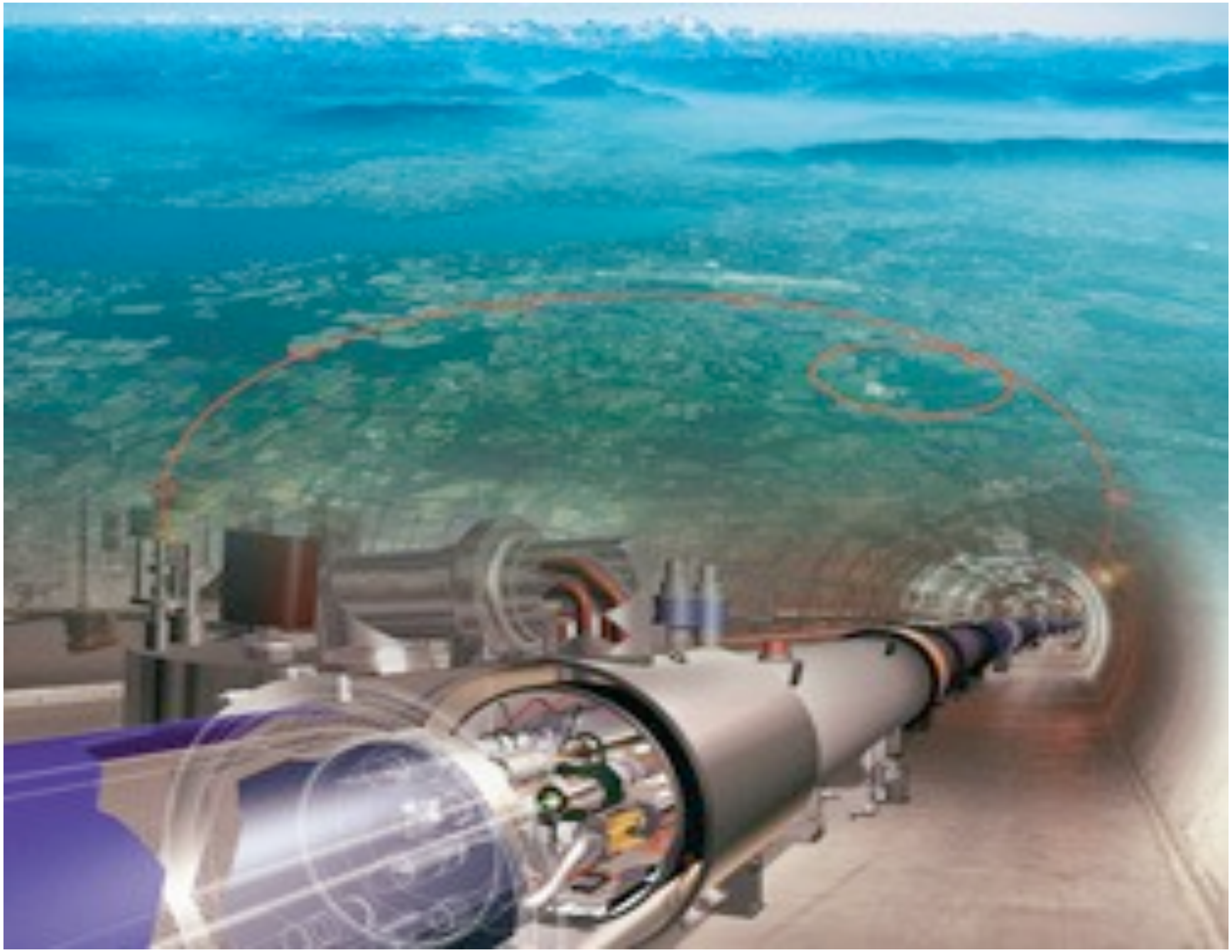
# Topics in Forward Physics at RHIC and the LHC



Sebastian White University of Geneva seminar Sept. 22 2010

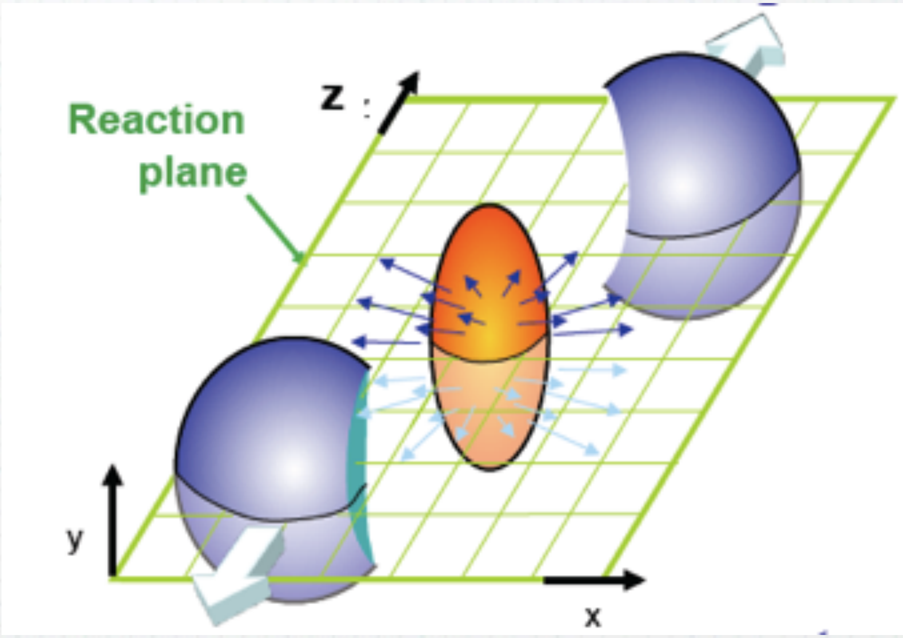
# Outline

- 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)

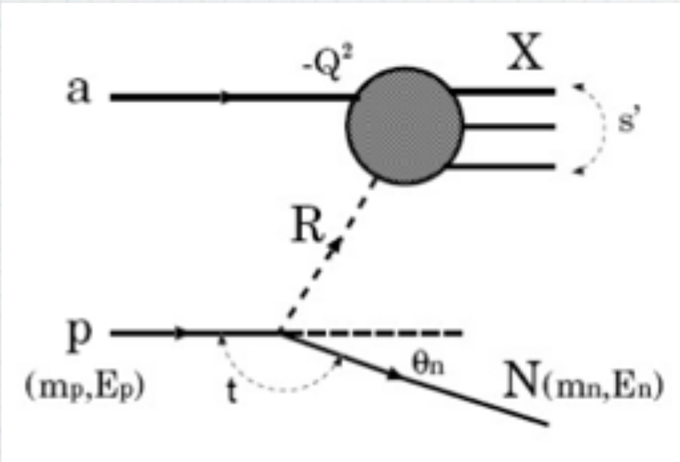



forward neutrons measure:
-impact parameter
-reaction plane (from directed flow, v_1)

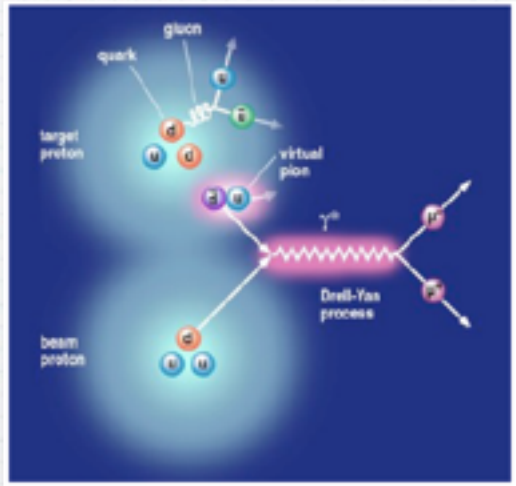
Surprisingly, significant aspects of this picture not modeled in HIJING !
- ie in HIJING, Fermi motion=0 !
-> new collaboration to include modeling of baryon "spectators"- Alvioli, Csorgo, Strikman, Vargyas, SNW

# Neutron Production in pp

* most people have the following picture



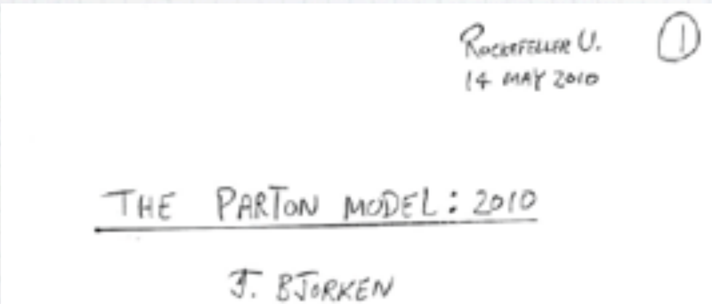

ie->

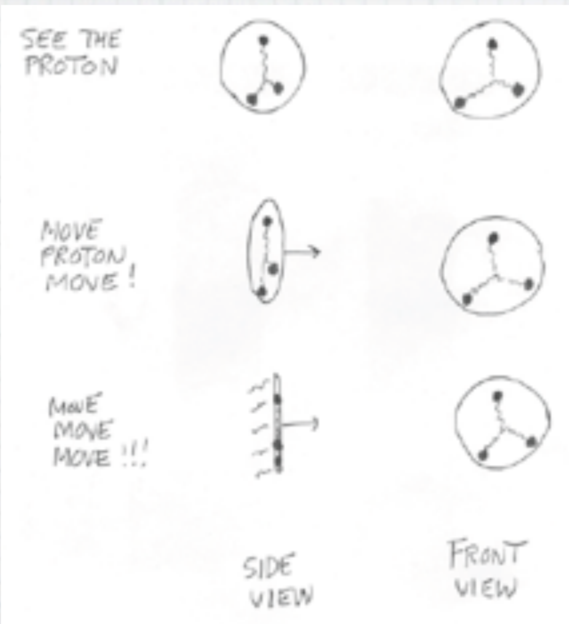


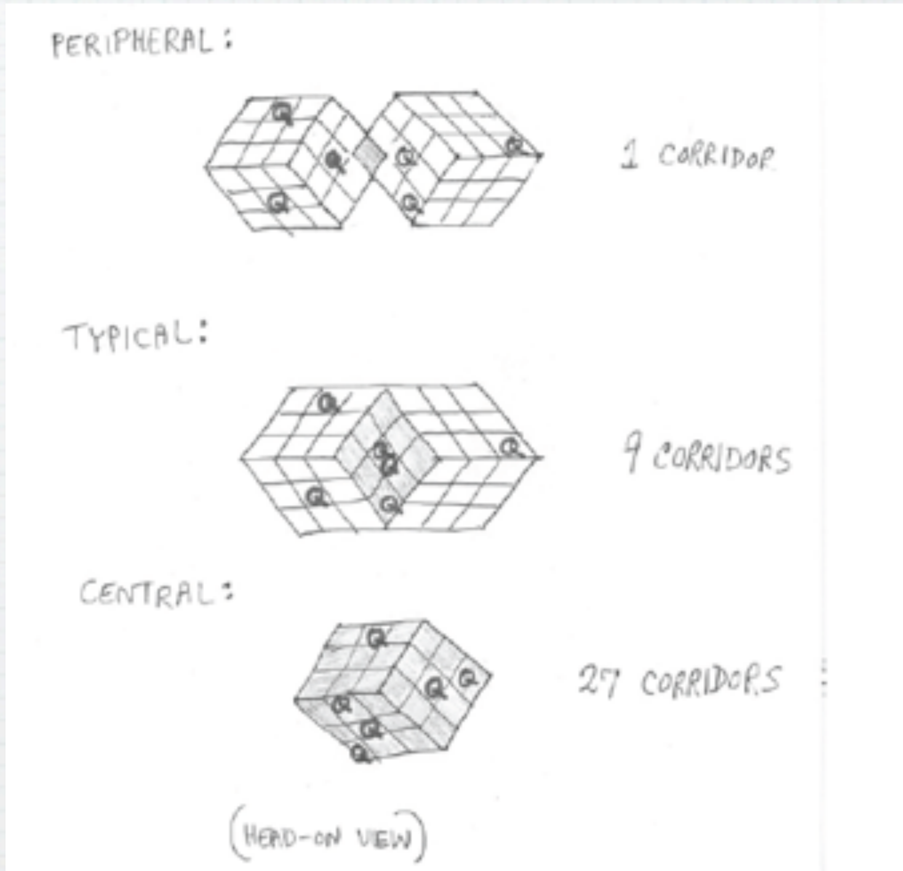

in RAPGAP "replace the Pomeron by pi+"

**inadequate (see Sunday's talk)**

# Bjorken's picture



* Phenomonology of Inclusive neutron production from ISR, FNAL, HERA, RHIC
* coincident 2 neutron only from PHENIX
* ->modeling of LHC cross sections "Neutron Production and Zero Degree Calorimeter Acceptance at LHC"–SNW– arXiv:0912.4320v2 [hep-ph]

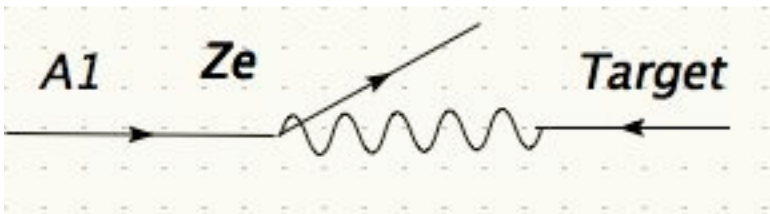
In this model of non-diffractive +diffractive:

  * 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):

| Trigger type | ZDC-A_and_ZDC-C | ZDC-A_inclusive |
|---|---|---|
| σ(Effective) mbarn | 4.4 +/- 0.6 | 17.6 +/- 1.3 |

# "Forward Physics"

- small momentum transfer to beam particle
- ie ATLAS-ALFA elastic scattering (nuclear +Coulomb):|t|=$p_T^2$~(10-20 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

**Sur le terrain du futur institut nucléaire**

Sous la conduite de M. A. Picot, les membres du Conseil européen pour la recherche nucléaire se sont rendus hier à Meyrin pour reconnaître le terrain où s'élèvera le Centre nucléaire (voir en Dernière heure)

(Photo Freddy Bertrand, Genève)

*La Suisse* du 30 octobre 1953

# 100 years of subatomic Structure

- Rutherford, Geiger, Marsden (1909)
  - Atom's $100^{th}$ Birthday!
  - Rutherford's teacher, JJ Thomson, discovered electron 10 years earlier
- "counter experiment"
  - Beam of 5 MegaVolt $\alpha$ particles

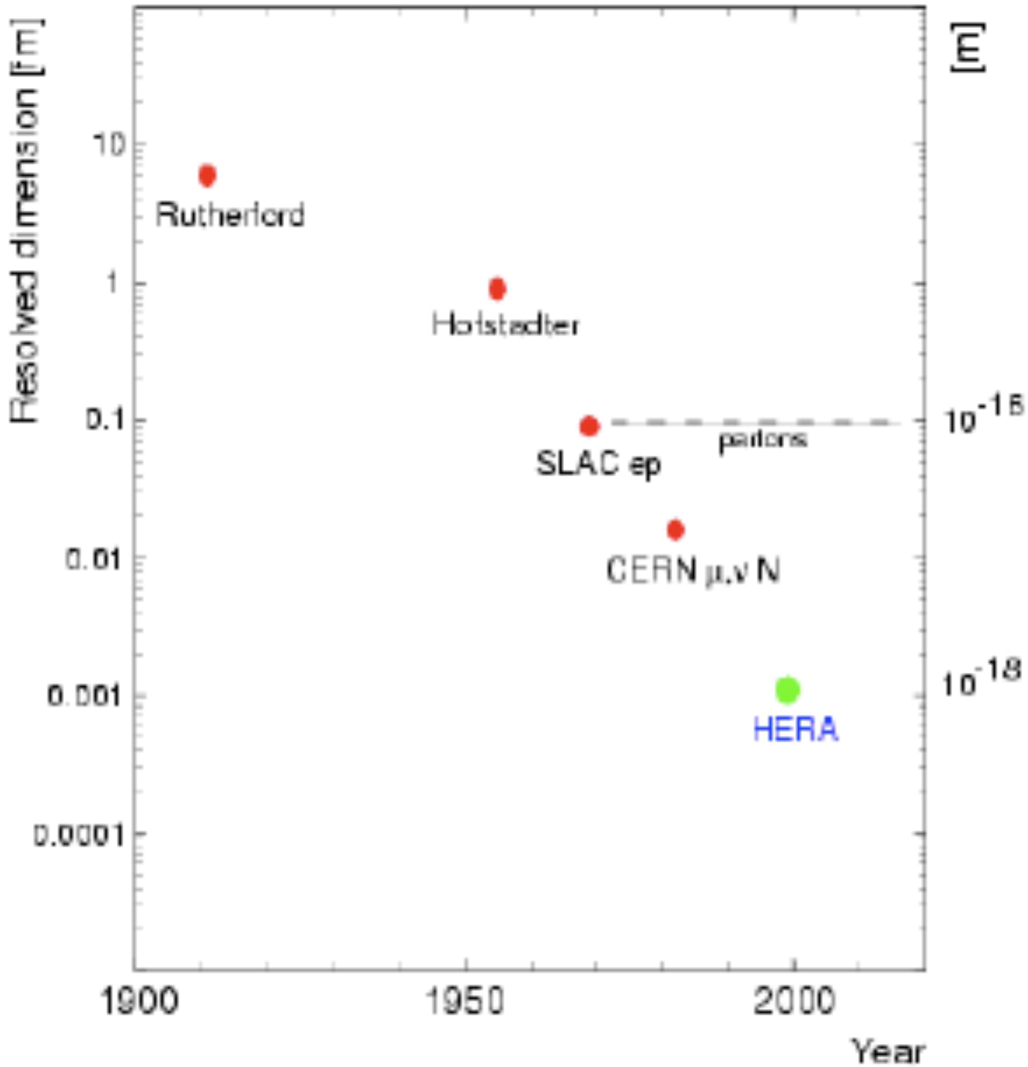
  from Radium C decay
- R. showed that $\alpha$= Helium Nucleus

JJ Thomson & Ernest Rutherford

# 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)

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- 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:

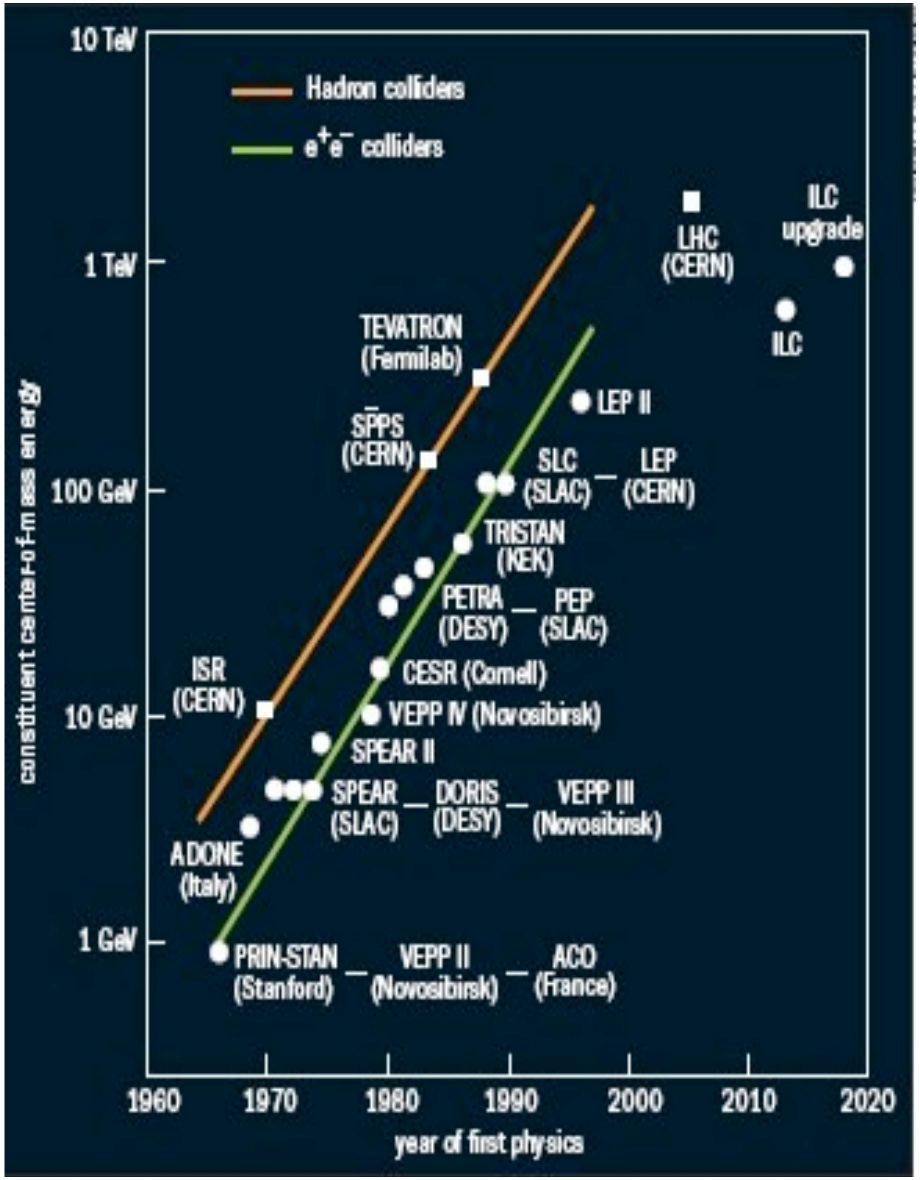
$E_{CM}$= $\sqrt{2 \times E_{Beam} \times M_{TARGET}}$
i.e. 7 TeraVolt beam->$E_{CM}$=0.12 TeV

•Collider:

$E_{CM}$=2* $E_{BEAM}$
i.e . $E_{CM}$->14 Teravolt

## Constituent $E_{CM}$

If the proton is composite
$E_{CM}$->2*$E_{BEAM}$*f,
f= momentum fraction of the quarks



# The Large Hadron Collider

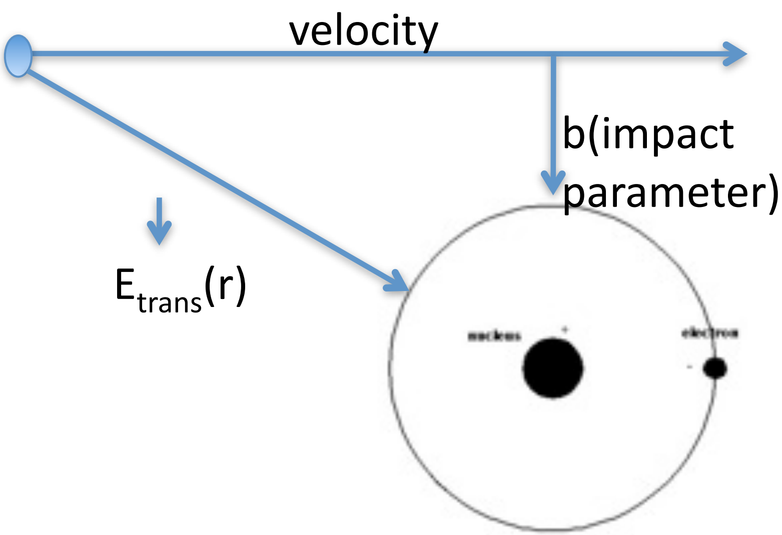
- Total Beam energy:
  - **$N_{proton}$=27km*Frequency*($10^{11}$proton/bunch) /c**

    **->$E_{total}$=$N_{proton}$*7*$10^{12}$eVolt=400 MegaJoule**

    **(=3 locomotives at top speed)**
- Magnetic Field:
  - **$E_{proton}$(GeV)=15*B(kilogauss)*$Rad_{LHC}$ (km)-> B=84 kgauss**
- Magnet Temperature: **$2^o$ Kelvin**
- Interaction Rate: **1 GigaHertz**
- Radiation Dose/year:
  - **2*$10^{14}$neutrons/$cm^2$(Si), 5 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




$$E_{trans} = \frac{q \times b}{(b^2 + v^2 t^2)^{3/2}}$$

Expand in harmonics:

$$E_{trans} = \sum a_n{}^2 Cos(\frac{2\pi n \times t}{T})$$

$\Rightarrow$ A "field of light" with intensity $a_n{}^2$ at frequency n/T

For resonant excitation all $a_n$ ineffective except at resonant frequency.

