



Research Showcase


Understanding the universe through precision measurements

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- tenure-track research fellow in Liverpool since Oct 24
- previously at PSI / Zurich, CH (PhD), Durham, UK, and Bern, CH (postdoc)
- research: precision particle physics
- author of the McMULE programme



McMULE

photo by Maisha Reza,
GW4 EDI Conference 2023

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- fairly good handle from the first trillionth of a second to now
- what happened before that?

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What happened during the first second?

- fairly good handle from the first trillionth of a second to now
- what happened before that?
- we don't investigate these questions with telescopes ...

... but with particle accelerators

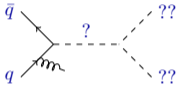
- simulate the conditions as close to the Big Bang as possible
- higher energies \rightarrow closer to the Big Bang
- current largest machine: LHC at CERN, 27km tunnel, 175m below Geneva
- plans to go even larger: 100km (FCC)



CERN-MI-0807031-01

energy frontier

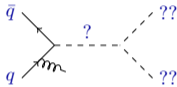
simulates Big Bang directly
produce unknown particle directly



strong signal
limited by energy

energy frontier

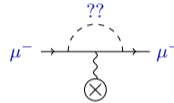
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strong signal
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intensity frontier

indirect measurements
see only footprints

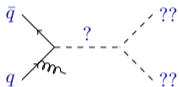


tiny signal
limited by precision

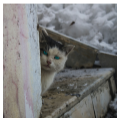
(\sim number of decimal places)

energy frontier

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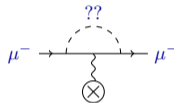


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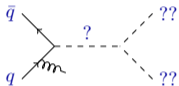
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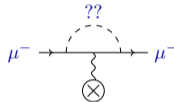
strong signal
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can characterise new particles
needs huge & expensive collider
 \approx £10 billion

intensity frontier

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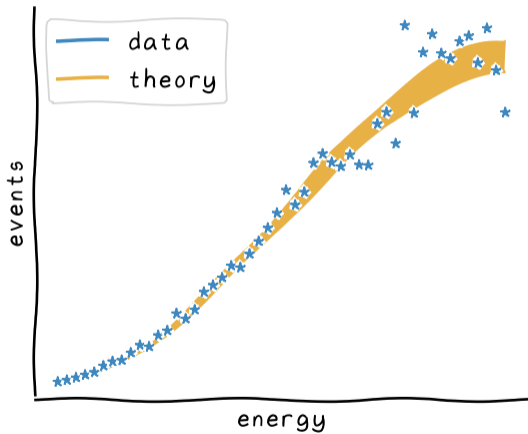
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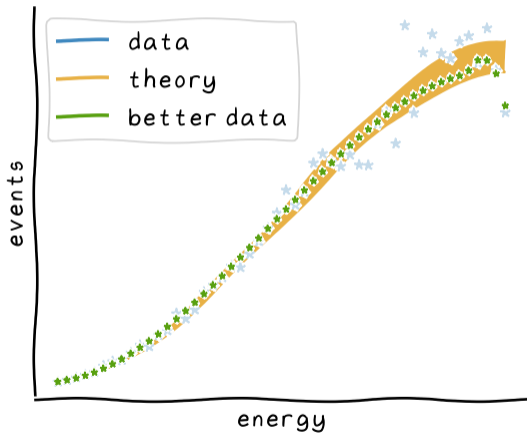


can only see if new particles exist
comparatively cheap
 \approx £10 million

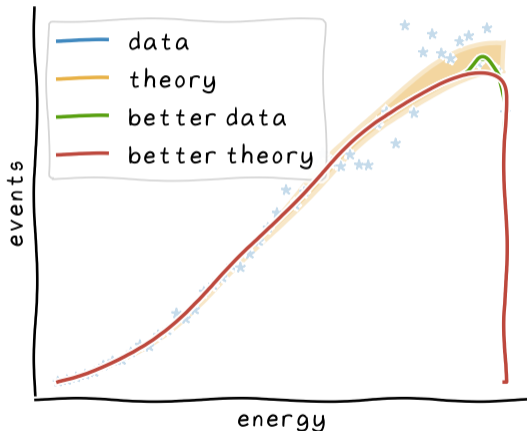
- effect is tiny,
 $1/1\,000 - 1/1\,000\,000$

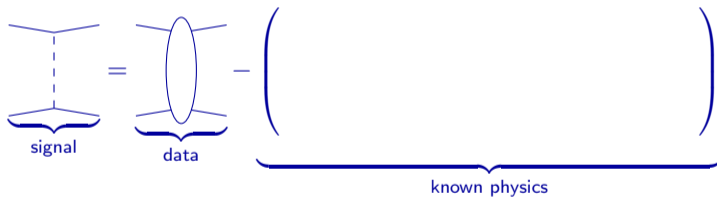


- effect is tiny,
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- require precise measurement!

