中组部“青年千人计划”面试评审答辩

电弱物理的实验研究

尹航

美国费米国家加速器实验室（Fermilab）

全职回国单位：华中师范大学

1. 个人简历
2. 主要贡献
3. 工作设想和研究计划

简历

- 1984年10月出生

- 2005年7月获山东师范大学物理学学士学位
- 2010年7月获中国科学技术大学近代物理系博士学位
  - 指导老师：韩良教授
  - 2007 -- 2010在美国费米国家实验室（Fermilab）访问学生

- 2010年至今在美国费米国家实验（Fermilab）做博士后研究
  - 2010 -- 2013在D0国际合作组工作
  - 2013至今在CMS国际合作组工作

科研经历

- **物理研究：**
  - D0实验上寻找超对称R宇称破缺eμ 共振态新粒子，[PRL 100, 241803]，[PRL 105, 191802]
  - D0实验上精确测量弱混合角，[PRL 101, 191801]，[PRD 84, 012007]
  - D0实验上精确测量W玻色子电荷不对称性，[PRL 112, 151803]
  - 2012-2014：作为D0国际合作组的电弱物理组召集人（Convener）推动>10篇文章的发表

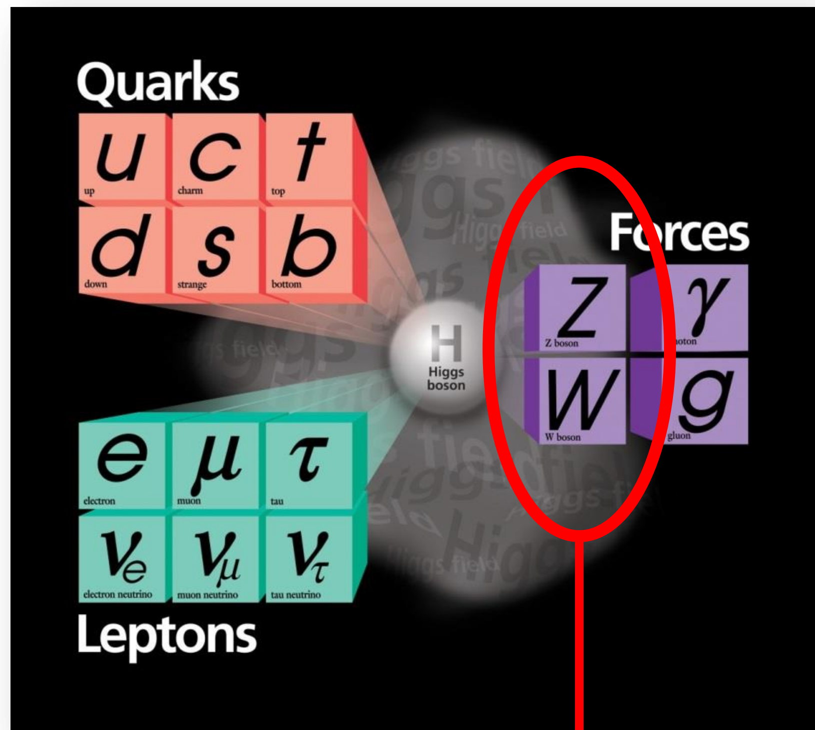
- **探测技术研究**
  - D0实验上量能器的精确刻度及能量测量
  - CMS探测器升级：硅径迹探测器触发系统的研发（Level-1 tracking trigger）

研究背景：粒子实验物理

- **基本科学问题：**
  - 物质世界最基本的构成及其基本相互作用
  - 质量与宇宙的起源
- **标准模型：**描述基本粒子及其相互作用的基本理论
  - 三代粒子：轻子，夸克
  - 规范玻色子传递相互作用：强相互作用，弱相互作用，电磁相互作用
  - 弱相互作用+电磁相互作用 → 电弱理论

学科特点：

- 大学科装置、尖端技术、高投入（LHC~$90亿）、长周期（~30年）
- 全球性的国际合作
- 产生了数十个诺贝尔奖



电弱物理的重要研究对象：W玻色子与Z玻色子

Tevatron加速器

<u>正反物质对撞最高能量</u>

- **Tevatron对撞机：**
  - 高能量质子反质子对撞：质心能量1.96万亿电子伏特（TeV）
  - 周长：6.28公里
  - 速度：质子/反质子加速到光速的 99.99999954%
- **Tevatron在28年的运行中产生了大量先进的科学成果（顶夸克的发现）**

D0合作组以及探测器

探测器:
尺寸：10*10*15 米
重量：5000吨
近100万读出通道

D0实验国际合作组（2014）：
- **15个国家，68个成员单位**
- **~400物理学家**

主要学术贡献

1. Z玻色子中测量弱混合角：
   – 标准模型的基本参量：强子对撞机上最精确测量

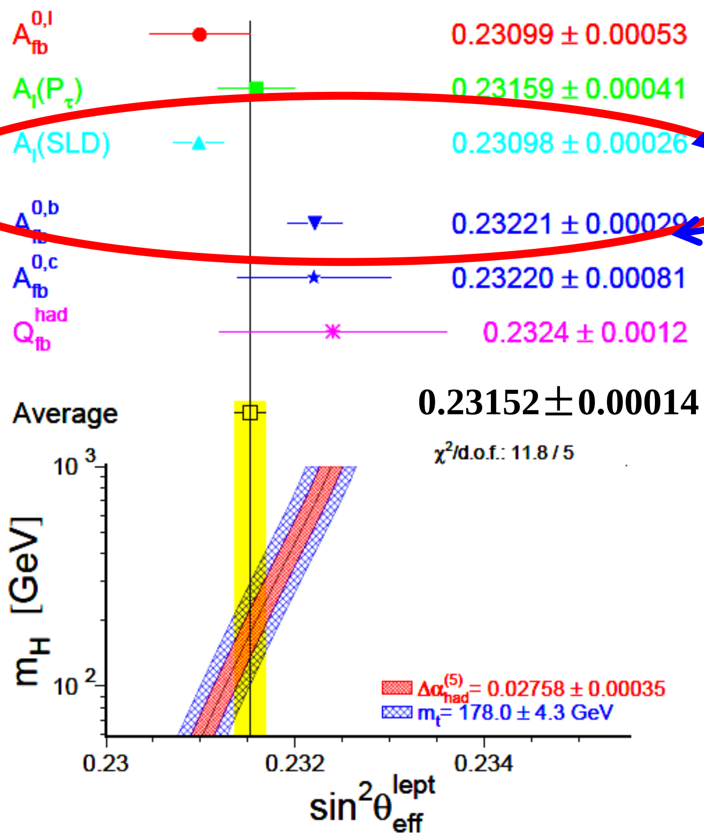
2. W玻色子的电荷不对称性研究
   – 为理论拟合提供了重要的实验输入

3. 与精确测量相关的探测器研究
   – 大型强子对撞机（LHC）高亮度下硅探测器触发系统研发

学术贡献一：Z玻色子中测量弱混合角

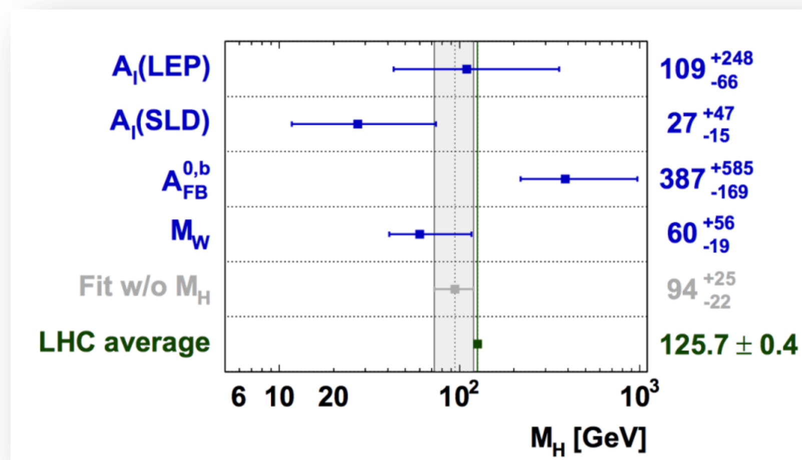
基本物理参数与标准模型的检验：

精细结构常数	W/Z玻色子质量	弱混合角		Higgs质量
$\alpha = e^2/_{4\pi}$	M_W, M_Z	$\sin\theta^2{}_W$	⟺	M_H



