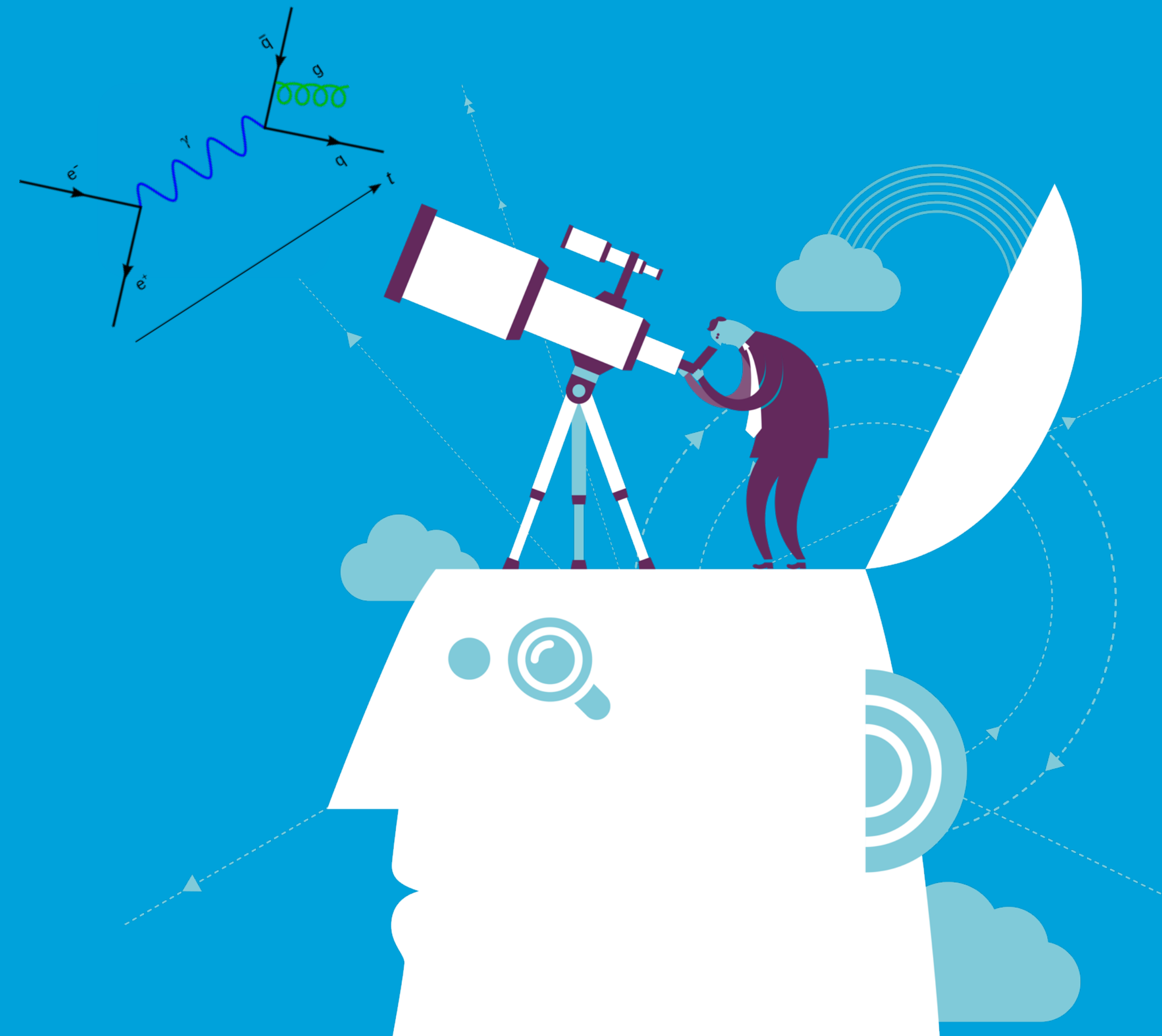


# “From the basics to the bleeding edge”

Searching for extremely rare decays in LHCb

Jacco de Vries

*GWFP symposium, 2 Dec 2025*



# Where do I lose you?

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$



$z(2, 2)$

$z(4)$

$z(1, 1, 2)$



[https://docs.google.com/forms/d/e/1FAIpQLSeFj6fLr9a4E3-ljpCrHKzu\\_xrKbnJgJOrC0xfikwwsVS6XA/viewform?usp=publish-editor](https://docs.google.com/forms/d/e/1FAIpQLSeFj6fLr9a4E3-ljpCrHKzu_xrKbnJgJOrC0xfikwwsVS6XA/viewform?usp=publish-editor)

# What is particle physics?

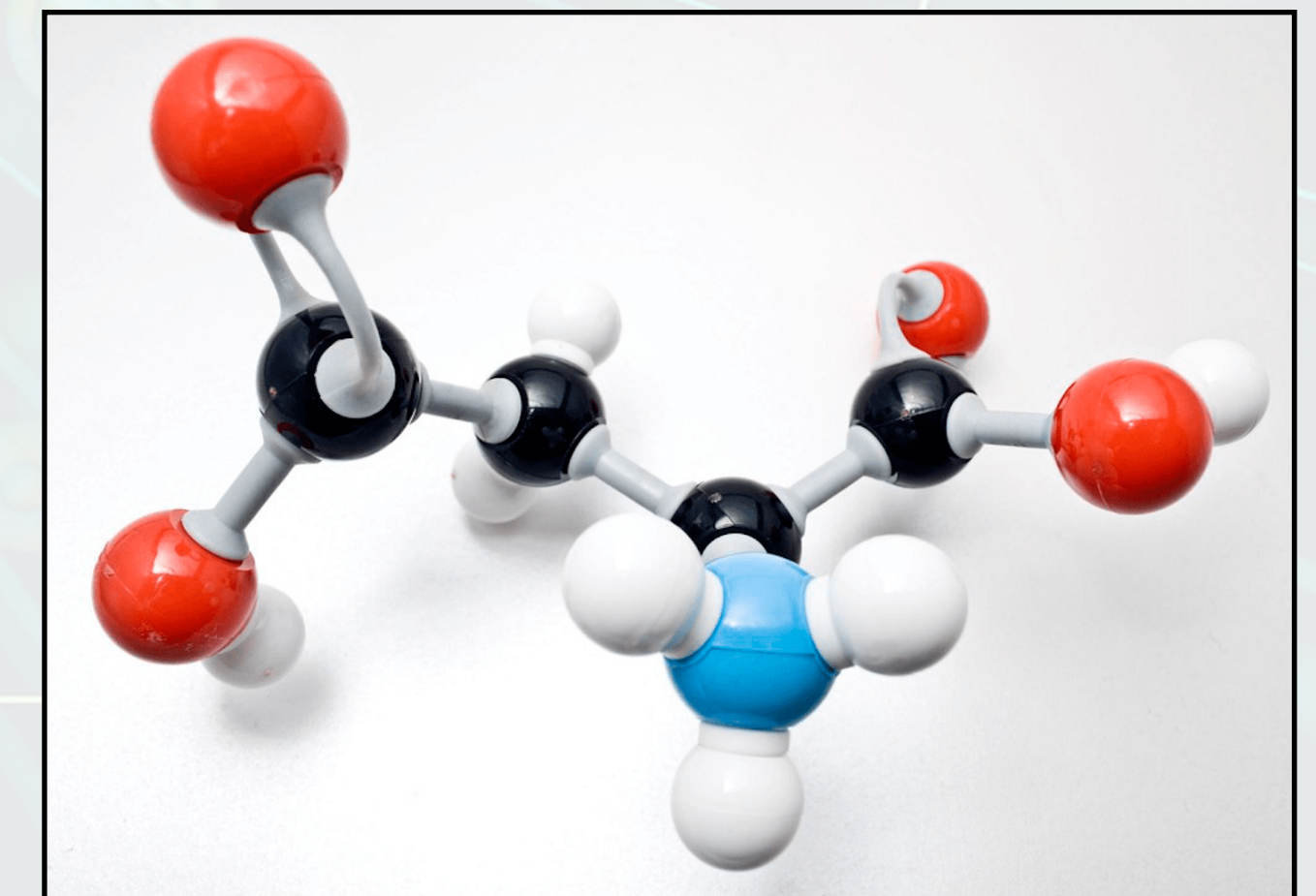
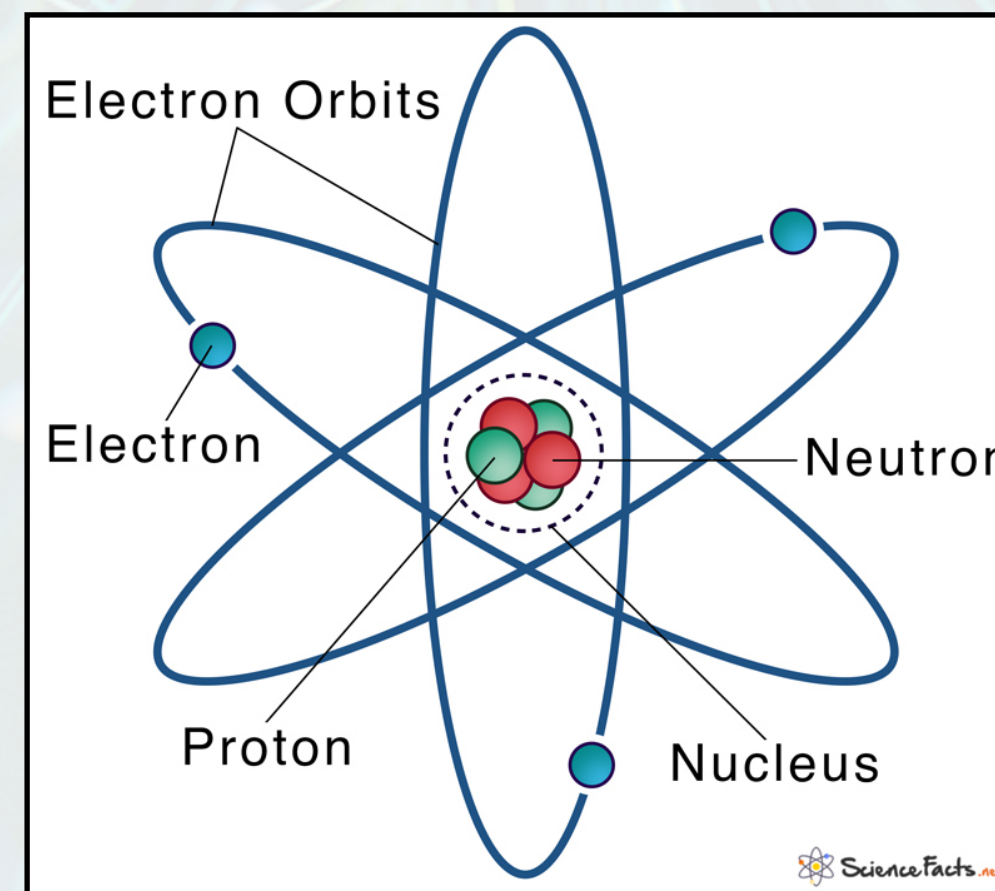
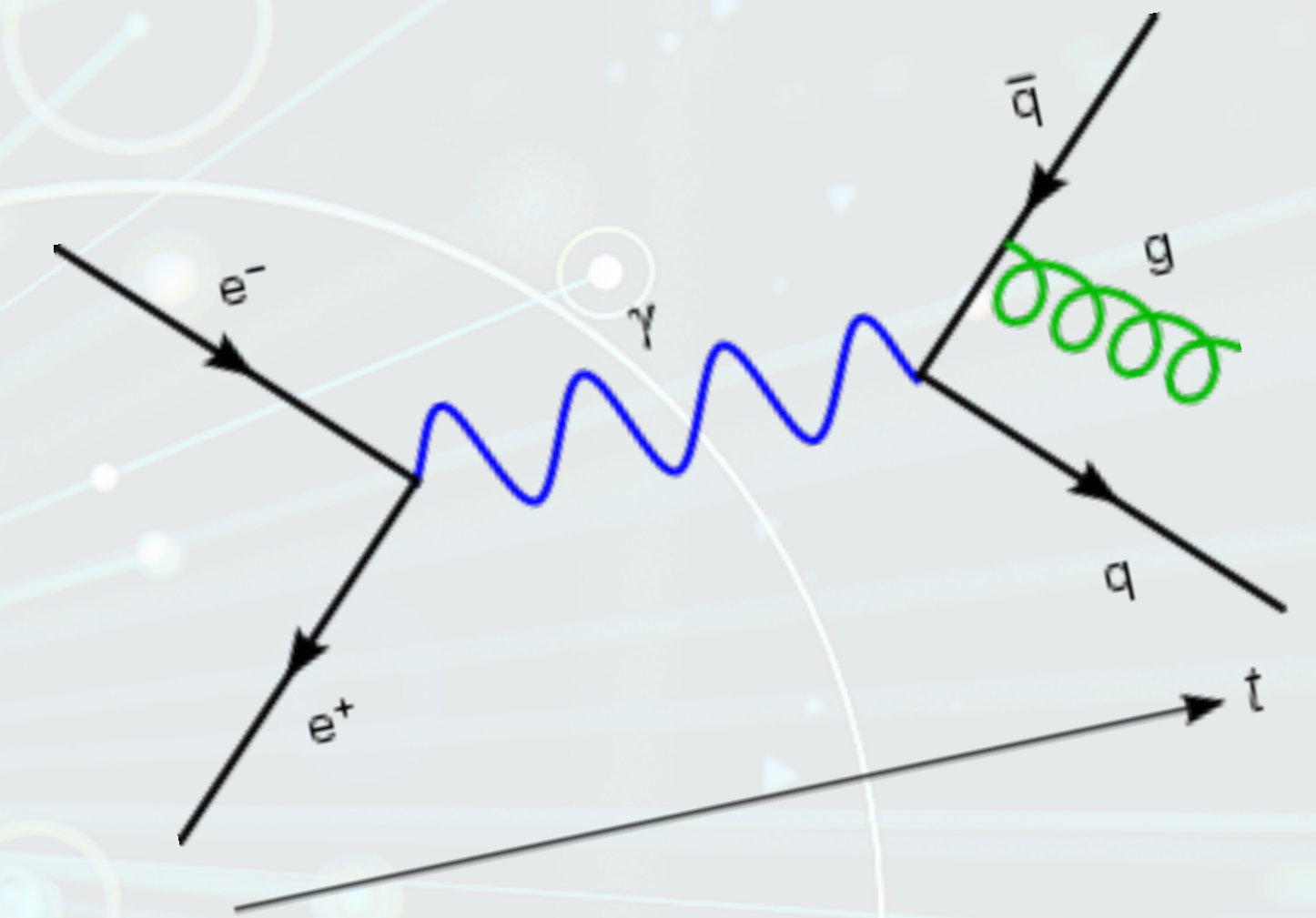
(aka 'High-Energy Physics')

The study of fundamentals of matter and their interactions

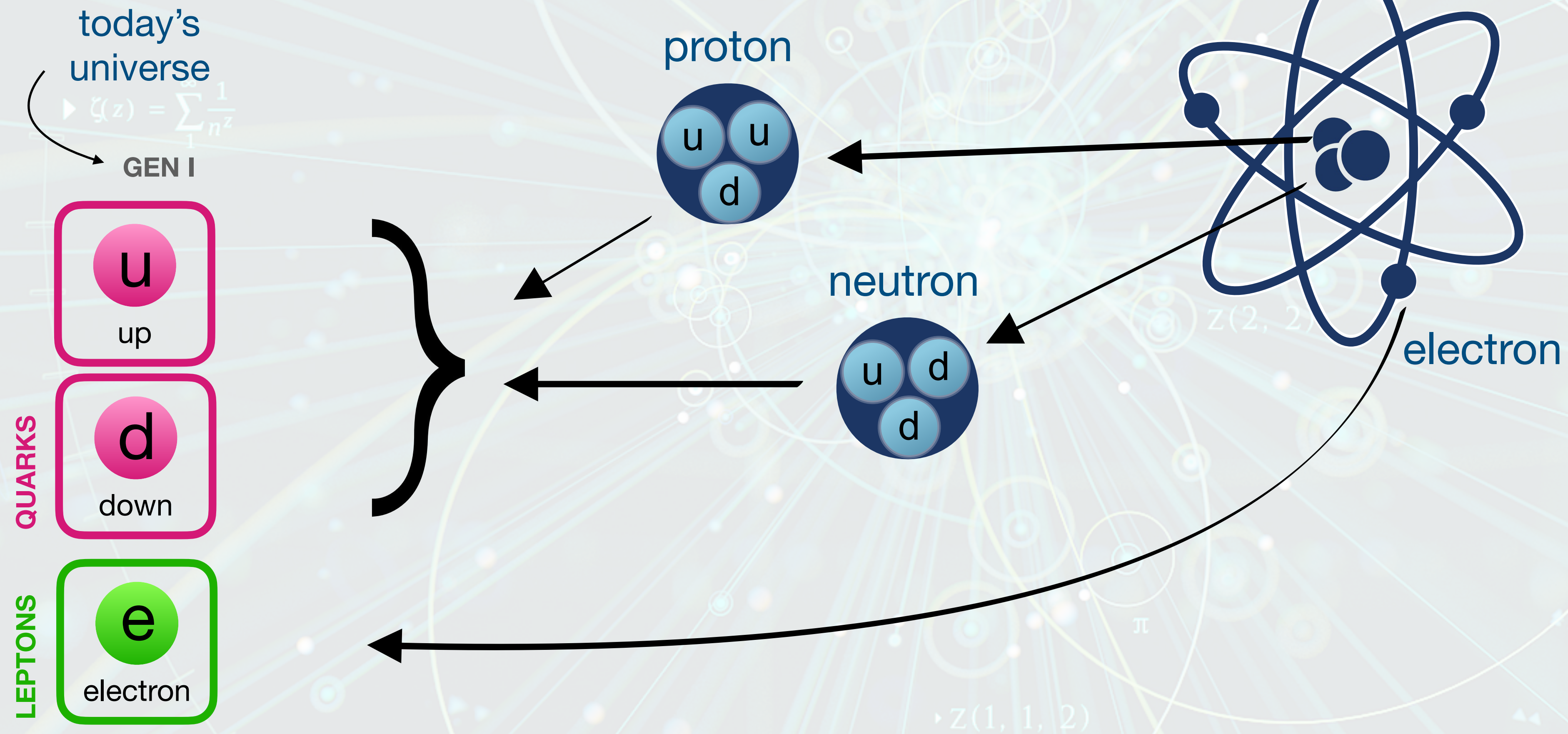
- protons, neutrons, electrons, ...
- electromagnetism, weak force, strong force
- 'radiation'

Atoms → Nuclear physics

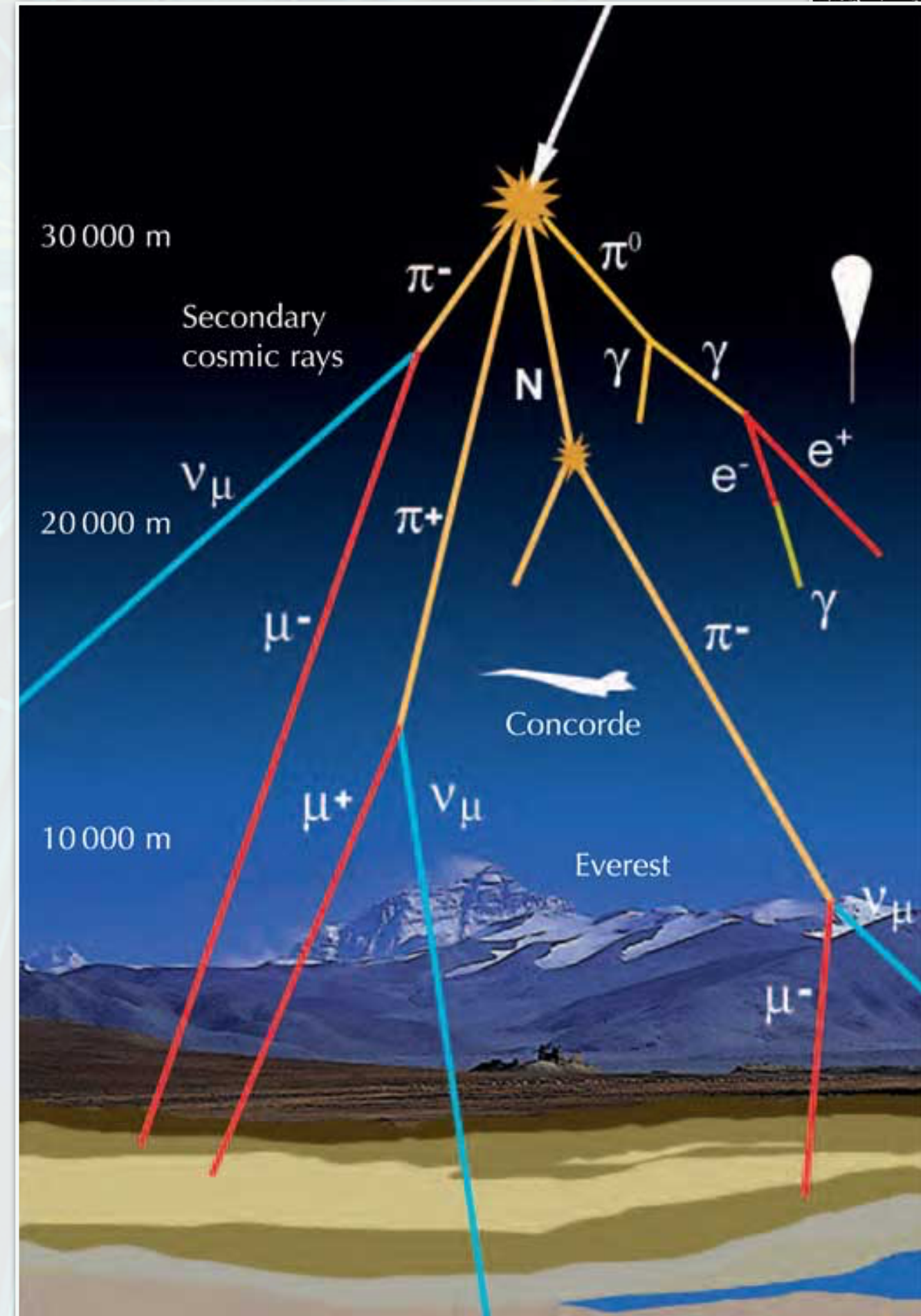
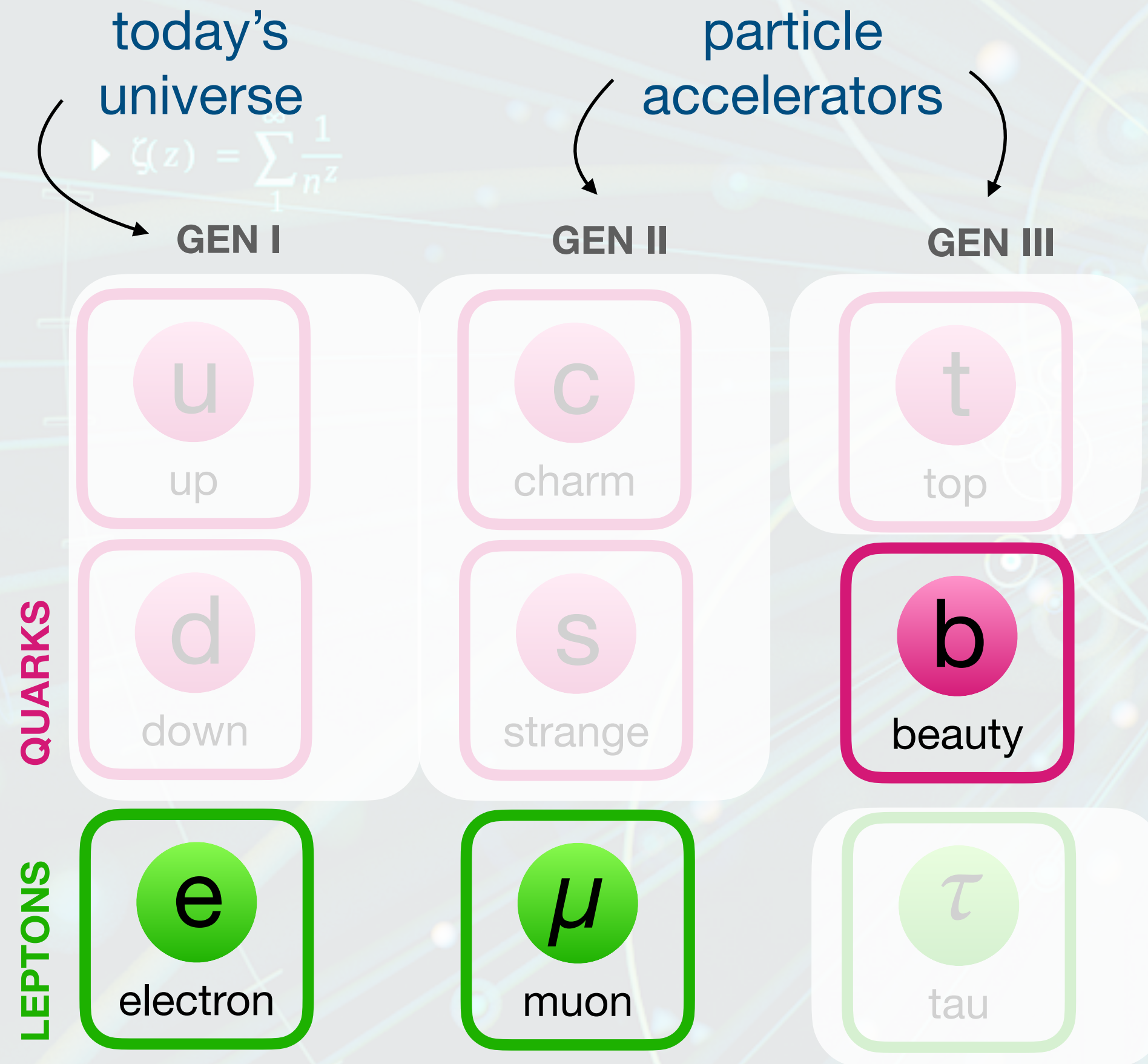
Molecules → Chemistry



# The structure of matter



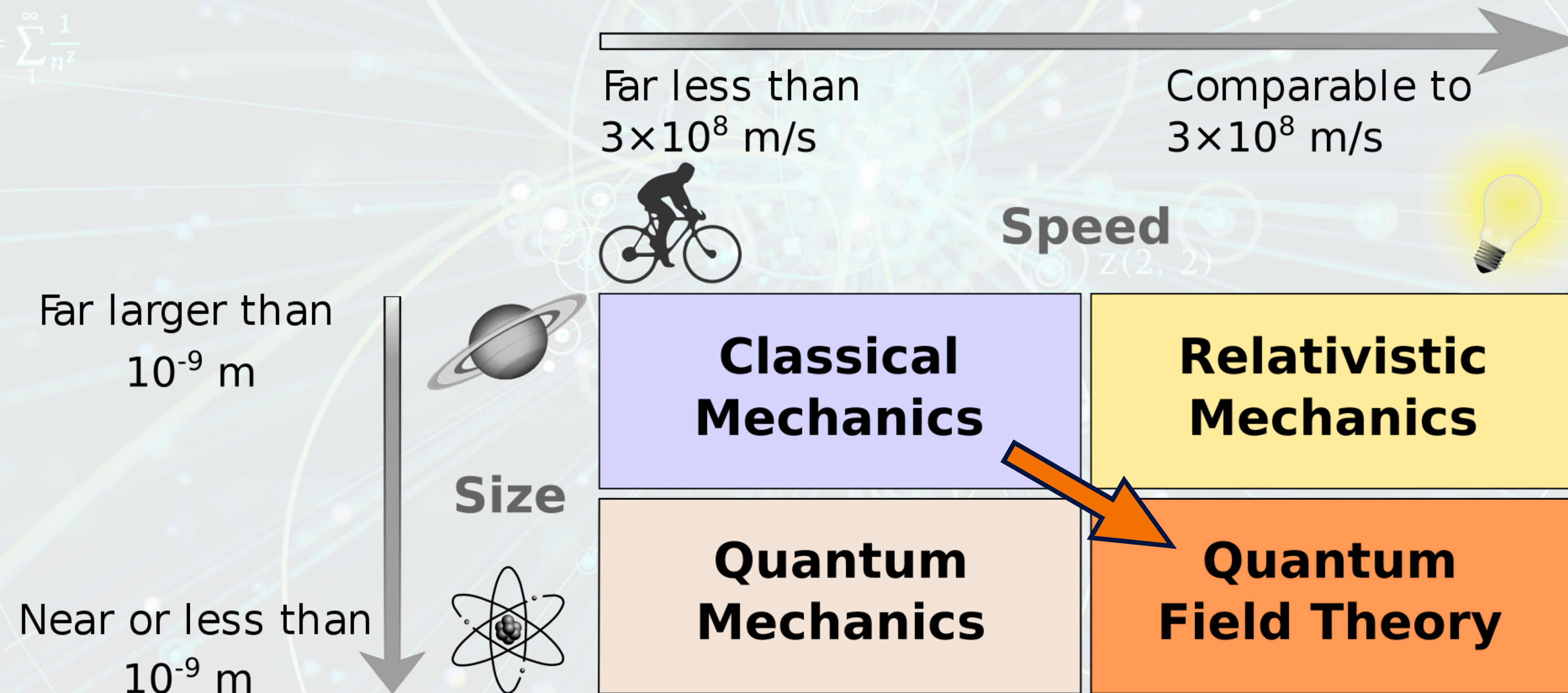
# The structure of high-energy matter



Many 'Flavours' of quarks & leptons!

# Quantum Field Theory

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$



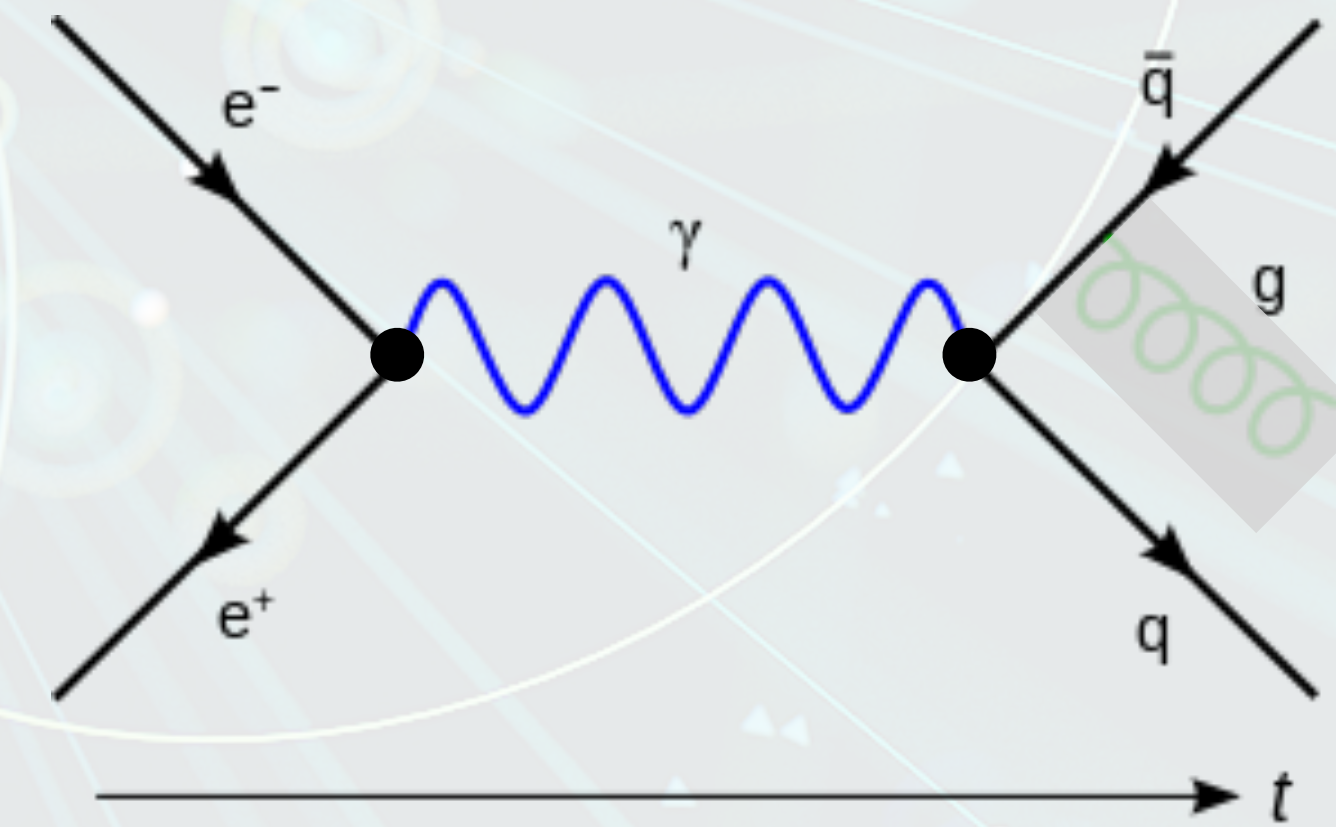
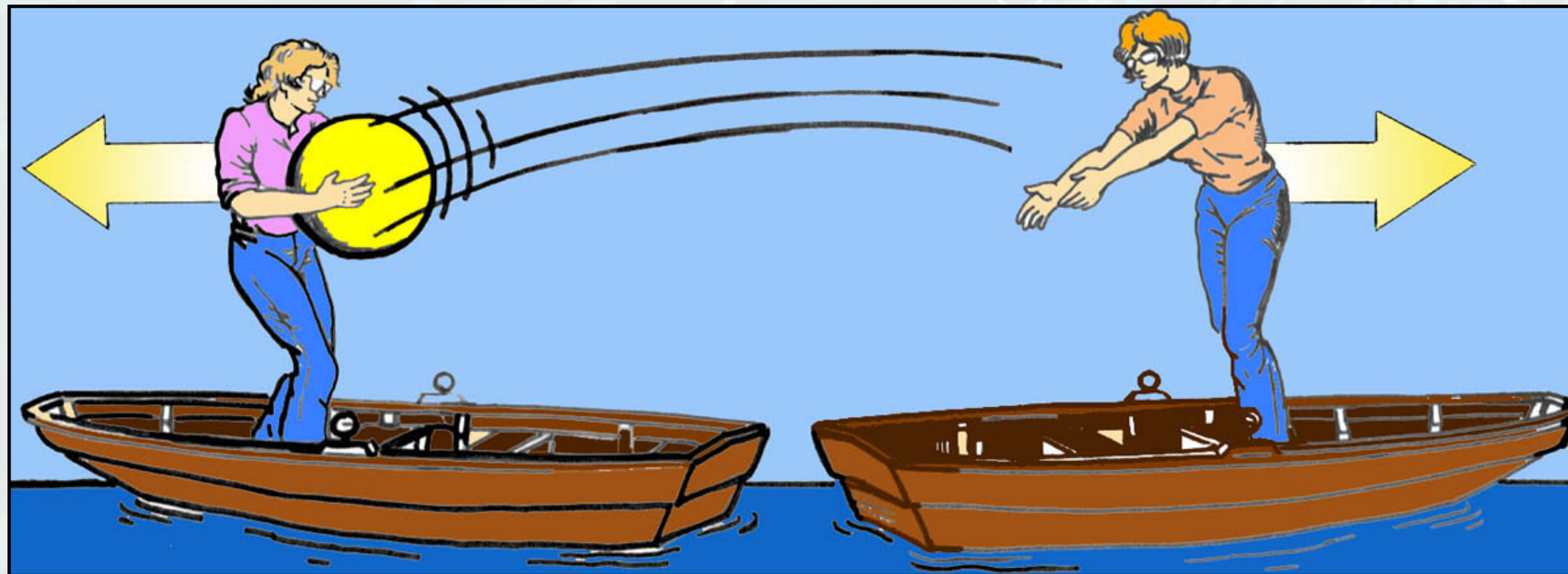
# Quantum Field Theory

- 'First quantisation': particles are *waves*, ( $p \rightarrow -i\hbar d/dx$ )
- 'Second quantisation': particle waves are *excitations* of their fields  
→ create / destroy particles in line with  $E=mc^2$



