Cross sections in particle physics

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ATLAS papers from 2022

Measurement of the total cross section and ρ-parameter from elastic scattering in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

Measurement of the total and differential Higgs boson production cross-sections at $\sqrt{s} = 13$ TeV with the ATLAS detector by combining the $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$ decay channels

Measurement of the $t\bar{t}$ production cross-section in pp collisions at $\sqrt{s} = 5.02$ TeV with the ATLAS detector

Measurements of W^+W^- production in decay topologies inspired by searches for electroweak supersymmetry

Production of $\Upsilon(\mathrm{nS})$ mesons in Pb+Pb and pp collisions at 5.02 TeV

Differential $t\bar{t}$ cross-section measurements using boosted top quarks in the all-hadronic final state with 139 fb^{-1} of ATLAS data

Cross-section measurements for the production of a Z boson in association with high-transverse-momentum jets in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

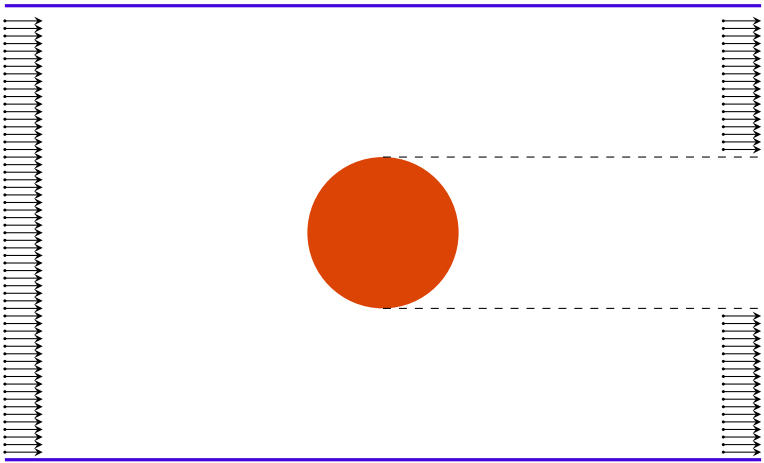
Measurement of cross-sections for production of a Z boson in association with a flavor-inclusive or doubly b-tagged large-radius jet in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS experiment

Measurements of differential cross-sections in top-quark pair events with a high transverse momentum top quark and limits on beyond the Standard Model contributions to top-quark pair production with the ATLAS detector at $\sqrt{s} = 13$ TeV

Measurements of the Higgs boson inclusive and differential fiducial cross-sections in the diphoton decay channel with pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

Measurements of Higgs boson production cross-sections in the $H \to \tau^+\tau^-$ decay channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

Rolling with Rutherford



Cross section(al area)

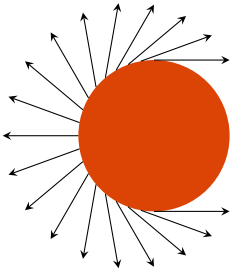
The formula

$$\frac{\text{Number in}}{\text{area}\,\text{time}} \times \text{cross section} = \frac{\text{Number out}}{\text{time}}$$

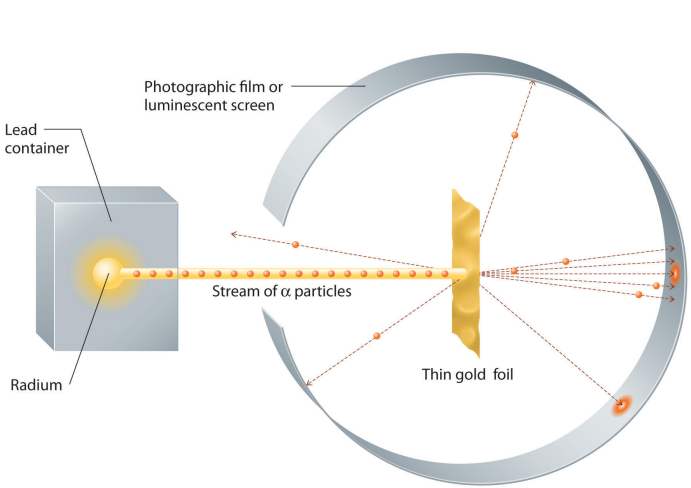
- How could you measure the shape of the target?

