Б.А. ДОЛГОШЕИН

Московский Инженерно-Физический Институт (Государственный Университет)

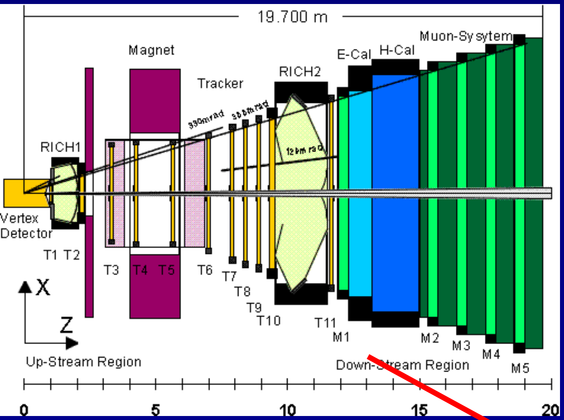
Трековый детектор переходного излучения для эксперимента ATLAS

Вторые Черенковские чтения, Москва, ФИАН, 14 апреля 2009 г.

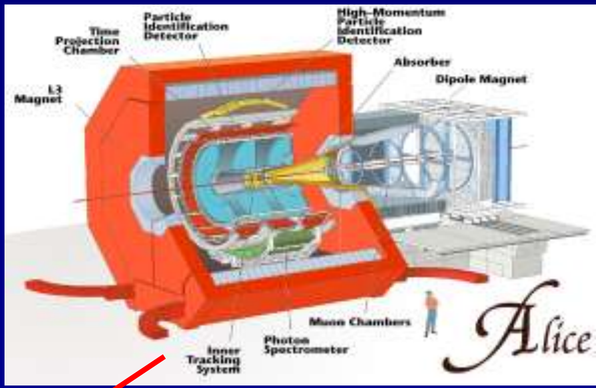
Большой адронный коллайдер LHC в ЦЕРН

Самый мощный протонный ускоритель в мире. Длина окружности 27 км.
Энергия протонов 2х7 ТэВ, светимость до 10^{34}/см^2/сек. Первый запуск - сентябрь 2008.
Четыре больших эксперимента. Основные цели - поиск Хиггс-бозона, определяющего массы частиц, поиск суперсимметричных частиц, “новая физика”.

LHCb

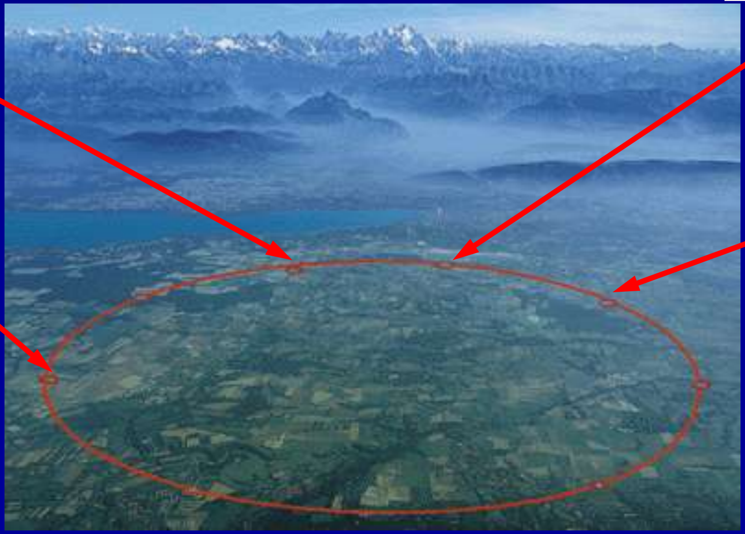


ALICE

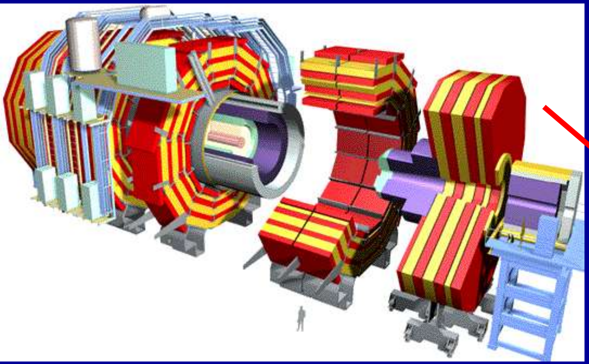


<u>Необходимые вычислительные ресурсы:</u>
- ~100000 современных процессоров

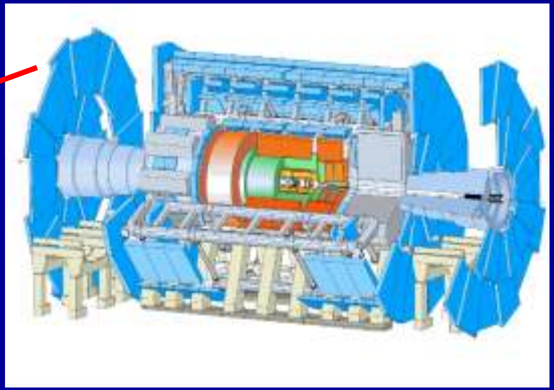
<u>Объемы данных:</u>
- Скорость набора 0.1 - 1 Гбайт/сек
- Накопление 5-8 Пбайт/год

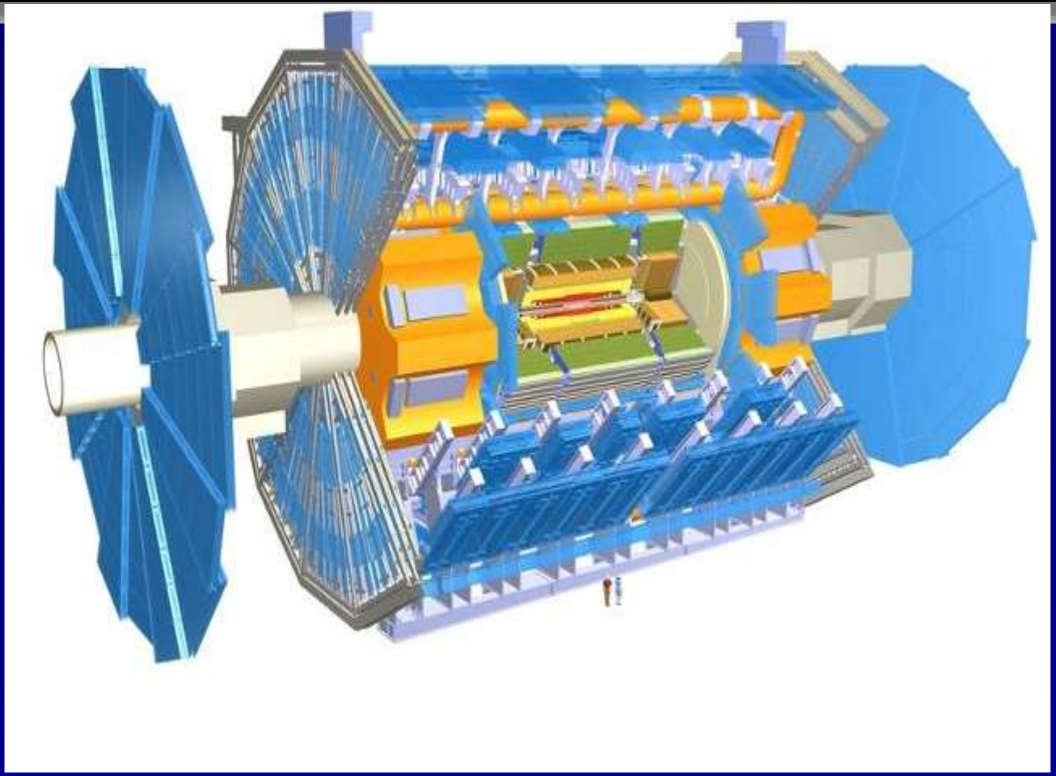


CMS



ATLAS





Diameter	25 m
Barrel toroid length	26 m
End-cap end-wall chamber span	46 m
Overall weight	7000 Tons

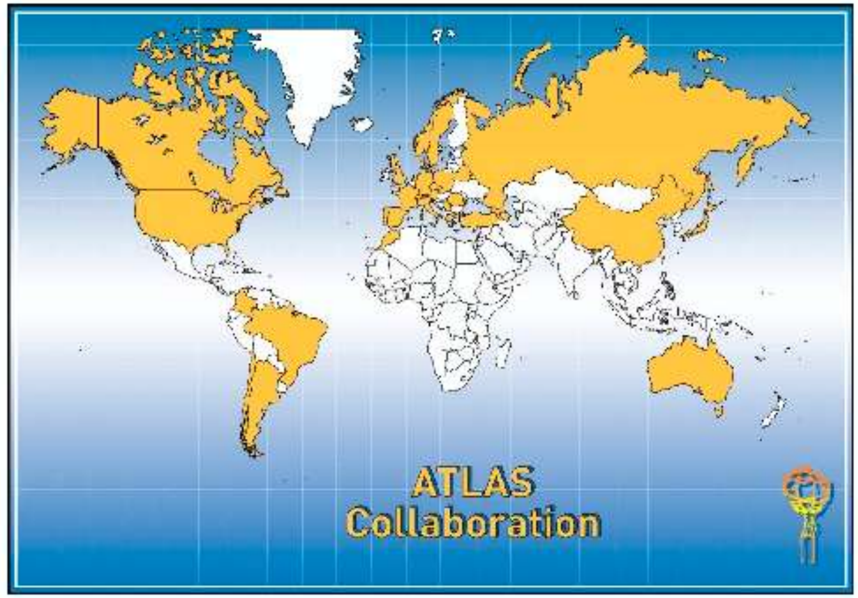
Эксперимент ATLAS

A few words of thanks….

ATLAS Collaboration

(Status July 2008)

37 Countries
169 Institutions
2500 Scientific Authors total
(1800 with a PhD, for M&O share)

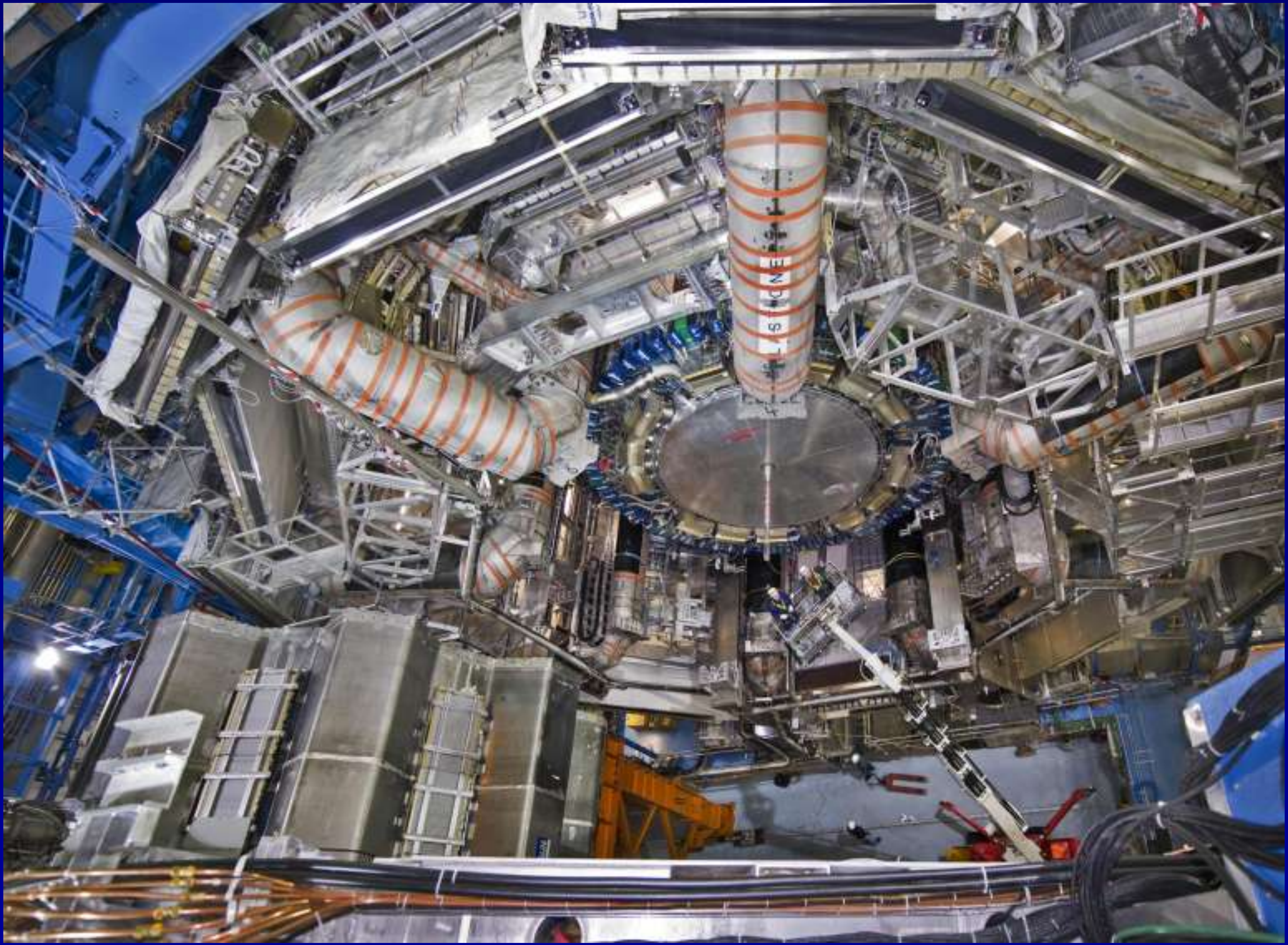


Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, UFRJ Rio de Janeiro, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

