



DETECTOR RECONSTRUCTION: HOW TO FIND A POSITRON

Beth Long
elizabeth.long@uniroma1.it
(Sapienza Università di Roma, INFN Sezione di Roma)

22/05/24

1

Outline

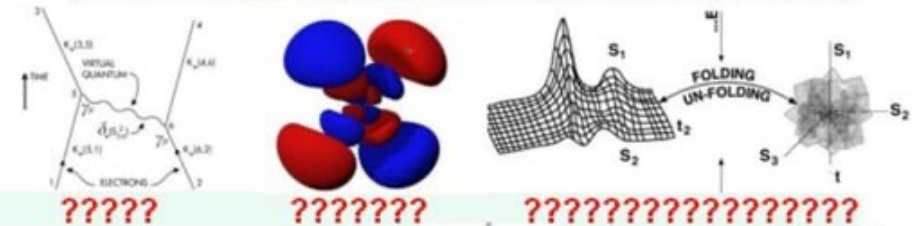
- The physics case
- The PADME setup
- The vetoes
- (Re)construction of physical quantities
- Conclusion

STOP DOING PHYSICS

- PARTICLES WERE NOT SUPPOSED TO BE LOOKED AT
- YEARS OF BONKERS THEORIES yet NO REAL-WORLD USE FOUND for looking beyond the FIRST ORDER DERIVATIVES
- Wanted to build a weirder model for a laugh? We had a tool for that: It was called "EXPERIMENTAL CONJECTURES"
- "Nice throw Jimmy, the ball really went $H(t)|\psi(t)\rangle = ih \frac{d}{dt} |\psi(t)\rangle$! I'm feeling very $\hat{H} = \sum_{n=1}^N \frac{\hat{p}_n^2}{2m_n} + V(x_1, x_2, \dots, x_N)$ today" - Statements dreamed up by the utterly Deranged

LOOK at what Physicists have been demanding your Respect for all this time, with all the labs & computer programs we built for them

(This is REAL Physics, done by REAL Physicists):



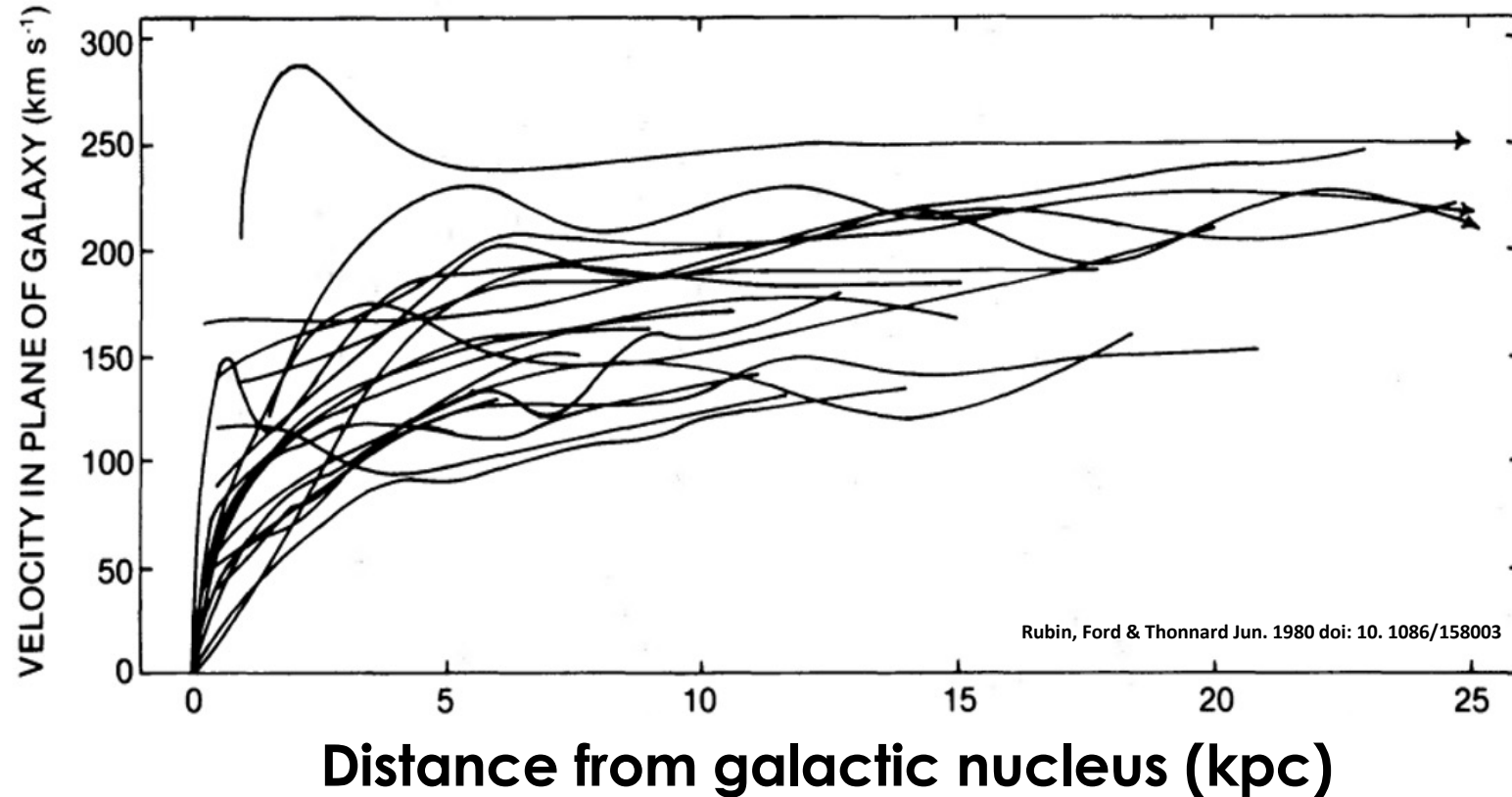
““““The uncertainty in  is ””””

They have played us for absolute fools

[u/BWY9](#)

The dark matter problem

- In 1930s studies of galaxy clusters Zwicky found **no clear mapping** between angular velocity and mass
- By the 1980s there was a large body of evidence showing the same effect

