

Що е то
Физика на елементарните
частици
и има ли почва тя у нас?



План



❖ Що е то?

- Фундментални частици
- Взаимодействия
- Стандартен модел
- Проблеми

❖ Как го правим

❖ Има ли почва у нас

❖ Минало

- HYPERON

Настояще

- NA48
- NA49
- CMS
- Grid

Бъдеще



Що е то?



Физика на елементарните частици

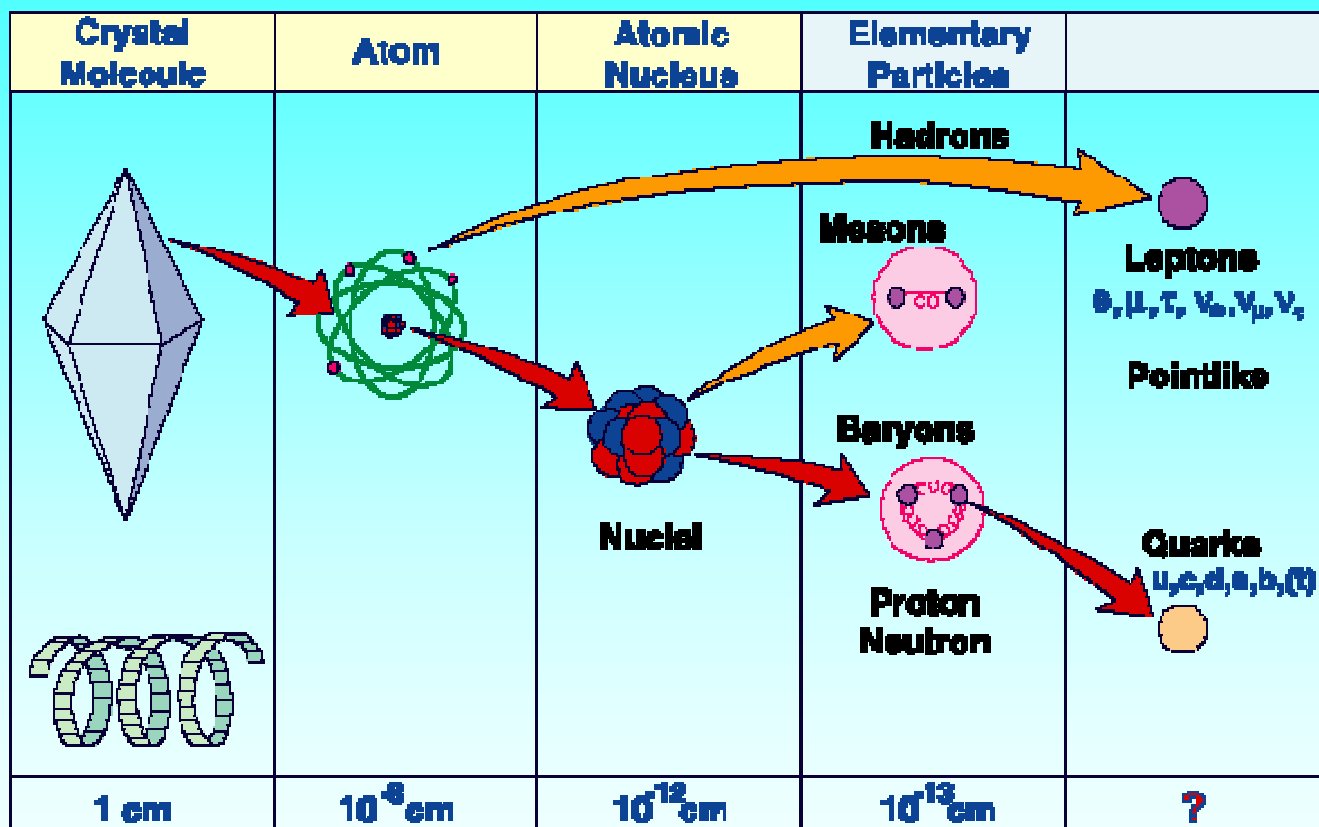


Опитва се да отговори на два фундаментални въпроса

-Кои са елементарните съставлящи на материята

-Кои са фундаменталните сили контролиращи
тяхното поведение

Deeper in the matter



21101

Катедра Атомна физика

Leptons

Tau		Electric Charge -1	Tau Neutrino		Electric Charge 0
Muon		-1	Muon Neutrino		0
Electron		-1	Electron Neutrino		0

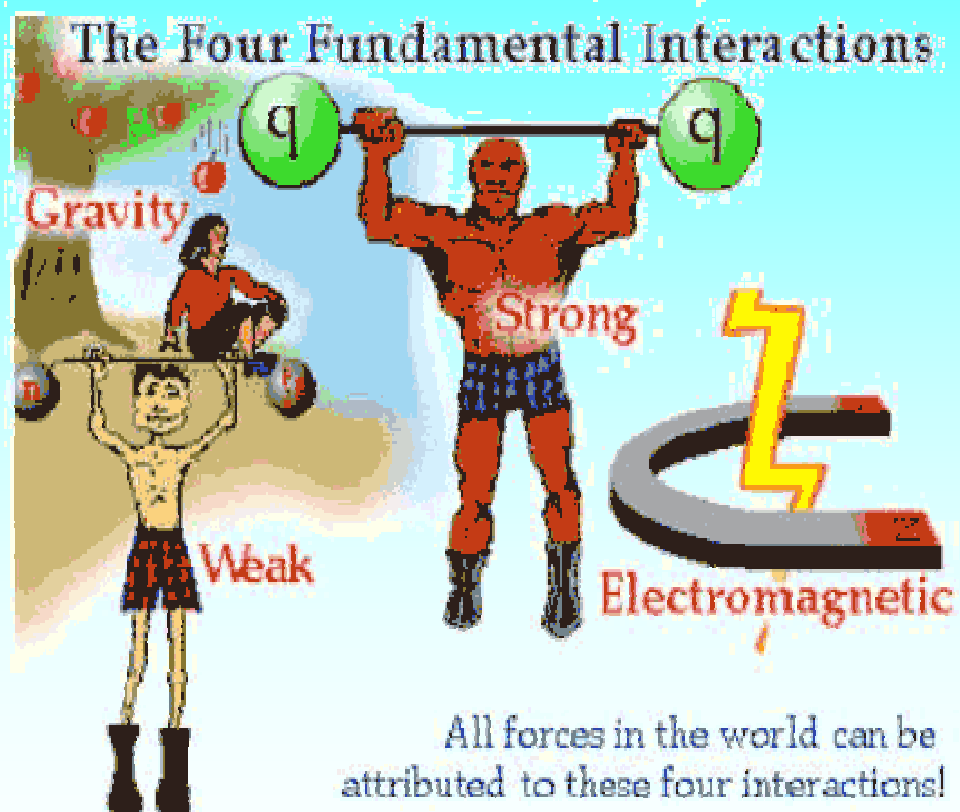
Quarks

Bottom		Electric Charge $-1/3$	Top		Electric Charge $2/3$
Strange		$-1/3$	Charm		$2/3$
Down		$-1/3$	Up		$2/3$

each quark: ● R, ● B, ● G 3 colors

The particle drawings are simple artistic representations

How are the composite objects held together ?
by forces





Стандартен модел



In QFT – the local invariance of $\mathcal{L}$ defines the interactions

Electromagnetic Interactions: γ
Quantum Electrodynamics (QED) $U(1)$

In the Standard Model

QED + Weak Interactions: $\gamma, Z^0, W^\pm$
Electroweak Theory $SU(2)_L \otimes U(1)_Y$

Strong Interaction **8 Gluons**
Quantum Chromodynamics (QCD) $SU_c(3)$

PROBLEM WITH MASS SCALES

Gauge Symmetry



$$m_\gamma = 0$$

Good

$$M_W = M_Z = 0$$

Bad!



$$M_W = 80.43 \text{ GeV}$$

$$M_Z = 91.19 \text{ GeV}$$

Moreover

$$\mathcal{L}_{m_f} \equiv -m_f \bar{f} f = -m_f (\bar{f}_L f_R + \bar{f}_R f_L)$$

Also Forbidden by Gauge Symmetry



$$m_f = 0$$

$\forall f$

All Particles Massless



Спонтанно нарушение на симетрията



In the SM masses are generated through

Spontaneous Symmetry Breaking (SSB) – Higgs Mechanism

Introduce Scalar Higgs doublet $\rightarrow$ The Lagrangian is invariant

However its vacuum state is degenerate – $\langle 0 | \Phi_0 | 0 \rangle = \frac{v}{\sqrt{2}}$

Choice of the vacuum state – leads to SSB

$SU(2)_L \times U(1)_Y \rightarrow U(1)_Q$

Couplings with gauge bosons and fermions – induce mass terms

Price – new particle **H-boson** – to be discovered



Смесване на кварките

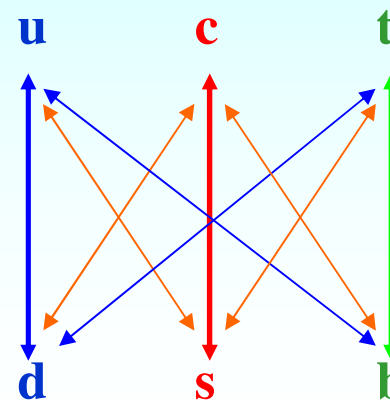
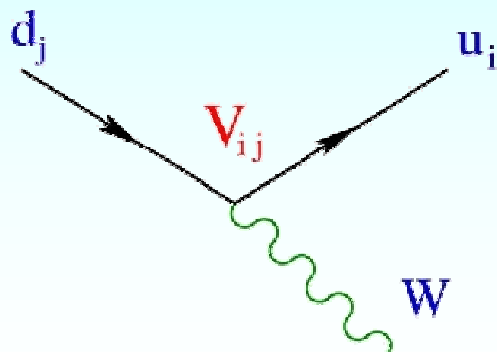


$$L_{NC}^Z = \frac{e}{2 \sin \theta_W \cos \theta_W} Z_\mu \sum_f \bar{f} \gamma_\mu [v_f - a_f \gamma_5] f$$

Flavour Conserving Neutral Current

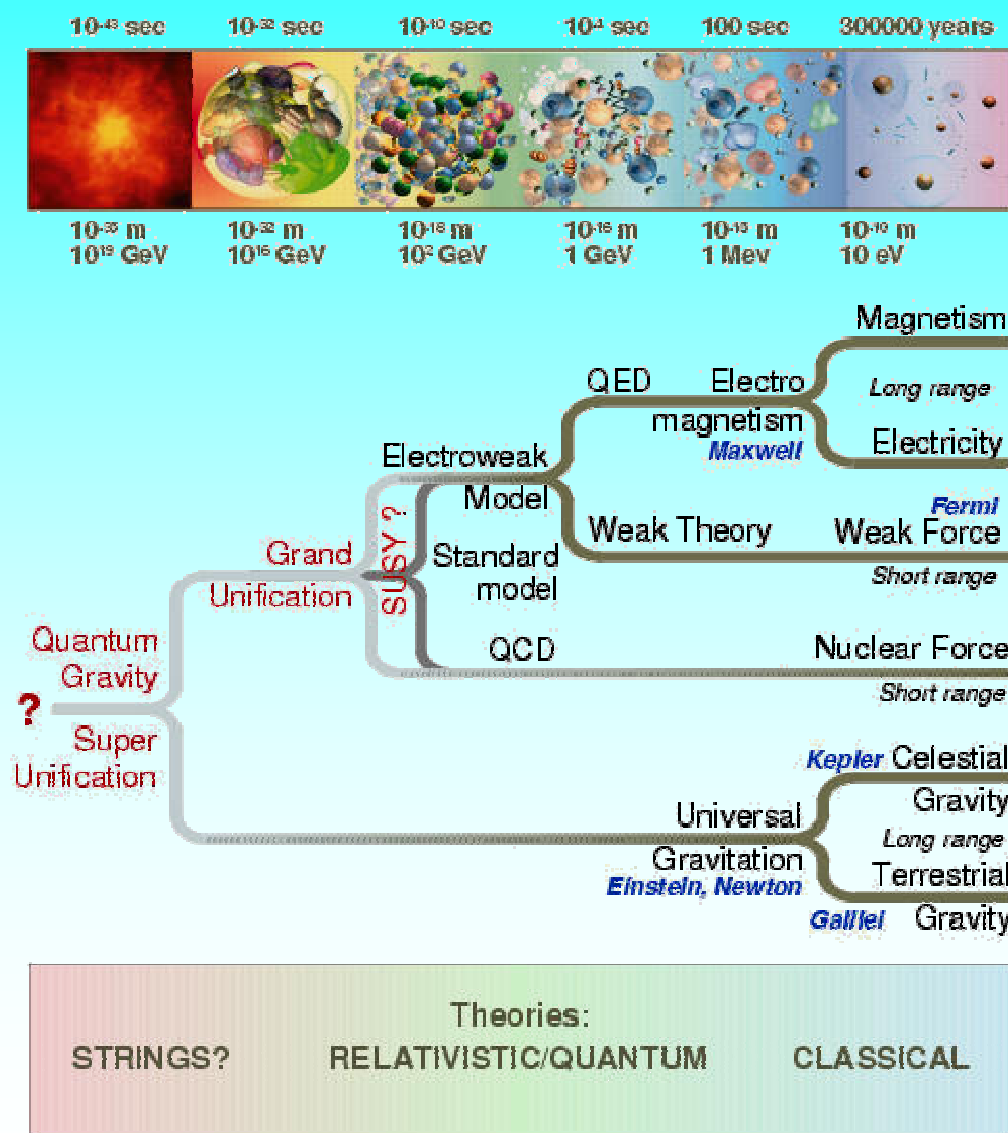
$$L_{CC}^W = \frac{g}{2\sqrt{2}} W_\mu^+ \left[\sum_{ij} \bar{u}_i \gamma^\mu (1 - \gamma_5) V_{ij} d_j + \sum_l \bar{\nu}_l \gamma^\mu (1 - \gamma_5) l_j \right] + h.c.$$

Flavour Changing Charged Current





Единно описание на взаимодействията





Суперсиметрия



How to unify ?

Gravity - space-time symmetry

Electroweak - internal symmetry

Strong - internal symmetry

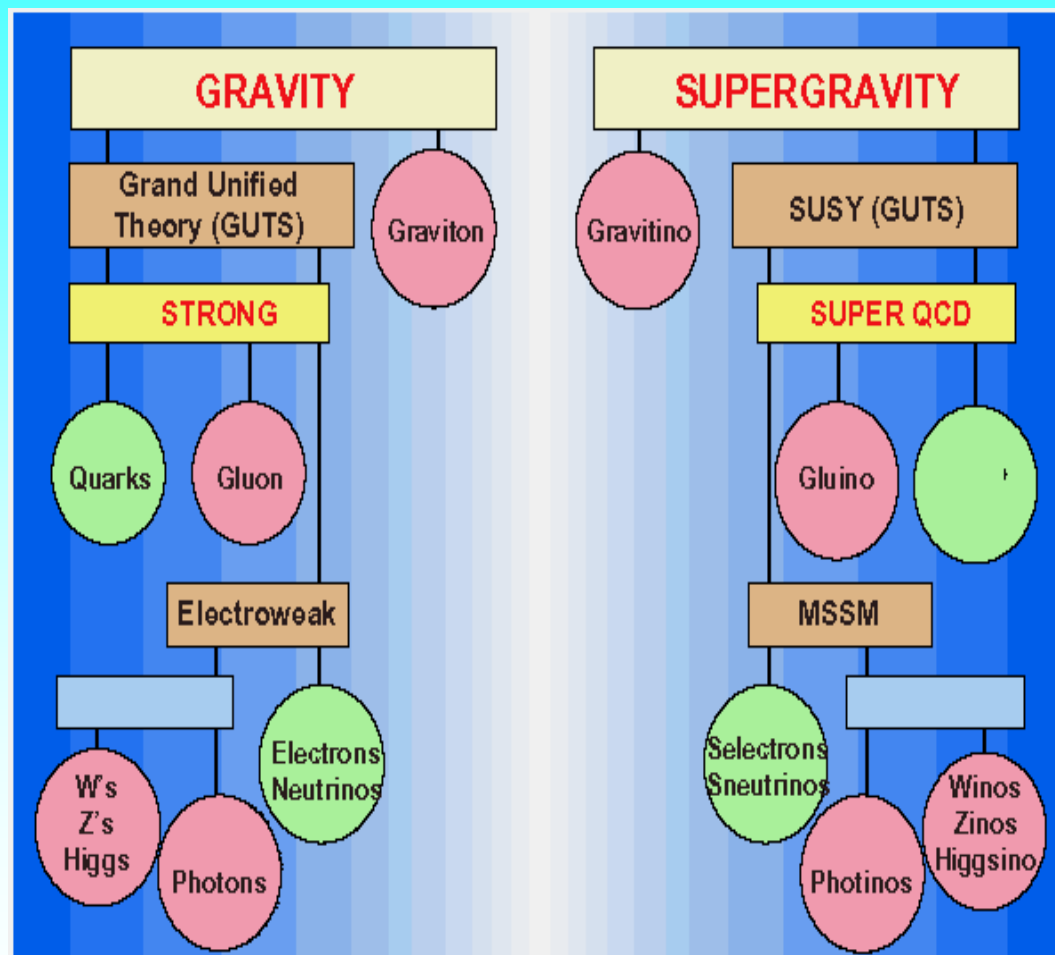
Supersymmetry – symmetry between bosons and fermions

Works well, but

Price to pay: many new particles!

To every fundamental particle – new boson

To every mediator – new fermion





Колко мерно е пространство-времето?



Two fundamental scales:

- Electroweak — $M_{EW} \sim 10^2\text{-}10^3 \text{ GeV}$
- Planck — $M_{Pl} \sim 10^{19} \text{ GeV}$

Observation:

- M_{EW} is established experimentally
 - EW interactions are tested down to distances $1/M_{EW} \sim 10^{-17} \text{ cm}$
- M_{Pl} is just a number
 - gravity tested only down to $\sim 1 \text{ mm}$, far away from $1/M_{Pl} \sim 10^{-35} \text{ m}$

Solution: cut the Gordian Knot!

- There is only one fundamental scale: M_{EW}
- M_{Pl} is just an effective constant
- Its high value is caused by additional spatial dimensions, compactified at radius $R \sim 1 \text{ mm}$

Extra dimension perspectives

Models with extra dimensions can

- **unify all interactions**
- **solve the hierarchy problem**
- **link String Theory to Standard Model**
- **make Quantum Gravity and String Theory accessible at LHC**

like Prometheus made the divine fire accessible for people

Perhaps it is only a dream...

But I wish you and me this dream to come true!

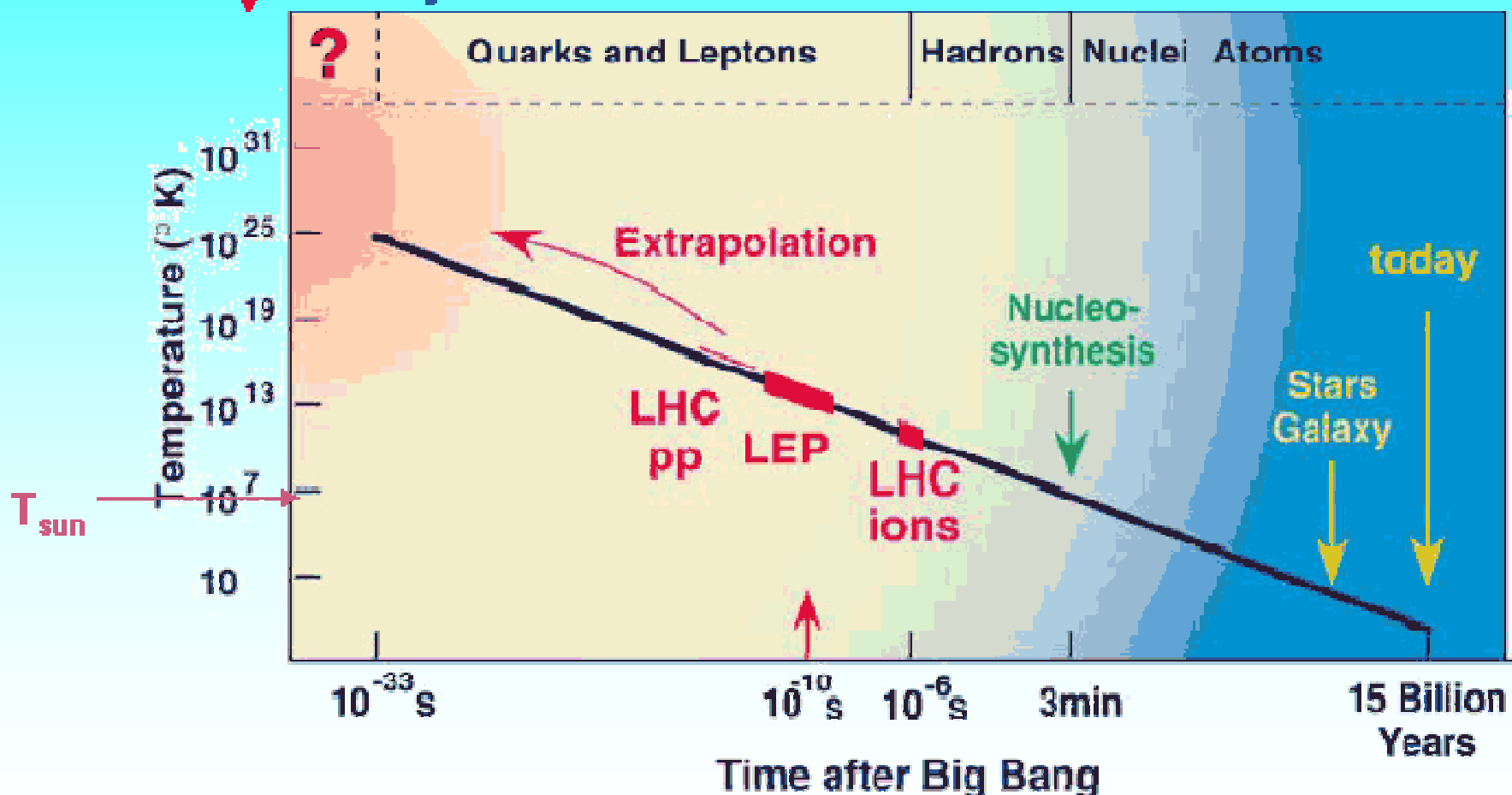


Назад към началото



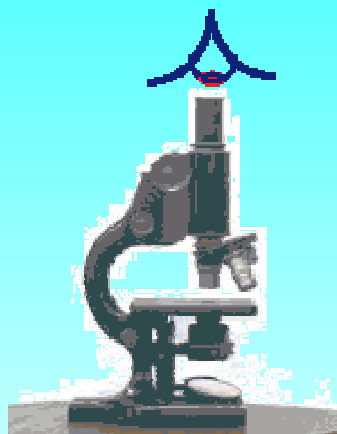
Metaphysics Quantum Gravity

Electroweak Transition





Как го правим?



Wavelength of probe radiation should be smaller than the object to be resolved

$$\lambda \ll \frac{h}{p} = \frac{hc}{E}$$

Object	Size	Energy of Radiation
Atom	10^{-10} m	0.00001 GeV (electrons)
Nucleus	10^{-14} m	0.01 GeV (alphas)
Nucleon	10^{-15} m	0.1 GeV (electrons)
Quarks	?	> 1 GeV (electrons?)

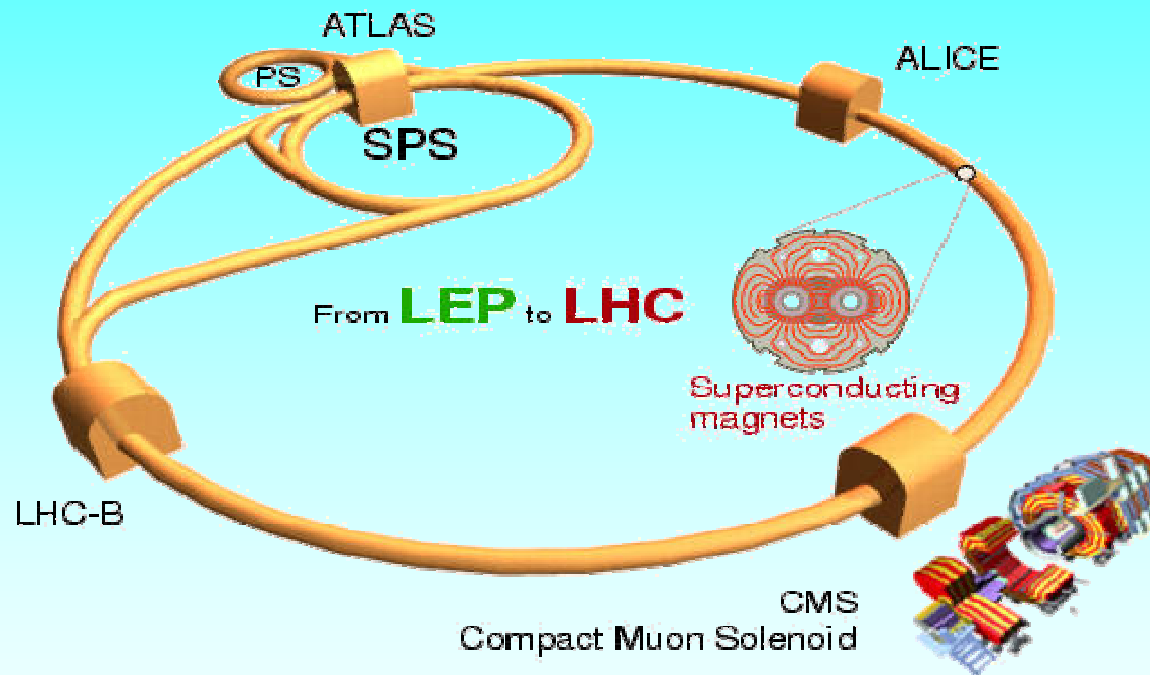


"electronic eyes"

Radioactive sources give energies in the range of MeV

Need accelerators for higher energies.

