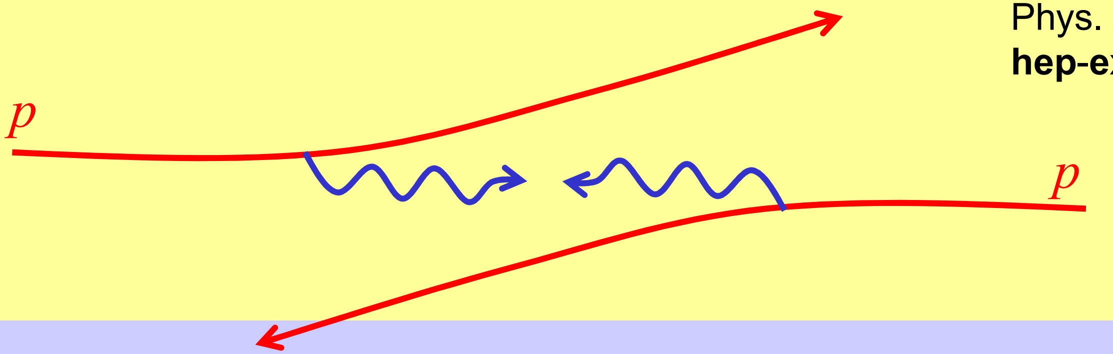
Studies of High Energy Photon Interactions at the LHC

Krzysztof Piotrzkowski
Université Catholique de Louvain

- Introduction: LHC as a high energy $\gamma\gamma$ and γp collider
- Photoproduction of WH (M. vander Donckt)
- Anomalous quartic couplings and WW and ZZ two-photon production (T. Pierzchała)
- Luminosity measurement with exclusive lepton pairs at the LHC (Y. Liu)
- Fast proton simulation (J.de Favereau+X.Rouby)
- Heavy Ion case

LHC as a High Energy γγ Collider

Phys. Rev. **D63** (2001) 071502(R)
hep-ex/0201027

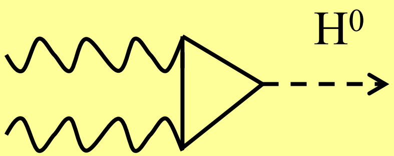


<u>Highlights</u>:

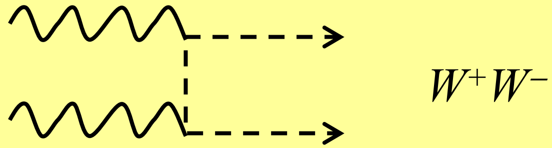
- **γγ CM energy *W* up to/beyond 1 TeV (and under control)**
- **Large photon flux *F* therefore significant γγ luminosity**
- **Complementary (and clean) physics to *pp* interactions, eg studies of** *exclusive* **production of heavy particles might be possible ➡ opens new field of studying very high energy γγ (and γp) physics**

<u>DISCLAIMER</u>:
This is <u>NOT</u> meant for studying all photon interactions at the LHC but those for which the QCD background is strongly suppressed, as for example in the exclusive production of leptons or gauge bosons.

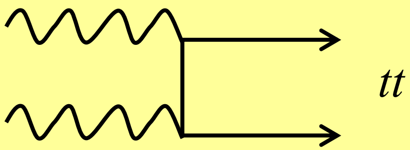
γγ Physics Menu - Highlights

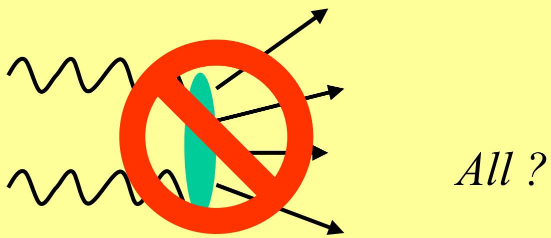


$\sigma \sim 80$ pb



$\sigma \sim 10$ pb (at $W = M_H = 200$ GeV)





$\sigma \sim 1$ pb

$\sigma \sim 100–500$ nb

+ ***SUSY processes***

γp interactions at the LHC - super HERA at CERN

Photon-proton interactions at the LHC have significantly higher energy reach and luminosity yield than for the $\gamma\gamma$ events is expected

Example assumptions:

- $0.01 < x_1 < 0.1$, photon tagging range
- $0.005 < x_2 < 0.3$, Bjorken-x range for quarks and gluons

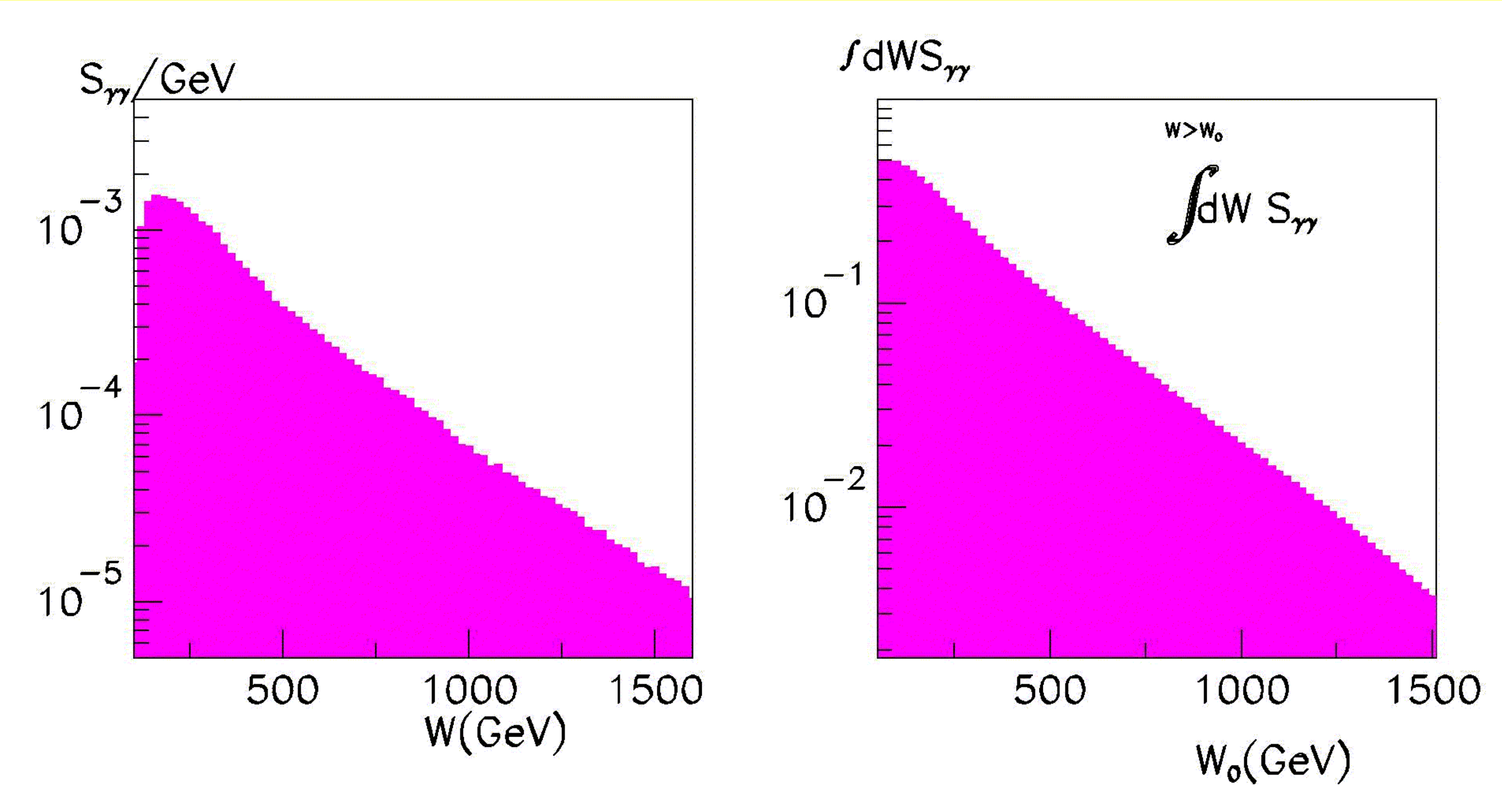
(arbitrary for the moment, could be extended)

+ use MRST2001 (at $Q^2=10^4$ GeV^2) for partons

$$S(W) = f_\gamma(x_1) \otimes f_p(x_2) \quad , \quad W^2=4E_p x_1 x_2$$

$$\sigma_{pp} = \int S \; \sigma_{\gamma p} \; dW$$

Photon-quark luminosity spectra



Note: at $W_{\gamma q}$ > 300 GeV photon-quark luminosity is about one third of the nominal *pp* (and still significant beyond 1 TeV)

