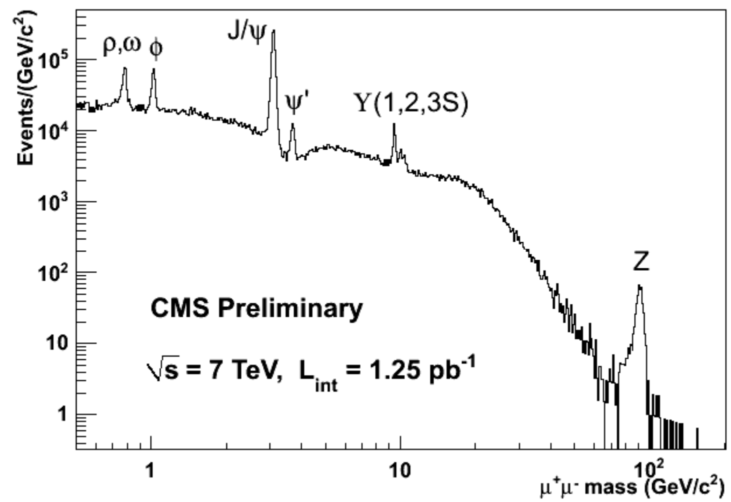
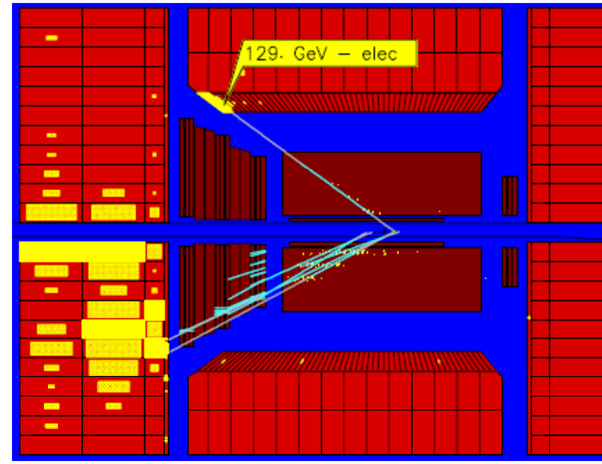
Particles

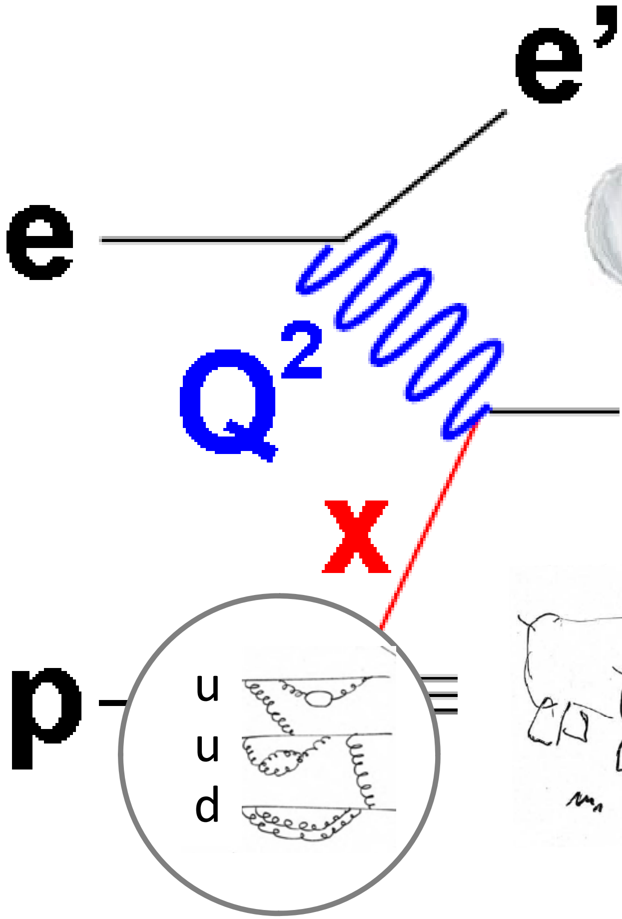


Prof. Dr. Martin Erdmann
RWTH Aachen University

7-Oct-2010

Proton



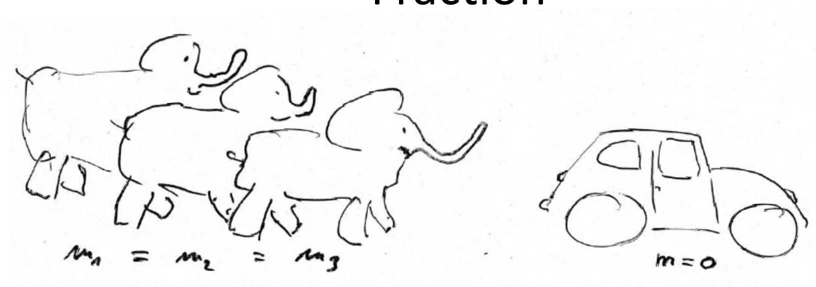


Microscopic Resolution

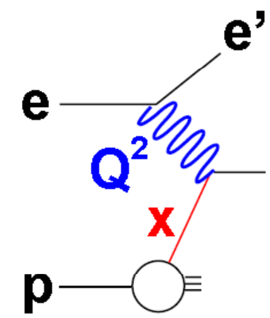
$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{Q^2}}$$

Momentum Fraction

$$x = \frac{p_q}{p_p}$$



Proton Structure Function



Σ Spins=0 — Rutherford — Quark charge squared

$$\frac{d^2\sigma(eu \rightarrow\leftarrow)}{dx\, dQ^2} \sim \alpha^2 \frac{1}{Q^4}\frac{4}{9}\frac{1}{x}\left[x\, u(x,Q^2)\right]$$

$u(x,Q^2)$ Wahrscheinlichkeitsdichte u – Quark im Proton bei (x, Q^2) finden

$x\, u(x,Q^2)$ Wahrscheinlichkeit = Partonverteilung

$$\frac{d^2\sigma(eu \rightarrow\rightarrow)}{dx\, dQ^2} \sim \alpha^2 \frac{1}{Q^4}\frac{4}{9}\frac{1}{x}\left[x\, u(x,Q^2)\right] \cos^4\left(\frac{\theta^*}{2}\right)$$

