

Top mass measurement with the CLIC_ILD detector at 500 GeV

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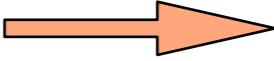
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- CLIC Introduction
 - Machine and Detector
 - CLIC background conditions
 - Event simulation and reconstruction
- Analysis Chain
 - Decay channel selection
 - Event topology reconstruction
 - Physical Background rejection
- Final results for CLIC CDR
- Summary

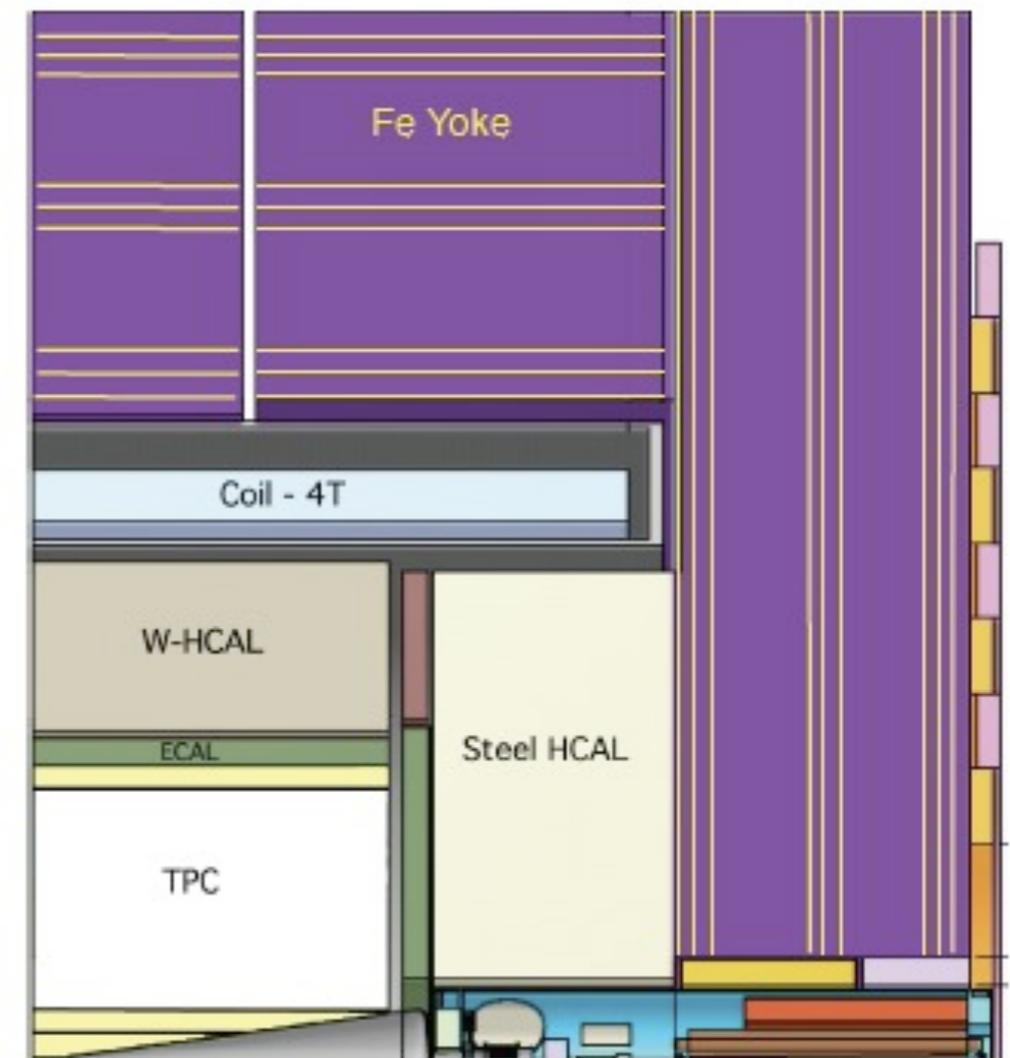
Machine:

- e⁺e⁻ machine 
- design $\sqrt{s} = 3 \text{ TeV}$
- different energies possible
- staged construction

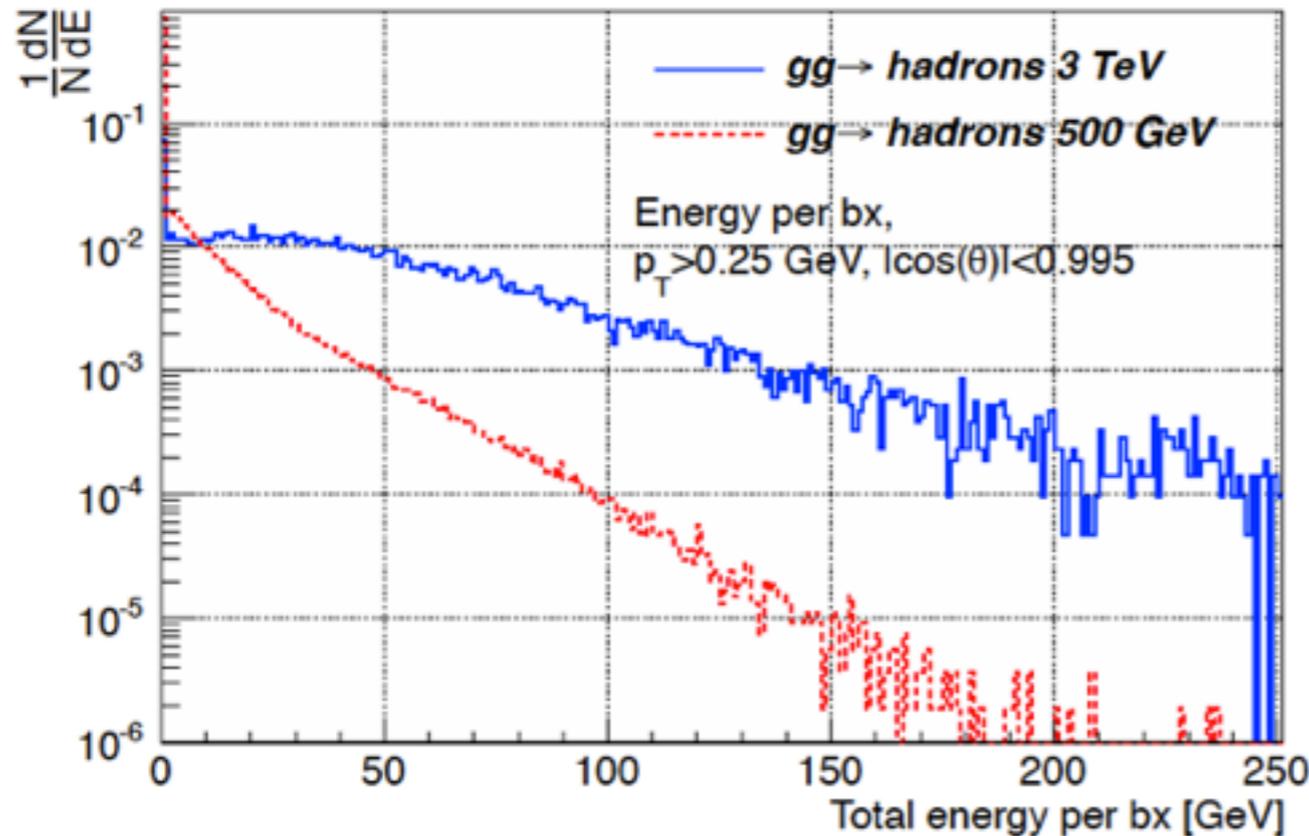
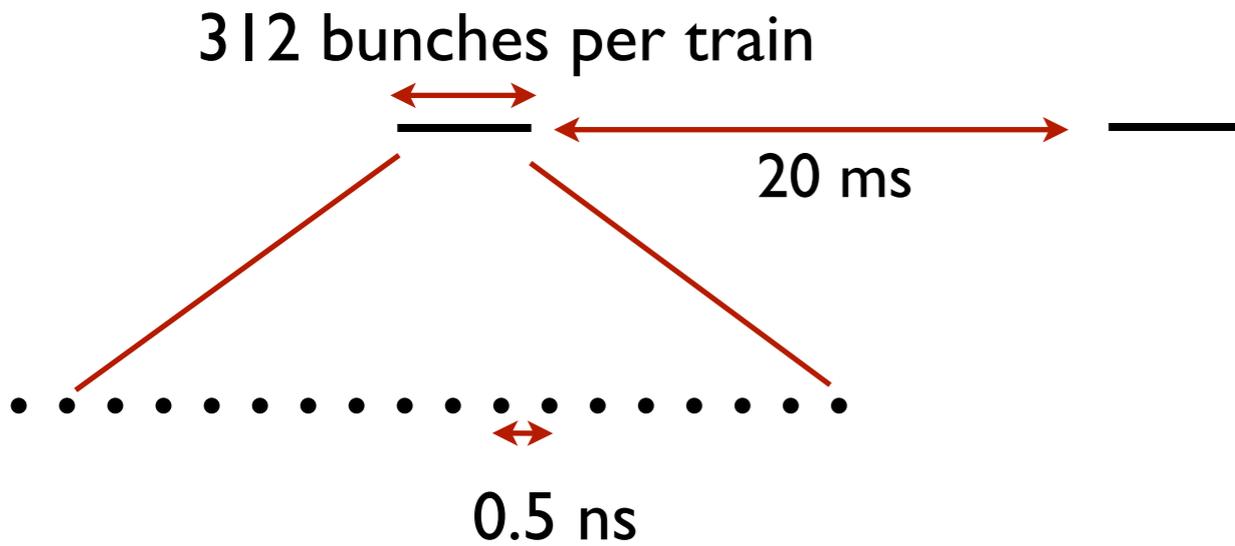
test SM and LHC results with high precision
search for physics beyond SM / LHC

Detector:

- Here: CLIC_ILD
- Optimized for Particle Flow
 - excellent tracking detectors
 - high granular calorimeter
 - time stamping capability