Higgs质量： 27^{+47}_{-15}GeV

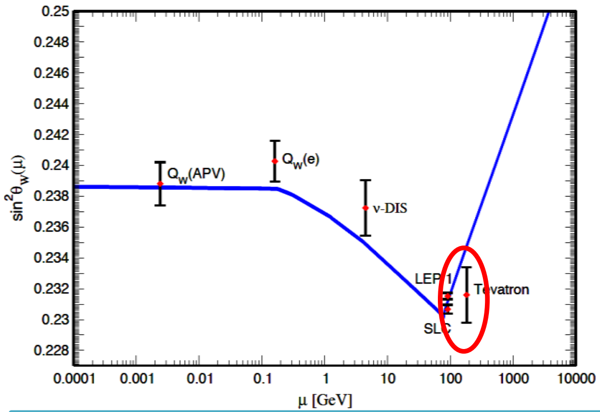
Higgs质量： 387^{+585}_{-169}GeV



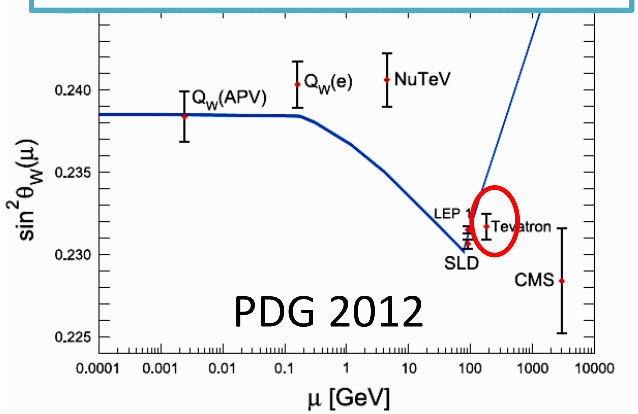
不同测量对应的Higgs质量不同

学术贡献一：Z玻色子中测量弱混合角

国际粒子物理数据库 Particle Data Group (PDG) 收录

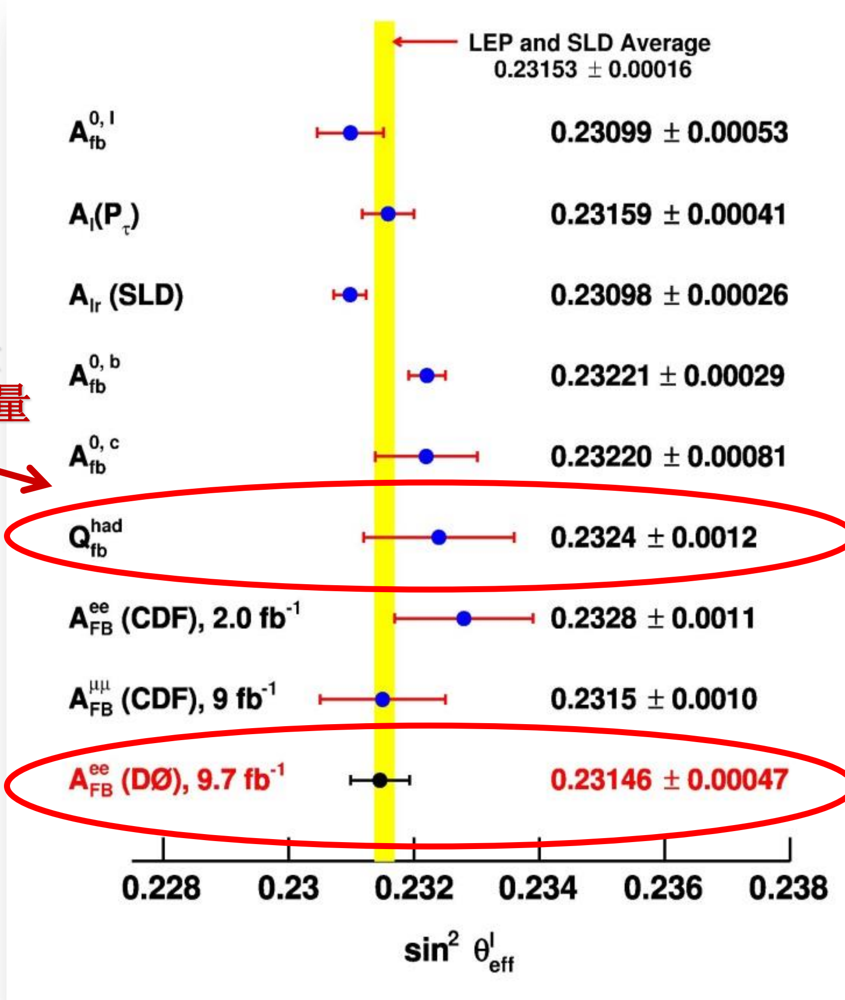


PDG 2010， **D0首次**测量
[PRL 101, 191801]



PDG 2012， **最精确与轻夸克相关测量**
[PRD 84, 012007]

LEP 4个实验
轻夸克末态测量



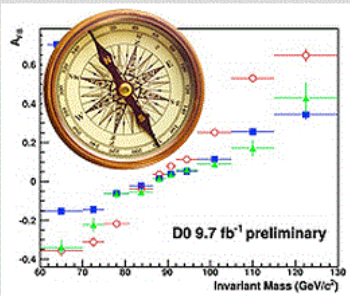
LHC/Tevatron未来10年最精确测量

学术贡献一：Z玻色子中测量弱混合角

Fermilab Today Friday, May 1, 2014

Frontier Science Result: DZero

Measuring the "direction" of the Standard Model



The weak mixing angle, recently measured by the DZero collaboration, expresses the relation between the observed photon and Z boson, and the more fundamental bosons of the unified electroweak interaction. This is analogous to expressing earthly interaction. This is analogous to expressing earthly directions in terms of the cardinal points of a compass. The angle is extracted by examining the variations in the forward-backward asymmetry of electron-positron pairs as a function of their combined mass.

Disponible en español

For some time, we've known that the apparently fundamental forces of electromagnetism and the weak interaction are actually just the low-energy manifestations of a single unified electroweak interaction. This beautiful concept was developed by theorists in the 1960s and has been confirmed resoundingly by years of rigorous experimentation, including the discovery of the *W*, *Z* and Higgs bosons. This theory has only a handful of parameters; measuring them with the highest possible precision is crucial to test the unification mechanism and search for possible hints of new physics signatures.