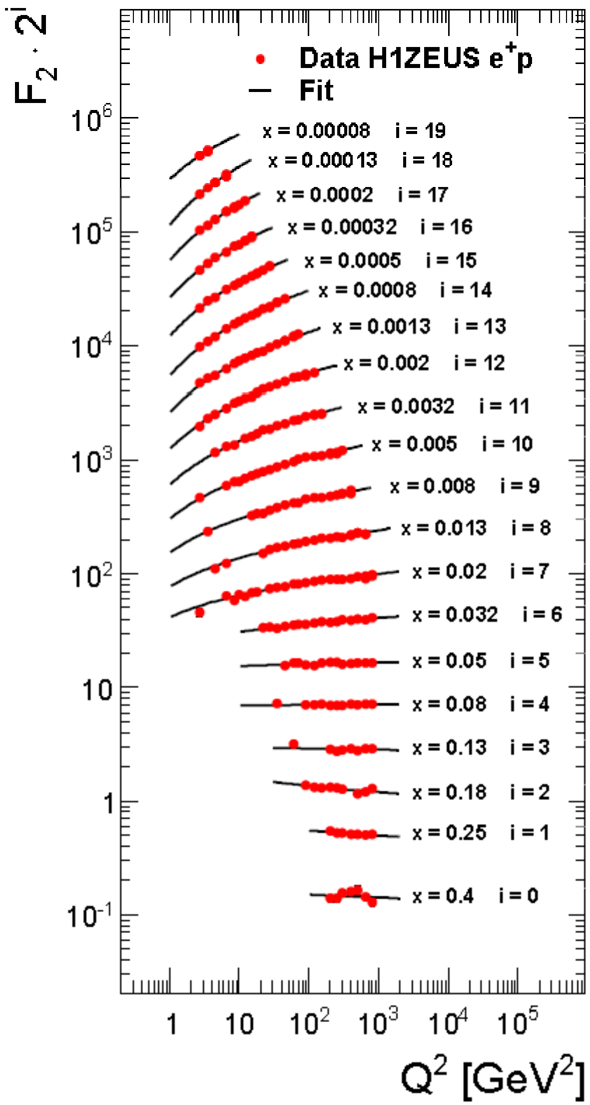
Σ Spins=1

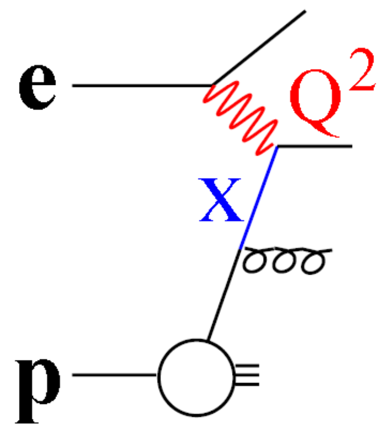
$\frac{d^2\sigma}{dx\, dQ^2}$ = Σ electron-quark cross sections

= Rutherford * Σ Spin term * Structure Function F_2

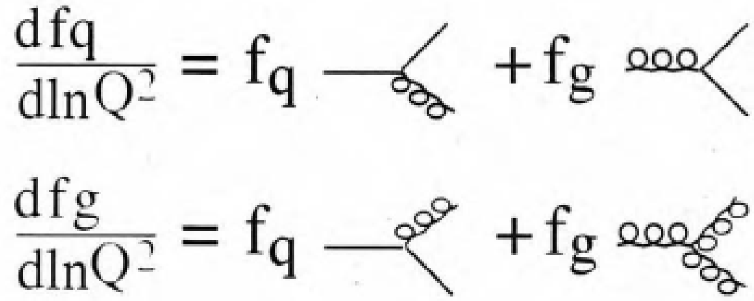
$$F_2(x,Q^2) = \left[\frac{4}{9}\, x\, u(x,Q^2) + \frac{1}{9}\, x\, d(x,Q^2) + \ldots\right]$$

Structure Function: Scaling Violations



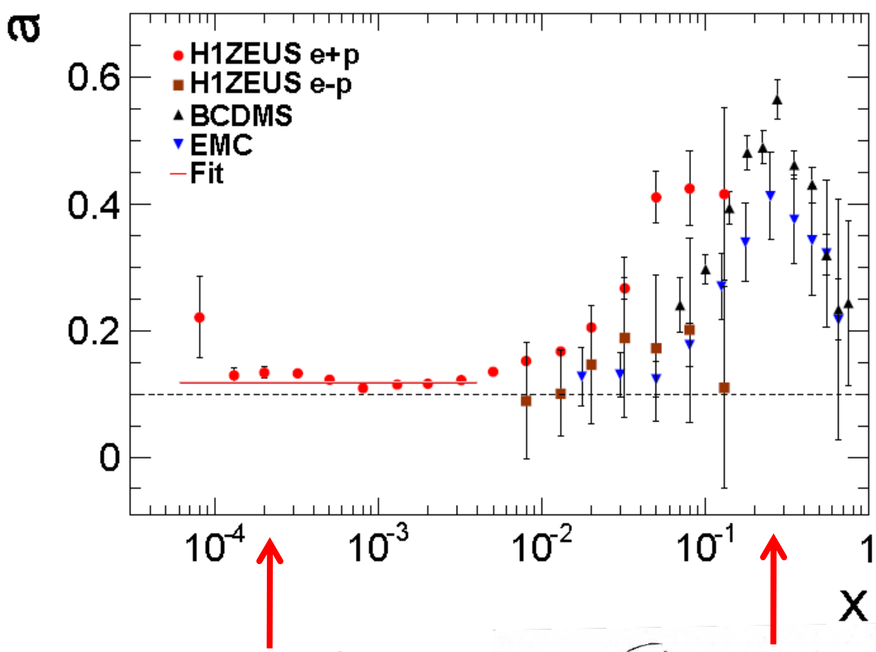


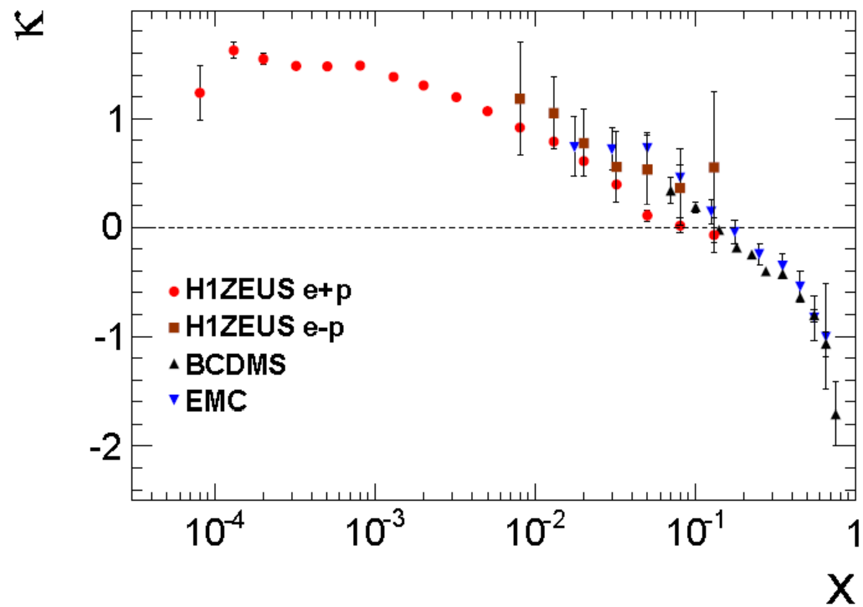
Q^2-Abh.: QCD-Entwicklungsgleichungen “DGLAP-Gln.”

