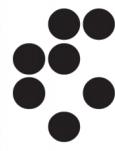




Univerza v Ljubljani



Uvod v analizo podatkov v eksperimentalni fiziki osnovnih delcev

doc. dr. Marko Bračko

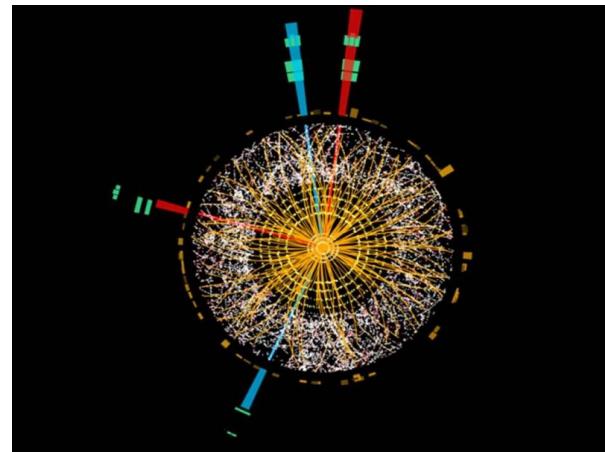
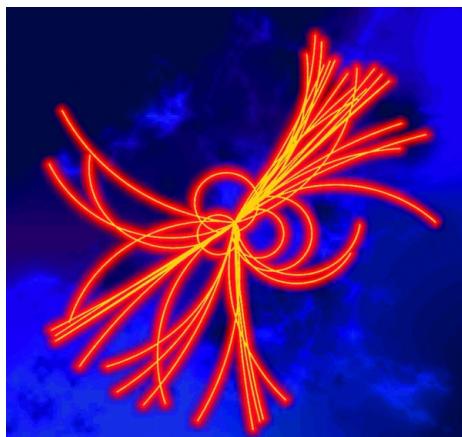
Univerza v Mariboru, FKKT
in

Institut Jožef Stefan

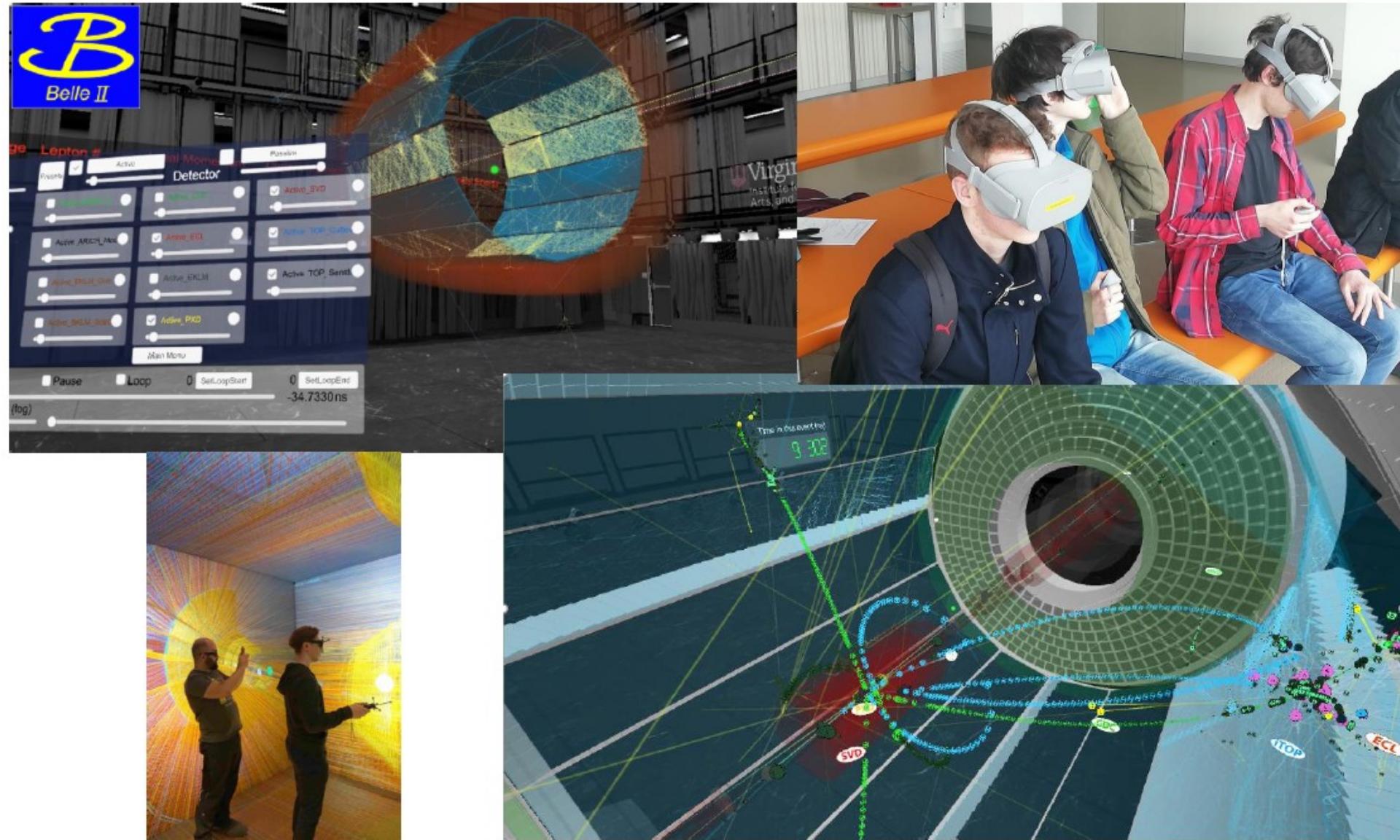
F9 – Odsek za eksperimentalno fiziko osnovnih delcev