One such fundamental parameter is the weak mixing angle (or Weinberg angle,

after one of the pioneers of the
electr
comp
can b
and e
angle
weak
the ov
electr
terms
(phot
carrie
blend
electr
W^0.

The D
perfor
weak
Stand
of ele
origin
inhere
are m
protor
positr
of the
syster
deper
weak
extrac

This i
impro
DZero
doubl
expar
previc
increa
400 p
of the
also u
accur
energ
the m
the m
corre
derive

mass.

The final measurement of the weak mixing angle, with all improvements taken into account, is expressed as the quantity $\sin^2\theta^l_{eff}$, which we measure to be 0.23106 ± 0.00053, corresponding to an angle of around 29 degrees. This is the most precise determination of this parameter ever made at a hadron collider and is consistent with previous measurements made at the SLC and LEP colliders. It is also the most precise instance of extracting the weak angle using this inclusive electron-positron asymmetry method. As such, it provides an important input for global tests of the electroweak theory.

—*Mark Williams*

These DZero members all made significant contributions to this publication.

费米实验室"每周物理评论"

http://www.fnal.gov/pub/today/archive/archive_2014/today14-05-01.html

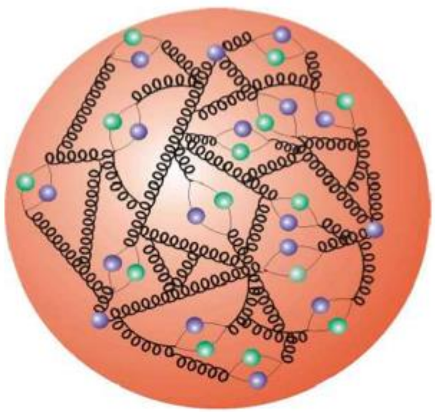
这是一个在强子对撞机上对弱混合角测量，并达到了前所未有的测量精度…

因此，它为电弱理论的各种全局检验提供了重要的输入。

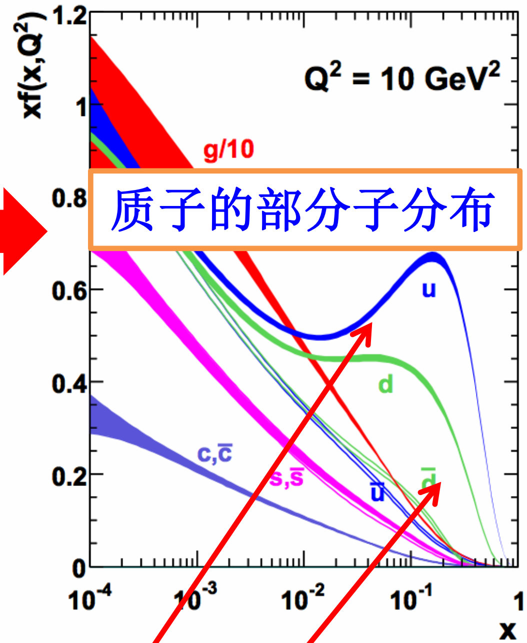
PRD 84, 012007

学术贡献二：W玻色子的电荷不对称性

- 质子的部分子分布函数（PDFs）



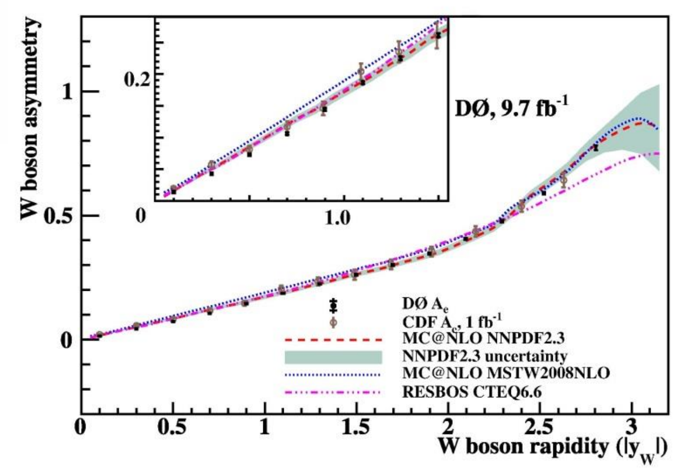
质子:高能标下



PDFs是强子对撞机上的基本输入：

- 几乎所有强子理论计算的输入值
- 不能精确计算，只能用实验输入

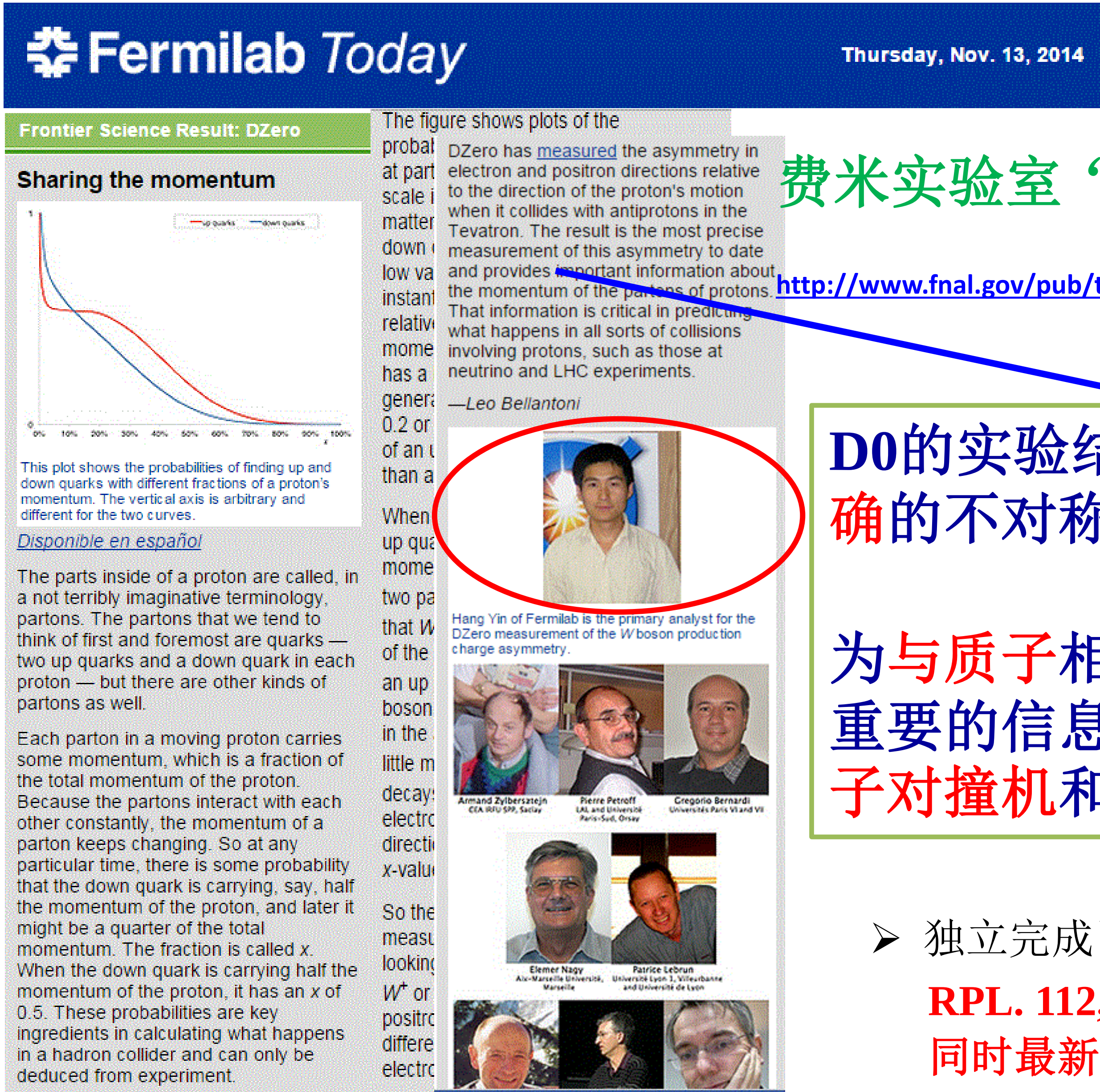
$$A(y_W) = \frac{\frac{d\sigma^+}{dy_W} - \frac{d\sigma^-}{dy_W}}{\frac{d\sigma^+}{dy_W} + \frac{d\sigma^-}{dy_W}} = \frac{u(x_p)\bar{d}(x_{\bar{p}}) - d(x_p)\bar{u}(x_{\bar{p}})}{u(x_p)\bar{d}(x_{\bar{p}}) + d(x_p)\bar{u}(x_{\bar{p}})}$$



