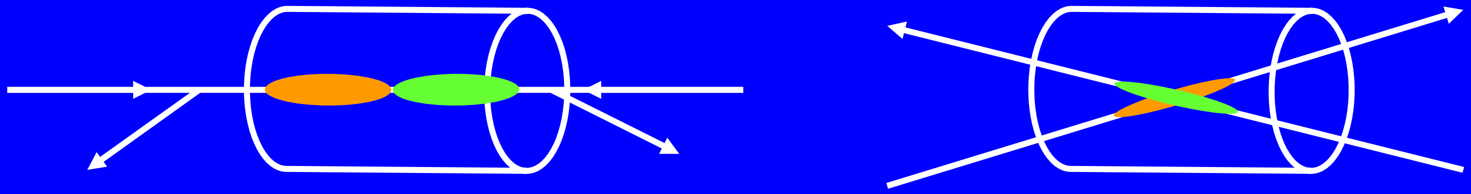
Physics and collider motivations for small crossing-angle IR

Philip Bambade
LAL-Orsay

Mini-worshop of small x-angle design challenges

Orsay & Saclay, 19-20 October 2006

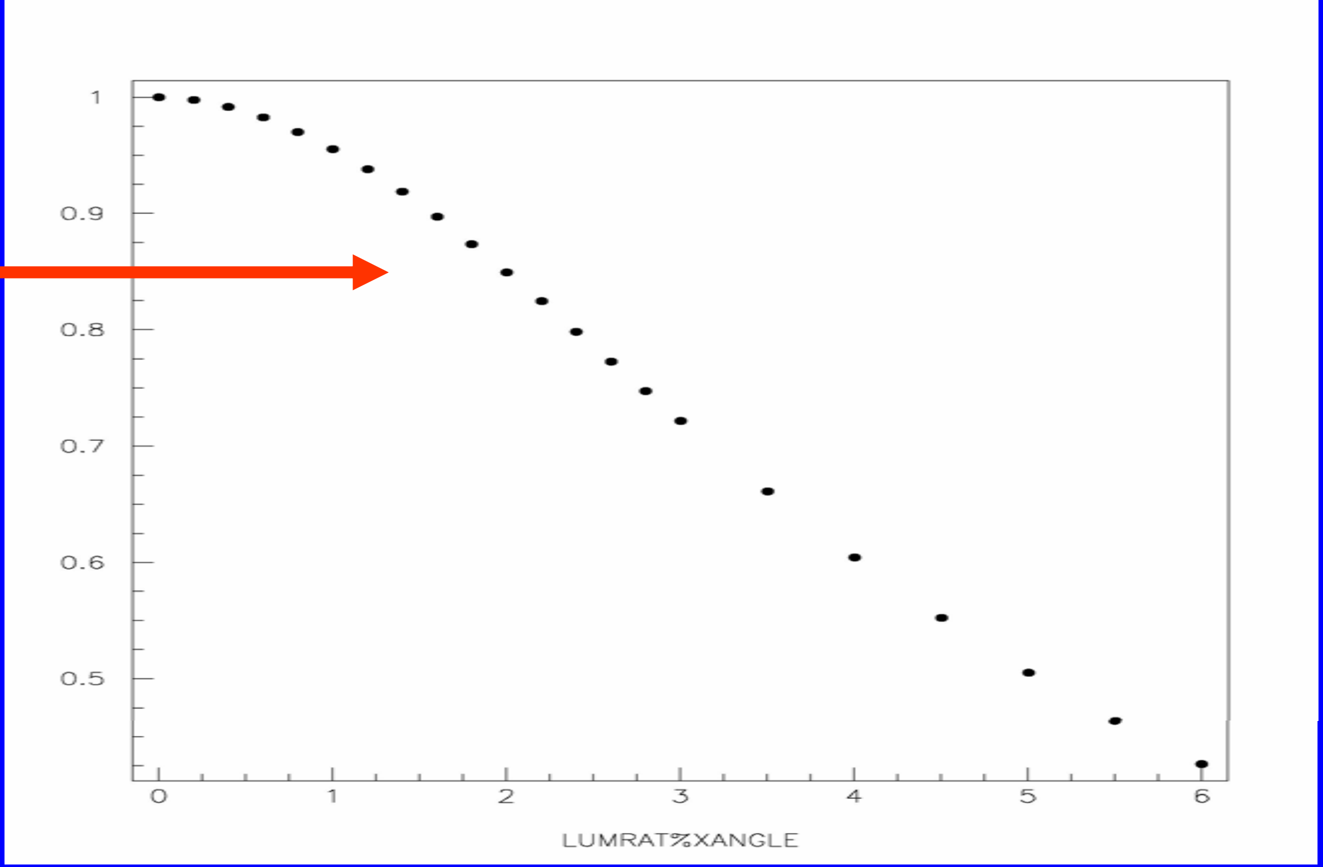
Collider motivations



	very small 0 – 2 mrad	large 14 – 25 mrad
injection & extraction	• shared magnets ⇒ coupled design	• separate channels
challenges & remedies	• post-IP losses → careful optics & collimation → large magnet bores → electr. separators	• large $\mathcal{L}$ loss : $< x\, z >$ → crab-crossing (R&D) • non-axial in solenoid → DID / anti-DID & post / pre-IP bumps
approach & risks	• preserve pre-IP beam • reflected background	• emphasize post-IP beam • adds pre-IP constraints

Both are valid viewpoints which can work…

Luminosity loss without crab-crossing (perfect conditions)



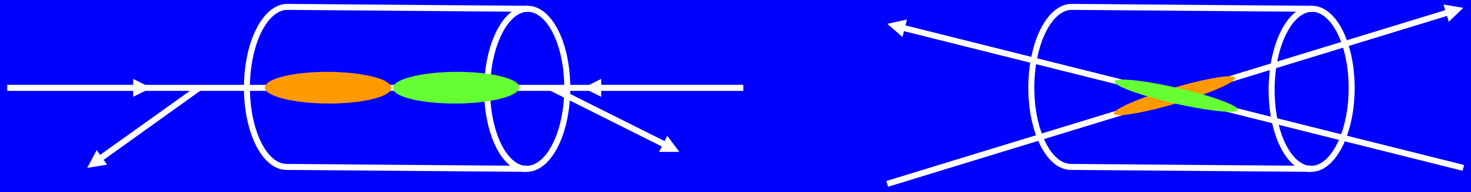
L/L_0

~ 0.85

2θ[mrad]

20 mrad → $L/L_0 \sim 0.2$

Collider motivations



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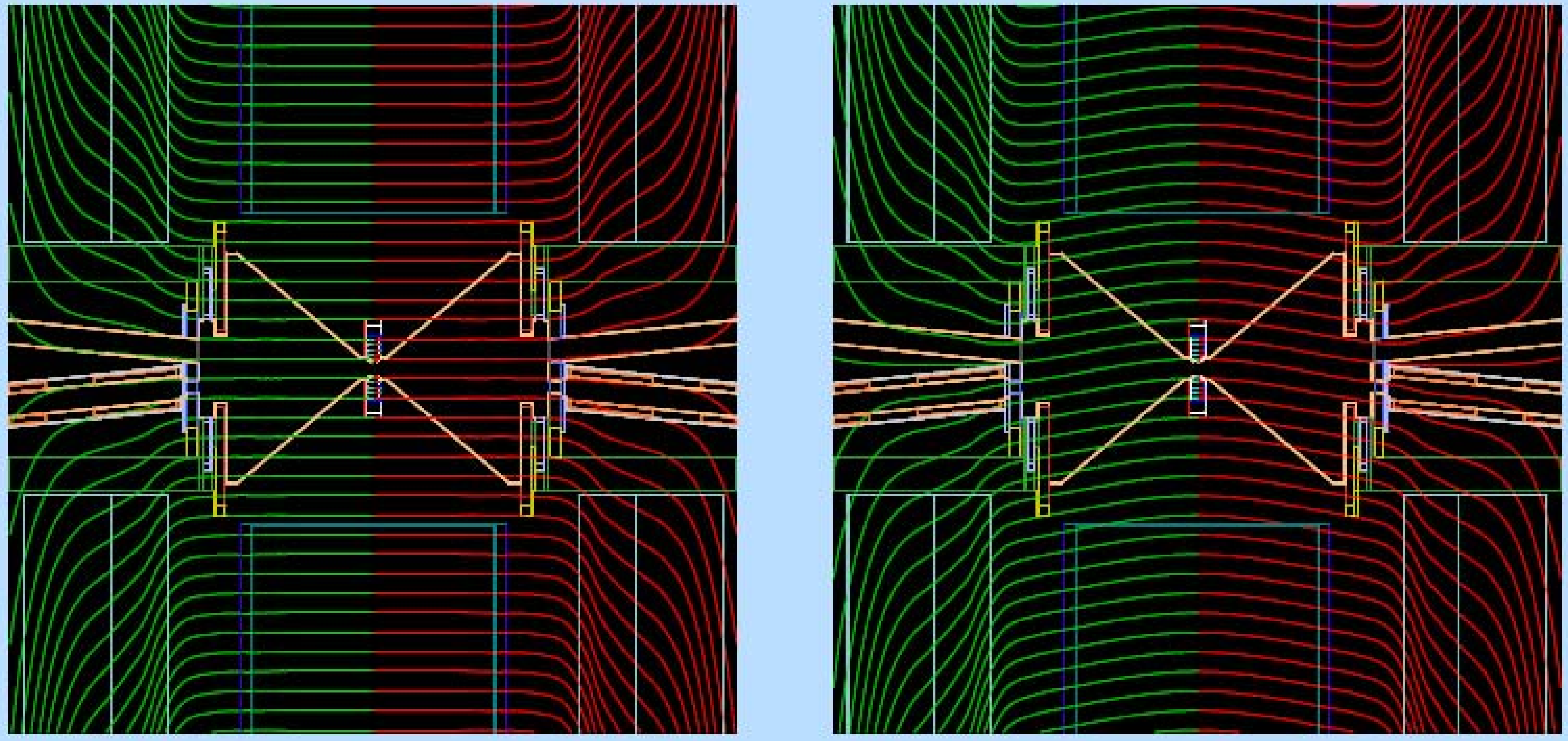


