The Abdus Salam
International Centre for Theoretical Physics

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Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2036-9

International Workshop: Quantum Chromodynamics from Colliders to Super-High Energy Cosmic Rays

25 - 29 May 2009

Forward Physics Topics from RHIC to the LHC

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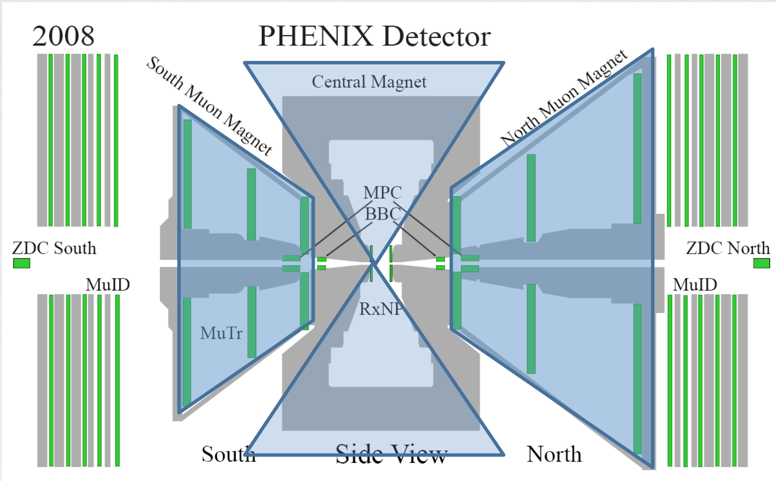
FORWARD PHYSICS TOPICS FROM RHIC TO THE LHC

Sebastian White, Brookhaven National Lab

TOPICS

- Forward Detectors
- Event Characterization
- Luminosity Determination
- Inclusive forward particle production
- Spin Dependent Asymmetries @ RHIC
- Coherence in EM processes
- Central Exclusive Production at the Higgs scale

PHENIX COVERAGE



forward:

BBC $(3.0 < |\eta| < 3.9)$

(charged)

MPC,ZDC

(calorimeters, neutral)

di-leptons the strong suit--->

Central arm : $0<|\eta|<0.35$ e-pair

Muon arm : $1.2<|\eta|<2.4$ μ-pair

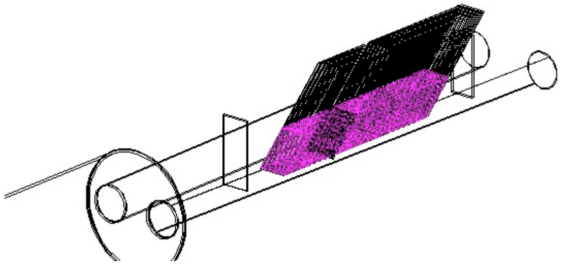
PHENIX Zero Degree Calorimeter

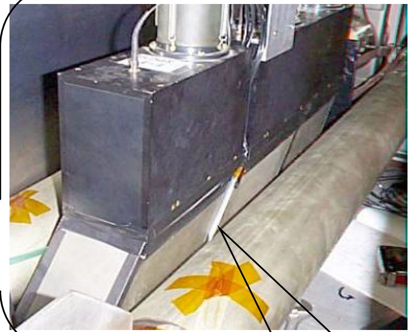
Measures large x_F neutrons

Large acceptance for "spectator neutrons"

in Heavy Ion collisions

Shower max. detector for asymmetries



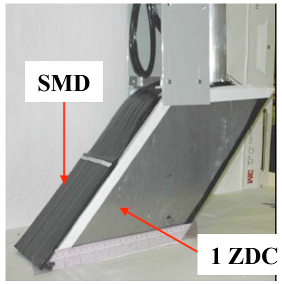


ZDC
(**Z**ero **D**egree **C**alorimeter)

10*10cm
→ ±2.8 mrad

3 modules
$150X_0$ $5.1\lambda_I$

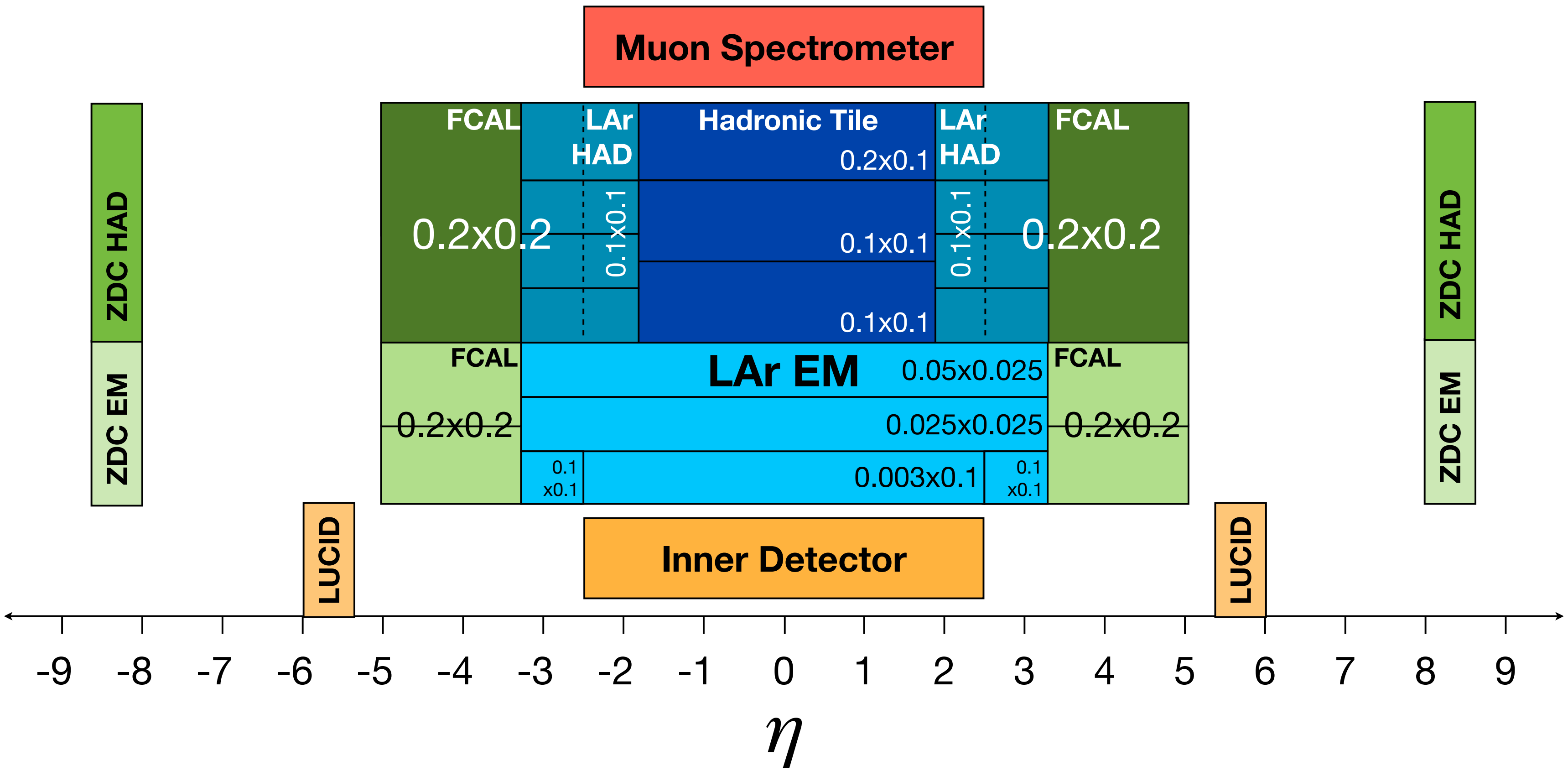
SMD
(**S**hower **M**ax **D**etector)



Neutron position can be determined by centroid method σ= 1cm).

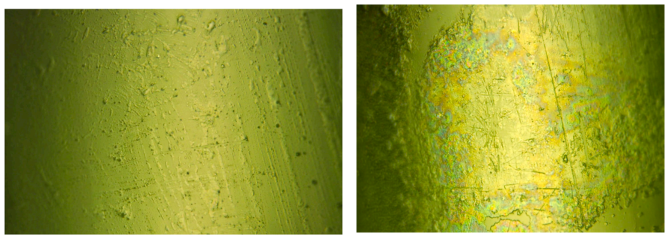
- Scintillator strip layer (SMD) used to measure pt of neutrons and azimuthal angle
- no coordinate readout for photons

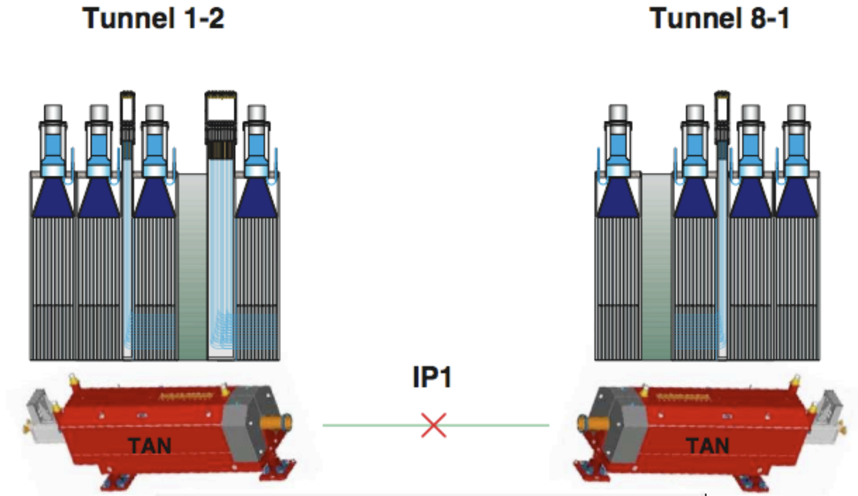
ATLAS coverage

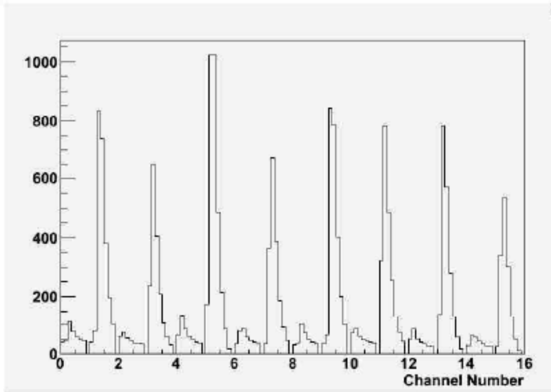


ATLAS ZDC fully integrated in TDAQ May '09

- measures high energy gamma and neutral hadrons
- hottest detector at the LHC
- unique in fine gained shower pos'n measurement->direct photon, pi0



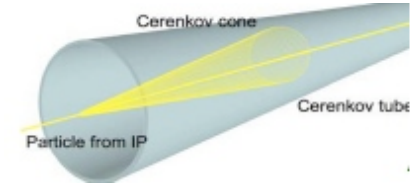




pre- and post-irradiated fibers to 28 Gigarad

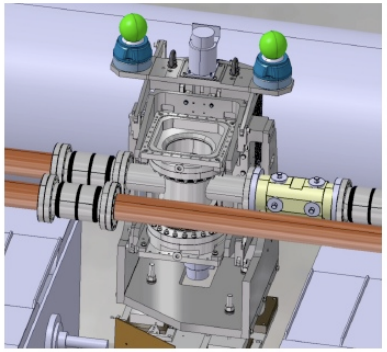
8 PMT * 7 time slices in ATLAS L1calo

ATLAS Forward Detector Suite



LUCID : ATLAS LUminosity using Čerenkov Integrating Detector

$5.5 < |\eta| < 6.0$



ALFA: tracker to measure absolute Luminosity for pp by elastic scattering in CNI region to ~3%.