由于u夸克所携带的动量大于d夸克动量, 0.002<x<0.99

PRL 112, 151803 (2014)

学术贡献二：W玻色子的电荷不对称性



Fermilab Today

Thursday, Nov. 13, 2014

Frontier Science Result: DZero

Sharing the momentum

This plot shows the probabilities of finding up and down quarks with different fractions of a proton's momentum. The vertical axis is arbitrary and different for the two curves.

Disponible en español

The parts inside of a proton are called, in a not terribly imaginative terminology, partons. The partons that we tend to think of first and foremost are quarks — two up quarks and a down quark in each proton — but there are other kinds of partons as well.

Each parton in a moving proton carries some momentum, which is a fraction of the total momentum of the proton. Because the partons interact with each other constantly, the momentum of a parton keeps changing. So at any particular time, there is some probability that the down quark is carrying, say, half the momentum of the proton, and later it might be a quarter of the total momentum. The fraction is called *x*. When the down quark is carrying half the momentum of the proton, it has an *x* of 0.5. These probabilities are key ingredients in calculating what happens in a hadron collider and can only be deduced from experiment.

The figure shows plots of the ...

DZero has measured the asymmetry in electron and positron directions relative to the direction of the proton's motion when it collides with antiprotons in the Tevatron. The result is the most precise measurement of this asymmetry to date and provides important information about the momentum of the partons of protons. That information is critical in predicting what happens in all sorts of collisions involving protons, such as those at neutrino and LHC experiments.

—*Leo Bellantoni*

Hang Yin of Fermilab is the primary analyst for the DZero measurement of the *W* boson production charge asymmetry.

Armand Zylbersztejn, CEA IRFU SPP, Saclay; Pierre Petroff, LAL and Université Paris-Sud, Orsay; Gregorio Bernardi, Universités Paris VI and VII; Elemer Nagy, Aix-Marseille Université, Marseille; Patrice Lebrun, Université Lyon 1, Villeurbanne and Université de Lyon

费米实验室“每周物理评论”

http://www.fnal.gov/pub/today/archive/archive_2014/today14-11-13.html

D0的实验结果是目前为止最为精确的不对称性测量…

为与质子相关的实验提供了至关重要的信息，例如欧洲的大型强子对撞机和中微子实验。

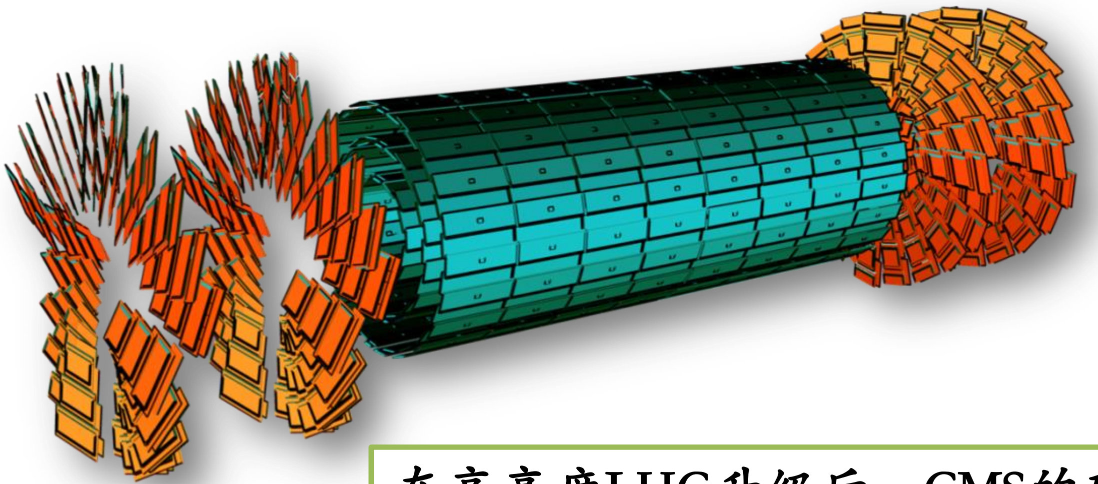
- 独立完成了整个物理分析

RPL. 112, 151803 (2014)