The Large Hadron Collider (LHC)



	Beams	Energy	Luminosity
LEP	e⁺ e⁻	200 GeV	10³² cm⁻²s⁻¹
LHC	p p	14 TeV	10³⁴
	Pb Pb	1312 TeV	10²⁷





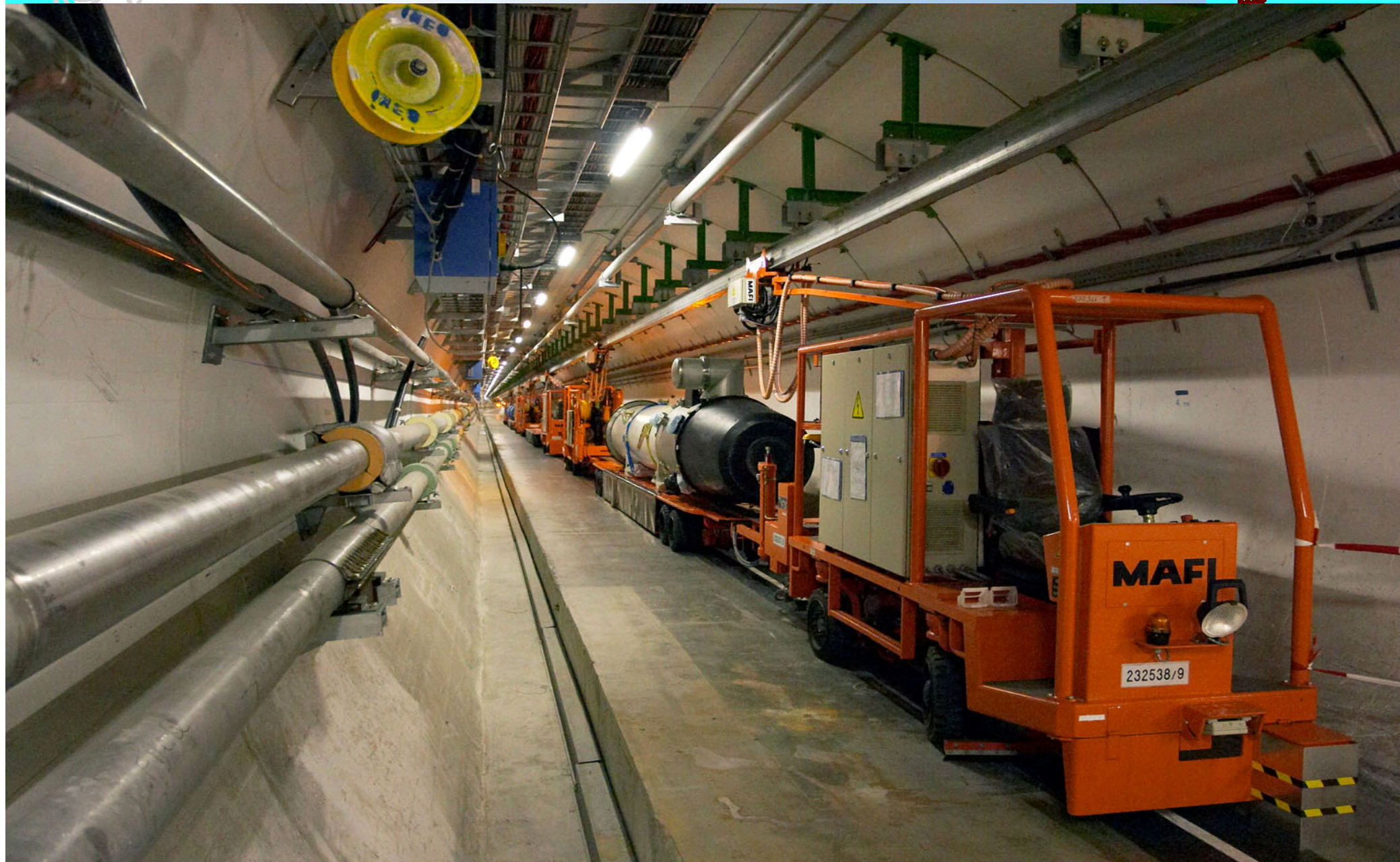
LHC: Контролна зала



L. Litov

Що е то физика на ел. частици и има ли тя почва у нас

Гулечица, 4 Март, 2006





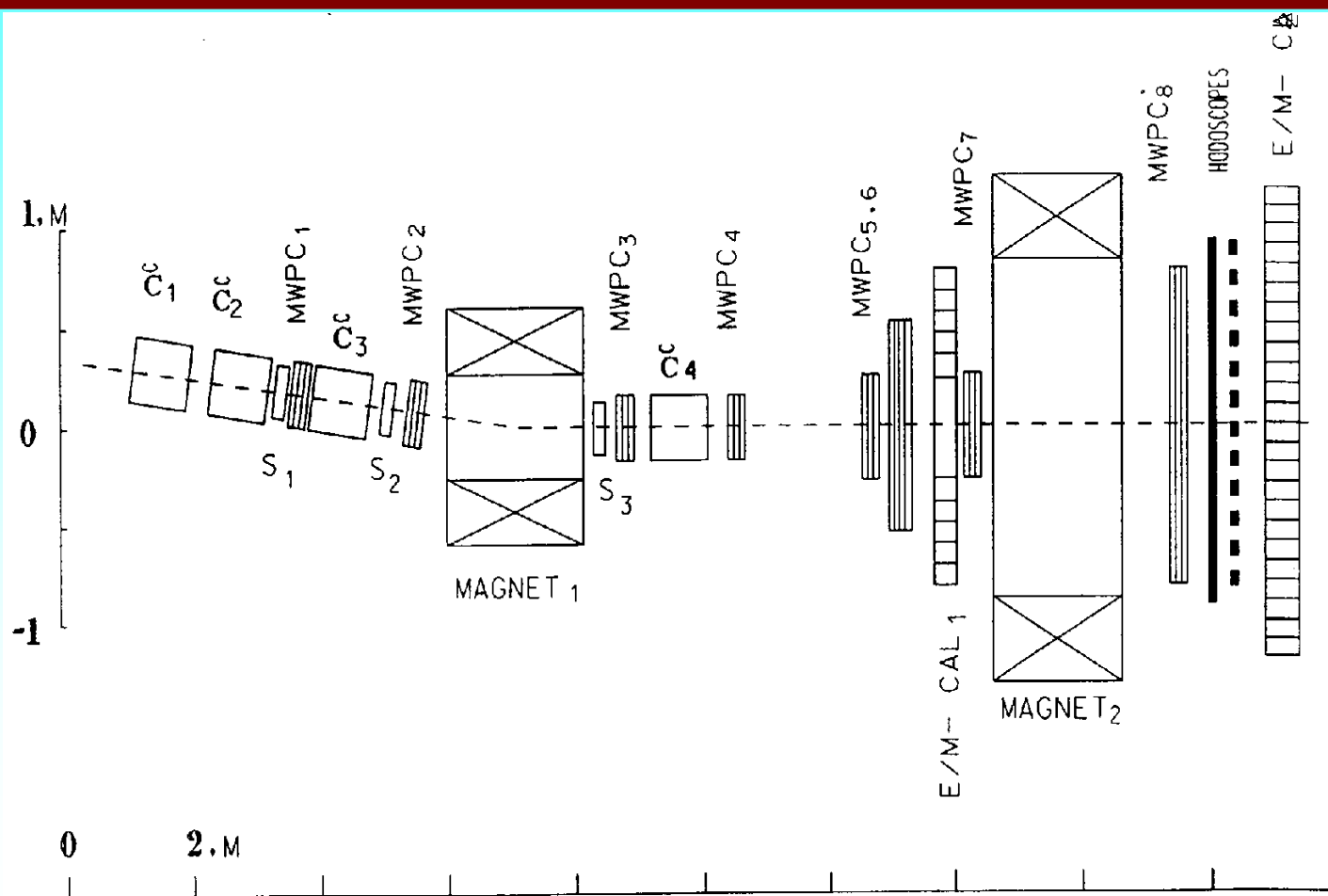
Има ли почва у нас?



История

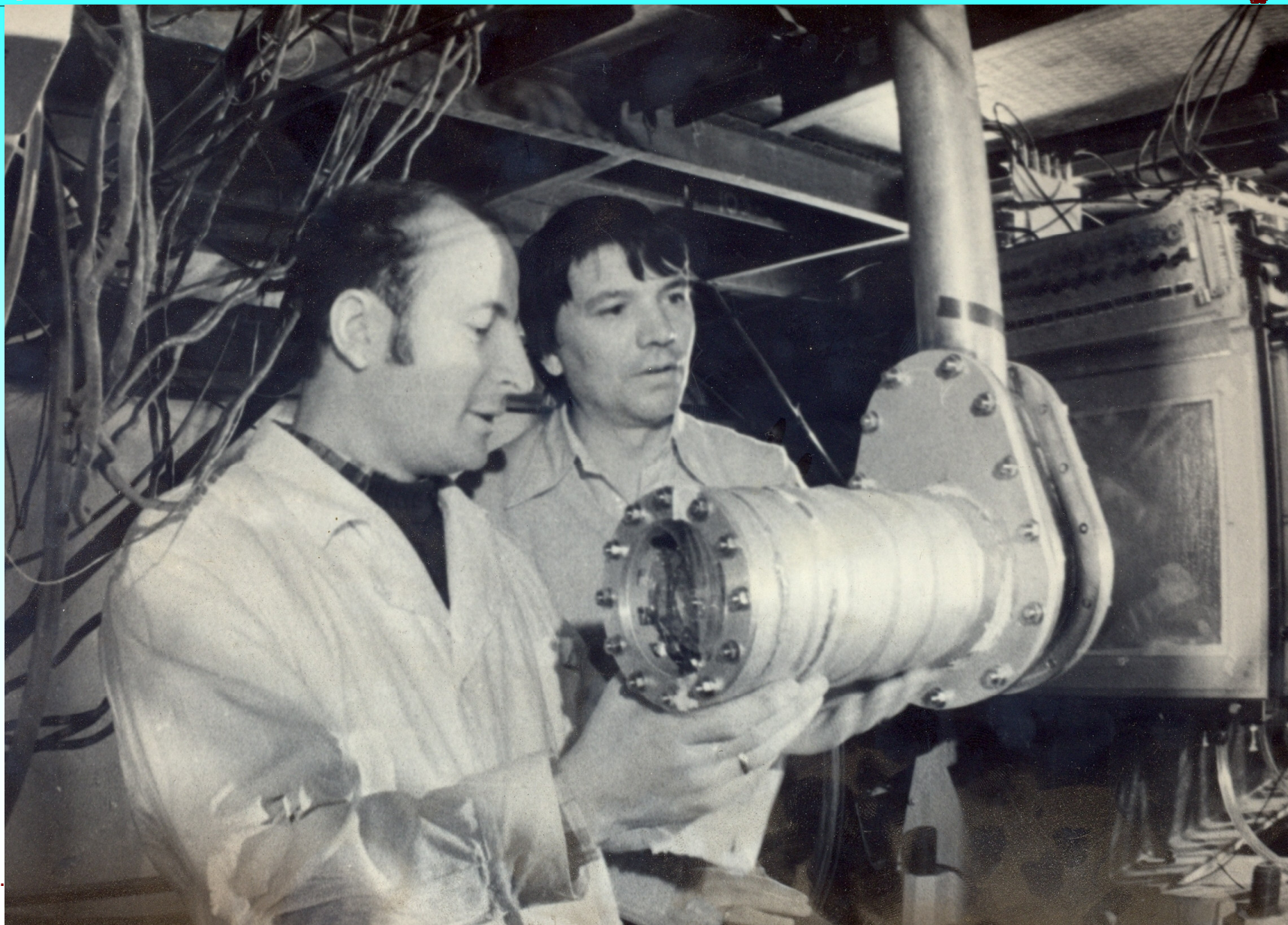


Като обикновено по идея на Цветан Бончев
Участие в експеримента HYPERON на Серпуховския ускорител - 1977





Той беше пръв!



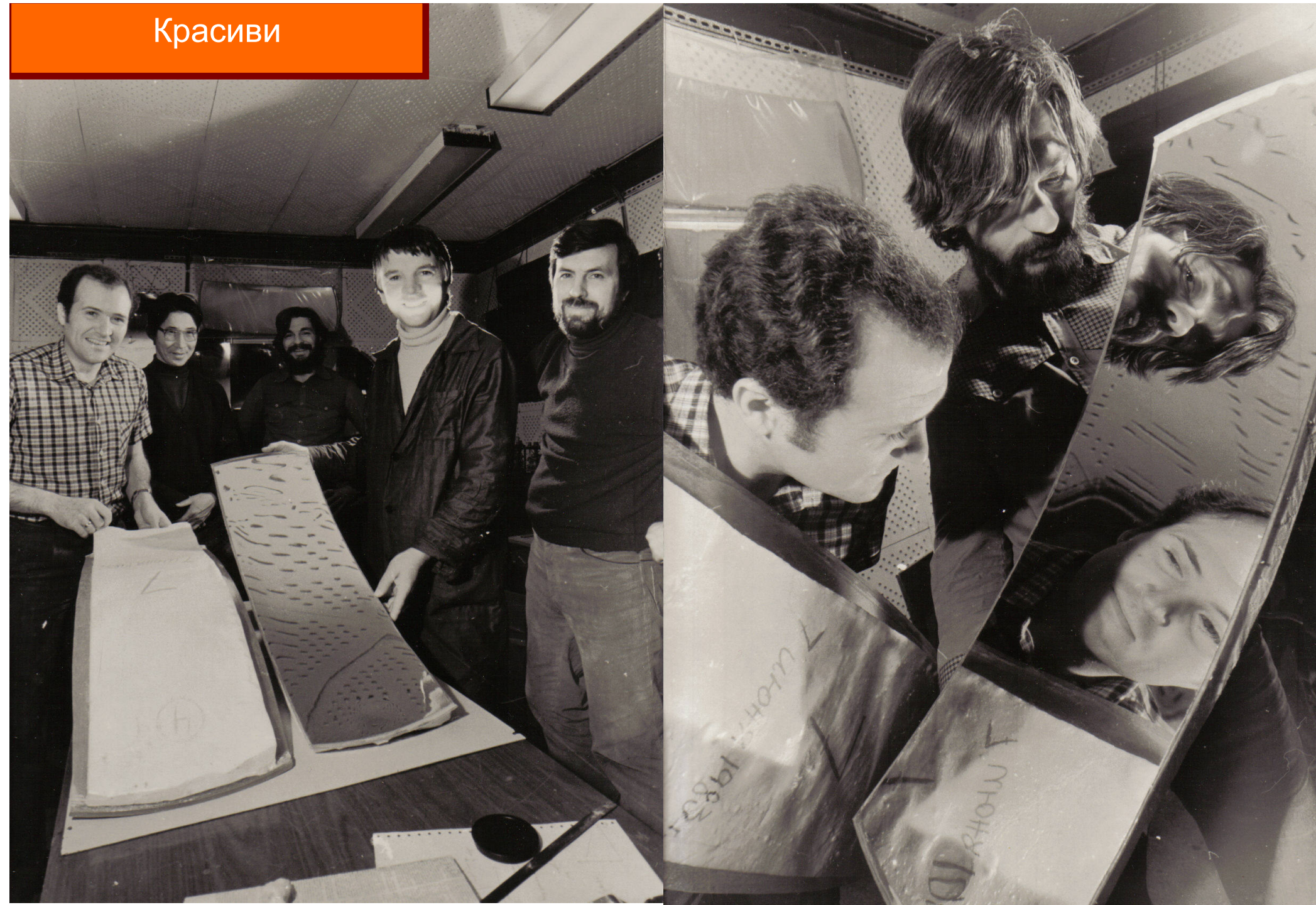
Бяхме млади



Умни



Красиви





HYPERON



- ❖ Черенковски многоканални броячи
- ❖ Електромагнитен калориметър (радиатор от оловно стъкло)
- ❖ Анализ на данни
- ❖ Monte-Carlo симулации
- ❖ Зарядово обменни реакции
- ❖ Адрон ядрени взаимодействия, ефекти на цветово екраниране
- ❖ Разпади на заредени K-мезони (от 1985 г.)



Настояще



NA48



NA48 Experiment



NA48 data



1997	ϵ'/ϵ run	$K_L + K_S$
1998	ϵ'/ϵ run	$K_L + K_S$
1999	ϵ'/ϵ run $K_L + K_S$	K_S Hi. Int.
2000	K_L only NO Spectrometer	K_S High Intensity
2001	ϵ'/ϵ run $K_L + K_S$	K_S High Int.
2002	K_S High Intensity	
2003	$K^\pm$ High Intensity	
2004	$K^\pm$ High Intensity	

NA48: 1997 – 2001

- Direct CP violation ($\text{Re}(\epsilon'/\epsilon)$)
- K_L decays (e.g. $K_{e3}^0 \rightarrow |V_{us}|$)

NA48/1: 2000, 2002

- High-intensity run for rare K_S decays.
- Hyperon decays (Ξ^0, Λ) ($\rightarrow |V_{us}|$)
- Neutral K_S decays (2000)

NA48/2: 2003 – 2004

- Search for direct CPV in $K^\pm$ decays.
- Rare decays
($K_{e4}, K^+ \rightarrow \pi^+ e^+ e^-, K^+ \rightarrow \pi^+ \gamma \gamma, \dots$)
- Semileptonic decays ($K_{e3}^+ \rightarrow |V_{us}|$)



NA48 experiment



□ Main detector components

❖ Magnet spectrometer

- Two drift chambers before and two after spectrometer magnet
- Momentum resolution $< 1\%$ for 20 GeV/c momentum

❖ Scintillator hodoscope (200 ps)

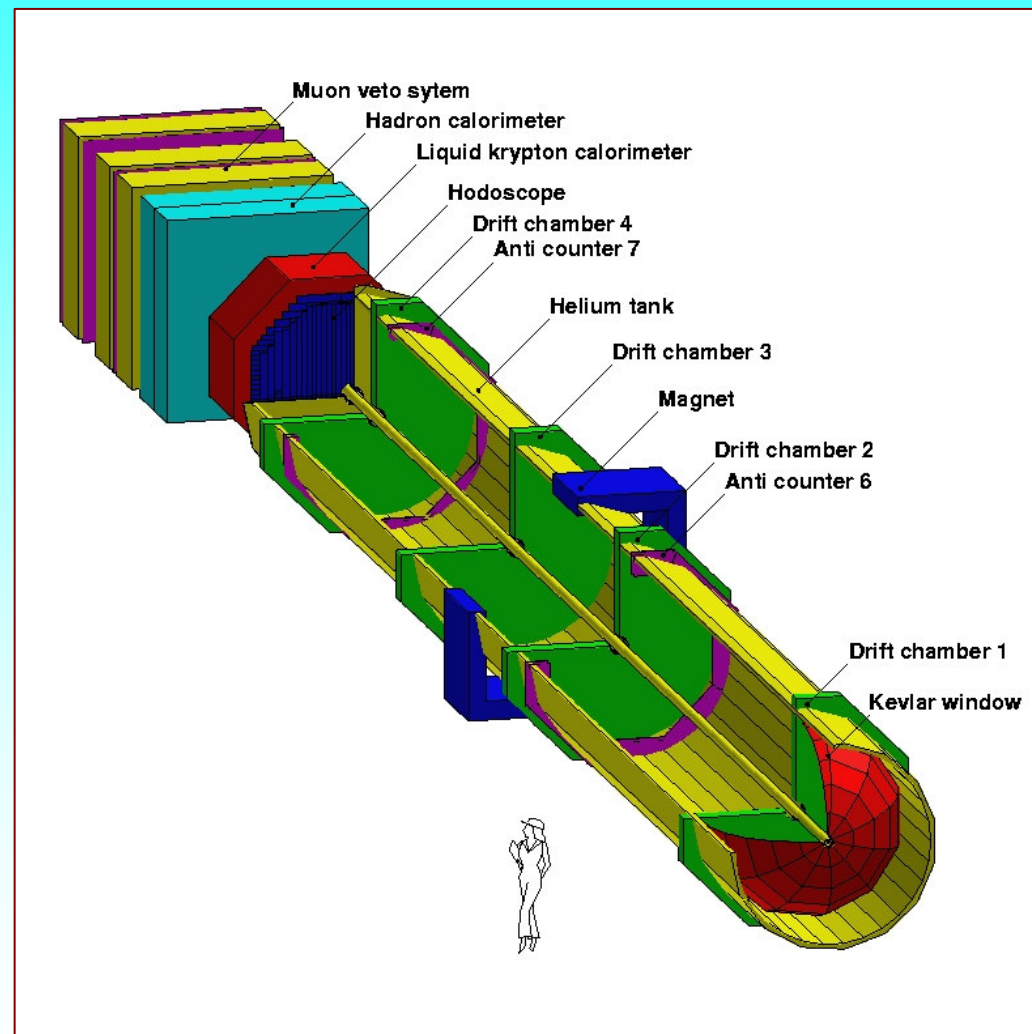
❖ Liquid Krypton Calorimeter

$$\frac{\delta E}{E} = \frac{3.2\%}{\sqrt{E[\text{GeV}]}} \oplus \frac{90\text{MeV}}{E} \oplus 0.42\%$$

❖ Hadron Calorimeter

❖ Muon Veto system

❖ Beams – $K_L^0, K_S^0, K^\pm$





NA48 experiment



2006



NA48 experiment



- ❖ Идентификация на типа на частиците (π , e) – Невронна мрежа – 10^6 \$
- ❖ Пълна отговорност за софтуера за анализ и симулация на експеримента
- ❖ Лидиращи позиции в изучаването на полуплеptonни разпади
- ❖ Измерване на V_{us}
- ❖ Изследване на редки разпади



New NA48 results



Някои резултати



Ke3 form factors



❖ $K_L \rightarrow \pi e \nu$ form factors - 1999 data

- 5.6 million reconstructed events
- Result for pure vector interaction

$$\lambda_+ = 0.0288 \pm 0.0005_{\text{stat}} \pm 0.0011_{\text{syst}}$$

- Result for 3-parameter fit:

$$\lambda_+ = 0.0284 \pm 0.0007 \pm 0.0013$$

$$\left| \frac{f_S}{f_+(0)} \right| = 0.015^{+0.007}_{-0.010} \pm 0.0012$$

$$\left| \frac{f_T}{f_+(0)} \right| = 0.05^{+0.03}_{-0.04} \pm 0.03$$

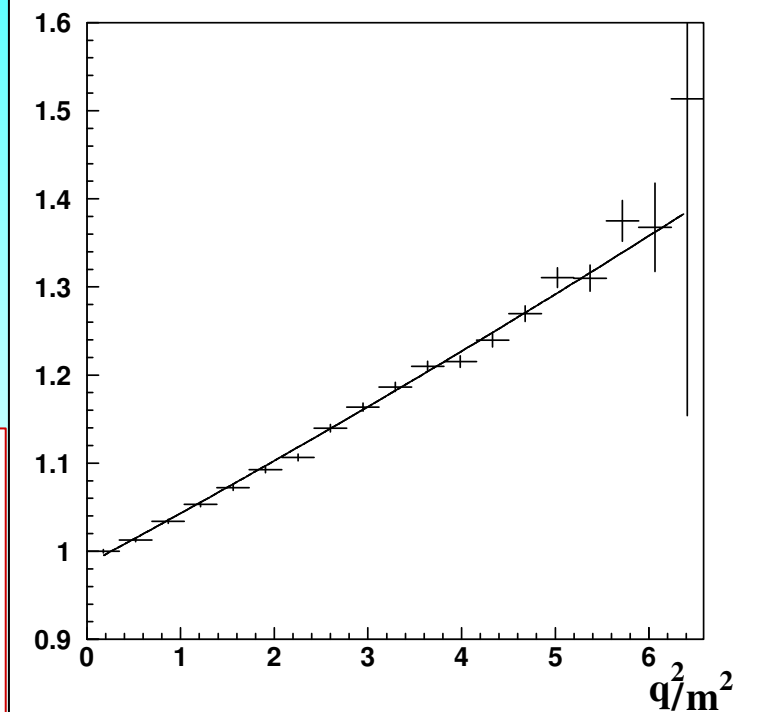
PDG(2004):

$$\lambda_+ = 0.0291 \pm 0.0018$$

$$\left| \frac{f_S}{f_+(0)} \right| < 0.04$$

$$\left| \frac{f_T}{f_+(0)} \right| < 0.23$$

DATA/MC



❖ No evidence for scalar and tensor couplings!