(A. Vogel)

Plain solenoid

Solenoid with DID

Realistic field maps (plus simplified quadrupoles)

Without DID

IP y angle ~ 100 µrad

IP y offset ~ - 20 µm

spin precession ~ 60 mrad

if uncorrected → ~ 0.2 % depolarization

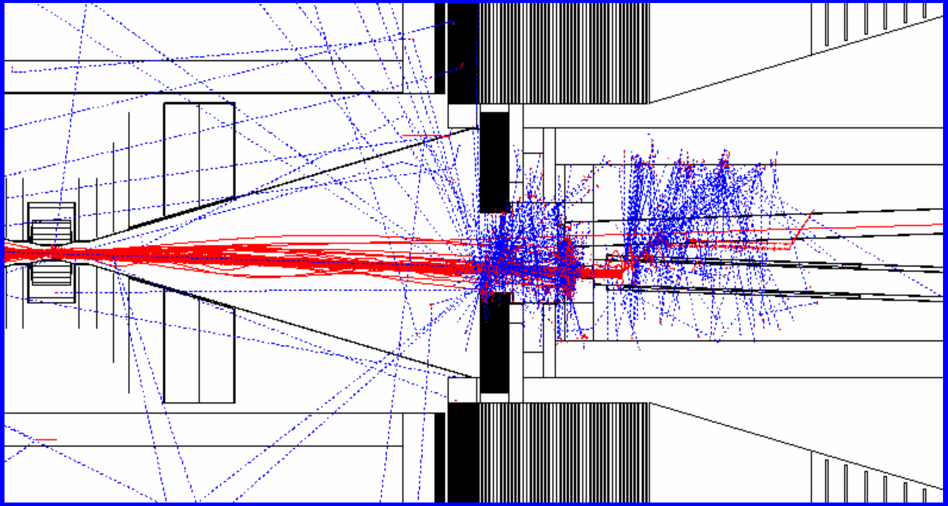
with perfect beams (or else larger)

anti-DID

⇓

× ~ 2

DID - - - - - - - ▶ anti-DID

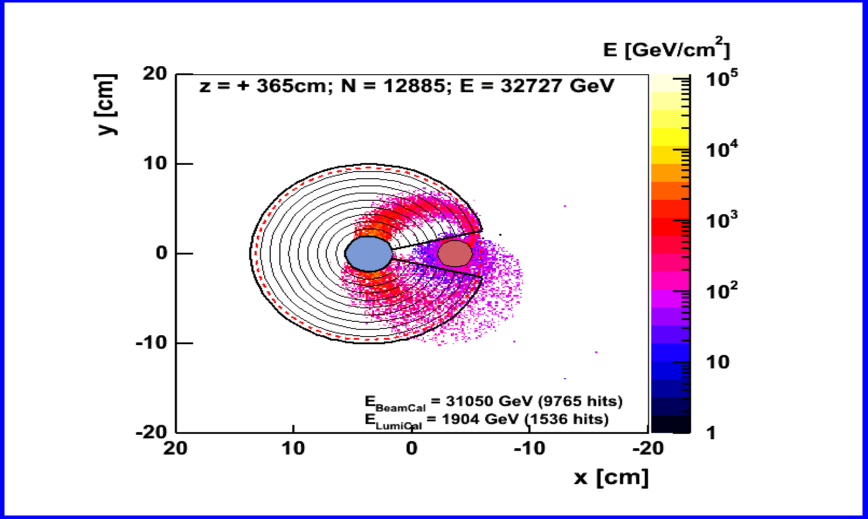


DID defocuses pairs

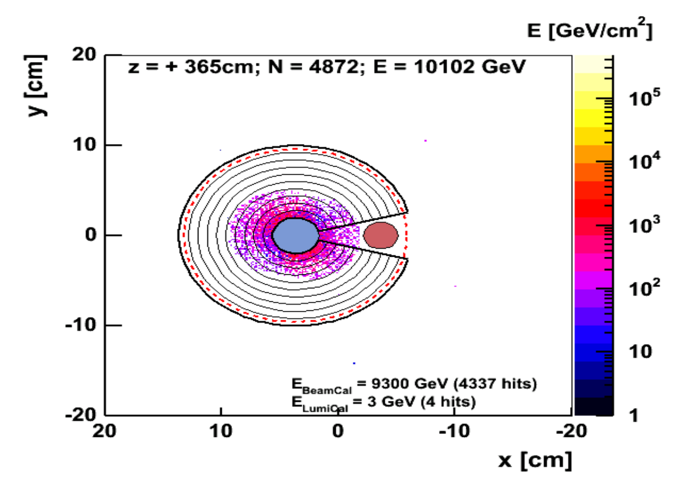
⇒ more backscattered backgrounds

⇒ degraded small angle veto

(C. Grah)



20mrad DID

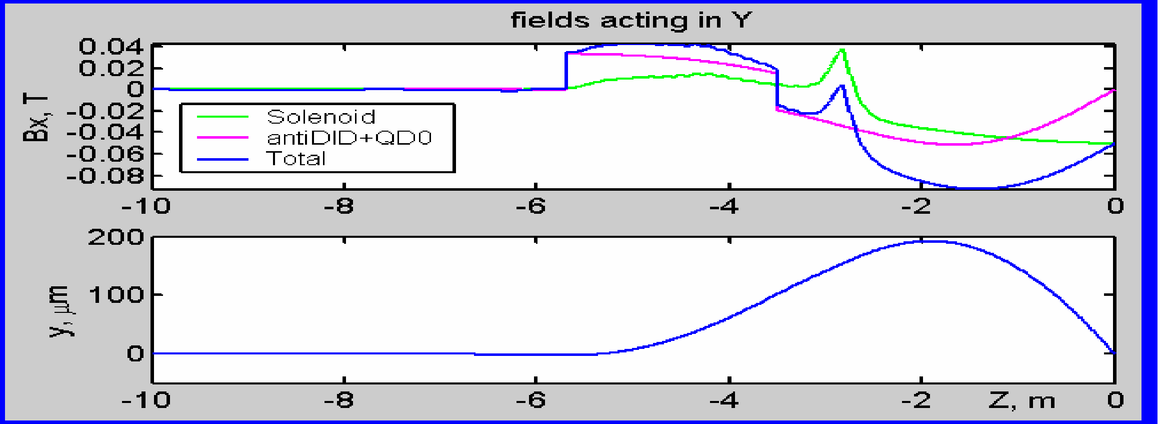


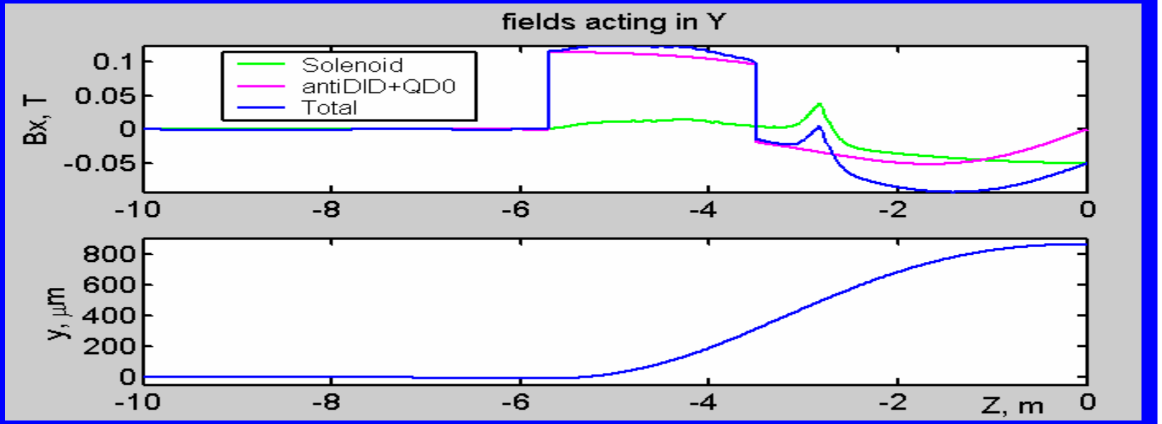
20mrad AntiDID

anti-DID: pre / post-IP trajectory bumps are needed to control Y and Y' at IP

(A. Seryi)