+ Minimum Bias Trigger scintillators (MBTS)

+Beam Conditions Monitor(BCM)

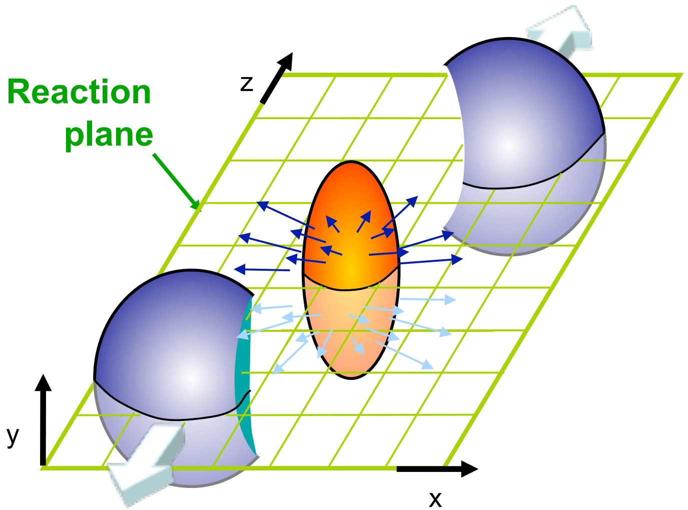
All used in conjunction with ZDC to measure and monitor Luminosity

Event Characterization in HI and pp

- Directed flow in distribution of forward neutrons in Hevy ion collisions defines reaction plane
  - L(b) vs. b known a priori

$$\frac{\int_0^b b'\,db'}{\int_0^\infty b'\,db'} \Leftrightarrow \%\text{Centrality}$$

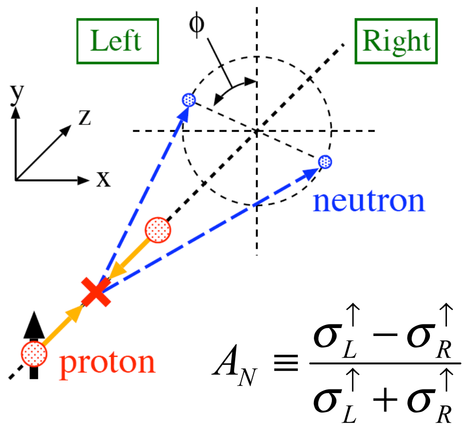
  - ZDC neutron multiplicity determines b



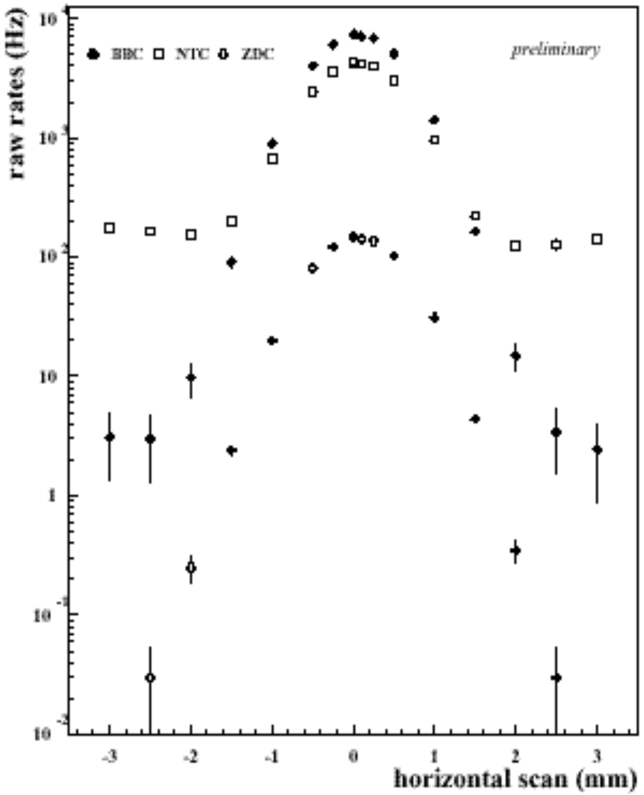
in polarized p beam running at PHENIX

spin orientation given by ~8% spin

dependent asymmetry in n distribution



Luminosity determination from beam scans: more forward->higher quality



machine based luminosity

$$L = \frac{3 f_{rev} \gamma}{2} \frac{N_b N^2}{\varepsilon \beta^*}$$

$$N_b = 56\,; N = 1 \times 10^9;$$

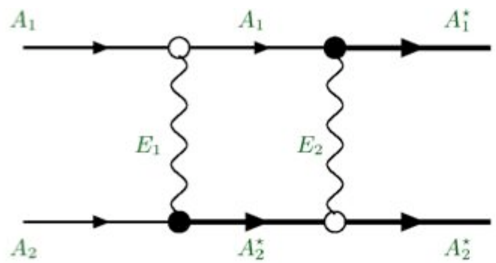
$$\varepsilon = 15 \text{ to } 40\pi mm;$$

$$\beta^* = 1 - 10\text{m}$$

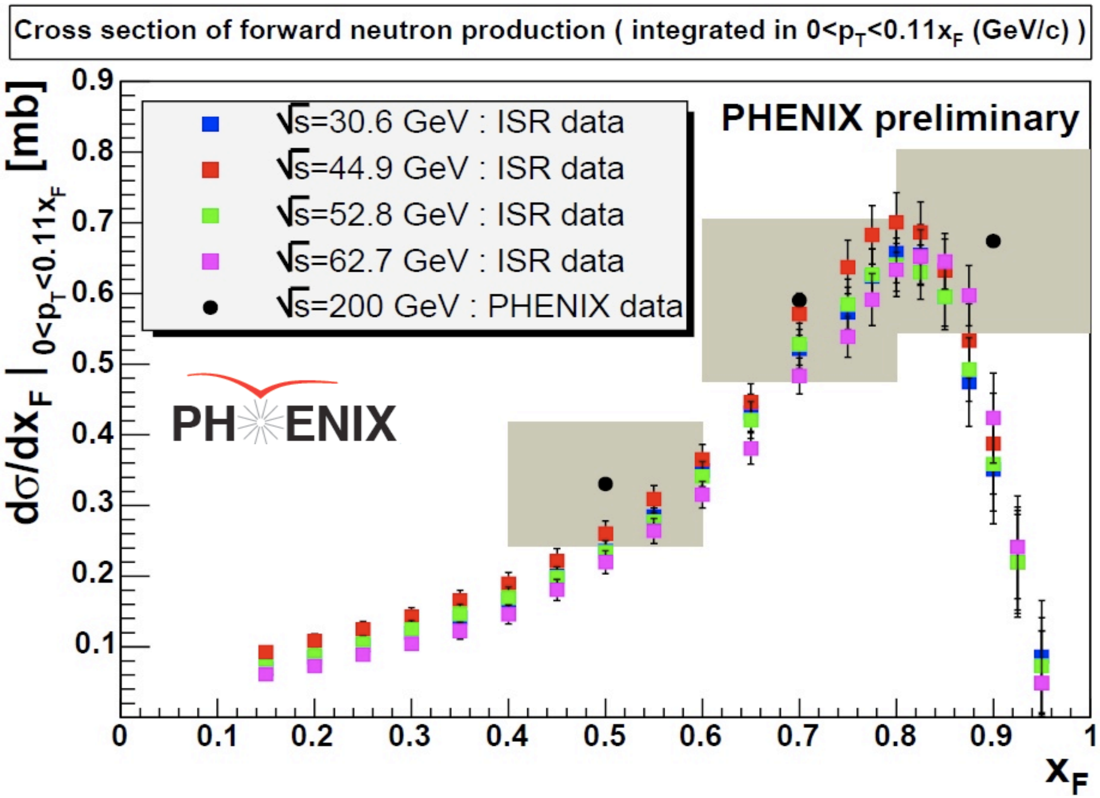
horizontal scan determines beam size
(lower curve is ZDC)

Absolute Luminosity from physics cross section

A.Baltz &SNW
sigma(ZDC)=10.3b ->dL/L~5% w. 4 hrs. of data. Same calculated for LHC.



Inclusive neutron production in PHENIX



p_T acceptance assumes ISR result

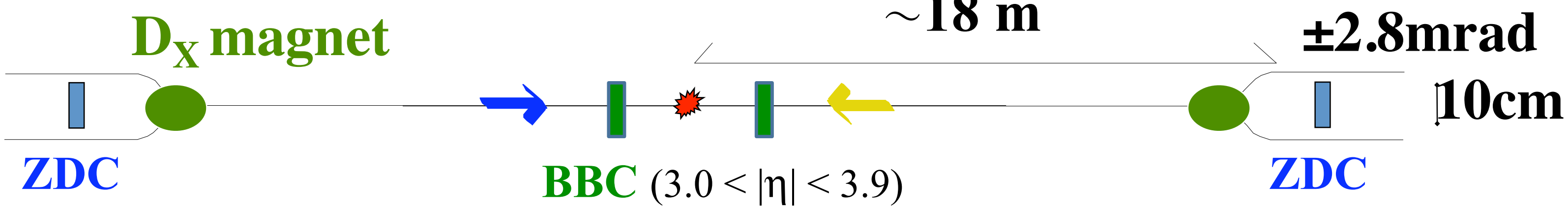
Integrated p_T area :
$0<p_T<0.11x_F$ GeV/c
at each x_F point.

Cross section consistent with the ISR data; No evidence for violation of x_F scaling at higher energy.

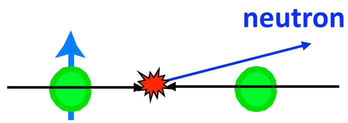
→ Leading neutrons at RHIC energy are also described by the OPE model.