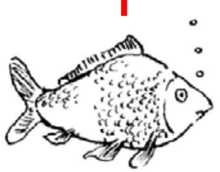


Visualizing Quarks in Proton

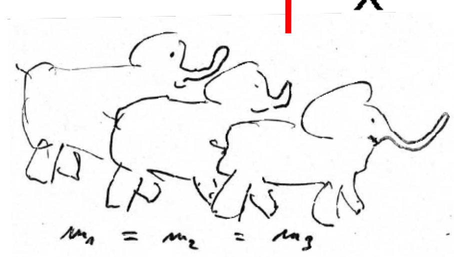
$$F_2(x, Q^2) = a(x) \left[\ln \left(\frac{Q^2}{\Lambda^2} \right) \right]^{\kappa(x)}$$







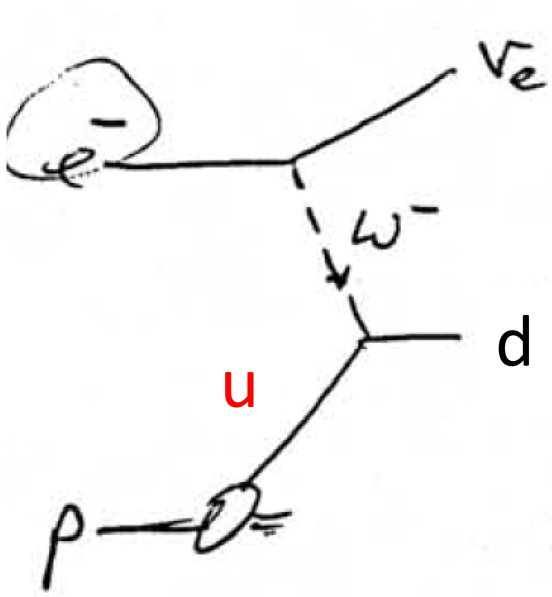
sea quarks

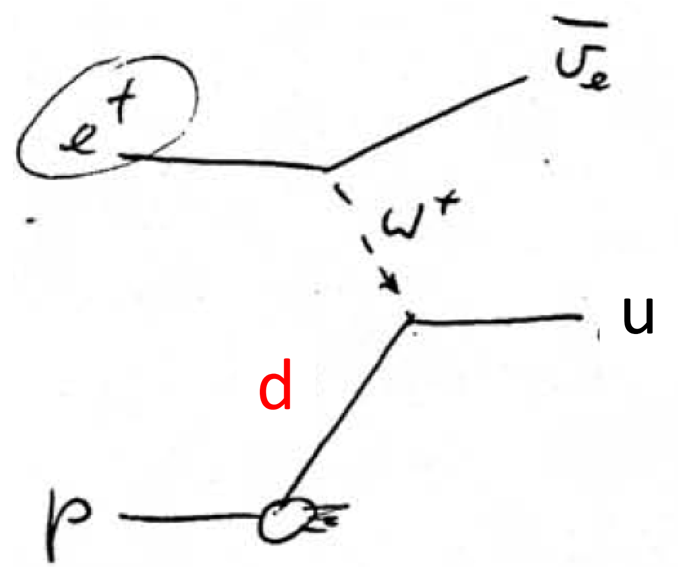


valence quarks

D. Van Aseldonk, M. Erdmann,
T. Klimkovitch, M. Nienhaus
DIS 2010, Florence

Quark Flavours in Proton





quark needs
positive charge

quark needs
negative charge

cross sections imply valence quarks of **proton=uud**

Nucleon Resonances

name

Mass [MeV]

Particle	$L_{2I \cdot 2J}$	status	$N\pi$	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\rho$	$N\gamma$
$N(939)$	P_{11}	****							
$N(1440)$	P_{11}	****	****	*			***	*	***
$N(1520)$	D_{13}	****	****	***			****	****	****
$N(1535)$	S_{11}	****	****	****			*	**	***
$\Delta(1232)$	P_{33}	****	****	F					****
$\Delta(1600)$	P_{33}	***	***	o			***	*	**
$\Delta(1620)$	S_{31}	****	****	r			****	****	***
$\Delta(1700)$	D_{33}	****	****	b		*	***	**	***

Δ BARYONS
$(S=0,\ I=3/2)$

$\Delta^{++} = uuu,\quad \Delta^{+} = uud,\quad \Delta^{0} = udd,\quad \Delta^{-} = ddd$

Δ^{++} antisymmetric wave function ?

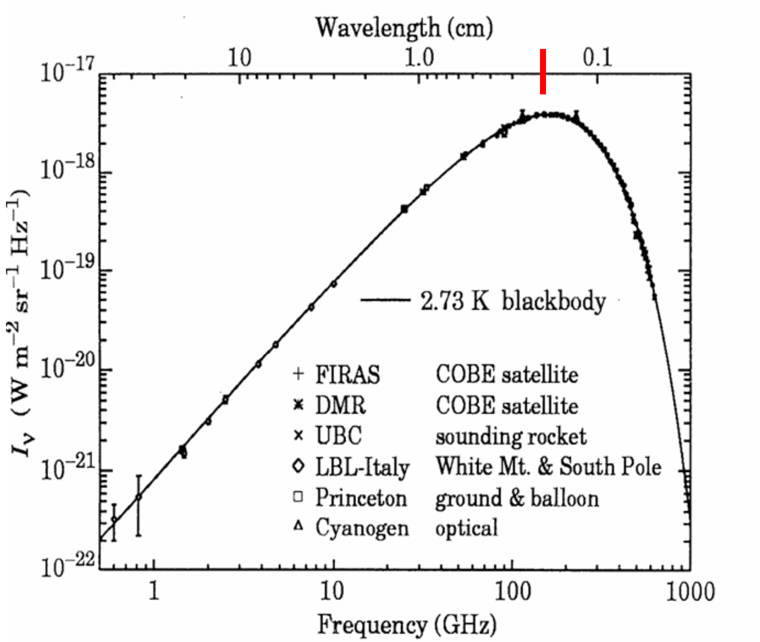
Quarks: 3 colors

Photon-Proton-Interactions

Photons: cosmic microwave background

T = 2.728 +/- 0.004 K

Target density: 380 Photonen pro cm^3



$$E_\gamma = \frac{2\,\pi\,\hbar\,c}{\lambda} = \frac{6*0.2\text{ GeV fm}}{0.2\text{ cm}}$$

$= 6\ 10^{-4}$ eV

Δ – Resonance: need Proton with

$$\mathbf{p}_p + \mathbf{p}_\gamma = \mathbf{p}_\Delta$$

$$\begin{pmatrix} E_p + E_\gamma \\ \vec{p}_p\, c + \vec{p}_\gamma\, c \end{pmatrix} = \begin{pmatrix} m_\Delta c^2 \\ 0 \end{pmatrix}$$