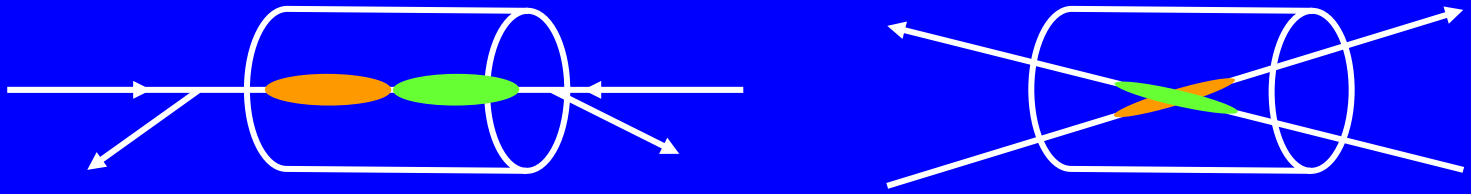
2 examples choosing to zero either Y or Y' with QD0 offsets





Need simultaneous (large) QD0 & QF1 offsets to zero both Y and Y'

Collider motivations



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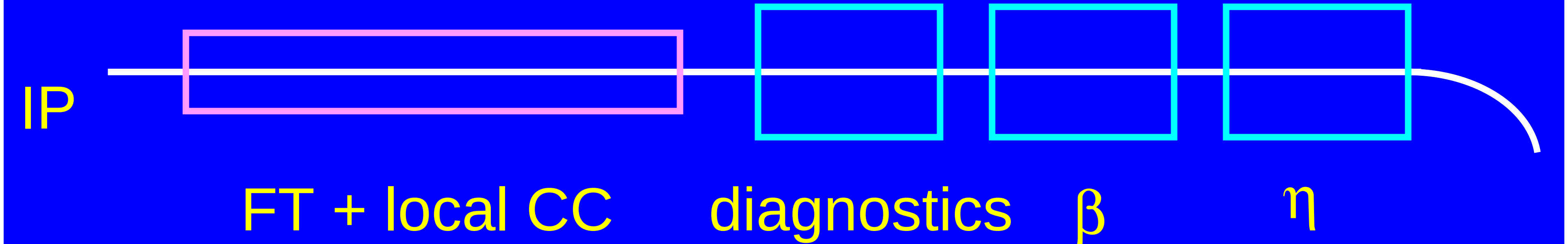
Beam parameter corrections at IP

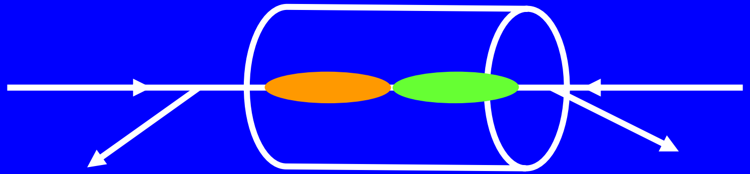
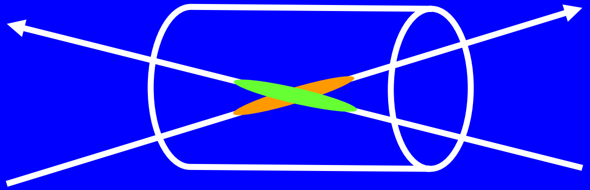


- x x’ y y’ beam centroids (luminosity & background)
- 8 betatron parameters $\alpha_{x,y}$ $\beta_{x,y}$ <xy’> <x’y> <xy> <x’y’>
  (flat emittances 0.001 – 0.01 → < 4 xy free parameters)
- 4 $\eta_{x,y}, \eta'_{x,y}$ (including finite η'_x)

Add 1) crab-crossing : 2 phases and 2 amplitudes
2) anti-DID : control backgrounds & post-IP steering
3) trajectory bumps in final doublet : control y_{IP} & y'_{IP}

Can complicate setup & tuning procedure ?

Collider motivations

	very small 0 – 2 mrad	large 14 – 25 mrad
		
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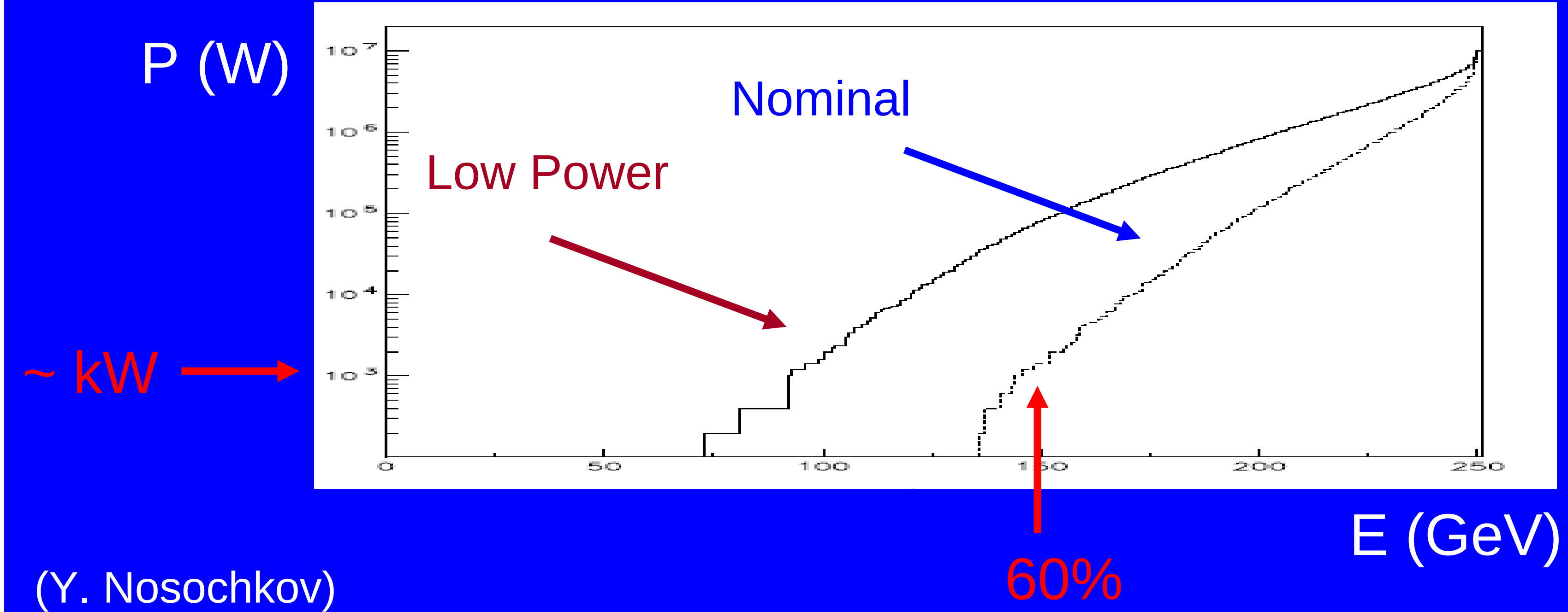
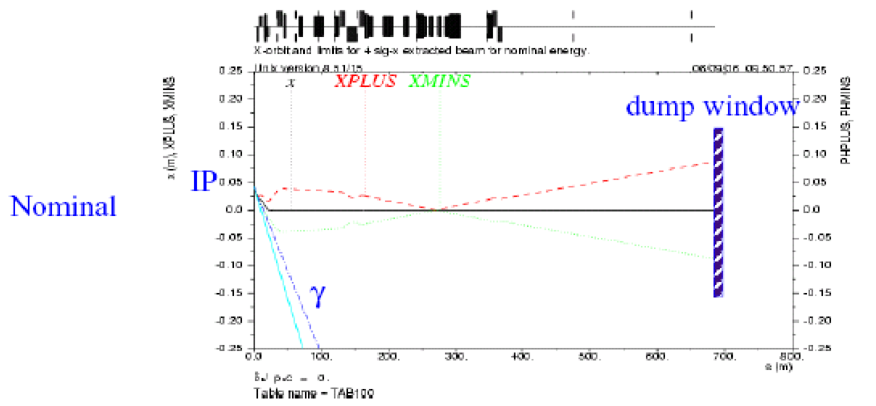
Post-IP transport needs large energy acceptance
0-2 mrad : bending & shared magnets → harder

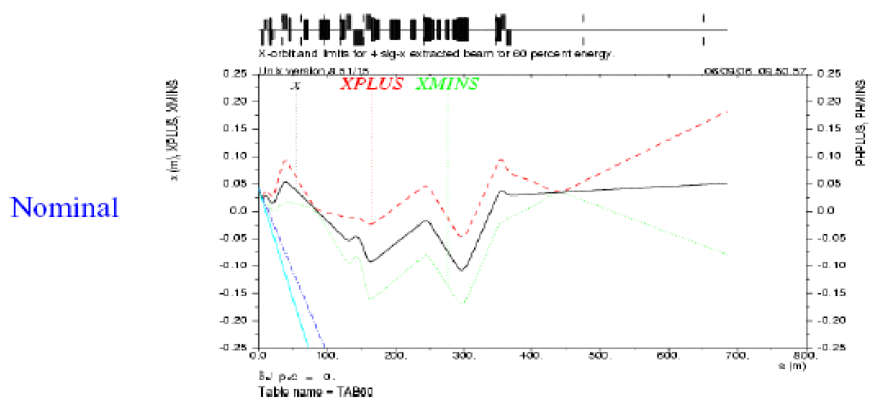


(Y. Nosochkov)

