O(1%) Luminosity Measurement at LHC

Krakow-Paris Luminosity Project

M.W. Krasny, J.Chwastowski, K. Slowikowski, J. Godlewski, J Blocki

IN2P3-COPIN grant 05-117 and the POLONIUM grant 17783NJ

Presented by M.W. Krasny

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CERN, 24 April, 2008

This talk:

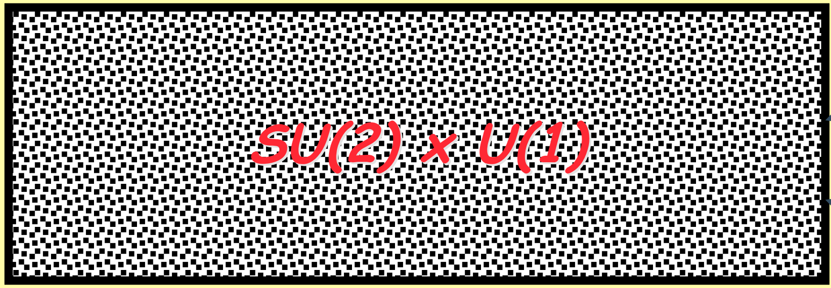
- *Why precision luminosity for LHC*
- *Point-like charges at LEP, HERA and LHC*
- *Coupling of photons to protons*
- *Seven reasons to chose intermediate pt leptons*
- *The project overview*
- *Outlook*

Why precision luminosity for LHC?

Main interest:

Generic experimental study of the phase-rigidity of the EW vacuum:

What is the nature of the SU(2)xU(1) medium?



Dedicated, precision measurement of the EW processes and consistency of their interpretation within a local QFT

Generic searches unbounded by the present QFT paradigms…

For an illustration what I mean by generic searches see e.g: M.W. Krasny, S. Jadach, W. Placzek: **The femto-experiment for the LHC: The W-boson beams and their target, Eur.Phys.J.C44:333-350,2005.**

The experimental tools of the solid state physics and (the available tools) of the elementary particle physics

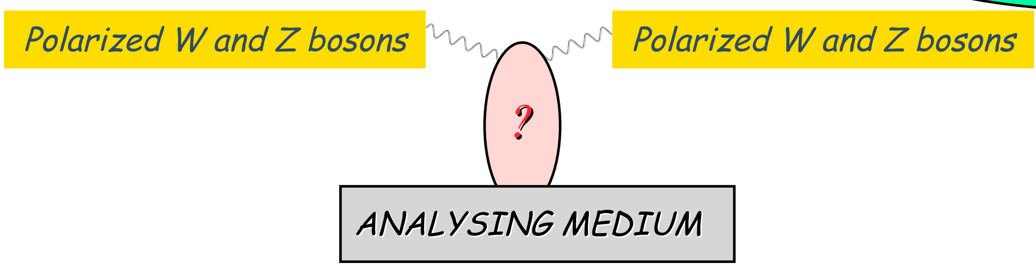
No!

- *Medium heating at „macroscopic" scales*
- *Medium modification (isotops, unpurities)*
- *External classical "gauge" field of adjustable strength and frequency*

Yes!

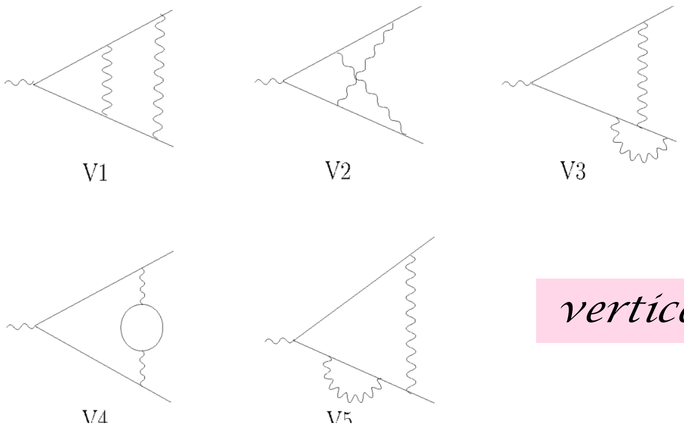
- *Local vacuum excitation using the gauge quanta of tunable polarisation and wavelength (hadronic matter as the analysing medium for "long wavelength" excitation modes of the EW vacuum)*

Precise Luminosity and its energy and beam-type dependence!

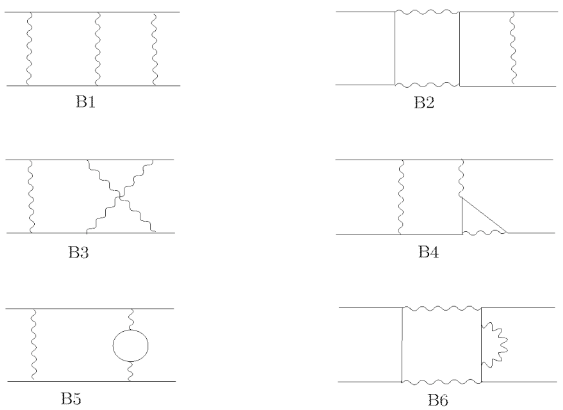


Point-like charges at LEP, HERA and LHC

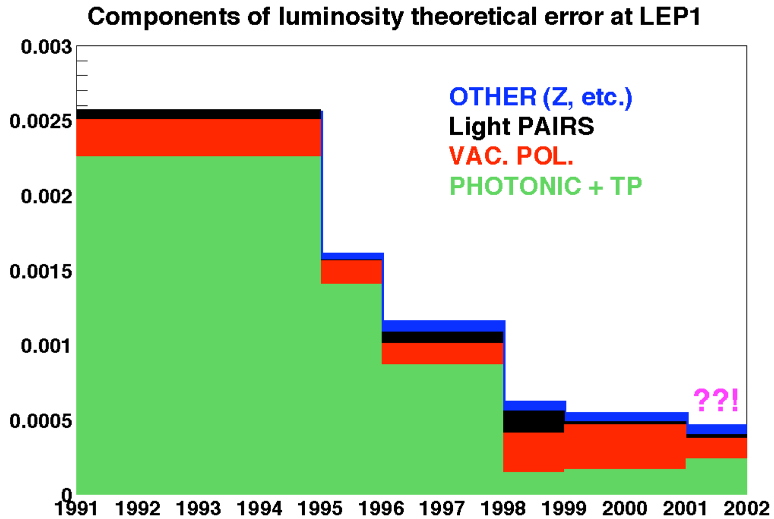
Where do we want to be? Theoretical control of processes involving point-like charges - LEP example

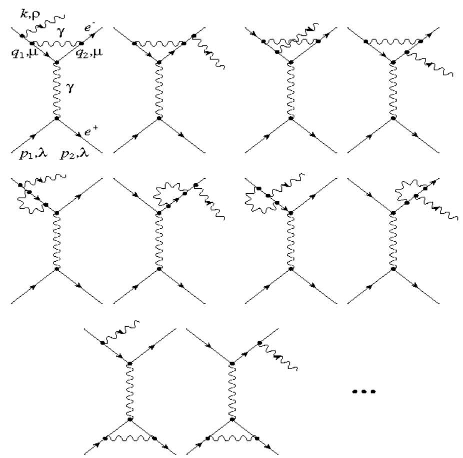


vertices



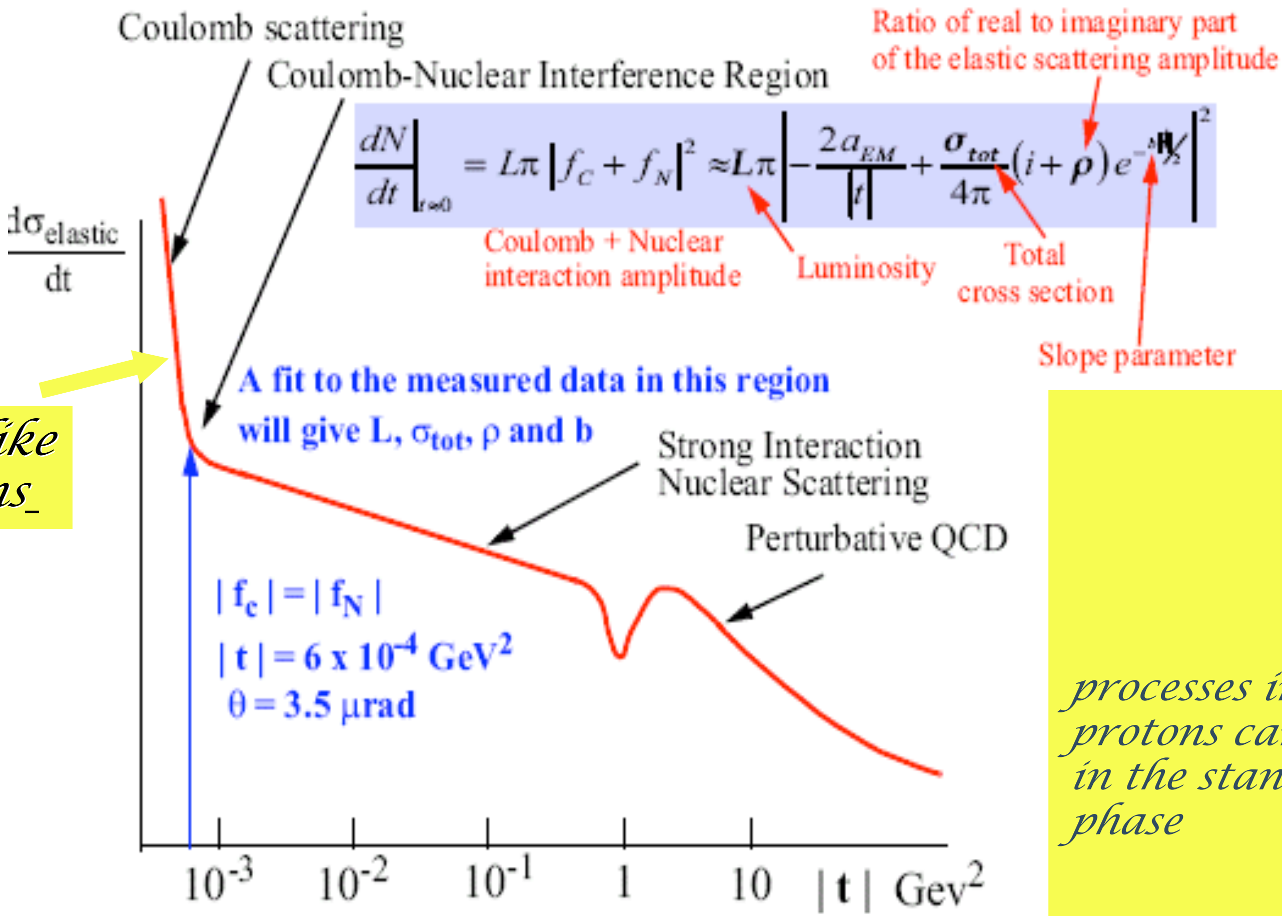
boxes





radiation

Where we are? Direct tagging of point-like protons at LHC



Point-like Protons

processes involving point-like protons can not be selected in the standard LHC operation phase

A remedy: *Point-like protons at HERA-indirect tagging*

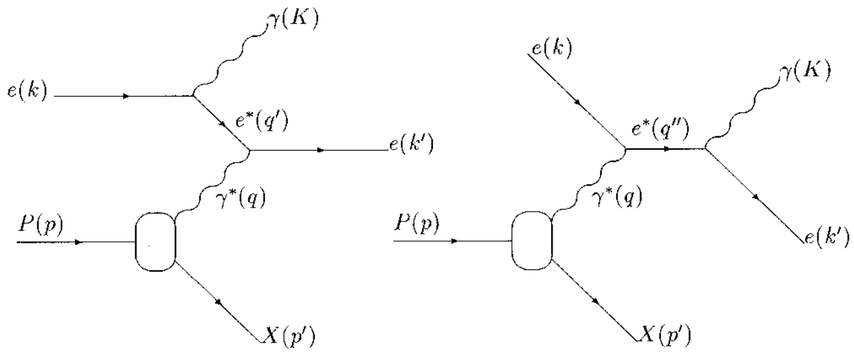


Fig. 1. The diagrams for the radiative ($ep \to e\gamma + X$) scattering

Electromagnetic processes at HERA
Z.Phys.C66:529-542,1995

DESY and H1 radiative corrections working group (coordinated by MWK 1990-1994)

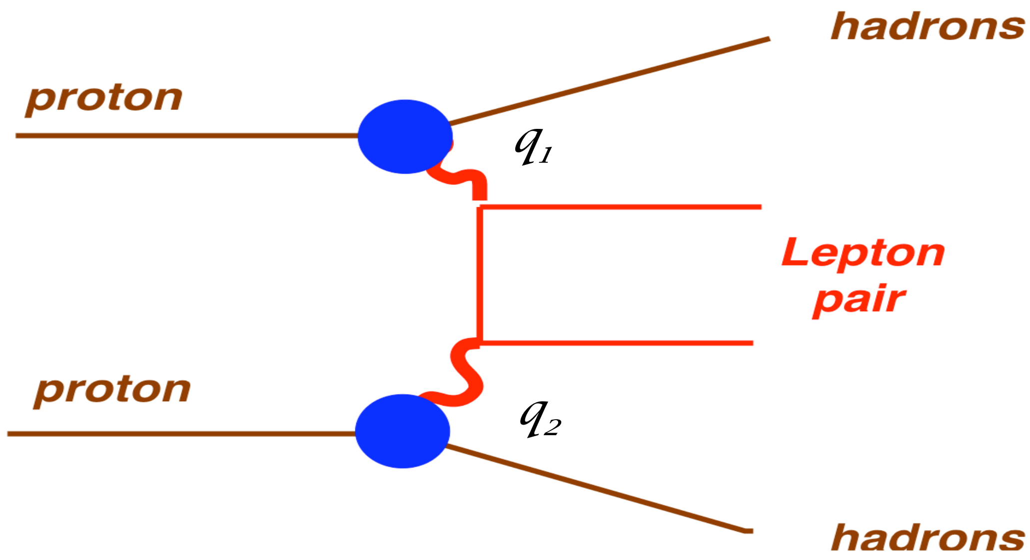
In the limit $q \to \mathbf{0}$ ($q << m_\pi$) purely elastic EM process (X=proton)

➡ *two experimental methods to control the four-momentum transfer*

- The *bremsstrahlung process* corresponding to the poles in both the virtual electron and the virtual photon propagators.
- The *QED Compton process* corresponding to the pole in the virtual photon propagator and to a large virtual electron mass.

