Session 3 summary: Particle Scattering

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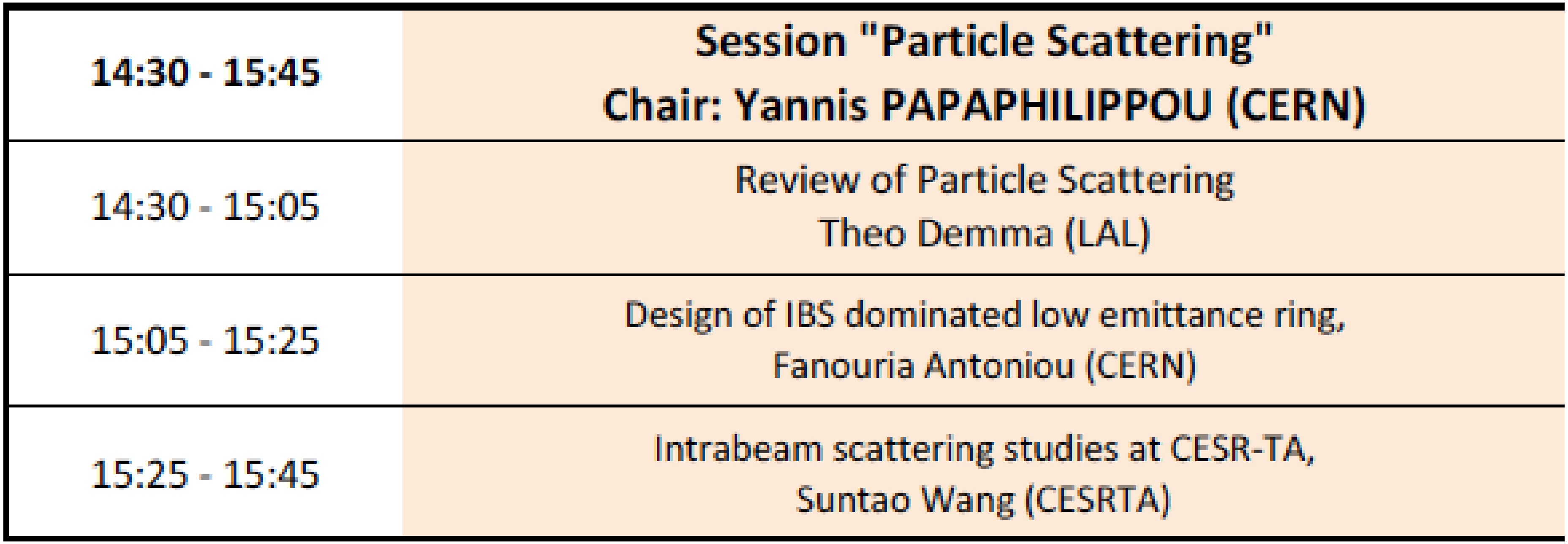
Session 3



14:30 - 15:45	**Session "Particle Scattering"** **Chair: Yannis PAPAPHILIPPOU (CERN)**
14:30 - 15:05	Review of Particle Scattering Theo Demma (LAL)
15:05 - 15:25	Design of IBS dominated low emittance ring, Fanouria Antoniou (CERN)
15:25 - 15:45	Intrabeam scattering studies at CESR-TA, Suntao Wang (CESRTA)

The Intrabeam scattering effect

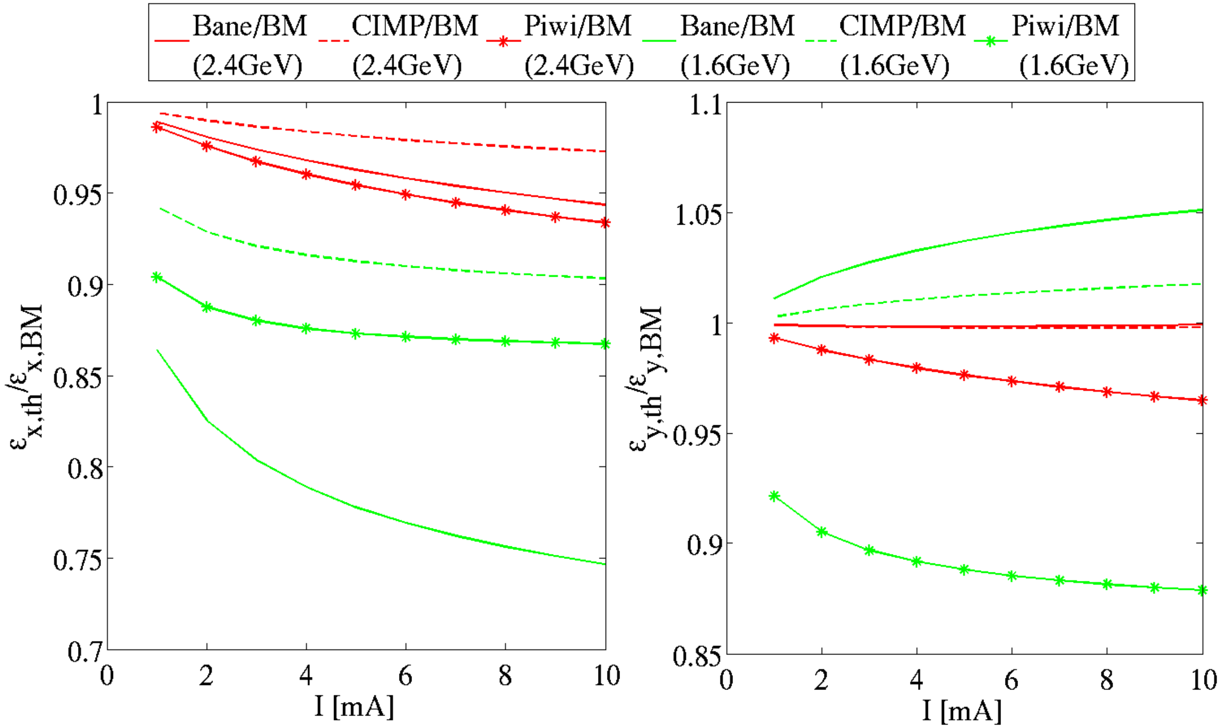
- Theoretical models calculate the **IBS growth rates**:
- Complicated integrals averaged around the rings
  - Depend on optics and beam properties

- Classical models of Piwinski (**P**) and Bjorken-Mtingwa (**BM**)
  - Benchmarked with measurements for hadron beams but not so well for lepton beams
- High energy approximations **Bane** and **CIMP**
  - Integrals with analytic solutions
- Tracking codes **SIRE** and **CMAD-IBStrack**
  - Based on the classical approach

- **Several theoretical models** and their **approximations** developed over the years → three main drawbacks:
  - Gaussian beams assumed
  - Betatron coupling not trivial to be included
  - Impact on damping process?