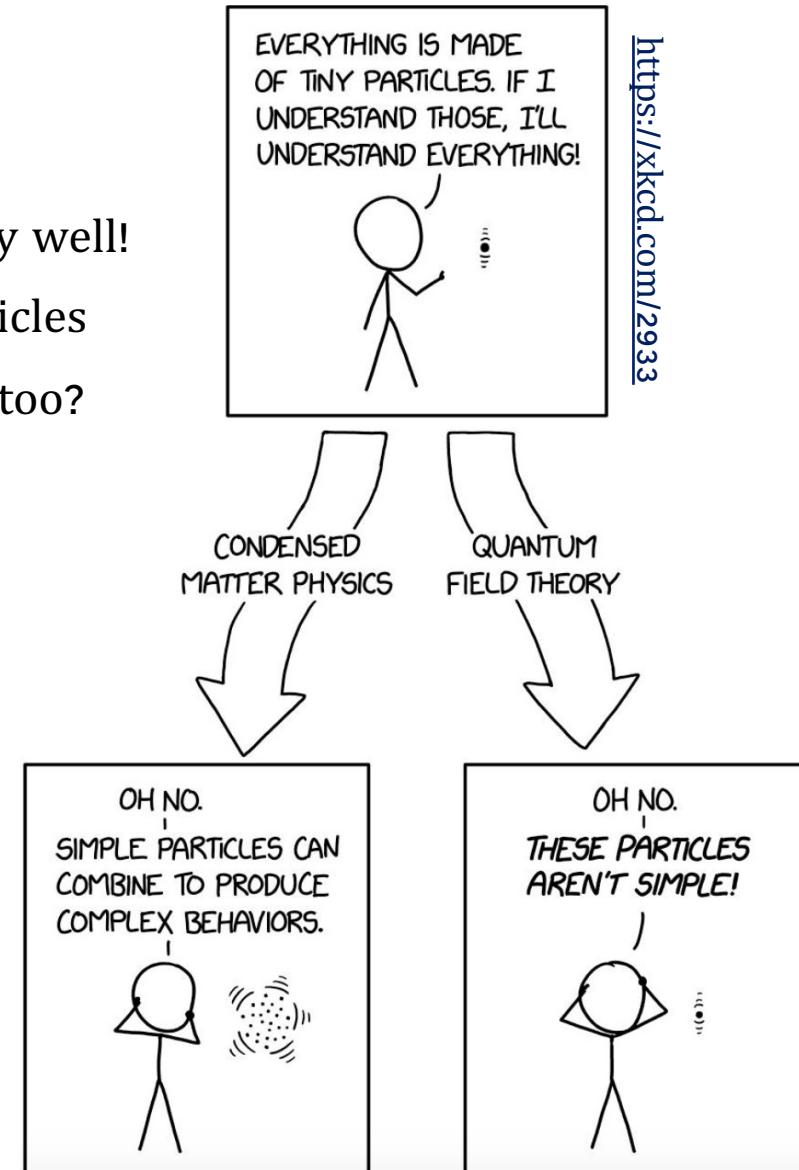


A particle physicist's reasoning



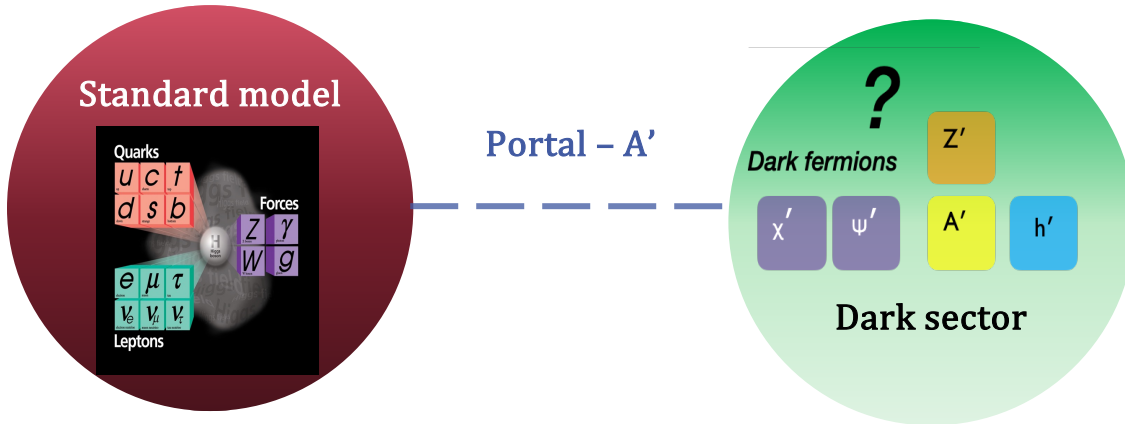
DARK FERMIONS???

- The standard model works really well!
- Everything (that matters) is particles
- What if dark matter is particles too?



The dark sector

- Assume dark matter exists in secluded “dark sector”
- Interacts with standard model only through exchange of massive “portal particle”
- If the particle has spin 1, it’s known as “**dark photon**” - “ A' / X /...”
- SM- A' coupling $\epsilon \ll 1 \Rightarrow$ hidden



This section features a grid of cute, character-like illustrations of various particles, each with a small tag and a brief description:

- QUARKS:**
 - UP QUARK:** A teeny little point inside the proton and neutron, it is friends forever with the down quark.
 - DOWN QUARK:** A tiny little point inside the proton and neutron, it is friends forever with the up quark.
 - CHARM QUARK:** A charming second generation quark.
 - STRANGE QUARK:** What's so strange about this second generation quark?
 - TOP QUARK:** This heavyweight champion doesn't live long enough to make friends with anyone.
 - BOTTOM QUARK:** This third generation quark is puttin' on the pounds.
- LEPTONS:**
 - ELECTRON-NEUTRINO:** This minuscule bandit is so light, he is practically massless.
 - MUON-NEUTRINO:** Like the other 2 neutrinos, he's got an identity crisis from oscillation.
 - TAU-NEUTRINO:** He's a tau now, but what type of neutrino will he be next?
 - ELECTRON:** A familiar friend, this negatively charged, busy li'l guy likes to bond.
 - MUON:** A "heavy electron" who lives fast and dies young.
 - TAU:** A "heavy muon" who could stand to lose a little weight.
- BOSONS:**
 - HIGGS BOSON:** He's the one everyone wants to meet and now we've seen his signal from years of data at the experiments at Fermilab and CERN. You'd be smiling too if everyone was looking to interview you.
 - PHOTON:** The massless waviwe we know and love.
 - GLUON:** The "glue" of the strong nuclear force.
 - W BOSON:** As the carrier particles of the weak nuclear force, they are downright obese.
 - Z BOSON:**
- DARK FERMIONS???:**
 - Dark Photon???** (Illustrated with a large black smiley face)

PADME production mechanisms

Assuming production **Positron Annihilation**

Centre of mass energy $\sqrt{s} \approx 20$ MeV

◦ Vector portal production at PADME:

Resonant annihilation:

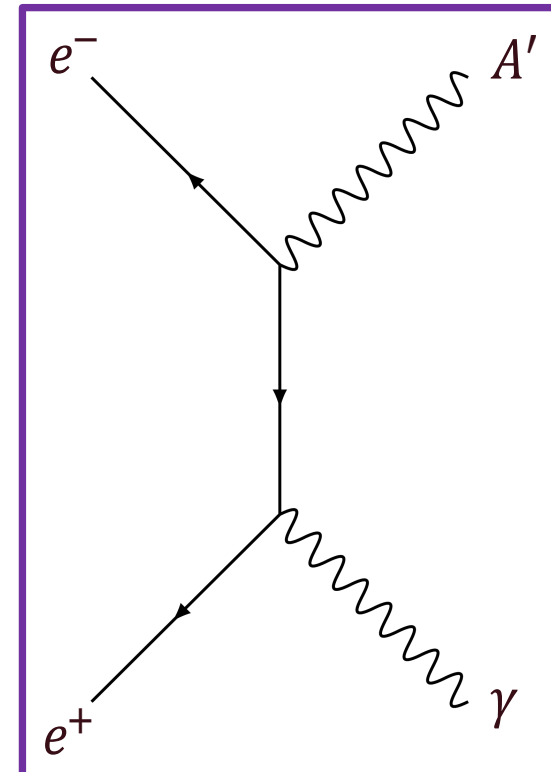
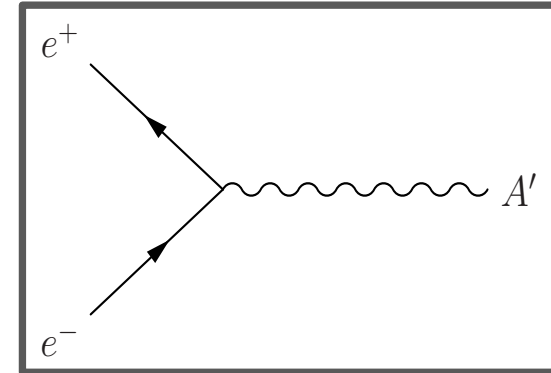
$$e^+ e^- \rightarrow A'$$

- Increased production when $\sqrt{s} \approx M_{A'}$
- Only useful if you know $M_{A'}$

