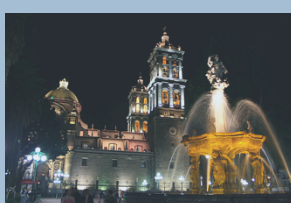
Cosmic rays / UPC activities (a taste) at the ALICE-LHC Experiment

Thanks a lot for your kind invitation ☺

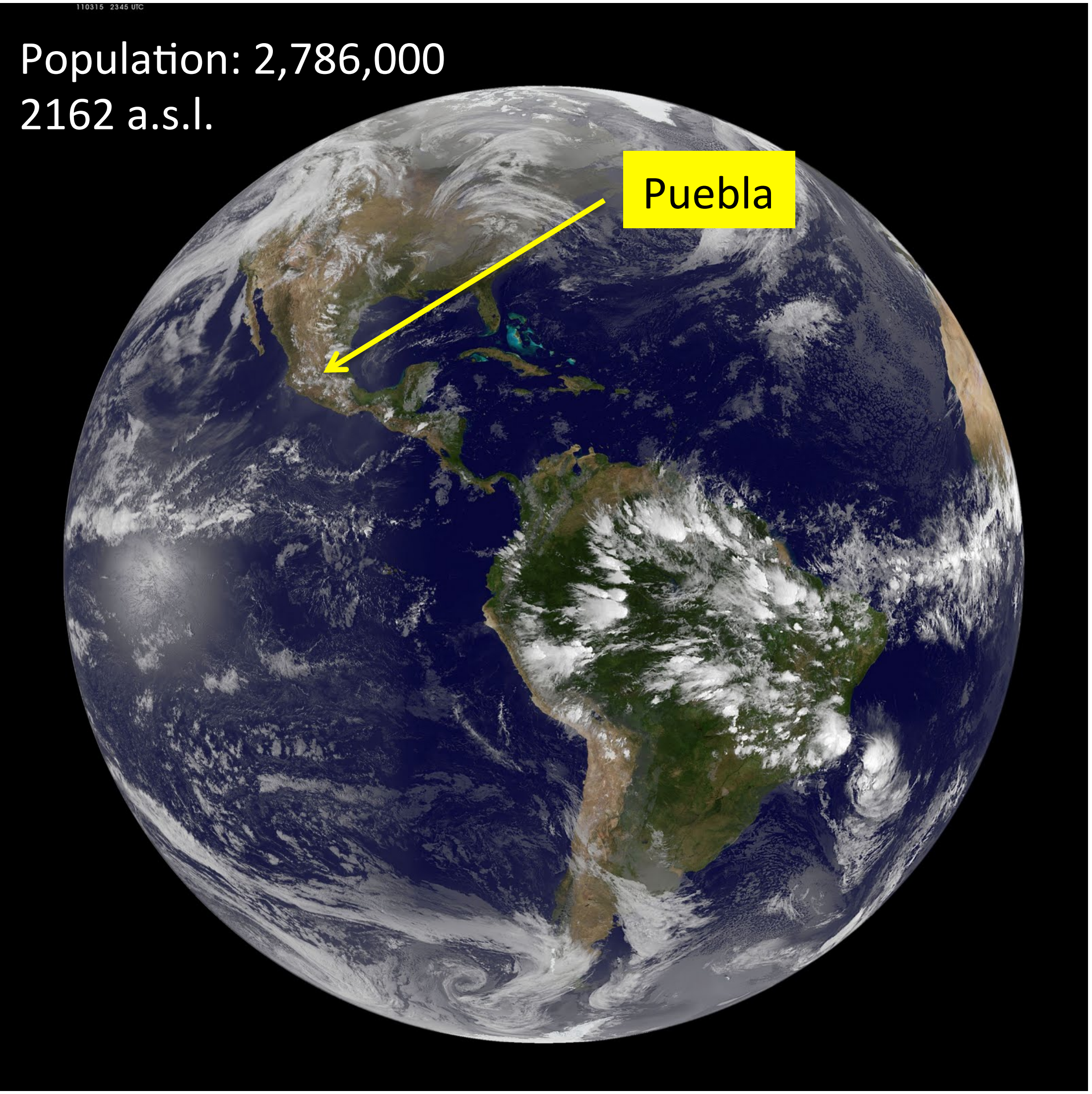


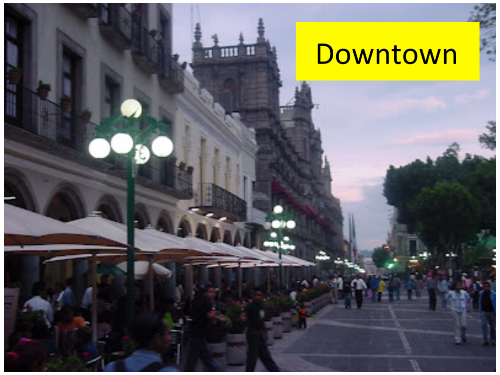
Mario Rodríguez Cahuantzi
Autonomous University of Puebla
(Faculty of Physics and Mathematics Sciences, BUAP – MEXICO)

Department Seminar

Friday 15th 2013 – Czech Technical University in Prague
(Faculty of Nuclear Sciences and Physical Engineering)

Where's Puebla? 19° 02' 43" N 98° 11' 51" O





Plan of this talk

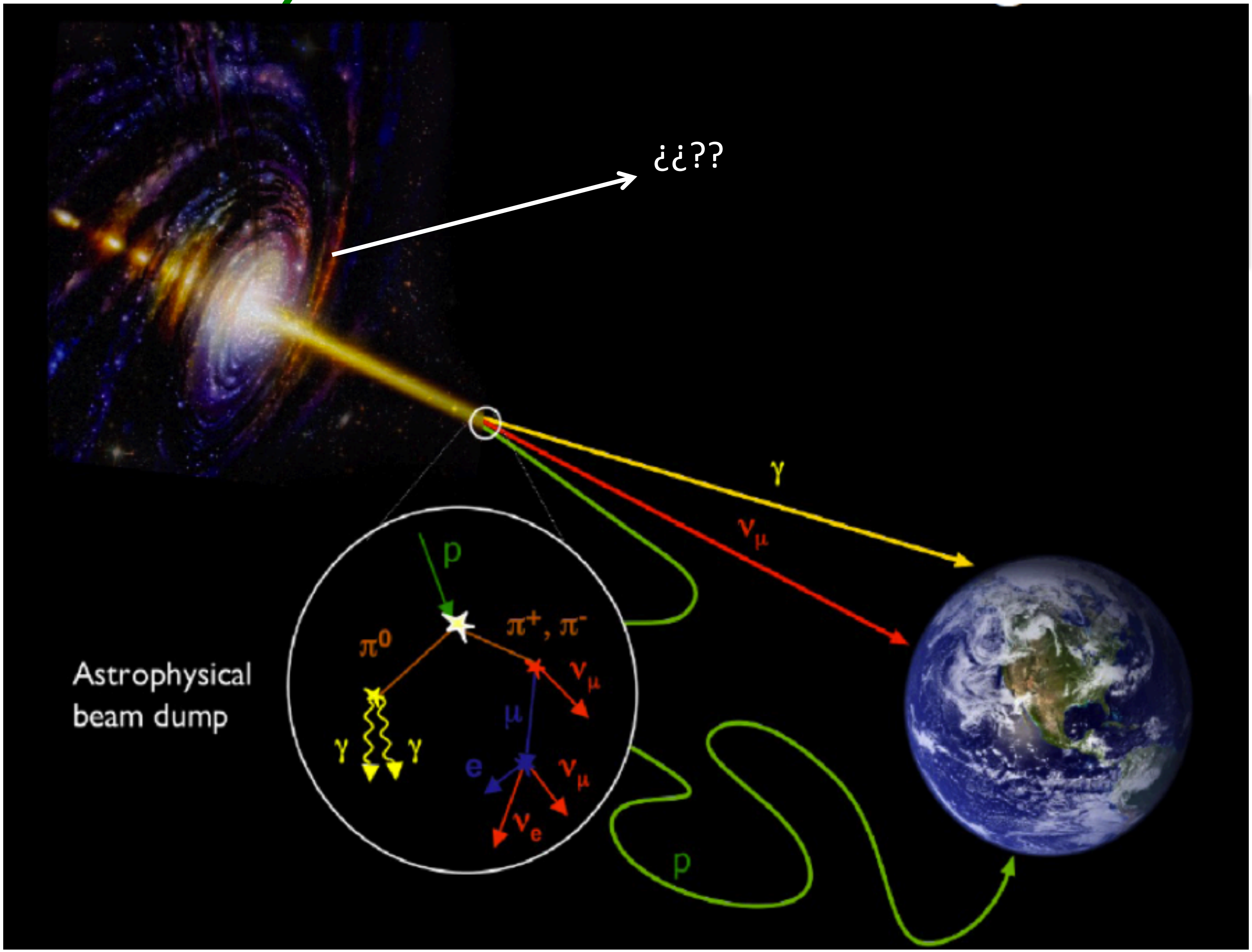
Cosmic ray activities (PWG-UD)

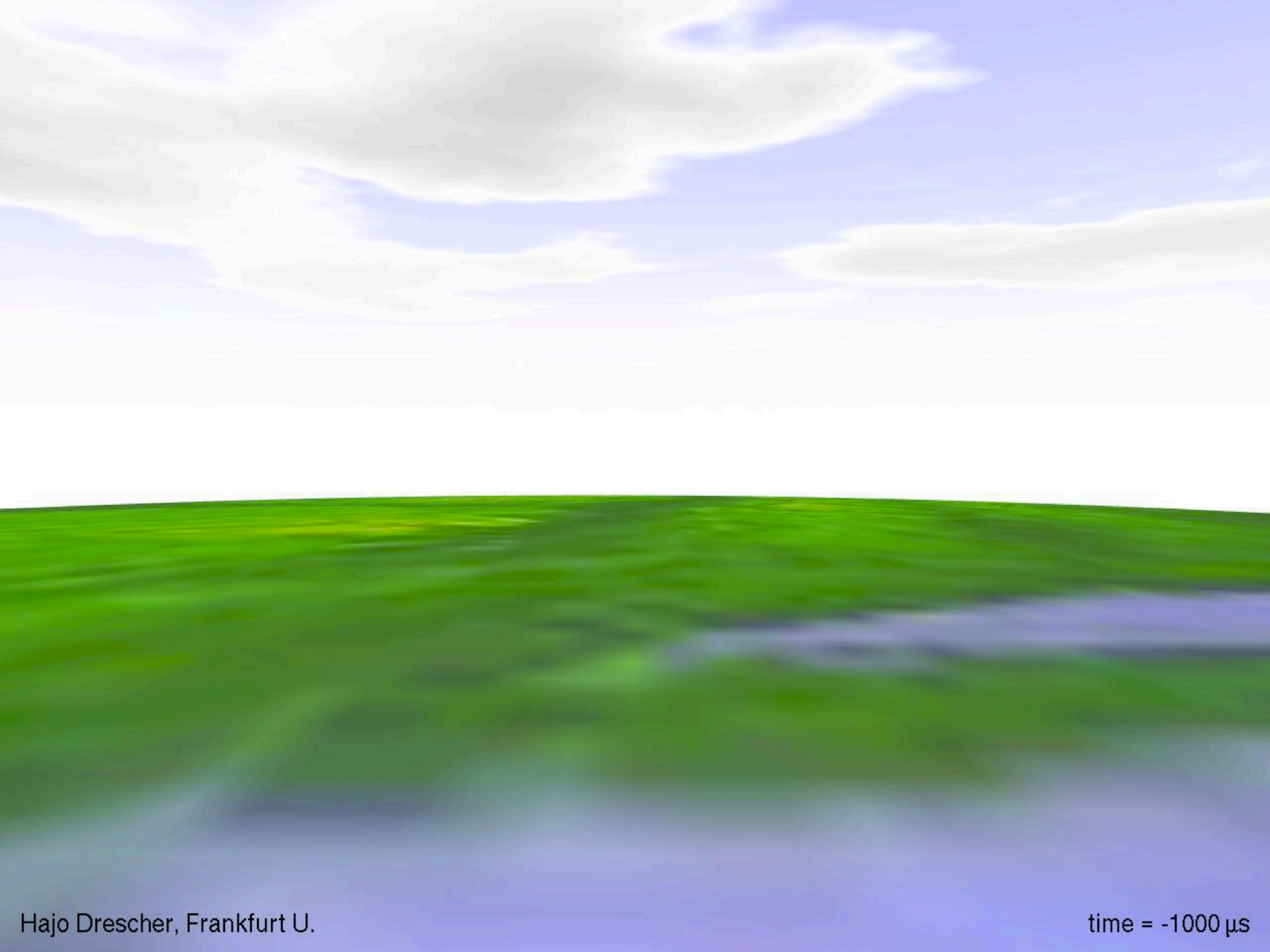
- Introduction
- ALICE Experiment: trigger and tracking detectors for cosmics
- Atmospheric Muon Multiplicity Distribution (MMD)
- Simple Monte Carlo to study High Atmospheric Muons Events
- Final remarks on cosmic ray activities

Ultra peripheral collisions studies (PWG-UD)

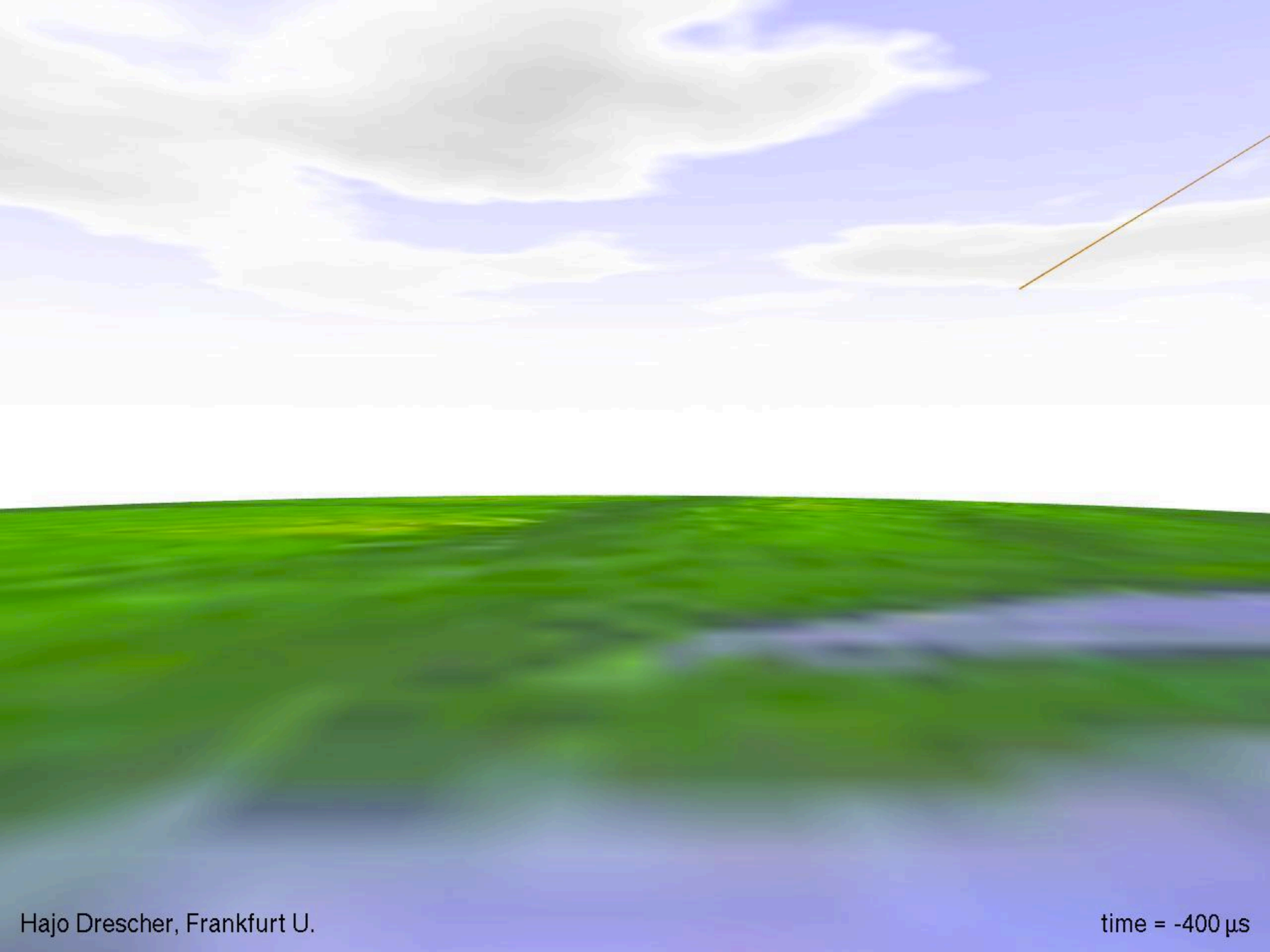
- Introduction
- Some results on forward region
- Work in progress
- Final remarks

Cosmic ray activities: Introduction





Hajo Drescher, Frankfurt U.
time = -1000 μs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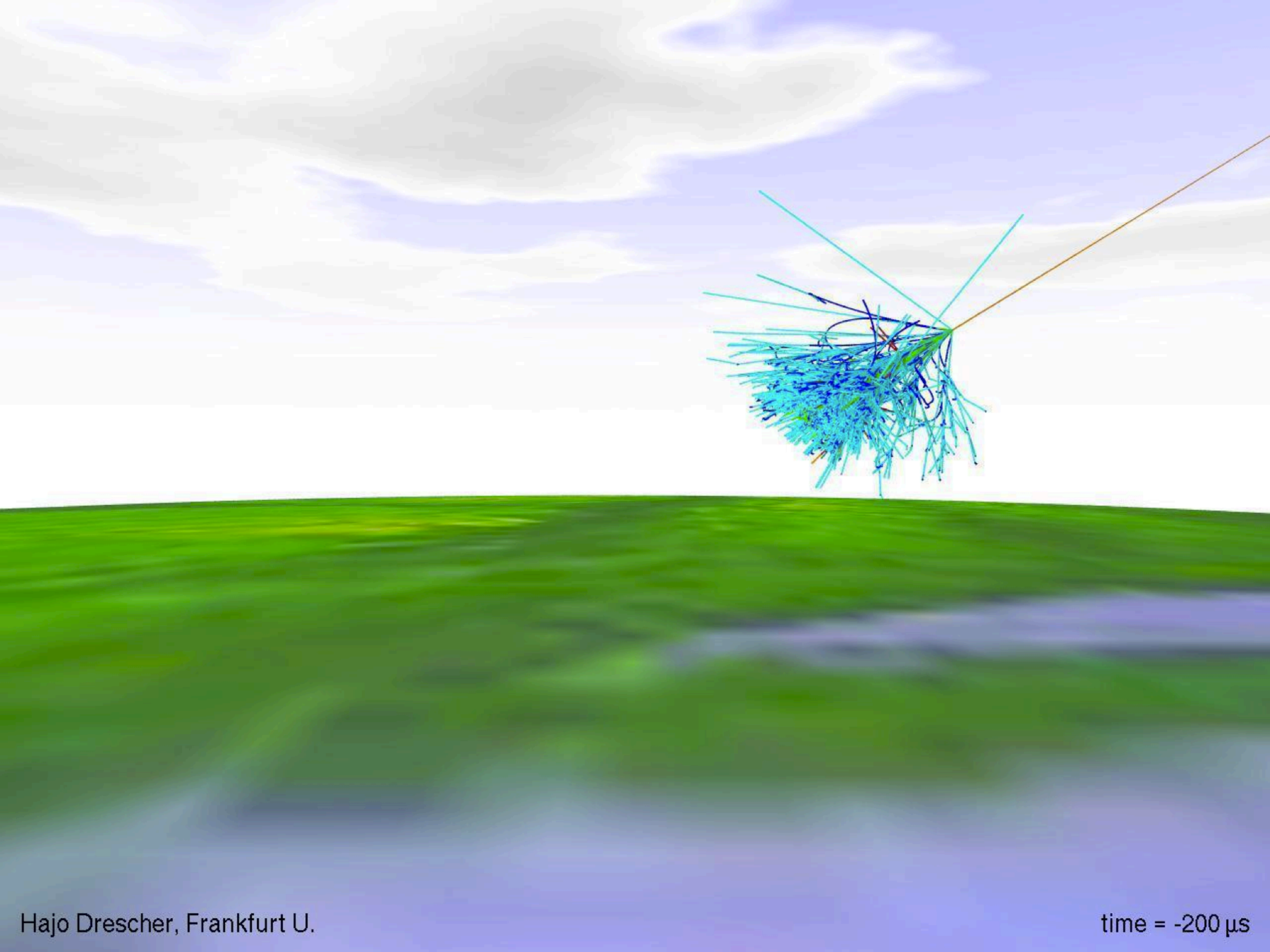
Hajo Drescher, Frankfurt U.
time = -300 µs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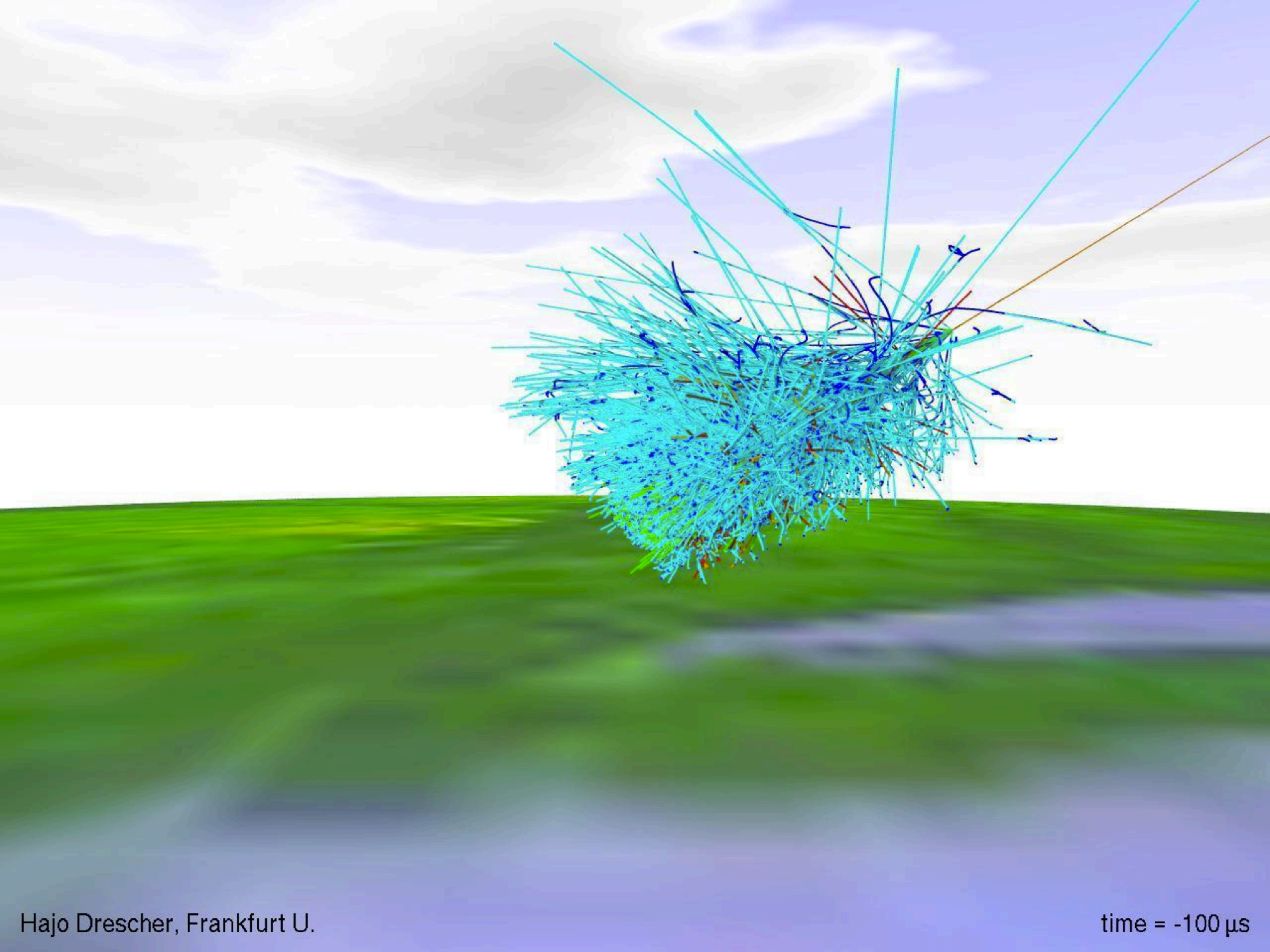
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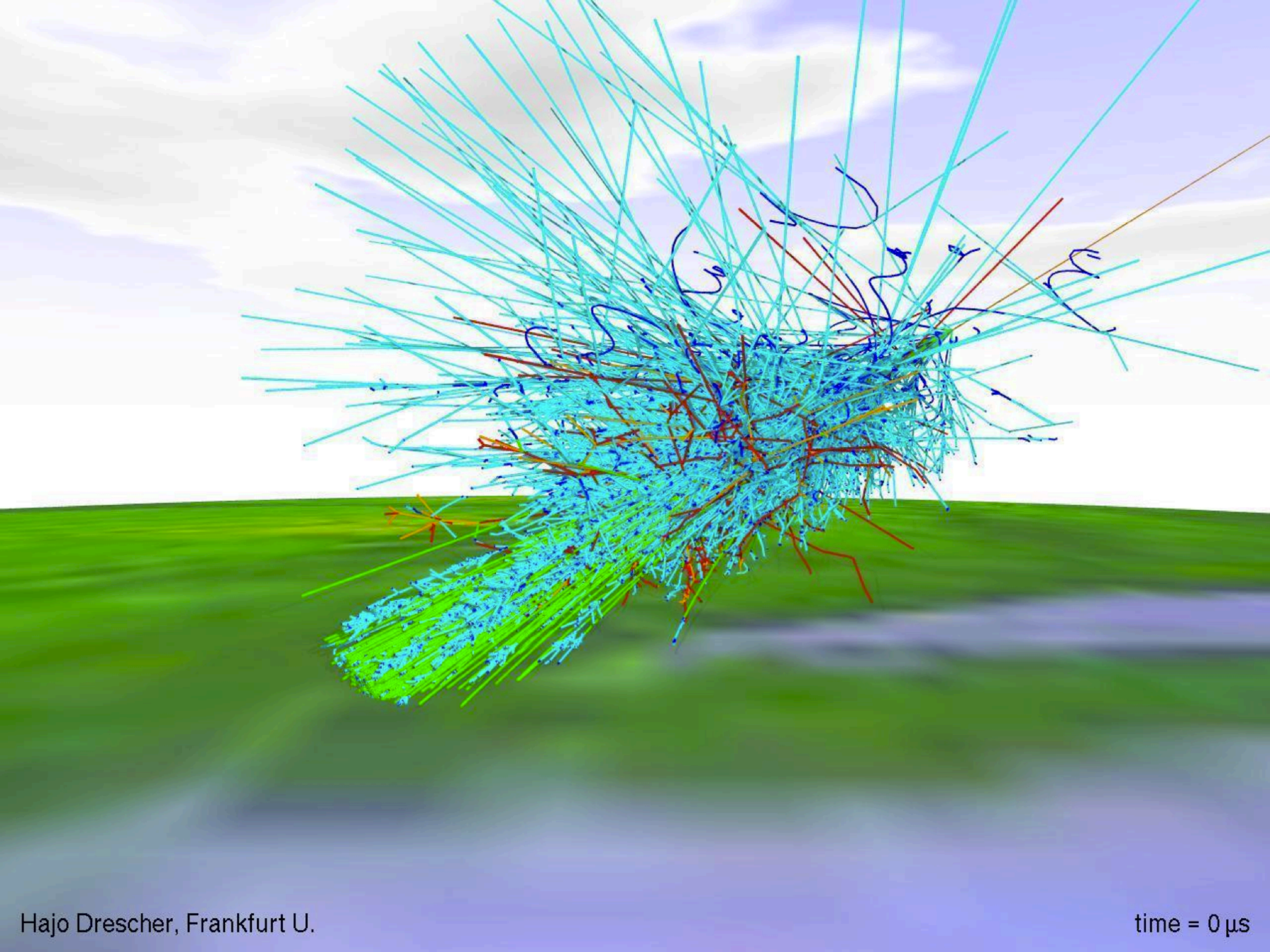
Hajo Drescher, Frankfurt U.
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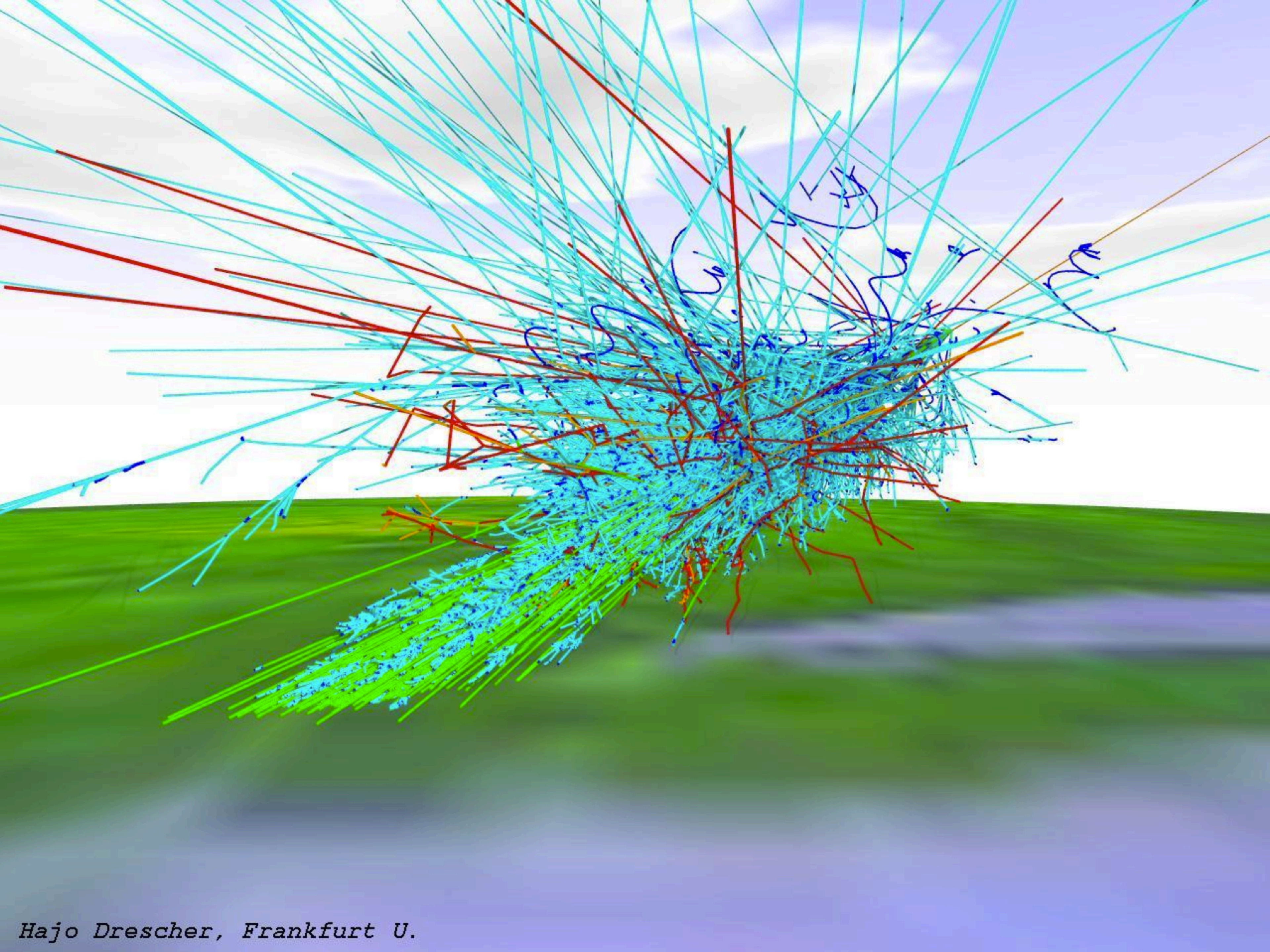
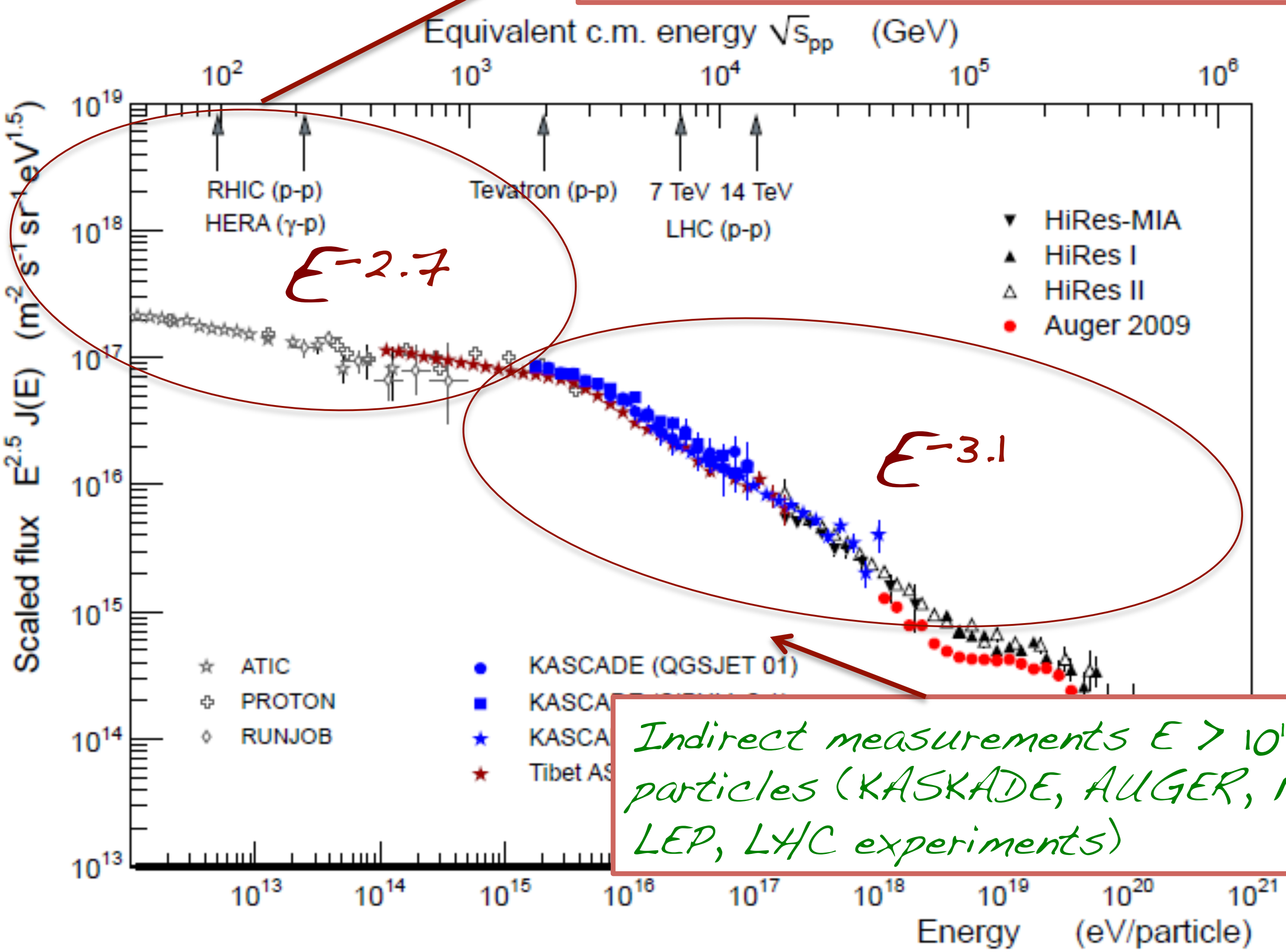