... point like process selected exclusively using the reconstructed momentum of the outgoing photon-electron pair (photon only) ...

A ``remedy”: Unfolding of point-like proton processes at LHC



Electromagnetic coupling of the lepton-pair to protons is controlled by the presence of rapidity gaps between the lepton pair and the outgoing protons(or proton remnants) … contribution of point like process “controlled“ using solely the reconstructed momentum of the outgoing, opposite-charge leptons…

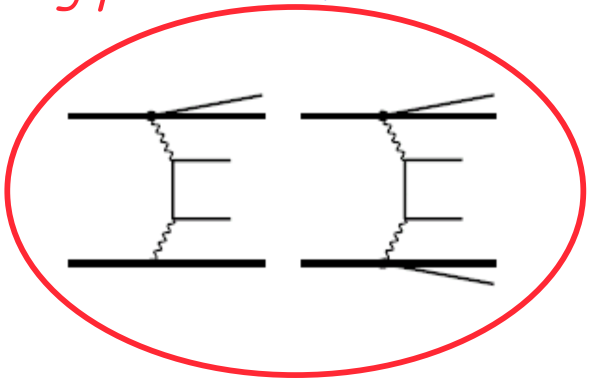
Note, the basic limitations of the “tagging” power :

Contrary to the HERA case :

1. *q_1 (q_2) are not fully constrained*
2. *Initial state strong interactions between colliding particles.*

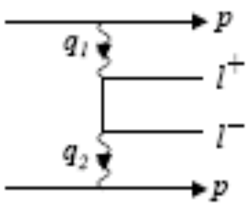
Point-like protons at LHC -indirect "tagging"

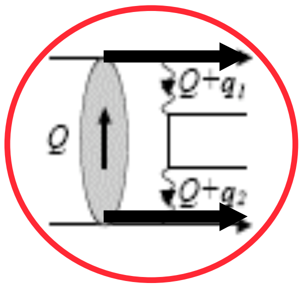
For any selected lepton-pair kinematic region one must demonstrate that the requisite theoretical precision can be achieved in the presence of the inelastic excitations of the proton and of the strong and electromagnetic rescattering processes.



→

Contribution negligible …
…or controlled theoretically
to a requisite precision





→

Contribution negligible …
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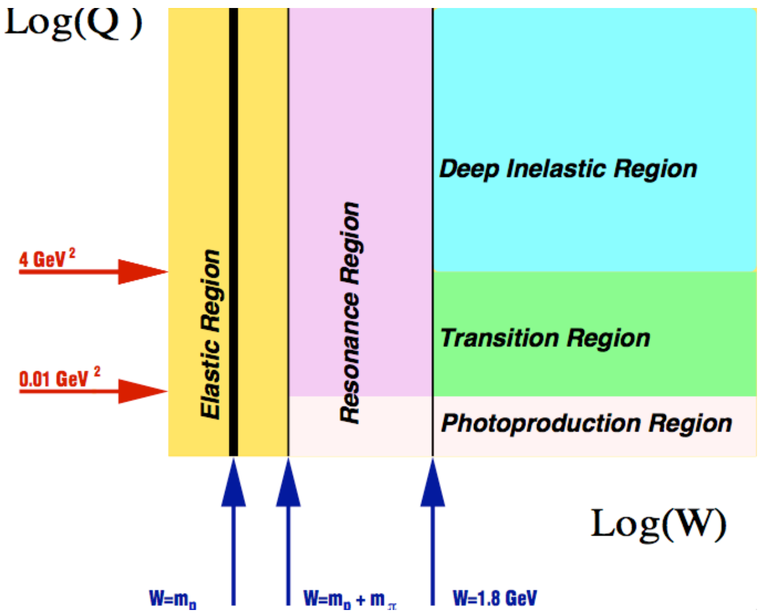
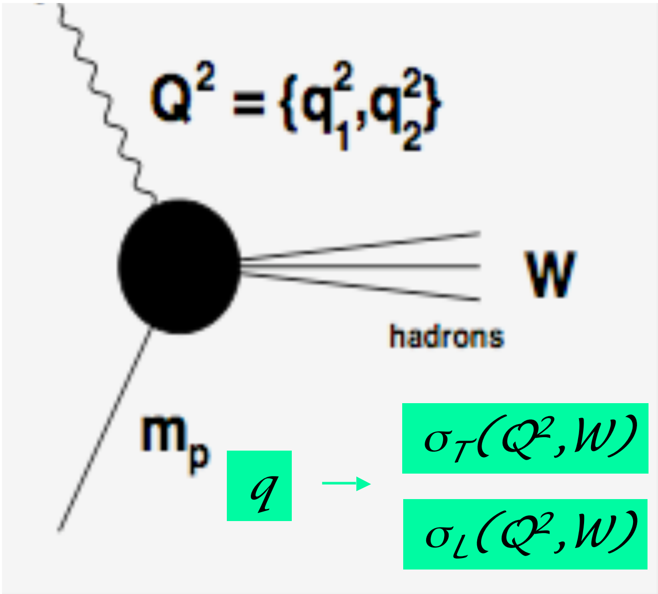
Unfolding the point-like proton contribution:

Coupling of photons to hadrons and re-scattering corrections

Coupling of photons to hadrons





→ *Four decades of experimental effort at SLAC, CERN and DESY to map, as much as possible, and model the full kinematical domain*

Seven reasons why we must chose centrally produced, intermediate-pt leptons

(M.W. Krasny, J. Chwastowski, K. Slowikowski, NIM A584 (2008) 42.)

Let us consider two measurement regions:

1. Case 1: p^l_t >0.2 GeV/c (central rapidity)
2. Case 2: p^l_t >6.0 GeV/c (central rapidity)

…(reasons why we want to avoid p^l_t < O(1 MeV/c) region (forward rapidities) are not discussed in this talk)

Earlier work on luminosity measurement with lepton pairs at LHC

[13] V. M. Budnev, I. F. Ginzburg, G. V. Meledin and V. G. Serbo, The possibility of applying the process pp → ppe+e− for calibration of cross-sections in colliding pp beams. Phys. Lett. B39, 521(1972).

[14] V. Telnov, On Possibility of Luminosity Measurement in ATLAS Using the Process pp → pp + e+e−. ATLAS note PHYS-94-044 (1994), unpublished.

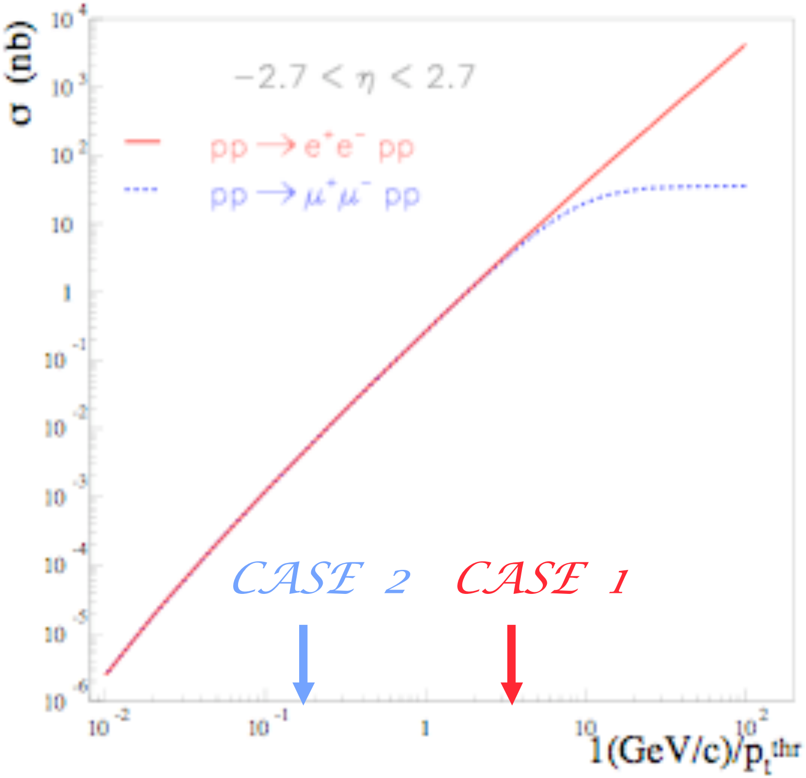
[15] K. Piotrzkowski, Proposal for Luminosity Measurement at LHC. ATLAS note PHYS-96-077 (1996), unpublished. D. Bocian, Luminosity Measurement of pp Collisions with the Two-Photon Process, PhD thesis (2005), unpublished.

[16] ATLAS Collaboration, Detector and Physics Performance. Technical Design Report. CERN/LHCC/99-14 TDR 14, (1999).

[17] A. Courau, Luminosity Monitoring of Experiments at e+e−, ep, p¯p Super Colliders. Phys. Lett. B151, 469 (1985).

[18] A. G. Shamov and V. I. Telnov, Precision Luminosity Measurement at LHC Using Two-Photon Production of μ+μ− pairs. Nucl. Instr. Meth. A494, 51 (2002).

Comparison 1: Rate and statistical accuracy



Rate difference:

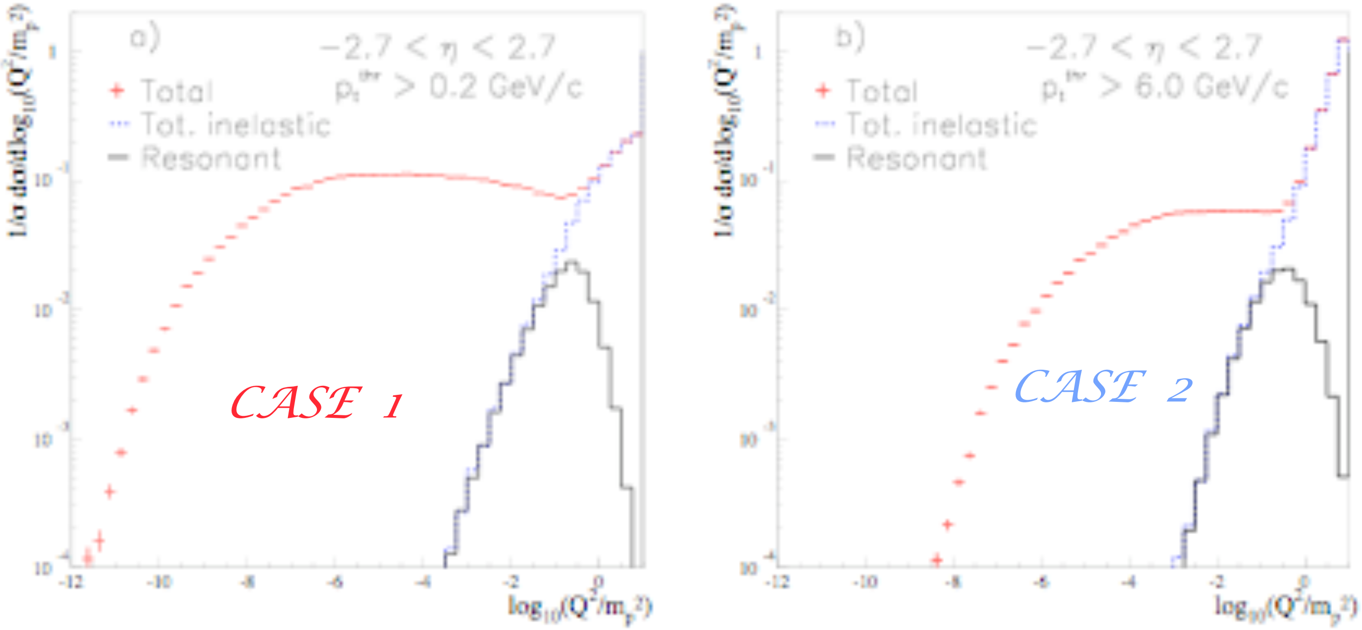
~ three orders of magnitude

(year-by-year

and/or

day-by-day luminosity)