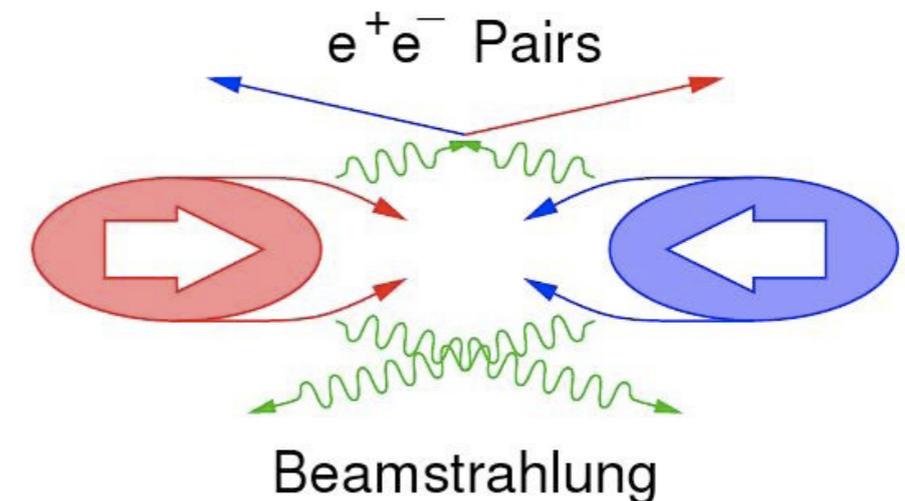
The bunch structure at CLIC



Beamstrahlung driven by energy and focusing

For 500 GeV:

- mean bunch:
 - $\Delta E/E \sim 7\%$
- coherent e^+e^- pairs:
 - 2.0×10^2 / bunch crossing
- incoherent e^+e^- pairs:
 - 8.0×10^4 / bunch crossing
- $\gamma\gamma \rightarrow \text{hadrons}$ interactions:
 - 0.2 / bunch crossing



CLIC event:

Integration over a full bunch train

- 312 bunches

Reconstruction challenge:

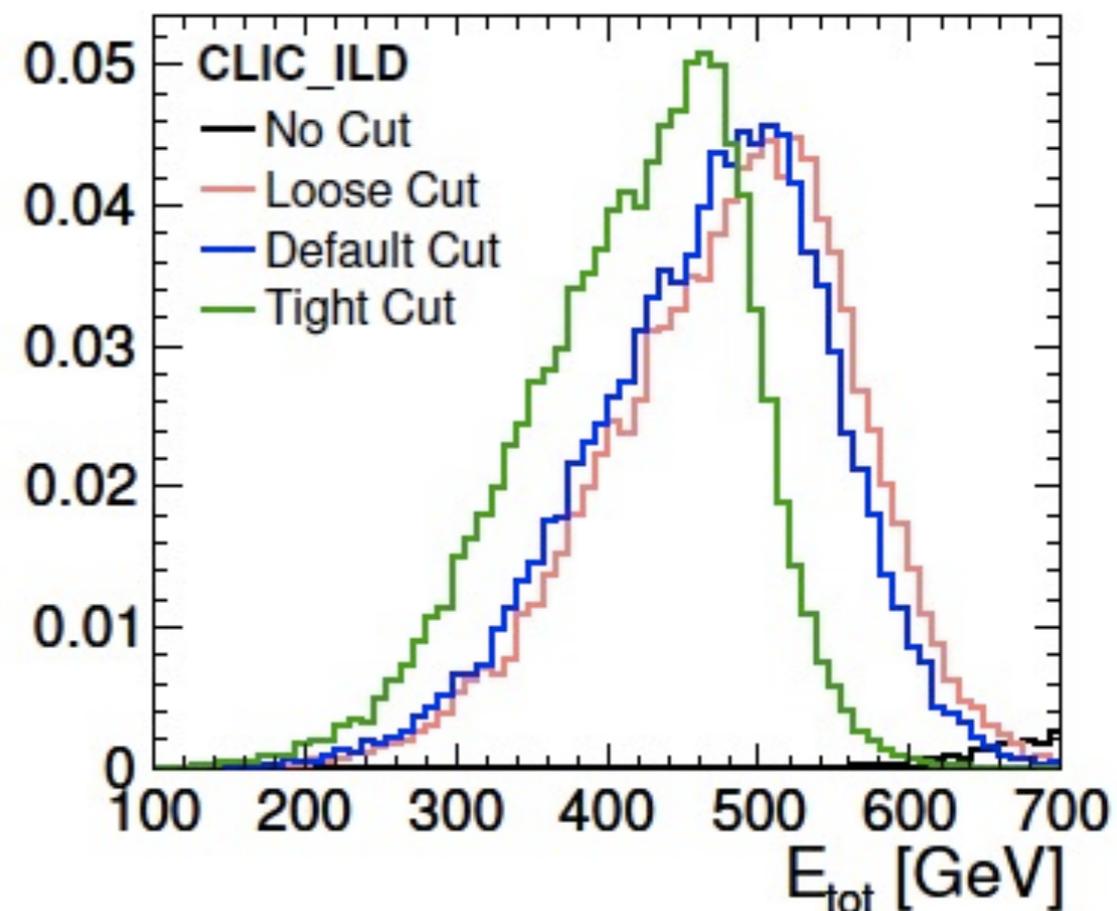
Suppress pile up from $\gamma\gamma \rightarrow$ hadrons interactions

- adds significant energy to events
- in particular in the forward region
- not in time with the physics event

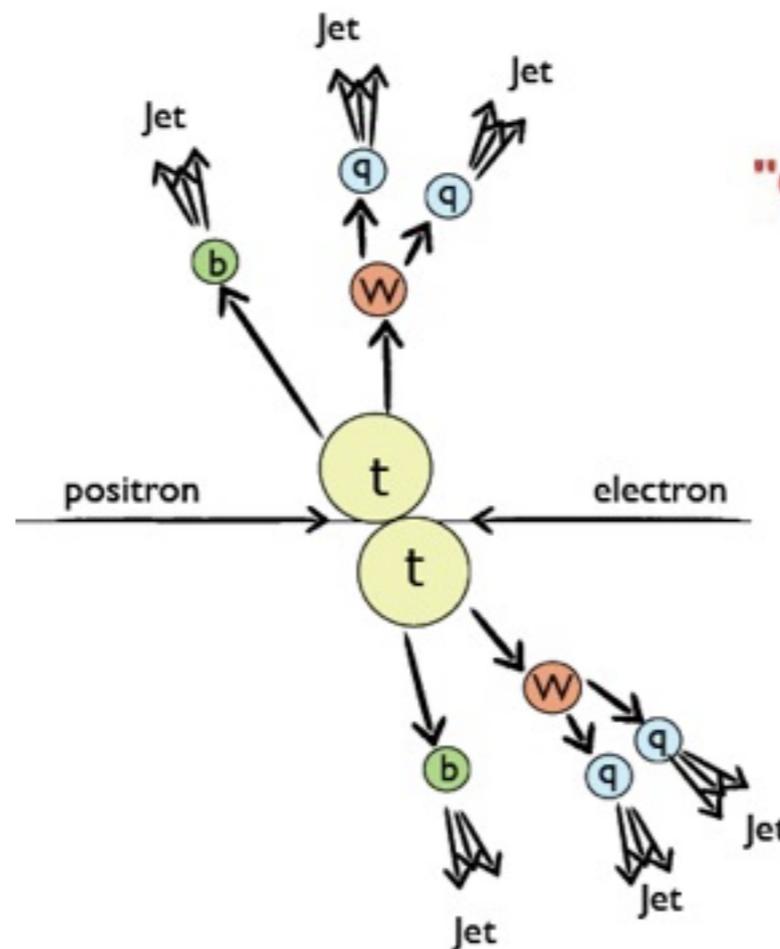
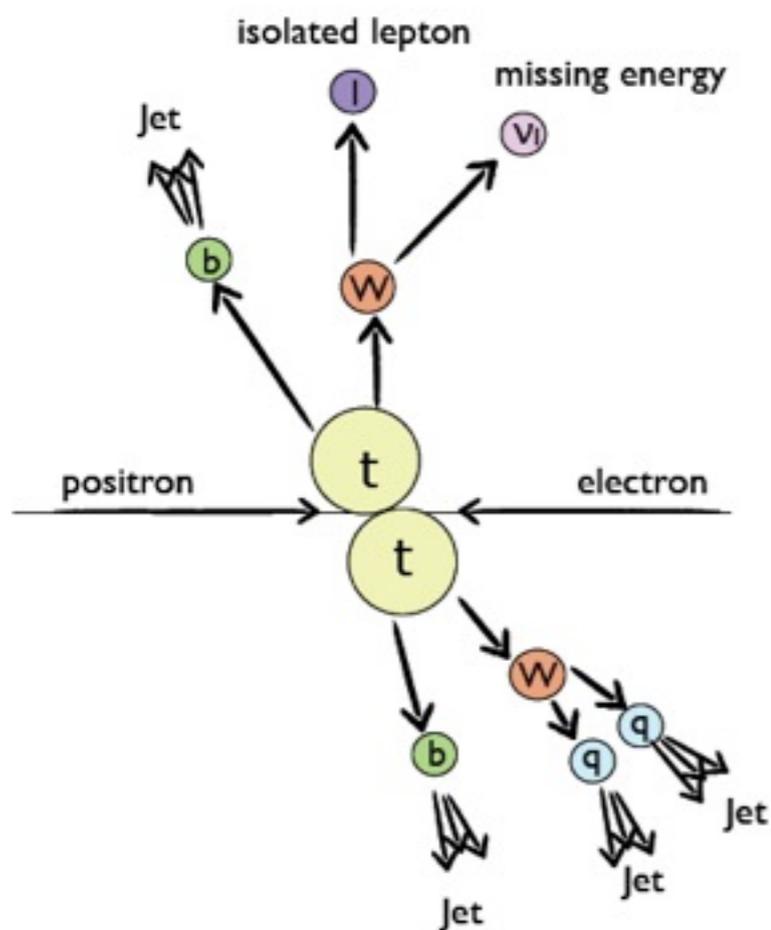
Reconstruction Technique: Particle Flow

- Pandora Particle Flow event reconstruction based on geometrical hit assignments
- Application of a combination of timing and p_t cuts specially for low p_t particles to reject $\gamma\gamma \rightarrow$ hadron background events
- Different strength of cuts are available for 3 TeV and 500 GeV center-of-mass energy