Hajo Drescher, Frankfurt U.

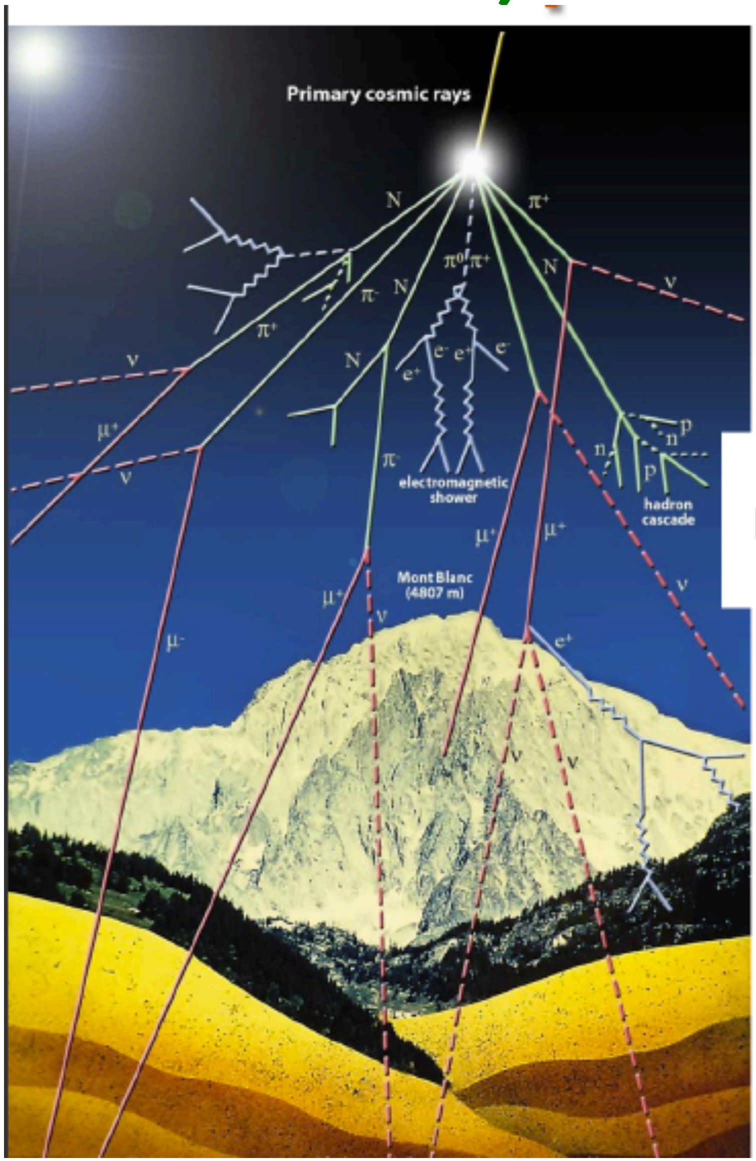
Cosmic ray activities: Introduction

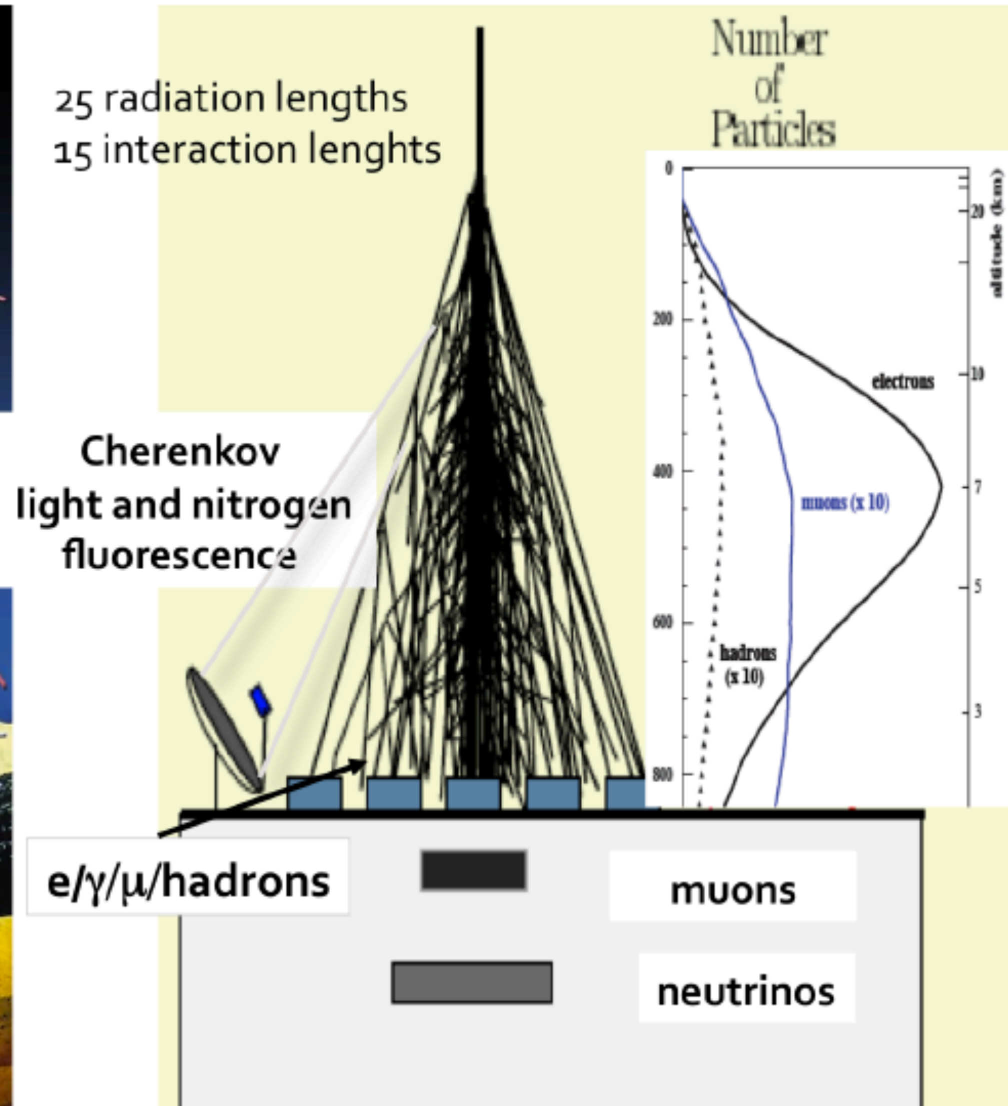
Direct measurements up to E ~ 10^{14} eV → Primary particles (balloons, satellites)



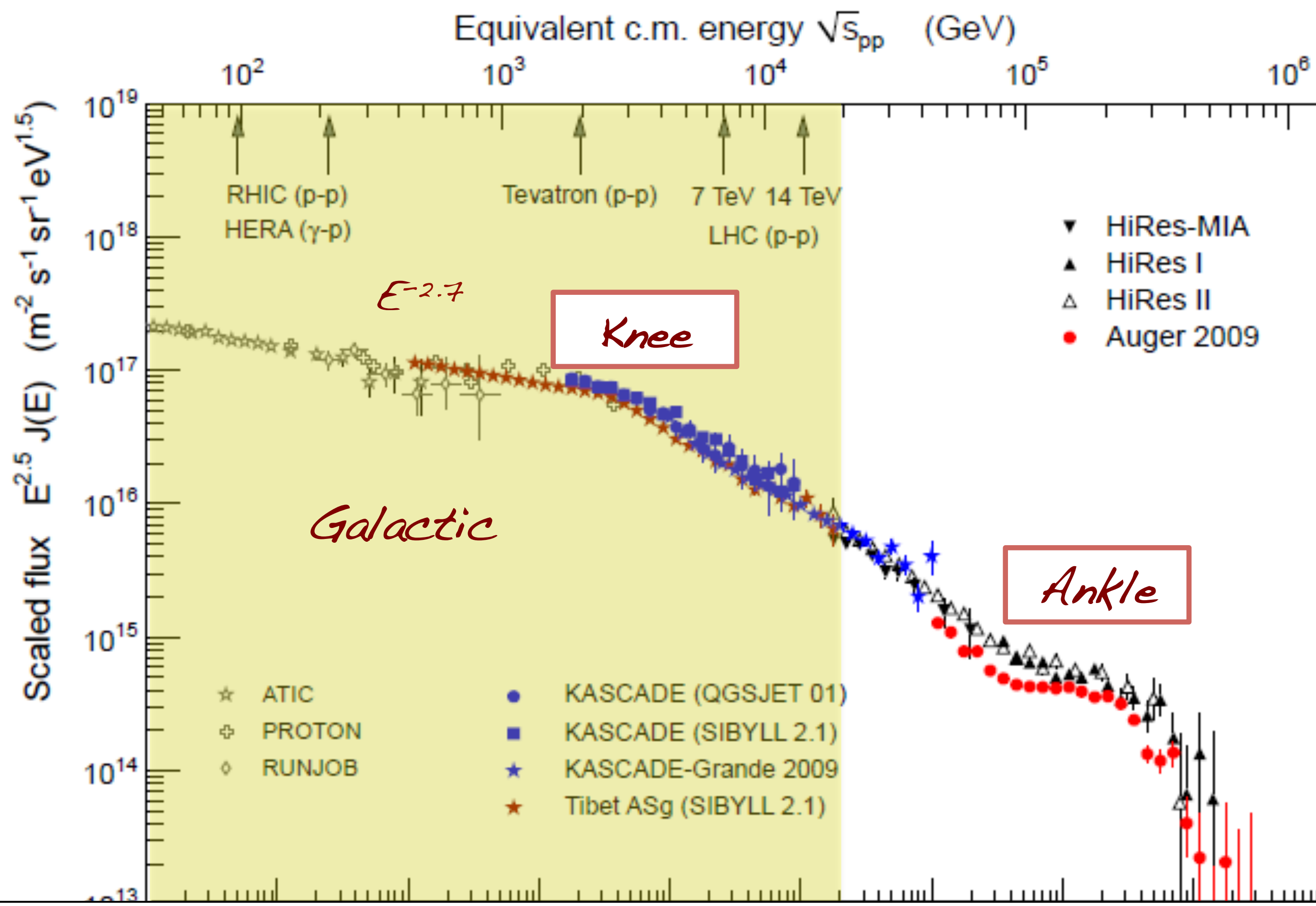
Indirect measurements E > 10^{14} eV → Secondary particles (KASKADE, AUGER, MACRO, EMMA, LEP, LHC experiments)

Cosmic ray activities: Introduction



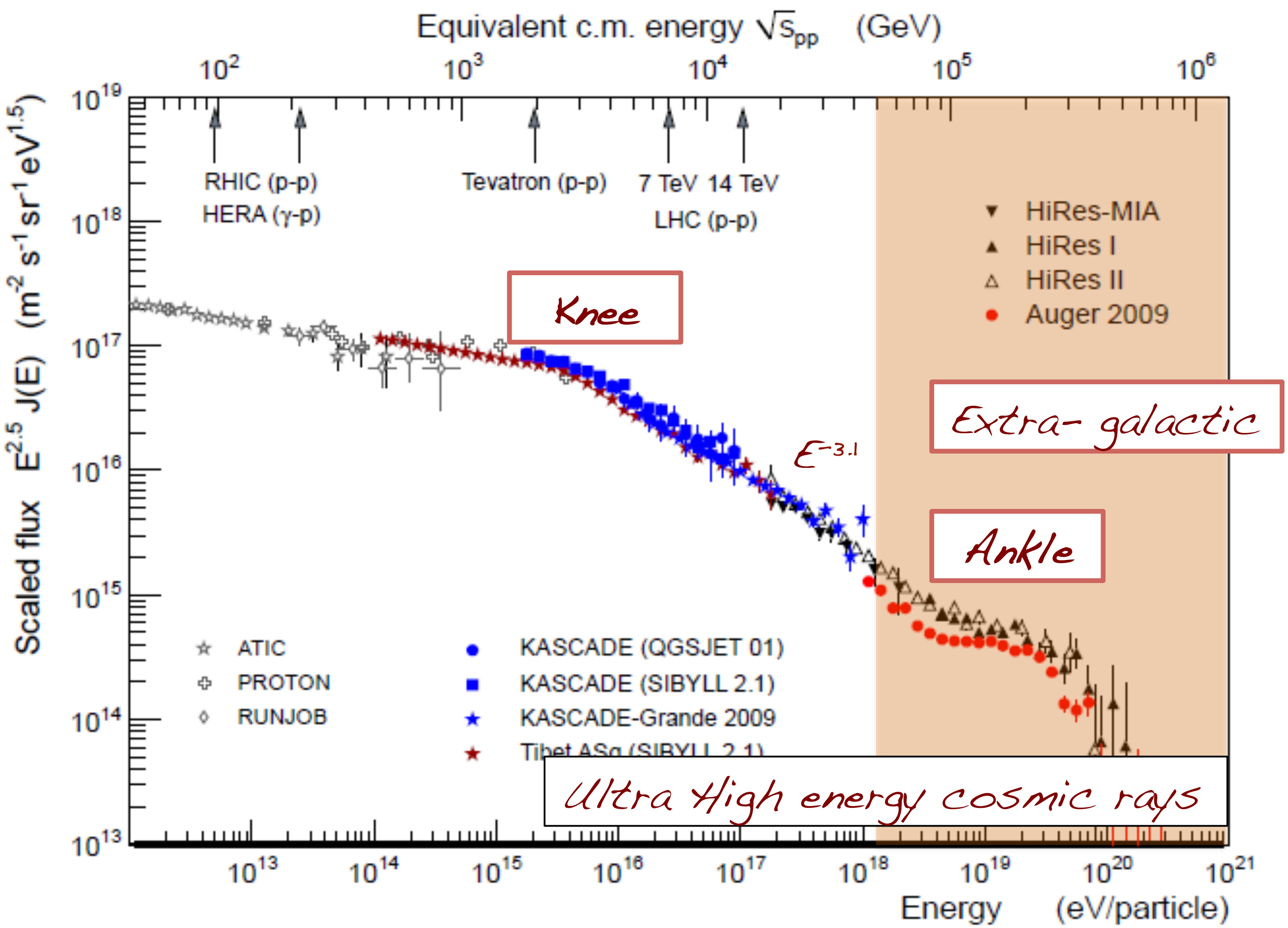


Cosmic ray activities: Introduction

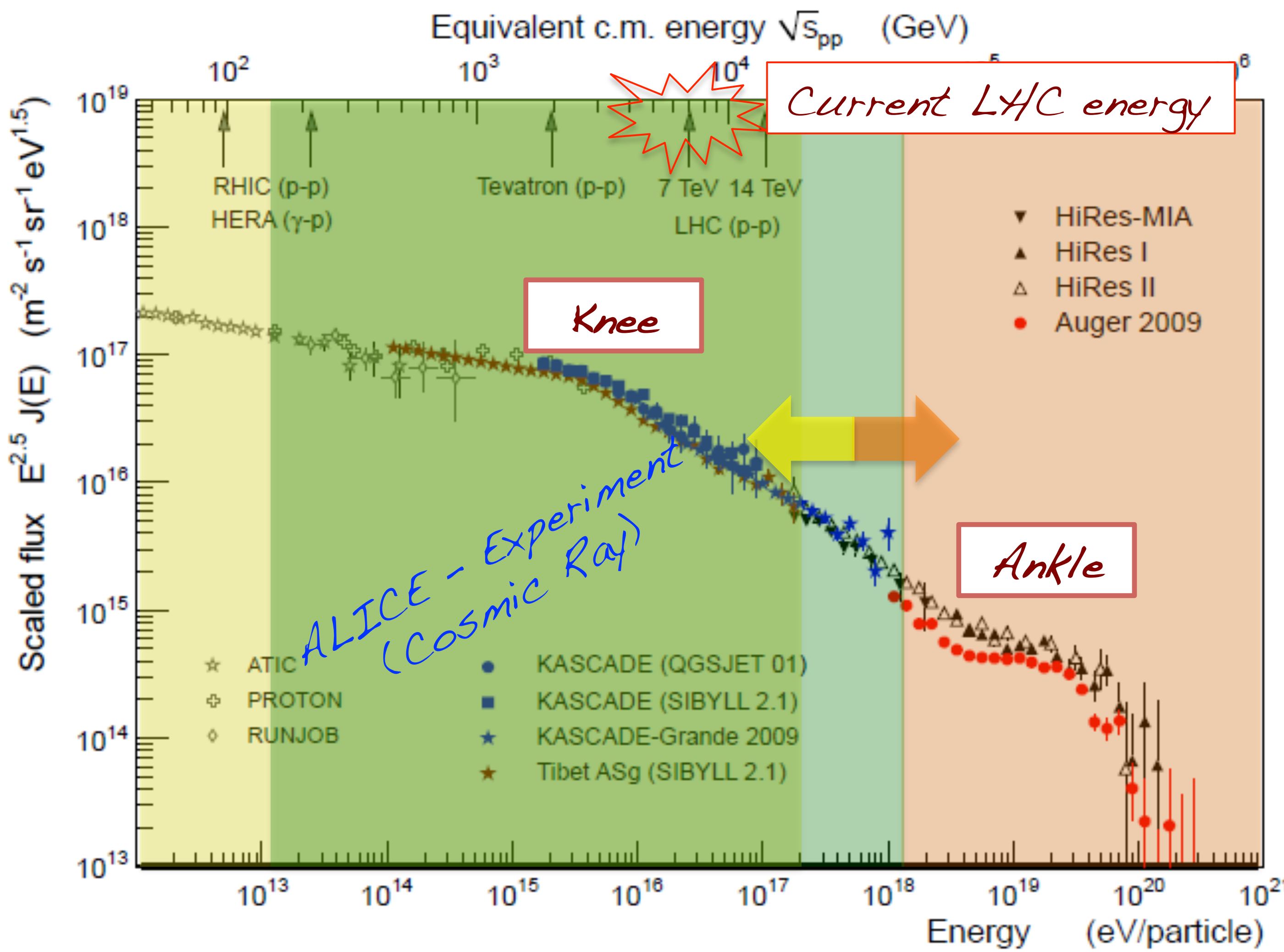


- Density of the galactic primary cosmic ray: ~ 1 eV/cm³
- Protons for energies below 10^{16} eV
- Heavy nuclei composition: ~ 8*10^{16} eV (Phys. Rev. Lett. 107, 171104 (2011))

