV τ that **can measure very well** but **its not important**
- μ and τ are **correlated** by amount ρ
- Using measurements of τ to improve precision of μ to:

$$\frac{\sigma'_\mu}{\mu} = \frac{\sigma_\mu}{\mu}\sqrt{1-\rho^2} \quad (1)$$

- In limit of $\frac{\sigma'_\mu}{\mu} >> \frac{\sigma_\tau}{\tau}$
- Doing so τ is called a Control Variate or CV

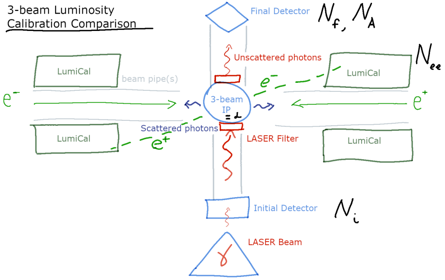
3Beam Diagram

- **What is the picture?**
  - Short pulse (ps) optical laser
  - Measure/control initial number of photons N_i
  - Measure number of attenuated when no IP N_A
  - Measure number of unscattered when IP N_f
- Can related number (power) of photons to number of scattered N_C

$$N_C = N_i - N_A - N_f \qquad (2)$$

- **DO NOT NEED TO MEASURE COMPTON DIRECTLY**!!!
- Indirect Compton method is already used by some synchrotrons

... 3 BEAMS?

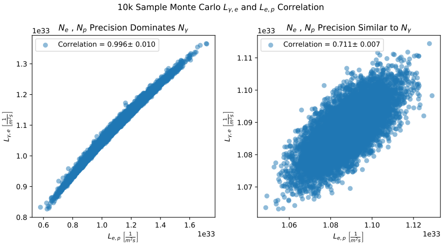


3Beam Math pt2: Lumi Boogaloo

- Now we have three luminosities:
- L_{ep} , $L_{e\gamma}$, $L_{\gamma p}$
- Where the latter two are $N_C = \sigma_C(L_{e\gamma} + L_{\gamma p})$
- **What does this get us?** $\rightarrow$
- Depends on precision of bunch densities of beams
- If N_γ is very precise correlation approaches 1!
- Do the math!
- If $\rho = 0.996$

$$\frac{\sigma'_{Lep}}{L_{ep}} = \frac{\sigma_{Lep}}{L_{ep}}\sqrt{1-\rho^2} \approx \frac{1}{10}\frac{\sigma_{Lep}}{L_{ep}} \quad (3)$$

Toy Monte Carlo of Luminosities



Factor of 10 improvement!

Summary

- Precision luminosity at Higgs factories is currently unsolved
- "Standard" luminosity method of Bhabhas may not be adequate unless significant improvements to analysis, detector, theory
- DiGammas may do better but also need work on analysis, detector, theory
- We proposed 3Beam luminosity method, using Compton scattering
- By using control variates method could improve L_{ee} measurement by factor of 10, without needing to improve analysis, detector, theory etc.
- Thus, outlook is that precision luminosity is on the horizon.