IMC2021 - Belle2, sestanek na daljavo (Zoom),

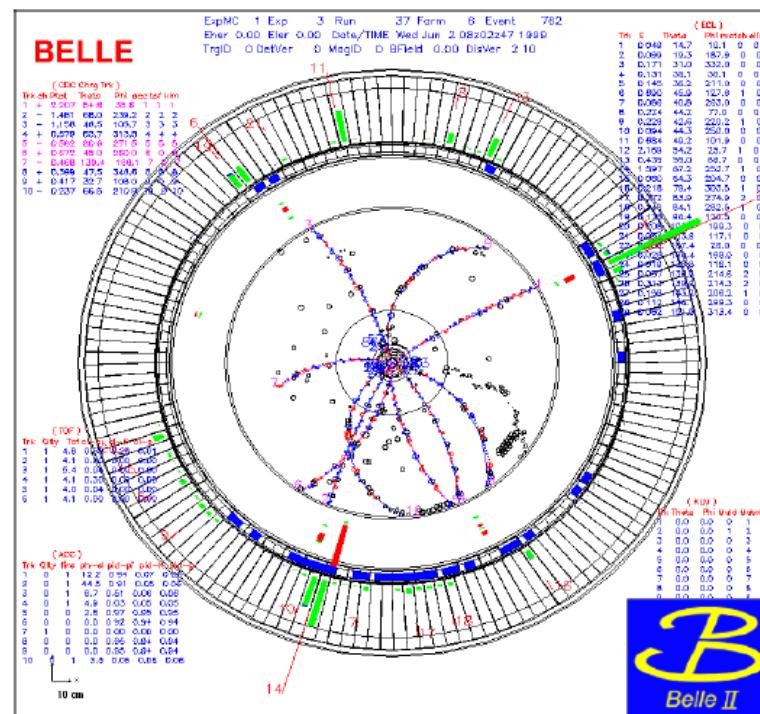
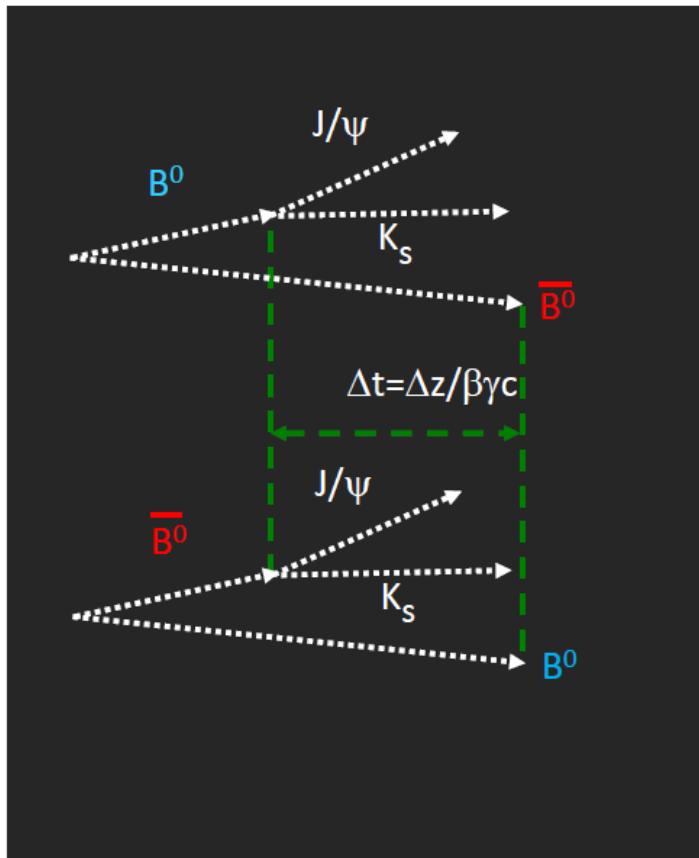
3. marca 2021