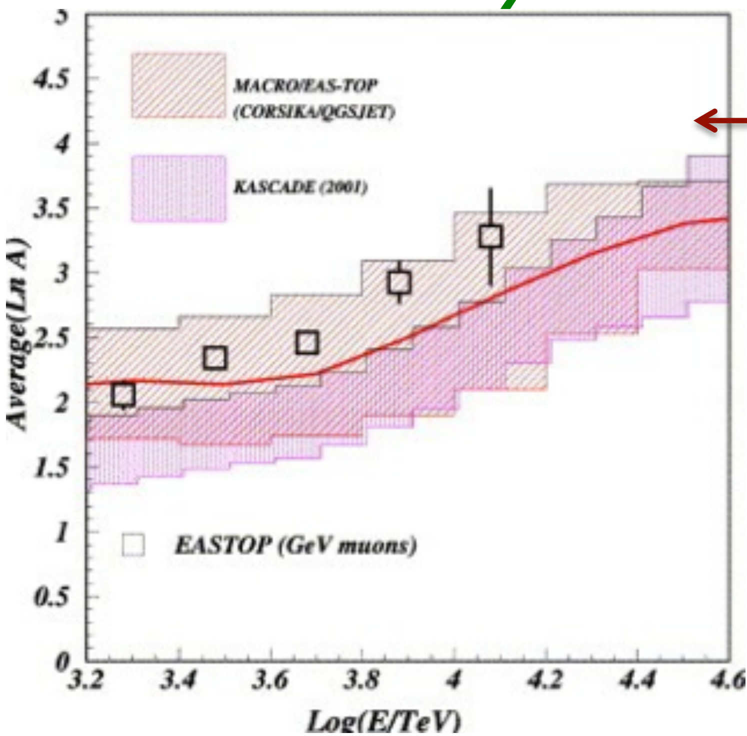
Cosmic ray activities: Introduction



Cosmic ray activities: Introduction



Cosmic ray activities: Introduction

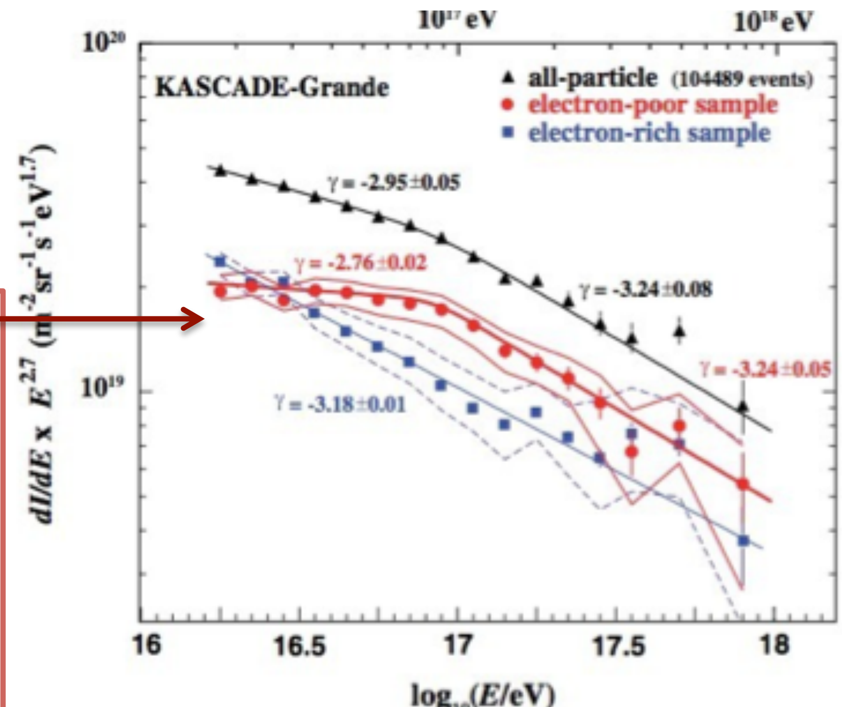


MACRO-EASTOP KASCADE :

- Primary Composition Ln(A) vs Energy
- A=mass of the primary nucleus

There is an increase of the:

- <A> above the knee
- <A> ~ 8 at 3×10^{15} eV
- <A> ~ 30 at 3×10^{16} eV

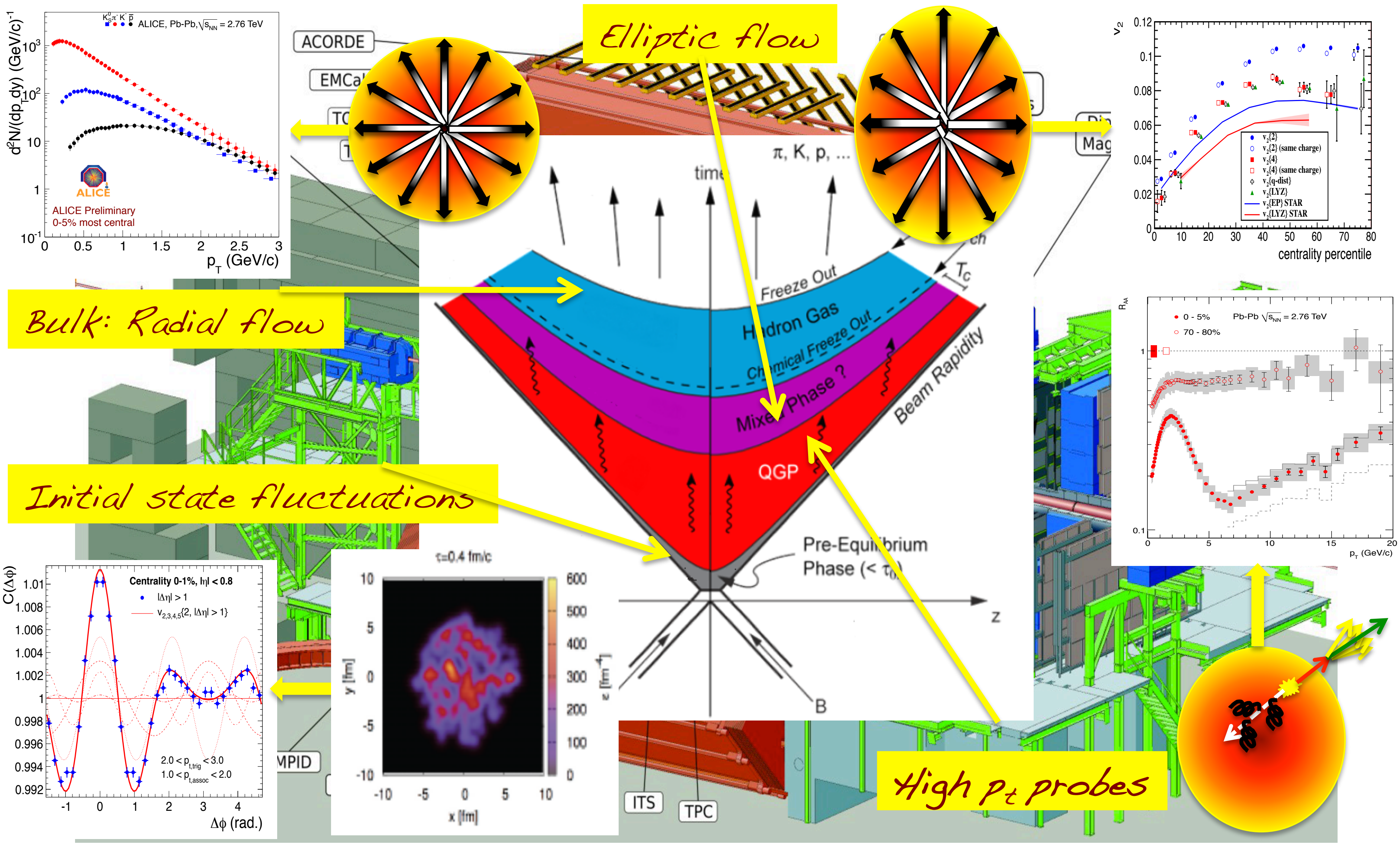


KASCADE-GRANDE :

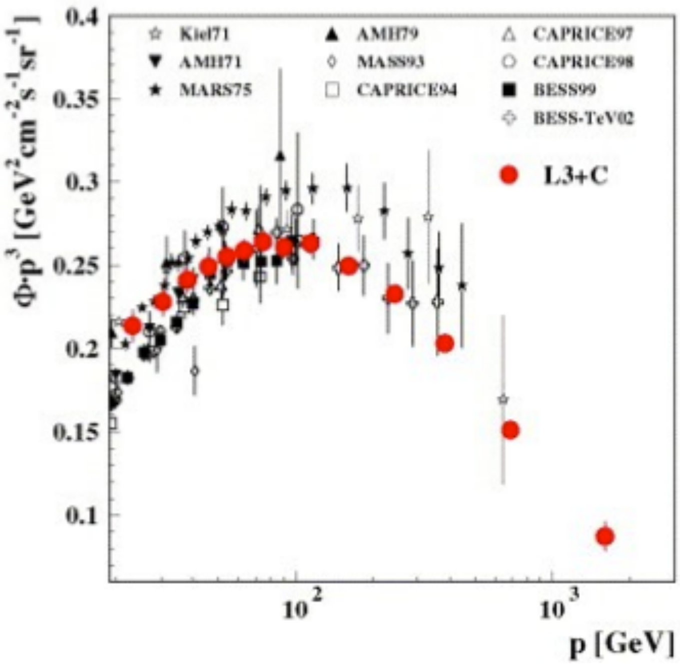
- electron-poor sample selects heavy elements (Fe) and shows a knee at E~ 8×10^{16} eV

- electron-rich sample selects light elements and the knee is at lower energy E ~ 3×10^{15} eV

• Cosmic ray activities: *ALICE Experiment: trigger and tracking detectors for cosmics*

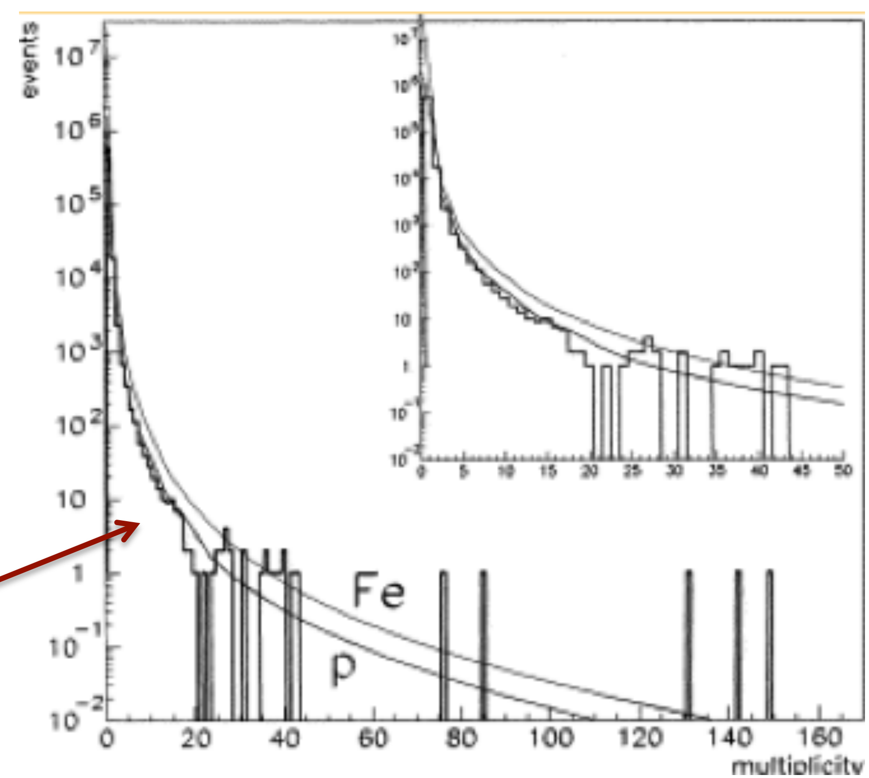


• Cosmic ray activities: *Main topics with accelerator apparatus*

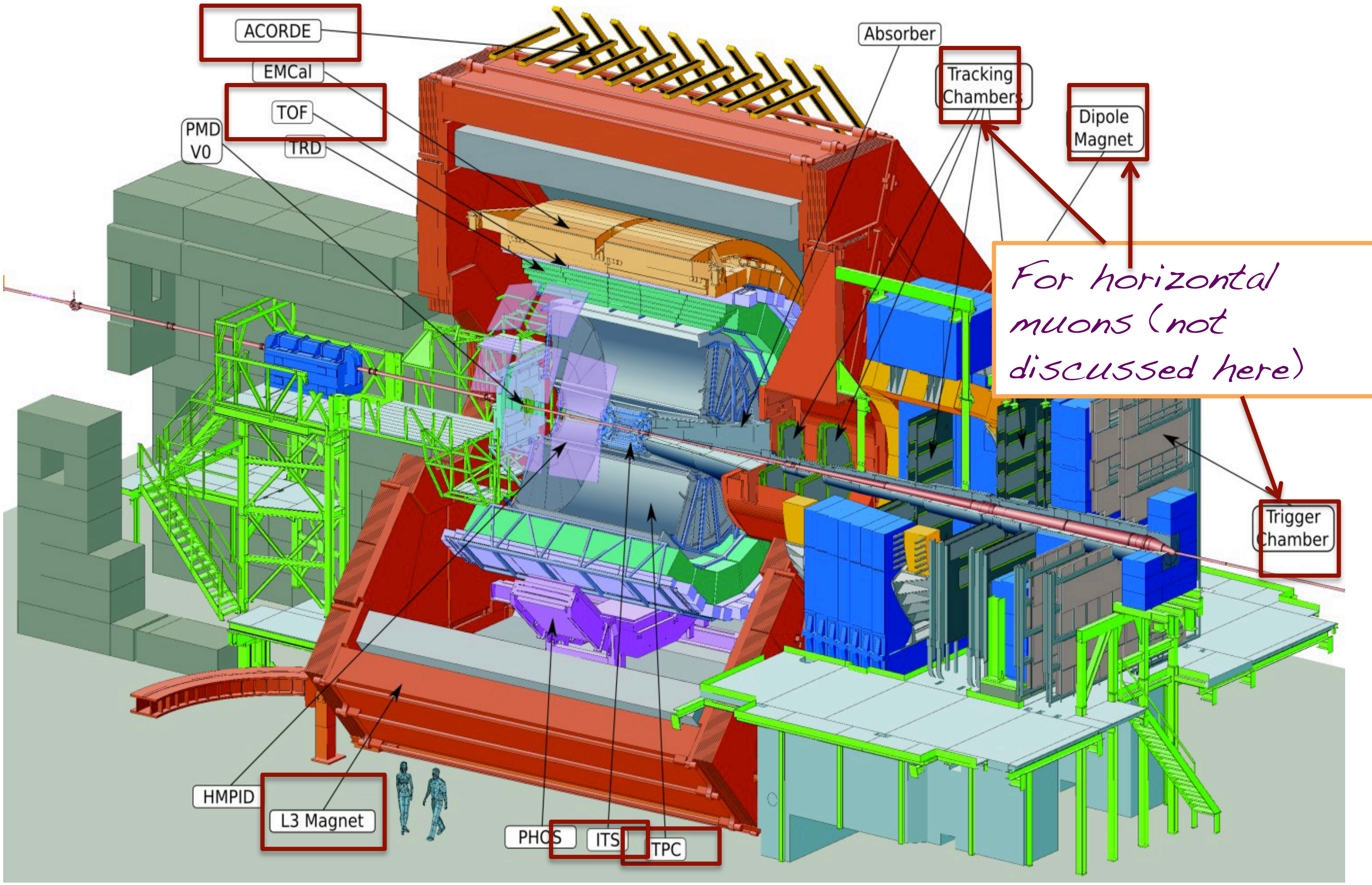


- Magnetic field + Precise P measurement
- Muon momentum spectrum and charge ratio (L3) Charge ratio (CMS)

- High tracking capabilities
- Muon-bundles (high muon density): Aleph Delphi Alice

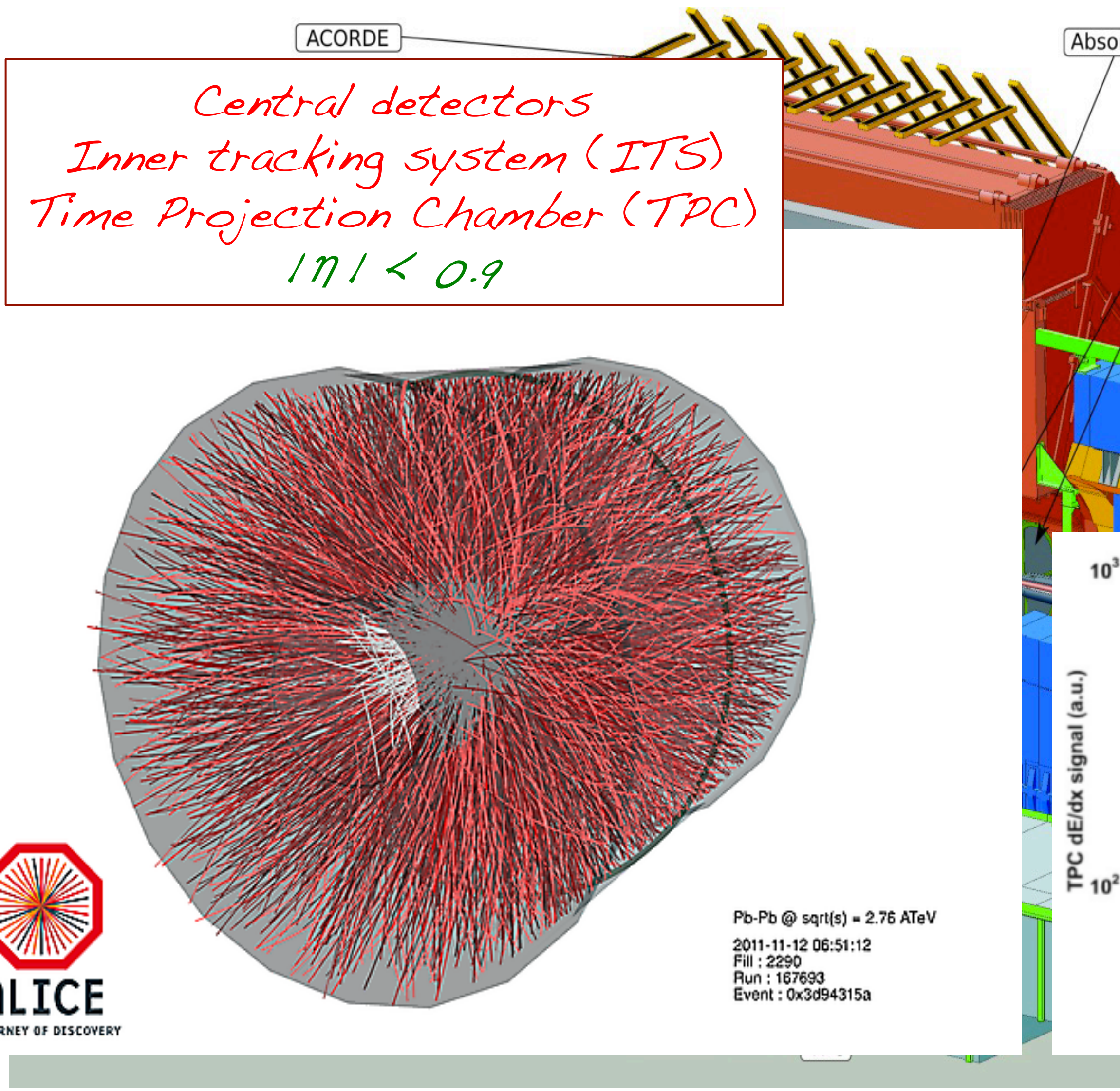


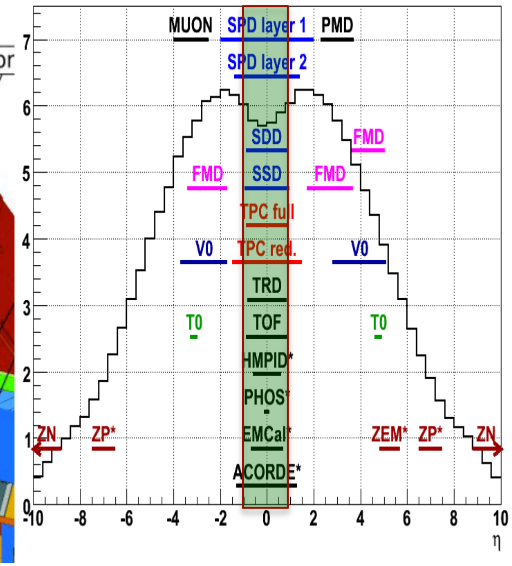
• Cosmic ray activities: *ALICE Experiment: trigger and tracking detectors for cosmics*

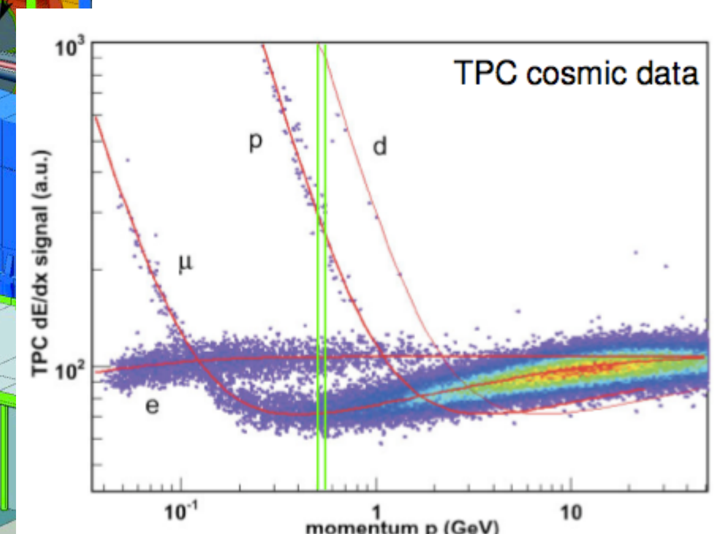


• Cosmic ray activities: *ALICE Experiment: trigger and tracking detectors for cosmics*

Central detectors
Inner tracking system (ITS)
Time Projection Chamber (TPC)
$|\eta| < 0.9$

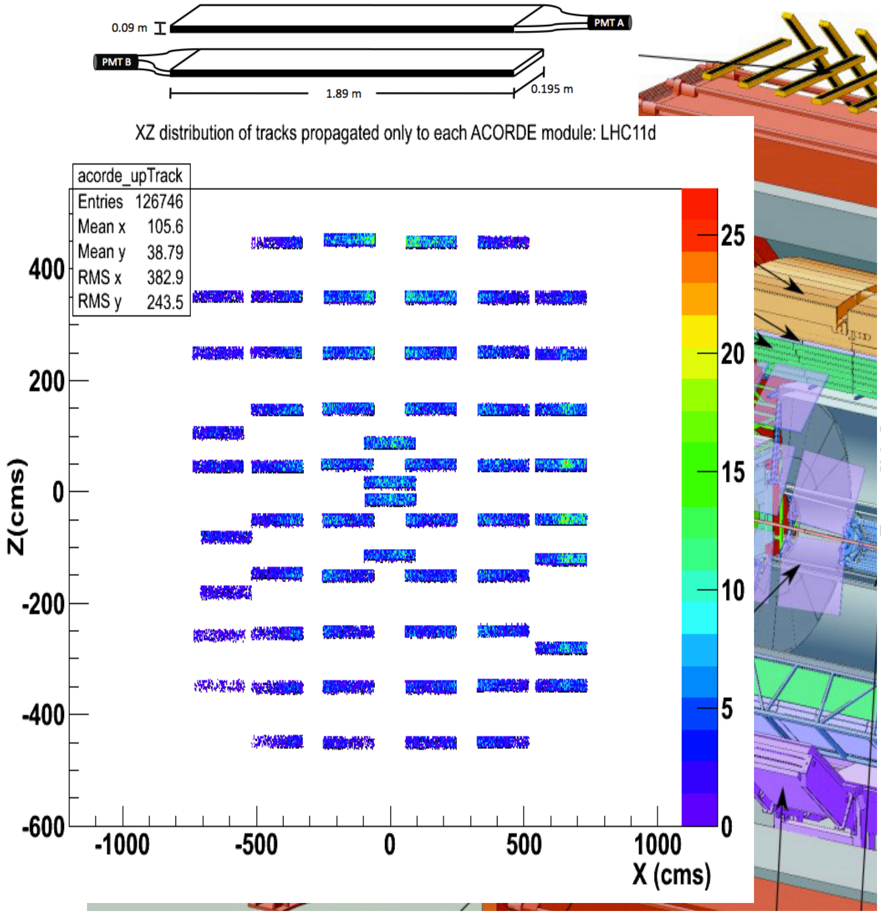


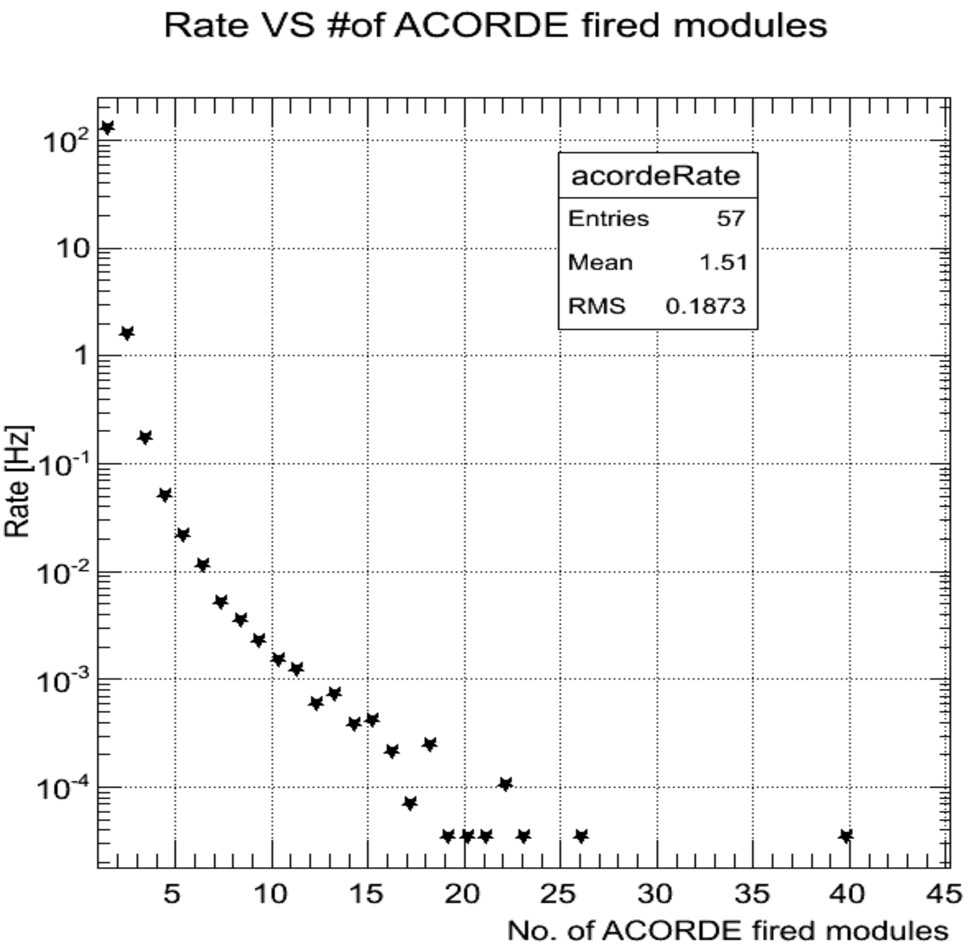




ALICE
A JOURNEY OF DISCOVERY

• Cosmic ray activities: *ALICE Experiment: trigger and tracking detectors for cosmics*