Associated production:

$$e^+ e^- \rightarrow \gamma A'$$

- Useful if you don't know $M_{A'}$



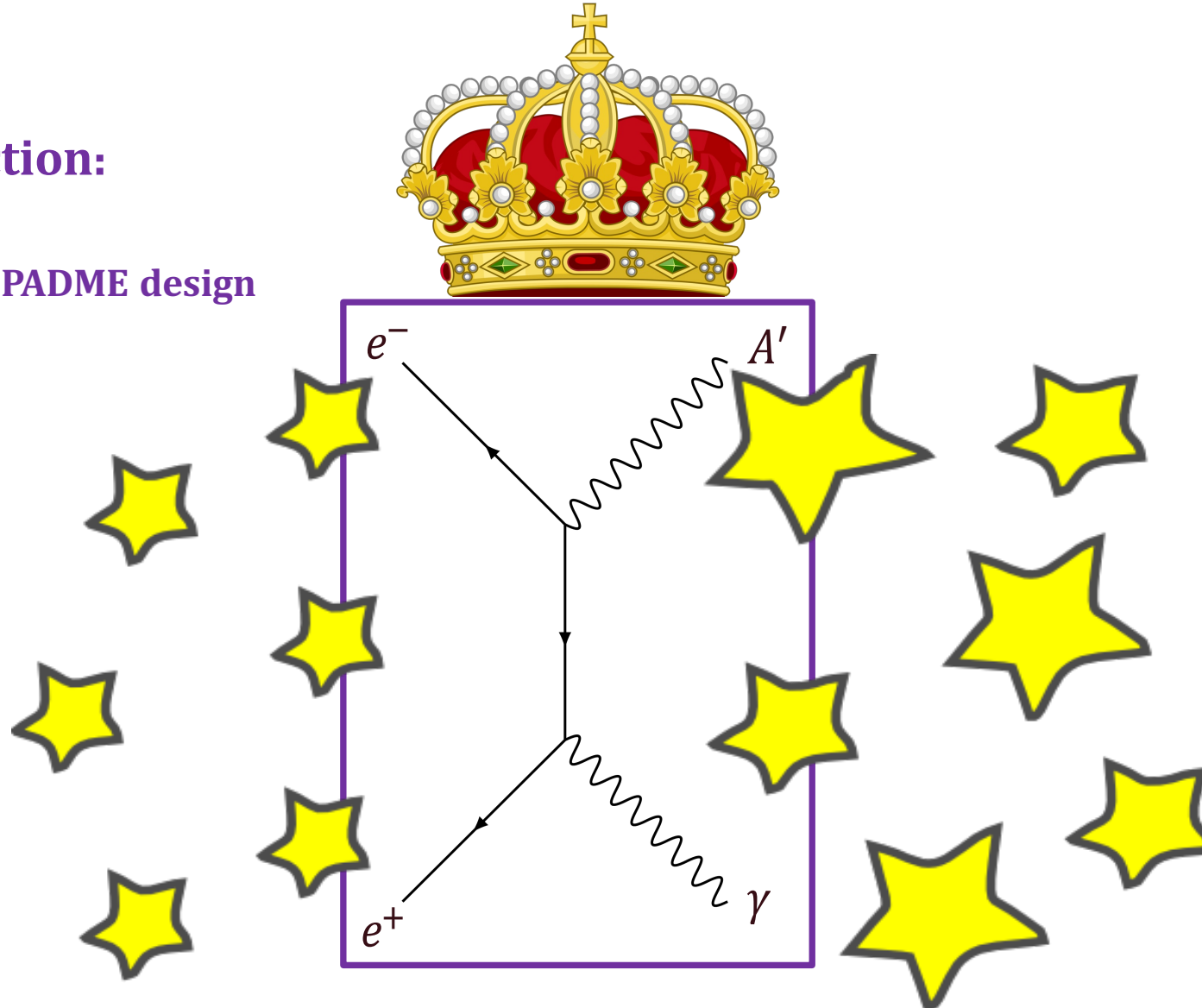
PADME production mechanisms

The winner:

Associated production:

$$e^+e^- \rightarrow \gamma A'$$

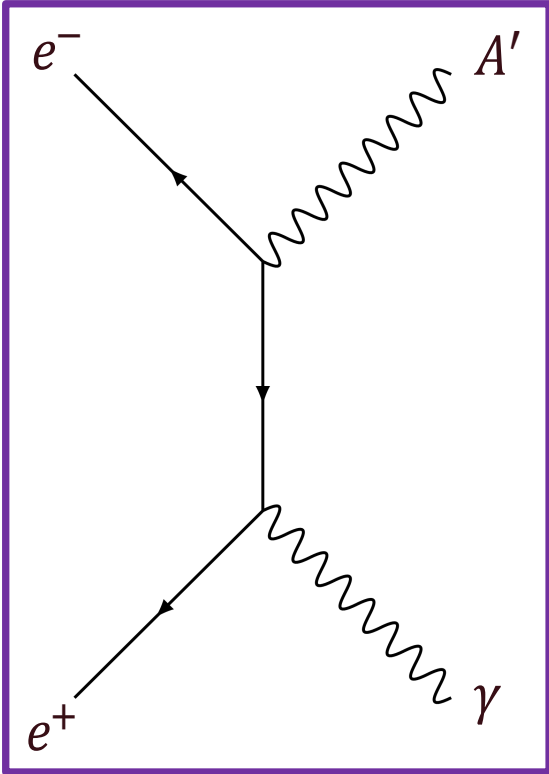
- Nominal process for PADME design



Every rose has its thorn

◦ Rose = signal ❤️ ❤️ ❤️ ❤️ ❤️

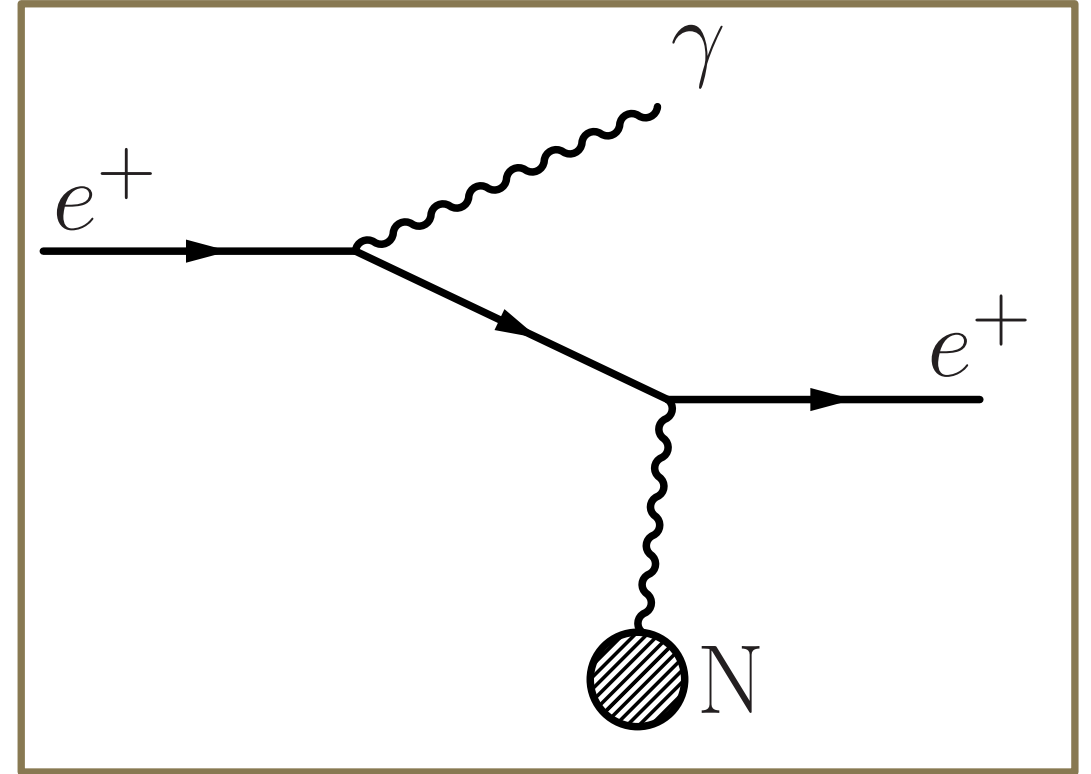
◦ $e^+e^- \rightarrow \gamma + (\text{undetectable stuff})$



