THESIS ABSTRACT

学位论文摘要汇编

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学 位 论 文 摘 要 汇 编

高能物理研究所学位委员会

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极高能宇宙线广延大气簇射研究

姓　名：戴宏跃
导　师：霍安祥
学　位：博　士

摘　要

论文主要研究了极高能宇宙线（大于 10^{17}eV）所引起的广延大气簇射（EAS）现象，包括：广延大气簇射横向分布结构以及次级粒子到达时间分布的测量，能量定标参数及次级粒子到达时间的 Monte Carlo 模拟，还讨论了能量决定误差对能谱测量的影响．另外，借助于明野（AKENO）的常规广延大气簇射阵列，对 Linsley 效应（以次级粒子的到达时间分布来估计簇心的距离）从实验上进行了估价．

为了确定广延大气簇射的横向分布结构，我们分析了明野 $1km^2$ 阵列六年来（1980～1986）所积累的数据，Linsley 的双参数函数被用来代替传统的 NKG 函数进行数据拟合，但在方法上作了一定的改进．本工作所给出的双参数 α、η 为（对 $10^{16.7}$eV～10^{18}eV 的大气簇射的拟合结果）：

$$<\alpha> = (1.76\pm0.02)-(0.23\pm0.15)(\sec\theta-1)+(0.30\pm0.06)\log(N/10^8)$$

$$<\eta> = (3.48\pm0.02)-(0.61\pm0.15)(\sec\theta-1)+(-0.09\pm0.05)\log(N/10^8)$$

此结果显著地不同于 Linsley 的结果．分析中发现，距簇射中心 1 个 Moliere 单位处的粒子数密度梯度（或称之为局部斜率）的涨落远小于 α 和 η 的涨落．局部斜率可以表述为：

$$slp(1)=(2.626\pm0.003)-(0.463\pm0.024)(\sec\theta-1)+(0.116\pm0.008)\log(N/10^8)$$

尽管总粒子数的涨落很小（10^{19}eV 的广延大气簇射总粒子数的涨落在海平面大约为 27%），但是，一个大间距的广延大气簇射阵列很难对总粒子数进行测量．通过模拟计算发现，远心区粒子数密度的涨落远小于近心区，而且也适合于明野 $20km^2$ 的阵列进行测量．模拟结果表明：S(600)（距簇射中心 600 米处的粒子数密度）在纵向发展过程中的涨落小于 20%，明野阵列对其的测量误差（大于 10^{18}eV 的大气簇射）小于 35%．Monte Carlo 模拟还给出在明野高度（930 g/cm^2）10^{17}eV 以上的垂直簇射 S(600) 与原初能量之间的关系为：

$E\,(eV) = (2.03\pm0.10)\times10^{17}\cdot S(600)^{(1.02\pm0.02)}$

在宇宙线能谱的测量中，由于能量决定误差的存在，宇宙线的表观通量会增加 $\exp((\gamma-1)^2\cdot\sigma^2/2)$ 倍（γ：宇宙线能谱的微分谱指数，σ: lnE 的误差）. 通过考虑明野阵列的测量误差和明野阵列有效触发面积，我们对明野阵列的能谱进行了误差模拟分析，结果发现能谱的通量和谱的拐折的位置都发生了变化. 对 Haverah Park 能谱分析的结果表明：能谱在 6×10^{19}eV 左右截断是合理的.

通过在明野常规阵列中设置一个微型阵列，我们对广延大气簇射次级粒子的到达时间分布进行了测量. 实验结果表明：平均来说，Linsley 关于次级粒子的时间分布宽度与距离 r（到簇射中心）的关系是成立的，但是，事例与事例之间的涨落很大. 从时间分布宽度推导簇心距离 r 的误差不小于 25%，推导总粒子数的误差 (σlnN) 不小于 0.8（～120%）. 以这样的精度来测量宇宙线能谱，表观通量约为实际通量的 2～3 倍，因此，如果不能有效地降低到达时间分布的测量误差，用微型阵列来测量宇宙线能谱是不太合适的. Monte Carlo 模拟计算表明：事例与事例之间到达时间分布的表观离散主要是由于测量到的粒子数太少所引起的小样本的统计涨落. 同时，模拟计算所显示的到达时间分布与原初能量、原初成绩和第一作用点高度无关的结果与实验结果相符。

Research of Extreme – High Energy EAS

Name: Dai Hongyue
Supervisor: Huo Anxiang
Degree: Doctor

ABSTRACT

The thesis concentrates on the extreme – high energy Extensive Air Shower (EAS) studies, including the measurements of the EAS lateral structure, and the arrival time distribution of shower secondaries at large distance. By the Monte Carlo simulation, the parameters forenergy estimation have been investigated, also, a simulation about the arrival time distribution has been made to compare with the measurements. The effect on energy spectrum due to the error in energy determination has been discussed. In addition, by the combination of Akeno conventional array with a mini – array, the Linsley Effect hasbeen evaluated experimentally.

