SQuark Massenbestimmung am CLIC

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DPG Frühjahrstagung
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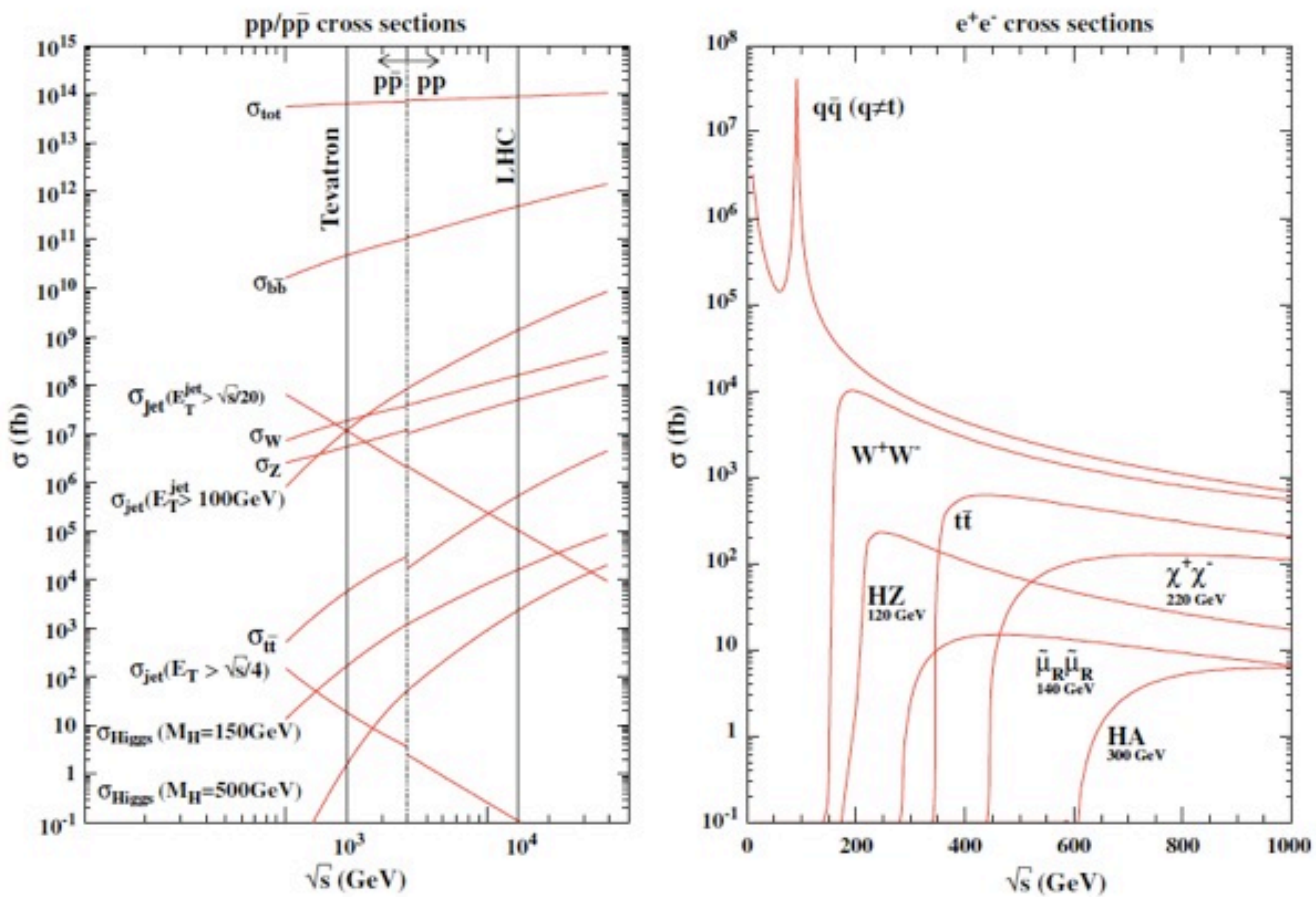
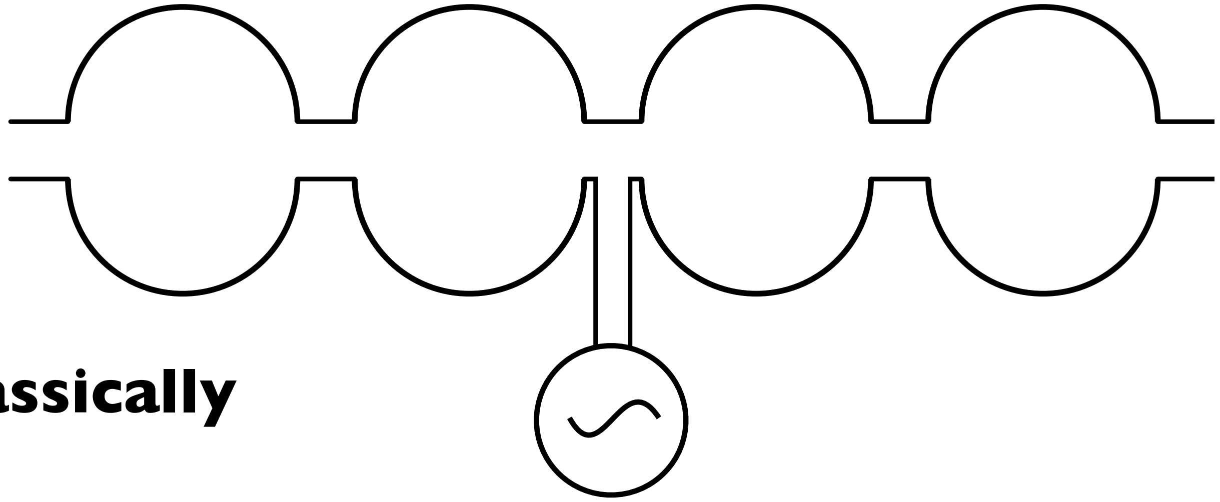
Current Colliders: The Large Hadron Collider

- Current Cutting Edge accelerator: Large Hadron Collider
  - Up to 14 TeV p-p
  - High Luminosity
  - Very good detectors
- Hadron collider ⇒ p-p
  - Initial State unknown
    - Energy
    - Particle
  - Underlying event(s)
  - Pile-Up
  - Huge xs for Background
- For precision measurements we need a much cleaner environment!
  - ➡ Lepton Collider

G. Weiglein et al. / Physics Reports 426 (2006) 47–358



The Compact Linear Collider



Classically

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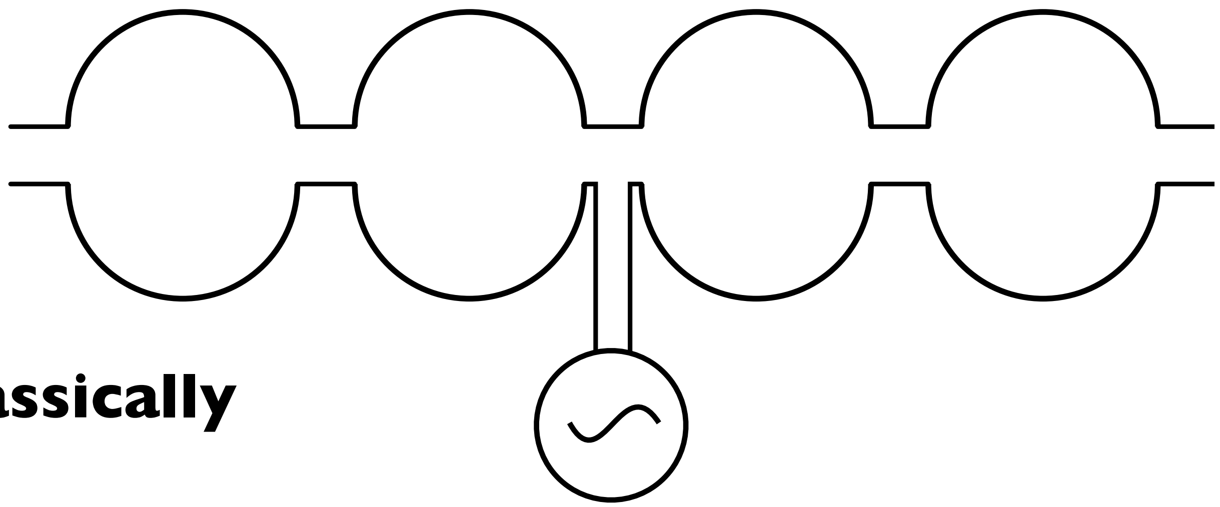
- Synchrotron radiation → Needs to be linear accelerator
- Acceleration of charged particles via Cavity



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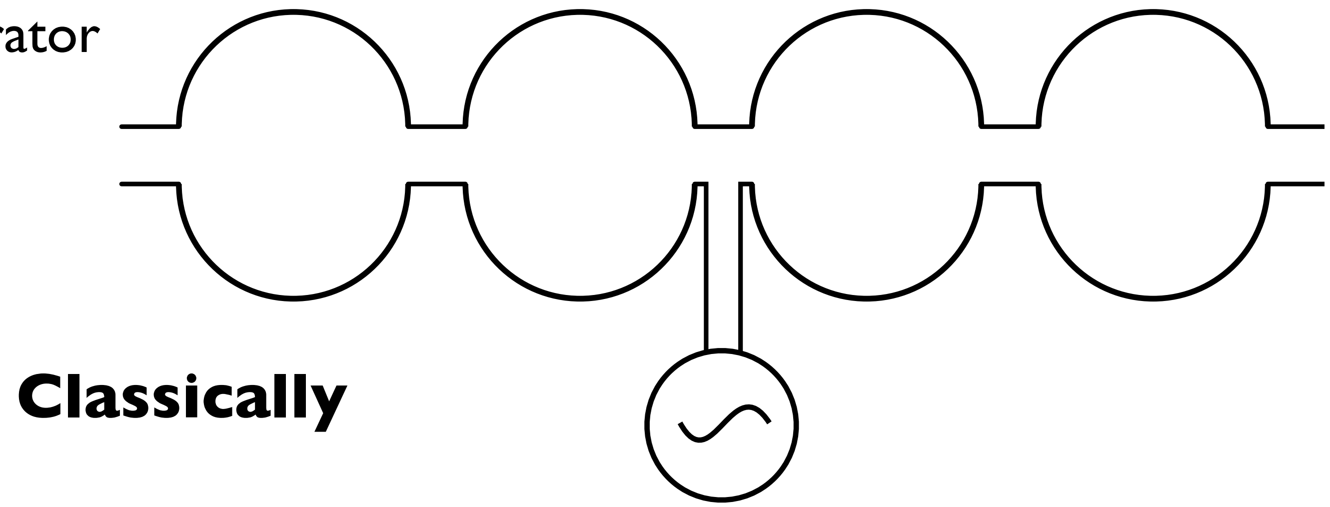

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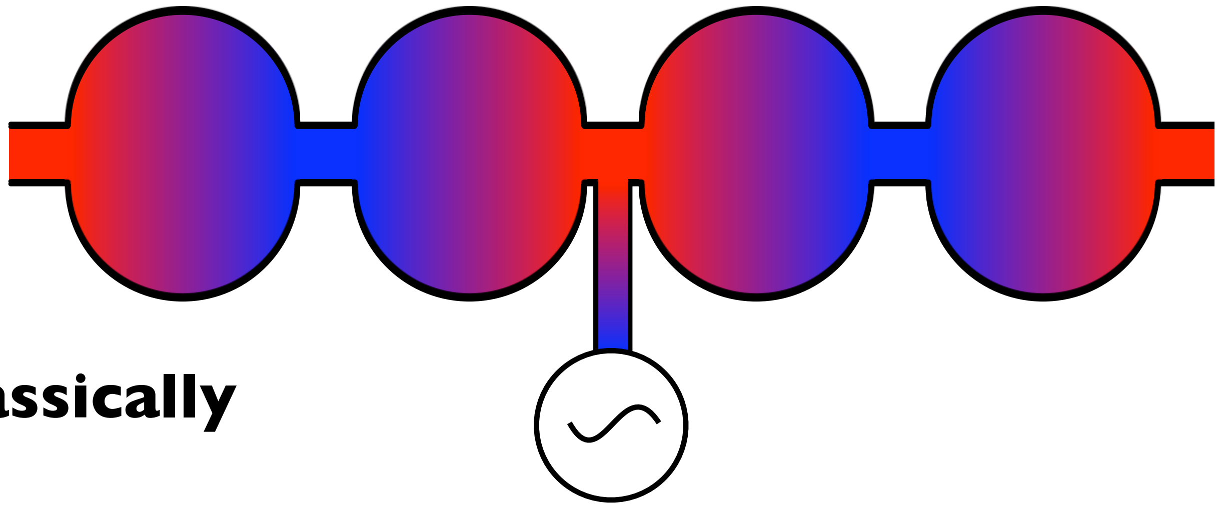