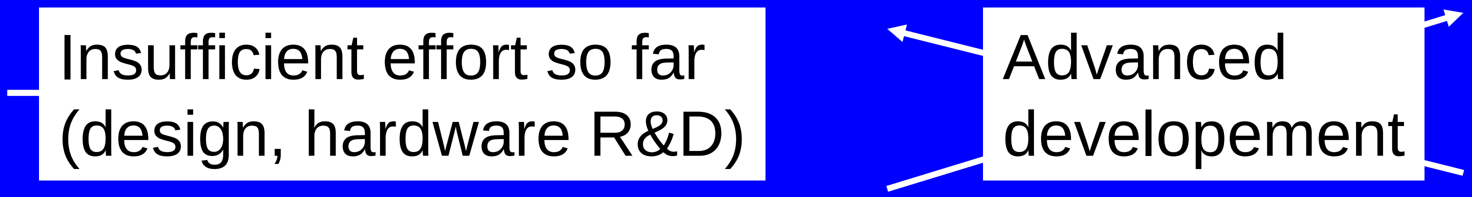
Horizontal disrupted envelopes for 100% energy particles



Horizontal disrupted envelopes for 60% energy particles



Collider motivations



	very small 0 – 2 mrad	large 14 – 25 mrad
	Insufficient effort so far (design, hardware R&D)	Advanced developement
injection & extraction	• shared magnets ⇒ coupled design	• separate channels
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Physics argument 1 : SUSY→ hermeticity

Detection of $\tilde{l} = \tilde{\mu},\tilde{\tau}$ sleptons for small Δm

P.B. et al. hep-ph/0406010

signal

$ee \rightarrow l\, \chi^0\, l\, \chi^0$

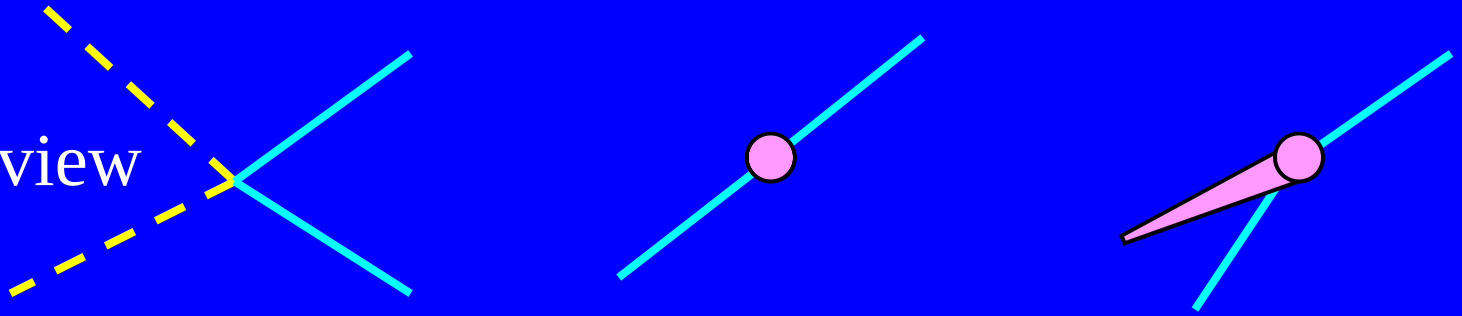
$\sigma \sim 10$ fb

major background : $\gamma\gamma$

$ee \rightarrow (e)(e)\, l\, l$

$\sigma \sim 10^6$ fb

Transverse view



Near threshold $E_l = \gamma\,(1 \pm \beta)\,(m_{\tilde{l}}^2 - m_\chi^2)\,/\,2\,m_{\tilde{l}} \sim \Delta m\,\gamma\,(1 \pm \beta)$

$\gamma\gamma$ background → must tag spectator electron (e.g. for Δm=5 Gev):

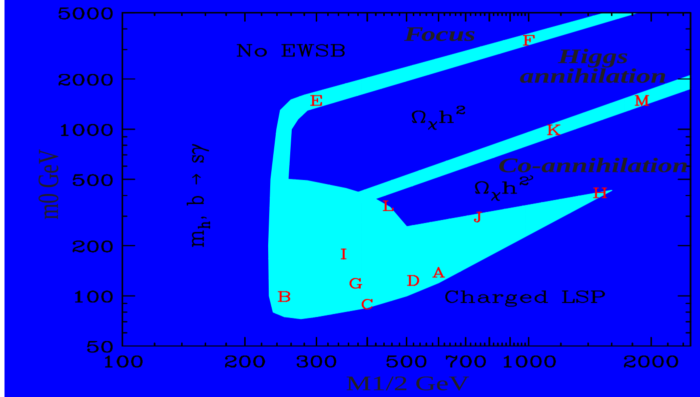
$\theta \sim \Delta m\,\gamma\,(1 - \beta)\,/\,E_{\mathrm{beam}} \times$ factor ~ 5-10 mrad (factor = 1 < 1 for μ τ)

Dark Matter ↔ SUSY ↔ LHC + LC

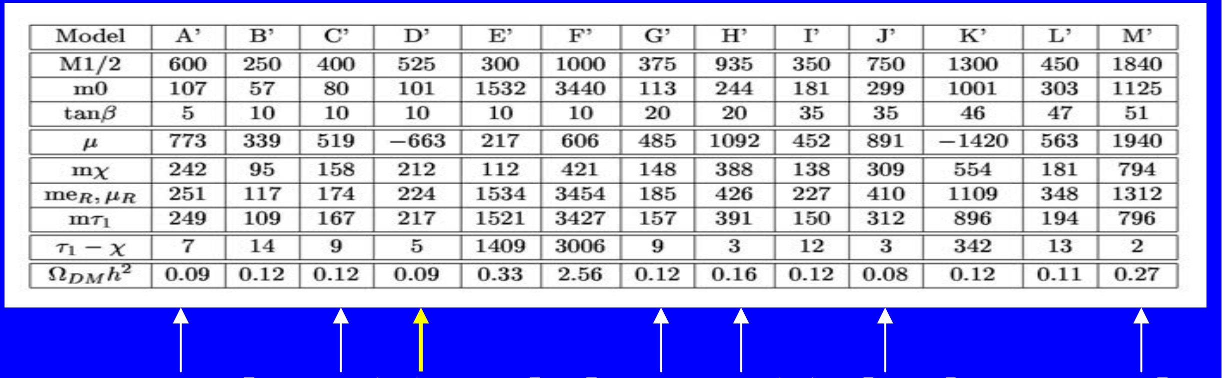
WMAP cosmic microwave background radiation measurement lead to :

$\Omega_{\text{total matter}}\,h^2 = 0.134 \pm 0.006$ and $\Omega_{\text{baryon}}\,h^2 = 0.023 \pm 0.001$ PDG July 2004

→ mSUGRA with WMAP constraint $0.094 < \Omega_{DM}\,h^2 < 0.129$ (2 sigma)



M. Battaglia et al. Eur.Phys.J.C33:273-296,2004



Model	A’	B’	C’	D’	E’	F’	G’	H’	I’	J’	K’	L’	M’
M1/2	600	250	400	525	300	1000	375	935	350	750	1300	450	1840
m0	107	57	80	101	1532	3440	113	244	181	299	1001	303	1125
$\tan\beta$	5	10	10	10	10	10	20	20	35	35	46	47	51
μ	773	339	519	−663	217	606	485	1092	452	891	−1420	563	1940
$m\chi$	242	95	158	212	112	421	148	388	138	309	554	181	794
me_R, μ_R	251	117	174	224	1534	3454	185	426	227	410	1109	348	1312
$m\tau_1$	249	109	167	217	1521	3427	157	391	150	312	896	194	796
$\tau_1 - \chi$	7	14	9	5	1409	3006	9	3	12	3	342	13	2
$\Omega_{DM} h^2$	0.09	0.12	0.12	0.09	0.33	2.56	0.12	0.16	0.12	0.08	0.12	0.11	0.27

→ for quasi mass-degenerate neutralino (χ) and slepton (τ), both χχ and χτ (co-)annihilations combine to regulate the amount of relic DM