The experimental data accumulated by Akeno 1km^2 array (1980 – 1986) have been used for determining the EAS lateral distribution. Instead of using NKG function to fit the experimental data, Linsley's doubleparameter function has been chosen, with improved analysis method. Present measurements gives

$$<\alpha> = (1.76 \pm 0.02) - (0.23 \pm 0.15)(\sec\theta - 1) + (0.30 \pm 0.06)\log(N/10^8)$$

$$<\eta> = (3.48 \pm 0.02) - (0.61 \pm 0.15)(\sec\theta - 1) + (-0.09 \pm 0.05)\log(N/10^8)$$

for showers between $10^{16.7}$ eV to 10^{18} eV, which is different from Linsley's results significantly. From the analysis, it is found that the fluctuation of local density gradient (or local slope) around1 Moliere unit is much smaller than that of p and η. The local slopecan be expressed as:

$$sl\,p(1) = (2.626 \pm 0.003) - (0.463 \pm 0.024)(\sec\theta - 1) + (0.116 \pm 0.008)\log(N/10^8)$$

Though the fluctuation of total number of particles is reasonably small

27% at sea level for 10^{19} eV showers), it is very difficult to measure it with the large span detector array. Through the Monte Carlo simulation, it is found that the fluctuation of the local density far from the core is much smaller than the one near the core, and the local densities at large distances are easy to be measured with the Akeno 20km ^{2} Array. Simulation shows that, the fluctuation of S(600) (density at 600 m from the core) is less than 20%, and the measurement error at Akeno is less than 35% for shows above 10^{18} eV. The simulation gives:

$$E\,(eV) = (2.03 \pm 0.10) \times 10^{17} . S(600)^{(1.02 \pm 0.02)}$$

for vertical showers above 1017 eV at Akeno level.

Due to the error in energy determination, the apparent flux increasesby a factor of $\exp((\gamma-1)^2/2 \cdot \sigma^2/2)$ (γ: differential spectra index, σ: fluctuation of lnE). By considering the measurement error and the effective area in Akeno, the effect of error on energy spectrum hasbeen investigated through simulation. It is found that both the flux and the kink position shifted. Analysis about the Haverah Park spectrum suggests an energy spectrum cut-off around 6×10^{19} eV.

The arrival time distribution of shower secondaries far from the core has been measured by a mini-array combined with Akeno conventionalarray. Experimental results show that in average, Linsley's relation between the time spread and axial distance is valid, but the fluctuation from event to event is very large. the uncertainity of axial distance estimation (from time spread) is not less than 25%, and of shower size is about 0.8 ($\sigma(\ln N)$). With such an uncertainity, the apparent flux at least increase 2-3 times, therefore, it is not suitable to measure the energy spectrum by the mini-array if the uncertainity can not be reduced. Monte Carlo simulation shows that the apparent fluctuation is due to the limited number of particles, and the arrival time distribution is independent of the primary energy, composition and first interaction height, in accordance with the experimental results.

气体取样铀强子量能器的实验研究

姓　名：张守宇
导　师：唐孝威
学　位：博　士

摘　要

为了精密验证现代粒子物理理论(弱电统一理论,各种大统一理论等)并寻找现新的粒子和它们之间的相互作用,目前正在进行和将要进行的加速器粒子物理实验要工作在几十 GeV到几十 TeV的能区。在此能区中感兴趣的大部分事例都伴随有终态的强子(例如:Z^{0}粒子衰变百分之七十以上的分支比都到强子),用一般的磁谱仪测量这些强子的动量等将非常困难,甚至不可能。本文将介绍的强子量能器则是记录这些强子终态的有力工具,它具有以下特点:

1). 对带电和中性的粒子都灵敏

2). 对粒子能量 E 的分辨率,随 $1/\sqrt{E}$ 变好

3). 随入射粒子能量 E 的增加,其尺只寸随 lnE 增加

4). 通过分析粒子簇射的分布可准确定出入射粒子的位置和方向

5). 对电子、Muon、强子有不同的响应,可用来鉴别粒子

6). 有很快的时间响应

论文首先介绍强子量能器的工作原理和它的现况,然后详细讨论作者参加L3强子量能器研制的全过程。L3强子量能器是以铀－238作吸收材料、气体取样型的强子量能器,其主要特点是以铀－238做吸收材料,用正比室作探测元件,这在世界上气体取样型强子量能器的研究中是第一次。作者参加进行的研制过程包括四个阶段:1.强子量能器正比室的制作和测试;2.强子量能器模块的安装和检测;3.强子量能器模块组在加速器束流上的测试;4.实验数据分析和讨论。