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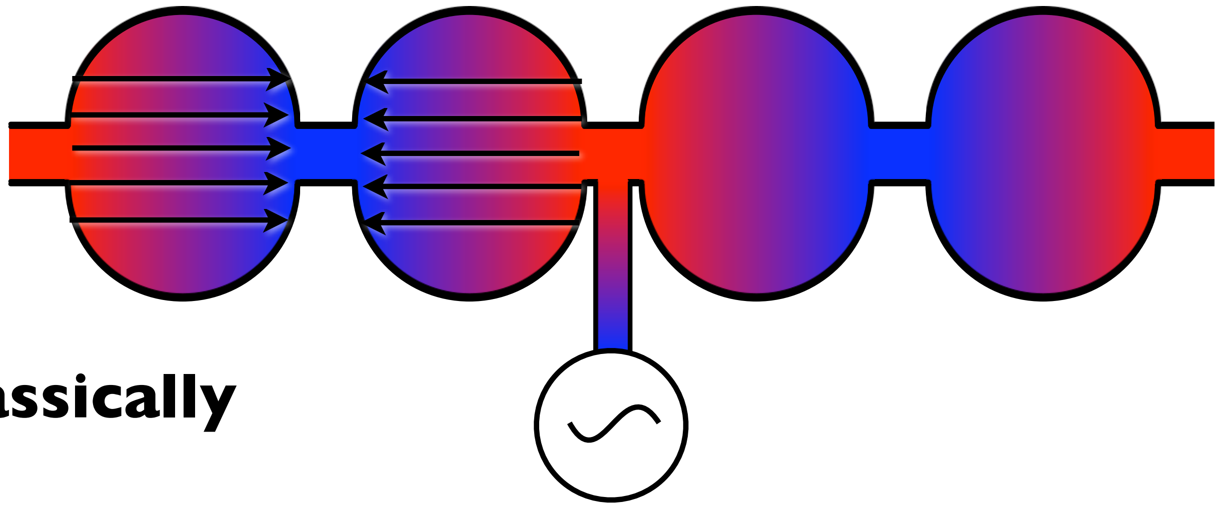

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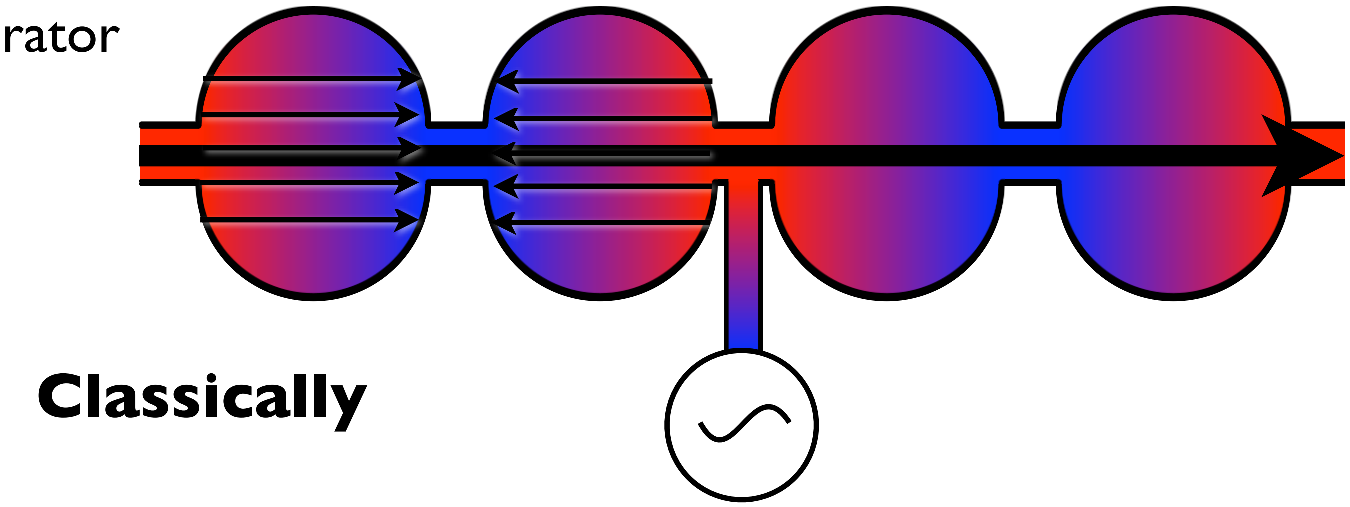

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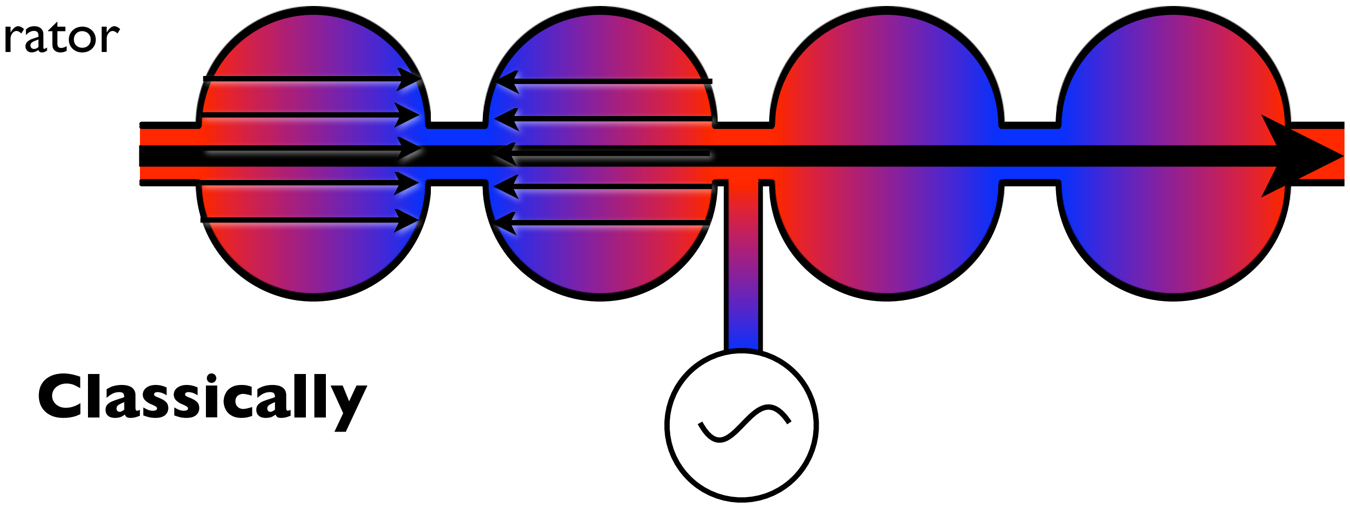
  - 2nd beam
    - Parallel to actual (high energy) beam
    - Low energy
    - High intensity
  - Extract RF from this beam via a „double cavity“



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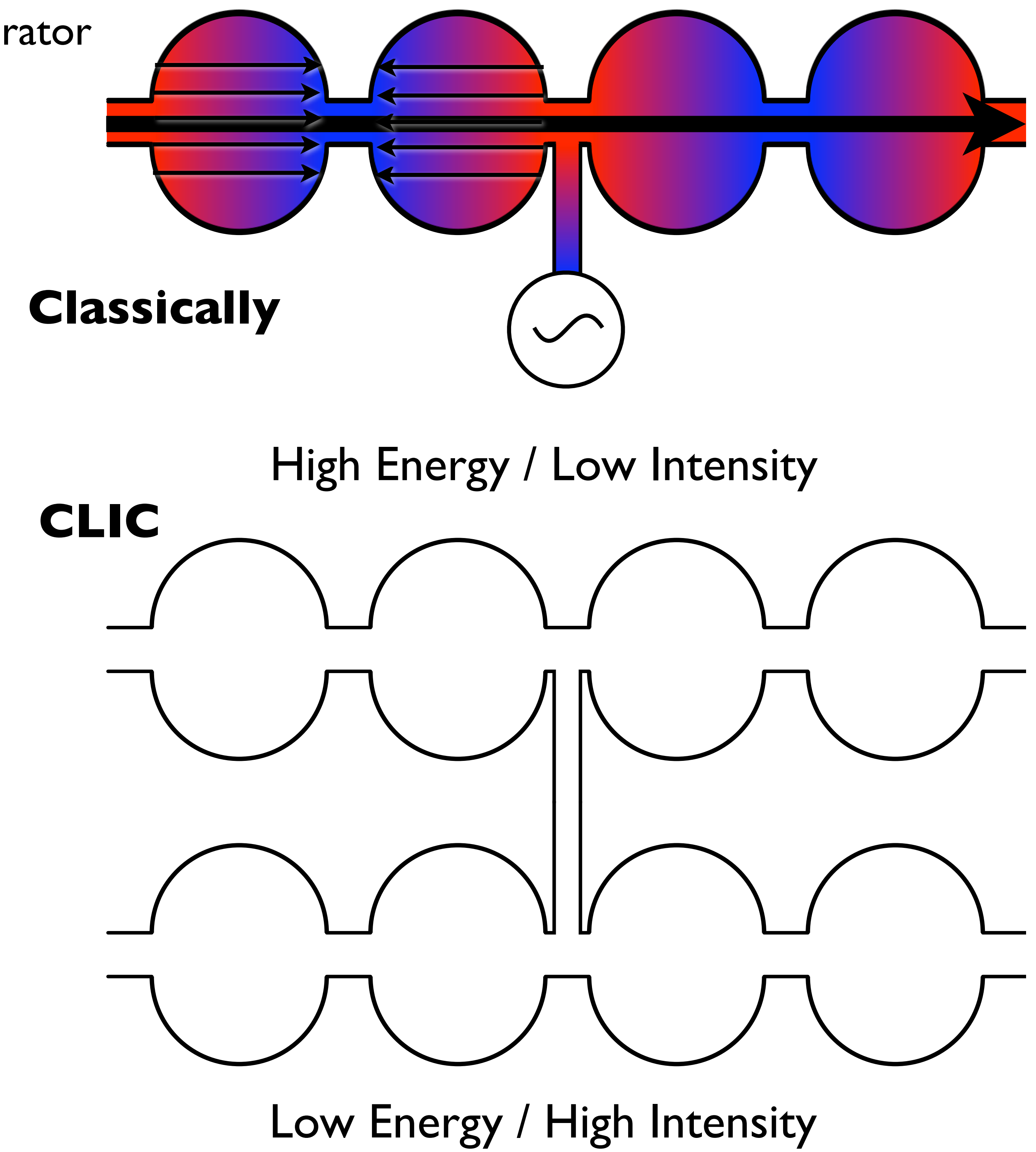

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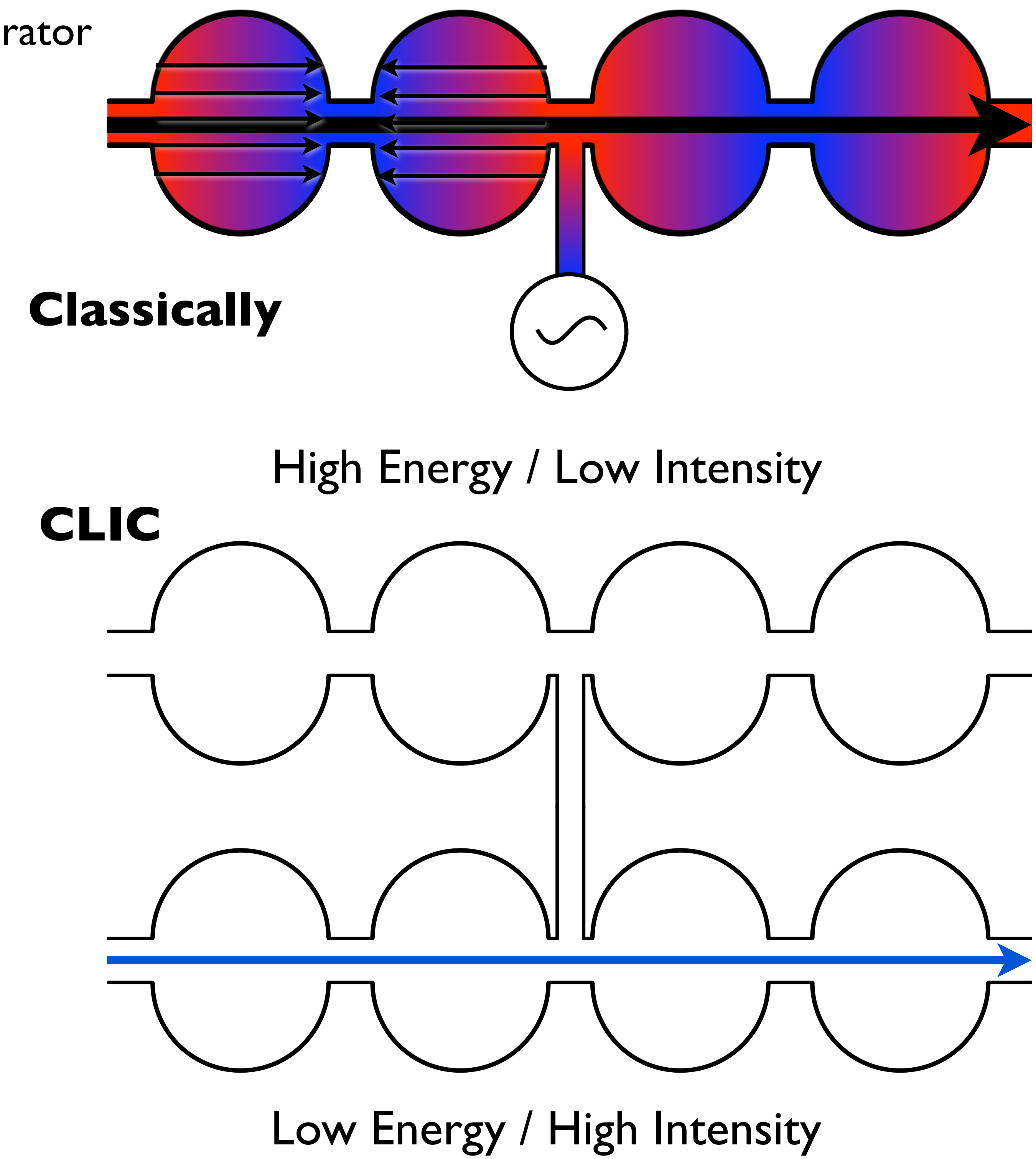