Шахта ATLAS

June 2003 Civil works complete, installation phase started

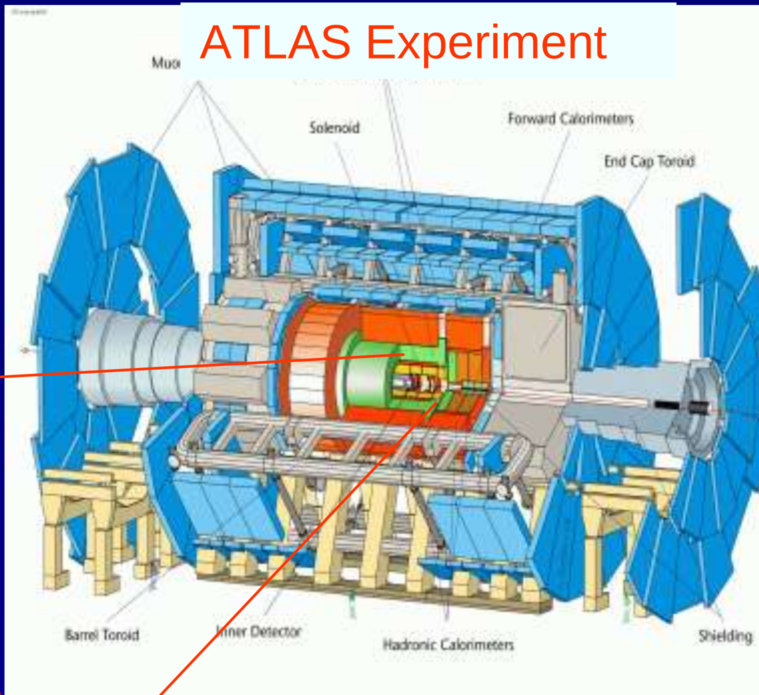
Завершение сборки установки ATLAS (2007)

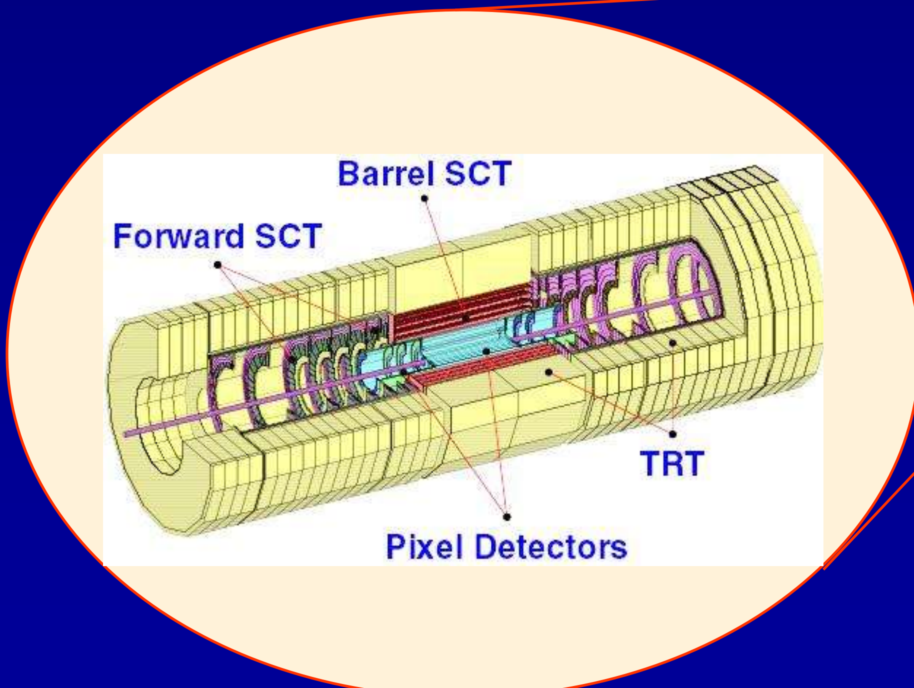


ATLAS Inner detector concept

General requirements:

- Combination of Central Tracker and TRD features
- Robust pattern recognition





- Bunch crossing rate - **40 MHz** (25 ns between interactions)
- Interactions per year - 10^{16}
- Selection level (Higgs) ~ $1:10^{13}$

RD-6 primary goals:

- Particle ID (e/hadron):

because e/jet ~10^-5 for
LHC

+ gamma conversion rejection

- Pattern recognition and tracking at high occupancy:

  ~30 hits (or more) tracking with 120-150 mkm accuracy

TRD → TRTracker

А.И.Алиханян
и рентгеновское излучение
в физике высоких энергий

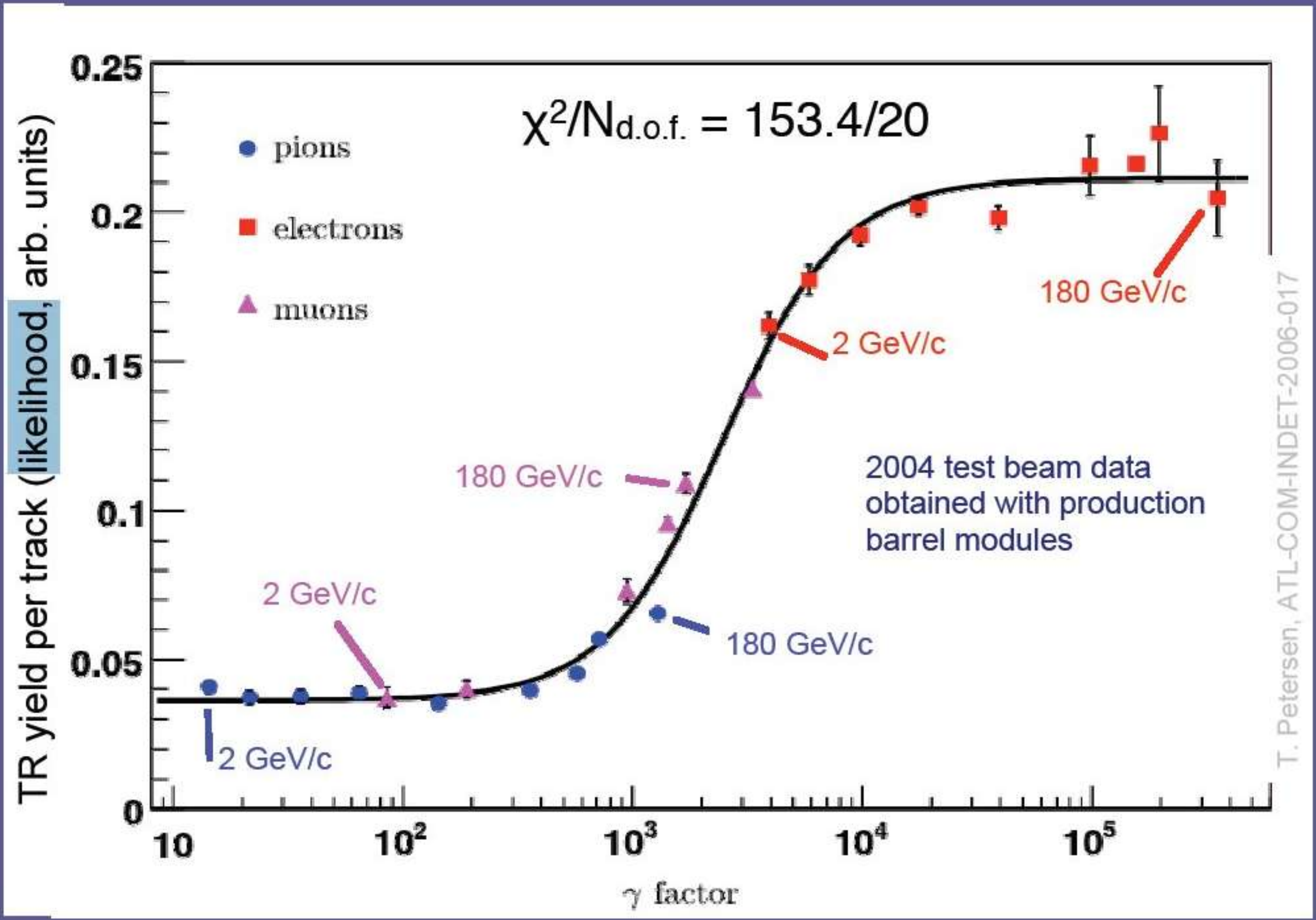
T R

- V.I.Ginzburg and I.M.Frank 1946

- G.M.Garibian : XTR 1958

- A.I.Alikhanian and his collaborators
  from Armenia :
  first XTR observations and investigations 1961-70
  → Particle Identification

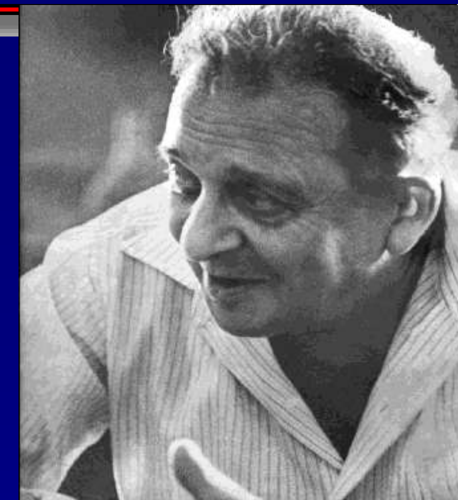
- A.I.Alikhanian:
  Two International Conferences
  on TR, Erevan seventies