- More e^+ undergo **Bremsstrahlung** than any other process
- e^+/γ not necessarily distinguishable

◦ Thorn = background 🤔 🤔 🤔 🤔 🤔

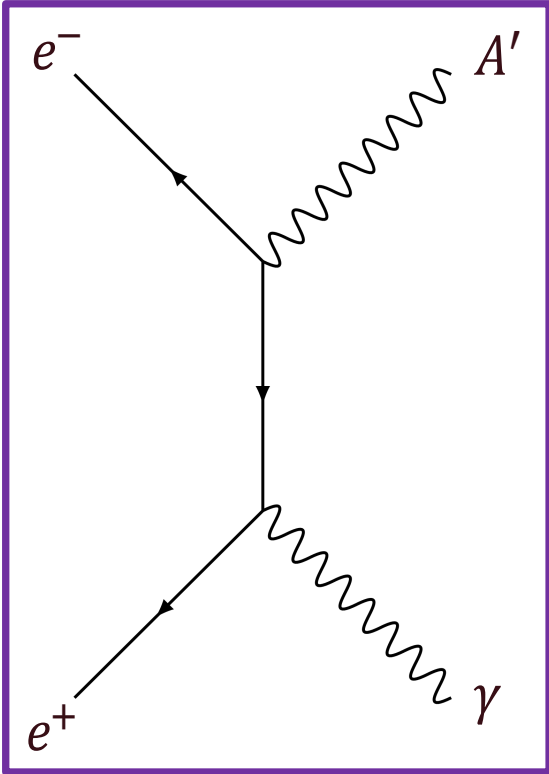
◦ $e^+ + \text{Nucleus} \rightarrow e^+ \gamma$



Every rose has its thorn

◦ Rose = signal ❤️ ❤️ ❤️ ❤️ ❤️

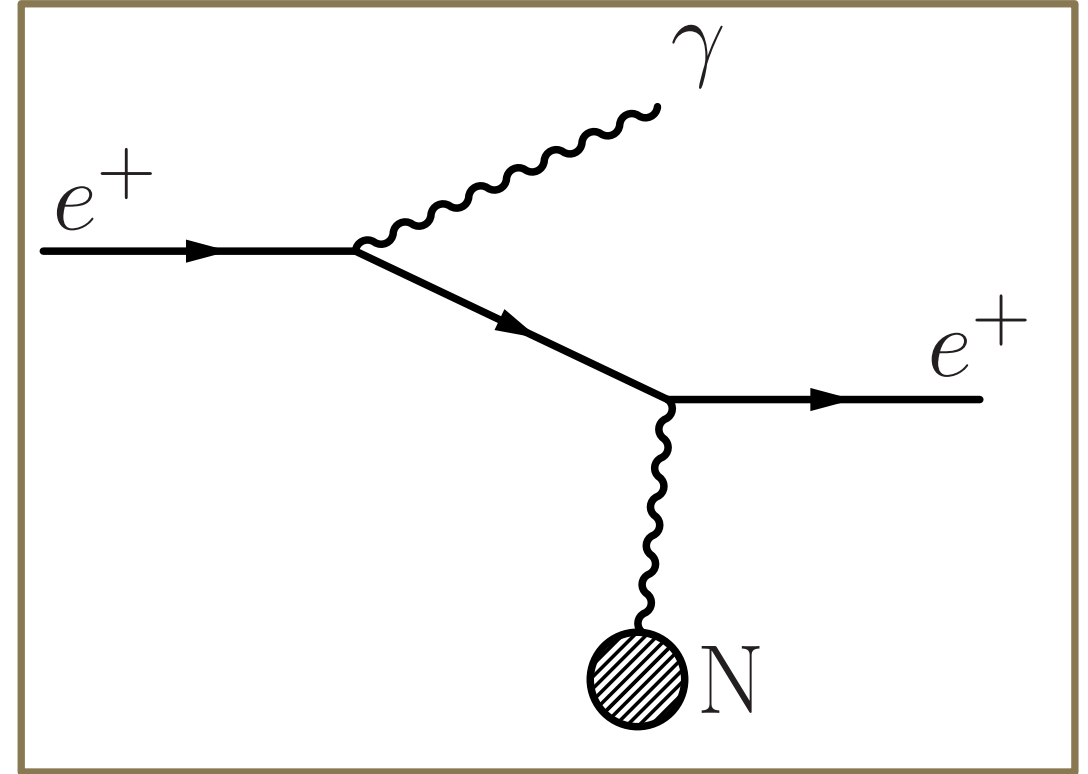
◦ $e^+e^- \rightarrow \gamma + (\text{undetectable stuff})$



- More e^+ undergo **Bremsstrahlung** than any other process
- e^+/γ not necessarily distinguishable

◦ Thorn = background 😱 😱 😱 😱 😱

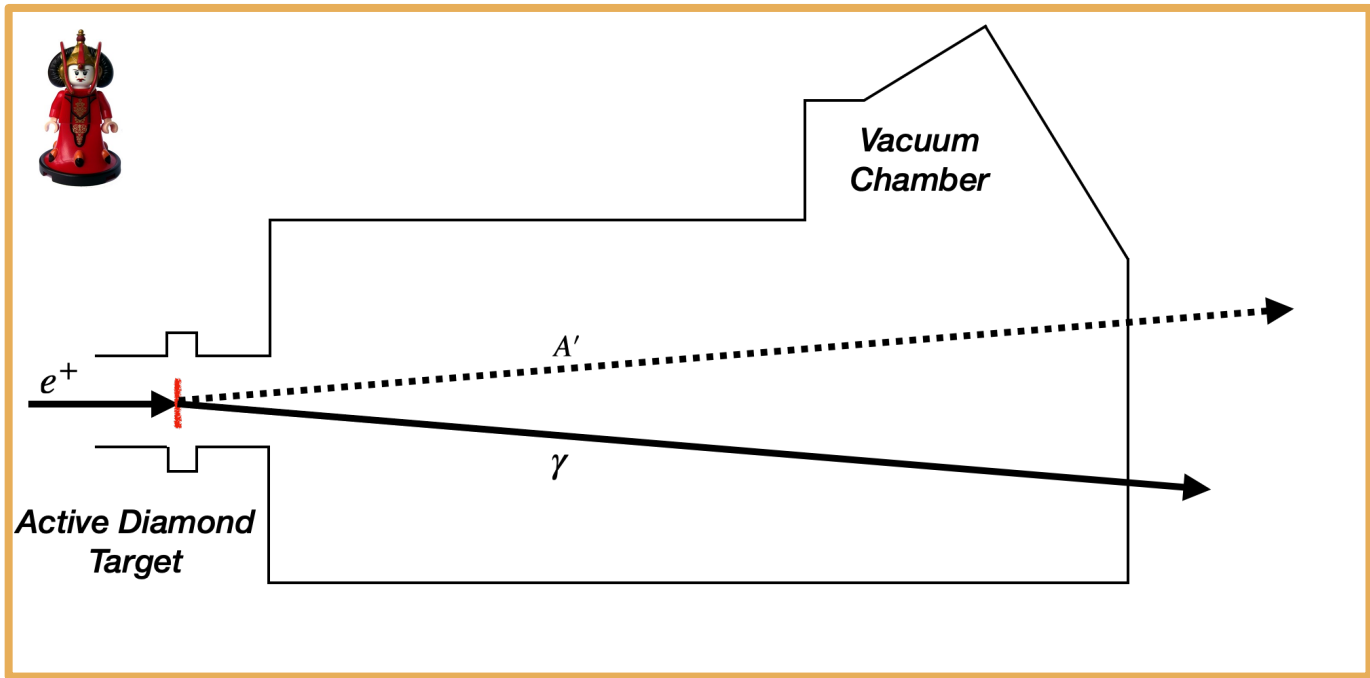
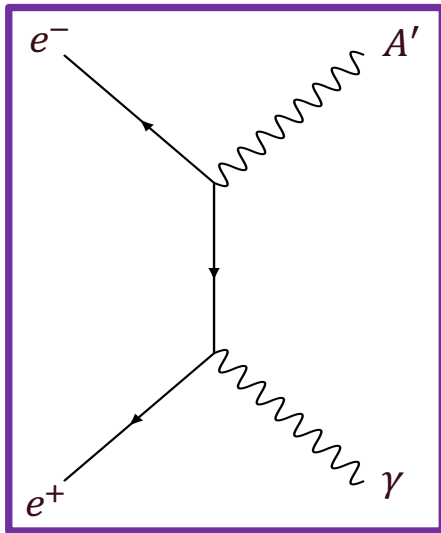
◦ $e^+ + \text{Nucleus} \rightarrow e^+ \gamma$



Luckily, this is a “reducible” background!