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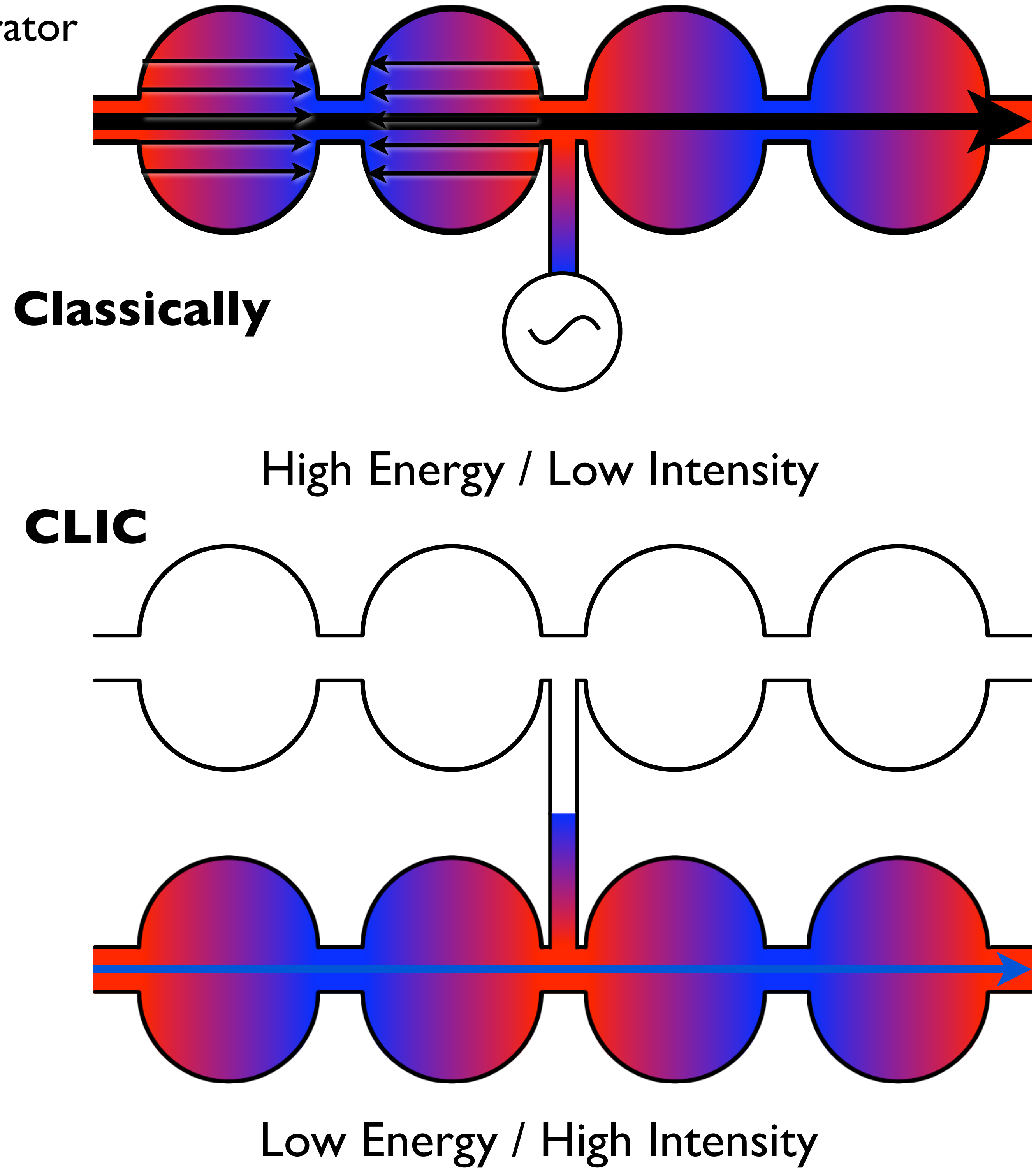

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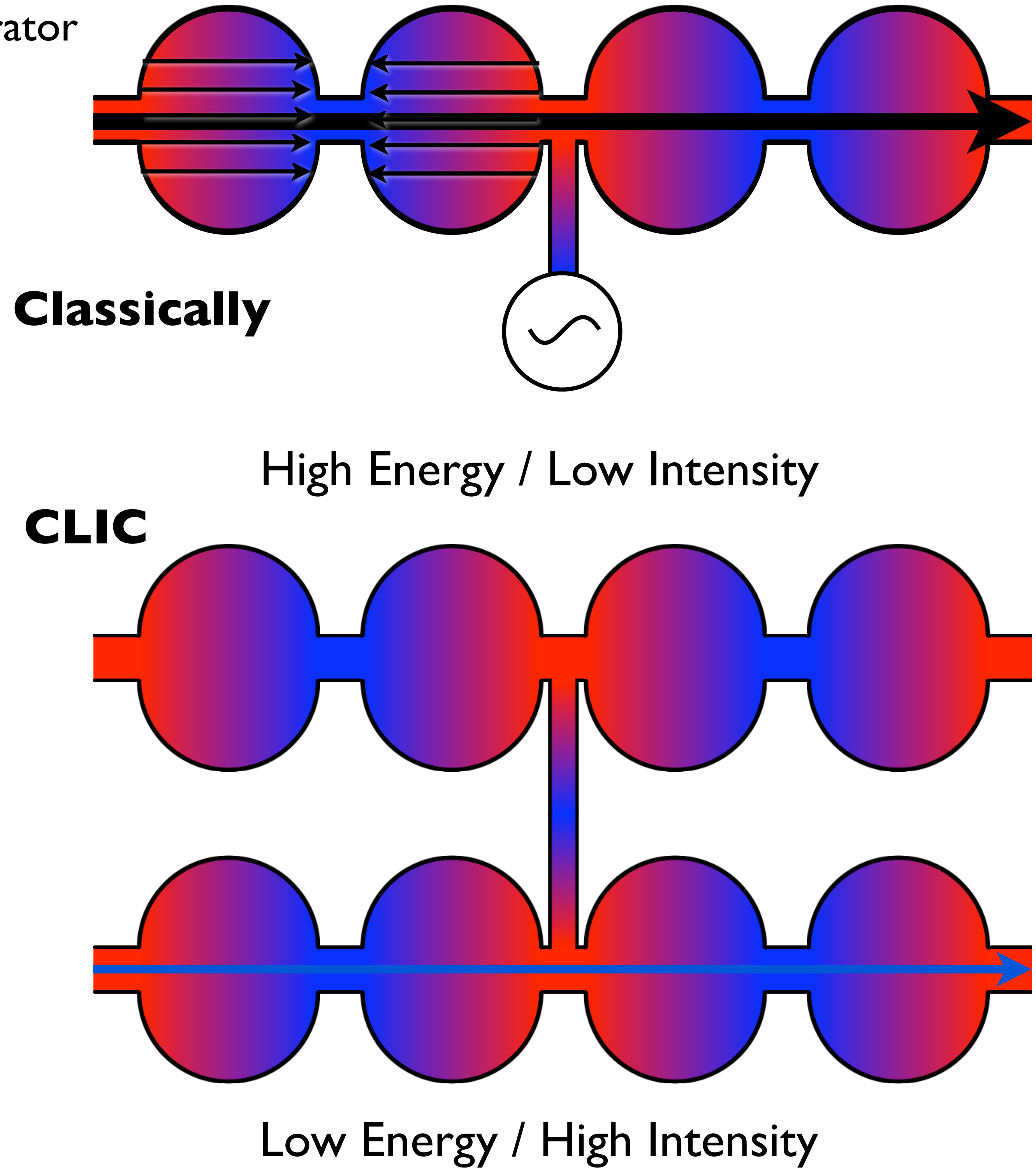

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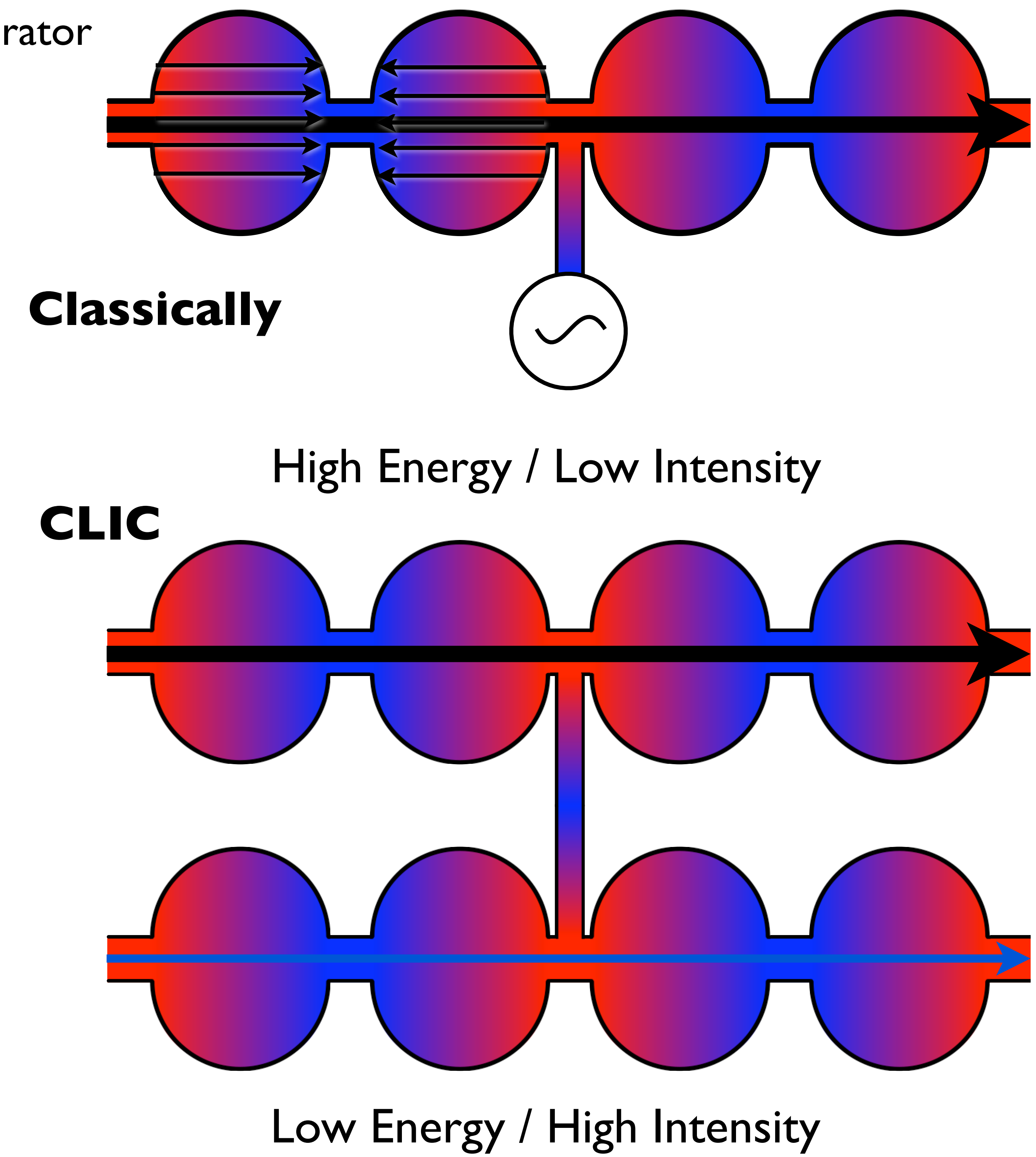