Izmerjeni signali (količine) → vizualizacija

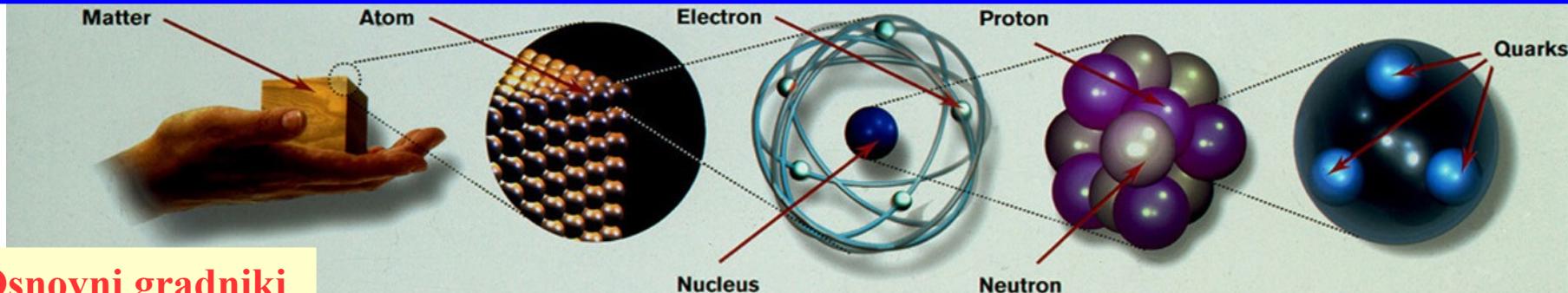


Izmerjeni signali (količine) → vizualizacija



- Za (ročno) pregledovanje je podatkov preprosto preveč ...
- Želimo določiti lastnosti delcev, izmeriti razne vrednosti, konstante, ...
→ Potrebujemo izračunane količine, statistične metode, ...

... in kako snov vidimo/razumemo danes?



Osnovni gradniki
snovi :

LEPTONS						QUARKS					
All ordinary particles belong to this group	FIRST FAMILY	Electron Responsible for electricity and chemical reactions; it has a charge of -1	e		Electron neutrino Particle with no electric charge, and possibly no mass; billions fly through your body every second	ν_e		Up Has an electric charge of plus two-thirds; protons contain two, neutrons contain one	u		Down Has an electric charge of minus one-third; protons contain one, neutrons contain two
These particles existed just after the Big Bang. Now they are found only in cosmic rays and accelerators	SECOND FAMILY	Muon A heavier relative of the electron; it lives for two-millionths of a second	μ		Muon neutrino Created along with muons when some particles decay	ν_μ		Charm A heavier relative of the up; found in 1974	c		Strange A heavier relative of the down; found in 1964
	THIRD FAMILY	Tau Heavier still; it is extremely unstable. It was discovered in 1975	τ		Tau neutrino not yet discovered but believed to exist	ν_τ		Top Heavier still	t		Bottom Heavier still; measuring bottom quarks is an important test of electroweak theory

→ vsak delec iz tabele ima svoj anti-delec, npr. e^- in e^+

→ leptoni so nesestavljeni

→ kvarki sestavljajo težje delce - hadrone, npr.

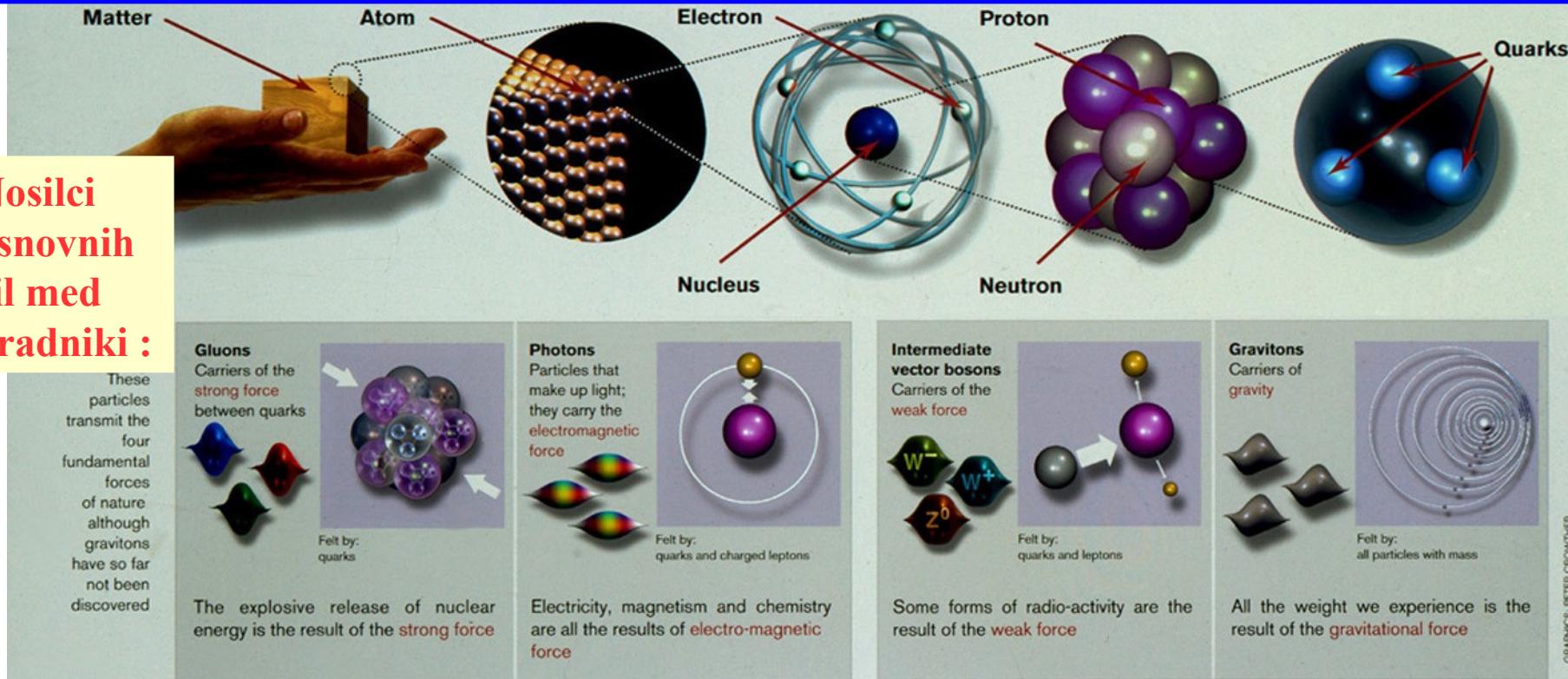
$$\mathbf{p} = uud \quad (+\frac{2}{3}e_0 + \frac{2}{3}e_0 - \frac{1}{3}e_0)$$