$E_p > 5\ 10^{19}$ eV

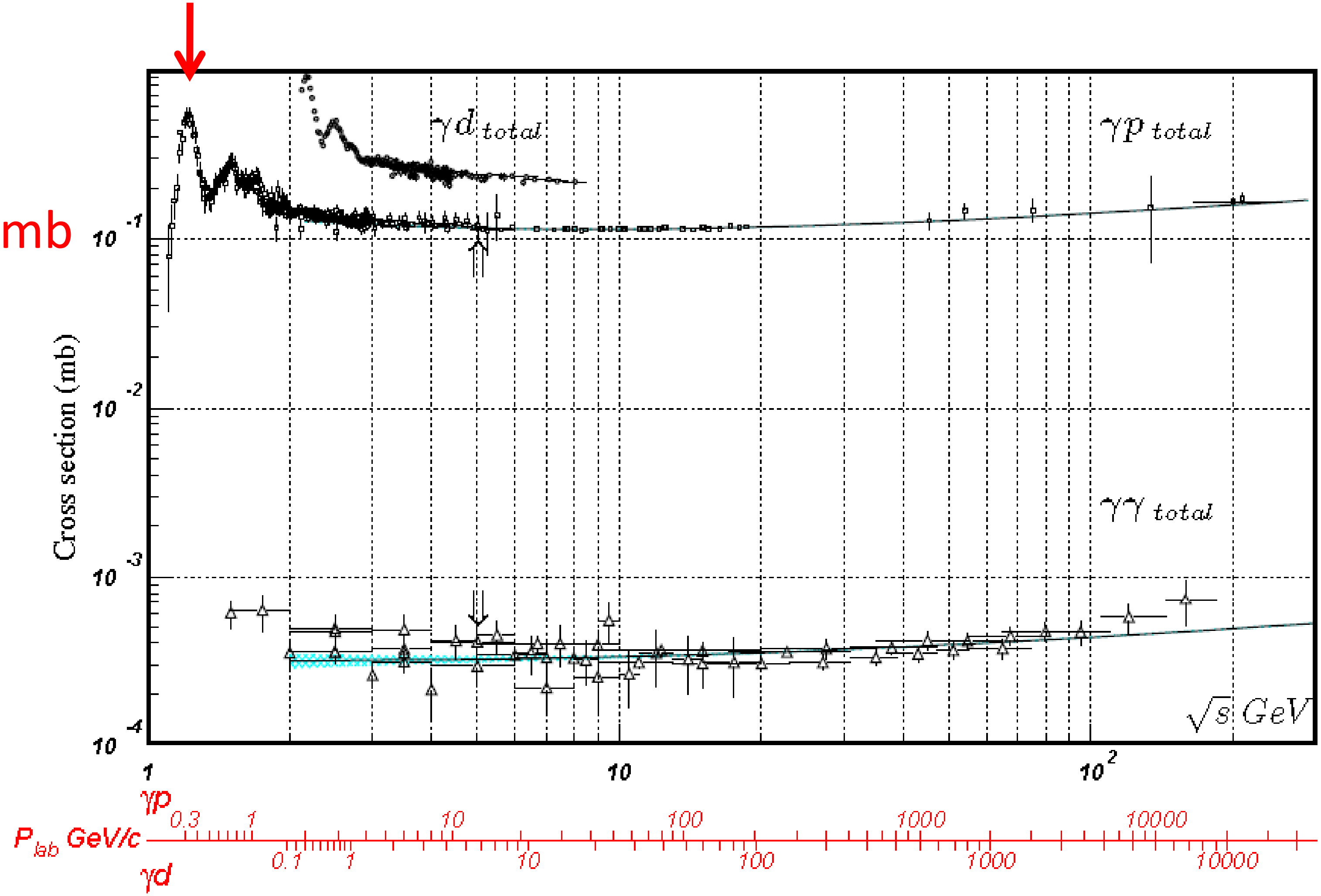
Greisen–Zatsepin–Kuzmin

(GZK-cutoff)

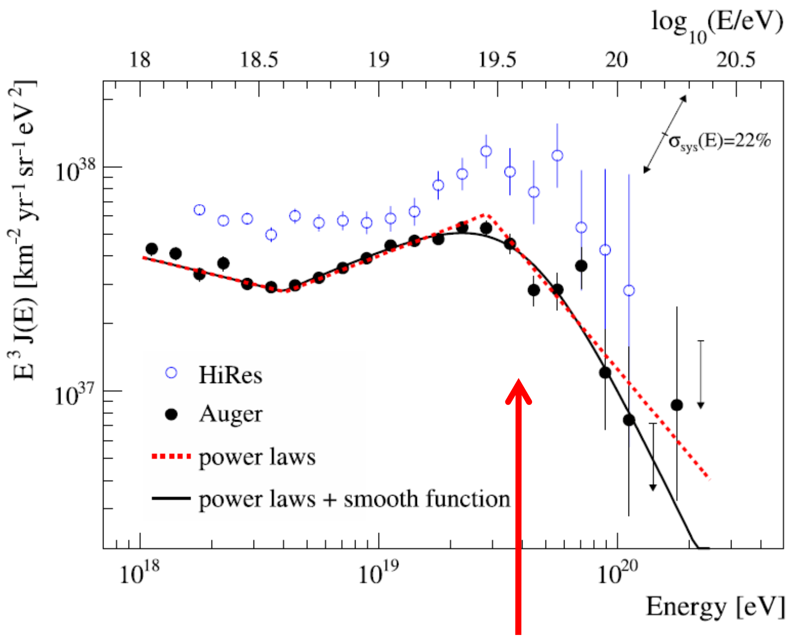
Cross Section γp Interactions

Δ Resonance we know the cross section

0.1 mb



Cosmic Ray Energy Spectrum



Proton from Δ Decay carries less energy

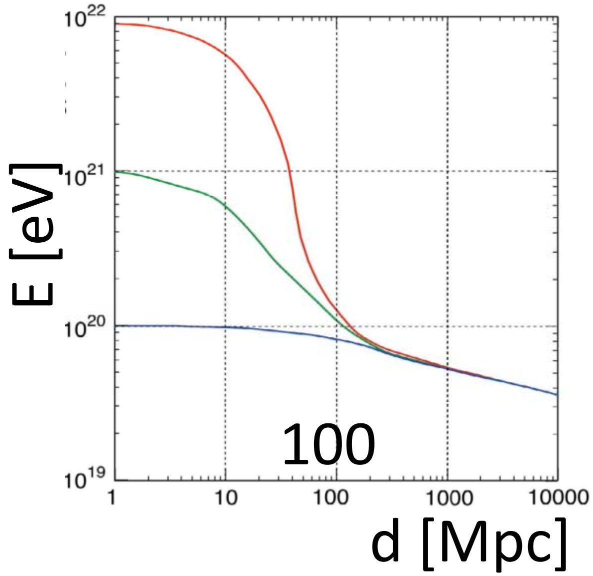
Δ(1232) DECAY MODES	Fraction (Γ_i/Γ)
$N\pi$	100 %