Introduction

Muriel vander Donckt

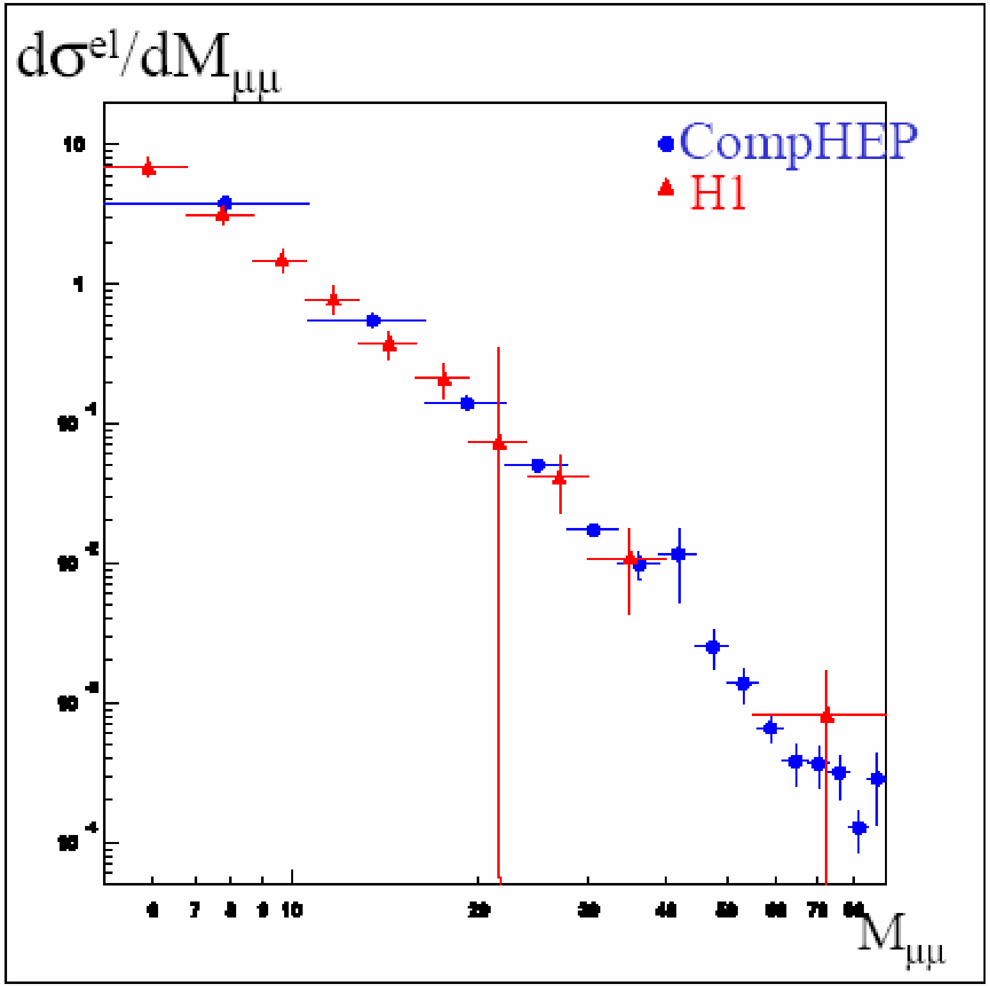
- For low SM higgs boson mass: $h \rightarrow bb$ is dominant but drowned in QCD background
- In γq interactions, the proton emitting an elastic γ, does not break up $\Rightarrow$ no energy in one HF (+ RP tag) $\Rightarrow$ QCD background reduction.
- BUT : $\sigma_{\gamma\gamma} < \sigma_{\gamma q} < \sigma_{qq}$
- GOAL: assess a possible alternative way to observe a 115-150GeV higgs, in a channel with different systematics from $h \rightarrow \gamma\gamma$.

generation of γq interactions

- γ pdfs: Equivalent Photon Approximation
  Budnev et al, Phys. Lett. C15 (1975), 181.
- Added and tested in CompHEP for elastic γ emission ($Q^2 < 1 GeV^2$)

$\sigma_{H1} = 25.3 \pm 1.0 \pm 3.5$ pb

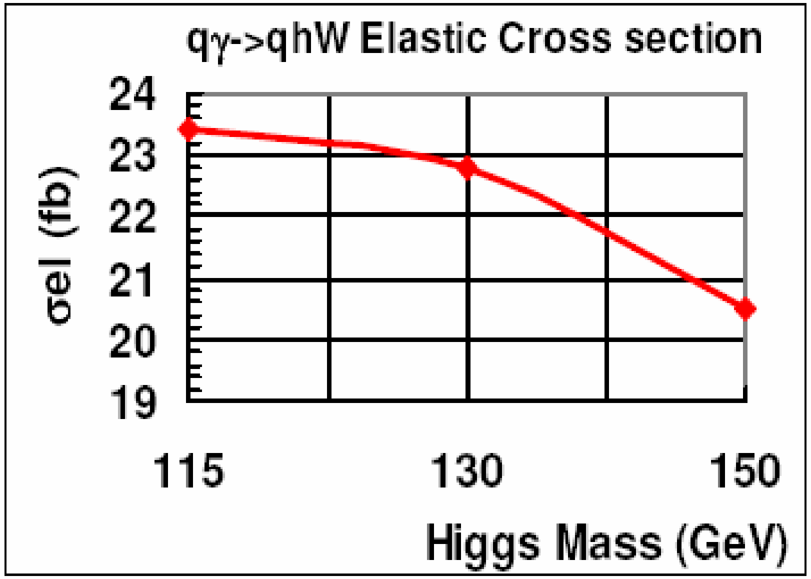
$\sigma_{compHEP} = 25.8$ pb



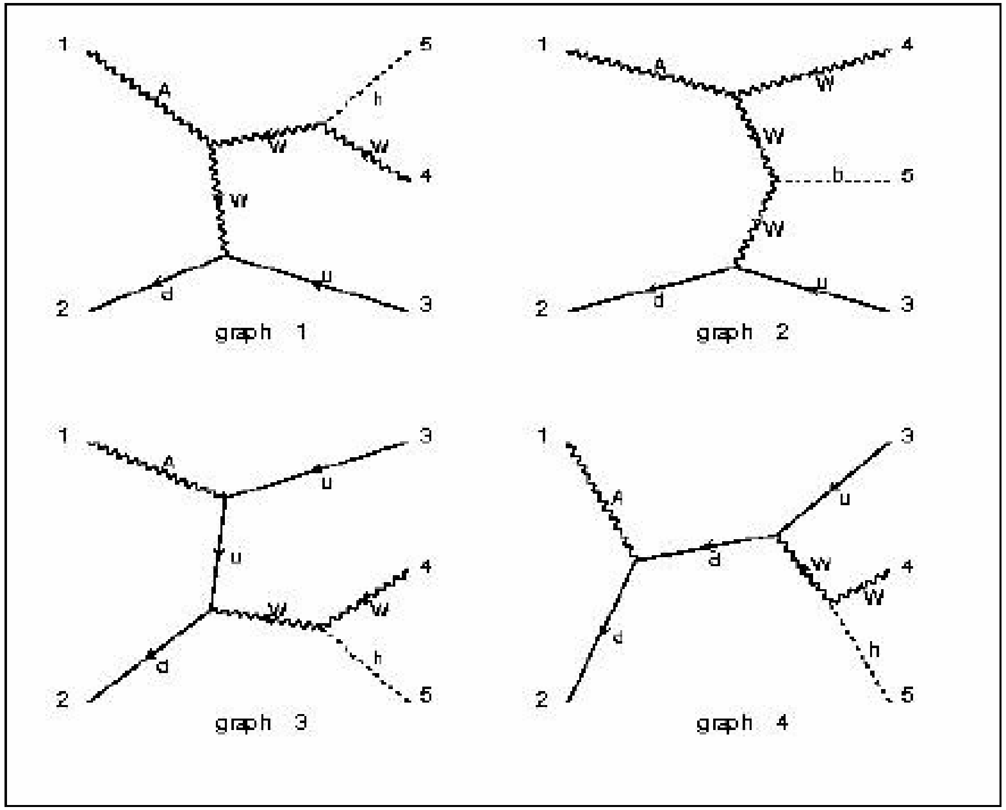
Aktas et al, Phys Rev Lett B583 (2004), 28-40

