Topics in Forward Physics at RHIC and the LHC

Sebastian White       University of Geneva seminar  Sept. 22 2010
Outline

• forward min-bias physics
• about 2009/2010
• Hard Photoproduction
  – Method of equivalent quanta
  – applications in particle and nuclear physics
  – quarkonia at RHIC, LHC (and eIC)
• Coherence and diffraction
• Charge Exchange- forward neutron production and asymmetry at RHIC
• **New results on performance of the ATLAS ZDC**
• Potential for New Physics at the LHC
what do we know about forward neutron production?

1) Heavy Ions

Standard Picture ->
(Masashi Kaneta/Shinichi Esumi)

forward neutrons measure:
- impact parameter
- reaction plane (from directed flow, \( v_1 \))

Surprisingly, significant aspects of this picture not modeled in HIJING!
- ie in HIJING, Fermi motion=0!

-> new collaboration to include modeling of baryon “spectators”- Alvioli, Csorgo, Strikman, Vargyas, SNW

Tuesday, September 28, 2010
Neutron Production in pp

* most people have the following picture

in RAPGAP “replace the Pomeron by pi+”
inadequate (see Sunday’s talk)
Phenomonology of Inclusive neutron production from ISR, FNAL, HERA, RHIC

- coincident 2 neutron only from PHENIX

- \( \Rightarrow \) modeling of LHC cross sections “Neutron Production and Zero Degree Calorimeter Acceptance at LHC”–SNW– arXiv:0912.4320v2 [hep-ph]

In this model of non-diffractive + diffractive:

- always a forward baryon, w. \( x_F \) & \( p_t \) given by HERA
- 45% of these baryons are neutrons
- to calculate 2 arm coincidence assume left-right distributions are uncorrelated. early comparison with this model by ATLAS (blessed in June):

<table>
<thead>
<tr>
<th>Trigger type</th>
<th>ZDC-A_and_ZDC-C</th>
<th>ZDC-A_inclusive</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma(Effective) \ mbarn )</td>
<td>4.4 +/- 0.6</td>
<td>17.6 +/- 1.3</td>
</tr>
</tbody>
</table>
“Forward Physics”

• small momentum transfer to beam particle
• i.e. ATLAS-ALFA elastic scattering (nuclear +Coulomb): $|t| = p_T^2 \sim (10-20 \, \text{MeV})^2$
• coherence enhances diffractive $\sigma$’s
• at LHC soft colorless exchange ($\gamma$, ”g-g”, $\pi^{\pm}$) can have very hard interaction with the target

• will discuss: Heavy Ion photoproduction, d-Au diffraction dissociation, forward n,CEP-Higgs
• not covered: fragmentation in RHIC/LHC HI
• Sited on Swiss-French border near Geneva
100 years of subatomic Structure

• Rutherford, Geiger, Marsden (1909)
  – Atom’s 100th Birthday!
  – Rutherford’s teacher, JJ Thomson, discovered electron 10 years earlier

• “counter experiment”
  – Beam of 5 MegaVolt α particles from Radium C decay

• R. showed that α= Helium Nucleus
Resolving Power: Radius (electron, quark) < 10^{-8} * Radius (atom)

i.e. 1 centimeter/(New York -> Mazatlan)

- Stanford (Hofstadter) measured size and profile of nucleus and proton
- SLAC saw first evidence for quarks
- 2009 -> quarks and electrons don’t have substructure
Electrostatic Accelerators

- Cockroft-Walton
  (~1 Megavolt)
- Rutherford $\alpha$'s
  (~5 Megavolt)
- Van der Graaf
  (10 Megavolt)
- Above 10 MeV use high field RF (0.1-1 GigaHz)
  up to 10’s MeV/meter
Colliders

Center of Mass Energy ($E_{CM}$)