Leading neutron A_N in PHENIX

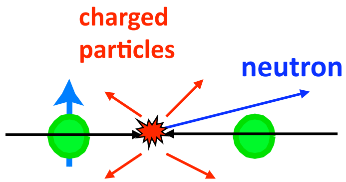
Polarized pp **collisions at $\sqrt{s}$ = 200GeV**

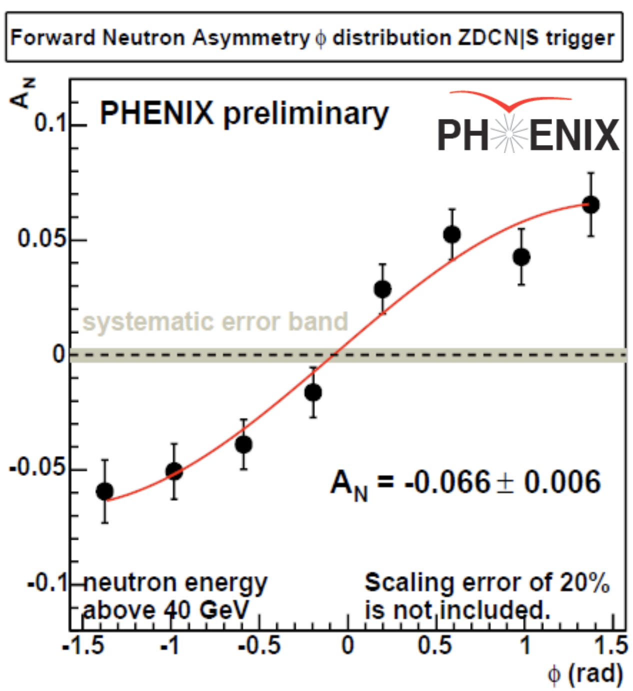


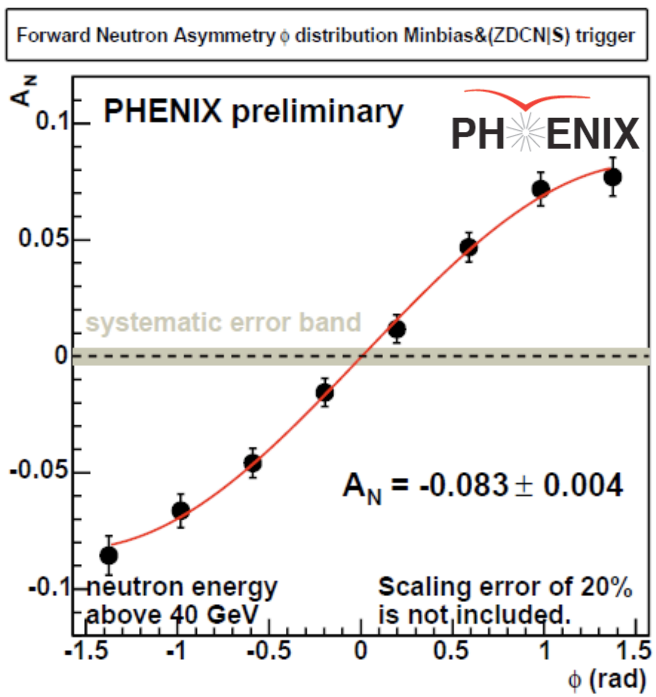
Without BBC hit



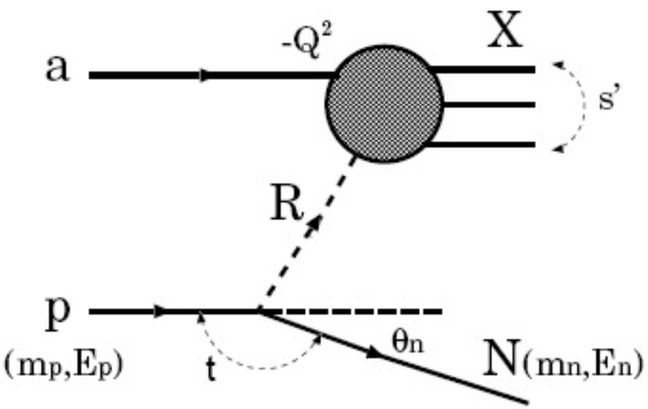
With BBC hit







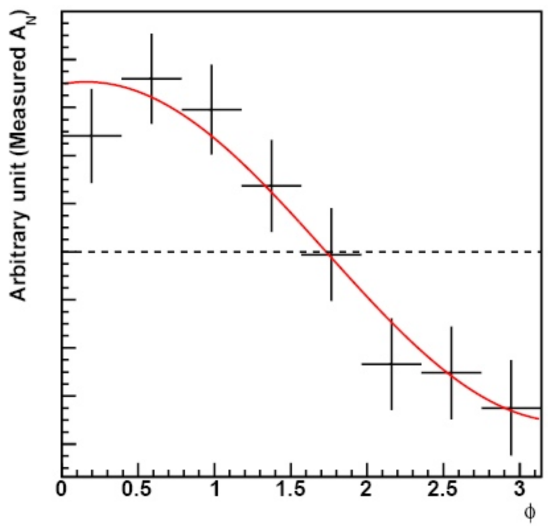
Future measurement :
A_N measurements at various √ s



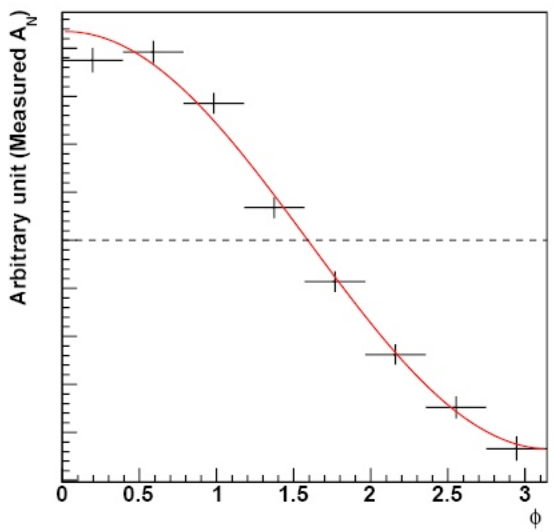
$$x_F = p_L/p_{L(max)} = E_n \cos\theta_n / E_p \sim E_n/E_p$$
$$p_T = E_n \sin\theta_n \sim x_F E_p \theta_n$$

- p_T is approximately proportional to the incident proton energy. → p_T-dependent A_N
- We have measured finite asymmetries at √ s=62, 410 and 500 GeV
- We already measured significant A_N in all.

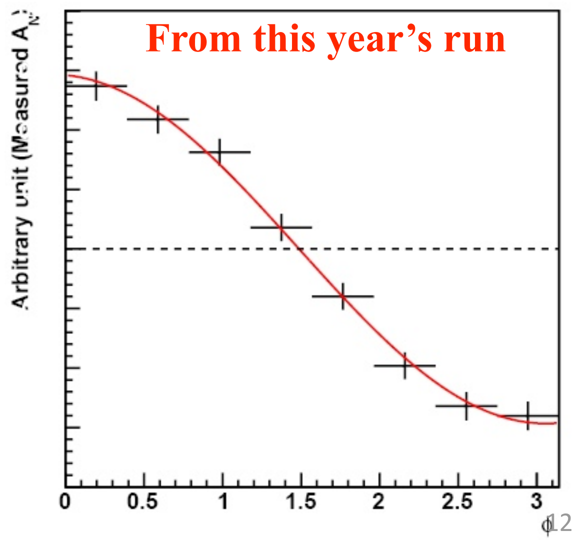
√ s = 62 GeV



√ s = 410 GeV

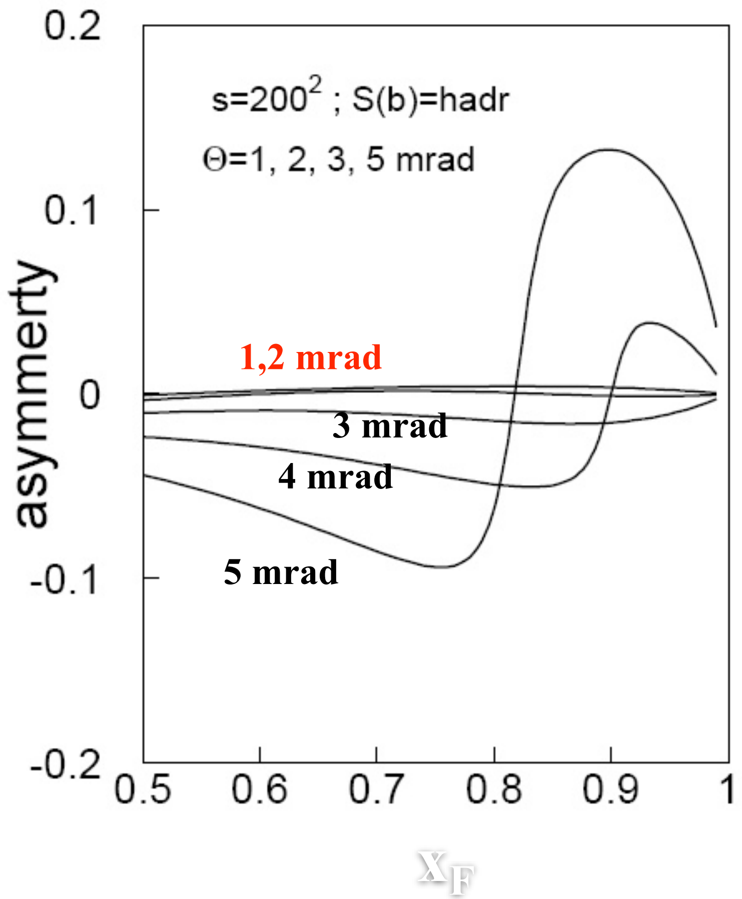


√ s = 500 GeV



Compare to calculated Asymmetry

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

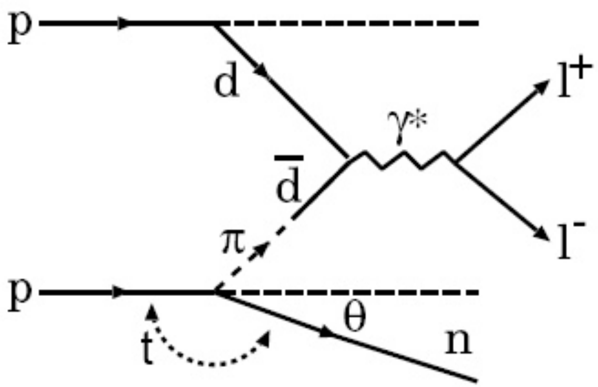


- Asymmetry calculated with one pion exchange model.
- calculated asymmetry is smaller than observed.
  - PHENIX kinematic region :
    x_F=0.6-0.8, and θ < 2 mrad.
  - possibly due to other reggeon exchanges. (*e.g.* a_1 exchange)
  - testable with neutron p_t dist.

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

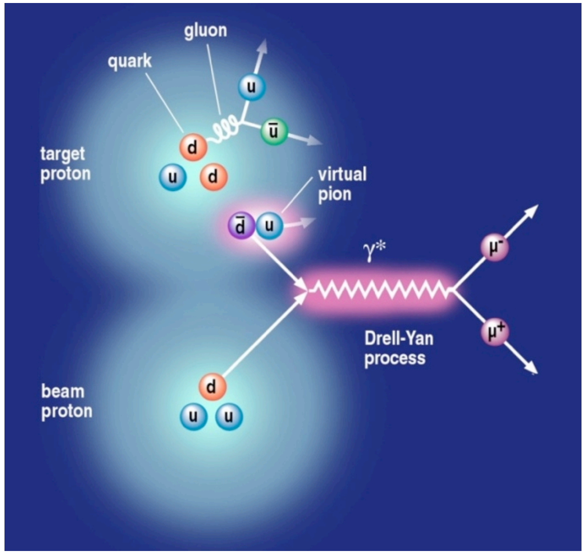
Potential Uses of neutron tagging in ATLAS and PHENIX

neutron tag selects pion component in the
  proton and hence $\bar{d}$
  application in 2009 PHENIX pp data on W+/- at
  $\sqrt{s} = 500\text{GeV}$
  ATLAS , PHENIX Drell-Yan



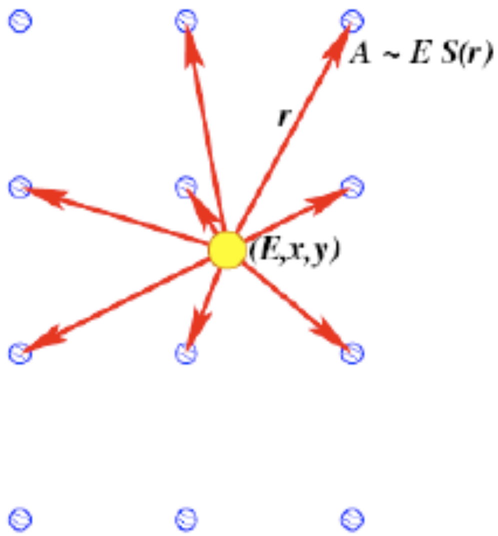
pp-> n+n+X potential measurement of pi+pi+ scattering at high energy