γq→q'hW

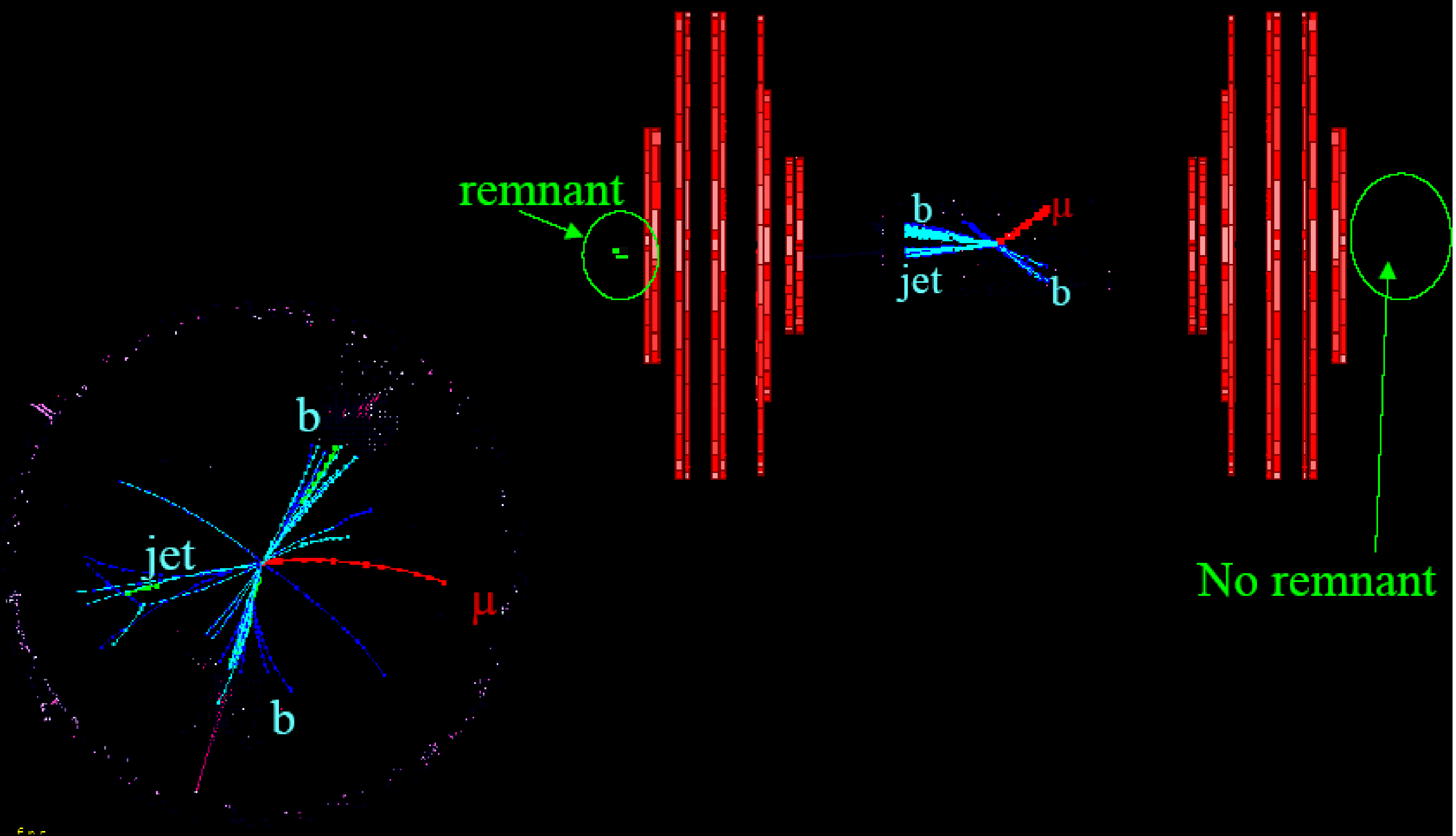
- 1 side of the detector with
  - Little energy in HF
  - Proton tag (only elastic events)
- 1 lepton from W→lν
- 1 extra jet
- Higgs decay: bb,ττ,WW



CompHep takes into account
Interferences between the 4 diagrams



γq→q'hW →q'bblν (iguana)



Expected signal events

2 samples:

- Elastic and quasi-elastic events without pile-up: $10 fb^{-1}$
- Elastic events with pile-up and Roman Pot tag : $100\ fb^{-1}$ at $2x10^{33}$

el+QE \ M_h	115
$10\ fb^{-1}$ full decay	585
+ $W \to l\nu$	185
+ $h \to bb$	135
$\|\eta_l\| < 2.5$	113
E_{HF}<70 GeV or RP	112

Elastic \ M_h	115
$100\ fb^{-1}$ full decay	2340
+ $W \to l\nu$	741
+ $h \to bb$	543
$\|\eta_l\| < 2.5$	462
RP tag (45.7%)	211

ORCA 8.2.0: trigger & reconstruction

	efficiency	#evts ($10fb^{-1}$)	#evts ($100fb^{-1}$)
L1	0.75	84	158
HLT	0.60	50	95
$\lvert\eta_b\rvert<2.5$	0.77	39	73
2 b-tags	0.125	5	9

W/o pile-up:
Design L1 & HLT:
HF<70 + soft lepton + jet
Under study

Assess best parameters & method.
Lepton tag?

Anomalous WW

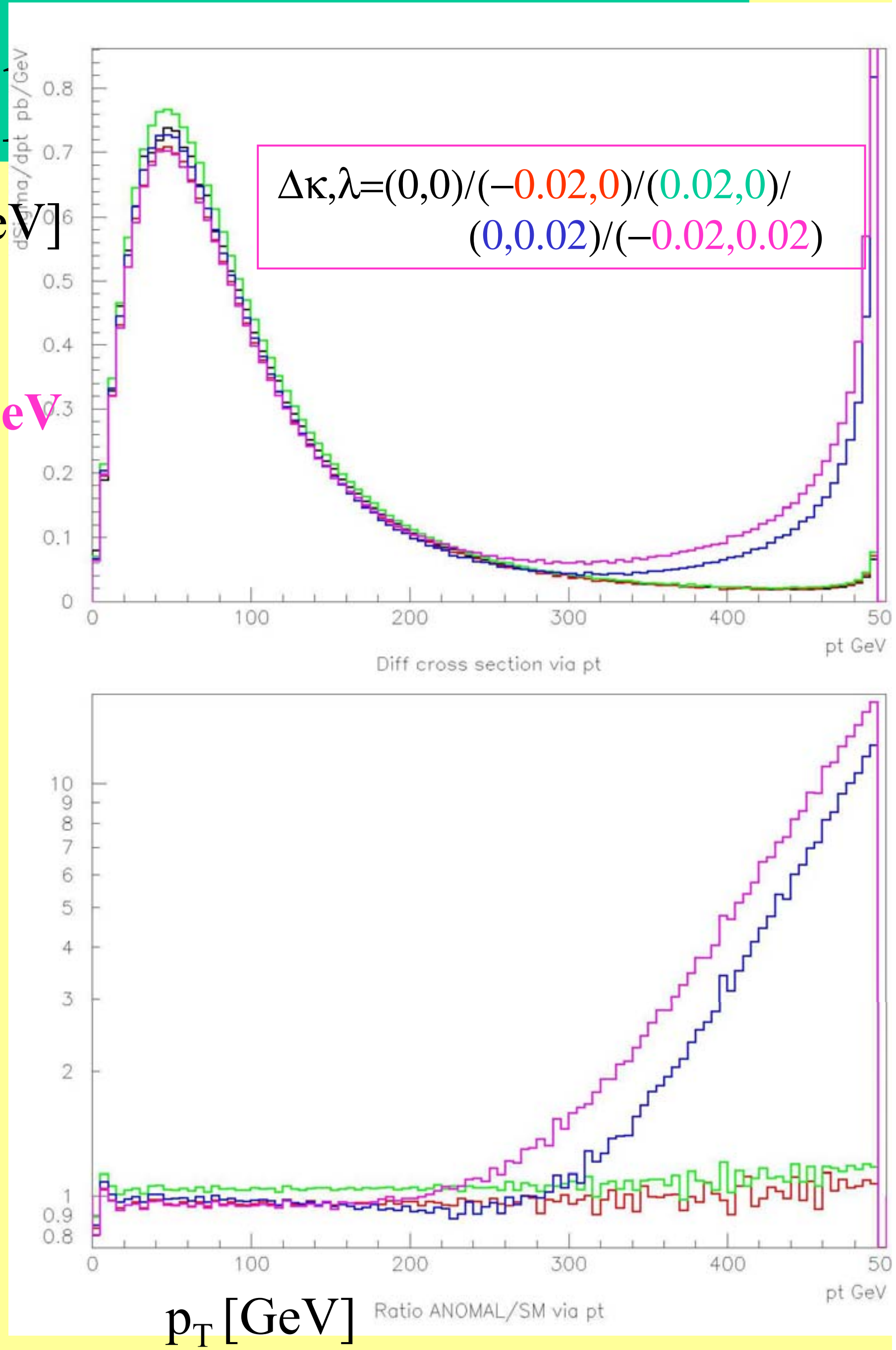
At a generator level so far:

- κ changes mostly normalization, λ also affects the p_T shape
- From statistical point of view better than LEP2 limits seems feasible
- Looking also into a single W photoproduction

$d\sigma/dp_T$ [pb/GeV]