H. Bartosik for F. Antoniou

Comparison between theoretical models



- Comparison between the theoretical models for the SLS lattice
- All results normalized to the ones from BM
- Good agreement at weak IBS regimes
- Divergence grows as the IBS effect grows
  - Benchmarking of theoretical models and MC codes with measurements is essential

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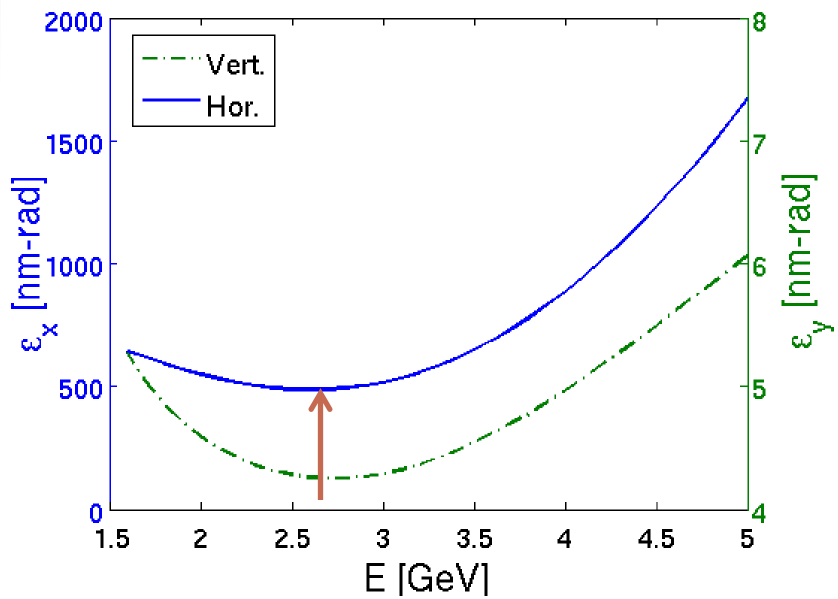
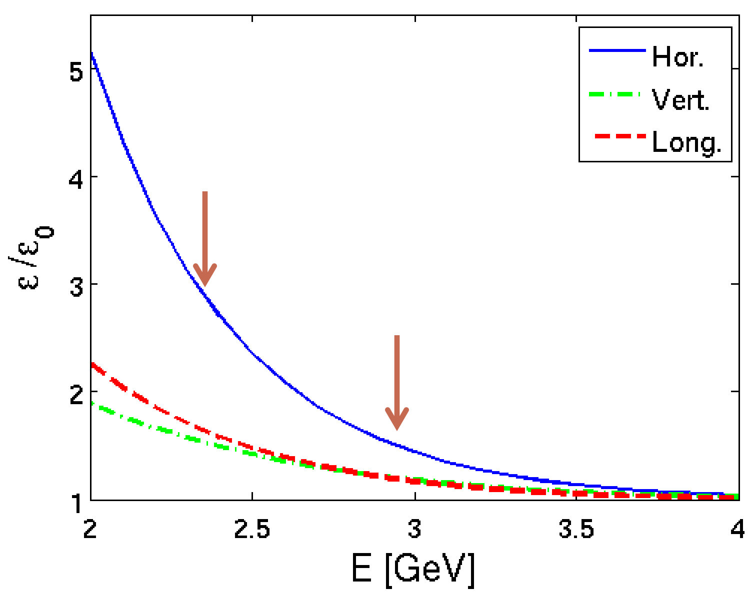
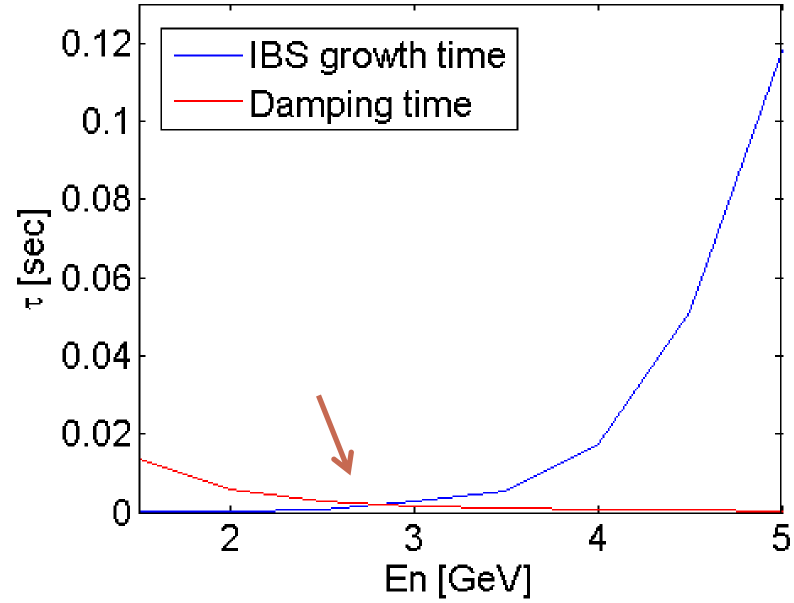
Energy choice for IBS reduction







- Broad minimum of the emittances around 2.5 GeV (left) while the IBS effect becomes weaker with energy (right)
  - Higher energies are interesting for IBS but not for the emittance requirements
- **Energy increase** (2.424 → 2.86 GeV) → **reduction of the IBS effect** by a factor of 2 (3 → 1.5)
- The scaling of the output emittance with energy reflects the domination of damping time or IBS growth time in each energy regime.