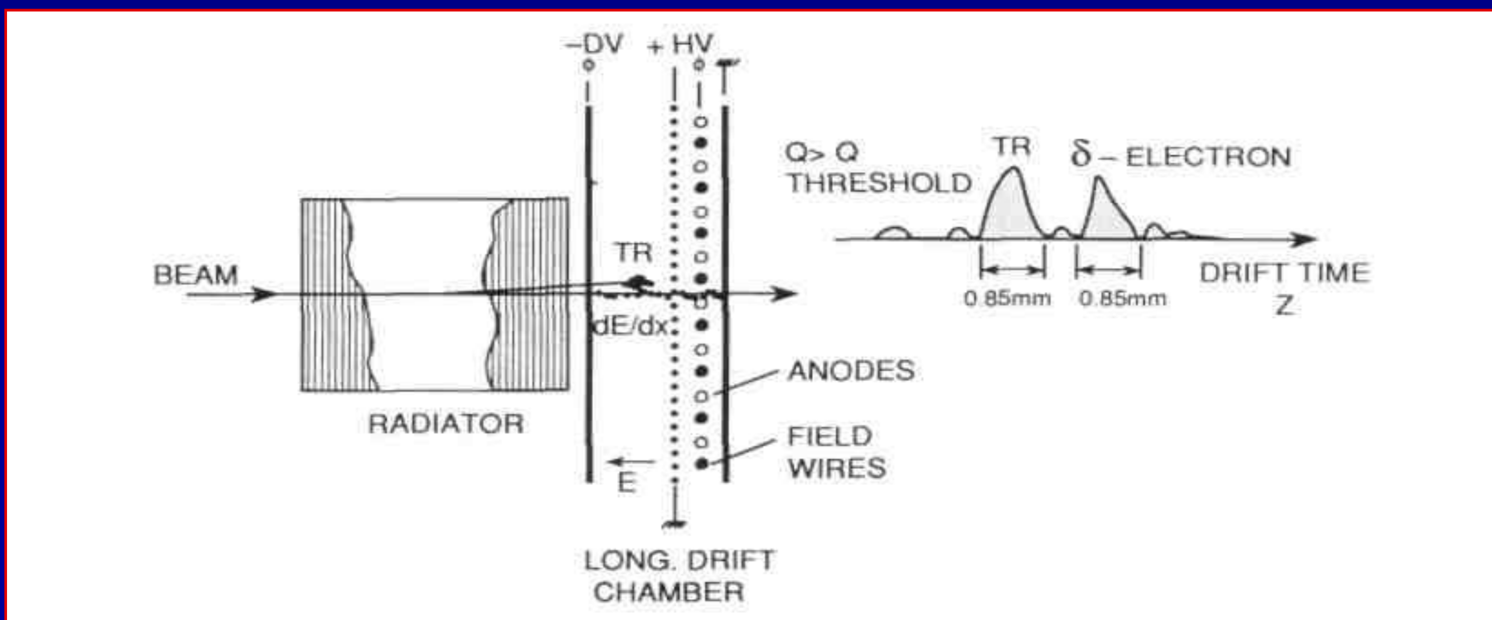


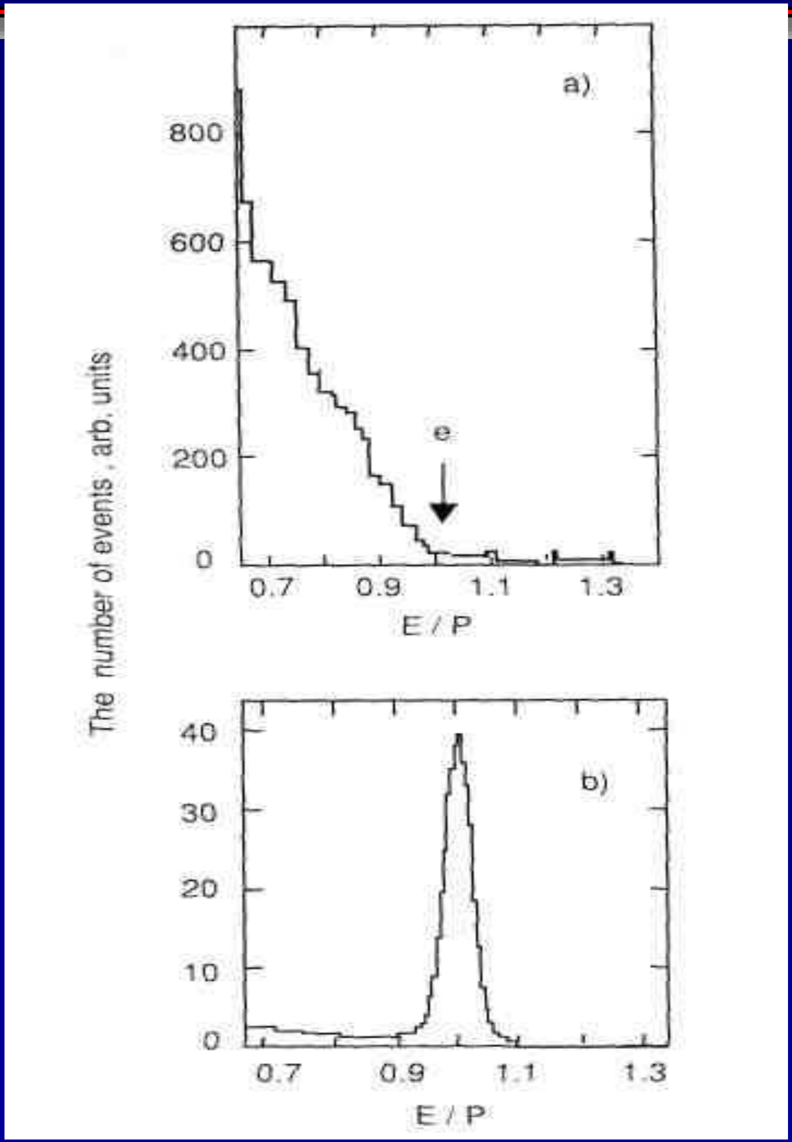
$\chi^2/N_{d.o.f.} = 153.4/20$
pions
electrons
muons
180 GeV/c
2 GeV/c
180 GeV/c
2004 test beam data
obtained with production
barrel modules
2 GeV/c
180 GeV/c
2 GeV/c
TR yield per track (likelihood, arb. units)
γ factor
T. Petersen, ATL-COM-INDET-2006-017

→ TR RADIATOR

Xe Streamer chamber photo







Electron efficiency 100%

Pion efficiency 100%

TRD OFF

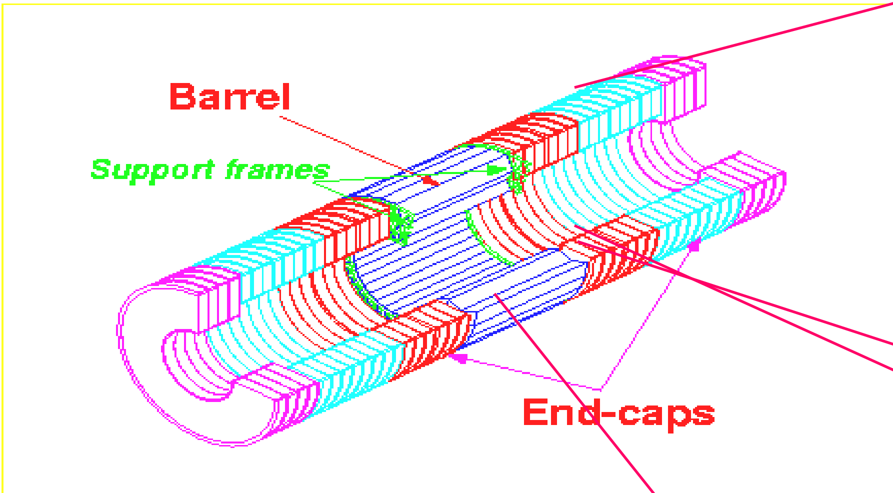
Electron efficiency 99.5%

Pion efficiency 0.06%

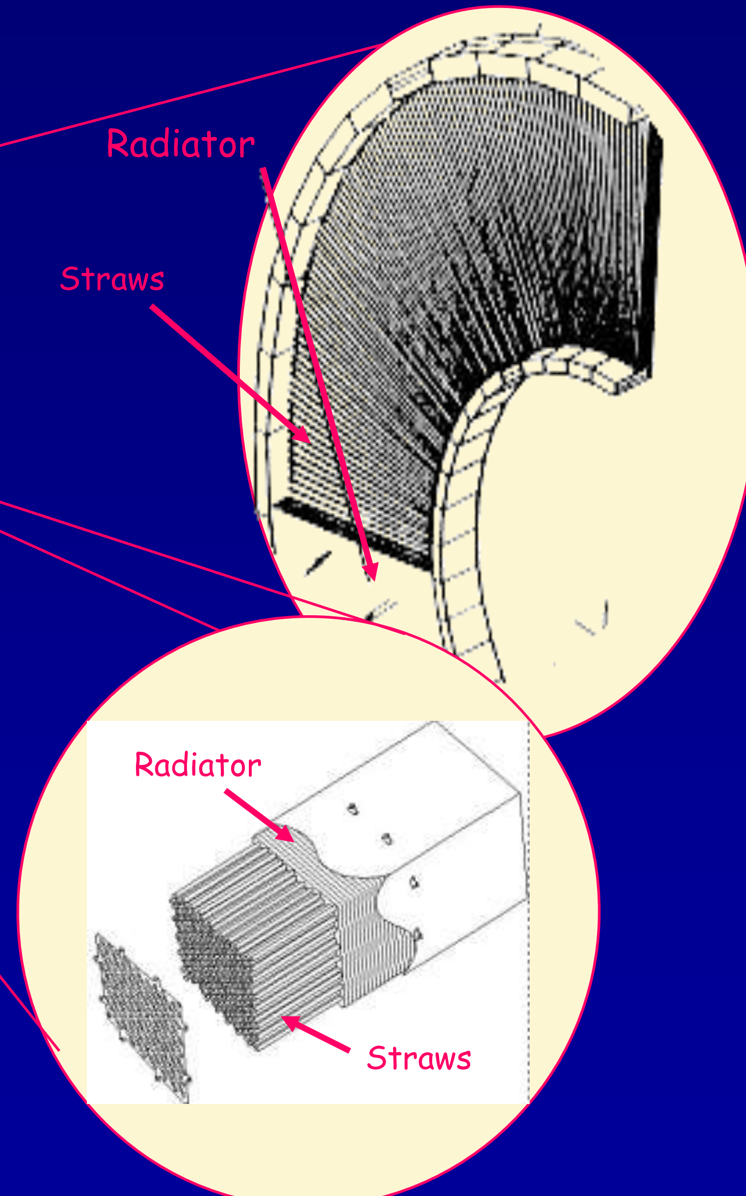
TRD ON

E-715 : Sigma hyperon beta decay experiment

TRT global parameters



Length:	Total	6802 cm	N straws:	Total	372032
	Barrel	148 cm		Barrel	52544
	End-cap	257 cm		End-cap	319488
Outer diameter		206 cm	N electronics channels		424576
Inner diameter		96-128 cm	Weight		~ 1500 kg



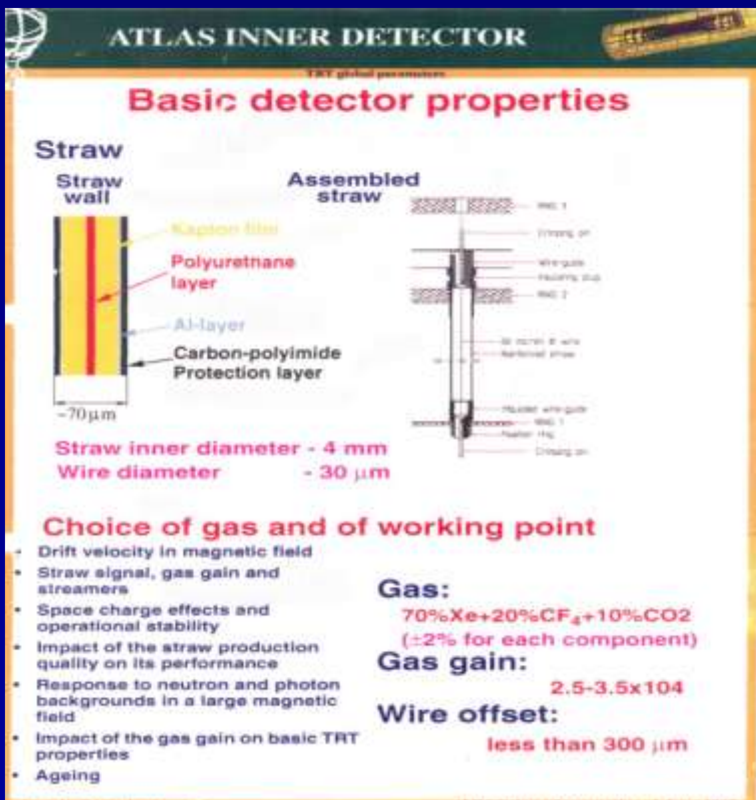
Трековый детектор переходного излучения TRT