# Cross sections

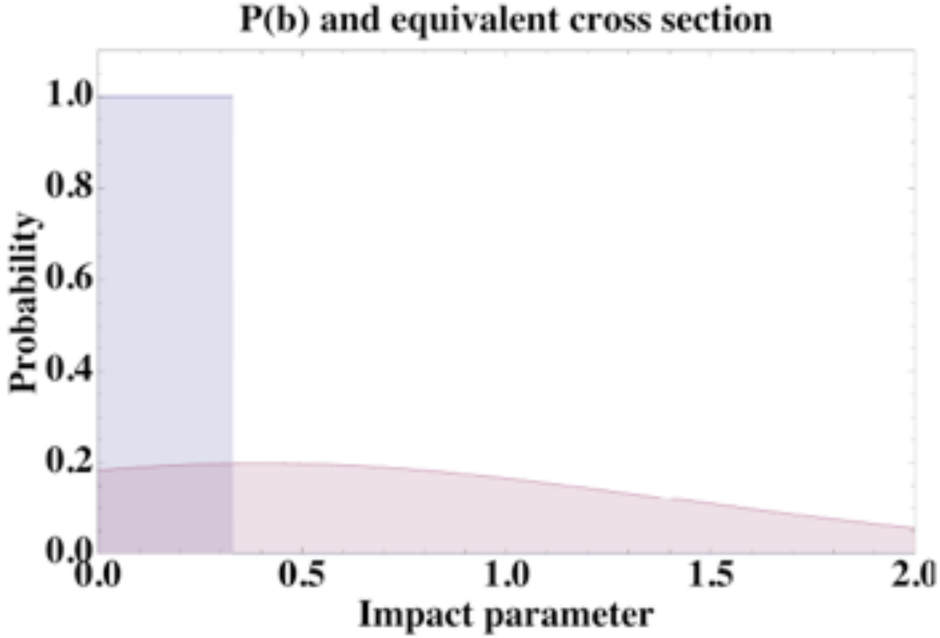
Equivalent field of light is calculated for each impact parameter.

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

->calculate an equivalent radius

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

-> cross section ($\sigma$)




Units:

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

1barn/atom->~1 interaction for typical target

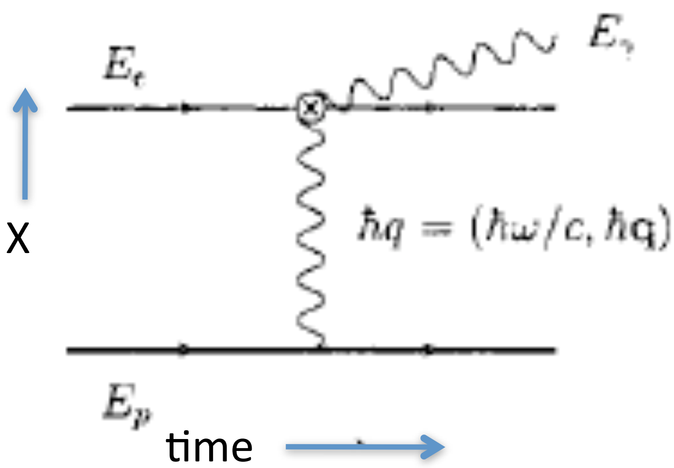
Examples:

| | |
|---|---|
| Gold+Gold->$e^+e^-$+Gold+Gold | = 33,000 barns |
| Proton-proton Interaction | ~0.1 barns |
| Diffractive Higgs@LHC | =$10^{-14}$ barn |

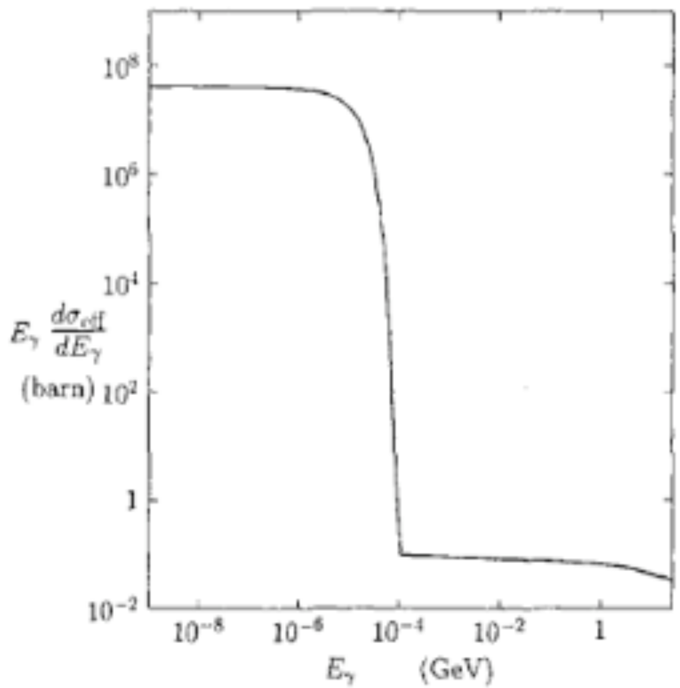
# Other Applications of Equivalent Photon Approximation(1)

- 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 $\sim 10^9$ proton bunch ($l \sim$ 1cm)

Coherence condition:




$$E_\gamma \leq 2\frac{\gamma^2_{Lorentz} hc}{l_{bunch}\pi}$$



# EPA(2)

- The effect of coherence is significant in collisions with composite targets
  - **Single photon process** **$\to (Z_{nucleus} * q_e)^2$**
  - **Two photon** **$\to (Z_{nucleus} * q_e)^4$**
- The price of coherence is the limit on momentum transfer,

  **$\Delta q < hc/(2\pi R_{nucleus})$ or $\lambda >$ target size**
- In high energy (colliding) beams the maximum

  $\Delta q$ is boosted by $2\gamma_{beam}^2$ ,where $\gamma$ =Lorentz factor

  **-> @LHC (2.75 TeraVolt/nucleon, Pb beam):**

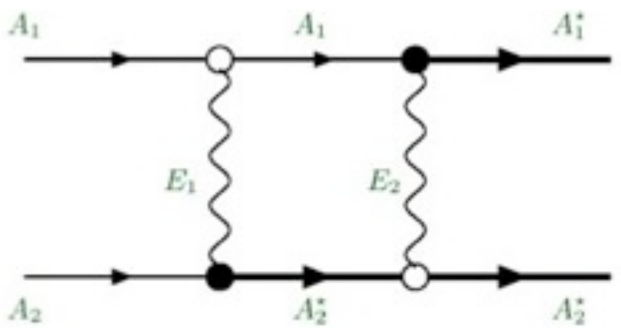
  **28 MeV->400 TeV**

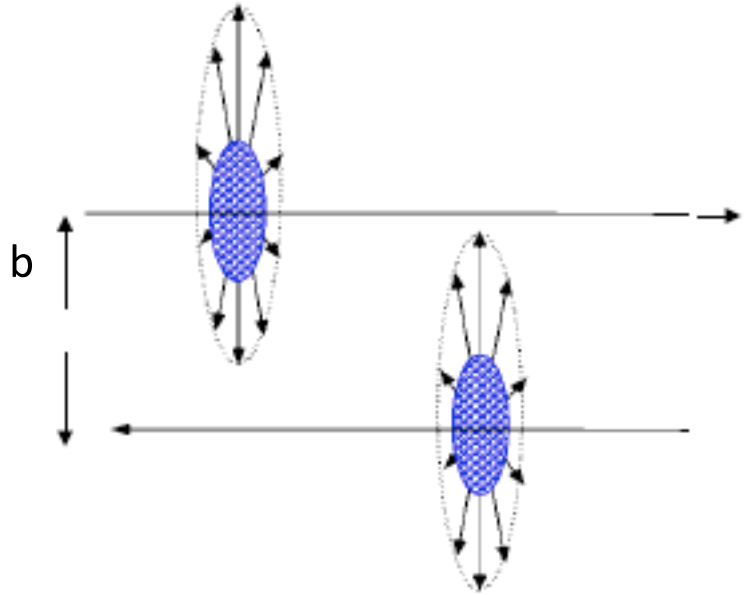
# Heavy Ion Collider parameters

| $AB$ | $L_{AB}$ ($\mathrm{mb}^{-1}\mathrm{s}^{-1}$) | $\sqrt{s_{NN}}$ (TeV) | $E_{\mathrm{beam}}$ (TeV) | $\gamma_L$ | $k_{\mathrm{max}}$ (GeV) | $E_{\mathrm{max}}$ (TeV) | $\sqrt{s_{\gamma N}^{\mathrm{max}}}$ (GeV) | $\sqrt{s_{\gamma\gamma}^{\mathrm{max}}}$ (GeV) |
|---|---|---|---|---|---|---|---|---|
| | | | | SPS | | | | |
| In+In | - | 0.017 | 0.16 | 168 | 0.30 | $5.71 \times 10^{-3}$ | 3.4 | 0.7 |
| Pb+Pb | - | 0.017 | 0.16 | 168 | 0.25 | $4.66 \times 10^{-3}$ | 2.96 | 0.5 |
| | | | | RHIC | | | | |
| Au+Au | 0.4 | 0.2 | 0.1 | 106 | 3.0 | 0.64 | 34.7 | 6.0 |
| $pp$ | 6000 | 0.5 | 0.25 | 266 | 87 | 46.6 | 296 | 196 |
| | | | | LHC | | | | |
| O+O | 160 | 7 | 3.5 | 3730 | 243 | 1820 | 1850 | 486 |
| Ar+Ar | 43 | 6.3 | 3.15 | 3360 | 161 | 1080 | 1430 | 322 |
| Pb+Pb | 0.42 | 5.5 | 2.75 | 2930 | 81 | 480 | 950 | 162 |
| $p$O | 10000 | 9.9 | 4.95 | 5270 | 343 | 3620 | 2610 | 686 |
| $p$Ar | 5800 | 9.39 | 4.7 | 5000 | 240 | 2400 | 2130 | 480 |
| $p$Pb | 420 | 8.8 | 4.4 | 4690 | 130 | 1220 | 1500 | 260 |
| $pp$ | $10^7$ | 14 | 7 | 7455 | 2452 | 36500 | 8390 | 4504 |

# 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**

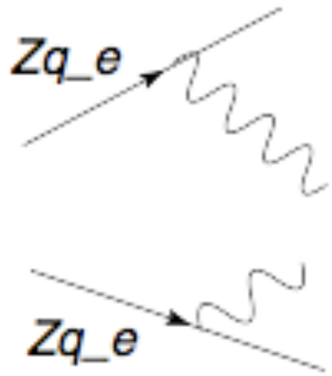



**•Coherent Pair Production (various)**

"inverse positron annihilation" (Breit-Wheeler)

("photon flux")$^2$

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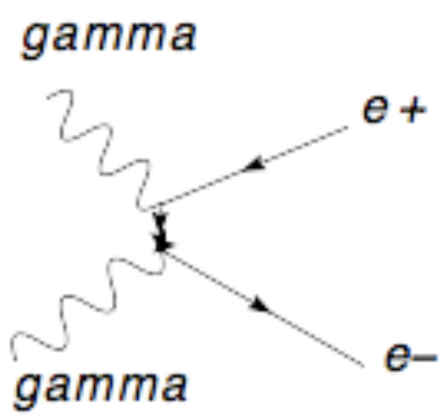
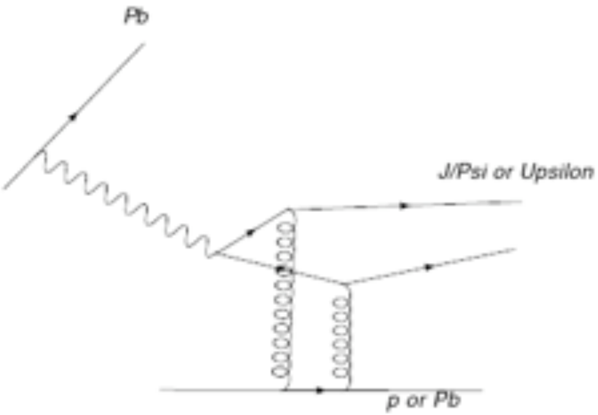


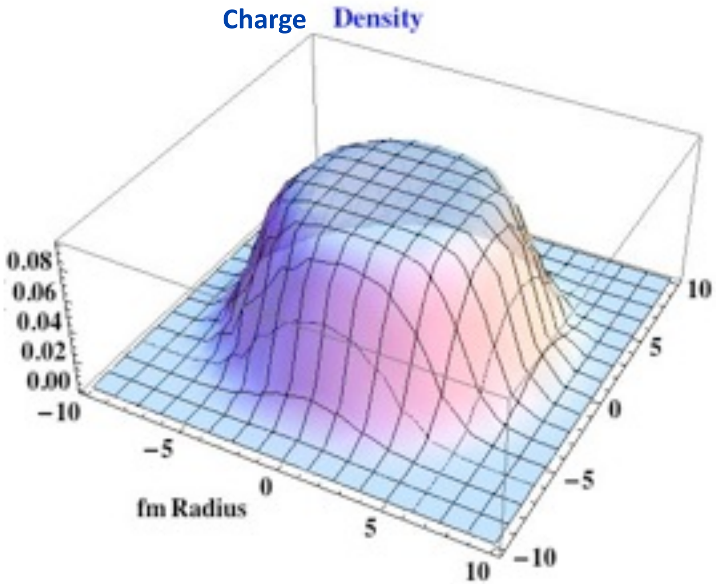
# EPA(4):Vector meson photoproduction

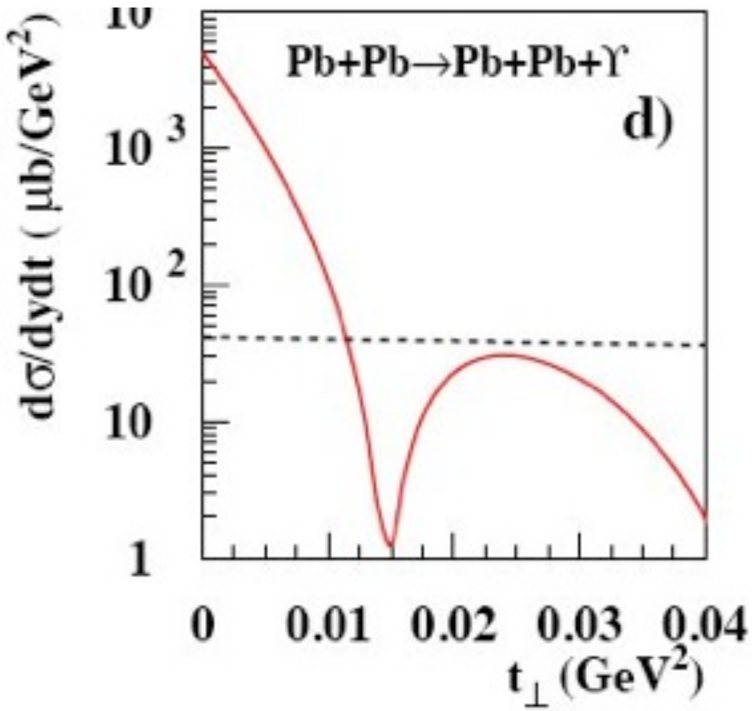
- gluon distribution in proton or nucleus



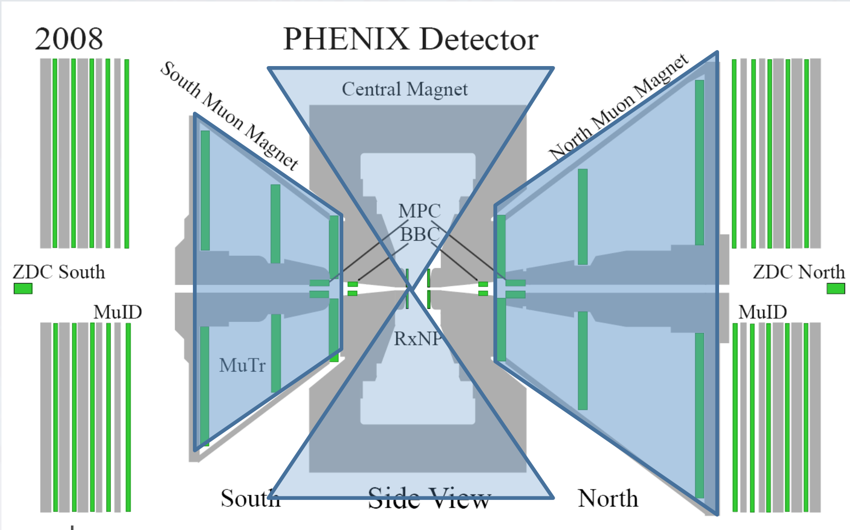

$$\frac{d\sigma}{dt}(J/Psi - Nucleus)$$

$\longrightarrow$ "QCD Rutherford scattering"



# PHENIX DI-LEPTONS




forward tags

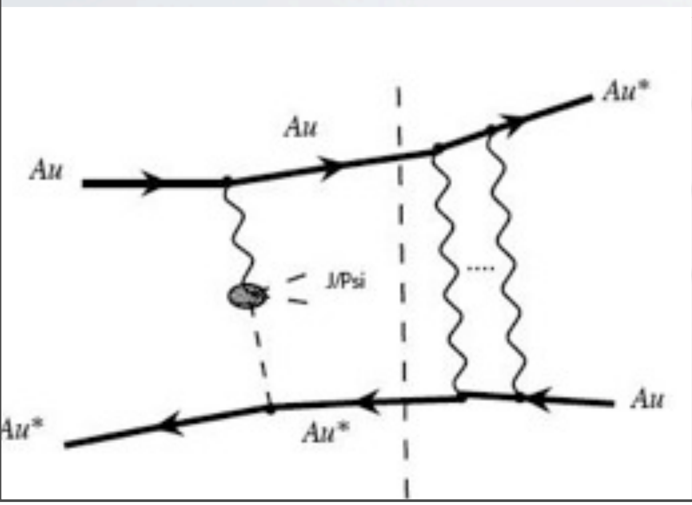
**BBC** (3.0 < |η| < 3.9)

(charged)

**MPC,ZDC**

(calorimeters, neutral)

additional photon exchange a la Baltz & SNW




Central arm : 0<|η|<0.35 e-pair( 50%*2pi)

Muon arm : 1.2<|η|<2.4 μ-pair

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

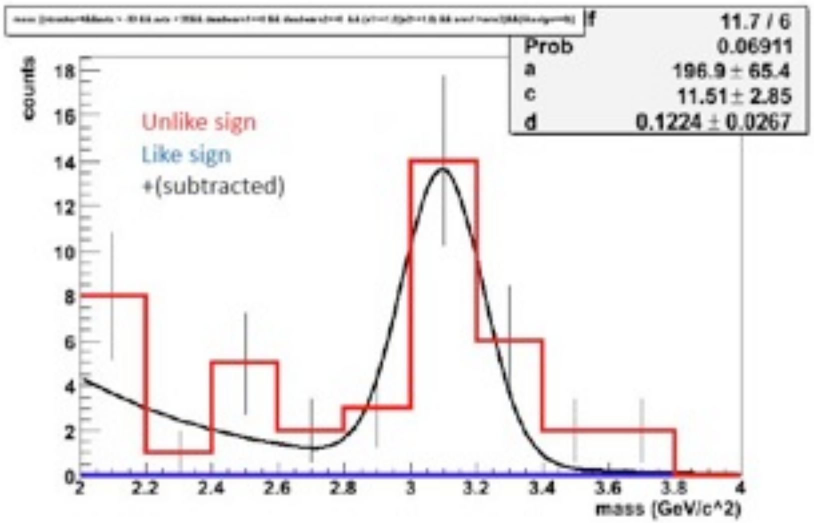
- **track cut to eliminate inelastic**
- **overwhelming pion rejection**