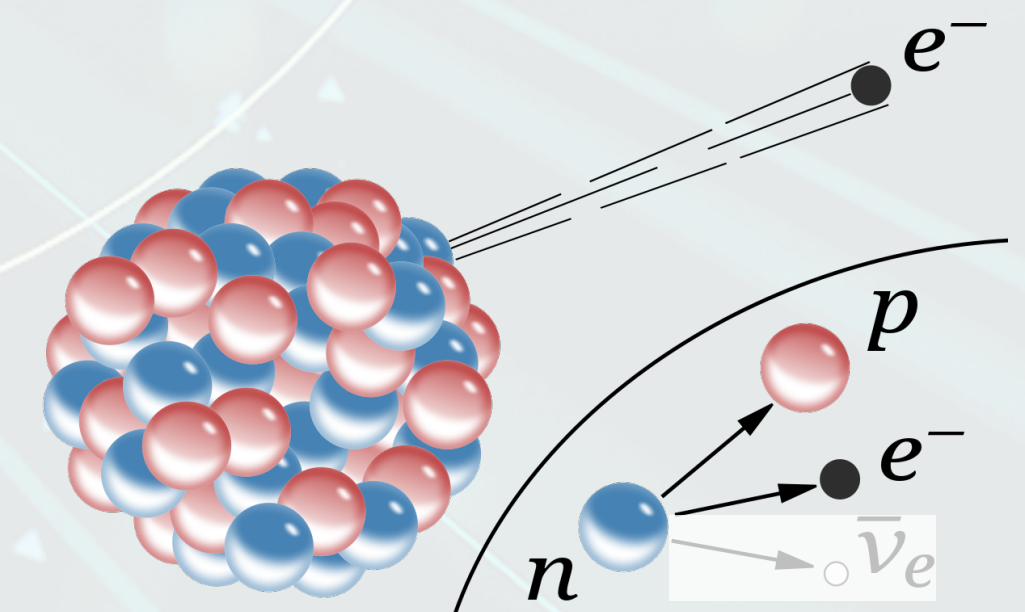
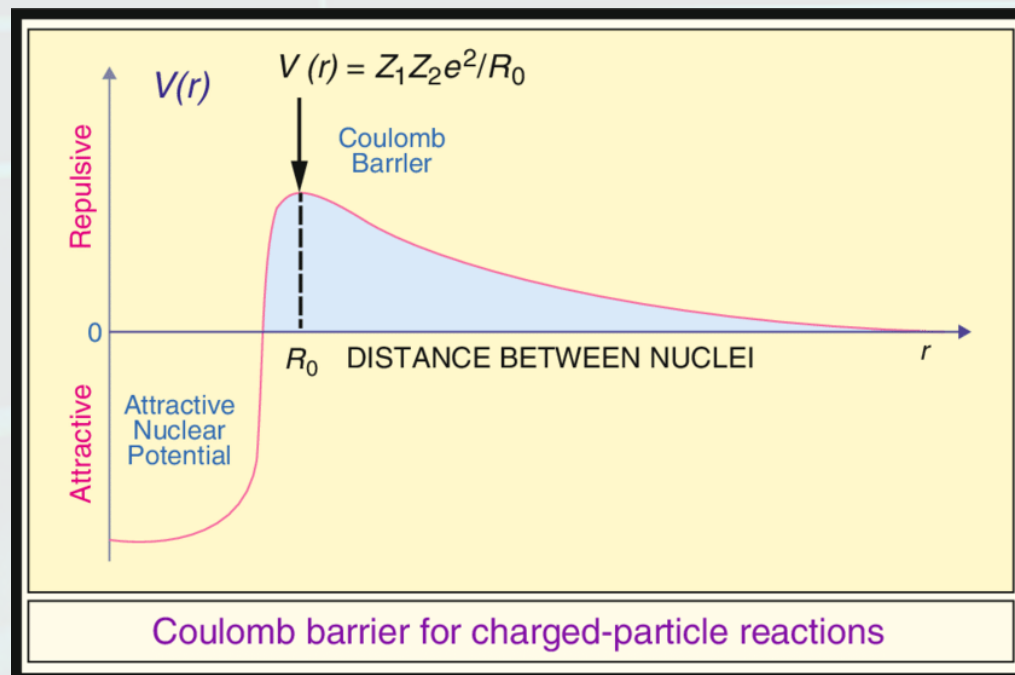
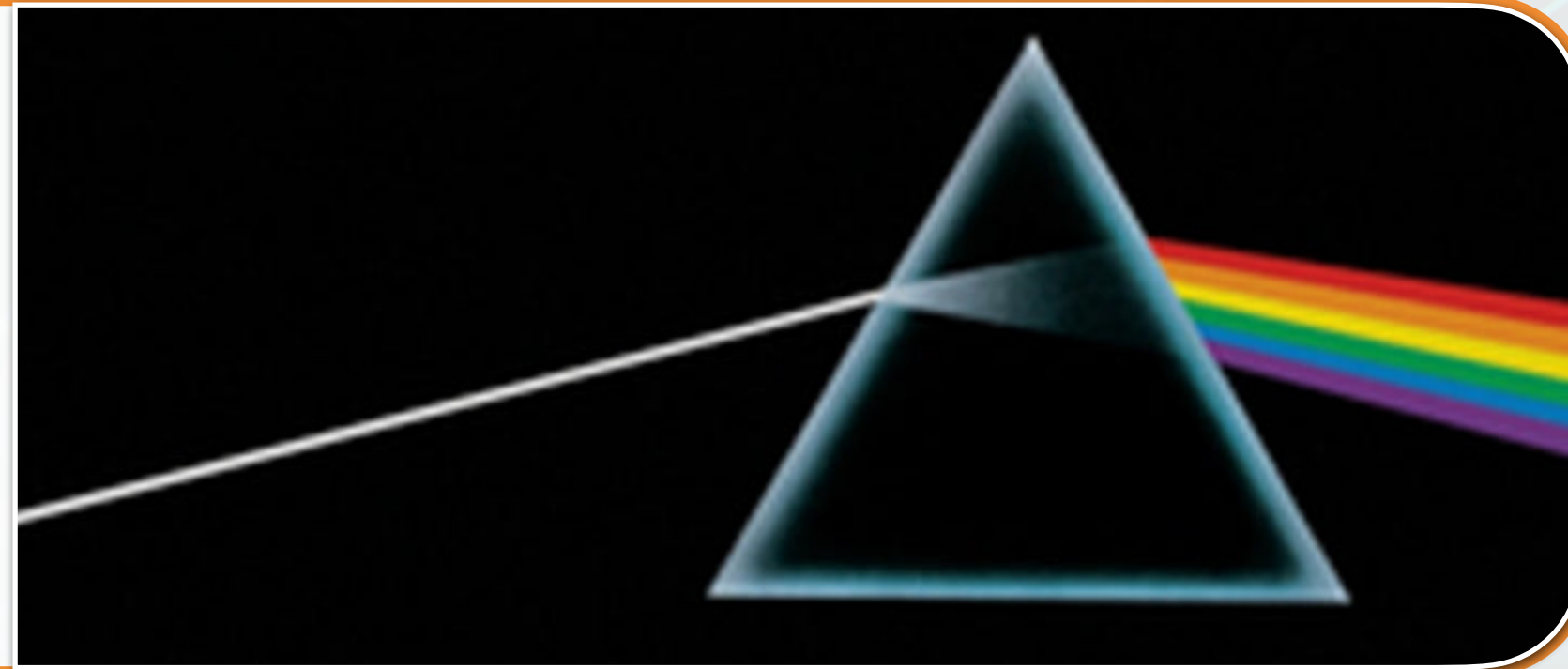
# Quantum Field Theory

- 'First quantisation': particles are *waves*, ( $p \rightarrow -i\hbar d/dx$ )
- 'Second quantisation': particle waves are *excitations* of their fields  
→ create / destroy particles in line with  $E=mc^2$
- 'Force' = exchange of *virtual* force particles ('gauge bosons')



# Forces

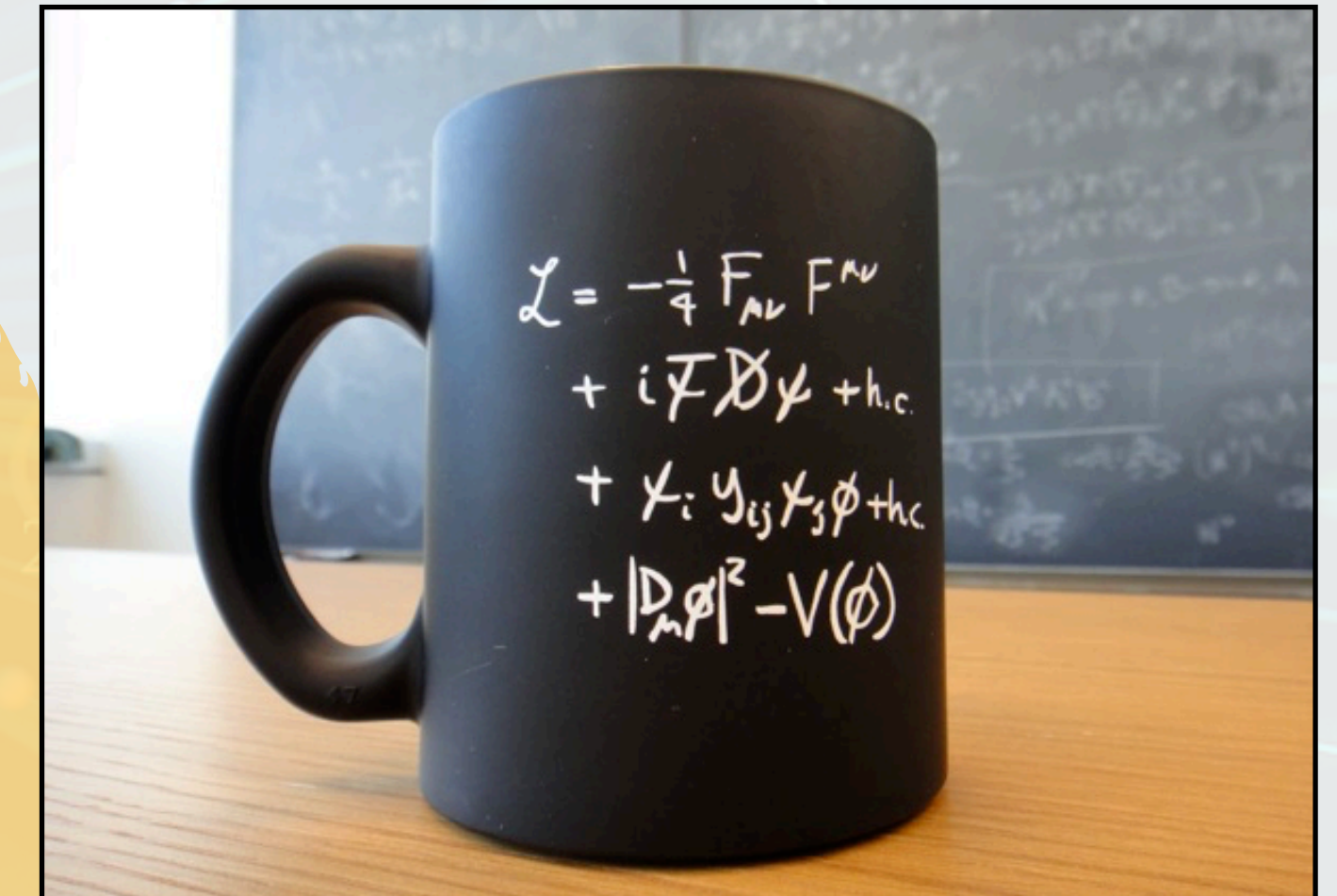
$$\Phi(z) = \sum_{n=1}^{\infty} \frac{1}{n^2}$$



# The standard model fields

## The Standard Model

	gen I	gen II	gen III		
mass →	≈2.3 MeV/c <sup>2</sup>	≈1.275 GeV/c <sup>2</sup>	≈173.07 GeV/c <sup>2</sup>	0	≈126 GeV/c <sup>2</sup>
charge →	2/3	2/3	2/3	0	0
spin →	1/2	1/2	1/2	1	0
	<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> Higgs boson
	≈4.8 MeV/c <sup>2</sup>	≈95 MeV/c <sup>2</sup>	≈4.18 GeV/c <sup>2</sup>	0	
	-1/3	-1/3	-1/3	0	
	1/2	1/2	1/2	1	
<b>QUARKS</b>	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b>γ</b> photon	
	0.511 MeV/c <sup>2</sup>	105.7 MeV/c <sup>2</sup>	1.777 GeV/c <sup>2</sup>	91.2 GeV/c <sup>2</sup>	
	-1	-1	-1	0	
	1/2	1/2	1/2	1	
	<b>e</b> electron	<b>μ</b> muon	<b>τ</b> tau	<b>Z</b> Z boson	
<b>LEPTONS</b>	<2.2 eV/c <sup>2</sup>	<0.17 MeV/c <sup>2</sup>	<15.5 MeV/c <sup>2</sup>	80.4 GeV/c <sup>2</sup>	
	0	0	0	±1	
	1/2	1/2	1/2	1	
	<b>ν<sub>e</sub></b> electron neutrino	<b>ν<sub>μ</sub></b> muon neutrino	<b>ν<sub>τ</sub></b> tau neutrino	<b>W</b> W boson	
				<b>GAUGE BOSONS</b>	



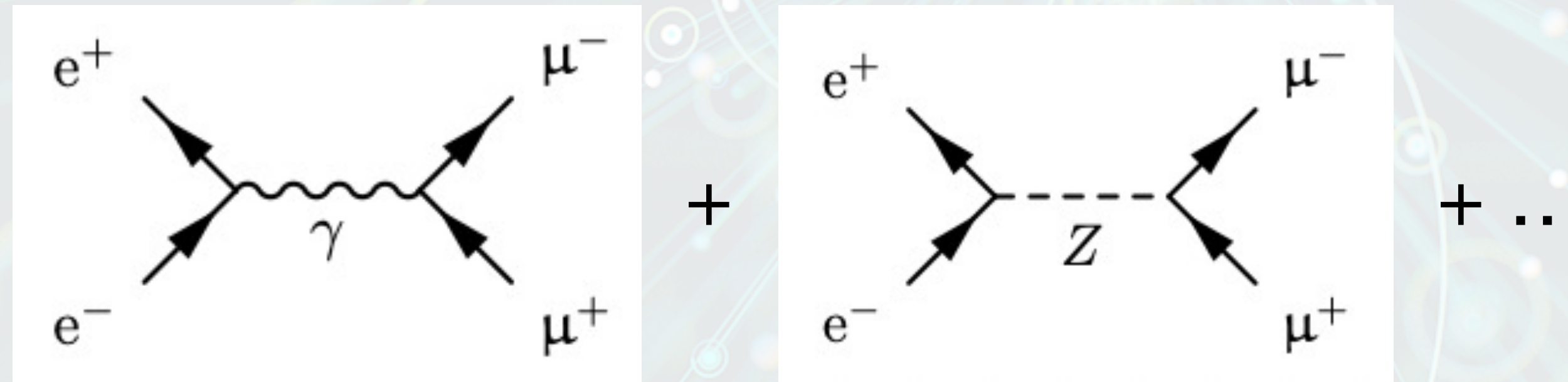
- ~ x2 (matter-antimatter)
- ~ x2 (left- and right-handed)
- ~ x3 (red, green, blue)

# 'The laws of physics'

- 'Laws of physics' = Lego box of Feynman vertices
  - 'lines' are particles / forces
  - 'vertices' are allowed interactions
- Any diagram you can build *will happen*.



$$P(ee \rightarrow \mu\mu) =$$



2

$$\begin{aligned} \frac{d\sigma}{d\Omega} [\gamma, \gamma] &= \frac{\alpha^2}{4s} (1 + \cos^2 \theta) \\ \frac{d\sigma}{d\Omega} [Z, Z] &= \frac{\alpha^2}{4s} |r|^2 \left[ (C_V^e)^2 + (C_A^e)^2 \right] \left[ (C_V^f)^2 + (C_A^f)^2 \right] (1 + \cos^2 \theta) + 8C_V^e C_V^f C_A^e C_A^f \cos \theta \\ \frac{d\sigma}{d\Omega} [\gamma, Z] &= \frac{\alpha^2}{4s} \text{Re}|r| \left[ C_V^e C_V^f (1 + \cos^2 \theta) + 2C_A^e C_A^f \cos \theta \right] \end{aligned}$$

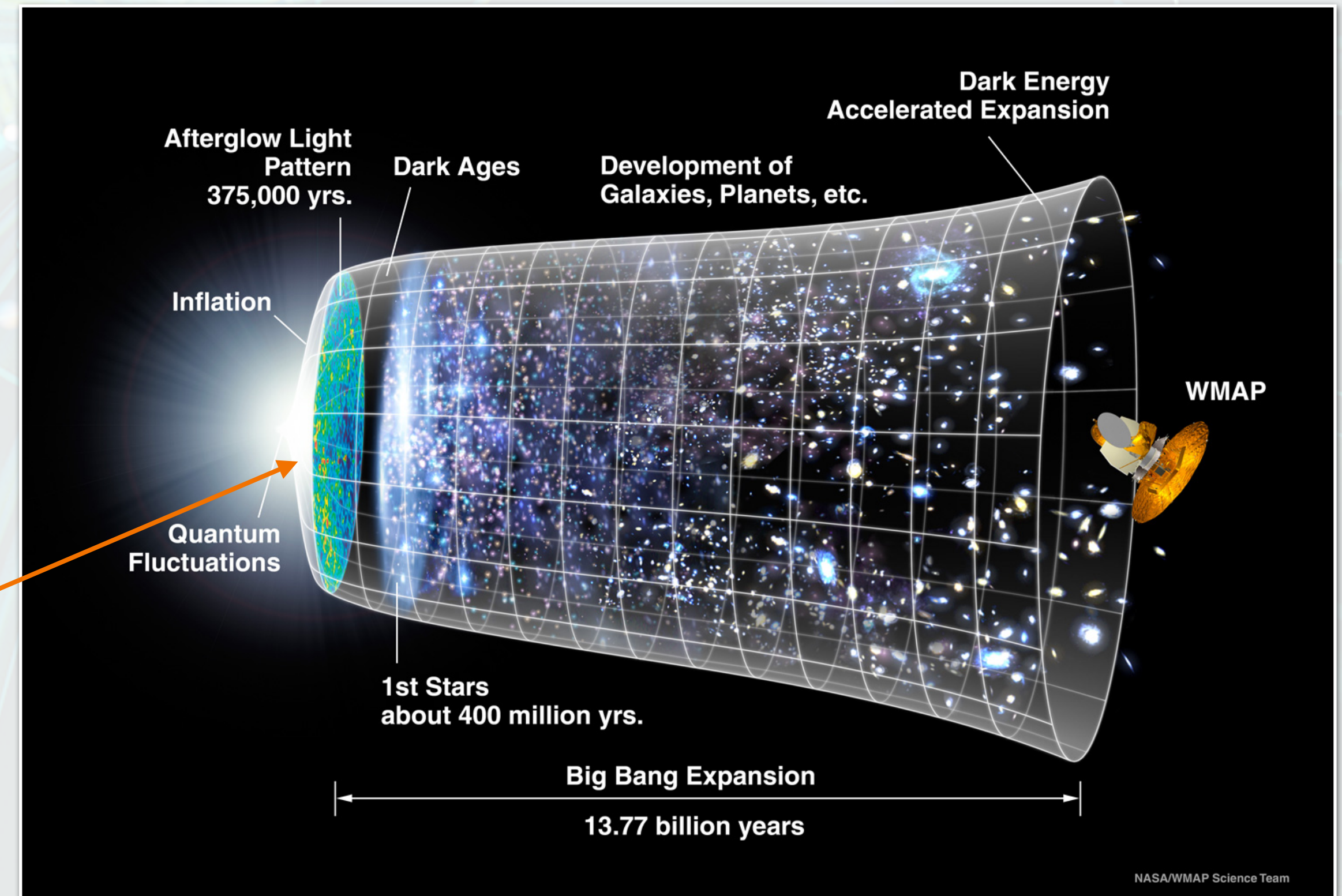
# Modern ambitions

*Use the Standard Model to explain the (early) universe*

- What happened during the electroweak phase transition? (Higgs,  $T=10^{-36}$  s)
- What is dark matter?
- Where did all the antimatter go?

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$

LHC

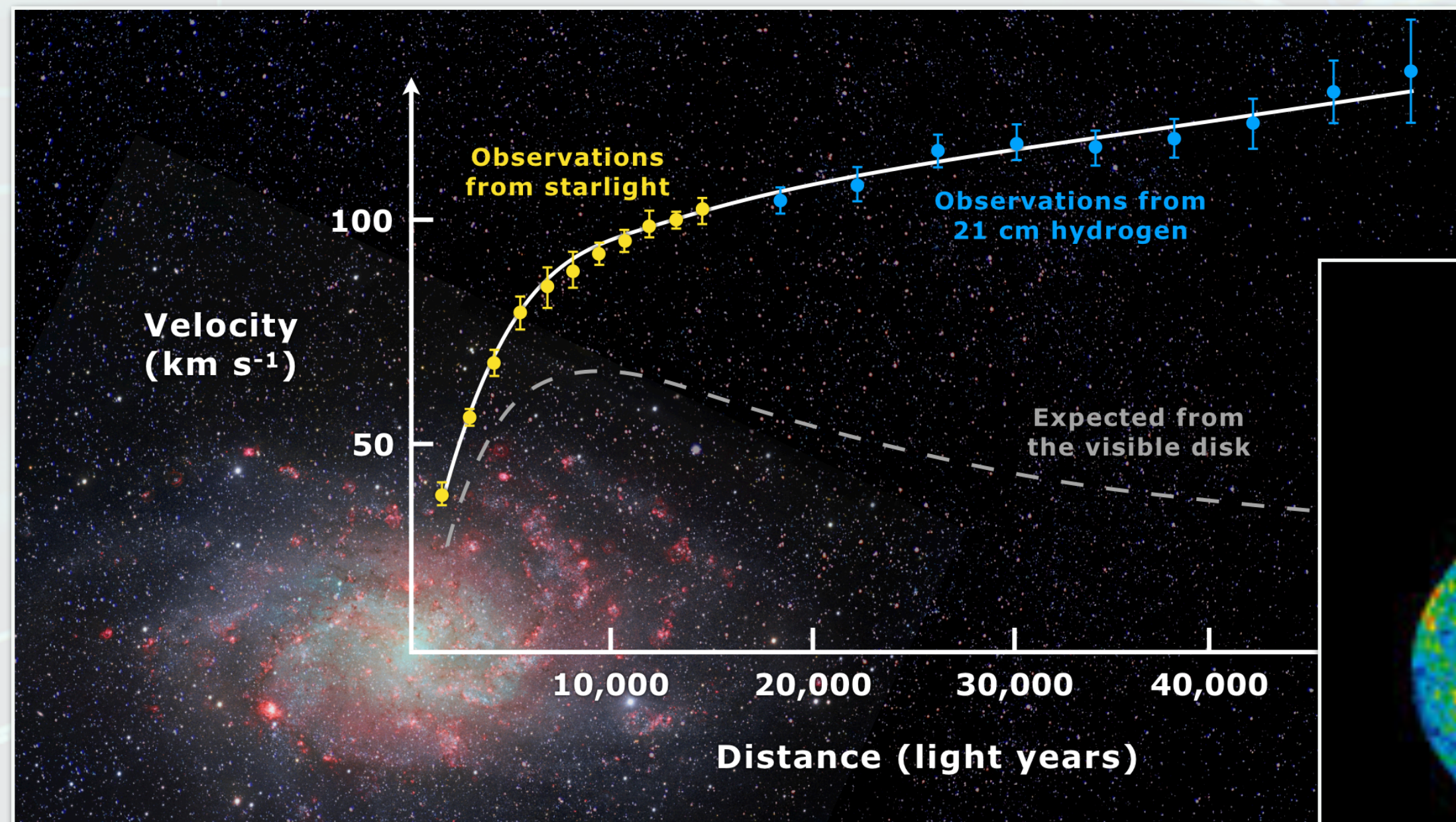


# Dark matter

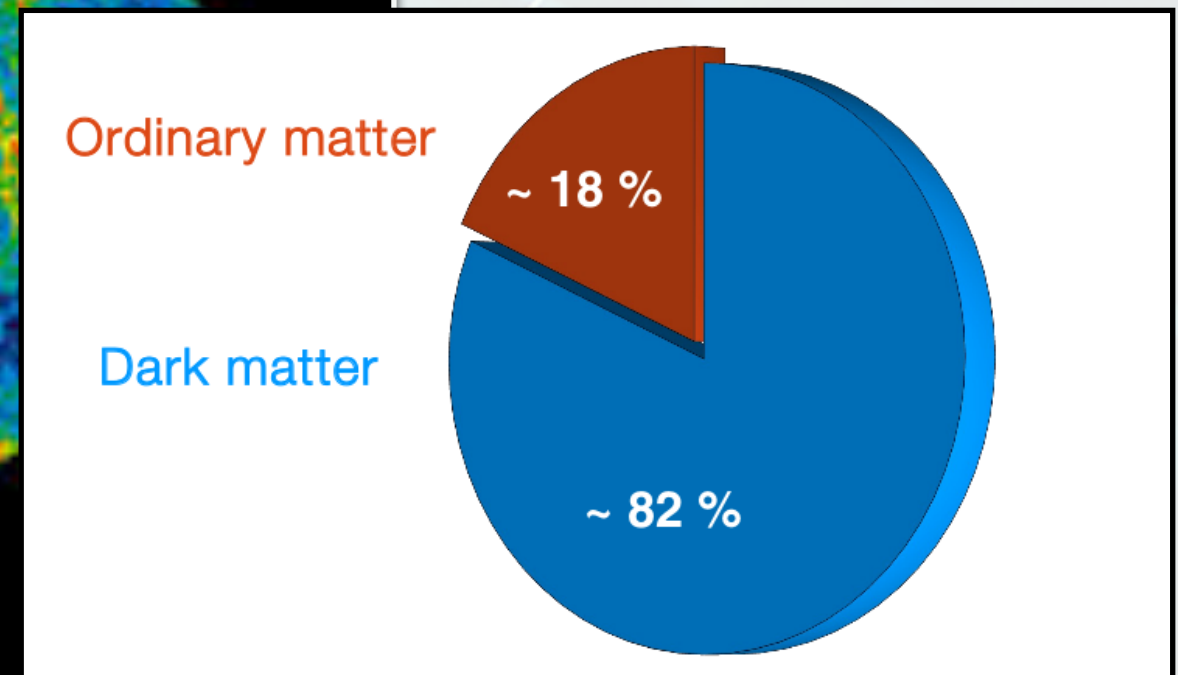
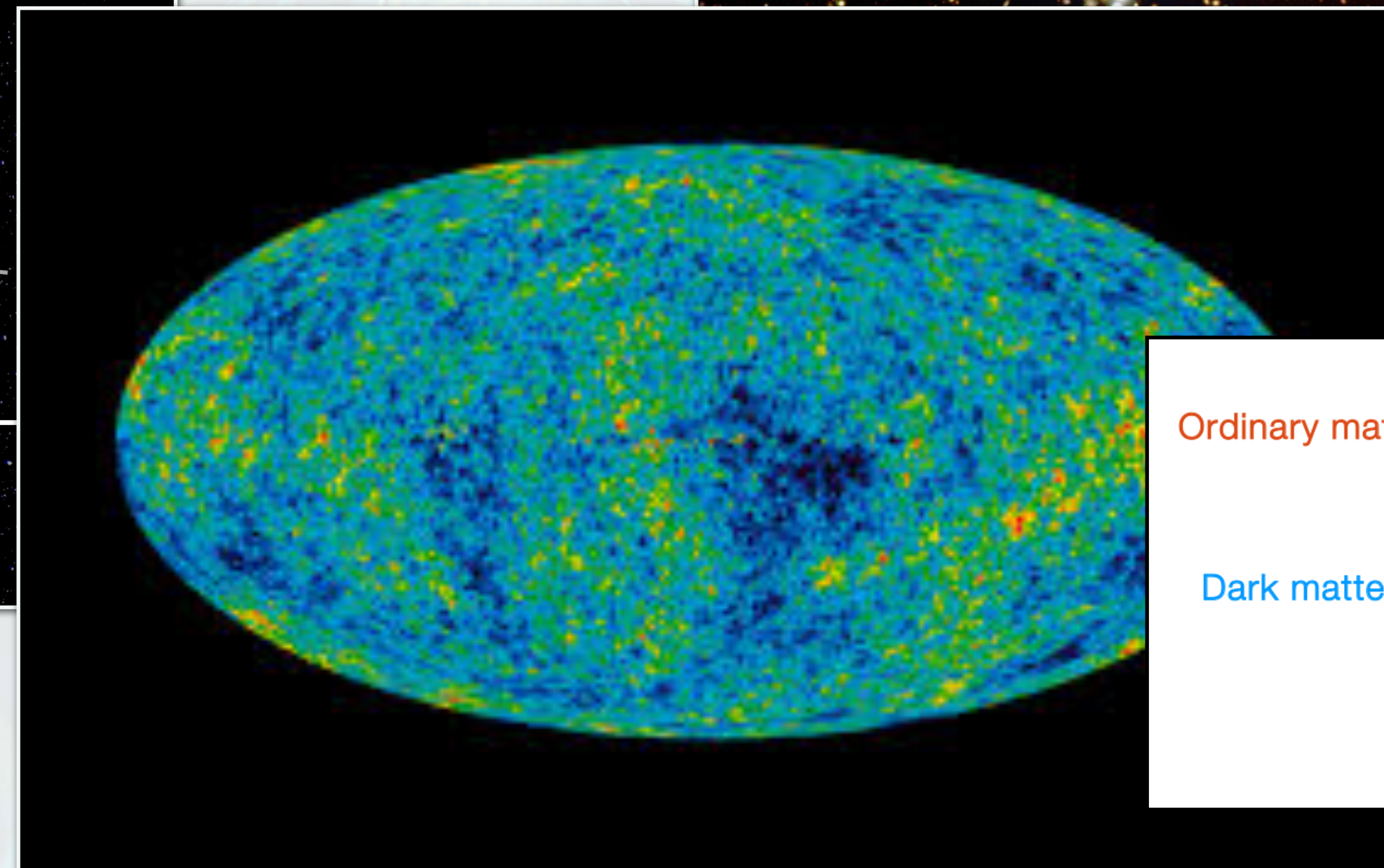
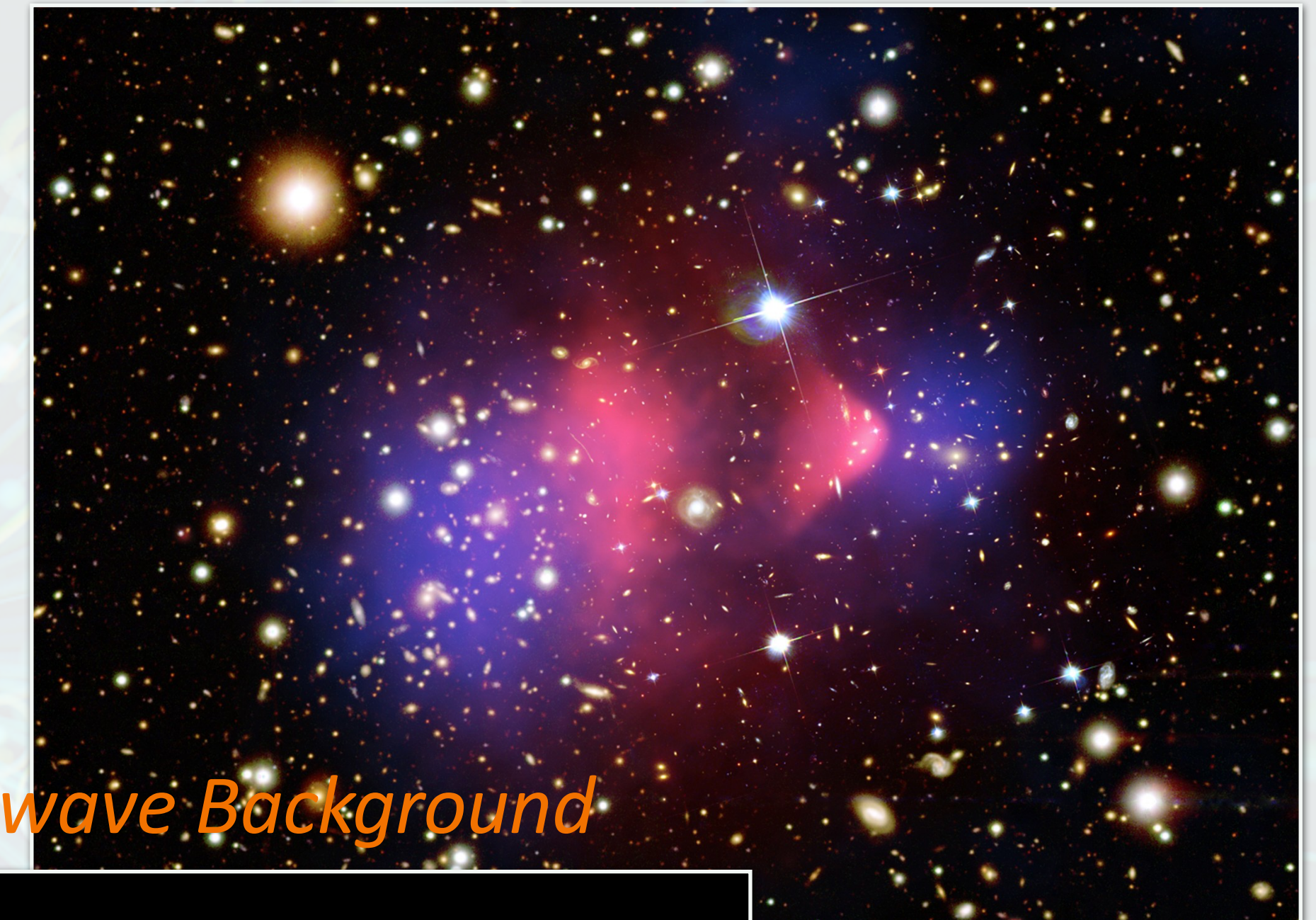
There is mass 'missing' in the universe...