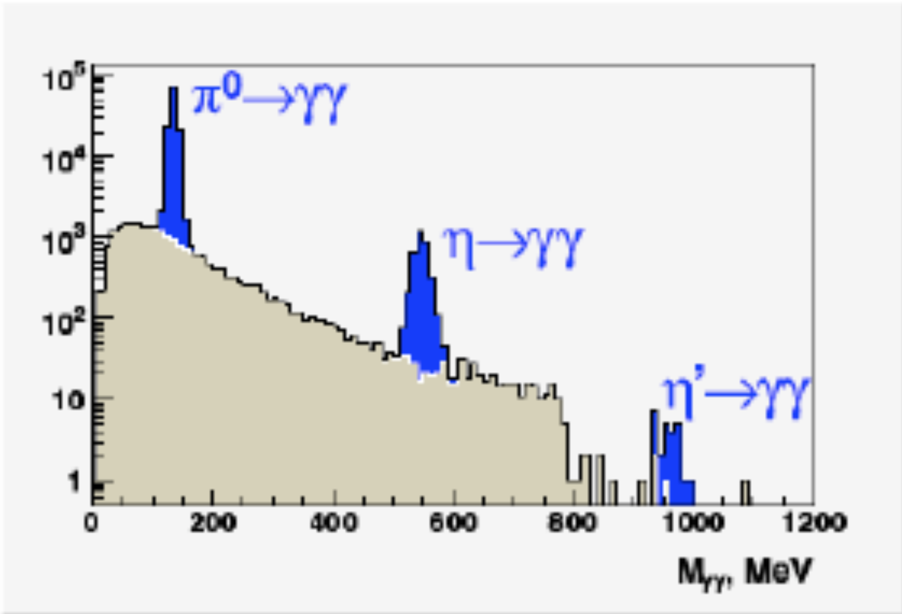
Used throughout in EM interactions of heavy ions.
Significant fraction of cross sections include a second (soft) photon exchange which produces a beam energy neutron at 0 degrees.
This is needed for triggering.



Other forward inclusive Production

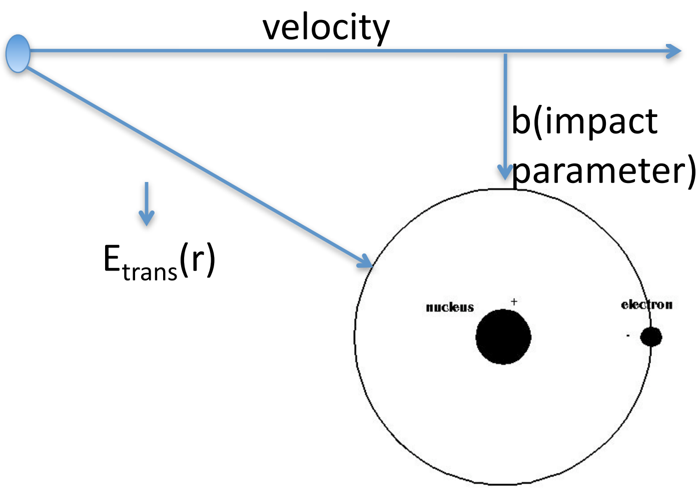
- ATLAS ZDC granularity opens possibility to measure Lambda, Gamma, pi0, etc. at large x_F





EM Production: The Equivalent Photon Approximation

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



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

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

Expand in harmonics:

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

For resonant excitation all a_n ineffective except at resonant frequency.

Cross sections

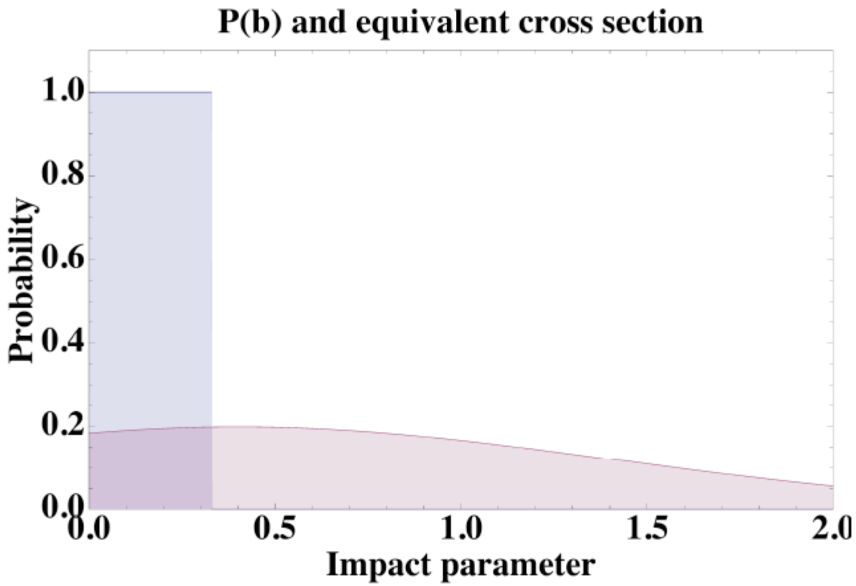
Equivalent field of light is calculated for each impact parameter.

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 (σ)



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

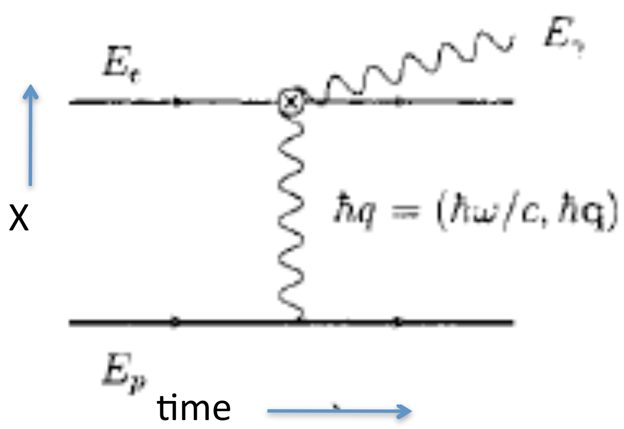
Diffractive Higgs@LHC =10^{-14} barn

Other Applications of Equivalent Photon Approximation(1)

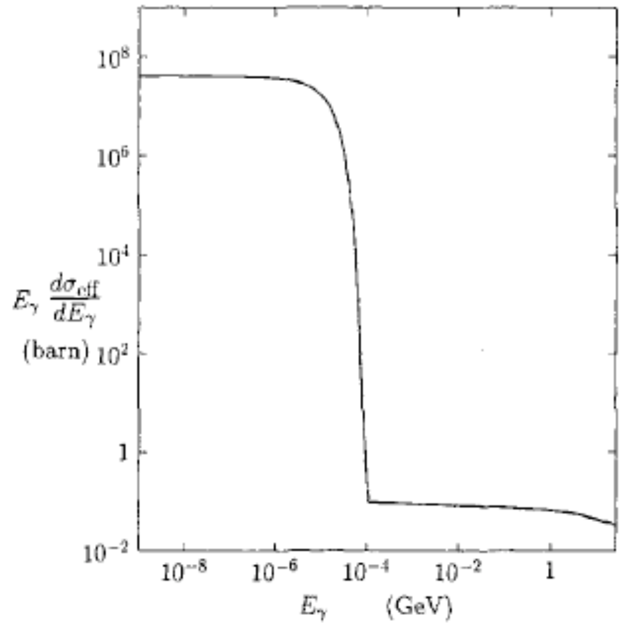
- N.Bohr (1914), C. von Weizsacker and E.Williams(1934, generalization to ultrarelativistic case)
- The power of coherence: beamstrahlung in electron-proton colliders(V.Serbo et al. 1996). Coherent radiation off

$\sim 10^9$ 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** **$\rightarrow (Z_{nucleus} * q_e)^2$**
  - **Two photon** **$\rightarrow (Z_{nucleus} * q_e)^4$**
- 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 minimum

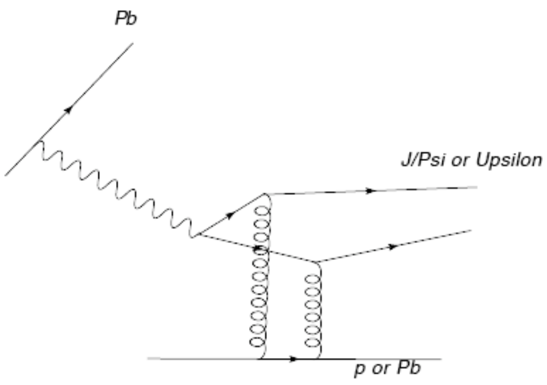
  Δq is boosted by $2\gamma_{beam}^2$,where γ =Lorentz factor

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

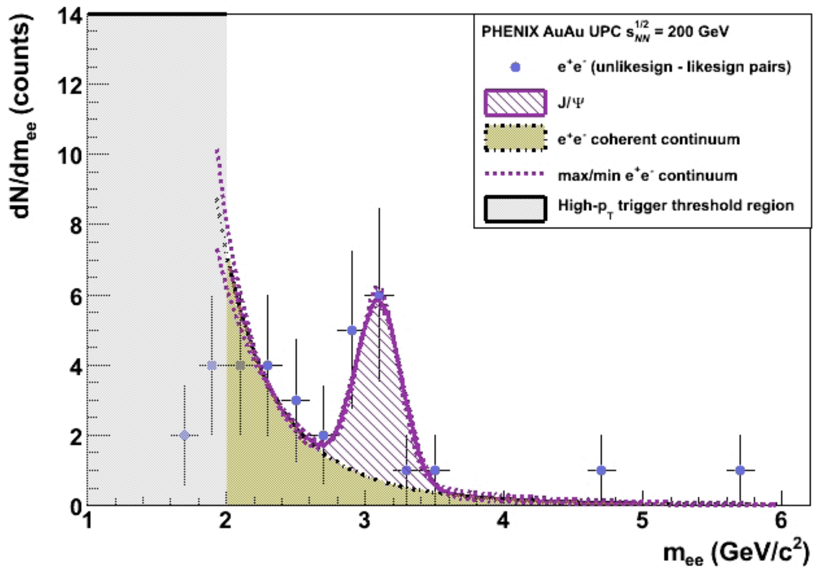
  28 MeV->400 TeV

EPA(3):Vector meson photoproduction

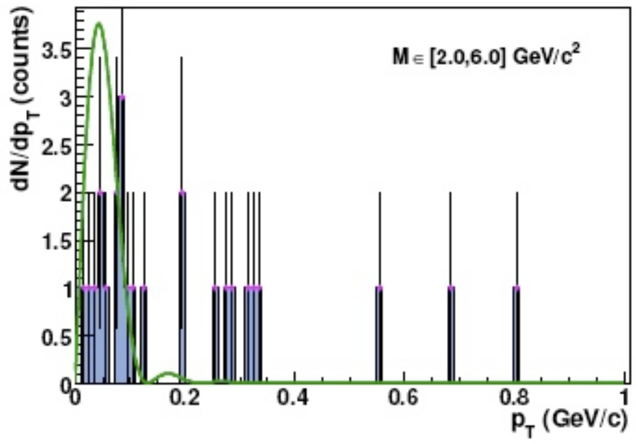
- measures gluon distribution in proton or nucleus