1.强子量能器正比室的制做和测试阶段

L3强子量能器中的取样探测器是内截面为5×10mm 的矩形正比管组成的正比室,中心穿有直径为50微米的镀金钨丝,张力为250克。作者独立完成了10块这样的正比室(平均每块45根正比管),并使它们通过了严格的耐高压检验、丝张力检验、气密检验、漏电流检验和噪声检验等。

2. 强子量能器模块的安装与检测

作者于1986年9月去瑞士联邦反应堆研究所(现称PSI),在这里做好的正比室被组装成模块。模块分长短两种,分别有60和53块正比室以及相应的铀板相间而成。作者在这里的主要任务是建立相应的测试系统,对安装中的和安装好的模块进行严格的检验以保证其满足L3实验的各项要求,其中包括模块中维持正比室工作的高压系统、气体系统和丝信号读出系统等。由于每个模块有2500多根正比管,它们组合成近200路信号输出,使检测系统和检测过程也不得不变得很复杂,所以采用了计算机进行控制和计录。最重要的是作者在检测最初几个模块中,总结出模块制做过程中经常出现的问题的原因,为以后大批模块制做中如何避免这些问题提供了依据。另外利用该研究所的游泳池反应堆等有利条件,作者还设计了专门的实验对强子量能器中所使用的胶、通气管道的耐辐射性能进行了检测,结论表明它们能够满足L3实验的要求。

3. 强子量能器模块组的加速器束流测试

在完全模拟L3强子量能器实际工作时的情况下,我们用在欧洲核子研究中心(CERN)的SPS加速器束流产生的2－50GeV的电子、强子(Pion)和Muon对做好的强子量能器模块分两次(1986年和1987年)进行了测试,得到了大批的实验数据。

4. 实验数据分析和讨论

1987年9月作者回到国内编写程序对以上数据进行了详细的分析。得到了该强子量能器的各种工作参数并给出了相应的讨论和解释。在L3强子量能器工作时的一个特点是它前面有BGO电磁量能器,实验数据表明,它们联合应用时对强子能量测量的影响是不大的,作者在论文中对这个结果提出了解释。L3强子量能器是目前制成的气体取样型强子量能器中能量分辨率最好的,作者提出这不是一般所谓"补偿"效应的结果,而是铀的低结合能、高原子序数和裂变性质所决定的。在未来超高能加速器粒子物理实验中,气体取样型强子量能器有着重要的地位。作者根据实验结果指出,气体取样型强子量能器的取样厚度对能量分辨率的影响比较显著,在能包括整个强子簇射的强子量能器物质中,尽可能提高气体取样比例对提高气体取样型强子量能器的能量分辨率有着重要的意义。作者在论文中还对L3强子量能器在LEP物理研究中的作用提出了看法。

Experimental Study of Uranium Gas Sampling Hadorn Calorimeters

Name: Zhang Shouyu
Supervisor: Tang Xiaowei
Degree: Doctor

ABSTRACT

To test the modern physics theory (electroweak theory, variousunificationn theories etc.) and search for new particles and newinteractions, experiments on accelerators are being done and are going to be done in the GeV to TeV region. In this region, many interesting events will have the final state with hadrons (eg. more than 70 per cent decay fraction of Z paiticles goes to hadronic channels). Using normal magnetic spectrum meter method to measure the momentum of these hadrons will be very difficult or impossible.

This thesis will study a kind of forceful detector – HADRON CALORIMETERS which have the following capabilities:

1). sensitive to both charged and neutral particles
2). the energy resolution improves as 1/sqrt(E)
3). its size increase logarithmically with particle energy E
4). with segmentation, one can pricisely get the positioand direction of incident particle from its shower inside the detector
5). their quit different response to electrons, muons and hadrons can be exploited for particle identification
6). fast time response

At first, this thesis introduces the principle and the general properties of hadron calorimeters, then discusses in detail the all my works on the study of L3 hadron calorimeter. The L3 hadron calorimeter is a gas sampling uranium

hadron calorimeter. It is the first time to use uranium as absorb material in the study of gas sampling hadron calorimeters. My works could be roughly dividied into four parts: 1). the assembling and testing of the proportional chambers for the L3 hadron calorimeter; 2). the built up of the L3 hadron calorimeter module test set-up and the general property test of the modules; 3). the module test with 2-50 Gev pion, electron and muon beams; 4). the analysis and discussion of the experimental data.