Ex.: $\gamma\gamma$ at 1 TeV

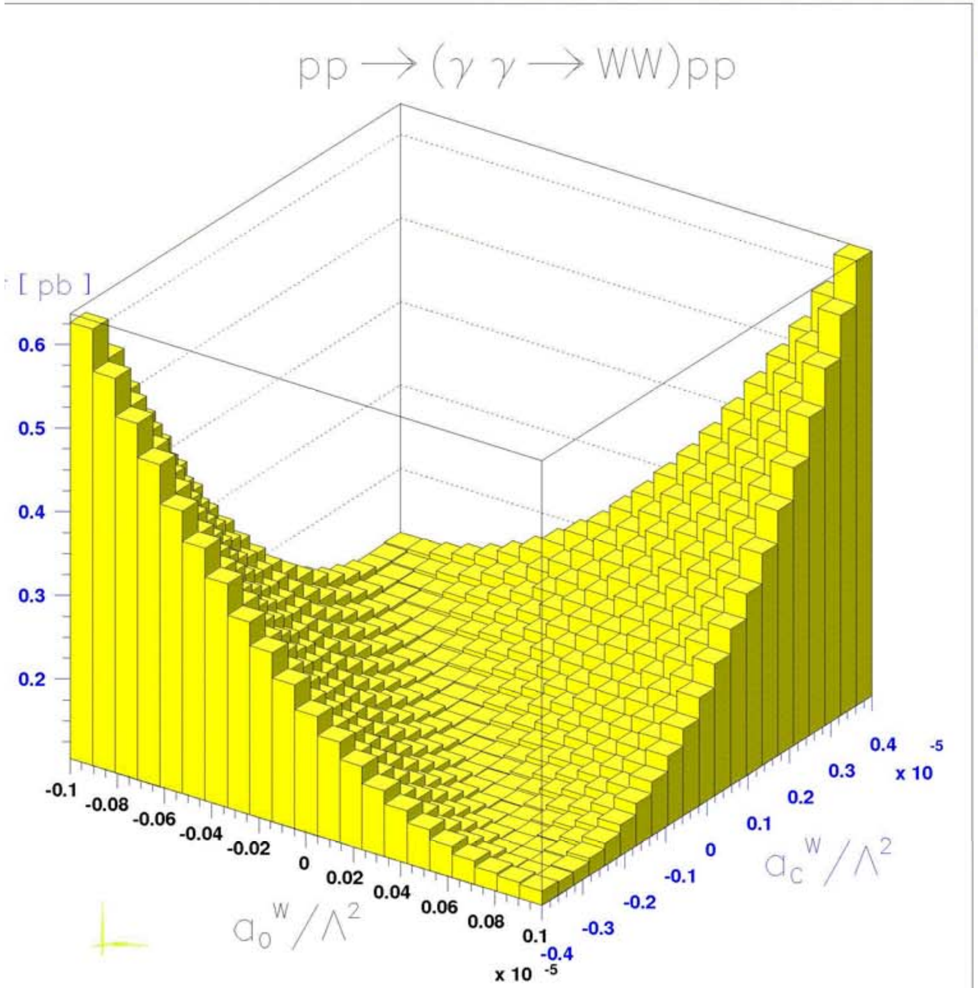
Anom/SM



p_T [GeV]

T.Pierzchala

Anomalous quartic vector boson couplings



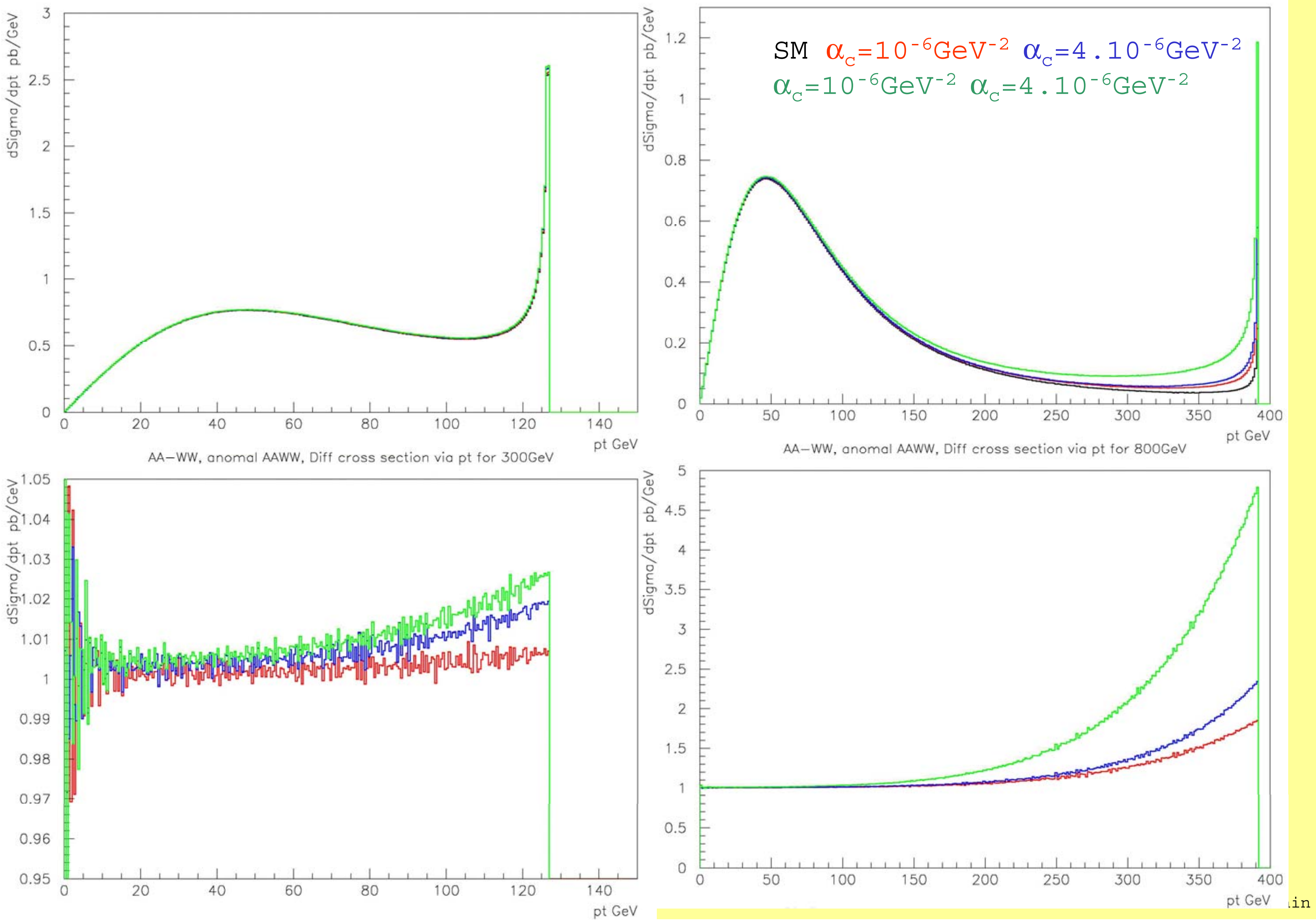
- SM $\gamma\gamma \to WW$ for $\int L_{pp}\, dt$=30fb^{-1} $\Rightarrow$ about 3000 W pairs will be produced
- we expect at least 10 000 $\times$ stronger limits:

$$-0.1{\cdot}10^{-5}\ \mathrm{GeV}^{-2} < a_0^{\mathrm{W}}/\Lambda^2 < 0.1{\cdot}10^{-5}\ \mathrm{GeV}^{-2}$$

$$-0.4{\cdot}10^{-5}\ \mathrm{GeV}^{-2} < a_c^{\mathrm{W}}/\Lambda^2 < 0.4{\cdot}10^{-5}\ \mathrm{GeV}^{-2}$$

$d\sigma/dp_T$ at W=300 and 800 GeV

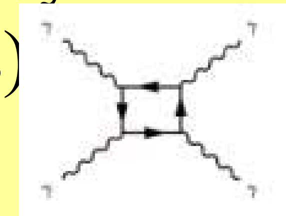
T.Pierzchala



Gauge boson photoproduction

- Hope for large sensitivity in QGC, will study WW anomalous production for LED and strong W sector

$\gamma\gamma \to \gamma\gamma$ (also not possible at tree level), eg. sensitivity to massive monopole contributions (large p_T physics)

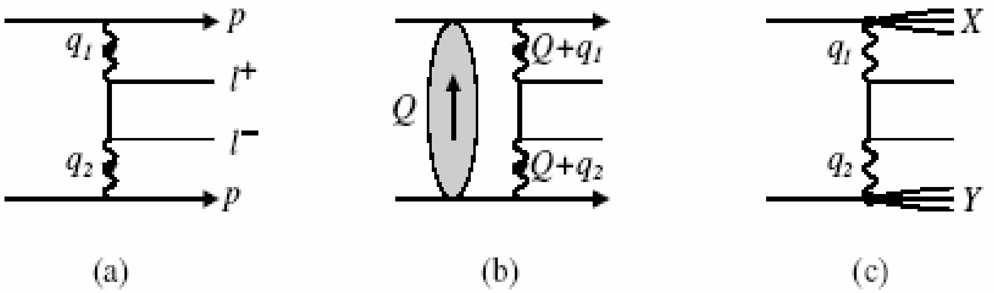


$\gamma\gamma \to ZZ$ suppressed in SM (~10^{-3}), good place to look for BSM

Introduction : $pp \to pe^+e^-p$

- QED process (a) production σ precisely known.

event generator LPAIR based on ME by Vermaseren



- Hadronic corrections [(b) (c)] small. Can suppress with experimental cuts and subtract by fitting final state kinematics.