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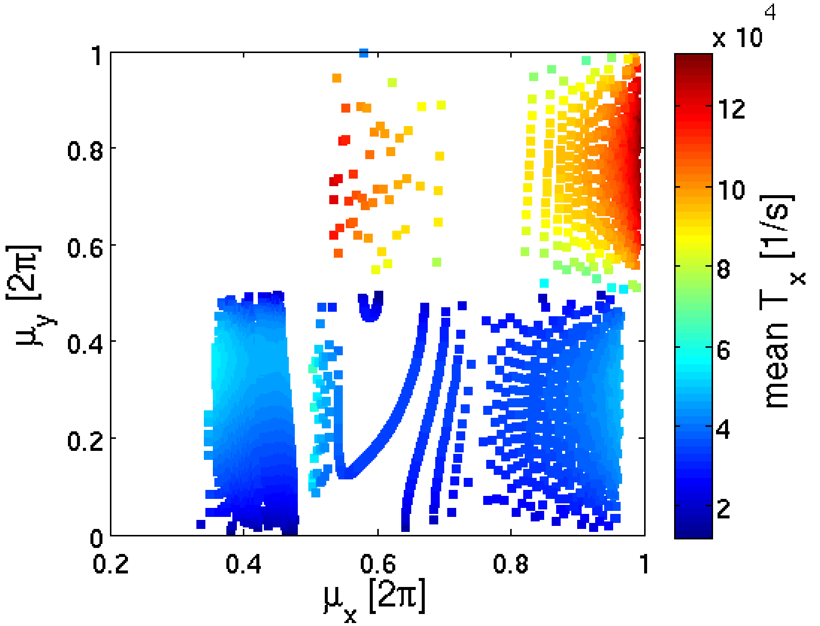
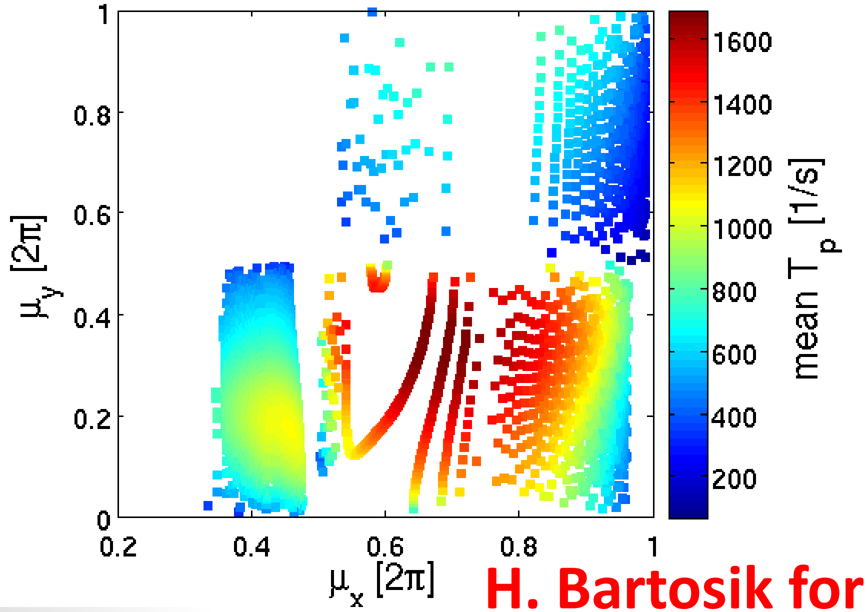
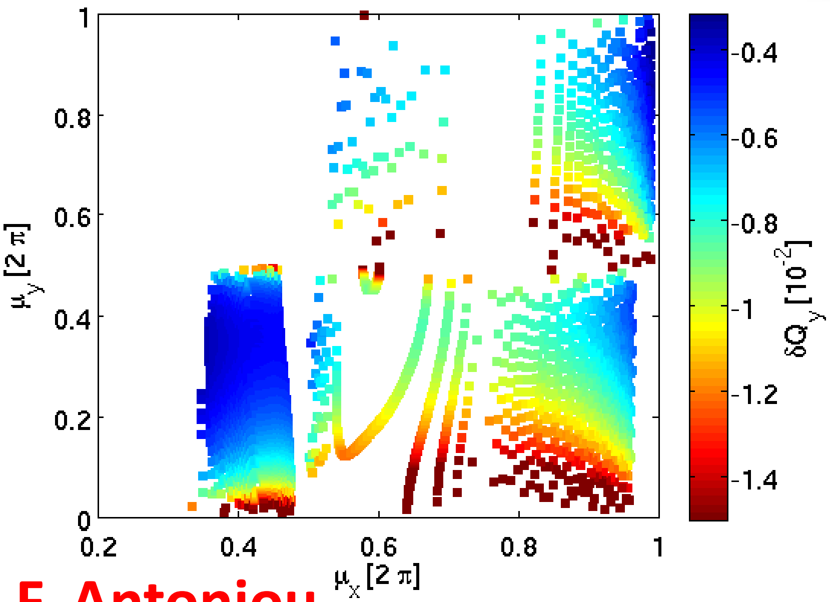
TME optimization with respect to IBS



- Scanning on the detuning factor (here DF=1..25), optimal phase advances can be found where chromaticity, IBS growth rates and space charge detuning are minimized
- Other interesting regions according to the requirements of the design also exist





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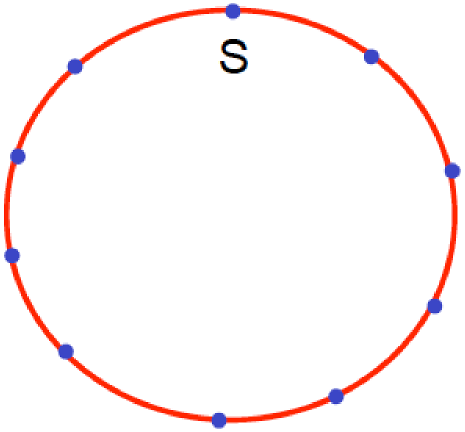
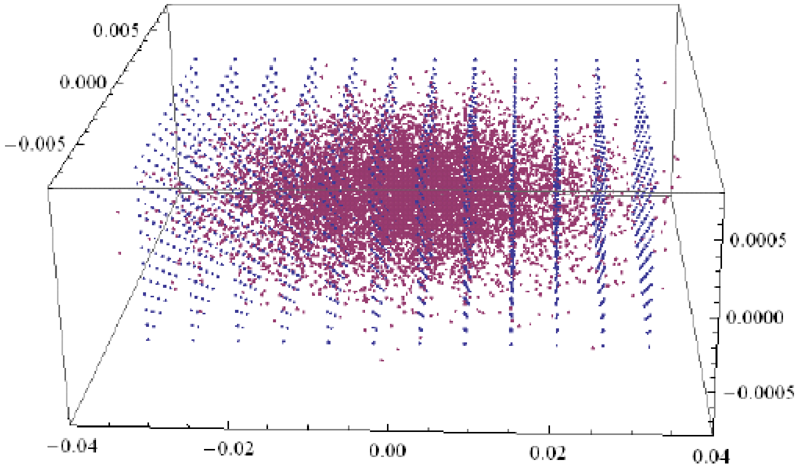
Algorithm for Macroparticle Simulation of IBS