$$\mathbf{n} = udd \quad (+\frac{2}{3}e_0 - \frac{1}{3}e_0 - \frac{1}{3}e_0)$$

{ e_0 je osnovni naboj:

$$\sim 1,6 \cdot 10^{-19} \text{ As}$$

... in kako snov vidimo/razumemo danes?



gluoni
(močna sila)

fotoni
(EM sila)

bozoni W^+ , W^- , Z^0
(šibka sila)

gravitonji
(gravitacija)

Higgsovo polje
(masa delcev) :

Higgsov bozon

Barioni in mezoni: vezana stanja kvarkov in antikvarkov

Barioni

proton: uud

masa

$1 m_p$

neutron: udd

$\sim 1 m_p$

Λ : uds

$1.2 m_p$

Mezoni

π^+ : kvark **u** + antikvark **\bar{d}**

masa

$1/7 m_p$

K_S : kvark **d** + antikvark **\bar{s}**

$1/2 m_p$

J/ψ : kvark **c** + antikvark **\bar{c}**

$3 m_p$

B^0 : kvark **d** + antikvark **\bar{b}**

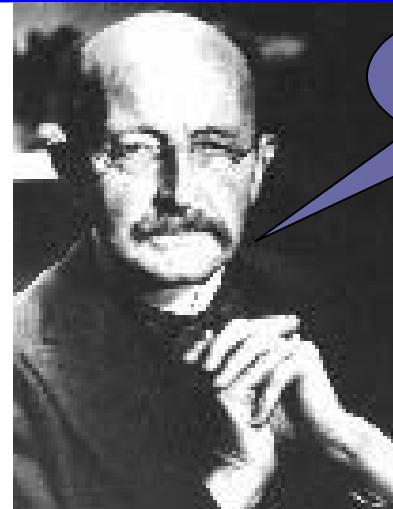
$5.5 m_p$

In seveda še mnogi drugi delci ...

Kako opazujemo majhne delce?

Kvantna mehanika:
delci se obnašajo kot valovanje
Max Planck

$$E = h\nu = h(c/\lambda)$$

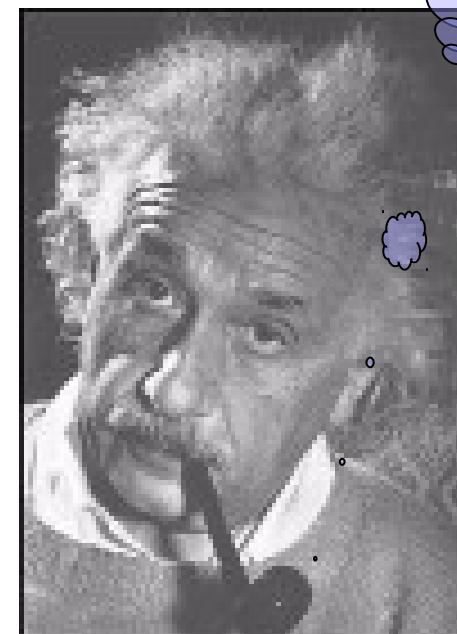


$$E=h\nu$$

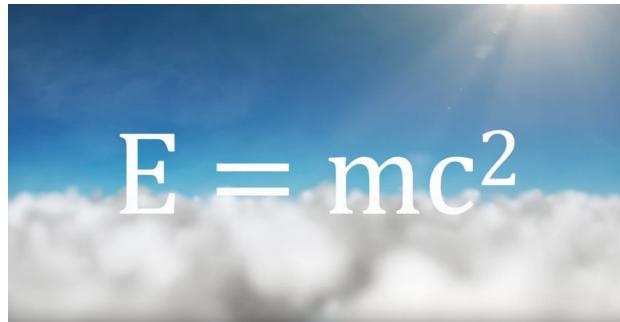
$$E=mc^2$$

**velika energija → velika frekvenca
→ majhna valovna dolžina**

Posebna teorija relativnosti:
energija in masa sta izmenljivi
Albert Einstein
 $E=mc^2$