• Stationary Target:

$$E_{CM} = \sqrt{2 \times E_{Beam} \times M_{TARGET}}$$

i.e. 7 TeraVolt beam -> $E_{CM} = 0.12$ TeV

• Collider:

$$E_{CM} = 2 \times E_{BEAM}$$

i.e. $E_{CM} -> 14$ Teravolt

Constituent $E_{CM}$

If the proton is composite

$$E_{CM} \rightarrow 2 \times E_{BEAM} \times f,$$

f = momentum fraction of the quarks
The Large Hadron Collider

• Total Beam energy:
  \[ N_{\text{proton}} = 27\text{km} \times \text{Frequency} \times (10^{11}\text{proton/bunch}) / c \]
  \[ \Rightarrow E_{\text{total}} = N_{\text{proton}} \times 7 \times 10^{12}\text{eVolt} = 400\text{ MegaJoule} \]
  (=3 locomotives at top speed)

• Magnetic Field:
  \[ E_{\text{proton}}(\text{GeV}) = 15 \times B(\text{kilogauss}) \times \text{Rad}_{\text{LHC}}(\text{km}) \Rightarrow B = 84\text{ kgauss} \]

• Magnet Temperature: \( 2^\circ \text{ Kelvin} \)

• Interaction Rate: \( 1\text{ GigaHertz} \)

• Radiation Dose/year:
  \[ 2 \times 10^{14}\text{neutrons/cm}^2(\text{Si}), 5\text{ Gigarad (Zero Degree Calorimeter)} \]
Inelastic Scattering: The Equivalent Photon Approximation

“On the theory of Collisions between Atoms and electrically Charged particles” E.Fermi translated by M.Gallinaro and SNW

\[ E_{\text{trans}}(r) = \frac{q \times b}{(b^2 + v^2 t^2)^{3/2}} \]

Expand in harmonics:

\[ E_{\text{trans}} = \sum a_n^2 \cos \left( \frac{2\pi n \times t}{T} \right) \]

⇒ A “field of light” with intensity \( a_n^2 \) at frequency \( n/T \)

For resonant excitation all \( a_n \) ineffective except at resonant frequency.

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Cross sections

Equivalent field of light is calculated for each impact parameter.

But Impact parameter unmeasurable (i.e. $\sim 10^{-10}$ meters)

$\rightarrow$ calculate an equivalent radius

$$\pi \rho^2 = 2\pi \int b \times P(b) \times db = \sigma$$

$\rightarrow$ cross section ($\sigma$)

**Units:**

1 barn $= 10^{-24}$ cm$^2$

1 barn/atom $\rightarrow \sim 1$

interaction for typical target

**Examples:**

Gold+Gold $\rightarrow e^+e^-+\text{Gold}+\text{Gold}$ $= 33,000$ barns

Proton-proton Interaction $\sim 0.1$ barns

Diffractive Higgs@LHC $= 10^{-14}$ barn
Other Applications of Equivalent Photon Approximation (1)

- N. Bohr (1914), C. von Weizsacker and E. Williams (1934, generalization to ultrarelativistic case)
- **The power of coherence**: beamstrahlung in electron-proton colliders (V. Serbo et al. 1996). Coherent radiation off ~10^9 proton bunch (L ~ 1 cm)

\[ E_\gamma \leq 2 \frac{\gamma_{\text{Lorentz}}^2 \hbar c}{l_{\text{bunch}} \pi} \]

Coherence condition:
• The effect of coherence is significant in collisions with composite targets
  - **Single photon process** \( \rightarrow (Z_{\text{nucleus}} * q_e)^2 \)
  - **Two photon** \( \rightarrow (Z_{\text{nucleus}} * q_e)^4 \)

• The price of coherence is the limit on momentum transfer,
  \( \Delta q < \frac{hc}{2\pi R_{\text{nucleus}}} \) or \( \lambda > \text{target size} \)