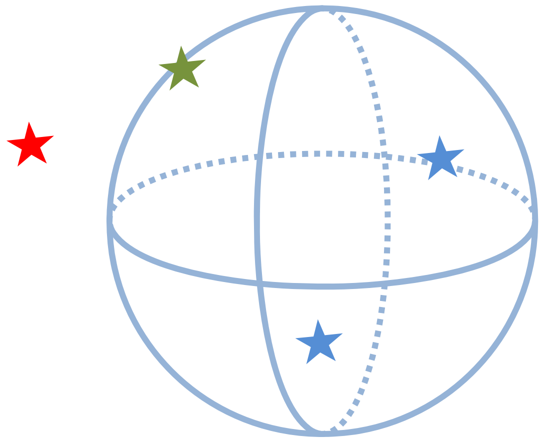
π^+ DECAY MODES			Fraction (Γ_i/Γ)	Confi
$\mu^+\nu_\mu$	„GZK Neutrinos“	[b]	(99.98770 ± 0.00004) %	

π^0 DECAY MODES		Fraction (Γ_i/Γ)
2γ	„GZK Photons“	(98.823 ± 0.034) %

GZK Horizon

Expected energy loss



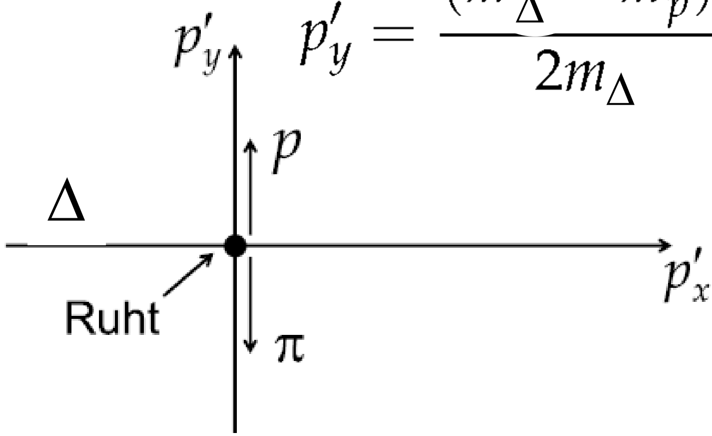


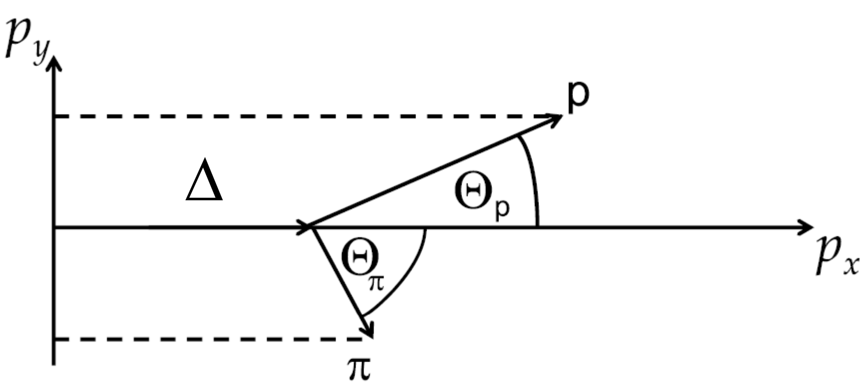
Expect sources of ultra high energy cosmic rays within a 100 Mpc sphere from earth

Δ Decay

Decay Momenta

$$p'_y = \frac{(m_\Delta^2 - m_p^2)c}{2m_\Delta}$$





Decay Angles

Pion Lab $\quad$ Δ kinematics $\quad$ Pion CMS

$$\begin{pmatrix} E \\ p_x c \\ p_y c \\ p_z c \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta & 0 & 0 \\ \gamma\beta & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} E' \\ 0 \\ p'_y c \\ 0 \end{pmatrix}$$

$$\gamma = \frac{E_\Delta}{m_\Delta c^2} \qquad \beta = \sqrt{1 - \frac{1}{\gamma^2}}$$

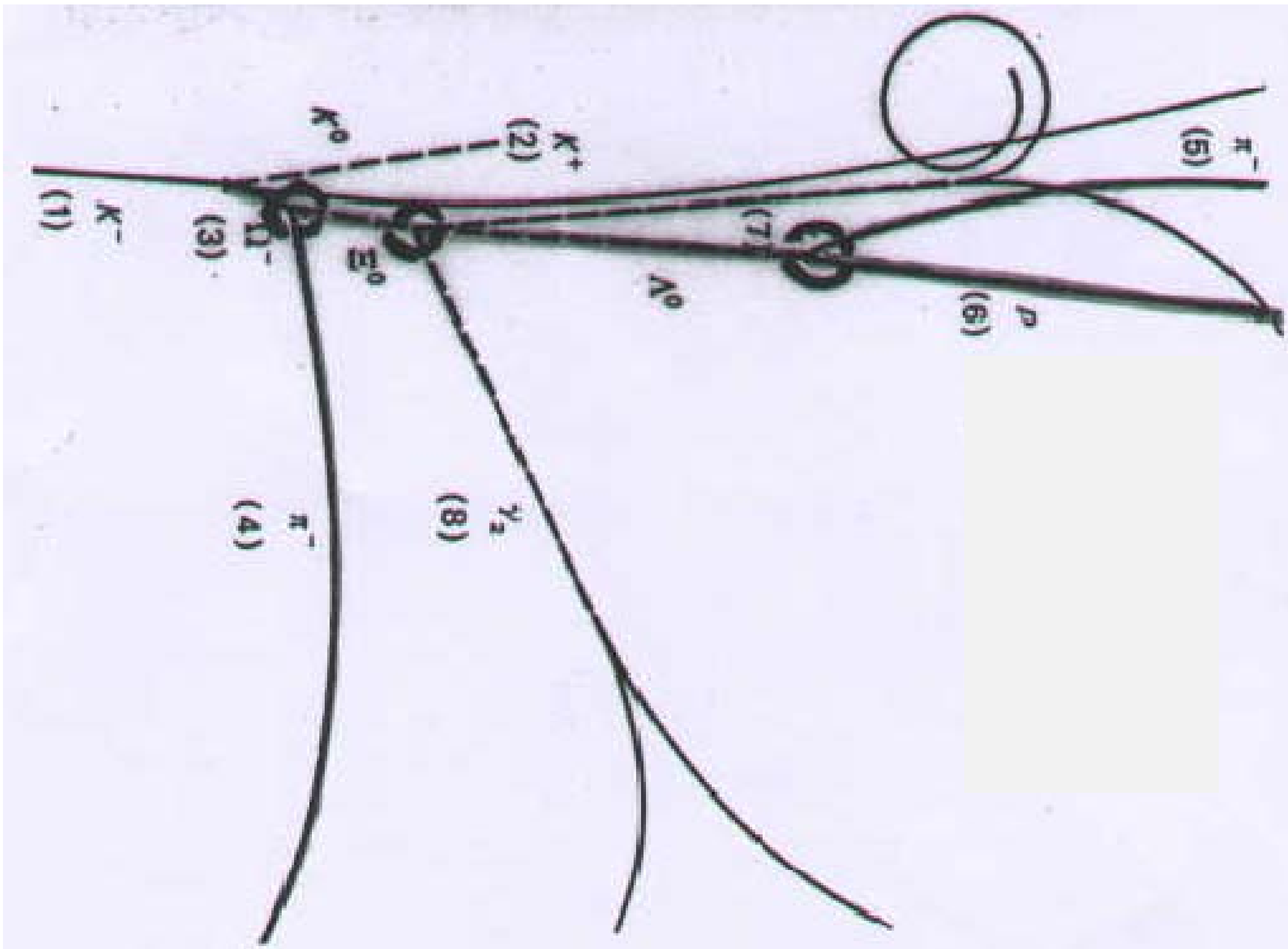
Proton (heavy) reflects the original Δ direction