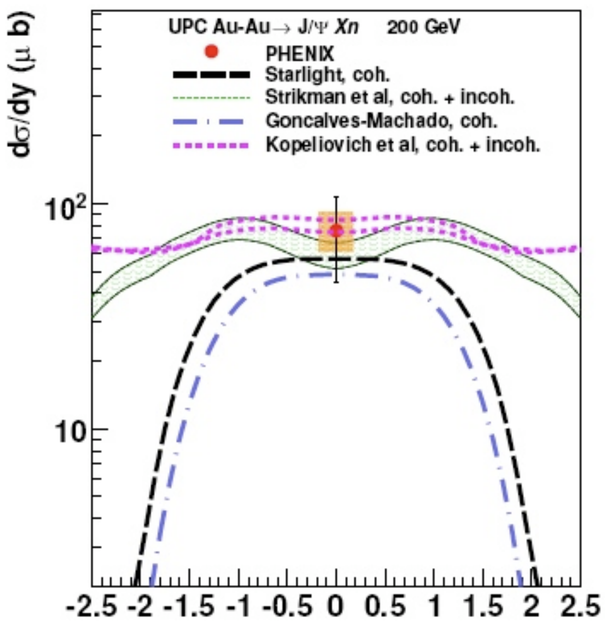
"Central Exclusive Production"



- **PHENIX low statistics run:**
  - **Quasi-elastic J/Psi + high mass $\gamma\gamma \to e^+e^-$ continuum**
- **ATLAS will also measure Upsilon with high statistics**
- **trigger->ee+gap+ZDC**



ee pt distribution (Mee> 2GeV)



Comparison to models including incoherent part

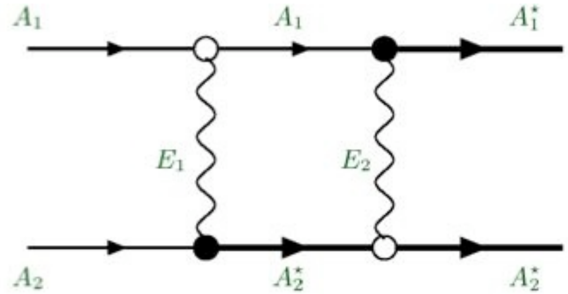
PHENIX Run 7 data will increase statistics by 3

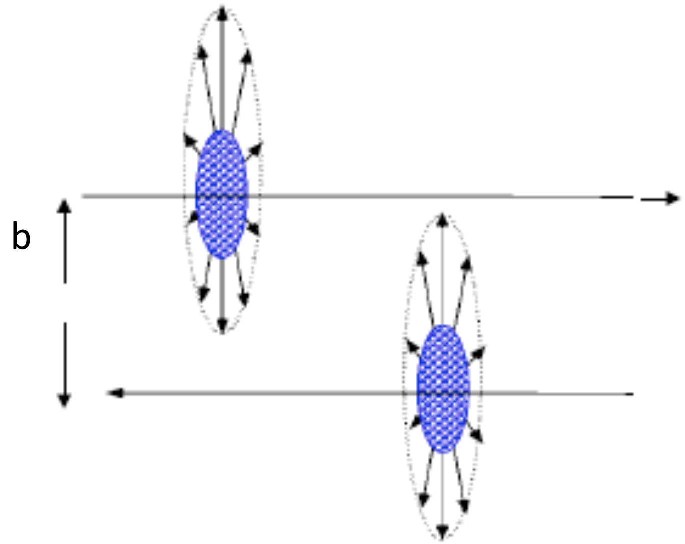
could implement recoil neutron cut to select incoherent

extension to forward muons interesting

EPA(4)-mechanisms of beam loss at the LHC

- **Mutual Coulomb Dissociation(A. Baltz, SNW)**

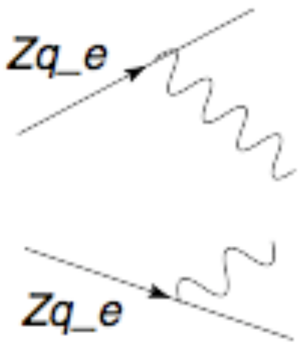




•**Coherent Pair Production (various)**

“inverse positron annihilation”
(Breit-Wheeler)

(“photon flux”)^2



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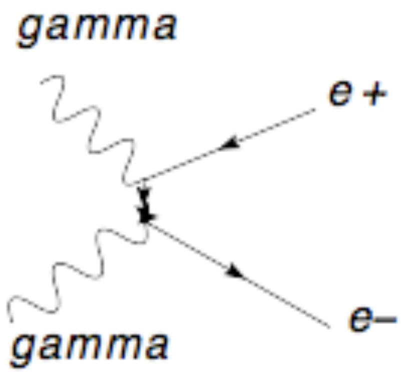
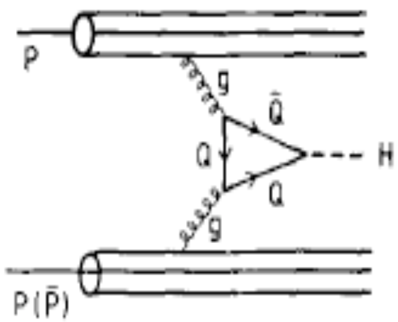
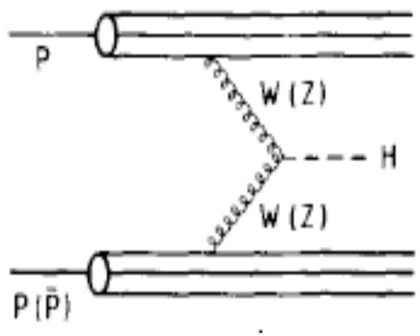


EPA(5)-Equivalent W Approximation

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



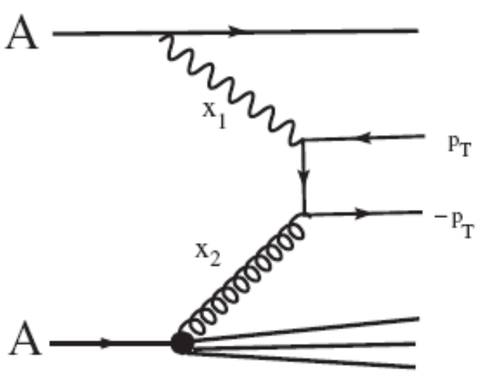
"gluon-gluon fusion"



"β-decay amplitude"

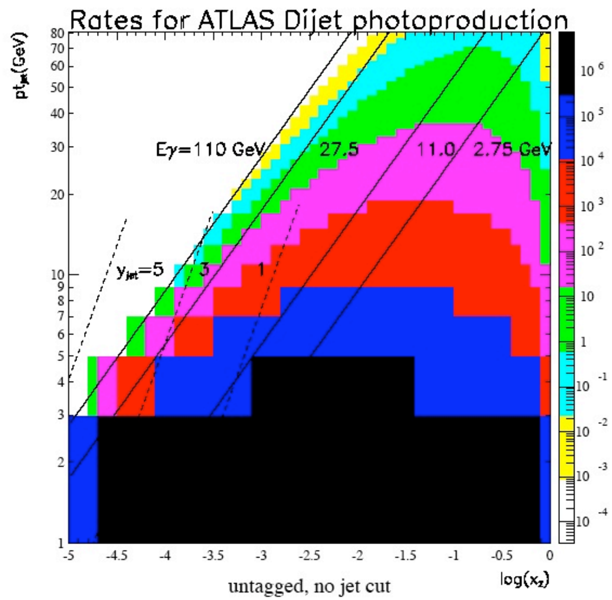
EPA(6): Measuring the structure of Protons and Nuclei

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



q,anti-q
"jets"

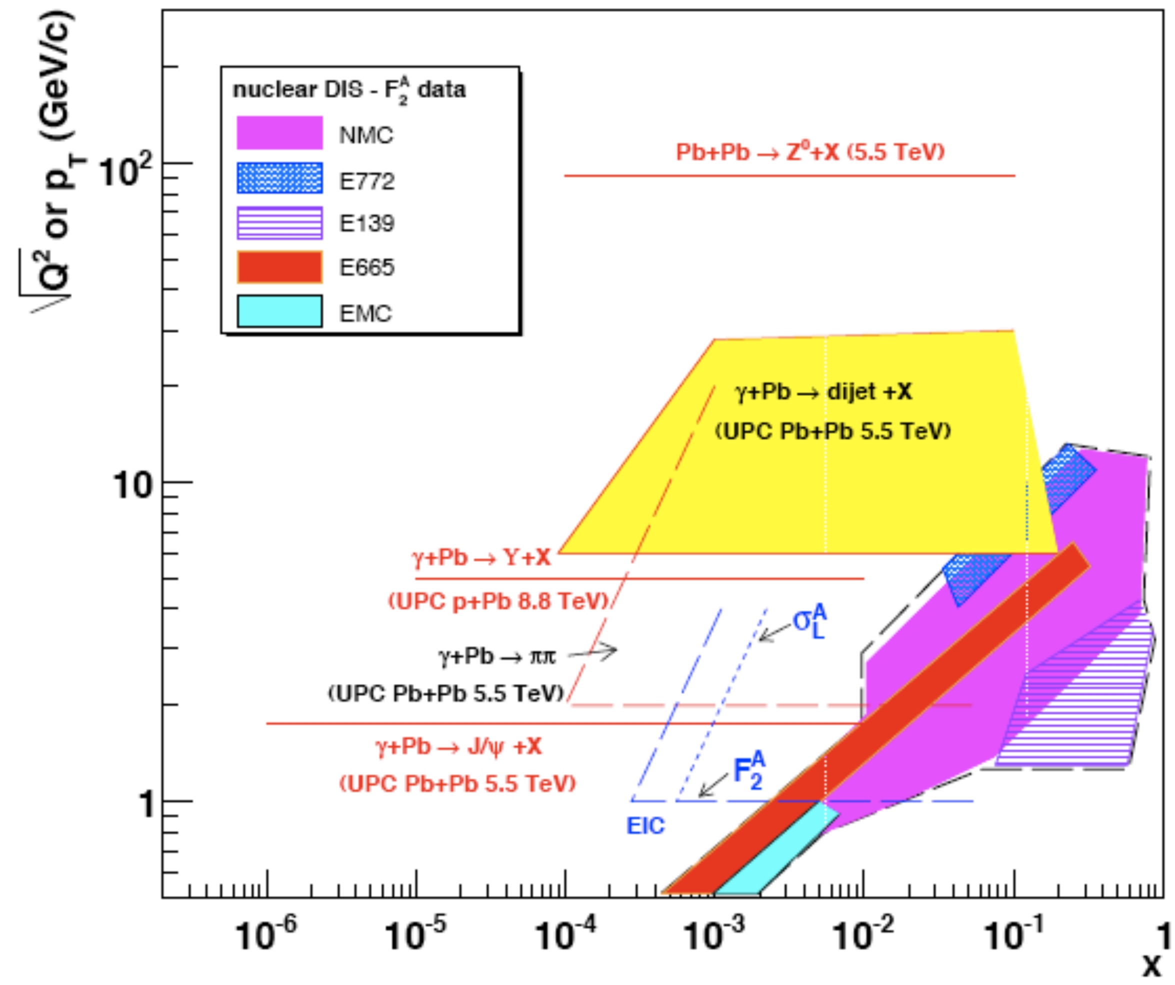
Resolving power



quark,gluon momentum fraction

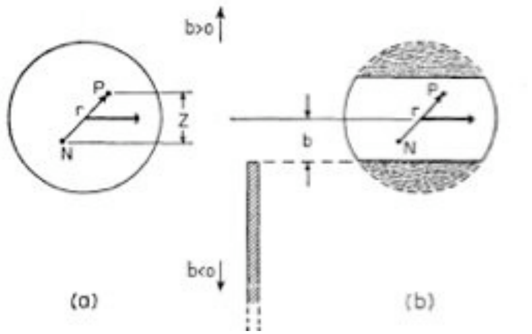
Structure ⟺ Distribution of partons(=quarks, gluons) inside proton- similar to EPA