Designing the experiment

- Target



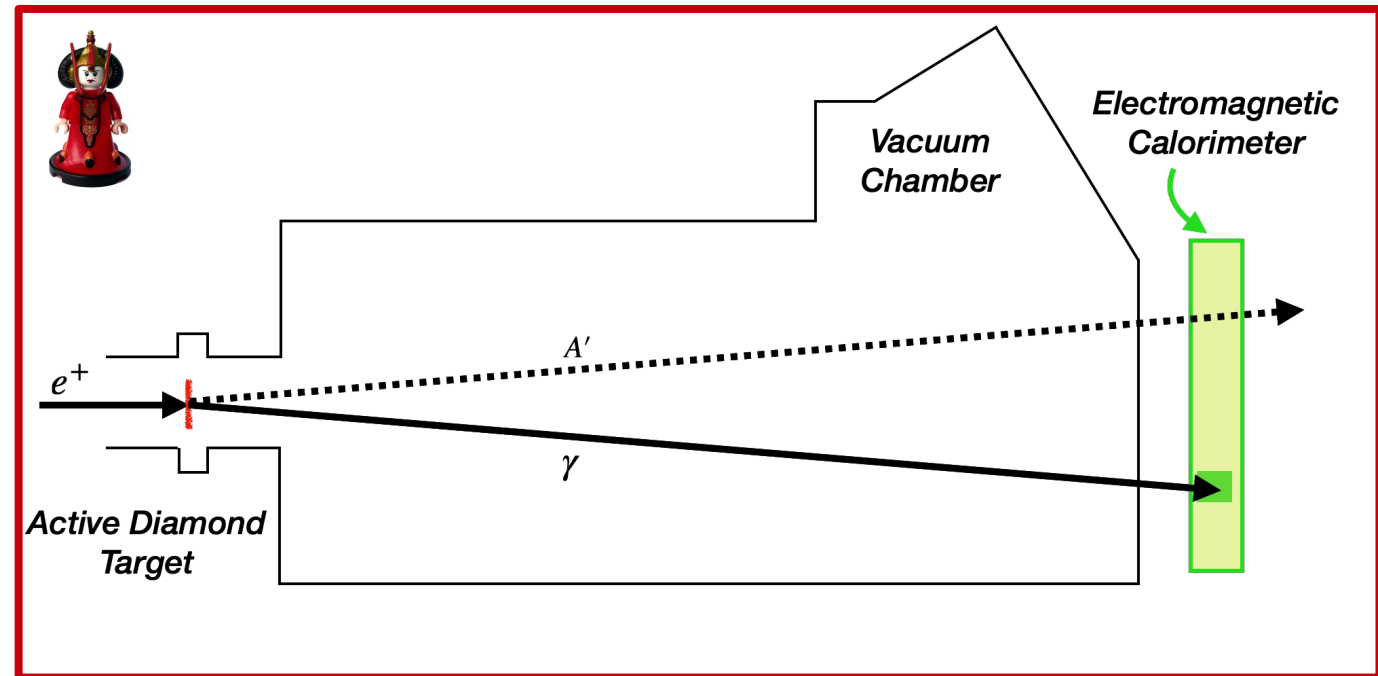
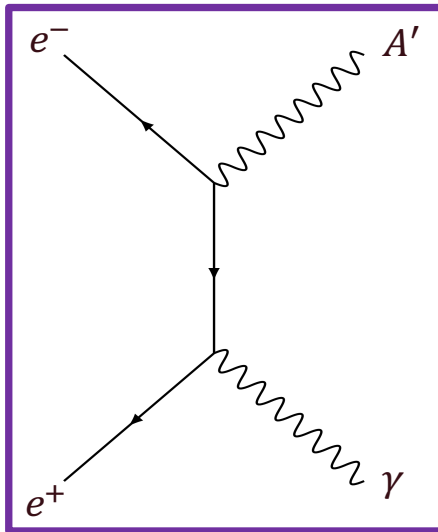
Designing the experiment

- **Target**

- **Nominal A' signal:** 1 γ & nothing else => **ECal**

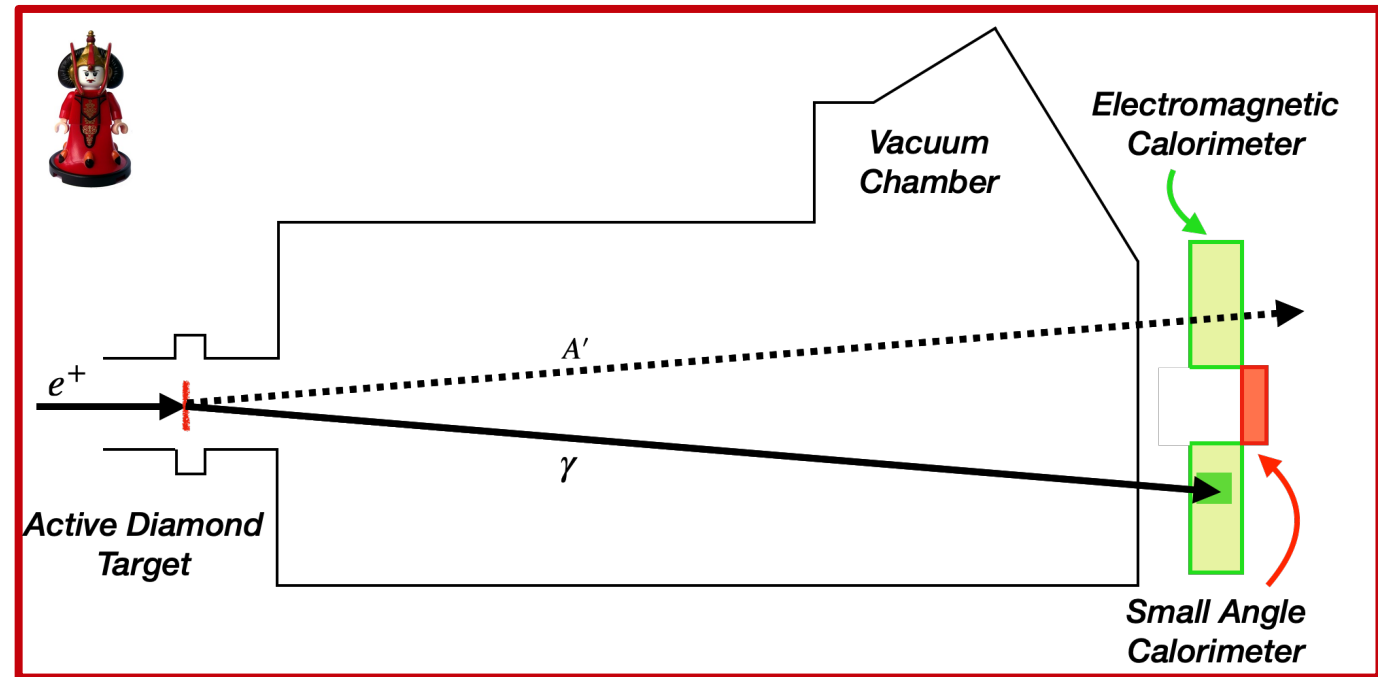
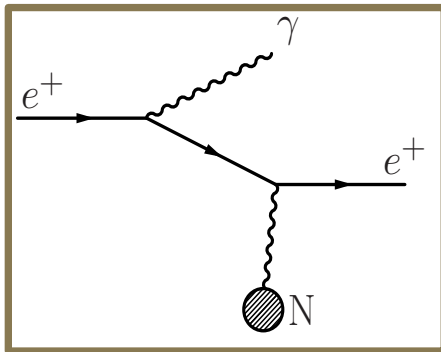
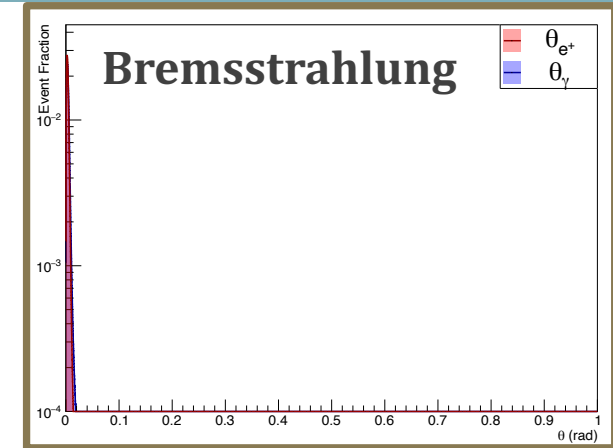
[Thanks Wiki](#)