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$

Galaxy rotation curves



Cosmic Microwave Background

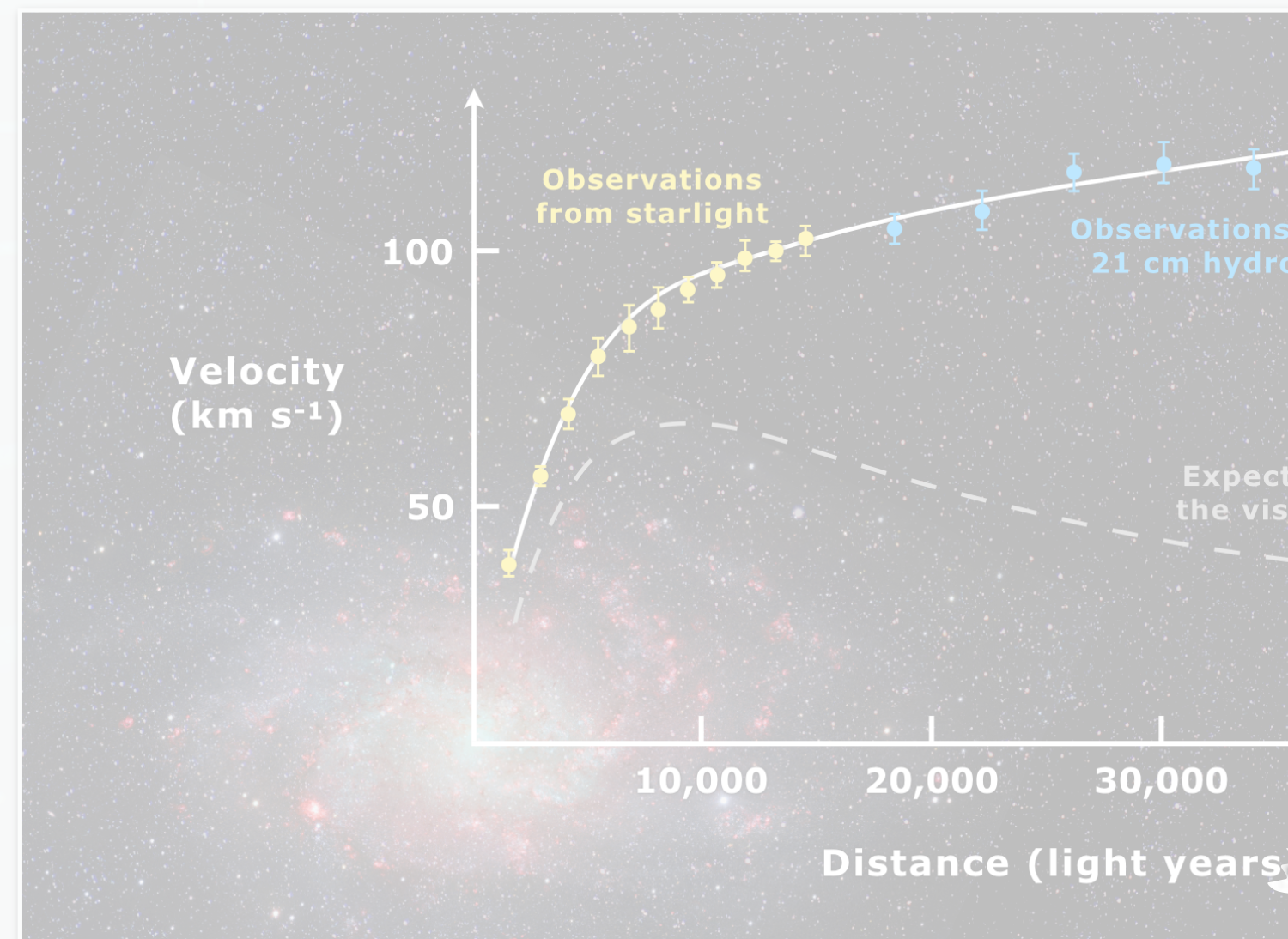


# Dark matter

There is mass 'missing' in

$$v(z) = \sum \frac{1}{r^2}$$

Galaxy rotation curves

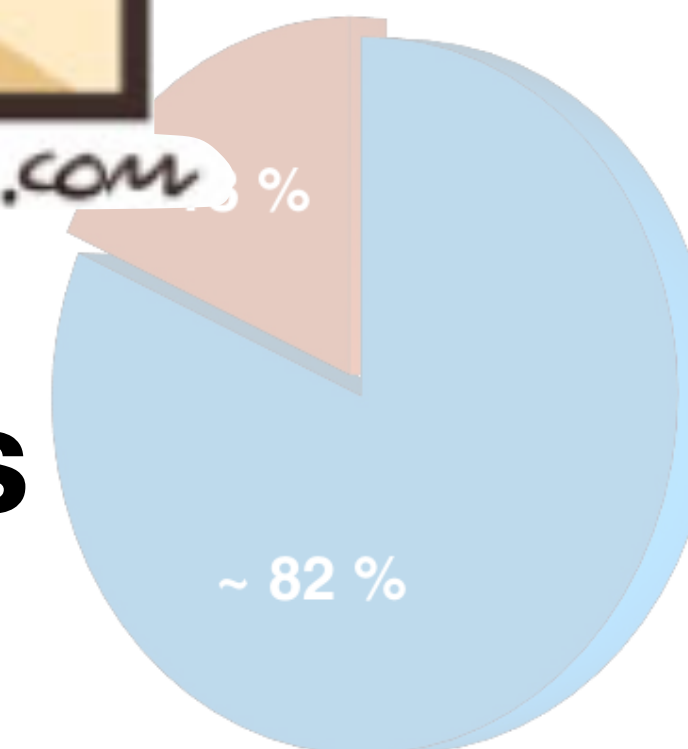


Gravitational microlensing



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## WIMPs vs MACHOs

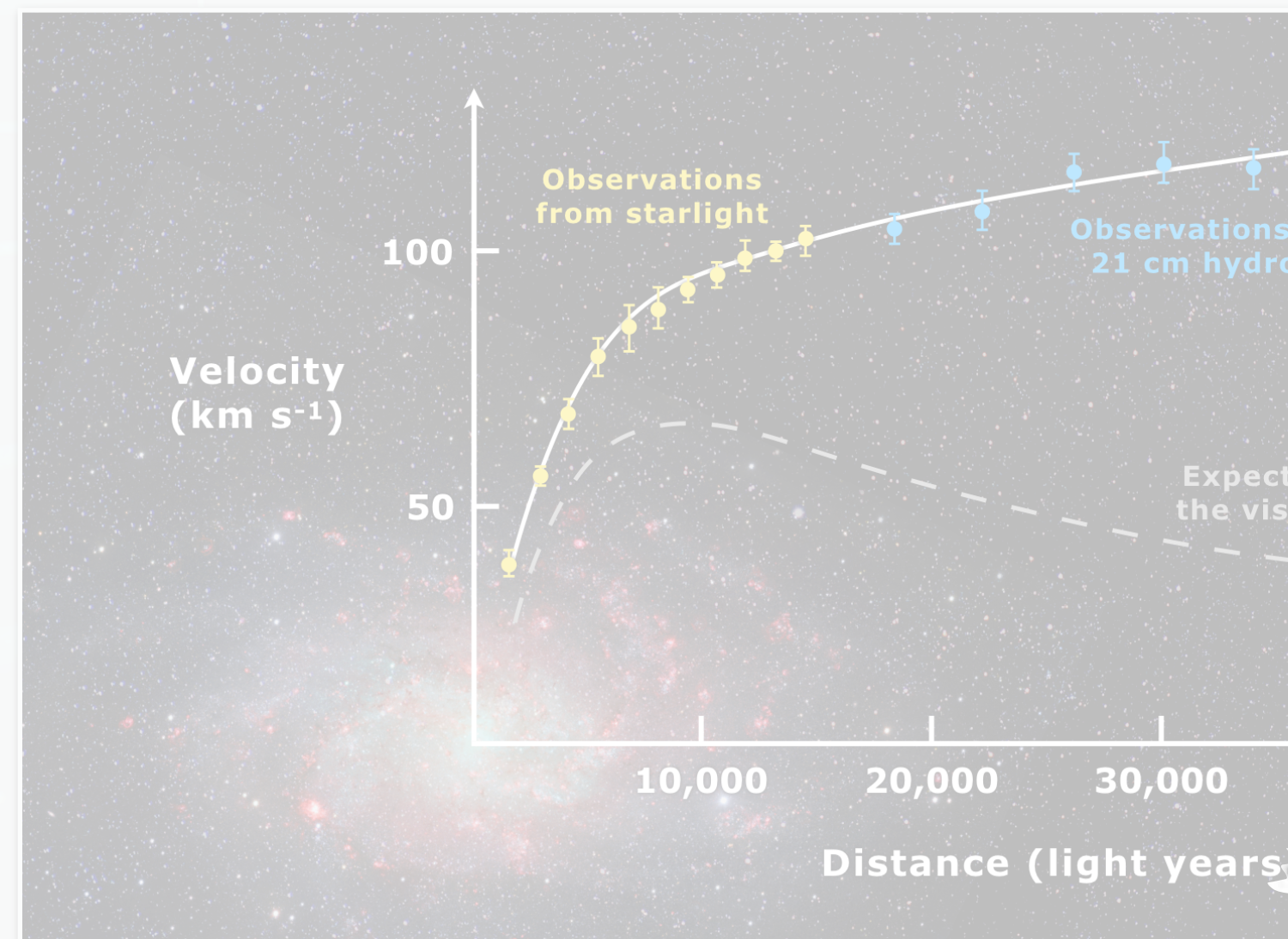


# Dark matter

There is mass 'missing' in

$$\Phi(z) = \sum \frac{1}{r^2}$$

Galaxy rotation curves



Gravitational microlensing



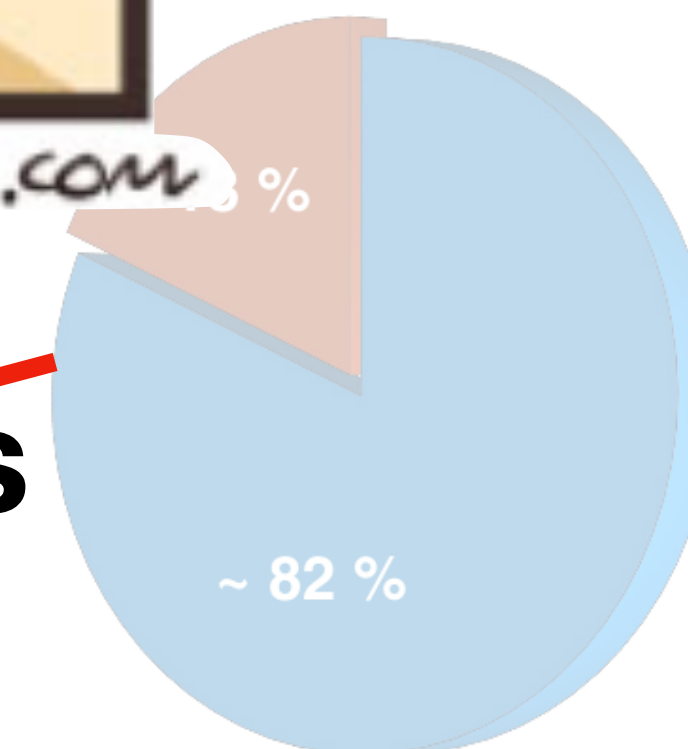
background



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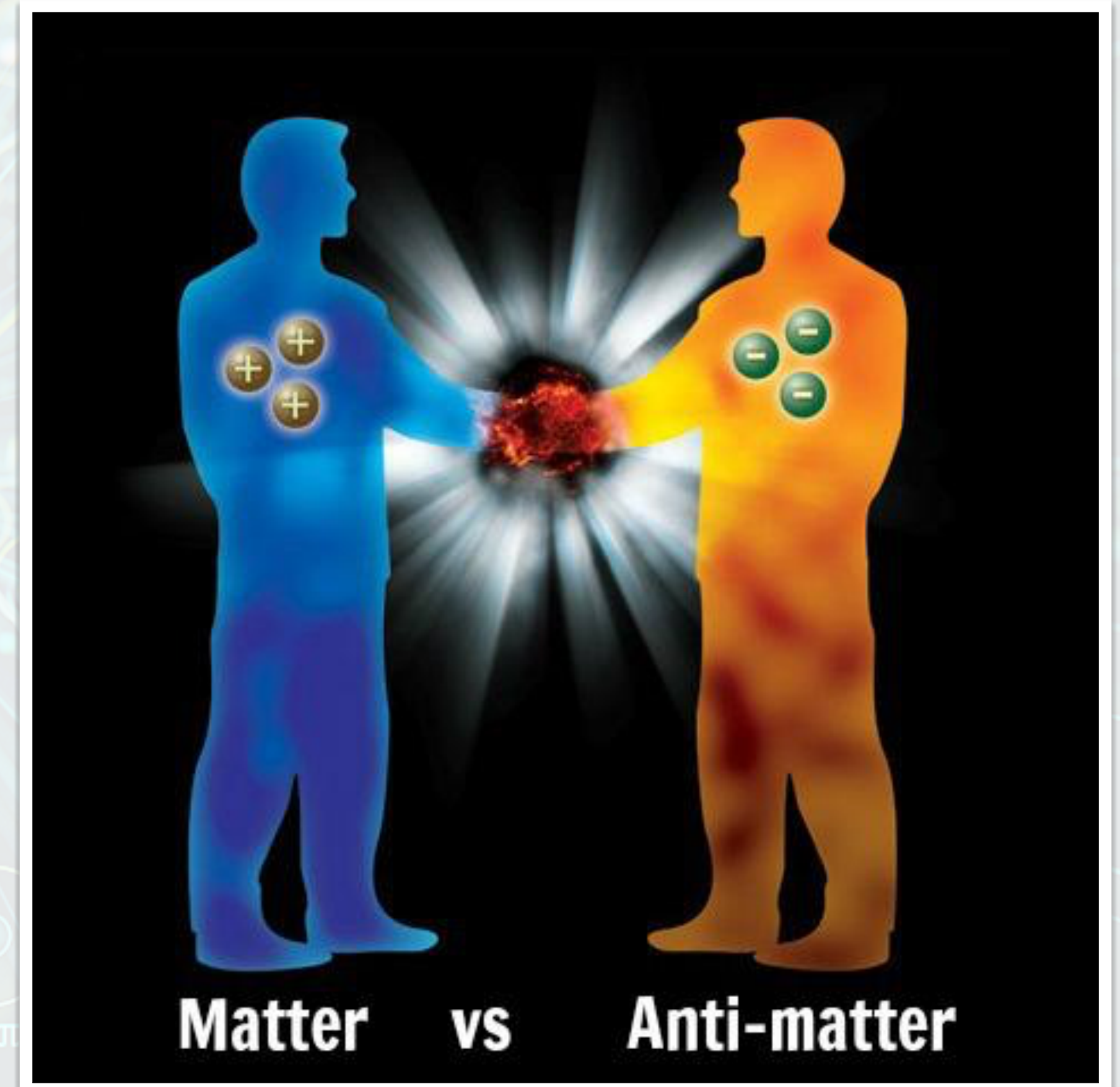
a new particle!

**WIMPs vs MACHOs**



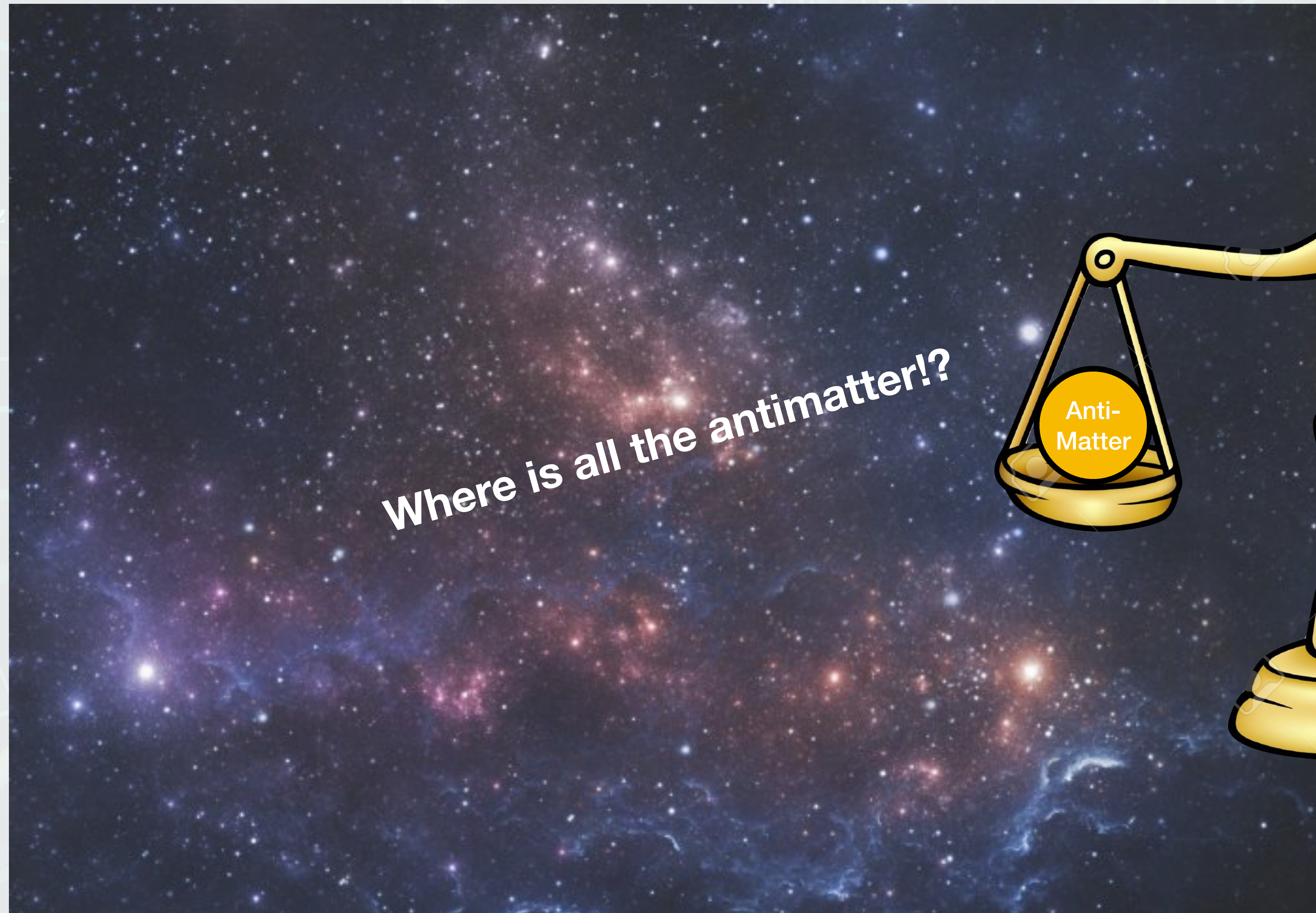
# Antimatter

*A very 'normal' phenomenon...*

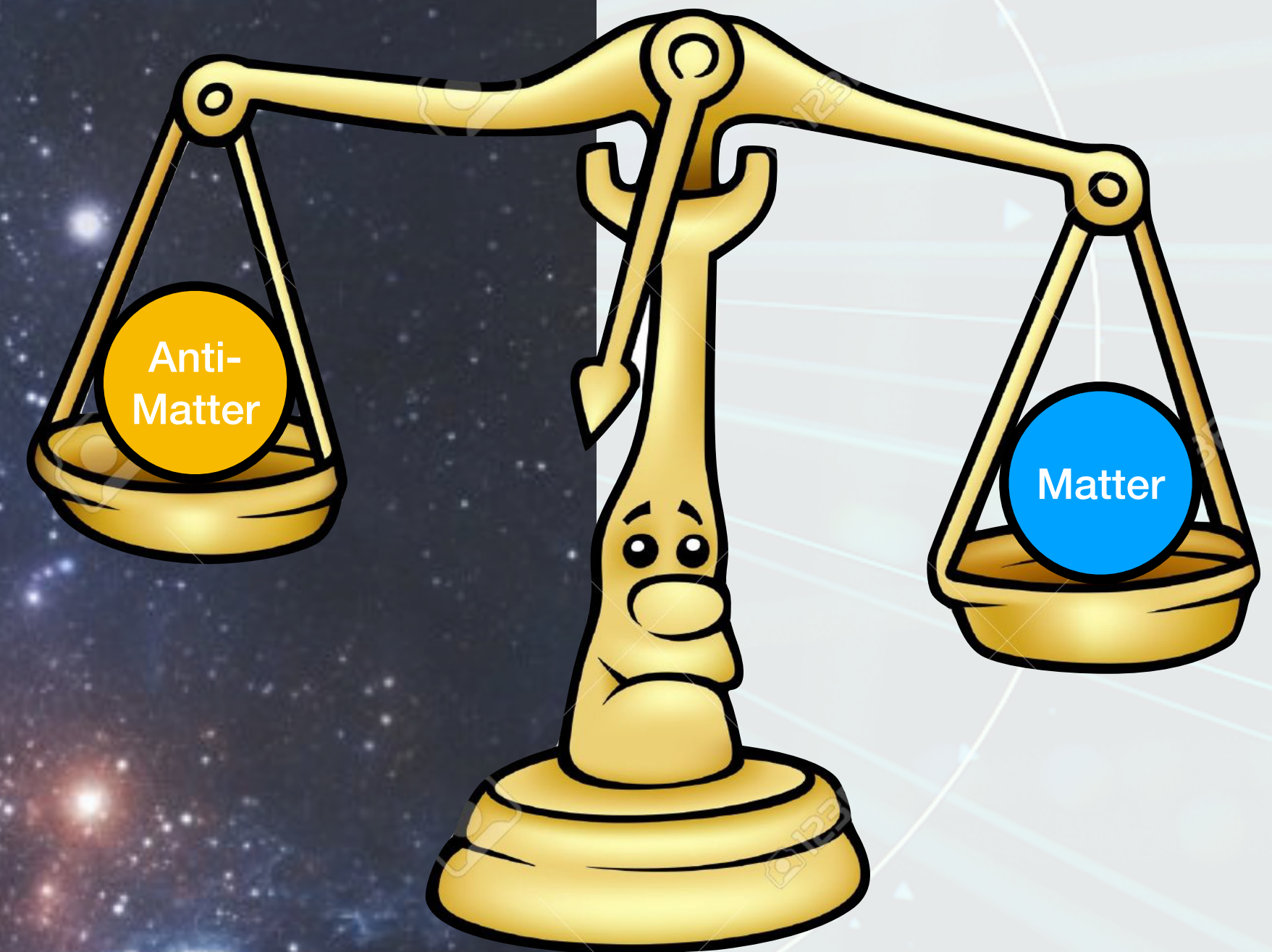


*...though quite destructive*

# Baryogenesis



Where is all the antimatter!?



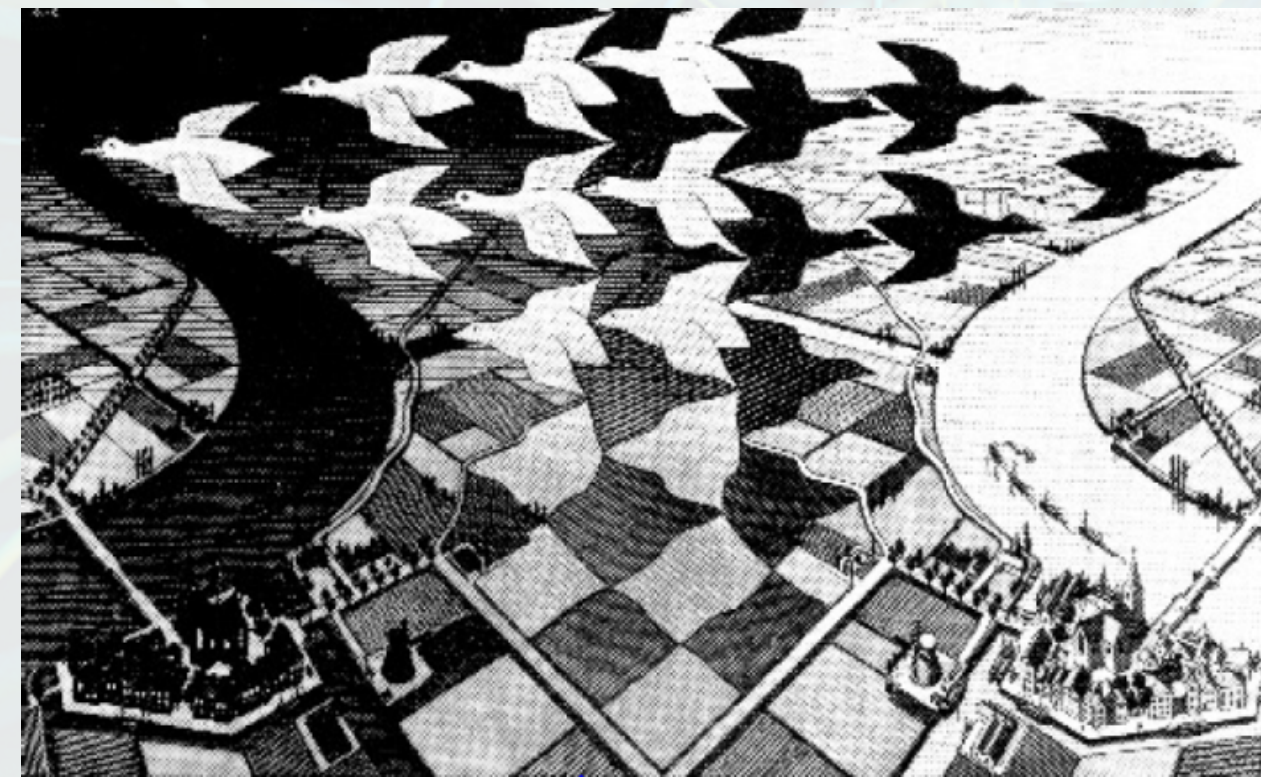
# Studying matter vs antimatter

- Theoretically, you need to perform 2 operations to conjugate\* matter to antimatter:

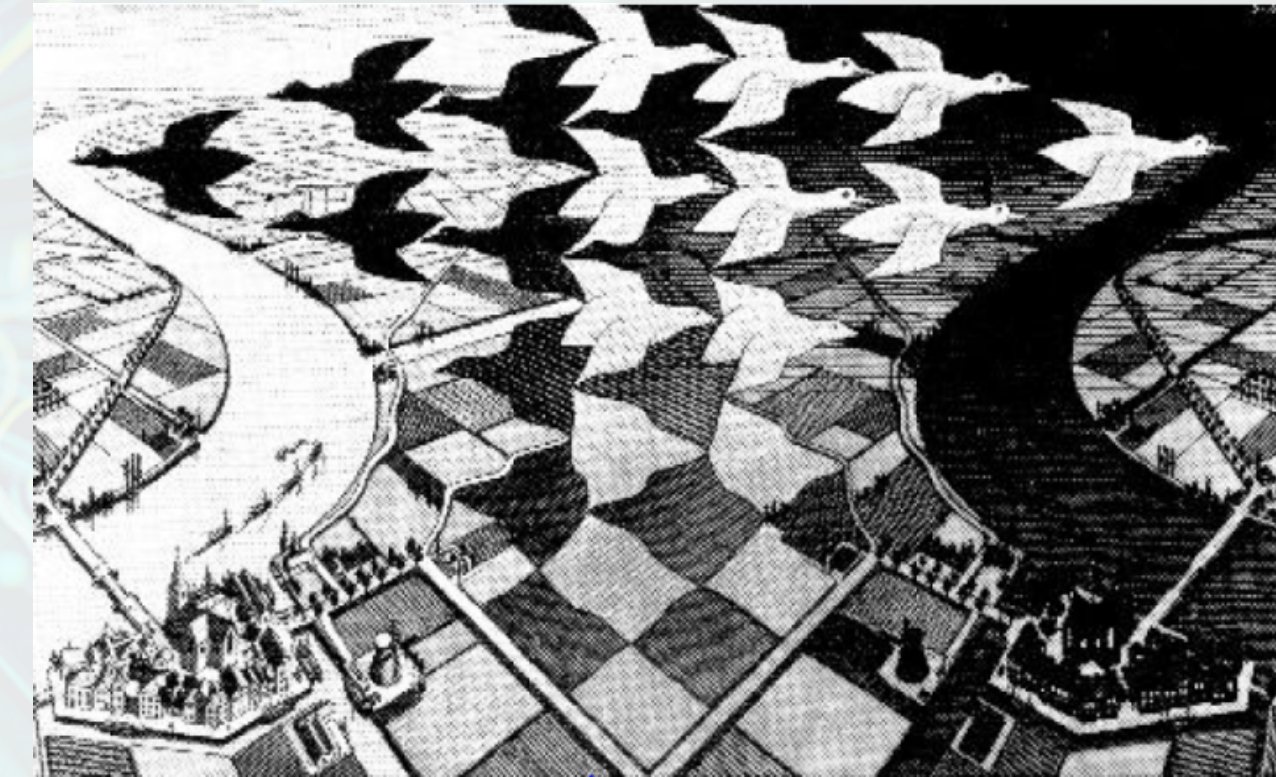
flipping **Parity** & **Charge**

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$

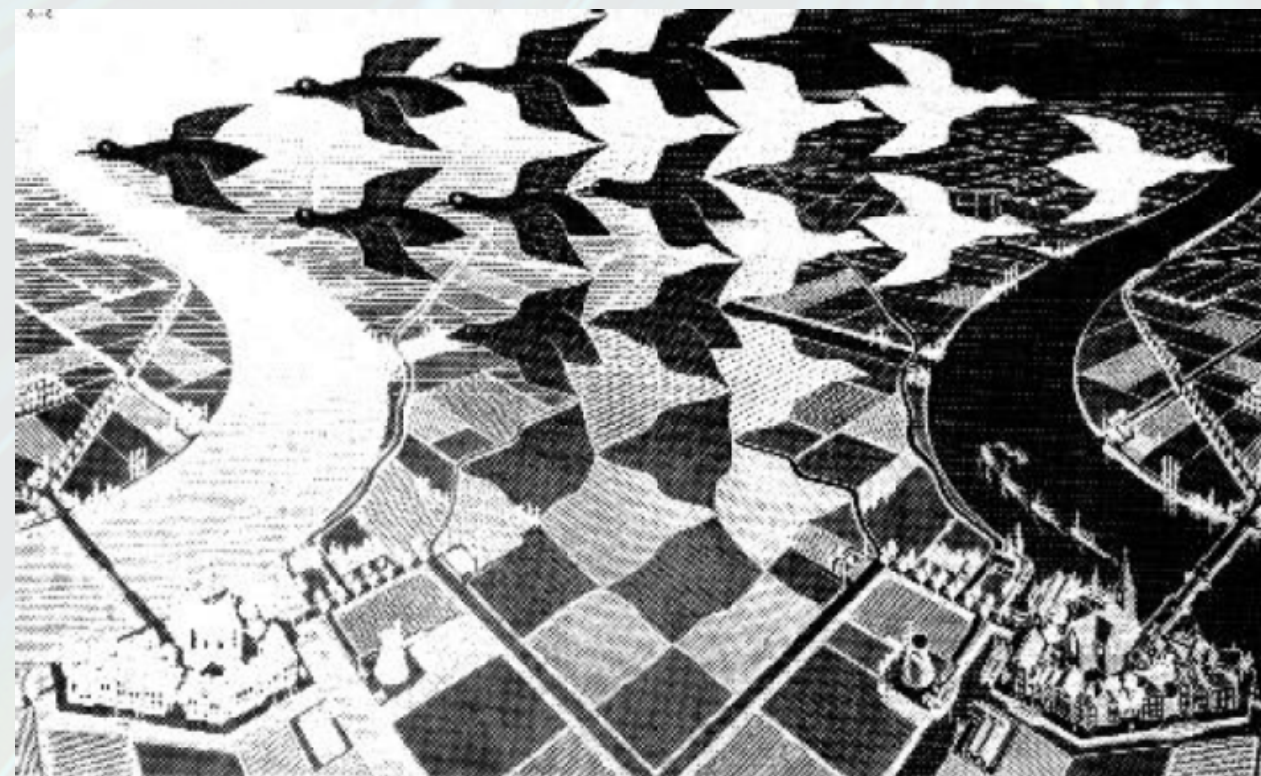
- Is that an exact symmetry?



P: Flip left/right



C: Flip colors



# Studying matter vs antimatter

- Theoretically, you need to perform 2 operations to conjugate\* matter to antimatter:

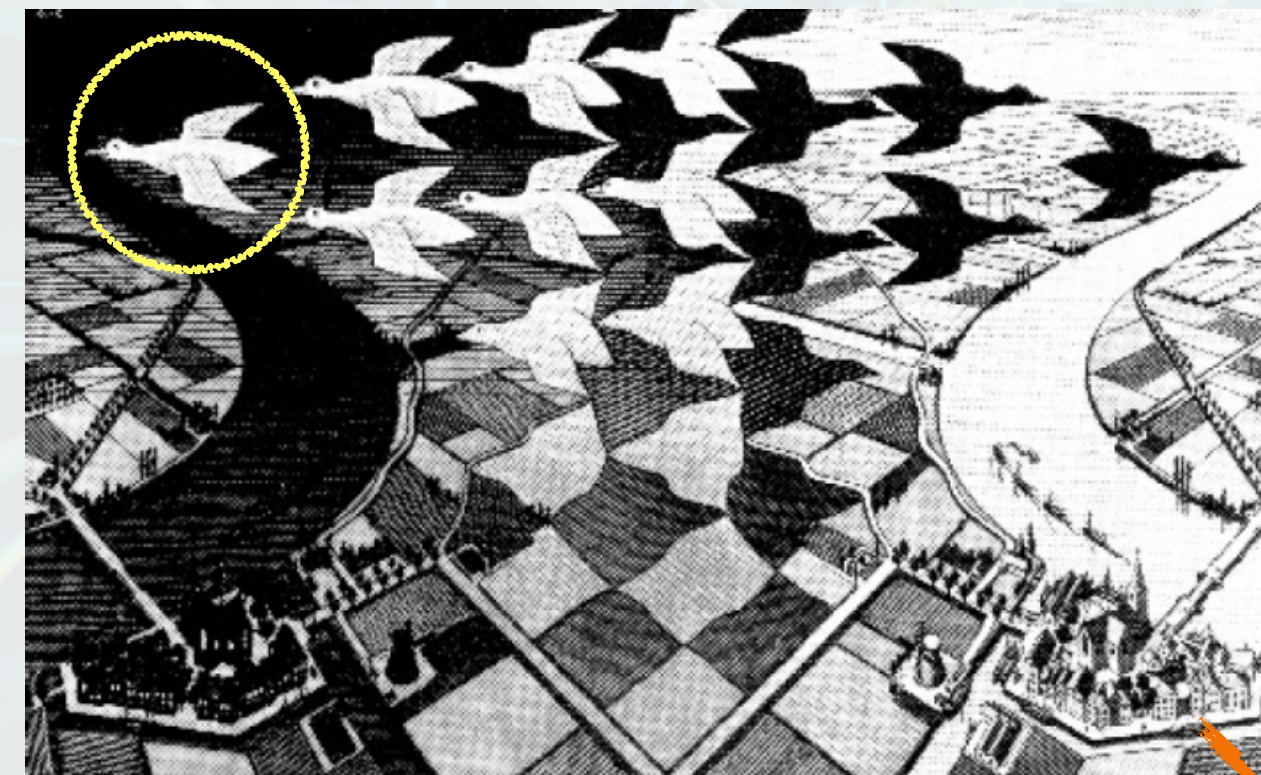
flipping **Parity** & **Charge**

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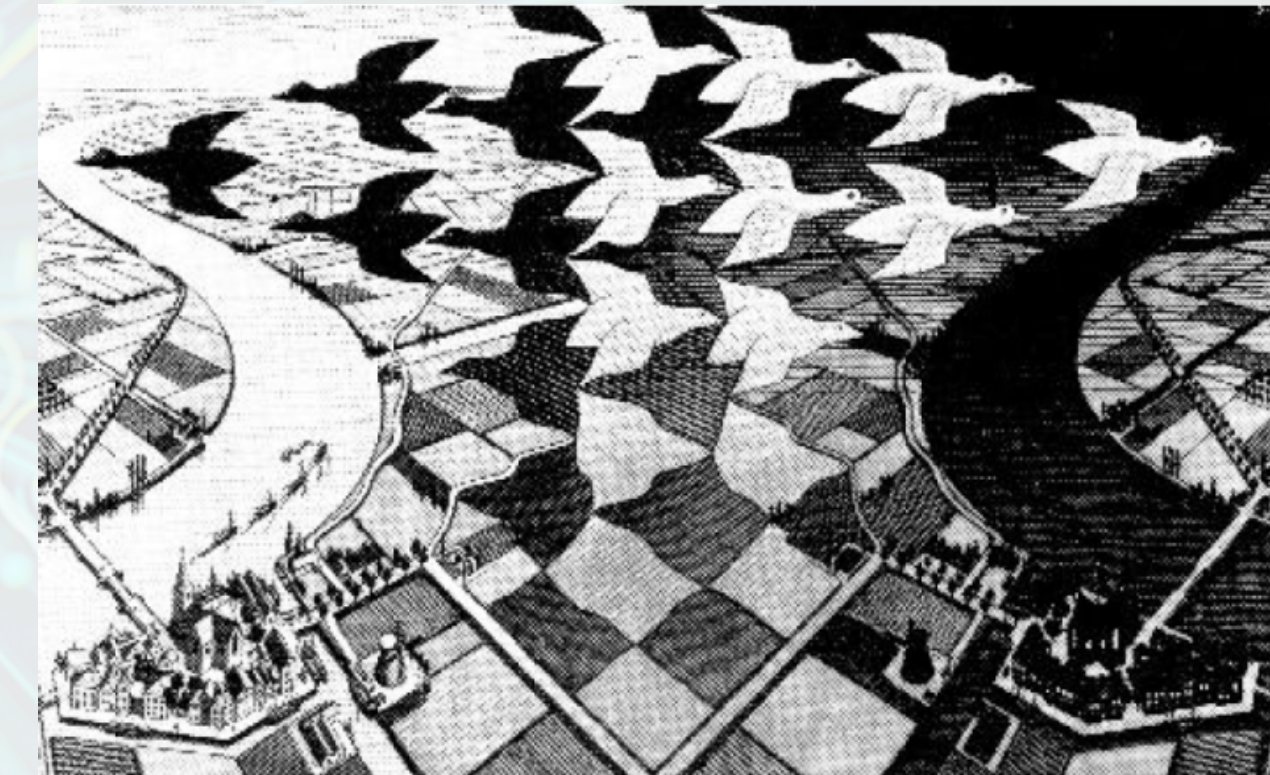
- Is that an exact symmetry?

—> Slightly violated  
in the Weak force only!