Coverage with UPC in ATLAS



Inelastic Diffraction

- **Glauber (1955)- deuteron "free dissociation"**
- **Feinberg & Pomeranchuk('56)**



Collisionless excitation to unbound n,p

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

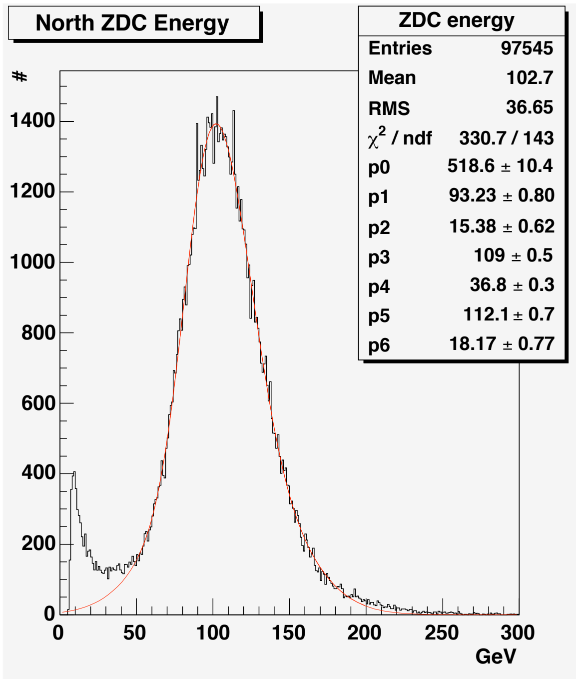
Calculated as a correction to deuteron stripping

- Measured in PHENIX
- **"Diffraction Dissociation-50 Years Later"-SNW**

PHENIX Measurement of deuteron Dissociation

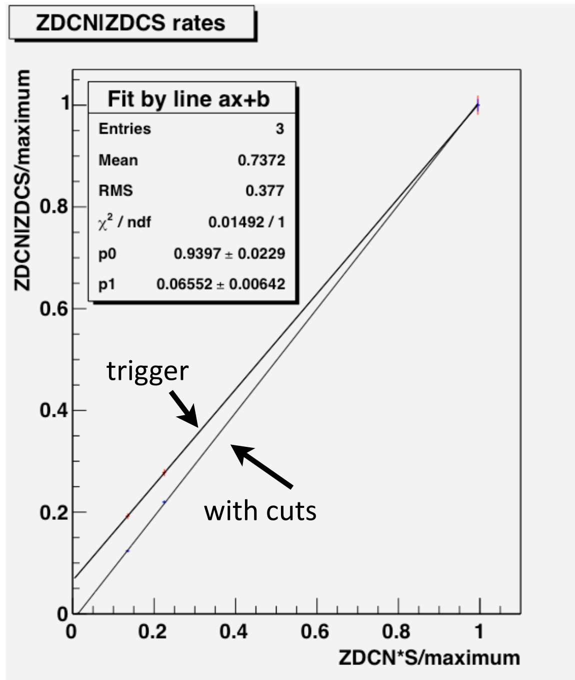
At RHIC energies electromagnetic dissociation becomes significant part of d+Au->n+p+Au

since both calculable -> basis for luminosity of PHENIX dAu data



neutron energy in d+Au->n+p+Au
(6% tail from inelastic)

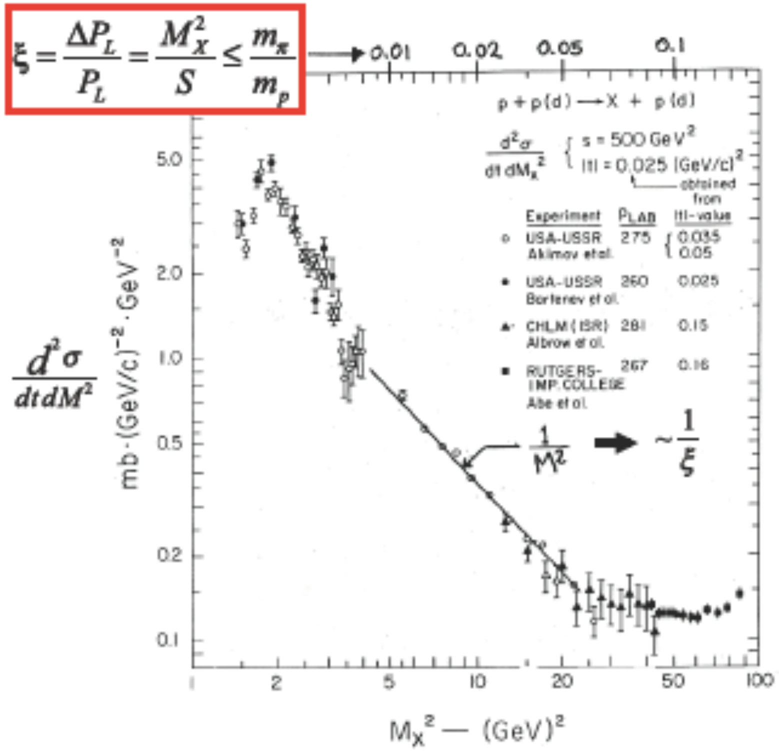
signal



Luminosity @ constant current

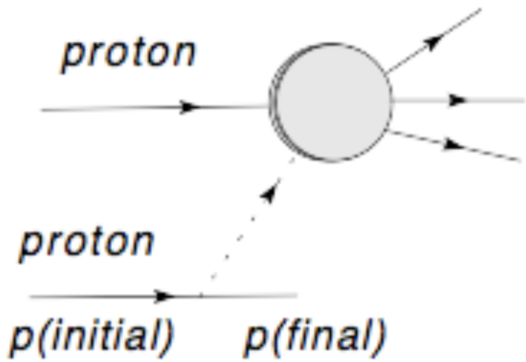
Proton diffraction dissociation

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



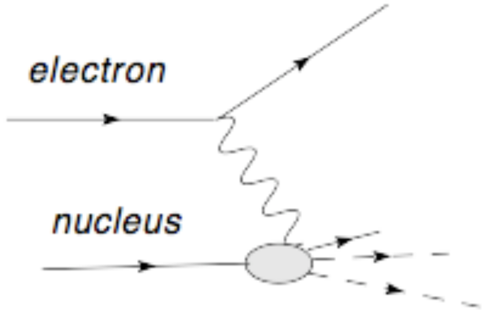
K.Goulianos('83)

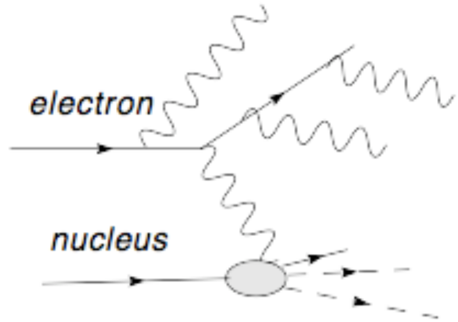
- Observed for p,π,K, high energy γ's and nuclei
- σ~$A^{1/3}$-> peripheral interaction
- Responsible for K_L regeneration in particle physics



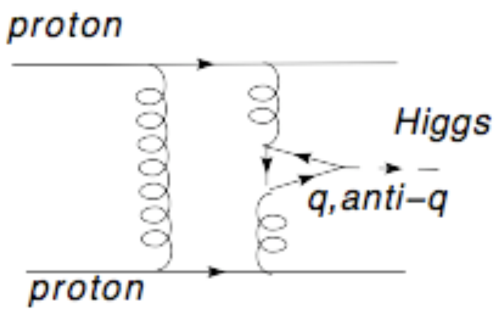
Diffraction(e-nucleus analogy)

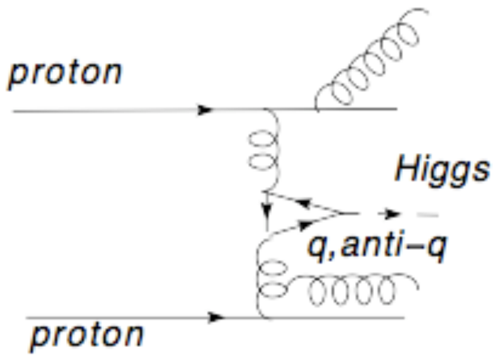
- **Diffractive electroproduction** **non-diffractive**





Diffractive Higgs production **non-diffractive**





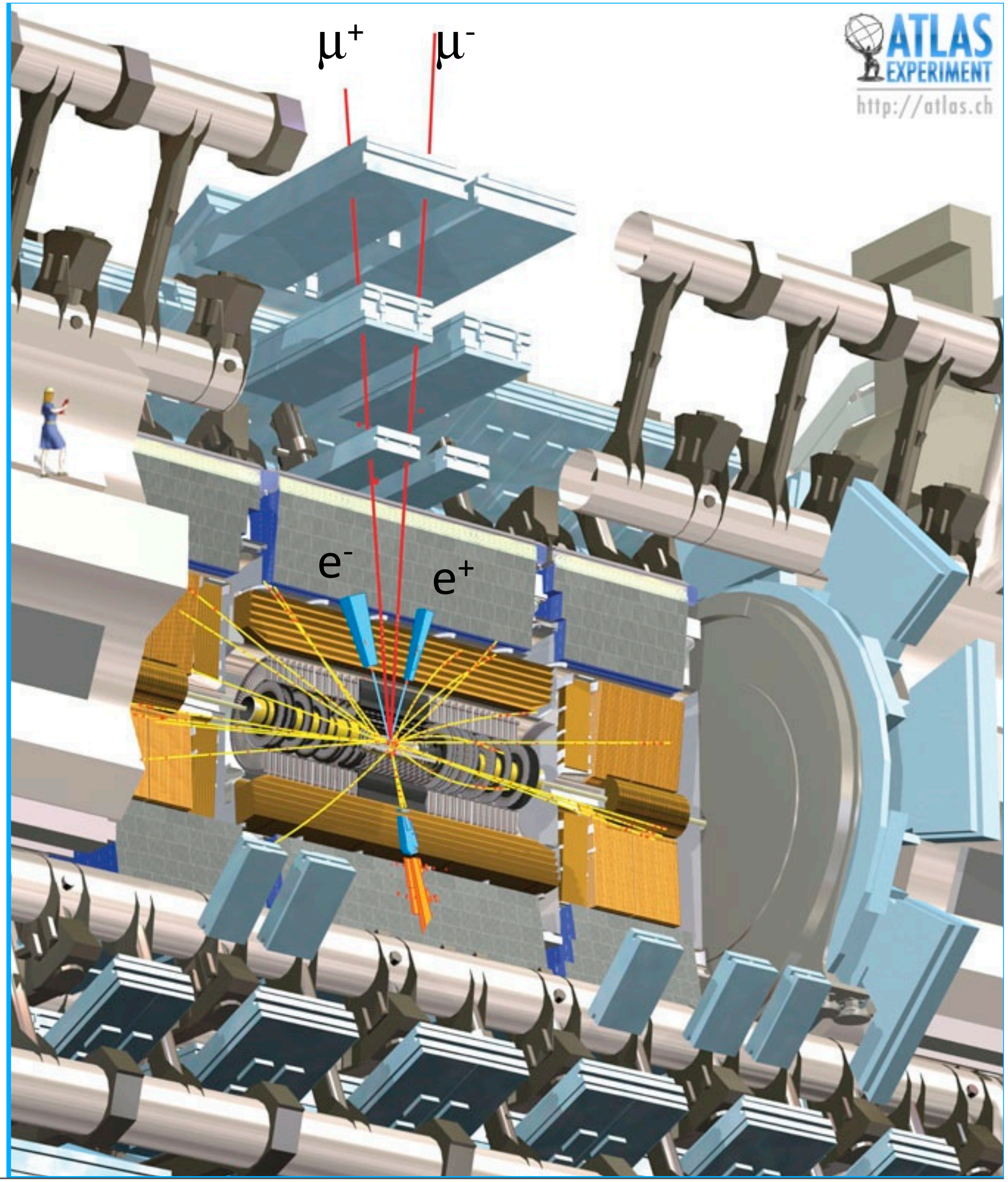
"color screening"