$$\tan\Theta_p = \frac{1}{\gamma\sqrt{\frac{m_p^2 c^2}{p_y'^2 c^2} + 1}} \approx 0$$

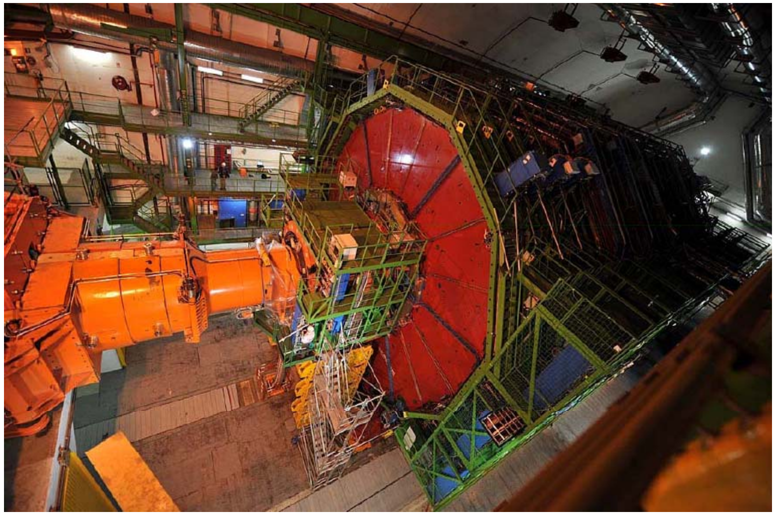
Pion (~massless) has angle

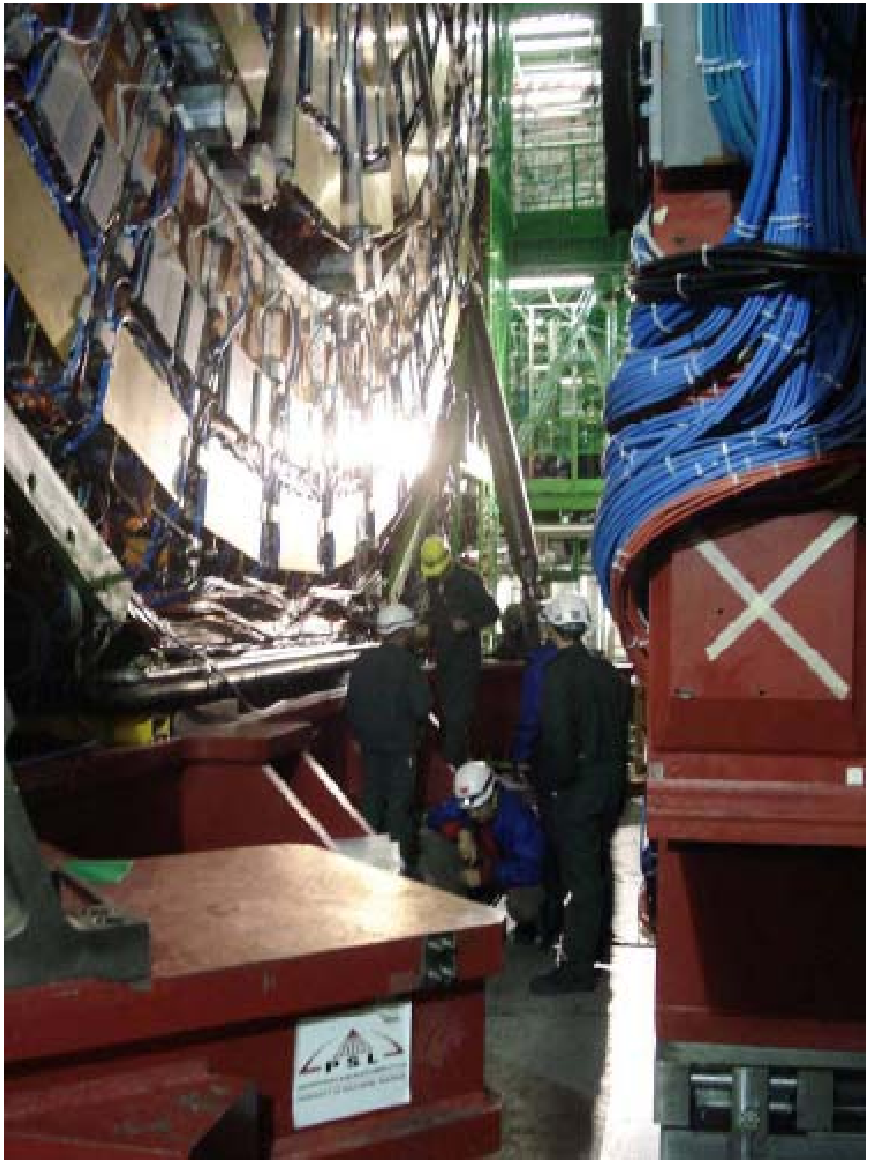
$$\tan\Theta_\pi \approx \frac{1}{\gamma}$$