1). the assembling and testing of the proportional chambers

The proportional chambers are composed by the proportional tubes which with the cross section of 5 10 mm , in the center of each tube there is a gold coted tugen wire with 50 micrometers in diameter, the tension on the wire is 250 g . The auther finished 10 of such proportional chambers (averagely 45 tubes for each chamber) and made them passed the test of high voltage, gas leakage, wire tension, leacage current and noise etc. 2). the built up of module test set-up and general module property test I worked in the Federal Institute of Reactor (now it is called PSI) of switzerland during the period of Sept. in 1986 to sept. in 1987, where chambers produced by several institutes were assembled into modules. There are two kinds of them: one contains 60 chambers, the other 53 chambers. My task in that period was to build up a series of test set-up for the module production and severe checking those produced modules to ensure they were good enough to be used in L3 detector. The checking contains high voltage test, gas leakage test and the uinformity test of gas gain for each wire grouping, etc. . Because of there are so many signal channels in each module, a personal computer was used to control the test process and record the test results. This procedure was been used latter in whole period of module production. Additionally, I've also designed a special test procedure that using the radiation background of a swiming pool reactor of the institute , to check if the glue and the gas conduct tube which were used in the modules are good enough to against the radiation of uraium decay, the results are OK.

3). The accelerator beam test of the modules

Uder the contion of fully simulating the actual working situation of

L3 hadron calorimeter at LEP, beams of electron, pion, muon with the energy of 2 − 50 Gev which were produced by the SPS accelerator at CERN were used to test and calibrate the modules. A lot of data was obtained q r

4). The data analysis and discussions

In Sept. of 1987 the auter went back to China and wrote programs to analysis the data. Various parameters of the hadron calorimeter were obtained. The experimental results of the hadron calorimeter were repoted, the discussion and explain about above by the author were also given. There is a BGO electromagnetic calorimeter in front of L3 hadron calorimeter is a special feature, experimental results told us that the energy resolution for hadron measurement is the same within error in both conditions: with and without BGO in frontof L3 hadron calorimeter. About this the author gave an explain. The energy resolution of the L3 hadron calorimeter is the best among those gas sampling hadron calorimeters already produced. The author pointed out that it is because of the low binding energy, high Z and fission property of uranium to give good energy resolution for L3 hadron caolrimeter, not as the so called "compensation" effect by neutrons. In the future, the gas sampling hadron calorimeters will possess a very important position in super high energy particle physics. According to our experiment, the author pointed out that the sampling unit thickness is obvously important in affecting the energy resolution for gas sampling hadron calorimeters.

To ob tain good energy resolution for a gas sampling hadron calorimeter, it is very important to increase the signal sampling ratio as more as possible under the condition of good containment of hadron showers. For the future dataanalysis of LEP experiment, as reference the author gave out some considerations about the function of L3 hadron calorimeter in the study of LEP physics.

论爱因斯坦引力论中的谐和条件

姓　名：黄超光
导　师：周培源
学　位：博　士

摘　要

论文系统地阐述了周培源的谐和条件是物理条件的观点，同时也综述了有关谐和条件的其它观点。谐和条件是物理条件这一观点可简述如下：在爱因斯坦引力理论中，物理时空是平直的，黎曼几何是作为描述引力物理现象而引入的数学语言，黎曼几何中的度规张量 $g_{\mu\nu}$ 代表引力势，它们满足爱因斯坦引力场方程组和谐和条件。由于谐和条件是物理条件，故在任何引力问题中都应采用这一条件。论文还较全面地考察了有关谐和条件的主要成果，它们包括静态和稳态引力场、平面引力波、实验检验、科西问题以及引力场的能量－动量－应力张量的表述等问题。在这里不仅仅是对已发表的结果进行综述，而且对其中的一些问题做了进一步的讨论。例如，我们重新讨论了实验检验的可能性，并说明了每一实验在澄清爱因斯坦引力论中坐标地位时所起的作用；我们还以 Reissner－Nordstrom 解为例说明了如果谐和条件是物理条件，则黎曼时空的所有物理区域都处于一个类空超曲面的依赖域内，即科西问题有解。论文的重点是将谐和条件是物理条件的观点用于相对论性宇宙论。我们首先将谐和条件是物理条件的观点用于静态de Sitter 宇宙这种较简单的情况，假定宇宙是空的静态de Sitter 宇宙，而星系在宇宙中沿测地线做径向运动，且星系之间没有引力相互作用。我们在这样的假定下把谐和条件用于星系的运动，给出了共动坐标系、de Sitter 坐标系及标准球坐标系之间的坐标变换。de Sitter 坐标系及标准球坐标系中的径向坐标的关系是：