• In high energy (colliding) beams the maximum
  \( \Delta q \) is boosted by \( 2\gamma_{\text{beam}}^2 \), where \( \gamma = \text{Lorentz factor} \)

\[ \rightarrow @\text{LHC (2.75 TeraVolt/nucleon, Pb beam)}: \]

\[ 28 \text{ MeV} \rightarrow 400 \text{ TeV} \]
# HeavyIon Collider parameters

<table>
<thead>
<tr>
<th>AB</th>
<th>$L_{AB}$ (mb⁻¹s⁻¹)</th>
<th>$\sqrt{s_{NN}}$ (TeV)</th>
<th>$E_{beam}$ (TeV)</th>
<th>$\gamma_L$</th>
<th>$k_{max}$ (GeV)</th>
<th>$E_{max}$ (TeV)</th>
<th>$\sqrt{s_{\gamma N}^{max}}$ (GeV)</th>
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<td>0.16</td>
<td>168</td>
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<td>1500</td>
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<td>7</td>
<td>7455</td>
<td>2452</td>
<td>36500</td>
<td>8390</td>
<td>4504</td>
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EPA(3)-mechanisms of beam loss at the LHC

- Mutual Coulomb Dissociation (A. Baltz, SNW)
- Measured with first RHIC data. Calibrates RHIC and LHC luminosity

Coherent Pair Production (various)

("photon flux")² × "inverse positron annihilation" (Breit-Wheeler)
EPA(4): Vector meson photoproduction

- gluon distribution in proton or nucleus

\[ \frac{d\sigma}{dt}(J/Psi - Nucleus) \]

\[ \rightarrow \text{“QCD Rutherford scattering”} \]
PHENIX DI-LEPTONS

Central arm : 0<|\eta|<0.35 e-pair (50%*2\pi)
Muon arm : 1.2<|\eta|<2.4 \mu-pair

1 or 2 forward neutrons
“rapidity gap”->veto BBC coincidence
E(EMC)>0.8 GeV

• track cut to eliminate inelastic
• overwhelming pion rejection

forward tags
BBC (3.0 < |\eta| < 3.9) (charged)
MPC,ZDC (calorimeters, neutral)

additional photon exchange a la Baltz & SNW
“new” 2007 ee sample

• results consistent with 2004 data publication
• PHENIX sees significant incoherent component

\[ \sigma(\gamma + Au \rightarrow J/\psi) = A^\alpha \sigma(\gamma + p \rightarrow J/\psi), \alpha_{coh} = 1.01 \pm 0.07 \]

new algorithm for event vertex

\[ \sigma(\gamma + Au \rightarrow J/\psi) = A^\alpha \sigma(\gamma + p \rightarrow J/\psi), \alpha_{coh} = 1.01 \pm 0.07 \]

• \(J/\psi + n\)-tag per minute at RHIC
• -> 10 mbarn (10/second) in ATLAS@ LHC
• similar to planned eIC but higher \(\sqrt{s}\)
• PHENIX studying high acceptance \(\mu\mu\) trigger

• access to incoherent
EPA(5)-Equivalent W Approximation

- Dominant Higgs production if $M_H \geq 300$ GeV (Dawson):

  "gluon-gluon fusion"  \hspace{1cm}  "β-decay amplitude"
EPA(6): Measuring the structure of Protons and Nuclei

- "Probing Small x parton densities in Ultraperipheral AA and pA collisions" (Strikman, Vogt, SNW)

Structure $\leftrightarrow$ Distribution of partons (quarks, gluons) inside proton - similar to EPA
Coverage by ATLAS hard photoproduction
• **Structure**

- Many other EPA analogies in QCD theory of strong interactions: e.g. Dokshitzer, Gribov, Lipatov, Altarelli and Parisi (DGLAP)

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[Diagram showing proton and quarks/gluons]

[Graph showing parton density function of proton]
Inelastic Diffraction

- Glauber (1955)- deuteron “free dissociation”
- Feinberg & Pomeranchuk (’56)
- “Diffraction Dissociation-50 Years Later”-SNW

\[ d = \sum c_n \Psi_n, \Psi_n = \text{Scattering basis states} \]