Heavy Particle Preserves Direction

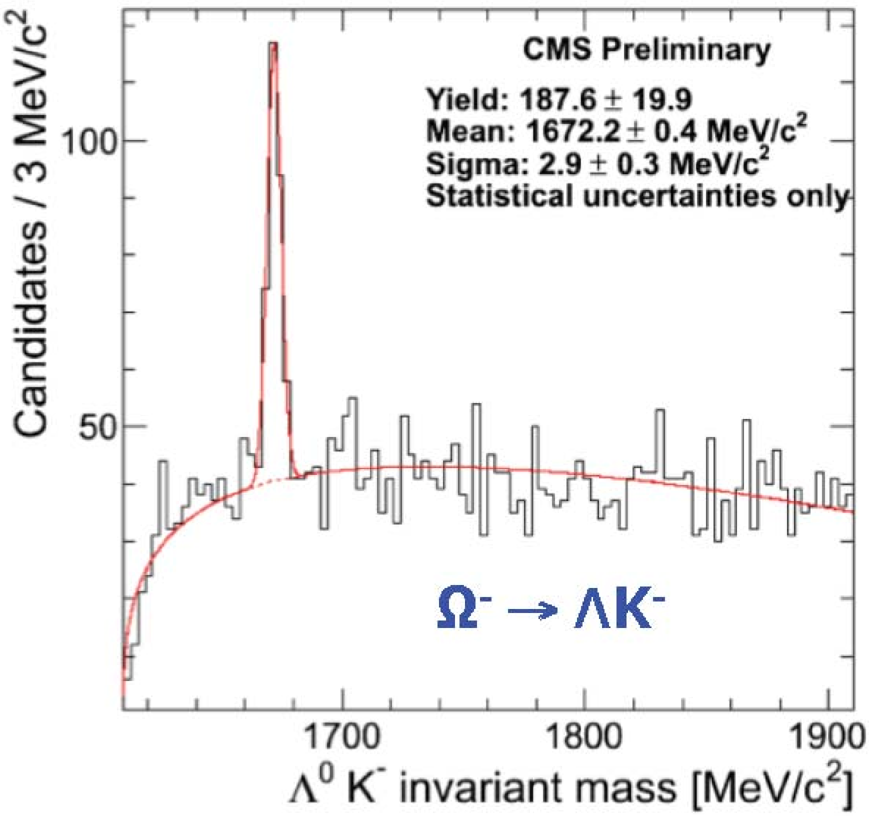


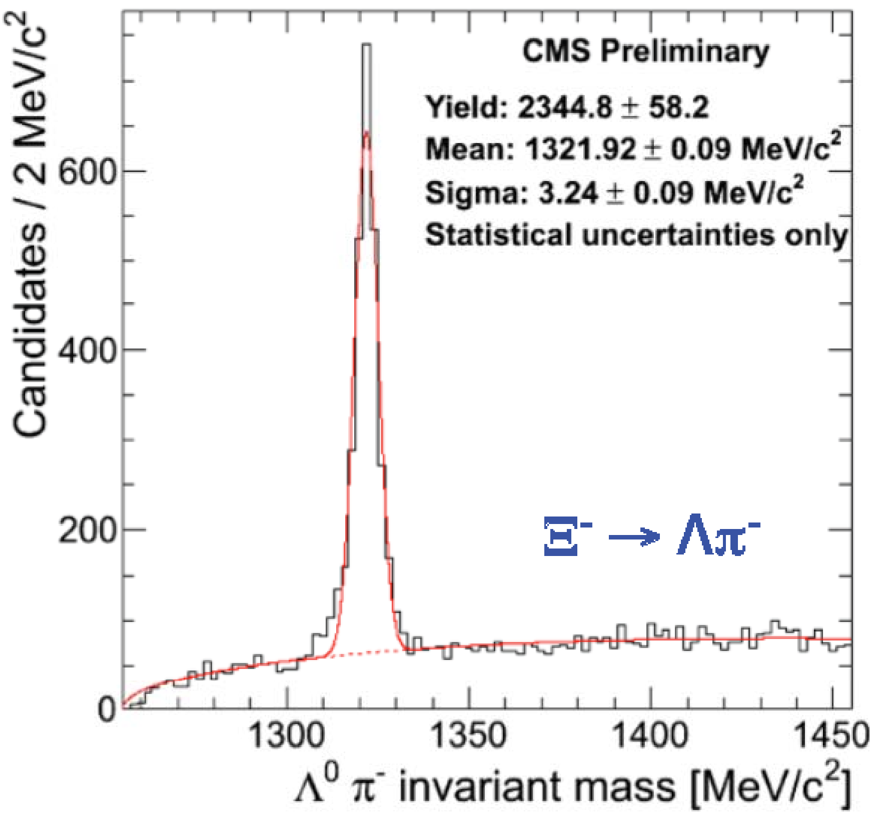
Compact Myon Solenoid at the LHC





CMS: Classic Baryons

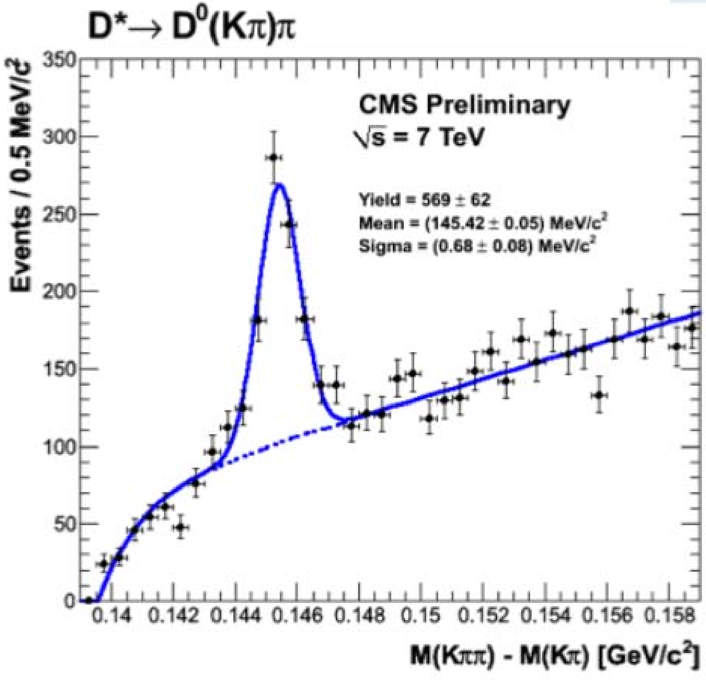


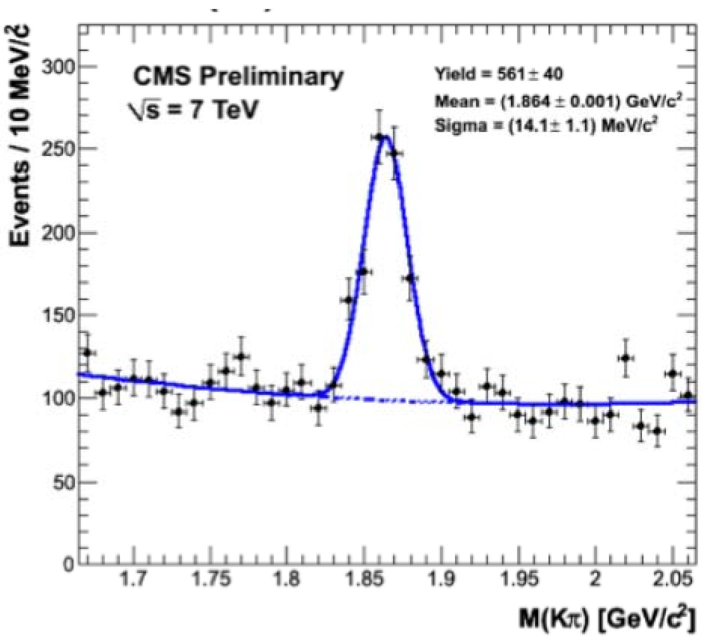


Silicon tracker

CMS: Charm

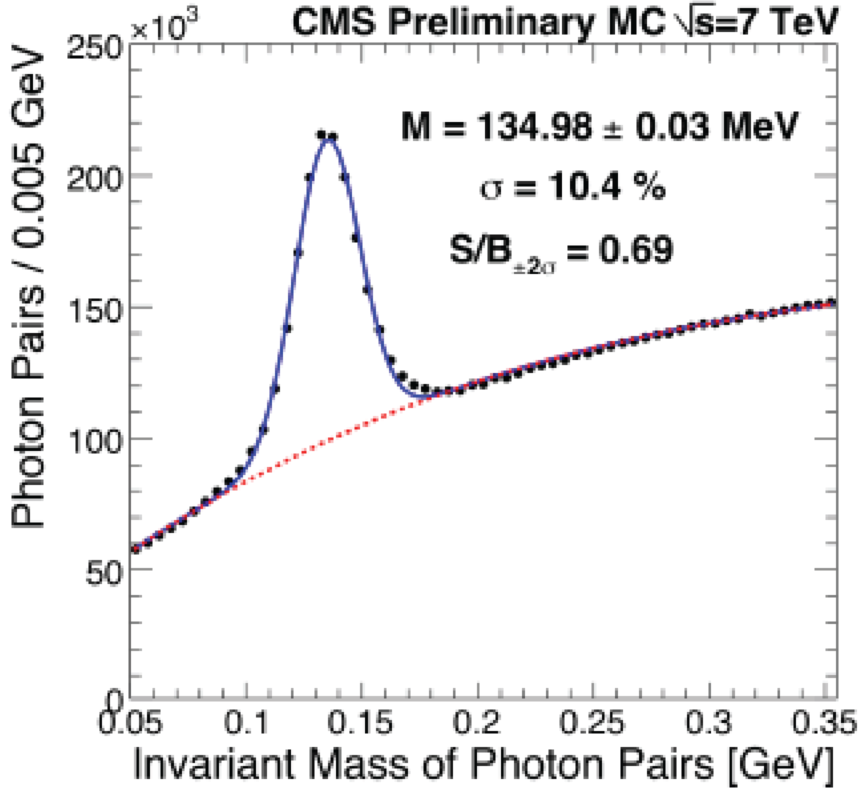