同时最新结果经合作组审核同意，提交到PRD

学术贡献三：硅探测器触发系统研究

- 硅探测器在高能物理中得到广泛的应用
- 处理大量的电子学信号成为了高能物理发展的瓶颈

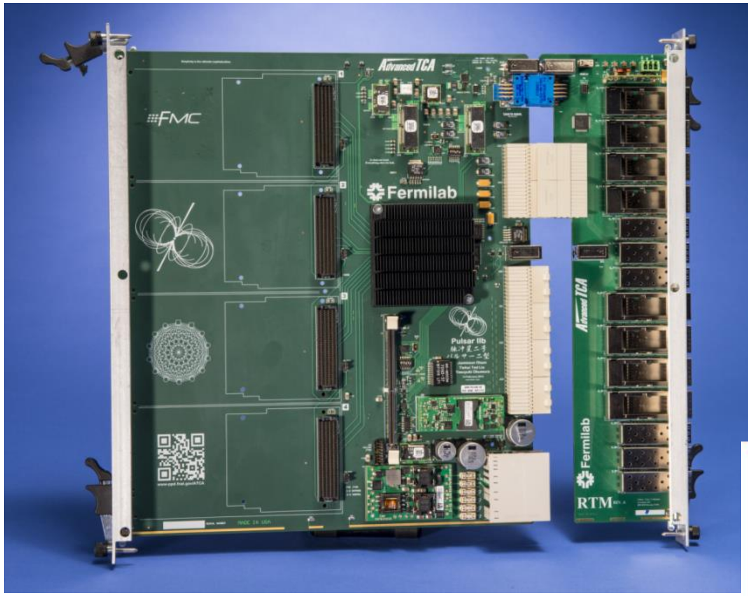


在高亮度LHC升级后，CMS的硅径迹探测器有大约7500万电子学读数通道

预计的数据峰值有50T每秒

- 大约等于2,3年前世界上因特网海底光缆的总带宽！！

学术贡献三：硅探测器触发系统研究



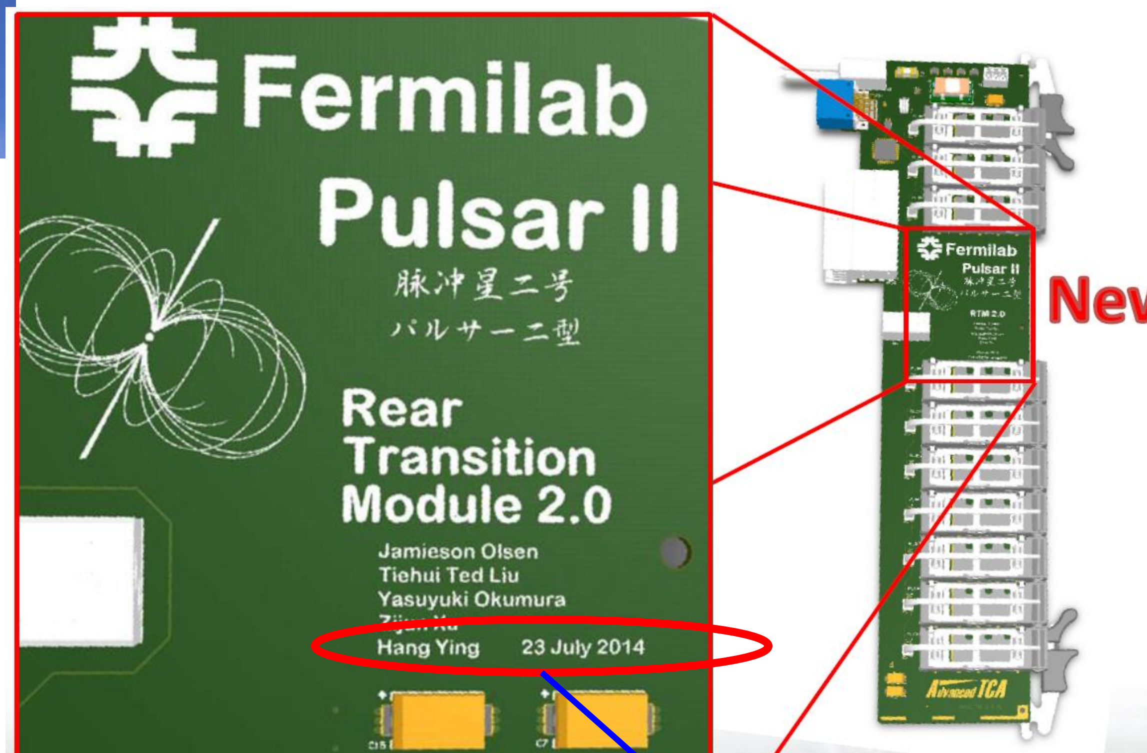
负责针对触发系统硬件的测试，
与演示系统的搭建

学习并掌握了 高级电信运算架构（ATCA），
可编程逻辑门阵列（FPGA）等核心技术

CMS硅探测器触发系统：

- 每秒4000万次碰撞
  （输出10万次）
- 最大延迟~10微秒（10^{-6}）

总造价估计：〉 $2000万



尹航

ATCA： Advanced Telecommunications Computing Architecture
FPGA： Field－Programmable Gate Array

科研成果及重要影响（1）

- 在国际主流学术期刊上发表学术论文5篇，主要包括
  - D0实验上寻找超对称R宇称破缺eμ共振态新粒子，[PRL 100, 241803]，[PRL 105, 191802]
  - D0实验上精确测量弱混合角，[PRL 101, 191801]，[PRD 84, 012007]
  - D0实验上精确测量W玻色子电荷不对称性，[PRL 112, 151803]
  - 经合作组审核批准，2篇最新论文分别提交到PRL与PRD

- D0国际实验的电弱物理研究组召集人（Convener）
  - D0国际合作组的6个一级物理组之一，~50人左右，下设3个分组。
  - 期间(2012-2014年) 共推动>10篇论文的发表

Physics Coordinators: Bob Hirosky and Rick Van Kooten

Physics conveners mailing list and archive; algorithm and physics conveners mailing list and archive

Physics Groups (Meeting time)	Conveners
Electroweak (9:30-11:00, Mon)	Breese Quinn, Hang Yin
B Physics (11:00-13:00, Fri)	Marjorie Corcoran, Mark Williams
Higgs (9:00-11:00, Thurs)	Ken Herner, Boris Tuchming
New Phenomena (Shared meeting with Higgs)	Mike Eads
QCD (10:00-12:00, Wed)	Dmitri Bandurin, Ashish Kumar
Top Quark (9:00-11:00, Thu)	Slava Sharry, Andreas Jung

科研成果及重要影响（2）

- 受邀在国际大型物理会议及讲座作物理报告11次
  - 国际物理会议：Moriond 电弱(EW)，LHC物理（LHCP）等
  - 受邀学术报告：费米实验室学术报告会，芝加哥大学物理学术报告会

- D0量能器刻度组召集人（ **Convener** ）：
  - 领导近10人小组，最后一年的量能器刻度工作，确保了能量流（Jet）、电子、光子能量精确测量

- 受邀在硬件国际会议上做报告1次
  - ieee：国际电气与电子师协会会议

- 获费米实验室“每周物理评论”报道近10次

The DZero collaboration thanks these members of
collaboration, who have ensured the highest
ity of scientific output from DZero by serving as
sics group conveners until this summer: Ashish
har (State University of New York, Buffalo),
vonne Peters (University of Manchester, England),
Elizaveta Shabalina (Georg-August Universität,
Göttingen, Germany), Mark Williams (Indiana
University), Hang Yin (Fermilab).

Fermilab *Today* Thursday, July 31, 2014

全职回国设想和研究计划

- 华中师范大学：
  - “理论物理”国家重点学科
  - “夸克与轻子物理”教育部重点实验室
  - 国家基金委“高能核物理创新研究群体”
  - 高能实验物理的三大国际合作组：
    - 美国RHIC-STAR实验组
    - 欧洲LHC-Alice实验组国内牵头单位
    - 欧洲LHC-LHCb实验组
  - 粒子物理研究所引进许怒和王新年两位千人计划专家

- 华中师范大学提供了十分理想的工作平台和发展空间

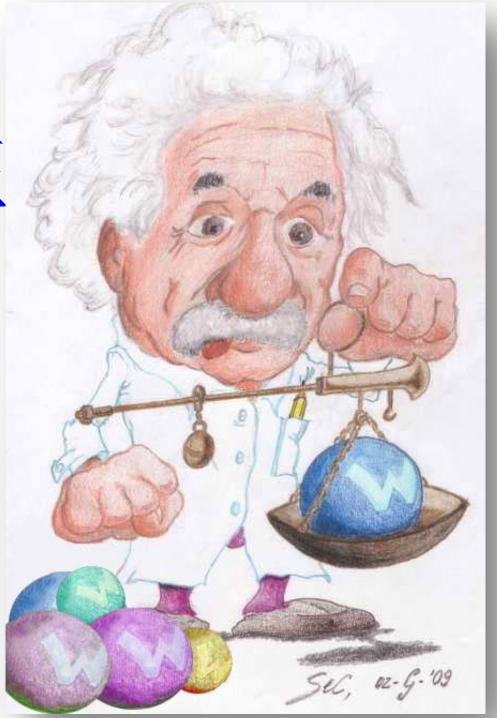
全职回国设想和研究计划

- 主要研究方向
  - LHCb实验上的B介子测量，LHCb探测器升级的研发工作
  - 参与硅探测器触发系统的研发工作、以及其他前沿硬件的研发（华中师范大学硅探测器实验室）
  - 积极参与中国未来的高能物理对撞机的预研
- 研究和教学相结合，指导学生从事前沿科学研究
- 和现有的团队成员密切合作，与华中师大的理论组优势互补，提高团队的整体创新能力