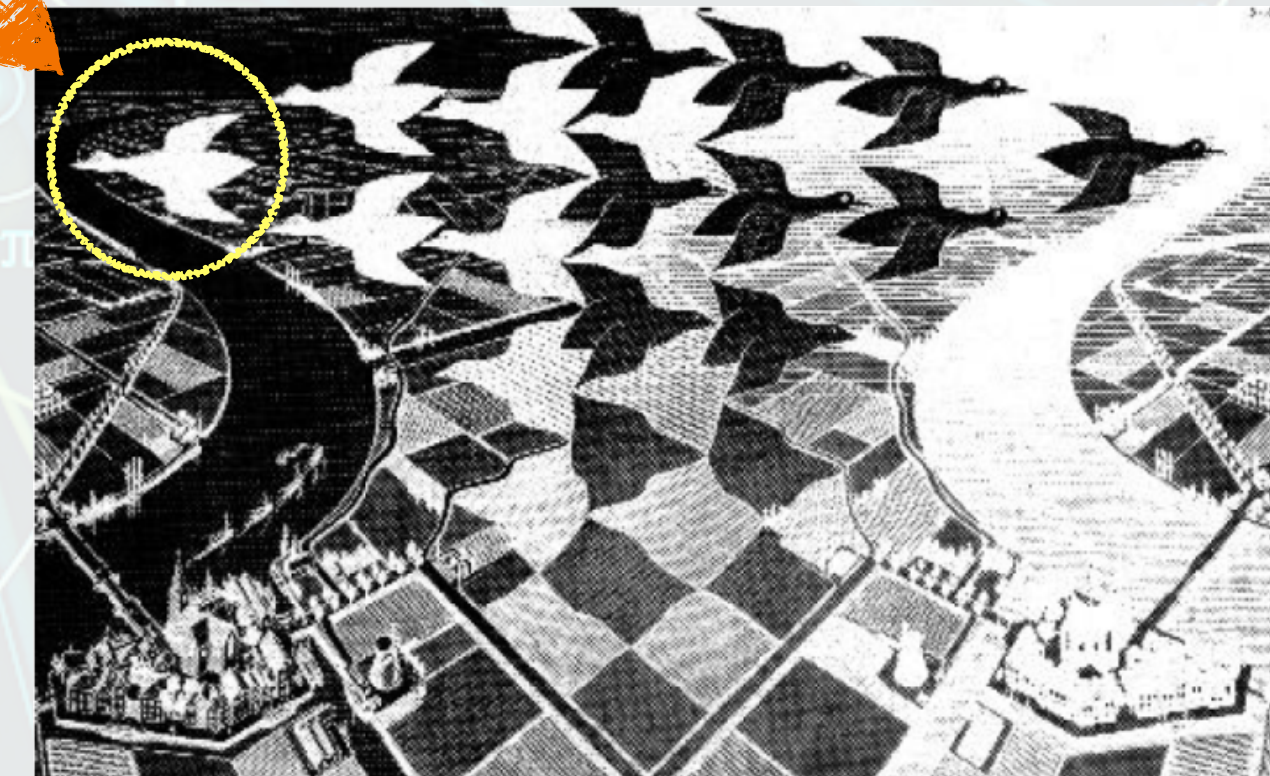
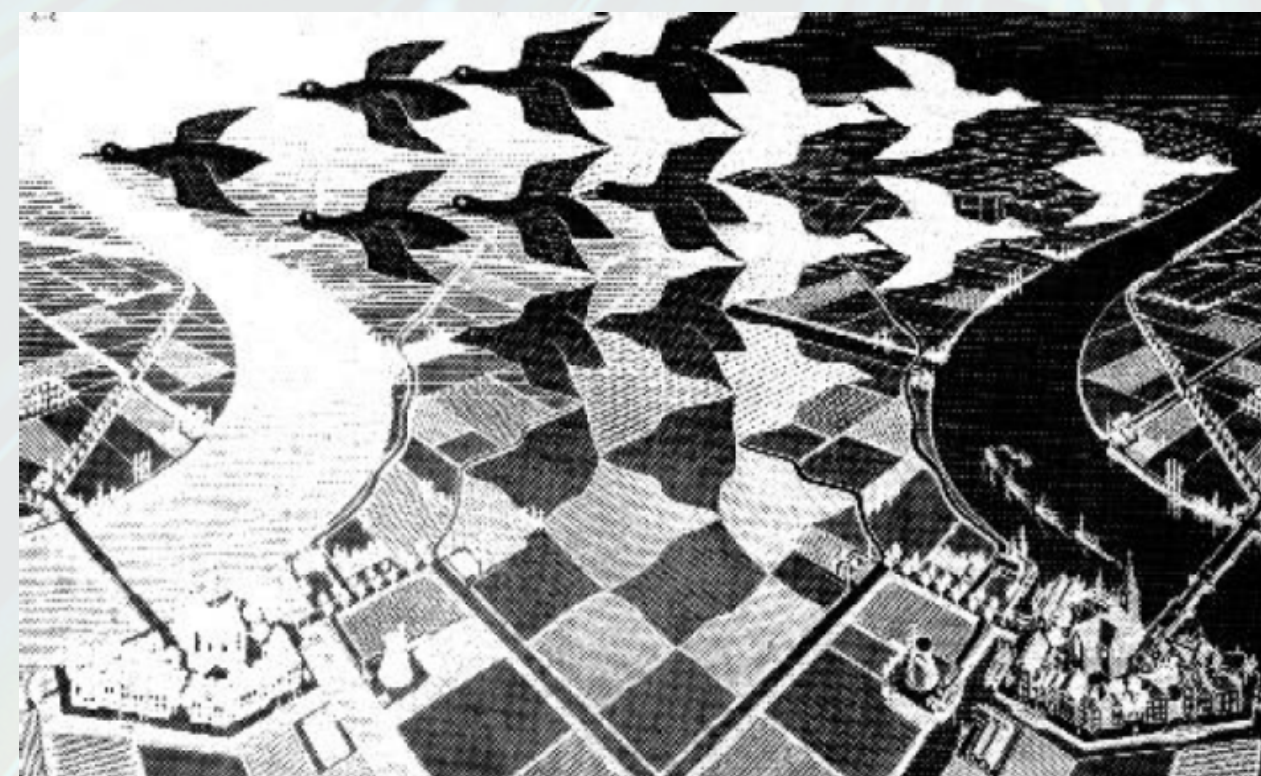
*“CP violation”*



P: Flip left/right



C: Flip colors



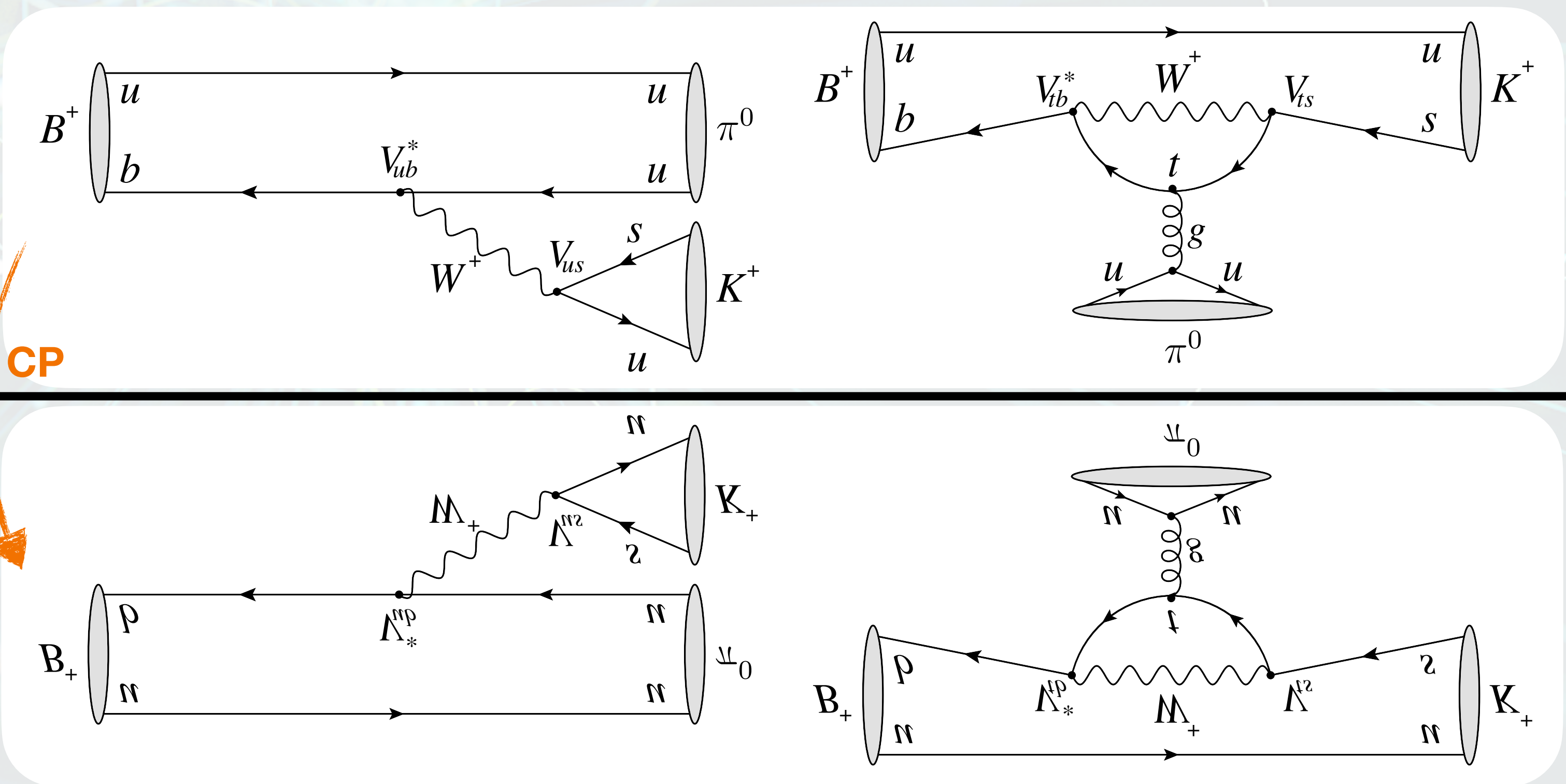
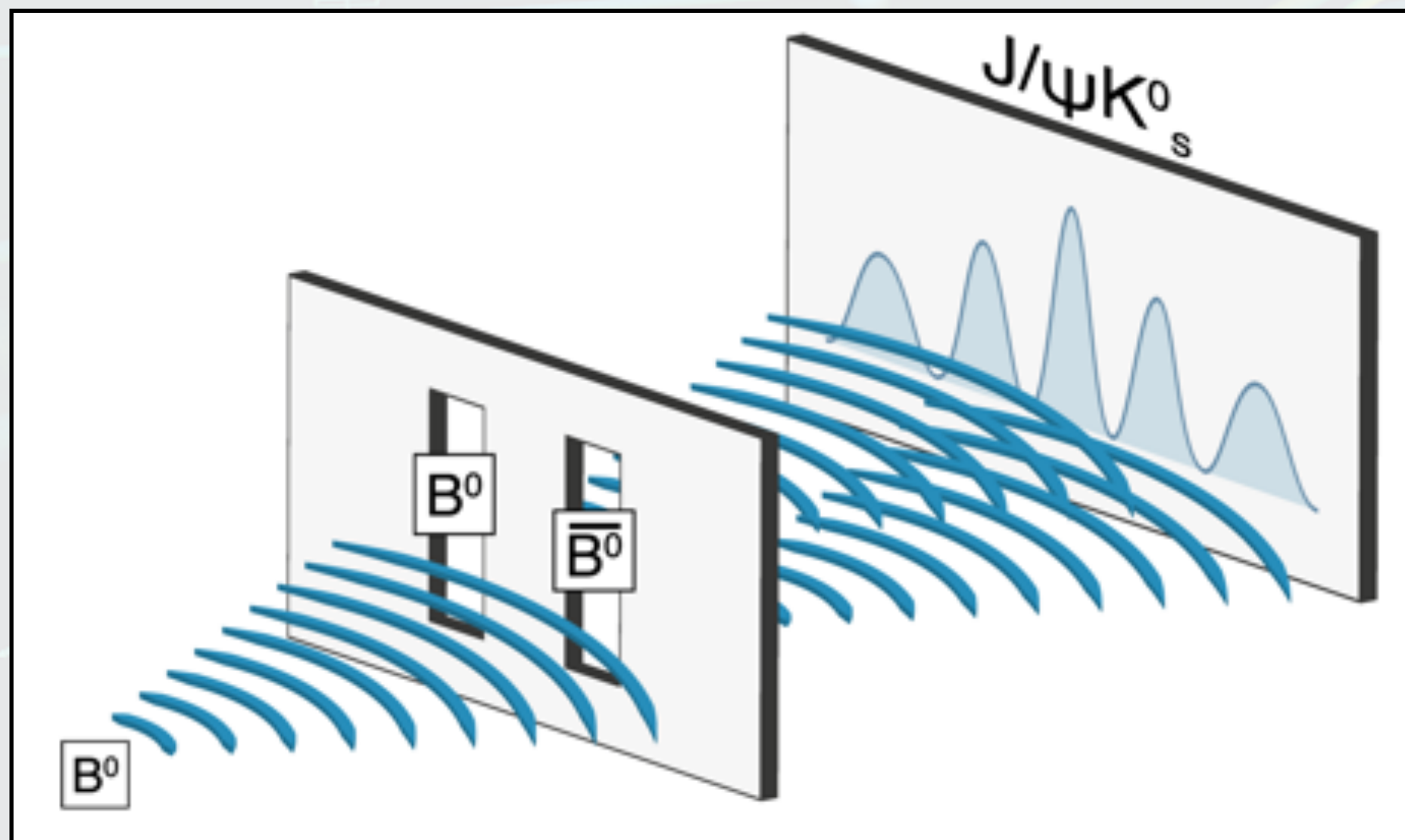
*“day and night” - M.C. Escher*

# Studying matter vs antimatter

CP violation: complex phase in the weak interaction

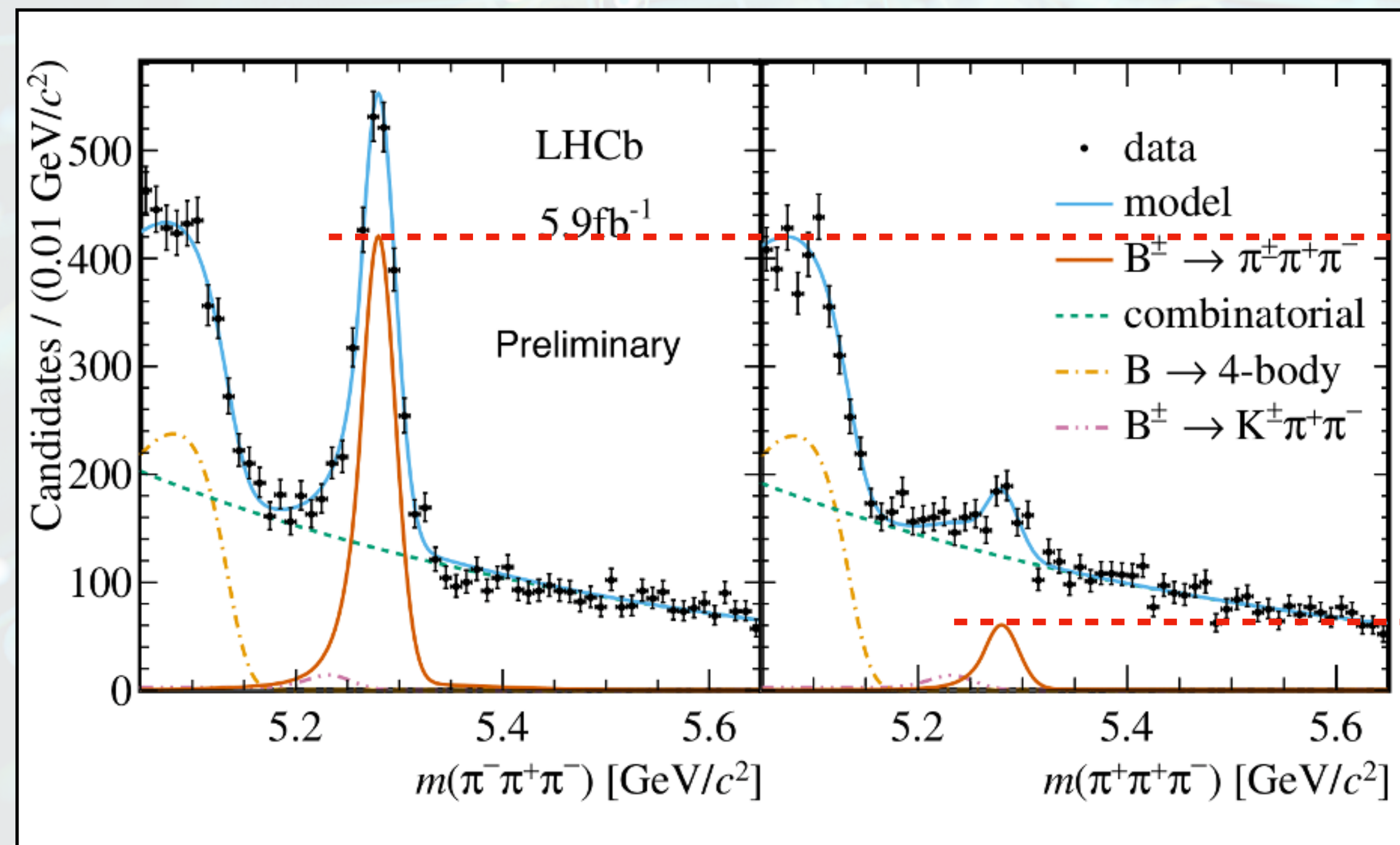
—> Visible via an interference effect (in some cases oscillating over time)

$$\zeta(z) = \sum \frac{1}{n^z}$$



# CP violation is not enough

- Many measurements of CP violation have been made
  - it's there! And matches the "Standard Model prediction".
  - it is  $\sim 10^{10}$  x too small to explain Baryogenesis
  - ▶  $\zeta(z) = \sum \frac{1}{n^z}$
  - : We need new diagrams (particles/forces)!

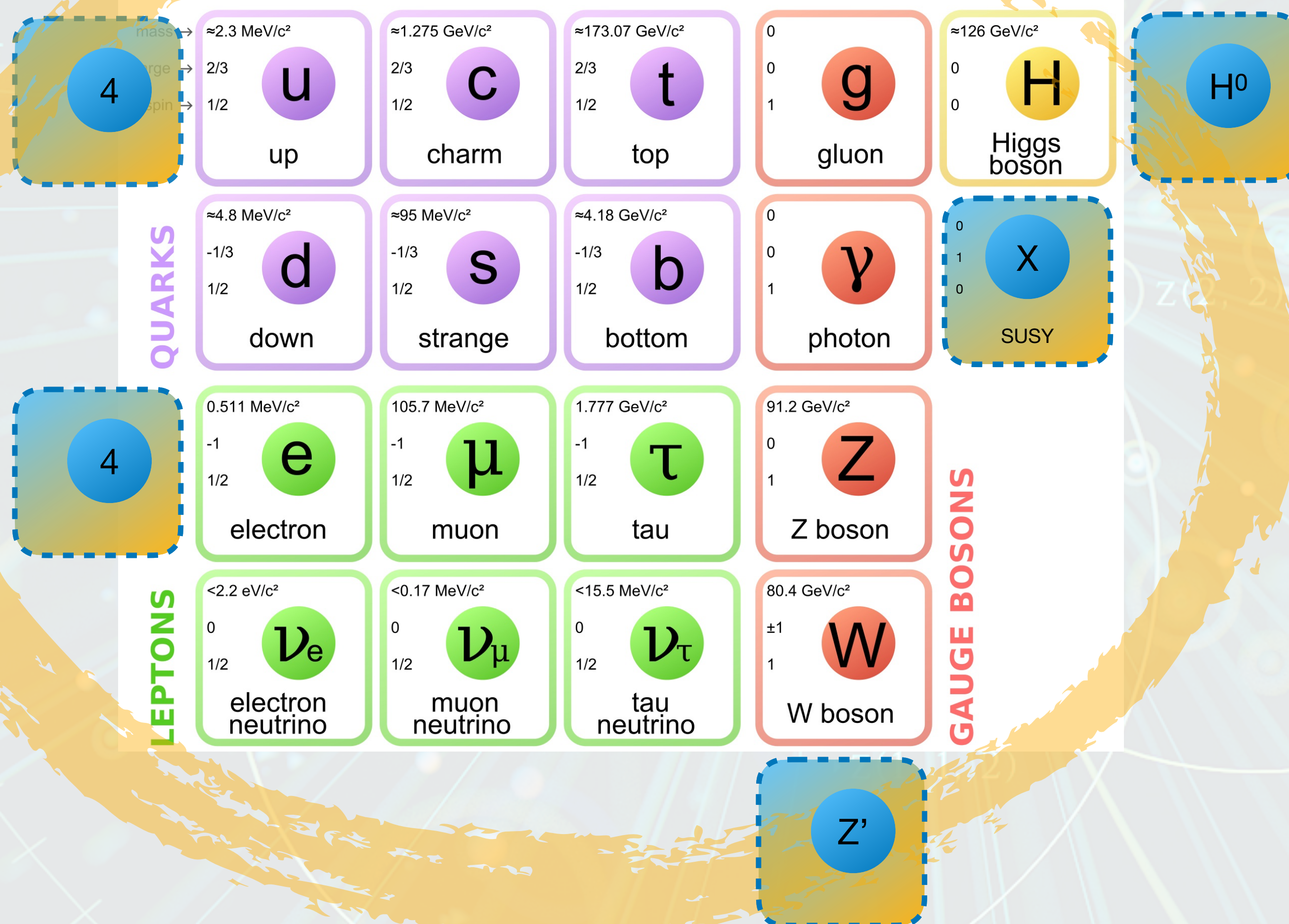


CP violation!

LHCb, CERN, 2022

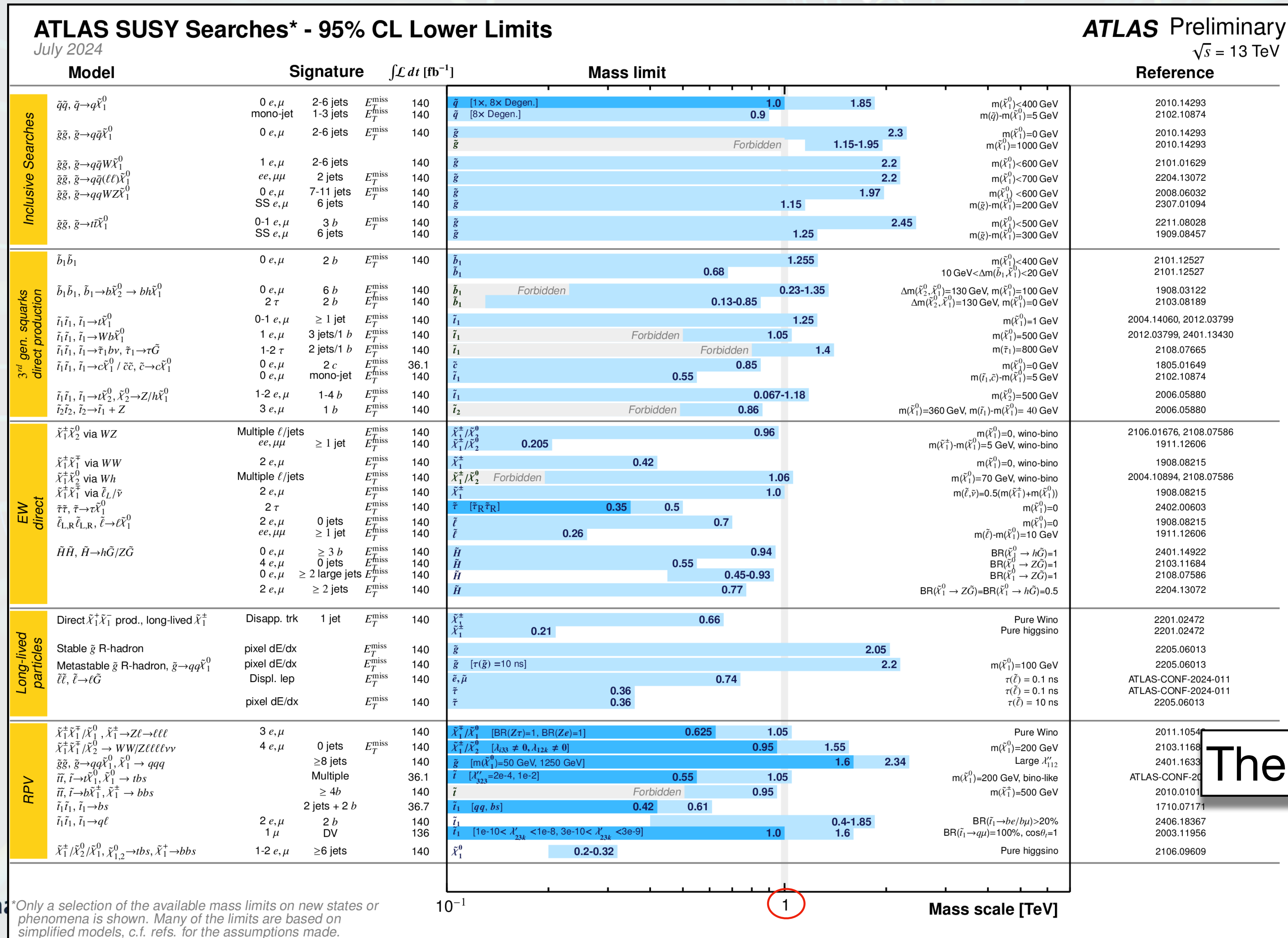
# Beyond the Standard Model / 'New Physics'?

## The Standard Model ++



—> How to find them?

# Direct production limits



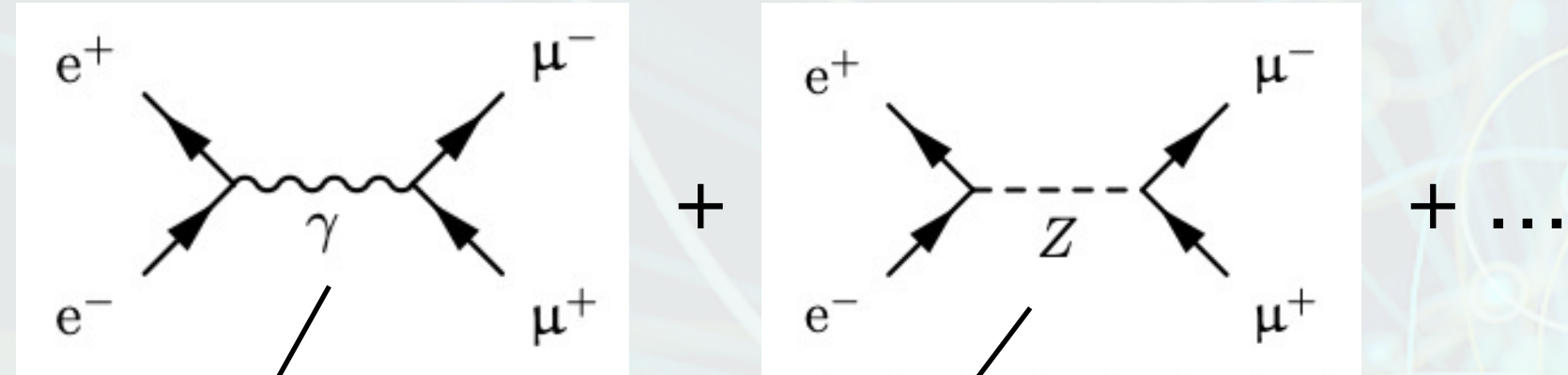
The search continues...

\*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

# Off-shell contributions

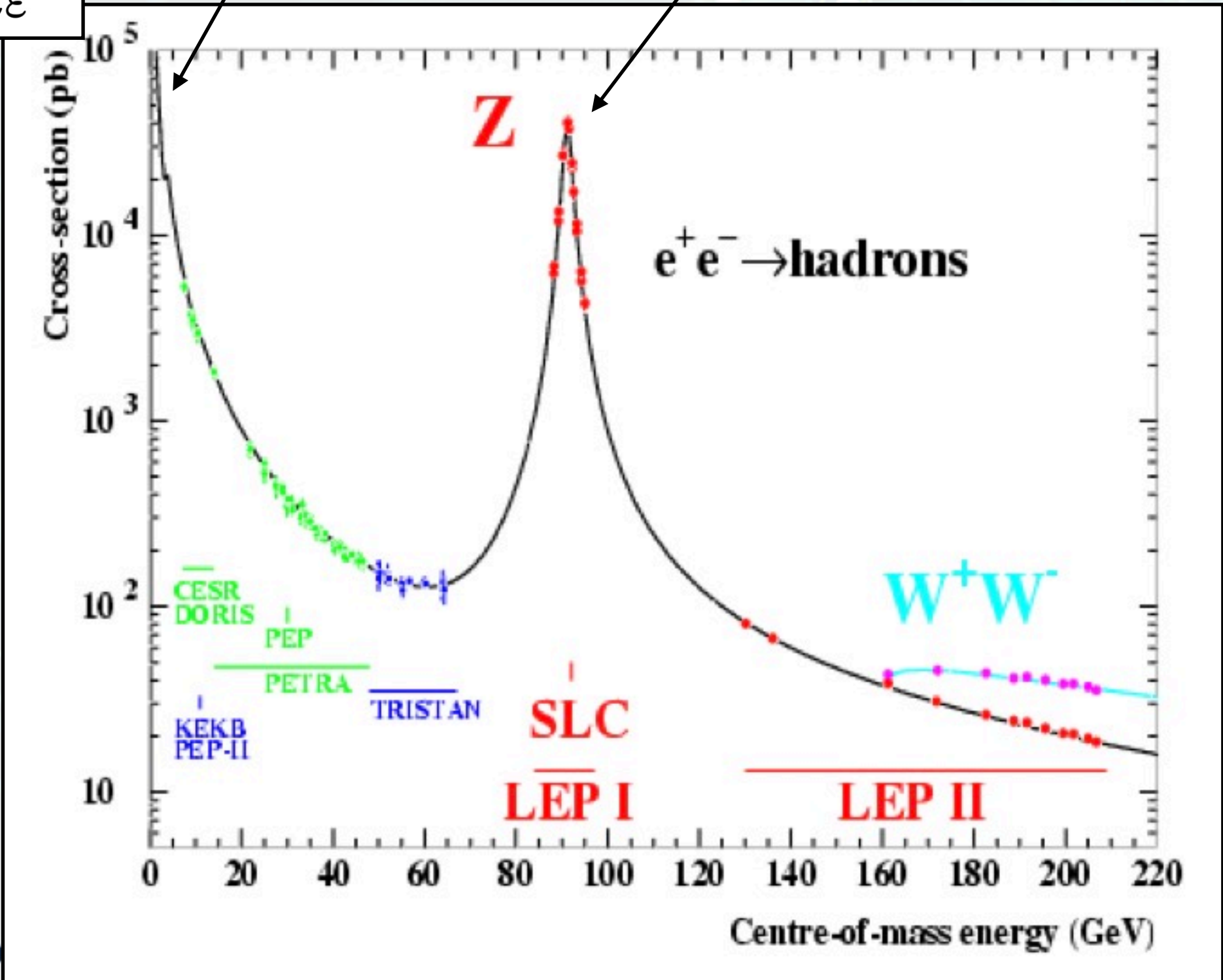
$$P(ee \rightarrow \mu\mu) =$$

$$\triangleright \zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$



2

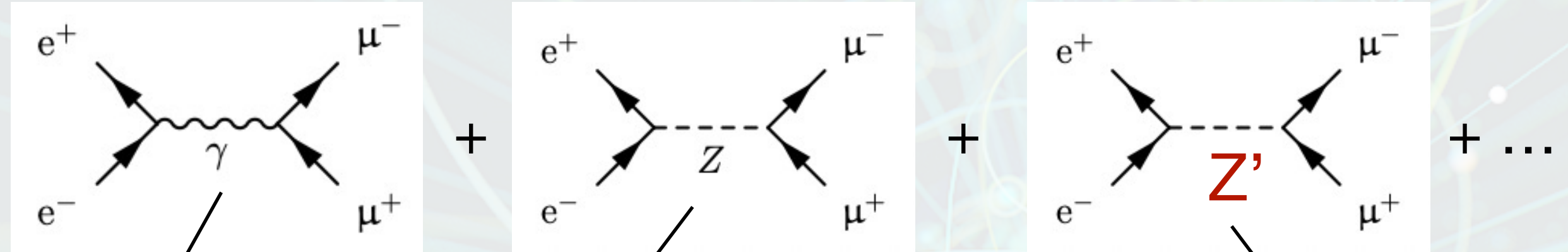
$$\tilde{G}_F(p) = \frac{1}{p^2 - m^2 + i\epsilon}$$



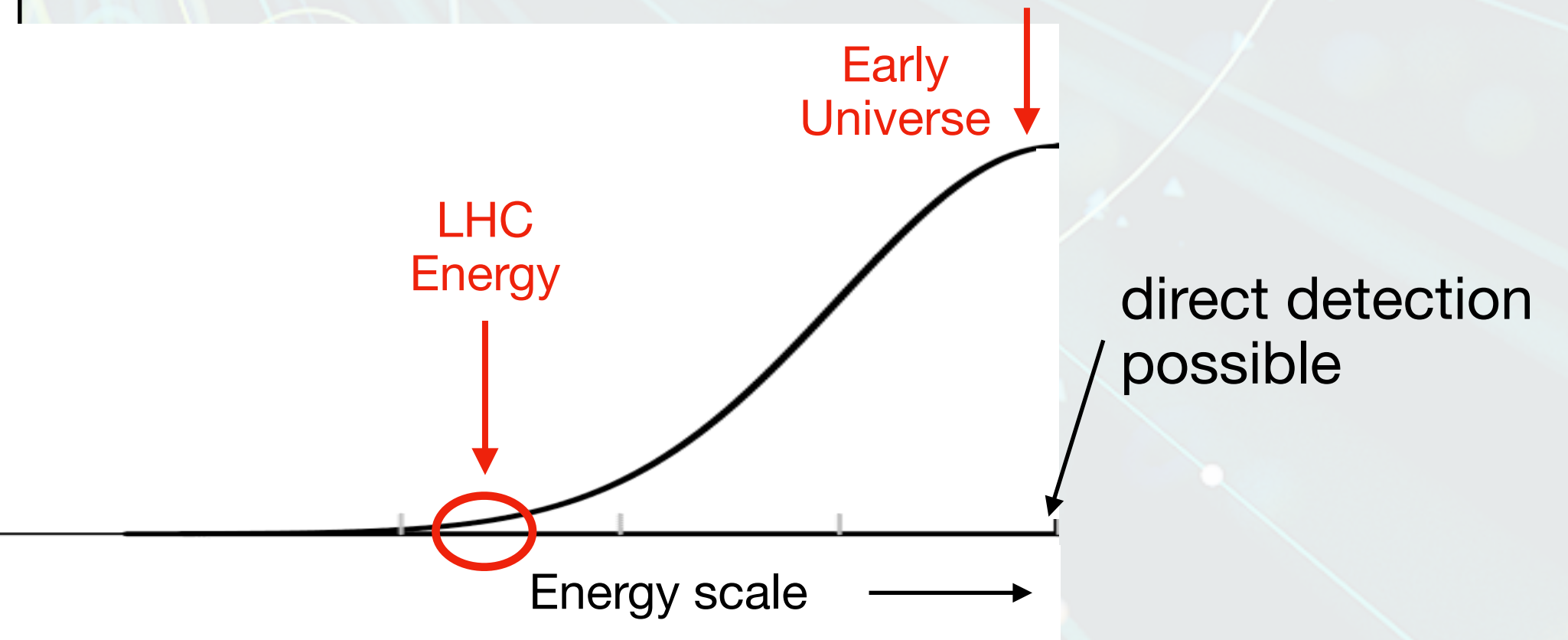
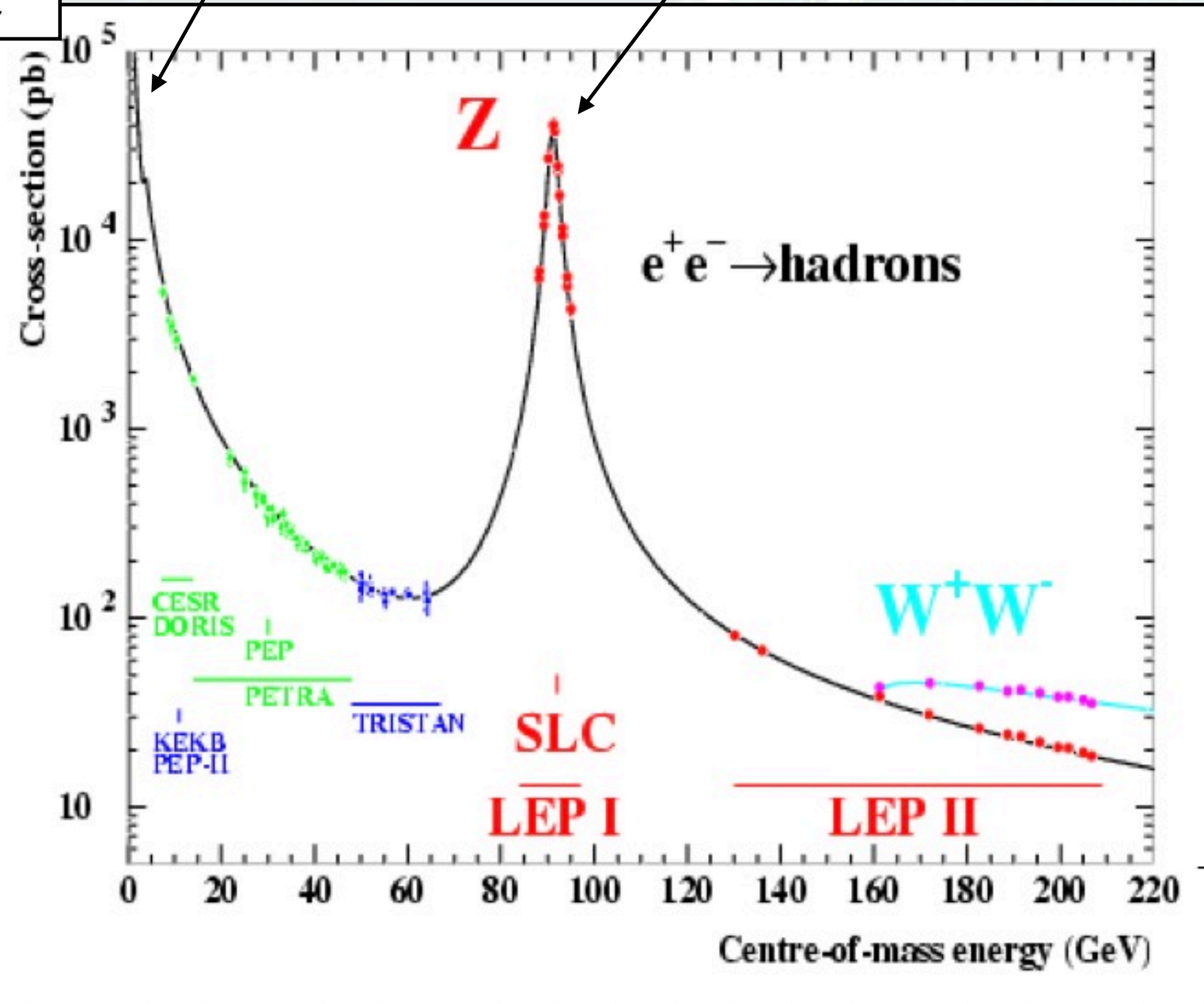
# Off-shell contributions