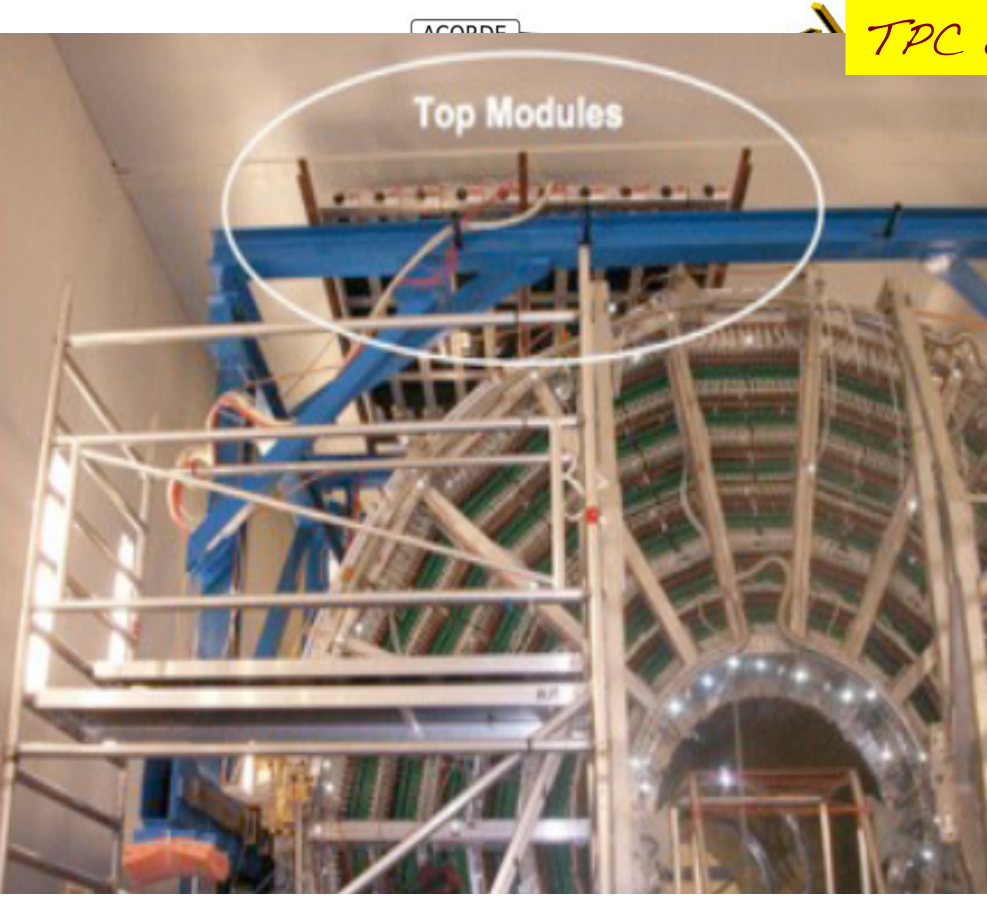




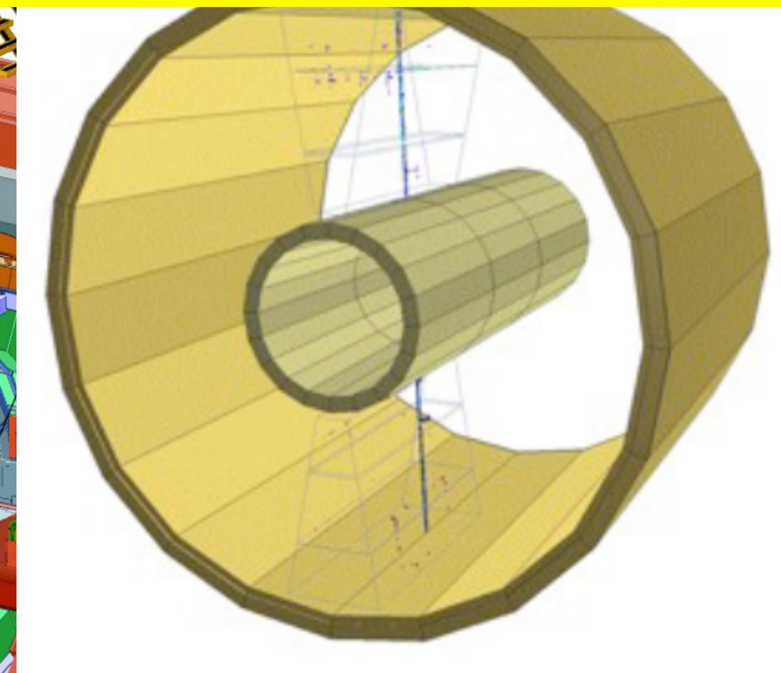
ACORDE is used to:

- *Trigger events of atmospheric muons. identify events with high multiplicity of atmospheric muons.*
- *Generate a fast signal of level zero that has been used for alignment and calibration of the inner central detectors in ALICE(single or multicoincidence mode).*

• Cosmic ray activities: *ALICE Experiment: trigger and tracking detectors for cosmics*



TPC calibration on surface @ ALICE-P2

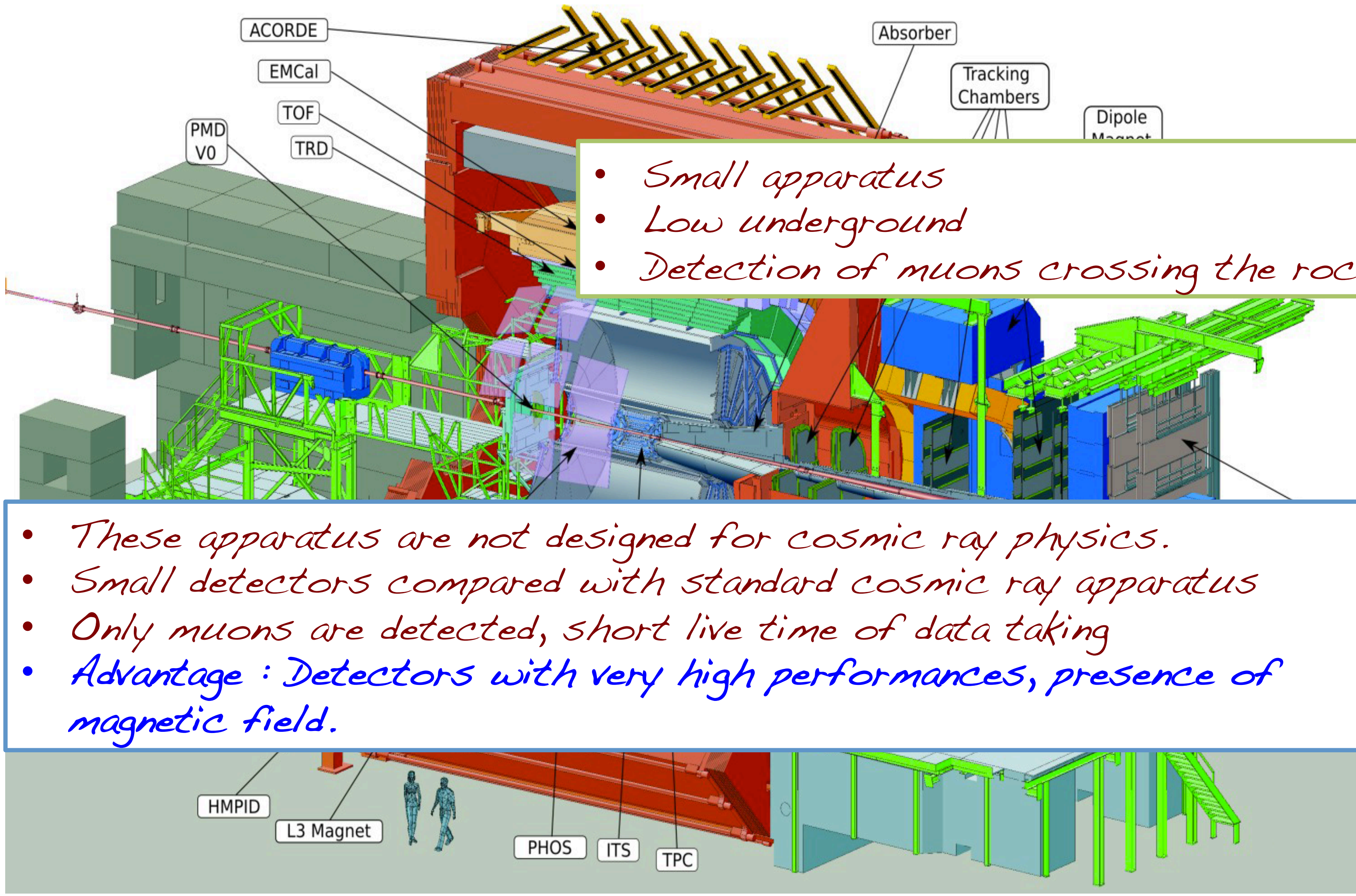


Reconstruction and visualization of a single calibration muon event

ACORDE is used to:

- Trigger events of atmospheric muons. identify events with high multiplicity of atmospheric muons.
- Generate a fast signal of level zero that has been used for alignment and calibration of the inner central detectors in ALICE(single or multicoincidence mode).

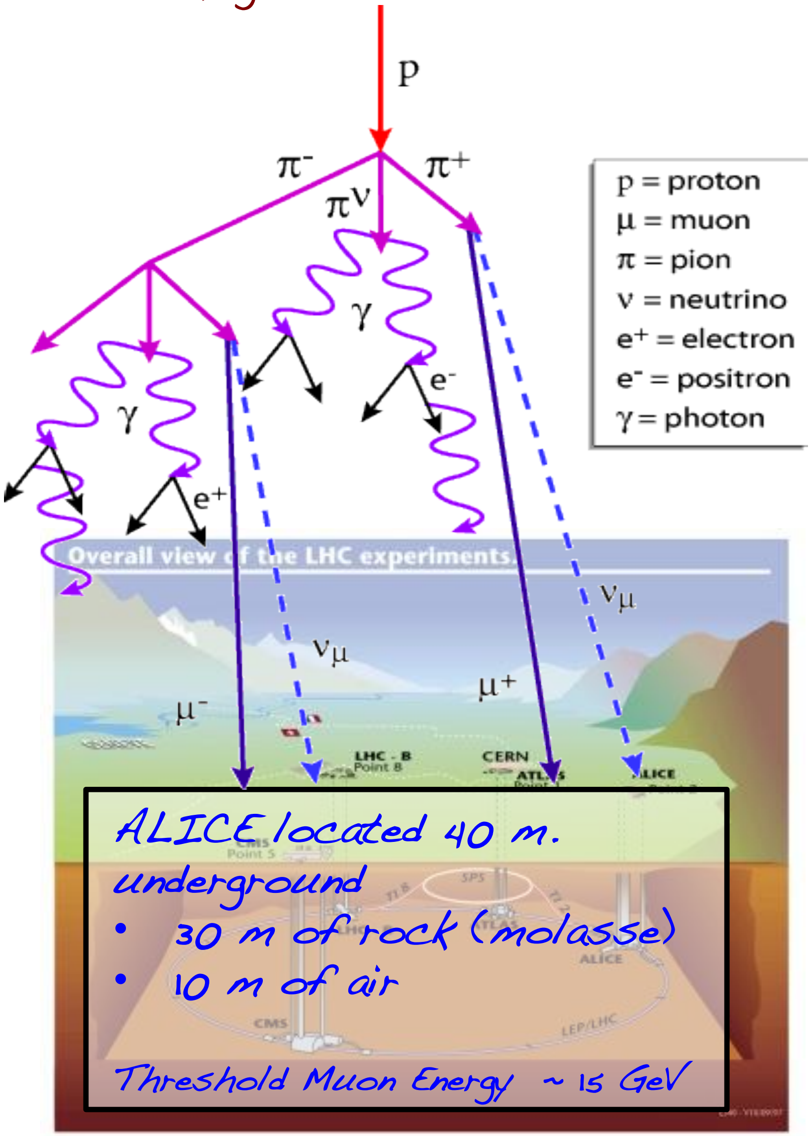
- # Cosmic ray activities: ALICE Experiment: trigger and tracking detectors for cosmics



- Small apparatus
- Low underground
- Detection of muons crossing the rock

- These apparatus are not designed for cosmic ray physics.
- Small detectors compared with standard cosmic ray apparatus
- Only muons are detected, short live time of data taking
- Advantage : Detectors with very high performances, presence of magnetic field.

• Cosmic ray activities: ALICE Experiment: trigger and tracking detectors for cosmics



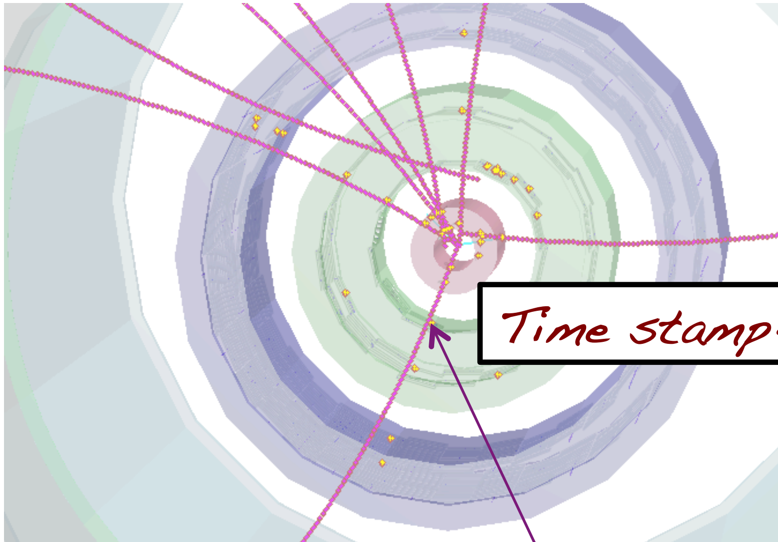
The bulk of the primary particle production is dominated by forward and soft QCD interactions, modeled commonly in Regge-Gribov-based approaches with parameters constrained by the existing collider data. When extrapolated to energies around the GZK-cutoff, the current MCs predict energy and multiplicity flows differing by factors as large as three, with significant inconsistencies in the forward region.

With the ALICE's detectors it is possible to detect those muons coming from the cosmic ray that reaches the P2.

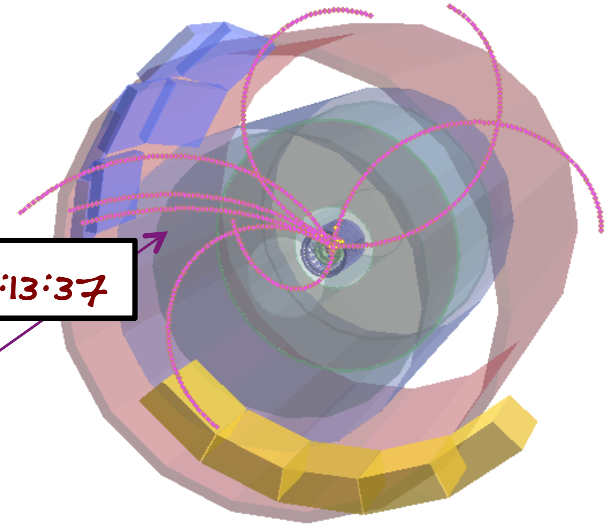
Topics of interest in Cosmic ray analysis in ALICE:

- ❑ Muon multiplicity distribution (in progress)
  - ❑ Study of cosmic muon bundles (in progress)
- ❑ μ^+/μ^- charge ratio measurement (in progress)
- ❑ Study of cosmic horizontal muons (stand by)

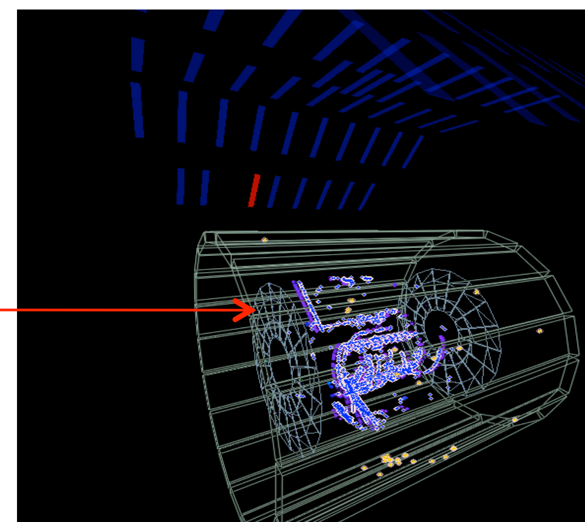
• Cosmic ray activities: ALICE Experiment: trigger and tracking detectors for cosmics



Time stamp: 2009-11-23 16:13:37



The algorithmes for reconstruction of tracks in the TPC have been created mainly for protons and heavy ions collisions.
These methods have been adapted and improved continuously during the analysis of CR - events which have a completely different topology.

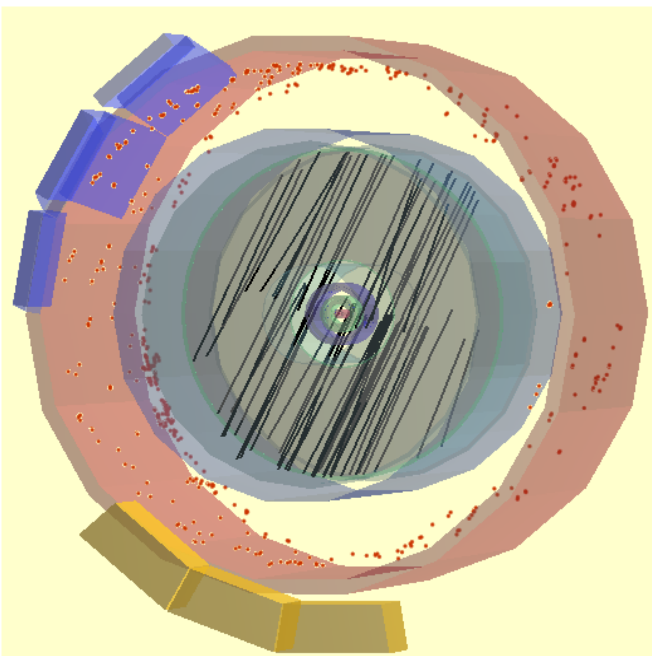


• Cosmic ray activities: *ALICE Experiment: trigger and tracking detectors for cosmics*

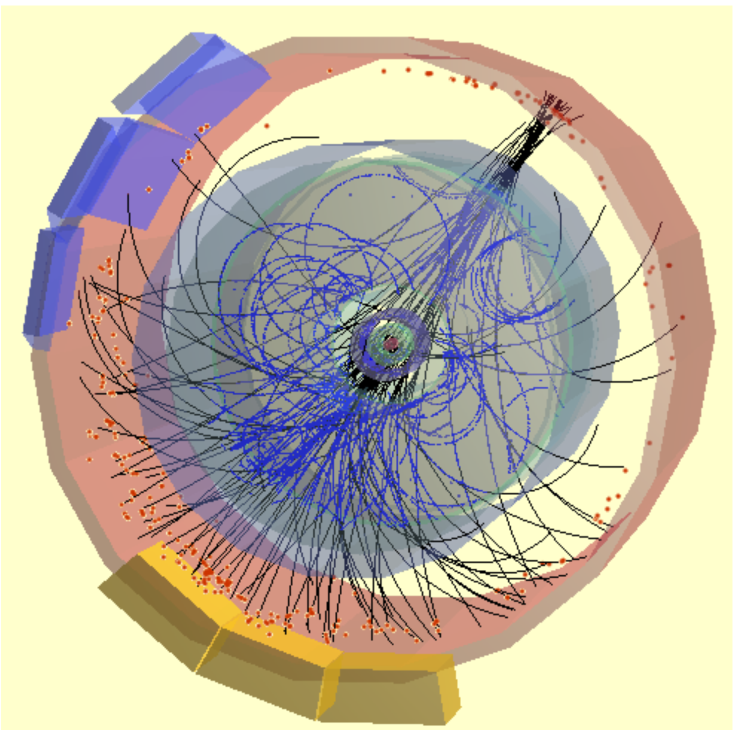
TIME PROJECTION CHAMBER (TPC) :

ALICE TPC Collaboration, J. Alme et al., "The ALICE TPC, a large 3-dimensional tracking device with fast readout for ultra-high multiplicity events.", Physics. Ins-Det/ 10011950 (2010).

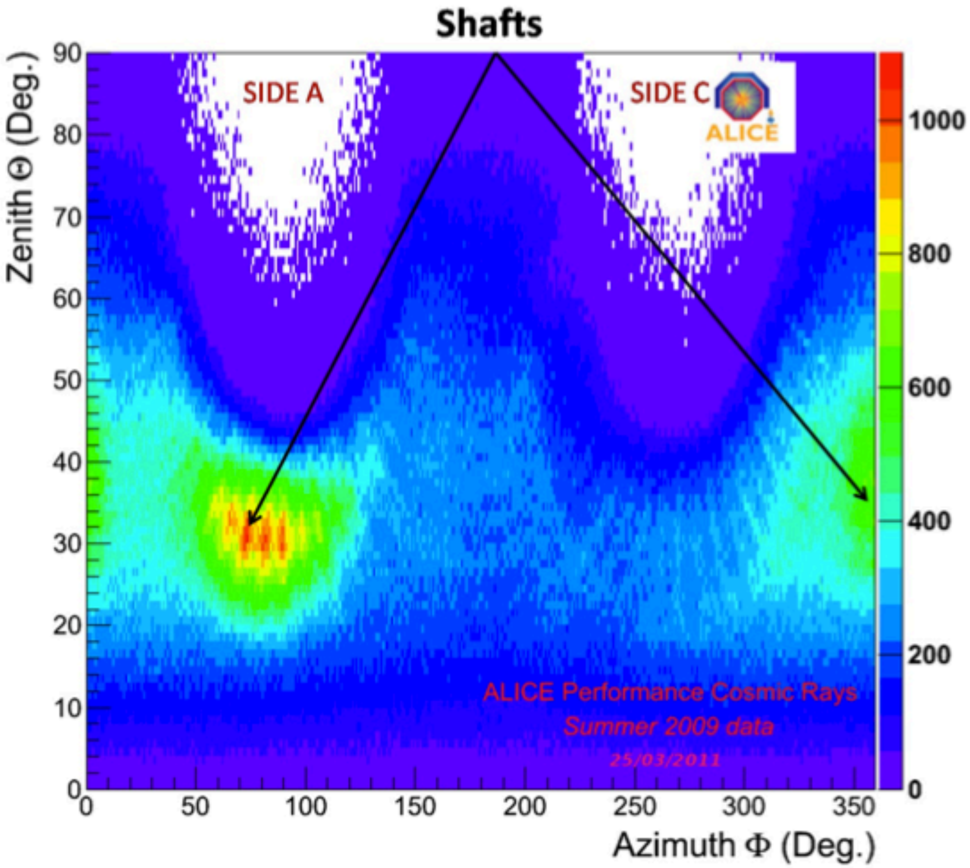
Muon Interaction Event



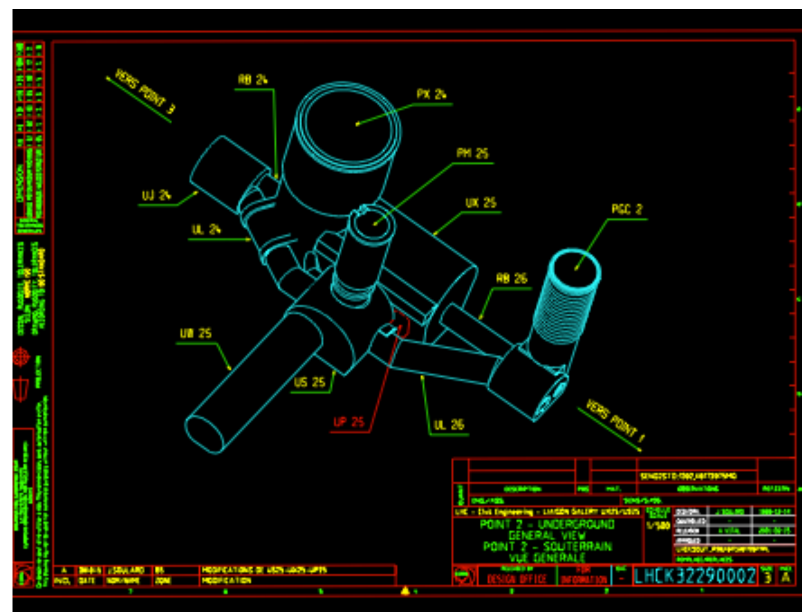
Standard Muon Event (multimuon)



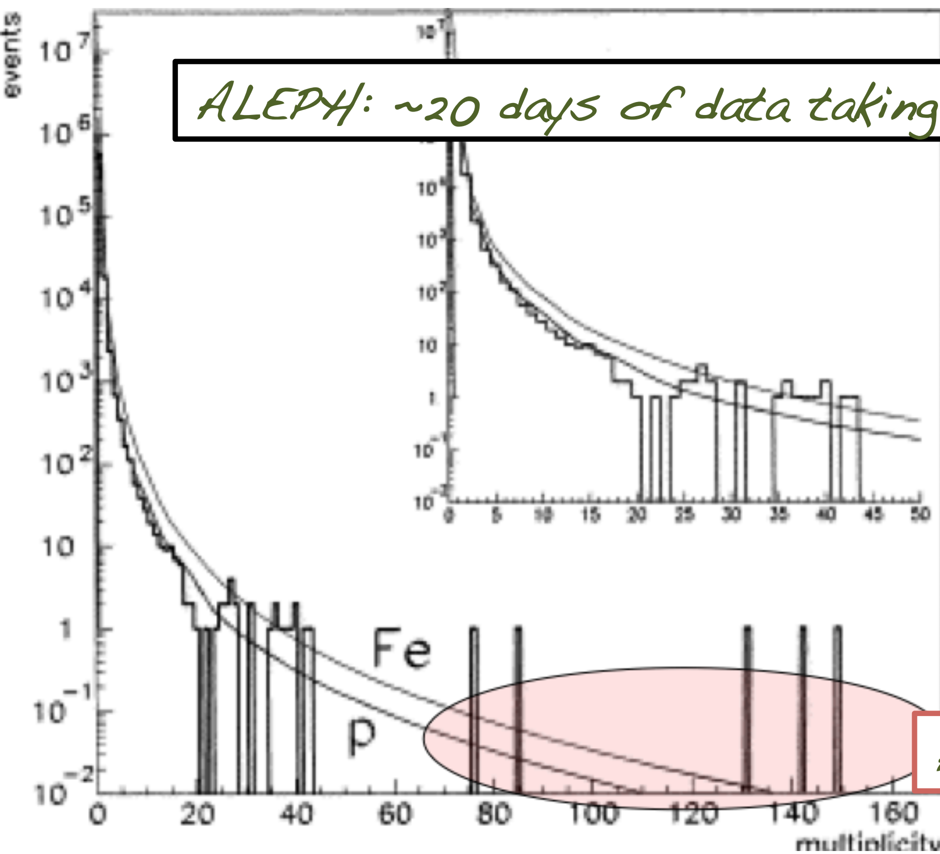
• Cosmic ray activities: ALICE Experiment: trigger and tracking detectors for cosmics



The muons crossing the shafts have a lower energy cut-off.
A larger number of muons arrive at the experiment in the directions of the shafts



• Cosmic ray activities: Atmospheric Muon Multiplicity Distribution (MMD)



ALEPH: ~20 days of data taking

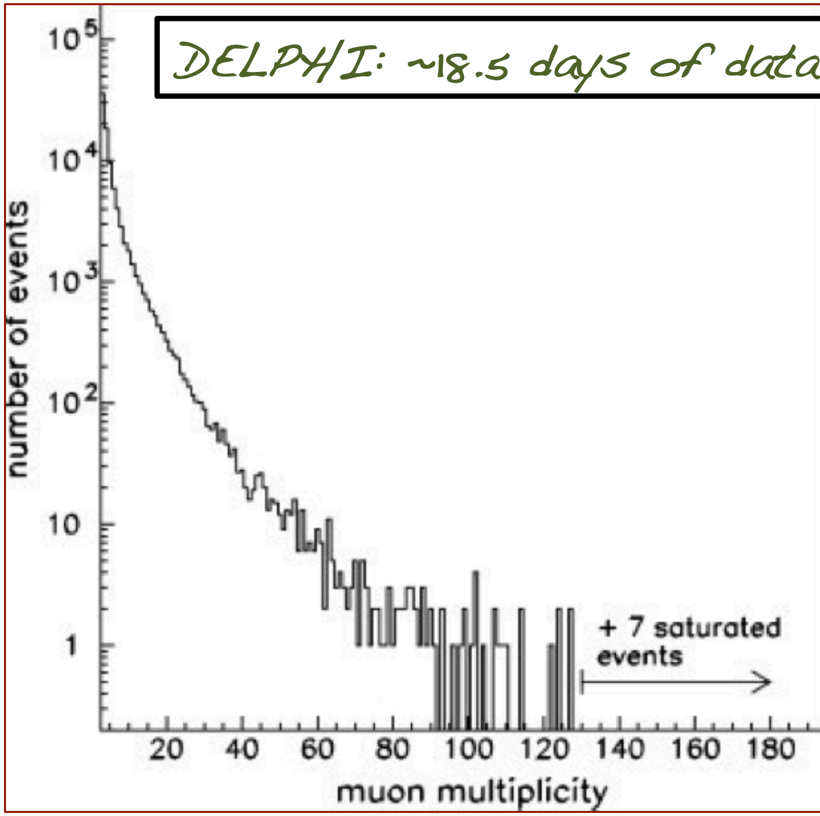
1) 4.75 μ / m² Zenith=40.8°
Primary energy = 3 × 10^{16} eV
2) 5.3 μ / m² Zenith=37.7°
Primary energy = 3 × 10^{16} eV
3) 8.9 μ / m² Zenith=40°
Primary energy = 6 × 10^{16} eV
4) 8.2 μ / m² Zenith=48.6°
Primary energy = 7 × 10^{16} eV
5) 18.6 μ / m² Zenith=27°
Primary energy = 10^{17} eV

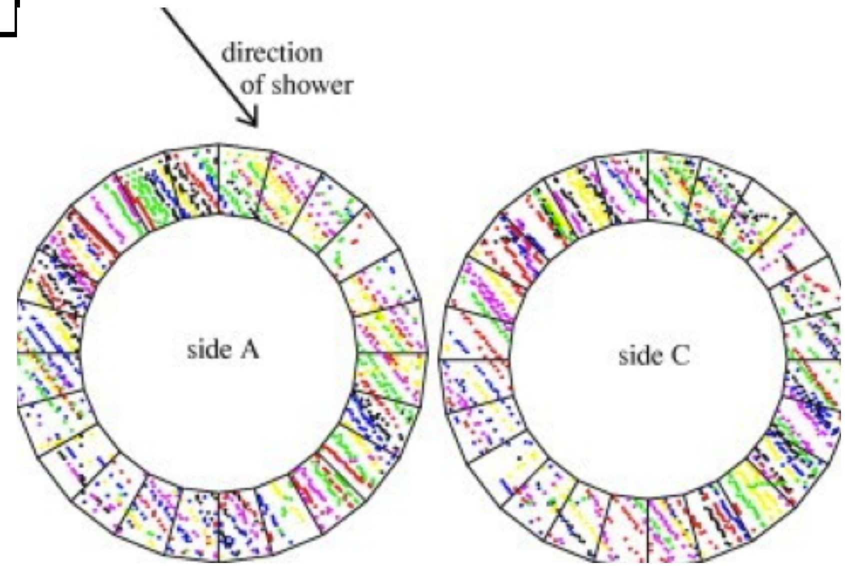
Astroparticle Physics 19 (2003) 513–523

The five highest multiplicity events, with up to 150 muons within an area of 8 m², occur with a frequency which is almost an order of magnitude above the simulation.