V. A. Khoze et al Eur. Phys. J **C19**, *313-322 (2001)*

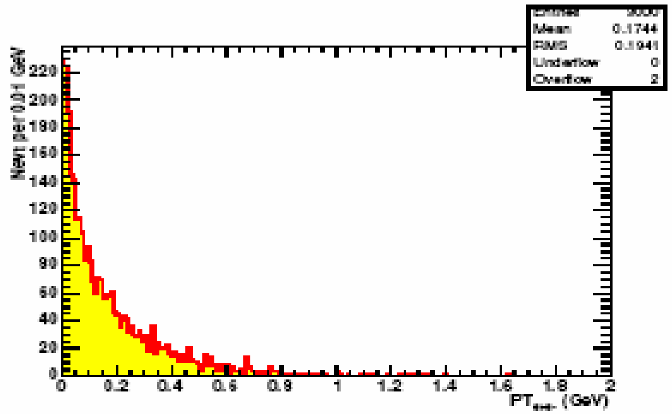
- Production rate considerable,

CMS week, March 18,20(

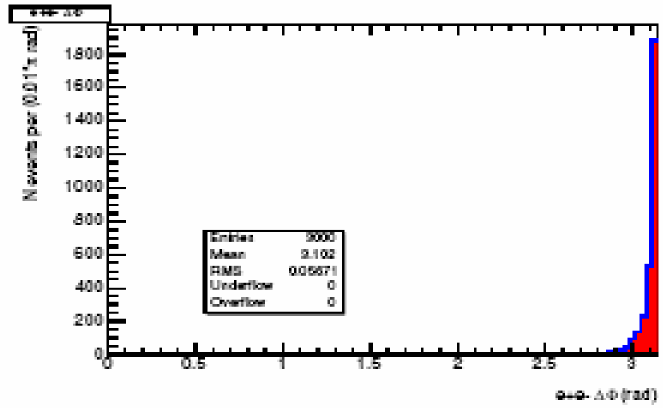
e.g. $\sigma_{(P_T>2\ \mathrm{GeV})} = 0.129\ \mathrm{nb} \pm 0.234\ \mathrm{pb}.$

Lpair:3K $pp \rightarrow pe^+e^-p$ (P_T>2GeV)

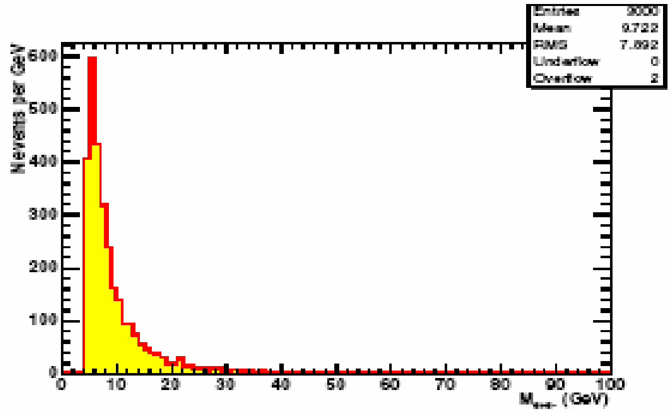
e^+e^- two body system P_T



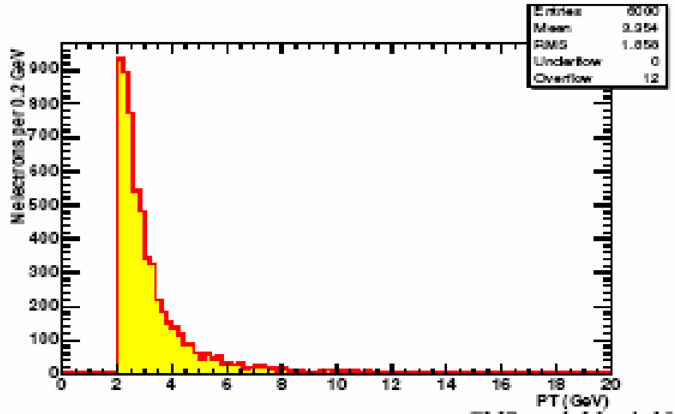
$\Delta\Phi$



Invariant mass of e^+e^-



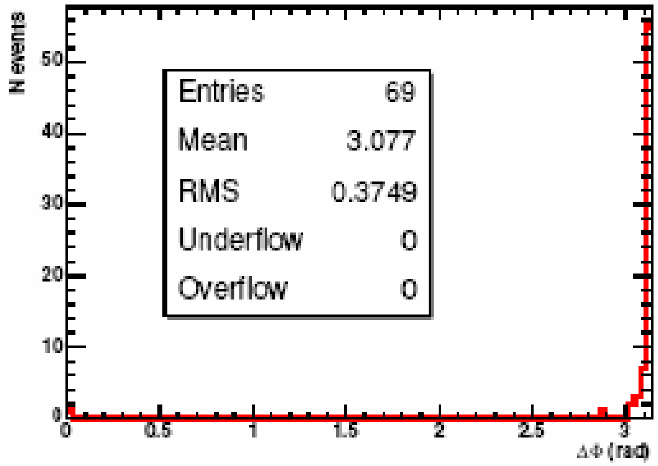
PT of the leptons



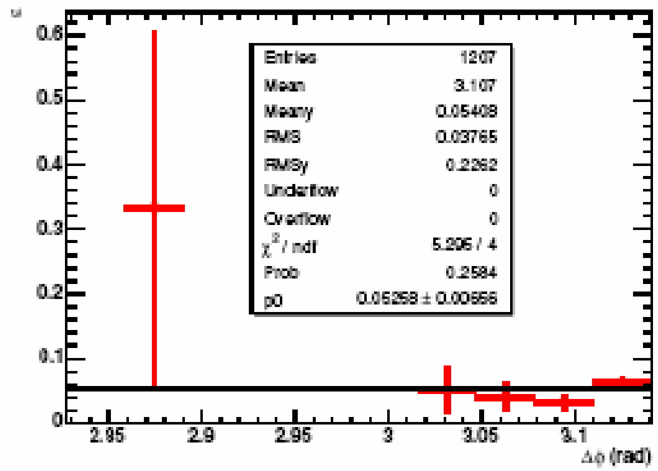
CMS week, March 18, 2005 –

events with both e^+e^- reconstructed

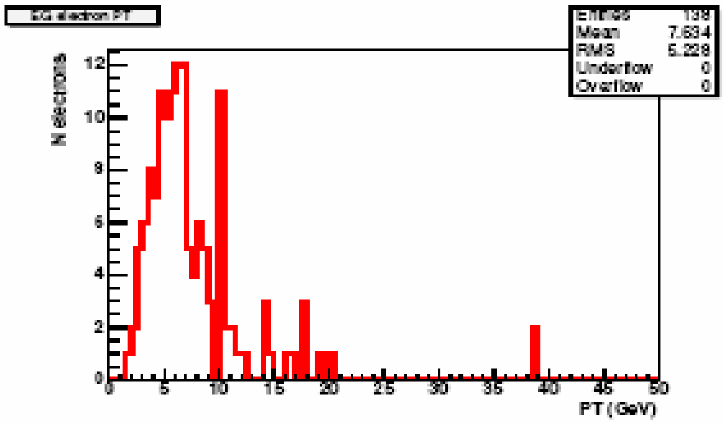
$\Delta\Phi$ distribution



Reco eff vs. $\Delta\Phi$



P_T of the electrons



CMS week, March 18, 2005

Infer E_γ at initial state.

- When both leptons are observed, the energy of the $\gamma\gamma$ at initial state can be infered -assumption : their transverse momenta are small

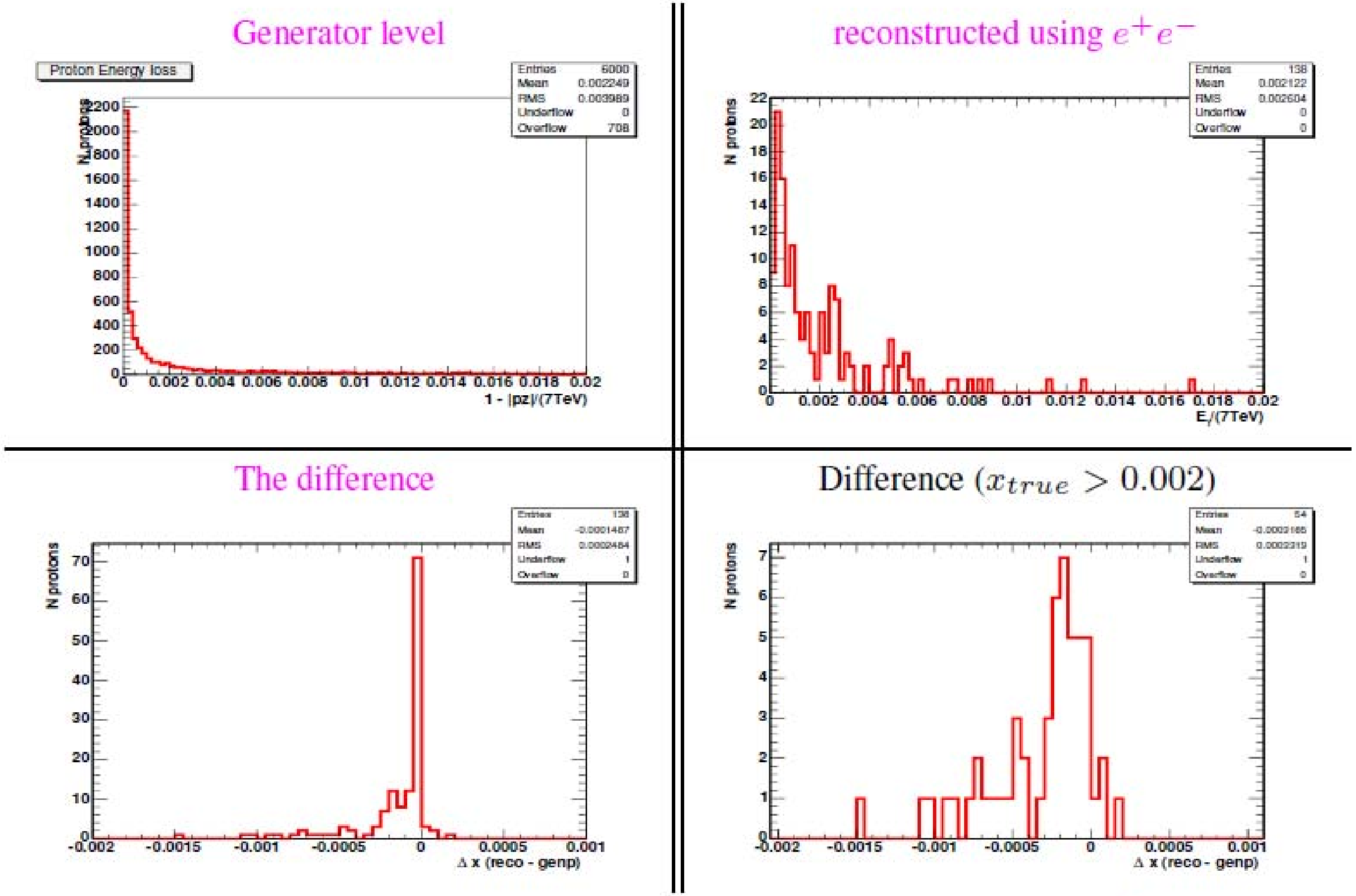
(1) $$M_{l+l-} = 4E_{\gamma 1}E_{\gamma 2};$$