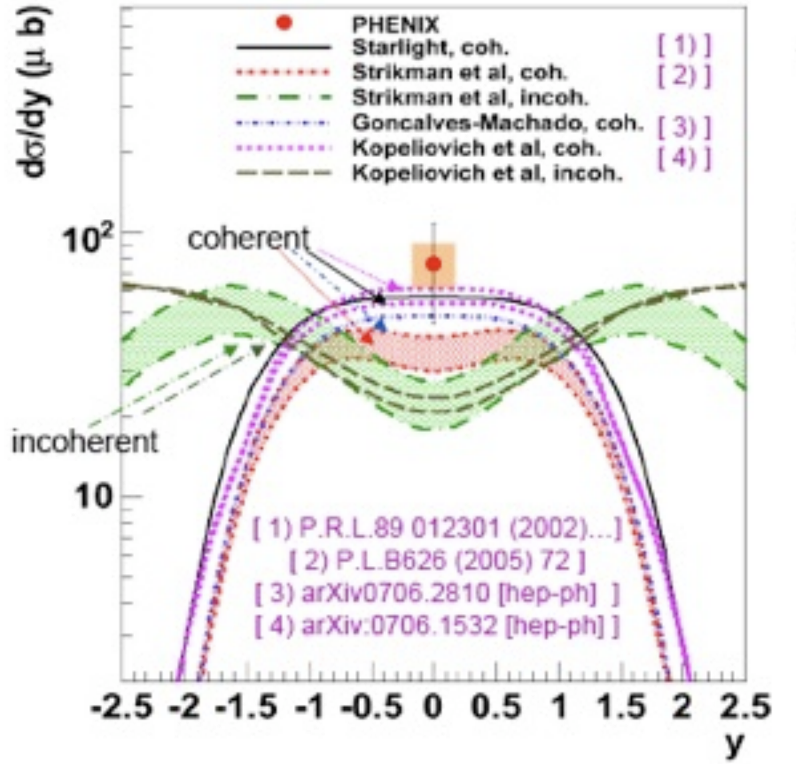
# "new" 2007 ee sample

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

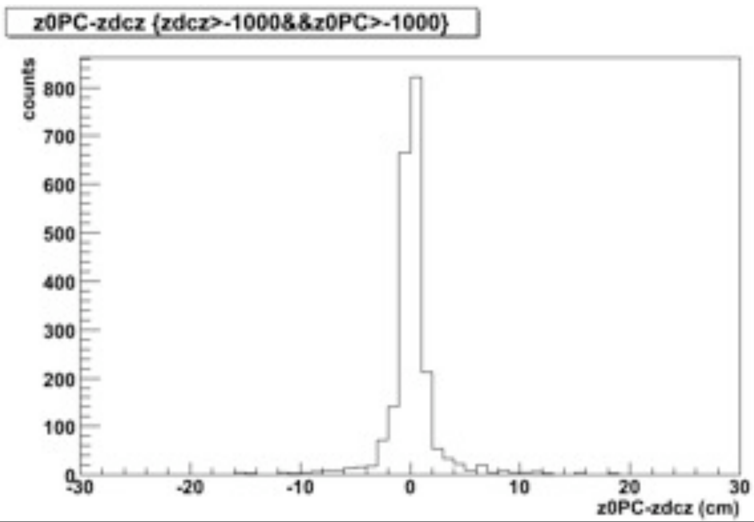
$$\sigma(\gamma + Au \rightarrow J/\psi) = A^{\alpha}\sigma(\gamma + p \rightarrow J/\psi), \alpha_{coh} = 1.01 \pm .07$$

Invariant mass distribution (Ntracks<4)



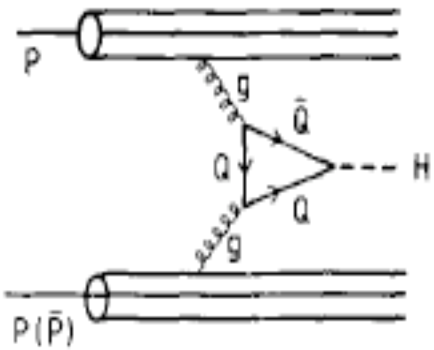

new algorithm for event vertex



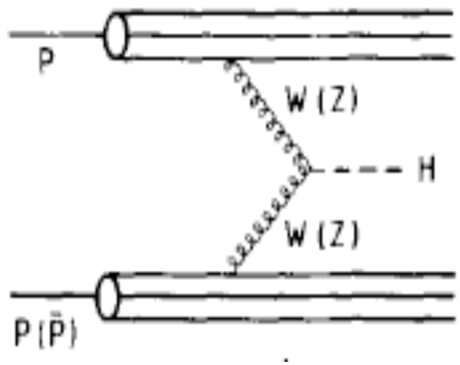

- ~1 $J/\psi$ + n-tag per minute at RHIC
- -> 10 mbarn (10/second) in ATLAS@ LHC
- similar to planned eIC but higher $\sqrt{s}$
- PHENIX studying high acceptance $\mu\mu$ trigger
  - access to incoherent

# EPA(5)-Equivalent W Approximation

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



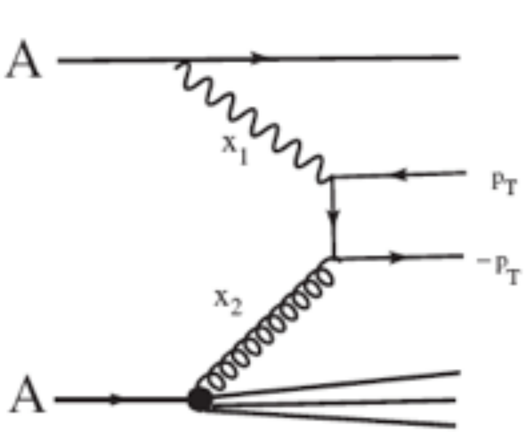

"gluon-gluon fusion"




"β-decay amplitude"

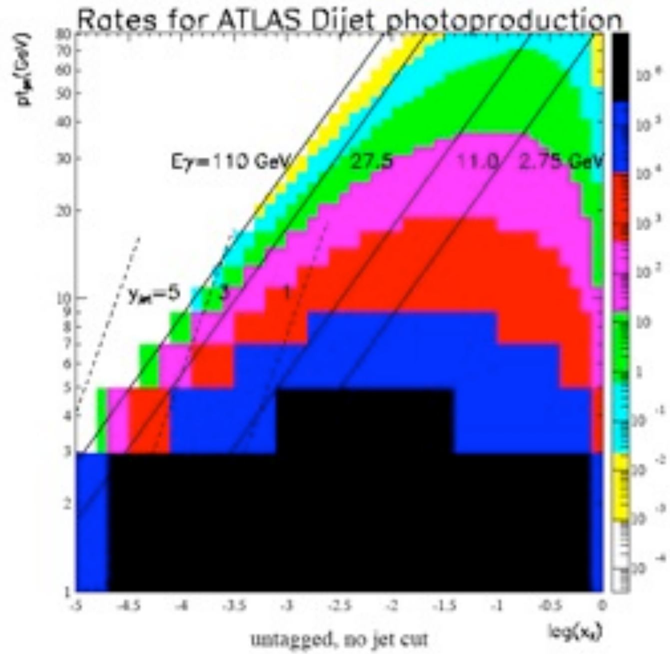
# EPA(6): Measuring the structure of Protons and Nuclei

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




q,anti-q
"jets"

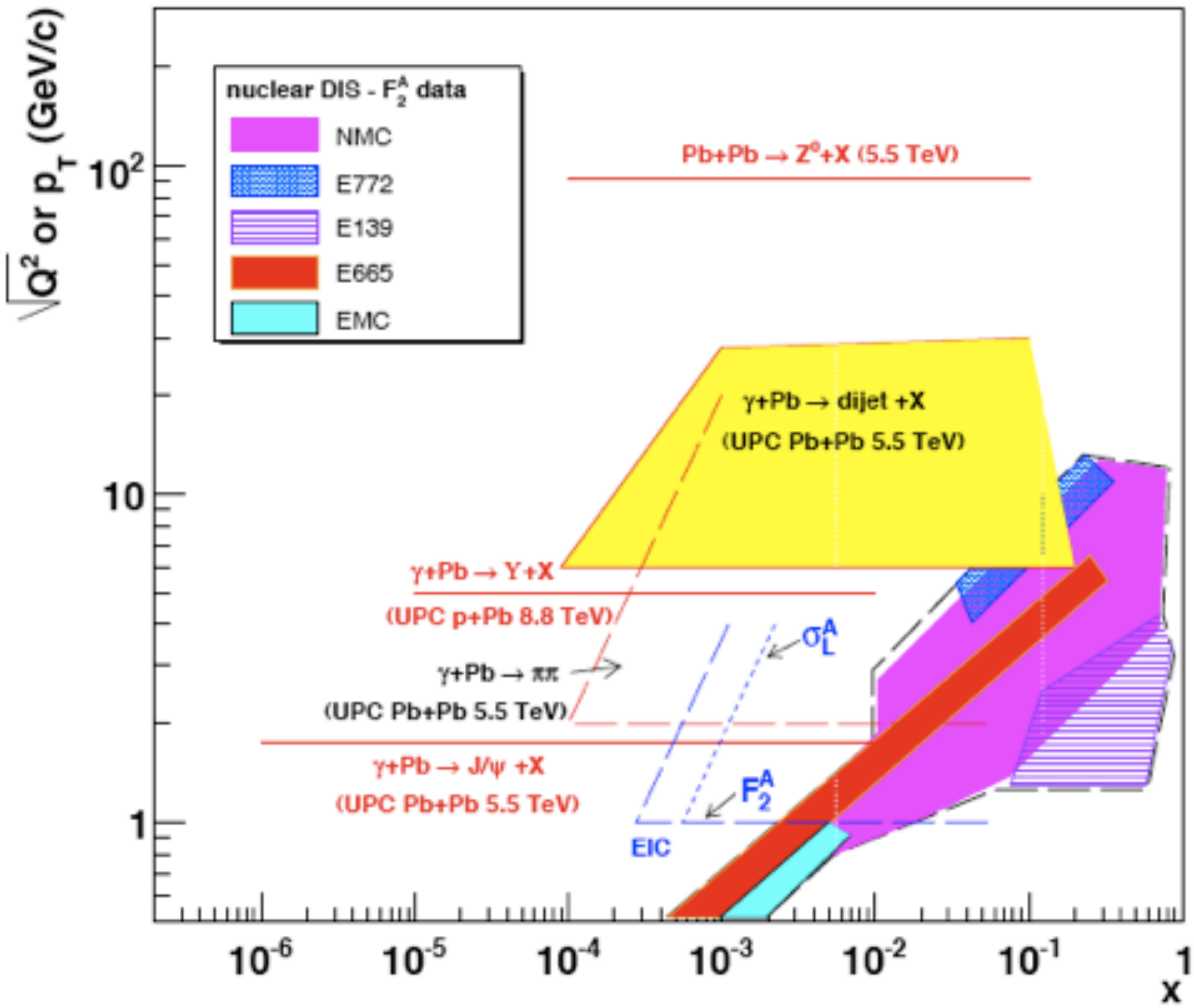
Resolving power



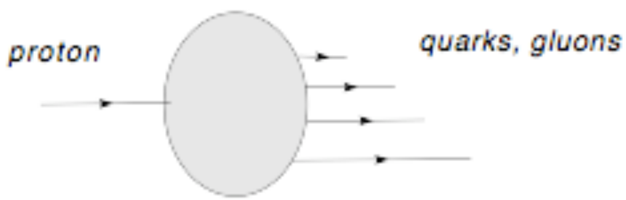

quark,gluon momentum fraction

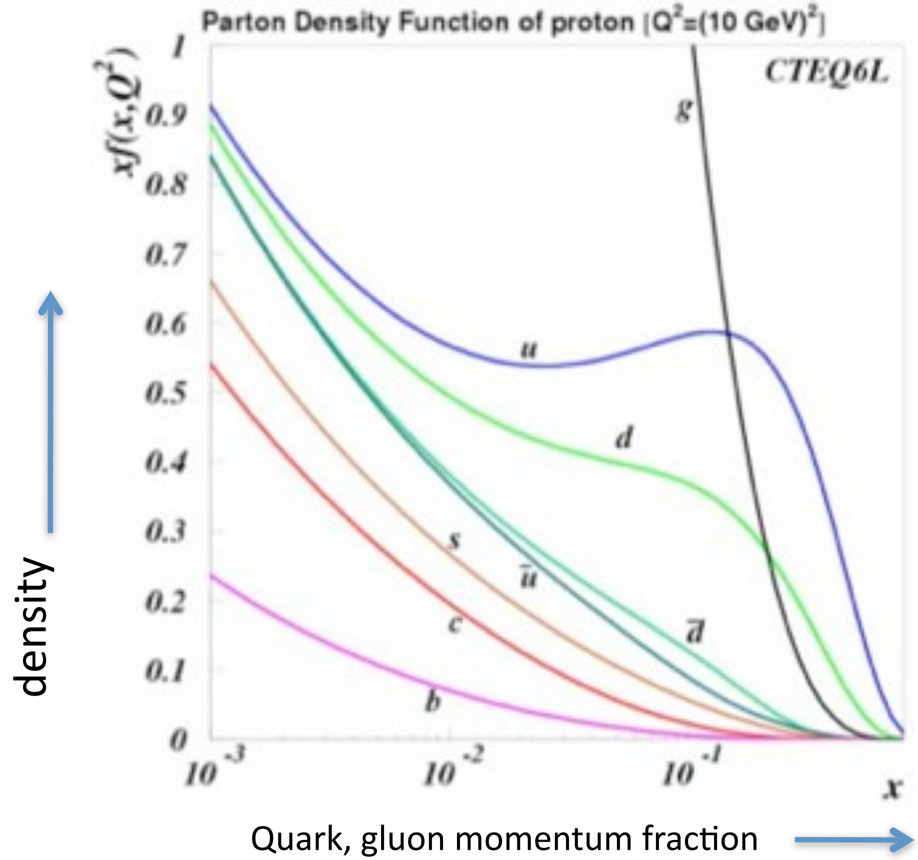
Structure ⟺ Distribution of partons(=quarks, gluons) inside proton- similar to EPA

# Coverage by ATLAS hard photoproduction



- **Structure**



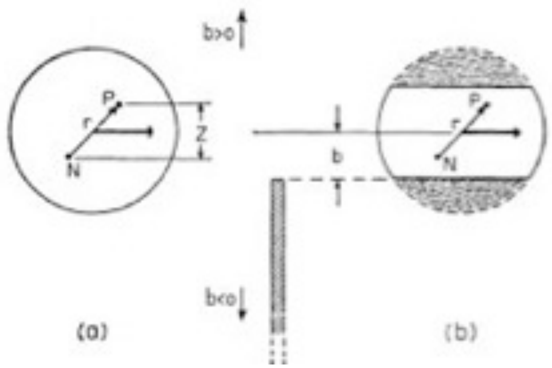




**•Many other EPA analogies in QCD theory of strong interactions: e.g. Dokshitzer, Gribov, Lipatov, Altarelli and Parisi (DGLAP)**

# Inelastic Diffraction

- Glauber (1955)- deuteron “free dissociation”
- Feinberg & Pomeranchuk(’56)

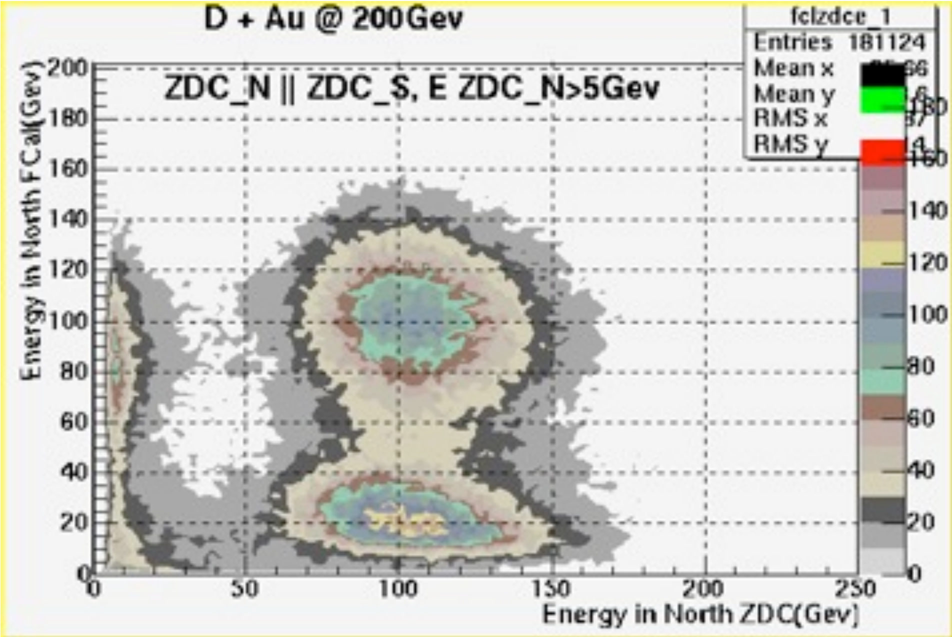
- “Diffraction Dissociation-50 Years Later”-SNW

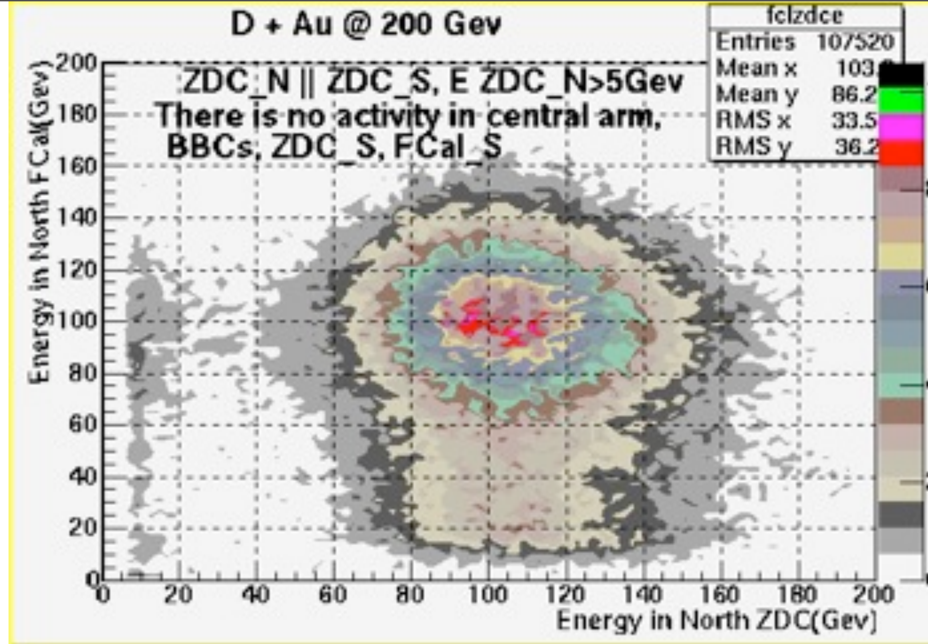


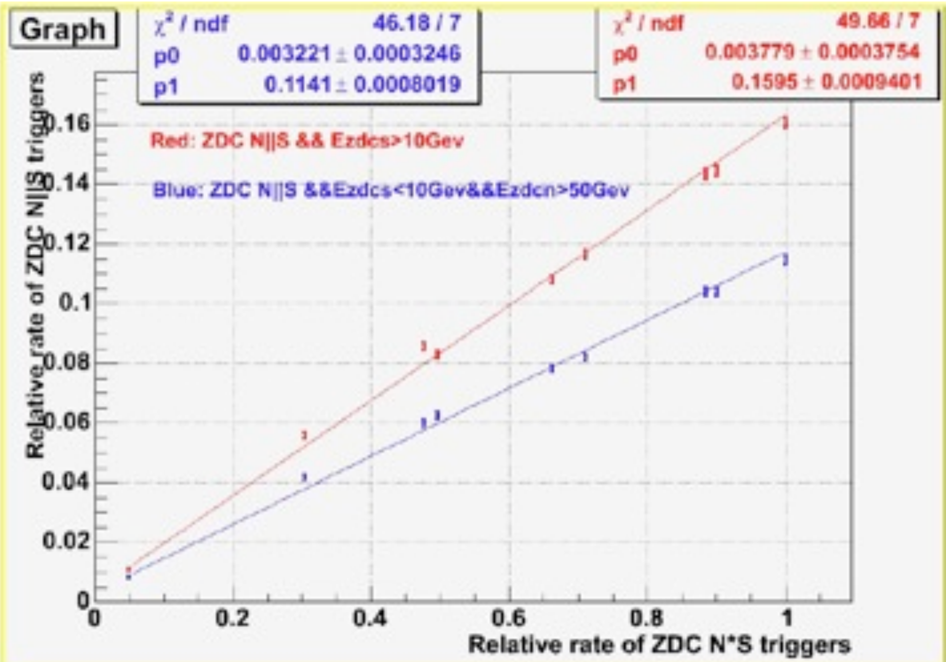

Collisionless interaction->excitation to unbound n,p

$d = \sum c_n \Psi_n, \Psi_n =$ Scattering basis states

•Measured in PHENIX: $\sigma$ =138 mbarn



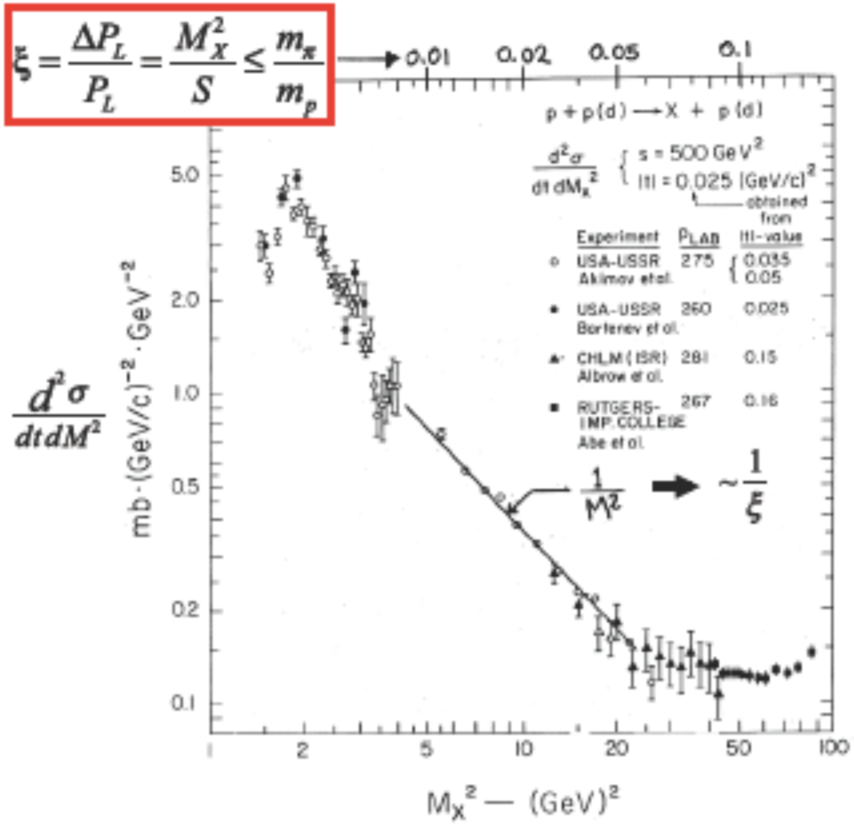




- R(d-AU dissociation)= Luminosity$\times\sigma$
- d breakup background ie on accelerator residual gas ->beam current
- -> special data runs changing beam separation
- This result became basis for PHENIX luminosity calibration