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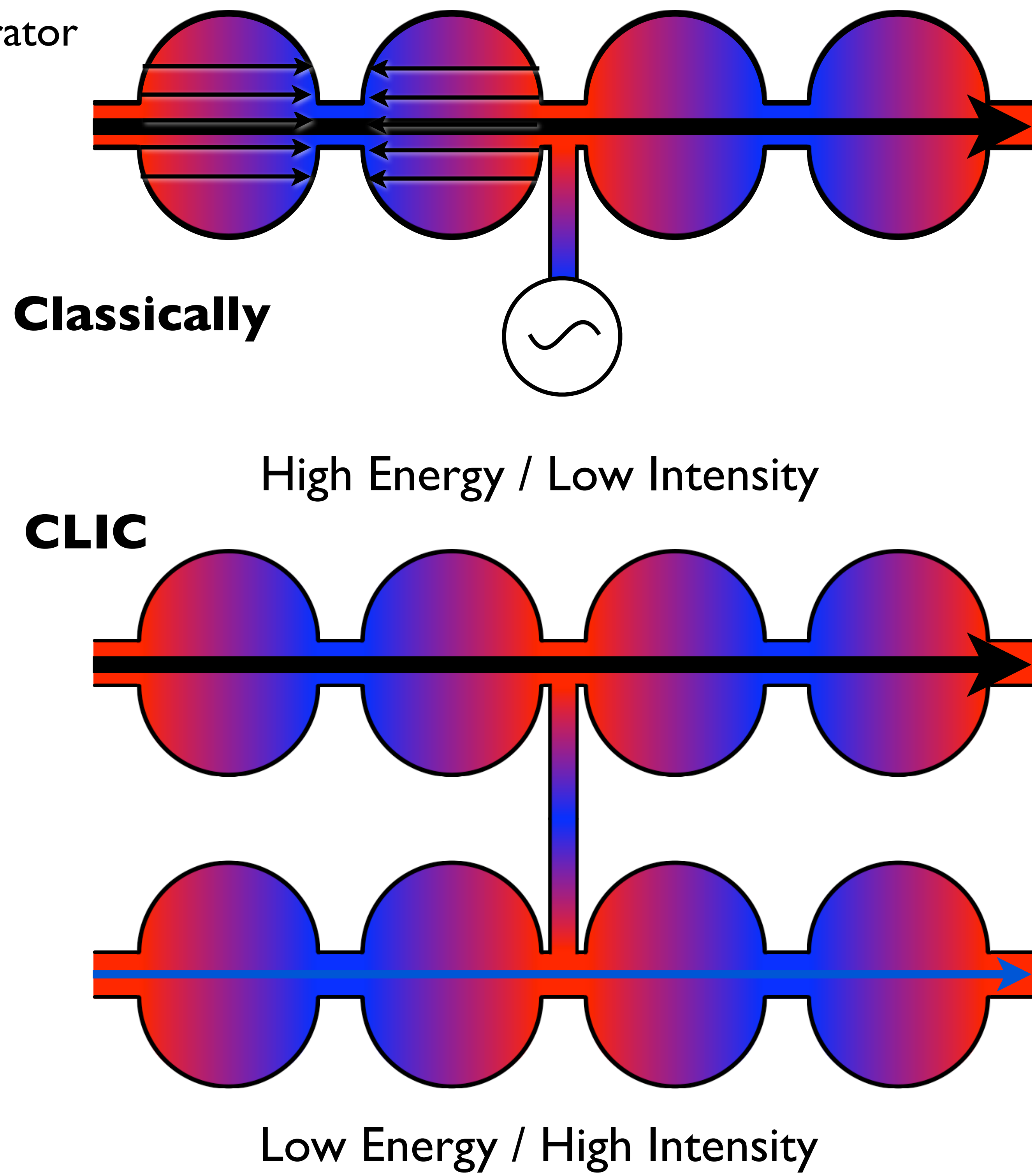
  - Extract RF from this beam via a „double cavity“
- More than 100MeV/m possible
  - 3 TeV: ~50km length
    (incl. beam delivery system)
  - ➡ Compact Linear Collider: CLIC
    - 300 Bunches / Train
    - 0.5 ns Repetition Rate

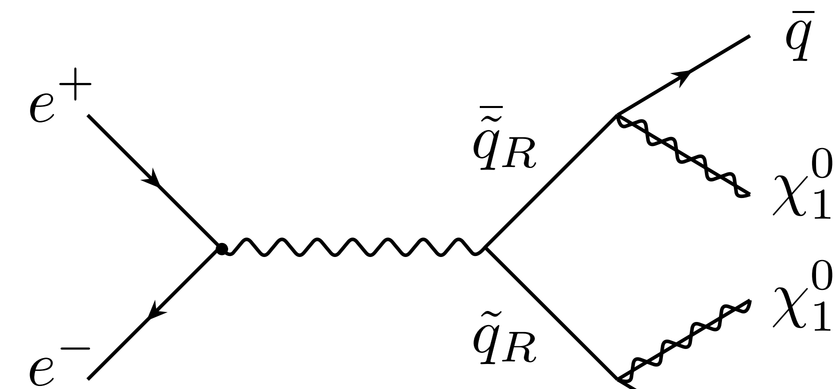


The CLIC Conceptional Design Report: A Benchmark

$$
\begin{aligned}
m_0 &= 303\text{GeV} \\
A_0 &= -750\text{GeV} \\
\mu &> 0 \\
\tan\beta &= 24 \\
M_1 &= 780\text{GeV} \\
M_2 &= 940\text{GeV} \\
M_3 &= 540\text{GeV}
\end{aligned}
$$

particle	mass [GeV]
χ_1^0	328.3
$\tilde{u}_R, \tilde{c}_R$	1125.7
$\tilde{d}_R, \tilde{s}_R$	1116.1
$\tilde{g}_R$	1239.7

- To show the Capabilities of CLIC: Conceptional Design Report (CDR)
  - Check performance of Detector/Accelerator
- Dedicated SUSY Scenario
- Benchmark: Measurement of mass of right handed SQuarks
  - Decay almost exclusively into 2 Quarks plus Neutralino
  - Low crosssection (~3000 events after 5 years running)
  - Event shape: 2 Quarks + E_{miss}
    - Very general (not bound to this SUSY scenario)
      - Easy to identify

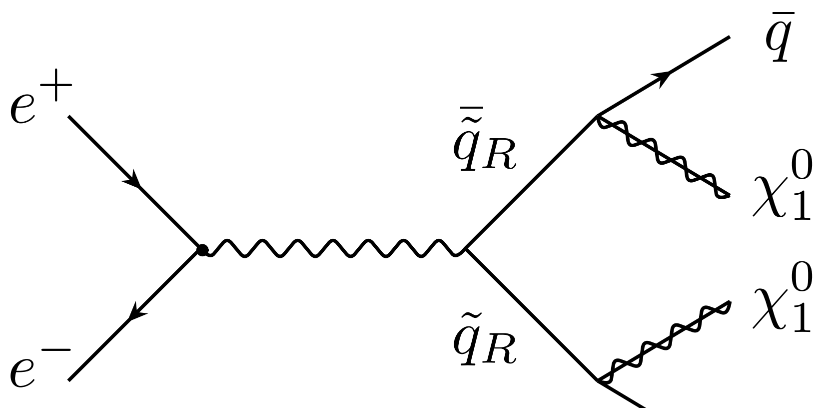


$$\tilde{q} \in \{\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}\}$$

$$e^+e^- \rightarrow \tilde{q}_R \bar{\tilde{q}}_R$$

$$\tilde{q}_R \xrightarrow{99.7\%} q + \chi_1^0$$

The Process + Background



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	Final State	σ
Signal	qqχχ (u,d,s,c)	~ 1.45 fb
SM	qq	~ 3000 fb
	qqee	~ 3300 fb
SM E_{miss}	qqνν	~ 1500 fb
	qqeν	~ 5300 fb
	ττνν	~ 130 fb
SUSY	qqννχχ	~ 1.0 fb
	qqlνχχ	~ 8.5 fb
	qqllχχ	~ 0.6 fb

} no E_{miss}

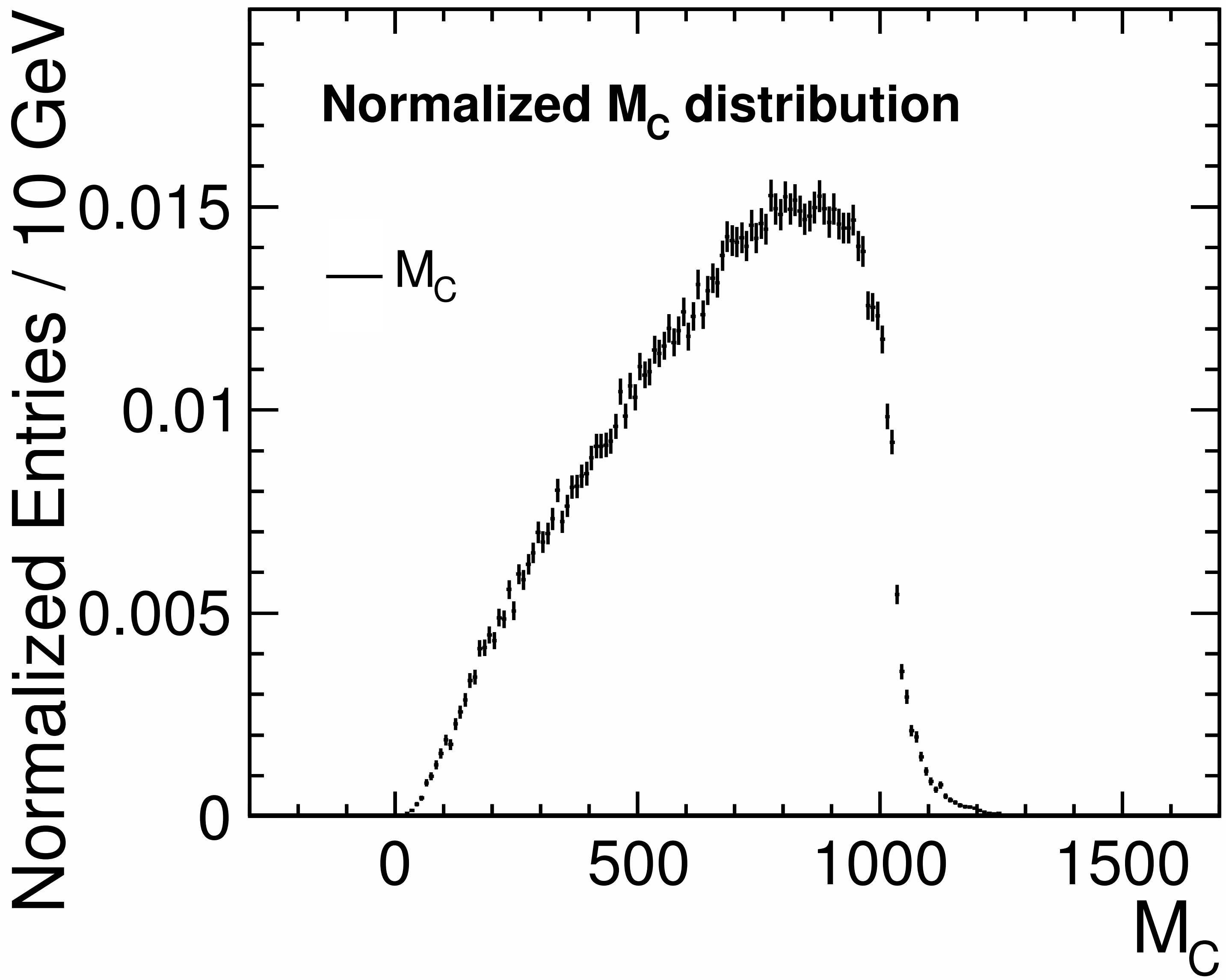
} dominant BG

- Signal Process signature:
  - 2 Jets + E_{miss}
- Background
  - Dominated by SM Neutrino Processes
  - Crosssection 3-4 orders higher!