- # Cosmic ray activities: Atmospheric Muon Multiplicity Distribution (MMD)

DELPHI: ~18.5 days of data taking

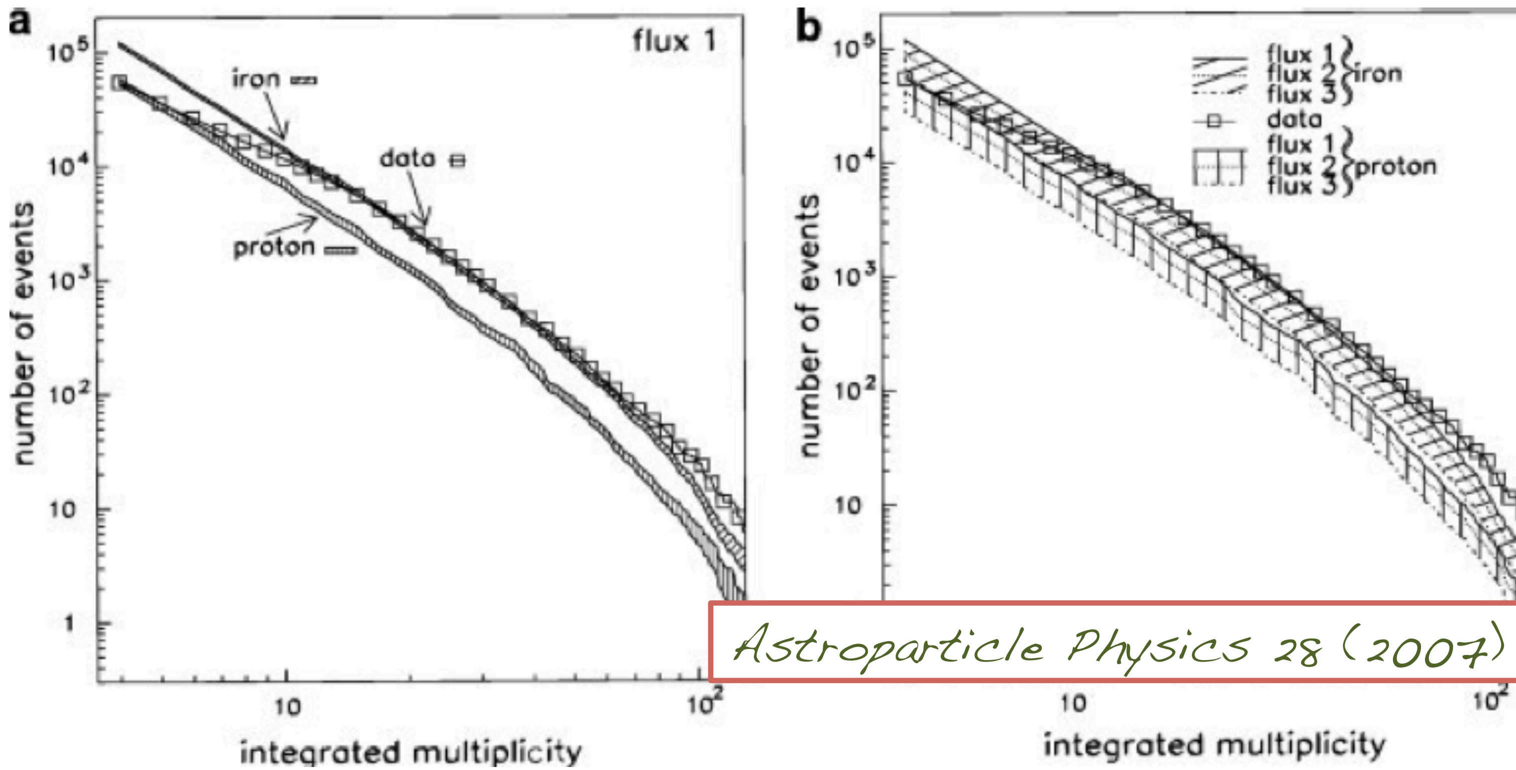




7 high multiplicity events that saturate the detector

Astroparticle Physics 28 (2007) 273-286

• Cosmic ray activities: Atmospheric Muon Multiplicity Distribution (MMD)

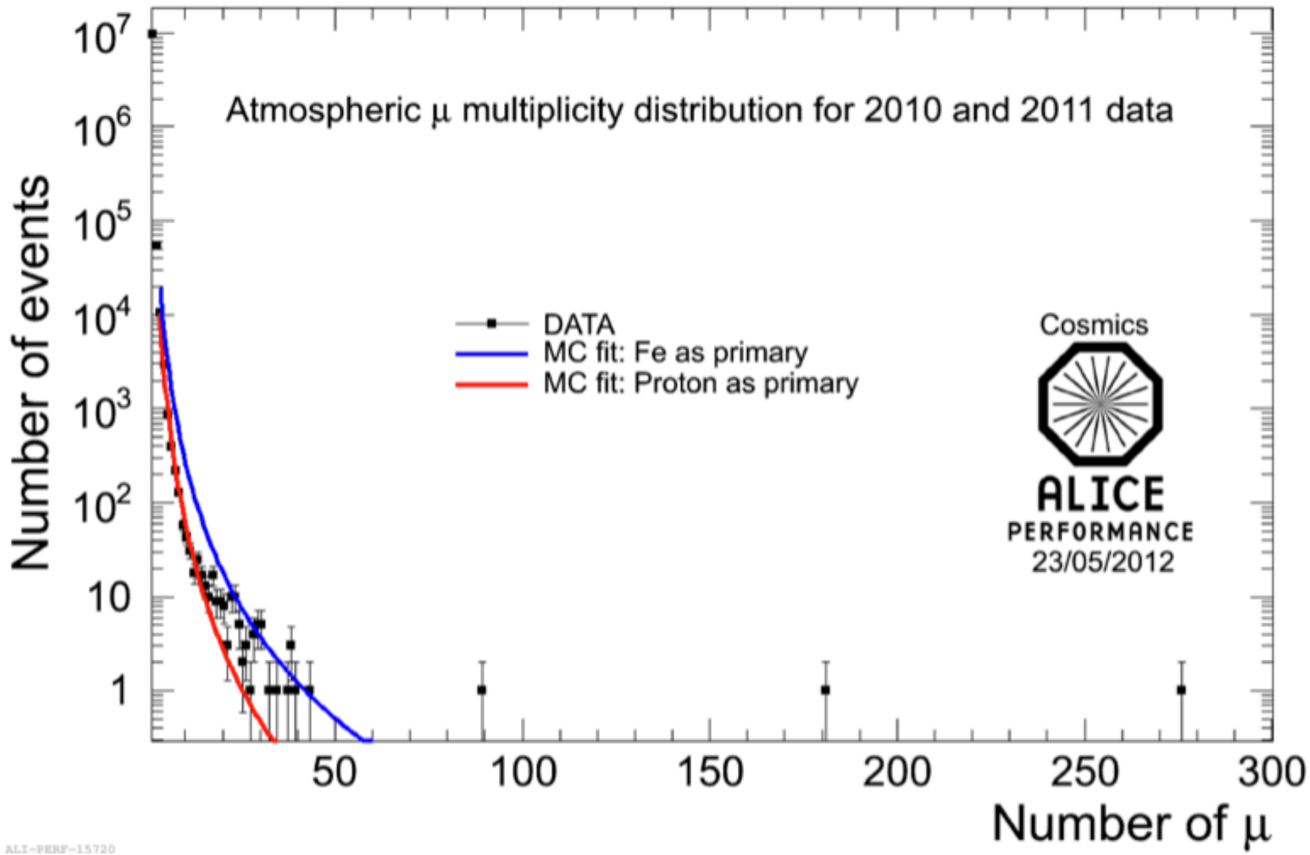


Astroparticle Physics 28 (2007) 273-286

The conclusion is similar to Aleph :

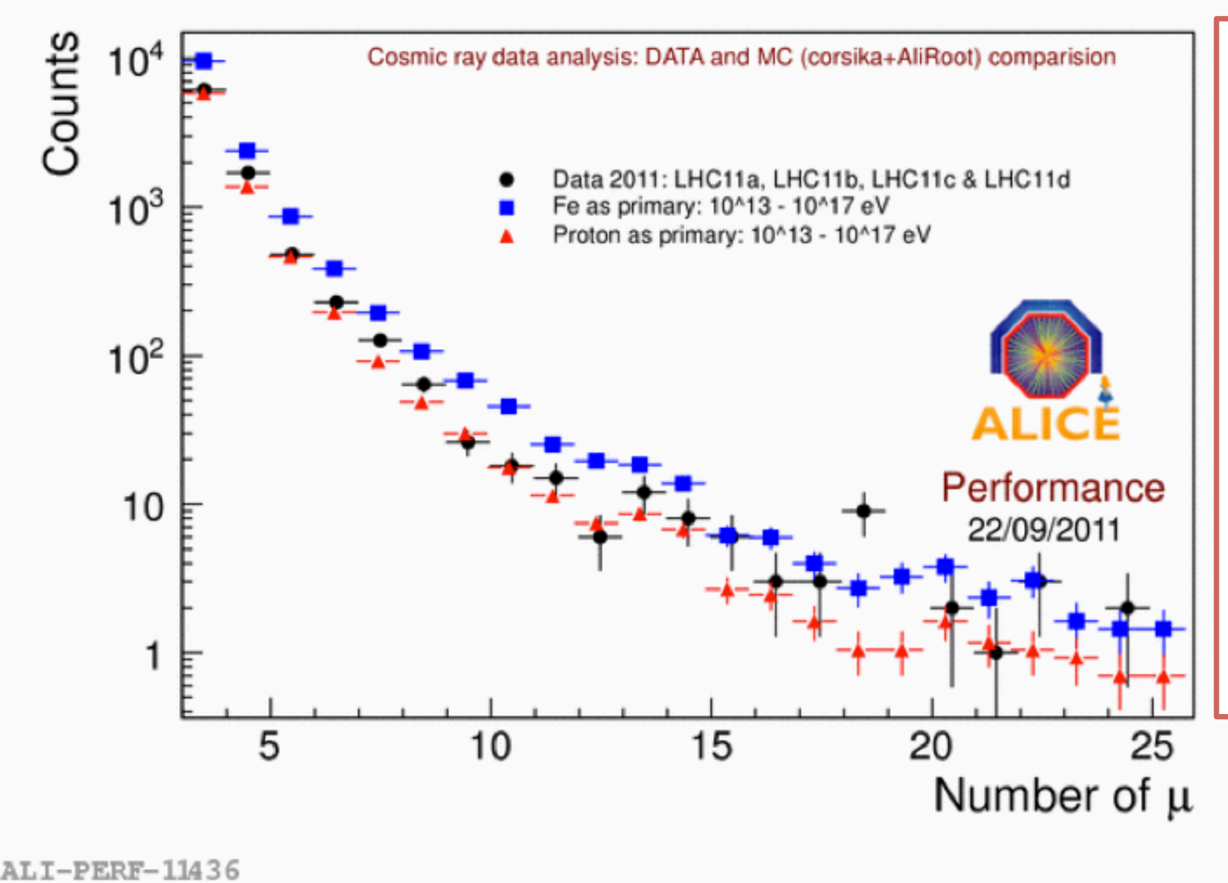
However, even the combination of extreme assumptions of highest measured flux value and pure iron spectrum fails to describe the abundance of high multiplicity events.

- # Cosmic ray activities: *Atmospheric Muon Multiplicity Distribution (MMD)*



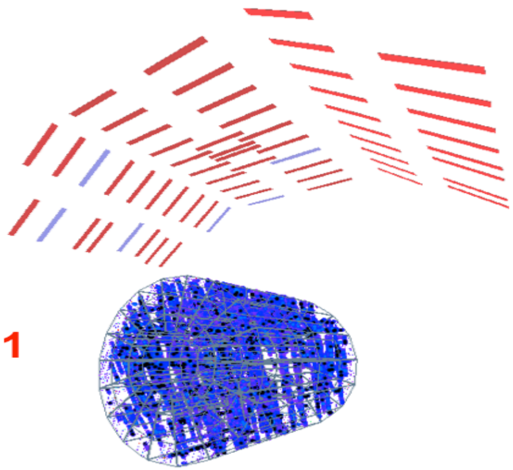
- In ~ 11 days of data we found three high muon multiplicity events (HME) not explained with the simulations.
- Two of them have more than 100 muons.
- We have to understand these events!!!

• Cosmic ray activities: Atmospheric Muon Multiplicity Distribution (MMD)

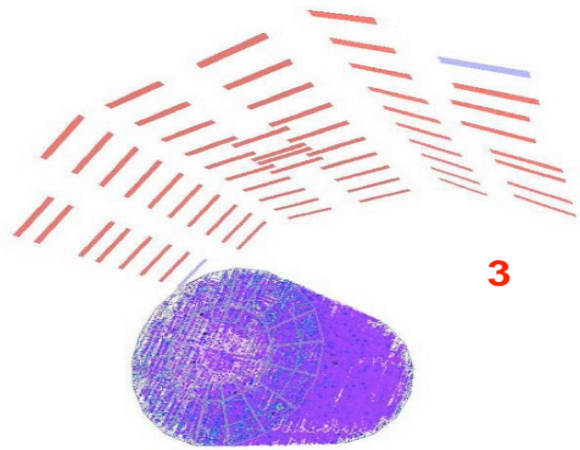


Data taken Feb.-Aug. 2011 ~ 9.5 days live time
Trigger : ACORDE + TOF
Comparison with simulation CORSIKA code with QGSJET II-03
Proton primary Fe primary
The data as expected are inside the pure proton and pure Fe composition. At low multiplicities (low primary energy) the data are closer to the proton curve approaching the Fe curve at higher multiplicities in agreement with previous results.

- # Cosmic ray activities: Atmospheric Muon Multiplicity Distribution (MMD)



1



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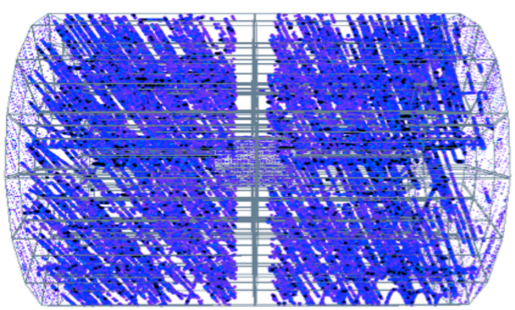

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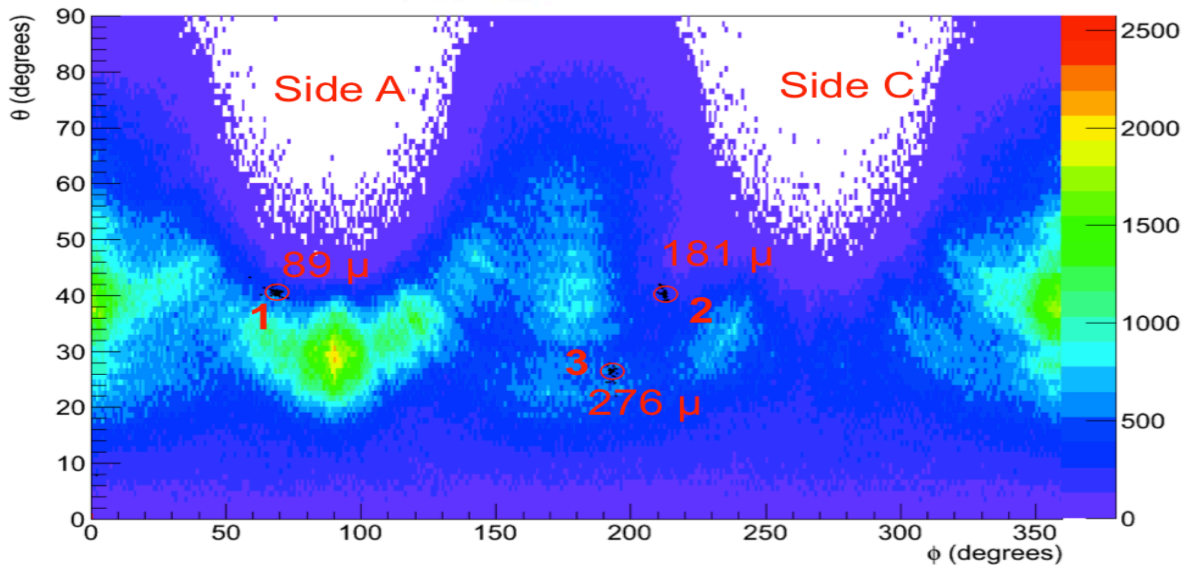
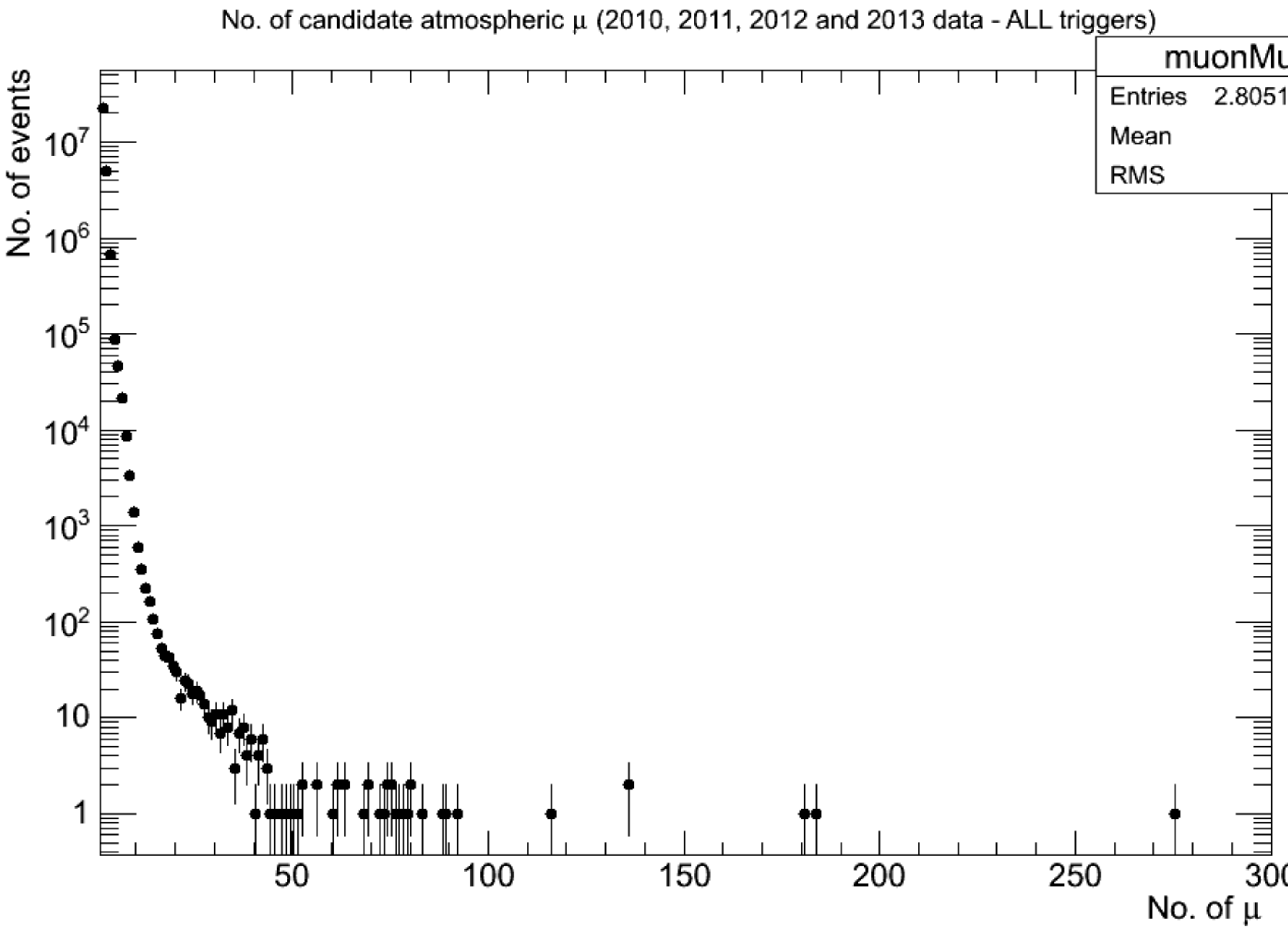
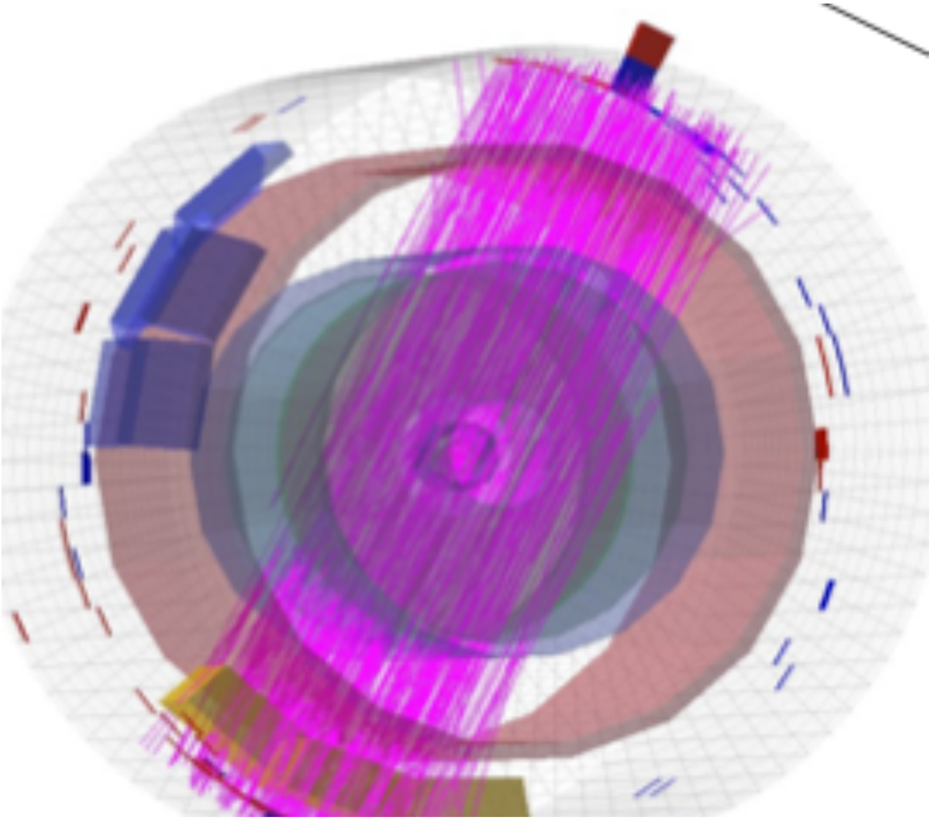


• Cosmic ray activities: Atmospheric Muon Multiplicity Distribution (MMD)

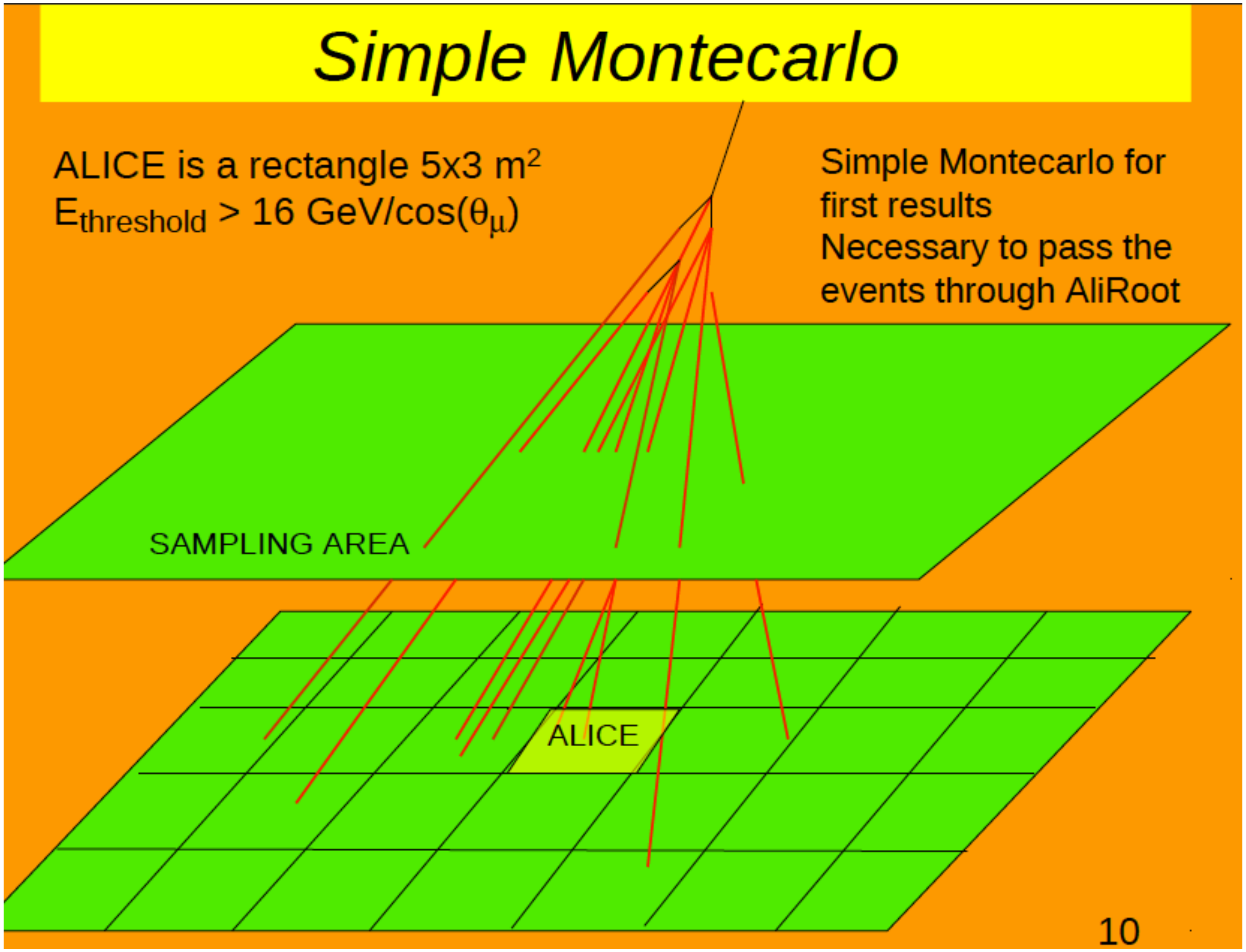


- ## Cosmic ray activities: *Atmospheric Muon Multiplicity Distribution (MMD)*

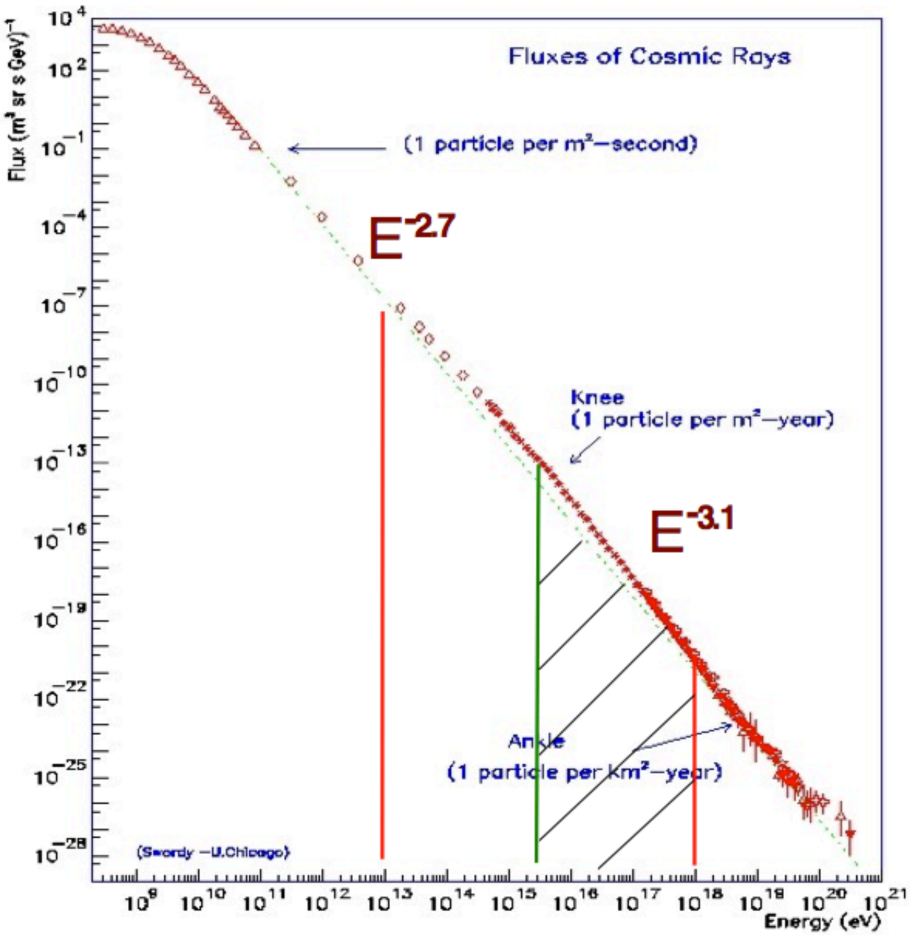


Is it possible to explain these high muon multiplicity events (HME) with a standard composition of primary cosmic rays and actual hadronic interaction model ?