The ATLAS detector

- dimensions ~1/2 Notre Dame de Paris
- weight ~ Eiffel tower
- A 100 MegaPixel detector with 40MHz frame rate
  - (~ 1 million CD's/10sec)
- 80% of pixels in first~ 30 cm.
- Trigger filters data in real time(1GHz->200Hz)
  - Data reduced to ~7km high stack of CD's/year

Higgs-> Z^0Z^0+…

Z^0->e^+e^-, $\mu^+\mu^-$



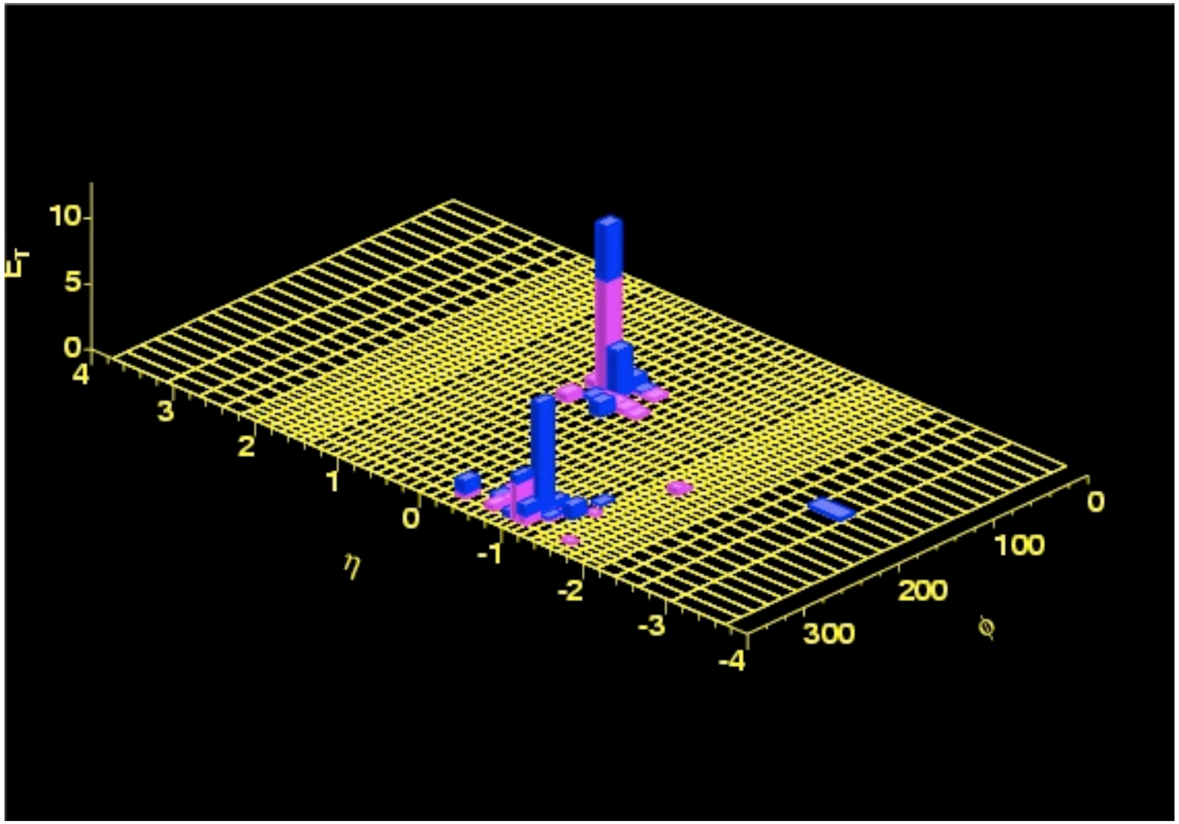
05/24/09

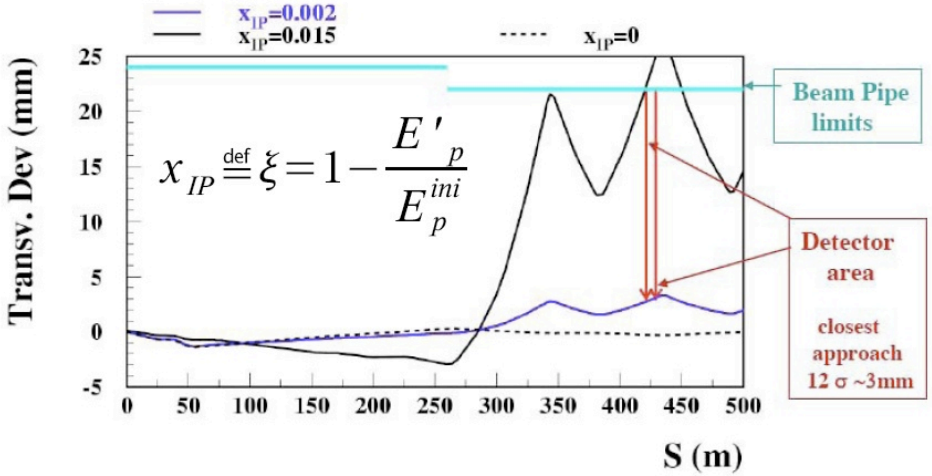
ATLAS FP :A Search for New Physics Using Forward Proton Detectors

Central Exclusive Dijet @Tevatron

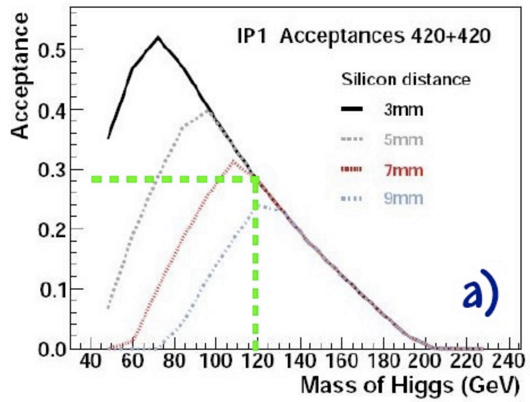
pp->p+JetJet+p

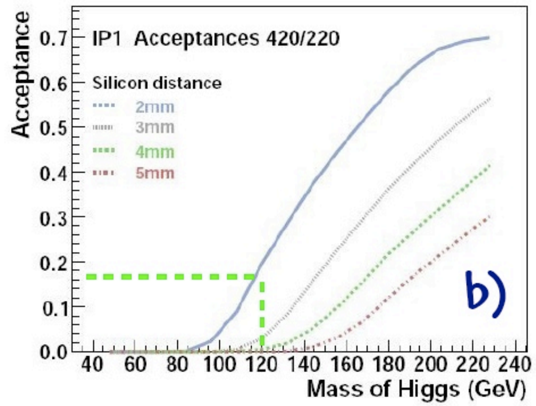
Supports exclusive H^0 prediction of Khoze, Martin & Ryskin





Acceptance for Higgs: a) 420+420 b) 420+220





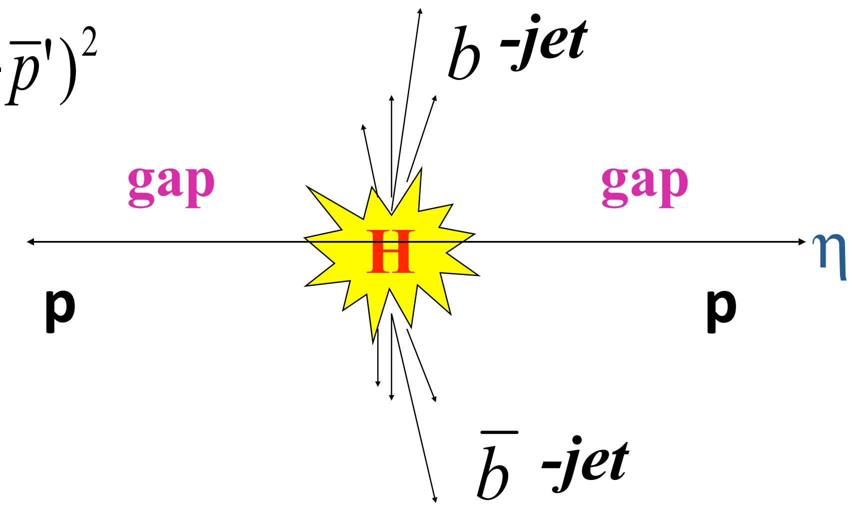
Central Exclusive Higgs Production

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

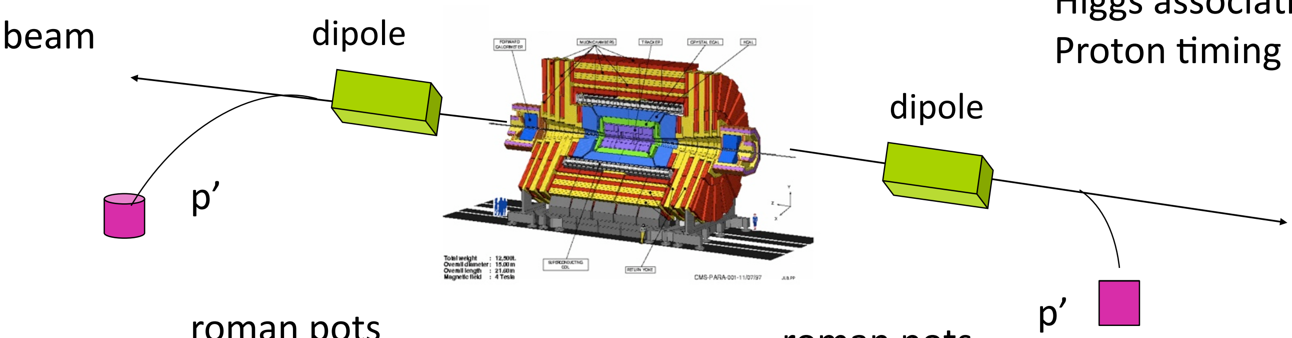
$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

ΔM = O(1.0 - 2.0) GeV

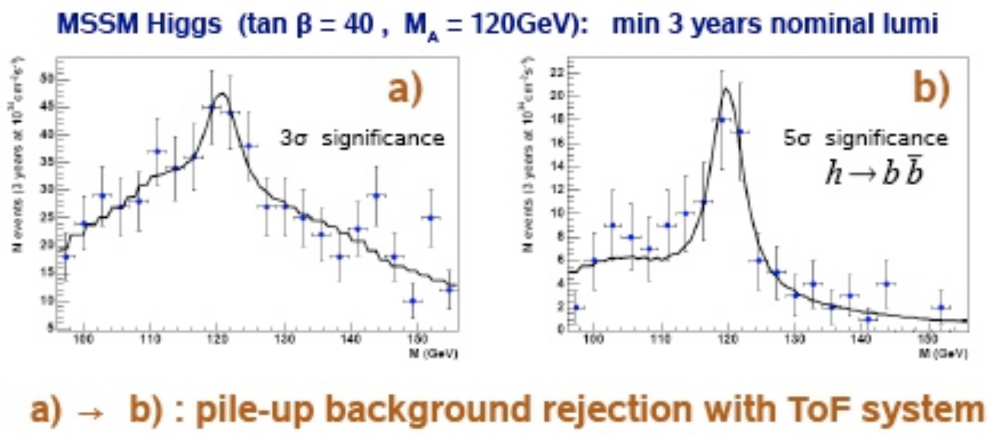
Background suppressed
By 0^+ selection rule