$$P(ee \rightarrow \mu\mu) =$$

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$

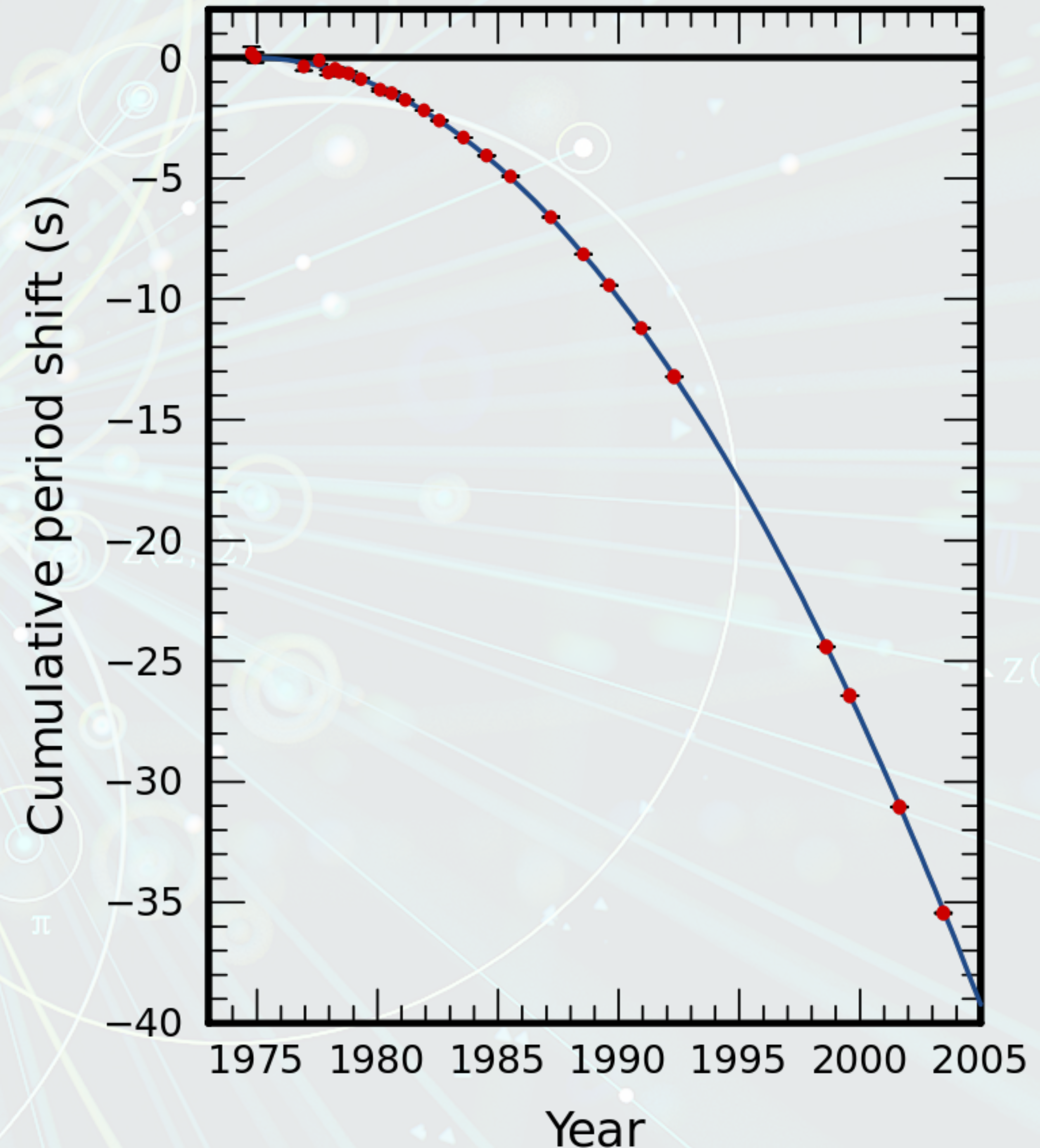


$$\tilde{G}_F(p) = \frac{1}{p^2 - m^2 + i\epsilon}$$



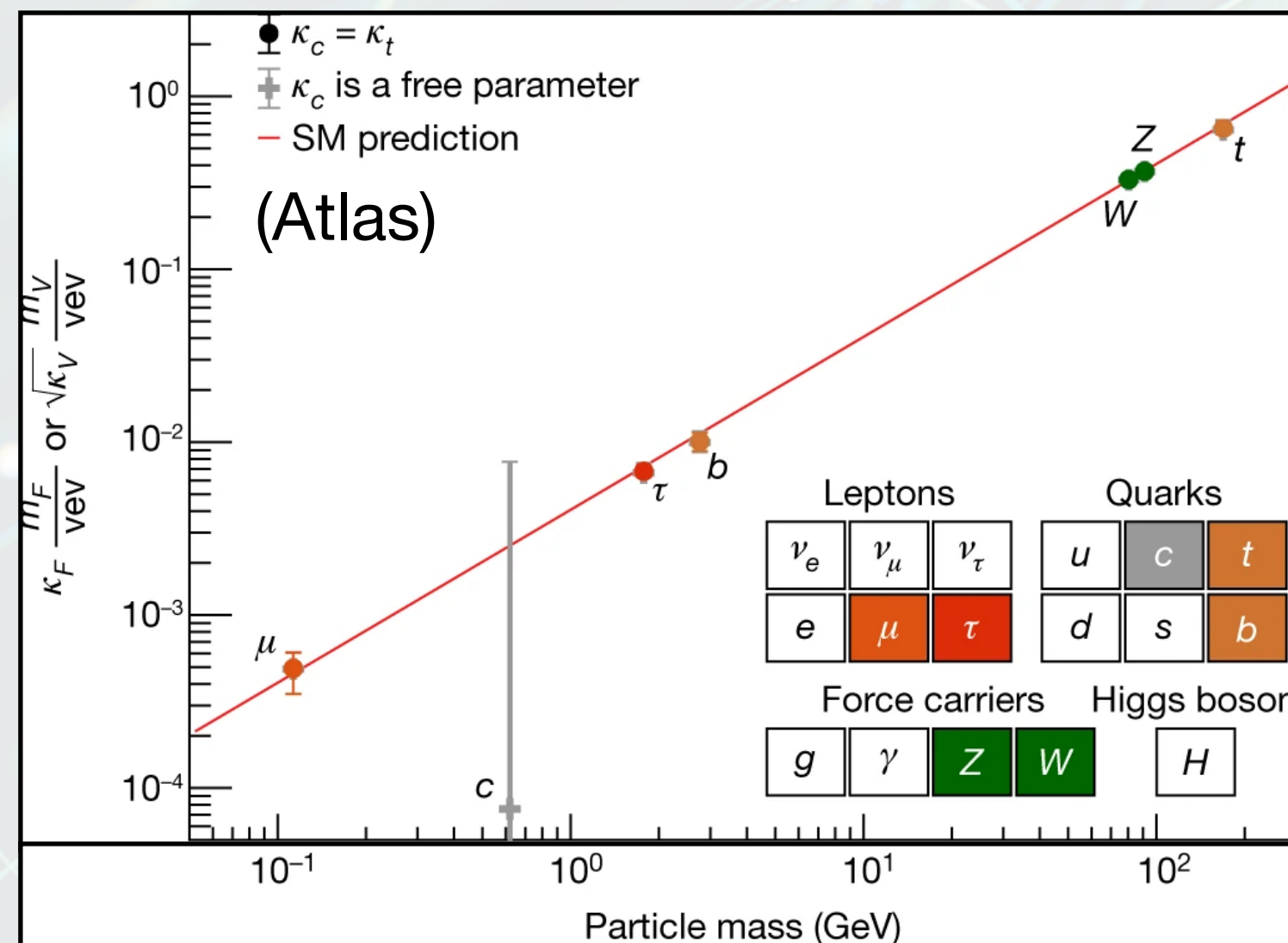
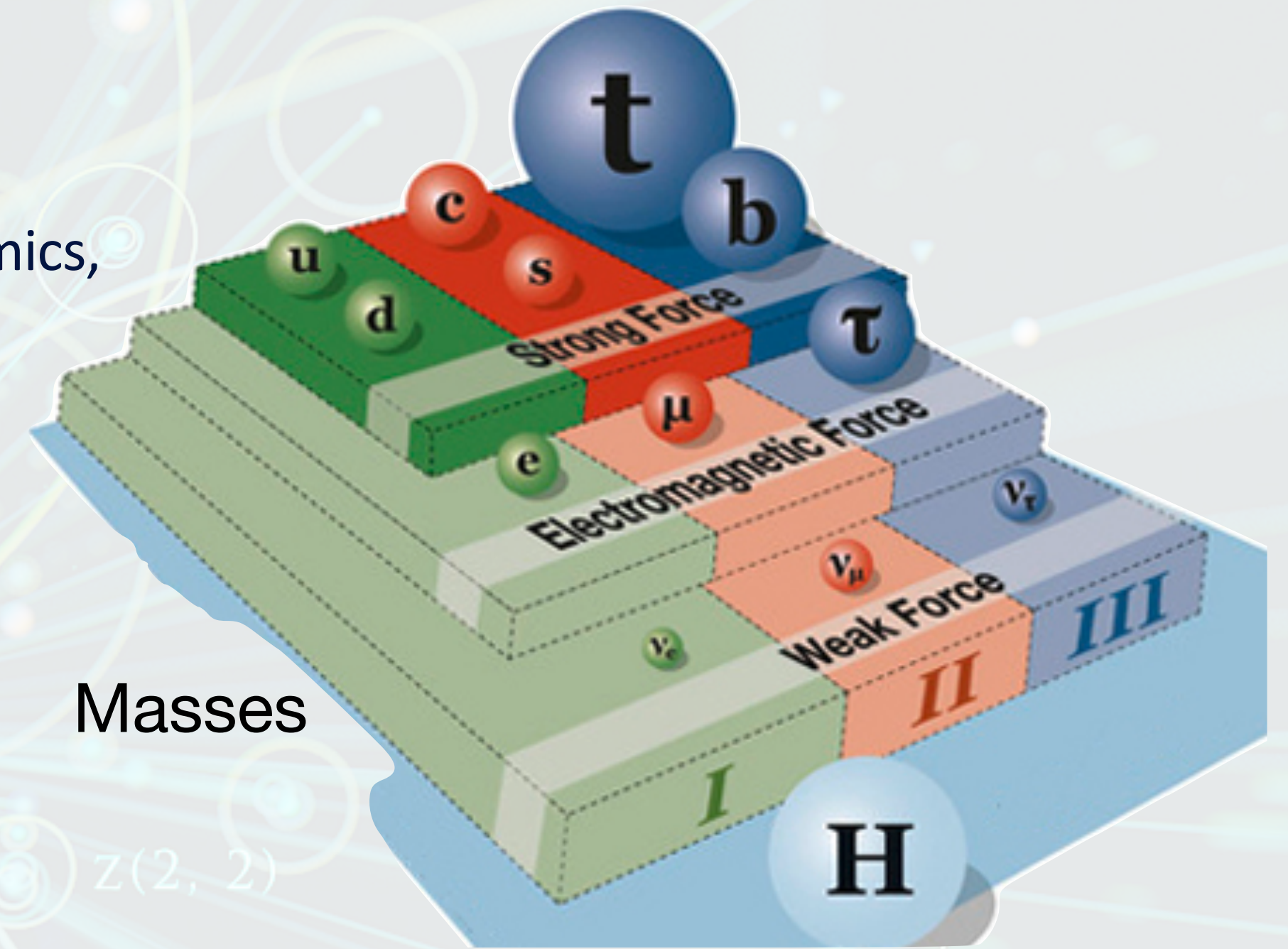
# Success of indirect detection

- **Charm quark:** suppression of  $K \rightarrow \mu\mu$  decays  
“a fourth quark would suppress FCNC” - GIM mechanism (1970)  
(discovered in 1974 in charmonium at Brookhaven / SLAC)
- **Beauty quark:** “need 3rd generation to explain CP violation” (1973)  
but ‘directly’ discovered in bottomonium (1977, Fermilab)
- **W/Z bosons:** “weak interaction seems left-handed” (1950s),  
direct discovery 1980s at SPS (CERN)
- **Top quark:** ‘must be heavy, fast neutral B oscillations’.  
Also W/Z mass, early 90s.  
direct discovery in 1995 (Tevatron)
- **Gravitational waves:** 1974  
Rotational energy loss in double-neutron star system  
PSR B1913+16

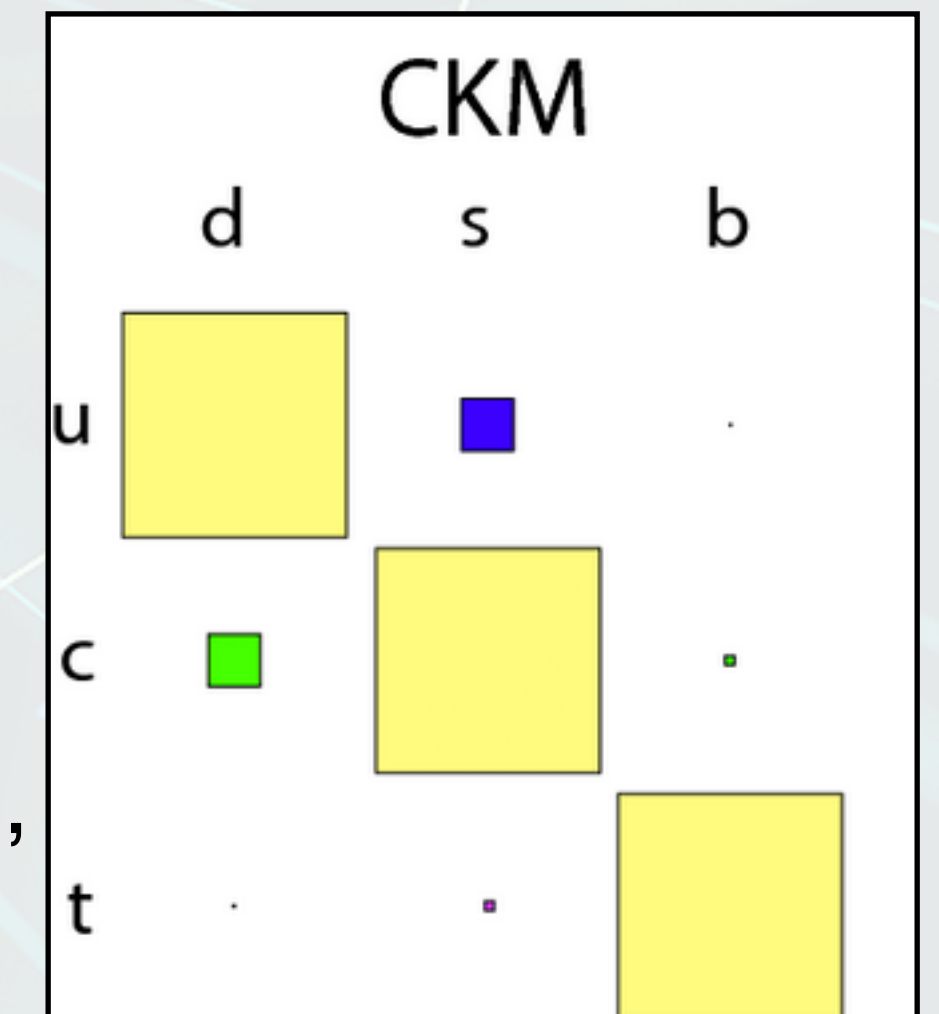


# Why Beauty

- **Strange** experiments have been done\*, **Charm** suffers from suppressed NP dynamics, Top is too heavy to form bound states
- Beauty has suppressed SM diagrams ( $V_{cb}$ ), large mixing parameters ( $\Delta m$ ), and high energy scales ( $q^2$ ) in decays  $\rightarrow$  up to 1000 TeV 'indirect' sensitivity
- Common BSM theories predict a stronger coupling to heavier flavours (& even 'flavour diagonal' theories create FCNC loops)
- **Theoretically calculable** due to heavy b quark factorisation (HQET, SCET, QCDf, ...)
- Clear signatures in detector due to long lifetimes
- ...

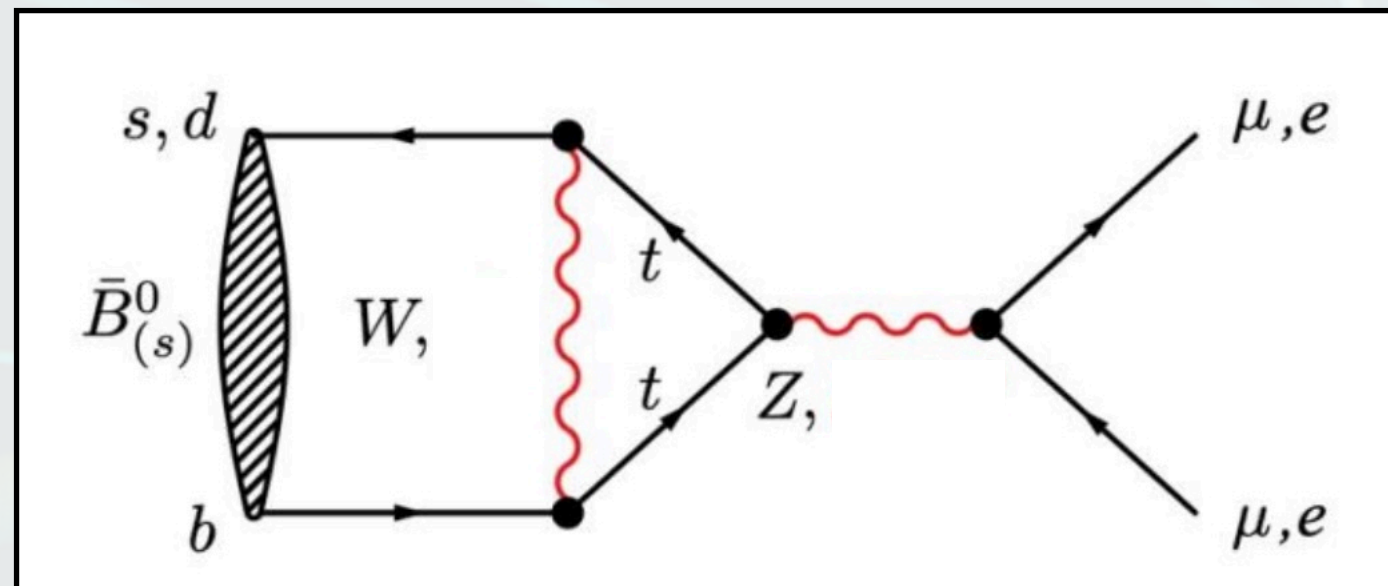


## Higgs coupling



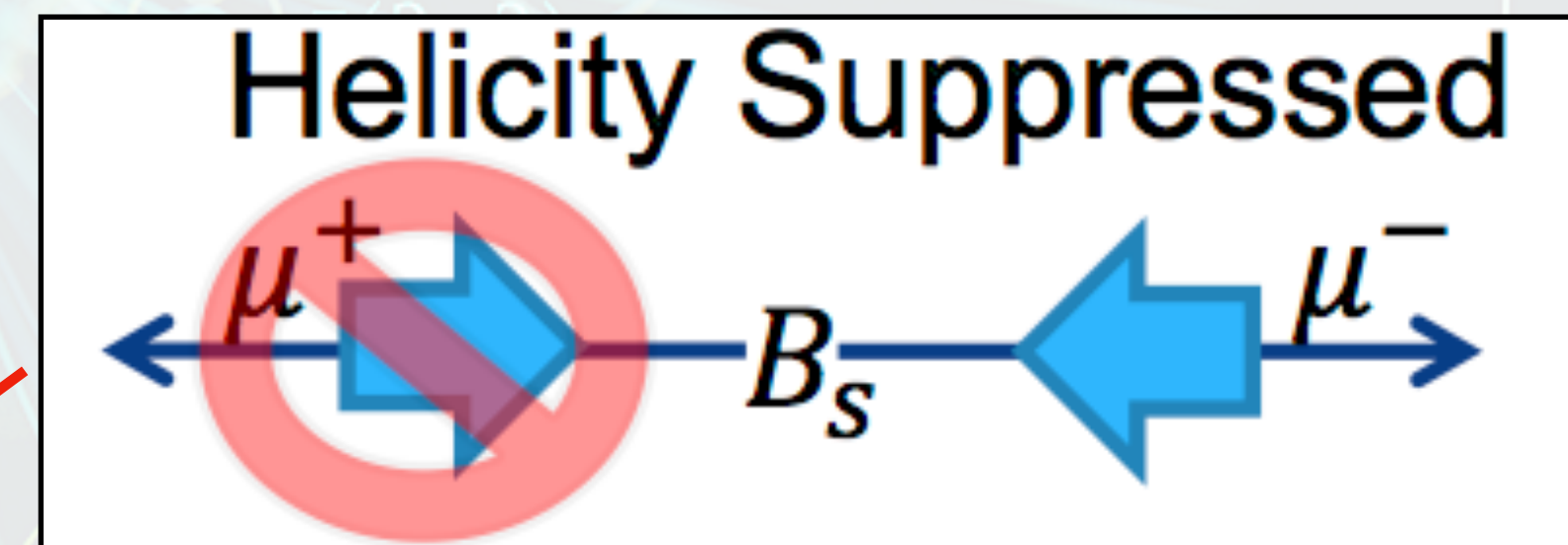
'Flavour changing'  $W^\pm$  interactions

# $B_s \rightarrow \mu\mu$ : why so rare?



~~Left-handed antimatter~~

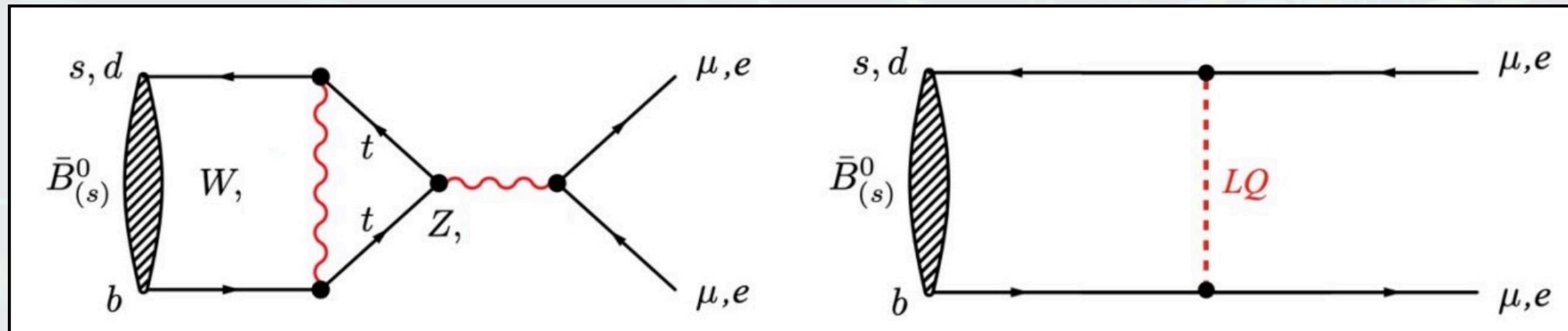
Left-handed matter



$$\mathcal{B} \propto |V_{tb}V_{tq}|^2 \left[ \left(1 - \frac{4m_\mu^2}{M_B^2}\right) |C_S - C'_S|^2 + |(C_P - C'_P) + \frac{2m_\mu}{M_B}(C_{10} - C'_{10})|^2 \right]$$

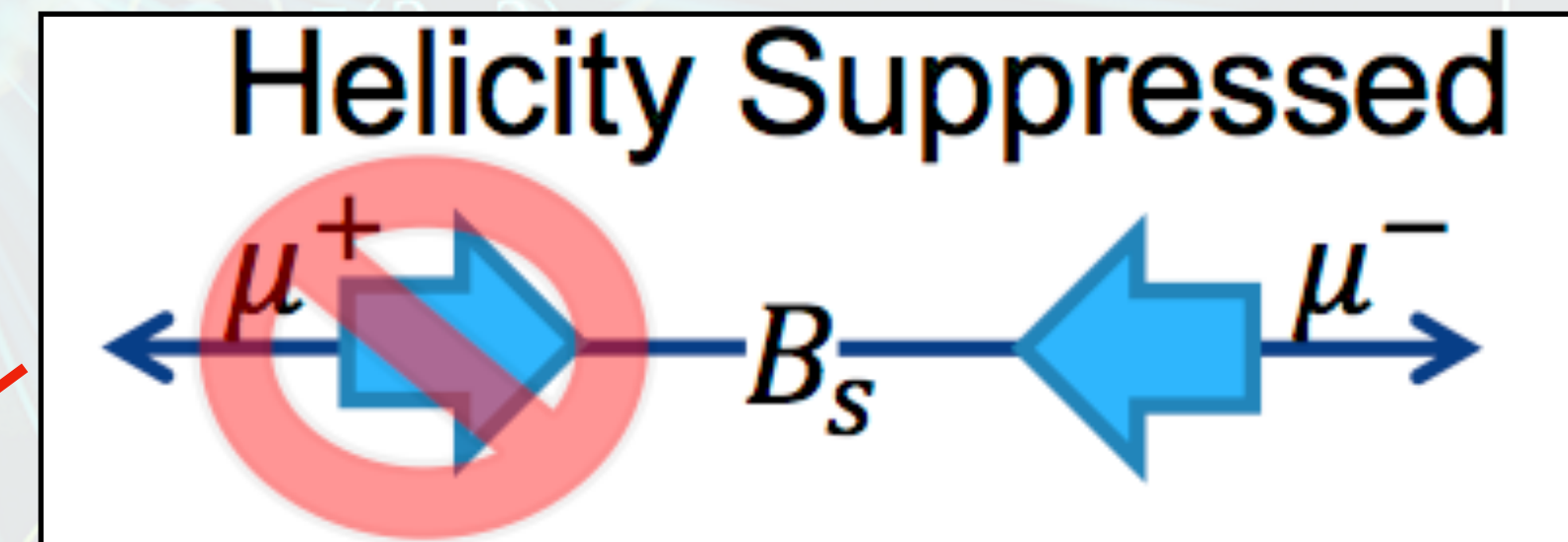
$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)_{\text{theory}} = (3.66 \pm 0.14) \times 10^{-9}$$

# $B_s \rightarrow \mu\mu$ : not so rare?



Left-handed antimatter

Left-handed matter



$$\mathcal{B} \propto |V_{tb}V_{tq}|^2 \left[ \left(1 - \frac{4m_\mu^2}{M_B^2}\right) |C_S - C'_S|^2 + |(C_P - C'_P) + \frac{2m_\mu}{M_B}(C_{10} - C'_{10})|^2 \right]$$

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)_{\text{theory}} = (3.66 \pm 0.14) \times 10^{-9} \quad ?$$

# LHCb experiment at CERN

$E = 13.000 \times m_p$   
Rate = 40 MHz

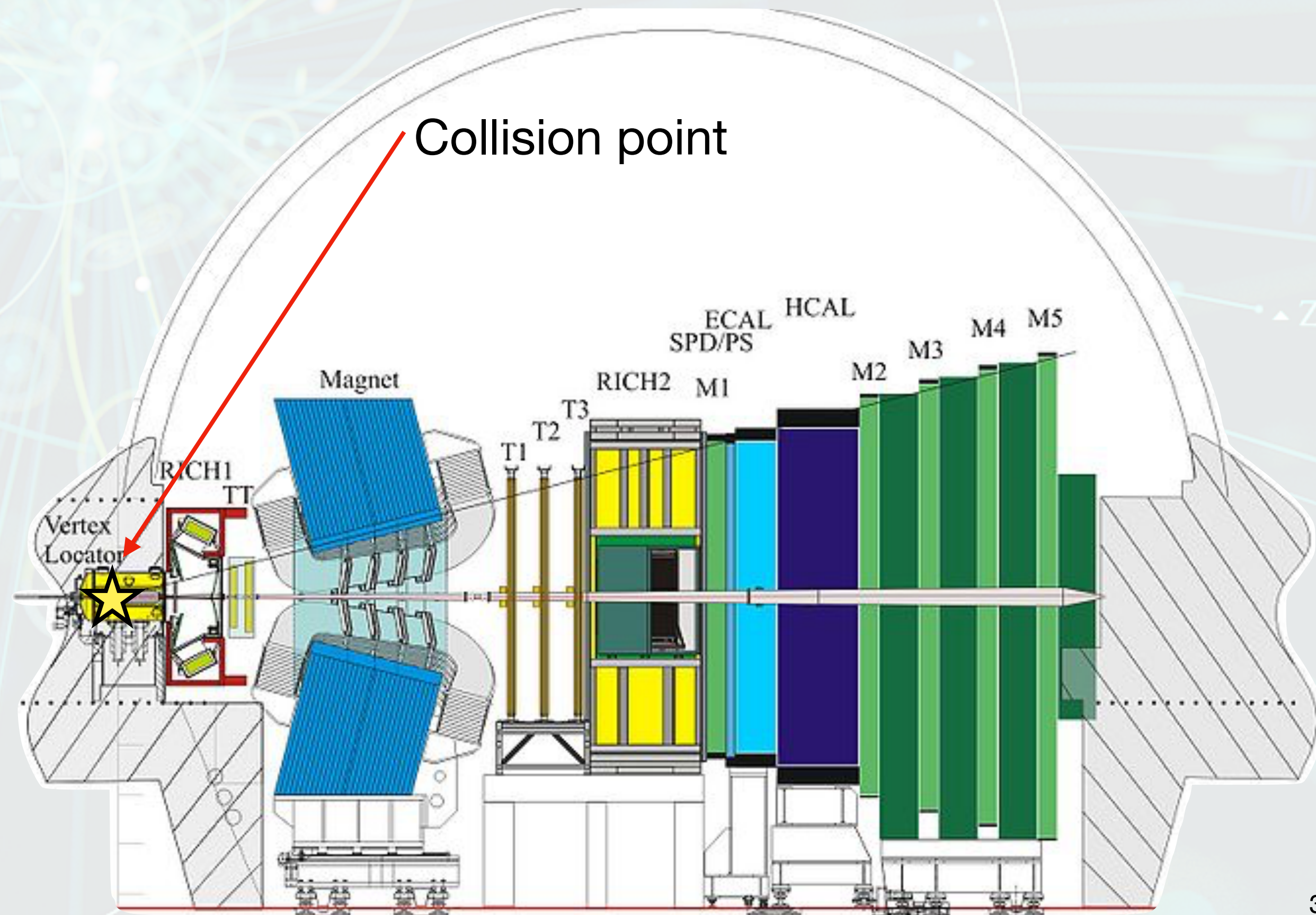


# Why a 'single arm forward spectrometer'

- protons colliding and making B's



$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$

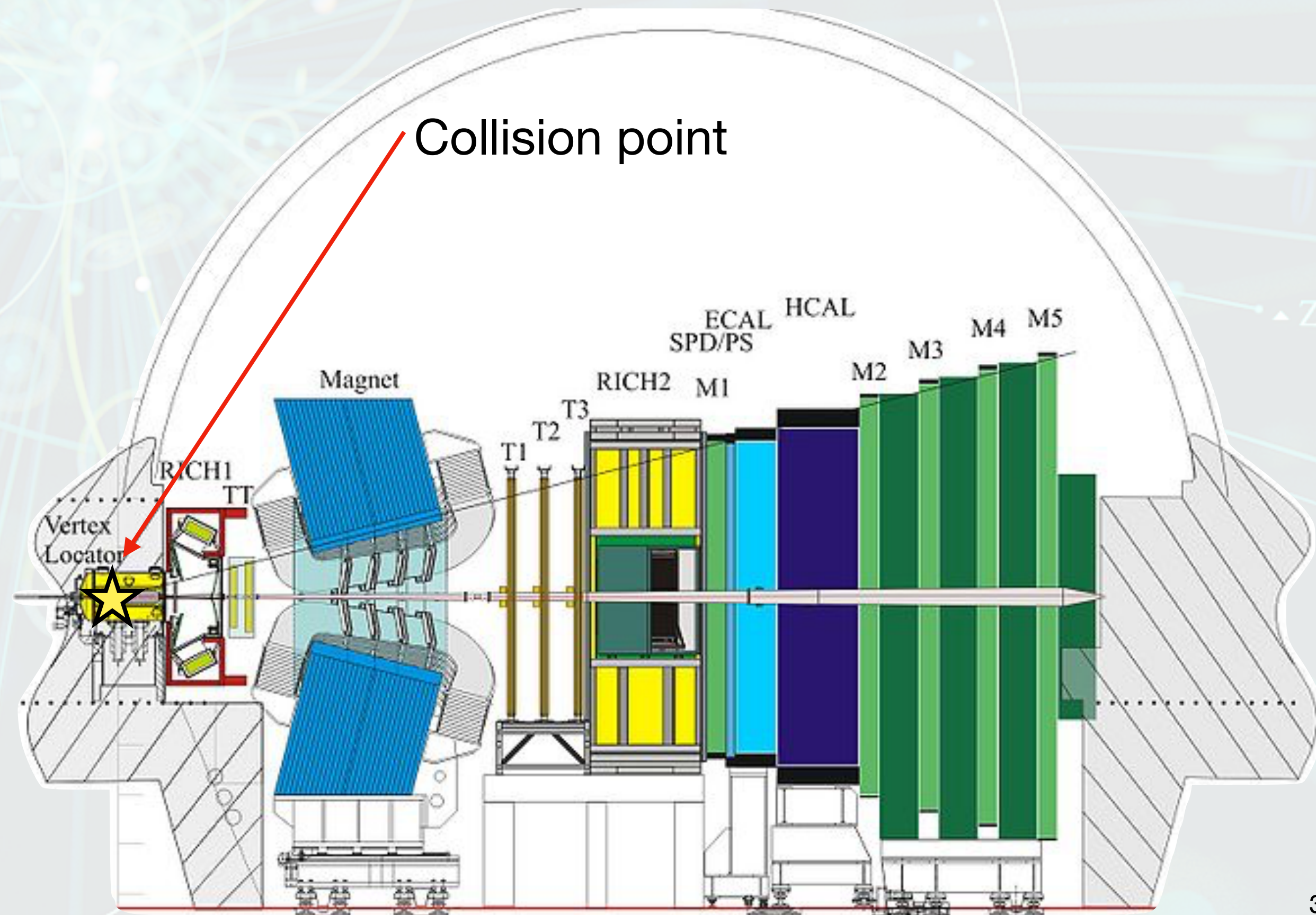
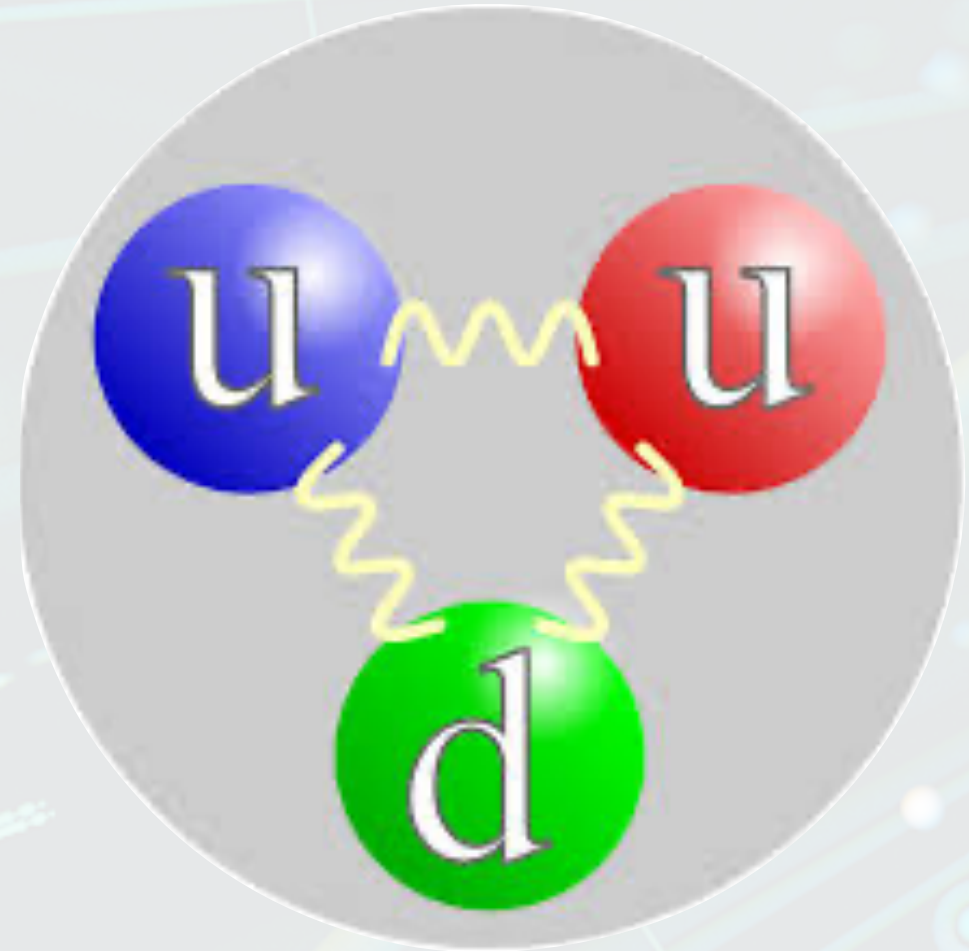