$K^0_L \rightarrow \pi e \nu \gamma$



❖ Data analysis

➤ Tight selection in order to suppress background from

$K_{3\pi}$, K_{e4} and

K_{e3} + accidental photon

➤ Selected events:

19000 : $K_{e3\gamma}$

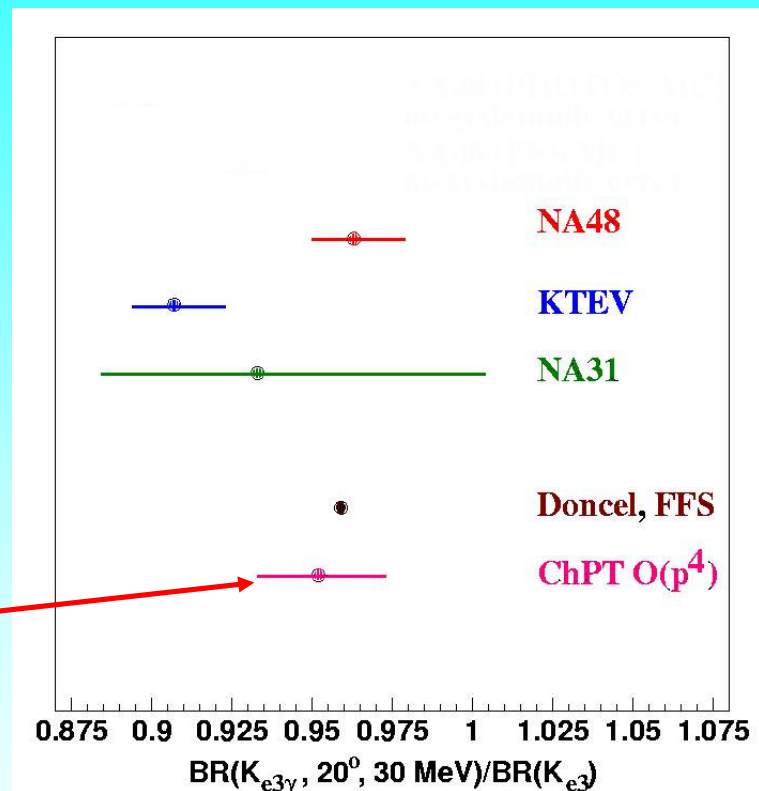
5.6 million : K_{e3}

Gasser et al.

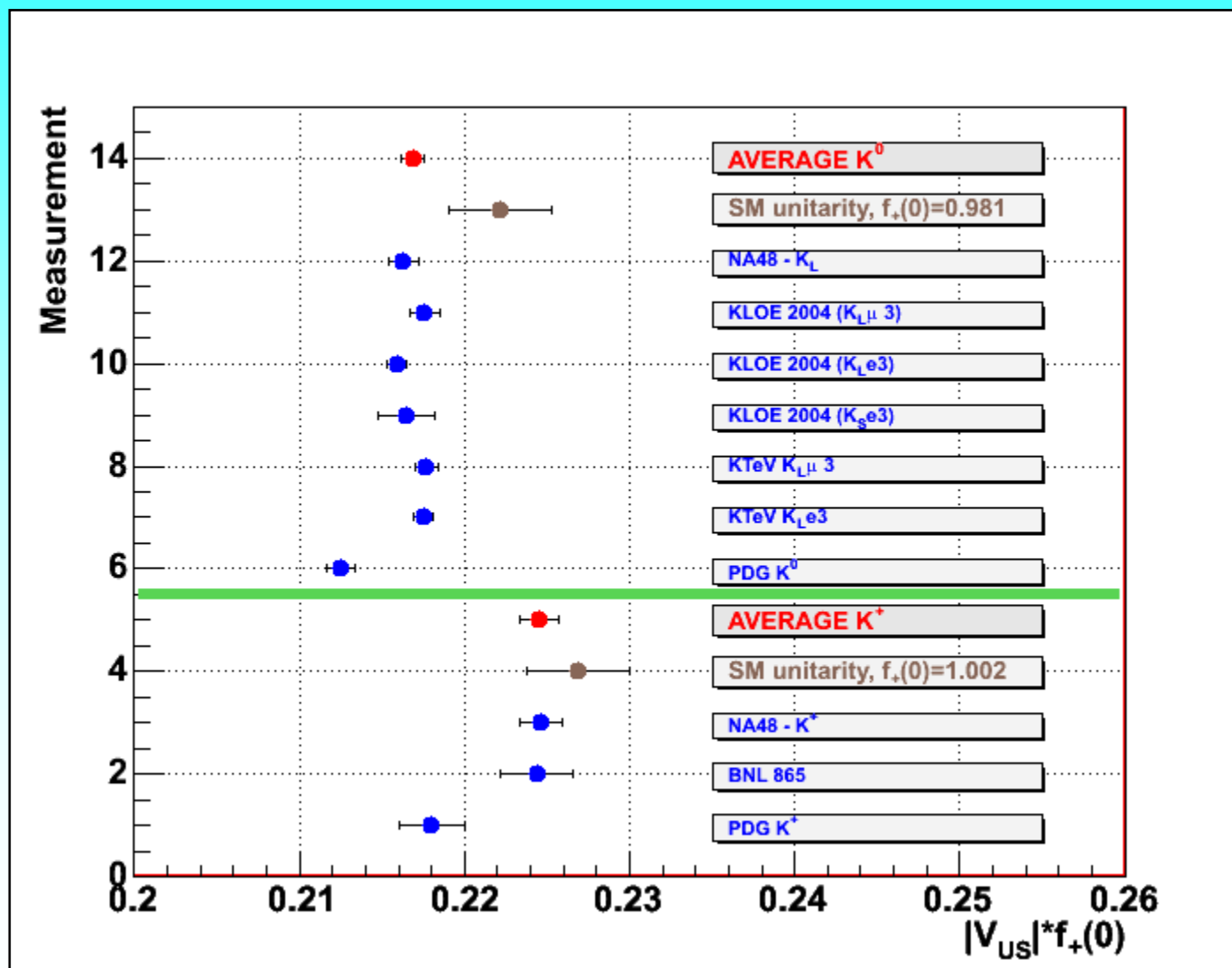
Result:

$$\frac{\Gamma(K_{e3\gamma}, E_\gamma^* > 30 \text{ MeV}, \theta_{e\gamma}^* > 20^\circ)}{\Gamma(K_{e3})} = (0.964 \pm 0.008^{+0.012}_{-0.011})\%$$

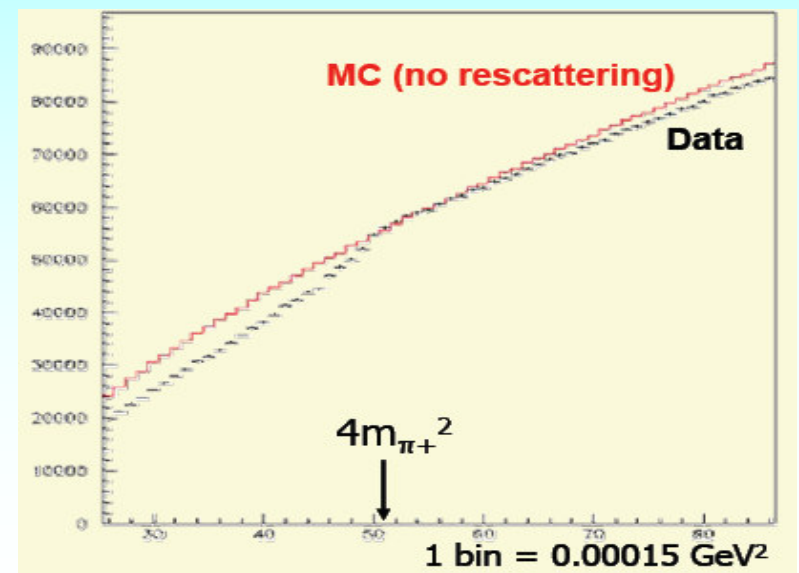
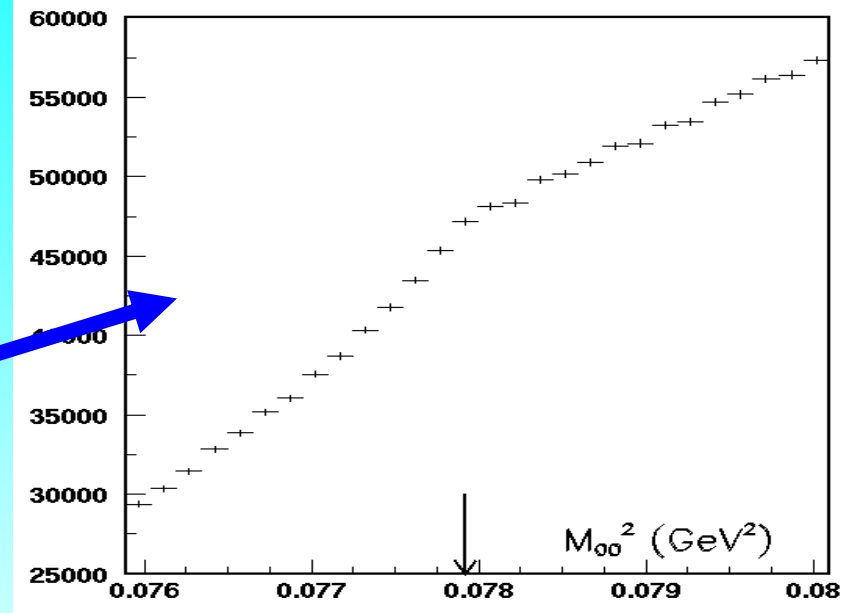
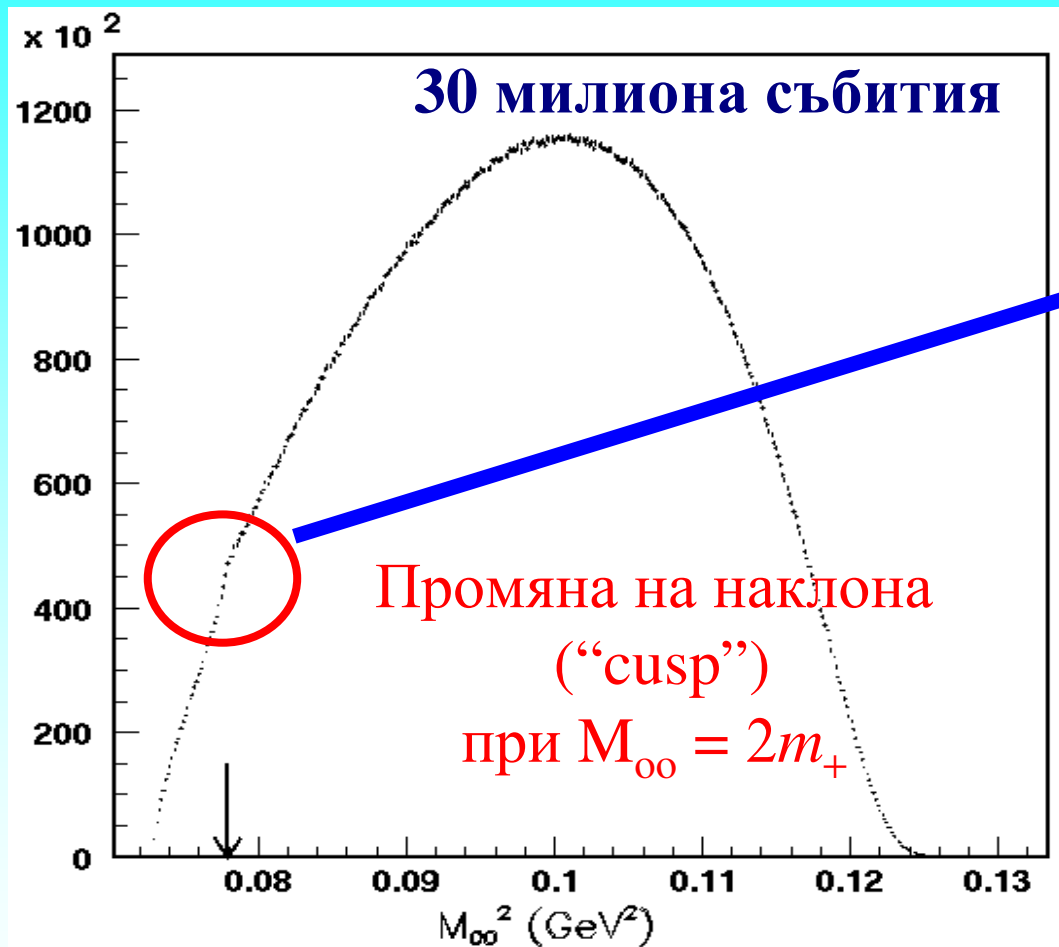
❖ Good agreement with theory predictions!



Determination of V_{us}



Ефект в $M\pi^0\pi^0$ в разпада $K^{+/-} \rightarrow \pi^{+/-} \pi^0\pi^0$



Благодарение на огромната статистика експериментът NA48 за **първи път** наблюдава този ефект



Определяне на (a_0-a_2) от разпада

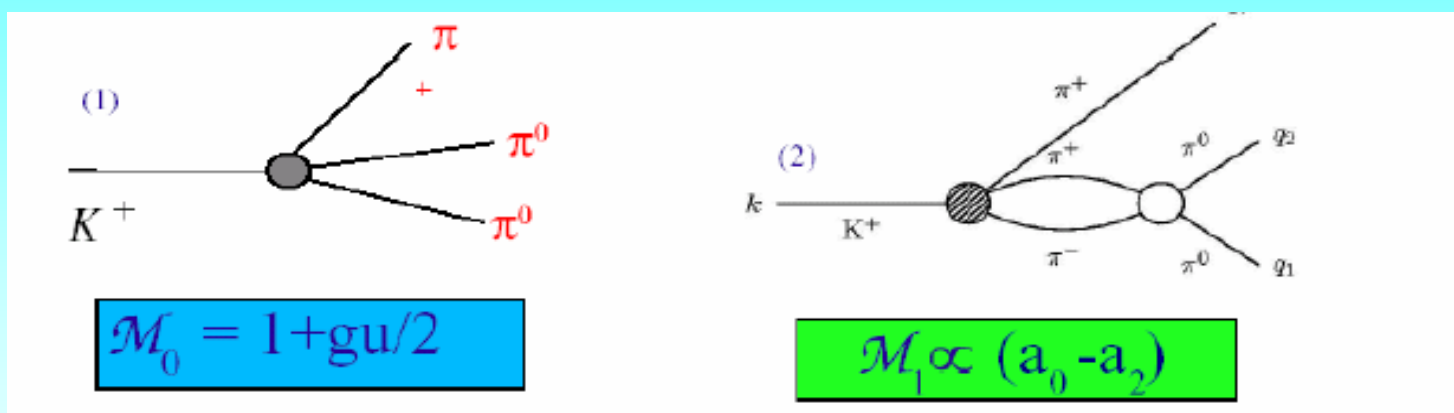
$$K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$$



Два процеса дават принос към този разпад:

Директен разпад на ...

Повторно разсейване на заредените пиони

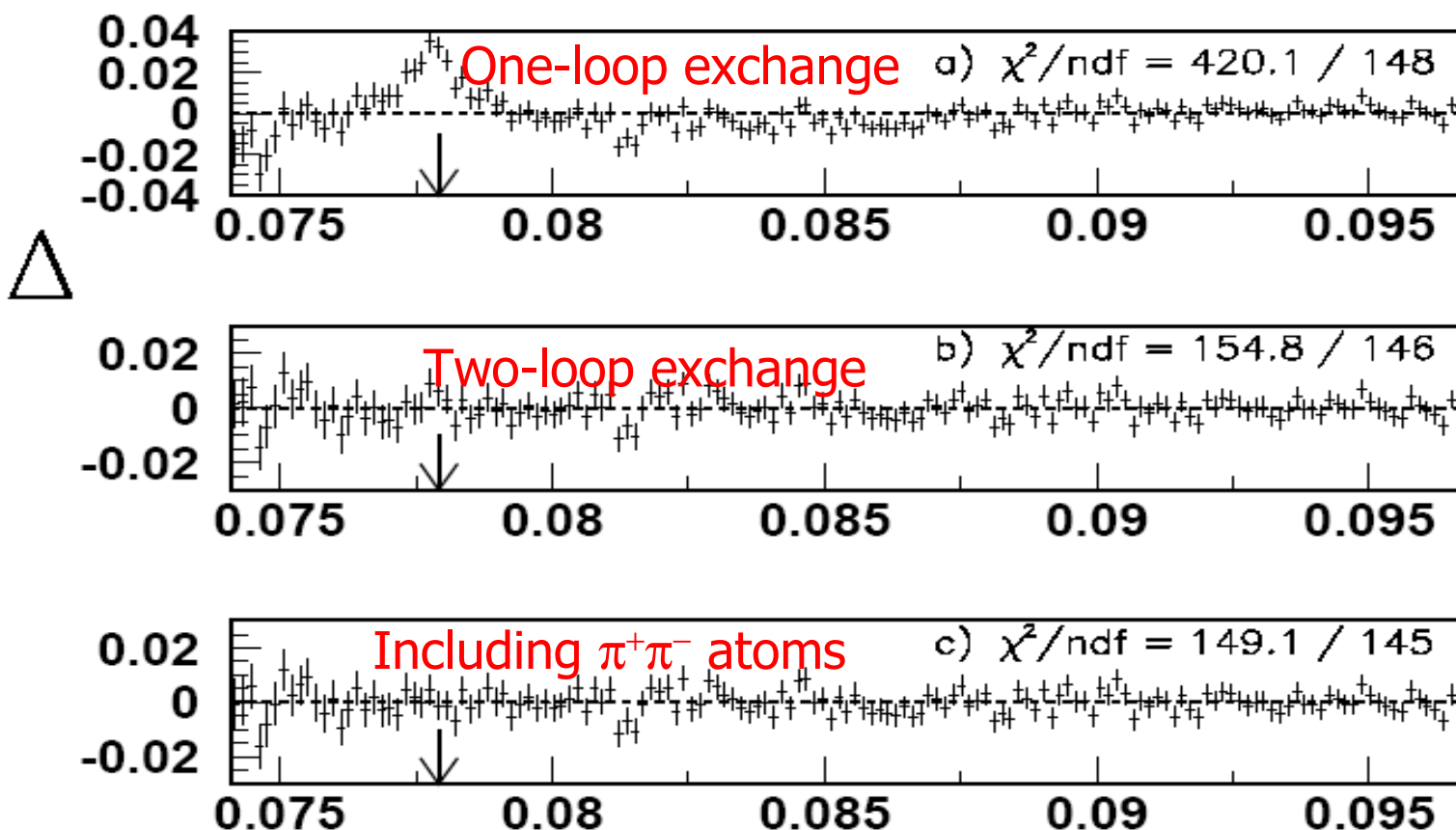


$$u = 2M_K(M_K/3 - E_{\text{odd}}^*)/M_K^2$$

$$d\Gamma/dm_{\pi\pi} \propto |\mathcal{M}_0 + \mathcal{M}_1|^2$$

*N. Cabibbo, hep-ph/0405001 Phys. Rev.Lett. **93**, 121801 (2004) one loop calculation*

*N. Cabibbo and G. Isidori, hep-ph/0502130 Phys. Rev.Lett. **93**, 121801 (2005) two loops*

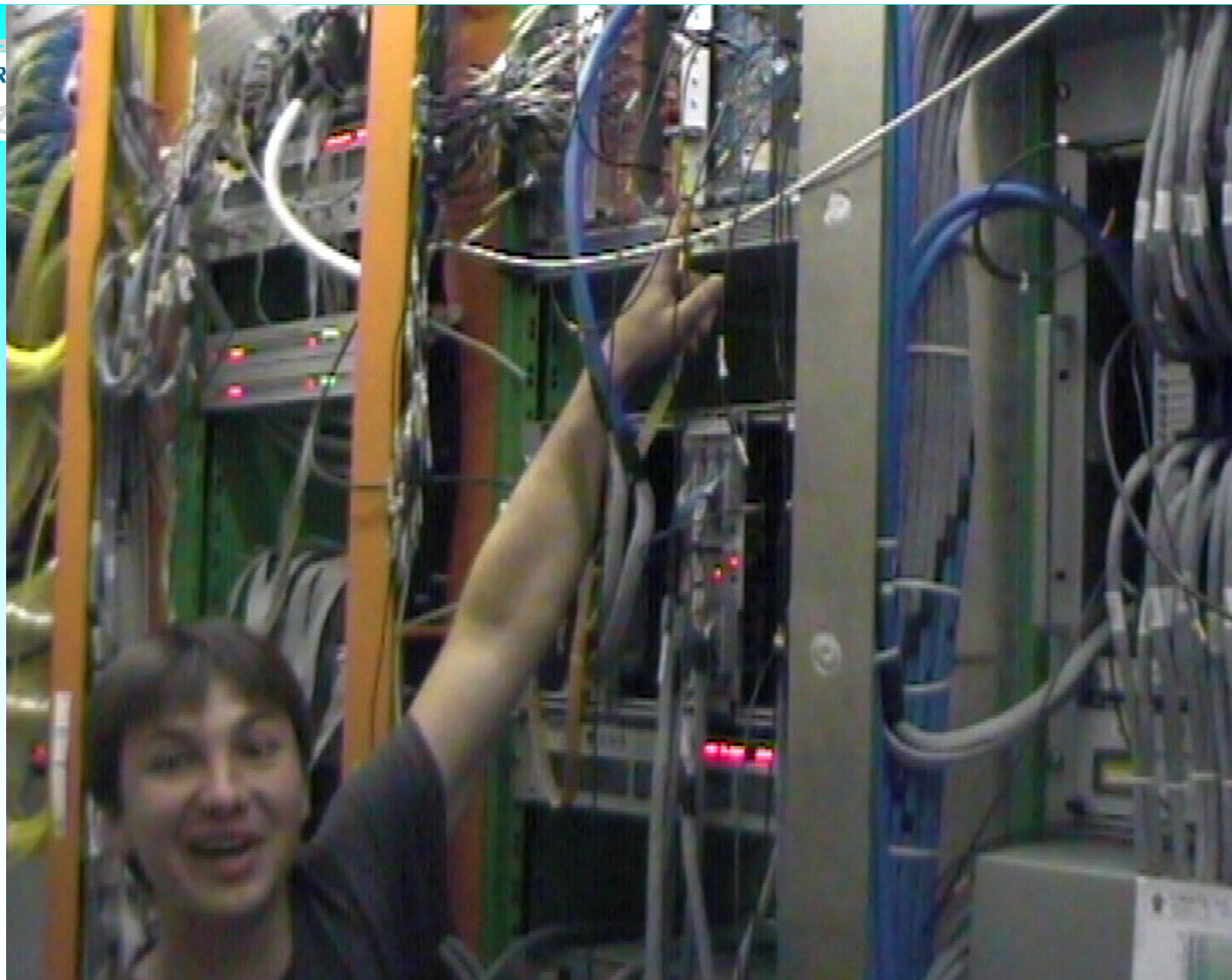


$$(a_0 - a_2)m_+ = 0.264 \pm 0.006 \text{ (stat.)} \pm 0.004 \text{ (syst.)} \pm 0.013 \text{ (ext.)}.$$

В съгласие с теоретичното предсказание:

$$(a_0 - a_2)m_+ = 0.265 \pm 0.004 \text{ (Colangelo2001)}$$







KAON 2005





NA49



NA49 Experiment



NA49



- ❖ Main goal of the experiment

- Search for signatures of quark – gluon plasma at SPS energies (20-158 A-GeV)