- The lattice is read from a MAD (X or 8) files containing the Twiss functions and R transport matrices.
- 6-dim Coordinates of particles are generated (Gaussian distribution at S).
- The scattering routine is called:
  - Particles of the beam are grouped in cells.
  - Particles inside a cell are coupled
  - Momentum of particles is changed because of scattering.
  - Invariants of particles and corresponding growth rate are recalculated.
- Particles are tracked at next elemenet a 6-dim R matrix.
- Radiation damping and excitation effects are evaluated at each turn.

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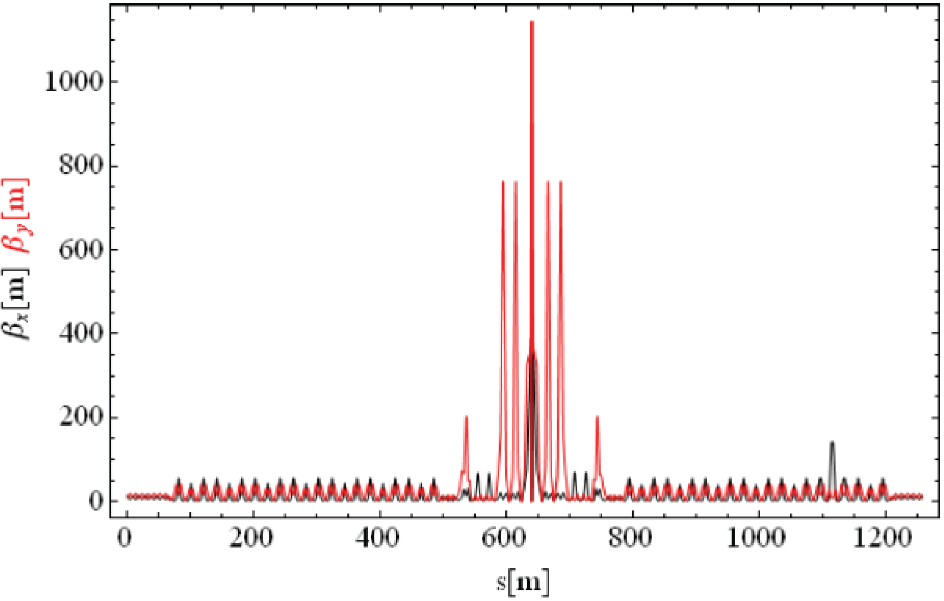
IBS evaluation in SuperB



SuperB V12 LER lattice (~1800IPs)

$\sigma_z=5.0*10^{-3}$ m

$\delta p=6.3*10^{-4}$

$e_x=1.8*10^{-9}$ m

$e_y=0.25/100*e_x$

ppb= 5.7 10^{12}

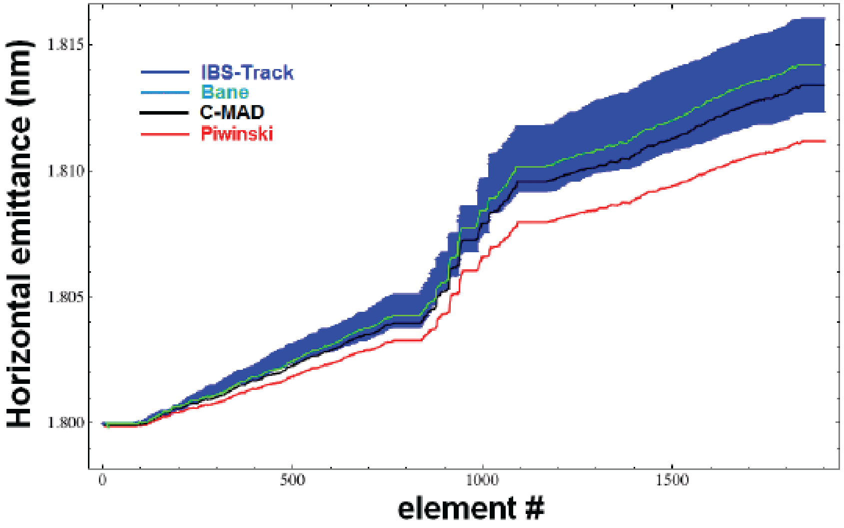
MacroParticleNumber=3 x 10^5

Grid size = $10\sigma_y$ x $10\sigma_x$

\# cells = 64 x 64

\# slices = 64

\# processors for this run = 64



Theoretical models compared with simulations for Super-B, using IBS-Track and C-MAD codes: one turn evolution of emittance with Intra-beam scattering.