# Why a 'single arm forward spectrometer'

- protons colliding and making B's



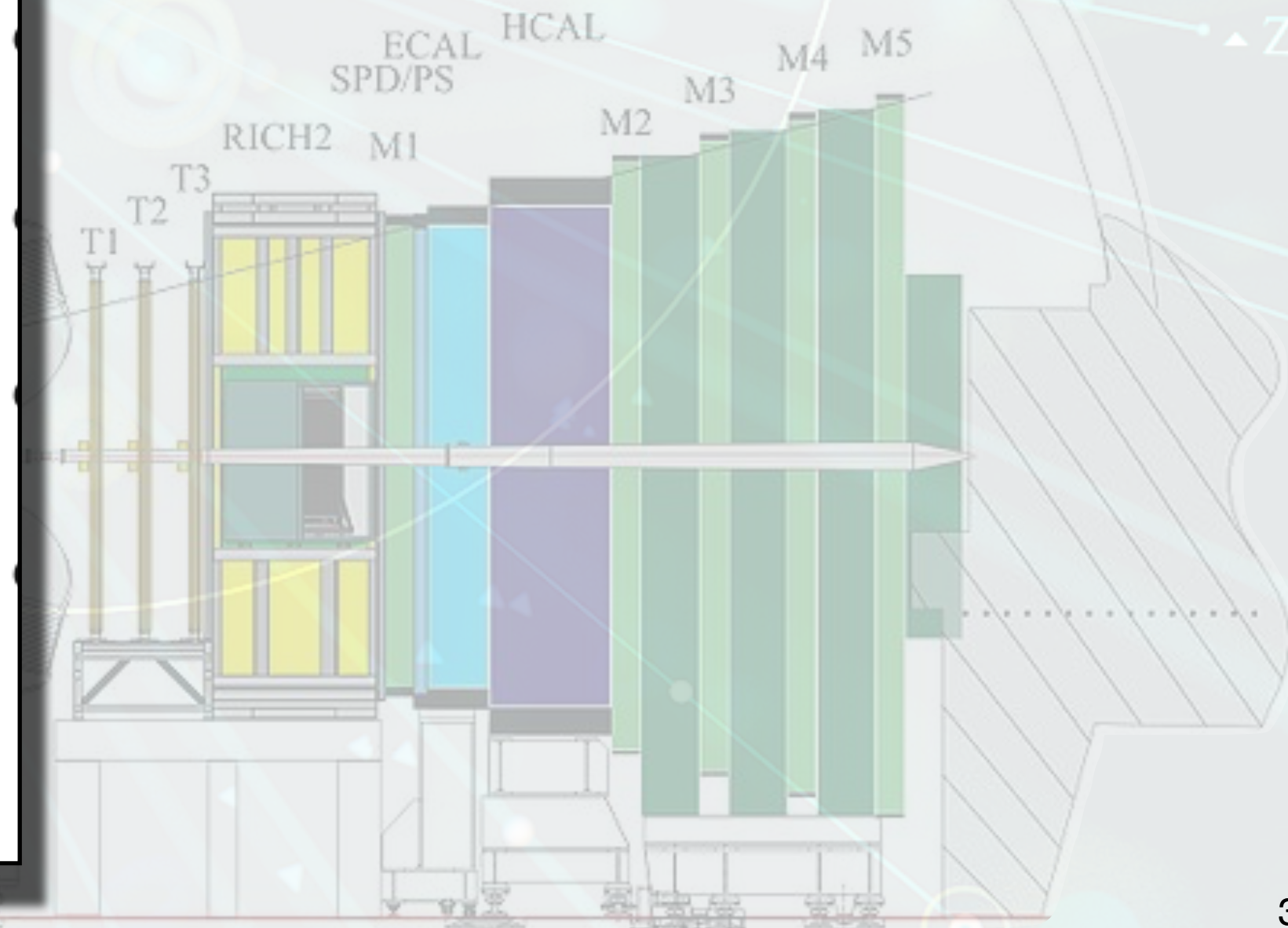
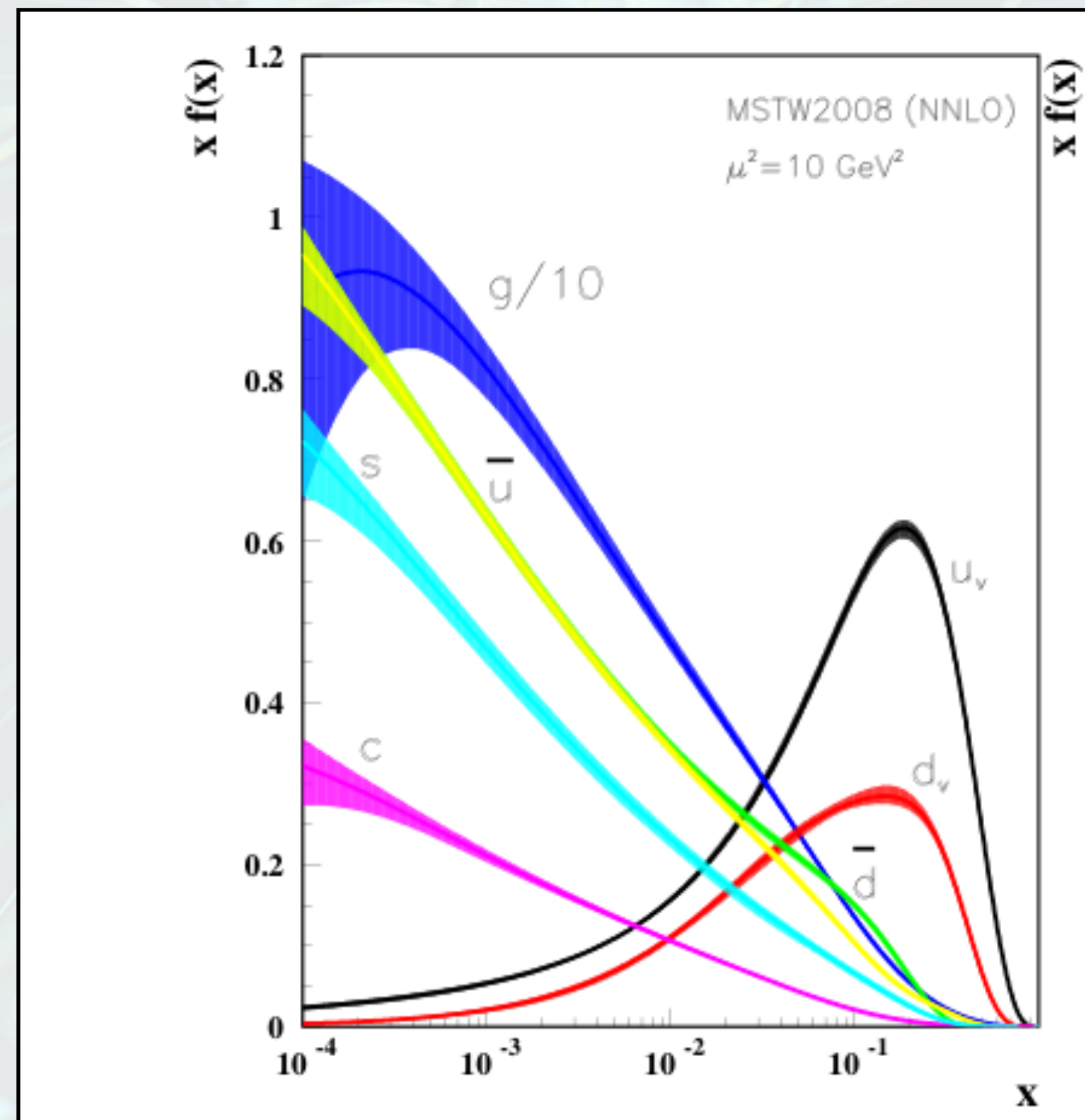
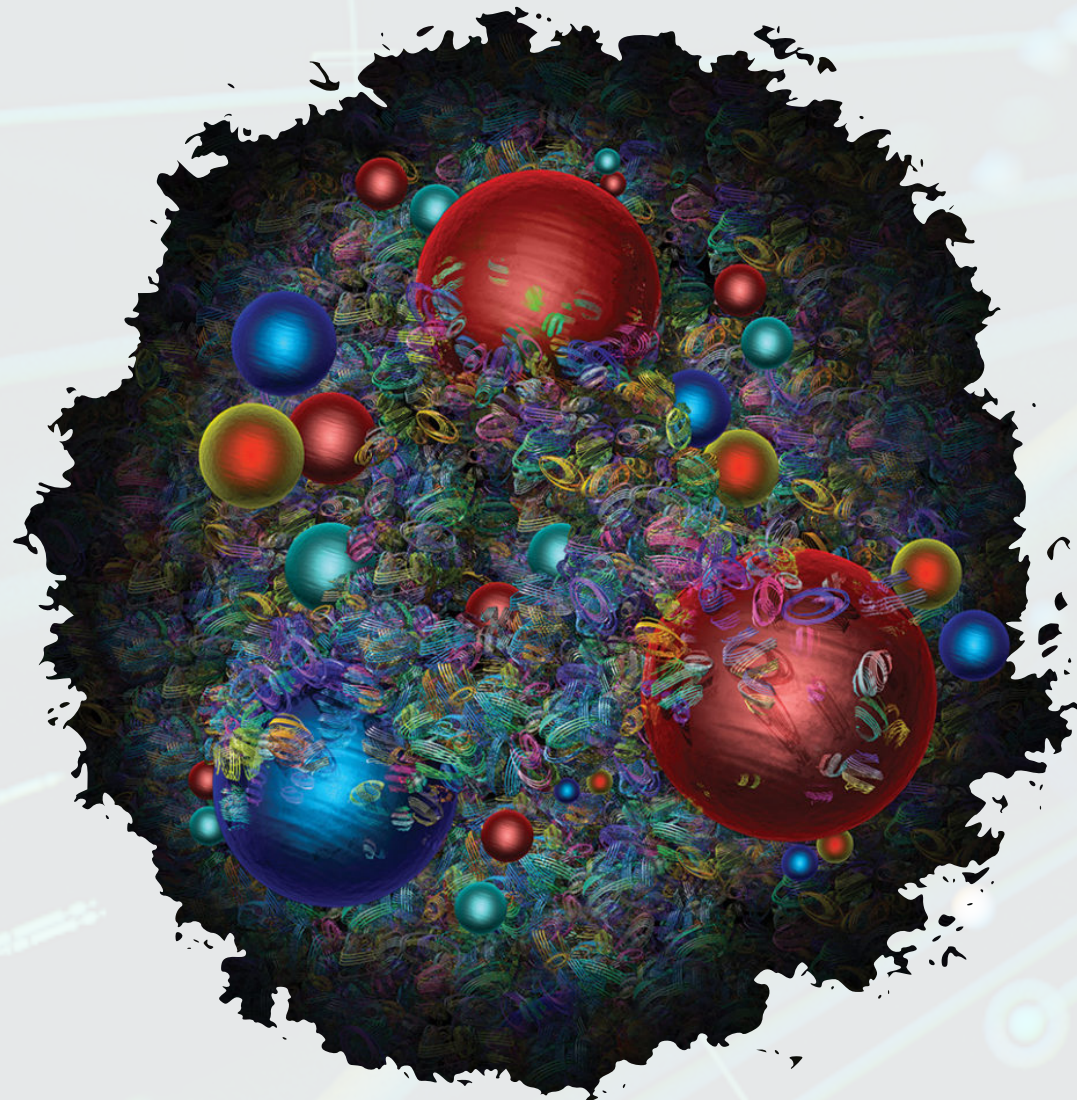
$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$




# Why a 'single arm forward spectrometer'

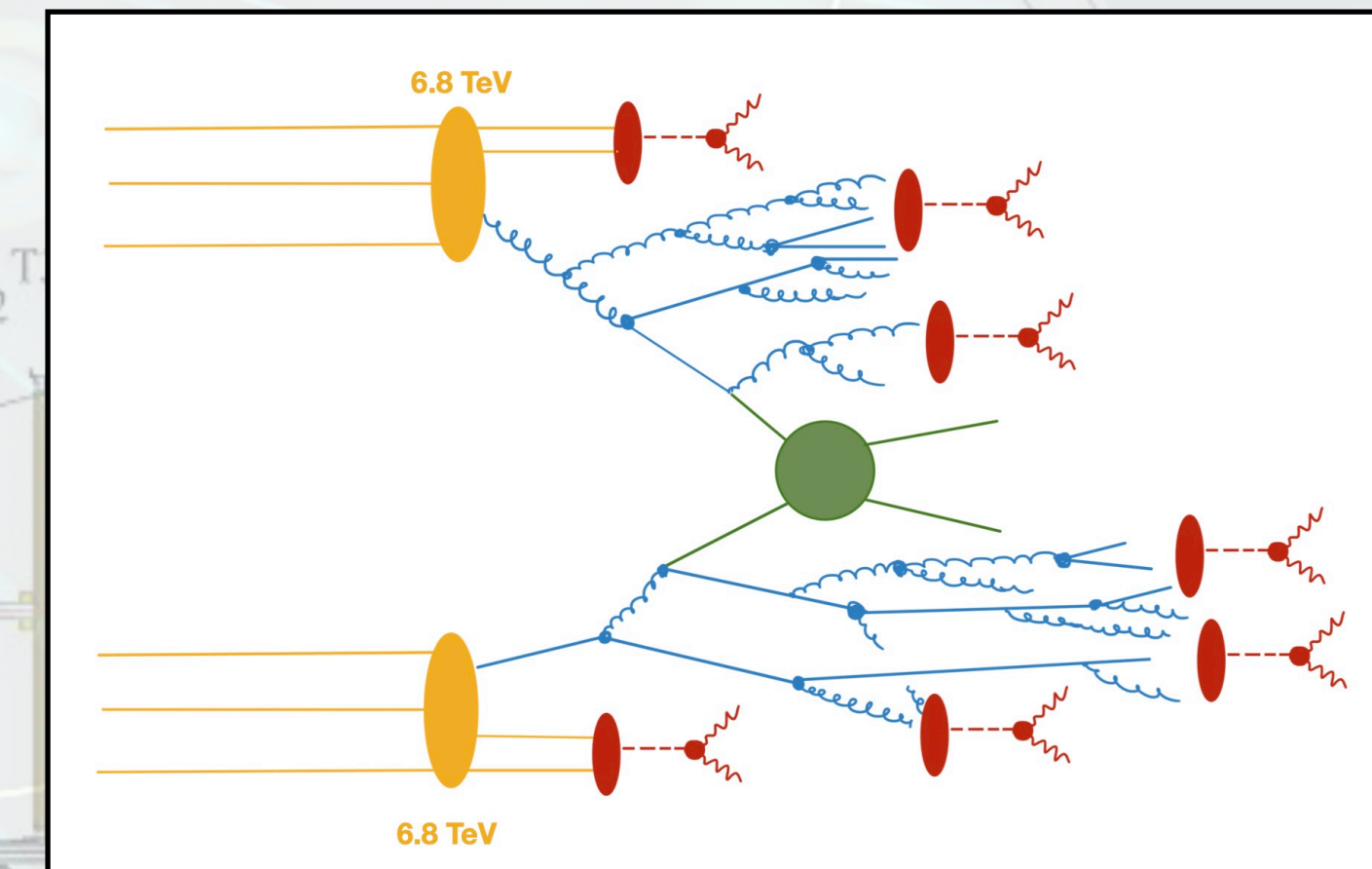
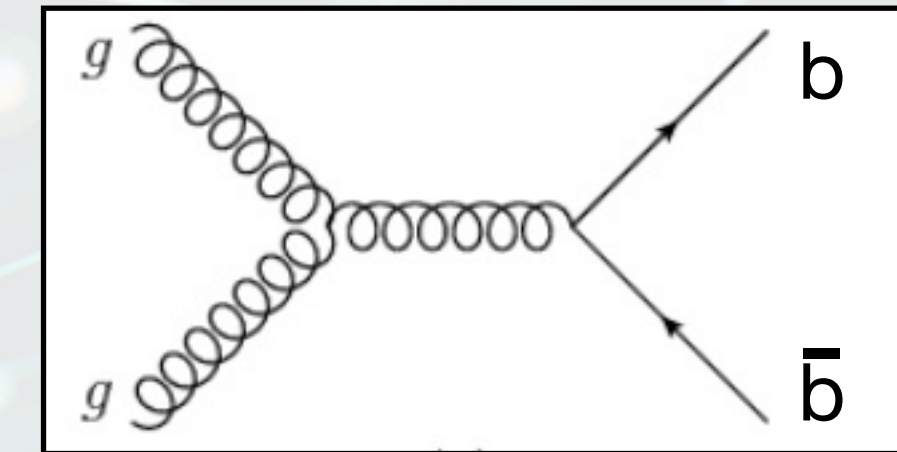
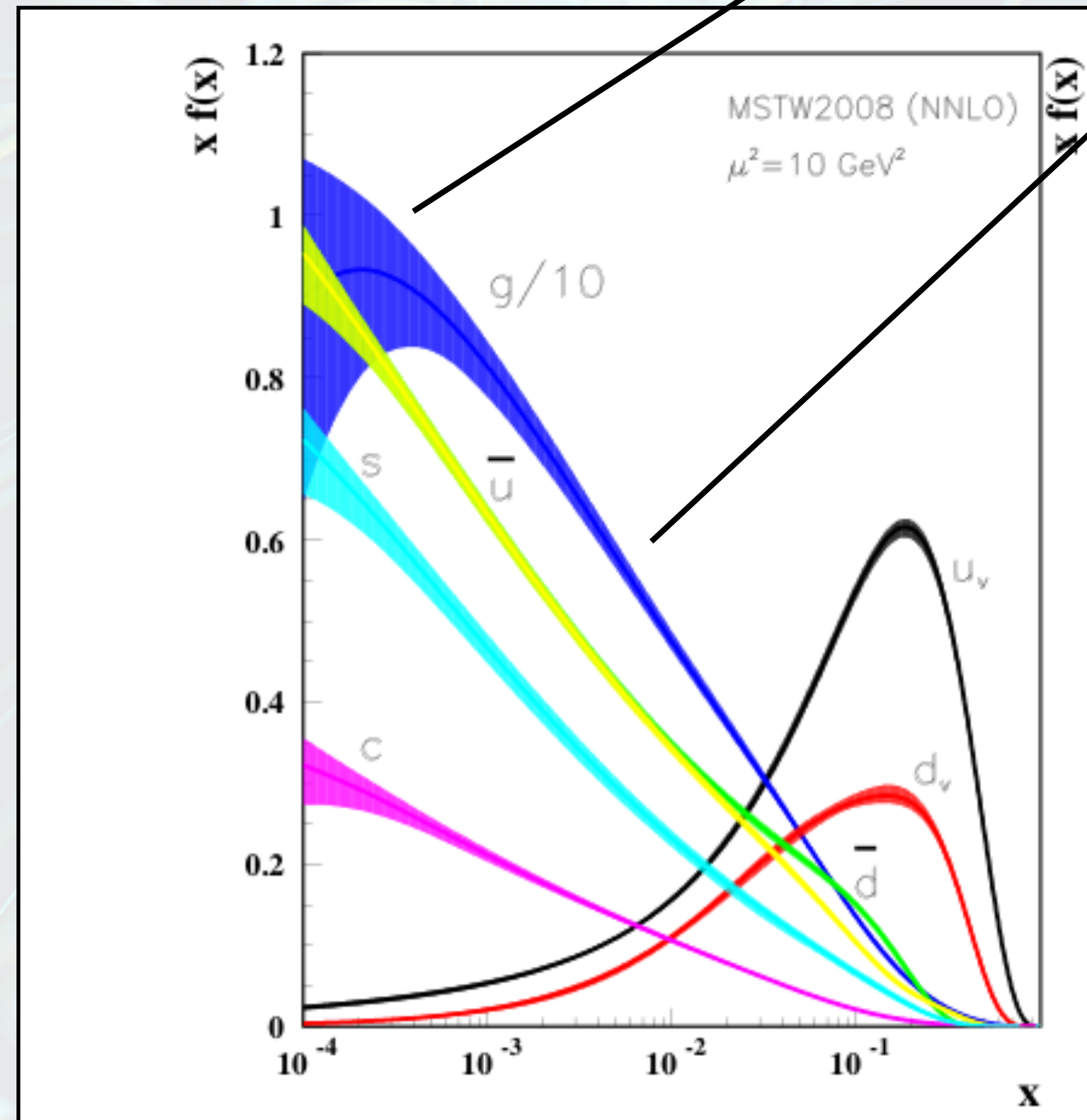
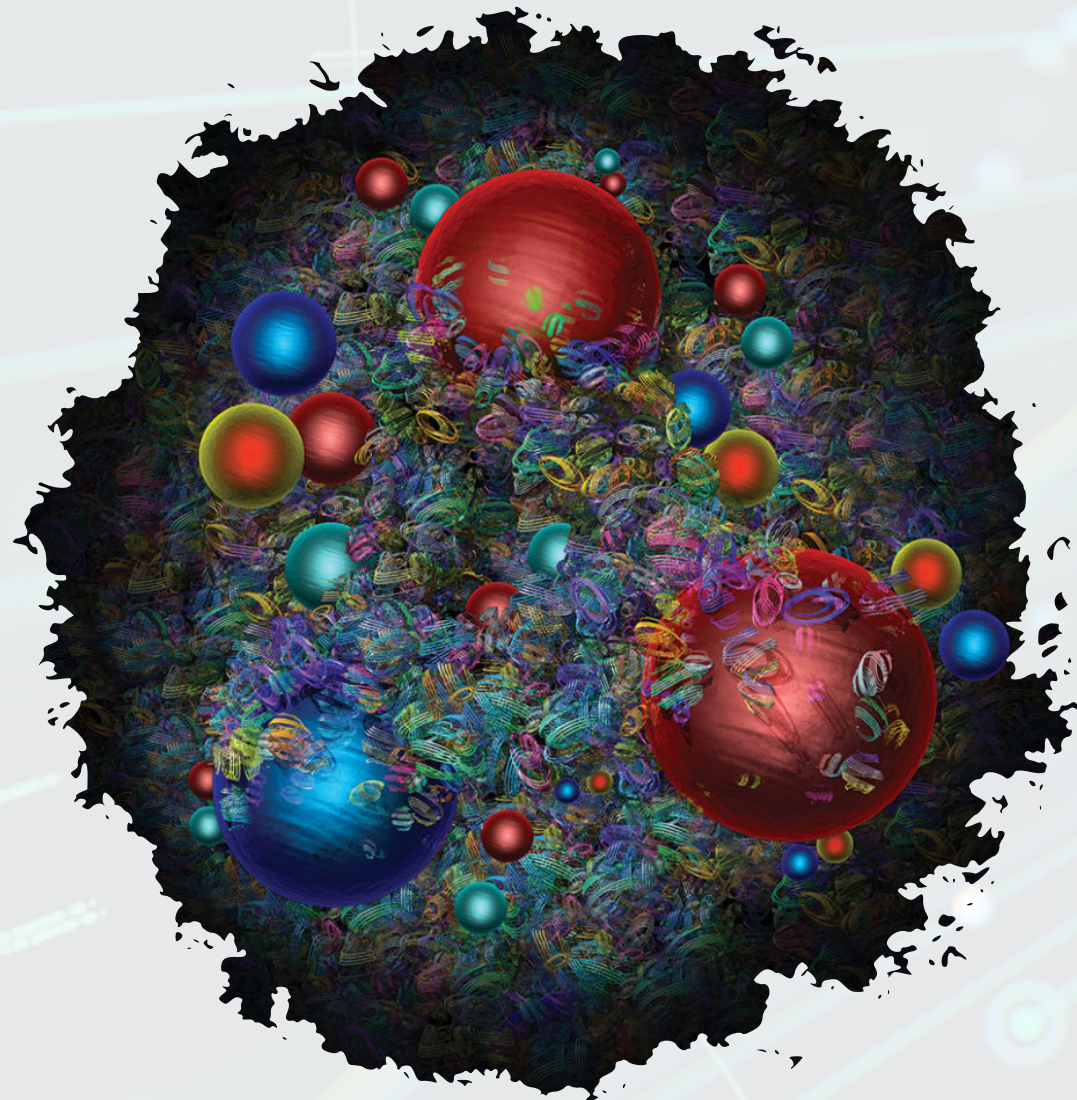
- protons colliding and making B's   
—> at high energies, gluons more likely

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$



# Why a 'single arm forward spectrometer'

- protons colliding and making B's 
- > at high energies, gluons more likely
- > non-equal gluon energies make highly boosted b-mesons
- > Collisions result in a 'hadronic mess'



# Reconstruction



Event 2208357  
Run 169080  
Fri, 04 Dec 2015 14:28:50

proton-proton collision  
creates O(100) particles

... leave Cherenkov  
radiation in gas

... are bent  
in magnetic field

... leave hits  
in silicon sensors  
or scintillating fibers

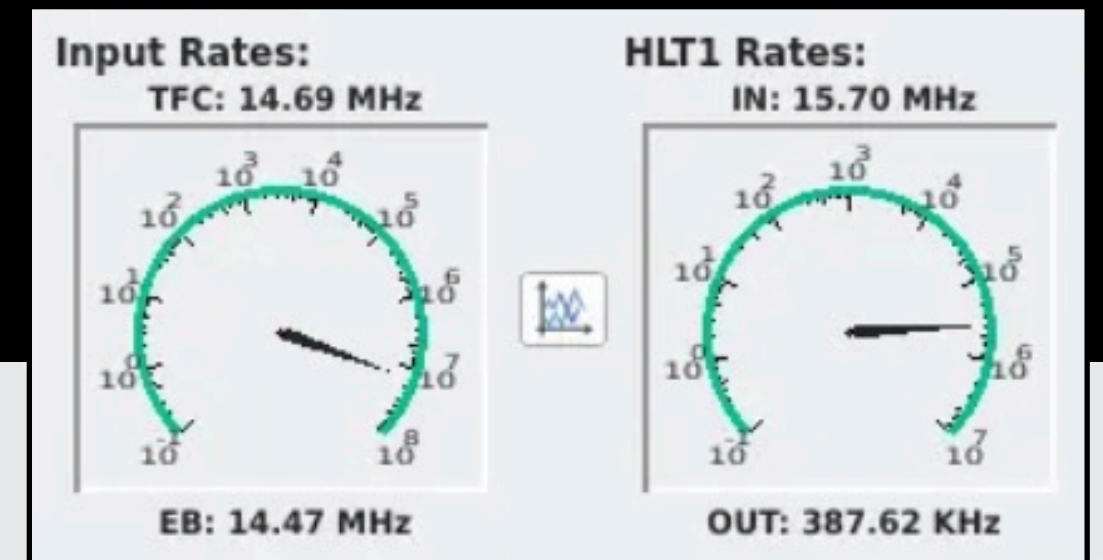
... smash  
into calorimeters

remaining muons  
hit muon stations  
(MWPC)

+ Front-end electronics  
send out data at 25ns clock

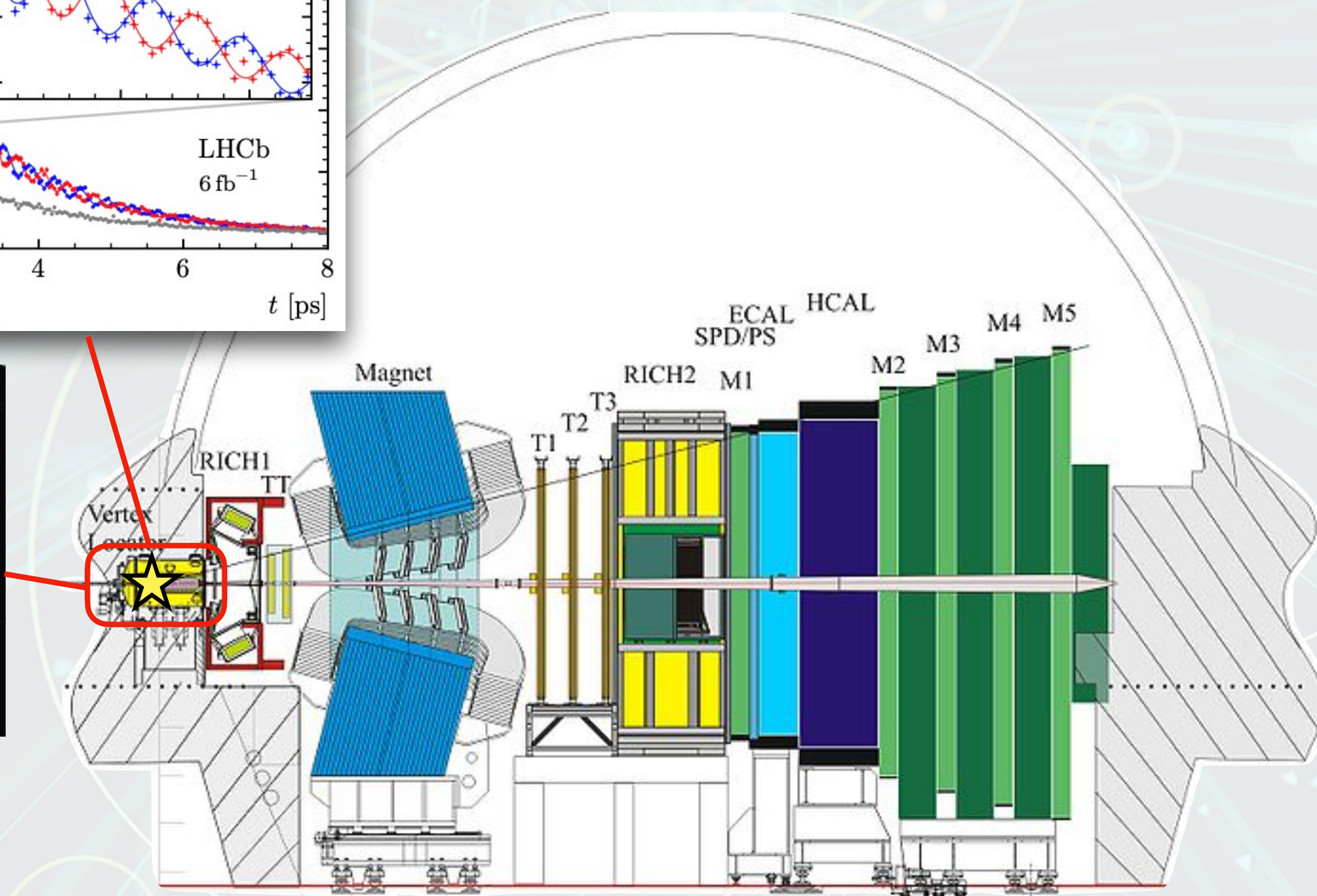
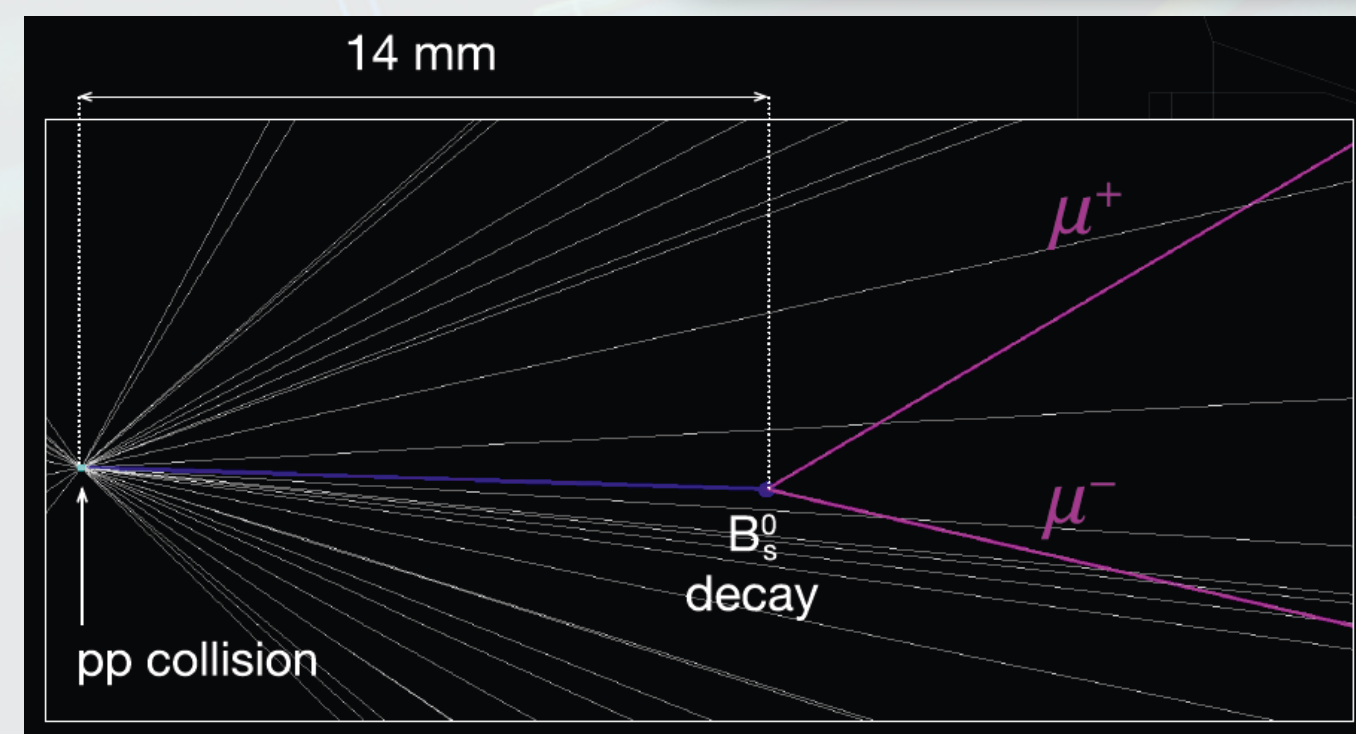
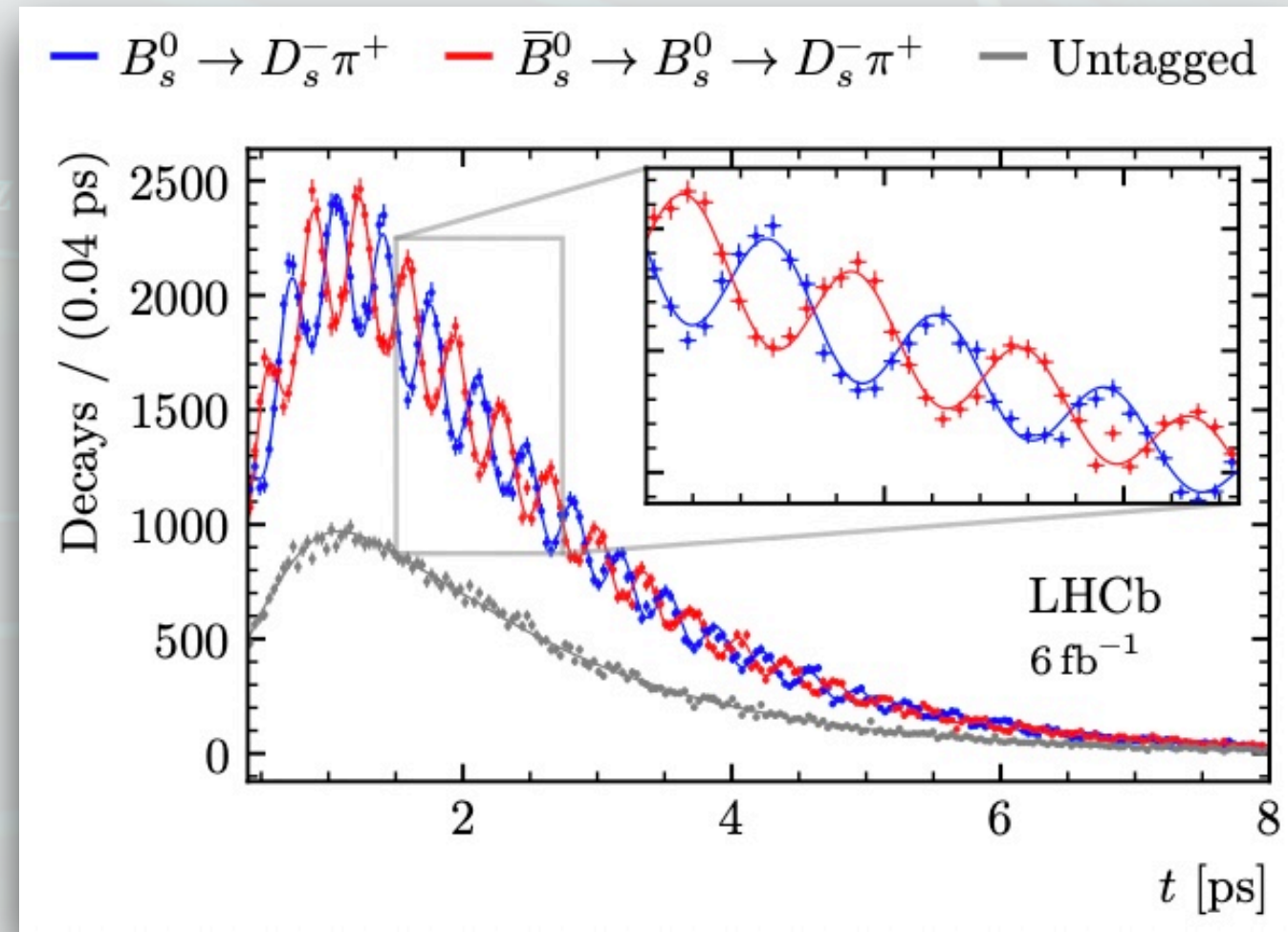
+ tell40 boards gather  
and pre-process data

+ event builder farm processes  
& GPUs reconstruct & trigger



# LHCb's excellence

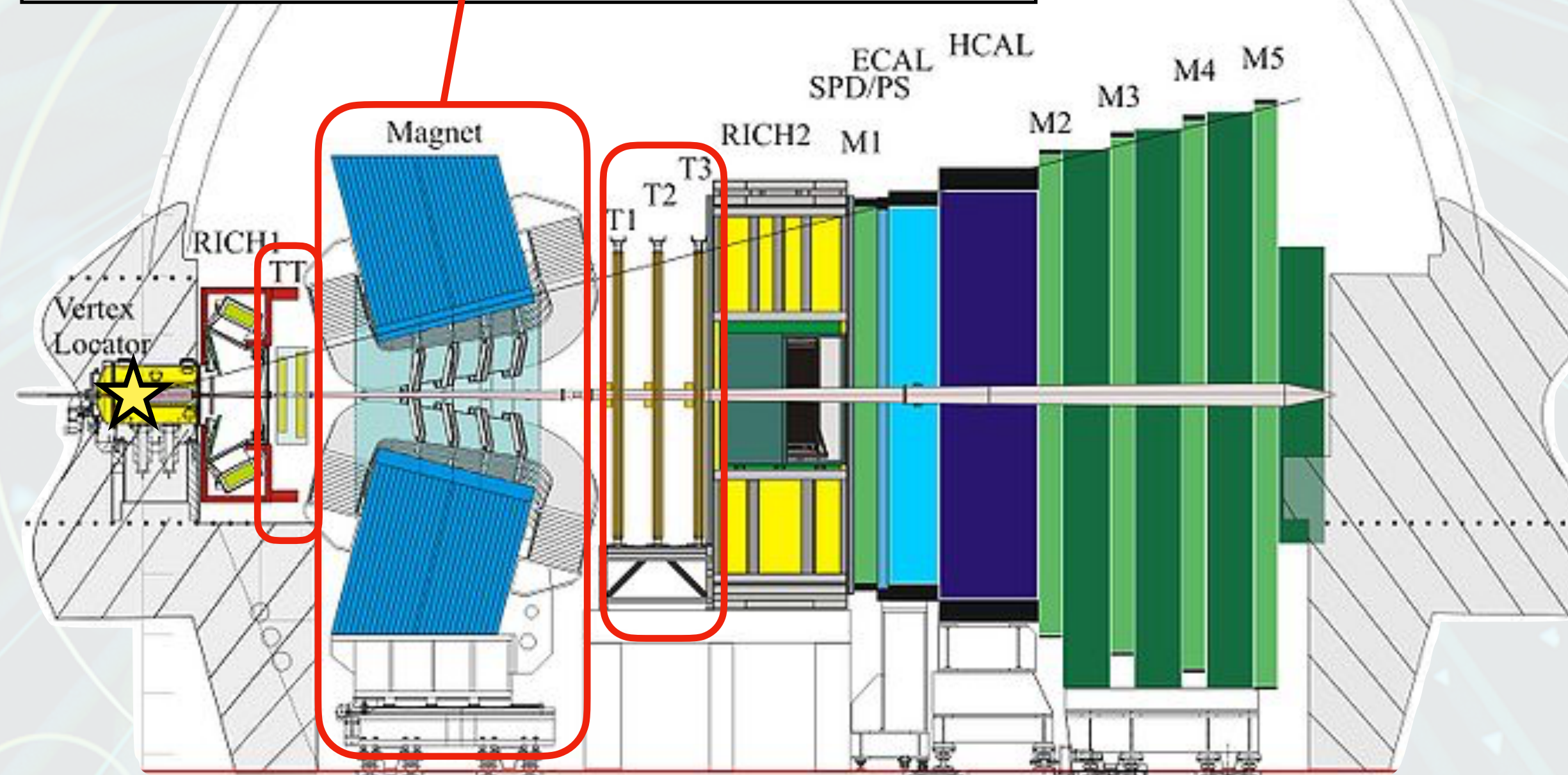
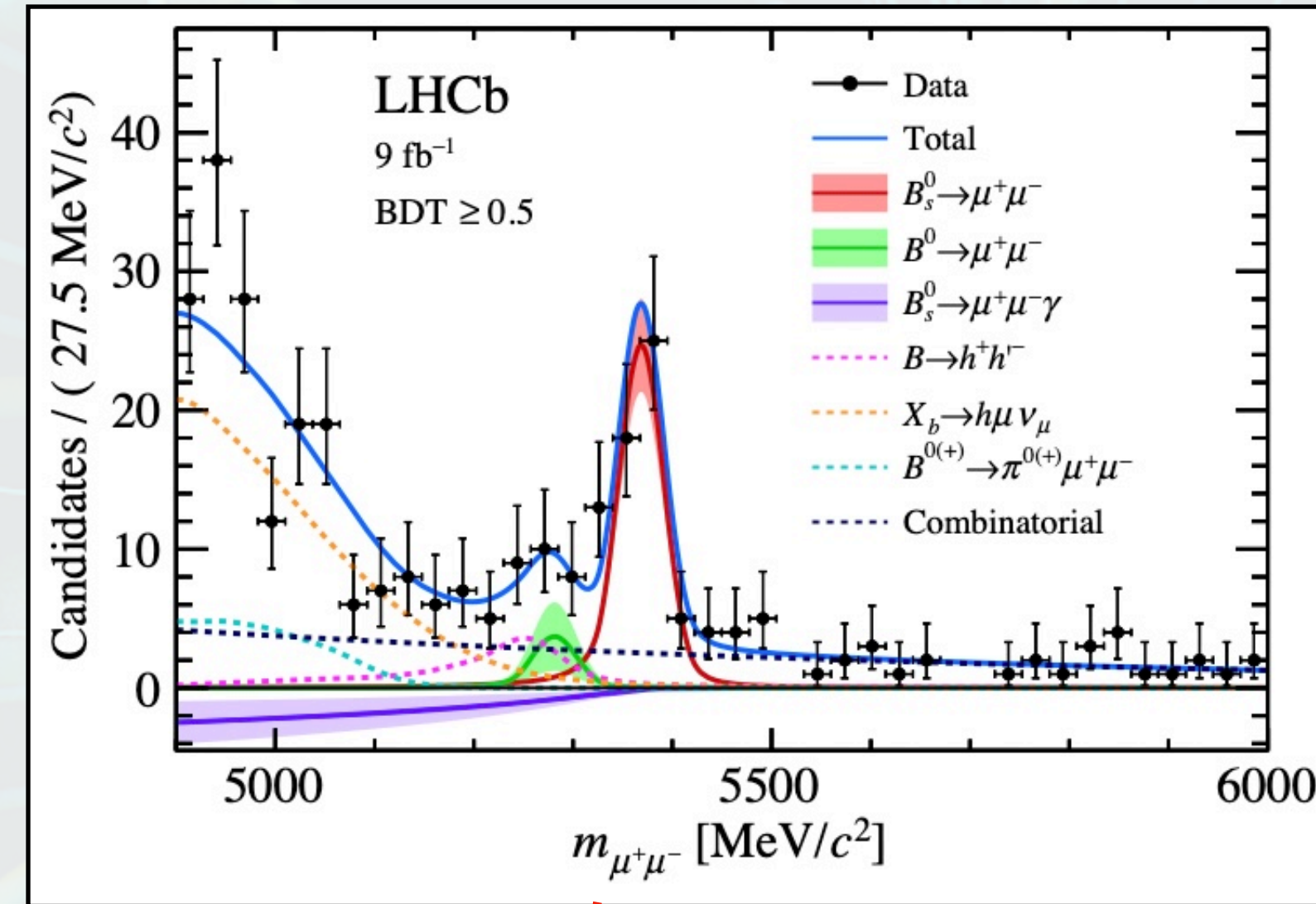
- Vertexing