- ❖ Data taking - till 2002

- ❖ Data analysis – several years more

- University of Sofia

- ✓ 2 physicists 2 PhD student

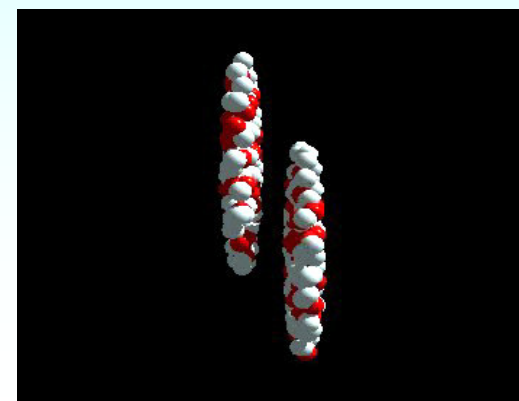
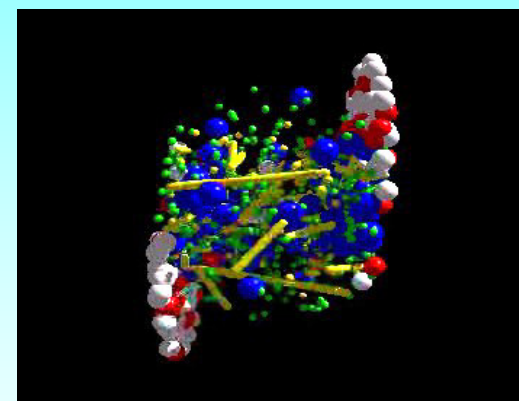
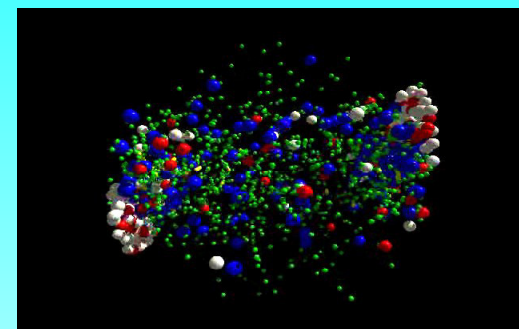
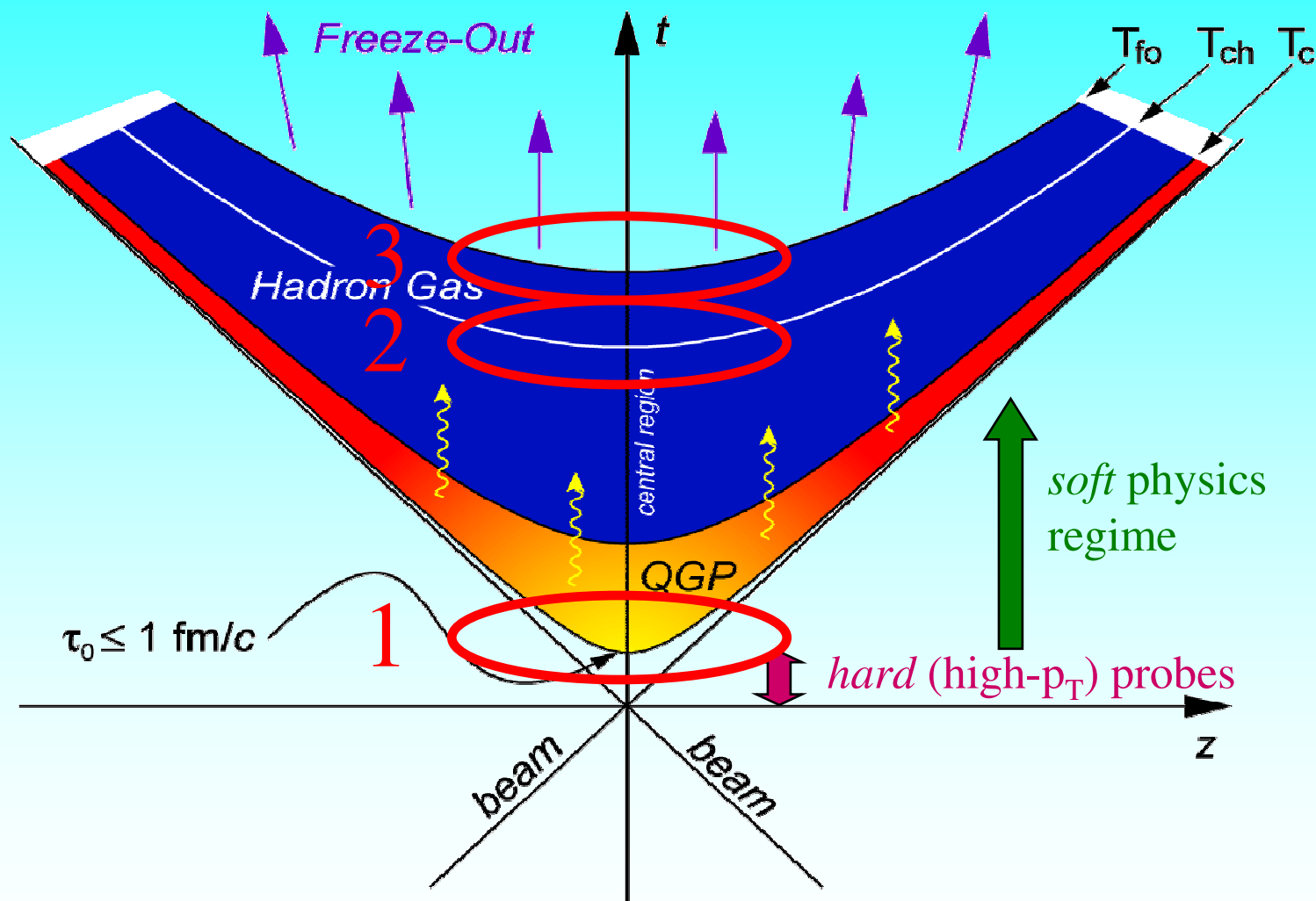
- ✓ dE/dx calibration of TPC

- ✓ Experiment running

- ✓ Software development and Data analysis



Кварк-глюонна плазма



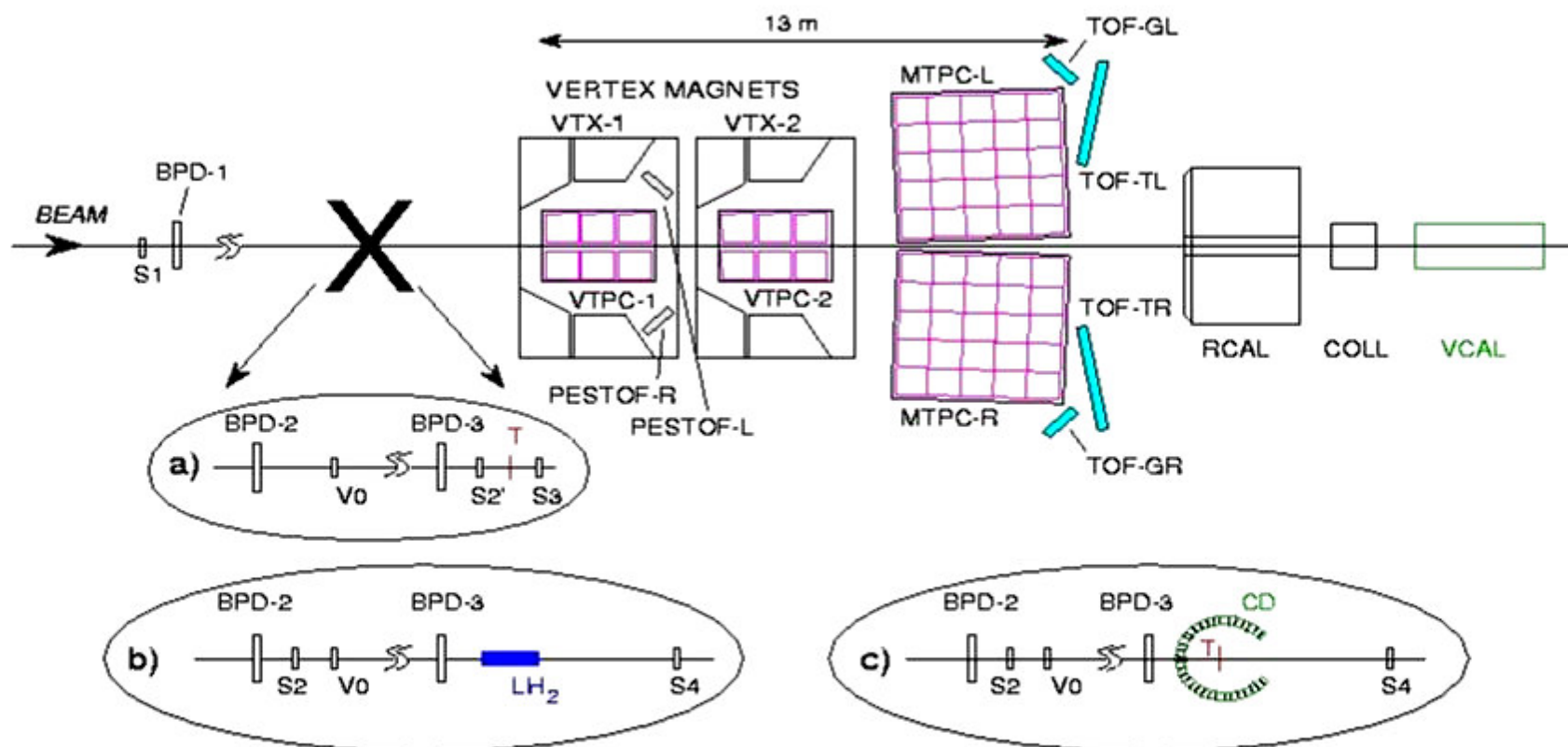
Chemical freezeout ($T_{\text{ch}} \leq T_c$): inelastic scattering ceases

Kinetic freeze-out ($T_{\text{fo}} \leq T_{\text{ch}}$): elastic scattering ceases



- ❖ **The aim:**
 - ❖ To localize and investigate the properties of the transition region from confined matter to quark gluon plasma
 - ❖ Existing data suggest – transition take place at low SPS energies
 - ❖ **For this purpose:**
 - ❖ Energy dependence of hadronic observables
 - ❖ System size dependence of hadronic observables
 - ❖ Investigation of event to event fluctuations (charge , mean p_t)
 - ❖ Better understanding of pp and pA interactions
-
- ❖ **Experimental setup**
 - Good momentum resolution
 - Good two track resolution – huge number of tracks in AA collisions
 - Good particle identification

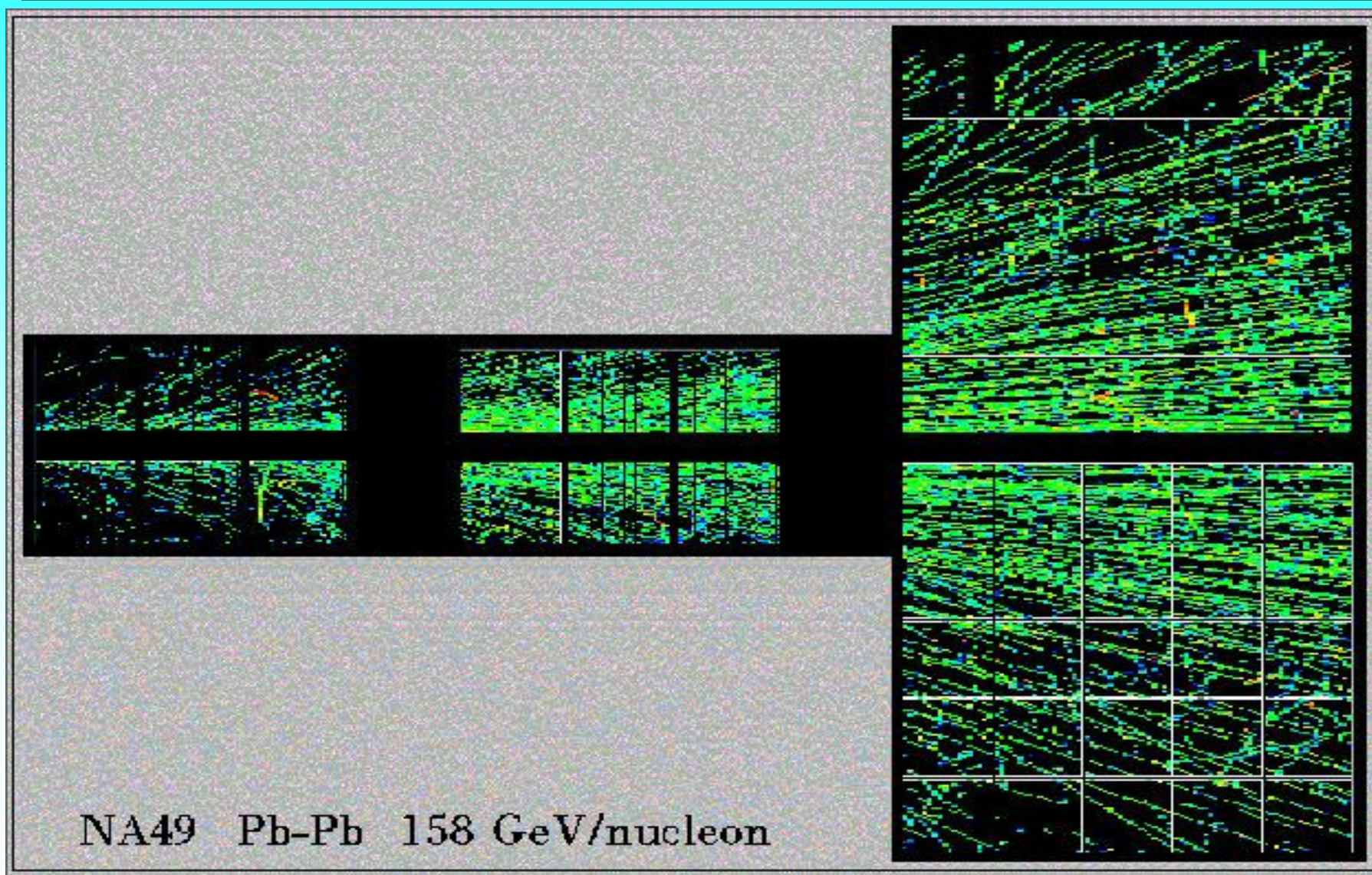
NA49 setup

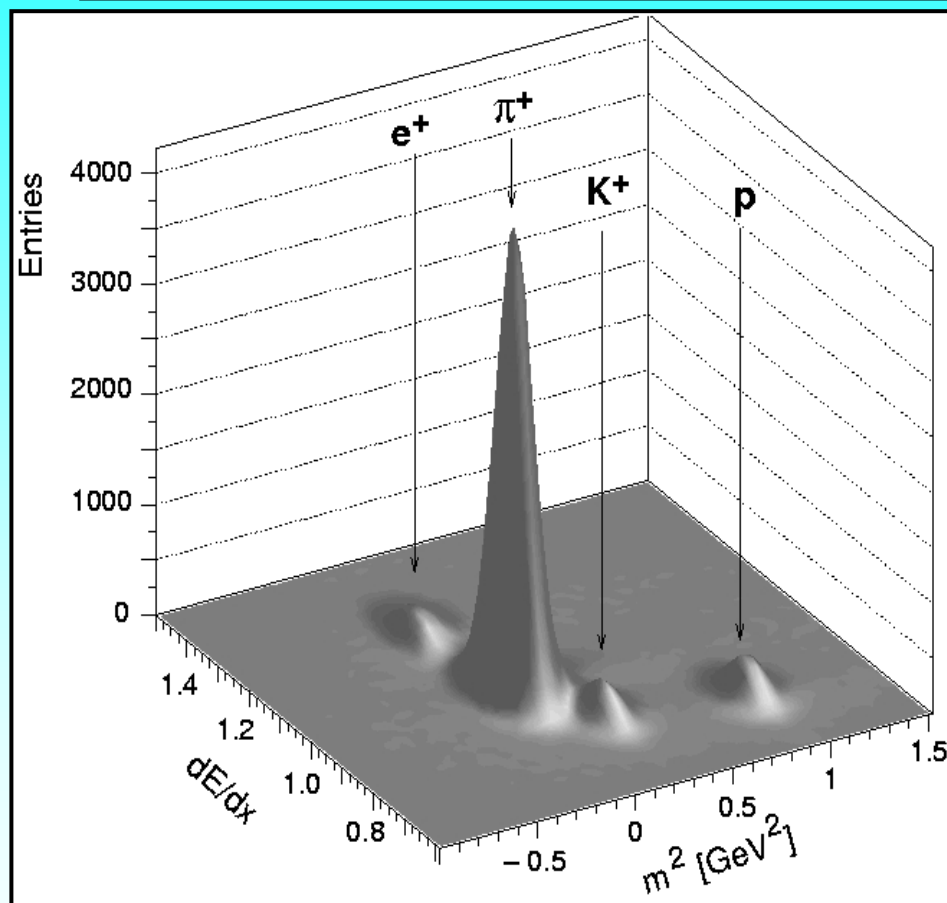


- Large acceptance hadron detector
- Three different target stations



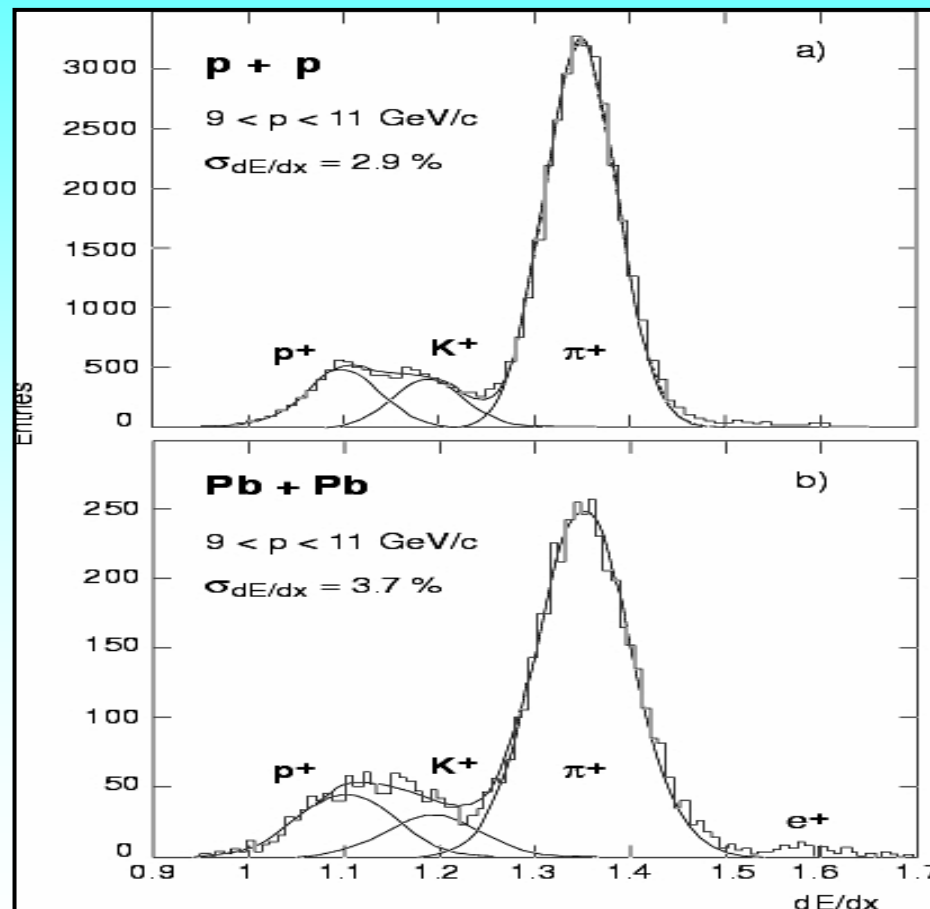
NA49 PbPb event



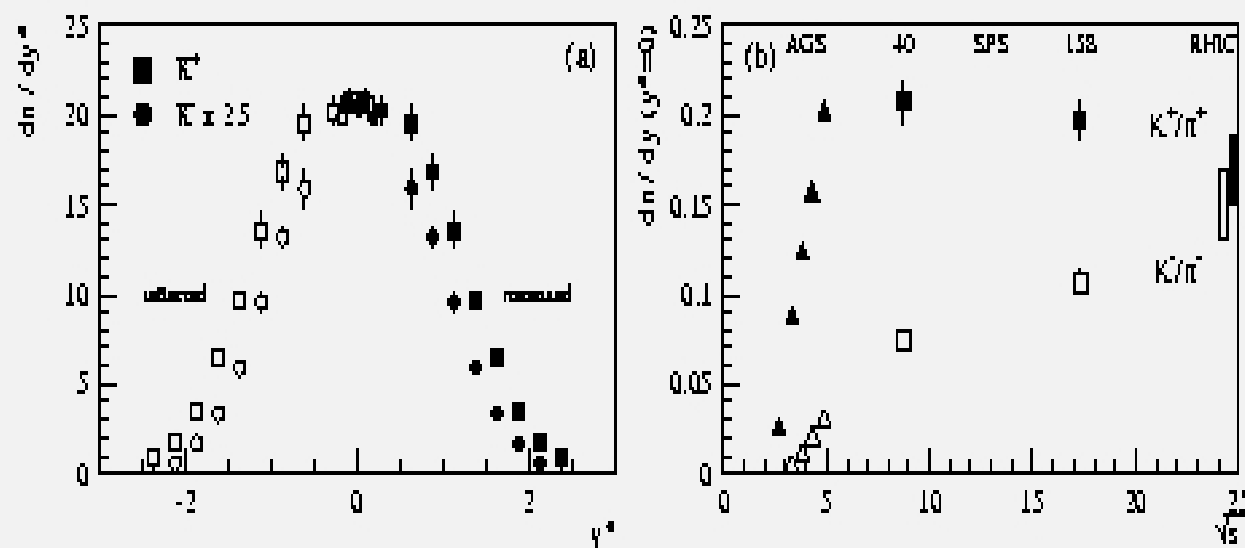


Low energy particles – TOF & dE/dx

High energy particles - dE/dx

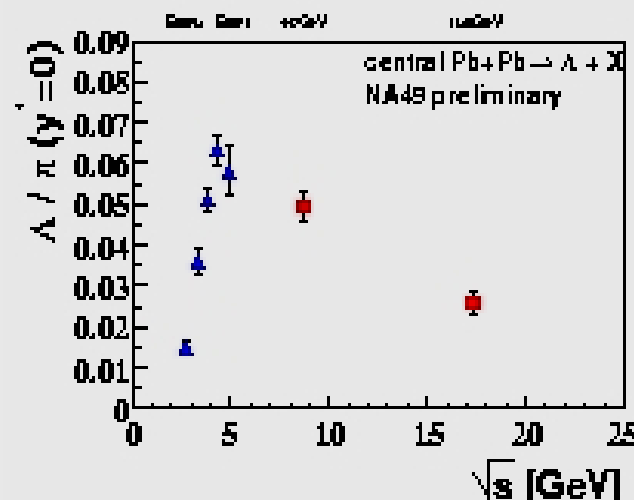
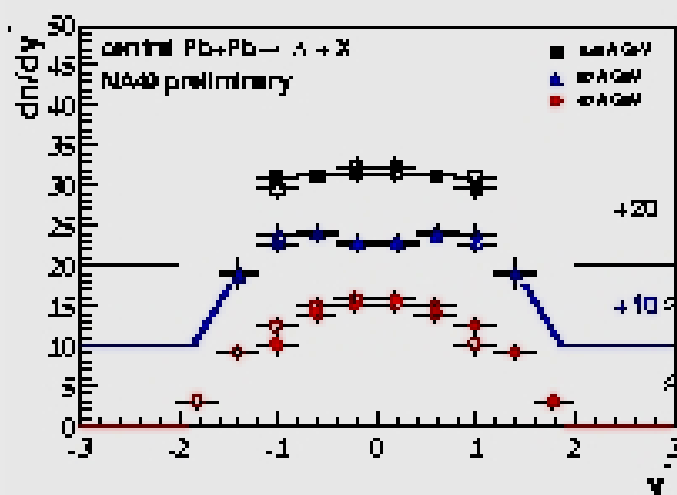


Energy dependence – K, Λ



K/π ratio as function of s
 K^-/π^- ratio – monotonic
 K^+/π^+ ratio – reach maximum at 30 -40 GeV
 The same for Λ/π ration
 The explanation – if assume a phase transition at ~ 40 GeV

Rapidity distribution for K and Λ at 40 GeV,
 The same behavior at other energies





Прецизни измервания



Голяма статистика

$p+p$ – 5 млн. събития

$p+C$ – 0.5 млн. събития

Голямо покритие на фазовото пространство

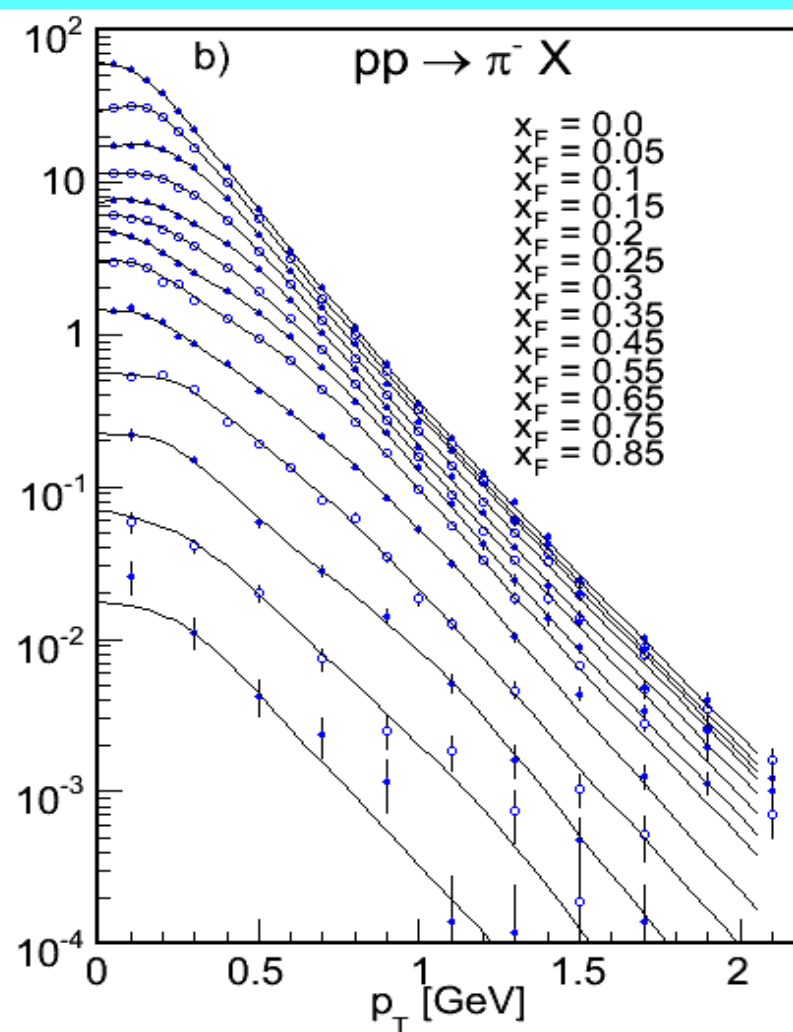
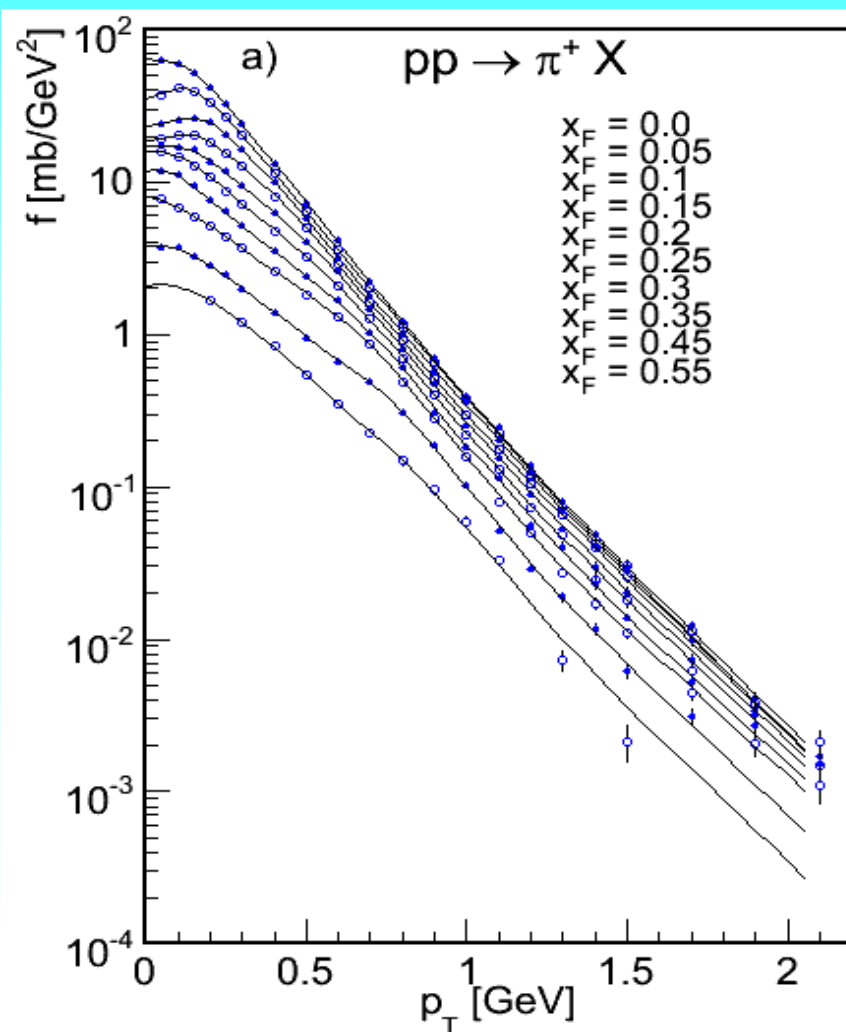
по x_F $0 \div 0.55$ (за π^- в $p+p$ до 0.85)