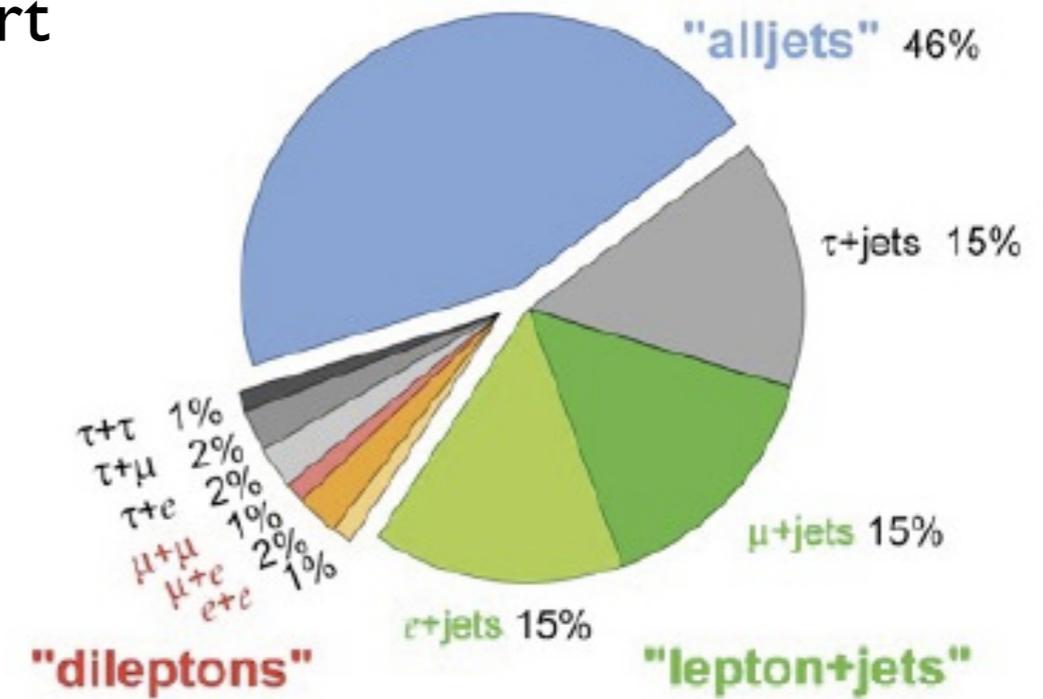
Effect of timing and p_t cut strengths



- Staged construction mode possible: 500 GeV
- Analysis part of the CLIC conceptual design report
- Analysis: Top mass measurement from top pair production
 - full-hadronic channel
 - semi-leptonic channel



Top Pair Branching Fractions

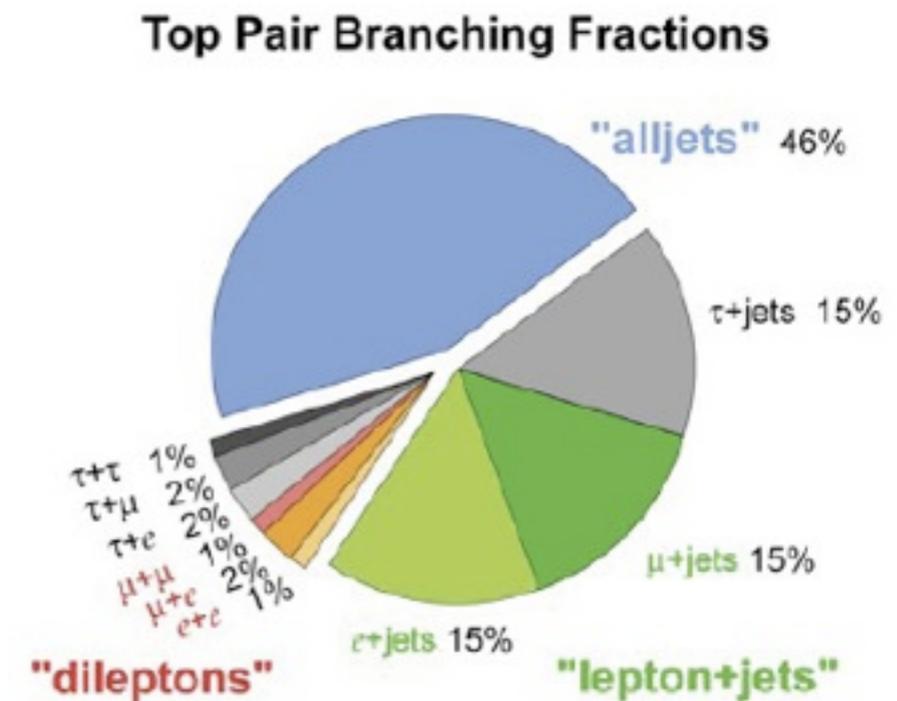


$$\sqrt{s} = 500 \text{ GeV}$$

type	$e^+e^- \rightarrow$	cross section σ	number of events generated for 100 fb^{-1}
Signal	$t\bar{t}$	550 fb	$5.5 \cdot 10^4$
Background	WW	7.1 pb	$7.1 \cdot 10^5$
Background	ZZ	410 fb	$4.1 \cdot 10^4$
Background	$q\bar{q}$	2.6 pb	$2.6 \cdot 10^5$
Background	WWZ	40 fb	$4.0 \cdot 10^3$

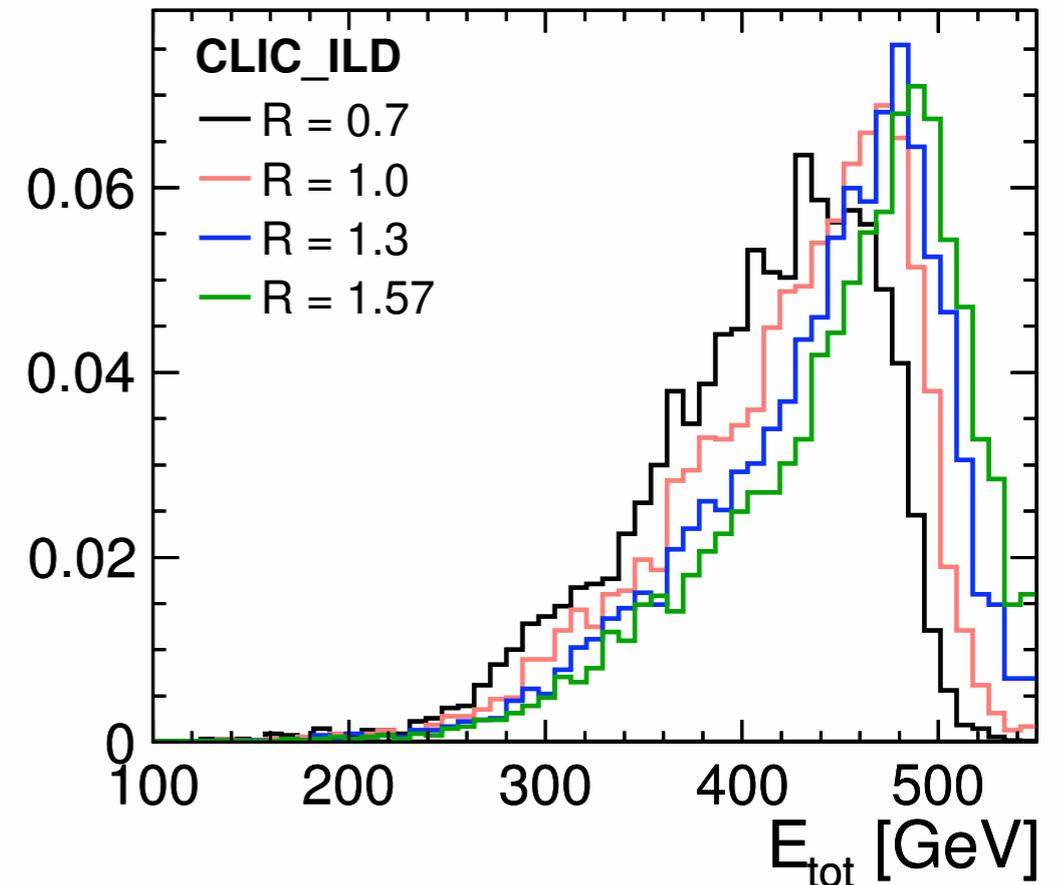
Classification of decay branch for each event

- depending on number of isolated jets found
- no isolated lepton: full-hadronic decay channel
- one isolated lepton: semi-leptonic decay channel
- more than one isolated leptons: full-leptonic decay channel
 - events rejected



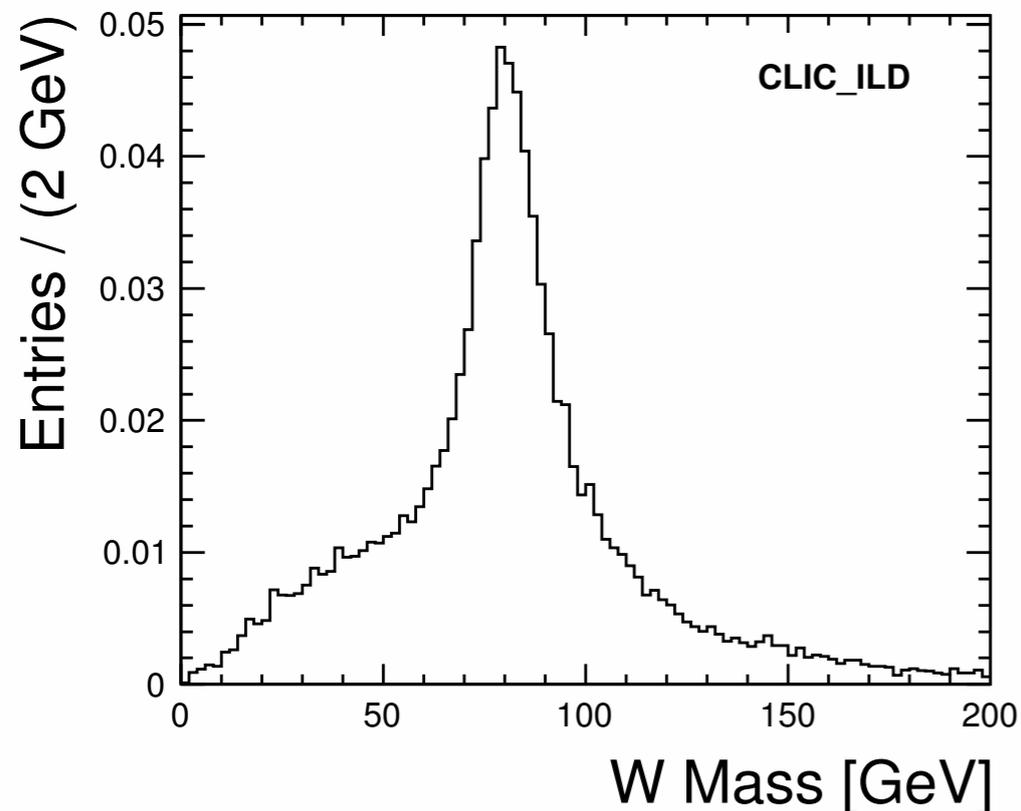
- Hadron k_t algorithm
 - Exclusive Mode: Force to 4 or 6 jets
 - Jet algorithm helps to reject background
 - R value defines size of jet, cross checked distribution of events without machine background
- Flavor tagging based on LCFI Vertex Package
 - Flavor Tagging is based on a neural net
 - Every jet gets assigned with a b-tag value
 - Jets with highest two b-tag values are chosen to be b-jets