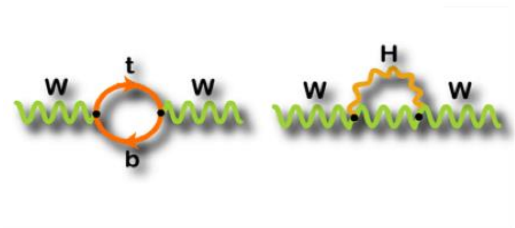
谢谢各位老师！

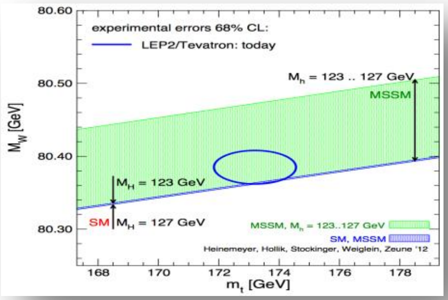
Backup

电弱物理的重要性



- 精确检验标准模型，确定参数值：
  - 精确测量W玻色子质量：



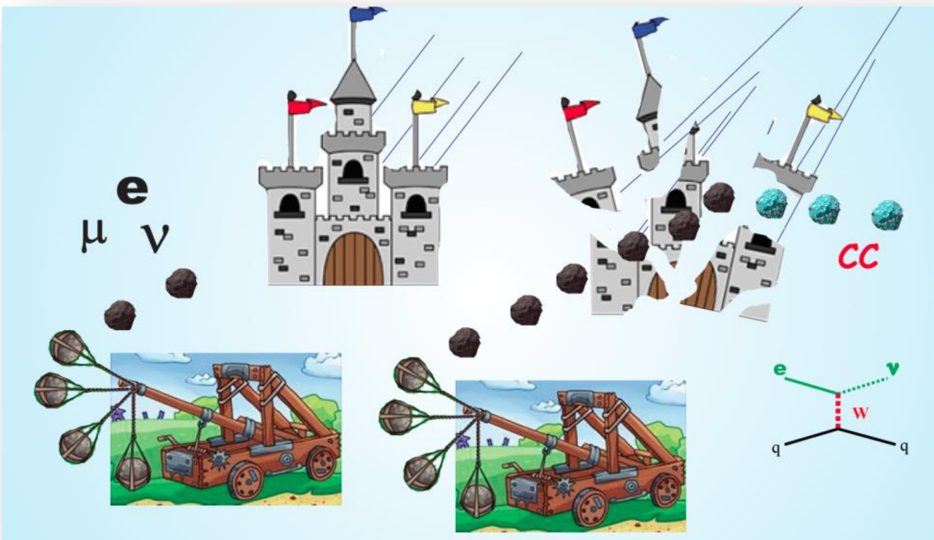


  - 弱混合角的测量：
    - 标准模型中少有的>2倍误差：最精确两个测量相互偏离2.3标准误差

- 质子的部分子分布函数（PDFs）：
  - 在强子对撞机上的重要误差来源
  - 可以用玻色子的性质来限制

学术贡献二：W玻色子的电荷不对称性

- 低能散射实验（DIS）

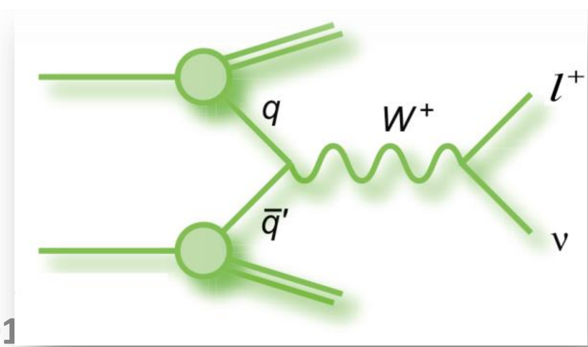


PDFs是强子对撞机上及其关键的输入：
- 几乎所有理论计算的输入值
- 实验上反应截面的计算
- 精确测量的重要误差来源
- 不能直接计算，只能用实验输入

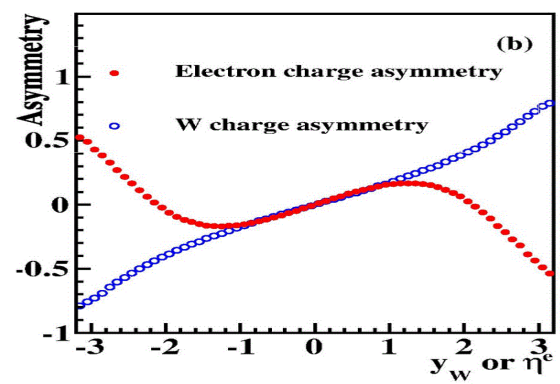
- 强子对撞机上的测量

质子

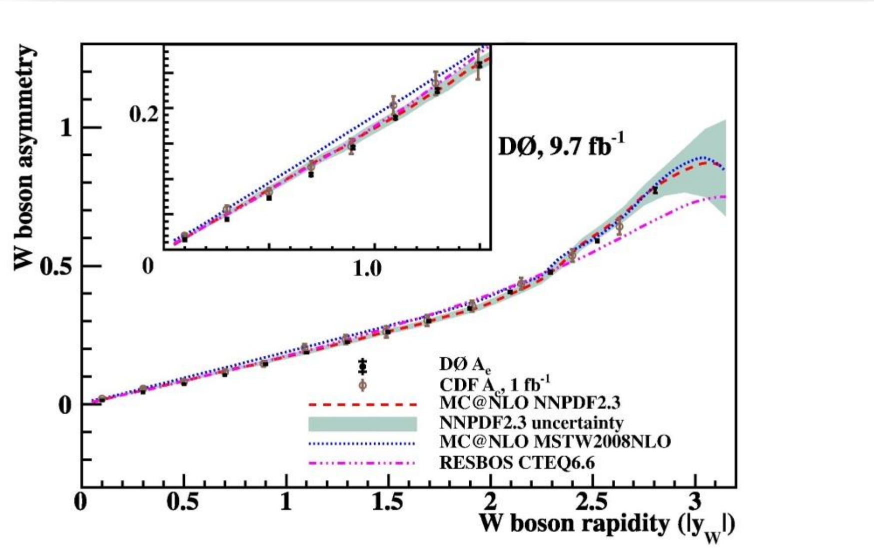
反质子



由于u夸克所携带的动量大于d夸克动量



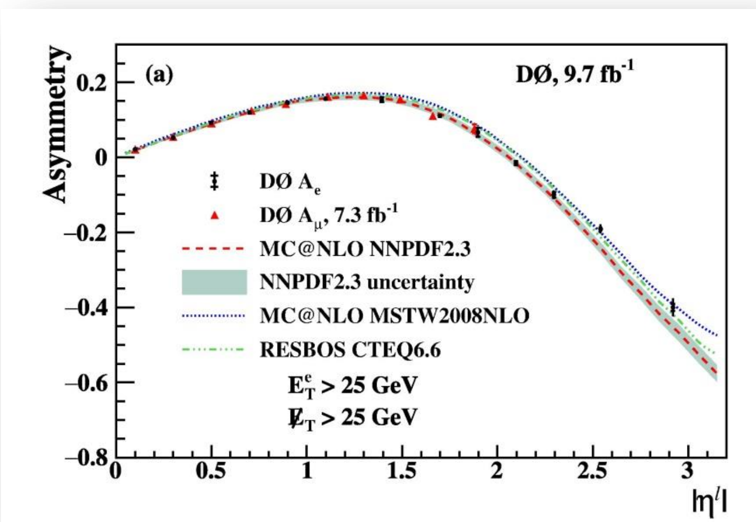
学术贡献二：W玻色子的电荷不对称性

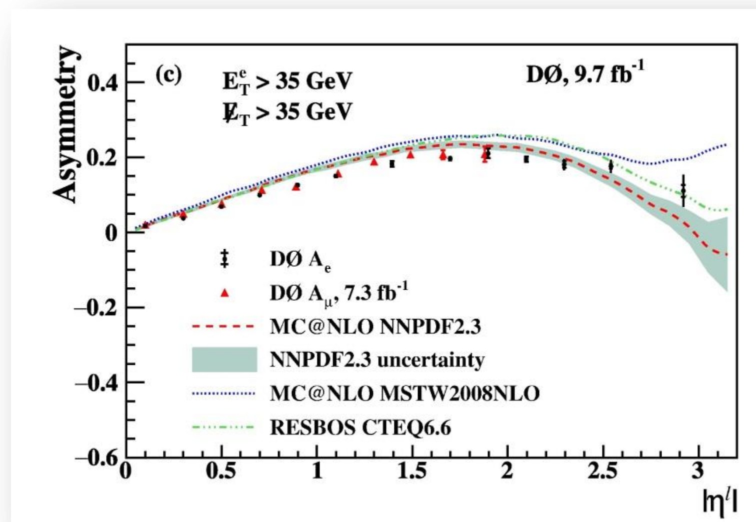


Phys. Rev. Lett. 112, 151803 (2014)
arXiv:1412.2863，提交到Phys. Rev. D

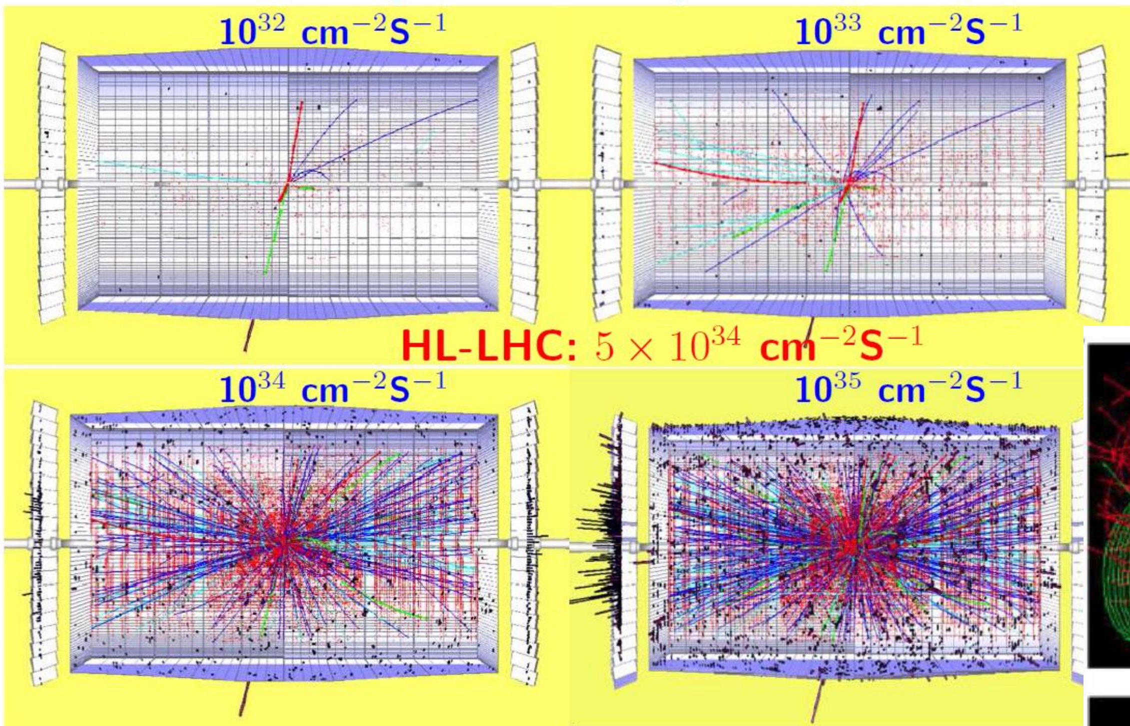
至今为止，在强子对撞机上最为精确的测量

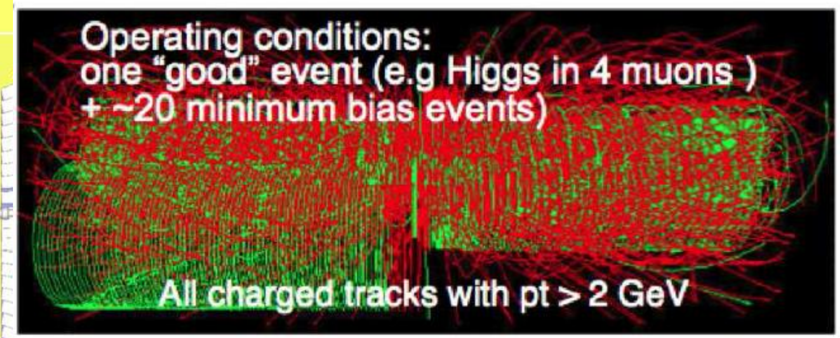
将会对PDFs的拟合产生重大影响

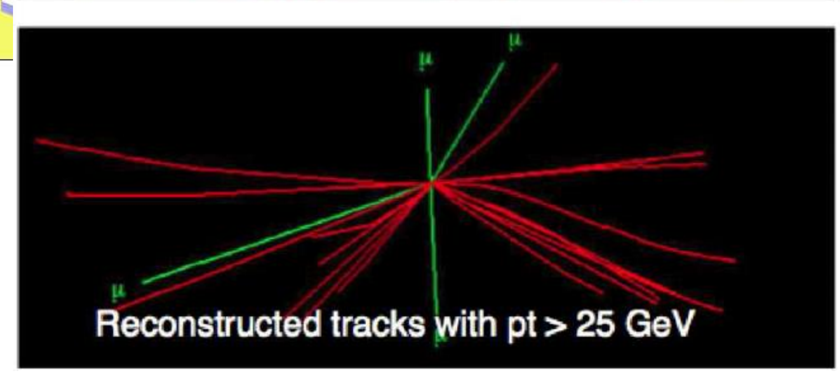




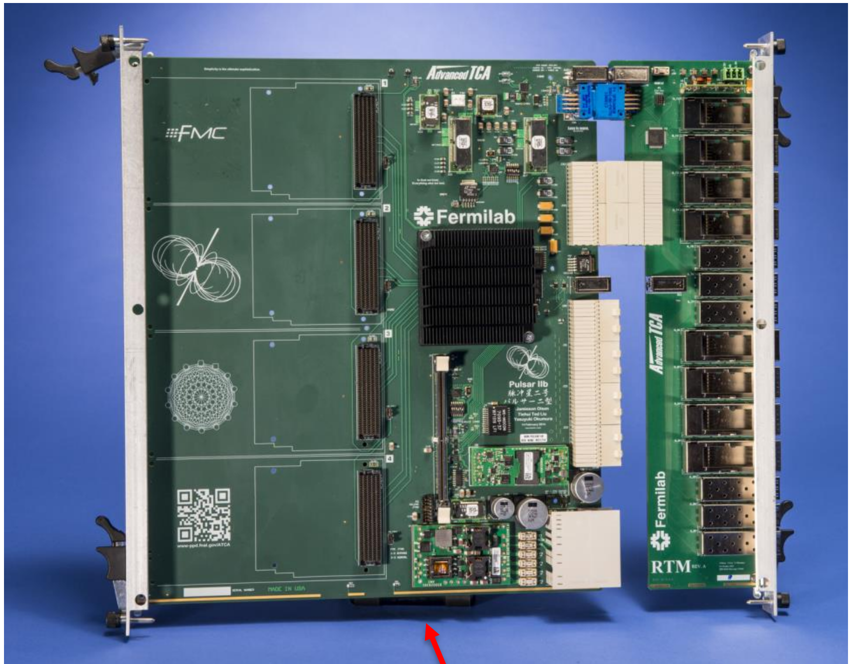
学术贡献三：硅探测器的触发研究



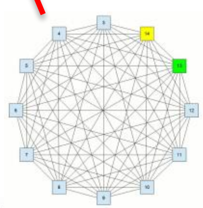


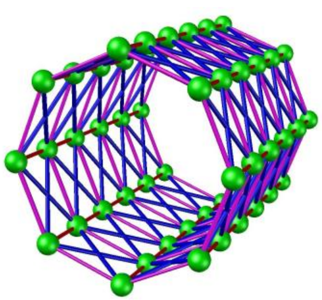


学术贡献三：硅探测器触发系统研究



CMS 径迹触发设计结构



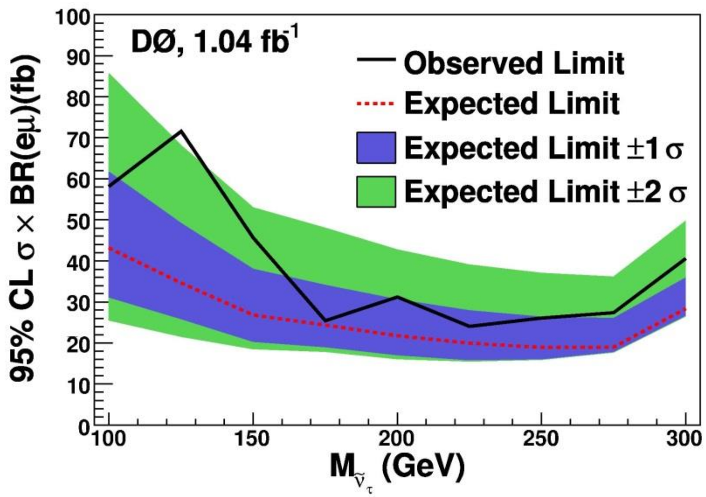


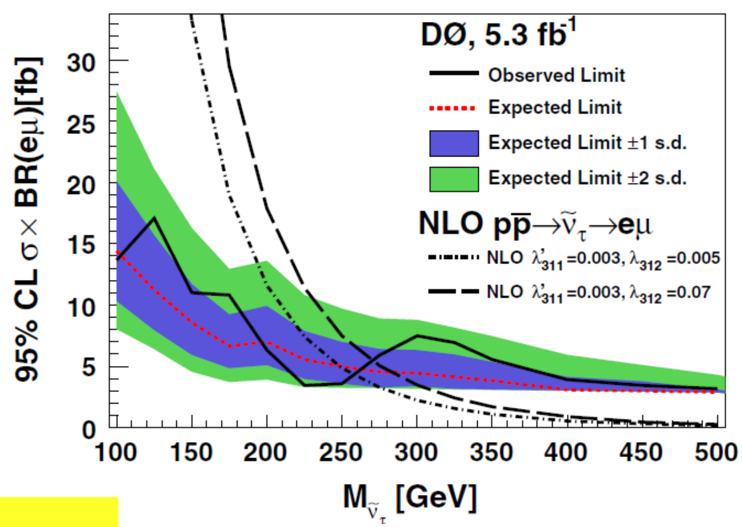
ATCA：高级电信运算架构

寻找超对称新粒子

负责信号的产生，电子的鉴别效率，还有最终结果的计算。

- 实验上**首次完成**DØ寻找，获得最严格参数限制





PRL100,241803

2TeV@ Tevatron