Differential cross sections

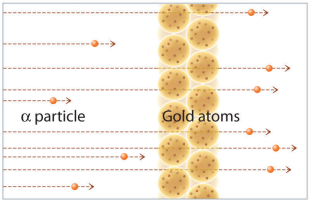
Differential cross sections



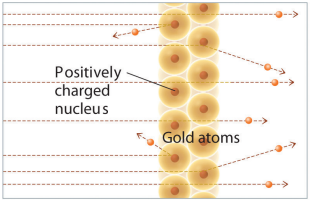
What about Rutherford?



(a) Rutherford's experiment



(b) What Rutherford expected if Thomson's model were correct

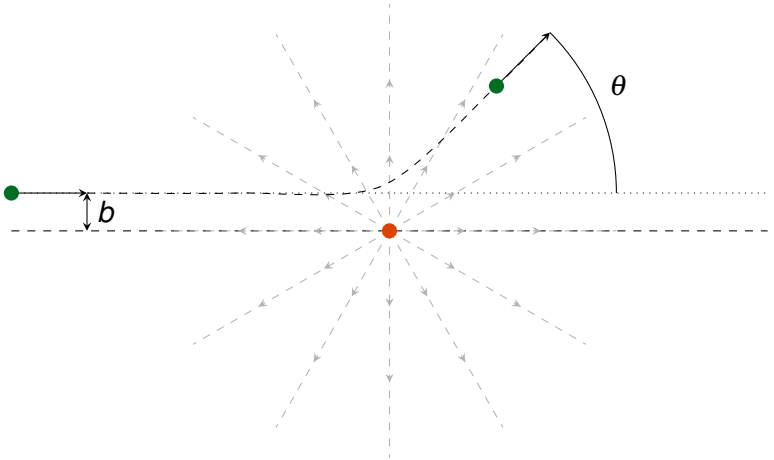


(c) What Rutherford actually observed

What they found

I.	II.	III.	IV.	V.	VI.
		SILVER		GOLD	
Angle of deflexion, ϕ	$\frac{1}{sin^4\phi/2}$	Number of scintillations, N	$\frac{N}{sin^4\phi/2}$	Number of scintillations, N	$\frac{N}{sin^4\phi/2}$
150	1.15	22.2	19.3	33.1	28.8
135	1.38	27.4	19.8	43.0	31.2
120	1.79	33.0	18.4	51.9	29.0
105	2.53	47.3	18.7	69.5	27.5
75	7.25	136	18.8	211	29.1
60	16.0	320	20.0	477	29.8
45	46.6	989	21.2	1435	30.8
37.5	93.7	1760	18.8	3300	35.3
30	223	5260	23.6	7800	35.0
22.5	690	20300	29.4	27300	39.6
15	3445	105400	30.6	13200	38.4
30	223	5.3	0.024	3.1	0.014
22.5	690	16.6	0.024	8.4	0.012
15	3445	93.0	0.027	48.2	0.014
10	17330	508	0.029	200	0.0115
7.5	54650	1710	0.031	607	0.011
5	276300			3320	0.012

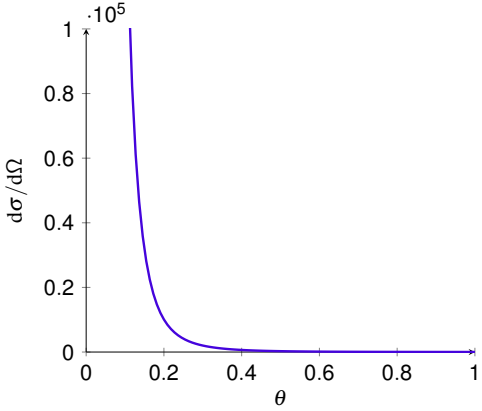
Scattering in E&M



Differential cross section

- Now fire many projectiles

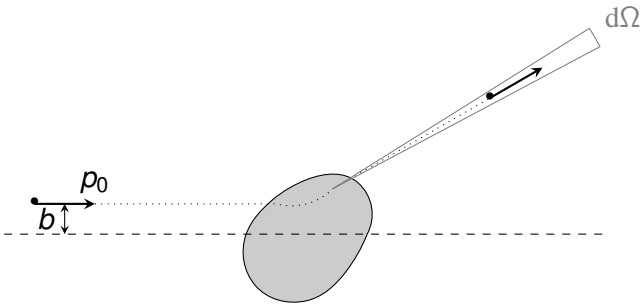
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \left(\frac{q_1 q_2}{16\pi\varepsilon_0 E \sin^2(\theta/2)} \right)^2$$



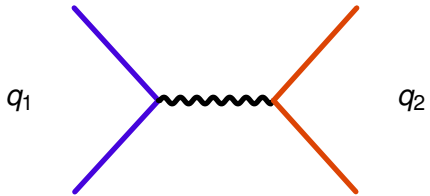
- What does it mean that it goes to infinity?