# LHCb's excellence

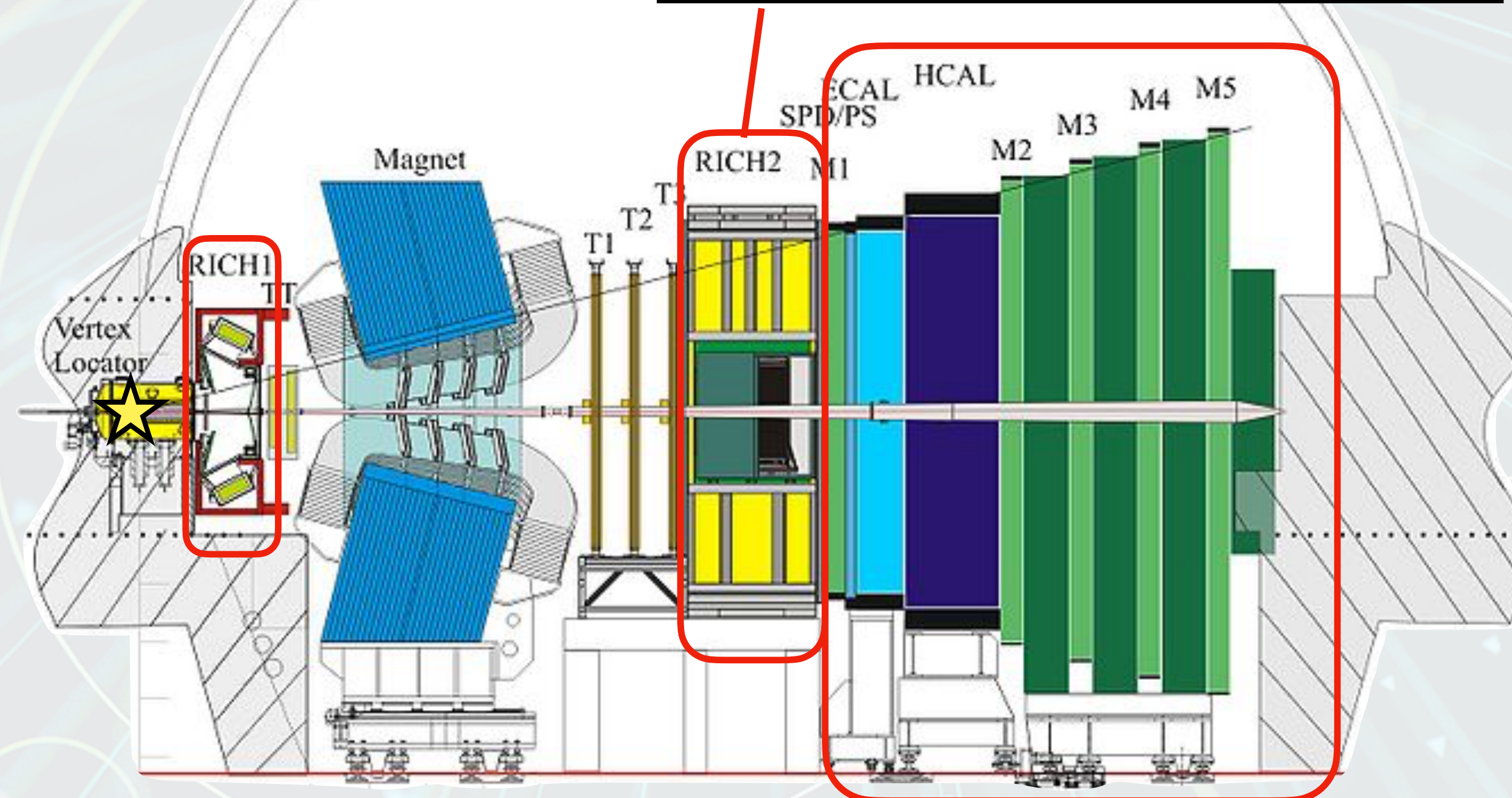
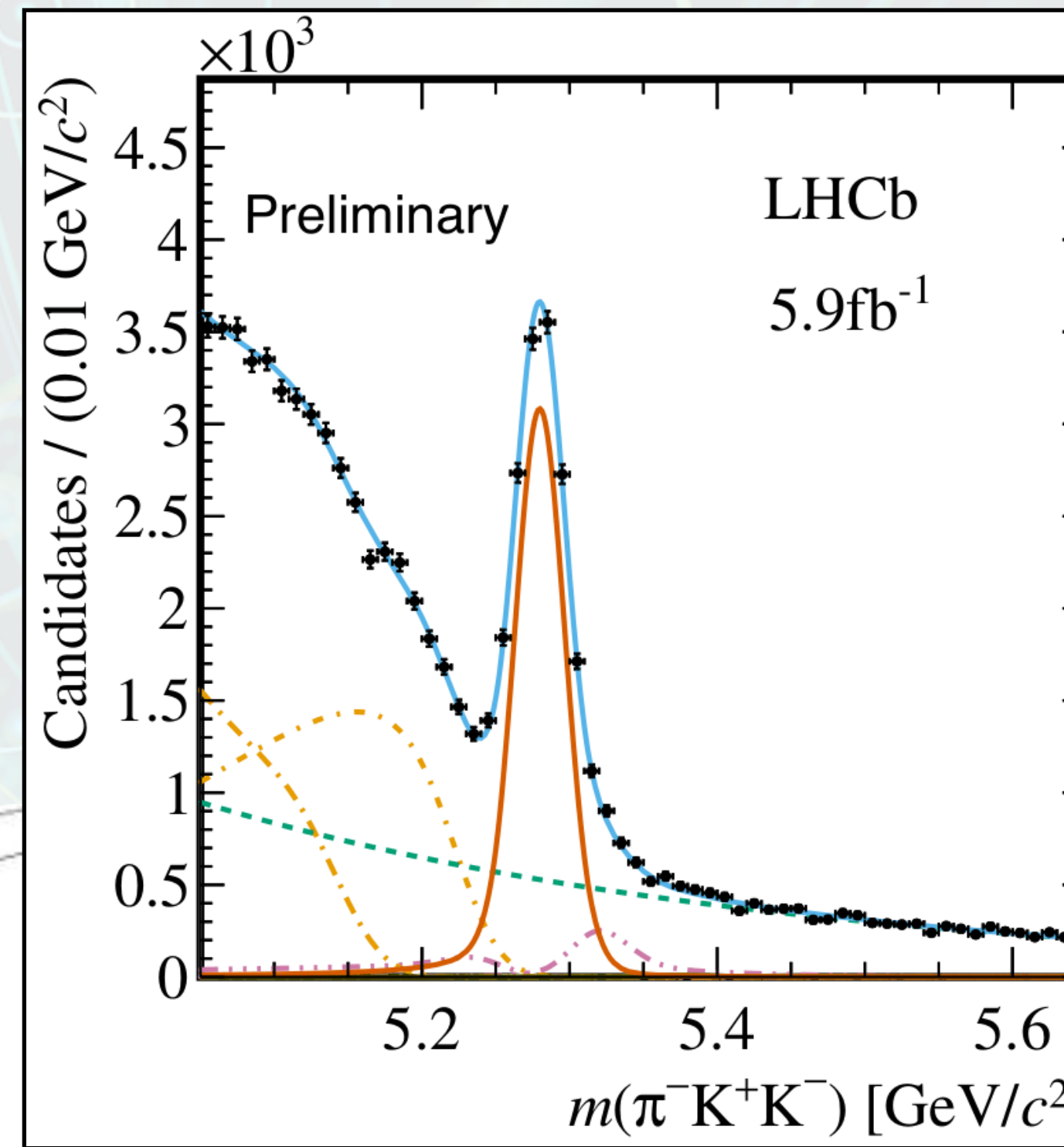
- Vertexing
- Tracking

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$



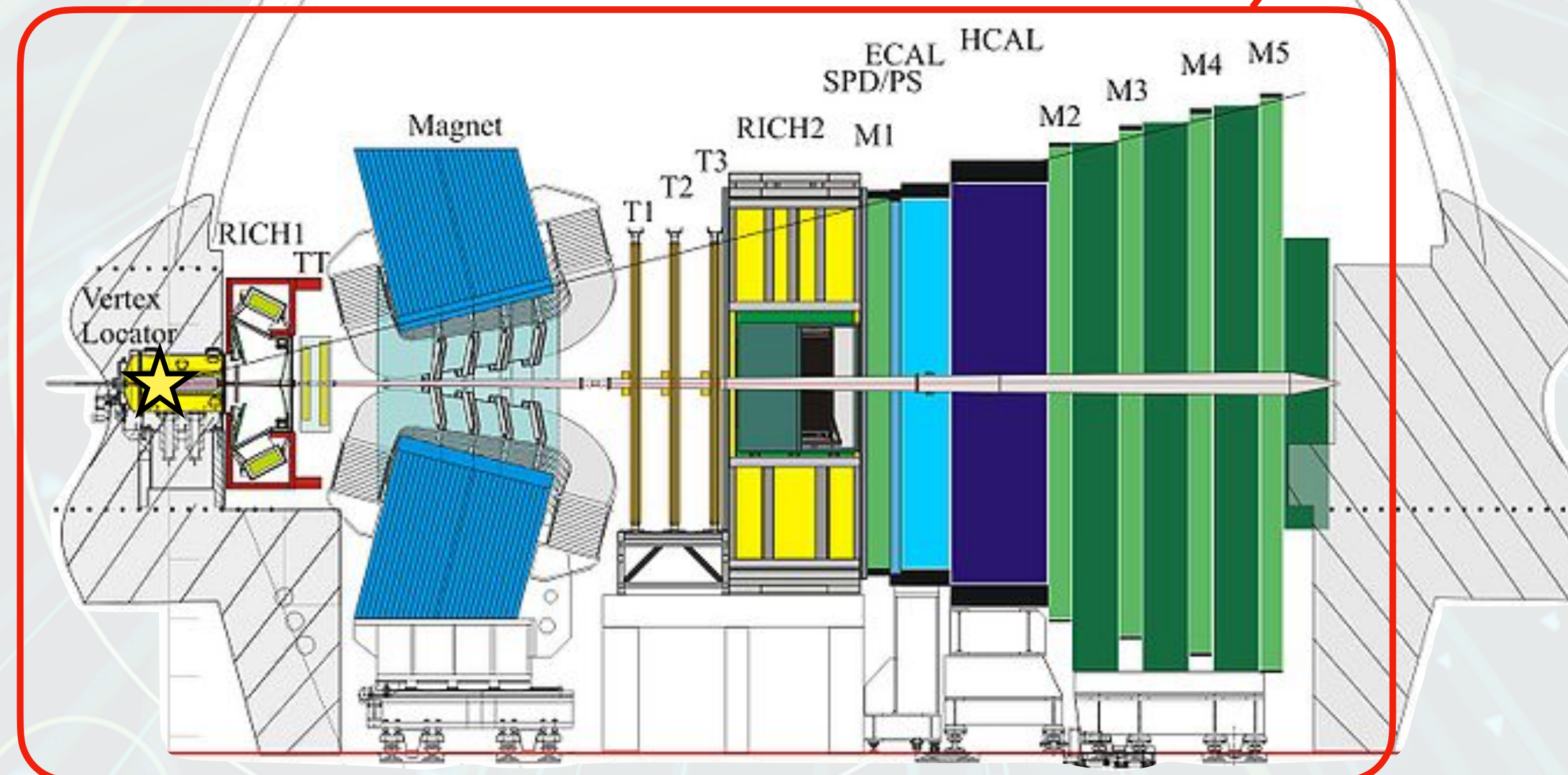
# LHCb's excellence

- Vertexing
- Tracking
- Particle ID  $\sum_{n=1}^{\infty} \frac{1}{n^2}$



# LHCb's excellence

- Vertexing
- Tracking
- Particle ID  $\sum_{n=1}^{\infty} \frac{1}{n^2}$
- Trigger  
(real-time reconstruction, GPU+CPU)



# LHCb operations

**System** State: LHCb RUNNING

**Auto Pilot** ON

**Sub-System State**

DCS	READY
DAI	READY
DAQ	RUNNING
RunInfo	RUNNING
TFC	RUNNING
EB-HLT1	RUNNING
Monitoring	RUNNING

**Run Info**

Run Number: 334909  
 Run Start Time: 30-Nov-2025 20:56:18  
 Run Duration: 000:56:06  
 Nr. Events: 48751236074  
 Step Nr: 0 To Go: 0

**Activity:** PHYSICS/IONS  
**Trigger Config:** hlt1\_PbPb\_PbSMOG\_2025\_v  
**Time Alignment:** TAE half window 3  
**Max Nr. Events:** 0  
**Automated Run with Steps:** 0 Steps

**Input Rates:** TFC: 14.69 MHz  
**HLT1 Rates:** IN: 15.70 MHz  
**Dead Time:** 100%  
**Incompl. Evs:** 100%  
**EB:** 14.47 MHz  
**OUT:** 387.62 KHz

**Alignment & Calibration:** Velo Tracker Rich1 Rich2 Muon Calo  
**HLT2:** Runs/Files: 2841 / 9150561  
 Processing: 0.0%  
 Disk Usage: 45%  
 Farm Node Status: 1

**Sub-Detectors:** VELO VELOC UTA UTC SFA SFC RICH1 RICH2 ECAL HCAL  
 MUONA MUONC PLUME

Run control

**System** State: Big Brother READY

**Sub-System State**

LHC	PHYSICS
SBCM	READY
Magnet	READY
LHCb Clock	EXTERNAL

**Handshakes** LHC LHCb  
 Com: STANDBY VETO

**Voltages**

System	State	Requested	Settings		
LHCb_LHC_HV	OK	PHYSICS	PHYSICS		
Sub-Detector	State	Req. HV	%Ok	HV State (A/C)	Settings
VELO_LHC_HV	OK	READY	99.04	READY	READY
UT_LHC_HV	OK	READY	100.00	READY	READY
SF_LHC_HV	OK	READY	100.00	READY	READY
RICH1_LHC_HV	OK	READY	100.00	READY	READY
RICH2_LHC_HV	OK	READY	100.00	READY	READY
ECAL_LHC_HV	OK	READY	100.00	READY	READY
HCAL_LHC_HV	OK	READY	100.00	READY	READY
MUON_LHC_HV	OK	READY	99.91	READY	READY
PLUME_LHC_HV	OK	READY	100.00	READY	READY

**Settings** Actions root

**LHC**  
 Mode: ION PHYSICS  
 Fill Number: 11359  
 Energy: 6800 GeV

**Magnet**  
 Set Current: 5849.9 A  
 Measured Current: 5850.0 A  
 Polarity: UP

**DB Interfaces**  
 Run DB Server: ON Cond DB Server: ON Archive Status: ON

**VELO Closing Manager**  
 Motion: ALLOWED  
 State: CLOSED  
 Beam Position: X: 0.25 mm, Y: 0.25 mm  
 Motion System Position: XA: 0.75 mm, XC: -0.25 mm, Y: 0.25 mm

**SMOG**  
 Regime: DISALLOWED  
 Shift Leader: ALLOWED  
 Injection: ALLOWED  
 SMOG2 ARGON Since: 2.6 hours

Big Brother

## Monitoring / Data quality

**OnlineMon/Shift/CALO**

ECAL ADC weighted position (Run = 334910)

ECAL LED ADCs (Run = 334910)

HCAL ADC weighted position (Run = 334910)

HCAL LED ADCs (Run = 334910)

Not Found: Hlt1P02GammaGamma/diphoton\_mass (Run = 334910)

**System Status** Running

04 Nov 2025 16:40:35

Learn Position Right IP6  
 Yellow: golden orbit from LHC

Beam 1 H (cm) -0.375  
 Beam 2 H (cm) -0.387  
 Beam 1 V (cm) 7.730  
 Beam 2 V (cm) -0.978

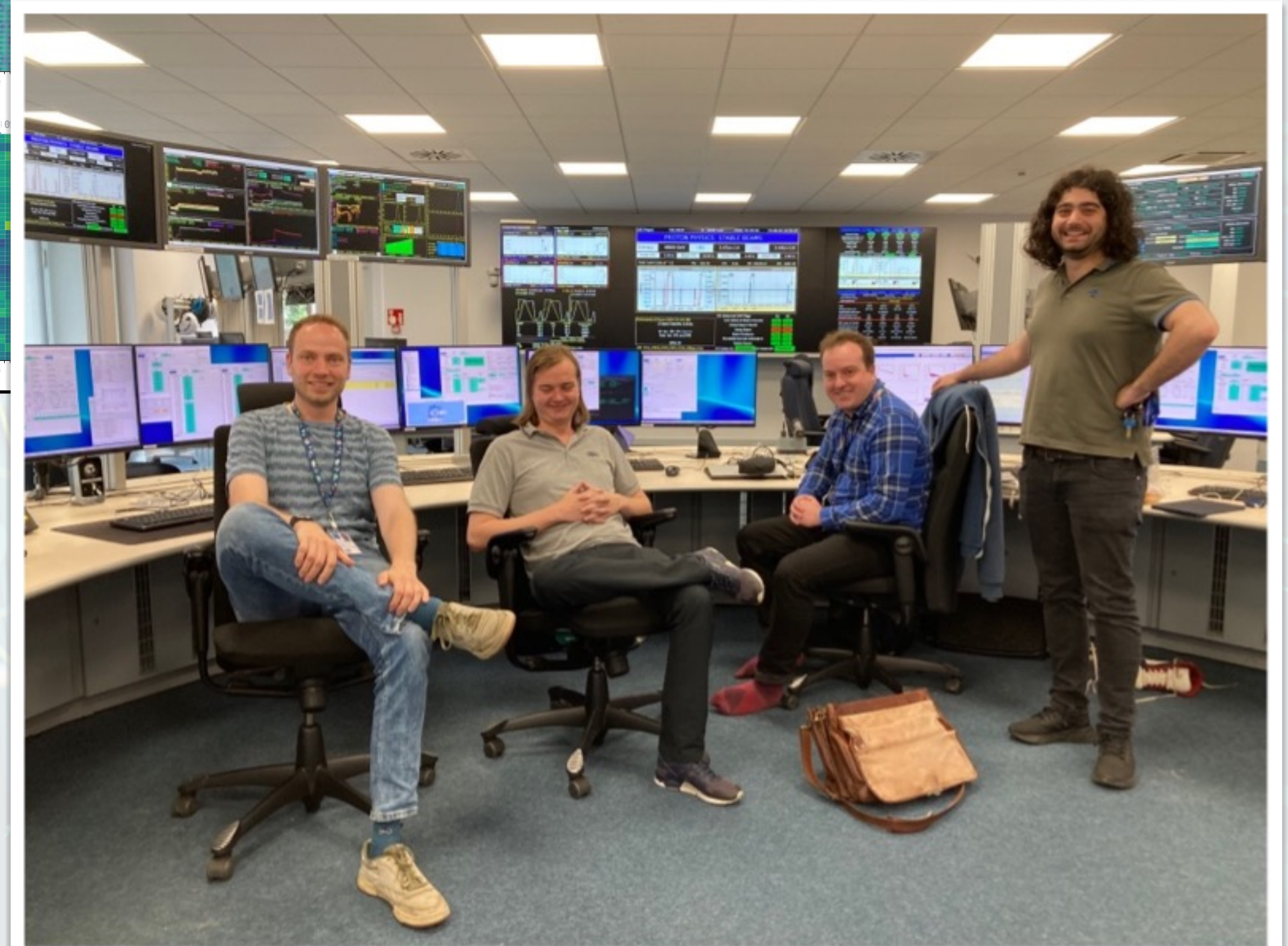
**LHCb Operation Info**

Internal Plan of the Day (IPOD): Tue November 4, 2025

LHC:  
 - Tuesday pp fill, followed by MD

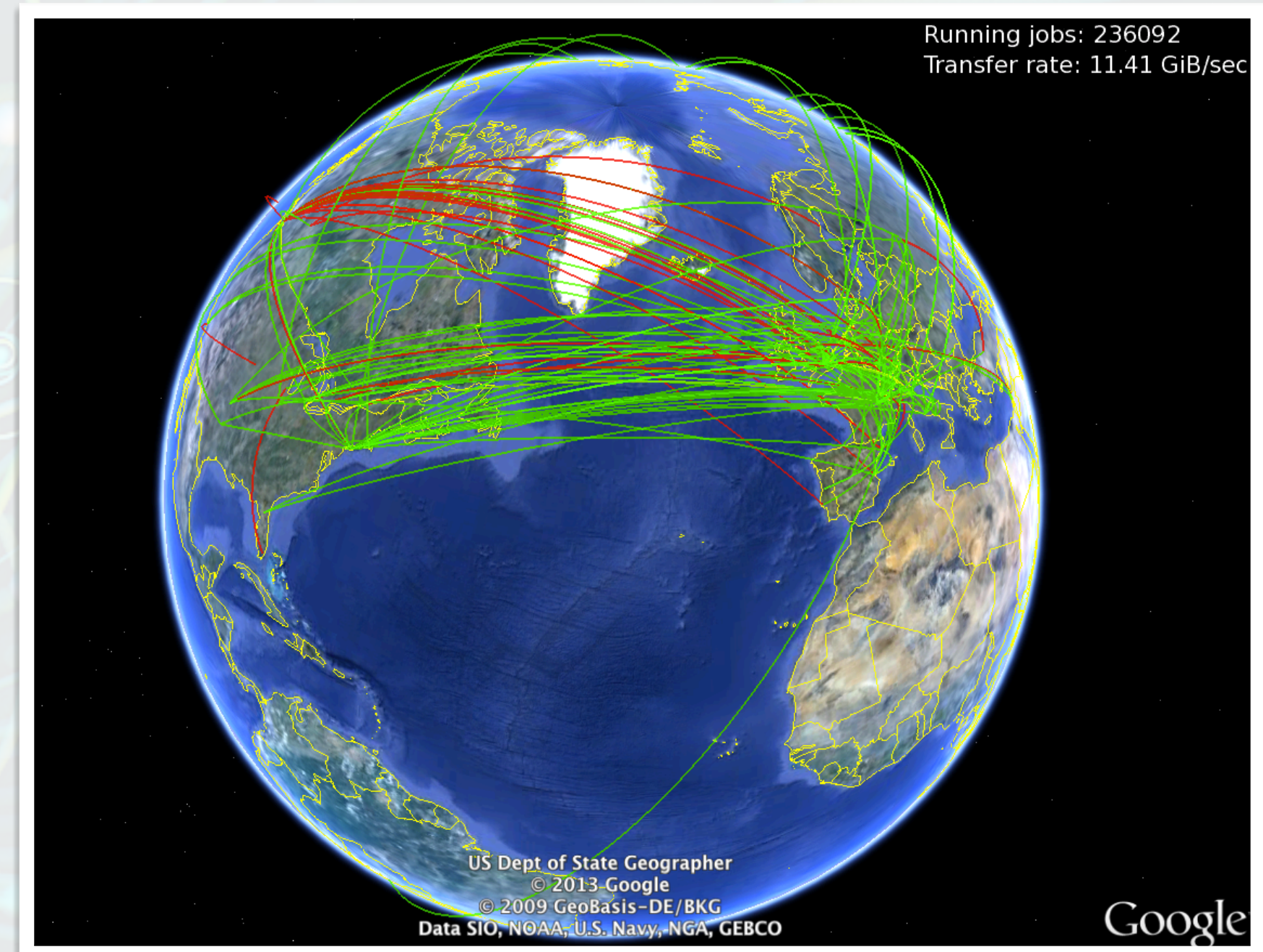
LHCb:  
 - Take pp and Ne SMOG data  
 - In case of 4-cell alarm btw. 10h-17h call CALO power-cycle

Next Run Meeting: Tuesday 11 Nov 9:30  
 Run Chief: Jacco de Vries



# Data flow

- Data (~40 TB/s) reconstructed & selected in real-time
- No 'beam time' per study, but all data collected simultaneously  
—> 'bandwidth' per channel politically decided
- Stored / processed on the Worldwide LHC Computing Grid



## 'Bookkeeping'

#	File Name	Event Stat	File Size	Run number
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000099_1.rd.dst	64947	3881492491	332307
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00002730_1.rd.dst	67840	3940802085	332314
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000156_1.rd.dst	65893	3885050189	332308
	/lhcb/LHCb/Collision25/RD.DST/00323827/0001/00323827_00011134_1.rd.dst	64279	3913368658	332376
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000098_1.rd.dst	65977	3909113224	332307
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000155_1.rd.dst	67633	3933443795	332308
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00001227_1.rd.dst	63327	3898993792	332307
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00002310_1.rd.dst	64917	3918976989	332312
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000303_1.rd.dst	67824	3924887242	332315
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000096_1.rd.dst	68090	3926926534	332307
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000302_1.rd.dst	68355	3911915332	332315
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00003255_1.rd.dst	67804	3940137535	332315
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00001728_1.rd.dst	63529	3885213037	332310
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00009376_1.rd.dst	65707	3905235930	332370
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000640_1.rd.dst	65917	3933198160	332309
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000464_1.rd.dst	66315	3910474069	332304
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000219_1.rd.dst	67833	3926121707	332312
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00000220_1.rd.dst	66025	3931957315	332312
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00005757_1.rd.dst	67557	3930498588	332327
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00005774_1.rd.dst	65175	3944937940	332327
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00006177_1.rd.dst	66426	3882303621	332370
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00009073_1.rd.dst	66355	3912332944	332368
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00009968_1.rd.dst	65223	3932842437	332371
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00001223_1.rd.dst	65288	3909626723	332307
	/lhcb/LHCb/Collision25/RD.DST/00323827/0000/00323827_00007667_1.rd.dst	65807	3934753314	332313

Configuration Name: LHCb

Configuration Version: Collision25

Simulation/DataTaking Conditions: Beam6800GeV-VeloClo

Processing pass: /Real Data/Sprucing25c

Event Type: 90000000

FileType: RD.DST

Number Of Files: 6342

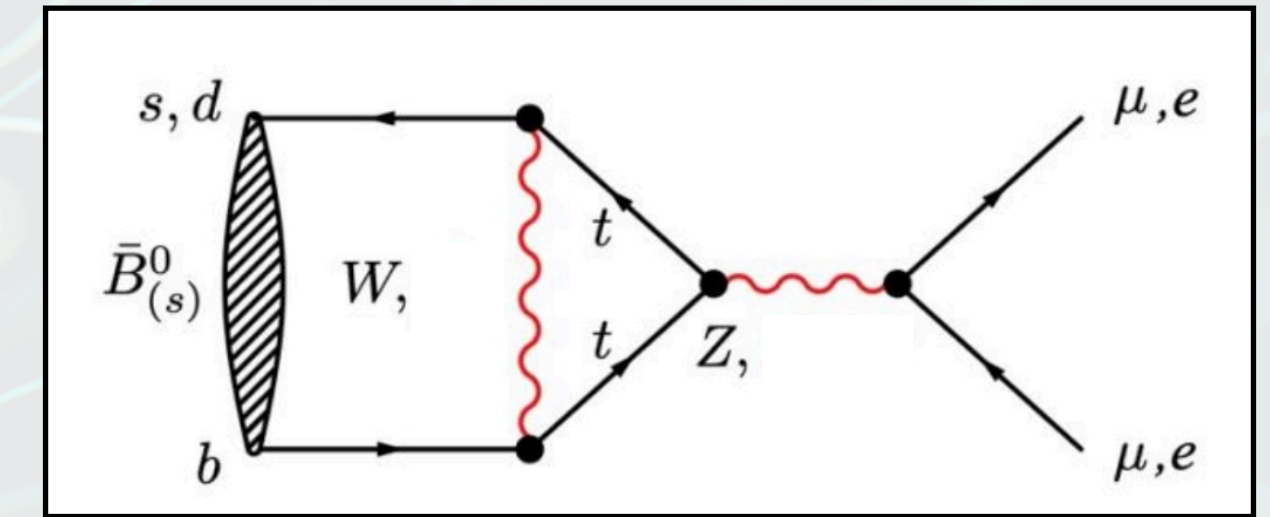
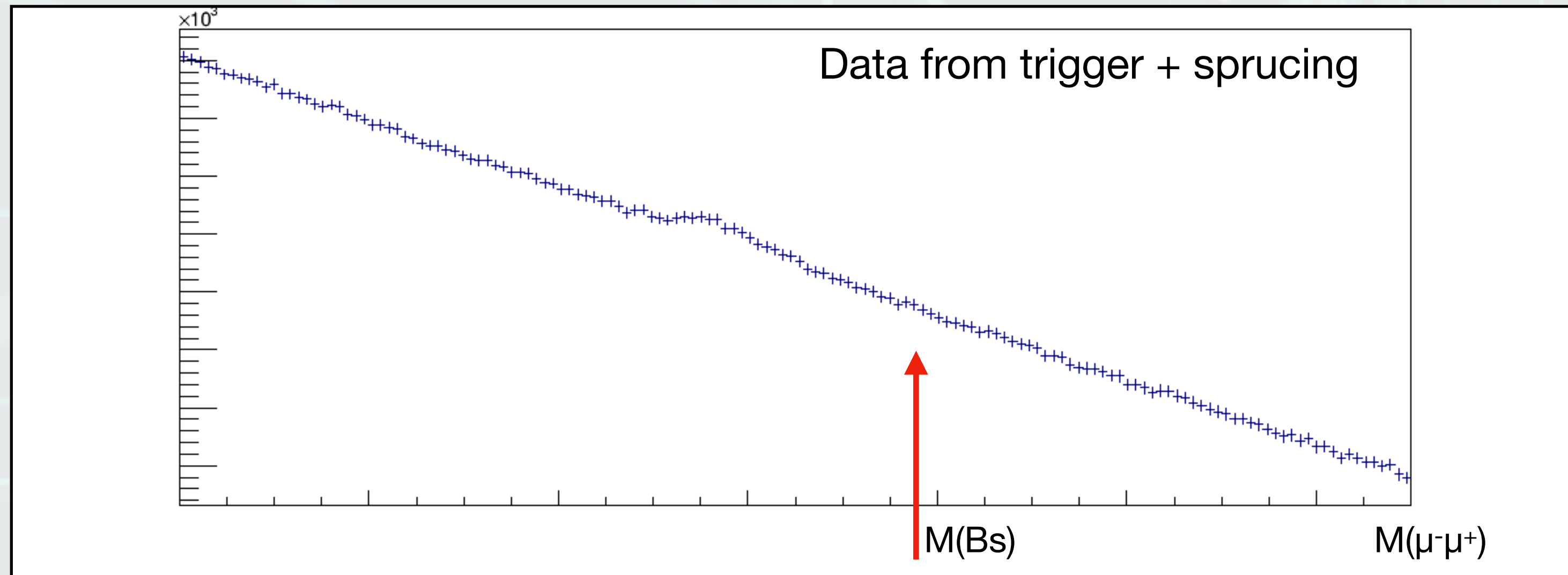
Number Of Events: 412335401

Luminosity: 1010711513.3744503

File(s) Size: **21.9 TB**

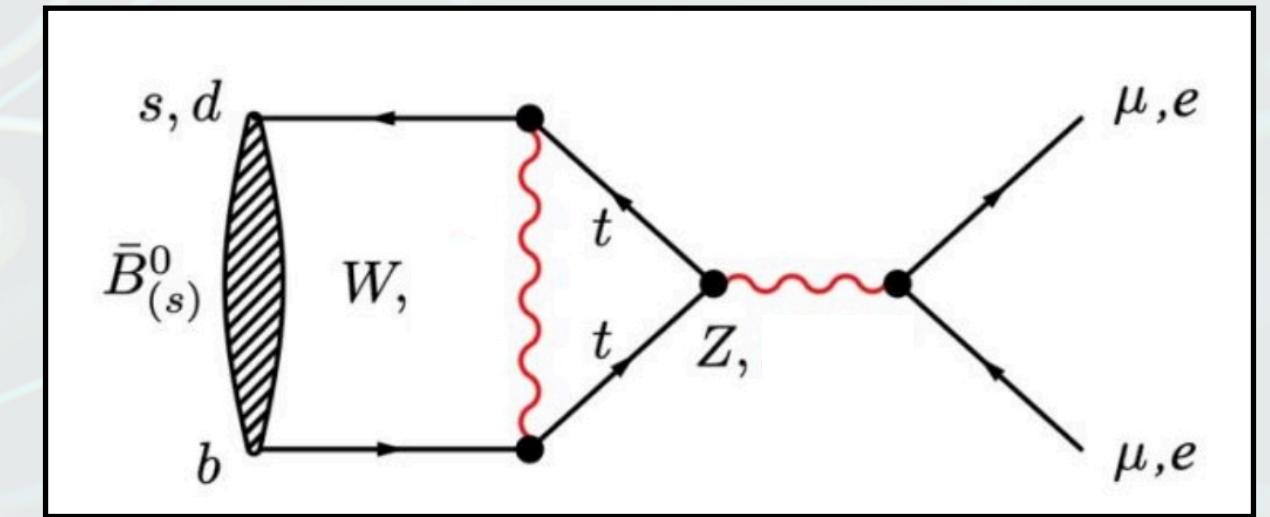
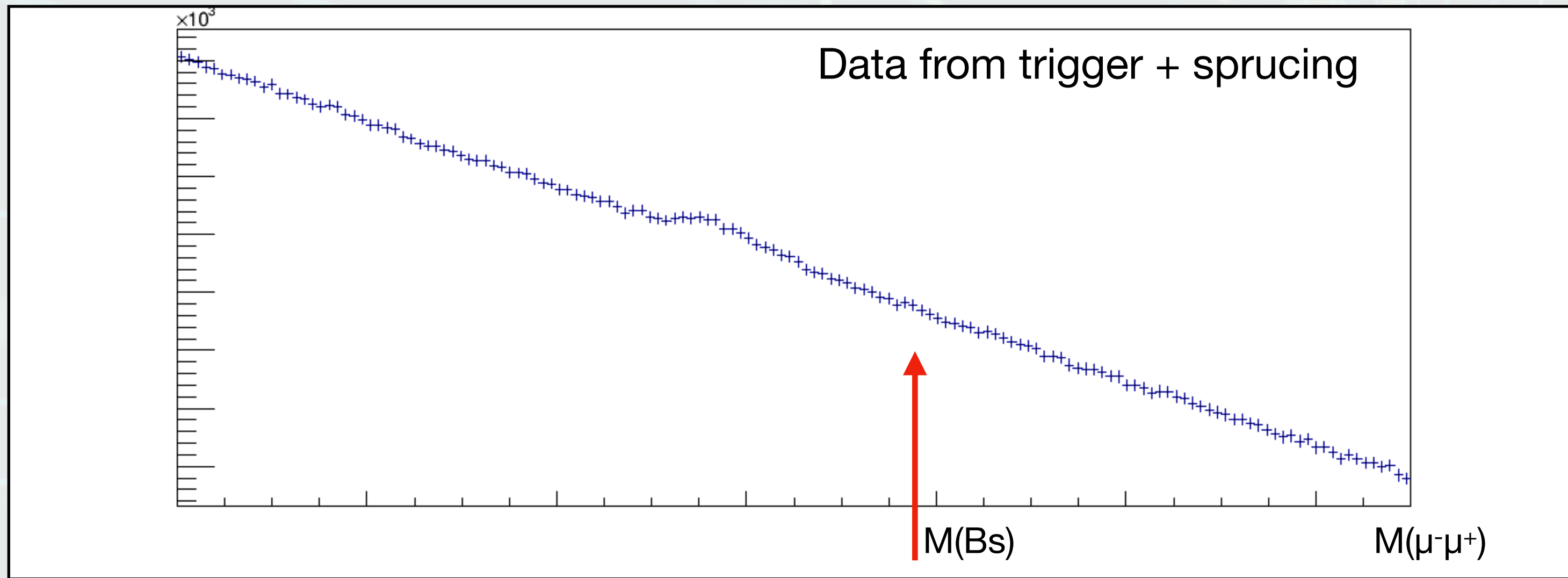


# $B_s \rightarrow \mu\mu$ : The needle in 10.000 haystacks



- Look for two muon tracks that 'cross' (make a vertex)
- The combined momentum must point back to the original collision point