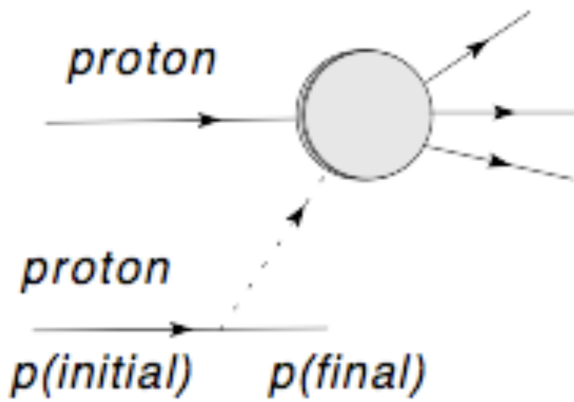
# Proton diffraction dissociation

- Large coherence peak for $\lambda > R_{proton}$



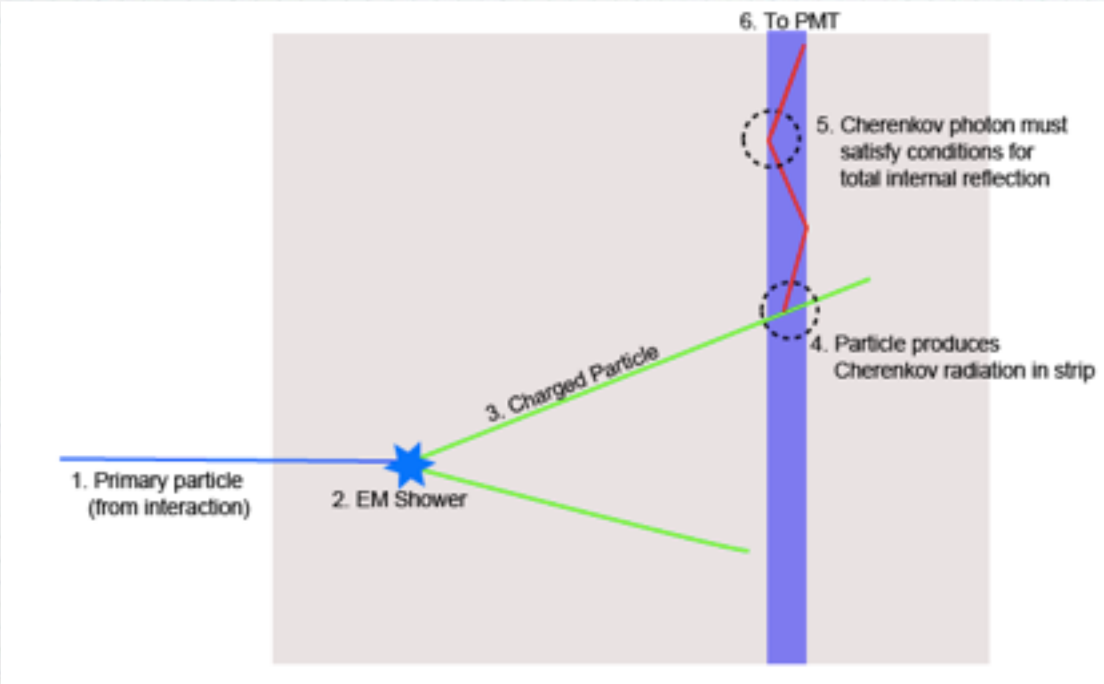

K.Goulianos('83)

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



# Asymmetries

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

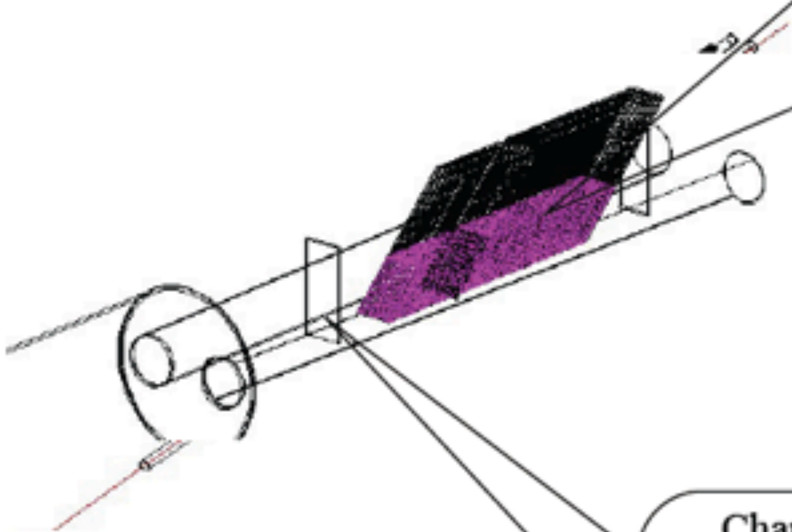


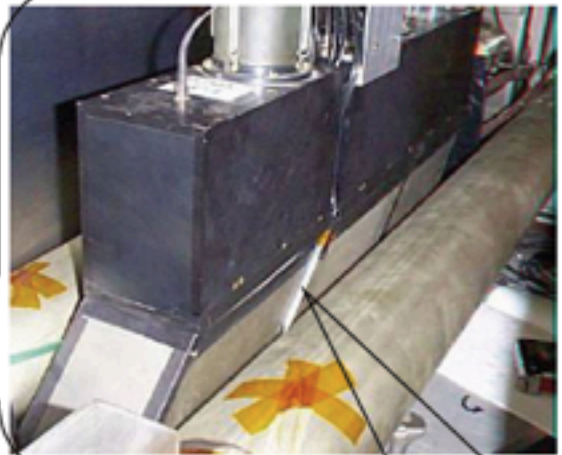

ZDC is based on Cerenkov sampling in optical fibers.
-very fast
-unusual response profile
-ATLAS uses quartz glass (5 GigaRad/year)

# Setup

Schematic view from simulation.

- GEANT3 (Geisha)
- From the pythia simulation, Main backgrounds are photon and proton.





**ZDC**
(**Z**ero **D**egree **C**alorimeter)

10*10cm
→ ±2.8 mrad

3 module
$150X_0$ $5.1\lambda_I$

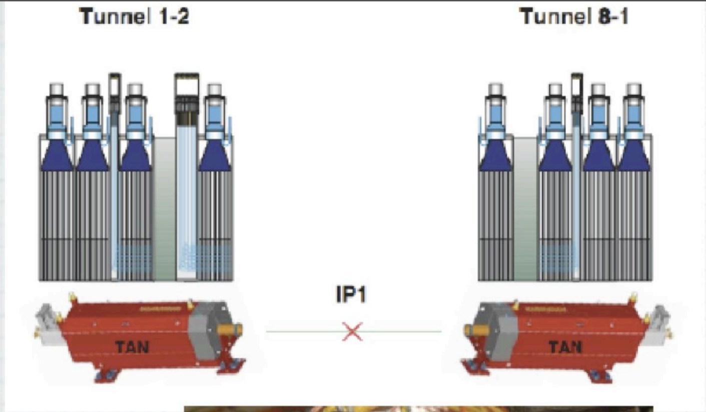
SMD
(**S**hower **M**ax **D**etector)


Neutron position can be found using centroid method (+/- 1cm).

Charge veto counter

veto

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




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...

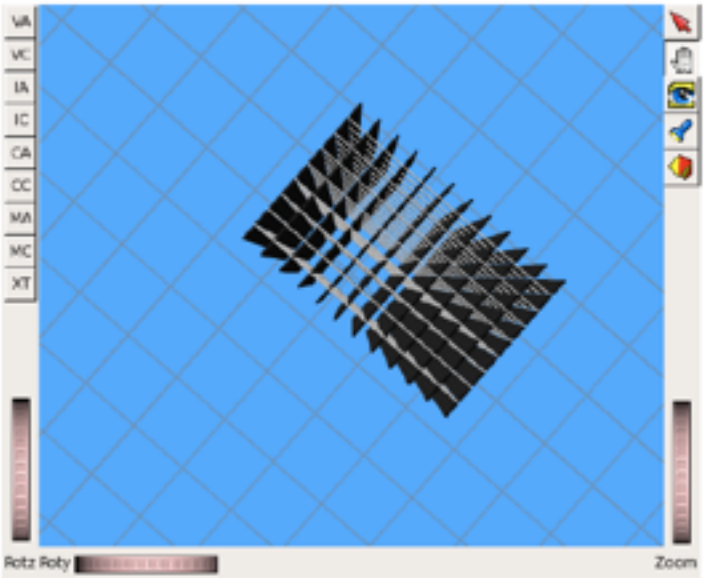



Figure 4: ZDC Drawn with VP1. Plot shows the grid of Strips and Pixels within the EMXY Module

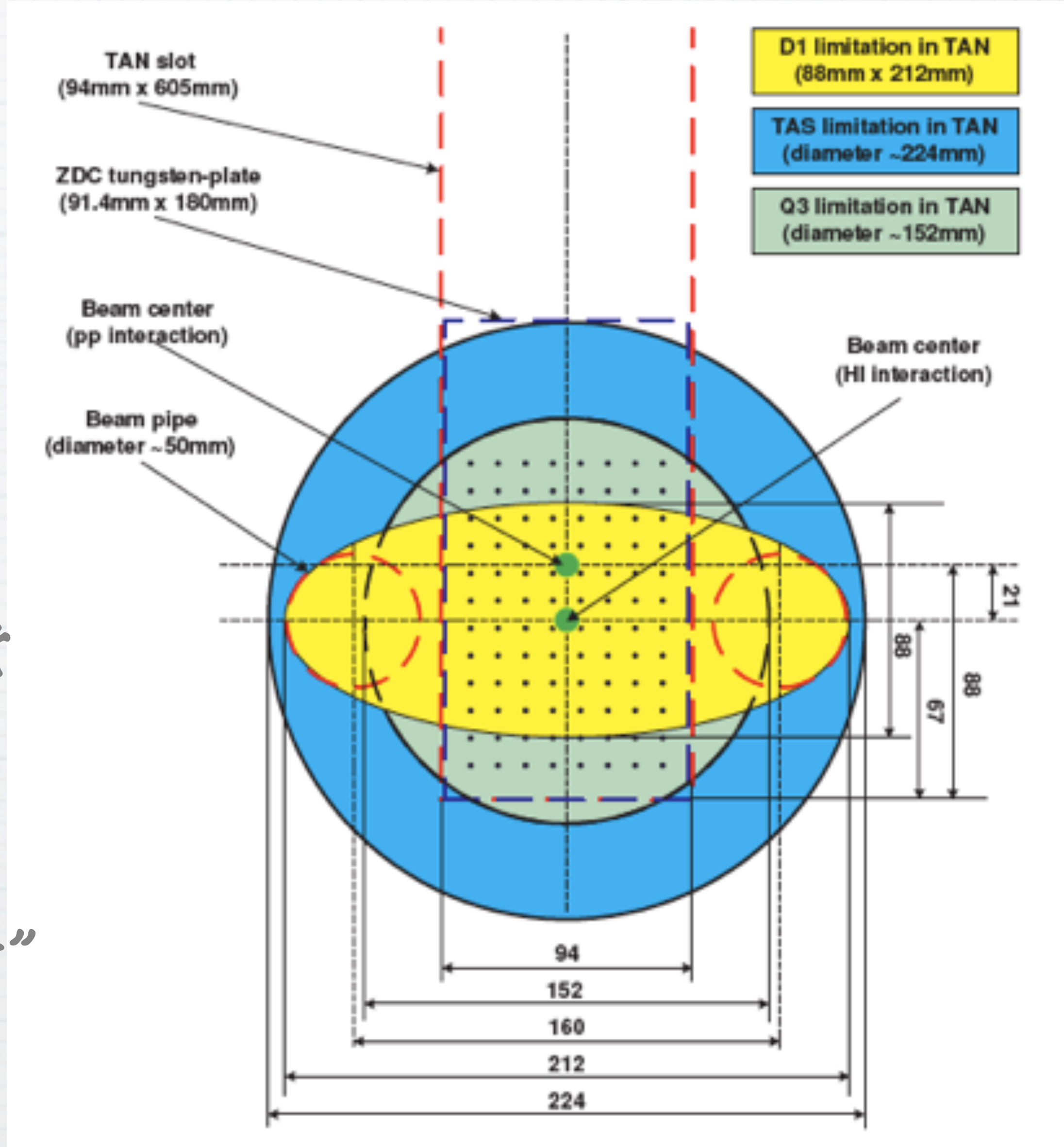
despite constraints
-> ATLAS is the only imaging ZDC (x,y,z) on the planet
"shashlik"/layer sampling hybrid

# the tunnel

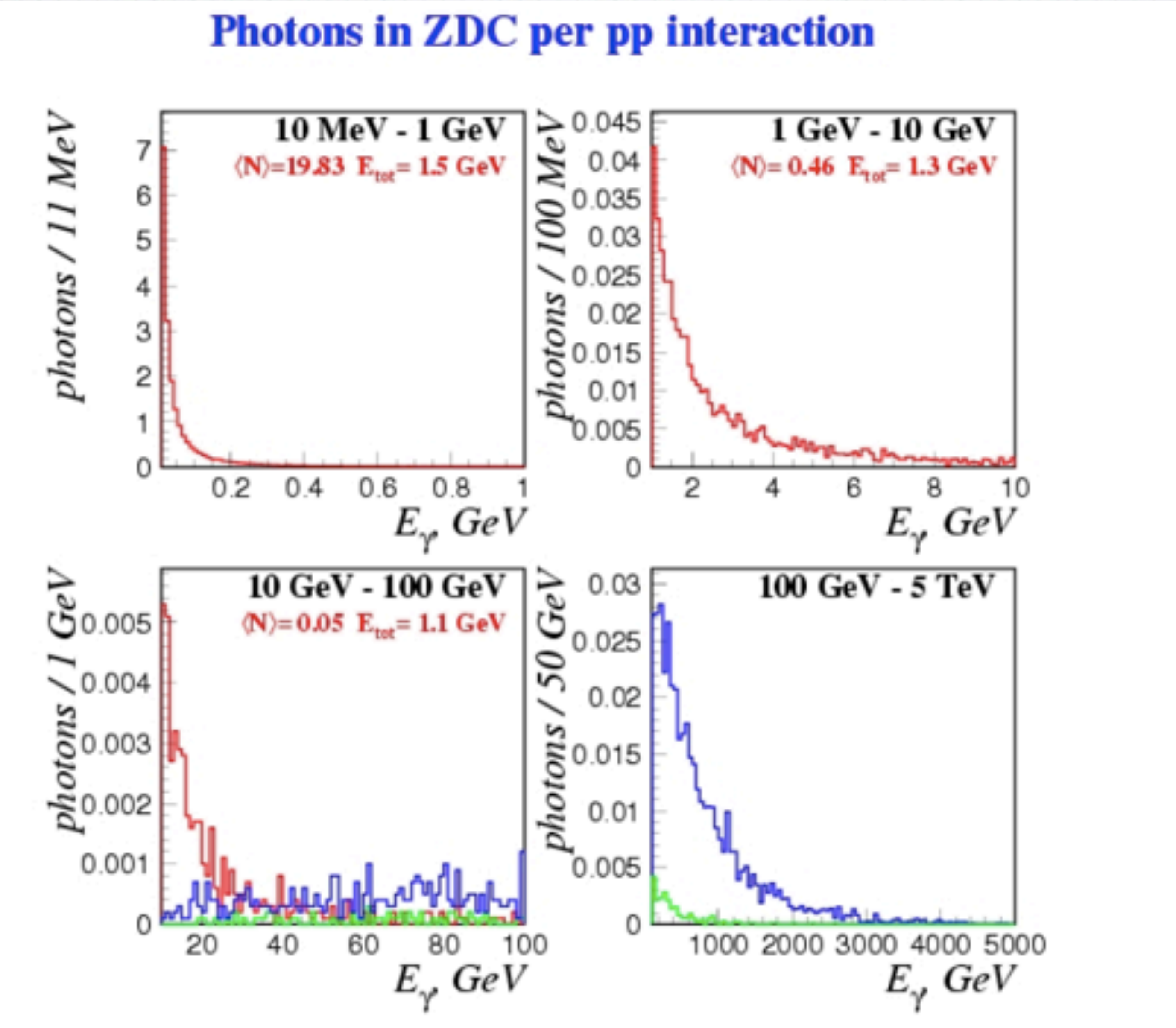
we worked with 2 transport packages designed for IP1, 5 geometry
-Hector
-FPTracker

all can interpret accelerator files about time-dependent LHC configuration

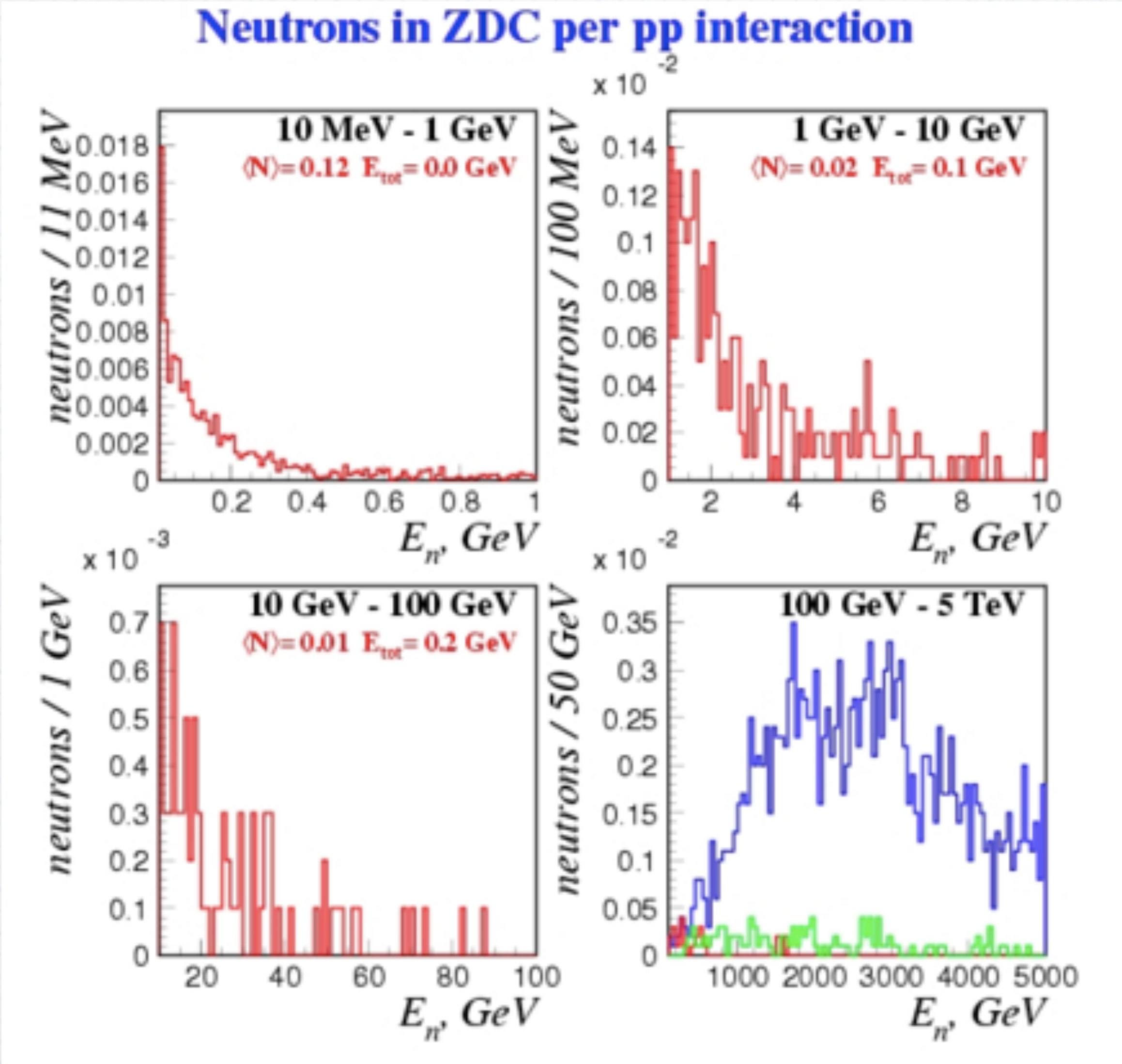
we develped "FNTracker"