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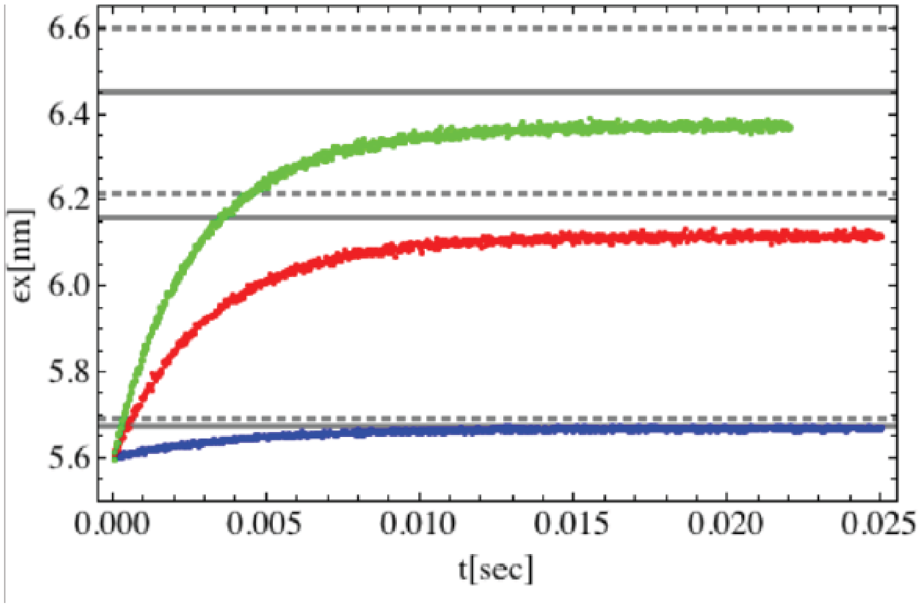
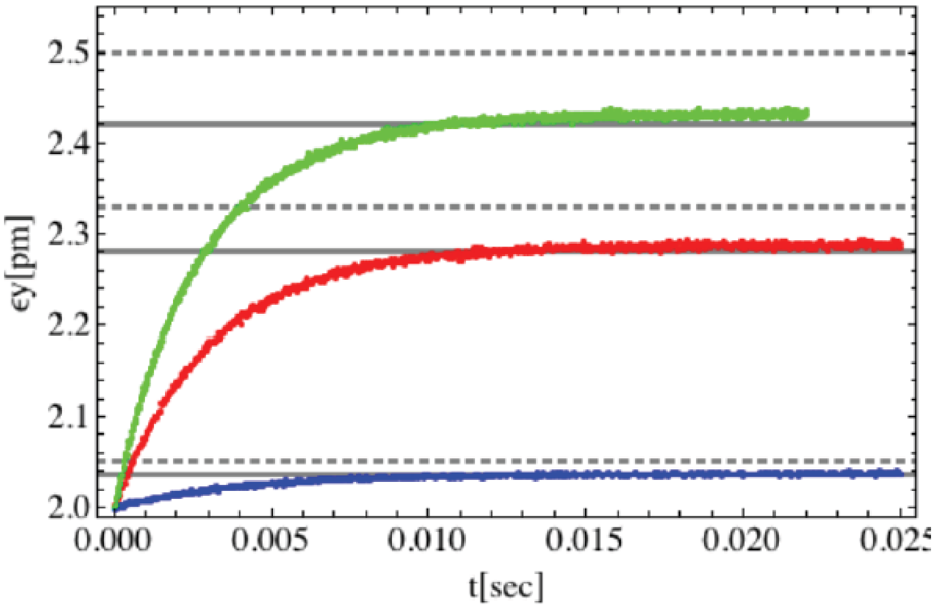
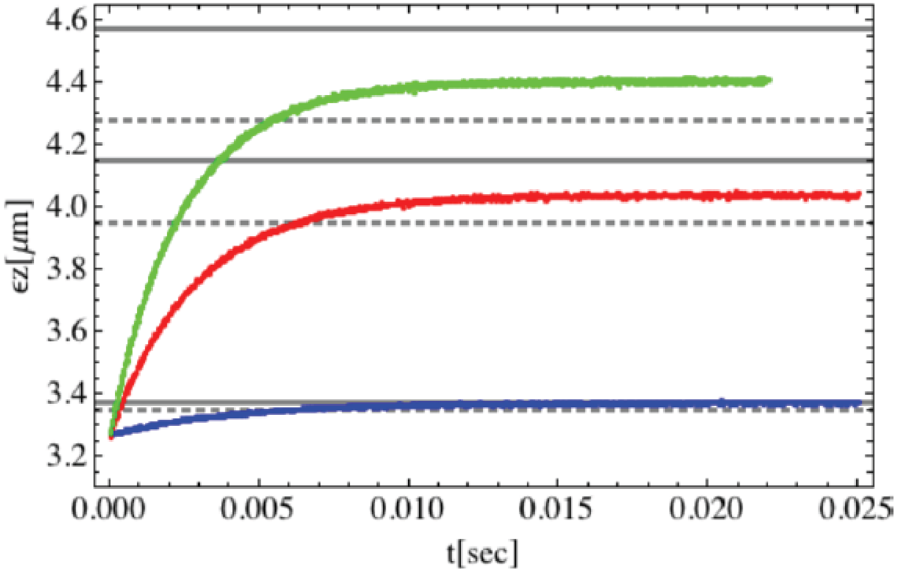
Emittance Evolution in SuperB LER







Evolution of horizontal, vertical and longitudinal emittances under the influence of IBS as obtained by the tracking code for different values of the bunch population: 6×10^9 (blue), 60×10^9 (red) and 100×10^9 (green). Horizontal lines represent the steady state values predicted by Piwinski (full) and Bane (dashed) models for the considered bunch populations.

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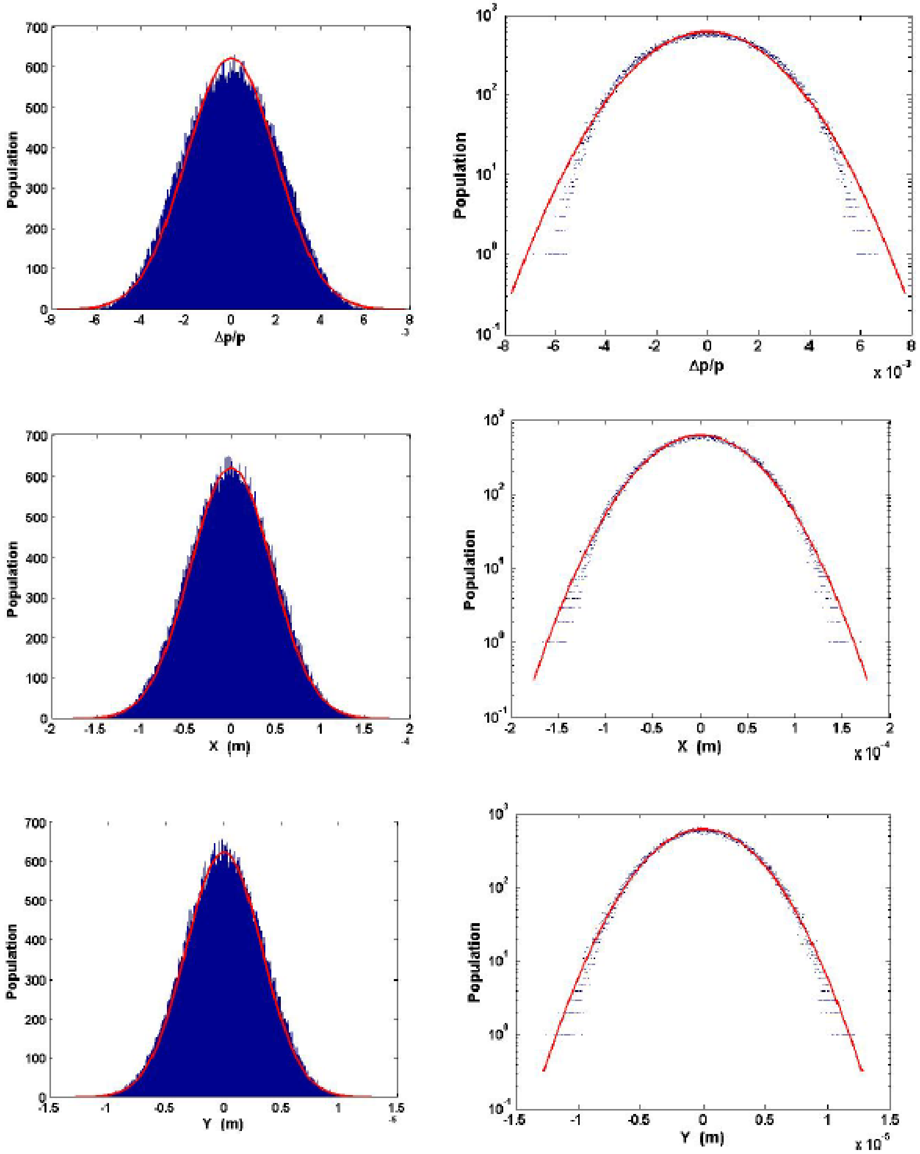
SIRE: IBS Distribution study