Quantum mechanics

- Now things are probabilistic: many things can happen with “same” start
- What we are measuring is effectively the same
- It’s also what we can calculate

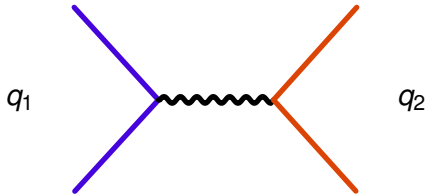


- Have you seen one of these before?

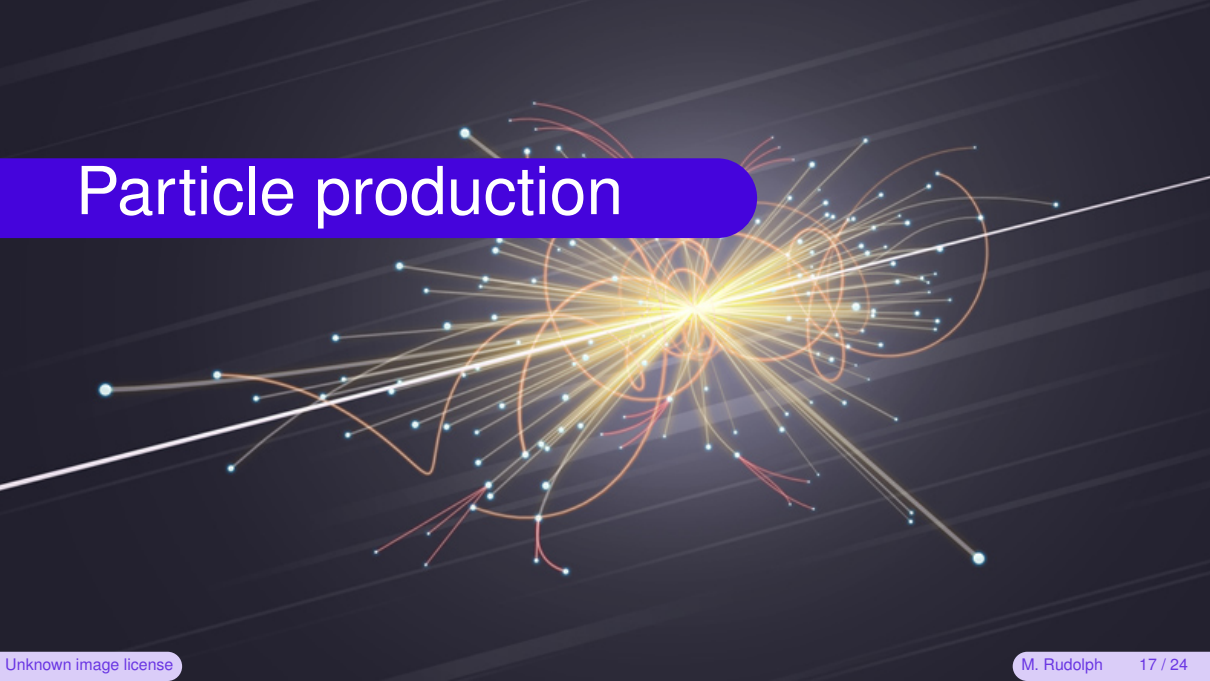


Theory

- Feynman diagrams are rules that correspond to integrals to compute (approximate) cross sections
  - Decay rates essentially done the same way
- Measuring those cross sections validates and refines the theory

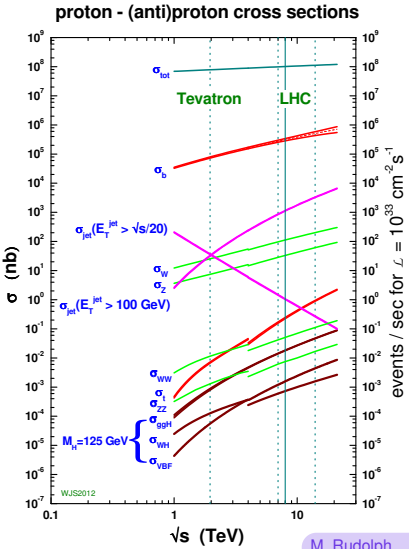


Particle production



Cross sections at LHC

- Total pp cross section is $\approx 0.1\,\mathrm{b}$



Barn?