- Good Background rejection needed
  - first step: p_t > 600 GeV
  - ➡ only SM E_{miss} relevant

Measurement Techniques: M_C

$$\begin{aligned} M_C^2 &= (E_1 + E_2)^2 - (\vec{p}_1 - \vec{p}_2)^2 \\ &= 2(E_1 E_2 + \vec{p}_1^2 \vec{p}_2^2) \end{aligned}$$



- Modification of invariant Mass
- Use @ LHC as transversal variant
- Neutralino mass has to be known
- Squark mass extraction:
  - Formula (using the upper edge)
  - Template Fit (used in this analysis)

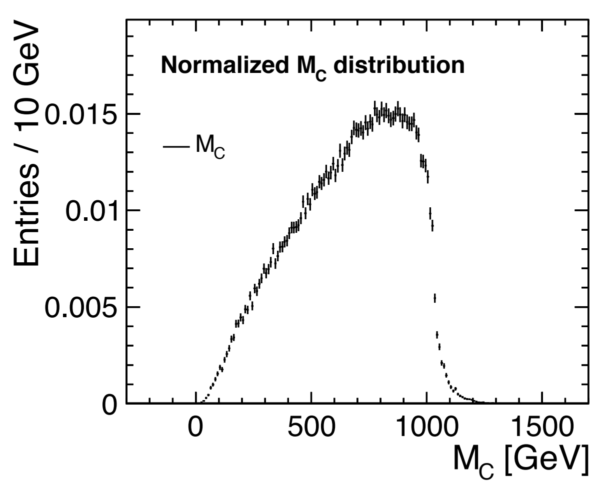
$$M_{C,\max} = \frac{m_{\tilde{q}}^2 - m_{\chi}^2}{m_{\tilde{q}}}$$

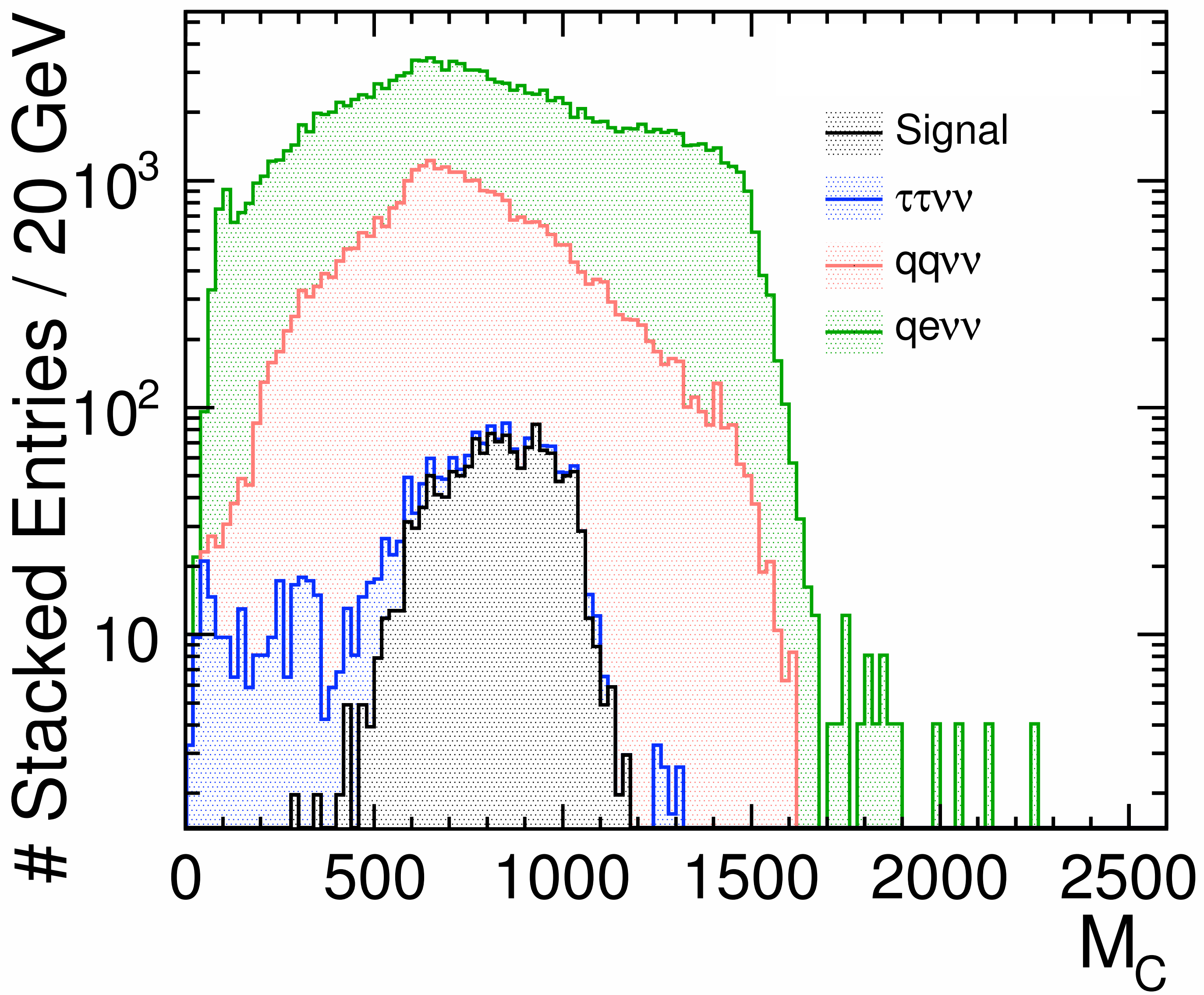
M_C: Signal plus Background

- After full reconstruction: p_t > 600GeV

  $\Rightarrow$ S/B = 1/1000
- Background rejection needed
  - Cut based
    - 1D Cuts on various distributions (e.g. E_{vis}, Jet angle,/energy, ...)
    - prooved inefficient
  - Multi dimensional Analysis
    - Boosted Decision Trees

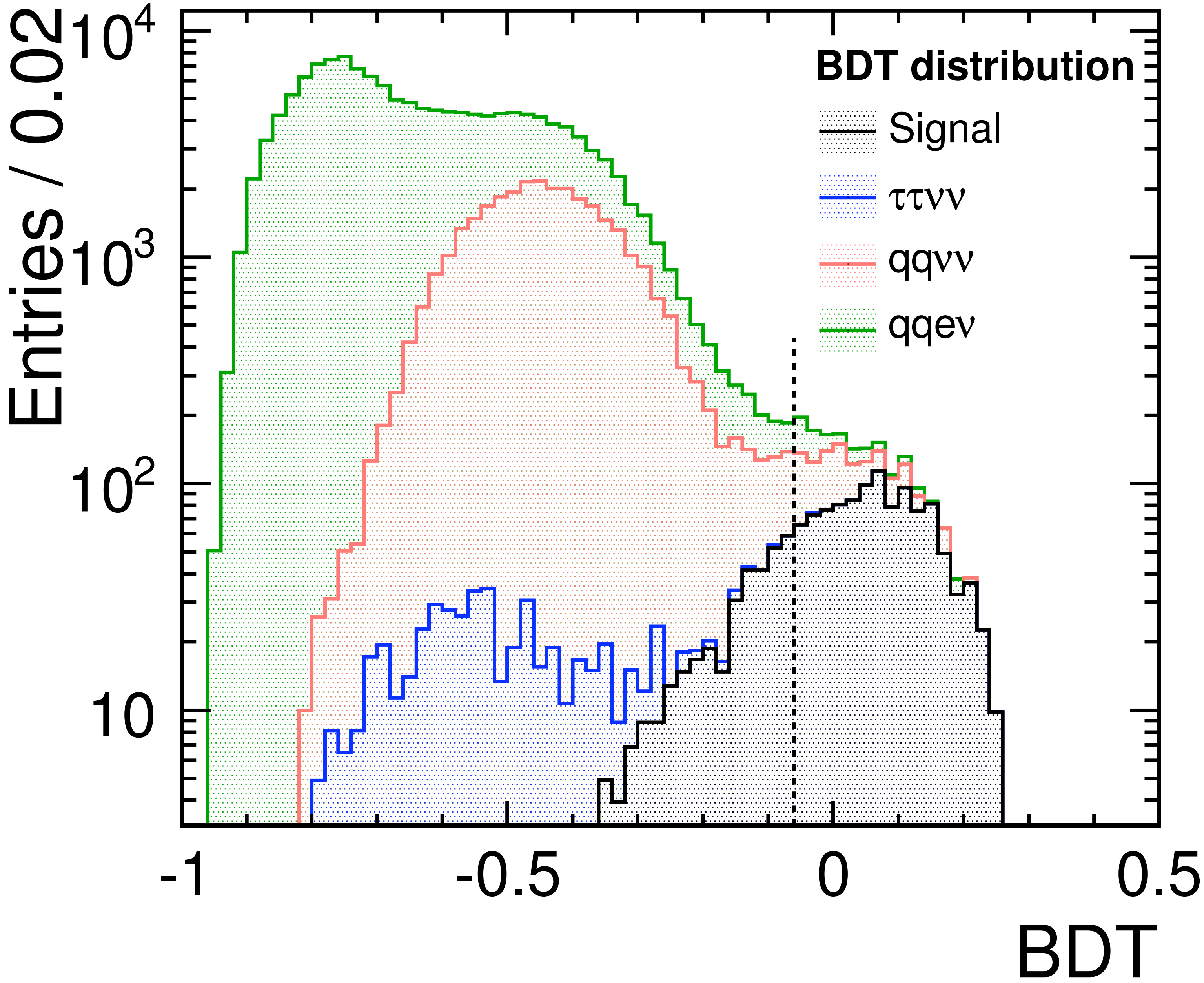
p_t>600GeV	# Events
Signal	1430
Background	145000





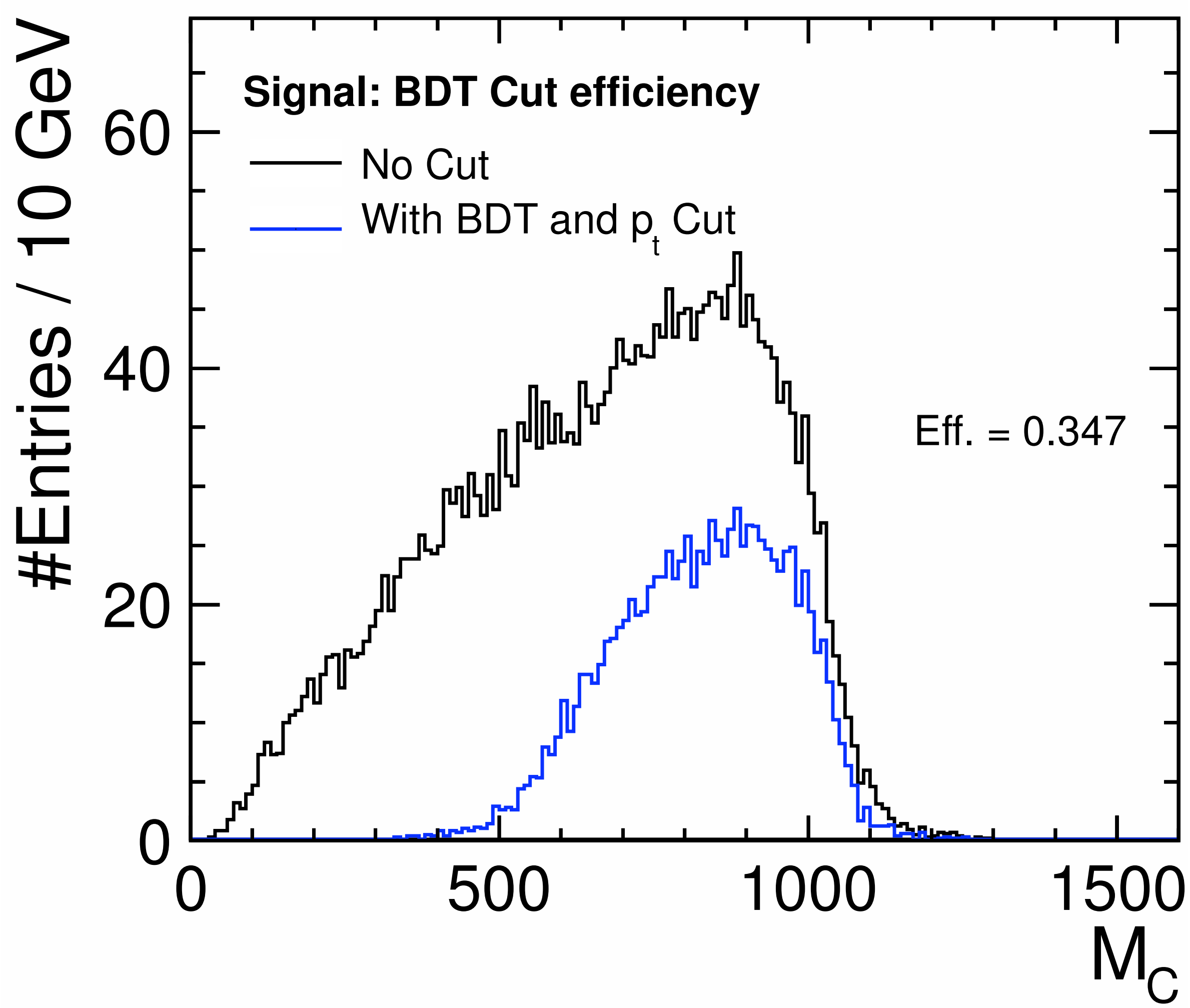
Background rejection: Boosted Decision Trees