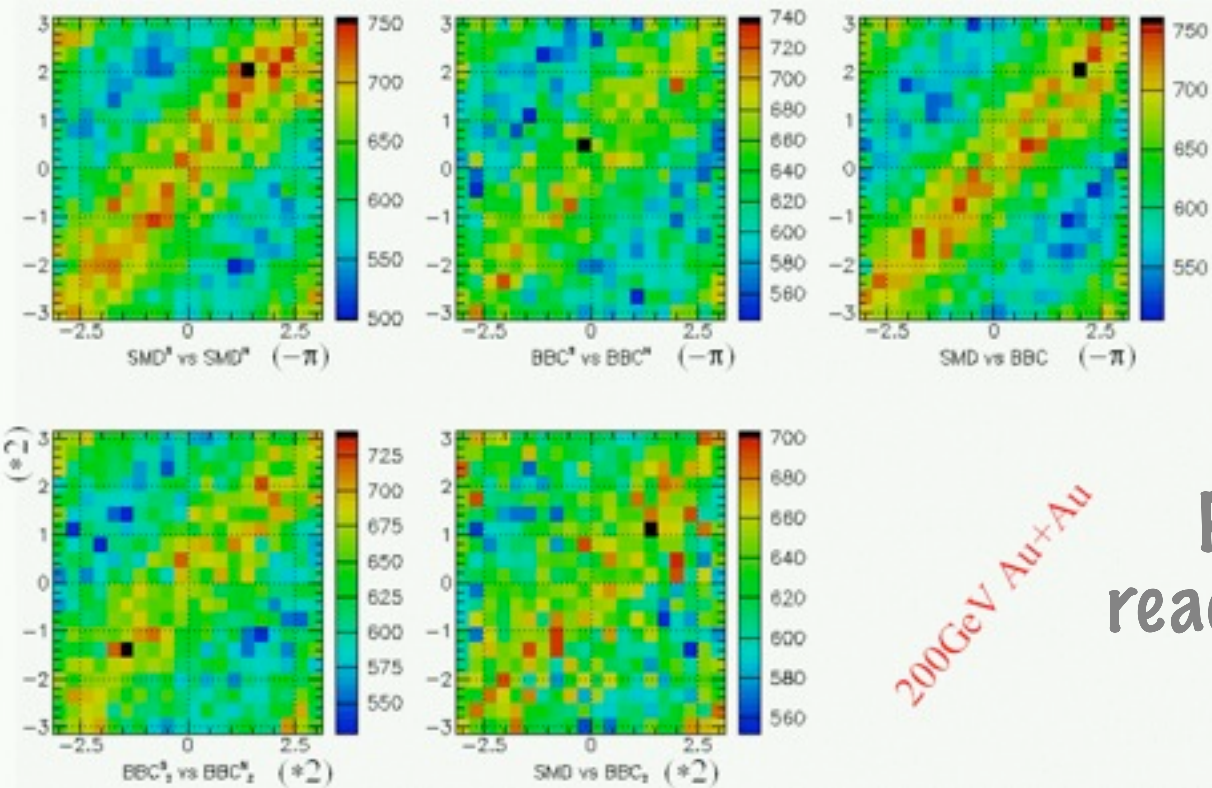
# ATLAS ZDC full simulation- validated by Mokhov accelerator studies



# 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)

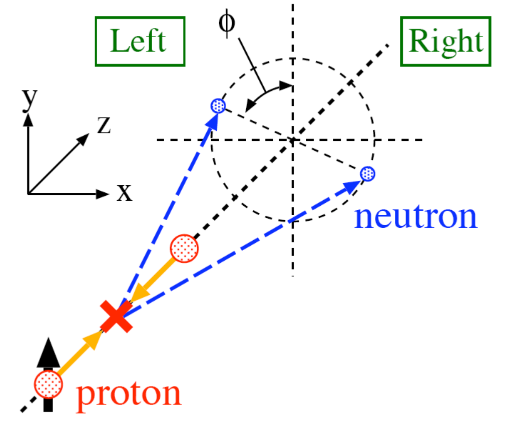


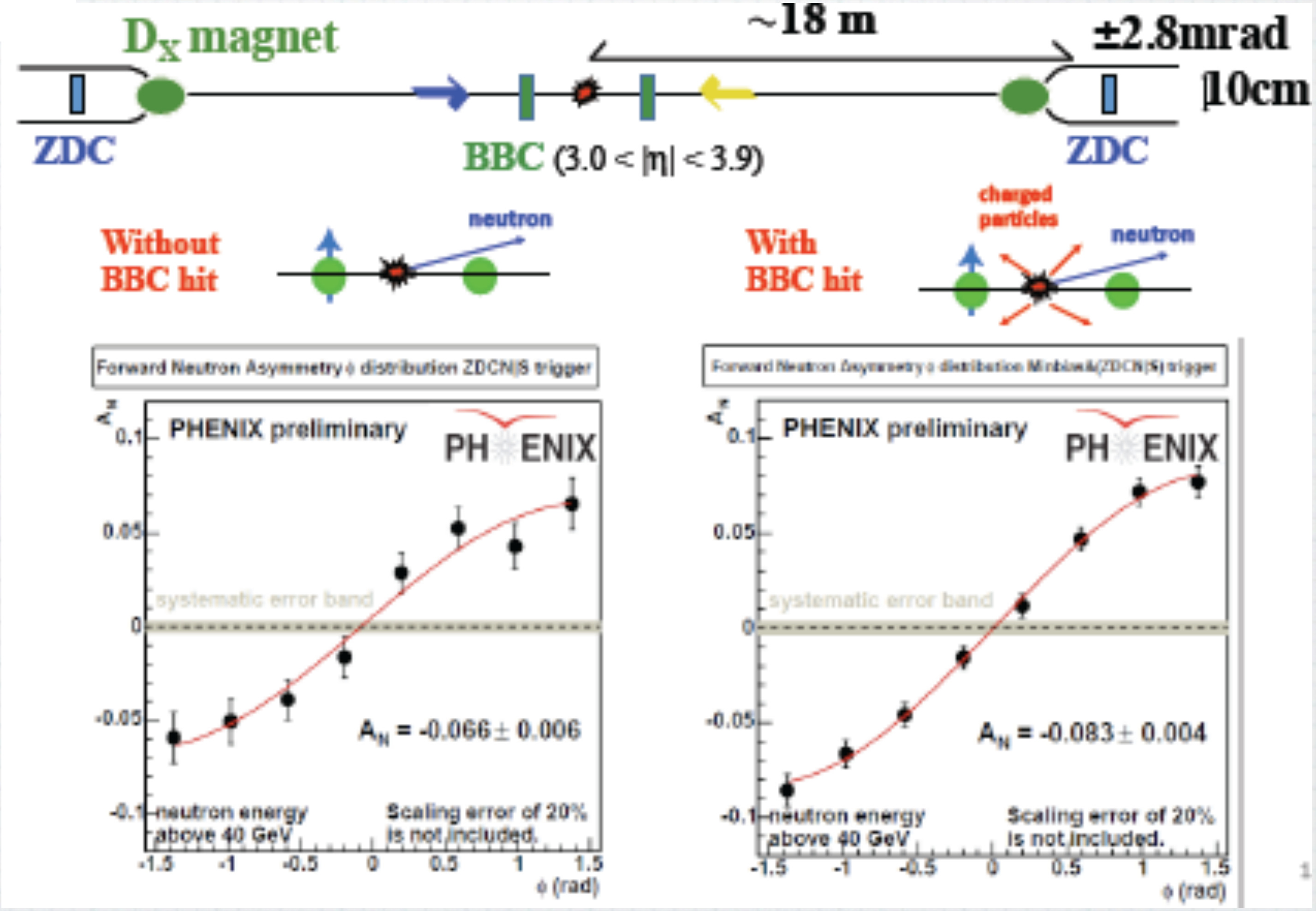
# PHENIX analysis of reaction plane resolution



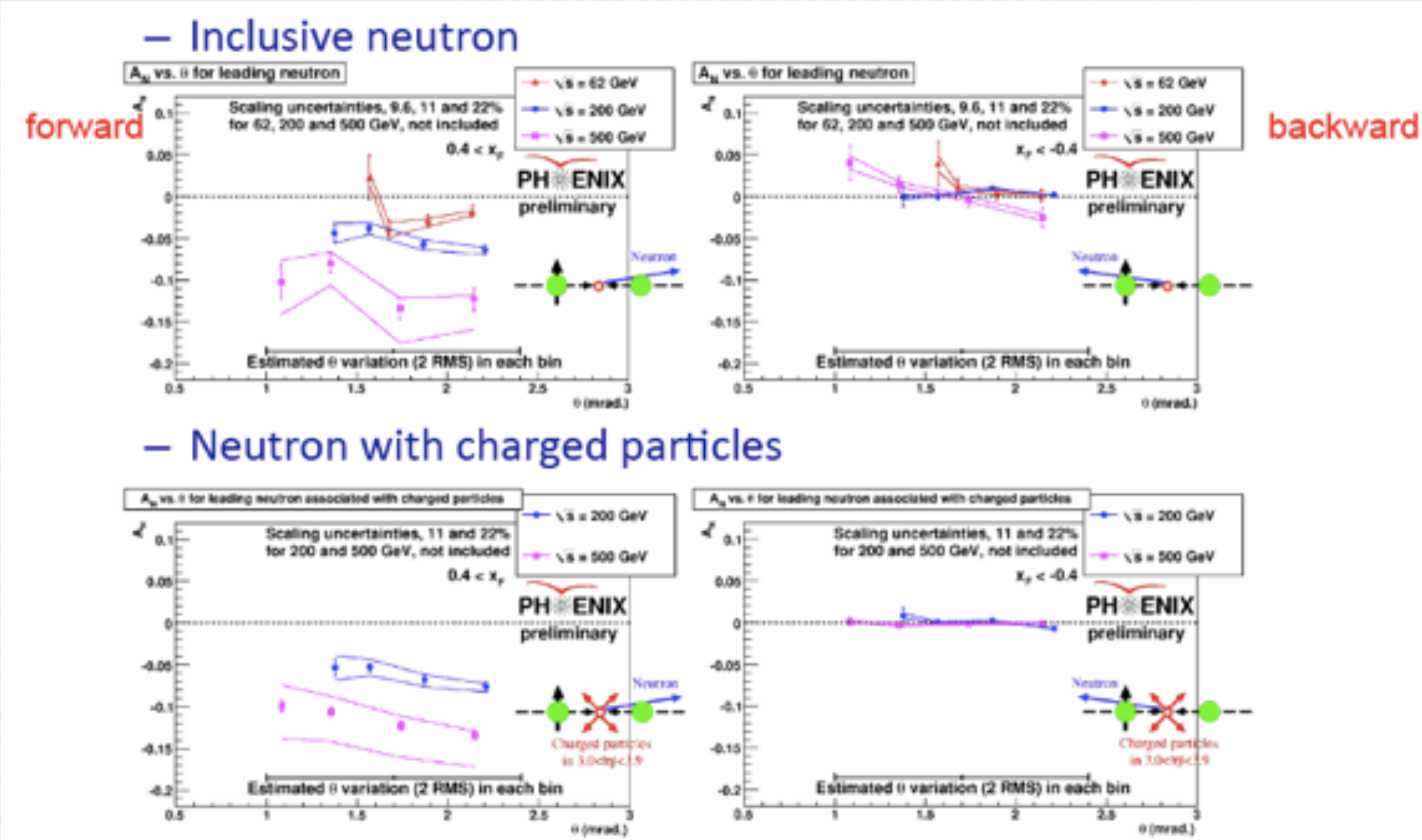

| | Au+Au 200GeV | Au+Au 62GeV | |
|---|---|---|---|
| | $y_{beam}^{(100GeV)}=5.3$ | $y_{beam}^{(31GeV)}=4.5$ | $(3<\eta_{bbc}<4)$ |
| $N_{ch}^{max}$(bbc) | ~1600 | ~600 | (multiplicity) |
| $v_1$(bbc) | 1~2% | 2~4% | (signal) |
| $v_2$(bbc) | 2~2.5% | 1.5~2% | (signal) |
| $\langle\cos\Delta\Phi_1^{BBC}\rangle$ | 4~5% | 4~5% | (resolution) |
| $\langle\cos 2\Delta\Phi_2^{BBC}\rangle$ | 8~9% | 2~3% | (resolution) |
| $\langle\cos\Delta\Phi_1^{SMD}\rangle$ | 7~8% | 1~2% | (resolution) |

# Spin dependent asymmetries in pp



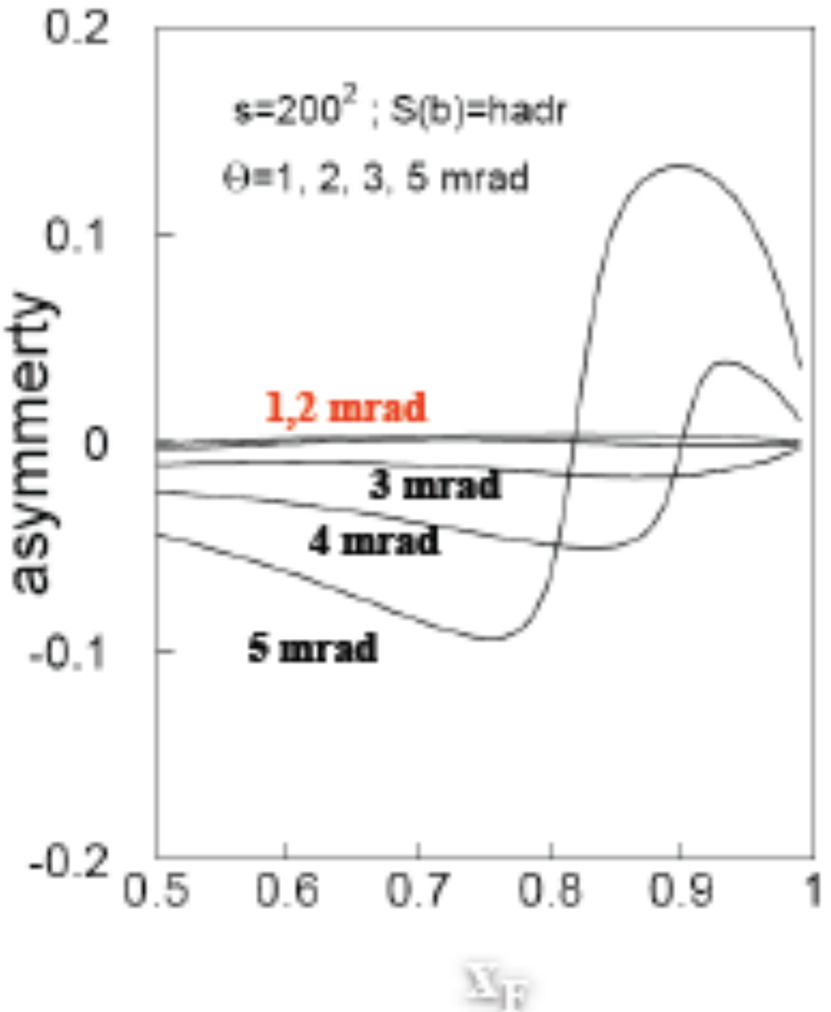



# New results on s-dependence



# 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, and $\theta$ < 2 mrad.
  - possibly due to other reggeon exchanges. (*e.g.* $a_1$ exchange)
  - testable with neutron $p_t$ dist.

$$\frac{d\sigma}{dp_t^2} ? \rightarrow \frac{1}{(p_t^2 + m_\pi^2)^2}$$

$$\text{OPE[pt\_]} := \frac{3.842\times 10^{-4}}{\left(pt^2 + m_\pi^2\right)^2}$$

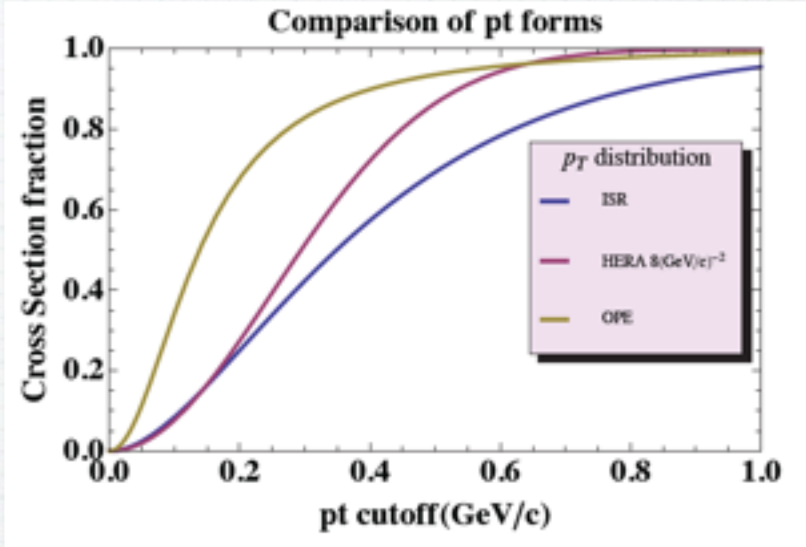
$$\text{OPEInt[y\_]} = \int_0^y pt \frac{.0393}{\left(pt^2 + m_\pi^2\right)^2}\, dpt;$$

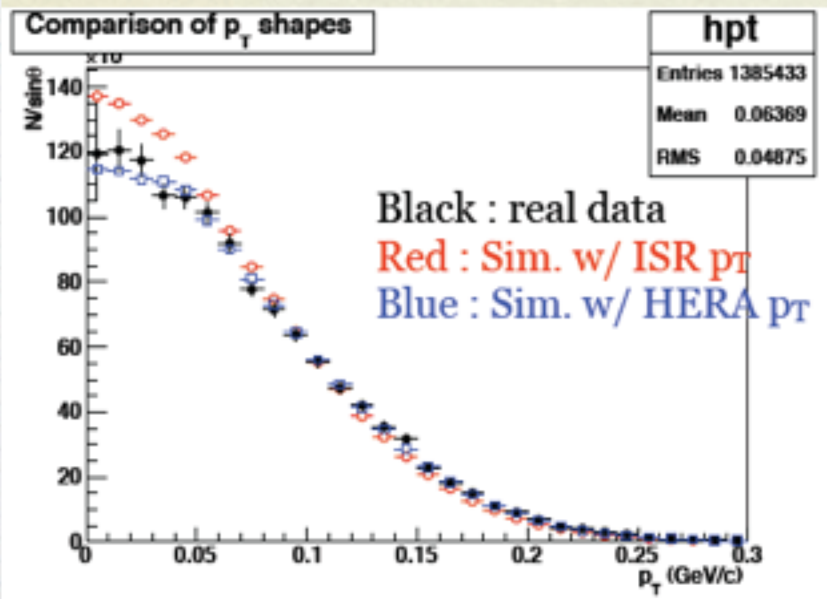
$$\text{ISR[pt\_]} := e^{-4.8\, pt}$$

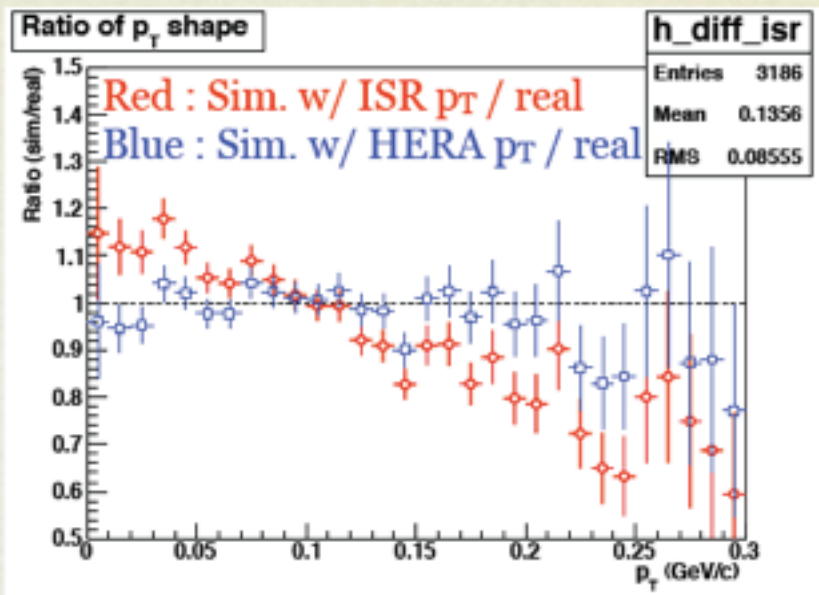
$$\text{ISRInt[y\_]} = 23.1 \int_0^y pt\ \text{ISR[pt]}\, dpt;$$

$$\text{HERA[pt\_]} := e^{-8*pt^2}$$

$$\text{HERAInt[y\_]} = 16 \int_0^y pt\ \text{HERA[pt]}\, dpt;$$

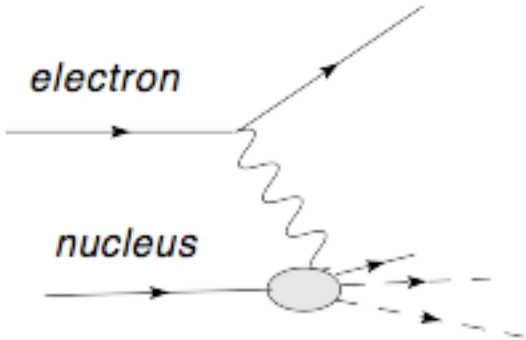


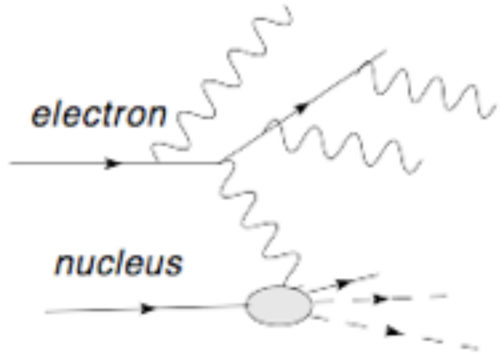



# Diffraction(e-nucleus analogy)

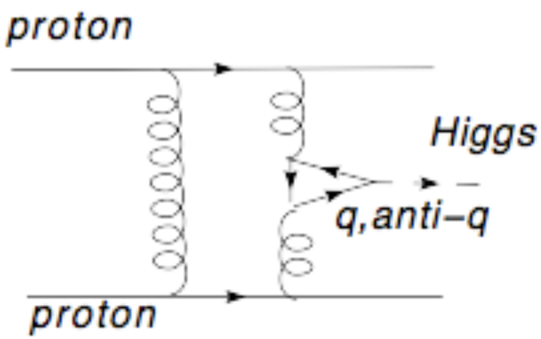
- **Diffractive electroproduction**




**non-diffractive**

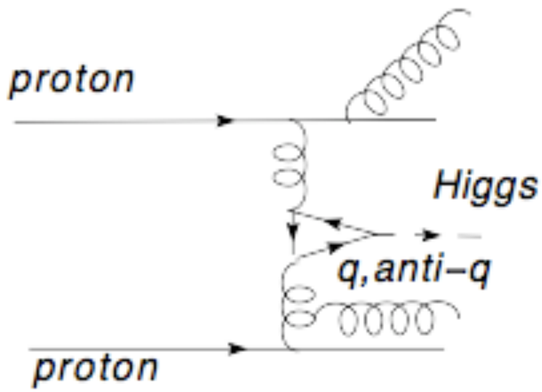



**Diffractive Higgs production**

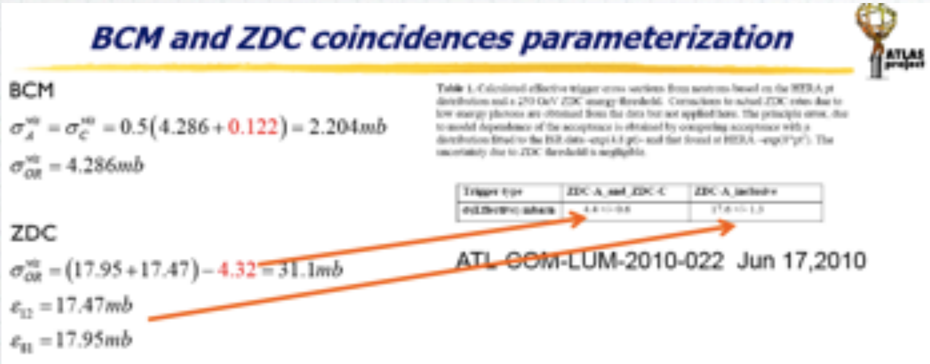



"color screening"