- Electromagnetic Calorimeter (ECal): a **calorimeter** is a type of detector that measures the **energy** of **particles**. An **electromagnetic calorimeter** (ECAL) is one specifically designed to measure the energy of particles that interact primarily via the **electromagnetic interaction** such as electrons, positrons and photons.



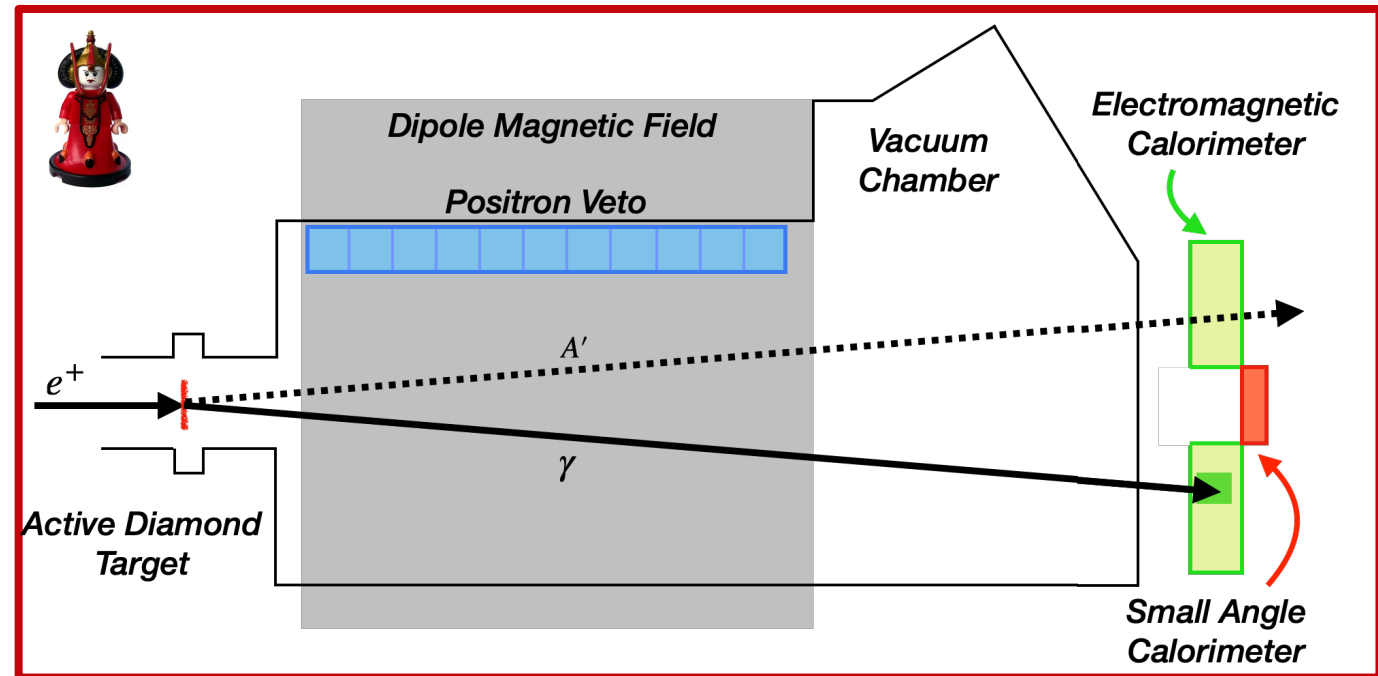
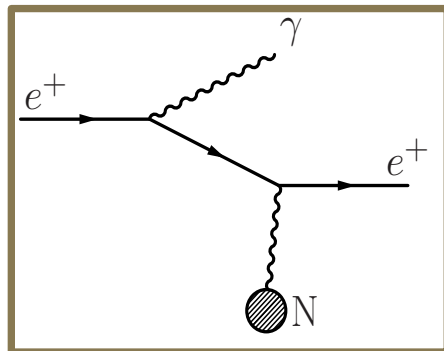
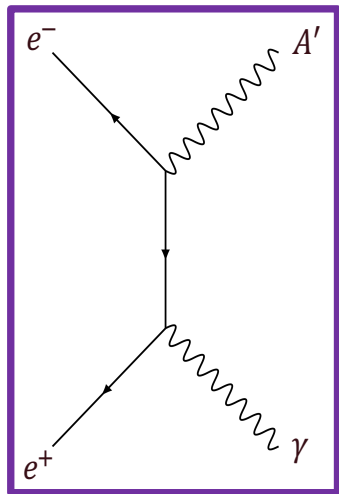
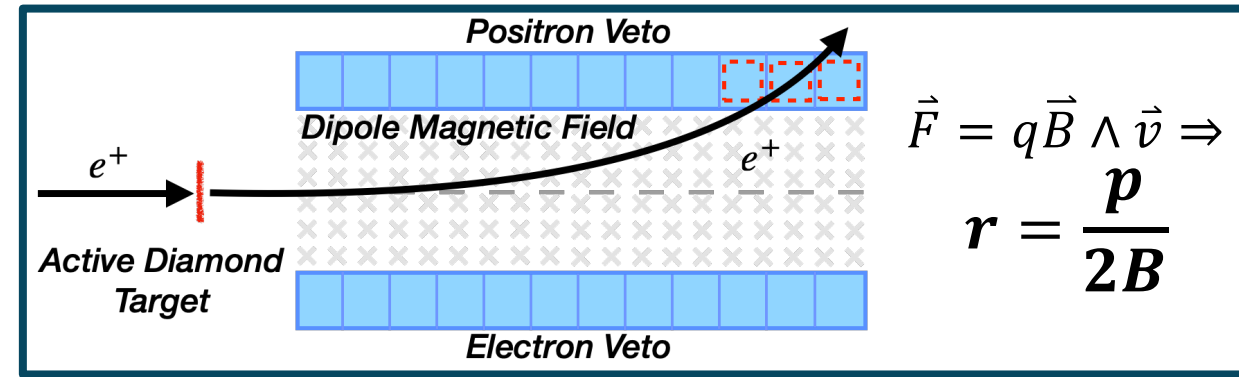
Designing the experiment