Effect of jet clustering settings



Semi-Leptonic events

- 2 b-jets
- 2 light-jets
- 1 lepton
- missing energy / neutrino

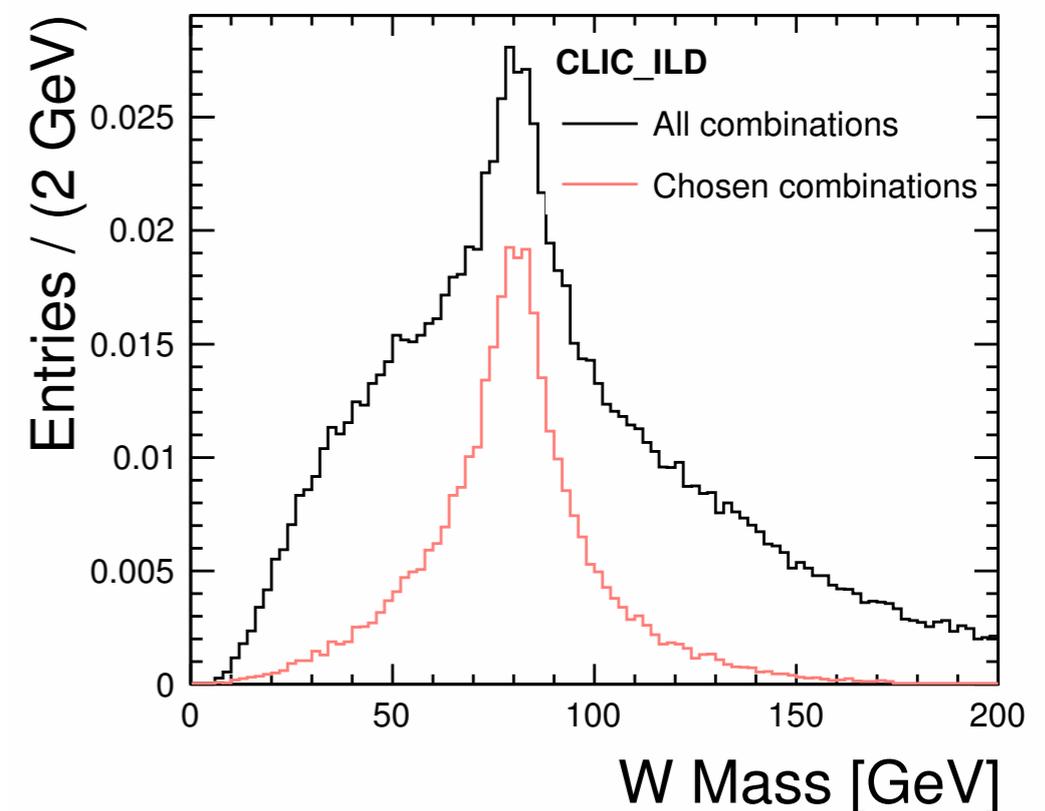


Full-Hadronic events

- 4 light-jets
- 2 b-jets
- Calculation:

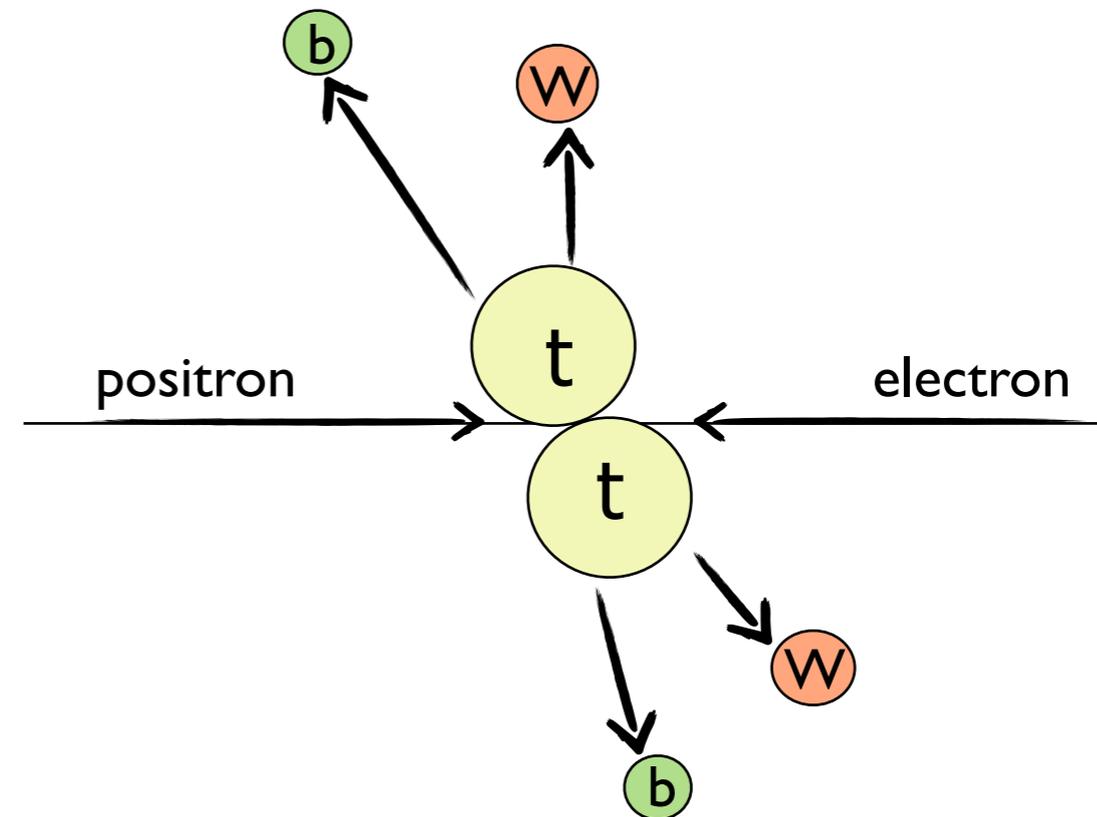
$$|m_{ij} - m_W| + |m_{kl} - m_W|$$

- Minimum value defines best permutation



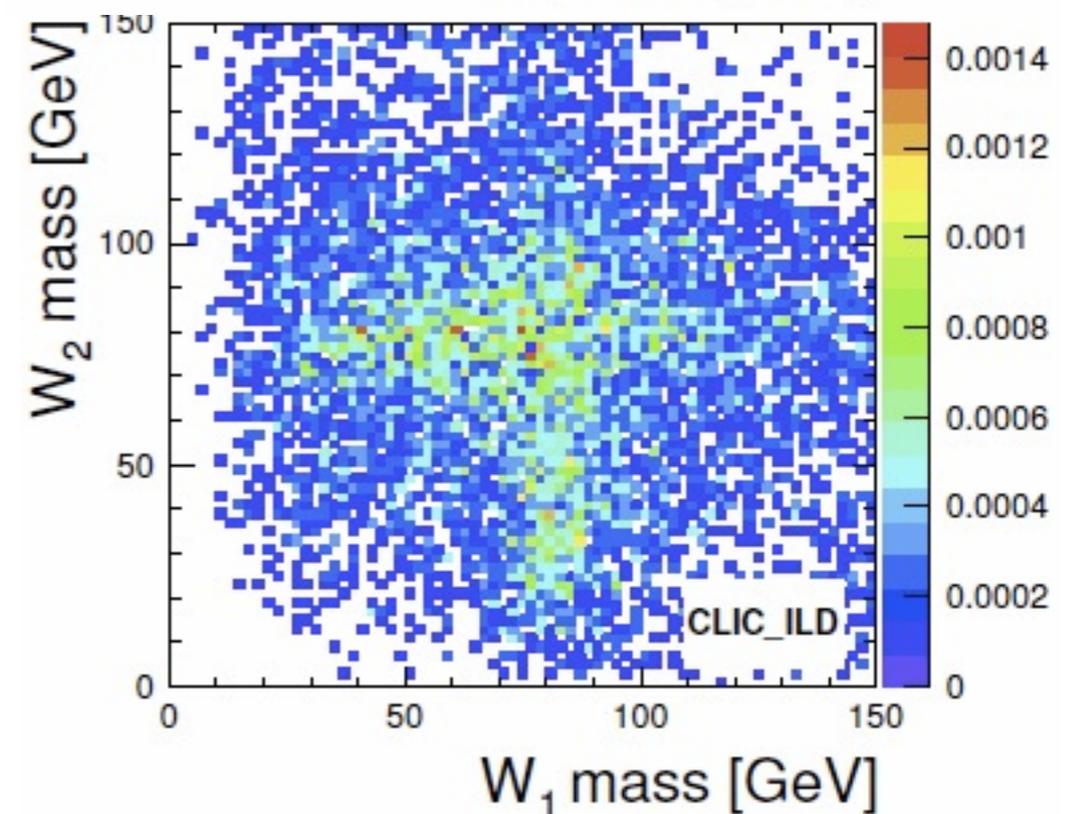
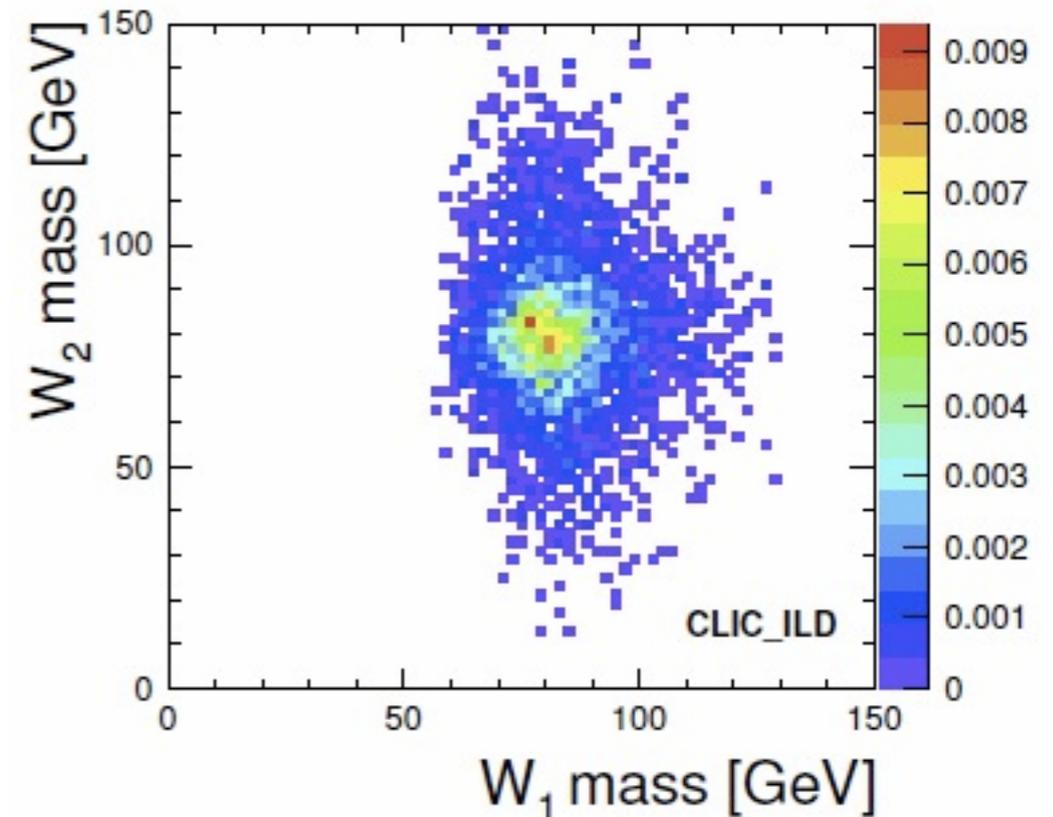
Kinematic fit uses constraints from signal event topology to correct measured properties of decay products