Collisionless interaction->excitation to unbound n,p

• Measured in PHENIX: \( \sigma = 138 \text{ mbarn} \)
\[ R(d-AU \text{ dissociation}) = \text{Luminosity} \times \sigma \]

- \( d \) breakup background ie on accelerator residual gas \( \rightarrow \) beam current

- \( \rightarrow \) special data runs changing beam separation

- This result became basis for PHENIX luminosity calibration
Proton diffraction dissociation
• Large coherence peak for $\lambda > R_{\text{proton}}$

$\xi = \frac{\Delta P_L}{P_L} = \frac{M_X^2}{S} \leq \frac{m_X}{m_p}$

• Observed for $p, \pi, K, \text{high energy } \gamma$'s and nuclei
• $\sigma \sim A^{1/3}$ -> peripheral interaction
• Responsible for $K_L$ regeneration in particle physics

K. Goulianos ('83)
Asymmetries

* Heavy Ions: Interest in sensitivity to reaction plane from $v_1$ led to position sensitive Shower Maximum Detector for the ZDC (Denisov & SNW)

ZDC is based on Cerenkov sampling in optical fibers.
- very fast
- unusual response profile
- ATLAS uses quartz glass (5 GigaRad/year)

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Setup
Schematic view from simulation.
- GEANT3 (Geisha)
- From the pythia simulation, Main backgrounds are **photon** and **proton**.

ZDC
(Zero Degree Calorimeter)
10*10cm → ±2.8 mrad
3 module
150X₀ 5.1λ₁

SMD
(Shower Max Detector)

Proton shower event
(In case of proton mom. = 50GeV/c)

Charge veto counter

Neutron position can be found using centroid method (+/- 1cm).
ATLAS ZDC had severe constraints compared to PHENIX
- 5 Giga Rad/yr rad dose @ design lum
= 200 Watt continuous beam deposition
LHC politics vis. LHCf, LUMI...

despite constraints

-> ATLAS is the only imaging ZDC (x,y,z) on the planet
"shashlik"/layer sampling hybrid

Figure 4: ZDC Drawn with VP1. Plot shows the grid of Strips and Pixels within the EMXY Module

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we worked with 2 transport packages designed for IP1, 5 geometry - Hector - FPTracker

all can interpret accelerator files about time-dependent LHC configuration

we developed “FNTracker”
ATLAS ZDC full simulation - validated by Mokhov accelerator studies

Photons in ZDC per pp interaction

10 MeV - 1 GeV
\( \langle N \rangle = 19.83 \quad E_{\text{tot}} = 1.5 \text{ GeV} \)

1 GeV - 10 GeV
\( \langle N \rangle = 0.46 \quad E_{\text{tot}} = 1.3 \text{ GeV} \)

10 GeV - 100 GeV
\( \langle N \rangle = 0.05 \quad E_{\text{tot}} = 1.1 \text{ GeV} \)

100 GeV - 5 TeV

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legend: blue = n, gamma from interactions, green = from decays in the accelerator, red = secondary photons and neutrons from all materials (magnets, pipes, collimators in the LHC)
**PHENIX analysis of reaction plane resolution**