• Стоимость – 10 млн $
• Участвуют 50 физиков из 5 российских и 7 западных лабораторий
• Концепция и базовая разработка TRT принадлежит российским физикам МИФИ-ФИАН
• Габариты: цилиндр из кольцеобразных модулей с внутренним диаметром 1 м, наружным – 2 м, длина 7 м.
• Структура: ряды цилиндрических дрейфовых камер малого диаметра (4мм) чередуются со слоистыми радиаторами переходного излучения
• Количество камер: ~300 000 длиной 0.5-1 м
• Пространственная точность: 150 мкм в каждой из ~35 точек на треке, коэффициент режекции электронов от адронов: 50-100

TRT challenges:

- Very high occupancy: up to 30%
- Very high counting rate: up to 20 MHz/straw
- Short bunch crossing interval: 25 ns
- High TR efficiency: Rejection e/h ~100 →Xe gas circulation, TRadiator
- High spatial resolution, good pattern recognition
- Radiation environment: ~10MRad
  10^14 n/cm^2 year
- Fast and chemically active straw gas: Ageing!
- Chemically resistant straw materials: operating straw works as an electrochemical reactor
- Min amount of material (in Radiation lengths)
- Extremely precise and robust mechanical structure ~100mkm/few m =~10^-5
- Temperature stable: cooling

Problem 1: Cathode of straw



More then 10000 m^2 of cathode film (MEPHI+Plastik Enterprize)

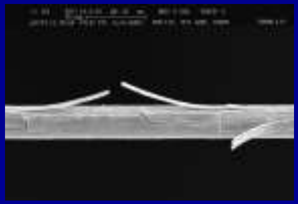
Cathode with carbon-polyimide protected layer survives more then 20 LHC years

Problem 1 :

Straw materials (anode + cathode) have to be "electro"-chemically and radiation hard under unique conditions:

-Total charge is ~10 C/cm of straw – at least one order of magnitude more than anywhere before

Anode wire



has been chosen after 15 iteration studies with wires from different producers

Problem 2:

Mechanical accuracy (min wire offset), stability and robustness

- **First step :**

Straw reinforcement by carbon fibers! (M. Price)

- **Second step:**

Usage of carbon composite material (very light, strong and precisely machined)

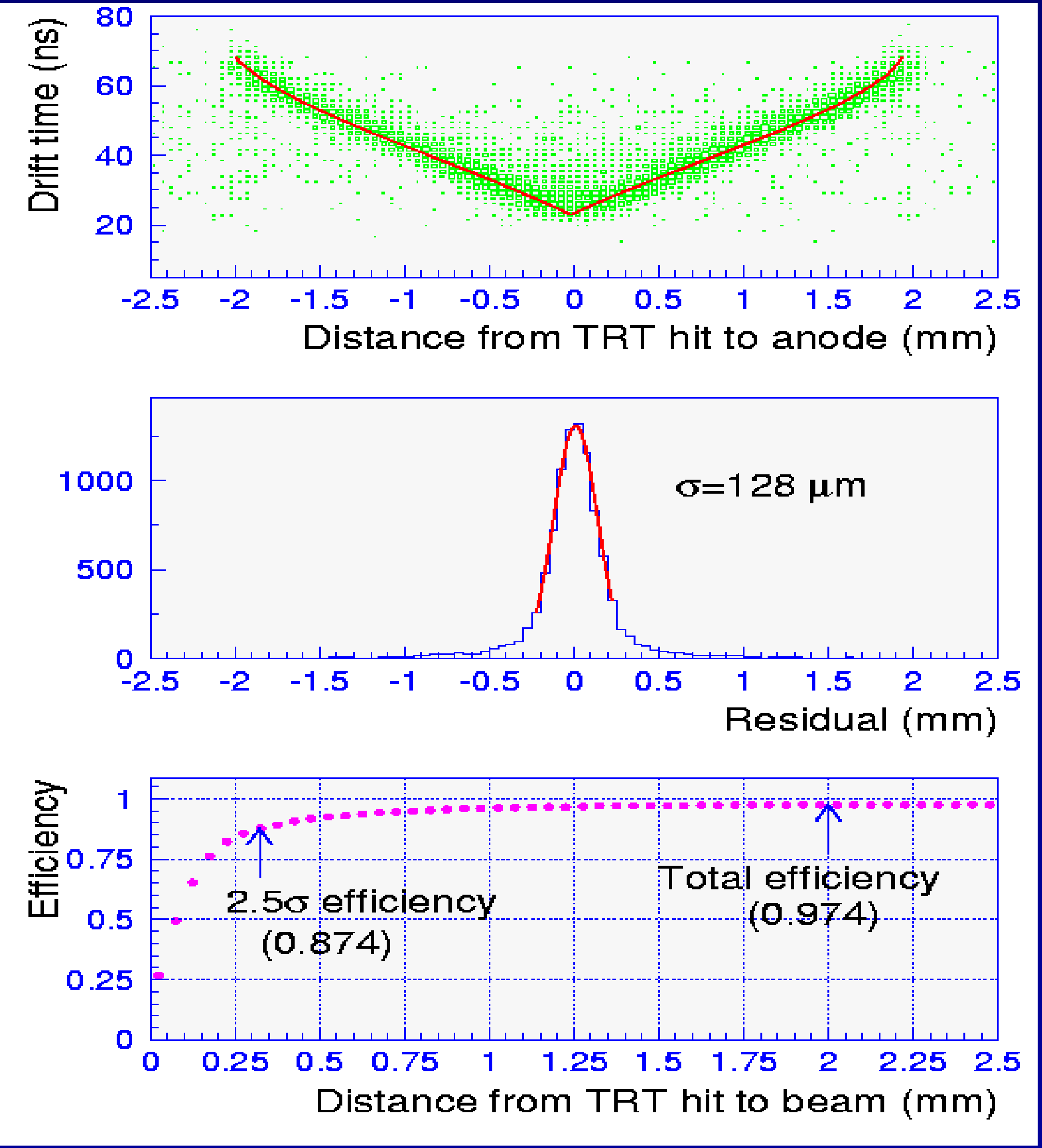
Plant Mashinostroitel, Perm

Problem 4 :

High TR efficiency
High spatial resolution

- The optimal TRadiator : CH2 foils, fibers
- Tracking in B field
- Fast low noisy FE (threshold of 200 eV): ASDBLR (PennU)

Tracking and efficiency



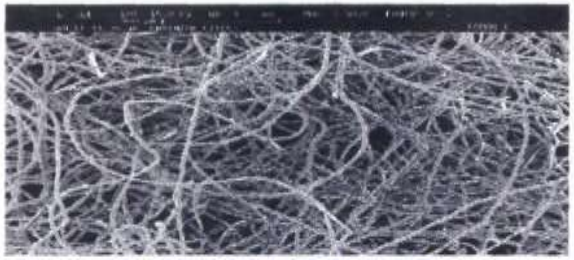
- Si track is used for precise prediction of beam particle position inside the straw
- Full collection time is around 44 ns (with new gas mixture)
- Third-degree polynomial fit of RT dependence is used to reconstruct hit coordinate via measured drift time
- Two kinds of efficiency: total (hit registration efficiency) and 2.5σ (drift-time efficiency). Later takes into account the position of reconstructed hit