- Constraints for four and six jet events:
 - Energy conservation
 - Momentum conservation
 - W mass equals 80.4 GeV
 - Equal top masses



Kinematic fit uses constraints from signal event topology to correct measured properties of decay products

- Constraints for four and six jet events:
 - Energy conservation
 - Momentum conservation
 - W mass equals 80.4 GeV
 - Equal top masses
- Use kinematic fit for final Wb pairing
- Only very clean events pass kinematic fit



Kinematic Fit

- Powerful Background Rejection for qq , WW , ZZ
- Rejection of unwanted signal events: full-leptonic events, tau-events

Binned likelihood rejection method

- Different input variables to compute a signal likelihood
- Training with independent sample

Kinematic Fit

- Powerful Background Rejection for qq, WW, ZZ
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Overall background rejection: $> 99\%$

Overall signal selection:

Full-Hadronic: 35%

Semi-Leptonic: 56%

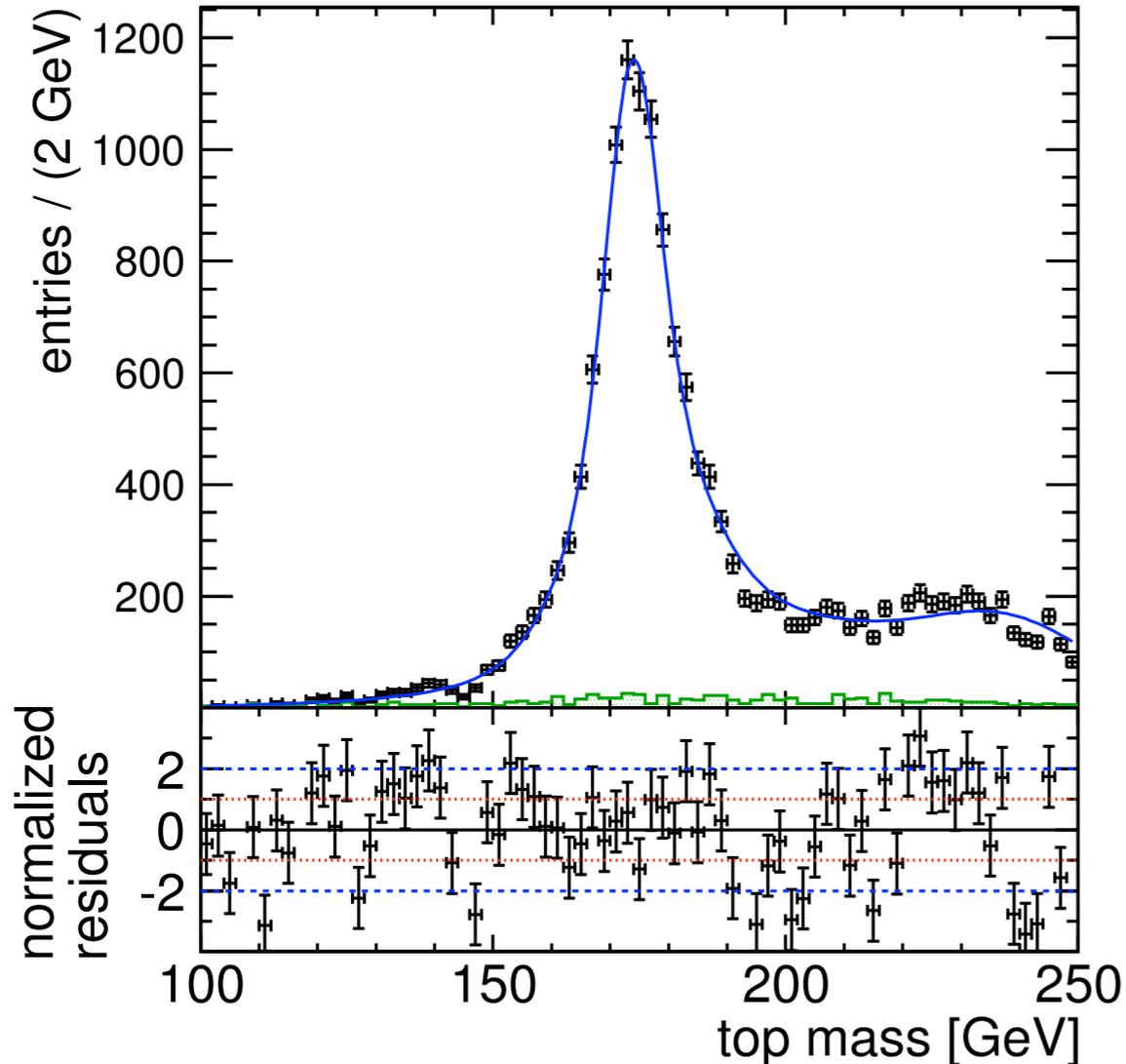
- Signal efficiency could be improved
- Analysis goal: clean events not amount of statistic

Fit of final distribution

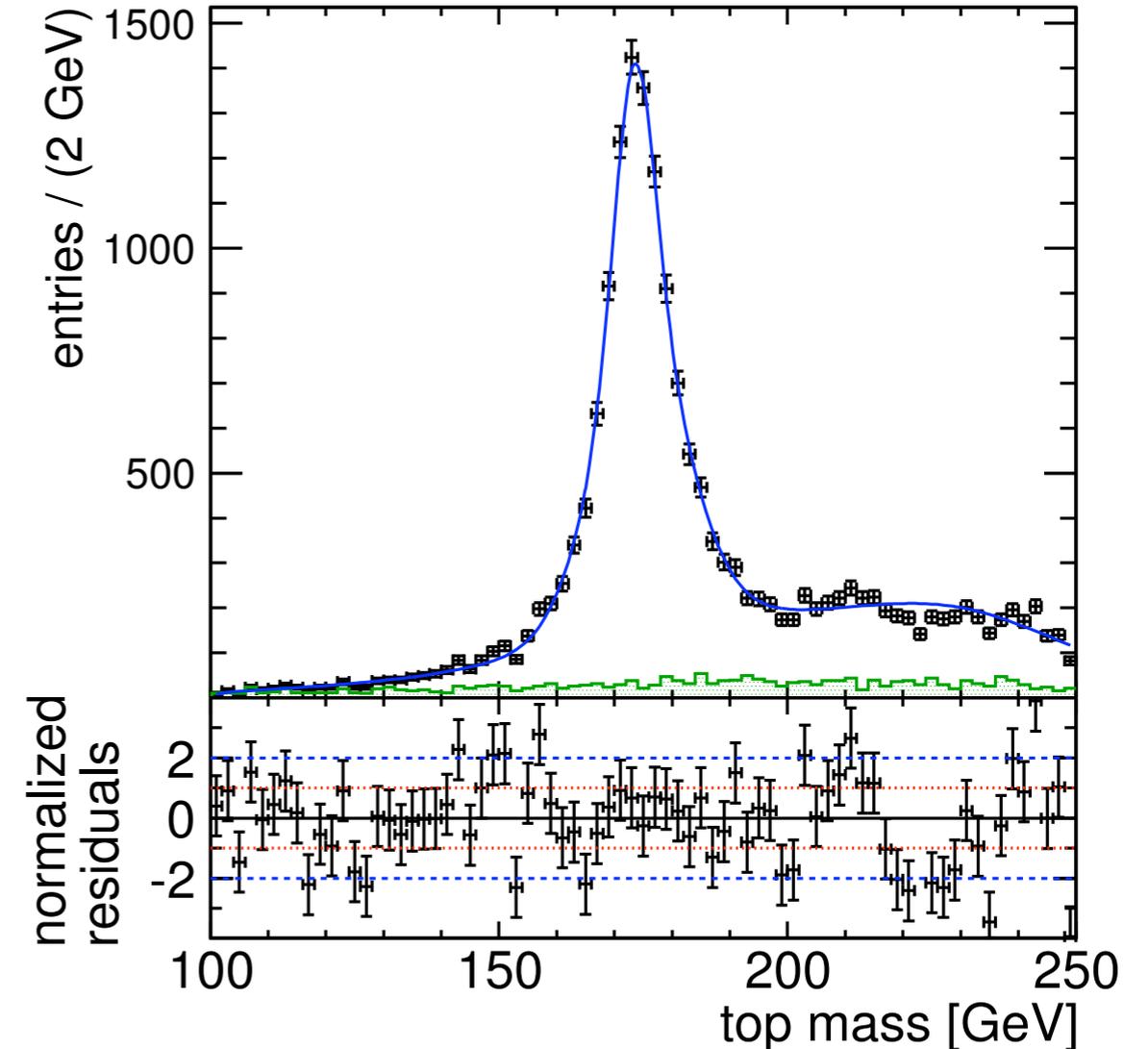
Un-binned maximum likelihood fit over full range