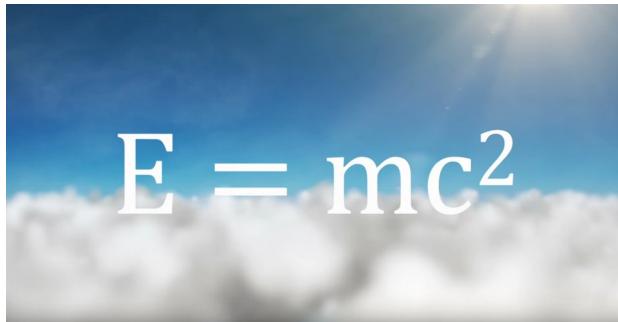


Sedaj pa še nekaj enačb:



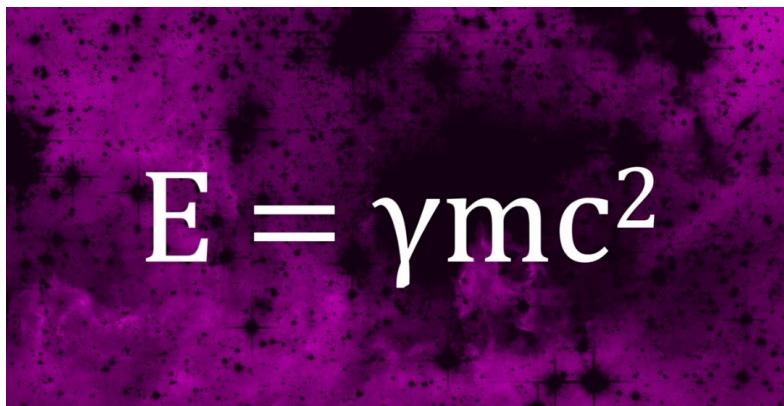
To je seveda samo poseben primer splošnejše enačbe...

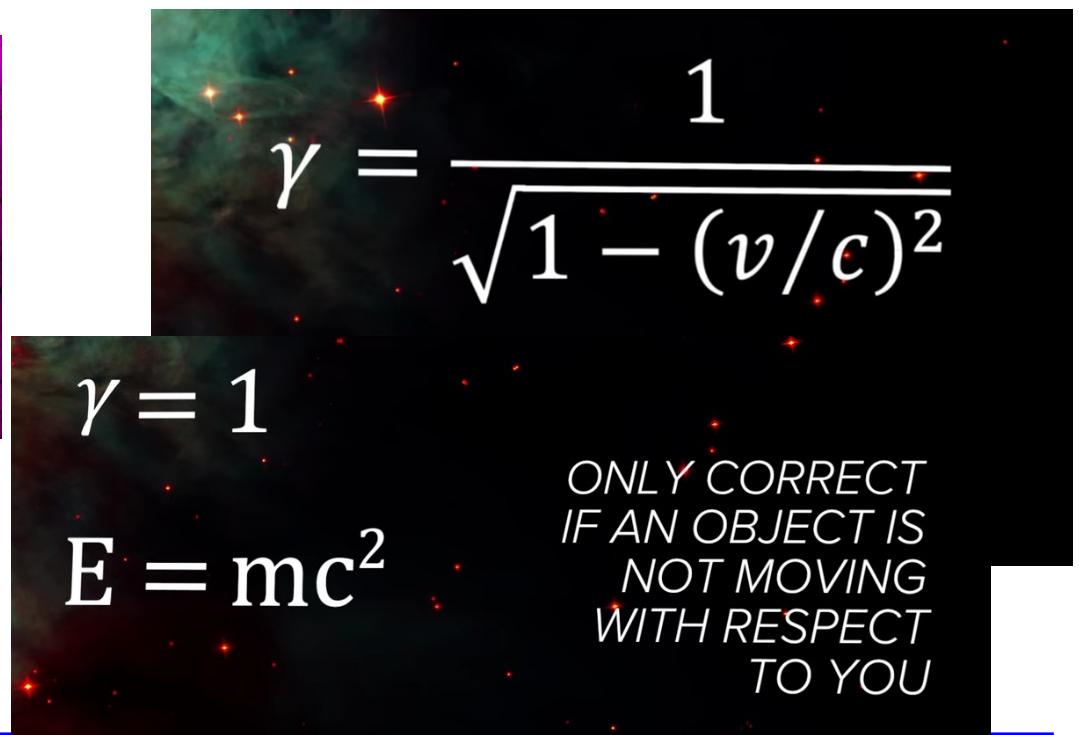
Sedaj pa še nekaj enačb:


$$E = mc^2$$

To je seveda samo poseben primer splošnejše enačbe...

zato bi morali v resni zapisati tole:


$$E = \gamma mc^2$$


$$\gamma = \frac{1}{\sqrt{1 - (v/c)^2}}$$

$\gamma = 1$

$$E = mc^2$$

*ONLY CORRECT
IF AN OBJECT IS
NOT MOVING
WITH RESPECT
TO YOU*

Sedaj pa še nekaj enačb: faktor gama (γ)

The diagram consists of two side-by-side panels. The left panel shows the classical formula for the factor of gamma as $\gamma = \frac{E}{mc^2}$, set against a background of a starry night sky. A large blue arrow points from the left panel to the right panel. The right panel shows the relativistic formula for the factor of gamma as $\gamma = \frac{E(\text{moving})}{E(\text{not moving})}$, also set against a background of a starry night sky.