по p_T $0 \div 2$ GeV/c (ограничението е от статистиката)

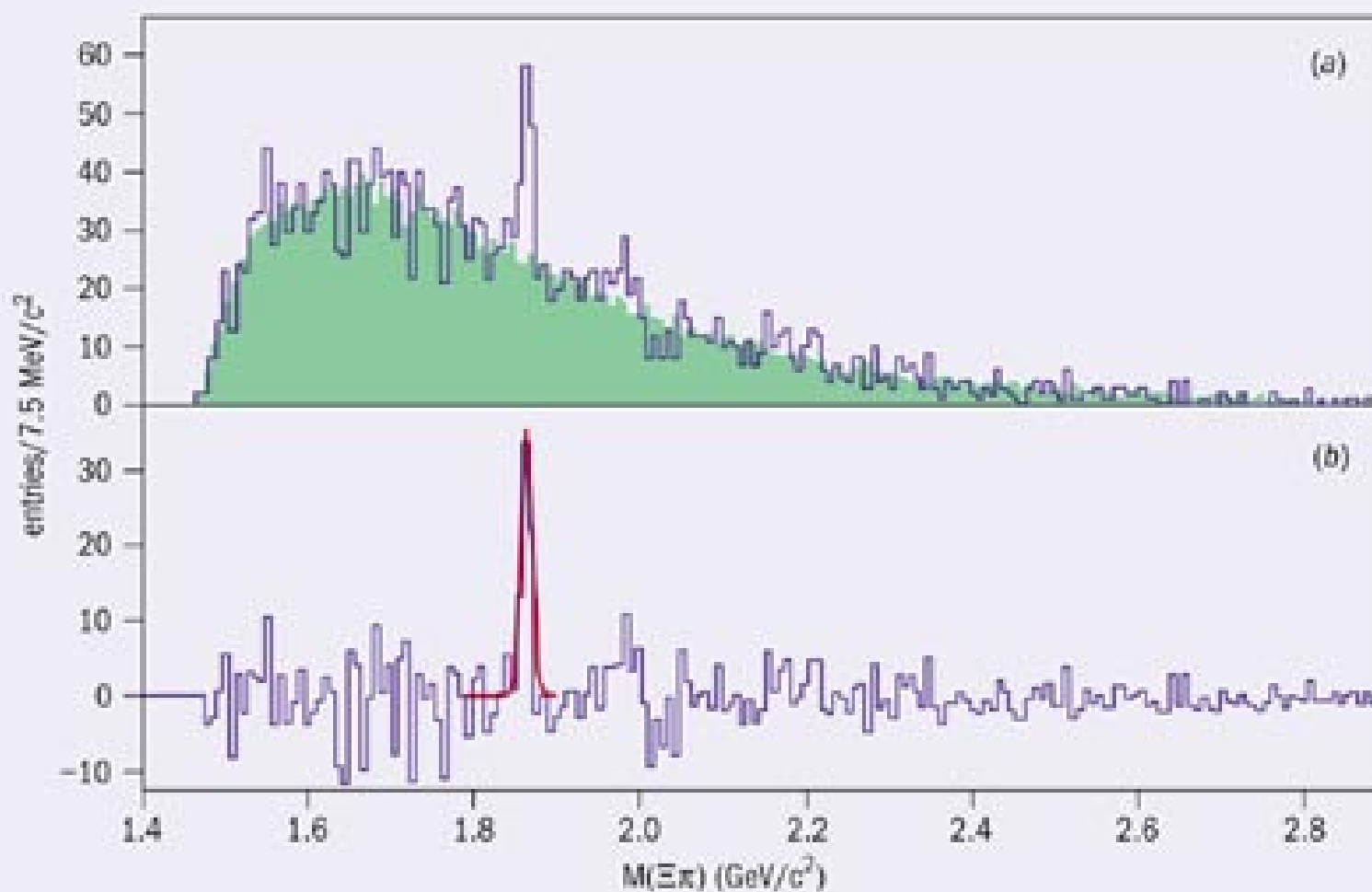
Малка систематична неопределеност

2% в $p+p$

3.5% в $p+C$



Пентакварк или “тука има тука нема”





CMS



CMS Experiment



CMS Detector



31 Nations, 150 Institutions, 1870 Scientists

TRIGGER & DATA ACQUISITION

Austria, CERN, Finland, France, Greece, Hungary, Italy, Korea, Poland, Portugal, Switzerland, UK, USA

TRACKER

Austria, Belgium, CERN, Finland, France, Germany, Italy, Japan*, Switzerland, UK, USA

CRYSTAL ECAL

Belarus, CERN, China, Croatia, Cyprus, France, Italy, Japan*, Portugal, Russia, Switzerland, UK, USA

PRESHOWER

Armenia, Belarus, CERN, Greece, India, Russia, Taiwan (PC), Uzbekistan

RETURN YOKE

Barrel: Czech Rep., Estonia, Germany, Greece, Russia
Endcap: Japan*, USA

SUPERCONDUCTING MAGNET

All countries in CMS contribute to Magnet financing in particular:
Finland, France, Italy, Japan*, Korea, Switzerland, USA

HCAL

Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Russia, Ukraine
HC: India

FEET

Pakistan
China

MUON CHAMBERS

Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain,
Endcap: Belarus, Bulgaria, China, Korea, Pakistan, Russia, USA

FORWARD CALORIMETER

Hungary, Iran, Russia, Turkey, USA

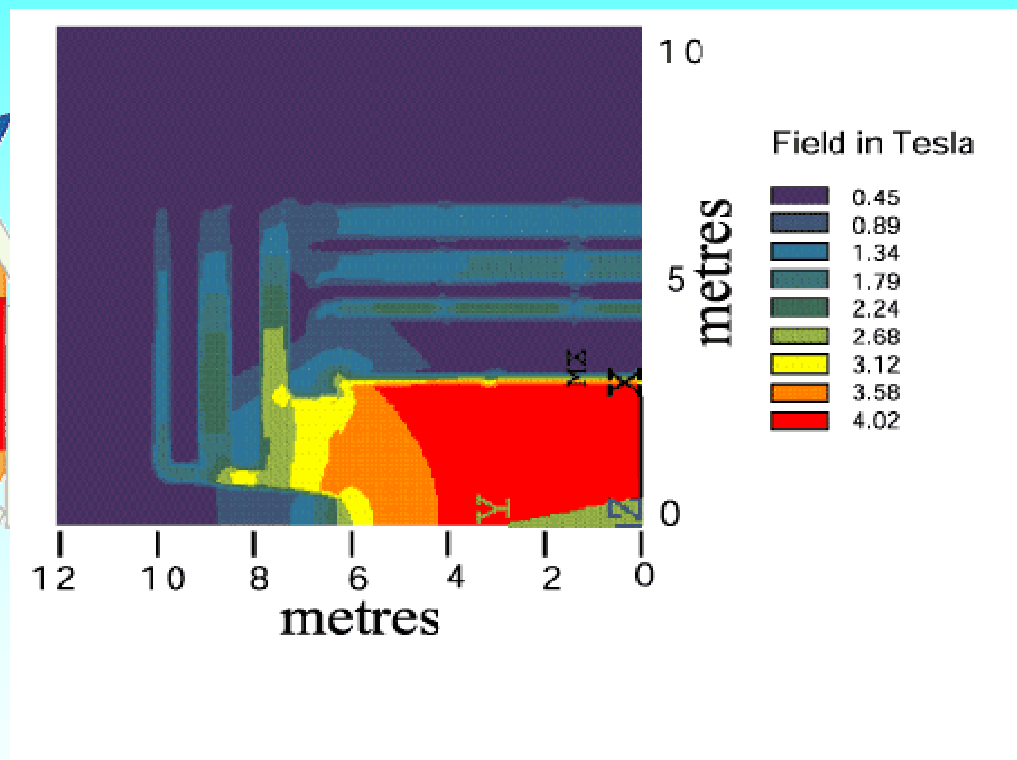
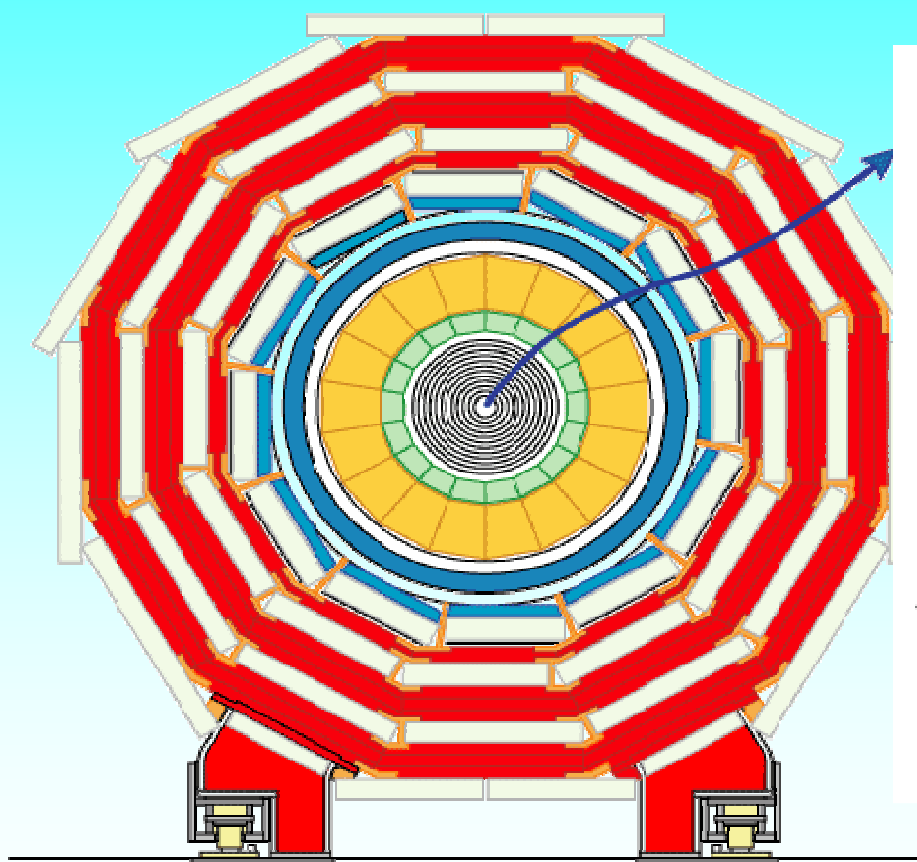
Total weight : 12500 T
Overall diameter : 15.0 m
Overall length : 21.5 m
Magnetic field : 4 Tesla

L. Litov

Що е то физика на ел. частици и има ли тя почва у нас

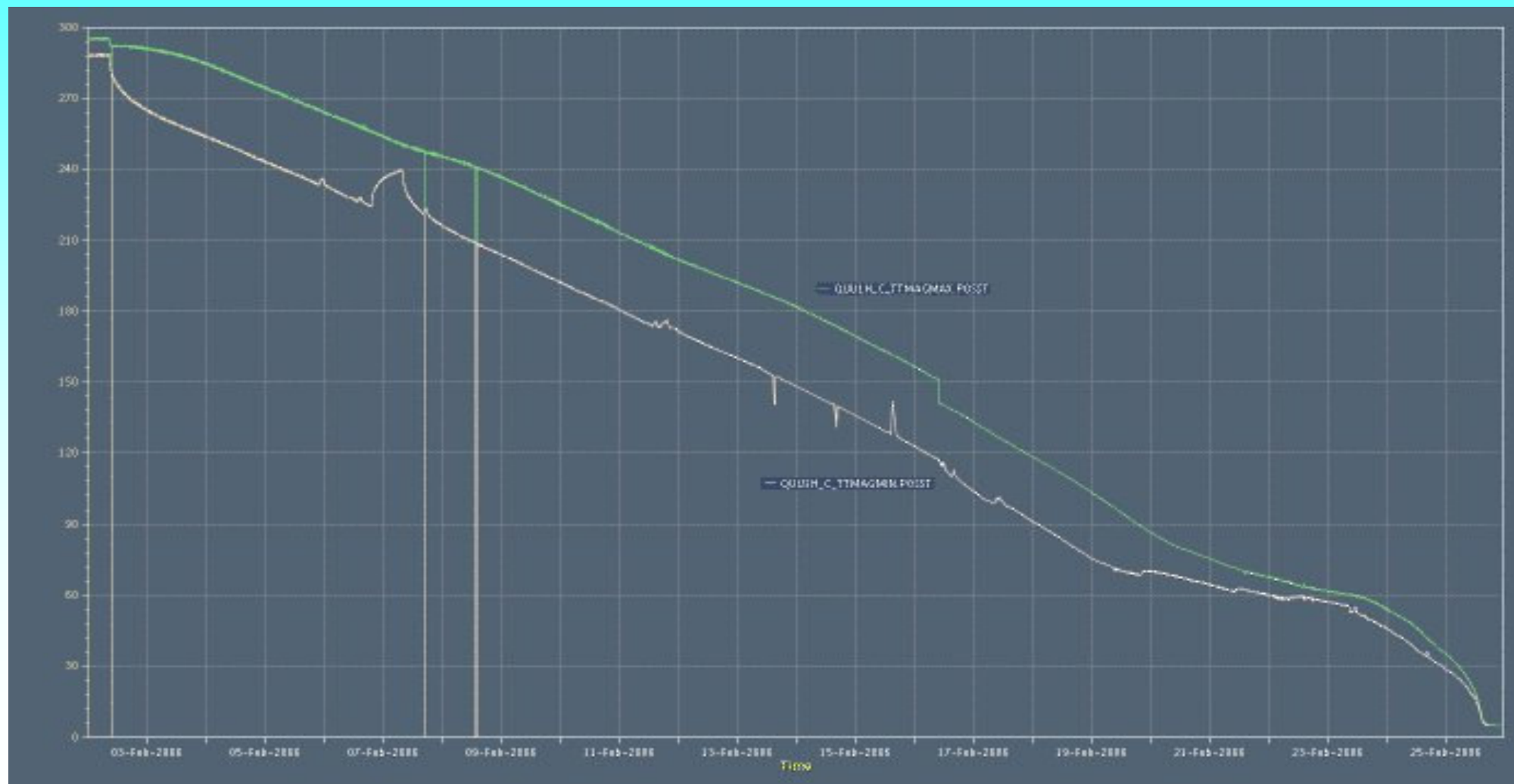
Гулечица, 4 Март, 2006

* Only through industrial contracts



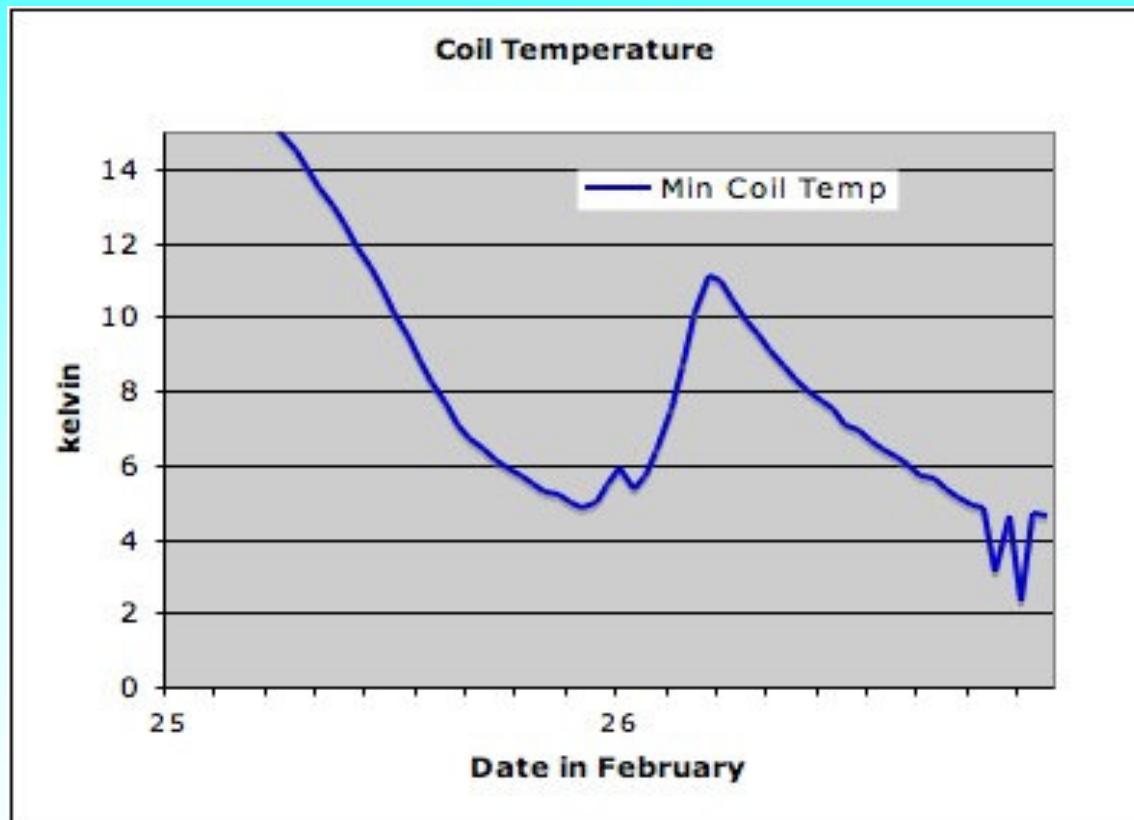


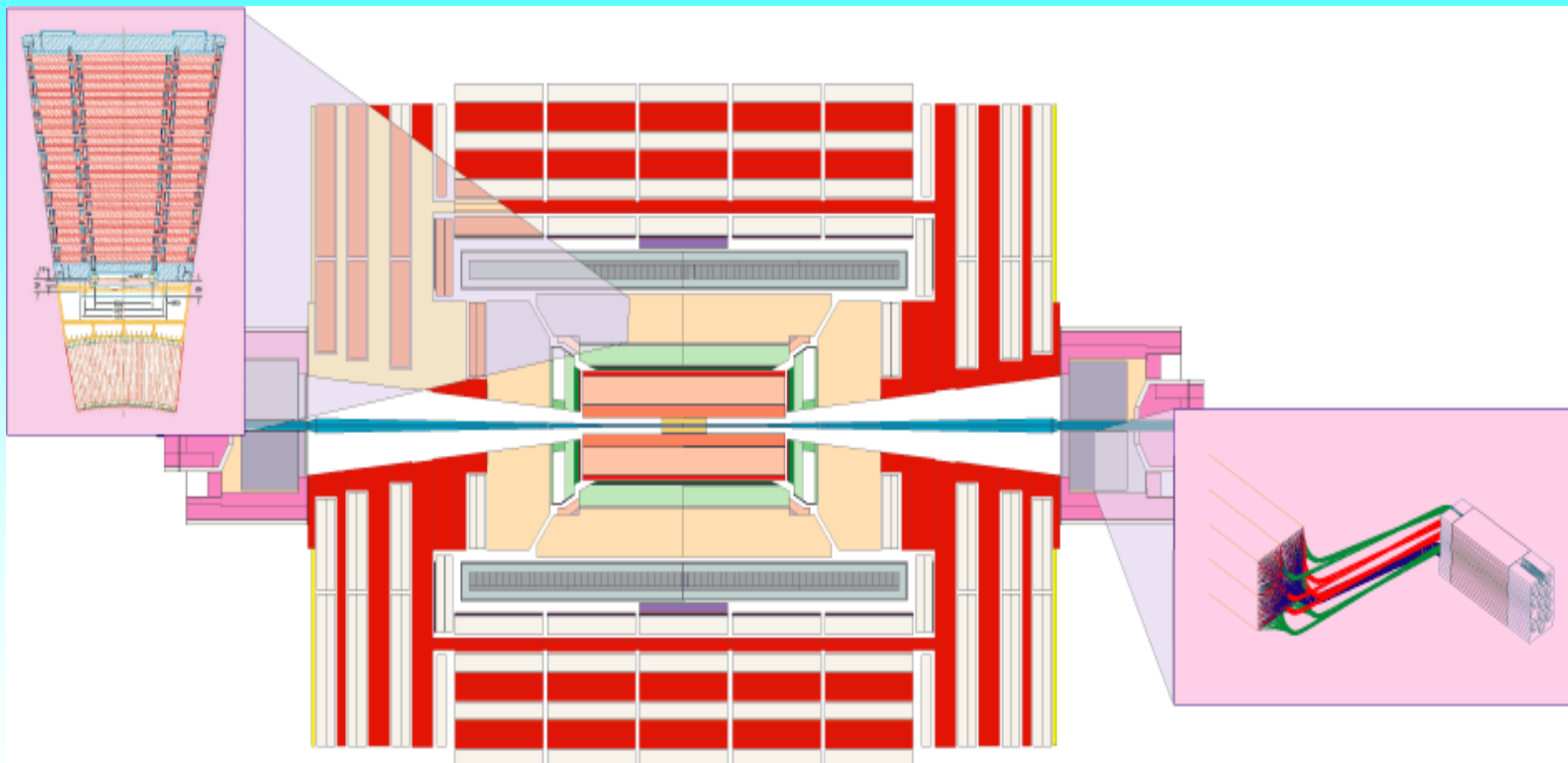
Сврѡхпроводящ магнит





Сврѡхпроводящ магнит







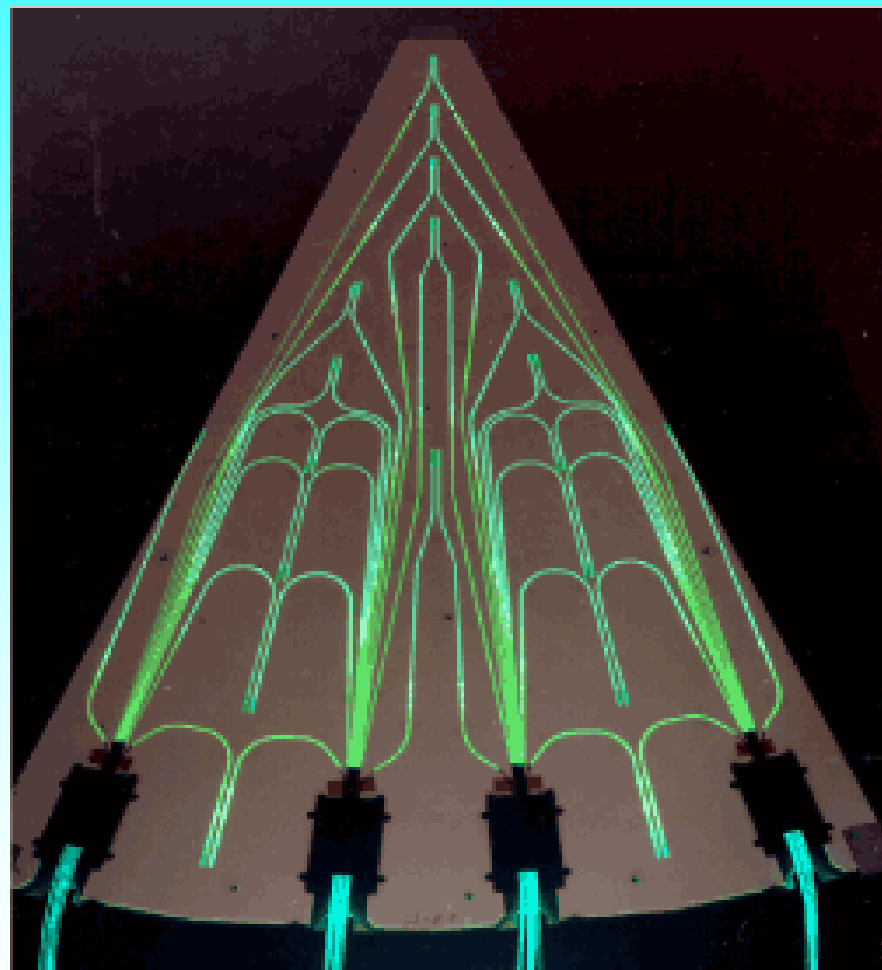
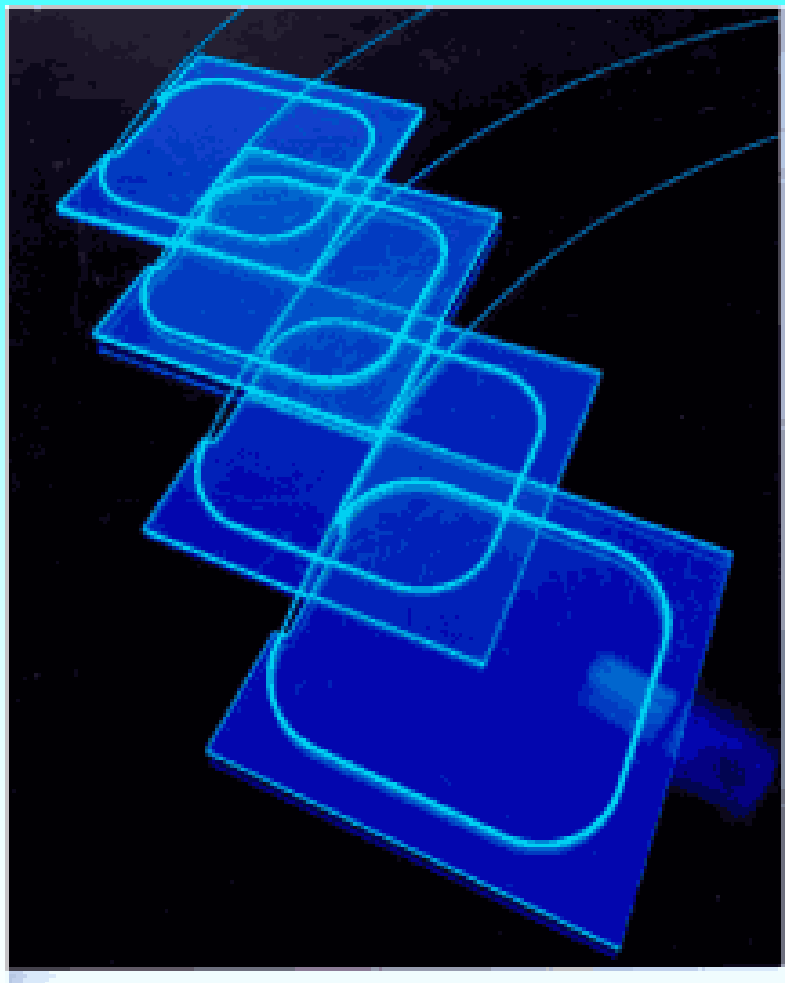
HCAL barrel wedge