Comparison 2: The relative size of the elastic and inelastic contributions

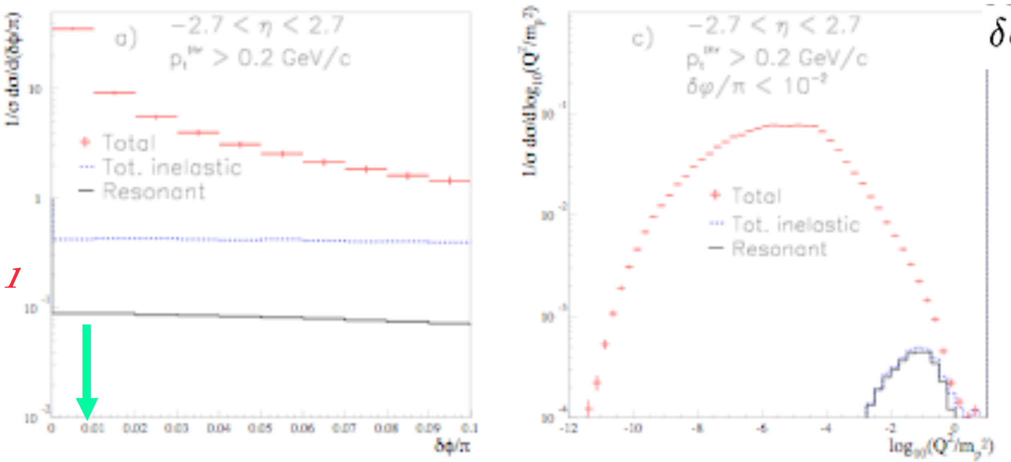


elastic.vs.inelastic contribution:

Note, the effective cut of the Q^2 spectrum (CASE 2) due to larger invariant masses of the lepton pairs (this cut affects mostly the elastic contribution)

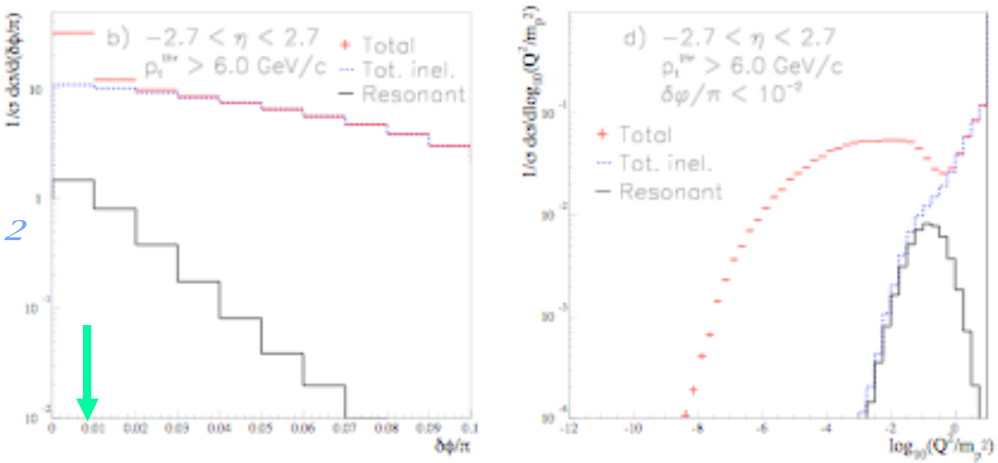
Comparison 3: The efficiency of suppression of inelastic contribution using acoplanarity cut

CASE 1

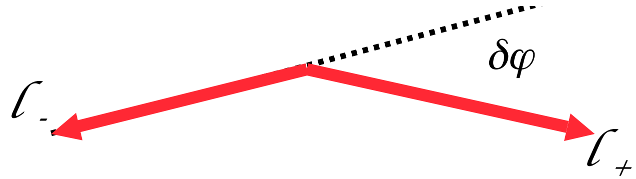


$$\delta\phi = \pi - min(2\pi - |\phi_1 - \phi_2|, |\phi_1 - \phi_2|)$$

CASE 2



$$\delta\phi = \pi - min(2\pi - |\phi_1 - \phi_2|, |\phi_1 - \phi_2|)$$



elastic.vs.inelastic contribution:

The acoplanarity cut:

$\delta\varphi / \pi < 0.01$

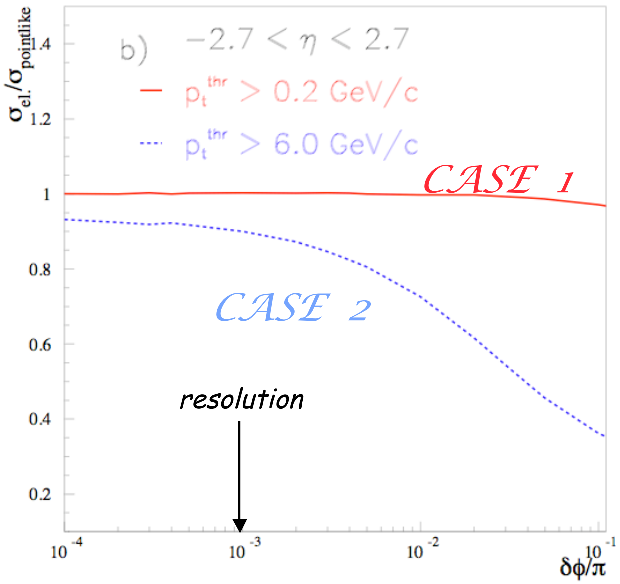
removes (<2%!!!) the inelastic contribution (CASE 1)

… but leaves sizable inelastic contribution for the CASE 2

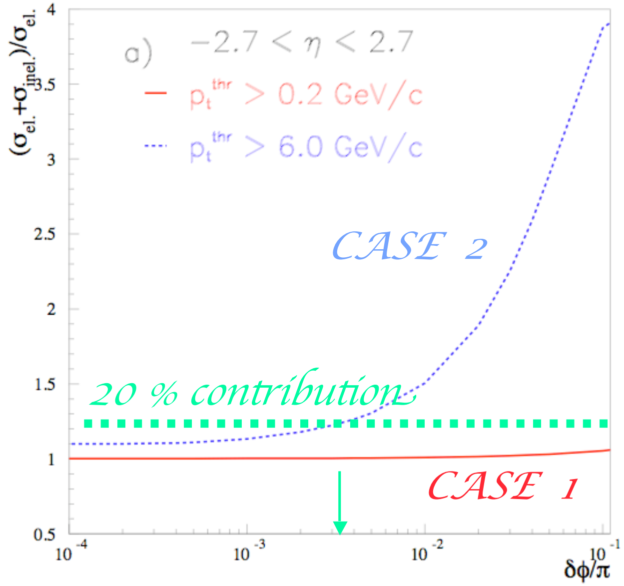
Comparison 4: Contribution of proton point-like processes

… Already a loose acoplanariry cut allows to tag point-like-proton processes in the Case 1,
in the Case 2 inelastic and dipole-form-factor driven processes contribute even for highly coplanar pairs

Sensitivity to the dipole form factor of the proton

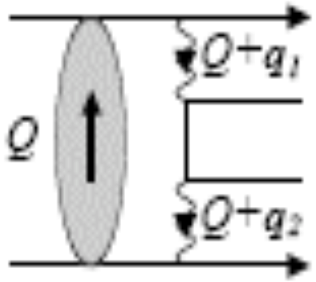


Sensitivity to inelastic excitation of the proton



Comment: Matching the precision of the proton structure modelling with the precision of the EM radiative corrections for CASE 1

Comparison 5: Estimated size of rescattering corrections

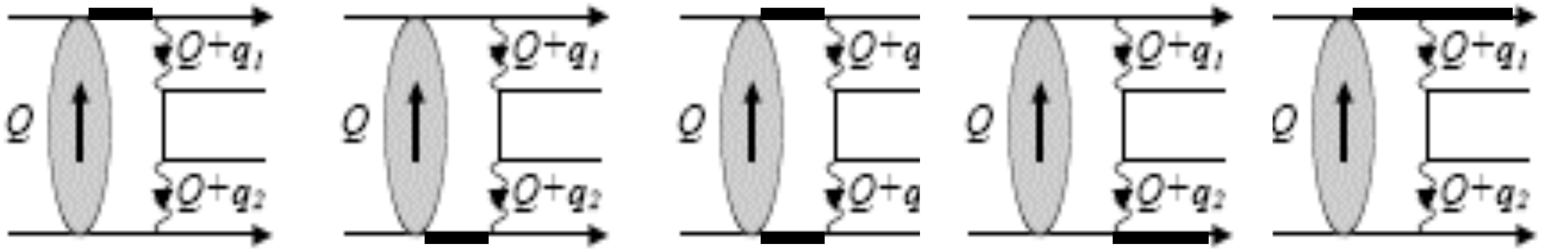


Case1:

Negligible ($<10^{-4}$)

Case2: $\sim 80mb/4\pi\, p_{t,pair}^2\, C$

~ 0,02%, 0.13%, 3.25%, 30%
for $p_{t,pair}$ = 10, 30 150, 450 MeV



, etc...

?

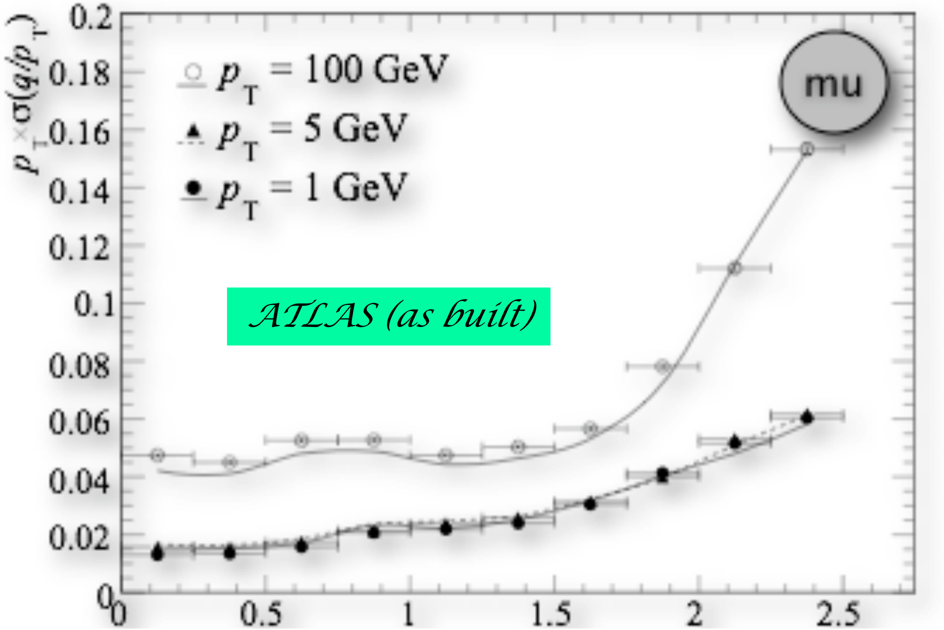
Luminosity monitors at the LHC

hep-ph/0010163 16 Oct 2000

V.A. Khoze[a], A.D. Martin[a], R. Orava[b] and M.G. Ryskin[a,c]

Note: The re-scattering corrections are highly correlated with the acceptance correction for the lepton pairs due to "exclusivity cut" (no charged particle tracks originate from the muon-pair vertex)

Comparison 6: Achievable $P_{t,pair}$ pair resolution



Case2:

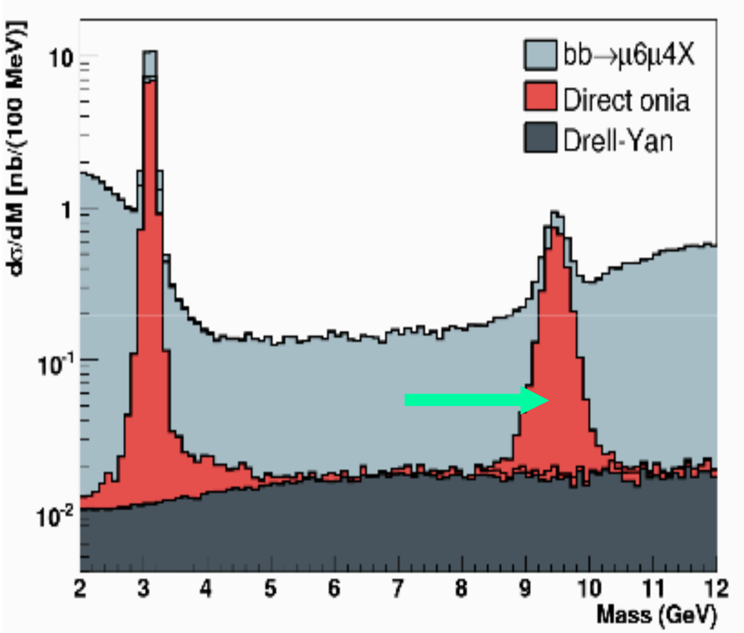
$\sigma(p_{t,pair}) \sim 140 MeV/c$

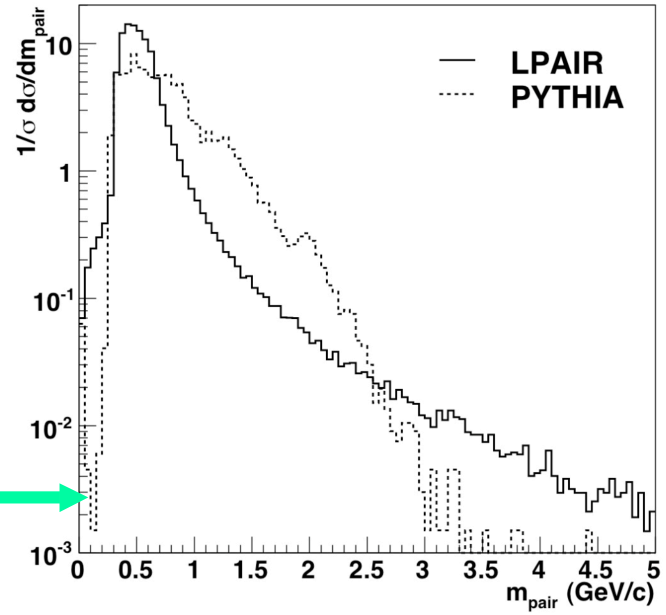
Case1:

$\sigma(p_{t,pair}) \sim 30 MeV/c$

Comparison 7: Available candles

Lepton identification efficiencies and acceptances must be determined, (time variation must be controlled) directly from the experimental data!





Case2: onia

1. Low statistics (dedicated trigger)
2. Large background
3. Transverse momentum scale must be controlled to better than ~25 MeV (4 times better than its resolution)

Case1: Dalitz pairs

1. Overlap events - abundant source
2. Clean sample
3. No need to control the transverse momentum scale - geometrical acceptance (B-field, detector position, vertex position)

At this point we concluded that there are not "a priori evident" showstoppers to achieve the precision of luminosity measurement down to ~0.4% for the CASE1 measurement region, while there are clear show-stoppers making the task of reaching the precision better than 4% for the CASE 2 extremely difficult…

…and discovered that measuring lepton pairs in the optimal kinematical region is not possible using the present LHC detectors…

→ ***"Krakow-Paris Luminosity Project"***

The project overview

Project supported by the IN2P3-COPIN grant 05-117 and by the POLONIUM grant 17783NJ. Institute of Nuclear Physics Krakow and Univ. P. et M. Curie Paris.

M.W. Krasny, J. Chwastowski and K. Slowikowski, J. Blocki

*Goal: Develop the method, the detector and the trigger system designs to achieve O(1%) absolute normalisation precision, and O(0.1%) precision of the relative normalisation of event samples taken at various energies and/or using different beam species**

1. *Selection of the optimal luminosity-monitoring physics-process .*
2. *Development of measurement strategies (absolute luminosity and relative O(1 sec) luminosity)*
3. *Specification of the detector requirements (fiducial volume, granularity , timing , etc…)*
4. *Modelling of the LVL1 trigger selection process*
5. *Specification of the HLT requirements (signal and monitoring triggers, selection algorithms , monitoring samples)*
6. *Development of dedicated methods for precision, off-line normalization of any user-defined samples of events.*
7. *Study of systematic measurement errors in the full chain of luminosity measurement process.*
7. *Detector and trigger proposal (postponed till the machine and detector operation conditions are known and …until there is an interest in precision luminosity measurement within the LHC community)*

← today (items 2–4)

The tools and techniques of simulations

Generators:

LPAIR (J.A.M. Vermaseren; S. P. Baranov et al.) - incorporating the most complete data (parameterizations) of the photon-proton coupling in the elastic, resonance, photoproduction, transition and DIS regions

PYTHIA (T. Sjostrand et al.) - proton-proton collisions involving diffractive contributions

Simulations:

Simulations of large (~ 10^8) samples of events.

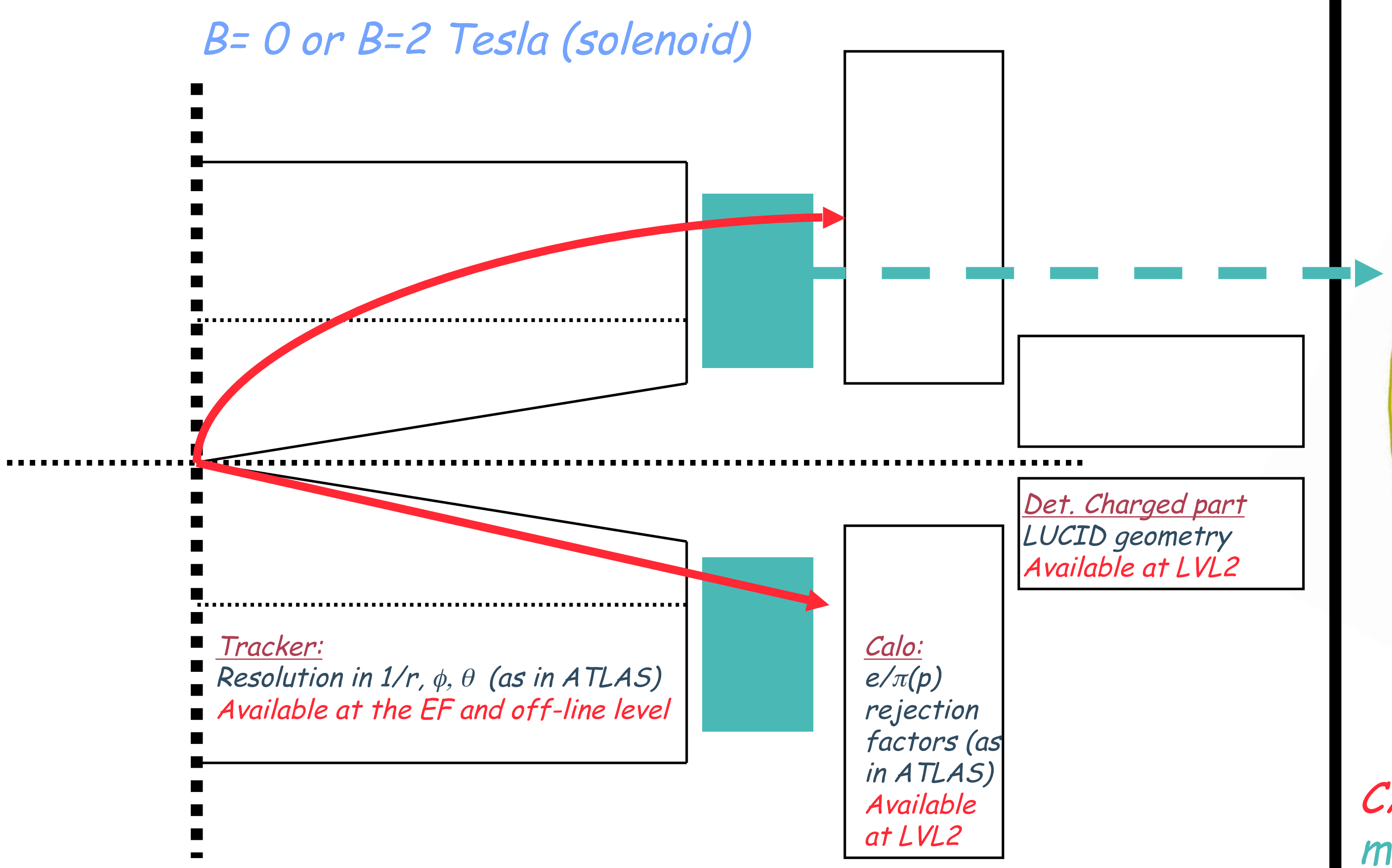
Dedicated (simplified) methods of particle tracking in magnetic field in the presence of dead material (multiple scattering, photon radiation) for particles in restricted fiducial volume →

Parameterized response of the parent detector (published ATLAS detector performance)

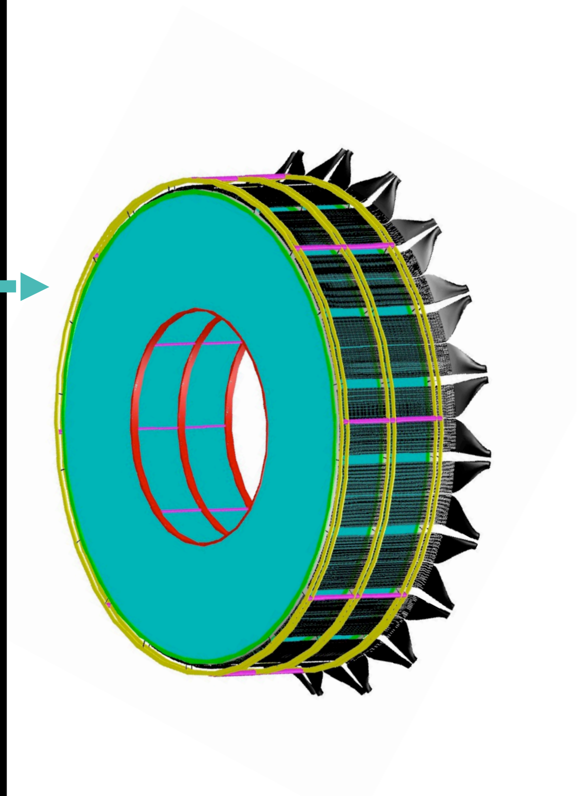
Dedicated tools to study large number of detector options (variable granularity, etc...).

Realistic simulation of bunch sizes and bunch timing.

The simulated detector set-up (not in scale)

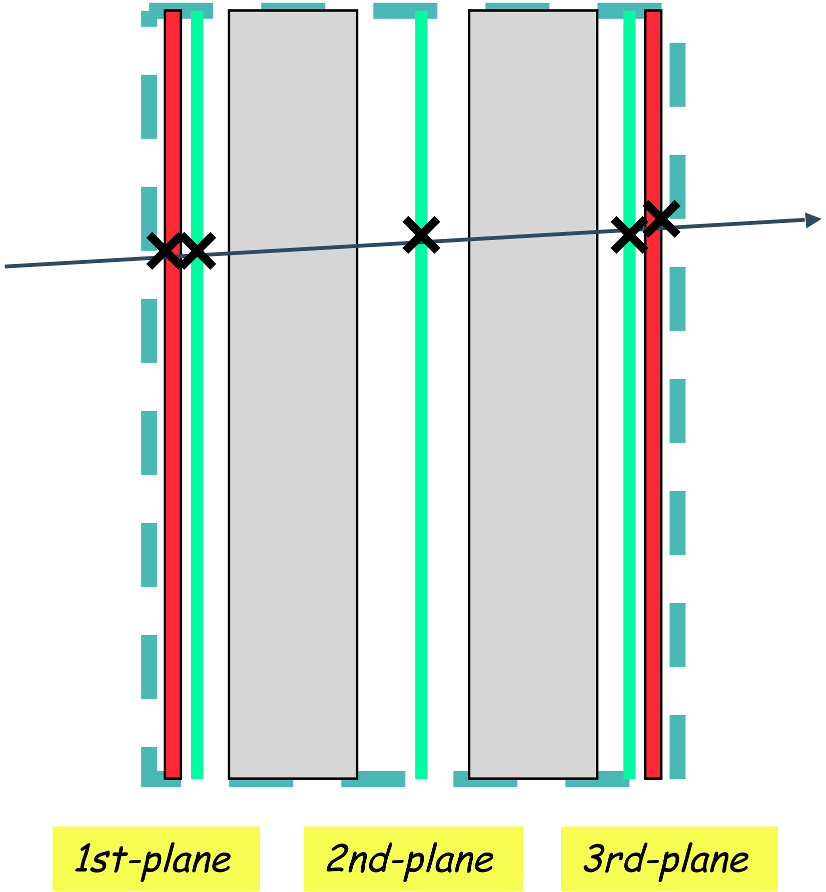


R-z plane



CAD drawing of the mechanical structure of the proposed detector

Minimal performance requirements for a proof of principle (parameter space)