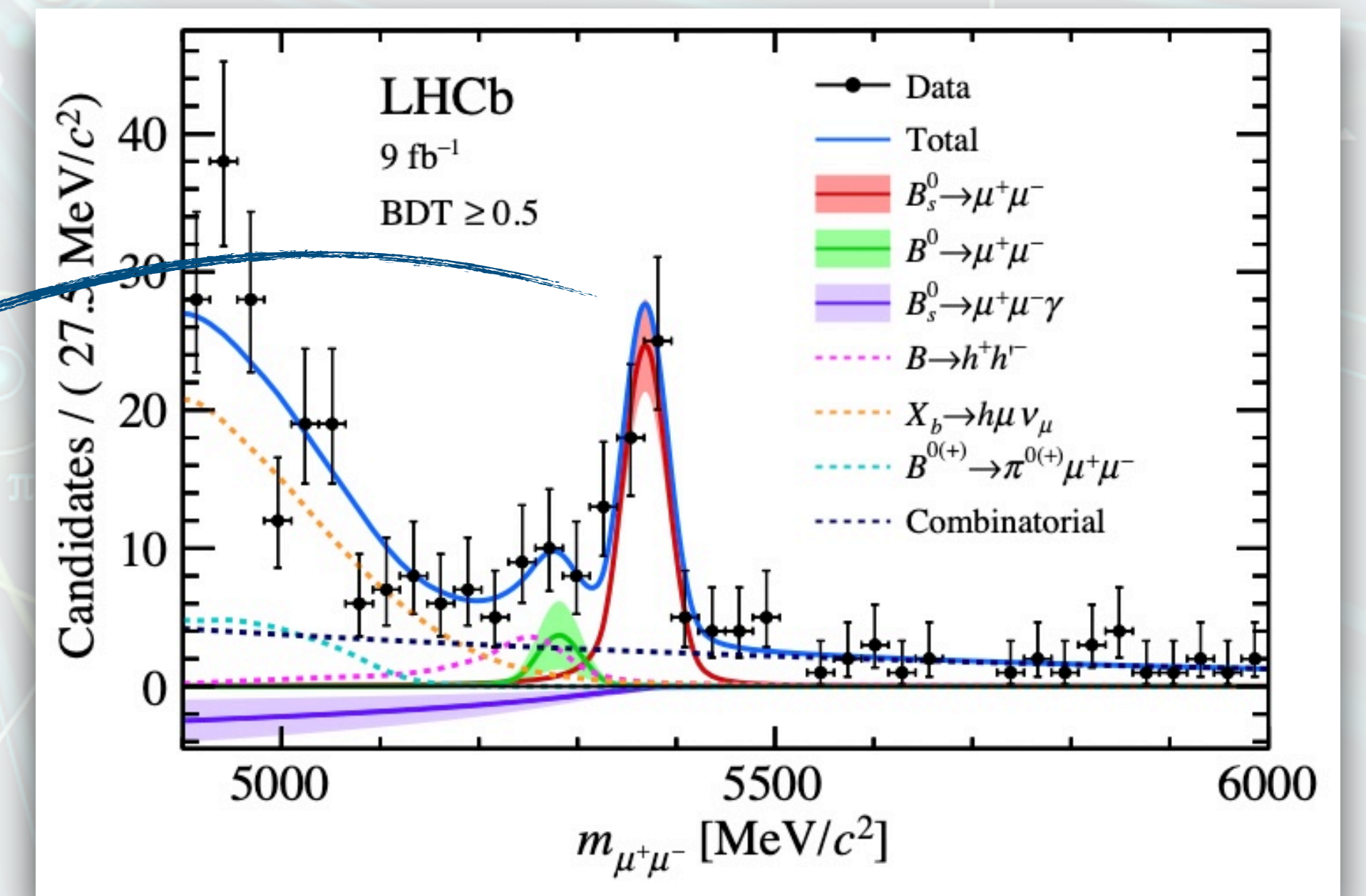
# Bs -> μμ: The needle in 10.000 haystacks



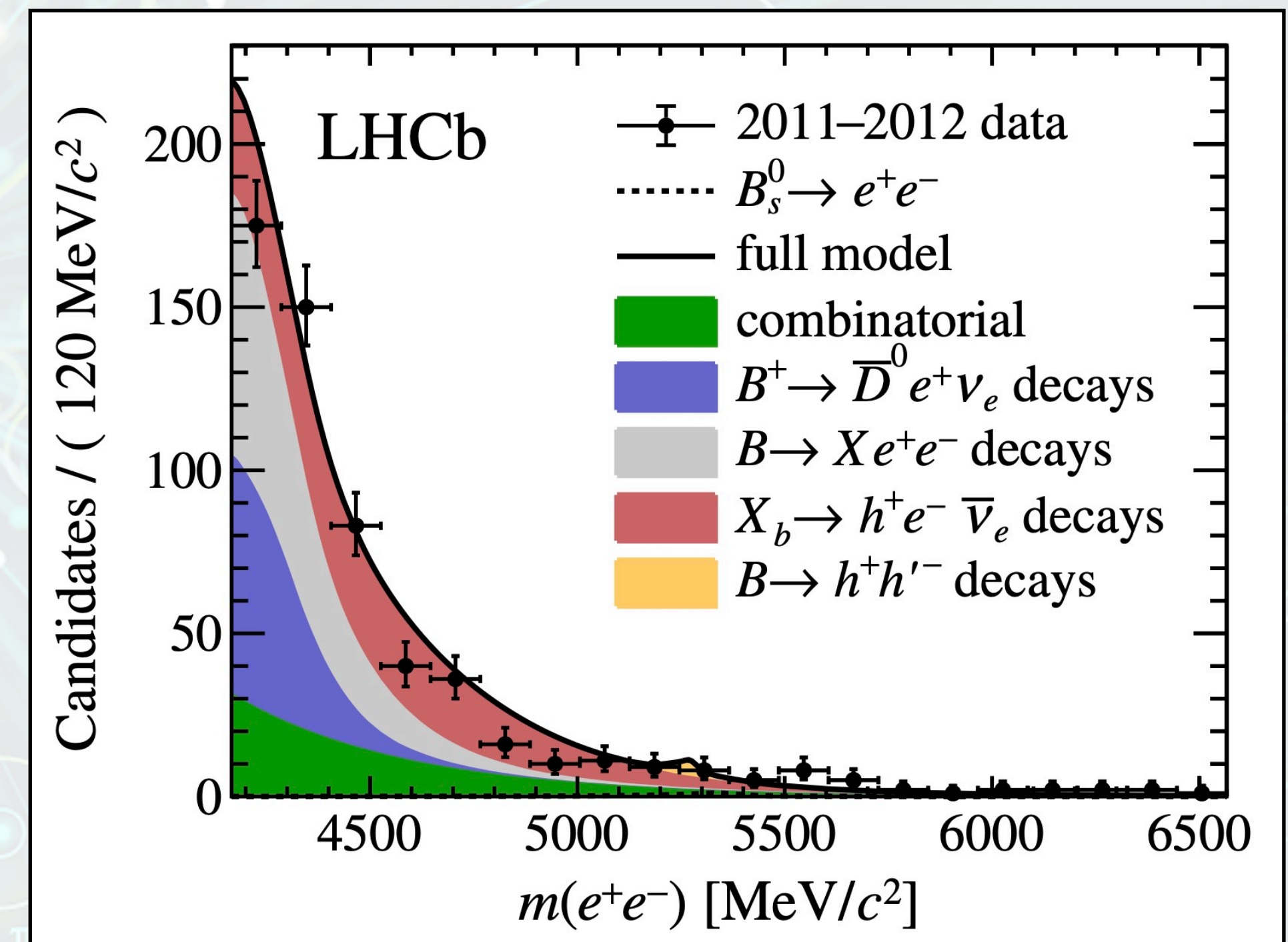
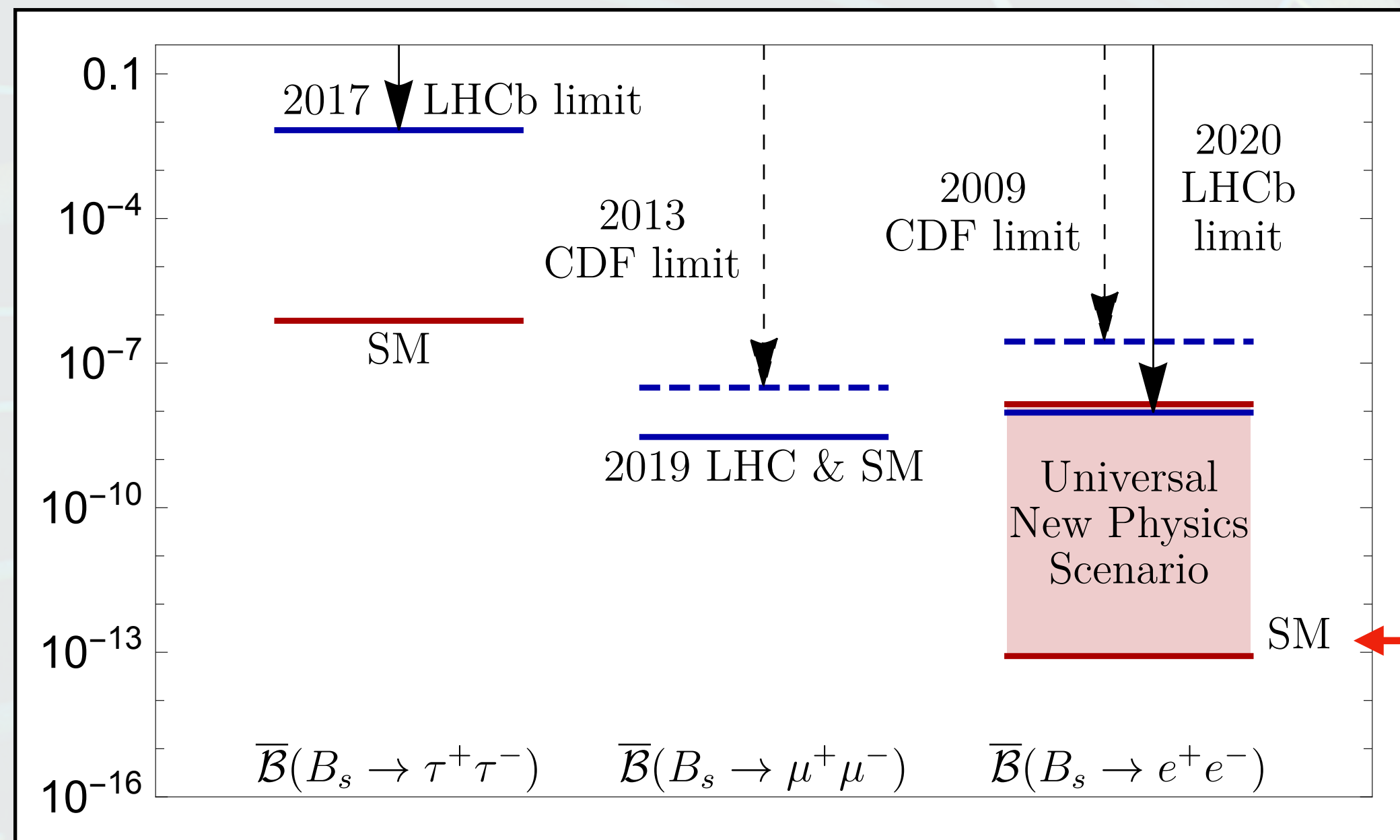
smart  
analysts

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)_{\text{LHCb}} = (3.09 \pm 0.47) \times 10^{-9}$$

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)_{\text{theory}} = (3.66 \pm 0.14) \times 10^{-9}$$

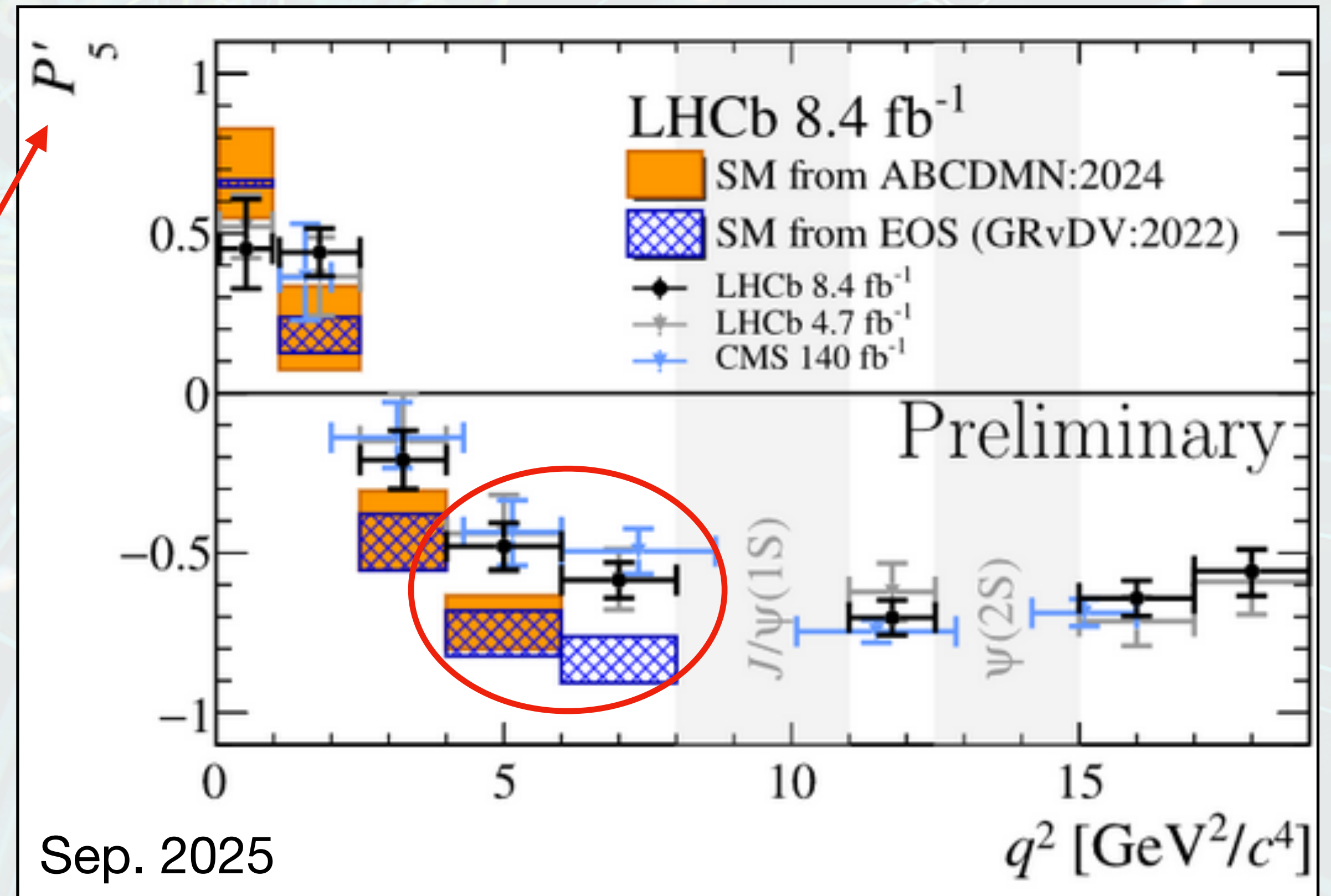
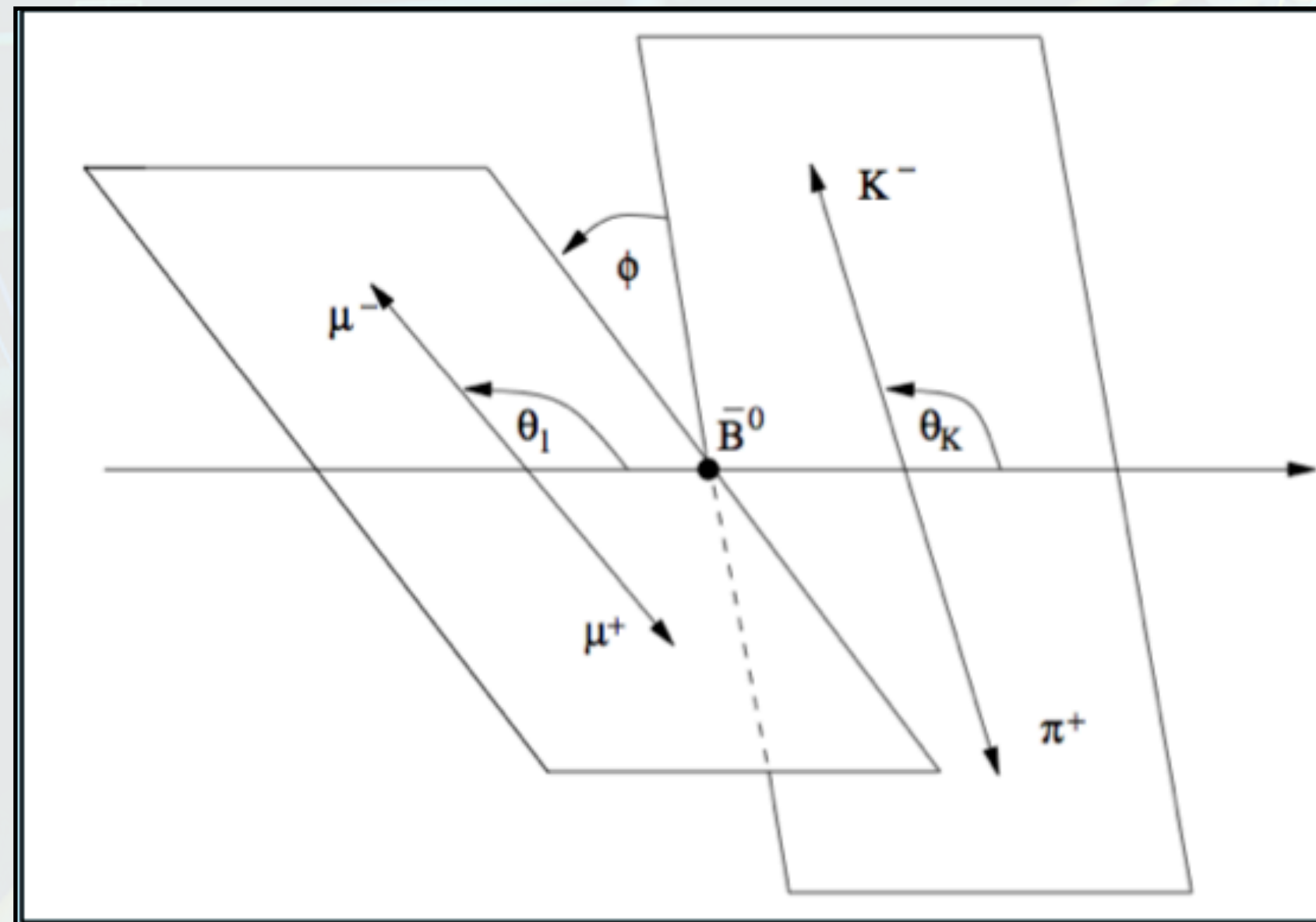
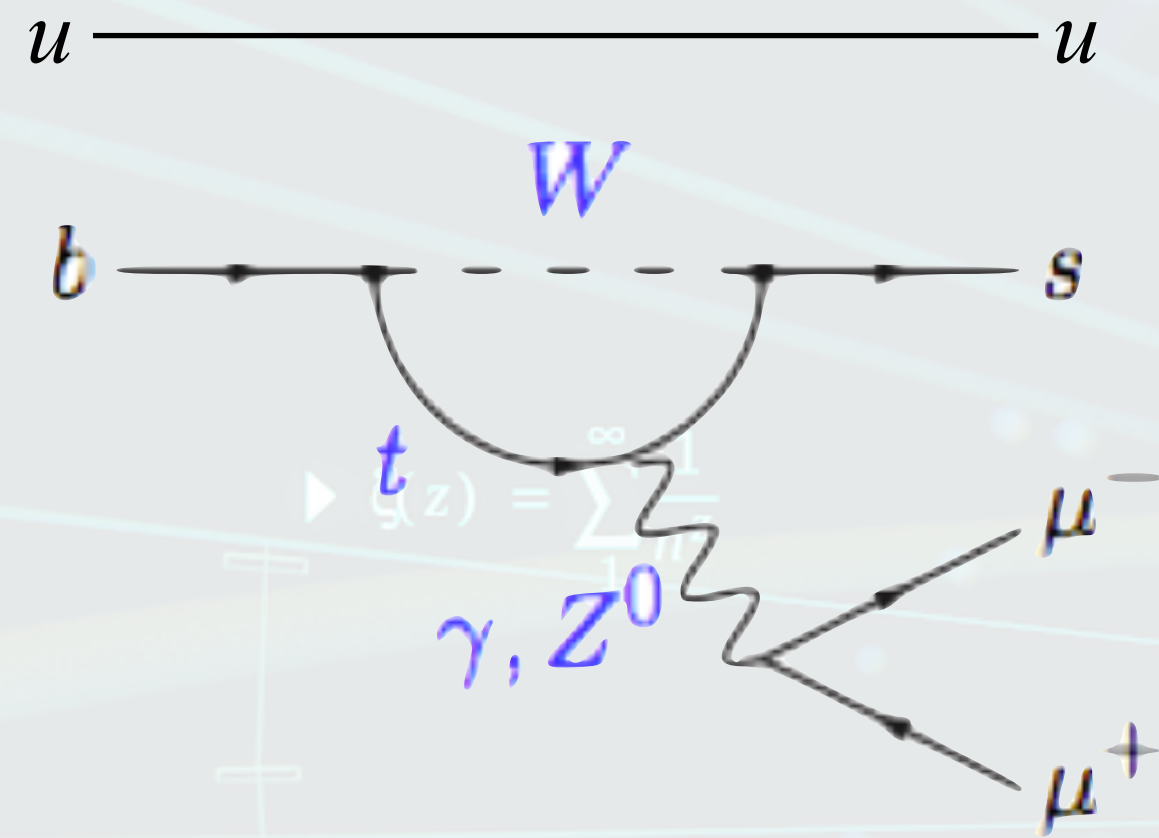


# Bs -> ee: The needle in 10.000.000 haystacks

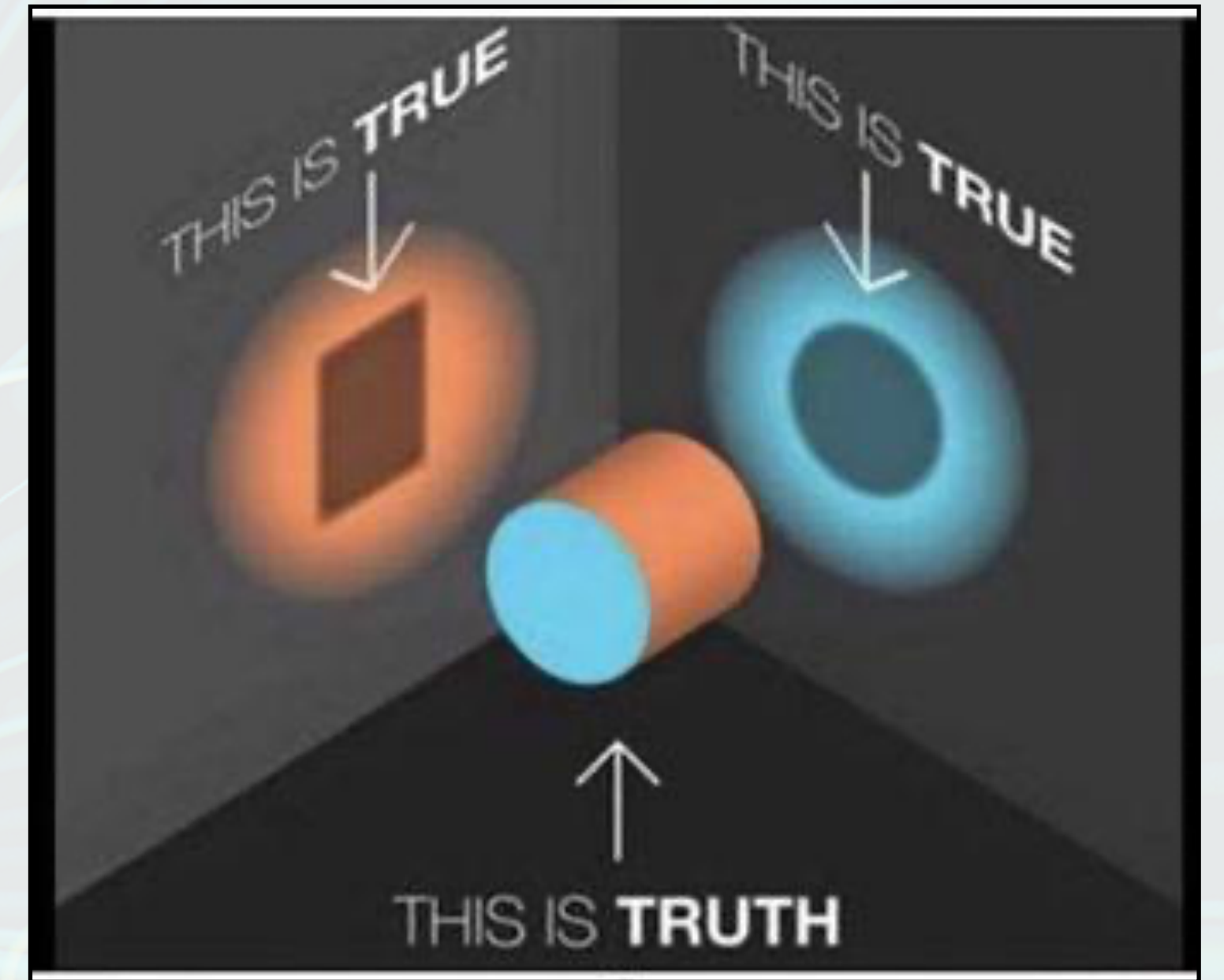
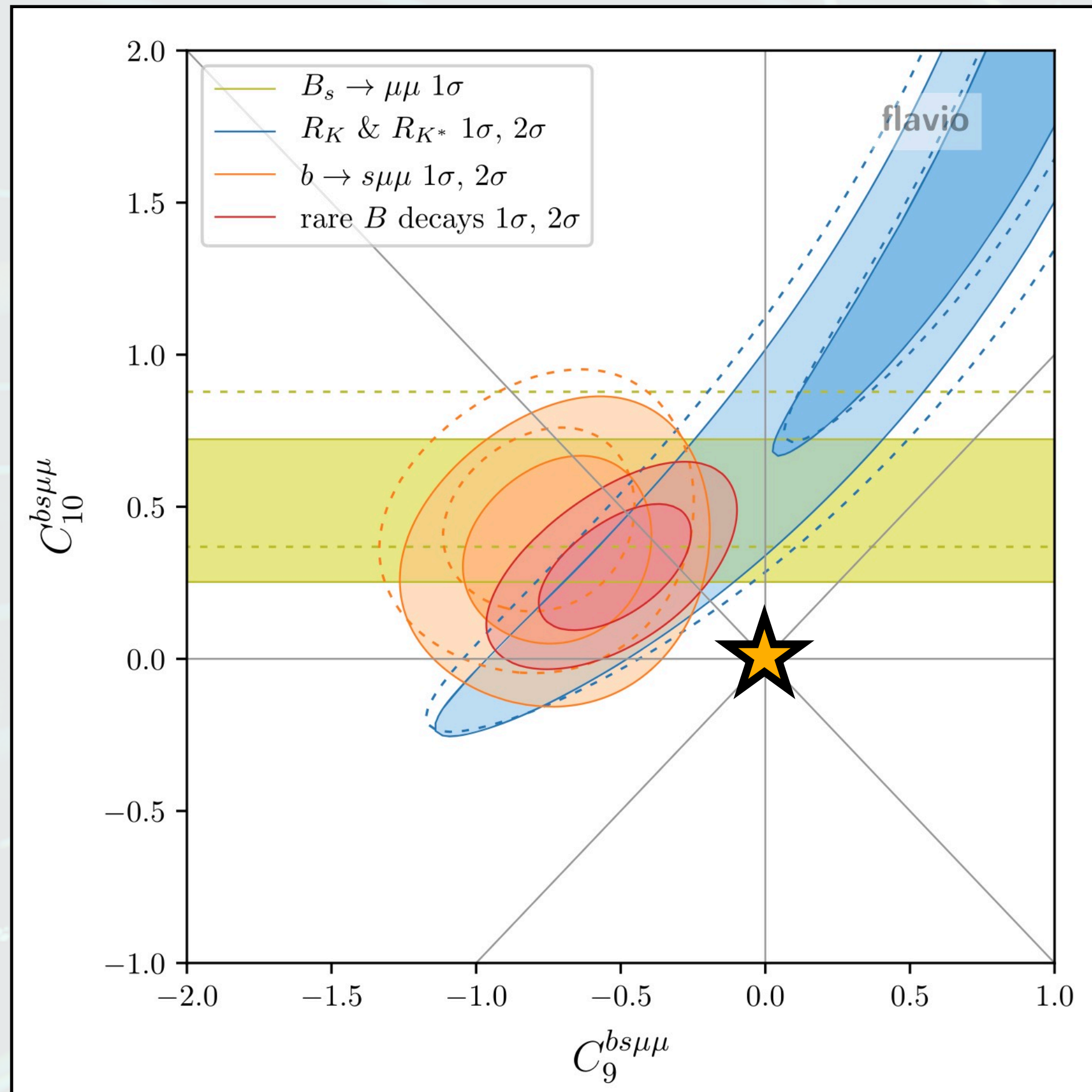


$$\mathcal{B} \propto |V_{tb}V_{tq}|^2 \left[ \left(1 - \frac{4m_e^2}{M_B^2}\right) |C_S - C'_S|^2 + |(C_P - C'_P) + \frac{2m_e}{M_B}(C_{10} - C'_{10})|^2 \right]$$

# Anomalous rare decays - $B^0 \rightarrow K^{*0} \mu^+ \mu^-$



# Effective Field theory

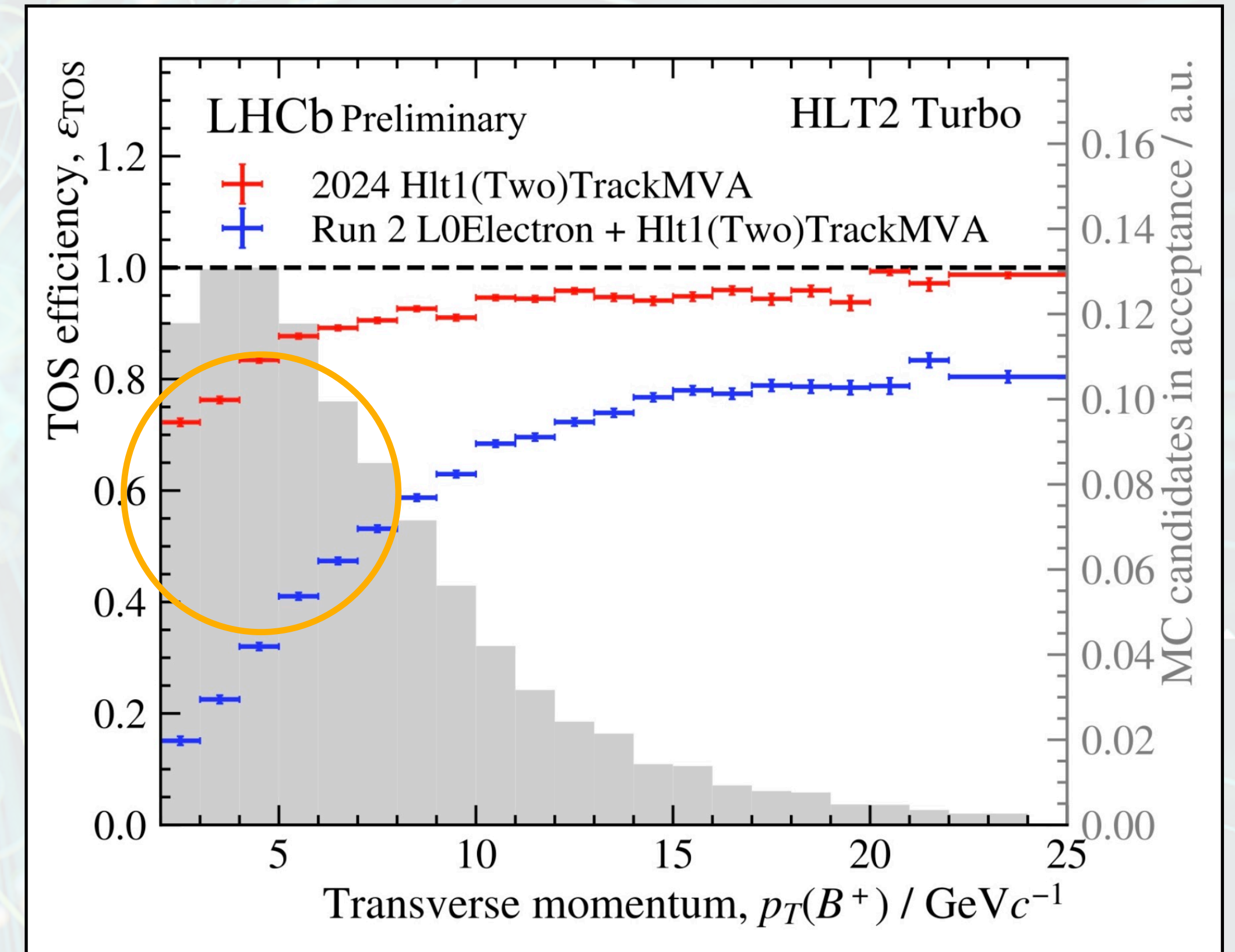
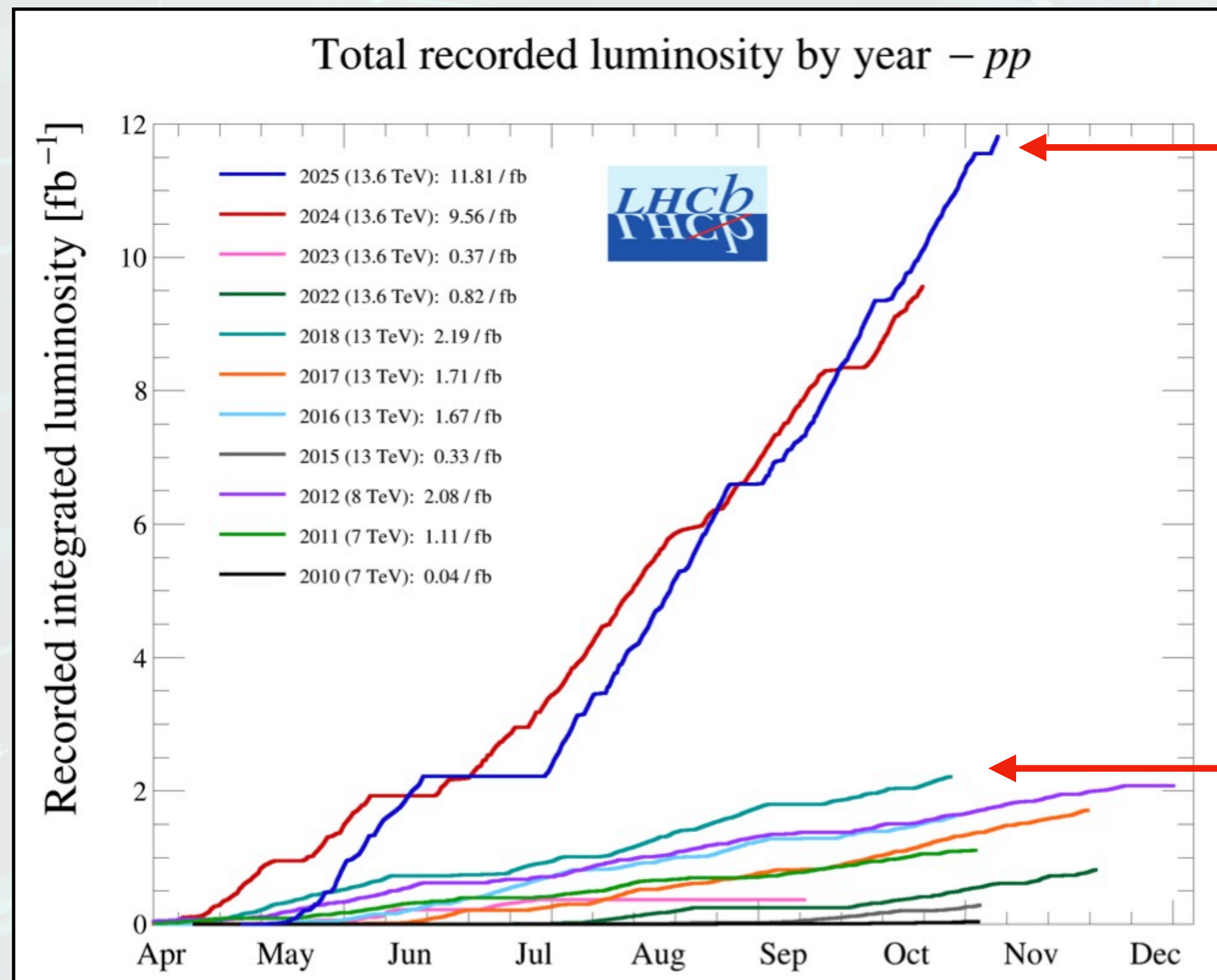


- Interpret all couplings as 'effective' interactions Without knowing the specific propagators/forces!
- Certain decays sensitive to different set of couplings
  - >  $B_s^0 \rightarrow \mu\mu$ : sensitive to  $C_{10}$  ( $C_S, C_P$ )
  - >  $B^0 \rightarrow K^{*0} \mu\mu$ : sensitive to  $C_9$  and  $C_{10}$
- **Combined interpretation**: far away from SM prediction ( $C_9 = C_{10} = 0$ ) —> favours  $C_9 = -1$ ?
  - > A consistent vector-like new force? What would it be?

# LHCb upgrade performance

- Measurements limited by amount of data
- Theoretical predictions challenging

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$



- > Much more data now!
- > Exciting updates the coming years

# “From the basics to the bleeding edge”

Searching for extremely rare decays in LHCb

Jacco de Vries

*GWFP symposium, 2 Dec 2025*