Higgs association from
Proton timing (~ 10 picosecond)



High Rate (20 MhZ) Very Fast timing (10 Picosecond) critical to the success of CEP Higgs measurement (see e.g. Cox and Pilkington)

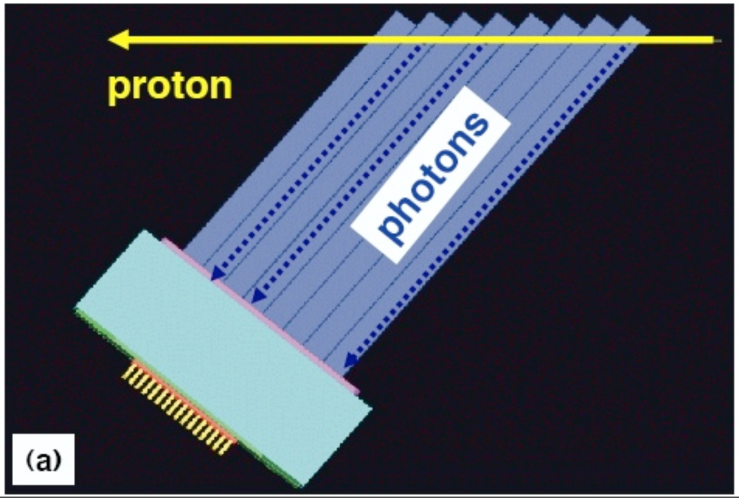


Fast Timing Principles developed in FP420

- Particles pass through Cerenkov radiator-> prompt light pulse(unlike scintillator)
- Photons are nearly along particle path for gas radiator: $\tan\theta_C \sim \surd(n^2-1)$ so very small transit spread
- Light peaked in UV- $N(\lambda) \sim (1-1/(n^2(\lambda)))/\lambda^2$
- For simple thin quartz radiator $\sigma_t^2 = \sigma_{RADIATOR}^2 + \sigma_{PMT}^2 \sim 1.7 * \ell(\text{cms.}) + 25/\ell$ picosec so optimum at length ~ 1-2 cms

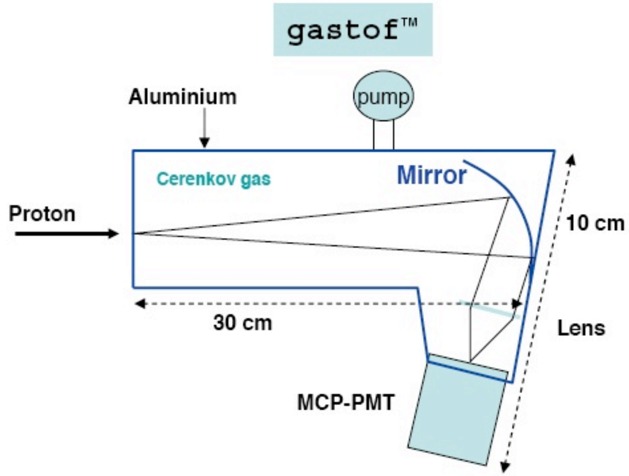
Quartz Radiator
Better suited for pixels

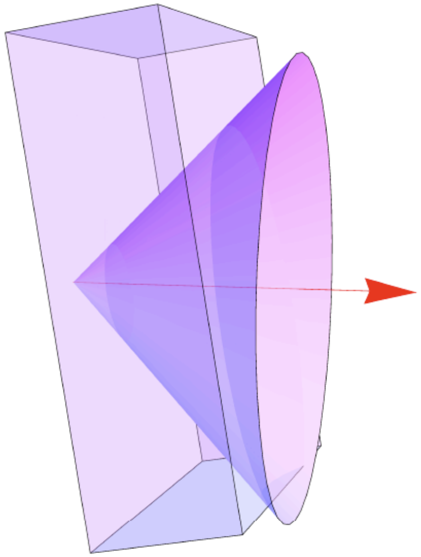
Achieved σ_t=40 psec/bar with PHOTONIS Planacon PMT



Gas Radiator
Better for light spread and collection bad for segmentation

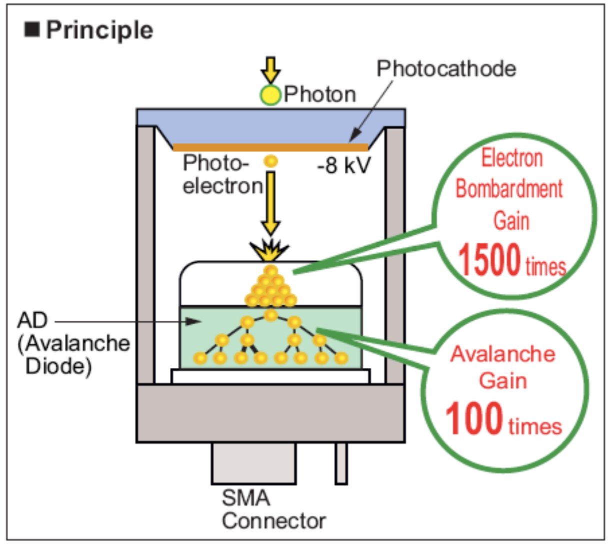
Achieved σ_t=13 psec with Hamamatsu R3809U MCP-PMT





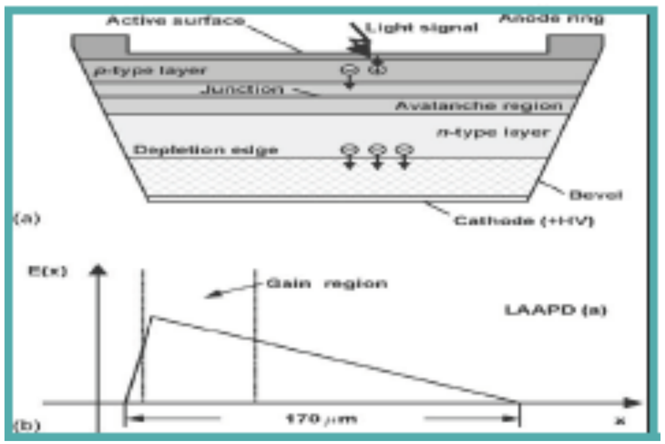
Cerenkov Radiation cone

Cerenkov
or
APD
option

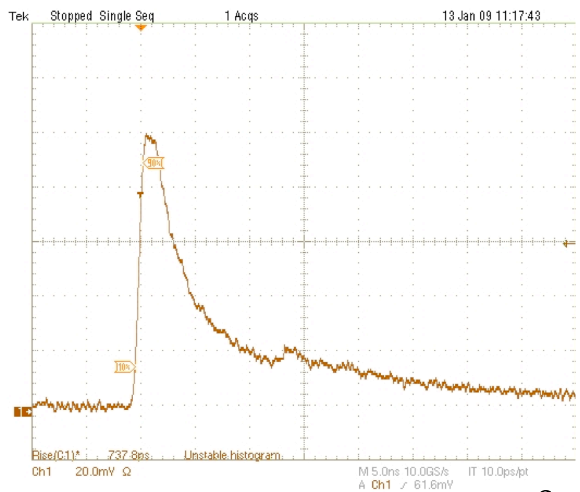


Pre-production Hybrid photodetector

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



Deep diffused avalanche photodiode

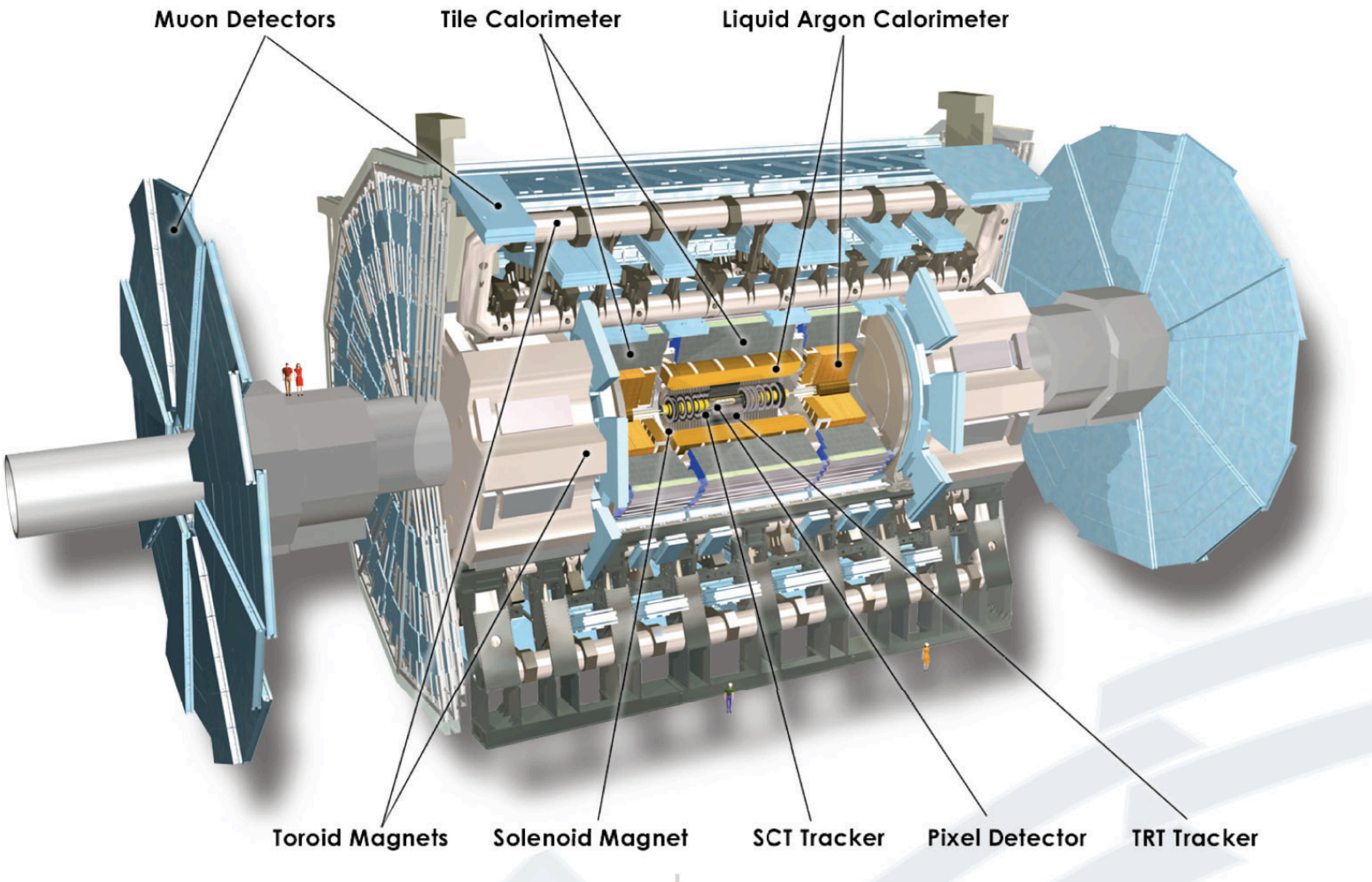


650 picosecond risetime (β’s)

Summary

- Forward detectors with capabilities beyond those of RHIC and Tevatron experiments have been built and commissioned for the LHC- despite the very difficult challenges imposed by radiation, rates and mometum compaction
- forward detectors increasingly important for new physics

the ATLAS detector



Handling antimatter(Sony Pictures)