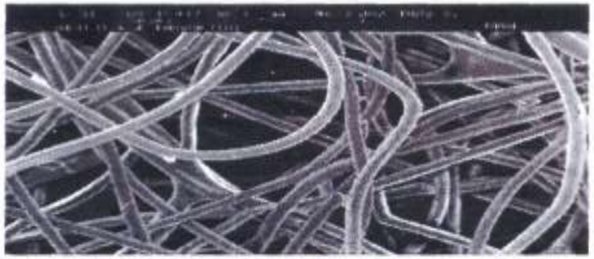
Basic detector properties

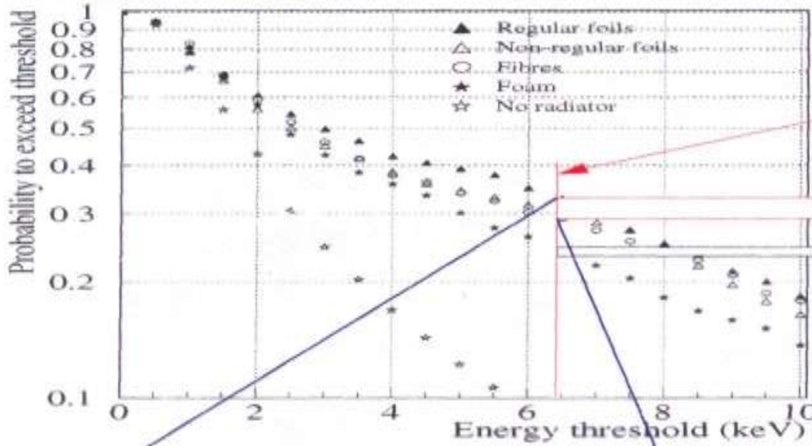
Radiator

Foils, foams and fibres

More than 30 specially developed samples have been studied

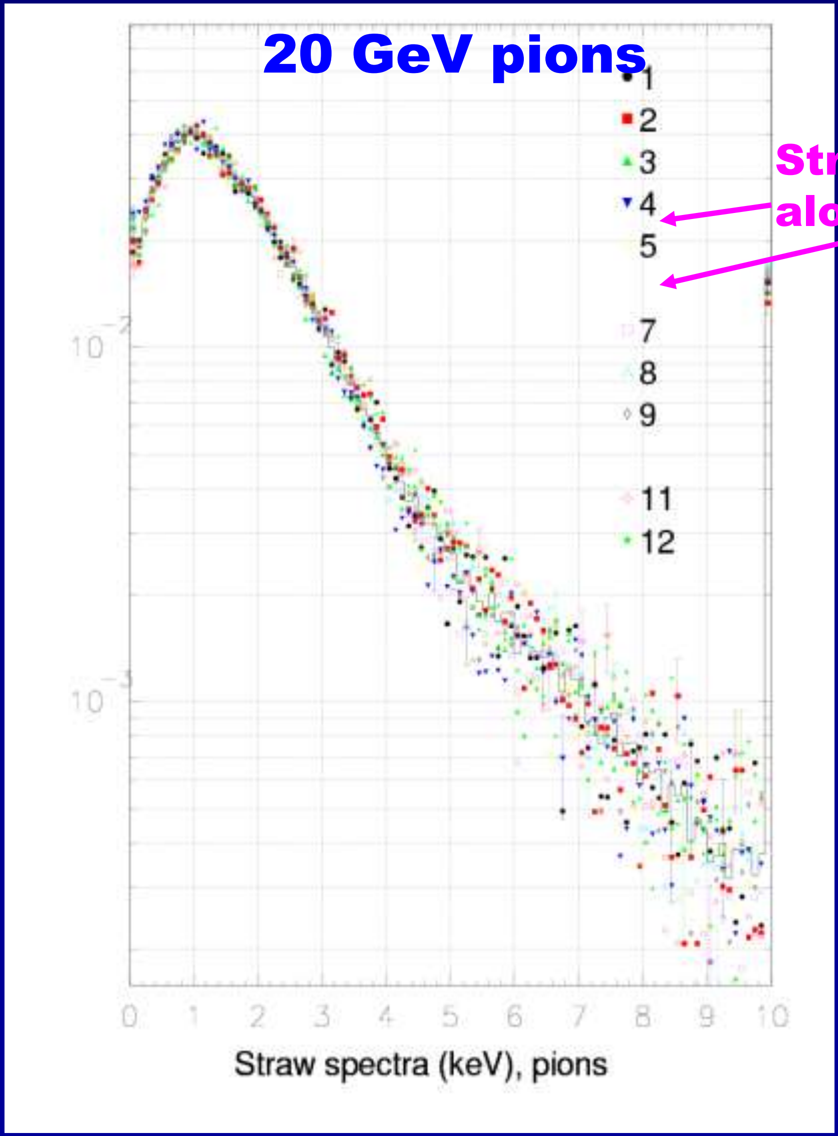




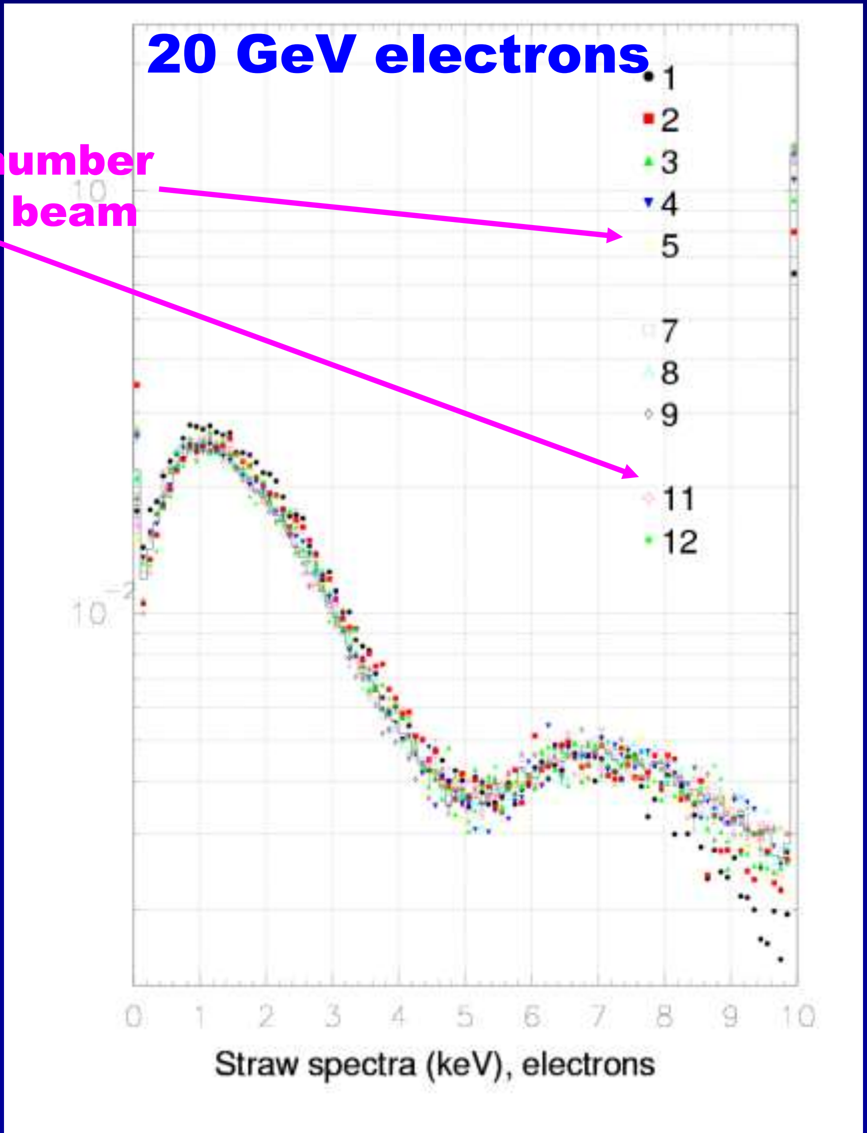


End-cap: foils Barrel: oriented fibres

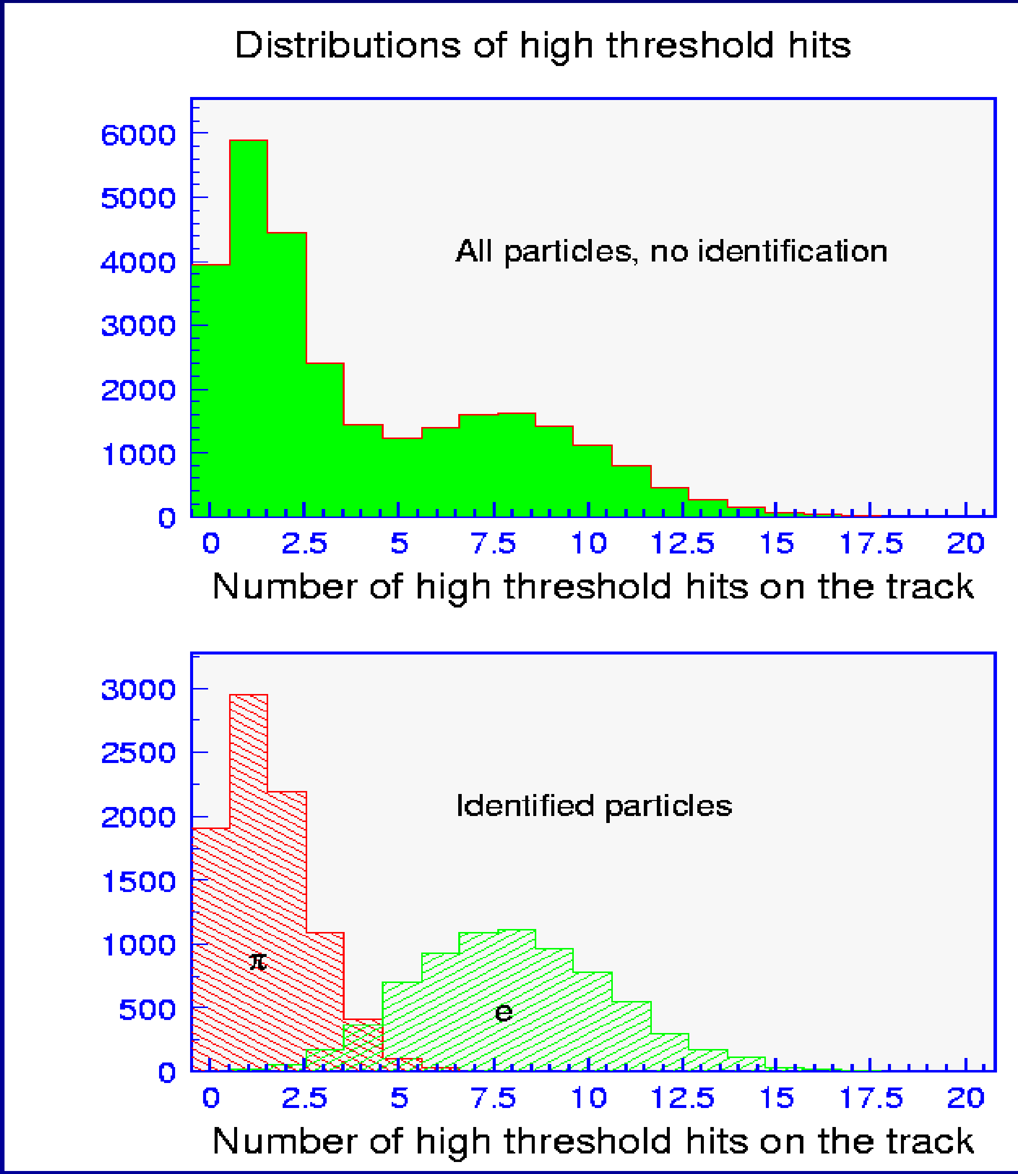
Pion and electron spectra in a straw



Straw number along a beam

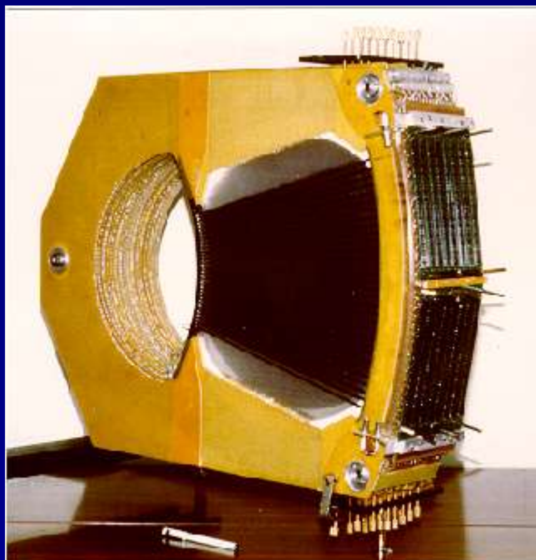


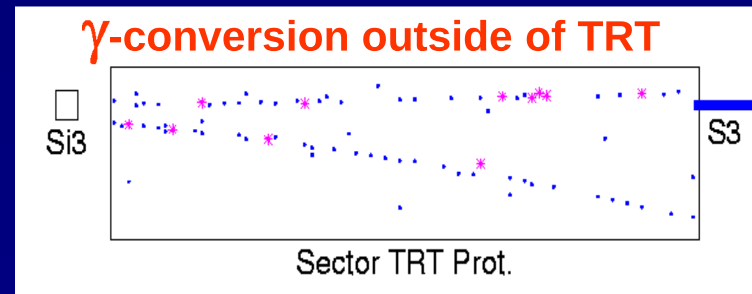
Rejection by number of high threshold hits

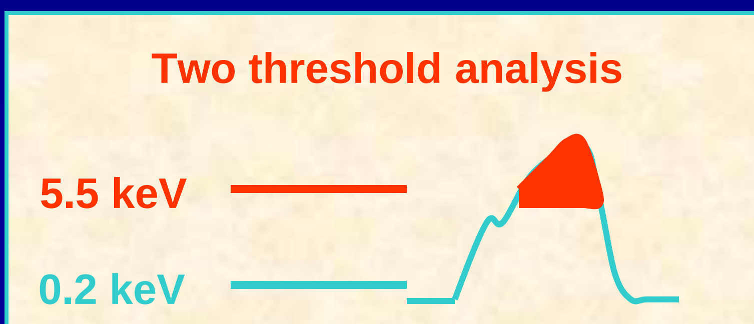


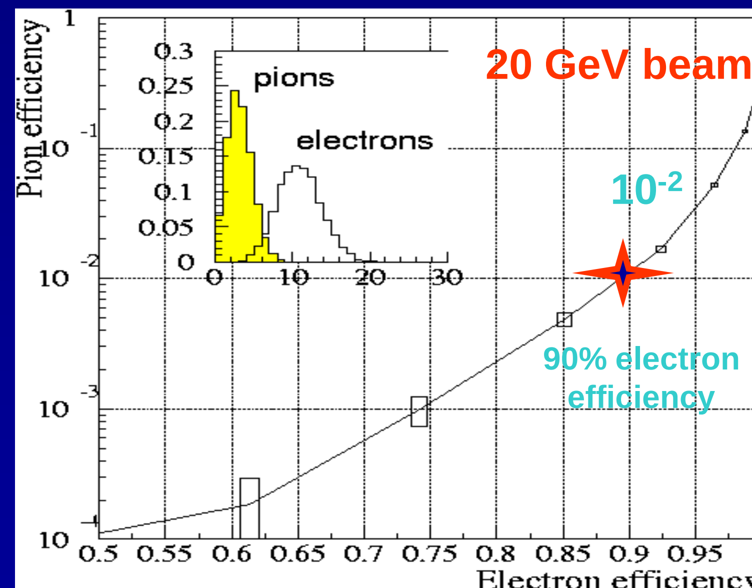
- Traditional method for pion/electron separation: calculate the number (or fraction) of high threshold hits in straws, crossed by the beam particle