(2) $$Y_{l+l-} = \frac{1}{2}\log\frac{E_{\gamma 1}}{E_{\gamma 2}} \quad (\text{take } P_{z\gamma 2} < 0)$$

where, M_{l+l-}, Y_{l+l-} are the invariant mass, rapidity of the l^+l^- two body system respectively.

- This can be used to calibrate forward detectors.

$x \equiv E_\gamma / E_p$



For 420m detectors ($x > 0.002$), resolution comparable with beam spread. 10^{-4}!

Summary & Outlook

- $\sigma * 69/3000 \approx 3$pb, i.e, possible to measure the luminosity to $2 - 3\%$ with 1 fb^{-1}
- It is a good tool to calibrate forward detectors.
- Need to think about triggering low P_T lepton pair + "exculsivity" .
- Need to consider backgroud, such as DY.
- This trigger (to propose) will collect $\Upsilon \rightarrow l^+l^-$: useful for detector calibration.
- Including $\mu^+\mu^-$ will be helpful.Currently in to-do's.
- Need to understand the (in)efficiency and fake rate for low P_T leptons. Source of systematics.

HECTOR – fast p simulation in the LHC

We perform a nominal (linear) simulation, by using transport matrices
We implemented :

- Beam-line elements : dipoles, quadrupoles and drifts;
  eg for a dipole:

$$\begin{pmatrix} x(s) \\ x'(s) \\ y(s) \\ y'(s) \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} \cos X & R\sin X & 0 & 0 & R(1-\cos X) \\ -(1/R)\sin X & \cos X & 0 & 0 & \sin X \\ 0 & 0 & 1 & s & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_0 \\ x'_0 \\ y_0 \\ y'_0 \\ \Delta p/p \end{pmatrix} \qquad \text{where } X = s/R$$

$$s = \text{element length}$$
$$x, y = \text{proton transverse coordinates}$$
$$x', y' = \text{proton transverse speeds}$$
$$R \approx 1/B$$

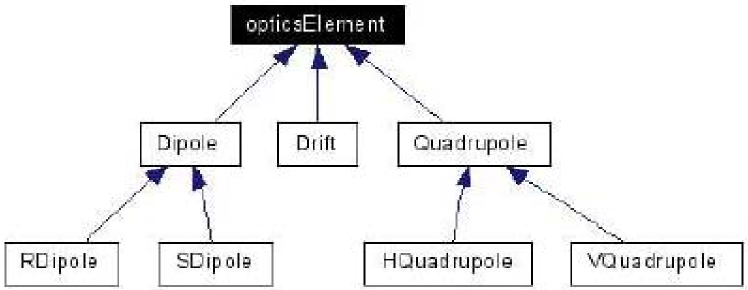
- The proton propagation through this beam-line, including
  the limited aperture effects

Program structure

The program code is based on C++ and ROOT 4.xx

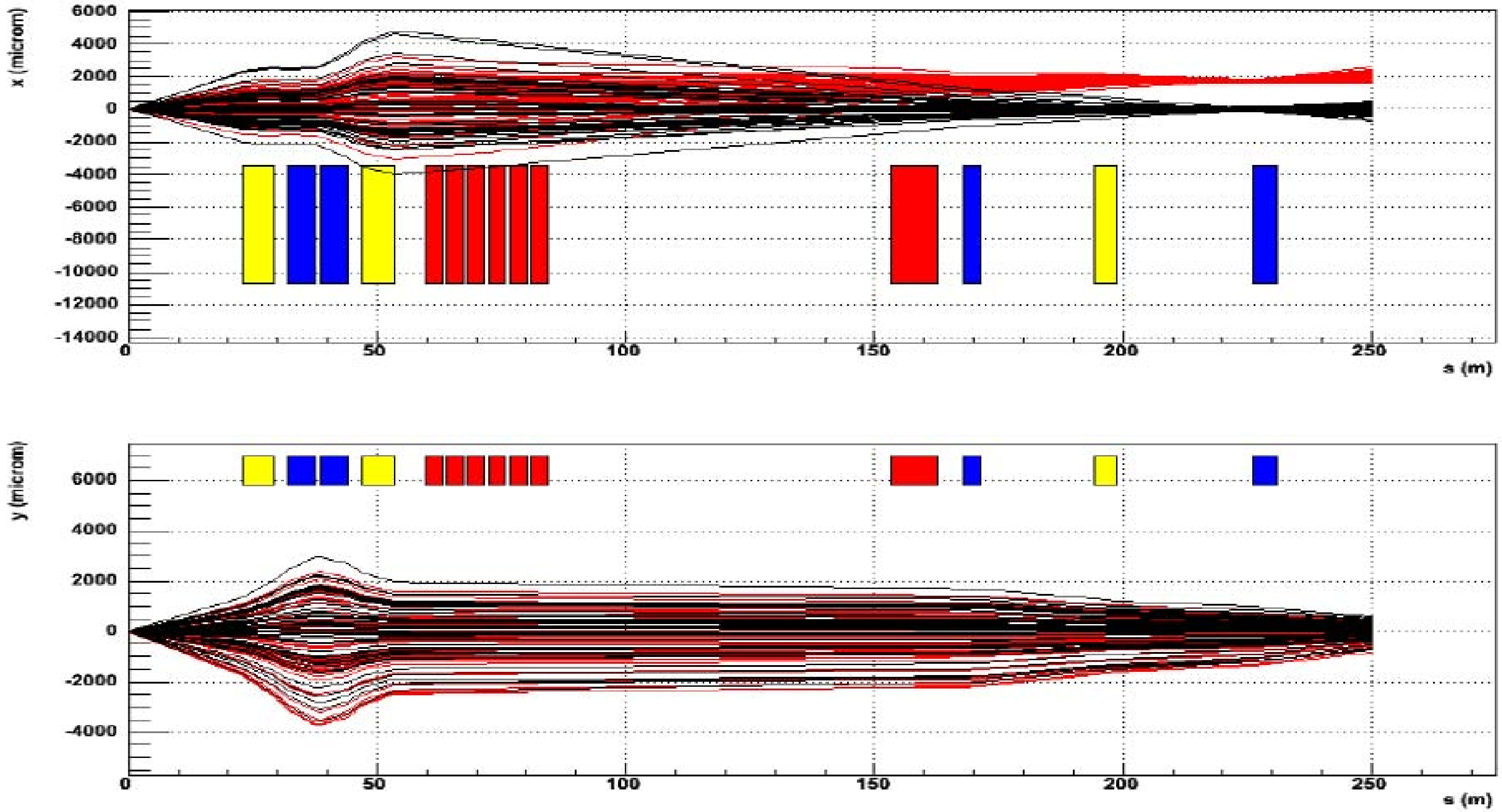
Hector allows :

- the simulation for thousands of protons really quickly ($< 100\ \mu s$/evt)
- using special/personal beam-line settings
- easy importing of the official LHC beam-line tables
- drawing the beam profile/a single proton trajectory