<table>
<thead>
<tr>
<th>Au+Au 200GeV $y_{\text{beam}}^{(100\text{GeV})}$=5.3</th>
<th>Au+Au 62GeV $y_{\text{beam}}^{(31\text{GeV})}$=4.5 (3&lt;$\eta_{\text{bcc}}$&lt;4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{\text{ch}}^{\text{max}}(\text{bcc})$ ~1600</td>
<td>~600 (multiplicity)</td>
</tr>
<tr>
<td>$v_1(\text{bcc})$ 1~2%</td>
<td>2~4% (signal)</td>
</tr>
<tr>
<td>$v_2(\text{bcc})$ 2~2.5%</td>
<td>1.5~2% (signal)</td>
</tr>
<tr>
<td>$&lt;\cos\Delta\Phi_1^{\text{BBC}}&gt;$ 4~5%</td>
<td>4~5% (resolution)</td>
</tr>
<tr>
<td>$&lt;\cos2\Delta\Phi_2^{\text{BBC}}&gt;$ 8~9%</td>
<td>2~3% (resolution)</td>
</tr>
<tr>
<td>$&lt;\cos\Delta\Phi_1^{\text{SMD}}&gt;$ 7~8%</td>
<td>1~2% (resolution)</td>
</tr>
</tbody>
</table>
Spin dependent asymmetries in pp
New results on s-dependence

- Inclusive neutron
- Neutron with charged particles
Compare to calculated Asymmetry

B.Z. Kopeliovich, I.K. Potashnikov, I. Schmidt and J. Soffer
arXiv:0807.1449

- Asymmetry calculated with one pion exchange model.
- Calculated asymmetry is smaller than observed.
  - PHENIX kinematic region:
    \[ x_F = 0.6-0.8, \text{ and } \theta < 2 \text{ mrad.} \]
  - Possibly due to other reggeon exchanges. (e.g. \(a_1\) exchange)
  - Testable with neutron \(p_t\) dist.
    \[
    \frac{d\sigma}{dp_t^2} \rightarrow \frac{1}{(p_t^2 + m_T^2)^2}
    \]
\[
\text{OPE}[p_t] := \frac{3.842 \times 10^{-4}}{(p_t^2 + m_{\pi}^2)^2}
\]

\[
\text{OPEInt}[y] = \int_0^\gamma p_t \frac{0.0393}{(p_t^2 + m_{\pi}^2)^2} \text{d}p_t;
\]

\[
\text{ISR}[p_t] := e^{-4.8 p_t}
\]

\[
\text{ISRInt}[y] = 23.1 \int_0^\gamma p_t \text{ISR}[p_t] \text{d}p_t;
\]

\[
\text{HERA}[p_t] := e^{-8.8 p_t^2}
\]

\[
\text{HERAInt}[y] = 16 \int_0^\gamma p_t \text{HERA}[p_t] \text{d}p_t;
\]
Diffraction(e-nucleus analogy)

- Diffractive electroproduction non-diffractive

Diffractive Higgs production non-diffractive

"color screening"
Marco Bruschi analysis of VdM data
Fantastic agreement with +/-7.3% physics based absolute luminosity!

New results this morning from Edson Carquin, Valparaiso

From Montecarlo Truth:
ZDC_A,
Phojet: 17.0805, Pythia6: 15.9996, Pythia8: 15.1162.

ZDC_AND,
Phojet: 2.70564, Pythia6: 2.4381, Pythia8: 2.33474.

From Transported Montecarlo:
ZDC_A,

ZDC_AND,
Phojet: 2.64128, Pythia6: 2.20468, Pythia8: 2.10102.

Even higher absolute luminosity precision should be expected from PbPb running using ZDC!
resulted in Shannon's 1940 PhD thesis at MIT, *An Algebra for Theoretical Genetics*.\[6\]

Victor Shestakov, at Moscow State University, had proposed a theory of electric switches based on Boolean logic a little bit earlier than Shannon, in 1935, but the first publication of Shestakov's result took place in 1941, after the publication of Shannon's thesis.

The theorem is commonly called the Nyquist sampling theorem, and is also known as Nyquist–Shannon–Kotelnikov, Whittaker–Shannon–Kotelnikov, Whittaker–Nyquist–Kotelnikov–Shannon, WKS, etc., sampling theorem, as well as the Cardinal Theorem of Interpolation Theory. It is often referred to as simply the sampling theorem.

The theoretical rigor of Shannon's work completely replaced the ad hoc methods that had previously prevailed.