**non-diffractive**

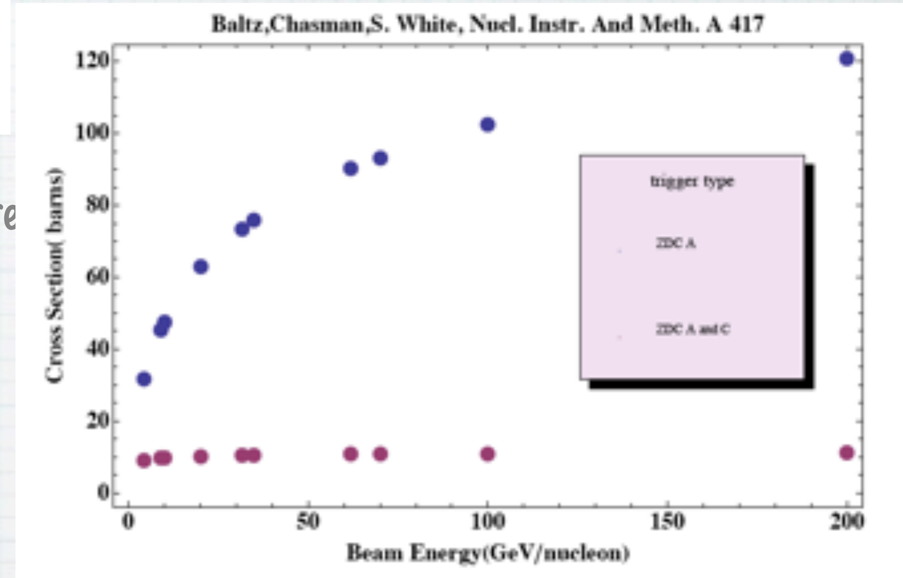


# Luminosity news




even higher absolute luminosity precision
should be expected from PbPb running using ZDC !

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.

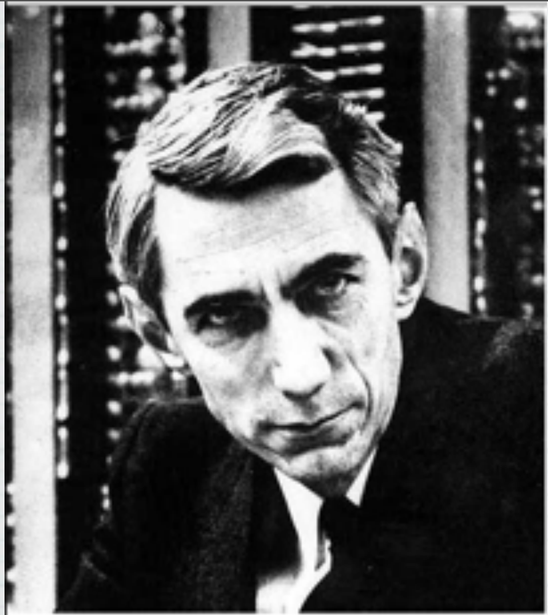
From Transported Montecarlo:
ZDC_A,
Phojet: 11.3696, Pythia6: 10.8631, Pythia8: 10.2577.

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

RHIC ZDC Rates and Corrections

Sebastian White, PHENIX note

March 15 '10



# Optimal reconstruction of sparsely sampled ZDC waveforms

- 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.

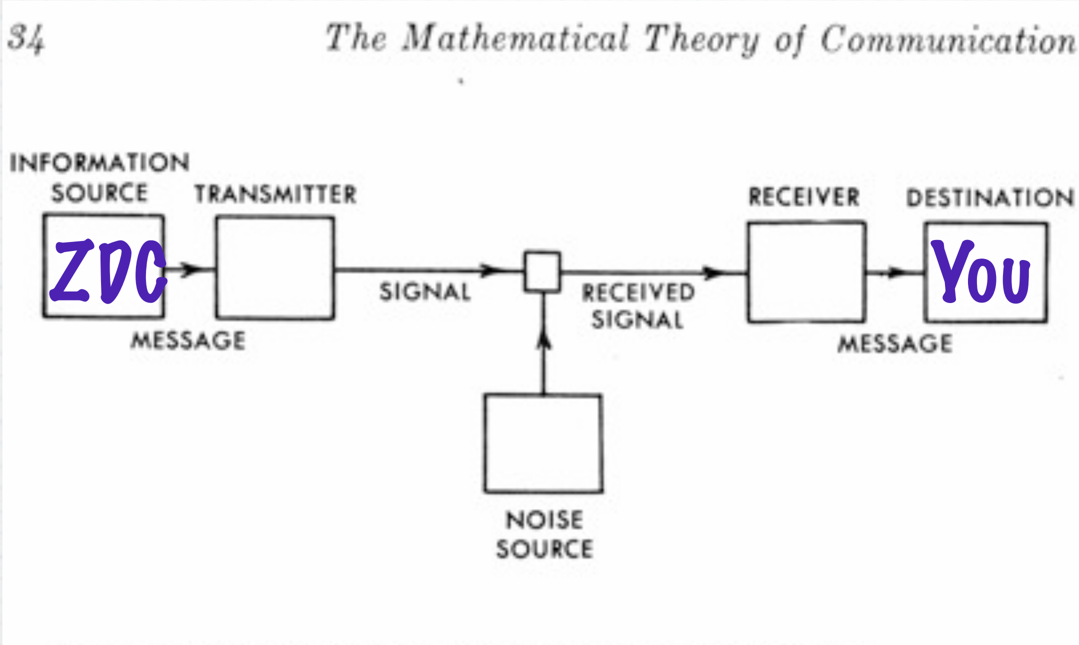
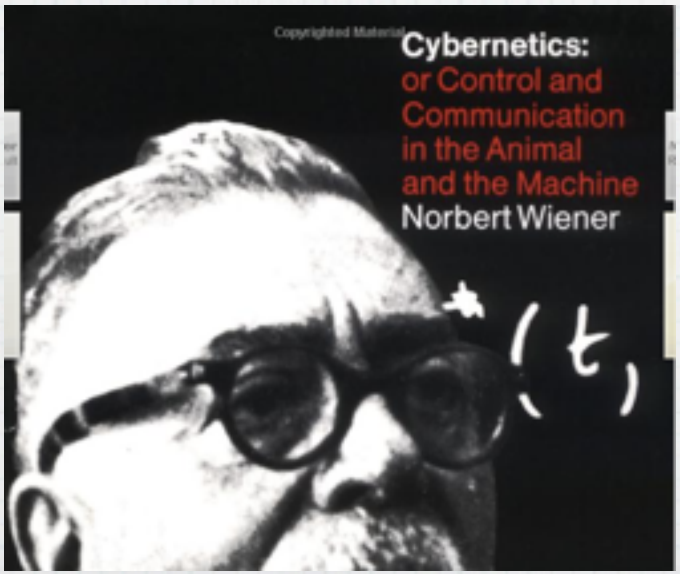
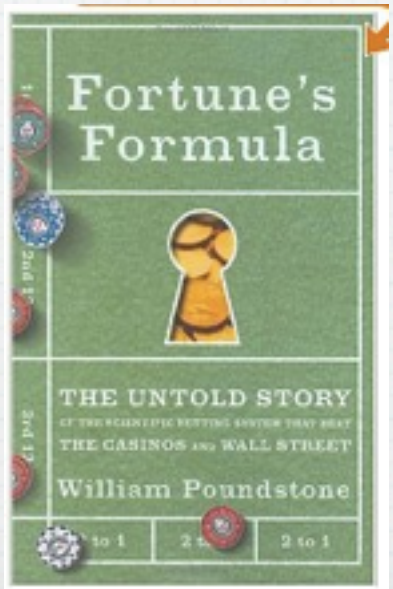



Fig. 1. — Schematic diagram of a general communication system.

## books about Shannon:



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

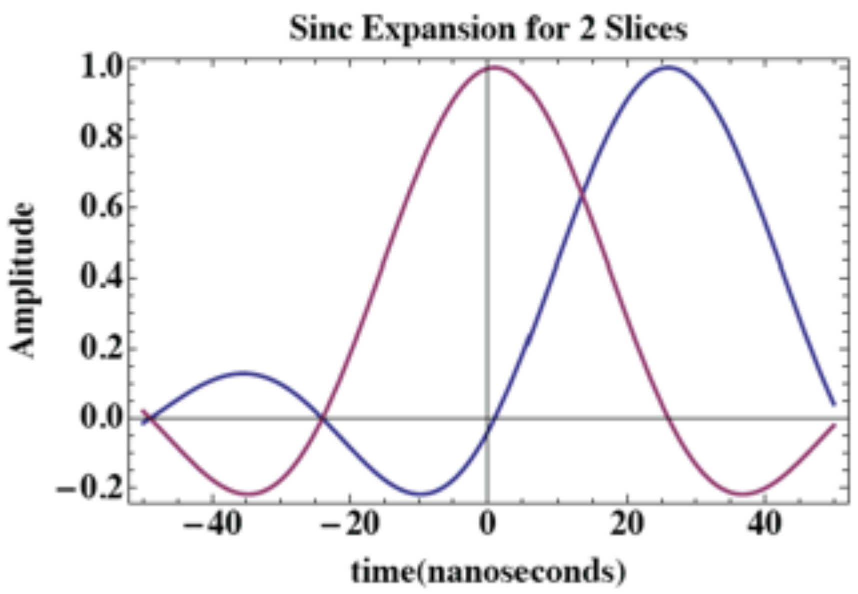
Soumya Mohapatra, Andrei Poblaguev and Sebastian White

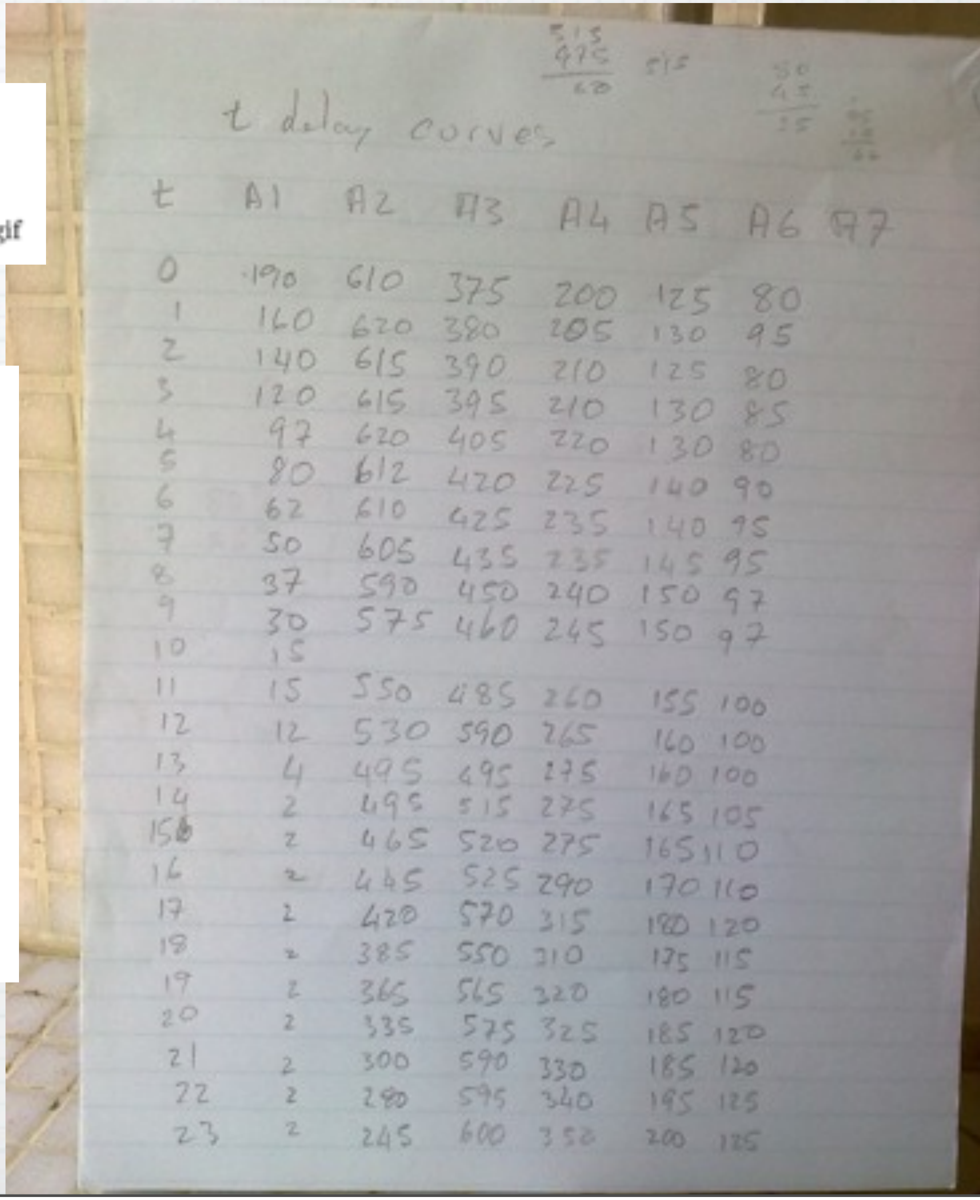
Aug.8,2010

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

$$shannon[t] = \sum_{i=1}^{nslice} slice[i] \times Sinc[\pi \times (t - time(i))/25] \qquad (6)$$

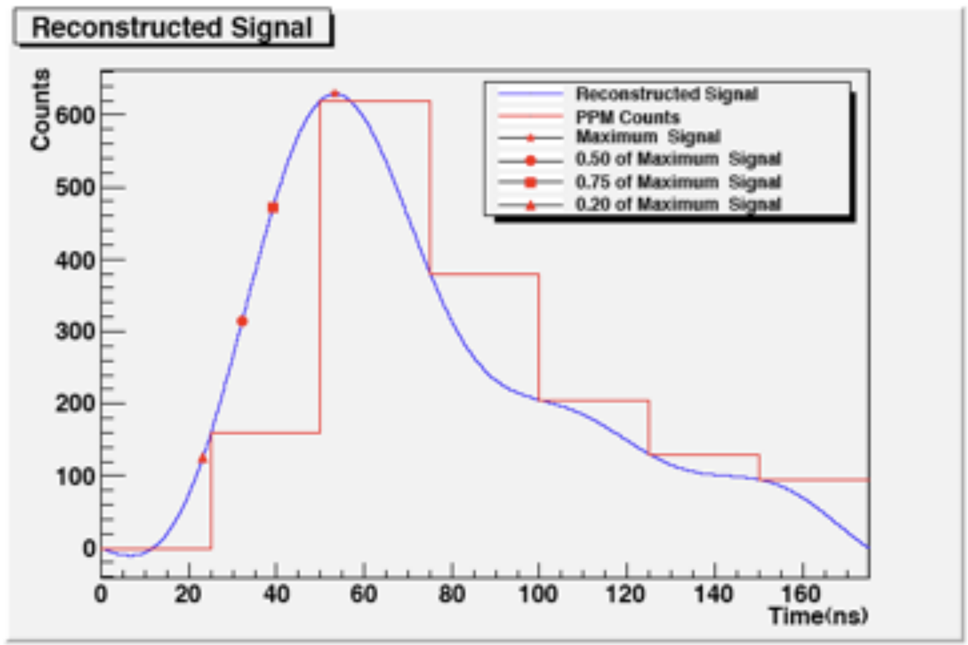
An animated gif can be found at:
http://www.phenix.bnl.gov/phenix/WWW/publish/swhite/ShannonFilm.gif

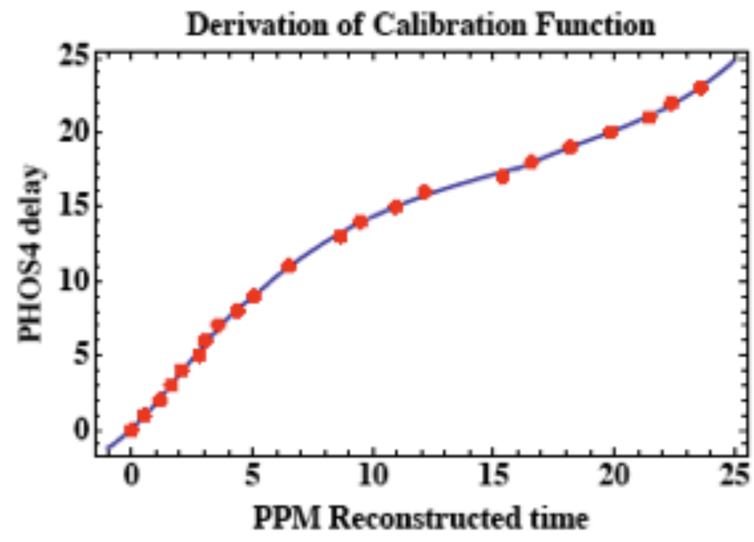


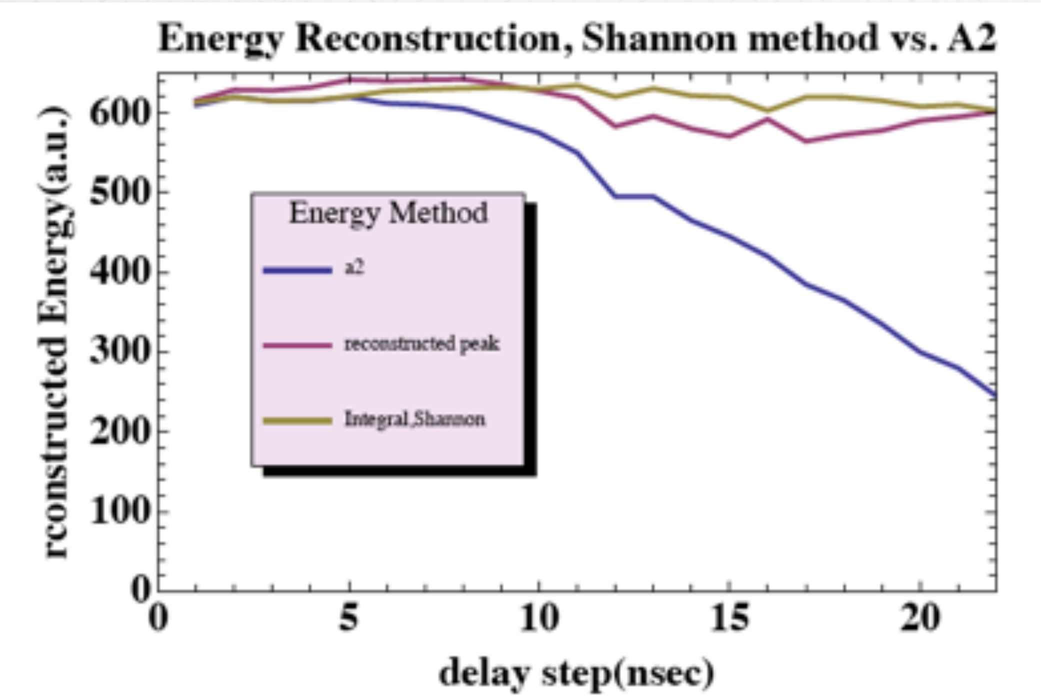
t delay curves

| t | A1 | A2 | A3 | A4 | A5 | A6 | A7 |
|---|---|---|---|---|---|---|---|
| 0 | 190 | 610 | 375 | 200 | 125 | 80 | |
| 1 | 160 | 620 | 380 | 205 | 130 | 95 | |
| 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 | | | | | | |
| 11 | 15 | 550 | 485 | 260 | 155 | 100 | |
| 12 | 12 | 530 | 590 | 265 | 160 | 100 | |
| 13 | 4 | 495 | 495 | 275 | 160 | 100 | |
| 14 | 2 | 495 | 515 | 275 | 165 | 105 | |
| 15 | 2 | 465 | 520 | 275 | 165 | 110 | |
| 16 | 2 | 445 | 525 | 290 | 170 | 110 | |
| 17 | 2 | 420 | 570 | 315 | 180 | 120 | |
| 18 | 2 | 385 | 550 | 310 | 175 | 115 | |
| 19 | 2 | 365 | 565 | 320 | 180 | 115 | |
| 20 | 2 | 335 | 575 | 325 | 185 | 120 | |
| 21 | 2 | 300 | 590 | 330 | 185 | 120 | |
| 22 | 2 | 280 | 595 | 340 | 195 | 125 | |
| 23 | 2 | 245 | 600 | 350 | 200 | 125 | |

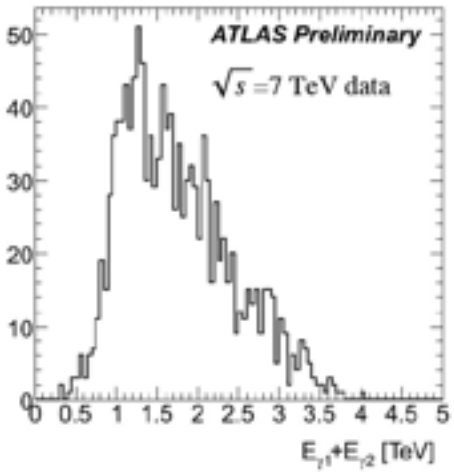


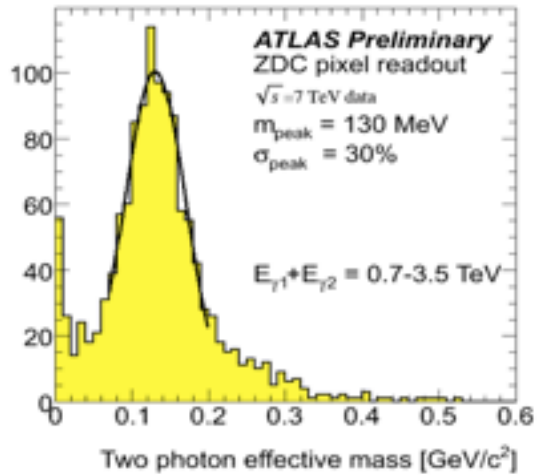

(d) Piecewise fit to the full range.