Ta faktor se torej povečuje, ko pospešujemo delce.

Isti faktor nastopa tudi v definiciji gibalne količine:

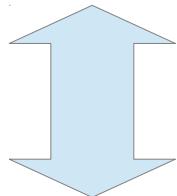
The diagram features a dark background with glowing blue particles. Three mathematical equations are displayed: $p = \gamma \times m \times v$, $m_{relativistic} = \gamma m$, and $p = m_{relativistic} v$.

S faktorjem γ lahko tudi predefiniramo maso delca.

Prave (relativistične) enačbe :

$$E = \gamma m c^2$$

$$p = \gamma \times m \times v$$



$$E^2 = (pc)^2 + (mc^2)^2$$

E - *energy*

m - *mass*

c - *speed of light*

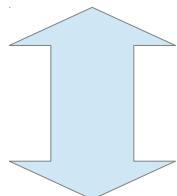
p - *momentum*

Z definicijo faktorja γ lahko
to enačbo preverite sami...

Prave (relativistične) enačbe :

$$E = \gamma m c^2$$

$$p = \gamma \times m \times v$$



$$E^2 = (pc)^2 + (mc^2)^2$$

E - energy

m - mass

c - speed of light

p - momentum

Dva posebna primera :

Za $p = 0$ (delec, ki miruje) :

$$E = mc^2$$

Za $m = 0$ (foton – γ) :

$$E = pc$$

Invariantna masa – eksperimentalna količina :

$$m c^2 = \sqrt{E^2 - p^2 c^2} \quad (1)$$

Maso delca lahko izrazimo (preverite!) iz prejšnje enačbe... in v idealnem primeru bi bila masa (1) natanko enaka masi delca

Neidealni primer - komplikacije :

- Delci razpadajo → uporabiti moramo razpadne produkte;
- Tudi če zaznamo/izmerimo vse razpadne produkte, povsem natančne meritve niso mogoče → masa (1) je torej ≈enaka masi delca
- Ozadje (npr. podobni razpadi) → še več razlik med maso (1) in maso delca ...

→ Invariantna masa delca :

$$m c^2 = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p}_i c\right)^2}$$

$$E_i = \sqrt{\left(\sum_i m_i c^2\right)^2 + \left(\sum_i \vec{p}_i c\right)^2}$$

Indeks i teče po razpadnih produktih delca!

Primer (prave) meritve z detektorjem Belle :

B Observation of Z⁺(4430) state

PRL 100, 142001(2008)
657 B̄B

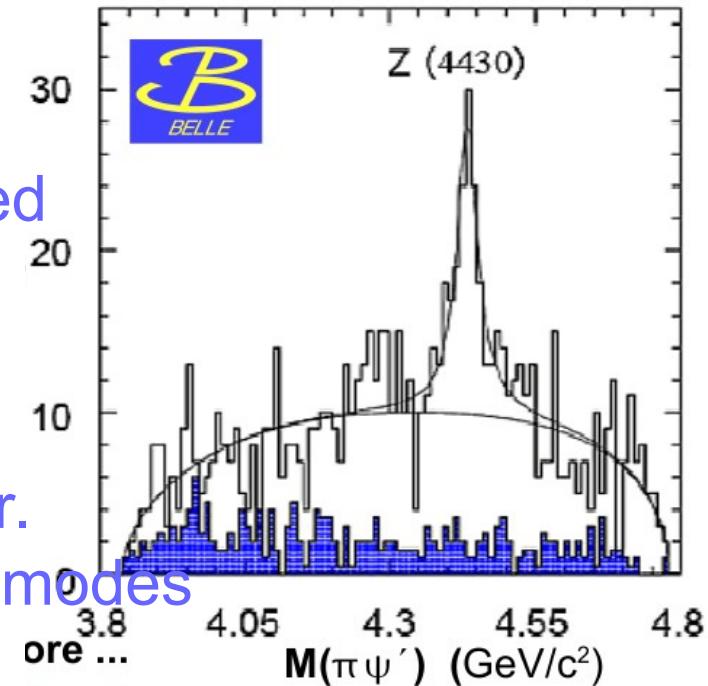
$Z(4430)^+ \rightarrow \Psi(2S)\pi^+$:
Charged state that decays like charmonium (= charged charmonium-like state)

$$Br(\bar{B}^0 \rightarrow K^- Z^+(4430)) \times Br(Z^+(4430) \rightarrow \pi^+ \psi') = (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$$

Necessary ingredients:

- Histogram → bins of $m_{\text{invariant}}$
- Just specific decay modes are used
- Errors from measurements ...
- Background:
 - wrong part. identification
 - missing particles in reconstr.
 - wrong combinations/decay modes
 - ...