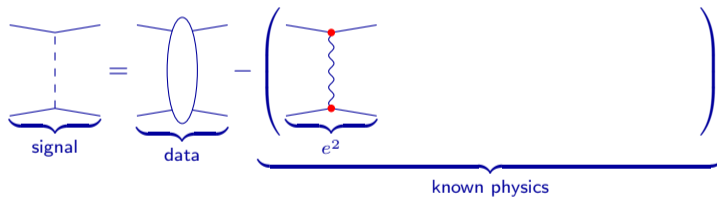


- effect is tiny,
 $1/1\,000 - 1/1\,000\,000$
- require precise measurement!
- but also precise theory
- otherwise signal will be lost in noise

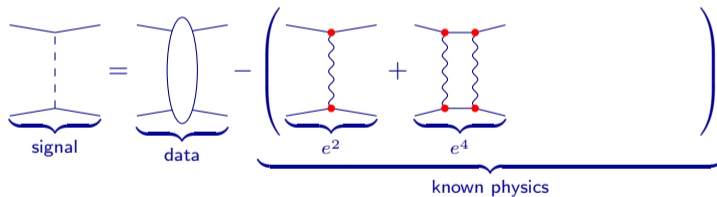




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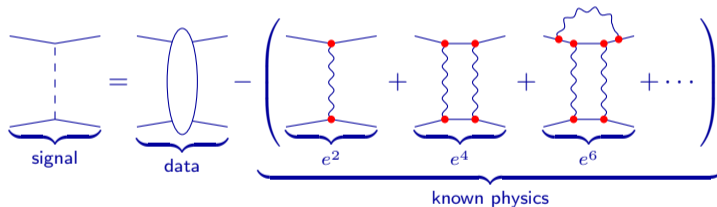
The diagram illustrates the relationship between signal, data, and known physics in a perturbative expansion. It shows the following equation:

$$\text{signal} = \text{data} - \left(\underbrace{e^2 + e^4}_{\text{known physics}} \right)$$

The terms are represented by Feynman diagrams:

- signal**: A diagram with two incoming lines on the left and two outgoing lines on the right, connected by a vertical dashed line.
- data**: A diagram with two incoming lines on the left and two outgoing lines on the right, connected by a vertical oval.
- known physics**: A bracketed sum of two diagrams:
 - e^2** : A diagram with two incoming lines on the left and two outgoing lines on the right, connected by a vertical wavy line with two red dots on the wavy line.
 - e^4** : A diagram with two incoming lines on the left and two outgoing lines on the right, connected by two vertical wavy lines, each with two red dots.

- expand in small parameter $e \approx 0.3$ •
- leading order e^2 : 10% error
- next-to-leading order e^4 : 0.1% error
- next-to-next-to-leading order e^6 : 0.01% error



The diagram illustrates the expansion of a signal in terms of data and known physics. On the left, a Feynman diagram labeled 'signal' shows two incoming lines meeting at a vertex connected by a dashed line to another vertex, which then splits into two outgoing lines. This is set equal to a Feynman diagram labeled 'data' showing two incoming lines meeting at a vertex connected by a solid oval to another vertex, which then splits into two outgoing lines. This is followed by a minus sign and a large bracketed sum of terms. The first term is a Feynman diagram with two incoming lines meeting at a vertex connected by a wavy line to another vertex, which then splits into two outgoing lines; this term is labeled e^2 . The second term is a Feynman diagram with two incoming lines meeting at a vertex connected by a wavy line to another vertex, which then splits into two outgoing lines; this term is labeled e^4 . The third term is a Feynman diagram with two incoming lines meeting at a vertex connected by a wavy line to another vertex, which then splits into two outgoing lines; this term is labeled e^6 . The sum is followed by a plus sign and an ellipsis. A large bracket under the sum is labeled 'known physics'.

- my project, McMULE, provides e^6 results for many processes



goals

conclusion

goals

- support more experiments at CERN, JLab, Sendai, Frascati, PSI, Fermilab, KEK, ...
(experiments with Liverpool contribution)
- improved precision: go to next-to-next-to-next-to-leading order (e^8)
- develop novel algorithms to support this

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- (precision) particle physics can help us understand the universe we live in