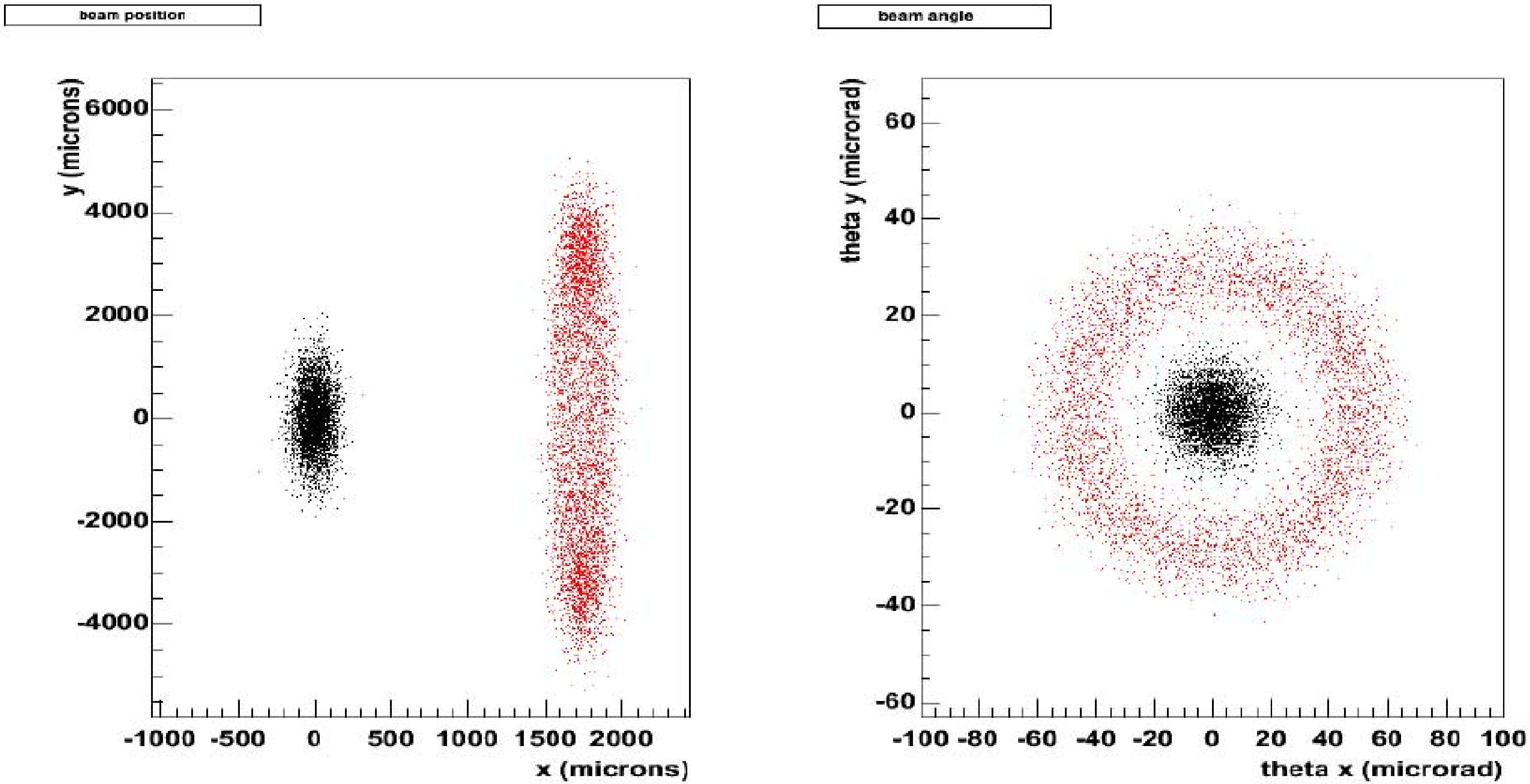
Output example (III)

The protons in red have emitted a 100 GeV gamma



Q² effects

The protons in red have emitted a 100 GeV, $Q^2 = 2\ GeV^2$ Photon ($\theta \sim 200\ \mu rad$)



Tagging two-photon interactions in HI collisions

Effective luminosity of $\gamma\gamma$ collisions is high, especially for *ArAr* case at LHC (comparable to *pp),* and two-photon production is enhanced ($\sim Z^4$), due to coherence, with respect to pomeron-pomeron case

⇒ LHC optics in Heavy Ion mode similar to the *pp* one, hence assume <u>same</u> tagging range $0.1>x>0.01$

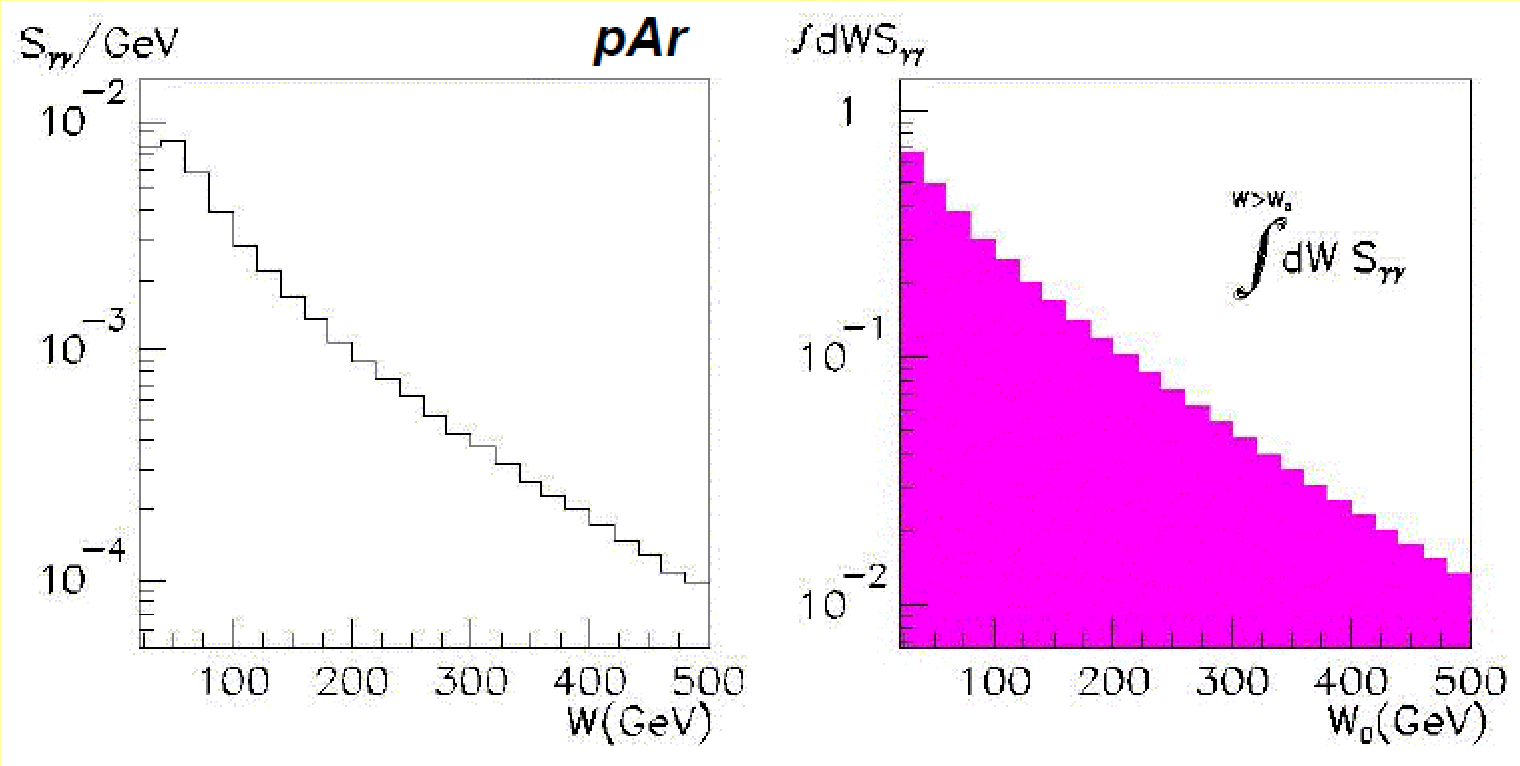
This has two consequences:

- Tagged *W* values are very large and corresponding luminosity is small (coherence loss), e.g. for 140 TeV beams *W* range is approximately 4-25 (0.5-25) TeV for double (single) tagging

- Intrinsic HI beam divergence results in large p_T smearing, much bigger than typical values for two-photon events

Tagging $\gamma\gamma$ interactions in HI collisions II

More exciting is possibility of measuring very forward protons in *pA* collisions - in such a case full signature of $\gamma\gamma$ events is recovered (for single tags)



At W = 100 GeV $S_{\gamma\gamma}$ is almost 100 bigger than for *pp* case, i.e. one needs 'only' 300 pb^{-1} *pAr* sample to achieve similar $\gamma\gamma$ statistics

FP420 changes the situation – tagging of a couple of per mille energy losses makes the coherent zone accessible (for not too heavy ions as *Ar* or *Ca*), i.e. (single-)tagged photon-photon collisions in ArAr case.