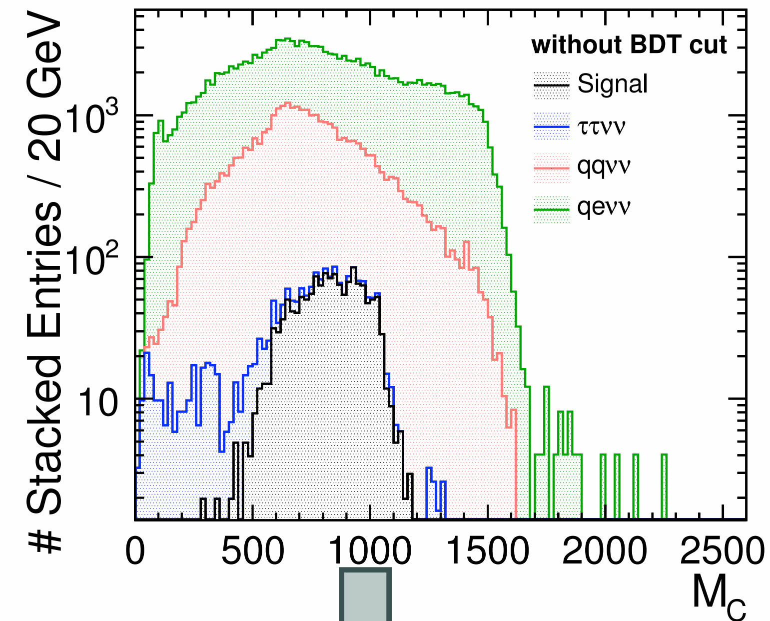
- Background rejection with Boosted Decision Trees:
  - Framework: TMVA (ROOT package)
  - Splitting Data into 2 independent samples:
    1. Training and Testing
    2. Analysis
- Used BDT Cut
  - BDT > -0.05
  - $S/\sqrt{S+B} \approx 25$



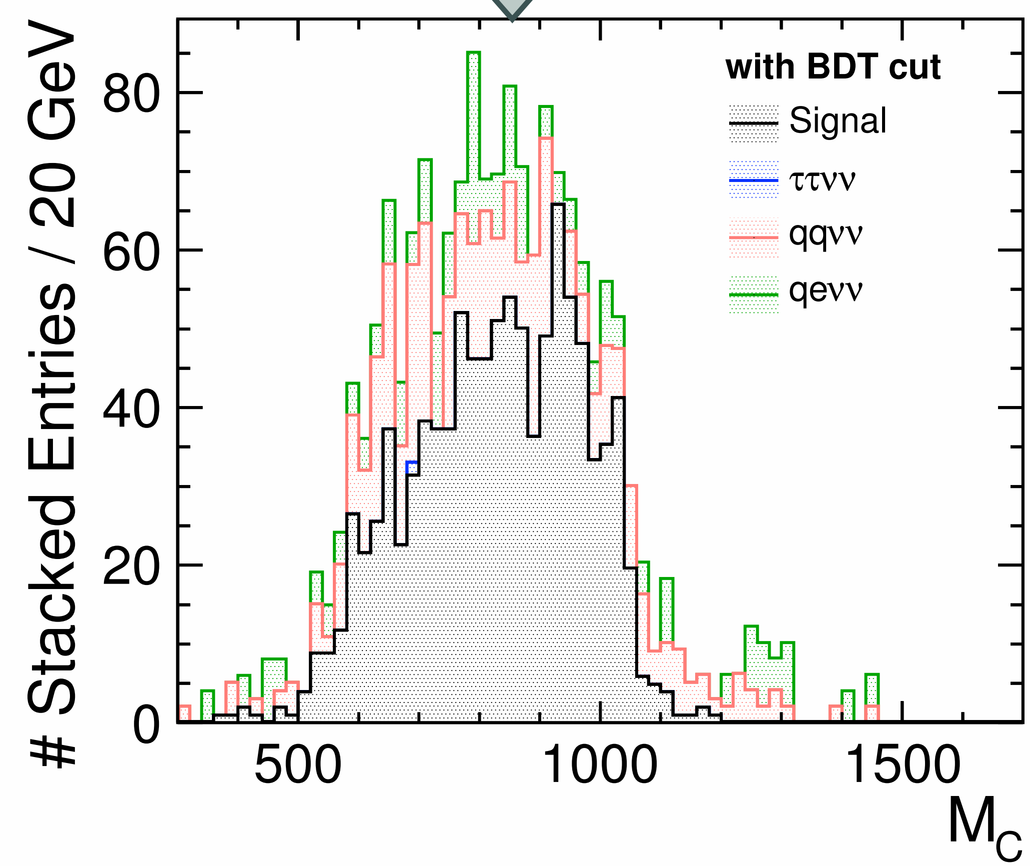
Background rejection: Boosted Decision Trees: Cut eff.

- After BDT and p_t Cut:
  - Purity: 0.60
  - Cut efficiency: 0.347
    (determined from independent sample)





Cut on BDT



Background rejection: Fit Background

- M_C Distribution not Background free after BDT cut
  - Fit Background on Train Sample
    - Gaussian
  - Subtract Fit on Analysis Sample

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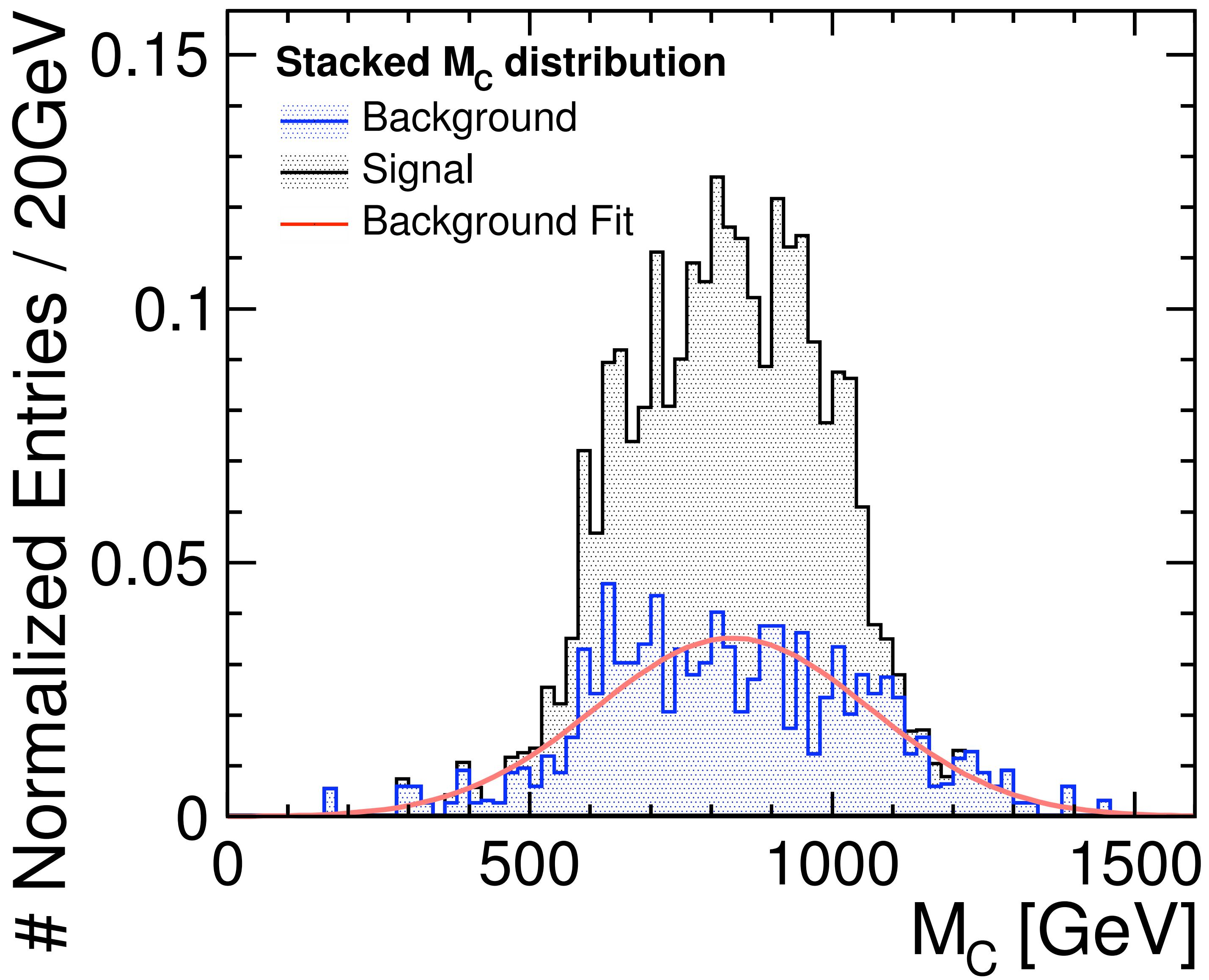

Squark mass extraction: Template Fit

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- Squark mass extraction with M_C: Template Fit

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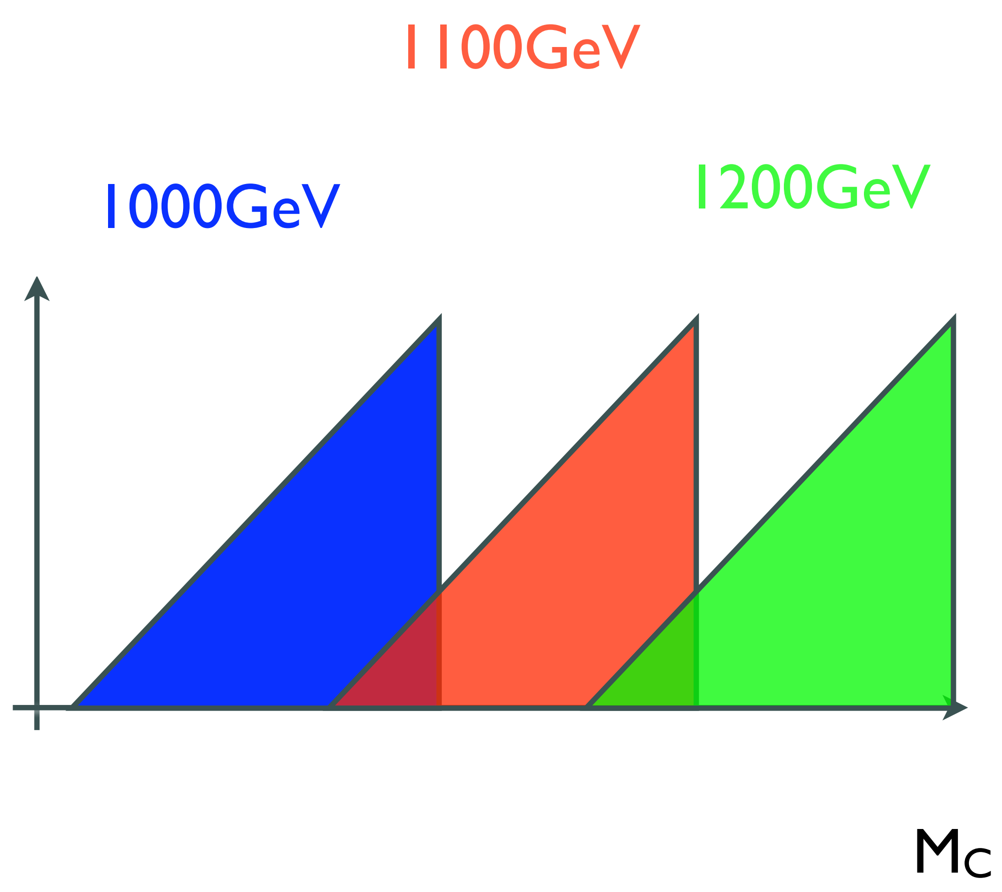
  - Create templates in steps of 3 GeV