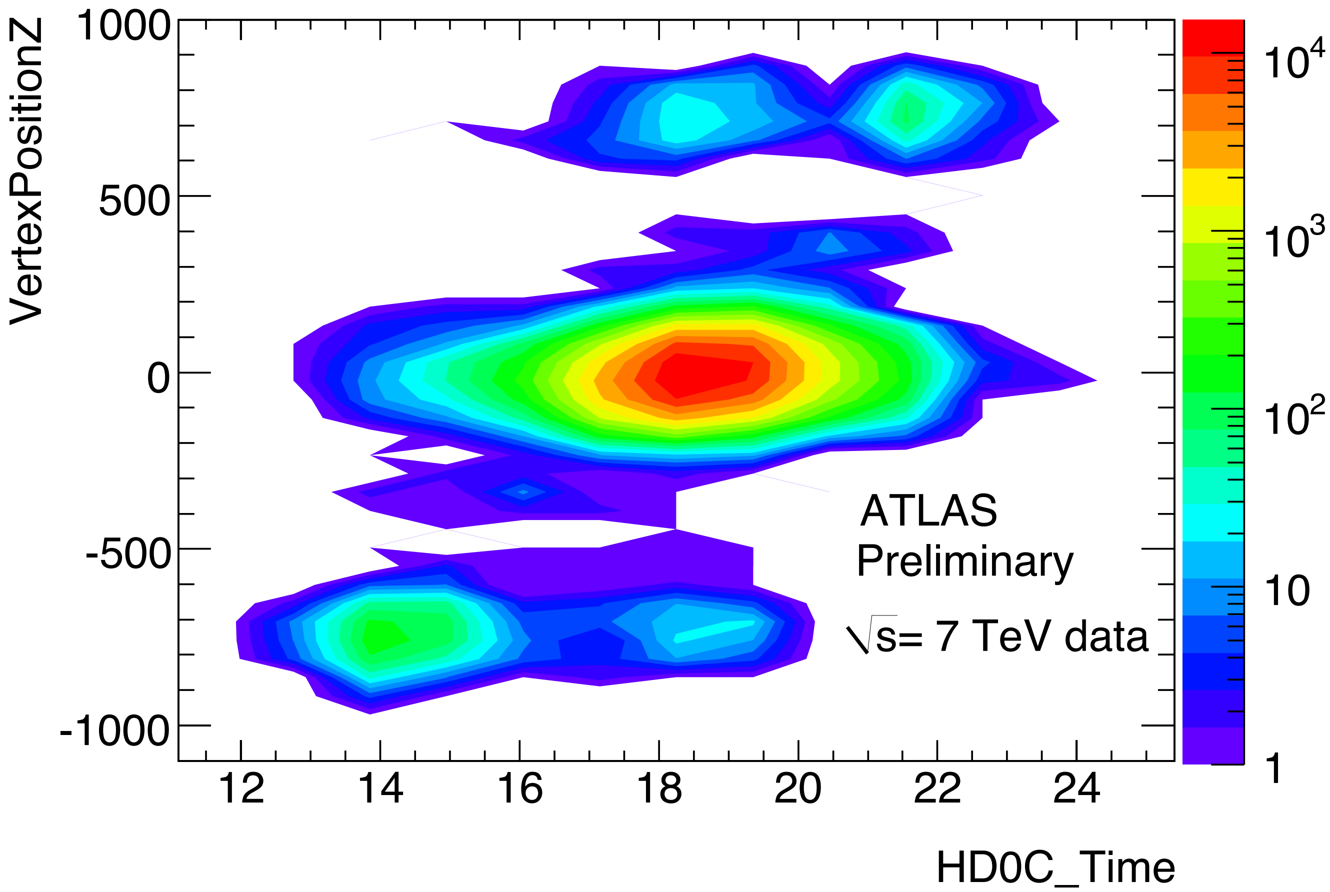
# 2 photon




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.

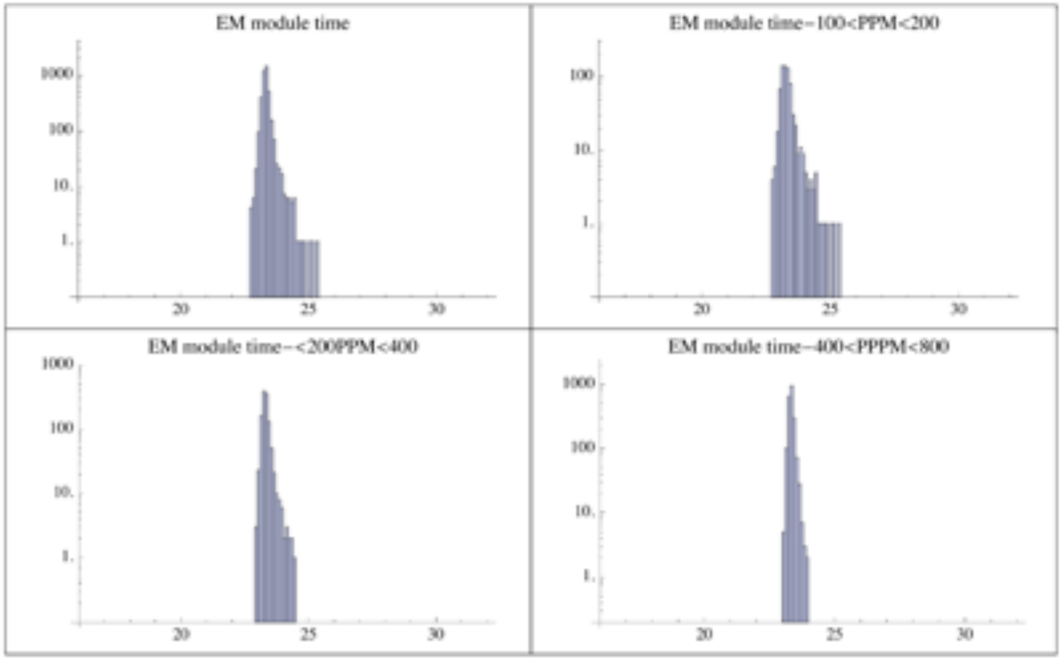



For 7 TeV collision data taken prior to LHCf removal the first ZDC module is the so-called "Hadronic x,y" which has identical energy resolution to all of the other ZDC modules. The coordinate resolution, however, is inferior to that of the high resolution EM, installed 7/20/10. Nevertheless, the reconstructed mass resolution is found to be 30% at m=130 MeV. As is foun in ongoing simulation of pi0 reconstruction within the full ATLAS framework (see ZDC simulati TWIKI), the pi0 width is completely dominated by the energy resolution. Therefore, the current state of ATLAS ZDC photon energy resolution can be inferred from this plot.

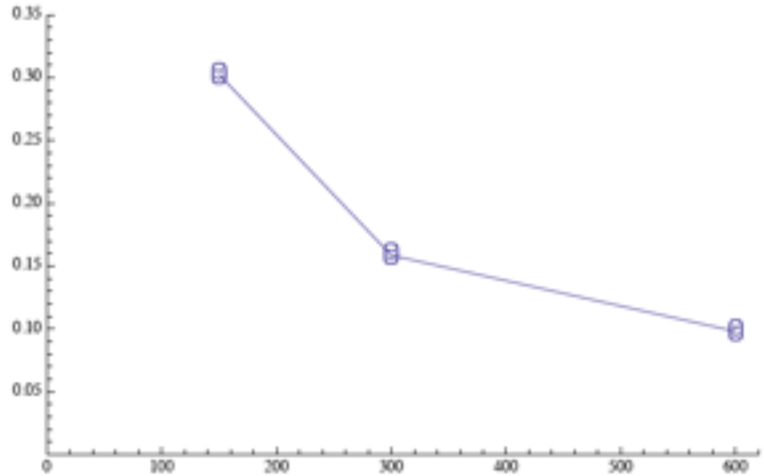



The Z vertex distribution from inner tracker vs. the time of arrival of showers in ZDC-C relative to the ATLAS clock calculated from waveform reconstruction using Shannon interpolation of 40 MegaSample/sec ATLAS data (readout via the ATLAS L1calo Pre-processor modules). Typical time resolution is ~200 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.

```
{7.0 for Mac OS X x86 (64-bit) (February 19, 2009), /Users/white, 15 786 240}

Timing[ATLASdata = Import["/afs/cern.ch/user/s/spagan/public/run160953.root"]] [[1]]

1.15994

nevents = Dimensions[ATLASdata][[1]]
{EMASignal, EMATime, EMAErrorFlag, HD0ASignal, HD0ATime, HD0AErrorFlag, HD1ASignal,
   HD1ATime, HD1AErrorFlag, HD2ASignal, HD2ATime, HD2AErrorFlag, EMCSignal,
   EMCTime, EMCErrorFlag, HD0CSignal, HD0CTime, HD0CErrorFlag, HD1CSignal, HD1CTime,
   HD1CErrorFlag, HD2CSignal, HD2CTime, HD2CErrorFlag} = Transpose[ATLASdata] ;

12 848

TEMA0 = Pick[EMATime, Thread[100 < EMASignal < 800]];
TEMA1 = Pick[EMATime, Thread[100 < EMASignal < 200]];
```




rms (nsec) of 3” H0 PMT vs. energy deposit




## Application of commercial software to ATLAS data analysis

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

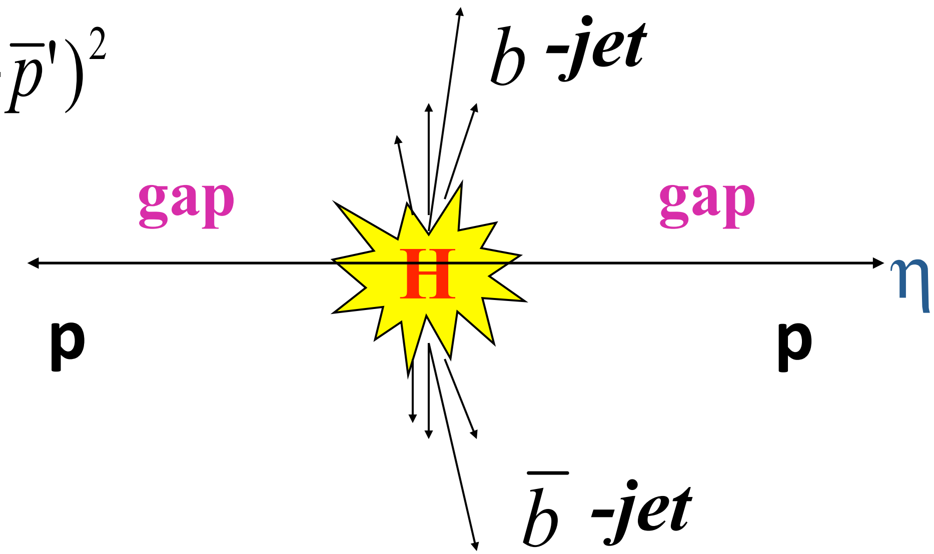
# Central Exclusive Higgs Production

Central Exclusive Higgs production pp→p H p : >3 fb (SM)
~10-100 fb (MSSM)

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

ΔM = O(1.0 - 2.0) GeV

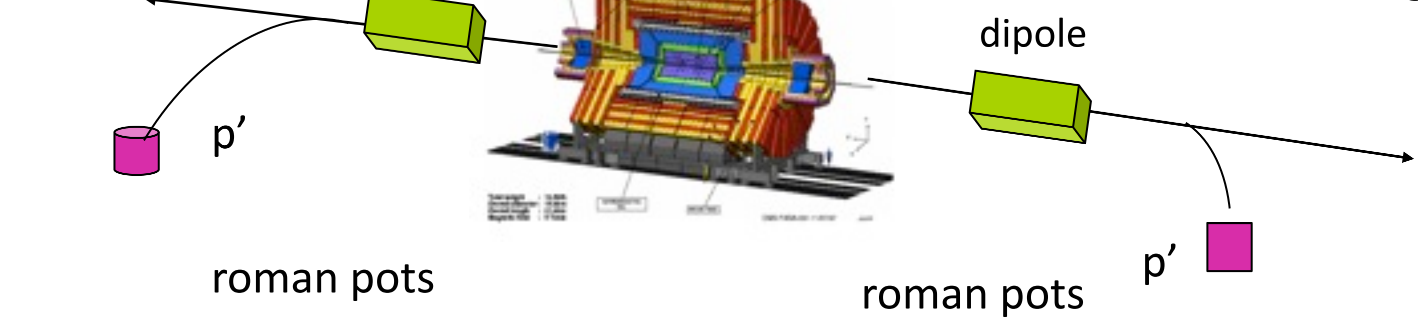
Background suppressed
By $0^+$ selection rule

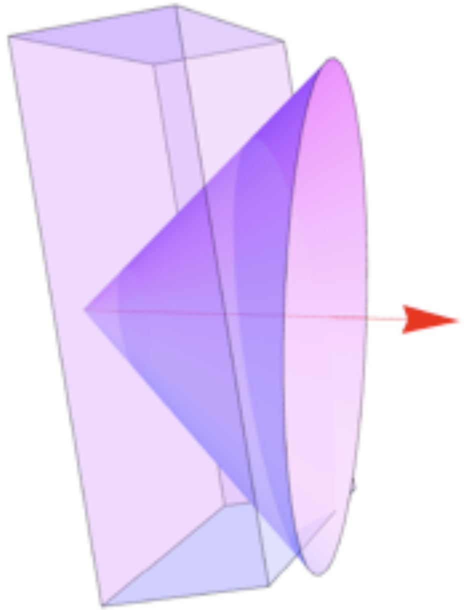



Higgs association from
Proton timing (~ 10 picosecond)

beam

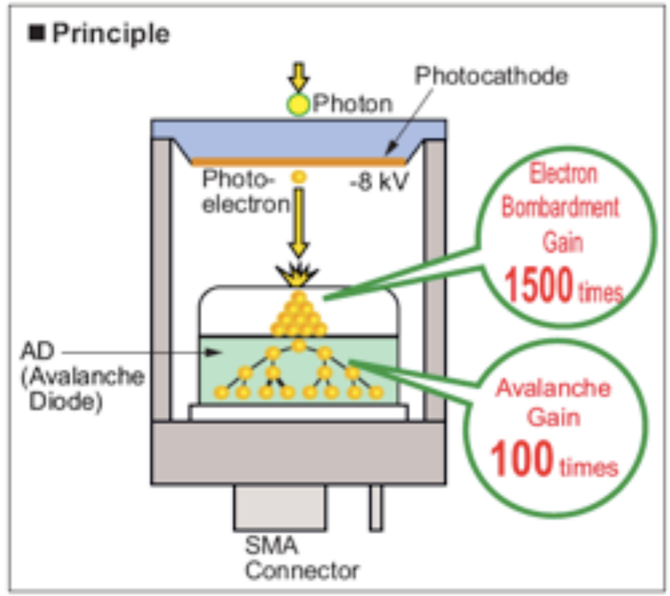
dipole





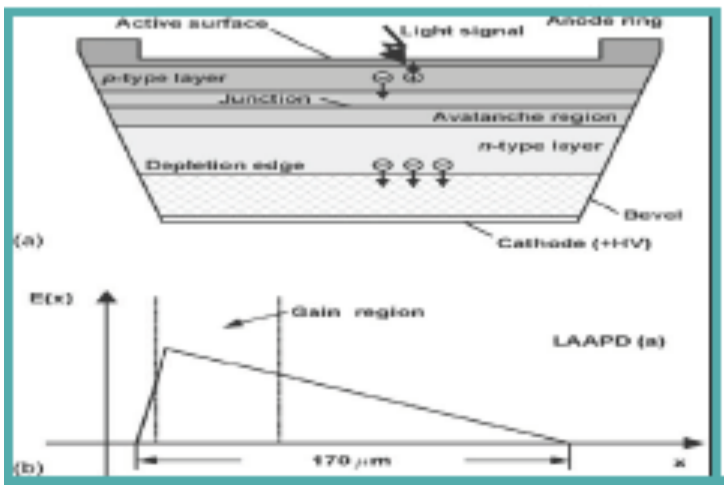
Cerenkov Radiation cone

**Cerenkov or APD option**

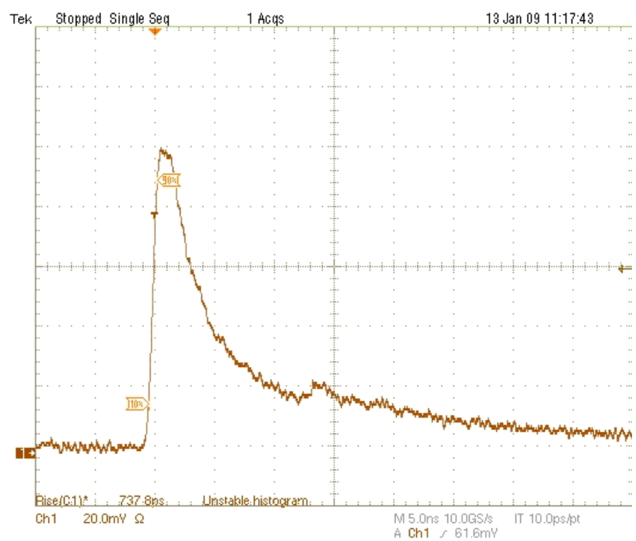



Pre-production Hybrid photodetector

"A 10 picosecond time of flight detector using APD's", SNW et al.