First serious tetraquark candidate

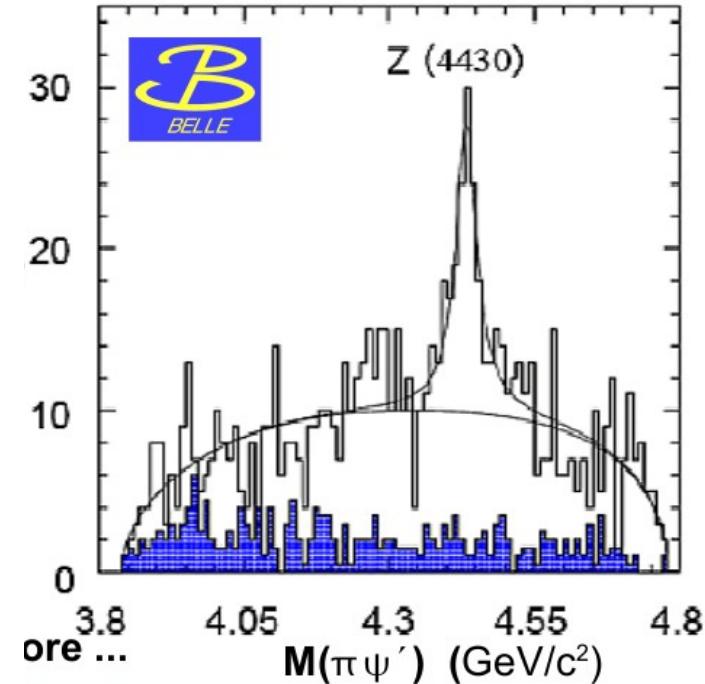


Primer (prave) meritve z detektorjem Belle :

B Observation of $Z^+(4430)$ state

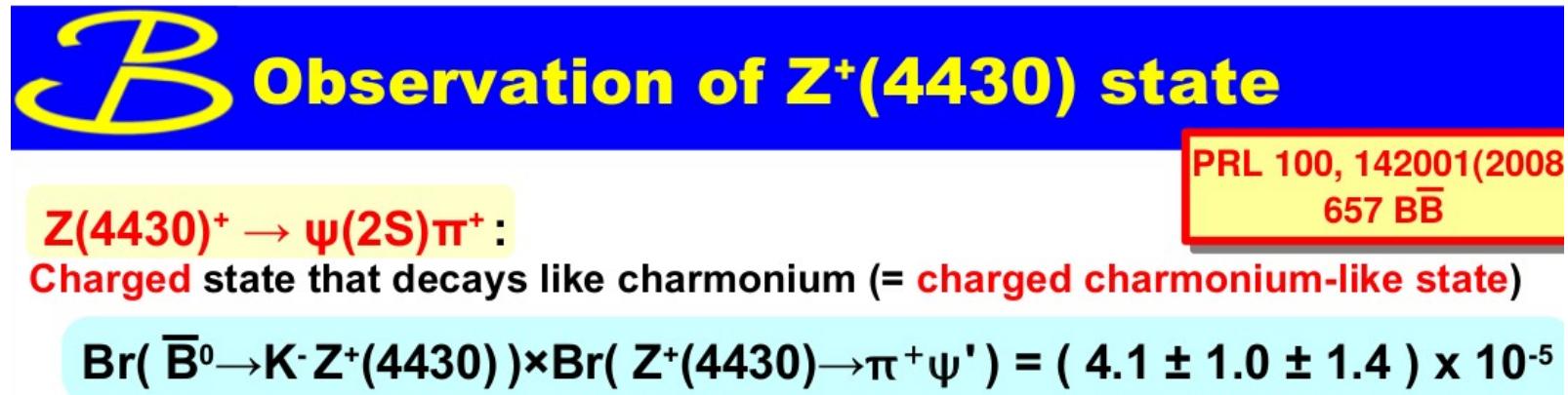
PRL 100, 142001(2008)
657 $B\bar{B}$

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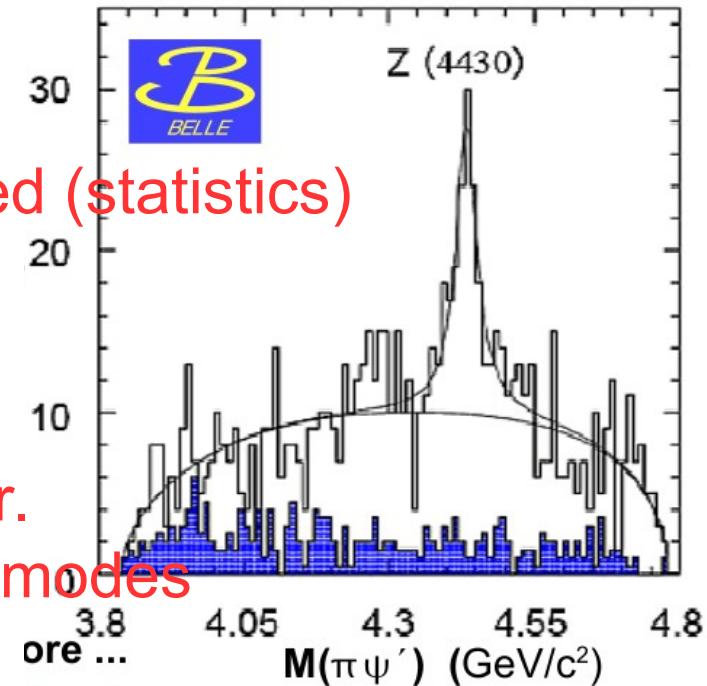
→ First serious tetraquark candidate