TRT Test beam prototypes

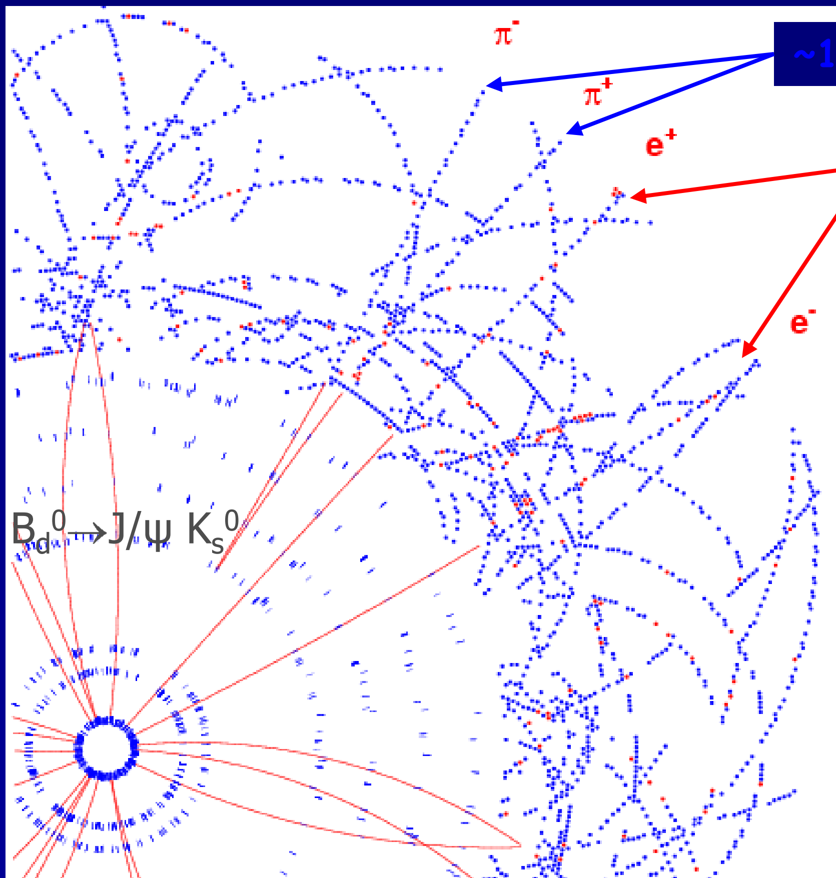


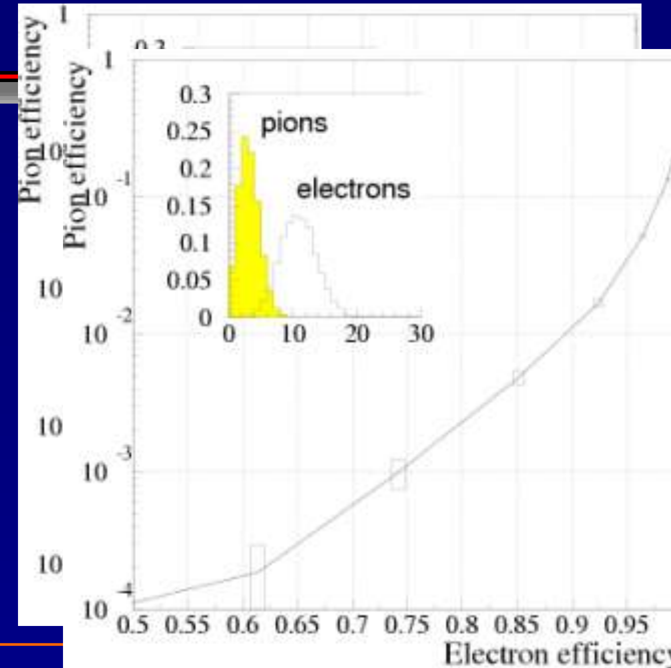






TRT performance



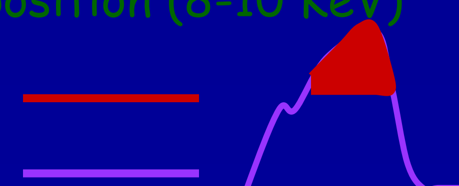


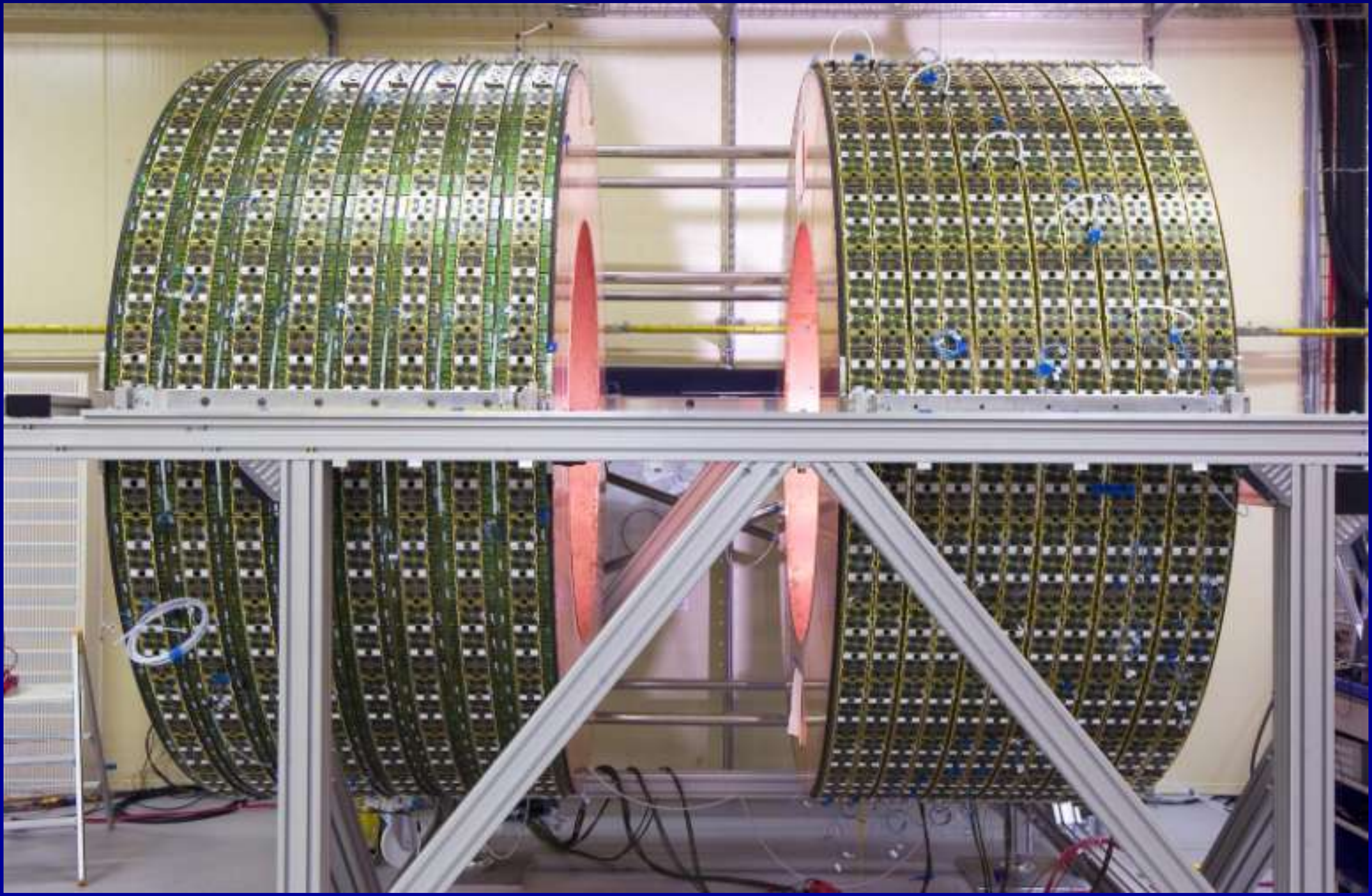
90% electron efficiency
10^{-2} pion rejection

High-γ charged particles (e.g. electrons) emit transition radiation (X-rays) when they traverse the radiators, detected in the straw tubes as larger energy deposition (8-10 KeV)

TR threshold – electron/pion separation **5.5 keV**

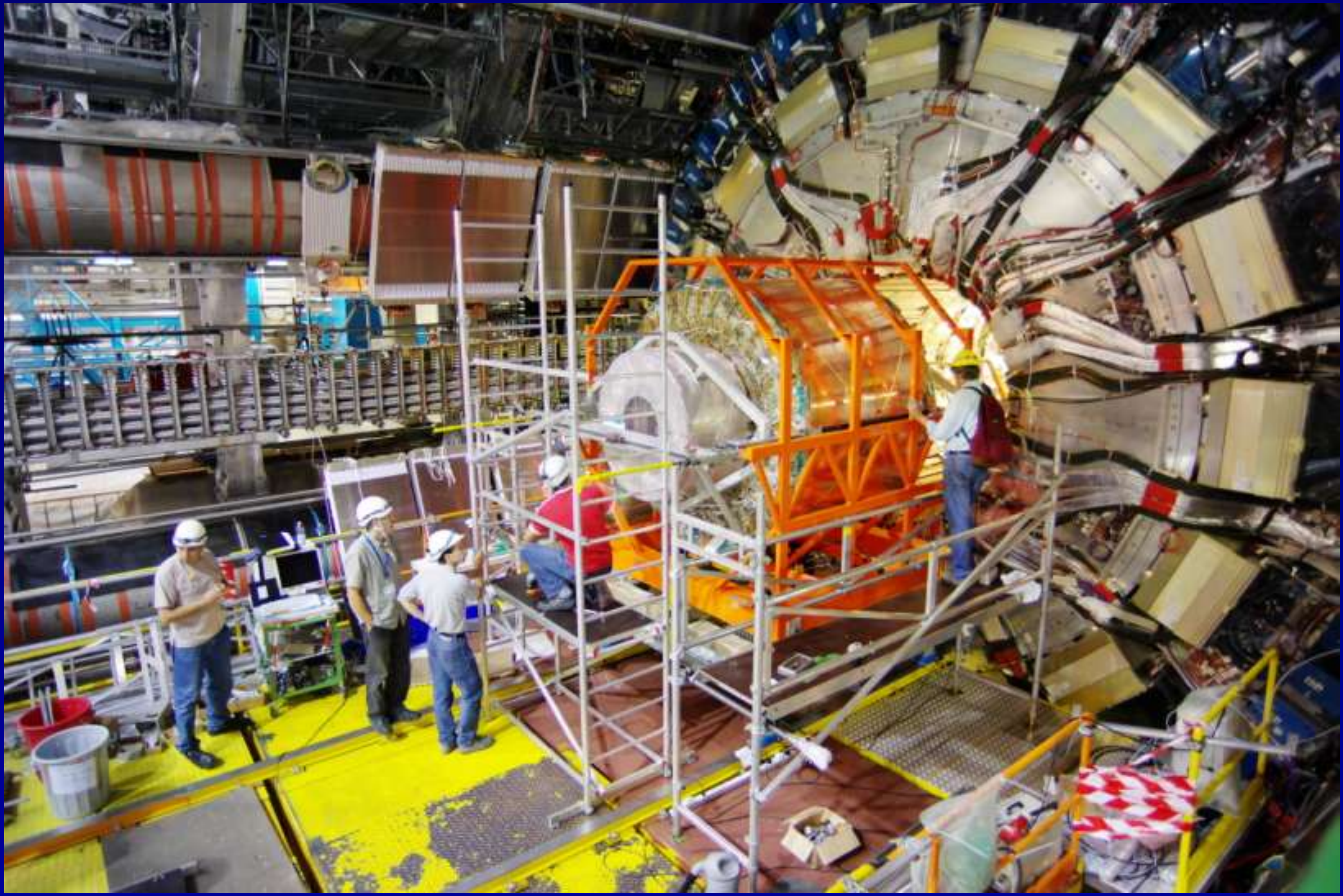
MIP threshold – precise tracking/drift time determination **0.2 keV**