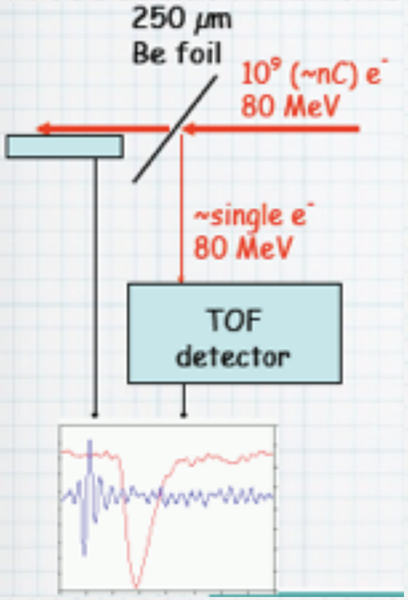


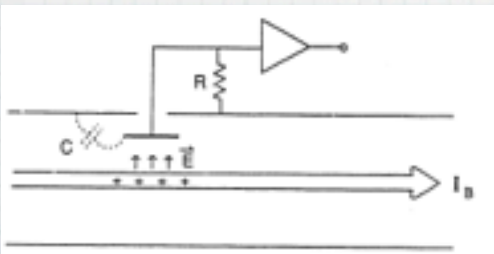

Deep diffused avalanche photodiode

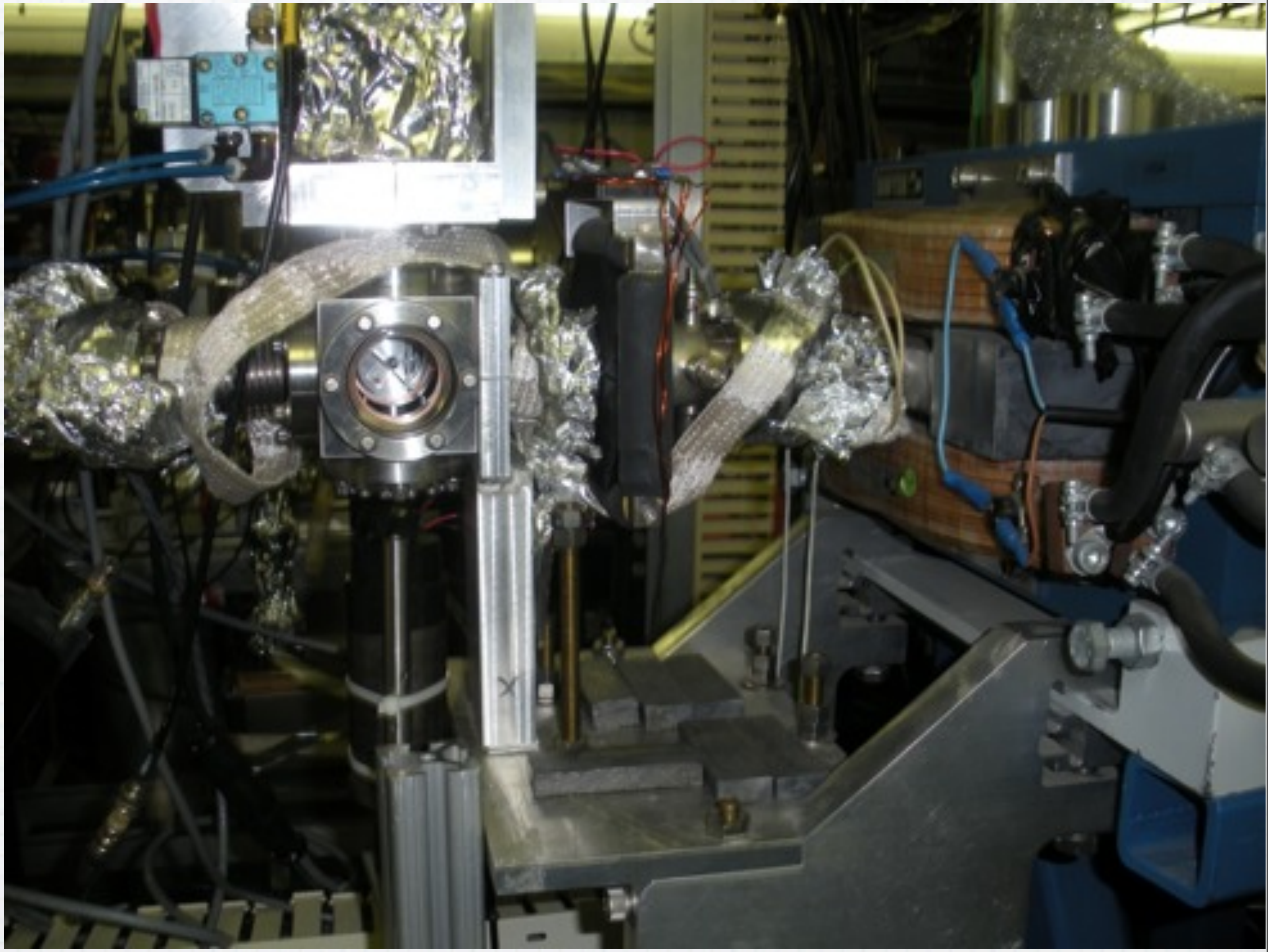



650 picosecond risetime (β's)

# The Future: a 3 picosecond testbeam (SNW & V. Yakimeno)

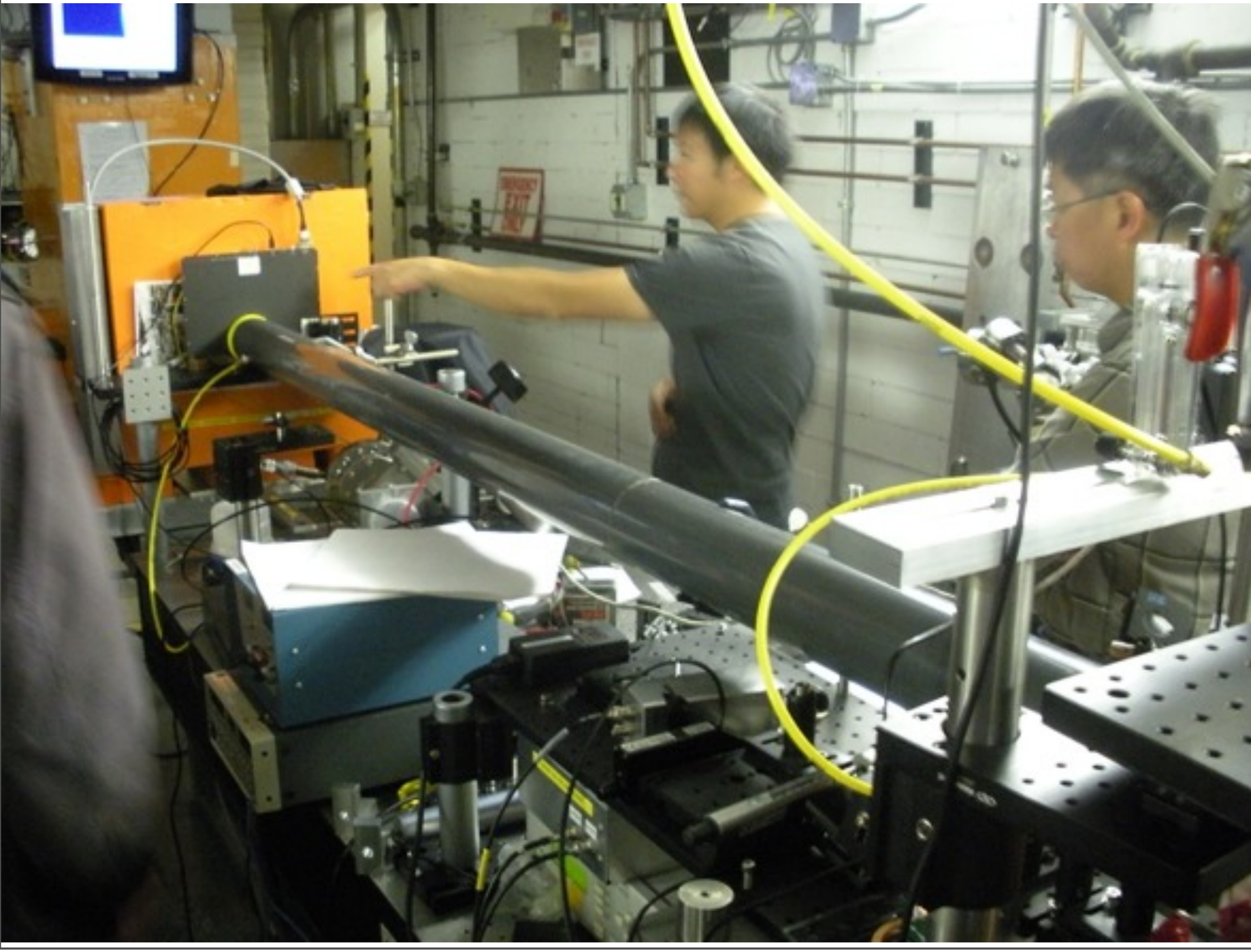


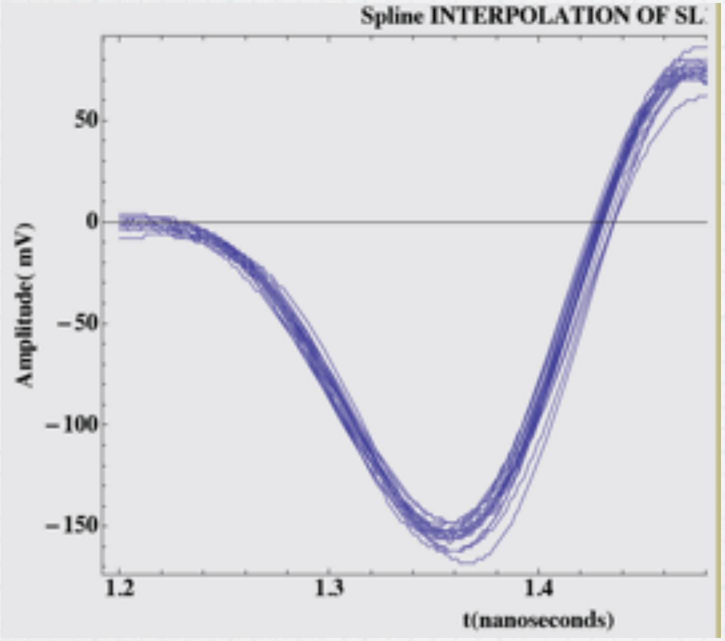



T. Tsang, M.Chiu, M. Diwan, S. White,G. Atoian, K. McDonald, K. Goulianos, D. Acker

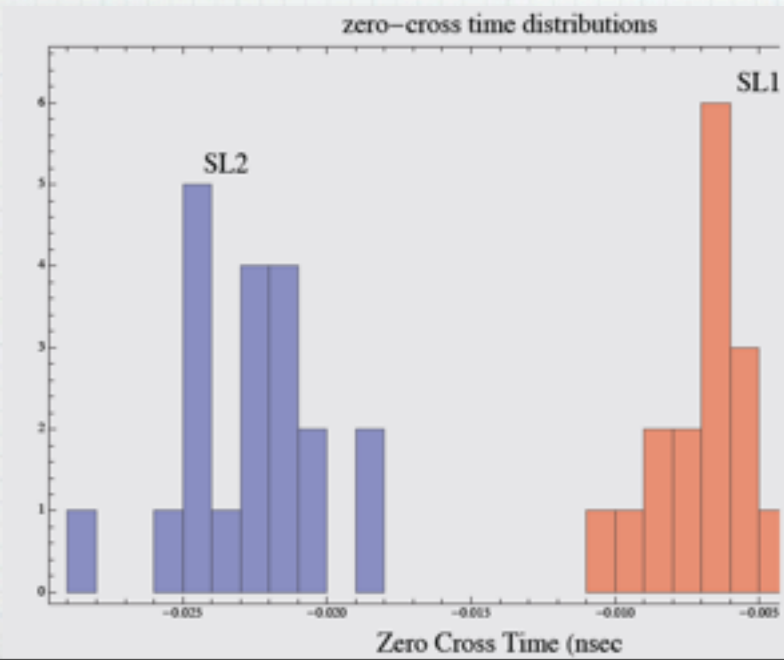
Applications: RHIC upgrades, electron-Ion Collider, SuperBelle, ATLAS- AFP

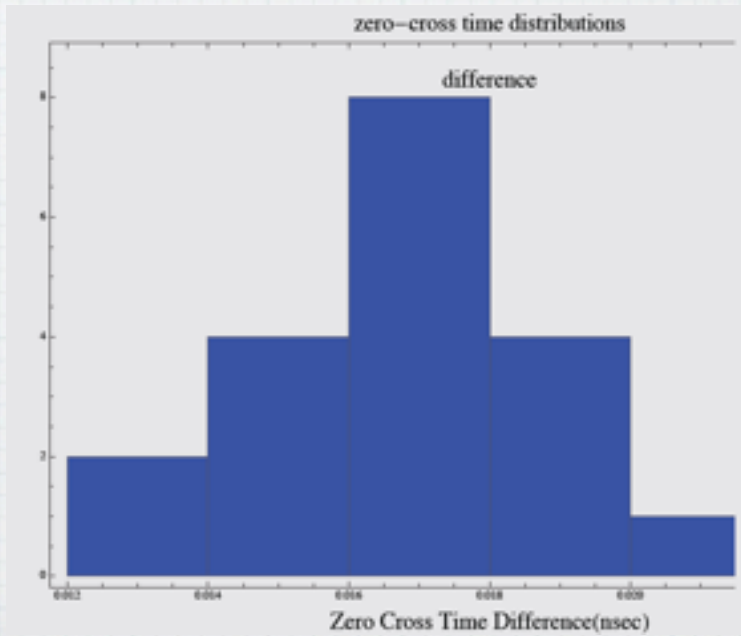





stripline waveforms w.
on-chip Sin[x]/x interpolation+spline

rms on time diff
between detectors <2.5 psec

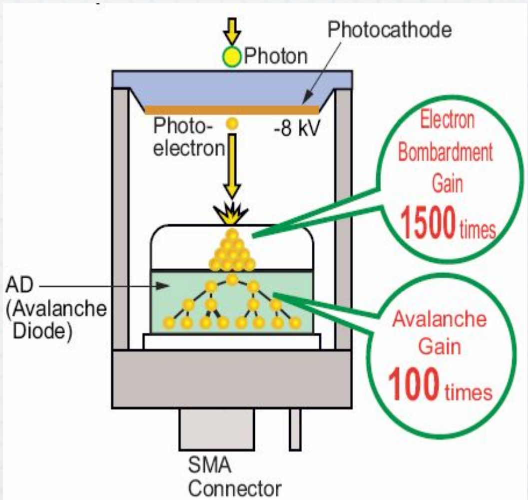


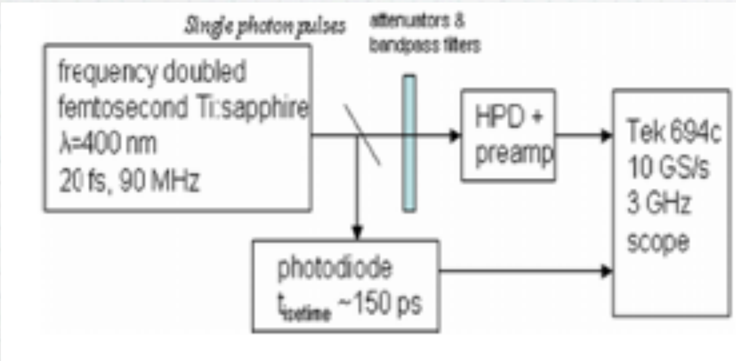
# driver for faster timing is leading protons @L=$10^{34}$

- 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)

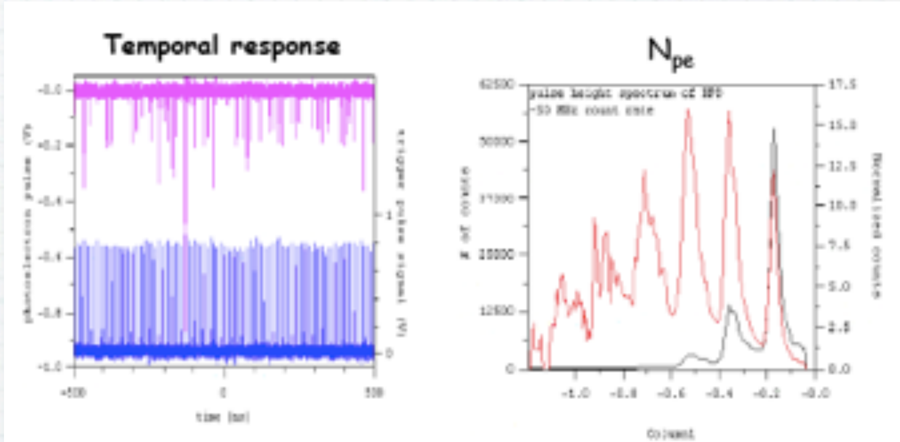
Communications industry->small area APDs w. G*BW>$10^{11}$ Hz

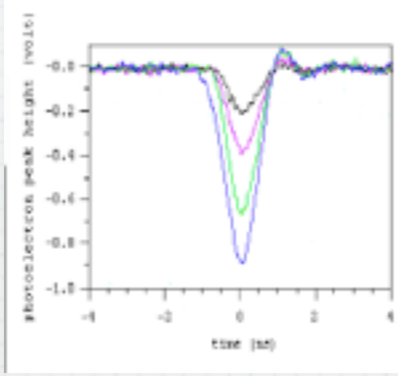



# Applications in eg fluorescence spectroscopy T.Tsang, S.White



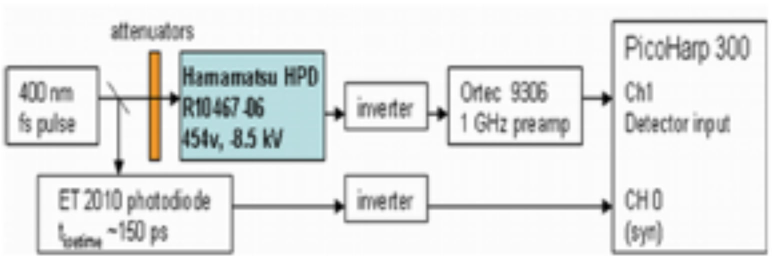

risetime=300 psec

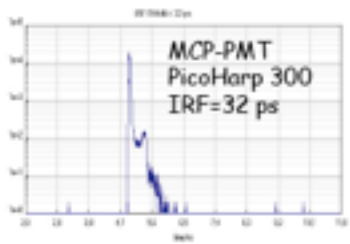


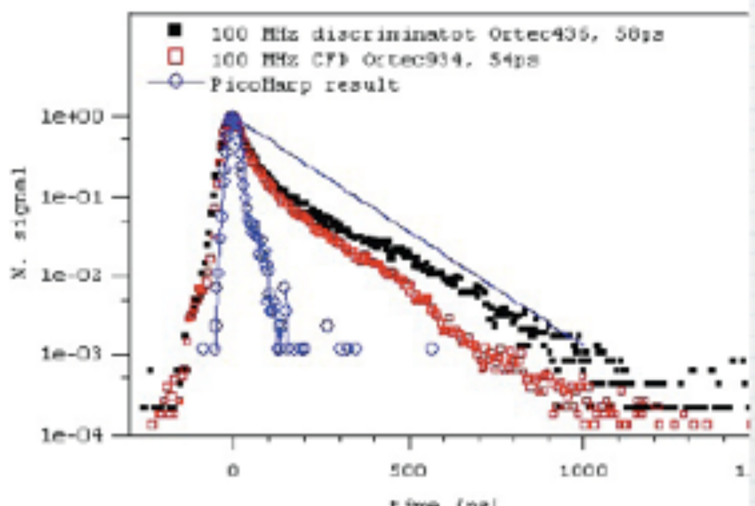



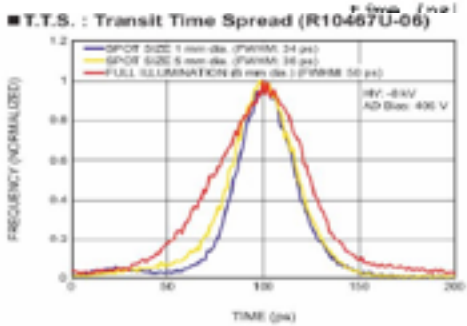
| $N_{pe}$ | pulse height after preamp (Volt) | pulse height before preamp (mV) | normalized count rate |
|---|---|---|---|
| 1 | 0.176 | 2.2 | 1 |
| 2 | 0.36 | 4.5 | 0.26 |
| 3 | 0.528 | 6.6 | 0.061 |
| 4 | 0.71 | 8.9 | 0.009 |
| 5 | | | ~0.0014 |
| 6 | | | ~0.0002 |

# 11 psec single photon response is not common



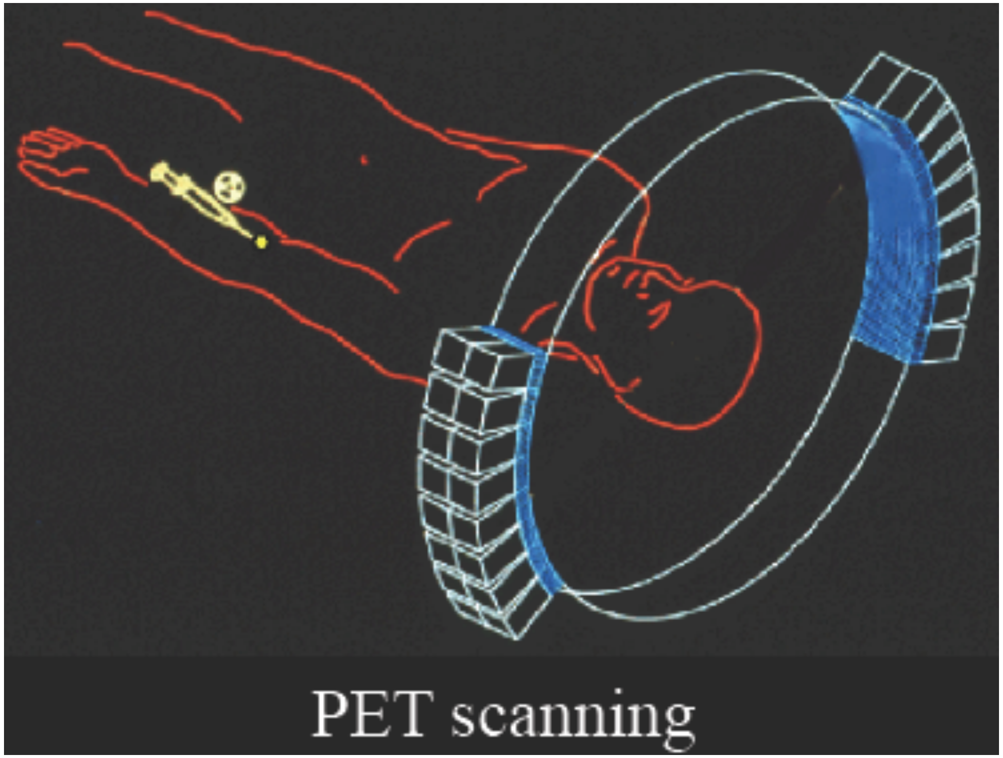




$$\sigma_{TOF} = \sqrt{\sigma^2_{HPD} + \sigma^2_{radiator} + \sigma^2_{electronics}}$$

$$\sigma_{HPD} = \frac{\sigma_{TTS}}{\sqrt{N_{pe^-}}} = \frac{11\ ps}{\sqrt{N_{pe^-}}}$$

# spinoff




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