- Combination of signal and background pdf
- Signal pdf is a convolution of a Breit Wigner and a detector resolution function

Semi-Leptonic

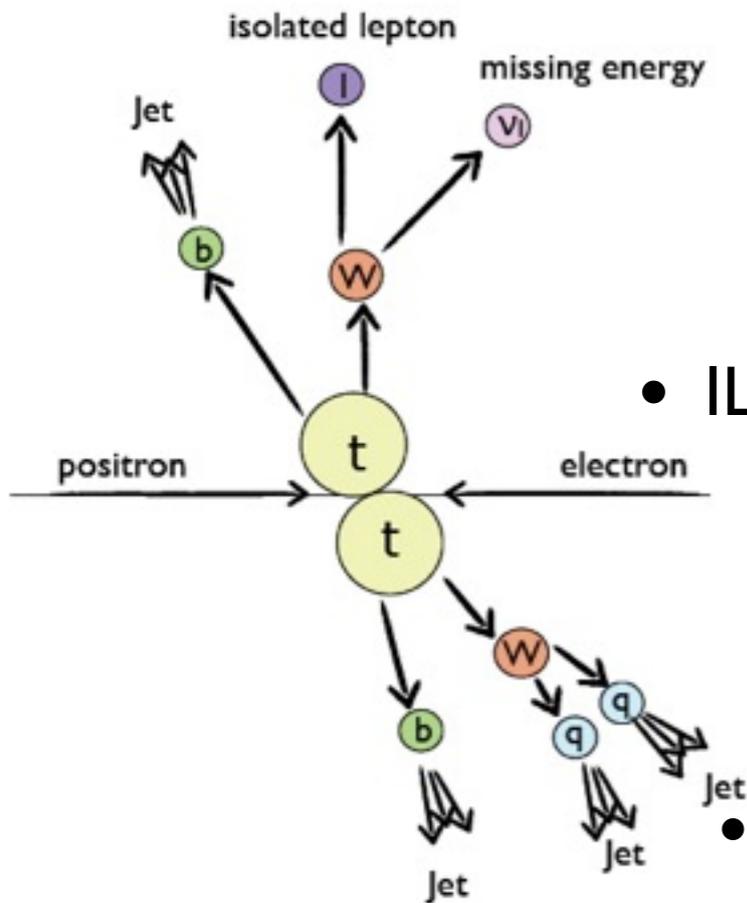


Full-Hadronic



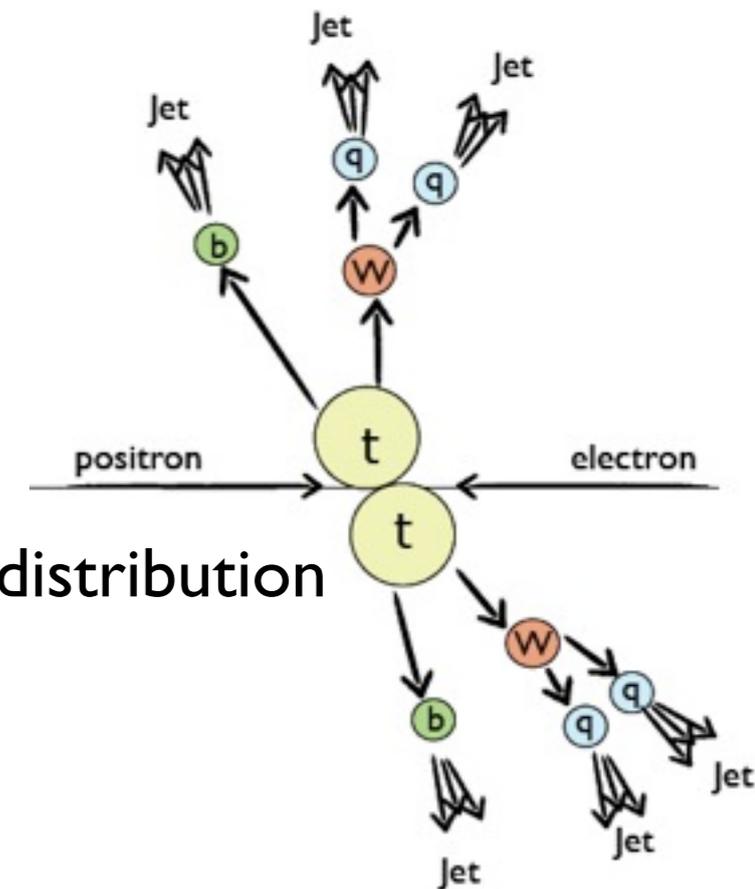
- Results of the overall fit:
 - **Full-Hadronic** : $m_{\text{top}} = 174.07 \pm 0.08 \text{ GeV (stat)}$
 - **Semi-Leptonic**: $m_{\text{top}} = 174.28 \pm 0.09 \text{ GeV (stat)}$

generator value:
 $m_{\text{top}} = 174 \text{ GeV}$



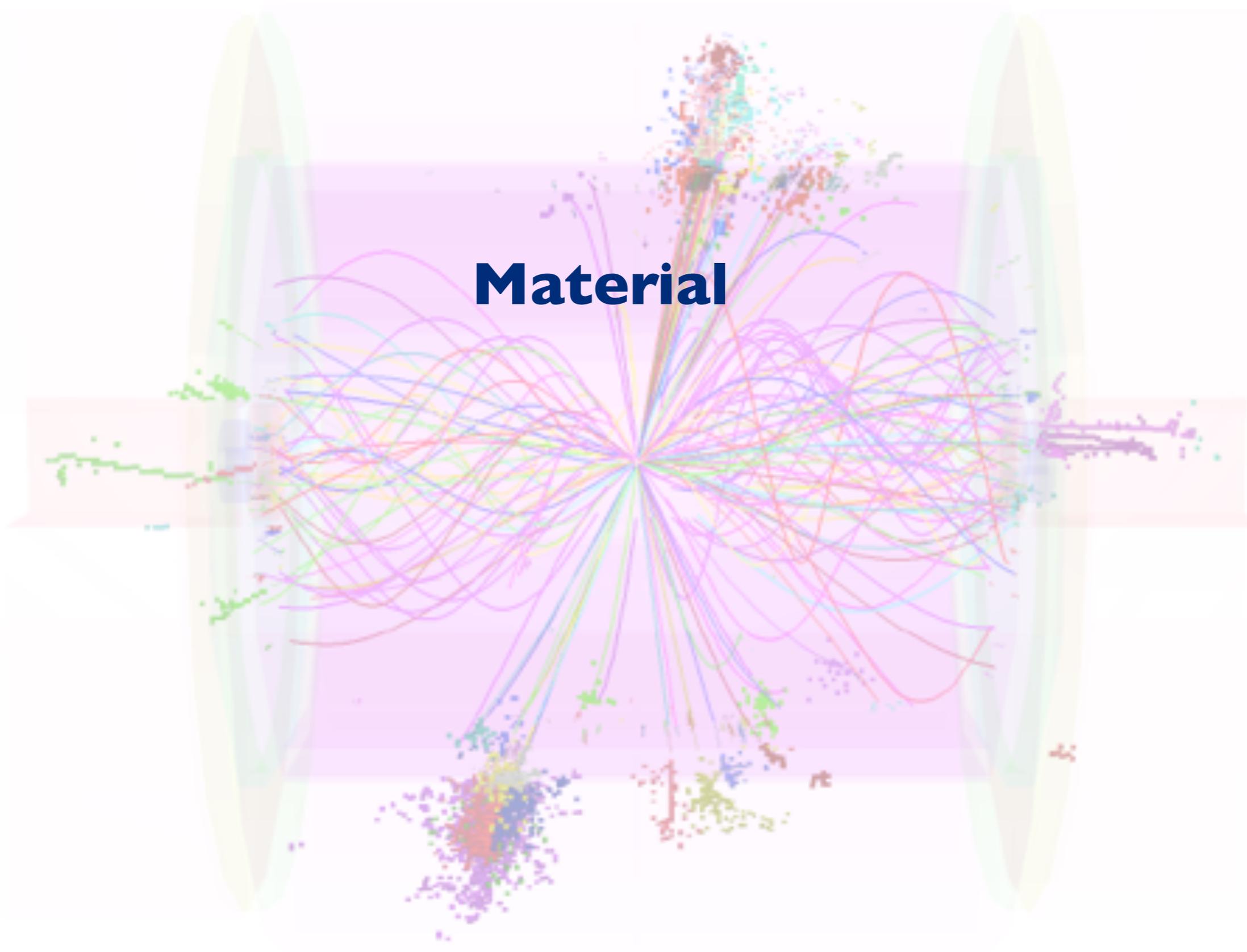
- ILC ILD top mass analysis for 100 fb^{-1} :

- statistical error:
 - Full-Hadronic: 0.11 GeV
 - SemiLeptonic: 0.14 GeV
- Full-Hadronic: Similar statistics in final distribution for ILD and CLIC_ILD study
- Semi-Leptonic: Higher statistics in final distribution in CLIC_ILD study