- **Target**
- **ECal** (with central hole)
- **Small Angle (electromagnetic) Calorimeter (SAC)**



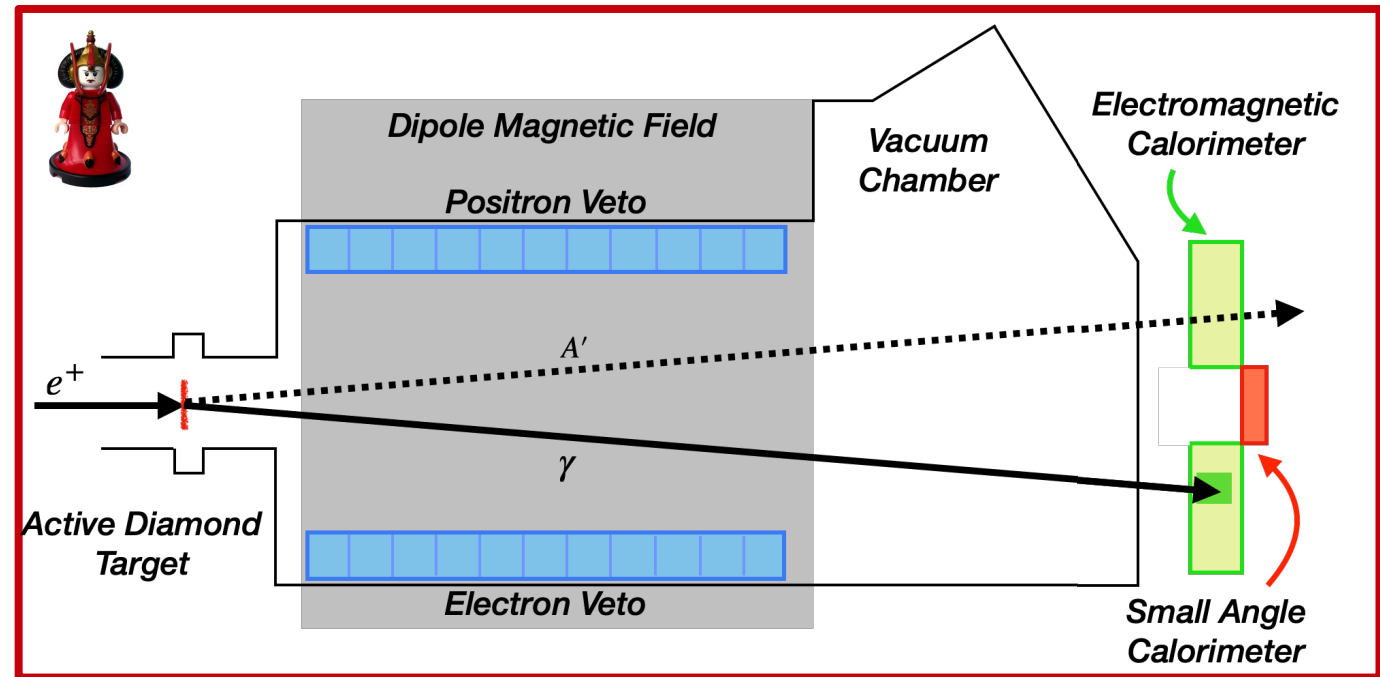
Designing the experiment

- **Target**
- **ECal** (with central hole)
- **Small Angle (electromagnetic) Calorimeter (SAC)**
- Dipole Magnetic Field (0.4 T)
- **Positron Veto (PVeto)**



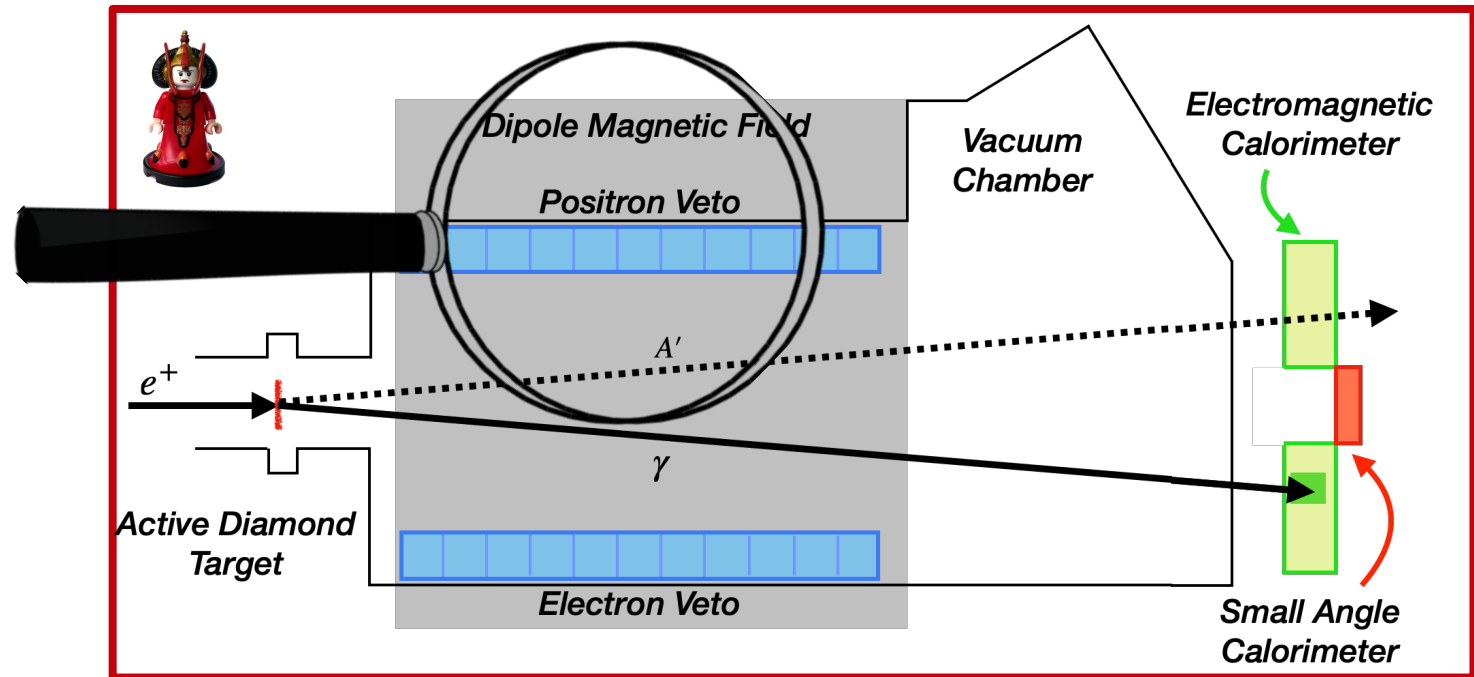
Designing the experiment

- **Target**
- **ECal** (with central hole)
- **Small Angle (electromagnetic) Calorimeter (SAC)**
- Dipole Magnetic Field (0.4 T)
- **Positron Veto (PVeto)**
- For fun, **Electron Veto (EVeto)**