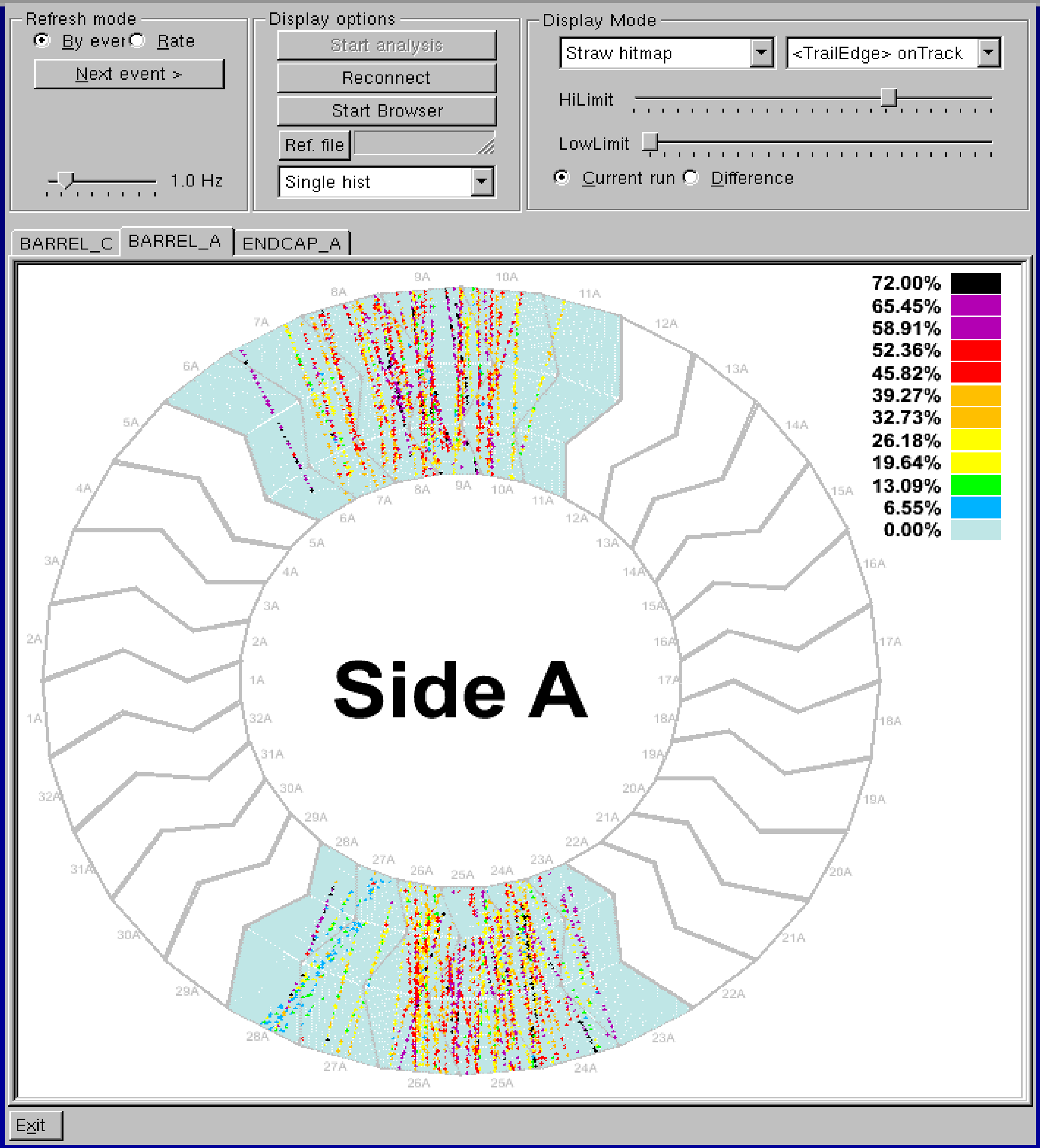




Спуск и установка end-cap TRT (2007)

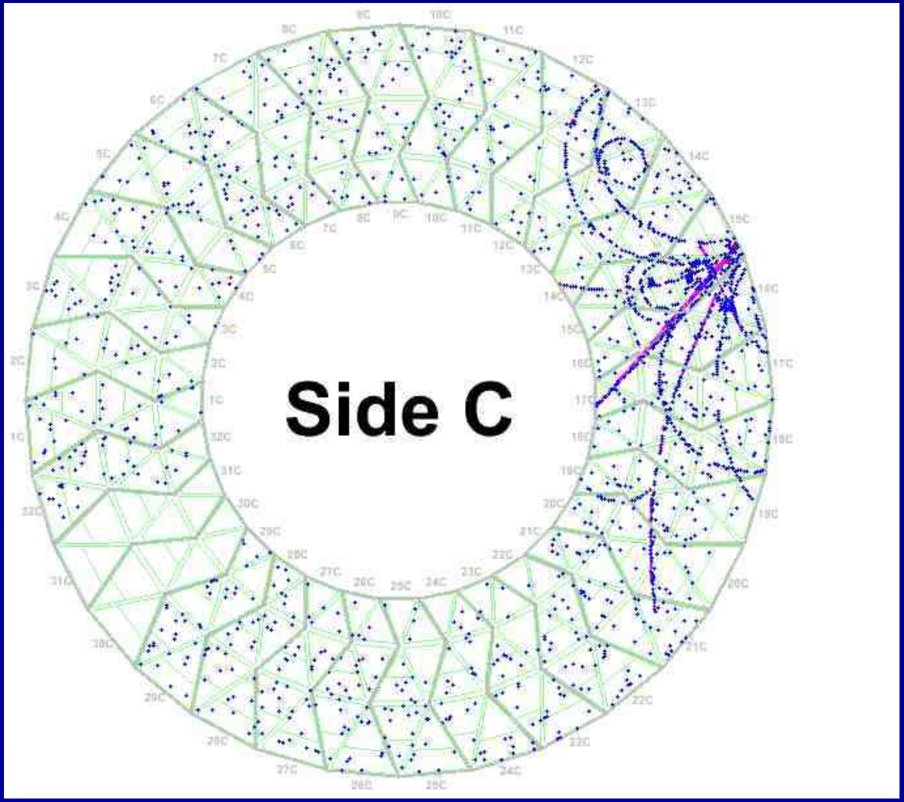
Установка barrel TRT в детектор ATLAS (2006)

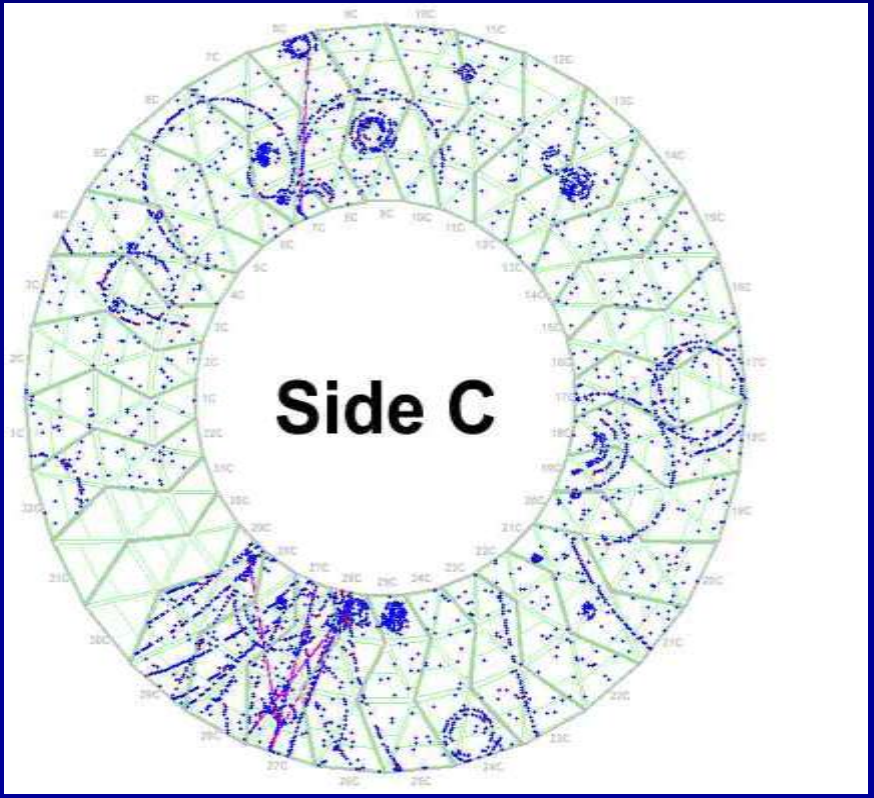


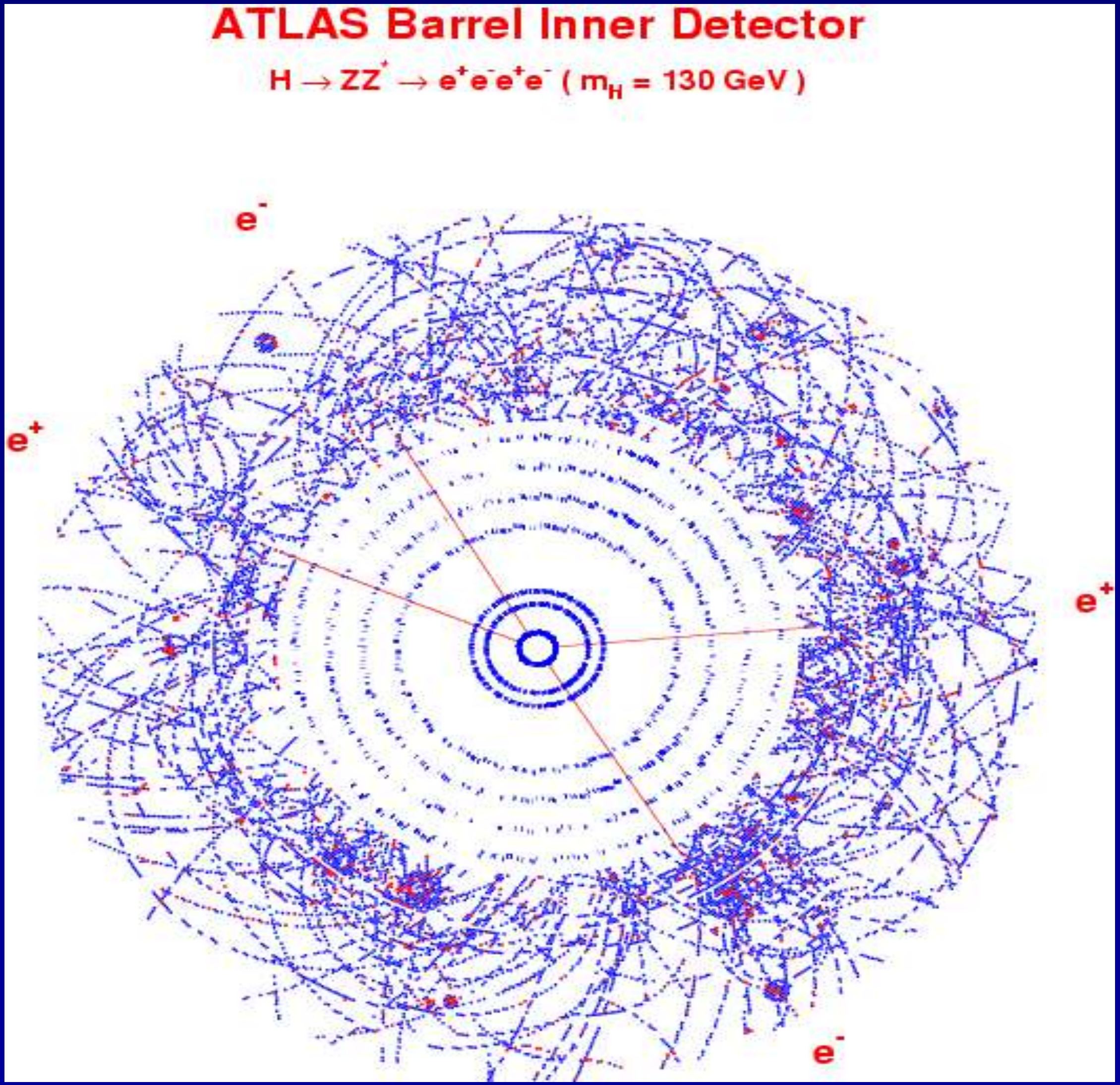

Refresh mode
By ever
Rate
Next event >
1.0 Hz
Display options
Start analysis
Reconnect
Start Browser
Ref. file
Single hist
Display Mode
Straw hitmap
<TrailEdge> onTrack
HiLimit
LowLimit
Current run
Difference
BARREL_C
BARREL_A
ENDCAP_A
Side A
72.00%
65.45%
58.91%
52.36%
45.82%
39.27%
32.73%
26.18%
19.64%
13.09%
6.55%
0.00%
Exit