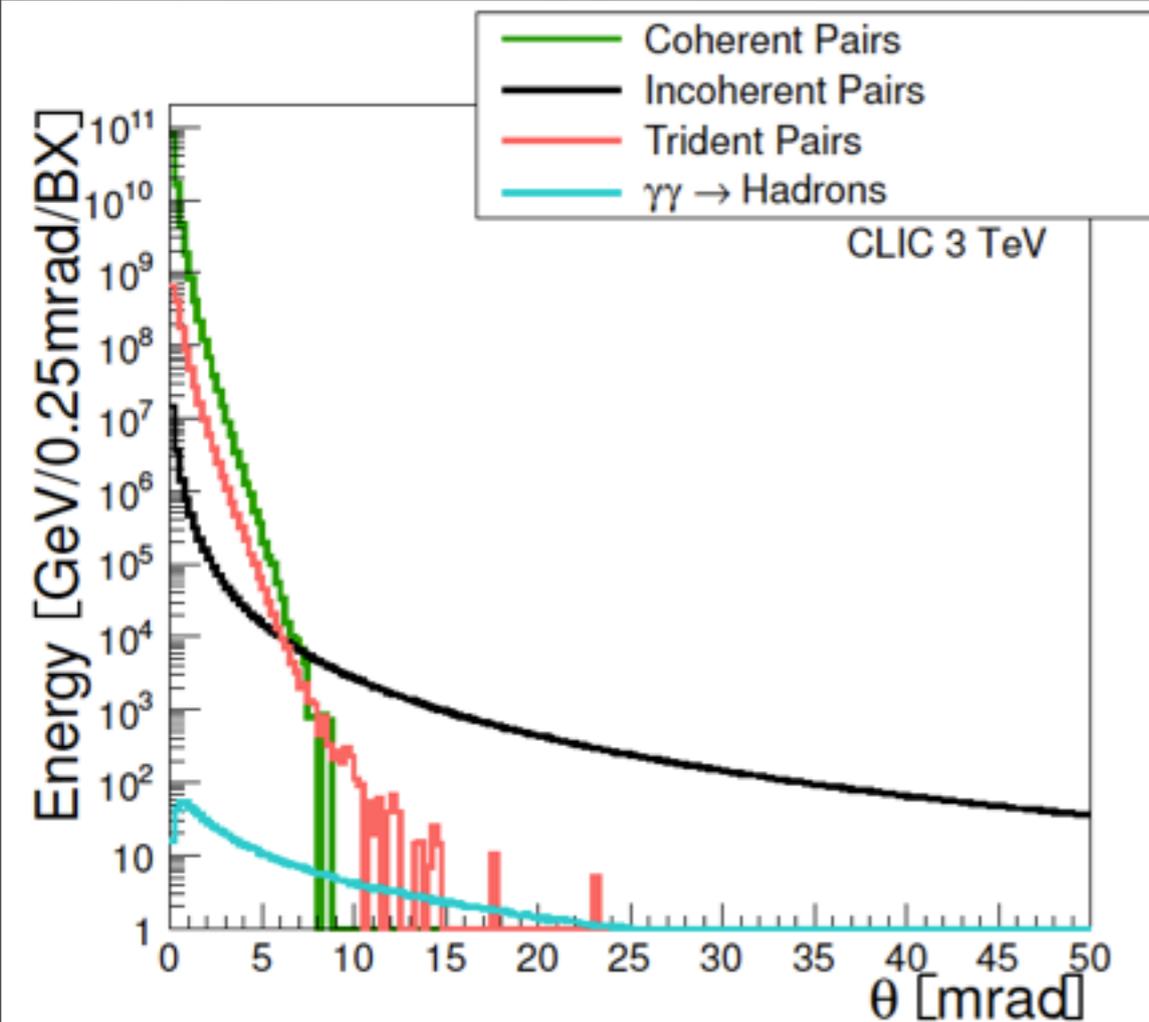


- Low energy version of CLIC also suitable for high precision measurements
 - More details in the CLIC_CDR:
<http://lcd.web.cern.ch/LCD/CDR/CDR.html>
- Machine background conditions and pile up under control
- Analysis of $t\bar{t}$ events at 500 GeV with the CLIC_ILD detector for 100 fb^{-1}
- Statistical error of 80-90 MeV on top mass
- Analysis of top mass for full-hadronic and semi-leptonic decay chain of top pairs
- Result comparable with studies for ILD and SiD for ILC at 500 GeV

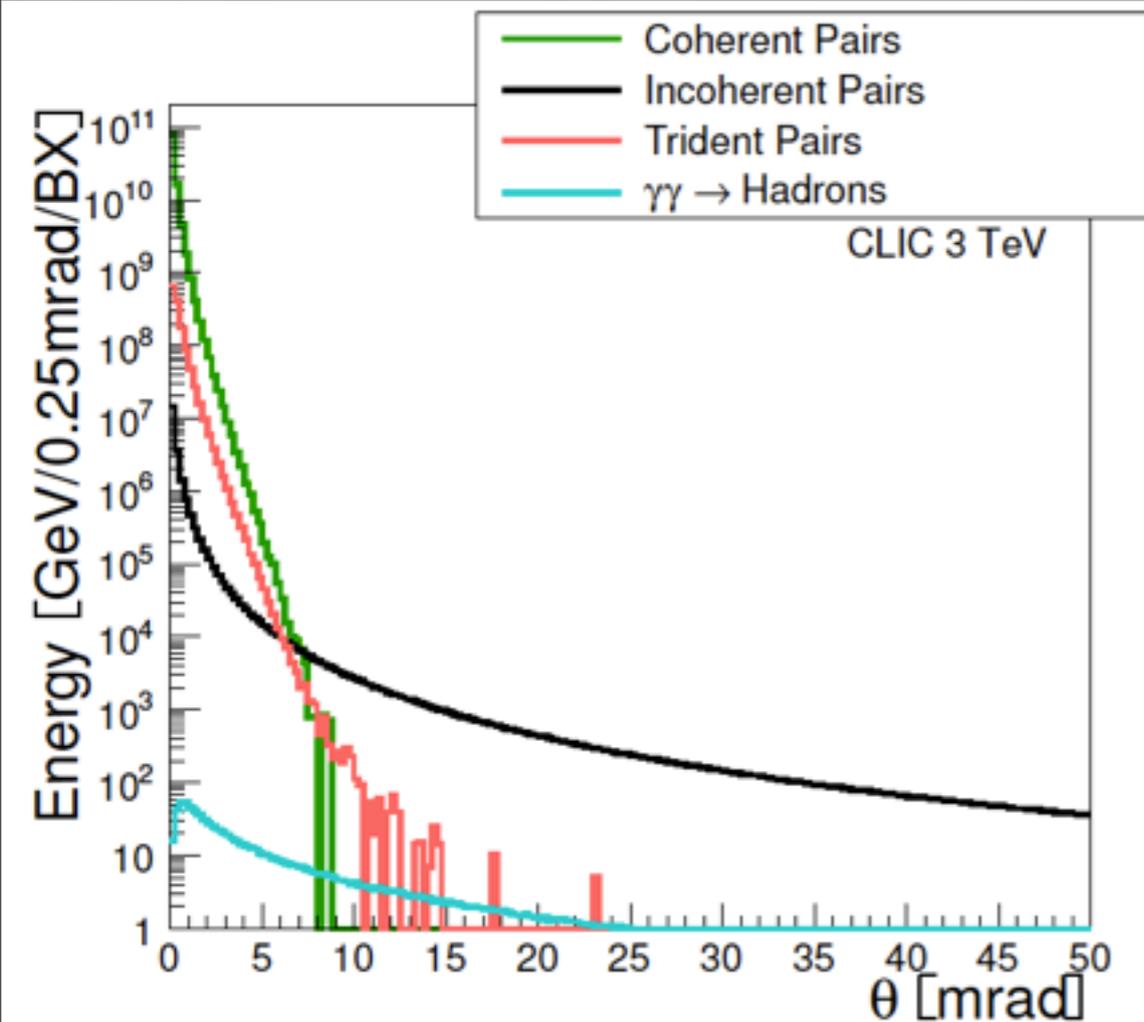
Material



		CLIC	CLIC	ILC
E_{cms}	[TeV]	0.5	3.0	0.5
f_{rep}	[Hz]	50	50	5
f_{RF}	[GHz]	12	12	1.3
G_{RF}	[MV/m]	80	100	31.5
n_b		354	312	2625
Δt	[ns]	0.5	0.5	369
N	[10^9]	6.8	3.7	20
σ_x	[nm]	202	40	655
σ_y	[nm]	2.26	1	5.7
ϵ_x	[μm]	2.4	0.66	10
ϵ_y	[nm]	25	20	40
\mathcal{L}_{total}	[$10^{34}\text{cm}^{-2}\text{s}^{-1}$]	2.3	5.9	2.0
$\mathcal{L}_{0.01}$	[$10^{34}\text{cm}^{-2}\text{s}^{-1}$]	1.4	2.0	1.45