Shannon and Turing met every day at teatime in the cafeteria.\[8\] Turing showed Shannon his seminal 1936 paper that defined what is now known as the "Universal Turing machine"\[9][10\] which impressed him, as many of its ideas were complementary to his own.

He is also considered the co-inventor of the first wearable computer along with Edward O. Thorp.\[16\] The device was used to improve the odds when playing roulette.
books about Shannon:

Cybernetics: or Control and Communication in the Animal and the Machine
Norbert Wiener

Fortune's Formula
The Untold Story of the Scientific Betting System that Beat the Casinos and Wall Street
William Poundstone
In 1956 two Bell Labs scientists discovered the scientific formula for getting rich. One was the mathematician Claude Shannon, neurotic father of our digital age, whose genius is ranked with Einstein’s. The other was John L. Kelly, Jr., a gun-toting Texas-born physicist. Together they applied the science of information theory—the basis of computers and the Internet—to the problem of making as much money as possible, as fast as possible. Shannon and MIT mathematician Edward O. Thorp took the “Kelly formula” to the roulette and blackjack tables of Las Vegas. It worked. They realized that there was even more money to be made in the stock market, specifically in the risky trading known as arbitrage. Thorp used the Kelly system with his phenomenally successful hedge fund Princeton-Newport Partners. Shannon became a successful investor, too, topping even Warren Buffett’s rate of return and

no time to discuss Shannon’s method for getting rich

will discuss Shannon’s method for reconstructing digitized waveforms
Reconstruction of ZDC Pre-Processor Data and its timing Calibration
Soumya Mohapatra, Andrei Poblaguev and Sebastian White
Aug.8,2010

ATLAS data set used to develop ZDC reconstruction and do L1calo calibration (in Mathematica 7.0)

\[ \text{shannon}[t] = \sum_{i=1}^{n_{\text{slices}}} \text{slices}[i] \times \text{Sinc}[\pi \times (t - \text{time}(i))/25] \] (6)

An animated gif can be found at:
http://www.phenix.bnl.gov/phenix/WWW/publish/swwhite/ShannonFilm.gif

Sinc Expansion for 2 Slices

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<th>Time (nanoseconds)</th>
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\begin{tabular}{cccccccccc}
0 & 190 & 610 & 375 & 200 & 125 & 80 \\
1 & 160 & 620 & 380 & 205 & 130 & 85 \\
2 & 140 & 615 & 390 & 210 & 125 & 80 \\
3 & 120 & 615 & 395 & 210 & 130 & 85 \\
4 & 97  & 620 & 405 & 220 & 130 & 80 \\
5 & 80  & 612 & 420 & 225 & 140 & 90 \\
6 & 62  & 610 & 425 & 235 & 140 & 95 \\
7 & 50  & 605 & 435 & 235 & 145 & 95 \\
8 & 37  & 590 & 450 & 240 & 150 & 97 \\
9 & 30  & 575 & 460 & 245 & 150 & 97 \\
10 & 15 & 560 & 485 & 260 & 155 & 100 \\
11 & 15 & 550 & 485 & 260 & 155 & 100 \\
12 & 12 & 530 & 590 & 265 & 160 & 100 \\
13 & 4  & 495 & 695 & 275 & 165 & 105 \\
14 & 2  & 495 & 895 & 275 & 165 & 105 \\
15 & 2  & 465 & 520 & 275 & 165 & 105 \\
16 & 2  & 445 & 525 & 290 & 170 & 110 \\
17 & 2  & 420 & 570 & 315 & 180 & 120 \\
18 & 2  & 385 & 550 & 310 & 175 & 115 \\
19 & 2  & 365 & 515 & 320 & 180 & 115 \\
20 & 2  & 335 & 575 & 325 & 185 & 120 \\
21 & 2  & 300 & 590 & 330 & 185 & 120 \\
22 & 2  & 280 & 595 & 340 & 190 & 125 \\
23 & 2  & 245 & 600 & 350 & 200 & 125 \\
\end{tabular}
(d) Piecewise fit to the full range.
Energy distribution of 2 photon candidates in the ZDC, selected using the longitudinal shower profile. The ZDC energy scale was established using the endpoint measured in 7 TeV collision data. Since the shower energy is concurrently measured in the “pixel” coordinate readout channels this allows energy calibration to be established for these channels also.