LVL1

ϕ-hit plane: fine ϕ resolution, "poor" time resolution

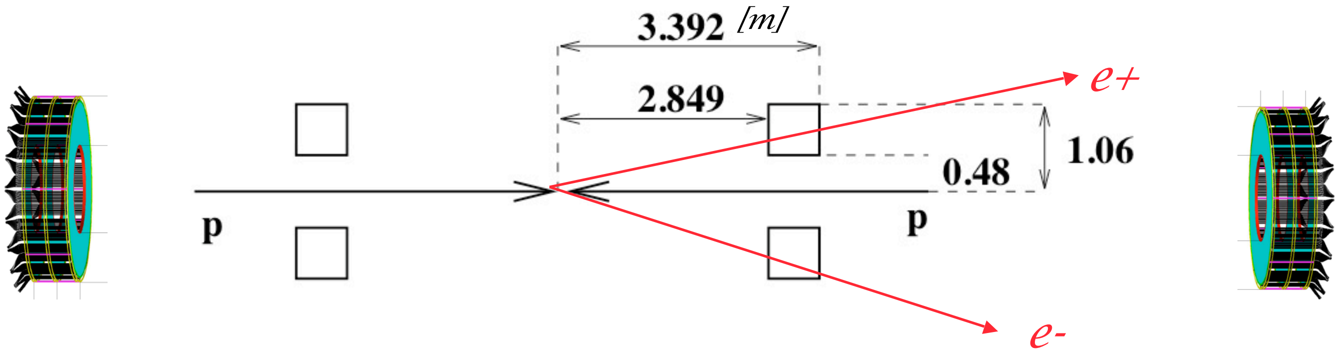
t-hit plane: "poor" ϕ resolution, fine timing resolution

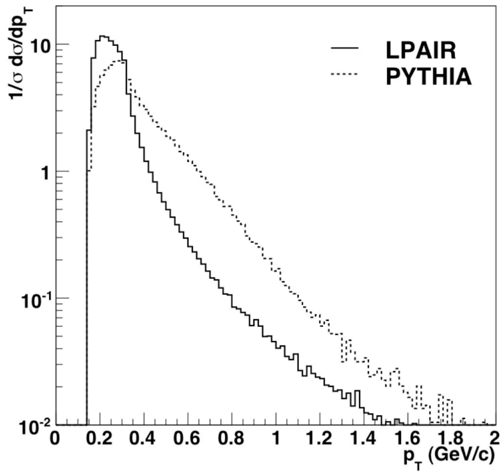
LVL2 EF

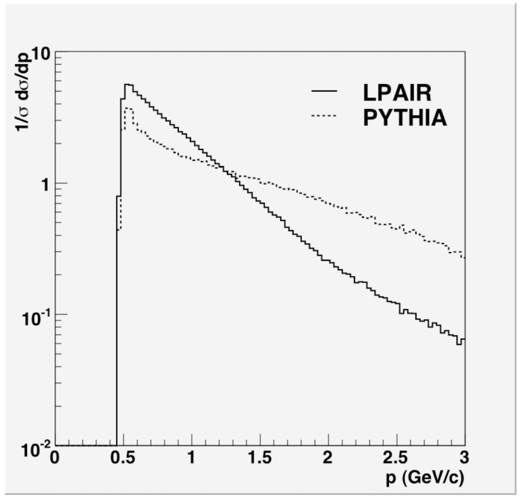
TRT-type detector with e/π rejection capacity

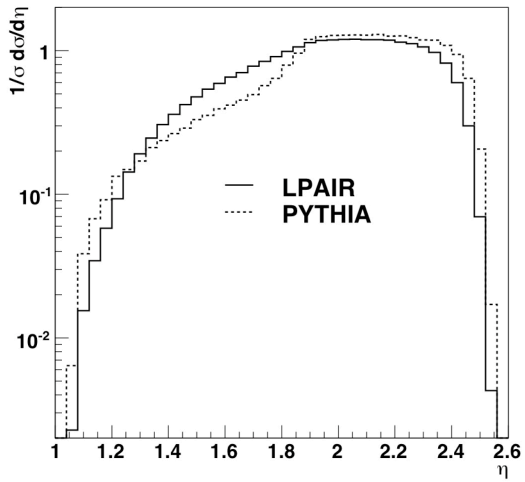
Note: Only ϕ segmentation in the minimal set-up

Fiducial volume and acceptances for B=2 Tesla



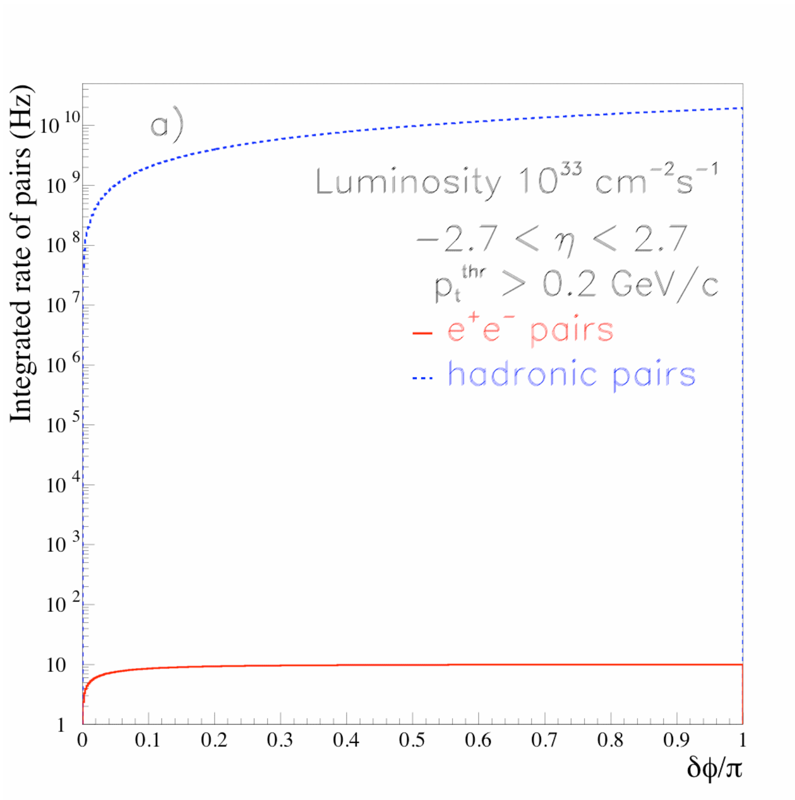






… acceptance specified by the geometry, the strength of the solenoid field, and by the beam longitudinal emittance

The challenge



pair acoplanarity

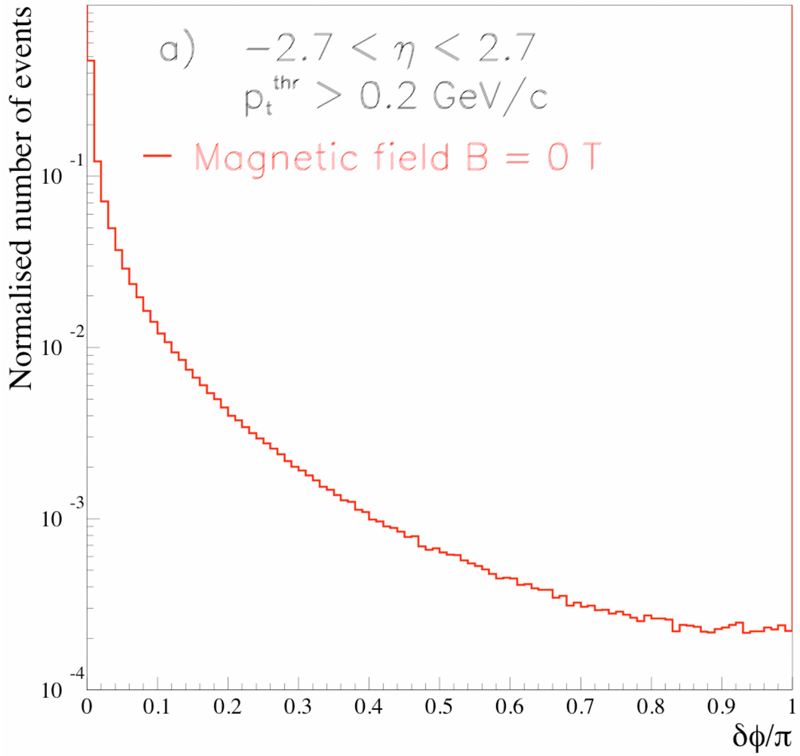
The overall rejection power of hadronic pairs of 10^{10} is required...

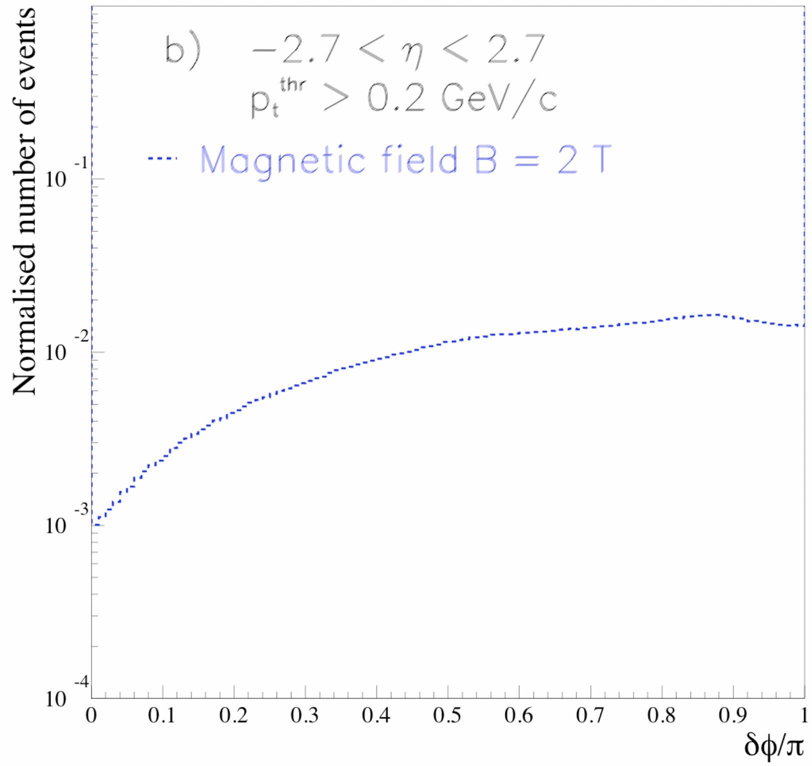
Moreover, a rejection factor of at least 10^{6} must be achieved by the LVL1 trigger, if the Luminosity events were to be collected within the host detector data acquisition chain (O(kHz) accept rate at LVL1)

…in addition

(only highly coplanar $\delta\varphi/\pi < 0.01$ pairs assure high precision)

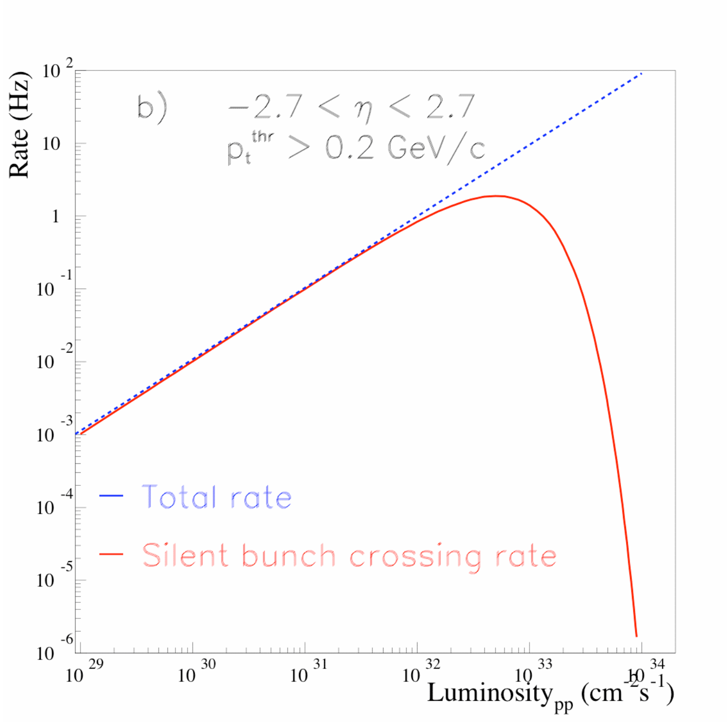
The coplanarity of the lepton pairs for B=2 T field is fully destroyed over the path from the collision vertex to the lumi-detector fiducial volume (note broad mass spectrum of accepted pairs)





The strategy

Search for the lepton pair candidates only in "silent" bunch crossings



Physics picture:

Silent Bunch Crossing = Bunch crossing with no strong interaction mediated collisions

In a real experiment:

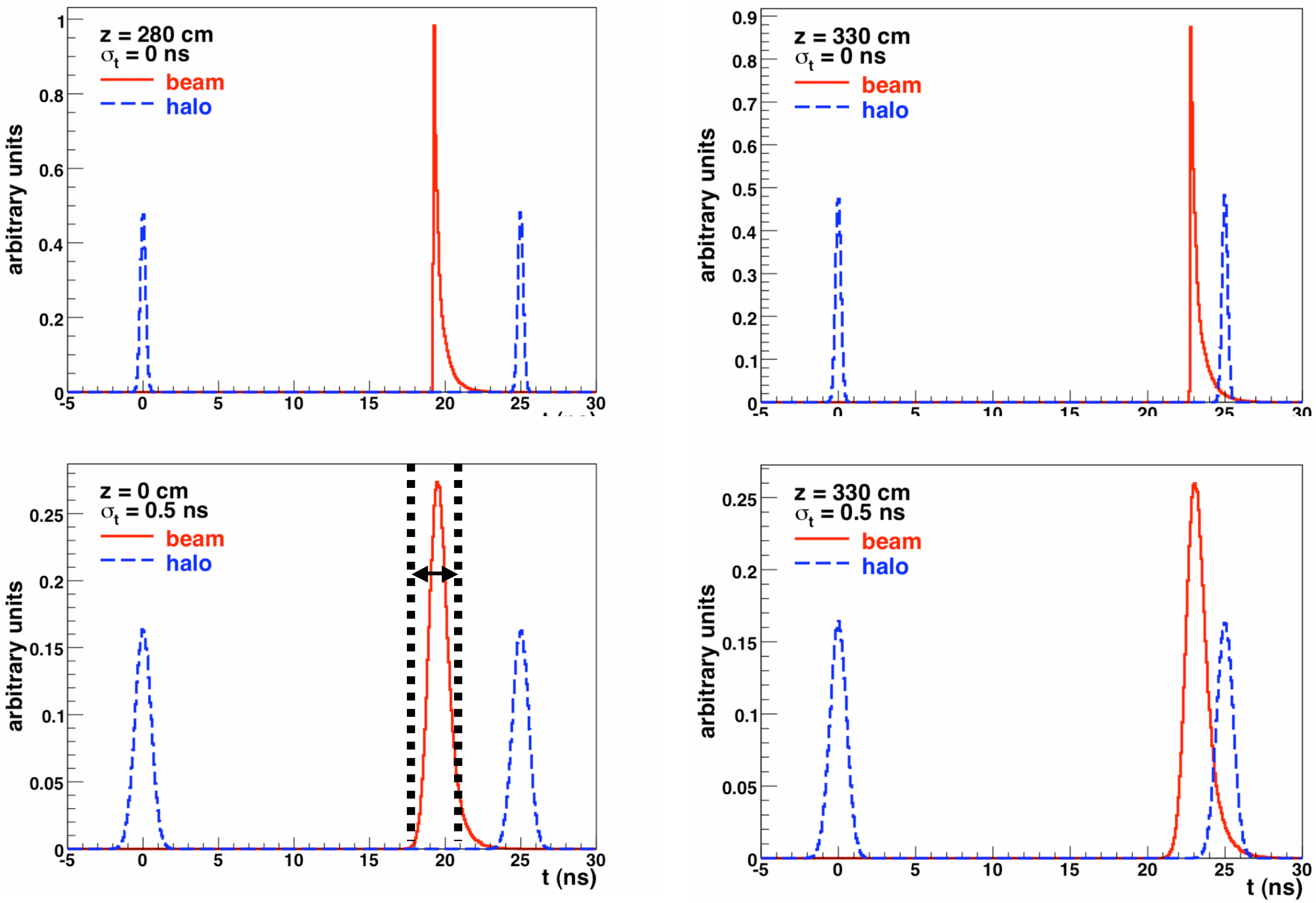
Silent Bunch Crossing (SBC)= Bunch Crossing with the number of "time-stamp validated" track segments satisfying:

$$N_{left(right)} < N_1 \text{ and } N_{right(left)} < N_2$$

The method works directly (SBC are LVL1 monitored) for $L < 2 \times 10^{33} s^{-1} cm^{-2}$

…….can be extended to higher luminosity using PACMAN bunches and/or end-run periods

Time-stamp validated track segments

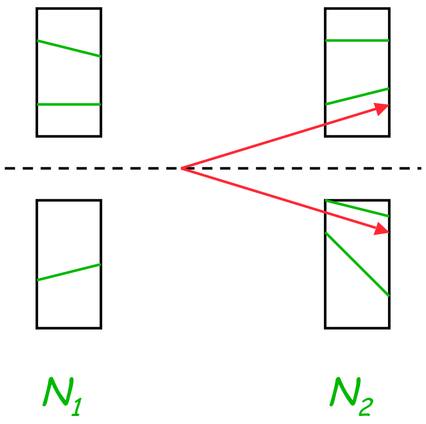


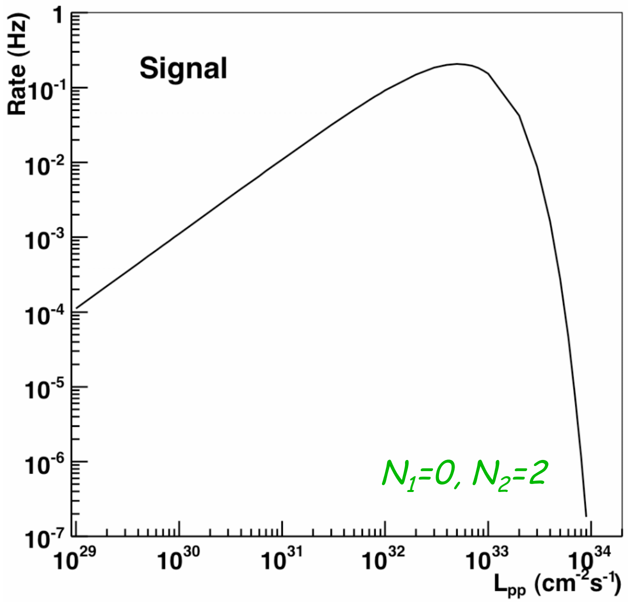
1st-plane

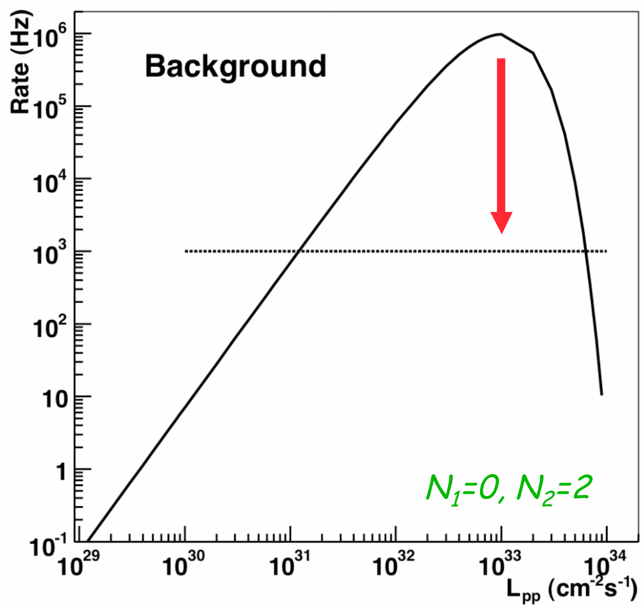
3rd-plane

The strategy - cont.

"N_1+N_2" topology of the time-stamp-validated track segments in "silent" bunch crossings

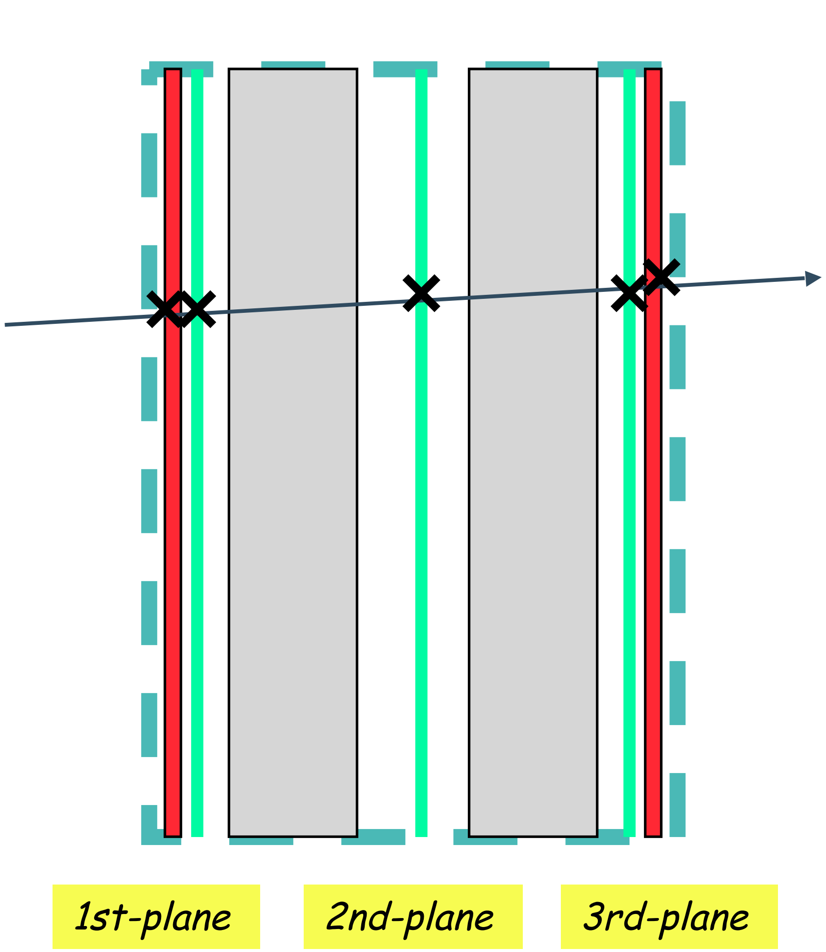






<u>Another specificity of our method:</u>
The requisite LVL1 Trigger rejection of hadronic pairs (to the level of 2-3 kHz) achieved by applying a topological cut using the time-stamp validated hits. Cuts optimized for p> 1 GeV/c, highly coplanar opposite charge particle track segments

Minimal performance requirements for a proof of principle (parameter space)



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LVL2
EF

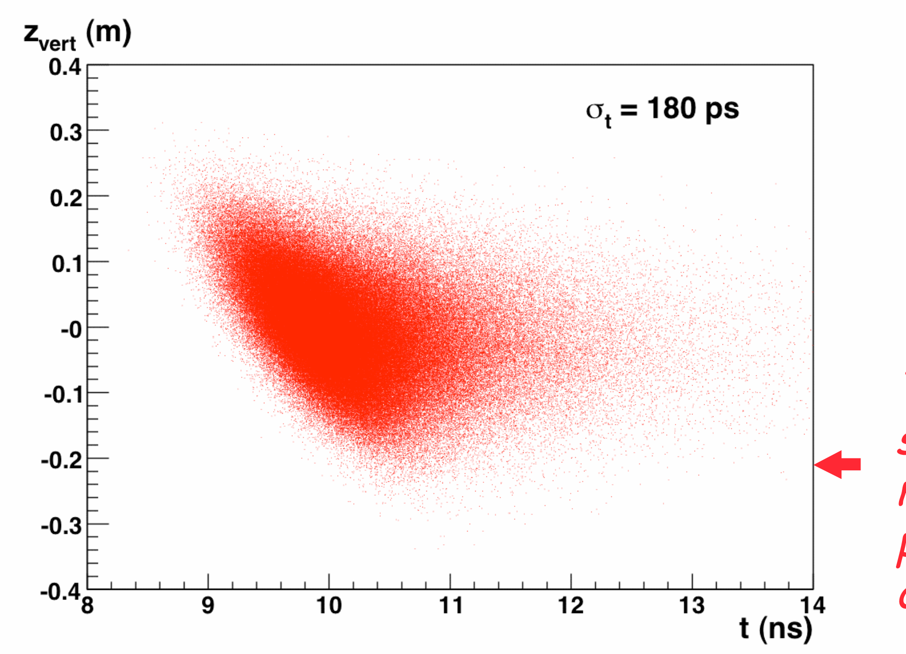
TRT-type detector with e/π rejection capacity

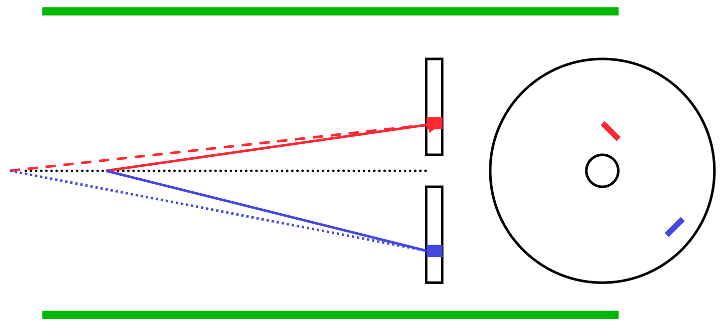
Note: Only ϕ segmentation in the minimal set-up

LVL1 trigger backtracking of coplanar lepton pairs - optimization of the ϕ- resolution