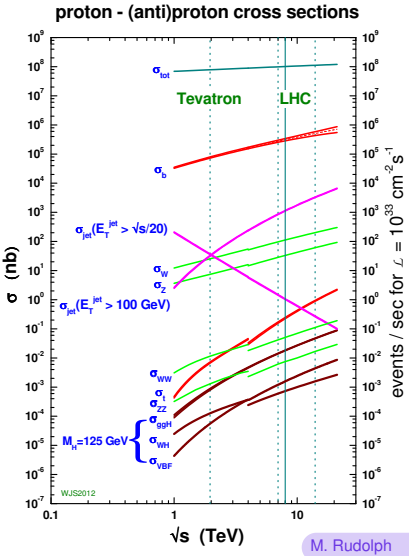
Barns

- We tend to use a special unit for nuclear and particle physics cross sections

$$1\,\mathrm{b} = 1 \times 10^{-24}\,\mathrm{cm}^2$$

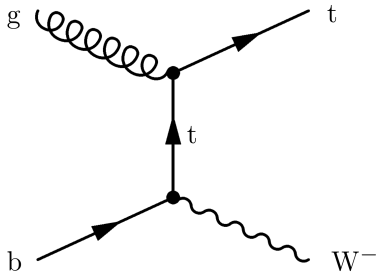
Cross sections at LHC

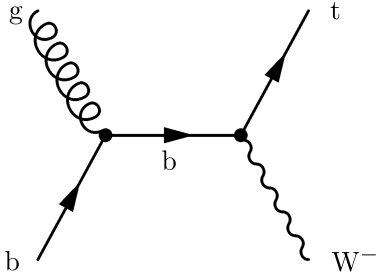
- Total *pp* cross section is $\approx 0.1\,\mathrm{b}$
- Run around $\mathscr{L} = 2 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- 10^9 collisions per second
- $100\,\mathrm{fb}^{-1}$ is about 10^{16} collisions: only a tiny fraction are “interesting”



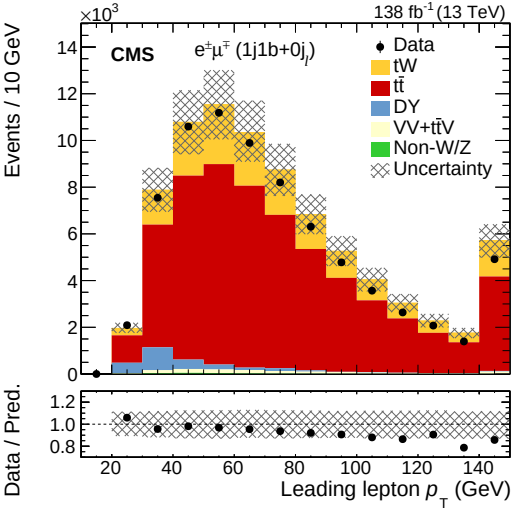
A recent measurement

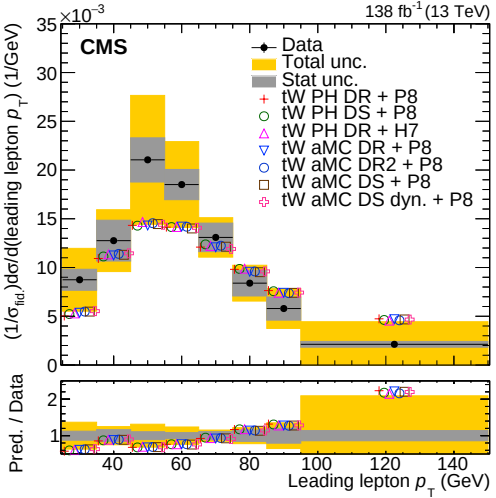
- inclusive and differential single top quark + W boson





A recent measurement





Conclusion

- Cross sections in particle physics are *similar* to bouncing projectiles off a target

$$\frac{\text{Number in}}{\text{area time}} \times \text{cross section} = \frac{\text{Number out}}{\text{time}}$$

- But process is probabilistic and there are many outcomes, including producing extra particles
- Cross section is the thing we can compute theoretically to compare to measurements