For 7 TeV collision data taken prior to LHCf removal the first ZDC module is the so-called “Hadronic x,y” which has identical energy resolution to all of the other ZDC modules. The coordinate resolution, however, is inferior to that of the high resolution EM, installed 7/20/10. Nevertheless, the reconstructed mass resolution is found to be 30% at m=130 MeV. As is found in ongoing simulation of p\(\pi^0\) reconstruction within the full ATLAS framework (see ZDC simulati

...
The Z vertex distribution from inner tracker vs. the time of arrival of showers in ZDC-C relative to the ATLAS clock calculated from waveform reconstruction using Shannon interpolation of 40 MegaSample/sec ATLAS data (readout via the ATLAS L1calo Pre-processor modules). Typical time resolution is ~200 psec per photomultiplier (see ATL-COM-LUM-2010-022). The two areas outside the main high intensity area are due to satellite bunches. Note that this plot also provides a more precise calibration of the ZDC timing (here shown using the ZDC timing algorithm not corrected for the digitizer non-linearity discussed in ATL-COM-LUM-2010-027). With the non-linearity correction the upper and lower satellite separations are equalized.
Dear Sebastian,

I have not yet contacted Tony as I also have been swamped with other tasks.

One potential issue of concern is that CERN ROOT is available under the Lesser General Public License (http://root.cern.ch/root/License.html). As I understand it (and I'll have this clarified by our legal department), we can not make use of any ROOT source code without exposing the Mathematica source code (which obviously is not an option). If true, this hurdle may be bigger than any technical problems we may face.

Ken
Central Exclusive Higgs Production

Central Exclusive Higgs production $pp \rightarrow p \ H \ p$ :

- $>3 \text{ fb (SM)}$
- $\sim 10-100 \text{ fb (MSSM)}$

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

$\Delta M = O(1.0 - 2.0) \text{ GeV}$

Background suppressed
By $0^+$ selection rule

Higgs association from Proton timing ($\sim 10 \text{ picosecond}$)

$$p \ H \ p'$$

Tuesday, September 28, 2010
Deep diffused avalanche photodiode

Cerenkov Radiation cone

Pre-production Hybrid photodetector

“A 10 picosecond time of flight detector using APD’s”, SNW et al.

650 picosecond risetime (β’s)
The Future: a 3 picosecond testbeam (SNW & V. Yakimeno)

Applications: RHIC upgrades, electron-ion Collider, SuperBelle, ATLAS- AFP
stripline waveforms w.
on-chip Sin[x]/x interpolation+spline

rms on time diff
between detectors <2.5 psec
driver for faster timing is leading protons @L=10^{34}

* encouraged by Brian Cox to look for new technologies that survive full Luminosity

* Hamamatsu (M. Suyama) provided a new device for evaluation. Lifetime tests show >250 Coulomb/cm² (cp. MCP, 20% loss @0.1 Coulomb)

Communications industry→small area APDs w. G*BW>10^{11} Hz
Applications in eg fluorescence spectroscopy
T. Tsang, S. White

risetime = 300 psec
A 11 psec single photon response is not common.
High resolution timing could significantly improve image resolution and speed
many recent developments by our group

new technologies tested for very high rate TOF (ie LHC @ 10^34). In the past this has been a major challenge for Superbelle, LHC, etc.

new electronics tested (achieved 2 psec w. DRS4)

what ultimate timing can be achieved with forward detectors?

usually the main hurdles are neither technical nor scientific......
Animations of:

* Fragmentation modelling
* SHannon reconstruction
* LHC satellite bunches