Effects affecting the LVL1 trigger back-tracking precision:

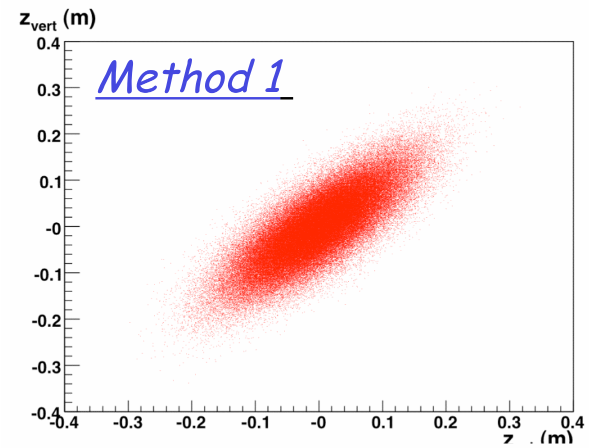
- ***ϕ- resolution, time-stamp resolution***
- *z-vertex and t-vertex smearing due to longitudinal emittance of the beam*
- *multiple scattering and bremsstrahlung in the dead material,*
- *"noise" track segments*

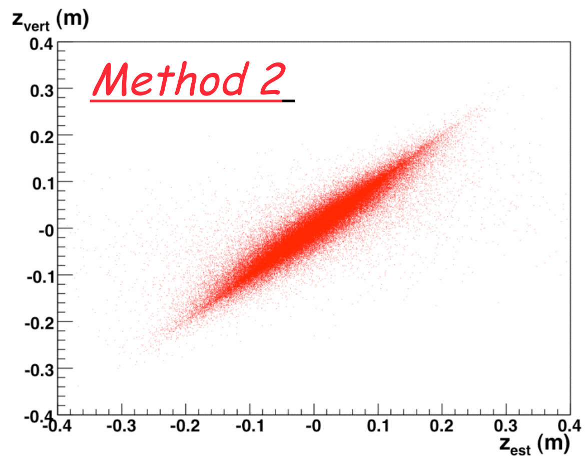


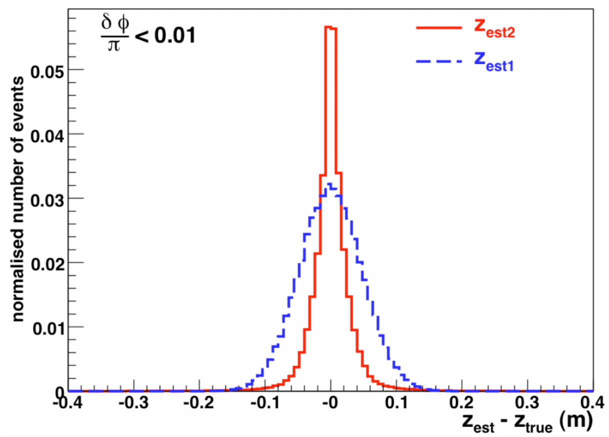


Time stamps of the lepton track segments reflect the lepton momentum (helix-length), position of the vertex, and time of collision

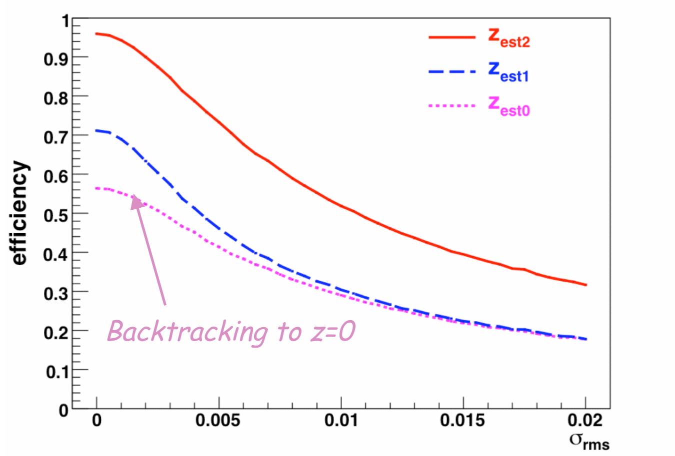
Example: Optimization of back-tracking precision - estimating z-position of a vertex







efficiency
for copalnar:
$\delta\phi/\pi$ <0.01
pairs



Φ-hit resolution [mrad]

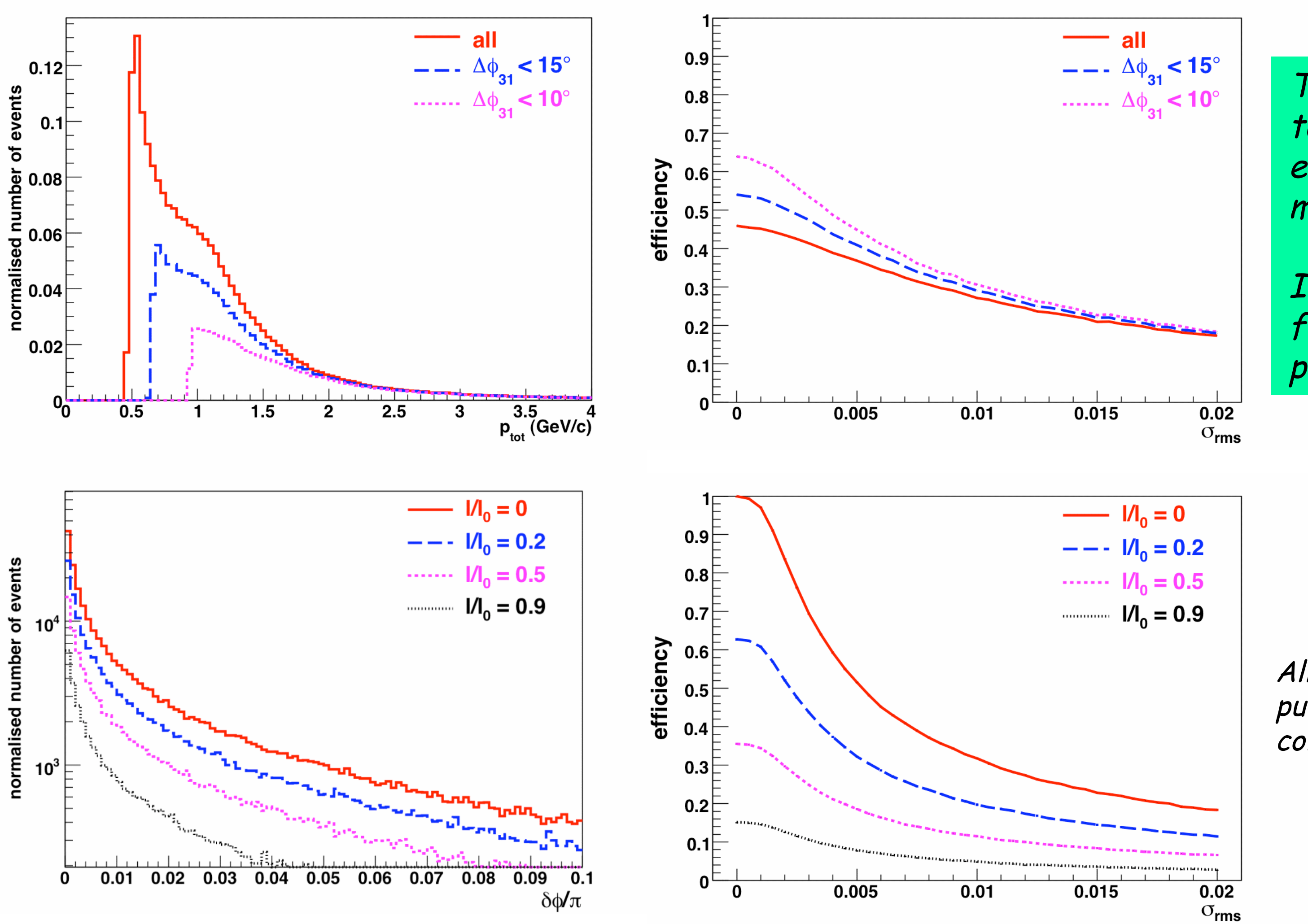
In this optimization step the following time resolution were assumed:

$\sigma(t_{hit\ 1\text{-}st\ plane}) = 100$ ps

$\sigma(t_{hit\ 1\text{-}st\ plane} - t_{hit\ 3\text{-}rd\ plane}) = 20$ ps
(only important for Method 2)

Example: Optimization of detector resolution in the presence of a dead material

(multiple scattering and bremsstrahlung)



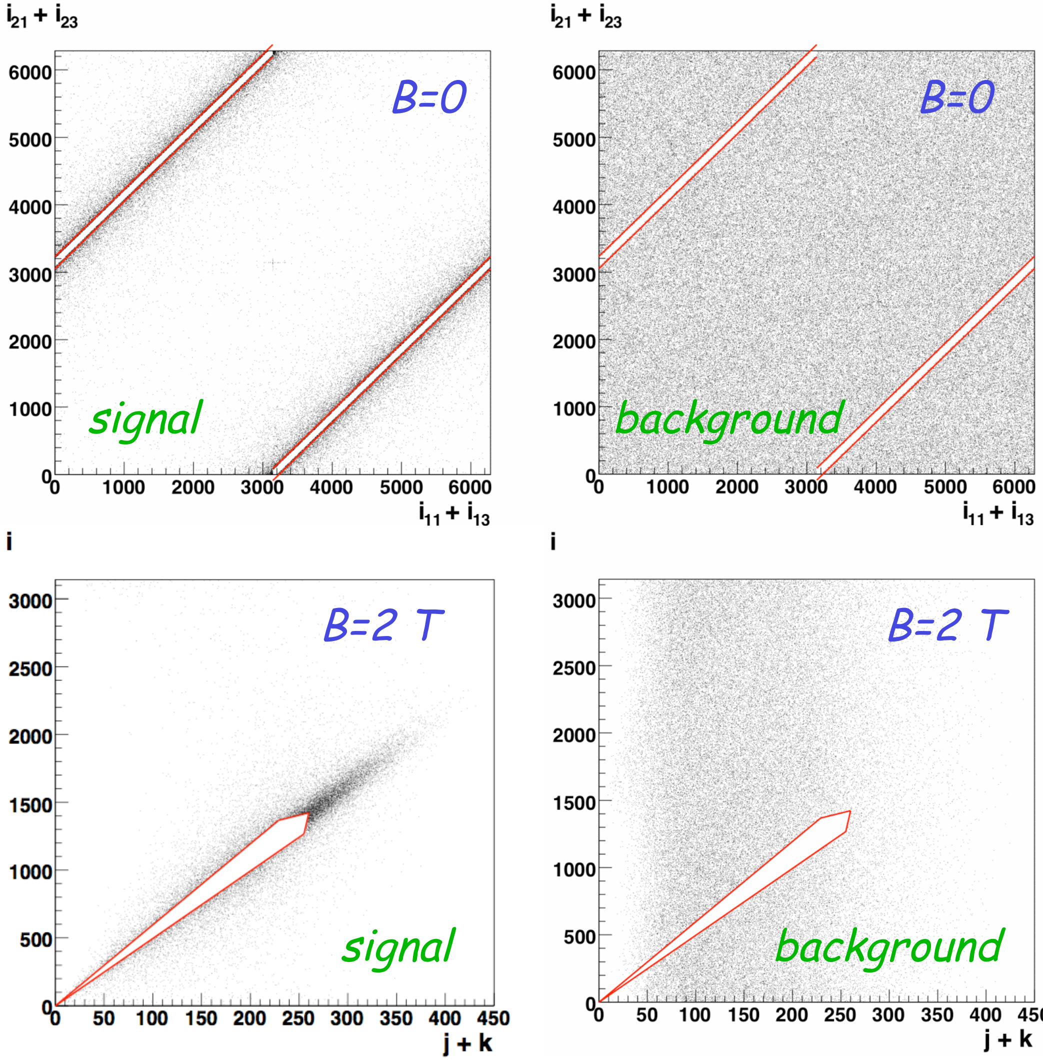
Topological means to impose the effective momentum cut!!!

Important for measurement precision

All dead material budget put in the vicinity of the collision vertex

LVL1 trigger algorithm

Example: 3124 ϕ-strips, three ϕ-hit planes; $N_1=3$, $N_2=1$, $N_{LVL1} < 2$ Hz



1.Select events with small multiplicities in the first t-hit planes $N_{left(right)} < N_1$ and $N_{right(left)} < N_2$

2.Search for the time-stamp validated track segments on the basis of hit triplets in the three ϕ–hit planes.