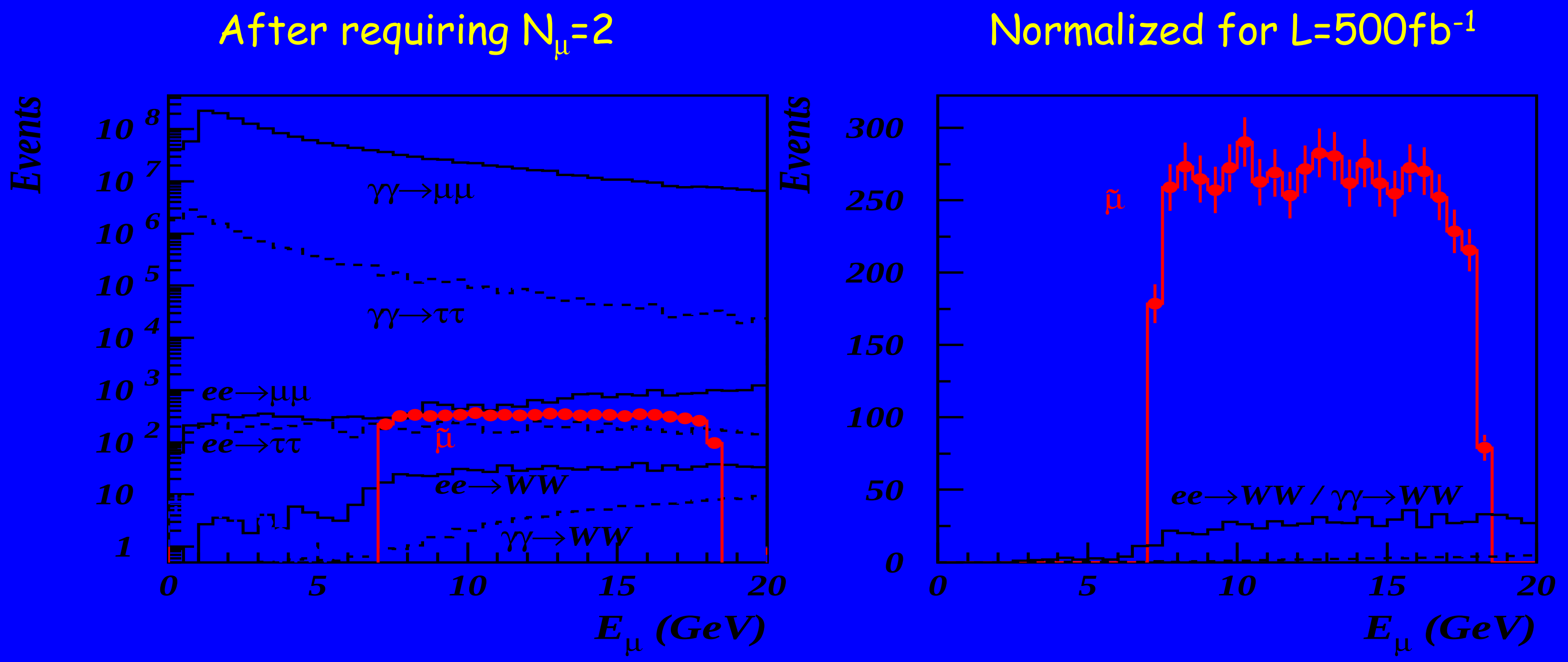
→ N(τ) / N(χ) ~ exp(-20Δm/m) ~ 1 ⇒ Δm < 10 GeV and m < 400 GeV

→ attractive mechanisms also beyond mSUGRA D.Hooper et al. Phys.Lett.B562(2003)18

Preliminary $\tilde{\mu}$ result

P.B. et al. hep-ph/0406010

benchmark point D' with $\Delta m_{\tilde{\mu}-\chi}$ = 12 GeV



After requiring $N_\mu=2$

Normalized for $L=500 fb^{-1}$

signal efficiency ~ 80%

spectrum end-points preserved

Mass extraction from endpoints : $\delta m_{s\mu}$= 0.18 GeV and δm_χ = 0.17 GeV

Δm = 12 GeV ⇒ assumed tagging down to θ ~ 25-30 mrad

Preliminary $\tilde{\tau}$ results

benchmark point D’ with $\Delta m_{\tilde{\tau}-\chi} = 5$ GeV

P.B. et al. hep-ph/0406010

H.-U. Martyn hep-ph/0408226

More difficult → Missing energies from neutrinos,

→ Very soft final state

→ electron tagging down to $\theta \sim 5$ mrad

Two complementary strategies :

i. For large signal cross section and $2m_{stau} \ll E_{cm}$

→ end-point method

➡ ii. For small signal cross section and $2m_{stau} \sim E_{cm}$

→ event counting method

Main selection cuts for $\tilde{\tau}$

Z. Zhang

1. Veto energetic forward electrons/photons
2. Number of charged tracks : 1 or 3 prongs, no 2 muons, charge conservation
3. $15^o < q_{thrust} < 165^o$, acoplanarity angle $< 160^o$
4. $P_{max} < 7$ GeV, $P_{Tmiss} > 2.5$ GeV
5. ρ_T : P_t sum w.r.t. the thrust axis in transverse plane to the beam > 2.75 (or 2) GeV (P_{Tmiss} dependent)
6. Azimuthal cut on ρ_T in the case of 20mrad crossing-angle

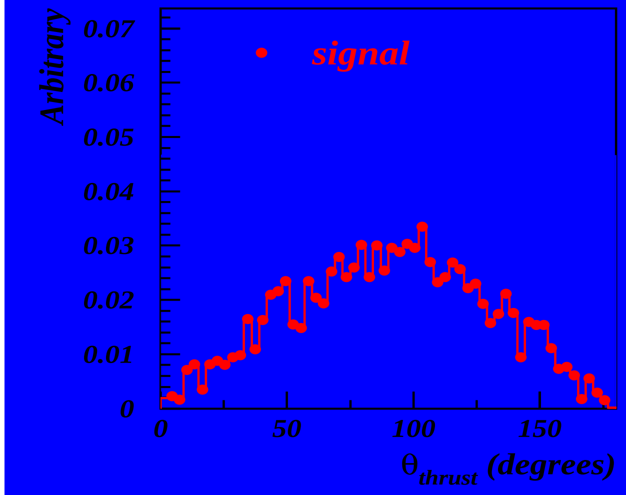
Assumed ideal reconstruction in detector acceptance (modeled in SGV)

Assumed ideal electron/photon veto down to 3.2mrad for $P_t > 0.8$ GeV

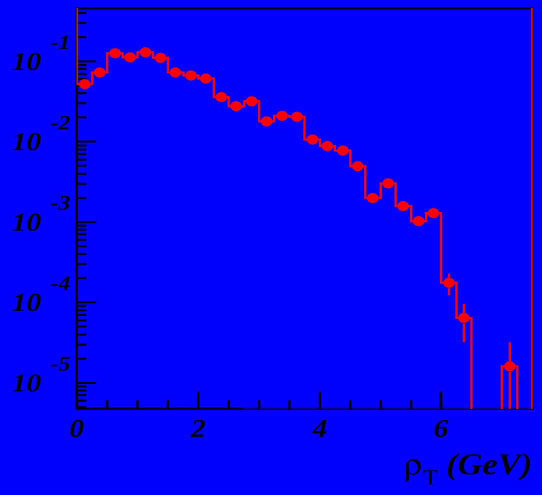
Preliminary $\tilde{\tau}$ result

P.B. et al. hep-ph/0406010

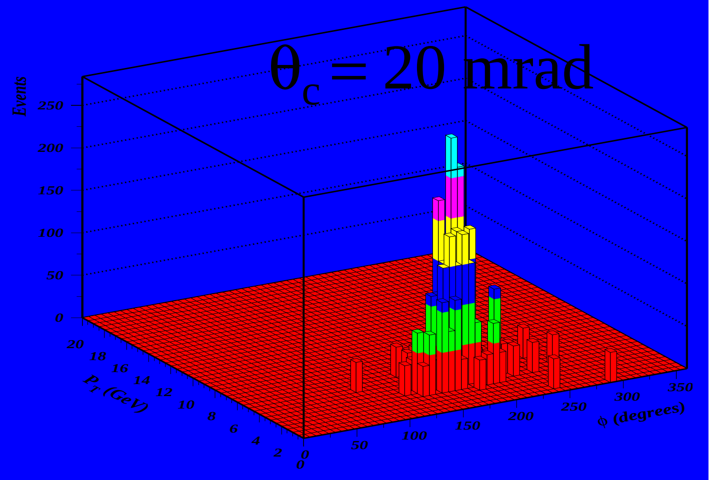
benchmark point D' with $\Delta m_{\tilde{\tau}-\chi}$ = 5 GeV