PRL105,191802

Fermilab

Fermi National Accelerator Laboratory
P.O.Box 500 • Batavia, Illinois • 60510
TEL:630-840-3851 • FAX: 630-840-8481

January 9, 2015

To: Whom It May Concern

From: Dr. Dmitri Denisov, DZero Experiment Spokesman
Particle Physics Division
Fermilab, Batavia, IL 60510 USA

This letter is to certify level of personal involvement of Dr. Hang Yin from Fermi National Accelerator Laboratory in the analyses which led to the publication of three excellent papers in one of the world most prestigious journals: *Physical Review Letters*.

First analysis was search for supersymmetric partner of neutrino, so called "sneutrino", predicted in modern theories, which decays into an electron and a muon. These are new, exotic particles expected to be produced at the energy frontier colliders such as Tevatron. Dr. Hang performed all steps of the analysis himself from data selection to calculation of backgrounds and efficiencies and comparison of data with theoretical predictions. He converged by publishing his world best search limits in *Physical Review Letters* with excellent comments from the referees.

Dr. Hang then concentrated on measurements of fundamental parameters of Nature using Tevatron data. He performed measurement of the so called "weak mixing angle" which could be determined from asymmetry of Z boson production in proton-antiproton collisions. Doing this study Dr. Hang demonstrated excellent ability to be very careful about all, even minor, details to obtain extremely precise measurements in many cases with accuracy well below 1%. He performed the analysis himself, personally answered on all reviews questions and successfully published his analysis in *Physical Review Letters* journal.

Recently Dr. Hang performed measurement of W boson forward-backward asymmetry. This parameter is sensitive to parton distribution functions of quarks and gluons inside proton which is critical for understanding internal structure of the proton. The measurement is very complex as it requires measurement with high precision, 0.1%, of a particle electric charge. Dr. Hang personally developed new method to identify charge of high momentum electrons which was critical for success of this analysis. Dr. Hang performed all steps of the analysis, defended his results in multiple collaboration reviews and submitted his fundamental result to the *Physical Review Letters* journal in early 2014.

Certified by

DDenisov

Dr. Dmitri Denisov
DZero Experiment Spokesman and Head of the Particle Physics Initiatives Department
Fermi National Accelerator Laboratory, USA