$$r=(3/8)H^{-3}r'^{-2}\{(1+H^2r'^2)\log[(1+Hr')/(1-Hr')]-2Hr'\}$$

易见，当 $r'\to 1/H$ 时，$r\to\infty$。按照谐和条件是物理条件的观点，这一结果表明 de Sitter 宇宙的静态区域是无限的(而通常认为de Sitter 宇宙的静态区域是有限的)。在讨论红移与光强的关系时，我们将能量－动量张量 $T^{\mu\nu}$ 的 i－0 分量(i=1、2、3)看作坡印廷矢量，并以它代表光强。我们在光源是一堆频率相同但相位与取向随机分布的电偶极子的假定下求解宇宙中的麦克斯韦方程组，进而计算出坡印廷矢量和红

移一 光强关系。在共动坐标系、de Sitter 坐标系及标准球坐标系中所得到的坡印廷矢量及红移一 光强关系的形式是不同的，在一级近似下，在所有这些坐标系中红移一 光强关系是相同的，但在高级近似中，它们是有区别的。按照谐和条件是物理条件的观点，所观测到的光强应是在标准球坐标中的坡印廷矢量，故所观测到的红移一 光强应是在标准球坐标中的红移一 光强关系，这一点只能通过天文观测来证实。在讨论了 de Sitter 宇宙之后，我们研究了有物质的宇宙模型。我们假定宇宙在大于一亿光年的尺度上是均匀、各向同性的，宇宙的引力场仅由宇宙物质的平均密度来决定，而星系仍看作测试粒子，沿测地线做径向运动。我们把谐和条件用于宇宙，并利用级数方法就一般宇宙模型求解谐和条件，得到通常所用的Robertson— Walker 坐标与标准球坐标之间的关系：

$$t=\bar{t}+a\dot{a}\bar{r}^2+\sum_{m=1}^{\infty}\frac{3}{(2m+3)!}\left[\left(\prod_{l=m}^{1}O_{2l}\right)a\dot{a}\right]\bar{r}^{2m+2}$$

$$r=a\bar{r}+\sum_{m=0}^{\infty}\frac{3(2m+4)}{(2m+5)!}\left[\left(\prod_{l=m}^{1}O_{2l+1}\right)a\dot{a}\right]\bar{r}^{2m+3}$$

$\theta=\bar{\theta}\quad \varphi=\bar{\varphi}$ 其中 a 是尺度因子，满足爱因斯坦方程

$$O_n=a^2\frac{d^2}{dt^2}+3a\dot{a}\frac{d}{dt}+Kn(n+2)$$

$$\prod_{l=m}^{1}O_{2l}=O_{2m}\,O_{2m-2}\ldots O_2$$

$$\prod_{l=m}^{0}O_{2l+1}=O_{2m+1}\,O_{2m-1}\ldots O_1$$

作为例子，我们对于包括 $\Lambda=0$，$K=0$，±1 的物质为主和辐射为主的 Friedmann 宇宙在内的几种常用的宇宙模型求出了级数的和式。我们还讨论了小尺度近似，在观察者(即原点)附近，以爱因斯坦引力理论为基础的宇宙论退化为以牛顿引力理论为基础的宇宙论。本文在最后将对de Sitter 宇宙中的红移与光强的结果推广到有物质的宇宙中去，所得结果是相似的。在Robertson－Walker 坐标系及标准球坐标系中红移一 光强关系分别为

$$\bar{T}^{10}=-DNH^2z^{-2}[1+(q-2)z+\ldots]$$

$$T^{10}=-DNH^2z^{-2}[1+q-1)z+\ldots]$$

在一级近似下，它们是相同的，但在高级近似中，它们是有区别的。和前面

一样，按照谐和条件是物理条件的观点，只有标准球坐标中红移－光强关系才代表实际观测到的红移－光强关系。本工作的特点是从星系的运动和宇宙中的麦克斯韦方程推得速度－距离关系(或红移－光强关系)，这是处理问题的动力学和电磁学途径，它不同于通常采用的几何学处理方法，后者是先由对称性考虑得到宇宙度规，然后由协变守恒律及宇宙度规计算速度－距离关系。