Thrust axis angle in 3-dim



ΣP_T wrt thrust axis in the transverse plane



Azimuthal dependence of the transverse momentum

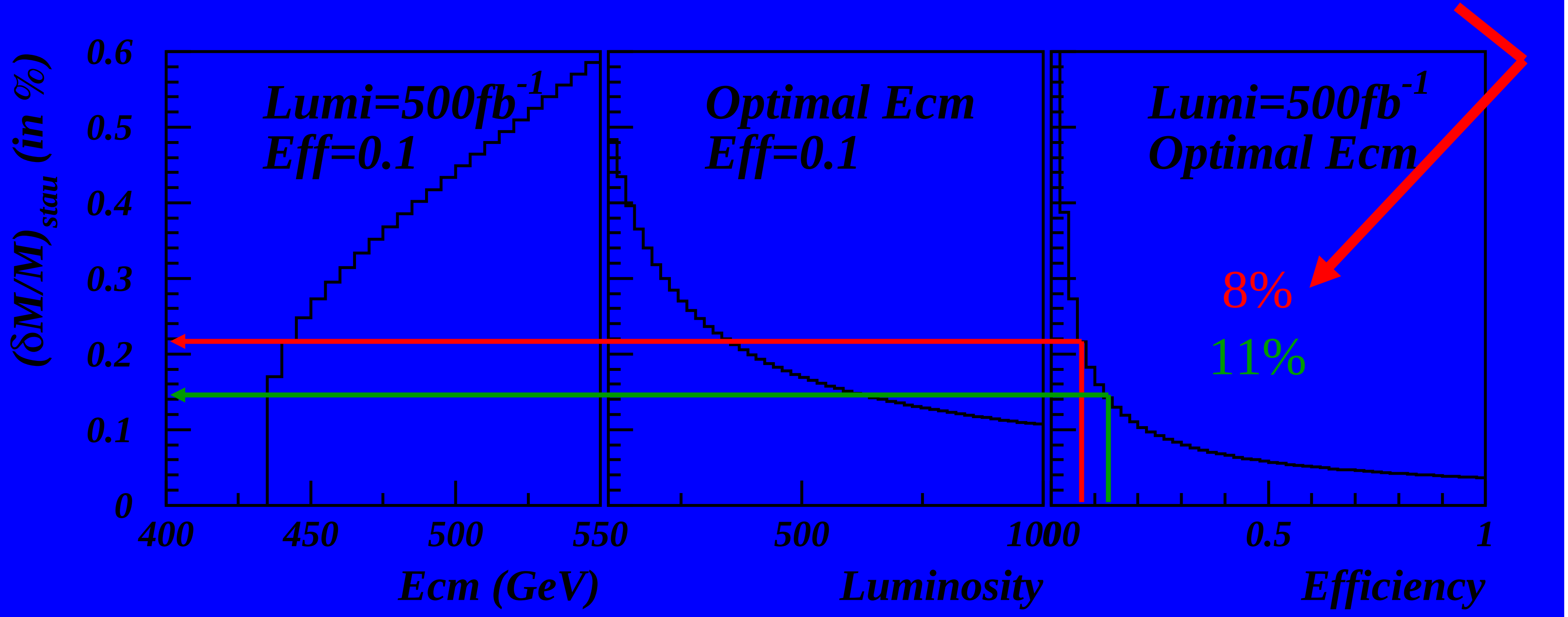
Moderate effect of 2nd hole after additional cut

	head-on	crossing-angle
efficiency	~ 11 %	~ 8 %

Luminosity, E_{CM} and efficiency optimization

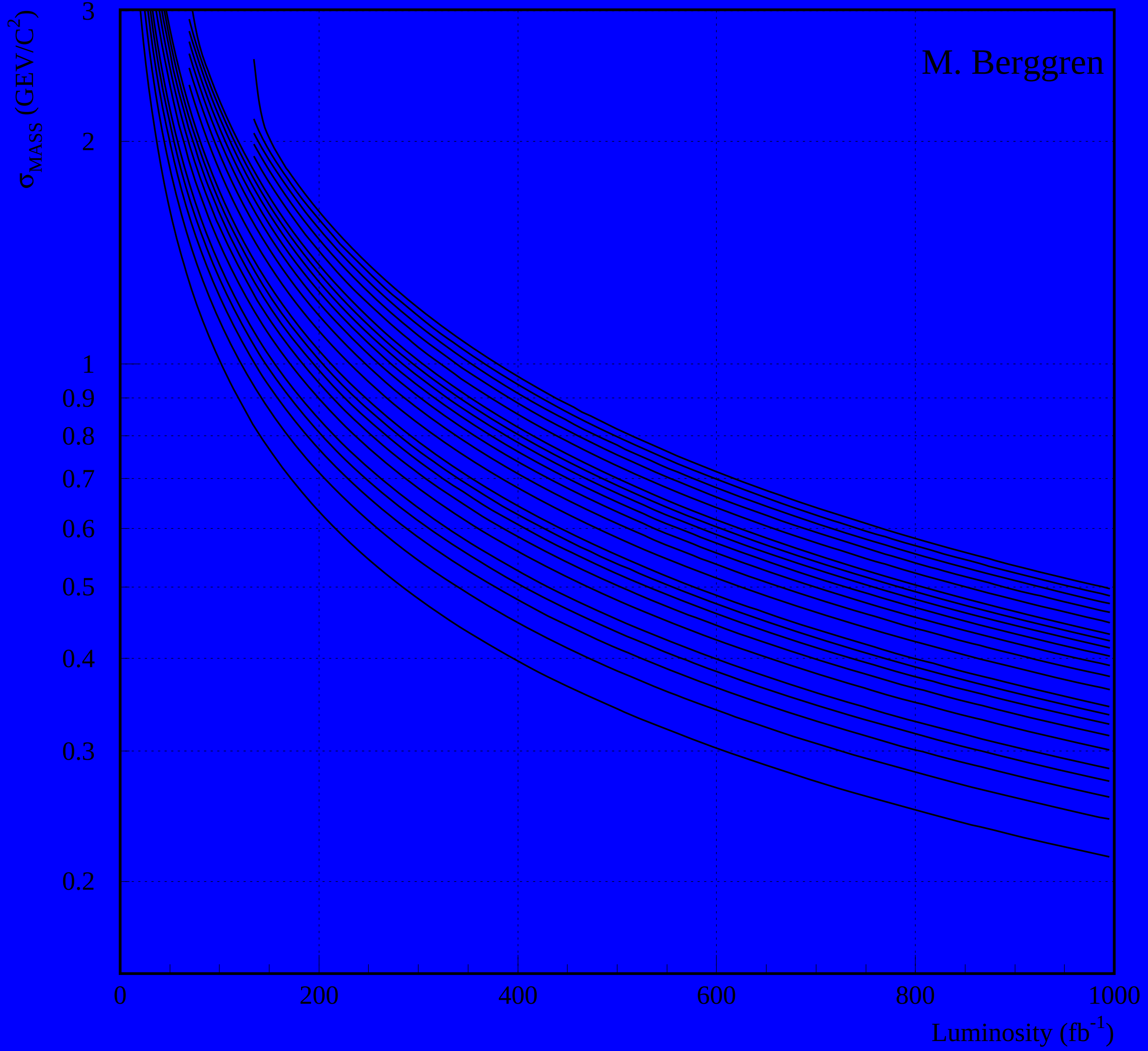
benchmark point D’ with $\Delta m_{\tilde{\tau}-\chi} = 5$ GeV

$\tilde{\tau}$ mass precision wrt efficiency **effect from 2nd hole only**



Relative $\tilde{\tau}$ mass precision from cross-section measurements near the production threshold with negligible background

Mass measurement in case of background



bkgd
events

100

20

7

1

Mass precision degrades when background contribution increases

Veto efficiency & analysis cut optimization essential

High integrated luminosity will always help

Stau mass threshold measurement for small stau-neutralino mass differences (e.g. 5 GeV)

BeamCal veto for dominant $\gamma\gamma$ background strongly affected by crossing-angle and ILC beam parameters

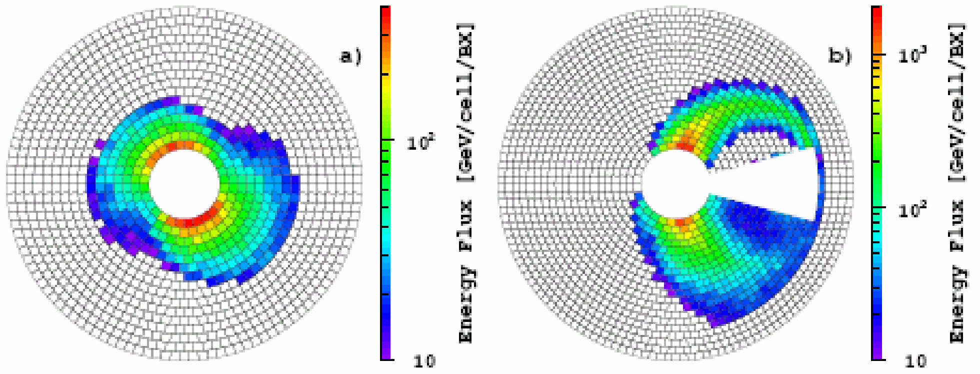


Figure 1. The energy density of beamstrahlung remnants per bunch crossing as a function of position in the $r-\varphi$ plane at the a) 2 mrad and b) 20 mrad with DID field crossing angles.