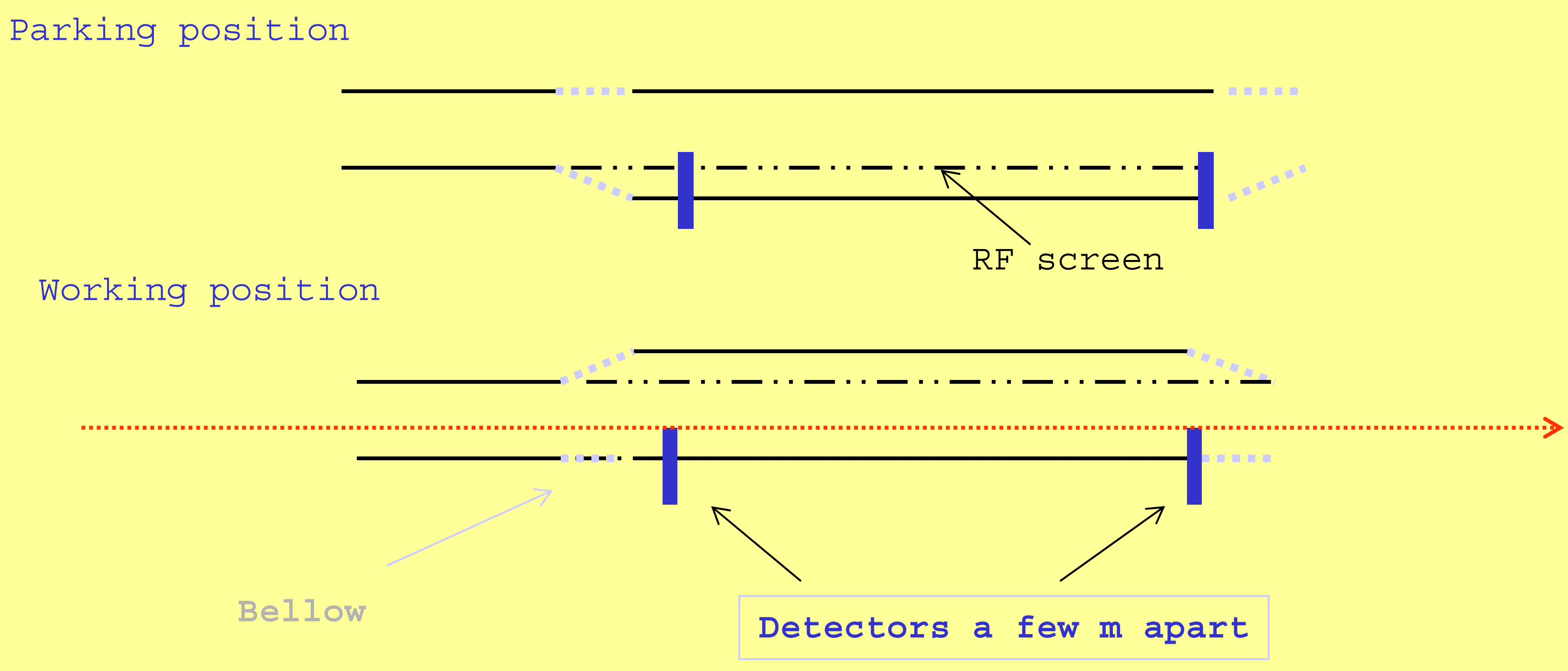
Remark 1: Tagged photon-ion and diffractive physics in ion collisions opens up.

Remark 2: Running FP420 during very high luminosity *pp* collisions will be very tricky, whereas there is 2-3 months/year of running ATLAS/CMS with ion collisions.

Ion collisions should also be considered in preparation of the FP420 proposals

A remark/addition to the discussion on the mechanical solution for the FP420 case

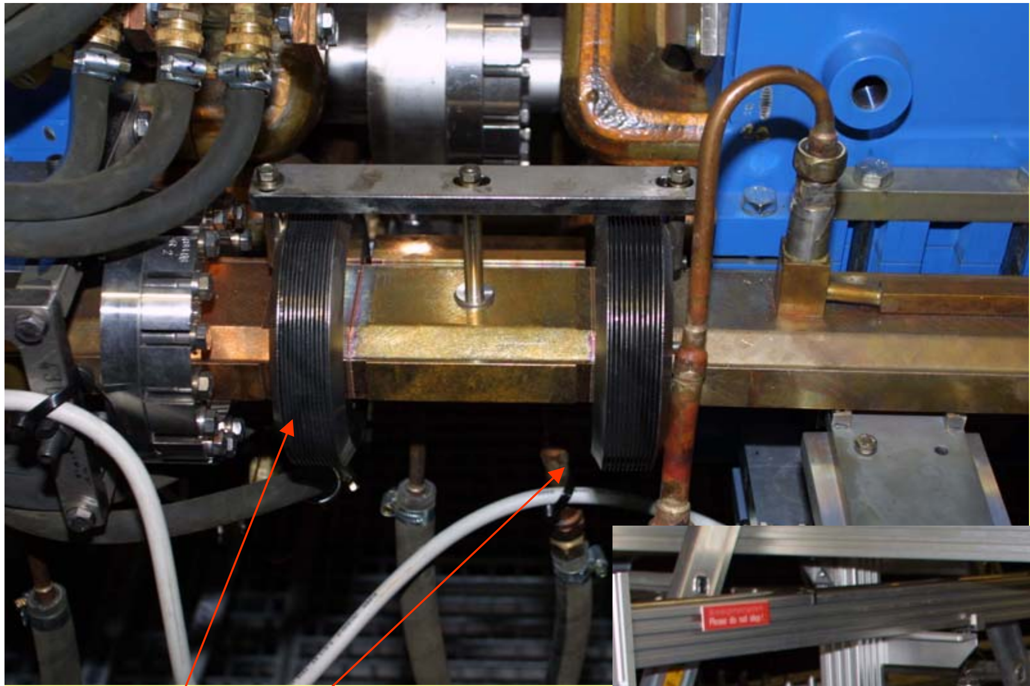
HERA tagging method (at the electron beam) without proper RPs – using a 'Hamburg pipe'!

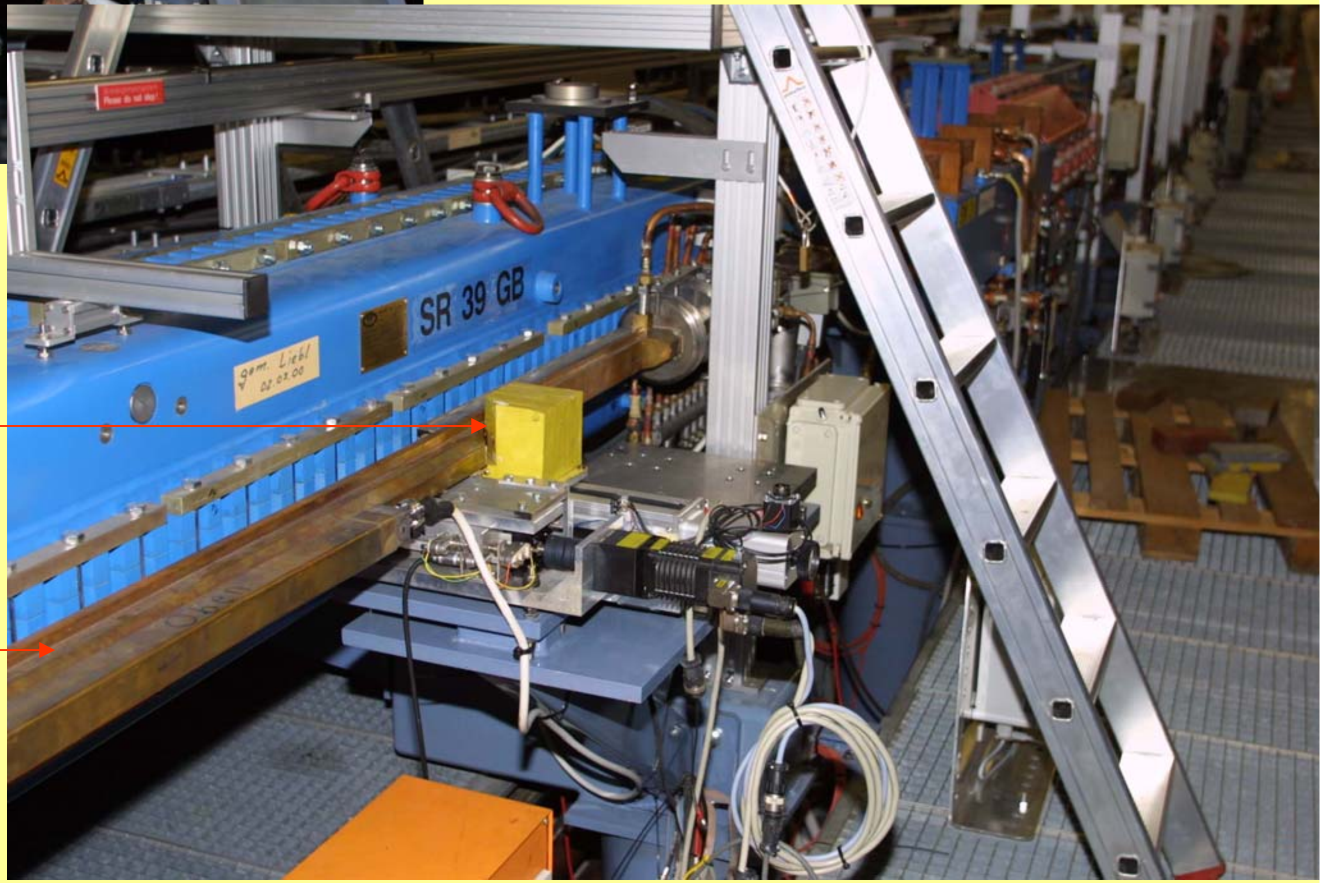


Hamburg pipe

→ Routinely used at HERA at high $\mathcal{L}$, since 1995 … :

Project leader:
Uwe Schneekloth (DESY)





bellows

detector

moving pipe