- # Cosmic ray activities: *Simple Monte Carlo to study High Atmospheric Muons Events*



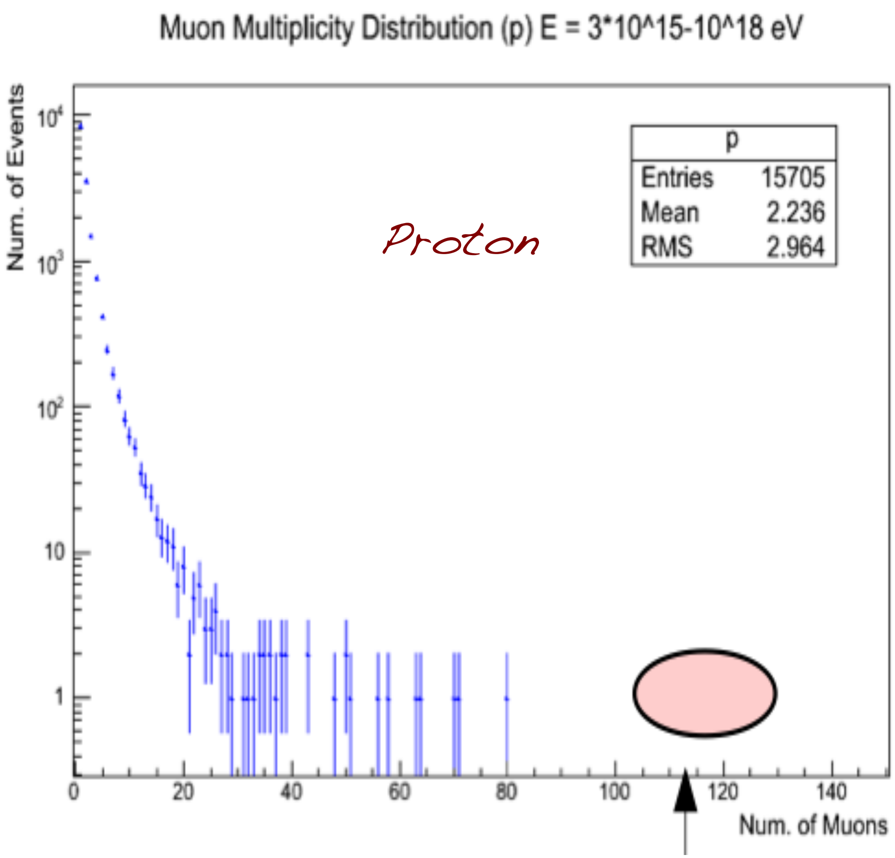
• Cosmic ray activities: *Simple Monte Carlo to study High Atmospheric Muons Events*

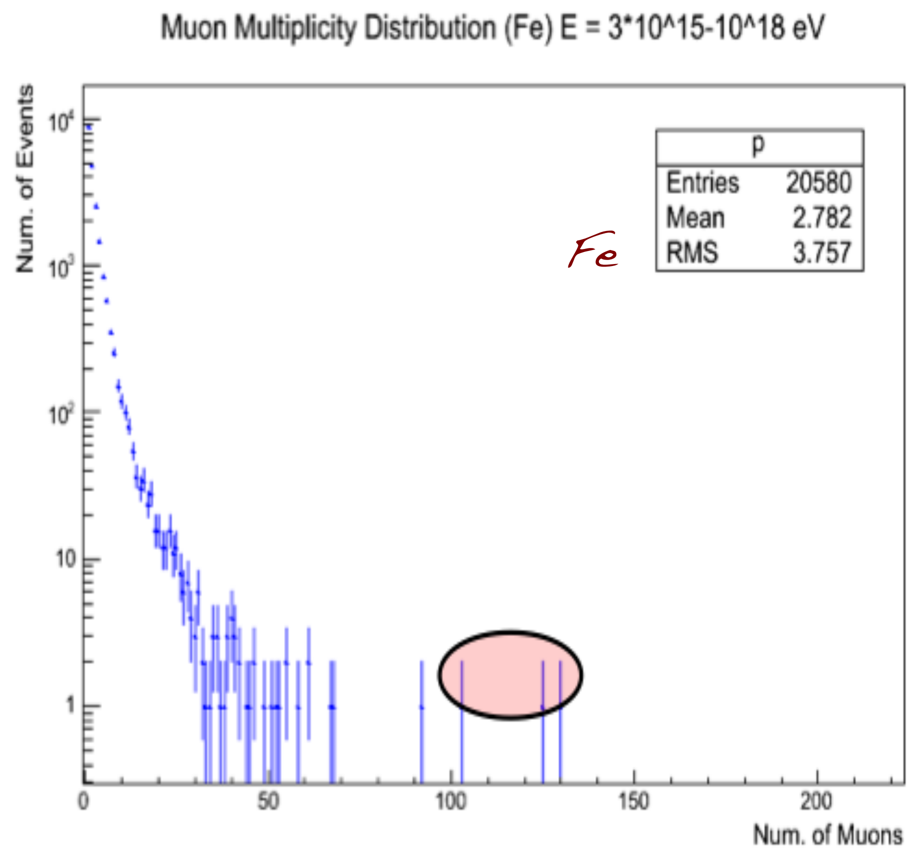


- Primary Energy in Alice : $10^{13} < E < 10^{18}$ eV
- To study high multiplicity events Restrict the energy range above the knee : $3 \times 10^{15} < E < 10^{18}$
- Flux of the all-particles extrapolated from J. Horandel, Astrop.Phys. 19 (2003) 193-220
- Try with 2 slopes of the energy spectrum above the knee = -3.0 , -3.1
- Real data ~ 22 days (5 HME)
- Start to simulate 36.5 days
- The purpose is to simulate 365 days to reduce the fluctuations

• Cosmic ray activities: *Simple Monte Carlo to study High Atmospheric Muons Events*

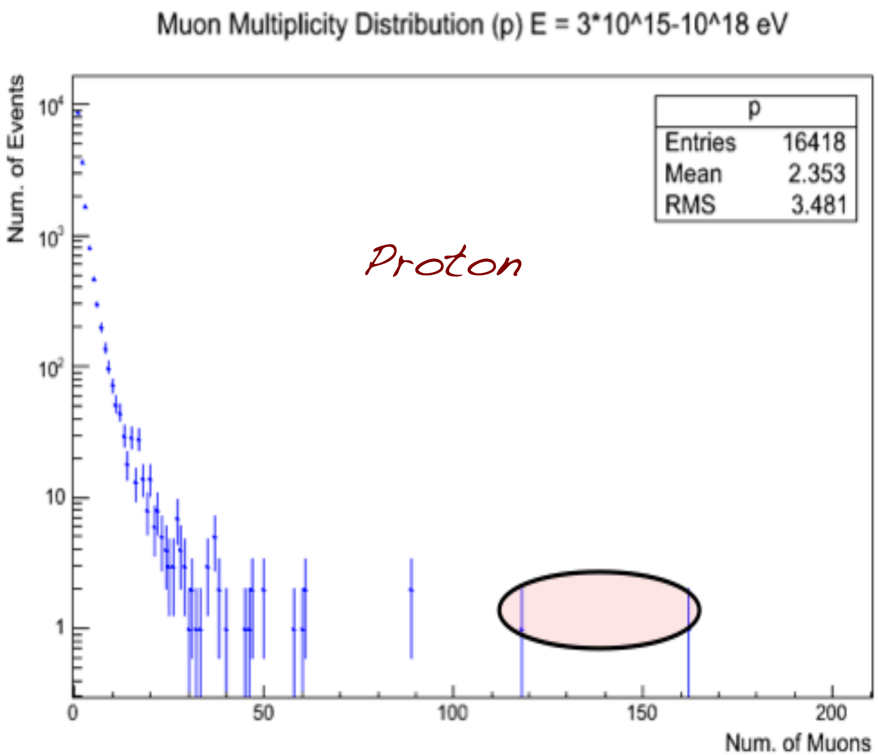
36.5 days of simulated data (slope=-3.1)

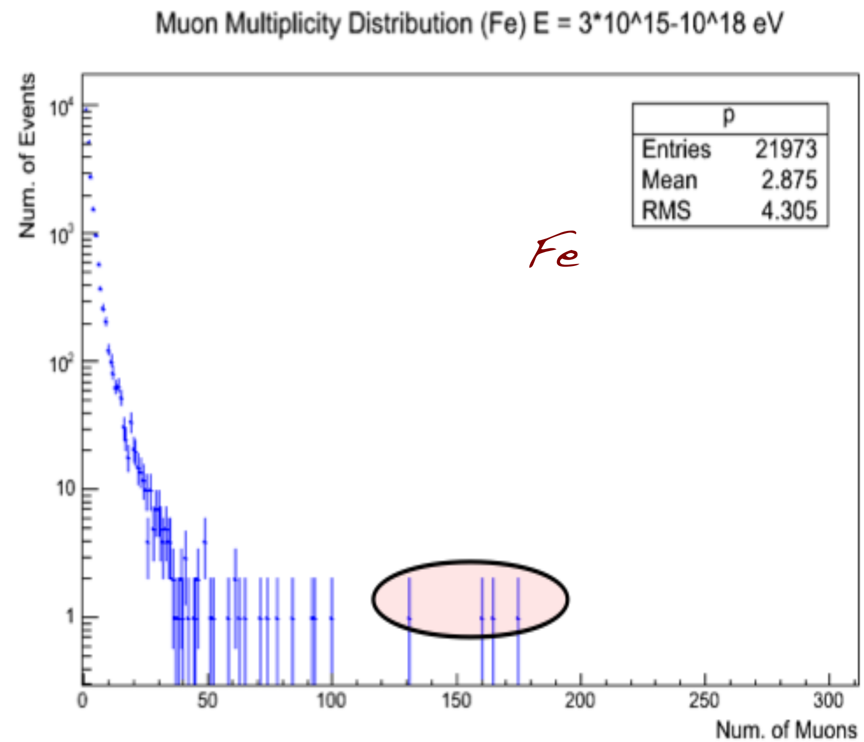




- # Cosmic ray activities: *Simple Monte Carlo to study High Atmospheric Muons Events*

36.5 days of simulated data (slope=-3.0)





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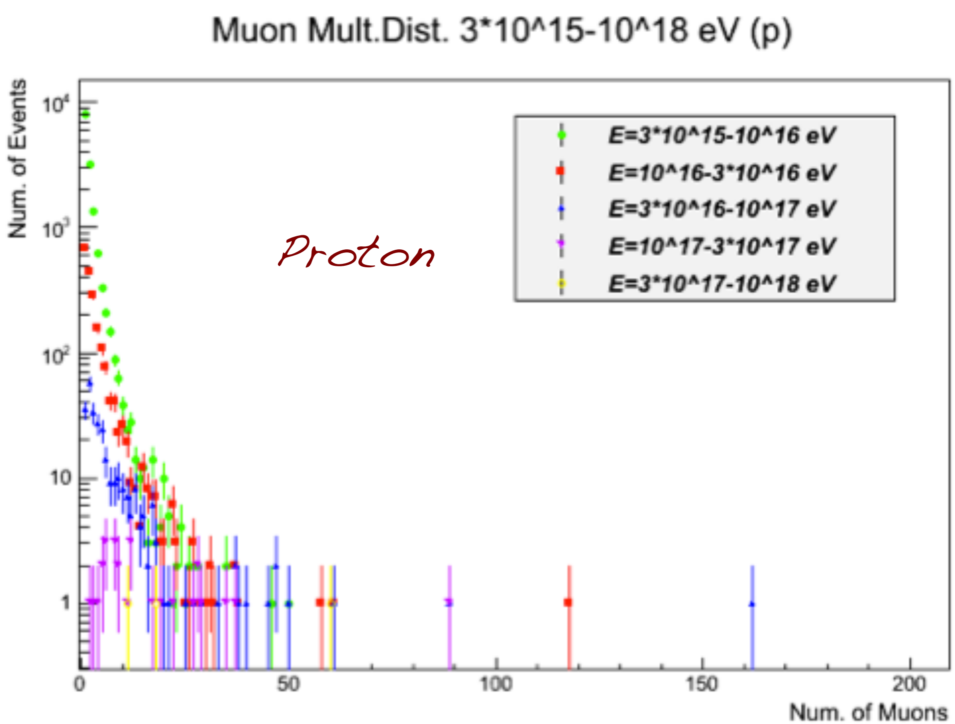
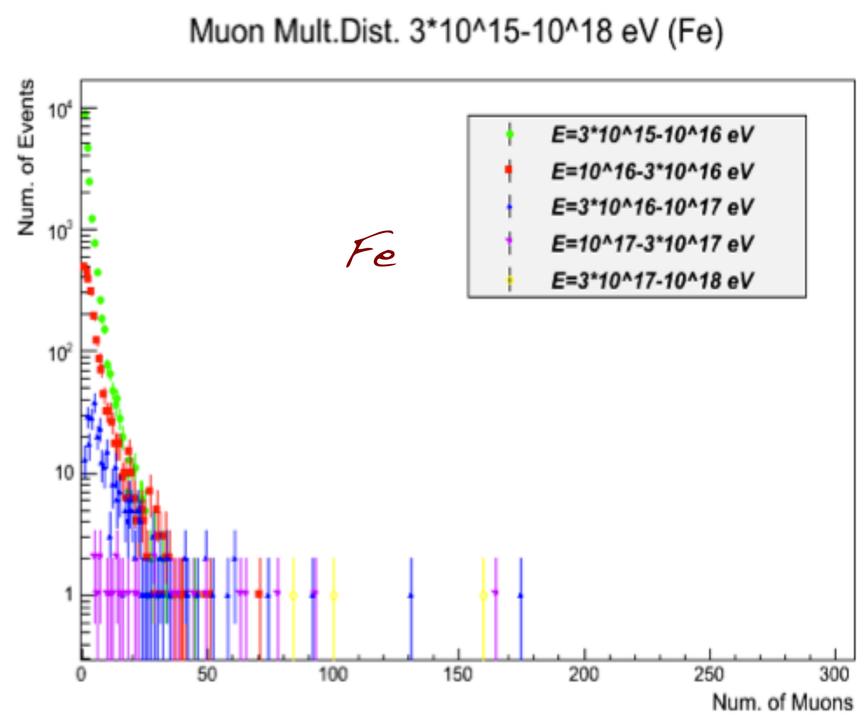
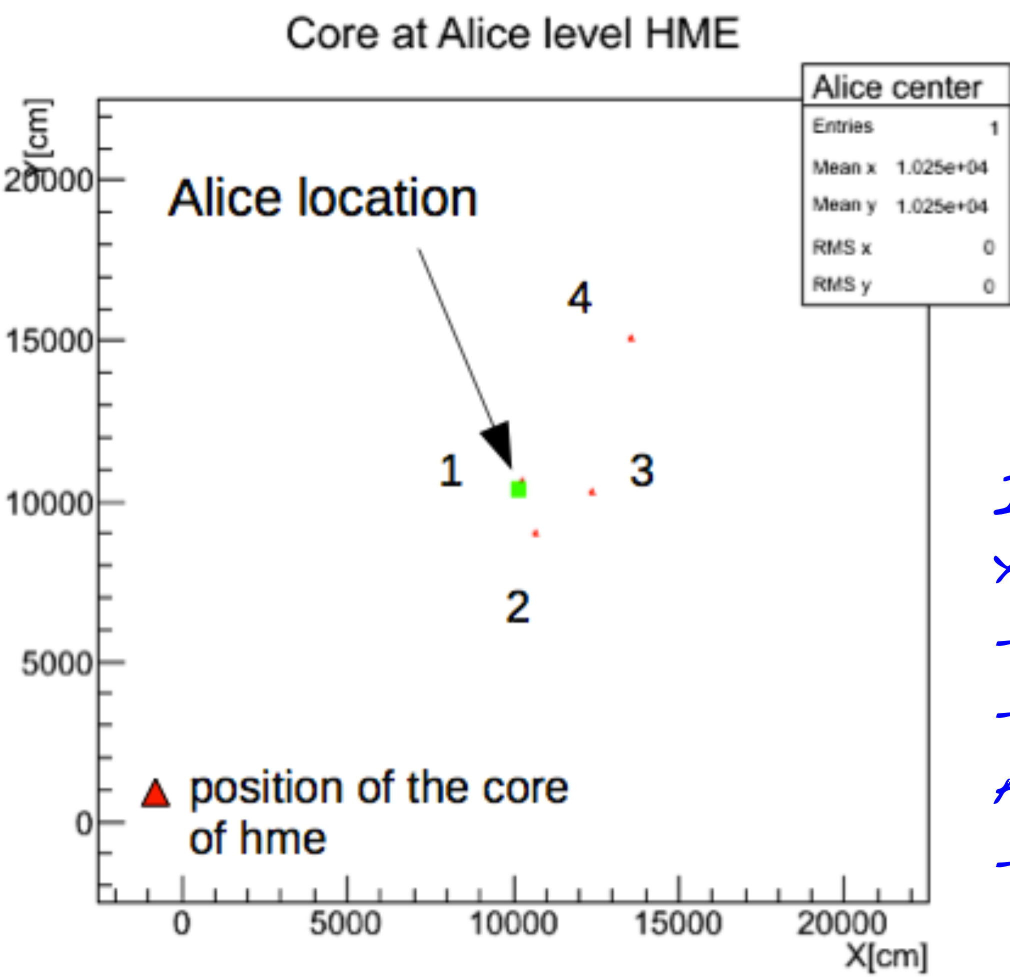




All the events with $N_\mu > 100$ have $E > 10^{16}$ eV

• Cosmic ray activities: Simple Monte Carlo to study High Atmospheric Muons Events



Event Num.	Dist. of the core [m]	Primary Ener. [PeV]	N. of muons
1	3.8	34	131
2	13.7	60	175
3	21.5	148	165
4	58.3	755	160

It seems possible to explain HME :

-primary energy $E > 10^{16}$ eV

-core location close to Alice

-probably heavy primary.

36.5 days of simulated data (slope=-3.0) → Pure Fe

- # Cosmic ray activities: *Simple Monte Carlo to study High Atmospheric Muons Events*

Contribution of each energy range in the number of muons per event

Prim. Ener. in eV	10^{13} 10^{14}	10^{14} 10^{15}	10^{15} $3\ 10^{15}$	$3\ 10^{15}$ 10^{16}	10^{16} $3\ 10^{16}$	$3\ 10^{16}$ 10^{17}	10^{17} $3\ 10^{17}$	$3\ 10^{17}$ 10^{18}
14.81 days	256,575,430	5,119,358	88,122	12,453	1094	124	10	1
p	1-4	1-10	1-20	1-47				
Fe	1-4	1-10	1-20	1-60				

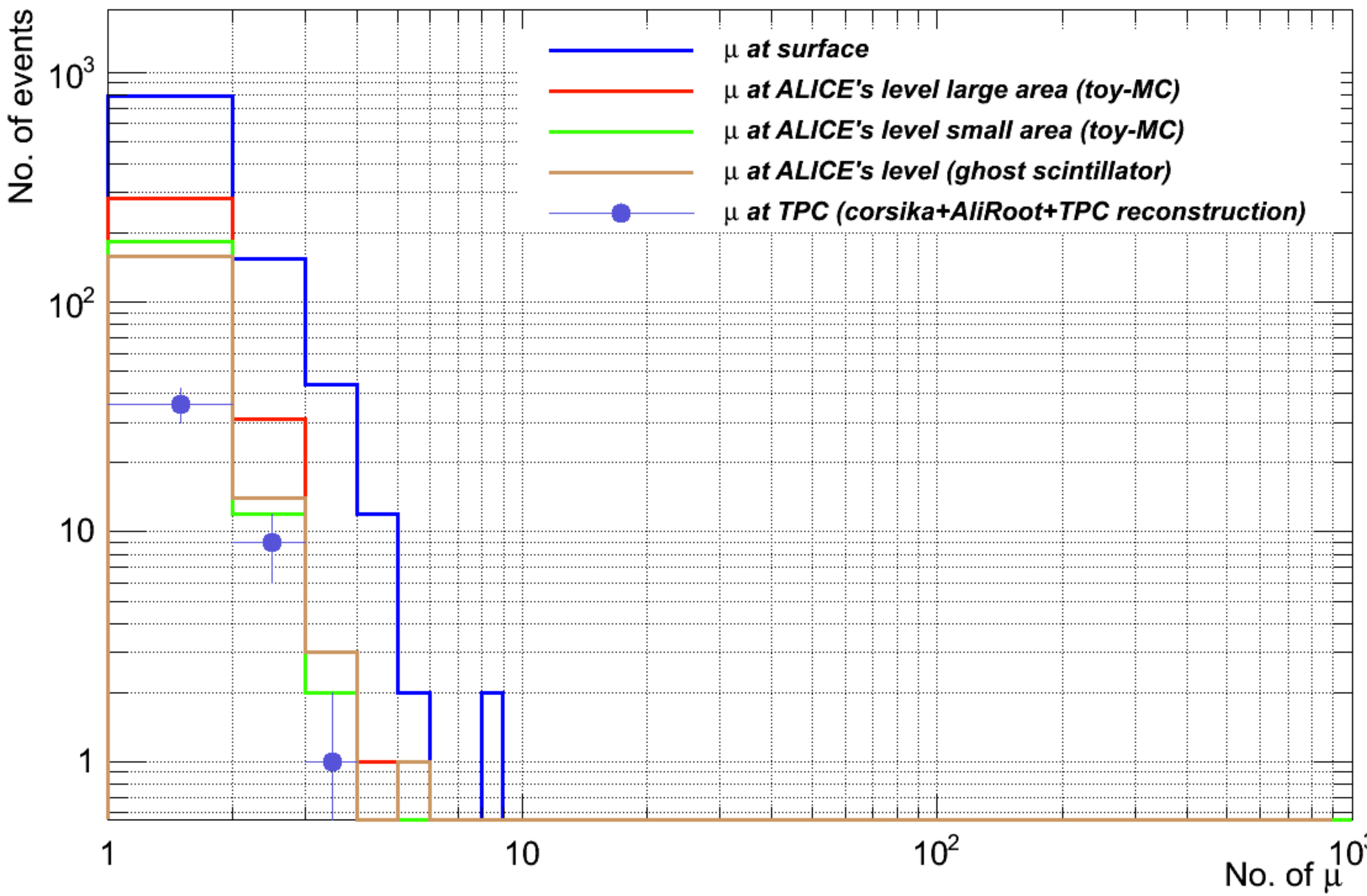
It is expected to have more than 60 muons for Fe and more than 47 muons for proton in this range of energy.