3.Select pairs of rigid ($\delta\phi_{13} < 10^o$) opposite curvatures track segments

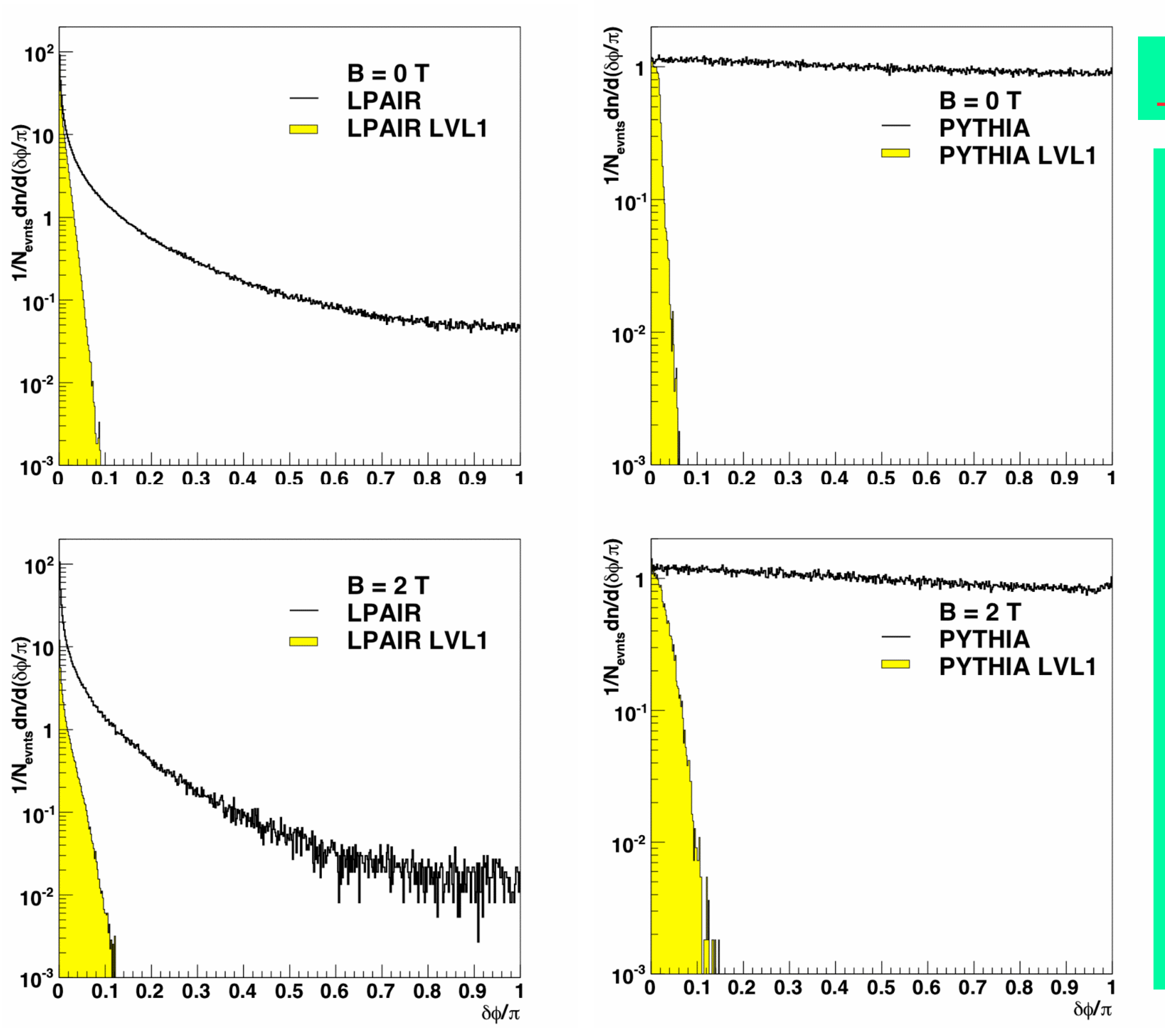
4.Compare the strip-hit combination to the look-up table (i11, i13, i21, i23)

5.If a given hit configuration is accepted on the right(left) side verify that there are no time-stamp validated segments on left(right) side

i_{mn} - particle m crosses strip i of the n-plane

$i = i_{11}-i_{21}$, $j=i_{13}-i_{11}$, $k= j=i_{23}-i_{21}1$

LVL1 trigger acceptance



<u>The "worst" case study</u>

All dead material (0.9 Xo) put in the vicinity of the collision vertex - maximal multiple-scattering and bremsstrahlung effects

No attempt to correct for the time and the z-position of the collision (detector precise-timing capacities switched off!) (7.5 cm bunch size RMS)

Host detector allows only for less than 2 kHz LVL1 accept rate for luminosity events

Example illustrating the overall event selection scheme

(minimal detector set-up, LVL1 accept rate < 2 kHz

B=0 Tesla case

LVL1

- fast lok-up table as described above

LVL2

- e/π calorimeter-rejection power 1/10, linked EM-cluster E>0.7 GeV
- no charged particle tracks in the forward detector

EF

- e/π TRT-like detector rejection power 1/10
- no charged particle tracks within the eta range [-2.5-+2.5] other than those selcted by LVL1

B=2 Tesla case

LVL1

- fast lok-up table as described above ($\Delta\phi_{13}$ < 15^o)

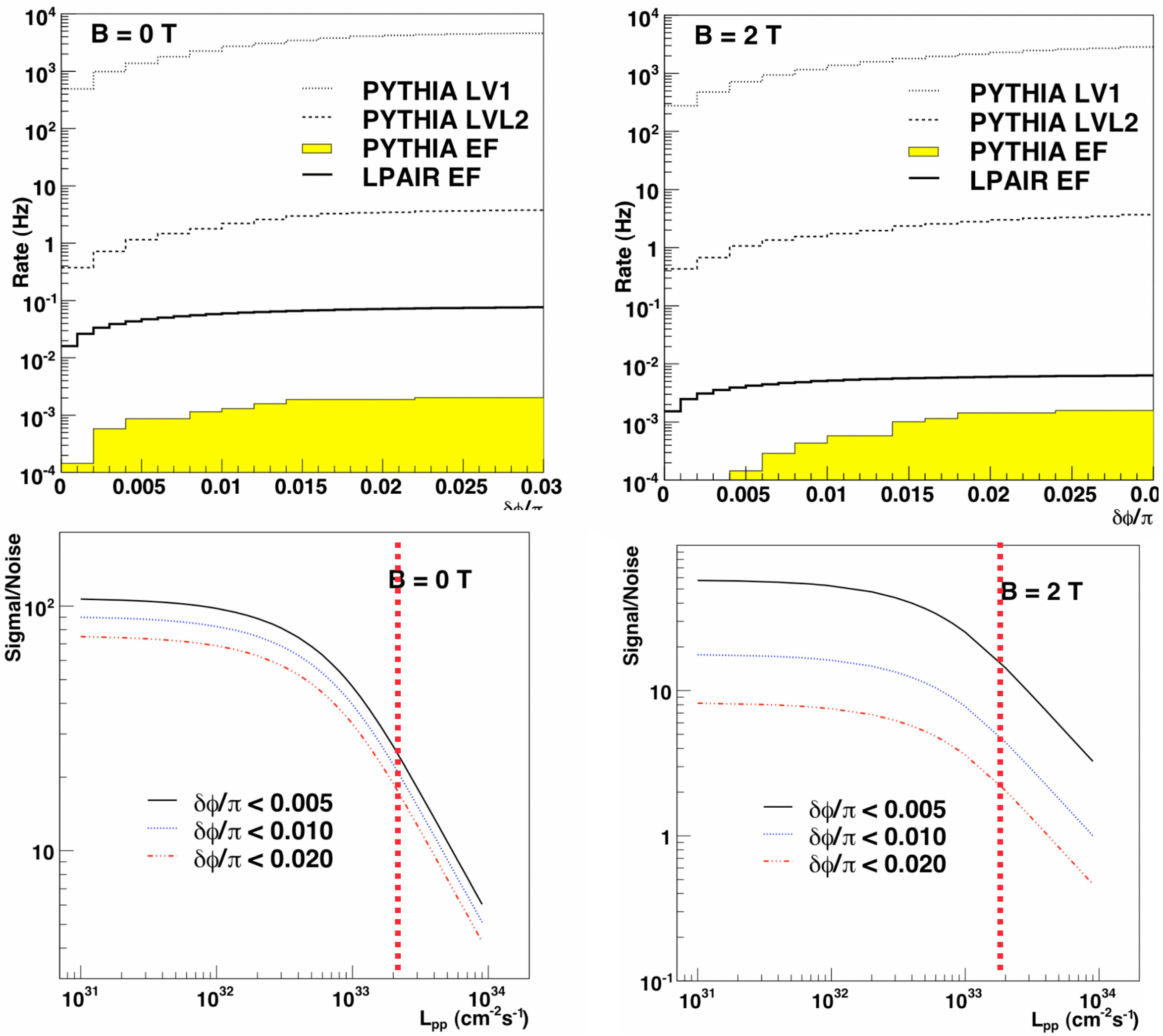
LVL2

- e/π calorimeter-rejection power 1/10
- no charged particle tracks in the forward detector

EF

- e/π TRT-like detector rejection power 1/10
- no charged particle tracks within the eta range [-2.5-+2.5] other than those selcted by LVL1
- pt_{pair} < 60 MeV/c

Signal and background *(the "worst" detector case scenario … but the "best" environment scenario - no "ghost" track segments)*



2% statistical precision for a 10 hour long machine run at $L=10^{33}\ cm^{-2}s^{-1}$ for the B=0 field configuration

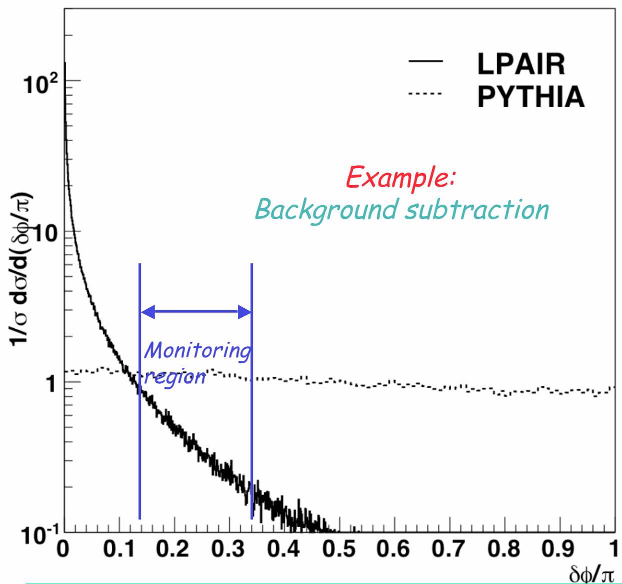
6% statistical precision per run for the B=2 Tesla field configuration (~3% for a detector with a precicse timing function and more realistic Dead-material distribution)

Luminosity measurement

$L(a.u.s^{*}) = \Sigma\,(N_s(t) - N_b(t)) * Acc(t) * eff_{pair}(t) * eff_1(t) * eff_2(t) * life(t) * EvLos(t) * P_{S.B.C}(t) / \sigma_{e+e-}$

*a.u.s = any user selected sample of events (algorithmically or lumi-block based)

Special steps taken in the proposed method to transform the observed rates into precise luminosity:



1. $N_b(t)$ verified using pileup min-bias events collected parasitically
2. ACC (LVL1) purely geometrical (residual bunch-length dependence monitored using parasitic minimum bias events)
3. Large parasitically collected samples of "tagged" electrons coming from Dalitz decays and photon conversions used to determine efficiencies and smearing corrections
4. Measurement independent of life(t) and EvLos(t)
5. $P_{S.B.C}(t)$ monitored with dedicated scalars - its lumi dependence verified using the rate of pile-up vertices

The method minimizes the necessity of modeling and simulating the background sources

Outlook

The luminosity measurement strategy , which has been developed over the last three years by the "Krakow-Paris Luminosity Project" group, appears to have a remarkable potential to become the most precise and versatile strategy for the LHC collider (for (1) the absolute luminosity, (2) its dependence on the type of the beam particle (ions)* and (3)on the beam collision energy).

The presented strategy is data-driven and is robust with respect to the MC modeling ambiguities of the background processes. It provides extremely easy method of absolute normalization of any user-defined off-line event sample.

The presented strategy cannot be realized using the present general purpose detectors. It requires a dedicated detector. Its performance requirements have been studied and are clearly specified. The optimal detector size and its position happens to coincide with the empty space within the ATLAS detector…

…but

The decisive feasibility proof and the concrete hardware realization of the project depends strongly on the real "in beam" ambient environment of the detector operation (the HERA lesson). This environment will be known only when the LHC beams will start colliding i.e. very soon.

The basic target of the necessary studies will be to determine the LHC and detector-operation "sound of silence" i.e. machine and the detector noise level, cell occupancies, and in particular the rate of spurious track segments. All that for (1)filled, (2)pilot , (3)empty bunches, as a function of bunch position within the LHC trains and bunch current … using random BC triggers.

The presented project was already immunized, with, in my view, sufficient flexibility to be adapted to a wide spectrum of the detector operation conditions.

Moreover, it could provide vital novel functionalities (bonuses) to the host detector…