(V. Drugakov)

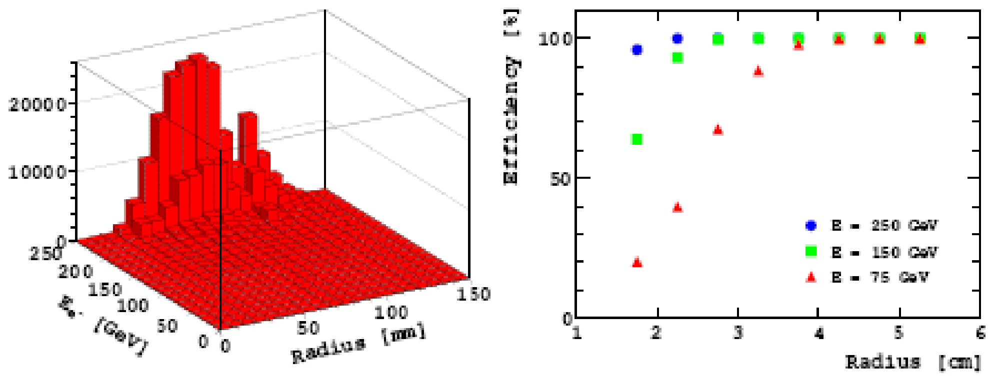
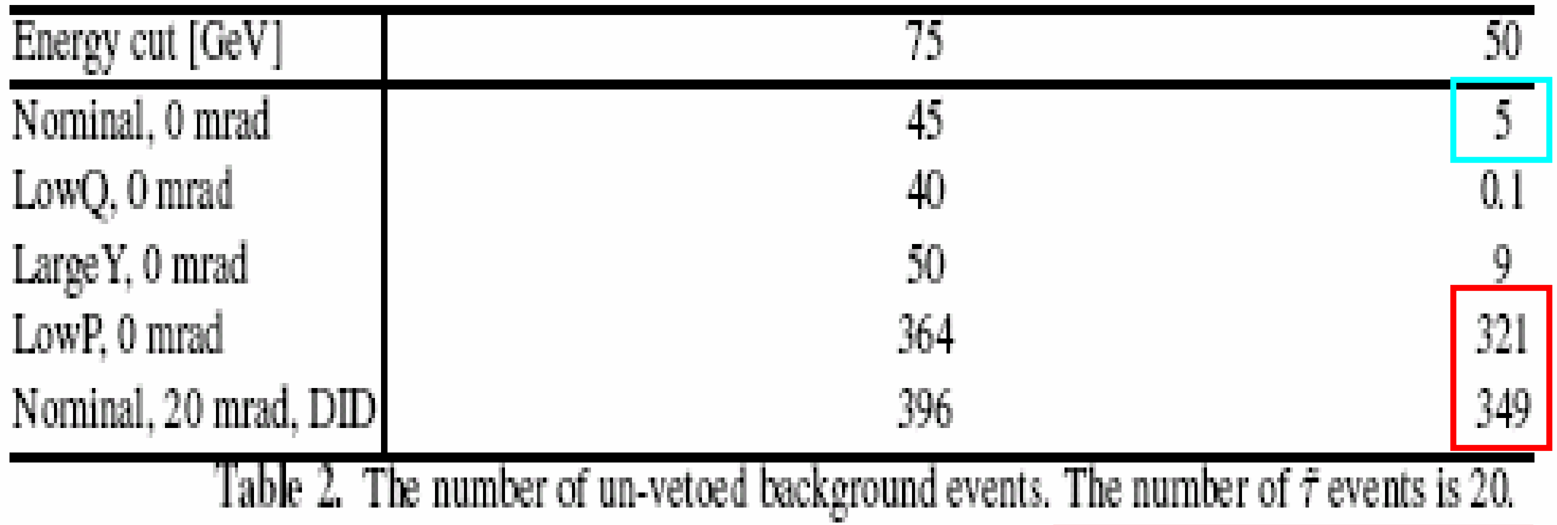


Figure 2. Left: Electron energy and spatial distribution of the 2-photon background events passed all selection cuts except the BeamCal veto. Right: The efficiency to veto an electron of energy 75, 150, 250 GeV as a function of the radius in the BeamCal.

Stau mass threshold measurement for small stau-neutralino mass differences (e.g. 5 GeV)



Energy cut [GeV]	75	50
Nominal, 0 mrad	45	5
LowQ, 0 mrad	40	0.1
LargeY, 0 mrad	50	9
LowP, 0 mrad	364	321
Nominal, 20 mrad, DID	396	349

Table 2. The number of un-vetoed background events. The number of $\tilde{\tau}$ events is 20.

(V. Drugakov & Z. Zhang)

Nominal + small x-angle → S/N ~ 4

Nominal + large x-angle & anti-DID → S/N ~ 2-3

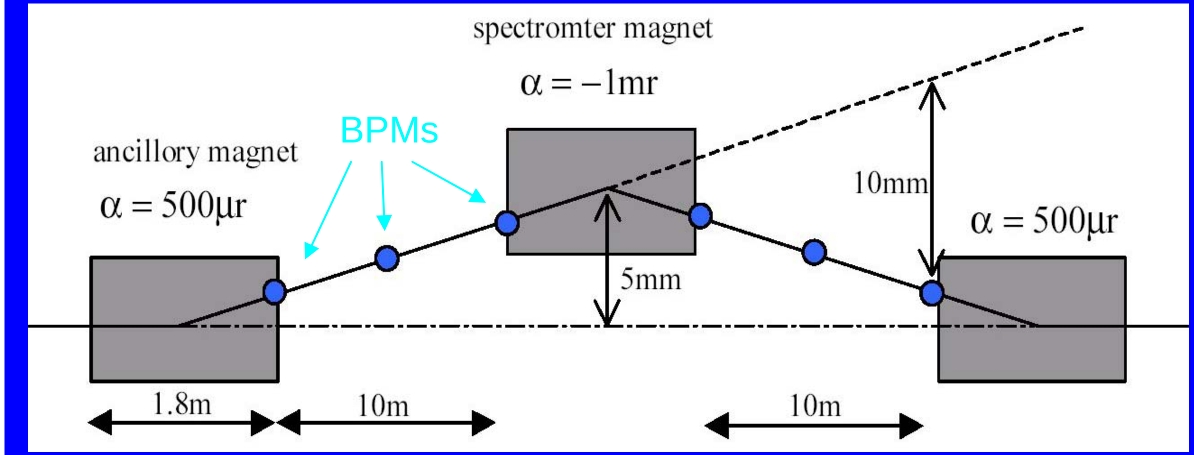
not OK for Low Power or large x-angle & DID

→ also study measure stau mass from spectrum above threshold (U. Martyn) ?!

Physics argument 2

Energy and polarization from beam-based measurements

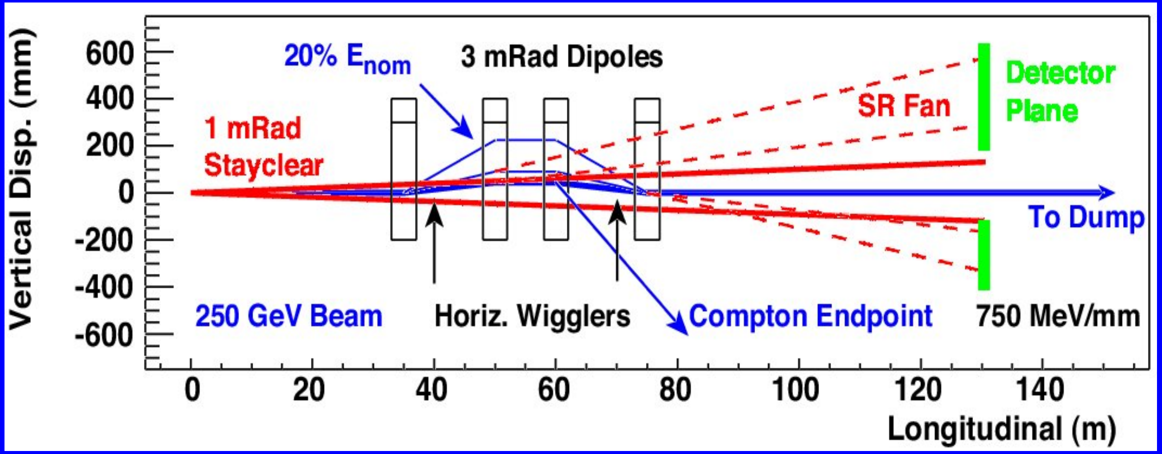
SPECTROMETRY pre – IP → all designs



$\delta E/E \sim (1 - 2) \times 10^{-4}$

linac E spread with
other pre-IP device

post – IP : a bit more difficult with small θ_c



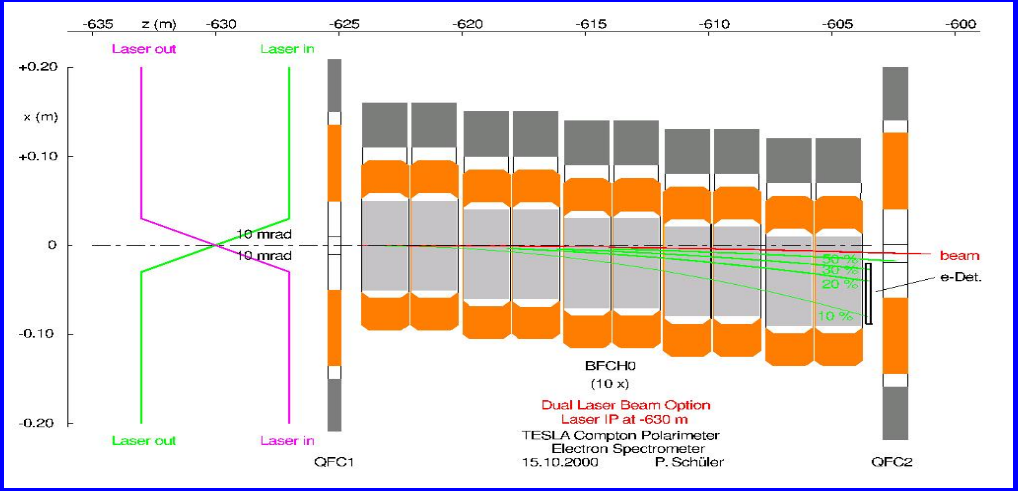
$\delta E/E \sim (1 - 2) \times 10^{-4}$