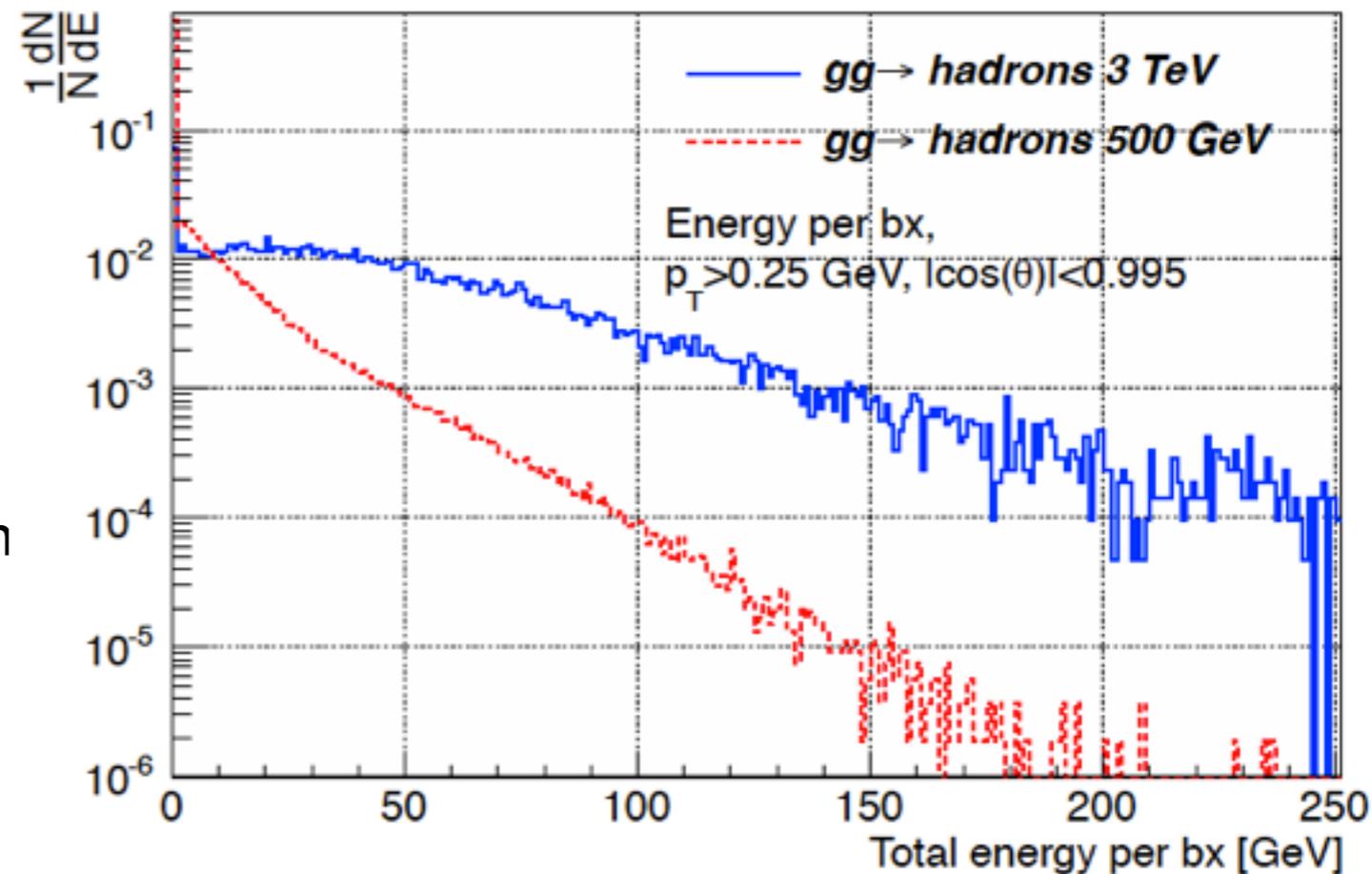


- Coherent e^+e^- pairs with angles < 10 mrad
 - ▶ Crossing angle and beam pipe opening at CLIC: 20 mrad
 - ▶ Outgoing beam: coherent pairs disappear in beampipe
- Incoherent pairs: reduced by solenoidal field, constrain innermost radius of vertex detector



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- $\gamma\gamma \rightarrow$ hadrons: ~ 3.2 events / bx,
 - ~ 28 ch. particles in detector acceptance
 - \Rightarrow 15 TeV in detector during bunch train forward peaked
 - \Rightarrow Requires precise time stamping and clever event reconstruction



CLIC_ILD Detector - Main Features



low-mass, high precision vertex detector:

Si pixel detector

Si strip inner tracker

ILD (500GeV): 15mm

CLIC_ILD (500GeV): 25mm

CLIC_ILD (3TeV): 31mm

Detectors concept follows the ILC designs: CLIC_ILD

forward calorimeters for luminosity measurements and overall detector hermeticity

magnet yoke with muon detector / tail catcher

precision tracking:

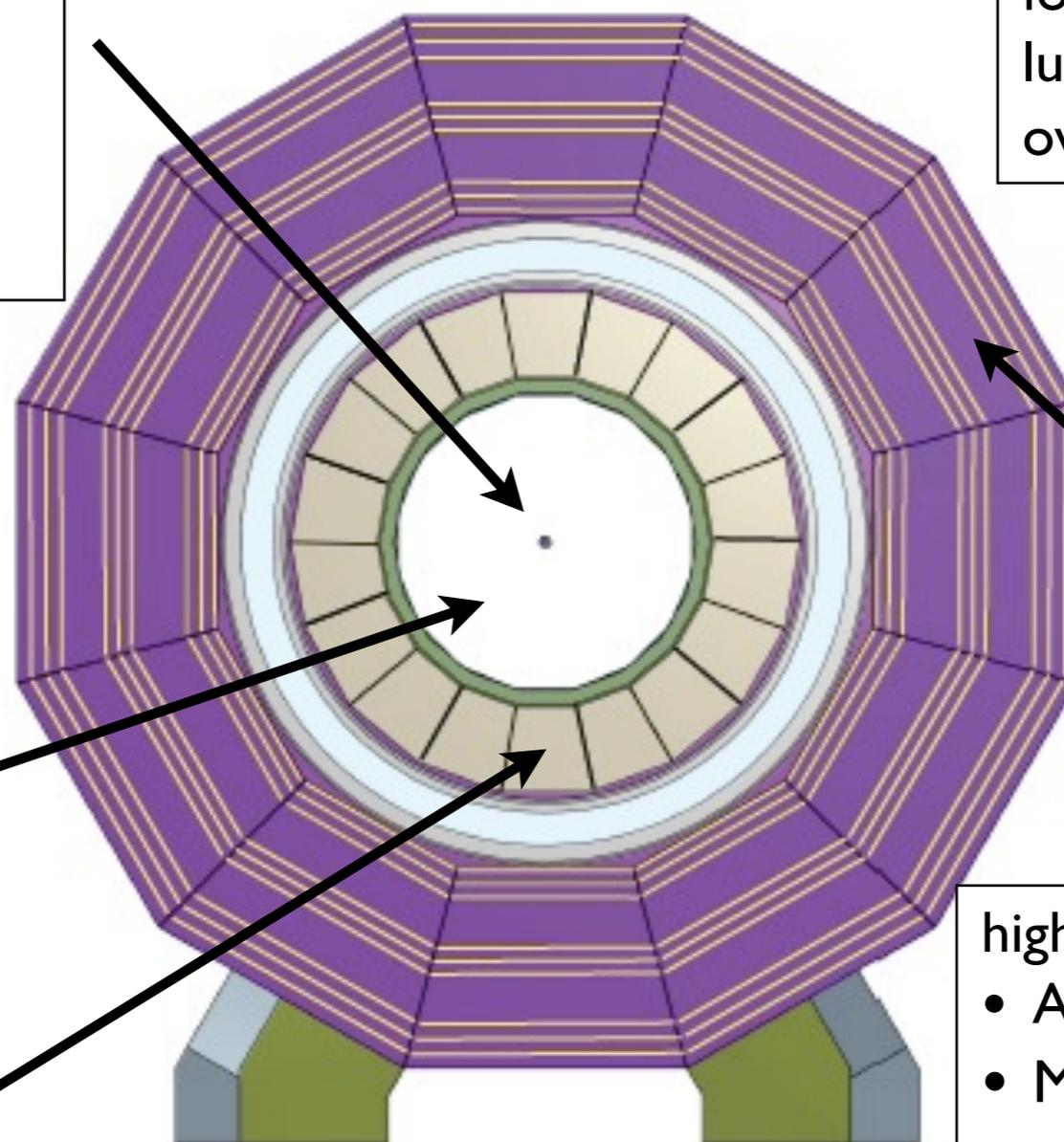
- SiD: Si strip main tracker
- ILD: TPC main tracker

high-field solenoid

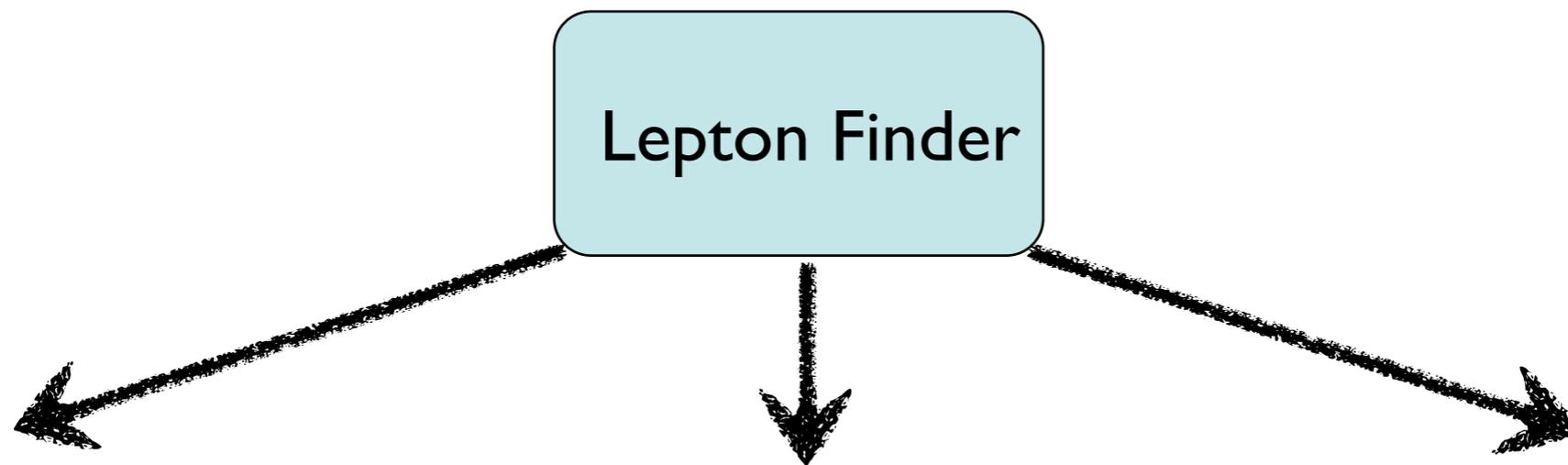
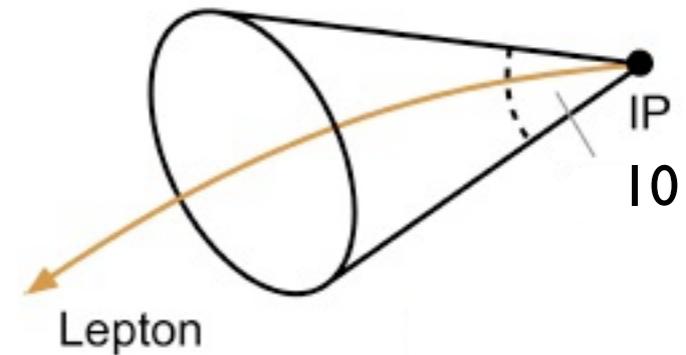
- All detectors inside solenoid
- Magnetic field: CLIC_ILD at 4 T

highly granular calorimeters for particle flow

- Hcal: 7.5λ , steel in endcap, tungsten in barrel



- Classification of decay branch for each event
- Search for isolated leptons in a cone
 - 10 degree cone opening angle
 - Lepton energy > 10 GeV
 - Particles in cone: charged, energy > 2.5 GeV



No isolated lepton found

- Full-hadronic decay branch
- 6 jets

One isolated lepton found

- Semi-leptonic decay branch
- 4 jets, isolated lepton, neutrino

> 1 isolated lepton found

- Full-leptonic decay branch
- Events rejected

Binned likelihood rejection

- Seven input variables (Number of particles in event, value of b-tags, sphericity, ...)
- Likelihood cut of 0.6 chosen
- Training with independent sample

Full-Hadronic