L. Litov

Що е то физика на ел. частици и има ли тя почва у нас

Гулечица, 4 Март, 2006





HCAL Barrel

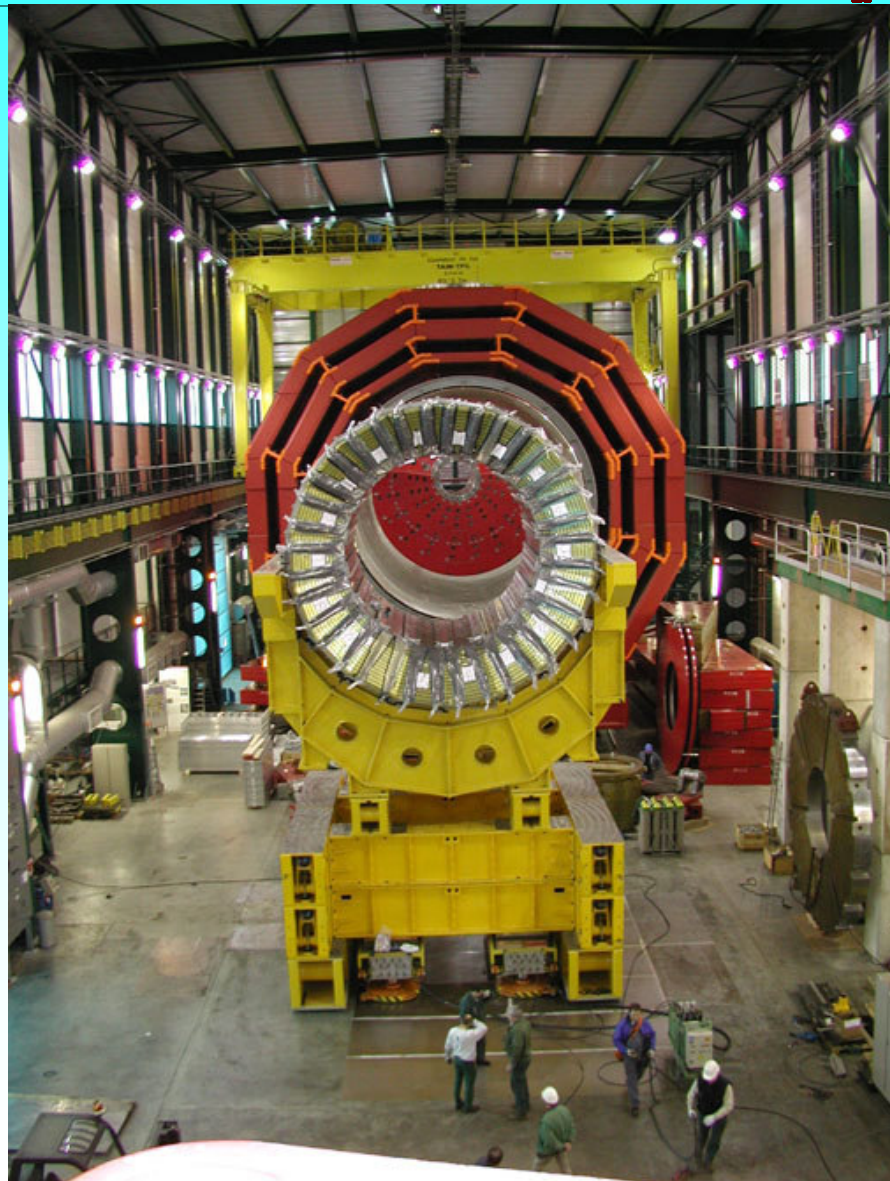
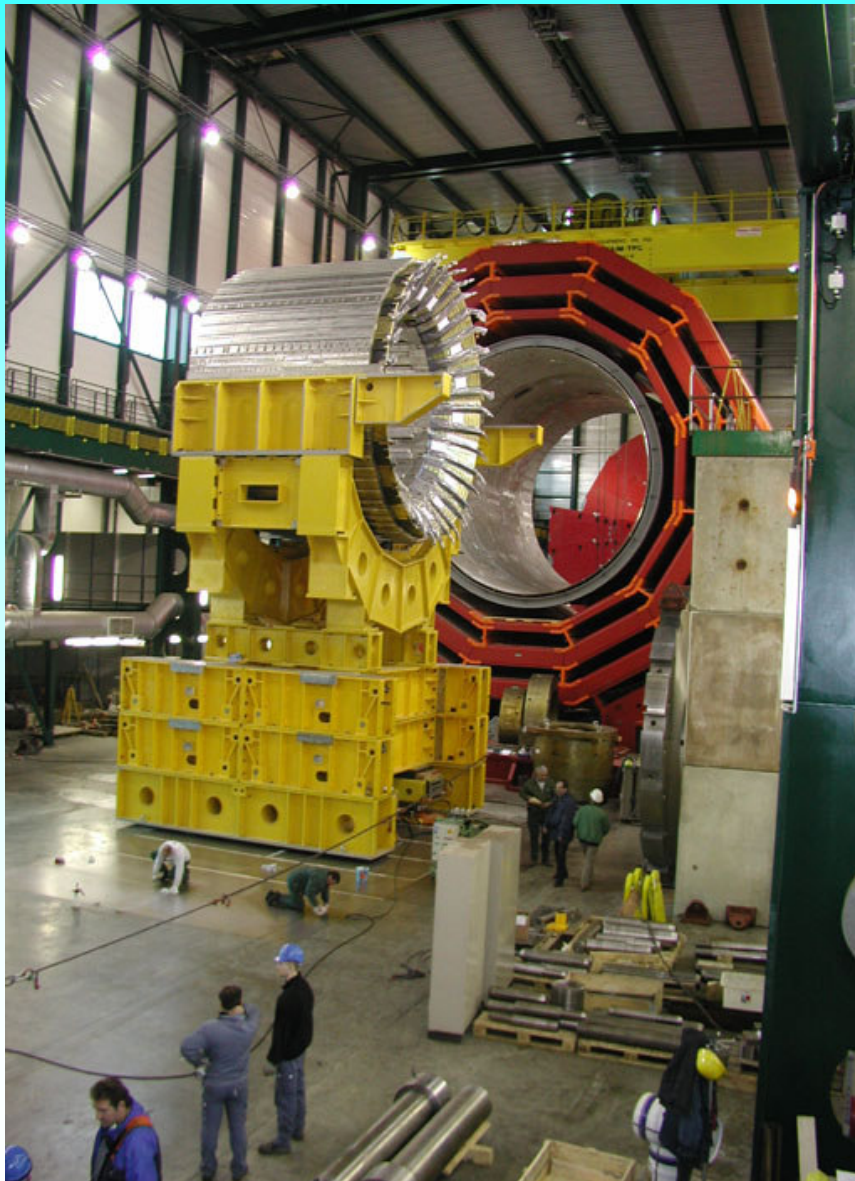


L. Litov

Що е то физика на ел. частици и има ли тя почва у нас

Гулечица, 4 Март, 2006

HCAL assembly

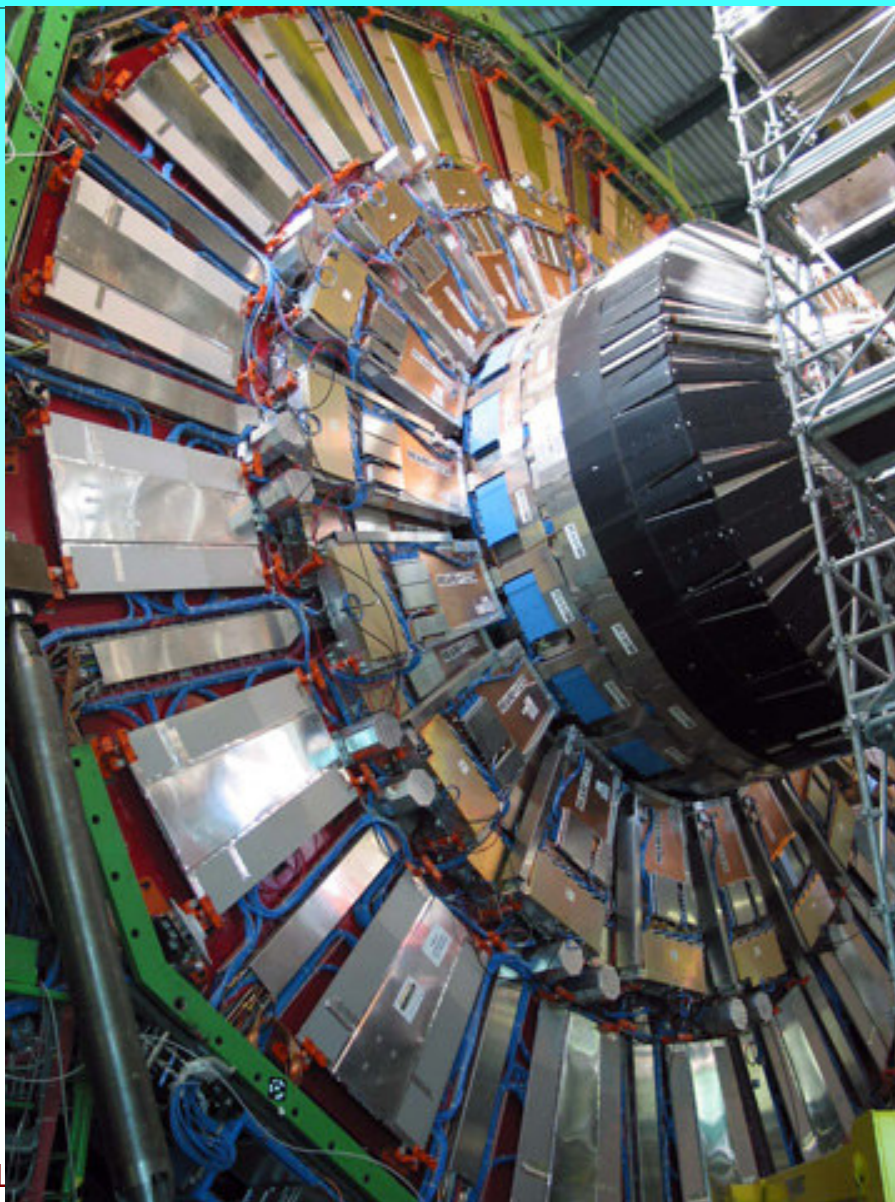


HCAL Endcap





HCAL – затваряща част



L. Litov

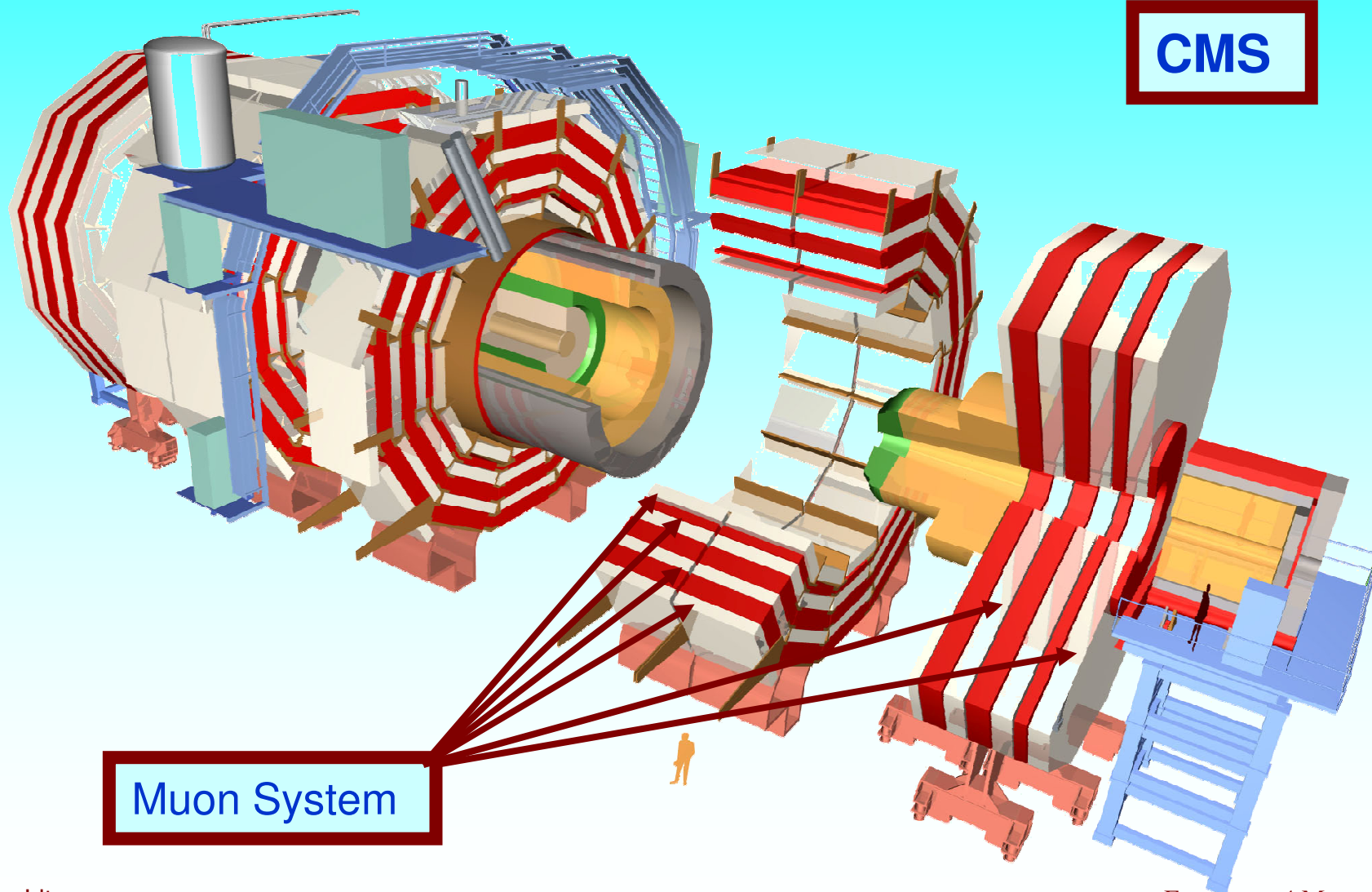
Гулечица, 4 Март, 2006



CMS: design & construction



CMS



Muon System

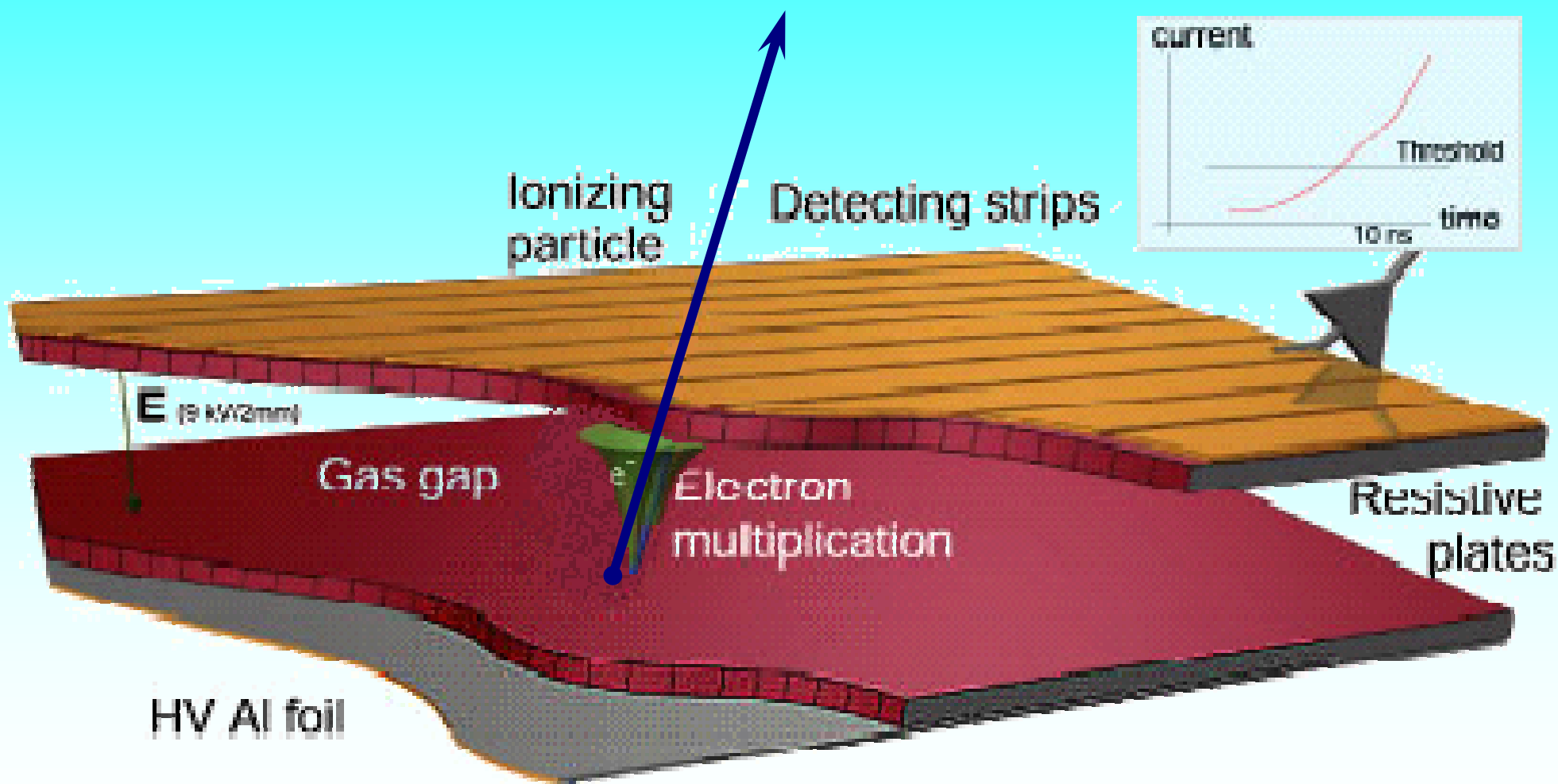


Resistive Plate Chambers (RPC)



Resistive Plate Chambers

RPC - Principle of Action

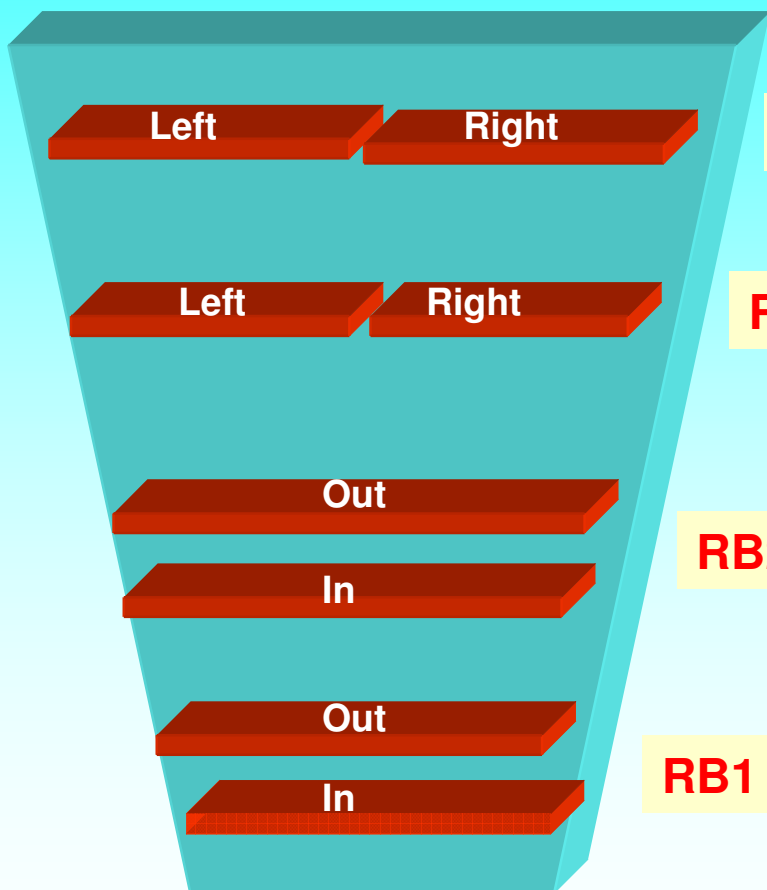




Main Barrel RPC Types



Length: 2.455 m



RB4

Width: 1.5, 2.0 , 2.5 m
Pitch: 40.8, 40.6, 41.0 mm
Strips for Gap: 48, 36, 48, 60

RB3

Width: 1.48 m
Pitch: 34.8 mm
Strips for Gap: 42

RB2

Width: 1.5, 2.0 , 2.5 m
Pitch: 27.3, 29.3 mm
Strips for Gap: 84, 90

RB1

Width: 1.5, 2.0 , 2.5 m
Pitch: 22.7, 24.3 mm
Strips for Gap: 84, 90

Bari

Sofia

RPC Production Sites

Pavia



Тестов стенд в Бари



L. Litov

Що е то физика на ел. частици и



София: маса за сглобяване на камери със съпротивителна плоскост и мюонен телескоп