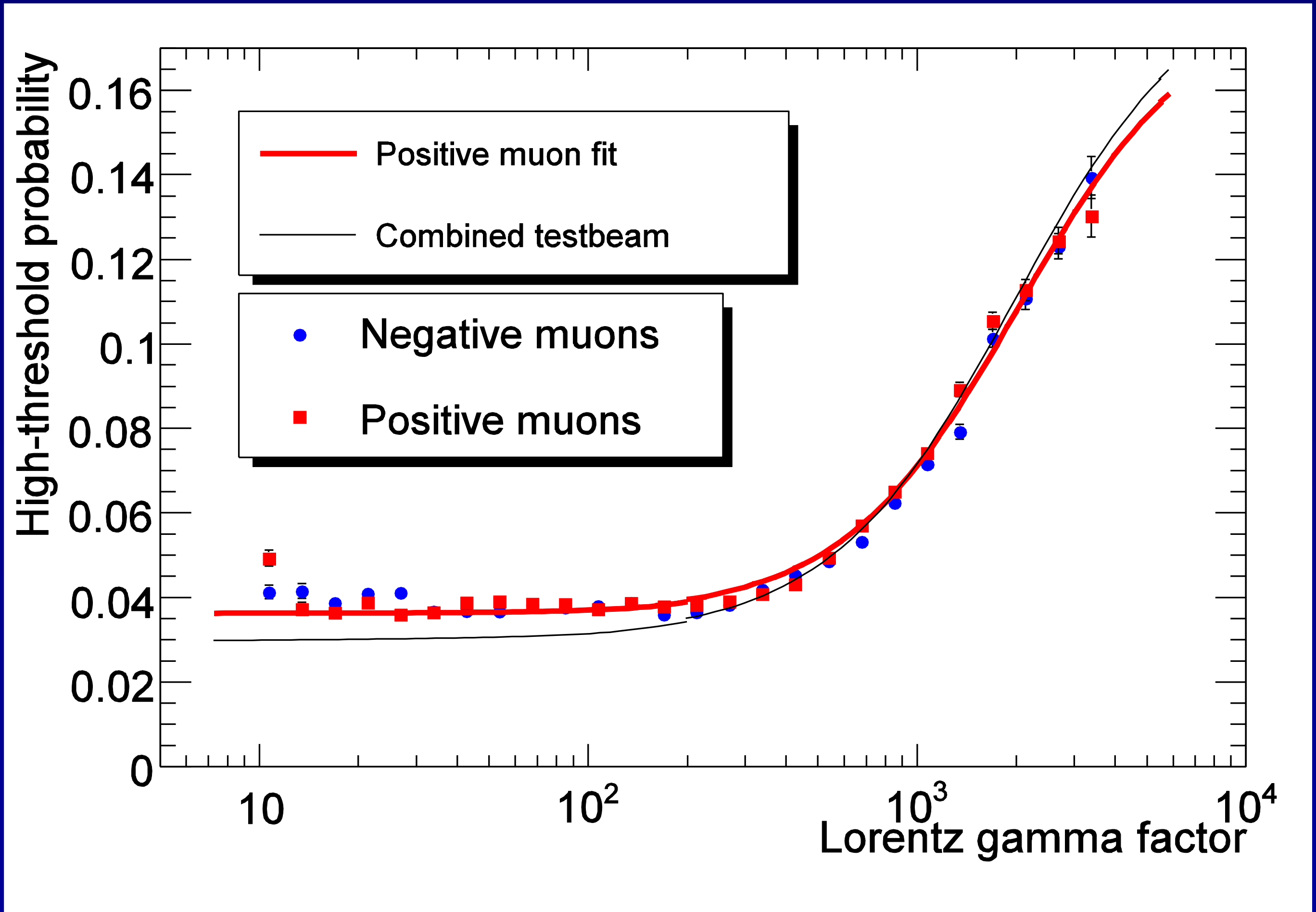
События, наблюдаемые в TRT от взаимодействий космических мюонов

First events seen in magnetic field: end of August 2008

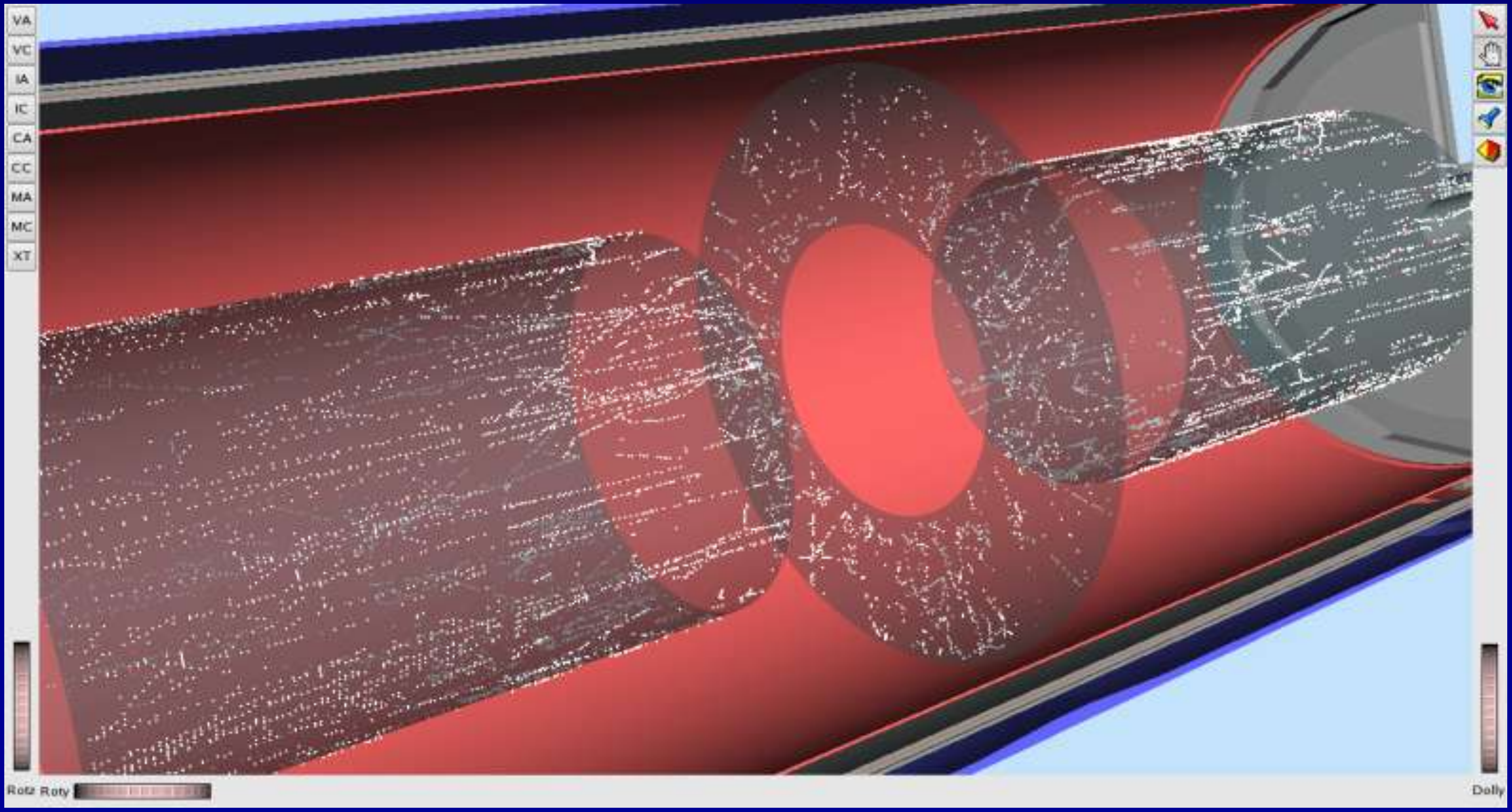





ATLAS Barrel Inner Detector
$H \to ZZ^* \to e^+e^-e^+e^-$ (m_H = 130 GeV)
e-
e+
e+
e-



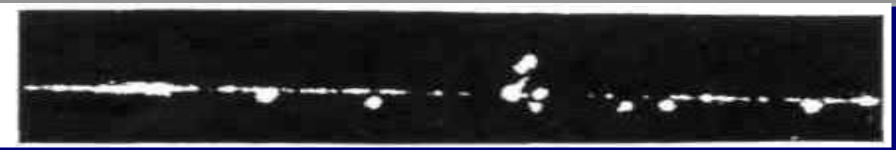
High-threshold probability
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Positive muon fit
Combined testbeam
Negative muons
Positive muons
10
10^2
10^3
10^4
Lorentz gamma factor

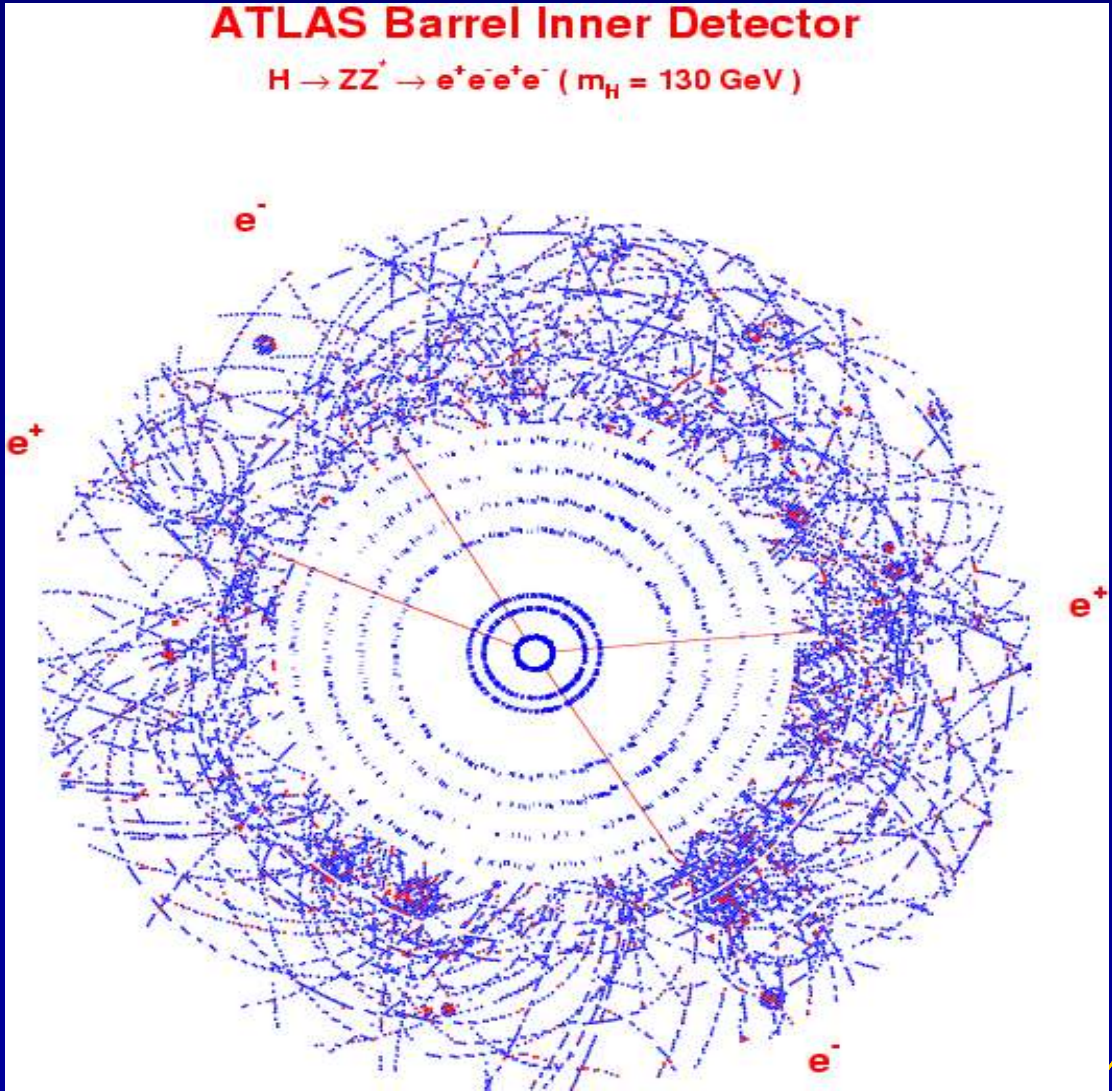

VA
VC
IA
IC
CA
CC
MA
MC
XT
Rotz Roty
Dolly

10 сентября 2008 в ATLAS Control Room

Xe Streamer chamber photo 1970

→ TR RADIATOR





2008