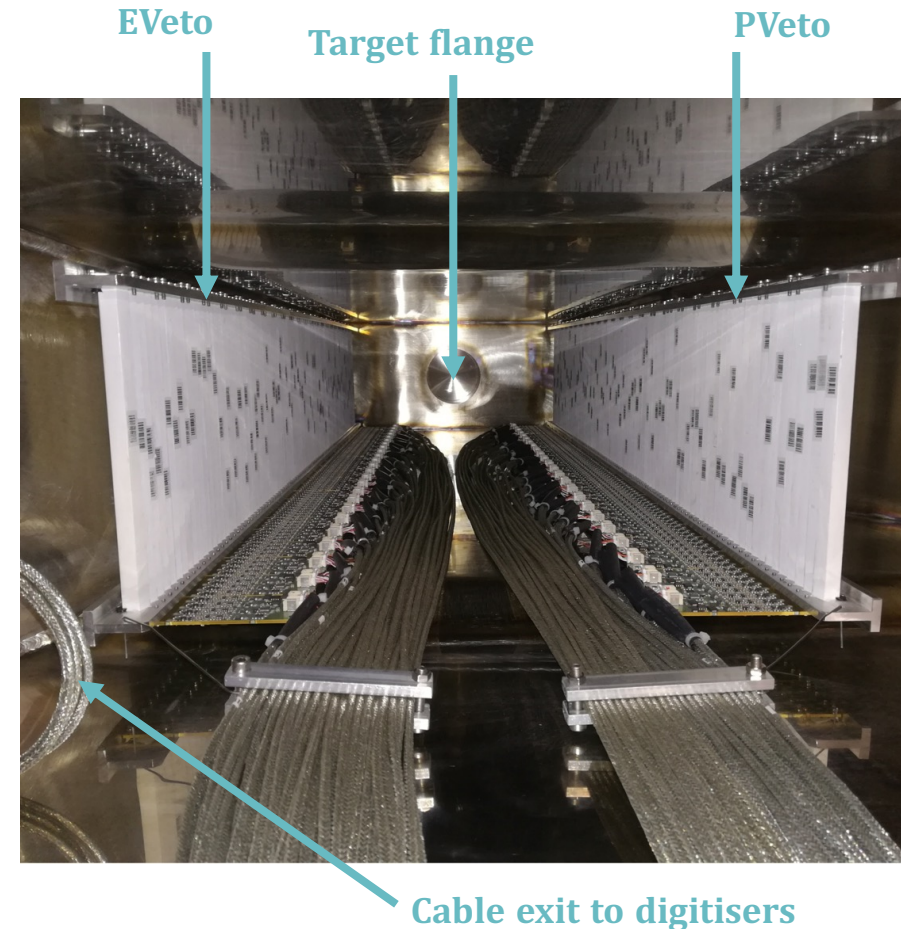
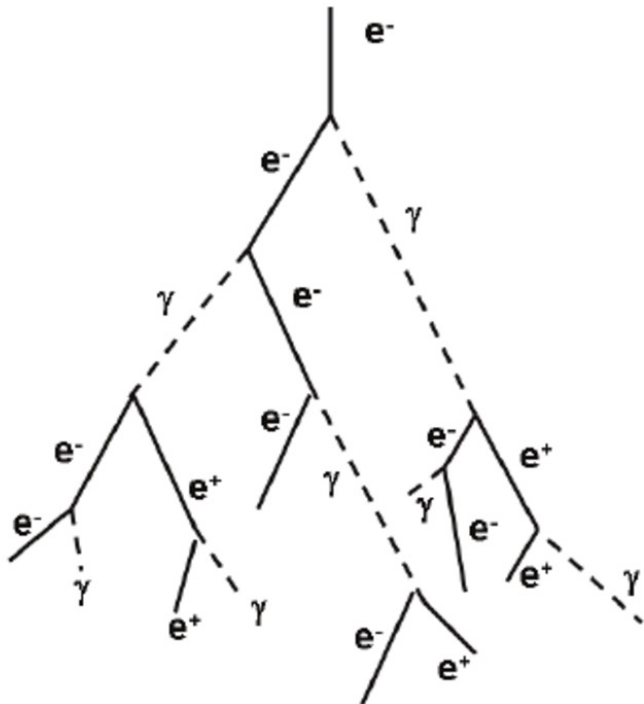
Designing the experiment

- **Target**
- **ECal** (with central hole)
- **Small Angle (electromagnetic) Calorimeter (SAC)**
- Dipole Magnetic Field (0.4 T)
- **Positron Veto (PVeto)**
- For fun, **Electron Veto (EVeto)**



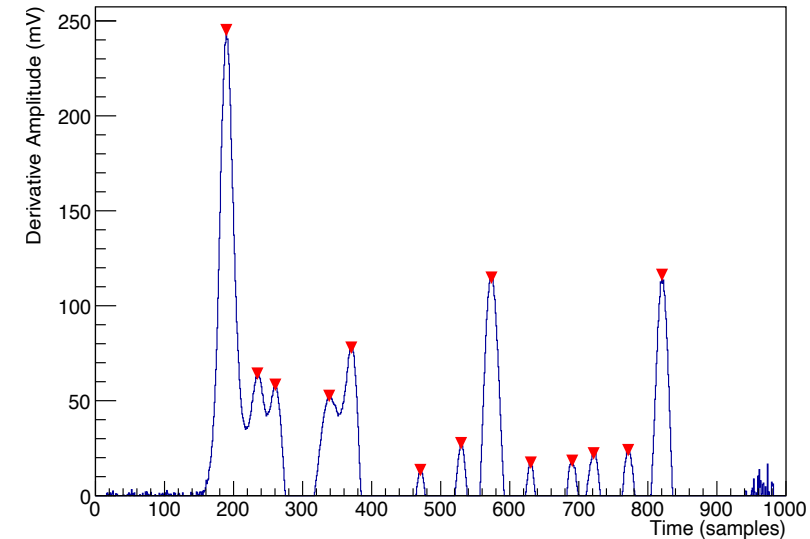
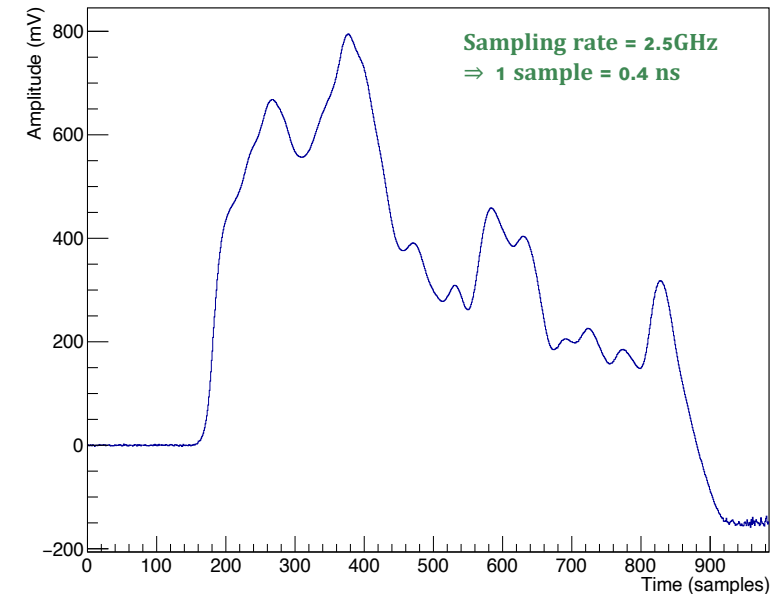
Designing the detector

- Plastic scintillator bars
 - Particle enters, causes electromagnetic shower
 - Photons from shower captured by photomultiplier tube
 - Photomultiplier tube produces electrical pulse, passed to a digitizer and saved



The digitised signal

- Worst case scenario on the right
- Identifying peaks even by eye is tricky!
 - Perform “derivative”:
 - $SignalDerivative[s] = Signal[s] - Signal[s - 15]$
 - Fit the derivative recursively, looking for gaussian peaks
 - Define **time** as centre of gaussian fit
 - Define **energy** as amplitude of peak after subtracting tails of previous peaks
 - Was it a positron, a photon or just noise?
- Now you have:
 - **Time** of particle
 - **Particle ID** (from energy in detector)
 - Position of impact -> energy
- Job done!! Your positrons are ready to use!



Conclusions

- When you're building your particle physics experiment ask yourself:
 - What's my signal?
 - What's my background?
- Once you've built your detector ask yourself:
 - What are the physical quantities I care about?
 - How do I get access to them?