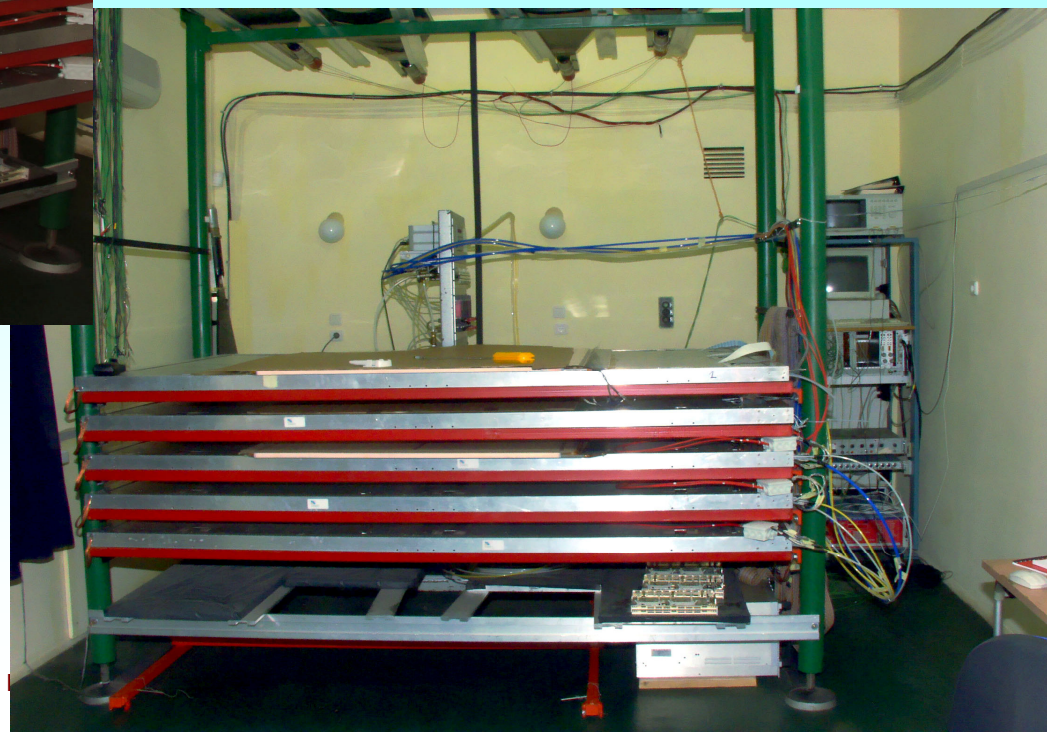


L. Litov

Що е то физика на ел. частици и и



София: мюонен телескоп



L. Litov

Що е то физика на ел. частици и



Реконструиране на мюонни следи



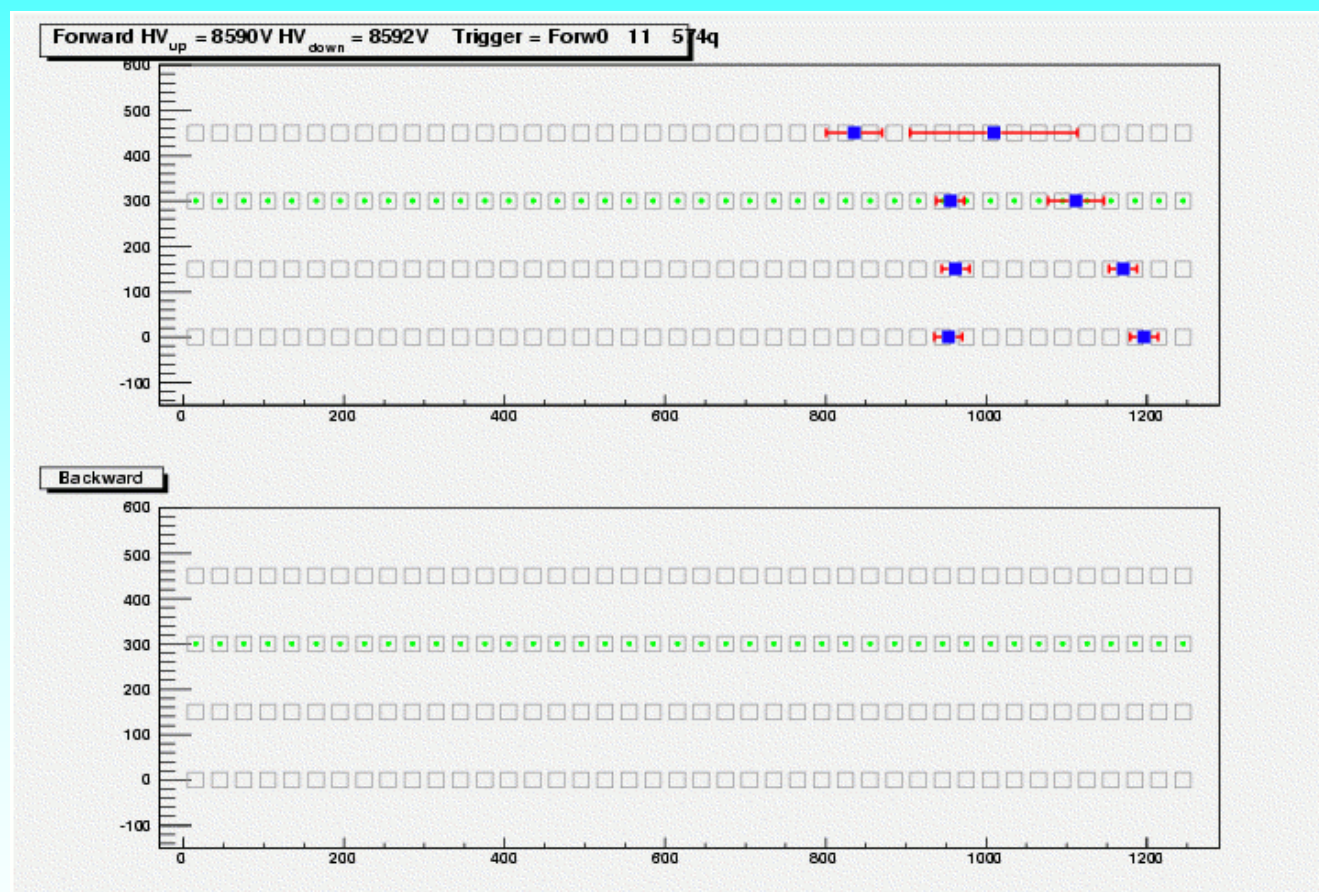
Брой камери = 4

Избор на тестова станция

3 съвместими клъстера в рефените станции, точно по един във всяка, с големина ≤ 7

Реконструиране на мюонната следа

Камерата се счита за ефективна, ако в нея има клъстер съвместим със следата



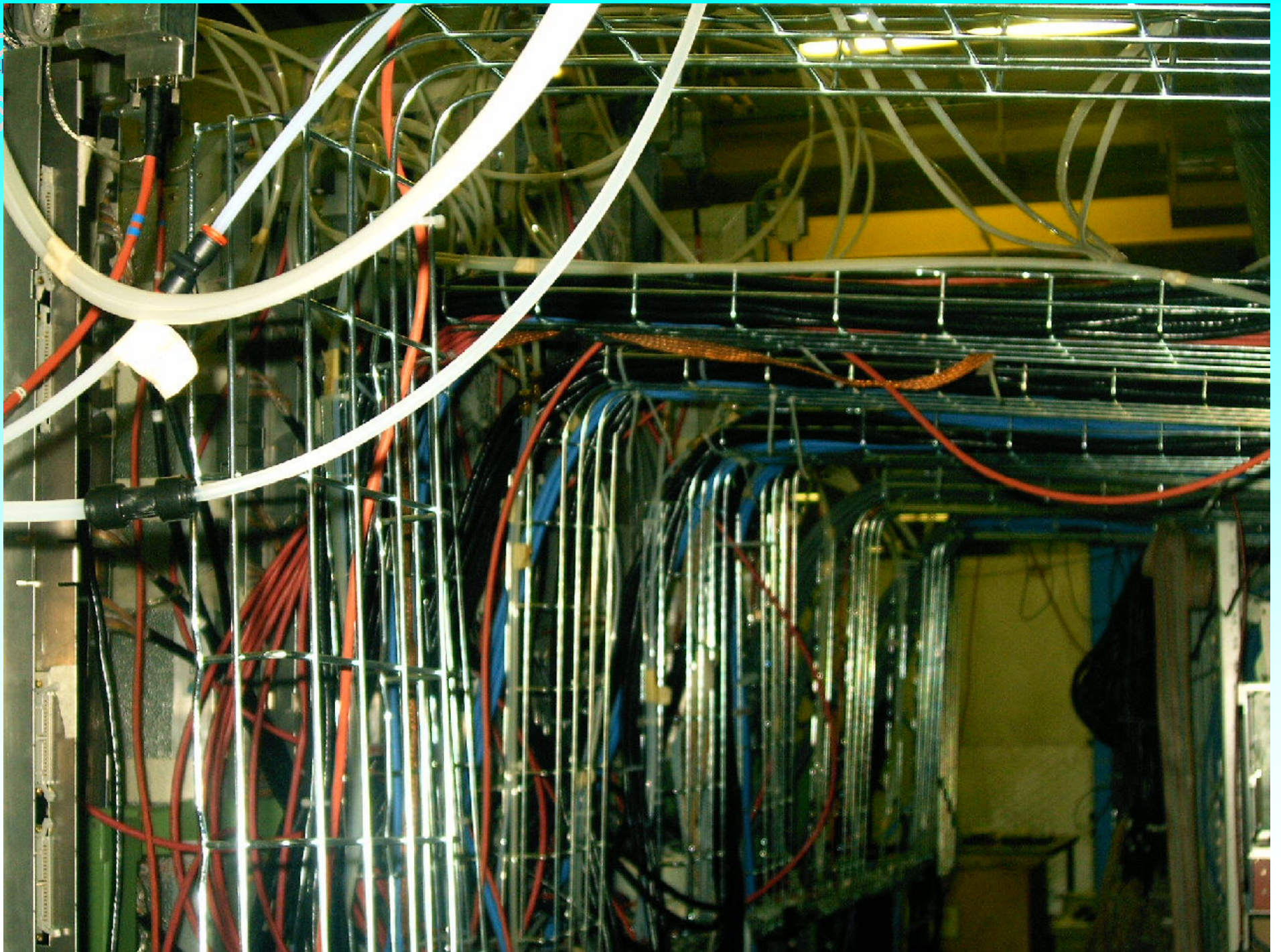


ISR RPC storage and test area

L. Litov

Що е то физика на ел. частици и има ли тя почва у нас

Гулечица, 4 Март, 2006





Installation of DT and RPC



At ISR

Coupling RPC to DT

Fast test

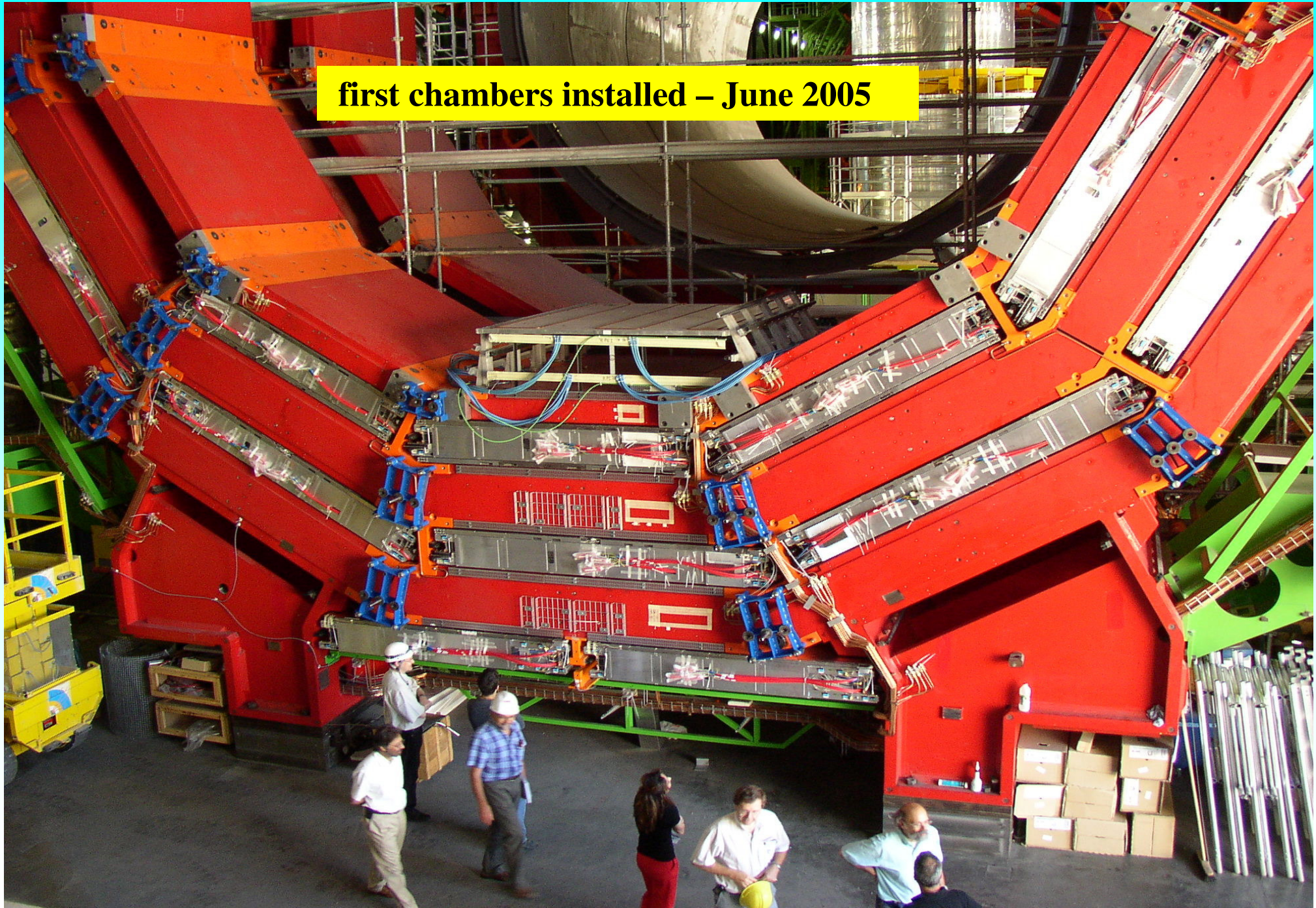
Transportation to SX5(CMS surface hall)

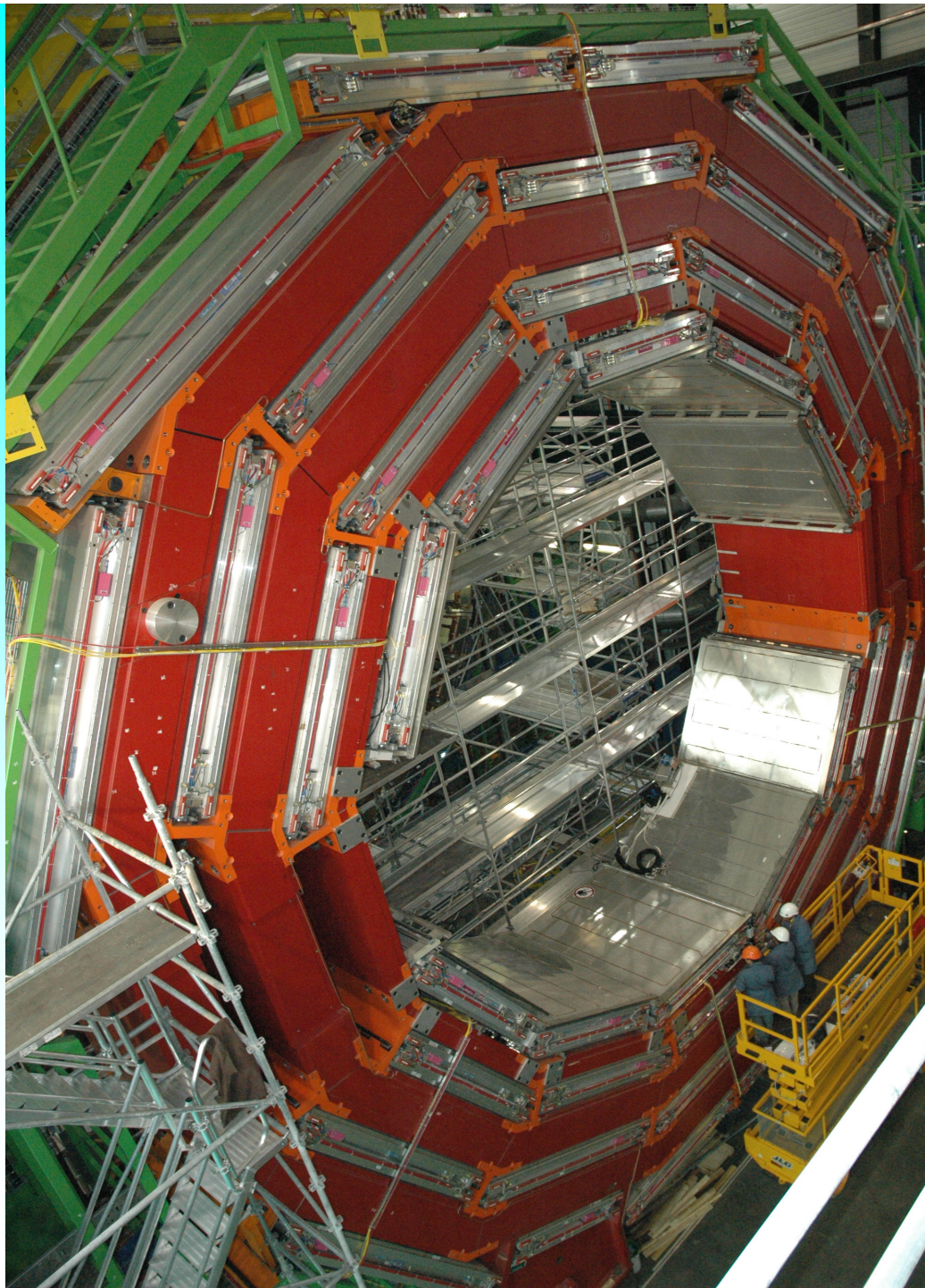
At SX5

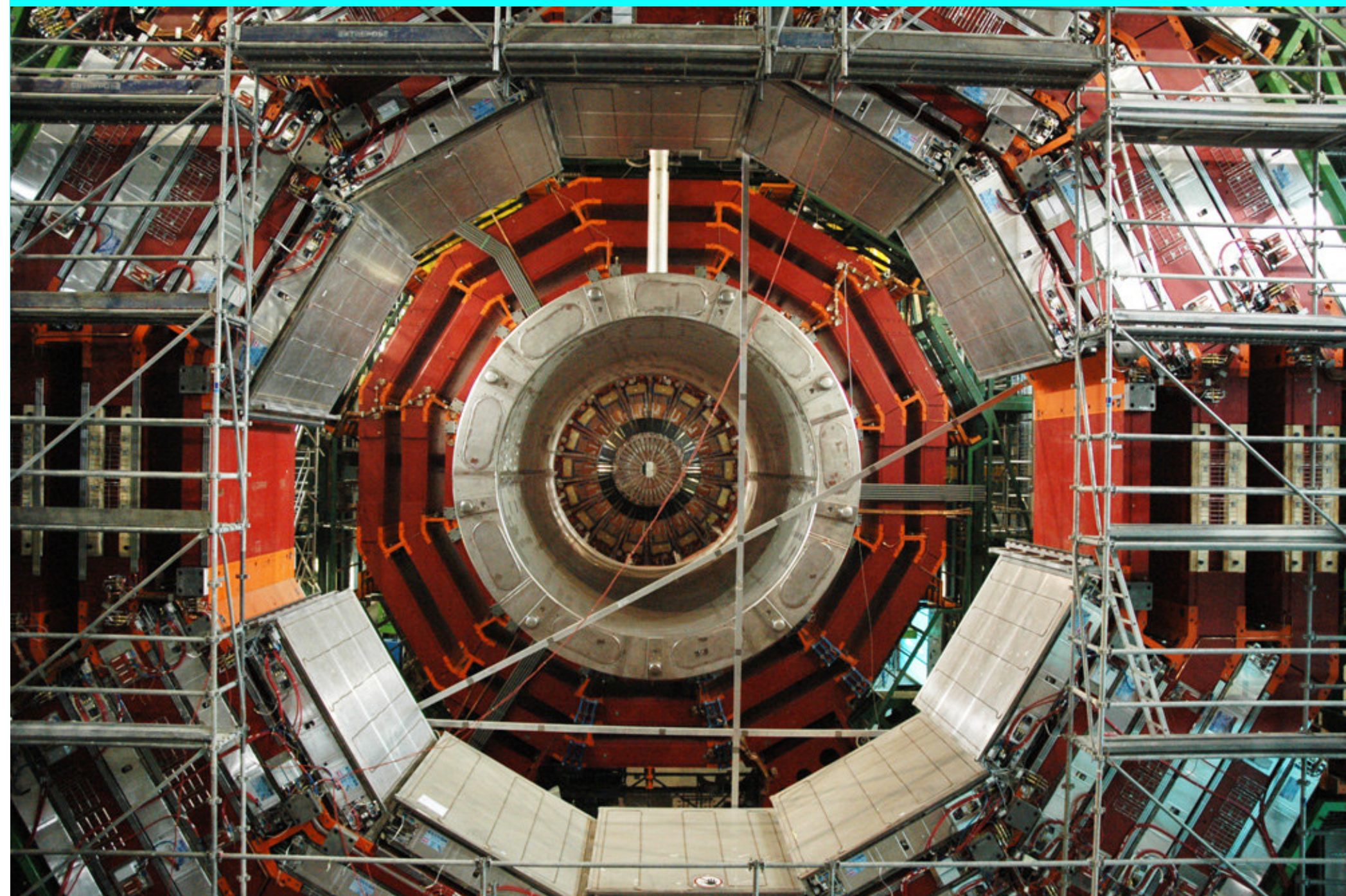
**Installation in the CMS Detector
Started in June**