$$p_k(\xi_k) = \frac{1}{\sqrt{2\pi}\sigma_k} e^{-\frac{\xi_k^2}{2\sigma_k^2}}$$

Parameter	χ^2_{999}	Confidence
Δp/p	3048.7	<1e-15
X	1441.7	<1e-15
Y	1466.9	<1e-15

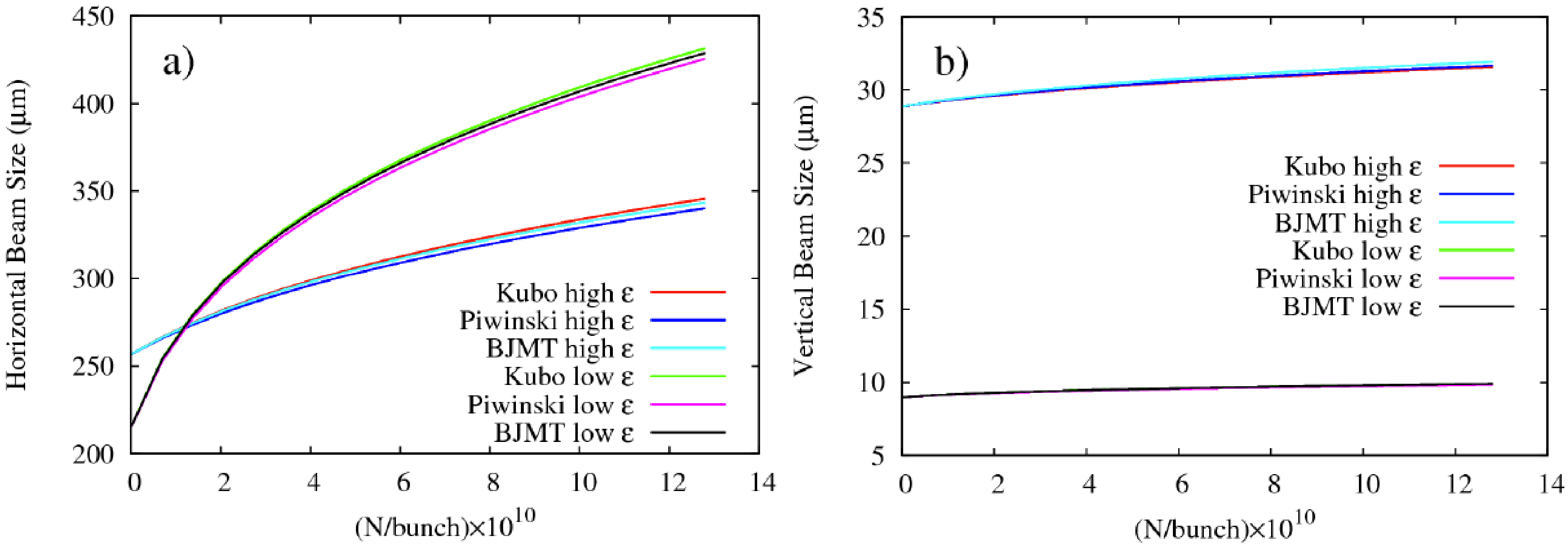
Parameter	Value
Eq. ε_x (m rad)	2.001e-10
Eq. ε_y (m rad)	2.064e-12
Eq. σ_δ	1.992e-3
Eq. σ_z (m)	1.687e-3

A. Vivoli

T. Demma

Various IBS Calculation Methods

- There are several methods for calculating IBS growth rates.
- As part of CesrTA, we have implemented and compared many of them.
- Over a wide range of parameters, we find all give very similar predictions.
- We treat the Coulomb Log the same for each method we have implemented.
    - Piwinski's formulas modified to take impact parameters.