Primer (prave) meritve z detektorjem Belle :



Necessary ingredients:

- Histogram → bins of m_{invar}
- Just specific decay modes are used (statistics)
- Errors from measurements ...
- Background:
 - wrong part. identification
 - missing particles in reconstr.
 - wrong combinations/decay modes
 - ...



- Extract the parameters: fitting the data distribution with functions

Primer komplikacij : različni razpadni načini delcev

Properties of kaons

Particle name	Particle symbol	Antiparticle symbol	Quark content	Rest mass (MeV/c ²)	I ^G	J ^{PC}	S	C	B'	Mean lifetime (s)	Commonly decays to (>5% of decays)
Kaon ^[1]	K ⁺	K ⁻	u ⁻ s	493.677 ± 0.016	½	0 ⁻	1	0	0	(1.2380 ± 0.0021) × 10 ⁻⁸	$\mu^+ + \nu_\mu$ or $\pi^+ + \pi^0$ or $\pi^+ + \pi^+ + \pi^-$ or $\pi^0 + e^+ + \nu_e$
Kaon ^[2]	K ⁰	\bar{K}^0	d ⁻ s ⁻	497.611 ± 0.013	½	0 ⁻	1	0	0	[a]	[a]
K- Short ^[3]	K _S ⁰	Self	$\frac{d\bar{s} + s\bar{d}}{\sqrt{2}}$ [b]	497.611 ± 0.013 ^[c]	½	0 ⁻	(*)	0	0	(8.954 ± 0.004) × 10 ⁻¹¹	$\pi^+ + \pi^-$ or $\pi^0 + \pi^0$
K- Long ^[4]	K _L ⁰	Self	$\frac{d\bar{s} - s\bar{d}}{\sqrt{2}}$ [b]	497.611 ± 0.013 ^[c]	½	0 ⁻	(*)	0	0	(5.116 ± 0.021) × 10 ⁻⁸	$\pi^\pm + e^\mp + \nu_e$ or $\pi^\pm + \mu^\mp + \nu_\mu$ or $\pi^0 + \pi^0 + \pi^0$ or $\pi^+ + \pi^0 + \pi^-$

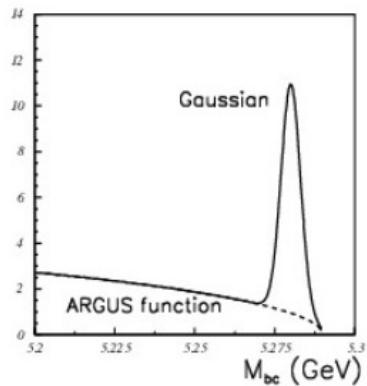
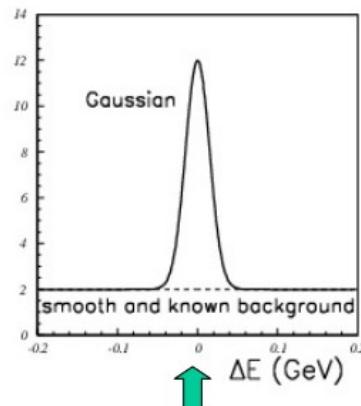
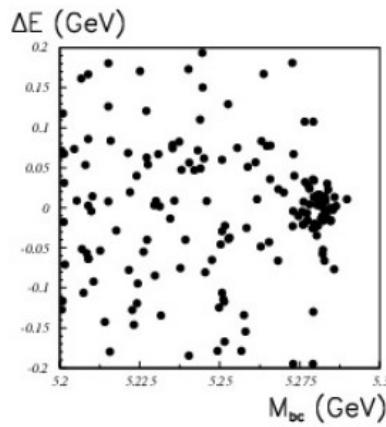
$$D^{\star+} \rightarrow D^0 \pi^+$$

$$D^{\star-} \rightarrow D^0 \pi^-$$

$$D^0 \rightarrow K^+ \pi^- / K^- \pi^+$$

Možne izboljšave :

B Analysis tools: B-meson selection



Reconstructing B meson decays at Y(4S):
use two variables,
beam-constrained mass M_{bc}
(energy-substituted mass m_{ES})
and
energy difference ΔE

$$\Delta E \equiv \sum E_i^{\text{CMS}} - E_{\text{beam}}^{\text{CMS}}$$

$$M_{bc} = \sqrt{(E_{\text{beam}}^{\text{CMS}})^2 - (\sum \vec{p}_i^{\text{CMS}})^2}$$



Zaključek :

Sedaj ste (vsaj v grobem) pripravljeni, da tudi sami poskusite priti do rezultatov ...

Srečno!