$D^{*+} \rightarrow D^{o}(K^{-}\pi^{+})\pi^{+}$





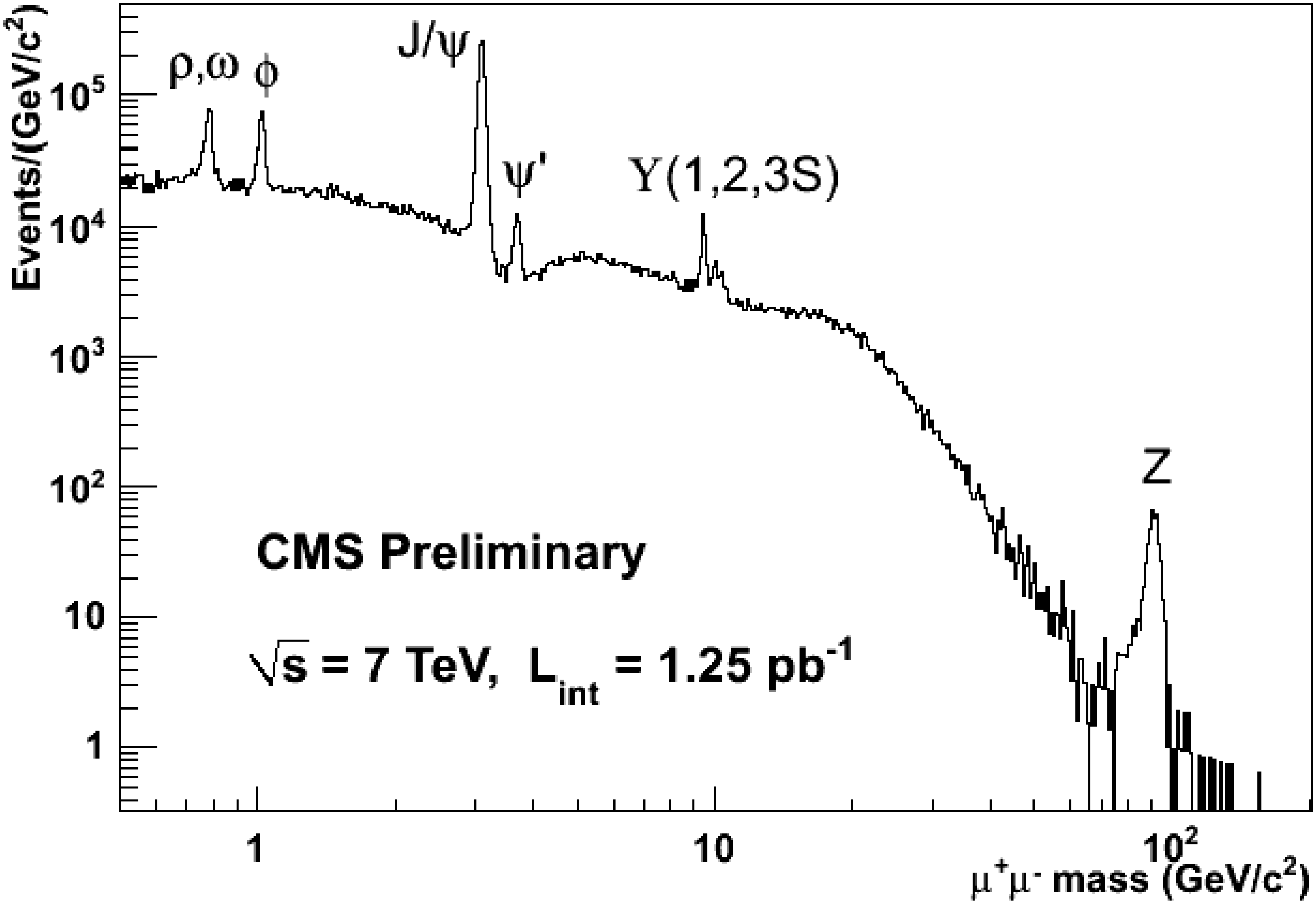
Silicon tracker

CMS: π_0 –> 2 γ



Electronmagnetic calorimeter

CMS: Myon Detector



Summary

- Proton is well understood
- LHC experiments re-discover the particle zoo
- Δ Resonance: limits observed cosmic ray energy spectrum
- GZK horizon limits the source candidates to within 100 Mpc