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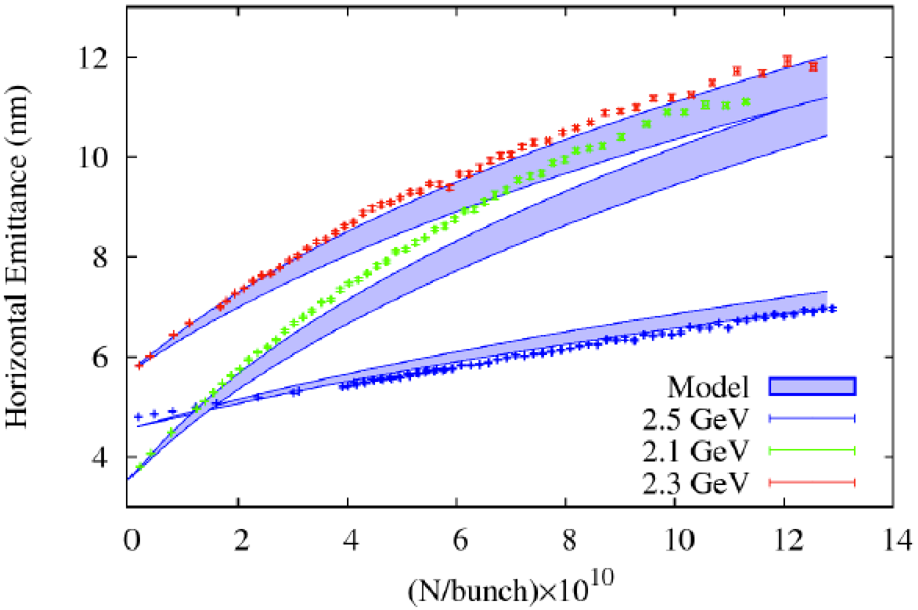
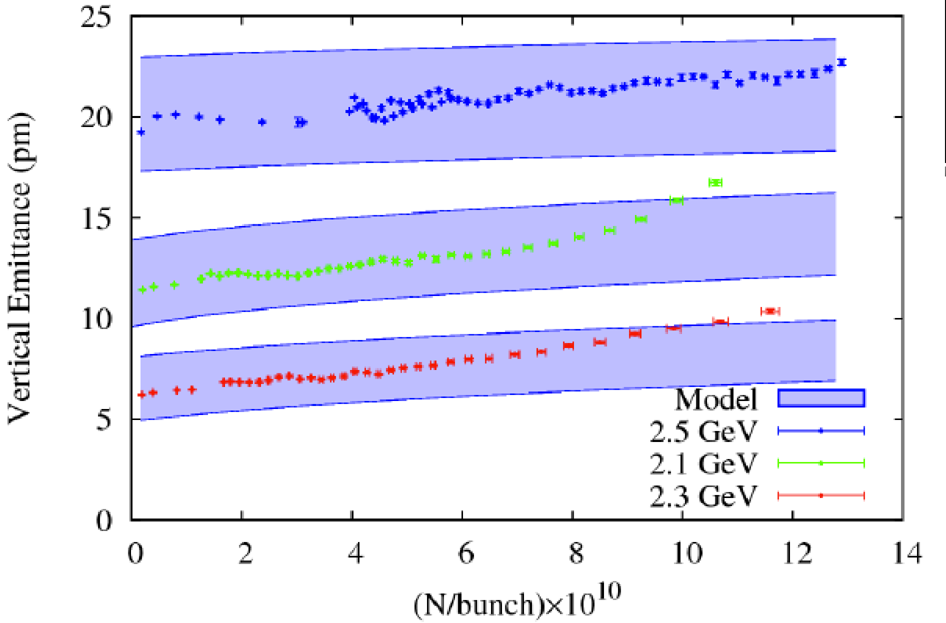
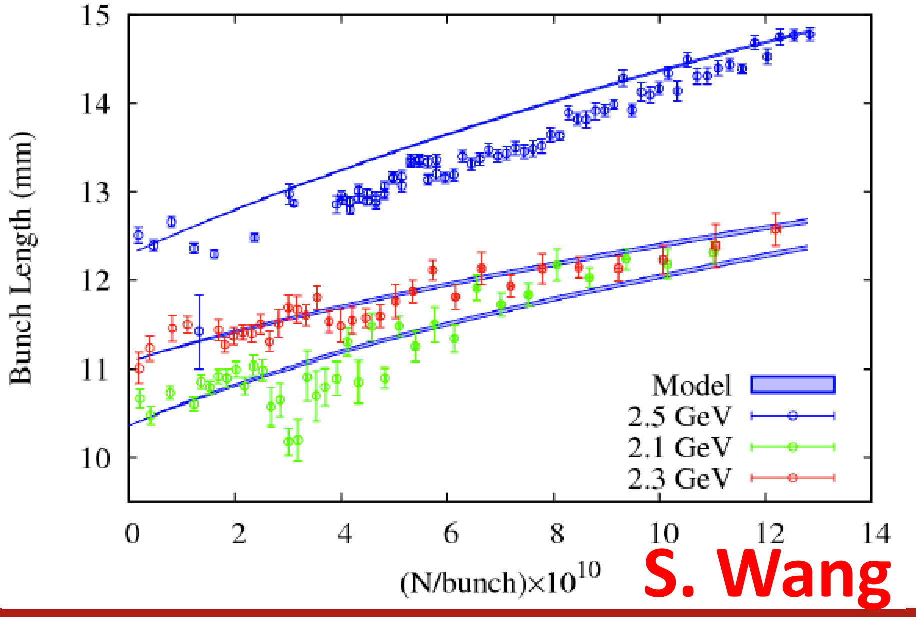
Combined Results vs. Energy





Low ε_y Conditions	
2.1 GeV	101 % ε_x Blowup
2.3 GeV	82 % ε_x Blowup
2.5 GeV	43 % ε_x Blowup
~ 50 um Vertical Beam Size Conditions	
2.1 GeV	81 % ε_x Blowup
2.3 GeV	33 % ε_x Blowup
2.5 GeV	27 % ε_x Blowup