The first range of energy does not have events with Nmu>4
The high mult. events (Nmu>100) have always E>10^{16} eV

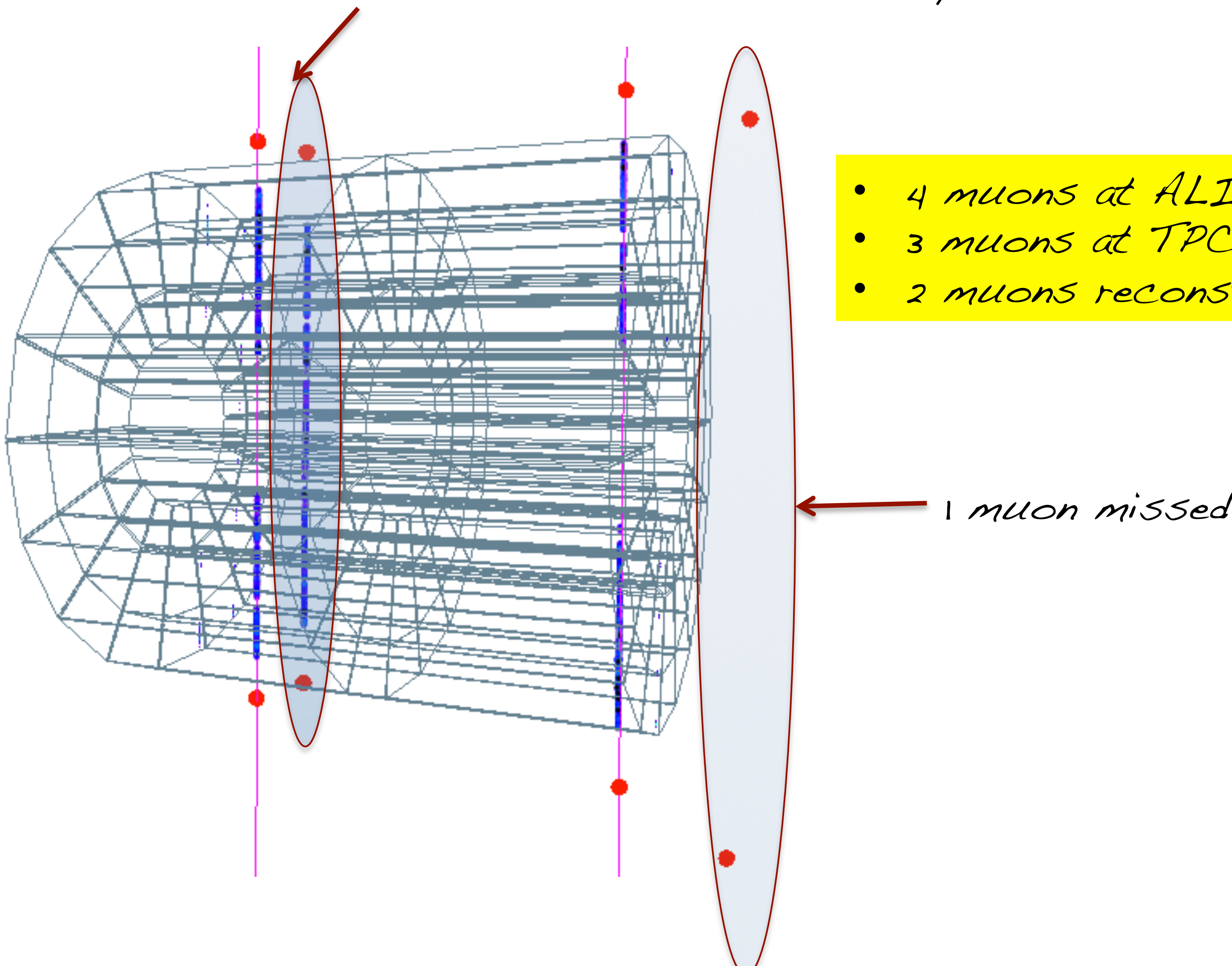
• Cosmic ray activities: Final remarks on cosmic ray activities

- Alice can detect atmospheric muons up to very high muon multiplicity with the possibility to measure for each muon the momentum, the charge, the direction, the spatial coordinates and the arrival time.
- It seems possible to explain the high multiplicity events as due to very high energetic primaries, probably of heavy component, with a core located near Alice
- To reach a final conclusion on these events we plan to :
  - Increase the statistics of simulated events to reduce the fluctuations
  - Passing the generated events in the AliRoot to have more realistic distributions to compare with data instead the actual upper limits.
  - Try to use different interaction models to see the changes
  - Use all the other measured variables like the momentum, the spatial distribution, the charge to reach a full comprehension of these events
- During 2012 it was implemented a dedicated cosmic ray trigger during BEAM RUNS (not discussed in this talk)

- # Cosmic ray activities: *Final remarks on cosmic ray activities*

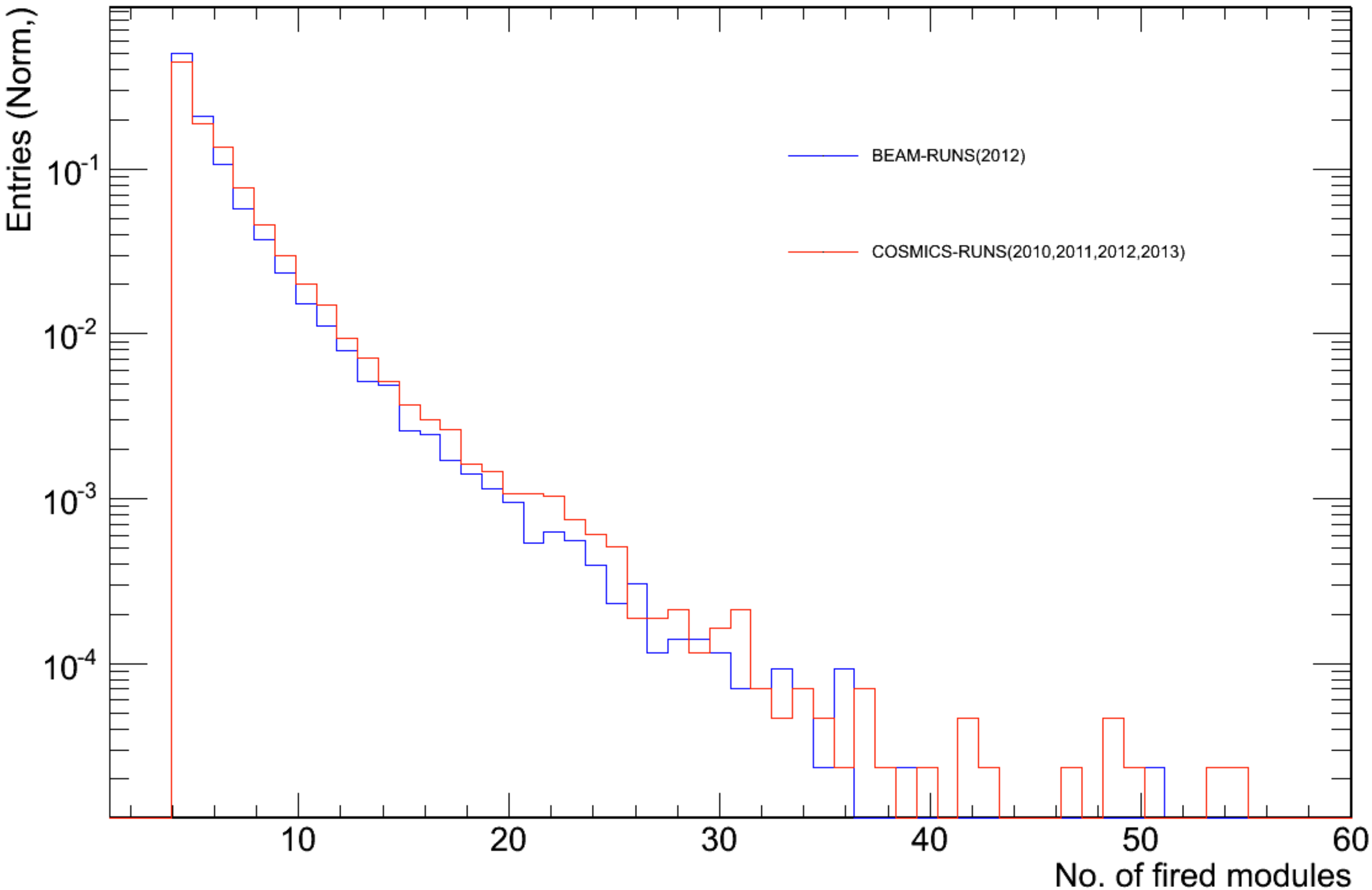


• Cosmic ray activities: *Final remarks on cosmic ray activities*



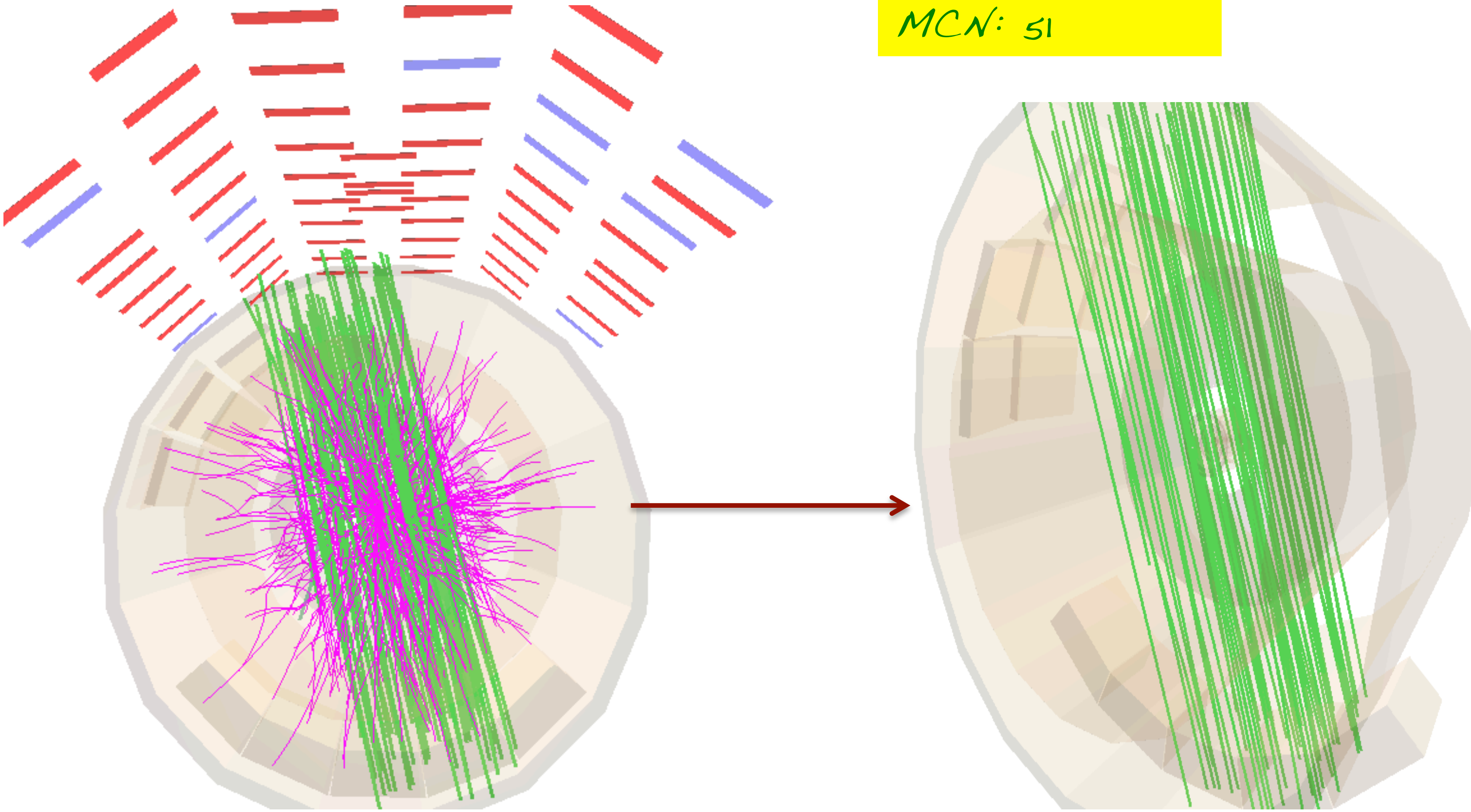
- 4 muons at ALICE's level
- 3 muons at TPC
- 2 muons reconstructed

• Cosmic ray activities: *Final remarks on cosmic ray activities*

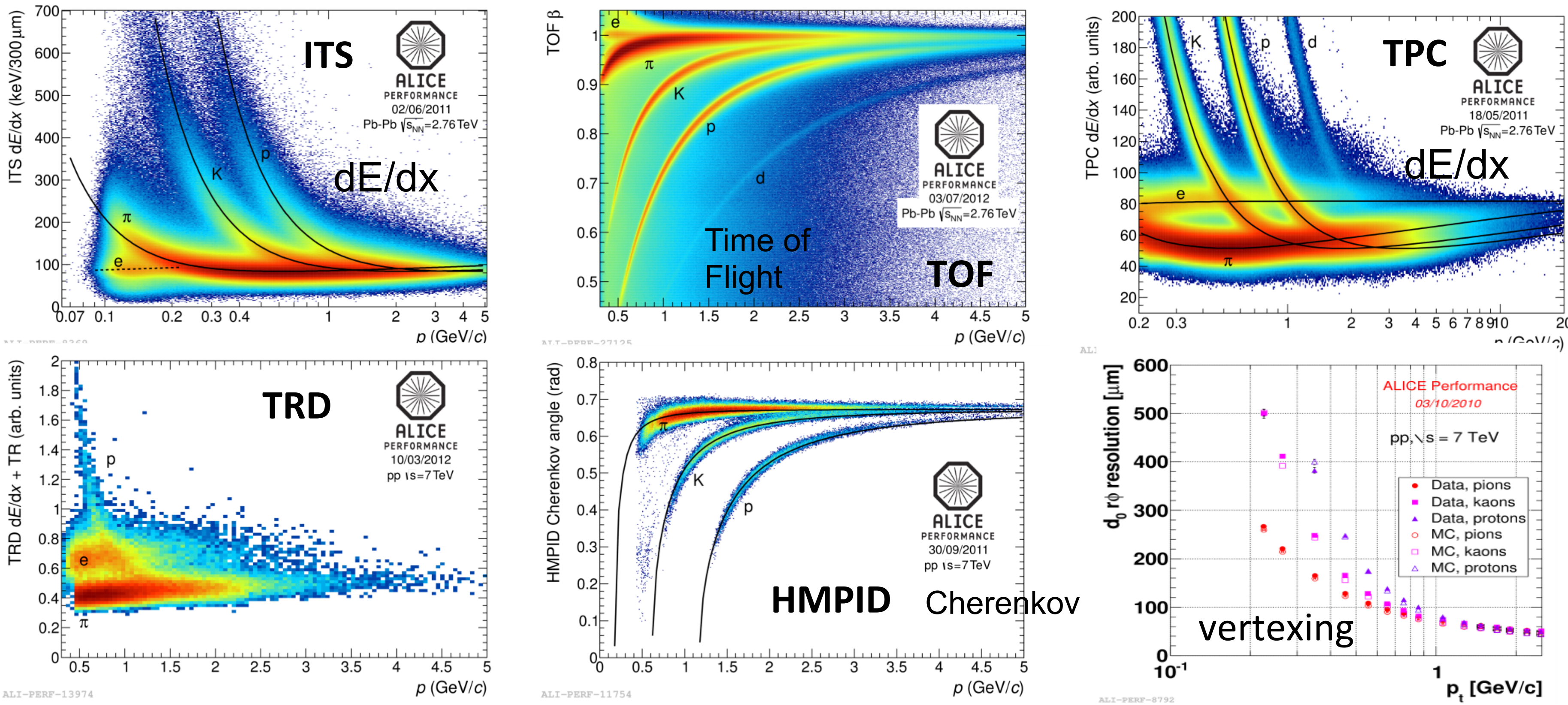


• Cosmic ray activities: *Final remarks on cosmic ray activities*

68 atm. Muons
MCN: 51



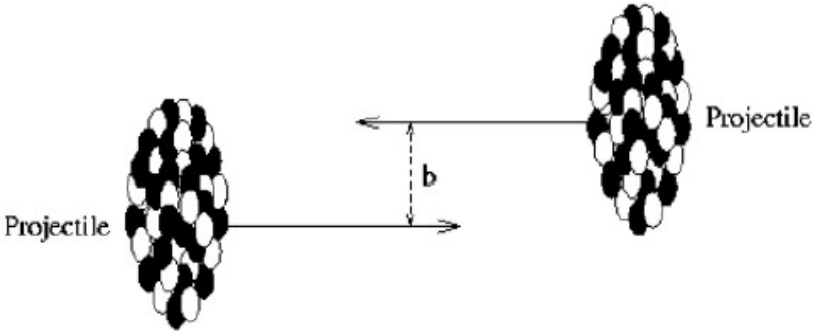
Ultra peripheral collisions studies (a taste)



The design is optimized for reconstruction and identification of particles in a wide range of transverse momentum.

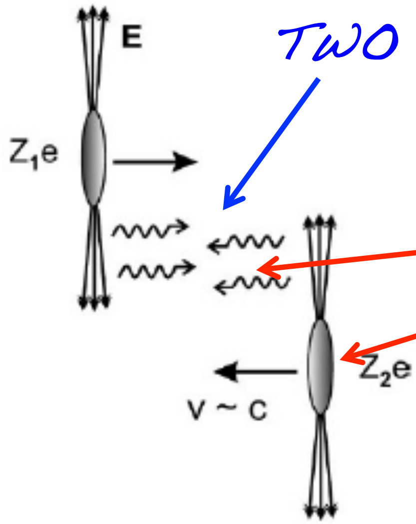
- particle identification (practically all known techniques)
- extremely low-mass tracker ~ 10% of X0
- excellent vertexing capability
- efficient low-momentum tracking - down to ~ 100 MeV/c

Ultra peripheral collisions studies (a taste)



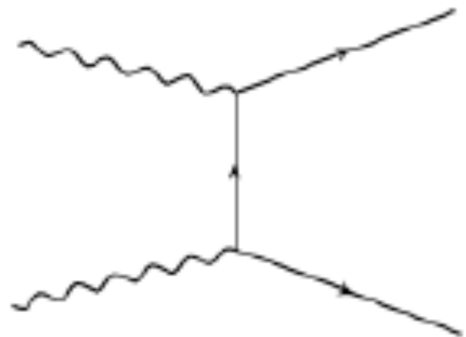
The ultra peripheral collisions occurs if $b > R_1+R_2$ ➔ the photons and nuclei can interact in several ways. Hadronic interactions are strongly suppressed.

Ultra peripheral collisions studies (a taste)

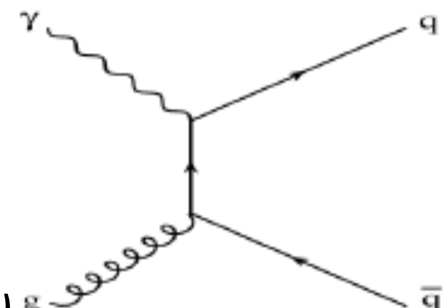


TWO BEAM OF PHOTONS

Two ions (or protons) pass by each other with impact parameters $b > 2R$



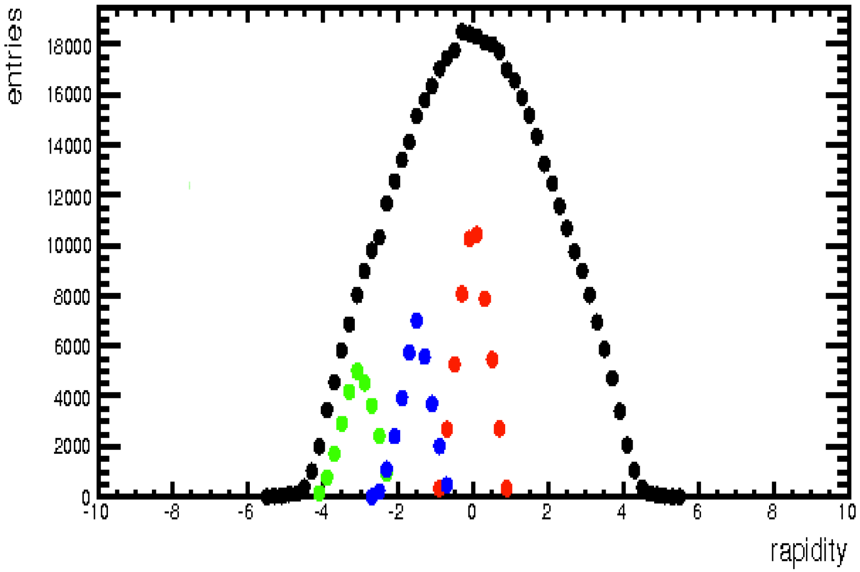
1. Electromagnetic interaction: $\gamma + \gamma$

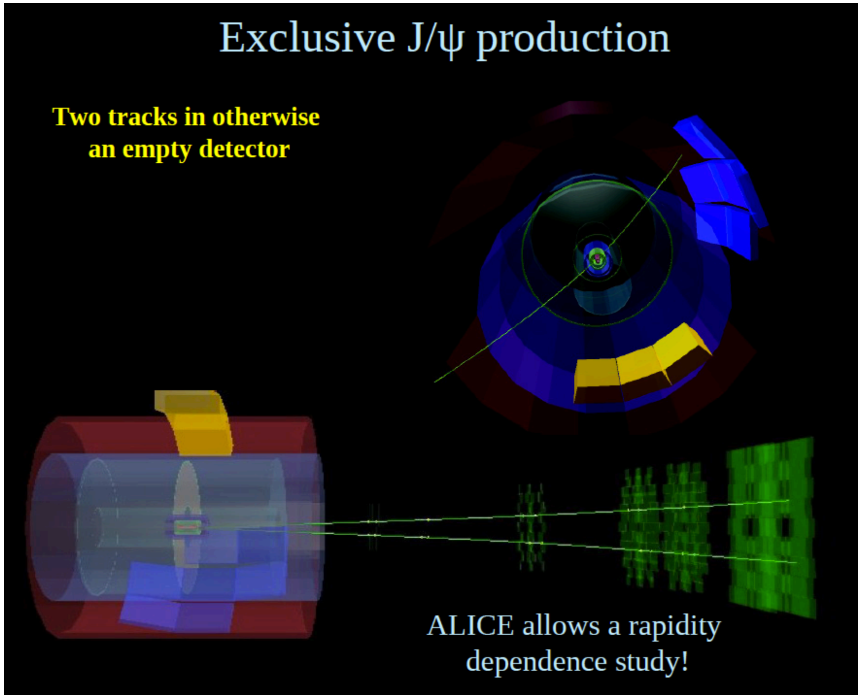


2. Direct photonuclear interaction: γ +parton (γ+g → qq, g+q→jet+jet)

Ultra peripheral collisions studies (a taste)

Starlight simulations for coherent J/ψ

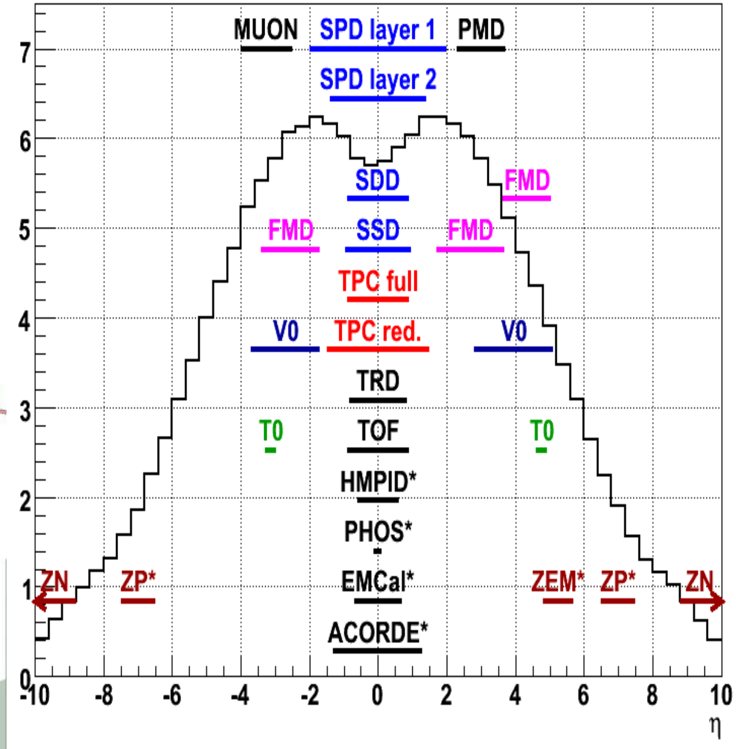


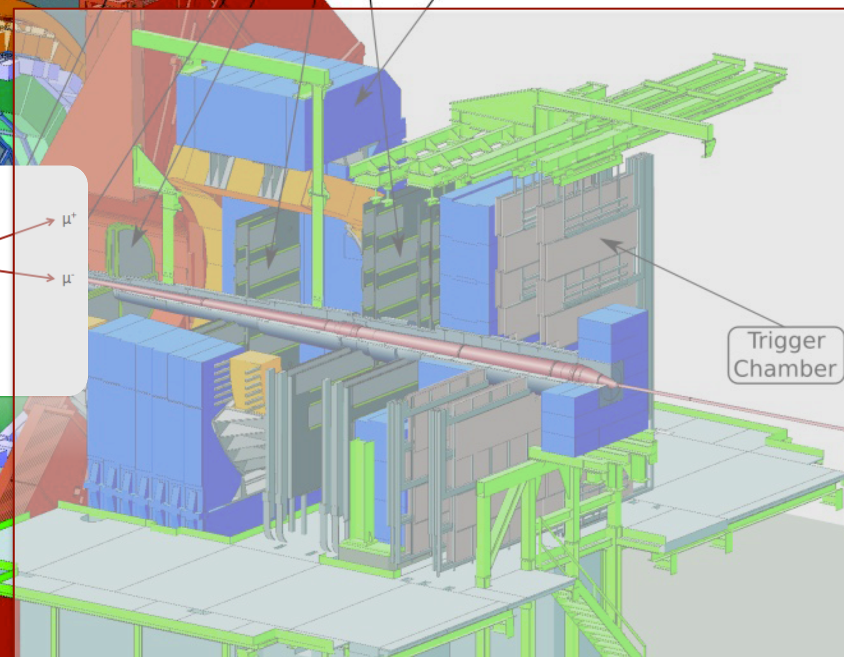


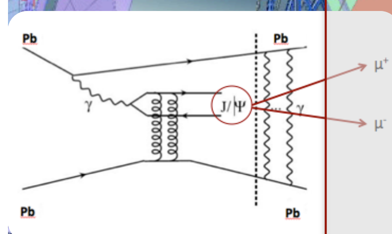
Three J/ψ analysis are possible in ALICE

1. Both dileptons (muons or electrons) at central rapidity, $-0.9<y<0.9$
2. Both muons at forward rapidity, $-4.0 <y< -2.5$
3. One forward muon and the other at mid-rapidity

Ultra peripheral collisions studies (a taste)







$J/\psi \rightarrow \mu^+\mu^-$

Inner tracking system (ITS)

Time Projection Chamber (TPC)

$-4 < \eta < -2.5$

Forward rapidity: Muon arm + VZERO trigger: at least one muon candidate + veto on VZERO-A.