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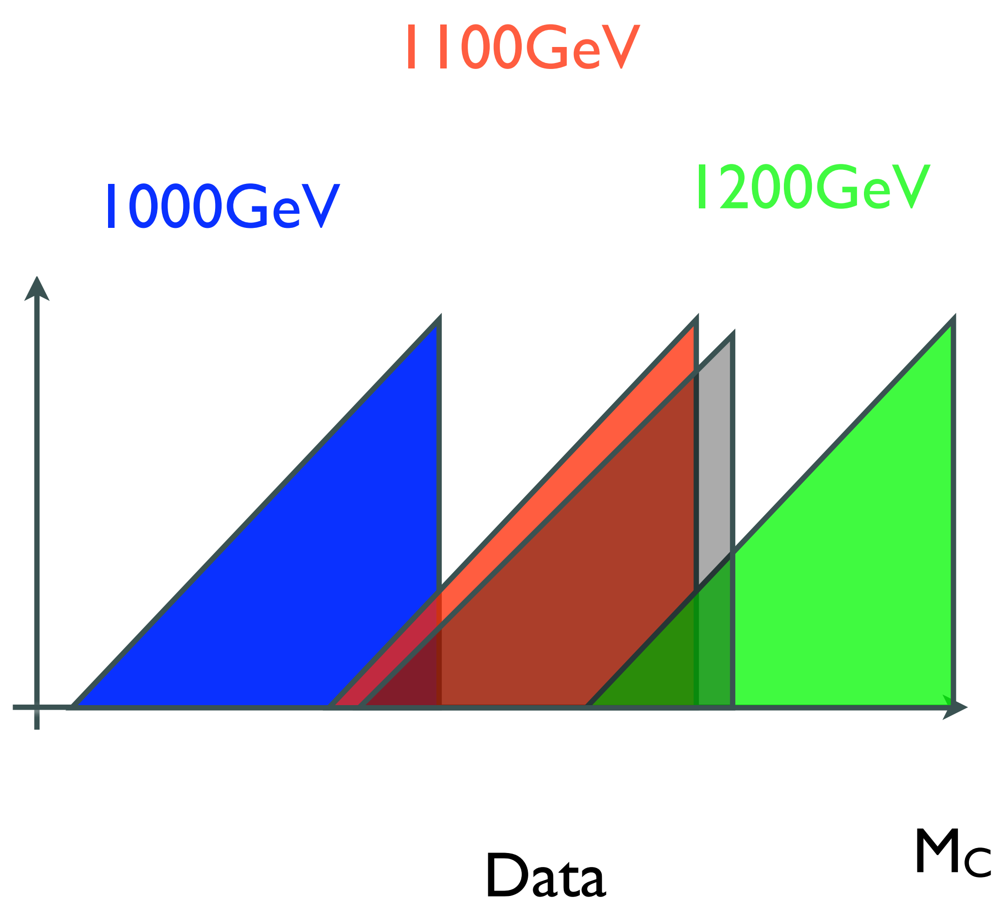
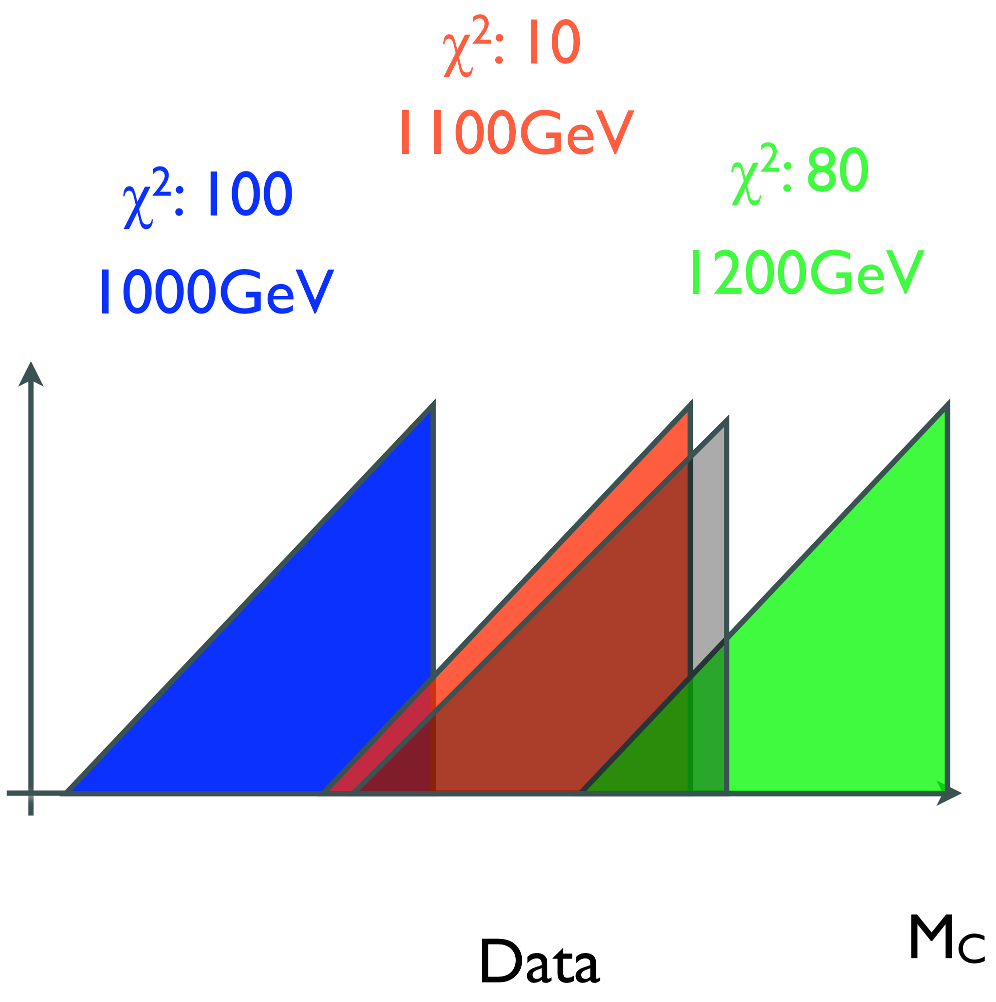


Squark mass extraction: Template Fit

$$\chi^2 = \sum_n^{\text{bins}} \frac{\Delta_n^2}{\sigma_{n,\text{t}}^2 + \sigma_{n,\text{m}}^2}$$

- Squark mass extraction with M_C: Template Fit
  - Create templates in steps of 3 GeV
  - Compare template with Data via χ^2



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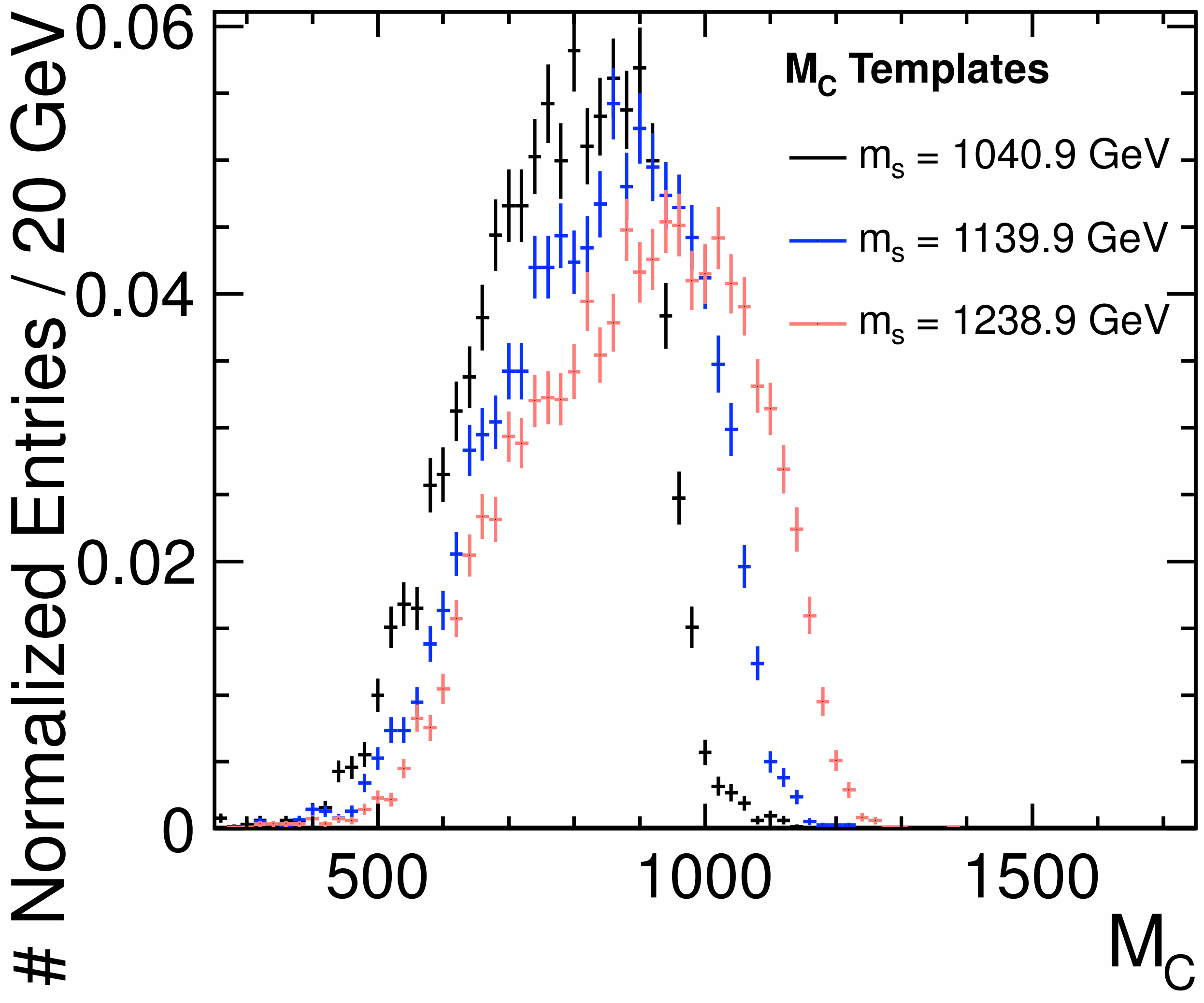

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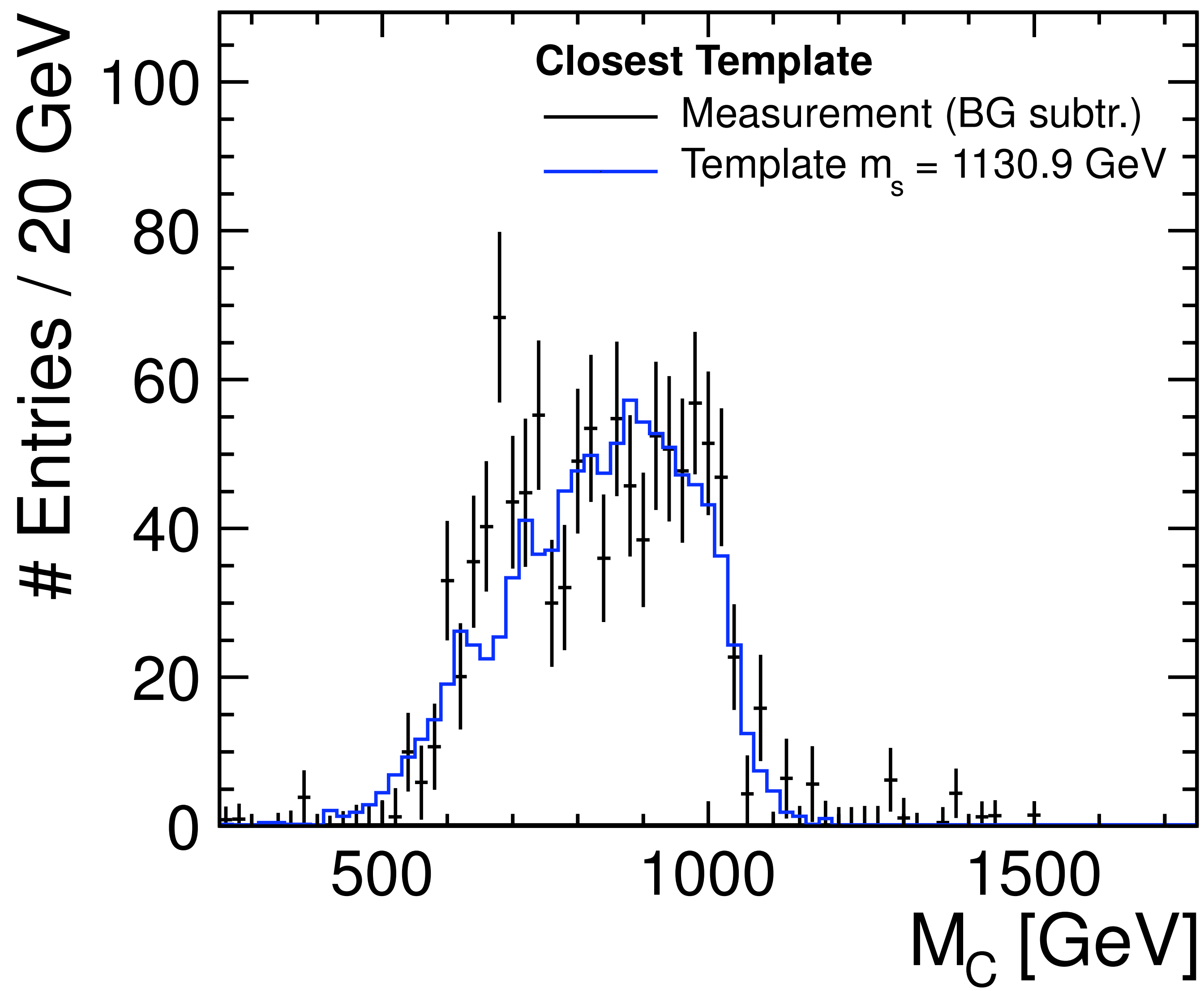