\+ linac E spread

\+ dL/dE

also from Bhabha
analyses

POLARIMETRY pre – IP → all designs

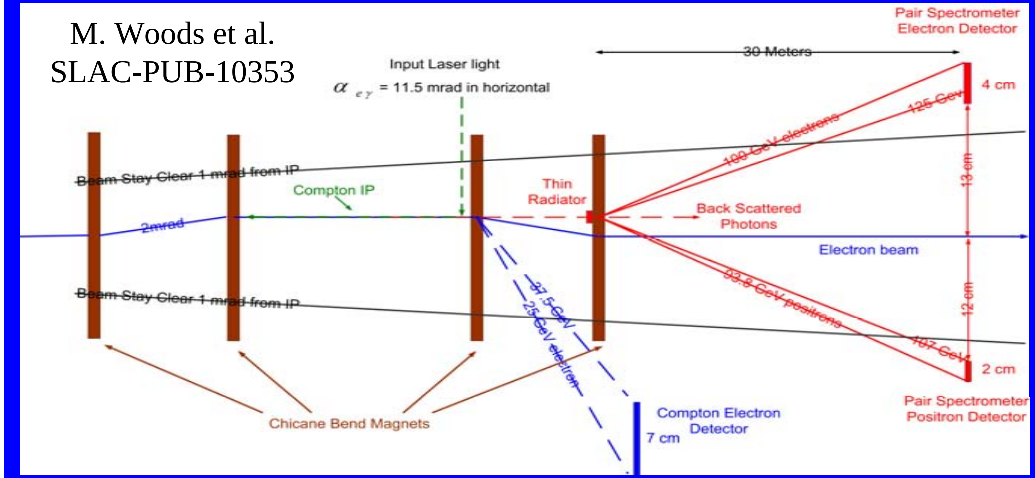


Dual Laser Beam Option
Laser IP at -630 m
TESLA Compton Polarimeter
Electron Spectrometer
15.10.2000 P. Schüler

$\delta P/P \sim (2.5 - 5) \times 10^{-3}$
Compton scattering
\+ extrapolation

optics constraints

post – IP : a bit more difficult with small θ_c


M. Woods et al.
SLAC-PUB-10353

$\delta P/P \sim (2.5 - 5) \times 10^{-3}$
Compton scattering
\+ extrapolation

clearance from spent beam
probes beam-beam effects

How important are additional post – IP spectrometer and polarimeter ?

- Different systematics !
- Errors → $\sim 1/\sqrt{2}$
- Beam-beam effects + correlations

Physics needs :

E

$\leq 2 \times 10^{-4}$ m_{top}, m_{higgs}
$\leq 5 \times 10^{-5}$ m_W, A_{LR}

P

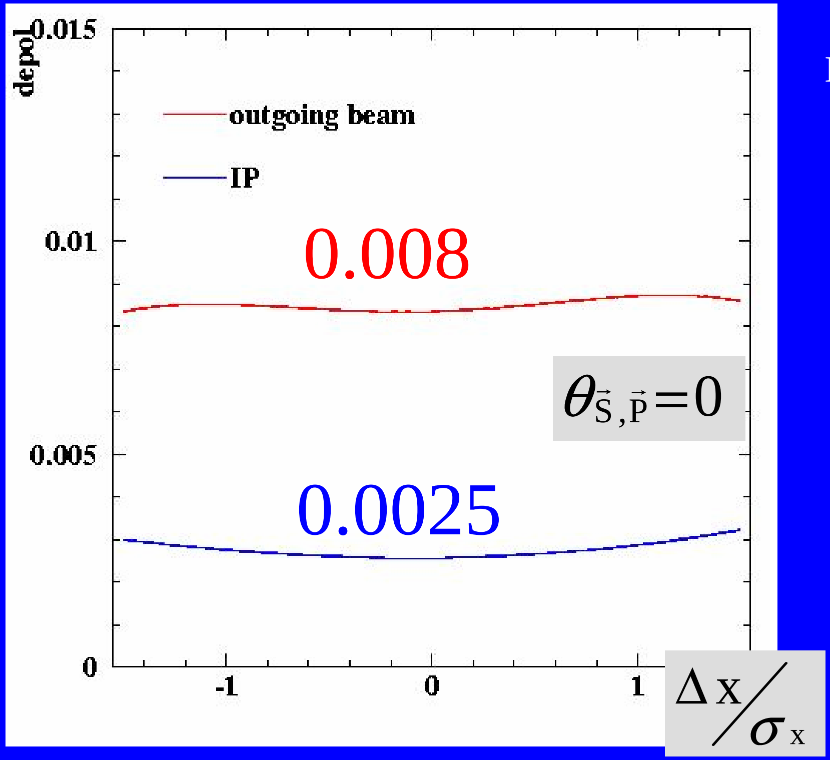
$\sim 5 \times 10^{-3}$ searches
$\leq 2 \times 10^{-3}$ HE SM tests
$< 1 \times 10^{-3}$ GigaZ

Precision of each pre- & post-IP measurement

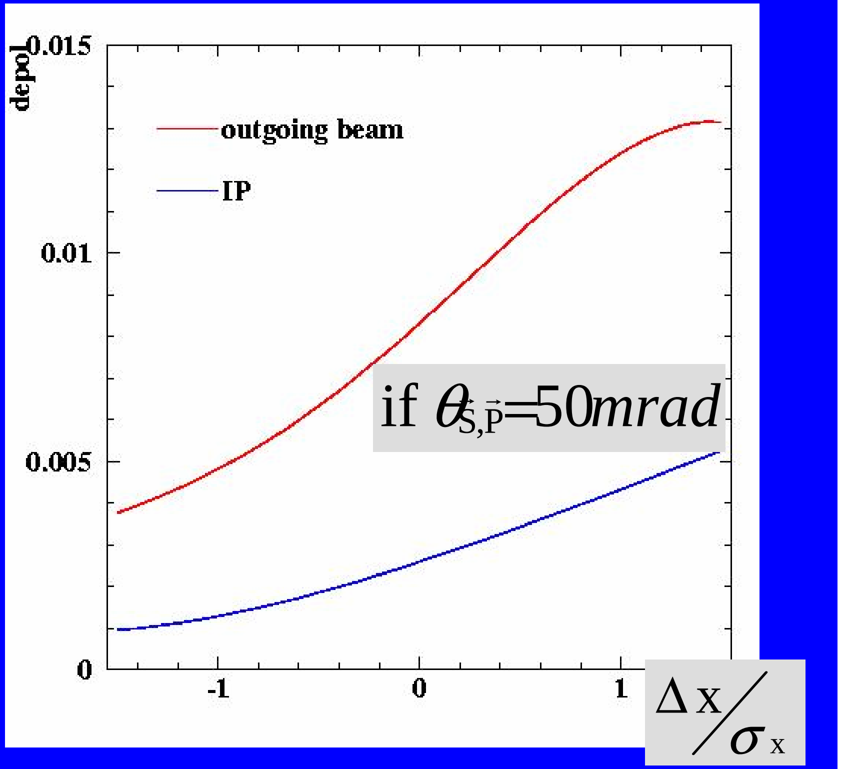
$(1 – 2) \times 10^{-4}$ $(2.5 – 5) \times 10^{-3}$

Will we really afford both pre + post-IP ?

Full beam-beam effect ~ 3 - 4 × lumi-weighted



K. Mönig



- Post-IP can compare with / without collisions
- Post-IP “magnifying glass” for beam-beam effect
- Real conditions : must correlate to offsets, currents,...

Detector argument

TPC tracking → B field to 0.0005 to control distortions

DID / anti-DID does not change the requirement to do a precise mapping, though it may complicate the procedure as several settings of DID / anti-DID must be foreseen

DID / anti-DID setting required to be kept fixed during data taking in order not to require constantly redoing the track based determination of field distortions → not a knob to tune !

It may be tricky to simultaneously optimise beam backgrounds, beam steering, hermeticity with DID / anti-DID and the keep it fixed → operation too constrained ?

Conclusion

Physics and detector slightly favour small crossing-angles over large ones (in my opinion), but the arguments are not overwhelming :

“small crossing-angle is of course preferred but we can live with a large crossing-angle…” (W. Lohmann, FCAL)

Main argument →
technical / operational for the collider