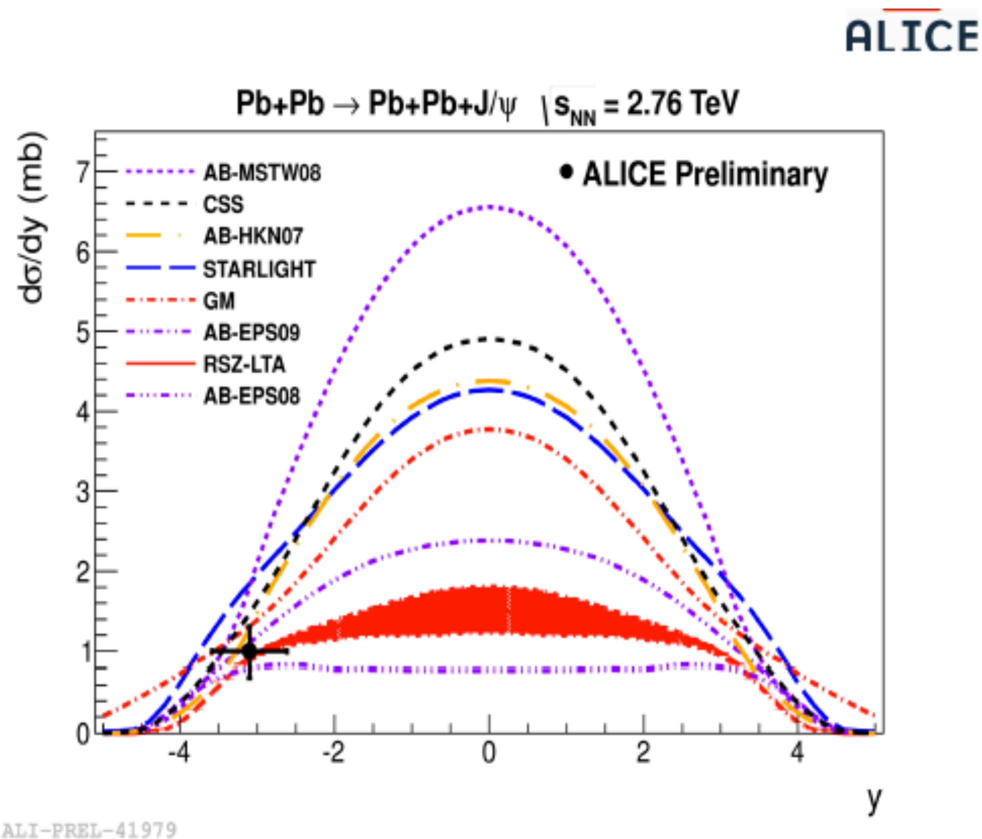
~ 3.4 M muon UPC triggers collected in 2011

Ultra peripheral collisions studies (a taste)

1. AB-MSTW08 - No nuclear effects
All nucleons contribute to the scattering dσ/dt at t=0 scales with A^2

2. STARLIGHT, CM and CSS Glauber approach to calculate the number of nucleons contributing to the scattering. Dependence on total J/ψ-nucleon cross section

3. Partonic models (AB-EPS08, AB-EPS09, AB-HKN07, RSZ-LTA)
Cross section proportional to the nuclear gluon distribution squared



Most forward J/ψs in UPC Pb-Pb at LHC are from low photon-proton c.m.s. energy

Either nucleus can serve as photon emitter or photon target, at forward rapidity (-3.6<y<-2.6), $x \sim 10^{-2}$ and $x \sim 10^{-5}$

The error is the quadratic sum of the statistical and systematic errors

Ultra peripheral collisions studies (a taste)

- **ALICE** has made the first LHC measurement on J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at 2.76 TeV, per nucleon pair

- **Coherent J/ψ differential cross section**

$$d\sigma^{coh}_{J/\psi}/dy = 1.00 \pm 0.18(\mathrm{stat})^{+0.24}_{-0.26}(\mathrm{syst})\ \mathrm{mb}$$

$-3.6<y<-2.6$
$p_T<0.3$ GeV/c

- AB-MSTW08 is strongly disfavoured. It assumes that the forward scatting cross section scales with the number of nucleons squared. STARLIGHT cross section is also disfavoured

- Best agreement is found with models that include nuclear gluon shadowing (RST-LTA, AB-EPS08, AB-EPS09)

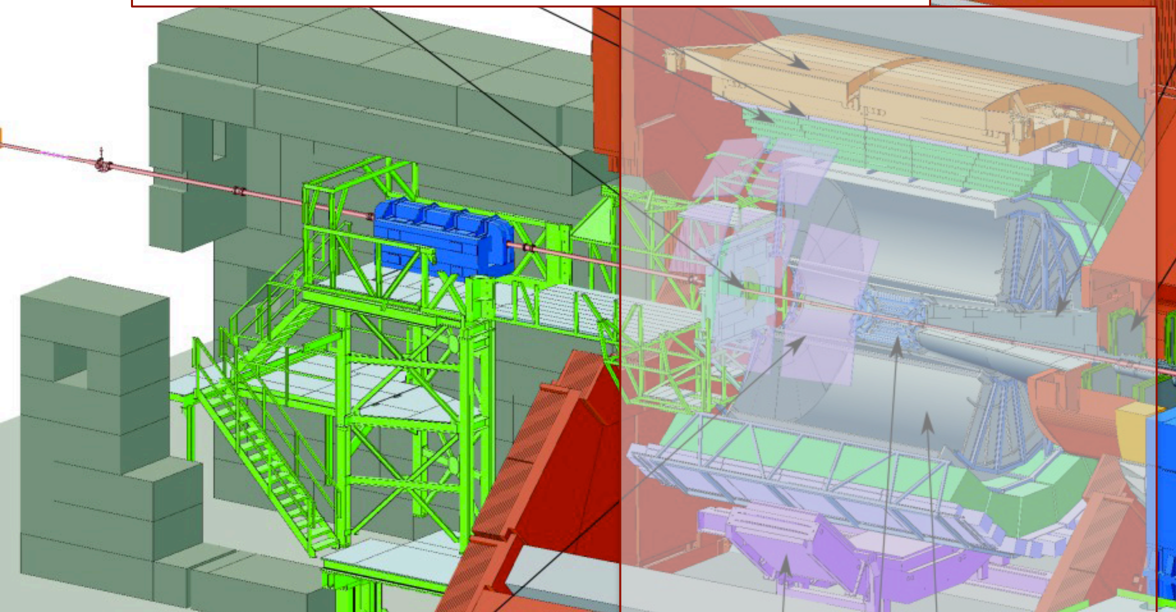
Ultra peripheral collisions studies (a taste)

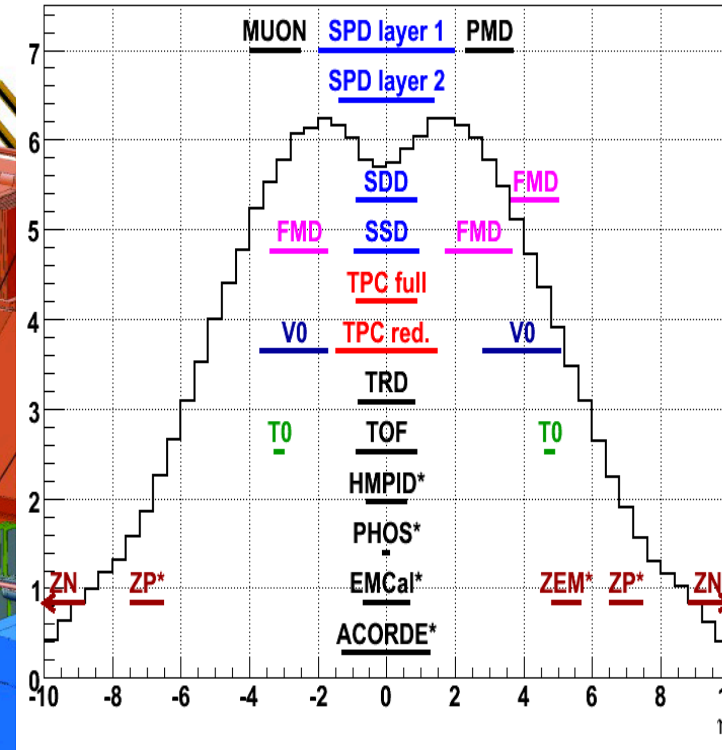
$J/\psi \rightarrow e^+e^-, \mu^+\mu^-$

Inner tracking system (ITS)

Time Projection Chamber (TPC)

$|\eta| < 0.9$





Central rapidity: TOF trigger requiring a hit multiplicity to be between 2 and 6, vetoing signals from both VZERO detectors, and with at least 2 hits in SPD. In addition, at least one of the triggered tracks by TOF has the angular correlation $150^0 < \Delta\phi < 180^0$

Ultra peripheral collisions studies (a taste)

Also, we can try to look for the rho in UPC events (2010 and 2011 data sample)

Two triggers used for central events (LHC10h period)

- C0OM2-B-NOPF- ALL: at least two hits in TOF
- CCUP2-B-NOPF-ALL: at least two hits in TOF + at least two hits in SPD + VZERO veto

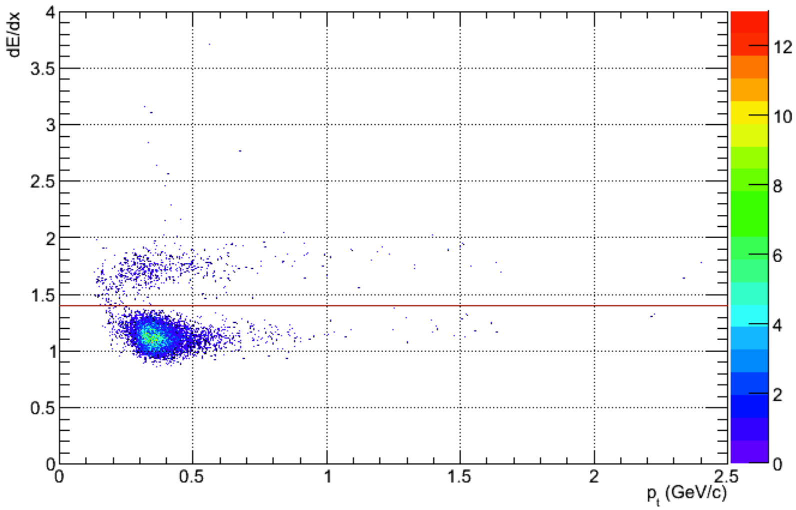
Event selection

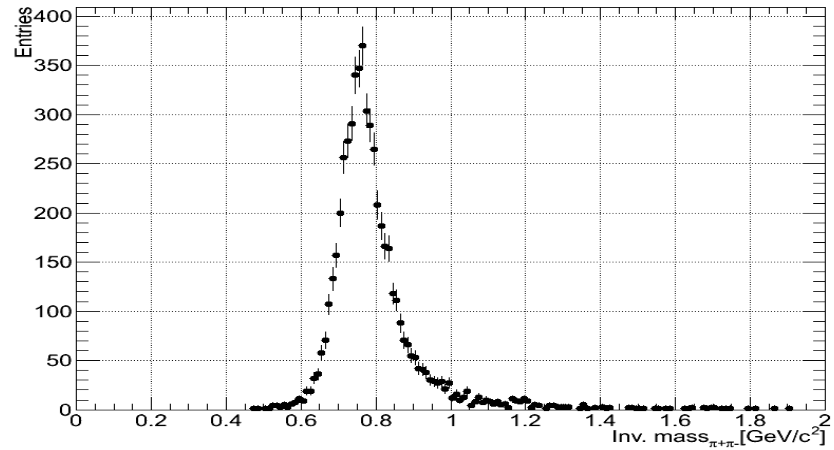
- C0OM2 (or CCUP2) triggers
- Primary vertex events
- VZERO veto
- Exactly 2 tracks

Track selection

- Standard track cuts for 2010 data (TPC clusters>70, chi^2/clusters <5)
- Opposite charged pair tracks
- Track rapidity (y): |y|<0.5
- Track dE/dx / 47 < 1.4
- Pair track p_t <0.15 GeV/c

Ultra peripheral collisions studies (a taste)





Cut	# of events
Events analyzed	3,926,902
C0OM2 triggers	1,273,230
Primary vertex	777,928
Two accepted tracks	33,334
Standard cuts (2010)	32,528
|Vz|<10 cms.	29,262
VZERO veto	9,326
dE/dx cut	8,113
|y|<0.5	3,079
Pt < 0.15 GeV/c	2,038

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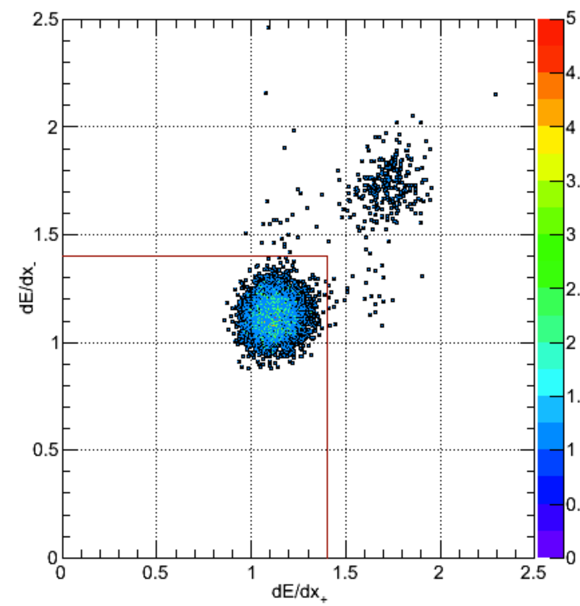


Ultra peripheral collisions studies (a taste)

Why to look for excited states of ρ^0 in Pb-Pb and p-Pb

- Not clear how many excited states exist, or their possible quantum numbers (see special PDG review)
- STAR already published a paper on four-pion production in UPC
- No HERA papers on the photoproduction of a ρ^0 excited state
- Look for $\rho^0(600)$?

Ultra peripheral collisions studies (a taste)

THE $\rho(1450)$ AND THE $\rho(1700)$

Updated May 2010 by S. Eidelman (Novosibirsk) and G. Venanzoni (Frascati).

In our 1988 edition, we replaced the $\rho(1600)$ entry with two new ones, the $\rho(1450)$ and the $\rho(1700)$, because there was emerging evidence that the 1600-MeV region actually contains two ρ-like resonances. Erkal [1] had pointed out this possibility

the τ mass. A recent very-high-statistics study of the $\tau \rightarrow \pi\pi\nu_\tau$ decay performed at Belle [18] reports the first observation of both $\rho(1450)$ and $\rho(1700)$ in τ decays.

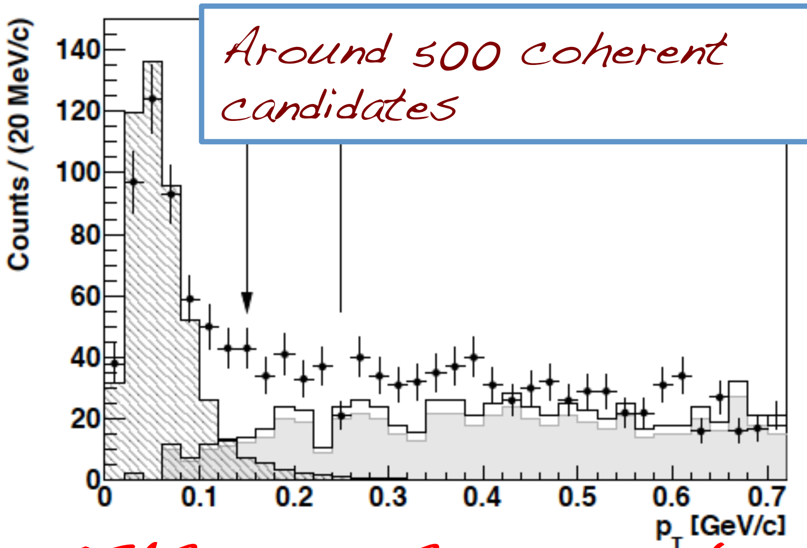
The structure of these ρ states is not yet completely clear.

Ultra peripheral collisions studies (a taste)

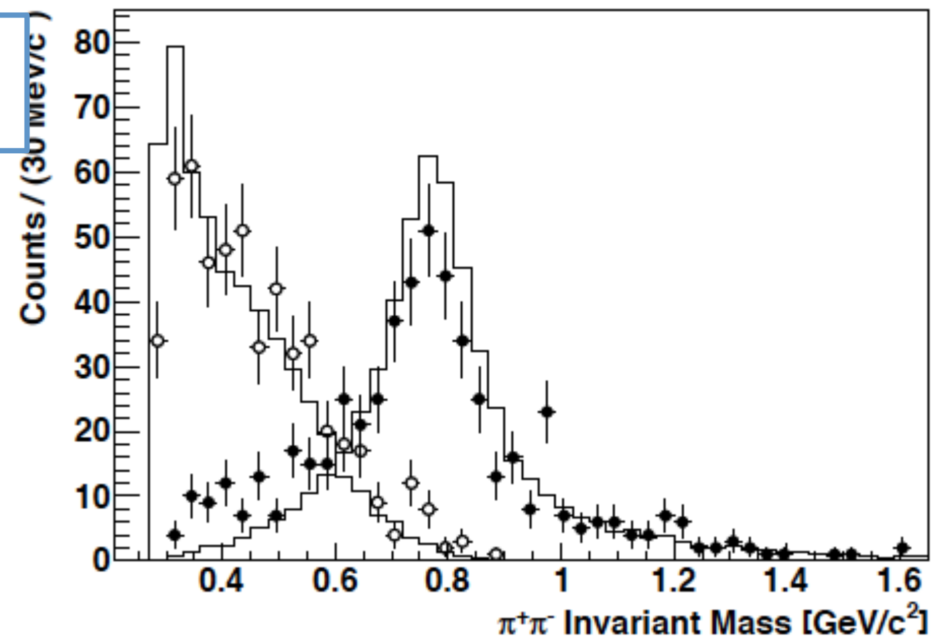
We now list under a separate entry the $\rho(1570)$, the $\phi\pi$ state with $J^{PC} = 1^{--}$ earlier observed by [27] (referred to as $C(1480)$) and recently confirmed by [28]. While [29] shows However, the sensitivity of the two latter is an order of magnitude lower than that of [28]. Note that [28] can not exclude that their observation is due to an OZI-suppressed decay mode of the $\rho(1700)$.

width is substantially larger. Recently [28] observed a structure at 1.9 GeV in the radiative return to the $\phi\pi$ final state, with a much smaller width of 48 ± 17 MeV consistent with that of [56,58]. We list these observations under a separate particle $\rho(1900)$, which needs confirmation.

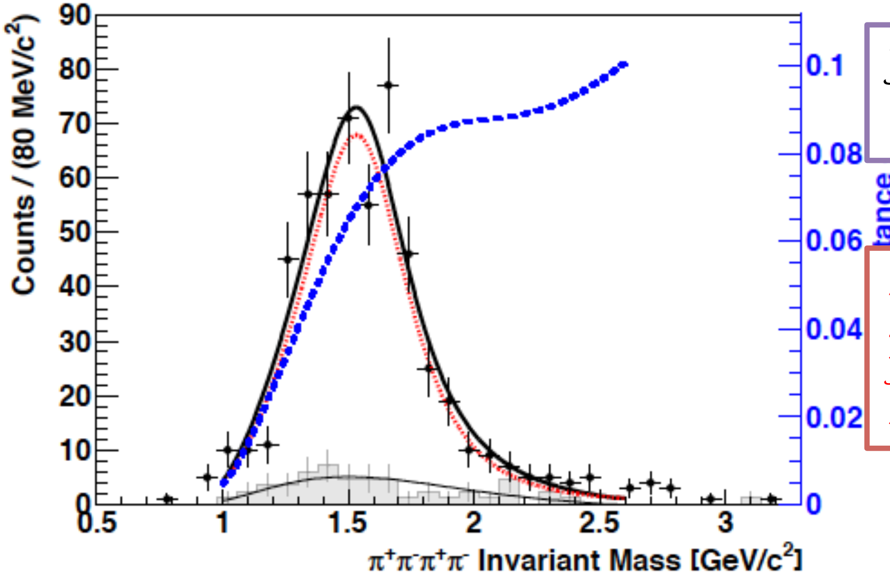
Ultra peripheral collisions studies (a taste)



Around 500 coherent candidates



STAR paper: PRC 81 044901 (2010)



Decay of $\rho^0(1700)$ assumed to be to a $\rho^0(770) + f_{0(600)}$ state

Main results:
Photoproduction of $\rho^0(1700)$ to 4π
Decay to 2π not seen
Ratio of $\rho^0(770) / \rho^0(1700)$ cross sections

Ultra peripheral collisions studies (a taste)

Event selection

- C0OM2 (or CCUP2 or CCUP4 for 2011 data) triggers
- Primary vertex events
- VZERO veto
- Exactly 4 tracks

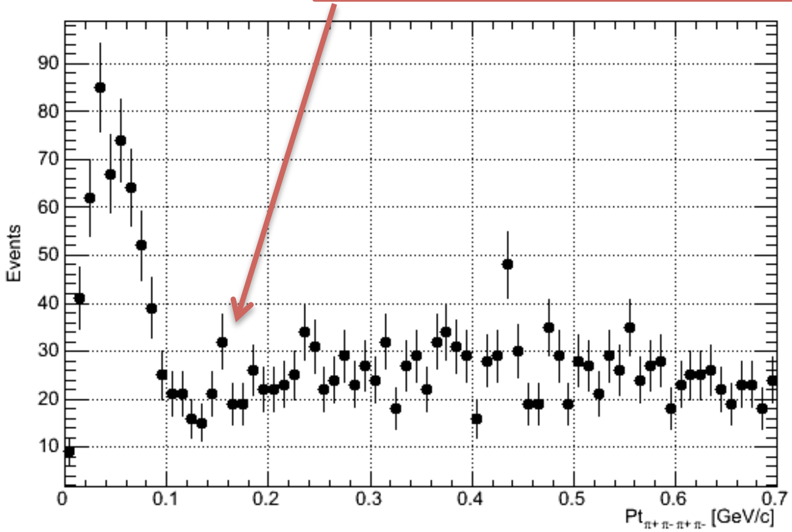
Track selection

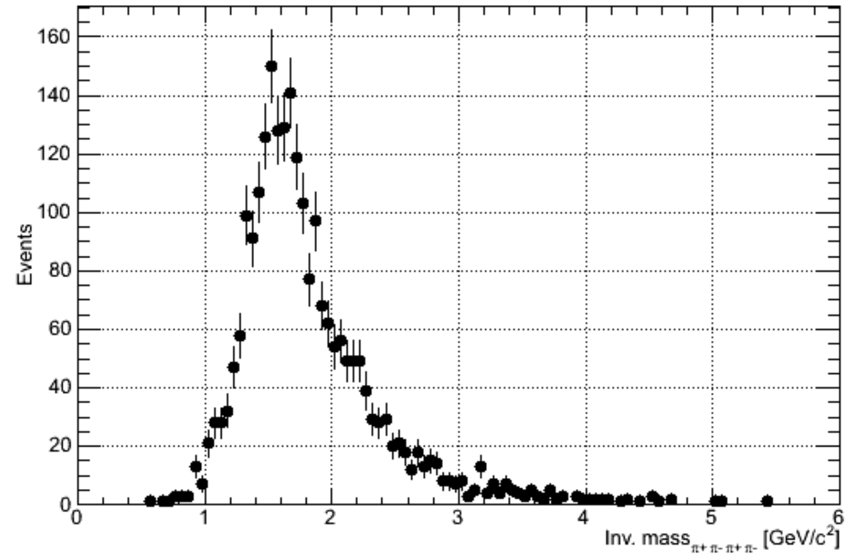
- 2 Opposite charged pair tracks

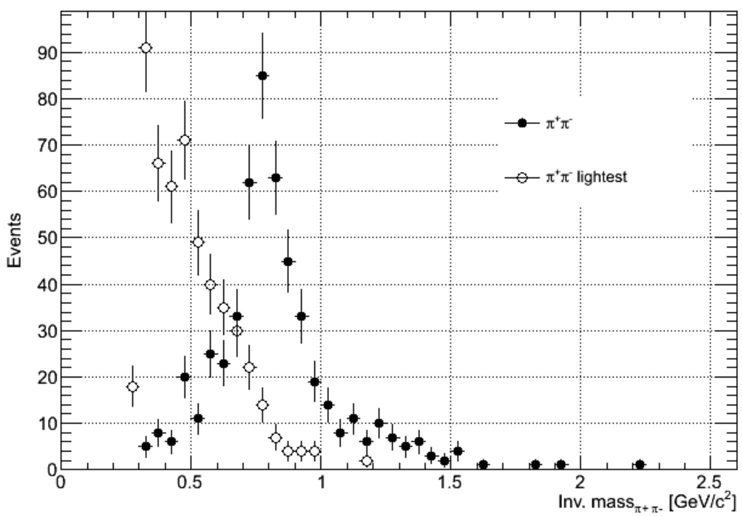
Ultra peripheral collisions studies (a taste)

$\pi^+\pi^-\pi^+\pi^-$ photo-production in UPC Collisions: A first look to the data (LHC10h)

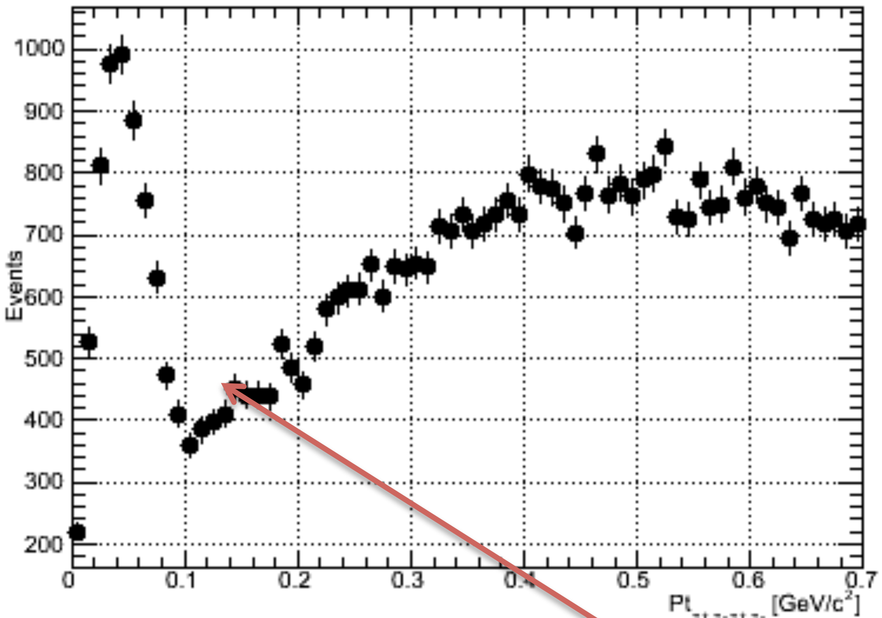
Pt of four π < 0.15 GeV/c (coherent events): 612

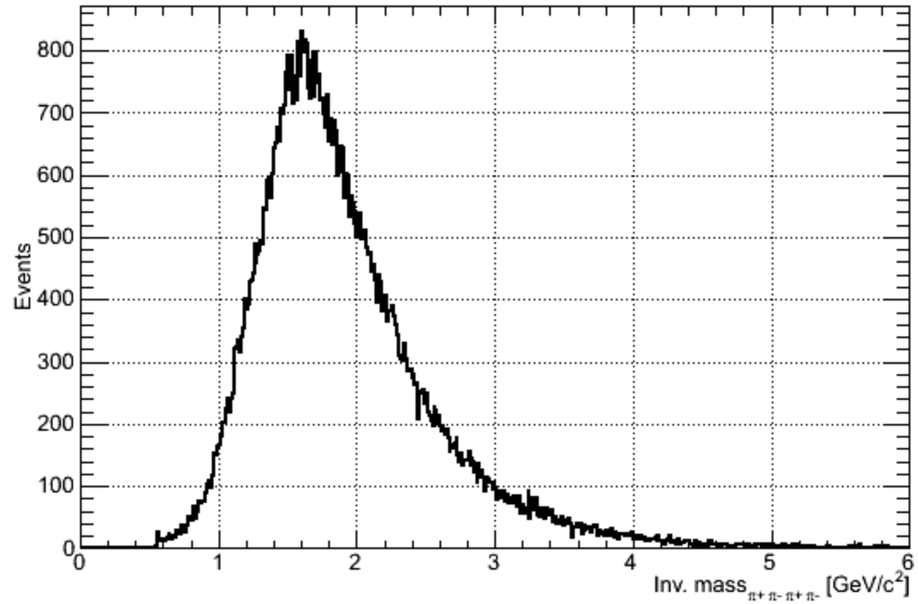


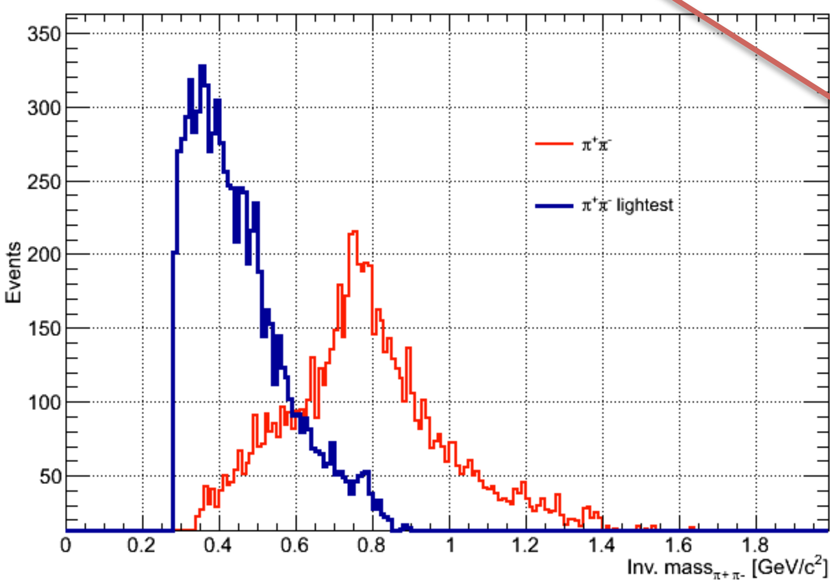




Ultra peripheral collisions studies (a taste)







Pt of four π < 0.15 GeV/c (coherent events): 8683

Ultra peripheral collisions studies (a taste)

We have carried out a first analysis at ALICE to look for excited states of rho0 - first results are very promising results!

--> Four-pion signal in 2010 very similar than what was published by STAR
--> Four-pion signal in 2011 → 10 times more statistics than in 2010
--> There may be a Rho prime signal also in the Two-pion channel for 2011 data