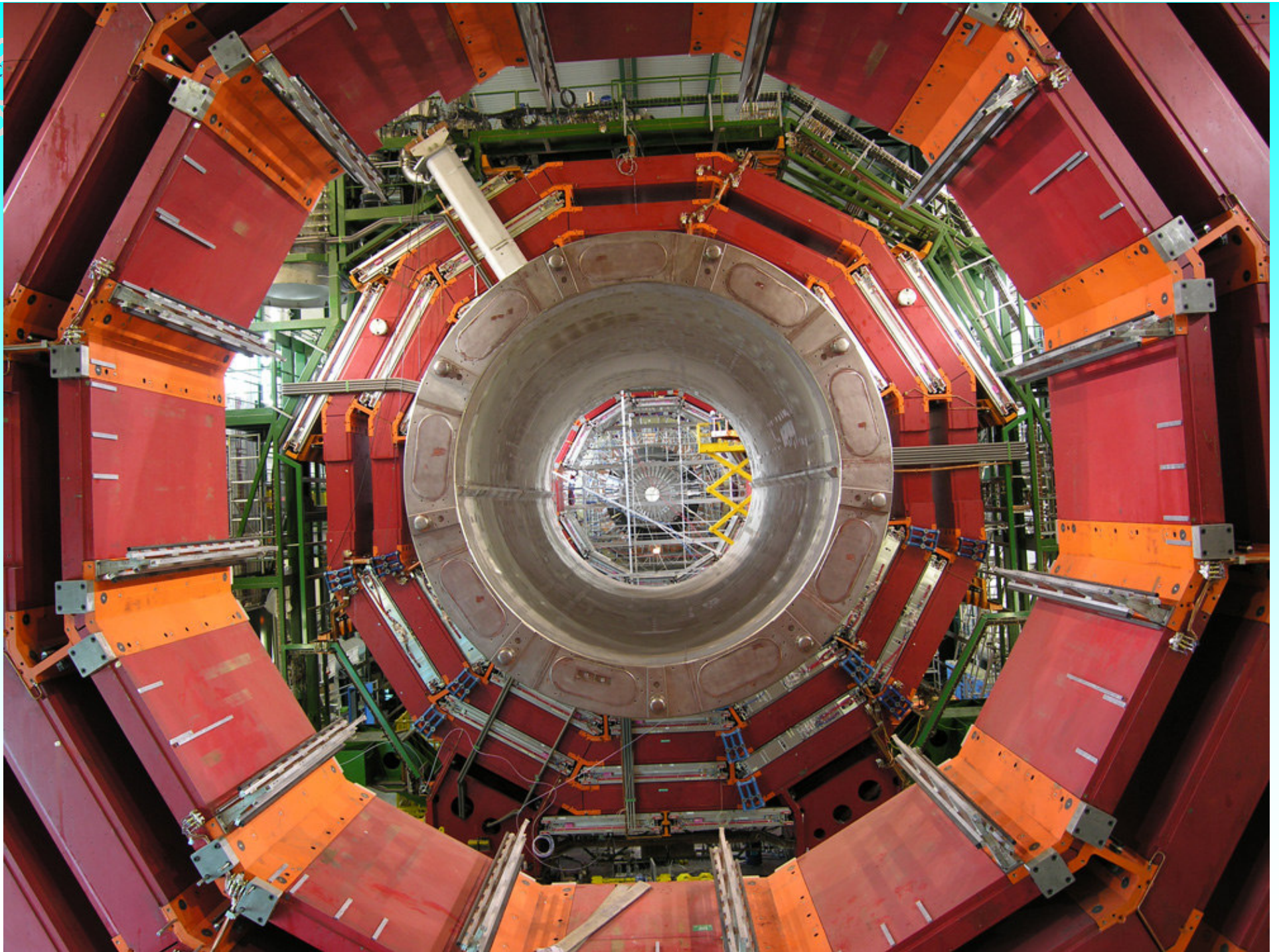


first chambers installed – June 2005



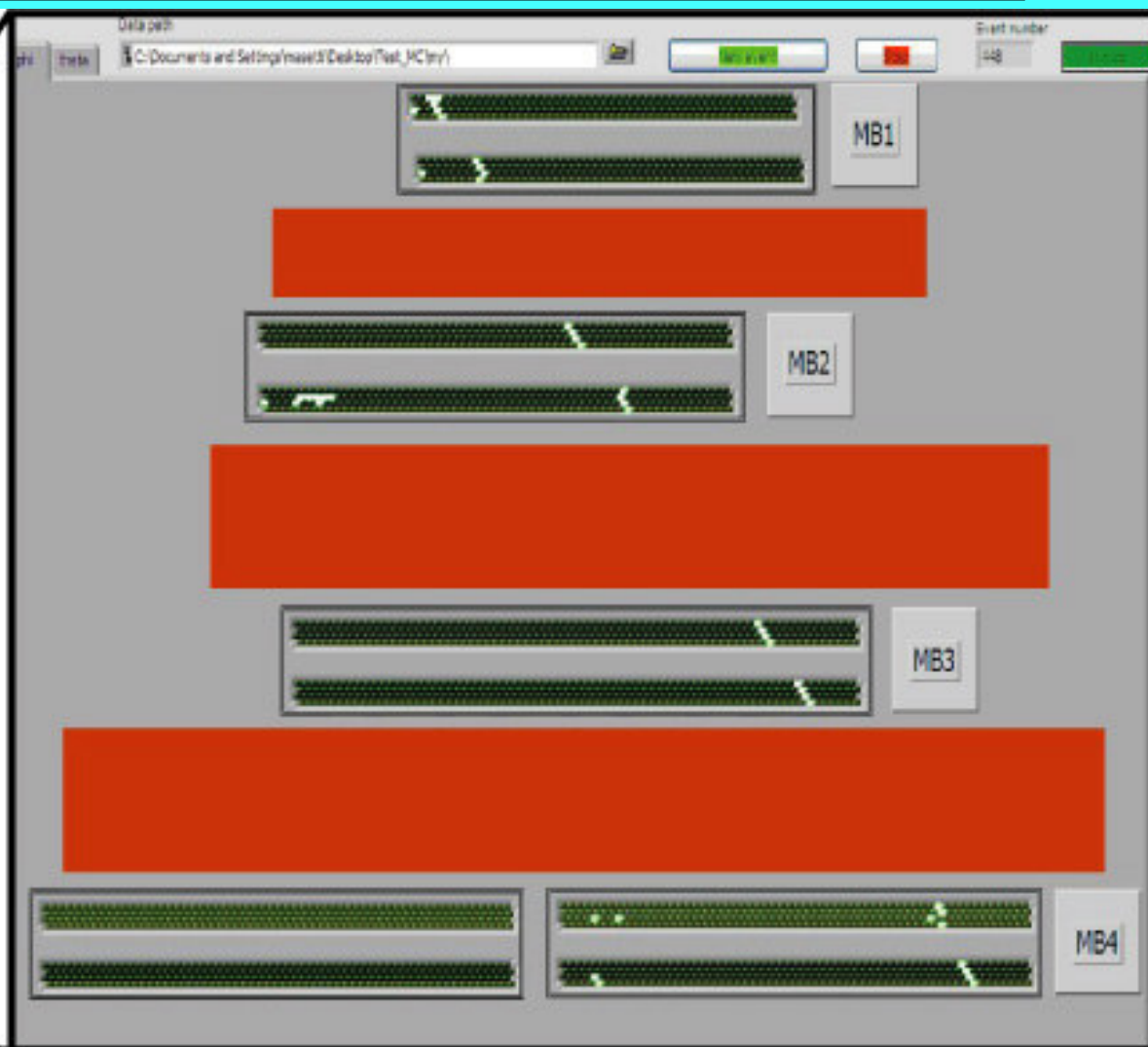
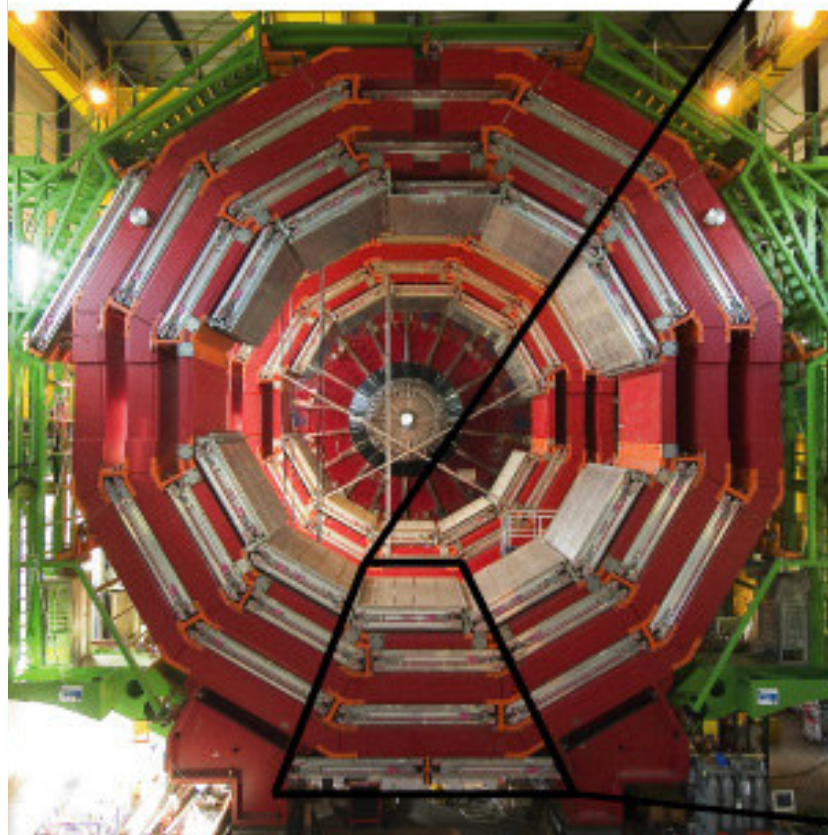




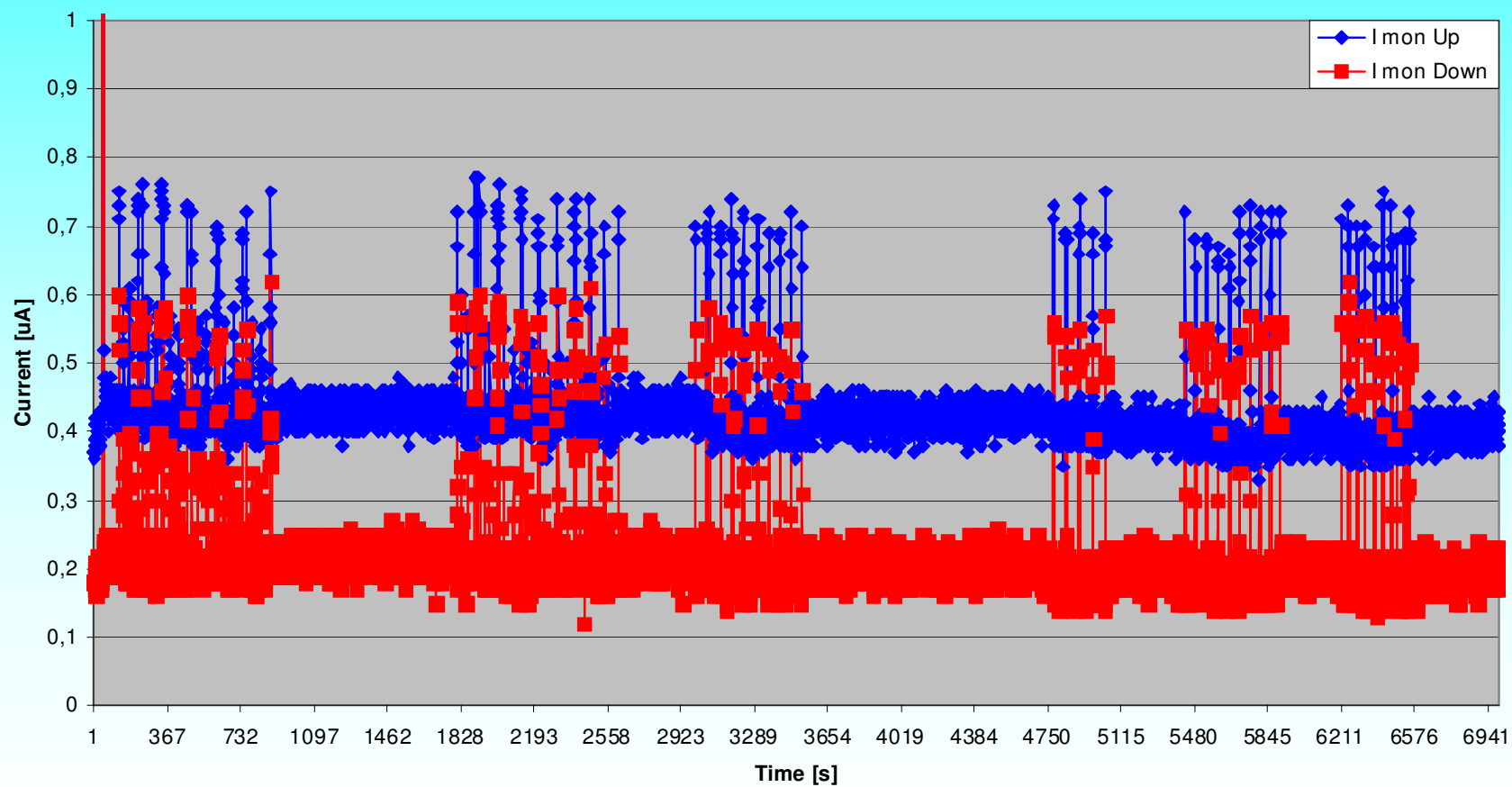




CMS Muon system



Current fluctuations due to gamma source





Endcap RPC production and test site at CERN



L. Litov

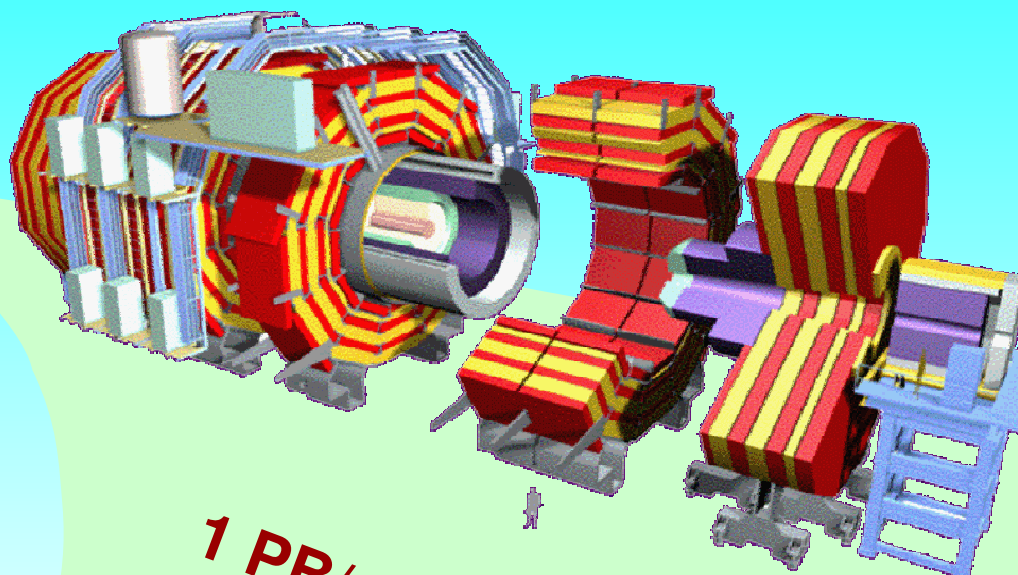
Що е то физика на ел. частици и



GRID



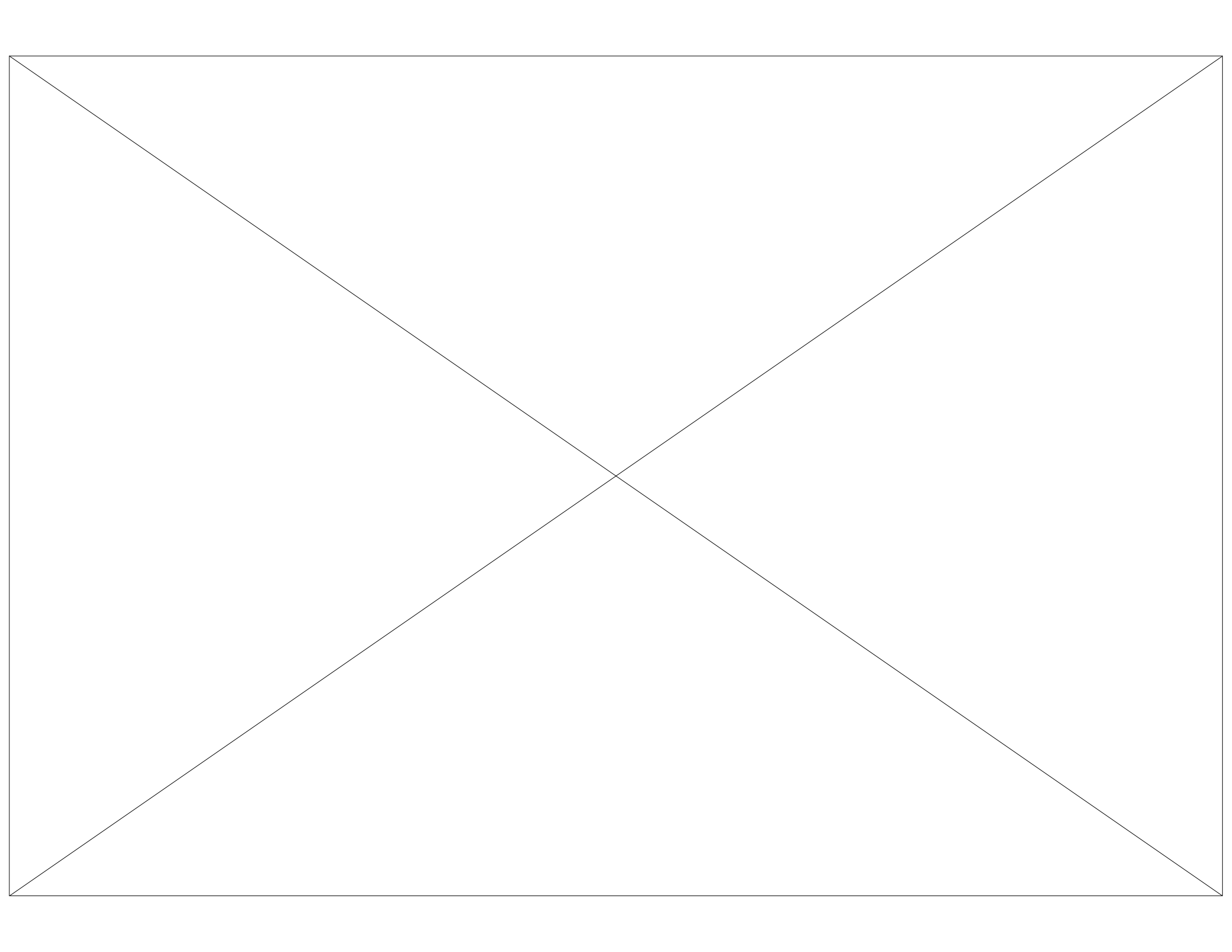
Grid



1 PB/sec

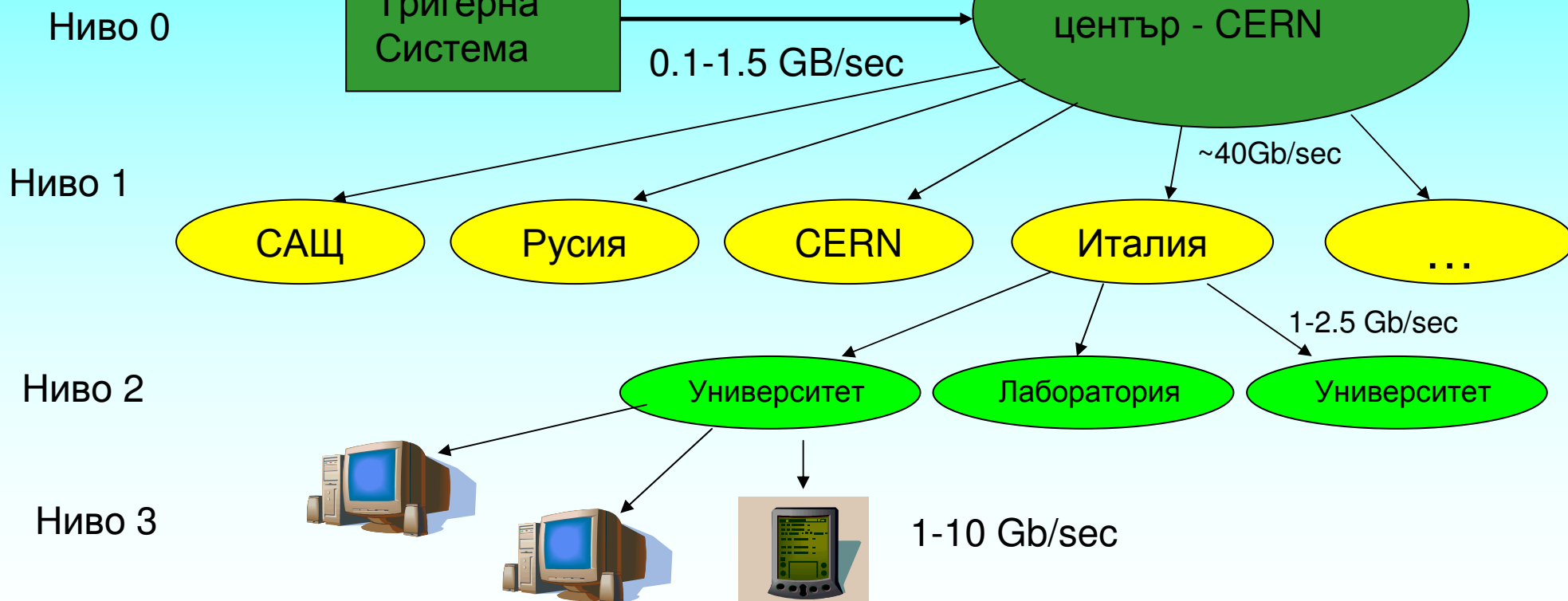
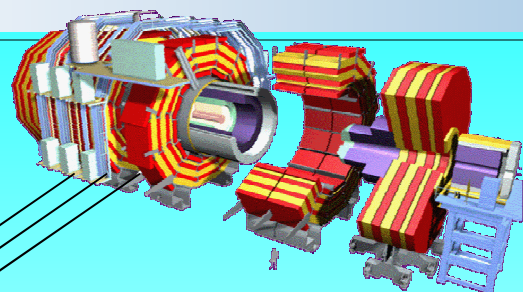
Филтриране в реално време:
Подбор на интересните събития
и компресия на данните

1 PB за година





LCG





Лаборатория по Grid технологии и ФЕЧ





Лаборатория по Grid технологии и ФЕЧ





Кои сме ние?



Групата по Физика на елементарните частици Състав

Доц. Леандър Литов

Доц. Румен Ценов

Доц. Димитър Колев

Ст. ас. Стоян Стойнев

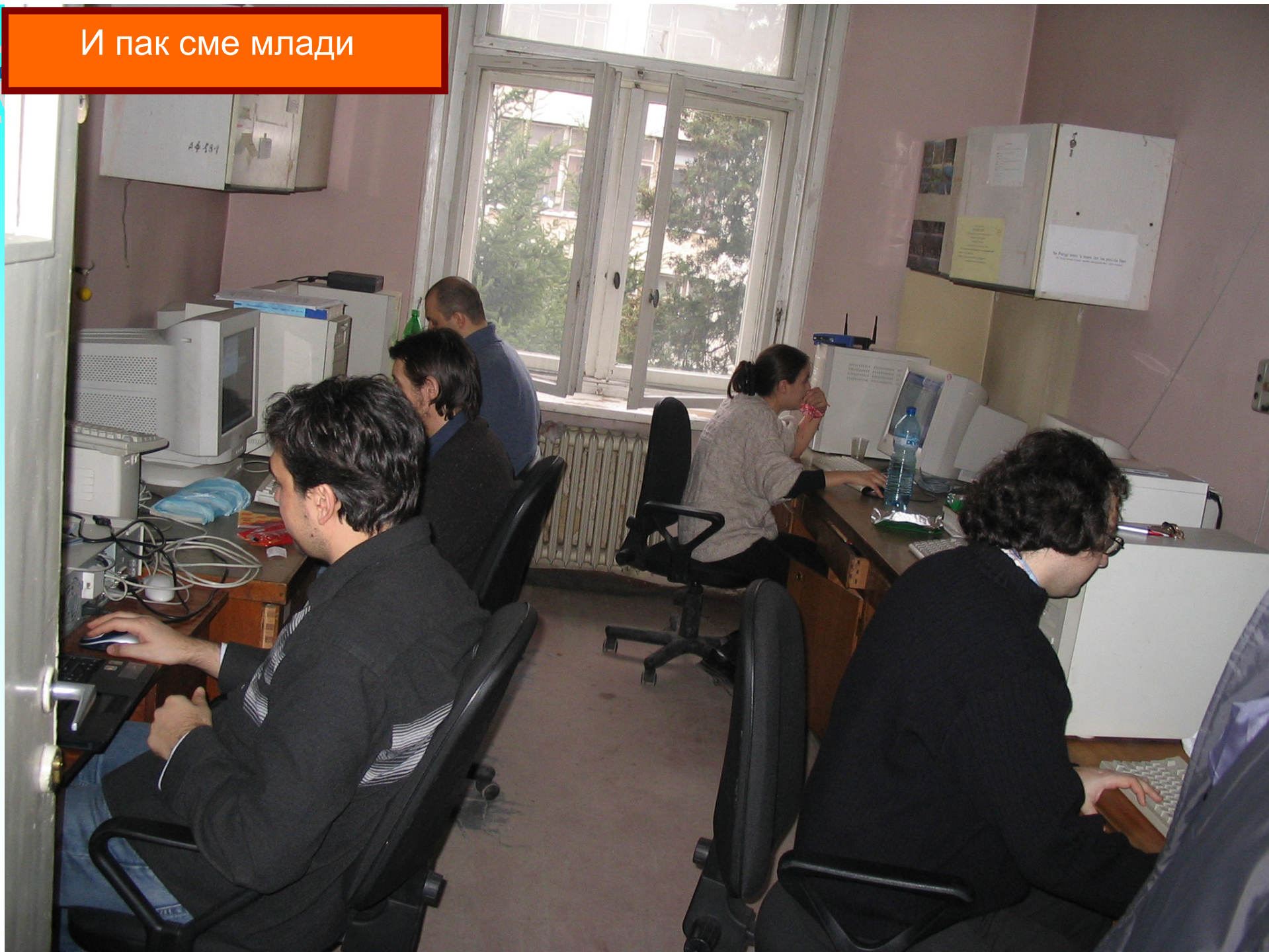
Физ. Пейчо Петков

Докторанти – 10

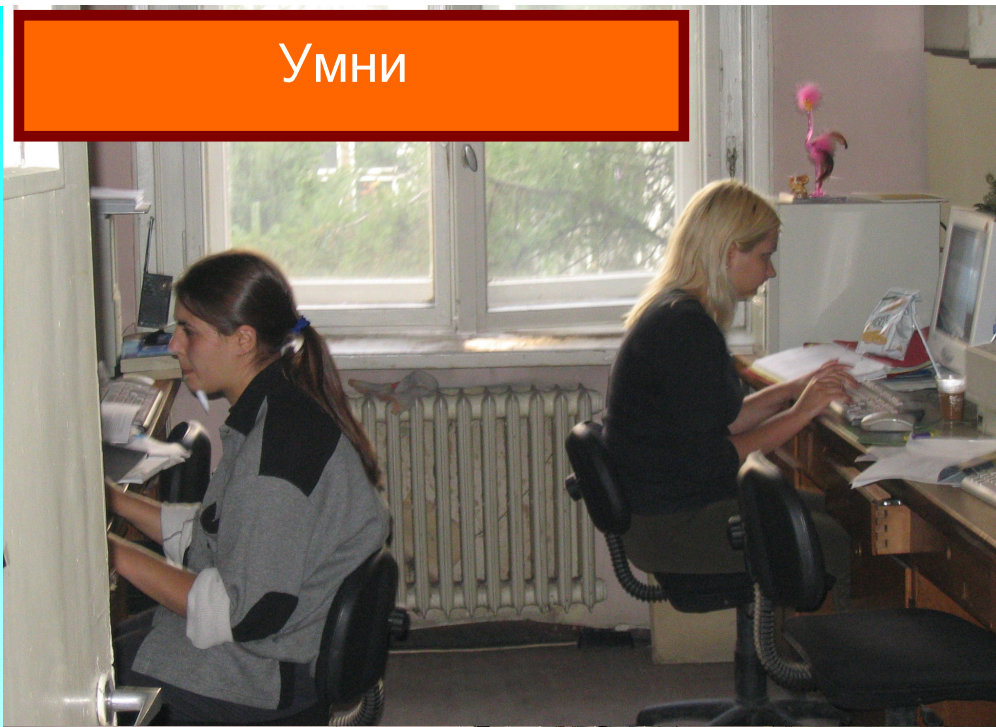
Студенти – 4

Общо 19 човека

И пак сме млади



УМНИ



Красиви





Понякога е трудно



L. Litov

Що е то физика на ел. частици и има ли значение



Може и така



L. Litov

Що е то физика на ел. частици и и



понякога се веселим





Бъдеще

Светло!!!



Conclusions



Particle Physics is most:

- Fundamental branch of physics
- Theoretically complicated
- Experimentally developed
- Expensive
- Exciting

Particle Physics gives:

- New knowledge and understanding of the World
- New technologies
- Great pleasure

Requires