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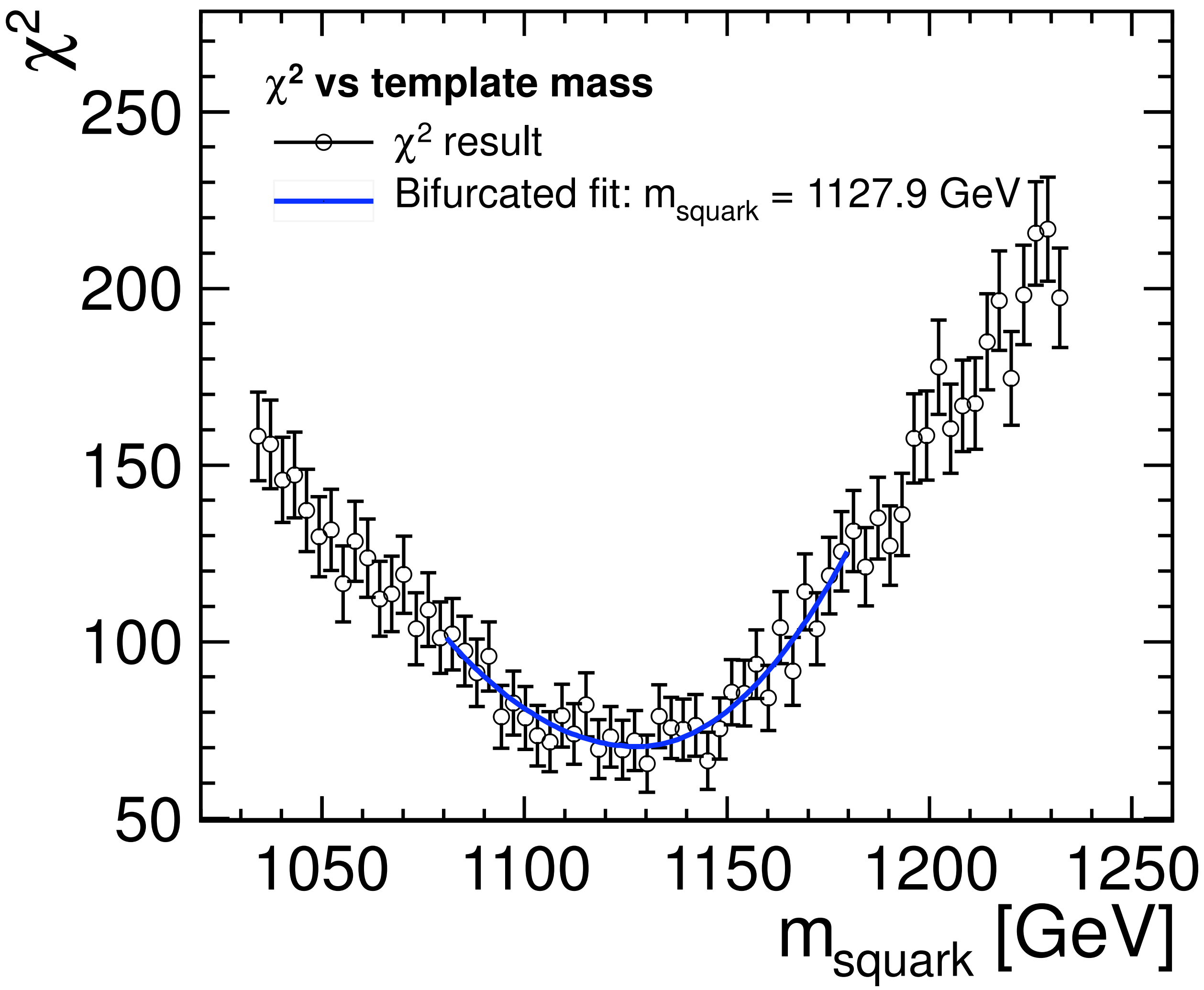
  - Fit resulting parabola
    - Minimum = m_{squark} = 1127.9 GeV



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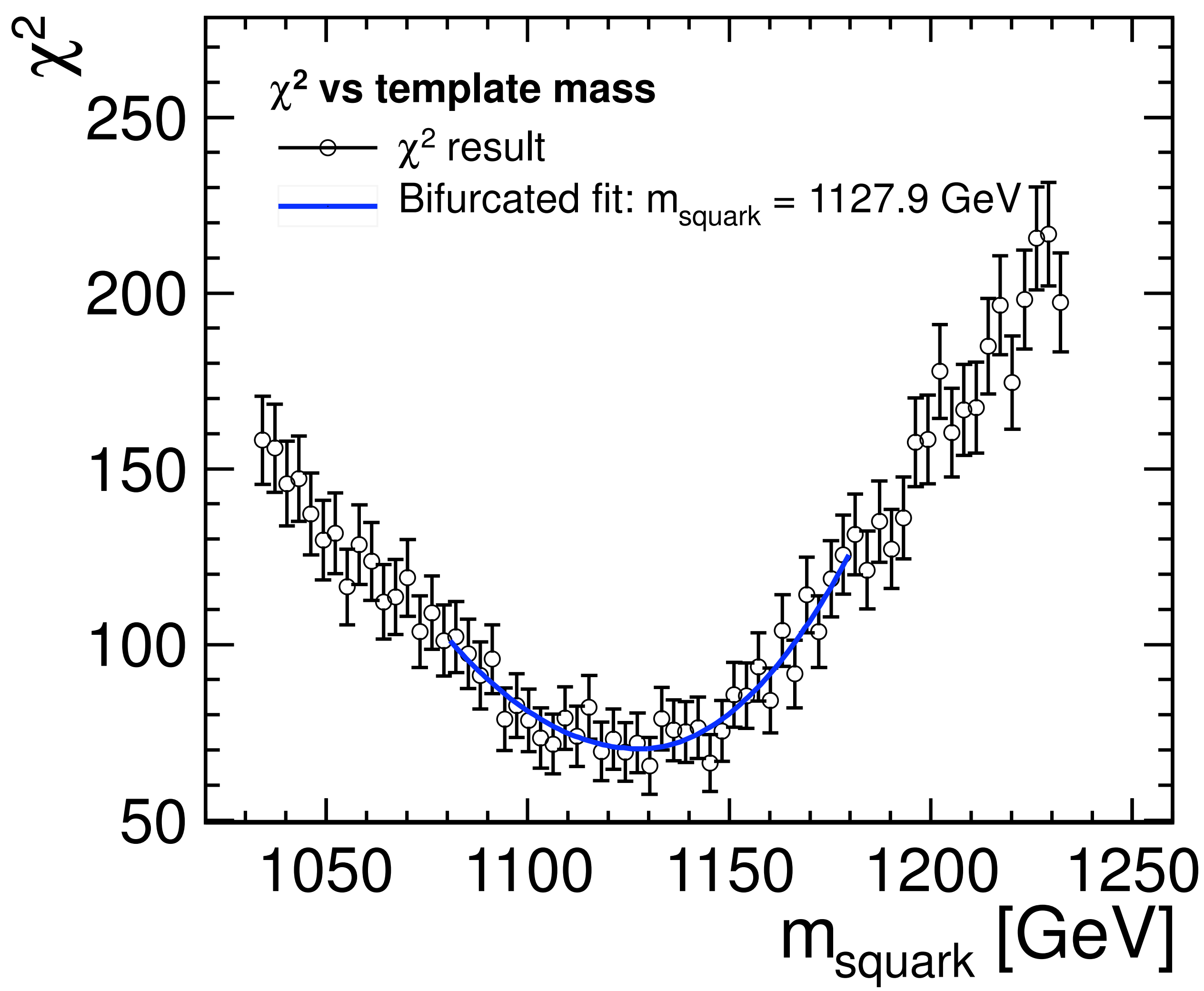
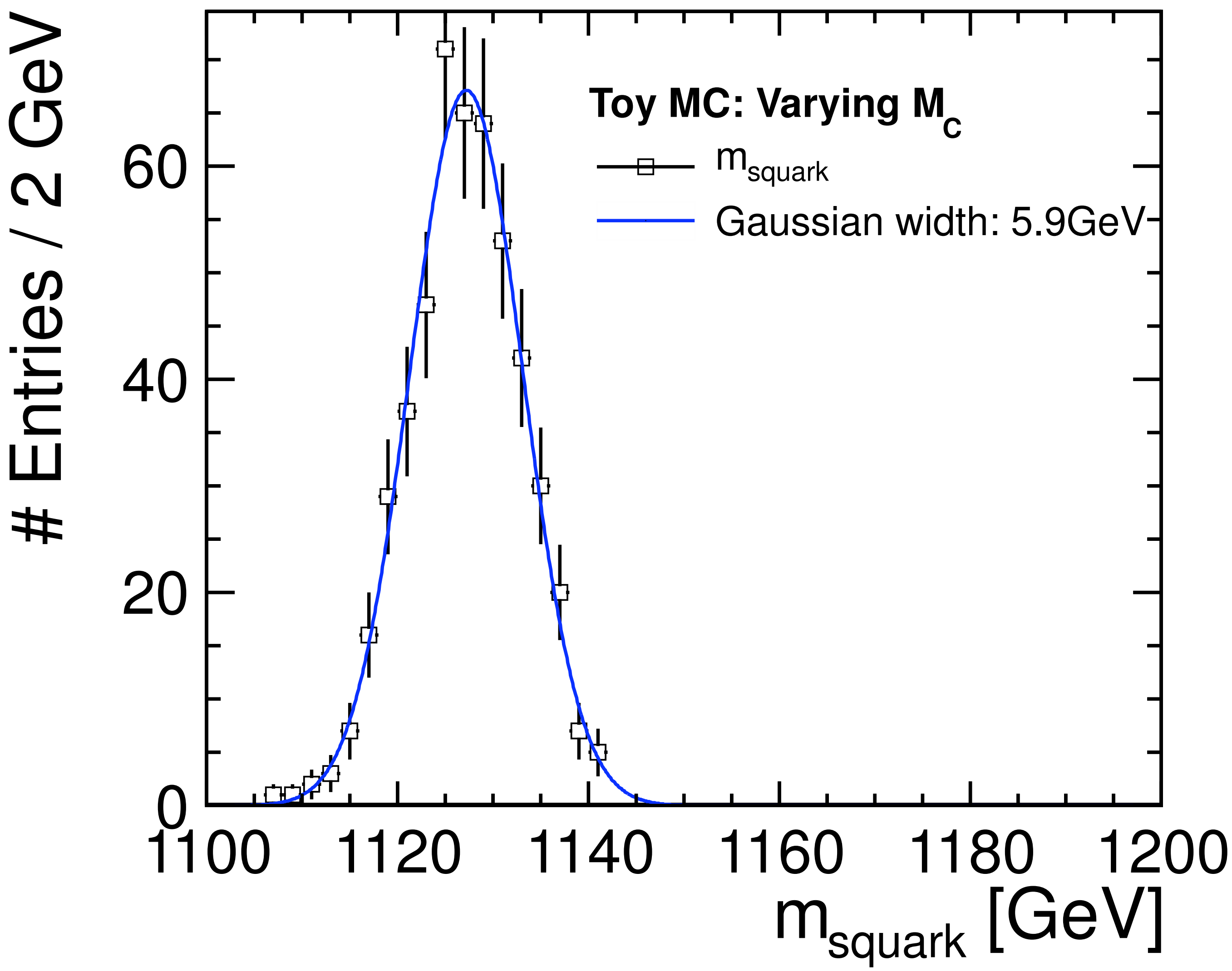
- Templates created via 4-Vector smearing (no full simulation)



Squark mass measurement: Statistical Error

- Extract statistical error with a Toy-MC
  - Repeat 500 times:
    - Bin-by-bin Gaussian smearing of measured M_C distribution
    - Extract m_{squark} for smeared M_C
- Final result within 1σ of input value



$$m_{squark} = 1127.9 \text{ GeV} \pm 5.9 \text{ GeV}_{(stat)}$$

$m_{squark,input} = 1123.7$ GeV

Crosssection

- Crosssection measurement
  - Analysis done for Luminosity of L = 2000 fb^{-1}
  - Subtract the Background from M_C distribution using the Fit
  - Integral = # Events after BDT and p_t cut ($N_{after\ cut}$)
  - Cut efficiency ε of BDT and p_t cut known

$$N_{\text{real}} = \frac{N_{\text{after cut}}}{\epsilon}$$

$$\sigma = \frac{N_{\text{real}}}{\mathcal{L}} = \frac{N_{\text{after cut}}}{\epsilon \mathcal{L}}$$

$$\boxed{\sigma_{squark} = (1.51 \pm 0.07)\ \text{fb}}$$

$\sigma_{squark,input}$ = 1.47 fb

Summary

- New accelerator technology: Compact Linear Collider
- Conceptional Design Report Benchmark: Squark pair production
  - Decay mainly into 2 jets an missing energy
- Background rejection done with Boosted Decision Trees
- Remaining Background fitted with Gaussian
- Squark mass extracted via Template Fit
- Statistical Error extracted with a Toy-MC

Event Classification: Boosted Decision Trees

- Decision trees are used for general classification
  - here: Signal (+1) vs Background (-1)
- „Weak Learner“:
  - Gives better results than flipping a coin
- Boosting: (⇒ „Strong Learner“)
  - Tree building requires training sample
    - Choose cut with maximum splitting of BG/Signal
  - Apply trees on sample:
    - Check if classification was correct
    - Weight misclassified events higher in next step
  - Build next tree
  - ➡ Forest of Trees
    - Classification via majority vote:
    - ➡ single variable BDT ∈ [-1;+1]