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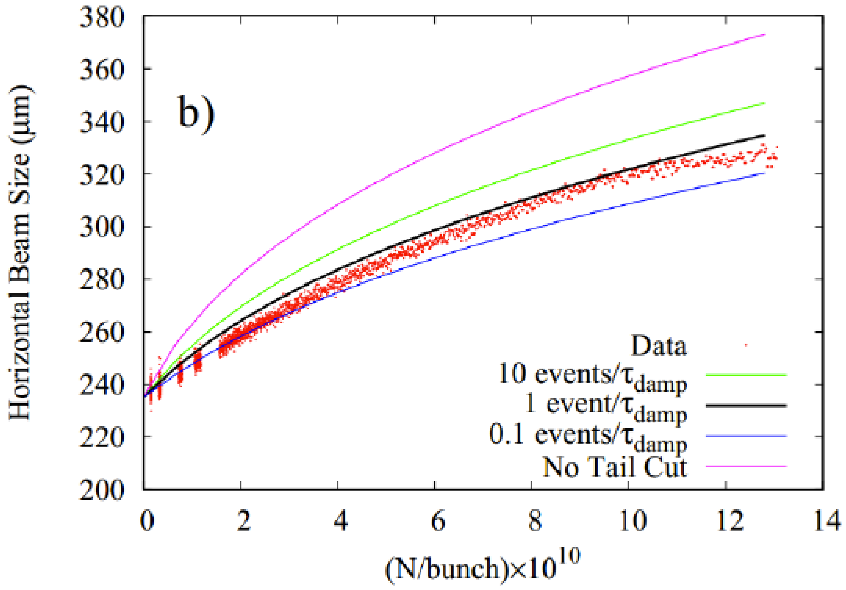
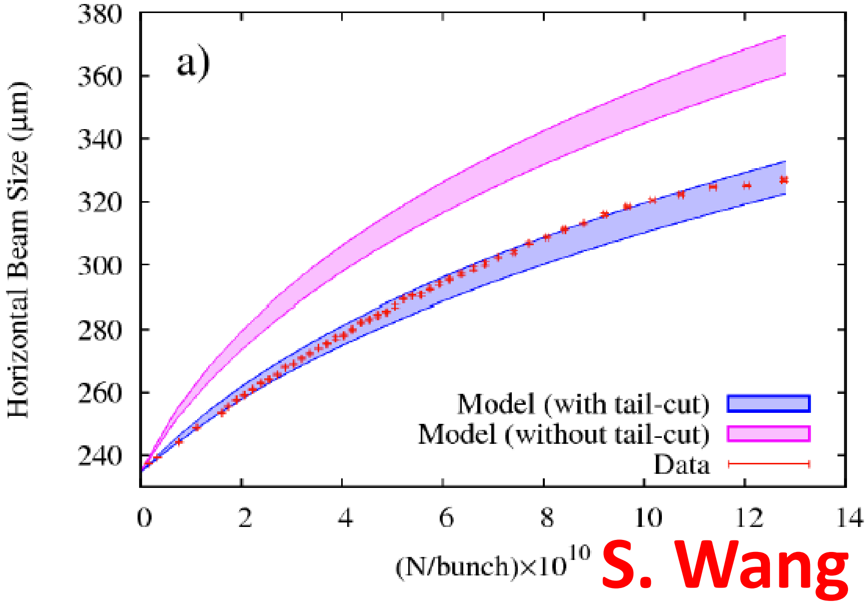
Highlight Tail-Cut

- The tail-cut is a modification to IBS theory that excludes from the rise time those scattering events that occur less frequently than once per particle per damping period.
- $$\frac{1}{\tau_{\mathrm{IBS}}} \propto \log \frac{b_{max}}{b_{min}}$$
- Weak application of the central-limit theorem.
- Significant in machines with strong damping.
- Without the tail-cut, IBS theory can significantly over-estimate the equilibrium beam size





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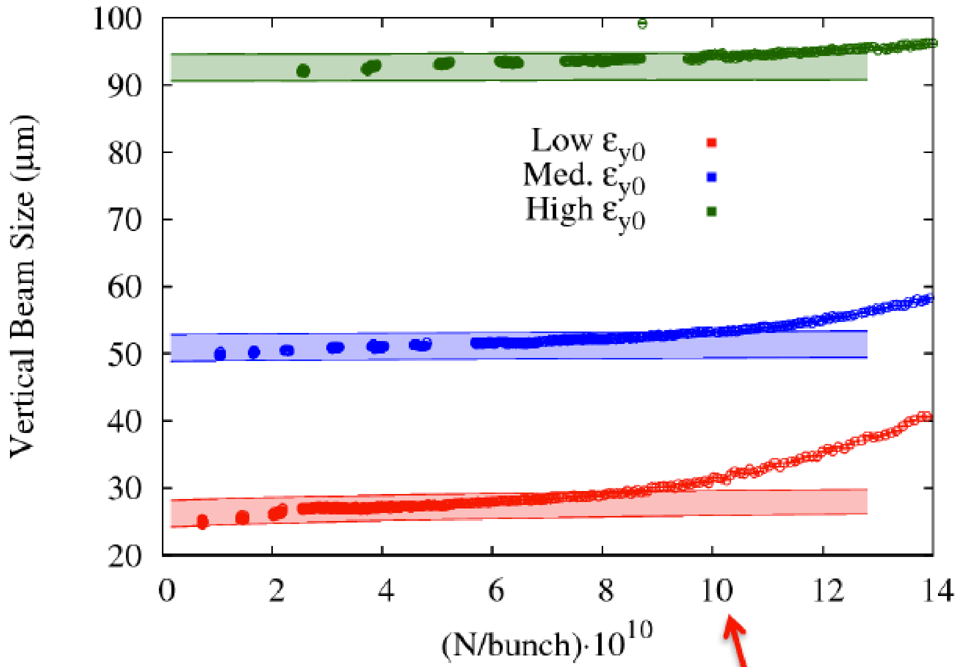
Anomalous Vertical Blow-Up

- Not consistent with IBS model
  - IBS size vs. current plot would be “log like”
- Species-independent
- Sensitive to betatron and synchrotron tunes
- Not sensitive to chromaticity
- FFT of vertical centroid and size does not show a strong signal above noise
- Energy spread measured to be constant, no threshold behavior seen in energy spread vs. current.
- Seen even in large beams
- Coupling (Cbar12) vs. current measured to be constant
- Coherent tune shift plays a part, but not the whole story
- Incoherent tune shift is a suspect, cannot be whole story



16 nC
~10^{22} part/m^3

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Open Questions

- Beam profile modification due to scattering
  - Theory for non-Gaussian beams (B. Nash, PhD thesis)
  - Effect in core particles is “known” (Gaussian core?)
  - Scattering in tails is less evident (Touschek-like effect dominant?)
  - Influence of lattice non-linearities and other collective effects (space-charge, impedance,…)
- Agreement of IBS theories
  - Only a matter of including tail cuts?
  - Influence of optics (especially in high-energy approximations)
- IBS theory including vertical coupling
  - Kubo and Oide formalism, other ideas?
- Impact on damping process
- Effect of Scattering in polarisation and vice versa

Open Questions

- Full employment of particle scattering codes for shedding light in previous questions
  - Benchmarking with measurements
- Disentangling IBS with other collective effects (especially in measurements)
  - Accurate knowledge of machine model and its current dependence (optics distortion, coupling)
- Instrumentation for resolving tails in beam profiles
- Measuring energy spread
  - Especially in absence of good model on longitudinal profile evolution

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LOW ε RING

THANK YOU!!!

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